Parker Solar Probe Mission

Ground Systems Architectures Workshop

February 26, 2019

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Parker Solar Probe

A NASA Mission to Touch the Sun

NASA

APL JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

The Mysteric

The Mysterious Corona

Mystery number 1

The temperature rises as you move away from the surface!

6,000 degrees K

Discovery of the Solar Wind

Parker (1958): hydrodynamic theory of the expanding solar corona

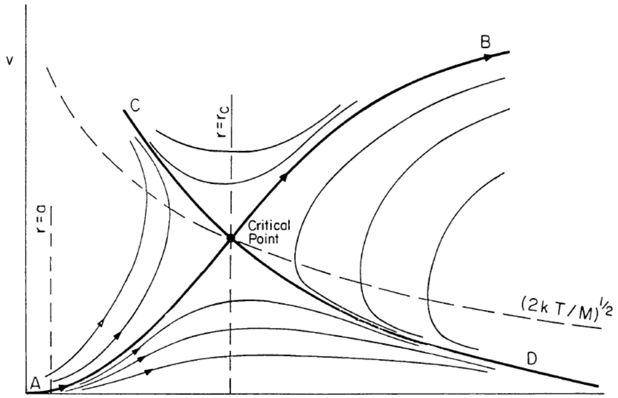
Prediction of a supersonic flow from the Sun toward the interplanetary medium

$$\nabla \cdot (\rho \mathbf{V}) = 0,$$

$$\rho(\mathbf{V} \cdot \nabla)\mathbf{V} = -\nabla p + \rho \mathbf{g},$$

$$p = \rho R T,$$

$$T = T_0.$$



Neugebauer & Snyder, Science, 138, 1095 (1962)

Solar Plasma Experiment

Abstract. A preliminary summary of the data received from the Mariner II solar plasma experiment for the period 29 August through 31 October 1962 is presented. During this period there was always a measurable flow of plasma from the direction of the sun. The velocity of this ion motion was generally in the range 400 to 700 km/sec. Time variations, plasma density, and ion temperatures are also discussed.

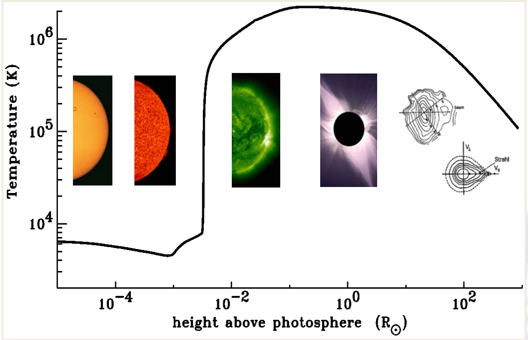
Indisputable evidence of the existence of the predicted supersonic flow, i.e., the "SOLAR WIND"

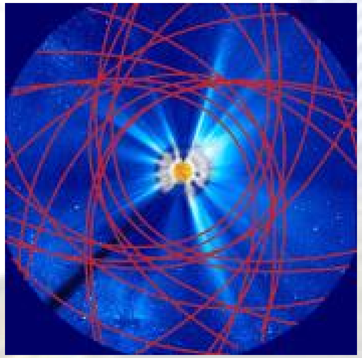
Start of a new era of heliospheric research

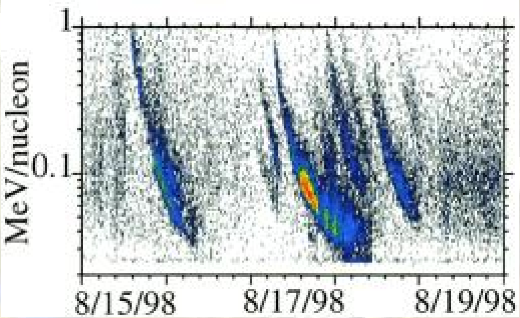
We are PARKER SOLAR PROBE!

Parker, meet Parker

Parker Solar Probe Science







- **Parker Solar Probe will study how energy flows out of the Sun, why the solar corona is so hot, and what makes the solar wind go so fast.**
  - Trace the flow of energy that heats and accelerates the solar corona and solar wind.
  - Determine the structure and dynamics of the plasma and magnetic fields at the sources of the solar wind.
  - Explore mechanisms that accelerate and transport energetic particles.

Launch and Mission Design Overview

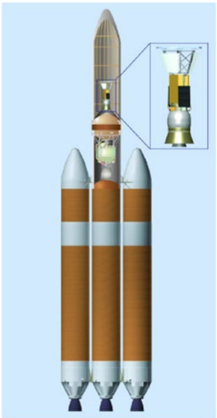
Launch

- Aug 12, 2018 at 3:31 a.m. EDT (7:31 UTC)
- Max. Launch C3: 154 km^2/s^2
- Delta IV-Heavy with Upper Stage
- From NASA's Kennedy Space Center

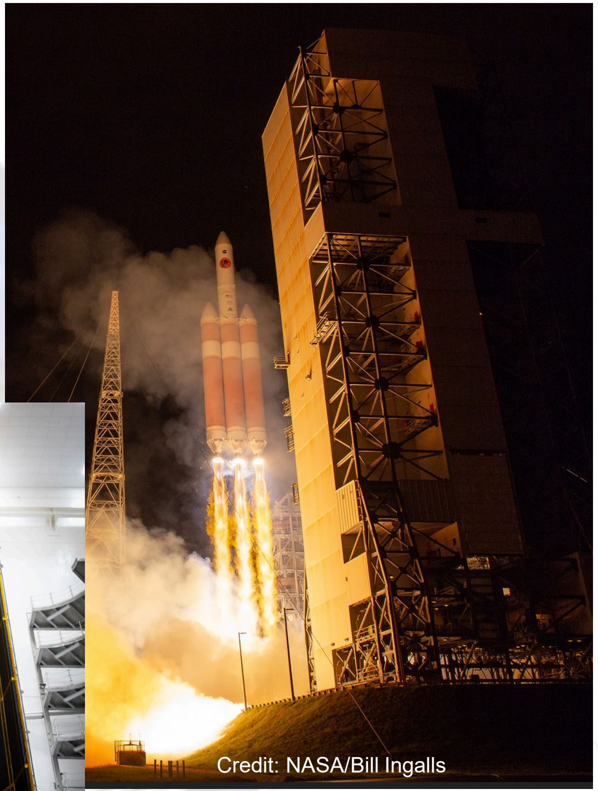
Trajectory Design

- 24 Orbits
- 7 Venus gravity assist flybys
- Orbit period: 168-88 days

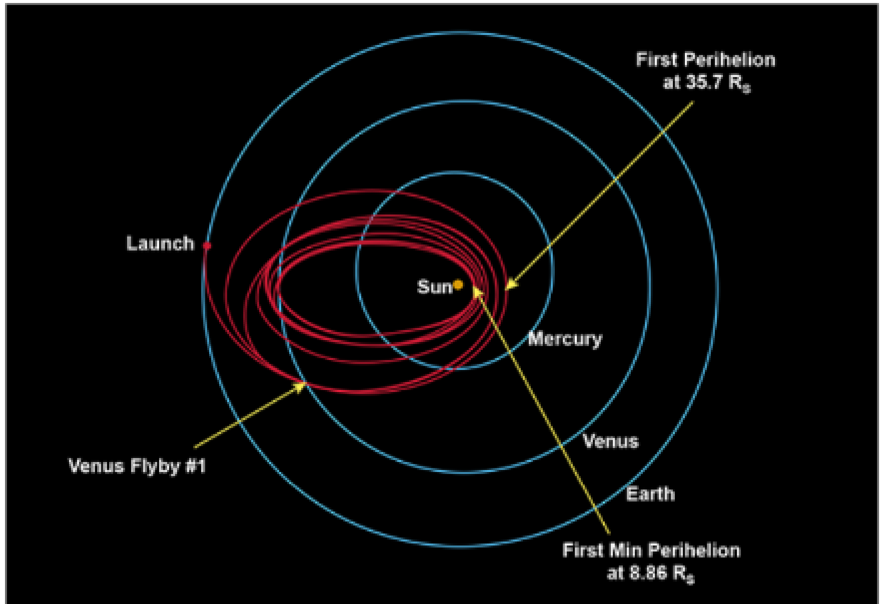
Mission duration: 7 years



Credit: NASA/Johns Hopkins APL/Ed Whitman

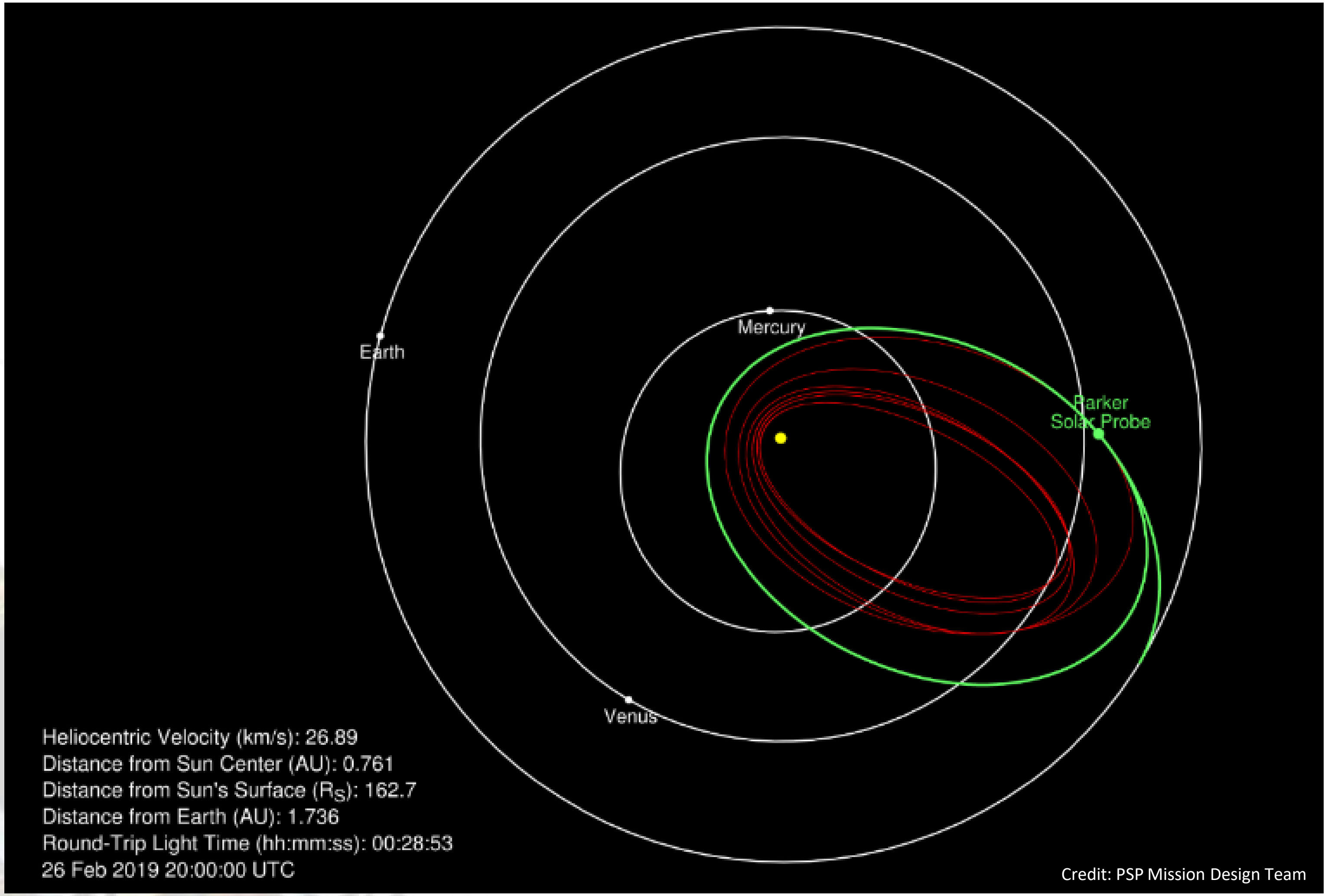


Credit: NASA/Bill Ingalls



- **Launch:** August 12, 2018 at 3:31 a.m. EDT (7:31 UTC)
- **Venus Flyby:** Oct. 3, 2018 at 4:44 a.m. EDT (08:44 UTC)
- **First Perihelion:** Nov. 5, 2018 at 10:27 p.m. EST (Nov. 6, 2018 at 03:27 UTC)

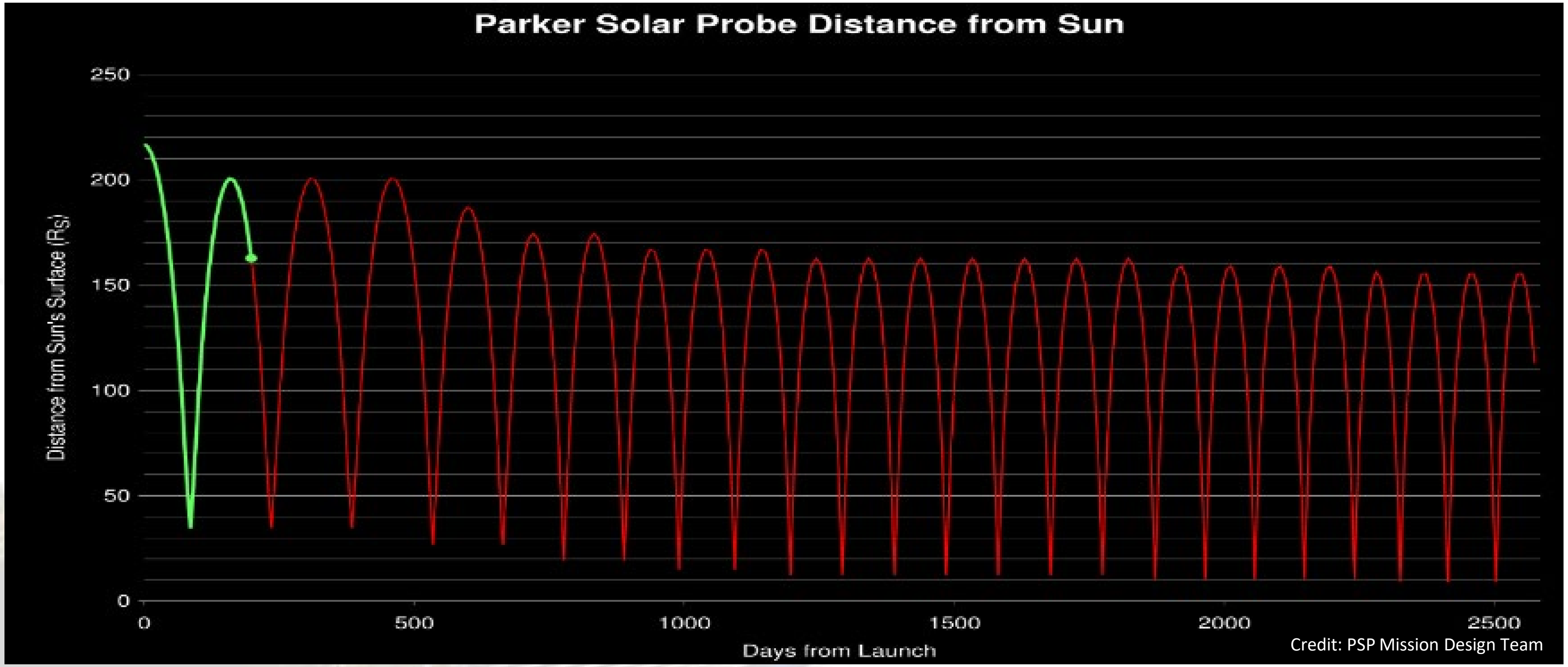
Mission Trajectory and Current Position



Credit: PSP Mission Design Team

Mission Design
Solar Orbits and Solar Distances

Orbit #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Period (d)	168	150	150	140	121	112	107	102	102	100	96	96	96	96	96	96	96	92	92	92	87	88	88	88



- 24 solar orbits, providing abundant opportunities for science investigations in the near Sun region
- Frequent visits of the Sun 3 to 4 times per year
- Perihelion gradually decreased to min solar distance of 0.04587 AU (9.86 R_S)

PSP is Small and Fast!

