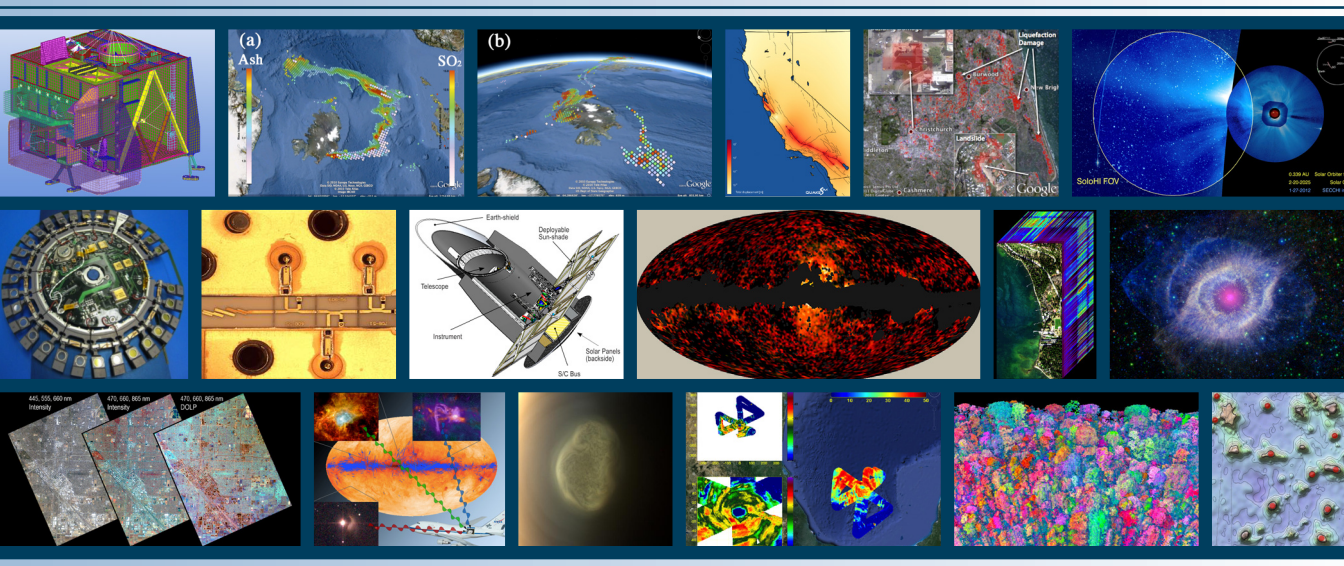
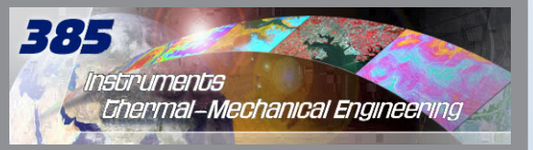
National Aeronautics and Space Administration

Jet Propulsion Laboratory

Instruments and Science Data Systems Division

FY 2012 Annual Report





Annual Report – FY 2012

Instruments and Science Data Systems Division

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Thomas S. Luchik, *Manager*
Annette Larson, *Deputy Manager*

Thomas Glavich, *Assistant Manager, Flight Instruments*
Robert L. Staehle, *Assistant Manager, Advanced Concepts*
Jonathan Bowman, *Business Administration Manager* (381)

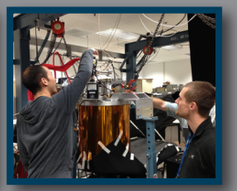
Instrument Systems Implementation & Concepts (382)
Curt Henry, *Manager*
Raul Romero, *Deputy Manager*

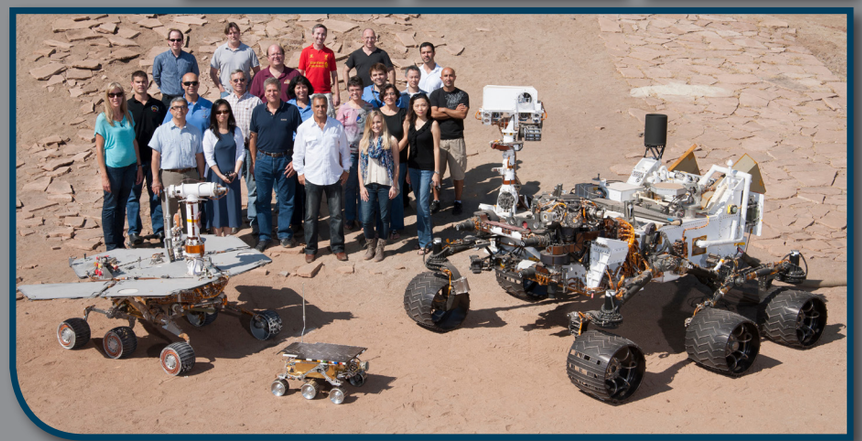
Optics (383)
Steve Macenka, *Manager*
Randall Bartman, *Deputy Manager*

Instrument Thermal-Mechanical Engineering (385)
Georg Siebes, *Manager*
Randall Lindemann, *Deputy Manager*

Instrument Software & Science Data Systems (388)
Elizabeth Kay-Im, *Manager*
Kon Leung, *Deputy Manager*

Instrument Electronics & Sensors (389)
Martin Herman, *Manager*
Elizabeth Kolawa, *Deputy Manager*





This publication was prepared at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Reference herein to any specific commercial product, process or service by trade name, trademark, manufacturer, or otherwise does not constitute or imply its endorsement by the United State Government or the Jet Propulsion Laboratory, California Institute of Technology.

Contents

Year in Review • 5
Advanced Concepts and New Business • 12
Instrument Systems Development • 24
Operational Missions • 38
Technology Development • 63
Publications • 88

INSTRUMENTS & SCIENCE DATA SYSTEMS DIVISION

Year in Review

ANNUAL REPORT FY 2012

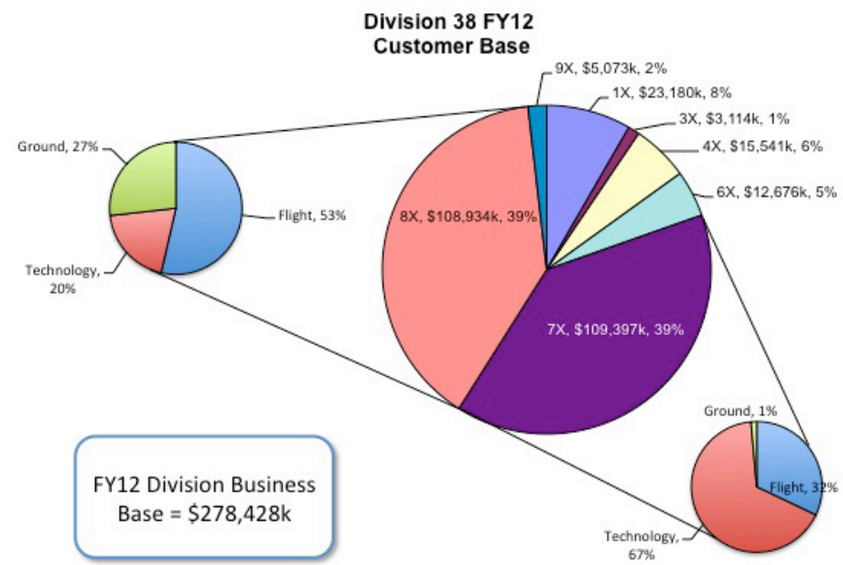
Year in Review

2012 brought significant changes for the Instruments and Science Data System Division.

In a bold move, the Engineering and Science Directorate approved organizational changes that enabled the Division to become vertically integrated and manage all the primary disciplines necessary to implement instruments end-to-end from within the Division. Specifically, the Division integrated the Thermal-Mechanical Engineering Section, managed by Georg Siebes and Randy Lindemann.

The business base for the Division grew dramatically during the past year, largely due to an increase in non-NASA business. This non-NASA work was performed under the Astronomy, Physics and Space Technology Directorate (7X), as it related most closely to technologies that would be applicable to that Directorate. In addition, there were also modest increases in Earth Science (8X) and Planetary Exploration (4X). Although the total amount of work and Directorate breakout changed substantially, the breakdown of flight implementation, technology development and operations center work remained largely the same as in previous years: the split was roughly 45-40-15, respectively, among 7X, 8X, and 4X work.

Finally, as in past years, the Division continued to develop numerous instrument and data system proposals. This is a trend we expect to maintain for the foreseeable future, as all instruments, both NASA and non-NASA, are and will continue to be selected through competitive processes.



Awards

This year once again we were pleased to see a number of people recognized for their achievements, as individuals and in teams both within JPL, NASA and external organizations.

Awards and Recognition

Fellows

The JPL Fellow classification carries with it an exceptional and sustained history of distinguished leadership and outstanding achievements contributing to the Laboratory's historical stature. People who carry this distinction are highly influential and are expected to play a critical role in shaping and contributing to the future work of JPL. A JPL Fellow is recognized by peers as an authority in his/her field and by management through a history of challenging assignments and/or recognition that contributes to the Lab's internal and external image. This classification continues to be viewed by the Laboratory as the highest acknowledgement of professional achievement.

Dr. Robert O Green

During the past three decades, Dr. Green has established himself as a respected leader and contributor to the field of imaging spectroscopy, not only here at JPL but around the globe. His sustained achievements have enabled JPL to hold a prime position and expertise in the field. Dr. Green has been the driving force behind new airborne and spaceborne scientific imaging spectrometers. He was a leader in establishing that the true power of imaging spectroscopy lies in the absolute values for surface radiance, rather than merely reflectance. When introduced, this idea and technique was considered to be controversial; it has, however, become today's "gold standard" and has enabled new scientific discoveries for Earth and planetary science. Dr. Green's own scientific studies in spectroscopic modeling and inversion of atmospheric constituents, as well as his involvement in many regularly referenced multidisciplinary applications of imaging spectroscopy, make him a key contributor to this branch of science.

Dr. David C. Redding

Dr. Redding is internationally recognized as a leader in the development and application of wavefront sensing and control (WFSC) systems, an enabling technology for large optical systems based on segmented and/or deformable mirrors. Dr. Redding has also been a leader in the development of optical and integrated modeling tools. Most recently, he has led the design and development for major projects. For example, he and the late Bill Breckenridge were responsible for the initial development of COMP (a general-purpose optical modeling code), which under Dr. Redding's leadership, evolved into Modeling and Analysis for Controlled Optical Systems (MACOS), an optical modeling code that has been and continues to be used extensively at the Lab and elsewhere. He was also the co-developer of the original Integrated Modeling of Optical Systems (IMOS) architecture, which brought together thermal, mechanical, optical, and controls modeling capabilities to analyze the performance of optical system designs. As observational instruments continue to grow in size, complexity, and performance, Dr. Redding's unique experience and expertise will be of great value in the Laboratory's atempts to capture and deliver on these large aperture projects.

Senior Research Scientist

The designation "Senior Research Scientist" (SRS) was established at JPL in 1977 to provide special recognition, benefits, responsibilities, and privileges for outstanding individual researchers in science and technology.

Dr. Gaier pioneered the use of monolithic microwave integrated circuit (MMIC) low-noise amplifier technology to enable a new generation of science instruments in astrophysics, Earth remote sensing and planetary exploration. Dr. Gaier is an expert in the field of low-noise millimeter wave amplifiers, MMIC technology, and microwave radiometry. Recognizing the broad applicability of MMIC technology to NASA projects, he made the first connection in the use of power amplifier technology at millimeter wavelengths to local oscillator generation, a technique ultimately adopted by the Hershel Heterodyne Instrument for Far-Infrared (HIFI) systems. This facility has become a national resource, used by multiple NASA missions, National Science Foundation (NSF) projects, as well as Department of Defense (DoD) sub-millimeter programs. Dr. Gaier has primarily worked in the areas of cryogenic low-noise amplifiers for astronomy and astrophysics, with considerable contributions to the field of cosmology. He was a key member and Co-Investigator in the development of the Planck-LFI (Low Frequency Instrument) receivers, leading the MMIC low-noise amplifier technology development and receiver prototyping activities. Dr. Gaier successfully invented proposed, and developed the technology that became the basis for the Q/U Imaging Experiment (QUIET). He led the QUIET project development for NASA (as PI) and for NSF (as Co-I). QUIET is just now completing its first phase of operations in Chile, having achieved unprecedented sensitivity at 40 GHz. Publications Dr. Gaier has authored span the fields of cosmology, instrumentation, low noise amplifiers and control components, and millimeter wave metrology.

Dr. Todd Gaier

Dr. Ting has led versatile and innovative semiconductor device and physics research that has generated major advances in infrared detector technology and spintronics. Dr. Ting has been engaged in semiconductor physics and device research for nearly thirty years. His early work on realistic band structure description of quantum transport in semiconductor heterostructures and nanostructures represented pioneering research in that field. His 1992 *Phys. Rev. B* paper on this subject is widely referenced (with 130 citations as of Nov 2010); the method introduced in that paper is used today by researchers worldwide for modeling quantum transport in a variety of novel structures, ranging from spintronic devices to DNA double helices. Since arriving at JPL in 1998, Dr. Ting has broadened his research interests to include spintronic devices, solar cells, lasers, and infrared detectors, as well as applications of infrared imaging. His recent focus on infrared detectors and applications at JPL has made exceptional contributions to the infrared detector field and played a pivotal role in propelling JPL to the forefront of quantum structure infrared detector technology.

Dr. David Ting

Dr. Shouleh Nikzad

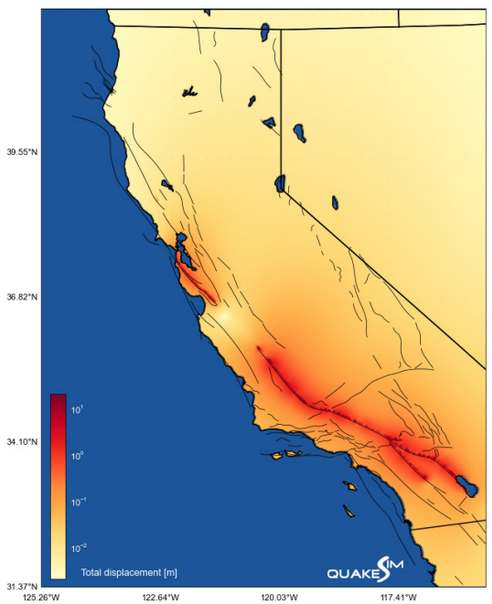
Dr. Nikzad is a highly respected and internationally recognized scientist who has made significant breakthroughs in the fields of ultraviolet/visible imagers and particle detectors. Given their essential role in the measurement process, detectors and imagers continue to be crucial components of most instruments and missions and are a vital part of JPL's core competencies. For example, a far ultraviolet Explorer mission is being proposed in the current cycle that is enabled by innovations developed during the past two years. Indeed, as a direct result of the efforts of Dr. Nikzad and her team, JPL now holds the world record in far-UV detector sensitivity.
Dr. Nikzad has also pioneered low-energy particle detectors that have enabled a new class of instrument concepts for space plasma physics, heliophysics, and planetary mass spectrometry and geochronology instruments. In addition, her work on the invention and development of solid-state curved detectors and focal plane arrays has opened up new possibilities in optical design and is particularly relevant for both very large and very small instruments.

Fellow of the American Physical Society

Dr. Shouleh Nikzad was elected a fellow of American Physical Society in recognition of her outstanding contributions to physics. This is an honor that is bestowed upon no more than one half of one percent of the APS membership. Shouleh Nikzad is also specifically recognized for her contributions to Applied Physics and her innovative development of bandstructure engineering techniques and their applications to produce unprecedented performance in sensors and devices.

NASA Software of the Year Award

QuakeSim, developed at the Jet Propulsion Laboratory (JPL), is a comprehensive, state-of-the-art software tool for simulating and understanding earthquake fault processes and improving earthquake forecasting.



QuakeSim

Initiated in 2002, QuakeSim uses NASA remote sensing and other earthquake-related data to simulate and model the behavior of faults in 3-D, both individually and as part of complex, interacting systems. This provides long-term histories of fault behavior that can be used for statistical evaluation. QuakeSim is also used to identify regions of increased earthquake probabilities, called hotspots.

The multidisciplinary QuakeSim team, led by Andrea Donnellan/Div 32, includes Division 38 members Robert Granat and Charles Norton. Other members of the team include Jay Parket and Greg Lyzenga of JPL; Geoffrey Fox and Marlon Pierce of Indiana University, Bloomington; John Rundle of the University of California, Davis; Dennis McLeod of the University of Southern California, Los Angeles; and Lisa Grant Ludwig of the University of California, Irvine

NASA Honor Awards

Exceptional Achievement Medal

Mark Boyles
Jeff Oseas
Sue Linick

Exceptional Service Medal

Larry Hovland
Robert Menzies

Exceptional Technology Achievement Medal

Kiri Wagstaff

Exceptional Public Achievement Medal

David Nelson

Group Achievement Awards

Airborne Multi-Angle Spectro Polarimetric Imager (AirMSPI) Team
Aquarius Launch, Early Orbit Ops, and Commissioning Team
Aquarius Instrument Development & ATLO Team
Carbon Dioxide Absorption Spectrometer (CO2LAS) 2011 ASCENDS Flight Campaign Team
Cryogenics and Gases Process Improvement Team
Earth Science Mission Operations (ESMO) Modernization Team
Exoplanet Exploration Public Engagement Team
Gravity Recovery and Interior Laboratory (GRAIL) Mission Operations System Design Team
GRAIL Payload Integration and Test Team
GRAIL Project Systems Engineering Team
IRAC Data Compression Improvement Team
ISRO Calibration Team
James Webb Space Telescope OTE Team
Juno ESA Launch Support Team
Juno Ground Data System Development Team
Juno Mission Operations Development Team
Juno Microwave Radiometer (MWR) Instrument Team
Juno Payload System Management & Engineering Team
Juno Payload System Reviews Team
Juno Project Management Team
Juno Proposal Team
Juno Science Team
M-Cubed/CubeSat Onboard Processing Validation Experiment (COVE) Flight Team
Mid-latitude Airborne Cirrus Properties Experiment
Nebula Test Team
Near-Earth Object Wide Field Infrared Survey Explorer (NEOWISE) Team
Next Generation Imaging Spectrometer (NGIS) Development Team
PanFTS Instrument Development Team
SDO Science Investigation Teams
Space Images Website Team
Spitzer/Deep Space Network PMAR Team
Suomi National Polar Orbiting Environmental Satellite System Preparatory Program Mission Development Team
Wide Field Infrared Survey Explorer (WISE) Science Data Center

Microdevices Laboratory (MDL)

POC: Siamak Forouhar

Since its founding in the late 1980s, work at the Microdevices Laboratory (MDL) has focused on innovative, high-risk, high-payoff concepts with potential applications in future space missions. These include flight-qualified devices that have enabled a wide variety of instruments and missions in Earth science, planetary exploration, and astrophysics.
MDL micro- and nanofabrication processes need sophisticated, state-of-the-art equipment for depositing, patterning, and etching of micro- and nanostructures required to manufacture a variety of devices. Thus, MDL houses tools for optical and electron beam lithography, epitaxial growth of materials, thin-film deposition, wet and dry etching, thermal processing, as well as structural, electronic, and optical characterization.

To maintain the state-of-the-art capabilities and effective operations, MDL facilities require continuous upkeep and investment. MDL has benefited significantly from JPL institutional support to sustain its central capabilities and capital investment in new equipment. For example, optical lithography capabilities were significantly upgraded during 2012 by purchasing two major pieces of equipment. First, a deep ultraviolet (DUV) Canon FPA 3000 EX6 stepper, which provides high resolution (150 nm) lithography capability that is needed for fabrication of large thermopile arrays, superconductor detector arrays for astrophysics (ground, balloon, satellite), single photon detectors for optical communications, and other devices. The Canon EX6 stepper is compatible with existing processes and mask sets and required minimum facilities work to install. Second, a Canon FPA-3000i4 stepper was added, which replaced a forty-year-old GCA stepper. The new stepper comes with functional options that will improve device processing. It is also equipped with automatic mask and wafer alignment features (within 0.1-µm tolerance) critical to shorten the processing time and to improve the device performance/yields and for reliable processing of microwave devices and infrared detectors.

MDL Canon FPA-3000i4

MDL CANON EX6 Stepper Installed

MDL Beneg Atomic Layer Deposition (ALD) System

The capability of depositing novel thin-film materials and structures is key to many types of detectors developed at MDL and, increasingly, their required performance relies on the application of the atomic layer deposition (ALD) technique. Atomic layer deposition is a thin-film deposition technique where a desired film is grown using sequential surface reactions, one monolayer at a time. The properties inherent to the ALD method enable growth of high-quality, smooth, dense, pin-hole-free films with precise, angstrom-level thickness control over arbitrarily large surface areas. ALD is also well-suited for the growth of multilayer stacks of films with sharp interfaces. These characteristics of ALD make it ideally suited for fabrication of all types of optical elements, including mirrors, filters, and coatings, with the highest possible performance. During fiscal year 2012, MDL added a new ALD system: the Beneq TFS200.

Other fiscal year 2012 investments in MDL equipment included a diamond-point turning machine, an ellipsometer, a Smart Equipment Technology (SET) Ontos7 surface preparation system for bonding indium oxide, laser-trimming equipment, and a HF vapor etcher.

INSTRUMENTS & SCIENCE DATA SYSTEMS DIVISION

Advanced Concepts and New Business

ANNUAL REPORT FY 2012

Some Winning Ideas and Collaborations…with More to Come

POC: Robert Staehle

Division-supported proposals during fiscal year 2012 ranged from instruments and science data systems for nanosats to full Mars lander missions. It is the nature of advanced concepts work that only a fraction of ideas conceived will be funded for early investigation and in turn, only a fraction of those will enter fully funded development. Division members continue to advance a wide spectrum of ideas, and collaborate on many more ideas originating elsewhere. Our business base is comprised of those concepts that make it into full development. Two instruments conceived more than a decade ago are now on Mars, aboard the Mars Science Laboratory (MSL): the CheMin x-ray diffraction/x-ray fluorescence instrument and the Tunable Laser Spectrometer (TLS). The origins of CheMin at JPL and NASA's Ames Research Center go back to the 1980s. Which concepts originating today will be deployed somewhere in the Solar System, or right here on Earth, during the next 5 years, decade, or longer? Some highlights are below, followed by summaries of selected advanced concepts and new business secured during fiscal year 2012.

During fiscal year 2012 in the Astrophysics discipline, NASA selected for implementation the HAWC+ proposal (PI Charles Dowell/JPL). Our Division supported this proposal for the US-German SOFIA airborne observatory. This will add a polarization measurement capability to the High-resolution Airborne Wideband Camera (HAWC), opening a new dimension of far-infrared measurement capability at rather low cost. NASA received 11 proposals for such second-generation instruments; HAWC+ was one of two selected.

The Division is supporting Dr. Mark Swain/JPL's proposal for Fast Infrared Exoplanet Spectroscopy Survey Explorer (FINESSE), one of five selected for Step 2 Explorer Mission consideration by NASA. Final selection of this or a competing proposal is expected during 2013. If funded, the FINESSE mission will use a space telescope to survey more than 200 planets around other stars. This would be the first mission dedicated to characterizing exoplanet atmospheres, and how our Solar System fits into the larger family of planets. Dr. Mark Swain's team includes science co-investigators from inside and outside JPL.

If selected by NASA in 2013 as an Explorer Mission of Opportunity, our Division is to provide key technology for the detector focal plane for Gal/Xgal U/LDB Spectroscopic/Stratospheric THz Observatory (GUSSTO), proposed by PI Christopher Walker/University of Arizona. This mission would launch a high-altitude balloon with a one-meter telescope to provide a comprehensive understanding of the inner workings of our Milky Way galaxy and one of our galaxy's companion galaxies, the Large Magellanic Cloud. POC: Jonathan Kawamura

During fiscal year 2012, an optical testbed, a modification of spare Orbiting Carbon Observatory (OCO-2) hardware, and the wind-measuring RapidSCAT payload were defined as candidates for accommodation aboard the International Space Station (ISS). These follow our success two years ago with the Vehicle Cabin Atmosphere Monitor (VCAM) operated aboard ISS.

Also in Earth science, the Division supported a variety of proposals covering several Earth Science disciplines, with principal investigators inside and outside JPL. Development work focused on four complex Earth-observing missions that could launch over the decade to come:

- Ocean Vector Winds Mission (OVWM), a.k.a. RapidSCAT.
- Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI).
- Surface Water and Ocean Topography (SWOT).
- Hyperspectral Infrared Imager (HyspIRI).

We have undertaken a number of advanced concepts studies focused on utilizing smallsats and CubeSats to perform Earth Science investigations. JPL now has at least seven funded CubeSat projects, plus one already flown, with direct Division involvement in or leadership of five of these. Three of these are part of the Earth Science Technology Office (ESTO)-funded initiative to advance space demonstration of high-value new technologies utilizing inexpensive CubeSat platforms. The fourth started as a JPL/Ames collaboration CubeSat Hydrometric Atmospheric Radiometer Module (CHARM), with PI Boon Lim, to make atmospheric water vapor measurements at 183 GHz. CHARM was competitively selected as part of NASA's Hands-On Project Experience (HOPE) program and is being executed by a group of early-career professionals at JPL. Most other JPL CubeSat projects involve at least one university as a primary collaborator. All universities are candidates for future collaborations with JPL. As with any successful collaboration, the different parties bring different complementary strengths that combine into a competitive proposal to meet a sponsor's need.

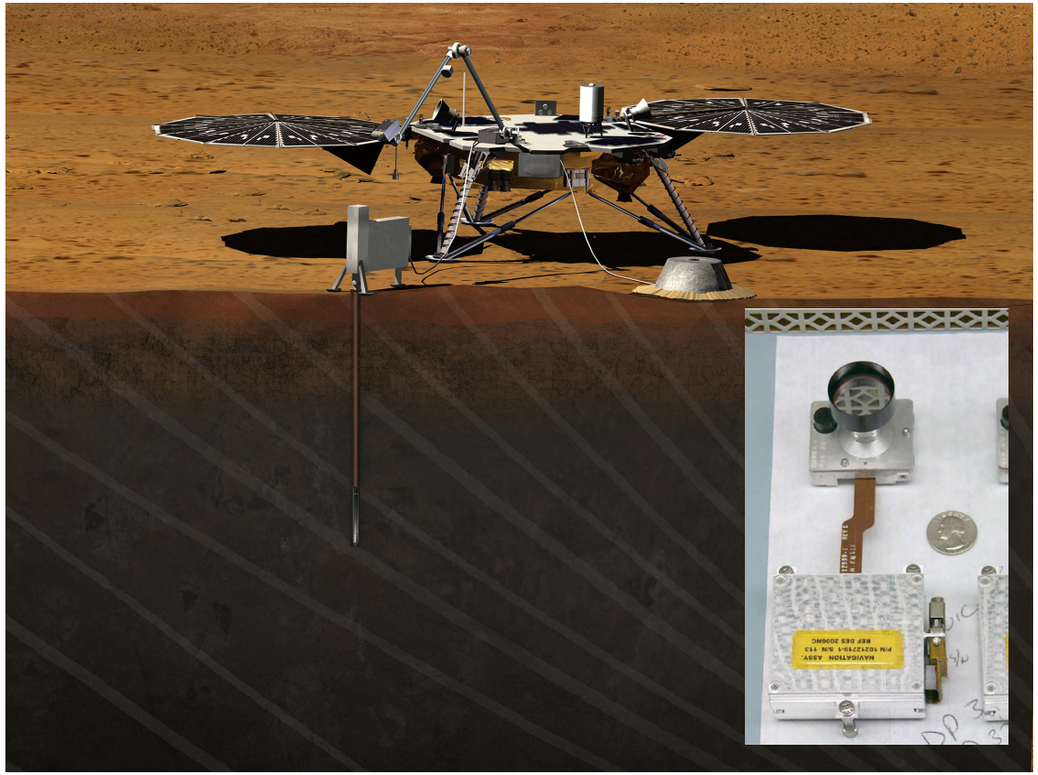
During fiscal year 2012, work sponsored by the NASA Innovative Advanced Concepts (NIAC) program defined a path by which CubeSats can be utilized to explore destinations throughout the inner Solar System and, in some cases, beyond.

Competitively selected Keck Institute for Space Studies (KISS) workshops, studies, and technology developments are a highly effective mechanism to bring together leading investigators from JPL, Caltech, and other organizations around a specific set of disciplines that together can create wholly new capabilities for space science and engineering. During fiscal year 2012, Division 38 staff led or participated in several KISS-sponsored activities, including:

- In-situ Science Instrumentation for Small Bodies: isotope geochemistry, cosmochemistry, astrophysics, mineralogy, geology, geophysics, and others.
- Geochronology: application of measuring potassium isotope composition using a Knudsen-cell effusion mass spectrometer (KEMS).
- Future Missions to Titan: Scientific and Engineering Challenges.
- Technologies for Cryogenic In Situ Chemical Analysis.
- Small Satellites—A Revolution in Space Science: advanced a broad range of Astro-physics, Heliophysics, and Solar System exploration concepts.
- CubeSat-based Radio Astronomy Missions: architecture and technologies for low-frequency radio astronomy from Earth orbit and beyond.
- xTerramechanics: Integrated Simulation of Planetary Surface Missions.
- Next Generation Ultraviolet Instrument Techologies: for Future Astrophysics, Cosmology, Planetary and Heliophysics Missions.

NASA's Discovery program selected the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSIGHT) proposal with Dr. Bruce Banerdt/JPL as principal investigator. Division 38-supplied Mars Exploration Rover-legacy cameras will be aboard, and Division staff will be responsible for integration of instruments from an international variety of customers. While InSIGHT is being built up, the Division is involved in formulating proposals for the next Discovery and New Frontiers NASA calls for proposals, as well as for future Mars landers.

Division personnel led instrument definition and proposals for instruments to be carried aboard the European Space Agency's JUpiter ICy moon Explorer (JUICE) mission, set for launch in 2022. Each proposal involves a multi-party collaboration among scientists and equipment providers at JPL and around North America and Europe. JUICE instrument selection decisions are expected from ESA and NASA during 2013.



InSIGHT, a modified Phoenix lander, will be the third to carry Mars surface cameras originally designed for the twin Mars Exploration Rovers (MER). Rover Opportunity continues to operate , returning nearly every day new pictures taken by Division 38-supplied cameras. The rover and its cameras were originally designed for 90 days of operation. Inset: MER Navcam. Credit: NASA/JPL artist's concept, NASA/JPL photo

Opportunities continue to be explored for applying NASA-developed technology outside the traditional space science community. One example is a recent selection to perform work using the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) and specialized algorithms to identify possible orchard disease vectors with a rapid, large-area survey. Other new work is underway for the oil and gas industry.

Instrument Concepts Team

POC: Alfred Nash

JPL's Instrument Concepts Team is a multi-Division asset used to rapidly innovate, develop, evaluate, and estimate the costs of new space instrumentation concepts. The team draws from more than 100 senior subject matter experts in all relevant disciplines. During calendar year 2012, the Instrument Concepts Team supported investigators with proposals for Earth Science (Earth Venture instruments), Astrophysics (Explorer and Explorer Missions of Opportunity), and Planetary Science (Jupiter Icy Moon Explorer (JUICE)).

In addition, the Instrument Concepts Team continued to provide support to JPL's mission concept development through Team-X and its new capability for the early stages of formulation, JPL's A-Team. The Instrument Concepts Team supported Team-X in more than 23 mission studies, led more than 4 Team-X instrument/payload studies, and participated in many of the more than 35 A-Team studies during fiscal year 2012, spanning four JPL program directorates (Solar System Exploration, Mars Exploration, Astronomy and Physics, and Earth Science).

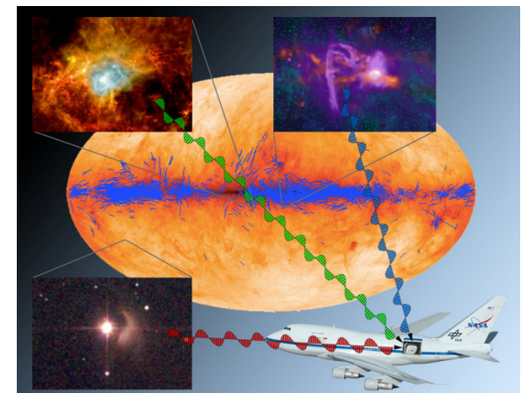
The Division's Instrument Concepts Team is a part of JPL's new A-Team early concept formulation and development capability. Investigations move rapidly over a few hours in formal and informal settings suited to the topic at hand. Credit: NASA/JPL-Caltech.

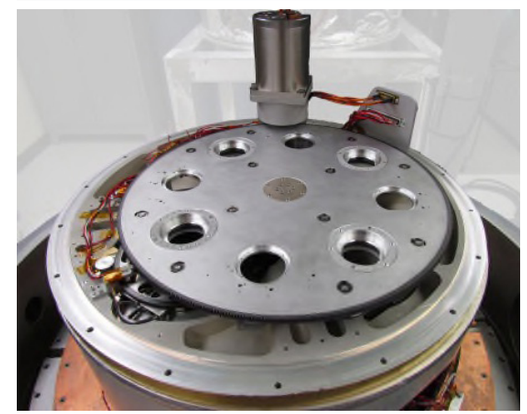
Selected Summaries of Specific Tasks

High-resolution Airborne Wideband Camera Plus (HAWC+)

PI: Darren Dowell
POC: Louise Hamlin

In April 2012, the NASA Stratospheric Observatory for Infrared Astronomy (SOFIA) program office selected the HAWC+ science instrument upgrade to measure polarization, inferring magnetic fields and other phenomena at thousands of light years' distance. This task is led by the Division for implementation on the SOFIA airborne observatory. HAWC+ will upgrade the existing High-resolution Airborne Wideband Camera (HAWC) to measure the structure and strength of magnetic fields in diverse objects throughout the universe, such as star-forming clouds and galaxies. This will help astronomers better understand how stars, planets, and galaxies form and evolve. The upgrade will consist of a sensitive, large-format detector array developed at John Hopkins University, Baltimore, and a polarimeter capable of making observations at far-infrared wavelengths developed here at JPL. SOFIA is a highly modified Boeing 747SP aircraft that carries a telescope with a 100-inch (2.5-meter) diameter mirror that conducts astronomy research not possible with ground-based telescopes. "SOFIA has the ability to become a world-class airborne observatory that complements the Hubble, Spitzer and Herschel space telescopes," said John Grunsfeld, NASA's Science Mission Directorate associate administrator. "This upgrade will greatly broaden SOFIA's capabilities."





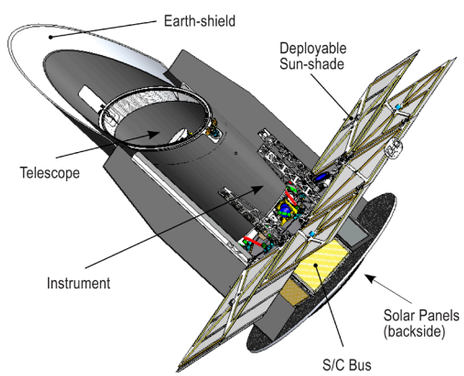
The HAWC+ upgrade will enable SOFIA to make polarimetric observations at far-infrared wavelengths.

Fast INfrared Exoplanet Spectroscopy Survey Explorer (FINESSE)

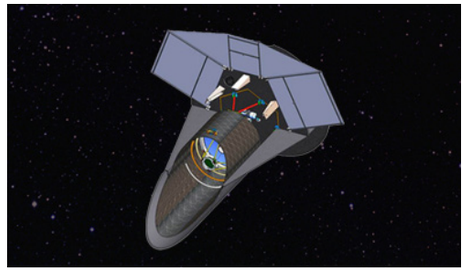
PI: Mark Swain
POC: Muthu Jeganathan

FINESSE is a mission dedicated to exploring new worlds around other stars, allowing us to understand the atmospheric conditions, composition, and chemistry for exoplanets as a class of objects. FINESSE is one of five Explorer Mission proposals that were selected by NASA in September 2011 to conduct an 11-month mission concept study. Based on the concept study, NASA plans to select up to two of the Explorer Mission proposals in April 2013 for flight development. The missions, capped at $200 million excluding the launch vehicle, could launch as early as 2016.

From a 570-km Sun-synchronous terminator orbit, FINESSE is to observe the light curves of at least 200 transiting exoplanets during its two-year mission. Using methods pioneered by PI Mark Swain of JPL and the science team with Hubble and Spitzer, spectroscopic light curve measurements from transiting planets enable the detection of molecules—such as water, methane, carbon monoxide, and carbon dioxide—in a wide variety of conditions. Once detected, these molecules can, in turn, be used to determine the conditions, composition, and chemistry of planetary atmospheres.



FINESSE



Artist's concept of the Fast INfrared Exoplanet Spectroscopy Survey Explorer (FINESSE). The Division is responsible for delivering FINESSE's single, high-stability payload. The spacecraft bus is to be built by Ball. The prominent Sun-shade and Earth-shield passively cool the payload to <130 K. A cryocooler cools the HgCdTe focal plane array to 75 K and the spectrometer to <90 K for observations out to 5 μm. Credit: NASA/JPL-Caltech

The payload, a spectrophotometer, is developed through a teaming arrangement between the Division, Raytheon, and Teledyne. The spectrophotometer consists of a spectrometer with continuous coverage from 0.7 to 5 μm coupled to a 76-cm all-aluminum telescope.

Ocean Vector Winds Mission (now RapidSCAT)

Science Data System POC: Jennifer Cruz
Antenna POC: Richard Hughes

Ocean winds are key drivers in weather and climate studies. Under NASA direction, the Ocean Vector Winds Mission (OVWM) pre-formulation team was formed to pursue low cost concepts for a QuikSCAT Follow-on implementation that would continue to advance NASA science research objectives to maintain/continue geophysical wind measurements. Science goals are continuity of OVW climate data record, including high-resolution winds and coupling to sea surface temperature and productivity.

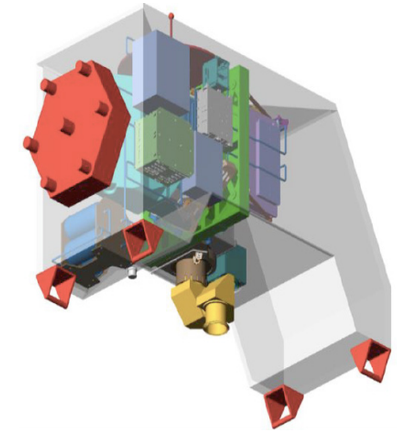
Three options were considered: a) Single-Frequency Scatterometer (SFS) on SpaceX DragonLab; b) SFS on the International Space Station (ISS); and c) Dual-Frequency Scatterometer on Japan Aerospace Exploration Agency's (JAXA) Global Change Observation Mission (GCOM) -W2. An instrument and mission concepts Technical, Management and Cost (TMC) Review was held in March 2012. The Division participated in the science data system architecture conceptual design, which was formulated for each option. The architecture is based on strong inheritance from the QuickSCAT data system, leveraging three of the five processors, and will be implemented in JPL's Communications, Tracking & Radar Division (33).

