

National Aeronautics and
Space Administration



EXPLORE

Achieving Game-Changing Science with CubeSats and SmallSats

Florence Tan

Chair, Small Spacecraft Working Group

Science Mission Directorate (SMD)

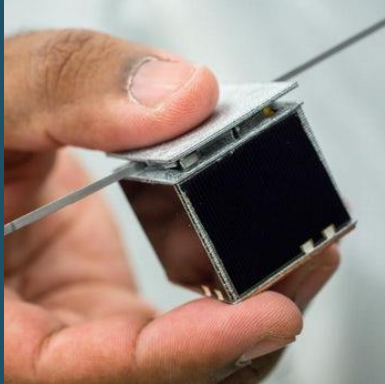
Chair, Small Spacecraft Coordination Group

NASA Headquarters

November 2021

Fundamentals of Small Spacecraft

Spectrum of Satellite Development



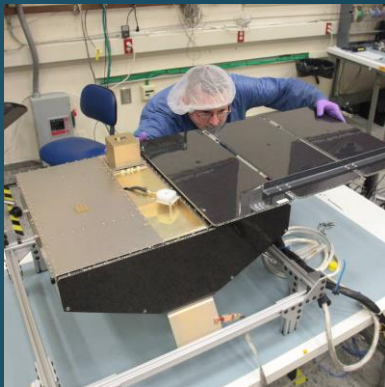
Picosatellite
PocketSat (0.1 – 1 kg)



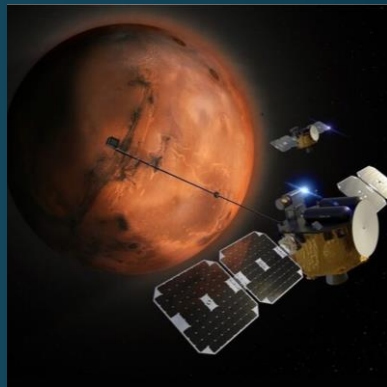
CubeSat/Nanosatellite
TROPICS 3U/6U (1 – 10 kg)



ESPA-Ring
Payload Port Limit (450 kg)



Microsatellite
CYGNSS (10 – 100 kg)



Small Satellite
ESCAPADE (100 – 500 kg)

SMD Handbook Definition: SmallSat

A spacecraft that is interface compatible with an ESPA Ring, a dedicated small or medium-lift launch vehicle, or a containerized dispenser, and with an upper mass limit of approximately 500 kg



ISS



Rideshare



Dedicated

Aug. 4, 1971 – Apollo 15 Particles and Fields Subsatellite (PFS-1) carrying a Magnetometer, a Charge Particle Detector, and an S-band transponder, released from the Service Module prior to Lunar Orbit Departure



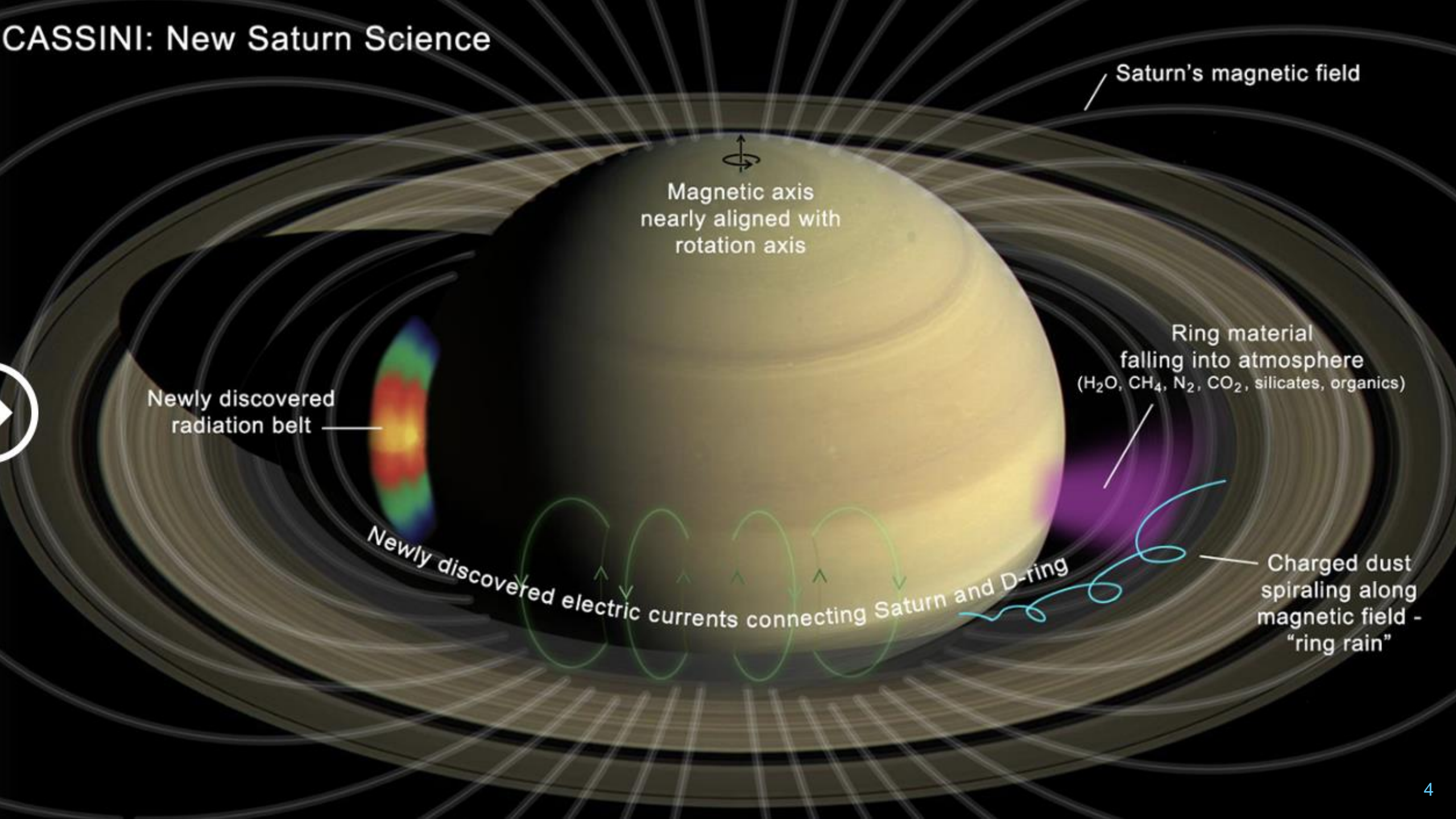
APOLLO SUBSATELLITES



Pictured: Apollo 15 astronauts, David Scott, Alfred Worden, and James Irwin

The Apollo 15 PFS-1 studied plasma, particle, and magnetic field of Moon's environment and mapped lunar gravity field

CASSINI: New Saturn Science



Saturn's magnetic field

Magnetic axis
nearly aligned with
rotation axis

Newly discovered
radiation belt

Ring material
falling into atmosphere
(H_2O , CH_4 , N_2 , CO_2 , silicates, organics)

Newly discovered electric currents connecting Saturn and D-ring

Charged dust
spiraling along
magnetic field -
"ring rain"

NASA Small Spacecraft Strategic Plan



An integrated and coordinated strategy supporting the NASA strategic plan

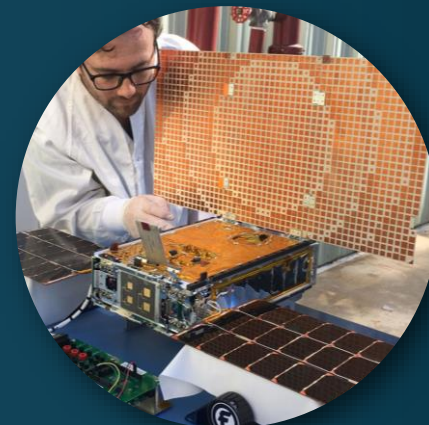
<https://www.nasa.gov/sites/default/files/atoms/files/smallsatstrategicplan.pdf>



High Priority Science



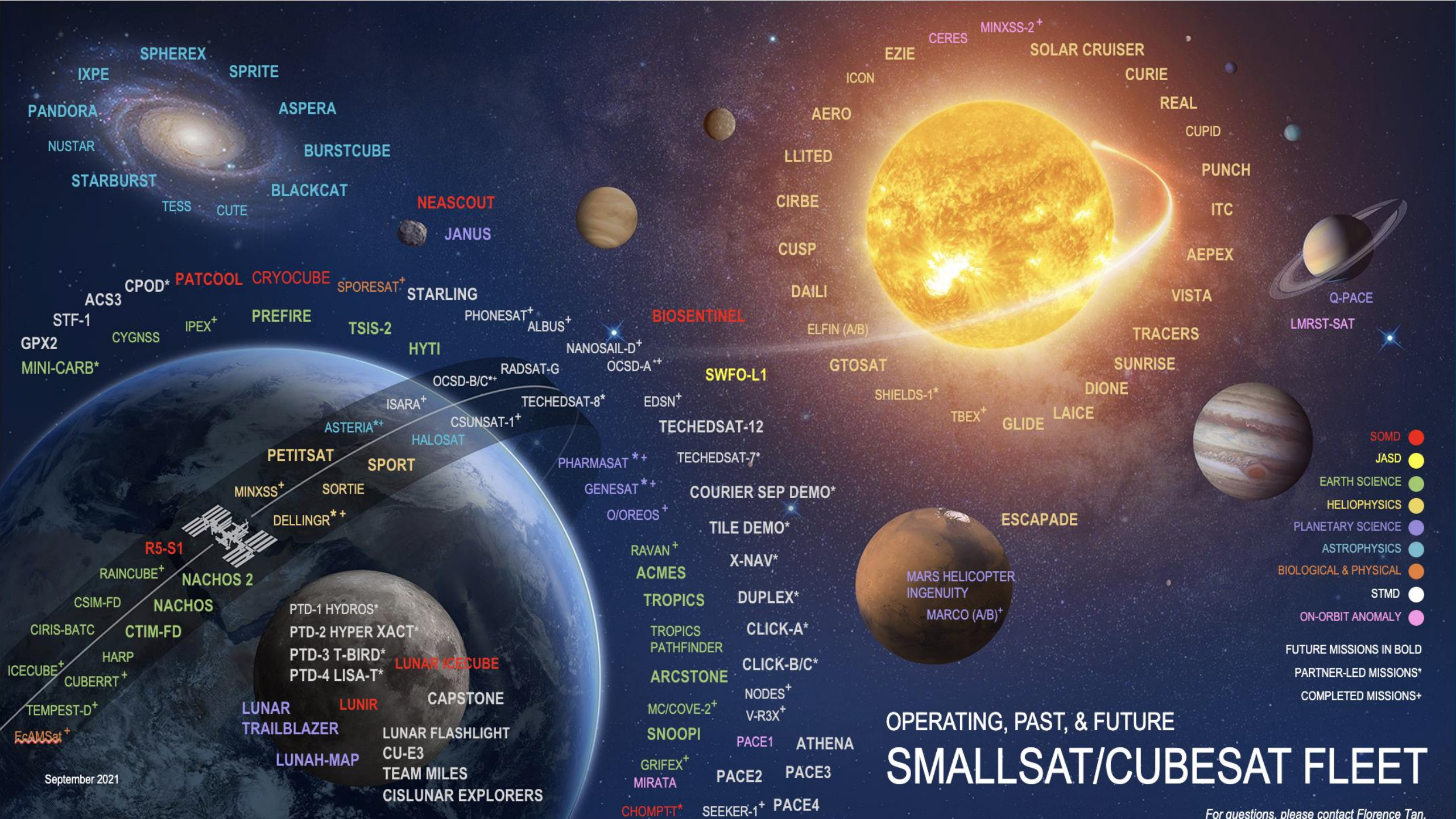
Support to Human Exploration



Disruptive Technology Innovation



Regular Access to Space



OPERATING, PAST, & FUTURE SMALLSAT/CUBESAT FLEET

NASA SmallSat Status

Missions (formulation or development)

ASPERA (APD)
BLACKCAT (APD)
BURSTCUBE (APD)
IXPE (APD)
PANDORA (APD)
SPARCS (APD)
SPRITE (APD)
STARBURST (APD)
ACMES (ESD)
ARCSTONE (ESD)
CTIM-FD (ESD)
HYTI (ESD)
NACHOS (ESD)
PREFIRE (ESD)
SNOOPI (ESD)
TROPICS (ESD)
TSIS-2 (ESD)
AEPEX (HPD)
AERO/VISTA (HPD)
CIRBE(HPD)
CURIE(HPD)
CUSP(HPD)
DAILI(HPD)
DIONE(HPD)
EZIE (HPD)
GLIDE(HPD)
GTOSAT(HPD)
LAICE(HPD)
LLITED(HPD)
PETITSAT(HPD)
PUNCH(HPD)
REAL(HPD)
SOLAR CRUISER(HPD)
TRACERS(HPD)
SPORT(HPD)
SUNRISE (HPD)
ITC (HPD)
ESCAPADE (HPD)
SWFO-L1 (JASD)
JANUS (PSD)
LUNAR TRAILBLAZER (PSD)
ACS3 (STMD)
CISLUNAR EXPLORERS(STMD)
CLICK A(STMD)
CLICK B/C(STMD)
CAPSTONE (STMD / HEOMD)
COURIER SEP DEMO (STMD)
CPOD (STMD)
CU-E3(STMD)
DUPLEX (STMD)
LUNAR FLASHLIGHT (STMD)
PACE-2(STMD)

PACE 3 (STMD)
PACE 4 (STMD)
PTD-2 HYPERXACT(STMD)
PTD-3 TBIRD (STMD)
PTD-4 LISA-T (STMD)
STARLING (STMD)
TEAM MILES (STMD)
X-NAV (STMD)
BIOSENTINEL (HEOMD)
LUNAR ICECUBE (HEOMD)
LUNIR (HEOMD)
NEASCOUT (HEOMD)

Flight Awards

ASPERA (APD)
PANDORA (APD)
STARBURST (APD)
ACMES (ESD)
ARCSTONE (ESD)
GLIDE(HPD)
SOLAR CRUISER(HPD)
PACE 3 (STMD)
PACE 4 (STMD)

Launched/Deployed

HARP (ESD)
CIRIS-BATC (ESD)
CUPID(HPD)
CUTE (APD)
SORTIE (HPD)
Q-PACE (PSD)
Tropics Pathfinder (ESD)
PACE 1 (STMD)
PTD11 HYDROS (STMD)
TECHEDSAT-7 (STMD)
TECHEDSAT-12 (STMD)
TILE DEMO (STMD)
V-R3X (STMD)

Studies Selected

DORADO (APD)
HELIOSWARM, ARCS (HPD)
MIDEX)

White: 3U or 6U units
Orange: MiniSat
Yellow: Multiple units
Blue: ESPA-Class Mission
Green: 12U Mission

Operating

CIRIS-BATC (ESD)
CSIM-FD (ESD)
CYGNSS (ESD)
CHOMPTT (STMD)
ELFIN(HPD)
ICON (HPD)
NUSTAR (APD)
ICON (HPD)
PTD-1 (STMD)
RADSAT-G (STMD)
SHIELDS (HPD)
TECHEDSAT-8 (STMD)
TESS(APD)

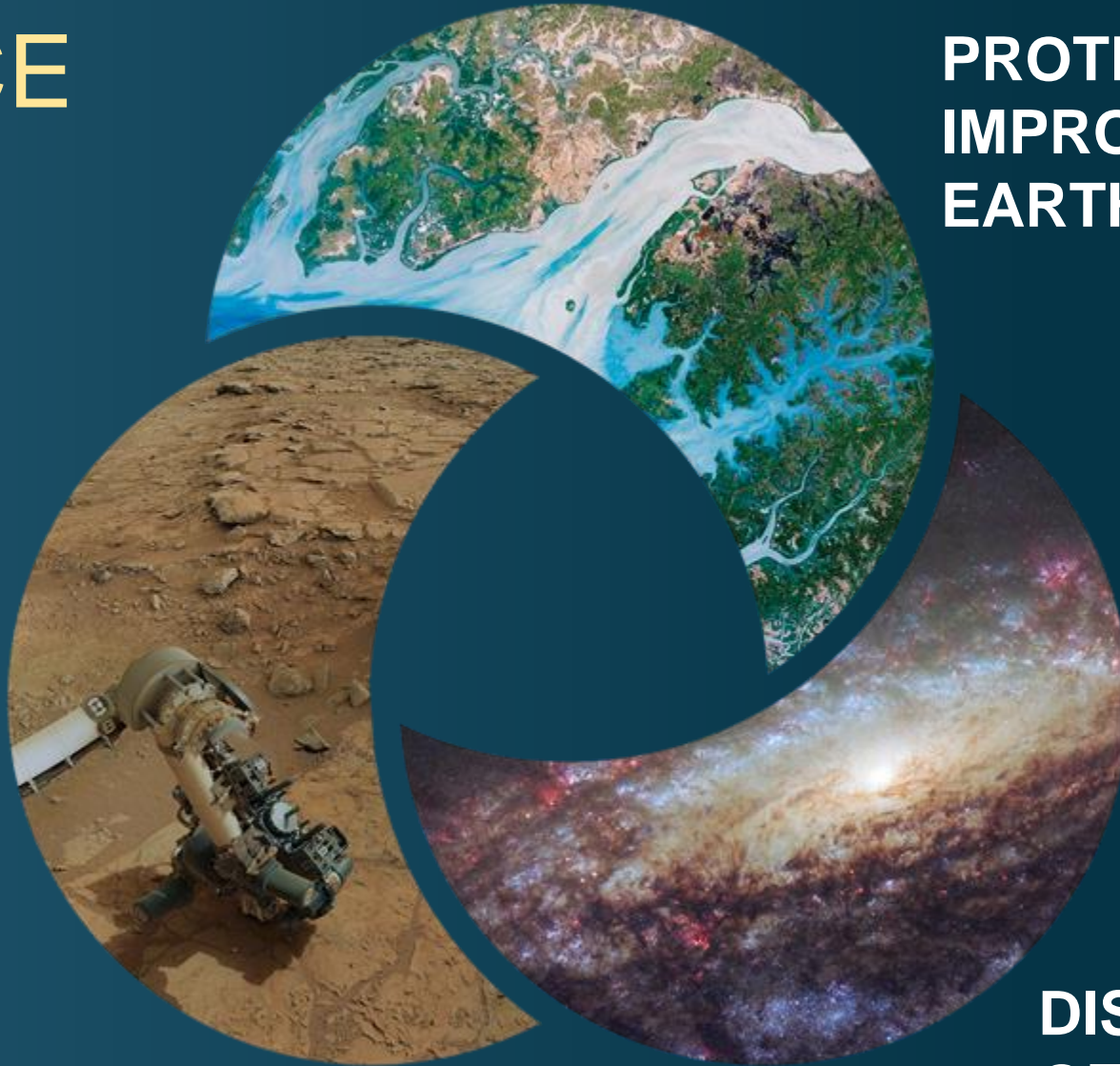
Deorbited

CUBERRT (ESD)
DELINGR (HPD)
HaloSat (APD)
RAINCUBE (ESD)
TBEX (HPD)
TEMPEST-D(ESD)
V-R3X (STMD)

KEY SCIENCE THEMES

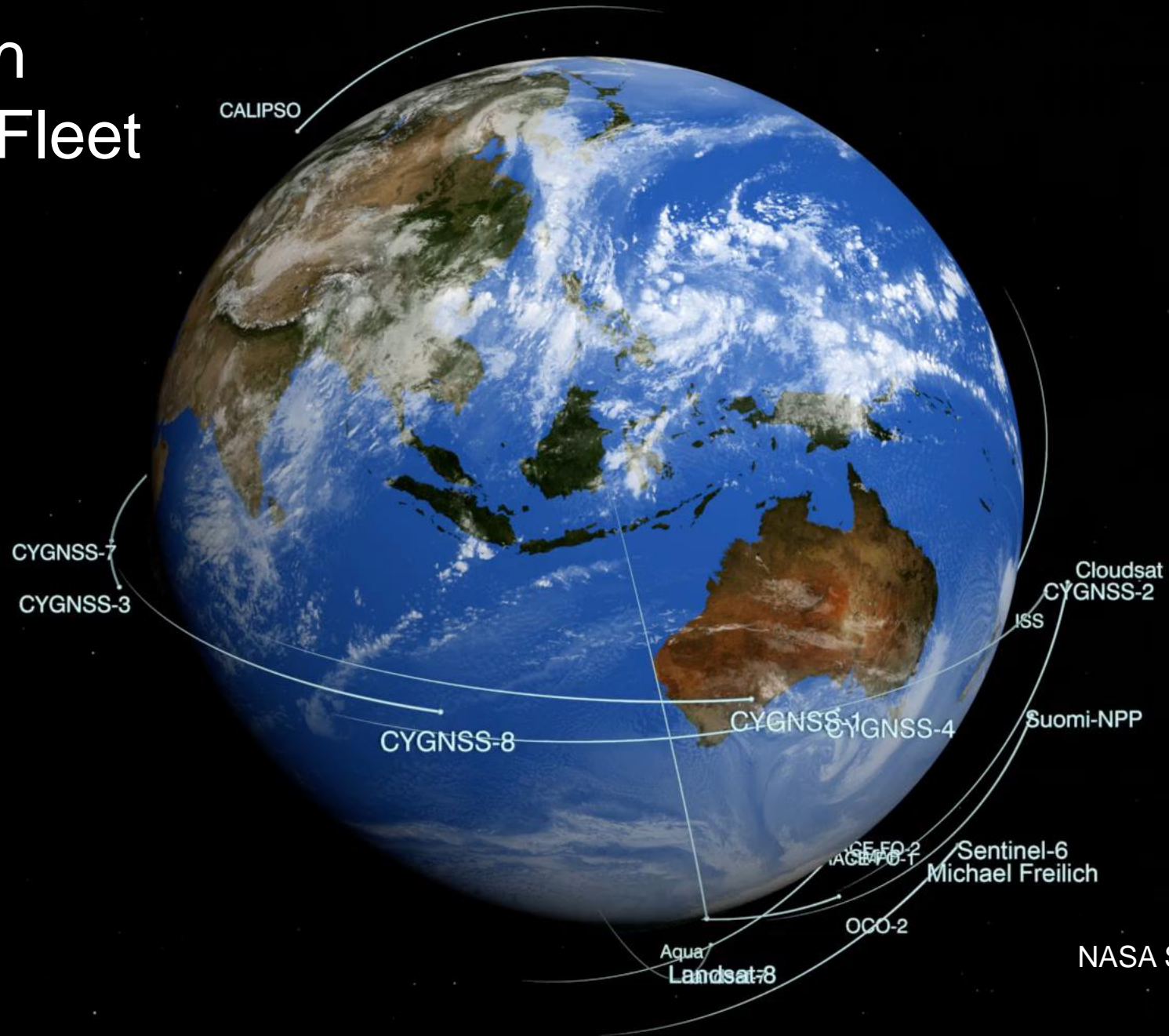
**PROTECT AND
IMPROVE LIFE ON
EARTH AND IN SPACE**

