Interstellar Probe Study Webinar Series

Our Boundary to Interstellar Space: A New Regime of Space Physics

Presenters

- Dr. Elena Provornikova (Lead Scientist for Heliophysics, Interstellar Probe Study, JHUAPL)
- Professor Merav Opher (Department of Astronomy, Boston University)
- Dr. Jamie Rankin (Space Physics Postdoctoral Research Associate, Princeton University)

12:05 PM Thursday, 11 June 2020

Interstellar Probe Study Website

http://interstellarprobe.jhuapl.edu

What is Interstellar Probe?

Achieving a Dream: A mission to the Interstellar Medium has been discussed since 1960

The First Step: Interstellar Probe is a mission concept through the boundaries of the heliosphere, in to the Local Interstellar Medium

<u>Not</u> A Starship: Uses available or near-term technologies to achieve asymptotic speeds larger than those of past missions

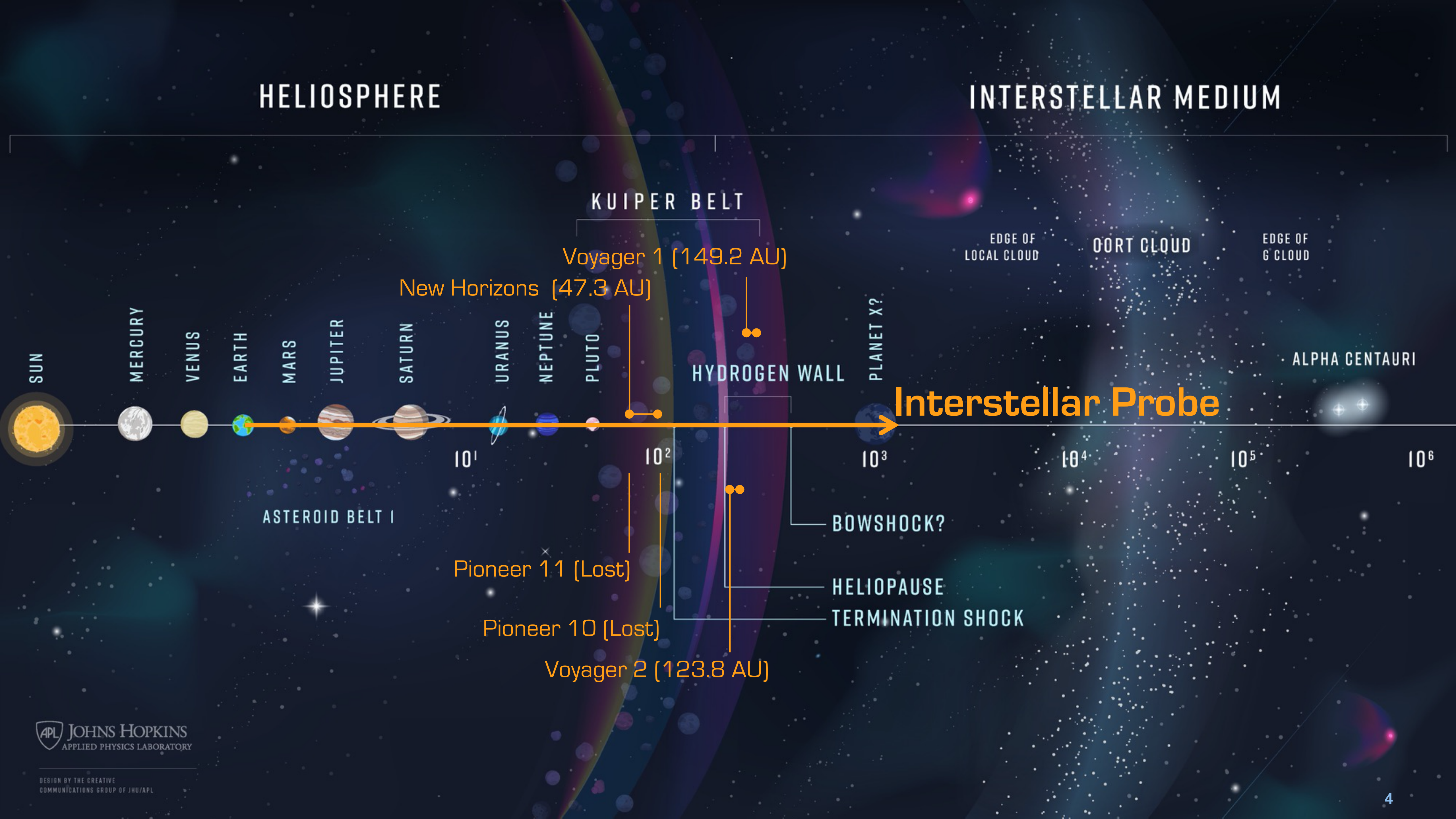
The Science: Our heliosphere as a habitable astrosphere, the unexplored interstellar medium beyond, and opportunities for planetary science and astrophysics

Paving the Way: Interstellar Probe paves the way scientifically, technically and programmatically for longer interstellar journeys that would require future propulsion systems

Mission Study Trade Space

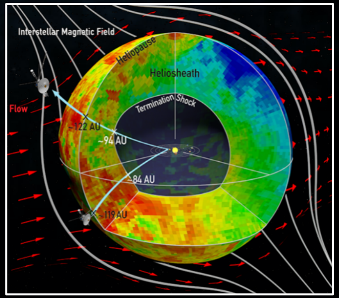
The "Pragmatic" Interstellar Probe

- Technology ready for launch by 2030
- Capability to operate and downlink out to 1000 AU
- Power no more than 600 W at the beginning of the mission
- Mission lifetime no less than 50 years


HELIOSPHERE
INTERSTELLAR MEDIUM
KUIPER BELT
Voyager 1 (149.2 AU)
New Horizons (47.3 AU)
SUN
MERCURY
VENUS
EARTH
MARS
JUPITER
SATURN
URANUS
NEPTUNE
PLUTO
HYDROGEN WALL
PLANET X?
EDGE OF LOCAL CLOUD
OORT CLOUD
EDGE OF G CLOUD
ALPHA CENTAURI
Interstellar Probe
10¹
10²
10³
10⁴
10⁵
10⁶
ASTEROID BELT
BOWSHOCK?
HELIOPAUSE
TERMINATION SHOCK
Pioneer 11 (Lost)
Pioneer 10 (Lost)
Voyager 2 (123.8 AU)
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY
DESIGN BY THE CREATIVE COMMUNICATIONS GROUP OF JHU/APL

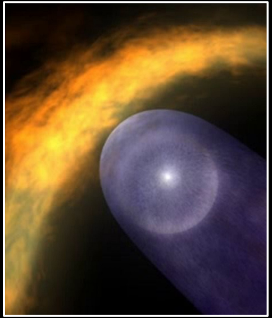
Interstellar Probe

Heliophysics Mission to the Local Interstellar Medium through the Outer Heliosphere



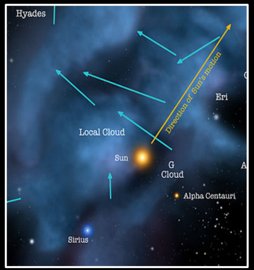
What is the global nature of the heliosphere?

- Discover the global shape
- Nature of the Heliosheath filled with energetic particles
- Physical processes behind the ENA Ribbon and Belt
- Structure of the Hydrogen Wall



How do the Sun and the Galaxy Affect the Dynamics of the Heliosphere?

- Discover the global response to Sun`s activity
- Influence of the Cloud on the heliosphere
- Galactic Cosmic Rays modulation



What is the Nature of the Interstellar Medium?

- First In-situ sampling of the Local Interstellar Cloud
- Discover Heliosphere Location within the Cloud
- Unique detection of Interstellar Dust grains

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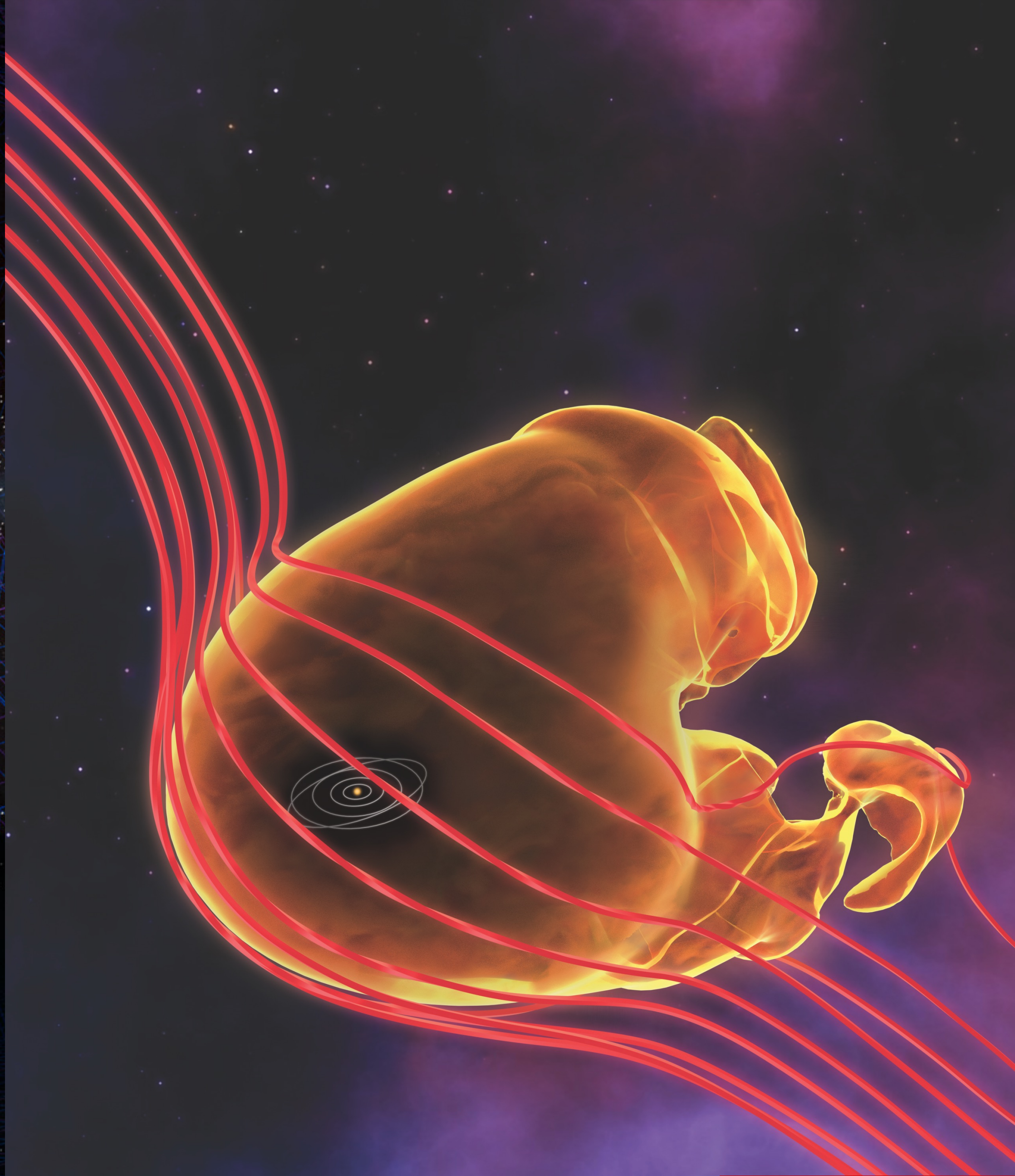
APPLIED PHYSICS LABORATORY

Our Heliospheric Shield

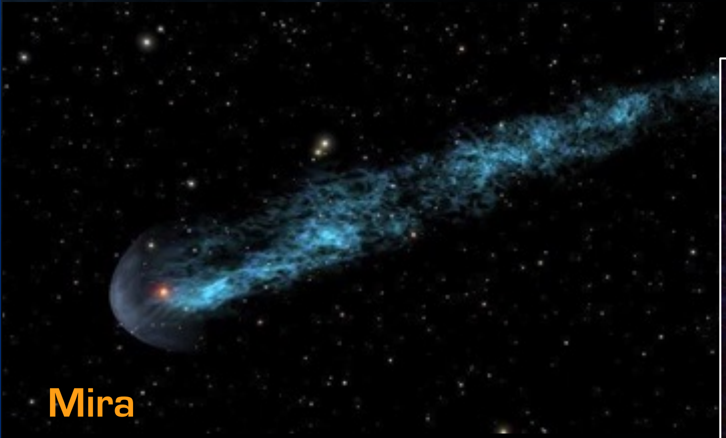
Merav Opher
Boston University

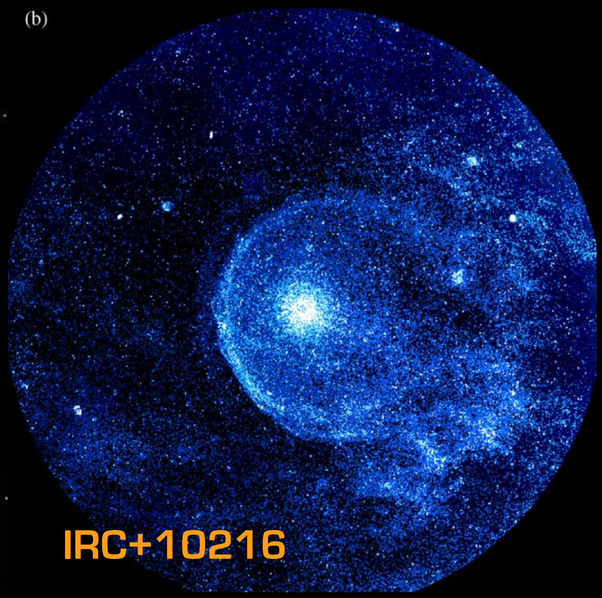


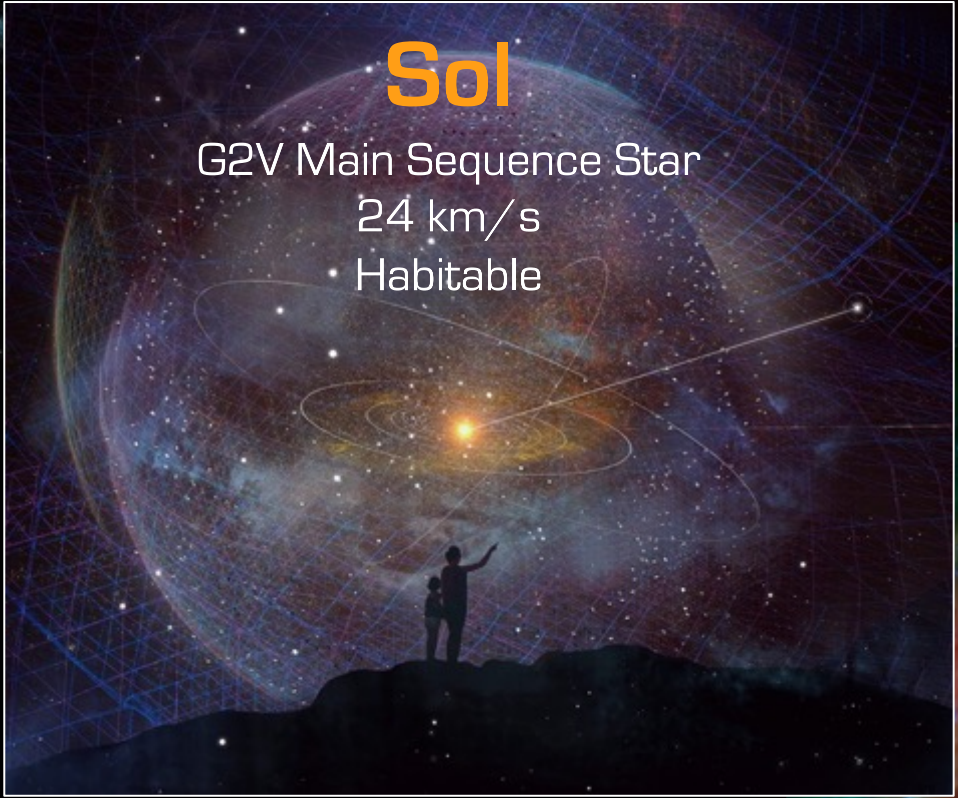
BOSTON UNIVERSITY

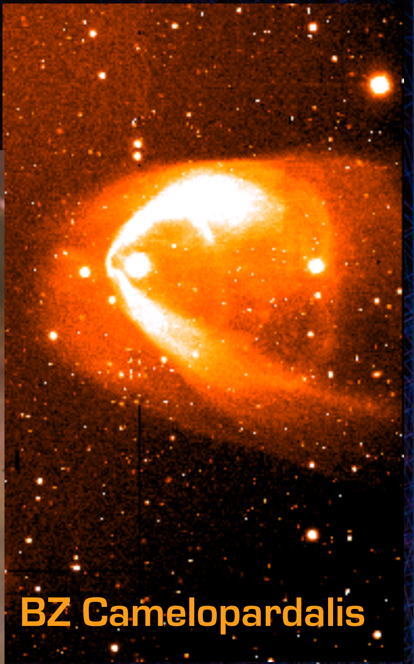
Stars have bubbles around them: astrospheres

