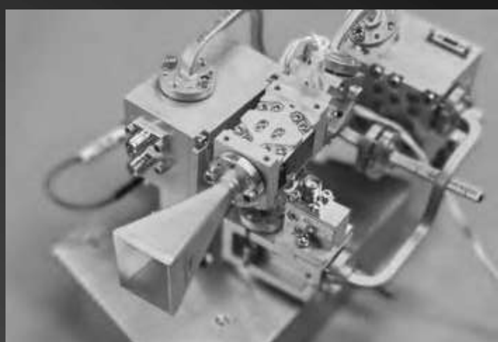
Advancing Technology

Earth Science Technology Office

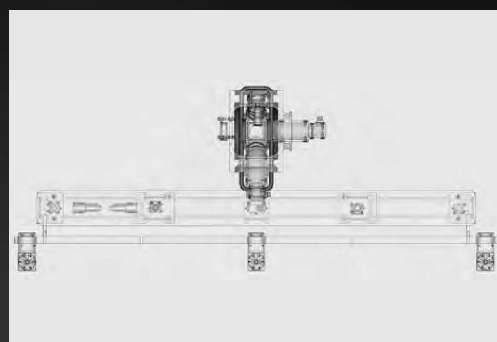
Mike Seablom, Associate Director

ESTO Projects Overview



Instrument Incubator

- Breakthrough Earth observing instrument and system technologies
- Decadal Survey high priority observables – Planetary Boundary Layer (PBL) and Surface Topography and Vegetation (STV)



Quantum Gravity (QG) Gradiometer

- Demonstrate critical technologies and observation technique
- Unprecedented, higher-accuracy measurements of Earth's gravitational field from a single satellite

Advanced Technology Initiatives

- On-orbit demonstrations through In-Space Validation of Earth Science Technologies (InVEST)
- Prizes and challenges in partnership with venture capital, and technology studies

Advanced Modeling Technology

- Breakthrough artificial intelligence, machine learning, and computational techniques

Key Technology Investment Areas

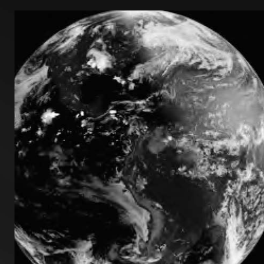
ESTO investments address a broad range of Earth observation needs. Maintaining some investment in all areas with increased investment in QG Gradiometry:

Electro Optical Earth Imaging

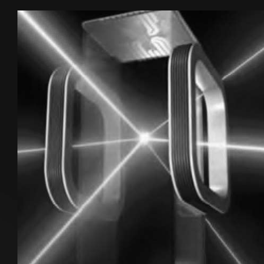
SW / MW / LW Infrared

Hyperspectral

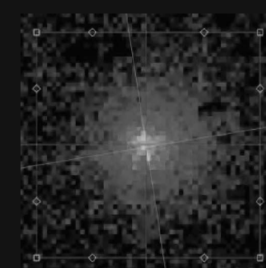
Multispectral



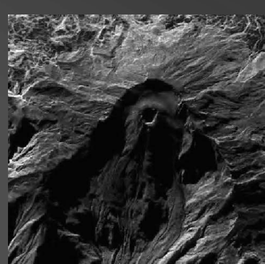
Quantum Sensing



Quantum Gravity Gradiometry



Radar



Laser / Lidar

Quantum Computing

AI / ML Modeling

Digital Twins

Decadal Survey Incubation (DSI): Building Future Earth Science Missions Today

Planetary Boundary Layer (PBL) – The connective tissue between Earth's surface and the free troposphere where 8 billion+ people live. Improved forecast models for better prediction of extreme weather, flooding, etc.

Surface Topography & Vegetation (STV): $1m^2$ global mapping of surface elevation and forests for resource management. Improved measurements of biomass fuels for wildfire, coastal changes/erosion

DSI = New Way for NASA ESD to do business: This program is a unique approach where ESTO (technology) and R&A (science) work closely together (DSI Program Manager + PBL/STV Program Scientists)

The goal of DSI is to develop novel, ambitious, and ground-breaking yet cost-effective technology partnered closely with science for missions in the 2030s.

