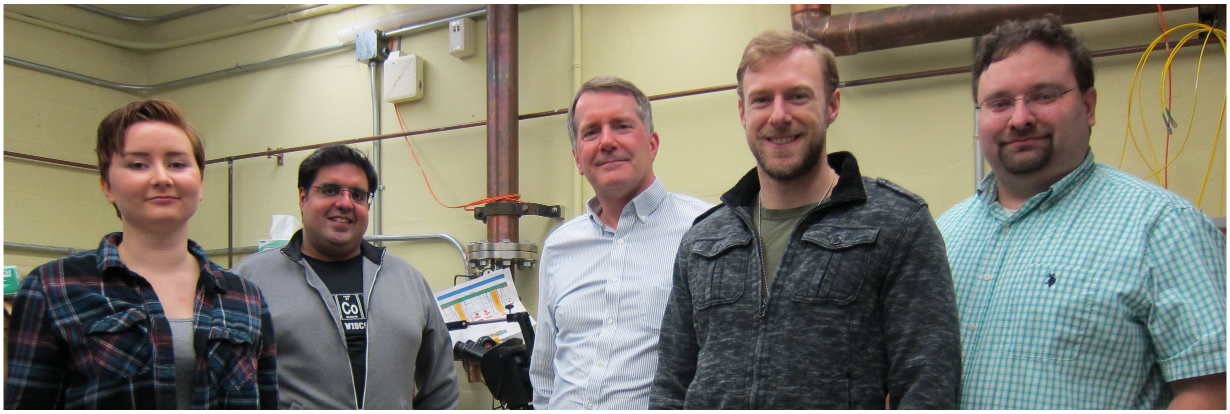
SMD Technology Highlights: 2020 Q1

Astrophysics



The CADR team in the lab at NASA Goddard. From left to right: Margaret Hudson, Amir Jahromi, Jim Tuttle, Evan Sheehan, and Richard Ottens.

Advanced Magnetic Cooling for Sub-Kelvin Instruments

Project: High-Efficiency Continuous Cooling for Cryogenic Instruments

Sponsoring Organization: Astrophysics Division, Cosmic Origins Program

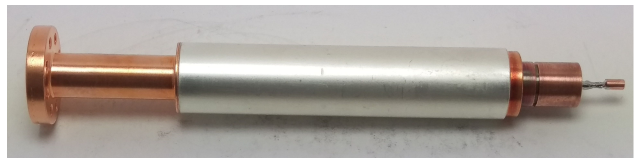
Project Lead: Dr. Jim Tuttle, NASA Goddard Space Flight Center

Snapshot: To cool proposed future science instruments to operating temperatures well below one Kelvin, NASA is developing an advanced spaceflight magnetic refrigeration system.

Key terms: adiabatic demagnetization refrigerator, magnetic cooling, sub-Kelvin, cryogenics

Several proposed future space-science instruments will operate at temperatures well below one Kelvin to enable high-sensitivity astronomical measurements. Magnetic refrigerators have been used to reach these temperatures on past space missions. As space-science detector technology matures and array size (similar to pixels on a camera) grows larger, future instruments will need higher cooling power at even lower temperatures. NASA is developing an advanced multi-stage magnetic cooling system to meet these needs.

Many astrophysics instruments, particularly those operating in the X-ray and infrared spectral ranges, can achieve maximum sensitivity by maintaining their detectors at temperatures close to absolute zero. However, conventional spaceflight refrigerators are unable to cool below about one Kelvin. To reach the required lower temperatures in space, NASA developed magnetic cooling systems many years ago. These devices, known as adiabatic demagnetization refrigerators (ADRs), use specially chosen paramagnetic materials that can be heated or cooled by increasing or decreasing a magnetic field surrounding them. Having no moving parts, they operate reliably and efficiently and produce no mechanical vibrations. A single ADR stage includes a paramagnetic refrigerant “pill,” which is suspended inside a superconducting electromagnet. One side of the pill is thermally linked to the instrument, and its other side is connected to a cold sink via a heat switch, which controls heat flow in a similar way to a light switch controlling electrical current. The cold sink is typically a commercial 4 Kelvin mechanical cryocooler or a 1.2 Kelvin liquid helium tank.

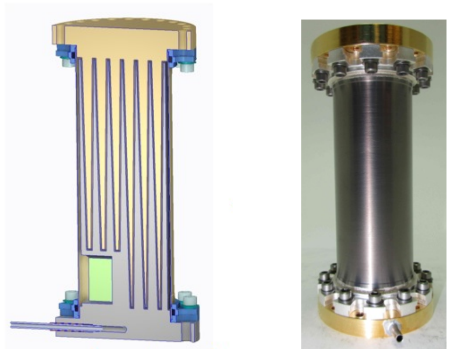


The paramagnetic pill is packaged inside a copper and stainless-steel assembly

The ADR stage’s cooling cycle begins by closing the heat switch and rapidly increasing the magnetic field to its maximum value. The pill temperature rises slightly above that of the heat sink, causing heat to flow through the switch to the sink. Then the switch is opened, and the magnetic field is rapidly decreased. The pill cools to its operating temperature, which is typically about 0.05 Kelvin. Now the instrument can collect science data, as its temperature is held constant by a feedback-loop which slowly ramps down the magnetic field until it reaches zero. At this point the instrument’s sensing temporarily ends, and the ADR is re-cycled. The length of time during which the instrument is held at its operating temperature depends on how much heat it generates. The first spaceflight ADR, built by NASA for the Astro-E2 mission and launched in 2005, cooled to 0.06 Kelvin from a 1.2 Kelvin sink and allowed the detectors to operate for nearly 40 hours between one-hour recycling events.

A more efficient system results from operating multiple ADR stages in series, separated by heat switches. The stages are demagnetized in a cascade scheme, with each one pre-cooling the remaining stages before they are brought to much lower temperatures. The ASTRO-H mission, launched in February 2016, included a two-stage NASA-built ADR that cooled from a 2 Kelvin sink to 0.05 Kelvin and weighed much less than the ASTRO-E ADR. The ASTRO-H ADR held its operating temperature for 48 hours during each cycle.

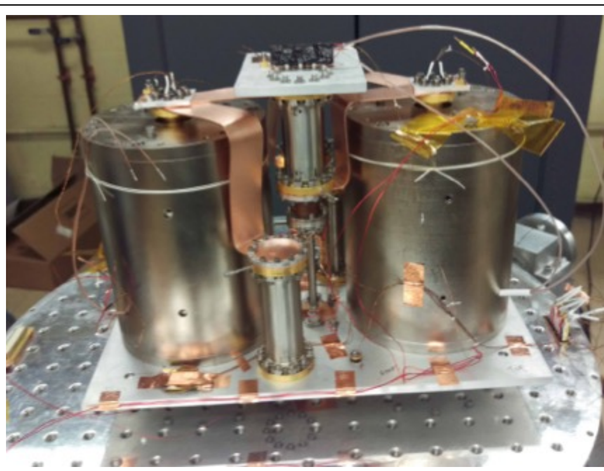
The most efficient multi-stage ADR scheme turns out to be one in which a single stage is held continuously at the operating temperature, and the other stages pass heat to each other in “bucket brigade” fashion, finally passing it to the sink. The Cryogenics branch at NASA Goddard Space Flight Center perfected a laboratory version of this Continuous ADR (CADR) more than ten years ago, and they have since duplicated it for both lab use and for a balloon mission. This four-stage system cools to 0.05 Kelvin from a 3 Kelvin sink, absorbs 15 times more heat than the ASTRO-H two-stage ADR, and weighs significantly less. In addition, the 0.05 Kelvin continuous stage never needs to be recycled, so scientific measurements remain uninterrupted.