The mission has formed and is named "RapidSCAT". The project Preliminary Design Review is scheduled for early 2013, with instrument integration with DragonLab early 2014 and launch targeted for Spring 2014.

Orbiting Carbon Observatory – 3 (OCO-3)

PI: Michael Gunson
POC: Douglas Lisman

OCO-3 successfully completed a Mission Concept Review. Pending NASA review, the current year's plan is to complete Phase A, culminating in a System Requirements Review. The mission concept is to fly the spare OCO-2 instrument onboard the Japanese Experiment Module (JEM) of the International Space Station (ISS). OCO-3 is currently included on the ISS manifest. Adding a payload bus system to interface with ISS and provide pointing and polarization control, as performed by the OCO-2 spacecraft, minimizes instrument modifications. OCO-3 science complements OCO-2, with the ISS non-Sun-synchronous orbit sampling different times of day and a more regular sampling of oceans. An agile pointing mirror system provides contiguous sampling of large urban areas for characterizing the influence of anthropogenic fossil fuel emissions, reducing uncertainty of the largest terms of the carbon cycle.



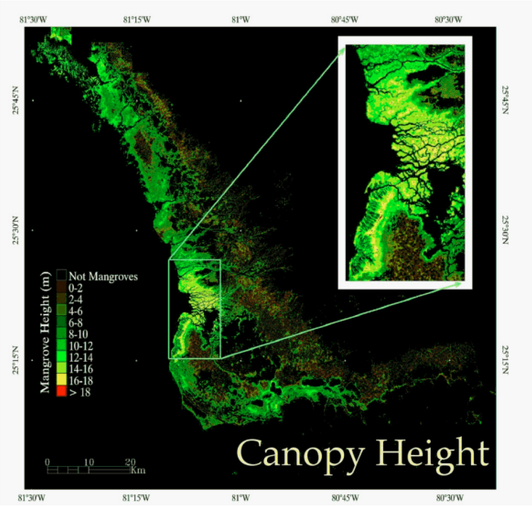
The OCO-3 instrument is configured within a standard-sized Japanese Experiment Module (JEM) enclosure with standard ISS and launch vehicle interfaces shown in red and a new (for OCO-3) 2-axis pointing mirror assembly shown in gold. Credit: NASA/JPL-Caltech

Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI)

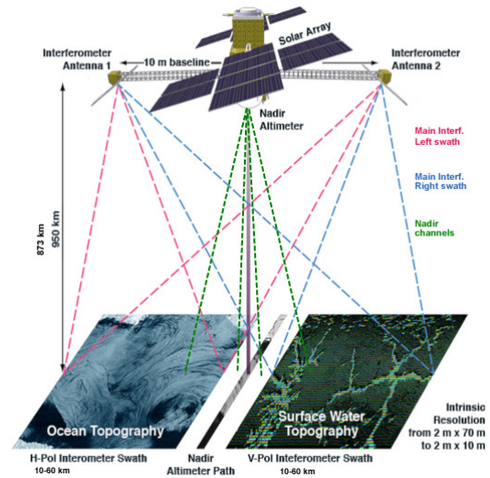
Science Data System POC: David Cuddy
Antenna/Structural POC: Fabien Nicaise

The DESDynI Mission concept is one of four first-tier Earth Observing Missions recommended by the National Research Council (NRC) 2007 Earth Science Decadal Survey.

During calendar year 2012, four alternatives for flying a DESDynI type L-band Interferometric Synthetic Aperture Radar (InSAR) were studied. These included a domestic option with SpaceX, two options with the Canadian Space Agency, and one with the Indian Space Research Organization (ISRO). After presenting these options to NASA, the project was directed to pursue the ISRO option, as it offered a chance to get a quad-pole L-band instrument in operation while remaining inside budget constraints. This mission variant would also feature science from an S-band SAR contributed by India. The project is currently



DESDynI Canopy Height Data Simulation



SWOT Instrument Fields of Regard

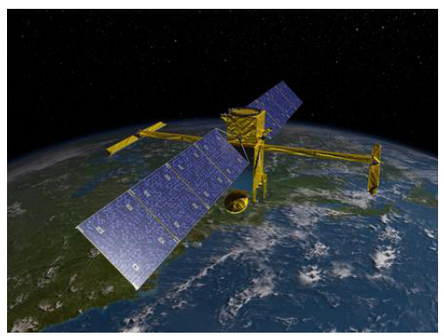
refining the ISRO-DESDynI concept design with the goal of convening a Mission Concept Review for the revised mission in 2013.

In the proposed DESDynI Science Data System (SDS) area, cost alternatives are under study for different operational data processing and handling. Raw data volume estimates for DESDynI are 14 Tbits/day from the L-band SAR and another 8 Tbits/day of S-band SAR data retrieved via the Space Network. Additional studies and concept development in the SDS area hinge on the ultimate mission concept decision and partnership arrangement made in early 2013.

Surface Water Ocean Topography (SWOT)

Microwave Radiometer POC: Ami Kitiyakara
Science Data System POC: Oh-Ig Kwoun
Antenna/Structural POC: Richard Hughes

The SWOT mission, with a target launch date of 2020, is one of five second-tier Earth Observing Missions recommended by the National Research Council's (NRC) Earth Science Decadal Survey. SWOT is a collaborative mission involving NASA and the French national space agency, Centre National d'Études Spatiales (CNES), with the goal of bringing together the hydrology and oceanography communities toward a better understanding of the world's oceans and its terrestrial surface waters. SWOT employs three remote sensing instruments: Ka-band Radar Interferometer (KaRIn), including the Near-Nadir Interferometer (NNI) or a Ka-band altimeter (KNA), and a radiometer. The KaRIn instrument employs two Ka-band Synthetic Aperture Radar (SAR) antennae placed at opposite ends of a 10-meter boom. The SWOT spacecraft also carries a Global Positioning System (GPS) receiver to augment in-flight calibration and to provide robust Precision Orbit Determination



Advanced Concepts and New Business

(POD), together with the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) data. The SWOT advanced microwave radiometer (AMR) is based on the Jason-3 radiometer developed within Division 38. AMR will provide path delay corrections for KaRIn and the nadir altimeter height measurements.

The SWOT Science Data System (SDS) is expected to ingest 7.3 Tb/day acquired by the KaRIN, the radiometer, and the Nadir altimeter instruments, process the data into 14 product types, and generate on average 21 TB of data products daily. The science data products are to be produced by both CNES and JPL; CNES is to process KaRIn data over Eurasia and all Nadir altimeter data and POD from DORIS, while JPL is to process KaRIn data for the rest of the world and the Radiometer data.

JPL's SWOT SDS will be based on the Division's evolving Object Oriented Data Technology (OOD-T)-based Process Control System (PCS) product line, sharing common infrastructure with and adapting common components from forerunning JPL missions, including the Orbiting Carbon Observatory, the National Polar-Orbiting Environmental Satellite System Preparatory Project (NPP) Sounder Product Evaluation and Analysis Tools Element (PEATE), and the Soil Moisture Active Passive (SMAP) mission.

Hyperspectral Infrared Imager (HyspIRI)

POC: Robert Green, Co-lead of Mission Concept

HyspIRI is another mission called for by the NRC's Earth Science Decadal Survey. Key science, applications, and climate objectives are:

- Climate: ecosystem biochemistry, condition and climate feedback; spectral albedo; soot/dust on snow and ice; biomass burning; and evapotranspiration.
- Ecosystems: global plant functional-type, physiological condition, and biochemistry, including agricultural lands.
- Water resources: water quality, evapotranspiration, and dust/soot on snow and ice.
- Fires: fuel status, fire occurrence, severity, emissions, and patterns of recovery globally.
- Coral reef and costal habitats: global composition and condition
- Volcanoes: eruptions, emissions, and regional and global impact
- Geology and resources: global distributions of surface mineral resources and improved understanding of geology and related hazards.

HyspIRI preparations: a) Concept for the HyspIRI spacecraft; b) Test measurements from the HyspIRI optimized visible & short-wave infrared (VSWIR) detector array; c) thermal IR read-out-integrated-circuit (ROIC). (d) Attendees at the 2012 HsypIRI Science Workshop. Credit: NASA/JPL-Caltech.

HyspIRI has three payload elements: a high SNR and high uniformity Visible-to-Short Wavelength Infra-Red (VSWIR) imaging spectrometer that measures the complete terrestrial and coastal regions every 19 days; a multispectral Thermal InfraRed (TIR) instrument with 8 bands between 4 and 12 microns, providing 5-day global land and coastal coverage; and a real-time direct broadcast capability to support science and applications with low latency measurements and products. In fiscal year 2012, the HyspIRI team completed an independent cost assessment, advanced the maturity of all three payload elements, and organized a community science workshop with 80 oral and poster presentations.

In Situ Science and Instrumentation for Primitive Bodies

Study Leaders: Jordana Blacksberg (JPL), John Eiler (Caltech), John Dankanich (Gray Research, Inc).
POC: Jordana Blacksberg

This Keck Institutes for Space Studies (KISS) study was to develop new methods to test the radically new understanding of Solar System formation that has recently emerged and to identify innovative instrumentation targeted to this purpose. While it is widely accepted that primitive bodies (asteroids, comets, meteorites, and interplanetary dust) hold secrets to unlocking that understanding, the task of how to access that primordial record presents a formidable challenge requiring wide expertise and innovative thinking. The first workshop included participants from diverse fields, including Solar System dynamics, planetary science instrumentation, isotope geochemistry, cosmochemistry, origins, planetary science, astrophysics, mineralogy, geology, and geophysics. This first workshop focused on identifying migrated bodies as candidates for more focused measurements and identifying preferred measurements that could provide evidence of their origins. The instrumentation for making these measurements was discussed, along with the performance goals of any future instrumentation developed for this purpose. The second workshop, scheduled for early 2013, will delve further into these questions and focus on some of the key instruments identified by the group.

Small Satellites: A Revolution in Space Science

Workshop Leaders: Charles Norton (JPL), Sergio Pellegrino (Caltech), Michael Johnson (JA)
POC: Charles Norton

Through the Keck Institute for Space Studies (KISS) a set of potential missions has been identified that could use small spacecraft (<500 kg), nano-spacecraft (<~10 kg), and spacecraft of even smaller size to satisfy key scientific objectives in astrophysics, heliophysics, and Solar System/planetary science. Inspired by rapidly developing technologies currently applied to CubeSats in low Earth orbit, the spectrum of missions was broadened to include investigations ranging from Earth orbit to cis-lunar space, and from Venus' atmosphere, through the inner Solar System, to Europa, Enceladus, Titan, Saturn's rings, and beyond.

KISS In Situ Science & Instruments Workshop participants. Credit: Keck Institute for Space Studies

xTerramechanics: Integrated Simulation of Planetary Surface Missions

Workshop Leaders: José Andrade (Caltech), Randel Lindemann (JPL), Karl Iagnemma (MIT).
POC: Randell Lindemann

The final report for this 2011 Keck Institute for Space Studies (KISS) workshop was delivered in fiscal year 2012, noting that regolith is the 'skin' of a celestial body that encodes its complex geologic processes. The ability to sense or infer the properties of regolith remotely or in-situ provides insight into a celestial body's geologic history. The workshop final report outlined how a successful research campaign must capture a wide range of physical phenomena: from small-scale granular physics and contact mechanics to large-scale spacecraft dynamics. The group described parallel modeling and characterization research campaigns to systematically and scientifically examine the underlying complexities of regolith in the context of space missions.

Next Generation Ultraviolet Instrument Technologies for Future Astrophysics, Cosmology, Planetary, and Heliophysics Missions

Workshop Leaders: Chris Martin (Caltech), Shouleh Nikzad (JPL), David Schiminovich (Columbia University)
POC: Shouleh Nikzad

The goal of the Keck Institute for Space Studies (KISS) study was to create a new paradigm in UV/Optical instrument design, detector technology, and optics that will form the technological foundation for the next generation of UV/Optical missions. This study built on discoveries from missions such as Galaxy Evolution Explorer (GALEX), Hubble Space Telescope, and Cassini as well as recent advances in related technologies.

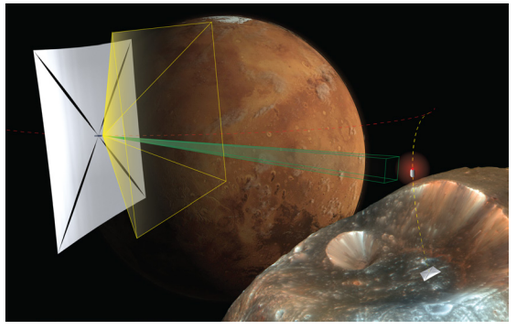
This study brought together a diverse international community and led to many new ideas and collaborations, bringing cohesion and common purpose to UV practitioners.

The study concluded that with UV technology developments within reach over the next 5-10 years, moderate-class and probe-class missions can be conceived that will answer many of the compelling science questions driving the field. One of the principal conclusions was that UV detector performance drives every aspect of the scientific capability of future missions and that two highly flexible detector technologies are at the tipping point for major breakthroughs. One of these is the Atomic Layer Deposition (ALD)-antireflection (AR) coated, delta-doped photon-counting detectors under development in the Division's Microdevices Laboratory (MDL). Other technologies with major impact include reflective coatings and nanotechnology-based advancements, including electron-beam fabricated UV gratings. Relatively modest investments in technology development over the next 5-10 years could provide advances in detectors, coatings, diffractive elements, and filters that would result in an effective increase in science capability by factors of 100-1000.

Interplanetary CubeSats-Opening the Solar System to a Broad Community at Lower Cost

Lead Investigators: Robert Staehle (JPL), Jordi Puig-Suari (CalPoly-San Luis Obispo), Louis Friedman (The Planetary Society), Tomas Svitek (Stellar Exploration)
POC and PI: Robert Staehle

Originally developed for operation in low-Earth orbit (LEO), within our sheltering magnetosphere, and communicating over distances of hundreds of kilometers, no CubeSats to date have gone beyond LEO. With coordinated advances in six technologies, CubeSats can be targeted for the Moon, asteroids, Mars, and high solar inclinations using a variety of achievable techniques. Advances were identified and, in some cases begun, in: a) surviving the radiation environment, b) telecommunications, c) solar sail and electric propulsion, d) navigation and the Interplanetary Superhighway, e) instrumentation, and f) onboard processing and autonomy. With these advances, focused science missions, and human exploration precursor missions, can be mounted at a fraction of the cost of "classical" Discovery and New Frontiers missions, albeit with smaller scope and higher risk tolerance. While some mission concepts, such as a Phobos Sample Return using two Interplanetary CubeSats, remain a decade or more in the future, others closer to Earth are feasible in the near term.



Far-out concept: Can two Interplanetary CubeSats retrieve a sample from Phobos or Deimos? The answer is probably "yes," in the decade starting 2026. The two solar sails shown are ~20 m on a side (one at lower right, on Phobos' surface), but are not to scale in this artist's concept. Credit: Ryan Sellers/CalPoly-SLO.

Therefore, the Division is supporting proposals for missions involving a variety of University, NASA, non-profit, and small business partners. This investigation was funded by the NASA Innovation Adv. Concepts (NIAC) program.

INSTRUMENTS & SCIENCE DATA SYSTEMS DIVISION

Instrument Systems Development

ANNUAL REPORT FY 2012

MARS/PLANETARY

ExoMars Climate Sounder (EMCS)

PI: John (Tim) Schofield
POC: Marc Foote

The ExoMars Climate Sounder (EMCS) is designed as an atmospheric limb sounding radiometer to map temperature, pressure, water vapor, water ice, CO_2 ice, and dust in the Martian atmosphere. EMCS is largely a build-to-print copy of the Mars Climate Sounder (MCS) instrument, which has been collecting Mars atmospheric data since 2006 aboard the Mars Reconnaissance Orbiter (MRO) spacecraft. The EMCS measurements would cover all Mars local times, adding a new dimension to data previously obtained from Sun-synchronous missions. EMCS was slated to fly as part of the science payload on the ESA Mars 2016 Trace Gas Orbiter mission; however, in 2012 NASA cancelled its delivery of science instruments for this mission.

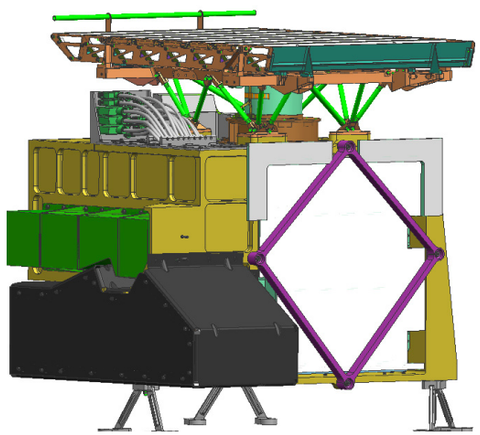
The EMCS team successfully completed its Preliminary Design Review in November 2011. After cancellation in early 2012, close-out funds were used to retire risks such that EMCS will be a viable, low-cost option for possible future Mars orbiters. The EMCS focal planes have been fully assembled and tested. A spectral filter development effort resolved issues in a filter meant for identifying water vapor in the Martian atmosphere. Most mechanical piece parts were fabricated and are ready for assembly. The electronics breadboard was assembled and tested with software and firmware. The two actuators for pointing the telescopes were partially assembled. All the work was captured to facilitate a smooth restart of this effort in the future.

EMCS will be a near copy of the Mars Climate Sounder instrument (shown), which is orbiting Mars on the MRO spacecraft.

ExoMars Mission Mars Atmospheric Trace Molecule Occultation Spectrometer (MATMOS)

PI: Paul Wennberg (Caltech)
POC: Wayne Hartford

The Mars Atmospheric Trace Molecule Occultation Spectrometer was proposed and selected for the ESA ExoMars Trace Gas Orbiter Mission as a partnership between the Division and an industrial/academic team led by the Canadian Space Agency. Among the targets of the investigation were methane, carbon, sulfur, sulfur dioxide, nitrogen-containing molecules, and hydrogen sulfide.



MATMOS Instrument Concept

The instrument concept is a solar occultation Fourier transform infrared spectrometer with a coaligned solar imager capable of parts-per-trillion sensitivity. This year saw cancellation of NASA's science instrument contributions to the TGO mission; however, a successful baseline design review was conducted before activities ceased.

ExoMars Trace Gas Orbiter (TGO)/ Science Operations Center (SOC)

POC: Steve Spohn

For the TGO SOC concept, the center would be located at JPL and would serve as the operational hub for all integrated TGO science planning activities, downlink instrument data processing, data management, science product distribution, and science data archive assurance. The SOC would have provided the operational interface between all five TGO instrument operations facilities, project relay operations facilities, and the ESA Mission Operations Center (MOC) located at the European Space Operations Center (ESOC) in Darmstadt, Germany.

The TGO SOC concept, including ground system architecture, interface descriptions, operations concepts, and overall design, has been fully leveraged in ongoing proposal activity and internal organizational planning. It is a tribute to the SOC team that their hard work has not been lost and that the SOC design is so adaptable to future mission concepts.

ExoMars Trace Gas Orbiter (TGO) Instrument Flight Software

POC: Alan Mazer

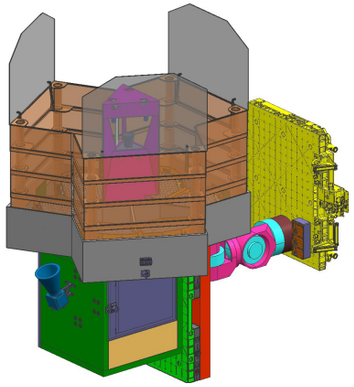
Both the MATMOS and EMCS instruments continued flight software development. MATMOS completed implementation and verification of all major science algorithms. Extensive algorithmic optimization reduced computational needs by two thirds, to a single RAD750 processor. Flight software successfully completed the MATMOS Baseline Design Review. EMCS passed Preliminary Design Review with no major issues and started software/electronics integration and testing. Flight software was fully prototyped at the close of the year.

ASTROPHYSICS

Optical Testbed and Integration eXperiment (OpTIIX) on the International Space Station (ISS)

POC: Mark Boyles

Optical Testbed and Integration eXperiment (OpTIIX) is in Phase B. The project received its start in December 2011, successfully completed its System Requirements and Mission Definition Review in March 2012, and successfully completed a Technical Preliminary Design Review (PDR) in September 2012. OpTIIX is a technology demonstration mission that is to assemble a 1.5-m telescope on the International Space Station. The project has two primary objectives: 1) assemble a telescope using ISS robots to alignment tolerances and 2) demonstrate near



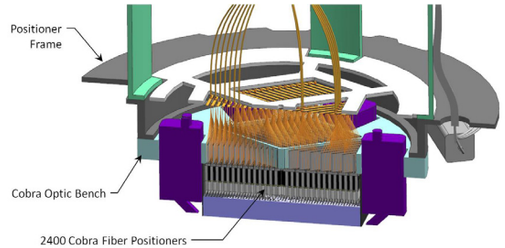
OpTIIX Assembled Configuration

diffraction-limited focusing using active hybrid mirror technology. Initial efforts have focused on finalizing Level-1 and Level-2 requirements, developing preliminary Level-3 and Level-4 requirements, developing the interface design with the ISS, and developing a preliminary design. If funding allows, next year's effort will focus on completing an implementation plan and gate products for Project PDR and developing the requirements, design, and analysis needed for Project Critical Design Review (CDR). One technical focus area will be pointing stability and control issues due to the high jitter environment on ISS. OpTIIX collaborators include JPL, Johnson Space Center (JSC), Space Telescope Science Institute (STScI), and Goddard Space Flight Center (GSFC).

Prime Focus Spectrograph (PFS)

PIs: Richard Ellis (Caltech), Michael Seiffert (JPL)
POC: Wes Schmitigal

The Prime Focus Spectrograph (PFS), in Phase B for a 2016 delivery to the Subaru telescope on Mauna Kea, will become the premier tool for addressing two dominant themes in contemporary astrophysics: the nature of the dark energy (DE) responsible for the cosmic acceleration and the assembly history of galaxies such as M31 and our Milky Way. Coordinated galaxy surveys delivering spectroscopic redshifts for more than 4 million galaxies will use baryonic acoustic oscillations and redshift-space distortions to bring a major advance in our understanding of dark energy; the potential for the first breakthrough in this area is high. Equally ambitious, Galactic Archaeology (GA) stellar surveys will provide kinematic and chemical abundance data in order to identify and study the history and nature of galactic sub-components and their relation to dark matter halos surrounding galaxies. The need for highly multiplexed multi-object spectroscopy (MOS) for these and other applications features prominently in the National Academy of Sciences *New Horizons, New Worlds (Astro2010)* Decadal Survey Report.



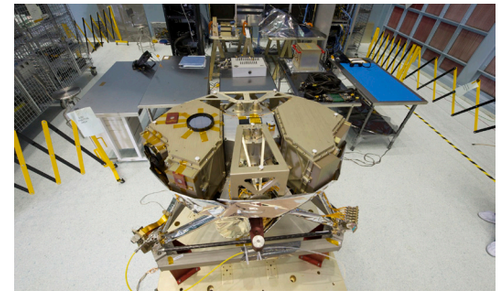
The Cobra optical bench supports the 2400 fiber positioners in a hexagonally close-packed array to form the focal plane.

The Division is providing the fiber positioning system and the system engineering for the portion of the instrument at the prime focus. The fiber positioner adjusts the positions of 2400 optical fibers in the prime focus image plane and is a key enabling element of the instrument. A hexagonally close-packed array of such elements will be mounted on an optical bench to form the focal plane. A set of prototype positioners has already demonstrated positioning accuracy and repeatability and is currently being used to develop collision avoidance software. The results from this prototype effort will feed the EM development, scheduled for 2013.

James Webb Space Telescope (JWST) Mid-Infrared Instrument (MIRI)

MIRI Focal Plane System and Cooler Subsystem

The MIRI Optical System Pre-ship and Acceptance Review was successfully completed in late 2011 with the following two issues related to the Focal Plane System: 1) instrument sensitivity loss and 2) spurious loss of detector data frames (i.e., occasional corrupted data frames). The Optical System was shipped to GSFC in May 2012 for the start of JWST Integrated Science Instrument Module (ISIM) integration and test. The Focal Plane System successfully completed all stand-alone post-delivery tests. The Focal Plane Electronics recently completed the pre-integration Electrical Isolation and Continuity Tests and an



The MIRI Optical Module in post-ship cleanliness inspection in a GSFC SSDIF cleanroom.

The MIRI Focal Plane Electronics assembly in post-delivery visual inspection in a GFSF SSDIF cleanroom.

Interface Verification Test (IVT). Also, two Focal Plane System characterization tests were conducted using the testbed at JPL. As a result, the majority of the sensitivity concerns have been retired — the FPS meets its requirements — and any residual issues will be dealt with in the data processing pipeline.

The investigation of the spurious data frame corruption found a command parameter trigger mechanism. The root cause for the trigger source is believed to be an error in the Signal Chain Electronics (SCE) FPGA. Potential risk reduction activities are being assessed at this time.

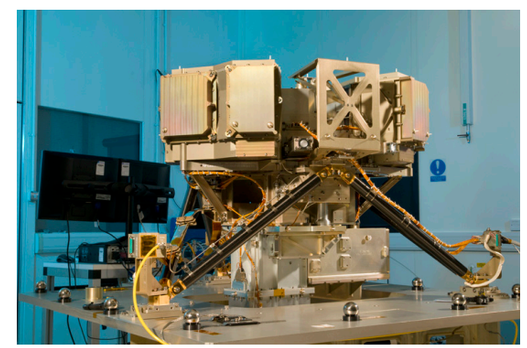
Development of the cooler subsystem continues. Progress has been made on the development of the electronics. Flight and spare Piloted By-pass Valves were delivered. The Division staff successfully completed a cryo-vacuum test of the Cold Head Assembly, which consists of a flight 6K Heat Exchanger, a non-flight 18K Heat Exchanger Stage Assembly, and non-flight 18K Refrigerant Lines.

MIRI Software

POC: Mori Khorrami
Project Scientist: Michael Ressler

One of the JWST instruments, Mid-Infrared Instrument (MIRI), contains both a mid-IR camera and an imaging spectrograph that is capable of measuring wavelength ranges from 5 to 27 µm. MIRI was developed through collaboration between JPL/NASA and ESA/EC (a consortium of European countries).

The MIRI flight focal plane system's hardware, flight software, and ground support equipment software were developed within the Division and delivered to our European partners in United Kingdom in 2011 to undergo integration and testing. Our partners conducted successful performance and thermal testing with the integrated instrument until early- to mid-2012. The instrument was then delivered to Goddard Space Flight Center (GSFC) in May 2012 for payload integration. At the same time, JPL delivered the flight version of flight software and the Project Reference Database (Command and Telemetry pages, parameters, and polynomial equations) to GSFC to be integrated into Integrated Science Instrument Module



MIRI Instrument Flight Model

(ISIM) flight software and GSFC ground software. Functional and performance testing were performed, and no problem reports were generated.

Also in fiscal year 2012, the Division delivered several interim versions of the MIRI Cryo-Cooler flight software application with its own ground software database to GSFC to support the on-going ISIM flight software integration testing.

EARTH SCIENCE

Orbiting Carbon Observatory-2 (OCO-2)

Project Scientist: Michael Gunson
POC: Thomas Glavich

OCO-2 is designed to provide space-based global measurements of atmospheric carbon dioxide (CO_2) with the precision and resolution needed to identify and characterize the processes that regulate this important greenhouse gas. With its three high-resolution grating spectrometers, data collected by OCO-2 could be combined with meteorological observations and ground-based CO_2 measurement to help characterize CO_2 sources and sinks on regional scales at monthly intervals for 2 years.

OCO-2 Instrument fabrication and calibration were completed in during fiscal year 2012. Instrument performance is excellent, with slit alignment (a critical parameter for atmospheric retrieval) meeting specification and radiometric performance well above the minimum specification. The instrument was delivered to Orbital Science Corp. (Gilbert, Arizona) and is currently integrated with the Orbital spacecraft. Several functional tests with the spacecraft have been completed, including a 7-day "Week-in-the-Life" test. Spacecraft testing is underway, with a thermal vacuum test planned for late in calendar year 2012. Additional spacecraft components will be added in early summer 2013, followed by final performance testing.

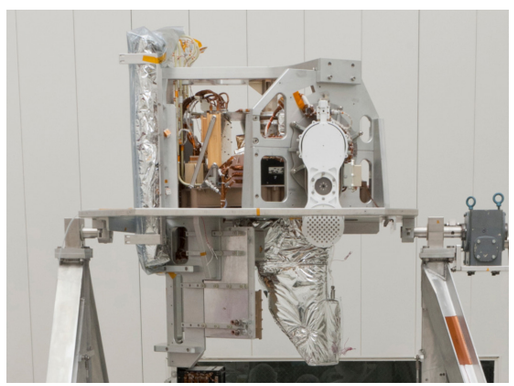
OCO-2 Science Data Operations System (SDOS)

POC: Charles Avis

The Science Data Operations System (SDOS) continued to process Greenhouse Gases Observing Satellite (GOSAT) CO_2 observations into Level-2 science products for public release. A reprocessing campaign was conducted using all GOSAT data back to 2009. Subsequently, Japan Aerospace Exploration Agency (JAXA) began delivering an updated Level-1B product, initiating another reprocessing campaign.

During the year, SDOS software development followed two tracks. The most time-critical track kept pace with instrument development. SDOS supported packet analysis from the flight and spare electronics boards and assemblies. This was followed by round-the-clock processing support for full instrument testing during four sets of Thermal/Vacuum testing. Later, during the spacecraft Thermal/Vacuum testing, daily processing of Solid State Recorder dumps was supported.

The second development track has progressed toward a flight-ready system in the areas of telemetry handling, processing infrastructure, geolocation, and data simulation. While SDOS generated significant amounts of



OCO2 Instrument Before Integration

simulated OCO-2 telemetry packets, Colorado State University delivered to SDOS simulated Level-1B products. Major updates to the processing control infrastructure were completed in the areas of database structure, control flexibility, scheduling algorithms, and performance of components.

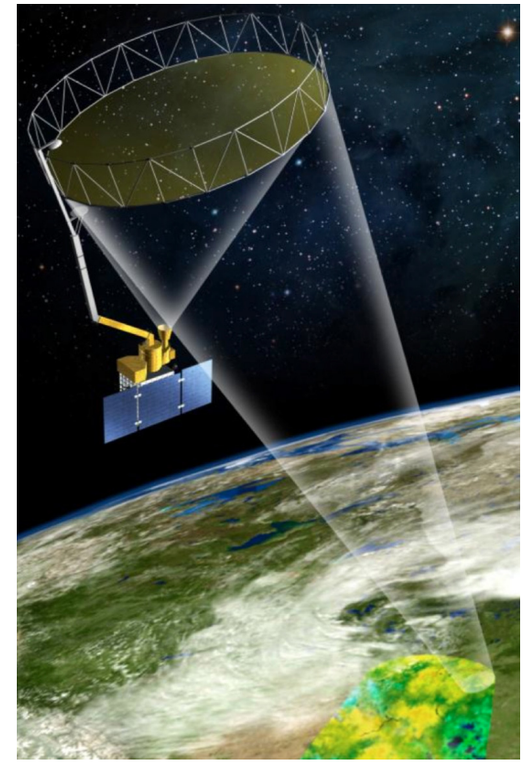
With the launch delay, the planned Verification & Validation process became a testing exercise for when the actual process occurs nearer the new launch date. A snapshot of the development flight system was built, procedures written, simulation data provided, procedures executed, and results analyzed during this useful exercise.

Progress was achieved on prototyping the use of the Pleiades supercomputer at Ames Research Center as a Level-2 reprocessing resource for SDOS. An interface was designed and implemented between the OCO-2 cluster and Pleiades. The various components (upload, download, monitor, etc.) were tested successfully on 590 simulated OCO-2 orbits. Incorporation of Pleiades into the baseline OCO-2 reprocessing plan will now be undertaken.

Soil Moisture Active Passive (SMAP) Science Data System

POC: Jennifer Cruz

Soil Moisture Active Passive (SMAP) is a tier-one mission recommended by the National Research Council Earth Science Decadal Survey (2007). The primary science objectives are: global, high-resolution mapping of soil moisture and; its freeze/thaw state to link terrestrial water, energy, and carbon-cycle processes, estimate global water and energy fluxes at the land surface, and quantify net carbon flux in boreal landscapes. SMAP launch is set for October 2014, on a Delta II. During this year, the SMAP SDS developed its detailed design and has started implementation. The SDS supports a three year science mission, processing 135 GB raw data per day, automatically producing 350 products daily, with an



SMAP in Orbit (Artist's Concept)

750 TB end-of-mission storage. The system is sized to accommodate simultaneous reprocessing. The science data products will be hosted at the Alaska Satellite Facility, and the National Snow and Ice Data Center for community distribution.

Partnering with science algorithm development team, JPL radar processing team, GSFC radiometer processing and model analysis teams, detailed design of the processing algorithms, data and control flows are formed for the Level-1, Level-2, Level-3, and Level-4 scientific processors. Ancillary data types necessary for calibration/validation, and product generation are identified. Ancillary data vary in frequency from multiple products in a day, to daily, weekly, monthly, or never. Detailed design is in place to manage the variety and frequency.

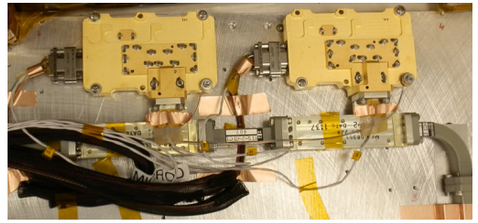
The SDS architecture leverages Apache Object-Oriented Data Technology (OODT) components, and a processor interface framework. The OODT architecture framework has been used for other earth missions, and includes workflow, file and resource manager. The processor interface framework includes are run-time configuration interface, HDF5 product input/output, ISO 19115 metadata series, uniform framework for handling variable bit-flags in data products, message handling to track run and error conditions. This model and design pattern is employed to integrate 28 processors with the processing and file management.

Jason-3 Advanced Microwave Radiometer (AMR-2)

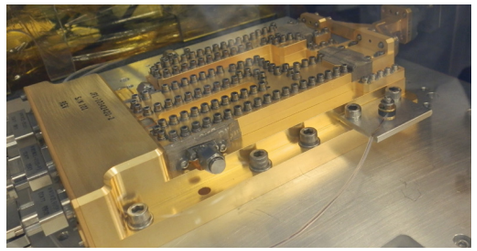
POC: Ami Kitiyakara

Continuing the multi-decadal ocean topography measurements of Jason-2, the Jason-3 project entered Phase C in October 2011, with a target launch date of April 8, 2014. Nearly one year later, the receivers, noise sources, and electronics unit were delivered for integration and testing to Jason-3 instrument integration and test in August/September 2012.

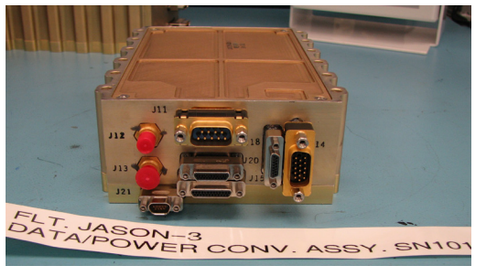
Signaling a transition to operational ocean altimetry, NOAA and EUMETSAT are now the lead agencies with NASA/JPL and implementation support provided by CNES. Among Jason 3's key roles are to provide insight into global climate phenomena such as El Niño and La Niña, to monitor the pattern of global sea level rise, and to improve models used for hurricane forecasting and predicting individual storm severity. The Division, in collaboration with CNES, developed the Advanced Microwave Radiometer-2 (AMR-2) for Jason-3, which measures the altimeter signal path delay due to tropospheric water vapor, a key element in meeting the Jason 3 science requirements. Jason-3 AMR-2 maximized the design inheritance from the successful Ocean Surface Topography Mission (OSTM) AMR instrument while seeking to reduce both development and performance risk. The design effort of Jason 3 AMR-2 incorporates experience from both OSTM AMR and Juno Microwave Radiometer to position the Division as a leader in ultra-stable radiometer design.



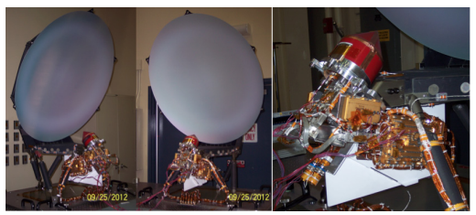
Jason 3 two noise sources



Jason 3 Flight Receiver



Flight Electronics Before Its Delivery to Instrument Integration and Test



Jason 3 Antenna II&T effort. Primary and redundant receivers, noise sources, and electronics units are integrated on the telescope. A close-up is provided on the right side.

Jason-3 Assistive Radiometer Calibration System (ARCS)

PI: Joshua Willis
POC: Guy Builta

A significant new development on the Instrument Data System is the Assistive Radiometer Calibration System (ARCS). This is a web-based tool that will be used by science experts to calibrate the Advanced Microwave Radiometer. Using this tool, an end user can manipulate numerous calibration coefficients and see the effect on various critical metrics through a single unified interface. This workflow replaces a relatively ad-hoc set of tools used by calibrators on Jason-2 and Jason-1 and will reduce the turn-around time on the verification of calibrations to be used in final data products. Given the similarity of the OSTM/Jason-2 mission, the tool is being built against the Jason-2 data archive that provides a robust set of representative in-flight data. Also, since radiometers on the two Jason missions are nearly identical, there is hope that the tool can be back-ported to provide additional value to the older missions.

Cubesat Hydrometric Atmospheric Radiometer Mission (CHARM)

PI: Boon Lim
POC: Michael Shearn

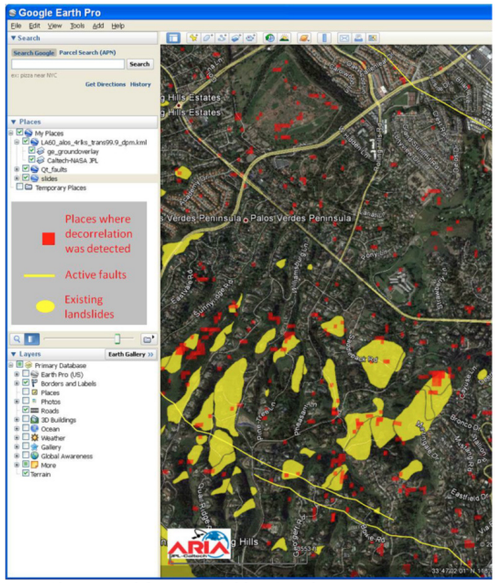
As part of the Phaeton program, JPL is developing the Cubesat Hydrometric Atmospheric Radiometer (CHARM) instrument. This program provides an opportunity for early career personnel to develop leadership and technical skills, with the mentorship of senior staff members. CHARM is a microwave radiometer observing the 183 GHz water vapor line, packaged to fly on a 3U Cubesat. The goal of this project is to advance the radiometer system to TRL6. CHARM represents a step in changing the paradigm of spaceborne Earth Science measurements utilizing physically smaller and significantly cheaper spacecraft to both distribute risk and improve revisit time.

