The International Space Station, A Unique Platform for Earth Observation

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Why do humans explore?
Exploration technology and discovery in new environments are linked – but science takes more time
Nations Explore... in order to advance

- Exploration drives technological breakthroughs and scientific discoveries that benefit society.
- Without exploration, the cycle of advancement is broken.
- The ISS Partnership has transformed exploration from an effort for the advancement of individual nations, to an endeavor committed to the advancement of humankind.
For more information on research sponsorship and funding, see:
http://www.nasa.gov/mission_pages/station/research/funding_information.html
What are we doing on ISS today?

**National Lab**
- Biology and Biotechnology
- Physical Sciences
- Earth Science
- Education

**NASA**
- Human Research
- Tech Demos
- Astrophysics
Remote sensing of Earth: Why ISS?

Polar orbit
- Sun-synchronous – designed for long term repeatability of data
- Typically nadir viewing, crosses every point on Earth ~ 12-14 days near local solar noon/local midnight
- Landsat series collecting data since 1972
- Pointing capability, satellite constellations

Inclined Equatorial Orbit: ISS
- Sun-asynchronous – similar illumination 3-4 days every 90 days
- Nadir to highly oblique imagery possible from hand-held cameras, WORF, external sensors
- Provides opportunity to collect unique datasets for scientific study, disaster response
- Data is complementary to polar-orbiting satellite data
- Opportunity for instrument cross-calibration
Earth Science

- Platform with full services (power, data, thermal) in LEO (~400 km)
  - All geographic locations between 51.6 North and South latitude
  - 85% of the Earth’s surface
  - 95% of the world’s populated landmass every 1-3 days
  - External sites for nadir, zenith, ram and wake
  - Variable (and precessing) lighting (changes with subsequent passes)
  - Well-suited for test bed concepts with hardware change out and upgrades
Applications of Remote Sensing from ISS

- Environmental Monitoring
- Climatology/Surface Fluxes
- Hydrology
- Soil Mapping
- Geomorphology/Landscape Characterization
- Climate Science
- Economic Resource Assessment
- Land Cover Mapping/Change
- Geologic Mapping
- Hazard Assessment
ISS Extension to at least 2024

- Obama Administration committed in 2014 to extend space station operations to at least 2024
- 2015, Congress authorized this extension
- ISS International Partners Japan, Canada and Russia have since announced their support for this extension. ESA (the European Space Agency) is currently working on an extension through their Ministerial process.
- Adding four years from 2020-2024 nearly doubled the opportunity for hosting instruments on ISS
- We are not beginning decommissioning and the ISS engineering life is at least 2028
INTERNAL INSTRUMENTS
**Sensor:** Crew Earth Observations (CEO)

**Location:** internal, Station windows

**Sponsor/ Funding:** ISSP

**Prime Mission:** collection of Earth imagery in support of disaster response, and dynamic events with other ISS sensor systems. Also supports education/outreach and focused short-term science objectives.

**ISS Timeframe:** 2000-2024

**Principal Investigator:** William L. Stefanov, JSC

**Pointing capability:** variable, dependant on window and lens

**Geometric resolution:** variable, depends on lens
< 3 m/pixel with 1000 mm lens to > 30 m/pixel with 110 mm and shorter lenses

**Spectral sensitivity:** visible RGB, poorly constrained bandpass (potential for NIR imagery using modified camera)

**Scene Size:** variable, depends on lens, ISS altitude

**Data take to availability time:** ~ 24 hours for full resolution data, may be possible to expedite

**Data availability:** Public; [http://eol.jsc.nasa.gov](http://eol.jsc.nasa.gov)
GeoCam Space System – late 2016/early 2017

GeoSens Hardware (NASA Ames)

