



National Aeronautics and
Space Administration

EXPLORE

Advances in Transformative Science with Small Satellites at NASA

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Chair, Small Spacecraft Coordination Group

NASA Headquarters

May 2022



NASA Science Strategic Approach

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's Key Science Themes

PROTECT & IMPROVE
LIFE ON EARTH &
IN SPACE



SEARCH FOR LIFE
ELSEWHERE



DISCOVER SECRETS
OF THE UNIVERSE



NASA SCIENCE

AN INTEGRATED PROGRAM

Astrophysics



Biological
& Physical



Earth
Science



Joint Agency
Satellite Division



Heliophysics

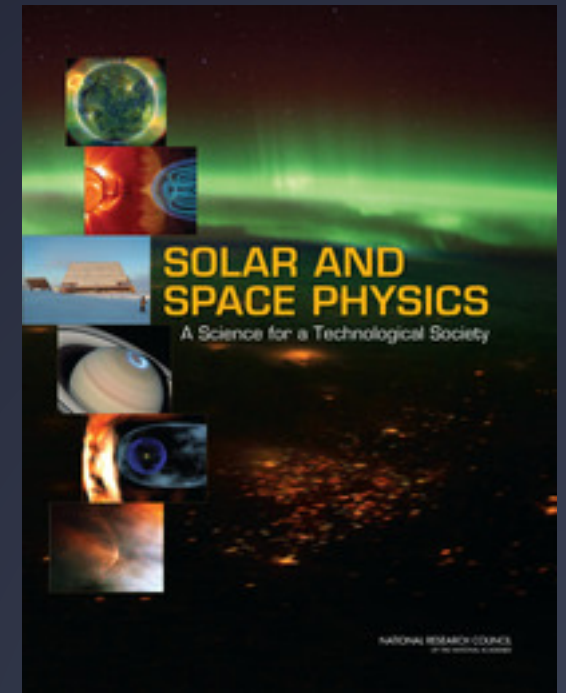
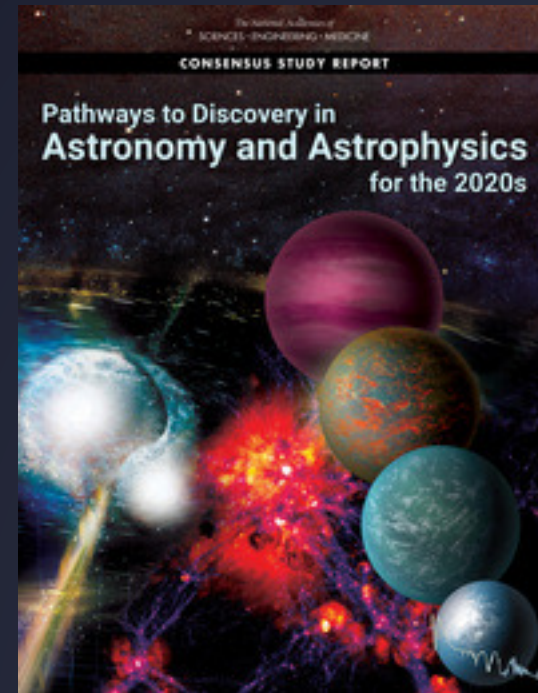
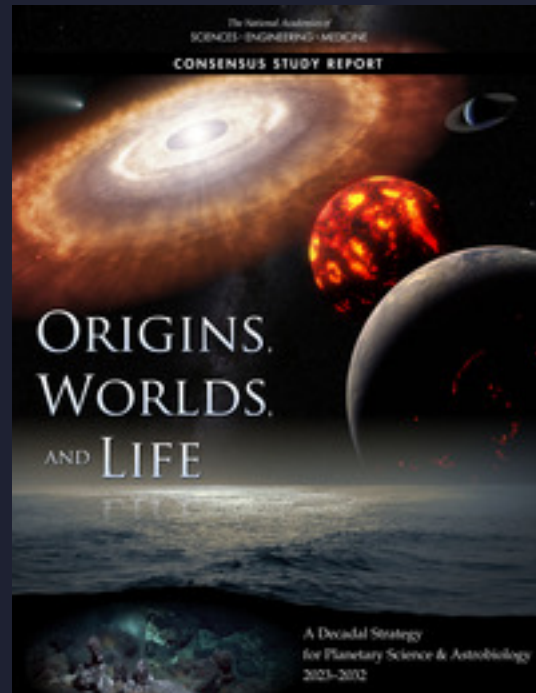
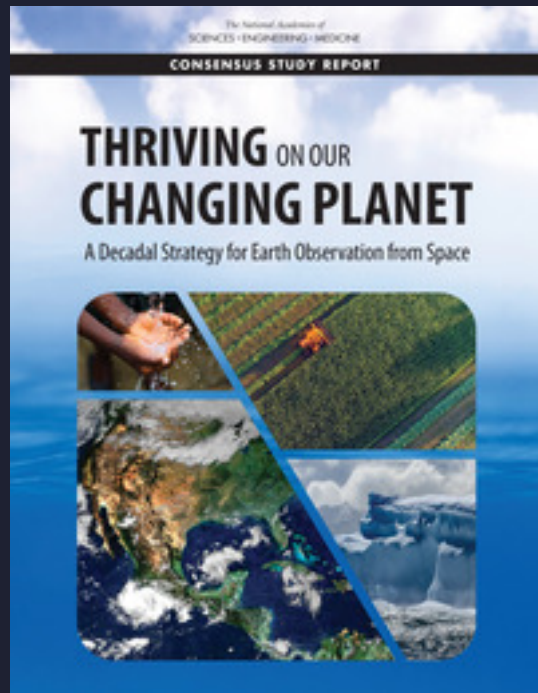


Planetary
Science

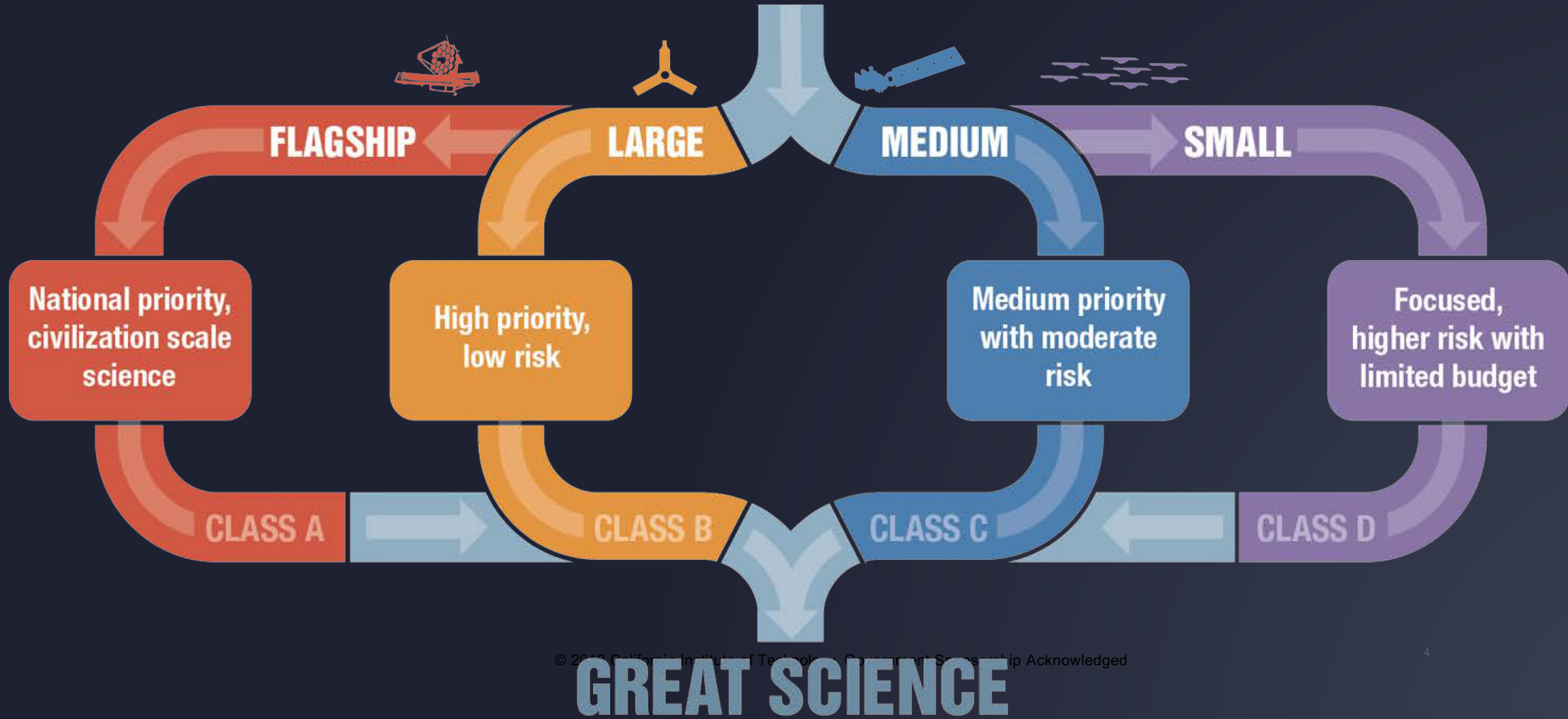


NASA SCIENCE

Guided by Decadal Studies



BALANCED MISSION PORTFOLIO



Establishing the Vision for Small Mission Science

Small satellite community can contribute to the scientific and technical rationale for a sustainable, productive, and relevant role within a balanced portfolio of strategic science missions



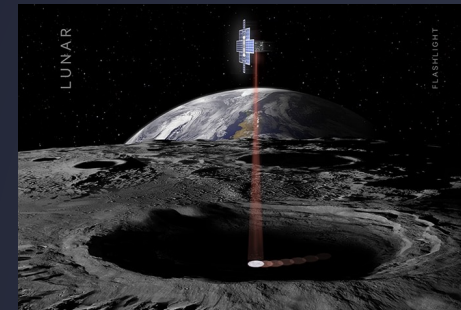
National Academies and NASA Reports Impact SmallSat/CubeSat Strategy

- NASA formed and chartered a Cross-Agency Coordination Group that Advises AAs on Strategy, Guidance, and Policy For Innovative Small Spacecraft Science Missions and Technology
- SMD, STMD, and HEOMD small spacecraft missions are actively pursuing science, space technology, and strategic knowledge gaps
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Science
Hurricane observations via
TROPICS constellation

