Solar Probe Plus

(SPP)

Committee on Solar and Space Physics

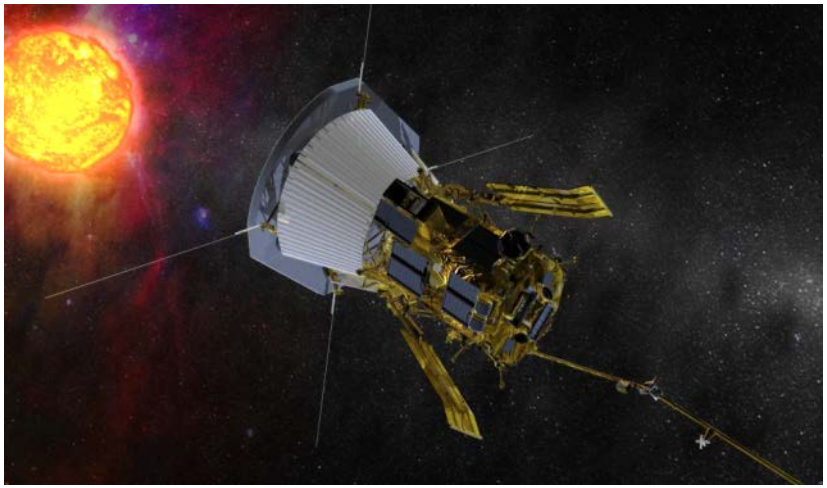
5 October 2016

Joe Smith
Program Executive
NASA Headquarters

NASA

APL JOHNS HOPKINS APPLIED PHYSICS LABORATORY

Solar Probe Plus (SPP)



Overview

Using in-situ measurements made closer to the Sun than by any previous spacecraft, SPP will determine the mechanisms that produce the fast and slow solar winds, coronal heating, and the transport of energetic particles.

Solar Probe Plus will fly to less than 10 solar radii (Rs) of the Sun, having "walked in" from 35 Rs over 24 orbits.

- Sponsor: NASA/GSFC LWS
- LWS Program Manager – Nick Chrissotimos GSFC
- LWS Deputy Program Manager – Mark Goans, GSFC
- Project Manager – Andy Driesman, APL
- Project Scientist – Nicky Fox, APL
- Spacecraft Development/Operations – APL
- Investigations selected by AO:
  - FIELDS – University of California
  - ISIS – Princeton University/SwRI
  - SWEAP – Smithsonian Astrophysical Obs
  - WISPR – Naval Research Laboratory
  - HelioOrigins – Jet Propulsion Laboratory

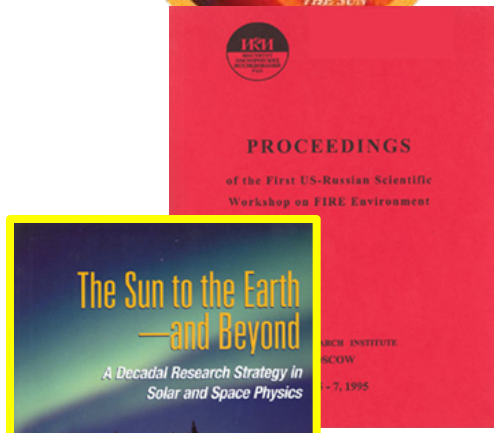
Milestones

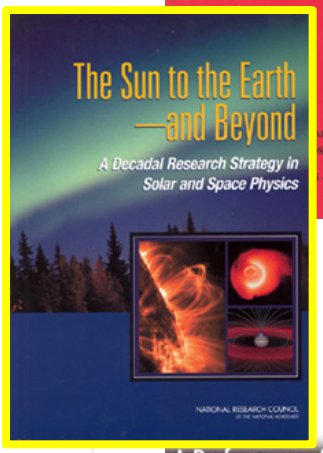
Pre-Phase A:	07/2008 – 11/2009
Phase A:	12/2009 – 01/2012
Phase B:	02/2012 – 03/2014
Phase C/D:	03/2014 – 09/2018
LRD:	31 July 2018
Phase E:	10/2018 – 09/2025

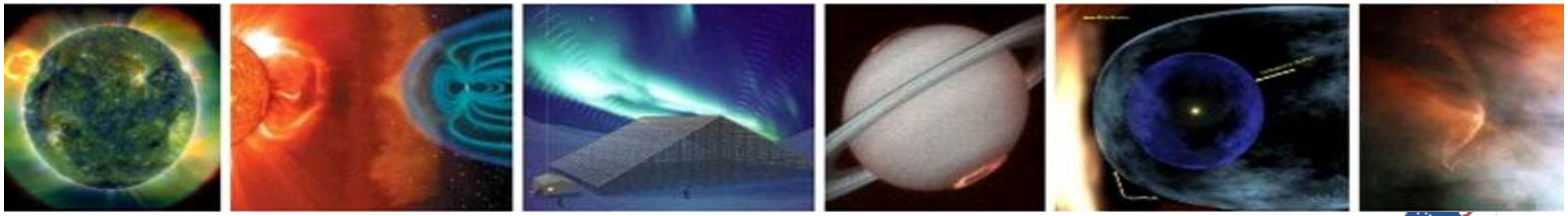
Management Commitment: $1,366M
Category 1, Risk Classification B

50 years into the space age and we still don't understand the corona and solar wind

- The concept for a "Solar Probe" dates back to "Simpson's Committee" of the Space Science Board (National Academy of Sciences, 24 October 1958)
  - The need for extraordinary knowledge of Sun from remote observations, theory, and modeling to answer the questions:
    - Why is the solar corona so much hotter than the photosphere?
    - How is the solar wind accelerated?
- The answers to these questions can be obtained only through **in-situ** measurements of the solar wind **down in the corona**
- Top priority in multiple Roadmaps and Decadal Surveys.





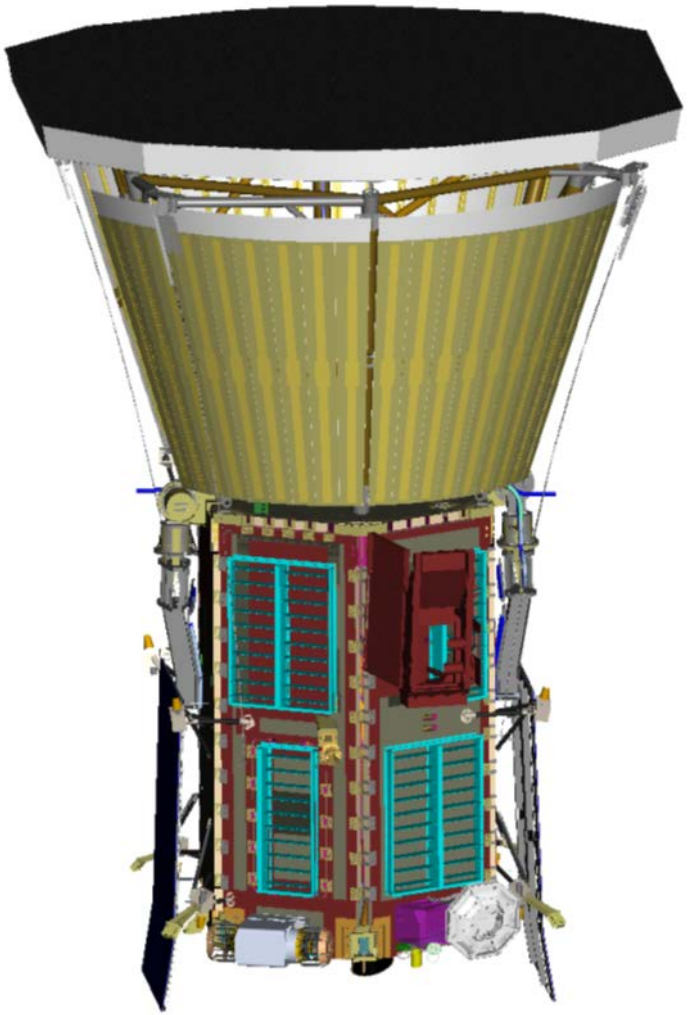


Level 1 Objectives & Processes Require High Quality, Integrated Measurements

L1 Science Objectives	Sample Processes	Needed Measurements	Instruments
1. Trace the flow of energy that heats and accelerates the solar corona and solar wind. 2. Determine the structure and dynamics of the plasma and magnetic fields at the sources of the solar wind. 3. Explore mechanisms that accelerate and transport energetic particles.	- Heating mechanisms of the corona and the solar wind; - Environmental control of plasma and fields; - Connection of the solar corona to the inner heliosphere. - Particle energization and transport across the corona	- Electric & magnetic fields and waves, Poynting flux, absolute plasma density & electron temperature, spacecraft floating potential & density fluctuations, & radio emissions - Energetic electrons, protons and heavy ions - Velocity, density, and temperature of solar wind e-, H+, He++ - Solar wind structures and shocks	FIELDS - Magnetic Field - Electric Field - Electric/Mag Wave ISIS - Energetic electrons - Energetic protons and heavy ions - (10s of keV to ~100 MeV) SWEAP - Plasma e-, H+, He++ - SW velocity & temperature WISPR - White light measurements of solar wind structures

L1 Requirements are unchanged since CDR.

Spacecraft Overview



- NASA selected instrument suites
- 685 kg max launch wet mass
- Reference Dimensions:
  - S/C height: 3 m
  - TPS max diameter: 2.3 m
  - S/C bus diameter: 1 m
- C-C Thermal protection system
- Hexagonal prism s/c bus configuration
- Actively cooled solar arrays
  - 388 W electrical power at encounter
  - Solar array total area: 1.55 m^2
  - Radiator area under TPS: 4 m^2
- 0.6 m HGA, 34 W TWTA Ka-band science DL
- Science downlink rate: 167 kb/s at 1AU
- Blowdown monoprop hydrazine propulsion
- Wheels for attitude control

Primary Mission: Launch and Mission Design Overview

Launch

- **Prime Window: 31 Jul 31 – 19 Aug 2018 (20 days)**
- **Back-Up Window: 21 May – 3 Jun 2019 (14 Days)**
- **Max. Launch C3: 154 km²/s²**
- **Delta IVH with Star-48BV based Third Stage**

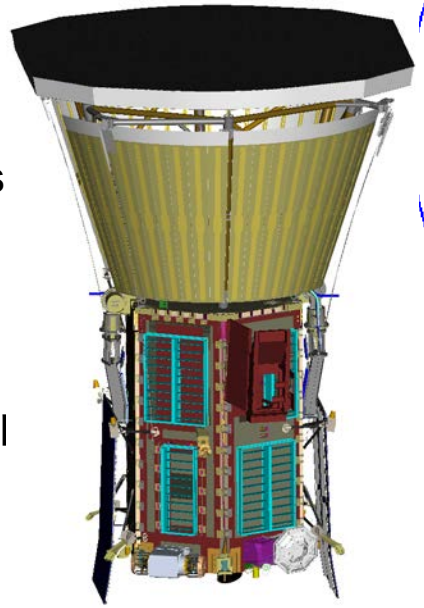
Trajectory Design

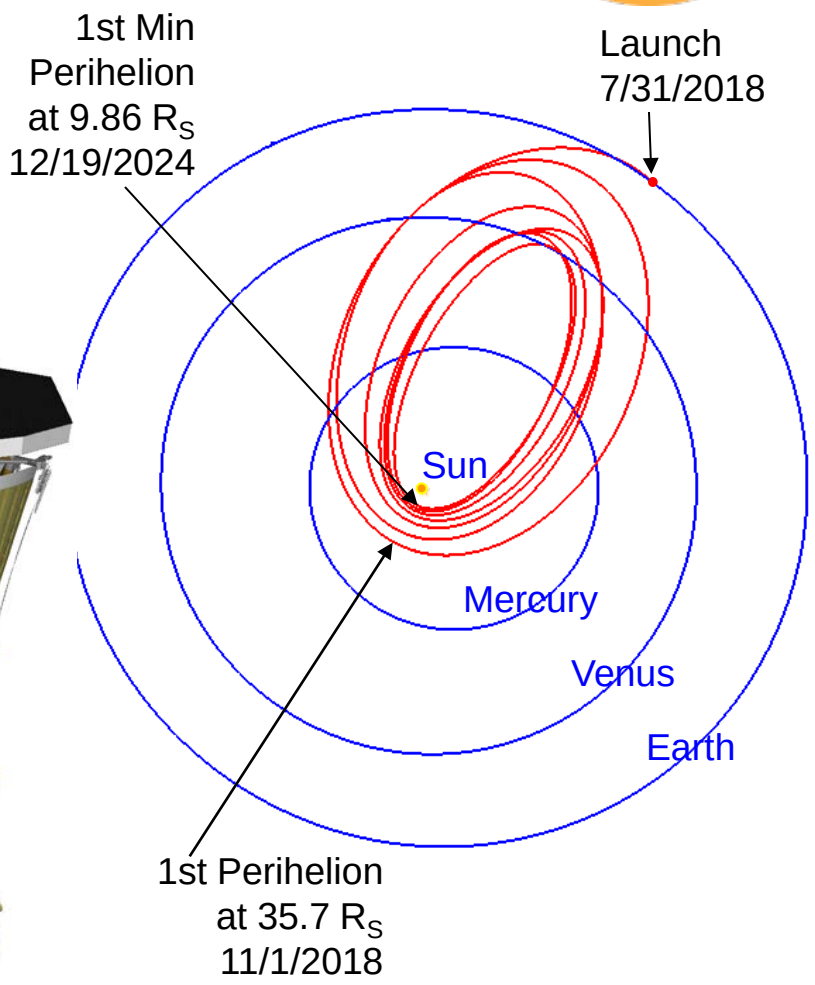
- **24 Orbits**
- **7 Venus gravity assist flybys**

