Interstellar Neutral Atoms and Their Journey Through the Heliosphere

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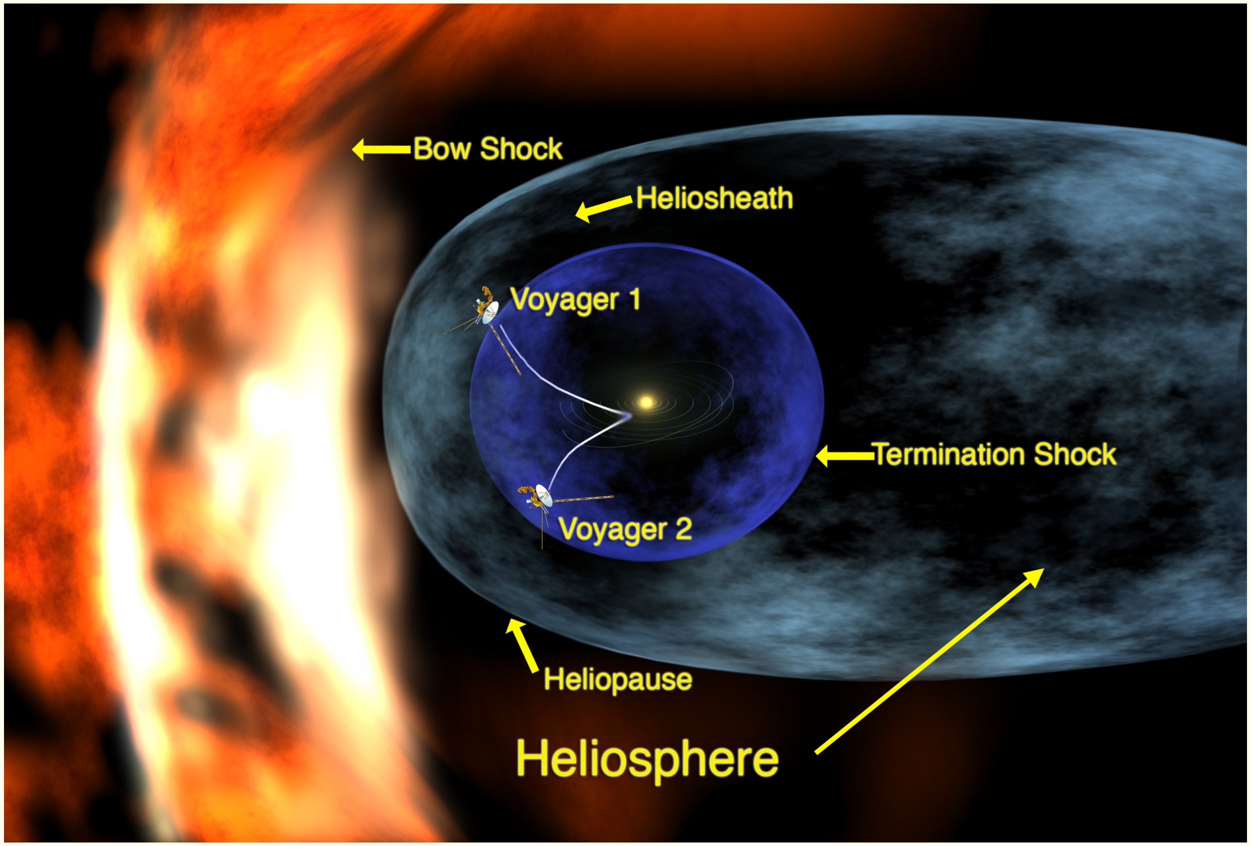
Solar and Heliospheric Influences on the Geospace
Bucharest, 1-5 Oct 2012

What is the Heliosphere?

- The solar wind, which expands radially from the Sun at supersonic speed, blows a huge cavity - **heliosphere** - into the surrounding interstellar cloud, filling it with solar material and magnetic field.



NASA/Walt FeimerL

- The size of the heliosphere is determined by a balance between the dynamic pressure of the solar wind and the pressure of the interstellar medium.

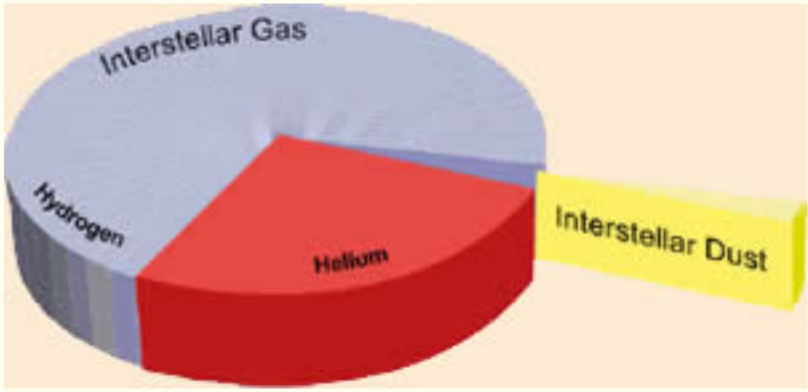
Importance of the Heliosphere

- Heliosphere is the **first defense** in the three-layer shield system of the Earth against high-energy galactic cosmic rays, which consists of:

1. **Heliosphere** with the Sun's magnetic field carried out by the solar wind
2. Earth's magnetic field (magnetosphere)
3. Earth's atmosphere.

What Is the Interstellar Medium (ISM)?