PBL: Hyperspectral Microwave Sounding is the Future

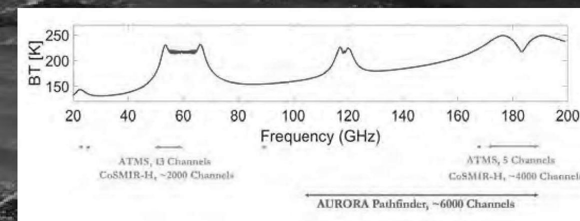
AURORA: Atmospheric Ultra-high Resolution Optical Radiometer

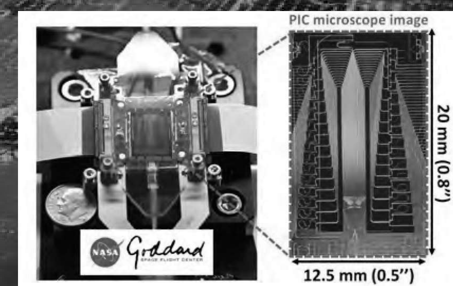
TRL 6 spaceborne instrument already in development at NASA GSFC. ATMS has 22 channels, AURORA will have ~2000 channels

Photonic Integrated Circuits (PICs) in space will allow for sounding profiles of temperature and water vapor in the window regions

Applications: Improved forecasts for severe weather, atmospheric rivers, flooding, PBL products will improve air quality forecasts

NOAA, ESA, and EUMETSAT have all expressed interest





PBL Architecture to include hyperspectral MW+IR and RO constellations for global coverage in combination with suborbital campaigns to understand PBL processes.

STV: Lidar, InSAR, and StereoImaging

CASALS: Concurrent Artificially Intelligent Spectrometry and Adaptive Lidar System Continues NASA's world-leading high precision laser altimetry expertise. Airborne version first flown in November 2024.

Work with commercial sector to combine optical imagery with high-precision laser altimetry to map the globe at meter scale

HALE InSAR: (High Altitude Long Endurance Interferometric Synthetic Aperture Radar An agile radar system for high resolution 3D surface topography and vegetation structure measurements from stratospheric and distributed platforms – measures sub-cm deformations in the Earth's crust for detection of earthquakes, landslides, etc.

Technology Highlight: Predicting What We Breathe

The City of Los Angeles used NASA data with machine learning to predict air quality in ways that can be acted upon to improve human health outcomes

Objective:

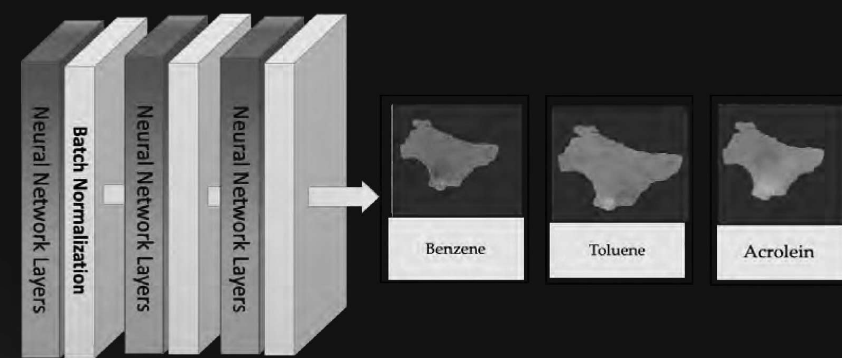
Develop machine learning (ML) algorithms to create predictive models for air quality based on measurements of 2.5 µm particulate matter ($PM_{2.5}$), Ozone, NOx and other air pollutants.

Develop a big data analytics algorithm for integrating ground and space data.

12 predictive models for predicting PM2.5, NO2, SO2, O3, CO, CO2 are developed & transferred to AWS to run on the cloud.

Build $PM_{2.5}$ stack for integrating ground and space data.