Final Solar Orbits

- **Perihelion: 9.86 R_S**
- **Aphelion: 0.73 AU**
- **Inclination: 3.4 deg from ecli**
- **Orbit period: 88 days**

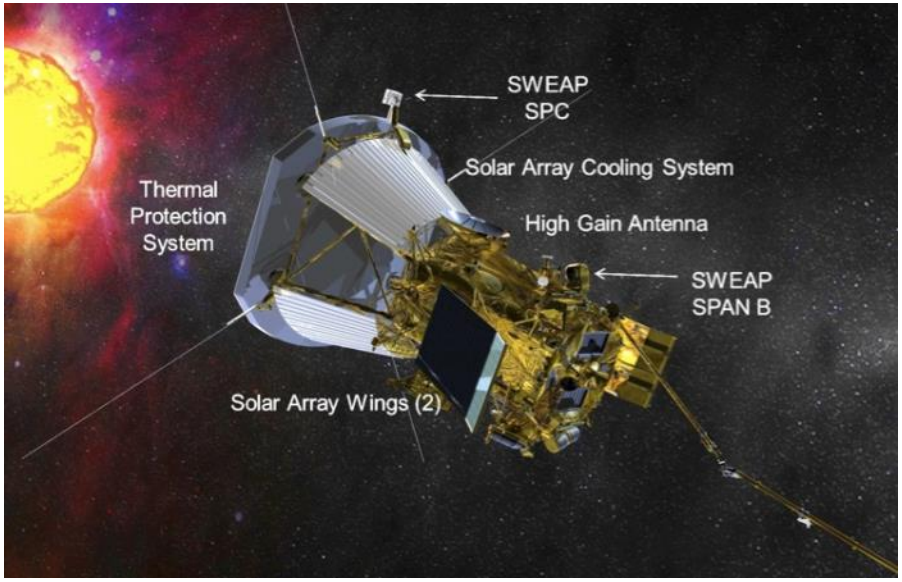
Mission duration: 7 years

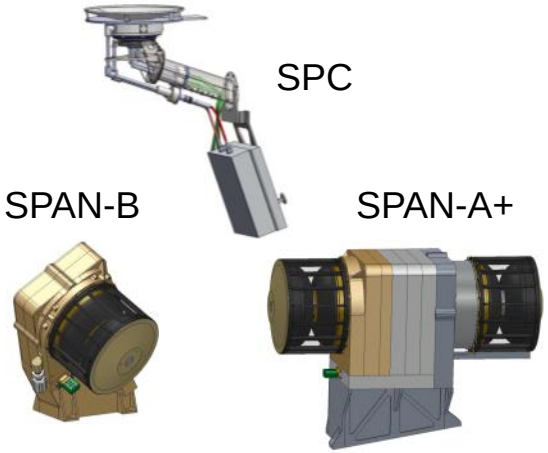




Solar Probe Plus Science Investigations (1/5)

- **Solar Wind Electrons Alphas and Protons (SWEAP) Investigation**: This investigation will count the most abundant particles in the solar wind -- electrons, protons and helium ions -- and measure their properties such as velocity, density, and temperature.





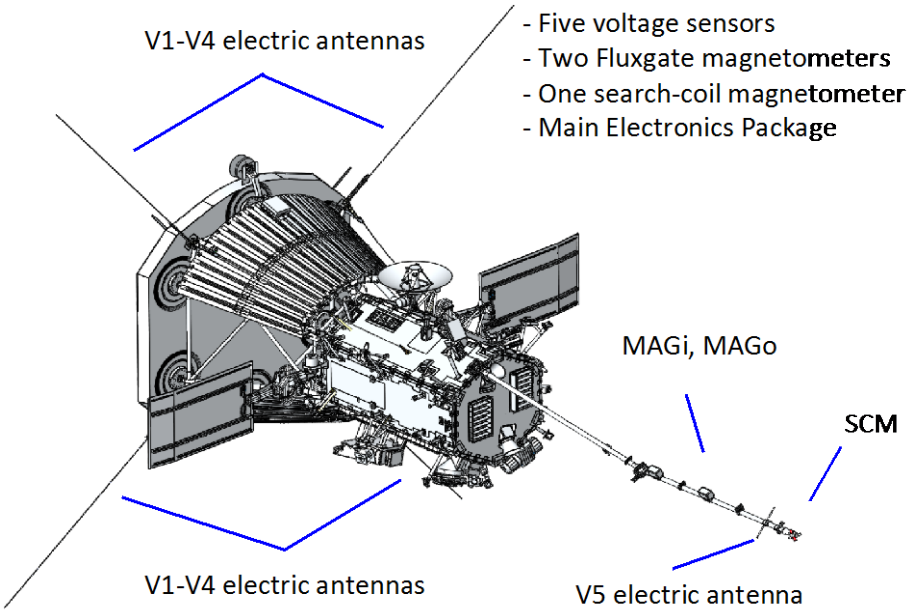
SWEAP Investigation

SWEAP PI
Prof. Justin Kasper
University of Michigan/ Smithsonian Astrophysics Observatory

Solar Probe Plus Science Investigations (2/5)

- **Fields Experiment (FIELDS):** This investigation will make direct measurements of electric and magnetic fields and waves, Poynting flux, absolute plasma density and electron temperature, spacecraft floating potential and density fluctuations, and radio emissions.

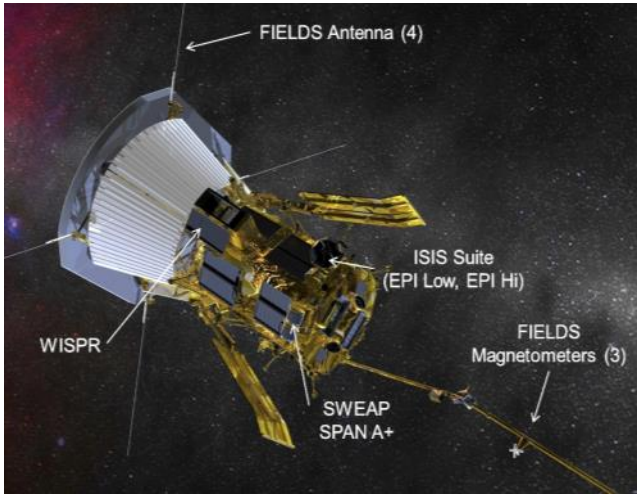
FIELDS Investigation



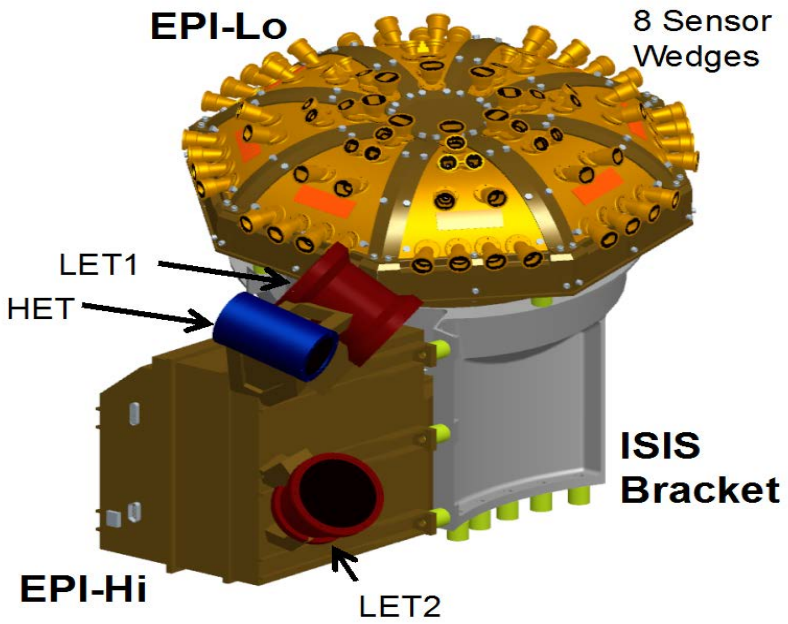
FIELDS PI
Prof. Stuart Bale
University of California, Berkeley

Solar Probe Plus Science Investigations (3/5)

- **Integrated Science Investigation of the Sun (ISIS)**: This investigation makes observations of energetic electrons, protons and heavy ions that are accelerated to high energies (10s of keV to 100 MeV) in the Sun's atmosphere and inner heliosphere, and correlates them with solar wind and coronal structures.



ISIS Investigation

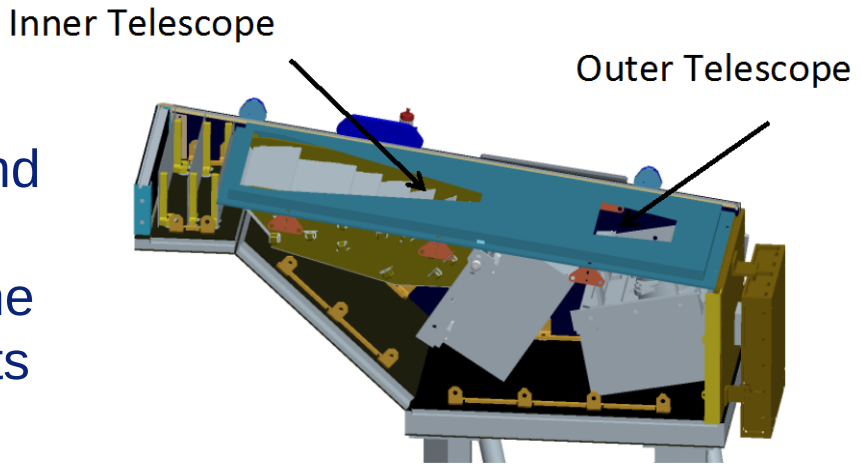


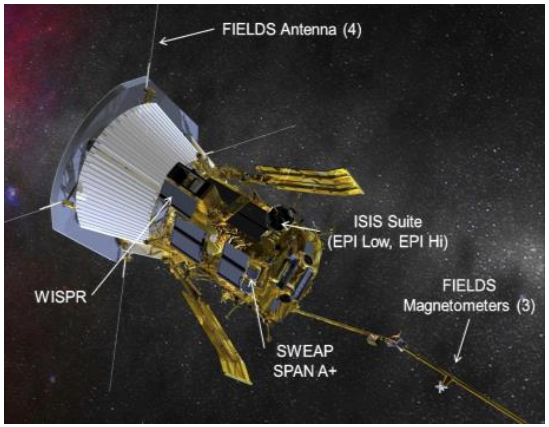
ISIS PI
Dr. David McComas
Princeton

Solar Probe Plus Science Investigations (4/5)

- **Wide-field Imager for Solar PRobe (WISPR)**: These telescopes will take images of the solar corona and inner heliosphere. The experiment will also provide images of the solar wind, shocks and other structures as they approach and pass the spacecraft. This investigation complements the other instruments on the spacecraft providing direct measurements by imaging the plasma the other instruments sample.

