Solar Probe Plus

a mission to touch the Sun…

T. Dudok de Wit
on behalf of the Solar Probe Plus team

Closest distance to the Sun

• HELIOS	0.31 AU	66 R_S above photosphere
• Solar Orbiter	0.28 AU	59 R_S above photosphere
• Solar Probe Plus	0.039 AU	8.8 R_S above photosphere

Closest distance to the Sun

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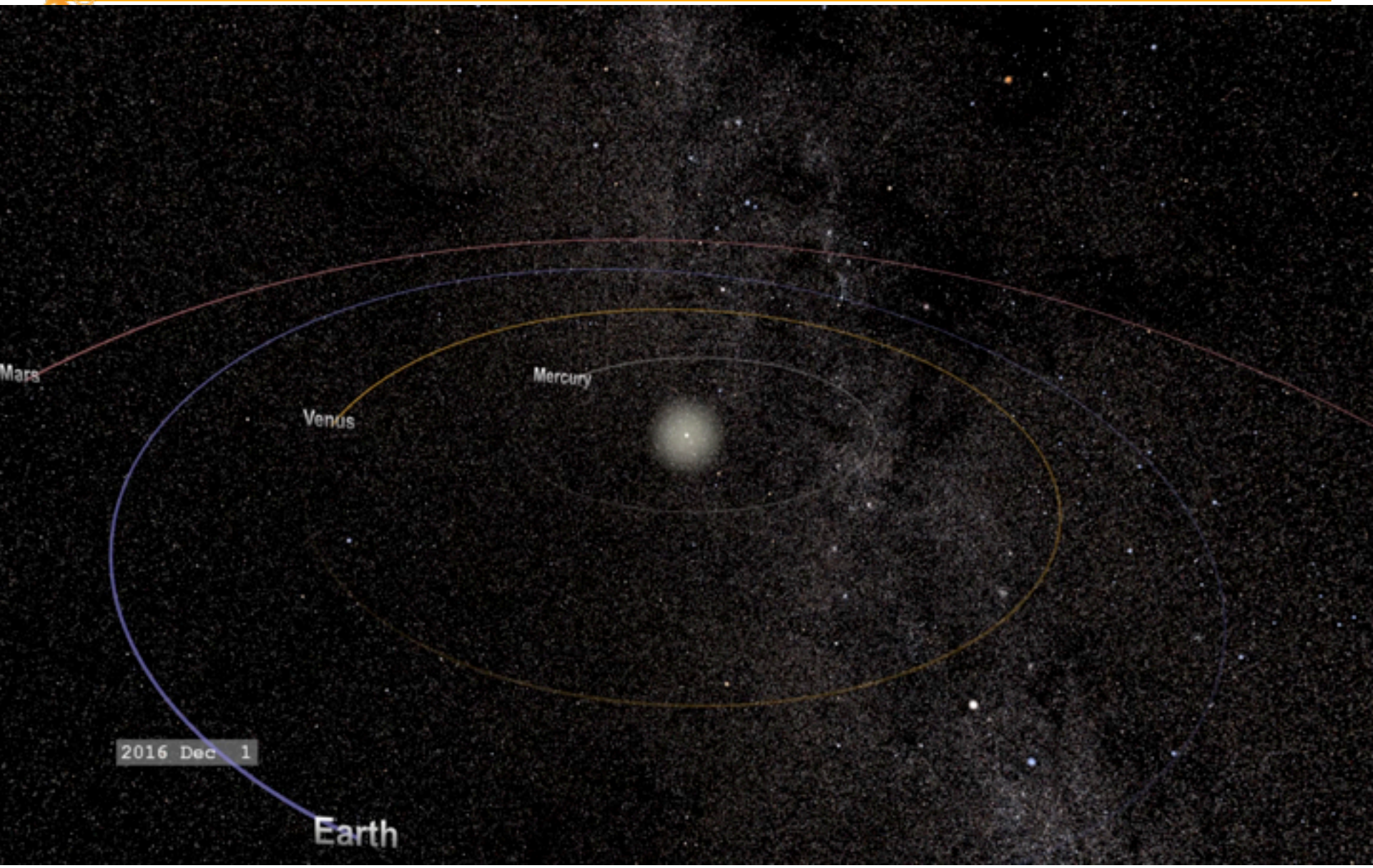
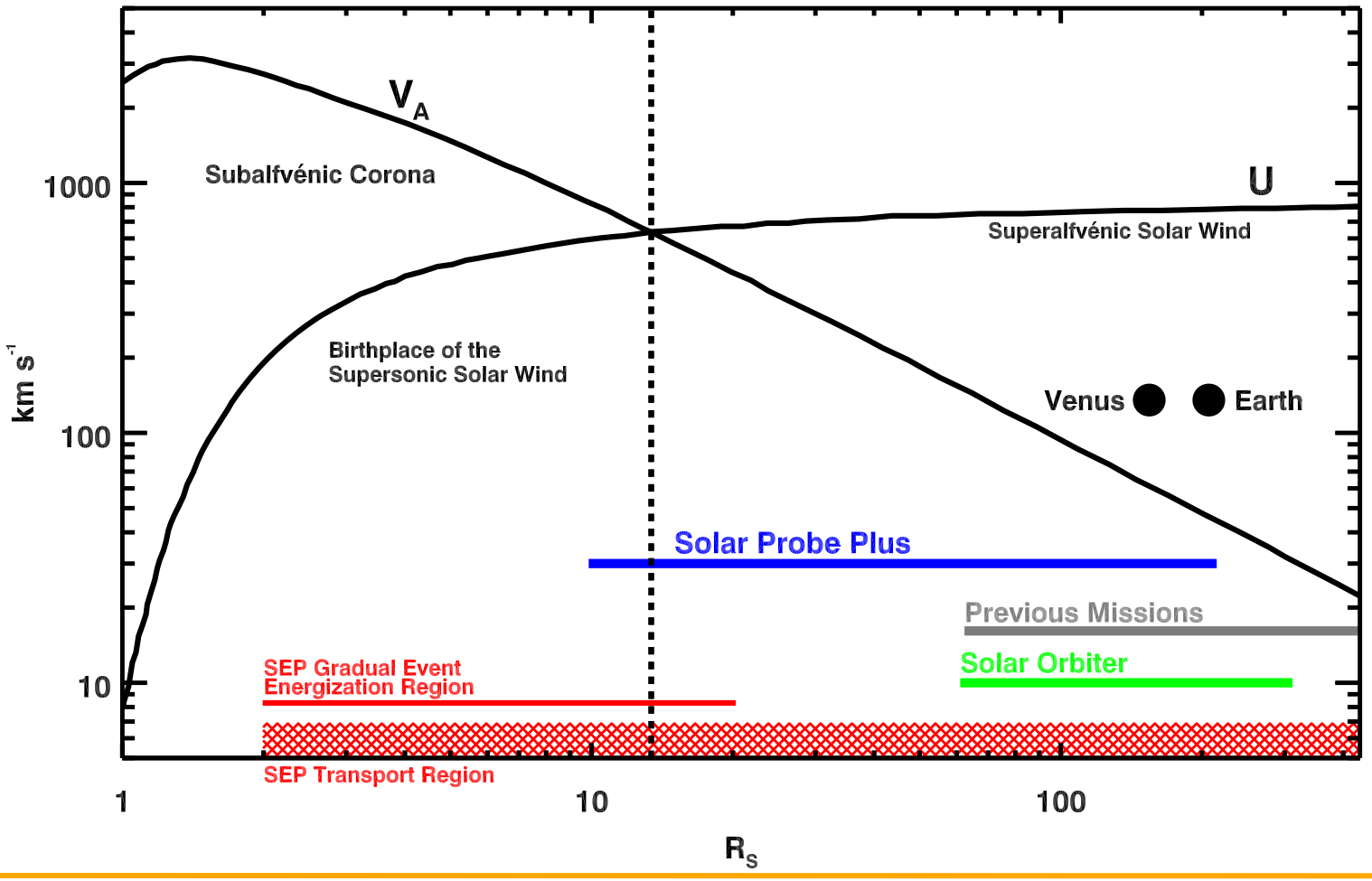
• Solar Orbiter	0.28 AU	59 R_S above photosphere
• Solar Probe Plus	0.039 AU	8.8 R_S above photosphere
• ICARUS (project)	0.0082 AU	1 R_S above photosphere

