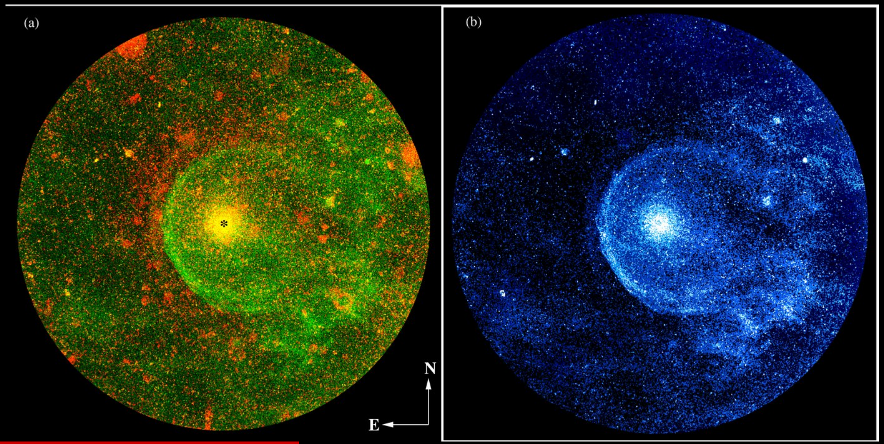
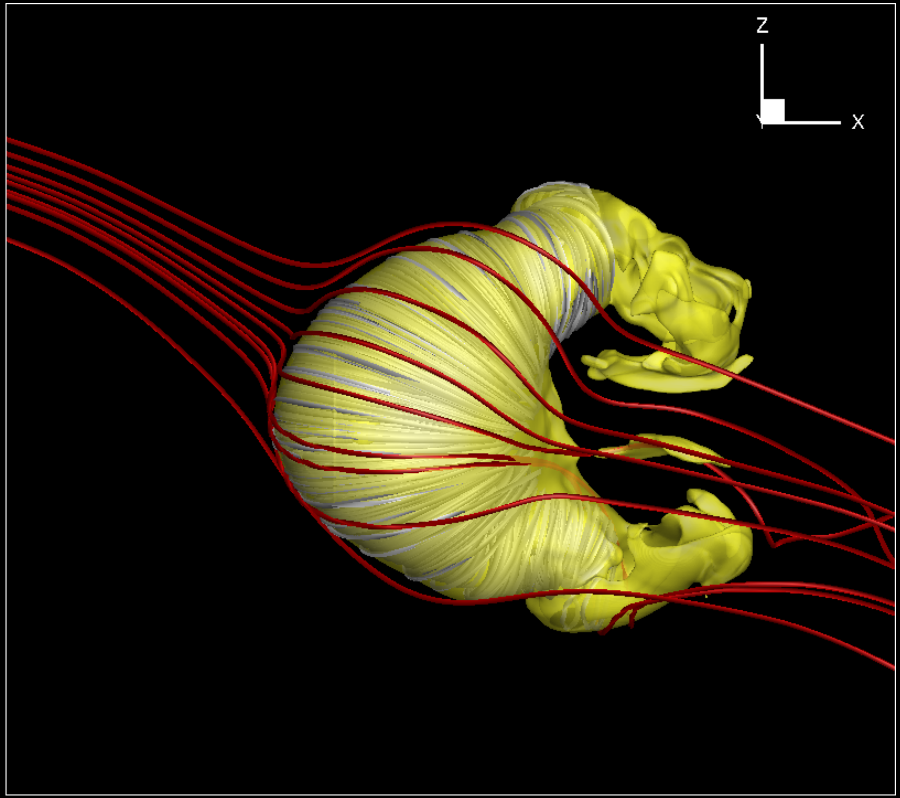
# The heliosphere: Lessons learned from Voyager, Cassini, IBEX about our home in the galaxy



