The Mysterious Corona

Mystery number 1: The temperature rises as you move away from the surface!

6,000 degrees K
What does the escaping atmosphere "look like"?
**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

\[ \nabla \cdot (\rho \mathbf{V}) = 0, \]
\[ \rho (\mathbf{V} \cdot \nabla) \mathbf{V} = -\nabla p + \rho \mathbf{g}, \]
\[ p = \rho RT, \]
\[ T = T_0. \]

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

*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 km²/s²
- 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
Mission Trajectory and Current Position

Heliocentric Velocity (km/s): 20.89
Distance from Sun Center (AU): 0.761
Distance from Sun's Surface (R$_\oplus$): 162.7
Distance from Earth (AU): 1.738
Round-Trip Light Time (hh:mm:ss): 00:28:53
25 Feb 2019 20:00:00 UTC

Credit: PSP Mission Design Team
Mission Design
Solar Orbits and Solar Distances

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

- 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

Credit: NASA/Johns Hopkins APL/Ed Whitman
At closest approach, the front of the heat shield will be at 1,400°C (2500 °F), but the payload will be near room temperature.
Solar Array Development

- Solar Array is unique: liquid cooled, operates under extreme solar flux.
Ram Facing View

FIELDS PI
Stuart Bale (UC, Berkeley)

ISOIS PI
David McComas (Princeton)

WISPR PI
Russ Howard (Naval Research Lab)

HelloPSP PI
Marco Velli (UCLA)
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.

FIELDS
Boom Deployment & Type III Burst

Measured magnetic fields as the boom swings away from PSP

First science measurement ever by Parker Solar Probe

First PSP Type-III radio burst from a solar flare
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).

SWEAP
Unexpected Signature of the Slow Solar Wind

PSP/SWEAP/SPC, Collector Plate A

Current (pA)

2018/09/06, Universal Time (UTC)

SWEAP Solar wind measurements (slew)

SPAN-A/B

Electron SPAN-A/B

SPC Solar Probe Cup (SPC)

SPAN-Ai
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.

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.

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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

- 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
TCMs and Communication Opportunities
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)

Cruise/Science Downlink Period
(outside 0.25 A.U.)

24 Solar Encounter Orbits
Orbital Periods Vary (168 days to 88 days)

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

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 MOC Data Products

MOC Data Product Sources

- flight data
- planning data
- navigation data

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 Telemetry Dictionary
- GND Telemetry Dictionary
- SSR Raw Directory File
- SSR Directory Listings
- Att Hist Report
- Ops SCLK Kernel
- Time History File
- MET Register History File

MOC
- 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)

PLANNING

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

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

DSN
- DSN Schedule File
Ground Software Heritage

1990s
One-Off Systems

2000s
Common Ground Architecture

2010s
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

The same set of software is used in each configuration
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

- 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

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
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

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

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

1,137,202
NAMES SUBMITTED TO TRAVEL TO THE SUN

JOHNS HOPKINS APPLIED PHYSICS LABORATORY
NASA
It has been almost 60 years since the Parker Solar Probe Concept was introduced. We are on our way! 

http://nasa.gov/solarprobe
http://solarprobe.jhuapl.edu
Facebook: @NASA Sun Science
Twitter: @NASASun