National Aeronautics and Space Administration

A Researcher's Guide to:

INTERNATIONAL SPACE STATION

Earth Observations

This International Space Station (ISS) Researcher's Guide is published by the NASA ISS Program Science Office.

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Cover and back cover:

a. Earth Observations taken by Expedition 30 crewmember. One of a series of time lapse photos.

b. Sarychev Peak Volcano eruption, Kuril Islands, is featured in this image photographed by an Expedition 20 crew member on the ISS. A fortuitous orbit of the IISS allowed the astronauts this striking view of Sarychev volcano (Russia's Kuril Islands, northeast of Japan) in an early stage of eruption on June 12, 2009.

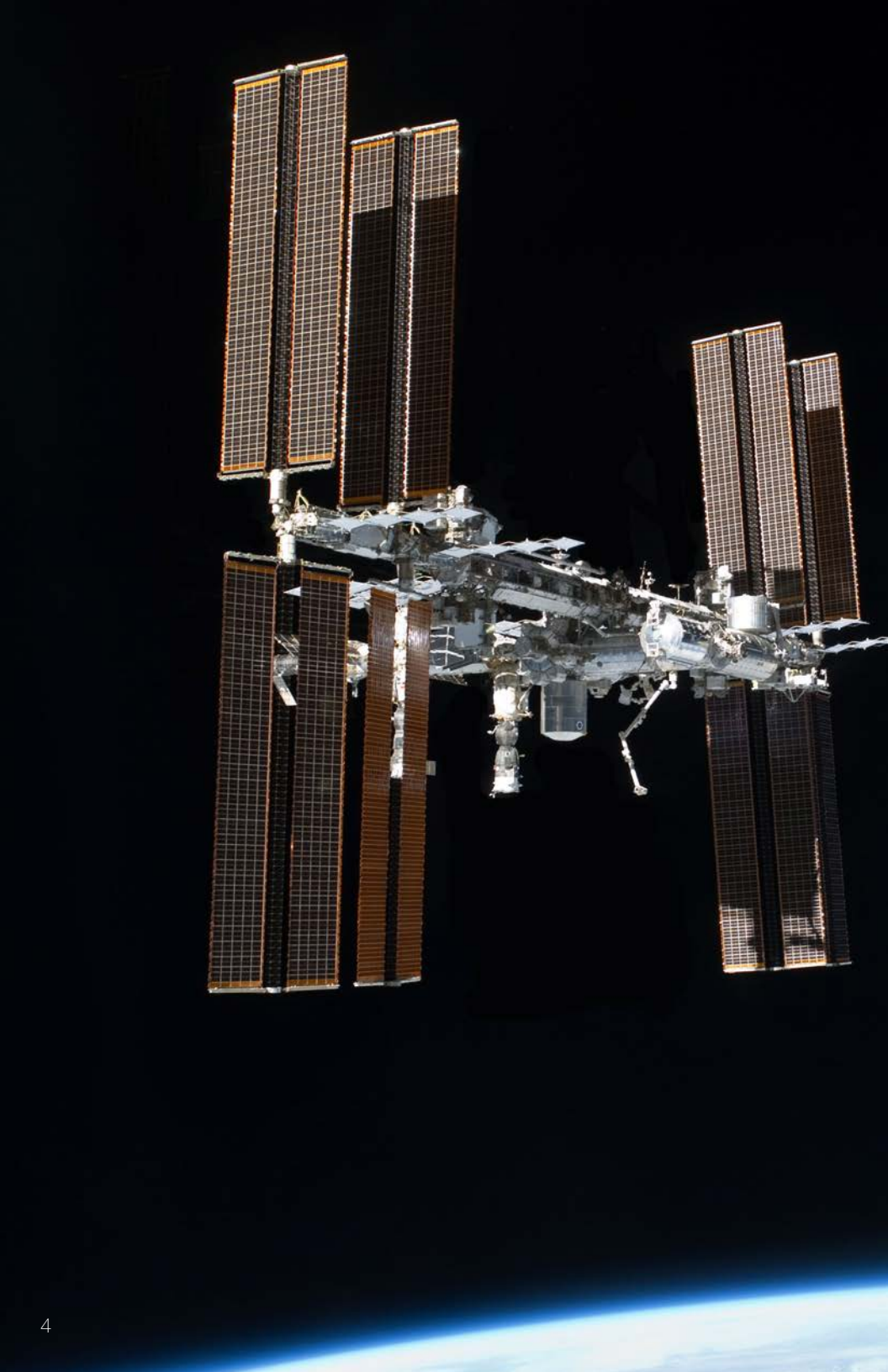
c. Inside the Cupola, NASA astronaut Chris Cassidy, an Expedition 36 flight engineer, uses a 400mm lens on a digital still camera to photograph a target of opportunity on Earth some 250 miles below him and the ISS.

The Lab is Open

Orbiting the Earth at almost 5 miles per second, a structure exists that is nearly the size of a football field and weighs almost a million pounds. The International Space Station (ISS) is a testament to international cooperation and significant achievements in engineering. Beyond all of this, the ISS is a truly unique research platform. The possibilities of what can be discovered by conducting research on the ISS are endless and have the potential to contribute to the greater good of life on Earth and inspire generations of researchers to come.

As we increase utilization of ISS as a National Laboratory, now is the time for investigators to propose new research and to make discoveries unveiling novel responses that could not be defined using traditional approaches on Earth.

These circular star trails and the rainbow of colorful lights of the Earth below them were created by a total of 18 images with prolonged time exposures combined into a composite photo. The bluish-white specks in the foreground that appear similar to balls of cotton are lightning from storms on Earth. This image depicts one of the many creative ways in which occupants of the International Space Station observe the wonder of the Earth below, the vast expanse of space and its many stars beyond. From this vantage point, we seek to understand the origins and composition of our universe.



Unique Features of the ISS Research Environment

1. **Microgravity**, or weightlessness, alters many observable phenomena within the physical and life sciences. Systems and processes affected by microgravity include surface wetting and interfacial tension, multiphase flow and heat transfer, multiphase system dynamics, solidification, and fire phenomena and combustion. Microgravity induces a vast array of changes in organisms ranging from bacteria to humans, including global alterations in gene expression and 3-D aggregation of cells into tissue-like architecture.

2. **Extreme conditions** in the ISS environment include exposure to extreme heat and cold cycling, ultra-vacuum, atomic oxygen, and high energy radiation. Testing and qualification of materials exposed to these extreme conditions have provided data to enable the manufacturing of long-life reliable components used on Earth as well as in the world's most sophisticated satellite and spacecraft components.

3. **Low Earth orbit** at 51degrees inclination and at a 90-minute orbit affords ISS a unique vantage point with an altitude of approximately 240 miles (400 kilometers) and an orbital path over 90 percent of the Earth's population.
   This can provide improved spatial resolution and variable lighting conditions compared to the sun-synchronous orbits of typical Earth remote-sensing satellites.

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Why Use ISS as a Remote Sensing Platform?

According to the Science Plan for NASA's Science Mission Directorate 2007-2016, the following are the priority Science Questions and Research Objectives for Earth Science.

Science Questions

- How is the global Earth system changing?
- What are the primary causes of change in the Earth system?
- How does the Earth system respond to natural and human-induced changes?
- What are the consequences for human civilization?
- How will the Earth system change in the future?

Research Objectives

- Understand and improve predictive capability for changes in the ozone layer, climate forcing, and air quality associated with changes in atmospheric composition
- Enable improved predictive capability for weather and extreme weather events
- Quantify global land cover change, terrestrial and marine productivity, improve carbon cycle and ecosystem models
- Quantify the key reservoirs and fluxes in the global water cycle and improve models of water cycle change and fresh water availability
- Understand the role of oceans, atmosphere, and ice in the climate system, and improve predictive capability for its future evolution
- Characterize and understand Earth surface changes and variability of Earth's gravitational and magnetic fields
- Expand and accelerate the realization of societal benefits from Earth system science

The Earth is a complex, dynamic system we do not yet fully understand. The Earth system, like the human body, comprises diverse components that interact in complex ways. In order to answer the above questions and address the objectives, we need to understand the Earth's atmosphere, lithosphere, hydrosphere, cryosphere, and biosphere as contributing elements of a single connected system. Our planet is changing on all spatial and temporal scales. The purpose of NASA's Earth science program is to develop a scientific understanding of Earth's system and

its response to natural or human-induced changes and to improve prediction of climate, weather, and natural hazards. (source: http://science.nasa.gov/earth-science/)

A major component of NASA's Earth Science Division is a coordinated series of satellite and airborne missions for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. This coordinated approach enables an improved understanding of the Earth as an integrated system. NASA is completing the development and launch of a set of foundational missions, new decadal survey missions, and climate continuity missions. The ISS now joins the current and planned fleet of Earth remote-sensing platforms, bringing unique capabilities and offering new opportunities for Earth remote-sensing research and applications.

Observing the Earth from Low-Earth Orbit

Advantages and Challenges to Earth Observing from the ISS

While NASA and other space agencies have had remote-sensing systems orbiting Earth and collecting publically available data since the early 1970s, these sensors have been primarily carried aboard free-flying, unmanned satellites. These satellites have typically been placed into sun-synchronous polar orbits that allow for repeat imaging of the entire surface of the Earth with approximately the same sun illumination (typically local solar noon) over specific areas, with set revisit times—this allows for uniform data to be taken over long time periods and enables straightforward analysis of change over time.

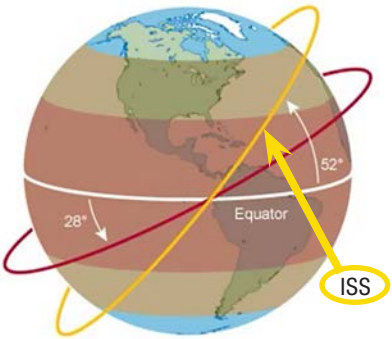
The ISS is a unique remote sensing platform from several perspectives—unlike automated remote-sensing platforms—it has a human crew, a low-orbit altitude, and orbital parameters that provide variable views and lighting. The presence of a crew provides options not available to robotic sensors and platforms, such as the ability to collect unscheduled data of an unfolding event using handheld digital cameras as part of the Crew Earth Observations facility and real-time assessment of whether environmental conditions (like cloud cover) are favorable for data collection. The crew can also swap out internal sensor systems and payloads installed in the Window Observational Research Facility (WORF) on an as-needed basis.