Our Habitable Astrosphere

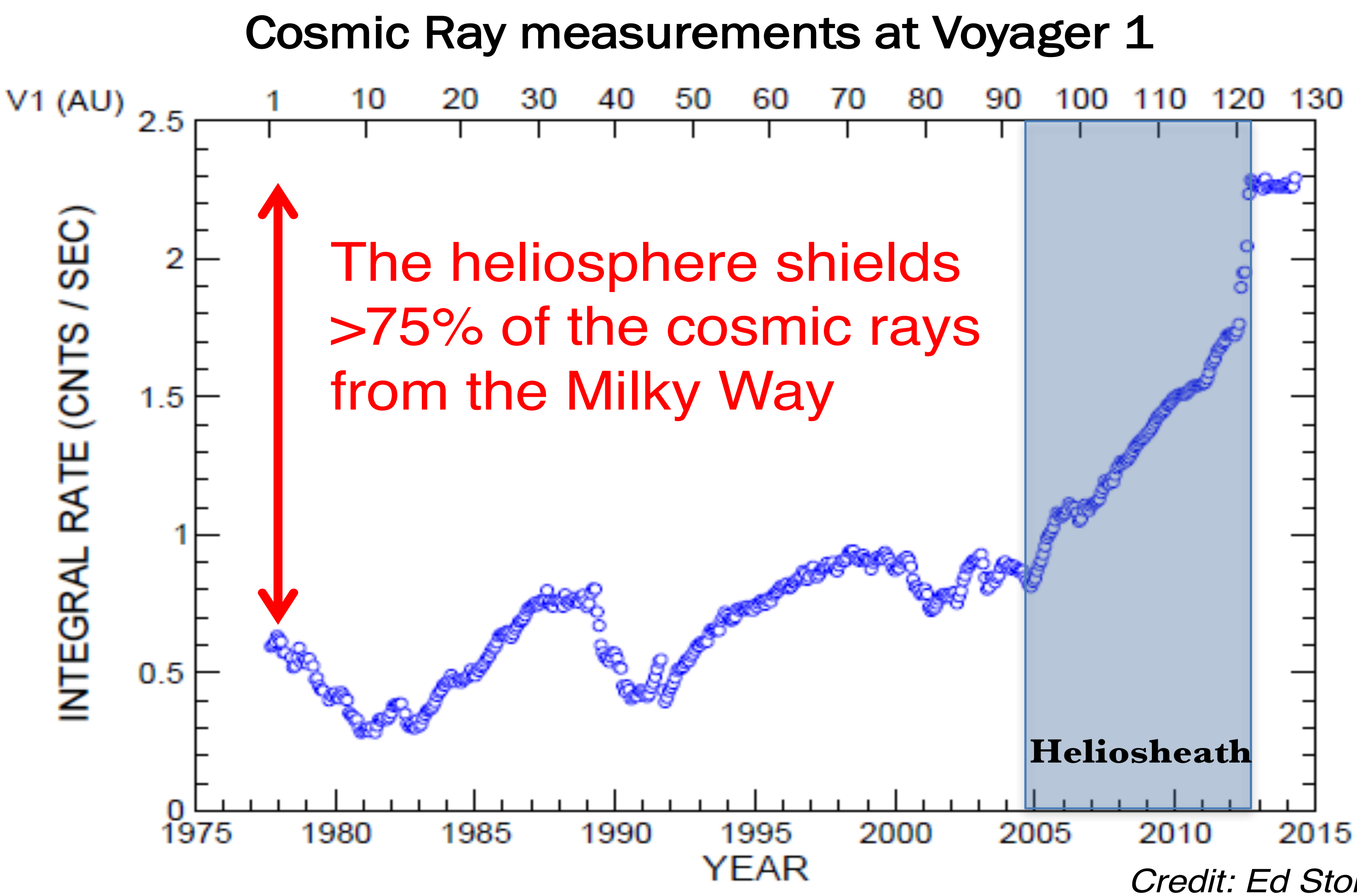




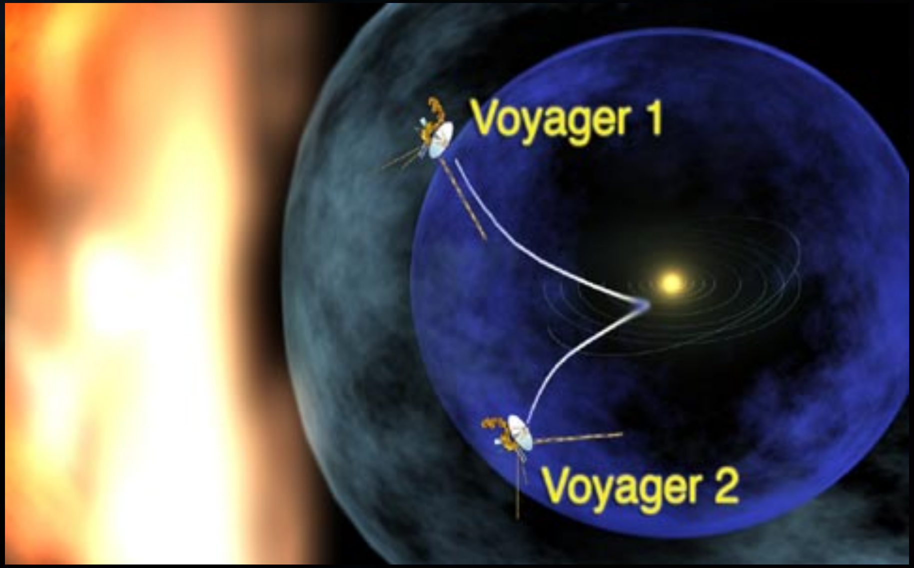




The Heliosphere Shields 75% of Cosmic Rays (up to 1GeV) from Milky Way Galaxy

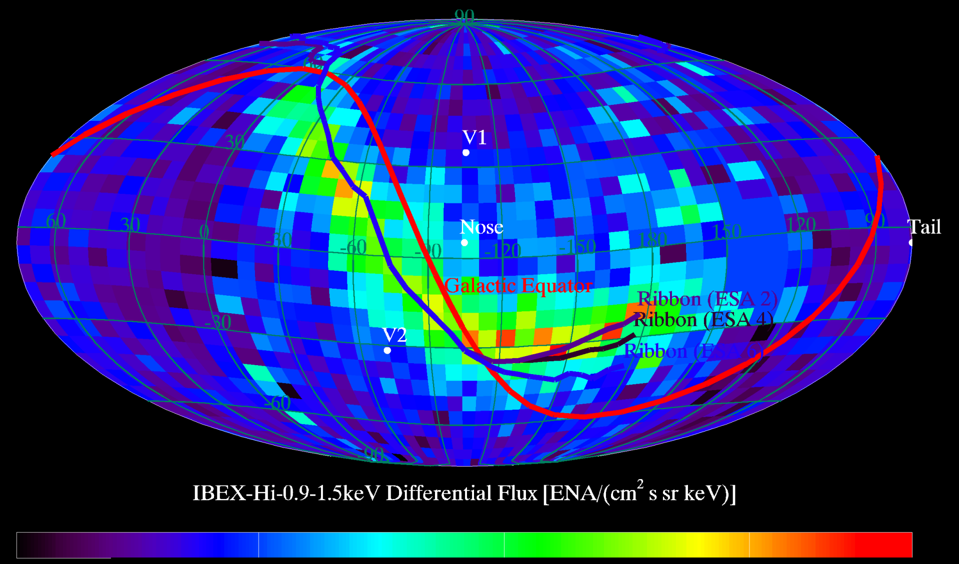


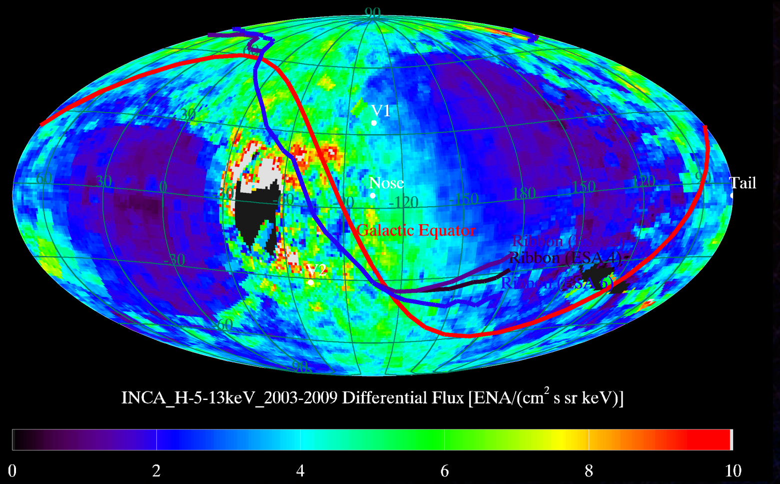
Credit: Ed Stone

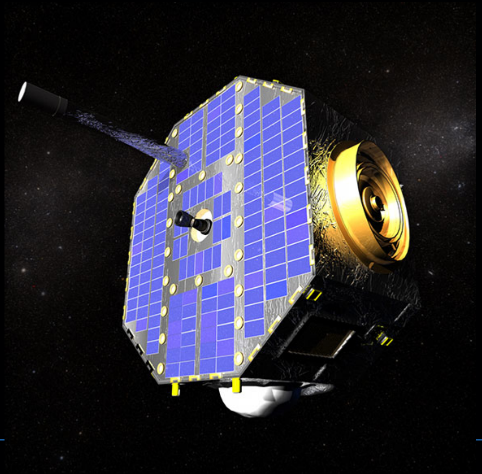


Voyager 1 and 2

In-situ data

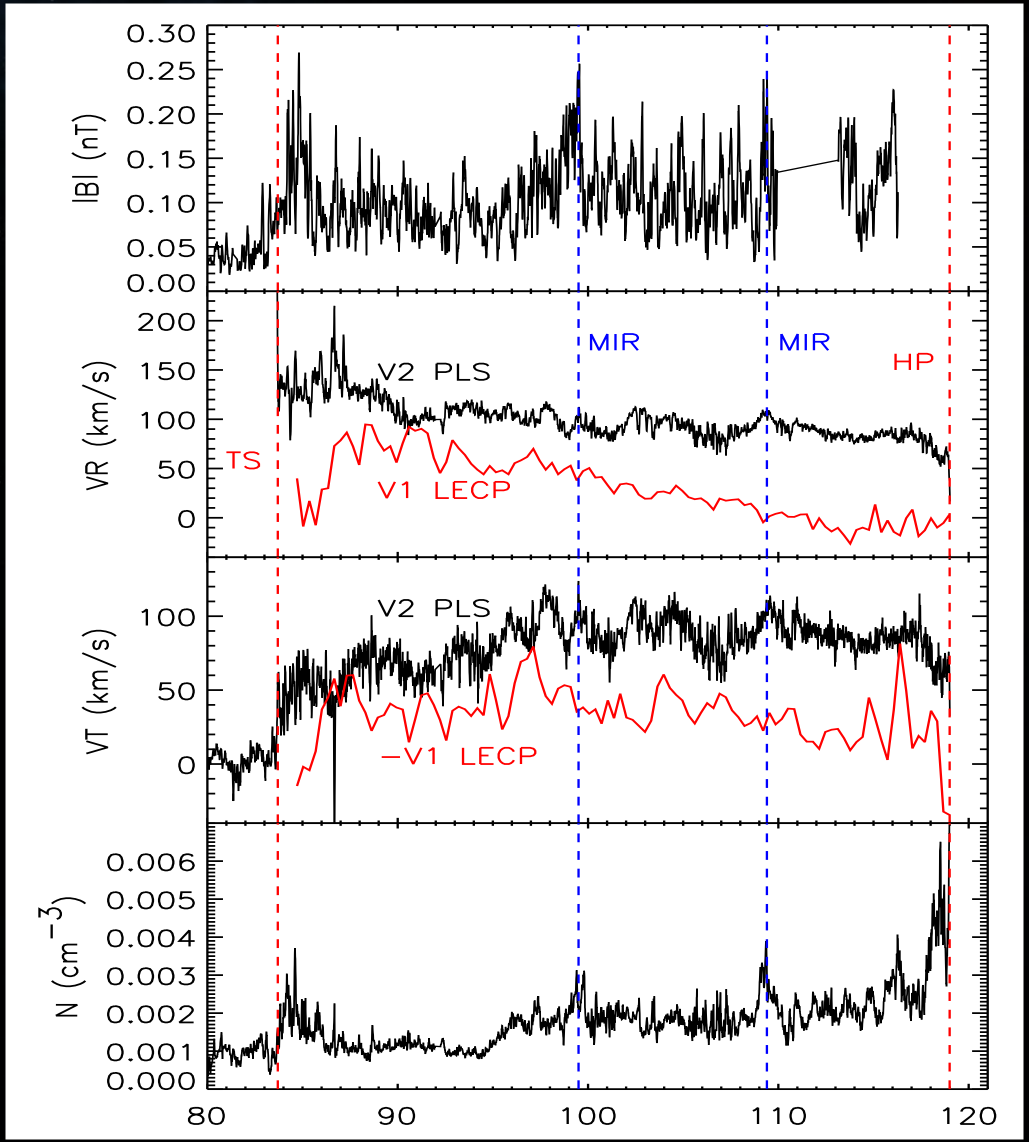






Global maps
of Energetic Neutral Atoms
(IBEX, Cassini)

Our Current Models Failed to Explain Key Observations

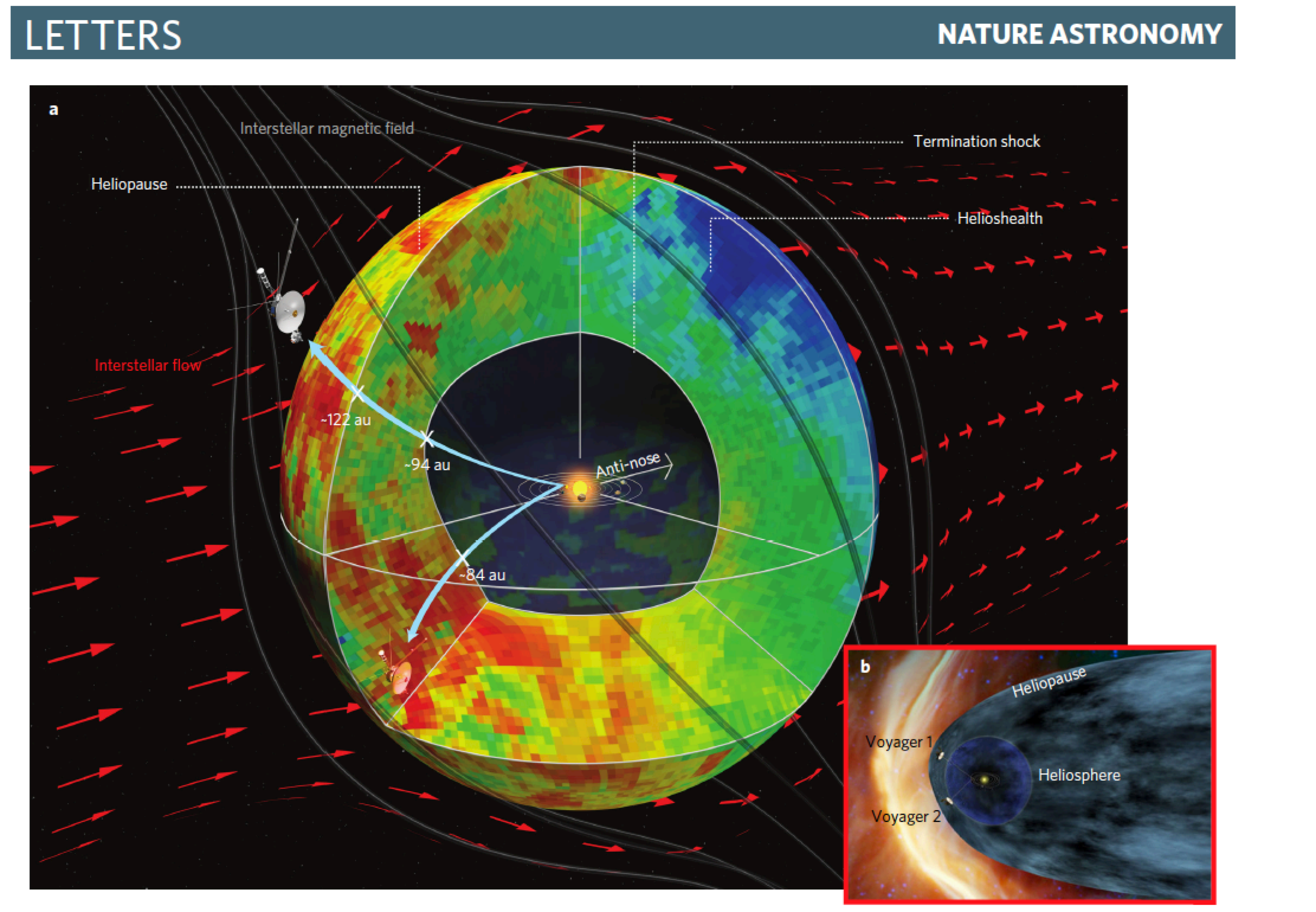


The differences are not understood and don't match current models

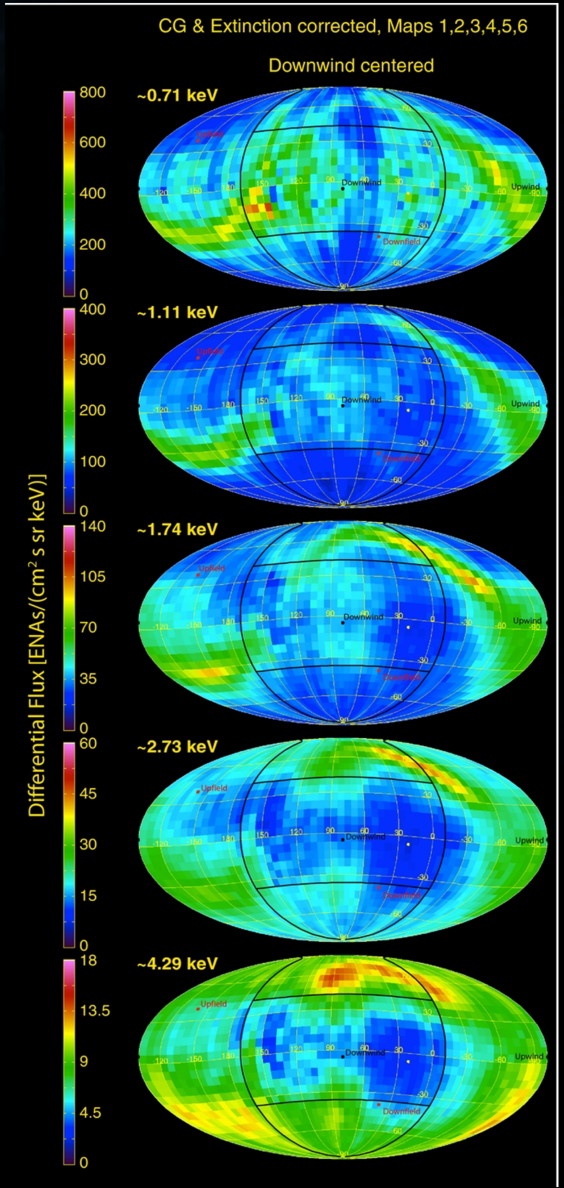
Voyager spacecrafts lack instrumentation capable to measure the weak magnetic fields in the heliosheath and a key component of the plasma (energetic particles ~ keV) ->
need to revisit this region with Interstellar Probe

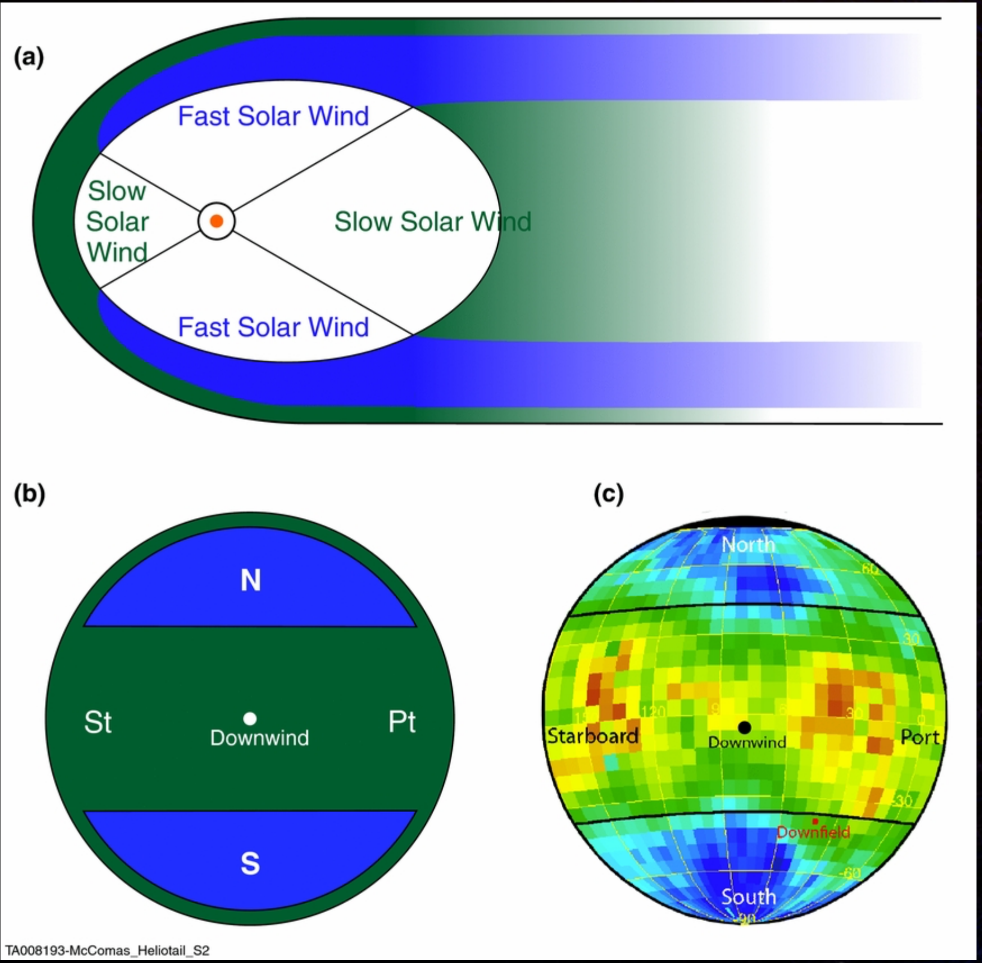
Science Question A:
What is the global structure of the heliosphere?

Bubble-like shape (Dialynas et al. 2017)



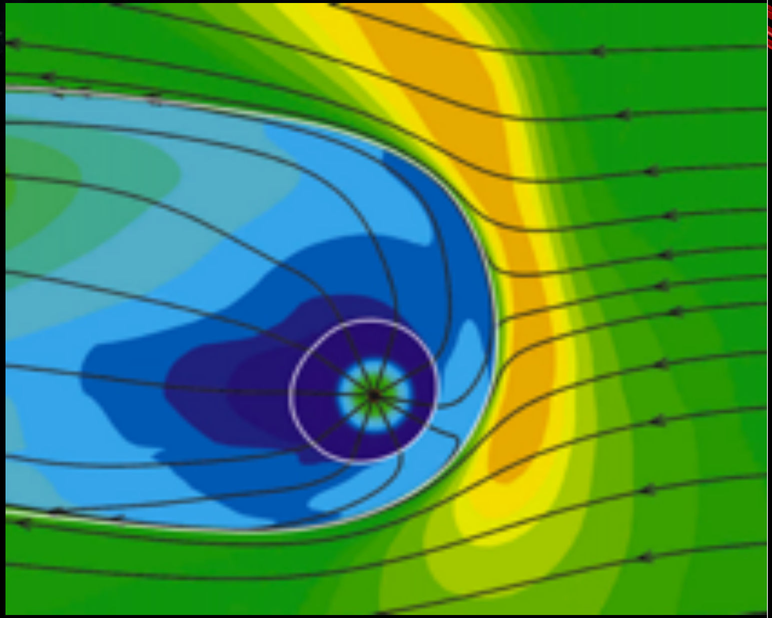
Comet-like shape (McComas et al. 2013)



