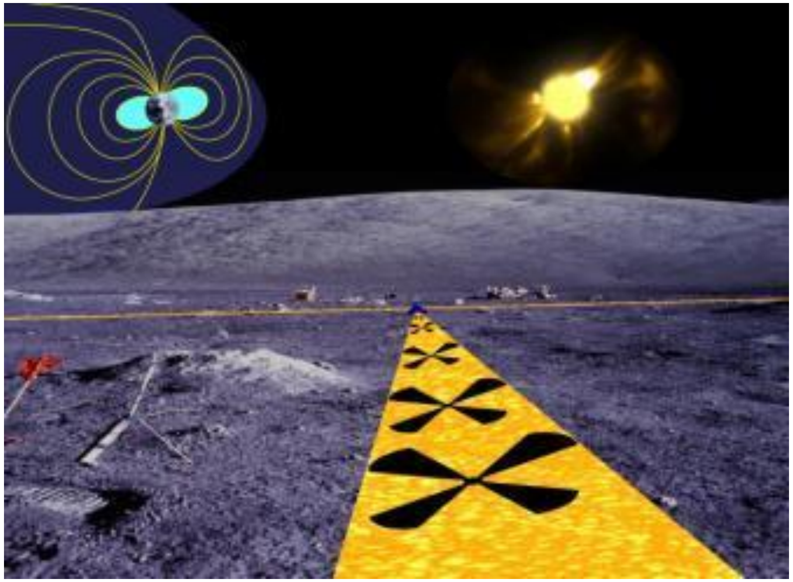
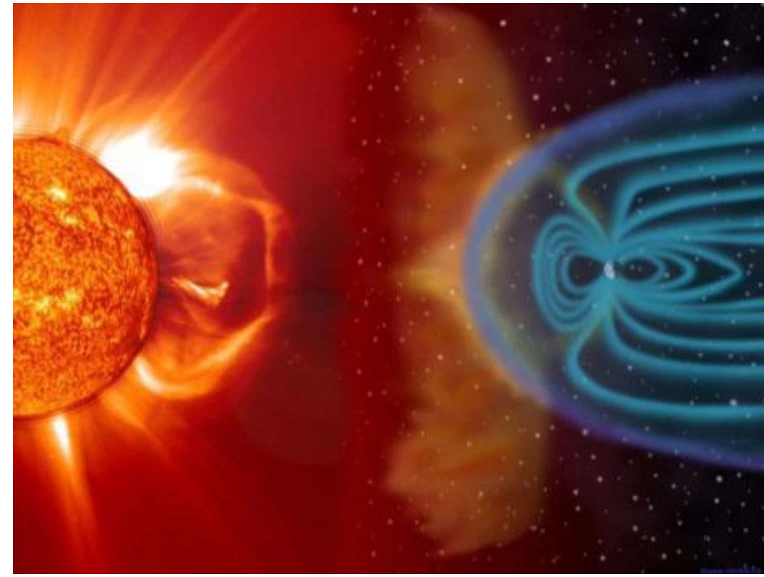




