Solar radio emission below the ionospheric cutoff: measurements

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outline

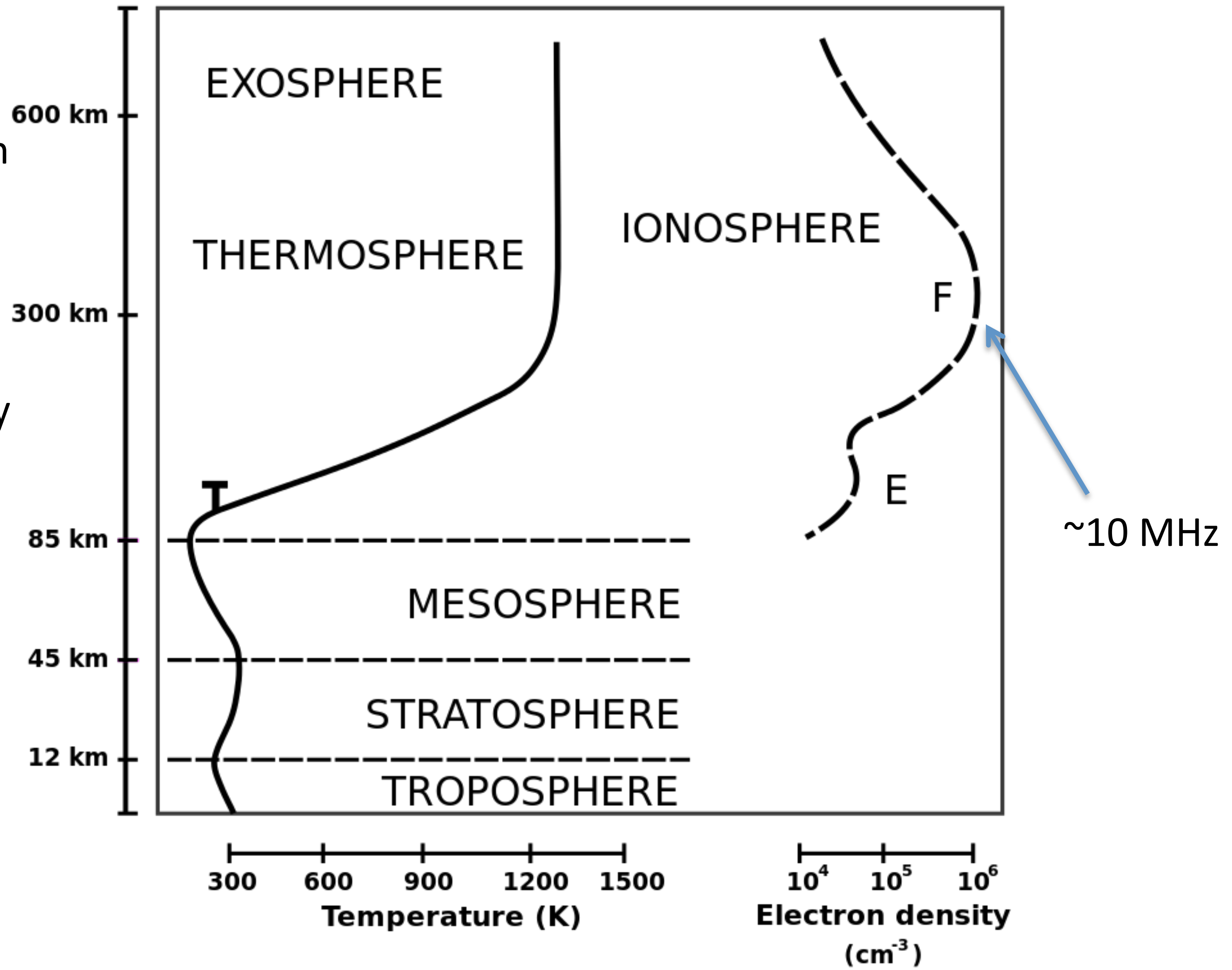
1) frequency range
   - a) need to be in space!

2) spacecraft measurements
   - a) Wind, STEREO
     - I) superheterodyne receivers
     - II) spacecraft electromagnetic compatibility - the picket fence
     - III) antenna pattern and direction-finding
   - b) Solar Probe Plus and Solar Orbiter
     - I) Radio Frequency Spectrometer on SPP
       - A) Polyphase Filterbank (PFB)

The terrestrial ionosphere

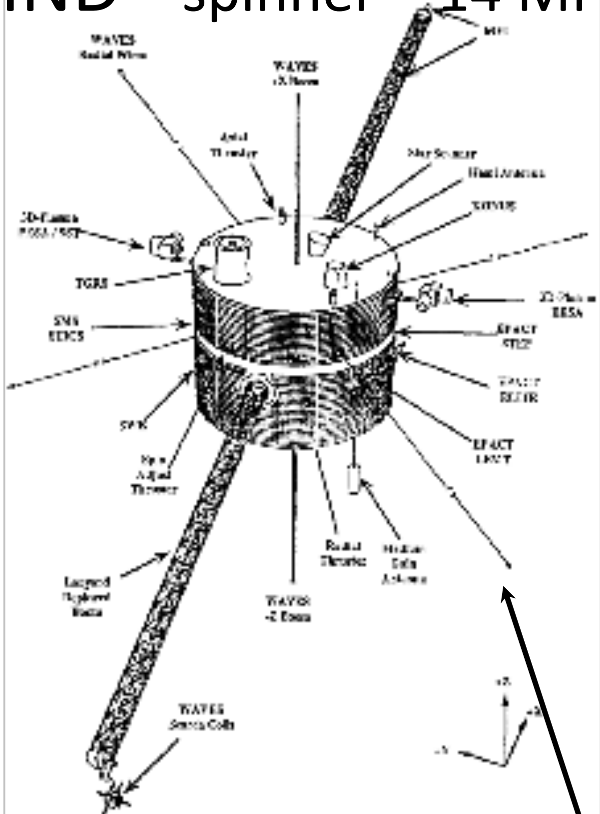
- UV ionization
- Recombination
- F-layer 200-1000km
- Diurnal variations
- Seasonal variations

- F-layer peak density is ~10^6 cm^{-3}
- Corresponding plasma frequency ~10 MHz
- We need to get above ~500 km to get to lower frequencies