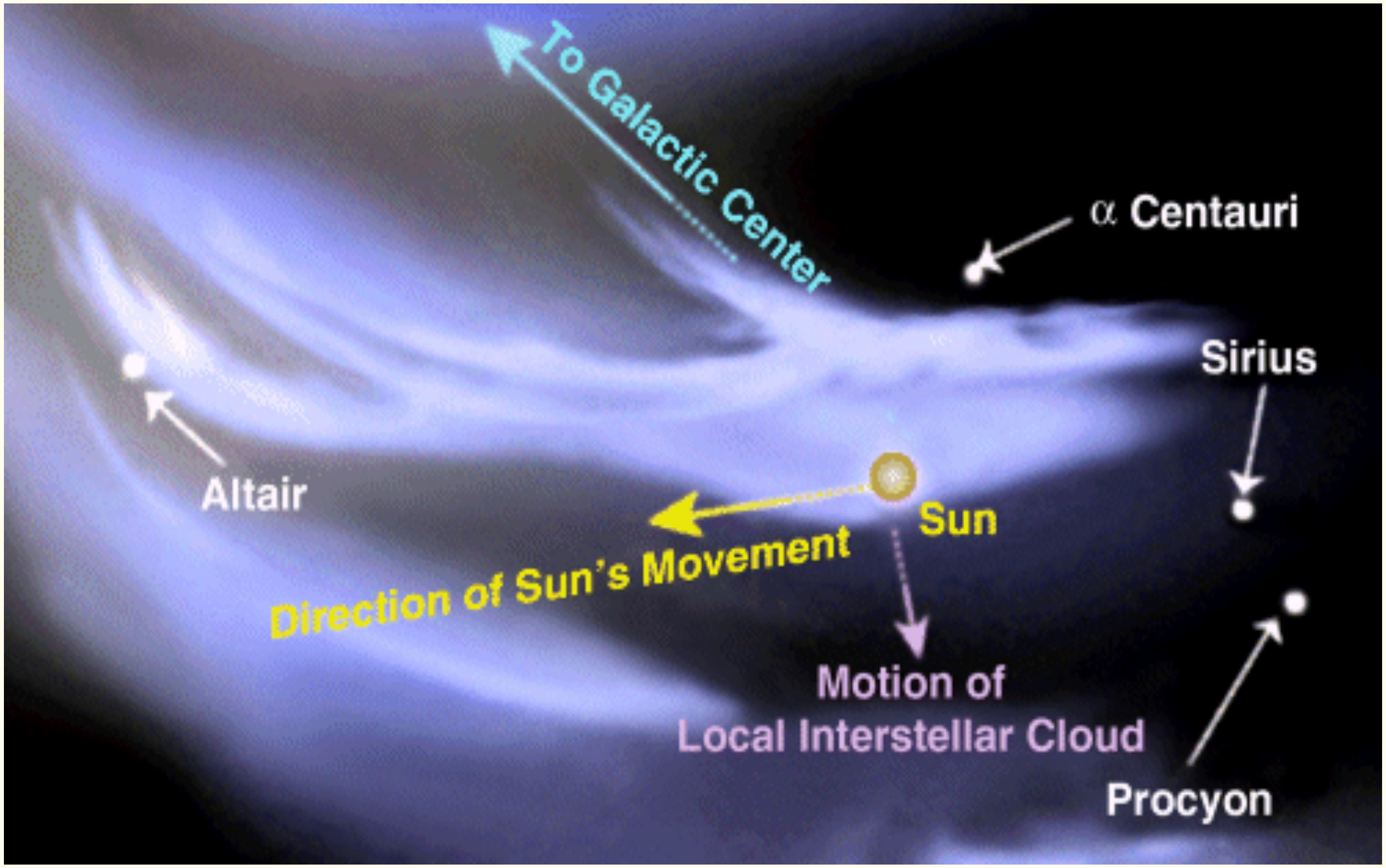
- ISM consists of an extremely dilute (by terrestrial standards) mixture of ions, atoms, molecules, dust grains, cosmic rays, and magnetic fields.
- Manly gas (99%) and some dust (1%)
- Temperature of 6000-7000K



http://www-ssg.sr.unh.edu/ism/what1.html

- Extremely low density: 1atom in $10cm^3$.
  - solar-wind density near Earth is 100 ions in $10cm^3$
  - in the air we breath contains 30,000,000,000,000,000,000 ($3x10^{19}$) molecules

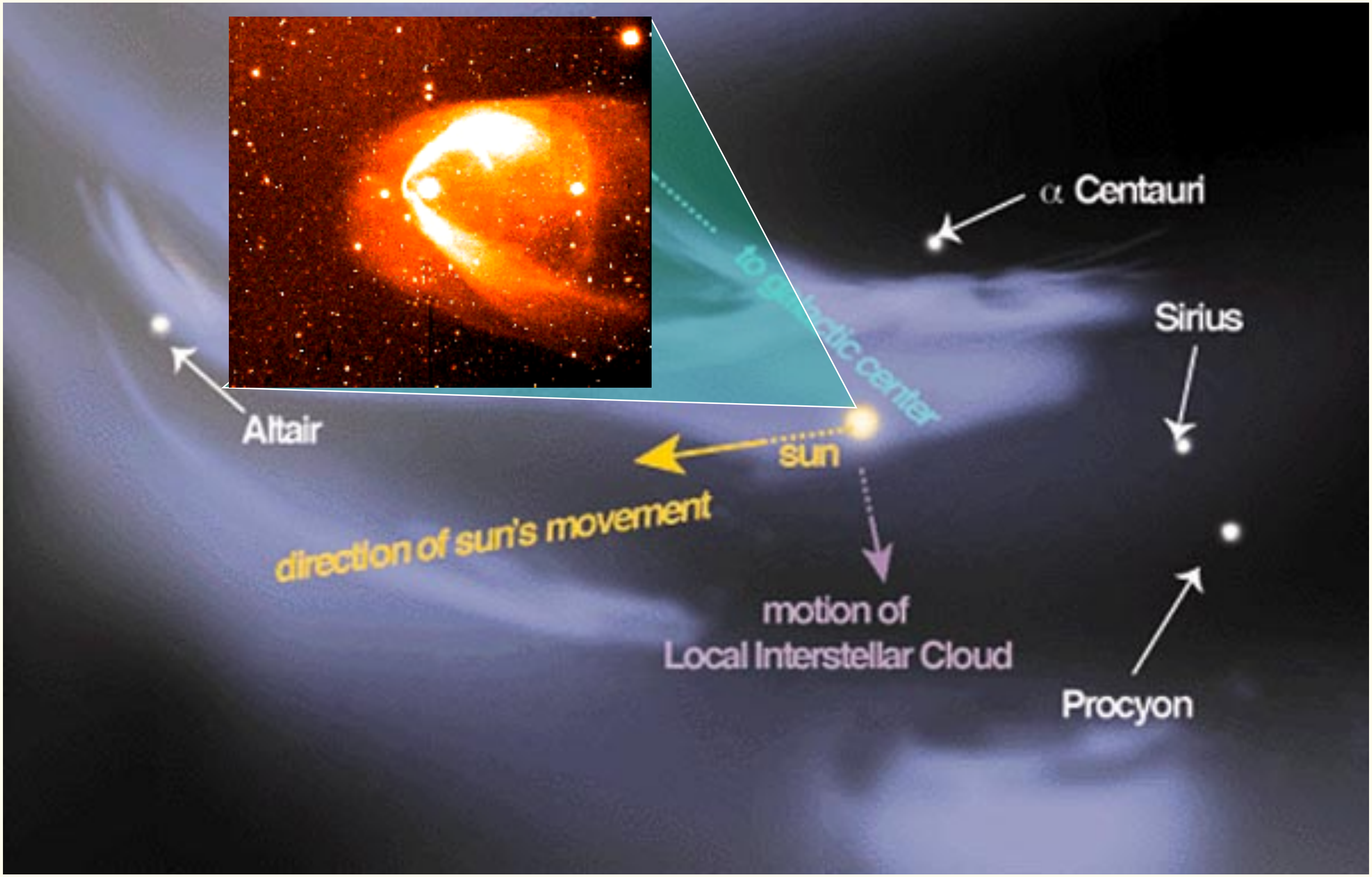
How Would Our Heliosphere Look from Outside?



