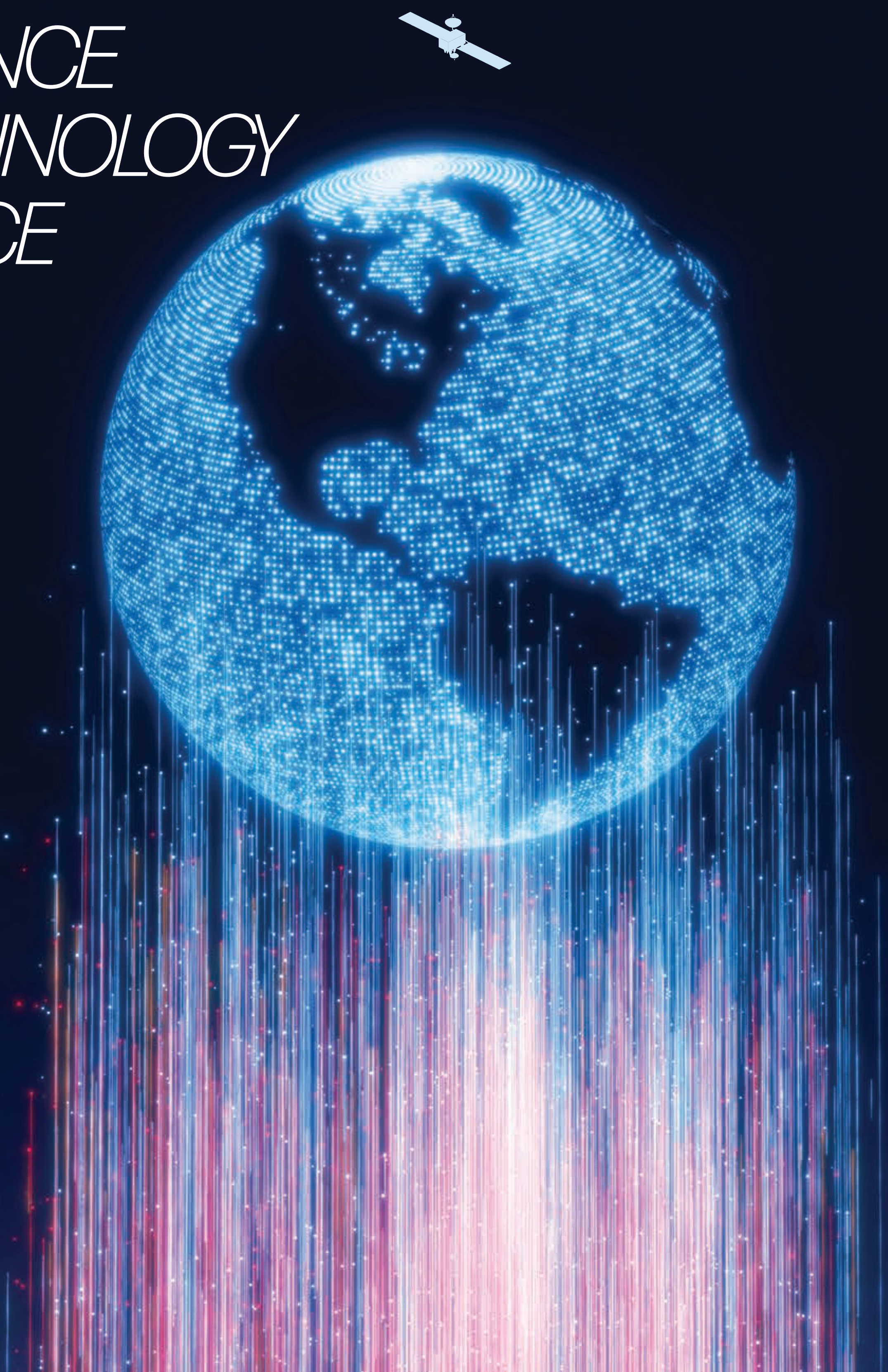
2025 ANNUAL REPORT *EARTH SCIENCE TECHNOLOGY OFFICE*

National Aeronautics and Space Administration



On Friday, March 14, 2025, SpaceX launched the Transporter-13 mission from Vandenberg Space Force Base in California. On board was ESTO's Aerosol Radiometer for Global Observation of the Stratosphere (ARGOS), which will validate a new tool for measuring the direct radiative effects of anthropogenic aerosols in the stratosphere, substantially advancing our limited understanding of how these particles behave and how they influence broader Earth systems. Credit: SpaceX

Executive Summary

The United States leads the world in Earth science research, attributable largely due to its dominance in space-based observations and Earth system modeling. NASA's Earth Science satellites are marvels of technological achievement, and the Earth Science Technology Office (ESTO) is proud to have supplied the world's most advanced sensors and information systems that have generated many hundreds of groundbreaking infusions into missions fielded by NASA, other agencies, and commercial partners.

Observation of the Earth system is critically important, as characterized by a recent study by the World Economic Forum, which determined the annual value added from Earth data will more than double to $700 billion by 2030. Potential benefits cited are nearly endless, but economic output from weather forecasts, air quality predictions, early warning of disasters such as floods and wildfires, environmental impact monitoring, post-event analyses, precision agriculture and aquaculture, route optimization, site selection, supply chain monitoring and vulnerability analysis lead the charge.

ESTO exists to help solve the most challenging problems in Earth observation and to achieve breakthroughs that dramatically improve capabilities of missions and lower their costs. Our sustained commitment and adaptability ensure fundamental technological advancement in a time when other nations are challenging U.S. leadership in this area. As we look toward the next decade, a new generation of sensing capabilities and information systems will be transitioning from early-stage development into implementation. Quantum sensing, artificial intelligence enabled by neuromorphic and quantum computing, and highly detailed digital twins of the Earth-human system will be part of our toolbox. ESTO is prepared for the future, as we already have active investments in all of these areas.

We're particularly proud of the many accomplishments of our projects during FY25, with numerous technology advancements, demonstrations, infusions to missions, and spinoffs to other agencies and commercial entities. More than 280 students — high school through PhD — were directly involved in ESTO-funded projects this year. New projects were added through competitive solicitations in programs such as Instrument Incubator, Advanced Modeling, and Wildland Fire Technology. By pairing pragmatic lessons learned with NASA's bold Earth Science to Action strategy, we will continue to serve the Nation with integrity, technical prowess, and a commitment to serve the public good.

Michael Seablom
Associate Director for Technology
NASA Earth Science Division

Betsy Forsbacka
Deputy Associate Director for Technology
NASA Earth Science Division

About ESTO

As the technology development function within NASA's Earth Science Division, the Earth Science Technology Office (ESTO) performs strategic planning and manages the development of a broad range of nascent technologies for future science measurements. ESTO relies on competition and peer review to select the best cutting-edge technologies, from advanced sensors aboard miniature satellites to software tools that plan new observations and harmonize, fuse, and analyze large data sets from various sources.

Our approach to Technology Development:

- **Strategy:** Engage with the Earth science community to plan investments through careful analyses of science requirements
- **Selection:** Fund technology development through periodic, competitive solicitations and partnership opportunities
- **Management:** Review and advise funded technology projects on progress and performance
- **Infusion:** Encourage and facilitate the use of matured technologies in science measurements

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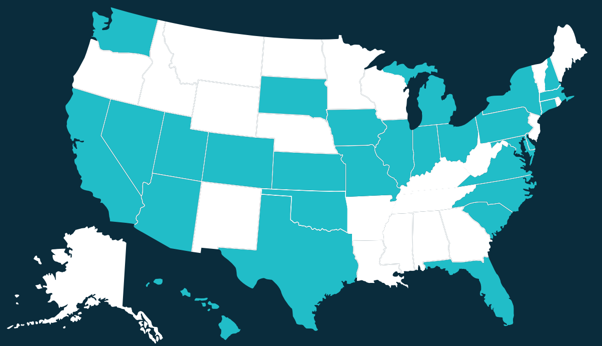
By The Numbers FY25

58 Projects Added in FY25

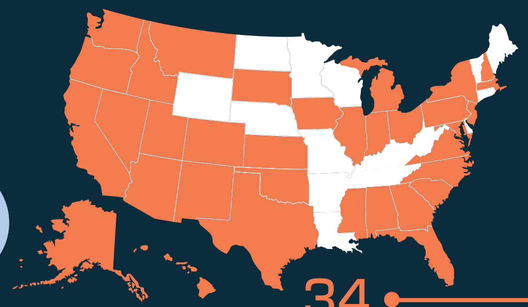
184 Projects Active in FY25

60 Projects Graduated in FY25



71 Unique PI Orgs

28 States



162 Unique Co-I Orgs

34 States

282 Students

3 Technology Demonstrations On Orbit

74 Colleges & Universities

11 Projects Airborne Tested

11 Journal Articles Published

370 Conference Publications

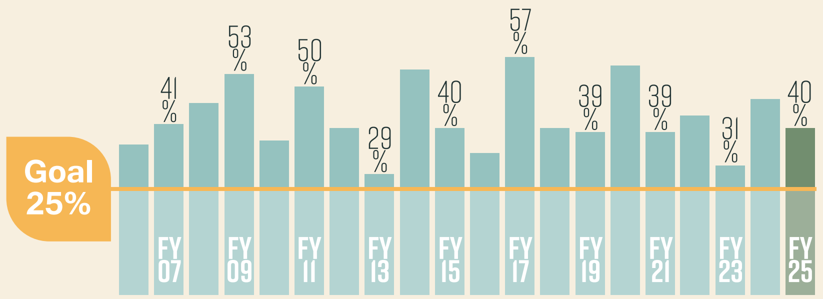
1 Patents

METRICS FY25

With over 1,172 technology investments made since 1999 and an active portfolio of 184 projects during FY25 (October 1, 2024, through September 30, 2025), ESTO drives innovation, enables future Earth science observations, and strengthens NASA's capability for developing and advancing leading-edge technologies. To highlight the FY25 achievements, what follows are the year's results tied to ESTO's performance metrics.

GOAL 1: TECH READINESS

>> Annually advance 25% of currently funded technology projects at least one Technology Readiness Level (TRL).



Percentage of Active Projects that advanced at least 1 TRL during each Fiscal Year.

40% of ESTO technology projects funded during FY25 advanced at least one TRL over the course of the fiscal year, and at least 15 projects advanced more than one TRL. Although the percentage of TRL advancements tends to be higher in years with large numbers of completing projects, ESTO has consistently exceeded this metric in every fiscal year since inception. The average annual TRL advancement for all years going back to 1999 is 43%.

40% advanced in FY25

GOAL 2: INFUSION

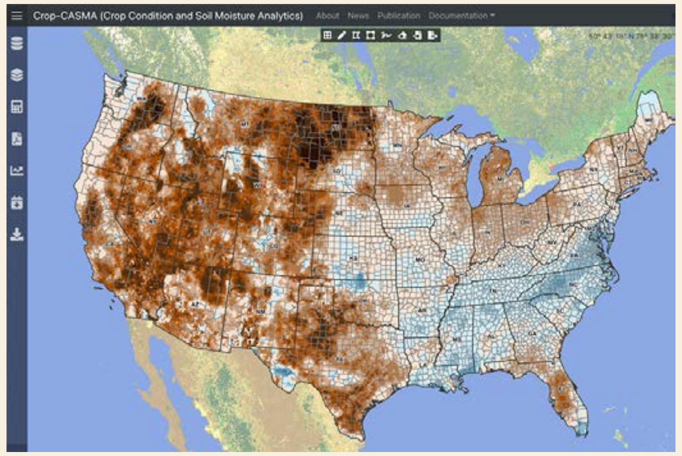
>> Mature at least three technologies to the point where they can be demonstrated in space or in a relevant operational environment.

11 Projects in FY25

In this fiscal year, at least 11 ESTO projects reported infusion into science measurements, airborne campaigns, data systems, or other operational activities. Additionally, at least 13 projects reported a transition to follow-on development opportunities. Three notable examples follow.

Infusion Highlight: Agricultural Forecasting

The U.S. Department of Agriculture (USDA) incorporated an Earth System Digital Twin (ESDT) developed with ESTO investment into its new Crop Condition and Soil Moisture Analytics (Crop-CASMA) tool, which will help farmers forecast potential yields, track droughts and floods, and predict the impact severe weather may have on their crops. Developed by Rajat Bindlish, a research associate in Earth science remote sensing at NASA's Goddard Space Flight Center (GSFC), the "Agricultural Digital Twin" incorporates data from NASA's Soil Moisture Active Passive (SMAP) and Moderate Resolution Imaging Spectroradiometer (MODIS) missions to improve crop and weather forecasts. Read more about Bindlish's digital twin on page 16.



Crop-CASMA is a web-based geospatial application that uses high-resolution NASA data to map soil moisture and crop vegetation conditions across the United States. The tool is designed to help farmers with spring planting, tracking damage after natural disasters, monitoring crop health, and more. Credit: USDA

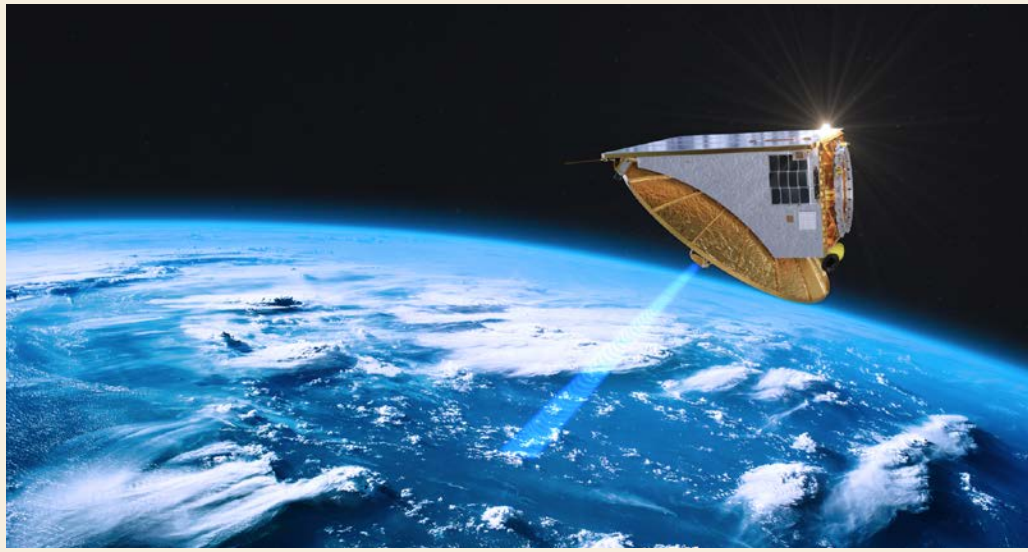
The Kennaook/Cape Grim Baseline Air Pollution Station provides an optimal setting for the study of aerosol-cloud-precipitation interactions, combining a comprehensive long-term record of aerosol and gas-phase chemistry with a location that regularly samples unpolluted air from the Southern Ocean. Credit: US Department of Energy

Infusion Highlight: Measuring Clouds in Australia

CloudCube, a novel, multi-frequency radar that transmits Ka-band, W-band, and G-band signals from a single antenna, participated in the U.S. Department of Energy's (DOE) Cloud And Precipitation Experiment at Kennaook (CAPE-K) field campaign in Tasmania, Australia. Alongside other instruments designed to detect and characterize atmospheric aerosols, CloudCube prototyped a new technique for determining the liquid water content in clouds, a key variable in weather models. The CloudCube team, led by Raquel Monje, a systems engineer at NASA's Jet Propulsion Laboratory (JPL), are currently working on a flight-ready prototype. Read more about Monje's project on page 24.