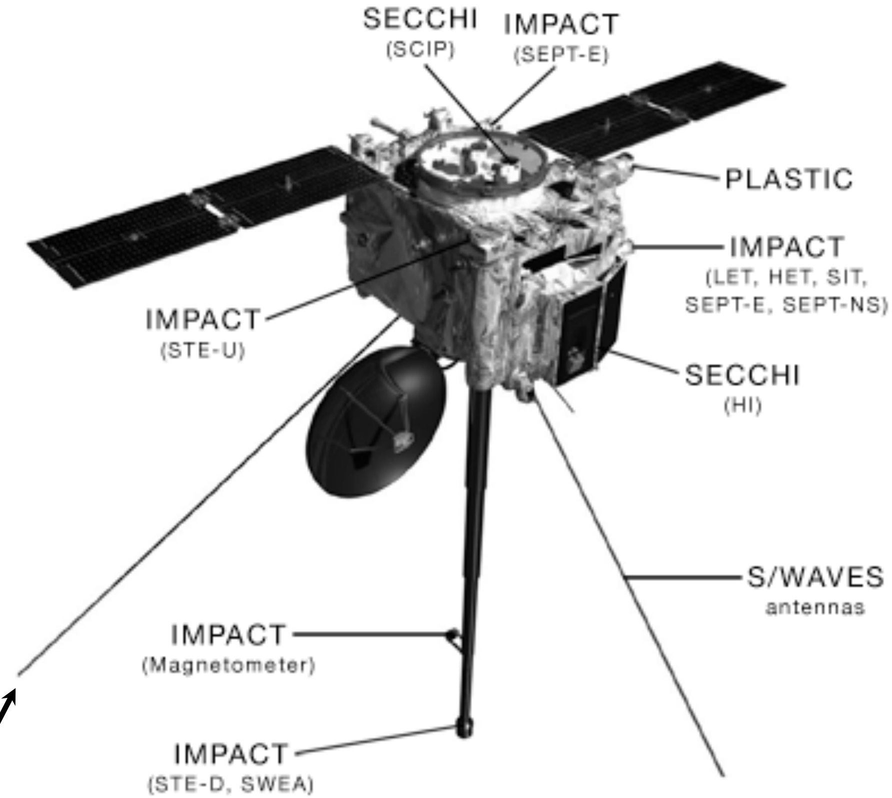


Space-borne solar/IP radio instruments

WIND – spinner – 14 MHz

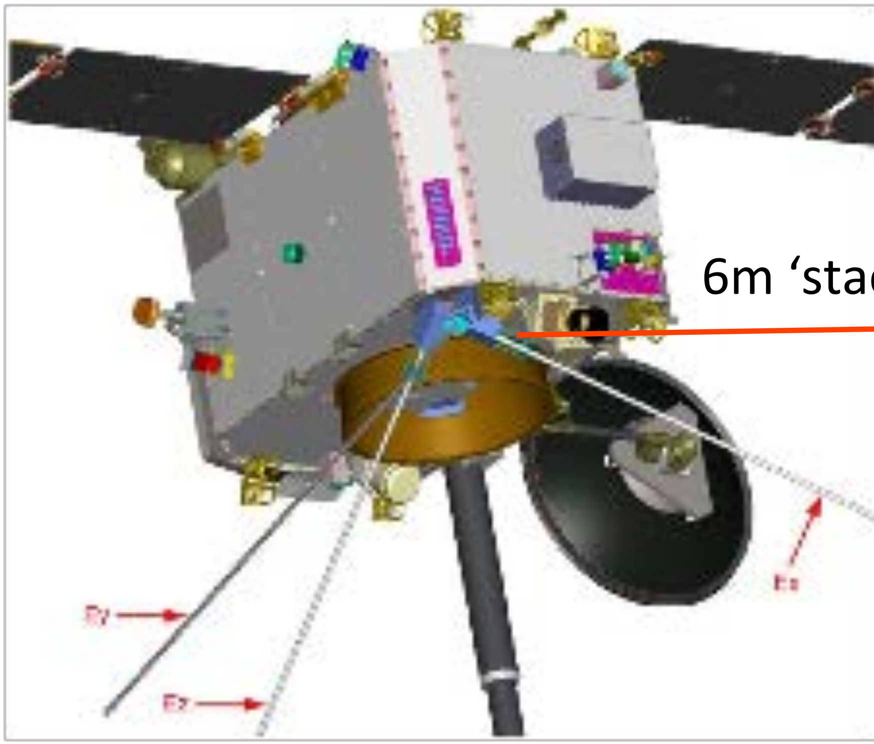


STEREO – stabilized – 16 MHz

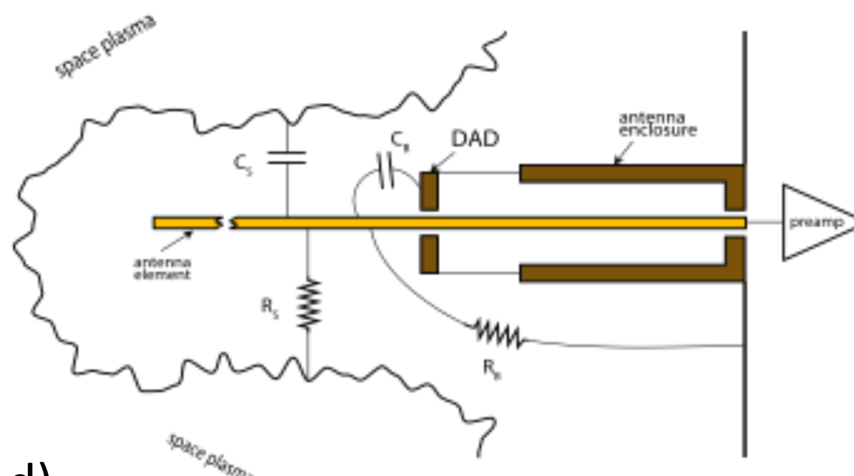


Deployable electric antennas

STEREO/WAVES - stabilized

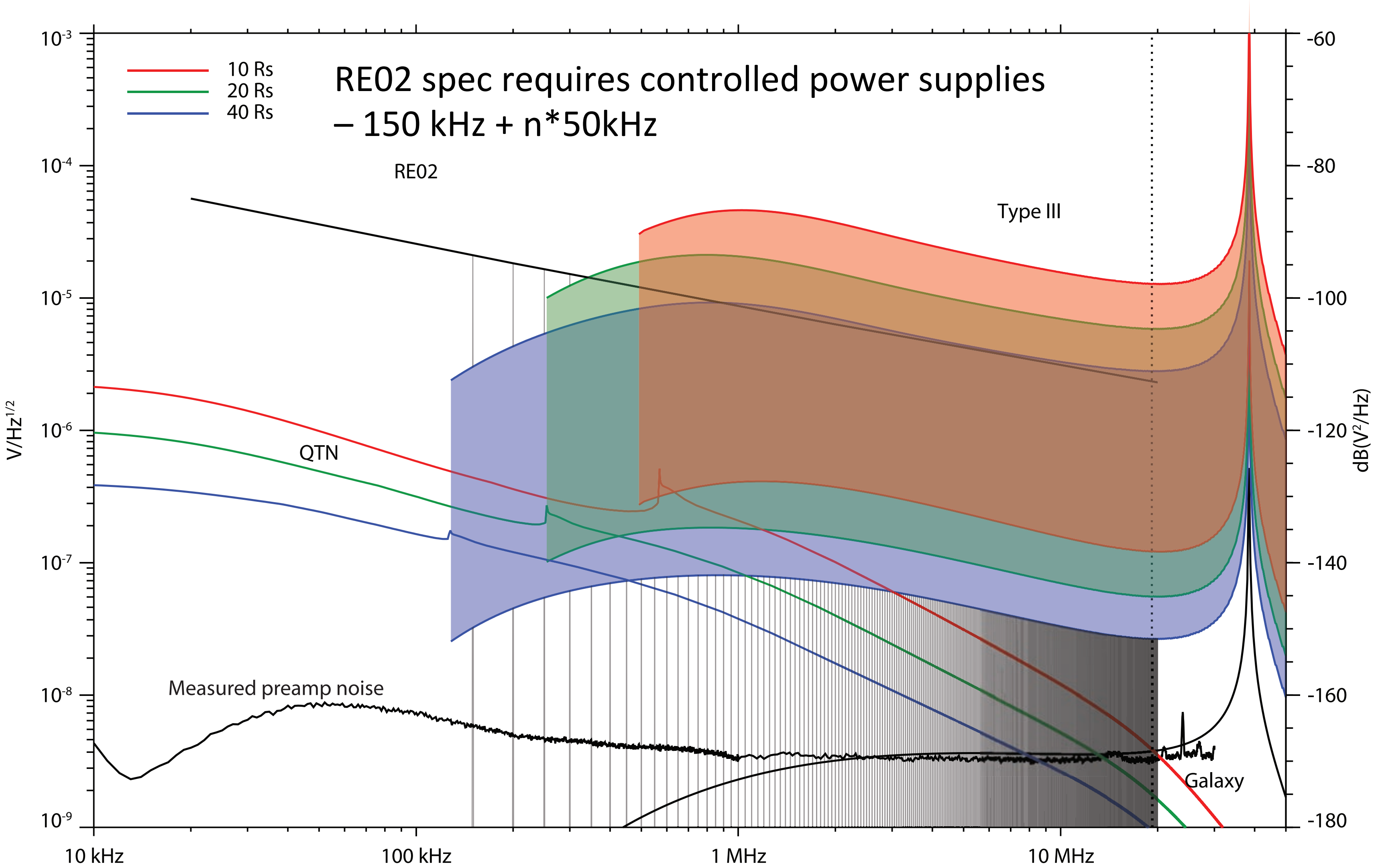


6m ‘stacer’

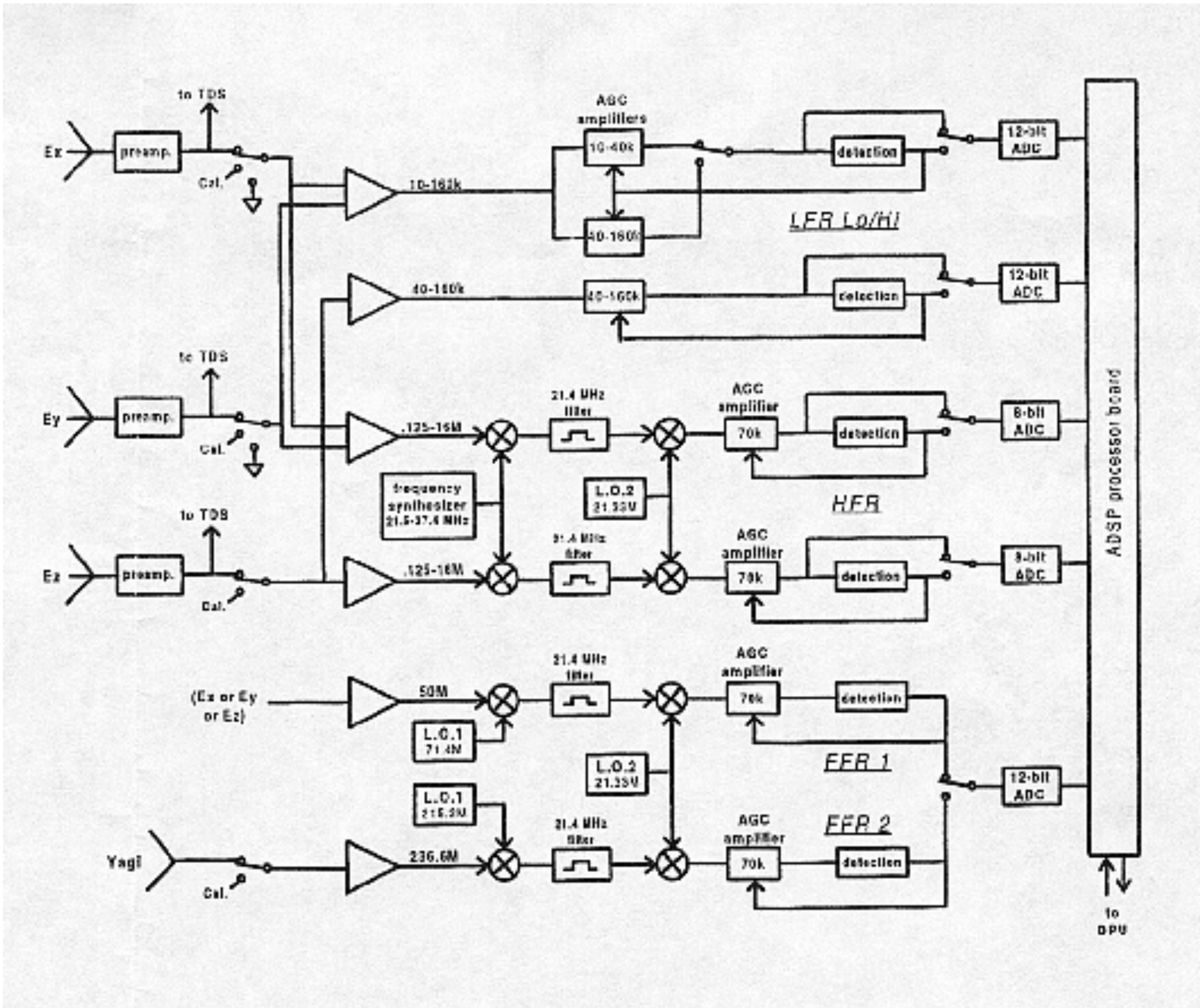


- Operated as a ideal voltmeter (unbalanced)
- Gain is limited by stray capacitance

Sensitivity and electromagnetic cleanliness

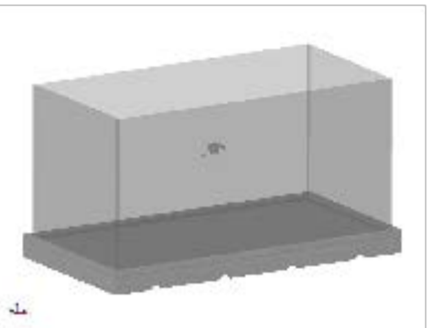


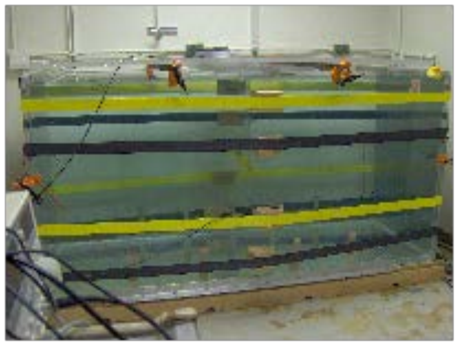
STEREO/WAVES instrument

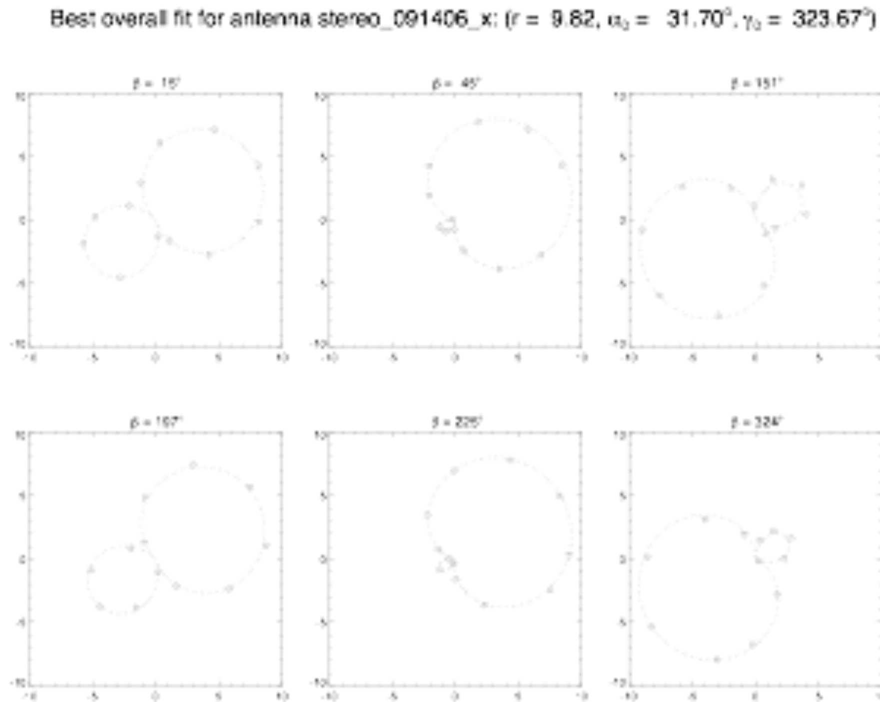


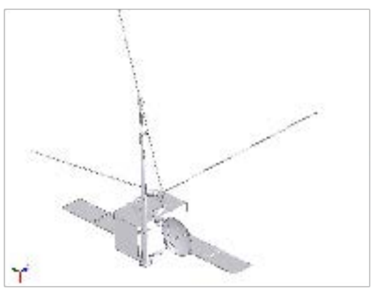
High Frequency Receiver (HFR) – superheterodyne receiver, 12bits

STEREO/WAVES - stabilized



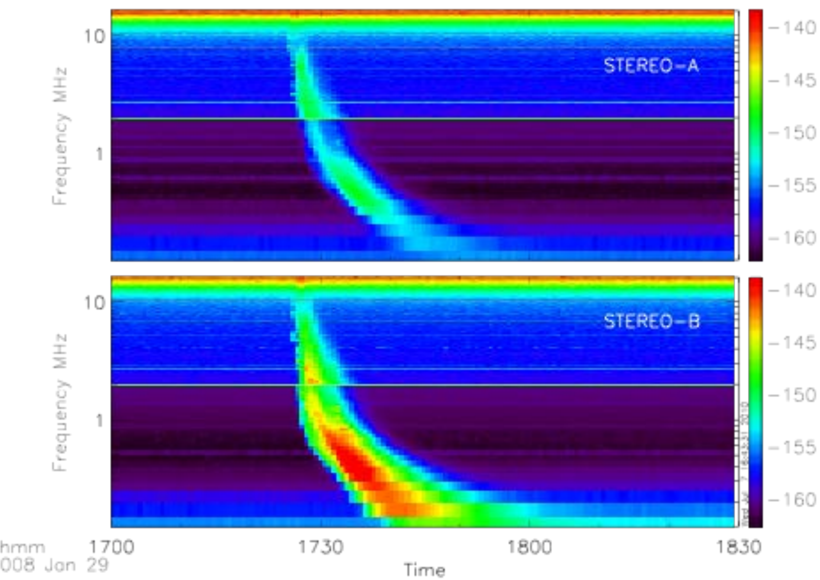






- Antenna pattern is modified by spacecraft structure and poor groundplane
- Antenna pattern can be measured in lab