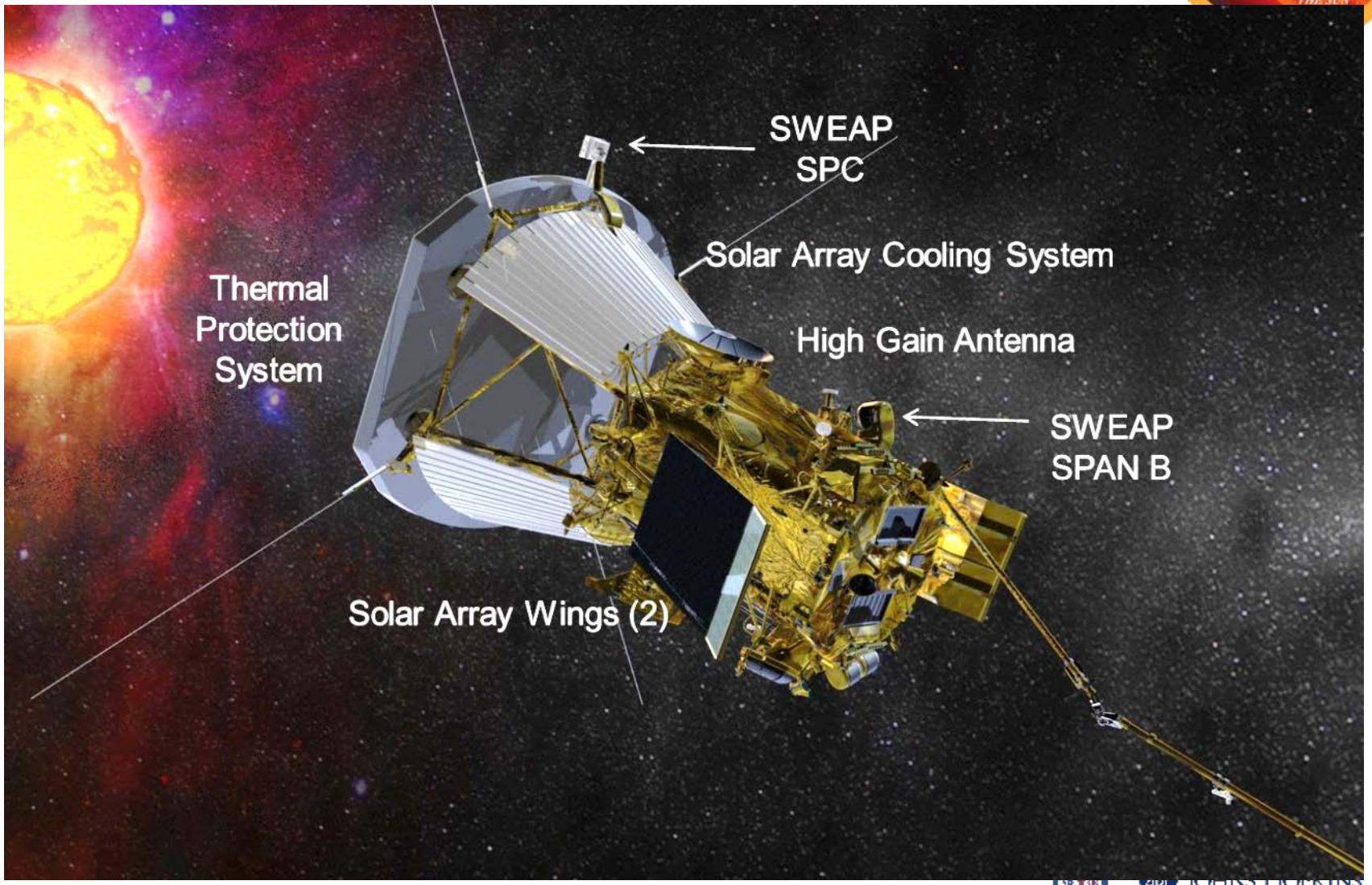
WISPR Investigation



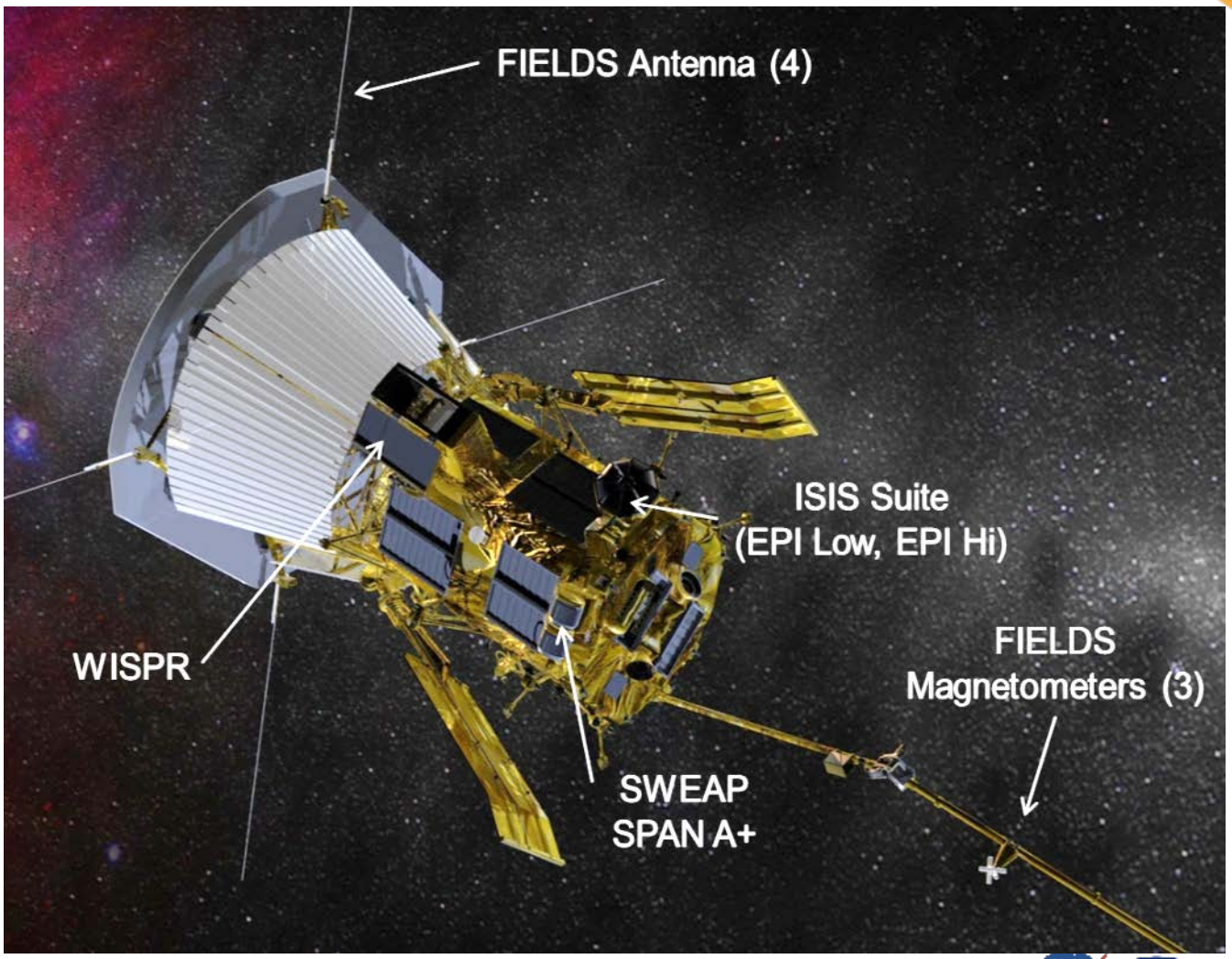


WISPR PI
Dr. Russell Howard
Naval Research Laboratory

Reference Vehicle: Anti-Ram Facing View



SPP Ram Facing View



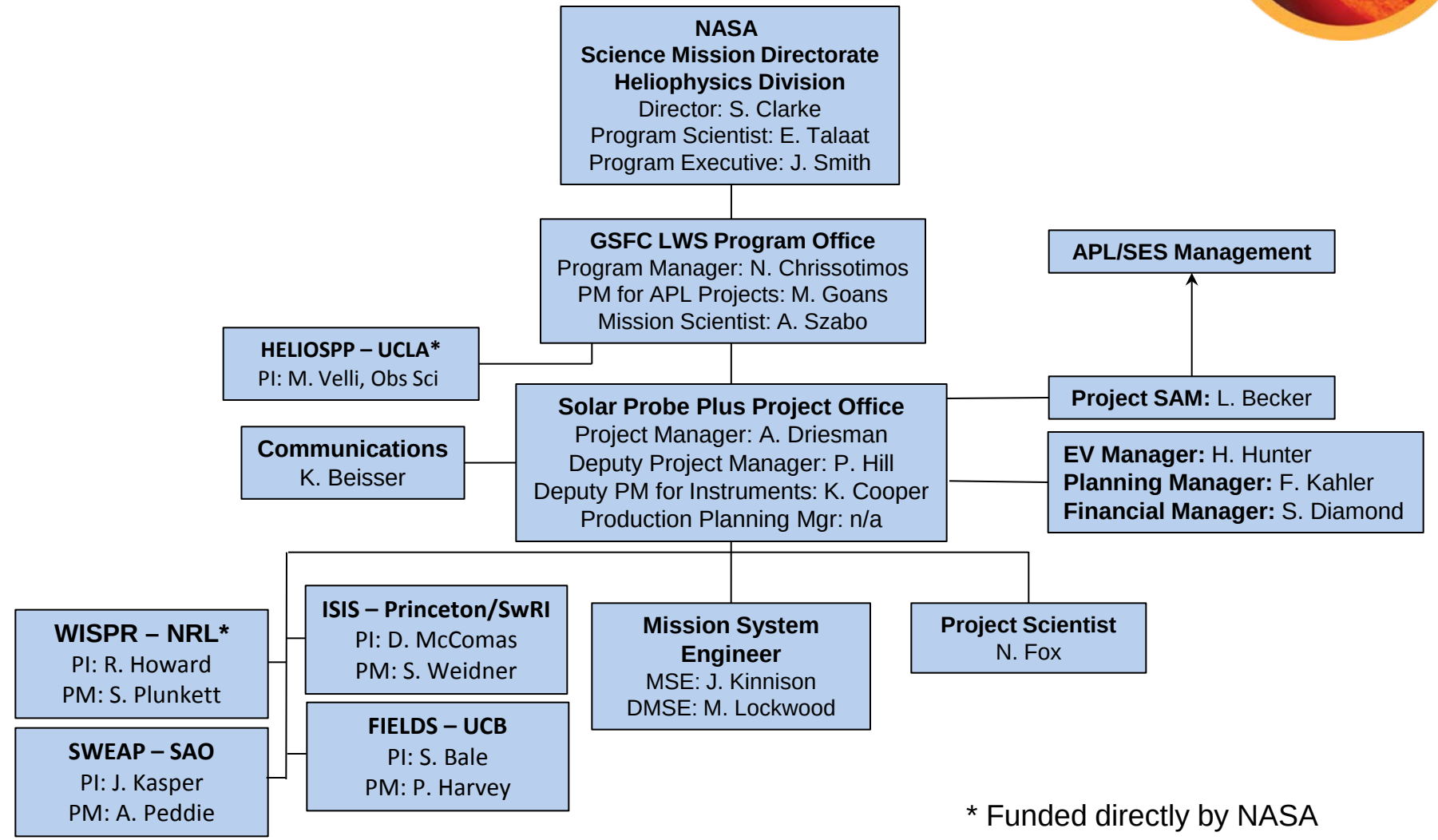
Solar Probe Plus Science Investigations (5/5)

- **Heliospheric origins with Solar Probe Plus (HeliOSPP)**: The HELIOSPP PI serves as the Observatory Scientist for the SPP Project, and carries out an inter-disciplinary science investigation that focuses on the goals and objectives of the SPP mission. He serves on the SPP SWG and provides independent (from the instrument PIs) input to the SPP Project Scientist.

Marco Velli

HelioSPP PI
Dr. Marco Velli
University of California, Los Angeles

SPP High Level Organizational Chart



* Funded directly by NASA

SPP Mission Summary – Overall Assessment

	JUN	JUL	AUG	COMMENTS
Technical	G	G	G	Technical concerns do not threaten system performance. Working through Critical Event Coverage. Spacecraft generating TLM and accepting commands
Cost	G	G	G	Funding through Mar 2017. Reserves on commitments-to-go remain healthy.
Schedule	G	G	G	I&T currently on schedule. Schedule reserve is at 90d w/ 55d guideline. SACS remains the biggest concern.
Science	G	G	G	SWG planned for 14/15 Sept 2016. Launch and Early Orbit Operations review scheduled for late Sept. Review includes commissioning.
Spacecraft	Y	Y	Y	Recent measurements of Processor margin remain at or about SIR levels: 13% on record, 11% on playback. Still considered red. Will be implementing some low-risk precision changes to increase margin. A parallel effort and timeline has been identified as a backup should margins continue to erode.
Instruments	G	G	G	Instrument reserves into I&T: FIELDS – 65d, SWEAP – 33d, ISOIS – 65d, WISPR – 33d
Ground System	G	G	G	On schedule.
Launch System	G	G	G	Launch system on track. Completing analysis of TFA results. Evaluating ULAs desire to move the daily launch window by 1 hour.
Programmatic	G	G	G	No issues.
Overall	G	G	G	Adequate cost and schedule reserves are sufficient to mitigate known technical risks.

Flight Computer Processor Margin

Technical:

Issue: Flight Computer Processor Margin

Risk to mission: - If available processor margin hits 0%, data can be lost on record or not sent as quickly with playback

- Spacecraft safety is not an issue. High priority tasks such as G&C and Autonomy always run before playback and record

Current Status:

- Critical CPU Margin is red.
  - Per SD-QP-600 red to yellow transition is 20% @ delivery to I&T, 10% @ launch
- Margin for recording at maximum rates: 13%
- Margin for playback at 833 kbps: 11%
- Record margin is the more critical margin; Data is lost if not recorded.
- For playback, CFDP assures data is received should processor be overtaxed.