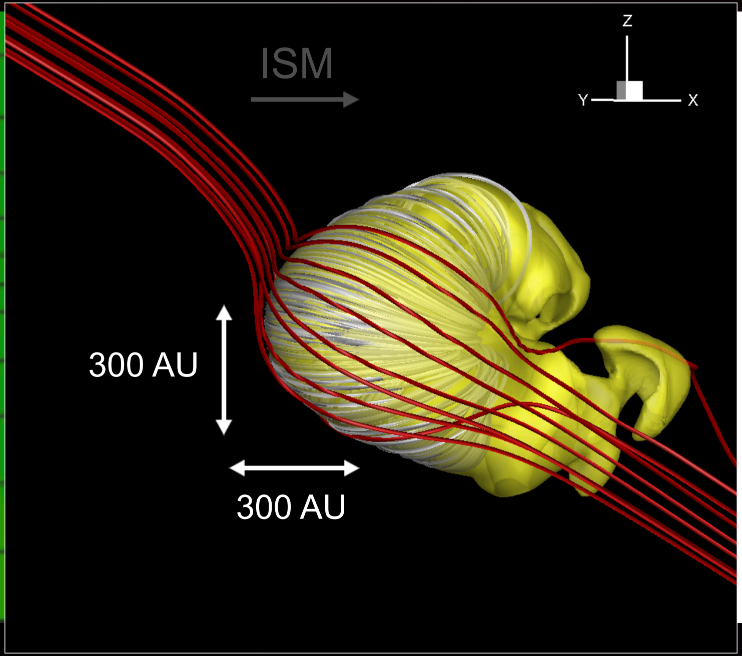


Structure of the tail was interpreted as signature of long tail

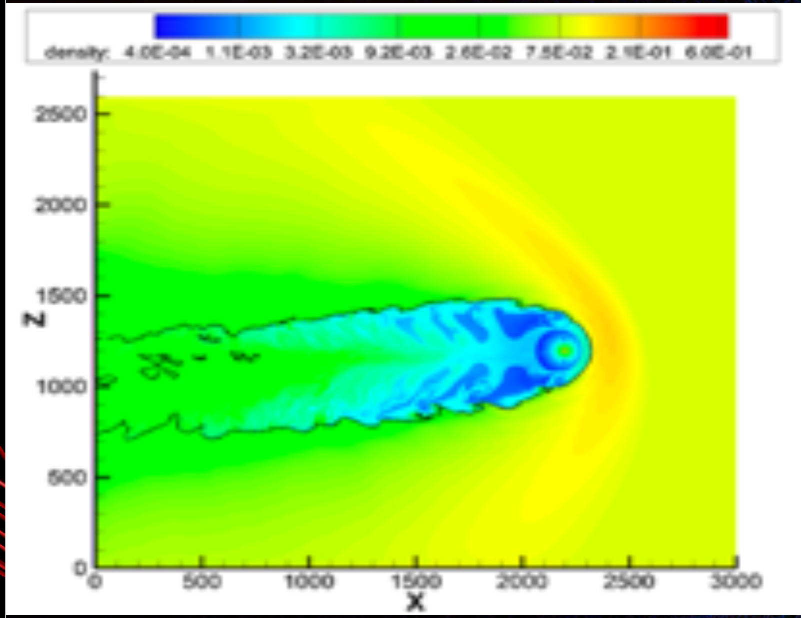
Models don't agree on the shape



Izmodenov et al. 2015

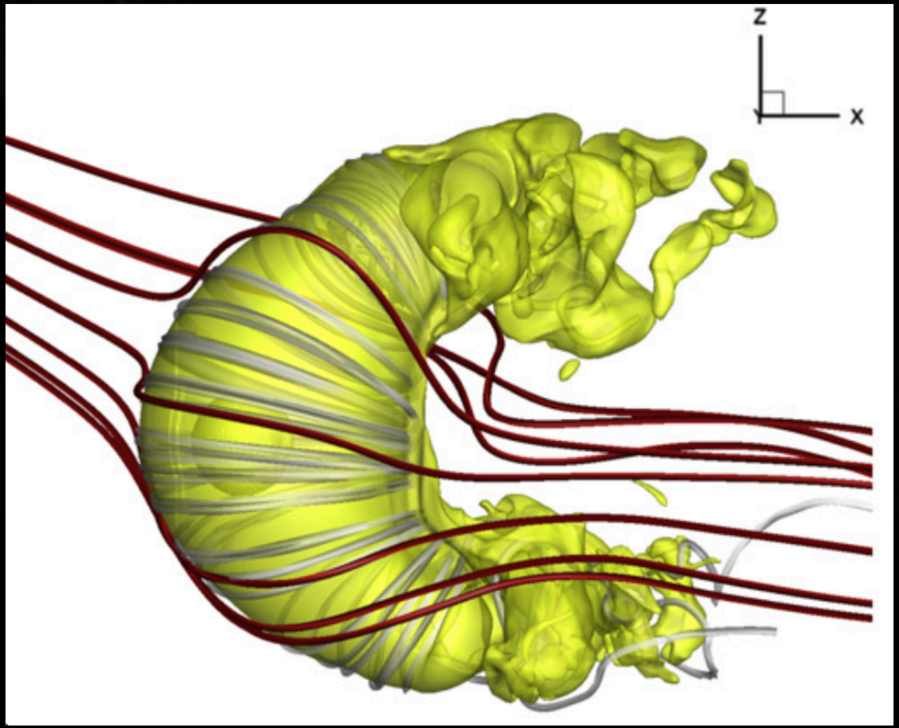


Opher et al. 2015; 2020

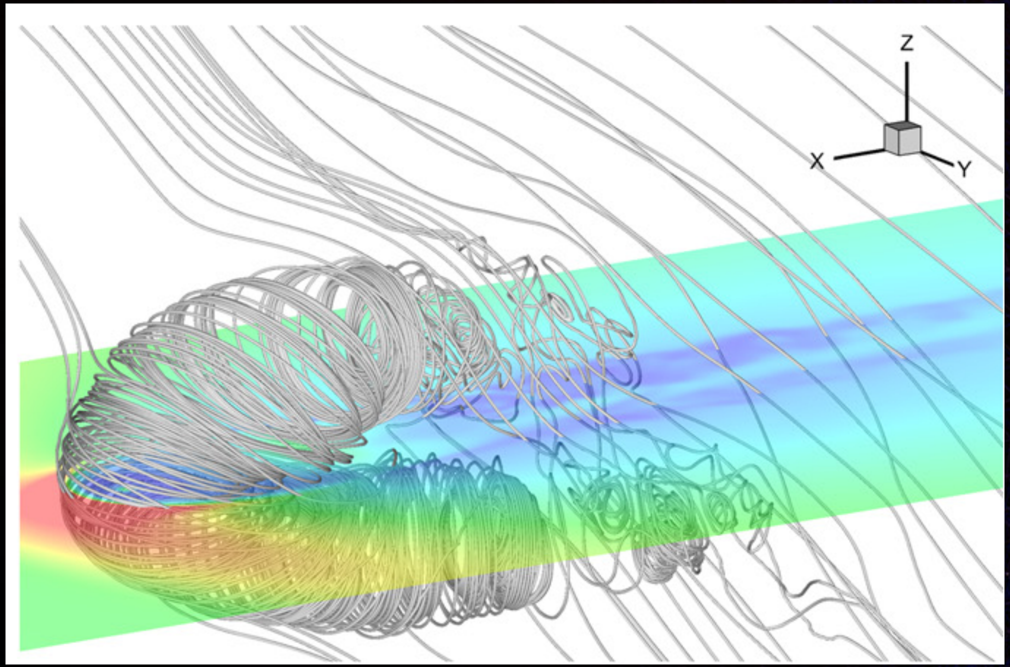


Pogorelov et al. 2015

New Understanding that the Solar Magnetic Field is the backbone of the heliosphere



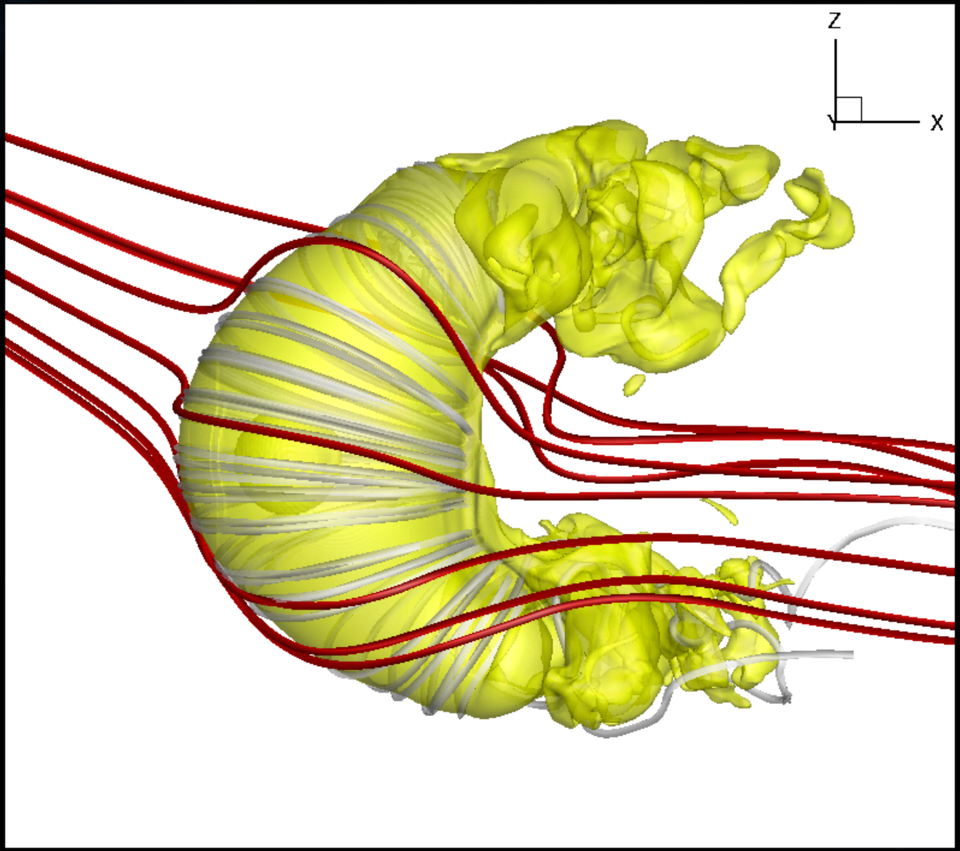
Opher et al. 2015

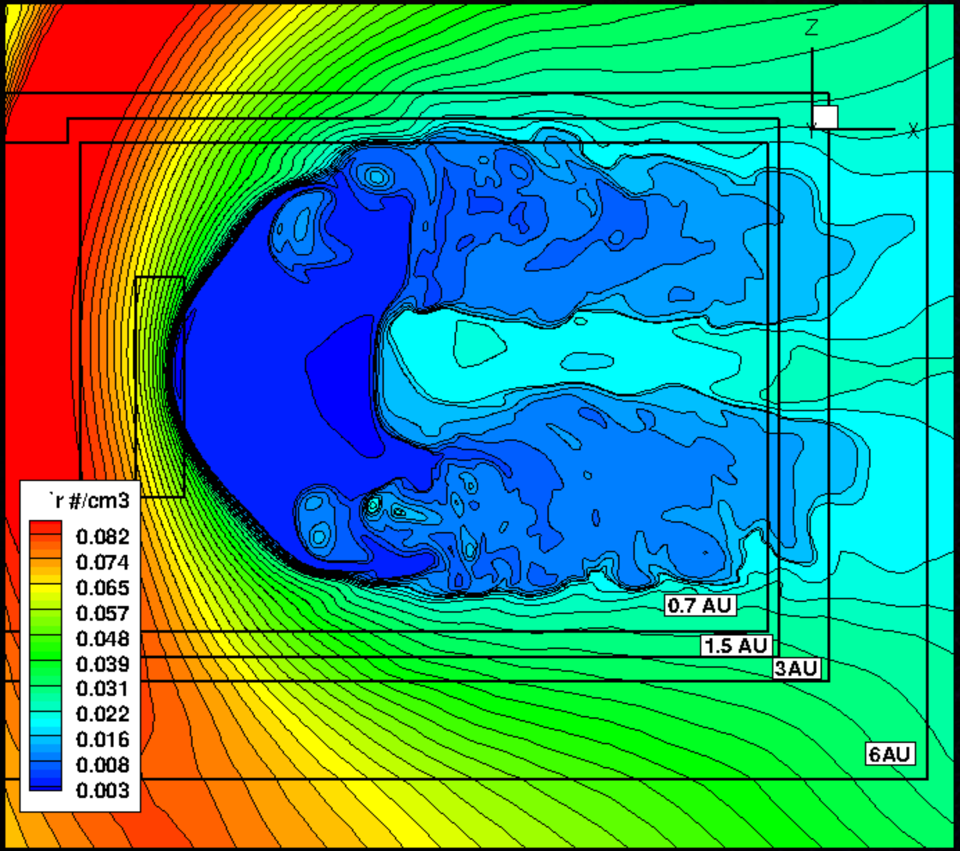


Pogorelov et al. 2015

The Solar Magnetic Field confine the solar wind in the heliosheath

A “Croissant-Like” Heliosphere



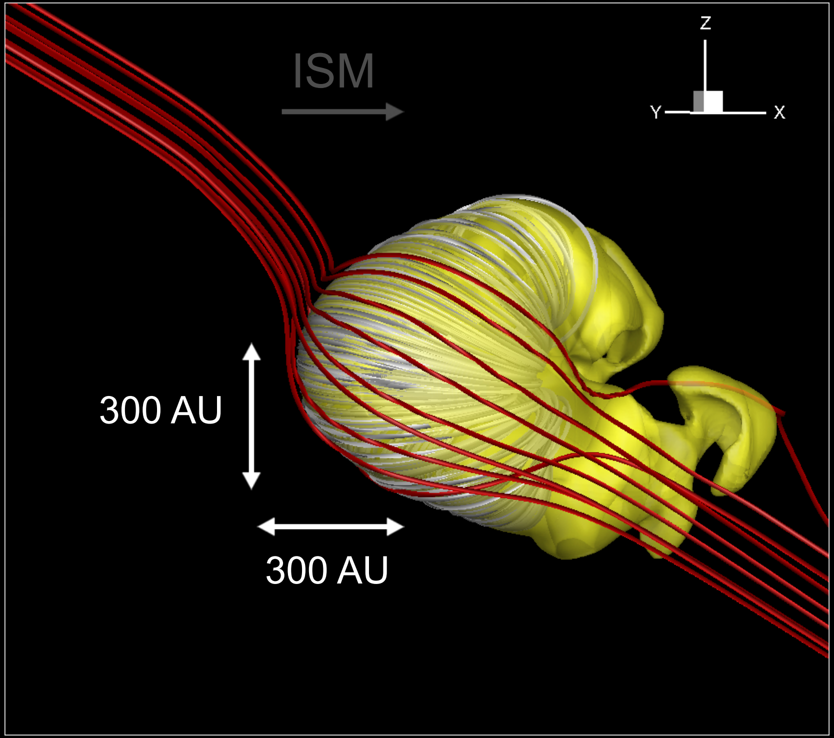


The tension force collimates the heliosheath flow in two jets (Opher et al. 2015; Drake et al. 2015)

Models predict a much thicker heliosheath than observations

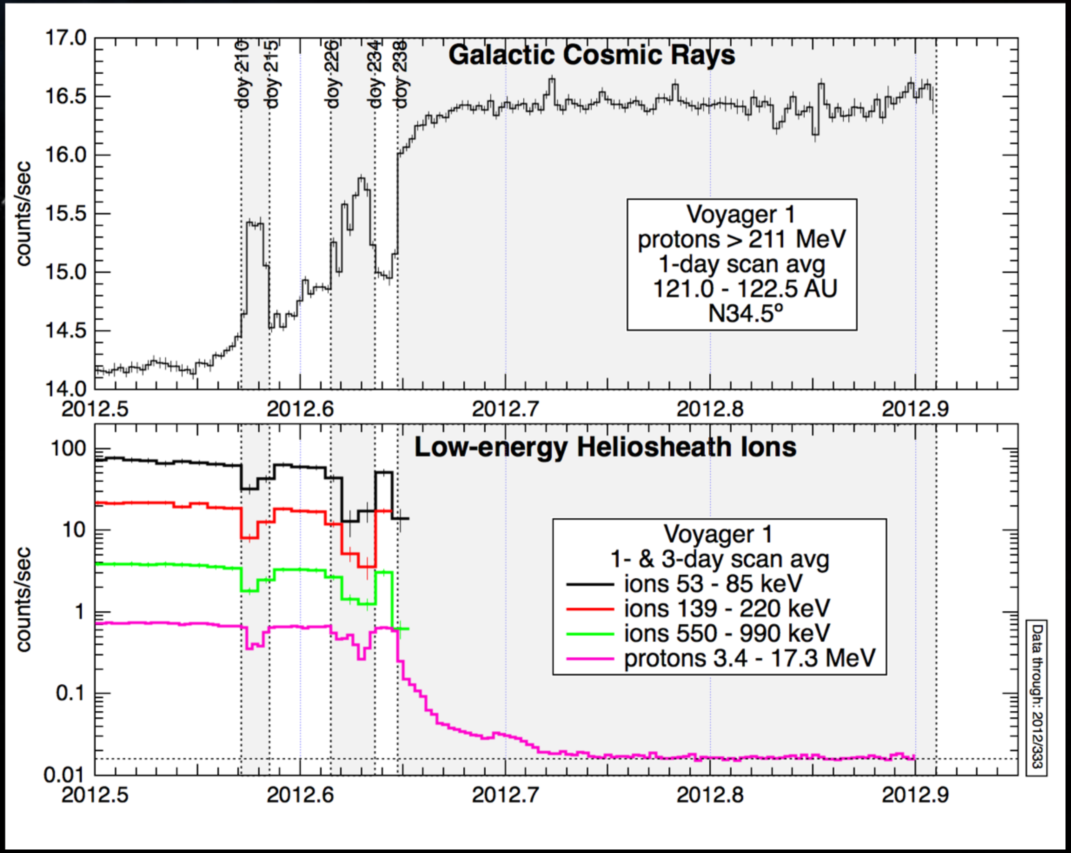
Models predict 60-70AU while thickness was 28AU at V1 and 35AU at V2

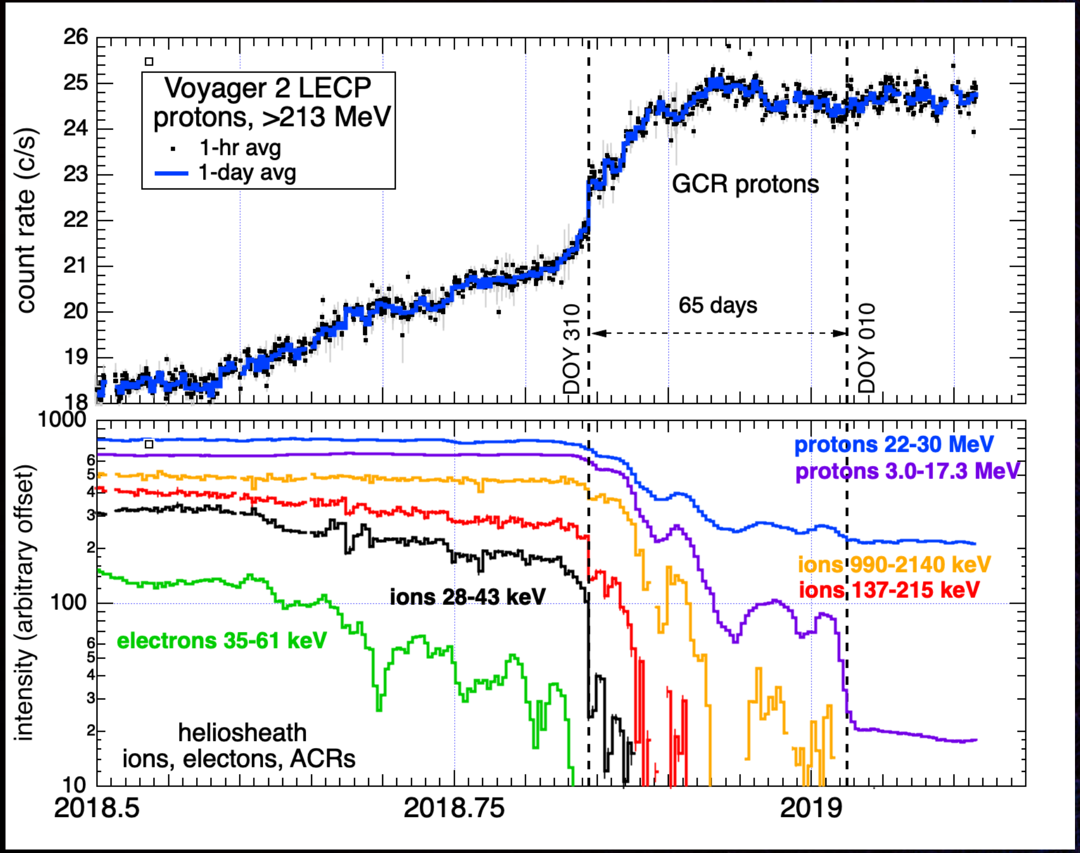
Time Dependent effects cannot reconcile these measurements (Izmodenov et al. 2005; 2008)



Indicating that some physics is missing in the models

How Porous is the Heliopause?





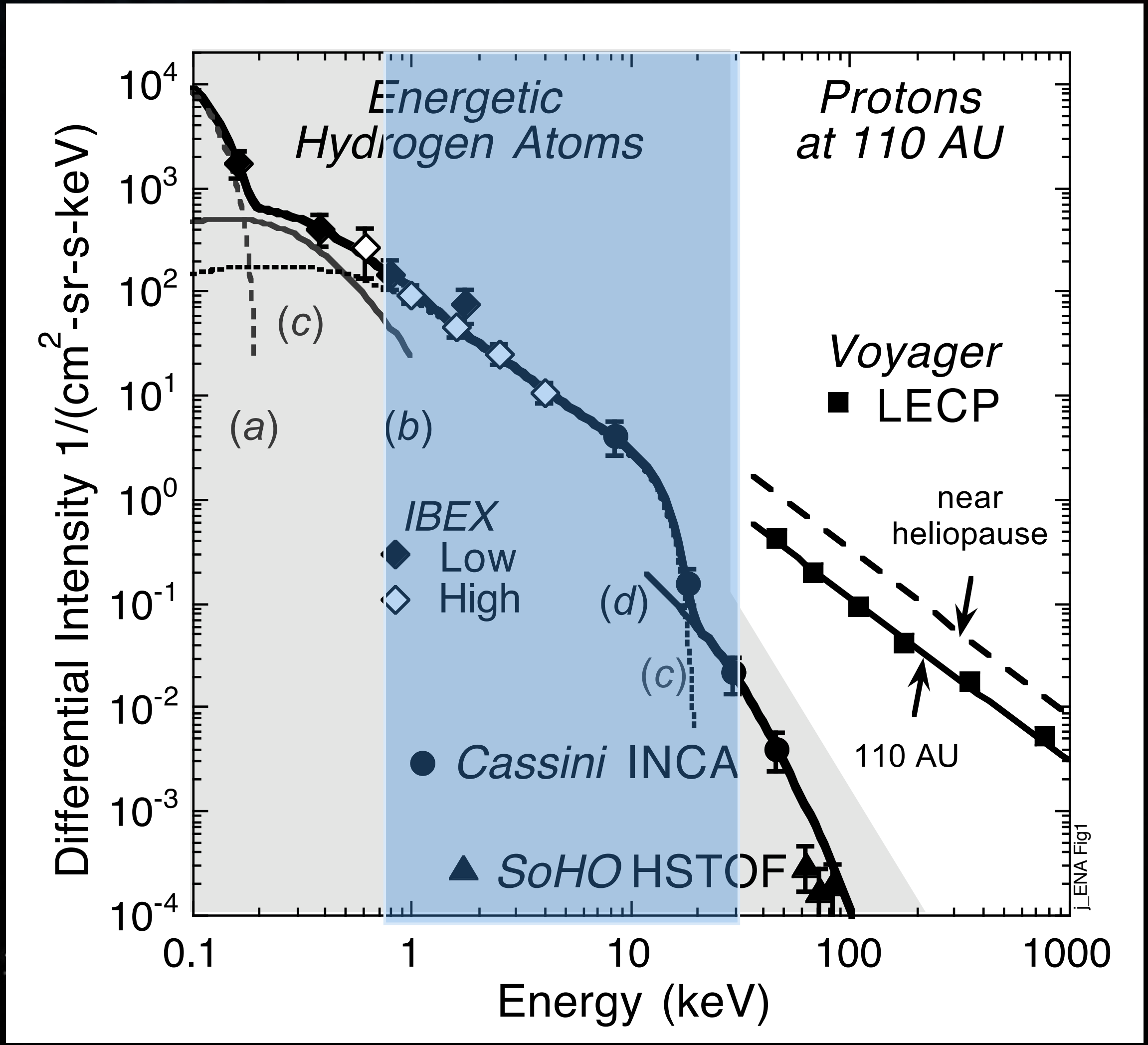
Voyager 1

Voyager 2

The Properties of the Heliopause are not understood

The crossing of the Heliopause were drastically different at Voyager 1 and 2.

