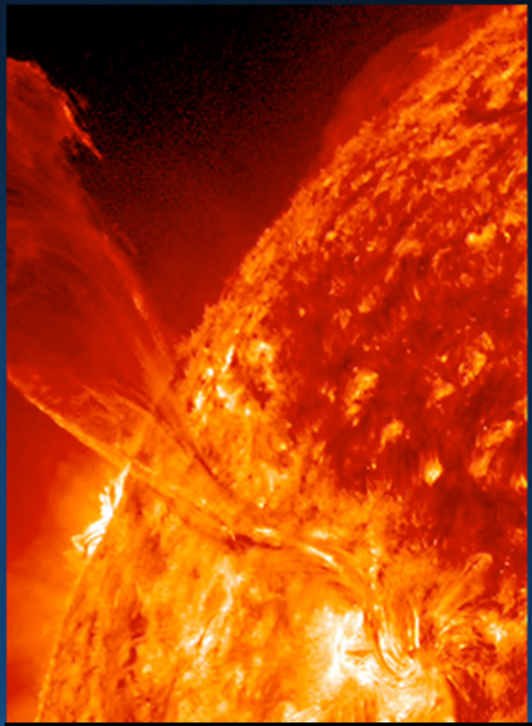
Advancing Technology for NASA Science with Small Spacecraft

SCIENCE MISSION DIRECTORATE

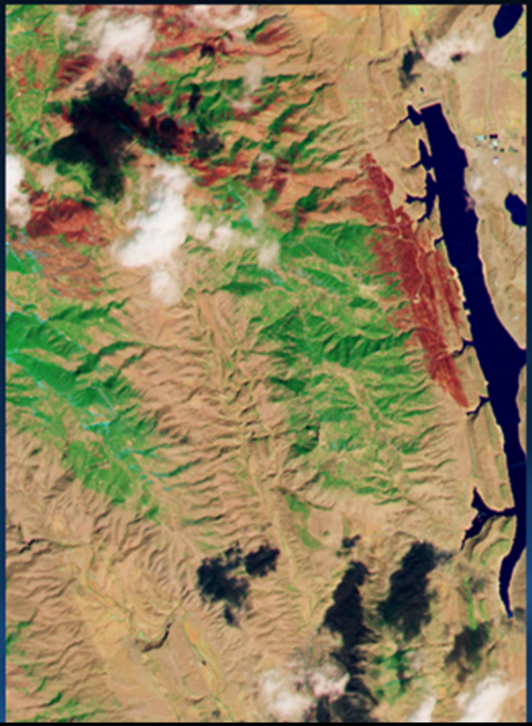
Michael Seablom
Chief Technologist, Science Mission Directorate
International Planetary Probe Workshop - Boulder, CO - June 11, 2018

OVERVIEW OF THE SCIENCE MISSION DIRECTORATE



HELIOPHYSICS

- What causes the Sun to vary?
- How do the geospace, planetary space environments and the heliosphere respond?
- What are the impacts on humanity?



EARTH SCIENCE

- How is the global Earth System changing?
- What causes these changes?
- How will the Earth System change in the future?
- How can our programs provide societal benefit?

PLANETARY SCIENCE

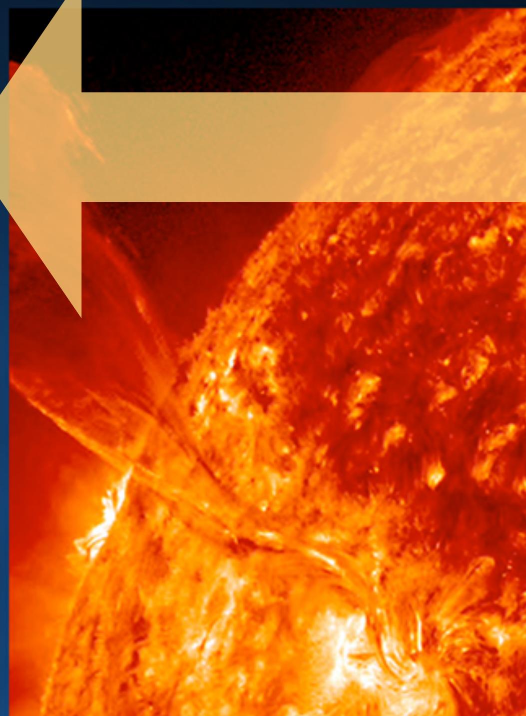
- How did our solar system form and evolve?
- Is there life beyond Earth?
- What are the hazards to life on Earth?

ASTROPHYSICS

- How does the universe work?
- How did we get here?
- Are we alone?