New Observation Methods



Exploration
Lunar volatiles via Lunar
Flashlight mission

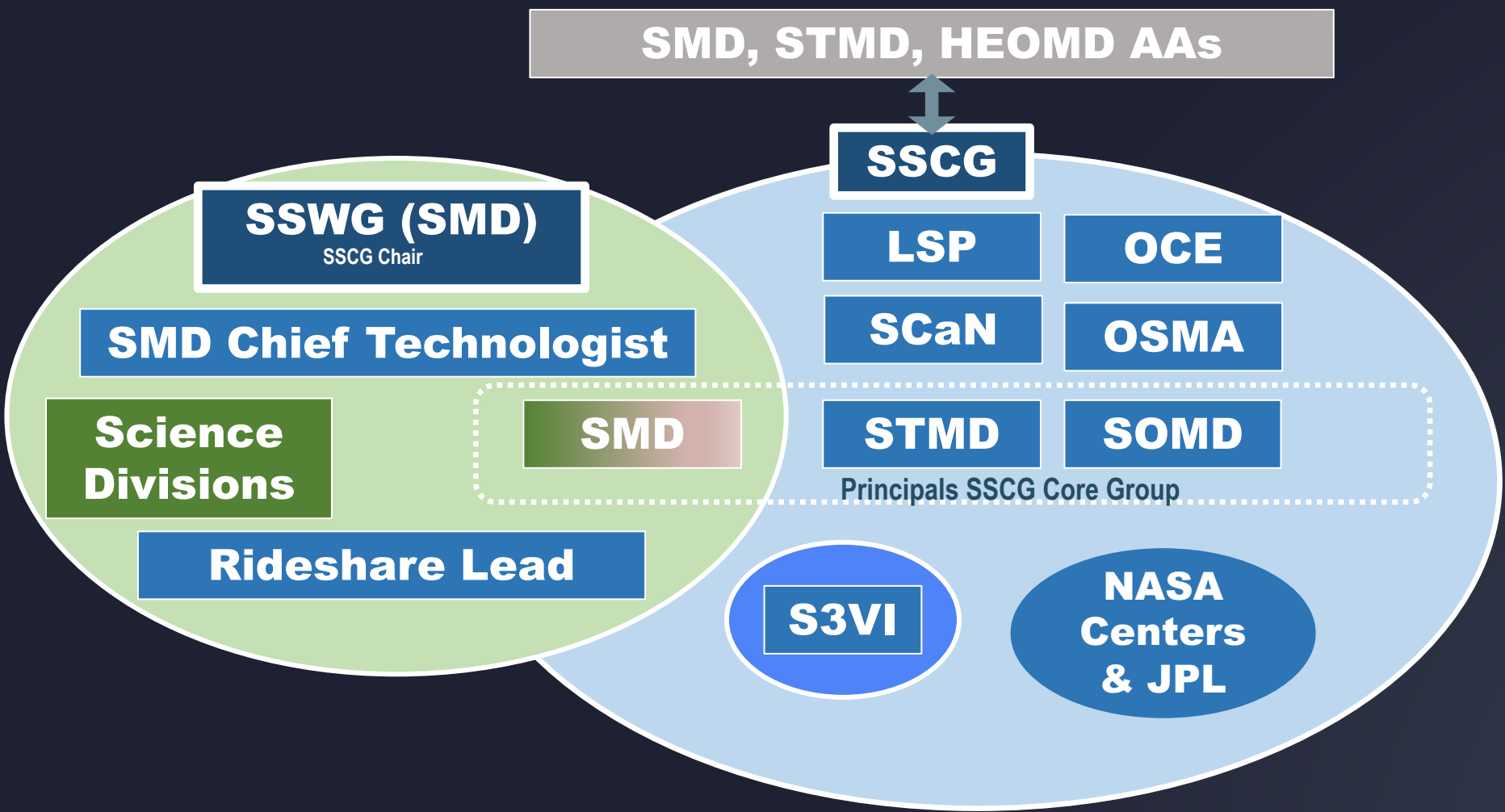
Strategic Knowledge Gaps



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

Spacecraft Subsystems

NASA Structure of Small Spacecraft Coordination Group



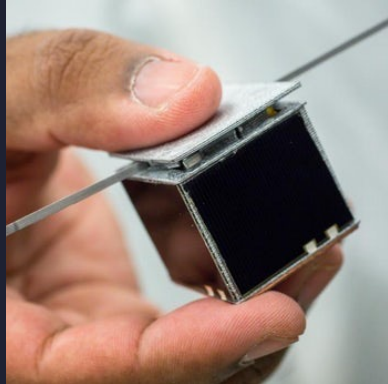
Small Spacecraft Coordination Group (SSCG) advises AAs on strategy to guide cross-agency initiatives and relevant policies, programmatic scope and priorities

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

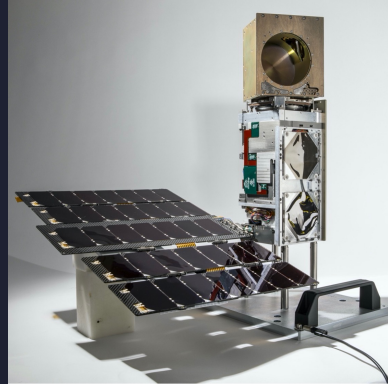
Organizational Alignment and Coordination to Support Small Mission Science and Technology Community

Fundamentals of Small Spacecraft

Spectrum of Satellite Development



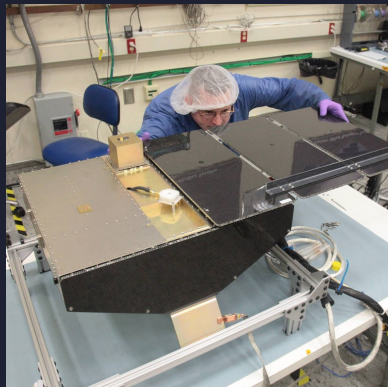
Picosatellite
PocketSat (0.1 – 1 kg)



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



SPA-Ring
Payload Port Limit (450 kg)



Microsatellite
CYGNSS (10 – 100 kg)



Small Satellite
ESCAPEDE (100 – 500 kg)

SmallSat Definition

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

RESEARCH

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

UPDATE

TECHNOLOGY DEVELOPMENT

~**\$397M** Invested Annually

EARTH-BASED INVESTIGATIONS

21 Airborne Missions
8 Global Networks

MISSIONS

114 Missions from
formulation through
extended operations

Science by the NUMBERS

SMALLSATS/ CUBESATS

49 Science Missions
29 Technology Demos

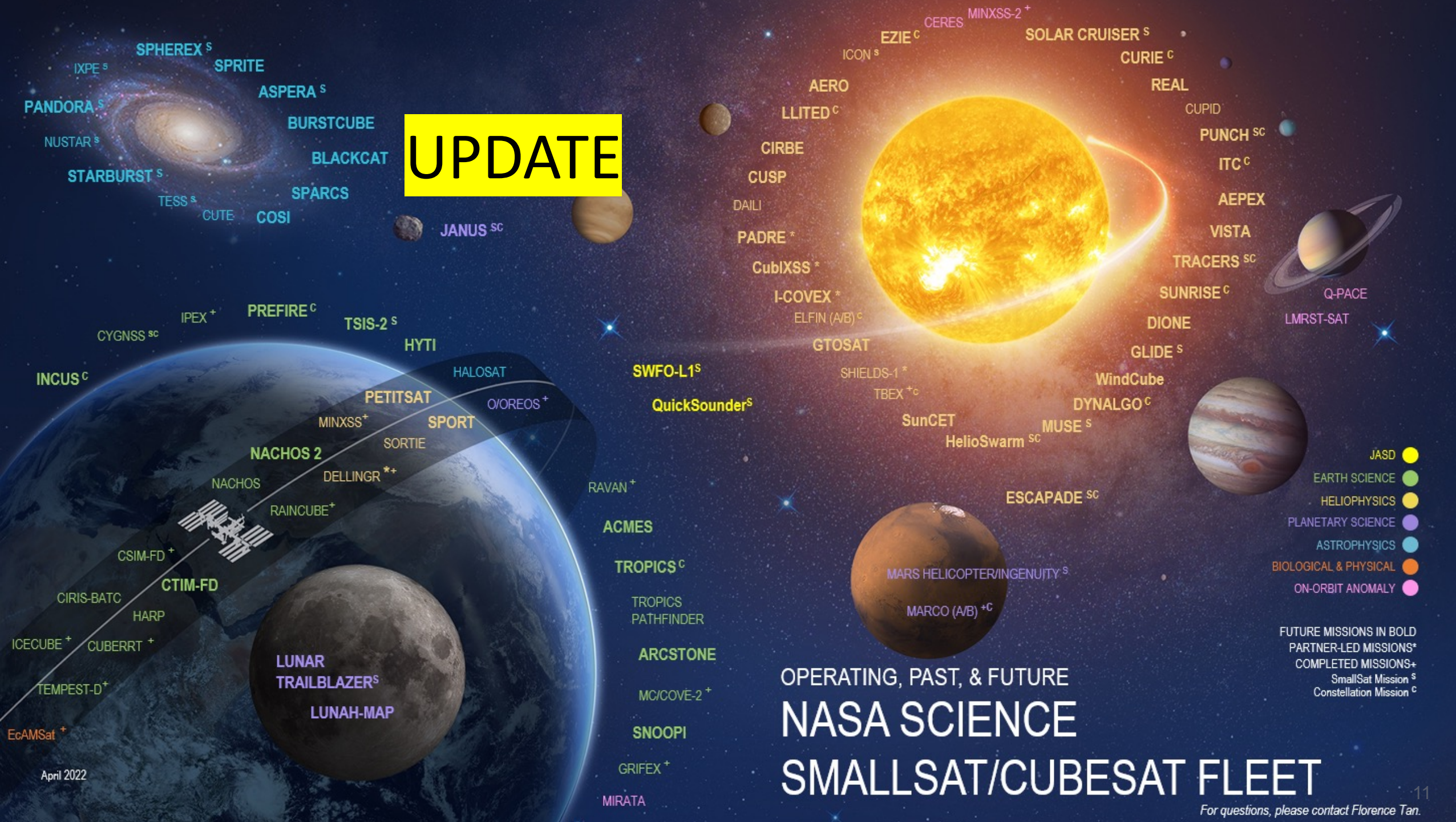
SOUNDING ROCKETS

2 Science Missions Launched
45 In Development

BALLOONS

54 Missions in Development

UPDATE



NASA Science SmallSat Status

Missions (formulation or development) as of April 2022

ASPERA (APD)
BLACKCAT (APD)
BURSTCUBE (APD)
COSI (APD)
PANDORA (APD)
SPARCS (APD)
SPHEREX (APD)
SPRITE (APD)
STARBURST (APD)
ACMES (ESD)
ARCSTONE (ESD)
CTIM-FD (ESD)
HYTI (ESD)
INCUS (ESD)
NACHOS (ESD)
PREFIRE (ESD)
SNOOPI (ESD)
TROPICS (ESD)
TSIS-2 (ESD)
AEPEX (HPD)
AERO/VISTA (HPD)
CIRBE (HPD)
CUBIXSS (HPD)
CURIE (HPD)
CUSP (HPD)
DIONE (HPD)

DYNAGLO (HPD)
ESCAPADE (HPD)
EZIE (HPD)
HELIOSWARM (HPD)
GLIDE (HPD)
GTOSAT (HPD)
I-COVEX (HPD)
ITC (HPD)
LLITED (HPD)
MUSE (HPD)
PADRE (HPD)
PETITSAT (HPD)
PUNCH (HPD)
REAL(HPD)
SOLAR CRUISER (HPD)
TRACERS (HPD)
SPORT (HPD)
SUNRISE (HPD)
SunCET (HPD)
WINDCUBE (HPD)
SWFO-L1 (JASD)
JANUS (PSD)
LUNAR TRAILBLAZER (PSD)
LunaH-Map (PSD)

Studies Selected

DORADO (APD)
ARCS (HPD MIDEX)

Launched/Deployed

CIRIS-BATC (ESD)
CUPID (HPD)
SORTIE (HPD)
DAILI (HPD)

Deorbited/ EOM

CSIM-FD (ESD)
CUBERRT (ESD)
DELINGR (HPD)
HaloSat (APD)
HARP (ESD)
RAINCUBE (ESD)
TBEX (HPD)
TEMPEST-D (ESD)

Failed

Q-PACE (PSD)