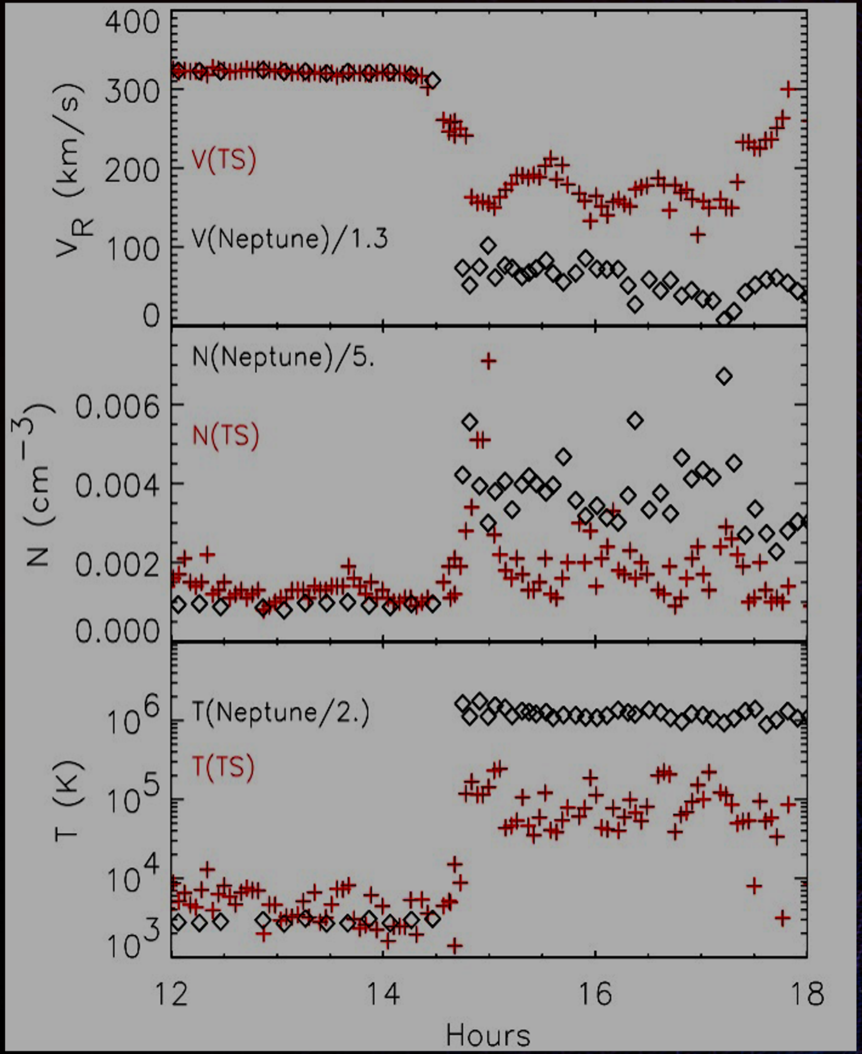
Science Question B:
How do Pick-Up Ions evolve from "cradle to grave"?



PUIs are particles with energy > ~0.5 keV (hotter than the thermal component of the solar wind)

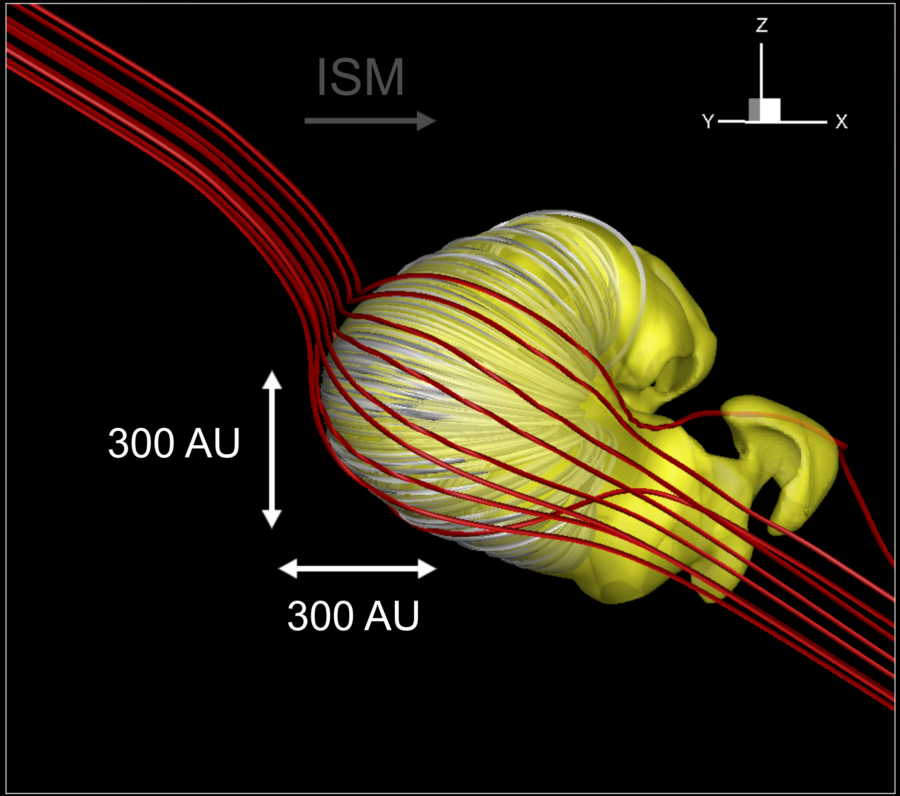
Voyager is "blind" to PUIs until 28keV

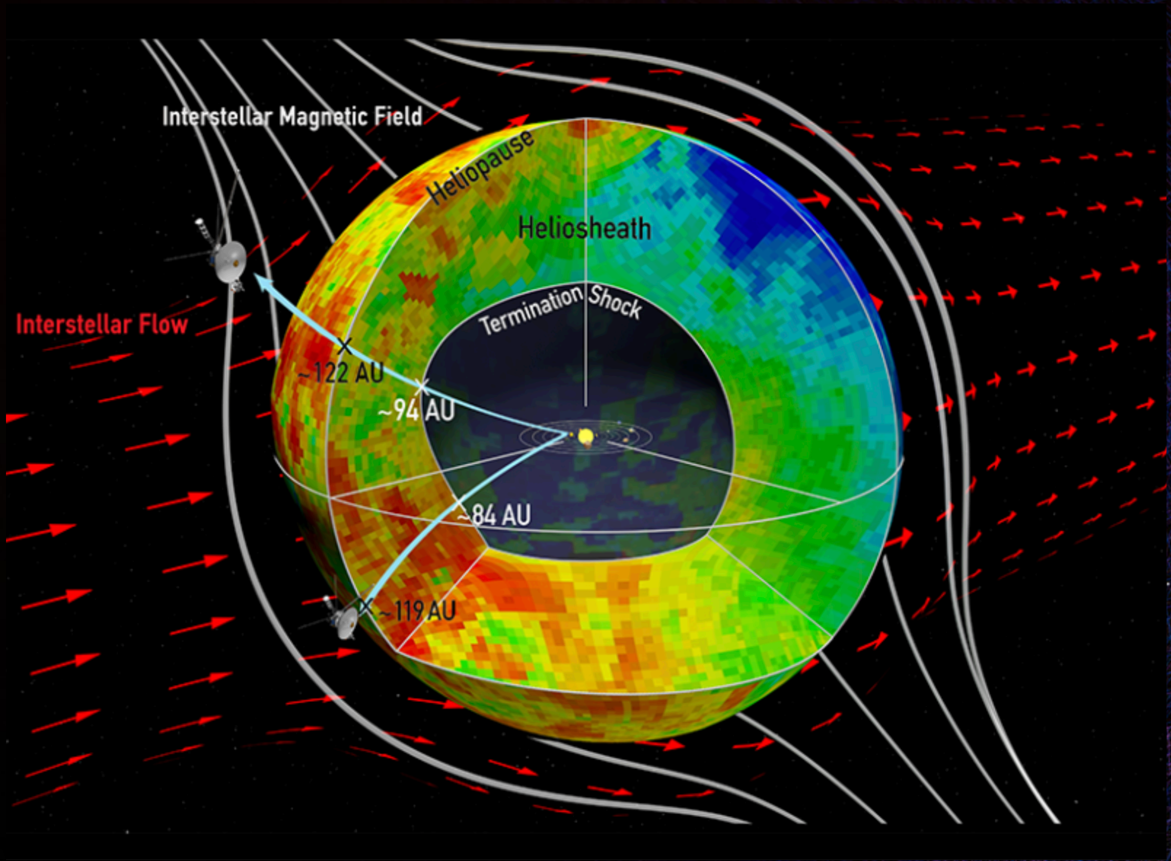
The Voyager 2 crossing of the Termination Shock showed that 80% of energy in the heliosheath is carried by PUIs



Richardson et al. Nature 2008

The inclusion of PUIs as a separate fluid deflate the Heliosphere

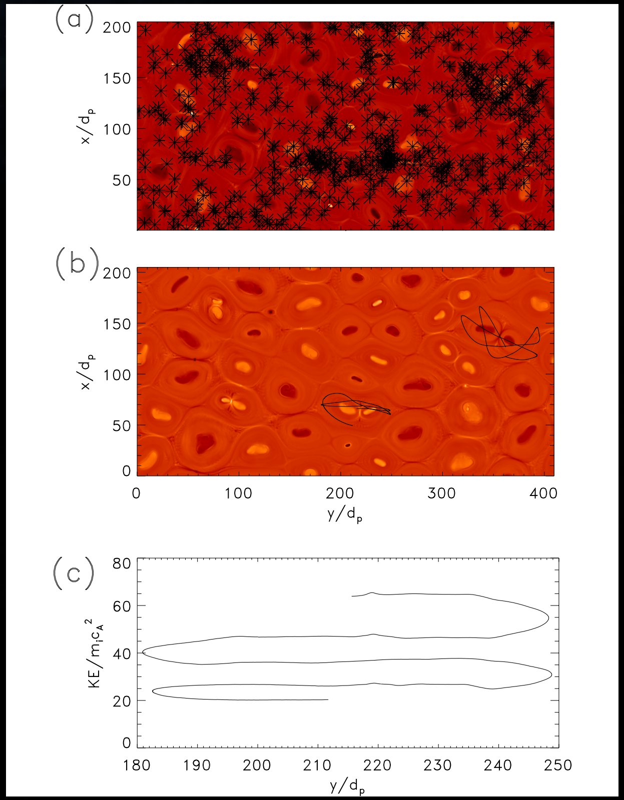




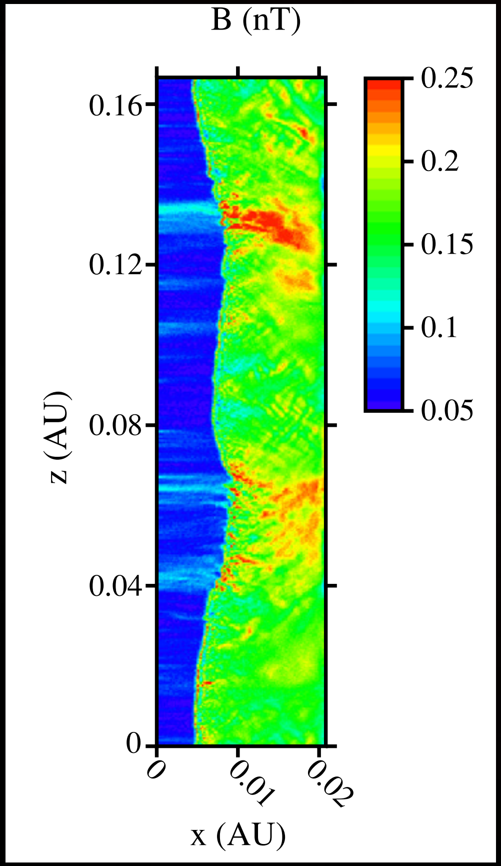
Opher et al. *Nature Astronomy* 2020

The heliosphere has distances from the Sun to the heliopause similar in all directions

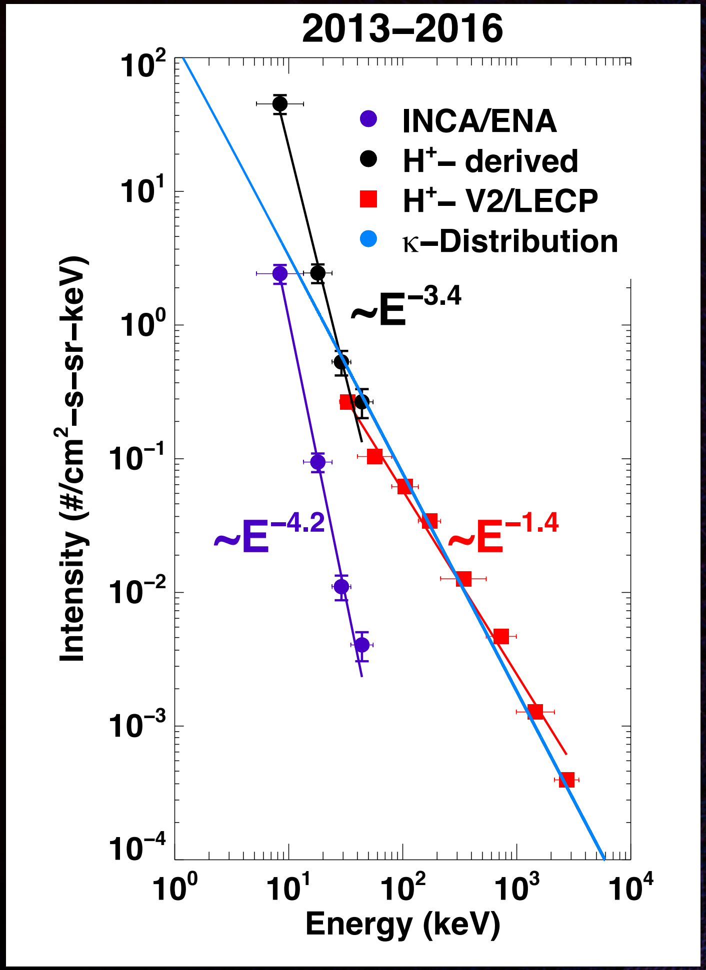
How the Pick-Up Ions evolve from "cradle to grave"?



Reconnection

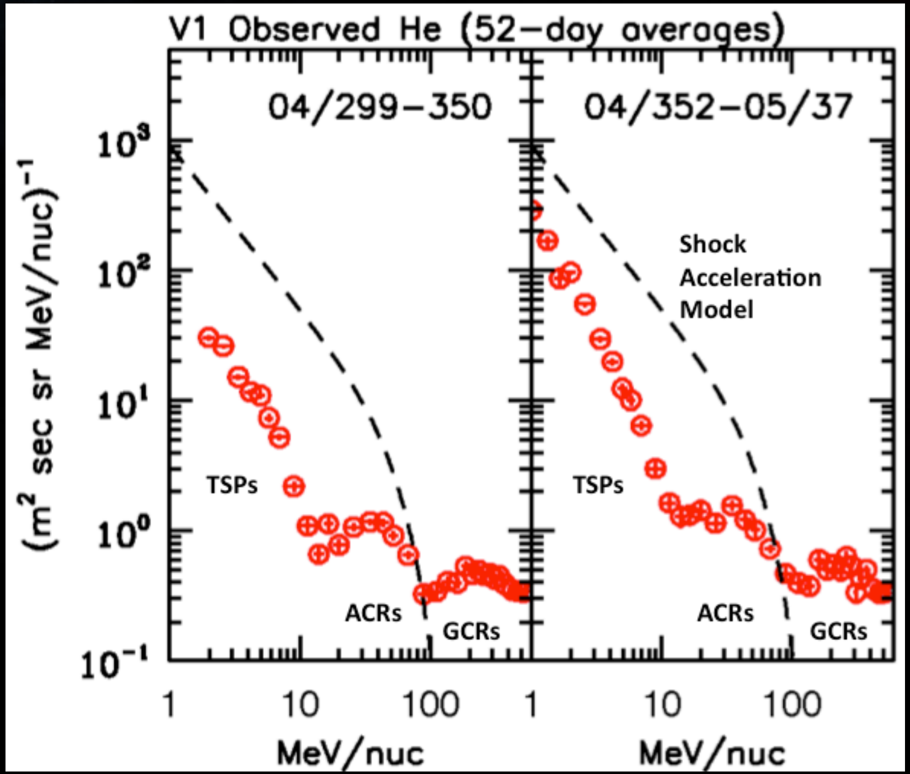


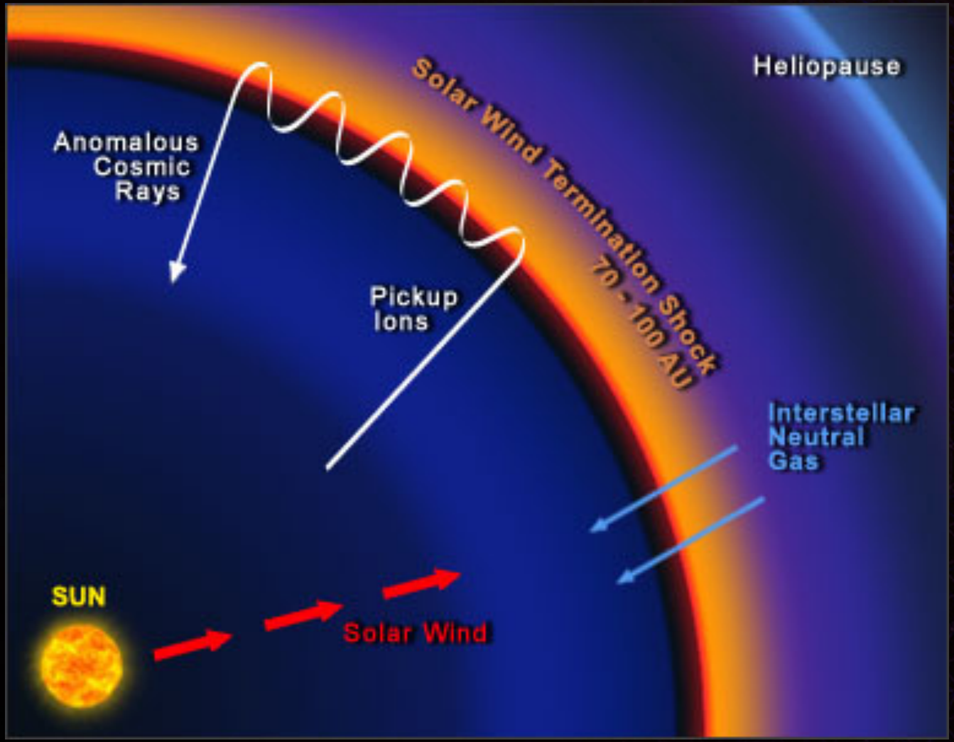
Turbulence



Dialyanas et al. 2019

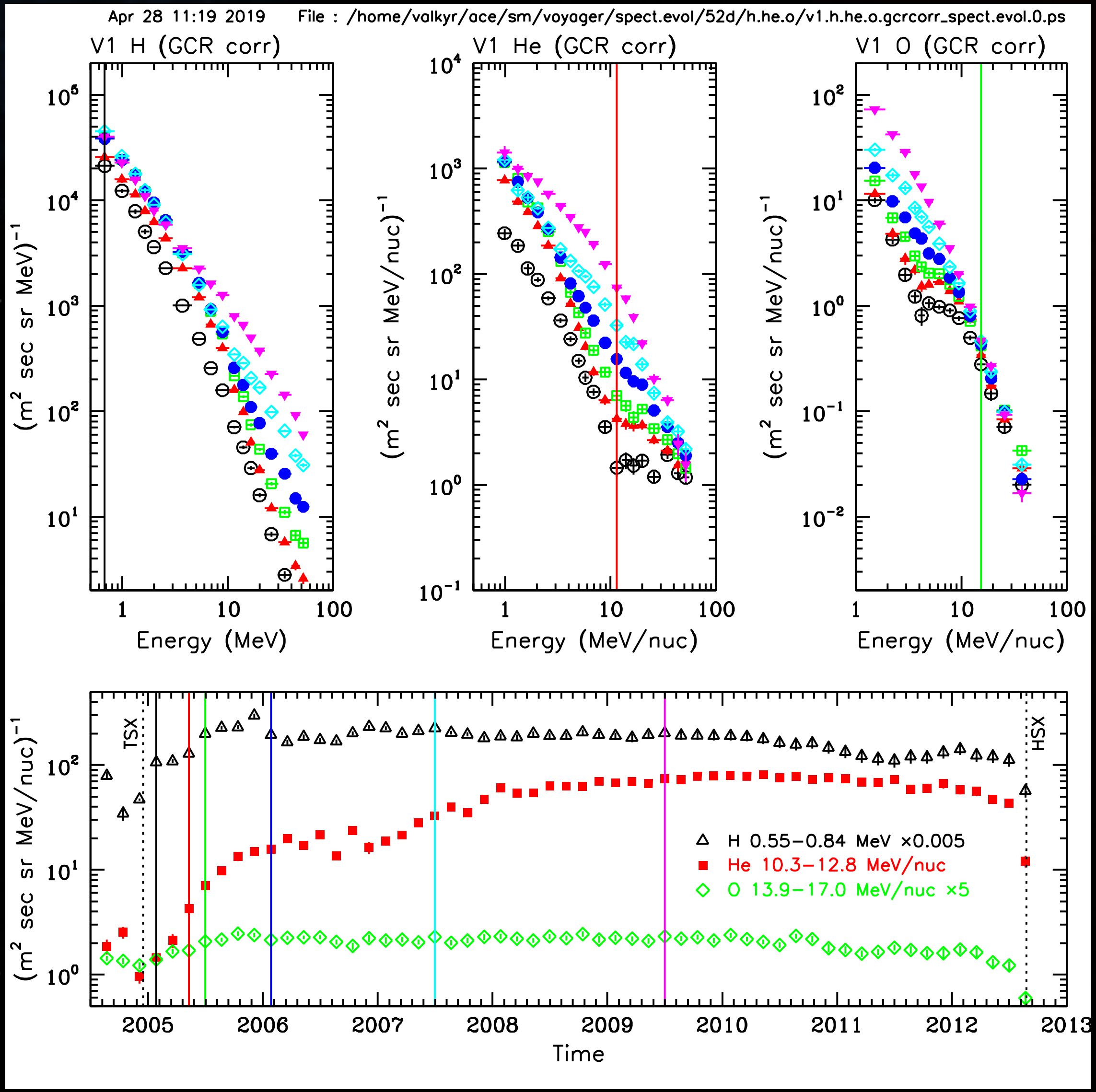
How and where the Anomalous Cosmic Rays (ACRs) accelerated?