- Parker Solar Probe launched on the most powerful rocket available in 2018 yet needs to be very light and compact to reach the sun

Credit: NASA/Johns Hopkins APL/Ed Whitman

685 kg max launch wet mass

S/C height: 3 m

TPS max diameter: 2.3 m

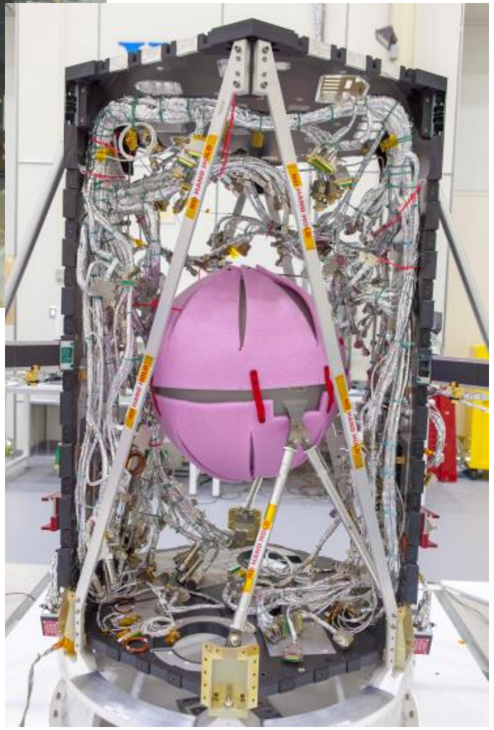
S/C bus diameter: 1 m

C-C Thermal protection system

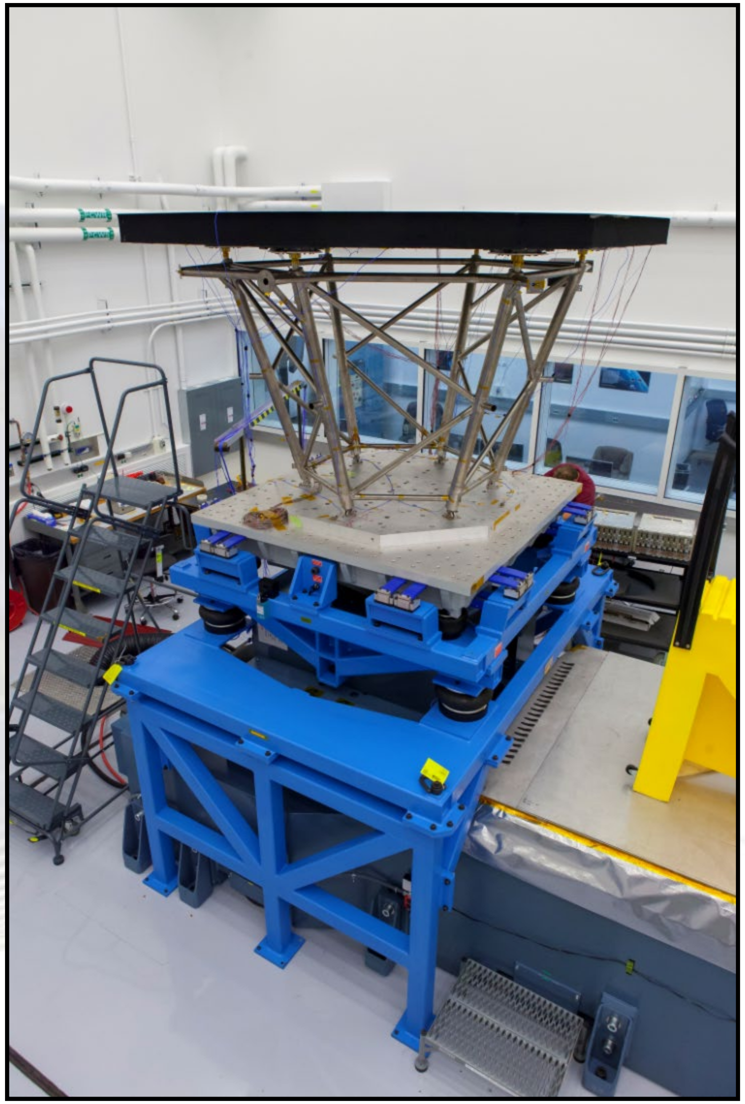
Hexagonal bus configuration

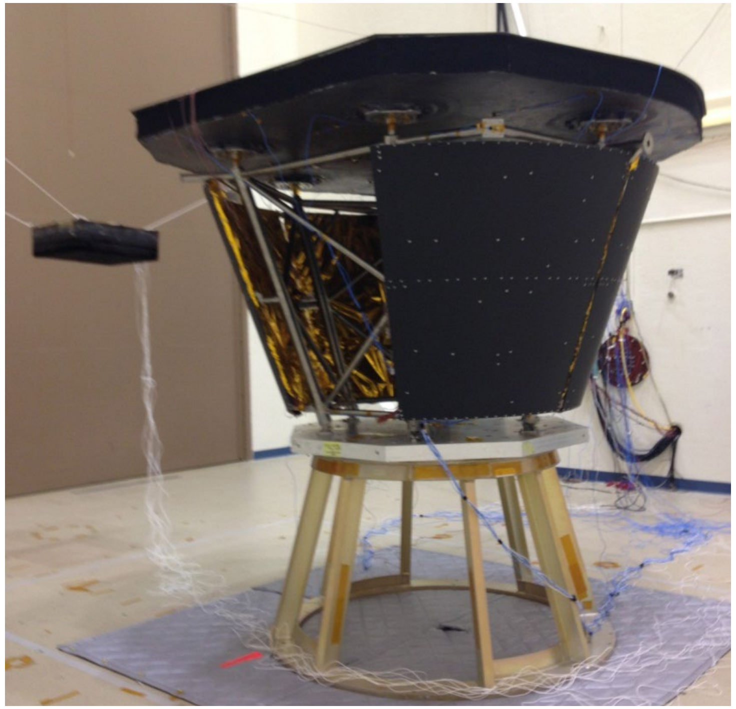
Actively cooled solar arrays

Wheels for attitude control



Thermal Protection System Assembly

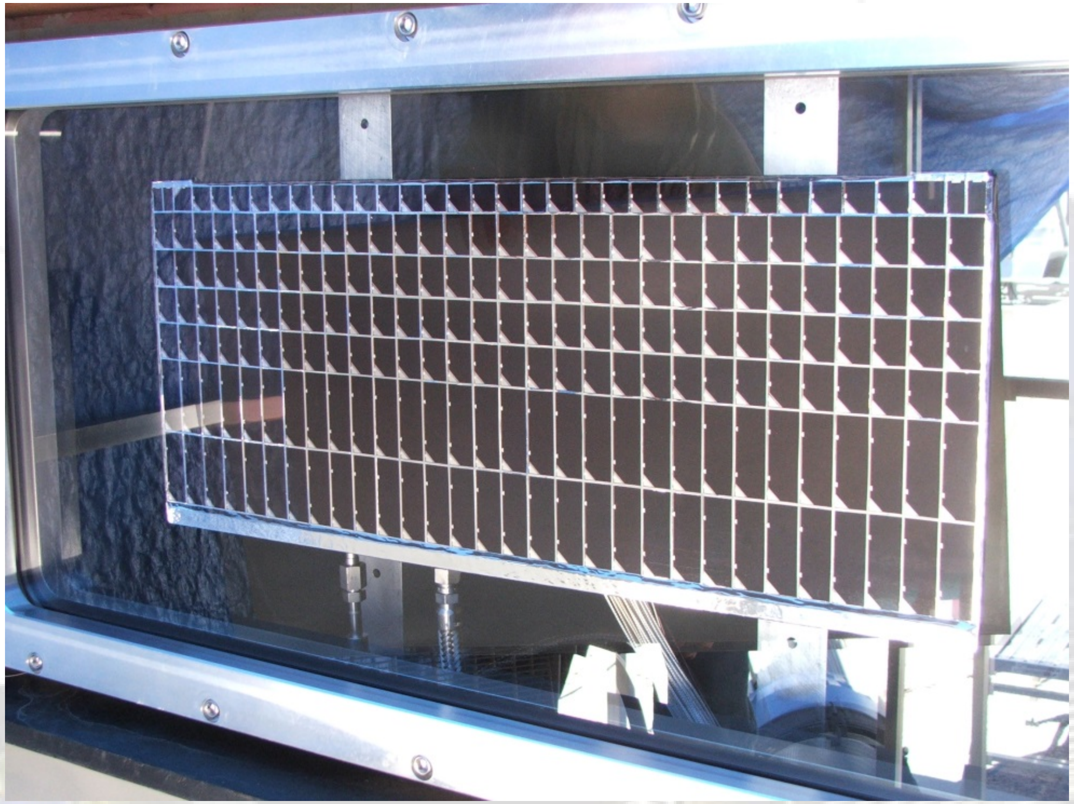




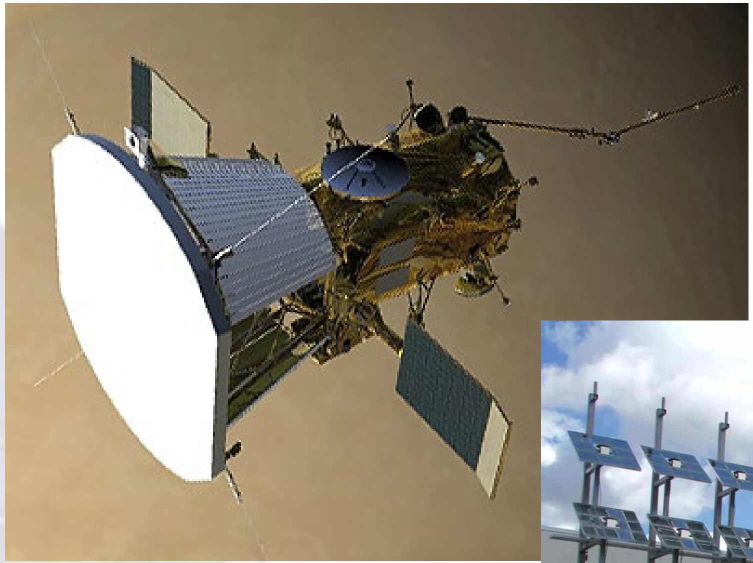
At closest approach, the front the heat shield will be at 1,400°C (2500 ºF), but the payload will be near room temperature

Solar Array Development

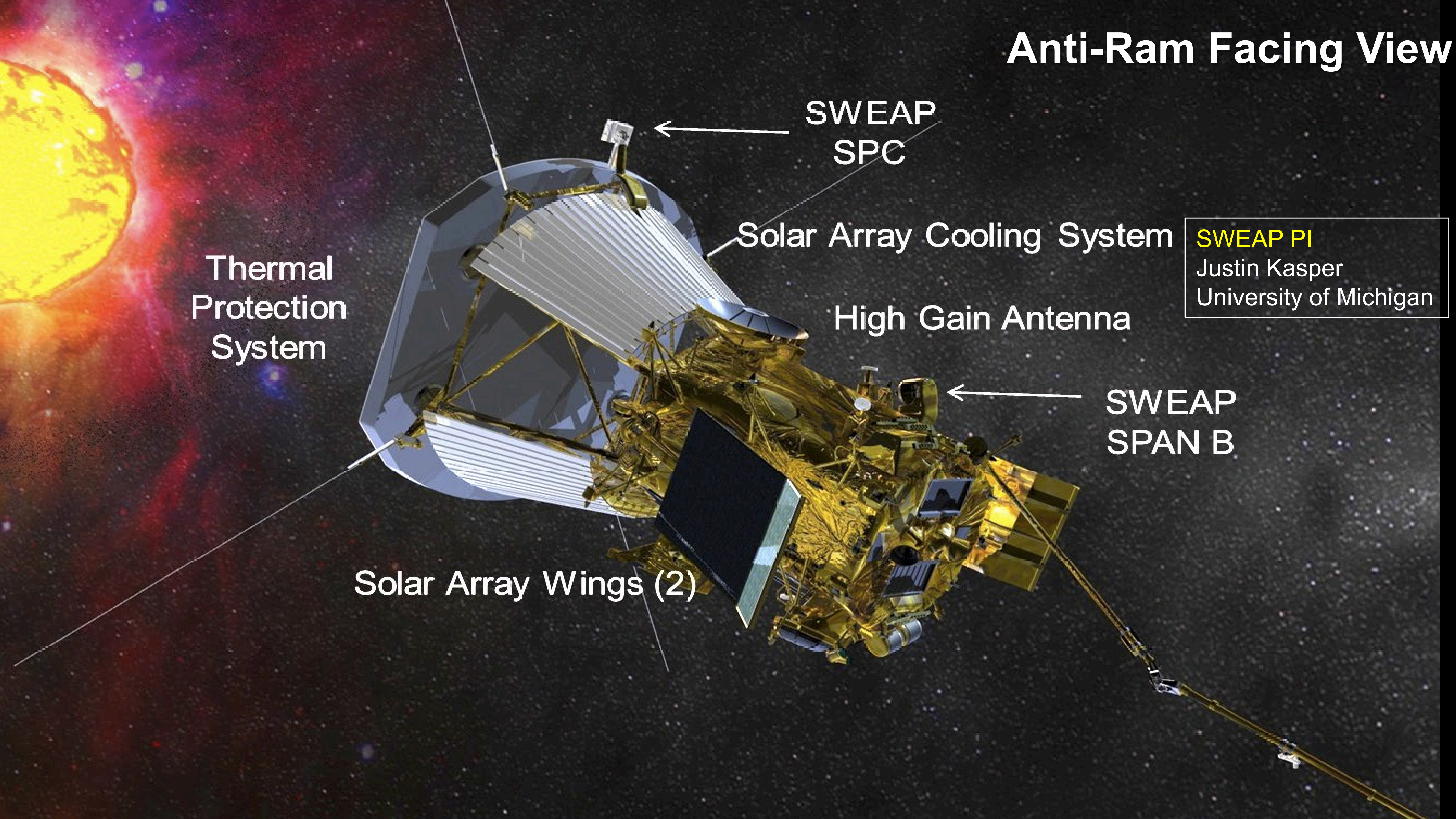
- **Solar Array is unique: liquid cooled, operates under extreme solar flux.**



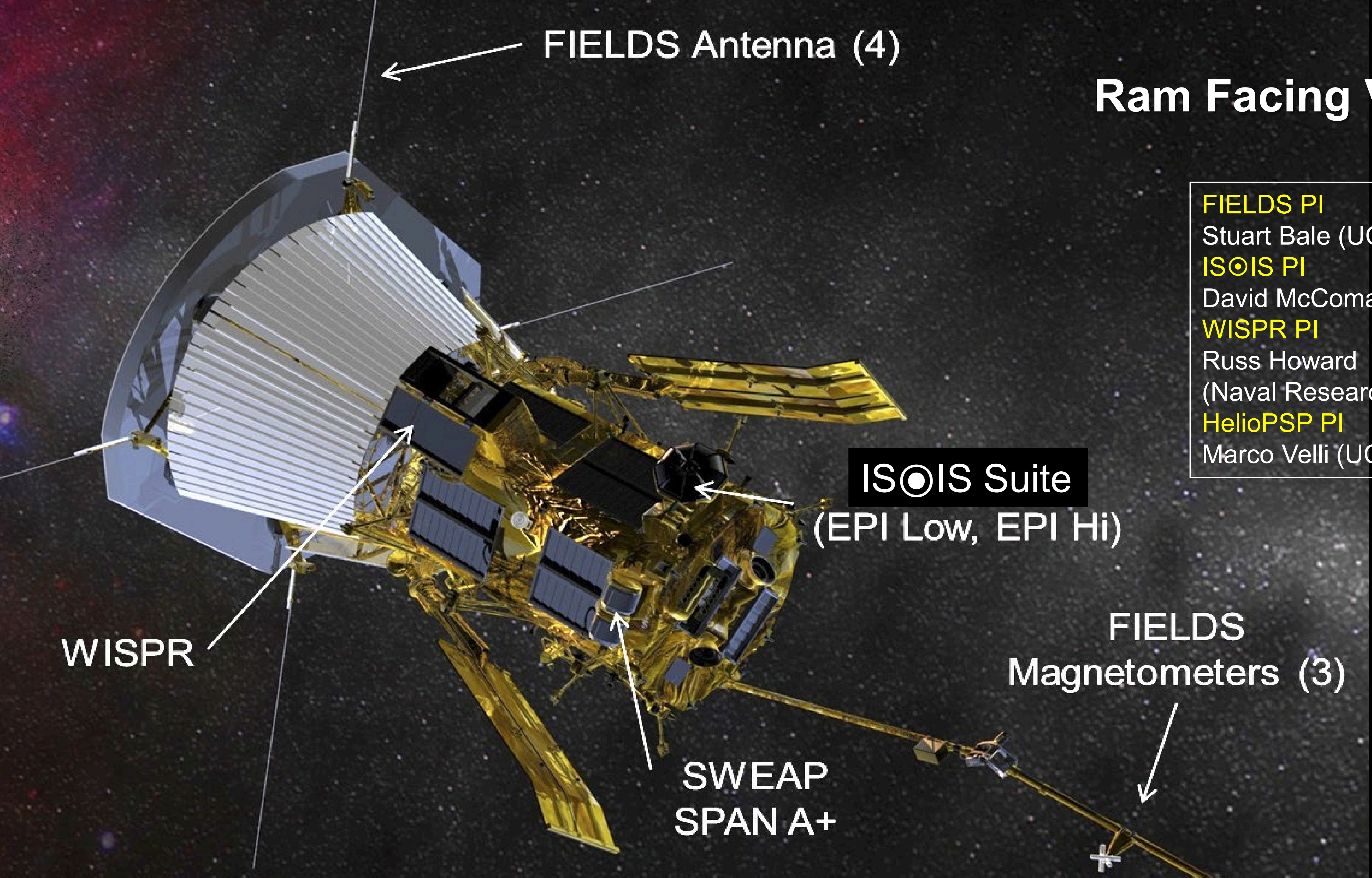
Full Sized Solar Array in Heliostat Vacuum Chamber