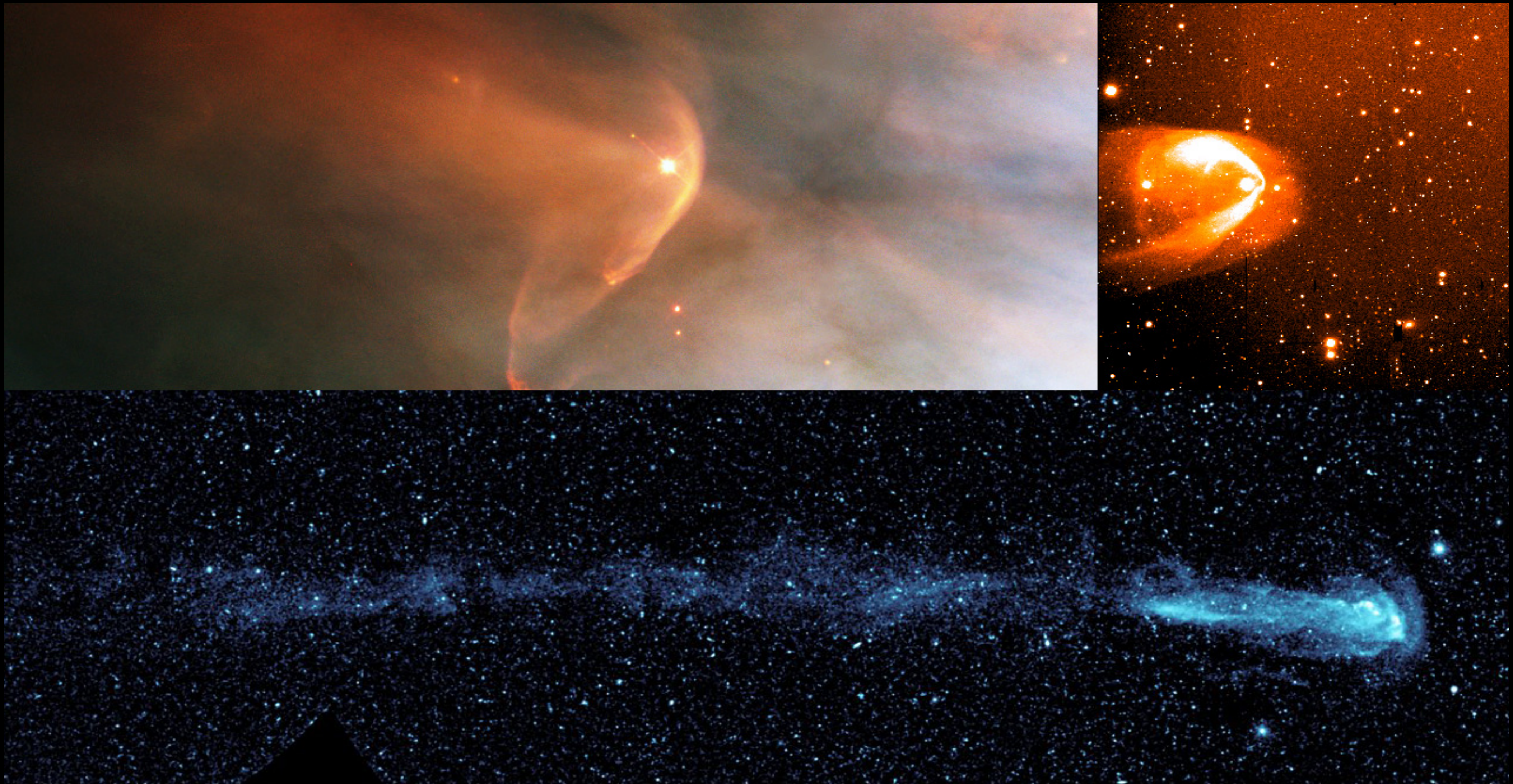




BOSTON UNIVERSITY

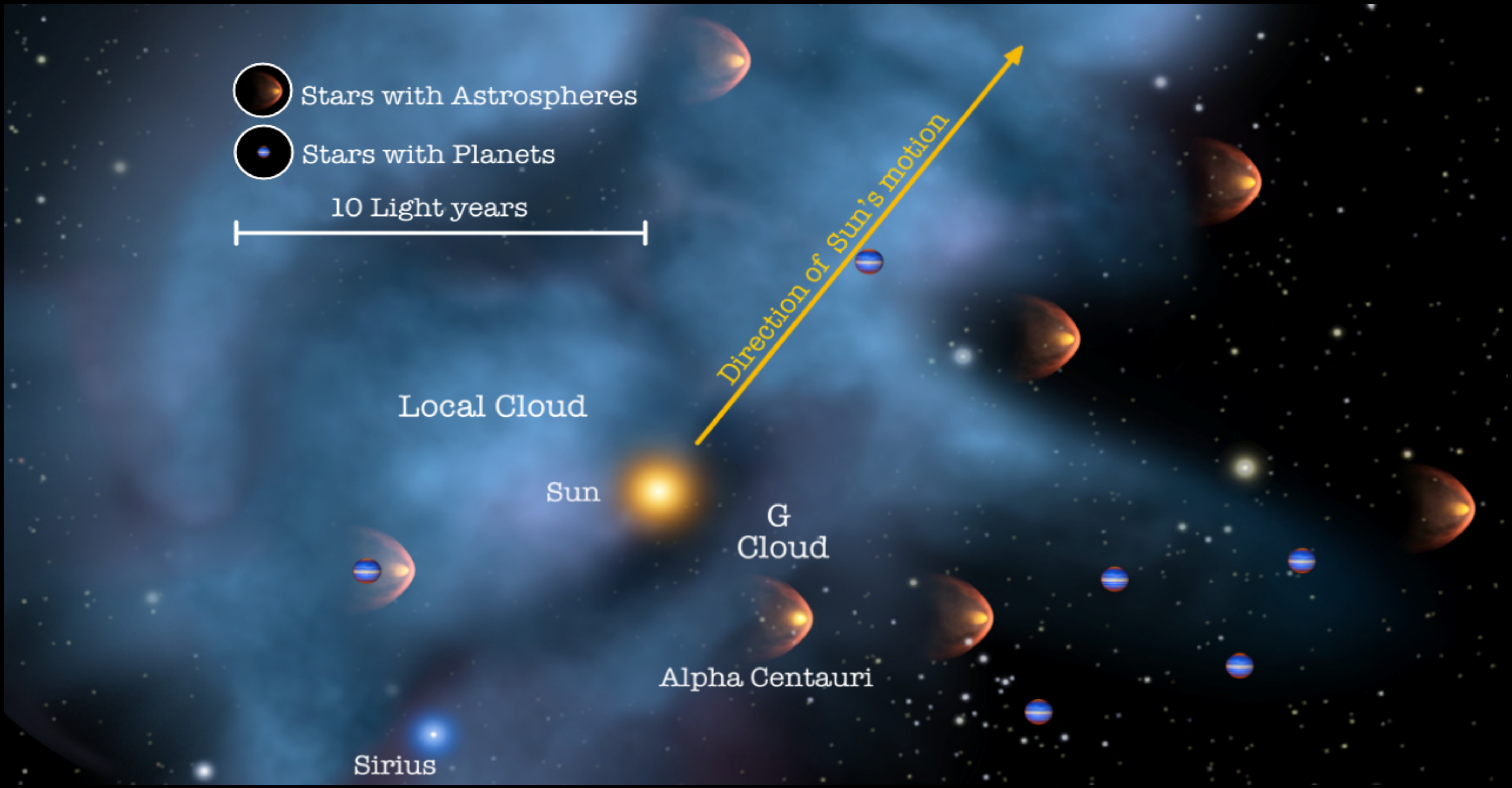

Merav Opher
Boston University, USA


HORIZON 2061

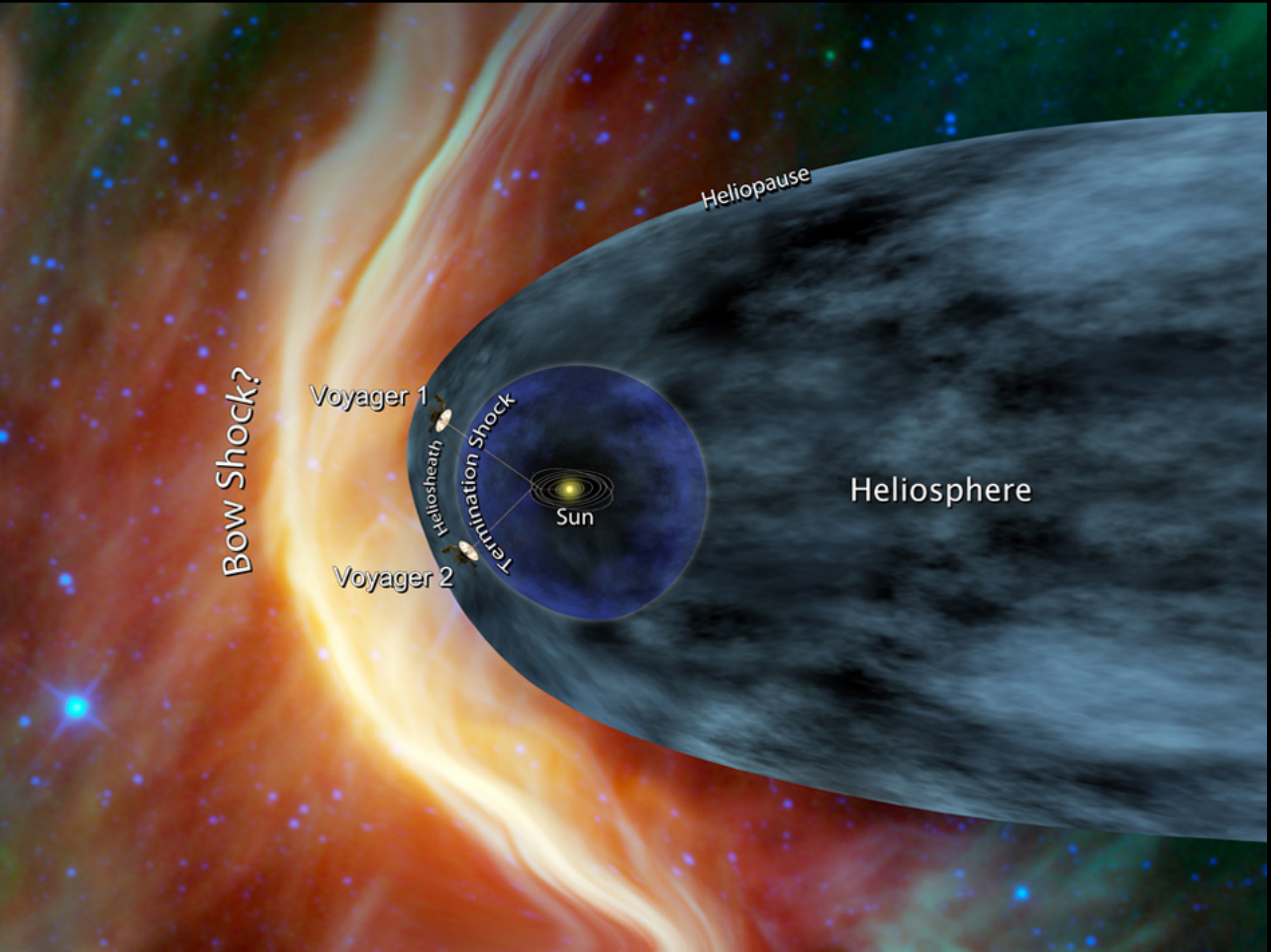
# Stars have bubbles around them: astrospheres



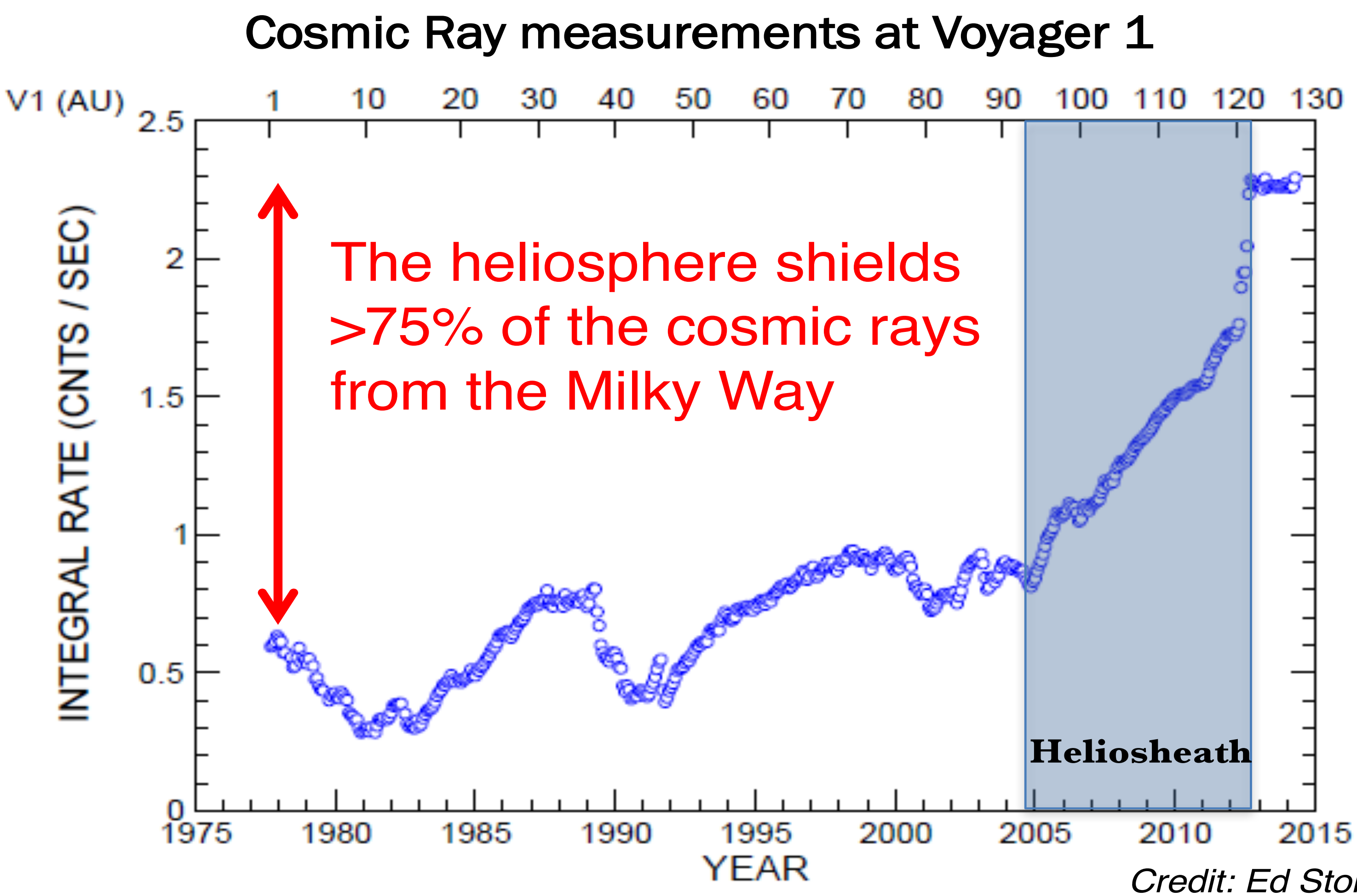
# These Astrospheres Protect Life



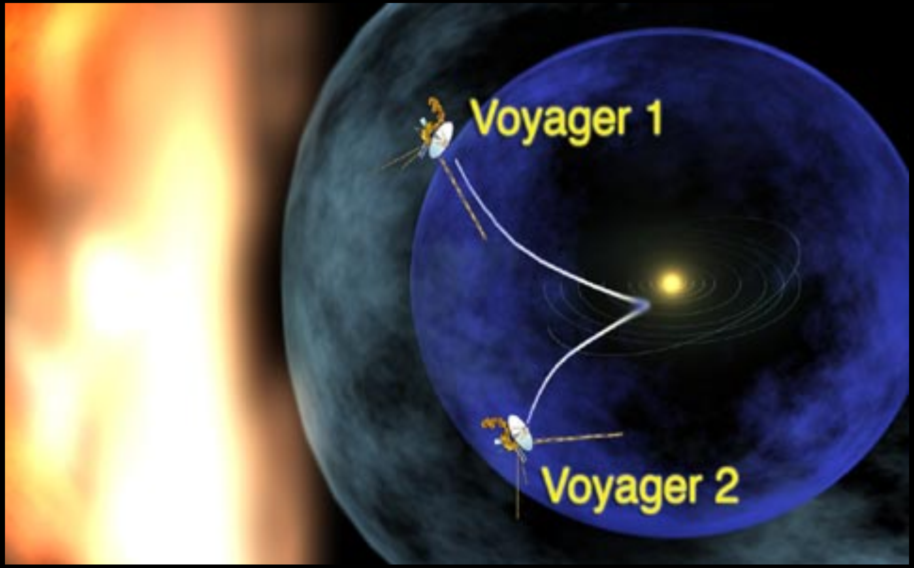
# Our Heliosphere is the only case we know of a habitable astrosphere –