Remote Imaging of Electron Acceleration at the Sun with a Lunar Radio Array

J. Kasper

Harvard-Smithsonian Center for Astrophysics

6 October 2010

Robotic Science From the Moon: Gravitational Physics, Heliophysics and Cosmology

Boulder, Colorado

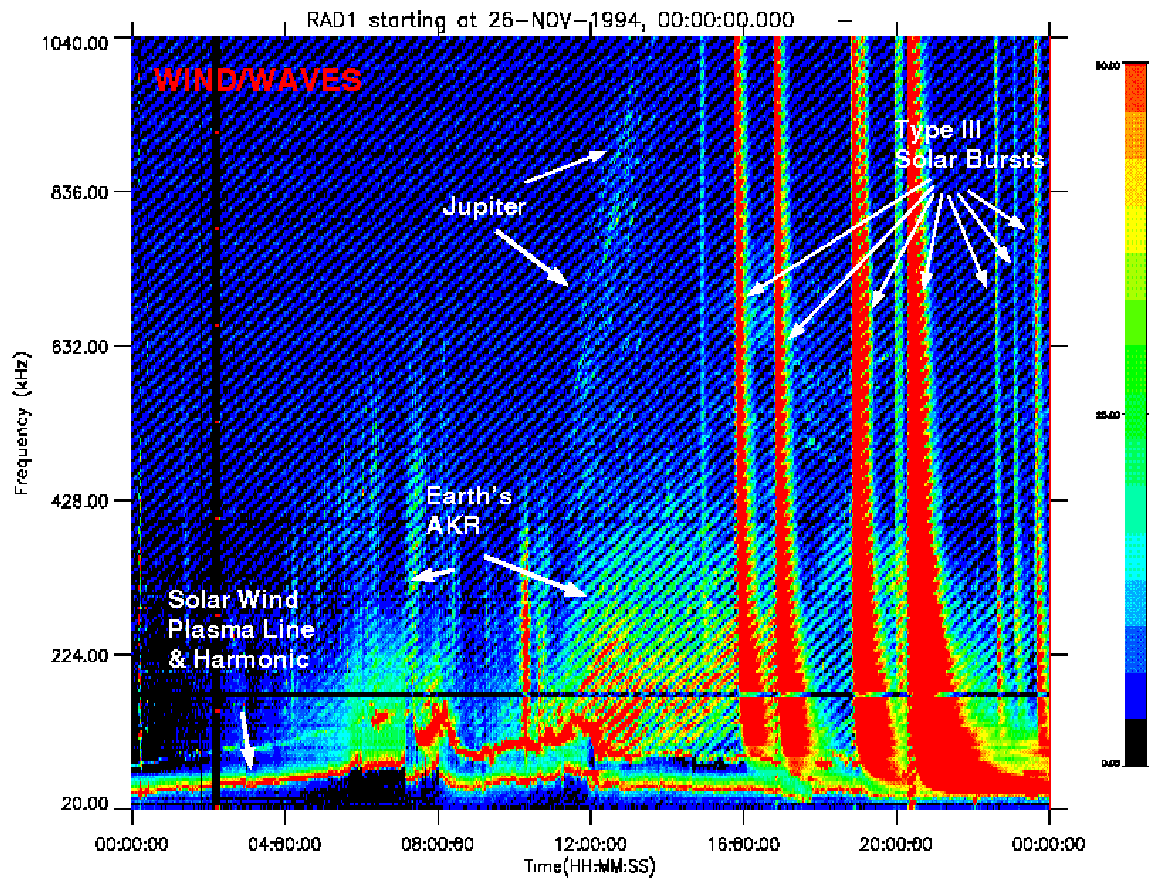
Outline

- Motivation for going into space and on the moon
- Description of ROLSS, a simple near-side radio array where antennas roll out onto surface of moon
- ROLLS science case, including providing context for the Solar Probe Plus mission to the atmosphere of our Sun

Why low frequency radio?

Coherent emission as a plasma probe

- As Stuart Bale showed in his talk, power spectra show strong sources of coherent emission in the inner heliosphere
- Generated by energetic electrons, the emission frequency is tied to quantities like local density
- If we can image this emission we can make 3D maps of particle acceleration



Radio Interferometry

Operating principle – or why no mile-wide dishes

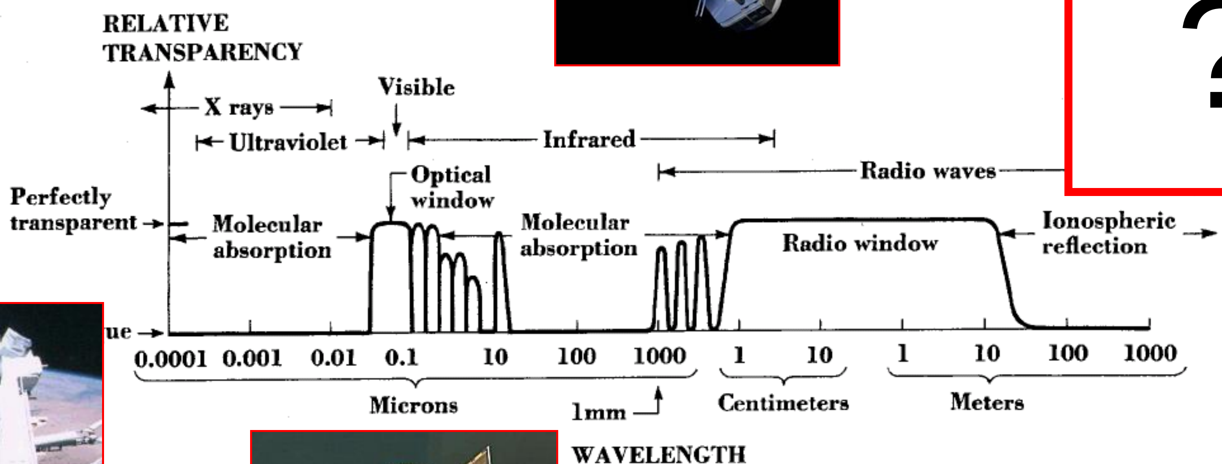
Aperture synthesis leads to angular resolution: $\theta \sim \lambda/D$

Why build an array in space?

Chandra

Spitzer

?



Hubble

CGRO

Why build an array on the moon?

- Element locations
  - Fixed instead of range finding
- Station keeping
  - Mission limitations due to fuel consumption
- Reduced field of view
  - Image reconstruction
- Structures
  - Build on the lunar surface
- Communications
  - Fixed line of slight to Earth on near side