Operating

CIRIS-BATC (ESD)
CYGNSS (ESD)
TROPICS Pathfinder (ESD)
CUTE (APD)
ELFIN (HPD)
ICON (HPD)
IXPE (APD)
NUSTAR (APD)
ICON (HPD)
SHIELDS (HPD)
TESS (APD)

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

Missions in formulation or development are trending towards larger form factors or constellations

Science Mission Directorate (SMD) SmallSat and CubeSat Programs

SMD Division or Office	Programs that fund CubeSats	Example CubeSat Missions	Programs that fund SmallSats	Example SmallSat Missions
Astrophysics	APRA	SPRITE, BLACKCAT, CUTE, BURSTCUBE, <u>HaloSat</u>	PIONEERS	Starburst, Aspera, PANDORA
Astrophysics			Explorer SMEX	IXPE
Astrophysics			Explorer MIDEX	<u>SPHEREx</u>
Earth Science	INVEST	ACMES, SNOOPI, <u>HyTI</u> , CTIM-FD, NACHOS, <u>RainCube</u> , RAVAN, <u>CubeRRT</u>	Earth Venture/SMEX	CYGNSS, TROPICS, PREFIRE, INCUS, TEMPEST-D
<u>Heliophysics</u>	H-FORT	GTOSAT, AEPEX, AERO/VISTA, CURIE, REAL, DAILI, LLITED, CUSP	SIMPLEX-2 /SMEX/MIDEX	ESCAPADE
<u>Heliophysics</u>	Explorer Mission of Opportunity	<u>SunRISE</u> , EZIE	Small Explorer (SMEX) Program	TRACERS, PUNCH
<u>Heliophysics</u>	MIDEX	CubeSat Constellations such as ARCS Phase A 2019 MIDEX	STP Science Mission of Opportunity	GLIDE
<u>Heliophysics</u>			STP Technology Mission of Opportunity	Solar Cruiser
<u>Heliophysics</u>			Medium <u>Explorer</u> (MIDEX) Program	<u>Helioswarm</u>
Planetary Science	SIMPLEX-1	Q-PACE, <u>LunaH-Map</u>	SIMPLEX-2	Janus
Exploration Science Strategy and Integration Office			SIMPLEX-2	Lunar Trailblazer

NASA's Science SmallSat Missions at a Glance

Inclusive Missions and Studies

Data as of March 2022, Solicited/Directed 2010-2022

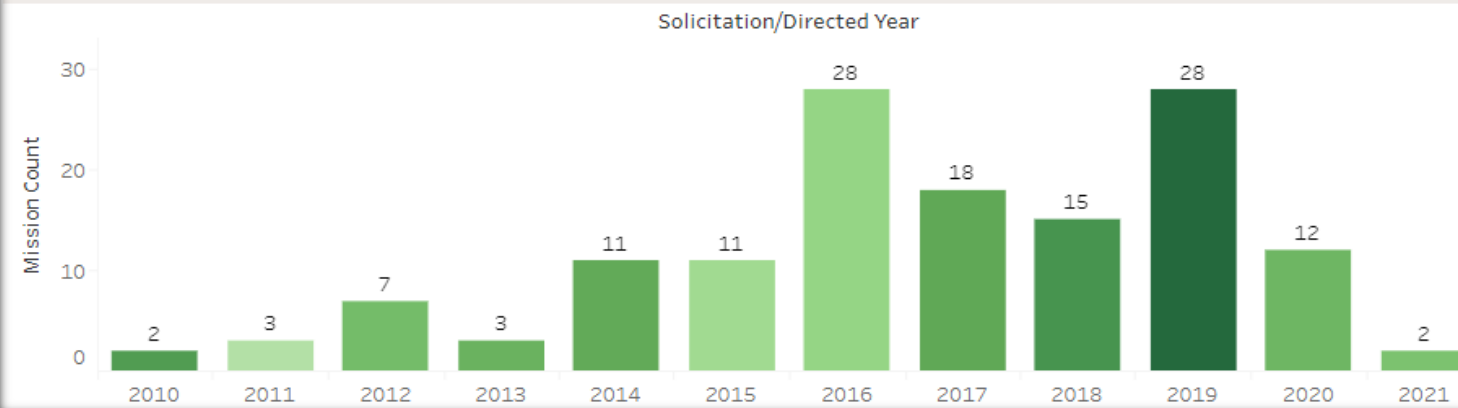
 **142** Total Science Missions & Studies

 **\$3B** Total Investment Across all SMD Divisions

SMD Overview of Missions by Solicitation/Directed Year

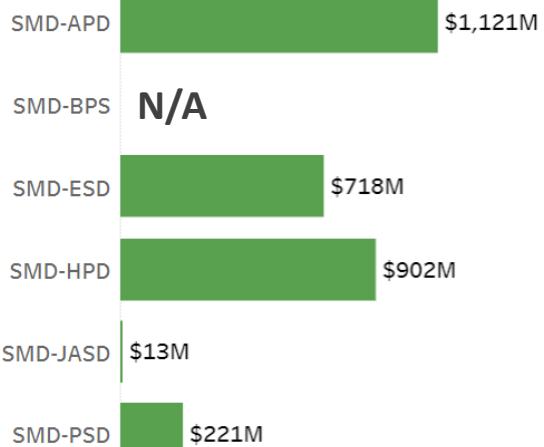
Inclusive of Missions & Studies

Total Mission Cost



Total Mission Cost

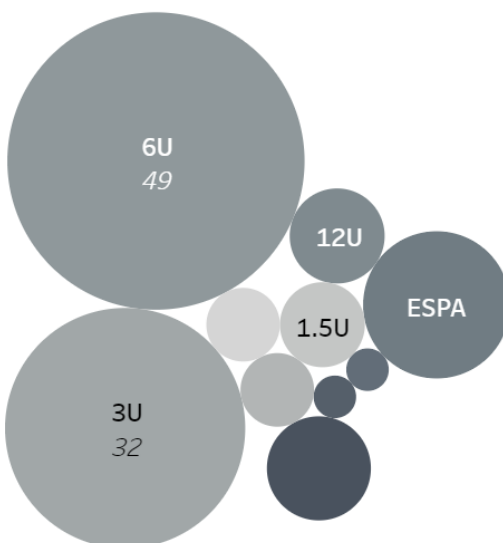
Spons. #



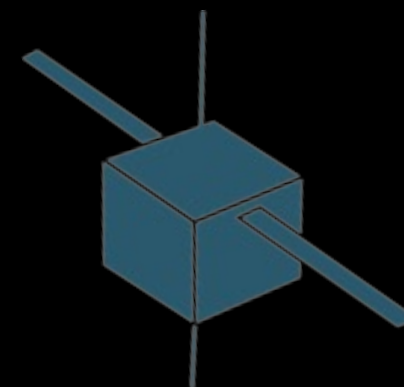
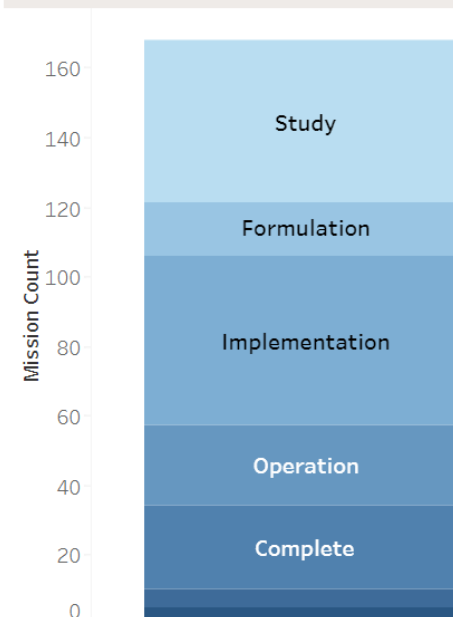
\$0M \$500M \$1,000M \$1,500M

Total Mission Cost

Spacecraft Size (excluding studies)



Mission Phase

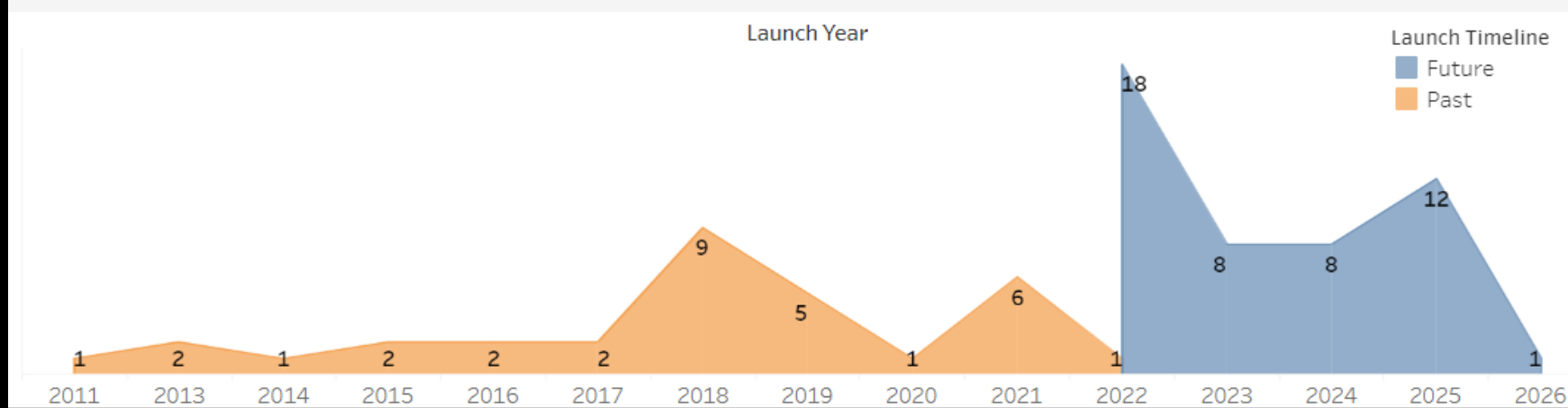


NASA's Science SmallSat Missions at a Glance

Inclusive Missions and Studies

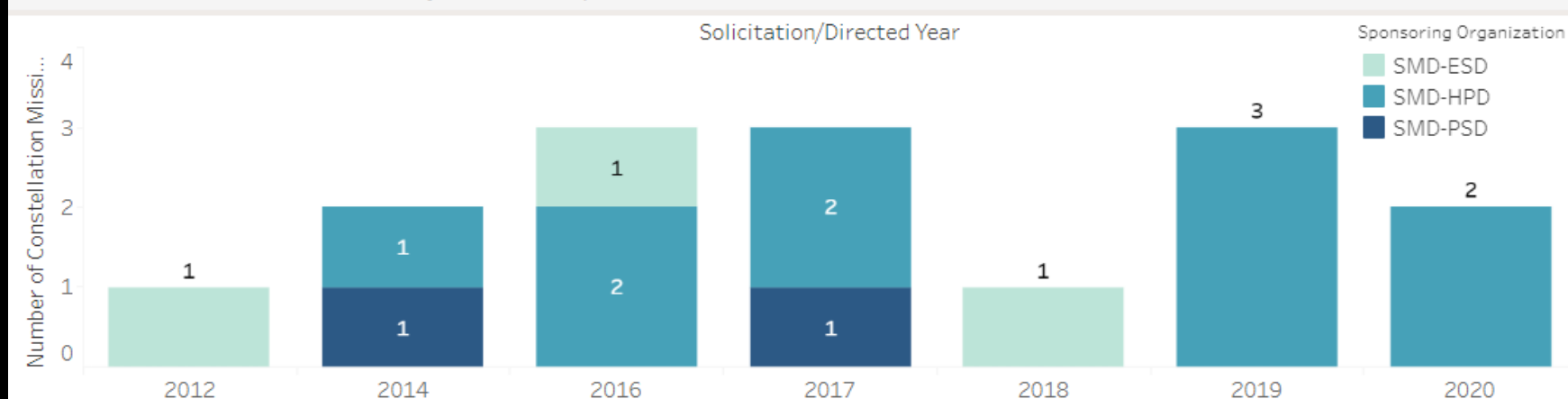
Data as of March 2022, Solicited/Directed 2010-2022