ISS Orbital Parameters

The ISS has an inclined, sun-asynchronous orbit (the solar illumination for data collections over any location changes as the orbit precesses) that carries it over locations on the Earth between approximately 52 degrees north and 52 degree south latitudes. The result is similar illumination for three to four days every 90 days.

The ISS orbit varies in altitude from approximately 350 to 455 km (217 to 283 miles) above sea level. Becauseof atmospheric drag, reboosting of the ISS to maximum altitude is required approximately every 90 days. And because of the westward precession of orbit tracks, the ISS has an approximate repeat time over the same location every three days with similar lighting conditions being repeated every three months, not correcting for seasonal lighting shifts (Stefanov et al. 2013).

The ISS orbit covers over 90 percent of the inhabited surface of the Earth and allows for the ISS to pass over ground locations at different times of the day and night. This is important for two main reasons: 1) certain surface and atmospheric processes have time variable characteristics that change throughout the day or occur at times other than a fixed equator crossing time (for example, development of coastal fog banks), making relevant data difficult to collect from sun-synchronous satellite platforms; and 2) with the appropriate targeting or pointing systems the ISS orbit provides opportunities for the ISS to collect data for short-duration events, such as natural disasters, that polar-orbiting satellites may miss because of their orbital dynamics—in essence, the ISS can be "in the right place and at the right time" to collect data. (Stefanov and Evans 2013; Gebelein and Eppler 2006). These capabilities enable ISS data to be complimentary to polar-orbiting satellite data.



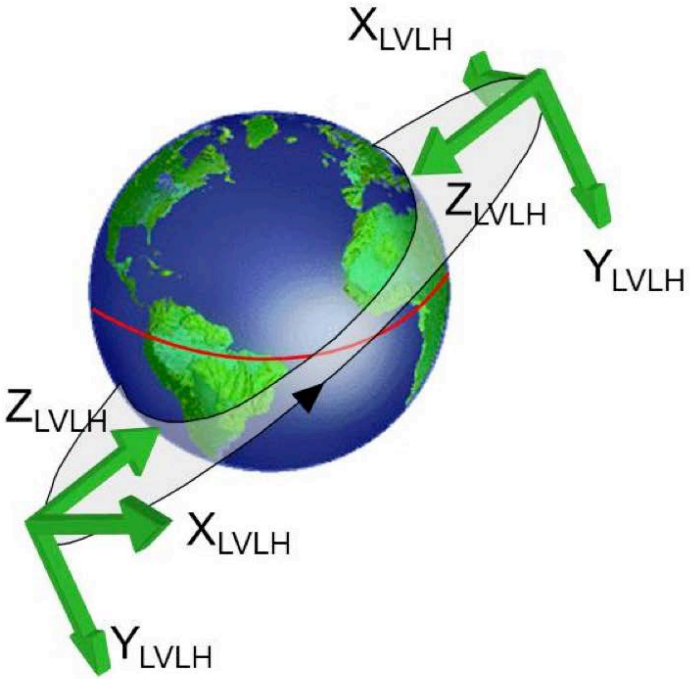
Most NASA satellites orbit over the poles, but the International Space Station's orbit is inclined 52°, which allows for imaging of approximately 90 percent of the Earth's populated surface. Shuttle missions launching from NASA's Kennedy Space Center often launched with a 28.5° inclination.

ISS Attitude Orientation

The ISS generally flies in a local vertical, local horizontal (LVLH) attitude orientation, as shown in the figure below, using Control Moment Gyros to maintain the attitude without need for thruster firings.

The ISS attitude varies about this LVLH hold in a sinusoidal motion every 90 minute orbit. An attitude is selected, called the Torque Equilibrium Attitude (TEA), that balances the torques on ISS such that the CMGs can be used to stabilize the ISS attitude. The TEA is within 15º degrees of 0,0,0 LVLH. The per orbit sinusoidal variation about the TEA is within 3.5º per axis.

Every 3 to 4 weeks a visiting vehicle docking occurs that necessitates thruster control and an attitude maneuver for the event. Sometimes the attitude maneuver is only a few degrees, and sometimes the maneuver is a 180º yaw or 90º pitch. The event can last a few hours up to a few days.



Results from Past Research

Early Remote Sensing from Crew-Tended Platforms (pre-ISS)

NASA has a long legacy of remote sensing from space, i.e. about 50 years. During the late 1950s in the unmanned Mercury test flights, hundreds of photographs were taken and proven useful to the scientific community. Then in the early 1960s approximately 55 handheld photographs were taken during the four manned Mercury flights. During the 10 manned flights of the Gemini Program (1963-1966), about 2,400 photos were taken, and during the Apollo Program (1961-1972), stereoscopic frames were taken from space for the first time. During the Apollo missions, investigators also verified the concept of applying multi-spectral, multi-temporal imagery from space to vegetation mapping and to the monitoring of land use. During the three manned Skylab missions (1973-1974) Earth resources research efforts were performed. The Earth Resources Experiment (EREP) consisted of a complex set of tests involving multiple onboard instruments (cameras, a multispectral scanner, spectrometer, and microwave devices) in conjunction with field investigations and aerial remote-sensing flights and hundreds of scientists (Amsbury 1989). These efforts led directly to the development of the unmanned satellite-based, remote-sensing systems (e.g., the Landsat series) that continue to form the core of our ability to examine and monitor the Earth system from space (Green and Jackson 2009).

During the Space Shuttle Program (1981-2011) space photography continued, in addition to other scientific experiments. On two missions (April/October 1994), the Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR) was flown. This was the most advanced civilian SAR ever built, providing the first multi-frequency data sets from space. The data provided a wealth of information about the Earth's changing environment as well as opening up new areas of potential use for spaceborne imaging radar data to include natural-hazard assessments (NASA JPL 5/99). On February 11, 2000, the Shuttle Radar Topography Mission (SRTM) payload aboard Space Shuttle Endeavour launched into space. SRTM acquired enough data during its 10 days of operation to obtain the first-ever, near-global, high-resolution dataset of the Earth's topography covering nearly 80 percent of the Earth's land surfaces (Farr, et al. 2007).

The Shuttle-Mir (1995-1998) Program was a collaborative program between the United States and the USSR/Russia. During the nine missions, over 22,000 Earth images were taken that documented long-term study sites and dynamic events on the Earth's surface. These events included land use change, seasonal change and long-term climate change, atmospheric events, ocean and coastal dynamic features, volcanoes, and cities/regional sites (Evans, et al. 2000).

Earth Science Research on ISS

The ISS was first inhabited in November 2000. This laboratory in space has continuously grown and supports multi-discipline research.

In 2009 a significant space exploration goal was reached when the number of astronauts capable of living aboard the ISS increased from three to six; and in 2011, the assembly of the ISS was completed. Since then, the time spent performing ISS research has continuously increased. ISS laboratories now accommodate an unprecedented amount of space-based research with new and exciting capabilities being continuously proposed and developed. This Earth-orbiting laboratory and living facility houses astronauts who continuously conduct science across a wide variety of fields including the Earth sciences. In addition to crew-tended experiments, the ISS also provides a variety of internal and external mounting locations, and common data transfer and power interfaces, that facilitate its use for automated remote-sensing systems. Current ISS utilization statistics including a cumulative history of research completed is continuously being tracked and updated and can be found here: http://www.nasa.gov/pdf/695701main_Current_ISS_Utilization_Statistics.pdf.

For up-to-date information regarding ISS activities, research and accomplishments, please visit the following link: http://www.nasa.gov/mission_pages/station/main/index.html

Crew Earth Observations (CEO)

From ISS Expedition 1 (November 2000) through May 2013, crew members have acquired nearly 1.2 million images of Earth as part of the CEO program. The total number of images taken from orbit by astronauts since the first Mercury missions is now more than 1.5 million. Scientists and the public around the world have access to CEO images captured by astronauts on ISS as well as images from earlier programs. These images are available through the Gateway to Astronaut Photography of Earth website (http://eol.jsc.nasa.gov).

Sample Research

CEO images captured from ISS of Pacific Ocean atolls (islands consisting of a circular coral reef surrounding a lagoon) allowed for an assessment of spatial resolution on estimates of landscape parameters. Data gathered indicated that landscape parameter estimates were fairly accurate regardless of spatial resolution changes from 5 to 30 meters. The most detailed images of Fangatau Atoll,

taken from ISS, were used to measure the biomass of the giant clam fishery at Fangatau Atoll with accuracy similar to that obtained from aerial photography (Andréfouët et al. 2005).

To date, ISS crew members have successfully documented the break-up of large tabular icebergs that have calved from the Antarctic ice shelves and drifted northward into the South Atlantic Ocean. Researchers from the National Snow and Ice Data Center have used the imagery from the ISS to examine surface features, including ice margins, cracks and surface meltwater ponds to better understand the mechanisms and timing of iceberg breakup. Large tabular icebergs can be used to model breakups of the Antarctic ice shelf (Scambos et al. 2005; 2008).

High-resolution astronaut photography collected from station has provided useful data for urban analysis, especially vegetation measurements. The accuracy of the data obtained from the astronaut photographs was similar to the data obtained by satellite remote sensors. The high-resolution astronaut photography obtained by the CEO investigation gives insights into vegetation density and phenology in urban, suburban, and agricultural areas (Stefanov and Robinson 2003).