Advanced Rapid Imaging Analysis for Earthquakes (ARIA-EQ) Data System

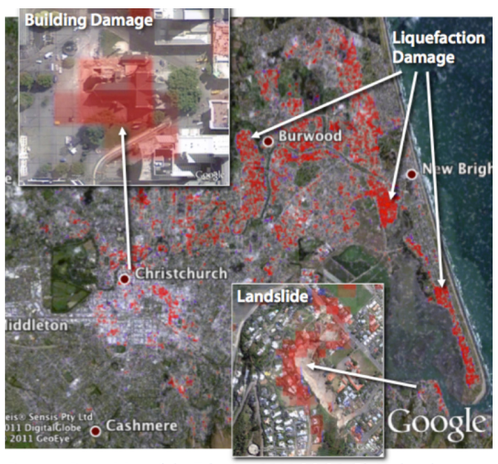
PI: Susan Owen
POC: Jennifer Cruz, Hook Hua

Advanced Rapid Imaging Analysis for Earthquakes (ARIA-EQ) is a strategic initiative to develop an earthquake hazards geodetic imaging prototype system producing reliable monitoring products, and near real-time science and assessment products for decision-making agencies and the public following an earthquake. This effort builds an end-to-end prototype geodetic imaging data system that would form the foundation for an envisioned operational hazard response center. The prototype science data system integrates the automatic ingestion and analysis of InSAR, GPS, seismology, and modeling to deliver near real-time products for situational awareness following an earthquake, as well as science and monitoring products as part of its nominal processing mode.

This year the team implemented an on-demand Damage Proxy Map generation capability with



Data Sharing Tool for use in Golden Guardian 2012 Exercise, developed Earthquake Product Annotation Tool



Damage Proxy Map of the February 2011 M 6.3 Christchurch Earthquake in New Zealand. Red pixels overlaid on top of Google Earth image indicate likely damage of various kinds: 1) building damage, 2) landslide, 3) extensive liquefaction damage. A pair of InSAR coherence from ALOS PALSAR data were used.

ALOS PALSAR data that indicates damage of various types (e.g., building damage, landslide, liquefaction damage). An automated GPS station position data ingestion capability was implemented that includes quality control analysis on GPS Sub-daily and Daily positions producing periodic QC reports. EnviSAT Interferogram processing and data management capabilities allow teams to generate and analyze historical data to establish trends and baselines.

In addition to the development of the prototype data system, ARIA provided geodetic imaging products to the science and response community following several earthquakes: 2011 M7.1 Van earthquake in Turkey, 2012 Brawley seismic swarm, and 2012 M7.6 Costa Rica quake. The team participated in the California Golden Guardian earthquake exercise.

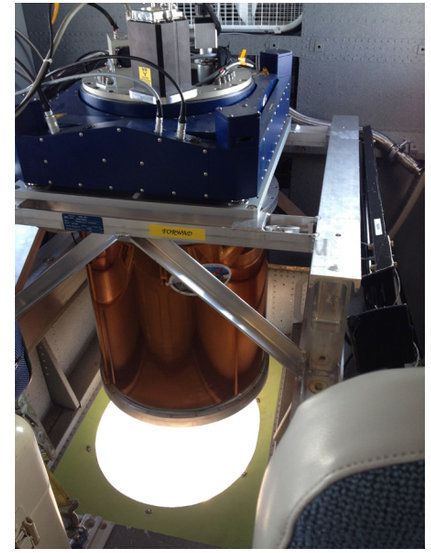
Hyperspectral Thermal Emission Spectrometer (HyTES) Software

PI: Simon Hook
POC: Bjorn Eng

The Hyperspectral Thermal Emission Spectrometer (HyTES) is an airborne instrument developed at JPL under the Instrument Incubator Program. The imaging instrument has 512 pixels across track and 256 spectral channels between 7.5 and 12 microns in the Thermal Infrared. The instrument was designed and built at JPL and the detector array, using QWIP technology, was developed and fabricated by JPL's Microdevices Laboratory (MDL).

HyTES data will provide a completely new measurement capability to Earth scientists working with Thermal data. The high spectral resolution is intended to provide precursor science data and guidance for thermal band placement for the proposed upcoming HysPIRI satellite mission. The Division provided the Environmental Control System software and are developing software for geo-location of HyTES data products.

The instrument flew its first engineering flights on a Twin Otter aircraft in July 2012. Initial data were collected in the corridor between Grand Junction CO and Burbank CA. Sites included geological and ecological targets as well as areas of gas emissions.

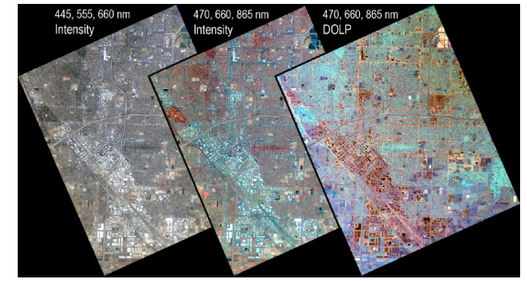


HyTES installed in Twin Otter

Airborne Multiangle SpectroPolarimetric Imager (AirMSPI)

PI: David Diner
POC: Veljko Jovanovic

JPL's Multiangle SpectroPolarimetric Imager (MSPI) concept is a follow-on to the Multi-angle Imaging SpectroRadiometer (MISR). MSPI will extend the observations from the visible and near-infrared (VNIR) to the ultraviolet (UV) and shortwave infrared (SWIR), and also include high-accuracy measurements of polarization, which will improve sensitivity to aerosol particle size and refractive index. MSPI is a candidate for the Earth Science Decadal Survey's Aerosol-Cloud-Ecosystem (ACE) mission, which aims to study the impacts of aerosols and clouds on climate.



AirMSPI imagery over Fresno, acquired on 6 January 2012. From left to right are: natural color intensity, false color intensity, and false color degree of linear polarization (DOLP). The images cover an area about 11 km wide and have a spatial resolution of about 10 m.

In collaboration with the University of Arizona and the University of Texas, JPL has developed an airborne prototype instrument, AirMSPI, which operates in the UV/VNIR. AirMSPI has been flying on NASA's High-Altitude Airborne Science Aircraft ER-2 since October 2010. On 6 January 2012, AirMSPI acquired imagery over Fresno, California. Skies were clear but hazy during the overflight. Detailed modeling of the imagery shows the AirMSPI radiance and polarization measurements to be consistent with aerosol properties measured independently by a ground-based Sun photometer stationed at the Fresno Aerosol Robotic Network site.

In July and August 2012, AirMSPI flew in conjunction with other ER-2 instruments, in preparation for an Aerosol-Cloud-Ecosystem (ACE) field experiment scheduled to take place in early 2013. During the August flights, AirMSPI made use of NASA's Airborne Science Data Acquisition and Transmission (NASDAT) unit, which has recently become operational on the ER-2. Using Iridium satellite downlinks, this system allows real-time monitoring of the AirMSPI instrument status in flight.

The MSPI team is currently developing a second-generation instrument, AirMSPI-2, which extends the spectral range into the SWIR. The optical system for this new instrument is complete, and the focal plane is currently being built.

Airborne Snow Observatory (ASO) Data System

PI: Thomas Painter
POC: Chris Mattmann

In the western United States, snowmelt runoff drives the water system, providing more than 75% of the total freshwater. However, we face significant water resource challenges due to the intersection of increasing demand from population growth and changes in runoff volume and timing due to climate change and acceleration of snowmelt by dust. The two most critical properties for understanding snowmelt runoff and timing are the spatial and temporal distributions of snow water equivalent (SWE) and snow albedo. JPL has created the Airborne Snow Observatory (ASO), an imaging spectrometer and scanning LiDAR system, to quantify SWE and snow albedo, generate unprecedented knowledge of snow properties, and provide complete, robust inputs to water management models and systems of the future.

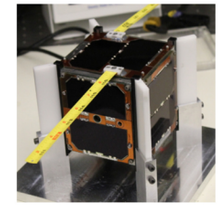
ASO will be evaluated during a multi-year Demonstration Mission of weekly acquisitions in each of the Uncompahgre River Basin (Upper Colorado) and the Tuolumne River Basin (Sierra Nevada) beginning in spring 2013, anchored by snow-free acquisitions in summer 2012. Against the baseline snow-free LiDAR measurements, co-registered weekly maps of snow water equivalent and snow albedo will be made available to partner water managers and the snow hydrology community with sub-24 hour latency. In turn, we will compare forecast total volumes and timing driven by current, limited data sources with modeled forecasts driven by the comprehensive products from the ASO. In the Uncompahgre, we will use the DHSVM hydrologic model and migrate it to Bureau of Reclamation/Tri-Country Water operations at the Ridgway Dam. In the Tuolumne, we will use the existing USGS Precipitation-Runoff Modeling System hydrologic model. Both models will leverage the ASO data for markedly improved forecasts. The Division is leading the algorithm processing and data management team for ASO.

Earth System Grid Federation (ESGF)

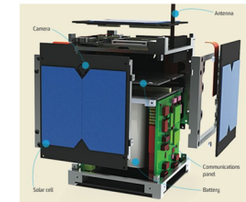
POC: Luca Cinquini

In summer 2012, the Earth System Grid Federation (ESGF) started operating a next-generation system for distribution and analysis of climate data worldwide, with particular emphasis on supporting the forthcoming 5th Assessment Report of the International Panel on Climate Change (IPCC-AR5). ESGF is a multi-agency, international collaboration that includes the Department of Energy (DOE) (PCMDI, ORNL, ANL etc.), NASA (JPL, GSFC, LaRC), the National Oceanic and Atmospheric Administration (NOAA) (GFDL, ESRL, PMEL), and other agencies and institutions around the world.

The new system is based on a federated architecture that allows real-time global searches, single-sign-on, distributed access control, and dynamic service availability via the underlying Peer-To-Peer (P2P) protocol. Overall, the system is composed of approximately 20 Nodes deployed in four continents (North America, Europe, Asia, and Australia) that, together, allow access to a global archive of more than 2 PB of climate model output, as well as supporting observations (obs4MIPs) and reanalysis (ana4MIPs) data. In particular, the JPL Node hosts several of the obs4MIPs datasets (AIRS, AMSRE, AVISO, MLS, MODIS, QuikSCAT and TES), which are Level-3 regridded products formatted specifically for easy comparison with models. The datasets are associated with scientific technical notes, written collaboratively by the NASA science and data preparation teams, that contain a wealth of information about the most appropriate use of these observations when comparing and validating climate models.

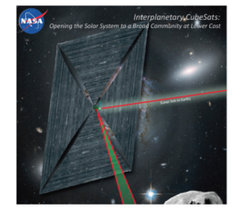


M-Cubed/COVE (NASA ESTO)
High data-rate on-board processing
P. Pingree: JPL, U. Michigan
Launched VAFB: Oct. 28, 2011 (NASA CLI)

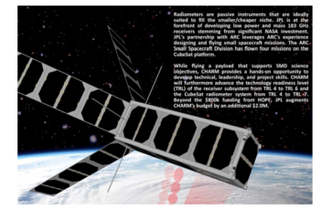


IPEX (NASA ESTO)
Autonomous low-latency product generation
S. Chien: JPL, GSFC, Cal Poly SLO
Launch Manifest: Sep. 2013 (NASA CLI)

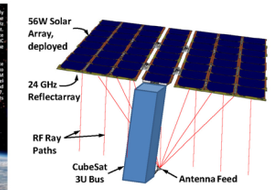
GRIFEX (NASA ESTO)
Unprecedented frame-rate ROIC/FPA
D: Rider JPL, U. Michigan
Launch Awarded (NASA CLI)



Interplanetary Concepts
Communications, Propulsion, Imaging
R. Staehle: JPL, Stellar, Cal Poly SLO
NASA Inst. for Adv. Concepts (NIAC)



CHARM (HOPE)
Hydrometric Atmospheric Radiometer
B. Lim: JPL, ARC
Launch Awarded (NASA CLI)



ISARA (EDISON)
Integrated Solar Array & Reflectarray Antenna
R. Hodges: JPL, Pumpkin Inc.
Launch TBD

At the End of FY2012 There Were Six Funded Cubesat Projects at JPL, of Which the Division Was Involved in 4 Plus the Interplanetory Concept Development. More Are Expected.

Small Satellite Development at JPL

POC: Charles Norton

JPL's presence within the small satellite community expanded in many directions over the past year. JPL's first CubeSat payload, Michigan Mulitpurpose Mini-satellite (MCubed)/CubeSat On-Board Processing Validation Experiment (COVE), was launched in 2011 to flight validate new on-board processing hardware and algorithm technology to support the Space Multiangle SpectroPolarimetric Imager (MSPI) instrument design for the Aerosol-Cloud-Ecosystem (ACE) mission concept. The team is working toward a reflight of this experiment in October 2013. The Intelligent Payload Experiment (IPEX) CubeSat, designed in partnership with NASA-GSFC and Cal-Poly San Luis Obispo to flight validate autonomous processing, control, and low-latency product generation in support of the HyspIRI mission concept, will also launch in October 2013, demonstrating the Intelligent Payload Module (IPM) capabilities. GEO-CAPE Readout Integrated Circuit In-Flight Performance Experiment (GRIFEX), a 3U CubeSat that will perform engineering assessment of a state-of-the-art hybridized Readout Integrated Circuit (ROIC) supporting development of the Panchromatic Fourier Transform Spectrometer (PanFTS) instrument for the Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission concept, has also been manifested for launch with spacecraft completion planned for fiscal year 2013. NASA's Earth Science Technology Office (ESTO) sponsored these projects, developed in collaboration with our partners at the University of Michigan and CalPoly SLO.

Competed solicitations have been announced within NASA's Office of Chief Technologist (OCT), Earth Science Technology Office (ESTO), and Second Stand Alone Mission of Opportunity Notice (SALMON-2). JPL won the Integrated Solar Array and Reflectarray Antenna (ISARA) project, from the NASA OCT Edison Program, to develop an innovative reflectarray

antenna integrated into a deployable solar panel array to demonstrate 100 Mbps Ka-band downlink. Furthermore, proposals are in development for new flight opportunities from ESTO's In-Space Validation of Earth Science Technologies (InVEST) NASA Research Announcement (NRA) and for science measurements in astrophysics from the SALMON-2 MoO. Flight opportunities have been won from NASA's CubeSat Launch Initiative (CLI). In addition, the CubeSat Hydrometric Atmospheric Radiometer Mission (CHARM) 3U CubeSat won a Hands-on Project Experience (HOPE) solicitation to fly radiometers for atmospheric science measurements.

JPL is actively developing concepts to extend SmallSats beyond low-Earth orbit (LEO). This includes a recently completed NASA Innovative Advanced Concepts (NAIC) study of interplanetary CubeSat mission and technology development as well as the Keck Institute for Space Science study program called Small Satellites: A Revolution in Space Science. Other internal workshops investigating CubeSat missions for near-Earth objects (NEOs), small bodies and radio astronomy have also been held within JPL. New publications have also been presented at major conferences and mission concepts are being explored for ESPA-class (<200 kg) scientific observations. This is a fast-moving field with deep interest for targeted scientific missions and technology risk reduction.

Early Detection Research Network (EDRN)

POC: Chris Mattman

The Early Detection Research Network (EDRN) of the U.S. National Cancer Institute (NCI), consisting of a research network of collaborating scientists from more than 40 institutions, is focused on identifying and validating cancer biomarkers at their earliest stages. "The work of the EDRN is concentrated on … the discovery of markers, the validation of markers in distinguishing the presence or absence of cancer, and testing markers for the ability to detect preclinical and early-stage disease." The EDRN was founded in 2000 and is currently led by the Cancer Biomarkers Research Group, the Division of Cancer Prevention, National Cancer Institute. It is comprised of Biomarker Discovery Laboratories, Biomarker Reference Laboratories, Clinical and Epidemiological Centers, and a Data Management and Coordinating Center. The Jet Propulsion Laboratory serves as the lead informatics center. For details, see www.cancer.gov/edrn and http://cancer.jpl.nasa.gov and http://edrn.jpl.nasa.gov

Critical to EDRN's mission is having an informatics infrastructure that is "biomarker-centric". This involves having a core ontology model that describes the elements of biomarker research that span the entire spectrum of activities of the EDRN investigators: i.e., from tissue banking, to managing information about proposed biomarkers, to validation studies. Capturing the information into a "virtual data grid" allows EDRN to construct the EDRN Knowledge Environment, which serves as an online, distributed resource of data and information described in EDRN's core ontology. The EDRN Knowledge Environment promises to dramatically improve the capability for scientific research by enabling real-time access to a variety of information that crosses institutional boundaries. There are clear scenarios for how such a system can improve the discovery process; flexibility and agility are at the core, given the dynamic nature of cancer biomarker research.

INSTRUMENTS & SCIENCE DATA SYSTEMS DIVISION

Operational Missions

ANNUAL REPORT FY 2012

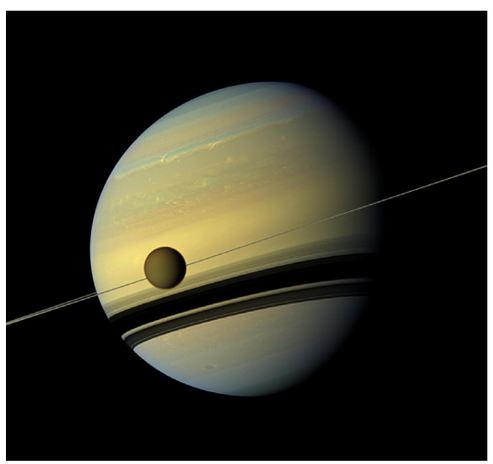
Solar System Exploration and Mars

Cassini

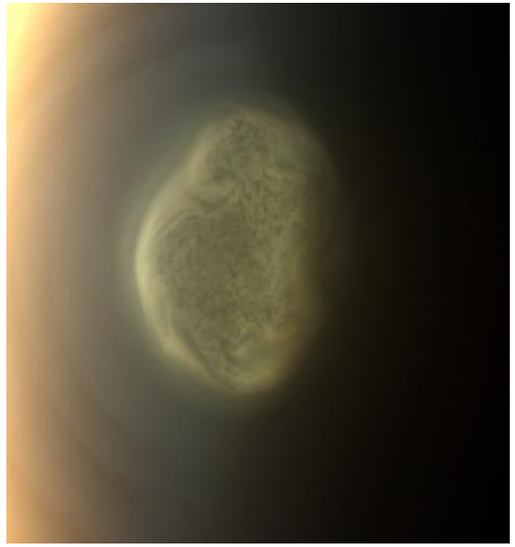
Imaging Science Subsystem (ISS) and Visual and Infrared Mapping Spectrometer (VIMS)

POC: Sue Linick/James Gerhard

The Cassini Solstice mission continued into its second Earth year with the approach of northern summer. Fiscal year 2012 was the first year where a significant workforce reduction was fully realized, and operations continued successfully. The Cassini instrument team commands, processes, and distributes data from the two Cassini instruments built in Division 38: the Imaging Science Subsystem (ISS) and the Visual and Infrared Mapping Spectrometer (VIMS). These two instruments continue to operate flawlessly, returning data from numerous Saturn encounters, six Enceladus flybys, eight Titan encounters, and numerous icy satellite flybys. During this year 24,731 ISS images and 14,572 VIMS 3-dimensional spectral data cubes were collected, processed, and distributed to science teams around the world.



Cassini Rings: Saturn and its largest moon, Titan, show spectacular colors.



Cassini Titan: This image depicts the newly discovered south polar vortex in the atmosphere of Titan, reported recently by Cassini scientists.

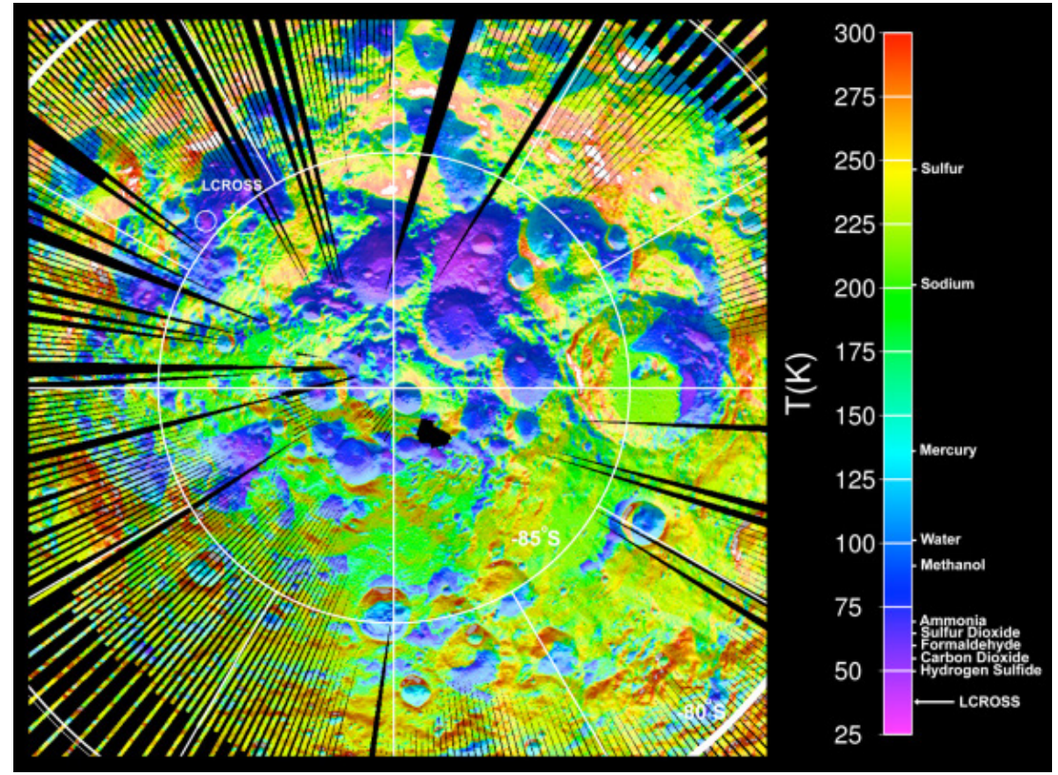
Diviner on Lunar Reconnaissance Orbiter

PI: David Paige (UCLA)
POC: Frank Leader

The JPL Diviner Science Operations Center (SOC) supports the commanding and instrument health monitoring of the Diviner Lunar Radiometer instrument and the receipt, processing, and distribution of the instrument's data. The SOC is the main interface between the science team and the Lunar Reconnaissance Orbiter (LRO) spacecraft team located at Goddard. Multi-mission tools are used to support instrument health and safety monitoring, manage the data processing pipeline (Multi-mission Automated Task Invocation Subsystem - MATIS), and enable a secure and automated distribution of data (File Exchange Interface - FEI).

During FY 2012, the Diviner instrument collected science data continuously, without commanding errors or instrument anomalies and with a normal 98% data return. In addition to continuous operations, the uplink engineers supported monthly calibration and several special activities, such as a total lunar eclipse, and multiple observations of off-nadir targets. The downlink team supported four Planetary Data System (PDS) archive deliveries. The deliveries included Diviner prelaunch calibration reports and data and instrument-specific SPICE (Spacecraft and Planet Ephemeris Instrument, C-Matrix, Events) kernels, along with the nominal Experiment Data Records (EDR) and Level-1B products.

The SOC receives Diviner data from Goddard and automatically sends it to monitoring, processing, and distribution tools. The SOC runs in a 24/7 lights dim automated environment producing EDRs, Level-1A -1B products that are distributed to UCLA and Oxford. The downlink team ensures that all data has been received and distributed, manually processes files not supported by the automated pipeline, and re-processes the Diviner dataset quarterly to ensure that a uniform dataset is delivered to the PDS. During FY 2012, the downlink team interacted with the science team to improve the geometry and calibration algorithms that are used in the generation of the Level-1B products and with multi-mission tool developers to improve the flexibility of the workflow manager software based on operations experience.



Diviner's South Pole Daytime Temperature Map. The color scale shows the maximum temperature at which a particular icy compound would remain frozen.

Juno Microwave Radiometers (MWR)

PI: Michael Janssen
POC: Payam Zamani

The Juno spacecraft successfully performed a deep space maneuver on September 3, 2012, and is on its way toward Earth for a gravity assist on October 9, 2013. The spacecraft, instruments, and subsystems are performing normally.

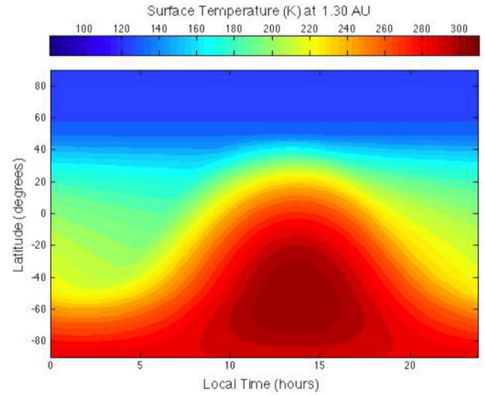
The Science Analysis Sub-system (SAS), supported by Division 38, performed non-science systematic processing and distribution of raw science products for all instruments in support of instrument checkouts and cruise science. On average, the load of science products has been around 20,000 files per week.

Division 38 also provides Level-1 science processing for the Microwave Radiometer (MWR) instrument. MWR is one of the three instruments active during cruise.

Microwave Instrument on the Rosetta Orbiter (MIRO)

PI: Samuel Gulkis
POC: Lucas Kamp

The Microwave Instrument on the Rosetta Orbiter (MIRO) team continues to work on plans for observations of comet *67P/Churyumov Gerasimenko;* these observations will start soon after the Rosetta spacecraft emerges from its hibernation in January 2014. For the science planning, the MIRO team has been developing forward and inverse models for comet properties from MIRO observations. Several new modeling capabilities have been added, including lateral heat transport in thermal models, the optimal estimation method for retrieval, and the escape probability method for molecular excitation calculations. In addition to the support of MIRO science planning, these models are currently



MIRO Thermal *Model results for the thermal profile of the comet 67P/Churyumov Gerasimenko nucleus.*

being used to support the Rosetta lander team and the flight dynamics team's characterization efforts.

This year, the team prepared two papers on asteroid analysis using a wide range of wavelengths. The first paper focused on *Lutetia*, which *Rosetta* encountered in 2010, and combined MIRO microwave data with infrared data from the VIRTIS instrument to demonstrate that combining these datasets greatly enhanced the diagnostic capabilities of the observations. This paper was published in August 2012. The second paper applied similar techniques to published Earth-based flux measurements from the infrared to centimeter wavelengths for four asteroids and is being prepared for submission.

Planetary Data System (PDS) Engineering Node (EN)

POC: Emily Law

The Engineering Node (EN) continued to make significant contributions to the overall PDS data collection and archiving efforts for FY 2012. The EN completed a number of operational data and software deliveries. The EN has been instrumental in leading the upgrade of the PDS and standards to the next generation, called "PDS4". PDS4 moves the data system into the era of Service Oriented and Model Driven Architectures, integrating both the PDS and international partners into an era of sharing distributed data and software services. This year, the effort included the development of the PDS4 system infrastructure, along with a corresponding upgrade to the data standards that will be used by Mars Atmospheric and Volatile EvolutioN (MAVEN) and Lunar Atmosphere and Dust Environment Explorer (LADEE) missions. A transition plan has been established to ensure existing mission pipelines will not be impacted and that the new system will support both current and new data standards (PDS3 and PDS4 respectively). The EN was also instrumental in driving the International Planetary Data Alliance (IPDA) by chairing the IPDA Steering Committee and successfully leading and completing multiple projects enabling adoption and international use of PDS standards and tools. In addition, we supported a number of outreach and networking activities including European Planetary Science Congress (EPSC)/ Division for Planetary Sciences of the American Astronomical Society (AAS) Joint Meeting 2011, PV 2011 (Ensuring Long-Term Preservation and Adding Value to Scientific and Technical Data 2011), American Geophysical Union (AGU) 2011, 2012 Planetary Data Workshop and Committee on Space Research (COSPAR) 2012.

Instrument Operations Subsystem (IOS) - Multi-Mission Instrument Processing Laboratory (MIPL)

POC: Steve Spohn

The Instrument Operations Subsystem (IOS) resides within the Multi-Mission Ground Systems and Services (MGSS) program office and is a critical element of the Advanced Multi-Mission Operations System (AMMOS). IOS provides a broad range of tools and services that support a project's instrument ground data processing requirements. The IOS sponsors a robust infrastructure facility, known as the Multi-Mission Instrument Processing Laboratory (MIPL), designed to be highly scalable and quickly deployed to support multiple projects' development, test, and/or operations activities.

Currently, the IOS and MIPL are providing tools and services to twelve flight missions in development and operations. This support includes robust MIPL infrastructure services provided for instrument data retrieval, storage, production, distribution, and archive activities. Currently, the IOS and MIPL are providing tools and services that support pipeline processing for more than twenty remote instrument teams.

IOS-MIPL project highlights for FY 2012 included: Successful transition to MSL surface operations. This included support for time-critical pipeline processing and display for tactical products and specialized 3-D, stereo, and surface-context products.

Successful Juno launch, instrument checkout, and cruise operations were supported, including specific MWR instrument processing.

Lunar Mapping & Modeling Project (LMMP)

POC: Emily Law

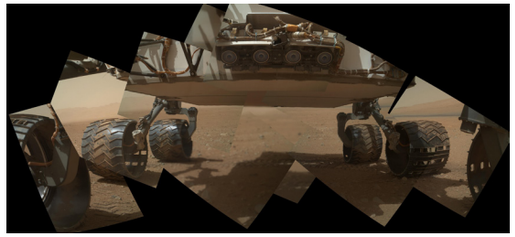
During FY 2012, JPL continued to make significant contributions to the Lunar Mapping & Modeling Project (LMMP) project. Specifically, Division 38 has taken on the project management responsibility for coordinating multi-division support of LMMP, in addition to playing a key role in leading the development effort and providing systems engineering and integration support to the project. We also continued to make significant contributions to the LMMP information system's underlying infrastructure, including new releases of an interoperable geographic information systems, data management systems and tools, and the LMMP portal, as well as mobile applications (such as iPhone, iPad, Android devices) for access to the lunar map and model products. These products

include maps and models generated from the Lunar Reconnaissance Orbiter, Lunar CRater Observation and Sensing Satellite (LCROSS), as well as other historical lunar missions. LMMP was showcased on the Hyperwall at the NASA HQ lobby this summer, as well as at various conferences, including the Fall AGU (December 2011), the Lunar and Planetary Science Conference (March 2012), the Planetary Data Systems (PDS) Data Developer Workshop (June 2012), and the Lunar Science Forum (July 2012). The team also participated and gave talks and demonstrations at the Columbia Memorial Space Center and Mount Gleason Middle School in support of the "International Observe the Moon Night" events. Link: *http://pub.lmmp.nasa.gov/LMMPUI/LMMP_CLIENT/LMMP.html*

Operations Product Generation Subsystem (OPGS) for Mars Science Laboratory (MSL)/ *Curiosity*

POC: Maher Hanna

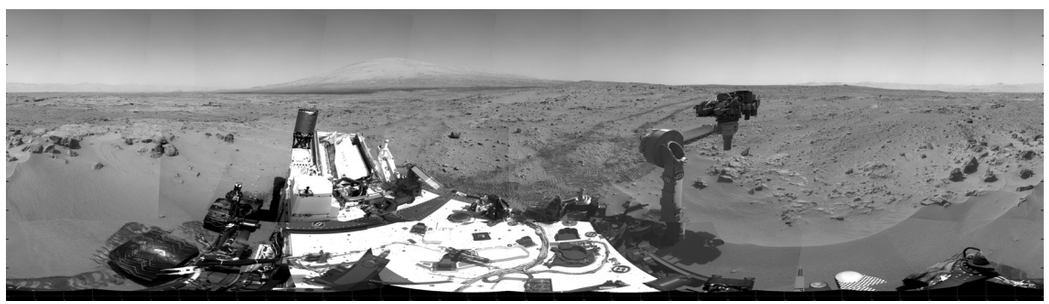
During fiscal year 2012, the Mars Science Laboratory (MSL) Operations Product Generation Subsystem (OPGS) initially concentrated on developing and implementing MSL instrument processing capabilities for surface operations. This effort included the development of an automated pipeline to meet a 30-minutes tactical timeline requirement.



This mosaic shows the underbelly and wheels of the rover. The four front hazcams are prominently visible at center top. This 9-frame mosaic was taken by the MAHLI arm-mounted camera on sol 34. The mosaic was assembled by MIPL/OPGS using their mosaic seam correction software, which corrects geometric seams in the mosaic.

In addition to the pipeline, several software products were developed: Position Localization and Attitude Correction Estimate Storage (PLACES) which is a database designed to store rover localizations. PLACES keeps track of where the rover was and how it was oriented at any specific time. PLACES serves as "one-stop shopping" for localizations, accessible to anyone on the Project. Additional Web-based tools were also developed to aid the science team in quality control, browsing, and analysis of raw science product images (Experiment Data Records, or EDRs) and derived image data products (Reduced Data Records, RDRs).

During the Cruise phase of MSL, the Division's Operations Product Generation Subsystem (OPGS) team processed and distributed more than 4200 data products for the Radiation Assessment Detector (RAD) instrument, while continuing to support surface Thread Tests and Operational Readiness Tests (ORTs).



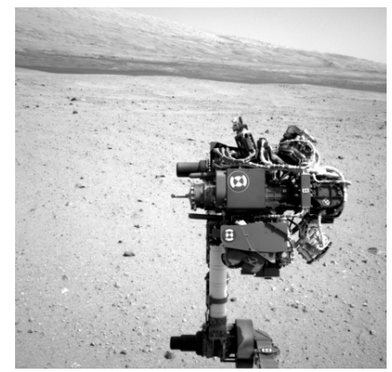
This navcam mosaic consists of 36 frames taken on sols 59 and 60. The rover's arm is deployed in preparation for scooping soil. Mt. Sharp is in the center background, with the region called Glenelg on the left. The rover tracks can be seen receding into the distance on the right. This mosaic was assembled by MIPL/OPGS using their mosaic seam correction software, which corrects both geometric and brightness seams in the mosaic.

On August 5, 2012, the team successfully received and processed the first Hazcam images that confirmed the safe landing of MSL. Before the end of 2012, more than 150,000 products were generated and distributed to science teams around the world.

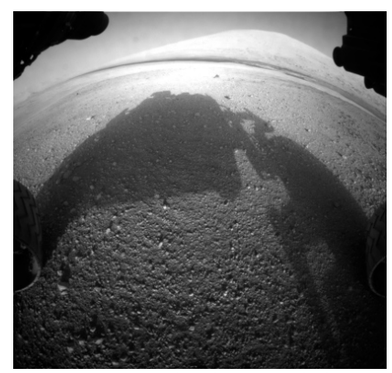
Engineering Cameras on Mars Science Laboratory/*Curiosity*

POC: Justin Maki

After launch in November 2011, the MSL Engineering Camera Operations Team (ECAM) participated in a series of Operational Readiness Tests (ORTs) that simulated the end-to-end uplink and downlink aspects of the rover surface mission, including the operation of the Hazcam and Navcam cameras. During this period, the team also successfully conducted instrument cruise checkout activities of the flight cameras en route to Mars. On August 5, 2012, the *Curiosity* rover successfully touched down on Mars and began sending back Hazcam images within seconds of landing. Navcam images were acquired shortly after the rover's Remote Sensing Mast (RSM) was deployed on Sol 2. The Engineering Camera images play a critical role in the operation of the *Curiosity* rover on the Martian surface. Images from the cameras are used to target the science instruments, drive the rover, and operate the Rover's robotic arm.



Curiosity mast as viewed by engineering camera shot



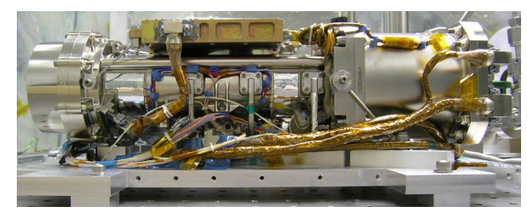
Engineering Camera shot of Curiosity's shadow

Tunable Laser Spectrometer (TLS) on Mars Science Laboratory/*Curiosity*

PI: Christopher Webster
POC: Curt Henry

The Tunable Laser Spectrometer (TLS) was developed by Division 38 and incorporated into the Sample Analysis at Mars (SAM) instrument suite led by Goddard Space Flight Center. TLS uses two tunable lasers and a Herriott cell to measure spectra of samples of the Martian atmosphere and gases heated from Martian rock samples. The principal targets of the investigation are methane, carbon dioxide, and water.

FY 2012 saw the successful landing on Mars and the first atmospheric samples measured by TLS. Analysis of these samples is underway with the announcement of the results expected in the final months of 2012. The first measurements of rock samples are also imminent.

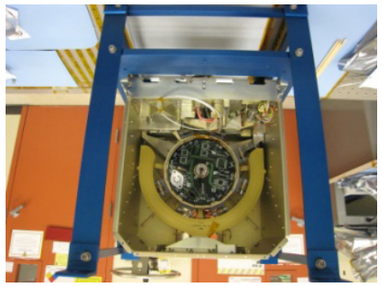


TLS Optics

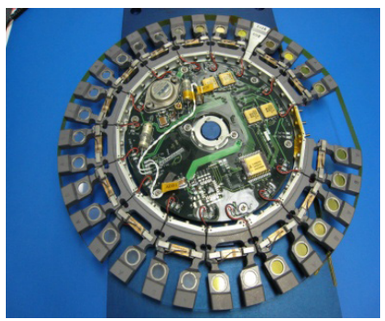
CHEMistry and MINeralogy Instrument (CHEMIN) on Mars Science Laboratory/*Curiosity*

PI: David Blake (NASA/Ames)
POC: Wayne Zimmerman

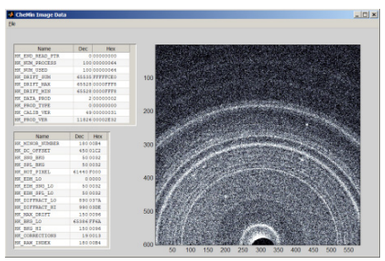
The CHEMistry and MINeralogy Instrument (CHEMIN) determines the mineralogy and elemental composition of crushed or powdered samples through the combined application of X-ray diffraction (crystal structure analysis) and energy-dispersive histogram spectra (elemental analysis).