Timeline of SmallSat/CubeSat Launches
2022 and beyond



53 SmallSat Missions (83 Spacecrafts) in Formulation/Implementation 2022 and beyond

Constellation Missions Awarded by Solicitation/Directed Year

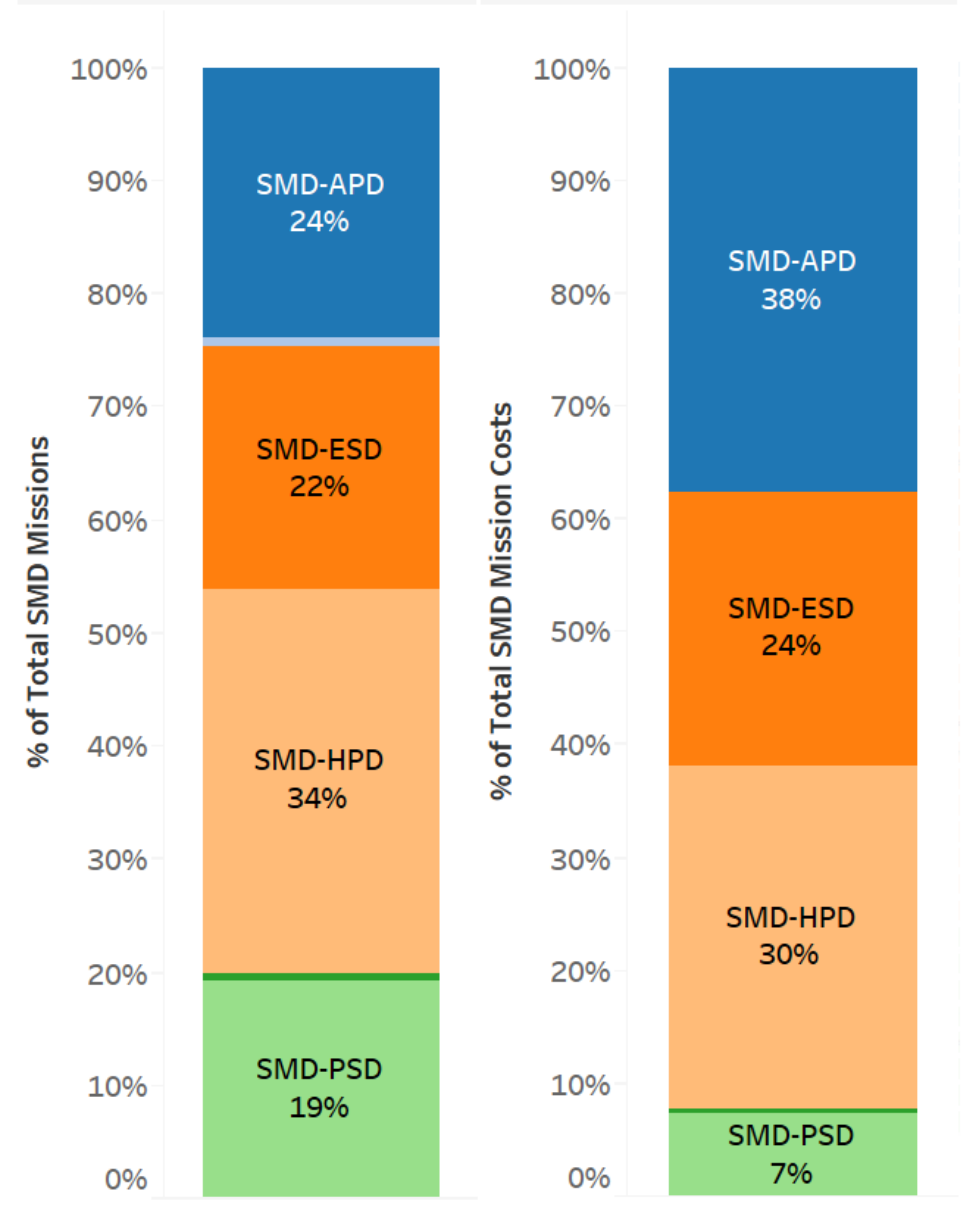


2022 will launch the most science constellation smallsat missions to date – four total across three of the Science divisions

Constellation missions refer to those missions consisting of two or more spacecraft.

Total Number of Missions

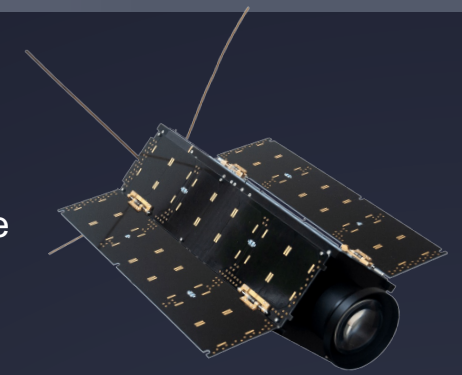
Total Mission Cost



NASA Science SmallSat and CubeSat Missions and Studies by Divisions

- Heliophysics missions has funded the most number of missions among SMD
- Astrophysics has invested the highest aggregate funding

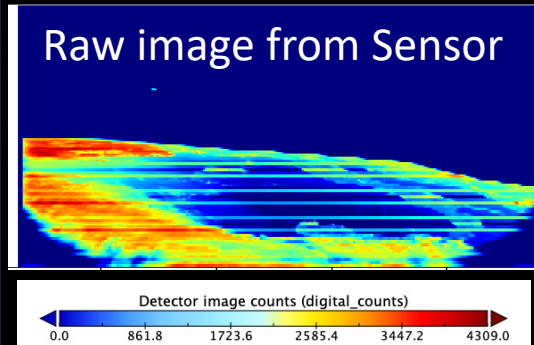
First Light/Partial Image from HARP CubeSat



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.

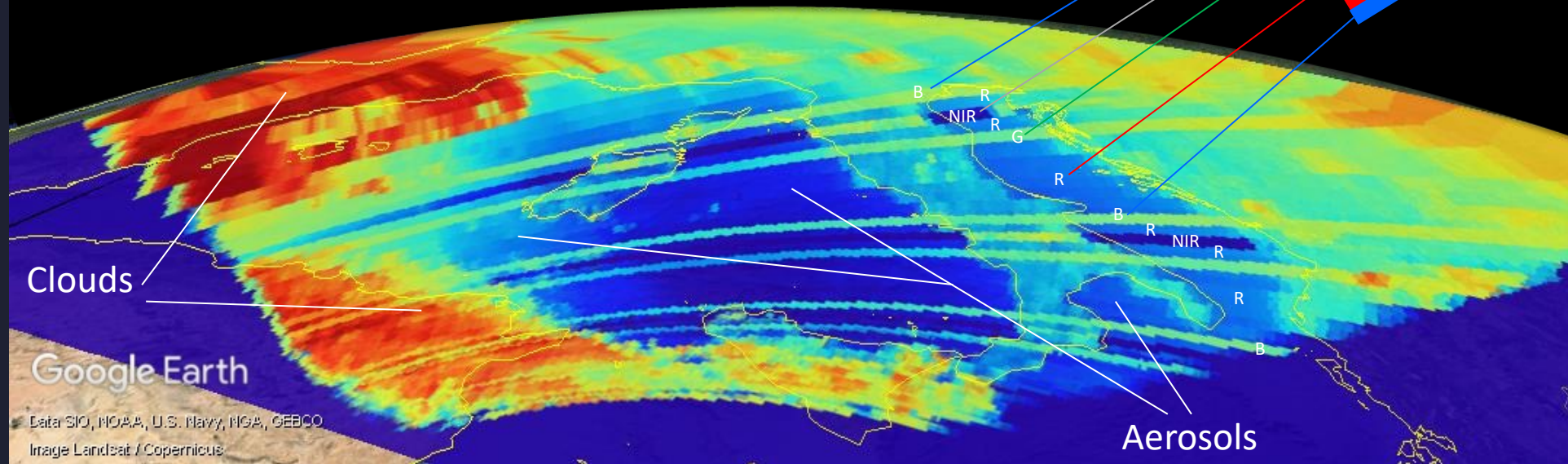
HARP's first image, a snapshot over Europe, was acquired by pointing its sensors at Earth's horizon. The three detectors are performing with nominal alignment needed for the polarization measurement.

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.



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



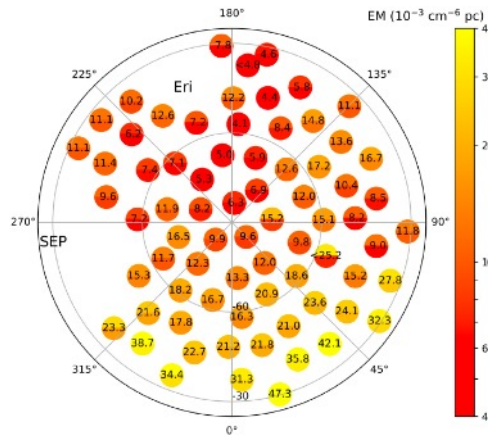
Sensor

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

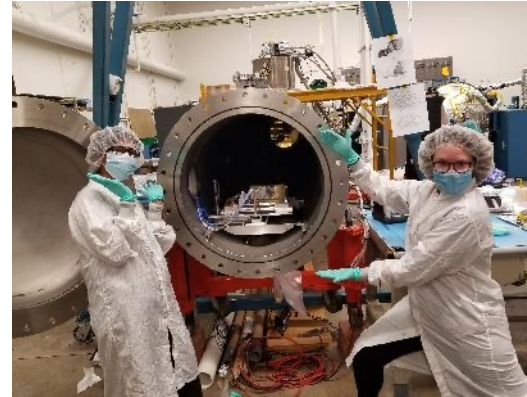
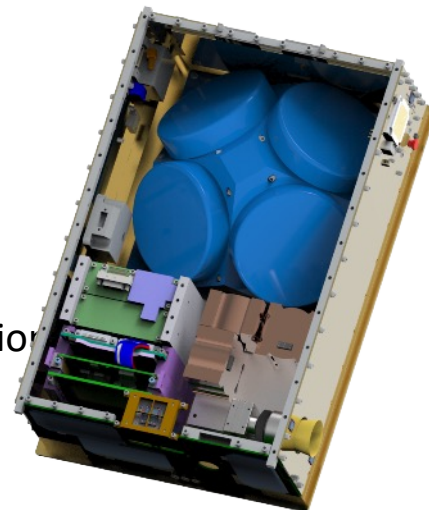
Astrophysics CubeSats

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

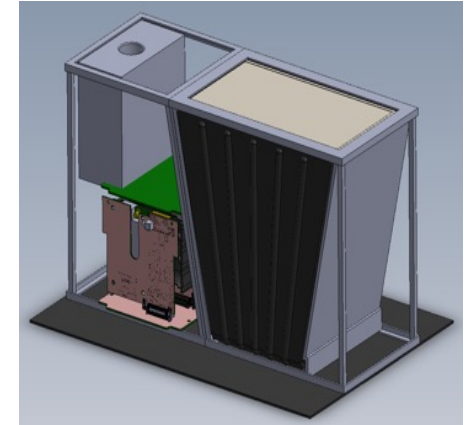
HaloSat: PI Phil Kaaret (U of Iowa),
Launch May 2018, Reentered Jan 2021,
OVII/OVIII lines in Galaxy halo, determine
mass and structure of Galaxy halo