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

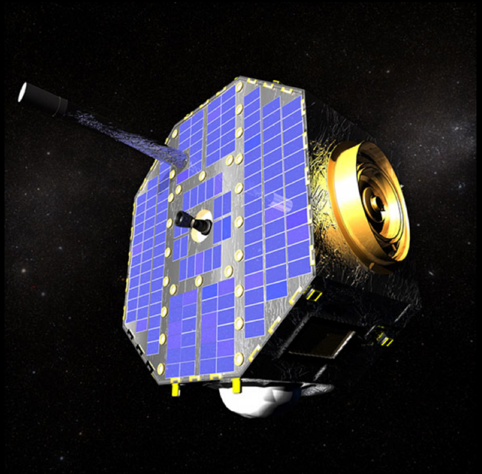


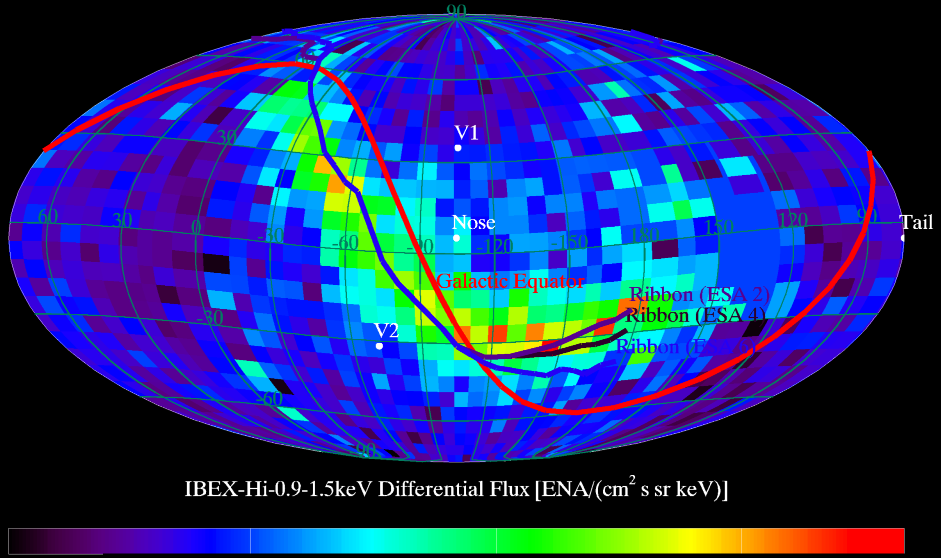

*Credit: Ed Stone*

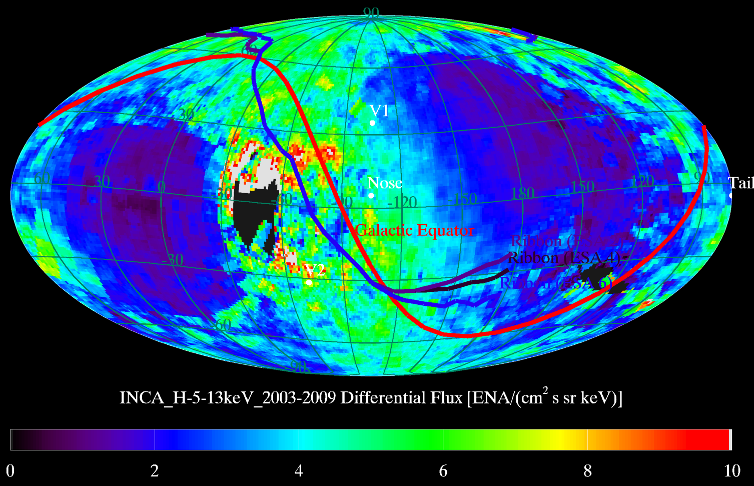



Voyager 1 in the north
Voyager 2 in the south

*In-situ data*





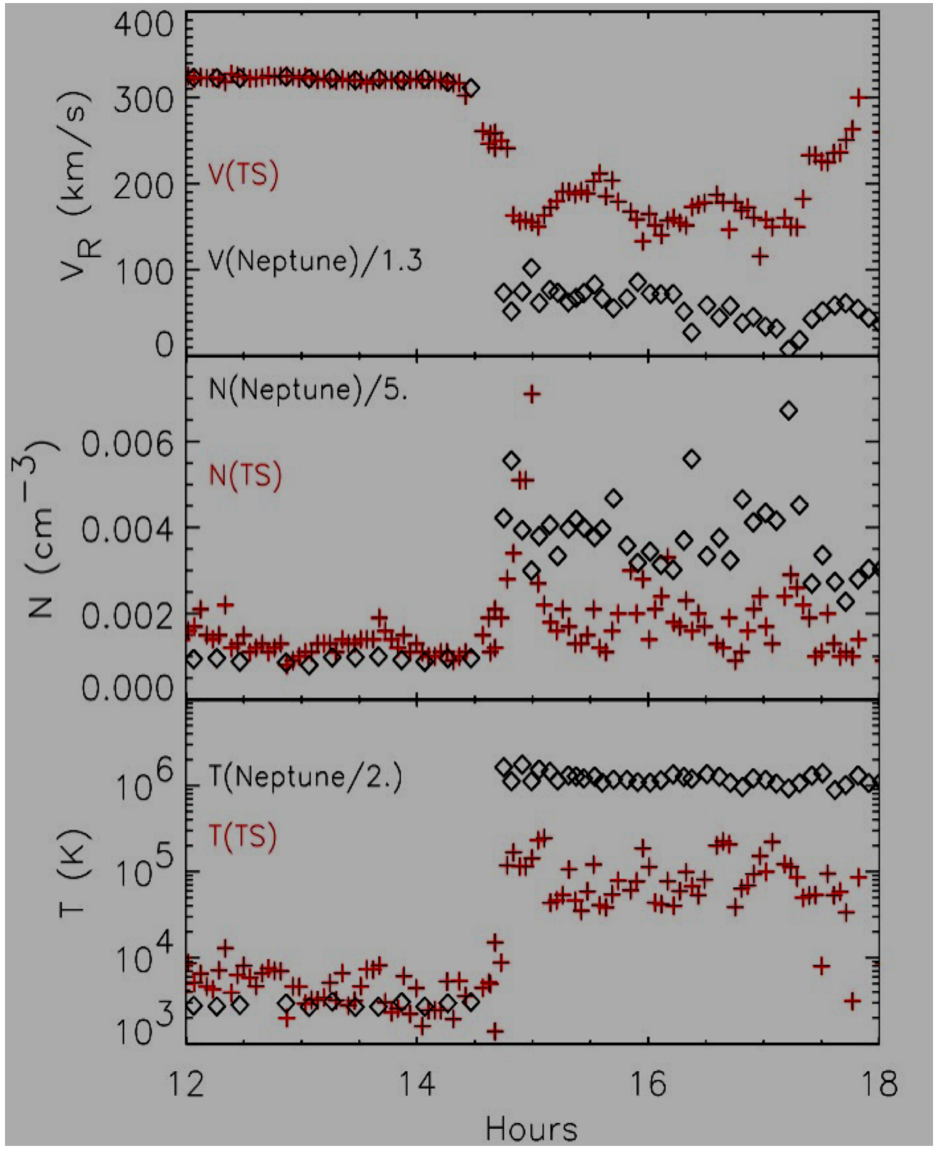




Global maps
of Energetic Neutral Atoms
(IBEX, Cassini)

# A Sheath Dominated Thermodynamically by Pickup Ions

- Shock is much colder than expected

- ~ 80% of the energy goes into supra-thermal particles

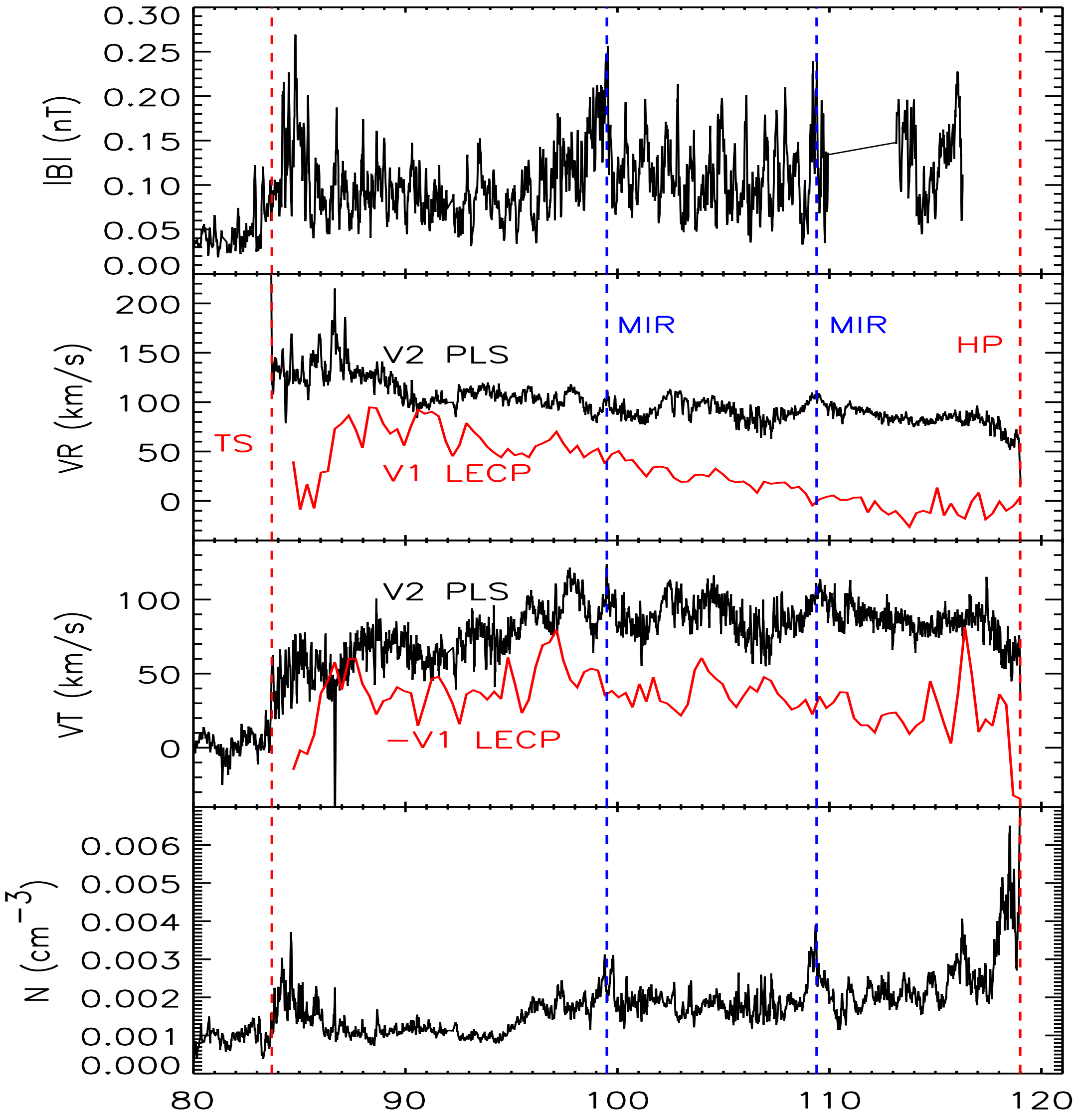



Discovery of a new paradigm:

Pickup ions carry most of the pressure

*Richardson et al. Nature 2005*

# Puzzles in the Heliosheath




VERY different flows at Voyager 1 and 2

# Concepts of the Heliosphere

Davis Jr., *Phys. Rev.*, 1955

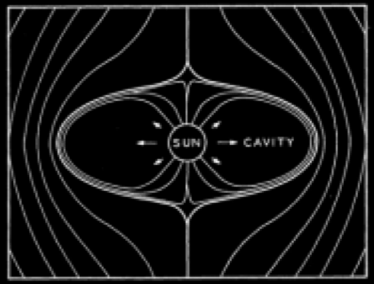



Fig. 1. A possible disposition of a solar magnetic field inside the cavity in the galactic field. The arrows represent the solar corpuscular radiation.

Parker, *ApJ*, 1961

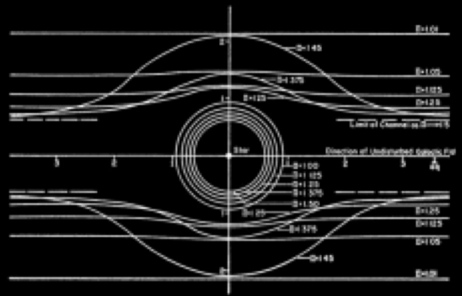


Fig 3 —The shock transition $r = R$, shown by the concentric circles, and the outer boundary of th stellar-wind region in the presence of a large-scale interstellar magnetic field, for various values of th stagnation pressure at infinity.

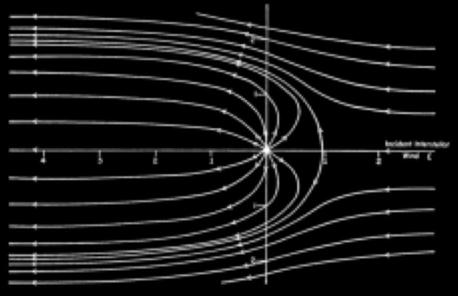


Fig. 1.—The streamlines of the subsonic, nearly incompressible, hydrodynamic flow of a stellar wind beyond the shock transition ($r = R$) in the presence of a subsonic interstellar wind carrying no significant magnetic field.

Axford, Dessler, and Gottlieb, *ApJ*, 1963

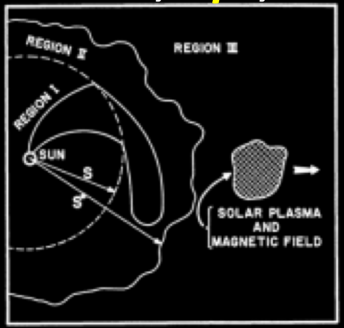



Fig. 4.—A sketch of the proposed cavity produced by the solar wind interacting with the galactic netic field For region I the solar wind is supersonic, and the solar magnetic field lines form Archies spirals that co-rotate with the sun A shock wave occurs at a heliocentric distance $S$. Beyond this, egion II (the boundary shell), charge-exchange between solar-wind protons and interstellar neutral rogen takes place, and dissipative effects permit oppositely directed solar magnetic-field lines to ge and form closed loops. $S^*$ is the distance to the boundary between the solar magnetic field and the ctic magnetic field. Blobs of solar plasma and magnetic field become detached from region II and e out into region III (galactic space), where they gradually diffuse away.