CHEMIN Instrument



CHEMIN Sample Wheel



1st Mars Regolith Sample – First Analysis

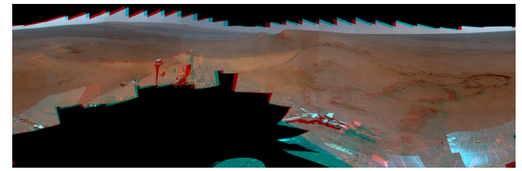
To prepare rock samples for analysis, the rover drills into rocks, collect the resulting fine powder, sieves it, and delivers it to a sample holder. It uses a scoop for collecting soil. In operation, a collimated X-ray beam from an X-ray tube source is directed through powdered or crushed sample material contained in a 1-cm diameter sample cell, sandwiched between two Kevlar or Mylar windows. An X-ray sensitive CCD imager is positioned on the opposite side of the sample cell and directly detects X-rays diffracted or fluoresced by the sample. Diffracted primary beam X-rays strike the detector and are identified by their energy. A two-dimensional image of these X-rays constitutes the diffraction pattern.

Scientists will use the information from X-ray diffraction to identify the crystalline structure of materials that the rover encounters on Mars. All of the X-rays detected by the CCD are summed into a histogram of number of photons vs. photon energy that constitutes an energy-dispersive histogram. To date the CHEMIN instrument is working well on Mars. The instrument received its first regolith sample for analysis on October 18, 2012.

Mars Exploration Rover (MER)

POC: Amy Chen

The Mars Exploration Rover (MER) Multimission Instrument Processing Laboratory (MIPL) team continued its outstanding operational support to the *Opportunity* rover during fiscal year 2012. Due to power concerns, *Opportunity* spent many months perched on the western ridge of Endeavour Crater during her fifth Martian winter. While wintering, she took a full panorama view of her surroundings using the Panoramic Camera (Pancam) from a location named Greeley Haven. The MIPL team provided the resources to generate a color stereo panoramic mosaic for the MER mission (see figure).



Color Stereo Greeley Panoramic Mosaic

The MER MIPL team also performed a quantitative localization analysis in response to the unexpected *Opportunity* attitude change or slip that occurred on Sol 2899 (around March 20, 2012). The team determined the rover attitude changes, pre-slip and after-slip, using a bundle-adjustment process. The results were validated several different ways and showed an error of less than 0.04 degrees in roll, pitch, and yaw. Localization analysis results and validations were provided to the Rover Planner and Science teams.

During FY 2012, the MIPL team adapted a 3-D orbital mesh workflow, developed for the MSL mission, as a part of continued product improvement process. The 3-D orbital mesh provides an improved visualization of the actual Martian terrain for MER mission planning teams.

Mars Reconnaissance Orbiter (MRO) Raw Science Data Server (RSDS)

POC: John Mayer

The Mars Reconnaissance Orbiter (MRO) Raw Science Data Server (RSDS) delivers science data products to nine instrument and experiment teams. During fiscal year 2012, RSDS distributed more than 87,000 products. MRO also continued to return volumes of data of significant science value during fiscal year 2012. Beginning in August 2012, MRO supported the Mars Science Laboratory landing and operations with extremely accurate targeting and high-resolution imagery from the HiRISE instrument.

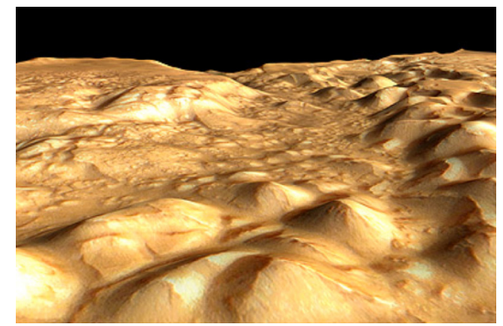
Mars Express (MEX)

POC: Payam Zamani

The Mars Express (MEX) spacecraft continues orbital operations for a third extended mission. Although the spacecraft suffered multiple memory "hits" during the past year, it is still performing new science and provides backup relay communications for JPL's rovers.

The High Resolution Stereo Camera (HRSC) data distribution, which is supported by Division 38, continues to perform normally. The level of returned data this year was reduced compared to previous years due to the spacecraft anomalies and a long eclipse season.

The European Space Agency has approved another extension to the mission through fiscal year 2014. NASA has also approved funding for that extension.



Projected image of Aureum Chaos region on Mars, taken by the High Resolution Stereo Camera onboard the Mars Express

Astrophysics

Spitzer

POC: Alice Stanboli

There have been several important scientific findings made by the Spitzer Space Telescope. The Sombrero

A dying star is throwing a cosmic tantrum in this combined image from NASA's Spitzer Space Telescope and the Galaxy Evolution Explorer (GALEX).

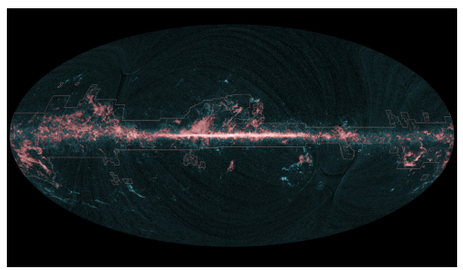
galaxy was observed to have a "split personality," having both a round elliptical galaxy with a thin disk embedded inside. This is the first identification of a galaxy that contains both characteristics. Another discovery made by Spitzer is that of a possible exoplanet smaller than Earth. UCF-1.01, an exoplanet candidate, is located 33 light-years away, making it the nearest known planet outside our Solar System. Spitzer has also detected the first instance of light emanating from a "super-Earth" planet, *55 Cancri e*, beyond our Solar System. This detection is a step toward the eventual search for signs of life on other planets. Some thought it to be a water world with a rocky core and surrounded by a layer of both liquid and gas, though other interpretations have been offered.

The Spitzer project is currently in the warm mission phase and is supported by the Multi-Mission Image Processing Laboratory (MIPL). MIPL provides 24×7 lights out telemetry processing services to the project and has delivered an average of > 99.99% of Infrared Array Camera (IRAC) data to the Spitzer Science Center (SSC).

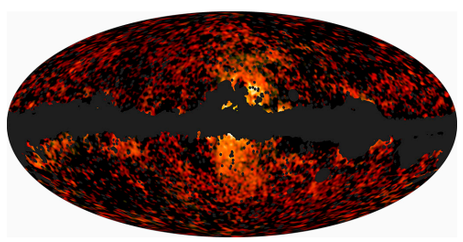
Planck Mission

POC: Warren Holmes

The ESA-managed Planck spacecraft has been operating since launch on May 14, 2009. The main goal of the Planck mission is to map the Cosmic Microwave Background to unprecedented precision to test cosmological models of the formation of the Universe. To do this, *Planck* measures galactic foregrounds to extraordinary precision, including dust emission and microwave to sub-millimeter emission from synchrotron, free-free, interstellar dust, and molecular clouds. Total intensity maps and cosmological science results from these maps will be released to the public early in 2013. On the road to producing sky maps useful for cosmology, many additional science results have been obtained. During fiscal year 2012, a high precision map of molecular clouds covering the entire sky was released. In addition, the microwave 'haze' first identified by the Wilkinson Microwave Anisotropy Probe (WMAP) was accurately measured by Planck and shown to correlate spatially with the gamma ray haze seen by the *Fermi* satellite.



All-sky image of molecular gas seen by Planck (blue) and previous surveys (red). Blue areas at high galactic latitude were discovered by Planck. Credits: ESA/Planck Collaboration.



Galactic foreground measured by Planck at 30 and 44 GHz. The galactic haze is most bright (yellowish color) around the galactic center (middle of image). Credits: ESA/Planck Collaboration.

There are two instruments aboard *Planck*, the Low Frequency Instrument (LFI) (PI Reno Mandeloi, Instituto Astrofisica Spaziale E Fisica Cosmica, Bologna, Italy) and the High Frequency Instrument (HFI), (PI Jean Loup Puget, Institute Astrophysique Spatiale, Université Paris XI, Orsay, France.), which, together, have mapped the intensity and polarization of the entire sky in 9 discrete frequency bands from 30 – 857GHz. The LFI (U.S. PI Charles Lawrence, JPL, Division 32) is cooled by the Division 35/38-made 20-K sorption cooler and continues to operate. The HFI (U.S. PI James Bock, Caltech and JPL) contains Division 38-made spiderweb bolometers (SWB) and polarization sensitive bolometers (PSB). The SWB and PSB are cooled to 100 mK by a continuous cycle dilution refrigerator (CCDR). To operate, the CCDR expends ^{3}He and ^{4}He gas that was loaded into the spacecraft before launch. On January 16, 2012, the ^{3}He gas was depleted and the HFI began to warm and ceased to collect astrophysical data. In total, HFI completed 5 full sky surveys, far exceeding the mission goal of 2 full sky surveys. In addition, the SWB and PSB met goal sensitivities in each detector set by the statistics of the photon flux.

Analysis of the data collected from the LFI and HFI are being analyzed for publication.

Herschel

HIFI U.S. PI: Thomas Phillips (Caltech)
SPIRE U.S. PI: James Bock (Caltech and JPL)
POC: John Pearson

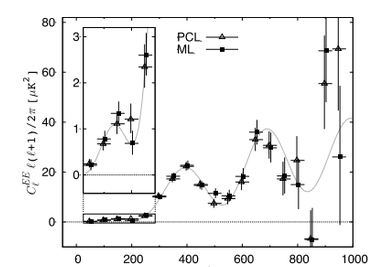
The Herschel Space Observatory continued routine science observations for all of fiscal year 2012. The observatory operating efficiency exceeded European Space Agency's expectations and only a small number of observations were lost to single event upsets of the instrument control units affecting Heterodyne Instrument for Far-Infrared (HIFI), the Photodetector Array Camera Spectrometer (PACS), and the Spectral and Photometric Imaging Receiver (SPIRE). Observations for the key projects were 99% complete. 75% of the first open time call observations have also been completed. Observations from the second open time call (awarded in May 2012) are underway. The liquid helium is expected to last until March 2013. Preparations for the post-operations phase are nearing completion. The instrument teams will continue work on calibration and data pipelines for another 35 years. The Herschel archive will be complete 5 years after exhaustion of helium.

The JPL supplied components on both HIFI and SPIRE continue to perform as expected. HIFI has survived for 3 years on the redundant side, and issues with the thermal control loop on the master oscillator and the frequency comb on the wideband spectrometer appear to be stable and likely to last the entire mission. JPL was not the supplier of the comb or the master oscillator; however, both were made by U.S. companies. The JPL-made detectors in both HIFI and SPIRE show no aging effects. Surprisingly, no aging has been detected in the HIFI local oscillators. As far as is evidenced by the telemetry, the units are unchanged after 3 years in orbit.

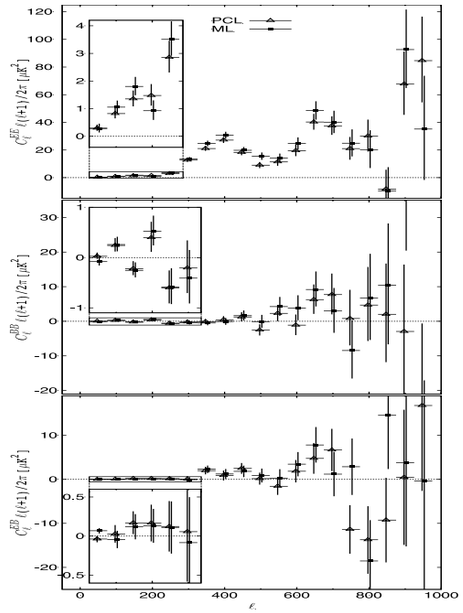
Q/U Imaging Experiment (QUIET)

PI: Todd Gaier
POC: Todd Gaier

The Q/U Imaging Experiment (QUIET) completed all observations and analysis, leading to two papers



E-mode power spectrum



B-mode power spectrum

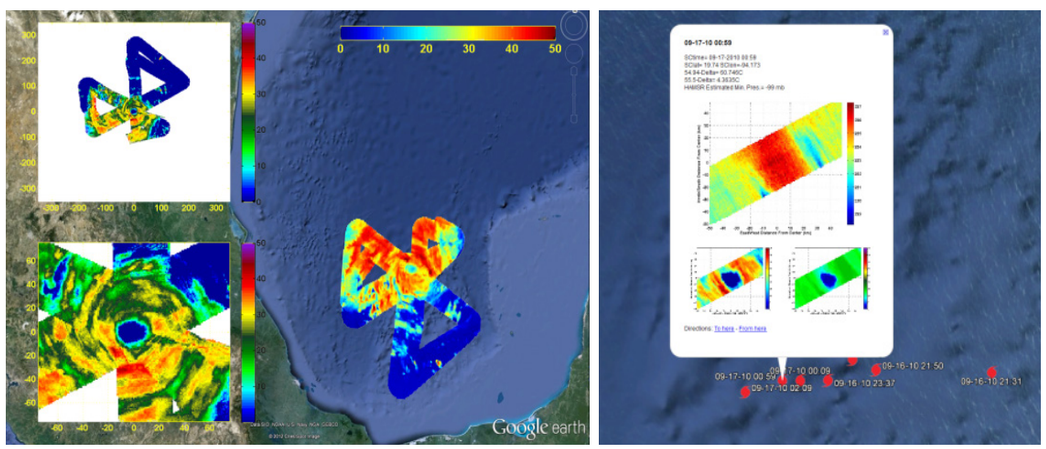
accepted by the Astrophysical Journal. The results released during FY 2012 map the polarization of the Cosmic Microwave Background at 90 GHz using the W-Band QUIET array with receivers developed in this Division. Stokes Q and U polarization maps of one of the four sky patches sampled with per pixel noise of a few μK. The resulting transformation of these maps into symmetric and anti-symmetric modes and then into spherical harmonics reveals the intrinsic E-mode cosmological signal and upper limits to the B-mode cosmological gravitational wave signature. The result demonstrated state-of-the-art sensitivity and record-low-level systematic effects. This result marks the conclusion of the QUIET Phase I project.

Earth Science

High Altitude MMIC Sounding Radiometer (HAMSR)

POC: Shannon Brown

This year, the High Altitude MMIC Sounding Radiometer (HAMSR), a state-of-the-art microwave sounder built and operated by JPL, was prepared to, once again, examine the inner workings of hurricanes from high above on the Global Hawk Unmanned Aerial Vehicle. HAMSR is participating in the Hurricane and Severe Storm Sentinel (HS3) NASA Earth Venture Mission. As a part of HS3, HAMSR flies on the so called "over-storm Global Hawk," which, as the name suggests, is responsible for providing detailed measurements of the moist thermodynamic structure of the storm. Prior to the start of the 2012 hurricane season, several instrument upgrades were undertaken, including a refurbishment of the digitizer system, that converts instrument measurements into digital data, and the addition of a new amplifier chain to the 50-GHz receiver system to significantly improve the performance of the 50-GHz radiometer. The other two receivers, at 118 and 183 GHz, were upgraded in 2009. In addition to the hardware upgrades, improvements to the ground data system and calibration and retrieval algorithms were made. HAMSR was one of the first instruments to demonstrate the utility of real time data display from the Global Hawk for meteorological awareness and in-flight mission science planning. Several new real-time products were introduced this year, including a storm centric display, which presents key thermodynamic information of the storm derived from HAMSR, such as temperature, water vapor, and precipitation, in a grid centered on the eye of the storm. Additionally, for each eye crossing, HAMSR data are used to generate storm center location and intensity estimates that are distributed in real-time.

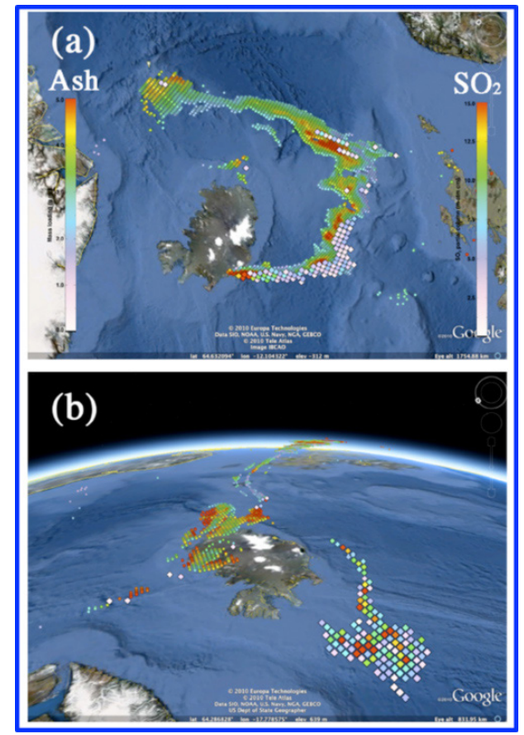


The figure shows an example of the HAMSR real time flight display using data from Hurricane Karl in 2010. The left figure shows the flight track swath display of HAMSR derived reflectivity and the two plots to the left side of the figure show the storm centric display clearly depicting the structure of the storm. The right hand figure shows the storm position information, accurate to 1 km, which also includes an experimental estimate of the hurricane intensity derived from the upper atmospheric temperature anomaly above the eye.

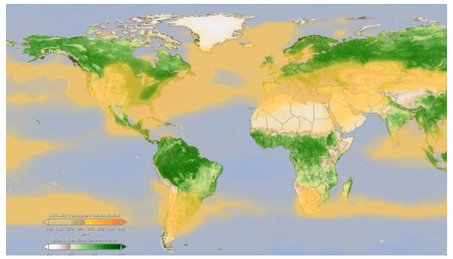
Atmospheric InfraRed Sounder (AIRS)

PI: Bjorn Lambrigtsen
POC: Steve Friedman

The Atmospheric InfraRed Sounder (AIRS) project continues to develop new research products while maintaining production of standard data products. After more than ten years in orbit, AIRS continues to provide daily global coverage of temperature and water vapor profiles of the Earth's atmosphere. Many trace gases are also "retrieved" from AIRS data. AIRS products have helped significantly improve global weather forecasting models, increasing the accuracy of long-range forecasts by more than 6 hours. AIRS data products have also been instrumental in improving the accuracy and timing associated with the tracking hurricanes and typhoons as they approach land. Last year, the AIRS project added routine mapping of mid-tropospheric CO_2 to its global products collection. This year, the CO_2 product will also cover stratospheric and lower tropospheric quantities, giving a



Transport of volcanic ash and other effluents, such as sulfur dioxide (SO2) affect human activities on the ground and in the air. Detection of current conditions and predictions for future transport has always been challenging. The above images depict distributions of volcanic ash and SO2 from Icelandic volcano Eyjafjallajökull during an eruption in 2010. Ash mass loadings from the Spin Enhanced Visible and Infrared Imager (SEVIRI), shown as colored dots, are combined with SO2 distributions from AIRS, shown as colored triangles, to provide a more complete view of transmission of volcanic effluents. As depicted here, transport of various volcanic materials may not be collocated. Source: Prata, A. J., and A. T. Prata (2012), Eyjafjallajökull volcanic ash concentrations determined using Spin Enhanced Visible and Infrared Imager measurements, J. Geophys. Res., 117, D00U23, doi:10.1029/2011JD016800.



This image depicts the vegetation cycle (green) derived from MODIS data and global distribution of CO2 (orange) derived from AIRS data. The dynamic relationship between the annual vegetation bloom in the northern hemisphere and subsequent absorption of atmospheric CO2 can be visualized and help us better understand the dynamic processes associated with the carbon cycle. Source: "Watching the Earth Breathe: An Animation of Seasonal Vegetation and its effect on Earth's Global Atmospheric Carbon Dioxide."

fuller picture of CO_2 distribution in the atmosphere. AIRS also continues to be useful in issuing air transportation warnings about volcanic eruptions and other severe dust events.

AIRS Science Data software Version 6 is currently scheduled for release late in calendar year 2012, and a complete reprocessing of all Level-2 and -3 products will be produced. Version 6 will yield significantly better products than previous versions, including higher retrieval yields nearer the surface and in the proximity of clouds. Additionally, new Level-3 products, including the first release of research products in 100 atmospheric layers, will be available for the first time.

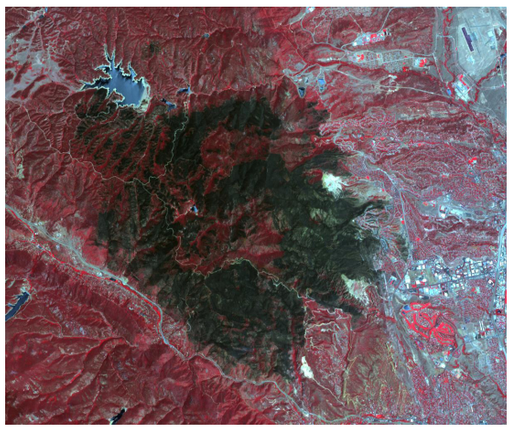
The AIRS Project, in conjunction with the Goddard Earth Sciences (GES) Data and Information Services Center (DISC), continues to distribute AIRS data products from the long-term data archives. Additionally, near-real-time data products, including temperature, water vapor, carbon monoxide, and ozone, are now also available at the GES DISC. These products, which supplement the long-term archival record of AIRS data, are mainly used for weather forecasting and issuing weather alerts. The AIRS Project celebrated ten years in orbit on May 4, 2012. The instrument continues to operate flawlessly.

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

Science Team Leader: Michael Abrams
POC: Bjorn Eng

ASTER continues to operate and acquire useful science products after nearly thirteen years on orbit. As the highest-resolution imager on *Terra*, ASTER provides detailed images to complement the wider-swath data from MODerate Resolution Imaging Spectroradiometer (MODIS).

The ASTER urgent acquisition scheduling capability continues to provide data for agencies responding to natural hazards, such as burn-assessment from wildfires.

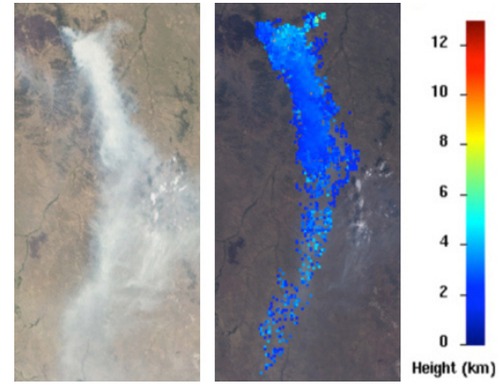


ASTER's image of the Waldo Canyon Fire, CO (July 4, 2012)

Multi-angle Imaging SpectroRadiometer (MISR)

PI: Dr. David Diner
POC: Earl Hansen

The Multi-angle Imaging SpectroRadiometer (MISR) instrument and Terra spacecraft completed 12 years of



MISR Fire: *Ash Creek Fire in Montana as viewed by MISR on July 2, 2012. (left) True color visible image, (right) MINX height retrievals showing the discrimination among different portions of the plume.*

successful operations during fiscal year 2012. During that time, more than 625 TB of publicly available data products were generated.

MISR, as part of the *Terra* instrument set, was directed to continue extended mission operations for at least the next two years as a result of the NASA 2011 Senior Review of Earth Science Operating Missions. Terra was given an outstanding science summary rating.

A new, fine spatial resolution wind retrieval algorithm was put into production in the past year along with other improvements, including increasing cloud height and winds coverage. The new MISR data products containing these improvements are now publicly available for the entire mission time period, more than 12 years. These height-resolved, cloud-tracked winds are available at 17.6-km resolution. Additional cross-track cloud motion information is provided at the same 1.1-km resolution as the current MISR cloud-top height parameters. Such winds are useful for revealing details of cloud-scale dynamics.

A number of students worked with scientists on the MISR project during the summer of 2012 using the MISR INteractive eXplorer (MINX) software tool to digitize plumes from wildfires, dust storms, and volcanoes. This information will be added to the MISR Plume Height Project Database, which already includes thousands of plumes from locations around the world. Studying the transport of smoke from wildfires is important to air quality and public health concerns. An example was for the Ash Creek Fire Complex in Montana. These images show a MISR view of the wildfire plume and its height as determined using the MINX software tool. The smoke reached 3 km above the ground level with winds of up to 10 m/s. The plume extended more the 250 km from the fire source. This type of information can be used in models to help predict the range of effects of wildfire plumes.

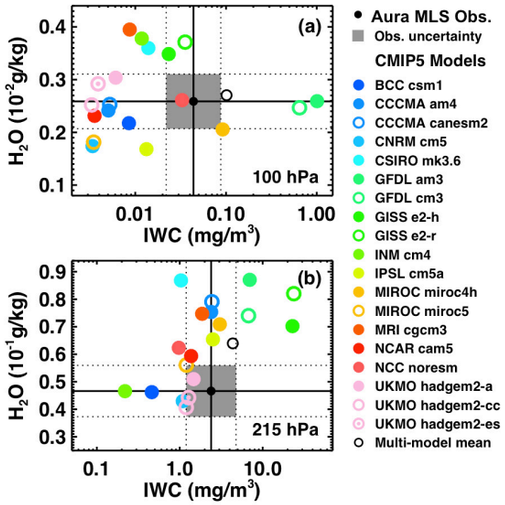
Microwave Limb Sounder (MLS)

PI: Nathaniel Livesey
POC: Elmain Martinez

The MLS instrument, operating on board the *Aura* spacecraft, completed its eighth year of operation. In that time, more than 10 million scans have been performed and more than 3000 data days have been made publicly available via the Goddard Earth Sciences (GES) Data and Information Services Center (DISC).

To continue the hydroxide (OH) record, the Terahertz (THz) module was returned to operations for a month in August 2012, where 89% of data was recorded. The THz module was returned to standby mode to extend the limited remaining life so that it can be powered on during the solar maximum in 2013.

This past year was marked by significant additions to the suite of MLS products. An improved version of MLS Near Real-Time production began in September 2012. This version employs a new forward model and generates five new products in addition to ozone and temperature: CO (carbon monoxide), H_2O (water vapor), HNO_3 (nitric acid), N_2O (nitrous oxide), and SO_2 (sulfur dioxide). The science team has also produced a new version of one of the 'noisy' products



Aura MLS and other A-Train satellite data provided unique observational metrics for IPCC climate model evaluations. Using bi-variate (cloud and water vapor) metrics, these scatter plots of tropical oceanic multi-year mean model output are compared to the MLS observed values. The gray area indicates the observation uncertainties with MLS data as the center reference (solid black dot), the colored dots/open circles are the values from the CMIP5 models, and the black open circles represent the multi-model mean. Source: Jiang, J.H. et al. (2012), Evaluation of Cloud and Water Vapor Simulations in CMIP5 Climate Models Using NASA "A-Train" Satellite Observations, J. Geophys. Res., doi:2011JD017237.

BrO (Bromine), the potent ozone depleting substance that is produced by both natural and industrial/agricultural processes. The importance of bromine-induced ozone loss is set to increase as levels of chlorine decrease in the atmosphere.

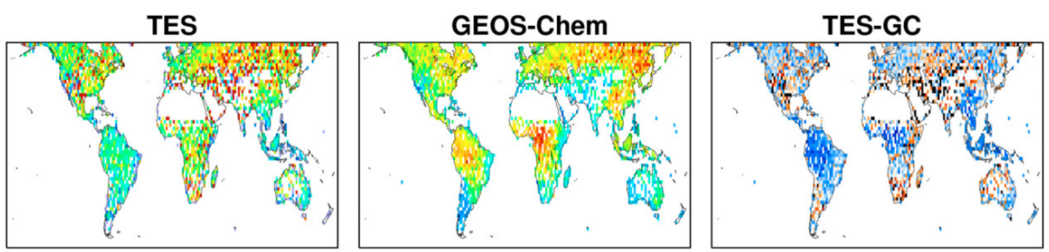
More than 40 peer-reviewed papers have been published in the last year using MLS observations. In July 2012, the MLS team and other collaborating scientists published a paper in the *Journal Geophysical Research* describing the use of A-Train satellite data to evaluate 19 climate models with regard to clouds and water vapor. As illustrated, the findings demonstrated that many of the new models showed improvement in simulating the amount and distribution of clouds and water vapor over the tropical oceans. However, more work is needed to address issues at high altitudes in the upper troposphere (10 – 15 km), where the model errors are much larger than in lower regions of the atmosphere.

Tropospheric Emission Spectrometer (TES)

PI: John Worden
POC: Doug Shepard

The Tropospheric Emission Spectrometer (TES) instrument was launched in July 2004 on the *Aura* platform and has since provided unique insight into the troposphere's chemistry and processes. With very high spectral resolution, TES can distinguish concentrations of gases at different altitudes, a key factor in understanding their behavior and impact on a global extent.

TES has completed the production of the Version 5 data set this year, providing validated profile data for ammonia, carbon dioxide, and nitrous oxide in addition to the standard TES data products. Methanol and formic acid products have been developed to expand our knowledge of tropospheric trace gases. Joint instrument products for TES/MLS carbon monoxide and TES/ Ozone Monitoring Instrument (OMI) ozone are currently being developed to improve boundary layer sensitivity and vertical resolution over that of individual instruments.

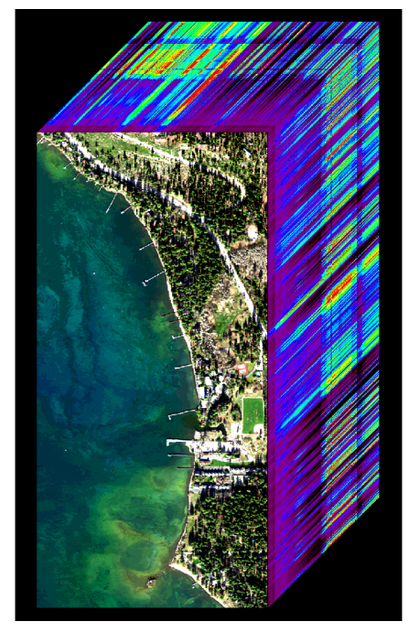


Methanol plays a key role in atmospheric chemistry; it reacts with OH to form CO, O_3 and HCHO. The principal source of methanol is plants, primarily during cell growth and, to a lesser extent, during decay. TES will provide the ability to determine spatial distribution, strength and seasonality of methanol. These measurements will improve estimates of this important volatile organic compound as compared to the GEOS-CHEM (Goddard Earth Observing System Chemical Transport Model) model alone, which overestimates methanol in tropical rainforests and underestimates in arid and boreal regions.

Portable Remote Imaging Spectrometer (PRISM)

PI: Heidi Dierssen (Univ. of Connecticut)
POC: P. Mouroulis

The Portable Remote Imaging Spectrometer (PRISM) completed its development and underwent engineering test flights as well as a science mission. PRISM is an airborne instrument specially designed for the challenges of coastal ocean research, comprising an imaging spectrometer that covers the 350- to 1050-nm range and a separate two-channel short-wavelength infrared (SWIR) radiometer at 1240 nm and 1610 nm to aid with atmospheric correction. PRISM is the first high-throughput and high-uniformity Dyson imaging spectrometer to operate in the visible near IR spectral range. It incorporates unique JPL technologies, including a broadband, concave, low-polarization grating and a lithographically formed slit on low-scatter substrate. Engineering calibration flights were undertaken on the Glenn Research Center Twin Otter aircraft over Ivanpah Playa and Lake Tahoe in May 2012. A science flight on a Twin Otter International aircraft with concurrent ground data collection by researchers from several institutions mapped the Elkhorn Slough estuary in Monterey Bay, CA, seeking to answer specific questions about the health of seagrass habitats. The bulk of science flight data is currently under study. The preliminary results indicate excellent agreement between PRISM-collected spectra and ground truth. PRISM is now awaiting further deployment as a NASA facility sensor. Its next mission is expected to be off the coast of Florida, around summer of 2013, to aid in the understanding of seagrass species competition and displacement of native varieties and the effects of exogenous nutrient influx into the Greater Florida Bay.



A PRISM spectral cube from the shore of Lake Tahoe. The top image is essentially a photograph and indicates PRISM's spatial resolution. Each underlying layer of the cube is a false-color image of the same area at a succession of wavelengths ranging from 350 to 1050 nm.

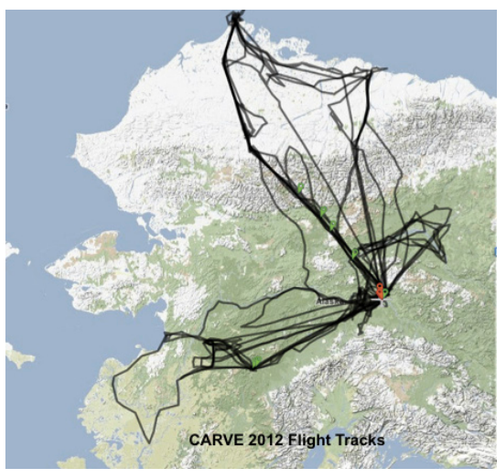
Aircraft installation. PRISM's unusually small size belies its high performance, made possible by use of a Dyson spectrometer based on Division 38's concave grating technology.

Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE)

PI: Charles Miller
Instrument POC: Steve Dinardo
Science Data System POC: Sean Hardman / Brian Chafin

The Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) quantifies correlations between atmospheric and surface state variables for the Alaskan terrestrial ecosystems through intensive seasonal aircraft campaigns, ground-based observations, analysis, and modeling sustained over its 5-year mission. The data will be used in a multidisciplinary investigation to determine spatial and temporal patterns, sensitivity to change, and potential responses of Arctic carbon budgets to observed and projected climate change.

The 2012 CARVE instrument system includes a navigation system, an outside air temperature sensor, a relative humidity probe, an ozone sensor, two Picarro real time gas analyzers (CH_4, CO_2, CO, H_2O), a Fourier Transform Spectrometer with a vibration isolation assembly, and two Programmable Flask Packages. The flask packages are portable, fully automated, non-contaminating grab samplers for atmospheric trace gases.



CARVE Flight Tracks for 2012, radiating from Fairbanks

The CARVE aircraft was deployed to Fairbanks, Alaska, from May to October 2012. CARVE flew more than 200 science flight hours, in 35 flight days, with 64 flight segments collecting 1.5 TB of science data. Locations observed included the North Slope, Barrow, Prudhoe Bay, Unalakleet, Innoko Valley, Minto Valley, Fort Yukon, Bethel, and Bettles.

During fiscal year 2012, the CARVE Science Data System team and its Airborne Cloud Computing Environment (ACCE) partners continued development of the Level-0/Level-1 processing system for the multi-instrument CARVE payload. Continued development included support for re-hosting and reconfiguration of the instruments on a new platform (a C-23 Sherpa) as well as support for new products and improved functionality. Although the system was not fully operational during fiscal year 2012, it did support the transfer and storage of 1.5 terabytes of data from the field. In 2013, the team looks forward to going fully operational and working with the CARVE Science Team to integrate their Level-2 product generation capabilities into the data system as well as adding support for Level-2 processing of the Fourier Transform Spectrometer data.

Airborne Cloud Computing Environment (ACCE)

POC: Dana Freeborn

ACCE is a reusable cloud capability for sub-orbital instruments providing process control and data management services at low cost and low risk, with a predictable, scalable cost model. To lower cost and increase scalability, ACCE has leveraged the science data system product line currently applied to spaceborne missions to provide support for algorithm development and testing as well as standard algorithms that can be plugged in. Through the sharing and

ACCE Website

commoditization of computing resources, ACCE provides those who cannot afford their own computing infrastructure a hosting environment on a pay as needed basis. Additional benefits of ACCE include risk reduction and increased usability. No longer needing to be concerned with computing issues, airborne instrument teams are free to concentrate on instrument innovation and science experiments. When an airborne instrument is ready for a spaceborne mission, the data processing environment is a direct plug-in to the mission Science Data System. Distribution and archive of airborne data are more systematic and uniform for future data analysis activities. Through unified portal access, the instrument teams have increased mobility, being able to access data and information from wherever they are located. ACCE is currently the backbone for the Venture 1 Carbon Arctic Reservoir Vulnerability Experiment (CARVE) Science Data System and provides data archive and distribution capabilities for the JLH/ULH instrument team. In addition, the NASA Airborne Science Program Manager continues to fund efforts to build out a NASA-wide strategy using ACCE as the model.

Physical Oceanography Distributed Active Archive Center (PO.DAAC)

POC: Andy Bingham

PO.DAAC manages and distributes satellite data and related information in support of research and applied sciences pertaining to physical oceanography and climate science.

The PO.DAAC currently manages more than 24 million files (90 TB compressed), making up more than 800 datasets created by NASA flight missions and projects. In FY 2012, more than 80,000 unique visitors accessed the PO.DAAC online tools and services and downloaded more than 200 TB of data.

In fiscal year 2012, PO.DAAC continued to develop innovative new technologies and processes for data stewardship and data access and deployed these capabilities into its operational system. Several new and important datasets needed by the ocean and climate communities were added to the data holdings, and major advances were made in the services that promote the uptake and usefulness of NASA's data.

New Technologies & Processes highlights:

- Developed and deployed web services to support data search, discovery, access, and visualization.
- Delivered a web-mapping service to power several visualization clients, such as World-View.
- Working in collaboration with the Aquarius Science Team, supported the production and distribution of the mission cal/val data products.
- Production of New Ocean Products
- Long-term global Earth science data records, created under the NASA MEaSUREs Program, for ocean wind, height and temperature were released.

- Products to support intercomparison of satellite observations with climate models for the IPCC Fifth Assessment Report were assembled and distributed through various portals.
- Altimetry datasets for the U.S. west coast were released, opening a new class of observations.
- Outreach

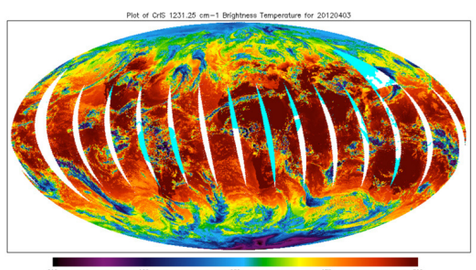
Several "science stories" and visualizations were added to the PO.DAAC portal to illustrate the applicability of key datasets.

PO.DAAC staff supported numerous educational activities, including presentations for public seminars, college and school engagements, demonstrations at science meetings, presentations at science and technology events, and presentations to Senators.

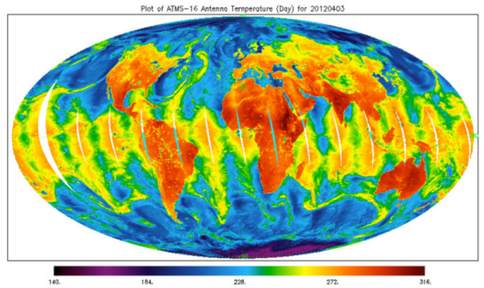
NPOESS Preparatory Project (NPOESS) Preparation Project (NPP) Sounder Project Evaluation and Test Element (PEATE) Science Data System

POC: Steve Friedman

The Joint Polar Satellite System (JPSS) is a NASA program to launch next generation environmental and weather forecasting satellites for National Oceanic and Atmospheric Administration (NOAA).



This image of daytime antennae temperature depicts typical daily coverage for the Advanced Technology Microwave Sounder (ATMS) on Suomi NPP. The overall quality of ATMS data appears to be quite good and surpasses other operational microwave sounders currently managed by NASA and NOAA. ATMS data products were declared beta during February 2012.



This image of daytime antennae temperature depicts typical daily coverage for Suomi NPP's Cross-track Infrared Sounder (CrIS). After outgassing was completed, CrIS was activated during January 2012. Initial analysis indicated that the instrument performance reaches and exceeds the pre-launch TVAC performance and specifications in terms of signal-to-noise characteristics. The CrIS Science Data Record (SDR) was declared beta during May 2012.