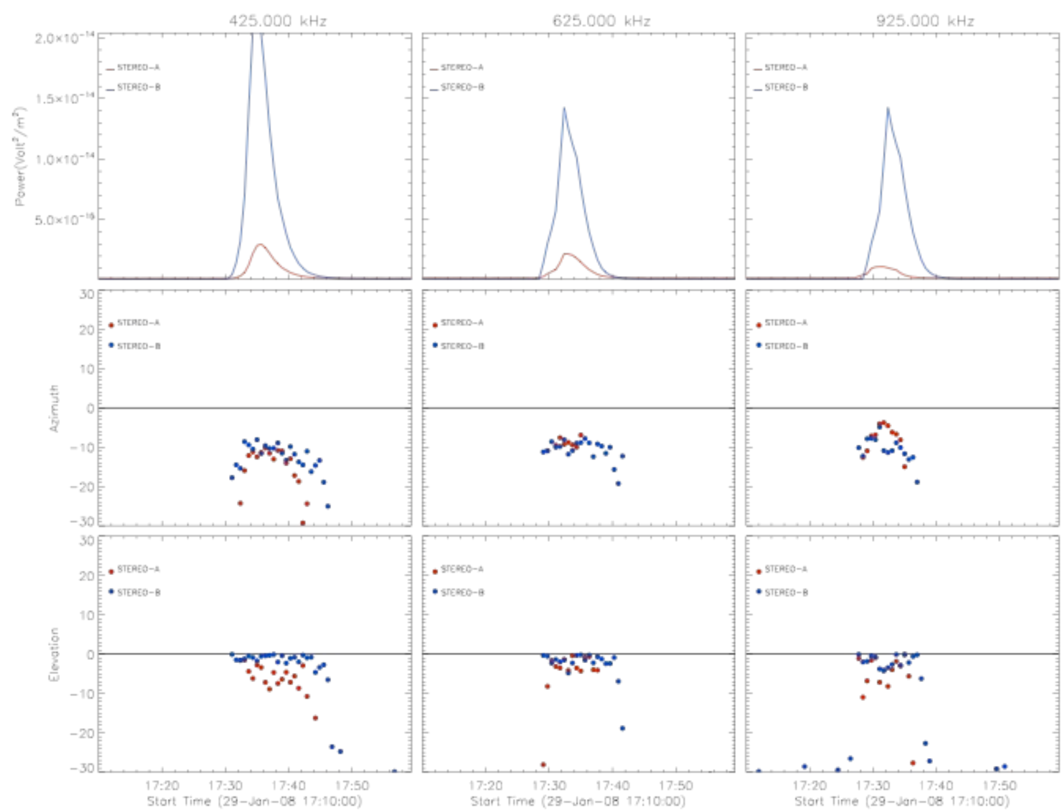
Radio direction-finding



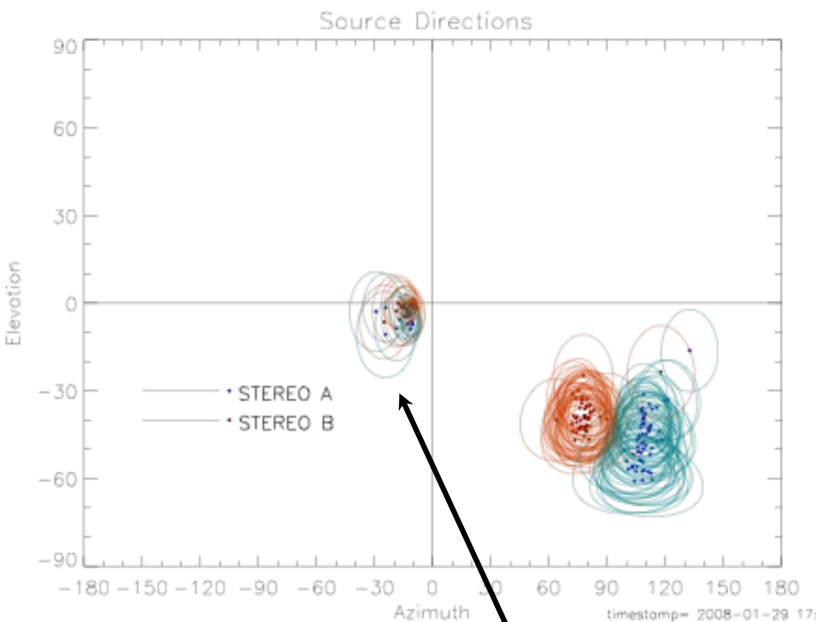
Isolated type III burst

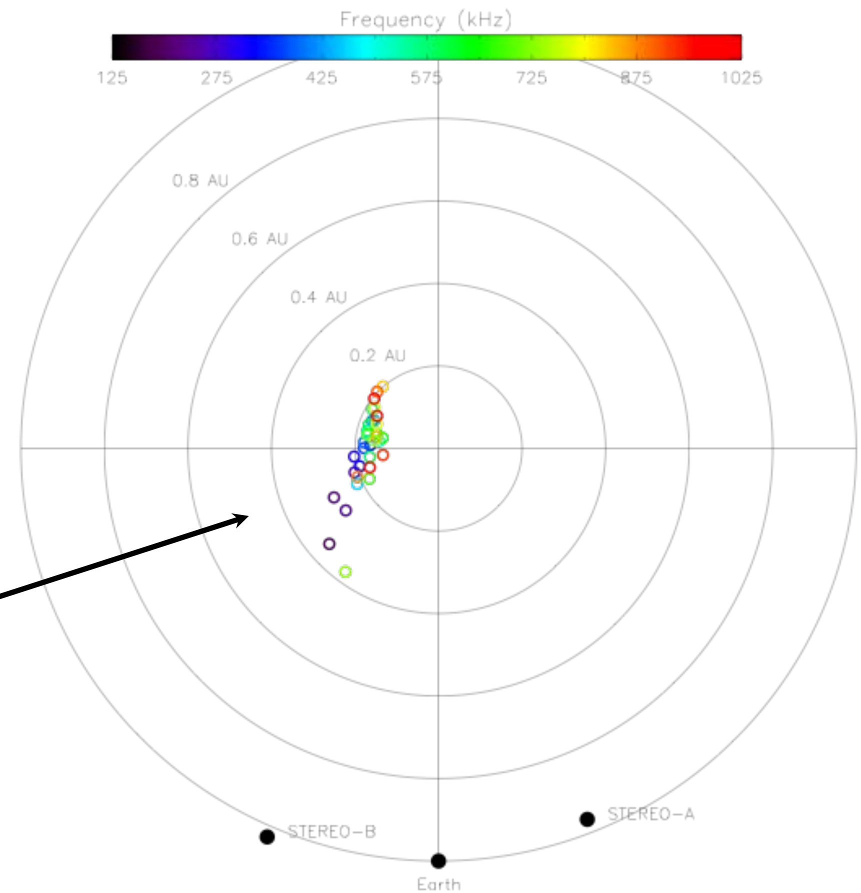
Power and angles

(red = A, blue = B)



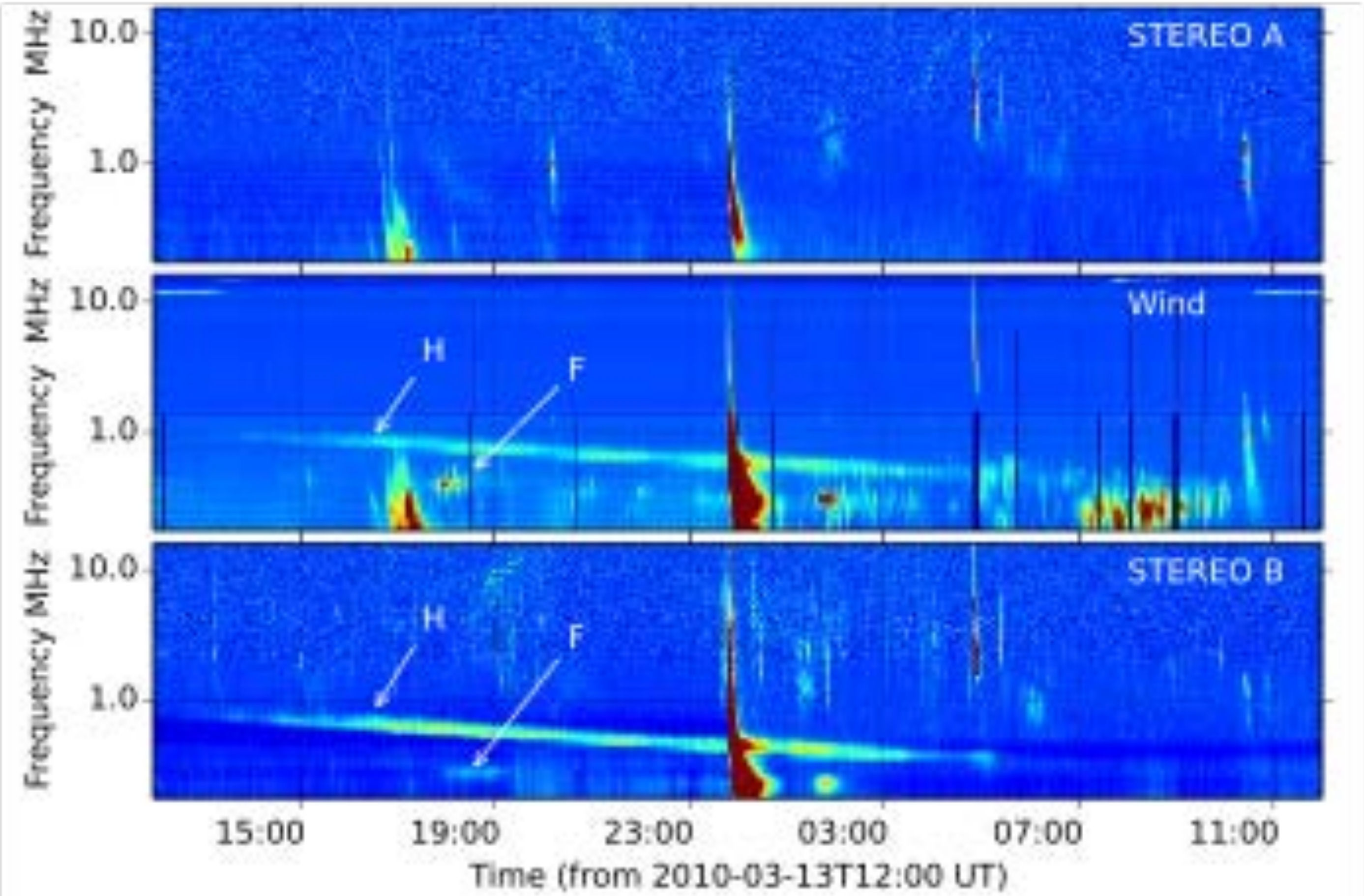
Radio direction-finding





- Technique gives source direction, size, and polarization (small)
- Two spacecraft used to triangulate to source

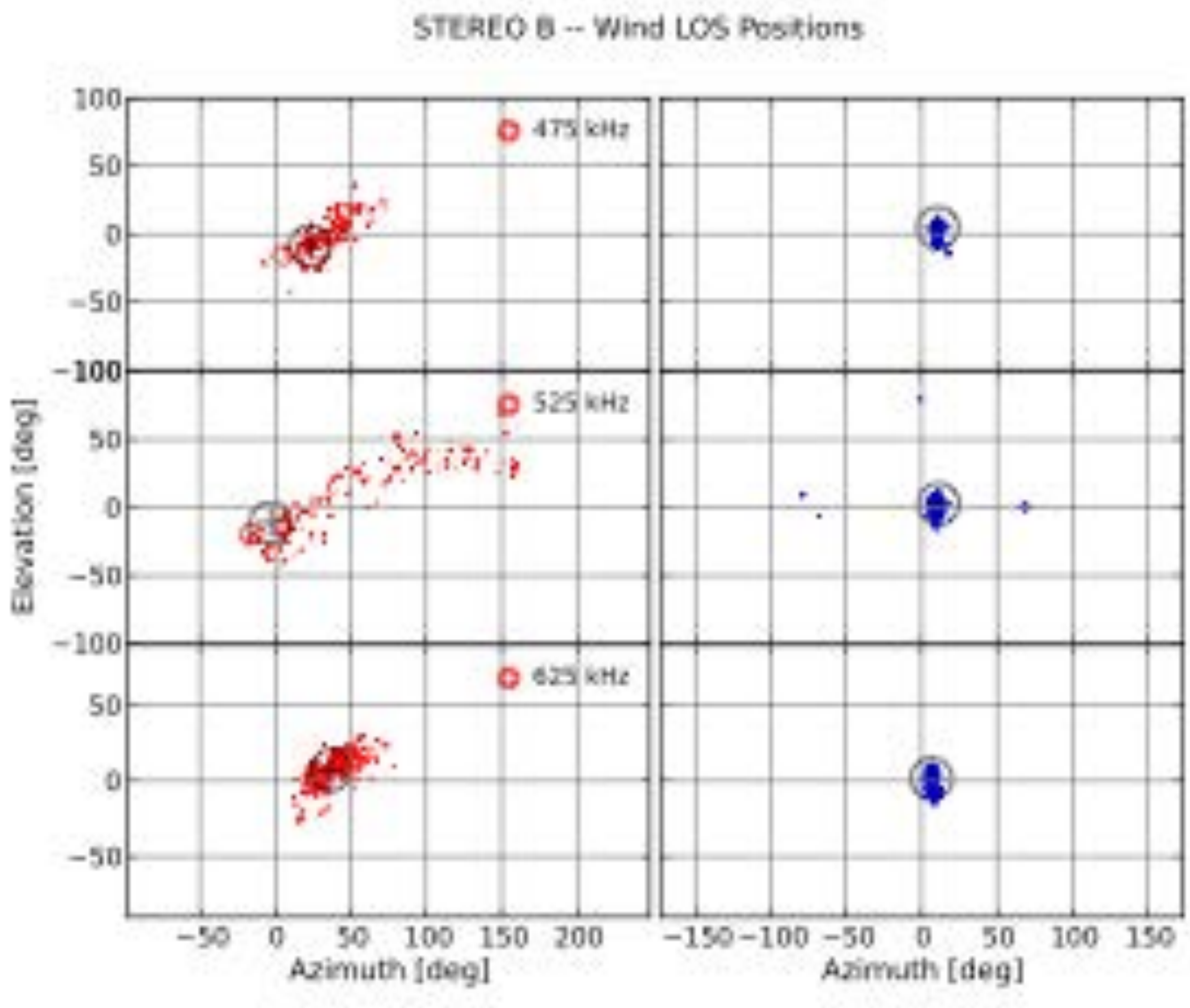
‘Slow drift’ radio bursts



Drift rates give ‘shock’ speeds of 30-50 km/s - subAlfvenic!