REVIEWS OF GEOPHYSICS

VOLUME 5 FEBRUARY 1967 NUMBER 1

Solar Wind and Interplanetary Magnetic Field

A. J. Dessler

*Department of Space Science*
*Rice University, Houston, Texas*

**First major review**

Dessler, *Rev. Geophys. Space Phys.*, 1967

Baranov et al., *Sov. Phys. – Dokl.*, 1971

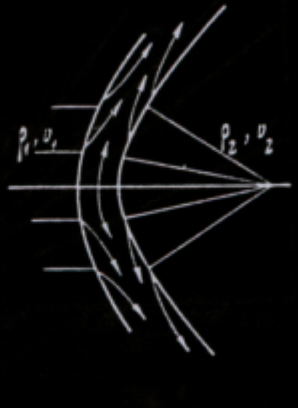
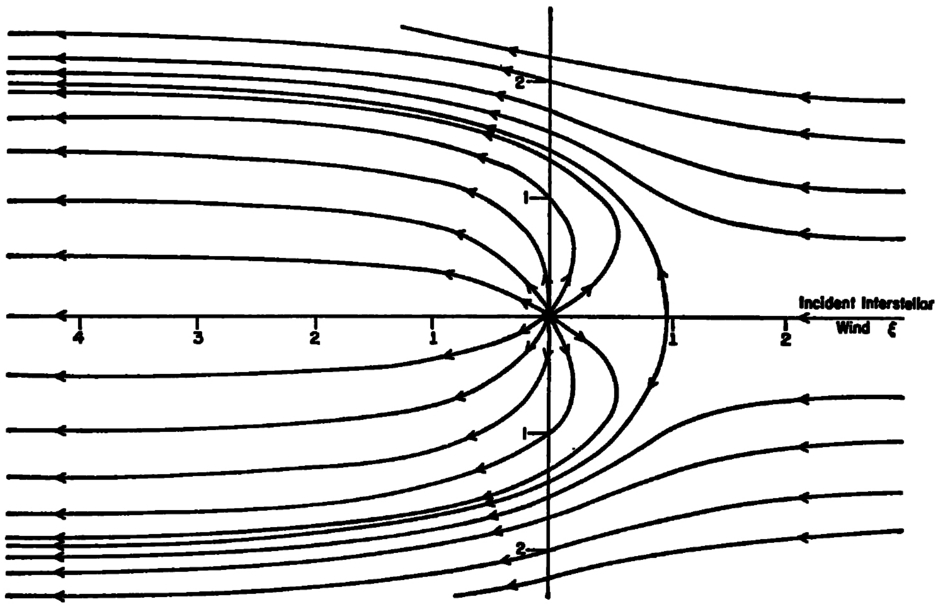
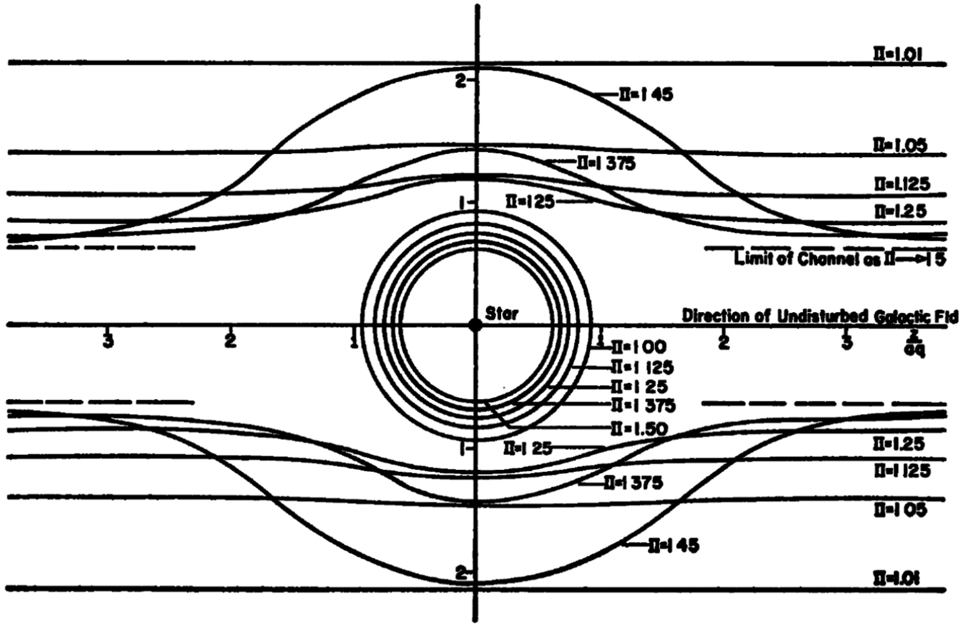


Fig. 1

# Two limiting cases of the shape of the heliosphere; from Parker (1961)




Weak Interstellar Magnetic Field




Strong Interstellar Magnetic Field

# Working Paradigm

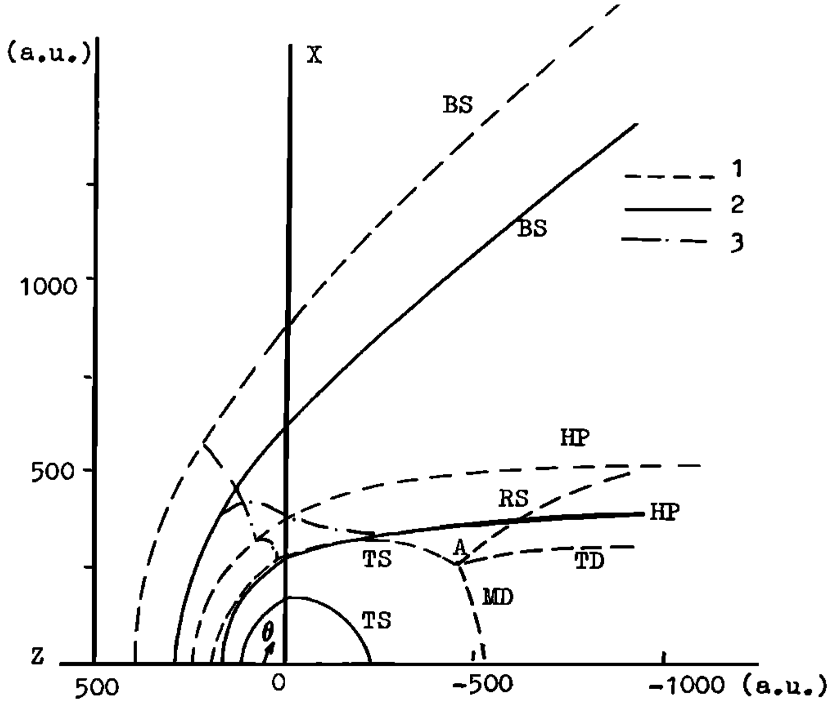
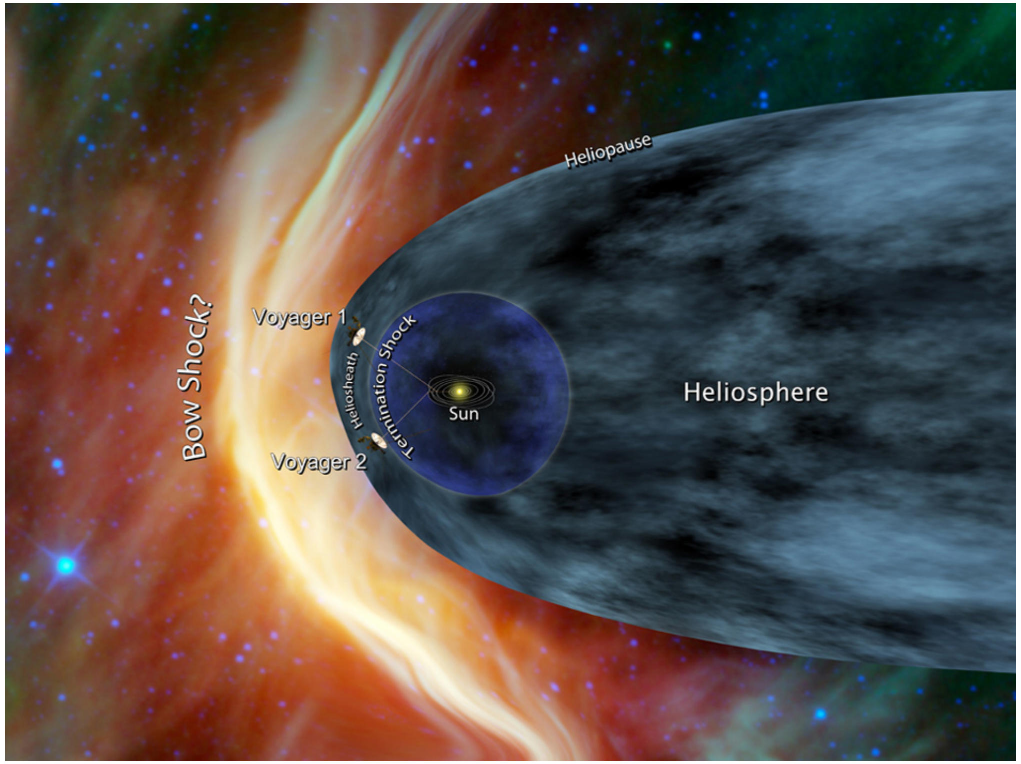
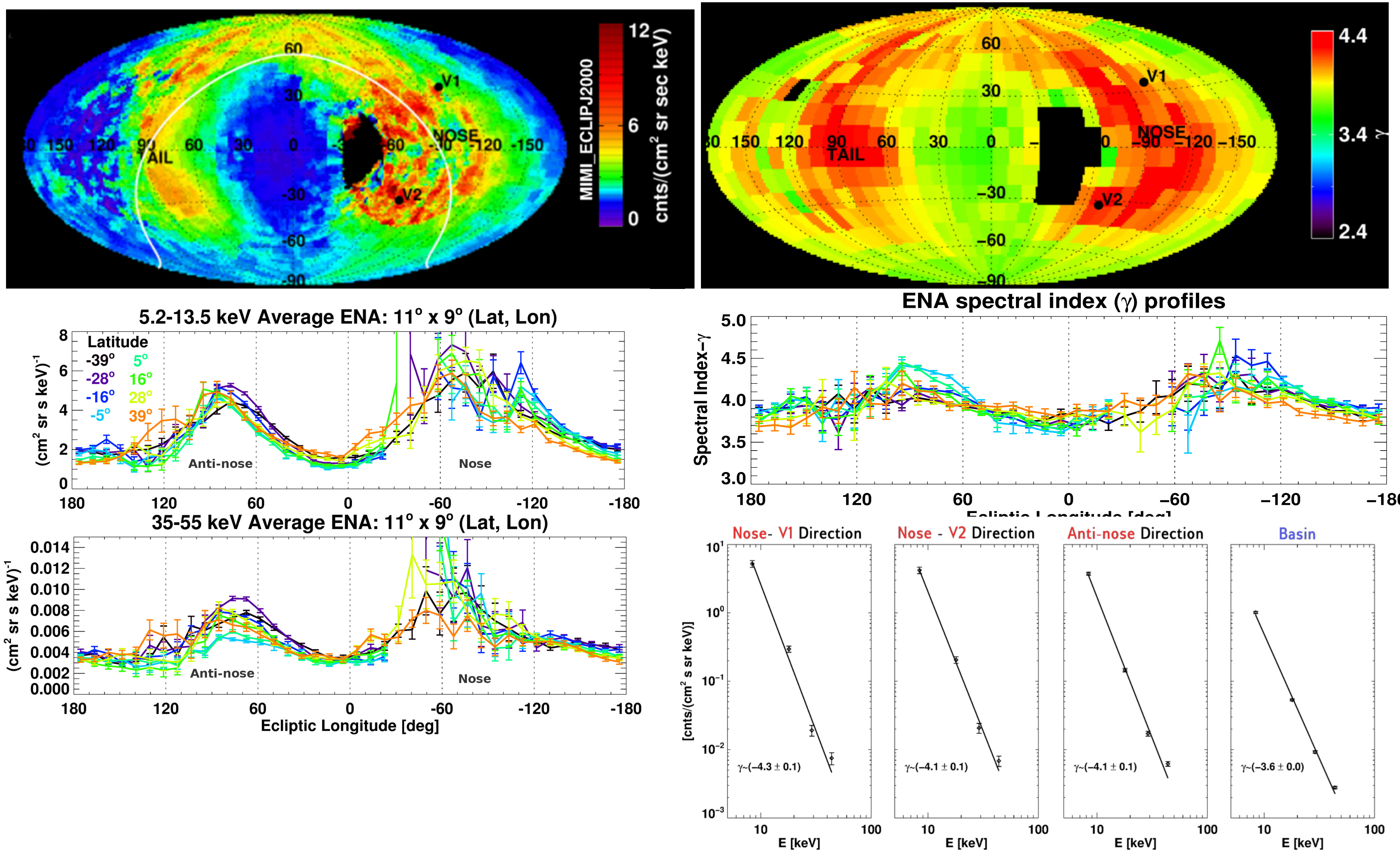



Fig. 2. Geometrical pattern of the interface. Results of the numerical calculations for $n_{H\infty} = 0$ (1) and $n_{H\infty} = 0.14$ cm$^{-3}$ (2); curves (3) are the sonic lines. Positions of bow shock (BS), termination shock (TS), heliopause (HP), reflected shock (RS), tangential discontinuity (TD), and Mach disc (MD) are shown.