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

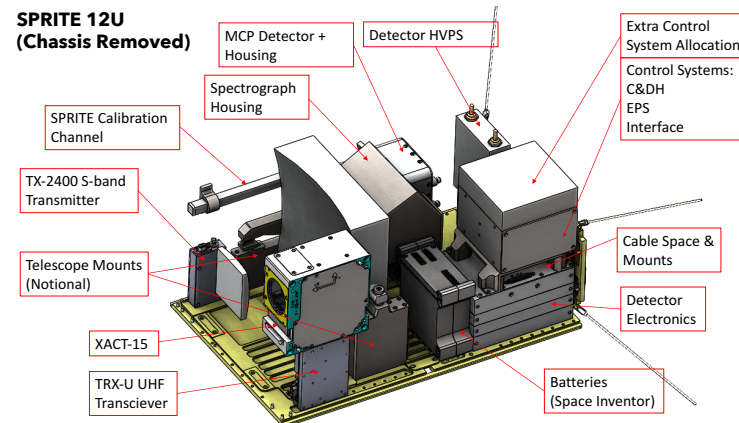


CUTE: PI Kevin France
(CU),
Launch Sep 2021,
UV Imaging of hot
Jupiter ablation,
(Arika Egan & Ambily Suresh in
lab)



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

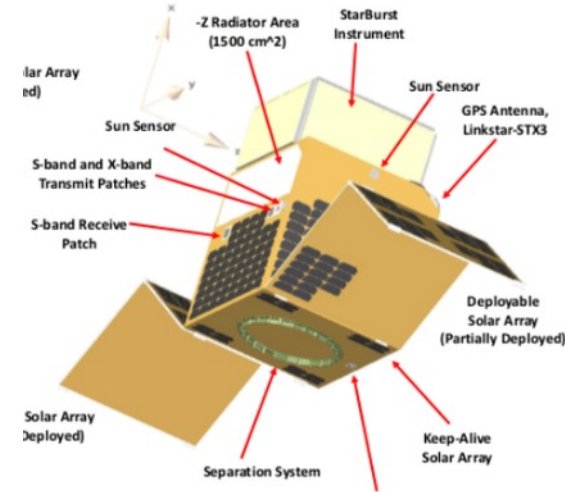
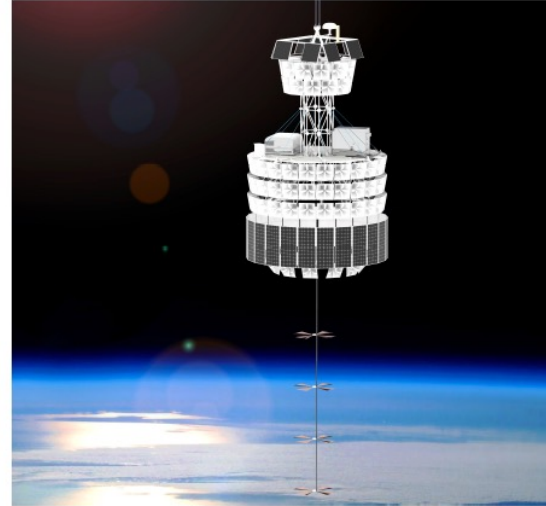
**SPRITE 12U
(Chassis Removed)**



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

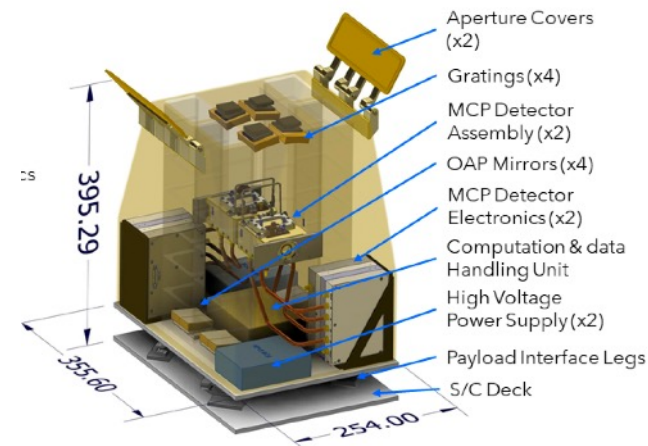
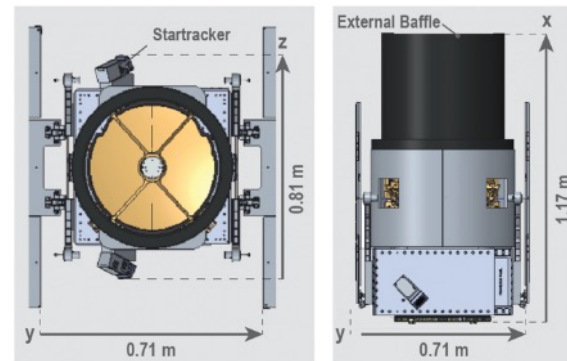
Astrophysics Pioneers-2020 Selections

PUEO: A Long-duration Balloon-borne Instrument for Particle Astrophysics at the Highest Energies (PI Abigail Vieregg, U. Chicago)



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

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



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

<https://www.nasa.gov/feature/nasa-selects-4-concepts-for-small-missions-to-study-universe-s-secrets>

INCUS Investigation of Convective Updrafts

INCUS Goal

To understand why, when, where tropical convective storms form, and why only some storms produce extreme weather.

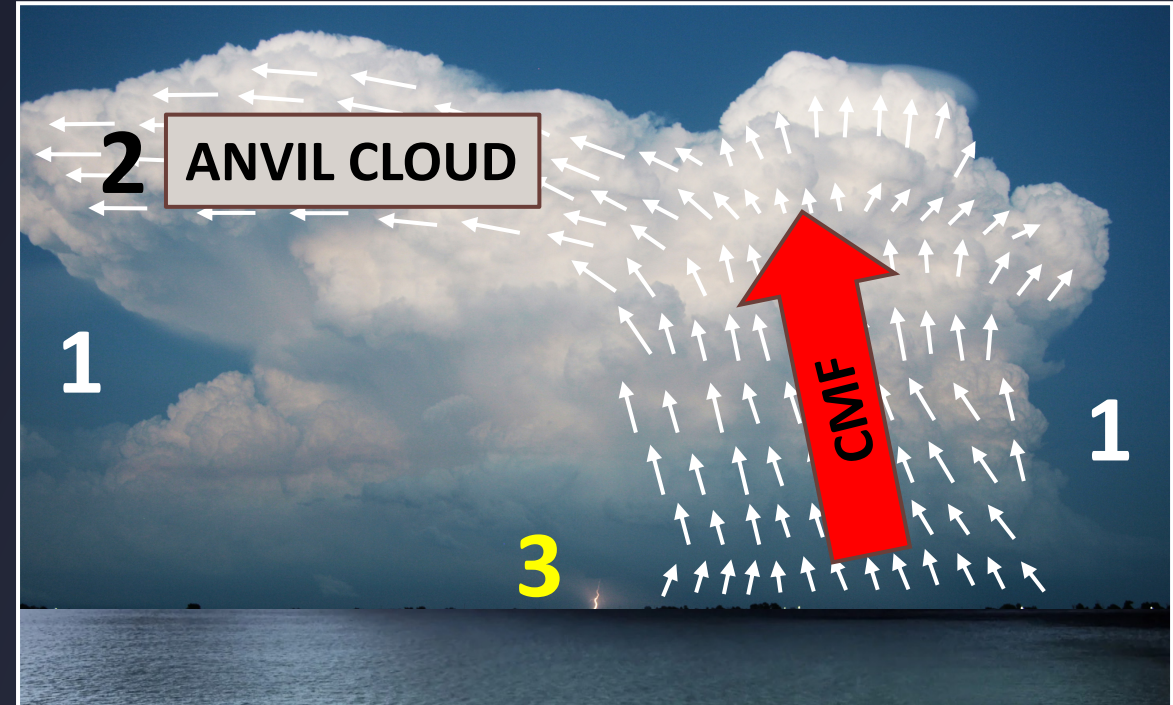
- Storms begin with rapidly rising water and air that create towering clouds primed for rain, hail, and lighting.
- The greater the mass of water and air that is transported upwards, the larger the risk of extreme weather.
- This vertical transport of air and water, known as convective mass flux (CMF), remains one of the great unknowns in weather and climate.
- Systematic CMF measurements would improve the representation of storm intensity and constrain high cloud feedbacks in weather and climate models.

Science Objectives

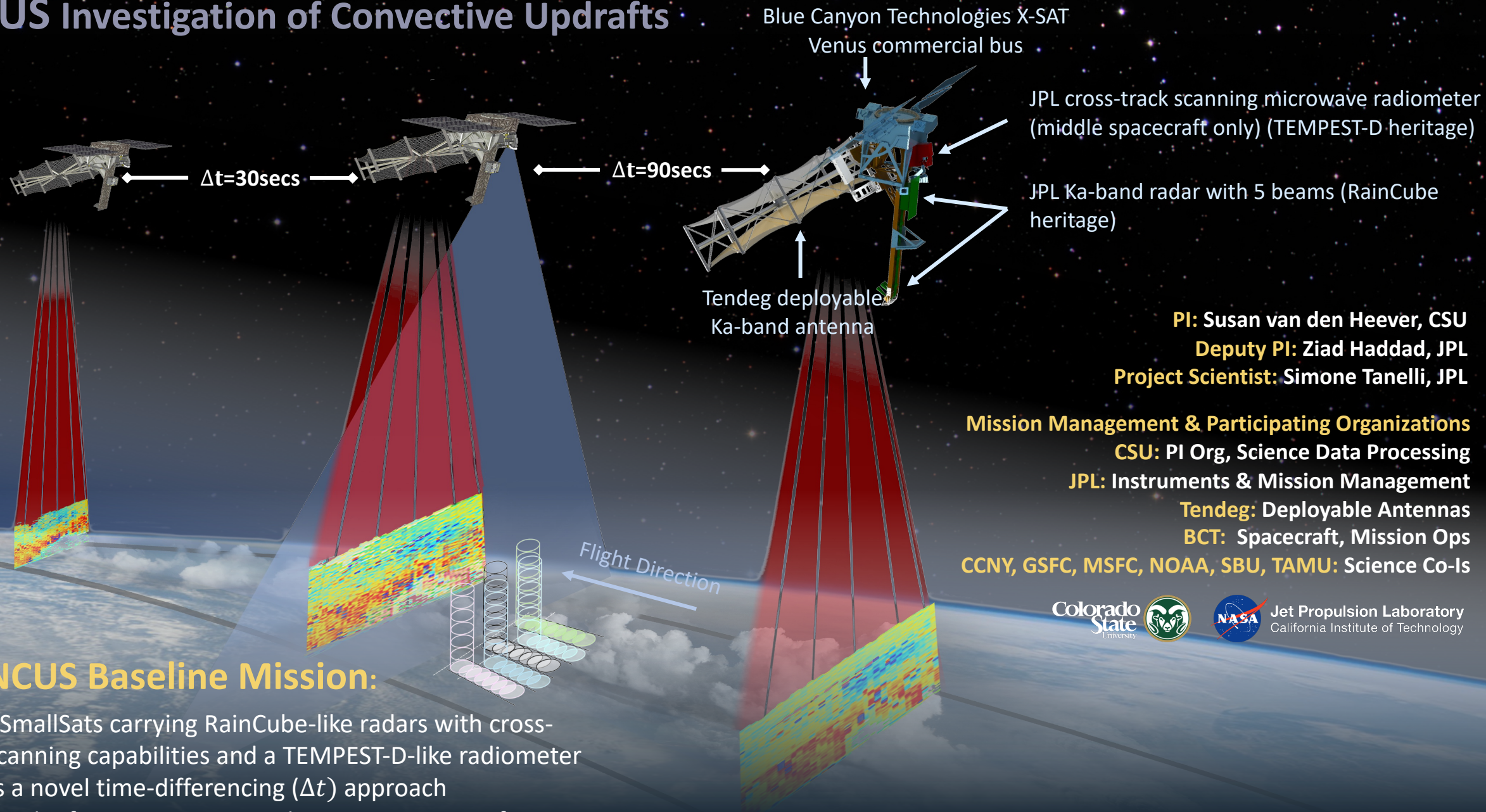
To determine:

1. The predominant environmental properties (RH, temperature, wind shear) controlling CMF in tropical convective storms;
2. The relationship between CMF and high anvil clouds (critical to cloud-climate feedbacks);
3. The relationship between CMF and the type (lightning, rainfall) and intensity of the extreme weather produced; and
4. Evaluate these observationally determined relationships between CMF and environmental factors, high anvil clouds, and extreme weather in weather and climate models.