ROLSS: A Pocket VLA for the Moon

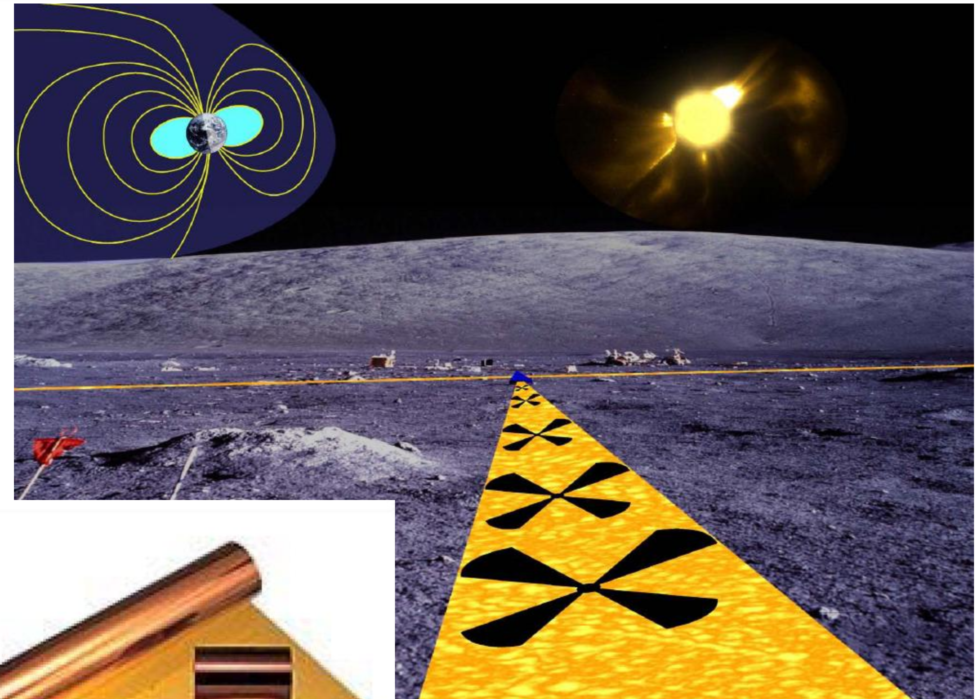
Parameter	Requirement	Explanation
Wavelength (Frequency)	30–300 m (1–10 MHz)	Matched to radio emission generated by particle acceleration in the inner heliosphere
		Obtain spectra of Galactic and extragalactic sources at longest wavelengths
		Probe lunar ionosphere
		Operate longward of Earth's ionospheric cutoff
Angular Resolution	2° (at 10 MHz)	Localize particle acceleration sites in CMEs and Type III solar bursts
		Order of magnitude improvement
Bandwidth	100 kHz	Track (time-)evolution of particle acceleration
Lifetime	1 yr	Obtain measurements during several solar rotations

- GSFC, UCB/SSL, SAO, JPL, NRL
- Radio array about 1km in diameter on the near side of the moon
- Designed to observe at low frequencies below ionospheric cutoff
- Key is simple dipole antennas deposited on rolls of thin polyimide film

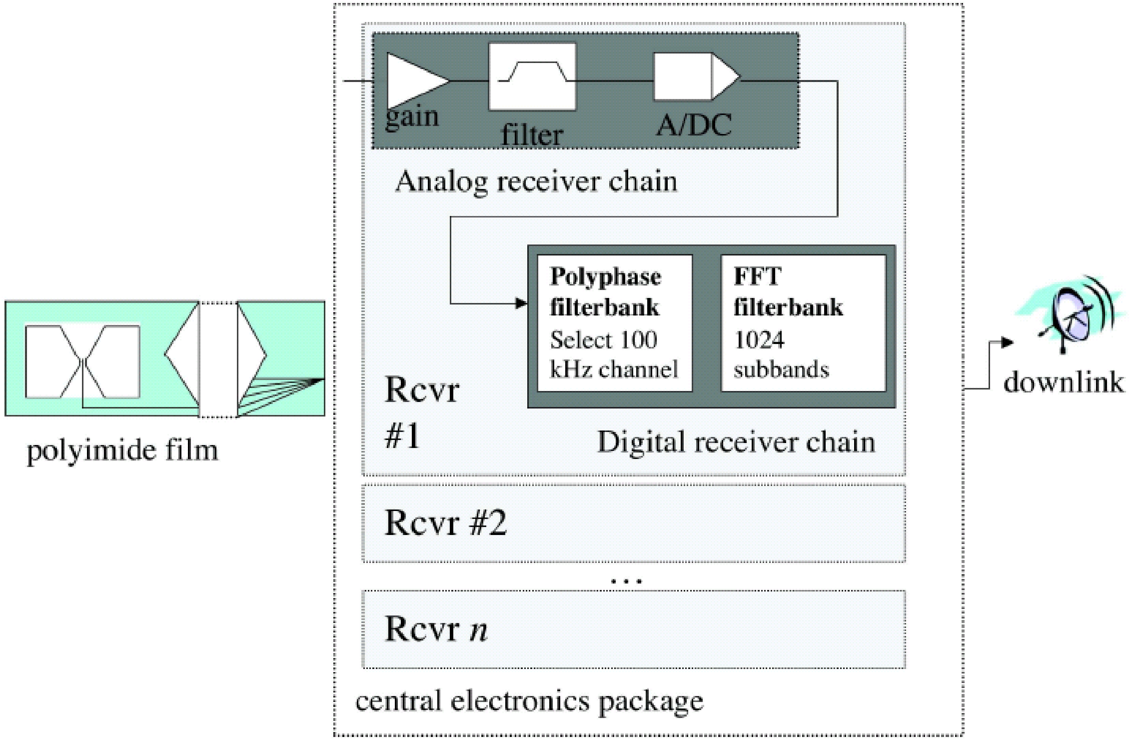
ROLSS design concept

Printed antennas on a roll

- Print the antennas on thin sheets of polyimide like circuit boards
- Three 500 meter rolls with ~ 16 antennas each
- Unroll from center to form “Y” shaped interferometer
- More on deployment in next talk by Bob MacDowall