**SEARCH FOR LIFE
ELSEWHERE**



**DISCOVER SECRETS
OF THE UNIVERSE**

NASA Earth Observing Fleet



August 2021

NASA Scientific Visualization Studio
svs.gsfc.nasa.gov/4931

EARTH SYSTEM OBSERVATORY

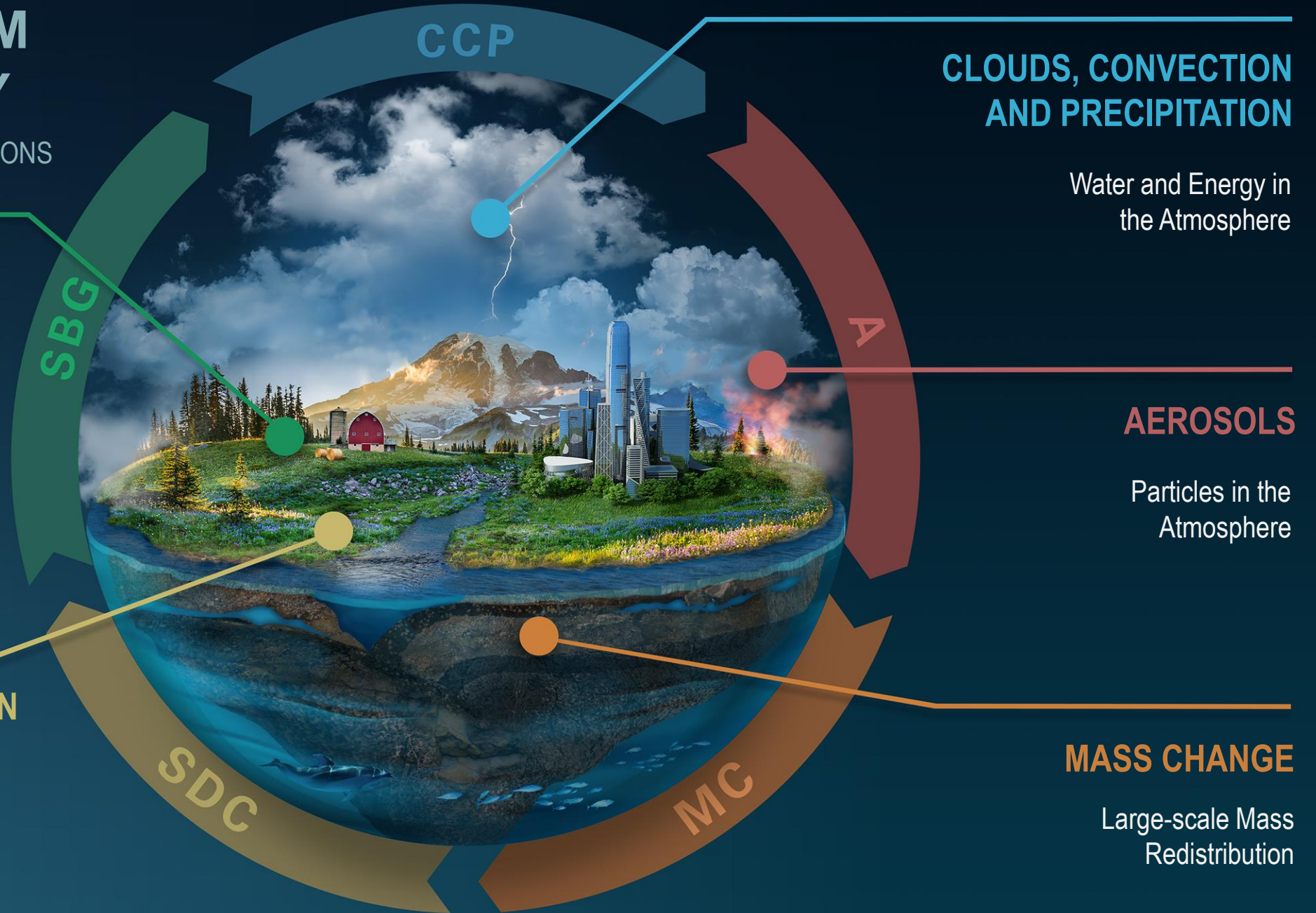
INTERCONNECTED CORE MISSIONS

SURFACE BIOLOGY AND GEOLOGY

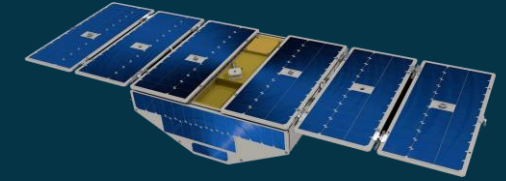
Earth Surface and Ecosystems

SURFACE DEFORMATION AND CHANGE

Earth Surface Dynamics

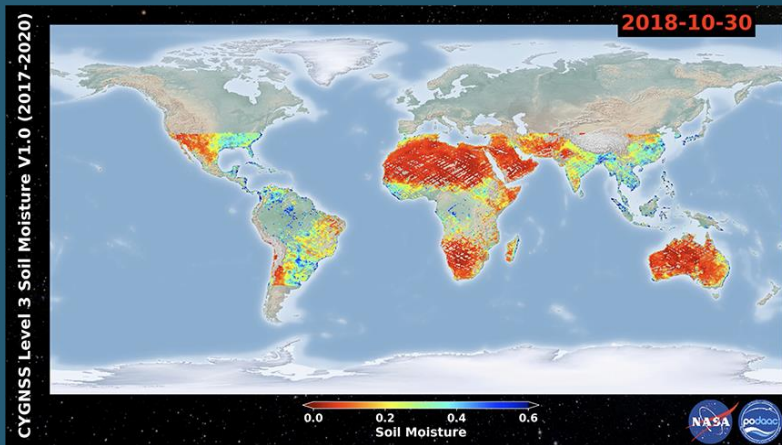


CYGNSS Scientific Results and Applications



Daily soil moisture data product

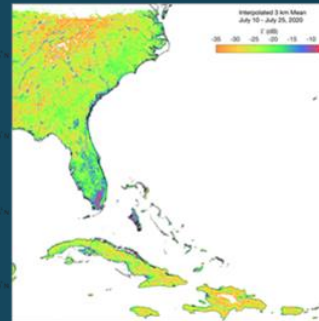
- Oct. 30, 2018



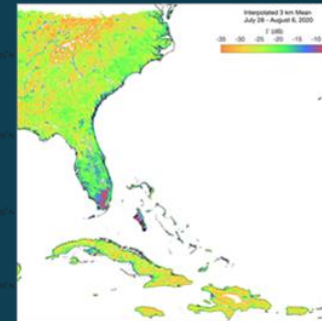
Map flood inundation after hurricane landfall

- Reflectivity before and after Hurricane Isaias landfall, July-August 2020

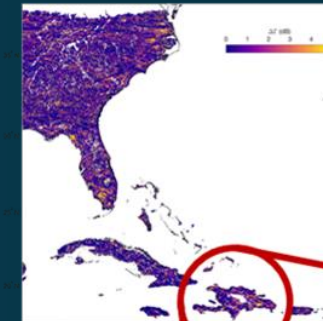
Before landfall



After

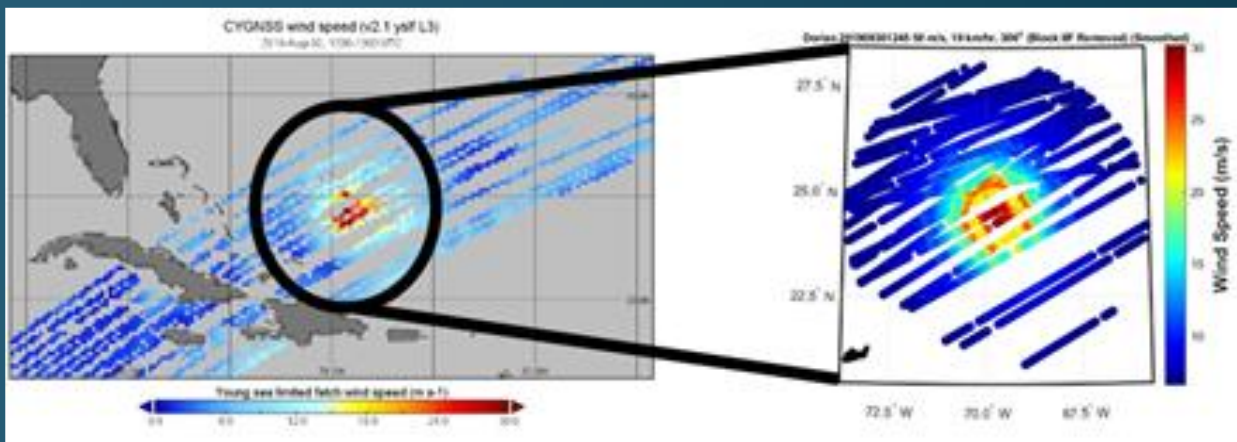


Delta

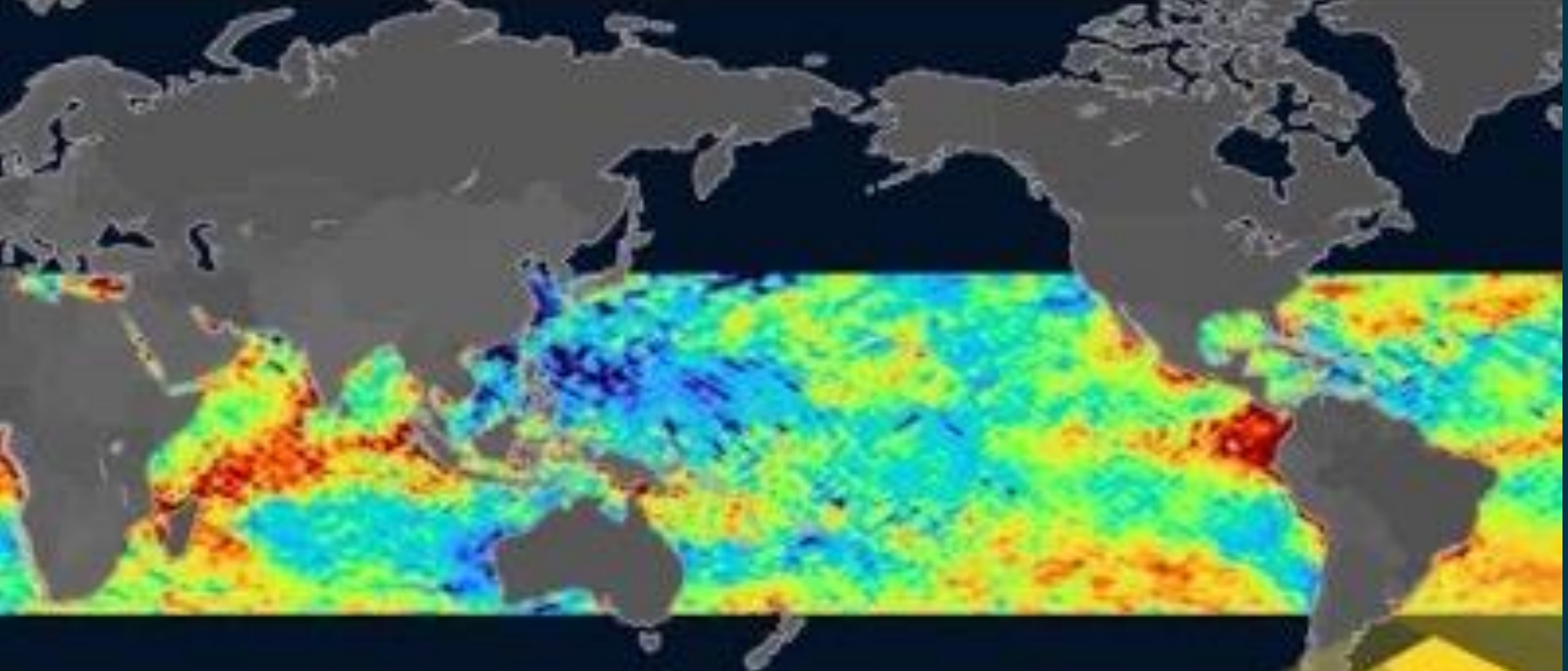


Measure winds in tropical cyclones

- Hurricane Dorian overpass, Aug. 30, 2019 at 02:45 UTC



Extensive flooding in the Dominican Republic



CYGNSS: Observations of sources of ocean microplastic from space

<https://www.youtube.com/watch?v=sQTGOU9LiJ0&t=5s>

Temporal Experiment for Storms and Tropical Systems (TEMPEST-D) CubeSat Mission

PI: Steven C. Reising, Colorado State University

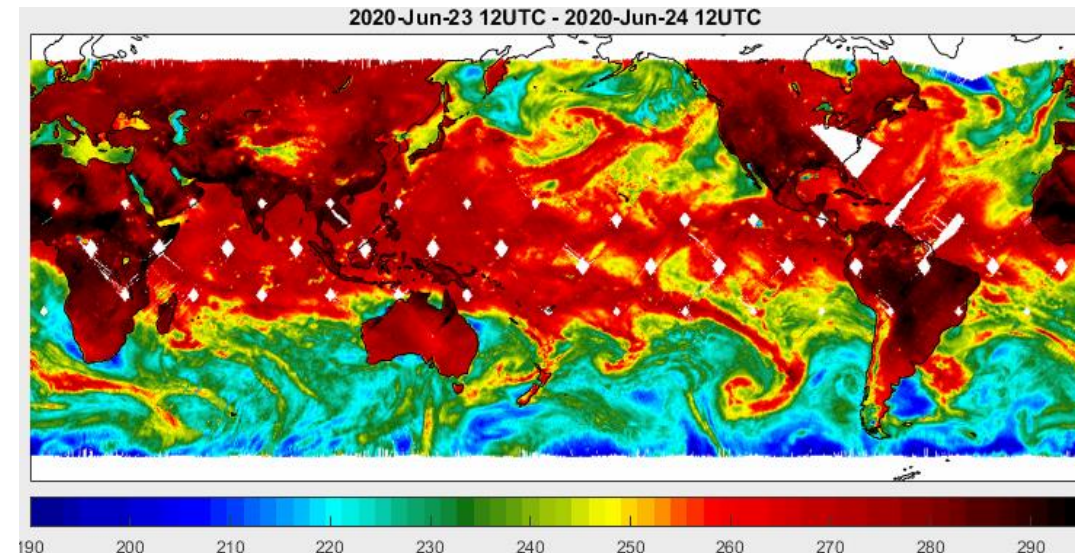
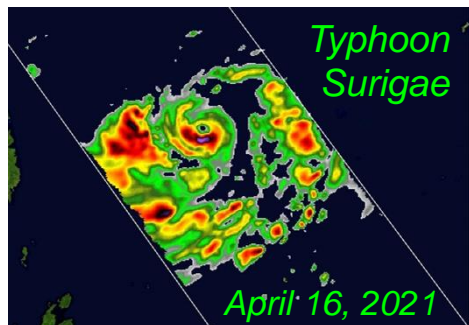
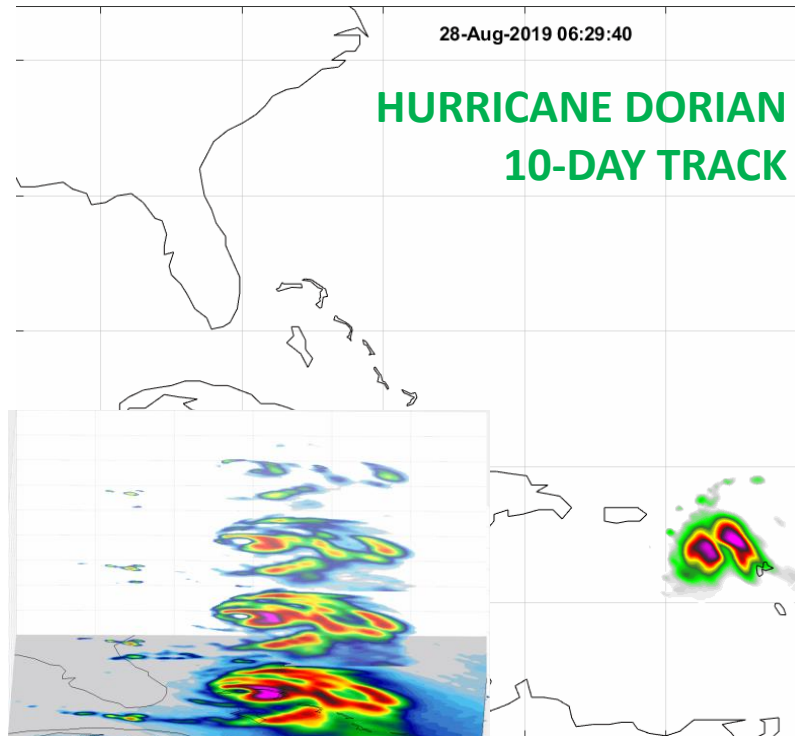
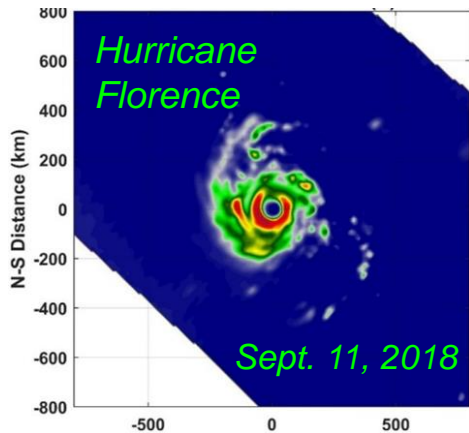
Technology Demonstration Accomplishments:

- First global Earth observations from a multi-frequency microwave radiometer on a CubeSat
- Performed continuous passive microwave observations from a CubeSat in LEO for nearly 3 years
- Demonstrated instrument performance equivalent to operational microwave sounders, i.e. radiometer calibration accuracy, precision and stability
- Performed altitude control of a CubeSat necessary to form a constellation from a single orbital deployment



Earth Science Accomplishments:

- Performed passive microwave observations of hurricanes, typhoons and TCs for 3 consecutive seasons
- Demonstrated first quantitative precipitation estimates from a CubeSat radiometer
- TEMPEST-D and RainCube demonstrated highly-correlated passive and active microwave storm observations from CubeSats
- First space-borne use of “hyperspectral” microwave sounding observations to retrieve planetary boundary layer (PBL) height



TEMPEST-D data publicly available at tempest.colostate.edu/data

TEMPEST-D data have been downloaded by 41 user groups in 12 countries on 4 continents.