OVERVIEW OF THE SCIENCE MISSION DIRECTORATE

INNOVATION & DISCOVERY



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Science Investments "By the Numbers"

current as of May 1, 2018

Spacecraft
106 missions
88 spacecraft

CubeSats
22 science missions
15 technology demonstrations

Balloon Payloads
13 science payloads
13 piggyback/ student payloads

Sounding Rocket Flights
16 science missions
3 technology/ student missions

Earth-Based Investigations
25 major airborne missions
8 global networks

Technology Development
~$400M invested annually

Research
10,000+ U.S. scientists funded
3,000+ competitively selected awards
~$600M awarded annually

Our Philosophy

Technology and continued technological progress is critical for SMD and its future missions

Technology investments are pathways to light as strategic elements of SMD programs

SMD will actively develop flight opportunities for new technologies as part of AOs.

- Based on our experiences, performance metrics, and feedback, we will continuously adjust.

Overarching Goal: Increase the capabilities of future missions and/or lower their costs

SMD Technology Programs

Heliophysics ~$15M

Sounding Rockets and Range Program	Develops new sounding rocket and range technologies; serves as a low-cost testbed for new scientific techniques, scientific instrumentation, and spacecraft technology eventually flown on satellite missions.
Heliophysics Technology and Instrument Development for Science (H-TIDeS)	Supports basic research of new technologies and feasibility demonstrations that may enable future science missions. Also supports science investigations through suborbital flights that often involve a significant level of technology development.

Astrophysics ~$70M

Astrophysics Research and Analysis (APRA)	Supports basic research of new technologies (TRL 1-3) and feasibility demonstrations that may enable future science missions. Also supports science investigations through suborbital flights that often involve a significant level of technology development.
Strategic Astrophysics Technology (SAT)	Develops mid-TRL technologies (TRL 3-6). Each focused Astrophysics program manages an SAT element separate from flight projects: Technology Development for Physics of the Cosmos (TPCOS), Technology Development for Cosmic Origins Program (TCOR), and Technology Development for Exo-Planet Missions (TDEM).
Roman Technology Fellowships (RTF)	Provides opportunities for early-career astrophysics technologists to develop the skills necessary to lead astrophysics flight instrumentation development projects, and fosters career development by providing incentives to help achieve long-term positions. Develops innovative technologies that enable or enhance future astrophysics missions.

SMD Technology Programs

Earth Science ~$60M

Advanced Component Technologies (ACT)	Develops a broad array of components and subsystems for instruments and observing systems.
Instrument Incubator Program (IIP)	Funds innovative technologies leading directly to new Earth observing instruments, sensors, and systems.
Advanced Information Systems Technology (AIST)	Develops tools and techniques to acquire, process, access, visualize, and otherwise communicate Earth science data.
In-Space Validation of Earth Science Technologies (InVEST)	Enables on-orbit technology validation and risk reduction for small instruments and instrument systems that could not otherwise be fully tested on the ground or airborne systems.

SMD Technology Programs

Planetary Sciences ~$120M

Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO)	Funds the development of low-TRL technologies (TRL 1-3) leading directly to the development of new Planetary Science observing instruments, sensors and in situ systems.
Maturation of Instruments for Solar System Exploration (MatISSE)	Matures innovative instruments, sensors, and in situ system technologies (TRL 3-6) to the point where they can be successfully infused into new Planetary Science missions.
Concepts for Ocean Worlds Life Detection Technology (COLDTech)	Supports the development of spacecraft-based instruments and technology for surface and subsurface exploration of ocean worlds such as Europa, Enceladus, and Titan.
Hot Operating Temperature Technology Program (HOTTech)	Supports the development of technologies for the robotic exploration of high-temperature environments, such as the Venus surface, Mercury, or the deep atmosphere of Gas Giants.
Radioisotope Power System Program (RPSP)	Strategically invests in nuclear power technologies to maintain NASA's current space science capabilities and enable future space exploration missions.