Imagery taken by astronauts has been collected and used to identify and build a global inventory of a new class of landform called megafans. These are large cones of sediments deposited by rivers that empty into large continental basins. Megafans are more easily identified using the wide, oblique views provided by astronaut photography. The results have been applied to interpreting features on both Earth and Mars. Wilkinson (2005) mapped megafans in South America from imagery collected by the space shuttle and ISS crews to understand how aquatic organisms might diversify in different river systems in South America. Another application of megafan landform analysis discusses how these features might provide a new perspective on mineral exploration (Wilkinson 2004).

Through CEO, ISS crew members share their view of the Earth with the public and take pictures of some of the most dramatic examples of change on the Earth's surface. These sites have included major deltas in south and east Asia, coral reefs, cities, alpine glaciers, volcanoes, large megafans (major fan-shaped river deposits), and features on Earth, such as impact craters, that are analogs to structures on other planets. Astronauts also record dynamic events: in 2004 and

2005, station astronauts took key photographs of the December 2004 tsunami, and Hurricanes Katrina and Wilma. Other notable images capture volcanic eruptions on Mt. Etna (Sicily) and Cleveland volcano (Alaska), dust storms, smog, forest fires in the western U.S., and the Kolka glacier collapse in Russia.

Sample CEO Images

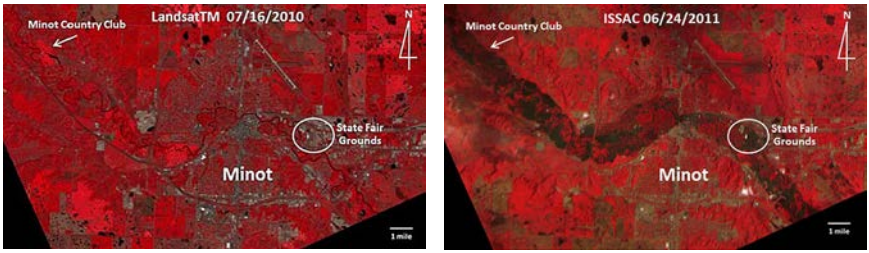
Sarychev Peak Volcano eruption, Kuril Islands, is featured in this image photographed by an Expedition 20 crew member on the International Space Station. A fortuitous orbit of the International Space Station allowed the astronauts this striking view of Sarychev volcano (Russia's Kuril Islands, northeast of Japan) in an early stage of eruption on June 12, 2009.

An Expediton 27 crew member aboard the International Space Station, 220 miles above Earth and the Mississippi River, captured this May 12 still photo, clearly showing the outlines of some heavily flooded agricultural fields on the Missouri side of the river. The center point for this 400-mm frame is 36.27 degrees north latitude and 89.57 degrees west longitude (north of Caruthersville, Mo. and west of Ridgely, Tenn.). North is towards the lower right corner of the image.

ISS Agricultural Camera (ISSAC)

The ISSAC was active aboard the ISS from January 2011 to January 2013. It was a multi-spectral camera installed in the ISS as a sub-rack payload of the WORF. A single 150-mm lens and optical beam splitter supplied light to three digital framing cameras, each with its own filter; green, red (630-690 nm) and near infrared (780-890 nm).

Normal payload operations were commanded via ground uplink. Commands were stored in an on-board command queue and executed based on system time supplied by the ISS. Imagery collected was downlinked via the medium-rate payload LAN. The onboard command queue capability allowed autonomous 24-hour operations, enabling routine worldwide target accessibility. (http://www.nasa.gov/mission_pages/station/research/experiments/81.html)



Comparison of Minot, N.D., and Souris River Valley during normal river flow conditions (left image, Landsat Thematic Mapper data) and during flood conditions (right image, ISSAC data). Both images have been processed to highlight actively photosynthesizing vegetation in red. Urban areas appear gray-brown.

The red and near-infrared bands within ISSAC were similar to those used on satellite-based broadband, multi-spectral systems used for studying vegetation. Agricultural efficiency and competitiveness can be enhanced through the practical application of data products that are derived from reflectance measurements taken in these spectral regions. ISSAC was focused on studying aspects of agricultural efficiency that are of particular importance to the northern Great Plains. More generally, these same capabilities of ISSAC were applicable worldwide to scientific study of any areas undergoing rapid ecosystem change. Targets ranged from natural systems (glacier melt, plant phenological transitions, spring green-up, fall senescence) to human impact (deforestation, urbanization).The sensor also contributed to the ISS capability to collect data for humanitarian aid to areas struck by natural disasters through the International Charter, Space and Major Disasters(IDC) (http://www.disasterscharter.org/home). The ISSAC collected data for several IDC activations including fires in northern Africa, flooding in Pakistan, and the aftermath of Hurricane Sandy in the U.S.A.

Opportunities for Research

Current Payloads

Internal Payloads

CEO

Historically the CEO program has been a major source of data provided by the ISS. While still an important aspect of the ISS, the additional remote sensing instruments currently aboard, as well as those planned for the future, will further enhance the opportunities for quantitative Earth remote-sensing research and applications from the ISS. Requests for new CEO data for scientific research and educational uses will require well-defined proposals from all users as the emphasis of CEO gradually shifts to primarily disaster response events in support of the International Disaster Charter (IDC). Additional capabilities of CEO include high-resolution night-time imagery of urban and suburban areas, and time-lapse sequence imagery of atmospheric phenomena such as airglow and aurora.

Night time images of cities are striking and useful for urban climate and light pollution studies, disaster response (blackouts), modeling urban land use, and population density. ISS photographs of cities at night are unique because they provide greater spatial resolution than any other orbital source of city light data.

A nighttime view of Riyadh, Saudi Arabia is featured in this image photographed by an Expedition 33 crew member on the International Space Station. The city appears as a brightly colored patchwork in this nighttime photograph.

The CEO program involves crew members using professional-grade, commercial, off-the-shelf, handheld digital cameras with a suite of lenses (from wide angle to an 800-mm lens equivalent) to take Earth observation photographs that support research and applications in a wide variety of Earth science sub-disciplines including disaster response. Scientists on the ground train the crew in basic areas of Earth system science and provide the crew a daily list of targets focused on dynamic events (such as IDC activations), educational outreach, and approved science targets. Crew members take these photographs as time is available and during their leisure time

These digital photographs are downlinked, their location identified and both images and meta-data are assimilated into a public database. The images can be used as educational and research tools, as well as historical records of global environmental change, special geological and weather events, and the growth and change of human-made features such as cities. Scientific analyses using CEO data have been published in scientific journals in a wide variety of disciplines. CEO are conducted from any available window on space station, but are now conducted primarily from the windows in the Russian Zvezda service module and the ISS Cupola.

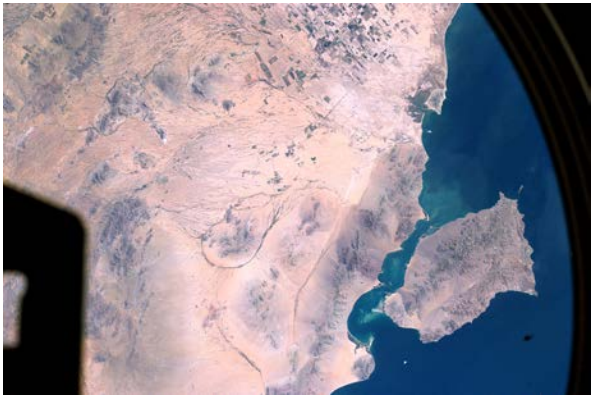
Through their photography of the Earth, ISS crew members build on the time series of imagery started with the first human spaceflights, ensuring that this continuous record of Earth remains unbroken. It is an axiom in the U.S. manned space program that a trained crew member is truly a part of the facilities.

Worldwide access to images captured by astronauts on ISS is available through the Gateway to Astronaut Photography of Earth Web site (http://eol.jsc.nasa.gov). Between 400,000 and 1,000,000 digital photographs of Earth taken from the CEO collection are downloaded by the public each month. The website also features searchable access to all the photographs and a public cataloging facility.

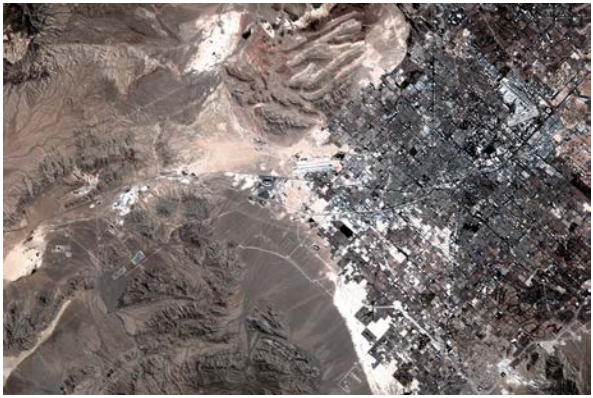
ISS EarthKAM

Earth Knowledge Acquired by Middle school students (EarthKAM) is a NASA educational outreach program enabling students, teachers, and the public to learn about Earth from the unique perspective of space. During ISS EarthKAM missions (periods when the ISS EarthKAM camera is operational), middle school students around the world request images of specific locations on Earth. The entire collection of ISS EarthKAM images is available in a searchable

ISS EarthKAM image archive (http://images.earthkam.ucsd.edu/main.php). This image collection and accompanying learning guides and activities are extraordinary resources to engage students in Earth and space science, geography, social studies, mathematics, communications, and art.



This EarthKAM image of Baja, Calif., was requested by students on Oct. 31, 2011, at 19:24 UTC (Coordinated Universal Time).



This EarthKAM image of Las Vegas, Nev., was requested by students on April 26, 2013, at 19:53 UTC (Coordinated Universal Time).

ISS SERVIR Environmental Research and Visualization System (ISERV)

The ISS SERVIR Environmental Research and Visualization System (ISERV) is comprised of a COTS (Commercial off the Shelf) camera, telescope and pointing system operated remotely from Earth by researchers at NASA's Marshall Space Flight Center in Huntsville, Ala. The ISERV camera system's mission is to gain experience and expertise in automated data acquisition from the space station. ISERV is an observatory mounted within the WORF rack

aboard the ISS. This facility provides Earth observation data and is unique, both in terms of orbital characteristics and available human and infrastructure support that makes it a highly useful platform from which to acquire rapid and changing Earth observational data. Initial versions of this hardware provide the necessary experience in automated system tasking, data acquisition, and data transfer. Ultimately, this kind of observational system has the capability to support environmental decision-making, and to assess and monitor the impact of disasters and other significant events of the surface of our planet.