Old paradigm: PUIs are accelerated at the Termination Shock to ACRs (MeV energies).
NOT seen at Voyager 1 and 2

ACRs intensities evolve throughout the Heliosheath

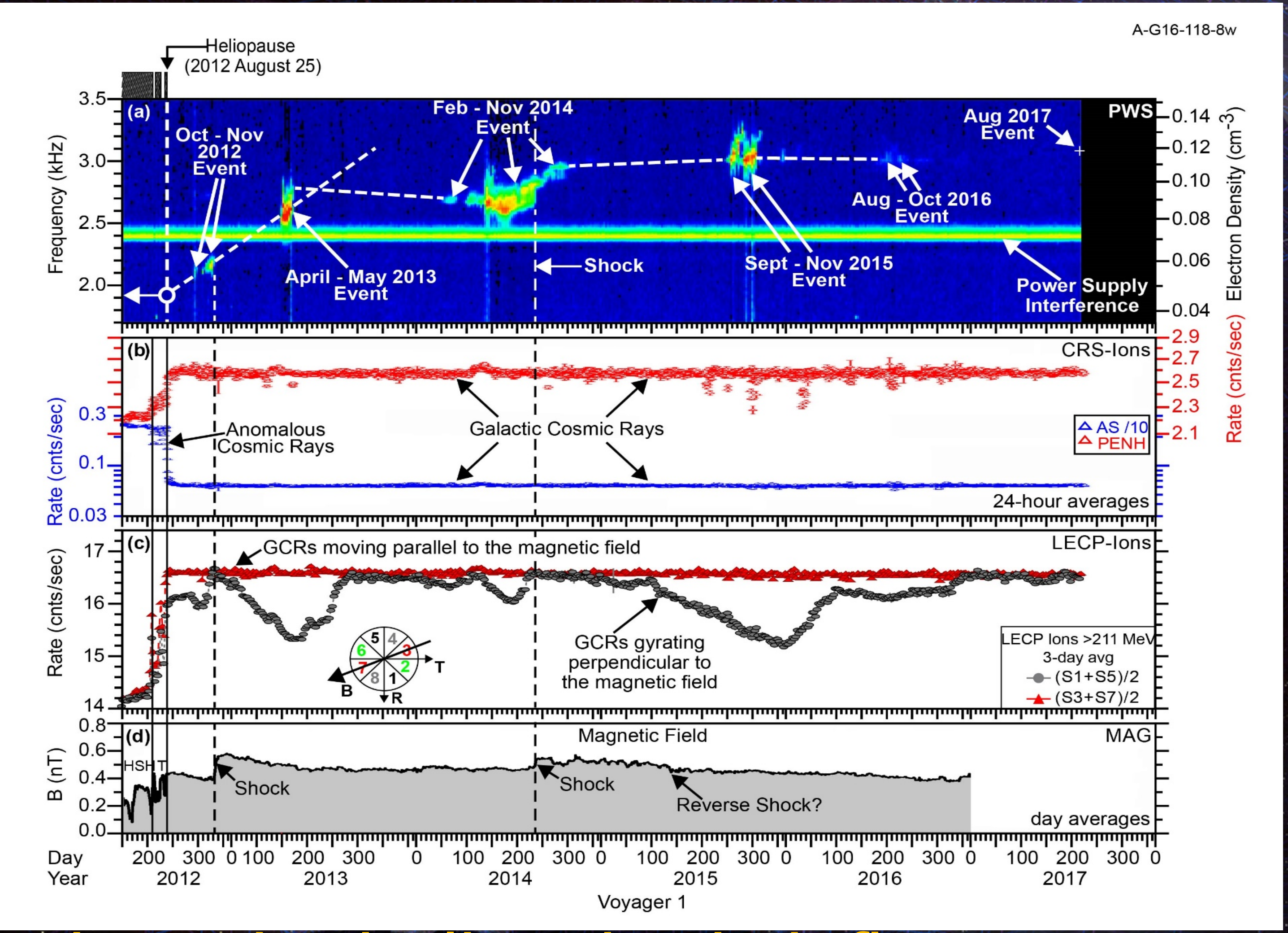


The intensity peaked just before the Heliopause

Broad Implications for acceleration of particles in space physics and astrophysics

Science Question C:
How does the heliosphere interacts with Interstellar Medium?

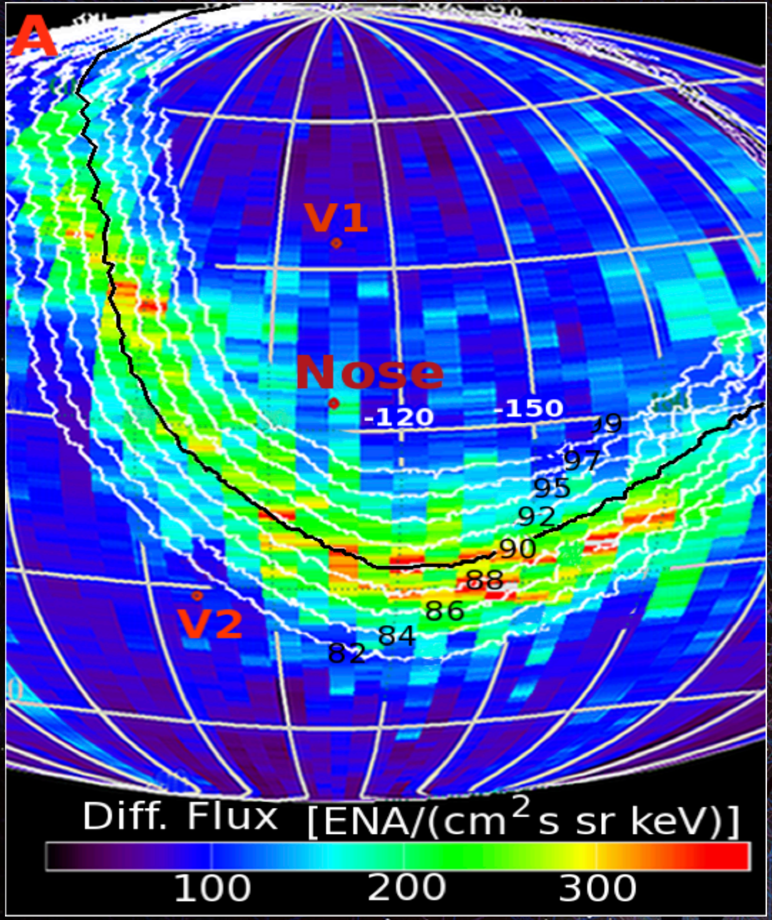
The medium ahead of the Heliosphere in the ISM is disturbed by the Heliosphere



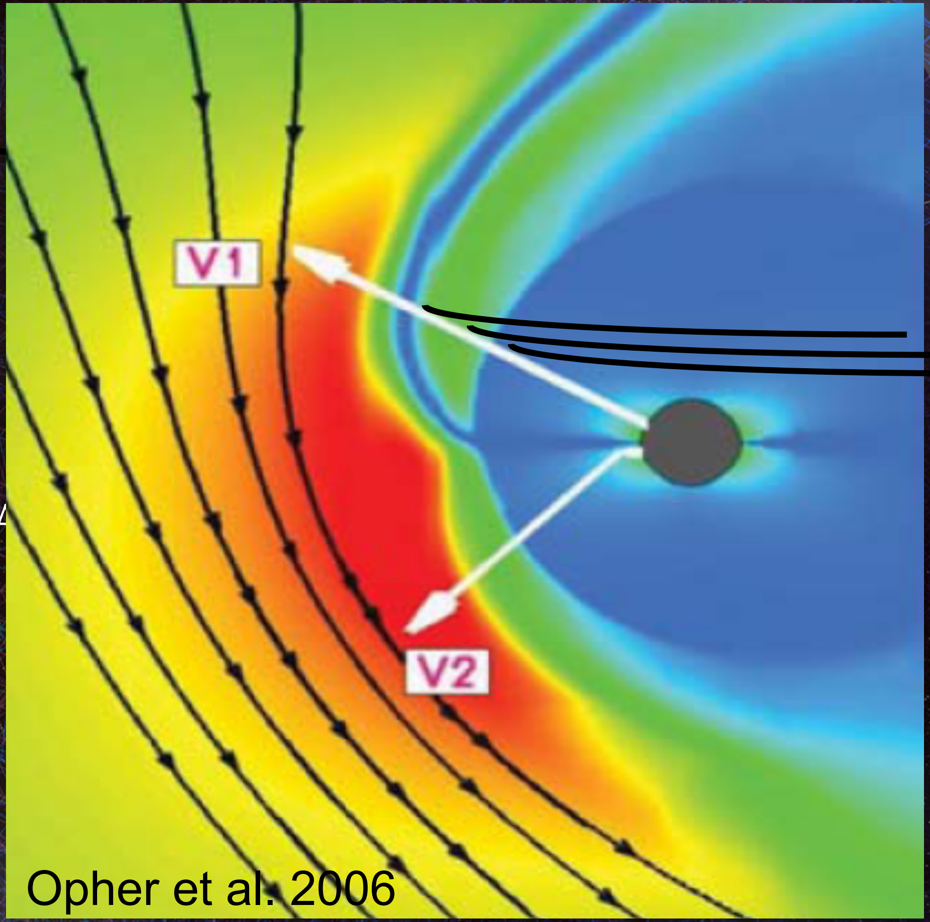
Gurnett et al.

How far does the heliospheric influence extends into the ISM?

Need to understand the draping of Interstellar Magnetic Field a round the heliosphere

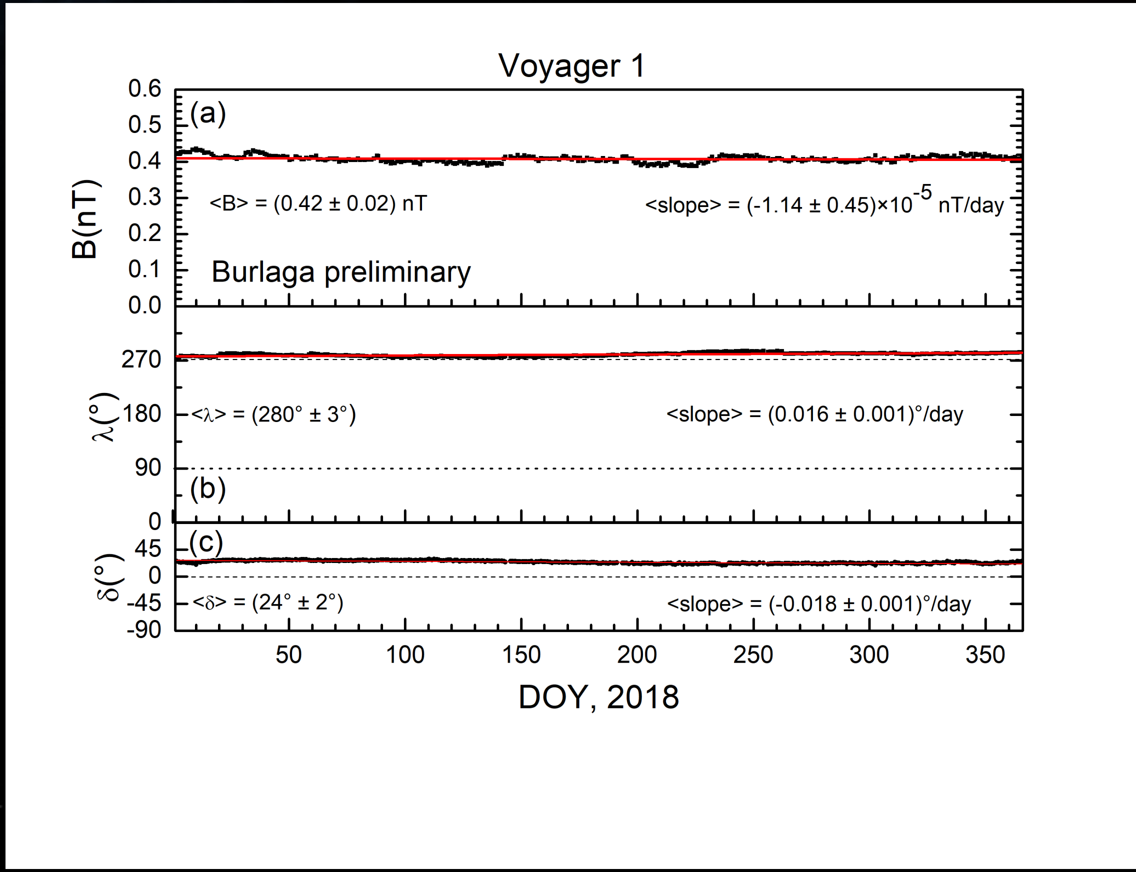


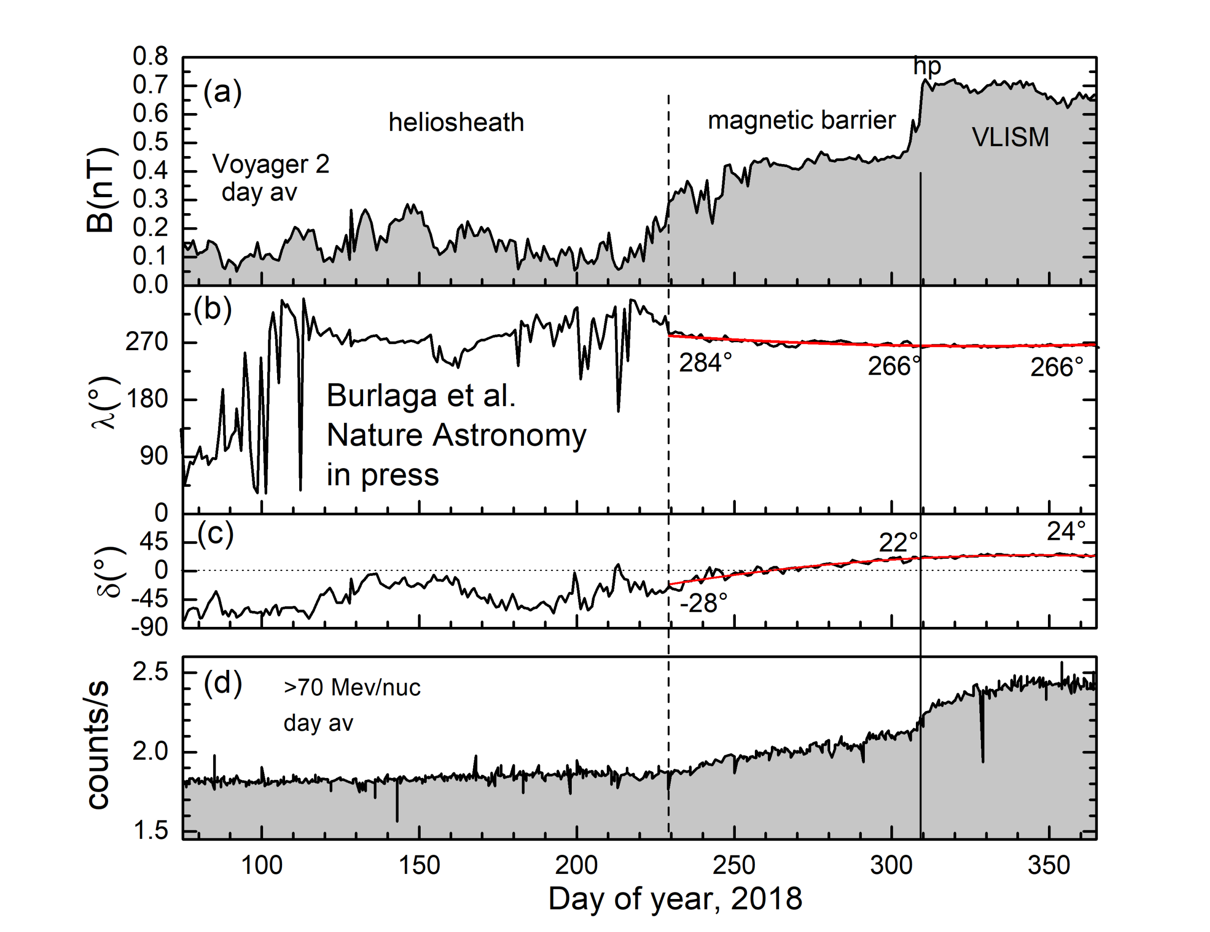
McComas et al. 2009



Models predicted a dramatic rotation of the magnetic field direction upstream of the Heliopause

The Interstellar Magnetic Field is Solar Ahead of the Heliosphere at Voyager 1 and 2

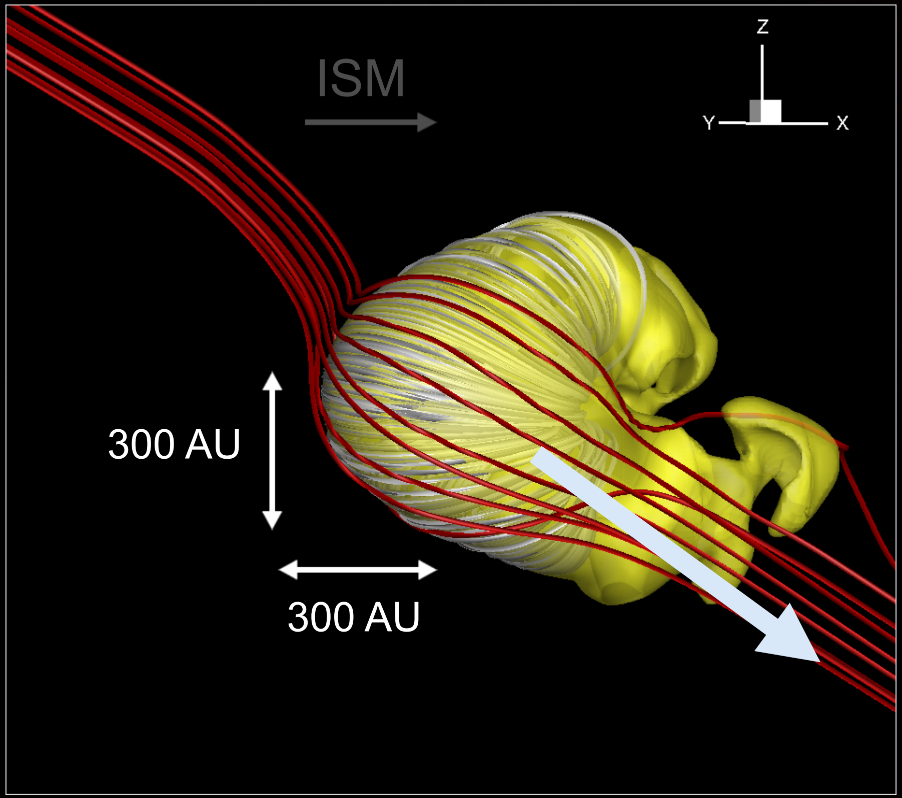




Voyager 1

Voyager 2

Proposed Trajectory of Interstellar Probe: Through the Flanks

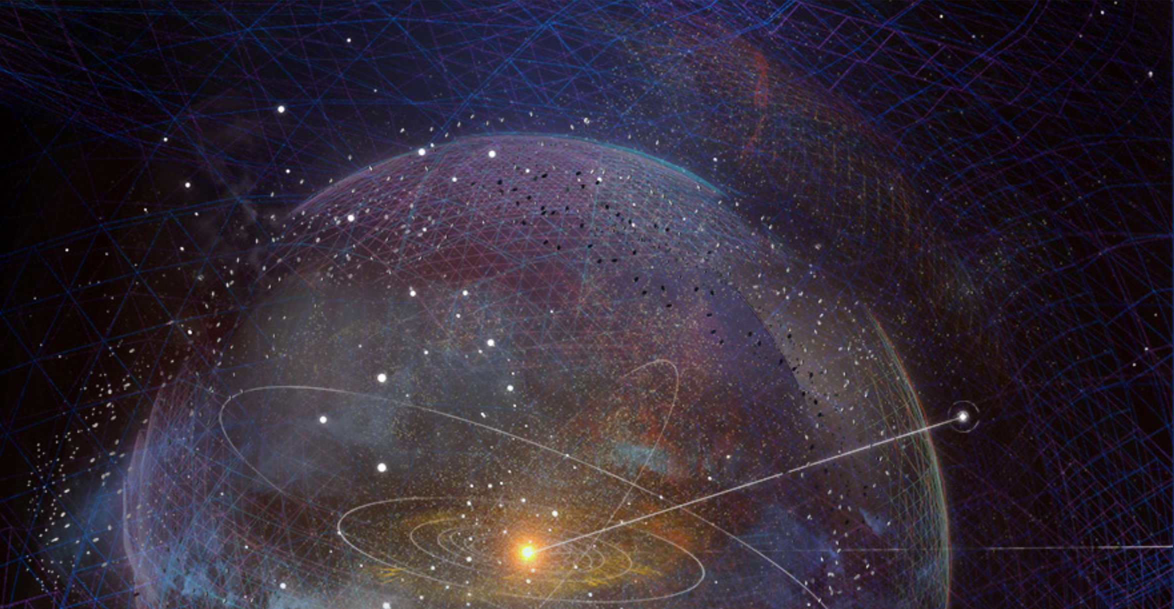


Science to be gain:

- Acceleration of ACRs
- New region in space: flows and particles; evolution of PUIs from “cradle to grave”
- Draping of BISM

Voyager spacecrafts lack instrumentation capable to measure the weak magnetic fields in the heliosheath and PUIs