Action:

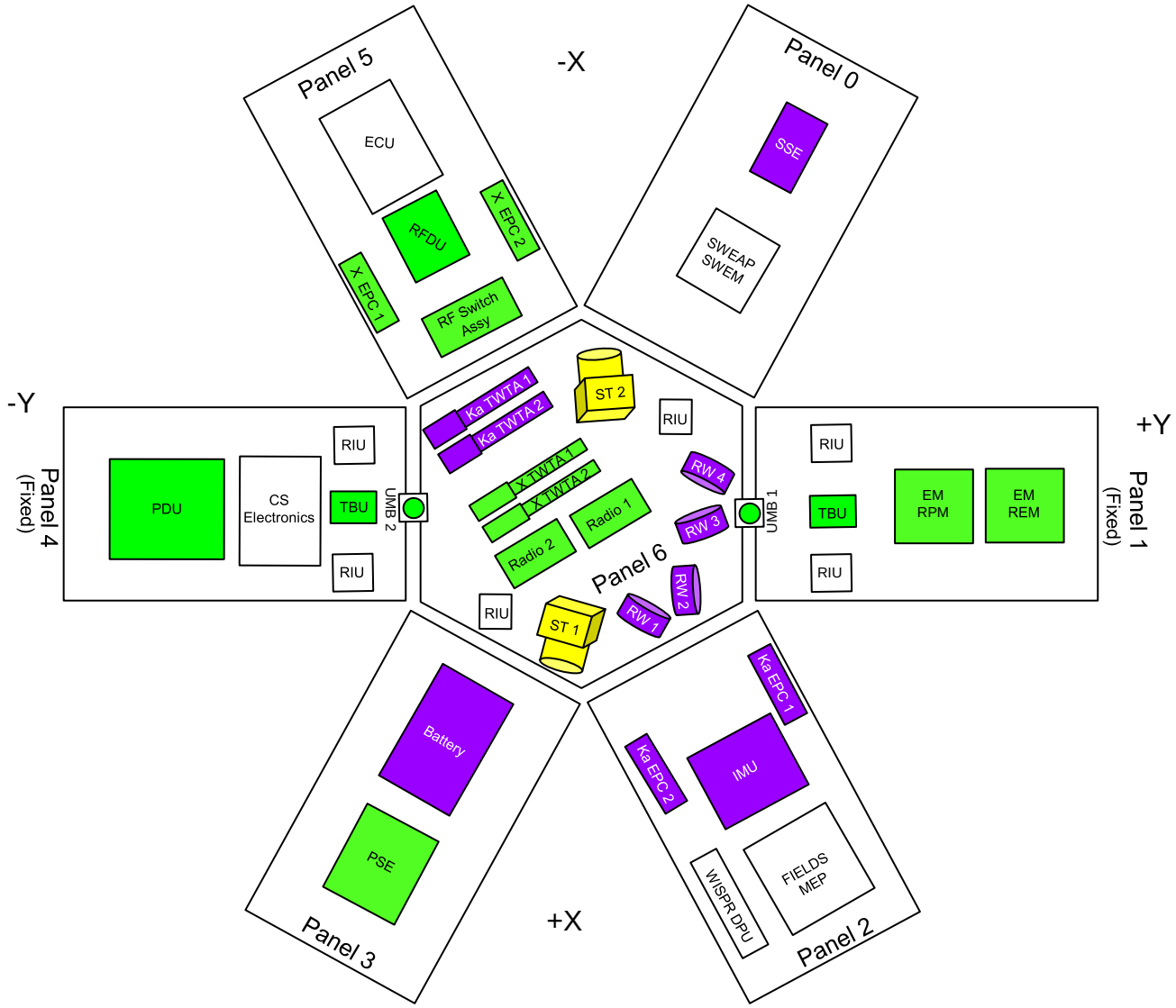
- Continue work to increase margin in a manner that minimizes impact to the flight software delivery schedule. Expectation is we can increase margins by low single digits in this manner. Risk to FSW schedule is low.
- After delivery of FSW B3.0 to I&T, assess additional methodologies for increasing margin, including: reducing data processing requirements and moving certain real-time tasking to background tasking. None of these items are considered to be architecture changes.
  - In this assessment we would identify trigger points when we would need to start this work in order to have final code prior to system TV.
  - Note this is back-up plan only. Risk to FSW would be moderate if implemented.

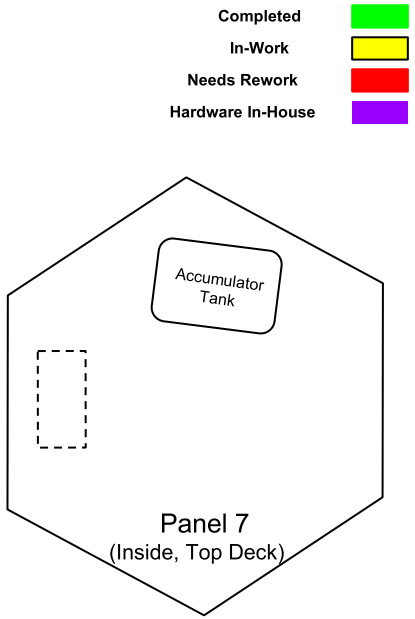
Significant Progress (as of 31 Jul 2016)

- Successfully passed KDP-D on 7 July 2016
- Integration and test formally started on 1 July 2016 with delivery of the flight structure with the integrated Propulsion Subsystem.
- Cooling System: Completed fabrication of all 4 Radiators
- Telecomm: Completed Radio acceptance testing
- Power: SolAero continued manufacturing of S/A strings
- Mag Boom: Completed flight inward boom bonding and flight outward boom bonding efforts
- G&C: Completed bench testing of star trackers and inertial measurement unit
- Software: Delivered Flight Software Build 3.0 to spacecraft integration and test
- Thermal: Received three of the four remaining louvers
- Dust: Completed estimate for impact based contamination of SPC sensor from TPS edge felt
- SWEAP: Completed QM SPC sensor assembly and vibration testing
- FIELDS: Digital Fields Board (DFB) FM1 successfully Integrated with the MEP
- WISPR: All instrument mount configurations (nominal intermediate, and tall) were shipped for welding
- ISʘIS: EMI Closeout concept developed for EPI-Hi. EPI-Lo flight assemblies being calibrated

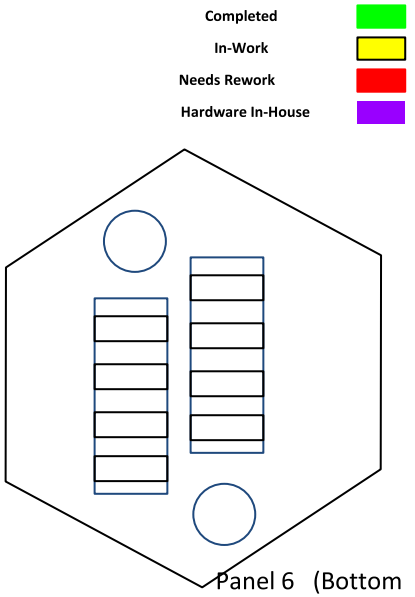
- SPP SWG-14 Meeting: 14-15 September 2016, Smithsonian Castle, Washington, DC

Hardware Status – Interior
(as of 10/5/2016)

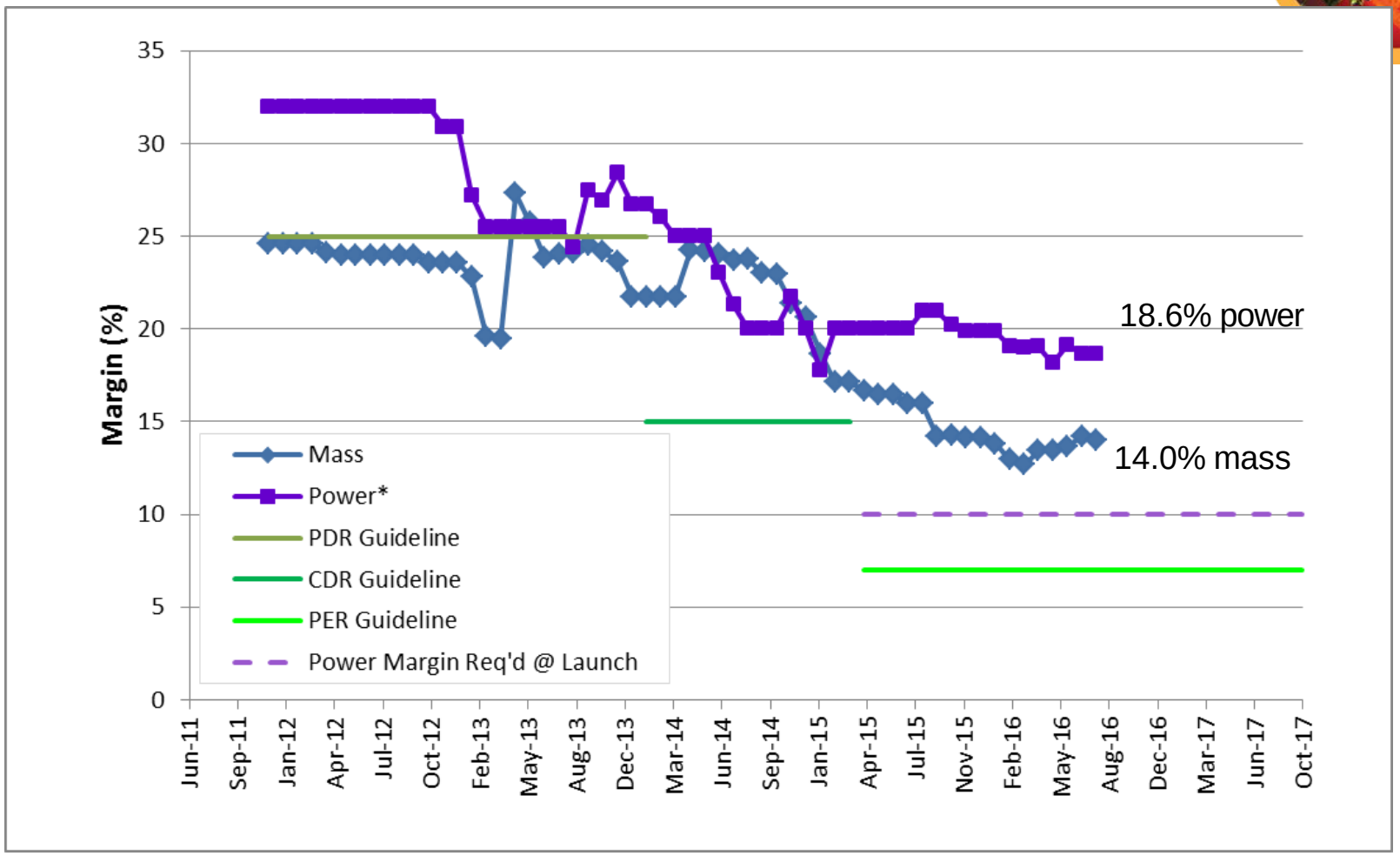




Hardware Status – Exterior
(as of 10/5/2016)