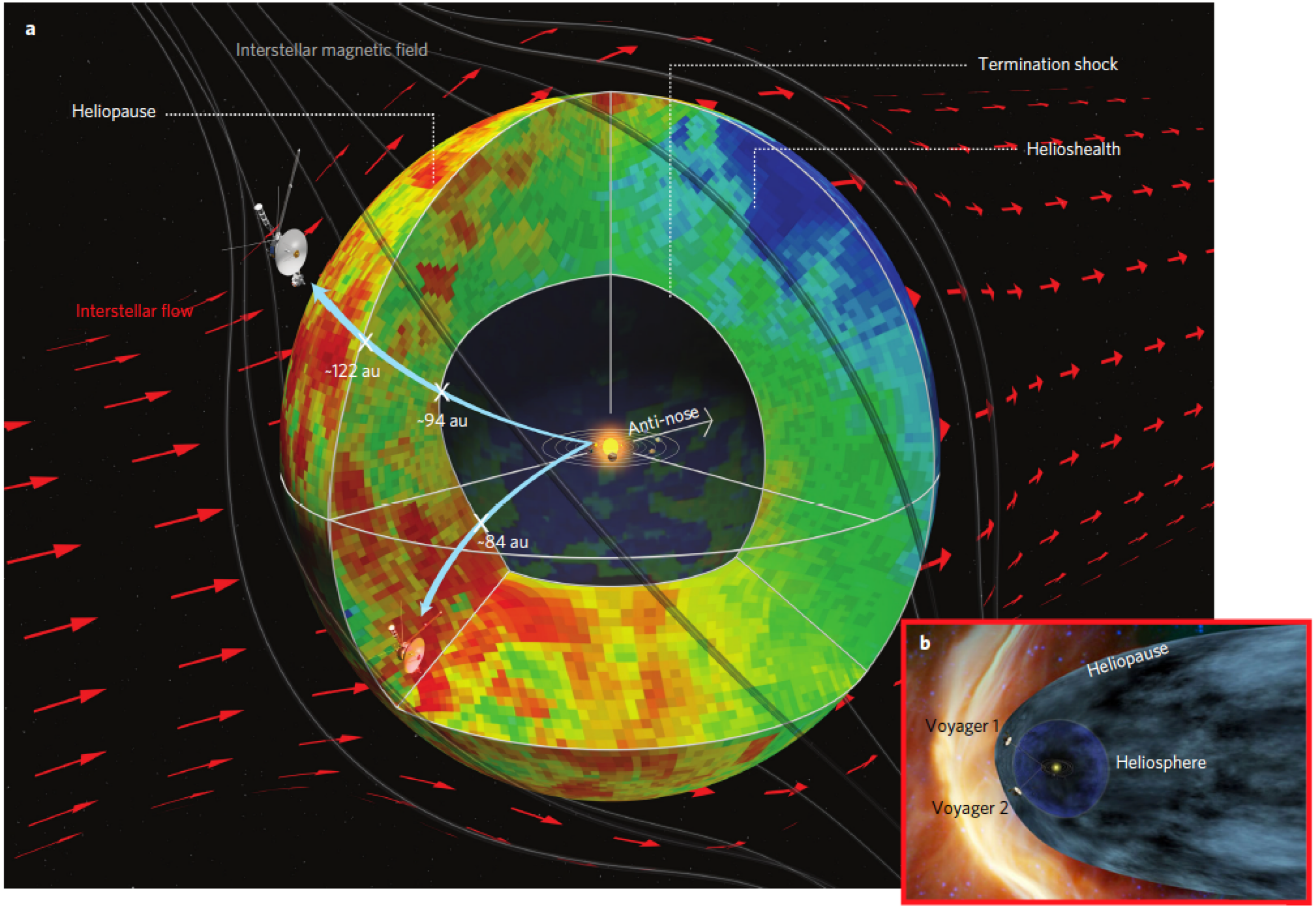

Baranov & Malama (1993) – Hydrodynamic calculations

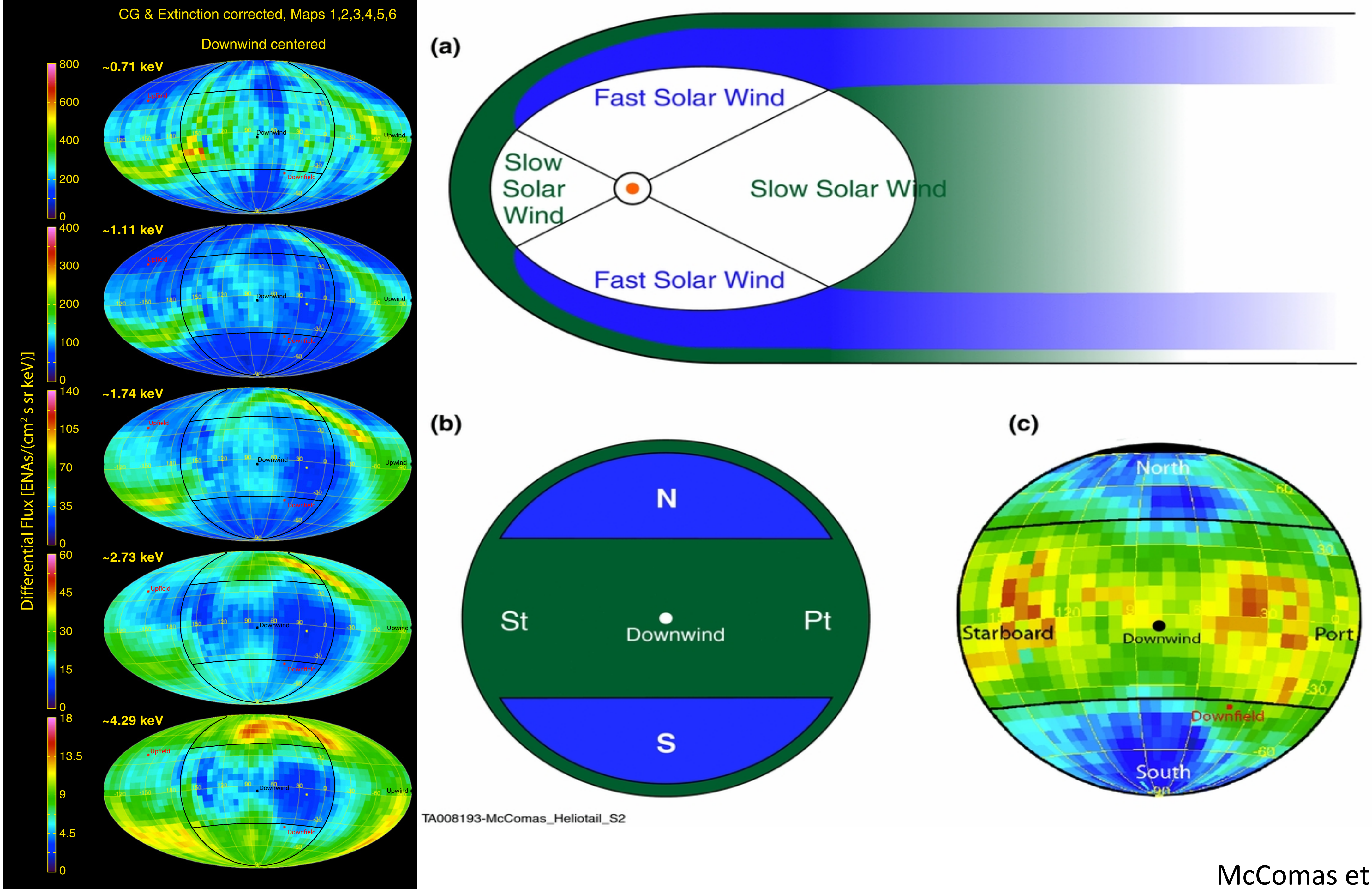
# INCA ENA spectra / Nose and Anti-nose symmetry
between 2003-2009 (from Dialynas et al. 2017)



# “Tailless Heliosphere” (Dialynas et al. 2017)

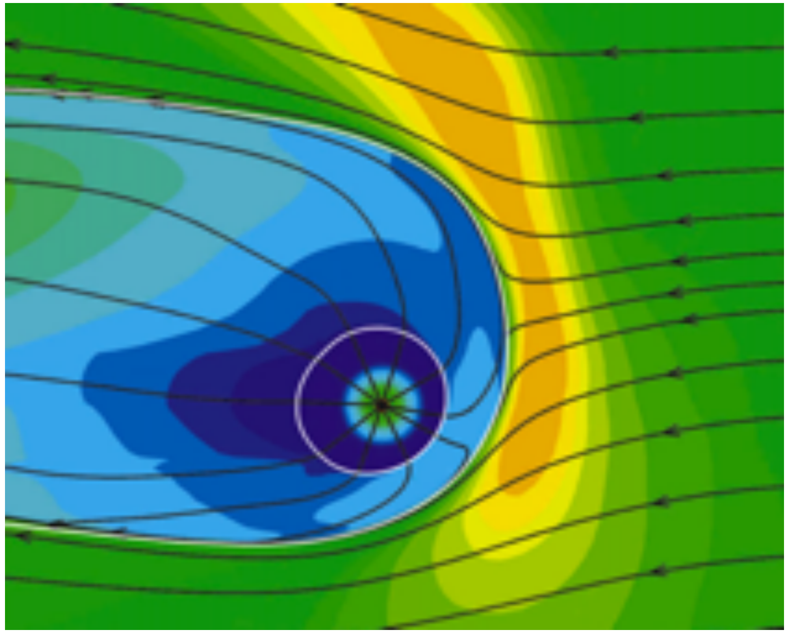
LETTERS May 5 issue, 2017 NATURE ASTRONOMY