Need to revisit this region with Interstellar Probe

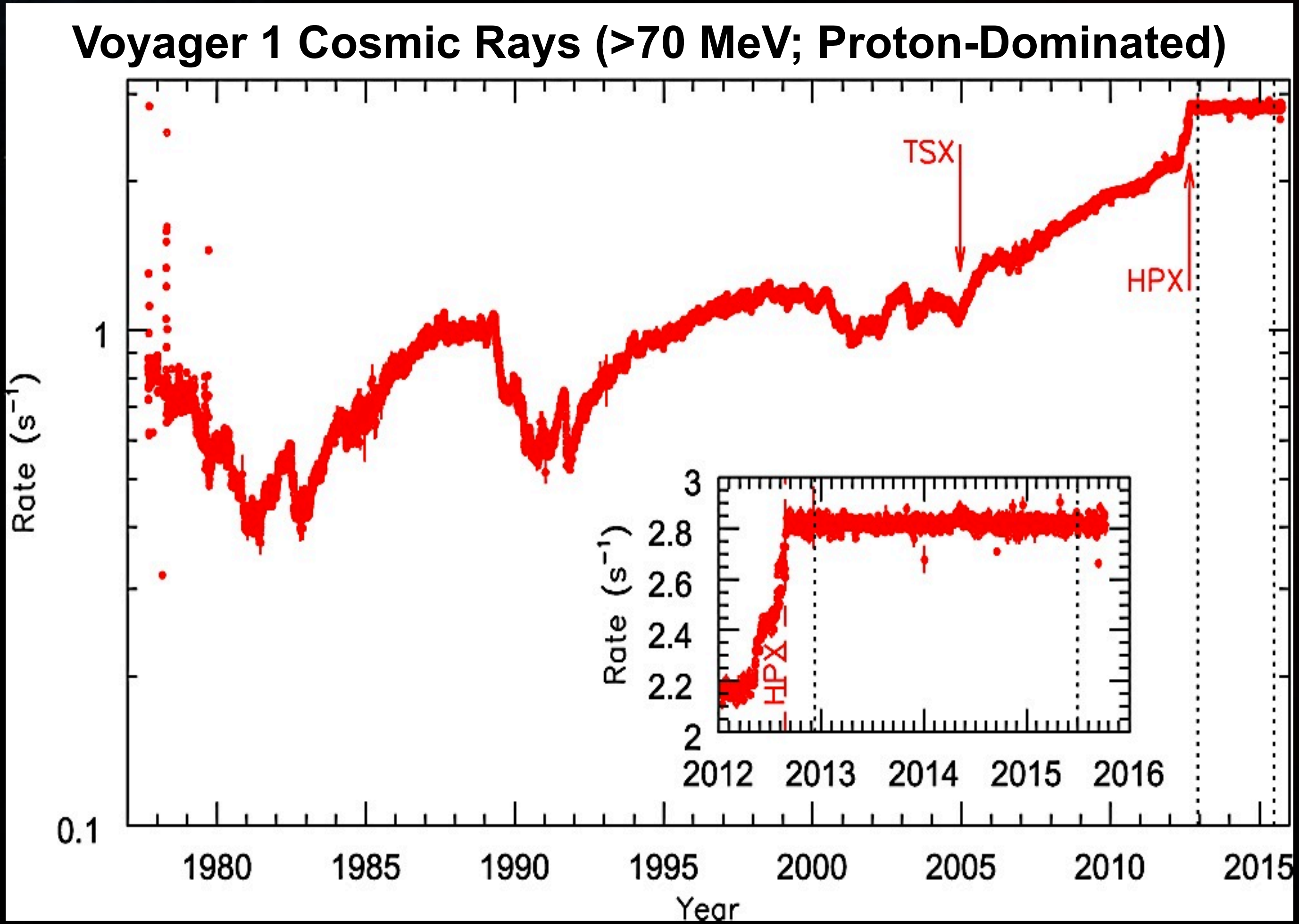


Solar Transients through the Heliosphere and Beyond: Opportunities for Interstellar Probe

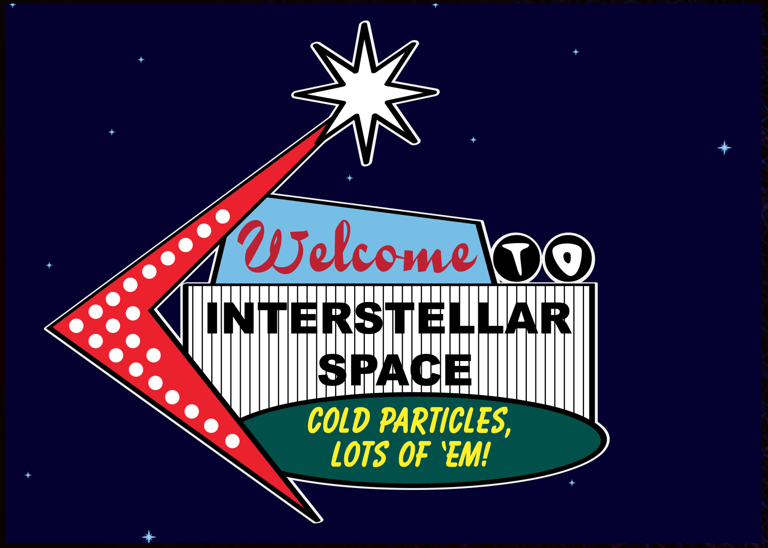
Jamie Sue Rankin

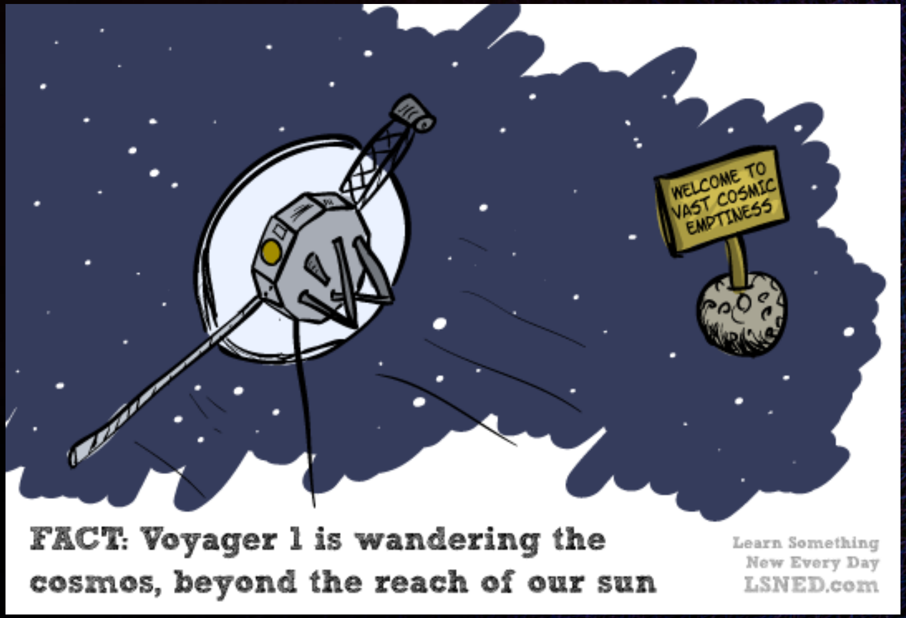
Interstellar Probe Webinar
June 11, 2020

Welcome to Interstellar Space



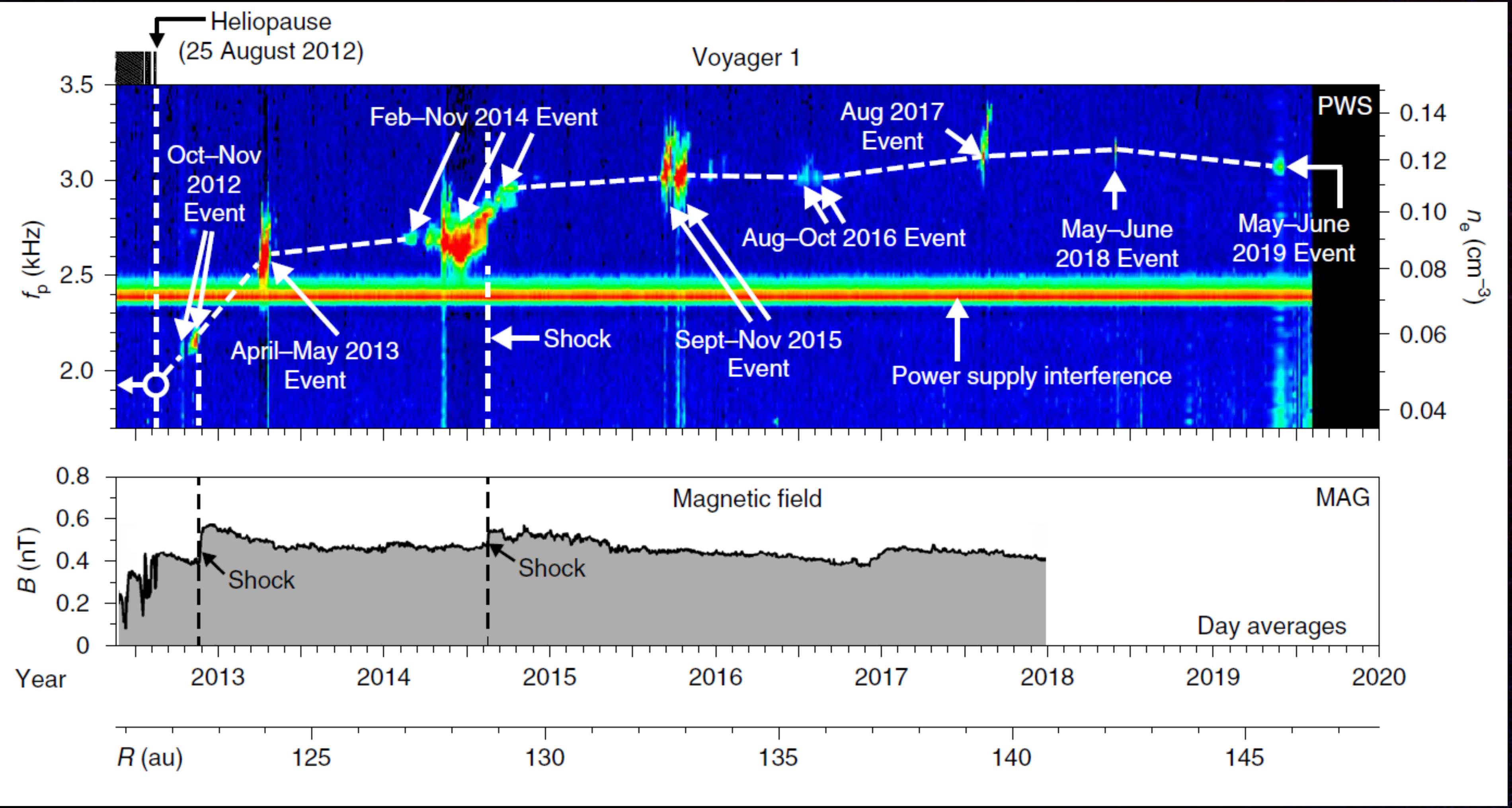
Cummings et al. 2016, ApJ, 831:18





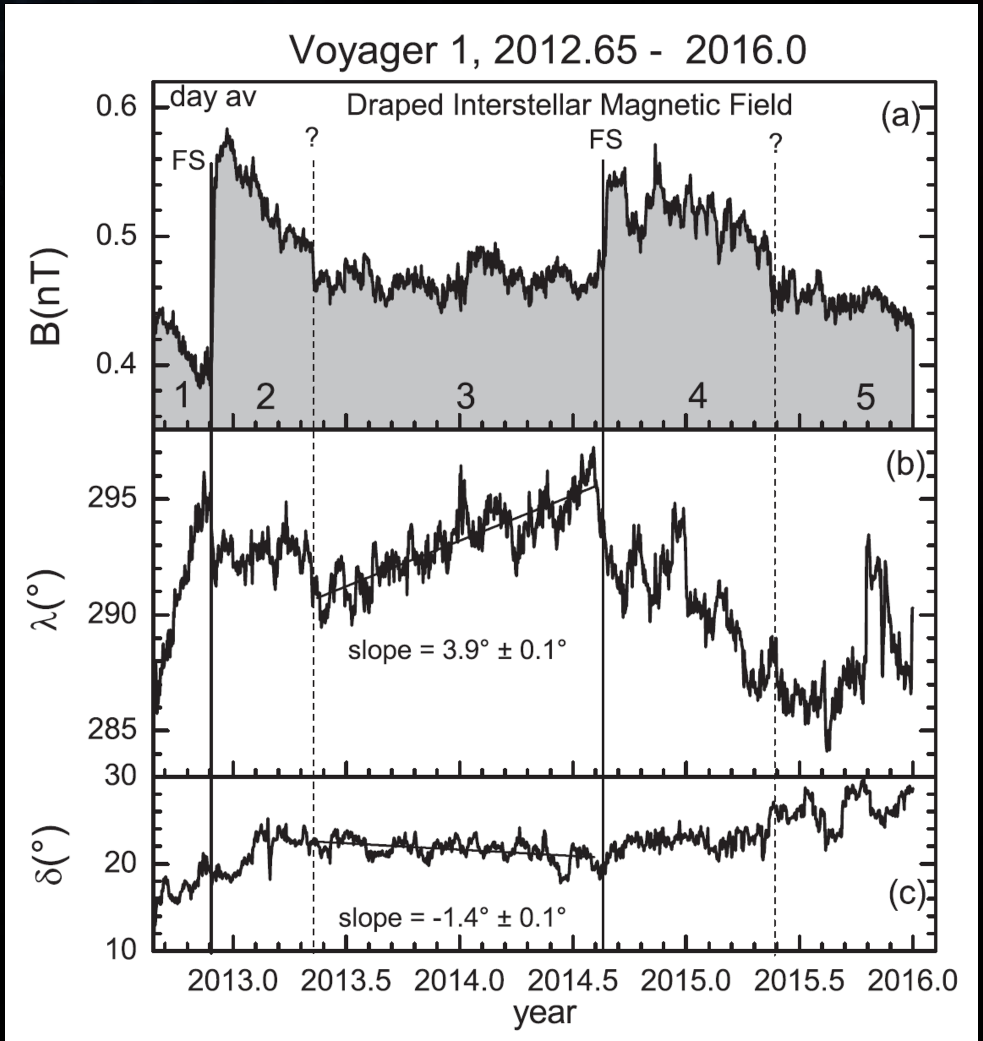
AKA: the "Very Local Interstellar Medium" (VLISM)

Electron Plasma Oscillations (Voyager 1)



Gurnett & Kurth 2019, NatAst 3:1024

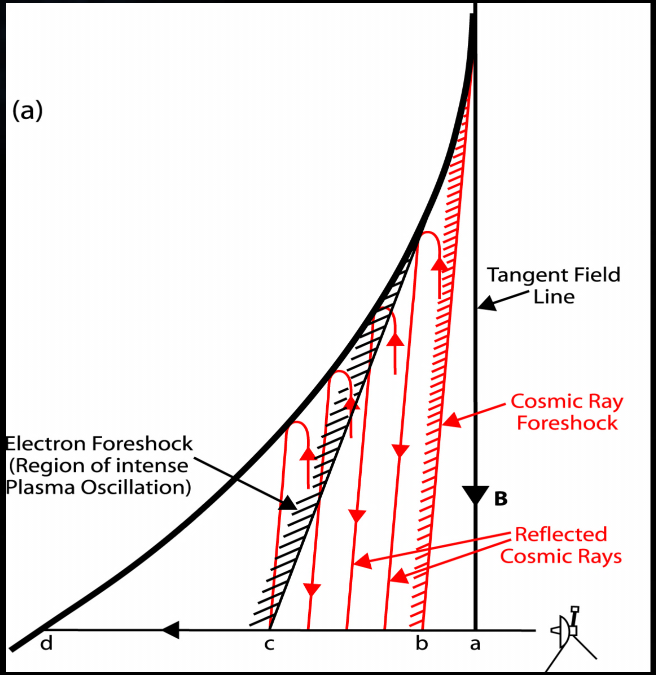
Transient-Perturbed Magnetic Field (Voyager 1)

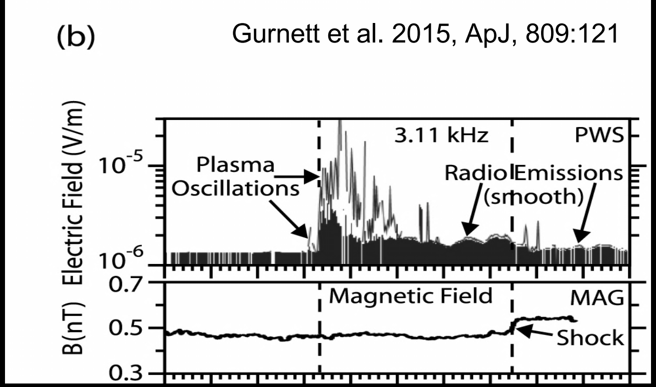


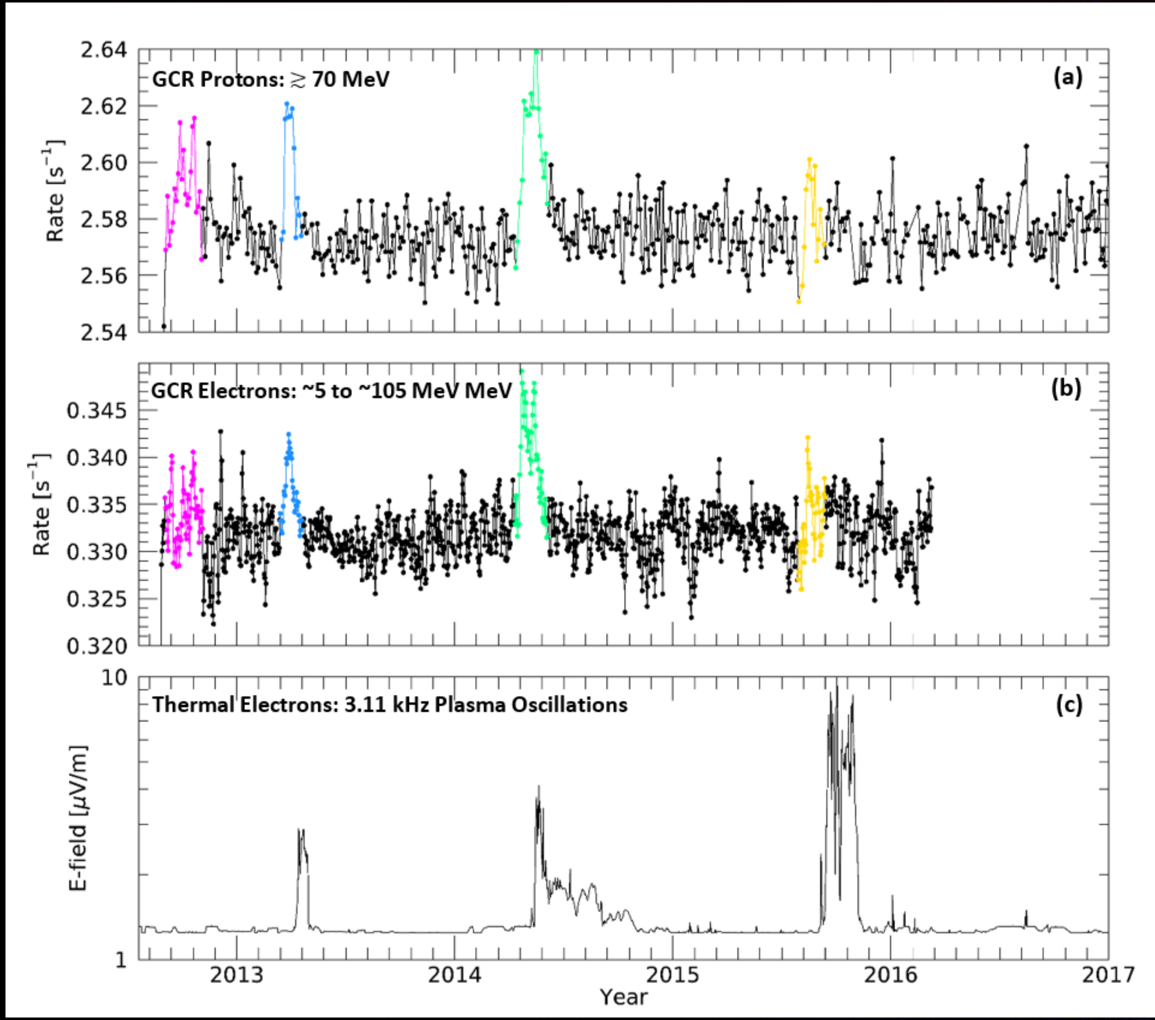
Burlaga & Ness 2016, ApJ, 829:134

- "Shocks"
  - weak, subcritical, laminar, resistive, and quasi-perpendicular.
  - 10^7 km thick
    - →1,000 x's thicker than 1-AU counterparts
  - small jump ratios
    - → ~1.4 in 2012; ~1.1 in 2014
  - Ramp takes ~5 days
    - → ~minutes near 1 AU
  - Likely collisional