Infusion Highlight: Enabling the Weather Satellites of Tomorrow

Several ESTO-funded technologies are now key components of commercial weather satellites operated by Tomorrow.io, an American weather company. Tomorrow.io's atmospheric sounders, Tomorrow-S1 and Tomorrow-S2, each carry an ultra-compact microwave receiver originally created by William Blackwell, a researcher at MIT Lincoln Laboratory, as part of an ACT project in 2010. And the company's Tomorrow-R1 and Tomorrow-R2 radar instruments feature technologies inspired by RainCube, an InVEST project from 2015 that became the first small satellite equipped with an active radar instrument to fly in space. Both of these components allow Tomorrow.io to create detailed models of severe weather with compact, cost-efficient instruments. Read more about these infusions on page 14.

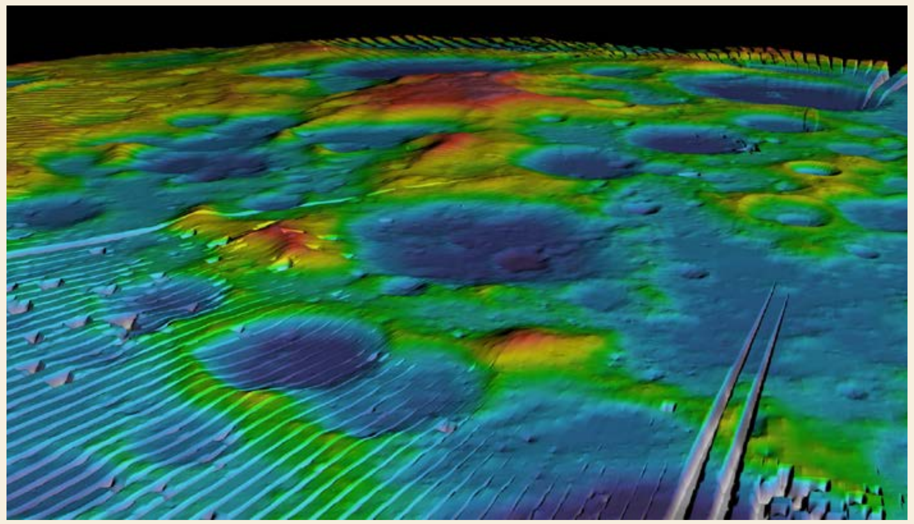


An illustration of Tomorrow.io's Resilience-series satellite. The Tomorrow.io Resilience Platform aims to utilize a constellation of more than 30 small satellites to provide near-realtime weather observations. The first satellite was launched in April 2023. Credit: Tomorrow.io

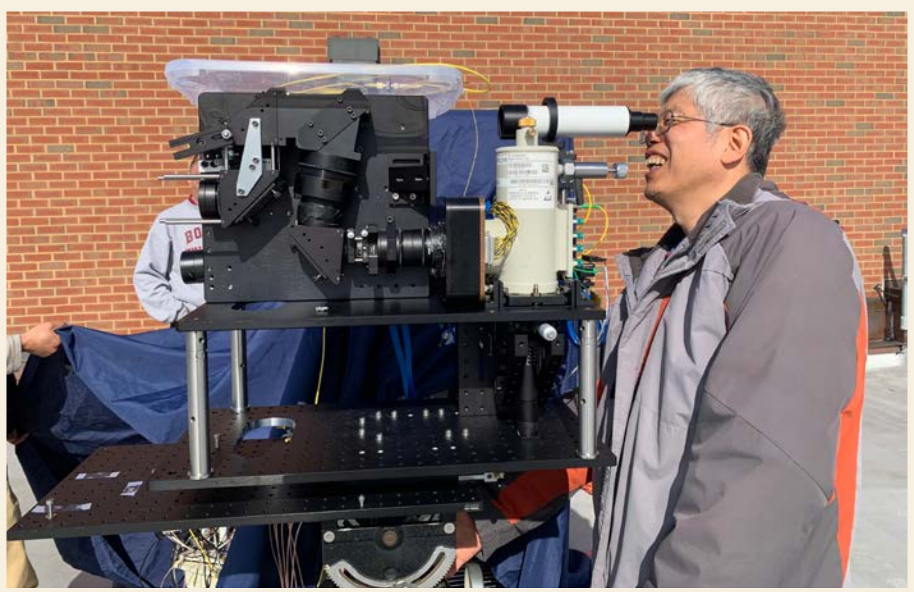
GOAL 3: SCIENCE MEASUREMENT

>> Enable a new science measurement or significantly improve the performance of an existing technique. Several projects satisfied this goal in FY25. One notable example follows:

Project Highlight: An AI-Powered Lidar for Mapping Earth's Surface



3D topography data describing the Moon's surface. CASALS could help scientists select potential landing sites for future lunar missions. Credit: NASA



Engineer Jeffrey Chen tests a lidar prototype on the roof of Building 33 at NASA's Goddard Space Flight Center in Greenbelt, Maryland. Chen and his team earned the center's 2024 Innovator of the Year award for their work on CASALS, a lidar system enhanced with artificial intelligence and other technologies. Credit: NASA

The Concurrent Artificially-intelligent Spectrometry and Adaptive Lidar System (CASALS), a novel lidar instrument developed by researchers at NASA's Goddard Space Flight Center, flew aboard a Beechcraft B200 Super King Air in October and November of 2024, marking a milestone in the quest for improved space-based altimeters.

CASALS adaptively distributes its laser beam to specified locations across a swath using a photonic integrated circuit seed laser, wavelength tuning circuitry, a high-power fiber amplifier, and a wavelength-to-angle mapping dispersive grating. This capability not only ensures measurement continuity with NASA's ICESat-2 and GEDI missions, but also, for the first time from space, images the observed swath in 3D. This will allow researchers to map Earth's surface and planetary boundary layer with unprecedented precision, improving ecosystem models and forecasts of fresh water supplies. Researchers could also use CASALS to produce detailed maps of the moon, giving scientists a better look at the subsurface structures beneath potential lunar landing sites.

CASALS integrates adaptive lidar technologies, hyperspectral imaging, and onboard artificial intelligence within a single instrument to reduce cost and improve performance when compared to traditional lidars, and its compact size makes it ideal for use aboard small satellites. Between October 30 and November 29, 2024, CASALS completed critical flight tests out of NASA's Langley Research Center (LaRC). Now, the team is eyeing future opportunities to fly their instrument in space.

Each of our program elements addresses a different aspect of Earth science technology, from modelling and information systems to full instruments and instrument subsystems. The following section details some of the latest developments in each of these programs and highlights a few projects that achieved significant milestones, including work dedicated to Earth System Digital Twins, quantum sensing, and metamaterials.

In-space Validation of Earth Science Technologies

NASA's vision for future Earth observations necessitates the development of emerging technologies capable of making new or improved Earth science measurements. Promising new capabilities, however, bring complexity and risk, and for some technologies there remains a critical need for validation in the hazardous environment of space. ESTO's In-space Validation of Earth Science Technologies (InVEST) program facilitates the space demonstration of technology projects that cannot be sufficiently evaluated on the ground or through airborne testing. Once validated in space, technologies are generally more adoptable, even beyond their intended use.

11 Projects Active in FY25

1 Project Added in FY25

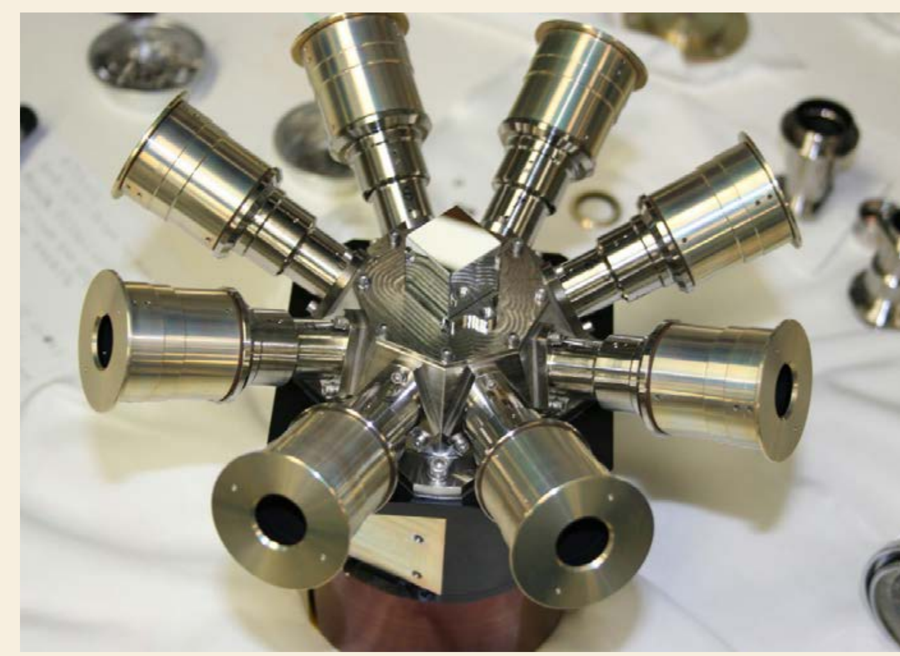
AFFORD - Advanced Format and Feature Optimized ROIC Design (component technology for future flight) — Atul Joshi, Saaz Micro Inc

1 Project Graduated

Compact Total Irradiance Monitor Flight Demonstration — David Harber, University of Colorado Boulder

InVEST Project Highlight

On March 15, the Aerosol Radiometer for Global Observation of the Stratosphere (ARGOS) InVEST technology demonstration mission launched aboard the SpaceX Transporter 13 Smallsat Rideshare vehicle. ARGOS will demonstrate the simultaneous collection of limb scattering data from eight viewing directions, a novel approach that has the potential to improve aerosol sensitivity globally when compared to current instruments.



A photo of ARGOS's eight-track telescope, which will help researchers characterize aerosols more accurately. Credit: M. DeLand / Science Systems and Applications, Inc

PROGRAM UPDATES FY25

FireSense Technology

17 Projects Active in FY25

FireSense Technology seeks new, innovative Earth system observation capabilities to predict and manage wildfires and their impacts. ESTO's FireSense Technology program is part of the broader Earth Science Division's FireSense initiative and works to transition scientific and technological advances to operational stakeholders, supporting the needs of state and local agencies on the ground. FireSense Technology will leverage NASA resources to improve the end-to-end management of wildfires in the United States and around the world. It will also conduct a series of airborne field campaigns to test novel technologies for assessing wildfire impacts. These technologies will make use of broad capabilities in instrument and information technology, along with new observing platforms in space, in the air, and on the ground.

4 Project Added in FY25

WAMI for Support of Wildland Fire Science, Management, and Disaster Mitigation — Alex Dzwill, Logos Technologies

Fuel-Driven Wildfire Risk Mapping Over CONUS to Guide Targeted Resources Allocation — Kiley Yeakel, MIT Lincoln Lab

UAS-mounted Canopy Penetrating Radar-Tag System for Understory Fuel Sensing — Elahe Soltanaghai, University of Illinois at Urbana-Champaign

Subcanopy UAS development for watershed-scale surface and ladder fuel quantification — Jonathan Greenberg, University of Nevada Reno

1 Project Graduated

Wildland Fire Pre-Formulation Concept Study — Rashmi Shah, JPL

FireSense Project Highlight

On April 14-20, FireTech participated in a multi-agency prescribed burn research operation at Fort Stewart-Hunter Army Field, Georgia, in partnership with the U.S. Department of War (DoW). Data collection during the three-day campaign, which covered more than 3,300 acres, focused on vegetation, fire, and smoke measurements and aimed to enhance understanding of fire behavior and smoke dynamics.

Credit: M. Loiacona / NASA

Sustainable Land Imaging-Technology

For over 40 years, the Landsat series of satellites has been providing a continuous stream of moderate resolution, multi-spectral images that have been used by a broad range of specialists to analyze our world. To continue the mission of Landsat, Sustainable Land Imaging – Technology (SLI-T) program explored innovative technologies to achieve Landsat-like data with more efficient instruments, sensors, components, and methodologies.

7 Projects Active in FY25

3 Projects Graduated

Improved Radiometric calibration of land Imaging Systems (IRIS) — John Bloomer, Raytheon

Land Calibration Satellite - Breadboard — Geir Kvaran, BAE Systems

TransCal – An Innovative, Highly Accurate, Transmissive Radiometric Calibration Approach — Nathan Leisso, BAE Systems

Decadal Survey Incubation

Decadal Survey Incubation (DSI) seeks to accelerate the readiness of two high-priority observables needing science-requirement refinement, technology development, and/or other advancements prior to cost effective flight implementation. DSI was recommended by the National Academies in the 2017 Earth Science Decadal Survey to target the Planetary Boundary Layer (PBL) and Surface Topography and Vegetation (STV) areas. These two fields are complex and dynamic systems with important science objectives and societal applications. Advancing technology to support these areas will improve observational capabilities that may unlock new insights into a wide variety of Earth processes.