‘Slow drift’ radio bursts

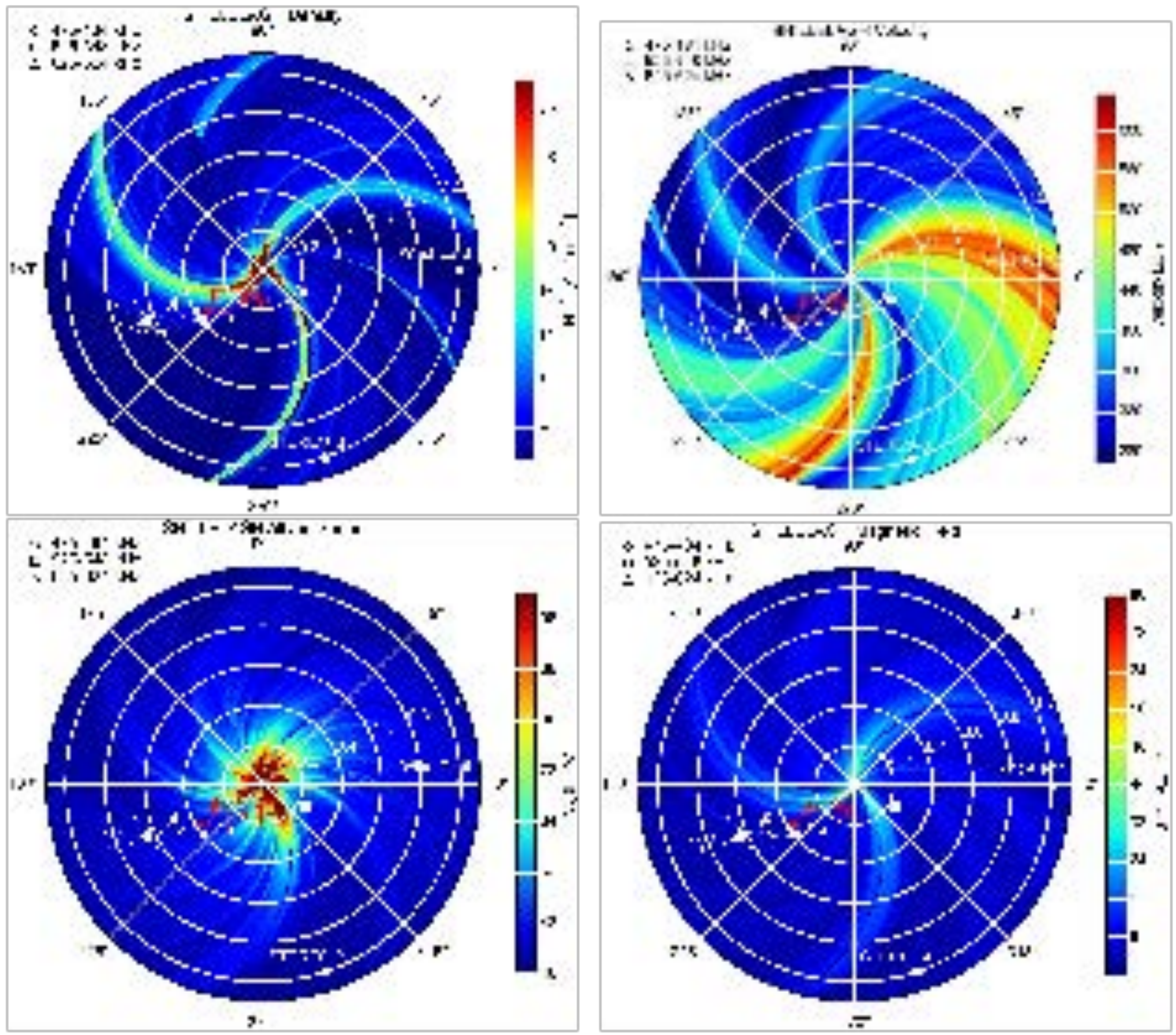
- Direction-finding with STEREO-A and Wind
- Ecliptic plane
- ST-A/Wind at 72°
- These angles can be triangulated to estimate source position



‘Slow drift’ radio bursts

- Triangulated source positions
- MHD model of heliosphere
- Regions of low Alfven speed (streamers) meet weak CMEs

LF radio bursts may be a good probe of plasma structure in the inner heliosphere

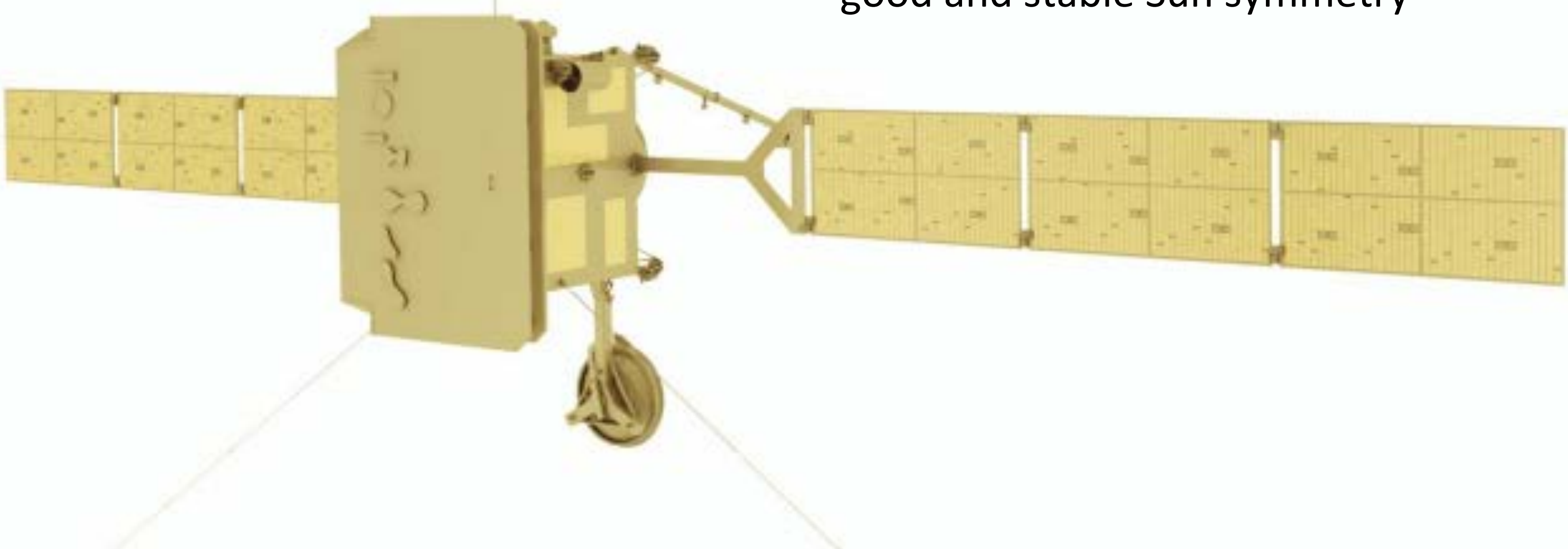


Future - Solar Orbiter, Solar Probe Plus

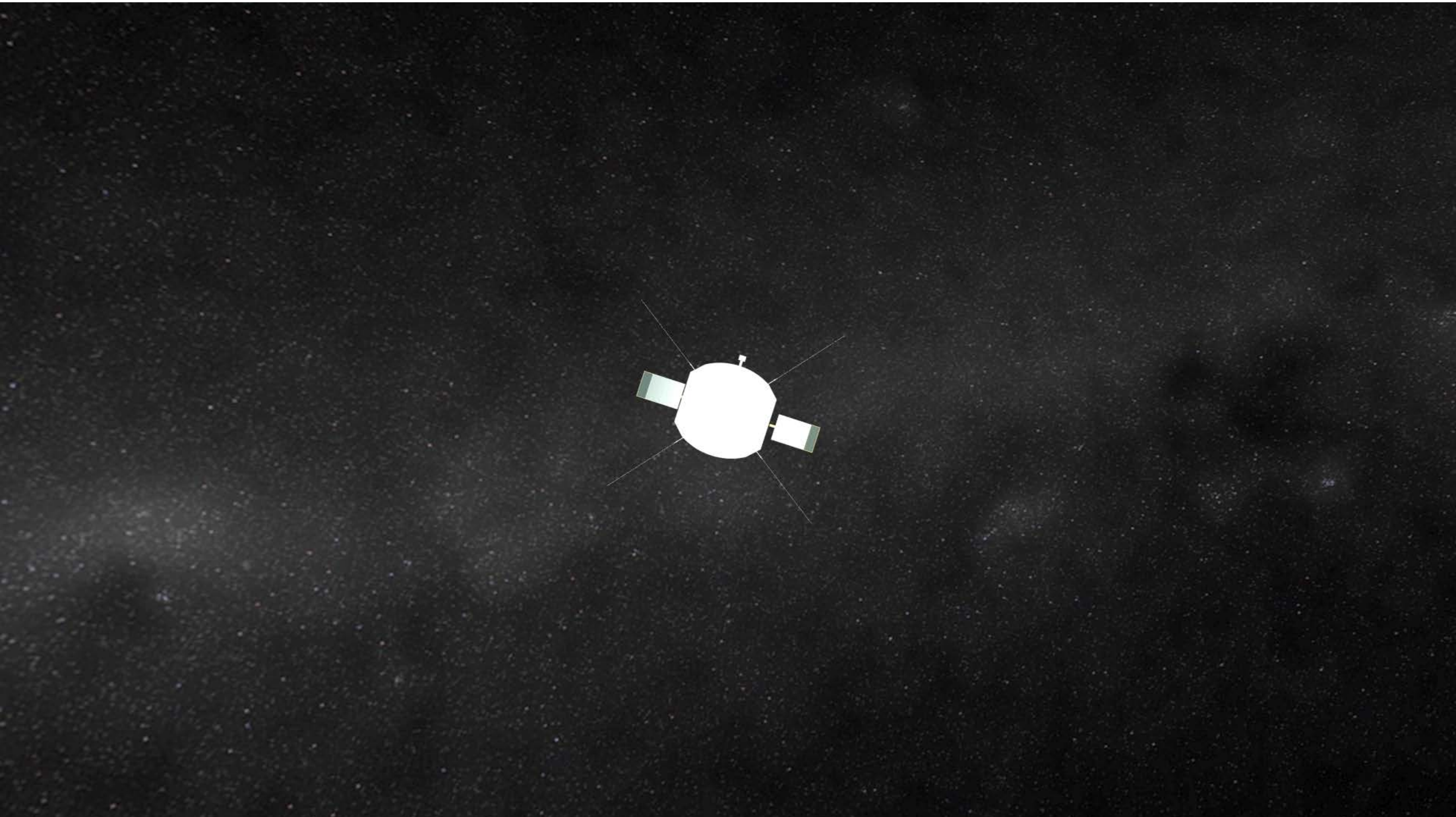
- ESA Cosmic Vision, M-class
- Inner heliosphere - 0.29 AU perihelion
- Particles and fields measurements
- 2018 launch

Radio and Plasma Waves = RPW
(PI Maksimovic)

- Selected with 3 antenna booms
- 5m x 1.5 cm sensor on a 1m boom
- 3-axis stable spacecraft
- good and stable Sun symmetry



NASA Solar Probe Plus (SPP)



SPP Level 1 Science Objectives

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 Fields - Electric Fields - Electric/Mag Wave/Radio 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

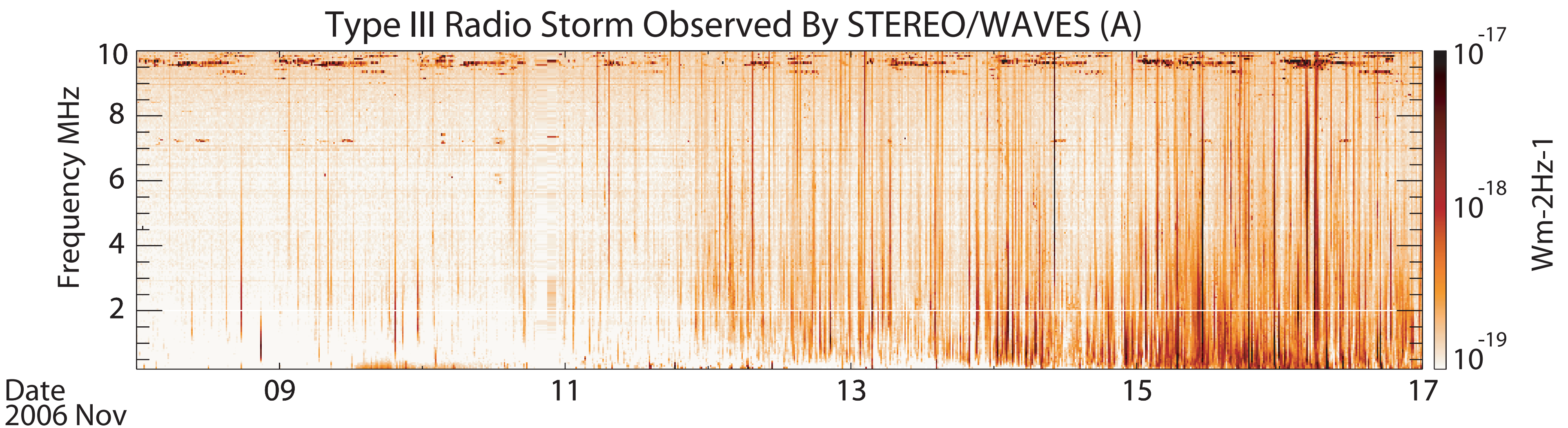
SPP/FIELDS Science Objectives

2. "Determine the structure and dynamics of the plasma and magnetic fields at the sources of the solar wind"