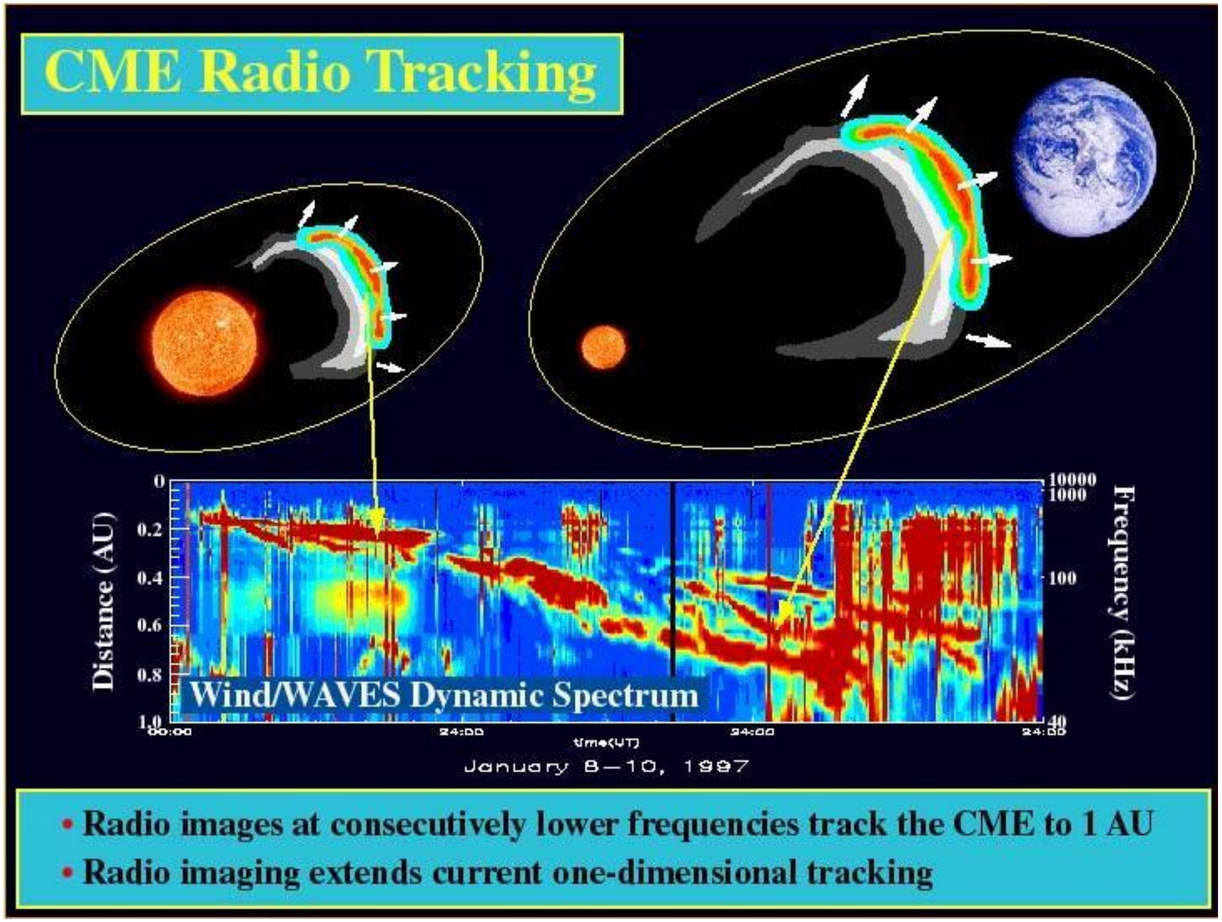


ROLLS data flow



Science questions

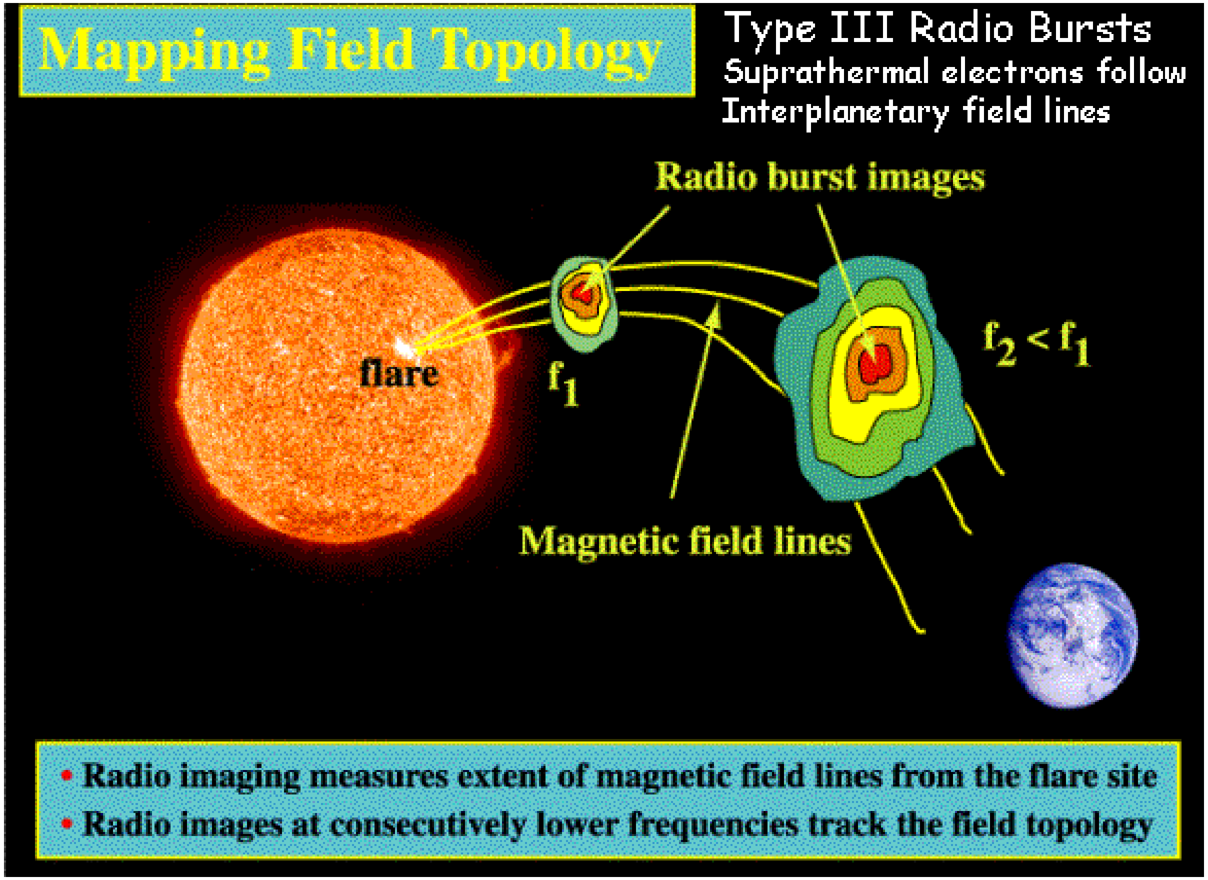
Tracking CMEs into heliosphere



SIRA website

Science questions

Tracing magnetic field lines

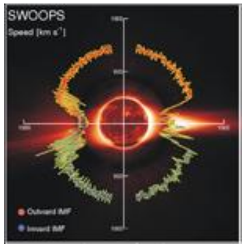


SIRA website

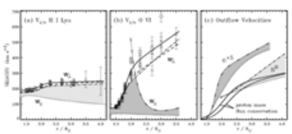
A New Urgency: Solar Probe Plus

- SPP is our first mission to the atmosphere of a star, directly sampling the solar corona
- Timeline
  - A mission like Solar Probe has been in play for more than fifty years
  - In September 2010 NASA announced selections for the Solar Probe Plus (SPP) mission
  - Launch no later than 2018
  - Science operations through 2026
- This $1.3B mission, ranked first in large category by last Decadal, has a $180M science payload including instruments that measure electrons and radio emission
- A lunar radio array could provide 3D context for energetic electrons in order to better understand particle acceleration and magnetic topology in the solar corona and wind

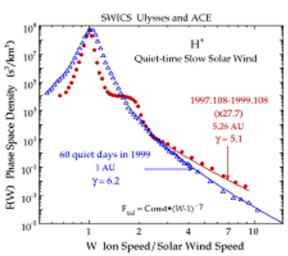
Solar Probe Plus Science Objectives



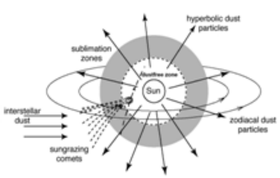
- Determine the structure and dynamics of the magnetic fields at the sources of the fast and slow solar wind.



- Trace the flow and elucidate the thermodynamics of the energy that heats the solar corona and accelerates the solar wind.