This "first light" image from ISERV shows the mouth of the Rio San Pablo in Veraguas, Panama, as it empties into the Gulf of Montijo. This wetland supports an important local fishery and provides habitat for many mammals and reptiles, as well as several species of nesting and wintering water birds. The image was captured Feb. 16, 2013.

ISERV supports the goals of NASA's SERVIR (Spanish for "to serve") project. SERVIR is a conglomerate system of data, models, and information products, designed to support and inform the environmental decision-making process in various regions. Through its various hubs around the world, SERVIR provides decision-support mechanisms in a variety of areas such as drought and flood monitoring, landslide probability mapping, disease incidence mapping, and air quality and environmental condition monitoring. In addition, SERVIR acts as a regional manager for disaster monitoring and assessment, and as such, is responsible for the acquisition and disbursement of a variety of data that describes the affected areas and is used for assessment and monitoring of conditions following these disasters. Principally supported by NASA and the U.S. Agency of International Development (USAID), a strong emphasis is placed on partnerships to fortify the availability of searchable and viewable earth observations, measurements, animations, and analysis.

External Payloads

Hyperspectral Imager for the Coastal Ocean (HICO)

HICO (Corson et al. 2008) is an imaging spectrometer based on the Portable Hyperspectral Imager for Low-Light Spectroscopy (PHILLS) airborne imaging spectrometers (Davis et al. 2002). It was launched to the ISS in 2009, mounted on the Japanese Experiment Module-Exposed Facility (JEM-EF) for operations, and integrated with the Remote Atmosphere and Ionospheric Detection Systems (RAIDS) to form the HICO and RAIDS Experiment Payload (HREP). The RAIDS device measures the thermosphere, which creates atmospheric drag on space vehicles and satellites and is affected by solar activity. RAIDS also studies the ionosphere, which has a strong influence on radio, radar, and satellite navigation signals. Imagery captured during HREP's long duration will provide new data about how sunlight, cloud cover and different viewing angles can affect images taken in low-Earth orbit.

HICO is the first space-borne imaging spectrometer designed to sample the coastal ocean. HICO samples selected regions at approximately 90 m Ground Sample Distance (GSD) with full spectral coverage (400 to 900 nm sampled at 5.7 nm), and signal-to-noise ratio sufficiently high to resolve the complexity of the coastal ocean. HICO data have much greater spatial (90 m vs. 1000 m) and spectral (87 channels vs. 9-15) resolution than current space-borne ocean color imagers, and the data are of great interest for studying the dynamics of the coastal ocean. Scientists from U.S. agencies, U.S. commercial interests, ISS International Partners, and academia (both nationally and internationally) have expressed interest in receiving and using HICO data to develop new algorithms and to study coastal ocean dynamics.

At the beginning of 2013, HICO transitioned from an investigator-sponsored instrument funded by the Department of Defense to an ISS facility with sustaining operational funding provided by the NASA ISS Program. The primary mission of HICO as an ISS facility is to provide hyperspectral remote-sensing data to U.S. users to benefit the nation, expand and extend the applications of hyperspectral data from orbit, and meet NASA science goals from the Earth Science Decadal Survey. HICO demonstrates the capability for retrieval of coastal ocean depth, chlorophyll content, sea floor composition and water visibility, which are vital for rapid and safe maneuvers in coastal environments.

The Naval Research Laboratory (NRL) will continue to operate the instrument, with support of the science management team comprised of representatives from NASA ISS, NASA Science Mission Directorate (SMD), the Center for the Advancement of Science in Space (CASIS), NRL and the HICO project scientist at Oregon State University (OSU). The HICO science management team will also support and manage the integration of authorized users. HICO tasking will be based on authorized investigator requests, with the goal of fully satisfying data collection needs for authorized users.

Yangtze River, China Oct 20 2009. Coastal water depth and visibility is delineated by variability in color shading as seen in image to the left. Coastal waters have historically been difficult areas to study using remote sensing platforms and so HREP-HICO is a major advancement for researchers studying coastal communities.

NASA ISS, CASIS, and NASA Science Mission Directorate (SMD) will work together to identify authorized users, decide acquisition priorities when necessary, and facilitate expansion of the use of HICO data. The existing public interface for receipt of new user proposals, and notification/delivery of acquired data (http://hico.coas.oregonstate.edu/join/join.shtml), will be modified as needed to track sponsorship of users. Data acquired by HICO is publically available at the OceanColor Web site (http://oceancolor.gsfc.nasa.gov).

Firestation

Firestation, a sensor attached to a US Department of Defense experimental pallet on the exterior of the ISS, watches for lightning on Earth, which regularly appears some 50 times a second around the globe. Firestation studies the link between lightning and mysterious events known as terrestrial gamma ray flashes, or TGFs. TGFs are very brief but intense bursts of gamma rays produced in Earth's atmosphere by the powerful electrical charges over thunderstorms. Gamma radiation is typically produced only in extreme environments, like nuclear fusion inside the sun or from within distant exploding stars, so

this suggests the environment near a lightning flash is much more energetic and complex than previously thought. In addition to being a fascinating and unexpected aspect of our planet, TGFs also may shed light on the processes that trigger lightning in thunderstorms.

Firestation has the unique ability to observe thunderstorms at multiple wavelengths simultaneously. It can record the radio static from lightning, measure its optical glow (including the red and blue light of sprites and elves), and detect the gamma-rays and electrons associated with TGFs and antimatter events. The sensor was delivered to the ISS aboard the JAXA Kounotori-4 spacecraft in August of 2013, and has an expected mission duration of one year.

Planned Future Payloads

Internal Payloads

METEOR [2014]

Project Meteor's mission objective is to fly a visible spectroscopy instrument to the ISS to observe meteors in Earth orbit. It is anticipated that Project Meteor will conduct operations for approximately two years from the date that in orbit operations commence. Southwest Research Institute (SwRI) will serve as the U.S. host and will conduct this experiment on behalf of Chiba Institute of Technology, which is based in Japan.

Meteor spectra are commonly observed from the ground or aircraft by instruments pointing at the sky during a reliably known meteor shower. Meteors cross the field of view of the observer's instrument and are recorded either photographically or electronically. Spectral measurements are made by a spectrograph, which records all wavelengths instantaneously. Investigators can then determine elemental abundances and temperatures by comparing known synthetic spectra to observed spectra. These ground or aircraft measurements, however, are limited to very short periods of observation time and small portions of the Earth's atmosphere. Additionally, ground and aircraft-based meteor observations are limited by ozone absorption in the terrestrial atmosphere. This absorption masks the important organic carbon spectral emission. Satellite detectors can overcome these limits. Project Meteor will provide a continuous monitor of meteor interaction with the Earth's atmosphere without limitations of the ozone absorption. The resultant data will be the first

measurement of meteor flux and will allow for monitoring of carbon-based compounds. Investigation of meteor elemental composition is important to our understanding of how the planets developed.

External Payloads

High-Definition Earth Viewing (HDEV) [2014]

The High-Definition Earth Viewing (HDEV) investigation places four different commercial high-definition cameras external to ISS on the Columbus External Facility. The payload will first test the capability to robotically remove a payload from the SPACEX3 trunk and place it on the nadir position of the Columbus External Payload Adapter (CEPA). The investigation will then assess the quality of the imagery over time in the harsh low-Earth orbit environment during the life-time of the payload.

The HDEV visible cameras are a fixed payload camera system that requires no zoom, no pan or tilt mechanisms. The four fixed cameras are targeted for imagery of the Earth's surface and its terminators as seen from the ISS (i.e., one camera forward-pointed into the station's velocity vector, two cameras aft [wake], and the other one camera pointing nadir). The video imagery is encoded into an Ethernet compatible format for transmit to the ground and further distribution. In this format, the video can be viewed from any computer connected to the internet.

The HDEV will operate one camera at a time. The HDEV is designed so that when the system is initially powered on, after a 1- to 2-minute warm-up period, the cameras will be turned on one at a time in a repeating cycle. The forward-looking camera is powered first, followed by the Nadir and each aft looking camera, such that the HDEV video will "follow" a location on the Earth as the ISS passes overhead. This auto-cycle mode of the HDEV does not require any input from ground operators, so the HDEV can be operated any time that the ISS power and data resources are available without requiring a ground controller present to operate the payload. The only command required is the initial "power on" command, which is performed by ESA's Columbus Control Center as scheduled by ISS Payload Operations.

Alternately as desired by ground controllers, the HDEV video can be commanded. Ground operators have the choice to change the cycle of the

images noted in the auto-cycle mode (either changing which cameras are powered on, or changing the length of time they are powered on), or, if desired, ground controllers can command a single camera to remain powered on and for no auto-cycle to take place.

The HDEV video will be available to the public over the internet, through a dedicated website under development by collaborators at the University of Houston-Clear Lake. The HDEV imagery will be displayed next to the ISS location map (showing where the ISS is located over the Earth as the video is viewed). The HDEV can be scheduled to be operated in support of special events, on request. Not all requests can be accommodated, but HD video of the Earth can be provided as resources permit.

Cloud Aerosol Transport System (CATS) [2014]

CATS is a high spectral resolution LiDAR (Light Detection And Ranging) that uses a laser to gather data about clouds and aerosols. Aerosols are tiny particles in the atmosphere such as dust, smoke or pollution. Similar instruments on existing satellites, such as CALIPSO (http://www.nasa.gov/mission_pages/calipso/main/), can detect aerosol plumes but cannot determine what they are made of. CATS can better detect aerosol particle properties, allowing researchers to better determine what kind of aerosols the plumes are made of and improve studies of aerosol transport and cloud motion. In addition to advancing the scientific understanding of aerosols and their role in atmospheric processes and climate, CATS is intended to provide important technology and instrument demonstration for the future Aerosol-Cloud Ecosystems (ACE) satellite mission which is currently under study. A version of CATS will be installed on the ISS in mid-2014 (TBR).

