National Aeronautics and
Space Administration

EXPLORE

Navigating SmallSat Development: Where to Begin and What to Expect

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Science Mission Directorate
NASA Headquarters

June 2019

https://science.nasa.gov/science-news/news-articles/small-satellites-yield-big-discoveries

Aug. 4, 1971 – Apollo 15 Particles and Fields Subsatellite (PFS-1) released from the Service Module prior to Lunar Orbit Departure

Discussion Objectives

Share Phase A-E experiences in SmallSat development targeted toward new investigators

Engage everyone's expertise through open conversations and storytelling

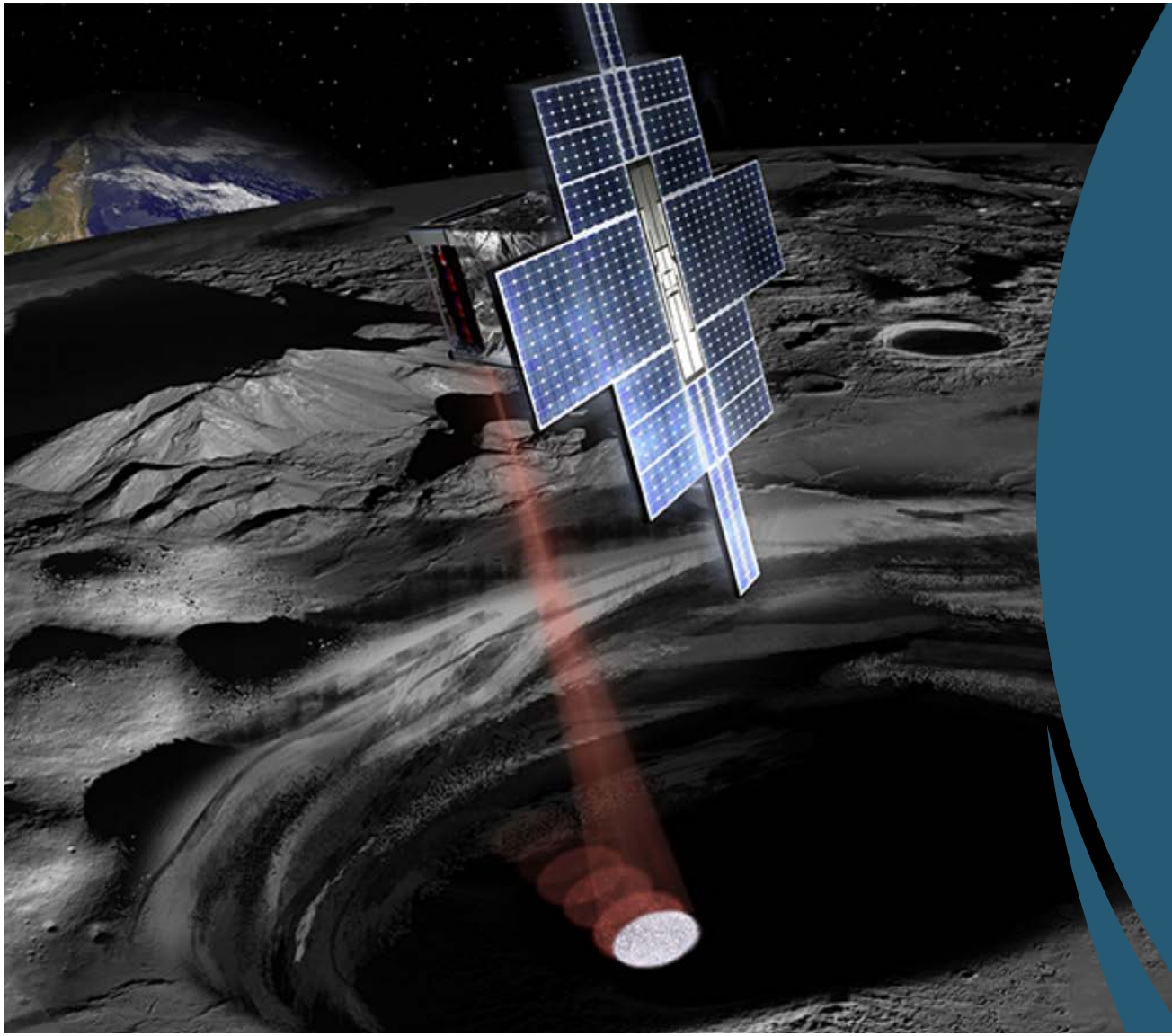
This is not a tutorial per se, we should all learn from each other

Courtesy: NASA Space Science Data Center Catalog

Apollo 15 Subsatellite

- Met objectives to study the plasma, particle, and magnetic field environment of the Moon and map the lunar gravity field
- Operated for 6 months prior to electronics failures
- Supported Explorer 35's finding that the Moon acts as a physical barrier to the solar wind creating a "hole" in the flow of charged particles
- Mass of 35.6 kg with 3 instruments: magnetometer, S-band transponder, and charged particle detector
- Astronauts David Scott, Alfred Worden, and James Irwin

Courtesy: NASA Space Science Data Center Catalog



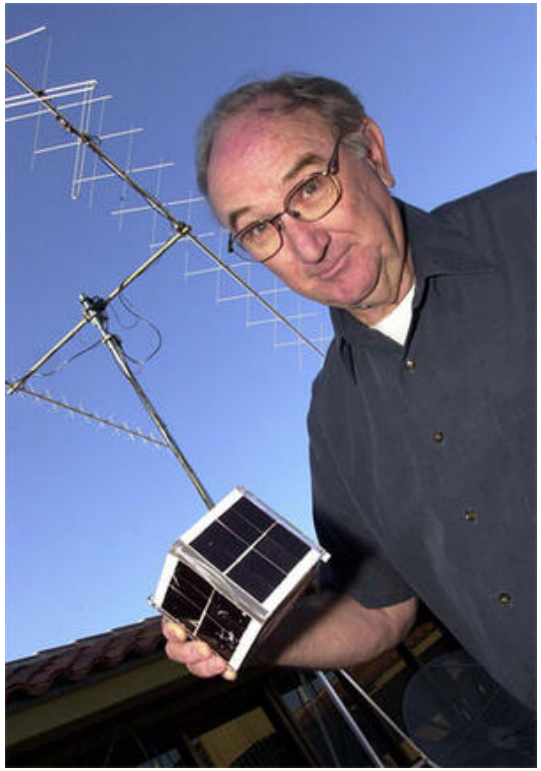
Topics for Discussion

- The Basics
- Mission Formulation
- Realities of Flight Development
- Access to Space
- Mission Operations
- Closing Remarks

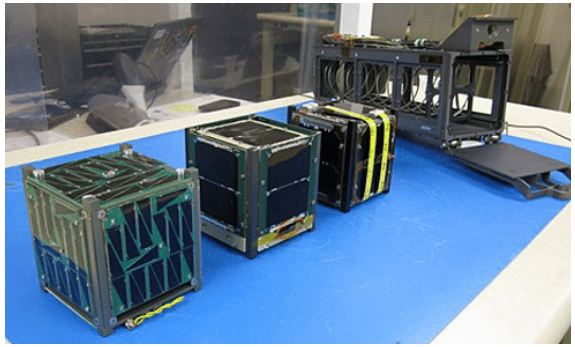
Founders of the CubeSat Standard

Focused on Education

Jordi Puig-Suari of Cal Poly San Luis Obispo

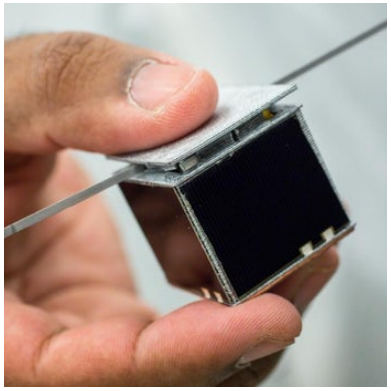


Bob Twiggs of Stanford University



The Basics

Spectrum of Satellite Development
Common Small Satellite Definitions

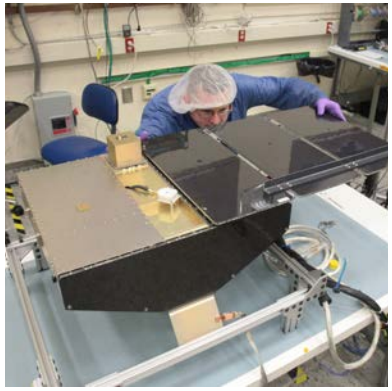


Picosatellite

PocketSat
0.1 – 1 kg

Nanosatellite

MCubed
1 – 10 kg



Microsatellite

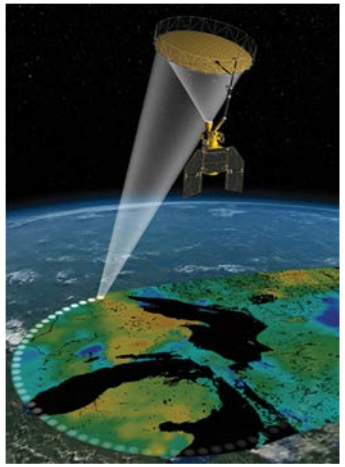
CYGNSS
10 – 100 kg

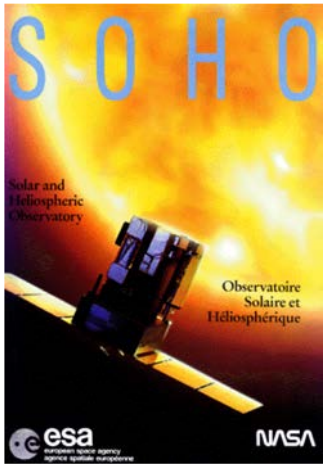
Small/Medium Satellite

SORCE
100 – 500 kg

Spectrum of Satellite Development

SmallSats are Penetrating Space Exploration Mission Classes

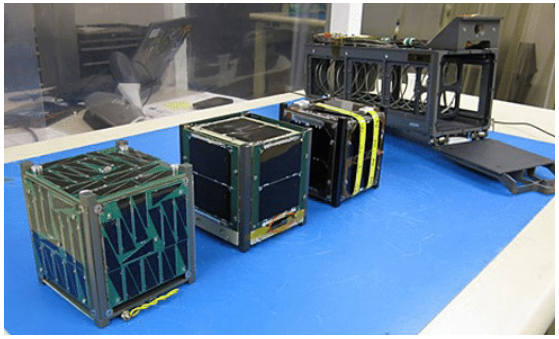


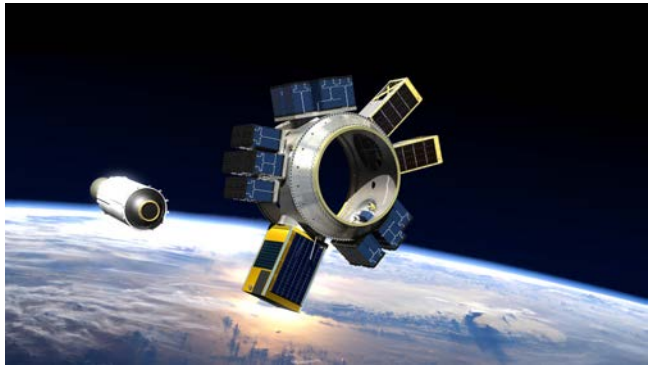


CubeSat / SmallSat	MiniSat / ESPA-Class	Medium-Class	Large-Class	Flagship-Class
CP-6	LCROSS	SMAP	SOHO	Aura
10+ cm (linear)	2 meters (linear)	9.7 meters (linear)	4.3 meters (linear)	17.37 meters (linear)
1 – 180 kg	585 kg (dry mass)	944 kg	1850 kg	2,967 kg
5 – 200 W	600 W	550 W (radar peak)	1,500 W	4,600 W

Fundamentals of Small Spacecraft

CubeSats, ESPA, Integration and Launch





The Basics

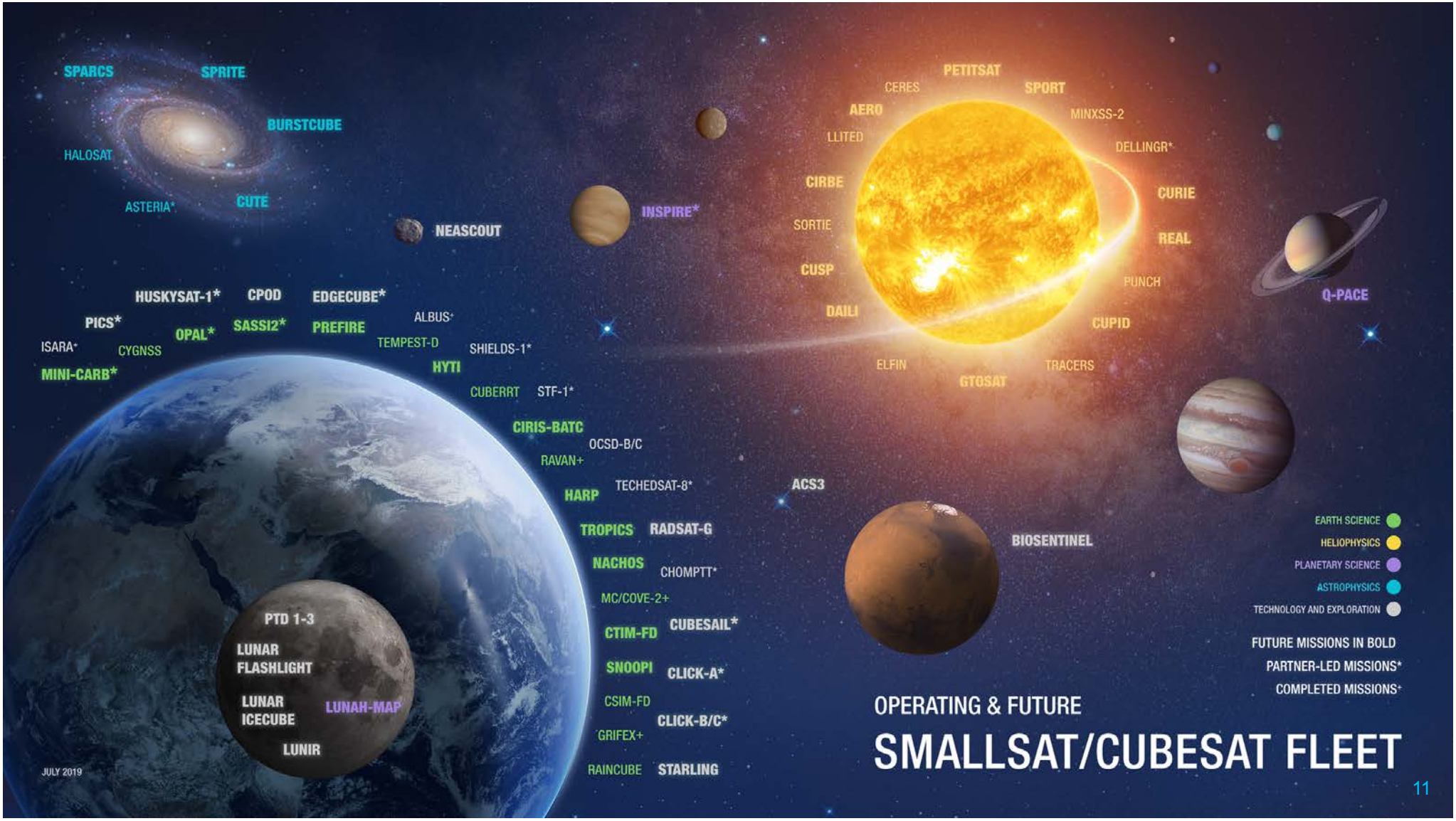
Multiple Launch Options via NASA's CSLI Program

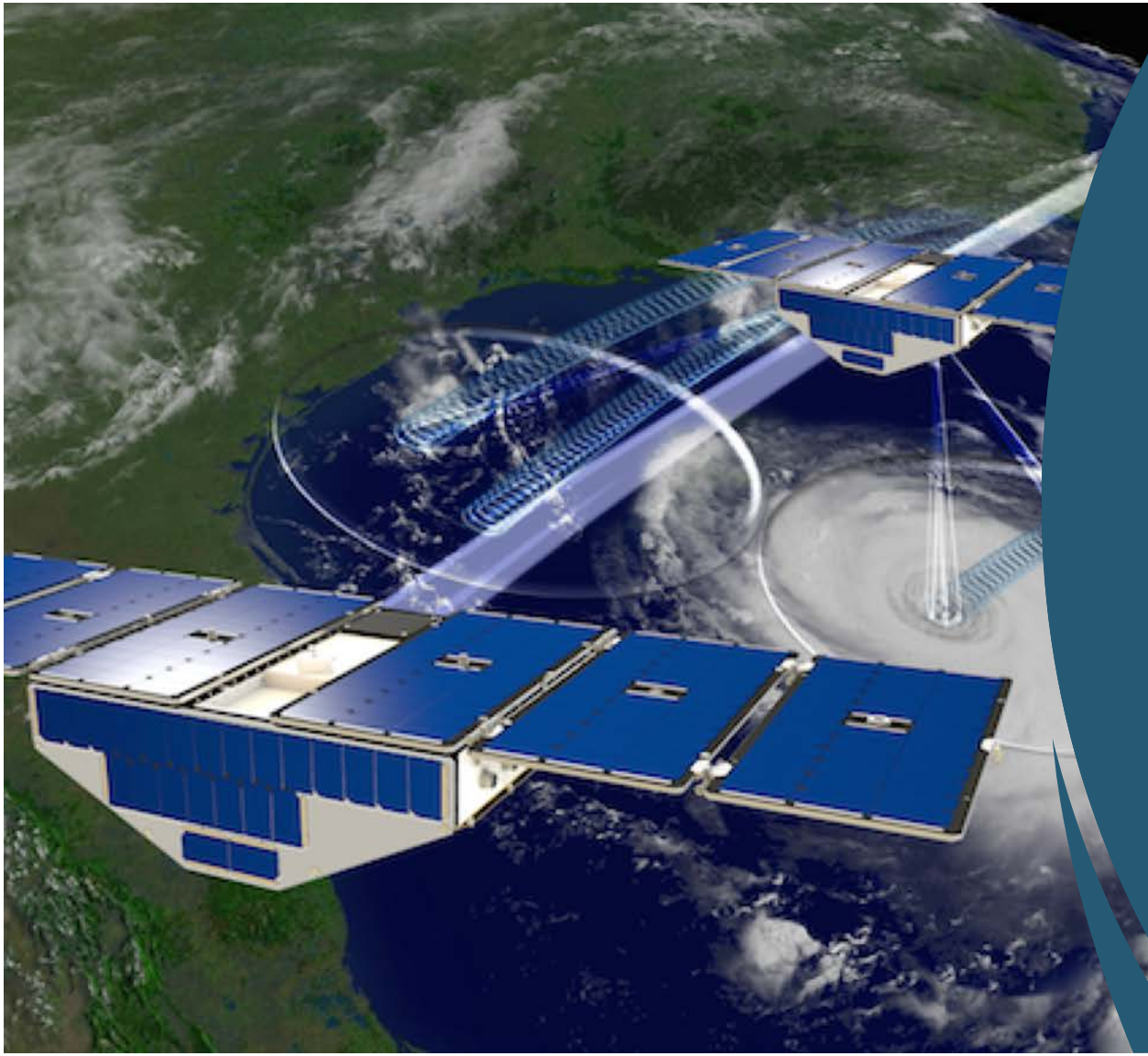
Cargo, Rideshare, Dedicated Launch

ISS via Nanoracks
~400km @ 51.6 deg.
Orbital lifetime (~3-18 months)

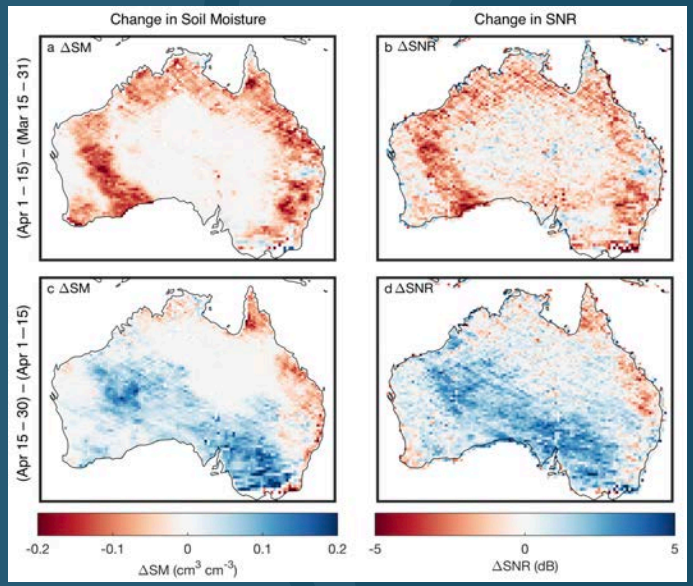
Secondary/Auxiliary Payload Rideshare
LEO, GEO, Earth Escape
Inclinations vary
Orbital lifetime (Years to Heliocentric)

Venture-Class Dedicated Launch
LEO ~500 km many inclinations
Orbital lifetime (varies)


SPARCS
SPRITE
BURSTCUBE
HALOSAT
ASTERIA*
CUTE
NEASCOUT
INSPIRE*
PETITSAT
CERES
SPORT
AERO
MINXSS-2
LLITED
DELLINGR*
CIRBE
CURIE
SORTIE
REAL
CUSP
PUNCH
Q-PACE
DAILI
CUPID
HUSKYSAT-1*
CPOD
EDGECUBE*
PICS*
ALBUS+
OPAL*
SASSI2*
PREFIRE
ISARA+
TEMPEST-D
CYGNSS
SHIELDS-1*
MINI-CARB*
HYTI
ELFIN
TRACERS
GTOSAT
CUBERRT
STF-1*
CIRIS-BATC
OCSD-B/C
RAVAN+
TECHEDSAT-8*
ACS3
HARP
TROPICS
RADSAT-G
BIOSENTINEL
NACHOS
CHOMPTT*
MC/COVE-2+
PTD 1-3
CTIM-FD
CUBESAIL*
LUNAR FLASHLIGHT
SNOOPI
CLICK-A*
LUNAR ICECUBE
LUNAH-MAP
CSIM-FD
CLICK-B/C*
GRIFEX+
LUNIR
RAINCUBE
STARLING
JULY 2019
EARTH SCIENCE
HELIOPHYSICS
PLANETARY SCIENCE
ASTROPHYSICS
TECHNOLOGY AND EXPLORATION
FUTURE MISSIONS IN BOLD
PARTNER-LED MISSIONS*
COMPLETED MISSIONS+
OPERATING & FUTURE
SMALLSAT/CUBESAT FLEET



CYGNSS



Nature Scientific Reports: Change in mean SMAP soil moisture compared to change in CYGNSS SNR

CSIM-FD

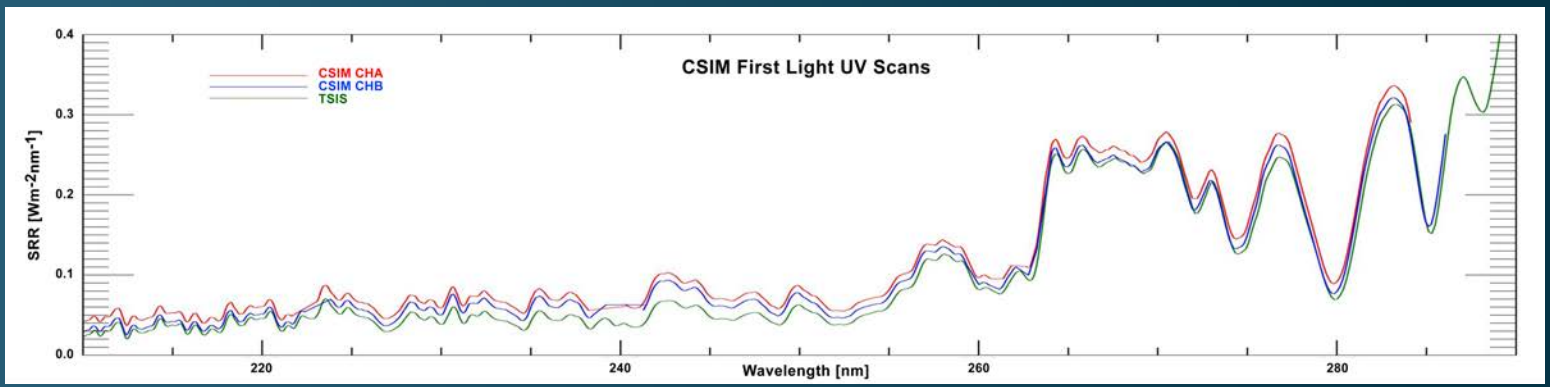
Compact Solar Irradiance Monitor Flight Demonstration

Measuring solar spectral irradiance (SSI), and how solar variability impacts the Earth's climate, contributing to long-term continuity measurements from SORCE SIM and TSIS SIM