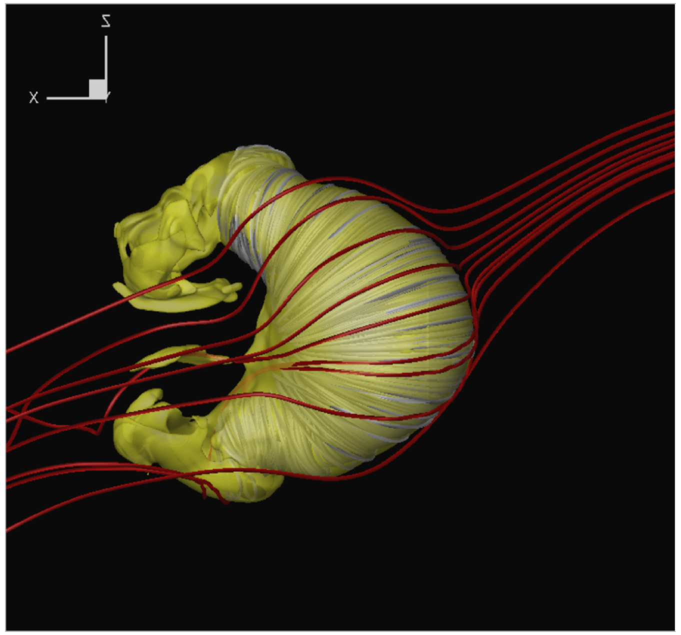



McComas et al. 2013

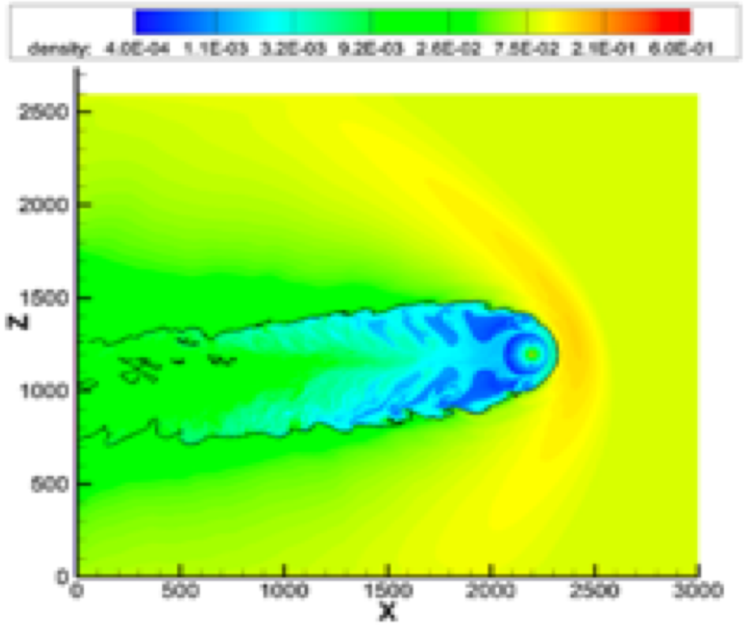
# Models don't agree on the shape



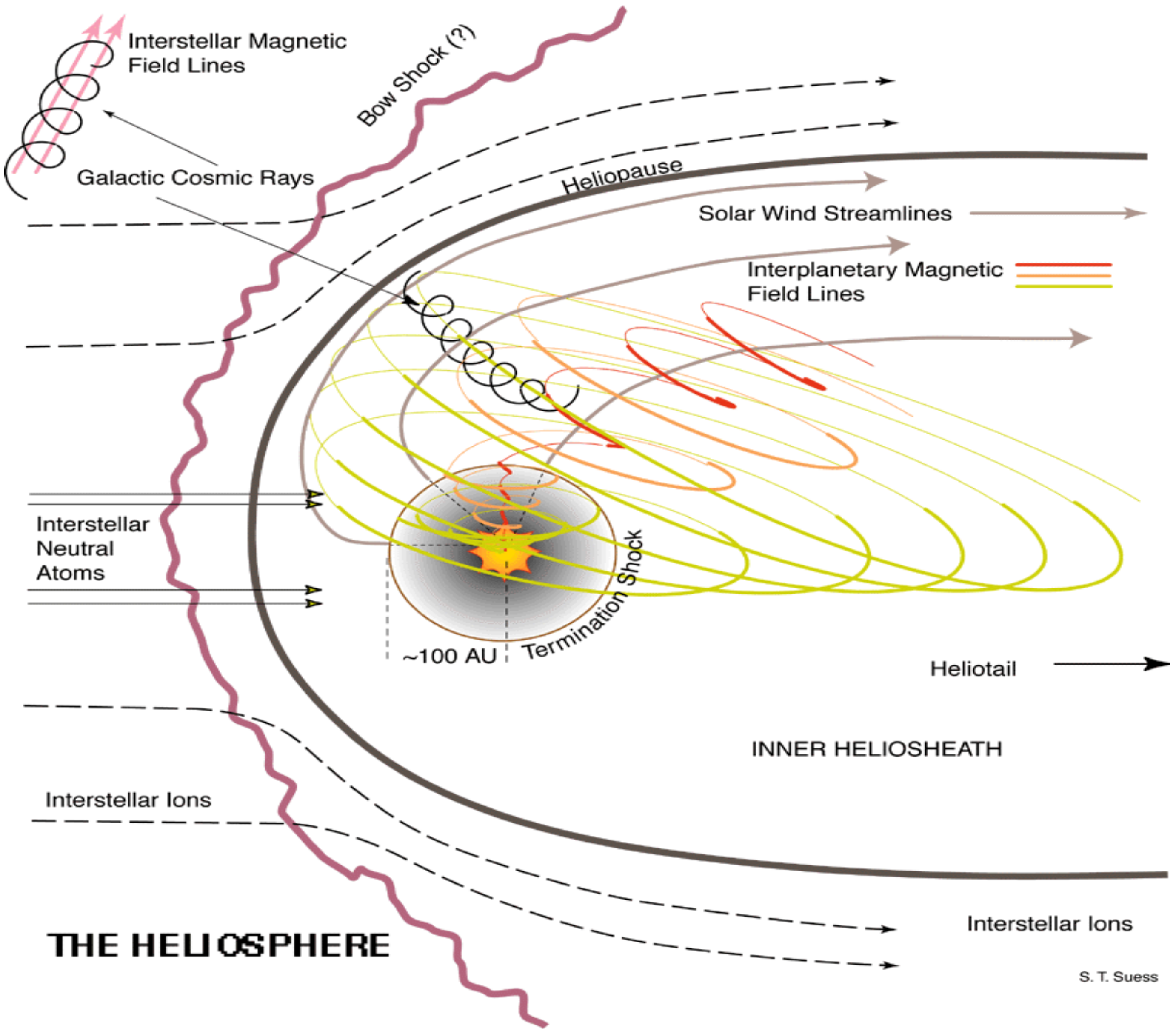
Izmdenov et al. 2015




Opher et al. 2015; 2019




Pogorelov et al. 2015




Previous assumption is that the solar magnetic field has a negligible role

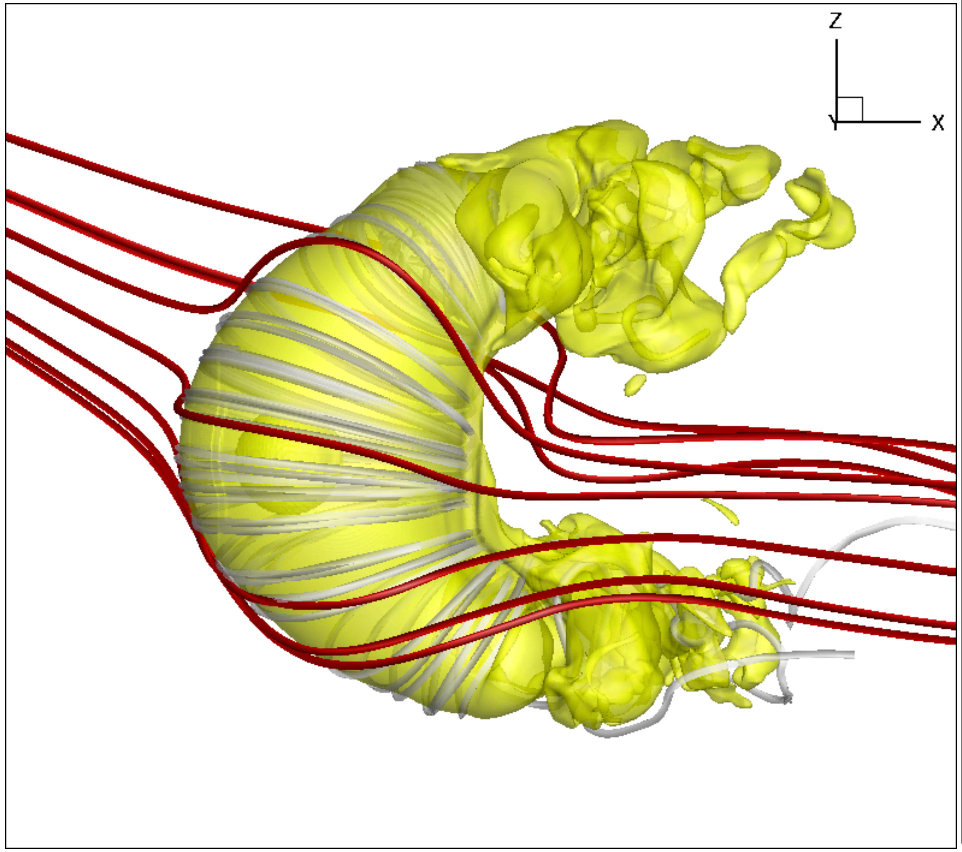
Probably because in the heliosheath, the plasma $\beta$ =PT/PB >> 1

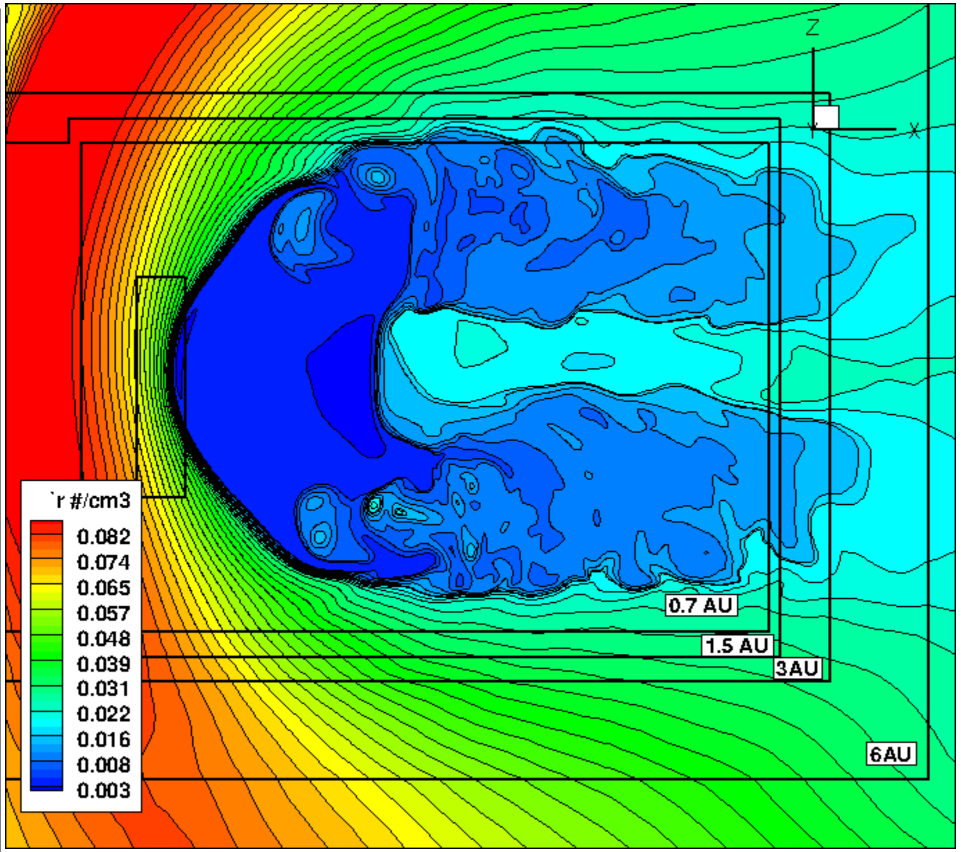
$$B = B_0 \left(\frac{R_0}{r}\right)^2 e_r - B_0 \left(\frac{R_0^2}{r}\right) \frac{\Omega \sin \Theta}{v_{\mathrm{SW}}} e_\phi,$$

Ω: stellar rotation rate
Θ: polar angle

Interplanetary Magnetic Field

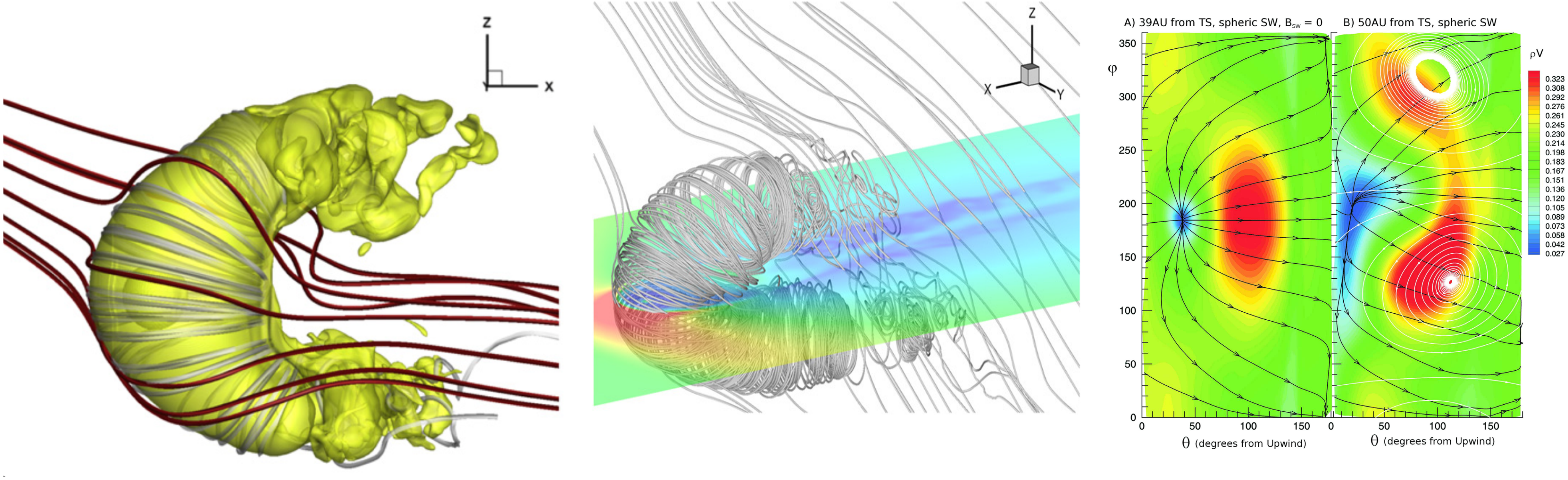
# Solar Magnetic Field is the backbone of the heliosphere



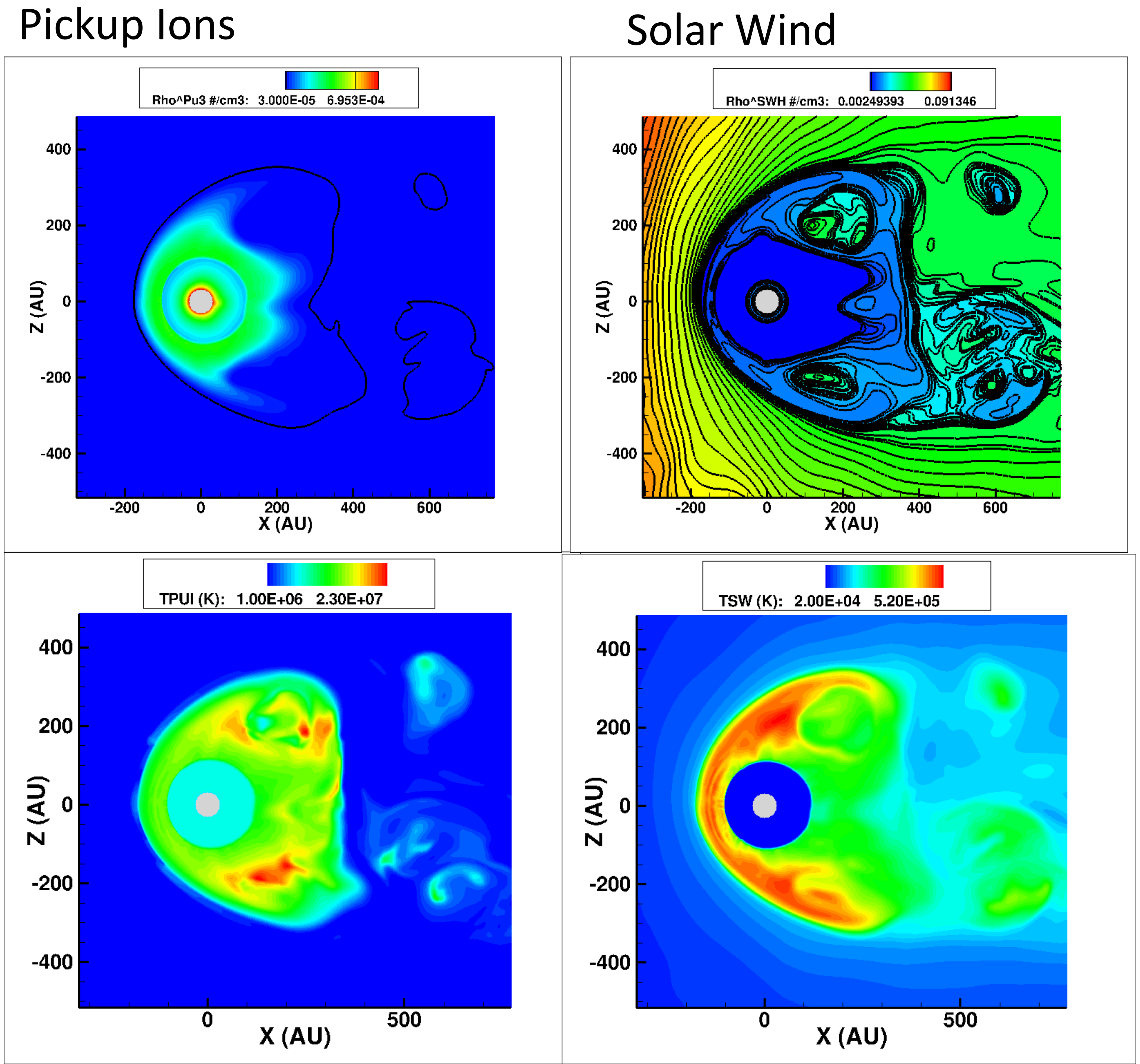

The Solar Magnetic field is not *passive* but instead (tension force) collimates the heliosheath flow in two jets (Opher et al. 2015; Drake et al. 2015)