Technology Investments at Multiple Stages

Mission Infusion

"Mission Pull" Technologies

"Push" Technologies

Late Stage / Flight Validation Projects

"Few" projects Total Budget >$300M

INVEST | FOP | TDM | Balloons | Rockets

Mid Stage / Development Projects

~200 projects
Total Budget ~ $300 million

IIP | AIST | APS | MARS | HTIDS | ACT | TIP | SBIR

ISST | MATISSE | ADVTCH | PSTAR | SAT | APRA | GCD | CC | SSTP

Early Stage / Transformational Development Projects

"Many" projects
Total Budget <$90M

HTIDS | IIP | PICASSO | NIAC | STRG | APRA | RTF | SBIR | CIF

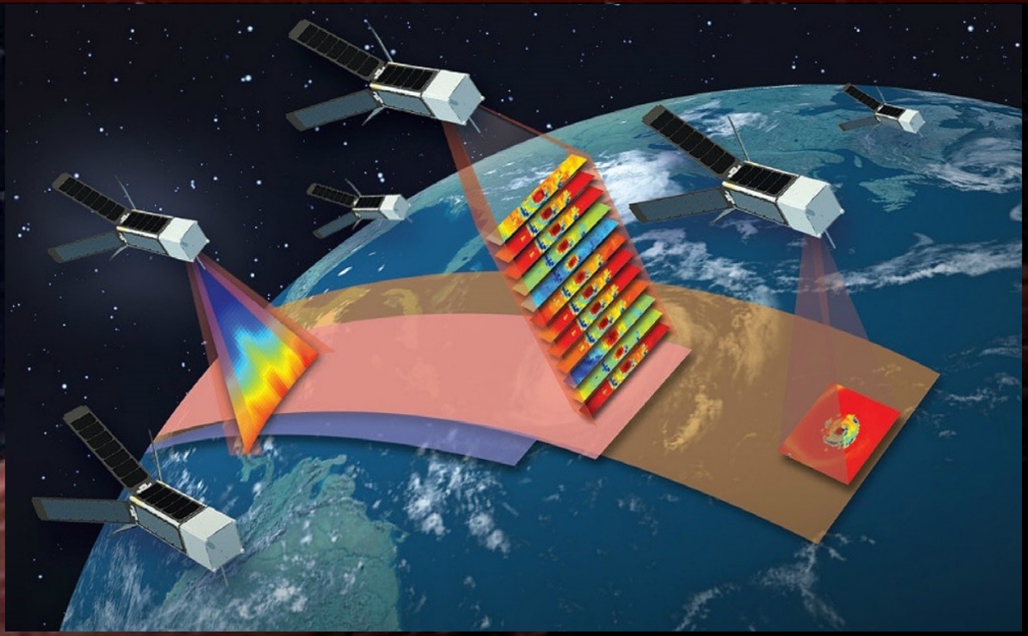
Platform Technologies - Space Technology Mission Directorate

CC	Centennial Challenges
CIF	Center Innovation Fund
FOP	Flight Opportunities Program
GCD	Game Changing Development
NIAC	NASA Innovative Advanced Concepts
SBIR	Small Business Innovation Research
SSTP	Small Spacecraft Technology Program
STRG	Space Technology Research Grants
TDM	Technology Demonstration Mission
TIP	Tipping Point

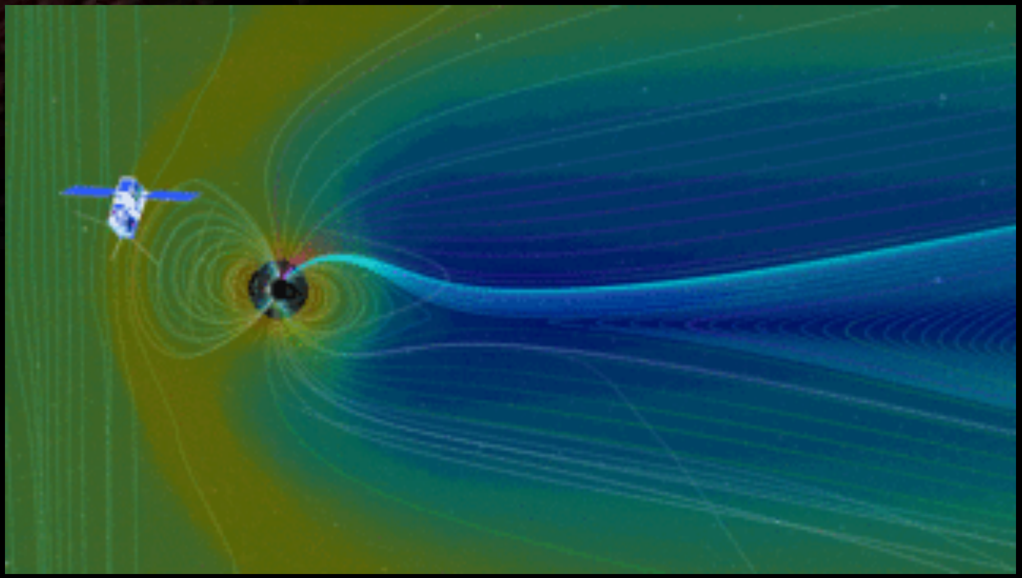
ASTROPHYSICS | EARTH SCIENCE | PLANETARY SCIENCE | HELIOPHYSICS

ADVANCING THE USE OF SMALL SPACECRAFT

- *The FY 2018 budget includes SMD-wide initiative to use small satellites to advance selected high-priority science objectives in a cost-effective manner*
- *SMD will implement recommendations from the National Academy of Sciences for advancing science with small spacecraft*
- *All four science divisions will include technology development for CubeSats/SmallSats and targeted science missions to exploit this value*
- *Multi-disciplinary approach will leverage and partner with a growing commercial sector to collaboratively drive instrument and sensor innovation*