13 Projects Active in FY25

6 Project Added in FY25

AURORA (Advanced Ultra-high Resolution Optical Radio frequency) Pathfinder — Antonia Gambacorta, NASA GSFC

A SmallSat Lidar Concept for PBL Height Measurements — John Yorks, NASA GSFC

A Trade Study on the Temperature and Moisture Vertical Information Content from Infrared Sounding — Chris Wilson, NASA JPL

Opportunistic procurement of HgCdTe for water vapor and methane lidar applications — Amin Nehrir, NASA LaRC

The Concurrent Artificially-intelligent Spectrometry and Adaptive Lidar System (CASALS) — John Yorks, NASA GSFC

An Agile Radar System for High-Resolution 3-D STV Structure Measurements from Stratospheric and Distributed Platforms — Lauren Wye, Aloft Sensing Inc

5 Projects Graduated

High Resolution PBL Profiling with LEO-LEO Occultation (HiPPO) — Chi Ao, JPL

Multi-Sensor Multi-platform Surface Topography and Vegetation Structure Data Fusion Information System (STV-FIS) — Sassan Saatchi, JPL

Embedded PNT Module for Distributed Radar Sensing — Patrick Rennich, Aloft Sensing Inc

STV Architecture Study — Mark Stephen, GSFC

A SmallSat Lidar Concept for PBL Height Measurements — John Yorks, NASA GSFC

DSI Project Highlight

Using novel instruments and innovative algorithms, the West-coast & Heartland Hyperspectral Microwave Sensor Intensive Experiment (WH²yMSIE) conducted test flights in October and November of 2024 onboard NASA's G-III and ER-2 aircraft. This airborne campaign was an essential first step toward an integrated, intelligent, and affordable system for improved measurements of the Planetary Boundary Layer (PBL).

ESTO Innovation Fund

ESTO's Innovation Fund (EIF) supplements NASA internal R&D funding to drive technology development projects focused on Earth Science priorities at low-TRL levels.

11 Projects in FY25

Continuing the evolution of CASALS — John Yorks, NASA GSFC

Developing interface between a Leach Gen III Camera Controller and Pandora V3 ground based spectroscopy instrument to enable evaluation of novel DUV detectors in mission representative applications — Peter Snapp, NASA GSFC

Photonic radar technology for Earth science — Lihua Li, NASA GSFC

Towards dynamic configuration for a cloud evolution targeting radar system — Adrian Loftus, NASA GSFC

Fery Grism prototype - Next Generation Atmospheric Gas Spectrometers and Solar Induced Fluorescence Imaging Spectrometers — Dan Wilson, NASA JPL

SoOp verification for Rydberg MW sensor - Demonstration of multi-frequency (L and S band) radar remote sensing using a quantum Rydberg receiver instrument — Rashmi Shah, NASA JPL

Advanced Water Vapor/Ocean Plastic Polarimetry — Snorre Stamnes, NASA LaRC

Developing an AI/ML transfer learning module for a PBL novel observing system (PBL NOS) — Antonia Gambacorta, NASA GSFC

SOA development for Cs based quantum applications - To reduce the power requirement of lasers in the QGG system — Siamak Forouhar, NASA JPL

HPC Support for Weather, Climate, and Ocean Dynamics Digital Twins Experiment — Andrew Michaelis, NASA ARC

Advance Foundation Modeling Use in Resilience Applications — Weile Wang, NASA ARC

PROGRAM UPDATES FY25

Instrument Incubator Program

The Instrument Incubator Program (IIP) provides funding for new instrument and observation techniques, from concept to breadboard and flight demonstrations. Instrument technology development of this scale, outside of a flight project, consistently leads to smaller, less resource-intensive instruments that reduce the costs and risks of mission instrumentation.

48 Projects Active in FY25

13 Projects Graduated

SToRM SAR — Kevin Maschhoff, BAE Systems

Compact Hyperspectral Air Pollution Sensor-Demonstrator (CHAPS-D) — William Swartz, JHU APL

Atmospheric Boundary-Layer Lidar PathfindEr (ABLE) — Amin Nehrir, NASA LaRC

Concurrent Artificially-intelligent Spectrometry and Adaptive Lidar System (CASALS) — Guangning Yang, NASA GSFC

DEMETER: DEMonstrating the Emerging Technology for measuring the Earth's Radiation — Anum Ashraf, NASA LaRC

Rydberg Radar: A quantum architecture covering the radio window for multi-science signal of opportunity remote sensing with focus on land surface hydrology — Darmindra Arumugam, NASA JPL

Quantum Parametric Mode Sorting (QPMS) Lidar — Carl Weimer, BAE Systems

Photonic Integrated Circuits (PICs) in Space: The Hyperspectral Microwave Photonic Instrument (HyMPI) — Antonia Gambacorta, NASA GSFC

Metamaterial-based Super Spectral Filter Radiometers for Atmospheric Sounding of Temperature and Water Vapor — Richard Lynch, JANUS Research Group

HALE InSAR for Continual and Precise Measurement of Earth's Changing Surface — Lauren Wye, Aloft Sensing Inc

L-Band Antenna Membrane Study — Rajat Bindlish, NASA GSFC

Deployable P and I band antenna TRL advancement for flight — Mark Bailey, MMA Design

4D Tomography Study — Mark Richardson, NASA JPL

19 Project Added in FY25

Rydberg Airborne Instrument Demonstration (RAID) — Darmindra Arumugam, NASA JPL

Global Orbital Research with a Diurnal Observing Network (GORDON): Towards realizing the potential of affordable spaceborne lidar — Matthew McGill, University of Iowa

CHAPS Flight Qualification — William Swartz, JHU APL

HiMAP: High-resolution Metagrating spectropolarimeter for Aerosol Profiling — Jun Wang, University of Iowa

Next generation of Intelligent Meteorological Radar with Built-in Understanding of the Scenery (NIMBUS) — Raquel Rodriguez Monje, NASA JPL

CHanneled IR Polarimeter (CHIRP) — Meredith Kupinski, University of Arizona

The Compact Hyperspectral Prism Spectrometer for Space (Space-CHPS): Advancing Spaceborne Prism-based Imaging Spectroscopy of the Earth — Thomas Kampe, BAE Systems

DEMETER: DEMonstrating the Emerging Technology for measuring the Earth's Radiation - Advancing Technology Readiness Level to 6 — Miko Coleman, NASA LaRC

TRL-6 Cross-Cutting Water Vapor and Methane DIAL Transmitter — Amin Nehrir, NASA LaRC

Multi-functional airborne fluorescence lidar to assess ocean systems health and marine pollution — Madeline Cowell, BAE Systems

Veery: Flat-panel Scatterometer for Hourly Ocean Surface Vector Winds — Michael Walton, Care Weather Technologies

L-Band Antenna Membrane Study — Rajat Bindlish, NASA GSFC

Lidar Instrument for Salinity and Temperature detection in the Ocean (LISTO) — Cecile Rousseaux, NASA GSFC

CMLS and AMLS Upgrade — Nathaniel Livesey, NASA JPL

Blue Lidar — Brian Collister, NASA LaRC

SLiFO3X/Tropospheric Ozone — Matthew Mullin, NASA GSFC

Multistatic Radar Demonstration — Robert Beauchamp, NASA JPL

Hyperspectral Radiometer — Pekka Kangaslahti, NASA JPL

Photonic Integrated Circuit/Photonic Lantern Expansion to Atmospheric Lidar Wavelengths — Nathan Dostart, NASA LaRC

IIP Project Highlight

The "Microwave Barometric Radar and Sounder" (MBARS) instrument, a joint project between NASA's Goddard Space Flight Center (GSFC) and Langley Research Center (LaRC), will help researchers improve global-scale models of Earth's weather patterns. It flew aboard NASA's ER-2 aircraft as part of the WH²yMSIE campaign.
Credit: NASA

Advanced Component Technology

Component and sub-system technologies are a principal driver of new instruments and measurement techniques. The Advanced Component Technology (ACT) program funds the research, development, and demonstration of component- and subsystem-level technologies to reduce the risk, cost, size, mass, and development time of missions and infrastructure.

22 Projects Active in FY25

10 Projects Graduated

Bandstructure Engineered Type-II superlattice Antimonide Avalanche Photodiodes (BETA-APD) for Space Lidar Instruments — Sanjay Krishna, The Ohio State University

W-band RF-photonics Receiver for Compact Cloud and Precipitation Radars — Razi Ahmed, NASA JPL

Advanced SAPHIRA HgCdTe APD Arrays for NASA Space Lidar Applications — Guangning Yang, NASA GSFC

A compact, high-power 167-174.8 GHz traveling-wave tube amplifier for planetary boundary layer differential absorption radar — Kenneth Kreischer, Northrop Grumman

Miniaturized Microwave Absolute Calibration (MiniMAC) for Sounders and Imagers on SmallSat and CubeSat Platforms — Steven Reising, CSU

Hyperspectral imaging on photonic-integrated-circuits for future GeoCARB missions — Ben Yoo, UC Davis

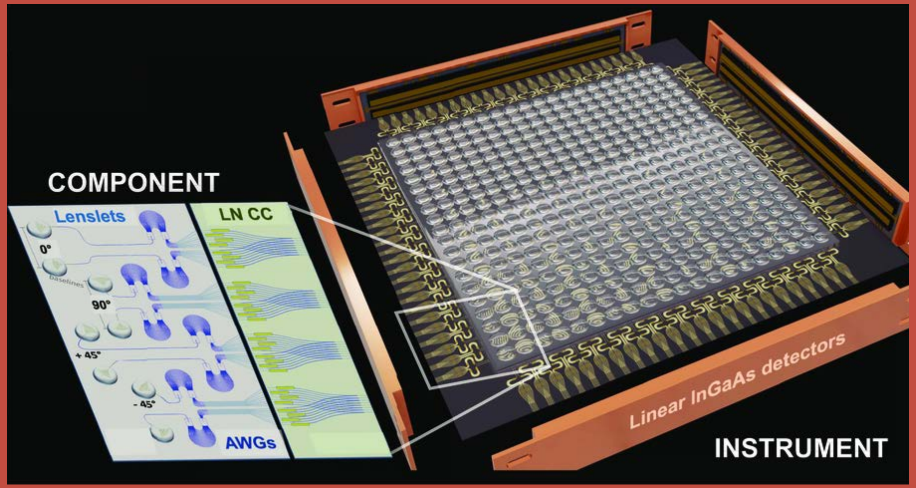
Stacked Miniaturized And Radiation Tolerant Intelligent Electronics (SMARTIE) — John Carson, Irvine Sensors

Multi-Frequency & Multi-Beam Metasurface Antennas for Spaceborne Millimeter-Wave Radars — Nacer Chahat, NASA JPL

Low SWaP-C Modular Laser Architecture for Laser-Cooled Quantum Sensors and Atomic Clocks — Kurt Vogel, Vescent Photonics Inc

Design for Atomic Gravity Gradiometer for Earth Research (DAGGER) — Matthew Cashen, Vector Atomic

Engineers at Lockheed Martin are working on a novel imaging spectrometer far smaller and lighter than traditional spectrometers. Their "Earth-observing Photonic Integrated Circuit" (EPIC) will significantly reduce the cost of smallsat constellations dedicated to observing aerosols and other features of Earth's atmosphere.



ACT Project Highlight

The EPIC Instrument concept is comprised of replicated copies of PIC structures that have been demonstrated on the EPIC component. The component structures are replicated 500 times to to create 4000 baseline samples per sensor using 8k detector pixels. Although the lenslets are arranged in a grid in this illustration, the optimal sampling arrangement of baselines will be determined by simulations during detailed instrument design. Credit: M. Adamkovics / Lockheed Martin Space Systems Co.

PROGRAM UPDATES FY25

Advanced Information Systems Technology

NASA's Advanced Information Systems Technology (AIST) Program identifies, develops, and supports adoption of software and information systems, as well as novel computer science technologies expected to be needed by the Earth Science Division in the 5-10-year timeframe. AIST's primary thrusts include New Observing Strategies (NOS) and Analytic Collaborative Frameworks (ACF).

43 Projects Active in FY25

13 Project Graduated

Predicting What We Breathe: Using Machine Learning to Understand Air Quality — Dawn Comer, City Of Los Angeles

Kernel Flows: emulating complex models for massive data sets — Jouni Susiluoto, NASA JPL

GEOS Visualization And Lagrangian dynamics Immersive eXtended Reality Tool (VALIXR) for Scientific Discovery — Thomas Grubb, NASA GSFC

Innovative geometric deep learning models for onboard detection of anomalous events — Jie Zhang, University of Texas at Dallas

A Framework for Global Cloud Resolving OSSEs — Thomas Clune, NASA GSFC

Integration of Observations and Models into Machine Learning for Coastal Water Quality — Stephanie Schollaert Uz, NASA GSFC

Multi-path Fusion Machine Learning for New Observing System Design and Operations — Mark Moussa, NASA GSFC

A scalable probabilistic emulation and uncertainty quantification tool for Earth-system models — Matthias Katzfuss, Texas A&M University

3D-CHESS: Decentralized, distributed, dynamic and context-aware heterogeneous sensor systems — Daniel Selva, Texas A&M University

Intelligent Long Endurance Observing System — Meghan Saephan, NASA ARC

Dynamic Targeting — Steve Chien, NASA JPL

Blockchain Distributed Ledger for Space Resource Access Control — Yelena Yesha, University of Miami

Identify Best-fit and Optimize AI/ML models to support the Digital Twins related to Air Quality — Chaowei (Phil) Yang, George Mason University

8 Projects Added in FY25

Event- and Feature-Based Observing System Design: Quantifying Science and Applications Benefit for Diverse Measurement Combinations — Derek Posselt, NASA JPL

Integrating Explainable Machine Learning with Physics for Enhanced Wildfire Detection in Observation-Constrained Environments — Leah Ding, American University

Flight Demonstration of Federated New Observing Strategies for Multiple Science Applications — Steve Chien, NASA JPL

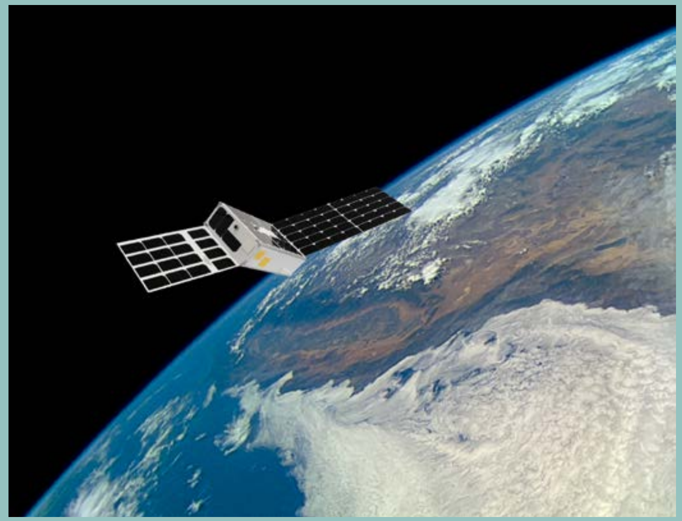
An Innovative Sunlight Denoising Technique To Improve Measurement Quality and Reduce Cost of Future Spaceborne Lidars — Xiaomei Lu, NASA LaRC

Time series multi-modal foundation model for near-real-time land surface dynamics characterization in support of ESDT — Hankui Zhang, South Dakota State University

Hybrid Neural Scene Representations for Earth Observation: Unifying Physics-Based Models, Heterogeneous Datasets, and Radiance Fields — Caleb Adams, NASA ARC

Physics-Aware Quantum Neural Network Modeling of Earth Science Phenomena — Eleanor Rieffel, NASA ARC

Providing Impact via Large Language models for Access and Retrieval (PILLAR) Pilot Project Plan, Optimized for Rapid Results — Hook Hua, NASA JPL



Artist depiction of Ubotica's Cognisat-6 satellite. Credit: Ubotica

AIST Project Highlight

Researchers at NASA's Jet Propulsion Laboratory (JPL) made significant progress on dynamic targeting, a new software technology that would allow satellites to make real-time decisions about which features they should prioritize for observation. The team is currently testing their technology aboard Ubotica's CogniSat-6 cubesat.