- Pointing Calibration Targets mounted in cupola
  - Ideally, semi-permanent mounting to avoid recurring setup time
- During photography, ensure some calibration target is occasionally in view of secondary camera
  - (Example: In view for at least 1 second every 5 minutes)
  - Given proper target placement, this may happen without explicit astronaut attention
- Sensor package can use an audible tone to indicate rare cases when astronaut attention is needed
- Trade-off: More targets vs. higher chance calibration activity is needed

LEFT-FACING SECONDARY CAMERA

POINTERING CALIBRATION TARGET IN ISS INTERIOR

LG Nexus 5
Reasonable rotation and geolocation to base image with only 3 tie points – developing fully automated geolocation
Meteor Composition Determination (METEOR)

**Description:** Meteor’s mission objective is to fly a visible spectroscopy instrument to the ISS for the primary purpose of observing meteors in Earth orbit. Meteor uses image analysis to provide information on the physical and chemical properties of the meteoroid dust, such as size, density, and chemical composition. Meteor plans to operate for 2 years (as allowed by science priorities) in the WORF volume.

**Research Overview:**
- 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.
- Meteor provides a continuous monitor of meteor interaction with the Earth’s atmosphere without limitations of the ozone absorption.
- The resultant data aims to record the first measurement of meteor flux and allows for monitoring of carbon-based compounds. Investigation of meteor elemental composition is important to our understanding of how the planets developed.

**Payload Description:**
- High-resolution video and still images of atmosphere with software triggering for bright “events”
- Camera system collects information in visible wavelengths (up to 700 nm) for spectral analysis of Fe, Ca, Mg, Na emission lines
- Mounted in Window Observational Research Facility (WORF)
EXTERNAL INSTRUMENTS
RapidScat on ISS

Description: Fly a radar scatterometer to continue ocean vector winds (OVW) measurements and to sample at all times of day enabled by ISS orbits (in contrast to twice a day sampling of sun-synchronous polar orbits) to observe diurnal variability of ocean winds and sea surface interaction not observable before.

Objectives:
• Continue more than 10-year Ku-band based vector winds observations
• Investigate the global diurnal cycle and remove the diurnal effect on scatterometer-based ocean vector winds
• Improve cross-calibration of and provide additional measurements to the international OVW constellation

Payload: Refurbished SeaWinds EM scatterometer hardware with modification/augmentation to meet ISS payload accommodation and operation requirements and certified for flight and operations

- H-pol and V-pol pencil beams looking at about 45° from nadir, scanning at about 18 rpm with 0.75 m (D) reflector
- 800-1000 km swath, covering within ±52° latitude in 48 hrs
- Wind resolution comparable to QuikSCAT
- Mass: 200 kg, Power: 250 W; Data Rate: 40 kbps, continuous

Cloud-Aerosol Transport System (CATS)

Key Science Objectives

- Demonstrate multi-wavelength aerosol and cloud retrievals.
- Provide cloud and aerosol data to help bridge the gap between CALIPSO and future missions.
- Enable aerosol transport models with near real-time data downlink from ISS.
- The ability of an aerosol plume to transport long distances is determined by its injection height relative to the local planetary boundary layer (PBL).
- Passive aerosol measurements from space provide valuable constraints on column aerosol loading.
- However, models lack observational constraints on vertical distribution.
- ISS orbit is intriguing for tracking of plumes and study of diurnal effects (something not possible with A-Train orbit).

- **CATS employs 2 high repetition rate lasers**
  - One operates at 532, 1064 nm
  - Second is seeded to provide narrow linewidth for HSRL measurements and frequency-tripled for use at 355 nm
- **CATS has a 60 cm beryllium telescope with narrow field-of-view (FOV)**
  - 4 instantaneous fields of view (IFOV)