Stratospheric and Aerosol Gas Experiment III (SAGE) [2014]

The SAGE III instrument is used to study ozone, a gas found in the upper atmosphere that acts as Earth's sunscreen. More than 25 years ago, scientists realized there was a problem with Earth's protective coat of ozone ... it was thinning. The SAGE family of instruments was pivotal in making accurate measurements of the amount of ozone loss in Earth's atmosphere. SAGE instruments have also played a key role in measuring the onset of ozone recovery resulting from the internationally mandated policy changes that regulated chlorine-containing chemicals—the Montreal Protocol—which was passed in 1987.

Today, the SAGE technique is still the best for the job, and NASA scientists are preparing to send a SAGE III instrument to ISS. More specifically, SAGE III - ISS will provide global, long-term measurements of key components of the Earth's atmosphere. The most important of these are the vertical distribution of aerosols and ozone from the upper troposphere through the stratosphere. In addition, SAGE III also provides unique measurements of temperature in the stratosphere and mesosphere and profiles of trace gases, such as water vapor and nitrogen dioxide,that play significant roles in atmospheric radiative and chemical processes.

Instead of flying on an unmanned satellite, SAGE III will be mounted to the ISS where it will operate alongside experiments from all over the world in the space-based laboratory. The orbital path of ISS will help maximize the scientific value of SAGE III observations.

Multi-User System for Earth Viewing (MUSES) [2014]

The Multi-User System for Earth Sensing (MUSES) is an Earth-imaging platform designed to host earth-looking instruments, such as high-resolution digital cameras, and provide precision pointing and other accommodations. It can host up to four instruments simultaneously and offers the ability to change, upgrade, and robotically service those instruments. MUSES will help expand the research capability of the space station and provide commercial companies as well as government researchers with a cost-effective means to collect Earth images.

RapidScat [2014]

NASA's ISS-RapidScat instrument will launch to the ISS in 2014 to measure ocean surface, wind speed and direction, and help improve weather forecasts, including hurricane monitoring. It will be installed on the end of the station's Columbus Laboratory. The ISS-RapidScat instrument is a speedy and cost-effective replacement for NASA's QuikScat Earth satellite, which monitored ocean winds to provide essential measurements used in weather predictions such as hurricane monitoring. So essential were QuikScat's measurements that when the satellite stopped collecting wind data in late 2009, NASA was challenged to quickly and cost-effectively conceive of a replacement. NASA's Jet Propulsion Laboratory and the agency's Space Station Program came up with a solution that uses the framework of the ISS and reuses hardware originally built to test parts of QuikScat to create an instrument for a fraction of the cost and time it would take to build and launch a new satellite.

Orbiting Carbon Observatory (OCO-3) [2016]

The Orbiting Carbon Observatory - 3 (OCO-3) is a complete stand-alone payload built using the spare OCO-2 flight instrument, with additional elements added to accommodate installation and operation on the International Space Station (ISS). The OCO-3 instrument consists of three high-resolution grating spectrometers that collect space-based measurements of atmospheric carbon dioxide (CO2) with the precision, resolution, and coverage needed to assess the spatial and temporal variability of CO2 over an annual cycle. After launch and docking with the space station, the OCO-3 instrument will be installed on the ISS Japanese Experiment Module – Exposed Facility (JEM-EF) where it will be operating for the duration of the mission.

The instrument will acquire data in three different measurement modes. In Nadir Mode the instrument views the ground directly below the space station. In Glint Mode, the instrument tracks near the location where sunlight is directly reflected on the Earth's surface. Glint Mode enhances the instrument's ability to acquire highly accurate measurements, particularly over the ocean. In Target Mode, the instrument views a specified surface target continuously as the ISS passes overhead. Target Mode provides the capability to collect a large number of measurements over sites where ground-based and airborne instruments also measure atmospheric CO2. The OCO-3 science team will compare Target Mode measurements with those acquired by ground-based and airborne instruments to validate OCO-3 mission data. The Observatory has a planned operational life of three years.

Lightning Imager Sensor LIS [2016]

The Lightning Imaging Sensor is a small, highly sophisticated instrument that detects and locates lightning over the tropical regions of the globe. Looking down from a vantage point aboard the ISS above the Earth, the sensor will provide information that could lead to future advanced lightning sensors capable of significantly improving weather "nowcasting," and will also support data collected by atmospheric sensors on the ISS operated by ESA and JAXA.

The Lightning Imaging Sensor promises to expand scientists' capabilities for surveying lightning and thunderstorm activity on a global scale. The lightning detector is a compact combination of optical and electronic elements including a staring imager capable of locating and detecting lightning within individual storms. The imager's field of view allows the sensor to observe a point on the

Earth or a cloud for 80 seconds, a sufficient time to estimate the flashing rate, which tells researchers whether a storm is growing or decaying.

The sensor was developed by the Global Hydrology Center at NASA's Marshall Space Flight Center in Huntsville, Ala., in conjunction with Lockheed Martin, Palo Alto, Calif., and Kaiser Electro Optics, Carlsbad, Calif. The sensor provides information on cloud characteristics, storm dynamics, and seasonal as well as yearly variability of thunderstorms. The sensor studies both day and night cloud-to-ground, cloud-to-cloud and intra-cloud lightning and its distribution around the globe.

The staring imager is made of an expanded optics lens system that provides a wide field of view and a narrow-band filter which minimizes background light. A highspeed, charge-coupled device detection array behaves similarly to the retina of the human eye by creating an image of the lightning event and the background scene. A real-time event processor then extracts the signal, thus determining when a lightning flash occurs.

The optics lens system allows lightning detection even in the presence of bright, sunlit clouds. Weak lightning signals that occur during the day are hard to detect because of background illumination. This system will remove the background signal, enabling the detection of 90 percent of all lightning strikes. Data recorded includes the time of a lightning event, its radiant energy—how bright the lightning flash is—and an estimate of the lightning location.

Future Earth-Observing Sensors

CASIS, in conjunction with NASA, continues to solicit ideas for new sensors that can take advantage of the ISS as a remote-sensing platform. In the future, multi-user sensors including multi- and hyper spectral imagers might be developed and become available for Earth-observing applications.

OPERATIONAL SUPPORT

The ISS and payload operations are supported by different mission control centers (MCCs). The prime operational mission control center is split between MCC in Houston, Texas, at NASA's Johnson Space Center (JSC), and the Russian Control Center near Moscow, Russia. Payload support is provided primarily through the Payload Operations and Integration Center (POIC) at NASA's Marshall Spaceflight Center (MSFC) in Huntsville, AL. However, some payload support is

provided by JSC, and at NASA's Kennedy Space Center. Additionally, international partners maintain control centers in Germany (the Columbus Control center near Oberpfaffenhofen, Germany); the Tskuba Space Center (TKSU) in Japan; the Canadian Space Agency Mission Control Center (CSA-MCC), in Longueuil, Quebec, Canada; and the CSA-Payloads Telescience Operations Center (PTOC), St. Hubert, Quebec, Canada.

The MSFC POIC coordinates all U.S. scientific and commercial experiments on the station, synchronizes payload activities of international partners and directs communications between researchers around the world and their onboard experiments. The WORF rack is also managed by the MSFC POIC. The Payload Operations Center integrates research requirements, planning science mis¬sions and ensuring that they are safely executed. It integrates crew and ground team training and research mission timelines. It also manages use of space station payload resources, handles science communications with the crew, and manages commanding and data transmissions to and from the orbiting research center. The Payload Operations Center processes hundreds of payload commands per day. It also continuously monitors the health and status of scien¬tific instruments deployed on the space station. Since 2001, the center has worked with 1,309 scientific investigators performing 1,251 research investigations. The Payload Operations Center is staffed around the clock by three shifts of flight controllers.

In addition, staff and facilities at JSC help support Earth Observation payloads through JSC's Remote Sensing Office within the ARES directorate. This organization includes the CEO group that is responsible for generating image target lists for the ISS crew, reviewing all imagery acquired, cataloging the processed imagery, and availing all imagery to the public via the website (http://eol.jsc.nasa.gov). In addition, the CEO staff provides crew training, produces varied proposals for scientific research, and serves as an important conduit for public outreach for both CEO and NASA in general. The Remote Sensing Office also coordinates disaster response among the ISS remote-sensing payloads and serves as a general remote-sensing resource for additional Earth science payloads, both present and future, within the ISS Program.

Launch services for the ISS are supplied by several sources, including Space X (Falcon), Orbital Sciences (Taurus), JAXA (HTV), ESA Roscosmos (Progress), and ESA (ATV). For more details, please see the ISS Reference Guide (http://www.nasa.gov/mission_pages/station/news/).

Lessons Learned

As an orbital, Earth-viewing platform, success or failure to collect data is dependent on several factors both internal and external to the ISS. Cloud cover can frequently preclude useful data collection over some parts of the Earth; likewise the ISS orbit and seasonal variations can limit the availability of sufficient illumination of ground targets. For human-tended systems, limiting constraints not only involve the environmental viewing constraints, but also limitations imposed by the crew's work schedule, including the time required for payload installation and tradeouts. Data downlink capacity must also be carefully evaluated when considering instruments or measurements with high data volume observations and time-sensitive data collection.

Precision targeting from the WORF was also an issue for ISAAC because of their inability to access the full temporal resolution ISS position feed (1 Hz). ISERV has had similar issues with focus of their telescope and camera as well as data downlink. While solutions to these issues are being pursued within the ISS operational and design community, these are potential issues payload designers should take into consideration prior to launch of their instruments.