Advanced Modeling Technology

In FY25, ESTO added the Advanced Modeling Technology (AMT) program to recognize the potential of AI-enhanced modeling. AMT aims to expand current modeling techniques and leverage state-of-the-art computer and information science that will be essential in the development of Earth System Digital Twins.

AMT Project Highlight

A team of researchers at the University of Wisconsin, Madison, are working on a new software toolbox for probabilistic model-data fusion. During FY25, the team increased the TRL level of their technology from TRL 4 to TRL 5, advancing a crucial component of future Earth System Digital Twins dedicated to modelling phenomena like severe weather.

Hurricane Lorenzo in the Atlantic. Earth System Digital Twins will improve severe weather tracking and forecasting. Credit: NASA

9 Projects Added in FY25

Pilot Deployment of TERRAHydro: A framework, demonstration, and vision for Earth System Digital Twins — Craig Pelissier, SSAI

An Earth System Digital Twin for Wildfire: Predicting Wildfire Progression and Behavior, and Its Downstream Impacts on Air Quality — Mohammad Pourhomayoun, California State University Los Angeles

A Digital Twin Integrating Knowledge and AI for Understanding Carbon and Biodiversity Corridors in Central Africa — Yiqun Xie, University of Maryland

Connecting a Broad Community to Earth System Digital Twin Technologies at the Interface of Atmospheric Composition with the Earth System — Randall Martin, Washington University in St Louis

Mapping anthropogenic water cycle impacts in a future climate: A global digital twin for scenario-driven exploration — Sujay Kumar, NASA GSFC

Pix4DCloud: A Suite of Physics-Constrained Transformer Models to Retrieve 4D Clouds in Real World and Digital Twins — Jie Gong, NASA GSFC

Machine-learning to improve cycling and forecasts with GEOS and expedite the evaluation of assimilating observations from new instruments — Romit Maulik, Pennsylvania State University

AI Climate Tipping-Point Simulator (ACTS) — Jennifer Sleeman, Johns Hopkins University

A forecasting scheme for accelerated harmful algal bloom monitoring (FASTHAB) — Craig Pelissier, SSAI

STORM CHASERS COMMERCIALIZED

NASA science and American industry have worked hand-in-hand for more than 60 years, transforming novel technologies created with NASA research into commercial products like cochlear implants, memory-foam mattresses, and more. Now, a NASA-funded device for probing the interior of storm systems has been made a key component of commercial weather satellites.

The novel atmospheric sounder was originally developed for NASA's TROPICS mission — Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats, which launched in 2023. Boston-based weather technology company Tomorrow.io recently integrated the same instrument design into some of its satellites.

Atmospheric sounders allow researchers to gather data describing humidity, temperature, and wind speed, important factors for weather forecasting and atmospheric analysis. From low Earth orbit, these devices help make air travel safer, shipping more efficient, and severe weather warnings more reliable.

In the early 2000s, meteorologists and atmospheric chemists were eager to find a new science tool that could peer deep inside storm systems and do so multiple times a day. At the same time, CubeSat constellations were emerging as promising, low-cost platforms for increasing the frequency with which individual sensors could pass over fast-changing storms, which improves the accuracy of weather models.

The challenge was to create an instrument small enough to fit aboard a satellite the size of a toaster, yet powerful enough to observe the innermost mechanisms of storm development. Preparing these technologies required years of careful development that was primarily supported by NASA's Earth Science Division.

William Blackwell and his team at MIT Lincoln Laboratory in Cambridge, Massachusetts, accepted this challenge and set out to miniaturize vital components of atmospheric sounders. "These were instruments the size of a washing machine, flying on platforms the size of a school bus," said Blackwell, the principal investigator for TROPICS. "How in the world could we shrink them down to the size of a coffee mug?"

With a 2010 award from ESTO, Blackwell's team created an ultra-compact microwave receiver, a component that can sense the microwave radiation within the interior of storms.

The Lincoln Lab receiver weighed about a pound (500 grams) and took up less space than a hockey puck. This innovation paved the way for a complete atmospheric sounder instrument small enough to fly aboard a CubeSat. "The hardest part was figuring out how to make a compact back-end to this radiometer," said Blackwell. "So without ESTO, this would not have happened. That initial grant was critical."

In 2023, that atmospheric sounder was sent into space aboard four TROPICS CubeSats, which have been collecting torrents of data on the interior of severe storms around the world.

By the time TROPICS launched, Tomorrow.io developers knew they wanted Blackwell's microwave receiver technology aboard their own fleet of commercial weather satellites. "We looked at two or three different options, and TROPICS was the most capable instrument of those we looked at," said Stephen Munchak, a senior atmospheric data scientist at Tomorrow.io.

In 2022, the company worked with Blackwell to adapt his team's design into a CubeSat platform about twice the size of the one used for TROPICS. A bigger platform, Blackwell explained, meant they could bolster the sensor's capabilities.

"When we first started conceptualizing this, the 3-unit CubeSat was the only game in town. Now we're using a 6-unit CubeSat, so we have room for onboard calibration," which improves the accuracy and reliability of gathered data, said Blackwell.

Tomorrow.io's first atmospheric sounders, Tomorrow-S1 and Tomorrow-S2, launched in 2024. By the end of 2025, the company plans to have a full constellation of atmospheric sounders in orbit. The company also has two radar instruments that were launched in 2023 and were influenced by NASA's RainCube instrument–the first CubeSat equipped with an active precipitation radar.

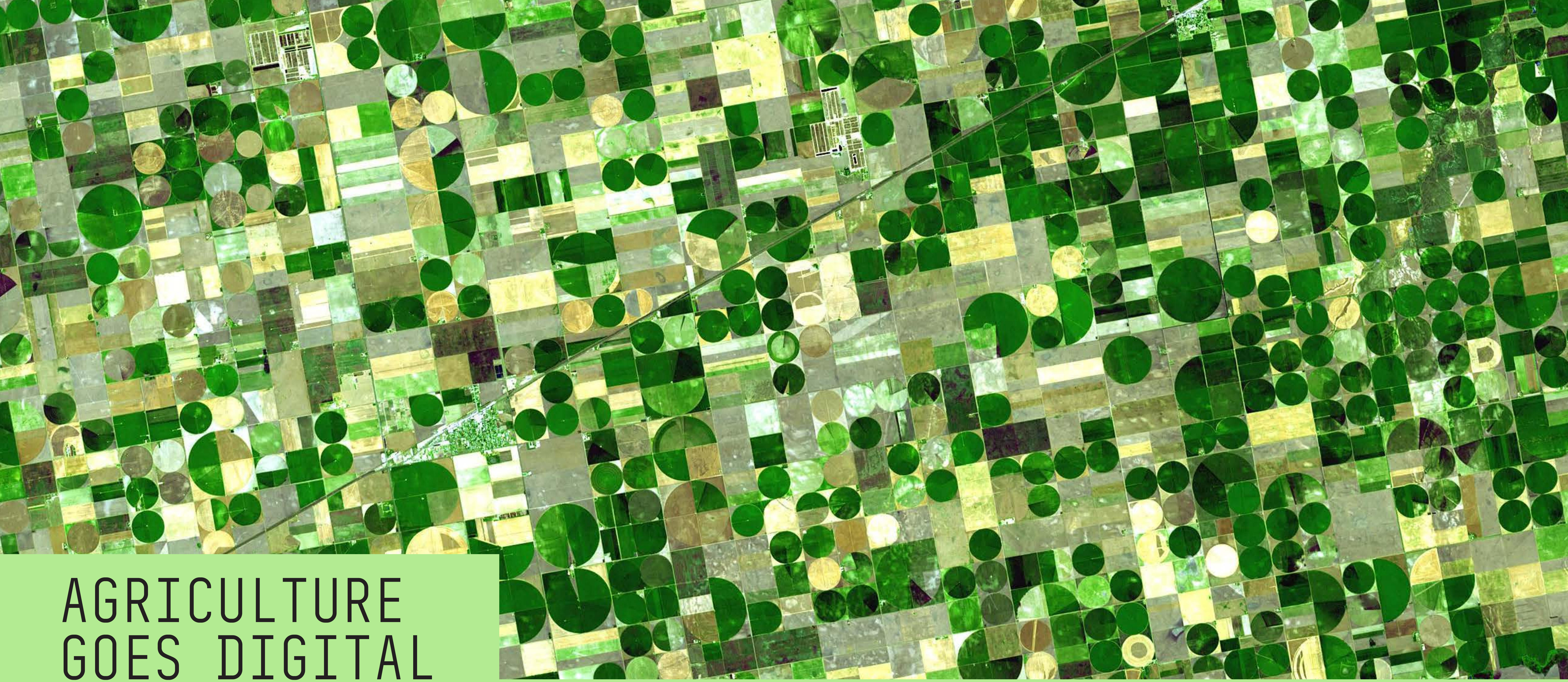
More CubeSats lead to more accurate weather data because there are more opportunities each day—revisits—to collect data. "With a fleet size of 18, we can easily get our revisit rate down to under an hour, maybe even 40 to 45 minutes in most places. It has a huge impact on short-term forecasts," said Munchak.

Having access to an atmospheric sounder that had already flown in space and had more than 10 years of testing was extremely useful as Tomorrow.io planned its fleet. "It would not have been possible to do this nearly as quickly or nearly as affordably had NASA not paved the way," said Jennifer Splaingard, Tomorrow.io's senior vice president for space and sensors.

The relationship between NASA and industry is symbiotic. NASA and its grantees can drive innovation and test new tools, equipping American businesses with novel technologies they may otherwise be unable to develop on their own. In exchange, NASA gains access to low-cost data sets that can supplement information gathered through its larger science missions.

Tomorrow.io was among eight companies selected by NASA's Commercial Smallsat Data Acquisition (CSDA) program in September 2024 to equip NASA with data that will help improve weather forecasting models. "It really is a success story of technology transfer. It's that sweet spot, where the government partners with tech companies to really take an idea, a proven concept, and run with it," said Splaingard.

TROPICS CubeSat Pathfinder with solar cell panel and radiometer. Credit: Blue Canyon Technologies



AGRICULTURE GOES DIGITAL

Whether crops fail or flourish depends on a complex web of variables, including soil moisture, nutrient load, and weather. Incorporating these variables into reliable models is essential for predicting crop yields and tracking food security in the United States.

A team of researchers supported by NASA's ESTO is developing an agriculture information system that will provide farmers with better agricultural productivity forecasts. The "Agricultural Digital Twin" merges data from NASA remote sensors with data from sources like the USDA's National Agricultural Statistics Service (NASS) to inform custom descriptions of crop yield for farmers, paving the way for detailed crop forecasts tailored to suit a farmer's specific needs.

For example, farmers could use the Agricultural Digital Twin to simulate how a certain variety of corn might fare in Iowa if there's a drought, or whether a particular species of soybean planted in Kansas fares better when it's planted earlier or later in the year.

"Farmers might find it useful for tracking the consequences of outlier events, like a derecho, or deciding which type of seed to use," said Rajat Bindlish, a Physical Research Scientist at NASA's Goddard Space Flight Center (GSFC) and Principal Investigator for the Agricultural Digital Twin.

Bradley Doorn, who managed the NASA's Agricultural Earth Action portfolio, explained that the goal is to help farmers leverage NASA, NOAA, and USDA data to assess risk and maximize their yield.

"We're not telling farmers when to plant crops or which crops they should plant, but we're giving them a tool to help them make those decisions," said Doorn.

The core of this effort revolves around the novel coupling of NASA's Land Information System (LIS) hydrology model with a crop yield model, the Decision Support System for Agrotechnology Transfer (DSSAT). Bindlish explained that crop yield models currently struggle to account for surface hydrology, and merging LIS with DSSAT make agricultural forecasts more reliable.

"The Agriculture Digital Twin leverages the strengths of state-of-the-art crop and hydrology model along with NASA's remote sensing observations," said Bindlish.

The result was a complete framework for a dynamic digital twin that simulates physical constraints related to agriculture. With this framework complete, Bindlish and his team are now exploring potential case studies to test their model's efficacy.

"This modeling framework makes it very easy to assess NASA remote sensing data," added Pang-Wei Liu, a Hydrological Research Scientist at GSFC and Co-Investigator for the Agricultural Digital Twin. "I think that is very valuable information for the agricultural community."