### Table: Specifications

<table>
<thead>
<tr>
<th>Laser 1 Type</th>
<th>Nd: YVO₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser 1 Wavelengths</td>
<td>532, 1064 nm</td>
</tr>
<tr>
<td>Laser 1 Rep. Rate</td>
<td>5000 Hz</td>
</tr>
<tr>
<td>Laser 1 Output Energy</td>
<td>~1 mJ/pulse</td>
</tr>
<tr>
<td>Laser 2 Type</td>
<td>Nd: YVO₄, seeded</td>
</tr>
<tr>
<td>Laser 2 Wavelengths</td>
<td>355, 532, 1064 nm</td>
</tr>
<tr>
<td>Laser 2 Rep. Rate</td>
<td>4000 Hz</td>
</tr>
<tr>
<td>Laser 2 Output Energy</td>
<td>~2 mJ/pulse</td>
</tr>
<tr>
<td>Telescope Diameter</td>
<td>60 cm</td>
</tr>
<tr>
<td>View Angle</td>
<td>0.5 degrees</td>
</tr>
<tr>
<td>Telescope FOV</td>
<td>110 microradians</td>
</tr>
</tbody>
</table>
Primary Science Objective:
Monitor the vertical distribution of aerosols, ozone and other trace gases in Earth’s stratosphere and troposphere to enhance understanding of ozone recovery and climate change processes in the upper atmosphere.

Mission Implementation

<table>
<thead>
<tr>
<th>Partners</th>
<th>LaRC</th>
<th>JSC/ISSP</th>
<th>ESA</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk</td>
<td>NPR 7120.5D/NM7120.81 Category 3 / NPR 8705.4 Payload Risk Class C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch</td>
<td>2016</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orbit</td>
<td>ISS Mid-Inclination orbit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Life</td>
<td>3 years (nominal) / ISS manifest through 2024 for extended mission</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Payload</td>
<td>Sensor Assembly (LaRC), Hexapod (ESA), CMP (LaRC), ExPA (JSC/ISS), ICE (LaRC), HEU (ESA), IAM (LaRC), DMP (LaRC) Nadir Viewing Platform (LaRC)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass &amp; Power</td>
<td>540 W (CBE, mix between 120Vdc and 28 Vdc)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>460 kg (CBE)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Orbiting Carbon Observatory (OCO-3) Project Overview

Primary Science Objectives

- Collect the space-based measurements needed to quantify variations in the column averaged atmospheric carbon dioxide (CO$_2$) dry air mole fraction, X$_{CO2}$, with the precision, resolution, and coverage needed to improve our understanding of surface CO$_2$ sources and sinks (fluxes) on regional scales (≥1000 km).
  
  Measurement precision and accuracy requirements same as OCO-2
  
  Operation on ISS allows latitudinal coverage from 51 deg S to 51 deg N

Major Features:

- Category 3 mission per NPR 7120.5E
- Risk classification C per NPR 8705.4
- High-resolution, three-channel grating spectrometer (JPL)
- Partnership between SMD and HEOMD
- Deployed on the International Space Station
- Launch Readiness: TBD

OCO-3 Requirements in Payload Interface Agreement

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>500 kg</td>
</tr>
<tr>
<td>Power</td>
<td>600 W</td>
</tr>
<tr>
<td>Data Rate</td>
<td>3 Mbps</td>
</tr>
<tr>
<td>Volume</td>
<td>1.85 m x 1.0 m x 0.8 m</td>
</tr>
<tr>
<td>Thermal</td>
<td>Fluid Cooling Loop</td>
</tr>
</tbody>
</table>
Lightning Imaging Sensor (LIS) on ISS

Mission Overview

- NASA developed and demonstrated space-based lightning observation as a remote sensing tool under Earth Observing System (EOS) and Tropical Rainfall Measuring Mission (TRMM) (*LIS still operational on TRMM*).
- LIS on the ISS will extend TRMM time series observations, expand latitudinal coverage, and provide real time observations in support of important and pressing science and applications objectives.
- Integrate as hosted payload on DoD Space Test Program (STP-H5)

Measurement

- LIS measures global lightning (*amount, rate, radiant energy*) during both day and night, with storm scale resolution, millisecond timing, and high, uniform detection efficiency.
  - LIS daytime detection is both unique and scientifically important (>70% occurs during day).
  - Only LIS globally detects TOTAL (*both cloud and ground*) lightning with no land-ocean bias.