NASA's Storm Chaser



INCUS Investigation of Convective Updrafts



The INCUS Baseline Mission:

- Flies 3 SmallSats carrying RainCube-like radars with cross-track scanning capabilities and a TEMPEST-D-like radiometer
- Applies a novel time-differencing (Δt) approach
- Provides the first ever tropics-wide measurements of CMF

RainCube Ka-band radar

+

TEMPEST-D mm-wave radiometer

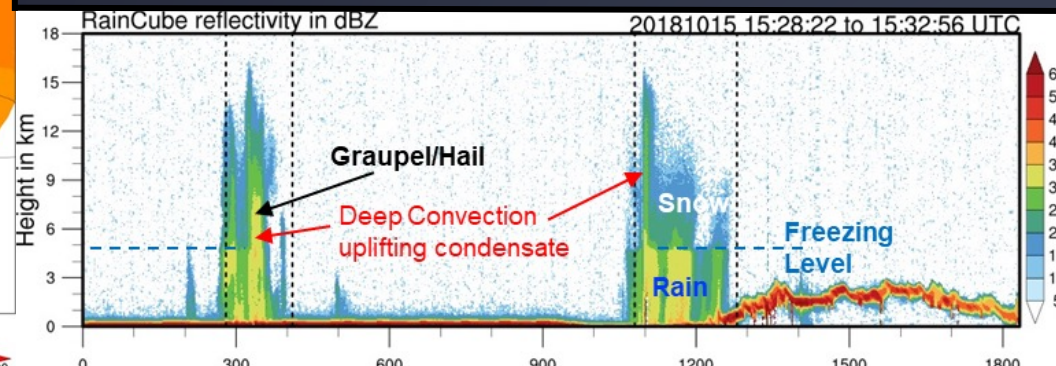
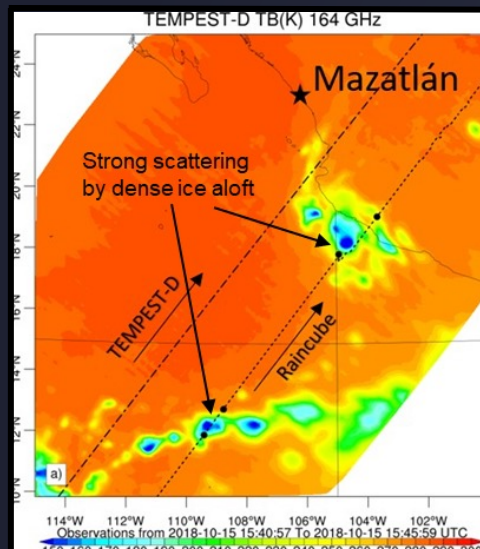
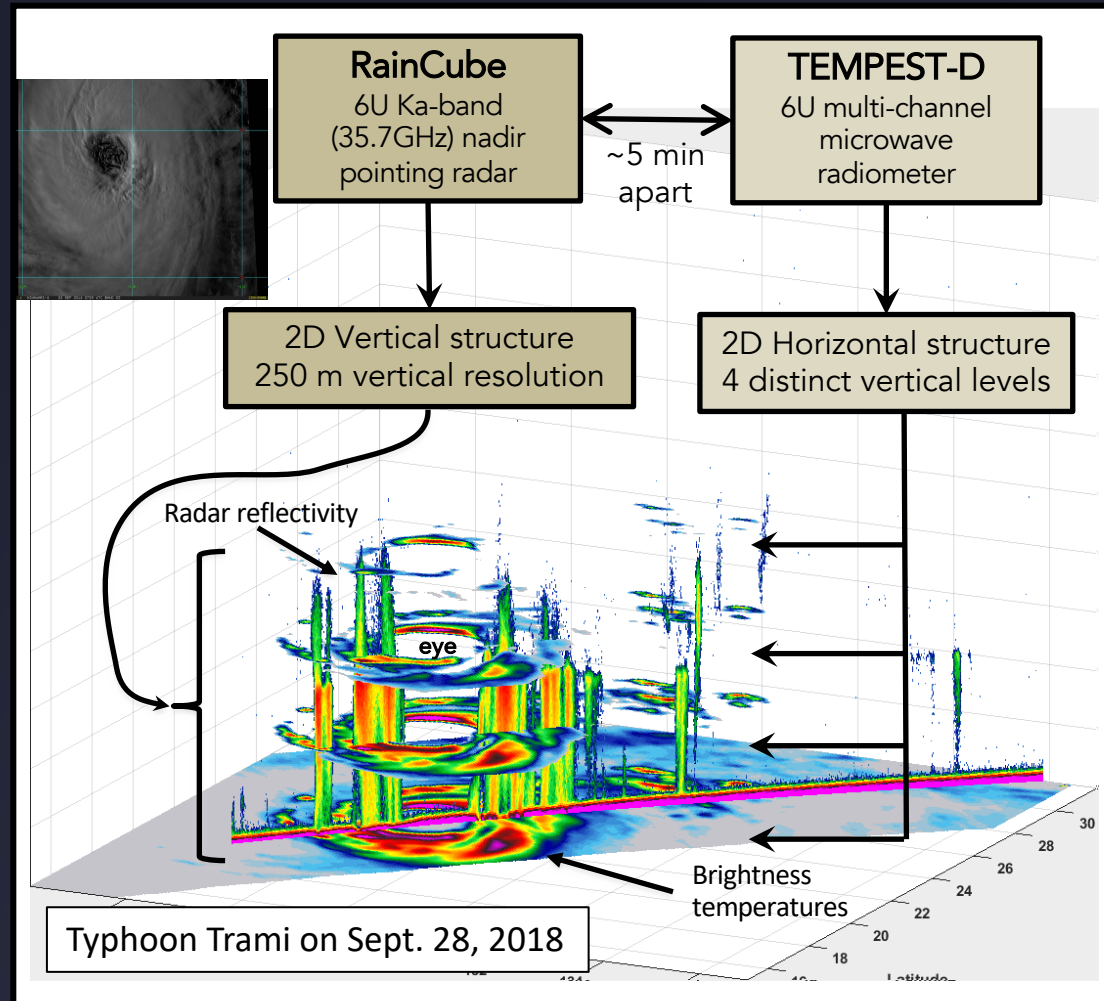
INCUS

INCUS draws on the strengths of BOTH RainCube and TEMPEST-D to provide unprecedented vertical and horizontal views of storm structure and processes.

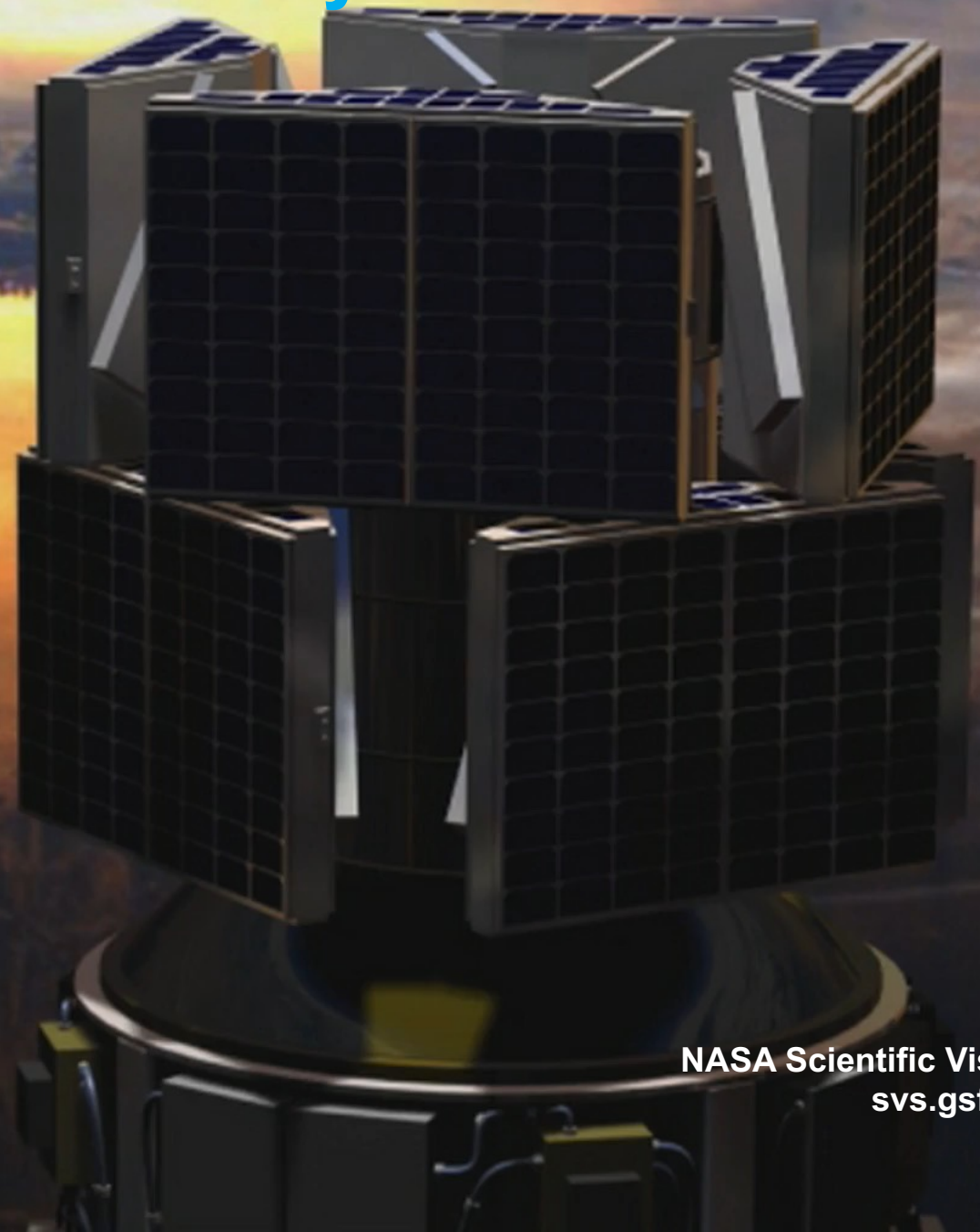
Figures and animations by Simone Tanelli, Shannon Brown and Steve Reising