This is a nice composite of RainCube and Tempest D

RainCube/TEMPEST-D Observing Typhoon Trami

Spacecraft constellation separated by 5 minutes revealing 3D storm structure

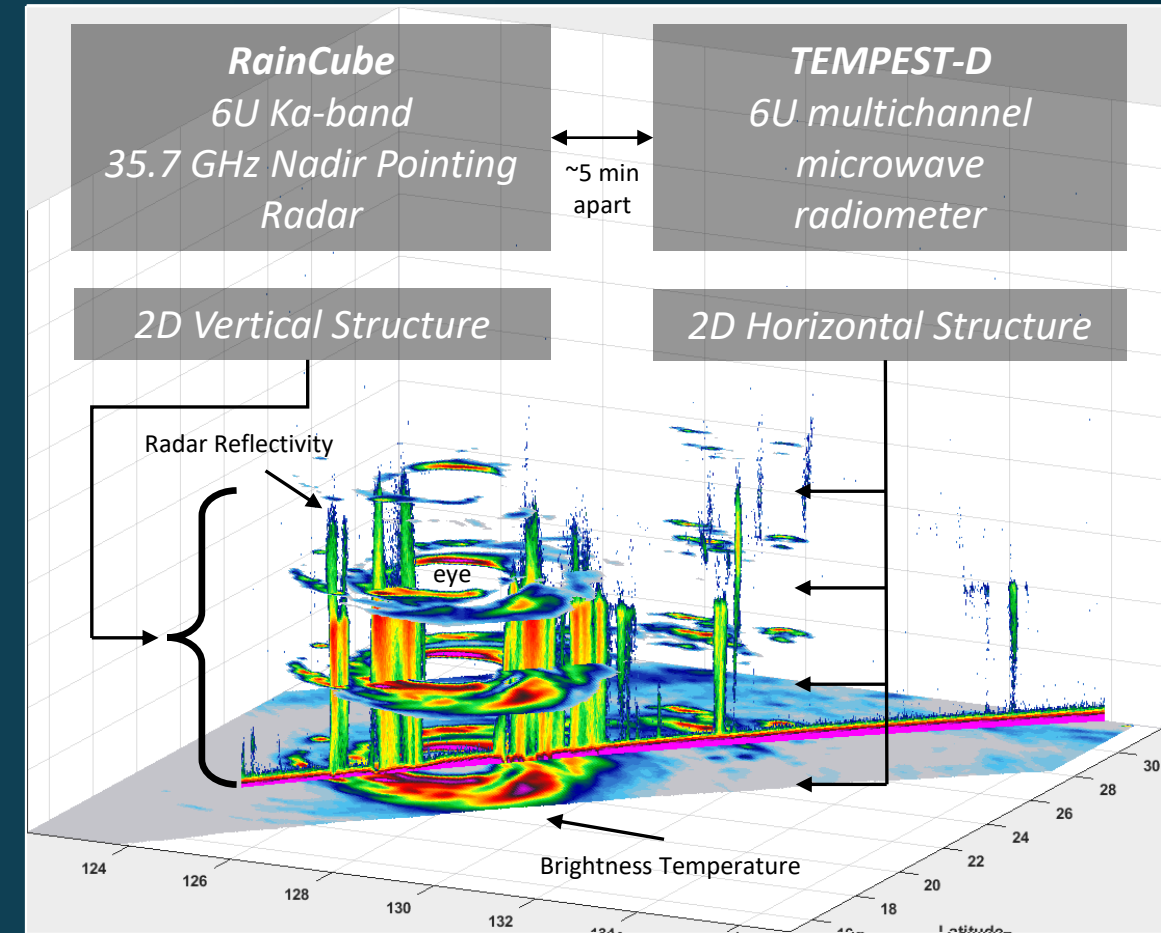
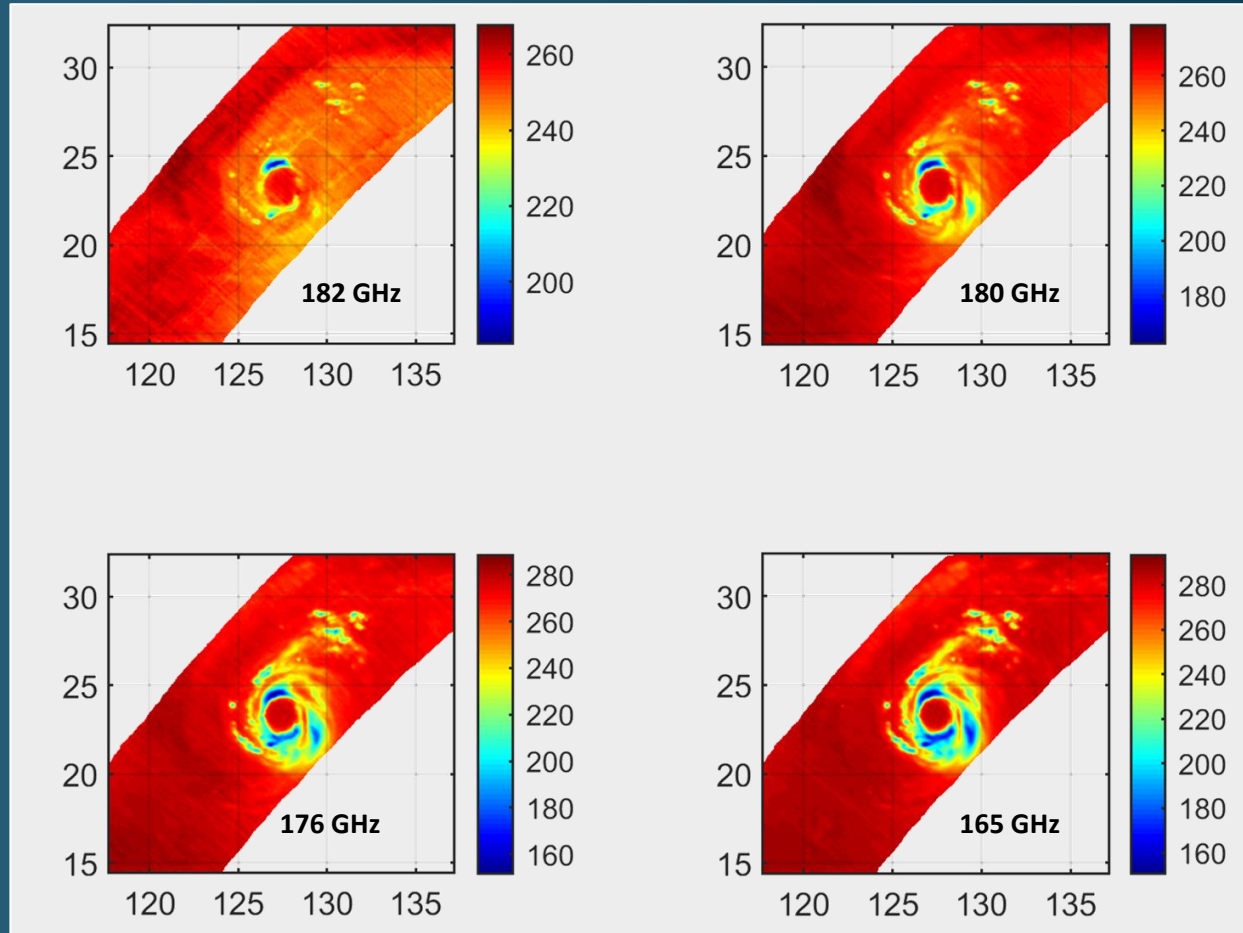
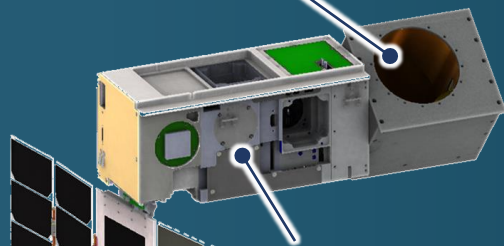


Illustration of complementary nature of these sensors flown in constellation for observing precipitation

Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of SmallSats (TROPICS)

Rotating microwave radiometer 1U Payload: 7 channels near 118 GHz, 3 near 183 GHz, and imaging at 89 and 205 GHz,



2U Bus: BCT XB-1

3U CubeSat
(10cm x 10cm x 36cm)



Articulating 5-panel
solar array

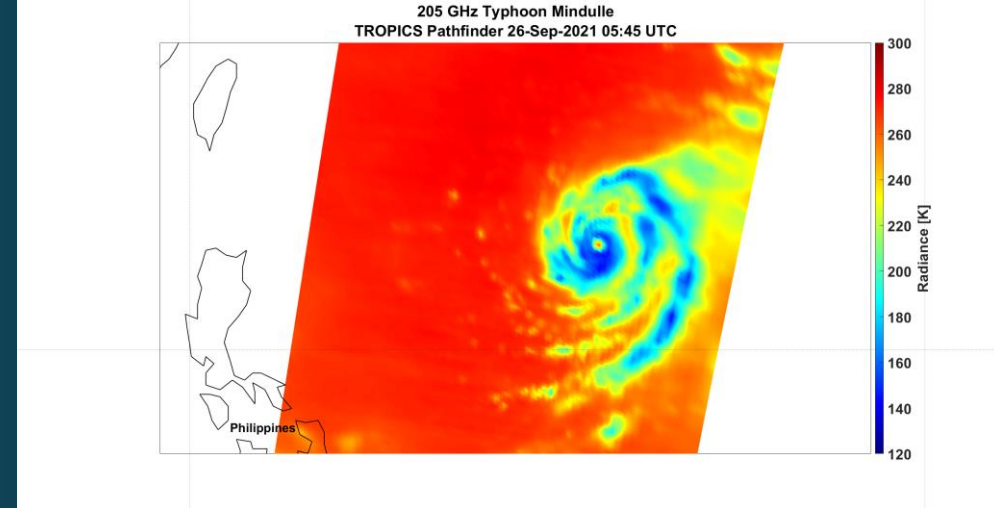
TROPICS Science

- Relates co-evolving precipitation structure, upper-level warm core and storm intensity changes
- Relates the occurrence of intense precipitation cores (convective bursts) to storm intensity evolution
- Relates environmental moisture measurements to coincident measures of storm structure (including size) and intensity
- Assimilates microwave radiances and/or retrievals in mesoscale and global numerical weather prediction models to assess impacts on storm track and intensity

- Constellation consists of 6 CubeSats in three orbital planes (30° Inclination / 550 km Altitude) with a 1 year operational life; launch in 2022
- Median revisit rate of 50 minutes
- Pathfinder Space Vehicle launched w Momentus' Vigoride in June 2021

TROPICS Pathfinder (Qualification Unit)

Launched June 30, 2021



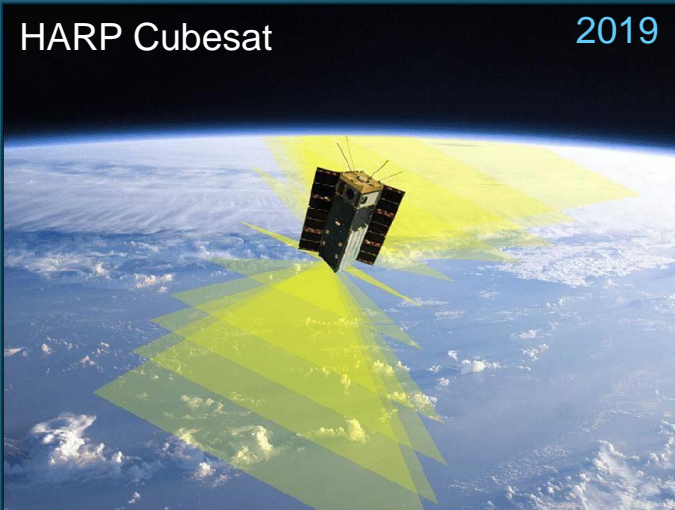
Imagery of Typhoon Mindulle before Landfall @ 205 GHz 26th Sept 2021

- Sun-synchronous orbit; 530 km altitude; 2:00 pm LTDN
- Satellite has been contacted and in excellent health
- Bus and Payload commissioning began in July and August
- Performance is excellent!
- NOAA-funded low-latency experiment to be conducted in October
- Data will be available to general public via GES-DISC

AirHARP (ACEPOL Campaign) 2017



HARP Cubesat 2019



HARP2 (PACE Mission) 2024



HARP: From Air to Space

Hyper Angular Rainbow Polarimeter (HARP)

- Wide field of view imaging polarimeter with NO moving parts
- Measures aerosol particles in clouds and can observe properties of land and water surfaces
- Data support analysis of public health, cloud life cycle, precipitation, and climate

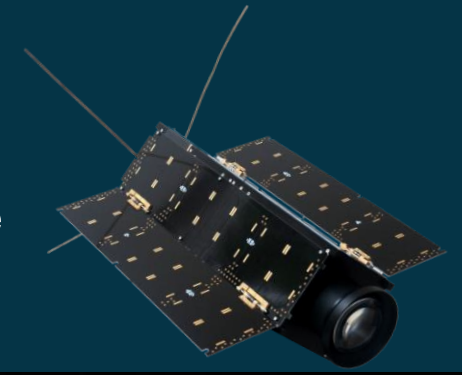
HARP Development

- 2017: AirHARP instrument part of ACEPOL (Aerosol Characterization from Polarimeter and Lidar) airborne campaign, developed algorithms for HARP/HARP2 use
- 2019: HARP CubeSat launched, to be deployed from ISS in February 2020
- 2024: HARP2 instrument on upcoming PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) mission

Earth Science Technology Highlight

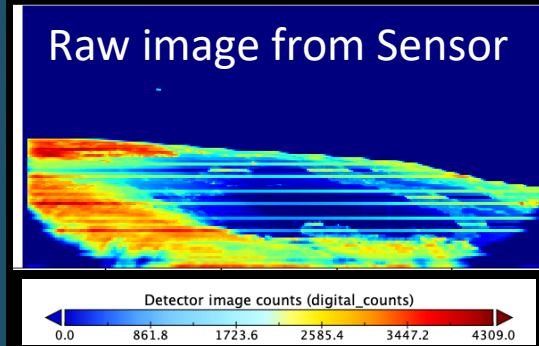
First Light/Partial Image from HARP CubeSat

The HyperAngular Rainbow Polarimeter (HARP), developed by Vanderlei Martins at the University of Maryland, Baltimore County, has acquired first light. This 3U CubeSat was deployed from the International Space Station on February 19, 2020 with the goal of validating a wide field-of-view hyperangular polarimeter, with no moving parts, for the characterization of aerosol and cloud properties.



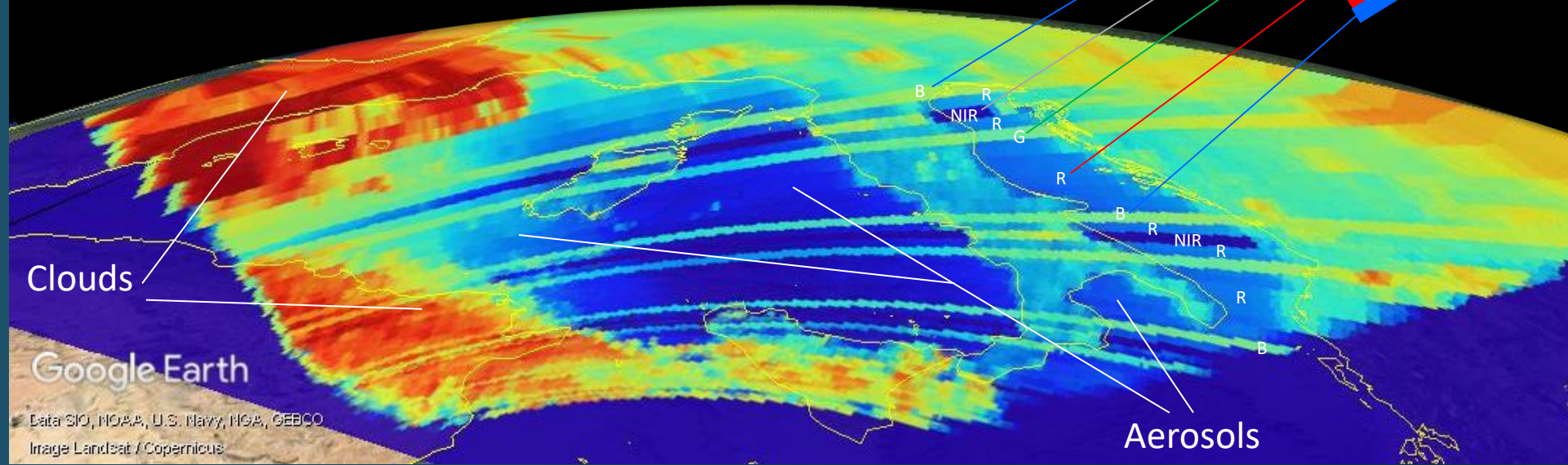
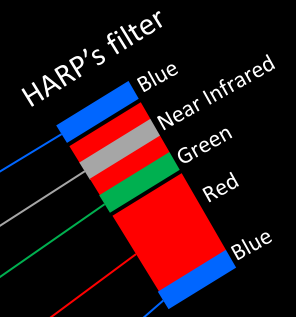
HARP's first image, a snapshot over Europe, was acquired by pointing its sensors at Earth's horizon. The three detectors are performing with nominal alignment needed for the polarization measurement.

The stripes in this image emphasize the different wavelengths measured, displaying the pattern of HARP's rainbow filter.



HARP Snapshot over Europe shows the pattern of HARP's rainbow filter

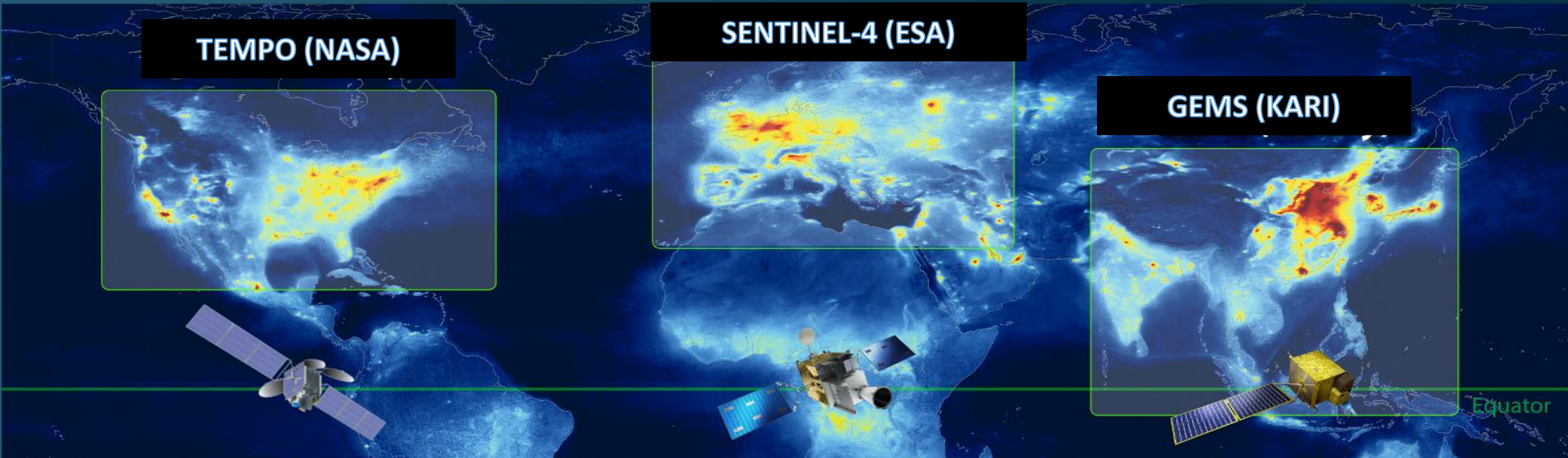
- First image was acquired pointing at Earth's horizon
- Stripes emphasize the different wavelengths
- Full push-broom reconstructions will aggregate hundreds of similar images pointing at nadir



Sensor

The HARP sensor allows for multiple wavelengths (440, 550, 660 and 870nm) and hyperangular wide FOV imaging capability with no moving parts. The architecture allows for accurate polarization imaging.

Virtual Global Constellation of Air Quality Monitors



Air Pollution, driven by Ozone (O₃) and particulate matter (aerosols), is hazardous & costly:

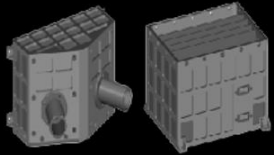
- **4.7 M** pre-mature deaths/year (*Global Burden of Disease*)
- **\$21 B** in healthcare costs/year (*World Health Organization*)
- **\$1.2 B** lost workdays/year (*Organization for Economic Co-operation and Development*)

A warming climate will worsen air quality, reversing years of progress from reducing emissions. Extreme air quality episodes will occur more often in a warmer climate.