Create a model for Los Angeles with shared attributes to understand predictions and effective interventions that can be used in other cities.



Technology Highlight: AI-Enhanced Lidar

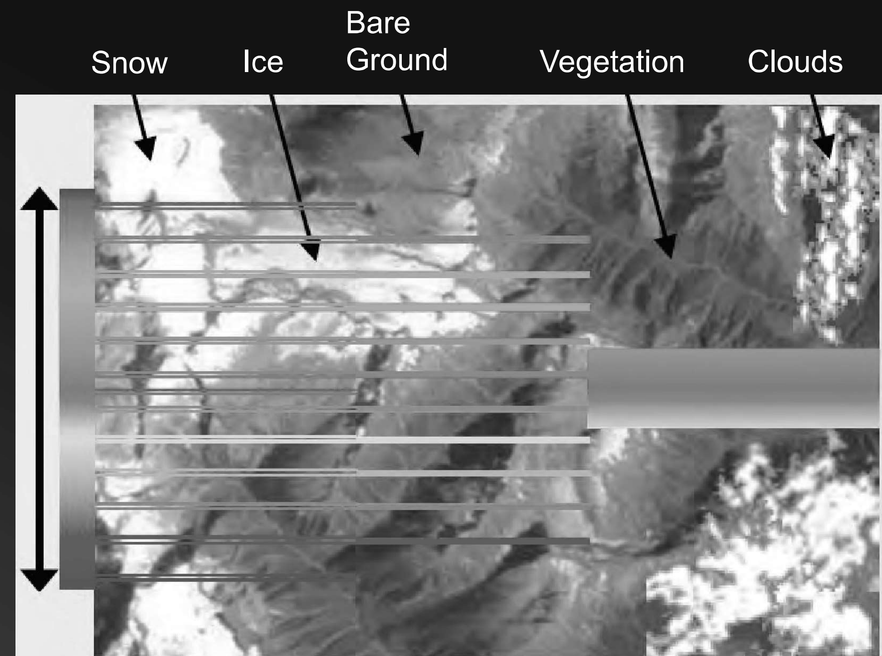
Goddard Space Flight Center is developing a highly efficient 1040nm lidar that uses multiple advanced technologies, including photonic integrated circuits, a linear-mode photon-sensitive detector array, and artificial intelligence.

Implementation of artificial intelligence:

Development of an observing system that integrates an adaptive lidar, concurrent hyperspectral imaging, and on-board AI technologies to measure structural and functional properties for topography, vegetation, snow, ice sheets, and the surface-atmosphere boundary layer.

Implementation of a look-ahead multispectral imaging radiometer to optimize on-orbit decision making for selection of optimal hyperspectral bands for autonomous lidar targeting.

Goal: Significant reduction in data volume and optimization of scientific return.



Adaptive Wavelength Scanning (7km wide swath)

Highlighted Areas for Earth Science Technology

Quantum Sensing*

- Gravity Gradiometer for mass change
- Rydberg Receiver for soil moisture and other surface-based quantities

Quantum Computing & Applications of Artificial Intelligence

- Quantum Denoising for spaceborne lidar
- Advanced neural networks that use quantum algorithms