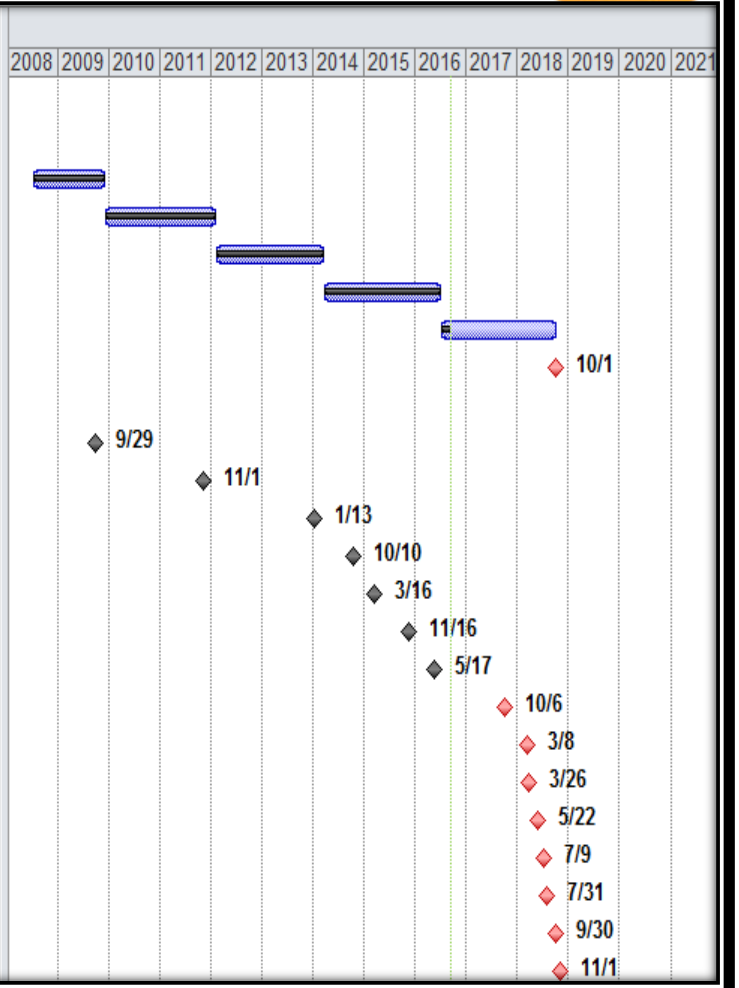
Mass, Power Margin



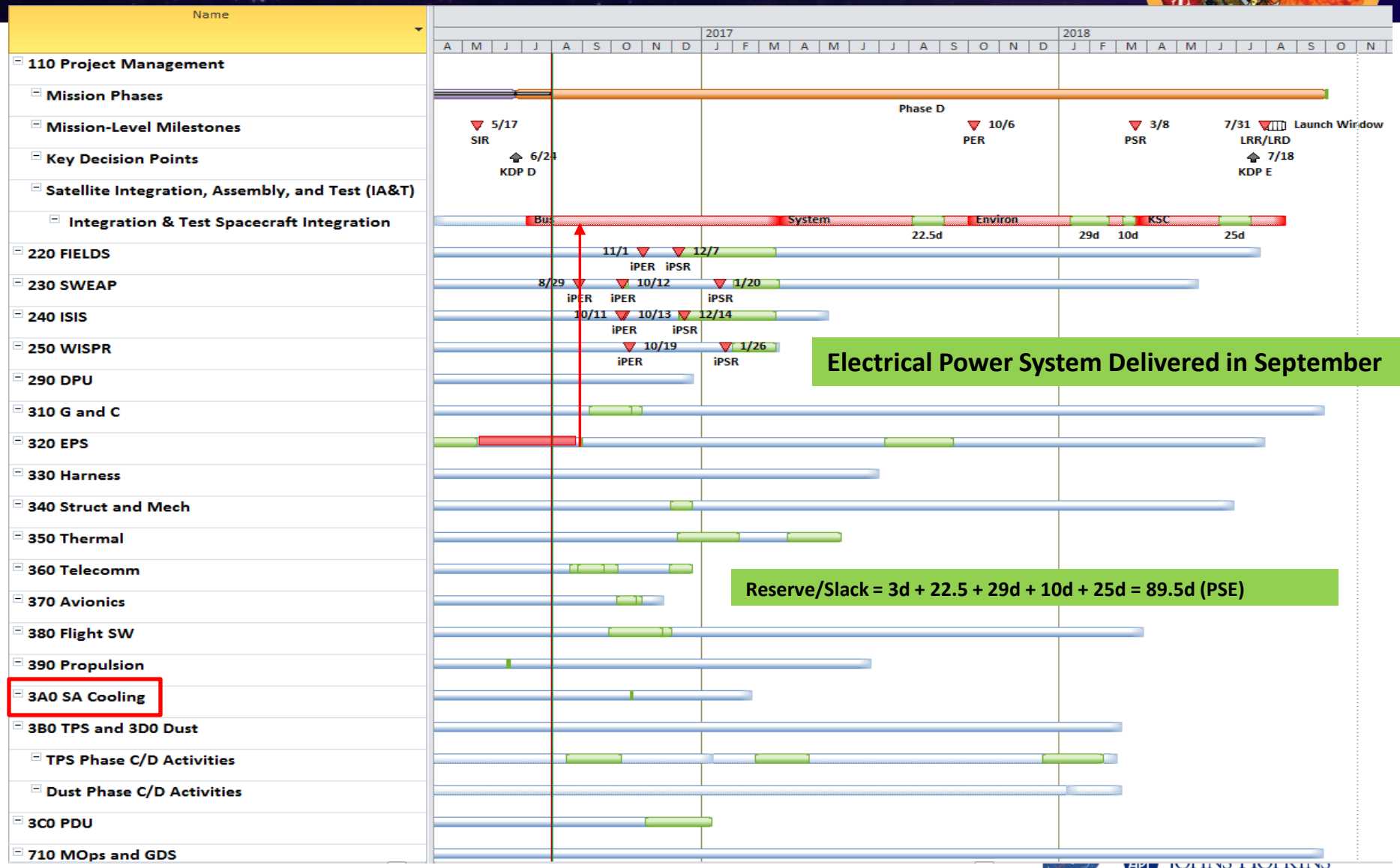
*Reporting minimum margin for driving configurations: Perihelion Science, Slew Data Downlink
Dec 2014 power margin rebaselined to 20%. Power margin previously above 20% was returned to cooling system margin.

Major Life Cycle Reviews

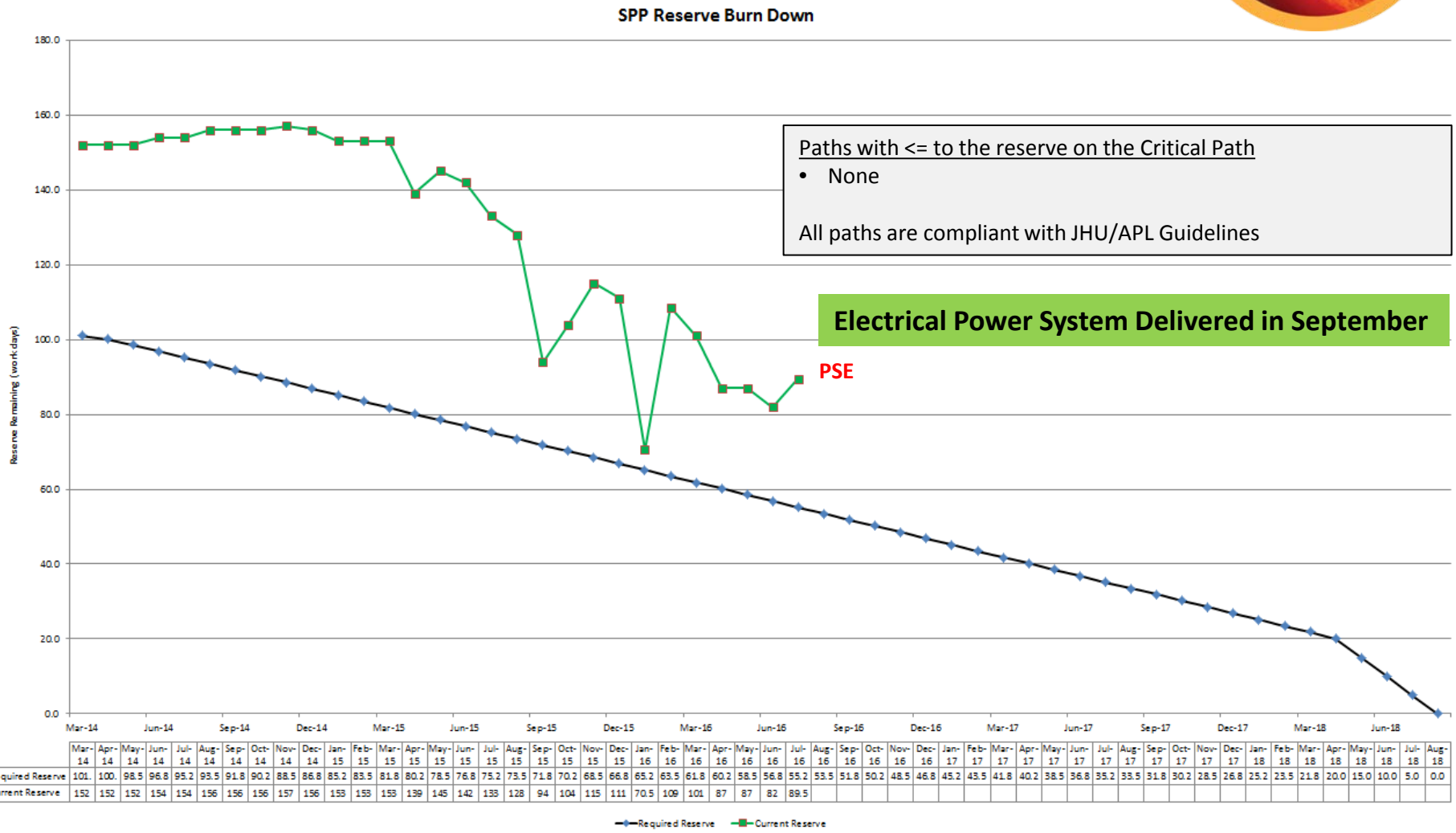
Task Name	Start	Finish
Solar Probe Plus Mission Schedule	**7/2/08**	**11/1/18**
Mission Phases	**7/2/08**	**10/1/18**
Pre-Phase A	7/2/08	12/1/09
Phase A	12/2/09	1/31/12
Phase B	2/1/12	3/14/14
Phase C	3/15/14	6/23/16
Phase D	6/24/16	9/30/18
Phase E Start (Ends 9/30/25)	10/1/18	10/1/18
Mission-Level Milestones	**9/29/09**	**11/1/18**
MCR	9/29/09	9/30/09
MDR	11/1/11	11/3/11
PDR	1/13/14	1/16/14
IBR	10/10/14	10/17/14
CDR	3/16/15	3/19/15
MOR	11/16/15	11/17/15
SIR	5/17/16	5/19/16
PER	10/6/17	10/6/17
PSR	3/8/18	3/8/18
Ship to KSC	3/23/18	3/26/18
ORR/FOR	5/22/18	5/22/18
MRR	7/9/18	7/9/18
LRR/LRD	7/31/18	7/31/18
Orbital Checkout Complete	9/30/18	9/30/18
First Perihelion	11/1/18	11/1/18



SPP Summary Schedule



SPP Critical Path Funded Schedule Reserve vs. APL Guidelines



	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18
Required Reserve	101.	100.	98.5	96.8	95.2	93.5	91.8	90.2	88.5	86.8	85.2	83.5	81.8	80.2	78.5	76.8	75.2	73.5	71.8	70.2	68.5	66.8	65.2	63.5	61.8	60.2	58.5	56.8	55.2	53.5	51.8	50.2	48.5	46.8	45.2	43.5	41.8	40.2	38.5	36.8	35.2	33.5	31.8	30.2	28.5	26.8	25.2	23.5	21.8	20.0	15.0	10.0	5.0	0.0
Current Reserve	152	152	152	154	154	156	156	156	157	156	153	153	153	139	145	142	133	128	94	104	115	111	70.5	109	101	87	87	82	89.5																									

Paths with <= to the reserve on the Critical Path

- None

All paths are compliant with JHU/APL Guidelines

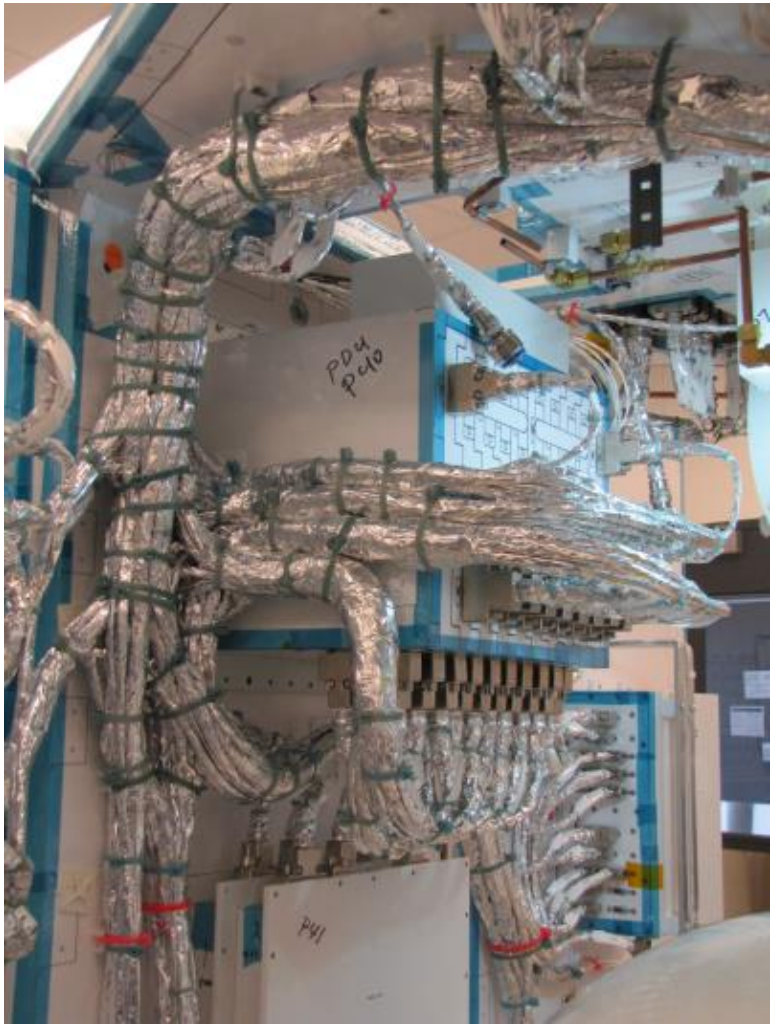
Electrical Power System Delivered in September