Heliostat


Anti-Ram Facing View
SWEAP
SPC
Solar Array Cooling System
SWEAP PI
Justin Kasper
University of Michigan
Thermal
Protection
System
High Gain Antenna
SWEAP
SPAN B
Solar Array Wings (2)

Ram Facing View

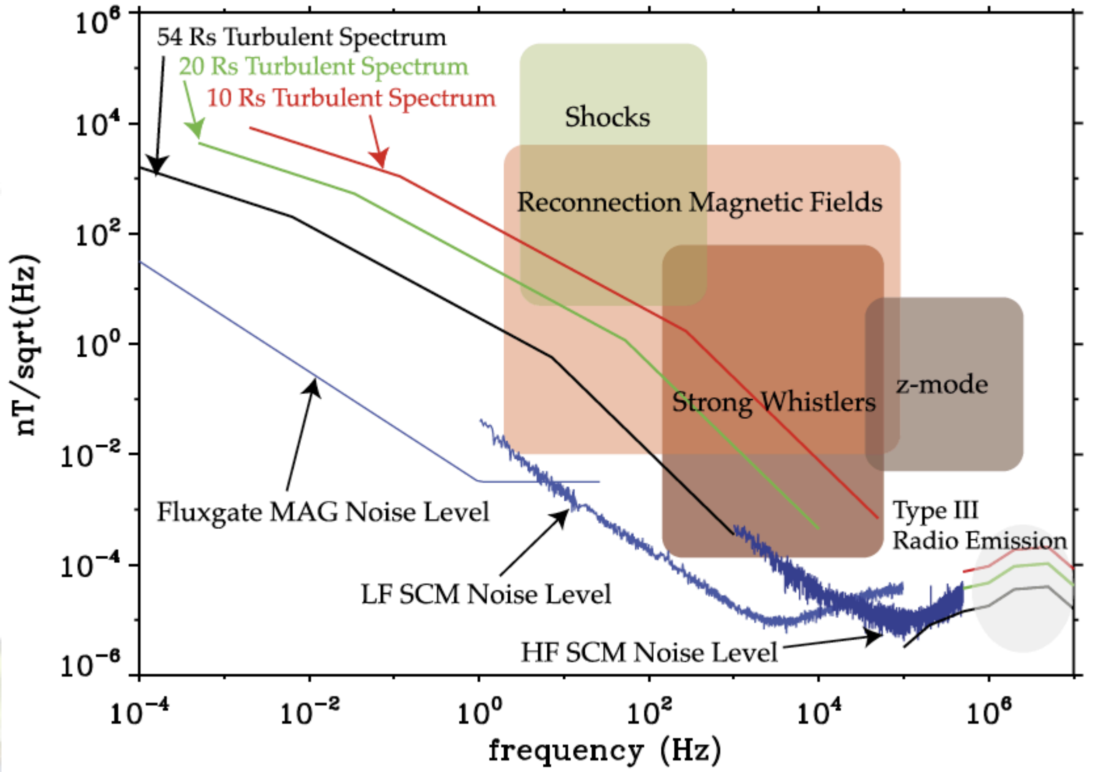


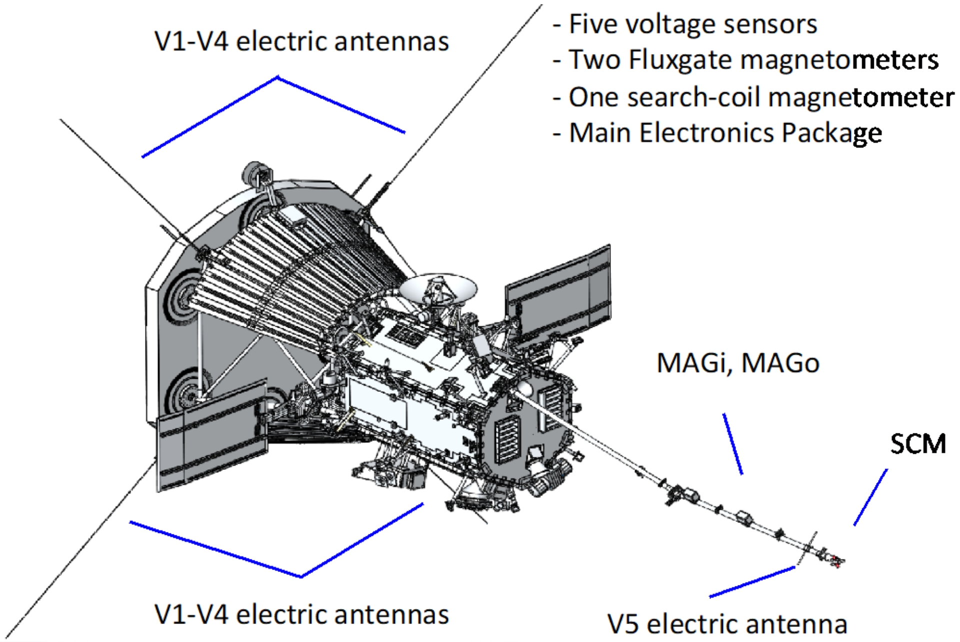
FIELDS PI
Stuart Bale (UC, Berkeley)
IS⊙IS PI
David McComas (Princeton)
WISPR PI
Russ Howard
(Naval Research Lab)
HelioPSP PI
Marco Velli (UCLA)

FIELDS

PI: Stuart Bale (UC Berkeley)

FIELDS will measure electric and magnetic fields and waves, Poynting flux, absolute plasma density and density fluctuations, electron temperature, spacecraft floating potential, and radio emissions.



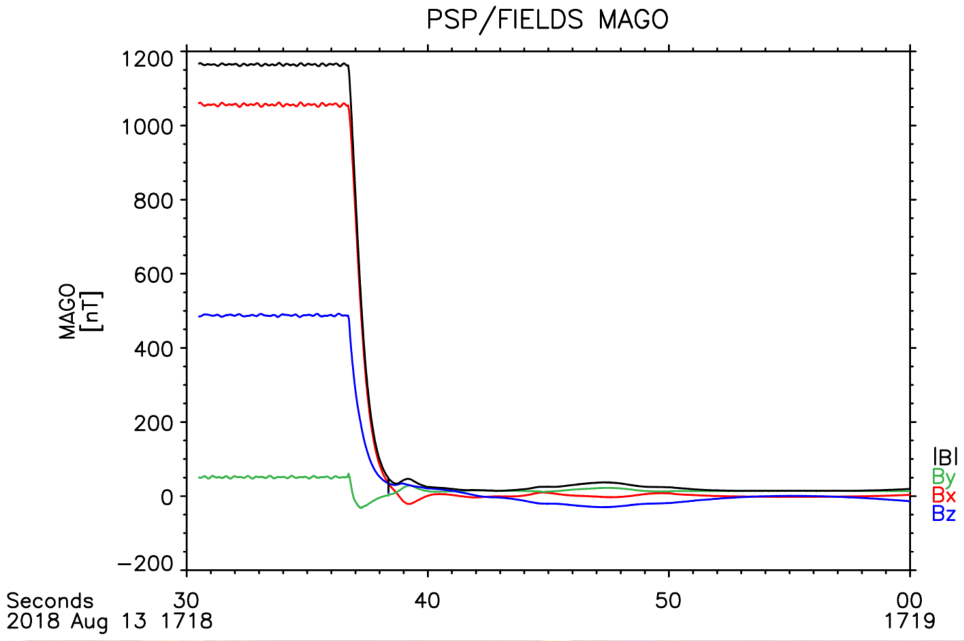


- Five voltage sensors
- Two Fluxgate magnetometers
- One search-coil magnetometer
- Main Electronics Package

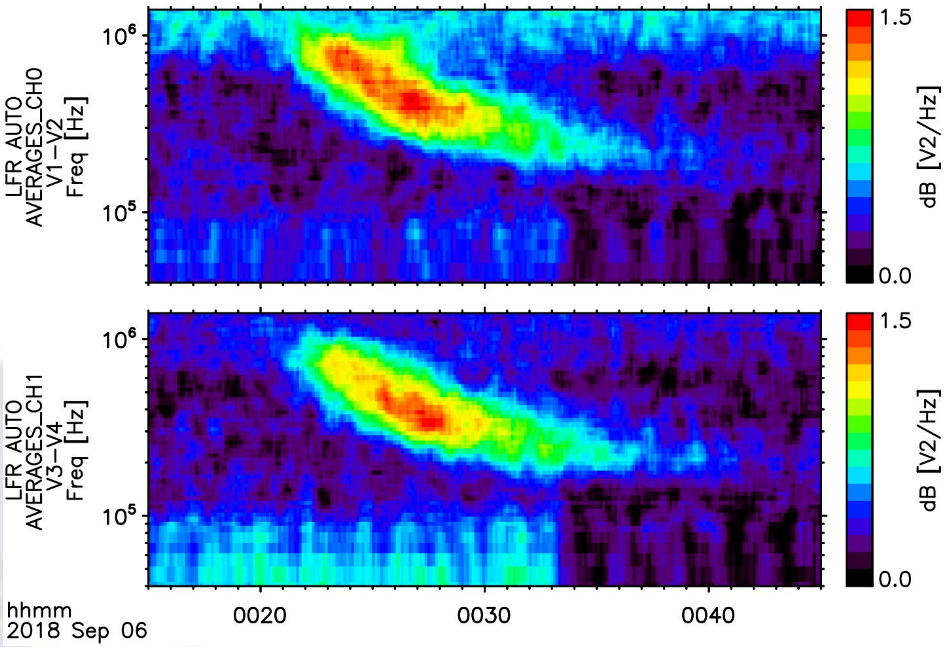
Bale, S. D., et al., "The FIELDS Instrument Suite for Solar Probe Plus … ," Space Science Reviews, 204, 49, 2016

FIELDS

Boom Deployment & Type III Burst



Measured magnetic fields as the boom swings away from PSP



First PSP Type-III radio burst from a solar flare

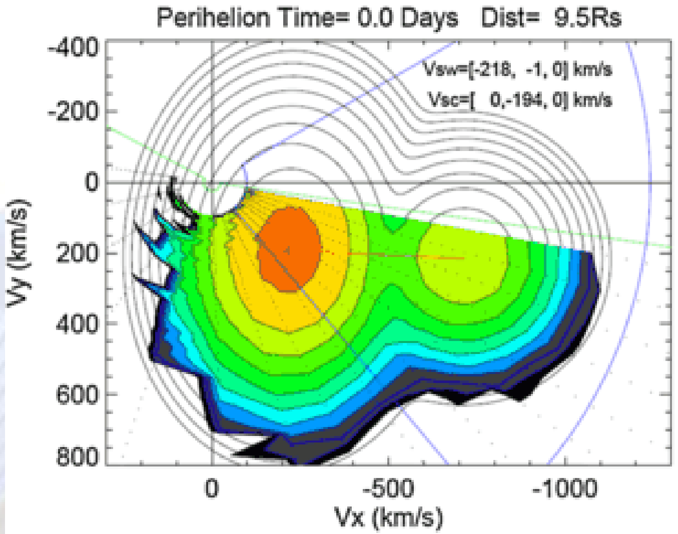
First science measurement ever by Parker Solar Probe

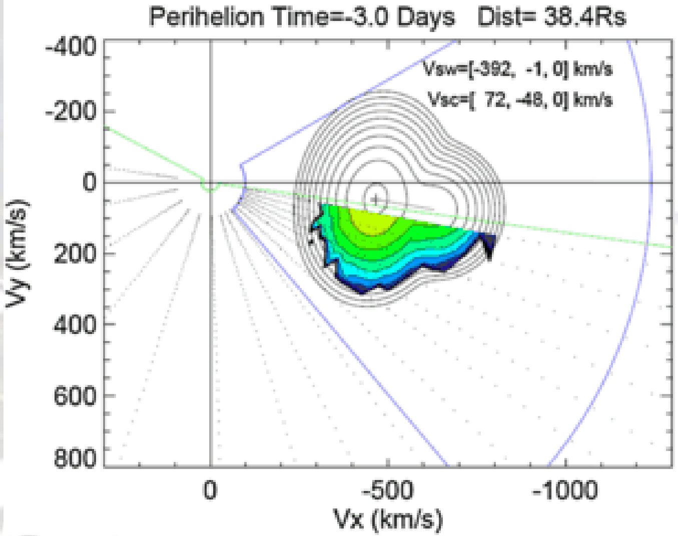
Solar Wind Electrons Alphas and Protons (SWEAP) Investigation

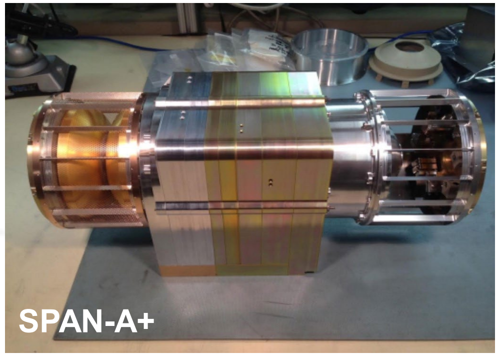
PI: Justin Kasper (Univ. Michigan/SAO)

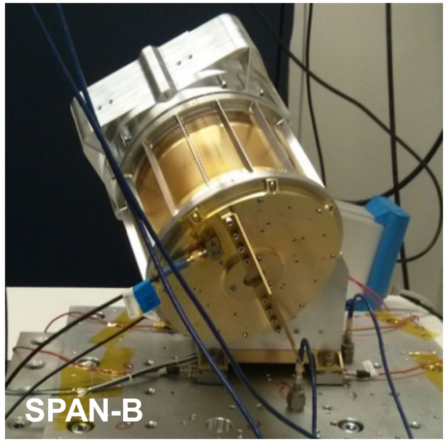
SWEAP will measure velocity distributions (velocity, density, & temperature) of electrons, protons, alphas, (and heavy ions).