Shock-Energized Particles Beyond the Heliopause

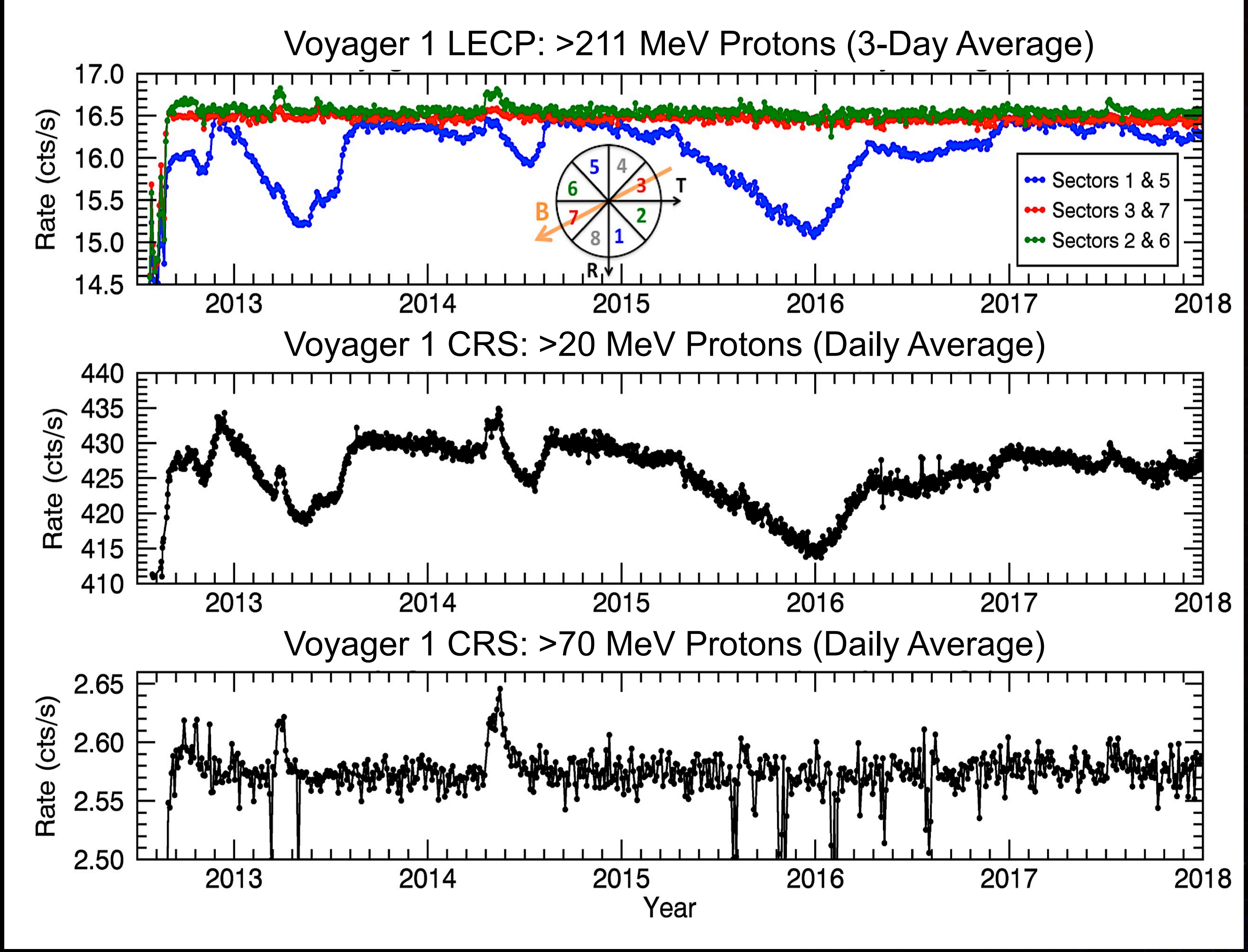






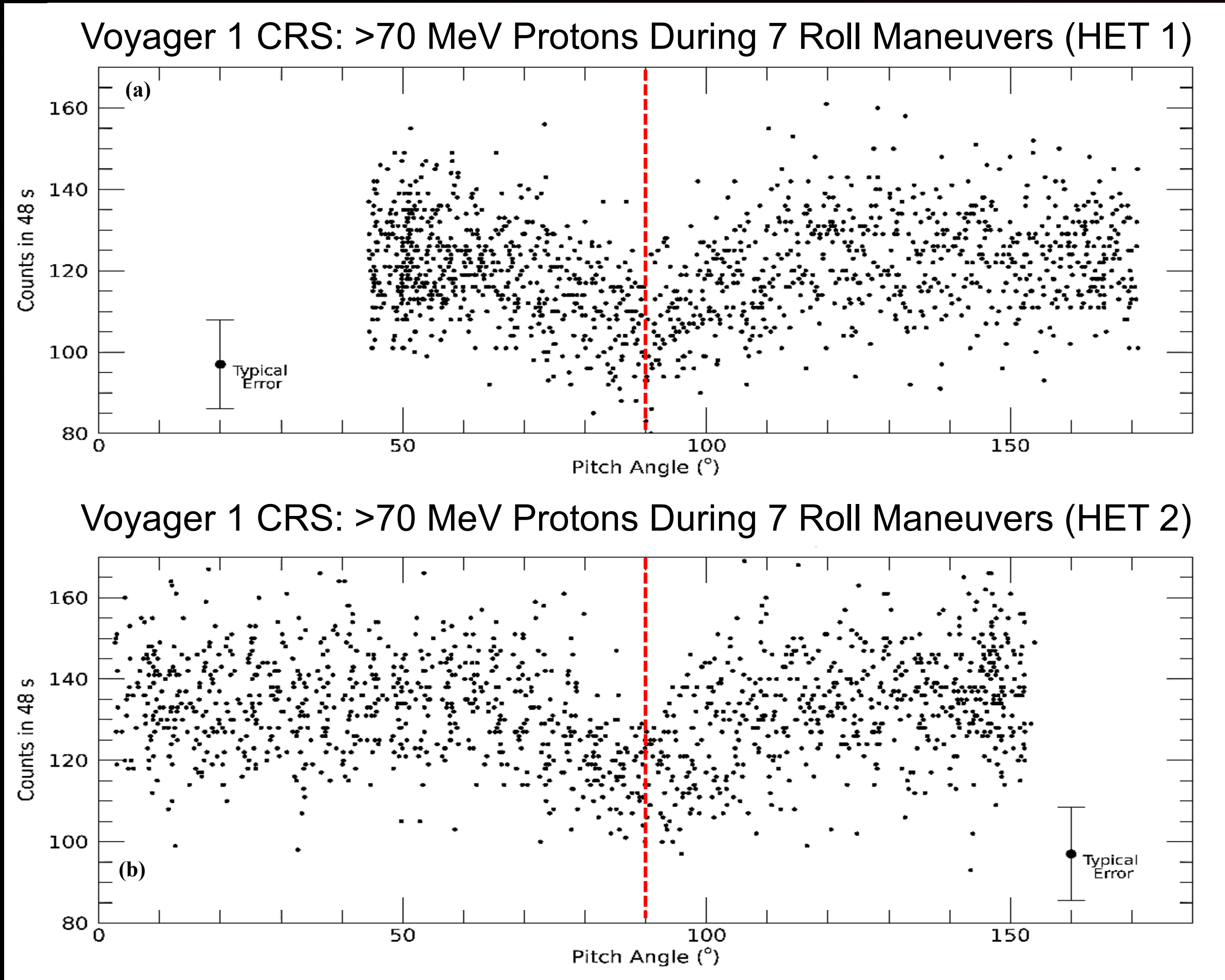
Rankin et al. 2020, ApJ 895:103

Galactic Cosmic Ray Anisotropies (Voyager 1)



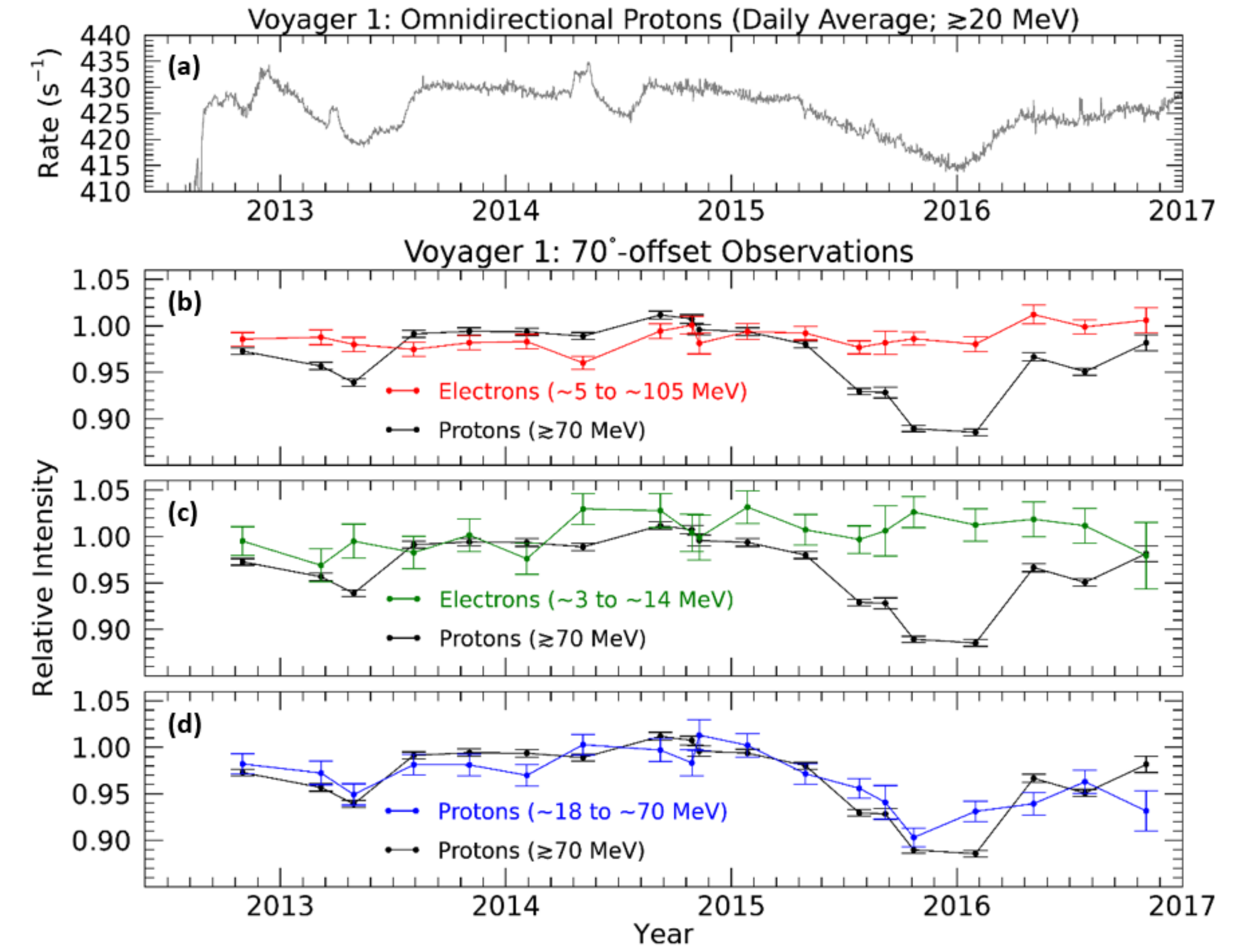
Rankin et. 2019, ApJ 873:46

Anisotropies: Centered on 90° Pitch Angle (Voyager 1)



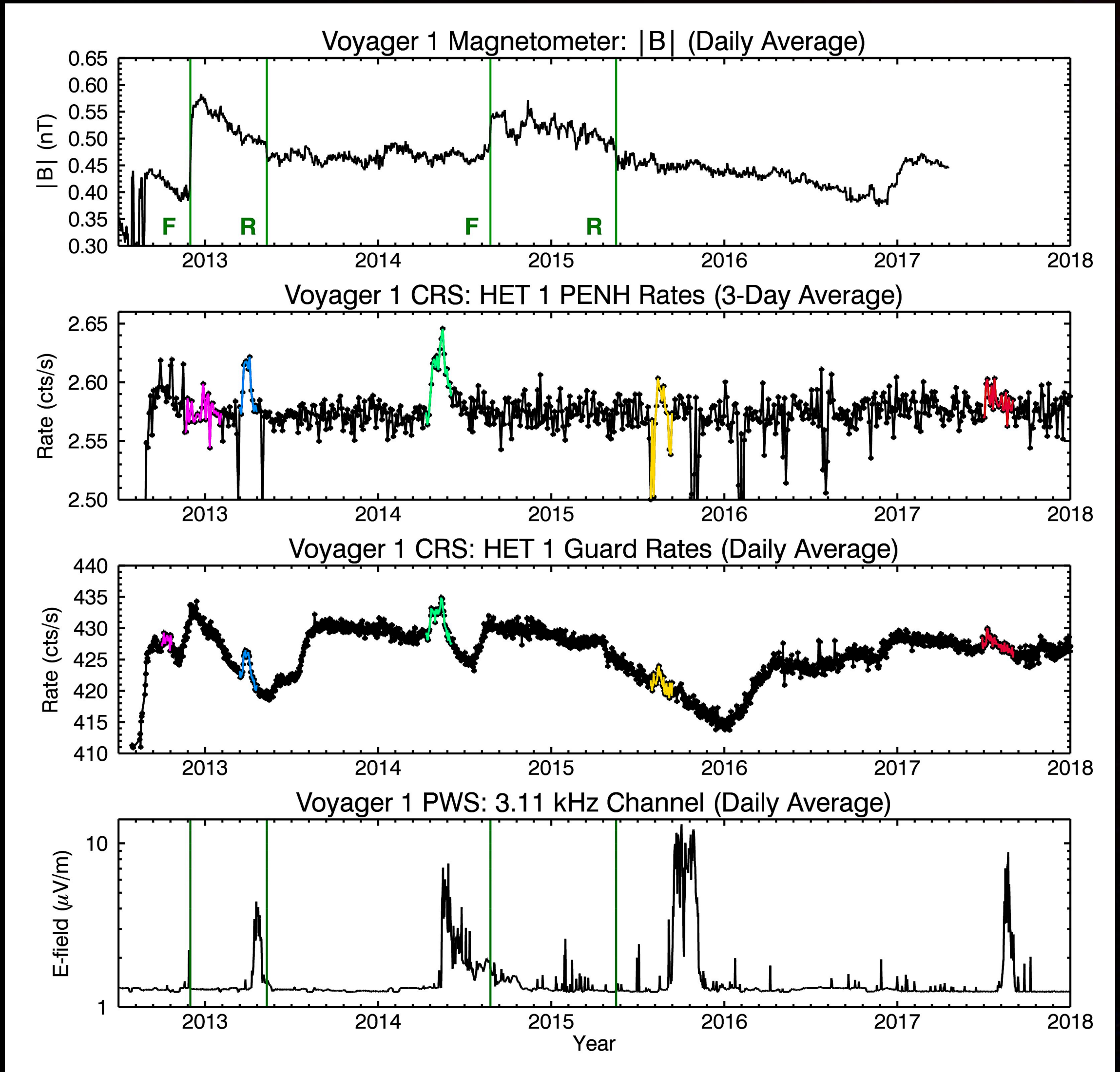
Rankin et al. 2019, ApJ 873:46

Anisotropies: Species-Dependent (Voyager 1)



Rankin et al. 2020, ApJ 895:103

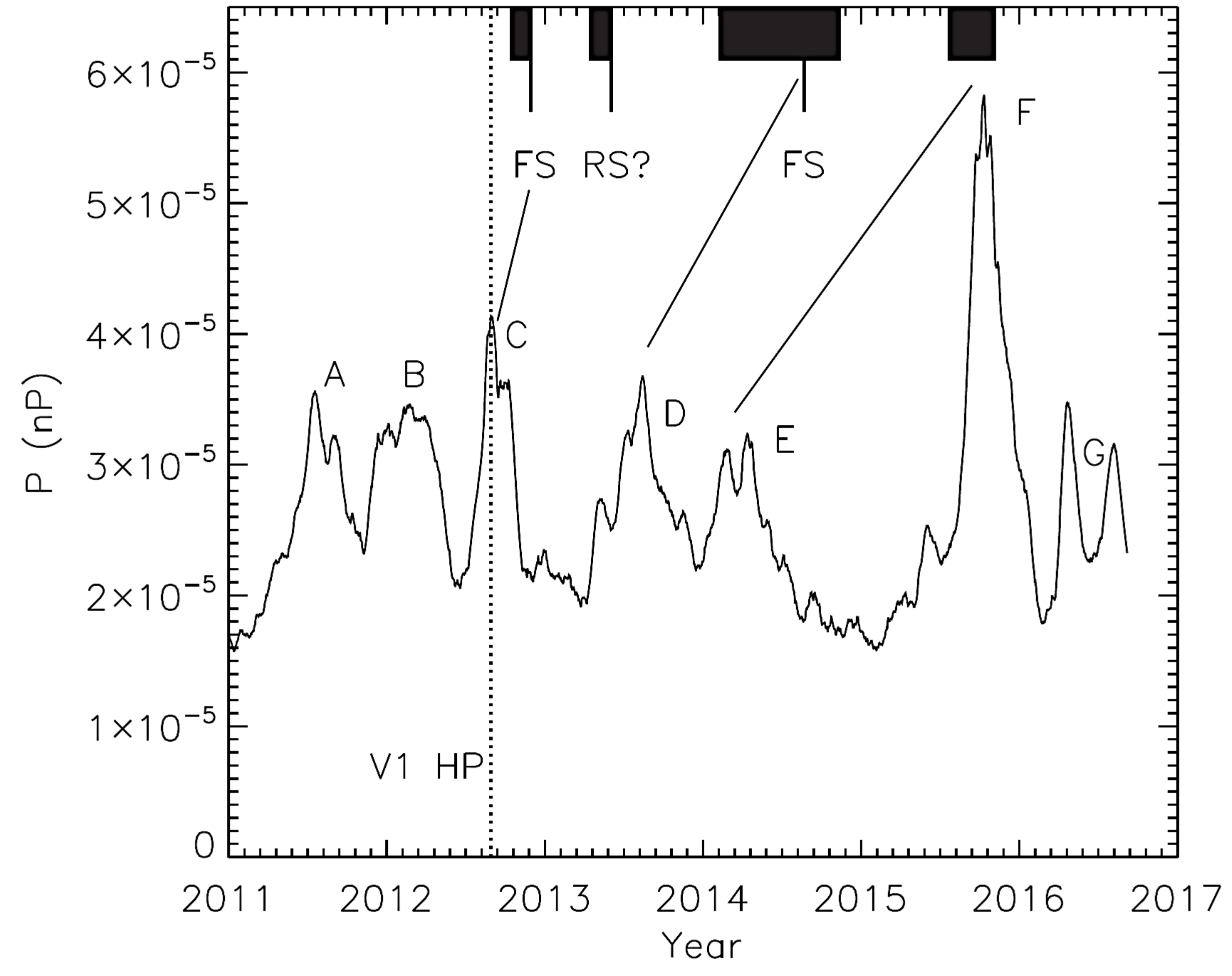
Transients in the Very Local Interstellar Medium (VLISM)



Rankin 2018, Caltech Thesis

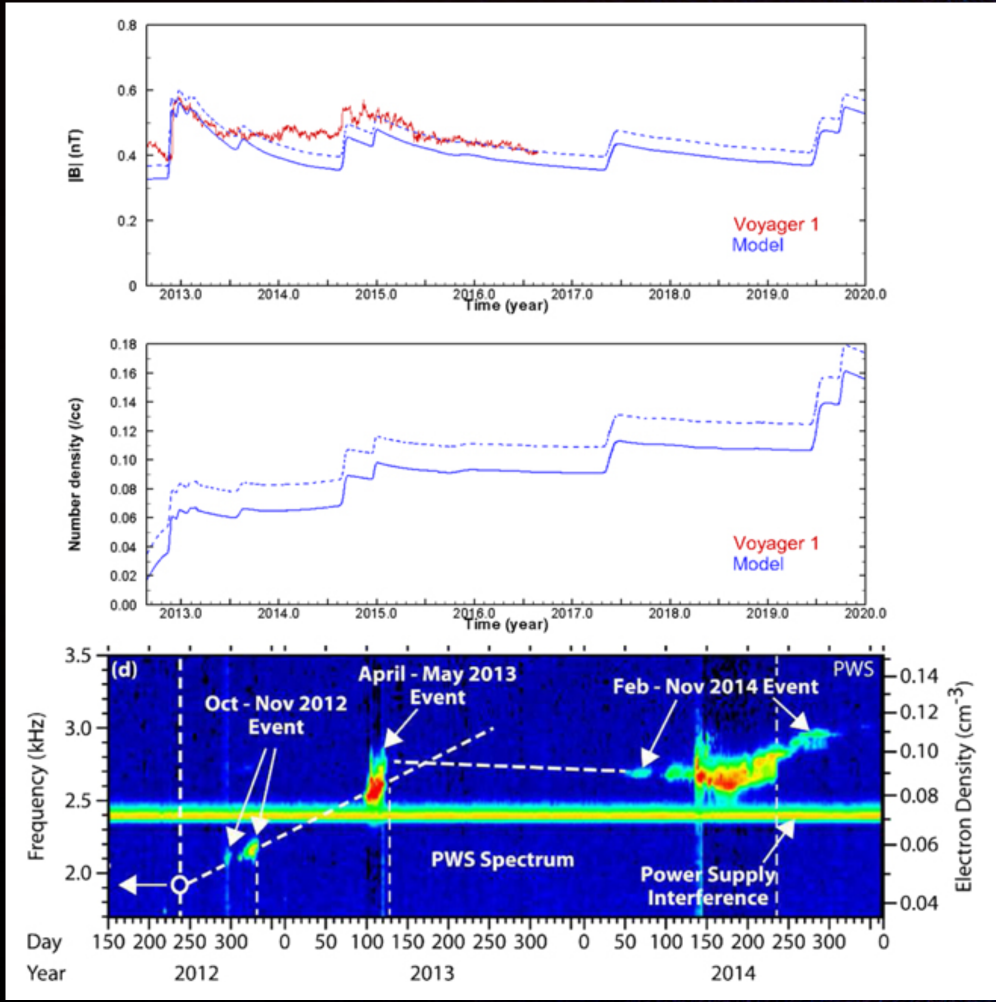
Pressure Pulses: Drivers of Interstellar Transients