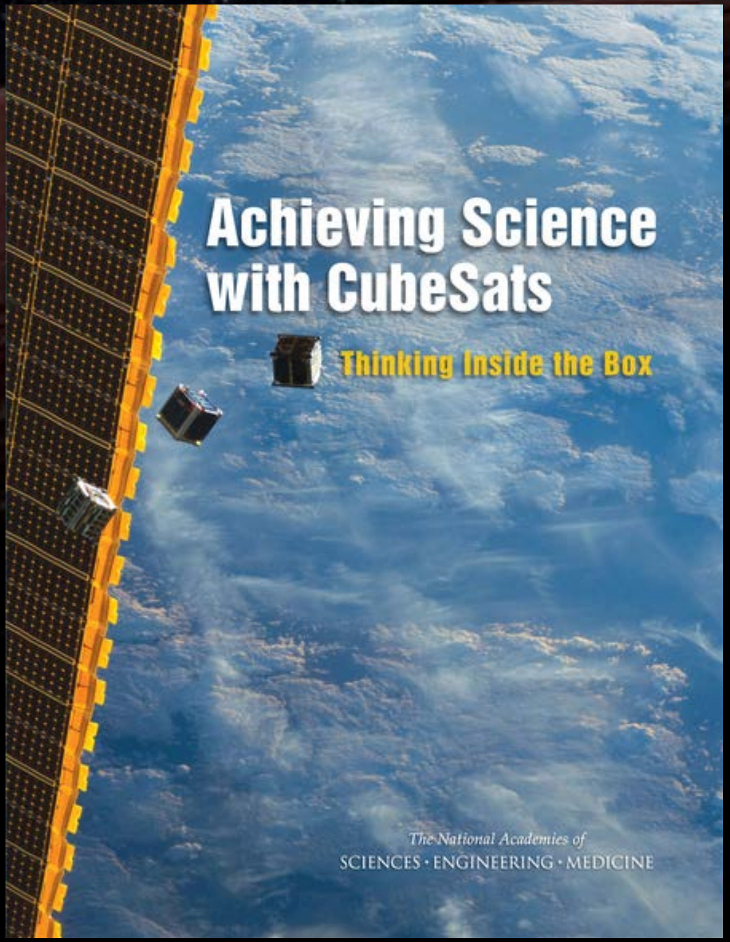
The TROPICS constellation of SmallSats will provide rapid-refresh temperature, humidity, and precipitation data over tropical regions.



The CubeSat to study Solar Particles, or CuSP, will launch from the inaugural flight of NASA's Space Launch System.

Some key recommendations and findings from NAS committee

- Many of NASA's activities have remained largely independent, mostly due to the rapid growth in the use of CubeSats
- Better coordination between NASA programs at Headquarters and at field centers will improve efficiency and will help maximize scientific output
- Diversity of programs should be maintained to encourage innovation with appropriate risk posture
- Investments should be made in high-impact technologies

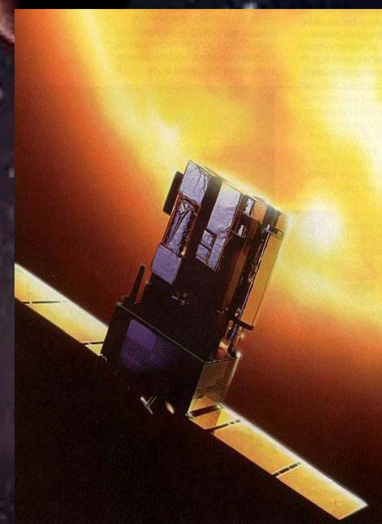


SMALL SATELLITES HAVE CREATED NEW MISSION CLASSES

FLAGSHIP CLASS

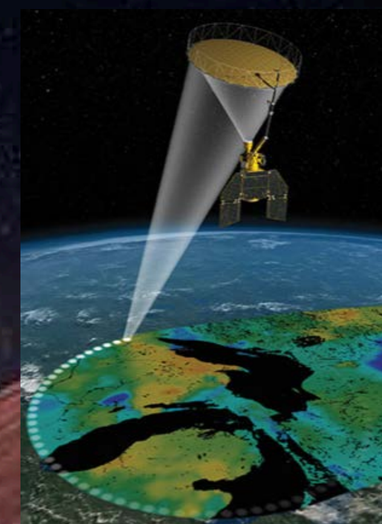
JWST (2019)
>22m linear, 6200kg, 2000W
$8,800 million

LARGE CLASS



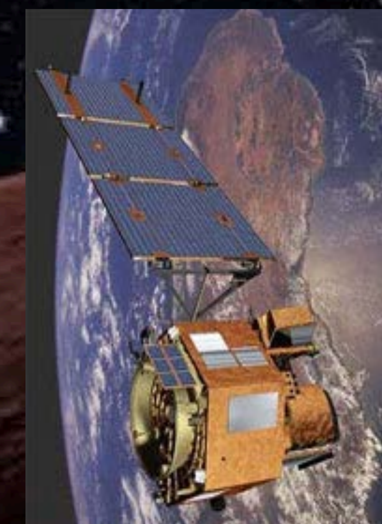
SOHO (1995)
>4.3m linear, 1850kg, 1500W
$1,100 million