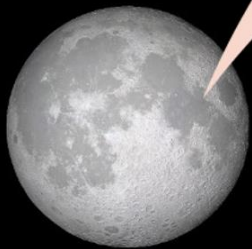
Leveraging Lunar Programs for Measurements Back on Earth



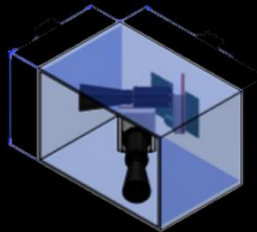
KPLO Spacecraft



PolCam



PolCam
Studying the Lunar Surface
PolCam (Moon):
320, 430, 650 nm I, DoLP
2 viewing angles



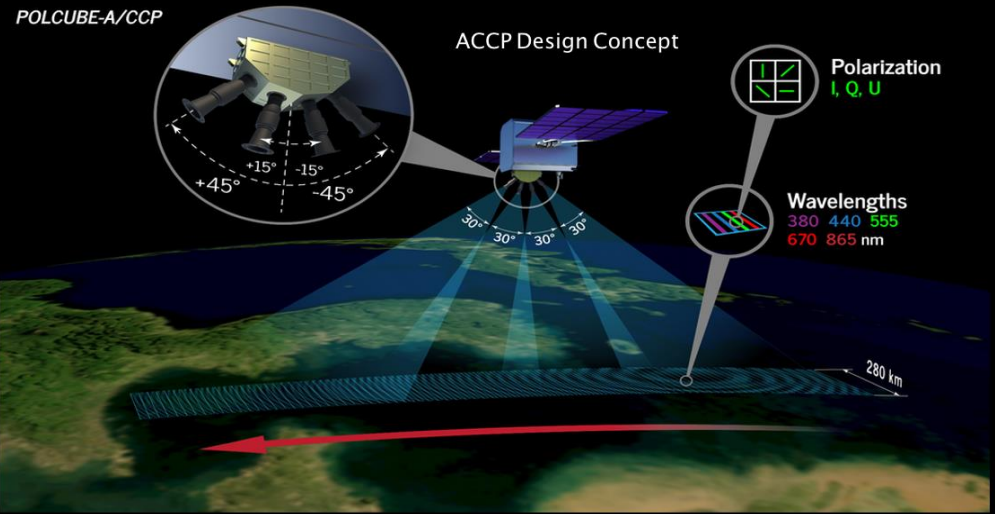
PolCam ↔ PolCube design



PolCube
Studying Clouds and Aerosols

PolCube (Earth):
380, 440, 555, 670, 865 nm
I, Q, U
120 viewing angles
~280 km swath

Flight Module Delivery: March 2022



PolCube builds upon our international partnership(s) with South Korea

Partnership with leading institutions in South Korea and the US:



NASA's Langley Research Center
NASA Goddard's Institute for Space Studies (GISS)



The Korea Astronomy and Space Science Institute (KASI)



Kyung Hee University



Hampton University



University of Rhode Island

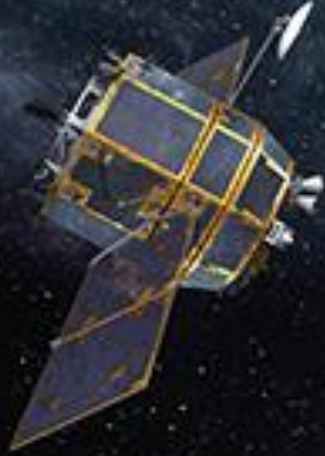


Army Research Lab and the city of Busan



Republic of Korea

KPLO

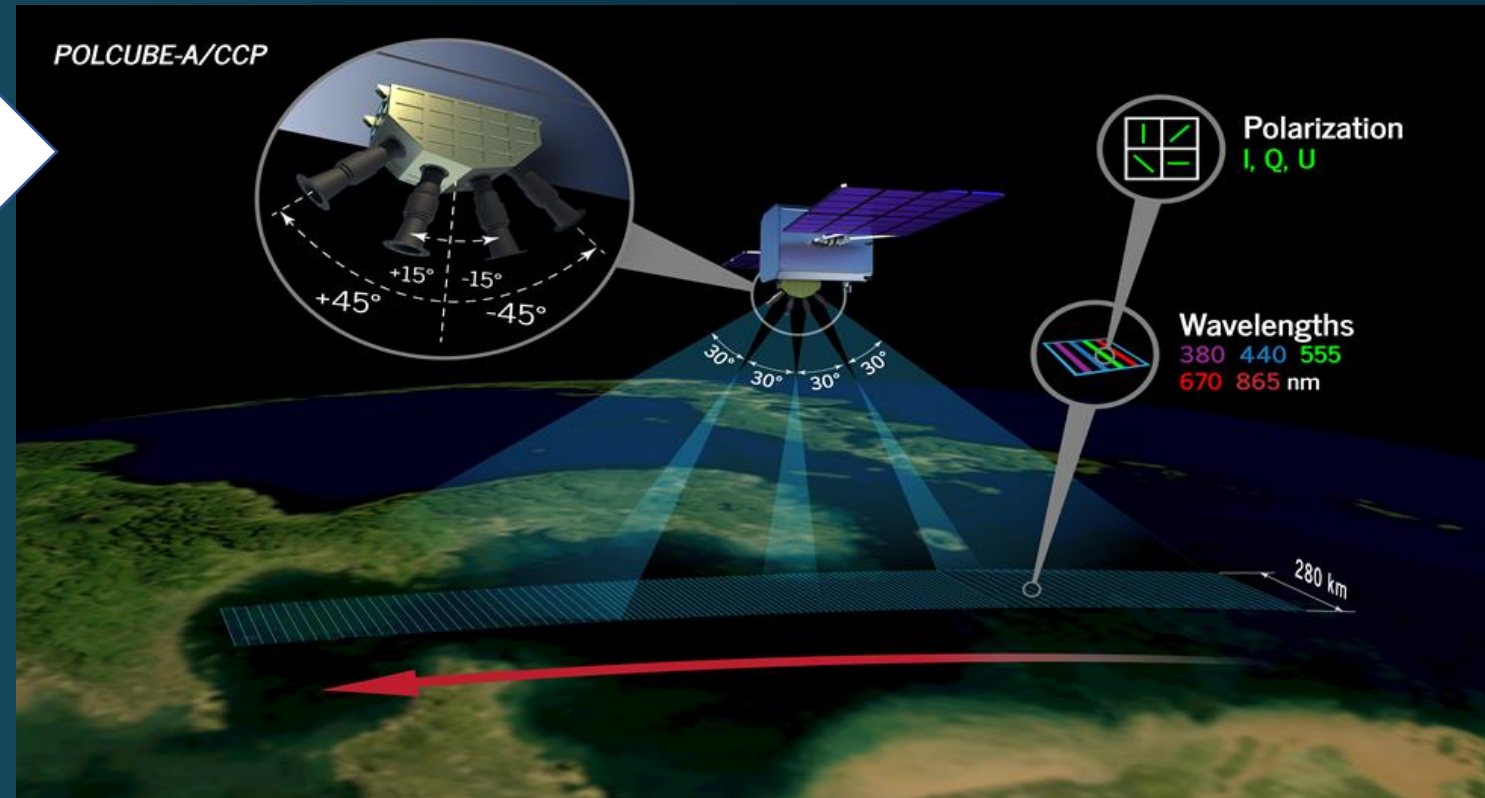


PolCube, is a next-generation mission based on KPLO, that can carry out **targeted observations of the Earth's aerosols and clouds** over land/ocean.

PolCube is an on-going partnership between KASI, Busan City, Kyung Hee University, US Army Research Lab, and NASA.

Polarimetric Map of Lunar Surface

The Korea Pathfinder Lunar Orbiter (KPLO) is South Korea's **first lunar mission**. It is developed and managed by the Korea Aerospace Research Institute (KARI) and is scheduled to **launch in July 2022** to orbit the Moon for 1 year carrying an array of South Korean experiments and one U.S. built instrument.



Polarimetric measurements of clouds and aerosols on Earth



Double Asteroid Redirection Test Mission (DART) / LICIACube

The Double Asteroid Redirection Test (DART) mission is directed by NASA to the [Johns Hopkins Applied Physics Laboratory \(APL\)](#) with support from several NASA centers: the Jet Propulsion Laboratory (JPL), Goddard Space Flight Center (GSFC), Johnson Space Center (JSC), Glenn Research Center (GRC), and Langley Research Center (LaRC). LICIACube is contributed by the Italian Space Agency (ASI) and designed, built and operated by the Italian aerospace engineering company Argotec.

DART is a planetary defense-driven test of technologies for preventing an impact of Earth by a hazardous asteroid.

DART will be the first demonstration of the *kinetic impactor* technique to change the motion of an asteroid in space.

Target: Binary asteroid (65803) Didymos' 160km Moonlet, Dimorphos. DART will crash itself into the moonlet at a speed of approximately 6.6 km/s. Depending on Launch date starting Nov 24, the impact will be late Sept to early Oct 2022

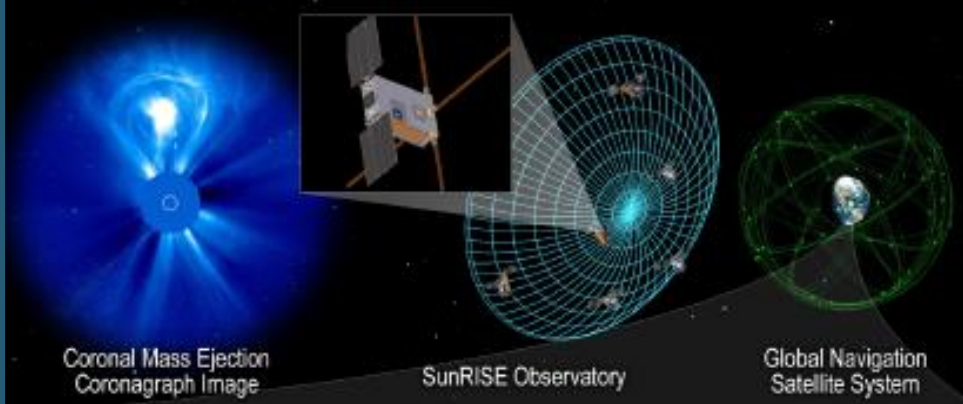
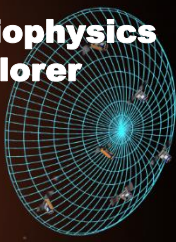
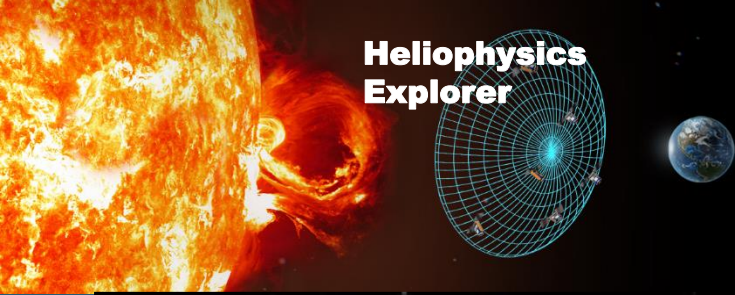
Effect: Speed of moonlet around the main body and the orbital period of the moonlet will change by several minutes - enough to be observed and measured using telescopes on Earth, DART's and LICIACube's Cameras

Sun Radio Interferometer Space Experiment (SunRISE)

PI: Justin C. Kasper/University of Michigan



Sun Radio Interferometer
Space Experiment



Mission & Science Team:

PI: Justin C. Kasper/University of Michigan (UM)

PM: James Lux/Jet Propulsion Laboratory (JPL)

PSE: Brian Cox/JPL

CubeSat Provider: Space Dynamics Laboratory (SDL);

Heritage: SDL: Pearl bus; JPL: MarCO and DHFR

Launch Provider: Space Systems/Loral (SSL) ComSat (deployed from).

Payload: JPL, with Heritage from DHFR and Cion/CICERO

Operations: UM: SOC; JPL: MOC.

Mission:

Using six identical 6U CubeSats composing a low-radio-frequency interferometer in space, the SunRISE Observatory will localize heliospheric radio emissions during its nominal twelve-month mission. SunRISE will determine the location of radio bursts from 0.1 MHz to 25 MHz, to provide data on particle acceleration mechanisms associated with coronal mass ejections (CMEs) and the magnetic field topology from active regions into interplanetary space.

EOM disposal: Remain in its supersynchronous mission orbit.

Objectives:

1. Discriminate among competing hypotheses for the source mechanism of CME-associated Solar Energetic Particles (SEPs) by measuring the location and distribution of Type II radio emission relative to expanding CMEs 2–20 R_s from the Sun where the most intense acceleration occurs.
2. Determine if a broad magnetic connection between active regions & interplanetary space is responsible for the wide longitudinal extent of some flare & CME SEPs by imaging field lines traced by Type III bursts from 2-20 R_s .

Instruments:

Each payload is a unified Solar Decametric-Hectometric (DH) and Global Navigation Satellite System (GNSS) receiver, with a common reference oscillator, and uses four 2.5m (deployed) STACER antennas (Solar DH subsystem), and four COSMIC radio occultation antennas (GNSS subsystem). Heritage: DHFR.

Flight:

Launch Readiness Date: 1 March 2022

Launch Vehicle: Unknown U.S. LV launching an SSL GEO ComSat as a hosted payload, and delivering SunRISE to a supersynchronous orbit (>200km above geostationary).

Launch to EOM: 13 months.

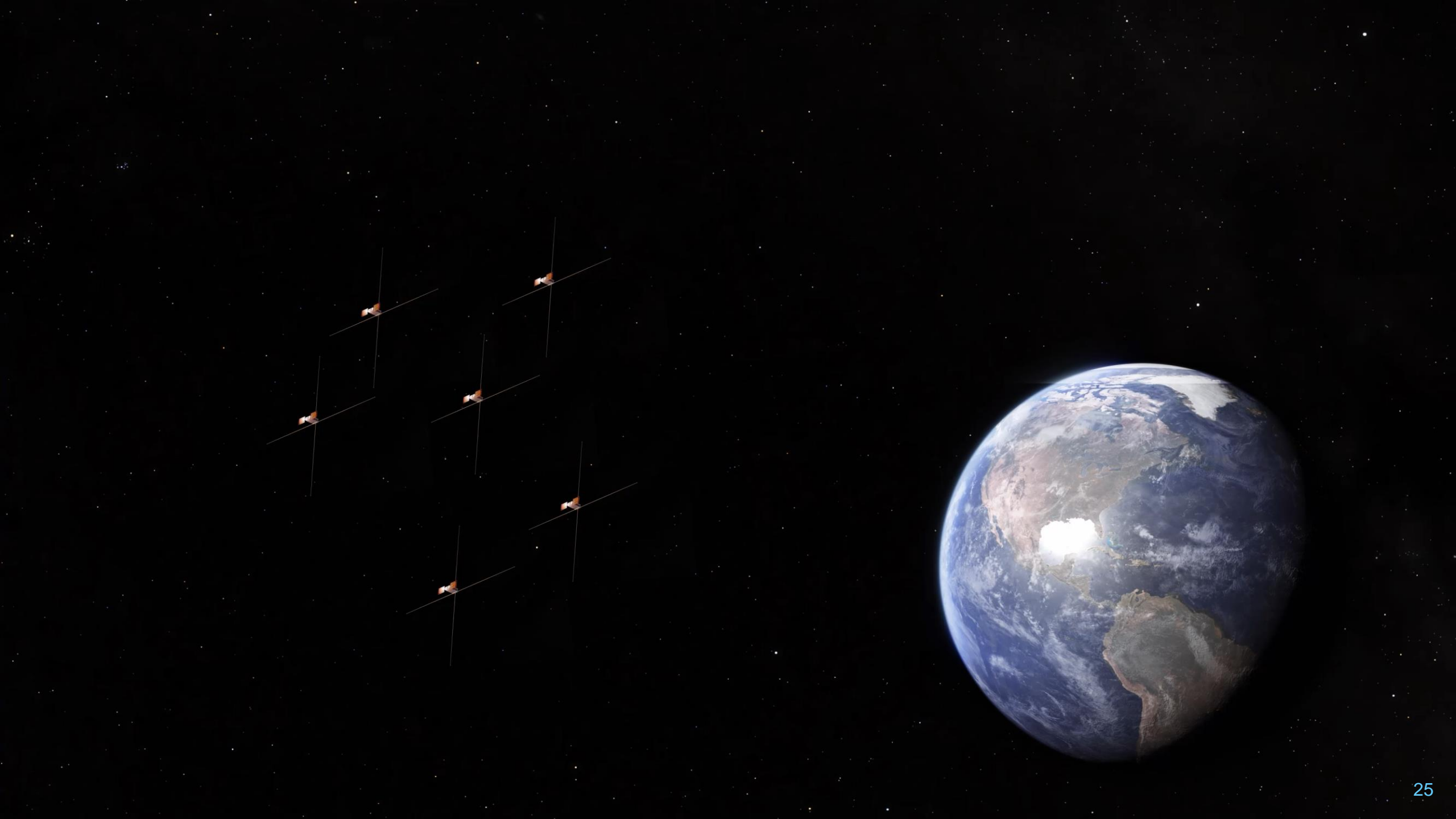
Flight Systems:

Each 6U CubeSat carries identical subsystems, and is deployed from the ComSat via the Canisterized Satellite Dispenser (CSD)

Threshold Mission:

Four of six CubeSats





Leveraging SmallSat Industry products and services



- Tsunami of commercial services and products from increasing accelerating commercial investments and consolidation in SmallSat industries
 - Commercial Data Buy
 - Variety of maturing SmallSat Spacecraft technologies
 - Global telecom and data services
 - Greater diversion of options for access to space
 - Launch capabilities play an important role for launching large numbers of SmallSats including constellations and to various destinations
 - Space Tugs and OTV
 - Hosting Payloads
 - Rideshare



Looking Forward

SmallSats for sustained decadal-class observations

Data products from large/small missions become indistinguishable

New insights from multi-instrument constellation data fusion and analytics

Cooperative synergies among large and small missions

International cooperation on key science measurements for societal benefit

Commercial infrastructure services

NASA

A vertical strip of space imagery runs through the center of the image. From top to bottom, it shows a blue and purple galaxy, a bright star, a ringed planet (Saturn), a crescent moon, and a large, glowing orange sun. In the foreground, a silhouette of a person stands with arms raised, looking out at the sun. The sun's light creates a bright glow on the floor below the person.

EXPLORE
with us

A vibrant space-themed background featuring a blue and green nebula, a bright yellow sun, and several planets including Saturn, Mars, and the Moon. The scene is framed by a large, dark blue circular graphic on the right side.

Internship Opportunities for International Students

NASA International Internship (NASA I²) Program

- Currently pursuing an undergraduate or graduate degree in science, technology, engineering or mathematics (STEM) in a topic relevant to NASA's mission priorities.
- Maintaining high academic standing.
- Demonstrating an active interest in the U.S. space program.
- Communicating Proficiently in English

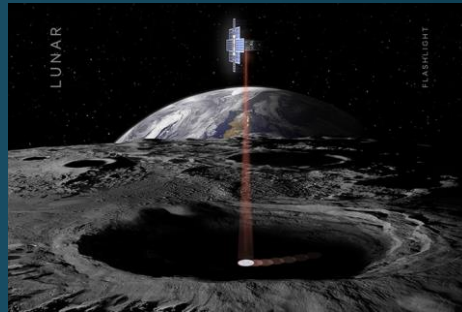
Small Spacecraft Coordination Group (SSCG)

- National Academies Report Recommendation: NASA should develop centralized management of the agency's CubeSat programs for science and science-enabling technology that is in coordination with all directorates involved in CubeSat missions and programs
- Formed and chartered by the NASA to advise the SMD, STMD, and HEOMD Associate Administrators on strategy to guide cross-agency initiatives, policies, and programmatic scope
- The SSCG represents a coordination (not management) function
- SMD, STMD, and HEOMD small spacecraft missions are actively pursuing science, space technology, and strategic knowledge gaps



Science

Hurricane observations via TROPICS constellation



Exploration

Lunar volatiles via Lunar Flashlight mission



Technology

Spacecraft subsystem technology maturation via PTD, TDM, FO, GCD

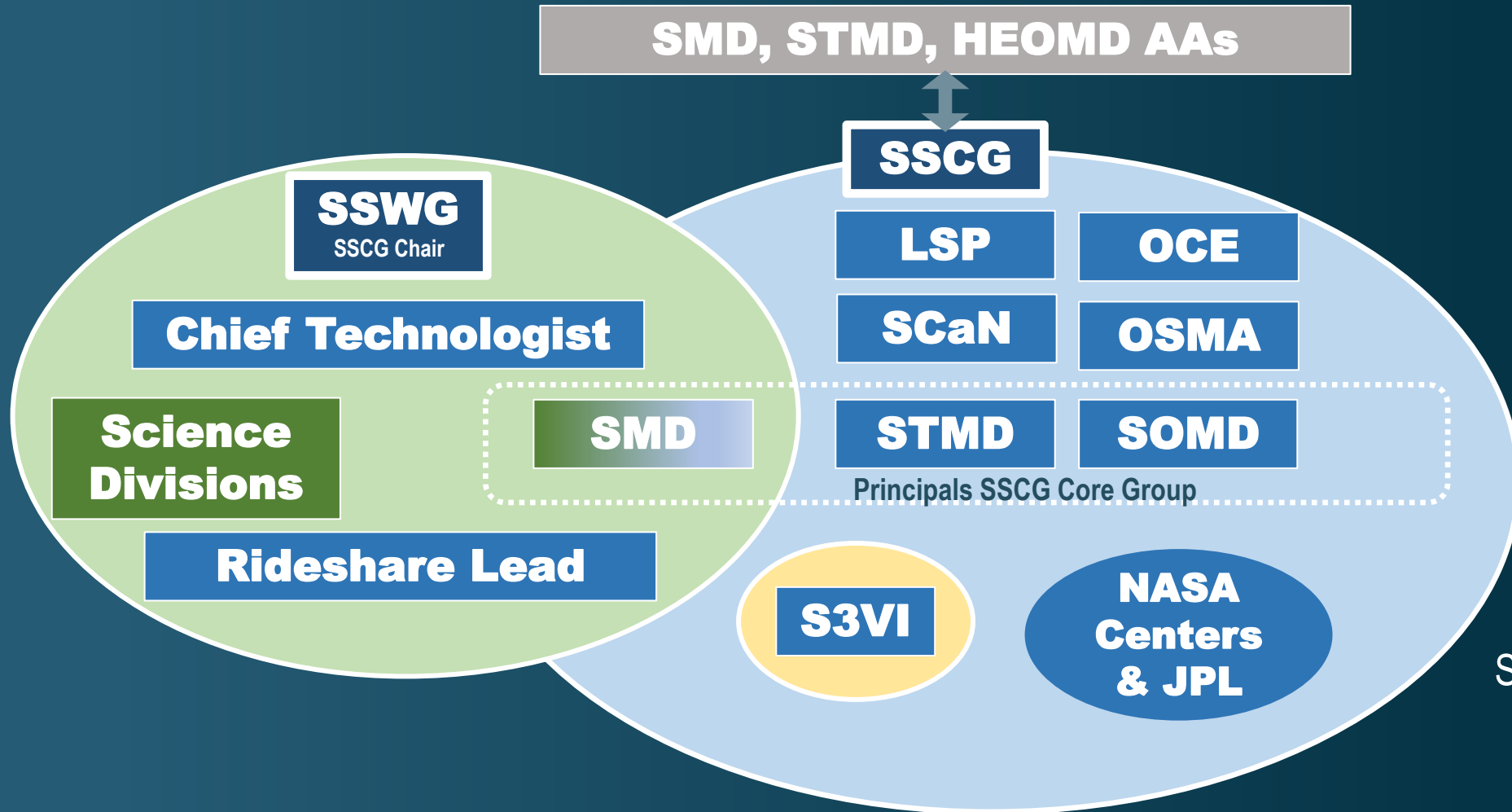
New Observation Methods

Strategic Knowledge Gaps

Spacecraft Subsystems

National Academies and NASA Reports Impact SmallSat/CubeSat Strategy

Structure of the SSCG



Small Spacecraft Coordination Group (SSCG) advises AAs on strategy to guide cross-agency initiatives and relevant policies, programmatic scope and priorities