Really close !


Mars
Venus
Mercury
2016 Dec 1
Earth

Main motivation

- get inside the Alfvén critical surface !

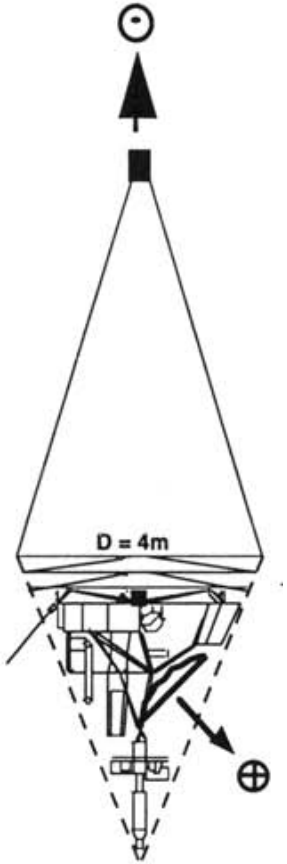


A looooong history

- 1958 National Research Council Space Science Board
- 1982 Solar Probe (JPL)
- 1988 VULCAN (ESA)
- 1992 Solar Corona Probe (E. Marsh, A. Roux, ESA)
- 2003 Solar Probe recommended by National Decadal Survey
- 2008 PHOIBOS (M. Maksimovic, ESA)
- 2008 Solar Probe Plus science and definition team (JHUAPL)
- July 2018 launch

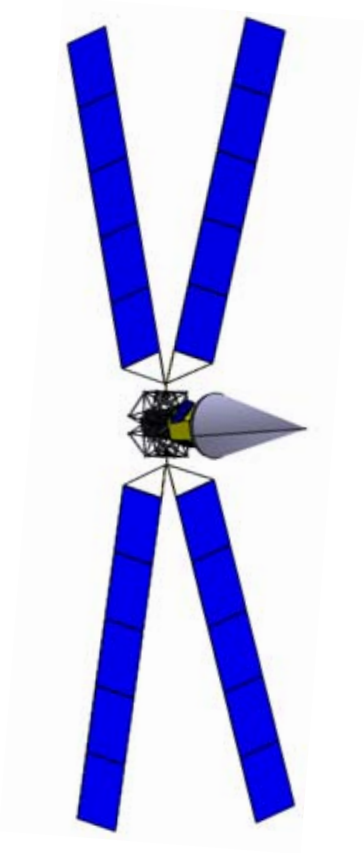
Solar Probe design evolution

JPL 1982

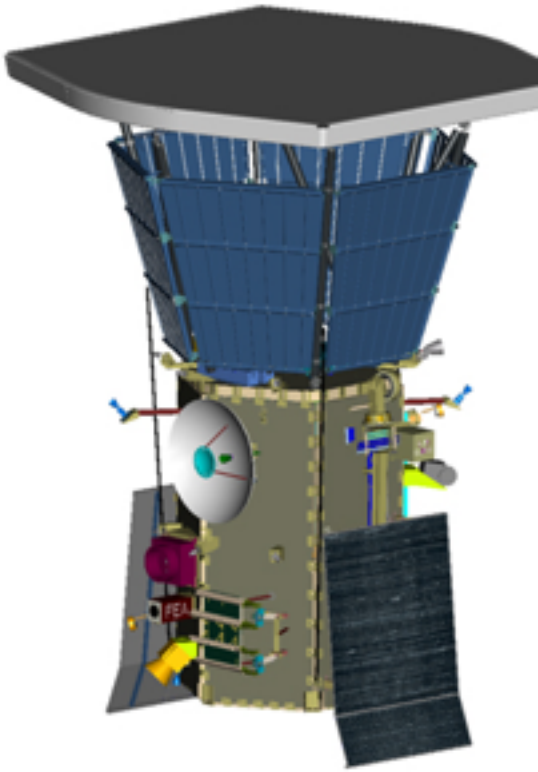


JPL 1995

PHOIBOS 2008



Solar Probe Plus 2009



4 instrument suites

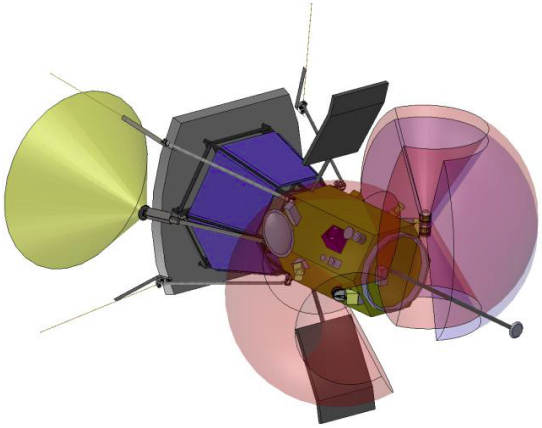
- **Solar Wind Electrons Alphas and Protons** (SWEAP) Investigation
  (J. Kasper, U. Michigan)
- **Wide field Imager for Solar Probe** (WISPR)
  (R. Howard, NRL)
- **Electromagnetic Fields** (FIELDS) Investigation
  (S. Bale, U. Berkeley)
- **Integrated Science Investigation of the Sun** (IS⊙IS),
  (D. McComas, SWRI)

project scientist N. Fox (APL)

principal investigator M. Velli (JPL)