This heat switch includes two copper ends with interleaving fins that do not touch, held in place by a thin stainless-steel shell. The switch closes when helium gas flows between the fins and opens when the gas is adsorbed by charcoal, seen in green at bottom left. The switch's open/closed state depends only on its cold-end temperature.

Since 2017, the Goddard team has been working to upgrade the laboratory CADR design so that it can survive a launch into space. Extensive structural analysis was performed to determine whether any components needed additional strength or stiffness. The most challenging aspect of the re-design effort has been the assemblies which hold the pills inside the magnets. Each suspension system, made with multiple tensioned Kevlar strings, must be very strong and stiff while keeping the pills thermally isolated from their surroundings. To survive a space launch, thicker Kevlar strings were needed, so their length had to be increased to avoid excessive heat flow into the pills. This led to redesign or relocation of nearby components, which would otherwise have interfered with the strings.

In addition, the CADR has two new stages which allow it to operate with a 10 Kelvin sink. This new design may enable future missions to couple an ADR to a new type of cryocooler that produces essentially zero mechanical vibrations. Concept missions such as the Large Ultraviolet Optical Infrared Surveyor (LUVOIR), with extremely tight stability requirements, may be candidates for this option. The Goddard team recently completed the two-stage part of the CADR that cools from 10 to 4 Kelvin and began testing it.



A two-stage 10 to 4 Kelvin continuous ADR is installed in a cryogenic test facility.

To fully qualify the design upgrades, an entire flight-worthy prototype CADR system must be built. A significant challenge faced by the Goddard team has been to accomplish this in parallel with a spaceflight mission, which is also producing a multi-stage ADR. Competition for specialized in-house Goddard resources has forced the CADR team to find and cultivate relationships with commercial shops. Although it delayed some work in the short term, expanding the source options for specialized machining and processing will be a benefit to future CADR campaigns.

The new advanced CADR will be enabling technology for several prospective future mission concepts. Two different instruments on [Origins Space Telescope](), as well as [Lynx](), the Probe of Inflation and Cosmic Origins, and the Galaxy Evolution Probe have all baselined the CADR to provide sub-Kelvin cooling. In addition to demonstrating the CADR's cooling capability and robustness, the Goddard effort is training experts and a new generation of engineers to build and test the flight systems for these projects in the future.

The iSAT study team members at a face to face meeting at NASA Langley Research Center.

In-Space Telescope Assembly: When is it worth it?

The conventional approach of carefully folding a large space observatory into a single rocket and deploying it in space involves many challenges and risks. In-Space Assembly (ISA) is an approach where a space system is designed and built as a set of discrete modules that are launched into space on one or more rockets, transported to a central location, and robotically assembled into a fully functional system. A NASA study found that ISA holds the potential to address many of the challenges facing the conventional approach to deploying a large space telescope.

Project: In Space Assembled Telescope (iSAT) Study

Sponsoring Organization: Astrophysics Division, Cosmic Origins Program

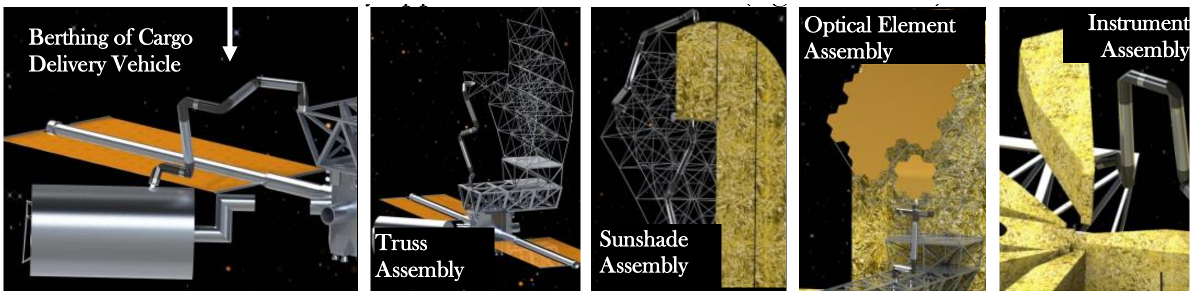
Study Leads: Dr. Rudranarayan Mukherjee, NASA Jet Propulsion Laboratory; Dr. Nick Siegler, NASA Exoplanets Exploration Program; Dr. Harley Thronson, retired

Snapshot: NASA conducted a detailed study to understand when it is worth assembling telescopes in space rather than folding them into a single rocket and deploying them in space.

Key terms: robotic assembly, space observatory, in-space

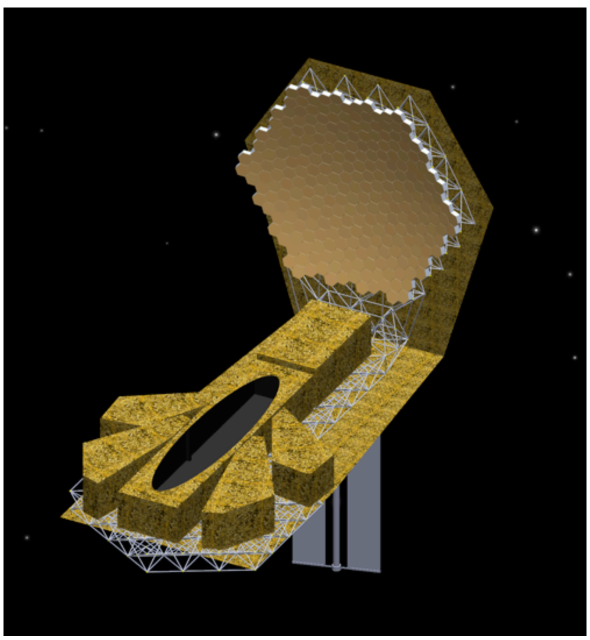
With an intent to inform the Astrophysics Decadal Survey (Astro2020), NASA's Astrophysics Division Director and the Science Mission Directorate Chief Technologist commissioned the in-Space Assembled Telescope (iSAT) study in April 2018 to answer the question, "When is it worth assembling space telescopes in space rather than building them on the Earth and deploying them autonomously from a single launch vehicle?"

The study was supported by more than 70 subject matter experts (including two former astronauts) from across NASA centers, universities, and major industry partners. The experts came from different but relevant technical domains such as launch systems, in-space rendezvous and proximity operations, space robotics, space structures, orbital dynamics, optics, astrophysics and instruments, and systems engineering. Many of them possessed important mission experiences from the James Webb Space Telescope (JWST), Hubble Space Telescope (HST), International Space Station (ISS), Robotic Servicing of Geosynchronous Satellites (RSGS) project, Restore-L, Mars missions, and others. The team studied the technical feasibility and merit of assembling space telescopes with four different primary mirror diameters sizes ranging between 5 and 20 meters. For reference, JWST has a 6.5-meter primary mirror. After 14 months of detailed study involving various trade-space studies, concepts of operations, notional implementation plans, and qualitative and quantitative relative risk and cost analyses, the study team determined several key findings.