CSIM is 11 kg based on a Blue Canyon Technologies bus

TSIS-1 is 363 kg built by LASP mounted to the ISS

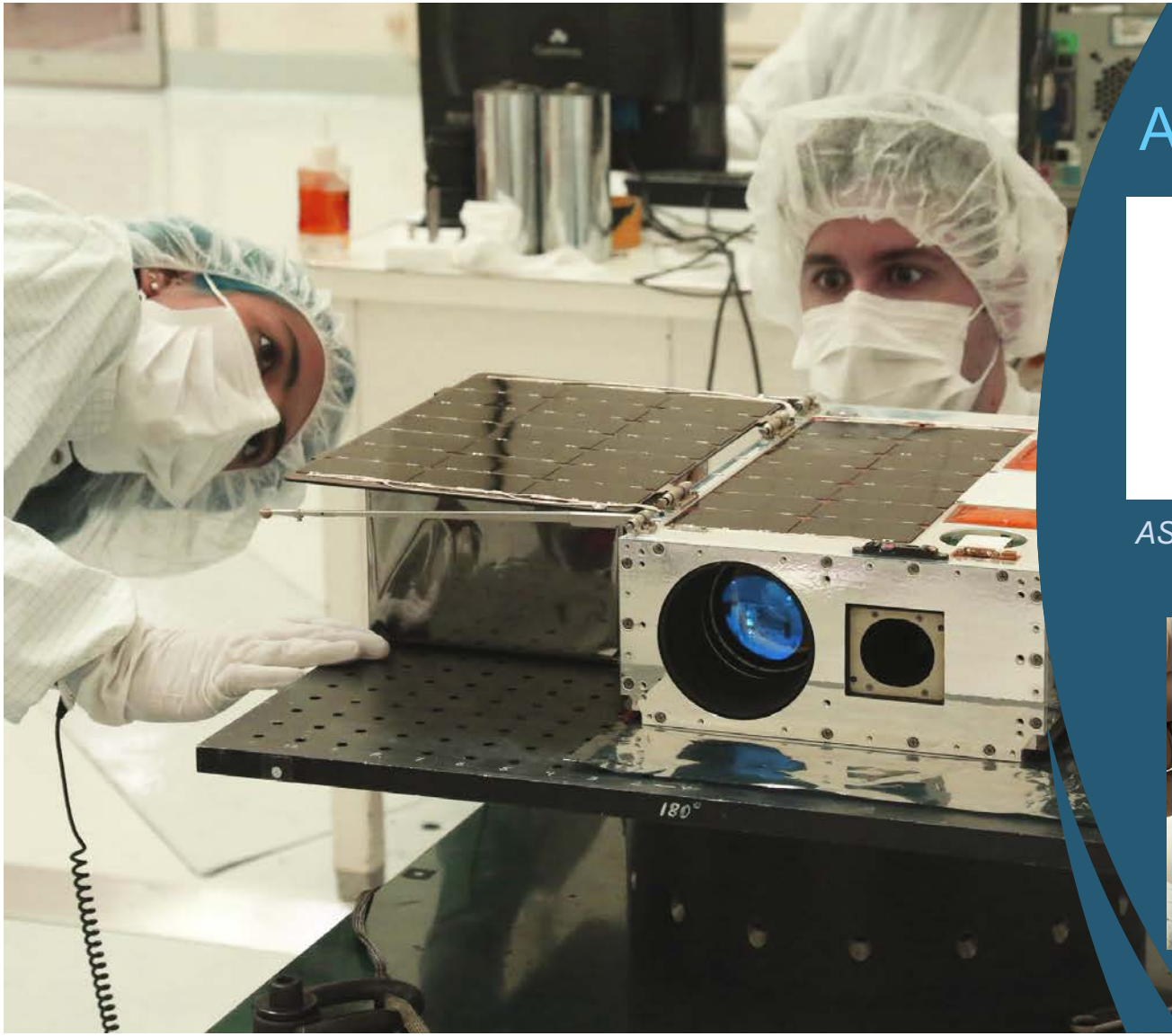
SORCE is 290 kg based on an Orbital LEOStar-2 bus



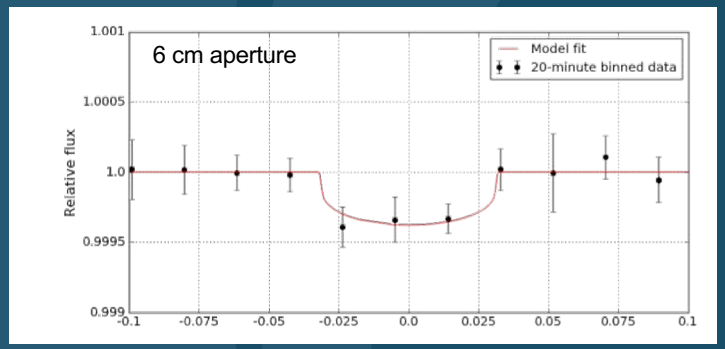
UV comparison of the first CSIM scan showing excellent agreement to the TSIS spectrum

Uncorrected CSIM data (channels A and B) compared to TSIS data in a portion of the UV spectrum

Data quality matters!

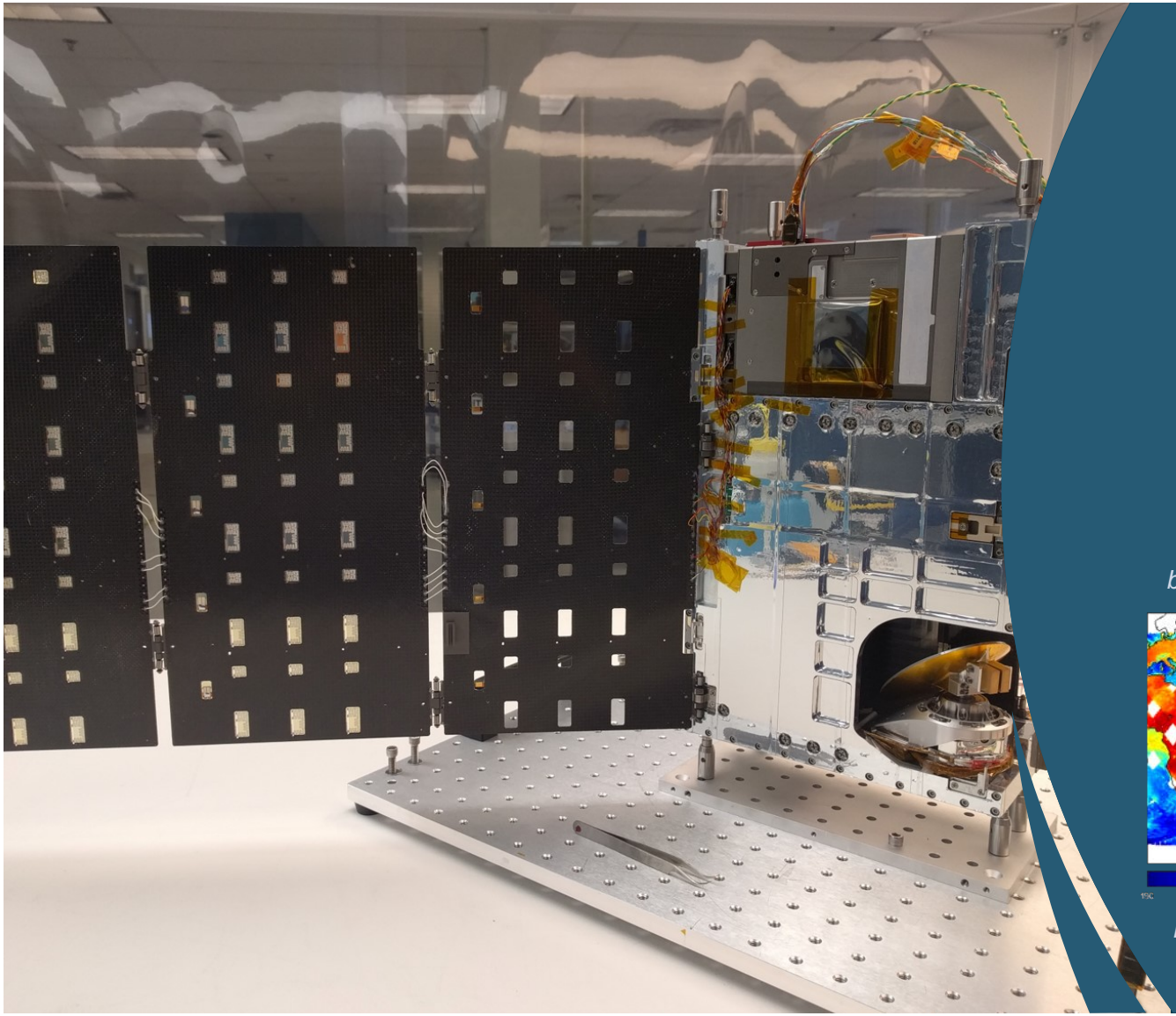


ASTERIA

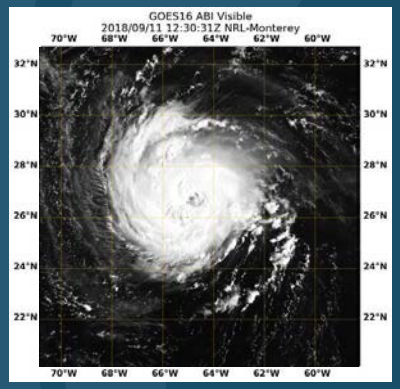


ASTERIA measurement of known super-Earth exoplanet 55 Cancri e

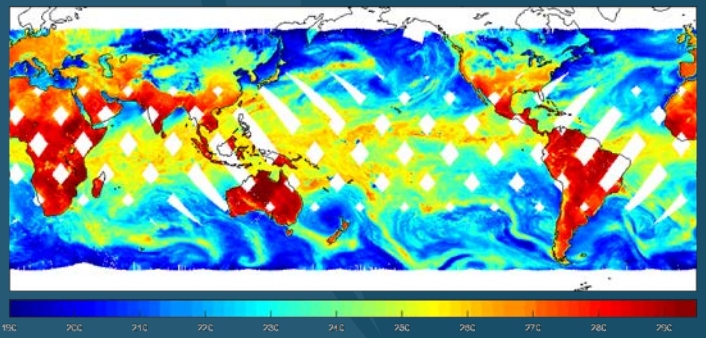
Technology demonstrated <0.5 arcsec RMS and +/- 0.01 K thermal stability over 20 minutes



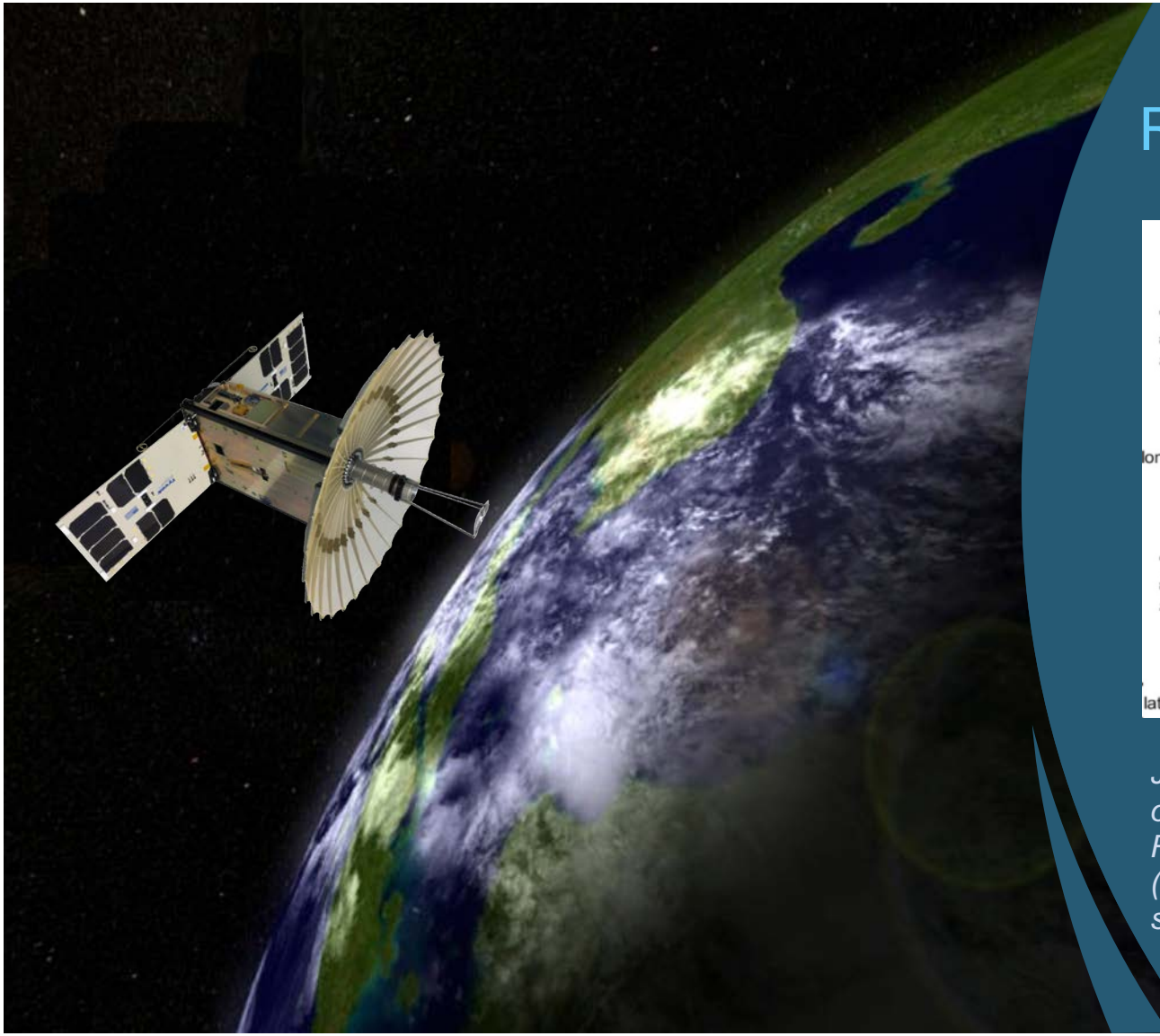
TEMPEST-D



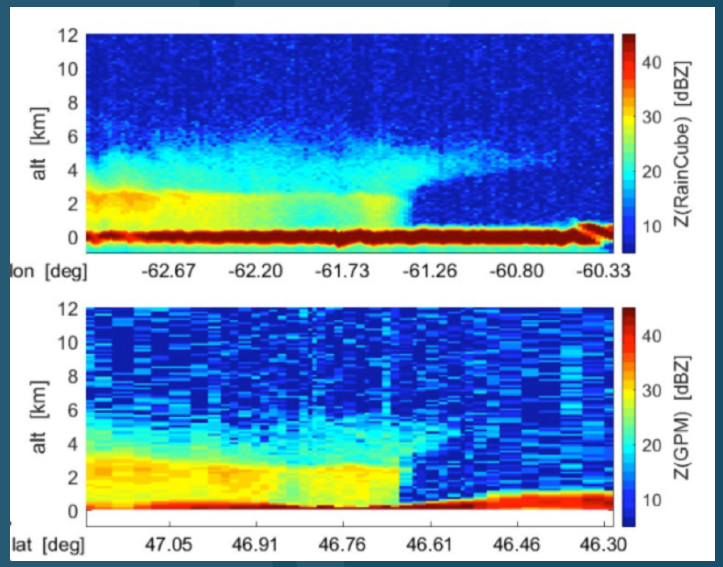
Sept. 11, 2018 – TEMPEST-D 167 GHz brightness temperatures of Hurricane Florence



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



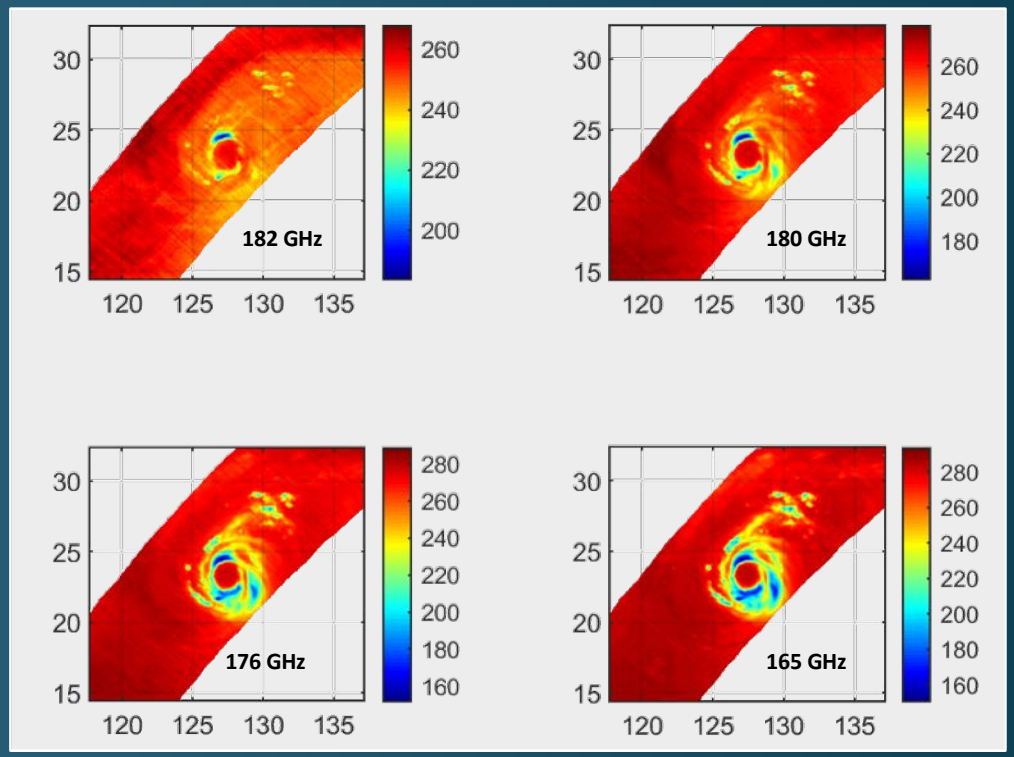
RainCube / GPM



Jan. 2019 – Near-collocated measurements of vertical rain reflectivity profiles from RainCube (top) and GPM's Ka-band radar (bottom) RainCube points Nadir while GPM scans along-track

RainCube/TEMPEST-D Observing Typhoon Trami

Spacecraft constellation separated by 5 minutes revealing 3D storm structure



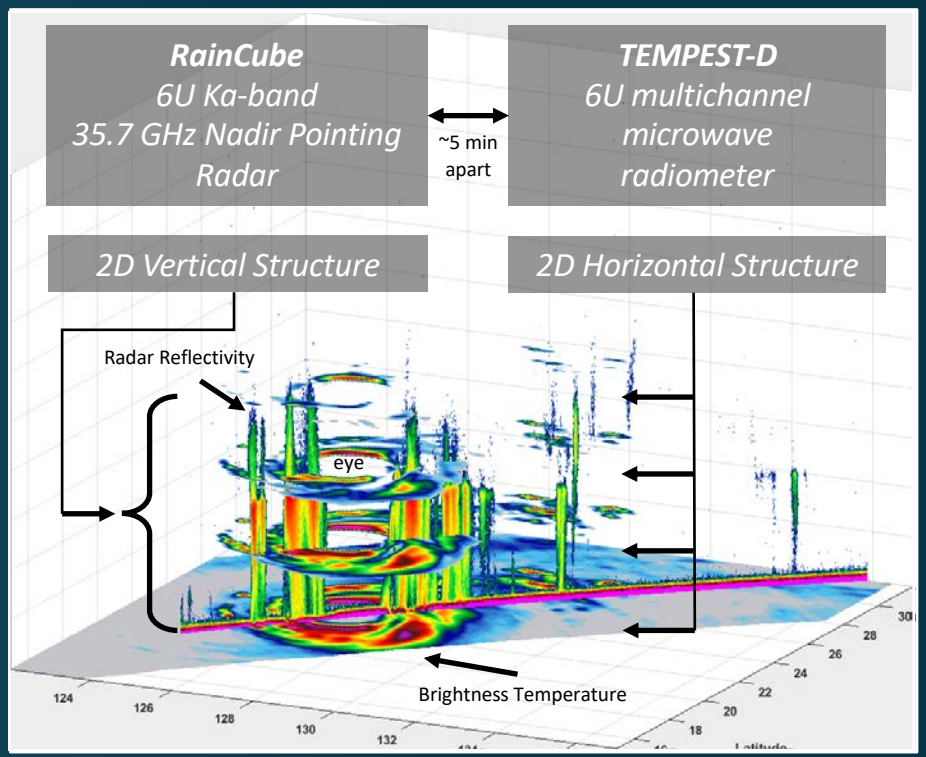
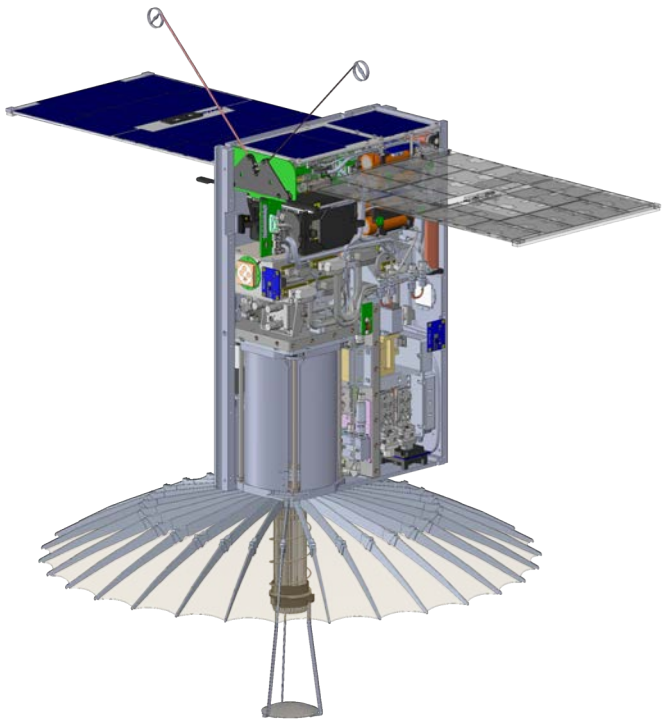


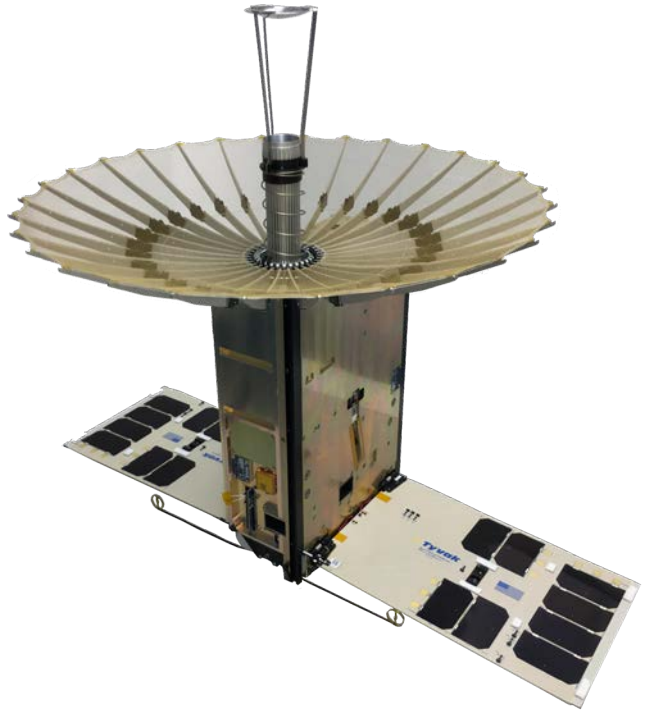
Illustration of complementary nature of these sensors flown in constellation for observing precipitation

Major Spacecraft Subsystems
Full Capability - Miniaturized….

RainCube



CAD System Design



Flight System Design

Subsystems
C&DH Processors
ADCS Processors
Battery Modules
Solar Panels
UHF Radio
S-Band Radio
ADCS Control
Thermal Control
Antennas
GPS

The Basics

ISARA/OCSD-B Optical Crosslink Demonstration

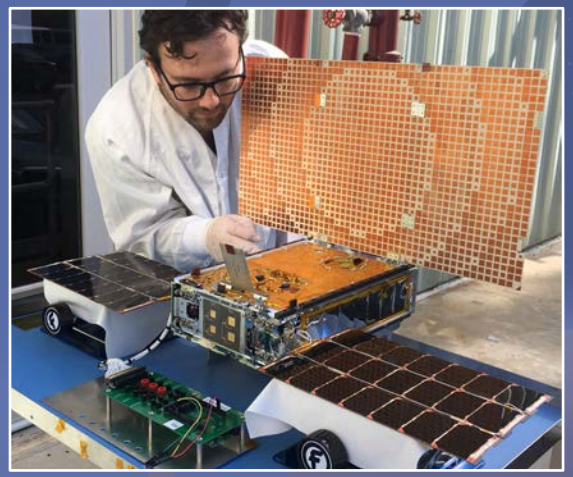
Integrated Solar Array and Reflectarray Antenna (ISARA)

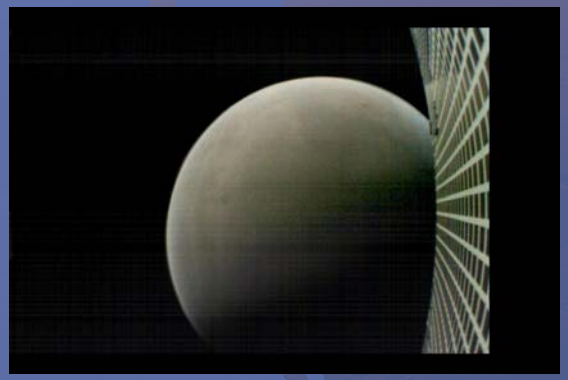
Optical Communications and Sensor Demonstration (OCSD)

Mar. 2019 – OCSD laser swept across and recorded by the CubeSat Multispectral Observation System (CUMULOS) SWIR camera on the ISARA spacecraft from 2,414km. The star R Doradus can be seen moving across the frame.