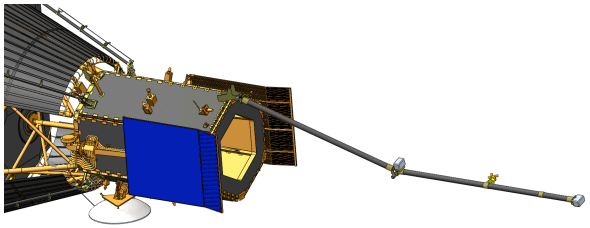
Instrument suites

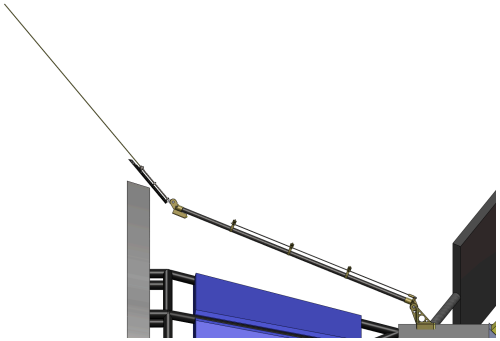
Solar Wind Electrons Alphas and Protons (SWEAP) Investigation (J. Kasper Smithsonian CFA



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

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



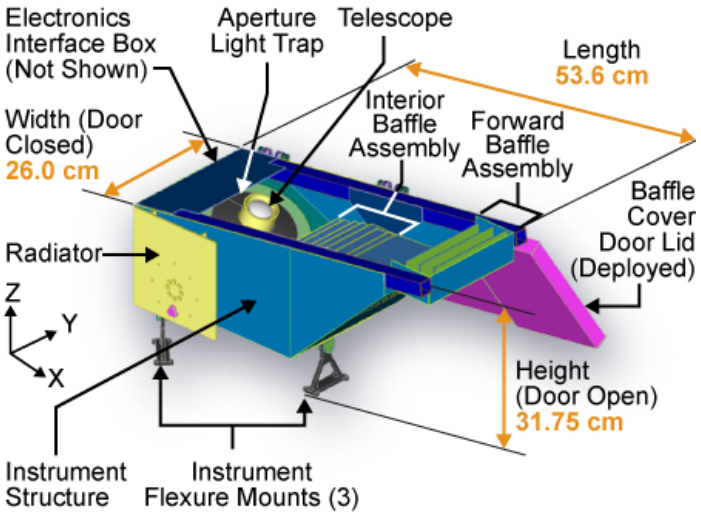


Electromagnetic Fields (FIELDS) Investigation (S. Bale, Berkeley)

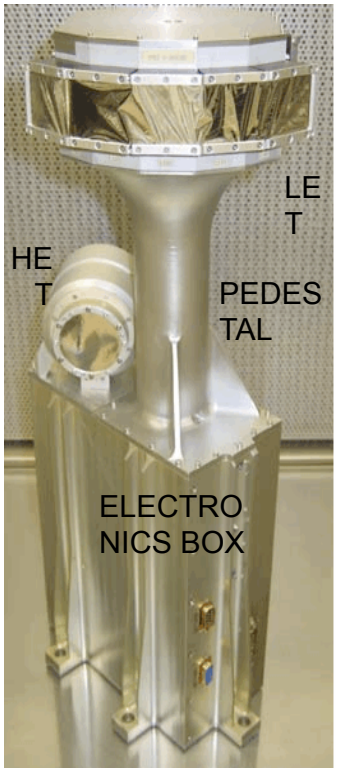
- DC/LF Electric Fields
- DC/LF Magnetic Fields
- Plasma Waves
- Spacecraft Floating Potential
- Rapid Density Fluctuations
- Electron Density and Temperature
- Solar/IP Radio Emissions
- Voltage Signatures of Dust Impacts

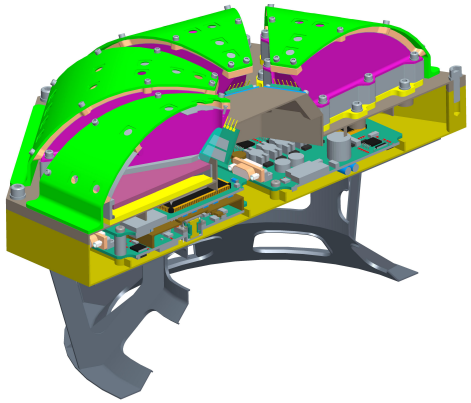
Instrument suites

Wide field Imager for Solar Probe (WISPR)
(R. Howard NRL)



- Wide-Field Imager of the Heliosphere From 13.5º to 118º from the Sun
- Visible Light Observations





EPI HI Measures energetic particle spectra, composition, and angular distributions. Cover ~1 to >100 MeV/ nuc for protons and heavy elements and ~0.5 to 6 MeV for electrons View directions covering 50% of the sky

EPI LO energetic electron (25-500 keV) ion spectra (~0.02-7 MeV protons and 0.02-2 MeV/nuc heavier ions) Resolves all major heavy ion species and 3He and 4He over much of this energy range in multiple directions

Integrated Scinece Investigation of the Sun (ISIS), D. McComas SWRI

The FIELDS instrument suite will measure directly

- DC/Low Frequency Electric Fields
- DC/Low Frequency Magnetic Fields
- Plasma wave (E and B) waveforms, spectra, and cross-spectra
- Spacecraft floating potential
- Solar and interplanetary radio (e/m) emissions