Artistic rendition of representative robotic assembly steps for the Study's iSAT reference concept

The study team found that when key capabilities demonstrated in space over the last decade are considered, ISA has emerged as a viable approach for observatory assembly. Many of the key capabilities are architecturally similar to those used in missions involving robotic instrument installation on the ISS (such as the Orbiting Carbon Observatory-3 and the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station) and in the upcoming NASA and Defense Advanced Research Projects Agency (DARPA) satellite servicing missions.



The iSAT Study Reference Telescope Concept

The study team found many technical and programmatic examples of how ISA changes the risk posture of observatory development and makes it potentially more manageable. For example, conventionally developed observatories are architected to accommodate the constraints of a single, specific rocket's launch capacity. They become more expensive and riskier as designs approach the rocket's payload mass and volume limits. The study team found that ISA removes the constraint of fitting the entire observatory in a single, specific rocket by using a modular design where the modules can be launched on one or more rockets and subsequently assembled in space. The ISA approach may mitigate many of the risks and cost challenges as the observatory does not have to be lightweight, folded in a complicated manner to fit in a single fairing, and then deployed in space using many (>100) deployment mechanisms. Using the conventional approach, it may be extremely challenging, if not impossible, to recover from failure or anomaly during deployments even with a separate servicing mission. ISA, on the other hand, may involve orders of magnitude fewer of such deployment mechanisms, if any, and would likely use robotically reversible and adjustable joining interfaces with an incremental assemble-and-verify approach. ISA may also provide the ability to recover from faults or anomalies with in situ servicing and the ability to replace a failed module.

Furthermore, the conventional requirement to fit inside a single rocket also introduces a single critical path in the conventional development schedule where all the elements enter the expensive design-build-test phases of the project at the same time. Funding fluctuations in these phases can result in adverse schedule and cost impacts. An ISA mission may be planned using a phased approach with multiple development paths, i.e., decoupled design-build-test phases (e.g., multiple swim lanes) with separate launches that do not have to be executed concurrently. The ISA approach offers NASA the opportunity to flatten the mission funding profile, reduce the strain on annual budgets, and reduce the sensitivity to budget variations.

Use of multiple rockets, in-space transportation, and subsequent assembly also makes ISA inherently scalable. It can achieve observatory sizes that cannot be achieved via the conventional, single-launch approach. With the conventional approach, observatories with apertures greater than 15m in diameter are unlikely to be deployed from a single rocket even when folded into a NASA's Space Launch System. However, the ISA approach is scalable and can enable observatories with aperture diameters larger than 15m, even using existing commercial rockets.

Perhaps even more profoundly, the study team found that ISA may provide an in situ approach to servicing the observatory to extend its life or upgrade the instruments for improved science returns (similar servicing was performed on HST by astronauts). For example, the robotic arms used to assemble the observatory might reside with the telescope and then be reused to service the observatory later. This approach may remove the dependence on future expensive and risky servicing missions involving astronauts or a custom-built robotic servicing spacecraft.

The study team also found that ISA may also offer opportunities for reducing the costs of conventional, single-launch observatories (see final report for details), particularly when the cost of servicing the observatory is considered in the overall mission cost. However, the extent of risk and cost benefits will ultimately depend on the design of the observatory and its specific technology needs. As is the case for most first-of-its-kind space missions, engineering development needs and technology gaps for specific observatory designs will have to be addressed.

In conclusion, the study team determined that ISA may be the preferred implementation approach compared to the conventional, single-launch approach for all observatory sizes considered in this study (i.e., observatories with aperture diameters sizes ranging between 5 and 20-meters), particularly when servicing of the observatory is considered as a part of the mission.

Earth

The air-LUSI deployment team in front of the ER-2 with the air-LUSI instrument distributed on two carts in front. Credit: NASA

High-flying Moon Sensor Will Help Improve Earth Observations

Project: airborne Lunar Spectral Irradiance Instrument (air-LUSI)

Sponsoring Organization: Earth Science Division, Airborne Instrument Technology Transition (AITT) Program

Project Lead: Kevin Turpie, University of Maryland, Baltimore County

Snapshot: A new instrument flew aboard a high-altitude NASA plane to measure the Moon's brightness and help Earth observing sensors make more accurate measurements.

Key terms: ER2, Moon, Earth, air-LUSI

A new instrument flew aboard NASA's ER-2 airplane to measure the Moon's brightness. Data from this instrument will eventually help other space-based sensors improve the Earth observations they collect.

The airborne Lunar Spectral Irradiance Instrument (air-LUSI) flew approximately 70,000 feet (about 21.3 km) above ground during multiple flights beginning Nov. 13 and wrapping up on Nov. 17, 2019 on the ER-2 from NASA's Armstrong Flight Research Center in Palmdale, California.

Air-LUSI measured "how much sunlight is reflected by the Moon at various phases in order to accurately characterize it and expand how the Moon is used to calibrate Earth observing sensors," said Kevin Turpie, a professor at the University of Maryland, Baltimore County, leading the air-LUSI effort. Turpie and his team are funded by NASA's Earth Science Division and the National Institute of Standards and Technology (NIST).

Air-LUSI's novel instruments are able to obtain highly accurate lunar spectral irradiance measurements that will have the lowest ever uncertainty (less than 1%), Turpie said, which establishes the Moon as an absolute calibration reference and helps remote sensing scientists determine if Earth observing sensors—like the Visible Infrared Imaging Radiometric Suite (VIIRS) aboard the NASA/NOAA/DOD Suomi National Polar-orbiting Partnership satellite and the NOAA-20 meteorological satellite—are recording actual changes on Earth or changes in their instruments.

Although Earth observing missions can look at the Moon at the same time and phase every month as a way to notice trends in their instruments' sensitivity, they haven't yet been able to use the Moon as an absolute calibration reference, Kurt Thome, a project scientist for Earth observing missions at NASA's Goddard Space Flight Center in Greenbelt, Maryland, said.

The air-LUSI crew and the ground crew from NASA's Armstrong Flight Research Center in Palmdale, CA move air-LUSI's components from the wingpod to the stand for hangar calibration. Credit: NASA/Ken Ulbrich

What does it mean to be an absolute calibration reference? If you compare two people standing next to each other, it's easy to see which person is taller. However, if these two people are at opposite ends of the world, the only way to compare their heights would be with an absolute reference, like a ruler. Air-LUSI is aiming to make the Moon an absolute calibration reference, which means an instrument would only need to look at the Moon once to determine the instrument's absolute sensitivity, and could compare looks over time to see if the instrument is changing, Thome said.

To gather information about the Moon, air-LUSI includes three subsystems, which require expertise from multiple organizations, said Turpie. His team includes people from NIST, the U.S. Geological Survey, the University of Guelph in Ontario, Canada and NASA.