Kasper, J. C., et al., "Solar Wind Electrons Alphas and Protons (SWEAP) Investigation ...," Space Science Reviews, 204, 131, 2016





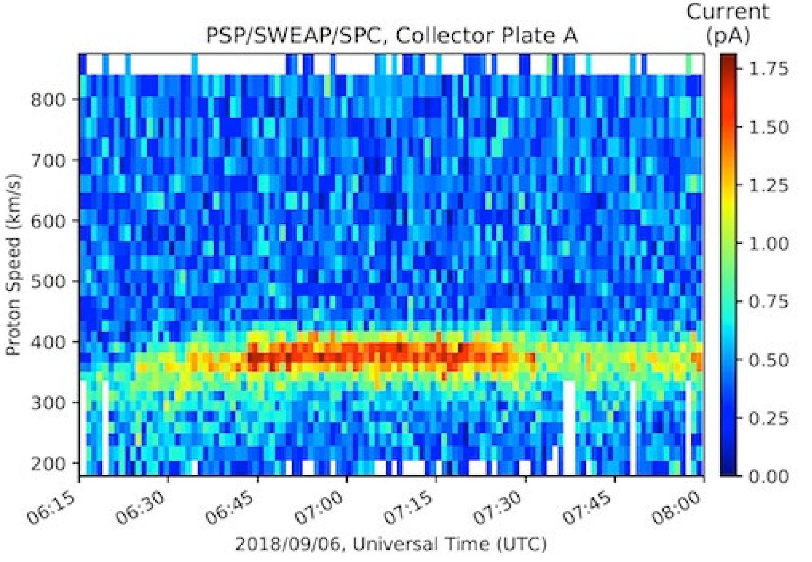




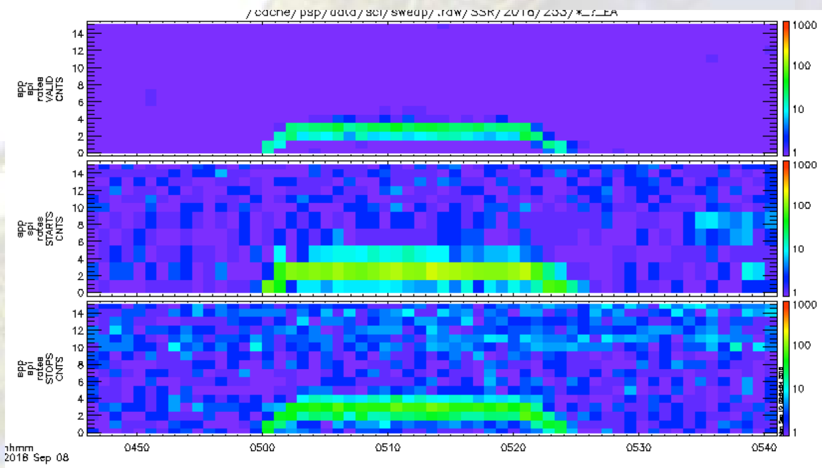
SWEAP
Unexpected Signature of the Slow Solar Wind

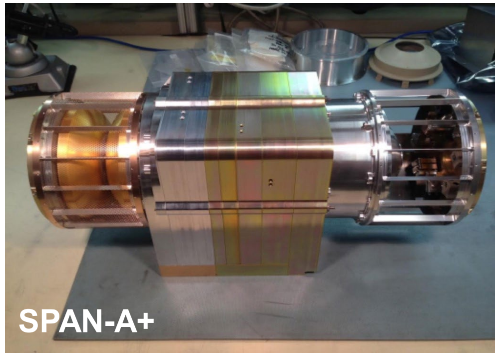
SWEAP Solar wind measurements (slew)

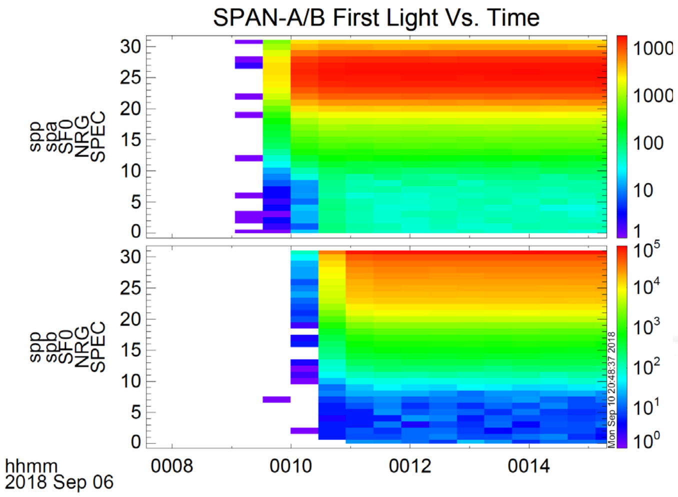
SPC



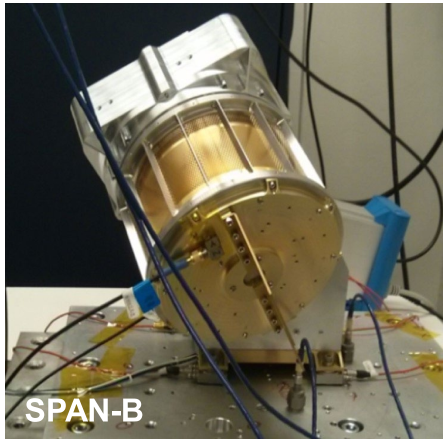
SPAN-Ai







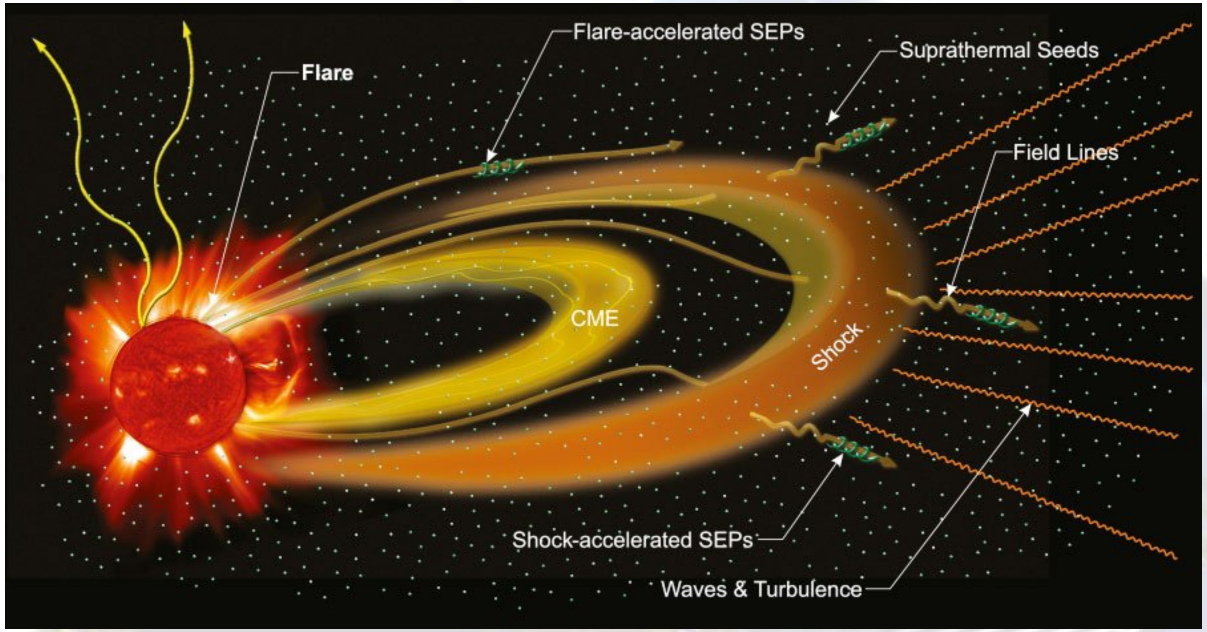
Electron SPAN-A/B

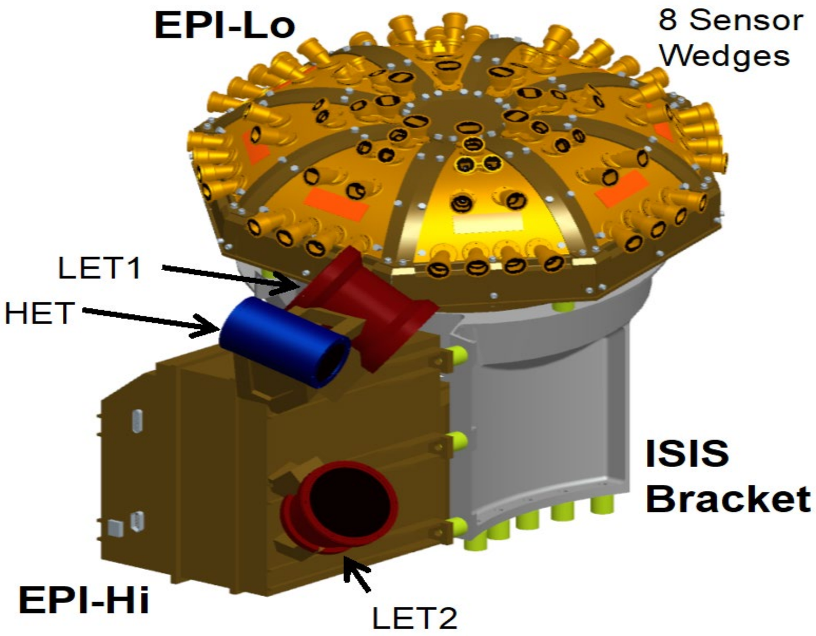


Integrated Science Investigation of the Sun (IS⨀IS)

PI: David McComas (Princeton University)

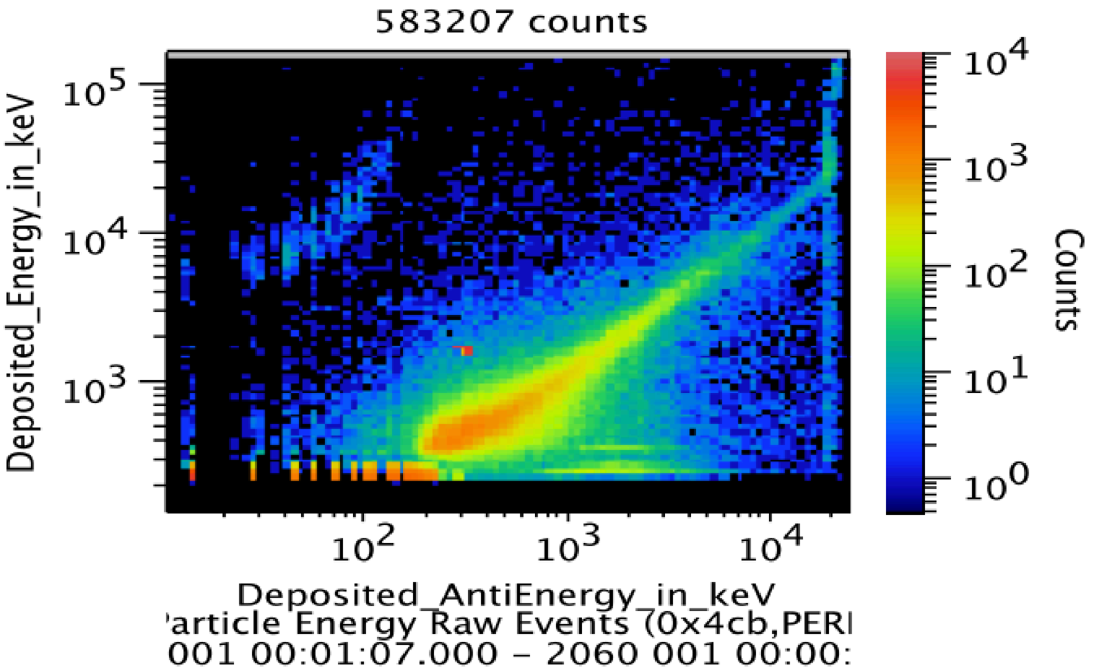
IS⨀IS will measure energetic electrons, protons and heavy ions within the energy range 10s of keV to 100 MeV and correlates them with solar wind and coronal structures.

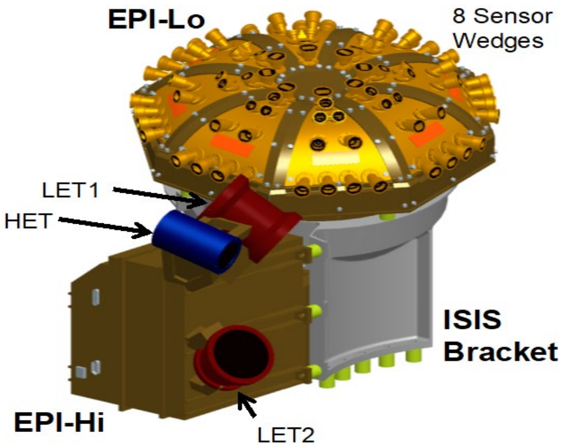


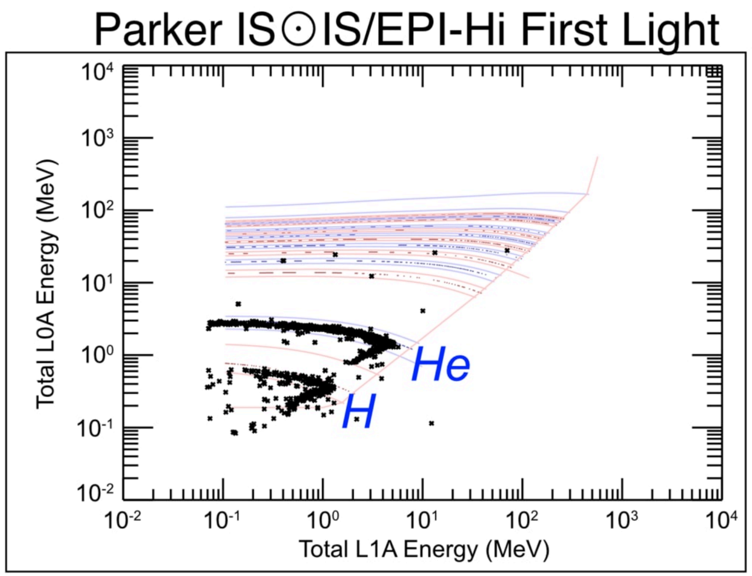


McComas, D. J., et al., "Integrated Science Investigation of the Sun (IS⨀IS): Design of the Energetic Particle Investigation," Space Science Reviews, 204, 187, 2016

Integrated Science Investigation of the Sun (IS⊙IS)







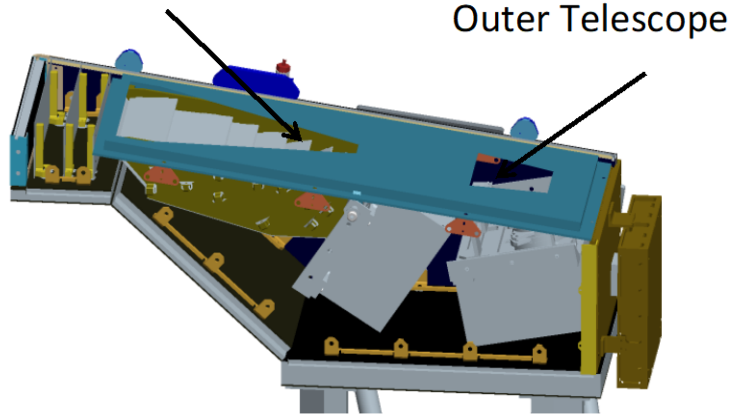
EPI-Lo: background cosmic rays

EPI-Hi: hydrogen and helium particles from the lower-energy telescopes

Wide-Field Imager for Solar Probe Plus (WISPR)

PI: Russ Howard (NRL)

WISPR will image of the solar wind, CMEs, shocks and other structures as they approach and pass the spacecraft.



Vourlidas, A., et al., "The Wide-Field Imager for Solar Probe Plus (WISPR)," Space Science Reviews, 204, 83, 2016

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PI: Russ Howard (NRL)

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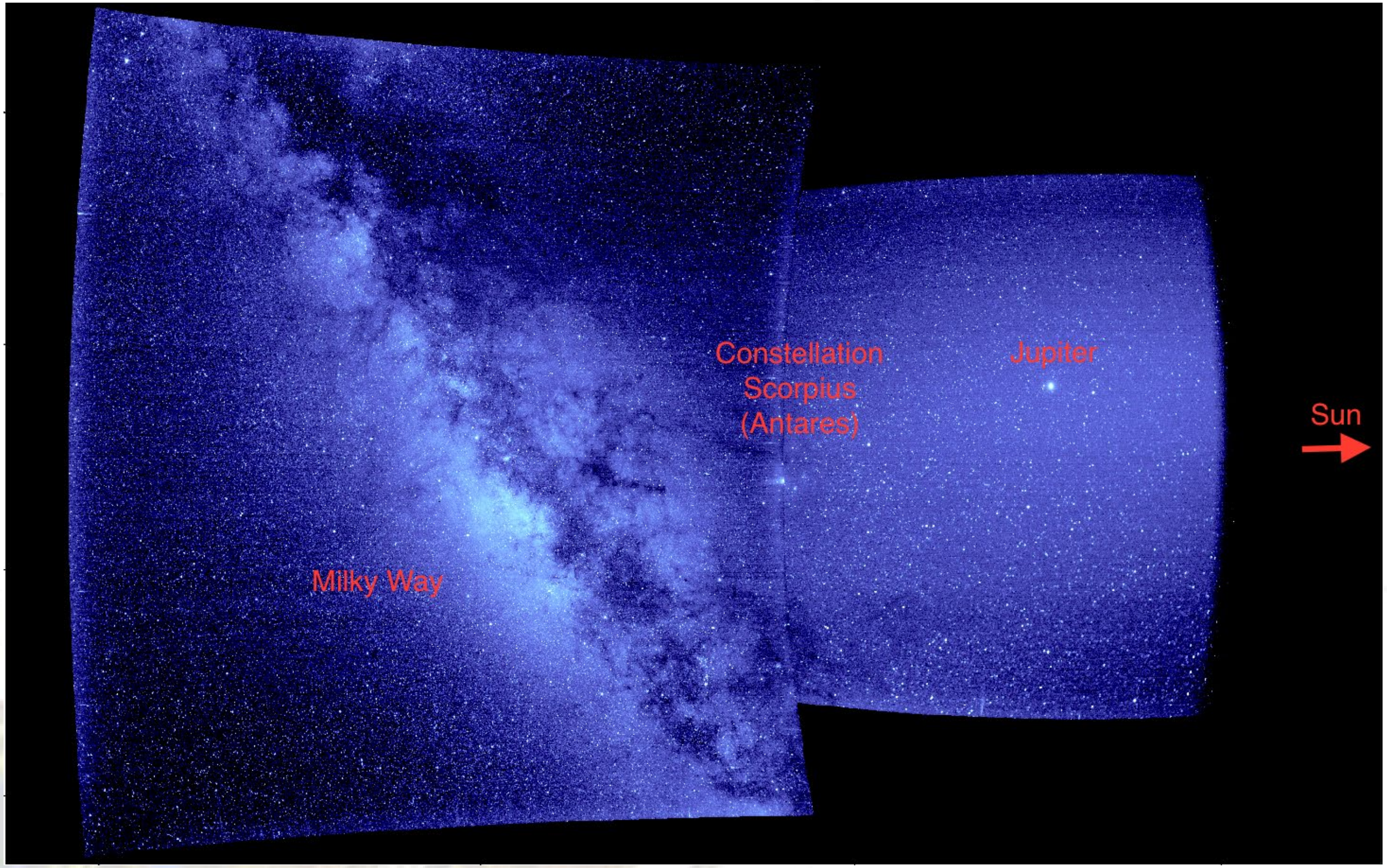
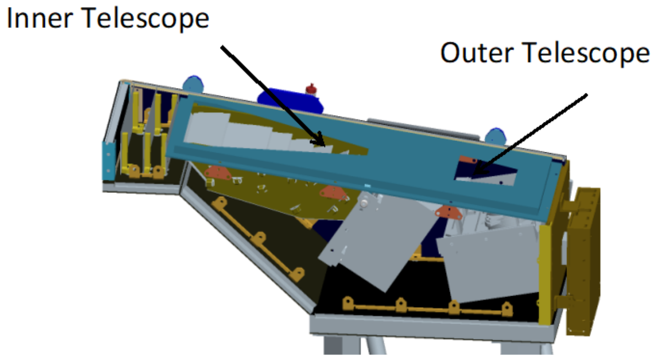