Courtesy: The Aerospace Corporation

MarCO
Mars Cube One



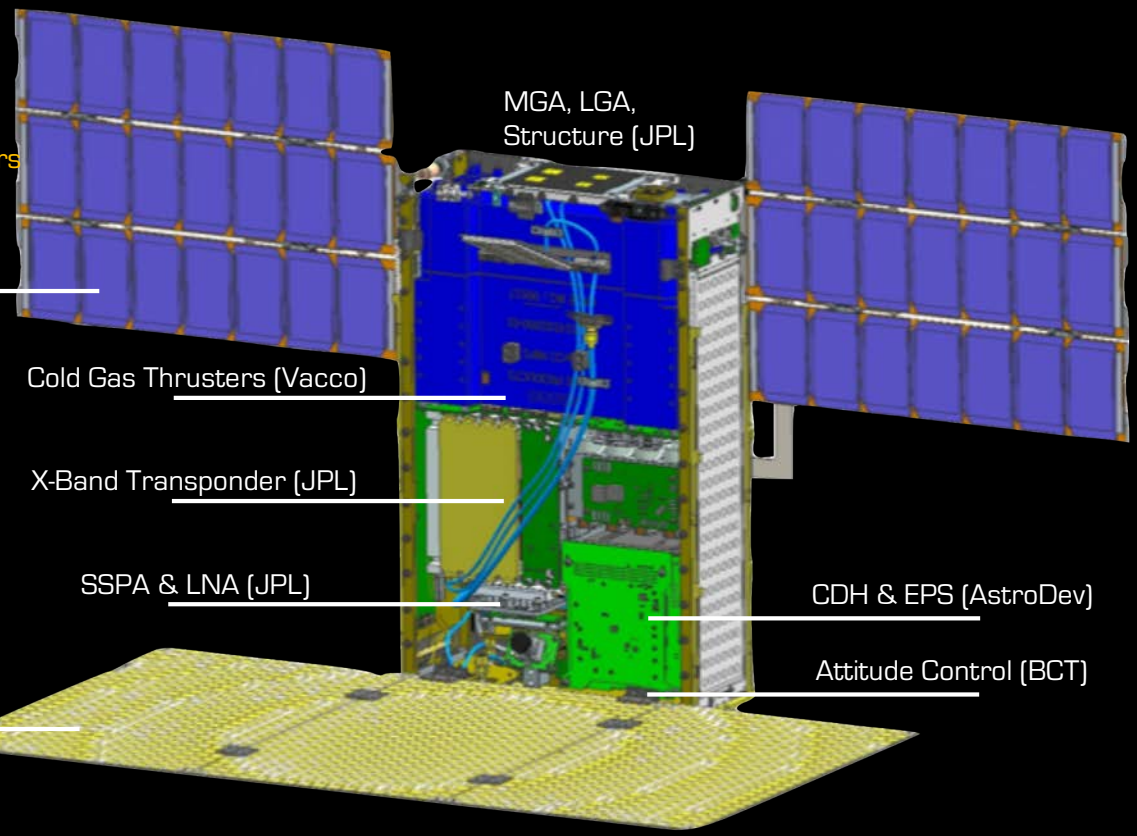


Nov. 26, 2018 - MarCO-B image of Mars from approximately 4,700 miles away during its flyby

The Basics

Mission Objective:

- Provide an 8kbps real-time relay for InSight's Entry, Descent and Landing at Mars



MarCO Overview:

Volume: 2 x 6U (12x24x36cm)
Mass: 14.0 kg
Power Generation:
Earth: 35 W
Data Rates: 62-8,000 bps
Delta-V: >40 m/s

Software:

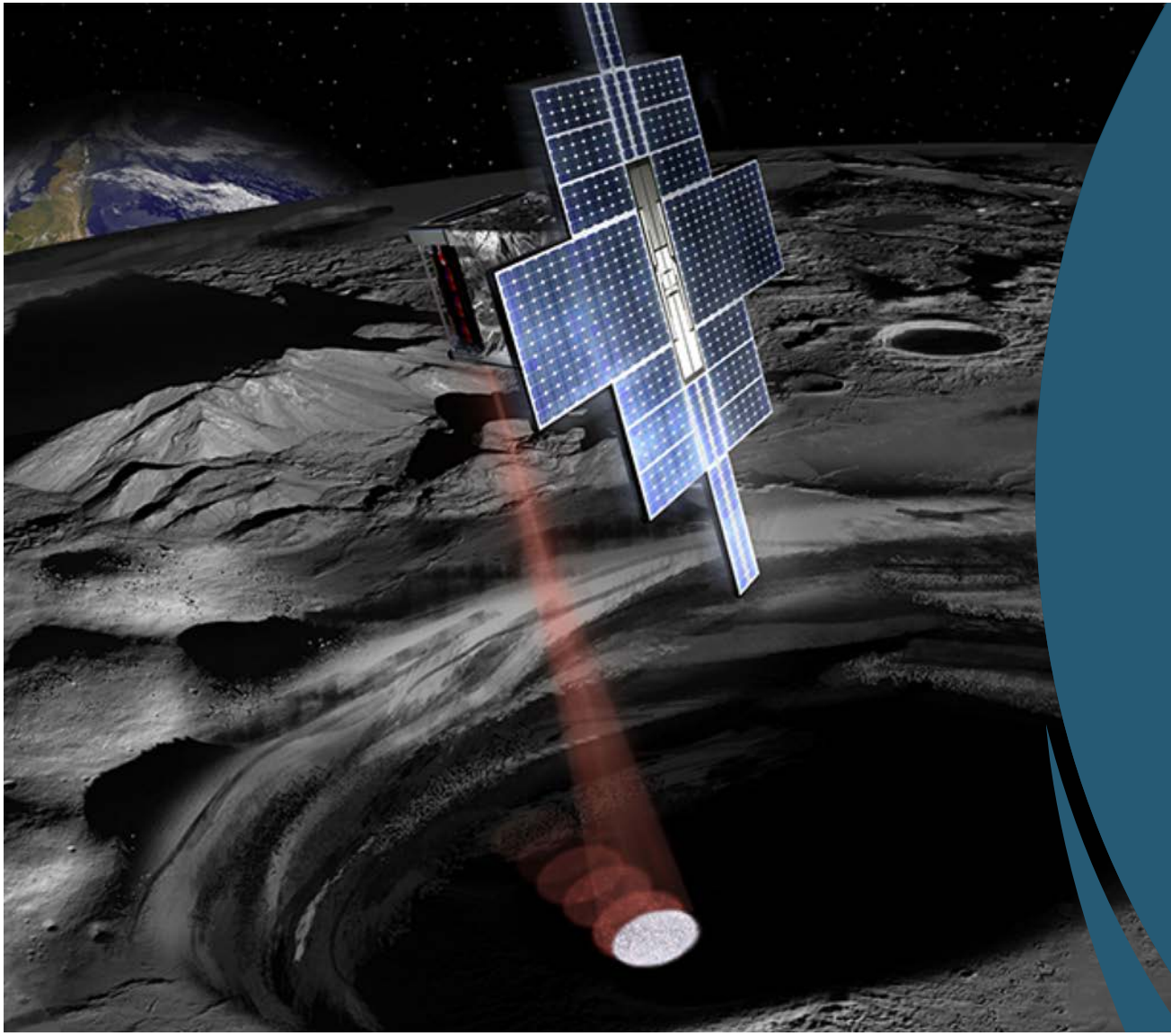
FSW: *protos (JPL)*
GSW: AMPCS (NASA/JPL)

I&T:

In-house S/C I&T, testing,
Tyvak NLAS/Launch Integration

Operations:

Primary: DSN 34m
EDL: Madrid 70m



Topics for Discussion

The Basics

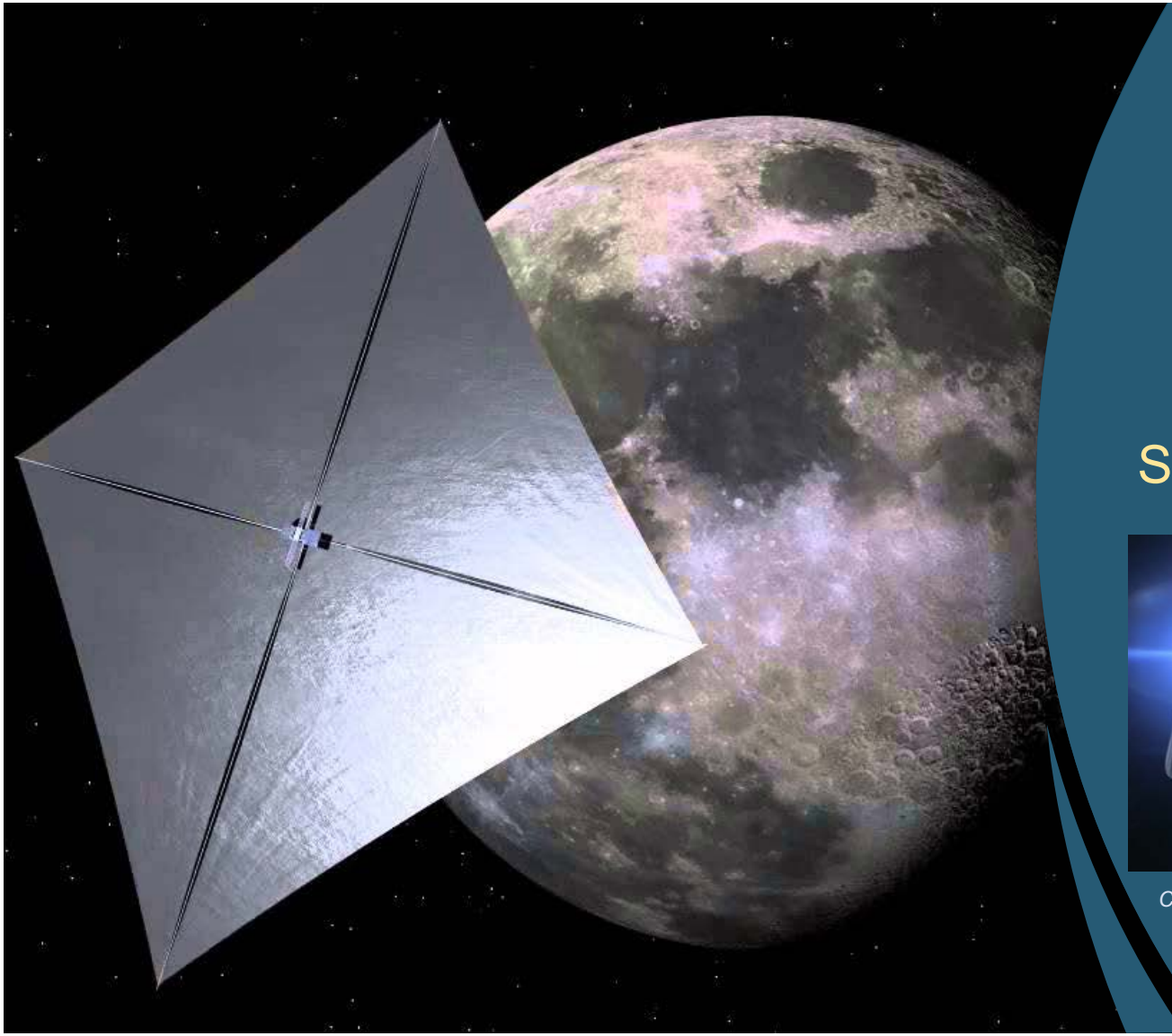
<u>Mission Formulation</u>

Realities of Flight Development

Access to Space

Mission Operations

Closing Remarks



Mission Formulation

The ”original” Lunar Flashlight Mission Concept

So, What Happened…

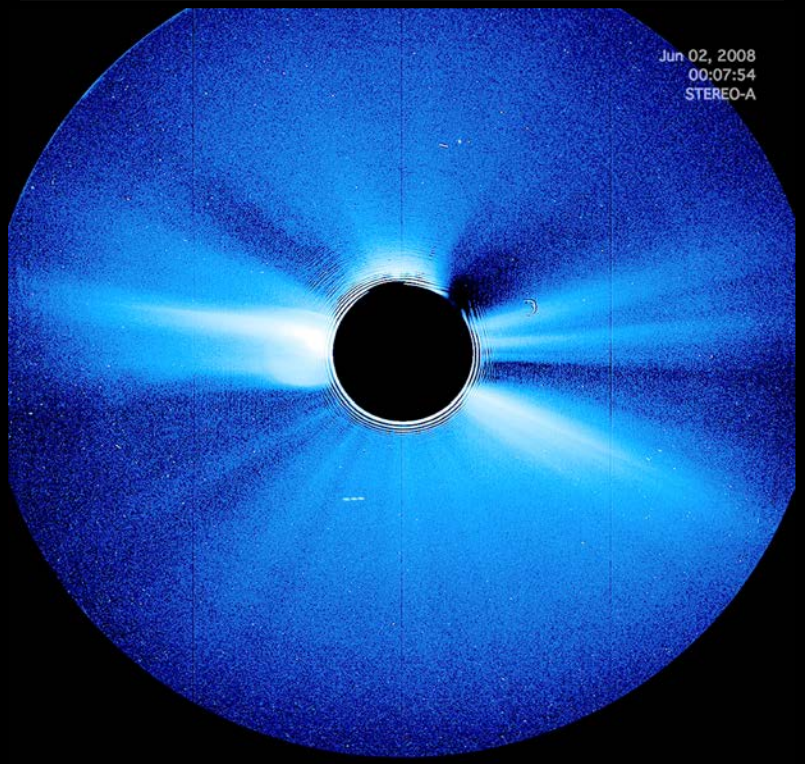
Courtesy: EON Productions, Die Another Day (2002)

Coronal Mass Ejection From STEREO A

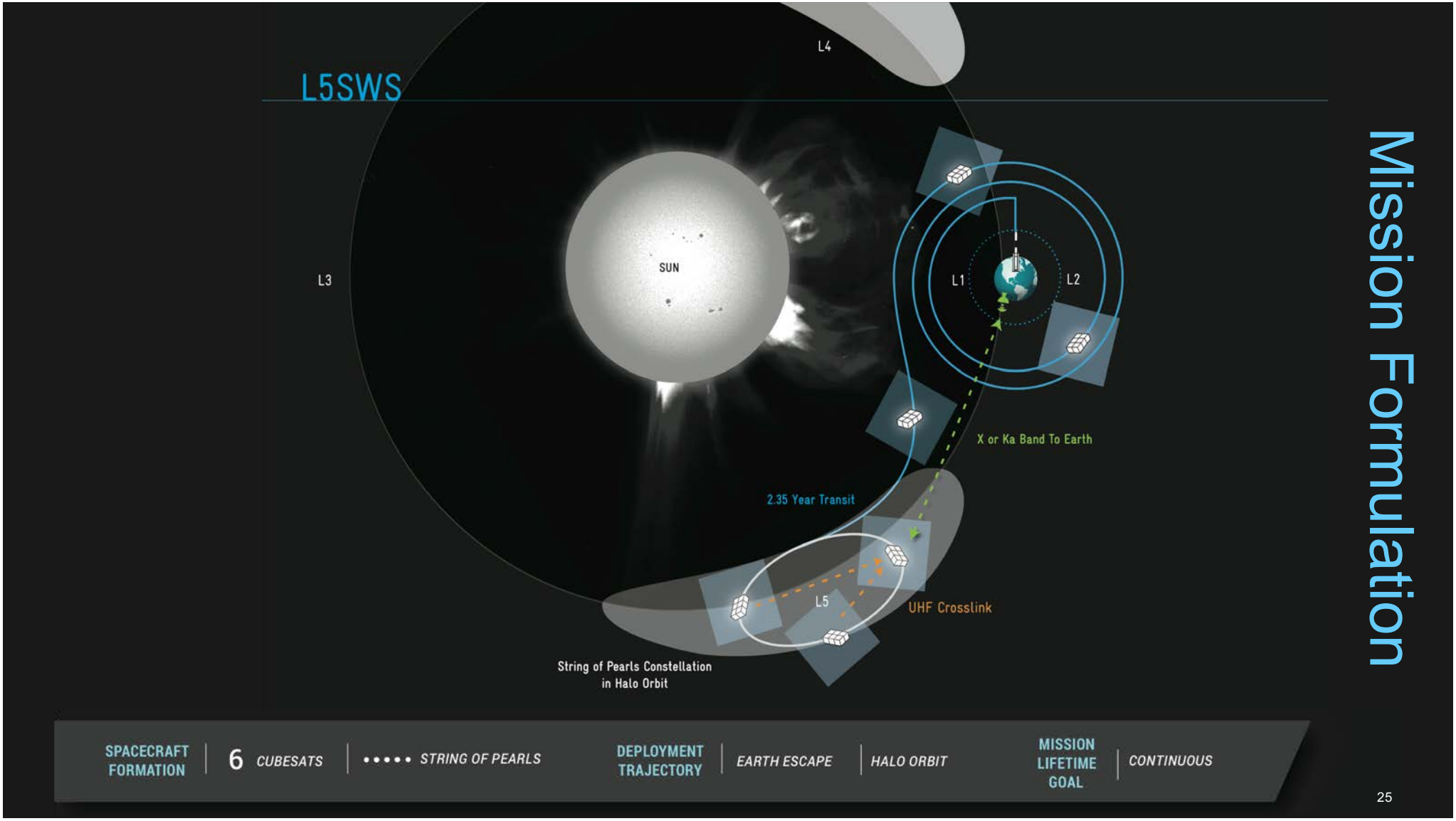
Event of June 2-8, 2008

Heliospheric Imager

Coronagraph



Mission Formulation

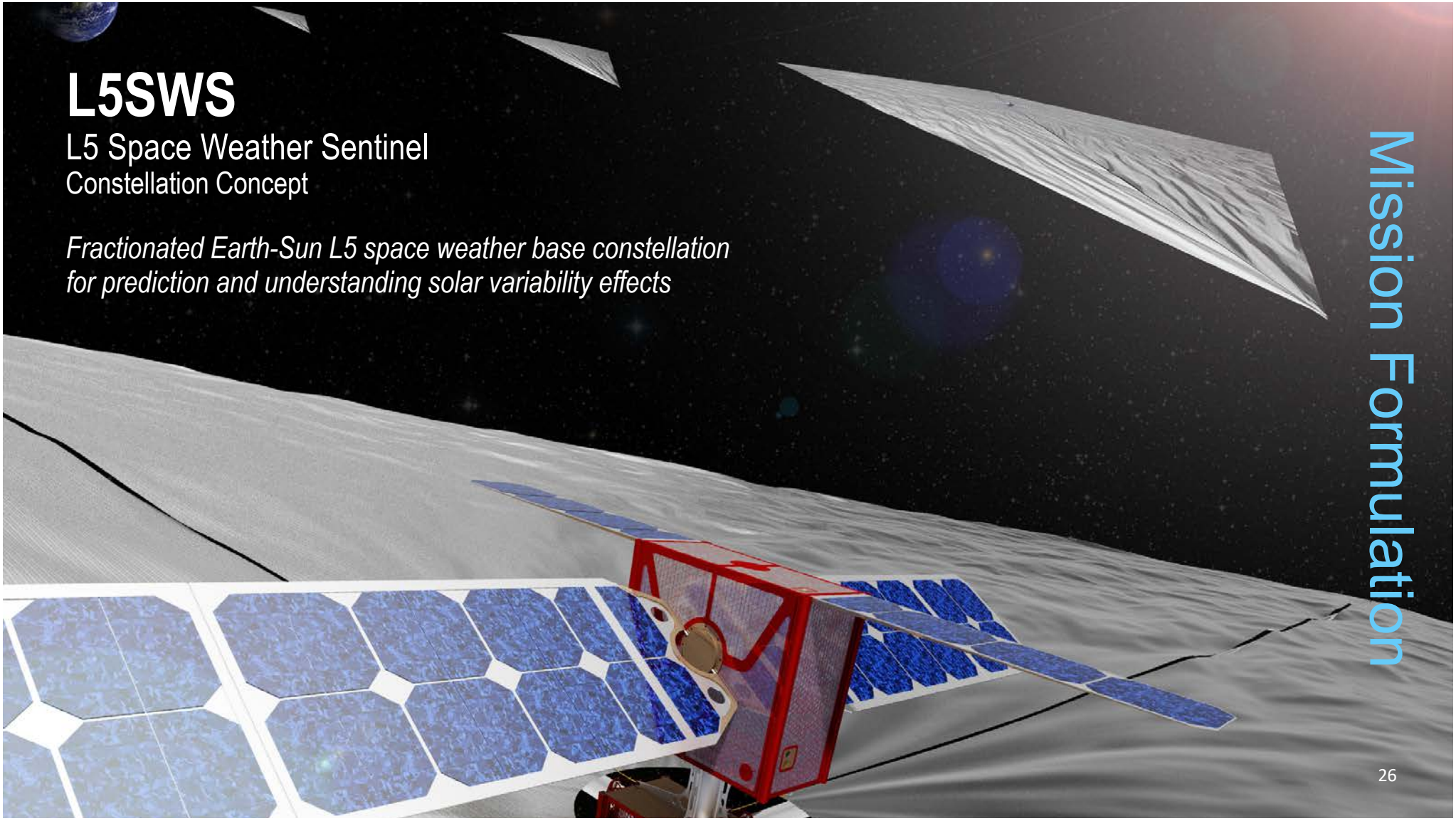


L5SWS

L5 Space Weather Sentinel

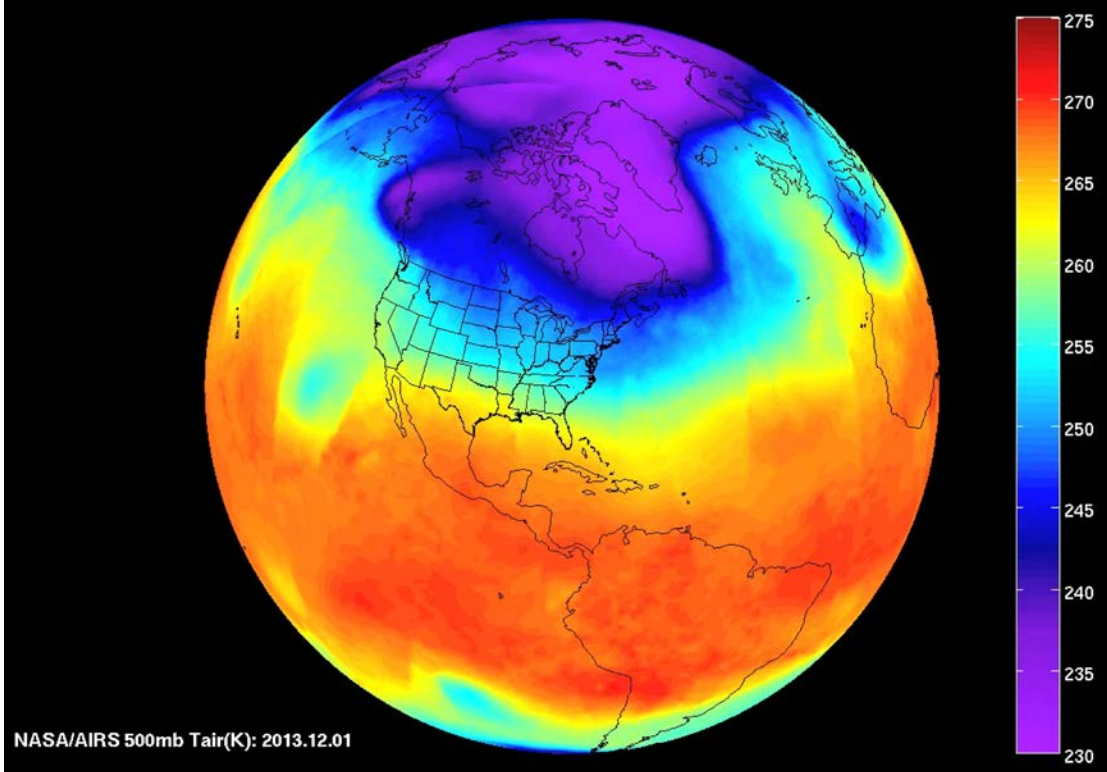
Constellation Concept

Fractionated Earth-Sun L5 space weather base constellation for prediction and understanding solar variability effects