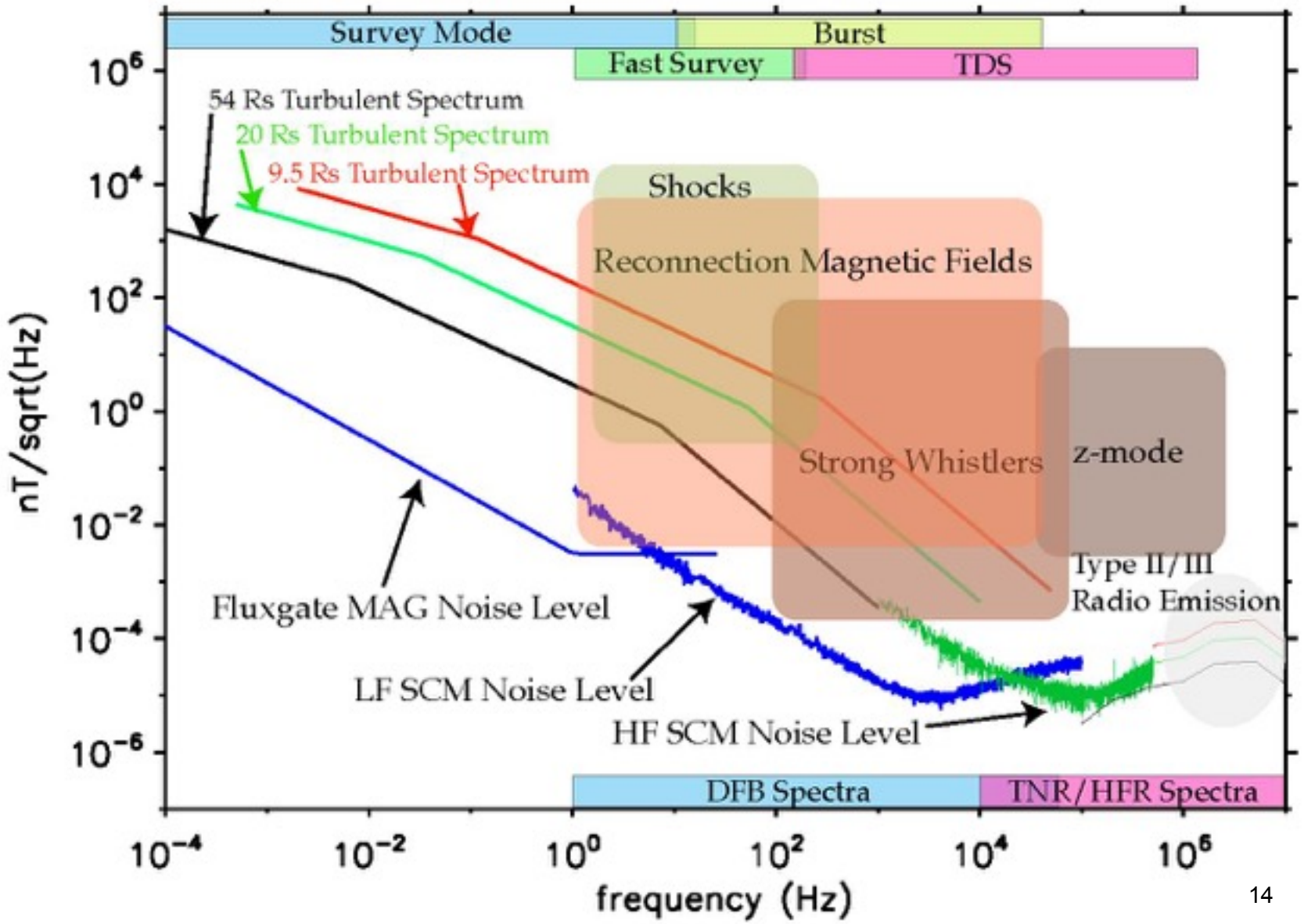
…and by analysis

- Perpendicular electron velocity and its spectrum
- Very accurate electron density and temperature
- Rapid (~kHz) density fluctuations and spectrum
- Voltage signatures of interplanetary dust

FIELDS Plasma Environment

Parameters		10 R_s	55 R_s	1 AU
Magnetic Field	$\|B_0\| \sim \delta B_A$	2000 nT	70 nT	6 nT
Electric Field	$\|E_c\| \leqslant v_{sw}\delta B_A$	100 mV/m	30 mV/m	3 mV/m
Density	$n_e \sim \delta n$	7000 cm^{-3}	120 cm^{-3}	7 cm^{-3}
Electron Temperature	T_e	85 eV	25 eV	8 eV
Solar Wind Speed	v_{sw}	210 km/s	400 km/s	450 km/s
Alfvén Speed	v_A	500 km/s	125 km/s	45 km/s
Plasma Frequency	f_{pe}	750 kHz	100 kHz	24 kHz
Electron Gyrofrequency	f_{ce}	60 kHz	2 kHz	160 Hz
Proton Gyrofrequency	f_{cp}	32 Hz	1 Hz	0.1 Hz
Convected Debye Length	v_{sw}/λ_D	4 µs	8 µs	22 µs
Convected Electron Inertial Length	$v_{sw}/(c/\omega_{pe})$	0.3 ms	1.2 ms	5.5 ms
Convected Proton Inertial Length	$v_{sw}/(c/\omega_{pi})$	13 ms	50 ms	250 ms
Convected Proton Gyroscale	v_{sw}/ρ_p	3 ms	30 ms	200 ms
DC/LF Electric Fluctuations	$\delta E_A \sim v_A \delta B_A$	1 V/m	10 mV/m	1 mV/m
Kinetic Electric Fluctuations	δE_L	1 V/m	70 mV/m	10 mV/m