FIELDS will measure:

1. Magnetic field polarity and flux tube structure
2. Reconnection current sheets
3. Statistics of (Parker) nano-/micro-flares
4. Streamer belt reconnection
5. Streamer belt latitudinal extent

Parker micro-flares will appear like a 'type III radio storm' against the galactic background

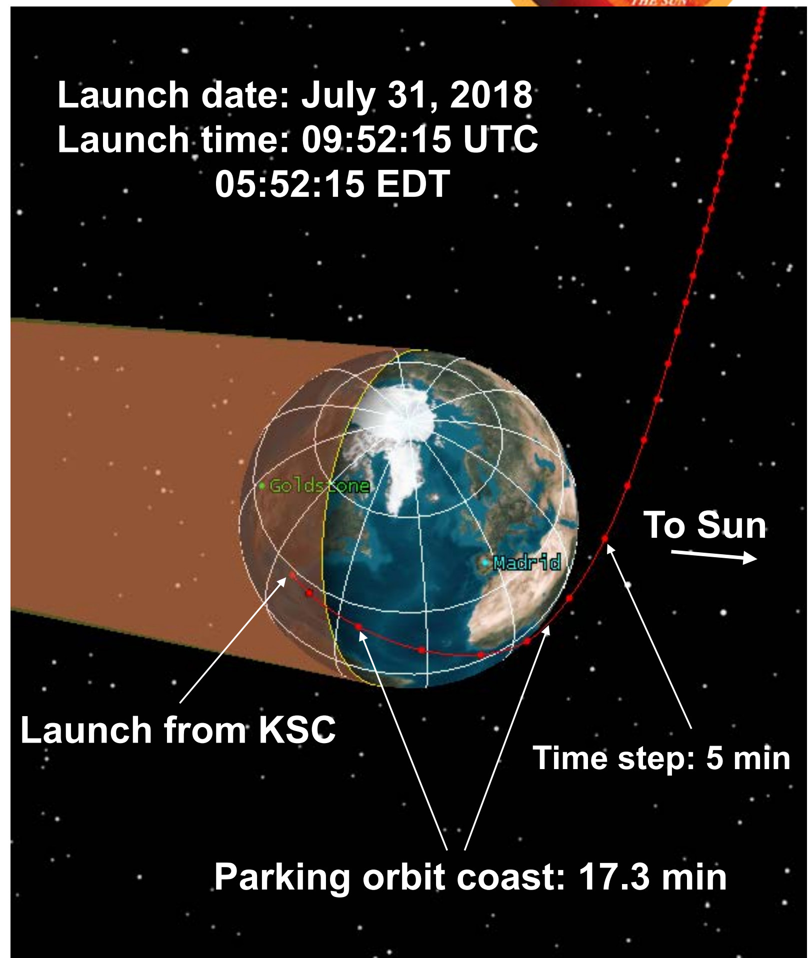


2018 Baseline Mission Design Launch Details

- **Launch Period**
  - 20 days (Jul 31 - Aug 19, 2018)
- **Launch Trajectory**
  - Use an Earth parking orbit
- **Daily Launch Window**
  - The one with the short coast duration
- **Daily Window Duration**
  - 30 minutes or longer (TBR until launch system is finalized)

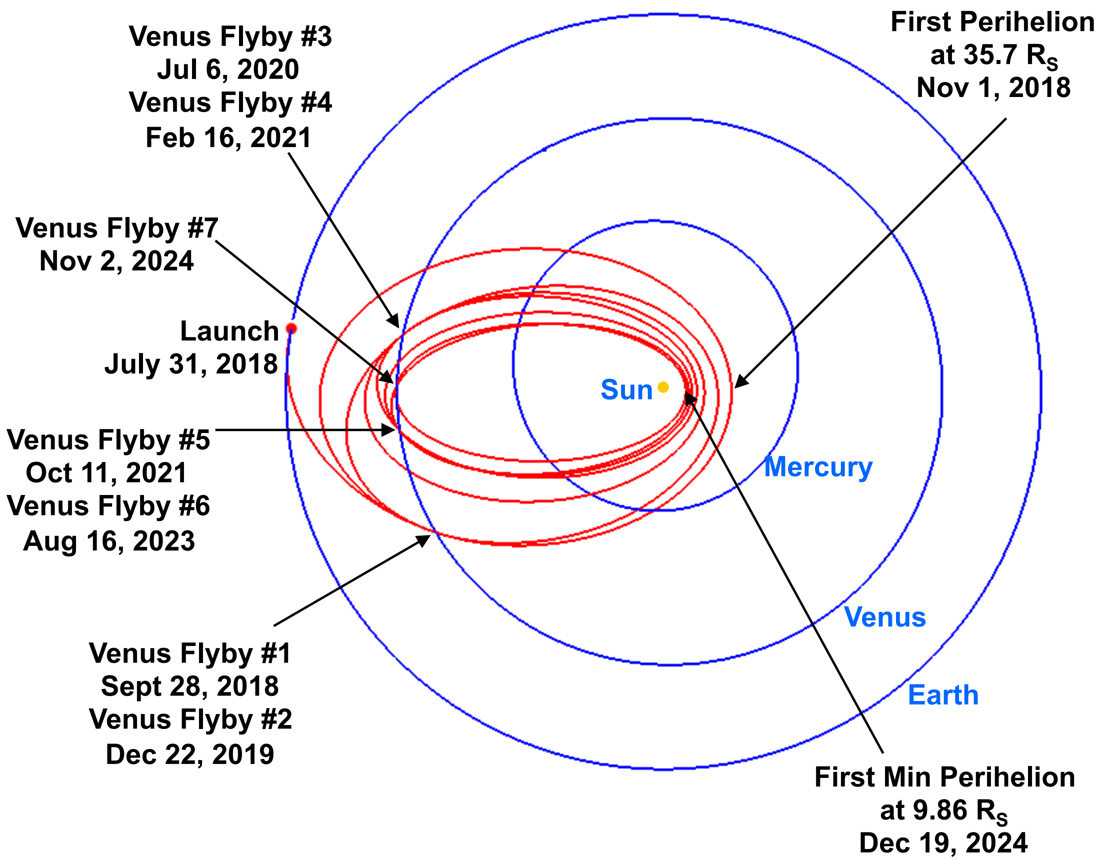
Launch Period	Open	Middle	Close
Launch Date	7/31/2018	8/9/2018	8/19/2018
Launch Time* (UTC)	9:52:15	9:35:10	9:05:58
Launch Time* (EDT)	5:52:15	5:35:10	5:05:58
Parking Orbit Coast* (min)	17.3	16.6	16.1

* Estimate based on simulated launch trajectory. Actual launch time and coasting depend on selected launch system.



2018 Baseline Mission Design
Mission Trajectory

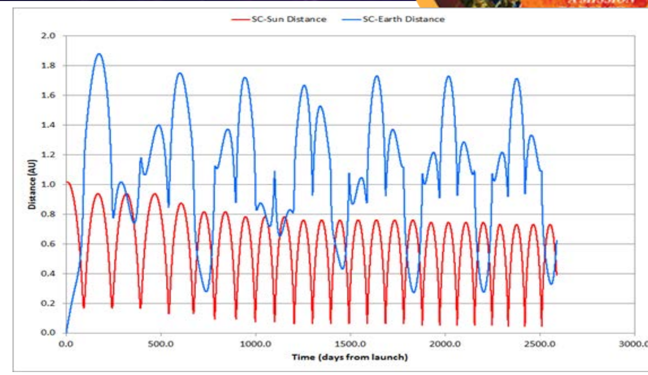
Venus-Venus-Venus-Venus-Venus-Venus-Venus-Gravity-Assist (V^7GA) Trajectory

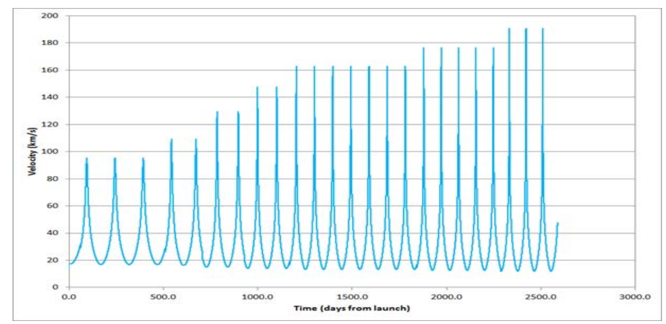


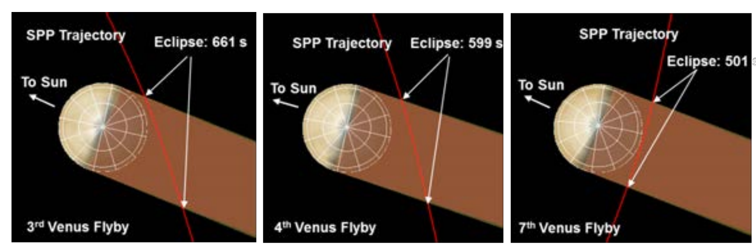
- **Repeated 7 Venus gravity assists to lower orbit to reach the Sun**
- **Switching between resonant and non-resonant Venus encounters to minimize mission duration**
- **Orbit phasing matched between flybys so that no deep space maneuvers are required**
- **Multiple solar encounters at various distances**
- **Solar distances not beyond Earth for a solar powered spacecraft**

2018 Baseline Mission Design
Mission Profile

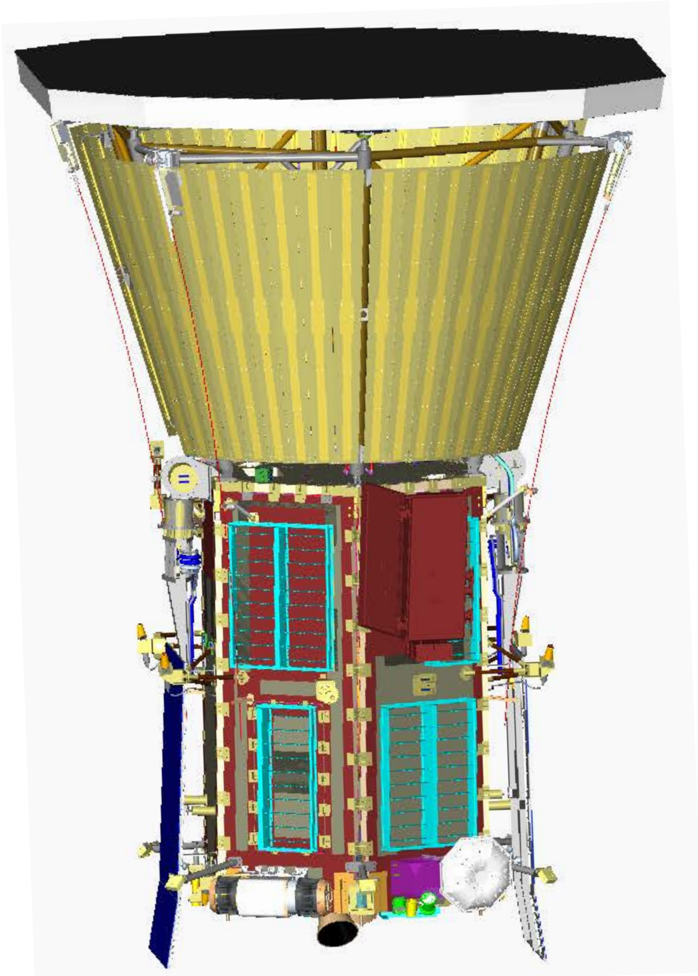
- **Solar Distance**
  - **0.04587 AU (9.86 R_S) – 1.018 AU**
- **Earth Distance**
  - **0 AU – 1.881 AU**
- **Heliocentric Velocity**
  - **11.2 km/s – 190.8 km/s**
- **Venus Flyby Altitude**
  - **316 km (V7) – 4026 km (V6)**
- **Post Launch Solar Eclipse**
  - **3 events, during 3rd, 4th, and 7th Venus flyby, duration < 12 minutes**
- **Sun-Earth- Probe (SEP) Angle**
  - **0.008° – 98.3°**
- **Sun-Probe-Earth (SPE) Angle**
  - **0.16° – 179.9°**