The first component is called IRIS, short for Irradiance Instrument Subsystem, and was designed by NIST. It includes an instrument able to take precise measurements of the Moon while sitting in a temperature and pressure-controlled enclosure.

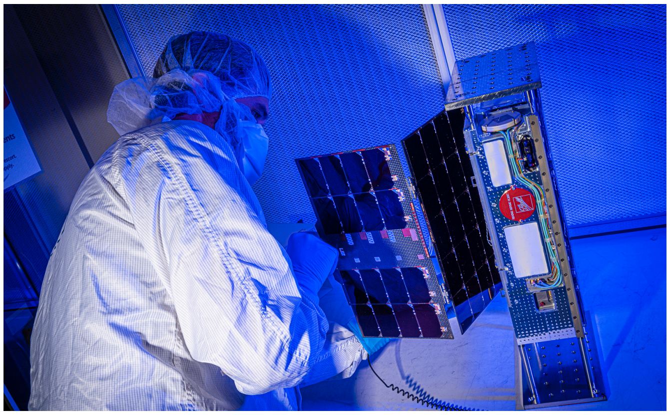
The second component is a robotic telescope mount called ARTEMIS (Autonomous, Robotic Telescope Mount Instrument Subsystem) designed and built by the University of Guelph. ARTEMIS has a camera that scans the sky until it finds the Moon and directs the telescope to point at it and keep it locked in place, regardless of aircraft motion.

The final component is the High-altitude ER-2 Adaptation, or HERA. HERA includes all the connective tissue, like cables and mounting equipment, which holds the instrument together and to the plane, as well as the thermal stabilizing components.

In the near future, an operational weather satellite would benefit from being able to look to the Moon as an absolute calibration reference, Thome said. Missions such as the currently-flying Suomi National Polar-orbiting Partnership (Suomi NPP) and Joint Polar Satellite System-20 (JPSS) satellites, as well as those to come in the future from both NOAA and their international partners could use this technology. Each satellite could calibrate its instruments by the Moon to compare how its sensors are holding up to the other satellites' sensors, Thome said.

NASA's upcoming Ocean Color Imager, aboard the Phytoplankton Aerosols Clouds and ocean Ecology (PACE) satellite, also intends to use the Moon for calibration, Turpie said.

"Air-LUSI's Moon measurements make it easier for people to justify using the Moon to calibrate their instruments," Thome said.



A technician conducts pre-ship inspection on the CIRiS instrument developed and built by Ball Aerospace. Credit: Ball Aerospace

Taking Earth's Temperature from a Tiny Satellite

Project: Compact Infrared Radiometer in Space (CIRiS) instrument on a CubeSat

Sponsoring Organization: Earth Science Division, In-Space Validation of Earth Science Technologies (InVEST) Program

Project Lead: David Osterman, Ball Aerospace

Snapshot: To demonstrate for the first time from a small satellite the ability to collect, process and calibrate infrared images of Earth.

Key terms: CubeSat, infrared, Earth, climate, water, radiation, small satellite, surface temperature

A new miniature sensor, in conjunction with robust data processing techniques, is enabling a satellite the size of a backpack is to reveal Earth's temperature from space. The Compact Infrared Radiometer in Space instrument on a CubeSat, also known as CIRiS, began its orbit around Earth on Jan. 31, 2020, following its launch from Cape Canaveral Air Force Station in Florida to the International Space Station on Dec. 5, 2019.

CIRiS aims to collect, process and calibrate infrared images of Earth. "If we can do this, we have greatly increased the value of the data for Earth science applications, as well as land and water management," David Osterman, the CIRiS Principal Investigator at Ball Aerospace, said.

Farmers could use CIRiS's data as they determine if a grove of orange trees needs more water or if a vineyard is too wet. In fact, farmers, water managers and other decision makers are beginning to use remotely sensed estimates of consumptive water use from larger sensors like the Thermal Infrared Sensor (TIRS) aboard Landsat 8, which is jointly run by the U.S. Geological Survey and NASA.

CIRiS aims to demonstrate new capabilities to complement future NASA Earth-observing missions like Landsat, increasing the frequency of image collection at a potentially reduced size and cost. "We're looking to achieve high performance in everything while still fitting into a small space," Osterman said.

Even before CIRiS left Earth, NASA funded its sibling, L-CIRiS, which has an "L" for lunar, to head to the Moon and use similar instruments to identify lunar minerals. L-CIRiS will also be built by Ball Aerospace and [was selected](#) as part of [NASA's Artemis lunar program](#), which will help NASA send astronauts to the Moon by 2024 as a way to prepare to send the first humans to Mars.

CIRiS takes off aboard the SpaceX Falcon 9 rocket on Cape Canaveral Air Force Station in Florida on Dec. 5, 2019. Credit: NASA

The Earth observing CIRiS CubeSat measures Earth's surface temperature by miniaturizing a number of components and eliminating others that conventional instruments use to collect longwave (infrared spectrum) images. These images indicate hot and cold regions as colors on a "heat map" display.

Once CIRiS collects these images, it calibrates them while in orbit, which means it assigns validated numerical values to each pixel. "Calibration allows you to take data and move them a step further to where they have scientific significance and can contribute to actual science," Osterman said. Not only can you see if a stretch of land is warmer than its surroundings, you can see by how much.

"Calibration allows you to take data and move them a step further to where they have scientific significance and can contribute to actual science."

-David Osterman

CIRiS collects infrared energy and uses a "focal plane" to convert that energy to an electrical signal, similar to how a digital camera turns visible light energy into an electrical signal. Many focal planes for infrared detection require operation at cryogenic temperatures, and therefore must incorporate a cryocooler to establish those temperatures, Osterman said. The team decided to use a different type of focal plane that operates without cryocooling to decrease the sensor's size.

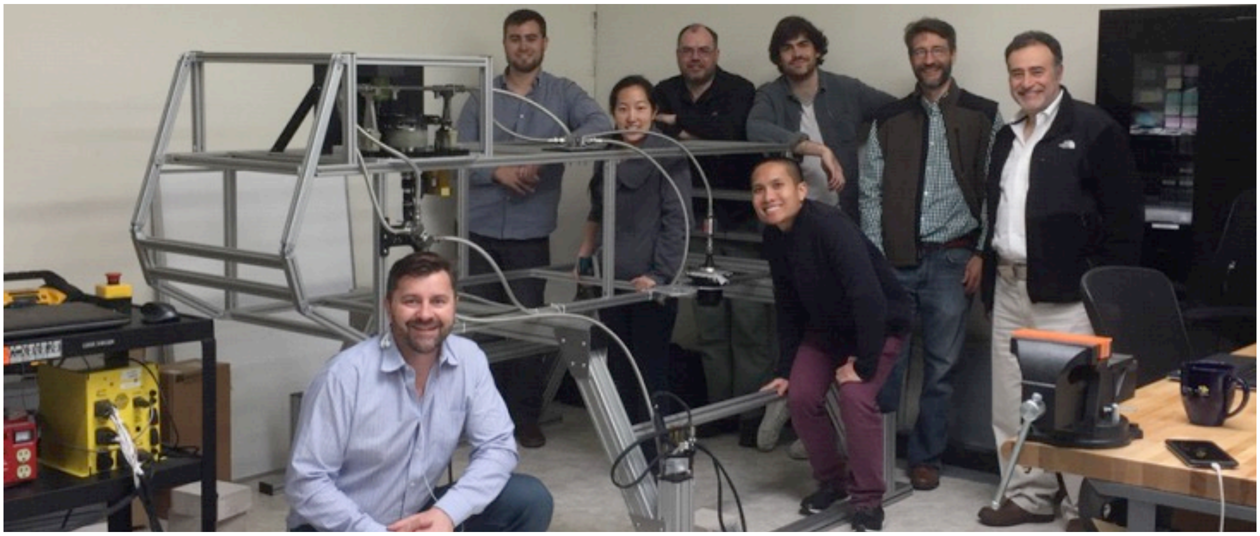
Although CIRiS's focal plane doesn't have the same level of sensitivity as a larger focal plane with a cryocooler, it hopes to make up for any deficiencies with robust abilities to process the data. "We're trying to substitute software performance for hardware performance," Osterman said. The software aspect, or data processing, is initiated on the spacecraft and then continues after the data are downlinked to the ground.