Science and Application Objectives

- Lightning is quantitatively coupled to both thunderstorm and related geophysical processes.
- Therefore lightning observations provide important gap-filling inputs to pressing Earth system sciences issues in a wide range of disciplines (e.g., *weather, climate, atmospheric chemistry, lightning physics*).
- Real time observations will be provided to operational users.
- LIS data is the “Gold Standard” for global lightning climatology.
ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)

**Description:** Multispectral thermal infrared sensor mounted on JEM-EF to measure the brightness temperature of plants, and use that information to better understand how much water plants need and how they respond to stress (evapotranspiration dynamics).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Science Requirement at 400 km</th>
<th>Expected Instrument Capability at 400 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Sample Distance (m)</td>
<td>≤ 100 x ≤100</td>
<td>≤69 x ≤38</td>
</tr>
<tr>
<td>Crosstrack x Downtrack at nadir</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swath width (ISS nominal altitude range is 385 to 415 km)</td>
<td>≥360</td>
<td>400</td>
</tr>
<tr>
<td>Wavelength range (µm)</td>
<td>8-12.5</td>
<td>8-12.5</td>
</tr>
<tr>
<td>Number of bands</td>
<td>≥3</td>
<td>≥5</td>
</tr>
<tr>
<td>Radiometric accuracy (K@300K)</td>
<td>≤1</td>
<td>≤0.5</td>
</tr>
<tr>
<td>Radiometric precision (K@300K)</td>
<td>≤0.3</td>
<td>≤0.15</td>
</tr>
<tr>
<td>Dynamic Range (K)</td>
<td>270-335</td>
<td>200-500</td>
</tr>
<tr>
<td>Data collection</td>
<td>CONUS, twelve 1,000 x1,000 km key climate zone and twenty-five Fluxnet sites for all opportunities. On average 1 hour of science data per day</td>
<td>≥1.5 hours per day of science data</td>
</tr>
</tbody>
</table>

**Science Questions:**
- How is the terrestrial biosphere responding to changes in water availability?
- How do changes in diurnal vegetation water stress impact the global carbon cycle?
- Can agricultural vulnerability be reduced through advanced monitoring of agricultural water consumptive use and improved drought estimation?

**Science Objectives:**
- Identify critical thresholds of water use and water stress in key climate sensitive biomes (e.g., tropical/dry transition forests, boreal forests);
- Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the diurnal cycle;
- Measure agricultural water consumptive use over CONUS at spatiotemporal scales applicable to improving drought estimation accuracy.
Global Ecosystem Dynamics Investigation Lidar (GEDI)

**Description:** Active sensor system to characterize the effects of changing climate and land use on ecosystem structure and dynamics to enable radically improved quantification and understanding of the Earth's carbon cycle and biodiversity. GEDI will provide the first global, high resolution observations of forest vertical structure.

**Science Questions:**
- What is the aboveground carbon balance of the land surface?
- What role will the land surface play in mitigating atmospheric CO2 in the coming decades?
- How does ecosystem structure affect habitat quality and biodiversity?

**Science Objectives:**
- Quantify the distribution of above-ground carbon at fine spatial resolution
- Quantify changes in carbon resulting from disturbance and subsequent recovery
- Quantify the spatial and temporal distribution of forest structure and its relationship to habitat quality and biodiversity
- Quantify the sequestration potential of forests through time under changing land use and climate.