# Solar Wind Confinement



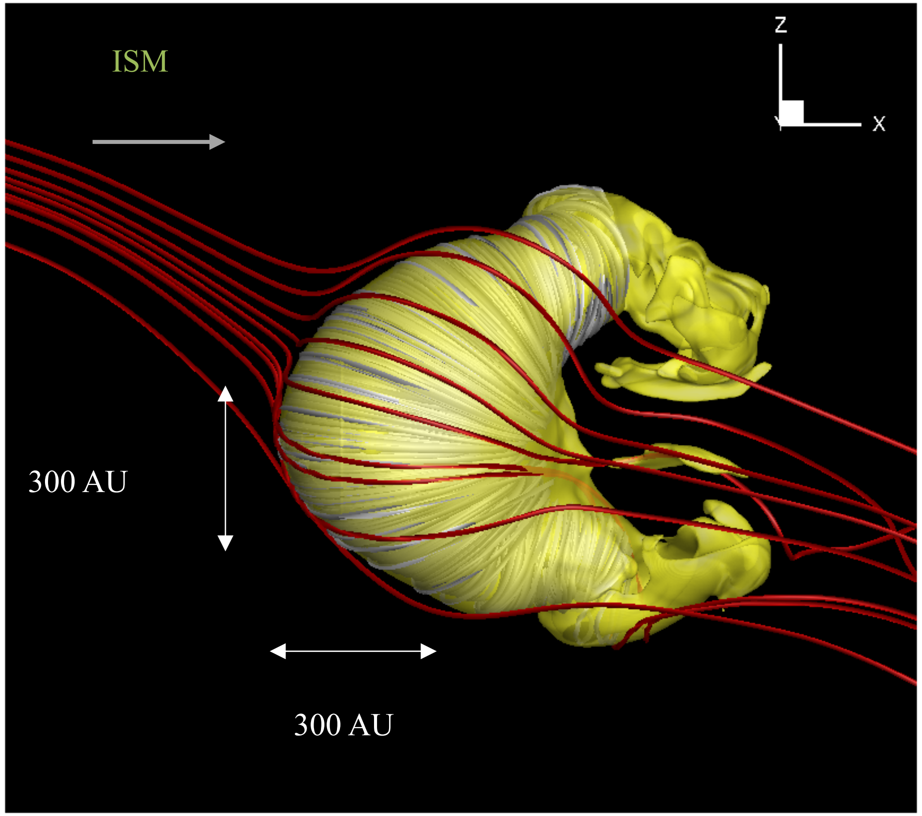

The solar magnetic field lines (gray) are shown in panels (a) and (b) in two different models. (c) Solar wind mass flux (rhp v) projected on a closed surface located in the inner heliosheath at equal distances from the heliopause – model (A) has no solar magnetic field and model B has solar magnetic field. White curves are the projections of the solar magnetic field.