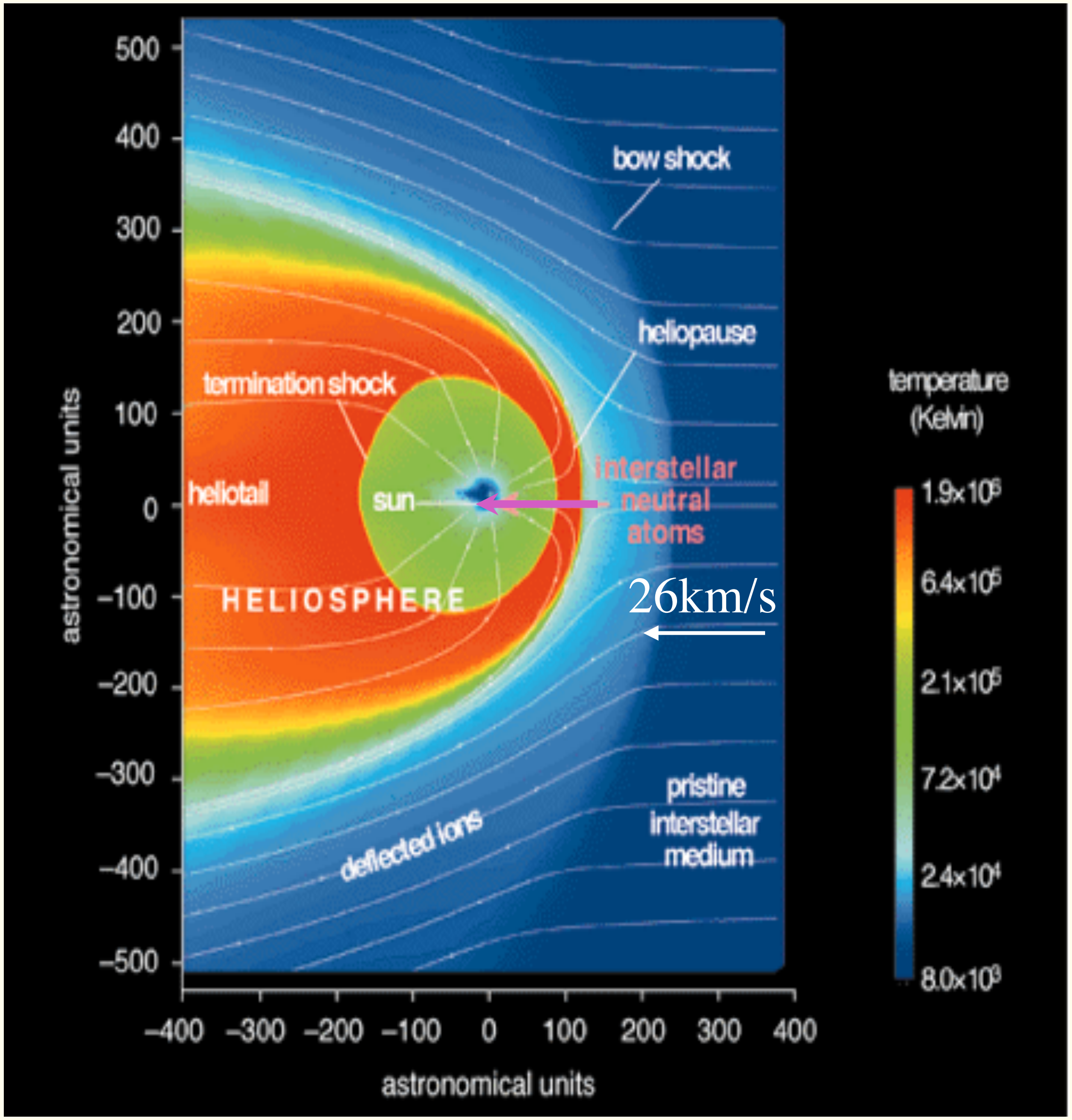
Linda Huff & Priscilla Frisch

- *Our sun is moving through the local interstellar gas cloud in approximately the direction of the constellation Scorpio, with a speed of about 25 km/s (900 m/h).*