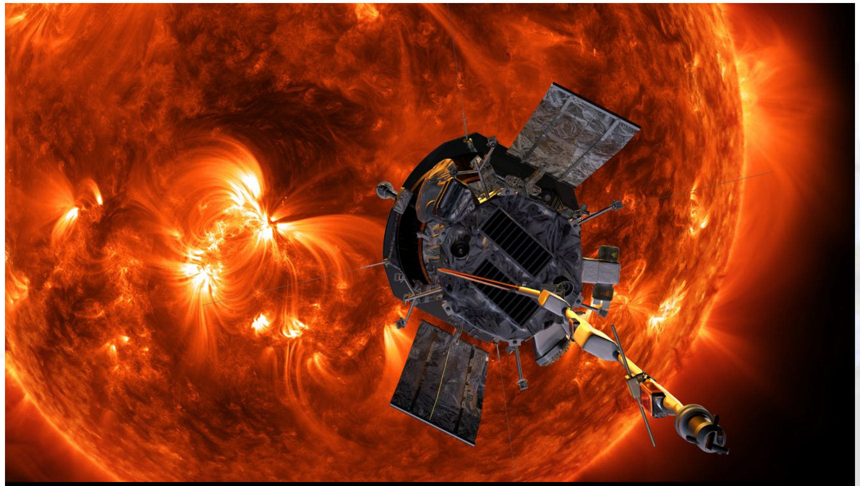
First WISPR images after the door deployment

Inner Telescope: Star field (right) – The bright object is Jupiter

Outer Telescope: Milky Way (left)

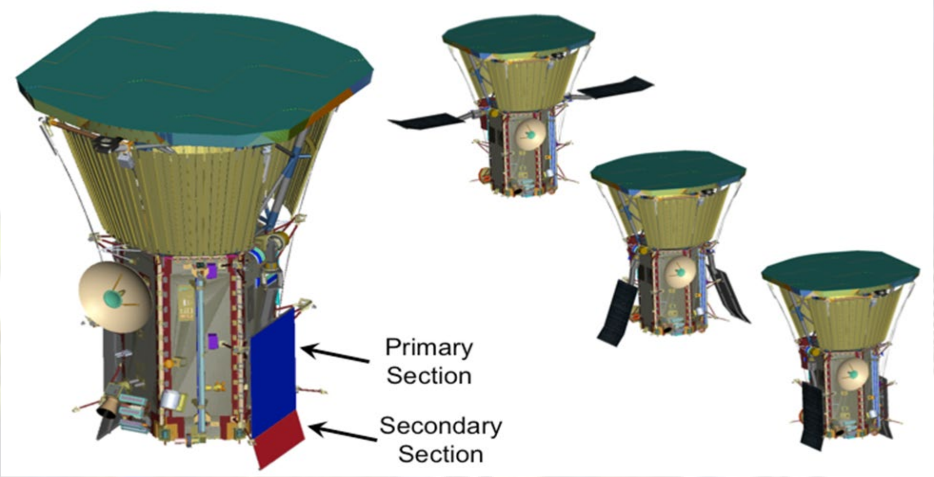
Parker Solar Probe Looks Back at Home

Key Mission Characteristics – Unforgiving Environment



Credit: NASA/Johns Hopkins APL/Steve Gribben

- TPS ***must be pointed at the sun*** at most solar distances!
  - Non-TPS components expect near room temperature and will not survive
  - Requirement to restore attitude and wing angle control within ***5 seconds*** of a processor reset!
- Design Impacts:
  - There is no safe mode without autonomous pointing and power management
  - Extensive on board G&C and autonomy fault handling required
  - Most spacecraft components are redundant
  - Mission is single fault tolerant wherever possible
  - **A flight processor reset is not a failure**!
    - 3 active processors so one can fail and the other two can satisfy attitude control requirement from a processor reset
    - Processor memory must be managed for all processors

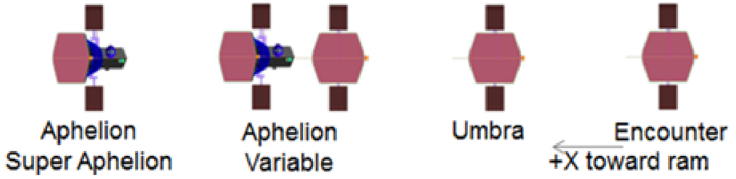


- Spacecraft power and heat must be maintained within acceptable limits
  - Autonomous closed-loop solar array control

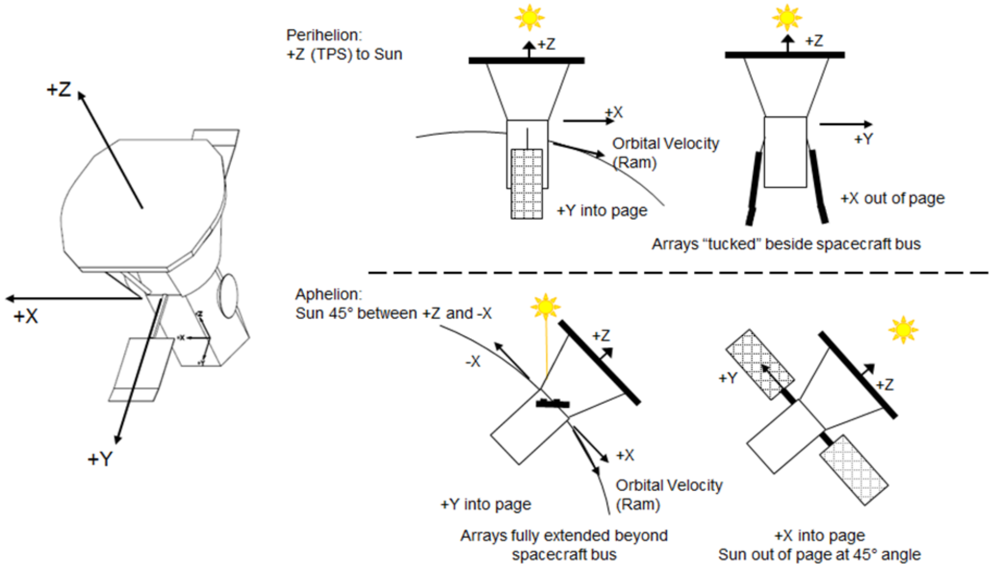
Key Mission Characteristics – Highly Constrained Spacecraft Attitude

- Attitude changes are infrequent
- No intensive pointing campaigns
- Enables decoupled payload commanding approach

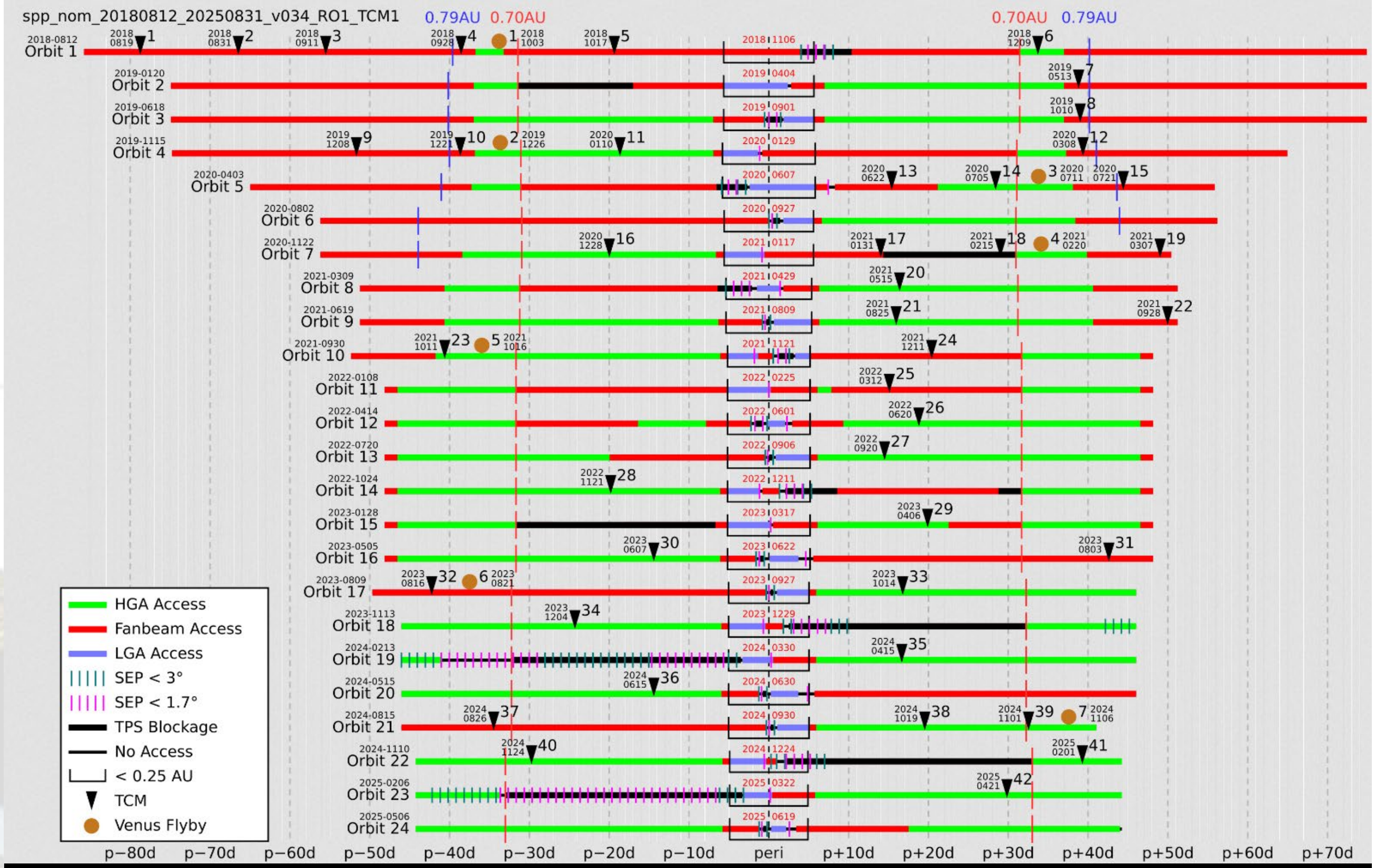
- Attitude constraints result in significant periods of very low uplink and downlink rates
  - Uplink from 7.8125 bps to 2000 bps
  - Downlink rates from 10bps, to 555 kbps
  - Beacon tone (2 bits of health information in 30 minute reception window)
  - Many occurrences of low uplink and high downlink such as (31.25 bps uplink with downlink of 30kbps - 150kbps)
- Downlink constrained by Solar distance and Sun-Spacecraft-Earth angle
- Software developed to take advantage of all Ka band science downlink periods including aggressive rate stepping



Spacecraft Pointing orientation viewed from sun



TCMs and Communication Opportunities



Credit: PSP Mission Design Team

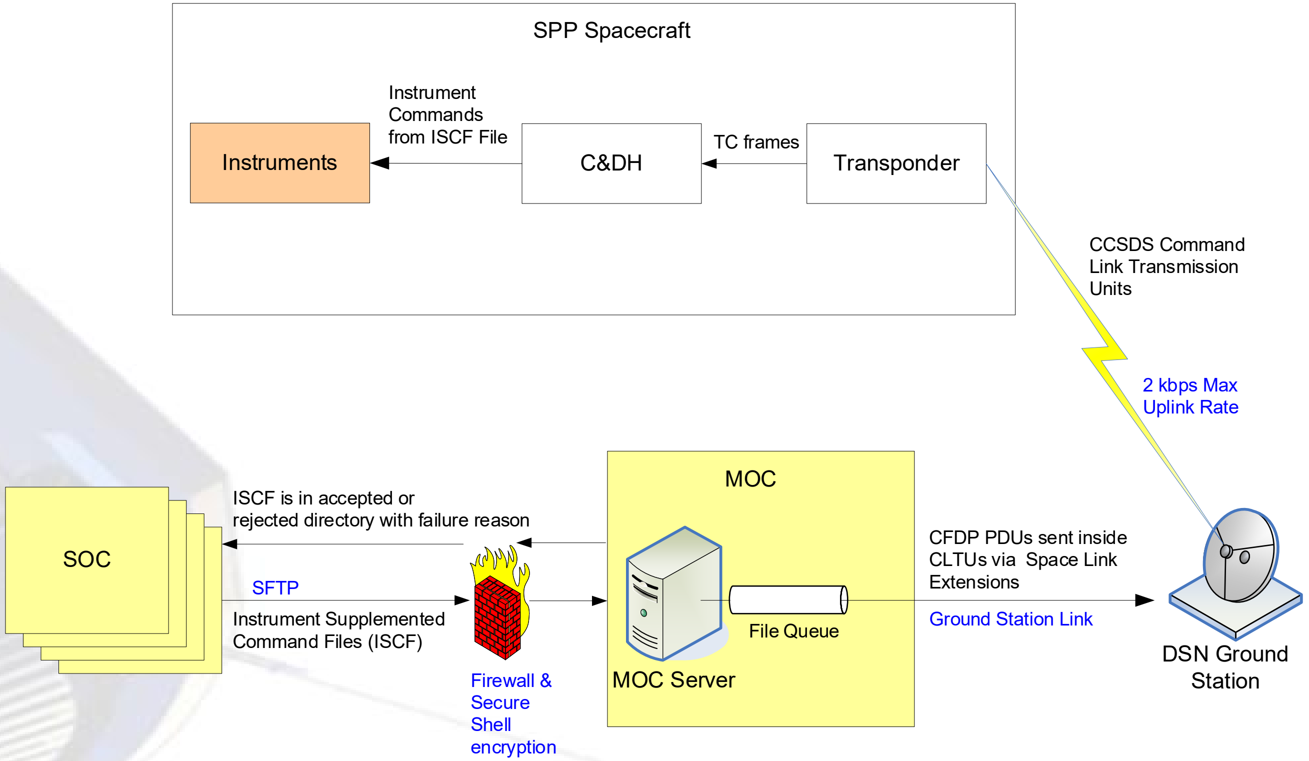
Key Mission Characteristics – Coordinated Decoupled Commanding

Decoupled

- SOCs command their own instruments via bent-pipe command file uplink using CFDP
- Instrument commands are not accessible by MOC and not in spacecraft time-tagged sequences
- SOCs monitor their instrument health and status
- Instruments must support recovering from being powered on/off at any time especially during encounter