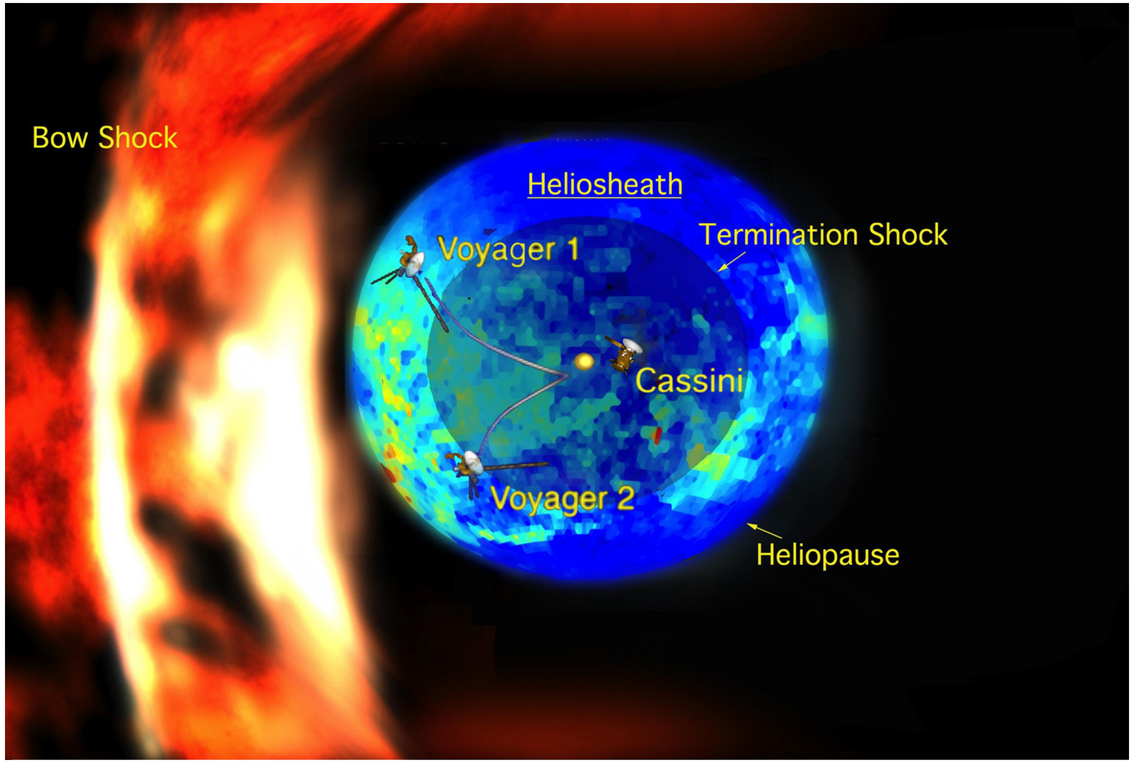
# Multi-Ion MHD




Opher et al. 2018

# A Predicted Smaller Rounder Heliosphere



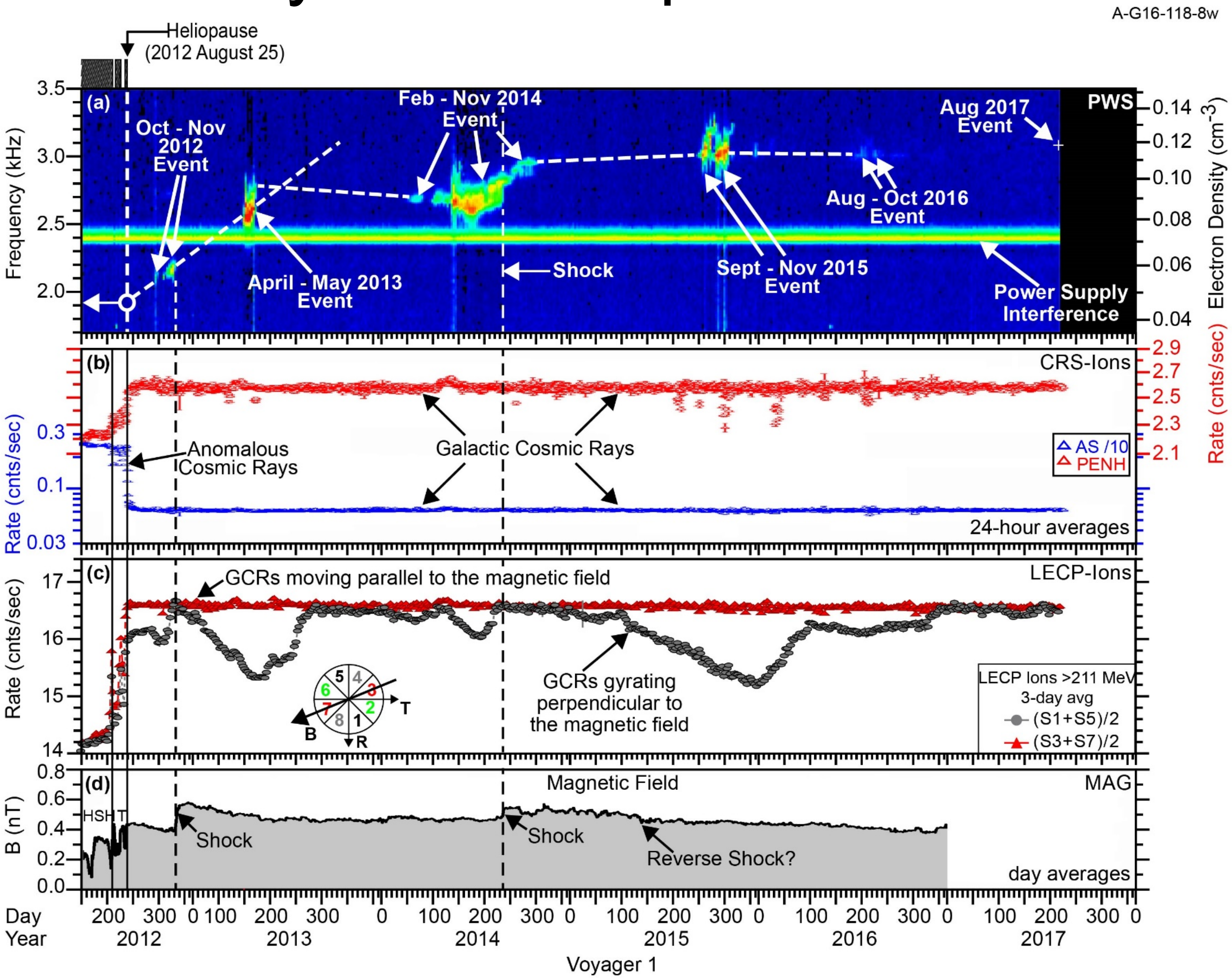




**Opher et al. 2018**

**Dialynas et al. 2017**

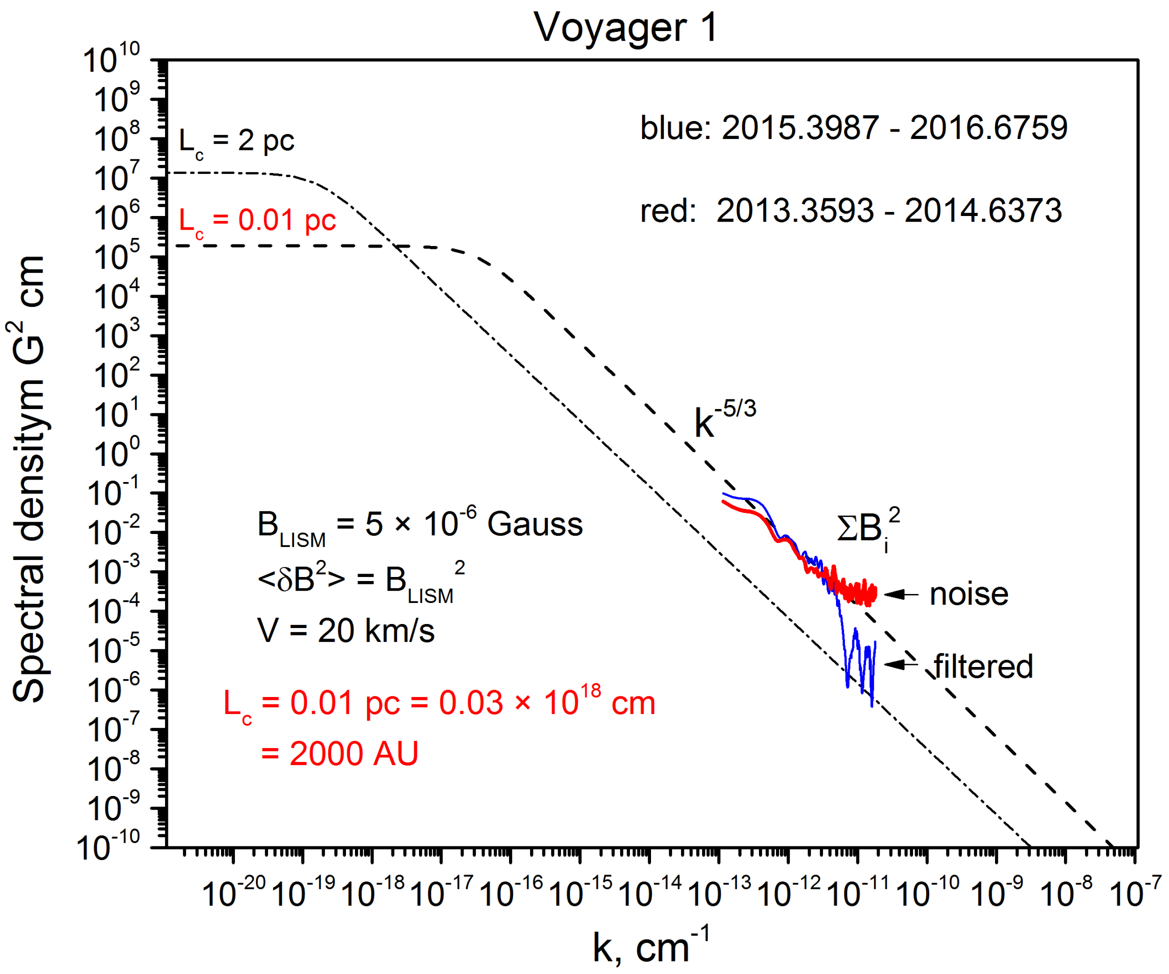
The round heliosphere has distances from the Sun to the heliopause similar in all directions

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




Curtesy of D. Gurnett

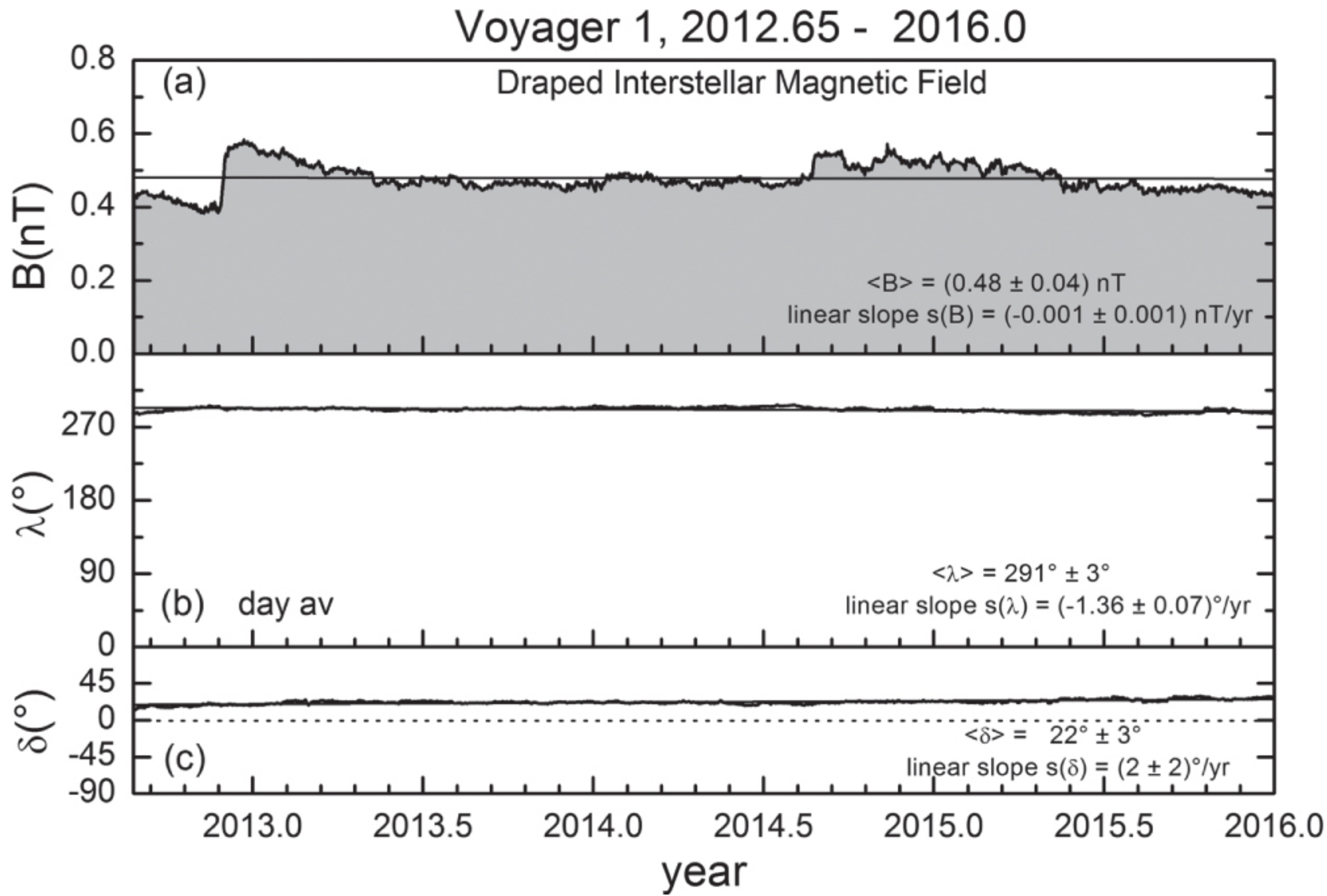
# Spectrum of Turbulence in the Local Interstellar Medium

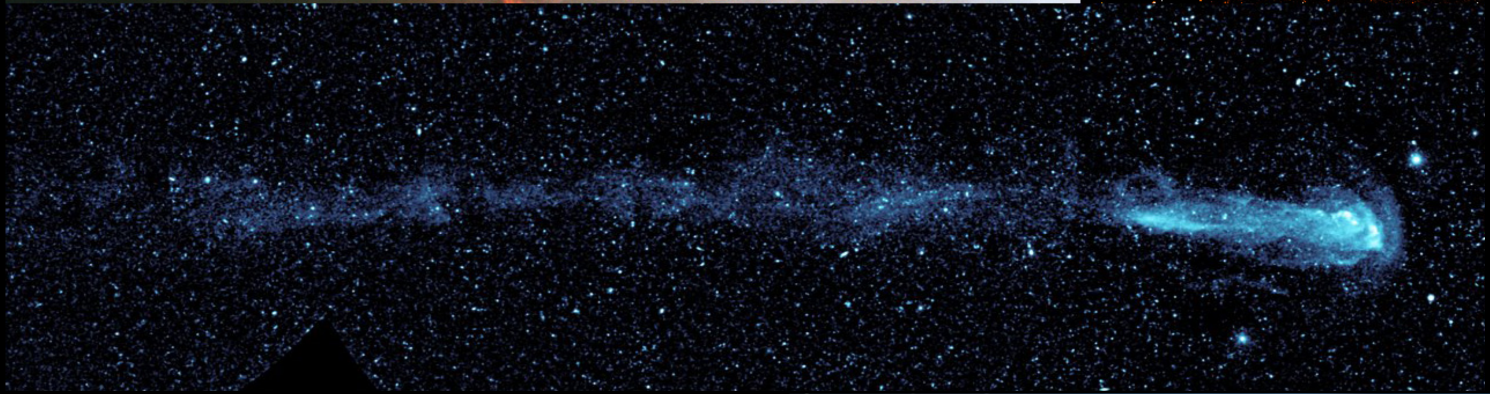


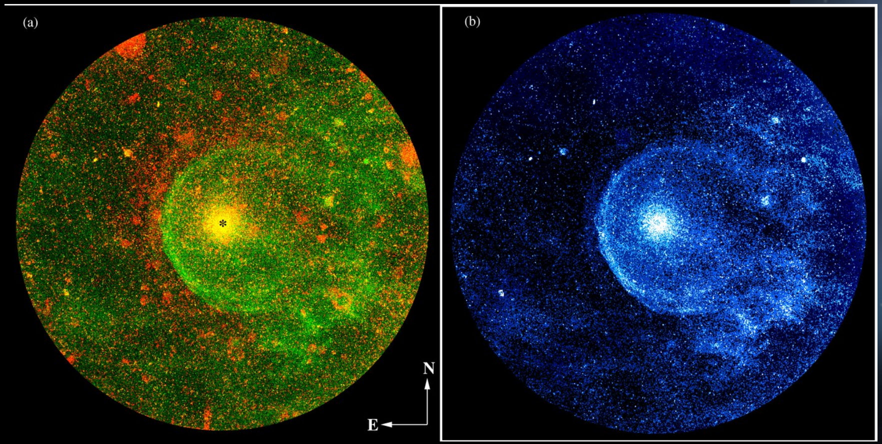

Driven at smaller scales than thought – 2000AU; at least at these distances close to the Heliopause

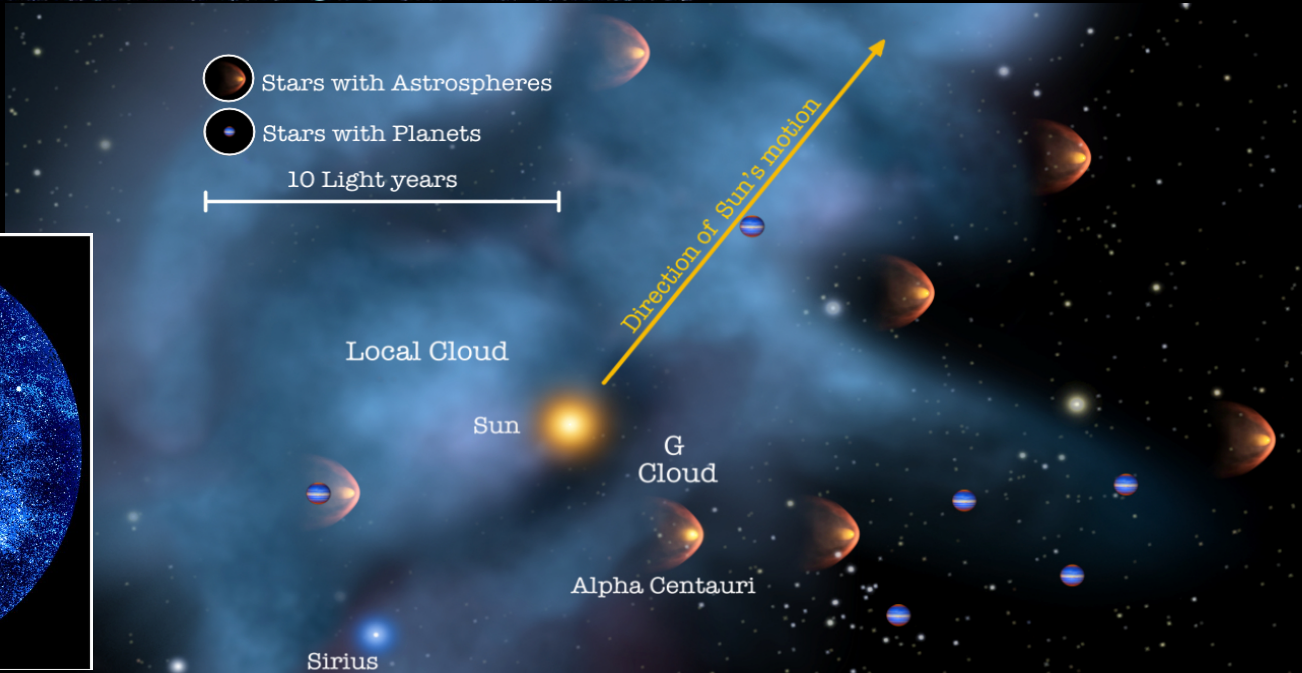
Curtesy of L. Burlaga

# Solar Like Magnetic Field Ahead of the Heliosphere






(a)
(b)
N
E


Stars with Astrospheres
Stars with Planets
10 Light years
Direction of Sun's motion
Local Cloud
Sun
G Cloud
Alpha Centauri
Sirius