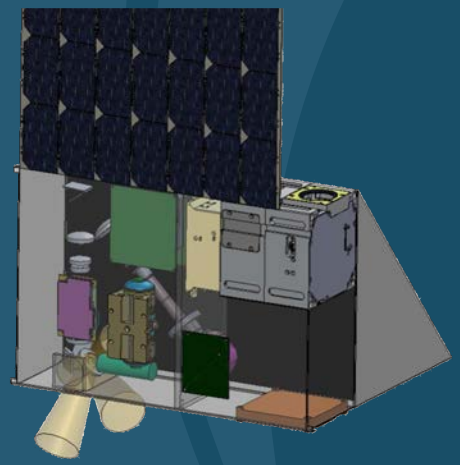
Polar vortex of 2013-2014

Dec 4, 2013: Denver weather: Temperature hits minus 13 — record low for the date



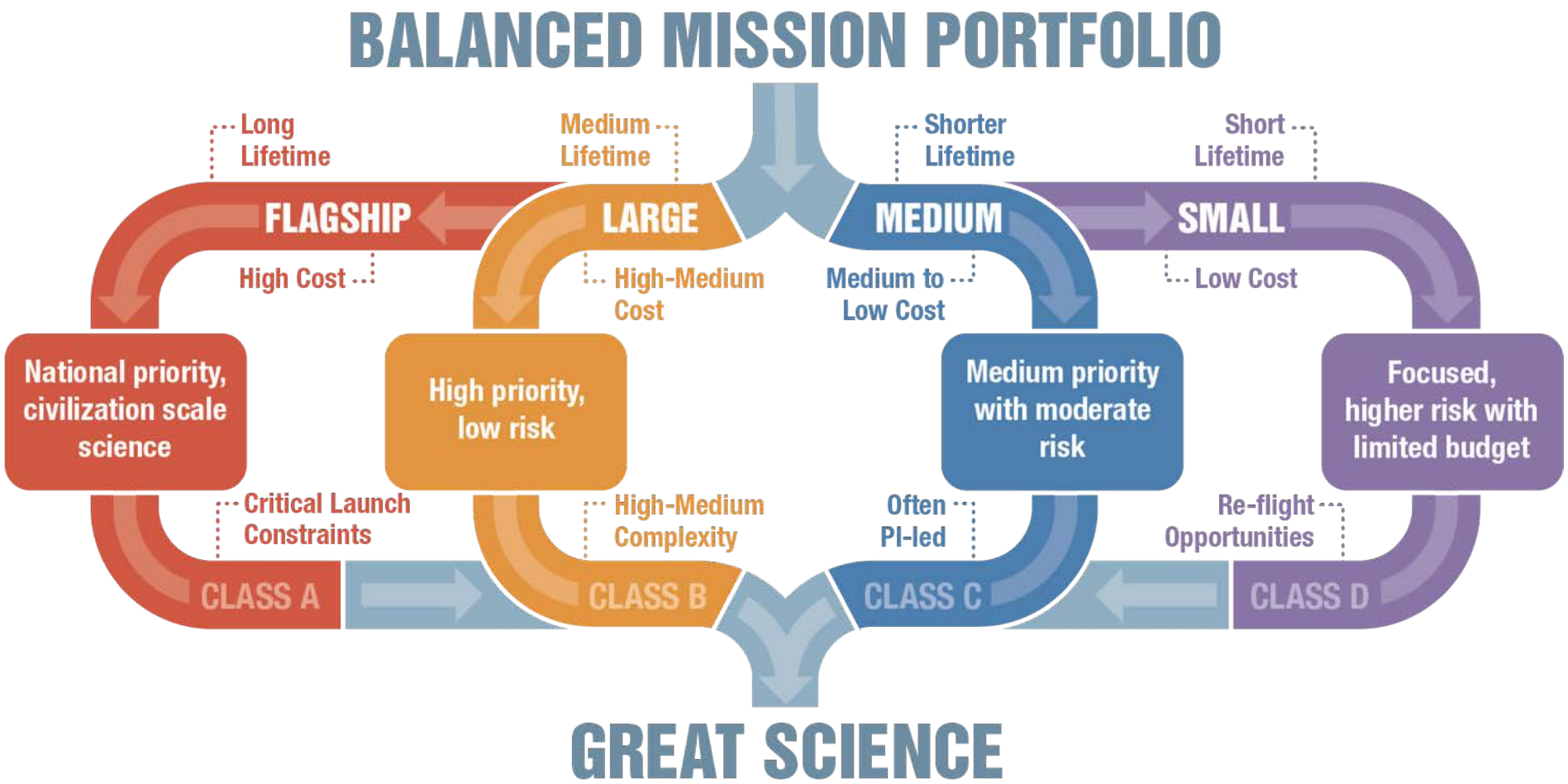
Mission Formulation

Essential to apply cost realism…



CubeSat Infrared Sounder will continue as a joint partnership with NOAA

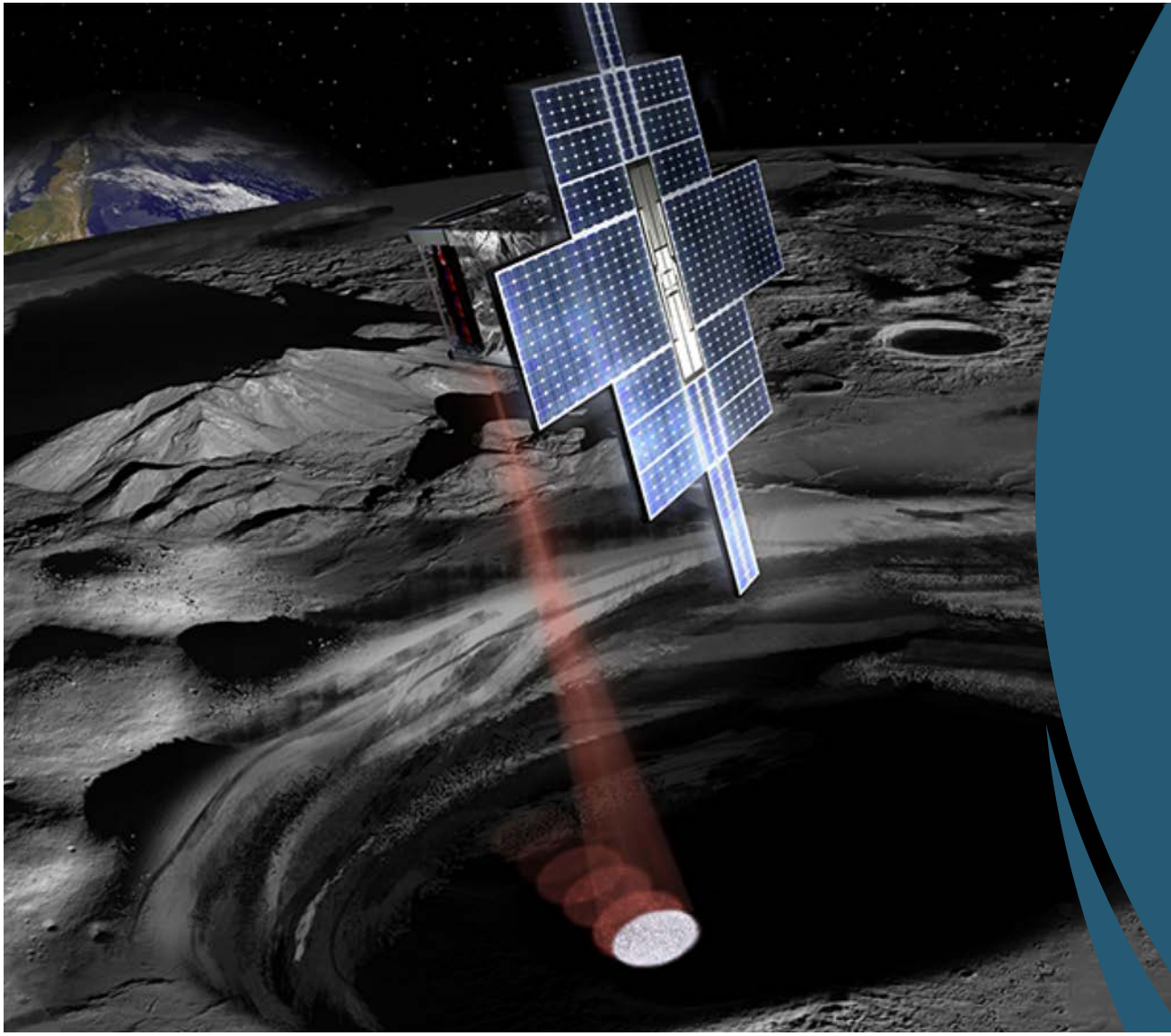
Essential to capturing severe weather events and improving operational forecasts


BALANCED MISSION PORTFOLIO
Long Lifetime
Medium Lifetime
Shorter Lifetime
Short Lifetime
FLAGSHIP
LARGE
MEDIUM
SMALL
High Cost
High-Medium Cost
Medium to Low Cost
Low Cost
National priority, civilization scale science
High priority, low risk
Medium priority with moderate risk
Focused, higher risk with limited budget
Critical Launch Constraints
High-Medium Complexity
Often PI-led
Re-flight Opportunities
CLASS A
CLASS B
CLASS C
CLASS D
GREAT SCIENCE

Mission Formulation

Utilize expertise from NASA's concurrent design formulation teams

Such services are appearing more frequently within the mission solicitation process



Topics for Discussion

The Basics

Mission Formulation

<u>Realities of Flight Development</u>

Access to Space

Mission Operations

Closing Remarks

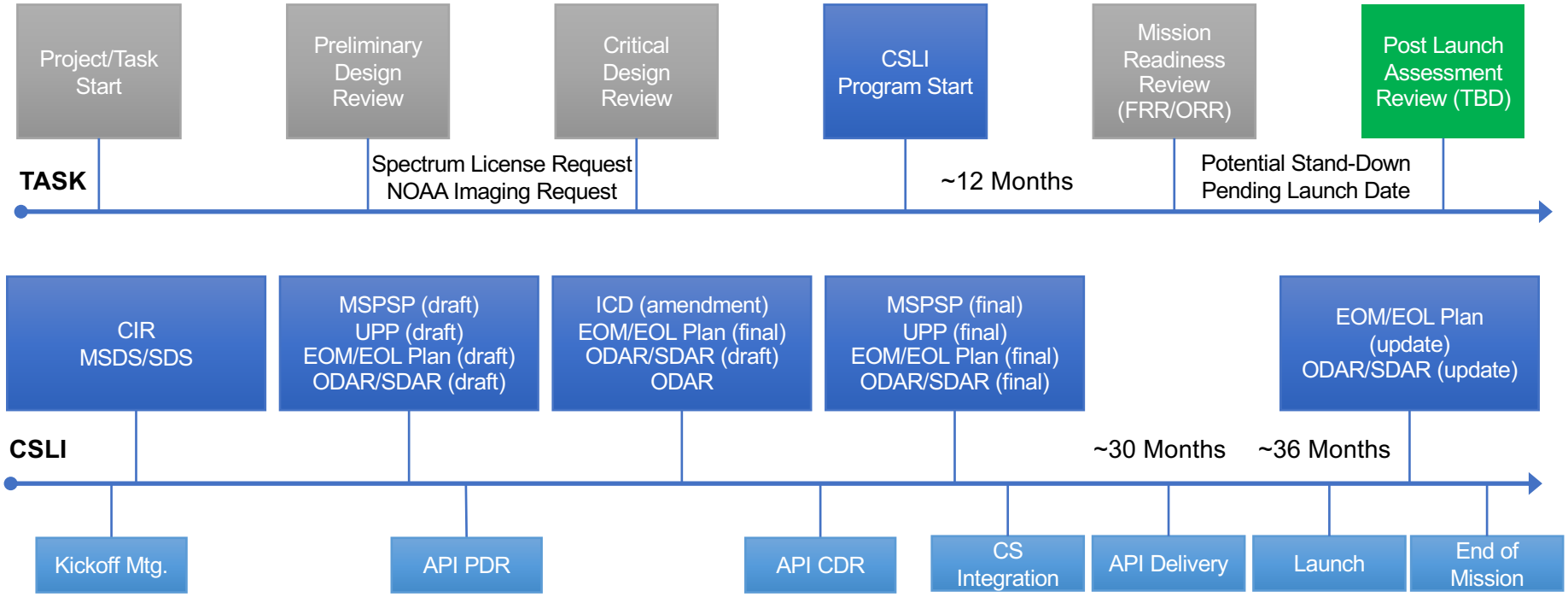
Flight Development Reality

- Mission Assurance Requirements
- Lifecycle Reviews
- Mission Success Criteria
- Formal and Informal Review Boards
- Independent Cost and Schedule Estimates
- Managing The Unexpected

Overview of Key Documentation Required (Not Comprehensive)

Acronym	Document	Comments
CIR	CubeSat Interface Review	General information from flight projects
MSDS	Mission Safety Data Sheet	Documentation of materials hazards
MSPSP	Missile System Pre-Launch Safety Package	Documents range safety hazards and containment
ODAR/SDAR	Orbital/Space Debris Assessment Report	Documents orbital debris hazards and containment
EOM/EOL Plan	End-of-Mission / End-of-Life Plan	End-of-Life passivation and de-orbit plan
UPP	Uplink Protection Plan	Documents plan to maintain spacecraft control
ICD	Interface Control Document	Integration Status, Risk Assessment, Open Items
ODR	Orbital Data Request	JFCC Space / JSpOC Collision/Conjunction Request
CDS	CubeSat Design Specification	Standards document for fit-check requirements
CAC	CubeSat Acceptance Checklist	Verifies form factor adherence to CDS guidelines

Notional Mission/Launch Manifest Integrated Program Schedule



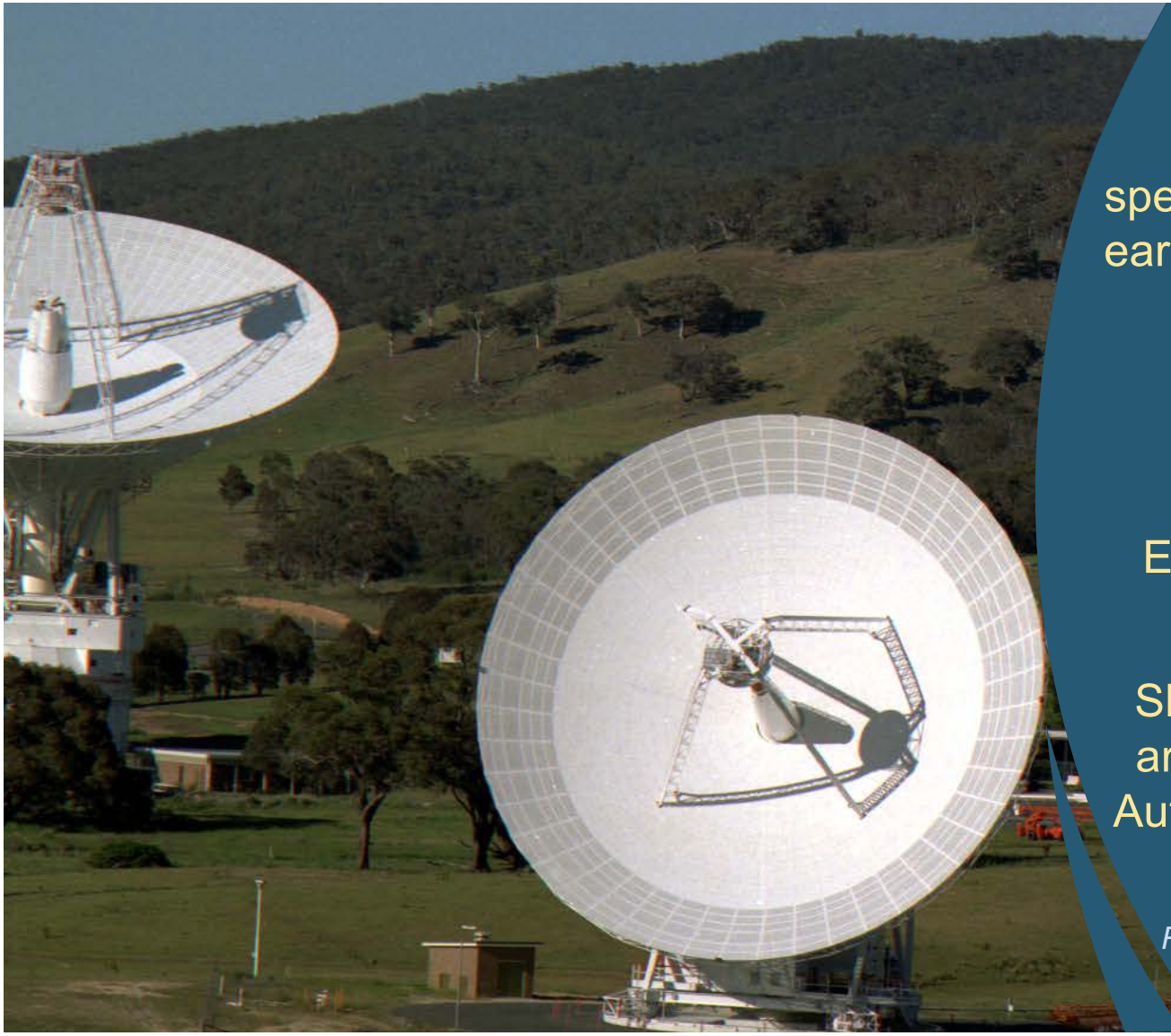
CS: CubeSat
AP: Auxiliary Payload Integrator

Flight Development Reality

Common Mission Readiness Review Topics

MRR High Level Agenda	Comments
CubeSat Project Overview	Summary of Flight Project
Mission Objectives	Current Project State vs. ELaNa Proposal
Organization Chart	Includes All Organizations
Schedule	Project Start Through Launch and Operations
Planned Work Through Final Flight CubeSat to P-POD Integration	Charging & Diagnostics, GSE, Shipment
CubeSat to P-POD Interface Compliance (Main Part of Review)	Address all ICD/LSP Program Requirements
CubeSat Flight Readiness	Integration Status, Risk Assessment, Open Items
CONOPS Plan	Event timeline, tracking/comm-link status, etc.

Successful completion will be documented and included in the CoFR package sent to NASA LSP
All testing must be completed by the MRR and spacecraft configuration is fixed after DITL test



Flight Development Reality

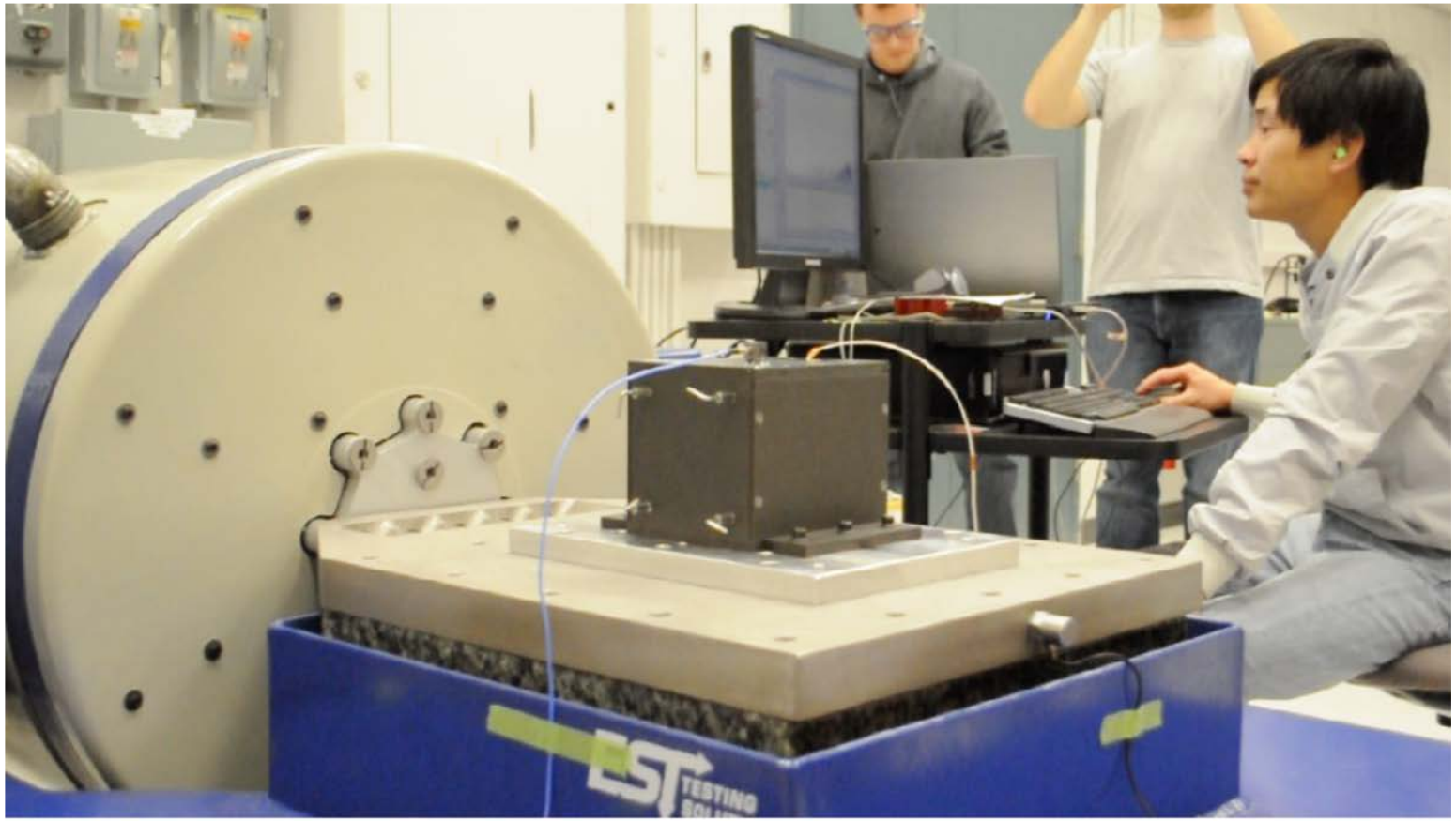
Please submit your spectrum allocation request early as an approved Radio Frequency Authorization (RFA) is required for mission integration

RFA should include all Earth stations planned for mission operations

Should exceptional issues arise a Special Temporary Authority (STA) request will be needed

Read your RFA for special directions

Qualification Random Vibe (23 G's for 104 seconds)



Flight Development Reality

More on Testing

General Guidelines:

- Project team is responsible for all testing up to delivery where acceptance testing is performed under the CubeSat Acceptance Checklist (CAC)
- If you build an EM for <u>qualification</u> testing build it as a flight spare
- Paths are qualification to acceptance test on an EM (promoted to an FM) or protoflight to acceptance on an FM
- Photo document all build/test activities, processes and procedures
- If you will have Test-As-You-Fly (TAYF) Exceptions seek waivers early (where allowed)

Table 1 – Dispenser and CubeSat Environments Test Table

Tests	Qualification by Test	Protoflight Test	Acceptance Test
Random vibration[6] (CubeSat and Dispenser) Ref Mil-Std 1540C	MPE + 6 dB for (3) minutes, each of (3) axes [1]	MPE+3 dB for (2) minutes, each of (3) axes [1]	MPE for (1) minute, each of (3) axes [1]
Sinusoidal Vibration[6] (CubeSat and Dispenser) Ref Mil-Std 1540C	MPE + 6 dB. Testing shall be performed for content that is not covered by random vibration testing	1.25 x MPE. Testing shall be performed for content that is not covered by random vibration testing	MPE. Testing shall be performed for content that is not covered by random vibration testing [1]
Shock[6] (CubeSat and Dispenser) Ref Mil-Std 1540C	MPE + 6 dB, 3 times in both directions of 3 axes [1, 3]	MPE + 3 dB, 1 times in both directions of 3 axes [1, 3]	N/A
Thermal Vacuum Cycle (Dispenser Only) Ref.: MIL-STD 1540 B, GSFC-STD-7000	MPE[2] +/- 10° C Minimum Range = -14 -3/+0°C to +71 -0/+3°C Cycles = 8 Dwell Time = 1 hour min. @ extreme Temp. after thermal stabilization Transition = < 5° C/minute Vacuum = $1x10^{-4}$ Torr	MPE[2] +/- 10° C Minimum Range = -14 -3/+0°C to +71 -0/+3°C Cycles = 4 Dwell Time = 1 hour min. @ extreme Temp. after thermal stabilization Transition = < 5° C/minute Vacuum = $1x10^{-4}$ Torr	MPE[2] +/- 5° C Minimum Range = -9 -3/+0°C to +66-0/+3°C Cycles = 2 Dwell Time = 1 hour min. @ extreme Temp. after thermal stabilization Transition = < 5° C/minute Vacuum = $1x10^{-4}$ Torr
Thermal Vacuum Bake out (Dispenser Only) Ref.: MIL-STD 1540 B, GSFC-STD-7000	N/A	Min. Temp 70°C [4, 7] Cycles = 1 Dwell Time = Min. 3 hour after thermal stabilization Transition = N/A Vacuum = $1x10^{-4}$ Torr	Min. Temp 70°C [4, 7] Cycles = 1 Dwell Time = Min. 3 hour after thermal stabilization Transition = N/A Vacuum = $1x10^{-4}$ Torr
Thermal Vac Bake out (CubeSat Only) Ref.: MIL-STD 1540 B, GSFC-STD-7000	N/A	Min. Temp 70°C [5, 8] Cycles = 1 Dwell Time = Min. 3 hour after thermal stabilization Transition = < 5° C/minute Vacuum = $1x10^{-4}$ Torr	Min. Temp 70°C [5, 8] Cycles = 1 Dwell Time = Min. 3 hour after thermal stabilization Transiton = < 5° C/minute Vacuum = $1x10^{-4}$ Torr
Hardware Configuration	Dispenser – Flight identical unit (includes NEA, cable and connector) **CubeSat** – Flight Identical unit	Dispenser – Flight unit (includes flight NEA, cable and connector) **CubeSat** – Flight unit	Dispenser – Flight unit (includes flight NEA, cable and connector) **CubeSat** – Flight unit