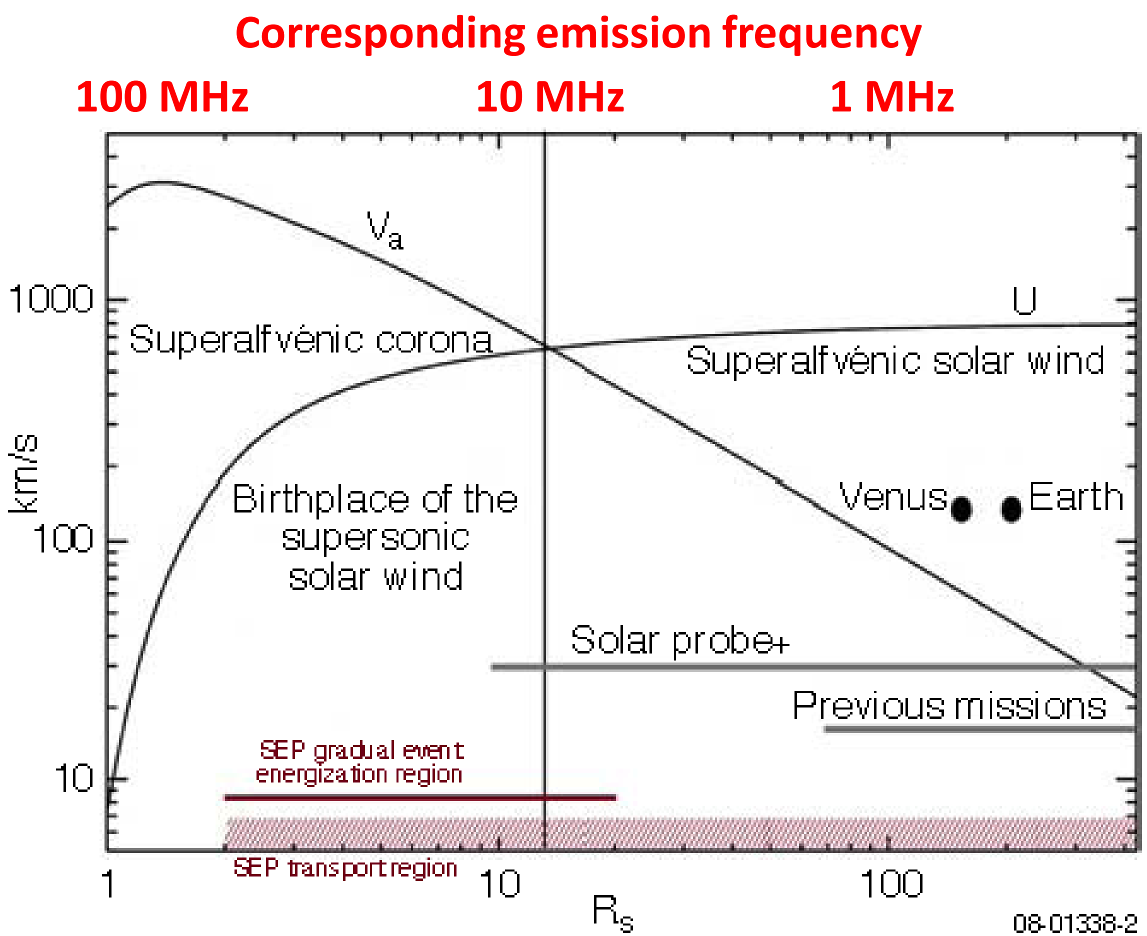


- What mechanisms accelerate and transport energetic charged particles?



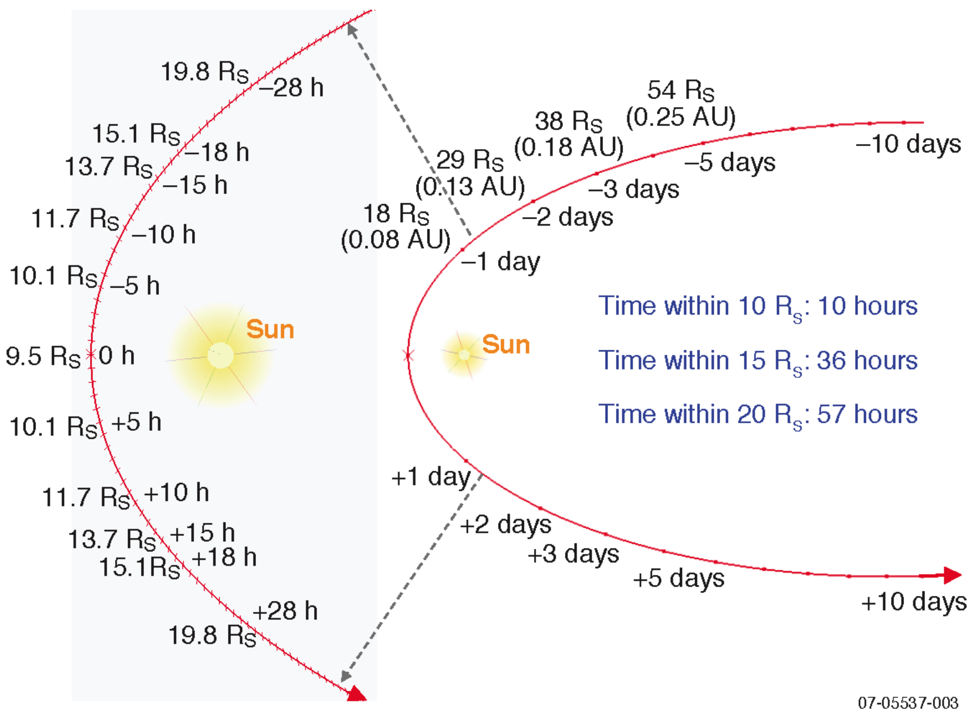
- Explore dusty plasma phenomena and their influence on the solar wind and energetic particle formation.

SPP will approach sun to within 9.5 R_S



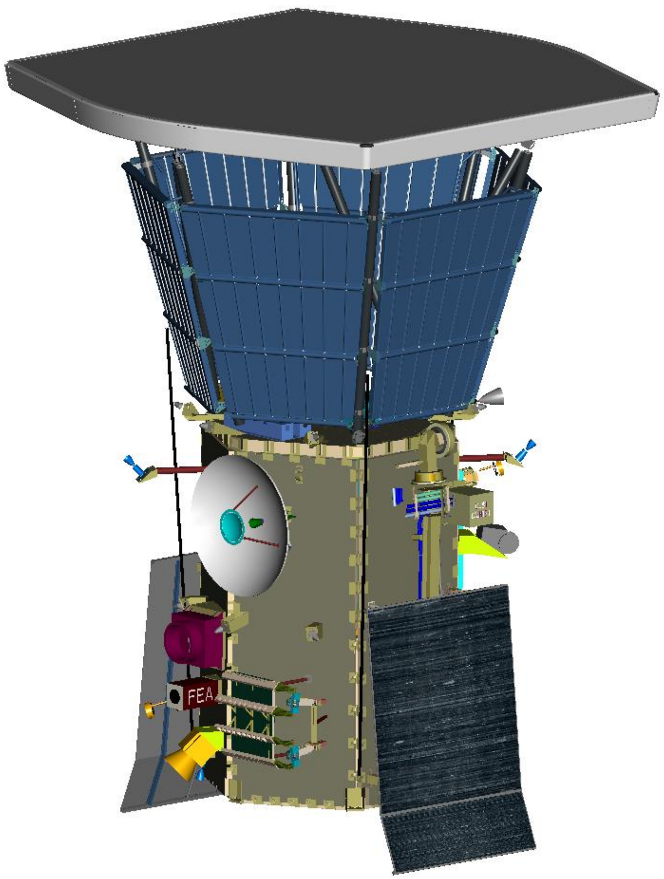
- Model profiles of solar wind speed and Alfvén wave speed with distance from the Sun.
- Vertical bar separates the source, or sub-Alfvénic, region of the wind from the supersonic solar wind flow.
- SPP will be the first mission to fly inside the solar wind source region and sample directly the critical region of the outer corona where solar energetic particles (SEPs) are generated.
- Corresponding radio emission all below ionospheric cutoff

SPP will take 30 hrs of data inside 10 R_S



- The trajectory of the Solar Probe Plus during one of its minimum perihelion passes.
- Seven Venus gravitational assists over eight years lower perihelion to 8.5 R_s above the surface of the Sun
- With three such passes during its prime mission, Solar Probe Plus will gather a total of 30 hours worth of data inside 10 R_S.