PSE

Budget Assessment

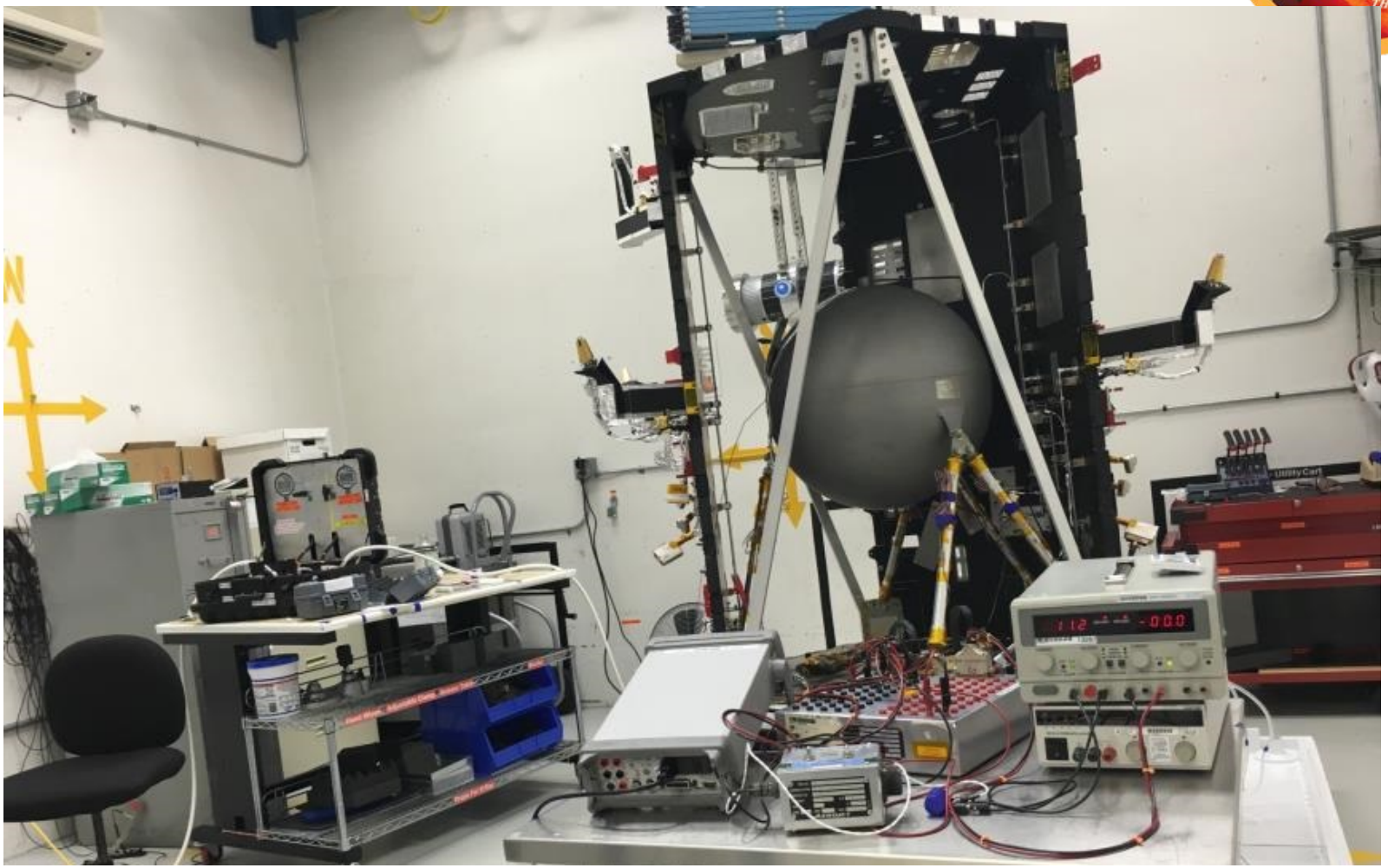
- SPP is in a very healthy financial position
  - Project estimates that reserves are 24% through liens
  - Headquarters UFE puts the project in a state of very low risk