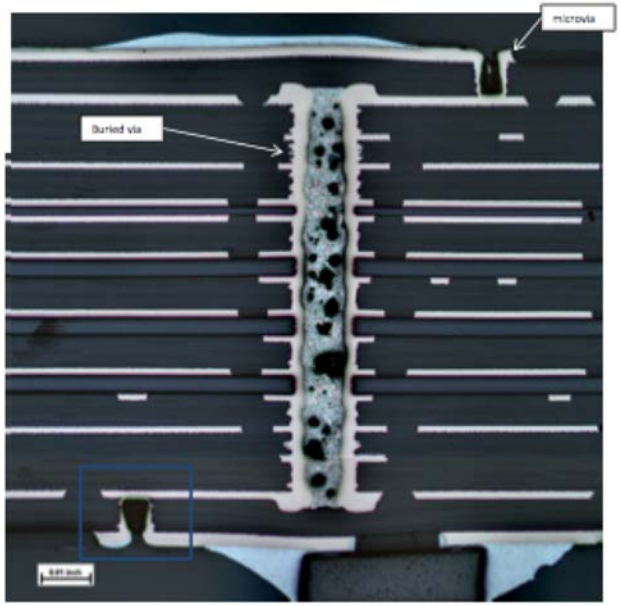
Flight Development Reality

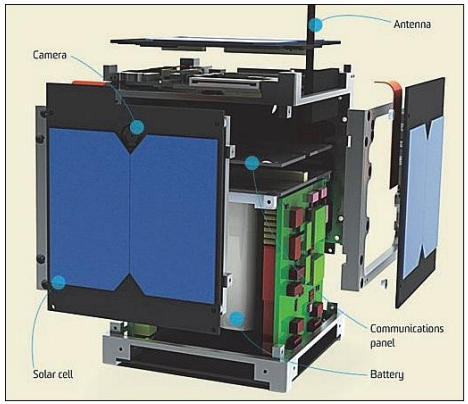
Microvia Separation in SpaceCube-Mini Subsystem

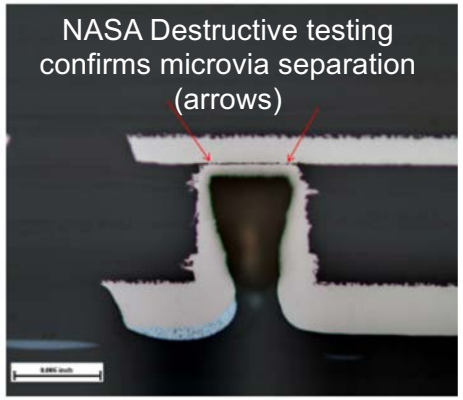
PCB manufacture passed vendor QA, but NASA detected open circuits

Computer Tomography (CT) scans were inconclusive thus destructive testing and microsection analysis were required

Subsystem descoped and replaced with contingency gumstix processor as SpaceCube-Mini was not a Level-1 requirement







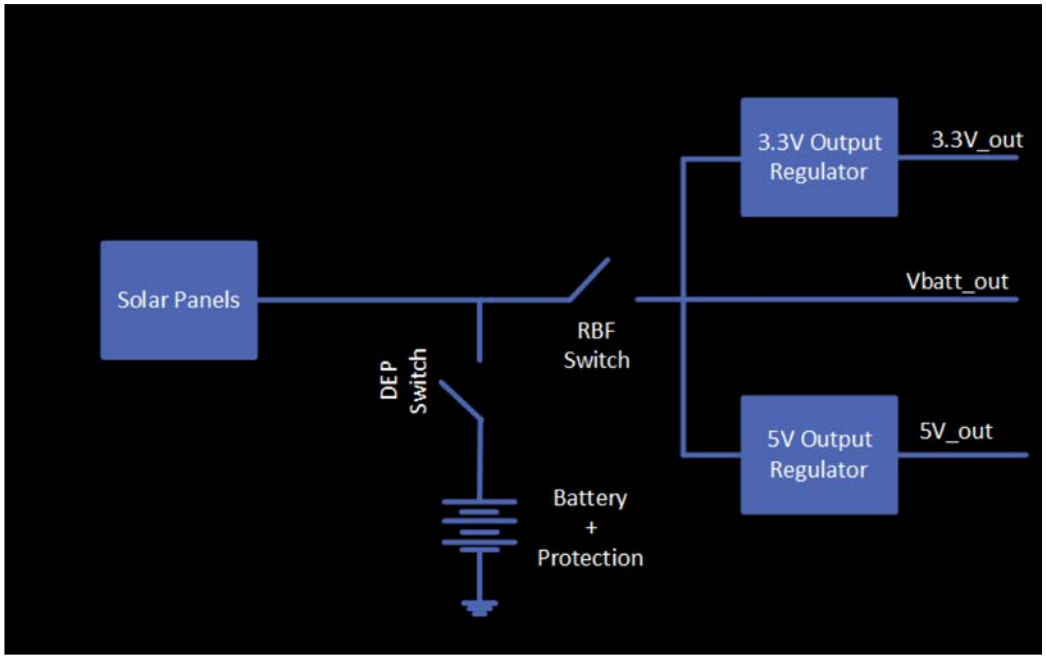
Flight Development Reality

Remove Before Flight (RBF) Pin Functionality, Power, and Inhibits

With the RBF pin in place the batteries and the solar panels are isolated from the spacecraft bus

However, once the RBF is removed (in the dispenser) an electron flow path does exist from the solar panels to the spacecraft bus

Analysis proved insufficient current to drive the flight hardware during P-POD integration, but careful inhibit design must be followed



Power system design used successfully in multiple flight projects

Radio Frequency Determination

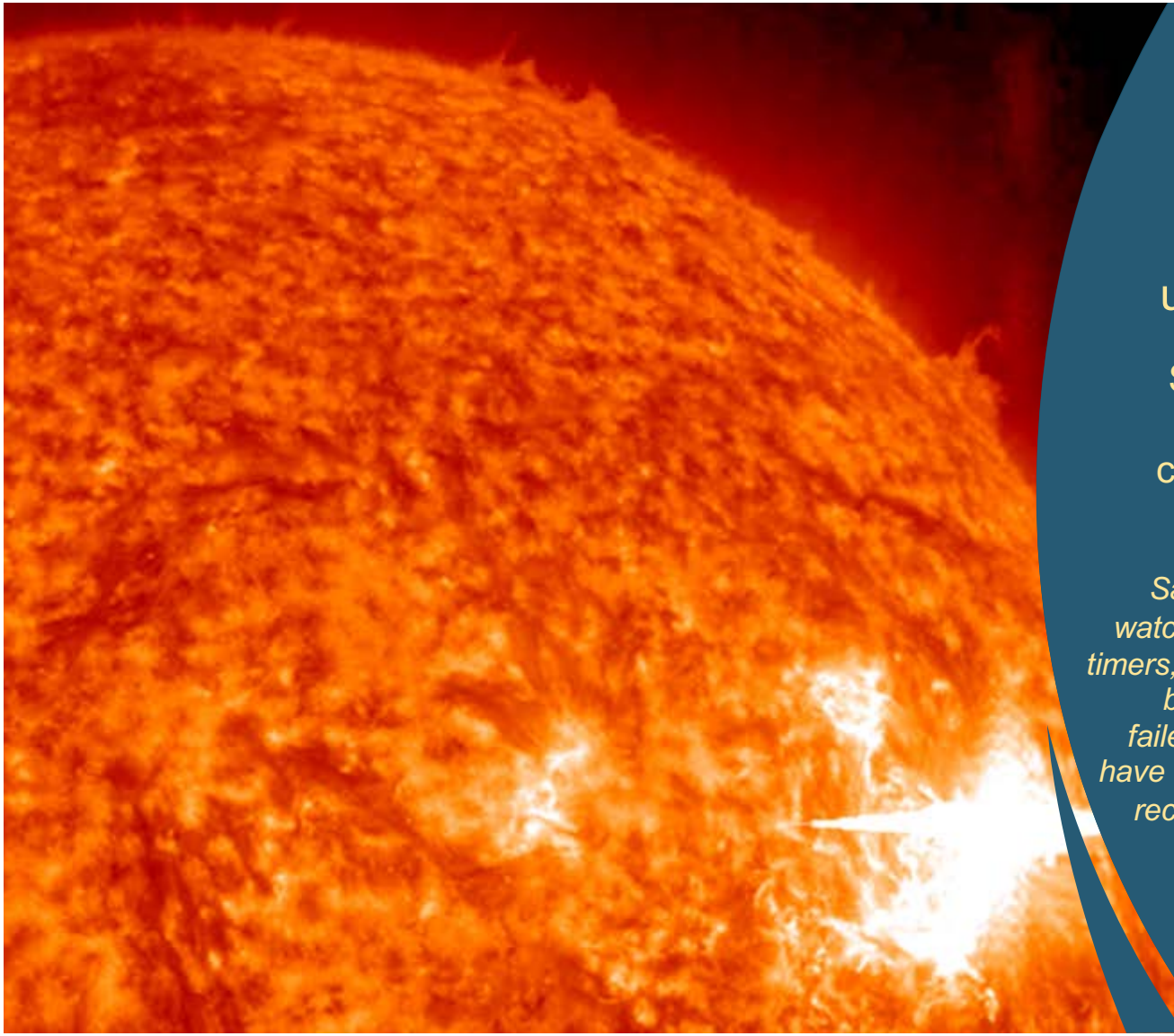
General Guidelines:

- Receiving a license can take anywhere from 40-180+ days
- NASA Center-Led missions follow the NTIA process (even with industry contracted operations)
- Non-NASA organizations shall follow the FCC process (with an experimental license noting that when paid such organizations are not amateurs)
- Always useful to carry a backup radio
- Consult NASA's "Spectrum Guidance for NASA Small Satellite Missions" for additional details

Table 5: System Status & Spectrum Authorization-Licensing: Two Criteria Model Approach*

Case	Belongs To (e.g., ownership)	Operated By (e.g., effective control**)	Regulatory Agency	Frequency Bands & Notes
1	Federal (NASA)	Federal (NASA)	NTIA	Government and Shared frequency bands are appropriate If a non-government or shared frequency is involved, NTIA coordinates with the FCC—such use by NASA missions is discouraged
2	Federal (NASA)	Non-Federal	FCC	Non-government and Shared frequency bands are appropriate If a government or shared frequency is involved, FCC coordinates with the NTIA—such use by NASA sponsored missions is highly discouraged Proof of FCC Authorization provided to NTIA
3	Non-Federal	Federal (NASA)	FCC	Non-government and Shared frequency bands are appropriate If a government or shared frequency is involved, FCC coordinates with the NTIA—such use by NASA missions is highly discouraged Such a scenario is uncommon
4	Non-Federal	Non-Federal	FCC	Non-government and Shared frequency bands are appropriate If a government or shared frequency is involved, FCC coordinates with the NTIA—such use by NASA missions is highly discouraged

* This approach may assist in defining the regulatory case, but should not be viewed as an explicit definition.
** Effective control may be exercised directly by NASA personnel or through contractual provisions.

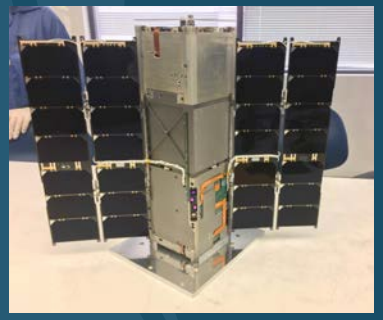


Flight Development Reality

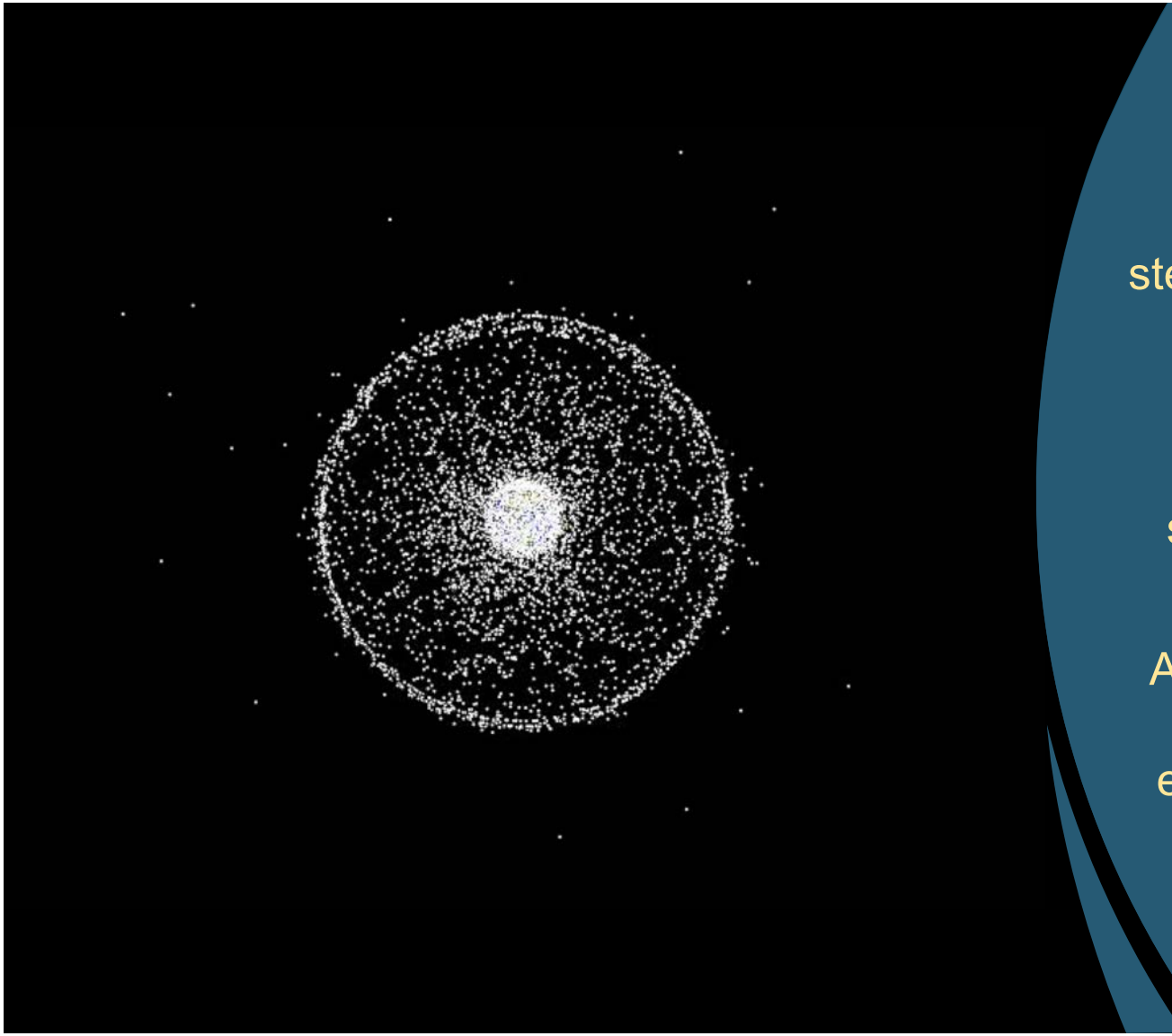
Radiation effects from SEPs, and the SAA, do impact missions with unprotected COTS parts

Symptoms include increased current draw, random command execution, SD card failures, data corruption, …

Safe modes, watchdog reset timers, as well as backups for failed devices, have allowed for recovery from SEUs



An aside…watch out for the impact of helium on MEMs devices



Flight Development Reality

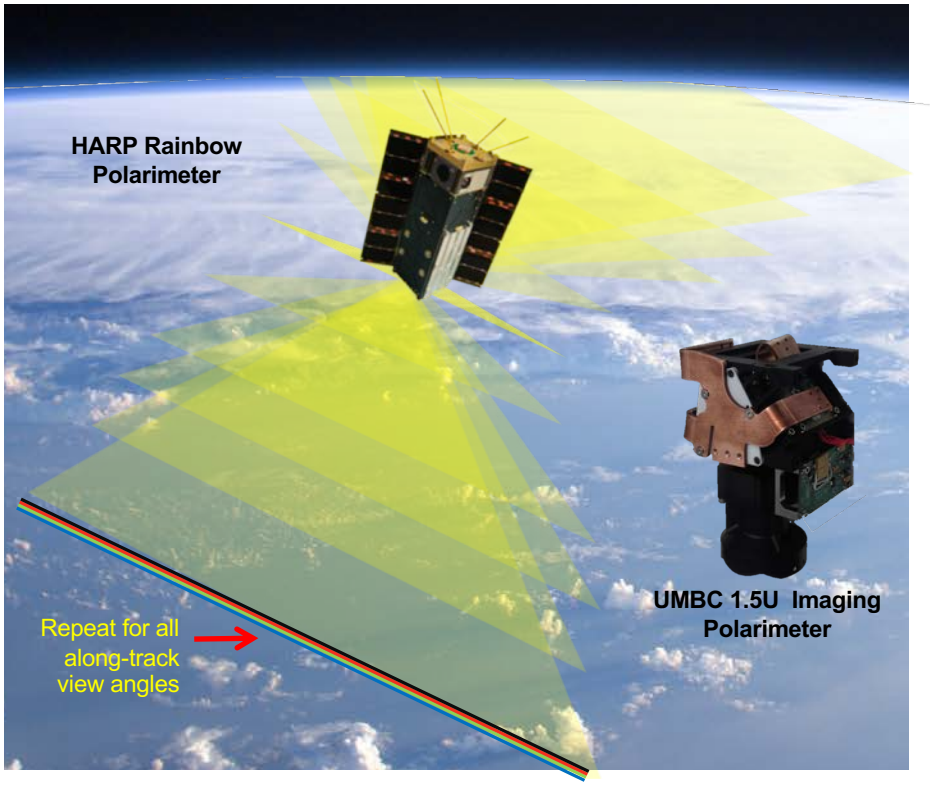
Accounting for orbital debris ensures good stewardship of the space environment

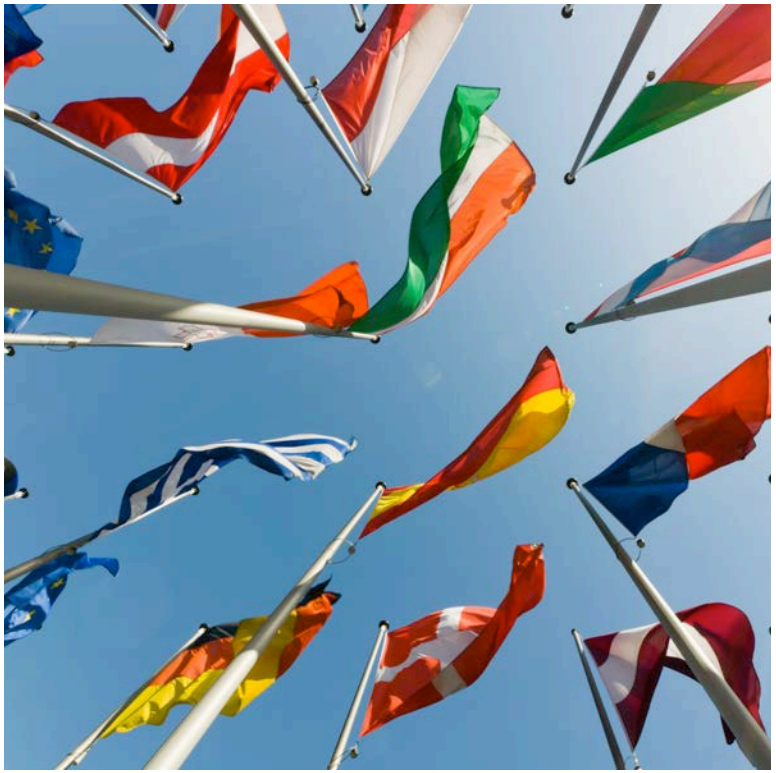
It's also required and directly impacts your spacecraft and mission design

Avoid high melting point materials to satisfy re-entry energy and risk of human casualty requirements

International Collaborations

Must carefully assess impact of international contributions to the mission





HARP enables characterization of aerosol and cloud properties across many viewing angles simultaneously

Flight Development Reality

Export Control

Most space technology is subject to export controls

Shipment, transmission, performing a defense service, or release of technical data to a foreign person is an export

US government authorization is required before releasing an export

International Traffic and Arms Regulations ***(ITAR)***

Export Administration Regulations ***(EAR)***

Flight Development Reality

International Traffic in Arms Regulations (ITAR)

ITAR controls items, information, or activities potentially used for threatening military purposes

US Munitions List (USML) identifies such ITAR items

Export authorization can be in the form of a license, agreement, or license exception

Flight Development Reality

Export Administration Regulations (EAR)

EAR controls items and technologies considered to be "dual use" i.e. commercial or military use

Commerce Control List (CCL) identifies such EAR items

Export authorization can be in the form of a license, agreement, or license exception

Most commercial spacecraft and components are under EAR jurisdiction

Flight Development Reality

National Defense Authorization Act (FY'13)

Authorized removal of satellites and related items from USML

Category XV (spacecraft and related articles) revisions eased many restrictions limiting exports to a "positive control list" of the most sensitive items

Most controls, transferred from USML to CCL, are now based on rational technical criteria

The environment for FN involvement on U.S. space projects is less restrictive under EAR, but ITAR-controlled parts must still be controlled…

Additional Practical Advice

All export control rules apply even if you develop and launch your spacecraft within the US

Be mindful of the import of components from foreign countries and their potential export when repairs are needed

Have appropriate protections in place to firewall FNs from ITAR/EAR data and always secure and/or encrypt sensitive information

Always consult with an authorized export control authority at your institution

Flight Development Reality

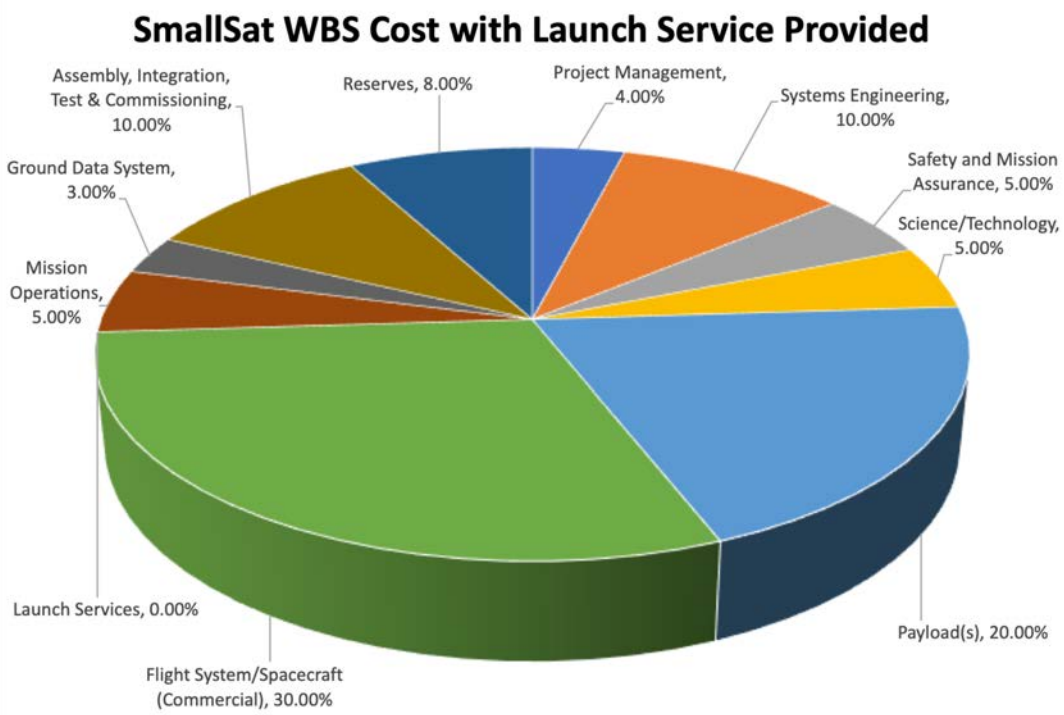
Budget and Cost Considerations

Rough order of magnitude example estimates for typical SmallSat mission work breakdown structure (WBS)

Assumes launch services at no cost

Note: Under CSLI only the first $300K of services is covered

	WBS Element	Percent
1	Project Management	4 %
2	Systems Engineering	10 %
3	Safety and Mission Assurance	5 %
4	Science/Technology	5 %
5	Payload(s)	20 %
6	Flight System/Spacecraft (Commercial)	30 %
7	Launch Services	0 %
8	Mission Operations	5 %
9	Ground Data System	3 %
10	Assembly, Integration, Test, & Commissioning	10 %
11	Reserves	8 %



Notional view of WBS by budget percentage for typical SmallSat

Personal option and not a basis for future proposed cost breakdown

Flight Development Reality

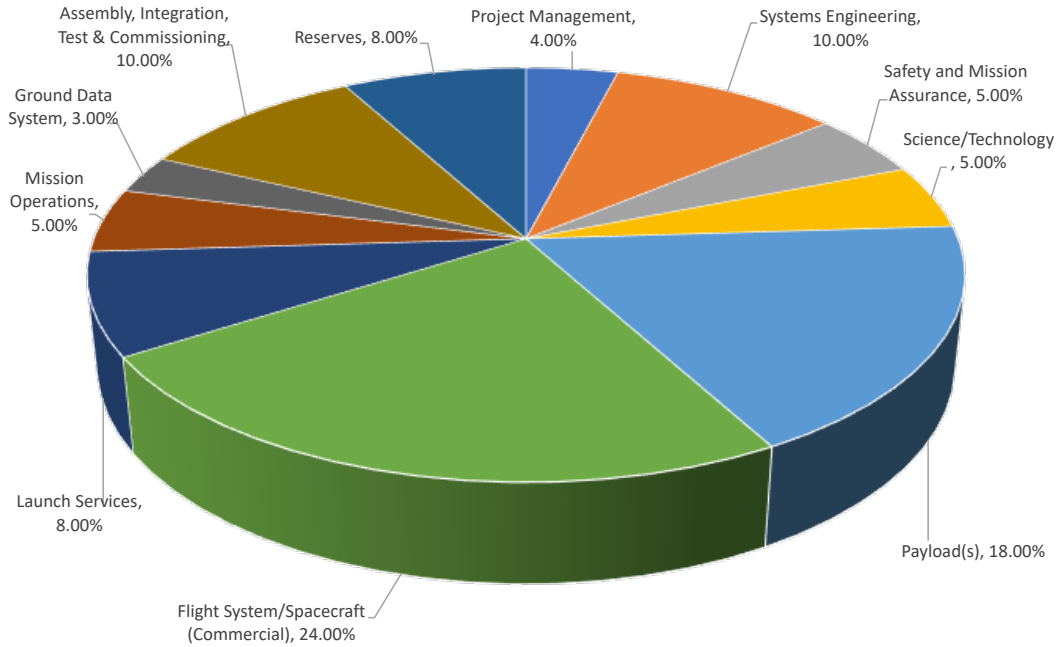
Budget and Cost Considerations

Rough order of magnitude example estimates for typical SmallSat mission work breakdown structure (WBS)