Small Spacecraft Working Group (SSWG) advises the SSCG and assists SMD in development of innovative science investigations

Areas of Focus Strategy & Implementation, Launch Accommodation & Rideshare, Services & Infrastructure, Safety, Mission Assurance, and Reliability, CyberSecurity & Enterprise Protection, Commercial Partnerships & New Space, International Relationships and Outreach

Organizational Alignment and Coordination to Support Small Mission Science and Technology Community

SmallSat Activities

- 2021 PI/PM/SE Lessons Learned Forum
- S3VI and Center-run Industry and Science Webinars and Seminars
- SmallSat Reliability Institute (SSRI) website
- 2020 Access2Space Workshop Report¹

¹http://access2space.jhuapl.edu/Agenda/A2S_Workshop_Results_Final%20Report_20200910.pdf

The image shows a screenshot of the '2021 NASA Small Spacecraft Virtual Forum' website on the left and a grid of video conference participants on the right. The website header includes 'SMALL SPACECRAFT VIRTUAL FORUM' and navigation links for 'Overview', 'Forum Agenda', and 'Questions & Answers'. The main heading is '2021 NASA Small Spacecraft Virtual Forum'. Below this, a paragraph states: 'Fast development cycles are a principal enabling feature of small satellite technology. The continual infusion of technology innovations, of creative approaches and of new capabilities is a key element of its successful utilization. Achieving these advancements requires open and efficient exchange of results, experiences, and ideas. For this reason, building and cultivating a community of practices around small satellite technology development and mission implementation are critical components of NASA's small satellite mission programs.' To the right of the text is a graphic titled 'OPERATIONAL PAST & FUTURE SMALLSAT/CUBESAT FLEET' showing various satellite orbits and missions. The video conference grid on the right consists of approximately 40 individual participant windows, each with a name and affiliation, such as 'Harris, Cynthia J. (ARC-RS)', 'Wilder, Frederick', 'Mary Khapp', 'Lori Feaga (Guest)', 'Perez, Craig R. (ARC-D)', 'Dervan, Jared A. (MSFC EEDS)', 'Dave Klumpar (Guest)', 'Boon Lim - JPL (Guest)', 'Hui, C Michelle (MSFC-ST12)', 'Amy Keezee (Guest)', 'Tom McMahon (UA (Guest))', 'Loring Research Center', 'Edwards, William C. (LARC-D2)', 'Abresch, Brian S. (WFF-5630)', 'Sanza, Luis H. (GSFC-5960)', 'Gonzalez, Kelly Lynn (Berry)', 'Mahnearing, Philip B. (GSFC...)', 'Cahill, Sally A. (ARC-RS)', 'LaRocca, Daniel M.', 'Abe Filkone (Guest)', 'Love, John F. (ARC-RS)', 'Marinan, Anne D. (US-313F)', 'Lakshin, Constantine (LARC...)', 'Pedroty, Samuel M. (JSC-EG...)', 'Ryan Raffaele (Guest)', 'Tan, Florence W. (HQ-DA000)', 'Brandon Allen', 'Bruce Yost', 'Sasha Courtade (Guest)', 'Johnson, Thomas E. (WFF-851)', 'WESTON, SASHA VICTORIA', 'Hillier, Pamela S. (GSFC-4970)', 'Crahan, Winston R. (ARC-RS)', 'Loren W Blum', 'Nicole Ela (NCAR/HAO) (Guest)', and 'David Sundqvist Sundqvist'.

SCIENCE 2020-2024: A Vision for Scientific Excellence

VISION

Lead a globally interconnected program of scientific discovery that encourages innovation, positively impacts people's lives, and is a source of inspiration

MISSION

Discover the secrets of the universe

Search for life elsewhere

Protect and improve life on Earth and in Space

VALUES

Excellence

Inclusion

Leadership

Integrity

Teamwork

Safety

PRIORITIES

Exploration and Scientific Discovery

Innovation

Interconnectivity and Partnerships

Inspiration



NASA SCIENCE

AN INTEGRATED PROGRAM



EARTH
SCIENCE



HELIOPHYSICS



PLANETARY
SCIENCE



ASTROPHYSICS



BIOLOGICAL &
PHYSICAL SCIENCE



JOINT AGENCY
SATELLITE

RESEARCH

~**10,000** U.S. Scientists Funded
~**3,000** Competitively Selected Awards
~**\$600M** Awarded Annually

TECHNOLOGY DEVELOPMENT

~**\$397M** Invested Annually

SMALLSATS/ CUBESATS

45 Science Missions
12 Technology Demos

SOUNDING ROCKETS

2 Science Missions Launched
45 In Development

BALLOONS

54 Missions in Development

EARTH-BASED OBSERVATIONS

23 Operating Missions
5 Upcoming Earth System
Observatory Missions

MISSIONS

114 Missions from
formulation through
extended operations

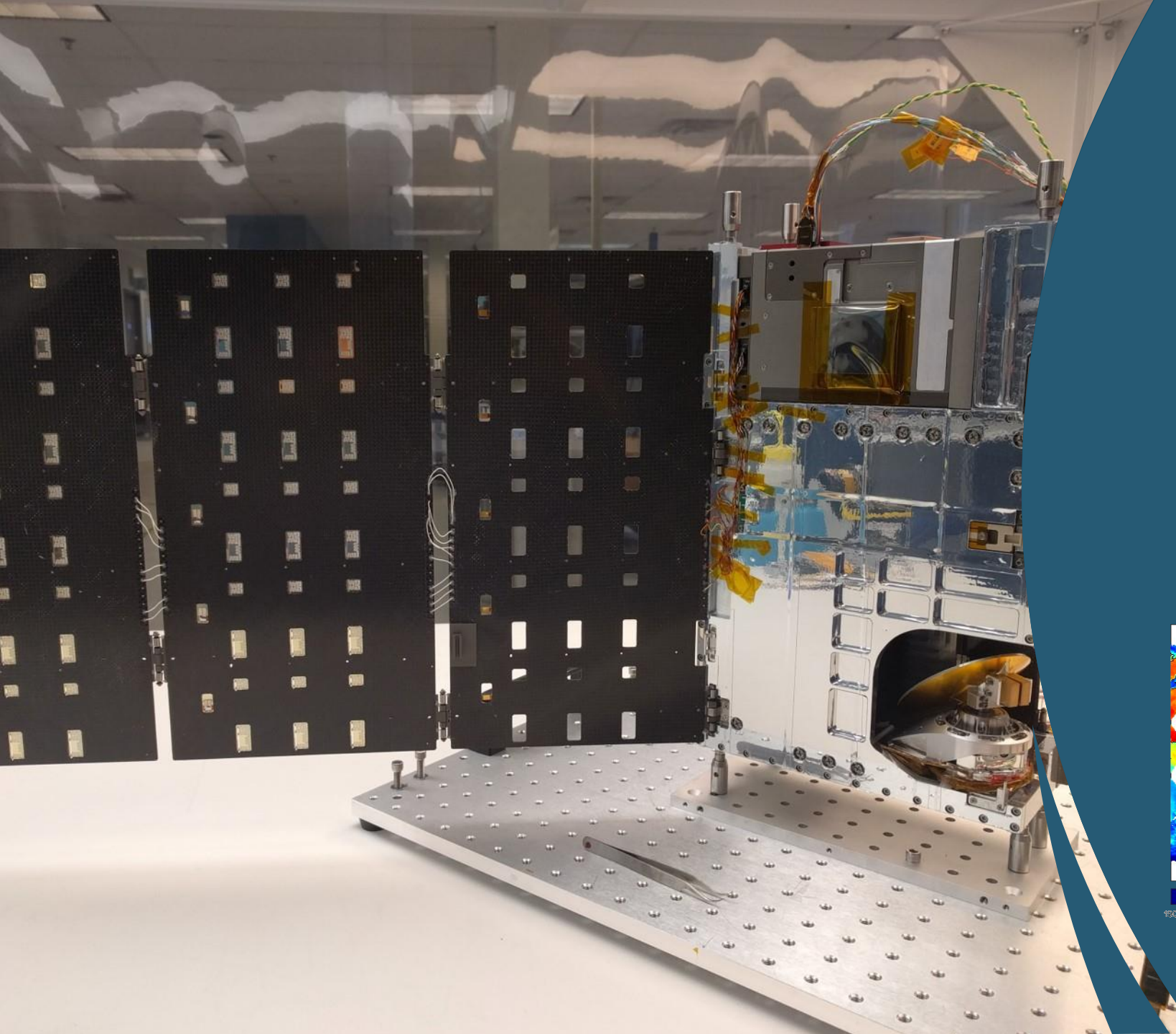
Science by the
NUMBERS



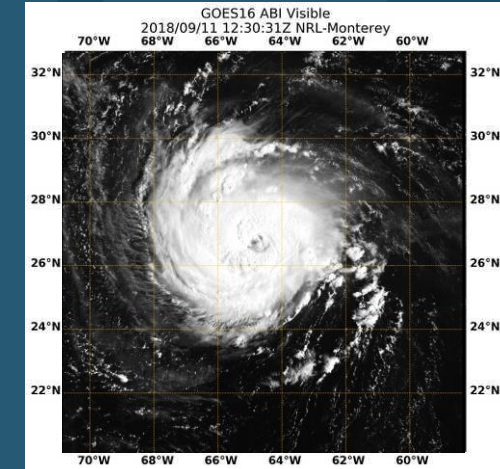
SMD SmallSat Related Policy

- **2018:**
 - Released SMD Document SPD-32: *Evolved Expendable Launch Vehicle (EEL V) Secondary Payload Adapter (ESPA) Secondary Payloads Rideshare Policy*¹ to “enable rideshare or launch accommodation opportunities using an ESPA ring as part of the launch service procured for an SMD primary payload”
- **2020:**
 - SMD Rideshare Office formed led by Aly Mendoza-Hill to maximize science, exploration, and technology returns by enabling accommodation opportunities for secondary payloads on SMD primary mission launches.

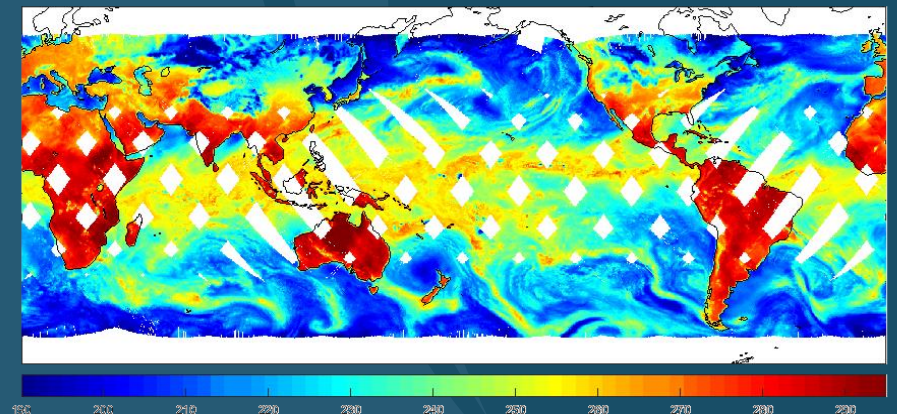
¹ https://www.nasa.gov/sites/default/files/atoms/files/spd-32_rev1.pdf



TEMPEST-D



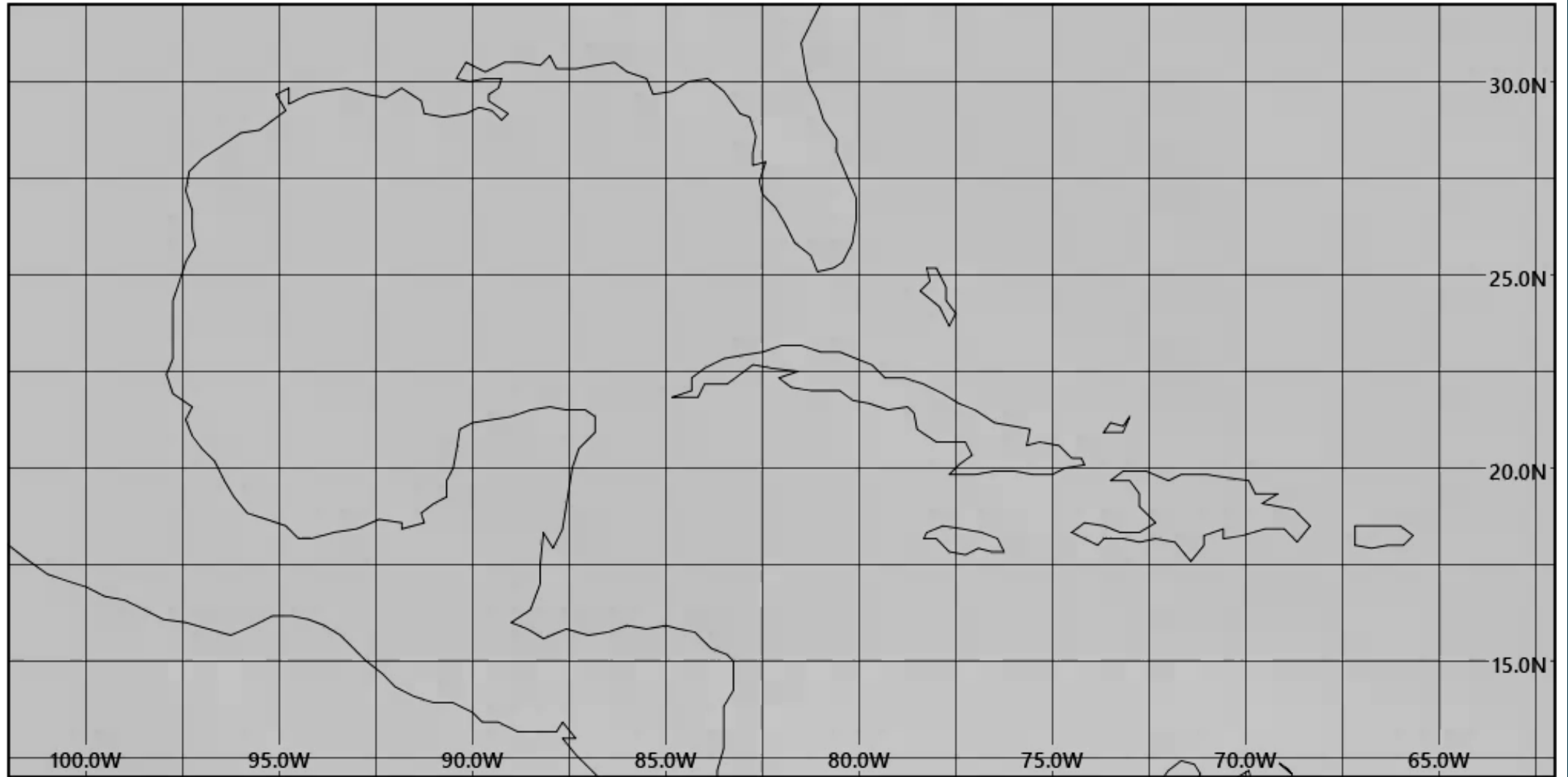
*Sept. 11, 2018 – TEMPEST-D 167 GHz
brightness temperatures of Hurricane Florence*



*Dec. 8-12, 2018 – TEMPEST-D 87 GHz near-
global brightness temperatures in ISS orbit*

CYGNSS / Hurricane Ida / 26-29 Aug 2021

Reference time of file: 2021-08-26 18:30

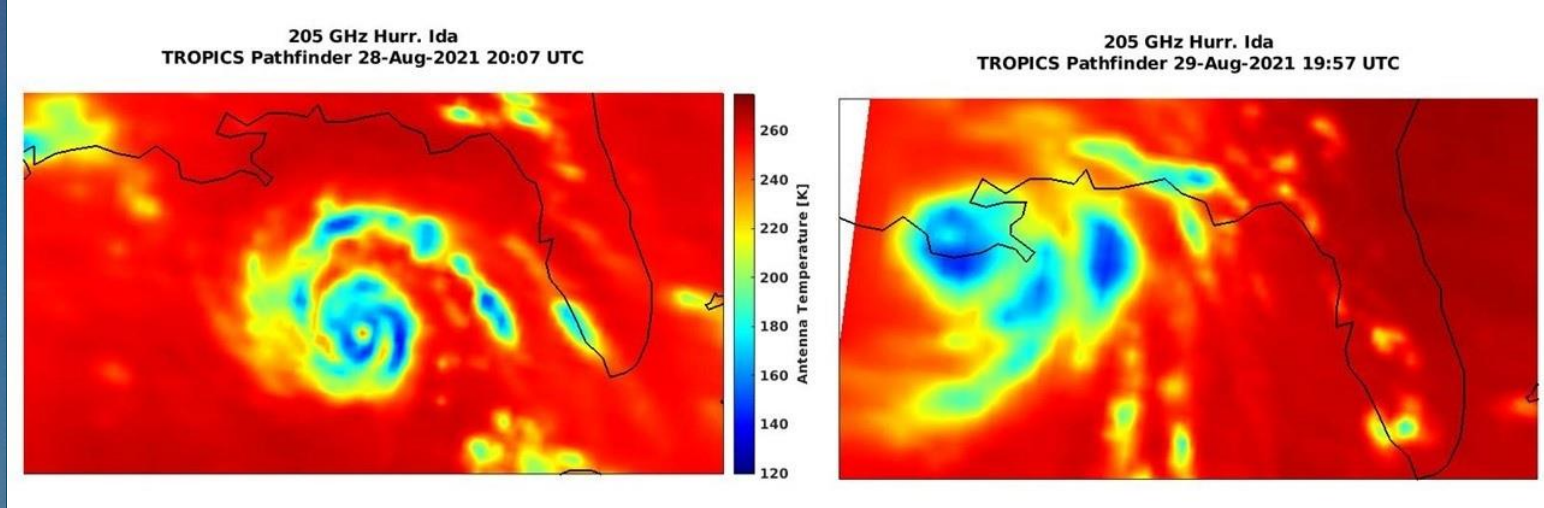


Young sea limited fetch wind speed (m s⁻¹)



Data Min = 0.4. Max = 43.8

TROPICS Pathfinder (Qualification Unit) Launched June 30, 2021



Imagery of Hurricane Ida Before/After Landfall @ 205 GHz

- Sun-synchronous orbit; 530 km altitude; 2:00 pm LTDN
- Satellite has been contacted and in excellent health
- Bus and Payload commissioning began in July and August
- Performance is excellent!
- NOAA-funded low-latency experiment to be conducted in October
- Data will be available to general public via GES-DISC

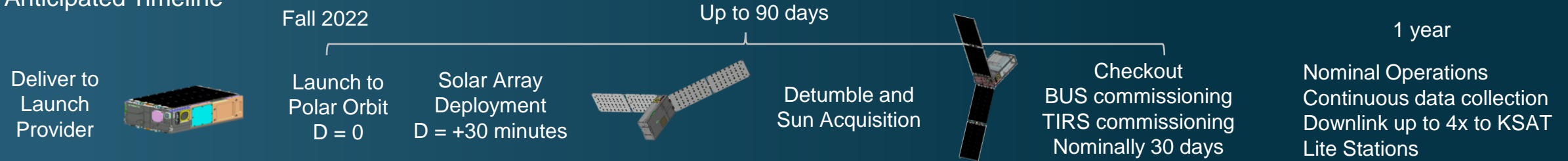
Science of PolCube

- PolCube measurement capabilities (swath/viewing angles) lie roughly in-between SPEXone and HARP2 on PACE.
- PolCube polarimeter measurements can improve retrieval and understanding of aerosol absorption (aerosol layer height, detection of absorbing aerosols, fine mode vs coarse mode aerosols)
- PolCube can provide polarized radiance measurements at high spatial resolution that will help characterize polarization sensitivity of cubesat VSWIR instruments (e.g., SBG pathfinder) and validate retrievals in the presence of aerosols.
- PolCube UV measurements complement GEMS/TEMPO observations.
- Planned orbit with a ground-repeat of 1 day will yield repeated observations of the same areas.
- PolCube builds upon our international partnership(s) with South Korea

Polar Radiant Energy in the Far-Infrared Experiment (PREFIRE)

<https://prefire.ssec.wisc.edu>

Anticipated Timeline

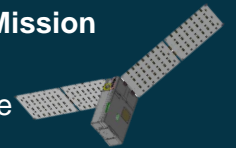


Facts and Firsts

- PREFIRE systematically maps Earth's far-infrared emission spectrum for the first time.
- PREFIRE observes the spectral fingerprints of surface and atmospheric processes using two satellites.
- PREFIRE science data is collected entirely by two 6U CubeSats.
- PREFIRE improves polar climate prediction by interfacing directly with ice sheet and climate models.