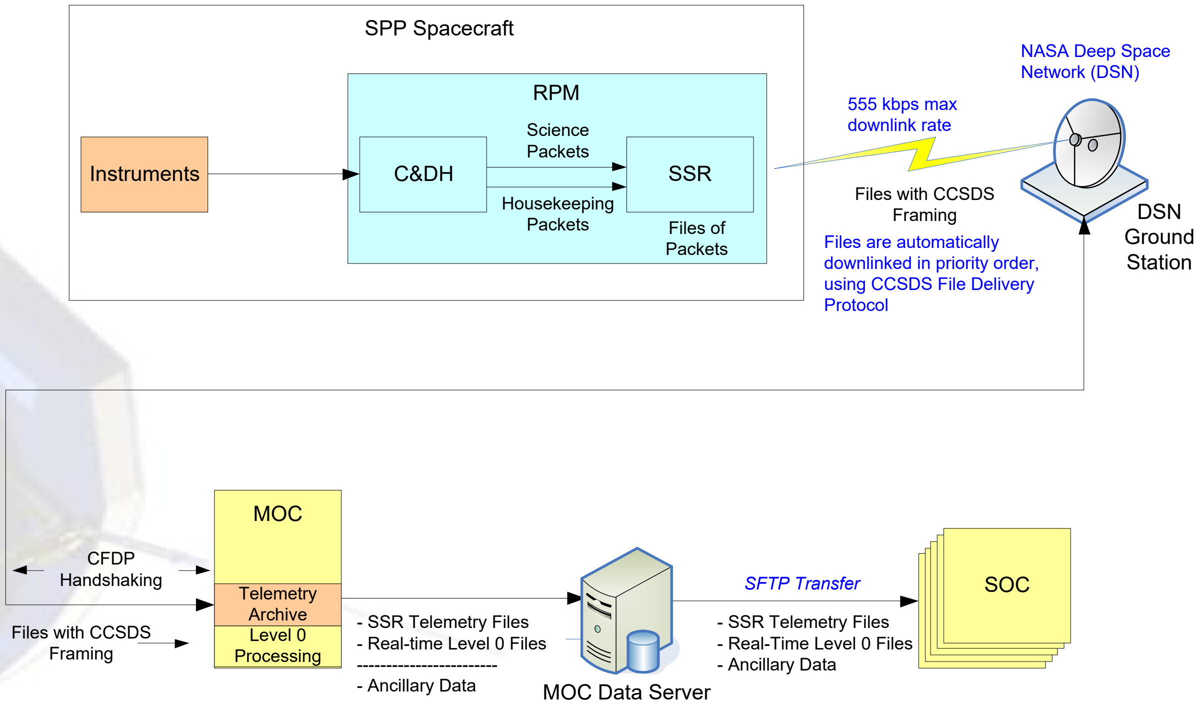
Coordinated

- Mission Operations manage instrument power on/off states (insufficient power for instruments and high gain antenna during science downlink)
- MOC and SOCs coordinate uplink periods to ensure timely delivery
- Instrument Command files can be uplinked while the instrument is powered off
- Some instruments have addition SSR and need to choose which data can be downlinked based on quick look.
- Transfer from Instrument SSR to spacecraft SSR must be scheduled and commanded by SOCs



Key Mission Characteristics – Prioritized CFDP Downlink

- **Mission has 10 priority levels of file recording priorities**
- **Automated file playback of recorded data in priority order**
- **Top priorities are spacecraft and instrument health**
- **SOCs prioritize science data between teams at different priority levels**
- **Lowest level priority is contingency spacecraft health data that will nominally never be downlinked**
- **CFDP provides guaranteed complete delivery of files**

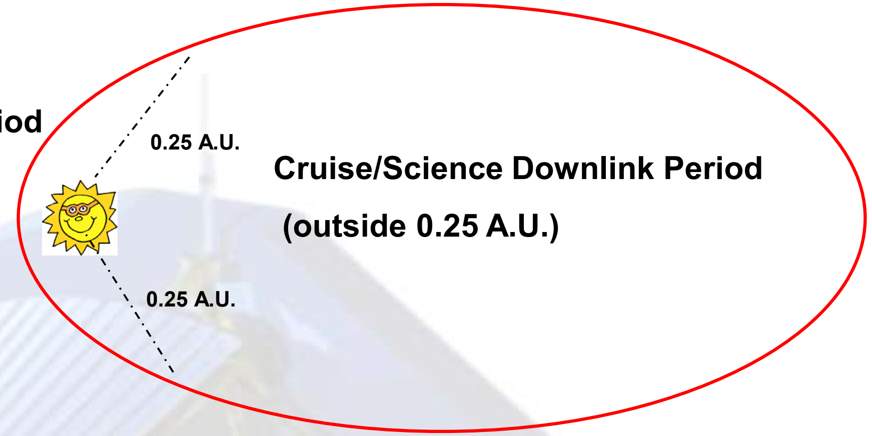


CONOPS Overview

Solar Encounter Period

(inside 0.25 A.U.)

(10-11 Days)



24 Solar Encounter Orbits

Orbital Periods Vary (168 days to 88 days)

Solar Encounter Period

Encounter Operations

- Primary science data collection phase – All instruments will be powered on
- Fanbeam/LGA antenna for communications (beacon tones) for monitoring H&S Doppler data to support navigation
- Minimal commanding expected (if any)
- G&C Maintains shade-to-sun attitude (Encounter Attitude)
- No SSR Playbacks

Cruise/Science Downlink Period

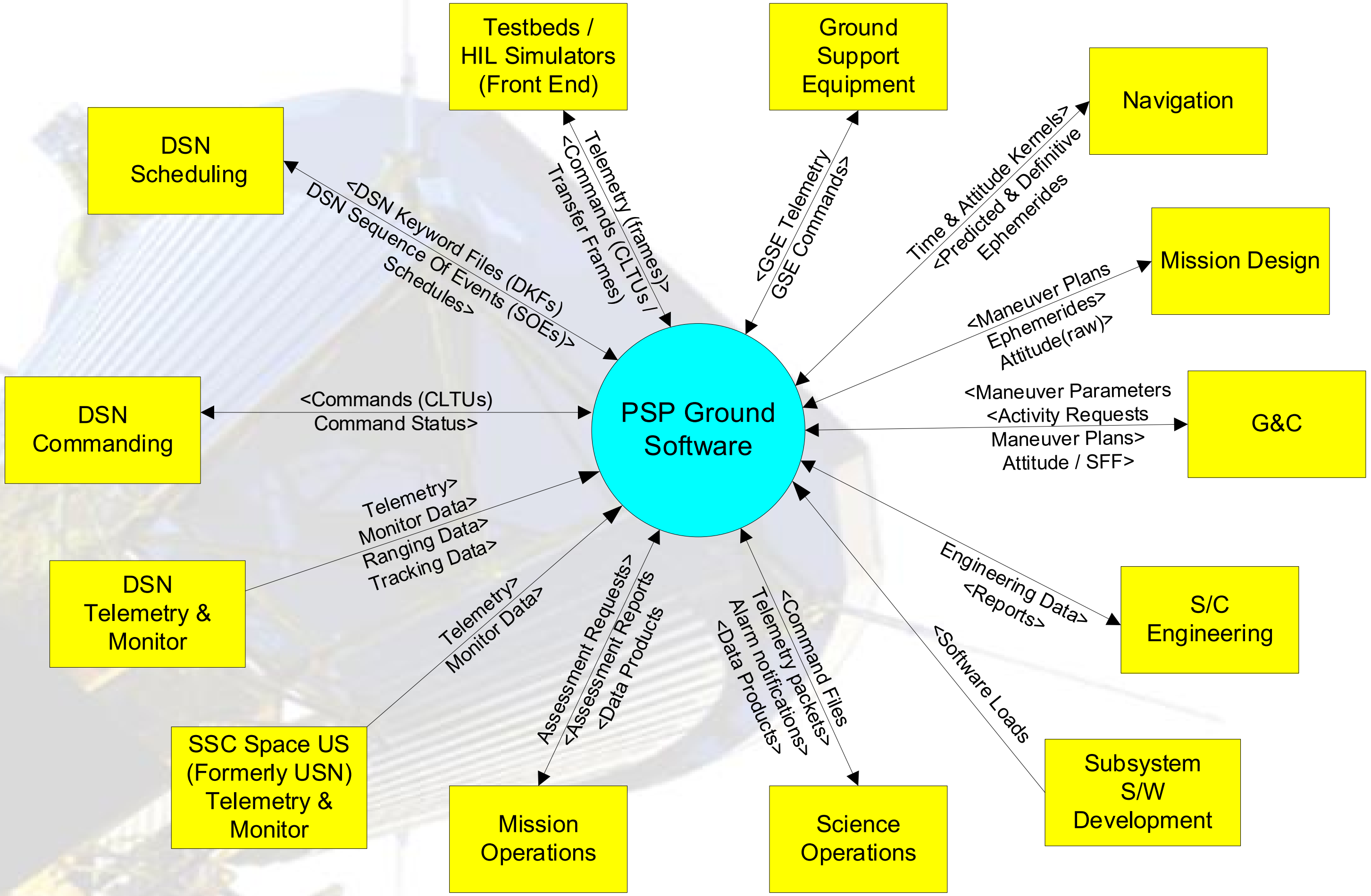
Science Downlink Operations

- All instruments powered off
- HGA for communications (Ka-Band, Science & HK data)
- Commanding as needed to support spacecraft maintenance
- Spacecraft Attitude Changes as needed
- SSR Playbacks Supported (High Rate)

Cruise Operations

- Instruments Can Be Powered On (Sun Distance < 0.82 AU)
  - Instruments off during some activities
- Fanbeam for communications (X-Band, H/K data only)
- Commanding as needed to support spacecraft & instruments
- Spacecraft Attitude Changes as needed
- SSR Playbacks Supported but not ideal (Low Rate)

PSP Ground Software Context



PSP MOC Data Products

MOC Data Product Sources

flight data | planning data | navigation data

MOC

ASSESSMENT

- Command History Report
- P/L Cmd History Report
- Event History Report
- File Activity Report
- Anomaly History Report
- P/L Telem Alarm Notice
- Level 0 RT Telemetry
- SSR Telemetry Files
- Span Report
- Gap Report
- Archive Change Report
- Weekly MOC Status
- S/C Telem Dictionary
- GND Telem Dictionary
- SSR Raw Directory File
- SSR Directory Listings
- Att Hist Report
- Ops SCLK Kernel
- Time History File
- MET Register History File

PLANNING

- Contact Plan
- DSN Keyword File (DKF)
- S/C Activity Schedule File
- Orbit Activity File
- Att Metakernel
- Leap Second Kernel
- Frame Kernel (FK)
- Planetary Constants Kernel (PCK)

SOC

- Weekly P/L Status
- P/L Activity Schedule File

DSN

- DSN Schedule File

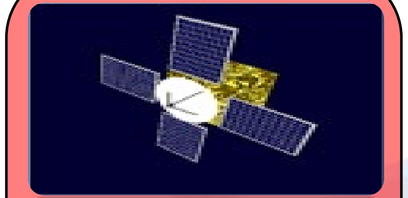
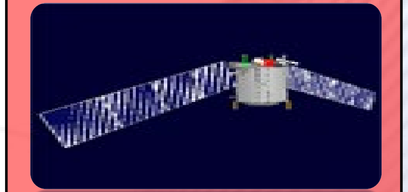
MD/NAV

- Planetary Ephem
- Predicted S/C Ephem
- Mission S/C Ephem
- Reconstructed S/C Ephem
- Ephem Metakernel
- NAV Tracking Requests
- MD Events File
- MD Data File
- MD Access File
- Maneuver Parameter File

ENG

- Power Load Report
- Solar Array Ops Report
- RF Activity Report
- Link Availability Report
- Maneuver Command File
- Estimated MNVR Error Rpt
- Small Forces File History
- Small Forces File Predict
- Att Short Term Predict
- Att Long Term Predict

Ground Software Heritage

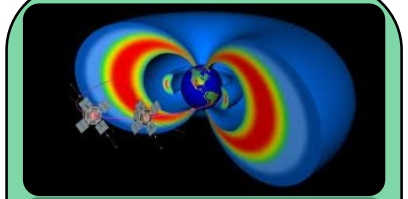

1990s

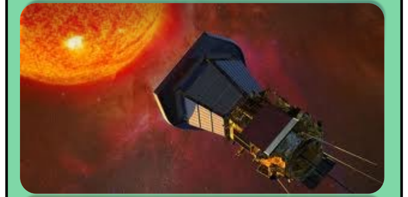
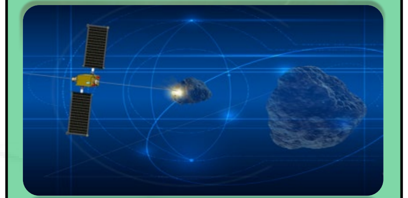
One-Off Systems



2000s

Common Ground Architecture

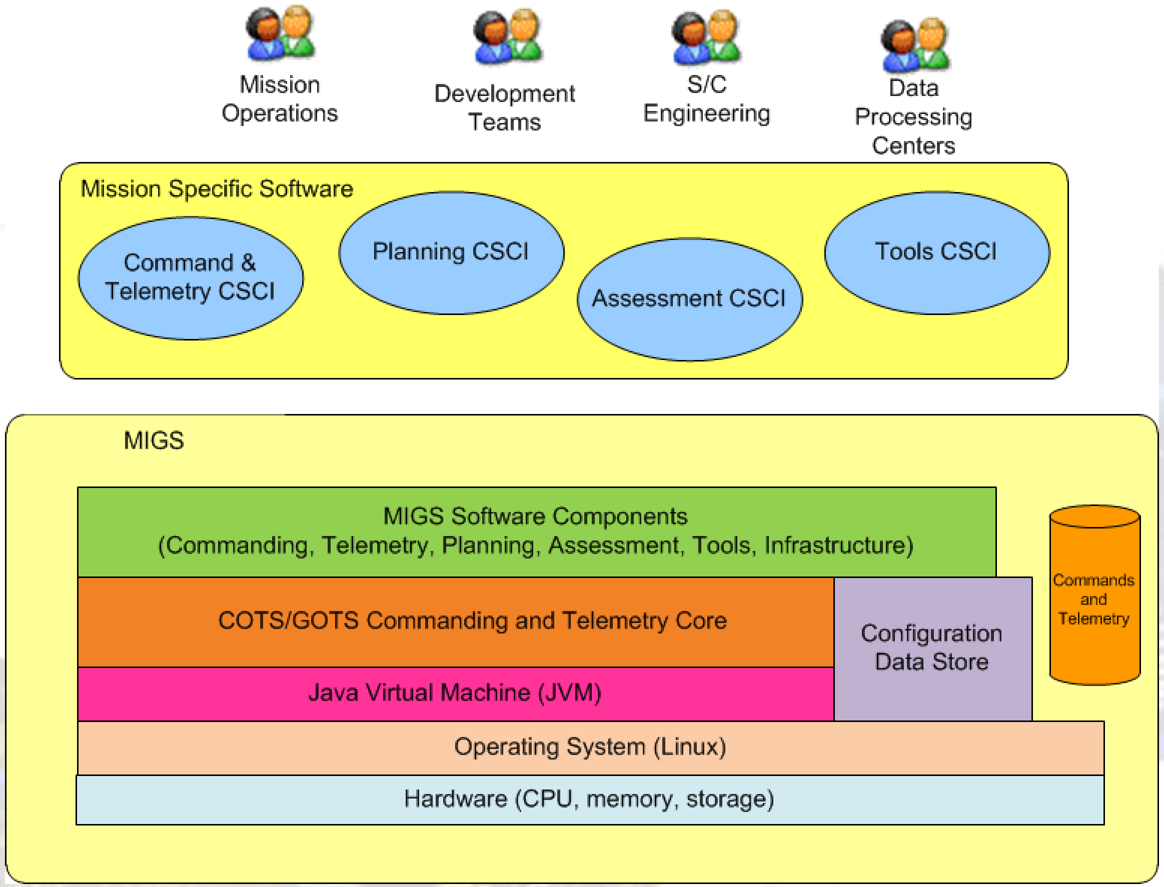


2010s

Mission / System Independent Architecture

Mission / System Independent Architecture

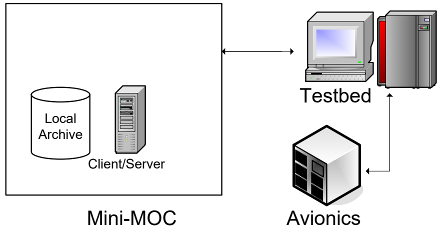


- **PSP Ground Software consists of 85 Computer Software Components (CSC)s**
  - **Most CSCs are java applications that run in separate JVM processes or application server**
  - **~40 CSCs are on-line applications running with an L-3 InControl-NG Commanding and telemetry system**
  - **Remainder are off-line planning or assessment applications**
- **Code is shared across missions and used with mission specific configuration**