Ultimately, Bindlish and his team hope to share their work through a user-friendly web portal. In addition, their software will be flexible enough for future improvements and infusions with other Earth system digital twins.

Bindlish stressed that this work couldn't have happened if it weren't for the productive collaboration between USDA and NASA. "It's all testament to the team that we are at this point," he said.

ESTO's Information Systems Technology (IST) program funds Bindlish's research and supports NASA's many other Earth System Digital Twin projects.

SENSING WILDFIRE

A novel space-based sensor for observing wildfires could allow first responders to monitor burns at a global scale, paving the way for future small satellite (SmallSat) constellations dedicated entirely to fire management and prevention.

Developed with ESTO's support, the "Compact Fire Infrared Radiance Spectral Tracker" (c-FIRST) is a small, mid-wave infrared sensor that collects thermal radiation data across five spectral bands. Most traditional space-based sensors dedicated to observing fires have long revisit times, observing a scene just once over days or even weeks. The compact c-FIRST sensor could be employed in a SmallSat constellation that could observe a scene multiple times a day, providing first responders data with high spatial resolution in under an hour.

In addition, c-FIRST's dynamic spectral range covers the entire temperature profile of terrestrial wild fires, making it easier for first responders to detect everything from smoldering, low-intensity fires to flaming, high intensity fires.

"Wildfires are becoming more frequent, and not only in California. It's a worldwide problem, and it generates tons of by-products that create very unhealthy conditions for humans," said Sarath Gunapala, who is an Engineering Fellow at NASA's Jet Propulsion Laboratory (JPL) and serves as Principal Investigator for c-FIRST.

The need for space-based assets dedicated to wildfire management is severe. During the Palisade and Eaton Fires earlier this year, strong winds kept critical observation aircraft from taking to the skies, making it difficult for firefighters to monitor and track massive burns.

Space-based sensors with high revisit rates and high spatial resolution would give firefighters and first responders a constant source of eye-in-the-sky data.

"Ground-based assets don't have far-away vision. They can only see a local area. And airborne assets, they can't fly all the time. A small constellation of CubeSats could give you that constant coverage," said Gunapala.

c-FIRST leverages decades of sensor development at JPL to achieve its compact size and high performance. In particular, the quarter-sized High Operating Temperature Barrier Infrared Detector (HOT-BIRD), a compact infrared detector also developed at JPL with ESTO support, keeps c-FIRST small, eliminating the need for bulky cryocooler subsystems that add mass to traditional infrared sensors.

With HOT-BIRD alone, c-FIRST gathers high-resolution images and quantitative retrievals of targets between 300°K (about 80°F) to 1000°K (about 1300°F). But when paired with a state-of-the-art Digital Readout Integrated Circuit (DROIC), c-FIRST can observe targets greater than 1600°K (about 2400°F).

Developed by Copious Imaging LLC and JPL with funding from NASA's Small Business Innovation Research (SBIR) program, this DROIC features an in-pixel digital counter to reduce saturation, allowing c-FIRST to capture reliable infrared data across a broader spectral range.

Artificial intelligence (AI) will also play a role in c-FIRST's success. Gunapala plans to leverage AI in an onboard smart controller that parses collected data for evidence of hot spots or active burns. This data will be prioritized for downlinking, keeping first responders one step ahead of potential wildfires.

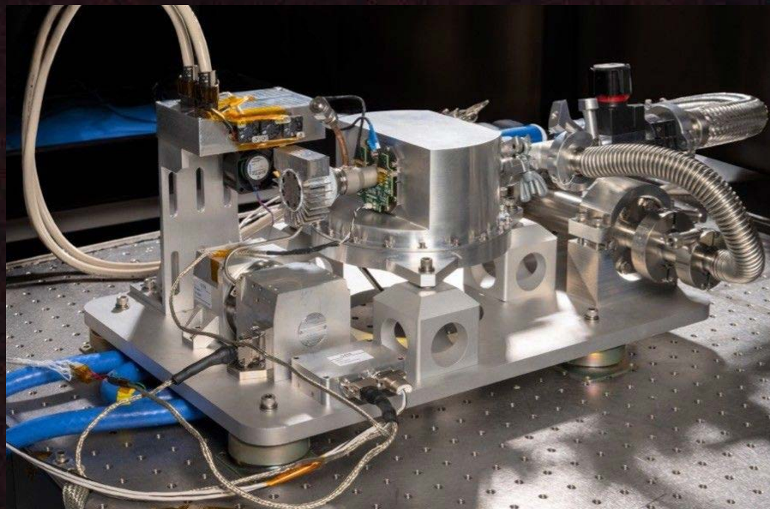
"We wanted it to be simple, small, low cost, low power, low weight, and low volume, so that it's ideal for a small satellite constellation," said Gunapala.

Gunapala and his team had a unique opportunity to test c-FIRST after the Palisade and Eaton Fires in California. Flying their instrument aboard NASA's B-200 Super King Air, the scientists identified lingering hot spots in the Palisades and Eaton Canyon area five days after the initial burn had been contained.

Now, the team is eyeing a path to low Earth orbit. Gunapala explained that their current prototype employs a standard desktop computer that isn't suited for the rigors of space, and they're working to incorporate a radiation-tolerant computer into their instrument design.

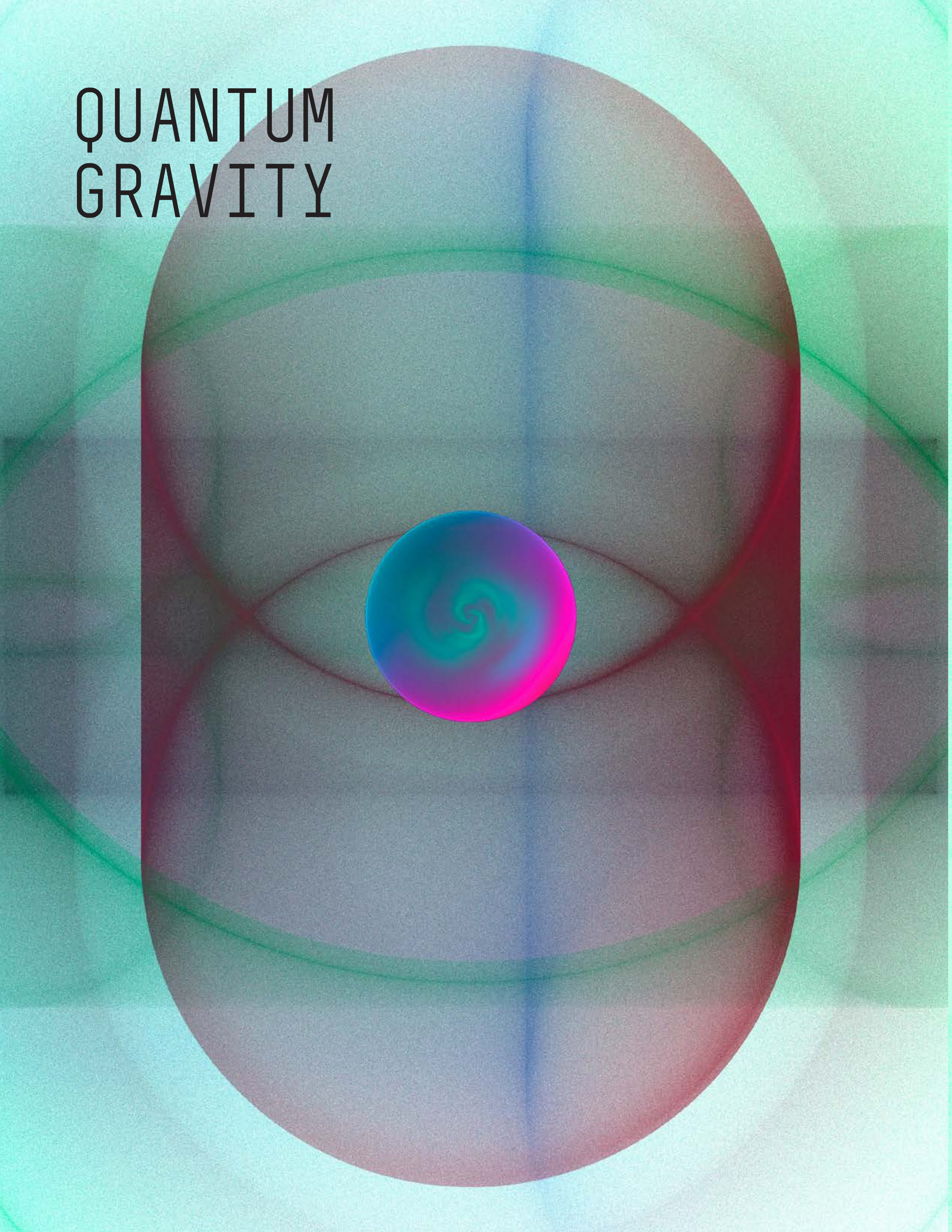
But this successful test over Los Angeles demonstrates c-FIRST is fit for fire detection and science applications. As wildfires become increasingly common and more destructive, Gunapala hopes that this tool will help first responders combat nascent wildfires before they become catastrophes.

"To fight these things, you need to detect them when they're very small," said Gunapala.



˅ **NASA's c-FIRST instrument could provide high resolution data from a compact space-based platform in under an hour, making it easier for wildfire managers to detect and monitor active burns. Credit: NASA**

QUANTUM GRAVITY



Researchers from NASA's Jet Propulsion Laboratory in Southern California, private companies, and academic institutions are developing the first space-based quantum sensor for measuring gravity. Supported by ESTO, this mission will mark a first for quantum sensing and will pave the way for groundbreaking observations of everything from petroleum reserves to global supplies of fresh water.

Earth's gravitational field is dynamic, changing each day as geologic processes redistribute mass across our planet's surface. The greater the mass, the greater the gravity.

You wouldn't notice these subtle changes in gravity as you go about your day, but with sensitive tools called gravity gradiometers, scientists can map the nuances of Earth's gravitational field and correlate them to subterranean features like aquifers and mineral deposits. These gravity maps are essential for navigation, resource management, and national security.

"We could determine the mass of the Himalayas using atoms," said Jason Hyon, chief technologist for Earth Science at JPL and director of JPL's Quantum Space Innovation Center. Hyon and colleagues laid out the concepts behind their Quantum Gravity Gradiometer Pathfinder (QGGPf) instrument in a recent paper in EPJ Quantum Technology.

Gravity gradiometers track how fast an object in one location falls compared to an object falling just a short distance away. The difference in acceleration between these two free-falling objects, also known as test masses, corresponds to differences in gravitational strength. Test masses fall faster where gravity is stronger.

QGGPf will use two clouds of ultra-cold rubidium atoms as test masses. Cooled to a temperature near absolute zero, the particles in these clouds behave like waves. The quantum gravity gradiometer will measure the difference in acceleration between these matter waves to locate gravitational anomalies.

Using clouds of ultra-cold atoms as test masses is ideal for ensuring that space-based gravity measurements remain accurate over long periods of time, explained Sheng-wey Chiow, an experimental physicist at JPL. "With atoms, I can guarantee that every measurement will be the same. We are less sensitive to environmental effects."

Using atoms as test masses also makes it possible to measure gravity with a compact instrument aboard a single spacecraft. QGGPf will be around 0.25 cubic meters (0.3 cubic yards) in volume and weigh only about 125 kilograms (275 pounds), smaller and lighter than traditional space-based gravity instruments.

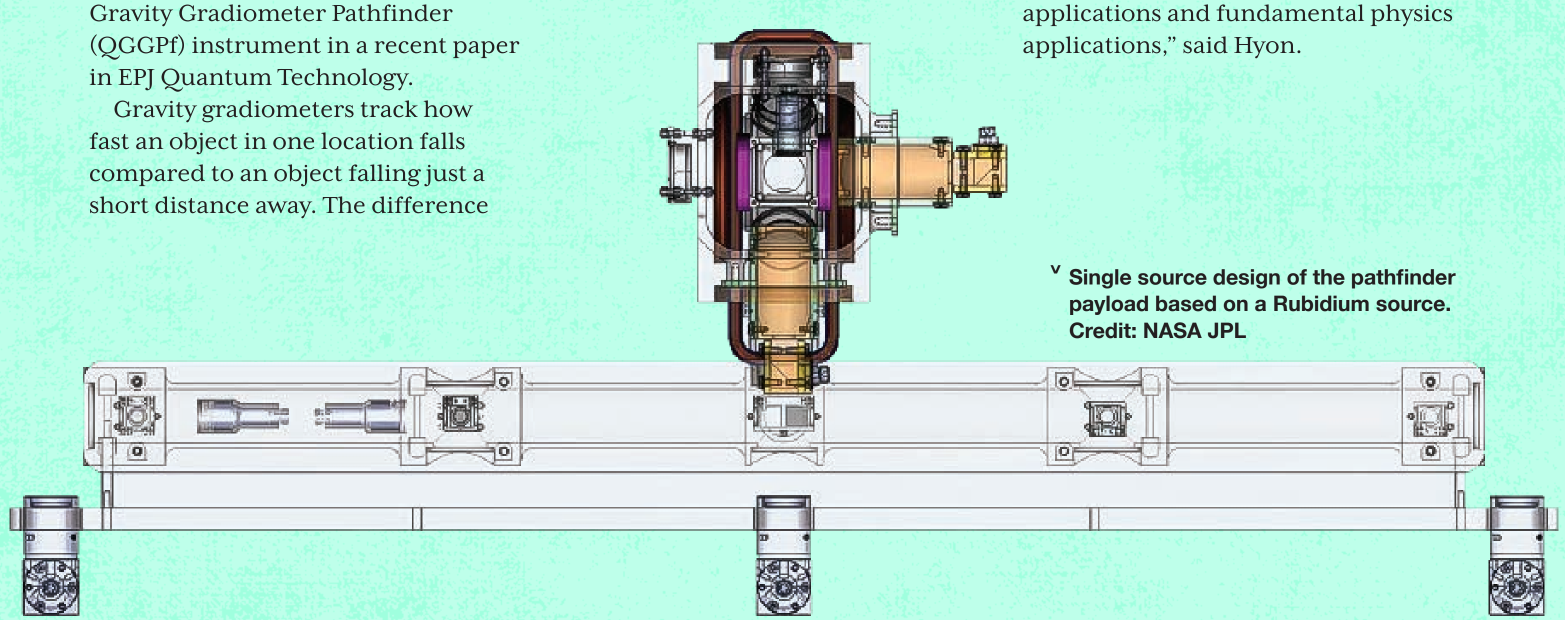
Quantum sensors also have the potential for increased sensitivity. By some estimates, a science-grade quantum gravity gradiometer instrument could be as much as ten times more sensitive at measuring gravity than classical sensors.