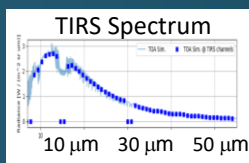
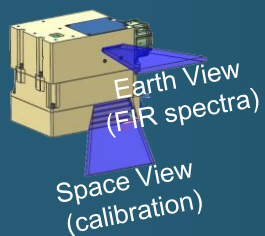
Spacecraft and Mission

2 6U CubeSats
 470-540 km altitude
 82-98° inclination
 1 year nominal lifetime



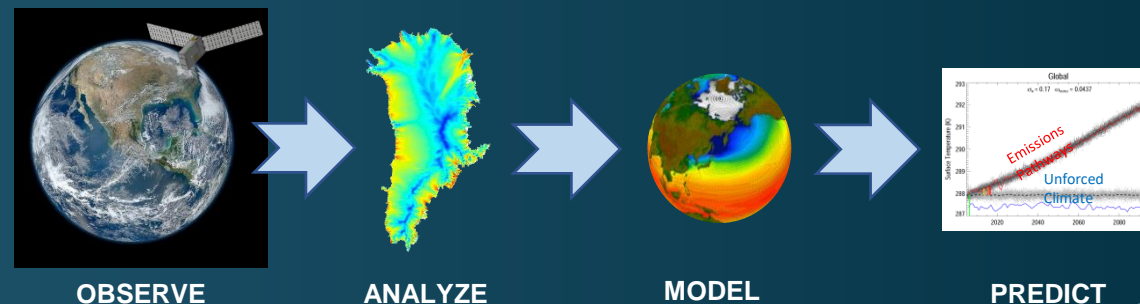
Thermal InfraRed Spectrometer (TIRS)

- 5 to 54 mm spectral range
- 0.84 mm sampling
- 8x64 spatial x spectral channels
- Size: 3U Mass: 3 kg Power: 4.5 W



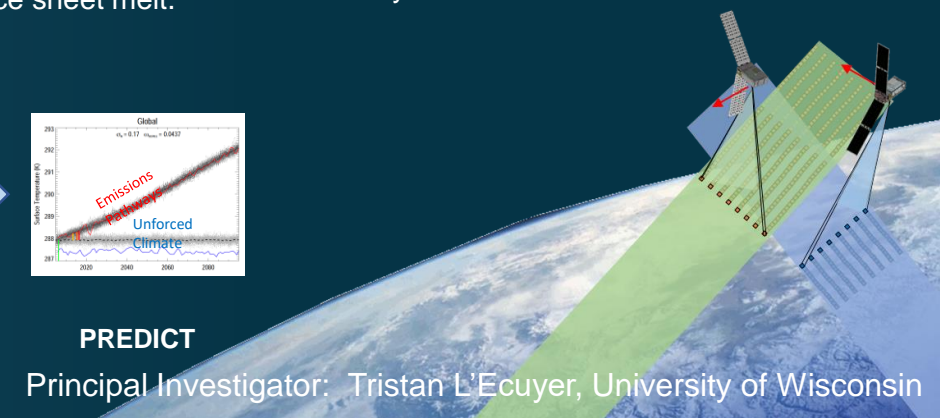
PREFIRE Science

- PREFIRE connects observations, analyses, and models to improve polar climate prediction including rates of Arctic warming, sea ice decline, and ice sheet melt.



Overlapping Measurements

- Co-located ground scenes separated by 1-12 hours.



Principal Investigator: Tristan L'Ecuyer, University of Wisconsin

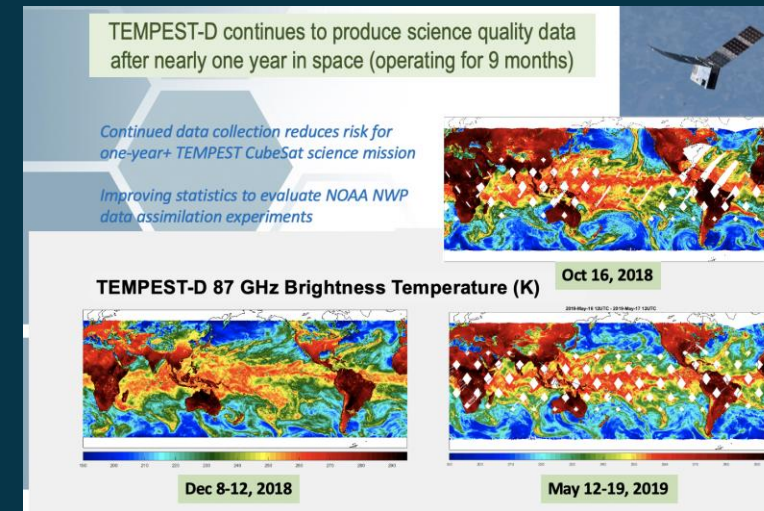
Current State of Science SmallSats

All Divisions have SmallSat programs

- All divisions have flown SmallSats
- No division has flown a rideshare on ESPA ring; however, several are in work: SIMPLEX, HPD STP Science and Tech MoO, EVMs, PIONEERS Studies
- Improved maturity and reliability of industry provided spacecraft Science results for SmallSats show great promise
- Every division has flown a CubeSat in
 - 2018 (MarCO A/B, HaloSat, CubeRRT, RainCube, TEMPEST-D, ELFIN A/B, CSIM-FD)
 - 2021 (QPACE, CUTE, CUPID, TROPICS Pathfinder)

TEMPEST-D Scientific Results and Applications

Produced well-calibrated atmospheric science data and improved statistics to evaluate NOAA NWP data assimilation experiments for more than two years on orbit



HARP

Optimizing algorithm retrievals of cloud and aerosol properties to be used on HARP-2, a near identical instrument on the PACE mission.

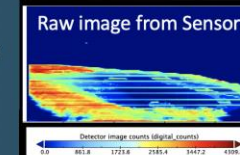
First Light/Partial Image from HARP CubeSat

The HyperAngular Rainbow Polarimeter (HARP), developed by Vanderlei Martins at the University of Maryland, Baltimore County, has acquired first light. This 3U CubeSat was deployed from the International Space Station on February 19, 2020 with the goal of validating a wide field-of-view hyperangular polarimeter, with no moving parts, for the characterization of aerosol and cloud properties.

HARP's first image, a snapshot over Europe, was acquired by pointing its sensors at Earth's horizon. The three detectors are performing with nominal alignment needed for the polarization measurement.

The stripes in this image emphasize the different wavelengths measured, displaying the pattern of HARP's rainbow filter. HARP data will aid in optimizing algorithm retrievals of cloud and aerosol properties to be used on HARP-2, a near identical instrument on the PACE mission.

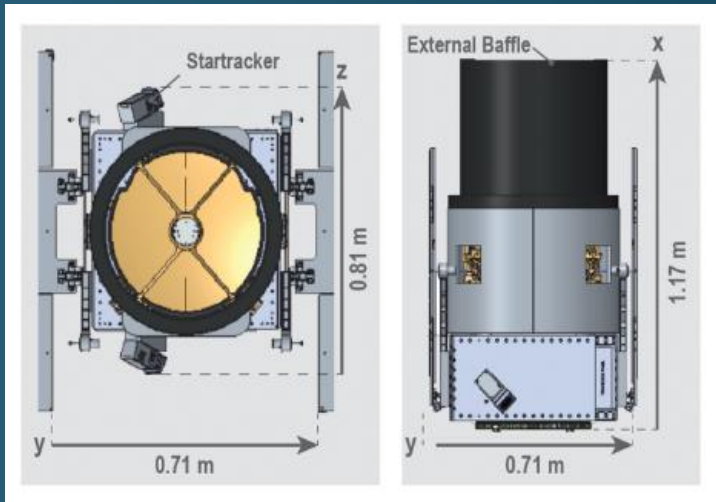
The HARP sensor allows for multiple wavelengths (440, 550, 670 and 870nm) and hyperangular wide FOV imaging capability with no moving parts. The architecture allows for accurate polarization imaging.



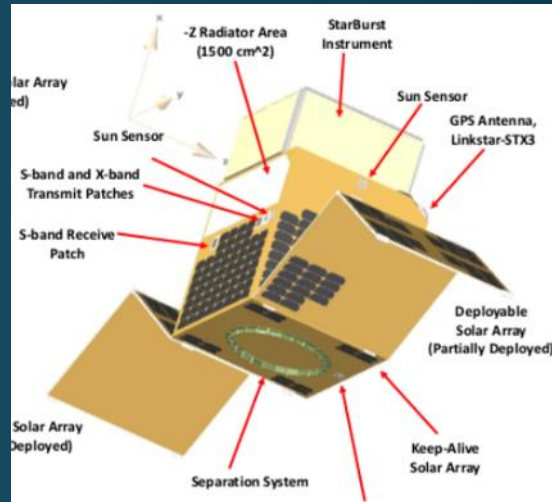
HARP Snapshot over Europe shows the pattern of HARP's rainbow filter

- First image was acquired pointing at Earth's horizon
- Stripes emphasize the different wavelengths
- Full push-broom reconstructions will aggregate hundreds of similar images pointing at nadir

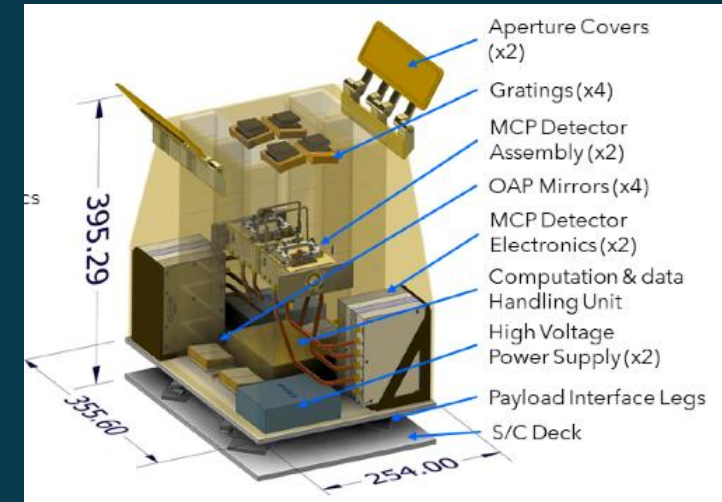
Astrophysics SmallSat Selections – 2020 Pioneers Program



Pandora: Multiwavelength Characterization of Exoplanets and their Host Stars
 PI Elisa Quintana
 NASA GSFC



StarBurst: Gamma-ray ASM, Simultaneous detection of NS/NS mergers with LIGO
 PI Daniel Kocevski
 NASA MSFC

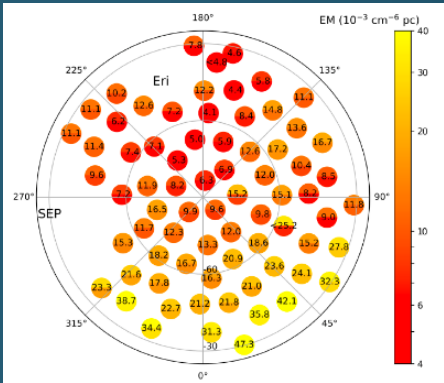


Aspera: IGM Inflow/outflow from galaxies via OVI 10^5K emission line imaging
 PI Carlos Vargas
 U. Arizona

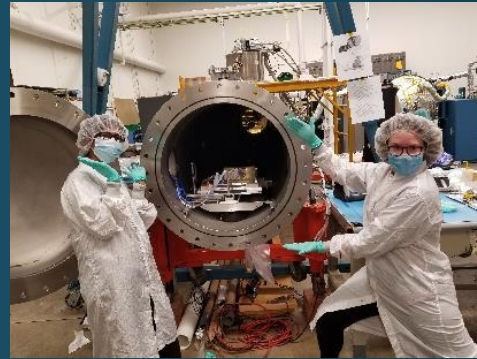
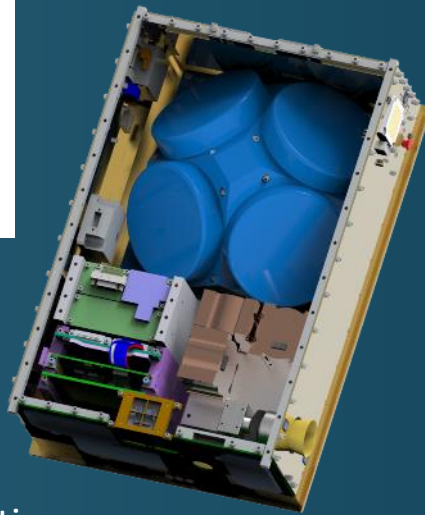
Astrophysics CubeSats

Solicited annually in ROSES/APRA, ~1 new start per year, ~<\$5M each total cost

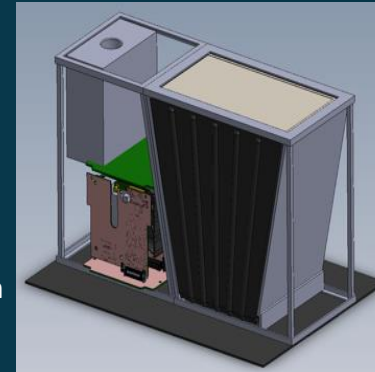
HaloSat: PI Phil Kaaret (U of Iowa),
Launch May 2018, Reentered Jan 2021,
OVII/OVIII lines in Galaxy halo, determine
mass and structure of Galaxy halo



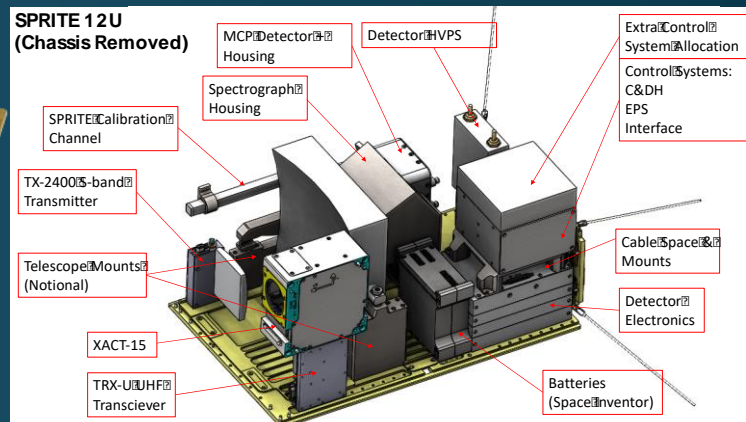
BurstCube: PI Jeremy Perkins (NASA GSFC),
Launch NET Dec 2021,
GRB monitor w/ TDRSS
real-time event notification



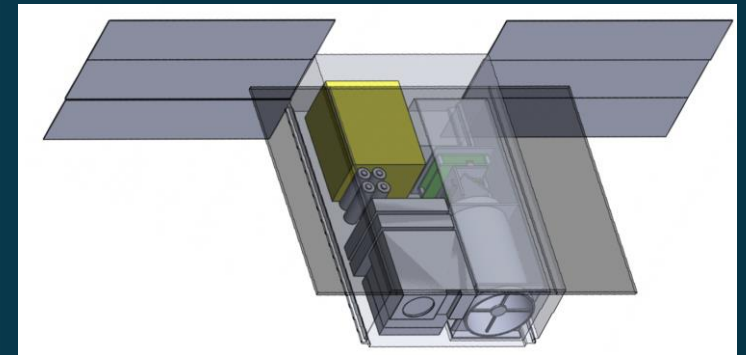
CUTE: PI Kevin France (CU),
Launch Sep 2021,
UV Imaging of hot
Jupiter ablation,
(Arika Egan & Ambily Suresh in lab)



BlackCat: PI Abe Falcone (Penn St U),
Launch NET Mar 2024,
2-20 KeV wide FOV
localization of X-ray
transients, real-time 'cell
phone' downlink



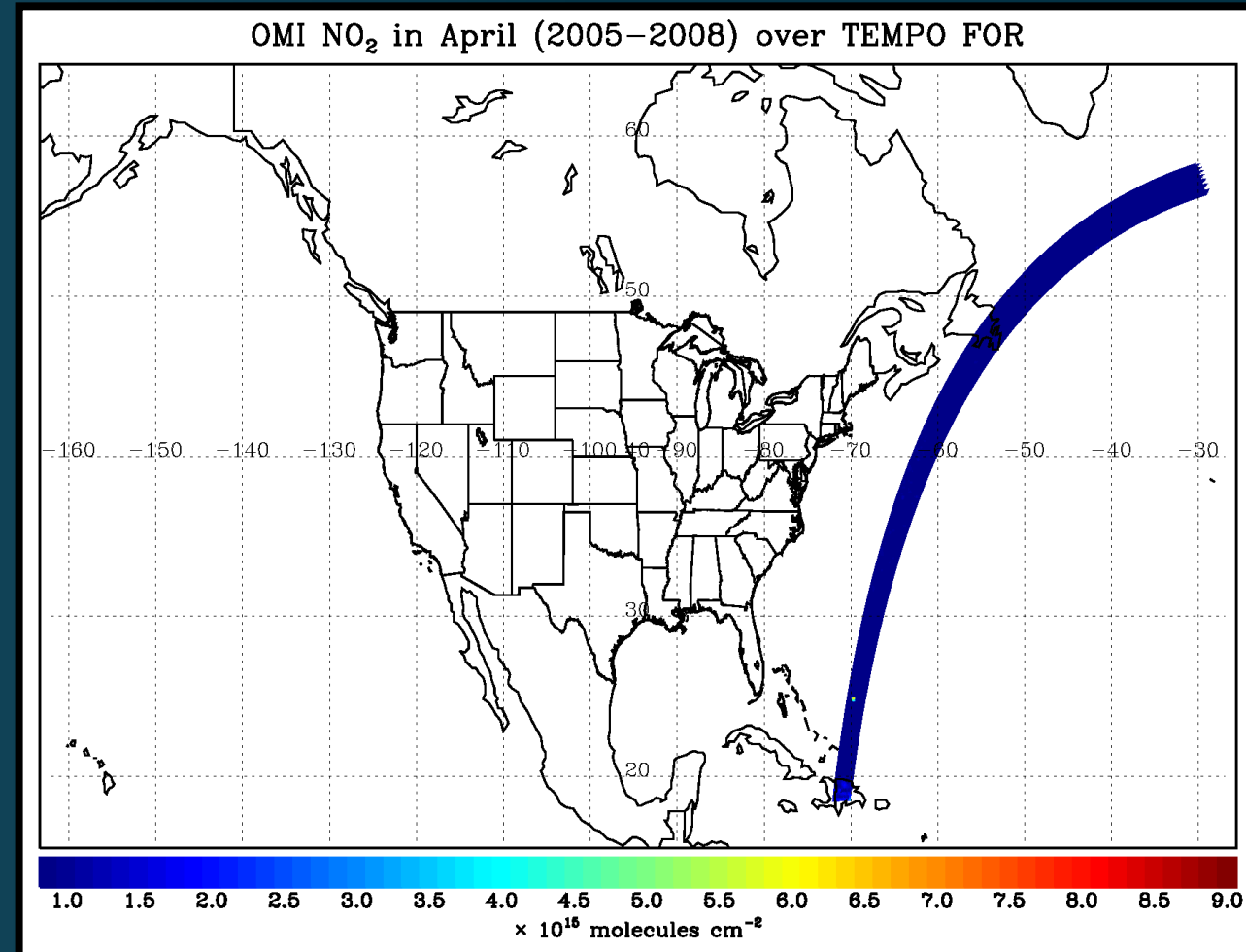
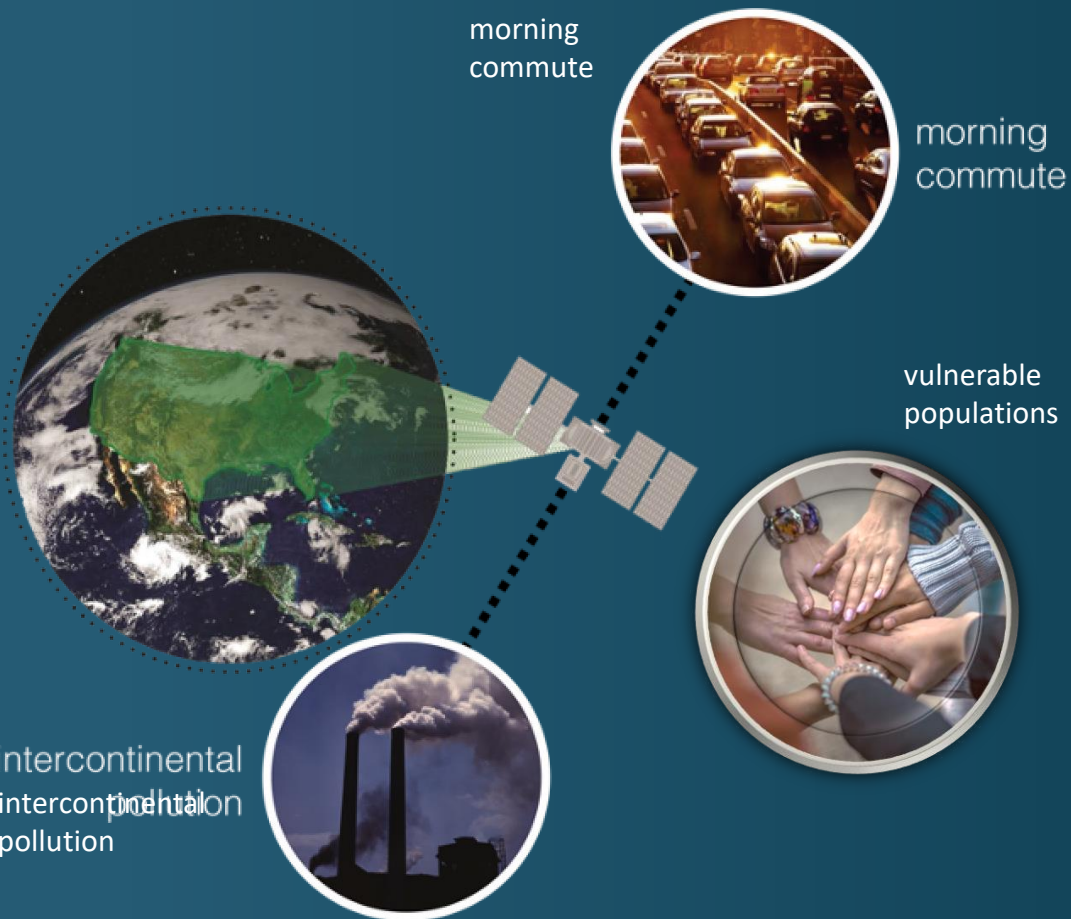
SPRITE, PI Brian Fleming (CU),
Launch NET Jan 2023,
UV spectra of ionizing radiation
from star forming galaxies



SPARCS, PI, Evgenya Shkolnik (ASU),
Launch NET Jan 2024,
monitor the flares and sunspot
activity of M-type stars, also called
red dwarfs, in the far- and near-
ultraviolet

TEMPO Societal Benefits

By measuring Ozone (O_3) and O_3 precursors, TEMPO provides critical understanding of air quality phases: **Emissions**, **Photochemistry**, and **Long-range transport**. TEMPO will launch as a hosted payload on an Intelsat satellite in 2022.