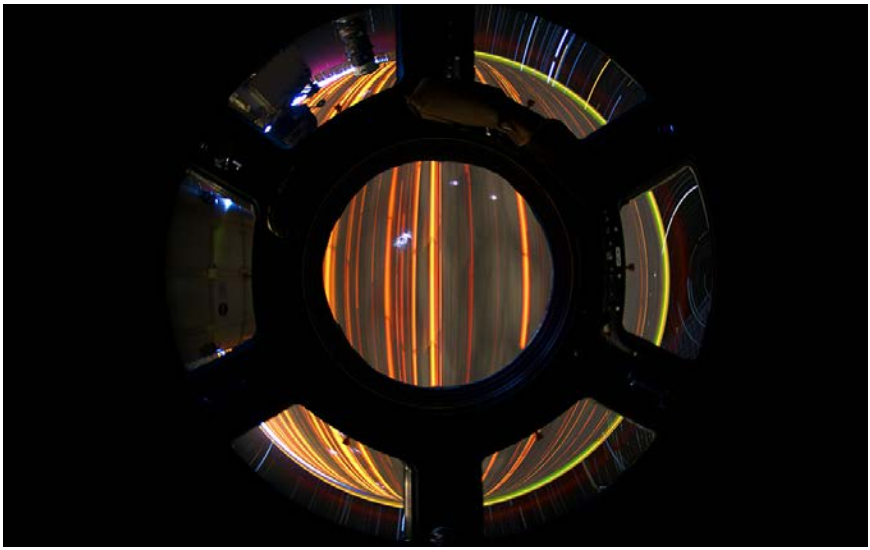
The sun is captured by photo as a spectacular starburst over Earth's horizon. The Expedition 36 crew aboard the International Space Station captured this sunny display while flying over southwestern Minnesota in the United States on May 21, 2013.

Facilities

ISS Research Facilities enable scientific investigations and are defined as:

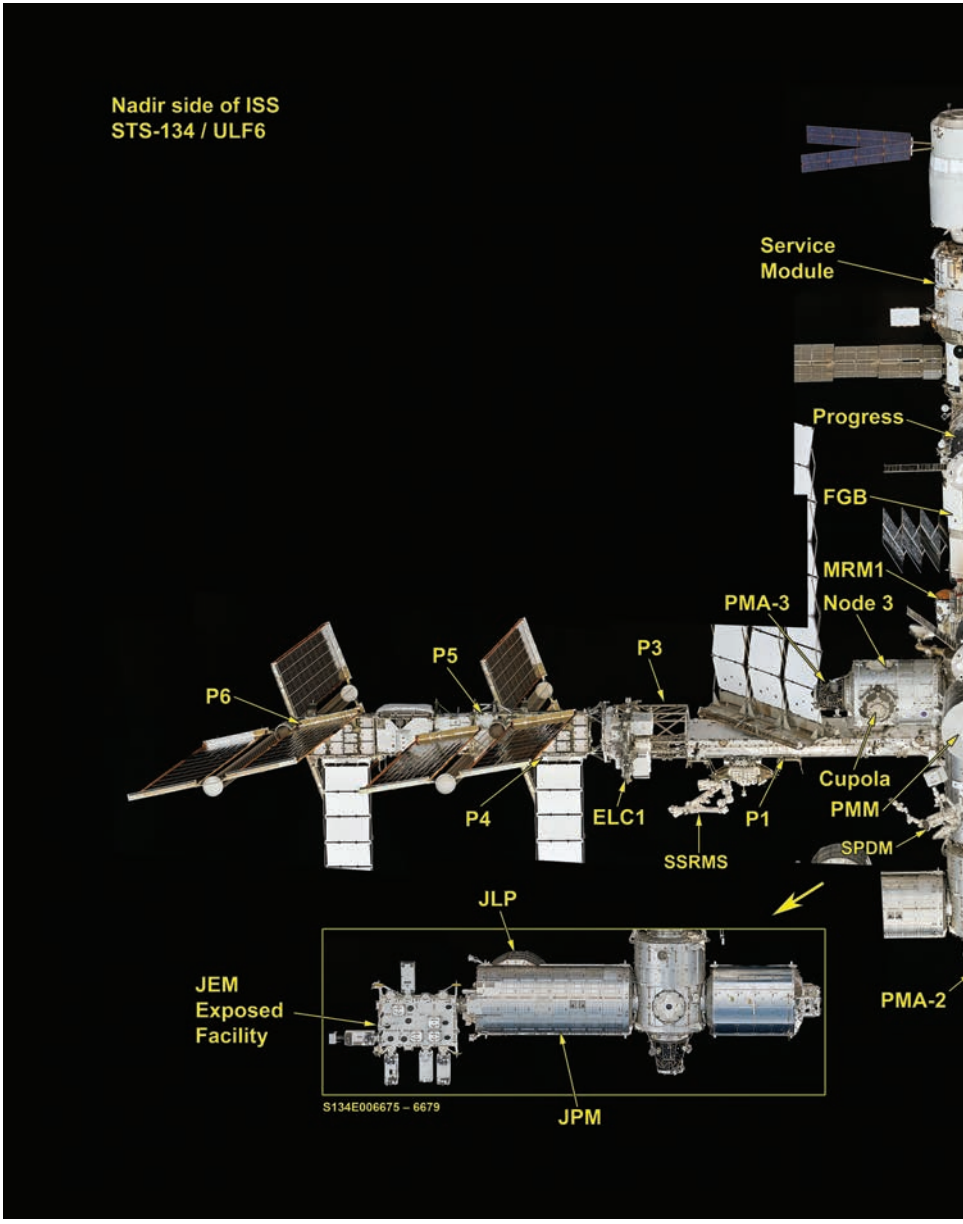
1. Available aboard ISS or as a sortie to ISS for long periods of time (i.e., more than a single increment)
2. Can be scheduled for use by investigators OR provide an interface for connecting investigations to the ISS/environment by other than the hardware's original developer/owner.

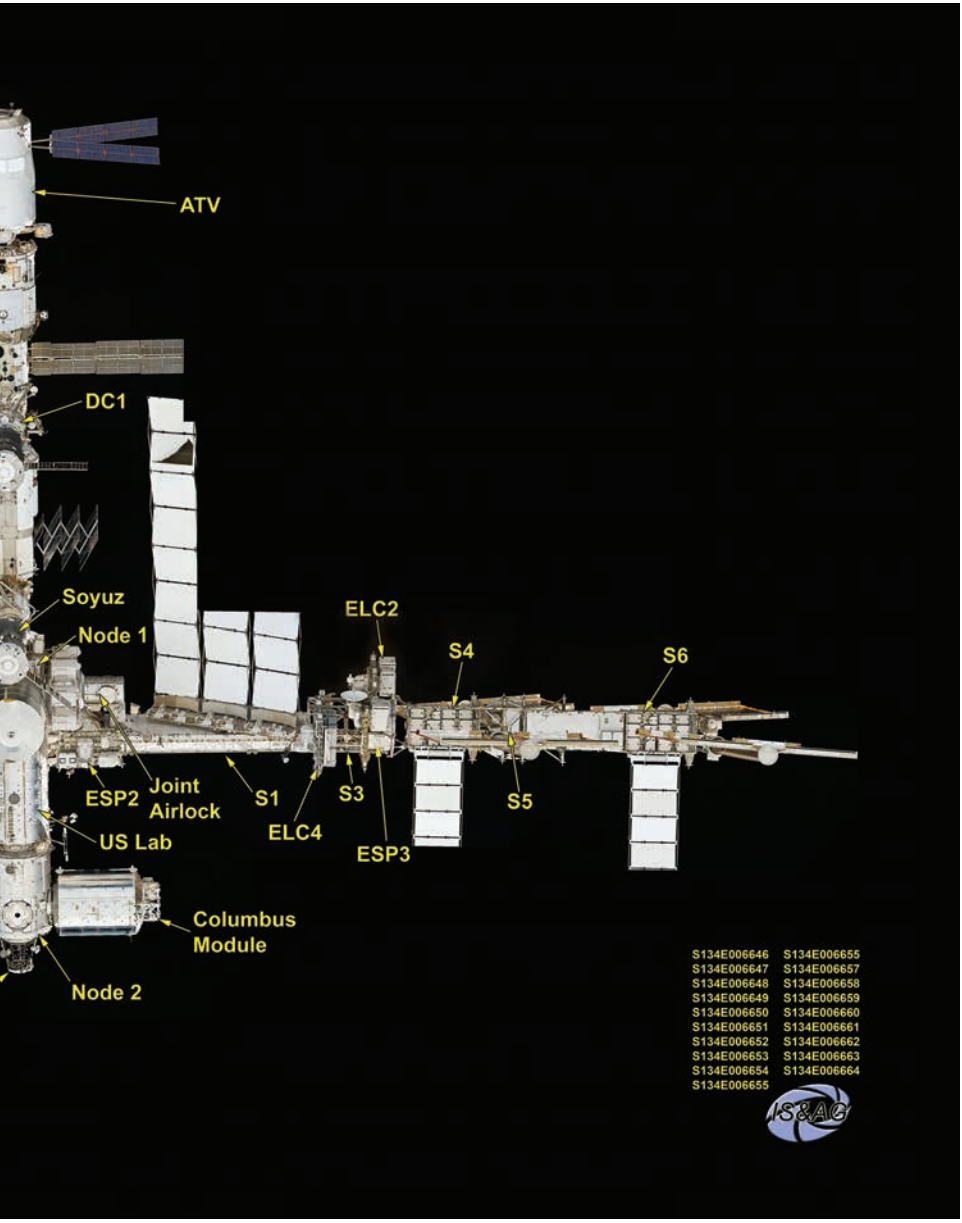
Circling the Earth every 90 minutes in a low-Earth orbit, covering over 90 percent of the planets habitable land mass, the ISS provides a unique vantage point for collecting Earth and space science data. From an average altitude of about 400 km (248.5 miles), detailed data regarding the space environment, land features, environmental changes and land use taken from the ISS can be layered with other sources of data, such as orbiting satellites and aerial photogrammetry, to compile the most comprehensive information available. Facilities in this section show some of the current and growing capabilities afforded by the ISS in the following fields of research: glaciers, agriculture, urban development, natural disaster monitoring, atmospheric observations, and space radiation.