May 2016 Accomplishments



Completed Fabrication of the Flight Spacecraft Harness at APL

June 2016 Accomplishments

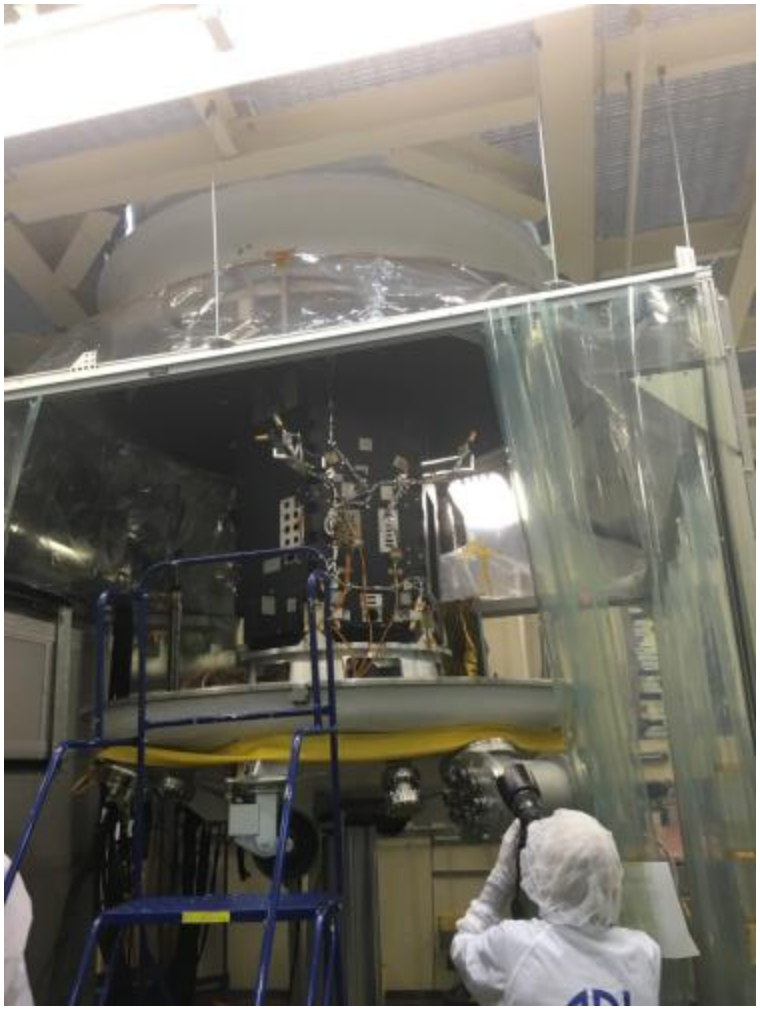


Completed Propulsion Subsystem Acceptance Testing at Aerojet Rocketdyne

June 2016 Accomplishments

Flight Primary Structure Shipped to APL from Aerojet

June 2016 Accomplishments

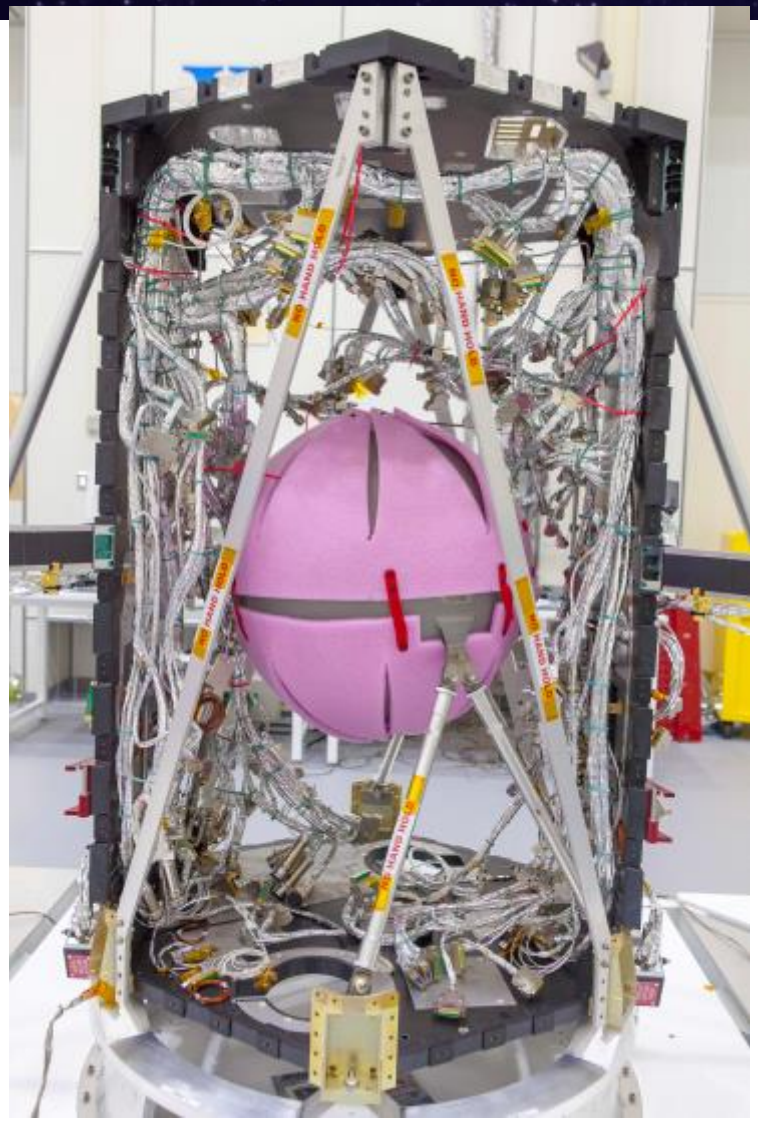


Started Flight Propulsion Thermal Verification Testing at APL

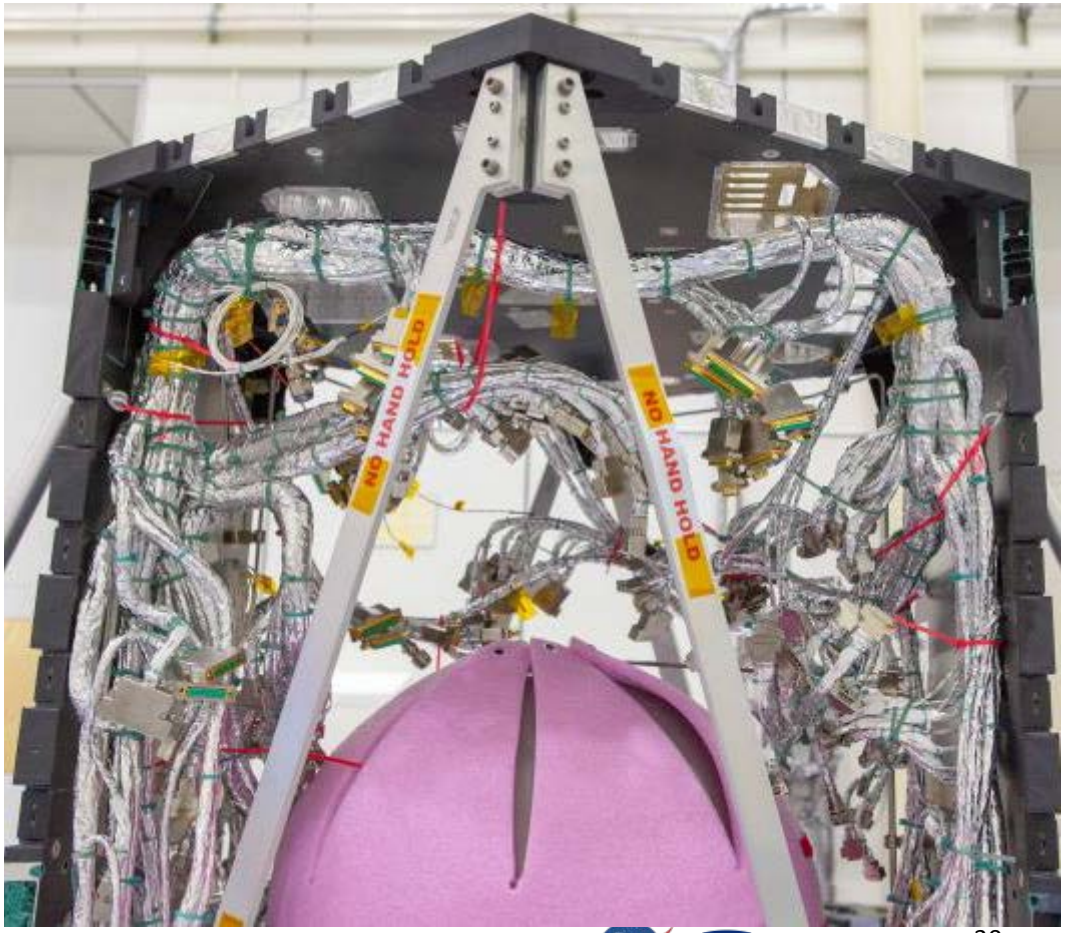
July 2016 Accomplishments

Flight Harness Installation

July 2016 Accomplishments



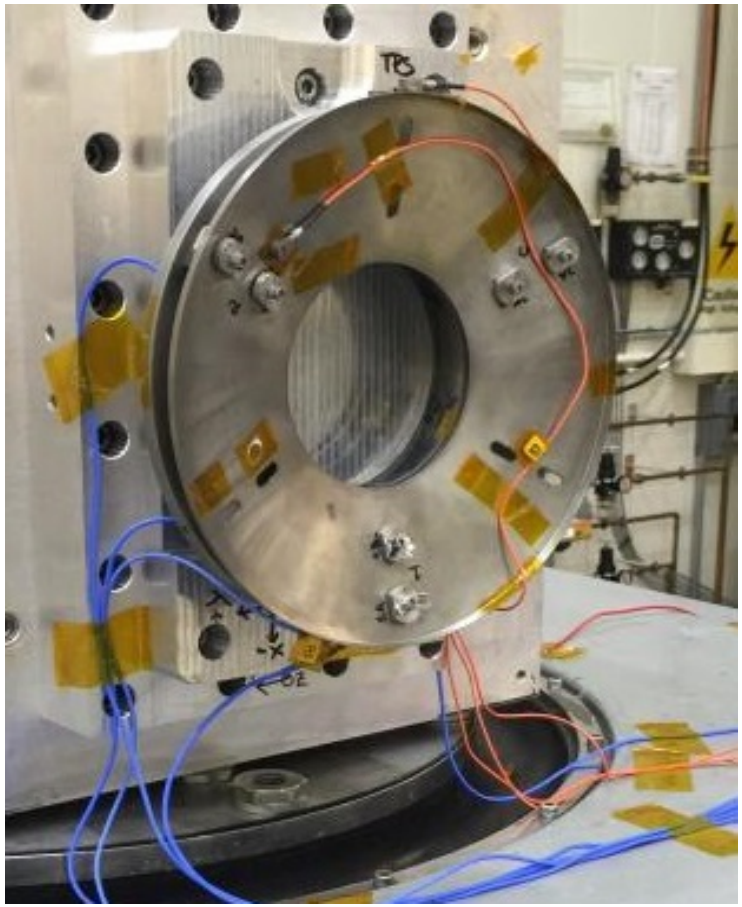
Flight Harness Installation



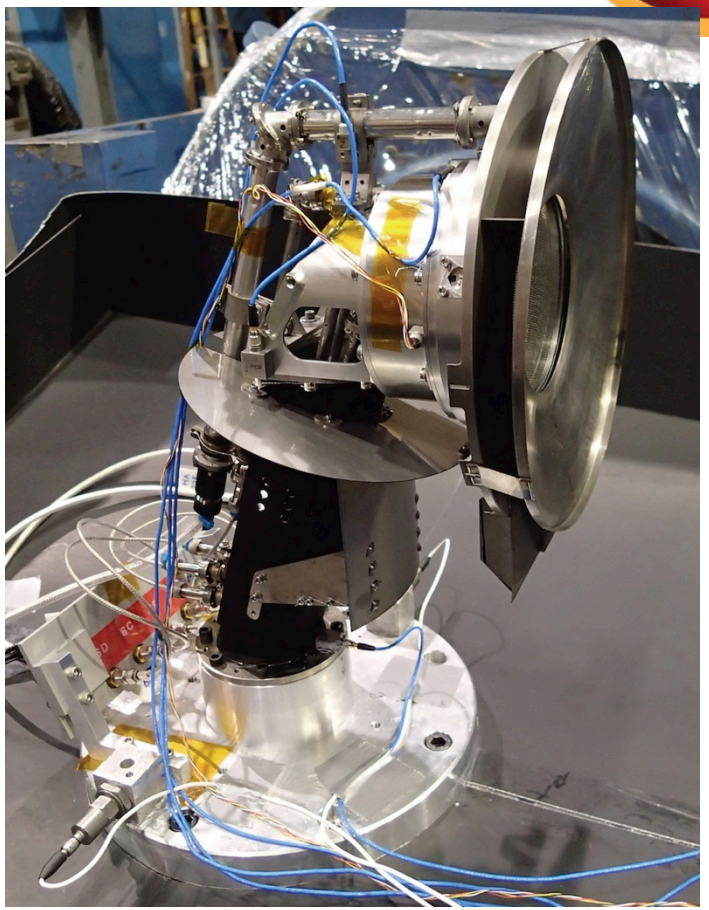
August 2016 Accomplishments

ISOIS EPI-Lo FM Wedge Assembly Complete
Undergoing Vacuum Testing with Sources

August 2016 Accomplishments

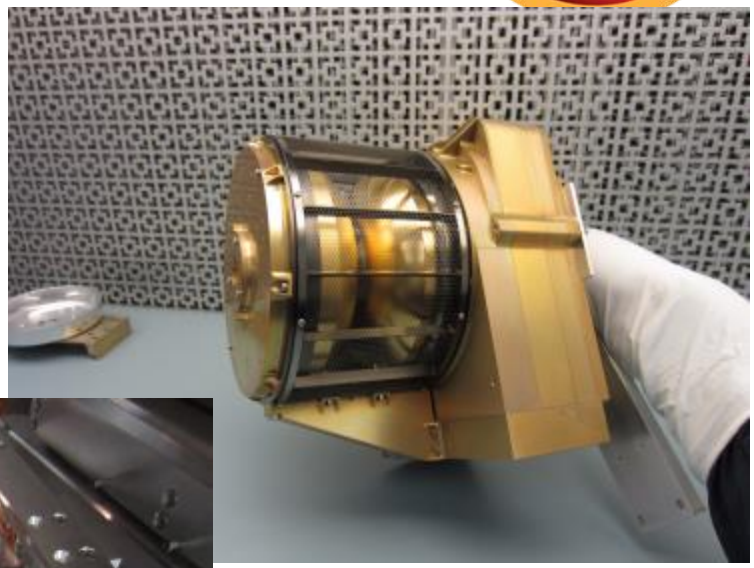


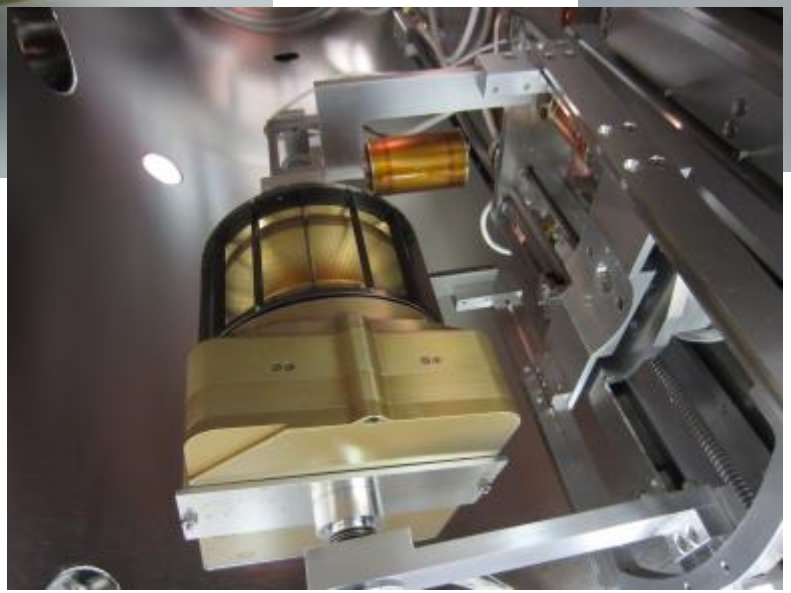
SWEAP SPC EDU Thermal Shield in Vibration Testing at APL



SWEAP SPC QM Sensor in Vibration Testing at SAO

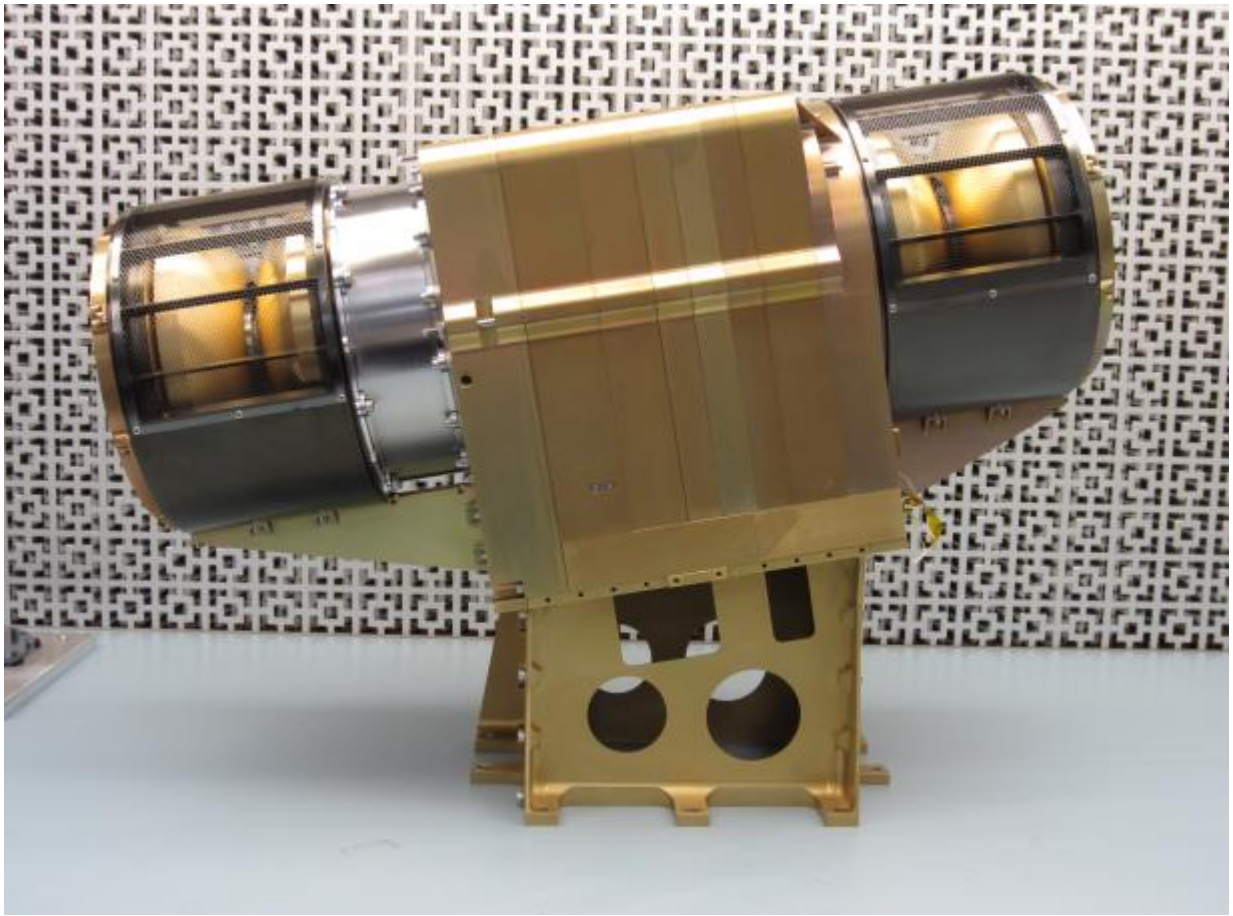
August 2016 Accomplishments





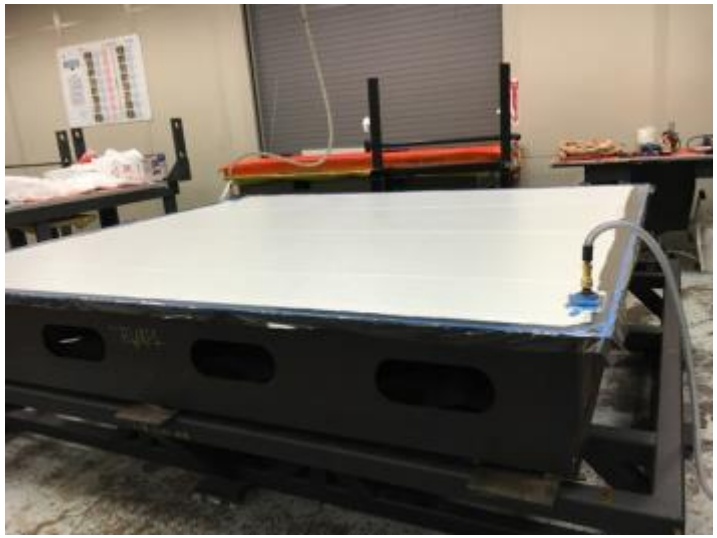
SWEAP SPAN-Ae FM Goes Into the Calibration Chamber

August 2016 Accomplishments



SWEAP SPAN-A (ion and electron) fully assembled for fit check

August 2016 Accomplishments

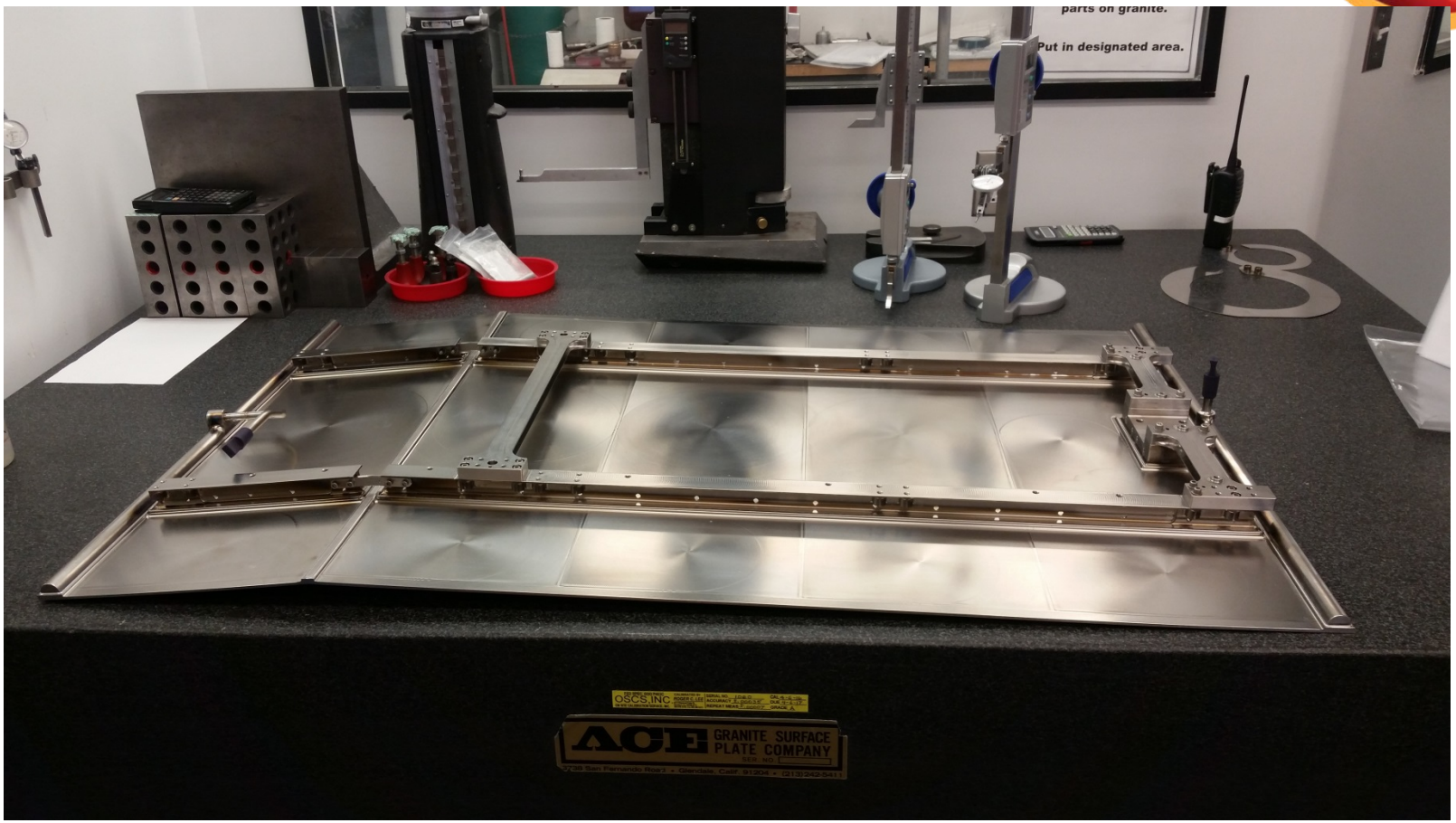


Spare Thermal Protection System fabrication continues - clockwise from left:
flat facesheet layup in progress;
pie pan facesheet in 0 condition;
interface plates