The main purpose of this technology validation mission, scheduled to launch near the end of the decade, will be to test a collection of novel technologies for manipulating interactions between light and matter at the atomic scale.

"No one has tried to fly one of these instruments yet," said Ben Stray, a postdoctoral researcher at JPL. "We need to fly it so that we can figure out how well it will operate, and that will allow us to not only advance the quantum gravity gradiometer, but also quantum technology in general."

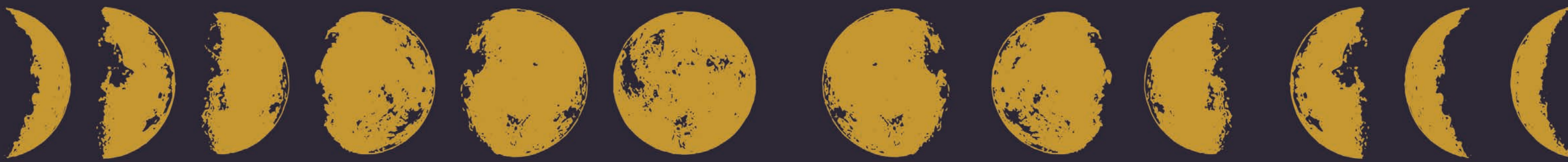
This technology development project involves significant collaborations with small businesses to advance the sensor head technology and the laser optical system.

Ultimately, the innovations achieved during this pathfinder mission could enhance our ability to study Earth, and our ability to understand distant planets and the role gravity plays in shaping the cosmos. "The QGGPf instrument will lead to planetary science applications and fundamental physics applications," said Hyon.



˅ Single source design of the pathfinder payload based on a Rubidium source. Credit: NASA JPL

LUNAR CALIBRATIONS



˅ The Arcstone spacecraft with solar panels installed as it is tested before being integrated for launch. Credit: Blue Canyon Technologies

In Summer 2025, NASA launched a one-of-a-kind instrument, called Arcstone, to improve the quality of data from Earth-viewing sensors in orbit. In this technology demonstration, the mission will measure sunlight reflected from the Moon— a technique called lunar calibration. Such measurements of lunar spectral reflectance can ultimately be used to set a high-accuracy, universal standard for use across the international scientific community and commercial space industry.

To ensure satellite and airborne sensors are working properly, researchers calibrate them by comparing the sensor measurements against a known standard measurement. Arcstone will be the first mission exclusively dedicated to measuring lunar reflectance from space as a way to calibrate and improve science data collected by Earth-viewing, in-orbit instruments.

"One of the most challenging tasks in remote sensing from space is achieving required instrument calibration accuracy on-orbit," said Constantine Lukashin, principal investigator for the Arcstone mission and physical scientist at NASA's Langley Research Center in Hampton, Virginia. "The Moon is an excellent and available calibration source beyond Earth's atmosphere. The light reflected off the Moon is extremely stable and measurable at a very high level of detail. Arcstone's goal is to improve the accuracy of lunar calibration to increase the quality of spaceborne remote sensing data products for generations to come."

Across its planned mission, Arcstone will use a spectrometer — a scientific instrument that measures and analyzes light by separating it into its constituent wavelengths, or spectrum — to measure lunar spectral reflectance.

"The mission demonstrates a new, more cost-efficient instrument design, hardware performance, operations, and data processing to achieve high-accuracy reference measurements of lunar spectral reflectance," said Lukashin.

Measurements of lunar reflectance taken from Earth's surface can be affected by interference from the atmosphere, which can complicate calibration efforts. Researchers already use the Sun and Moon to calibrate spaceborne instruments, but not at a level of precision and agreement that could come from having a universal standard.

Lukashin and colleagues want to increase calibration accuracy by getting above the atmosphere to measure reflected solar wavelengths in a way that provides a stable and universal calibration source. Another recent NASA mission, called the Airborne Lunar Spectral Irradiance mission also used sensors mounted on high-altitude aircraft to improve lunar irradiance measurements from planes.

There is not an internationally accepted standard (SI-traceable) calibration for lunar reflectance from space across the scientific community or the commercial space industry.

"Dedicated radiometric characterization measurements of the Moon have never been acquired from a space-based platform," said Thomas Stone, co-investigator for Arcstone and scientist at the U.S. Geological Survey (USGS). "A high-accuracy, SI-traceable lunar calibration system enables several important capabilities for space-based Earth observing missions such as calibrating datasets against a common reference – the Moon, calibrating sensors on-orbit, and the ability to bridge gaps in past datasets."

If the initial Arcstone technology demonstration is successful, a longer Arcstone mission could allow scientists to make the Moon the preferred reference standard for many other satellites. The new calibration standard could also be applied retroactively to previous Earth data records to improve their accuracy or fill in data gaps for data fields. It could also improve high-precision sensor performance on-orbit, which is critical for calibrating instruments that may be sensitive to degradation or hardware breakdown over time in space.

"Earth observations from space play a critical role in monitoring the environmental health of our planet," said Stone. "Lunar calibration is a robust and cost-effective way to achieve high accuracy and inter-consistency of Earth observation datasets, enabling more accurate assessments of Earth's current state and more reliable predictions of future trends."

THE WEIGHT of CLOUDS

In 2018, NASA's RainCube instrument paved the way for cost-efficient commercial weather missions. Now, NASA is building on that success to create CloudCube, a next-generation radar instrument that will significantly improve our ability to forecast precipitation and severe weather.

Developed with ESTO support, CloudCube features a multi-frequency radar configuration that transmits Ka-band, W-band, and G-band signals from a single antenna. Designed to fit aboard an ESPA-class small satellite, CloudCube will be one of the first compact radar instruments capable of probing weather systems with multiple radar signals simultaneously.

These multi-scale measurements will make it easier for researchers to collect information about dynamic cloud systems, increasing the accuracy of weather forecasts and models.

"We're making a low-power, low-mass instrument to facilitate new cost-efficient missions for atmospheric observations. Doing a multi-frequency radar, especially with G-band, is pretty novel," said Raquel Monje, a systems engineer at JPL and principal investigator for CloudCube.

Monje explained that there are relatively few instruments in space dedicated to observing weather with active radar instruments. Those that are in orbit tend to operate within a single frequency, like Ka-band for precipitation profiles or W-band for measuring cloud particles.

To date, no G-band radar has ever been flown in space. This high-frequency radar signal is ideal for measuring liquid water content in shallow clouds, a key variable in weather predictions and precipitation forecasts.

"Basically, we're weighing clouds using these combinations of frequencies in a way that we couldn't do before we had the G-band," said Matt Lebsock, a researcher at NASA's Jet Propulsion Laboratory (JPL) and co-investigator for CloudCube.

To fly all three radar instruments aboard the same compact satellite would be an unprecedented feat. RainCube ushered in a new era of commercial weather missions, and CloudCube could make those commercial missions even more useful to data users and emergency managers.

CloudCube leverages several technology innovations to produce multi-scale radar measurements from a compact platform. First, the instrument features a multifrequency feed horn that eliminates the need for separate antennas for each signal.

Second, CloudCube employs a novel, miniaturized radar architecture that requires less power and takes up less space than previous atmospheric radar instruments. This reduces the cost of dispatching high-frequency radars into space aboard small satellites, without reducing data quality.

Like RainCube before it, CloudCube opens the door to advanced remote sensing capabilities, setting the stage for next-generation commercial weather missions even better equipped to forecast weather events and severe storms than they are today.

"This technology could have phenomenal commercial applications," said Pavlos Kollias, an atmospheric scientist at Stony Brook University and collaborator for CloudCube, adding that the miniaturized G-band alone could be valuable not just for weather prediction, but also medical devices and other consumer products.

"This will affect every aspect of weather prediction," said Kollias.

Last year, CloudCube participated in the Eastern Pacific Cloud Aerosol Precipitation Experiment (EPCAPE), a ground campaign sponsored by the Department of Energy. A paper describing the results of their experiment was published in the journal of Earth System Science Data.

Most recently, the CloudCube team validated their instrument design in a ground campaign in Tasmania and is now working on a flight-ready prototype.

TOWARD METAMATERIAL SENSORS

Water droplets in burgeoning storm systems; particulates launched to the stratosphere by volcanic eruptions; ash from western wildfires drifting eastwards across the continental U.S. Aerosols such as these impact everything from severe weather to air quality. Polarimeters, which characterize aerosols and cloud particles by observing how they interact with light, are scientists' best tool for understanding the massive role these tiny particles play in atmospheric events.

But while there are many airborne polarimeters available to scientists, only a few of these instruments have ever flown in space. NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission, launched in 2024, marked the first space-based science mission featuring polarimetry in over a decade.

Kirk Knobelspiesse, an atmospheric scientist at NASA's Goddard Space Flight Center, explained that creating advanced polarimeters to study the atmosphere is essential for studying Earth's climate. "The composition of aerosols, the shape, the size – that's something that we really need to understand better to improve climate modeling," Knobelspiesse said.

A team of researchers from the Capasso Group at Harvard University, supported by ESTO, recently completed an early concept study exploring a new technology for space-based polarimetry. Specifically, the team investigated whether a novel polarization-sensitive metasurface optical element might be useful for observing atmospheric particles.

The study, which spawned papers in Optics Express and Applied Optics, concluded that this metasurface optical element can reliably detect polarized light within the 550, 670, and 870 nanometer wavelengths, ideal light signatures for observing aerosols and clouds particles.

"I think all of this will play well for the long-term plans of NASA," said Federico Capasso, the Robert Wallace Professor of Applied Physics at Harvard and Principal Investigator for this project.

Traditional optics, like lenses in a telescope, rely on a material's bulk properties to control observed light. Metasurface optics, on the other hand, rely on complex arrays of micrometer-sized structures arranged in a grating pattern across a flat surface. The spacing and shape of these structures modifies the phase and polarization of light reaching the detector.

Also known as flat optics, metasurface optics are lighter and smaller than their traditional counterparts, making them less expensive to send into orbit. As NASA plans future Earth science missions, metasurface optics could be key to building a new generation of compact polarimeters.

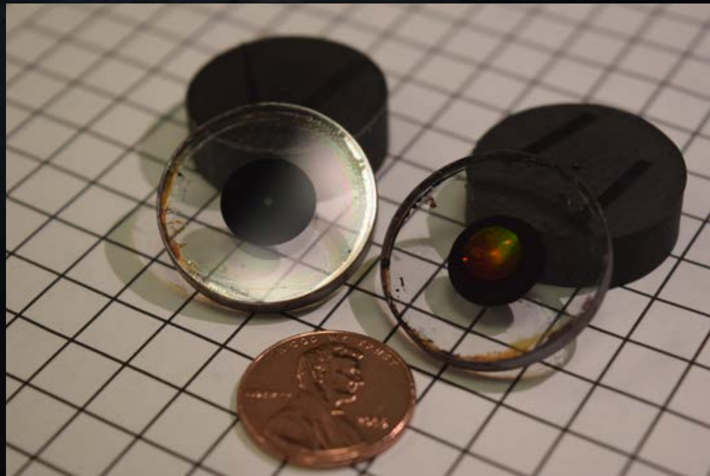
"The size, weight, and mass production possibility are often quoted as advantages for metasurface optics," said Lisa Li, a former member of the Capasso Group who played a key role in manufacturing this unique metasurface. Lighter, smaller components easily produced at scale can reduce the overall cost of a science mission.

What makes Capasso's metamaterial unique is its bespoke grating pattern– etched across a silica glass substrate– which splits an observed scene into distinct polarization channels. This ability to discriminate between polarization states without bulky subsystems could allow researchers to produce a complete polarimetric system, a polarization sorter and an imager, within a single element.

Noah Rubin, another former member of the Capasso Group and a Co-Investigator for this project, explained that this was the key achievement of their project: proving that their metasurface grating could measure signatures of polarized light with the accuracy researchers would require from a space-ready science instrument.

"We realized it would be possible to make, essentially, what we call a flat polarimeter," said Rubin.

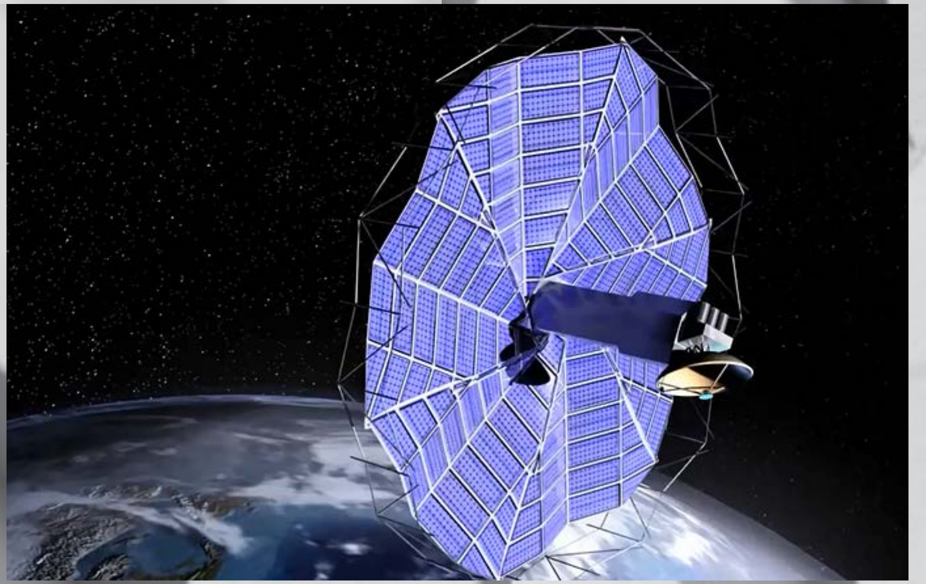
There is still much work to be done before NASA has a flight-ready metasurface polarimeter at its disposal, but, Rubin said, this early work sponsored by ESTO's Instrument Incubation Program produced a scientific bedrock on which future metasurface breakthroughs will rely. "I'd like to extend some of this work, some of this polarization sensitive imaging, to include long wave infrared light, which is a very important wavelength regime for ice cloud remote sensing," he said.