Data collected by CIRiS can be compared with images from other NASA thermal sensors currently in space, such as the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS). Collectively, NASA research instruments like CIRiS and ECOSTRESS help to identify optimal sensor characteristics that can be transitioned into long-term monitoring programs, Martha Anderson, a scientist with the USDA's Agricultural Research Service in Beltsville, Maryland, said.

If CIRiS is successful in proving it can operate in space, Osterman hopes to see a small constellation of CIRiS-like instruments orbiting Earth. Multiple CubeSats in orbit would allow us to measure changes in evapotranspiration and other phenomena potentially as often as every day.

"It's been really exciting to see how small instruments and spacecraft can contribute to our understanding of Earth and eventually the Moon," Osterman said.

Planetary Science



The DrACO team in the lab at Honeybee Robotics. From left to right: Kris Zacny (PI), Joey Sparta, Bernice Yen, Ralph Lorenz (JHU-APL), Phil Ng, Tighe Costa, Fredrik Rehnmark, Dara Sabahi.

Project: Integrated Sampling System (ISS) for Ocean Worlds

Sponsoring Organization: Planetary Science Division, COLDTech Program

Project Lead: Dr. Kris Zacny, Honeybee Robotics

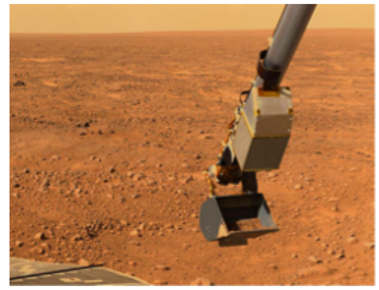
Snapshot: Honeybee Robotics has developed a pneumatic based sample acquisition and transfer system that is self-metering, gravity agnostic, works with sticky materials, and is flexible in terms of delivery location. The system is designed to operate on planetary bodies both with and without an atmosphere.

Key terms: sample acquisition, sample transfer, sample delivery, metering, drilling, sampling.

Playing Lacrosse on Titan

The next phase of groundbreaking planetary science requires access to the sub-surface and a means to capture planetary material for analysis. NASA has flown several missions with the goal of acquiring surface material and delivering it to onboard analytical instruments. These surface-sampling architectures relied on gravity to move a sample from a scoop or a drill into an instrument inlet port. This method, however, poses a challenge when dealing with sticky materials. An SMD-funded Honeybee Robotics team has developed an Integrated Sampling System (ISS) that is gravity-agnostic and can work equally well with both non-cohesive and cohesive materials. This new approach employs an "old school" technology—vacuum cleaners—to acquire samples in conjunction with a "lacrosse stick" to transfer the samples to onboard instruments.

Robotic arms with drills and scoops have been the traditional approach to sample acquisition and delivery on planetary surfaces. An example of such a system includes the successful Mars Phoenix mission that landed in the Northern Polar region of Mars. The Phoenix lander had a five-degree-of-freedom robotic arm with a scoop, referred to as the Icy Soil Acquisition Device (ISAD). The ISAD included a small drill, named "rasp," for cutting into icy soil and ice to create chips that were then scooped and delivered to two instruments within the lander. The nominal operational sequence was relatively straightforward: drill several holes with the rasp, scoop up the icy chips, position the scoop over the instrument inlet port, and finally rotate and dump the material into the inlet port. During the very first sampling attempt, the samples that were successfully collected in the scoop would not fall out into the inlet port. Given the low temperature (-100°C) and low-pressure environment, the expectation was that any ice would remain stable. However, while waiting for a signal from Earth, faint rays from the Sun warmed the scoop and the icy soil inside. The resulting increase in material temperature, coupled with the unexpected antifreeze salts in the soil, was sufficient to thaw the ice. When the Sun angle dropped, the material refroze and adhered to the scoop, a phenomenon that is very familiar on Earth. Fortunately for the Phoenix mission, the ISAD had a “percussive mode.” In this percussive mode, rasp-created rattling helped dislodge the adhered material from the scoop. Moving forward, the Phoenix team addressed this issue operationally by sampling early in the morning and as quickly and efficiently as possible to limit solar heating of the scoop.

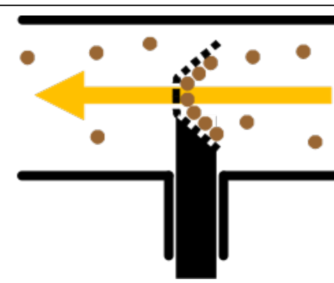


Martian soil inside the Mars Phoenix scoop had difficulty falling out.

When developing a sampling system for Titan and icy moons under the COLDTech program, Honeybee Robotics leveraged the lessons learned from Phoenix and prior missions. They used this experience to define a number of key requirements: 1) Enable the system to handle the inevitable issues of sticky samples, 2) Enable small volume analysis from a large input sample volume and deliver the sample to a chemical analysis instrument in small (~10 mm) diameter cups, and 3) Deliver a sample from the surface to an instrument that sits in the middle of a spacecraft.

Under the NASA COLDTech program Honeybee developed a fundamental understanding of pneumatic sampling systems. Initially, the Honeybee team employed the century-old ‘cyclone separator’ technique. While the cyclone is widely used in industrial settings, this gravity-based system performed poorly with sticky materials. On a moon with lower gravity, sticky materials would be even more of a challenge than here on Earth. Honeybee realized that gravity needed to be removed from the equation and that a non-traditional solution—the combination of a household vacuum cleaner with a small lacrosse stick—was required.

A lacrosse stick is very good at capturing fast-moving objects. And a pneumatic vacuum is able to move sample particles quickly, rather than letting the particles slow down, as a cyclone system would. The Honeybee team used these two concepts together in an innovative design: a vacuum system pulls sample particles through a tube and quickly past a small “lacrosse stick," where some of the flying particles get caught in the net. The captured sample particles can be moved to where they are wanted, and the sample size can be increased or decreased by simply changing the size of the net.