Seen through the windows of the Cupola on the space station, this neon-colored composite of the lights of Earth and a few outward star trails uses multiple photos to produce an other worldy effect similar to a "lightspeed" effect in a science fiction movie.

ISS Windows


Nadir side of ISS
STS-134 / ULF6
Service Module
Progress
FGB
MRM1
Node 3
PMA-3
P3
P5
P6
P4
ELC1
P1
SSRMS
Cupola
PMM
SPDM
JLP
JEM Exposed Facility
JPM
PMA-2
S134E006675 – 6679


ATV
DC1
Soyuz
Node 1
ELC2
S4
S6
ESP2
Joint
Airlock
S1
S3
S5
ELC4
ESP3
US Lab
Columbus
Module
Node 2
S134E006646
S134E006647
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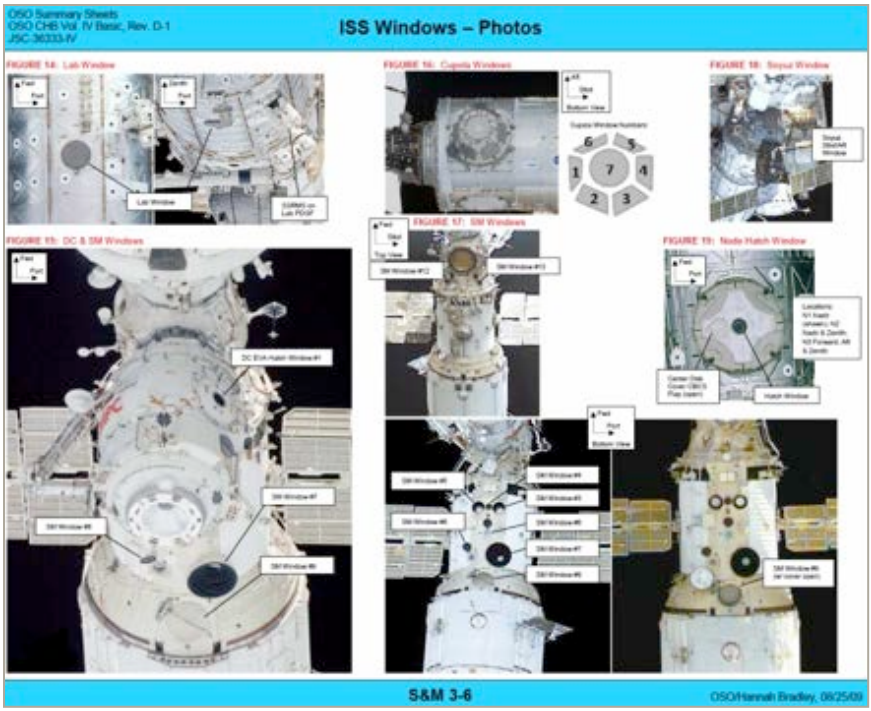


There are more than 30 windows with varied optical properties within the ISS providing many viewing opportunities for researchers. Variability within these properties include pane material, thickness, coating, and the presence or absence of pressure covers. Potential proposers of instruments that require specific window properties or fields of view are strongly encouraged to contact the International Space Station Research Integration Office, or the International Space Station Program Science Office early in the conceptual design process in order to verify that the desired viewing locations are appropriate and available. Both offices can be contacted through jsc-iss-research-helpline@mail.nasa.gov.

Internal Facilities

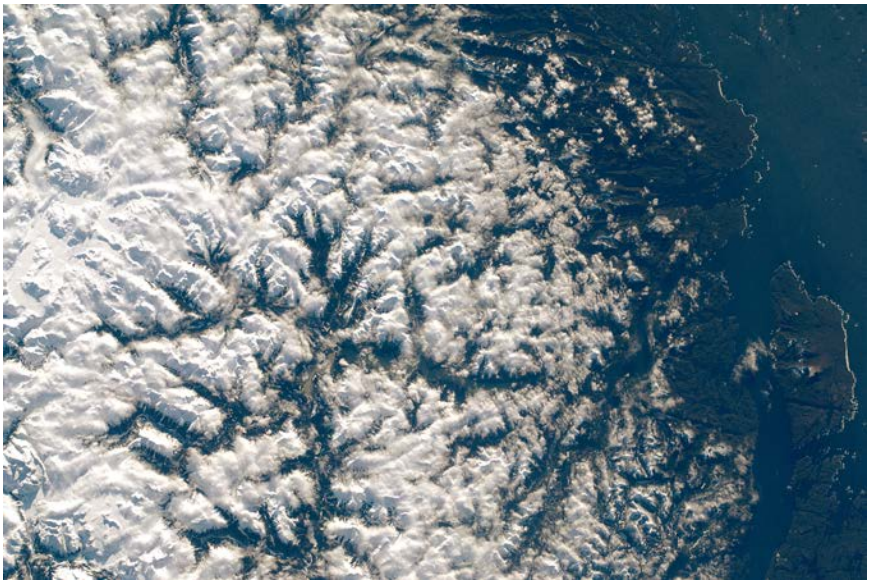
Window Observational Research Facility (WORF)

The WORF was delivered to the ISS in April 2010 on the STS-131 mission of Space Shuttle Discovery. It was installed and prepped in the Destiny Laboratory. WORF occupies the location in the U.S. Lab adjacent to the highest quality optical window ever installed on a human-tended spacecraft. The WORF provides a unique ISS facility for conducting crew-tended or automatic Earth observation and scientific research. WORF is a multipurpose facility that provides structural support hardware, avionics, thermal conditioning, and optical quality protection in support

of a wide variety of remote-sensing instruments and scientific investigations. The arrival of the WORF has allowed astronauts to permanently remove a protective, non-optical "scratch pane" on the window, which had often blurred images. The WORF also provides a highly stable mounting platform to hold cameras and sensors steady, while offering power, command, data, and cooling connections.

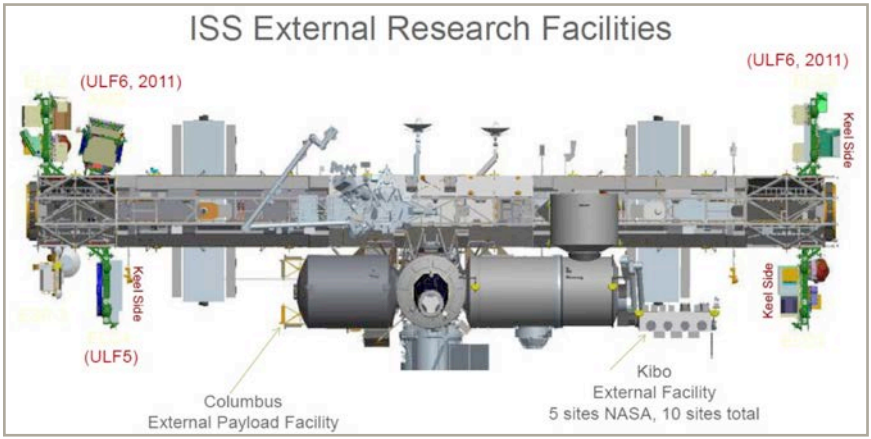
As a facility the WORF can provide power, data, and cooling water for up to three payloads simultaneously by interfacing with existing ISS systems. At present, the WORF can provide an average downlink data rate on the order of 2 Mbps, although this is being improved with communications infrastructure improvements to ISS. Investigators can operate their payloads autonomously at their institution, with up- and downlink data going through the Huntsville Operations Support Center at MSFC in Huntsville, AL. The general design philosophy of WORF favors autonomous payloads, but crew members can operate payloads from the Destiny Laboratory aisle using an externally mounted laptop computer.

Image of the Window Observational Research Facility (WORF) rack after installation in Multi-Purpose Logistics Module (MPLM) Port Bay 2. View of WORF rack in MPLM Port Bay 2.



The subject of the first test image from the WORF was British Columbia's snow-capped mountains and coastline in western Canada. The image, captured with a 50 millimeter lens on January 17, 2011, features an area just north of Vancouver Island, centered at 51.8 degrees north latitude and 127.9 degrees west longitude, and covering an area approximately 200 kilometers (124 miles) by 134 kilometers (83 miles). (source: http://earthobservatory.nasa.gov/Features/EarthKAM/)

External Facilities



Columbus [ESA]

Columbus-External Payload Facility (Columbus-EPF) provides four powered external attachment sites for scientific payloads or facilities, and has to date been used by ESA and NASA. Each of the four attachment sites will hold a mass of up to 290 kg, and provide utility connections for power and data. Included with Columbus at launch, the Solar Facility was one of the first two European investigations supported by the Columbus-EPF. In the future the Atomic Clocks Ensemble in Space (ACES) investigation holding two high-precision atomic clocks and the Atmosphere Space Interaction Monitor (ASIM) will be installed on the lower, Earth-facing external attachment sites.

Columbus EF resources

Location	Viewing	Payload Size	Power	Data
SOZ	Zenith	226kg +CEPA	1.25 kW at 120VDC 2.5 kW max	Ethernet 1553
SOX	Ram			
SDX	Ram			
SDN	Nadir			

Kibo [JAXA]

The Japanese Experiment Module (JEM), known as “Kibo” (pronounced key-bow), which means “hope” in Japanese, is Japan’s first manned space experiment facility, and it is the largest experiment module on the ISS. This is the Japan Aerospace Exploration Agency’s (JAXA’s) first contribution to the ISS program. Kibo was designed and developed with a view to conducting scientific research activities on orbit. In Kibo, a maximum of four astronauts can perform experimental activities. Currently educational, cultural, and commercial uses of Kibo are also planned.