If We Could See Our Heliosphere from Outside



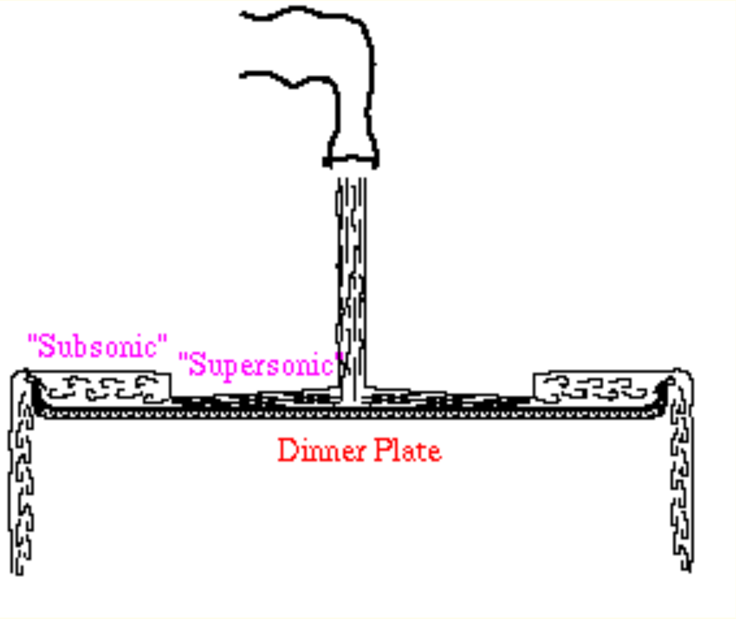
Heliosphere and Local Interstellar Medium (LISM) Interaction



- Heliosphere moves with 26km/s through LISM
- Bow Shock (BS)
  - If supersonic relative motion between heliosphere and LISM
- Heliopause (HP)
  - Separates the heliosphere from the LISM plasma
- Termination Shock (TS)
  - Boundary where solar wind becomes subsonic
  - Passed by Voyager 1 in 2004 at 94 AU and Voyager 2 in 2007 at 84AU