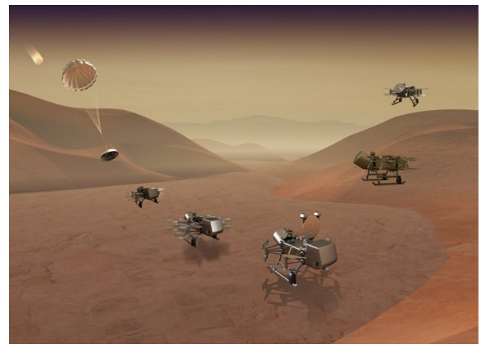


“Lacrosse stick” is used to capture a sample in the ‘vacuum

> "This technology has potential to revolutionize planetary sampling systems."
> -Dr. Kris Zacny

While this architecture is not traditional, it addressed all of the key requirements. Pneumatic systems are significantly more powerful than gravity as dense particles, like pennies, can be moved up a vacuum cleaner hose even in Earth gravity. Pneumatic systems can also work well with dry and sticky materials as observed by powerful shop vacs being used to clean water and mud. Additionally, the flexible vacuum hose can be routed around any obstacle, enabling a connection between the sampling nozzle on the surface to the instrument on the other side of the lander. The lacrosse net is an effective, unbiased means of metering out the sample – it captures all that is required, no more, no less, and allows the particles flying past it back into the environment.

The "vacuum and lacrosse stick" concept now form the backbone of the sampling system for Dragonfly, selected in 2019 as NASA's next New Frontiers mission. The sampling system, DrACO (Drill for Acquisition of Complex Organics), consists of two redundant drills, a carousel with dozens of cups (modified lacrosse nets), and a vacuum system with two redundant blowers. The drills and blowers are in a cross-strapped configuration as any of the two drills can be used with any of the two blowers. The sampling operation starts with a drill cutting into Titan's surface to grind up material. The vacuum system then sucks up material into a transfer tube, while the cup with a lacrosse net captures some of this material for analysis. The carousel subsequently moves the cup into one of the two onboard instruments (a gas chromatography mass spectrometer or a laser desorption mass spectrometer) for analysis.

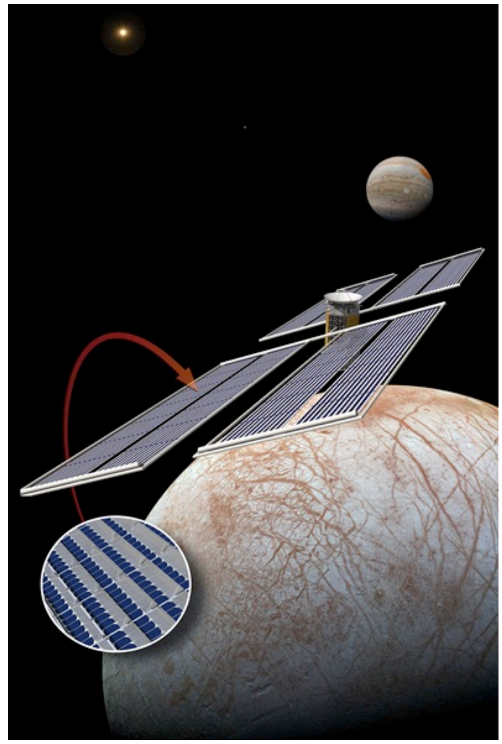


This technology has been infused in NASA Dragonfly mission to Titan.

The technology has also been demonstrated for applicability to airless bodies such as Earth's Moon. In these cases, compressed gas is brought from Earth to mobilize surface material and create this dusty flow. PlanetVac and Pneumatic Sampler are utilizing this approach and will fly to the Moon in 2023 using NASA Commercial Lunar Payload Service (CLPS) and to the Martian moon, Phobos, in 2024, respectively.

Lightweight Mirrors Enhance Power Generation Near Gas Giants

Spacecraft frequently employ solar cells and arrays to collect energy from the Sun to power onboard systems. But just like any other spacecraft system, these cells and arrays must be capable of operating in the harsh environments that their host satellite encounters. The Science Mission Directorate's (SMD) Planetary Science Division is funding an effort conducted by the Space Technology Mission Directorate's (STMD) Game Changing Development Program (GCDP) to develop solar cell and array technologies with improved performance in low intensity, low temperature (LILT) environments like those around Jupiter and Saturn. Near Jupiter, such systems will also face the challenge of a high radiation environment. SMD is designing spacecraft powered by photovoltaics to better understand Jupiter, Saturn, and their moons. GDCP's Extreme Environments Solar Power (EESP) Project is working to ensure longer life and more available power to these missions.



Conceptual image of the Transformational Array near Jupiter's moon Europa. The entire solar array consists of rows of solar cells and concentrators.

Project: Extreme Environments Solar Power (EESP) Project demonstration of Transformational Array elements on DART

Sponsoring Organization: SMD Planetary Science Division in conjunction with STMD GCDP

Project Lead: Frederick Elliott, NASA Glenn Research Center

Snapshot: The EESP Project is developing advanced solar cell and concentrator technology that will be flight-tested on the upcoming DART mission. The Transformational Array containing this new technology is designed to yield improved performance in the extreme environments encountered by missions exploring destinations like Jupiter and Saturn.

Key terms: photovoltaics, LILT, concentrators

The Johns Hopkins University Applied Physics Laboratory (APL) partnered with Deployable Space Systems (DSS), newForge Technologies, and SolAero Technologies to develop a Transformational Array (TA), which includes advanced solar cells and pop-up concentrator elements that are radiation tolerant and help mitigate the LILT effects. LILT environments have been shown to cause performance degradation of the power output of the solar array, as verified by ground-based testing. The effect is variable from cell to cell and affects the reliability of accurately predicting solar array performance throughout the life of a mission.

The TA consists of alternating rows of solar cells and reflective pop-up concentrators. When stowed for launch, the concentrators lie flat, overlapping each other, and the solar array blanket is rolled up around a mandrel. As the array deploys, the curved concentrator elements pop up with the help of kick-up springs under each element, reflecting the light that hits them onto the solar cells, and increasing the light intensity on the cells. The increase in intensity also results in an increase in operating temperature, which helps to offset some of the LILT impacts.

APL is also partnering with DSS and SolAero to develop the Double Asteroid Redirection Test (DART)—a mission to demonstrate a kinetic impactor technique. DART's goal is to use this technique to change the trajectory of Didymos (65803), a binary near-Earth asteroid.