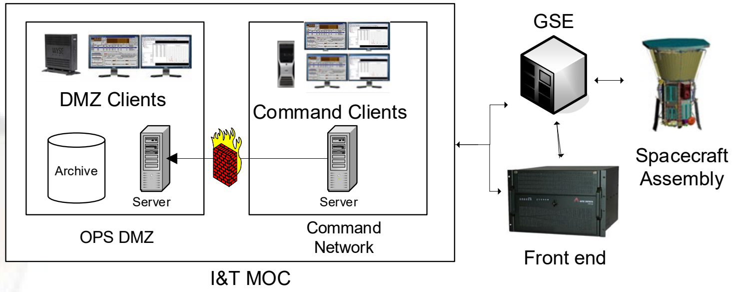
Ground Software MOC Configurations

The same set of software is used in each configuration

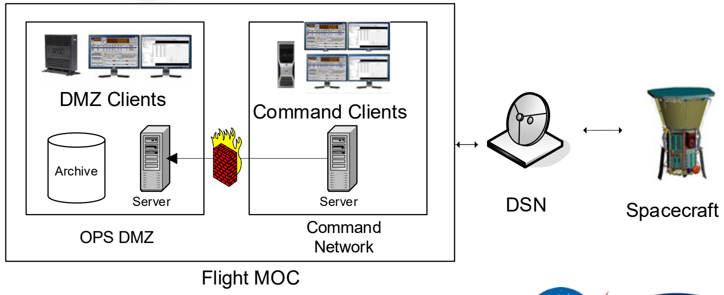
- **Mini-MOC / Hardware-In-The-Loop Simulator**
  - **Supports local test of a spacecraft processor subsystem and avionics via a single computer**
  - **Provides primary user interface for the testbed (commanding and telemetry)**
  - **Local archive**



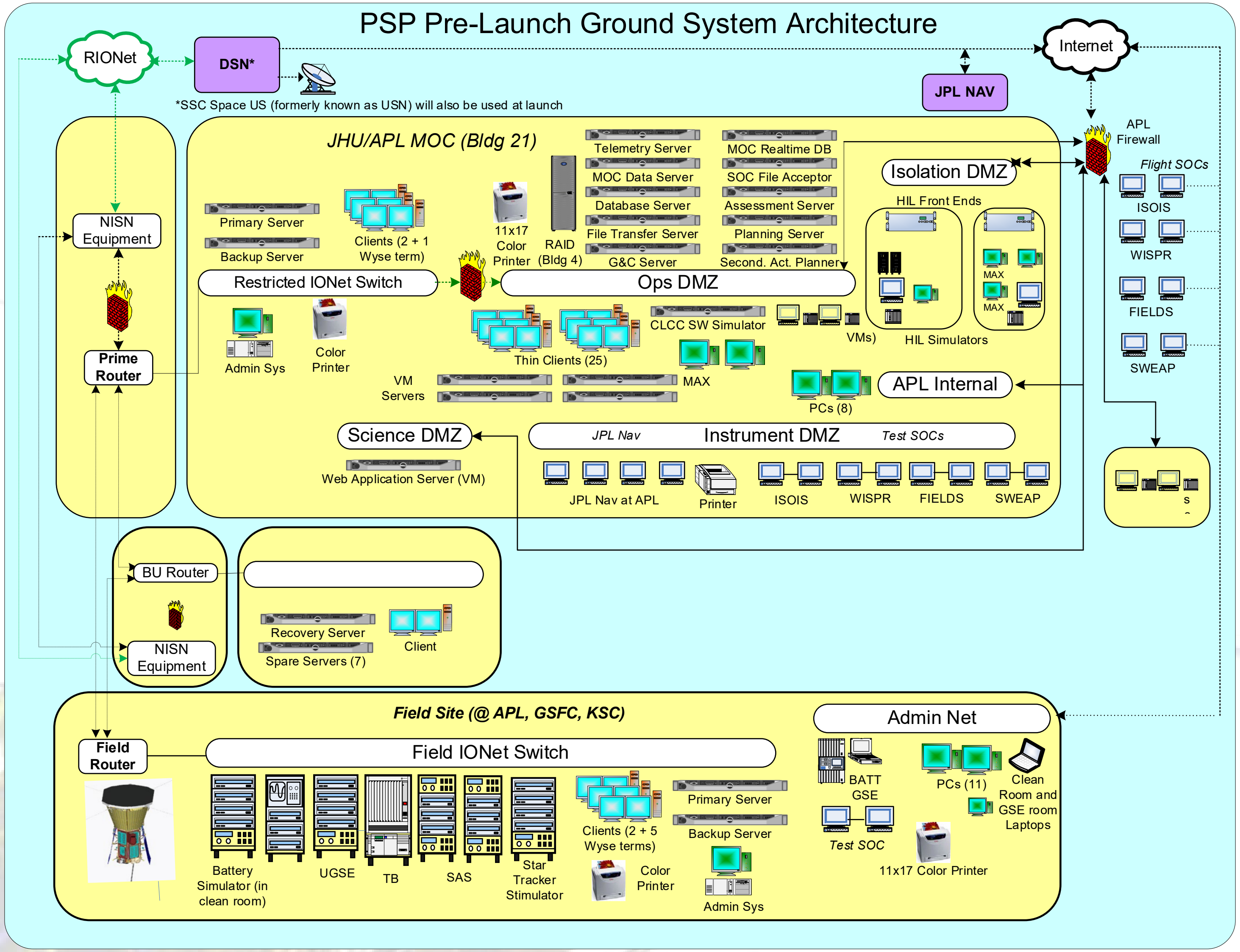
- **I&T MOC**
  - **Supports spacecraft I&T, allowing users to send commands to and receive telemetry from the spacecraft under test and GSE**
  - **Central archive in the OPS DMZ**
  - **Other users may view status and telemetry information simultaneously from client workstations connected to controlling I&T MOC workstation and in the OPS DMZ**



- **Flight MOC**
  - **Supports mission simulations, launch and operations, including via ground stations**
  - **Central archive in the OPS DMZ**
  - **Other users may view status and telemetry information simultaneously from client workstations connected to controlling Flight MOC workstation and in the OPS DMZ**



Ground System Architecture

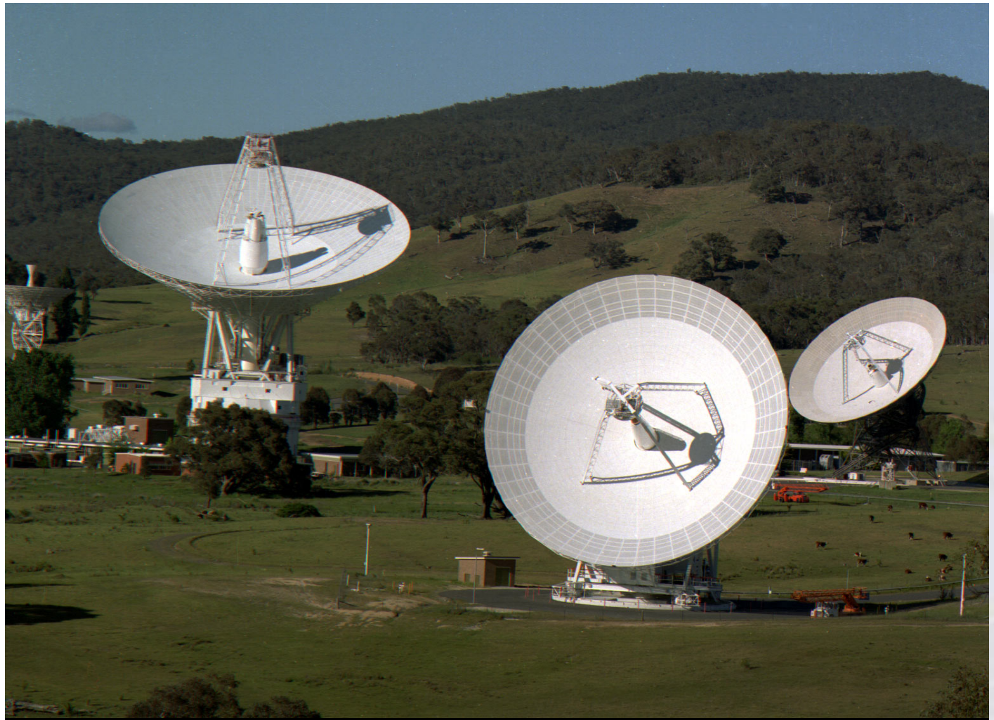


- Most ground software systems run Redhat EL7
- Many systems are Virtual Machine instances
- Systems are automatically backed up and meet NASA IT security requirements
- Spare hardware is ready to recover from any hardware failure
- Mission has a longevity plan that includes replacing computers as they go out of warranty

At peak development:

- 10 Mini-Moc Systems paired with testbeds
- 10 Operational Planning/Assessment Servers
- 25 operational client systems (mostly telemetry viewers)
- 3 OPS Commanding systems
- 2 I&T Commanding systems
- 6 script / page development Mini-Mocs
- 20 ground software development and test systems

NASA Deep Space Network (DSN) Interfaces



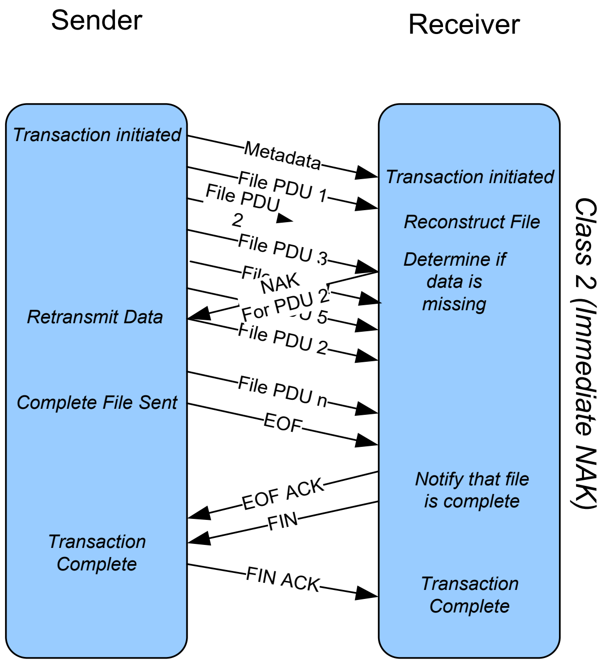
Credit NASA Deep Spaece Network:
https://deepspace.jpl.nasa.gov/assets/images/gallery/canberra4.jpg

- PSP is the first of the Mission/Architecture Independent Software Missions to interact with the DSN.
  - APL developed gateway to InControl-NG using C++ library from JPL for Commanding, telemetry, and beacon tone
  - APL developed DKF, IDR, and Monitor data interfaces

- DSN Interfaces
  - Space Link Extension Blue Book 2010 CLTU Service
  - Space Link Extension Blue Book 2010 RAF Service
  - 0233-Telecomm Return Beacon Tone Service
  - 0223-Comm-Web - Internet IDR file delivery of Telemetry Frames
  - 0158-MON – DSN station monitor data
  - DSN Keyword File for station configuration
  - DSN schedule retrieval from spsweb

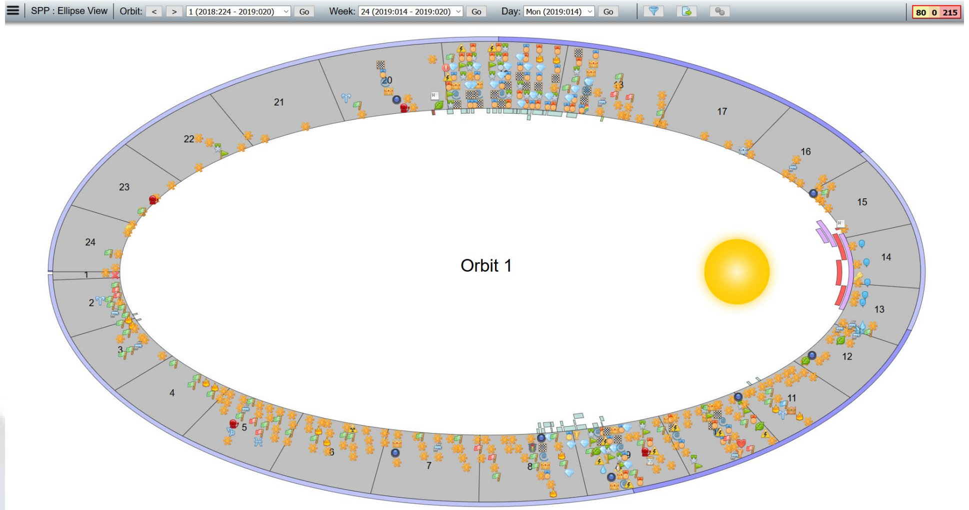
CCSDS File Delivery Protocol (CFDP) Uplink

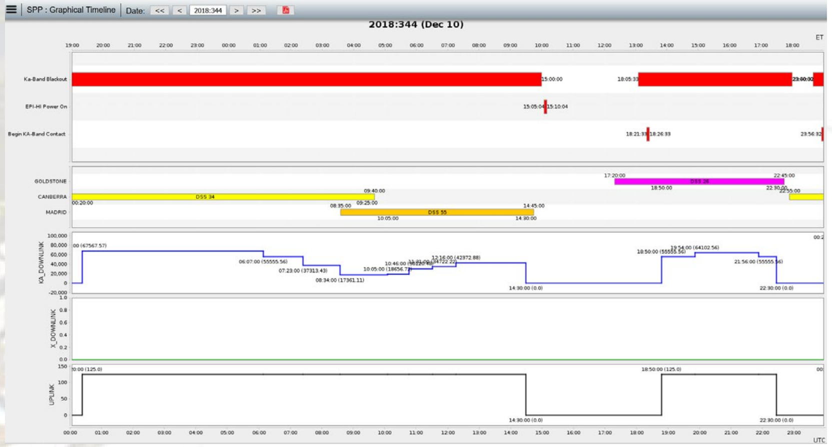
- **PSP is the first JHU/APL mission to use CFDP for reliable commanding**
- **PSP command files contain a series of binary CCSDS TC packets.**
- **Provides recovery from a dropped command to a deep space spacecraft more efficiently than COP-1 or COP-1 Lite used on previous APL missions**
- **Enables commanding file delivery to continue across contacts**
- **Saves uplink bandwidth for command loads going to multiple processors via onboard file copy**
- **Allows instrument command files to be uplinked while instrument is powered off and later delivered when powered on**

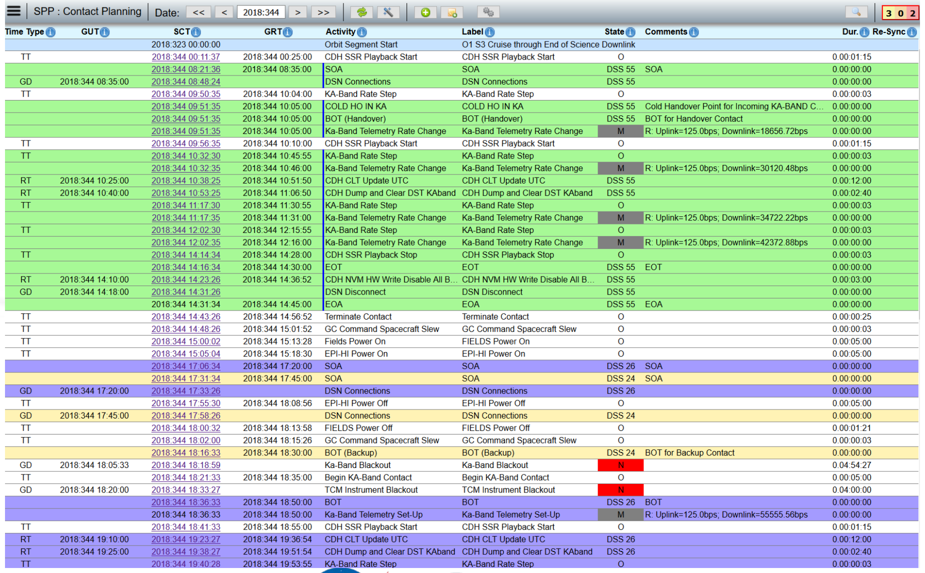


Activity Planner

- Modern web application used to plan, schedule, visualize, and communicate spacecraft and ground activities
- Generates spacecraft command loads
- Handles RF configuration and rate stepping activities
- Generates DSN Keyword file to configure DSN ground equipment
- Provides constraint checking between activities