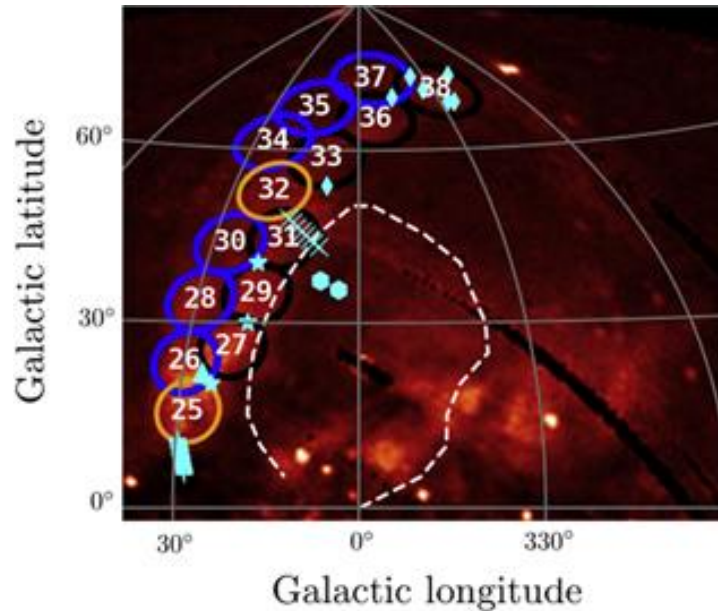
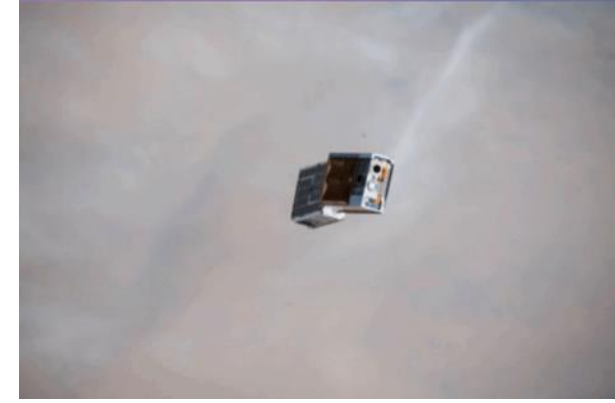
HaloSat – A CubeSat to Study the Hot Galactic Halo

First CubeSat funded by Astrophysics

- PI Philip Kaaret (U of Iowa), collaborators at GSFC, Johns Hopkins, LATMOS.
- Funding start 1/2016, launch 5/2018, deployed 7/2018, re-entry 1/2021.
- Two full sky surveys over two years of science operations.

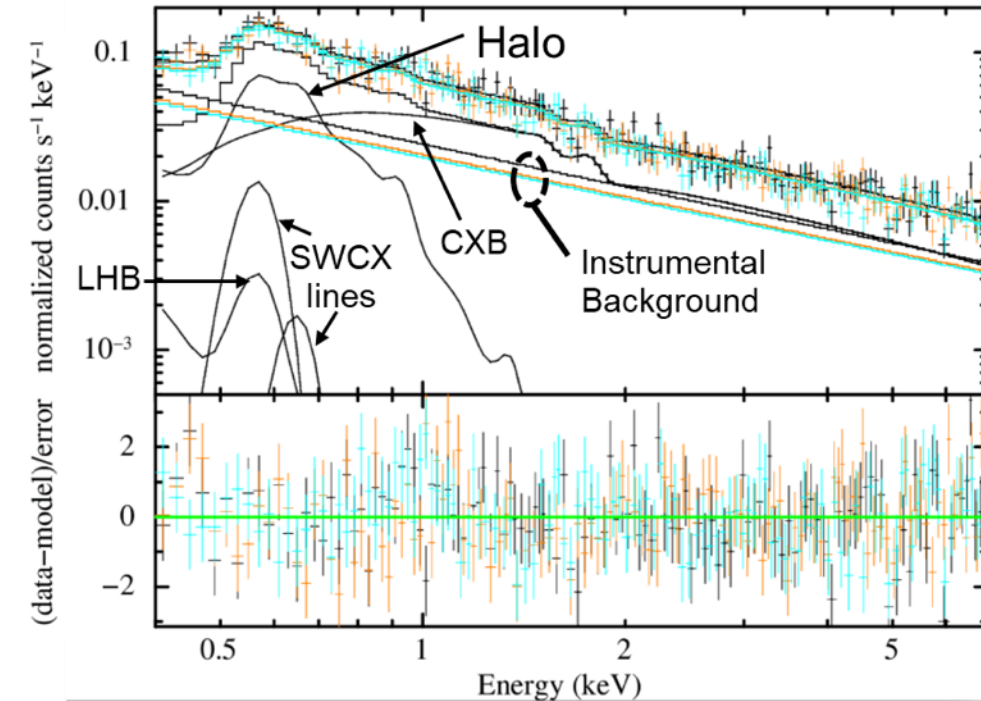
Student and early career researcher training:

- PhDs: one complete (postdoc on BlackCat), two in progress. One Masters (at USGS/EROS)
- Undergraduates: seven in Physics (grad at Berkeley, Caltech, PSU, Iowa), four in Engineering.
- Postdocs: one now at GSFC/UMBC, one now at GSFC/CCMC.



Science highlights:

- “A disk-dominated and clumpy circumgalactic medium of the Milky Way seen in X-ray emission” – Nature Astronomy
- “An Analysis of the North Polar Spur Using HaloSat” – ApJ
- “A HaloSat Analysis of the Cygnus Superbubble” – ApJ
- Ten refereed papers (3 by grad, 3 by undergrad), three more in prep.



Colorado Ultraviolet Transit Experiment (CUTE)

Mission Overview:

- 4-year NASA funded project to design, build, integrate, test, and operate a 6-unit CubeSat
- 1-year nominal mission
- Instrument will measure near-ultraviolet (NUV) transmission
- **Successfully launched from Vandenberg Air Force Base on September 27th, 2021!**
- Successful Communications and commissioning currently in process

Science Overview:

- Exoplanet atmosphere characterization of composition and mass loss rates

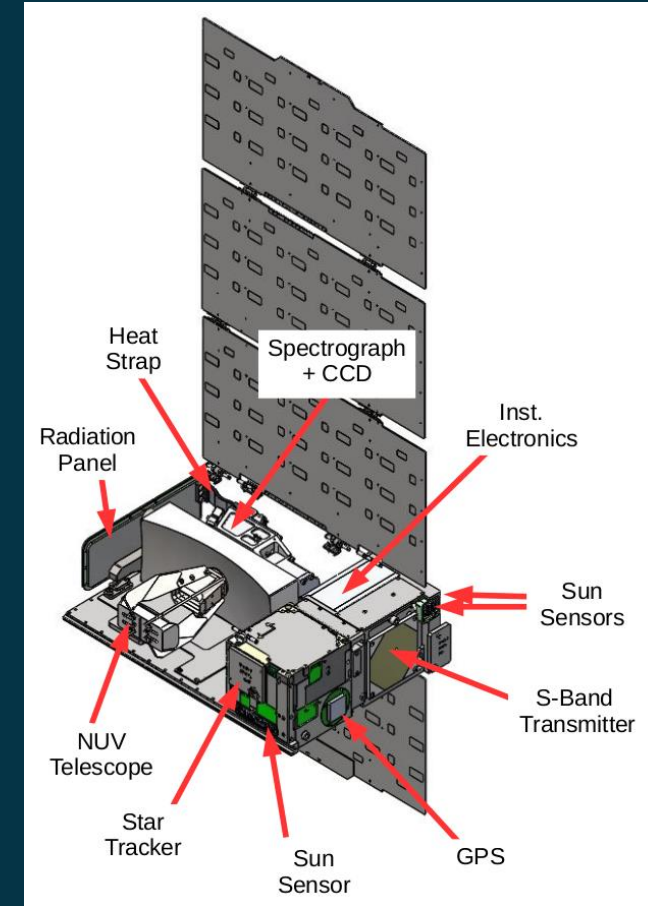


Image from: <https://lasp.colorado.edu/home/cute/>

Lunar Polar Hydrogen Mapper (LunaH-Map)

PI: Craig Hardgrove, Arizona State University

Science Objective:

Evaluate uniformity of bulk hydrogen abundance at the lunar south pole

- Determine if the top meter of the lunar south pole hydrogen distribution is consistent with expected permafrost depths and frost distributions.
- Spatially resolve the permanently shadowed regions and determine if hydrogen enrichments are contained within 15 square-km.
- Determine if hydrogen is enhanced in regions of the lunar south pole outside of permanent shadow and where ice is not predicted to be stable <1m.

Mission Design:

- 6U CubeSat
- Launch on Artemis I (Dec 2021)
- Solar electric propulsion used to enter highly elliptical lunar polar orbit (~10 km periapsis)
 - 70 days for lunar capture; 360 days to reach science orbit; 60 days prime mission
- Miniature Neutron Spectrometer (Mini-NS) with novel CLYC ($\text{Cs}_2\text{LiYCl}_6:\text{Ce}$) scintillator will provide high-resolution maps of hydrogen within ~5 degrees of the pole



Congratulations Landsat 9 and CuPID!

- The Landsat 9 satellite launched from the Vandenberg Space Force Base in California Atlas V rocket at 2:12pm ET.
- The rocket then took the ESPA ring to a different altitude and deployed the Cusp Plasma Imaging Detector (CuPID) CubeSat and another 3 CubeSats
- CuPID will image the boundary where Earth's magnetic field interacts with the Sun's



Image: CuPID in December 2019, when the chassis met the avionics.
Credits: Emil Atz

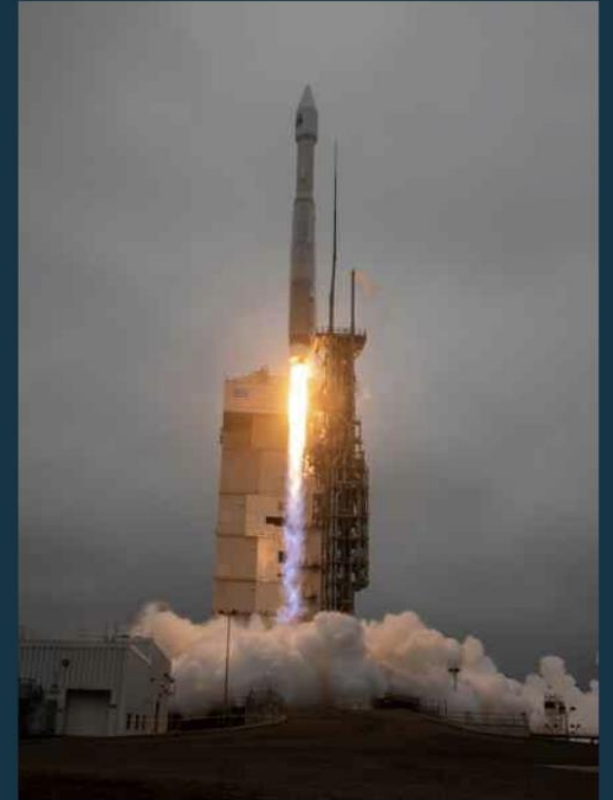


Image: Liftoff of AtlasV with Landsat9
Credits:United Launch Alliance



Escape and Plasma Acceleration and Dynamics Explorers



(ESCAPADE)

PI: Rob Lillis, UC Berkeley

Science Objective: To understand the evolution of Mars' climate by studying the transfer of solar wind energy and momentum through Mars' unique magnetosphere and how the solar wind drives ion and sputtering escape. We will uncover the structure, composition, variability and dynamics of a unique magnetosphere of Mars.

Mission Facts:

- 2 ESPA Class-spacecraft, Solar powered, Class D tailored mission
- Selected in 2019 under SIMPLEx-2, budget \$80M
- Launch: 2024
- Leverage use of PROTON bus from Rocket Labs
- Instruments:
 - EESA-I - Suprathermal ions
 - EESA-e - Suprathermal electrons & Magnetic topology
 - EMAG - Magnetic field
 - FPP, PIP, mNLP - Thermal plasma



Cusp Plasma Imaging Detector (CuPID)

Mission Overview

Mission Overview

The CuPID observatory will overcome the spatial/temporal ambiguity by innovatively imaging ion dispersions in soft X-rays. Soft X-rays are emitted from charge-exchange between high-charge-state solar wind and neutral hydrogen atoms in the Earth's geocorona. By imaging ion dispersions, one can map and understand the full spatial and temporal features of ion injections and therefore the macroscale nature of magnetopause reconnection.

Science Objectives

The CuPID Cubesat observatory is designed to address science objectives regarding the nature of magnetic reconnection. Specifically, the 6U, highly inclined, spacecraft will address the questions, 1. What conditions favor single versus multiple reconnection sites? And 2. What conditions favor steady versus bursty reconnection? The primary science goals would be accomplished through imaging X-rays emitted from the cusps. A bonus science result of the first all-sky map of the magnetospheric in soft X-rays is also possible from the mission.

Key Mission Requirements

Design Life	6 months
Orbit Type	Low Earth Orbit(LEO)
Selection Date	July 28, 2017
Spacecraft	6U
Launch Date	9/27/21 on the Landsat-9 ULA launch

Instruments

The CuPID mission will carry two science instruments, a soft X-ray telescope focusing on 0.1-2keV and a microdosimeter.



Project Organization

Principal Investigator: Brian Walsh

Organization: Boston University

Student involvement In addition to developing novel science instruments, the project has supported significant training for students under the watch of professional scientists and engineers. Thus far 26 undergraduate and graduate students have been involved in the project. It is currently supporting one PhD thesis in heliosphysics instrument development and one postdoctoral scholar

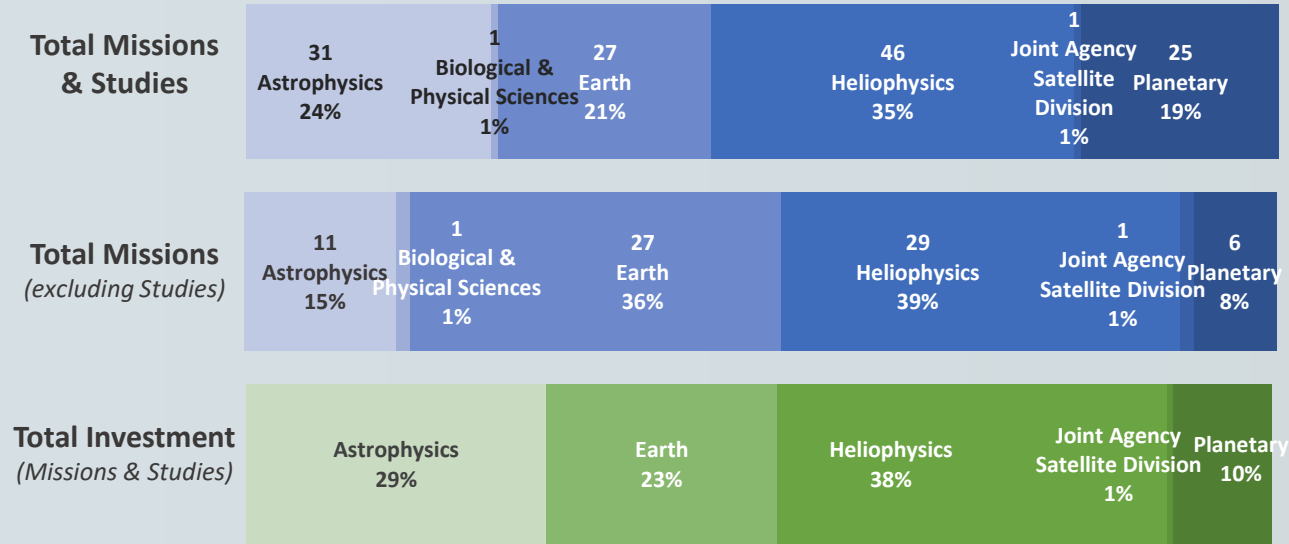
Recent papers Kuntz, K. D. (2019). Solar wind charge exchange: an astrophysical nuisance. *The Astronomy and Astrophysics Review*, 27(1), 1.