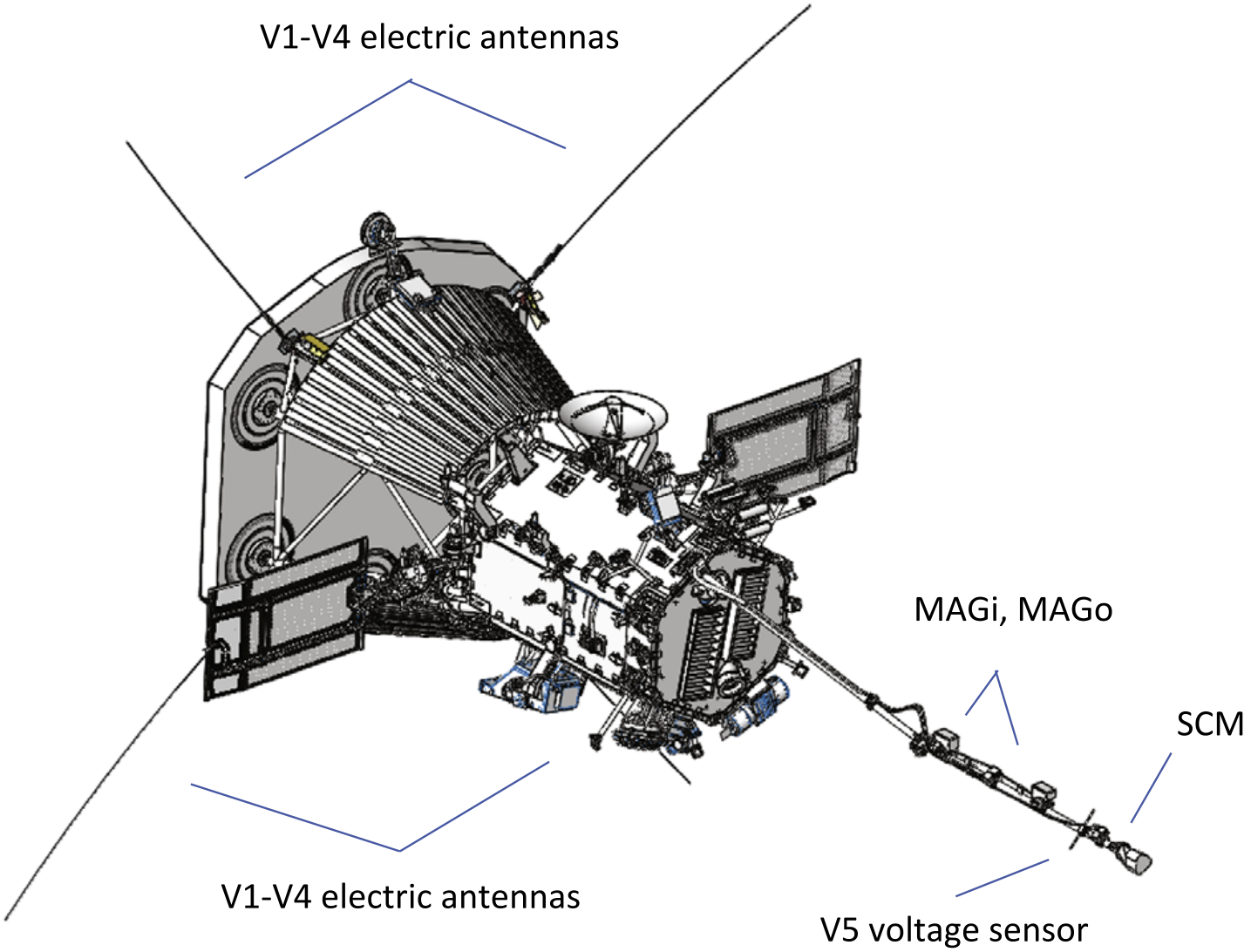
FIELDS Magnetic Field Measurements



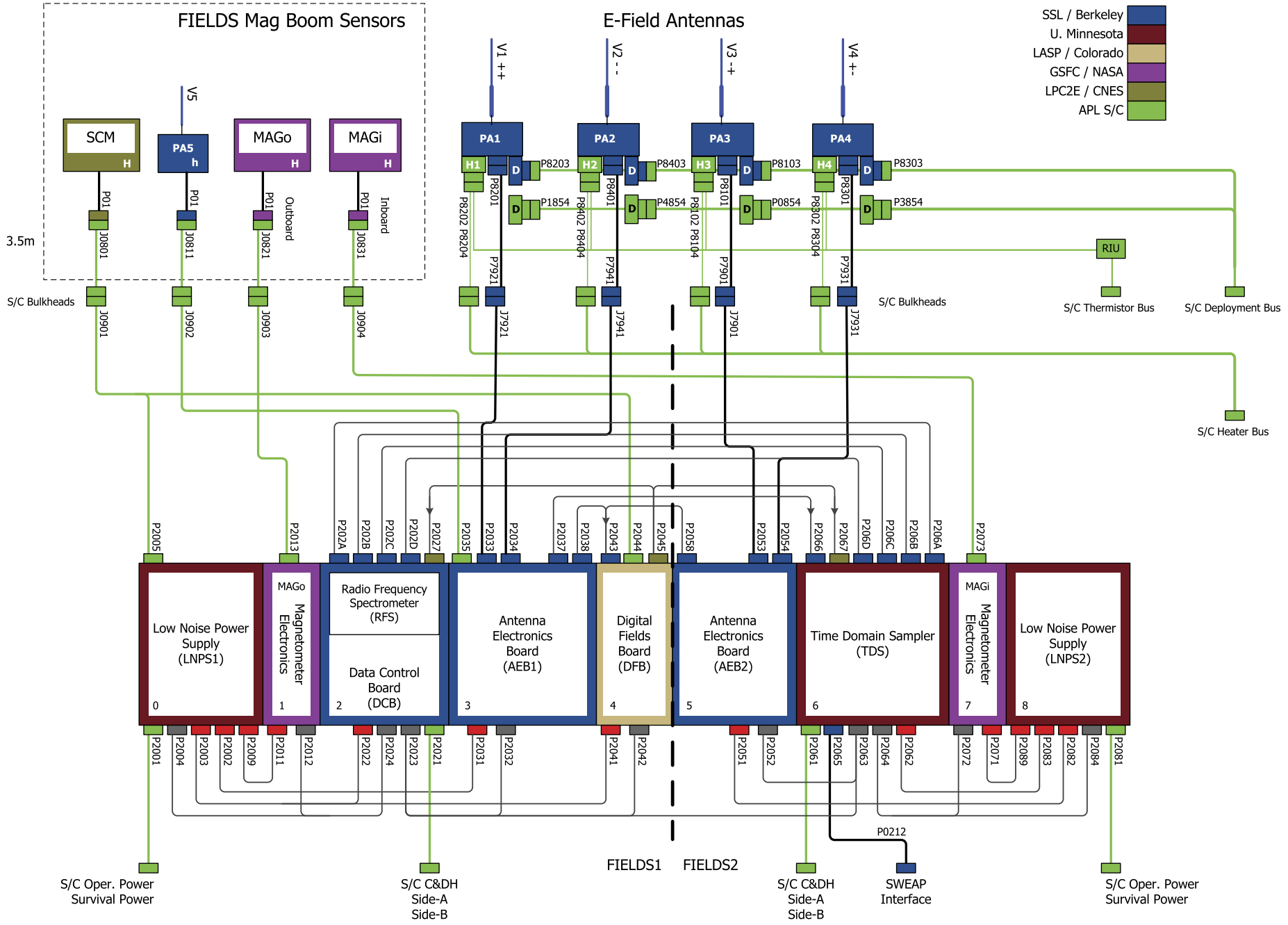
FIELDS Level-1 Requirements

Measurement	Dynamic Range	Slow cadence	High cadence	Bandwidth
B waveforms	140dB	256 vectors/s	100k vectors/s	DC - 50 kHz
E waveforms	140dB	256 vectors/s	2M vectors/s	DC - 1 MHz
E / B spectra	140dB	1 spectrum/10s	1 spectrum/s	5Hz - 1 MHz
QTN/Radio	100dB for QTN 80dB for radio	1 spectrum/32s 1 spectrum/32s	1 spectrum/4s QTN 1 spectrum/16s radio	10-2'500 kHz QTN 1-16 MHz radio

FIELDS Sensors

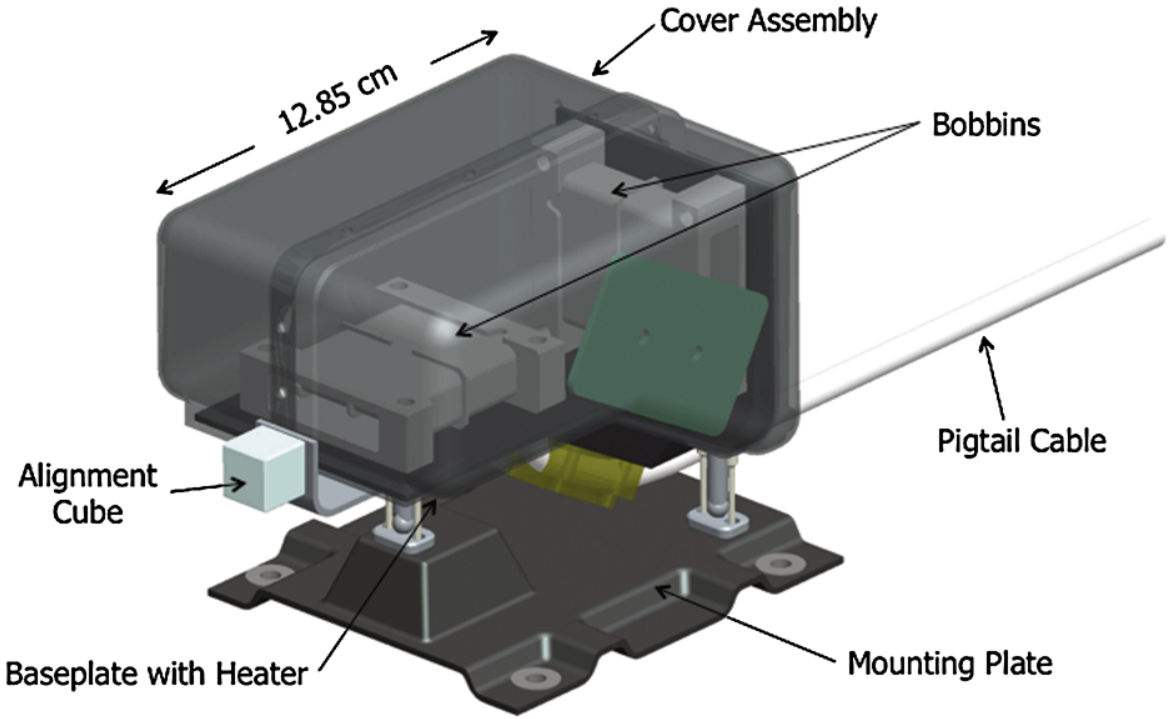


Block diagram



MAG fluxgate

- Built at GSFC (lead CoI: R. McDowall)
- Bandwidth 140 Hz (sampled at 32-100 Hz)
- Max amplitude 65536 nT (4 ranges), 16 bits