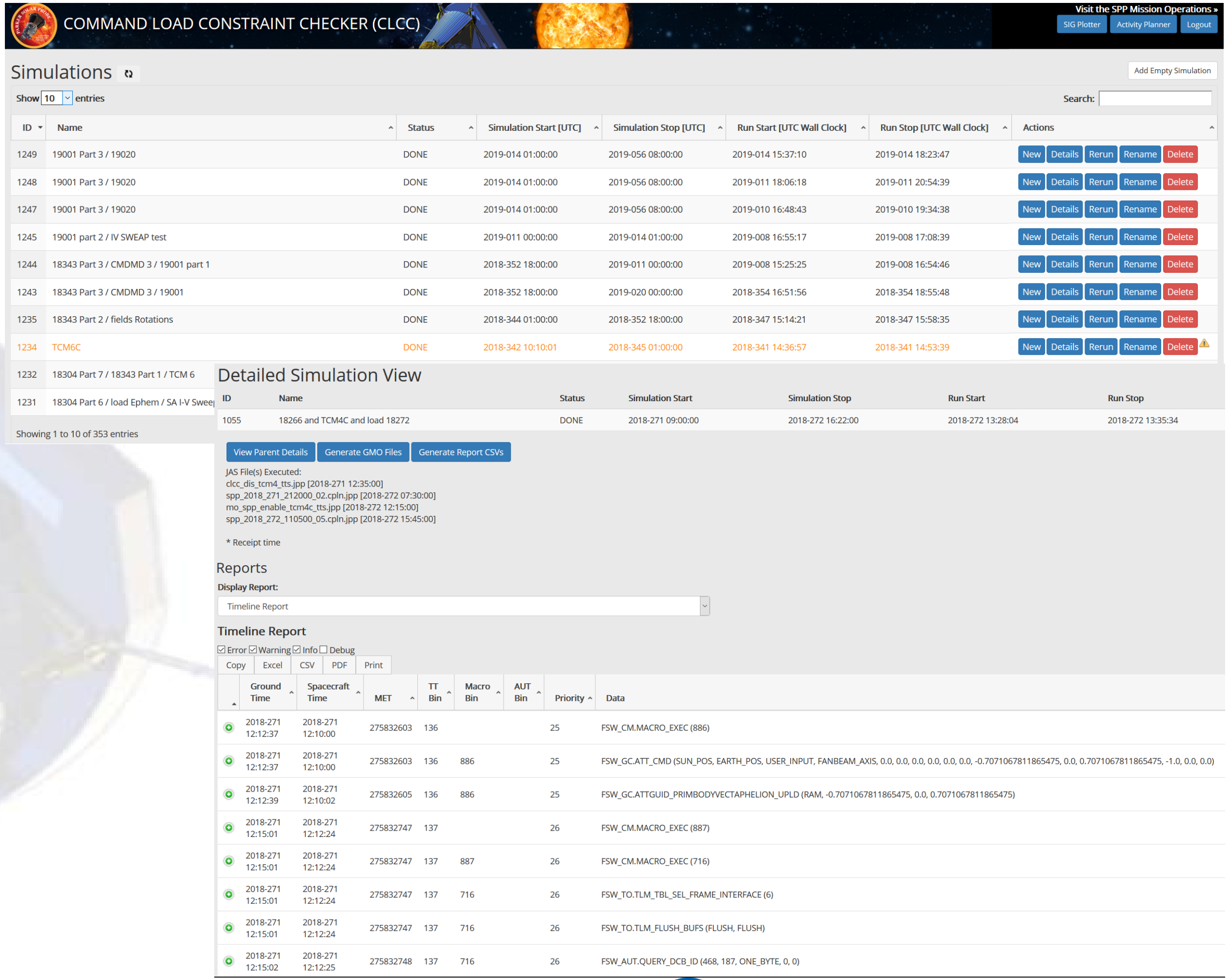




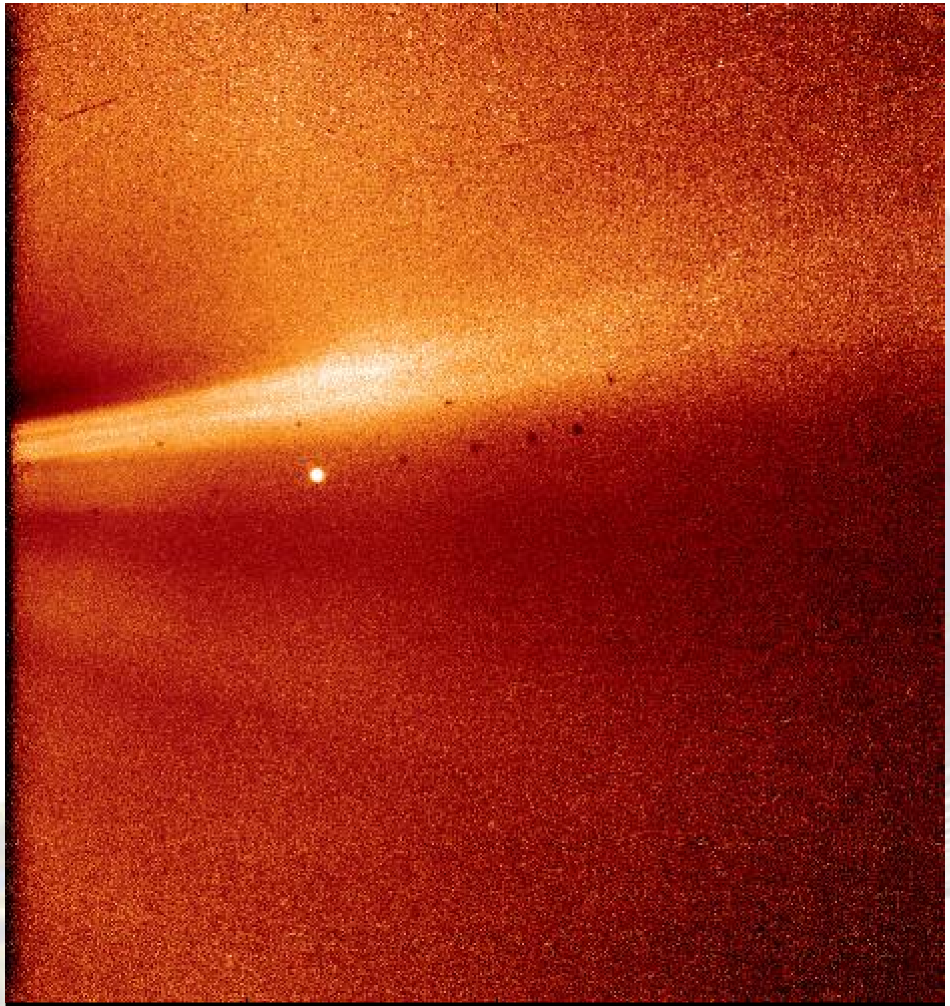


Command Load Constraint Checker (CLCC)

- CLCC is the faster-than-realtime PSP software spacecraft simulator
- Command loads generated by activity planner are checked by this tool before loading to hardware-in-the-loop simulator and spacecraft
- CLCC uses python models of flight behavior at the lowest fidelity required to verify constraints
- Spacecraft memory configurations are initialized and maintained in CLCC and used a baseline for comparison against hardware simulator and spacecraft



Coronal Streamer

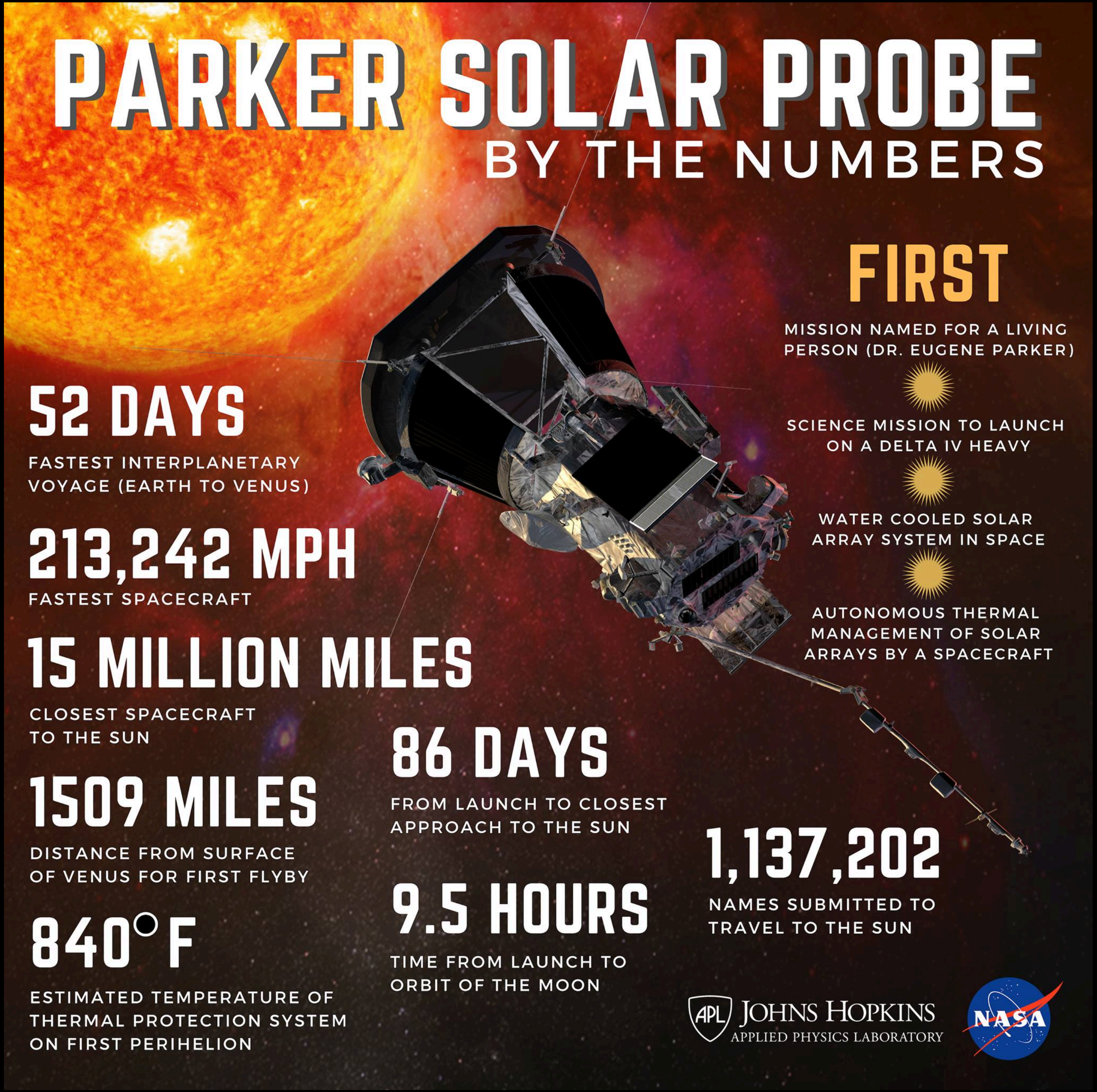


Credit: NASA/NRL/Parker Solar Probe

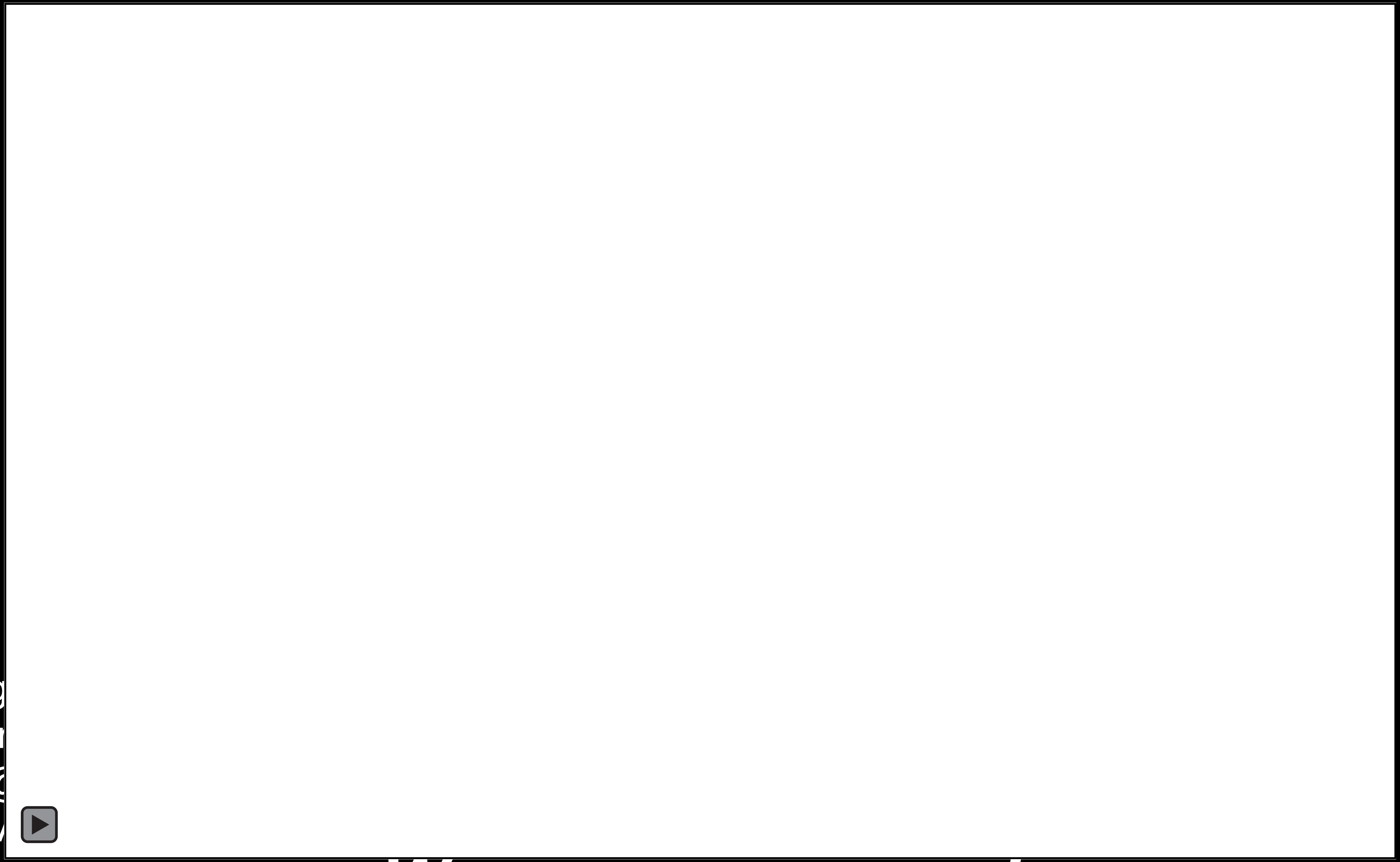
WISPR image of a coronal streamer, seen over the east limb of the Sun Nov. 8, 2018, at 1:12 a.m. EST. Coronal streamers are structures of solar material within the Sun's atmosphere, the corona, that usually overlie regions of increased solar activity.

Parker Solar Probe was about 16.9 million miles from the Sun's surface when this image was taken.

The bright object near the center of the image is Mercury, and the dark spots are a result of background correction.


PARKER SOLAR PROBE
BY THE NUMBERS
52 DAYS
FASTEST INTERPLANETARY VOYAGE (EARTH TO VENUS)
213,242 MPH
FASTEST SPACECRAFT
15 MILLION MILES
CLOSEST SPACECRAFT TO THE SUN
1509 MILES
DISTANCE FROM SURFACE OF VENUS FOR FIRST FLYBY
840° F
ESTIMATED TEMPERATURE OF THERMAL PROTECTION SYSTEM ON FIRST PERIHELION
86 DAYS
FROM LAUNCH TO CLOSEST APPROACH TO THE SUN
9.5 HOURS
TIME FROM LAUNCH TO ORBIT OF THE MOON
FIRST
MISSION NAMED FOR A LIVING PERSON (DR. EUGENE PARKER)
SCIENCE MISSION TO LAUNCH ON A DELTA IV HEAVY
WATER COOLED SOLAR ARRAY SYSTEM IN SPACE
AUTONOMOUS THERMAL MANAGEMENT OF SOLAR ARRAYS BY A SPACECRAFT
1,137,202
NAMES SUBMITTED TO TRAVEL TO THE SUN
APL JOHNS HOPKINS
APPLIED PHYSICS LABORATORY
NASA

It has been almost 60 years since the Parker



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We are on our way!