Assumes launch services expense

	WBS Element	Percent
1	Project Management	4 %
2	Systems Engineering	10 %
3	Safety and Mission Assurance	5 %
4	Science/Technology	5 %
5	Payload(s)	18 %
6	Flight System/Spacecraft (Commercial)	24 %
7	Launch Services	8 %
8	Mission Operations	5 %
9	Ground Data System	3 %
10	Assembly, Integration, Test, & Commissioning	10 %
11	Reserves	8 %

SmallSat WBS with Incurred Launch Service Fee



Notional view of WBS by budget percentage for typical SmallSat

Personal option and not a basis for future proposed cost breakdown

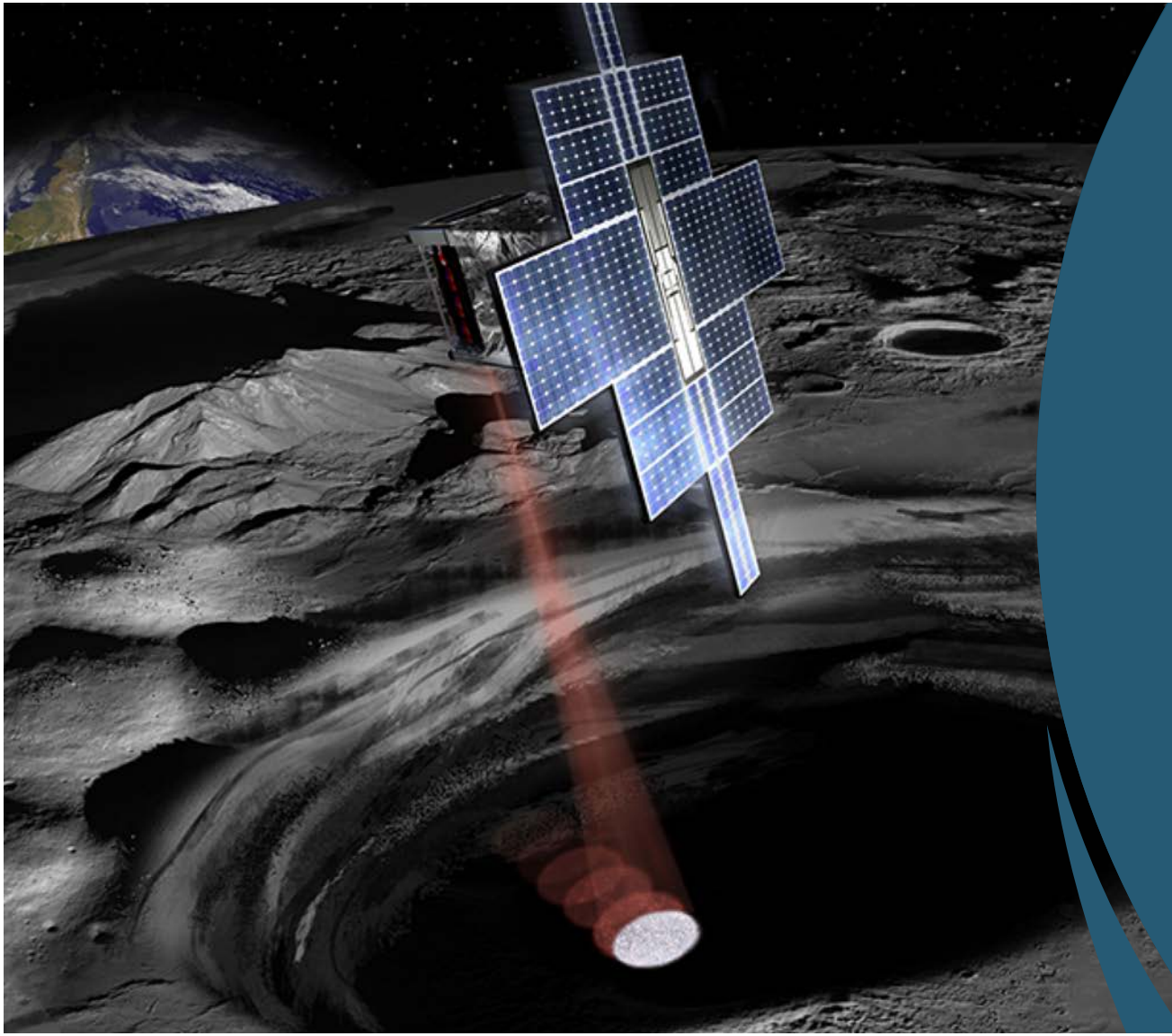
Flight Development Reality

Flight Development Reality

Remember that once awarded NASA supports you, your team, and your mission

Reach out EARLY for programmatic and technical assistance

Don’t let manageable problems grow into unmanageable ones



Topics for Discussion

The Basics

Mission Formulation

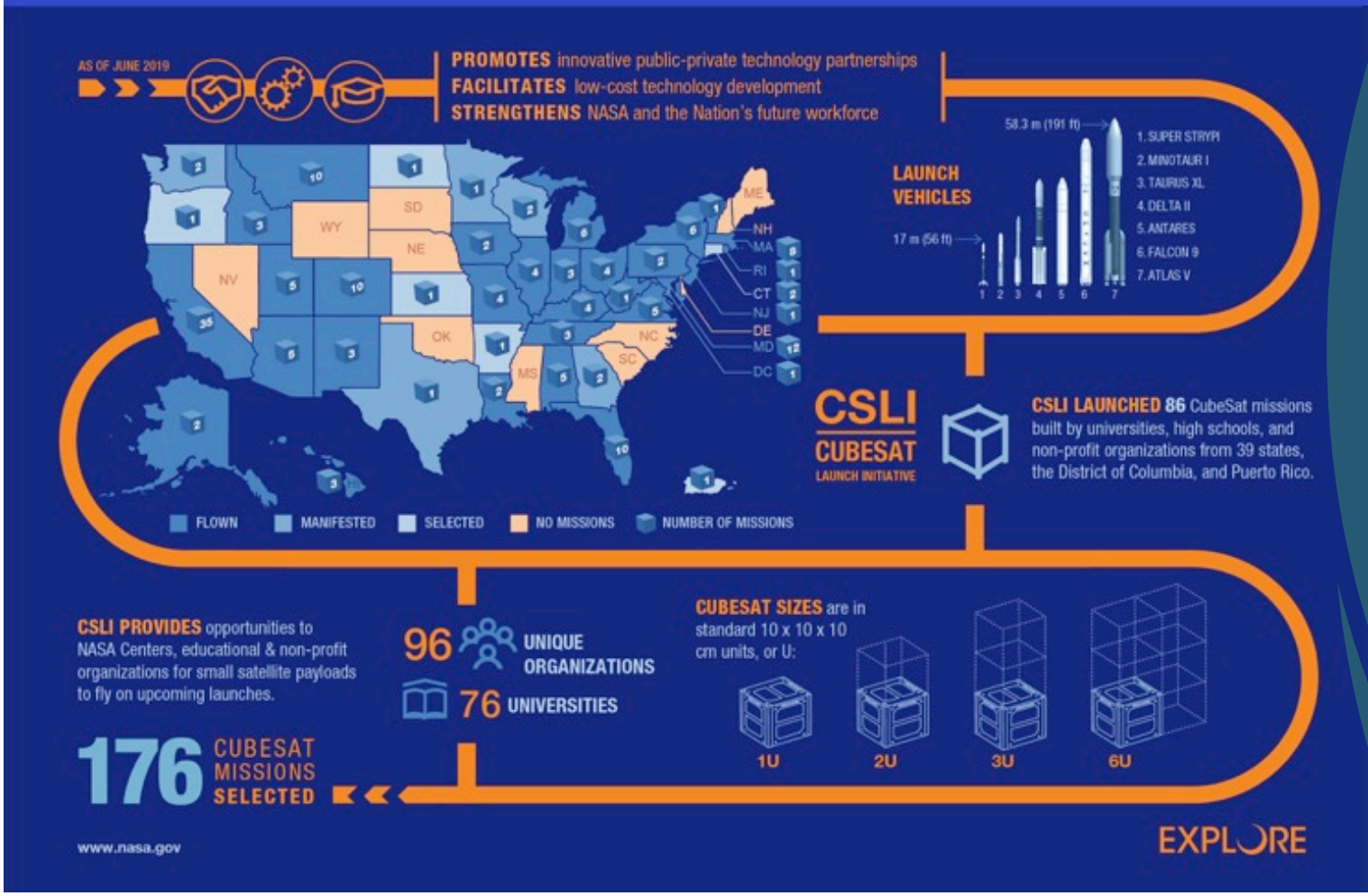
Realities of Flight Development

<u>Access to Space</u>

Mission Operations

Closing Remarks

Access to Space



No-Cost Access to Space for NASA Centers, Not-For-Profit orgs, and accredited educational institutions in the US via competition

Note: CLSI payloads are tertiary with fewer rights than others

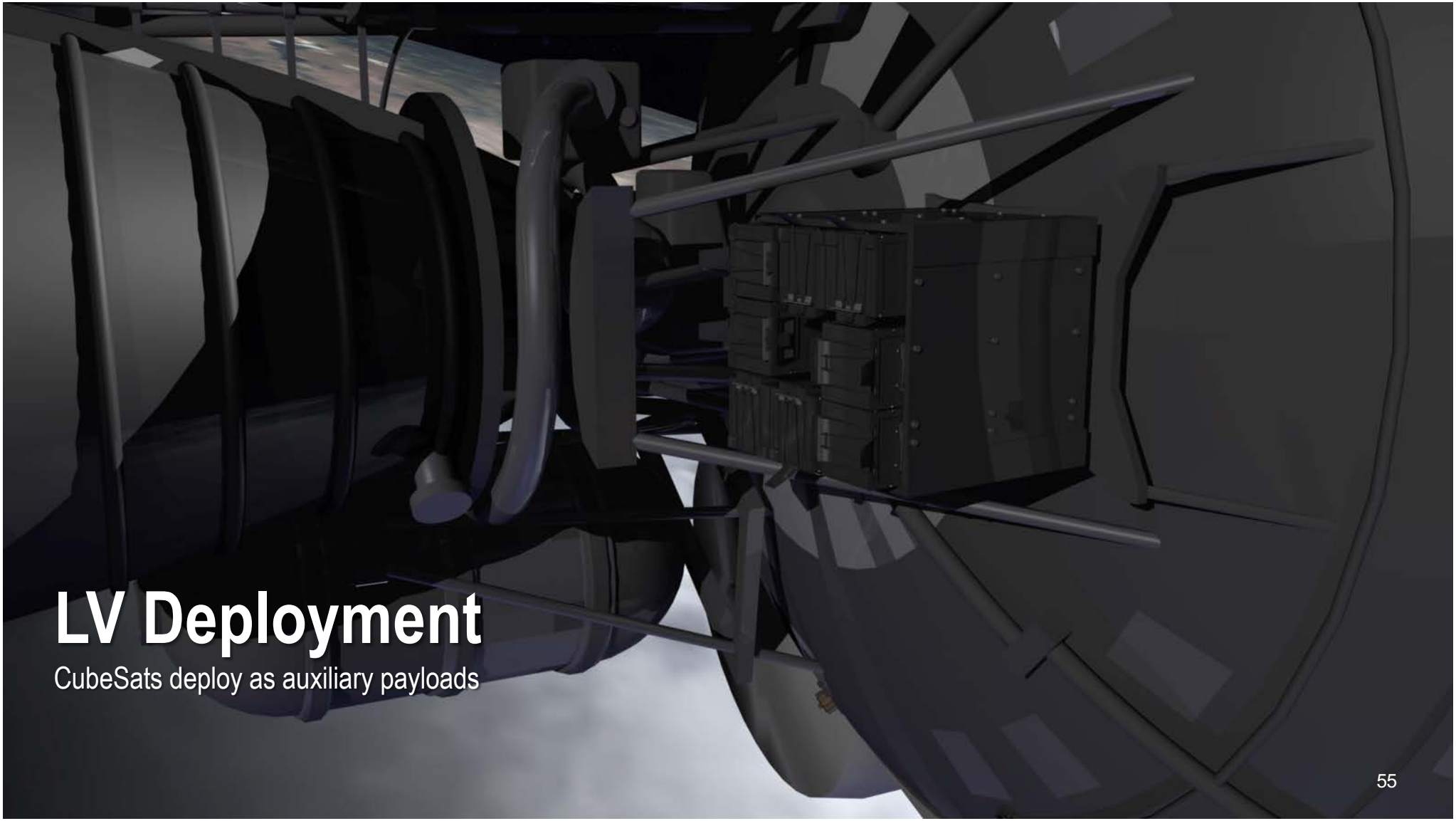
Respondents may need to reimburse NASA for integration and launch activities if contract obligations are not met

Access to Space

Commercial and Government Rideshare is a hot topic, but there is complexity

Some industry forecasts show SmallSat lunar activity will triple in the next 5 years

Respondents may need to reimburse NASA for integration and launch activities if contract obligations are not met



LV Deployment

CubeSats deploy as auxiliary payloads

Access to Space

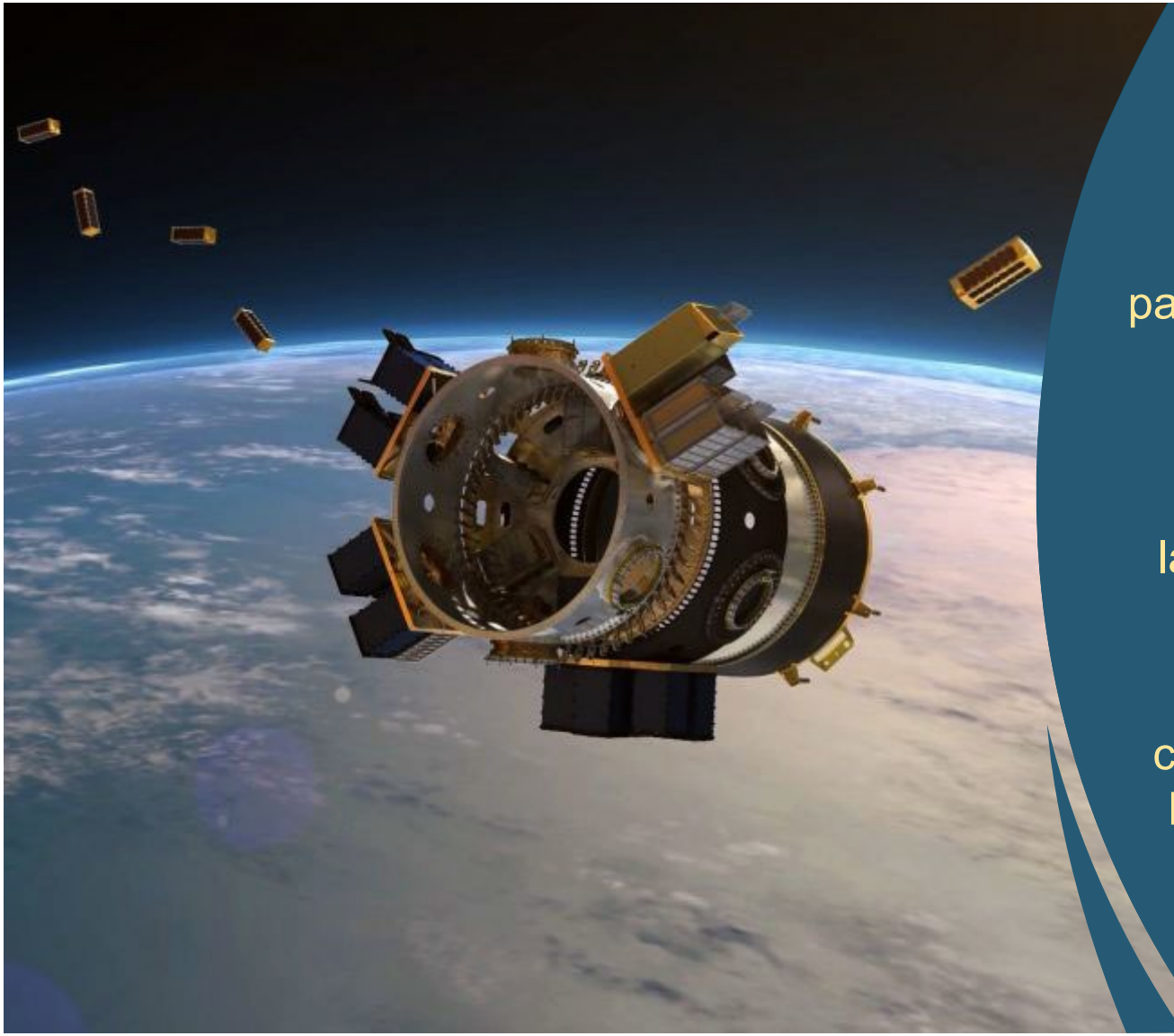
ISS Deployment

HaloSat/RainCube deploy from the ISS

Access to Space

Access to Space

Courtesy: Spaceflight Industries



Access to Space

SSO-A demonstrated complex multi-manifest payload of 60 spacecraft is possible

Involved partnerships between a commercial launch broker and launch provider

Joint leveraging of commercial capabilities is becoming more common (to include ground services)

Future Launch Capability

Performance Increases Impact Future Concept Design

Industry transition to higher capability launch vehicles will provide new opportunities

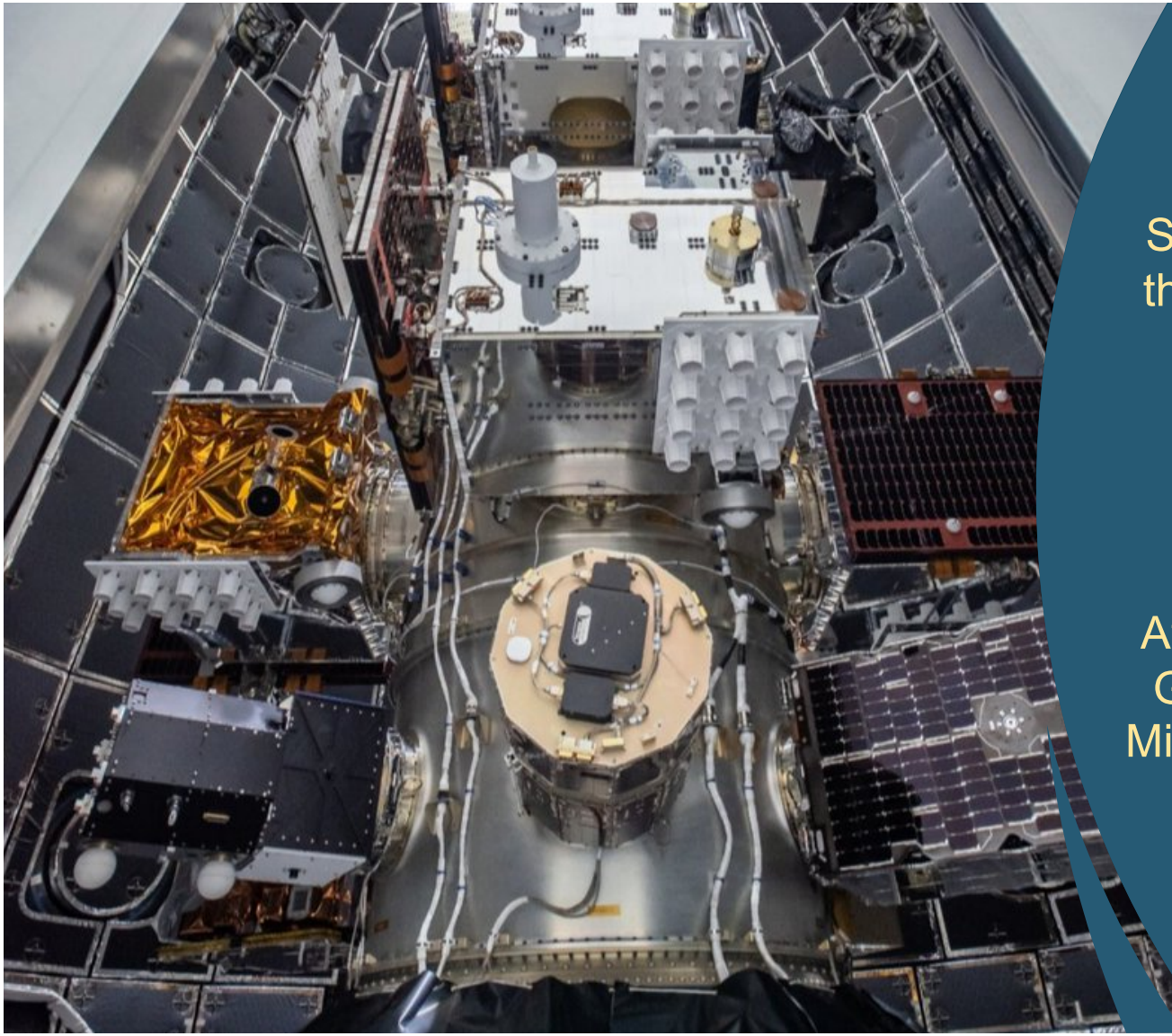
Partnerships, via multi-mission or secondary/tertiary payload manifests, will be essential to the future of beyond LEO science and exploration

Future launch vehicles will drive greater innovation in mission design and science return

International cooperation should also be pursued to extract the most science from various beyond LEO targets

Courtesy: eBaum's World

Access to Space



Access to Space

STP-2 with 24 satellites in the SpaceX Falcon Heavy Fairing

3,700 kg Integrated Payload Stack

NASA's Deep Space Atomic Clock (DSOC) and Green Propellant Infusion Mission (GPIM) are among the payloads

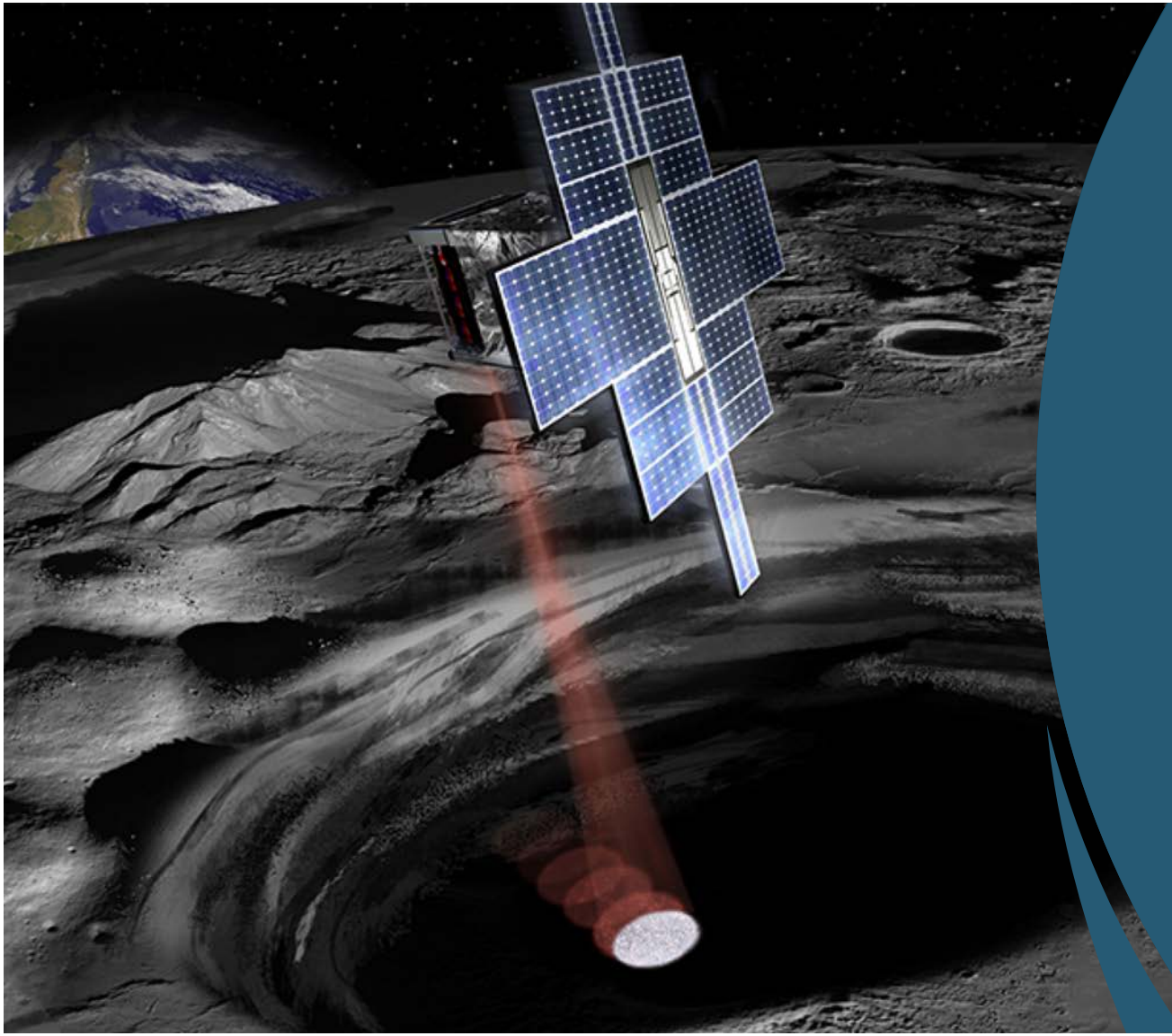
Access to Space

Future mission architectures will leverage propulsive ESPA as the complete spacecraft bus