MEDIUM CLASS



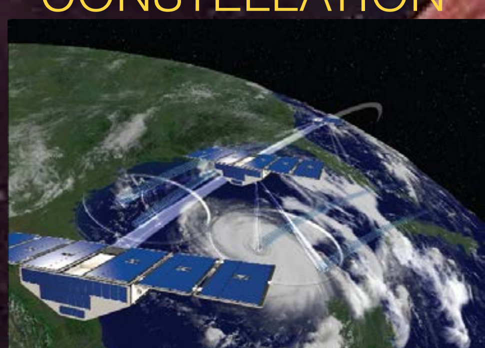
SMAP (2015)
10m linear, 944kg, 550 W (peak)
$916 million

MINI-SAT



EO-1 (2000)
2m linear, 588kg, 315W
$74 million

SMALLSAT CONSTELLATION

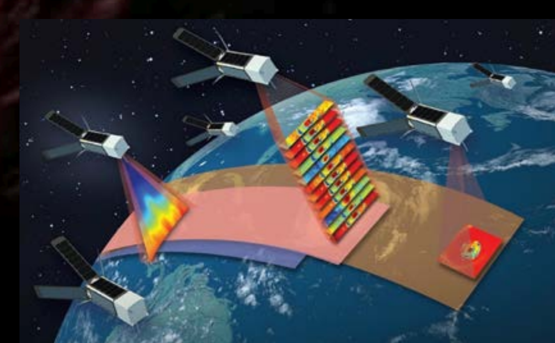


CYGNSS (2016)