The Kibo consists of two experiment facilities, the Pressurized Module (PM) and the Exposed Facility (EF). The EF is directly exposed to space, and it is a unique facility among ISS laboratories as it enables long-term experiments in open space as well as Earth and astronomical observations. The PM is equipped with an airlock, allowing astronauts to move an experiment device directly from the PM to the EF, and vice-versa, through the airlock by manipulating the Kibo’s robotic arm (JEM-RMS). Kibo’s docking and assembly operations have been completed

as the Pressurized Module was assembled in June 2008, and the Exposed Facility in July 2009. Kibo provides extensive opportunities for utilization of the space environment as well as Earth remote sensing investigations.

JEM External resources

JEM EF Resources	Mass Capacity	550 kg (1150 lb) at standard site 2250 kg (5550 lb) at large site
	Volume	1.5 m3
	Power	3 – 6 kW, 113 – 126 Vdc;
	Thermal	3 – 6 kW cooling
	Low-rate data	1 Mbps (MIL-STD-1553)
	High-rate data	43 Mbps (shared)
	Sites available per ELC	2 Sites
	Sites available to NASA	5 Sites

EXPRESS Logistics Carrier [several external locations on ISS truss]

Expedite the Processing of Experiments to the Space Station (EXPRESS) Logistics Carrier (ELC) is a pallet designed to support external research hardware and store external spares (called Orbital Replacement Units, ORUs) needed over the life of ISS. Currently, 4 ELCs are mounted to ISS trusses providing unique vantage points for space, technology and Earth-observation investigations. Two ELCs are attached to the starboard truss 3 (ITS-S3) and two ELCs to the port truss 3 (ITS-P3). By attaching at the S3/P3 sites, a variety of views such as Zenith (deep space) or Nadir (Earthward) direction with a combination of ram (forward) or wake (aft) pointing allows for many possible viewing opportunities.

ELC External Research Accommodations

ELC Single Adapter Resources	Mass capacity	227 kg (500 lb)
	Volume	1 m3
	Power	750 W, 113 – 126 Vdc; 500 W at 28Vdc per adapter
	Thermal	Active heating, passive cooling
	Low-rate data	1 Mbps (MIL-STD-1553)
	Medium-rate data	6 Mbps (shared)
	Sites available per ELC	2 Sites
	Total ELC sites available	8 Sites

The medium rate data interface will be updated at each ELC location to 100 Mbps two-way wireless LAN.

Small Satellite Deployment

Another option of potential interest for Earth remote sensing is the use of deployable small satellites (such as CubeSats) either singly or in constellations. Following construction on the ground these small satellites can be transported to the ISS for launch into free flight and eventual re-entry to Earth's atmosphere.

	Size, Approximate mm (Inches)	**Mass (Max of Deployed satellite)**	**Location of Deployment**
J-SODD	*1U - 100 x 100 x 113.5 mm (3.9 x 3.9 x 4.7 inches)* *2U - 100 x 100 x 227.0 mm (3.9 x 3.9 x 8.9 inches)* *3U - 100 x 100 x 340.5 mm (3.9 x 3.9 x 13.4 inches)*	*1.33 Kg/1U*	*Deployed from ISS (JEM EF)* *Currently in-orbit* 
CYCLOPS	*1117.6 x 762 x 279.4-533.4 mm (44L x 30W x 11-21H inches)*	*100 kg*	*Deployed from ISS (JEM EF)* *In-orbit post SpX3 launch*
Space X	*1U - 100 x 100 x 100 mm (3.9 x 3.9 x 3.9 inches)* *2U - 100 x 100 x 200 mm (3.9 x 3.9 x 6.8 inches)* *3U - 100 x 100 x 300 mm (3.9 x 3.9 x 10.7 inches)*	*1.33 kg/1U*	*Deployed from Space X prior to ISS docking* *Available post SpX3*

ISS Pointing, Interface, and Environmental Information

This information is presented in Hornyak (2013), in the sections ISS Accommodations – Software and Avionics, ISS Command and Data Handling; and ISS Characteristics.

Funding, Developing and Launching Research to ISS

There are several sources of funding available to scientists to be used for research, payload development, payload processing at NASA facilities, in-orbit operation, and more.Once a payload has been selected for development, engineering and operations staff in the ISS Program Office are available to work with payload teams through the design, test, certification, build, and launch phases prior to beginning mission operations on ISS. More detailed information on this process, and information on current and planned launch vehicles, is available in Hornyak (2013), in the sections Transportation to ISS, and Payload Integration Process [note to editor, not sure how best to call this out and/or link within the mini-book format, so doing it in scientific journal style]. In general, NASA funding for space station use is obtained through NASA Research Announcements (NRAs). National Laboratory funding for other government agencies, private, and non-profit use of the space station is obtained through research opportunities released by CASIS. Space Station International Partner funding can be obtained through their prospective processes. (http://www.nasa.gov/mission_pages/station/research/ops/funding_information.html). Potential proposers to any program should contact the relevant Program Scientist to discuss the appropriateness of their sensor concept to the specific solicitation, and for contacts within the ISS Program Office to discuss expected development costs for their proposal budgets.

National Funding Sources

NASA SMD (ROSES)

NASA's Science Mission Directorate (SMD) provides Research Opportunities in Space and Earth Sciences (ROSES) through the Applied Science Program. The Applied Sciences Program promotes and funds activities to discover and demonstrate innovative uses and practical benefits of NASA Earth science data, scientific knowledge, and technology. The Program's portfolio of projects deliver results in applying NASA Earth science to support improvements in aviation safety, malaria early warning, agricultural productivity, water management, earthquake response, and many other important topics.

NASA SMD EXPLORER/SALMON

SMD also solicits for Missions of Opportunity via a Stand Alone Mission of Opportunity Notice (SALMON) and the Explorers Program. The mission of the Explorers Program is to provide frequent flight opportunities for world-class scientific investigations from space utilizing innovative, streamlined and efficient

management approaches within the heliophysics and astrophysics science areas. The program seeks to enhance public awareness of, and appreciation for, space science and to incorporate educational and public outreach activities as integral parts of space science investigations.

NASA SMD/Earth Venture (EV)

The Earth System Science Pathfinder (ESSP) Program within SMD is a science-driven Program designed to provide an innovative approach to Earth science research by providing periodic, competitively selected opportunities to accommodate new and emergent scientific priorities. ESSP Projects include developmental, high-return Earth Science missions including advanced remote sensing instrument approaches to achieve these priorities and often involve partnerships with other U.S. agencies and/or with international science and space organizations. These Projects are capable of supporting a variety of scientific objectives related to Earth science, including the atmosphere, oceans, land surface, polar ice regions and solid earth. Projects include development and operation of space missions, space-based remote sensing instruments for missions of opportunity, and airborne science missions, and the conduct of science research utilizing data from these missions. ESSP missions encompass the entire Project life-cycle from definition, through design, development, integration and test, launch, operations, science data analysis, distribution and archival.

ESSP is home to NASA's Earth Venture (EV) class of missions: a series of uncoupled, relatively low-to-moderate cost, small- to medium-sized, competitively selected, full-orbital missions (EVM), instruments for orbital missions of opportunity (EVI) and sub-orbital projects (EVS).

(http://science.nasa.gov/about-us/smd-programs/earth-system-science-pathfinder/)

CASIS

In 2011 NASA finalized a cooperative agreement with the Center for the Advancement of Science in Space (CASIS) to manage the portion of the International Space Station that operates as a U.S. national laboratory. CASIS is located in the Space Life Sciences Laboratory at NASA's Kennedy Space Center in Florida. The independent, nonprofit research management organization will help ensure the station's unique capabilities are available to the broadest possible cross-section of U.S. scientific, technological and industrial communities.

CASIS develops and manages a varied research and development portfolio based on U.S. national needs for basic and applied research. It establishes a marketplace to facilitate matching research pathways with qualified funding sources and stimulates interest in using the national lab for research and technology demonstrations and as a platform for science, technology, engineering and mathematics education. The goal is to support, promote and accelerate innovations and new discoveries in science, engineering and technology that will improve life on Earth.

Other Government Agencies

Potential funding for research on the ISS is also available via governmental partnerships with CASIS and includes such government agencies as:

- Naval Research Lab (NRL)
- National Science Foundation (NSF)
- US Department of Agriculture (USDA)

International Funding Sources

One of the most unique and integral aspects of the ISS is the partnerships established between the United States, Russia, Japan, Canada and Europe. All partners share in the greatest international project of all time, providing various research and experimental opportunities for all. These organizations – the Japan Aerospace Exploration Space Agency (JAXA), Canadian Space Agency (CSA), European Space Agency (ESA), and the Russian Federal Space Agency (Roscosmos), provide potential funding opportunities for international scientists from many diverse disciplines.

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http://www.nasa.gov/externalflash/ISSRG

Acronyms

BAD	Broadcast Ancillary Data
C&DH	Command and Data Handling
CEPA	Columbus External Payload Adapter
ECLSS	Environmental Control & Life Support Systems
EEU	Experimental Exchange Unit
ELC	EXPRESS Logistics Carrier
ESA	European Space Agency
EVA	Extravehicular Activity (spacewalk)
EXPRESS	Expedite the Processing of Experiments for Space Station Rack
FRAM	Flight Releasable Attachment Mechanism
ICD	Interface Control Document
ICU	Integrated Communications Unit
ISS	International Space Station
JEM	Japanese Experiment Module
JEM-EF	JEM Exposed Facility
LEO	Low Earth Orbit
LOS	Loss of Signal
MCC	Mission Control Center
MSS	Mobile Servicing System
NASA	National Aeronautics and Space Administration
PIM	Payload Integration Manager
PL MDM	Payload Multiplexer De-Multiplexer
PRCU	Payload Rack Checkout Unit
RIM	Research Integration Manager
RMS	Robotic Manipulator System
SE	Safety Engineer
TDRSS	Tracking and Data Relay Satellite System
TEA	Torque Equilibrium Attitude
TREK	Telescience Resource Kit
TRL	Technology Readiness Levels
WORF	Window Observational Research Facility

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http://www.nasa.gov/iss-science

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