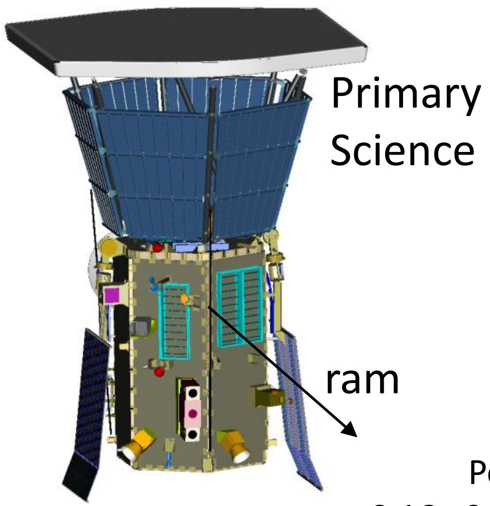
Vehicle Overview

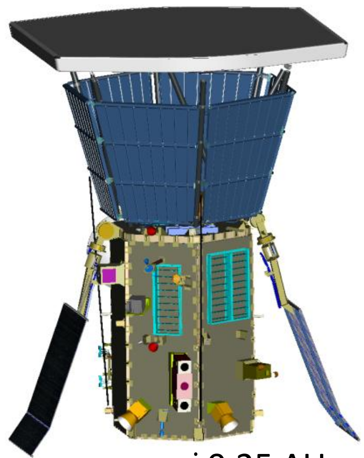


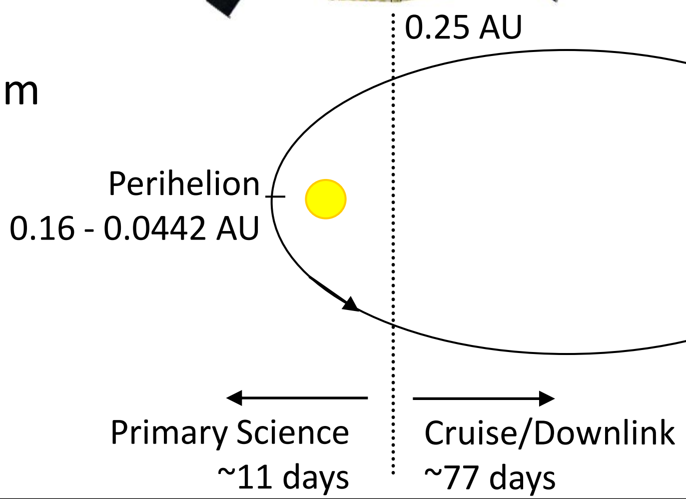
- Spacecraft construction, instrument integration and spacecraft operations by JHU/APL
- 610kg max launch wet mass
- Reference Dimensions:
  - S/C height: 3m
  - TPS max diameter:2.3m
  - s/c bus diameter: 1m
- C-C Thermal protection system
- Hexagonal prism s/c bus configuration
- Actively cooled solar power system
- Design Drivers: solar environment, mass, power

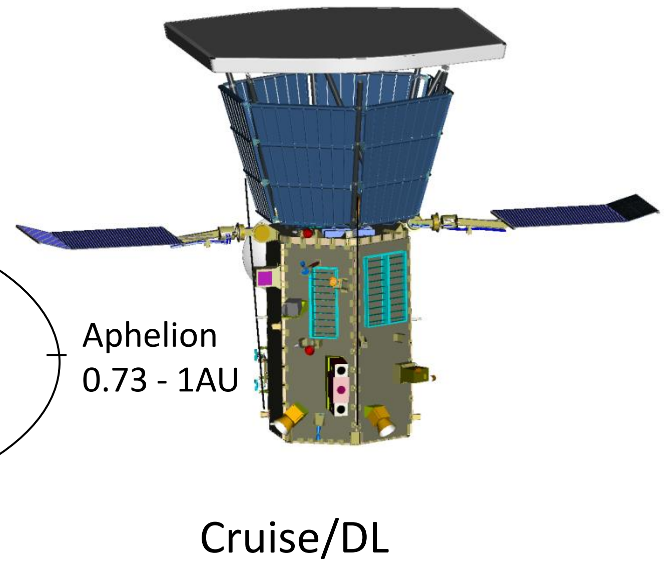
Science and Cruise Configurations

- TPS is pointed at sun throughout orbit (exceptions are at s/c sun distances > 0.7AU: science DL, Delta-V, cooling system start-up)
- S/C is ram pointed during primary science (perihelion through ~0.25AU)