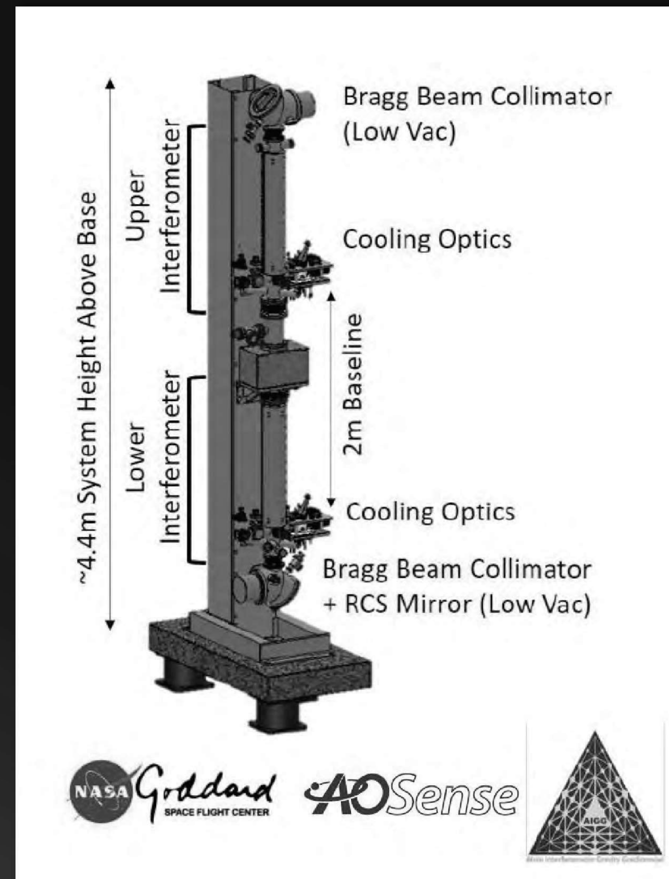
*The manipulation of quantum states of matter through the effects of superposition and entanglement.

Quantum Gravity Gradiometer (QGG)

A QGG has the potential to collect more precise measurements of Earth's gravitational field than existing methods such as the GRACE-FO mission – and could do so from a single satellite.

New and/or higher precision science measurements include:

- Global sea level
- Ocean Heat
- Ice sheet mass change
- Glacial Isostatic Adjustment
- Groundwater recharge
- Water availability and storage
- Groundwater flux