**Payload Description:**
- Nominal one-year mission, will collect > 16 billion vertical profile waveform observations
- 3 laser system to produce 14 parallel track measurements with 25 m footprints
- Mounted on Japanese Experiment Module Exposed Facility
Total and Spectral Solar Irradiance Sensor (TSIS)

**Description:** Mounted on the ExPRESS Logistics Carrier 3 (ELC-3), TSIS will acquire measurements of total and spectral solar irradiance (TSI and SSI, respectively). TSI is required for establishing Earth’s total energy input while SSI is needed to understand how the atmosphere responds to changes in the sun’s output. Solar irradiance is one of the longest and most fundamental of all climate data records derived from space-based observations.

**Payload Description:**
- Dual-instrument package of Total Irradiance Monitor (TIM) and Spectral Irradiance Monitor (SIM), both heritage instruments from NASA Solar Radiation and Climate Experiment (SORCE)
- TIM measures TSI incident at outer boundaries of atmosphere
- SIM measures SSI from 200 – 2400 nm (96% of TSI)

**Science Objectives:**
- Nominal five-year mission, provides continuation of TSI record from SORCE and USAF STPSat-3
- Quantify variability in incoming solar radiation, as the most precise indicator for changes in Sun’s energy output
- Determine regions/layers of Earth’s atmosphere that are affected by solar variability, in order to quantify solar forcing mechanisms causing changes in climate
- Determination of whether the Sun’s spectral ultraviolet output is in- or out-of-phase with visible wavelength output
- Provision of TSI and SSI data to support community science in climate, atmosphere, solar physics, and radiative transfer modeling
Other USOS Sensor Systems & Capabilities relevant to Earth Science

**Internal**

NHK 4K Camera [2013] – super-sensitive 4K camera system, Kibo (JAXA)

**External**

High Definition Earth Viewing (HDEV) [2014] – four-camera fixed system (fore, aft, and nadir) for collecting HD imagery of Earth and monitoring exposure degradation, Columbus EF

NanoRacks External Platform (NREP) [2016] – pointable, stable platform for Earth-viewing instruments and technology tests, ELC. Four users of the platform were announced in August 2015:
- Gumstix/Solar Cells (Yosemite Space) radiation effects on System on Chip (SoC) processors
- Charge Injection Device (CID, Florida Institute of Technology) high contrast imaging technology test in low Earth orbit radiation
- A-76 Technologies –test of preservation coatings and lubricants in the high stress space environment
- Dependable Multiprocessing (DM7, Honeywell Aerospace/Morehead State University- DM7 processor test for CubeSat technology

Multi-User System for Earth Viewing (MUSES) [2016] – pointable, stable platform for Earth-viewing instruments, ELC; additional capabilities beyond DESIS available

Atmosphere-Space Interactions Monitor (ASIM) [2017] measure high altitude lightning that is discharged from thunderclouds, at altitudes of 90-100 km. These formations of lightning are known as "red sprites", "blue jets", and "elves“ (ESA)

GNSS Reflectometry, Radio Occultation and Scatterometry on ISS (GEROS-ISS) [2019] – sea surface roughness and wind speed from navigation satellite data (ESA)
DLR Earth Sensing Imaging Spectrometer (DESIS)

**Description:** Commercial hyperspectral instrument to be installed on the Teledyne-Brown Engineering Multi-User System for Earth Sensing (MUSES) platform for ISS. The instrument is being built by DLR (Deutsches Zentrum für Luft- und Raumfahrt e.V.; German Aerospace Center).

Details of the final sensor configuration and commercial user data pricing structure are still being finalized.