August 2016 Accomplishments

TPS Thermal Simulator

August 2016 Accomplishments



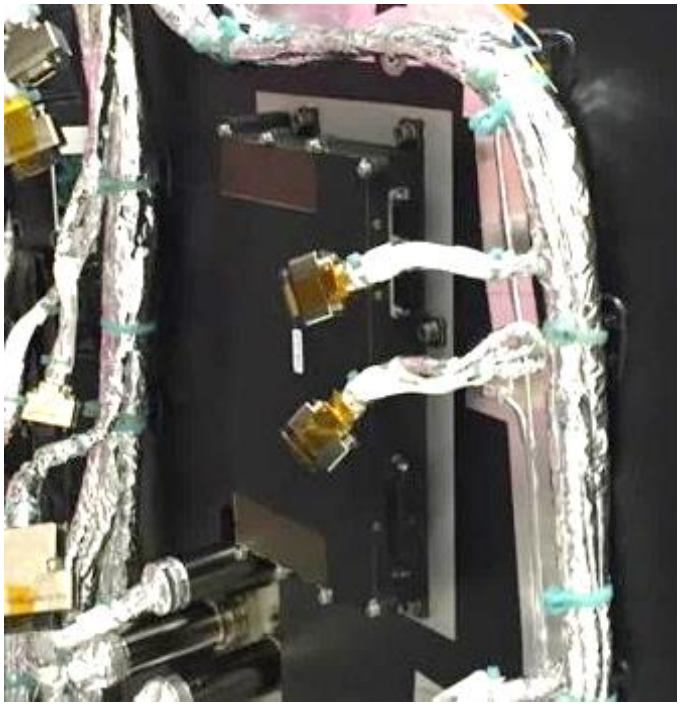
SACS SN01 Flight Solar Array Platen has completed fabrication

August 2016 Accomplishments

SACS Top Deck Component Fit-up and Welding has started

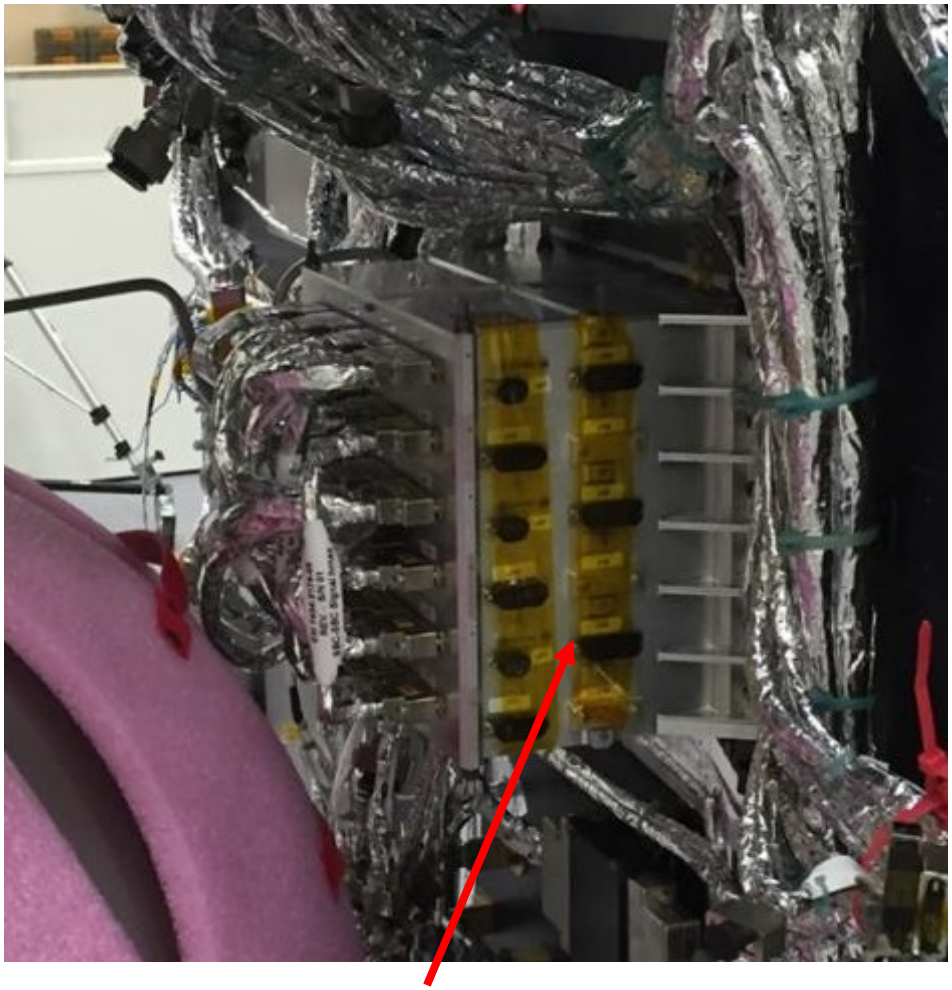
August 2016 Accomplishments

Flight PDU integrated on S/C

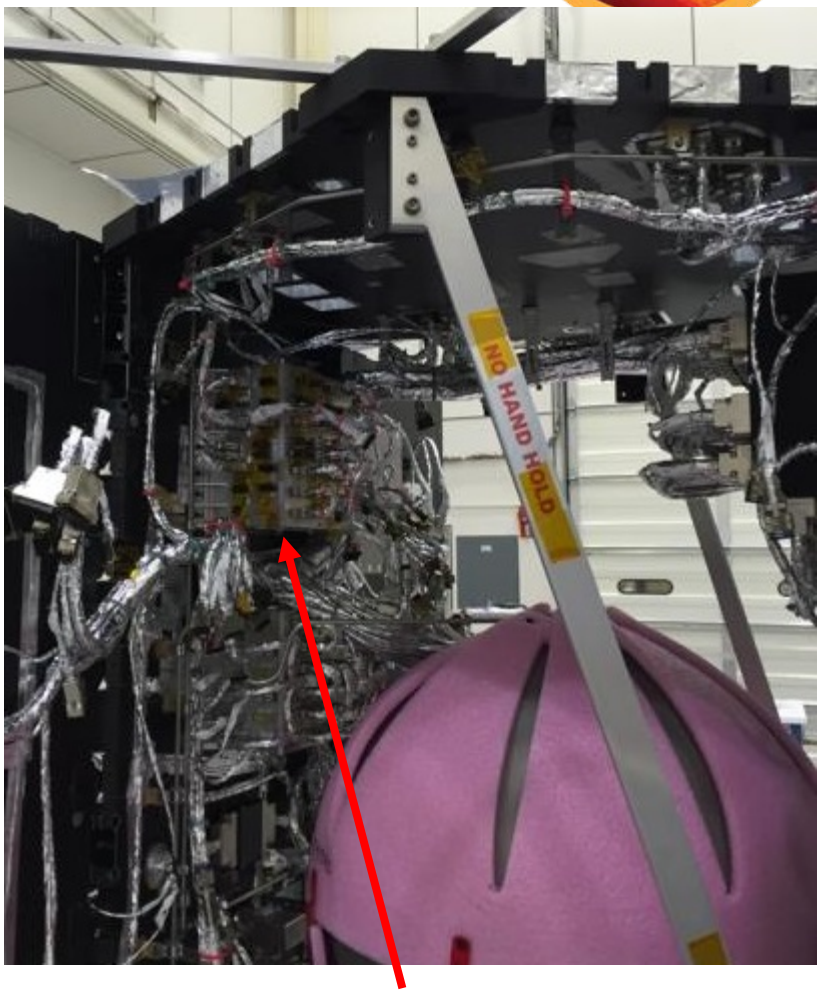


Flight RFDU integrated on S/C

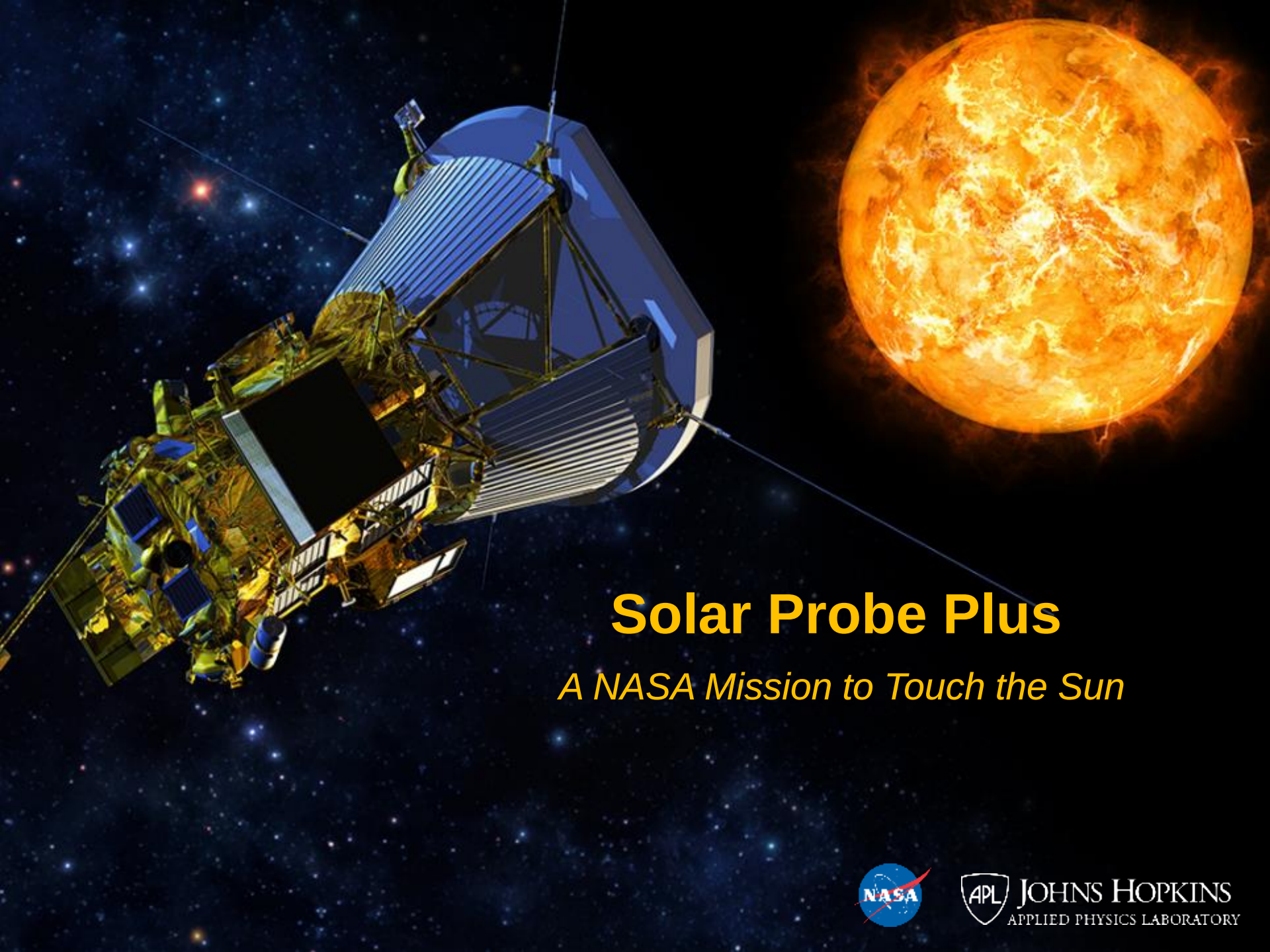
August 2016 Accomplishments



EM RPM integrated on S/C



EM REM integrated on S/C



Solar Probe Plus

A NASA Mission to Touch the Sun

NASA

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