Spacecraft Overview

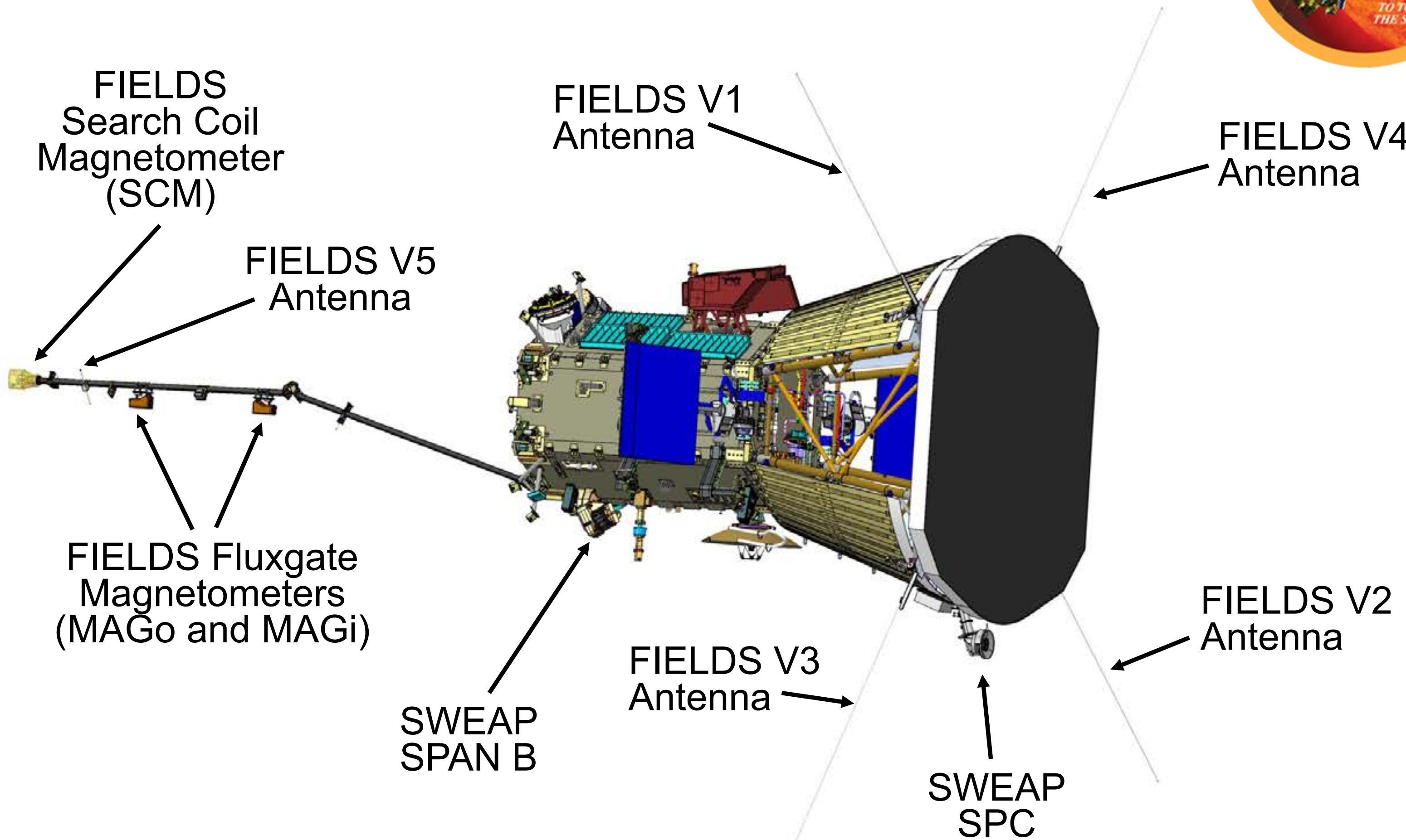


- NASA selected instrument suites
- 685kg max launch wet mass
- Reference Dimensions:
  - S/C height: 3m
  - TPS max diameter:2.3m
  - S/C bus diameter: 1m
- C-C Thermal protection system
- Hexagonal prism s/c bus configuration
- Actively cooled solar array
  - 388W electrical power at encounter
  -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

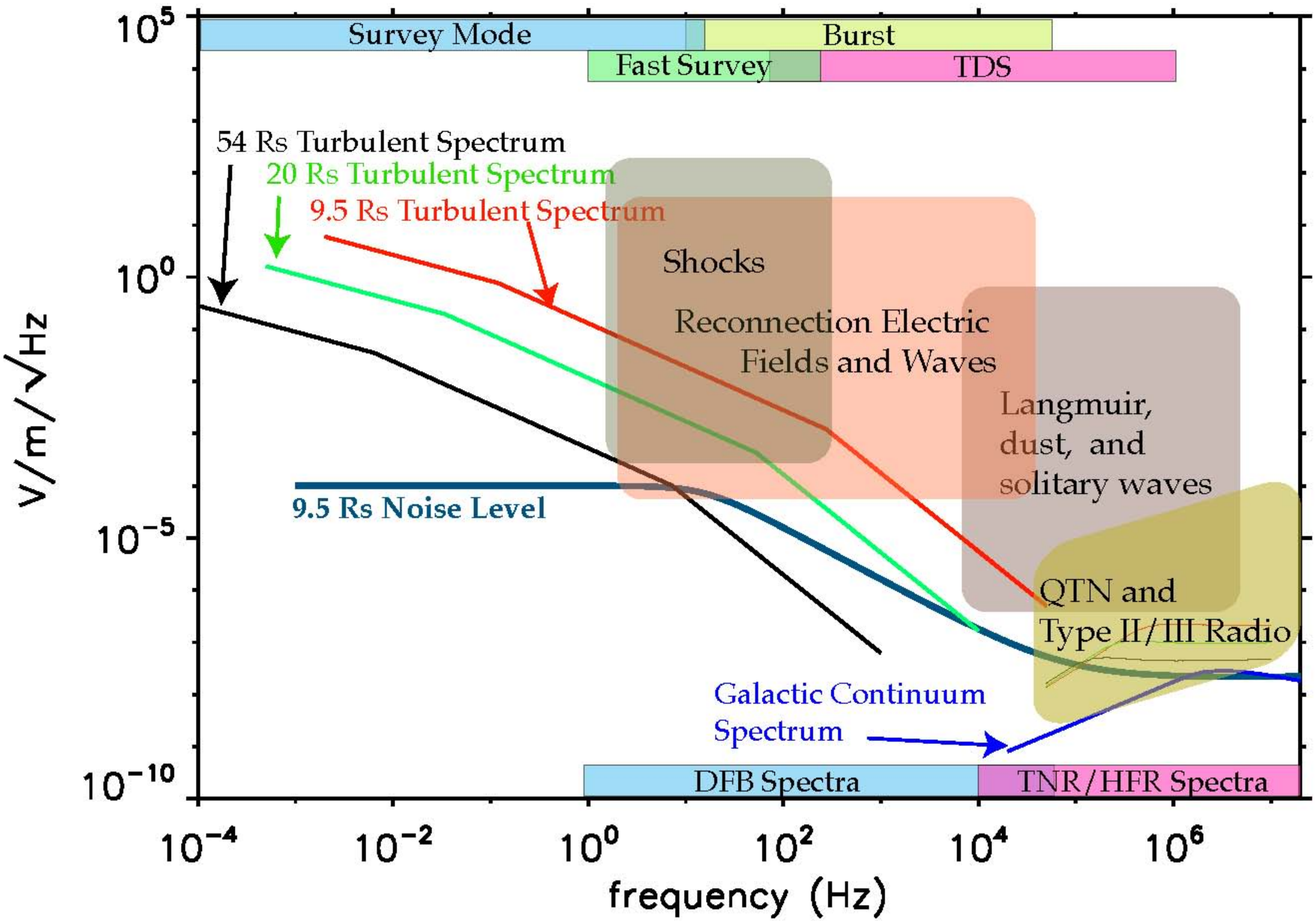
Investigation Overview

Investigation	Instruments	Principal Investigator
Fields Experiment (FIELDS)	5 x Electric Antennas 2 x Fluxgate Magnetometer (MAG) 1 x Search Coil Magnetometer (SCM)	Prof. Stuart D. Bale, University of California Space Sciences Laboratory, Berkeley, CA
Integrated Science Investigation of the Sun (ISIS)	High energy Energetic Particle Instrument (EPI-Hi) Low energy Energetic Particle Instrument (EPI-Lo)	Dr. David J. McComas, Southwest Research Institute, San Antonio, TX
Solar Wind Electrons Alphas and Protons (SWEAP)	Solar Probe Cup (SPC) 2 Solar Probe ANalyzers (SPAN)	Dr. Justin Kasper, University of Michigan, Ann Arbor, MI & Smithsonian Astrophysical Observatory, Cambridge, MA
Wide-field Imager for Solar PRobe (WISPR)	White light imager	Dr. Russ Howard, Naval Research Laboratory, Washington, DC
Heliospheric Origins with Solar Probe Plus (HeliOSPP)	Observatory Scientist - addresses SPP science objectives via multi-instrument data analysis to optimize the scientific productivity of the mission	Dr. Marco Velli, Jet Propulsion Laboratory, Pasadena, CA

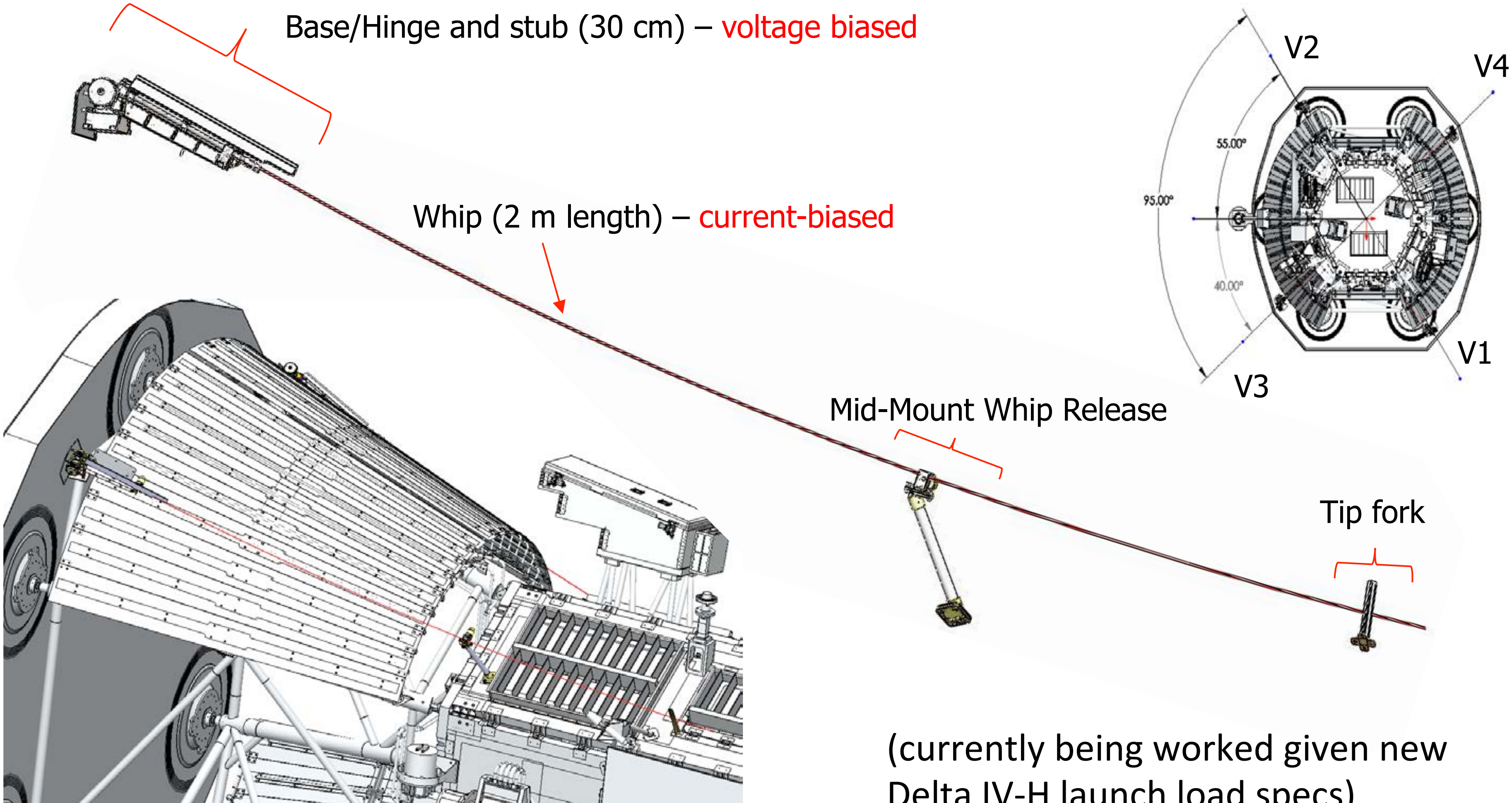
Payload Accommodation on S/C (1/3)



FIELDS Electric Field Measurements



V1-V4 electric sensors



(currently being worked given new Delta IV-H launch load specs)