**Example Markets/Research Areas:**
- Agriculture
- Atmospheric Studies
- Maritime Awareness
- Surface Mineralogy and Resource Assessment
- Forestry
- Ocean Studies
- Urban Ecology, Climatology, and Planning
- Water Quality Studies

**Specifications:**

<table>
<thead>
<tr>
<th><strong>Lens objective</strong></th>
<th>F# = 4 / f = 100mm (telecentric)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FOV / swath</strong></td>
<td>7.6° / 44km/57km</td>
</tr>
<tr>
<td><strong>IFOV / GSD</strong></td>
<td>0.0074° / 79m/104m</td>
</tr>
<tr>
<td><strong>Spectral range</strong></td>
<td>450nm – 950nm (400 - 1000nm)</td>
</tr>
<tr>
<td><strong>Spectral sampling</strong></td>
<td>≈ 2,32nm</td>
</tr>
<tr>
<td><strong>Spectral channels</strong></td>
<td>240 (without binning)</td>
</tr>
<tr>
<td><strong>Polarization sensitivity</strong></td>
<td>≤ 0,3%</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>430 mm × 190 mm × 135 mm</td>
</tr>
<tr>
<td><strong>In orbit calibration</strong></td>
<td>2 internal lamps, LED screen</td>
</tr>
<tr>
<td><strong>Pointing (along-track)</strong></td>
<td>± 15°</td>
</tr>
</tbody>
</table>
I4 Search Tool for ISS Earth Obs Data

http://isseearthserv.jsc.nasa.gov
International Charter “Space and Major Disasters”

The International Charter aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through Authorized Users. Each member agency has committed resources to support the provisions of the Charter and thus is helping to mitigate the effects of disasters on human life and property.

Member Agencies:
Americas
![CSA ASC logo](image)
![NOAA logo](image)
![USGS logo](image)
![INPE logo](image)
![CONAI logo](image)

Europe
![esa logo](image)
![DLR logo](image)
![EUMETSAT logo](image)
![CNES logo](image)
![International Imaging logo](image)

Asia
![JAXA logo](image)
![ISRO logo](image)
![KARI logo](image)
![CNES logo](image)
Since late April/early May 2012, ISS has received 154 IDC activations; data collected for 43 events and delivered to USGS (ISSAC, CEO, HICO, ISERV)
Example of IDC targeting “nugget” delivered to NASA ISS sensor teams to aid in data collection.

Site Plan Information

Site objective: Document any visible evidence of the recent earthquake in Nepal and north-central India with special attention to urban areas like Kathmandu and to infrastructure such as roads and bridges.

Window: Any available

Lens: 50-130mm oblique, 400-1200mm near nadir

Viewing angle: Near Vertical, Oblique

Season: 25APR15 through 05MAY15

Maximum clouds: 50%

Frequency: As visible

Nugget

A 7.9 magnitude earthquake struck Nepal at GMT 115 at 11:56 (local time). The epicenter of the earthquake was in central Nepal at 28 degree north latitude and 84 degrees east longitude. It has been described as the worst disaster to affect Nepal in 90 years. Some remote villages and towns in the region have been entirely buried by landslides. The capital city of Kathmandu, 80 km away from the epicenter also was affected with several locations of historical importance in the city suffering severe damage. Northern India, which borders Nepal, suffered damage in the earthquake with the states of Bihar and Sikkim particularly affected. The earthquake also caused avalanches on Mount Everest which left hundreds of mountain climbers stranded on the mountain when they lost their climbing gear in the avalanches.

Recommended Site Coordinates:

Type: Box

Coordinates:
28.6N 79.6E
27.1N 83.7E
24.3N 83.0E
24.3N 87.8E
28.1N 89.3E
23.2N 86.2E
30.3N 81.1E
USGS Hazards Data Distribution System

http://hddsexplorer.usgs.gov/
ISERV – Calgary Flood, June 2013

• 140 images taken to support mapping of flooded areas (red)
• Images given to Royal Canadian Mounted Police and other agencies for disaster response
Guide to Earth Observation on ISS

Available for download at

Existing facilities and instruments:
ISS Research & Technology
http://www.nasa.gov/iss-science/

@ISS_Research

ISS Research Blog “A Lab Aloft”
http://go.usa.gov/atI

Space Station Research Explorer
App for Apple and Android

• iPad
• Android
Thank you for your attention!

Questions or Comments?