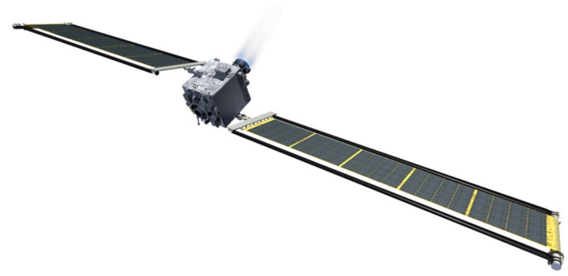
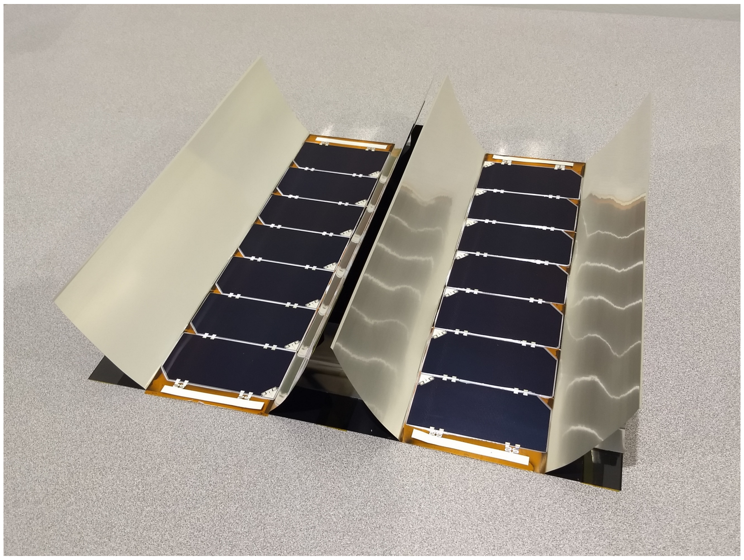


Illustration of the DART spacecraft with the Roll Out Solar Arrays (ROSA) extended. Each of the two ROSA arrays measures 8.6 meters by 2.3 meters.

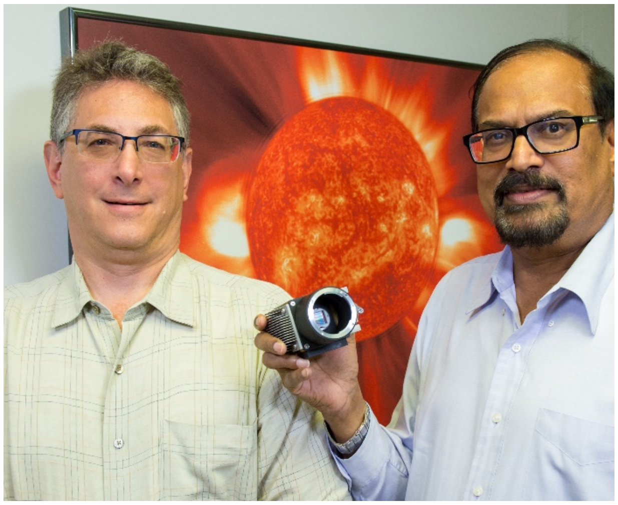
The TA and the DART solar array both use the Roll Out Solar Array (ROSA). This power system structure commonality presents an opportunity to perform a flight test of the TA solar cells and concentrator elements in a near-Earth application. Demonstrating the TA near Jupiter would be ideal, but this near-Earth test on DART will provide useful data to validate the technology and prove the deployment of the pop-up concentrators.



Flight hardware concentrator standard power module prepared for integration into DART. Credit: Deployable Space Systems

A TA test article will replace one of the solar cell modules on each wing of the DART solar array system. The demonstration will allow determination of the operational performance on deployment and during the duration of the DART mission. Since any solar array traveling to Jupiter or Saturn (or their moons) would need to start operating near Earth, the DART demonstration is an excellent opportunity to show how the technology would work.

The EESP Project, managed by NASA Glenn Research Center, was responsible for the overall TA technology development. The goal of this effort was to support future SMD missions to locations between 5 and 10 astronomical units from Earth, including Jupiter and Saturn and their moons, as well as the Trojan and Greek asteroids. These technology developments have increased solar cell conversion efficiency and improved power electronics, enabling solar power to become more useful for missions at ever increasing distances from the Sun.



Dr. Jeff Newmark (left) and Dr. Nat Gopalswamy (right) with a prototype of the polarization camera flown on BITSE. This new technology eliminates the need for an extra mechanism.

Balloon-borne Investigation Provides First Simultaneous Measurements of Crucial Coronal Parameters

An observational technique first proposed more than four decades ago to measure the physical parameters of the corona that determine the formation of the solar wind—the source of disturbances in Earth's upper atmosphere—was recently demonstrated. For the first time, a coronagraph provided crucial measurements of the density, temperature, and speed of electrons in the corona.

Project: Balloon-borne Investigation of Temperature and Speed of Electrons in the corona (BITSE)

Sponsoring Organization: Heliophysics Division, Flight Opportunities in Research and Technology

Project Lead: Dr. Nat Gopalswamy, NASA Goddard Space Flight Center

Snapshot: New technology demonstrated on BITSE has simultaneously detected the 2D density, temperature, and speed of electrons in the solar corona for the first time.

Key terms: coronagraph, solar wind

Nat Gopalswamy and Jeff Newmark, heliophysicists at NASA's Goddard Space Flight Center in Greenbelt, Maryland, recently demonstrated BITSE — short for the Balloon-borne Investigation of Temperature and Speed of Electrons in the corona — aboard a high-altitude scientific balloon launched from Ft. Sumner, New Mexico.

The scientific instrument on the BITSE mission, which also involves the Korea Astronomy and Space Science Institute, is a coronagraph. These devices block the Sun's bright surface to reveal its faint, but very hot upper atmosphere called the corona. However, the BITSE coronagraph has added features that can measure some very important properties of the solar wind, which can travel as fast as a million miles per hour as it flows off the Sun carrying charged particles or plasma and embedded magnetic fields outward across the solar system. Although scientists know that the solar wind originates in the corona, they don't know precisely how it forms or accelerates.

"This flight marks the first time we've flown a coronagraph to detect the density, temperature, and speed of electrons in the corona. No coronagraph has ever done this before," said

Gopalswamy. According to Gopalswamy, previously flown coronagraphs measured only the density of electrons in the Sun's corona. "We need all three physical properties to understand how solar wind forms," he explained.

This question is of particular importance to scientists. Understanding the source of the solar wind--which determines how coronal mass ejections, or CMEs, propagate between the Sun and Earth--can help improve space-weather forecasts, particularly in the near-Earth environment. CME-caused space weather effects can interfere with radio communications or Global Positioning System (GPS) signals. During particularly strong geomagnetic storms sparked by the release of tons of charged particles during a CME, particles that make up the solar wind can flow along magnetic fields through Earth's protective magnetosphere onto the planet's surface where they can disrupt power grids and electronics.

During its sojourn approximately 40 km above Earth's surface, BITSE spent over four hours imaging the Sun's corona. In addition to an occulter that blocks light from the Sun's surface — much like how the Moon blocks the bright light during a solar eclipse — BITSE carries two other important technologies.

The filter wheel blocks all wavelengths of visible light except for those in four specific bands in the violet range — 3850, 3987, 4100, and 4233 Angstroms. And the camera, which serves as BITSE's detector, is able to directly collect polarized light — that is, light where the electric and magnetic fields oscillate in specific directions. Scientists need the polarized light to derive the electron properties. Because the camera can collect polarized light, BITSE doesn't require an extra mechanism to carry out the same task as do more traditional detectors.