64cm linear (8), 25kg, 50W
$150 million

6U CUBESAT

LUNAH-MAP (2020)
60cm linear, 1kg, 2W
$1-30 million

3U CUBESAT CONSTELLATION

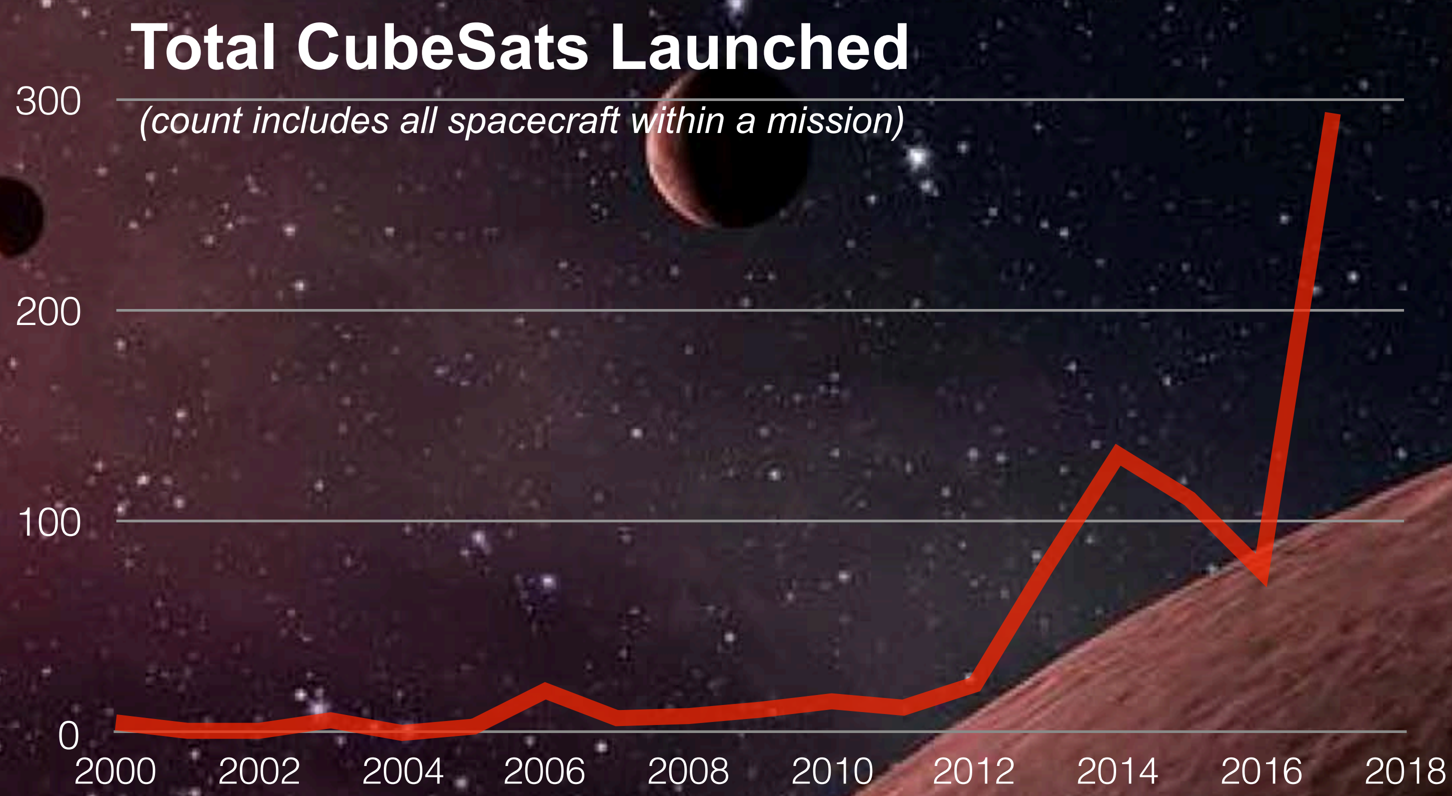


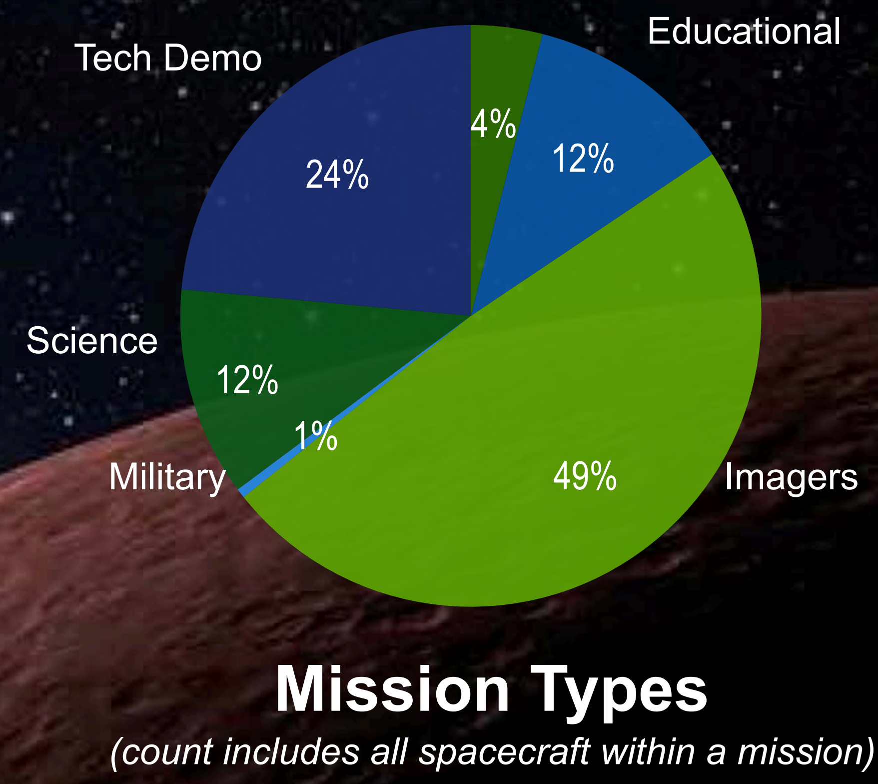
TROPICS (2019)
30cm linear, >5kg, 2W
$1-30 million