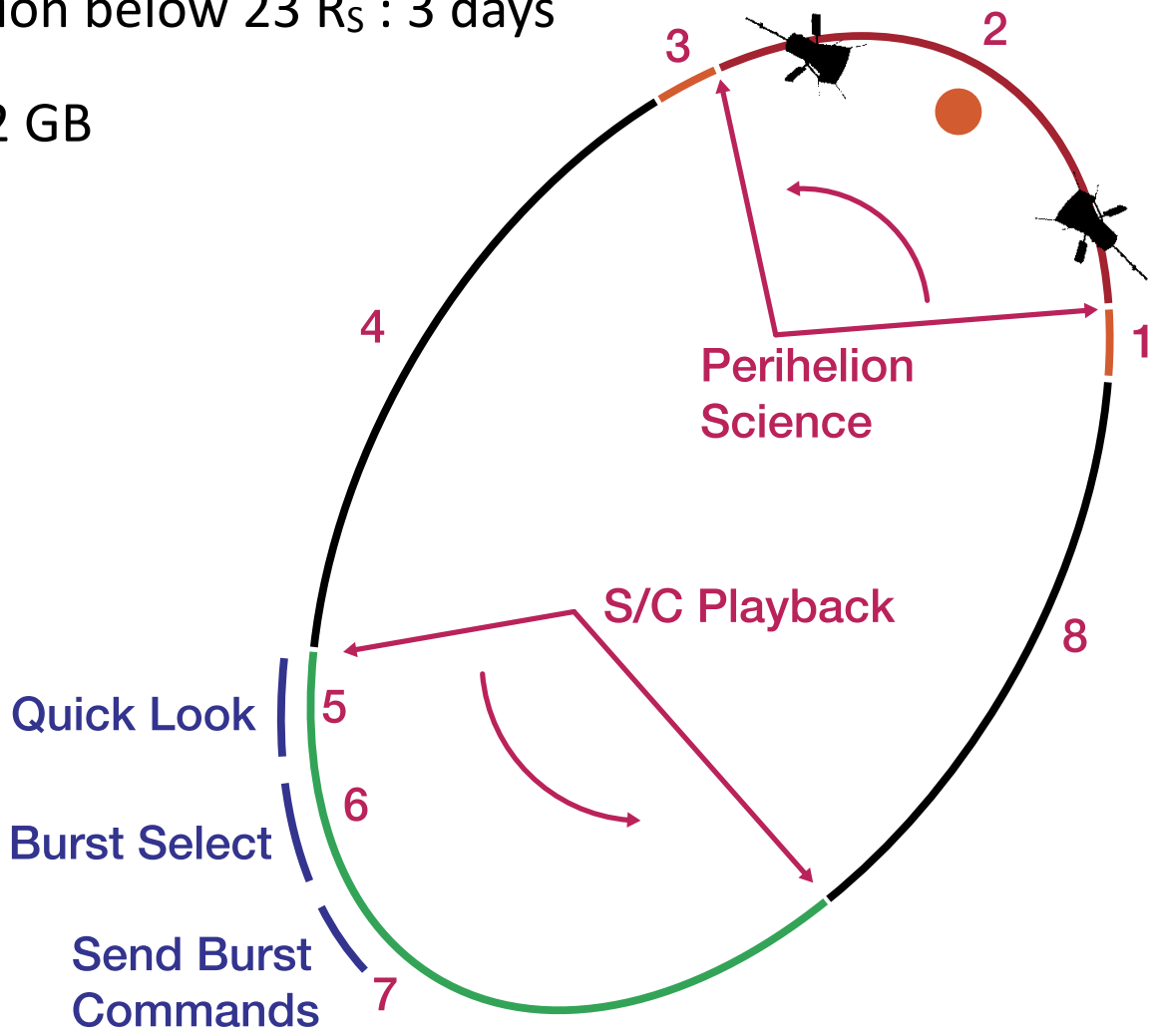


SCM Search-coil

- Built at LPC2E (lead CoI: T. Dudok de Wit)
- Bandwidth : 10 Hz - 50 kHz (x 3), 1 kHz - 1 MHz (x 1)
- Dynamic range 160 dB