Kitchen Sink Model of the Termination Shock

- In the center of the plate the water is flowing faster than the speed of water waves (it's 'supersonic' for water waves).
- The rim of the plate provides resistance, similar to the pressure from the Interstellar Medium
- A shock forms as the water slows down in response to the resistance.



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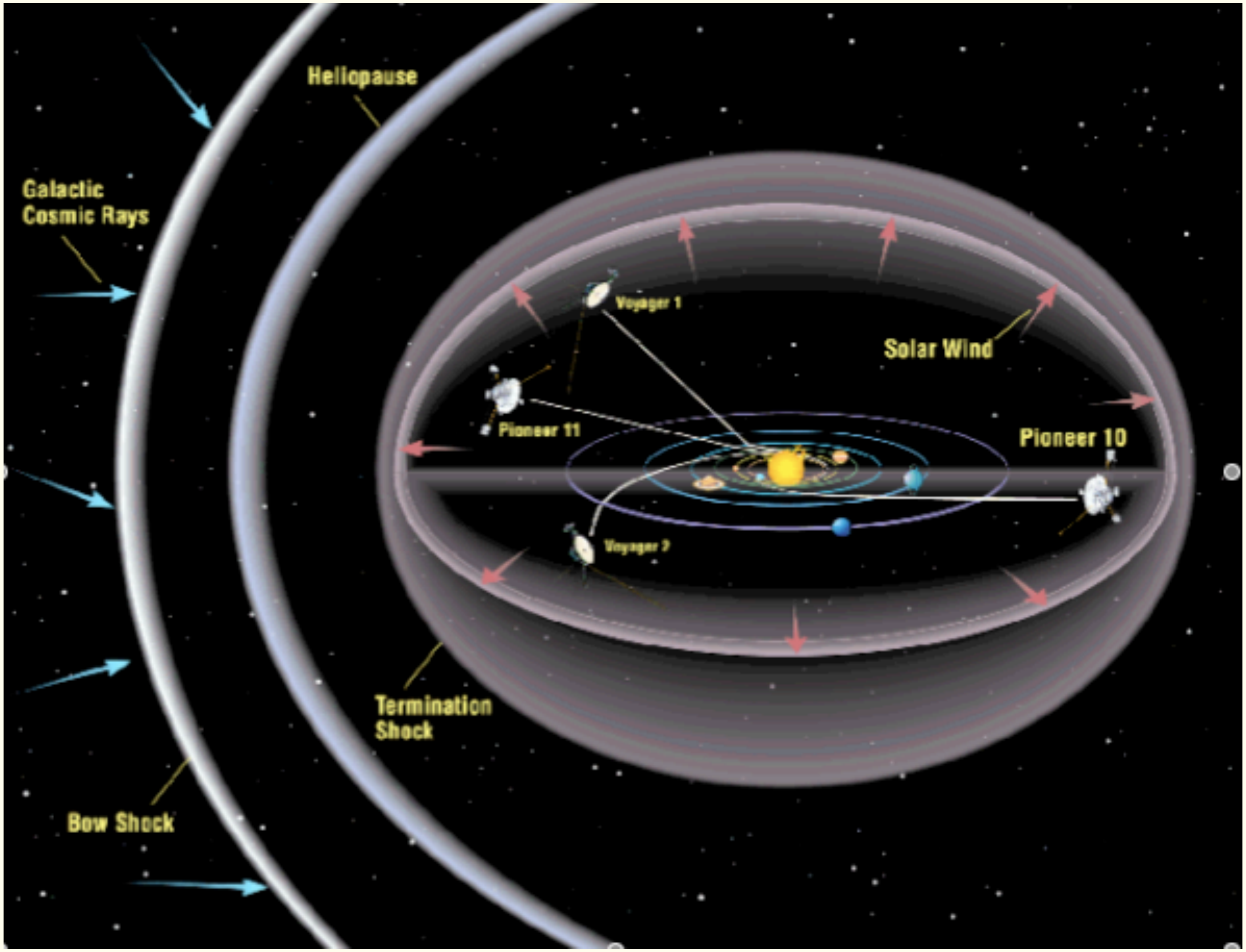
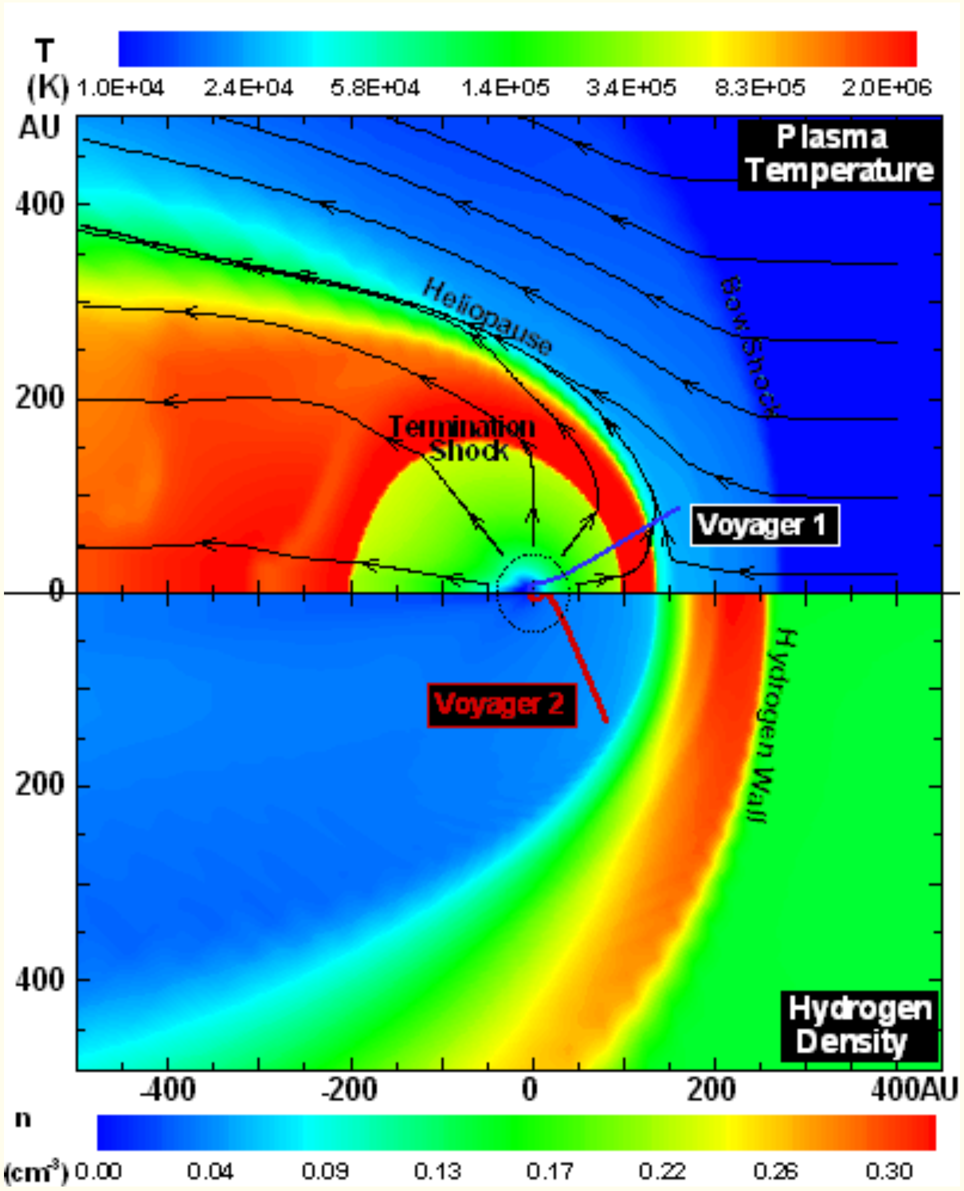