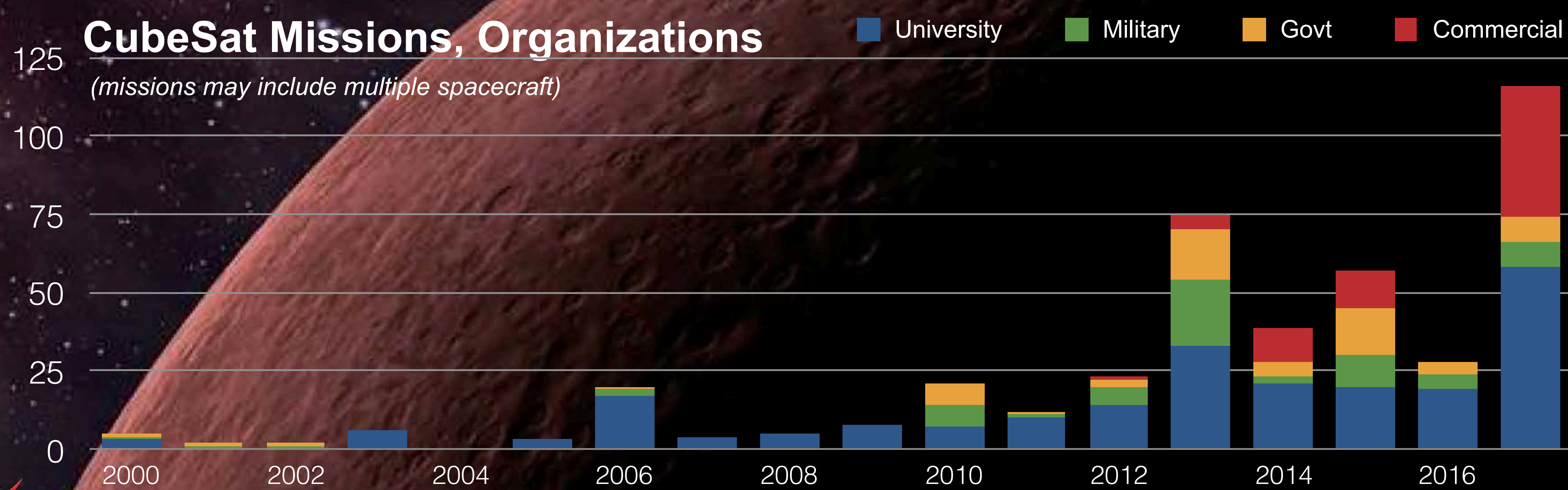
3U CUBESAT

RAVAN (2016)
30cm linear, 5kg, 2W
$1-30 million

GROWTH OF CUBESATS







Sources: M. Swartwout, St. Louis Univ. and NAS - Engineering & Medicine 2016: *Achieving Science with CubeSats: Thinking Inside the Box*, Washington, DC. NAS Press doi: 10.17226/23503.
Note: statistics conclusive through December 2017

Ongoing study being conducted to help guide investments for small spacecraft

Investigate paradigm shifts in the miniaturization of science instruments and disruptive small satellite platform technologies

Determine the potential for novel approaches that could break the cycle of "larger but fewer" expensive missions

Identify key SMD science measurement requirements that could be satisfied through such paradigms

Identify technology gaps that could be addressed through solicitations such that barriers to alternative paths are removed

Technology Studies - Status	
Earth Science	Decadal-focused studies completed in 2015 and 2016; new study/RFI planned for 2018
Heliophysics	Decadal-focused studies completed in 2015 and 2016
Planetary Science	RFI issued in 2016, subsequent funding provided in 2017
Astrophysics	RFI issued in 2017; small satellite solicitation is now open

EXAMPLE FROM 2016 EARTH SCIENCE SMALLSAT STUDY

MISSION CONCEPT	MEASUREMENT(S)	SMALL SAT CANDIDATE?	POSSIBLE CONFIGURATION	KEY TECHNOLOGY NEEDS
Global Atmospheric Composition Mission (GACM)	High vertical resolution O3 measurements better than 2km in mid/lower troposphere with concurrent profiles of aerosols and atmospheric structure to better than 150m	YES, UV/VIS/SWIR miniaturized spectrometer, microwave limb sounder	12U to ESPA Constellation	Further miniaturization of scientific instruments (lidars, spectrometers)
Geostationary Coastal and Air Pollution Events (GEOCAPE)	UV-visible-near-IR wide-area imaging spectrometer (7-km nadir pixel) capable of mapping North and South America from 45°S to 50°N at about hourly intervals, a steerable high-spatial-resolution (250 m) event-imaging spectrometer with a 300-km field of view	YES, UV/VIS/NIR wide area spectrometer, event imaging spectrometer, TIR radiometer	ESPA Constellation: one spacecraft per instrument	UV-NIR wide-field imaging spectrometer
Hyperspectral Infrared Imager (HYSPIRI)	VSWIR: 60m spatial resolution, 19-day revisit. TIR: 60m spatial resolution, 5-day revisit	YES, VSWIR: 30m spatial resolution, 16-day revisit. TIR: 80m spatial resolution, 5-day revisit	ESPA class Constellation (one spacecraft per instrument)	None
NASA-ISRO Synthetic Aperture Radar (NISAR)	Measure >2 component vector displacement ≤12 days, 3.5mm accuracy, resolution 100m; sea ice velocity accuracy 100m/day; vegetation biomass of 20Mg/ha	LIKELY: Circularly polarized SAR (CP-SR) L-band small satellite	Constellation or Standalone	Deployable antenna (2m x 5m)
Soil Moisture Active / Passive (SMA/P)	Measure soil moisture in top 5cm with error no greater than .04cm³/cm³ at 10km spatial resolution; estimate freeze/thaw state	UNLIKELY	Constellation w/ GNSS reflectometry possible, but resolution would be degraded	N/A

Earth Science

- About 40% of the measurements from the original 2007 Decadal Survey missions could be satisfied from small satellites - mostly ESPA-class
- Miniaturization of imagers, spectrometers, radiometers, radars was deemed to be most impactful; constellations and formation-flyers were also important
- Next study/RFI will focus on classes of measurements identified by 2017 Decadal Survey

Heliophysics

- All four of the 2013 Decadal Survey mission measurements could be satisfied by small satellites (ESPA-class or CubeSats)
- Miniaturization of magnetometers and particle detectors was deemed to be most impactful; solar sails, constellations, and formation-flyers were also important