(Right) On September 28, 2018, TEMPEST-D and RainCube overflew Typhoon Trami < 5 minutes apart

(Bottom) Correlated storm measurements from RainCube radar and TEMPEST-D radiometer over Texas, Mexico and Pacific Ocean

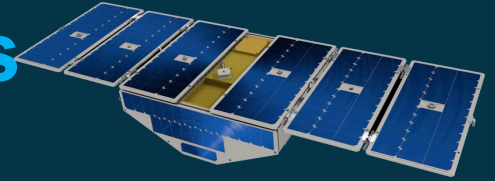


CYGNSS: Eight Eyes in the Sky



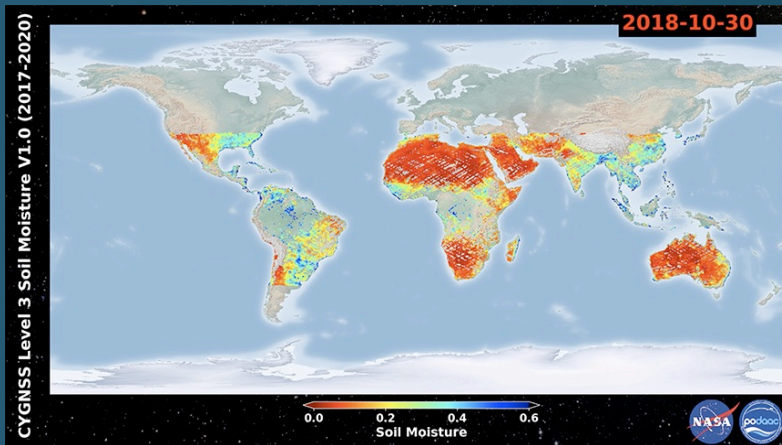
NASA Scientific Visualization Studio
svs.gsfc.nasa.gov/12447

CYGNSS Scientific Results and Applications



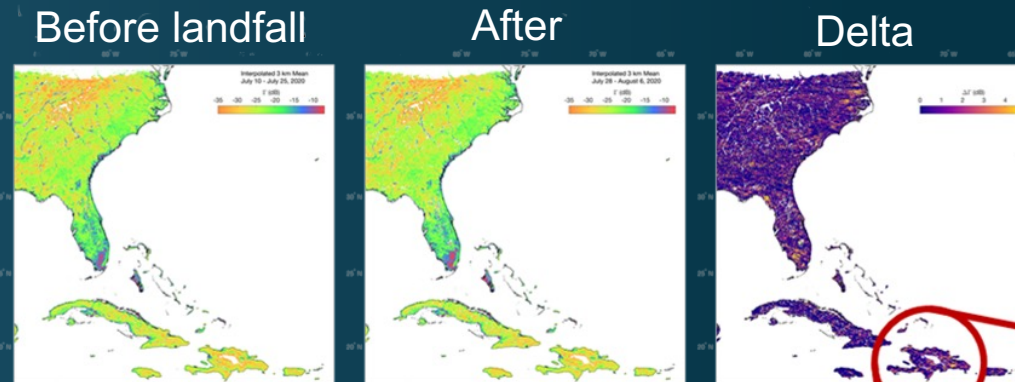
Daily soil moisture data product

- Oct. 30, 2018



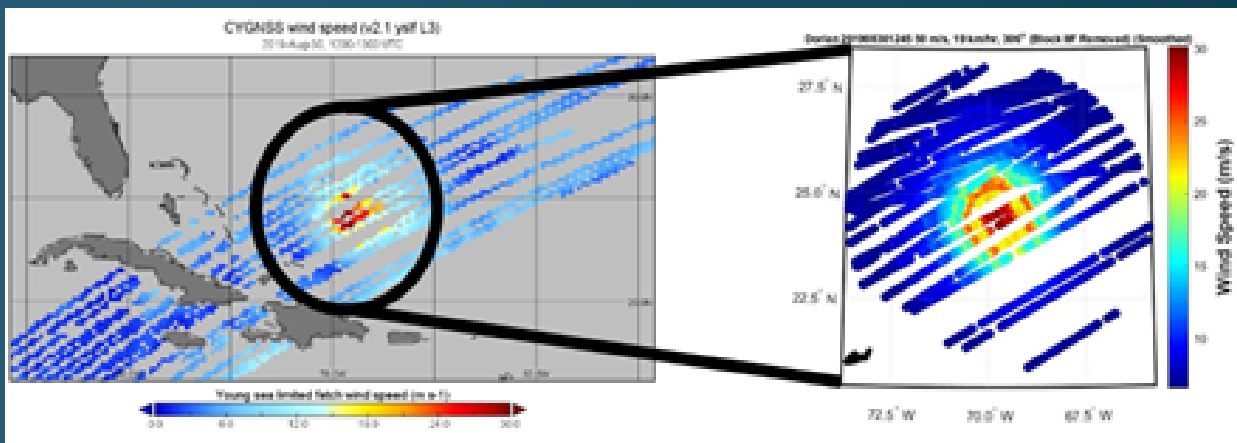
Map flood inundation after hurricane landfall

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

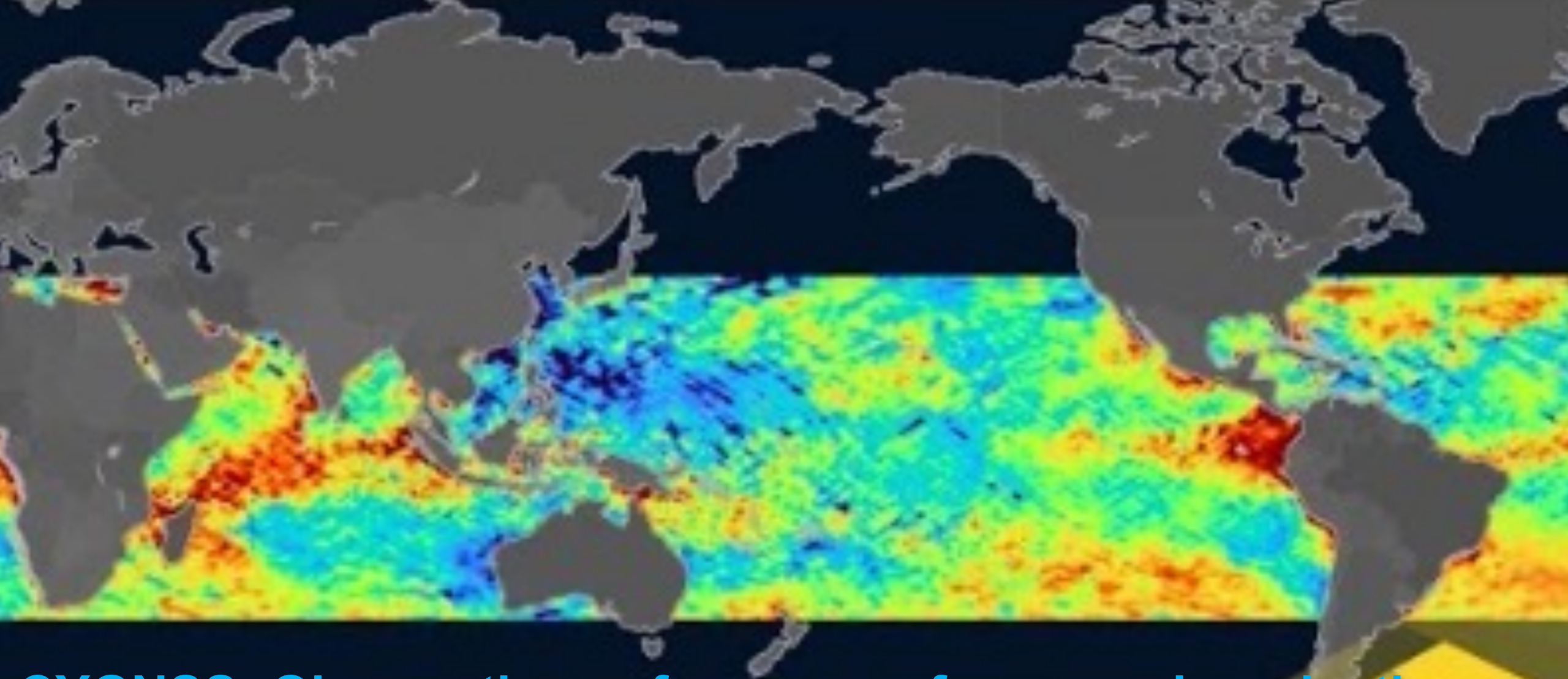


Measure winds in tropical cyclones

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



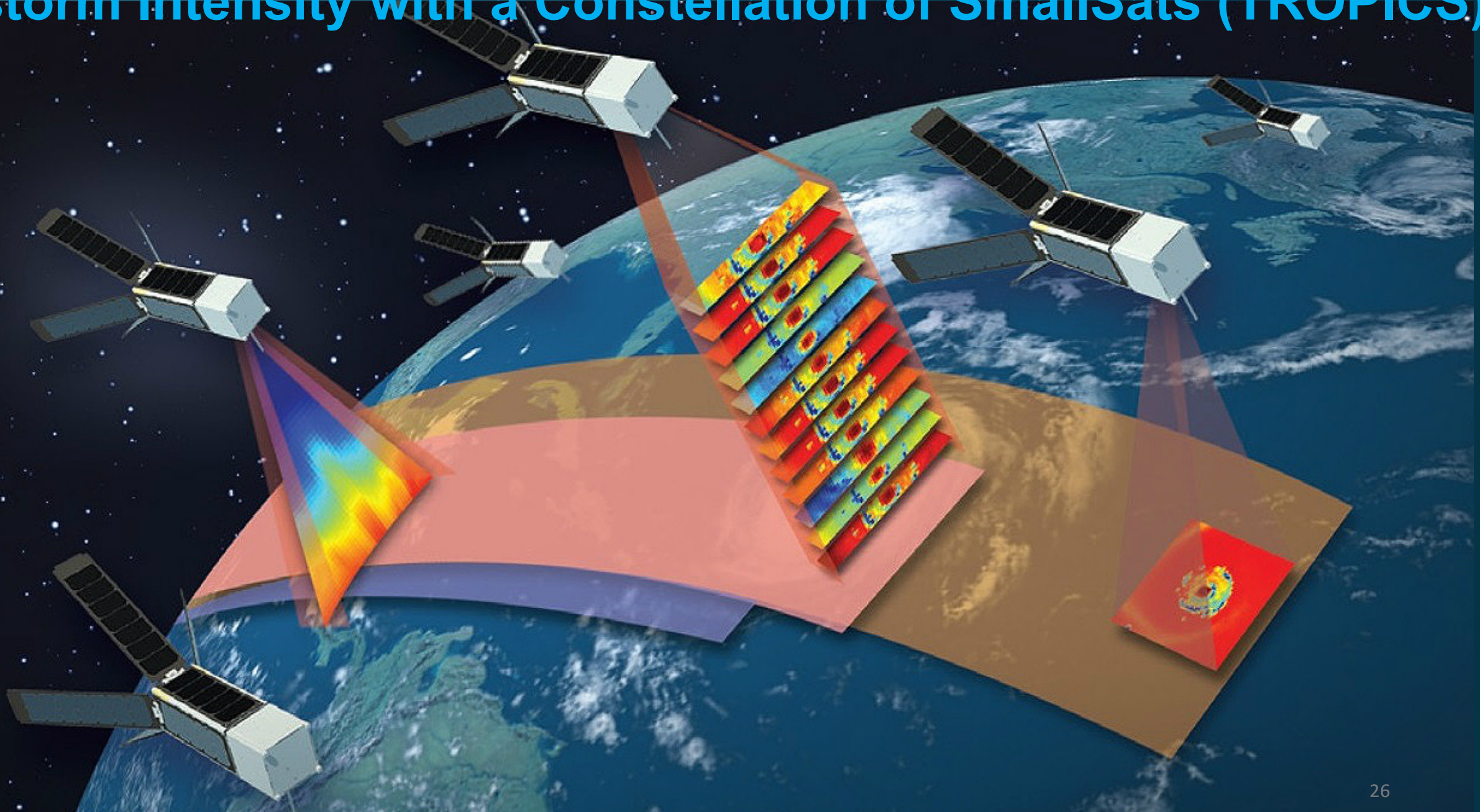
Extensive flooding in the Dominican Republic