Could provide a mission unique capability for managing complex deployments for a single mission application

Failures Occur

Antares ORB-3 Launch Failure



Topics for Discussion

The Basics

Mission Formulation

Realities of Flight Development

Access to Space

<u>Mission Operations</u>

Closing Remarks

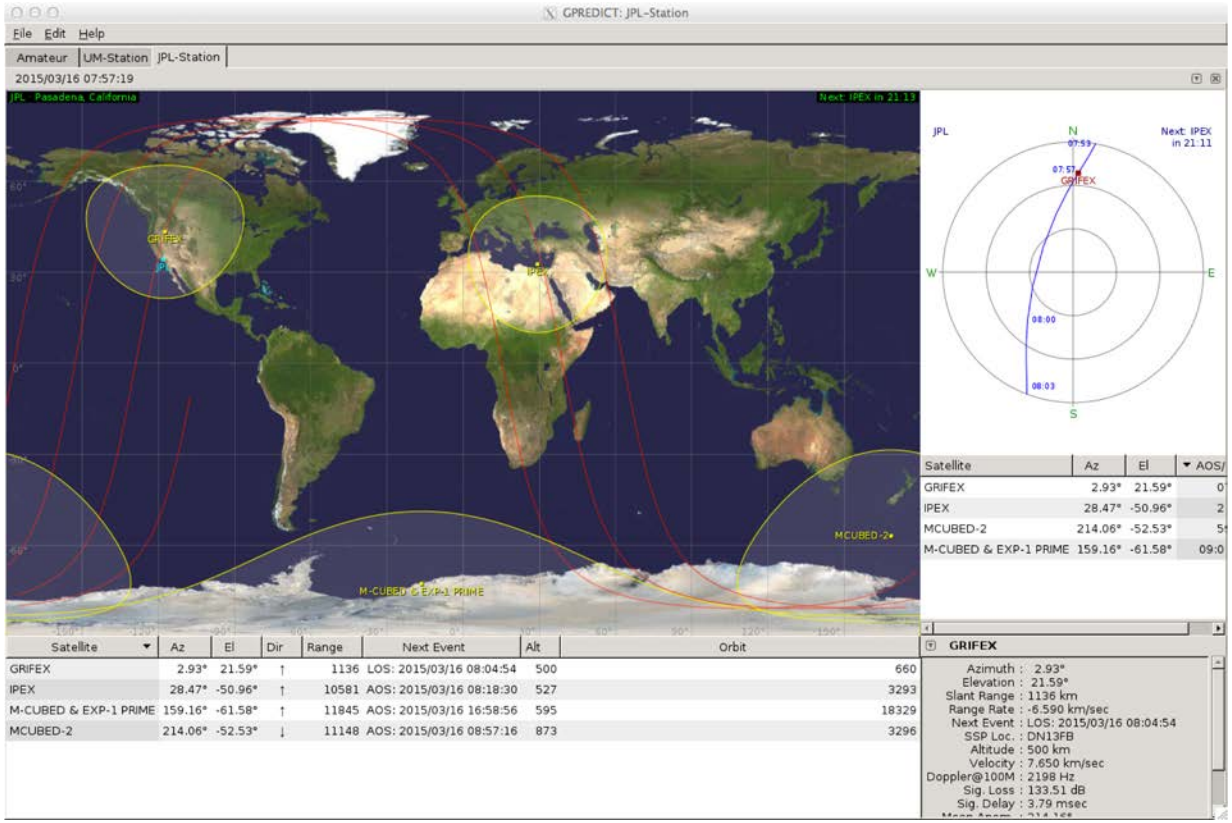
Mission Operations

Schedule rehearsals prior to launch, focusing on anomaly procedures

Perform field testing to verify, to the extent possible, link budget and margins

Operation budgets are not flight delivery reserve funds, so plan accordingly

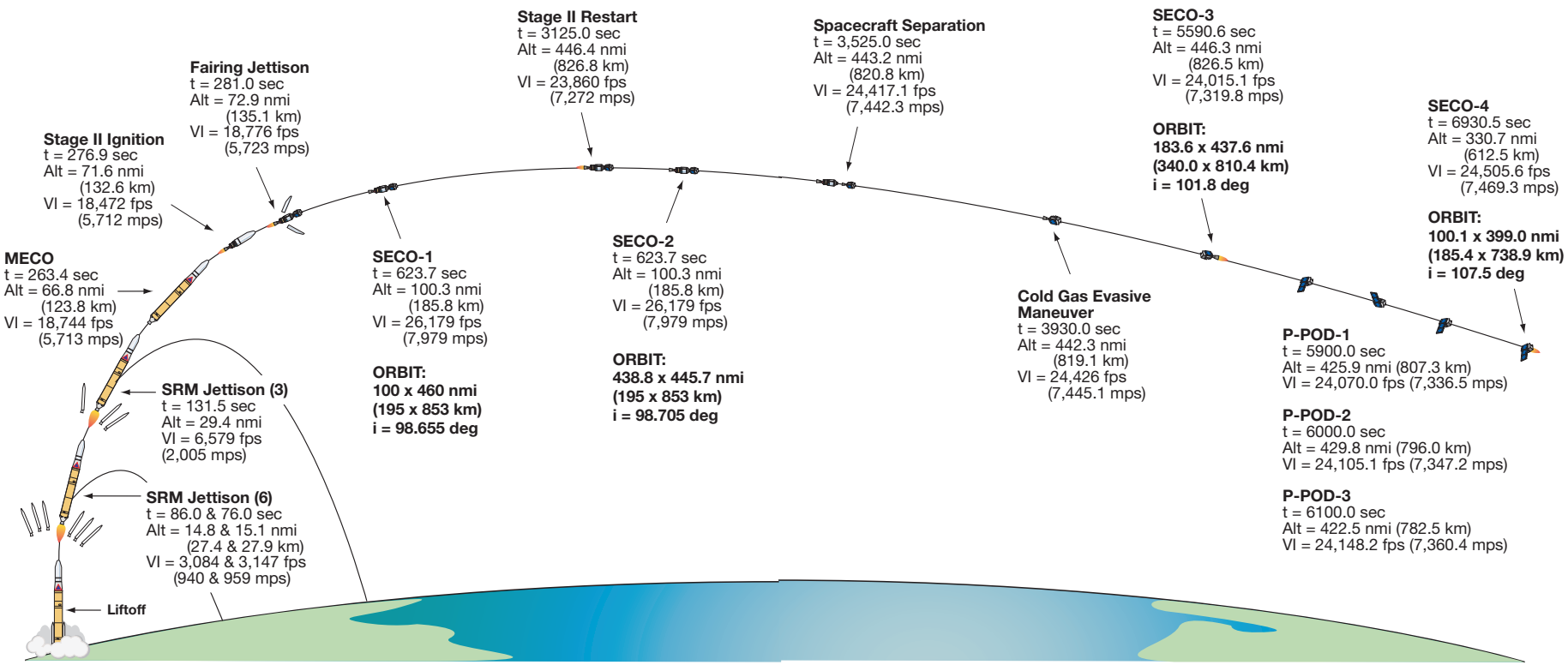
Ground Station Preparation



Mission Operations

Launch Profile and Deployment Sequence

NPP Mission Flight Profile



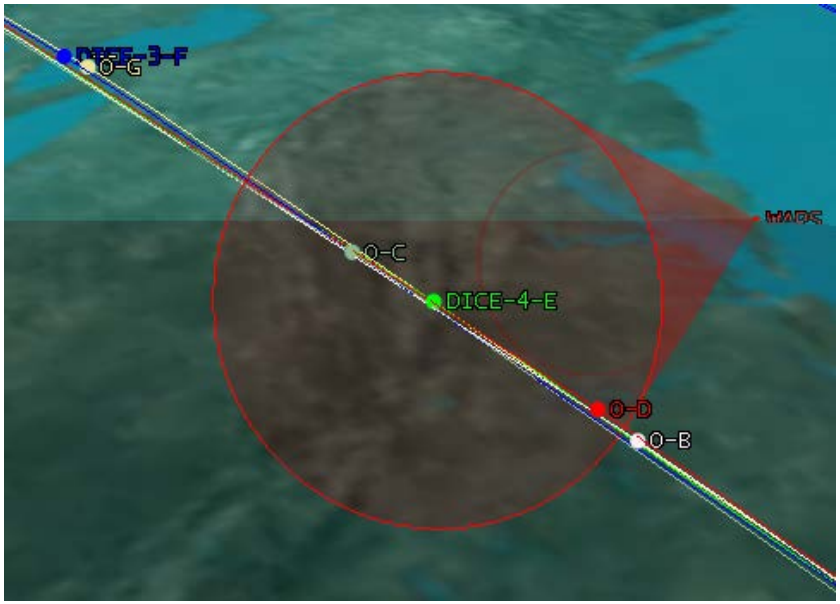
Two-Line Element (TLE) Identification and Analysis

USSTRATCOM (28th Air Force Wing) Provides Position Estimates and Radar Cross Section (RCS)

M-CUBED & EXP-1 PRIME

1 37855U 11061F 11346.19686108 .00005502 00000-0 44695-3 0 412

2 37855 101.7076 296.1999 0254710 165.5785 195.2864 14.78355333 6590



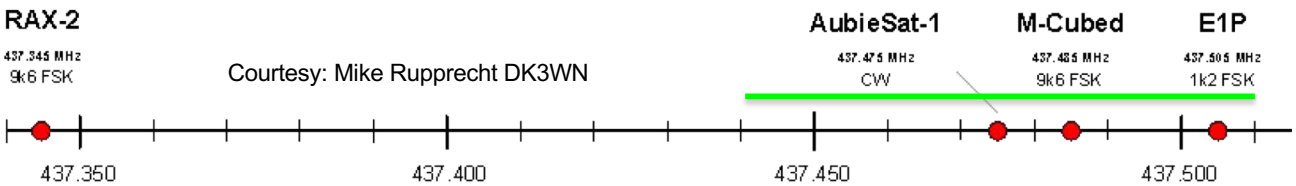
WFF October 29th Pass

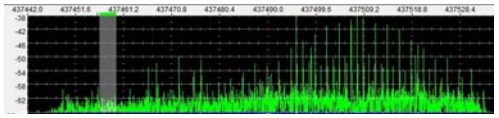
WFF November 2nd Pass

USSTRATCOM tracked NPP and 6 other objects from launch (Objects B, C, D, E, F, G)
Object B was not an NPP launch object

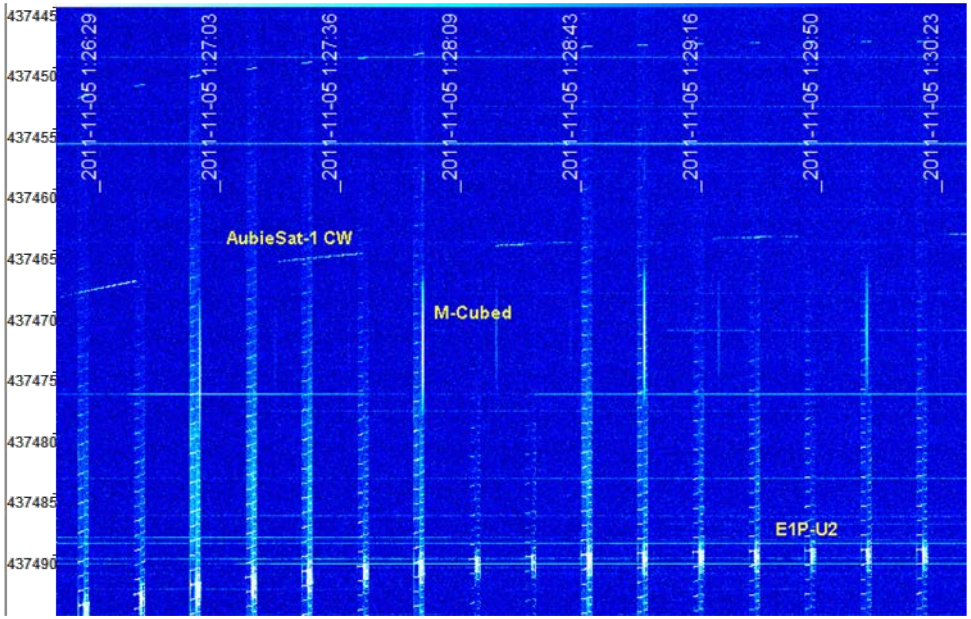
Mission Operations

RF Interference and Center Frequency Shifting (ELaNa-3)

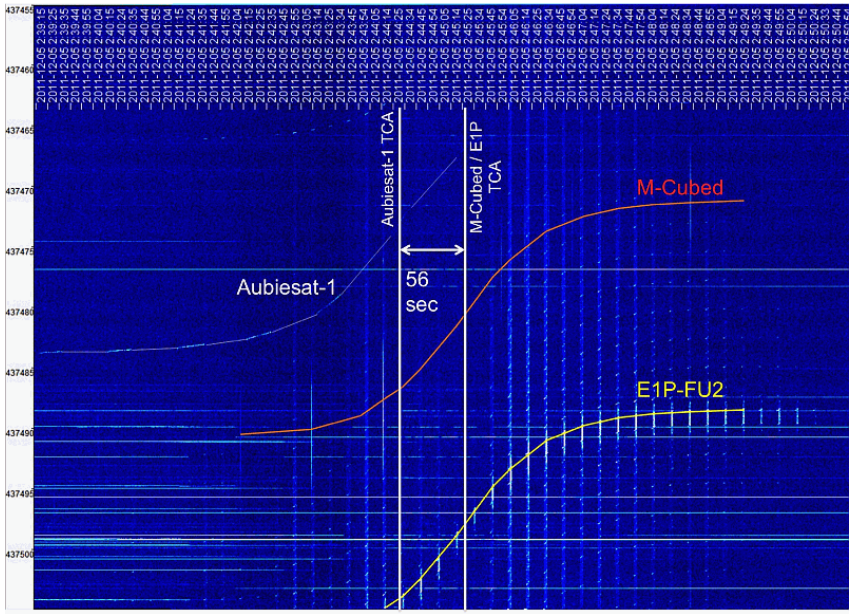




CubeSat Observed Spectrum Bandwidth



Very Strong Broadband Beacon Heard by HAMs Actually Augmented Signal Strength of Conjoined Spacecraft on Common 60s Period



Strong Correspondence from Time to Closet Approach (TCA) in Spectral and Doppler Implies Conjunction Event

Mission Operations

Telemetry Housekeeping Data Beacons from Global HAM Operators

Producing telemetry beacons, with a public client for global tracking of spacecraft health, is a valuable status monitoring tool

Must ensure compliance with all regulatory agencies

Michigan Exploration Laboratory (MXL)
February 11 ·

THE FIRST MARINA RUN WAS SUCCESSFUL!! In the screenshot below, you can see the data points that indicate that the first run was completed successfully. Over the next three days, we will downlink the experimental data and GRIFEX's first image from orbit! Following that, we will continue to gather payload data for the JPL researchers. Thank you again to NASA, Cal Poly, and the countless operators around the world who made this a possibility!

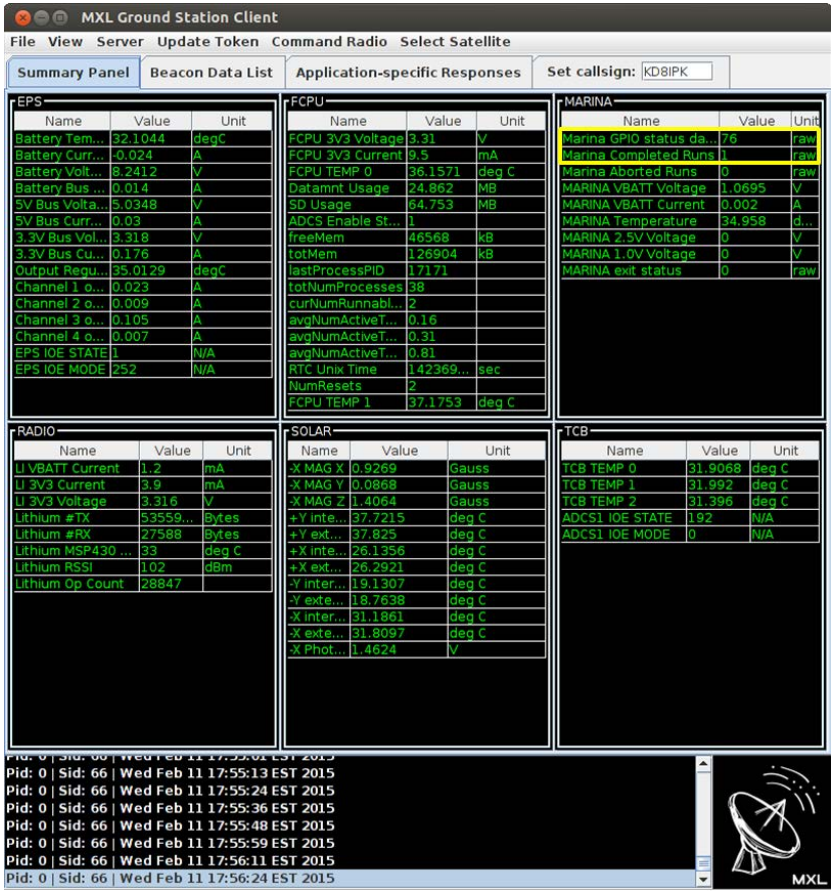
Brian Jefferson, PE0SAT, Dan Abramov and 17 others like this. Top Comments

2 shares

Mark Hammond Happy to help you collect telemetry and data 🙂 Mark N8MH
1 · February 12 at 3:39am

1 Reply

Daniel Smith Awesome! Glad to see GRIFEX fulfilling its mission!
1 · February 12 at 4:40am



MXL Ground Station Client

File View Server Update Token Command Radio Select Satellite

Summary Panel | Beacon Data List | Application-specific Responses | Set callsign: KD8IPK

EPS

Name	Value	Unit
Battery Tem...	32.1044	degC
Battery Curr...	-0.024	A
Battery Volt...	8.2412	V
Battery Bus ...	0.014	A
5V Bus Volta...	5.0348	V
5V Bus Curr...	0.03	A
3.3V Bus Vol...	3.318	V
3.3V Bus Cu...	0.176	A
Output Regu...	35.0129	degC
Channel 1 o...	0.023	A
Channel 2 o...	0.009	A
Channel 3 o...	0.105	A
Channel 4 o...	0.007	A
EPS IOE STATE	1	N/A
EPS IOE MODE	252	N/A

FCPU

Name	Value	Unit
FCPU 3V3 Voltage	3.31	V
FCPU 3V3 Current	9.5	mA
FCPU TEMP 0	36.1571	deg C
Datamnt Usage	24.862	MB
SD Usage	64.753	MB
ADCS Enable St...	1	
freeMem	46568	kB
totMem	126904	kB
lastProcessPID	17171	
totNumProcesses	38	
curNumRunnabl...	2	
avgNumActiveT...	0.16	
avgNumActiveT...	0.31	
avgNumActiveT...	0.81	
RTC Unix Time	142369...	sec
NumResets	2	
FCPU TEMP 1	37.1753	deg C

MARINA

Name	Value	Unit
Marina GPIO status da...	76	raw
Marina Completed Runs	1	raw
Marina Aborted Runs	0	raw
MARINA VBATT Voltage	1.0695	V
MARINA VBATT Current	0.002	A
MARINA Temperature	34.958	d...
MARINA 2.5V Voltage	0	V
MARINA 1.0V Voltage	0	V
MARINA exit status	0	raw

RADIO

Name	Value	Unit
LI VBATT Current	1.2	mA
LI 3V3 Current	3.9	mA
LI 3V3 Voltage	3.316	V
Lithium #TX	53559...	Bytes
Lithium #RX	27588	Bytes
Lithium MSP430 ...	33	deg C
Lithium RSSI	102	dBm
Lithium Op Count	28847	

SOLAR

Name	Value	Unit
-X MAG X	0.9269	Gauss
-X MAG Y	0.0868	Gauss
-X MAG Z	1.4064	Gauss
+Y inte...	37.7215	deg C
+Y ext...	37.825	deg C
+X inte...	26.1356	deg C
+X ext...	26.2921	deg C
-Y inter...	19.1307	deg C
-Y exte...	18.7638	deg C
-X inter...	31.1861	deg C
-X exte...	31.8097	deg C
-X Phot...	1.4624	V

TCB

Name	Value	Unit
TCB TEMP 0	31.9068	deg C
TCB TEMP 1	31.992	deg C
TCB TEMP 2	31.396	deg C
ADCS1 IOE STATE	192	N/A
ADCS1 IOE MODE	0	N/A

Pid: 0 | Sid: 66 | Wed Feb 11 17:55:13 EST 2015
Pid: 0 | Sid: 66 | Wed Feb 11 17:55:24 EST 2015
Pid: 0 | Sid: 66 | Wed Feb 11 17:55:36 EST 2015
Pid: 0 | Sid: 66 | Wed Feb 11 17:55:48 EST 2015
Pid: 0 | Sid: 66 | Wed Feb 11 17:55:59 EST 2015
Pid: 0 | Sid: 66 | Wed Feb 11 17:56:11 EST 2015
Pid: 0 | Sid: 66 | Wed Feb 11 17:56:24 EST 2015

MXL

Mission Operations

Telemetry Housekeeping Data Beacons from Global HAM Operators

FCPU		
CDH 3.3V Current	68.90000	mA
FCPU 3.3V Voltage	3.30800	V
FCPU 5V Voltage	4.99400	V
FCPU Temperature	14	deg C
RTC Unix Time	17,117	
NumResets	72	
avgNumActiveTasks1	0	
avgNumActiveTasks5	0	
avgNumActiveTasks15	0	
curNumRunnableTasks	4	
totNumProcesses	44	
lastProcessPID	1,237	
totMemkB	61,932	
freeMemkB	52,812	
LI1	0	
LI0_RX	1	
LI0_TX	1	
CDH GPIO MPPT Status	0	
LI0	0	
EPS_ANTENNA_DEPLOY	0	

EPS Solar Input Board		
V_1.1REF	0.96750	V
V_SA1 (+Y)	4.63000	V
V_SA2 (-Z)	3.70000	V
V_SA3 (-Y)	4.67000	V
I_SA1 (+Y)	0	A
I_SA2 (-Z)	0.00550	A
I_SA3 (-Y)	0.01850	A
T_SA123A	10.73320	deg C
V_SA4 (+X)	1.05000	V
V_SA5 (-X)	2.42500	V
V_SA6 (+Z)	4.68500	V
I_SA4 (+X)	0	A
I_SA5 (-X)	0.00100	A
I_SA6 (+Z)	0.15050	A
T_SA456A	8.57336	deg C
EPS Register MPPT Status	0	
ADC Reference	3	Reference
GND	0	V
T_SA123B	10.51736	deg C
T_SA456B	9.00558	deg C
Reset Condition	5	

EPS Output Board		
3.3V Regulator Temp	11.94135	deg C
5V Regulator Temp	12.71750	deg C
Raw Battery Current	-14.82730	mA
Battery Warning	0	
Antenna Release Current	2	mA
Cell Voltage	3.95700	V
3.3V Current	137	mA
5V Current	17	mA
3.3V Voltage	3.32400	V
VBatt Current	9	mA
5V Voltage	4.99600	V
VBatt Voltage	8.05800	V

Radios		
Lithium VBatt Current	0	mA
Lithium 3.3V Current	6.10000	mA
Lithium NCMD	1,666	commands
Lithium Radio Temp	-210	deg C
Lithium T2	-64	deg C
Lithium RSSI	-27.50000	dBm
Queue Status	5	packets
Lithium #RX	0	bytes
Lithium #TX	152,256	bytes

Camera		
Camera 3.3V Current	0	mA
Camera 2.8V Voltage	0.01800	V
CAM_I2C_SDA	1	
CAM_I2C_SCL	1	
CAM_O_D2	1	
CAM_O_D3	0	
CAM_O_D4	0	
CAM_O_D5	0	
CAM_O_D6	0	
CAM_O_D7	0	
CAM_O_D8	0	
CAM_O_D9	0	
CAM_O_PCLK	0	
CAM_O_VSYNC	0	
CAM_O_HREF	0	
CAM_I_XCLK	0	
PWRDN_CAM	1	
Camera Status	1	

COVE	
COVE_CONFIG0	0
COVE_UART_TX	0
COVE_UART_RX	0
COVE_PROCESS_DONE	0
COVE_CONFIG1	1
COVE Flash	0
COVE_MODE	0
COVE_BUFF_EN_n	1
COVE	0
COVE_DONE	0

Key Parameters

EPS Output Board
- Vbatt Voltage: 8.05 V

Radios
- Lithium RSSI: -27.5 dB

FCPU
- NumResets: 72

EPS Solar Input Board
- V_SA4 (+X): 1.05 V
- V_SA5 (-X): 2.42 V
- V_SA1 (+Y): 4.63 V
- V_SA3 (-Y): 4.67 V
- V_SA6 (+Z): 4.68 V
- V_SA2 (-Z): 3.70 V

Cybersecurity

Protecting space and ground-based assets via encryption and monitoring network security

Mission Operations

New NASA Directive has defined criteria for uplink protection for cybersecurity and enterprise protection