Transients Observed by Voyager 2 in the Heliosheath



Richardson et al. 2017, ApJ 834:190

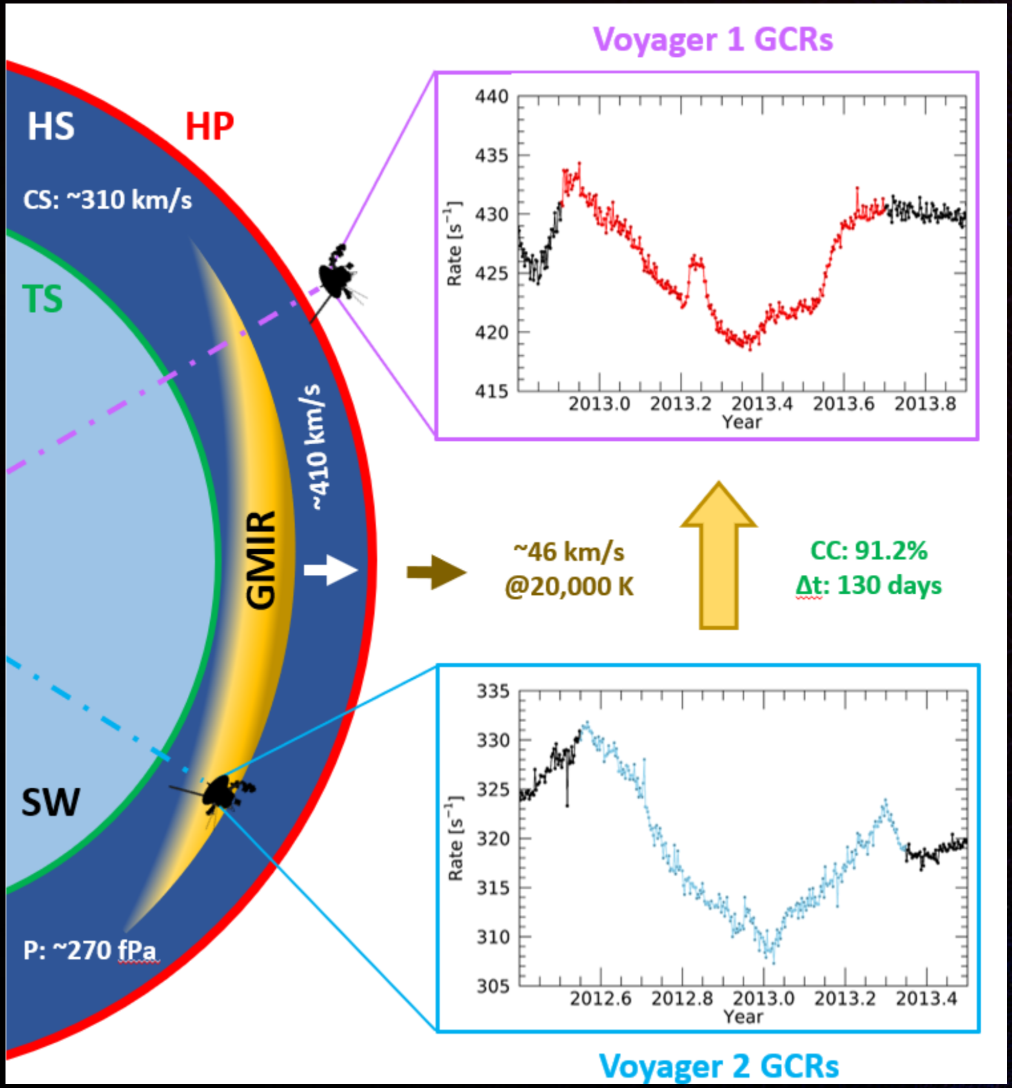
Solar-Wind Data-Driven Model



Kim et al. 2017, ApJ 843:2

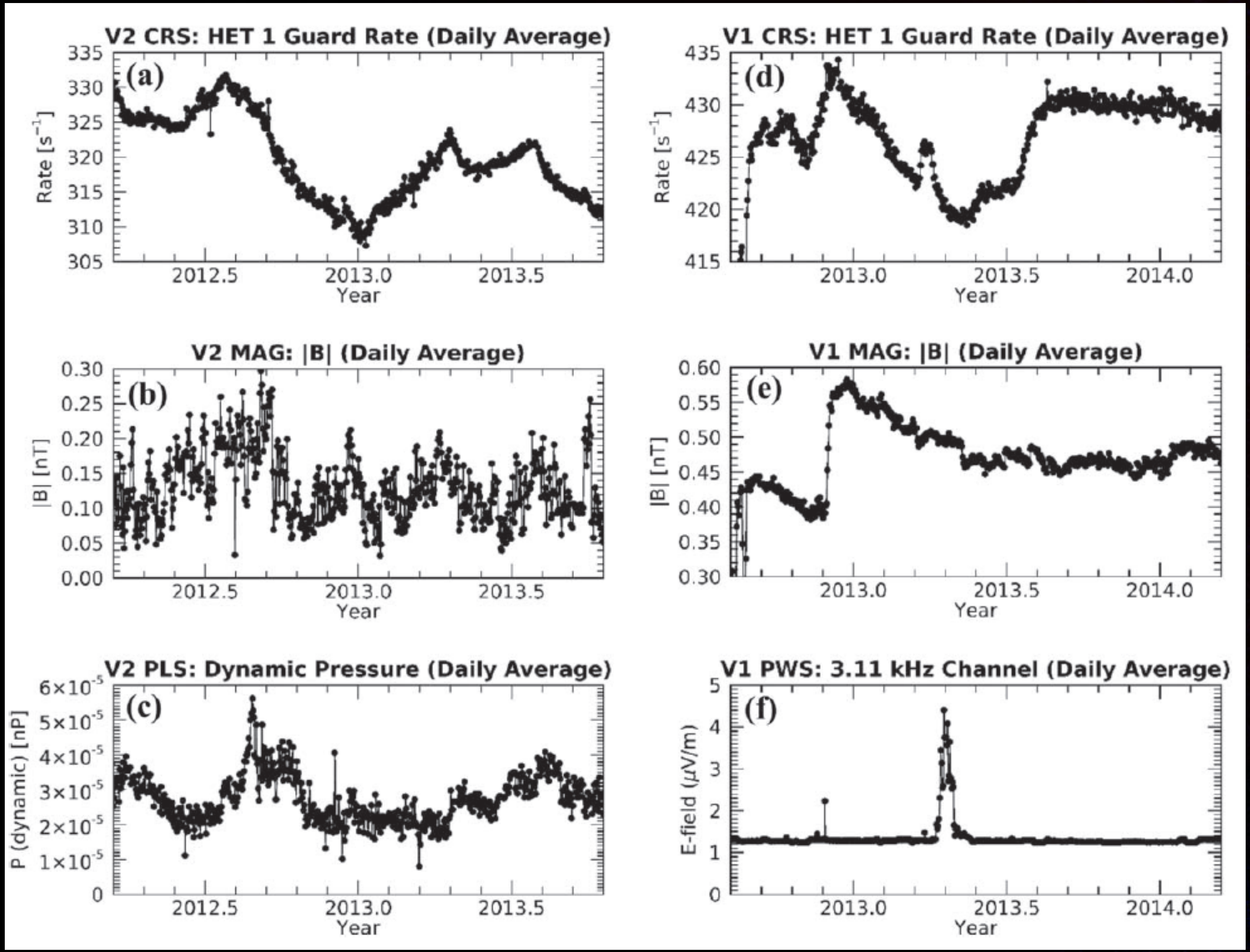
Heliosheath Pressure Derived from a Voyager 2 to Voyager 1 Transient

- **Very Local Interstellar Medium**
  - T_{VLISM} = 20,000 K
  - v_{VLISM} ~46 km/s
- **Heliosheath**
  - v_{GMIR} ~ 410 km/s
  - cs_{HS} ~ 310 km/s
  - P_{total} ~270 fPa
- **P_{Total} ~ 270 fpa**
  - **Magnetic, thermal, dynamic: ~15%**
  - **IBEX PUI: ~45%**
  - **ACR/GCR: ~22%**
  - **Remaining: ~18%**



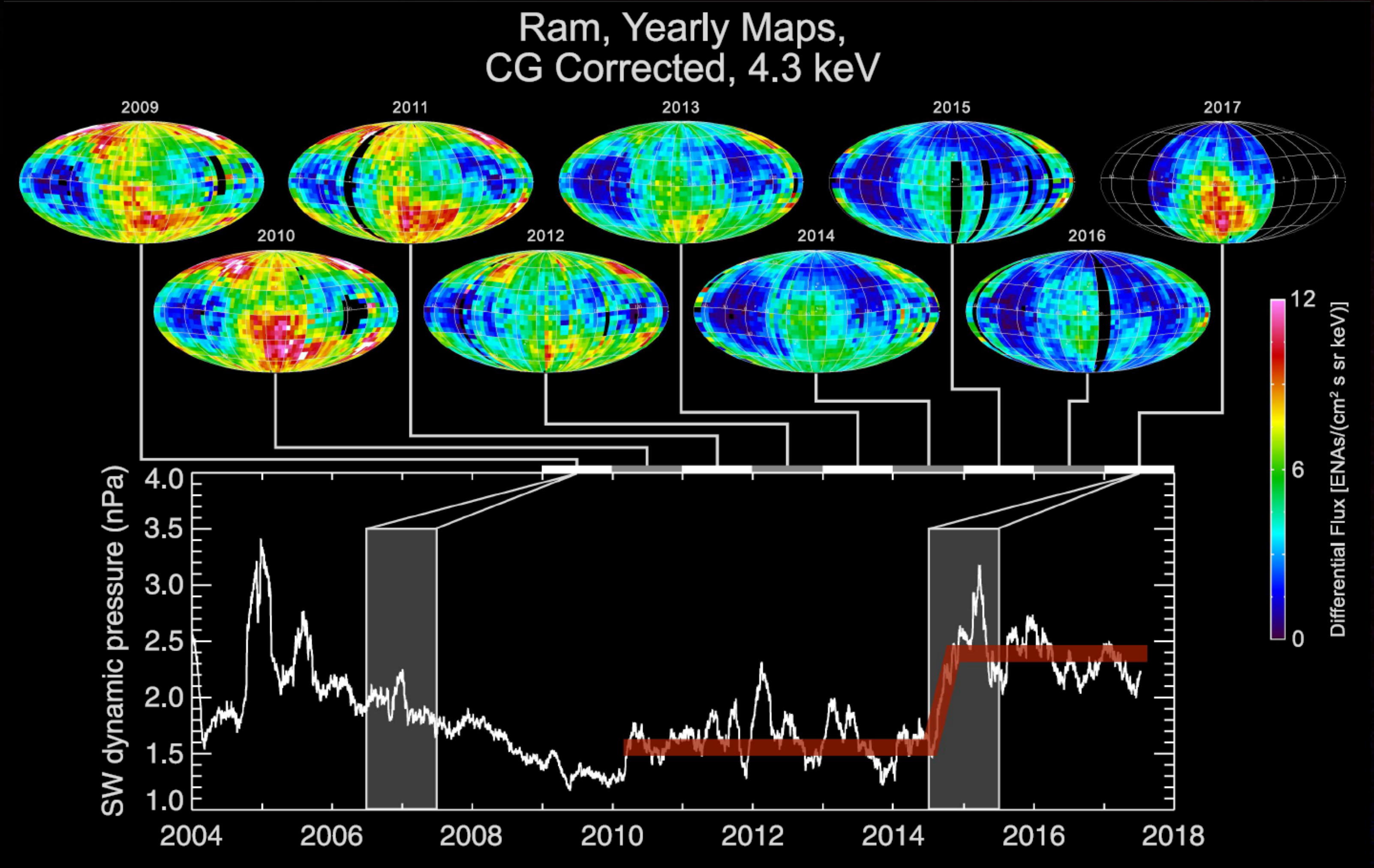
Rankin et al. 2019, ApJ 883:101

Heliosheath vs. Very Local Interstellar Medium



Rankin et al. 2019, ApJ 883:101

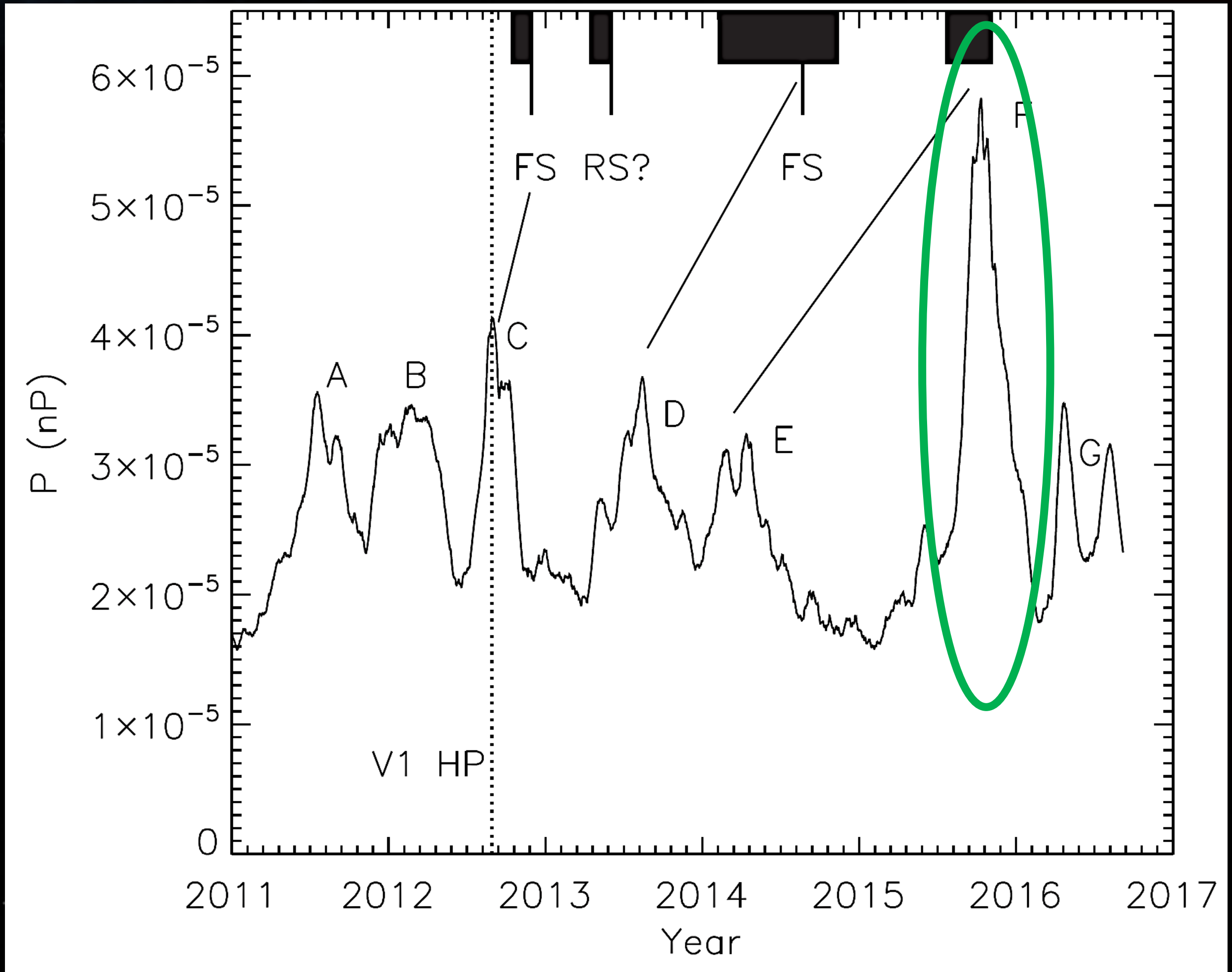
“Heliosphere Responds to Large Solar Wind Intensification: Decisive Observations from IBEX”



McComas et al. 2018, ApJL 856:L10

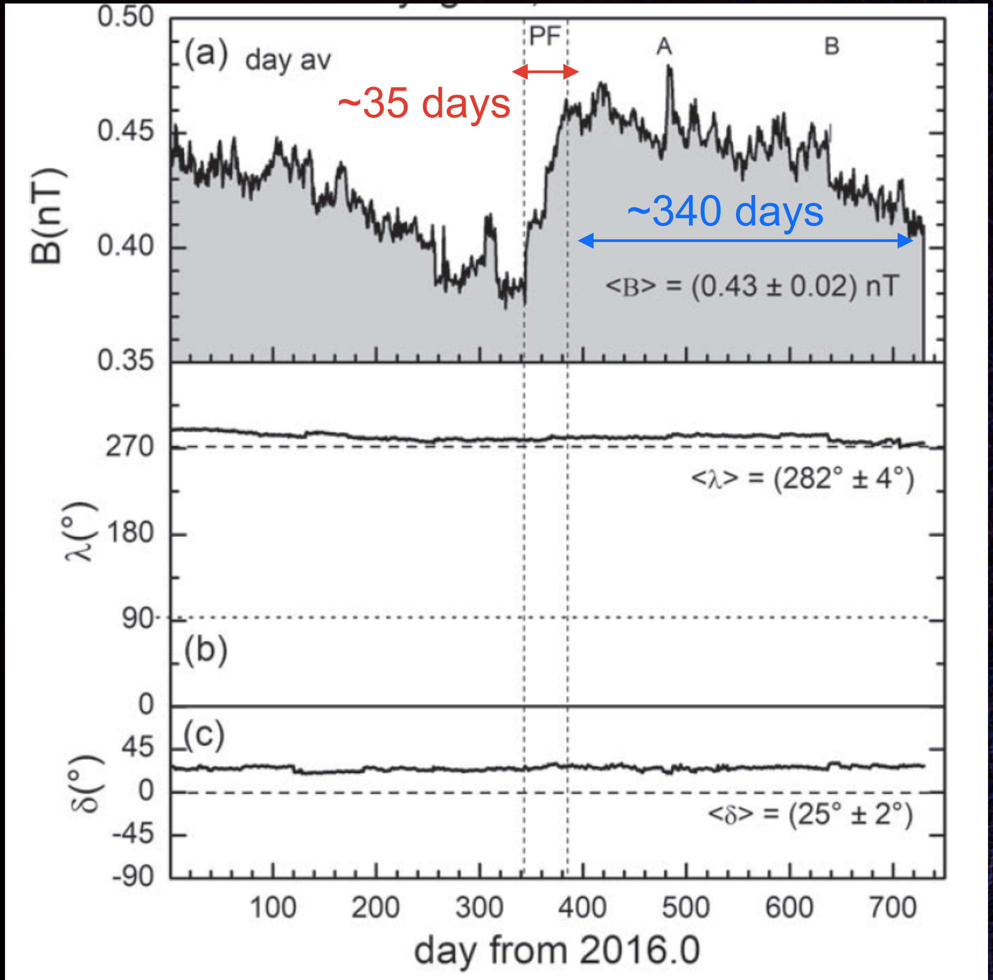
Massive Pressure Fronts Arrive at Voyager 2 and Voyager 1

Voyager 2 Plasma Observations in the Heliosheath



Richardson et al. 2017, ApJ 834:190

Voyager 1 Magnetic Field Observations in the VLISM



Burlaga et al. 2019, ApJ 877:31

A Selection of Open Questions

- **How far beyond the heliopause can the effects of transients from the sun be observed?**
- Why are the galactic cosmic ray perturbations isotropic in the heliosheath but anisotropic in the very local interstellar medium?
- Why is the pitch angle anisotropy seen in protons but not in electrons?
- How do in-situ observations caused by merged events differ from those caused by large changes in solar wind dynamic pressure?
- What can these events tell us about fundamental physics in the heliosheath and very local interstellar medium?
- What drives particle transport and acceleration beyond the heliopause?
- How do these effects compare to the solar wind?
- How do different particle populations contribute to the total pressure in the heliosheath?
- What are the characteristics of the plasma near and beyond the heliopause?

A Selection of Open Questions

How far into the interstellar medium can these transients be observed?

Why do the cosmic ray electrons behave so differently than the protons?

Why are there anisotropies beyond the heliopause but not in the heliosphere?

What new things can we learn about fundamental physics in the interstellar medium?

Opportunities for Interstellar Probe

- **Monitor space weather beyond the heliopause**
  - Connect to the broader heliophysics fleet
  - Track events from the Sun to the interstellar medium
  - Map the boundaries of the Sun’s material influence
  - Gain perspective on the heliosphere from outside-in
- **Provide in-situ context for global observations**
  - Interstellar Mapping and Acceleration Probe (IMAP)
- **Watch the heliosphere evolve under very different solar conditions**
  - Cosmic ray modulation through the heliosphere
  - Boundary conditions
  - Transient propagation
- **Uncover yet-to-be understood properties of the heliosheath and interstellar medium**
  - → temperature beyond the heliopause
  - → pressures in the heliosheath
  - → plasma and suprathermal particles
  - → electrons

Question and Answer Session

Interstellar Probe Study
Webinar Series

Imaging the Heliospheric Boundary

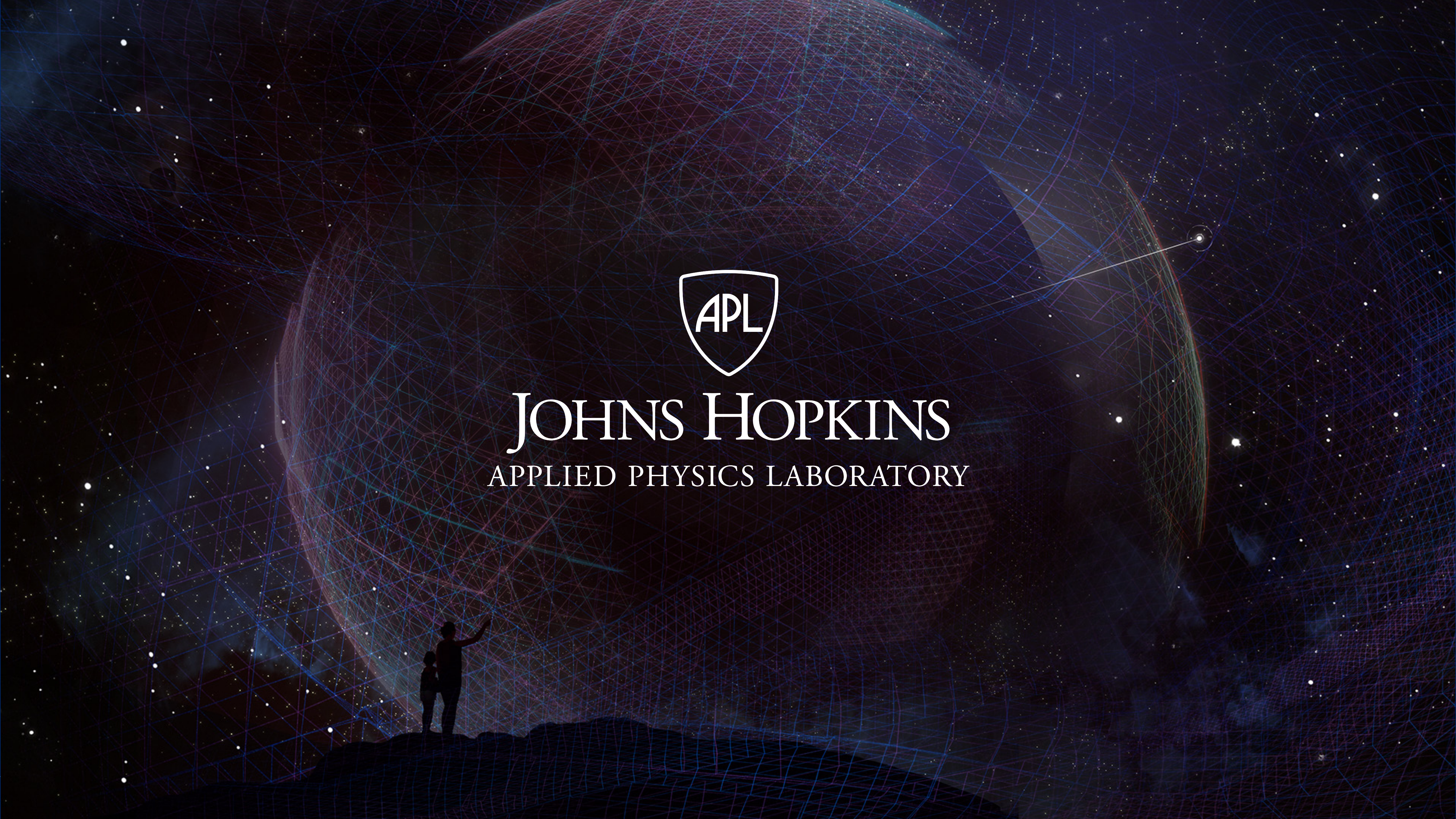
Presenters

- **Pontus Brandt**
  - Project Scientist, Interstellar Probe Study, JHUAPL
- **Kostas Dialynas**
  - Research Associate, Office of Space Research and Technology, Academy of Athens, Greece
- **Eric Quemerais**
  - Director of Research at Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS), Université Versailles Saint-Quentin, France

12:05 PM Thursday, 25 June 2020

Interstellar Probe Study Website

http://interstellarprobe.jhuapl.edu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