The first satellite of the JPSS mission, *Suomi NPP*, was launched on October 28, 2011. While NASA's primary role is to manage the fabrication and launch of the spacecraft, its secondary mission is to evaluate the continuity and quality of data products and to determine whether these products can be used for climate studies. The specific role of the Sounder Project Evaluation and Test Element (PEATE) is to assist the NPOESS Preparation Project (NPP) Sounder Science Team in determining whether temperature and water vapor products are "climate quality." These products will be produced from the Cross-Track Infrared Microwave Sounder Suite (CrIMSS) consisting of two instruments: NPP's Cross-track Infrared Sounder (CrIS) and the Advanced Technology Microwave Sounder (ATMS). The Sounder PEATE developed a data computing facility for use in evaluating the data products. The first year after launch has been heavily dedicated to calibration activities, and the Sounder PEATE has assisted in the evaluation of sounder products, such as Science Data Records (SDRs) and Environmental Data Records (EDRs).

Simultaneous Nadir Observation (SNO) products are now being produced for all Nadir intersections of *Suomi* NPP with *MetOp-A* and *Aqua* spacecraft. SNO products enable evaluation of similarities and dissimilarities between each satellite's sounder's observed spectral products. Calibration subsets are currently being developed to support analysis of *Suomi NPP*'s sounders. Combined with SNO products, calibration subsets will provide the data products necessary to evaluate the stability of the sounders and to compare them with precursor instruments on *Aqua* and *MetOp-A*. Additional tools, including the capability to generate simulated radiances and temperature/water vapor profiles, are being developed to enable comparison of observed products with products produced from forecast models. Gridded global products, also under development, will be produced for all standard products to support the evaluation of whether *Suomi NPP*'s products are of sufficient quality to be used for climate change studies. The NPP Sounder PEATE team will continue to work with the Sounder Science Team to tailor existing products and create new analysis products as needed.

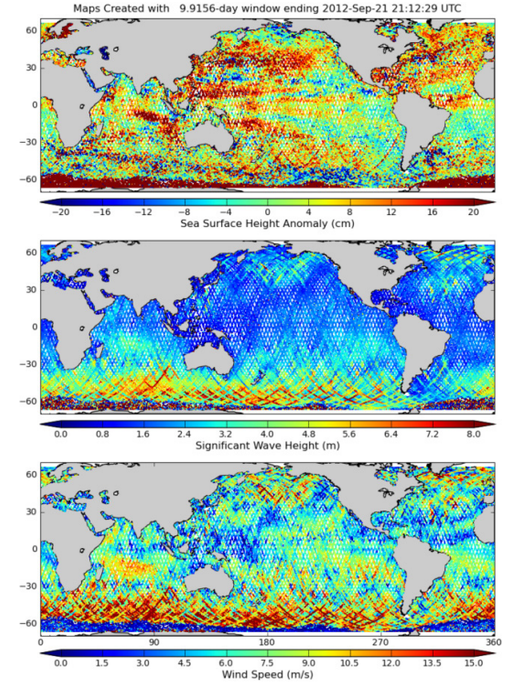
Jason-1 and Ocean Surface Topography Science Team (OSTST) /Jason-2

POC: Glenn Shirtliffe

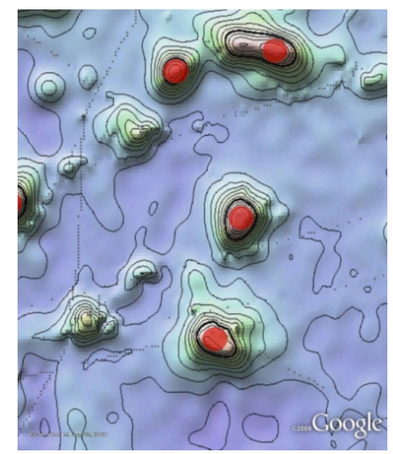
The Ocean Surface Topography Science Team (OSTST) and its associated scientists and investigators have continued to add significantly to research studies directly attributed to the 20-year climate data record produced by the TOPography EXperiment for Ocean Circulation (TOPEX)/Poseidon, Jason-1 and Ocean Surface Topography Mission (OSTM) /Jason-2 missions.

In December 2011, *Jason-1* completed ten years of successful science operations, more than doubling its expected five-year mission lifetime. The mission recently celebrated the completion of 50,000 operational orbits.

In May 2012, *Jason-1* was maneuvered to a lower orbit and began a new geodetic mission phase. This new orbit has a longer revisit time that will still permit oceanographic research, but will also result in a substantial improvement in the resolution of the marine



JPL has developed a NRT SSHA/Wave/Wind product that combines the OSTM/Jason-2 and Jason-1 NRT data. TOP: Combined JA1+JA2 10-Day NRT SSHA; MIDDLE: Combined JA1+JA2 10-Day Sig. Wave Height; BOTTOM: Combined JA1+JA2 10-Day Wind Speed



The Jason-1 geodetic mission could help map more than 50 thousand previously uncharted seamounts.

geoid. This will enable new research into gravity and ocean topography, including:

- Mapping uncharted seamounts.
- Plate tectonics.
- Planning ship surveys.
- Inertial guidance (military).
- Petroleum exploration.
- Seafloor roughness.
- Linear volcanic chains.
- Tsunami models.
- Tide models, tidal friction, thermohaline circulation.
- Planning undersea cables.
- Law of the sea.

In June 2011, *OSTM/Jason-2* successfully completed its fourth year of operations. JPL has developed new near–real-time data products assimilating both *Jason-1* and *OSTM/Jason-2* data that provide operational agencies with important data on wave height, winds, and sea-surface-height anomalies.

Next Generation Imaging Spectrometers (NGIS)

PI: Tom Kampe (NEON) and Greg Asner (Carnegie Institution of Washington)
POC: Louise Hamlin

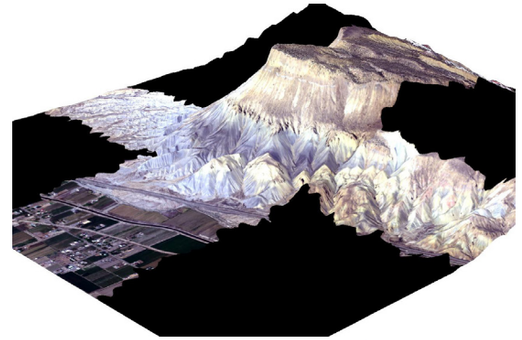
The Next Generation Imaging Spectrometers (NGIS), high-fidelity airborne instruments, were delivered to the National Ecological Observatory Network (NEON Inc.) of Boulder, Colorado, and the Carnegie Airborne Observatory (CAO) based in Washington, D.C. Both CAO and NEON use their instruments to study, explore, and conserve ecosystems at large geographic scales.

The NEON Observatory will collect and synthesize ecological data across North America for 30 years. Data products are designed to address the impacts of climate change, land use change, and invasive species on natural resources and biodiversity. When complete, data will be collected from 60 sites across the U.S. (including Alaska, Hawaii, and Puerto Rico) through field sampling, aerial towers, and three airborne platforms. NEON will also allocate resources for PI-driven science and natural disaster responses.

The NEON Airborne Observation Platform (AOP) consists of the JPL-provided imaging spectrometer, a LiDAR instrument, and a high-definition camera. The first NEON imaging spectrometer was delivered in December 2011; two more units will be delivered during the spring of 2013. During autumn of 2012, the initial AOP was used to study the effects of the High Park Wildfire, one of the worst in Colorado history. "NEON's airborne system will collect rich ecological data over the entire fire area with exceptional detail - down to one yard," said Tom Kampe, NEON assistant director for Remote Sensing. "NEON's technology will provide researchers with almost as much information as if we walked the entire landscape, and will allow land managers to make much more informed decisions for restoration."

The Carnegie Airborne Observatory is in its second year of operation and has just returned from another mission to explore, map, and scientifically evaluate ecosystems stretching from lowland Amazonia to the treeline in the Andes of Northern Peru. The areas surveyed by CAO are rich with life – some 50 hectare

The NEON and JPL team pose by the Twin Otter aircraft with AOP aboard. (Image credit: NEON)

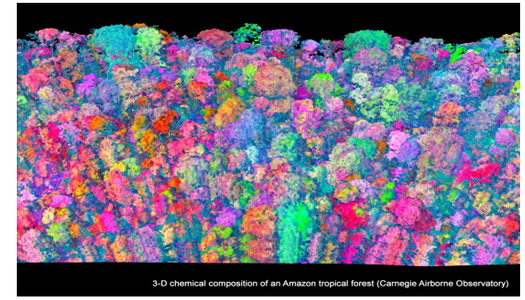


The NEON crew during a test flight. (Image credit: NEON)

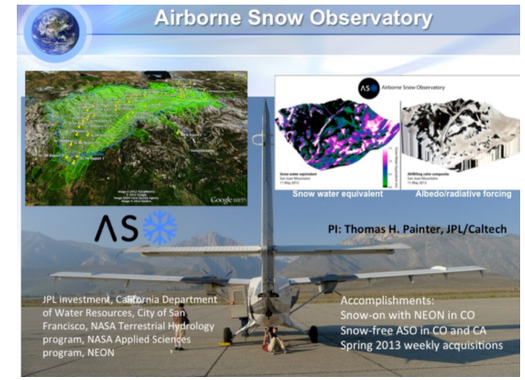
CAO, flying in the Andes of Northern Peru, summer 2012. (Image credit: CAO)

The CAO Imaging Spectrometer delivered in May 2011. (Image credit: CAO)

plots contain more plant species than in all of North America – and hard to get to. "We might as well be exploring Mars," says Asner. "These are areas where no human has ever been. There's no access." The 2012 campaign covered an area of about 130 million acres and took about two months to complete the data collection phase. Results will help the Peruvian



Imaging spectrometer data paired with LiDAR reveal 3-D chemical composition of an Amazon tropical forest. (Image credit: CAO)



Airborne snow observatory

government map biodiversity, develop a better mechanism for monitoring deforestation and degradation, and alleviate uncertainty regarding carbon emissions from deforestation.

Airborne Visible/Infrared Imaging Spectrometer Classic (AVIRIS-C)

POC: Robert O. Green, Experiment Scientist

The Airborne Visible/Infrared Imaging Spectrometer Classic (AVIRIS-C) flew during fiscal year 2012 to support a range of NASA science research objective that included monitoring of the impact and recovery of the Gulf Coast ecosystems from the 2010 oil spill (Fig AC-1). AVIRIS was the first full solar reflected energy range imaging spectrometer, with first flights

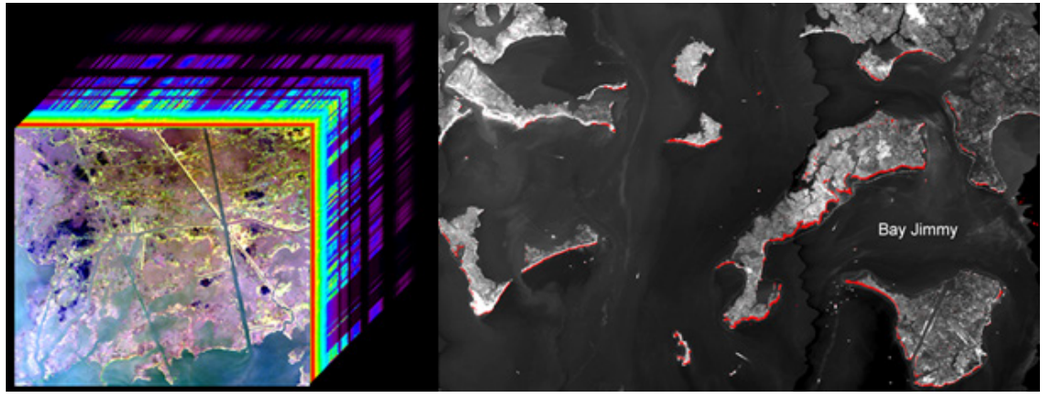


Fig. AC-1. AVIRIS Classic image cube from the Gulf Coast and spectroscopically derived map of oil impacted zones of Barataria Bay, Louisiana.

in 1986, and has flown in every year since. In 2013 and 2014, AVIRIS flying on the ER-2 aircraft at 20 km altitude is baselined to support the large area coverage HyspIRI preparatory science campaigns in California. Currently, more than 800 refereed journal articles reference AVIRIS-C.

AVIRIS-Next Generation (AVIRIS-NG)

PI and POC: Robert O. Green

The instrument development of AVIRIS Next Generation (AVIRIS-NG) was completed early in calendar year 2012. AVIRIS-NG exceeds the performance of AVIRIS-C in spectral, radiometric, and spatial measurement characteristics. Alignment and cold calibration was completed in March of 2012, achieving the highest uniformity of any imaging spectrometer to date: >98%. The first flight of AVIRIS-NG was April 22, 2012. Through the remainder of fiscal year 2012, a series of calibration and validation data sets have been collected using the low altitude Twin Otter airborne platform. Spatial sampling as fine as 30 cm has been demonstrated. AVIRIS-NG will be used for science investigation in 2013 and plans will be developed to integrate it onto a high-altitude airborne platform. The design of the AVIRIS-NG instrument — to operate in a vacuum at cryogenic temperatures — provides important technology and implementation validation as well as enabling straightforward scaling to a range of space opportunities, such as the NASA HyspIRI Earth Decadal Survey Mission.

AVIRIS-NG in final assembly, alignment team upon achievement of >98% cross-track spectral uniformity, and image cube form first flight April 22, 2012.

CO_2 Laser Absorption Spectrometer (LAS)

POC: Gary Spiers

JPL developed the airborne Laser Absorption Spectrometer instrument for the purpose of measuring high-accuracy CO_2 concentrations and variability in the lower atmosphere. This instrument employs continuous-wave laser transmitters and coherent detection receivers at wavelengths ~2.05 µm. The Integrated Path Differential Absorption (IPDA) method is used to retrieve CO_2 column mixing ratios. Several flights on the NASA DC-8 research aircraft were conducted during a summer 2011 campaign, supported by the NASA ASCENDS (Active Sensing of CO_2 Emissions over Nights, Days, and Seasons) mission development program.

During FY 2012, the CO_2LAS team refined data processing and analysis capabilities and generated high-precision CO_2 data products. CO_2 drawdown due to photosynthetically active surface vegetation was evident in data products from the airborne CO_2LAS instrument during an August 10, 2011, flight segment extending from over the Colorado plains into Nebraska during early afternoon. The flight altitude was 20,000 ft. The observation of the relatively small decrease in CO_2 as the aircraft ground track transitioned from barren to vegetated surface type is a significant step in the validation of the NASA ASCENDS laser-based mission concept. An ASCENDS objective is improved characterization of the geographical distribution of CO_2 sources and sinks, CO_2 being the most influential greenhouse gas that is directly augmented by human activities.

CO_2 LAS flew with other instruments aboard NASA's DC-8

Human Exploration and Operations Support

Vehicle Cabin Atmosphere Monitor (VCAM)

PI: Ara Chutjian
POC: Nikzad (Benny) Toomerian

The Vehicle Cabin Atmosphere Monitor (VCAM) instrument was operated to measure the major constituents and trace gases of the air within the International Space Station. The instrument was comprised of a gas chromatograph and mass spectrometer. VCAM operations on the ISS commenced in June of 2010 and concluded in June of 2012. VCAM successfully provided measurements of both parts-per-billion (ppb) levels of volatile trace-gas constituents and of the atmospheric major constituents (nitrogen, oxygen, argon, and carbon dioxide) aboard ISS.

INSTRUMENTS & SCIENCE DATA SYSTEMS DIVISION

Technology Development

ANNUAL REPORT FY 2012

Division 38 actively develops instrument and data system technology for JPL's three main science themes of Astrophysics and Space Science, Earth Science, and Solar System/Planetary Science, as well as related technology for other organizations. Our main technology areas are:

- Optical spectrometers and cameras.
- Advanced optics.
- Imagers, lasers, and semiconductor devices.
- Science data systems and algorithms.
- Superconducting devices and instruments.
- Coolers and thermal control.
- Micro- and submillimeter-wave instruments.
- In situ instruments.

Optical Spectrometers and Cameras

Next Generation Time Resolved Raman Spectrometer for Planetary Mineralogy

POC: Jordana Blacksberg

The Division, in collaboration with the Technological University of Delft, is developing a mineralogy tool that promises to perform both phase and elemental analysis on rock, soil, and regolith in undisturbed natural settings. The instrument uses a new time-resolved detector, a Single Photon Avalanche Diode (SPAD) array, which exploits the unique time scales of Raman scattering and fluorescence. This development, which allows separating the temporally distinct Raman (immediate) and fluorescence (delayed) responses, is particularly important because it offers a significant reduction in instrument size, weight, power, and overall complexity, while providing enhanced science return. This unique technique also offers the possibility of simultaneously collecting microscopic Laser Induced Breakdown Spectra (LIBS), which provide complementary elemental information.

Novel Compact Imaging Spectrometer Modules

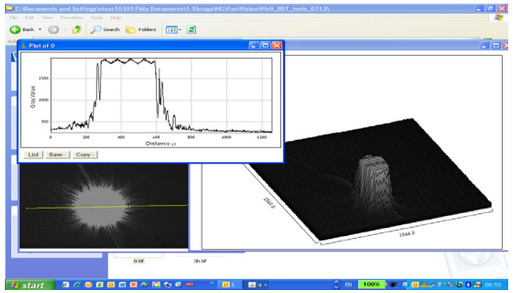
POC: Andreas Kuhnert

The Division is developing modular, high-resolution, wide-field, near-IR (NIR) spectrometer modules that will enable imaging spectrometer missions that can be quickly assembled with minimal redesign and testing. These compact modules, which can be ganged together to cover multiple spectral ranges simultaneously, will enable low-cost, wide-coverage, greenhouse gas observation missions for a variety of science requirements. In turn, this will allow unequivocally identifying sources on small regional scales, quantifying them as a function of environmental parameters, and disentangling natural from anthropogenic fluxes. Only a wide-swath instrument measuring all major carbon gases with OCO-2 instrument sensitivity plus global coverage can achieve this. Full mapping will also unleash the potential of combining atmospheric information with remotely sensed Earth surface characteristics (such as soil moisture, vegetation, and surface temperature).

Radiation-Hard Superlattice Passivation Technology for Deep Ultraviolet Silicon Imaging Detectors

POC: Michael Hoenk

The Division teamed with Alacron LLC to achieve a breakthrough in deep ultraviolet imaging detectors for machine vision applications. Silicon Complementary metal–oxide–semiconductor (CMOS) imaging arrays, passivated by molecular beam epitaxy and coated using atomic layer deposition, were exposed to high-power, pulsed 263-nm excimer lasers as part of accelerated lifetime testing. No other Deep Ultraviolet Silicon (DUV) detector technology has survived this level of testing for more than a few hours. The detectors exhibited no measurable changes in either quantum efficiency or dark current at a sensitivity



Commercial three-megapixel CMOS imaging array passivated using the new superlattice doping technology. The figure shows images and line scans from the CMOS array with a high-power pulsed excimer laser focused on the imaging surface (image courtesy of Alacron).

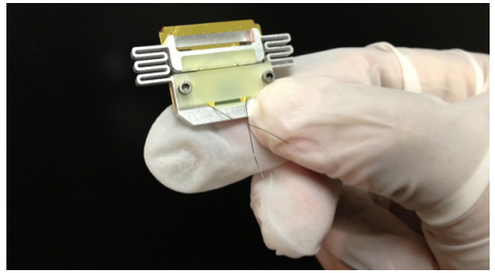
level of 1% after exposure to ~10^8 laser pulses at 500× saturation and they exhibited no discernable persistence or hysteresis at room temperature. This level of stability and robustness against DUV-generated interface traps is unique.

This milestone was accomplished by growing a 5-nm silicon passivation layer with embedded two-dimensional ordered surface phases of boron on thinned, back-illuminated CMOS imaging arrays using low-temperature molecular beam epitaxy (LTMBE). The unique characteristics of this passivation layer are derived from quantum confinement of majority carriers and quantum exclusion of minority carriers from the surface. In addition to its applications to CMOS detectors, superlattice doping has also been used to passivate large-format astronomical CCDs. In all cases, superlattice doping achieves quantum efficiencies equivalent to prior work on delta-doped CCDs, while substantially improving the robustness, dark current, and back-surface conductivity.

Micro Shutter for Spectrometer Calibration

POC: Byron Van Gorp

Development of a 2- to 3-g micro-shutter with low power consumption is being explored for use in imaging spectrometer applications. The shutter is placed



SMA actuated shutter prototype assembled for testing with lithographic slit.

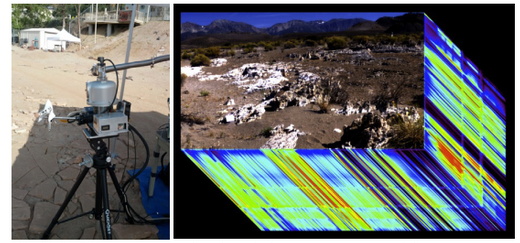
directly in front of the spectrometer slit, so only a minimal amount of motion is required. The total travel of the shutter, which uses Shape Memory Alloy (SMA) actuation, is ~70 µm, which effectively covers the spectrometer slit of 27 µm × 17 mm dimensions with ~50% of the width overhang.

This technology could enable new in situ and remote sensing imaging spectrometer instruments that were previously not feasible due to the mass, power, and reliability issues related to mechanical shutters or the calibration challenges posed by instruments without active dark frame measurement capability. Potential instruments and missions include Mars rovers and orbiters, Europa and asteroid missions, and Earth-orbiting and airborne spectrometers.

Ultra Compact Imaging Spectrometer (UCIS) for Planetary Mineralogy

POC: Pantazis Mouroulis

Ultra Compact Imaging Spectrometer (UCIS) is a miniature instrument designed for resource-constrained platforms such as Mars and asteroid rovers and landers. On a rover mast, and using the mast scan mechanism, UCIS can image an area of 33 × 100° (440,000 pixels) in ten minutes or less, while simultaneously recording the spectrum of every pixel in the scene with a resolution of 10 nm over the 500- to 2500-nm band. UCIS can be a valuable asset



(Left) UCIS instrument head and electronics on tripod for scanning. (Right) 50° wide in situ spectral image cube panorama of Navy Beach tufa site at Mono Lake, CA. Shown is a color composite image using the RGB wavelengths selected out of the 3-dimensional data set.

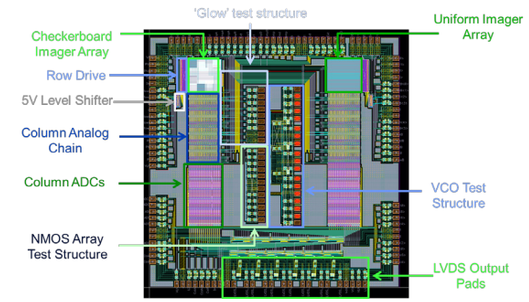
in understanding local mineralogy, selecting areas of geologic interest, and identifying promising samples for detailed analysis by other instruments. Although imaging spectrometers for mineralogic mapping are commonly used for orbital planetary missions, this is the first demonstration of a broadband miniature unit suitable for arm- or mast-mounting on an in situ platform.

This year, a version suitable for outdoor use was assembled, calibrated, and tested in the laboratory and in the field. The optomechanical design and parts of the thermal design were flight-like, with a mass of <1 kg. The remainder of the system was adapted for terrestrial use, utilizing a small vacuum shell and commercial electronics. Other important parameters demonstrated were high uniformity, good depth of field (from less than 3 m to infinity), and a power-saving cold shield that reduced thermal background from the spectrometer by an effective 45 K. High-quality UCIS spectra were collected in the laboratory, the JPL Mars Yard, and in the field at Mono Lake, CA. With a special microscope adapter, UCIS was also able to collect rock spectra with a spatial resolution of ~80 µm).

Next-Generation Integrated Camera (NIC)

POC: Colin McKinney

The first CMOS test imager chip for the Next-Generation Integrated Camera (NIC) has been



NIC2012 test imager chip layout

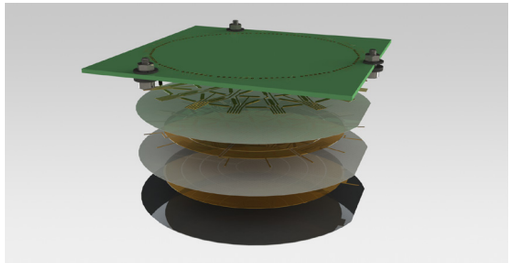
successfully fabricated. NIC is a modern, compact, highly modular and extreme-environment capable replacement for the highly successful Mars Exploration Rover (MER) camera. NIC will use a low-cost, JPL-designed, 1-Megapixel monolithic imager fabricated using commercial CMOS process technology to provide engineering-quality images similar to those provided by the MER cameras. The new CMOS imager includes low power, high-speed readout electronics capable of operating between -135° C and +125° C, which eliminates the need for environmental control systems and enables significant reduction in the camera power consumptions. NIC has direct technology infusion possibilities where engineering-quality cameras are desired and is suited to support such target applications, including spacecraft proximity observations, rover hazard detection, or Sun tracking.

Advanced Optics

Lightweight Deformable Membrane Mirror Development for Reconfigurable Space Telescopes

PI: Sergio Pellegrino (Caltech)
POC: Harish Manohara

The Division, in collaboration with the Caltech campus, is developing lightweight deformable mirrors



Graphic representation of the membrane mirror stack fabrication and assembly

(DM), with the objective of realizing functional deformable mirrors that can be used by multiple nanosatellites to demonstrate on-orbit self-assembly of reconfigurable space telescopes. These membrane mirrors are made of thin layers of a piezoelectric polymer, polyvinylidene difluoride (or PVDF), patterned in unique ways to provide surface-parallel actuation, which adjusts the optical surface as needed to achieve the correct optical figure. Each wafer-scale mirror contains on the order of 100 independent actuating elements that can be controlled individually.

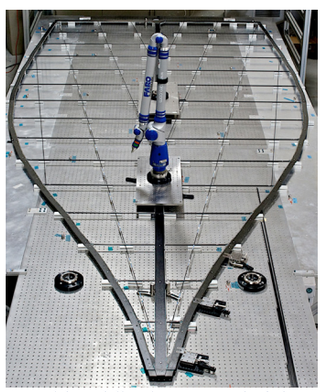
The membrane mirror stacks are fabricated using complementary facilities at the Kavli Nanoscience Institute (KNI) of Caltech and the JPL Microdevices Laboratory (MDL). The mirrors themselves comprise the mirror stacks, an ultra-low thermal expansion bi-metallic reflective layer that uses a mechanical grid to provide thermal stability, and a silicon wafer substrate with the required electrode patterns. After joining the elements, the actuator film-electrode stack is released through plasma-based reactive ion etching (RIE) followed by a non-plasma dry etch with Xenon Difluoride (XeF2).

Technology Development for Exoplanet Missions (TDEM)

POC: Marie Levine

NASA's Exoplanet Exploration Program Technology (ExEP) funds and manages Technology Development for Exoplanet Missions (TDEM) and provides infrastructure and technical support for demonstrations, most notably in the Division's world-class High Contrast Imaging Testbed (HCIT). The goal is to mature technologies to image and characterize exoplanets to seek signs of life. Two main approaches are being considered: 1) internal coronagraphs that reject starlight through diffractive occulting masks or apodization within the observatory in order to image orbiting planets that are 10 orders of magnitude fainter, and 2) external occulters that reject starlight by placing a free-flying 40-m-class Starshade, with specially designed petals, at a distance of about 50,000 km in front of the observatory.

During fiscal year 2012, all five 2010 TDEM tasks using JPL support successfully completed their technology demonstrations and received Exoplanet Technical Analysis Committee (ExoTAC) approval. Demonstrations included: sub-milliarcsecond phase-induced amplitude apodization (PIAA) coronagraph pointing (with University of Arizona/Subaru); a hybrid lyot mask (with Division 32), which achieved the best contrast of all coronagraphs at 5.2×10^{-10} at 10% bandwidth; a novel and more precise speckle sensing methodology; high-accuracy optical models of selected coronagraph masks; determining and demonstrating the starshade fabrication tolerances required for imaging Earth-like planets (with Princeton University).

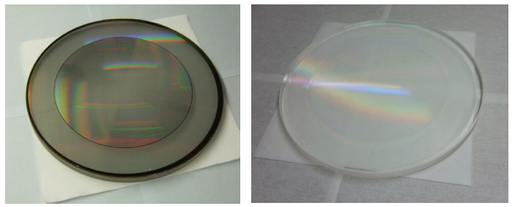


A petal for a full scale 32-m starshade has demonstrated fabrication tolerances required for imaging Earth-like exoplanets

Fabrication of Large Computer-Generated Holograms for Large Aperture Optics Testing

POC: Daniel Wilson

The Division, with the University of Arizona, has developed electron-beam lithography techniques for fabricating large (230 mm diameter, 12 mm thick) computer-generated holograms (CGHs). Large CGHs enable high-accuracy interferometric testing of mirrors that are needed for large aperture optical systems. To successfully develop this technology, a number of challenging hurdles had to be overcome. First, a new cassette was modified to mount the large diameter, thick fused silica substrates in JPL's electron-beam lithography tool. Second, new electron-beam exposure and resist development processes had to be created to allow writing such large areas in reasonable times (weekend exposures). The e-beam voltage was reduced from 100 kV to 50 kV, since 50 kV operation approximately doubles the resist sensitivity (reduces required dose) and doubles the e-beam field size (reduces stage move time). Third, the absolute pattern placement uncertainty of the e-beam tool had to be reduced to tens of nm for the CGHs to achieve very low wavefront error. The placement accuracy of test patterns was measured and then used to create pattern pre-distortion error correction algorithms. This approach worked well, reducing the measured placement error for a pre-distorted pattern to less than 20 nm RMS. The resist is transparent, is a good refractive index match to the substrate glass, and is durable (can be cleaned with alcohol and acetone).



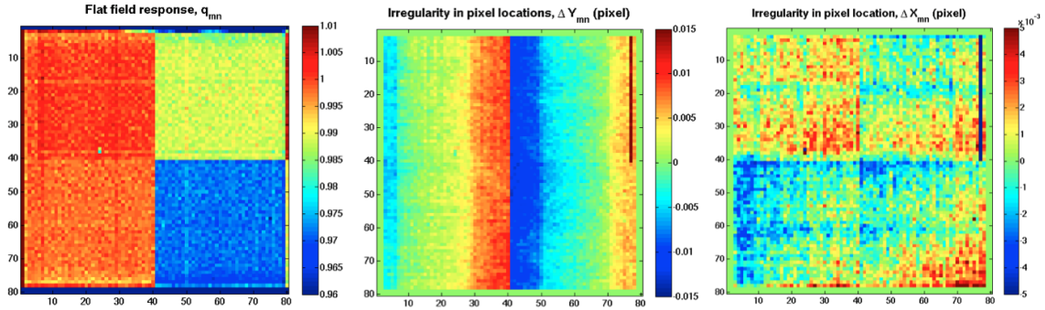
230-mm diameter × 12-mm thick computer generated holograms (CGH) fabricated by e-beam lithography at JPL: (a) chrome-on-glass amplitude CGH, (b) resist-on-glass phase-only CGH.

The process requires only a single spin-on coating of resist and, after e-beam exposure, a single aqueous development step to clear the exposed areas, leaving the pi-phase CGH pattern. These phase CGHs have approximately 40% diffraction efficiency, which is 3-4 times that of a chrome-on-glass CGH. Since the CGHs are used in double pass, the phase CGH gives approximately 10 times the wavefront measurement signal compared to the amplitude CGH.

Micro-Pixel Centroiding Technology and Validation Experiment for Staring Telescope Astrometry (VESTA) Project

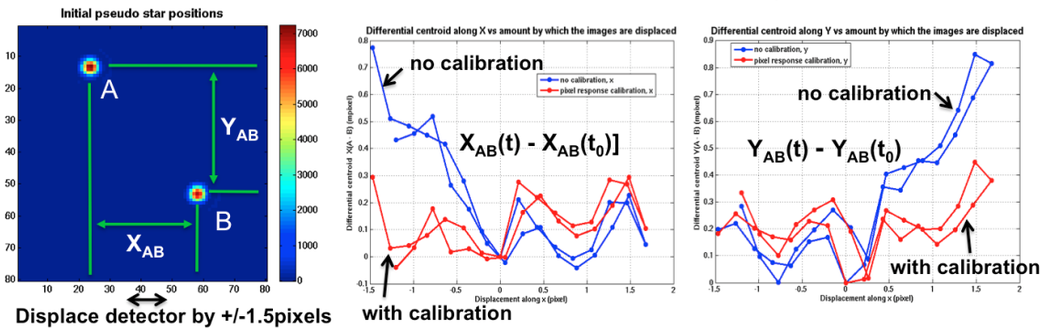
PI: Mike Shao
POC: Chengxing Zhai

High-precision centroiding using focal plane arrays is a crucial technology that has multiple applications. Centroiding at the micro-pixel level enables astrometry of micro-arcsecond accuracy using a 1-meter space telescope and, thus, detecting Earth-like exoplanets. It is a cornerstone supporting the relatively young and novel Nearby Exo-Earth Astrometric Telescope (NEAT)-lite mission concepts for searching for Earth-like planets around nearby stars. Project VESTA, currently funded by Defense Advanced Research Projects Agency (DARPA), applies the precise centroiding to accurate optical navigation using asteroids as references relative to background stars. The Division has developed a centroid estimation algorithm by reconstructing the point spread function using the sampling theorem and incorporating pixel response calibration in Fourier space to achieve micro-pixel level accuracy. Laser fringes are projected at various spatial frequencies on the detector to directly measure the pixel responses in Fourier space so as to calibrate systematic errors from non-ideal pixel response and thermal deformations of the focal plane array. For example, zero spatial frequency measurements give flat field response and, using fringes as rulers in space, the irregularity in the effective pixel locations can be obtained. Recent results on the VESTA testbed show



Pixel response function in Fourier space: $\tilde{Q}_{mn}(k_x,k_y) \approx \overline{Q}(k_x,k_y) q_{mn} \exp\{i(k_x \Delta X_{mn} + k_y \Delta Y_{mn})\}$,

q_{mn} – flat field response, $\Delta x_{mn}, \Delta y_{mn}$ – irregularities in effective pixel locations, $\overline{Q}(k_x,k_y)$ – average pixel response



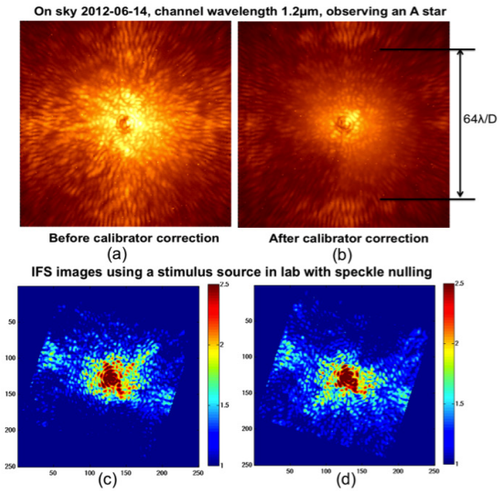
Distance between two pseudo-stars varied as an 80 × 80 CCD detector was displaced by +/-1.5 pixels along X direction. This variation is an error caused by non-ideal pixel response. After applying the pixel response calibration, the variation becomes significantly lower, with the standard deviation being 100 mpixel.

that the differential centroid between two pseudo-stars can be calibrated to 100-mpixel accuracy, confirming previous results from simulations.

Post-Coronagraph Wavefront Sensing for P1640 High Contrast Imaging

PI: Gautam Vasisht
POC: Chengxing Zhai

The P1640 project is a joint effort of the American Museum of Natural History (AMNH), Caltech, and the Division to study self-illuminating Jovian exo-planets in near infrared using high-contrast imaging on the 200-in Hale Telescope at the Palomar Observatory. The high-contrast image is achieved by using a coronagraph working with the Palm 3000 (P3K) adaptive optics (AO) plus the P1604 Calibrator, a post-coronagraph wavefront sensor developed at JPL using interferometry. To achieve high-contrast images, it is important to correct the residual wavefront errors after the AO system, which can be sensed by the P1640 Calibrator. In the figure below, the two images in the top row are from the science camera showing the scenes before (a) and after (b) correcting the residual wavefront errors by offsetting the deformable mirror (DM) of the AO system according to the P1640 Calibrator's sensing. Because the P1640 Calibrator measures the post-coronagraph E-field, we can do a direct speckle nulling to improve the contrast in a specific region, which is extremely valuable for observing a known target or searching deeply in a smaller



Top row contains images for before (a) and after (b) the P1640 calibrator wavefront improvement. The square dark region of size 64λ/D corresponding to the AO control band shows only after correcting the residual wavefront errors measured by the P1640 Calibrator. The images at the bottom row show the results using the speckle nulling technique to improve the contrast in the lower (c) and upper (d) half plane.

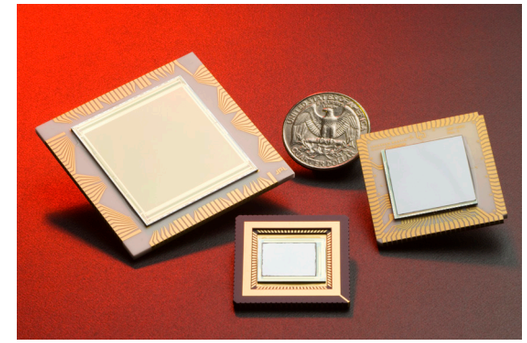
region. The two images at the bottom correspond to cases of speckle nulling for improving contrast in the lower (c) and upper (d) half of the image plane, respectively.

Imagers, Lasers and Semiconductor Devices

Infrared Sensor Technology

POC: Sarath Gunapala

The Center for Infrared Sensors (CIS) in the Division develops infrared sensor technologies using Barrier Infrared Detectors (BIRDs) based on III-V compound semiconductors. BIRDs have depletion layers only in the wide bandgap barrier material, so the Generation-Recombination (G-R) process is nearly eliminated in the photosensitive absorber region and the dark current becomes diffusion limited, allowing



Three large format infrared focal plane arrays developed in the Division's Center for Infrared Sensors

operating temperatures higher than those of homojunction photodiodes with no performance loss. Barrier Infrared Detector Video Graphics Array (BIRD VGA) format focal planes grown on GaSb substrates with lattice matched InAsSb photo-sensitive layers and lattice-matched AlSbAs barrier layers have been developed and have shown strong suppression of G-R currents at operating temperatures as high as 150 K. This breakthrough development enables passively cooled, high-performance infrared instruments for space-borne Earth and Solar System science applications.