- The heliospheric boundaries are invisible and fluctuating.

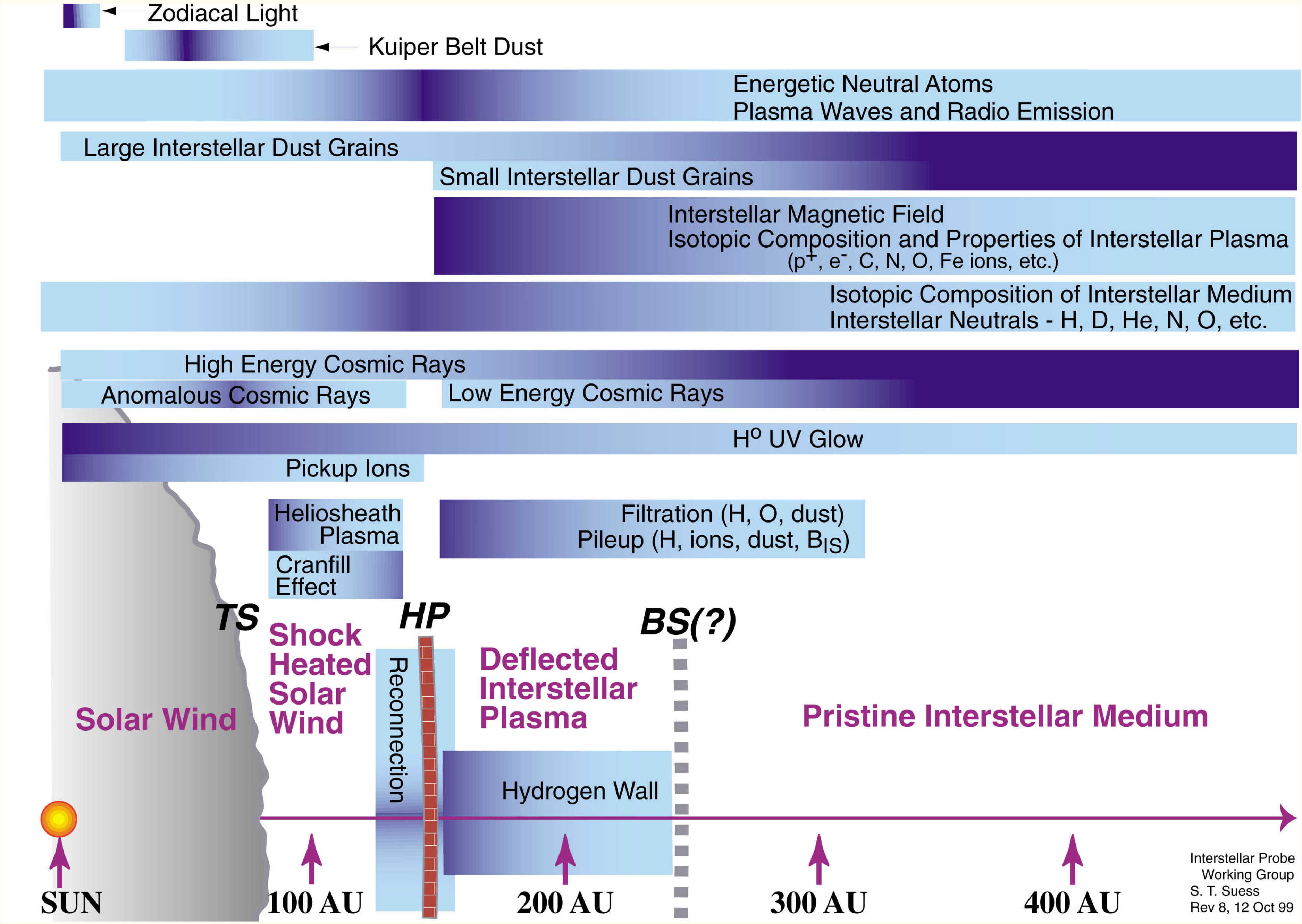
Hydrogen Wall

- Most neutrals stream in unperturbed, except neutral hydrogen, which due to charge exchange reactions, is heated and decelerated forming the **Hydrogen Wall**



Müller (2004)

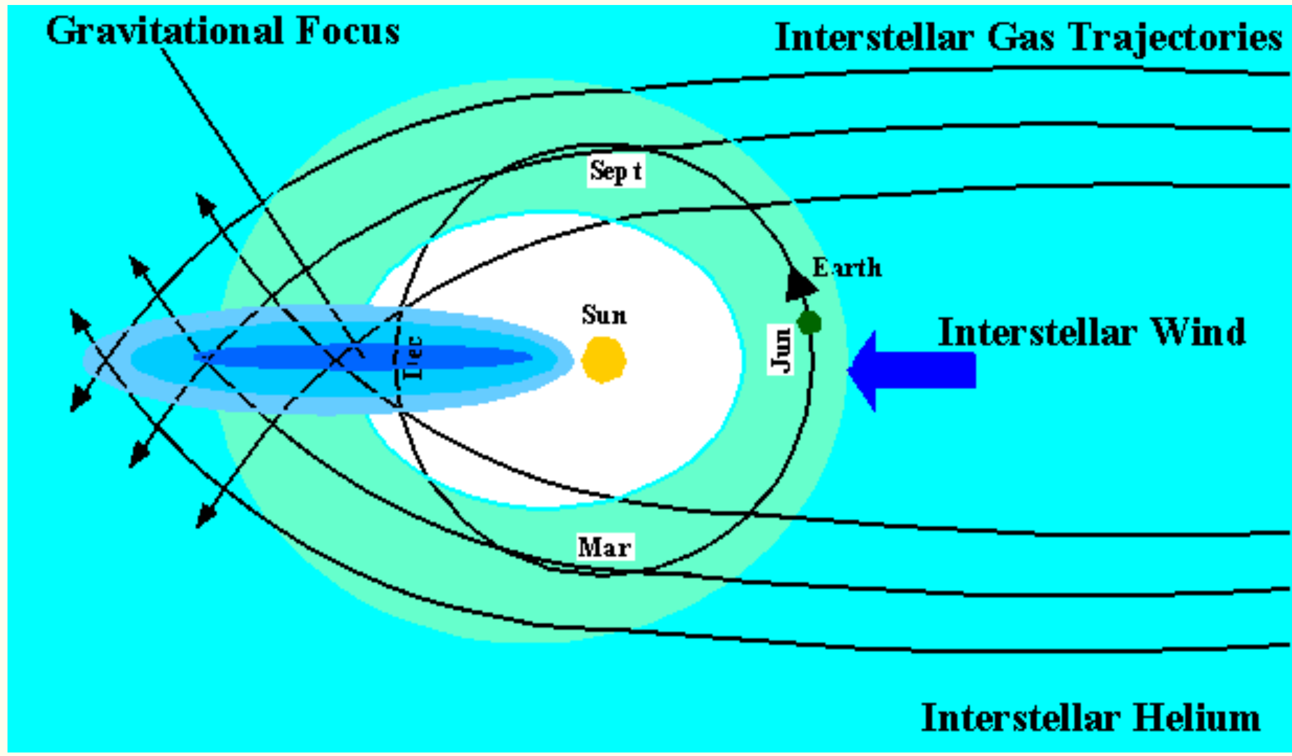
Entry of LISM into Heliosphere



Interstellar Neutrals in the Heliosphere: He

- LISM He velocity 26km/s T=6500K, n=0.013 cm^{-3}

- Photoionization of He lifetime ~100days at 1AU



- He is focused by the Sun's gravitational field on the downwind side
- Interstellar neutrals are ionized -> pickup ions (PUI)
  - First detected in 1985
- PUI are accelerated at TS -> anomalous cosmic rays (ACRs)