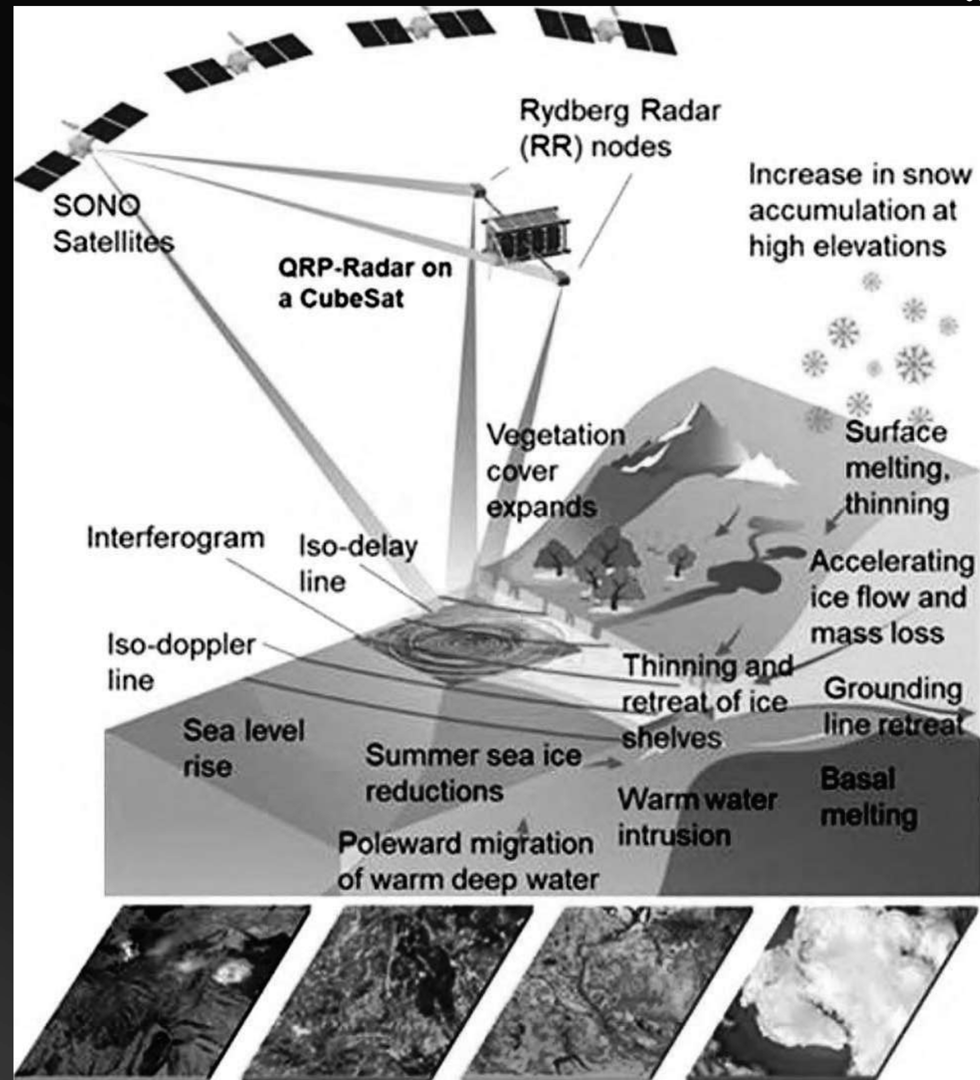


Quantum Atomic Rydberg Receiver

NASA, through investments at JPL, is at the forefront of Rydberg Receiver development, which uses the unique properties of excited Rydberg atoms to directly detect and sense electromagnetic fields.

Without the need for bulky antennas, Rydberg atom-based instruments offer enormous potential advantages in size, weight, and power, as well as in-flight tunability for a wide range of applications.

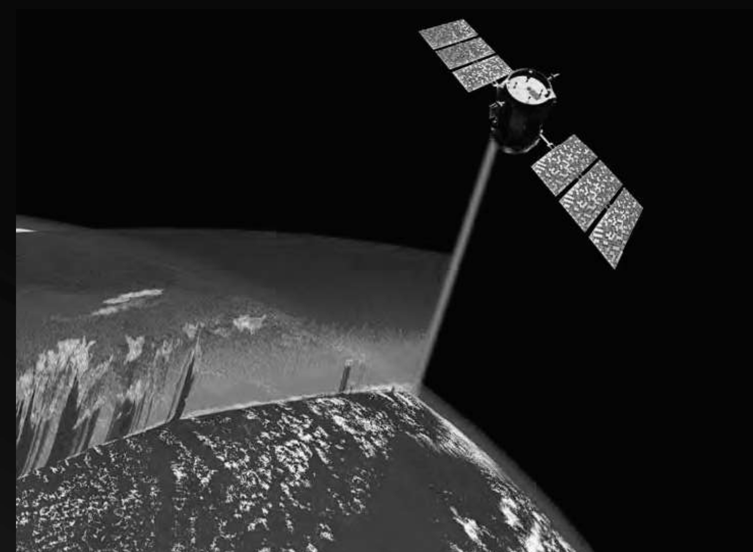
Key measurements include atmospheric temperature and humidity profiles that will enhance our understanding of the planetary boundary layer.



Sunlight Denoising using Quantum Computing

An innovative quantum computing project that aims to mitigate the effects of sunlight noise in spaceborne lidar data analysis.

- While lidar systems excel at capturing high-quality measurements at night, their effectiveness during the day is hindered by solar interference.
- Denoising is possible by differentiating between sunlight noise and backscatter signals (spatially incoherent vs. coherent), but this cannot be accomplished with classical computers.
- This research will investigate three distinct quantum approaches to subtract sunlight noise from lidar images by solving constrained minimization problems, using the state-of-the-art Dirac-3 quantum computer.
- If this technique is successful, the cost of space lidar missions will be greatly reduced, resulting in scientific breakthroughs.



Physics-Aware Quantum Neural Network Modeling of Earth Science Phenomena

At present, Earth Science physics-based models cannot take advantage of quantum algorithms for solving the primitive equations of the atmosphere.

Goal is to develop physics-aware quantum and quantum-classical hybrid models to solve complex partial differential equations that describe the interconnected Earth System.

This research will develop models that use quantum and quantum compatible approaches, with the aim of obtaining accurate solutions in a fraction of the time necessary with classical techniques.