Low Operating Temperature Ultra Sensitive (LOTUS) Barrier Infrared Detector (BIRD) for Potential Astronomy Applications

POC: David Ting

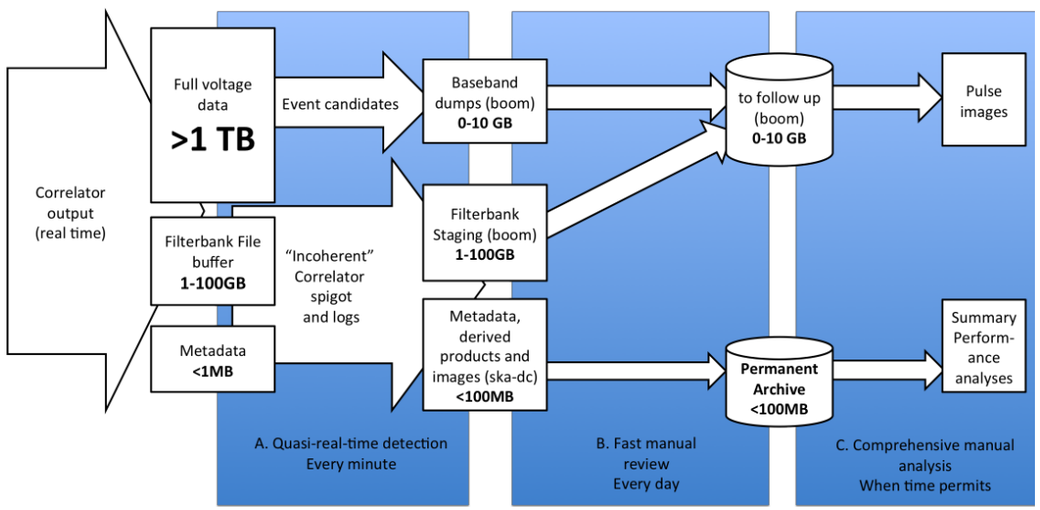
The Division, collaborating with the Science Division, investigated methods for reducing low-temperature dark current in the 5-μm cutoff Mid-Wave Infrared MWIR BIRD devices, which have excellent high operating temperature characteristics, to levels appropriate for astronomy applications and worked on developing infrared detector material and device structures for detectors with shorter cutoff wavelength. Previously identified Generation-Recombination (G-R) dark current produced by defect states

via the Shockley-Read-Hall (SRH) mechanism is a key limiting factor of low-temperature performance; therefore, this task focused on defect reduction by reducing local strain in the detector material. The figure shows the photoluminescence (PL) spectrum taken from the detector material. The minority carrier lifetime for this material, 580 ns, compares very favorably with published minority carrier lifetimes (<100 ns) in InAs/GaSb type-II superlattice structures at comparable wavelengths. The team fabricated detector structures and measured the spectral response and dark current density. The detector showed good quantum efficiency, with cutoff wavelengths of 5.9 µm, 6.3 µm, and 6.6 µm at 77 K, 150 K, and 200 K, respectively. The device dark current density is also quite good. When normalized with respect to the cutoff wavelength (in general dark current density is high in detectors with a longer cutoff wavelength), the new structure has ~10 times lower dark current at ~150 K, and ~40 times lower at 77 K than the detector results reported during fiscal year 2011 year. The new infrared detector material with shorter cutoff wavelength also shows promise, with PL peaks at 4.3 µm (estimated) and 3.84 µm, respectively.

Tunable Laser Diodes at 2.65 µm for HDO Deuterated Water Detection

POC: Siamak Forouhar

A number of critical atmospheric and industrial monitoring tools would benefit significantly from high power single frequency tunable lasers in the 2.65- to 2.75-µm band. In this spectral window, greenhouse gases and atmospheric tracers, such as CO_2, $^{13}CO_2$, H_2O, HDO, exhibit far stronger infrared absorption than in the near-infrared windows that are commonly used. While even stronger absorption is available in the mid-infrared region centered near 4.3 µm, the lasers and detectors required to access these features remain expensive and inefficient. During fiscal year 2012, the Division developed single-mode Laterally Coupled-Distributed Feedback (LC-DFB) diode lasers at 2.65 µm for use in the next generation instruments designed to measure stratospheric H_2O/HDO. The same technology can be adapted to slightly longer wavelengths near 2.75 µm for examination $^{13}CO_2$/$^{12}CO_2$ ratios in the arctic troposphere.



V-FASTR data pipeline. Left to right: data comes into NRAO from the VLBA and is reduced using a Quasi-real-time detection algorithm and, then, via Fast manual review.

Science Data Systems and Algorithms

Scalable Data Archiving and Mining

POC: Chris Mattmann

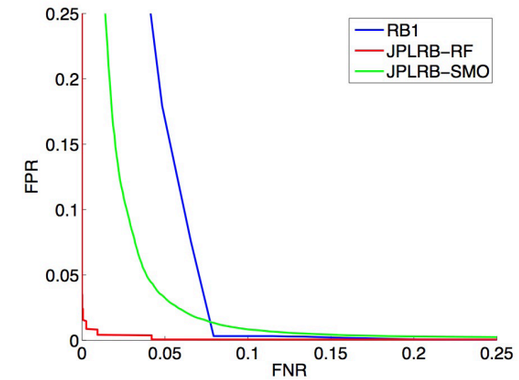
The Division, working with the Communications, Tracking, and Radar Division, developed computing technology to handle the vast amounts of data from new radio astronomy arrays, such as the Square Kilometer Array (SKA) and the U.S. Hydrogen Epoch of Reionization Arrays (HERA) program.

In the area of immense data archiving, there are a number of challenges that the Division addressed directly as part of this effort. The division worked with the U.S. National Radio Astronomy Observatory (NRAO) to deploy and implement an Expanded Very Large Array (EVLA) data reduction pipeline at facilities in Socorro, NM. In addition, the Division worked with the Square Kilometre Array (SKA) South Africa/MeerKAT science algorithm processing team to construct correlator data archiving technology. The Division built and delivered the Very Fast Transients Experiment (V-FASTR) data review portal for use in the nightly radio transient review pipeline. This and related work positions JPL as a leader in the Radio Astronomy and Big Data areas.

Reliable Detections of Astronomical Optical Transients

POC: Umaa Rebbapragada

The Division is developing a system to reduce false positives in the real-time vetting of transient events in the Palomar Transient Factory (PTF), a fully automated synoptic sky survey that has demonstrated real-time discovery of astronomical optical transient events (e.g., supernovae). Early detection of transient events is critical for timely follow-up on designated instruments. PTF currently produces one million



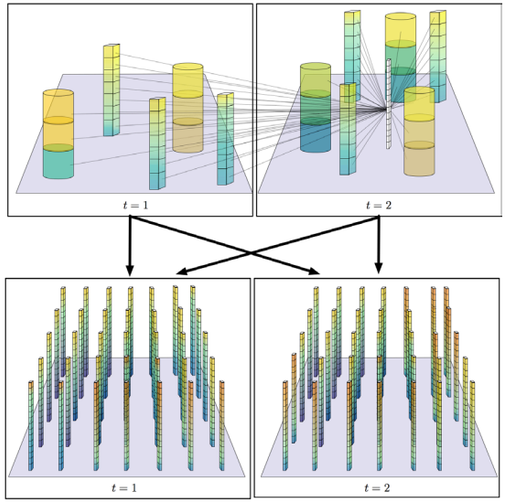
False positive rate vs. the false negative (missed events) rate as the threshold for "real" event is varied. The blue line shows the results for the classifier currently in use. The green and red lines (JPLRB-SMO and –RF) show the results of training with improved contextual information and training data using Support Vector Machine and Random Forest classifiers respectively.

candidate objects per night, a data rate that necessitates automation. The vetting system currently in use produces thousands of mostly false detections per night (false positive rate of 80%) and is not trusted to make autonomous decisions. The system under development in this task focuses on encapsulation of vital contextual information that human experts themselves use to make real/false decisions, including the source's location on the imaging chip, neighboring sources, image subtraction quality, prior detections, and other historical information. These improvements yielded classification performance that beat the current solution and reduced the false positive and negative rates to 0.4% and 0.9% respectively.

Multivariate Data Fusion and Uncertainty Quantification for Remote Sensing

POC: Amy Braverman

NASA's constellation of Earth-observing satellites produces massive, high-resolution data sets for climate and environmental studies that are collected by many different instruments with different sampling



Schematic diagram depicting the relationship between a field of true profiles at two time points (t=1 and t=2) in the bottom two panels and observed profiles of those two time points by two different instruments in the top two panels. One instrument sees profiles on circular footprints, shown here as stacked barrels. The other observes on square footprints, shown here as stacked cubes. A given true profile, shown in the top-right panel as the thin white stick, is correlated with all observations at all locations at all times. Therefore, all observations provide information used to make inferences about the true profile. This is true of every true profile in the bottom panels. By exploiting all this information, minimum uncertainties are achieved in the estimates of the true field.

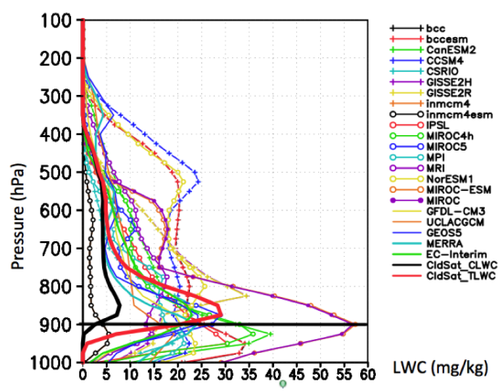
characteristics, resolutions, accuracies, and measurement errors. In short, they are highly heterogeneous, yet still complementary. Combining these data in a way that capitalizes on their respective strengths and preserves relationships between related quantities observed by different instruments is essential to realizing maximum scientific return.

The current effort extends the methods developed under the predecessor project, Geostatistical Data Fusion for Remote Sensing Applications. Within that project, the Spatio-Temporal Data Fusion (STDF) algorithm was developed and implemented to fuse two scalar-valued measurements to create an estimate of a bivariate geophysical field from massive, heterogeneous inputs. STDF employs a hierarchical, spatio-temporal statistical model that relates the true field to observations of it and uses this model to make inferences about the true field from the incongruous observations. These inferences include not just estimates but also uncertainties of the estimates; this is crucial for subsequent scientific applications.

The current effort extends STDF to fuse multiple vector-valued observations, like observations of atmospheric profiles, from different instruments. It will enable optimal (minimum uncertainty) estimation of 3-D fields that provide a single best observationally based data set for evaluation of physical models and for more general exploratory studies. The initial target domain application is the joint inference of CO_2 and potential temperature profiles observed by the Orbiting Carbon Observatory-2 (OCO-2) and the Atmospheric Infrared Sounder (AIRS).

Evaluating CMIP5 Global Climate Models with Satellite Observations

POC: Seungwon Lee



Globally-averaged (80N-80S), annual mean vertical cloud liquid water content profiles (in unit of mg/kg) from CMIP5 models and CloudSat observations. The red thick line is the CloudSat total liquid water content (TLWC), while the black thick line is the CloudSat estimated cloud liquid water content (CLWC). The "true" cloud liquid water content is expected to be between the CloudSat TLWC and CLWC. The horizontal line at 900 hPa is to indicate that the CloudSat retrieval is not reliable for pressures higher than 900 hPa due to the radar clutter near the surface.

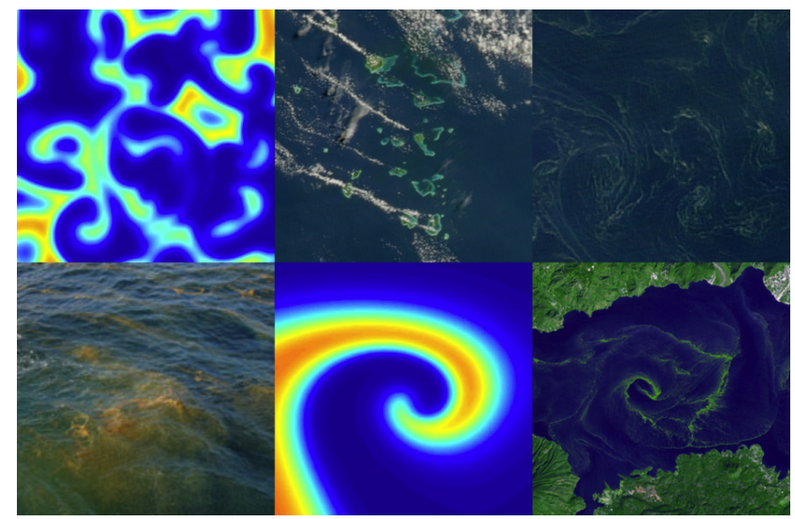
This work is a part of the NASA ROSES COUND (Enhancing the Capability of Computational Earth System Models and NASA Data for Operation and Assessment) program. The goal is to evaluate the cloud components of Phase 5 of Coupled Model Intercomparison Project (CMIP5) global climate models using global satellite observations from A-Train instruments. CMIP5 is a set of coordinated climate model experiments to evaluate how realistic the models are in simulating the recent past, to provide projections of future climate change, and to understand why similarly forced models produce a range of responses.

In the first year of this project, observational datasets relevant for CMIP5 model evaluations on cloud liquid water representations were generated utilizing the CloudSat, MODIS, and AMSR-E cloud liquid water products. For each of the products, observational uncertainties and retrieval assumptions and caveats were characterized. With the characterized observational datasets, the team evaluated the cloud liquid water simulations of the CMIP5 models. Most of CMIP5 models persistently overestimate the cloud liquid water content throughout all pressure levels, as is clearly illustrated in the figure. The misrepresentation of cloud liquid water leads to systematic biases in radiative fluxes related to clouds. In the second year of this project, useful constraints for cloud parameterizations of next-generation climate models will be identified by carefully filtering the observational datasets with sub-grid scale cloud conditions.

Using Reaction-Diffusion Equation to Model Atmospheric Turbulence & West Nile Virus Epidemiology

PI: Joao Teixeira
POC: Martin Lo

The goal of this project is to find more efficient stable numerical schemes to solve the diffusion equation with reaction and advection terms. Joao Teixeira (PI) is using this to model the vertical turbulent mixing in the atmosphere. By adding a predator-prey term, this equation can also model epidemiology; we are, therefore, also using this to model the spread of West Nile Virus in collaboration with the University of California at Davis Vectorborne Disease Center. Alan Turing realized that this equation could be used to explain many of the patterns seen in biological systems, like



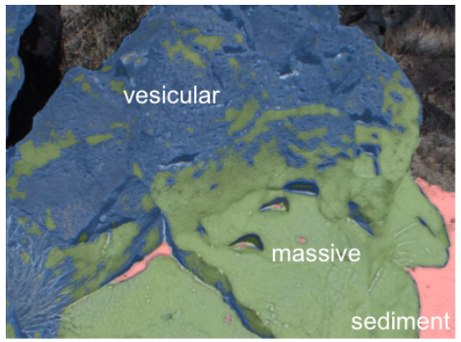
(top left) Simulated distribution of prey (yellow=prey, blue=no prey) from the reaction-diffusion-predator-prey model of Turing's Morphogenesis Theory, compare with Fiji atolls and algae bloom. (top middle) Image of coral building atolls at Fiji. (top right) Cyanobaterial (Bluegreen Algae) bloom near Fiji. (bottom left) Cyanobactiria, Bluegreen Algae in ocean. (bottom middle) Simulated prey distribution detail. (bottom right) Cyanobaterial bloom in Lake Atitlán, Guatemala, due to sewage, compare with (bottom middle).
Image Credits: Top middle, right: Aqua MODIS image from Oct. 18, 2010, from OceanColor Web. Bottom left: Oregon State University Remote Sensing Ocean Optics Group. Bottom right: Earth Observatory, ASTER data on Terra Satellite.

the spots and stripes on various animals and plants. He called his theory "Morphogenesis" and this year is the 60th anniversary of the publication of this seminal work. The figure shows some comparison of simulated results of this equation to real biological structures. The simulated prey distribution in the top left figure looks very similar to the atolls built by corals in Fiji shown in the top middle and the bluegreen algae, cyanobacterial bloom near Fiji shown in the top right. Interestingly, both images (top middle) and (top right) were cropped from the same MODIS image. The bottom left image shows what the cyanobacteria look like in water. A detail of the simulated prey image in the bottom middle figure looks very similar to the actual cyanobacterial bloom in Lake Atitlán, Guatemala, due to sewage. Not surprisingly, this equation has many applications in image processing and shape analysis. The simulations used a model by M. Garvie.

TextureCam Project

POC: David Thompson

During fiscal year 2012, the TextureCam team focused on developing geologic surface classification algorithms based on machine learning techniques, evaluating automatic target detection and mapping, and demonstrating performance on several tasks relevant to autonomous and single-cycle instrument placement. These tasks included: detection of layered material using images of layered Stromatolites; mapping of rock and sediment surfaces in more than 40 Mars Exploration Rover Pancam images with more than 10,000 hand-labeled rocks; a surface condition index (that is, a map that indicates suitability for instrument placement by showing fracture- and dust-free surfaces); and mapping of smooth and vesicular basalt surfaces in Mojave desert scenes. The figure shows a typical result of smooth vs. vesicular basalt surface mapping. For this final demonstration the team gathered in situ imagery during a first field expedition to the Mojave Desert. They gathered more than 300 stereo images in several dozen simulated rover traverses and approach sequences at ranges from 20 m to 50 cm.

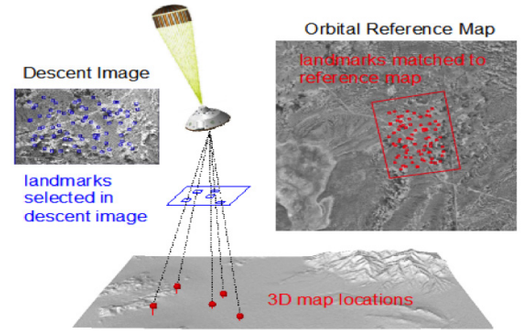


Automatic blind classification of a Mojave scene collected during the Year 1 field expedition. (Top) Original image. (Bottom) Fully automatic labels of "vesicular" and "massive" basalt surfaces.

Fault Tolerant Computing on Multi-Core Architecture for Entry, Descent and Landing (EDL) in Future Spaceflight Missions

PI: J. Lai
POC: Lei Pan

The goal of this project is to design, implement, and demonstrate a robust fault tolerance framework for future space missions using a multi-core processor that can achieve Fail Operational capability and with graceful degradation under simulated faults. A multi-core architecture provides the high computational capability, energy optimization, enhanced autonomy, and system robustness required by future planetary



Terrain Relative Navigation (TRN) using image to map correlation. Image from "Fault Mitigation Schemes for Future Spaceflight Multicore Processors," AIAA Infotech@Aerospace 2012 Conference, by J. Alexander, B. Clement, K. Gostelow, and J. Lai.

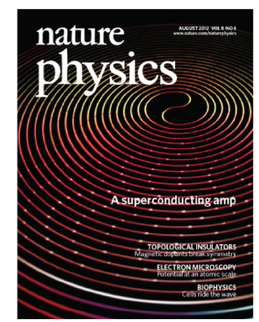
or small body landing missions with proximity operations. The hardware redundancy facilitates software fault tolerant schemes at a lower cost. The focus of this research is to specify the approaches for fault detection, isolation, and recovery using software methods. There are two scenarios for which software schemes to leverage hardware redundancy were developed: (1) Fail Operation, in which the same calculations for Terrain Relative Navigation (TRN) state estimation are redundantly carried out in multiple cores and a voting mechanism is used to determine correct result and identify failed cores; and (2) Graceful Degradation, in which TRN image processing is farmed out to many cores to achieve high performance and, in the case of core failure, degraded but still acceptable, useful results. The results of this research: (1) demonstrated that multi-core based avionics architecture has many advantages over the traditional single core; (2) demonstrated Algorithm Based Fault Tolerance (ABFT) methods for image processing; and (3) provided prototype design and implementation of software to mitigate various fault scenarios. The Division designed and developed the Core Allocation Functions (a.k.a., "the supervisor") module that is responsible for multi-core resource management and TRN task-to-core affinity control. This supervisor module is the basis and centerpiece of the multi-core fault tolerant image processing and feature detection software for future EDL.

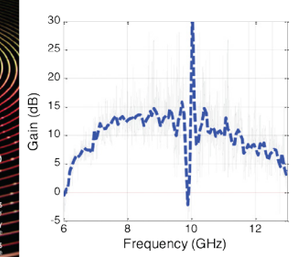
Superconducting Devices and Instruments

Superconducting Parametric Amplifier

POC: Peter Day, Jonas Zmuidzinas, (Caltech and JPL)

During fiscal year 2012, a broadband parametric amplifier operating at 10 GHz made in the Microdevices Laboratory (MDL) using niobium titanium nitride (NbTiN) was demonstrated. A New Technology Report was filed for this concept (NTR 48257) and the results of testing on a prototype device were featured in the August issue of *Nature Physics.* The primary disadvantage of previous implementations of parametric amplifiers has been their limited bandwidth. The traveling wave parametric amplifiers developed here, have approximately 10 dB of gain over about an octave around 10 GHz and a noise temperature <2 K, which is near the quantum limit. Parametric amplifiers of this type can operate at higher frequencies as long as the in-band loss is small. For superconductors, the loss should remain low up until a significant fraction of the gap frequency (720 GHz for Nb and 1400 GHz for NbTiN).





Left: Image of the superconducting parametric amplifier made of NbTiN as featured on the cover of Nature Physics. Right: Gain as a function of frequency for a pump tone at 10 GHz.

Breakthrough for Optical Communication Links Using Tungsten Silicide Nanowire Detector

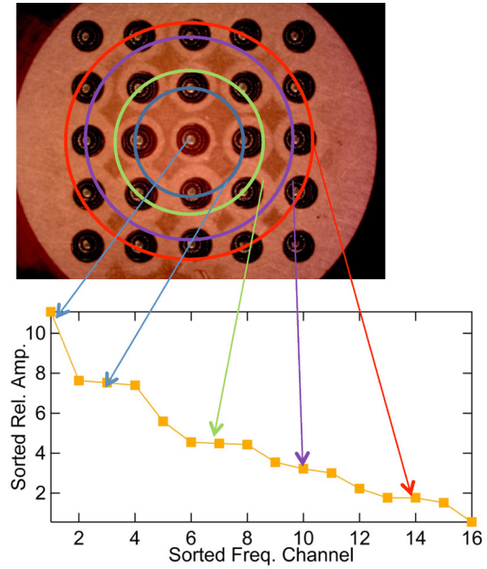
PI: William Farr
POC: Matt Shaw

A close collaboration between the JPL Microdevices Lab and National Institute of Standards and Technology (NIST) has achieved a significant advancement in nanowire detectors for optical communications. The new advance is twofold: first, nanowires made of WSi were found by researchers at NIST to be more robust compared to previous state-of-the-art devices made from NbN; second, when the nanowire is formed into a carefully optimized multilayer optical cavity, system detection efficiencies (SDE), which account for all coupling loses in real applications, exceed 93% and are less sensitive to incident light polarization. The device applications are intended for optical communication wavelengths (1550 nm); during testing, however, it became clear that the devices are responsive to room temperature blackbody radiation. This indicates that nanowire detectors can be used at wavelengths >5 µm for different applications.

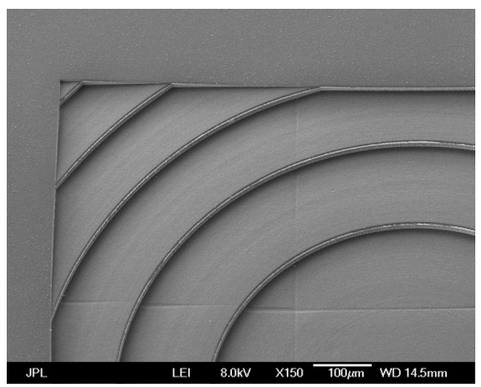
Quantum Capacitance Detector – World Record Optical NEP = 7 x 10^{-20} W/$Hz^{1/2}$

POC: Pierre Echternach

During fiscal year 2012, the Quantum Capacitance Detector (QCD) imaging array achieved world record optical Noise Equivalent Power (NEP) of 7×10^{-20} W/$Hz^{1/2}$. The measured discrete electron tunneling events corresponded to theoretical predictions. Detailed characterization of these tunneling events was used to calibrate the optical response of the QCD in a narrow bandpass filter at 200 µm while illuminated by a cryogenic blackbody. The QCD array was integrated with a planar Fresnel lens array, shown in Figure 3-i. The 5×5 array with 2-mm spacing was designed for a wavelength of 200 µm and can be easily scaled to shorter wavelengths. For longer wavelengths, the process must be adjusted to allow for deeper etch profiles. Data analysis is under way to characterize the performance.



Top: Fresnel lens array as installed in a cryostat behind an apeture array. Bottom: Response of pixels in the QCD array when illuminated by a light source with a 2-mm diameter aperture aligned with the central pixel in the array.

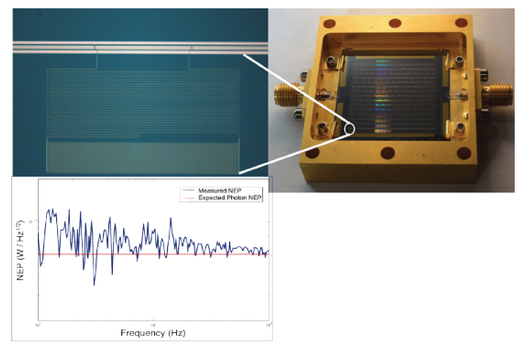


Fresnel lens array

MAKO – Lumped Element Microwave Kinetic Inductance Detector (MKID) 432 Pixel Array Performs at Photon Noise Limit

POC: Henry LeDuc

MDL researchers, in collaboration with the Caltech group of Professor Jonas Zmuidzinas, have significantly advanced the state of the art in Far Infra-Red (FIR) detector array development by fabricating and testing FIR prototype lumped element Microwave Kinetic Inductance Detector (MKID) arrays that are now photon noise limited. Initial tests were performed at the Caltech Submillimeter Observatory (CSO) on the 100-pixel array shown. At the end of the summer 2012, the first 432-pixel array, with a net operational pixel yield of 96% was designed, fabricated, and tested. A key feature of the lumped element design is that it requires only 3 lithographic layers. Thus, the development path toward larger arrays of ~2000 pixels per feedline that can be fielded at the future Cerro Chajnantor Atacama Telescope (CCAT) is straightforward.

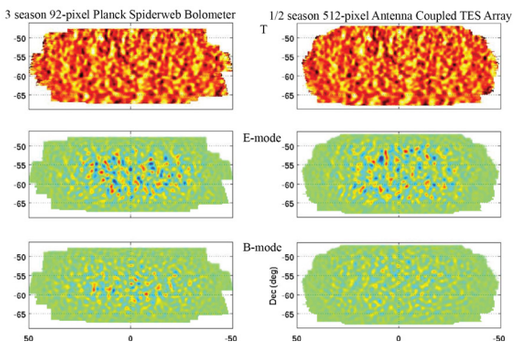


Top left: Zoomed in view of a single lumped element MKID pixel in MAKO. To the top, the three white lines are the microwave feedline and the middle meander segment is the inductive element where the incident far IR photon is absorbed and to the bottom is the interdigitated capacitor. Top right: View of the 100 pixel packaged for test showing the single input and output microwave feedline. Bottom right: Measure noise equivalent power (NEP) spectrum of a representative pixel in dark blue. The red line is the computed photon noise expected at a ground-based telescope such as CSO or CCAT.

New Transition Edge Sensor (TES) mm-Wave Polarimeters on the Sky at the South Pole

PI: Jamie Bock (Caltech and JPL)
POC: Anthony Turner

During fiscal year 2012, four science grade mm-wave focal plane arrays were fabricated and delivered to the astrophysics group at Caltech led by Prof. Jamie Bock. These are the new, fully lithographed arrays consisting of 256 dual polarization spatial pixels, or 512 detectors. The beam pattern for each pixel is defined by a phased array of slot antennas combined using Nb superconducting microwave striplines. The mm-wave power is detected by terminating the stripline on a suspended superconducting transition edge sensor (TES) bolometer readout using a multiplexed Superconducting Quantum Interference Device (SQUID) ammeter from National Institute of Standards and Technology (NIST). During fiscal year 2012, these arrays were deployed in two telescopes, Keck and BICEP 2, both of which are fielded at the South Pole. Data from the first few months of operation of BICEP 2 has obtained a signal-to-noise ratio better than that of 3 years of operating BICEP 1 using 'old' generation



Left: Sky map produced after 3 winter seasons at the south pole obtained from an mm-wave telescope, called BICEP 1, which contained a focal plane with 92 polarization sensitive bolometers (PSBs) (like those used in Planck). Right: Sky map on the same portion of sky produced after only ½ a winter season at the South Pole obtained from an upgraded mm-wave telescope, called BICEP 2, which contained a focal plane with 512 antenna coupled TES bolometers made in the MDL.

technology using feedhorn coupling to spiderweb 'Polarization Sensitive Bolometers' (PSBs) similar to those flown in space on the *Planck* satellite.

High-Temperature Superconductor Resonator Detectors

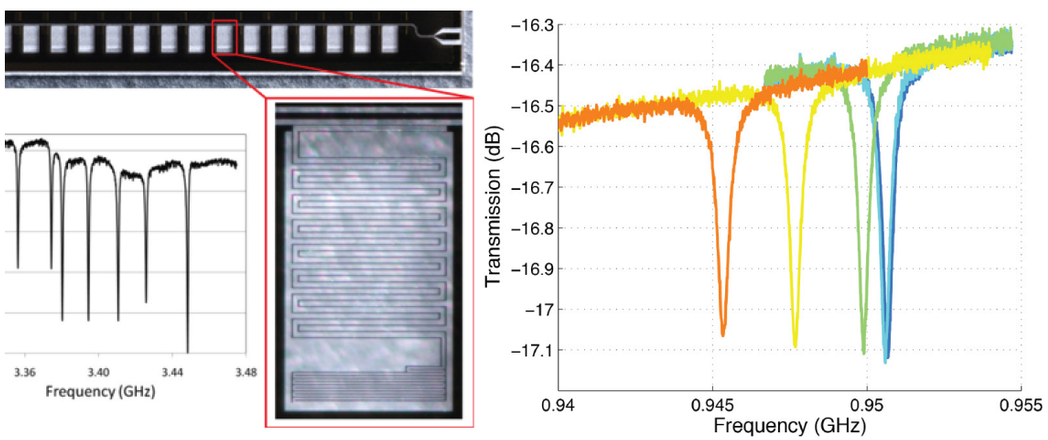
POC: Alan Kleinsasser

High-temperature superconductor (HTS) bolometric detectors are of potential interest as passively cooled infrared sensors in a variety of space applications. This work is aimed at demonstrating HTS resonator bolometer arrays on thermally-isolated membranes. High-quality, 50-nm-thick YBCO films (T_c = 85 K) were grown on amorphous SiN layers on Si substrates by employing crystalline MgO buffers deposited using ion beam-aided deposition. The YBCO films were patterned into series lumped-element resonator arrays with inductors on thermally isolated SiN membranes produced by selective removal of Si substrate material using micromachining techniques. NTR 48711 was submitted for the device fabrication process that has now been proven to produce working pixels.

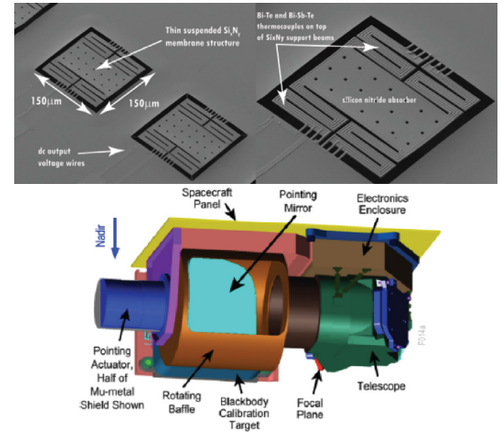
Thermopile Arrays for Space Applications

POC: Matt Kenyon

During fiscal year 2012, 64×8 element thermopile arrays were fabricated in the Microdevices Laboratory. The measured sensitivity in terms of detectivity is $D^*>10^9$ cmHz$^{1/2}$/W; response time is 70 ms. This array has four times the pixels of the thermopile arrays flying on the DIVINER Lunar Radiometer Experiment (Diviner) on LRO and the Mars Climate Sounder (MCS) on MRO and better sensitivity and speed. Compact pixels for a larger 2D array for future planetary and primitive bodies missions were also built and measured. The Thermal Infrared Ganymede Radiometer Experiment (TIGRE) is based on our newly fabricated arrays. TIGRE was proposed this year for the European Space Agency's Jupiter Icy Moons Explorer (JUICE) mission to Jupiter. TIGRE has 32% less mass, 10× larger detector arrays, and 44% more spectral channels than Diviner or MCS, due in large part to these new large-format, small-pixel arrays.



Left: A 16-element series bolometer on a bulk substrate with a single pixel magnified and a plot of frequency dependence of the scattering parameter S_{12} for 8 of the elements. Right: S_{12} versus frequency for a single membrane-isolated device at 30 K showing the decrease in resonant frequency with increasing infrared radiation intensity due to the increase in kinetic inductance.

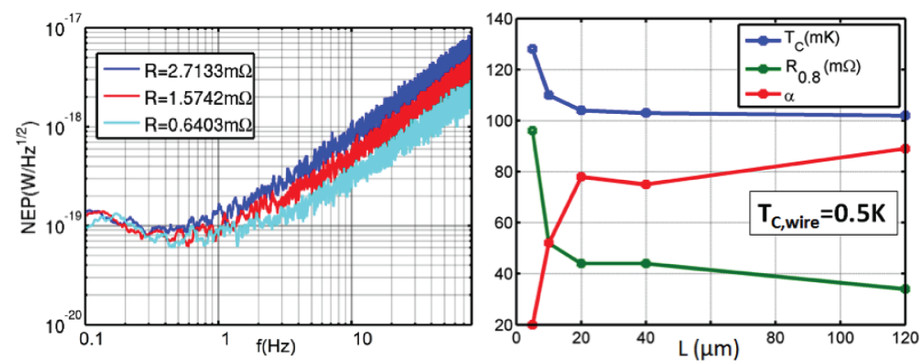


TOP: Micrograph of 150×150 um² pixels built and characterized in MDL. BOTTOM: Thermal Infrared Ganymede Radiometer Experiment (TIGRE) is a proposed next-generation multi-spectral radiometer to study the Jovian system. A 64×16 element thermopile array developed during FY 2012 is the enabling technology.

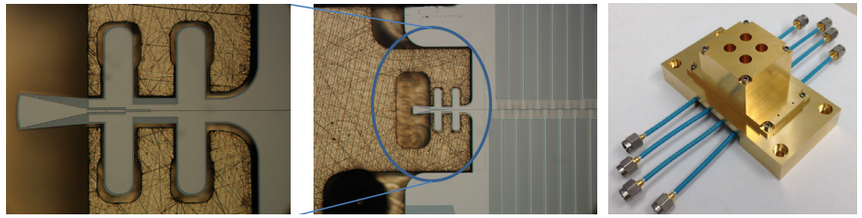
Transition-Edge Sensors (TESs) for the Background-Limited Infrared/Submm Spectrograph (BLISS)

PI: Matt Bradford
POC: Andrew Beyer

During fiscal year 2012, a world record for the noise equivalent power (NEP) of a membrane-isolated transition-edge sensor (TES) was achieved. This NEP achieves the baseline requirement for the Background-Limited Infrared/Submm Spectrograph (BLISS), as shown in Figure LEFT. In particular, 1×32 element arrays of TESs in a time-domain SQUID multiplexer (MUX) were measured to have a system electrical NEP=(0.9±0.25)×10^{-19}W/Hz$^{1/2}$. The packaging and filtering in the testbed was modified to lower the stray power coupling into the TESs to the remarkably low level of 0.135±0.085 fW. The baseline design and process for a TES suitable for BLISS was developed and is comprised of a bilayer of Mo/Cu. The Mo/Cu recipe and thermistor geometry was tuned to have a normal state resistance, superconducting transition T_c, and sharpness of the transition α=dlogR/dlogT optimized for BLISS. To reach this baseline, undesired proximity effects, including the so-called longitudinal proximity effect (LoPE) and the latitudinal inverse proximity effect (LaiPE), were studied. These effects alter both the superconducting transition temperature T_C and the sharpness of the transition α of the thermistor, as shown in Figure 8-i RIGHT. Based on this study, a contact separation of 30 microns was chosen, but could be made as small as 20 microns.



Left: Representative noise equivalent power (NEP) as measured on the most sensitive device in a typical array. The measurement was performed at 45 mK. Here, the noise equivalent current has been divided by the electrical responsivity $(1+(\omega\tau)^2)^{1/2}/V_{bias}$. The measured NEP=(0.9±0.2)×10^{-19}W/Hz$^{1/2}$, while the expected value is NEP~(0.8±0.2)×10^{-19}W/Hz$^{1/2}$. Excess 1/f noise is the dominant contribution to the lack of agreement. Here, the normal state resistance is R_N=6.5mΩ and the red, green, and black curves have the R value that was measured in the transition. Right: Summary of T_c, α, and $R_{0.8}$ (defined as 80% of the normal state resistance) vs. the length L of Mo/Cu thermistors.



Broadband waveguide probe coupling radiation from the horn array to the superconducting spectrometer chip. The assembled chip in a 2×2 horn array (right).

Ultra-Compact Superconducting Spectrometers for BLISS/SPICA and CCAT

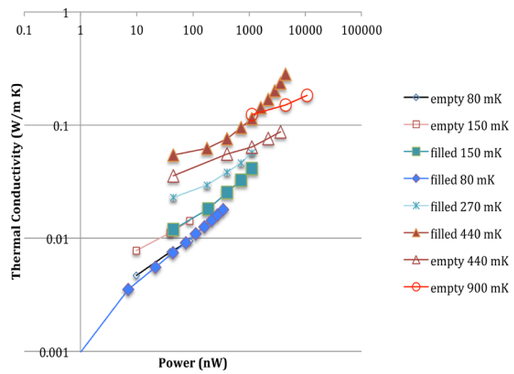
POC: Goutam Chattopadhyay

A novel ultra-compact spectrograph-on-a-chip for submillimeter- and millimeter-wave bands is being developed. The spectrometer uses planar lithography to fabricate superconducting transmission line filters to sort incident radiation by frequency to an array of direct detectors, such as Microwave Kinetic Inductance (MKIDs). One of the major challenges is how to efficiently couple the incoming radiation to the spectrometer chip. Under this task, we designed, fabricated, and tested a 2×2 multi-flare angle, smooth-walled horn array coupled to broadband waveguide probes. The figure shows a photo of the fabricated array with the spectrometer chip inside.

Superfluid Film Heat Spreader/ Heat Pipe for Large Cold Focal Planes

POC: Chris Lindensmith

Superfluid heat pipes offer the possibility of high thermal conductivity and low mass for missions that require large, sub-Kelvin focal planes. Several versions of heat pipe were constructed. Initial testing was done using simple hollow tubes filled with enough helium gas to form a thick (~70-μm) film on the inside surface of the tube. These heat pipes demonstrated superfluid performance down to 0.080 K, as shown in the figure.



Thermal conductivity vs. conducted power.