˅ **A photograph of two fully fabricated flat polarimeter samples. Metasurfaces could become the foundation for future, ultra-light instruments, including space-based polarimeters. Credit: Capasso Group.**

UNFOLDING NEW SCIENCE

˅ A illustration of a future MoDEL-T instrument Credit: Ux Connections



A team of researchers at NASA's Goddard Space Flight Center are taking cues from the ancient Japanese art of paper folding to develop a compact deployable telescope, which could dramatically reduce the cost of sending lidar missions into space.

The "Metalens Origami Deployable Lidar Telescope (MODeL-T)," developed with support from ESTO, would be a composite lens made of more than 50 segments that fold together to form a cooler-sized cube. In space, that compact cube would unfold into a flat, star-shaped structure nearly two meters wide, tailored to shuttle direct captured lidar signals towards a receiver. Compact at launch and large in space, MODeL-T could allow small space craft to host lidar instruments as powerful as those found on larger, more expensive platforms.

Compact lidar systems equipped with MODeL-T would fit aboard ESPA-class satellites, allowing scientists to take advantage of cost-efficient rideshare launch opportunities. Compared to previous missions, lidar equipped with MODeL-T could reduce the cost of space-based lidar by as much as a factor of 20.

"It's like moving from launching a large refrigerator into orbit to launching a suitcase," said Mark Stephen, a Research Engineer at GSFC and Principal Investigator for MODeL-T.

Stephen, who helped develop the lidar instruments for ICESat and ICESat-2, explained that MODeL-T would replace the large receiver telescopes traditional lidar instruments rely on to capture photons and guide them towards a detector, which are essentially empty tubes with large beryllium optics.

MODeL-T would be smaller than these traditional telescopes at launch, but larger once deployed. Whereas the telescope aboard ICESat-2 has an aperture one meter wide and takes up 400 liters of stowed space, MODeL-T would have an aperture 1.8 meters wide and take up just 100 liters of stowed space.

Larger apertures mean more photons reach a lidar detector, which improves data resolution and lowers the power requirements for lidar transmitters. If fewer photons are lost more return photons are captured per laser pulse, a lidar instrument can employ a smaller, lighter laser without sacrificing an effective signal-to-noise ratio.

To develop MODeL-T, Stephen's team overcame two significant technology hurdles: first, finding a flat, foldable material that manipulates light with the same reliability as traditional bulk optics; second, creating a lightweight mechanism for unfolding that flat material once in space.

Xingjie Ni, Associate Professor of Electrical Engineering at Pennsylvania State University, led the development of the foldable metamaterial optic, while Larry Howell, Associate Academic Vice President and Professor at Brigham Young University, led the development of the deployment mechanism.

Metamaterials use complex arrays of sub-micrometer-sized structures arranged across a flat surface to manipulate light. Ni, a metamaterials expert, said producing a metamaterial split across more than 50 unique elements that operate as a single, unified aperture was a rewarding challenge.

"I think that's why we are very excited about this. We can make this metamaterial big enough that it can be used for space applications, in a way that no one else has done before," Ni said.

Howell, who specializes in deployment mechanisms, said that the toughest challenge of this particular project has been ensuring the unfolded metamaterial segments are deploy perfectly aligned.

"We've done deployable solar panels, for example, and if you're off by a degree or two, it doesn't really impact performance. Here, the margin for error is much smaller," Howell said.

Each of these key components–the metamaterial optic and the deployment mechanism–have been demonstrated in a laboratory environment. Now, Stephen and his team are working to incorporate them within a single prototype.

"Lowering the cost of space-based lidar, turning this into an operational tool where we're getting more science data, that's really what I hope to achieve out of it all," said Stephen.

PRECISION FROM HIGH ALTITUDE

Long before a volcano erupts or a mountainous snowpack disappears, millimeter-scale changes in Earth's surface indicate larger geologic processes are at work. But detecting those minute changes, which can serve as early warnings for impending disasters, is difficult.

With support from ESTO a team of researchers from the small aerospace company Aloft Sensing is developing a compact radar instrument for observing Earth's surface deformation, topography, and vegetation with unprecedented precision.

Their project, "HALE InSAR," has demonstrated the feasibility of using high-altitude, long-endurance (HALE) vehicles equipped with Interferometric Synthetic Aperture Radar (InSAR) to observe changes in surface deformation mere millimeters in size and terrain information with centimetric vertical accuracy.

"It's a level of sensitivity that has eluded traditional radar sensors, without making them bulky and expensive," said Lauren Wye, CEO of Aloft Sensing and principal investigator for HALE InSAR.

HALE vehicles are lightweight aircraft designed to stay airborne for extended periods of time, from weeks to months and even years. These vehicles can revisit a scene multiple times an hour, making them ideal for locating subtle changes in an area's geologic environment.

InSAR, a remote sensing technique that compares multiple images of the same scene to detect changes in surface topography or determine structure, is also uniquely well-suited to locate these clues. But traditional InSAR instruments are typically too large to fly aboard HALE vehicles.

HALE InSAR is different. The instrument is compact enough for a variety of HALE vehicles, weighing less than seven kilograms (15 pounds) and consuming fewer than 300 watts of power, about as much energy as it takes to power an electric bike.

HALE InSAR leverages previously-funded NASA technologies to make such detailed measurements from a small platform: a novel electronically steered antenna and advanced positioning algorithms embedded within an agile software-defined transceiver. These technologies were developed under ESTO's Instrument Incubation Program (IIP) and Decadal Survey Incubation (DSI) Program, respectively.

"All of the design features that we've built into the instrument are starting to showcase themselves and highlight why this payload in particular is distinct from what other small radars might be looking to achieve," said Wye.

One of those features is a flat phased array antenna, which gives users the ability to focus HALE InSAR's radar beam without physically moving the instrument. Using a panel about the size of a tablet computer, operators can steer the beam electronically, eliminating the need for gimbles and other heavy components, which helps enable the instrument's reduced size and weight.

"SAR needs to look to the side. Our instrument can be mounted straight down, but look left and right on every other pulse such that we're collecting a left-looking SAR image and a right-looking SAR image essentially simultaneously. It opens up opportunities for the most mass-constrained types of stratospheric vehicles," said Wye.

Using advanced positioning algorithms, HALE InSAR also has the unique ability to locate itself without GPS, relying instead on feedback from its own radar signals to determine its position even more accurately. Brian Pollard, Chief Engineer at Aloft Sensing and co-investigator for HALE InSAR, explained that precise positioning is essential for creating high-resolution data about surface deformation and topography.

"SAR is like a long exposure camera, except with radio waves. Your exposure time could be a minute or two long, so you can imagine how much smearing goes on if you don't know exactly where the radar is," said Pollard.

Navigating without GPS also makes HALE InSAR ideal for field missions in austere environments where reliable GPS signals may be unavailable, increasing the instrument's utility for national security applications and science missions in remote locations.

The Aloft Sensing team recently achieved several key milestones, validating their instrument aboard an airship at 65,000 feet as well as small stratospheric balloons. Next, they'll test HALE InSAR aboard a fixed wing HALE aircraft. A future version of their instrument could even find its way into low Earth orbit on a small satellite.

Wye credits NASA support for helping her company turn a prototype into a proven instrument.

"This technology has been critically enabled by ESTO, and the benefit to science and civil applications is huge," said Wye. "It also exemplifies the dual-use potential enabled by NASA-funded research. We are seeing significant military interest in this capability now that it is reaching maturity. As a small business, we need this hand-in-hand approach to be able to succeed."

HALE InSAR flies aboard a high-altitude balloon during a test-flight. This lightweight instrument will help researchers measure ground deformation and dynamic Earth systems. Credit: Aloft Sensing

DRIVING THE QUANTUM FUTURE

As a future capability, quantum technologies have the potential to revolutionize the accuracy and precision of science measurements. By utilizing various properties of quantum mechanics — entanglement, superposition, interference, squeezing, etc. — quantum sensing technologies may offer significant advantages over traditional sensing methods, reducing measurement uncertainties and potentially lowering size, weight, power, and cost of future missions. ESTO technology investments also serve the national goal to establish U.S. quantum leadership. Below are some of the investments ESTO has made in our quantum future.

Quantum Gravity Measurements

NASA's Quantum Gravity Gradiometer Pathfinder (QGGPf) mission will mark the first time a quantum sensor has flown in space to measure gravity. Equipped with a first-of-its-kind atom interferometer, it will allow researchers to detect petroleum reserves, freshwater aquifers, and other natural resources with unprecedented precision. Pursuing this mission will not only establish the United States as the world leader in space-based quantum sensing, but also open the door to future science missions that could dramatically impact the way we understand our planet.

Enabling Lasers

A key component of atom interferometry is the laser subsystem, which allows scientists to cajole clouds of atoms into measurable states. Two ESTO projects are exploring potential lasers for QGGPf and other quantum sensors. One, led by Matthew Cashen, Chief Scientist at the small business Vector Atomic, explores a rubidium based laser subsystem. The other, led by Kurt Vogel, Chief Technology Officer at the small business Vescent Photonics, explores a cesium-based laser subsystem. Both projects will help inform the final QGGPf design, as well as future improvements to existing quantum sensors like atomic clocks.

Low-Power Acousto-Optics

To better control lasers for manipulating atoms, Peter Rakich, Professor of Applied Physics at Yale University, is working on an integrated acousto-optical modulator that leverages cutting-edge semiconductor technology to guide lasers more efficiently. It will offer an alternative to free-space acousto-optic frequency shifters, which tend to be bulky and require lots of energy to function. Rakich's acousto-optical modulator will reduce the overall energy requirements of QGGPf from 300 watts to less than 50 watts. Ultimately, this also reduces the overall size of the instrument and the cost of sending it to space.

Encapsulating Quantum

Manipulating atoms in zero gravity requires a pristine environment. A research team led by Eric Bottomley, Senior Physicist at the small business Infleqtion, will build a novel vapor cell to precisely control atoms for Rydberg radars. The project will prototype different integrated structures to replace the glass vials currently used for containing Rydberg atoms, increasing the system's space readiness. This component will also include an optimized dual purpose of radio-frequency waveguiding and laser-induced fluorescence, both of which would improve a Rydberg radar's ability to observe Earth's surface and atmosphere.

Quantum Enhanced Neural Networks

Eleanor Rieffel, Senior Research Scientist at NASA's Ames Research Center, will explore whether cutting-edge machine learning techniques could train a collection of neural networks to solve partial differential equations on quantum computers. In scenarios where underlying processes aren't fully understood, these neural networks could enable pattern discovery and predictive modelling, which would be especially useful for studying fluid dynamics and ocean processes.

Signal in the Noise

Xiaomei Lu, a Research Scientist at NASA's Langley Research Center, will leverage quantum annealing to prototype a new technique for increasing the signal-to-noise ratio in space-based lidar instruments. Lu, who also served on the science team for the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission, will use lidar data from CALIPSO to test her technique. Once proven, it will dramatically reduce the cost of dispatching lidar into low Earth orbit.

High-Dimensional Spaces

Alexandre Guillame, a researcher at NASA's Jet Propulsion Laboratory, will create a quantum computing framework for improving our ability to model cloud physics. Using quantum sampling, Guillame and his team hope to outperform traditional Markov Chain Monte Carlo methods when modelling high-dimensional spaces. This work marks a significant step forward for using quantum computing to model weather.

Real Time Fire Data

Credit: Urban Sky

An aerospace startup is working with NASA to create a new tool for observing wildfires from the stratosphere, setting the stage for a future in which first responders will have consistent, secure access to real-time data describing active burns.

Urban Sky, based in Denver, Colorado, is using a grant from ESTO's FireSense Technology (FireTech) program to create a balloon-based thermal infrared sensor that can spot a nascent wildfire from its perch 11 miles (18 kilometers) above the surface. The sensor, known as "Hot Spot," can scan 3,000 acres of wilderness in a single minute with a spatial resolution of 5 meters per pixel. It also features a communications system that will help fire fighters stay in touch with one another and their main base of operations.

Using AI algorithms, the system will also be capable of automatically identifying and downlinking particularly useful data to first responders, as well as charting its own flight path.

Urban Sky has spent the past six years developing instrument payloads for stratospheric balloons. These balloons are quick to deploy and can stay aloft for days at a time, providing end users with a steady stream of surface data.

For fire prone areas, these balloon-based sensors could serve as a near-constant lookout for wildfires. In an emergency, they could be dispatched to provide firefighters with a birds-eye view of the fire they're fighting and a reliable communications system for receiving new data.

Hot Spot includes a compact multispectral imager with a modified sensor array that will allow the instrument to better differentiate between thermal signatures from wildfires and thermal signatures from non-fire sources. The new imager will also help Hot Spot better measure the health and density of an area's surface vegetation – a key variable for forecasting wildfire risk.

The mesh communications antenna, produced by a partner company, is tiny, weighing about as much as a AAA battery and taking up about the same amount of volume as a sugar cube. But it'll have a huge impact on firefighters' ability to receive and share new information about a fire.

"Through this communications hub, we'll not only enable web-connected communication, but also direct communication to firefighters in the field, so they can see the data that's being generated with our system," explained Jared Leidich, co-founder and Chief Technology Officer at Urban Sky and principal investigator for Hot Spot.

Urban Sky has already validated much of its Hot Spot hardware. The team is finishing up several software components, including a visualization tool to display gathered wildfire data in an intuitive, user-friendly way.

Without FireTech funding, this novel sensor for observing wildfires wouldn't exist. As a key element of NASA's FireSense program, FireTech bridges the gap between technology producers and end users, validating new tools for wildfire management through comprehensive field campaigns and working closely with wildfire managers to make sure these tools suit their needs.

"Very genuinely, FireTech enabled this system to exist," Leidich said.

Tech Demos On Orbit

ESTO validates new technologies in the harsh environment of space with the aim to reduce the overall risk of incorporating new technologies into future Earth science missions. Recent advancements in small, standardized satellites and low-cost access to space have transformed the way technologies are demonstrated and validated. Meaningful risk reduction for hardware components and information systems can be accomplished quickly for future flight instruments. Here are some recent highlights:

Launched in FY25

ARGOS

The Aerosol Radiometer for Global Observation of the Stratosphere (ARGOS), launched March 14, 2025, is a hosted payload instrument that is testing a new technique for observing atmospheric aerosols. Leveraging eight distinct limb views, the compact instrument will be useful for understanding how wildfires, volcanoes, and severe weather events might affect aerosols.