Together, these payload components allowed the team to execute an observational technique called passband ratio imaging — an approach originally proposed in 1976. This technique determines electron temperature and speed, along with the density information that coronagraphs traditionally gather. It works like this: "The visible light we're seeing is actually light from the Sun's disk that scatters from the electrons in the solar wind," Newmark explained. "This scattering smears out the light from the disk, which is actually lots of individual spectral lines or wavelengths. If we choose the right wavelengths to look at, then the amount of smearing tells us the temperature and speed the electrons must exhibit to smear the light in that way."

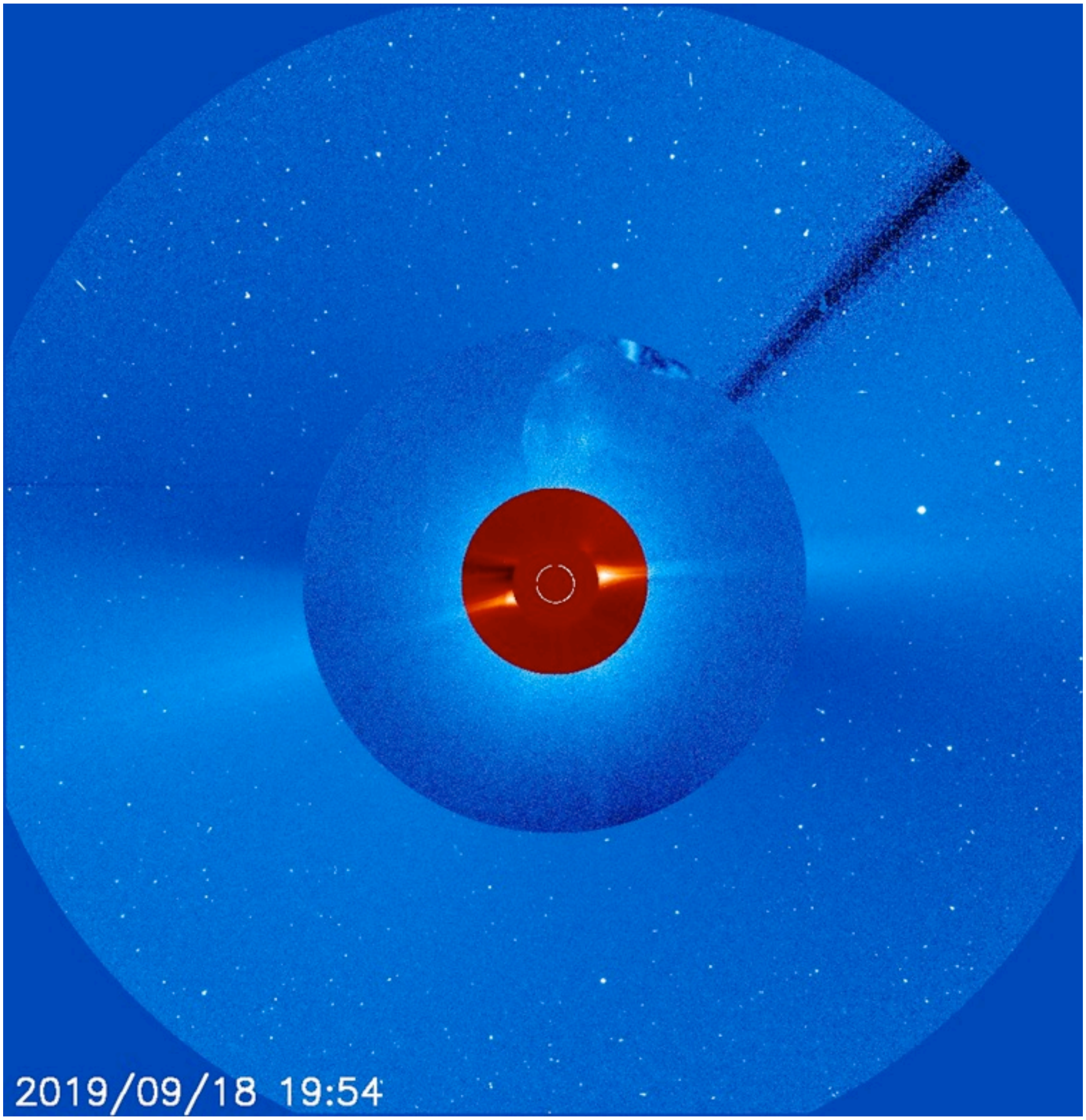
"Anyone can make a filter wheel tuned to four individual visible wavelengths, but we put this technology together to make our instrument do what we want it to do. It's cool. It's the first time we've done this," Newmark added.

The BITSE balloon flight was just the start of this new science exploration. Drs. Newmark and Gopalswamy are currently developing an improved version of this technology, called Coronal Diagnostic Experiment (CODEX). Also funded by SMD/HPD, CODEX will fly on the International Space Station, with an expected launch in early 2023.

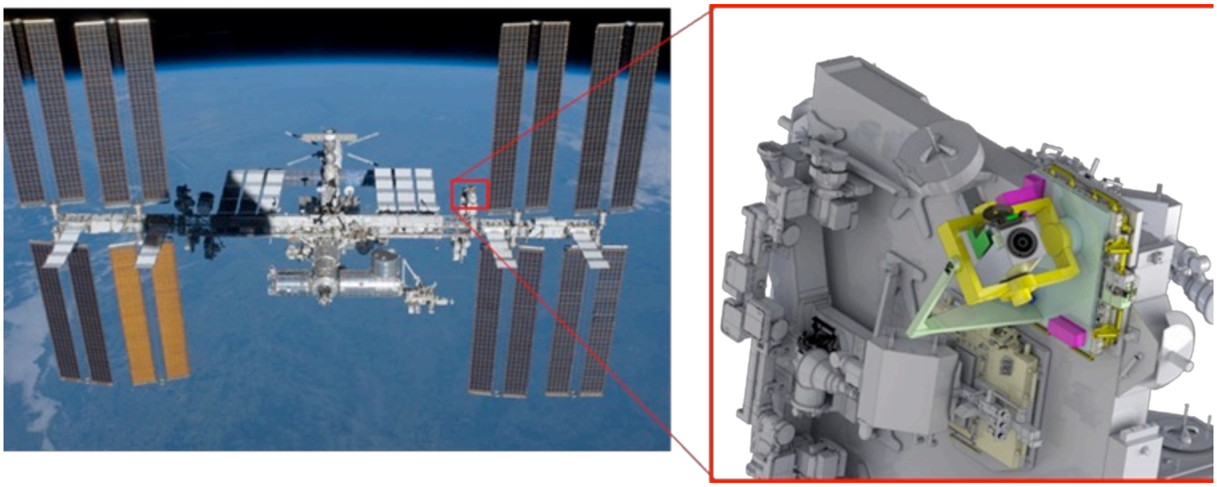
The BITSE coronagraph, pointed to the Sun at float altitude.

The BITSE coronagraph being readied in the NASA hanger in Fort Sumner.

A balloon measuring over 1.1 million cubic meters carried BITSE to an altitude of 40 km.



A BITSE coronal Image sandwiched between two coronal images obtained by SOHO coronagraphs.



A model of the CODEX coronagraph (right) and its anticipated location on the International Space Station (left)