NASA's Science SmallSat Missions at a Glance

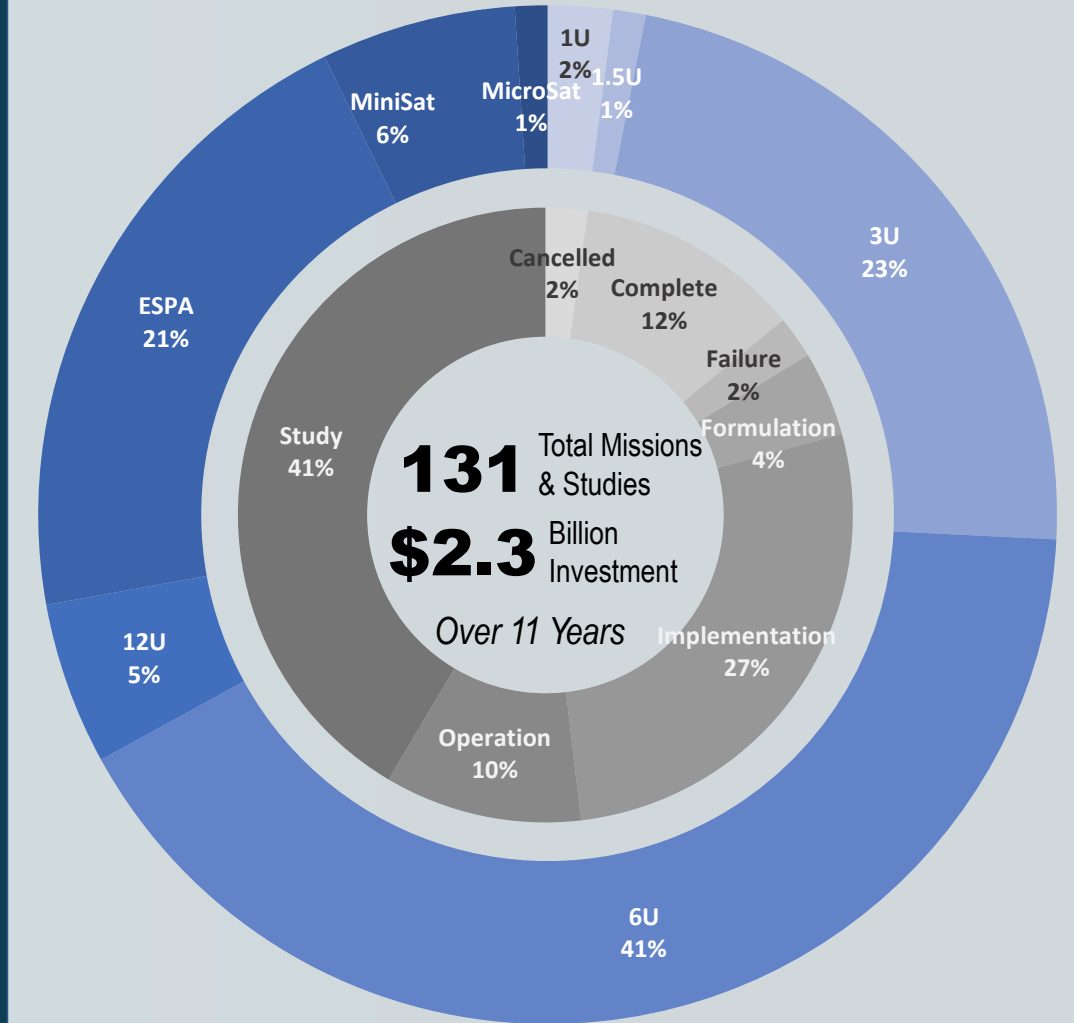
Inclusive Missions and Studies

Data as of October 2021

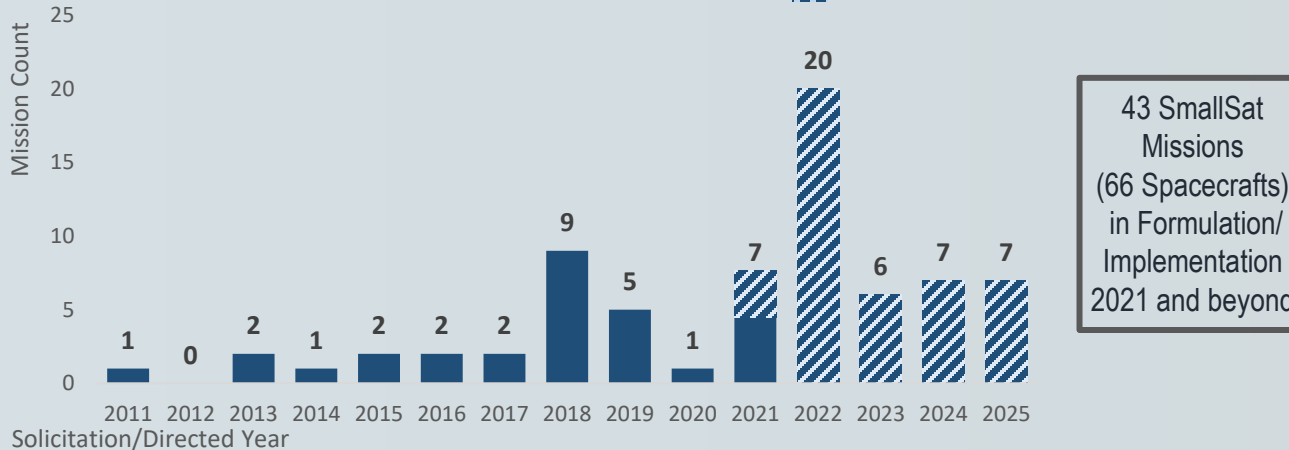
SmallSat/CubeSat Missions by Division



Total Missions by Phase and Satellite Size



NASA Science SmallSat Launches Per Year



*Data inclusive of missions solicited or directed from 2010-2021.

NASA Science Mission Architecture Trends

Science Mission Directorate, Missions Solicited/Directed from 2010-2021, Data as of August 2021

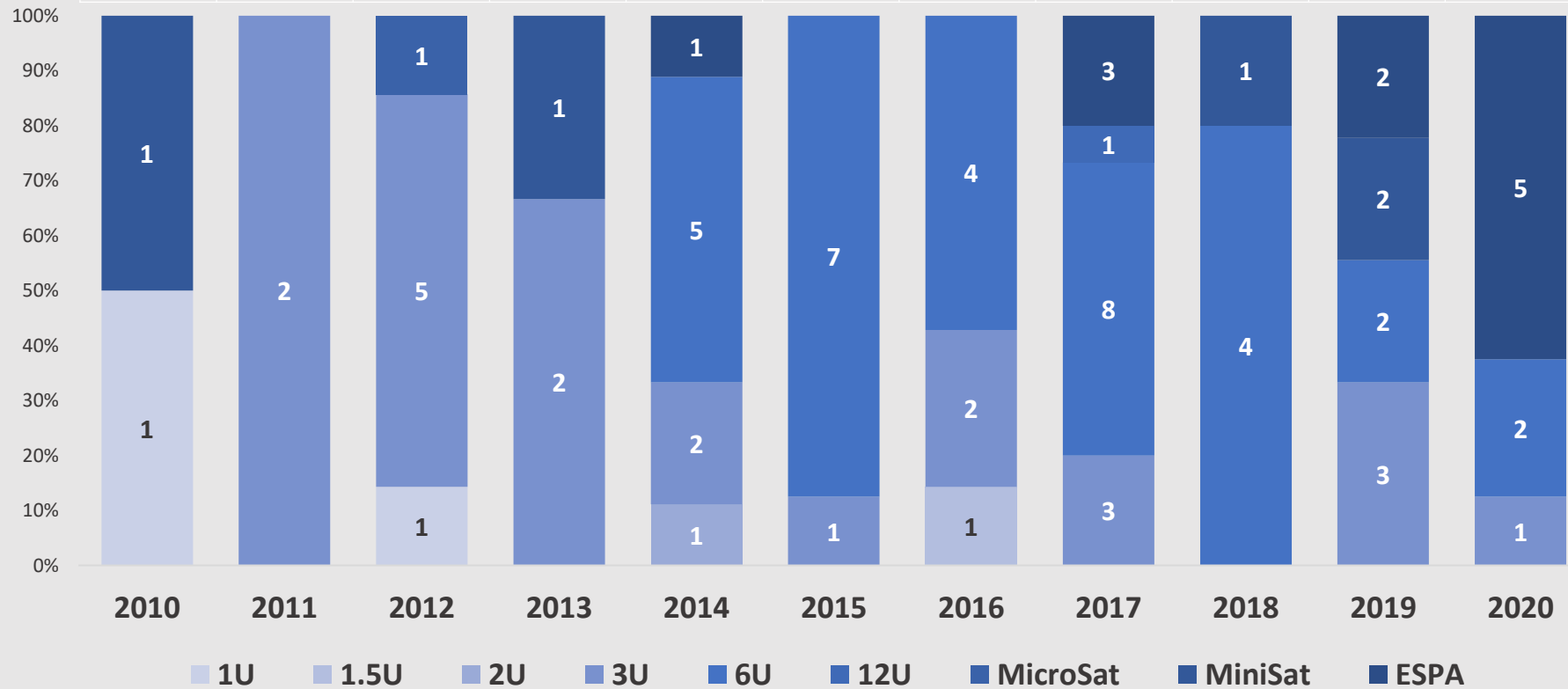
A shift away from 3U or smaller to larger satellites, ESPA-class missions, and constellations

Total Number of Missions (excluding studies)

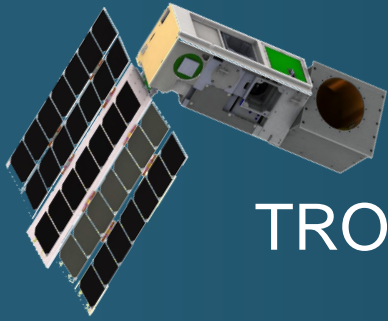
2	2	7	3	9	8	7	15	5	9	8
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% of Total Missions that are Constellations (excluding studies)

-	-	14%	-	22%	-	29%	20%	20%	44%	13%
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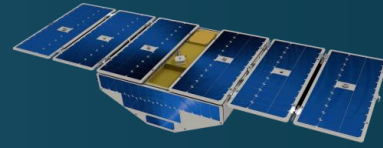


SmallSats Measurements are Coming of Age



TROPICS

- Constellation of 6 3U CubeSats.
- Scanning microwave radiometers will measure temperature, humidity, precipitation, and cloud properties.
- The CubeSats will be launched into three separate orbital planes to enable the overall constellation to monitor changes in tropical cyclones as frequently as every 21 minutes.



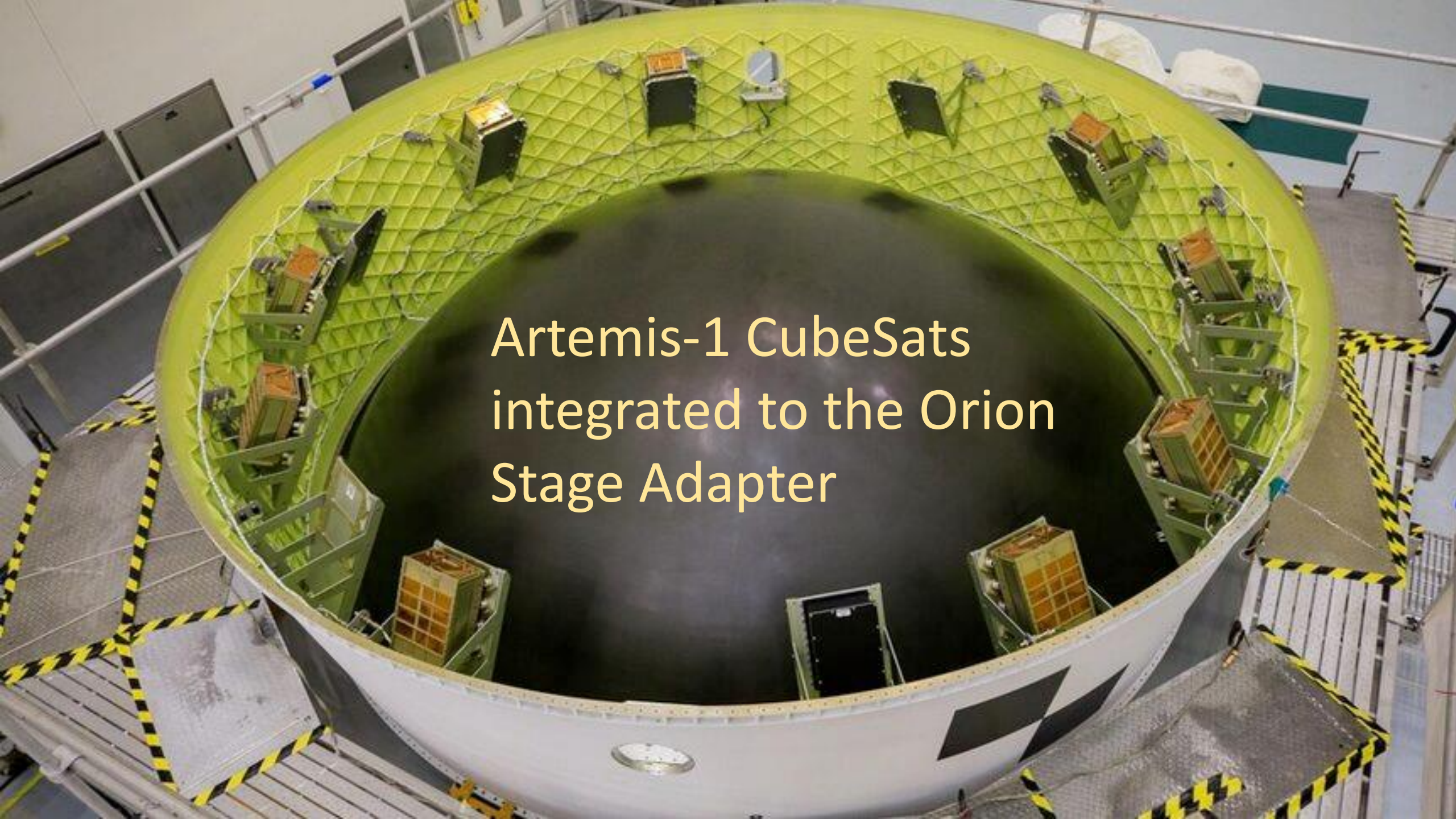
CYGNSS

- Constellation of 8 microsattellites.
- Uses GPS to measure wind speed over oceans to help understand and predict hurricanes and typhoons.
- Successive satellites pass over the same region every 12 minutes.
- Interaction with GPS results in a new image of wind speed over the entire tropics every few hours, compared to every few days for a single satellite.



PREFIRE

- 2 6U CubeSats
- Will systematically map Earth's far-infrared emission spectrum for the first time and observes the spectral fingerprints of surface and atmospheric processes.
- Will improve polar climate prediction by interfacing directly with ice sheet and climate models.

The image shows the interior of the Orion Stage Adapter (OSA), a large, cylindrical structure with a white exterior and a green, diamond-patterned interior. The interior is filled with various electronic components and equipment, including several CubeSats mounted on green racks. The OSA is situated in a cleanroom environment, with yellow and black hazard tape visible on the floor and walls. The text "Artemis-1 CubeSats integrated to the Orion Stage Adapter" is overlaid in the center of the image.

Artemis-1 CubeSats
integrated to the Orion
Stage Adapter

SmallSat/CubeSat Challenges and Opportunities

Strengths

SmallSats are platform for transformative science, technology maturation and demonstration and support to exploration
Access-to-Space options linked to “popular” destinations
Increased commercial services and products – opportunities for “Buy vs Fly”

Challenges

Communications and Encryption for Missions in LEO and beyond, miniaturization of sensors, Interoperability and operating as constellations
Access to space – “the Devil’s in the Details” for ESPA class missions
Understanding SMA/risk approach for SmallSats; training on building SmallSats
Technology: Reliable High Delta-V Propulsion, Aerocapture

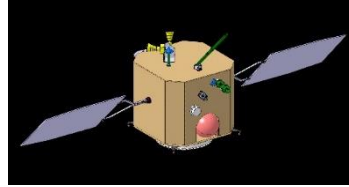
Opp.

Training and growing of NASA workforce with each SmallSat mission
Partnership with STMD and within divisions for technology maturation/demo
Leveraging Industry innovation/services
Coordination and partnership between NASA Centers to create vibrant SmallSat User community

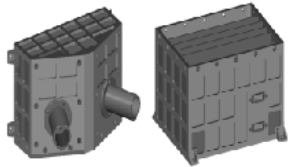
Threats

COVID pandemic continues to affect supply chain, interactions, and affects mission schedules
Conjunction operational requirements and constraints and risks especially in LEO due to the rise of the Mega-constellations causes increased costs
SmallSat and CubeSats
CyberSecurity and Enterprise Protection requirements

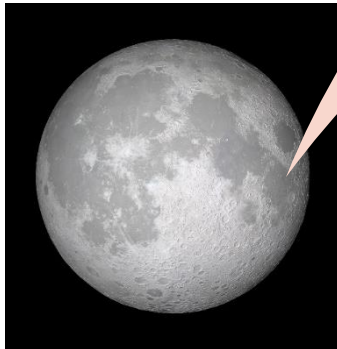
Leveraging Lunar Program for Measurements Back on Earth



KPL0 spacecraft



PolCam



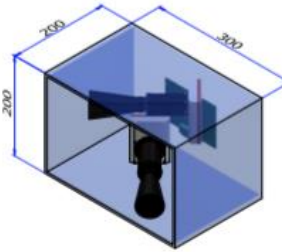
PolCam

Studying the Lunar Surface

PolCam (Moon):

- 320, 430, 650 nm I, DoLP
- 2 viewing angles

PolCam → PolCube
Design



PolCube

Studying Clouds and Aerosols

PolCube (Earth):

- 380, 440, 555, 670, 865 nm
- I, Q, U
- 120 viewing angles
- ~280 km swath

Flight Module Delivery: March 2022

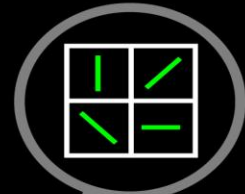
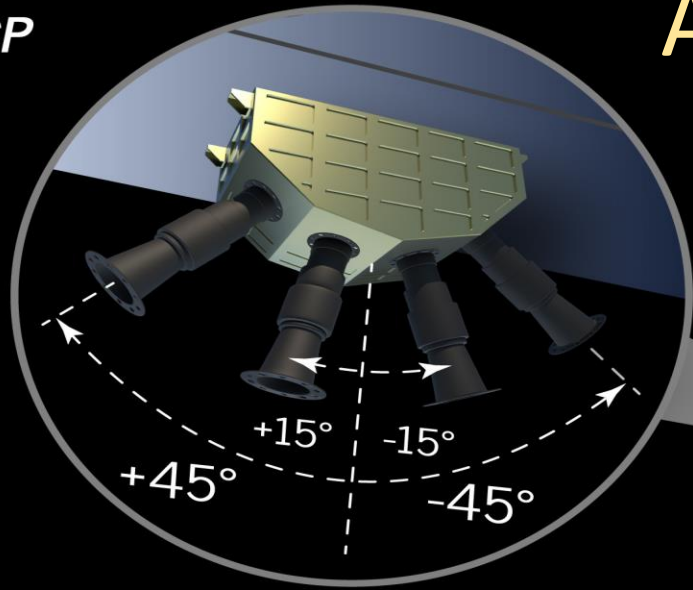


Partnership with leading institutions in South Korea and the US:

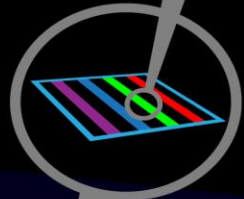
NASA Langley Research Center (LaRC), NASA Goddard Institute for Space Studies (GISS), the Korea Astronomy and Space Science Institute (KASI), Kyung Hee University, Hampton University, University of Rhode Island, Army Research Lab and the city of Busan, Republic of Korea

POLCUBE-A/CCP

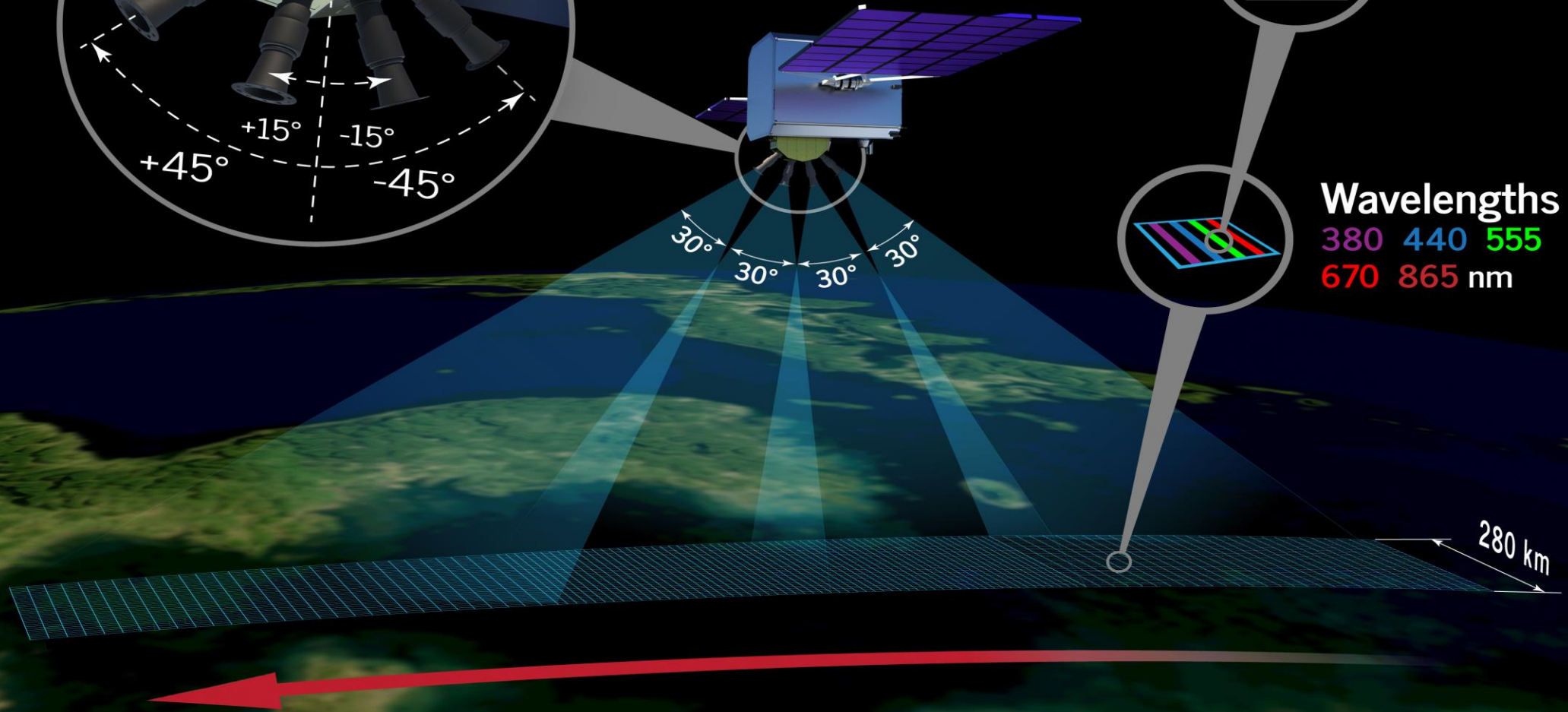
ACCP Design Concept



Polarization
I, Q, U



Wavelengths
380 440 555
670 865 nm



- PolCube builds upon our international partnership(s) with South Korea