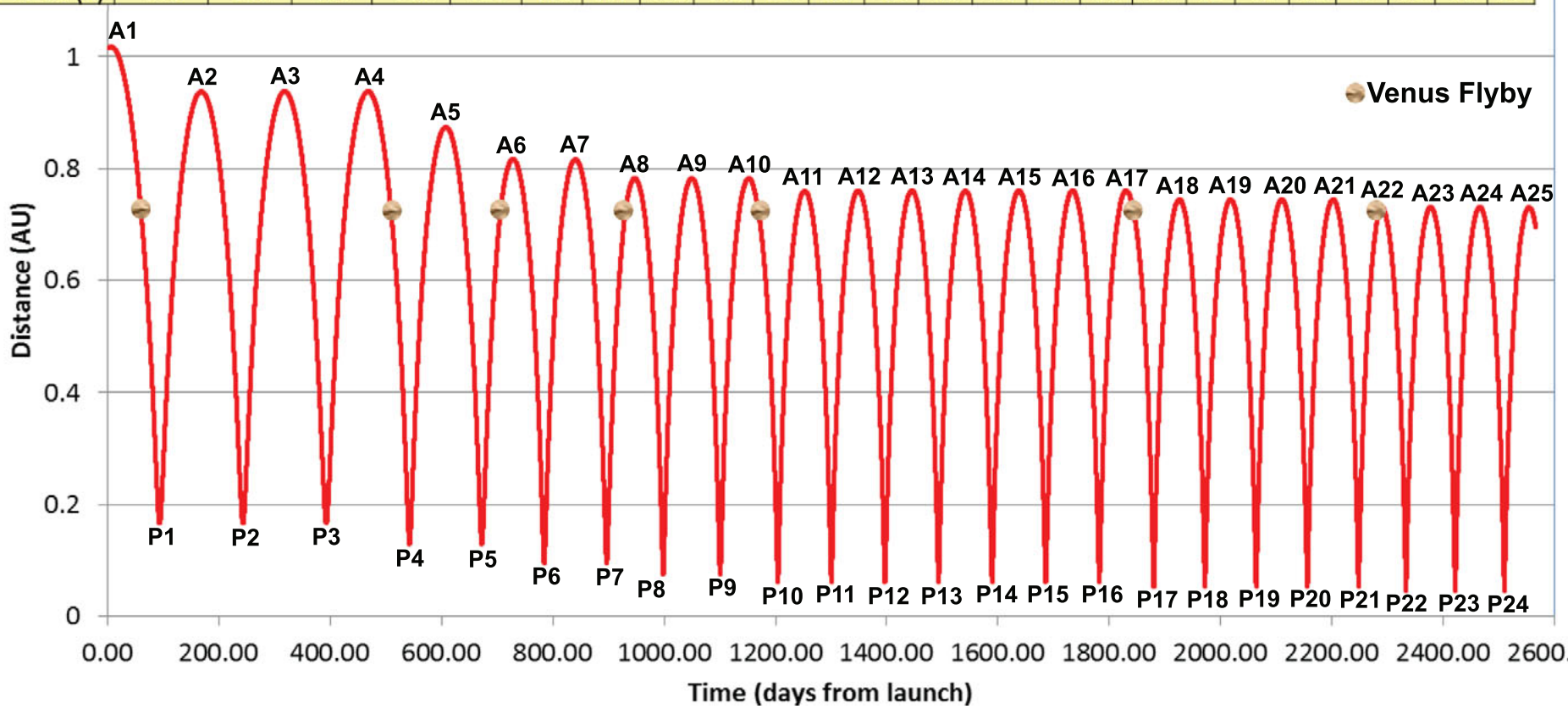
Science operations

- Perihelion investigation below 23 R_S : 3 days
- Storage memory : 32 GB
- Recoverable : 9 GB



Orbits

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

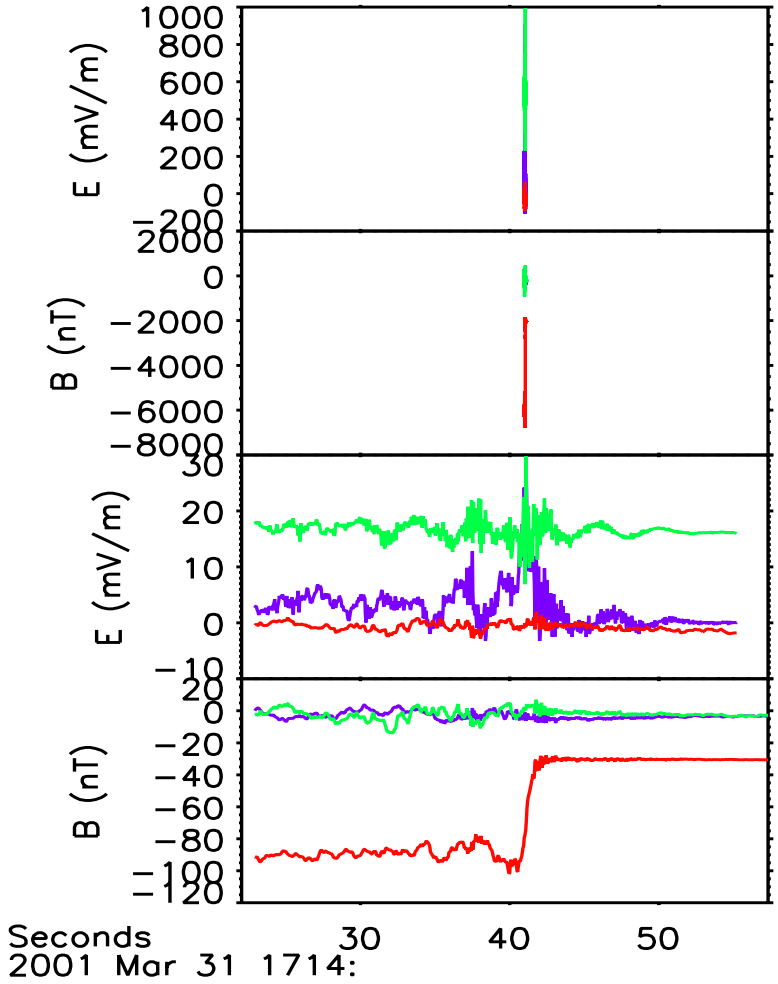


Fox et al. (2016)

Why we are interested in Helios B field data

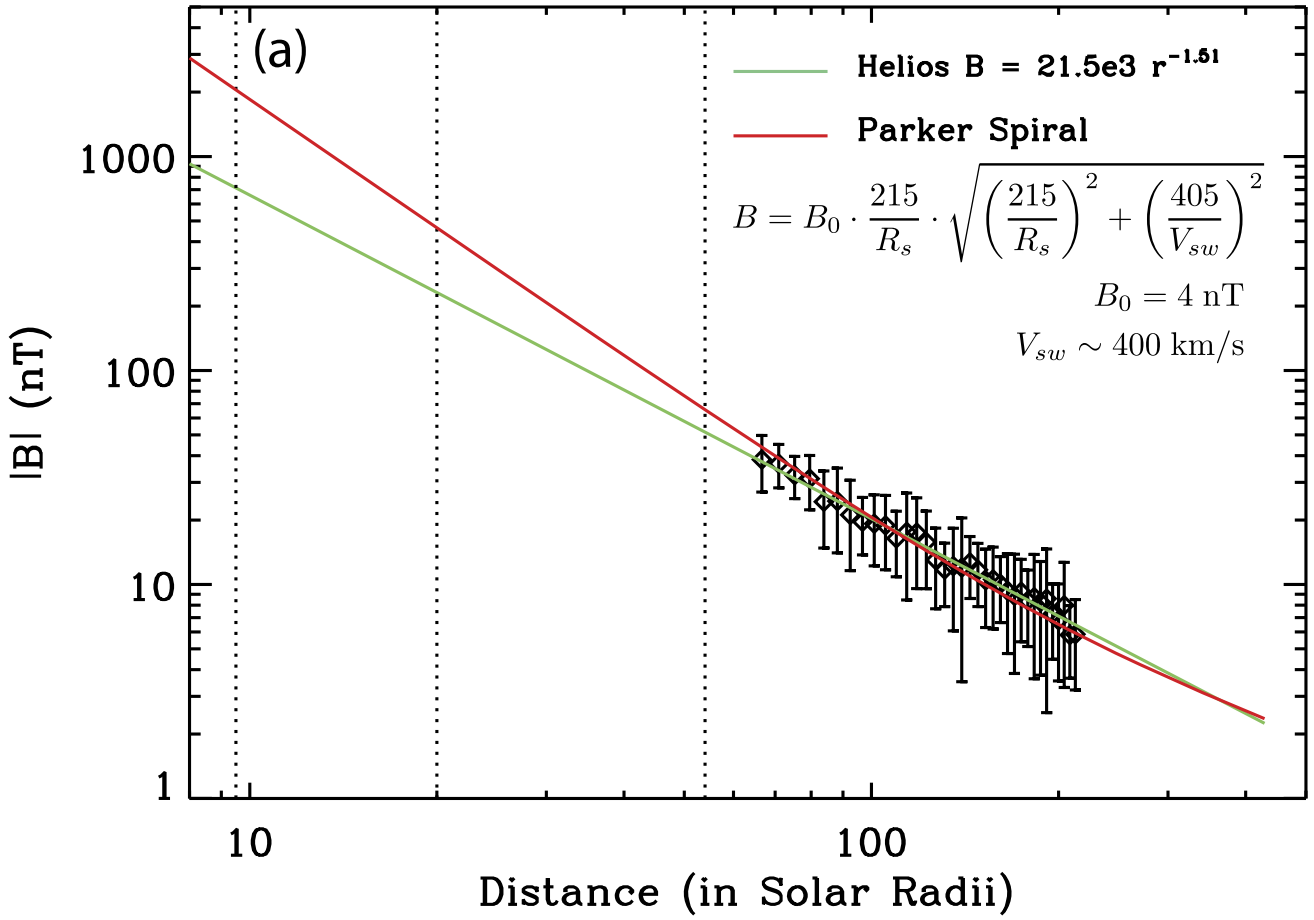
Short time scales

- FIELDS will explore processes on much **shorter time scales** and with **larger amplitudes** than before