The thermal conductivity is plotted vs. the conducted power at each temperature to determine if an upper limit of heat flow is observed. At 900 mK and above it was not possible to produce a measurable temperature gradient in the heat pipe with a superfluid film. Below 0.4 K, the heat transport appears to be limited by thermal boundary resistance between the superfluid helium and the copper end caps.

Micro- and Submillimeter-Wave Instruments

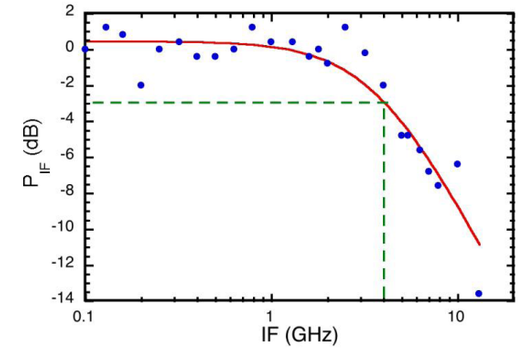
Two-Dimensional Electron Gas (2 DEG) THz Radiation Mixer

POC: John Gill

The 2 DEG THz Radiation Mixer effort is developing a novel submillimeter/THz heterodyne mixer using a 2 DEG (Two-Dimensional Electron Gas) for use in future planetary, Earth and astrophysics missions. A 2 DEG formed between two hetero-structure semiconductor layers can work as a bolometer to detect incident submillimeter/THz signals. A 2 DEG mixer would operate at a much higher temperature — ~ 150 to 200 K achievable by passive radiative cooling — than the ~4 K required for superconducting detectors. Also, the required local oscillator input power would be 1 to 10 μW, ~2 to 3 orders of magnitude lower than Schottky diodes. In addition, a single multiplier chain can drive an entire array of 2 DEG mixers, which will enable heterodyne imaging applications with increased sensitivity due to the use of many parallel channels. The expected noise temperature of a 2 DEG mixer would be 1,000 to 4,000 K.

Antenna-coupled THz 2 DEG mixer devices have been designed, fabricated, and tested, achieving an intermediate frequency bandwidth of 4 to 6 GHz at 80 to 300 K. The conversion mixer conversion efficiency reaches its peak value at ~ 80 K, which exceeds the value at 300 K by ~ 17 dB. At the same time, the device total resistance decreases to about 100 Ω, which is a very suitable value for a good impedance match with a spiral antenna (70 Ω).

A 2 DEG mixer device integrated with a spiral antenna (the gap between the antenna arms at the feedpoint is ~1.5 μm). The mixer chip is placed on the back side of the Si lens for quasioptical coupling to radiation up to 2 THz.

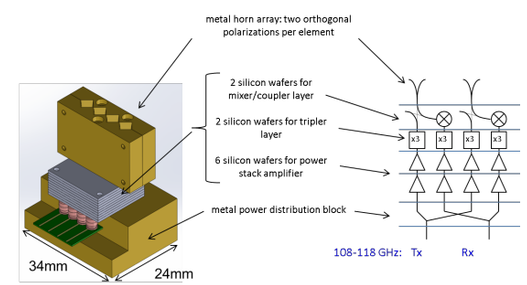


IF response of a AlGaN/GaN 2 DEG (hot electron bolometer) HEB device. The IF bandwidth of ~ 4 GHz is set by the energy relaxation time inherent in the material.

THz Imaging Radar

POC: Ken Cooper

Imaging radar technology at >300 GHz is being developed for commercialization and deployment in domestic security venues. The immediate objective is to develop a heterodyne submillimeter-wave transceiver array that will enable a standoff imaging radar to operate at video frame rates. A micro-fabrication run was successfully completed, yielding dozens of working Schottky diode multipliers and mixers that will be used to populate transceiver arrays operating at either 340 or 680 GHz. In parallel, a two-element 340-GHz transceiver array was designed that is compatible with a novel stacked-silicon-wafer geometry to route the



Design (left) and circuit model (right) for a two-element, 340-GHz radar transceiver integrated in a stack of micro-machined silicon wafers.

waveguide interconnects in three dimensions and house the Schottky diodes. Previous micro-fabrication process development work has fabricated the array stack with high feature precision and excellent uniformity, as well as with integrated gold-on-silicon bias circuitry. The Figure below shows a CAD model and circuit schematic of the two-element, 340-GHz transceiver module that is nearly complete and ready to be tested. This silicon waveguide technology development is leading to new approaches for building compact arrays of terahertz sources and sensors that can be used in a variety of science missions.

Portable THz Imaging Radar

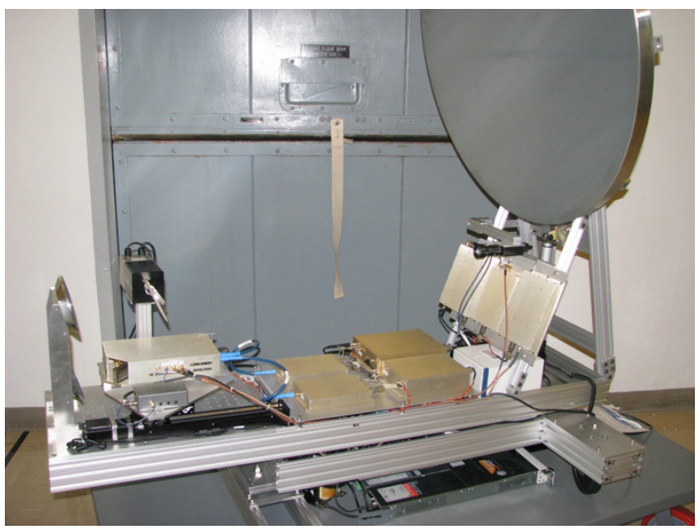
POC: Peter Siegel

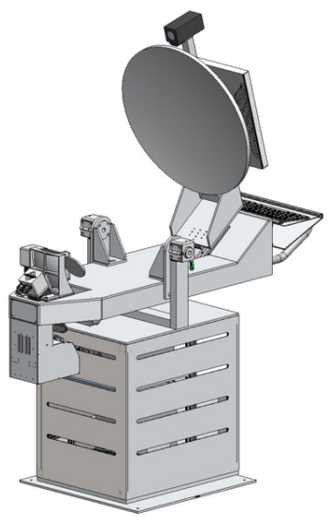
The 25-m standoff THz radar imager has been re-designed and re-packaged to operate at shorter ranges (5 to 10 m) and faster frame rates. Building a more transportable and rugged imager has also been an emphasis during fiscal year 2012; the Figures show a photograph of the current long-range imager and a CAD model of the planned short-range imager. The short-range imager is on track to be completed in the first half of fiscal year 2013; by utilizing two independent transceiver modules simultaneously, it will reach frame rates of 4 Hz, four times faster than the long-range system. The short-range imager will incorporate several enhancements to the long-range imager that were implemented in fiscal year 2012, including automatic refocusing to enable subject tracking over a wide depth of ranges, as well as fast and parallel signal processing implemented on a compact embedded computer/FPGA module. The short-range system will also include entirely new back-end RF electronics modules based on integrated microwave assemblies, along with better-designed packaging for panning, tilting, and rapidly scanning the radar beams. The new radar imager has been designed to be readily transitioned to an external industry partner for commercialization during fiscal years 2013 & 2014.

THz Hot Electron Bolometers (HEBs)

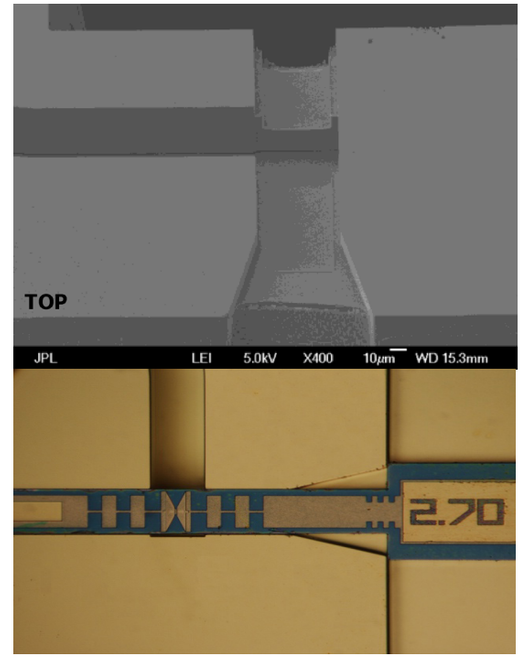
POC: Jon Kawamura

Waveguide-based blocks have been designed for packaging Hot Electron Bolometers (HEBs) mixers in the





A compact THz imaging radar prototype has been developed. This system will be used in a van for field testing.



Scanning Electron Microscope (SEM) pictures of waveguide and channel structures defined into two square silicon substrates of 2×2×0.5 mm by photolithography and DRIE techniques.

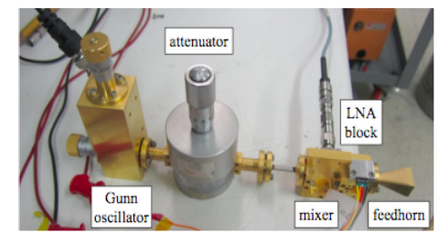
2- to 3-THz range. This packaging scheme sets JPL apart from most other HEB developers, who tend to utilize open, quasi-optical feed structures. Using waveguide based structures we can provide a more controlled matching environment for the device, thus reducing out-of-band noise. Moreover, the waveguide approach allows one to implement more sophisticated circuit topologies, such as balanced mixers, and provides a straightforward path toward arrays.

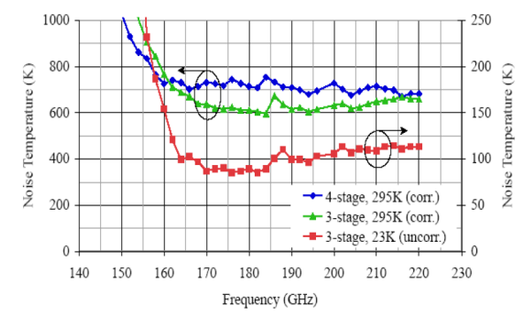
A 2.7-THz, single-ended mixer has been developed and characterized. Since the waveguide block requires very small features (<25 μm), fabricating the waveguide blocks required a novel process: The mixer chip channel and the waveguide structure are directly fabricated in silicon using Deep Reactive Ion Etching (DRIE) techniques. This eliminates the micro-plating step and results in fairly robust waveguide structures.

Millimeter and Submillimeter MMIC Low Noise Amplifier Modules

POC: Lorene Samoska

The goal of this work, being done with Stanford University and Northrop Grumman Corporation, is to develop low-noise, space-mission amplifiers for frequencies as high as 700 GHz using a low-loss, low-mass packaging technique and employing low-risk, rectangular Monolithic Millimeter-wave Integrated Circuit (MMIC) technology. Of particular interest are waveguide-compatible, low-loss, packaged amplifier modules capable of operation at ambient and cryogenic temperatures. These circuits should have noise performance similar to SIS mixers (cooled to 4 K) even though they only require cooling to 20 K. To function with receiver components, the MMIC





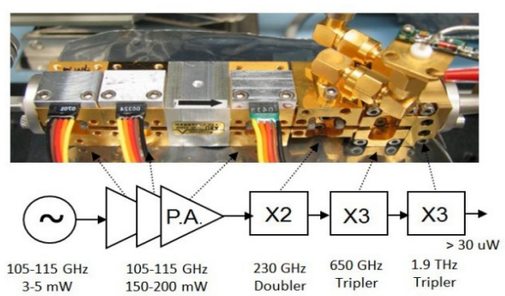
Noise figure testing of LNA MMIC module. Top: Y-factor noise figure test set. Bottom: Measured room temperature and cryogenic noise temperature of a WR5 (140-220 GHz) module. Cryogenic measurements of 80 to 115 K between 164 to 220 GHz are the first ever measured cryogenic amplifier noise data up to 220 GHz and represent record results.

Low Noise Amplifiers (LNAs) need to be interfaced with waveguide components. This can be done with a transition from the 50-Ohm MMIC transmission line environment to the higher impedance waveguide environment. A scalable waveguide transition for full waveguide band performance has been designed using membrane GaAs technology that was previously used to demonstrate flight-qualified mixers and multipliers. The waveguide transitions are frabricated from GaAs and quartz and have thickness of 10 to 50 µm to interface with standard rectangular MMIC chips for use up to 500 GHz and beyond. The best results to date show a world record noise temperature of 80 to 115 K from 164 to 220 GHz when the devices are cooled to 20 K.

Broadband Multiplied Sources for 1900 GHz

PI: Imran Mehdi

This task is developing the next generation of local oscillator (LO) sources in the 1- to 5-THz range, especially for array receivers. The compact LO chain is shown below. This chain has been demonstrated to provide 30 to 60 µW at room-temperature when pumped with 100 to 200 mW around 105 to 115 GHz. This represents an improvement of a factor of 20 with regards to the 1.9-THz LO chain onboard the Herschel Heterodyne Instrument for the Far-Infrared (HIFI) instrument. Assuming that 2 to 5 µW are necessary to adequately pump a single-pixel HEB receiver, this power level is already sufficient to pump an array of HEB mixers (at least 4 pixels with a healthy contingency margin to account for waveguide and coupling losses in the 1900-GHz regime).



Next-generation, 1.9-THz LO source schematic and completed hardware.

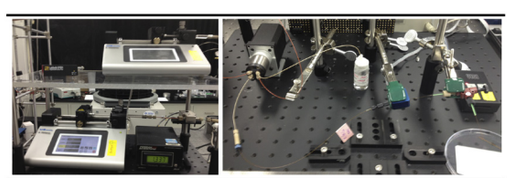
In Situ Instruments

Lab-On-a-Chip Geochemical Ion Chromatograph (LOGIC)

POC: Andrew Aubrey

Lab-On-a-Chip Geochemical Ion Chromatograph (LOGIC) is a compact Lab-On-a-Chip microfluidic chromatograph that will provide capabilities for the high-resolution in situ aqueous detection and characterization of inorganic chemical species. LOGIC adapts the proven methods of bench-scale ion chromatography to the microfluidic scale, providing low reagent demand with low mass and power requirements.

During fiscal year 2012, a breadboard proof-of-concept using COTS products was demonstrated (see figure). Testing has shown that the packing approach for the fused silica columns is robust and that the solvent delivery, valving, and conductivity detection approaches are functional. The complete system was shown to be effective at separating of cations using pressure-driven flow through the packed fused silica capillaries, but the ideal separation conditions are still being refined to provide the highest resolution between species and the most sensitive detection.

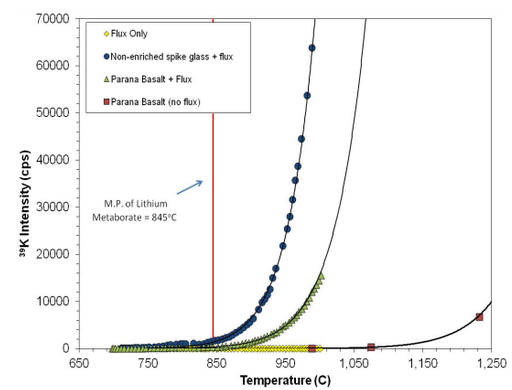


The LOGIC Breadboard. The pump setup is shown on the left, while fused silica capillary separation system is shown on the right. The system includes dual syringe pumps, a high-pressure electronically actuated sample injector valve, a packed fused silica capillary column, a contactless conductivity detector (CoCD), and a pressure regulator.

Geochronology Instrument Development

PI: Ken Farley (Caltech)
POC: Wayne Zimmerman

As part of the ongoing Potassium-Argon (K-Ar) Geochronology instrument development, experiments were conducted during fiscal year 2012 at the NASA Glenn Research Center to determine whether Potassium-isotopic composition using a Knudsen-Cell Effusion Mass Spectrometer (KEMS) could provide a suitable means of measuring the isotopic composition of vaporized Potassium during low-temperature flux-assisted melting. KEMS involves melting of the sample in a specially designed Molybdenum cell, production of a vapor that exits the top of the crucible in the Knudsen flow regime, line-of-sight ionization of the neutral vapor species, and measurement of the ionized isotopes on a magnetic sector mass spectrometer. The magnetic sector spectrometer's high resolution allows separation of the ^{39}K peak from background hydrocarbons and, hence, more accurate measurements. Experimental results are shown in the figure, which is a plot of measured ^{39}K as a function of temperature for: (1) Parana basalt, (2) Parana basalt melted in the presence of flux, (3) non-isotopically enriched spike glass melted in the presence of flux, and (4) flux as a control.



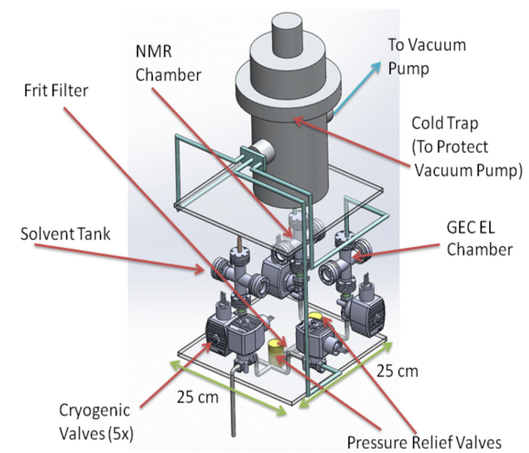
^{39}K signal measured on the NASA Glenn Research Center KEMS as a function of temperature.

This experiment, paired with an experiment conducted using a noble gas mass spectrometer at Caltech, allowed determining the basalt age as 337 Ma: within 5% of the known value of 354 Ma. This shows that KEMS is an effective tool for K-Ar age dating. Additional efforts are currently ongoing to provide a more rigorous calculation of the measured age and its uncertainty.

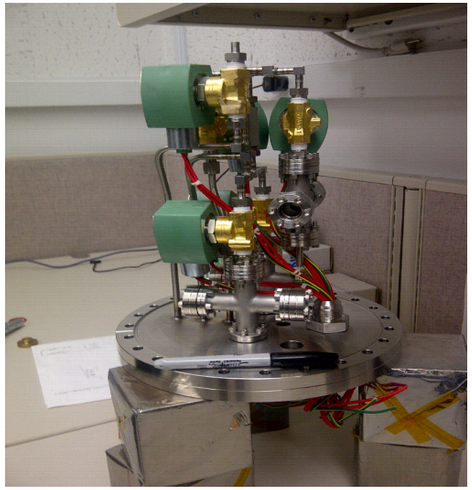
Technologies for Cryogenic In Situ Chemical Analysis on Titan

POC: Wayne Zimmerman

The long-term objectives of the this effort, a collaboration with the Caltech campus, is to develop a low-mass, low-power instrument concept and to advance sub-system technologies to produce a high-resolution, high-sensitivity instrument that has the dynamic range and sensitivity to find and identify the complex chemical species within the light hydrocarbon soup of Titan's lakes. As part of this effort, the Division has designed and built a sipper sample acquisition system, illustrated in the figure below. This is the first proof-of-concept cryo-sampling prototype developed for testing new cryo-valves and sample distribution pumps.



Titan Lake Sampler Prototype



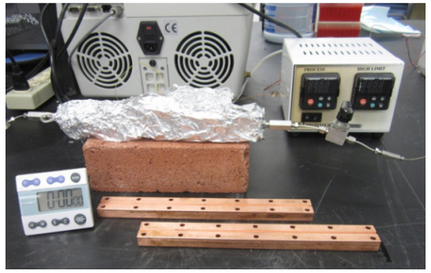
Titan prototype cryogenic sampling system.

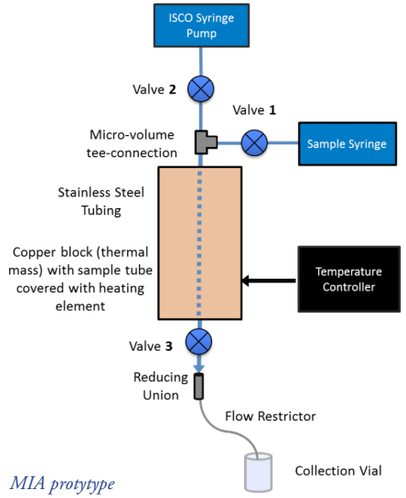
Micro-Scale Sample Processing Instrument for Potential Lunar, Mars, and Near Earth Object (NEO) In Situ and Sample Return Missions

POC: Risaku Toda

Extraction is a well-established technique in analytical and environmental chemistry, where hundreds of methods have yielded efficient (100%) extractions of target compounds for various applications. Unfortunately, many standard sample-preparation methods cannot be used for flight instruments because of their highly specific, narrowly focused approach to extraction, where each procedure is individually developed for a specific class of molecules and is typically based on complex organic solvent/acid/base manipulations. To be widely useful in characterizing Solar System bodies, a sample preparation technology must have the capability to extract a broad range of compounds with very different chemical and physical properties. This capability is provided by the Micro-scale Ion Analyzer (MIA), an aqueous extraction approach based on the ability to change water's pH by manipulating temperature and pressure. pH manipulation causes H-bonding network disruption, enabling acid/base catalysis. MIA significantly simplifies the chemical complexity of the extraction process, leading to a reduction of the engineering complexity and risk typically associated with sample-preparation instrumentation.

The current MIA prototype (see the Figure) involves an insulated copper block machined to fit around stainless steel tubing equipped with high-pressure valves and a syringe pump capable of applying significant head pressure. The copper block is heated with thermal tape connected to a temperature controller. This approach provides chemical reactivity similar to reactions that may be needed to extract target molecules from soil matrices.





MIA protytype

INSTRUMENTS & SCIENCE DATA SYSTEMS DIVISION

Publications

ANNUAL REPORT FY 2012

Publications:

Due to the large number of publications, this section contains only selected publications. To access the complete listing of publications submitted in FY 2012, please visit **http://instrument.jpl.nasa.gov/**.

1. Aatrokoski, J.; Holmes, Warren A.; et al.; Planck early results. XV. Spectral energy distributions and radio continuum spectra of northern extragalactic radio sources. Astronomy and Astrophysics, 536:A15, 2011.

2. Ade, P.A.R.; Holmes, Warren A.; et al.; Planck early results. VIII. The all-sky early Sunyaev-Zeldovich cluster sample. Astronomy and Astrophysics, 536:A8, 2011.

3. Ade, P.A.R.; Holmes, Warren A.; et al.; Planck early results. XI. Calibration of the local galaxy cluster Sunyaev-Zeldovich scaling relations. Astronomy and Astrophysics, 536:A11, 2011.

4. Ade, P.A.R.; Holmes, Warren A.; O'Dwyer, Ian J.; et al.; Planck early results. XIX. All-sky temperature and dust optical depth from Planck and IRAS. Constraints on the "dark gas" in our Galaxy. Astronomy and Astrophysics, 536:A19, 2011.

5. Ade, P.A.R.; Holmes, Warren A.; et al.; Planck early results. XXIII. The first all-sky survey of Galactic cold clumps. Astronomy and Astrophysics, 536:A23, 2011.

6. Aghanim, N.; Holmes, Warren A.; et al.; Planck early results. IX. XMM-Newton follow-up for validation of Planck cluster candidates. Astronomy and Astrophysics, 536:A9, 2011.

7. Aghanim, N.; Holmes, Warren A.; et al.; Planck early results. X. Statistical analysis of Sunyaev-Zeldovich scaling relations for X-ray galaxy clusters. Astronomy and Astrophysics, 536:A10, 2011.

8. Aghanim, N.; Holmes, Warren A.; O'Dwyer, Ian J.; et al.; Planck early results. XII. Cluster Sunyaev-Zeldovich optical scaling relations. Astronomy and Astrophysics, 536:A12, 2011.

9. Aghanim, N.; Holmes, Warren A.; O'Dwyer, Ian J.; et al.; Planck early results. XXIV. Dust in the diffuse interstellar medium and the Galactic halo. Astronomy and Astrophysics, 536:A24, 2011.

10. Alonso, M.; Chattopadhyay, Goutam; Mehdi, Imran; et al.; Silicon micro-lens antennas for THz integrated arrays. IRMMW-THz 2011 - 36th International Conference on Infrared, Millimeter, and Terahertz Waves vo. 6104804, 2011.

11. Angeli, George Z.; Seo, Byoung-Joon; Nissly, Carl; Troy, Mitchell; et al.; Integrated modeling and systems engineering for the thirty meter telescope. Proceedings of SPIE - The International Society for Optical Engineering, 8336:833605, 2011.

12. Aubrey, Andrew D.; Grunthaner, Frank J.; Greer, Frank F.; Lee, Michael C.; Lab-on-a-chip aqueous chemical sensing technologies for planetary science. Abstracts of papers of the American Chemical Society, 242:, 2011.

13. Bada, Jeffrey L.; Aubrey, Andrew D.; Grunthaner, Frank J.; Searching for organic compounds on Mars: Intensive in situ investigations are required prerequisites to a sample return mission. Abstracts of papers of the American Chemical Society, 242:, 2011.

14. Bae, Sam Y.; Korniski, Ronald J.; Shearn, Michael J.; et al.; Single lens dual-aperture 3D imaging system: Color modeling. Proceedings of SPIE - The International Society for Optical Engineering, 8288:828807, 2012

15. Bartlett, J. G.; Holmes, Warren A.; et al.; Planck early results. IV. First assessment of the High Frequency Instrument in-flight performance. Astronomy & Astrophysics, 536:A4, 2011.

16. Beichman, C. A.; Tanner, Alan B.; et al.; Multi-Epoch Observations of Hd 69830: High-Resolution Spectroscopy and Limits to Variability. Astrophysical Journal, 743:(1) 85, 2011.

17. Besikci, C.; Gunapala, Sarath D.; et al.; Proceedings of the International Conference on Quantum Structure Infrared Photodetector (Qsip) 2010 Preface. Infrared Physics & Technology, 54:(3) 131-131, 2011.

18. Bethermin, M.; Nguyen, Haley T.; et al.; HerMES: deep number counts at 250 mu m, 350 mu m and 500 mu m in the COSMOS and GOODS-N fields and the build-up of the cosmic infrared background. Astronomy & Astrophysics, 542:A58, 2012.

19. Beyer, A.D.; Kenyon, Matthew E.; Echternach, Pierre M.; Day, Peter K.; Holmes, Warren A.; et al.; Ultra-sensitive Transition-Edge Sensors for the Background Limited Infrared/Sub-mm Spectrograph (BLISS). Journal of Low Temperature Physics, vol. 39452, 2011.

20. Bhandari, P.; Holmes, Warren A.; Nash, Alfred E.; O'Dwyer, Ian J.; et al.; Planck early results. II. The thermal performance of Planck. Astronomy & Astrophysics, 536:A2, 2011.

21. Bischoff, C.; Gaier, Todd C.; Kangaslahti, Pekka P., et al.; First Season Quiet Observations: Measurements of Cosmic Microwave Background Polarization Power Spectra at 43 Ghz in the Multipole Range 25 <= L <= 475. Astrophysical Journal, 741:(2) 111, 2011.

22. Bloemhof, E. E.; An, Xin; Kuan, Gary M.; Moore, Douglas M.; Page, Norman A.; Tang, Hong; et al.; Telescope alignment from sparsely sampled wavefront measurements over pupil subapertures. Applied Optics, 51:(3) 394-400, 2012.

23. Bonetti, Joseph A.; Holmes, Warren A.; et al.; A Novel Superconducting Detector Based on Fluxoid Quantization. Journal of Low Temperature Physics, 167:(3-4) 39452, 2012.

24. Bonetti, Joseph A.; Turner, Anthony D.; Day, Peter K.; Holmes, Warren A.; Kenyon, Matthew E.; LeDuc, Henry G.; Nguyen, Haley T.; et al.; Characterization and Fabrication of the TES Arrays for the Spider, Keck and BICEP2 CMB Polarimeters. Journal of Low Temperature Physics, 167:(3-4) 39452, 2012.

25. Bornstein, Benjamin J.; Thompson, David R.; Castano, Rebecca; et al.; Efficient spectral endmember detection onboard the EO-1 spacecraft. Workshop on Hyperspectral Image and Signal Processing, Evolution in Remote Sensingvol. 6080886, 2011.

26. Borstad, C. P.; Larour, Eric; et al.; A damage mechanics assessment of the Larsen B ice shelf prior to collapse: Toward a physically-based calving law. Geophysical Research Letters, 39:L18502, 2012.

27. Boussaha, F.; Kawamura, Jonathan H.; Stern, Jeffrey A.; Skalare, Anders; White, Victor E.; Mehdi, Imran; et al.; Development of waveguide balanced HEB receivers beyond 2 THz. IRMMW-THz 2011 - 36th International Conference on Infrared, Millimeter, and Terahertz Waves, vol. 6104836, 2011.

28. Bradford, C. M.; Nguyen, Haley T.; et al.; The Water Vapor Spectrum Of Apm 08279+5255: X-Ray Heating And Infrared Pumping Over Hundreds Of Parsecs. Astrophysical Journal Letters, 741:(2) L37, 2011.

29. Bradley, Eliza S.; Green, Robert O.; Eastwood, Michael L.; Lundeen, Sarah R.; et al.; Google Earth and Google Fusion Tables in support of time-critical collaboration: Mapping the deepwater horizon oil spill with the AVIRIS airborne spectrometer. Earth Science Informatics, 4:(4) 169-179, 2011.

30. Brauer, Carolyn S.; Pearson, John C.; et al.; Empirical line intensities of methanol in the 300-500 cm(-1) region. Journal Of Quantitative Spectroscopy & Radiative Transfer, 113:(2) 128-139, 2012.

31. Braverman, Amy J.; Manning, Evan M.; Oliphant, Robert B.; et al.; Massive dataset analysis for NASA's atmospheric infrared sounder. Technometrics, 54:(1) 39461, 2012.

32. Bue, Brian D.; Thompson, David R.; Castano, Rebecca; et al.; Metric learning for hyperspectral image segmentation. Workshop on Hyperspectral Image and Signal Processing, Evolution in Remote Sensingvol. 6080873, 2011.

33. Bueno, J.; Day, Peter K.; Echternach, Pierre M.; et al.; Optical characterization of the quantum capacitance detector at 200m. Applied Physics Letters, 99:(17) 173503, 2011.

34. Bunte, Melissa; Thompson, David R.; Castano, Rebecca; et al.; Image processing onboard spacecraft for autonomous plume detection. Planetary and Space Science, 2011.

35. Cable, Morgan L.; Fisher, Anita M.; Greer, Harold F.; Willis, Peter A.; et al.; Micro-total-analysis technologies for in situ organic analysis of Titan environmental aerosols. Abstracts of papers of the American Chemical Society, 242:, 2011.

36. Cable, Morgan L.; Willis, Peter A.; et al.; Titan tholins: Simulating Titan organic chemistry in the Cassini-Huygens era. Chemical Reviews, 112:(3) 1882-1909, 2012.

37. Cady, Eric; Design of mirrors and apodization functions in phase-induced amplitude apodization systems. Astrophysical Journal Supplement Series, 201:(2) 25, 2012.

38. Cady, Eric; Boundary diffraction wave integrals for diffraction modeling of external occulters. Optics Express, 20:(14) 15196-15208, 2012.

39. Calvo, M.; LeDuc, Henry G.; et al.; LEKIDs Developments for mm-Wave Astronomy. Journal of Low Temperature Physics, 167:(3-4) 39453, 2012.

40. Cassidy, T.A.; Kamp, Lucas W.; et al.; Magnetospheric ion sputtering and water ice grain size at Europa. Planetary and Space Science, 2012.

41. Catalano, A.; Holmes, Warren A.; et al.; Planck early results. IV. First assessment of the High Frequency Instrument in-flight performance. Astronomy & Astrophysics, 536:A4, 2011.

42. Chanan, Gary; Troy, Mitchell; Gutt, Gary; et al.; Fresnel phasing of segmented mirror telescopes. Applied Optics, 50:(33) 6283-6293, 2011

43. Chattopadhyay, Goutam; Lee, Choonsup; Lin, Robert H.; Cooper, Ken B.; Schlecht, Erich T.; Mehdi, Imran; et al.; Terahertz array receivers with integrated antennas. 2012 IEEE International Workshop on Antenna Technology, iWAT 2012, pp. 319-322, 2012.

44. Chen, Ke; Kleinsasser, Alan W.; et al.; Multiple Andreev reflection in MgB2/MgO/MgB2 Josephson junctions. Applied. Physics Letters, 100:(12) 122601, 2012.

45. Chopping, Mark; Bull, Michael A.; et al.; Forest canopy cover and height from MISR in topographically complex southwestern US landscapes assessed with high quality reference data. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 5:(1) 44-58, 2012.

46. Chow, C. Channing; Lo, Martin W.; et al.; Optimizing spacecraft placement for LiAISON constellations. Advances in the Astronautical Sciences, 140:1829-1844, 2011.

47. Christensen, L.E.; Spiers, Gary D.; Menzies, Robert T.; Jacob, Joseph C.; Tunable laser spectroscopy of CO2 near 2.05m: Atmospheric retrieval biases due to neglecting line-mixing. Journal of Quantitative Spectroscopy and Radiative Transfer, 113:(10) 739-748, 2012.

48. Coffee, Thomas M.; Lo, Martin W.; et al.; Multiobjective optimization of low-energy trajectories using optimal control on dynamical channels (Part I). Advances in the Astronautical Sciences, 140:401-413, 2011.

49. Colley, J.-M.; Holmes, Warren A.; et al.; Planck early results. VI. The High Frequency Instrument data processing. Astronomy and Astrophysics, 536:A6, 2011.

50. Conrad, Pamela G.; Johnson, Joel A.; et al.; The Mars Science Laboratory Organic Check Material. Space Science Reviews, 170:(39450) 479-501, 2012.

51. Cooper, K.B.; Dengler, Robert J.; et al.; Carrier noise-limited penetration in THz radar imaging. IEEE MTT-S International Microwave Symposium Digest, vol. 6258431, 2012.

52. Cooper, Ken B.; Chattopadhyay, Goutam; Dengler, Robert J.; Cofield, Richard E.; Lee, Choonsup; et al.; A grating-based circular polarization duplexer for submillimeter-wave transceivers. IEEE Microwave and Wireless Components Letters, 22:(3) 108-110, 2012.

53. Crichton, Daniel J.; Mattmann, Chris A.; et al.; Bioinformatics: Biomarkers of early detection. Cancer Biomarkers, 9:(39452) 511-530, 2011.

54. Crichton, Daniel J.; Mattmann, Chris A.; Cinquini, Luca; Braverman, Amy J.; Hart, Andrew F.; Goodale, Cameron E.; et al.; Sharing satellite observations with the climate-modeling community: Software and architecture. IEEE Software, 29:(5) 73-81, 2012.

55. Dahl, Kristen P.; Thompson, David R.; et al.; Current-sensitive path planning for an underactuated free-floating ocean sensorweb. IEEE International Conference on Intelligent Robots and Systems, pp. 3140-3146, 2011.

56. Day, Peter K.; LeDuc, Henry G.; et al.; A wideband, low-noise superconducting amplifier with high dynamic range. Nature Physics, 8:(8) 623-627, 2012.

57. De Beck, E.; Pearson, John C.; et al.; On the physical structure of IRC+10216: Ground-based and Herschel ˙ observations of CO and C2H. Astronomy and Astrophysics, 539:A108, 2012.

58. Deal, William R.; Chattopadhyay, Goutam; InP HEMT integrated circuits for Submillimeter Wave radiometers in earth remote sensing. IEEE MTT-S International Microwave Symposium Digest, vol. 6258434, 2012

59. Diener, P.; Leduc, Henry G.; et al.; Design and Testing of Kinetic Inductance Detectors Made of Titanium Nitride. Journal of Low Temperature Physics, 167:(3-4) 39452, 2012.

60. Diner, David J.; Hodos, Rachel A.; von Allmen, Paul; et al.; An optimization approach for aerosol retrievals using simulated MISR radiances. Atmospheric Research, 2011.

61. Dobbs, Richard; Maiwald, Frank; et al.; Fabrication and test of terahertz extended interaction klystrons. IRMMW-THz 2011 - 36th International Conference on Infrared, Millimeter, and Terahertz Waves, vol. 6105058, 2011.

62. Drouin, Brian J.; Pearson, John C.; et al.; Terahertz spectroscopy for space applications: 2.5-2.7 THz spectra of HD, H2O and NH3. Journal of Molecular Structure, 1006:(1-3) 2-12, 2011.

63. Dudik, Rachel P.; Pravdo, Steve; et al.; Interpixel crosstalk in teledyne imaging sensors H4RG-10 detectors. Applied Optics, 51:(15) 2877-2887, 2012.

64. Edgett, Kenneth S.; Maki, Justin N.; Willson, Reg G.; et al.; Curiosity's Mars Hand Lens Imager (MAHLI) Investigation. Space Science Reviews, 170:(1-4) 20089, 2012.

65. Ekstrand, Angela L.; Garay, Michael J.; et al.; A multi-sensor plume height analysis of the 2009 Redoubt eruption. Journal of Volcanology and Geothermal Research, 2012.

66. Estlin, Tara A.; Bornstein, Benjamin J.; Thompson, David R.; Burl, Michael; Castano, Rebecca; et al.; AEGIS automated science targeting for the MER Opportunity rover. ACM Transactions on Intelligent Systems and Technology, 3:(3) 50, 2012.

67. Farr, William H.; Stern, Jeffrey A.; Shaw, Matthew D.; Superconducting nanowire arrays for multi-meter free space optical communications receivers. Proceedings of SPIE - The International Society for Optical Engineering, 8246:82460R, 2012.

68. Faverzani, M.; Day, Peter K.; et al.; Developments of Microresonators Detectors for Neutrino Physics in Milan. Journal of Low Temperature Physics, 167:(5-6) 39453, 2012.

69. Fogarty, L.; Goodsall, Timothy M.; et al.; SWIFT observations of the Arp 147 ring galaxy system. Monthly Notices Of The Royal Astronomical Society, 417:(2) 835-844, 2011.

70. Forouhar, Siamak; Briggs, Ryan M.; Frez, Clifford; Ksendzov, Alexander; et al.; High-power laterally coupled distributed-feedback GaSb-based diode lasers at 2 um wavelength. Applied Physics Letters, 100:(3) 31107, 2012.

71. Frankenberg, C.; McDuffie, James; et al.; Remote sensing of near-infrared chlorophyll fluorescence from space in scattering atmospheres: implications for its retrieval and interferences with atmospheric CO2 retrievals. Atmospheric Measurement Techniques, 5:(8) 2081-2094, 2012.

72. Fung, Andy; Samoska, Lorene A.; Pukala, David M.; Dawson, Douglas E.; Kangaslahti, Pekka P.; Gaier, Todd C.; et al.; On-wafer S-parameter measurements in the 325-508 GHz band. IEEE Transactions on Terahertz Science and Technology, 2:(2) 186-192, 2012.

73. Gawande, R.; Kangaslahti, Pekka P.; Samoska, Lorene A.; Gaier, Todd C.; et al.; W-Band cryogenic InP MMIC LNAs with noise below 30K. IEEE MTT-S International Microwave Symposium Digest, vol. 6258356, 2012.