Block Diagram

FIELDS System

Two Sides

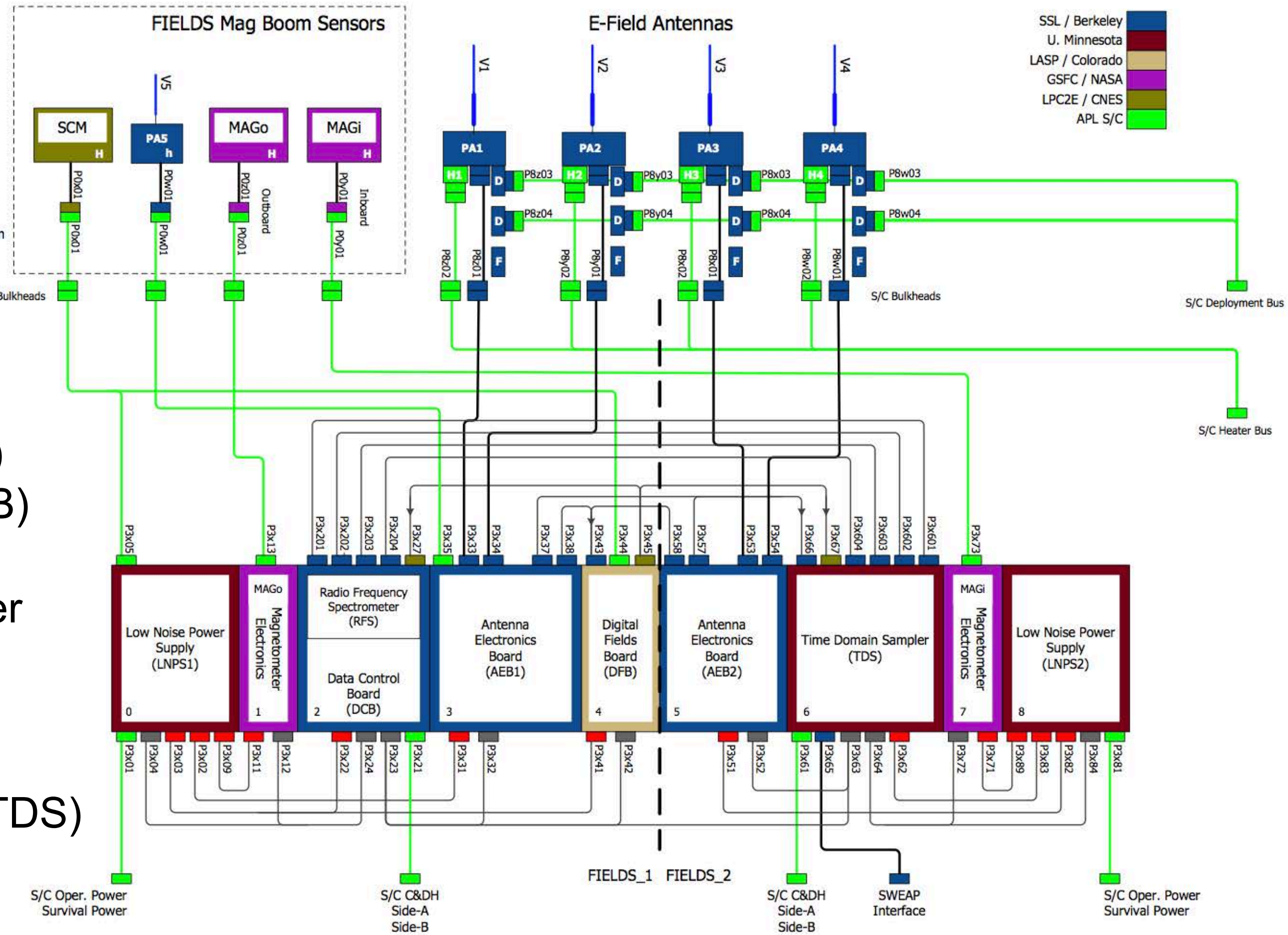
- Each has Spacecraft I/F
- Each has Magnetometer
- Each has Antenna Elect.
- Each has Power Supply

FIELDS1 also has

- Radio Freq Spect. (RFS)
- Digital Fields Board (DFB)
- SCM Calib Control
- Absolute Time Sequencer
- TDS I/F

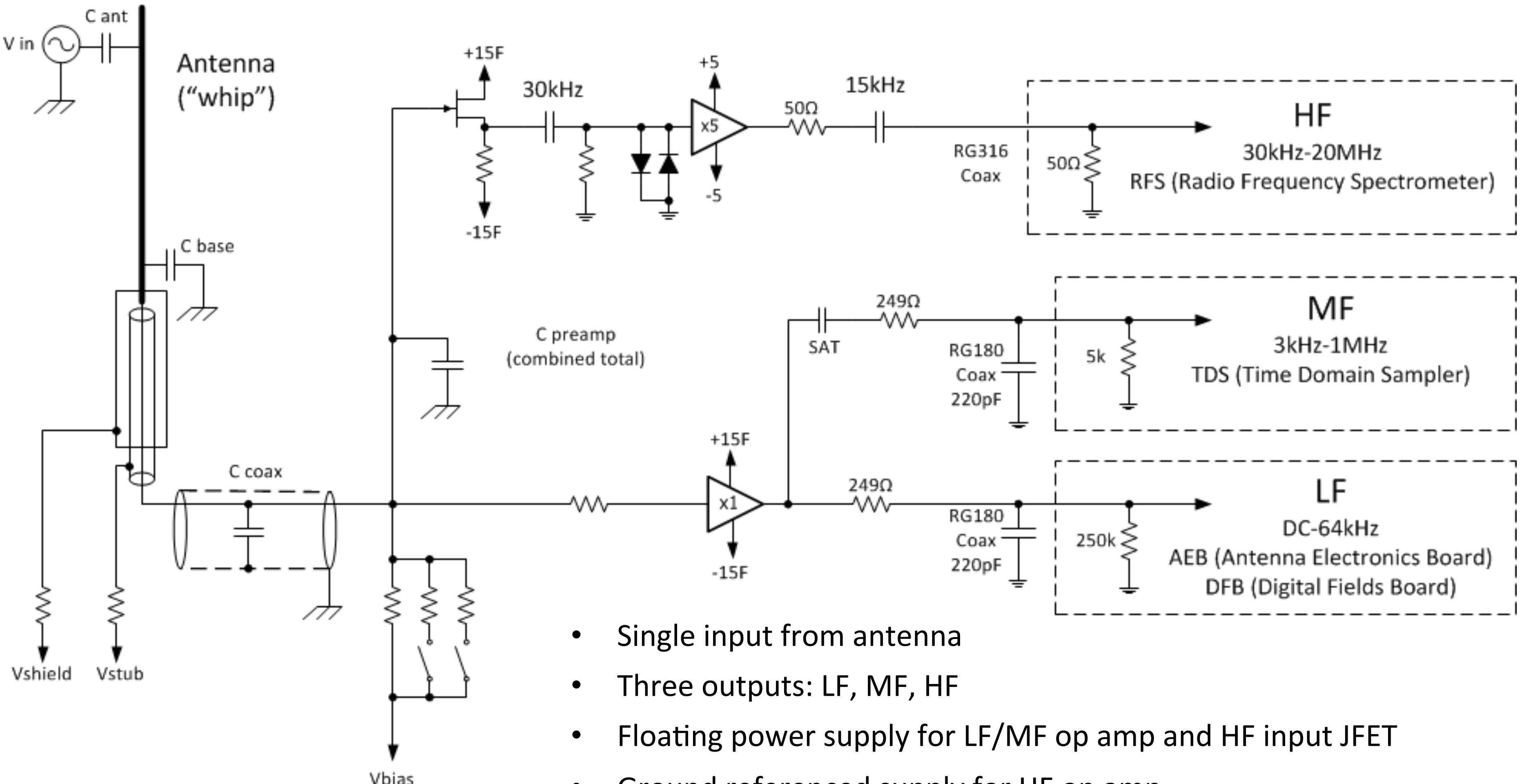
FIELDS2 also has

- Time Domain Sampler (TDS)
- DCB I/F
- SWEAP I/F



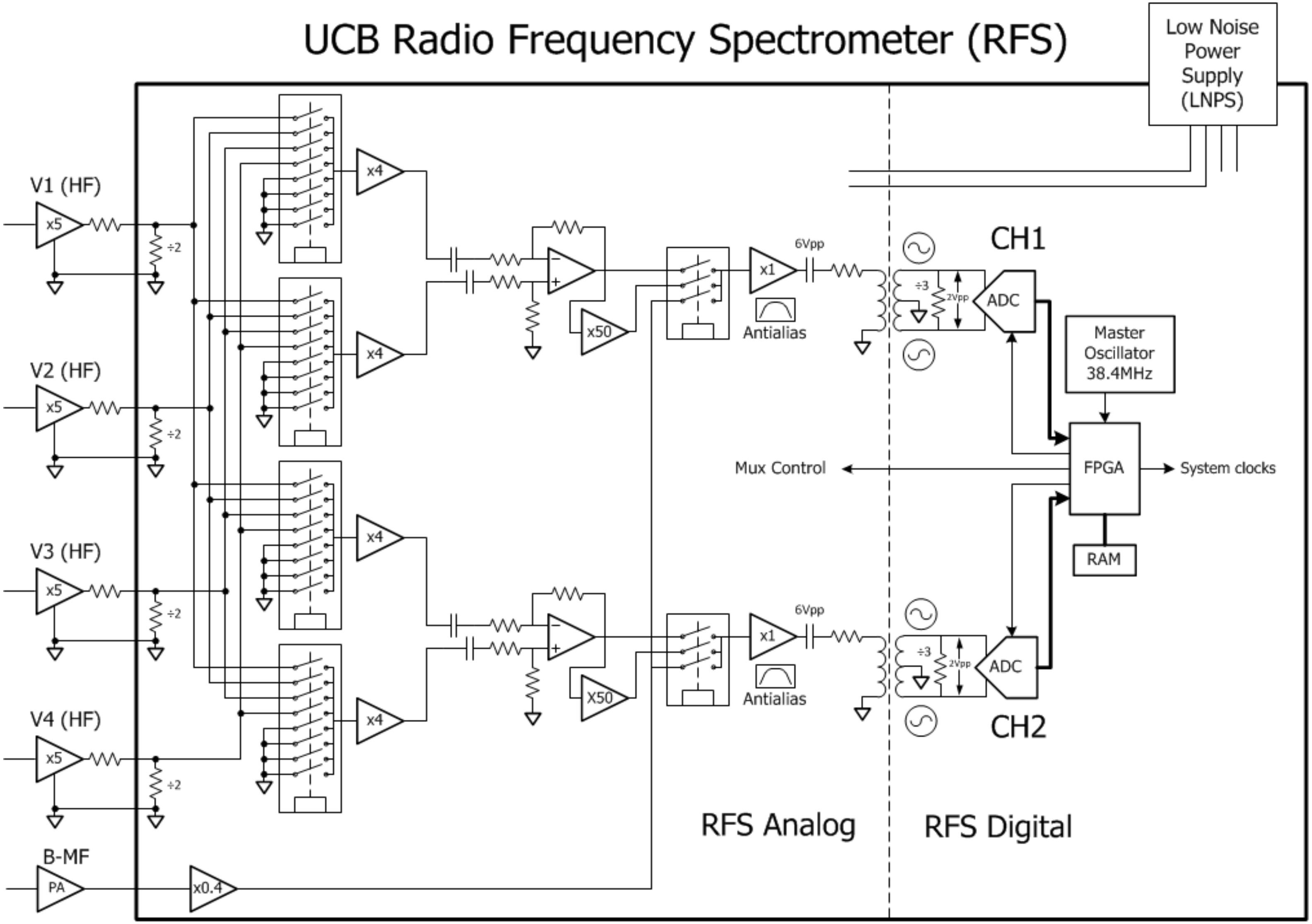
(see Malaspina DFB poster on Thursday)

Preamp Functional Diagram



- Single input from antenna
- Three outputs: LF, MF, HF
- Floating power supply for LF/MF op amp and HF input JFET
- Ground referenced supply for HF op amp
- Relay-selected bias resistances

UCB Radio Frequency Spectrometer (RFS)