Planetary Sciences

RFI issued by the Planetary Science in 2016 (“Planetary Science Deep Space SmallSat Studies”) solicited mission concepts and technologies; 102 responses

Miniaturization of various science instruments, propulsion systems, high-performance solar arrays, extreme-environment batteries, precision-landing systems were cited as technology development needs

Astrophysics

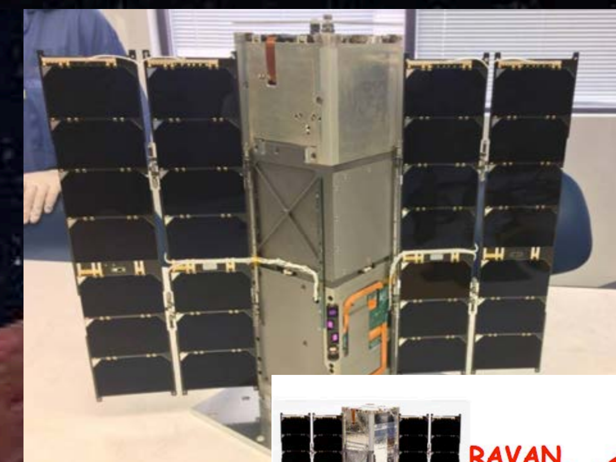
RFI for SmallSats asked for ideas to do high priority Astrophysics science projects at a price point between typical R&A and Explorer MOO projects ($10M-$35M), and advanced mission concepts for which “significant” investments in instrument and/or platform technologies would be required, without budget constraints

55 responses received; platform technologies included power systems, antennas, miniaturized cryocoolers, on-board processing, and advanced propulsion systems for formation flying

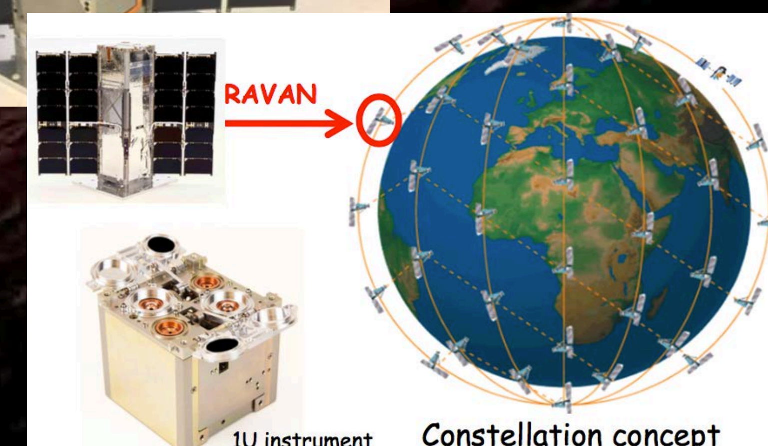
Instrument technologies included advanced mirror coatings and miniaturized detectors

Validating New Technologies

PI: William Swartz, JHU-Applied Physics Lab



- Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN)
- Goal: Test new method to accurately measure the Earth's radiation imbalance
- New Technology: Vertically Aligned Carbon Nanotubes (VACNTs)



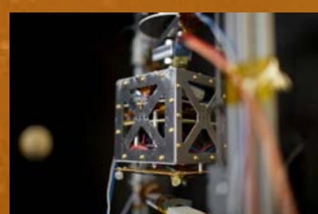
Demonstrate the instrument's ability to measure Total Outgoing Radiation

Verify VACNT's electrostatic properties do not interfere with spacecraft / instrument electronics

Results / Outcomes

- VACNTs as radiometer absorbers are robust in the space environment and show long-term stability
- RAVAN's absolute accuracy is limited by instrument thermal knowledge and control well above 0.3 W/m^2 — the level needed to perform meaningful climate science
- Thermal knowledge / stability proved to be a challenge in the CubeSat form factor
- Lessons learned were extremely valuable and achieved at low cost

Hyperspectral Imaging from CubeSats: Crosscutting Needs (Planetary Science + Earth Science)

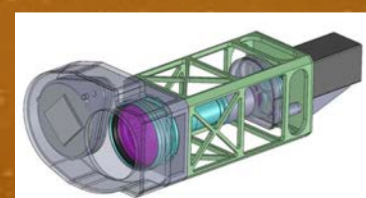


3 years

Development of Platform Technologies (communications, thermal management, propulsion, etc.)

SMALL SPACECRAFT TECH PROGRAM

GAME-CHANGING TECH PROGRAM



5 years

Development of Instrument Technologies (imagers, spectrometers, etc.)

PICASSO PROGRAM

INSTRUMENT INCUBATOR PROGRAM

7 years

Late Stage Development and Flight Testing

SMALL SPACECRAFT TECH PROGRAM

INVEST PROGRAM