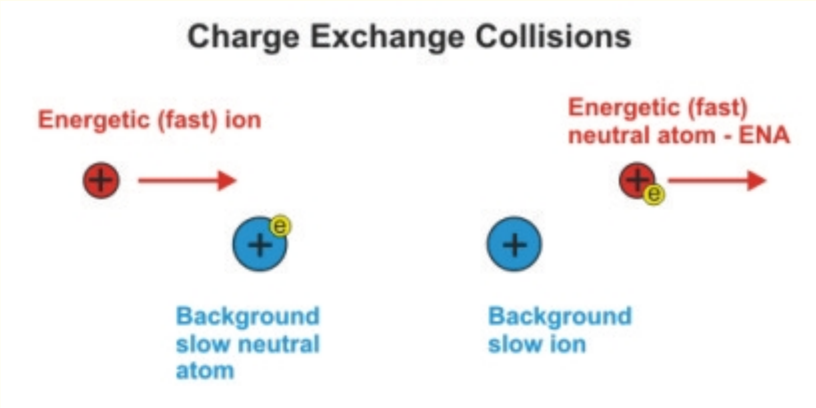
Energetic Neutral Atoms and Pickup Ions

- Charge exchange between incoming interstellar neutral H (26km/s) and solar wind protons H^+ (300-800km/s) → energetic neutral atoms (ENA) and pick-up ions (PUI)

$$H + H^+ \rightarrow H^+ + H$$

Pickup Ion (PUI)

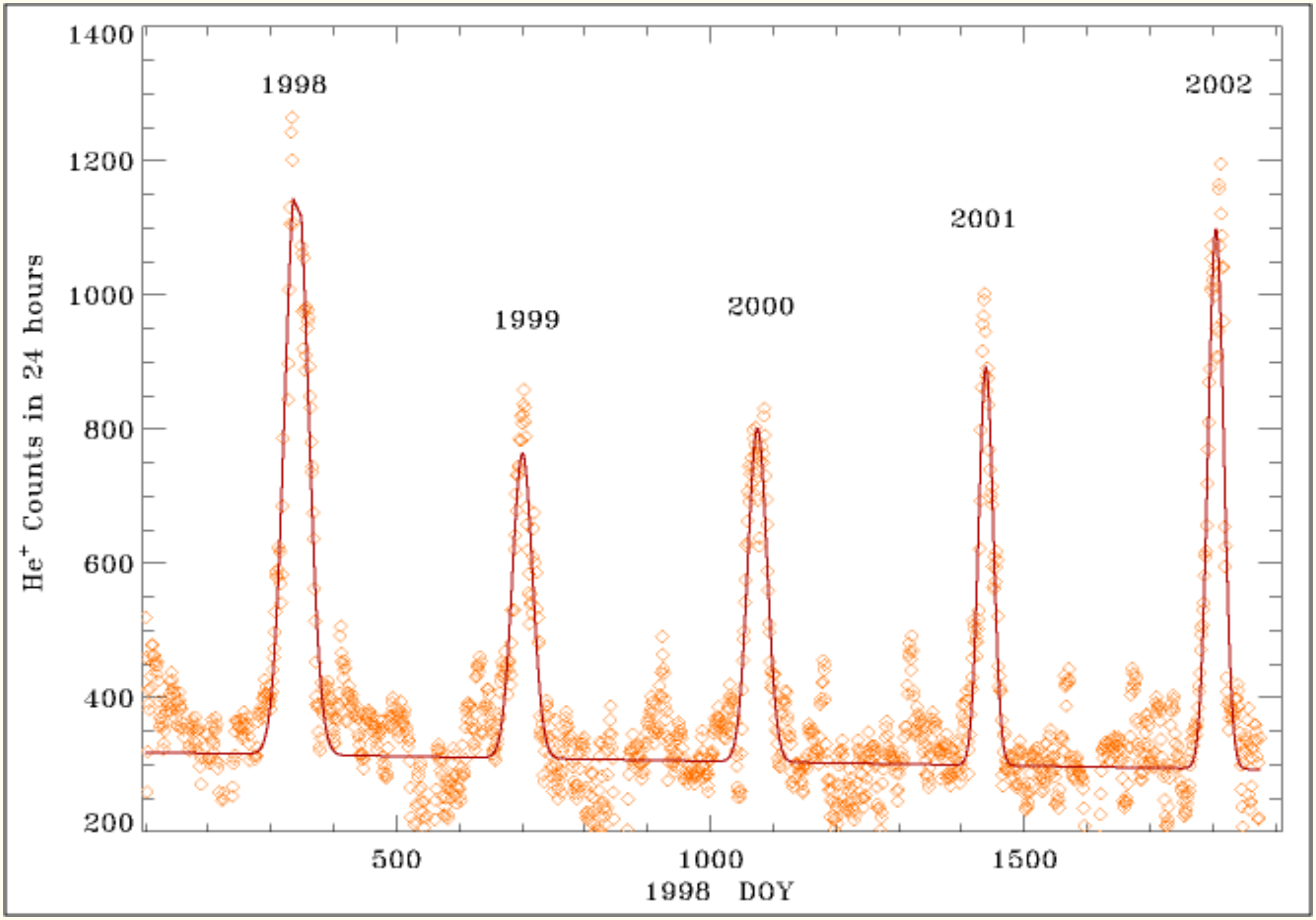
Energetic Neutral Atom (ENA)