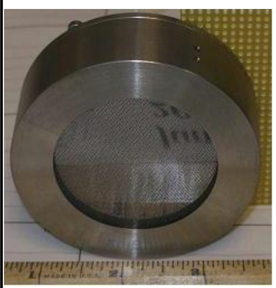
Instruments

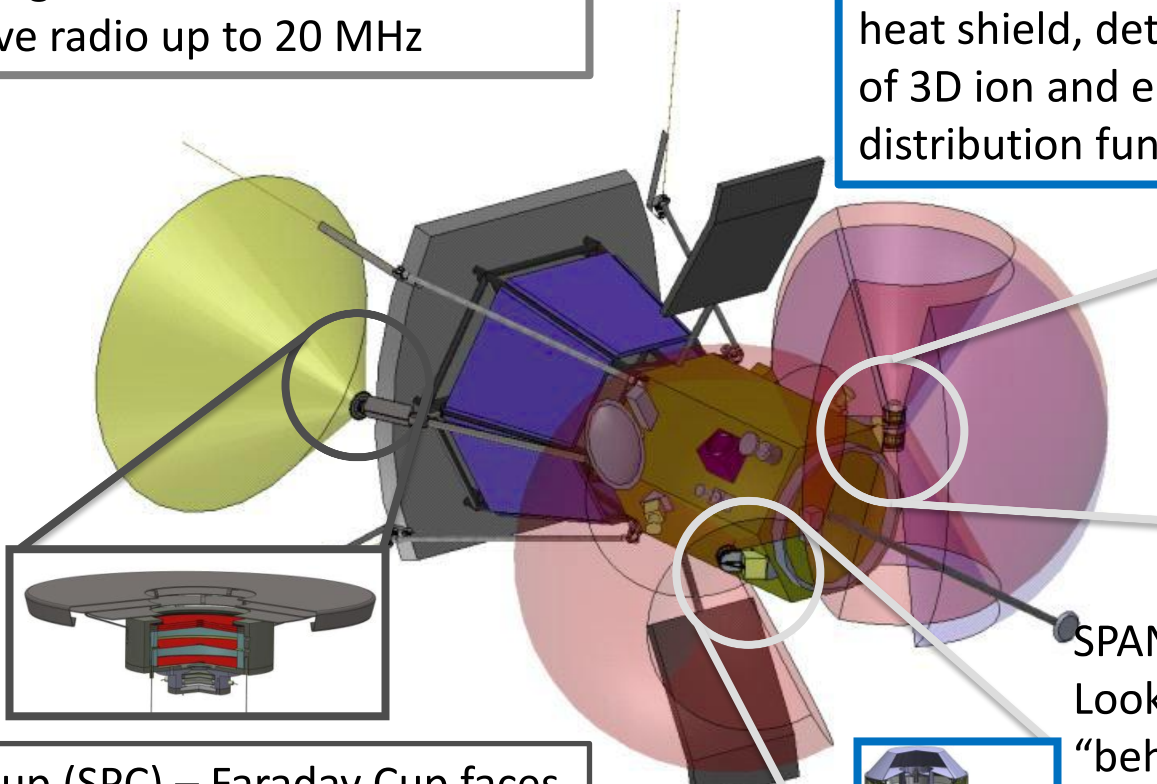
- **Solar Wind Electrons Alphas and Protons (SWEAP) Investigation**. The purpose of SWEAP is to scoop up samples of the atmosphere of the Sun during each of the encounters. SWEAP measures the detailed properties of electrons, protons, and helium ions. PI: Justin C. Kasper, SAO
- **The Fields Experiment**. FIELDS will make direct measurements of electric and magnetic fields, radio emissions, and shock waves that course through the sun's atmospheric plasma. The experiment also serves as a giant dust detector. PI: Stuart Bale, UCB/SSL
- **Integrated Science Investigation of the Sun**. This investigation consists of two instruments that will monitor electrons, protons and ions that are accelerated to high energies in the sun's atmosphere. Principal Investigator: David McComas, SwRI.
- The **Wide-field Imager**, a telescope that will make 3-D images of the sun's corona, or atmosphere. This investigation complements instruments on the spacecraft providing direct measurements by imaging the plasma the other instruments sample. Principal Investigator: Russell Howard, NRL

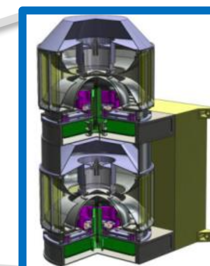
SWEAP and FIELDS

FIELDS Electric Field Antennas – Four antennas facing the Sun around the heat shield, observe radio up to 20 MHz

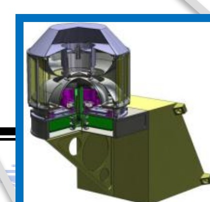
Solar Probe ANalyzers (SPAN) – Electrostatic Analyzers behind the heat shield, detailed measurements of 3D ion and electron velocity distribution functions up to 30 keV



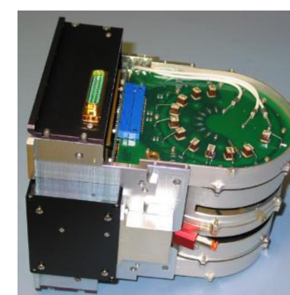




SPAN-A: Looks “ahead”, ions and electrons



SPAN-B: Looks “behind”, electrons



Themis

Solar Probe Cup (SPC) – Faraday Cup faces the Sun, high cadence (up to 128 Hz) bulk ion and electron measurements

Conclusions

- Imaging in low frequency radio is a compelling scientific program
  - Can only be done in space
  - Solid reasons for doing this at the moon
- A simple radio array is technically feasible
  - Mass, power, deployment, processing
  - New science even from simple demonstrator
- Highly desirable to have a lunar array operating during the SPP mission (2018-2026)