74. Geng, Xueyang; Mojarradi, Mohammad M.; et al.; High speed channel resistive sensor interface with RHBD in 0.5 um SiGe BiCMOS for UWT from -180C to 120C. Proceedings of the IEEE Bipolar/BiCMOS Circuits and Technology Meeting, pp. 79-82, 2011.

75. Golombek, M.; Calef, Fred J.; Lee, Seungwon M.; et al.; Selection of the Mars Science Laboratory Landing Site. Space Science Reviews, 170:(1-4) 33969, 2012.

76. Green, Robert O.; Mouroulis, Pantazis; Eastwood, Michael L.; Glavich, Thomas A.; Cate, Dennis P.; Geier, Sven; Haemmerle, Vance R.; Hovland, Larry E.; Lundeen, Sarah R.; Sellar, R. G.; Sobel, Harold R.; Wilson, Daniel W.; et al.; The Moon Mineralogy Mapper (M(3)) imaging spectrometer for lunar science: Instrument description, calibration, on-orbit measurements, science data calibration and on-orbit validation. Journal Of Geophysical Research-Planets, 116:E00G19, 2011.

77. Greer, Frank F.; Hoenk, Michael E.; Jones, Todd J.; Dickie, Matthew R.; Monacos, Steve P.; Nikzad, Shouleh; Day, Peter K.; Leduc, Henry G.; et al.; Enabling high performance instruments for astronomy and space exploration with ALD. ECS Transactions, 41:(2) 263-268, 2011.

78. Grotzinger, John P.; Maki, Justin N.; et al.; Mars Science Laboratory Mission and Science Investigation. Space Science Reviews, vol. 17532, 2012.

79. Grunthaner, Frank J.; Coleman, Max; Aubrey, Andrew D.; et al.; Enabling technologies for in situ chemical astrobiology in planetary exploration. Abstracts of papers of the American Chemical Society, 242:, 2011.

80. Gulkis, S.; Keihm, Stephen J.; Kamp, Lucas W.; Lee, Seungwon M.; von Allmen, Paul A.; et al.; Continuum and spectroscopic observations of asteroid (21) Lutetia at millimeter and submillimeter wavelengths with the MIRO instrument on the Rosetta spacecraft. Planetary and Space Science, 66:(1) , 2012.

81. Gunapala, Sarath D.; Ting, David Z.; Nguyen, Jean T.; Soibel, Alexander; Rafol, Sir B.; Keo, Sam A.; Mumolo, Jason M.; Lee, Michael C.; Liu, John K.; et al.; Large area III-V infrared focal planes. Infrared Physics & Technology, 54:(3) 155-163, 2011.

82. Gunapala, Sarath D.; Ting, David Z.; Nguyen, Jean T.; Soibel, Alexander; Rafol, Sir B.; Khoshakhlagh, Arezou; Mumolo, Jason M.; Liu, John K.; Keo, Sam A.; et al.; Demonstration of high performance LWIR superlattice focal plane array. IEEE Photonic Society 24th Annual Meeting, PHO 2011, pp. 93-94, 2011.

83. Guyon, Olivier; Shaklan, Stuart B.; Nemati, Bijan; et al.; High-precision Astrometry with a Diffractive Pupil Telescope. Astrophysical Journal Supplement Series, 200:(2) 11, 2012.

84. Harris, A.I.; Samoska, Lorene A.; et al.; Note: Cryogenic microstripline-on-Kapton microwave interconnects. Review of Scientific Instruments, 83:(8) 86105, 2012.

85. Hayden, David S.; Thompson, David R.; Castano, Rebecca; et al.; Using clustering and metric learning to improve science return of remote sensed imagery. ACM Transactions on Intelligent Systems and Technology, 3:(3) 51, 2012.

86. Hecht, Michael H.; Aqueous soil chemistry on a not-so-dry planet: Retrospective on the Phoenix Wet Chemistry Laboratory. Abstracts of papers of he American Chemical Society, 242:, 2011.

87. Hogerheijde, Michiel R.; Pearson, John C.; et al.; Detection of the Water Reservoir in a Forming Planetary System. Science, 334:(6054) 338-340, 2011.

88. Jacquot, Blake C.; Hoenk, Michael E.; Jones, Todd J.; Cunningham, Thomas J.; Nikzad, Shouleh; Direct Detection of 100-5000 eV Electrons With Delta-Doped Silicon CMOS and Electron-Multiplying CCD Imagers. IEEE Transactions On Electron Devices, 59:(7) 1988-1992, 2012.

89. Jiang, Jonathan H.; Zhai, Chengxing; Perun, Vincent S.; et al.; Evaluation of cloud and water vapor simulations in CMIP5 climate models using NASA A-Train satellite observations. Journal of Geophysical Research-Atmospheres, 117:D14105, 2012.

90. Johnson, William R.; Shoen, Steven M.; Microbolometer imaging spectrometer. Optics Letters, 37:(5) 803-805, 2012.

91. Jung, C.; Chattopadhyay, Goutam; Lin, Robert H.; Cooper, Ken B.; Mehdi, Imran; et al.; Silicon nanofabrication technologies for compact integrated receivers working at THz frequencies. IRMMW-THz 2011 - 36th International Conference on Infrared, Millimeter, and Terahertz Waves, vol. 6104765, 2011.

92. Jung-Kubiak, Cecile; Gill, John J.; Chattopadhyay, Goutam; Lin, Robert H.; Cooper, Ken B.; Mehdi, Imran; et al.; Silicon microfabrication technologies for THz applications. 2012 IEEE Silicon Nanoelectronics Workshop, SNW 2012, vol. 6243285, 2012.

93. Kampe, Thomas U.; Hamlin, Louise; Green, Robert O.; et al.; Progress in the development of airborne remote sensing instrumentation for the National Ecological Observatory Network. Proceedings of SPIE - The International Society for Optical Engineering, 8156:81560A, 2011.

94. Kangaslahti, Pekka; Lim, Boon; Tanner, Alan B.; Dawson, Douglas E.; Samoska, Lorene A.; Montes, Oliver; Gaier, Todd C.; Tanabe, Jordan M.; Brown, Shannon T.; et al.; Low noise amplifier receivers for millimeter wave atmospheric remote sensing. IEEE MTT-S International Microwave Symposium Digest, vol. 6259468, 2012.

95. Karasik, Boris S.; Soibel, Alexander; et al.; Energy-resolved detection of single infrared photons with lambda 8 um using a superconducting microbolometer. Applied Physics Letters, 101:(5) 52601, 2012.

96. Kassin, Susan A.; Goodsall, Timothy M..; et al.; Oxford SWIFT integral field spectrograph and multiwavelength observations of the Eagle galaxy at z=0.77. Monthly Notices Of The Royal Astronomical Society, 417:(4) 2882-2890, 2011.

97. Kaul, Anupama; Coles, James B.; Megerian, Krikor G.; Eastwood, Michael L.; Green, Robert O.; et al.; Carbon nanomaterials for optical absorber applications. Sensors and Transducers, 13:(SPEC.ISSUE) 109-116, 2011.

98. Kaul, Anupama B.; Carbon nanofiber switches and sensors. 2012 IEEE International Frequency Control Symposium, IFCS 2012, Proceedings, pp. 796-799, 2012.

99. Kausinis, Saulius; Yee, Karl; et al.; Estimation of thermo-elastic damping of vibrations in micro-electro-mechanical systems resonators: finite element modeling. Journal Of Micro-Nanolithography Mems And Moems, 11:(3) 33005, 2012.

100. Kitching, Thomas; Moghaddam, Baback; et al.; Gravitational Lensing Accuracy Testing 2010 (Great10) Challenge Handbook. Annals Of Applied Statistics, 5:(3) 2231-2263, 2011.

101. Krasnicki, Adam; Pearson, John C.; et al.; Terahertz spectroscopy of isotopic acrylonitrile. Journal of Molecular Structure, 1006:(1-3) 2-12, 2011.

102. Ksendzov, A.; Forouhar, Siamak; Briggs, Ryan M.; Frez, Clifford F.; Bagheri, Mahmood; et al.; Linewidth measurement of high power diode laser at 2m for carbon dioxide detection. Electronics Letters, 48:(9) 520-522, 2012.

103. Lahteenmaki, A.; Gaier, Todd C.; Holmes, Warren A.; Kangaslahti, Pekka P.; et al.; Planck early results. I. The Planck mission. Astronomy and Astrophysics, 536:A1, 2011.

104. Lahteenmaki, A.; O'Dwyer, Ian J.; Holmes, Warren A.; et al.; Planck early results. VII. The Early Release Compact Source Catalogue. Astronomy and Astrophysics, 536:A7, 2011.

105. Lahteenmaki, A.; O'Dwyer, Ian J.; Holmes, Warren A.; et al.; Planck early results. XIII. Statistical properties of extragalactic radio sources in the Planck Early Release Compact Source Catalogue. Astronomy and Astrophysics, 536:A13, 2011.

106. Lahteenmaki, A.; Holmes, Warren A.; et al.; Planck early results. XIV. ERCSC validation and extreme radio sources. Astronomy and Astrophysics, 536:A14, 2011.

107. Lahteenmaki, A.; Holmes, Warren A.; et al.; Planck early results. XVI. The Planck view of nearby galaxies. Astronomy and Astrophysics, 536:A16, 2011.

108. Lahteenmaki, A.; Holmes, Warren A.; et al.; Planck early results. XVII. Origin of the submillimetre excess dust emission in the Magellanic Clouds. Astronomy and Astrophysics, 536:A17, 2011.

109. Lahteenmaki, A.; O'Dwyer, Ian J.; Holmes, Warren A.; et al.; Planck early results. XX. New light on anomalous microwave emission from spinning dust grains. Astronomy and Astrophysics, 536:A20, 2011.

110. Lahteenmaki, A.; Holmes, Warren A.; et al.; Planck early results. XXI. Properties of the interstellar medium in the Galactic plane. Astronomy and Astrophysics, 536:A21, 2011.

111. Lahteenmaki, A.; O'Dwyer, Ian J.; et al.; Planck early results. XXVI. Detection with Planck and confirmation by XMM-Newton of PLCK G266.6-27.3, an exceptionally X-ray luminous and massive galaxy cluster at z ~ 1. Astronomy and Astrophysics, 536:A26, 2011.

112. Lawson, Peter; et al.; Technology for future exoplanet missions. 62nd International Astronautical Congress 2011, IAC 2011, 3:2420-2430, 2011.

113. Lee, Choonsup; Chattopadhyay, Goutam; Mehdi, Imran; et al.; Silicon micromachined microlens array for THz antenna. IRMMW-THz 2011 - 36th International Conference on Infrared, Millimeter, and Terahertz Waves, vol. 6104856, 2011.

114. Lee, Seungwon; von Allmen, Paul; Kamp, Lucas; et al.; Non-LTE radiative transfer for sub-millimeter water lines in Comet 67P/Churyumov-Gerasimenko. ICARUS, 215:(2) 721-731, 2011.

115. Li, W.; Raskin, Robert G.; et al.; Semantic-based web service discovery and chaining for building an Arctic spatial data infrastructure. Computers and Geosciences, 37:(11) 1752-1762, 2011.

116. Liebe, Carl Christian; Meras, Patrick L.; et al.; Design, qualification, calibration and alignment of position sensing detector for the NuSTAR space mission. IEEE Sensors Journal, 12:(6) 2006-2013, 2012.

117. Lupu, R. E.; Naylor, Bret J.; Nguyen, Hai M.; et al.; Measurements of Co Redshifts with Z-Spec for Lensed Submillimeter Galaxies Discovered in the H-Atlas Survey. Astrophysical Journal, 757:(2) 135, 2012.

118. Macmynowski, Douglas G.; Colavita, M. Mark; et al.; Control system modeling for the thirty meter telescope primary mirror. Proceedings of SPIE - The International Society for Optical Engineering, 8336:83360R, 2011.

119. Maestrini, Alain; Mehdi, Imran; Lin, Robert H.; Lee, Choonsup; Gill, John J.; Chattopadhyay, Goutam; Schlecht, Erich T.; Pearson, John C.; Siegel, Peter H.; et al.; Design and characterization of a room temperature all-solid-state electronic source tunable from 2.48 to 2.75 THz. IEEE Transactions on Terahertz Science and Technology, 2:(2) 177-185, 2012.

120. Mahabal, A. A.; Moghaddam, Baback; Turmon, Michael J.; et al.; Discovery, classification, and scientific exploration of transient events from the Catalina Real-time Transient Survey. Bulletin of the Astronomical Society of India, 39:(3) 387-408, 2011.

121. Mahaffy, Paul R.; Forouhar, Siamak; et al.; The Sample Analysis at Mars Investigation and Instrument Suite. Space Science Reviews, 170:(1-4) 27029, 2012.

122. Maki, Justin N.; Thiessen, David L.; Pourangi, Ali M.; Kobzeff, Peter A.; Dingizian, Arsham; et al.; The Mars Science Laboratory Engineering Cameras. Space Science Reviews, 170:(39450) 77-93, 2012.

123. Malbet, Fabien; Goullioud, Renaud; et al.; High precision astrometry mission for the detection and characterization of nearby habitable planetary systems with the Nearby Earth Astrometric Telescope (NEAT). Experimental Astronomy, 34:(2) 385-413, 2012.

124. Mandrake, Lukas; Rebbapragada, Umaa; Wagstaff, Kiri L.; Thompson, David R.; et al.; Surface sulfur detection via remote sensing and onboard classification. ACM Transactions on Intelligent Systems and Technology, 3:(4) 77, 2012.

125. Manohara, Harish; Mojarradi, Mohammad M.; Toda, Risaku; Lin, Robert H.; Carbon nanotube-based high temperature vacuum microelectronics for E&P applications. Society of Petroleum Engineers - SPE International Oilfield Nanotechnology Conference 2012, pp. 190-194, 2012.

126. Martin, Stefan R.; Raouf, Nasrat A.; Loya, Frank M.; Tang, Hong; et al.; High performance testbed for four-beam infrared interferometric nulling and exoplanet detection. Applied Optics, 51:(17) 3907-3921, 2012.

127. Maruyama, Yuki; Blacksberg, Jordana; et al.; A time-resolved 128x128 SPAD camera for laser Raman spectroscopy. Proceedings of SPIE - The International Society for Optical Engineering, 8374:83740N, 2012.

128. Mason, Brian D.; Roberts, Lewis C., Jr.; et al.; Know The Star, Know The Planet. II. Speckle Interferometry of Exoplanet Host Stars. Astronomical Journal, 142:(5) 176, 2011.

129. Mattmann, Chris A.; et al.; A Middleware Platform for Providing Mobile and Embedded Computing Instruction to Software Engineering Students. IEEE Transactions on Education, 55:(3) 425-435, 2012.

130. Mattmann, Chris A.; A simple model illustrating the virtue of replication for long-term information preservation. Earth Science Informatics, 5:(2) 105-109, 2012.

131. Maurice, S.; Kan, Edwin P.; et al.; The ChemCam Instrument Suite on the Mars Science Laboratory (MSL) Rover: Science Objectives and Mast Unit Description. Space Science Reviews, 170:(39450) 95-166, 2012.

132. Mazin, Benjamin A.; Bumble, Bruce; et al.; A superconducting focal plane array for ultraviolet, optical, and near-infrared astrophysics. Optics Express, 20:(2) 1503-1511, 2012.

133. Mennesson, B.; Martin, Stefan R.; et al.; High-contrast Stellar Observations within the Diffraction Limit at the Palomar Hale Telescope. Astrophysical Journal, 743:(2) 178, 2011.

134. Miller, Darren A.; Wilson, Daniel W.; et al.; Novel design and alignment of wire-grid diffraction gratings on a visible focal plane array. Optical Engineering, 51:(1) 14001, 2012.

135. Mitrofanov, I. G.; Kan, Edwin P.; et al.; Dynamic Albedo of Neutrons (DAN) Experiment Onboard NASA's Mars Science Laboratory. Space Science Reviews, 170:(39450) 559-582, 2012.

136. Moore, D.C.; Bumble, Bruce; Day, Peter K.; LeDuc, Henry G.; et al.; Phonon Mediated Microwave Kinetic Inductance Detectors. Journal of Low Temperature Physics, 167:(3-4) 39452, 2012.

137. Moore, D.C.; Bumble, Bruce; Day, Peter K.; Leduc, Henry G.; et al.; Position and energy-resolved particle detection using phonon-mediated microwave kinetic inductance detectors. Applied Physics Letters, 100:(23) 232601, 2012.

138. Mora, Maria F.; Willis, Peter A.; et al.; Microchip capillary electrophoresis instrumentation for in situ analysis in the search for extraterrestrial life. Electrophoresis, 33:(17) 2624-2638, 2012.

139. Mora, Maria F.; Greer, Frank F.; Willis, Peter A.; et al.; Toward total automation of microfluidics for extraterrestrial in situ analysis. Analytical Chemistry, 83:(22) 8636-8641, 2011.

140. Muller, Holger S.P.; Pearson, John C.; et al.; Spectroscopic parameters for silacyclopropynylidene, SiC2, from extensive astronomical observations toward CW Leo (IRC +10216) with the Herschel satellite. Journal of Molecular Spectroscopy, 271:(1) 50-55, 2012.

141. Nesnas, Issa A.D.; Peters, Robert D.; et al.; Axel and DuAxel rovers for the sustainable exploration of extreme terrains. Journal of Field Robotics, 22:(12) , 2012.

142. Nguyen, Jean; Soibel, Alexander; Rafol, Sir B.; Liu, John K.; Mumolo, Jason M.; Hoeglund, Linda; Keo, Sam A.; Ting, David Z. -Y.; Gunapala, Sarath D.; et al.; Inductively Coupled Plasma Etching of Complementary Barrier Infrared Detector Focal Plane Arrays for Long-Wave Infrared Imaging. IEEE Photonics Technology Letters, 24:(18) 1581-1583, 2012.

143. Nikzad, Shouleh; Hoenk, Michael E.; Greer, Frank F.; Monacos, Steve P.; Jones, Todd J.; Blacksberg, Jordana; et al.; Delta-doped electron-multiplied CCD with absolute quantum efficiency over 50% in the near to far ultraviolet range for single photon counting applications. Applied Optics, 51:(3) 365-369, 2012.

144. Nissly, Carl; Seo, Byoung-Joon; Troy, Mitchell; et al.; High fidelity optical modeling for the TMT. Proceedings of SPIE - The International Society for Optical Engineering, 8336:83360B, 2011.

145. Bock, J.J.; Day, Peter K.; Turner, Anthony D.; et al.; Suppressing Beam Systematics in Antenna-Coupled TES Bolometers for CMB Polarimetry. Journal of Low Temperature Physics, 167:(3-4) 39453, 2012.

146. O'Dell, C.W.; Castano, Rebecca; McDuffie, James; Oyafuso, Fabiano A.; Smyth, Mike M.; et al.; The ACOS CO2 retrieval algorithm - Part 1: Description and validation against synthetic observations. Atmospheric Measurement Techniques, 5:(1) 99-121, 2012.

147. Oliver, S. J.; Nguyen, Haley T.; et al.; The Herschel Multi-tiered Extragalactic Survey: HerMES. Monthly Notices of the Royal Astronomical Society, 424:(3) 1614-1635, 2012.

148. O'Neil, Glen D.; Aubrey, Andrew D.; Greer, Frank; Hecht, Michael H.; et al.; NERNST: An electrofluidic platform for planetary surface analysis. Abstracts of papers of the American Chemical Society, 242:, 2011.

149. Orleanski, Piotr; Pearson, John C.; et al.; Controlling the THz heterodyne - Lesson learned from HIFI/Herschel mission. 2012 19th International Conference on Microwaves, Radar and Wireless Communications, MIKON 2012, 2:426-432, 2012.

150. Pearson, John C.; et al.; Microwave spectroscopy of methanol between 2.48 and 2.77 THz. Journal of the Optical Society of America B: Optical Physics, 28:(10) 2549-2577, 2011.

151. Pearson, John C.; et al.; The ground state torsion rotation spectrum of CH2DOH. Journal of Molecular Spectroscopy, 2012.

152. Pegna, R.; Spero, Robert E.; et al.; Abatement of thermal noise due to internal damping in 2D oscillators with rapidly rotating test masses. Physical Review Letters, 107:(20) 200801, 2011.

153. Persson, C. M.; et al.; Nitrogen hydrides in interstellar gas II. Analysis of Herschel/HIFI observations towards W49N and G10.6-0.4 (W31C). Astronomy & Astrophysics, 543:A145, 2012.

154. Pietrobon, Davide; Jewell, Jeffrey B.; et al.; Analysis of Wmap 7 Year Temperature Data: Astrophysics of the Galactic Haze. Astrophysical Journal, 755:(1) 69, 2012.

155. Pike, W.T.; Hecht, Michael H.; et al.; Quantification of the dry history of the Martian soil inferred from in situ microscopy. Geophysical Research Letters, 38:(24) L24201, 2011.

156. Pinty, Bernard; Haemmerle, Vance R.; et al.; Biogeophysical effects of land use on climate: Model simulations of radiative forcing and large-scale temperature changes (vol 142, pg 216, 2007). Journal Of Climate, 24:(17) 4769-4769, 2011.

157. Poberezhskiy, Ilya Y.; Chang, Daniel H.; Spiers, Gary D.; et al.; Flash lidar performance testing - Configuration and results. Proceedings of SPIE - The International Society for Optical Engineering, 8379:837905, 2012.

158. Polk, James E.; Schneider, Analyn C.; et al.; A high power ion thruster for deep space missions. Review of Scientific Instruments, 83:(7) 73306, 2012.

159. Poutanen, T.; Gaier, Todd C.; Jewell, Jeffrey B.; Kangaslahti, Pekka P.; et al.; Planck early results. III. First assessment of the Low Frequency Instrument in-flight performance. Astronomy and Astrophysics, 536:A3, 2011.

160. Poutanen, T.; Gaier, Todd C.; Jewell, Jeffrey B.; et al.; Planck early results. V. The Low Frequency Instrument data processing. Astronomy and Astrophysics, 536:A5, 2011.

161. Poutanen, T.; Holmes, Warren A.; et al.; Planck early results. XXV. Thermal dust in nearby molecular clouds. Astronomy and Astrophysics, 536:A25, 2011.

162. Poutanen, T.; O'Dwyer, Ian J.; Holmes, Warren A.; et al.; Planck early results. XVIII. The power spectrum of cosmic infrared background anisotropies. Astronomy and Astrophysics, 536:A18, 2011.

163. Poutanen, T.; Holmes, Warren A.; et al.; Planck early results. XXII. The submillimetre properties of a sample of Galactic cold clumps. Astronomy and Astrophysics, 536:A22, 2011.

164. Pueyo, Laurent; Cady, Eric; Roberts, Lewis C., Jr.; Burruss, Rick S.; et al.; Constraining Mass Ratio and Extinction in the Fu Orionis Binary System with Infrared Integral Field Spectroscopy. Astrophysical Journal, 757:(1) 57, 2012.

165. Quinn, Richard C.; Hecht, Michael H.; et al.; The oxidation-reduction potential of aqueous soil solutions at the Mars Phoenix landing site. Geophysical Research Letters, 38:(14) L14202, 2011.

166. Reising, Steven C.; Gaier, Todd C.; Dawson, Douglas E.; Kangaslahti, Pekka P.; Brown, Shannon T.; Montes, Oliver; et al.; InP HEMT low-noise amplifier-based millimeter-wave radiometers from 90 to 180 GHz with internal calibration for remote sensing of atmospheric wet-path delay. IEEE MTT-S International Microwave Symposium Digest, vol. 6259773, 2012.

167. Roberts, Dar A.; Green, Robert O.; et al.; Synergies between VSWIR and TIR data for the urban environment: An evaluation of the potential for the Hyperspectral Infrared Imager (HyspIRI) Decadal Survey mission. Remote Sensing of Environment, 2011.

168. Roberts, Lewis C., Jr.; et al.; Know The Star, Know The Planet. I. Adaptive Optics of Exoplanet Host Stars. Astronomical Journal, 142:(5) 175, 2011.

169. Roberts, Lewis C., Jr.; Lockhart, Thomas G.; Burruss, Rick S.; Roberts, Jennifer E.; Zhai, Chengxing; et al.; Spectral Typing of Late-Type Stellar Companions to Young Stars from Low-Dispersion Near-Infrared Integral Field Unit Data. Astronomical Journal, 144:(1) 14, 2012.

170. Roeder, Adrienne H. K.; Burl, Michael C.; et al.; A computational image analysis glossary for biologists. Development, 139:(17) 3071-3080, 2012.

171. Samoska, L.; Gaier, Todd C.; Kangaslahti, Pekka P.; et al.; W-Band cryogenic InP MMIC LNAs with noise below 30K. IEEE MTT-S International Microwave Symposium Digest, vol. 6258356, 2012.

172. Schlaerth, J.A.; Day, Peter K.; LeDuc, Henry G.; Nguyen, Haley T.; et al.; The Status of Music: A Multicolor Sub/millimeter MKID Instrument. Journal of Low Temperature Physics, 167:(3-4) 39453, 2012.

173. Scott, Valerie J.; Shearn, Michael J.; Siegel, Peter H.; et al.; An RF-powered micro-reactor for the detection of astrobiological target molecules on planetary bodies. Review of Scientific Instruments, 83:(8) 84102, 2012.

174. Seo, Munkyo; Lin, Robert H.; Skalare, Anders; et al.; A single-chip 630 GHz transmitter with 210 GHz sub-harmonic PLL local oscillator in 130 nm InP HBT. IEEE MTT-S International Microwave Symposium Digest, vol. 6259745, 2012.

175. Seo, Munkyo; Skalare, Anders; Peralta, Alejandro; Lin, Robert H.; Pukala, David; et al.; InP HBT IC technology for terahertz frequencies: Fundamental oscillators Up to 0.57 THz. IEEE Journal of Solid-State Circuits, 46:(10) 2203-2214, 2011.

176. Seroussi, Helene; Larour, Eric; et al.; Coupling ice flow models of varying orders of complexity with the Tiling method. Journal of Glaciology, 58:(210) 776-786, 2012.

177. Sibthorpe, Ant; Brown, Shannon T.; et al.; Calibration and Validation of the Jason-2/OSTM Advanced Microwave Radiometer Using Terrestrial GPS Stations. Marine Geodesy, 34:(39510) 420-430, 2011.

178. Sidick, Erkin; Shaklan, Stuart B.; Give'on, Amir; Kern, Brian D.; Studies of the effects of optical system errors on the HCIT contrast performance. Proceedings of SPIE - The International Society for Optical Engineering, 8151:815106, 2011.

179. Siegel, Peter H.; Editorial. IEEE Transactions on Terahertz Science and Technology, 1:(2) 337-340, 2011.

180. Sieth, Matthew; Gaier, Todd C.; Kangaslahti, Pekka P.; Samoska, Lorene A.; Soria, Mary M.; et al.; Technology developments for a large-format heterodyne MMIC array at W-band. International Journal of Microwave and Wireless Technologies, 4:(3) 299-307, 2012.

181. Sieth, Matthew; Gaier, Todd C.; Kangaslahti, Pekka P.; Samoska, Lorene A.; Soria, Mary M.; et al.; Technology developments for a scalable heterodyne MMIC array at W-band. European Microwave Week 2011: 'Wave to the Future', EuMW 2011, Conference Proceedings - 41st European Microwave Conference, EuMC 2011, pp. 527-530, 2011.

182. Small, Jennifer D.; Zhai, Chengxing; et al.; Relationship between aerosol and cloud fraction over Australia. Geophysical Research Letters, 38:(23) L23802, 2011.

183. Soibel, Alexander; Nguyen, Jean; Ting, David Z.; Keo, Sam A.; Mumolo, Jason M.; Lee, Mike C.; Gunapala, Sarath D.; et al.; InAs/GaSb superlattice based long-wavelength infrared detectors: Growth, processing, and characterization. Infrared Physics & Technology, 54:(3) 247-251, 2011.

184. Soibel, Alexander; Nguyen, Jean; Rafol, Sir B.; Hoeglund, Linda; Khoshakhlagh, Arezou; Keo, Sam A.; Mumolo, Jason M.; Liu, John; Ting, David Z.; Gunapala, Sarath D.; et al.; High-performance LWIR superlattice detectors and FPA

based on CBIRD design. Proceedings of SPIE - The International Society for Optical Engineering, 8268:82680Y, 2012.

185. Staehle, Robert L.; Blaney, Diana; Hemmati, Hamid; Jones, Dayton; Klesh, Andrew; Liewer, Paulett; Lazio, Joseph; Lo, Martin W.; Mouroulis, Pantazis; Murphy, Neil; Pingree, Paula J.; Wilson, Thor; et al.; Interplanetary Cubesat Architecture and Missions. AIAA Space 2012, AIAA #2012-5128, 2012.

186. Stockton, Amanda M.; Greer, Frank F.; Fisher, Anita M.; et al.; Automation of fluidic sample handling and analysis for extraterrestrial chemical exploration. Abstracts of Papers of the American Chemical Society, 242:, 2011.

187. Stone, K.J.; Megerian, Krikor G.; Day, Peter K.; Echternach, Pierre M.; et al.; Real time quasiparticle tunneling measurements on an illuminated quantum capacitance detector. Applied Physics Letters, 100:(26) 263509, 2012.

188. Thomas, Valerie C.; Pavri, Betina E.; et al.; The Dawn spacecraft. Space Science Reviews, 163:(39450) 175-249, 2011.

189. Thompson, David R.; Jiang, Yibo; Oyafuso, Fabiano A.; Castano, Rebecca; et al.; Atmospheric validation of high accuracy CO2 absorption coefficients for the OCO-2 mission. Journal of Quantitative Spectroscopy and Radiative Transfer, 2012.

190. Ting, David Z-Y.; Soibel, Alexander; Nguyen, Jean; Keo, Sam A.; Rafol, Sir B.; Lee, Mike C.; Mumolo, Jason M.; Liu, John K.; Gunapala, Sarath D.; et al.; Antimonide superlattice complementary barrier infrared detector (CBIRD). Infrared Physics & Technology, 54:(3) 267-272, 2011.

191. Urquiza, E.; Rodriguez, J.; Van Gorp, B.; et al.; Development and testing of an innovative two-arm focal-plane thermal strap (TAFTS). Cryogenics, 52:(39543) 306-309, 2012.

192. Voll, Patricia; Samoska, Lorene A.; Gaier, Todd C.; Kangaslahti, Pekka P.; Soria, Mary M.; et al.; A G-band cryogenic MMIC heterodyne receiver module for astronomical applications. European Microwave Week 2011: 'Wave to the Future', EuMW 2011, Conference Proceedings - 41st European Microwave Conference, EuMC 2011, pp. 523-526, 2011.

193. Wagstaff, Kiri L.; et al.; Dynamic landmarking for surface feature identification and change detection. ACM Transactions on Intelligent Systems and Technology, 3:(3) 49, 2012.

194. Wagstaff, Kiri L.; Machine learning that matters. Proceedings of the 29th International Conference on Machine Learning, ICML 2012, 1:529-534, 2012.

195. Wallace, J. Kent; Rao, Shanti; et al.; Phase-shifting Zernike interferometer wave front sensor. Proceedings of SPIE - The International Society for Optical Engineering, 8126:81260F, 2011.

196. Wang, JQ; Licata, Stephen J.; et al.; The influence of tropospheric biennial oscillation on mid-tropospheric CO(2). Geophysical Research Letters, 38:L20805, 2011.

197. Wayth, Randall B.; Thompson, David R.; Wagstaff, Kiri L.; et al.; Limits on the Event Rates of Fast Radio Transients from the V-Fastr Experiment. Astrophysical Journal Letters, 753:(2) L36, 2012.

198. Wiens, Roger C.; Kan, Edwin P.; Lindensmith, Chris A.; Reiter, Joseph W.; et al.; The ChemCam Instrument Suite on the Mars Science Laboratory (MSL) Rover: Body Unit and Combined System Tests. Space Science Reviews, 170:(39450) 167-227, 2012.

199. Woillez, J.; Colavita, M.; et al.; Self-Phase-Referenced Spectro-Interferometry on the Keck Interferometer. Publications Of The Astronomical Society Of The Pacific, 124:(911) 51-61, 2012.

200. Wunch, D.; Mandrake, Lukas; Castano, Rebecca; Oyafuso, Fabiano A.; Thompson, David R.; et al.; A method for evaluating bias in global measurements of CO2 total columns from space. Atmospheric Chemistry and Physics, 11:(23) 12317-12337, 2011.

201. Ye, Jian; Yanovsky, Igor; et al.; Multigrid narrow band surface reconstruction via level set functions. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 7431 LNCS:(PART 1) 61-70, 2012.

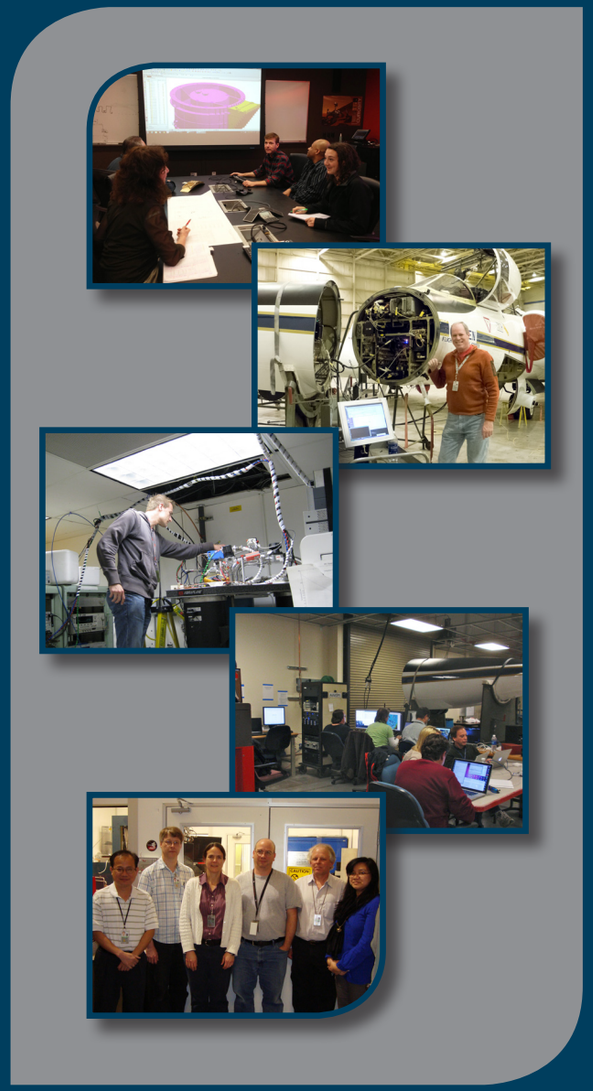
202. Yong, Alan; Braverman, Amy; et al.; A terrain-based site-conditions map of california with implications for the contiguous united states. Bulletin of the Seismological Society of America, 102:(1) 114-128, 2012.

203. Yu, Shanshan; Pearson, John C.; et al.; Measurement and analysis of new terahertz and far-infrared spectra of high temperature water. Journal of Molecular Spectroscopy, 279:16-25, 2012.

204. Zhai, Chengxing; Goullioud, Renaud; Nemati, Bijan; et al.; Micro-pixel accuracy centroid displacement estimation and detector calibration. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 467:(2136) 3550-3569, 2011.

205. Zhang, Wenhui; Pan, Lei; et al.; Incremental parallelization with migration. Proceedings of the 2012 10th IEEE International Symposium on Parallel and Distributed Processing with Applications, ISPA 2012, pp. 223-230, 2012.

206. Zima, Hans P.; Springer, Paul L.; et al.; Fault-tolerant onboard computing for robotic space missions. Concurrency Computation Practice and Experience, 23:(17) 2192-2204, 2011.



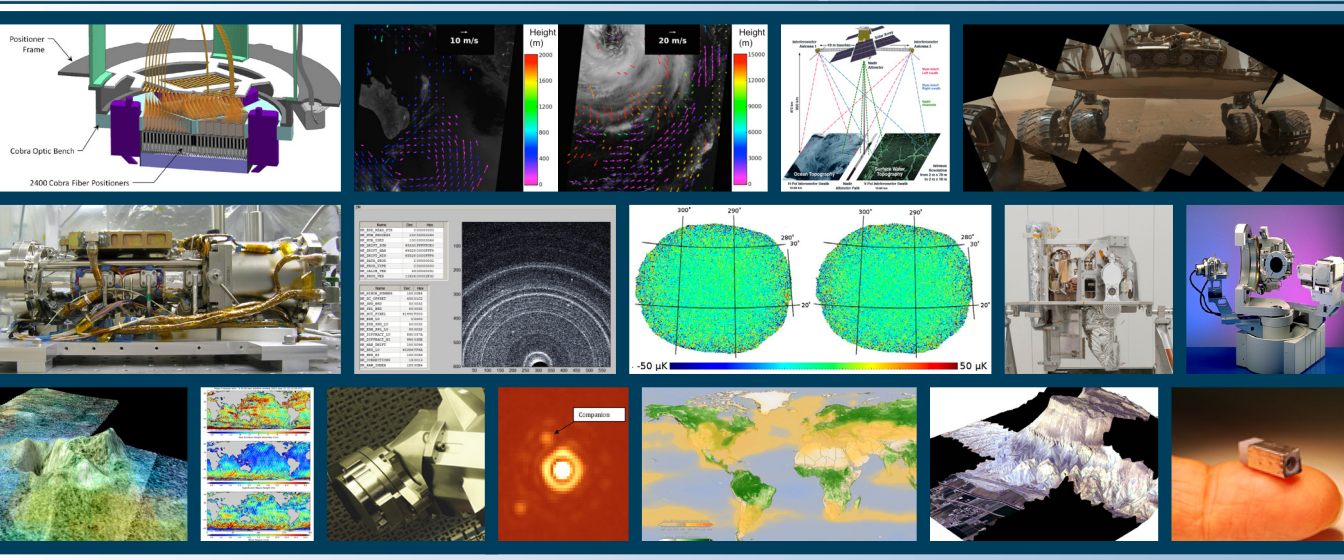
JPL's Instruments and Science Data Systems Division has been providing unique expertise in instrument system and technology development for over 45 years, beginning with the first Pioneer mission to the Moon in 1958.

Our success comes from bringing highly trained and technically diverse cross-disciplinary teams of hardware engineers, software engineers and scientists together to solve unique and challenging problems and create first-of-a-kind instrument systems. Our expertise spans the entire instrument system life-cycle, beginning with research in advanced technologies that maximize scientific knowledge capture and delivery, infusing those technologies into instrument and data system concepts, engineering the design and implementation, fabrication, integration and test operating the flight and ground instrument system, delivering the science and instrument data products, and finally archiving the products.

To learn more about our areas of expertise and to dig deeper and discover more about the Instruments & Science Data Systems Division, visit us at http://instrument.jpl.nasa.gov/

All work described in this report was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Copyright 2013 California Institute of Technology. Government sponsorship acknowledged.



National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

JPL 400-1517 01/13