Directive does not apply to SmallSats without propulsion capability

Propulsion capability and maneuverability are not the same thing

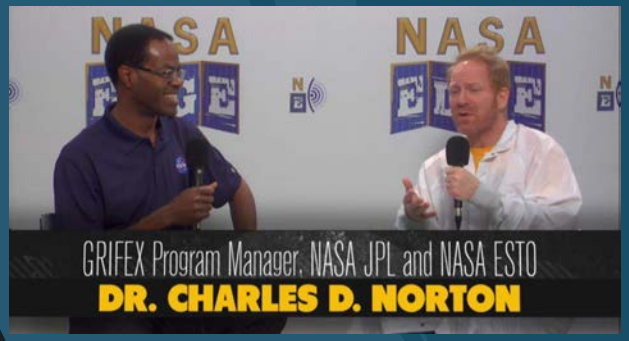
Image: Courtesy of KSAT

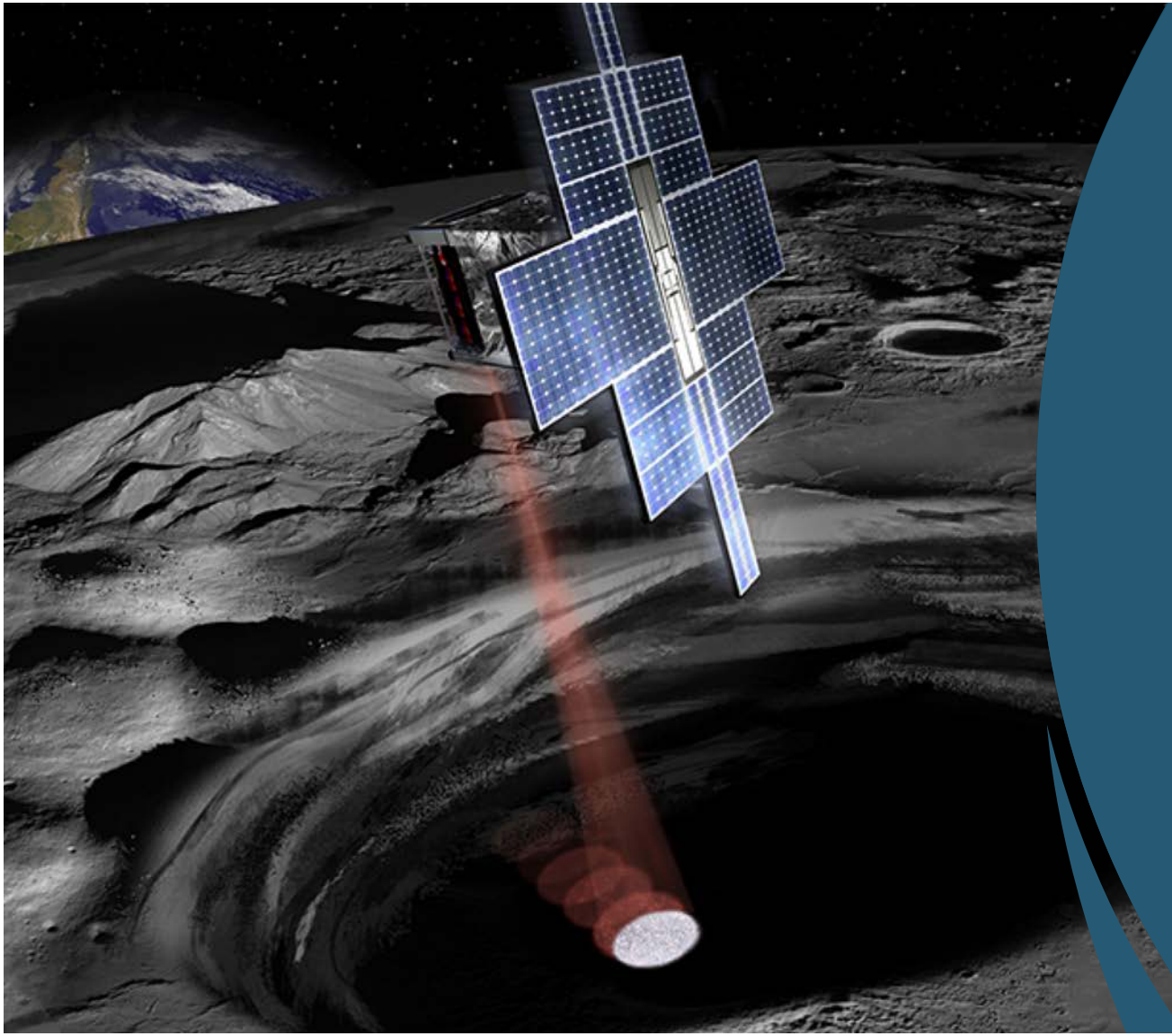
Mission Operations

Reserve budget for Launch Media Events

Prepare realistic models and high quality video

Attend speaker training





Topics for Discussion

The Basics

Mission Formulation

Realities of Flight Development

Access to Space

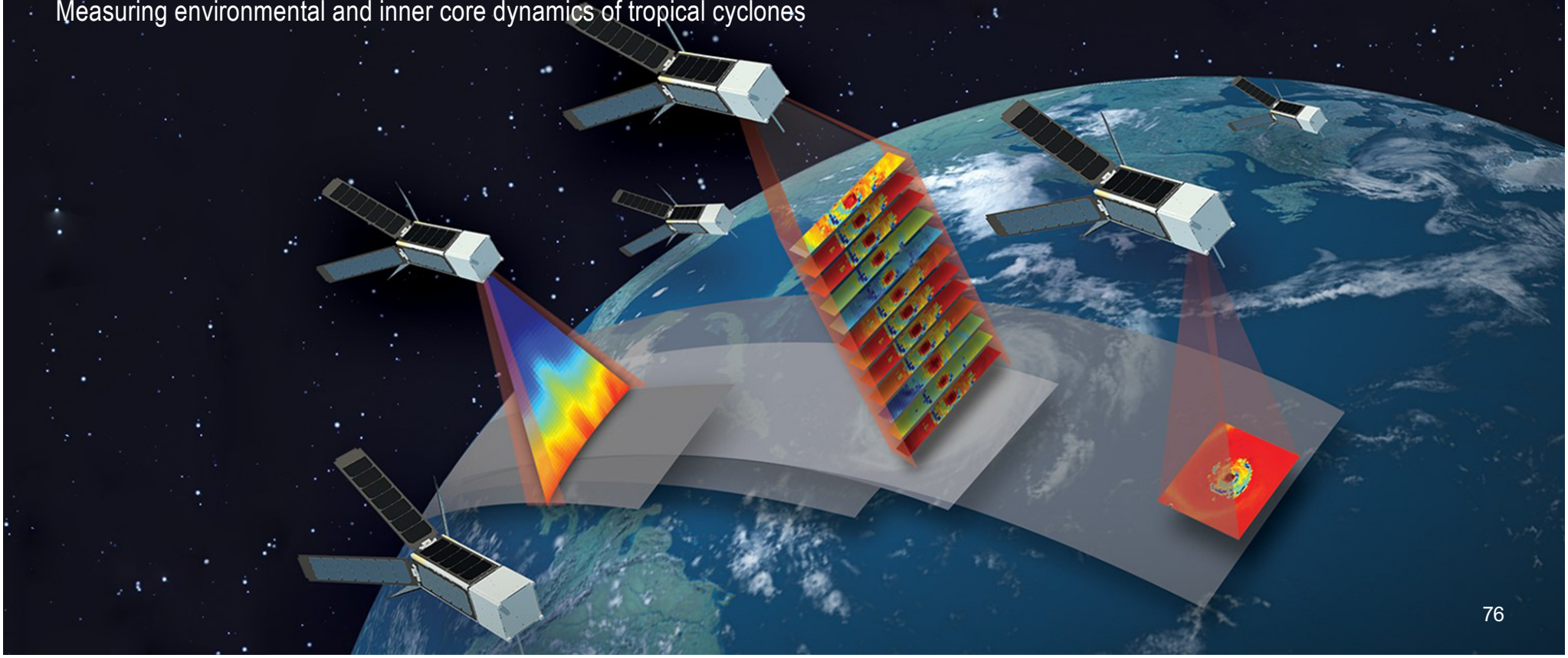
Mission Operations

<u>Closing Remarks</u>

TROPICS

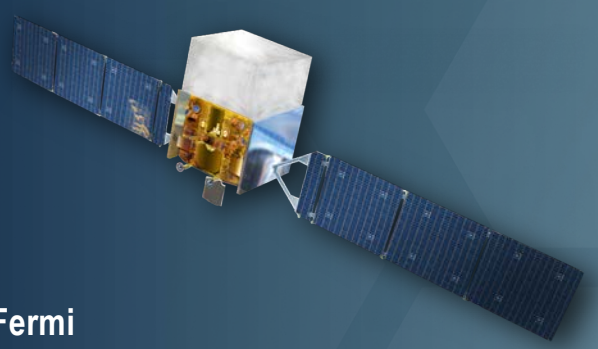
Time-Resolved Observation of Precipitation Structure and Storm Intensity with a Constellation of CubeSats

Measuring environmental and inner core dynamics of tropical cyclones

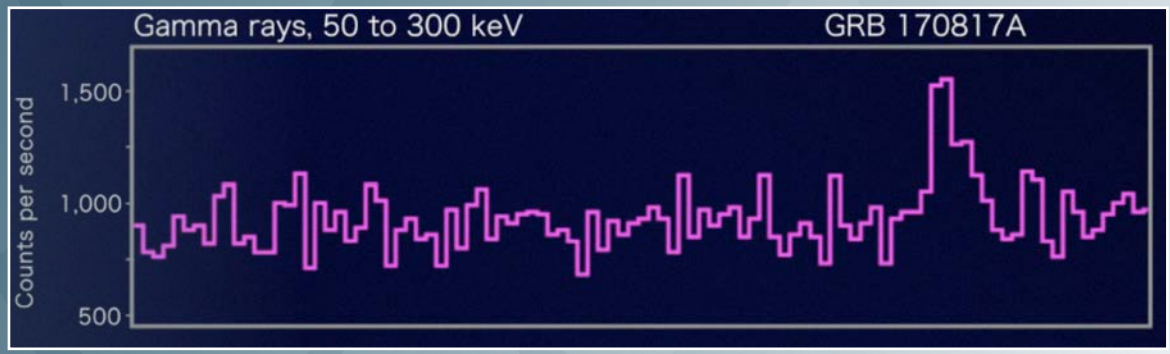


BurstCube

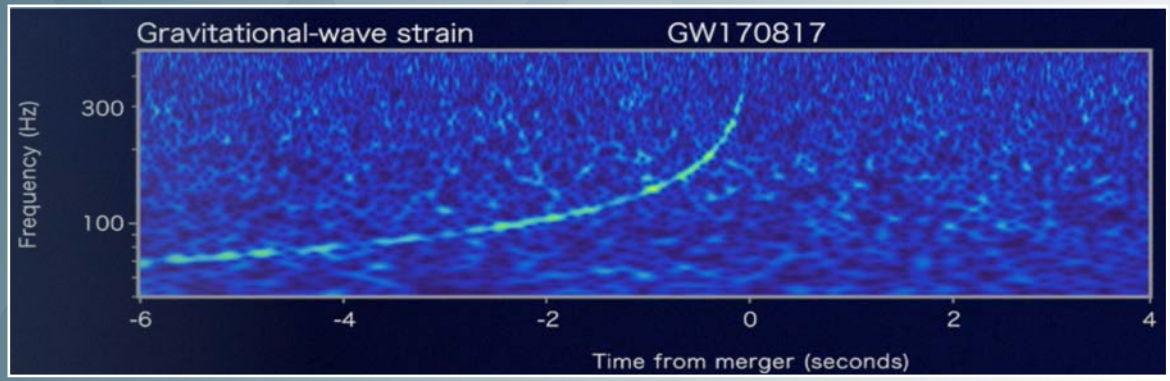
Detect and localize Gamma-ray Bursts as GW-Wave Counterparts



Fermi



LIGO



Study on Large Constellations and Formations for Exploring Interstellar Objects and Long Period Comets

ISOs and LPCs

Exploring Once-in-a-Lifetime Targets: Creating Habitable Worlds

Image: Courtesy of Karen Meech

Oumuamua is central stationary light source as imaged by W. M. Hershel telescope on 10/28/17

Oumuamua

First interstellar object observed in our solar system

Small Spacecraft Coordination Group

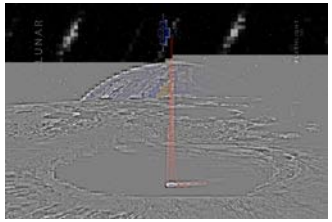
Formed to advise the SMD, STMD, and HEOMD AAs on strategy to guide cross-agency initiatives, policies, and programmatic scope

SmallSat Agency Integrated Strategic Plan

Release at SmallSat 2019 Conference

NASA Strategic Plan

Science
New Observation Methods



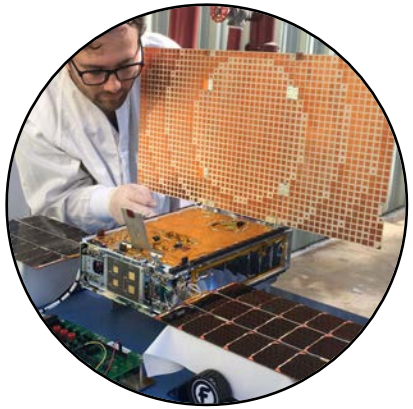
Exploration
Strategic Knowledge Gaps

Technology
Spacecraft Subsystems

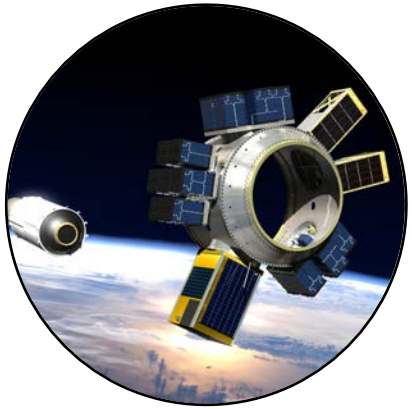
NASA SmallSat Integrated Strategic Plan

High Priority Science

Support to Human Exploration



Disruptive Technology Innovation

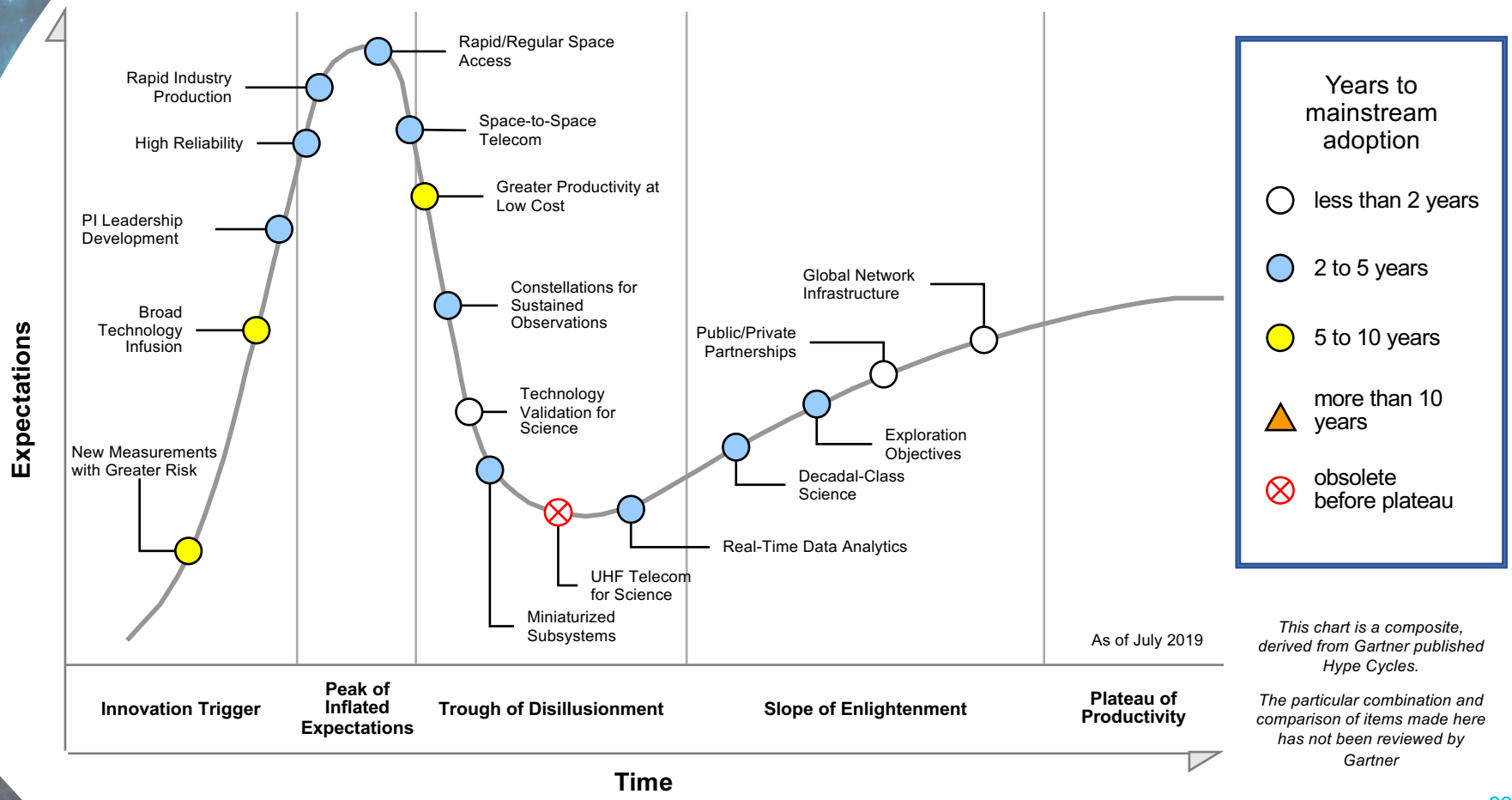


Regular Access to Space

An integrated and coordinated strategy supporting the NASA strategic plan objectives of Discover, Explore, Develop, Enable

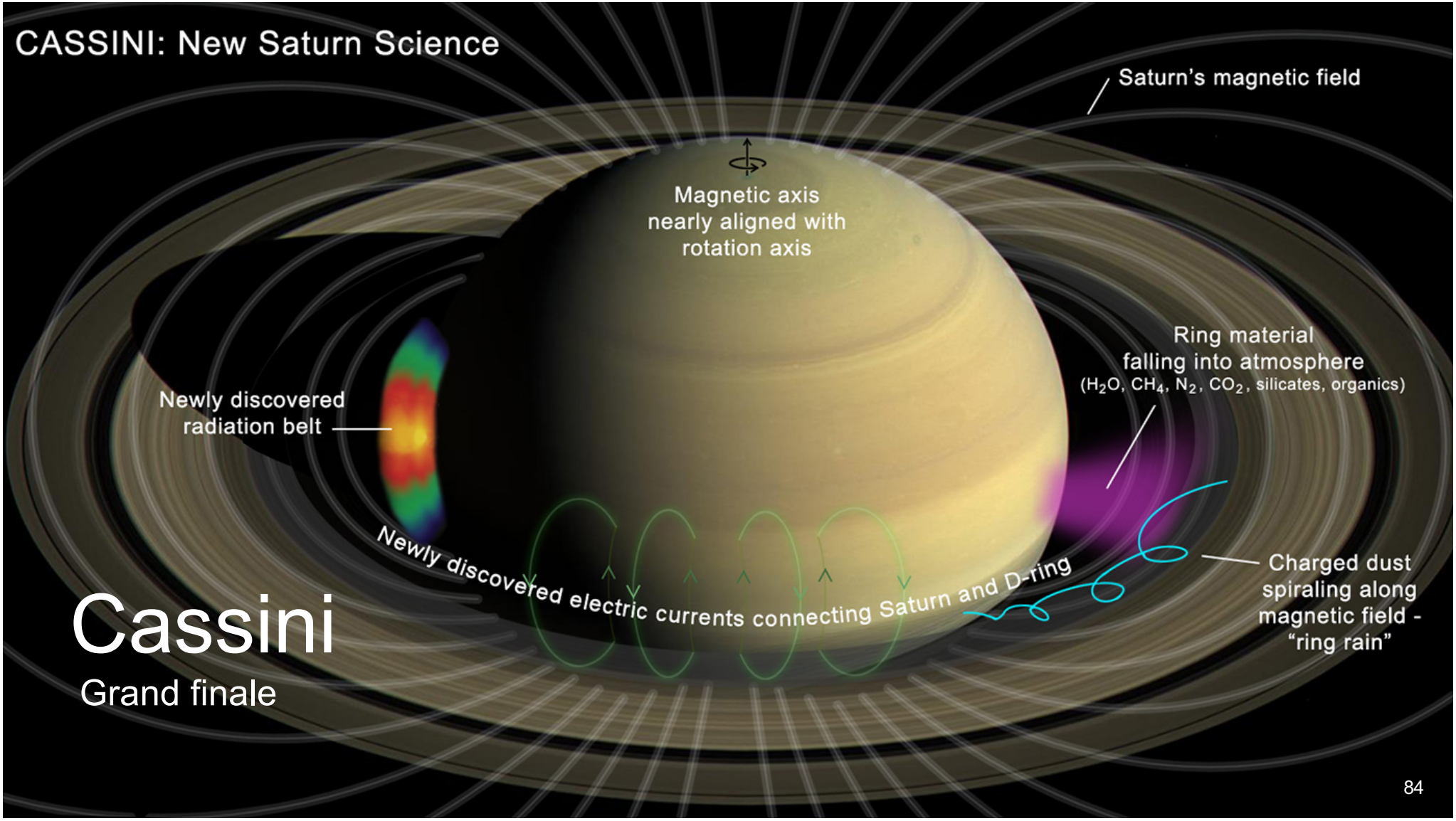
Engaging the Community for Mission Success

Thoughts on Achieving a SmallSat Utopia…



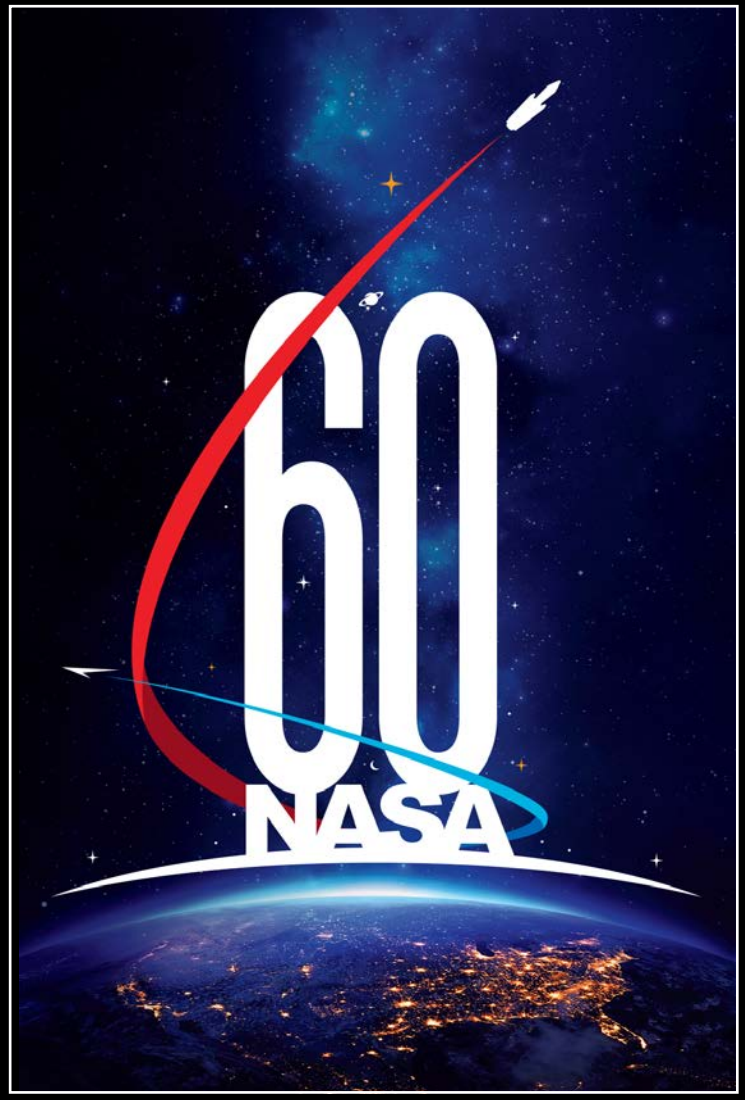
This chart is a composite, derived from Gartner published Hype Cycles.

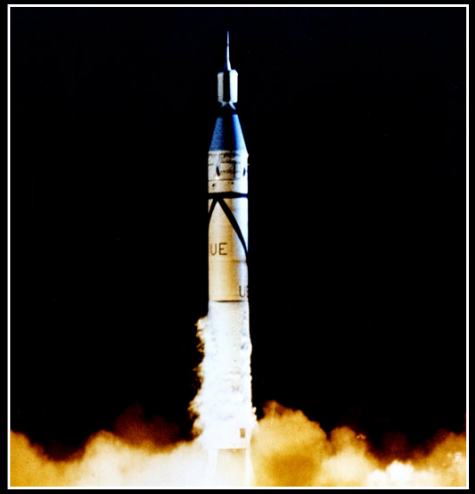
The particular combination and comparison of items made here has not been reviewed by Gartner



Cassini

Grand finale


60
NASA



NASA
EXPLORE
with us