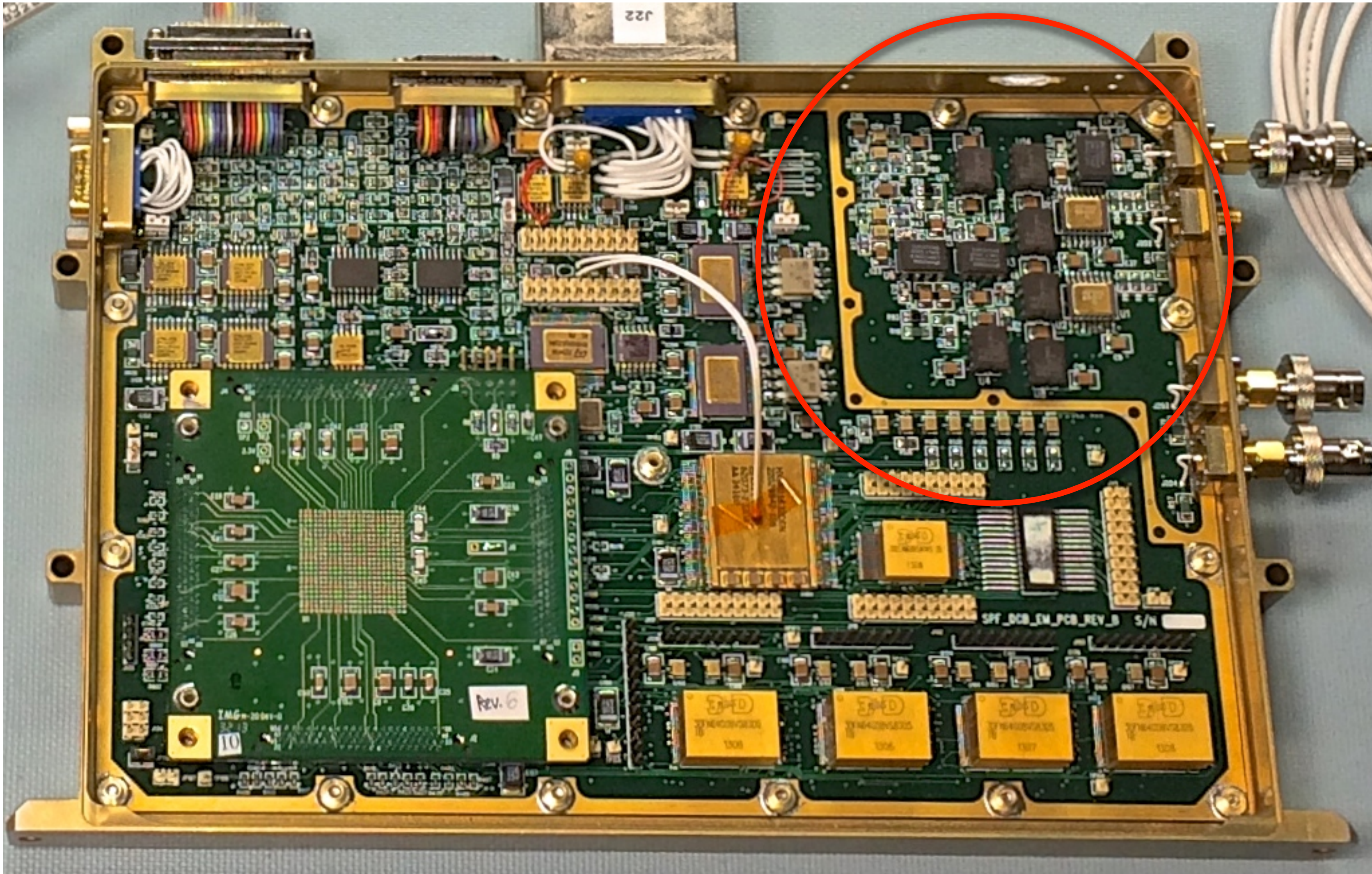


Data Controller Board (DCB)

RFS_Blk_Diagram_05JAN15 D. Seitz

- 2 channel, 40 MSPS, baseband digital receiver
- Polyphase Filter Bank provides >120dB narrowband rejection

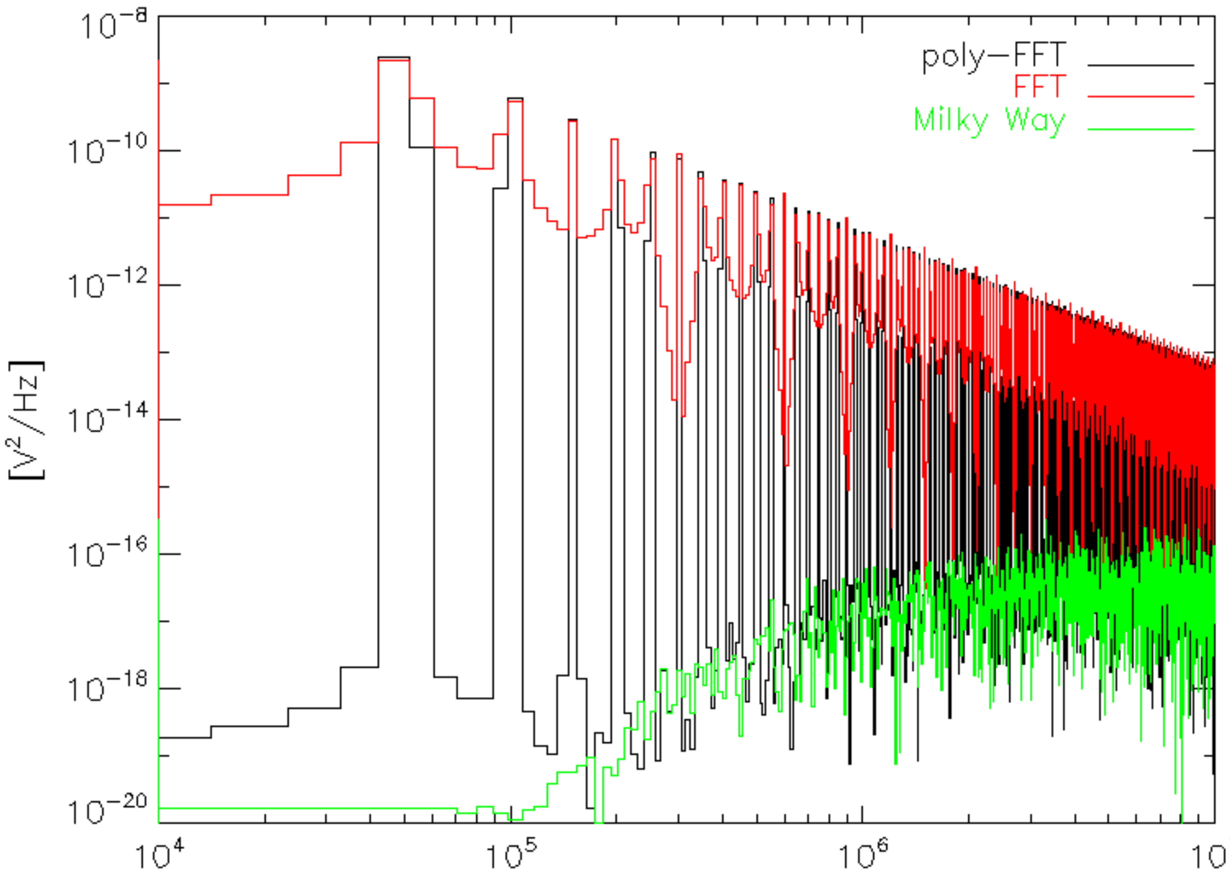
FIELDS RFS Analog EM



Polyphase Filter Banks

Test signal: PFB vs. regular FFT:

(4096 pts, 8 taps, BH and sinc with a=0.00027)



Polyphase Filter Banks

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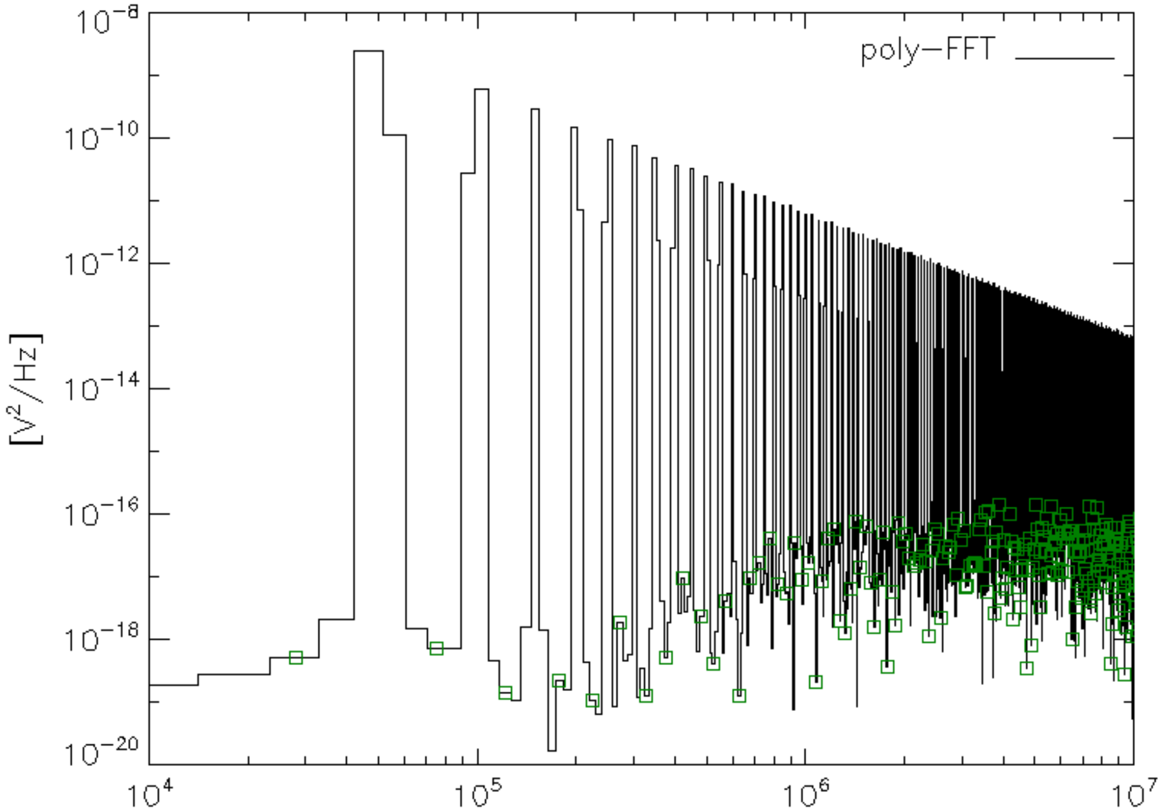
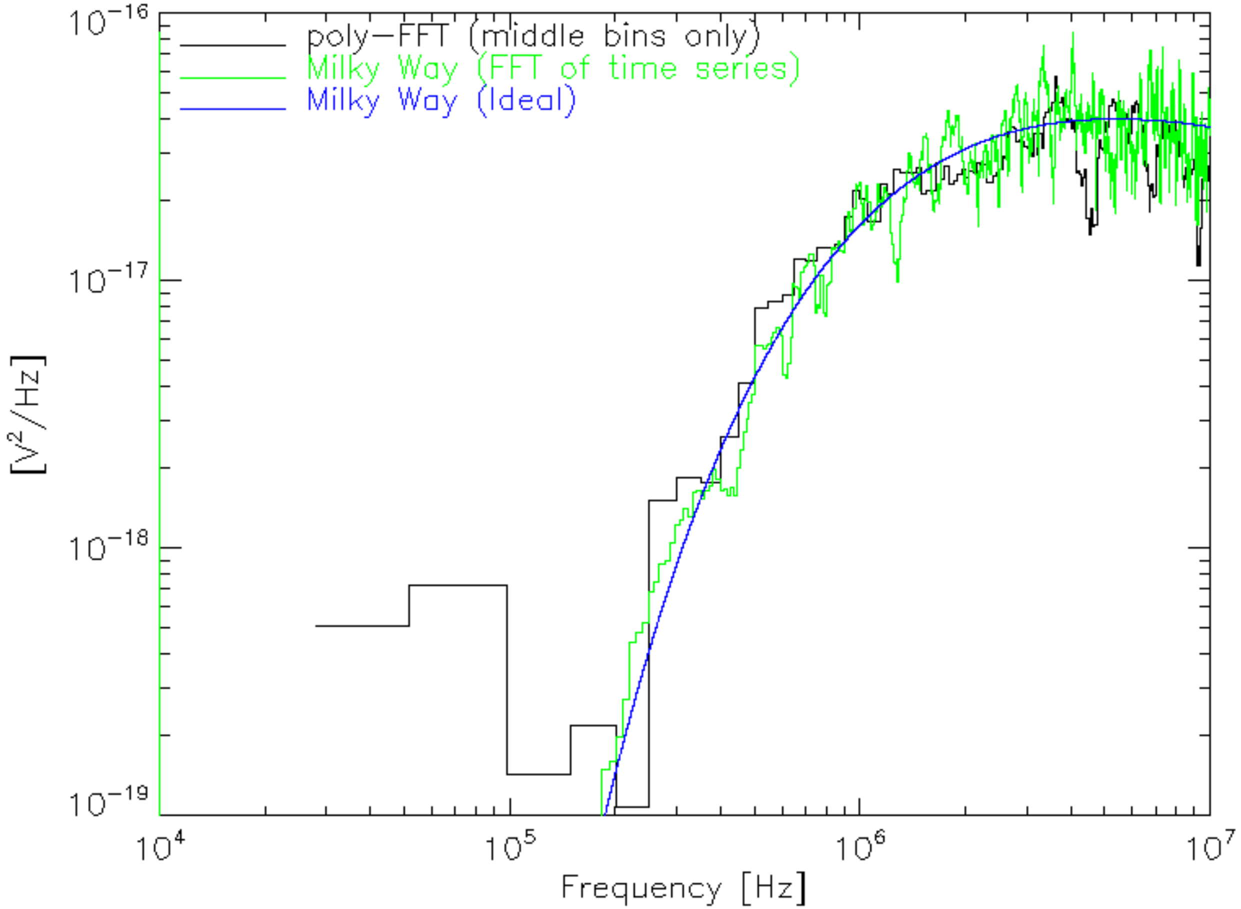


Taking only bins in between the power spikes…

Polyphase Filter Banks

Smoothed (window length: 10)…

(4096 pts, 8 taps, BH and sinc with a=0.00027)



Summary

- Radio measurements < 10 MHz must be made from space
- Spinner and 3-axis stablized spacecraft can be used for 'direction-finding' analysis
- Spacecraft and instrument (power supply) noise can dominate
- Solar Orbiter and Solar Probe Plus in 2018