CYGNSS: Observations of sources of ocean microplastic from space

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

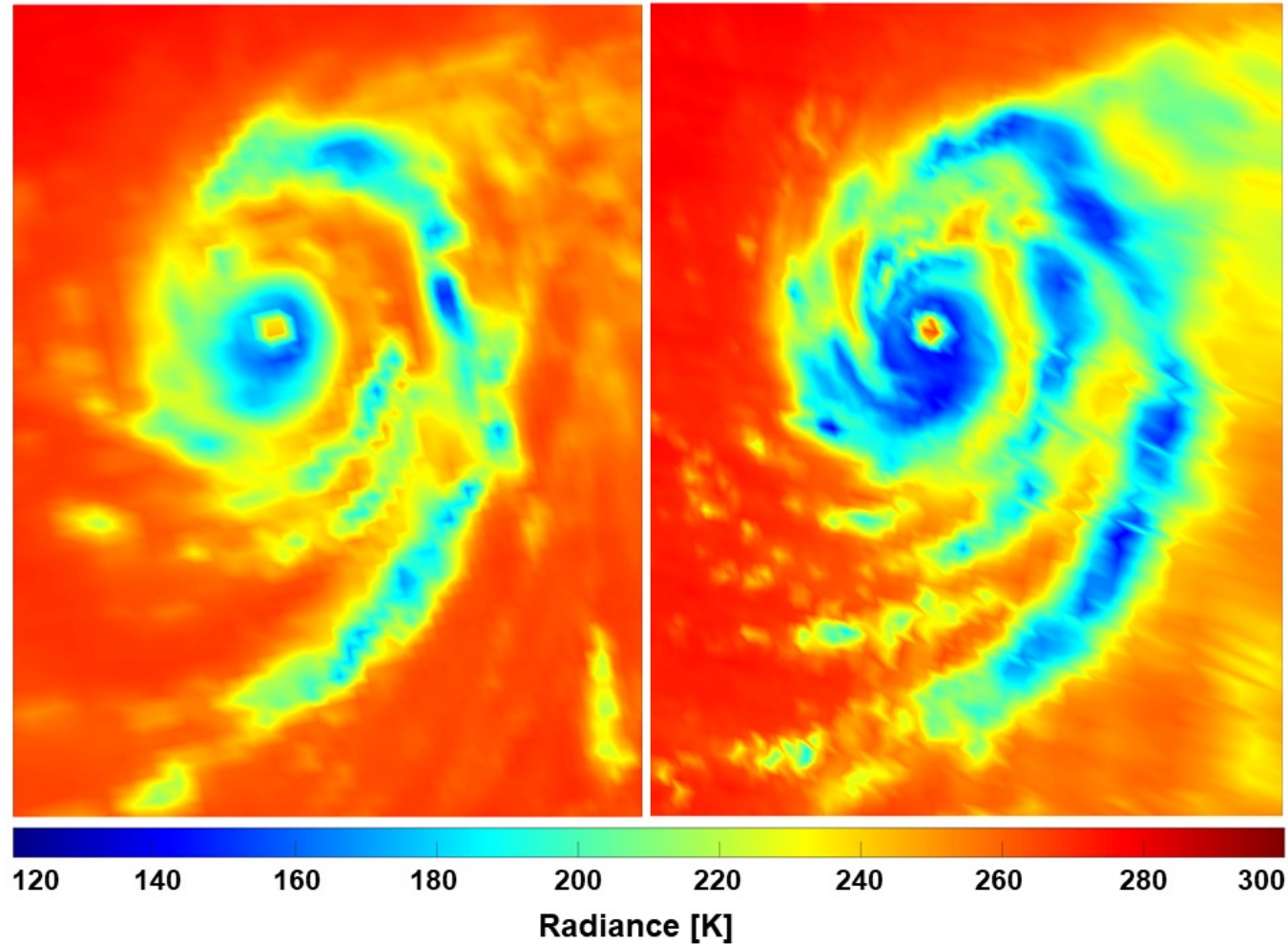
Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of SmallSats (TROPICS)



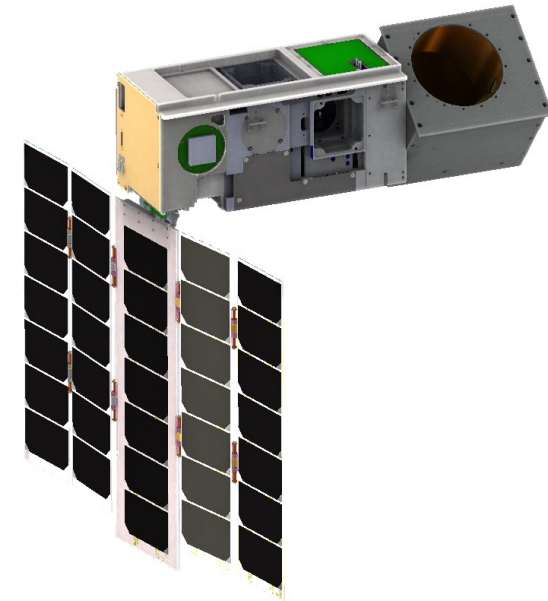
TROPICS is Lighting a Path to Future Observing Systems

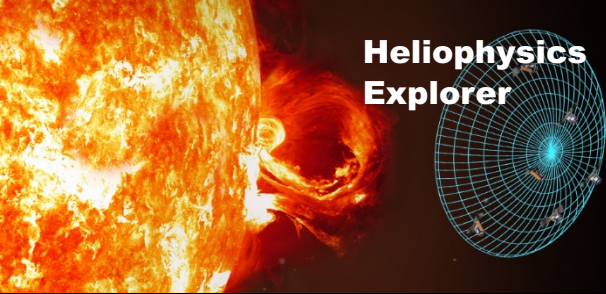
Super Typhoon Mindulle (Sep 26, 2021)

NOAA SNPP Satellite
>2000 kg



TROPICS Pathfinder Satellite
5.4 kg





Heliophysics
Explorer

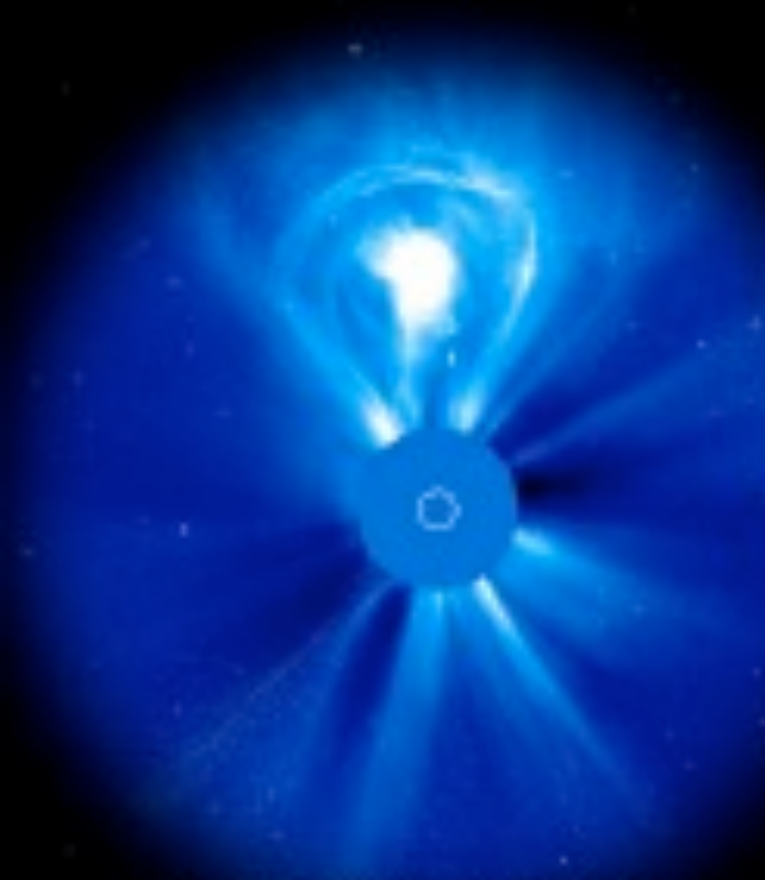


Sun Radio Interferometer Space Experiment (SunRISE)

PI: Justin C. Kasper/University of Michigan



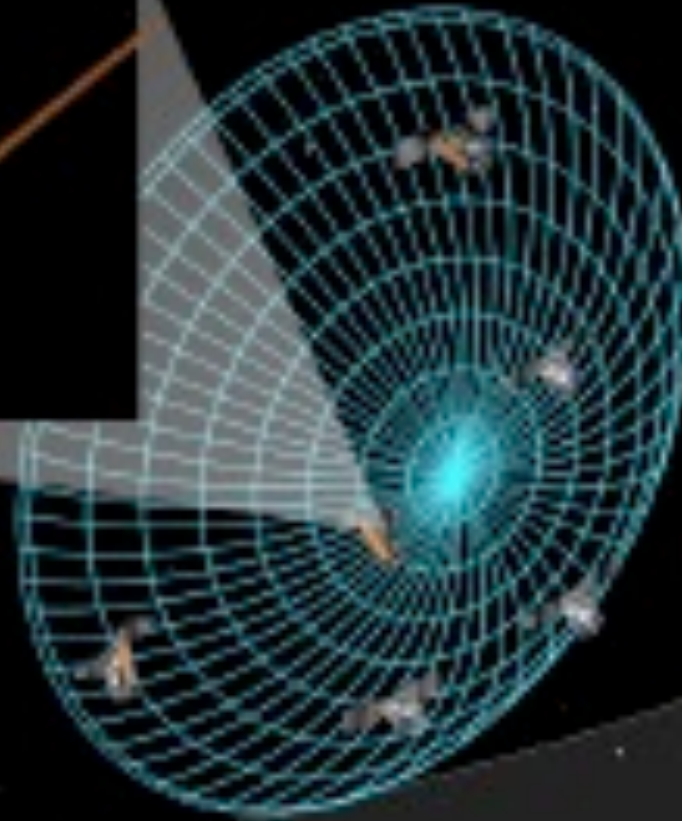
Sun Radio Interferometer
Space Experiment



Coronal Mass Ejection
Coronagraph Image



SunRISE Observatory



Global Navigation
Satellite System



National Aeronautics and
Space Administration



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"Twenty years from now you will be more disappointed by the things that you didn't do than by the ones you did do. So throw off the bowlines. Sail away from the safe harbor. Catch the trade winds in your sails. Explore. Dream. Discover." Mark Twain