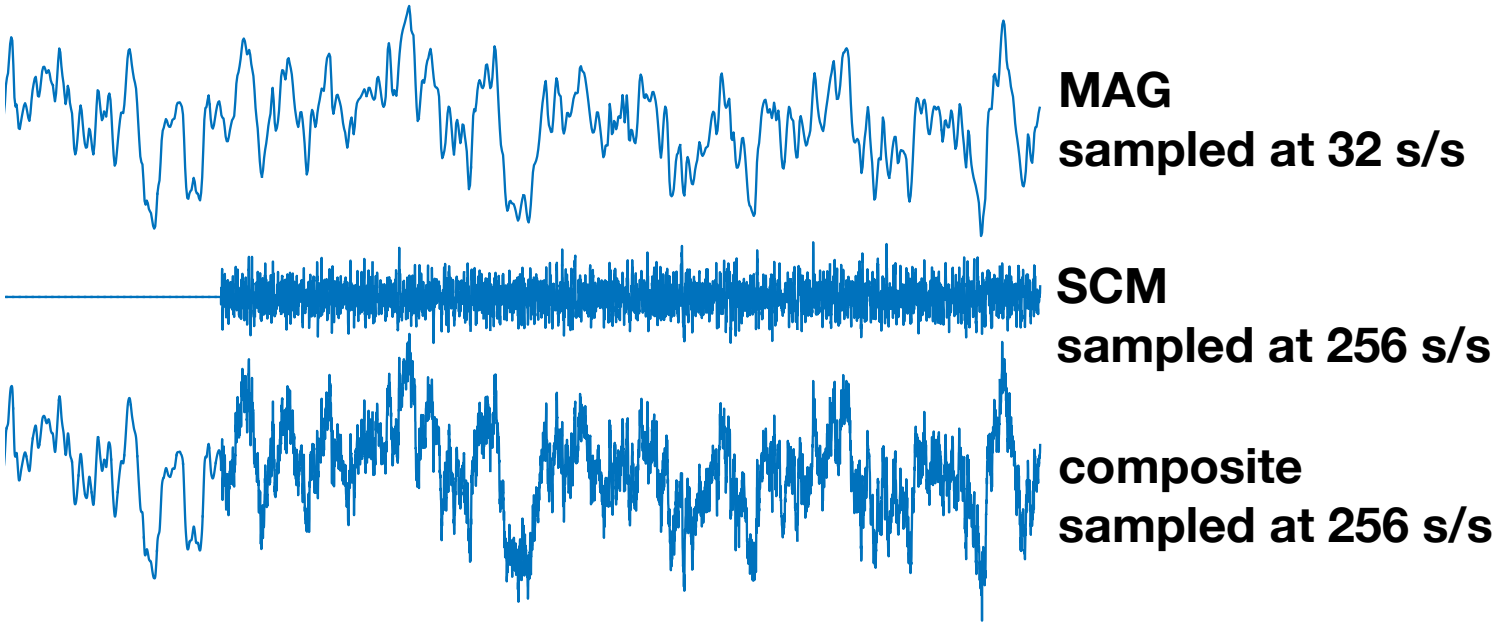
What B(t) should we expect ?

- What is the magnetic field fluctuation level at 9.5 R_S ?



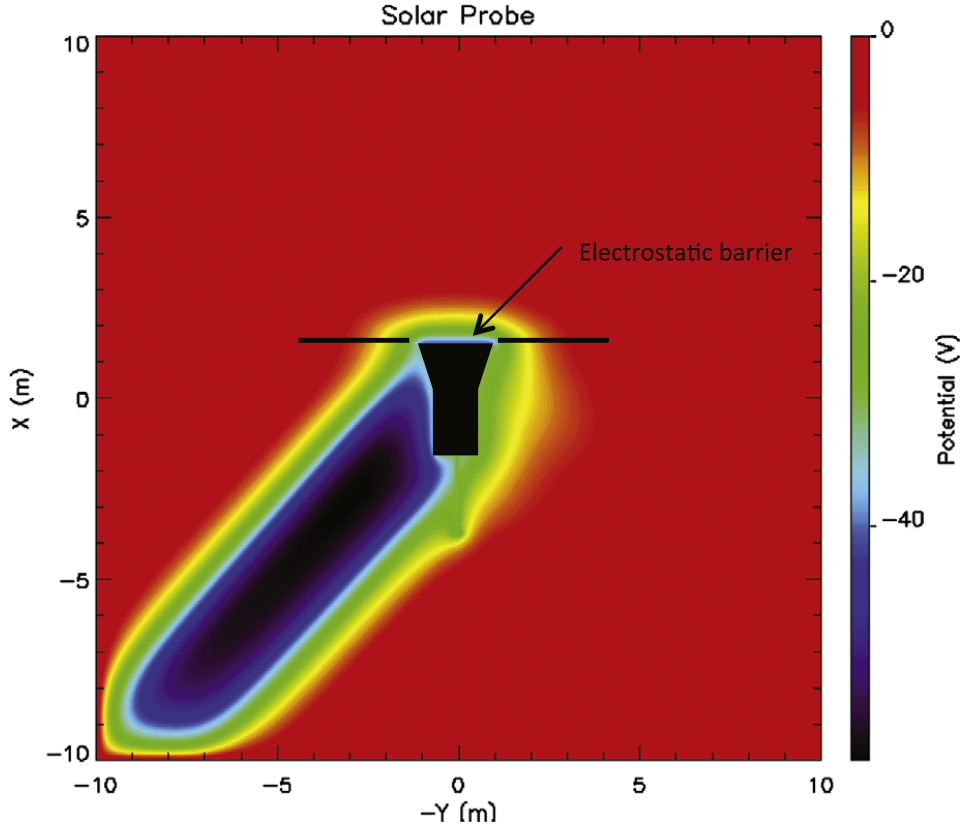
Merge fluxgate and search-coil in single composite

- A merged magnetic field dataset will be provided routinely (0-256 Hz)



Issues

- Near the Sun : too much heat, not enough power
- Large electric field potential = important wake



Ergun et al. (2010)

The FIELDS Instrument Team

HELIOS workshop June 2016 - Köln