Arcstone

Arcstone, launched June 23, 2025, is testing a new on-orbit calibration technique using the Moon as a reference to ensure space-based Earth science instruments remain accurate over time. From a 6-unit CubeSat, the hyperspectral instrument will provide lunar spectral reflectance measurements needed to establish an absolute lunar calibration standard for past, current, and future Earth observing sensors.

Dynamic Targeting

Dynamic Targeting is a new AI-driven capability that enables satellites to analyze imagery onboard and autonomously decide where to point their instruments. Demonstrated on the CogniSAT-6 CubeSat, the system can look ahead along the spacecraft's orbit, detect clouds in real time, and capture only clear-sky imagery—all in under 90 seconds. This approach increases the amount of usable data returned from orbit and paves the way for future autonomous targeting of short-lived events such as storms, wildfires, and volcanic eruptions.

Launching in FY26

SUM Component

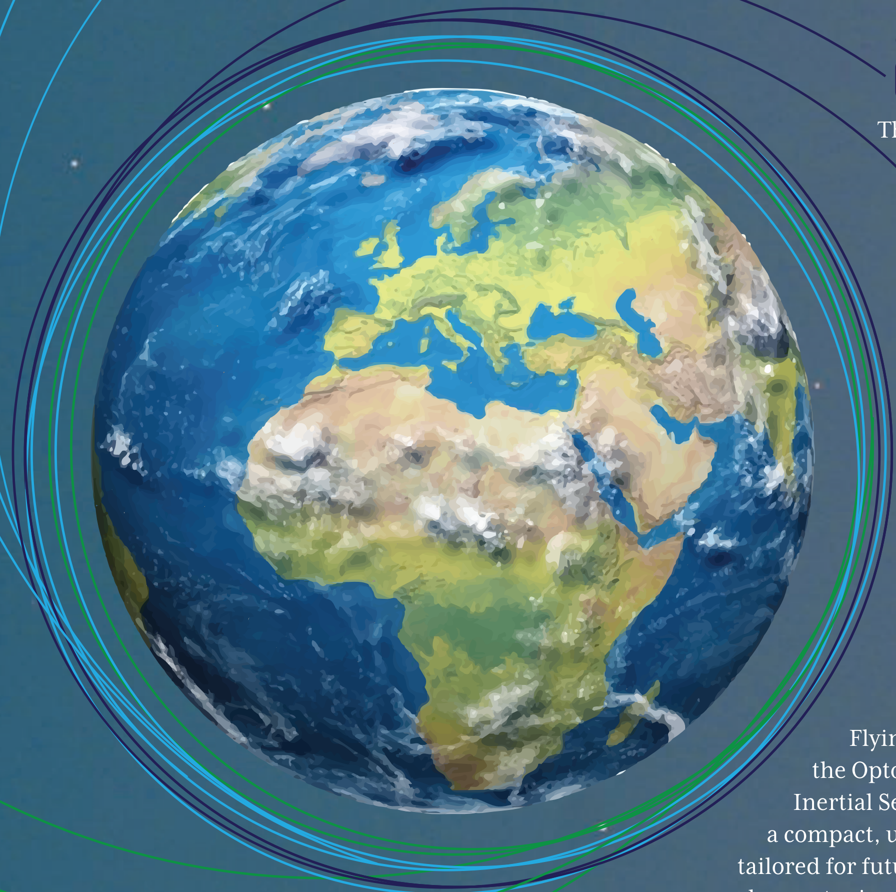
A specialized joint will be demonstrated in space for a Solid Underconstrained Multi-Frequency (SUM) deployable antenna. The overall project is developing a large (2.4 m), multi-segment, parabolic aperture that can deploy from a compact volume, enabling low-cost constellations of radars and radiometers for a variety of Earth and planetary observations.

GRITTS

The Geodetic Reference Instrument Transponder for Small Satellites (GRITTS) will verify a new geodetic measurement concept on a 16-unit CubeSat. Functioning as a GNSS L-to-S-and-X-band transponder, GRITTS could pave the way for a more cost-effective mission, employing a constellation of spacecraft for better global coverage and improved accuracy.

ACMES

Also a 16-unit CubeSat, the Active Cooling for Multispectral Sensor (ACMES) instrument will prototype a complete end-to-end solution for active thermal control of cryogenic instruments on nano- and small-satellites, using the previously developed Hyperspectral Thermal Imager (HyTI) as its test instrument. ACMES will also fly two student projects: the Filter Incidence Narrow-band Infrared Spectrometer (FINIS); and the Planer Langmuir/Impedance Diagnostic (PLAID).



Launching in FY27

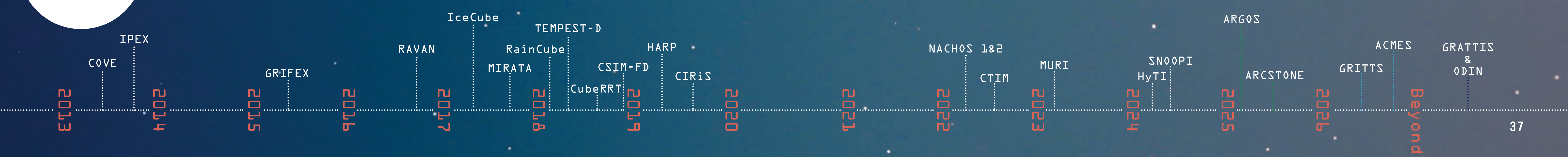
GRATTIS

The Gravitational Reference Advanced Technology Test In Space (GRATTIS) mission will flight-test the Simplified Gravitational Reference Sensor (S-GRS), a precision inertial sensor essential for future Earth geodesy missions. By validating S-GRS performance in orbit, GRATTIS will enable the use of a domestically produced, higher-precision sensor designed for drag-compensated operations.

ODIN

Flying as a secondary payload with GRATTIS, the Optomechanical Distributed Instrument for Inertial Sensing and Navigation (ODIN) will deliver a compact, ultra-sensitive inertial sensing system tailored for future mass-change missions. High-precision accelerometry is essential for detecting subtle shifts in Earth's gravity field, and ODIN offers a low-cost, low-SWaP approach to meeting this need.

Timeline of ESTO Launches



STUDENT SPOTLIGHT FY25

Students are integral to the work and success of technology development teams. Since ESTO's founding, at least 1,415 students from 186 institutions have worked on various ESTO-funded projects. Aided by their experiences, these students have often gone on to work in the aerospace industry and in related fields. In FY25 alone, at least 282 students from 74 institutions were involved with active technology development projects.

Phoebe Pan

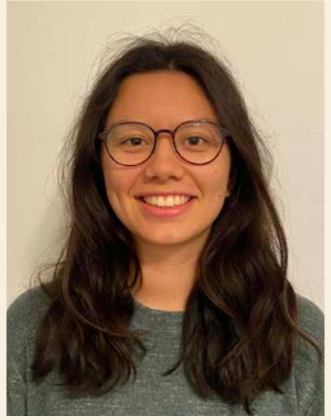
Phoebe Pan is a freshman at Harvard University, where she plans to study Computer Science and Human Developmental and Regenerative Biology. Supporting Chaowei Yang's AIST project, Pan helped create a Generative Adversarial Network (GAN) for missing aerosol optical depth data manipulation and managed an independent research project that investigated new techniques for predicting PM2.5 pollution emitted by wildfires. "Working on this project helped me realize how much I enjoy applying computational techniques to solve real-world problems," Pan said. Pan is also an avid artist and crafter, and she recently started playing the steelpan.

Humphrey Chen

Humphrey Chen recently graduated from the University of California, Davis, with his PhD in Electrical Engineering. Supporting Ben Yoo's IIP project, Chen helped design and fabricate Photonic Integrated Circuits (PICs). He also worked on measurement and assembly test beds for the PIC designs. "The experience I gained from the project has greatly enhanced my skills, allowing me to quickly measure PIC-based systems and work towards higher TRL scientific instruments," said Chen. Chen's hobbies include art, especially ceramics, and weightlifting.

Aashish Panta

Aashish Panta is a fifth year PhD student at the University of Utah. As a member of Kyo Lee's AIST project, Panta leveraged his expertise in artificial intelligence to help build integrated retrieval-augmented generation pipelines to help process large Earth science data sets more efficiently. "These experiences, as a whole, helped me develop the ability to design scalable AI-driven systems for scientific data, work collaboratively across disciplines and turn research into impactful solutions," Panta said. In his free time, Panta enjoys soccer, hiking, skiing, and traveling.



Leila Freitag

Leila Freitag is a third-year graduate student at MIT, where she studies mechanical engineering. Supporting John Leckey's SPECIES project, which aims to create deployable diffractive optics for low-SWaP, space-based lidar, Freitag developed a custom model to assess system design tradeoffs and choices. The model uses signal-to-noise ratio as a performance metric, and it will be used to help inform feasible mission architectures. Freitag is also analyzing ground-based lidar data gathered by teammates at NASA's Langley Research Center. "I really value John's mentorship and career advice," she said, adding that she'd like to leverage her experience with NASA to continue researching exciting problems after graduation. Outside of the lab, Freitag enjoys backpacking and making pottery.

Jaiden Luna

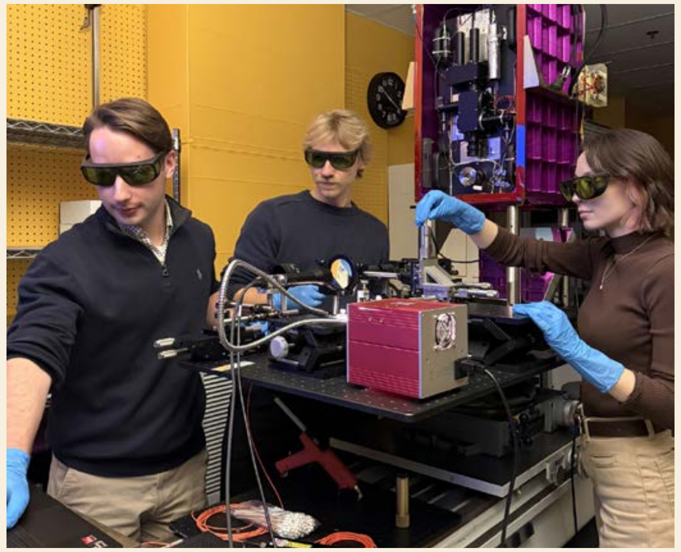
Jaiden Luna is a junior at California Polytechnic State University, where he majors in Aerospace Engineering. Supporting Sun Wong's FireTech project, Luna played an important role as the team integrated their instrument and prepared it for airborne flights, setting up the lab and preparing build instructions. Luna also helped design and assemble optical ground support equipment. "My experience has undoubtedly been a huge influence on my career trajectory and has been a great introduction to the field of optical engineering," said Luna. In his free time, Jaiden plays chess and tennis, and serves as the mechanical architect for his school's Poly1Rover team.

Laela Bitahey

Laela Bitahey is a sophomore engineering student at the University of Arizona. As a member of Meredith Kupinski's IIP team, Bitahey measured the transmission of float-zone silicon wafers and the noise equivalent differential temperature for the instrument's LWIR camera and fore optics. "As an Indigenous woman, this experience has reaffirmed my purpose to continue my education in science and engineering. I hope to carry the knowledge I've gained and give back to my community and continue to increase indigenous representation in STEM fields," said Bitahey. Bitahey enjoys volunteering, playing the cello, and collecting vinyl records.

GORDON Team

Three students have been working with Matthew McGill on his IIP project, Global Orbital Research with a Diurnal Observing Network (GORDON), an effort to produce a cost-efficient, spaceborne lidar instrument. The students, Jackson Begolka, Grant Finneman, and Sabrina Vlk, are all PhD students at the University of Iowa. Together, they have been developing interface control documents, testing lidar instrument components, developing data collection and processing algorithms, and testing the polarization sensitive camera. "IIP projects can provide excellent training opportunities for students, allowing them to gain hands-on experience while learning how projects are conceived and implemented," said McGill. "It should be a point of pride at ESTO that these three students will all use GORDON as part of their PhD theses."



Luke Jacobs

Luke Jacobs is a third-year PhD candidate in Electrical and Computer Engineering at the University of Illinois, Urbana-Champaign. Supporting Elahe Soltanaghai's FireTech project, Jacobs helped develop electromagnetic models of forests, as well as signal processing algorithms for drone-mounted radar systems dedicated to observing wildfires. "This experience helped me develop my research skills and understanding of radar physics," Jacobs said. In his free time, Jacobs enjoys reading and hosting Bible study with his friends.

NASA Beyond the Algorithm Challenge

Novel Computing Architectures for Flood Analysis

In September, ESTO sponsored NASA's Beyond the Algorithm Challenge Pitch Event, awarding $300,000 among three teams presenting novel solutions to improve flood water analysis using unconventional computing methods, especially those related to quantum computing.

The event concluded months of careful selection and competition between some of the finest universities, companies, and research institutions in the country. Ultimately, a panel of computing and quantum technology experts picked nine finalists to deliver live presentations describing their work. Of these nine, three received grants of $100,000 to turn their proposed flood water analysis projects into science-ready projects.

The three winners were "Neuromorphic Onboard Flood-mapping" (NEO-FLOOD); "Quantum Hyperdimensional Computing for Surface Water Signatures," from Case Western Reserve University and the University of Louisiana, Lafayette; and "Quantum Tensor Hydronauts" (QT-Hydro), from Deloitte Consulting, LLP.

After receiving their prize money, each team will participate in a "Funding 101" webinar course to prepare them to make best use of their award. The teams will also participate in a follow-up interview in 2026 to provide feedback for future competitions.

For more information about the event, the finalists, and NASA's Beyond the Algorithm, visit https://www.nasa-beyond-challenge.org.

National Aeronautics and Space Administration
Earth Science Technology Office
Earth Science Division, NASA Headquarters
Mary W. Jackson Building - 300 E St SW
Washington, DC 20546

www.esto.nasa.gov