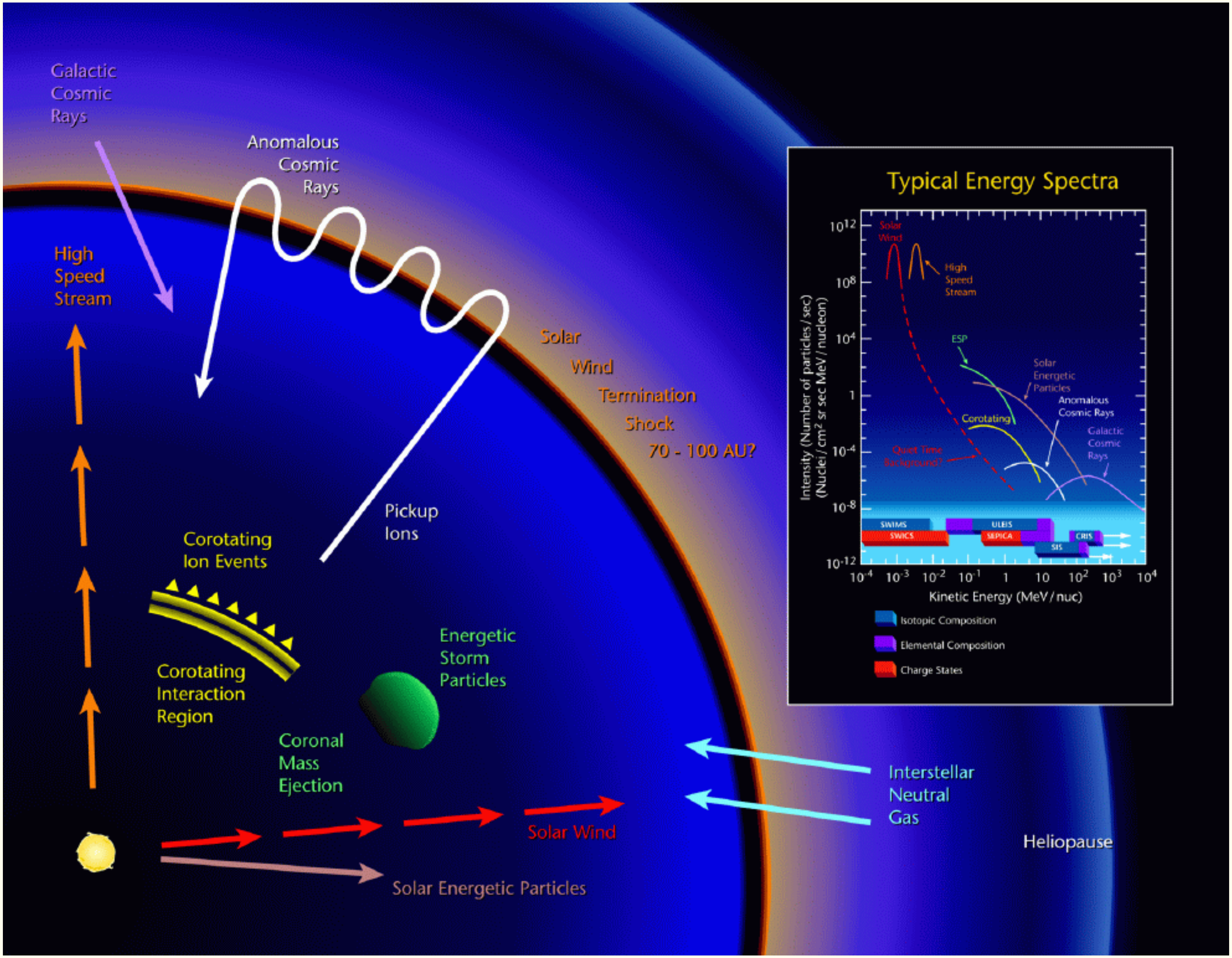
Mike Gruntman

- Only charge is exchanged, not momentum!

He-Cone Variability Over the Solar Cycle

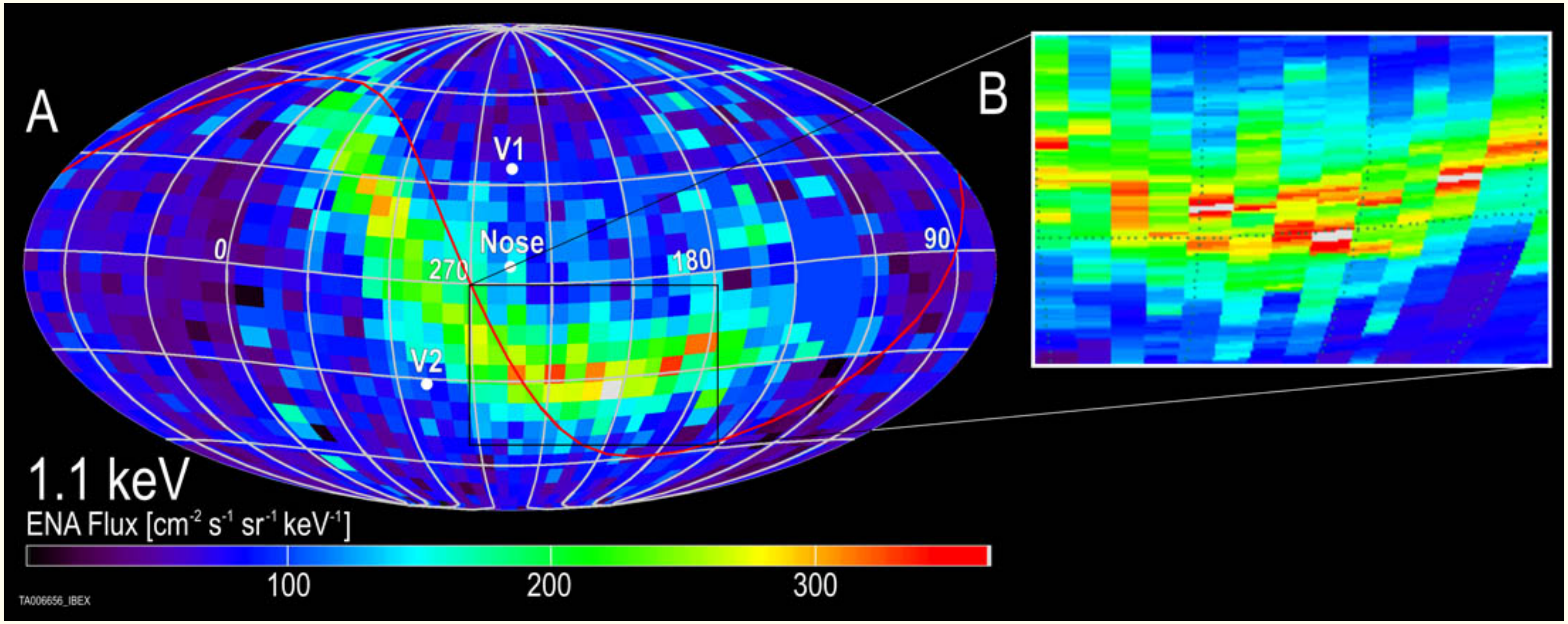


Acceleration of Pickup Ions

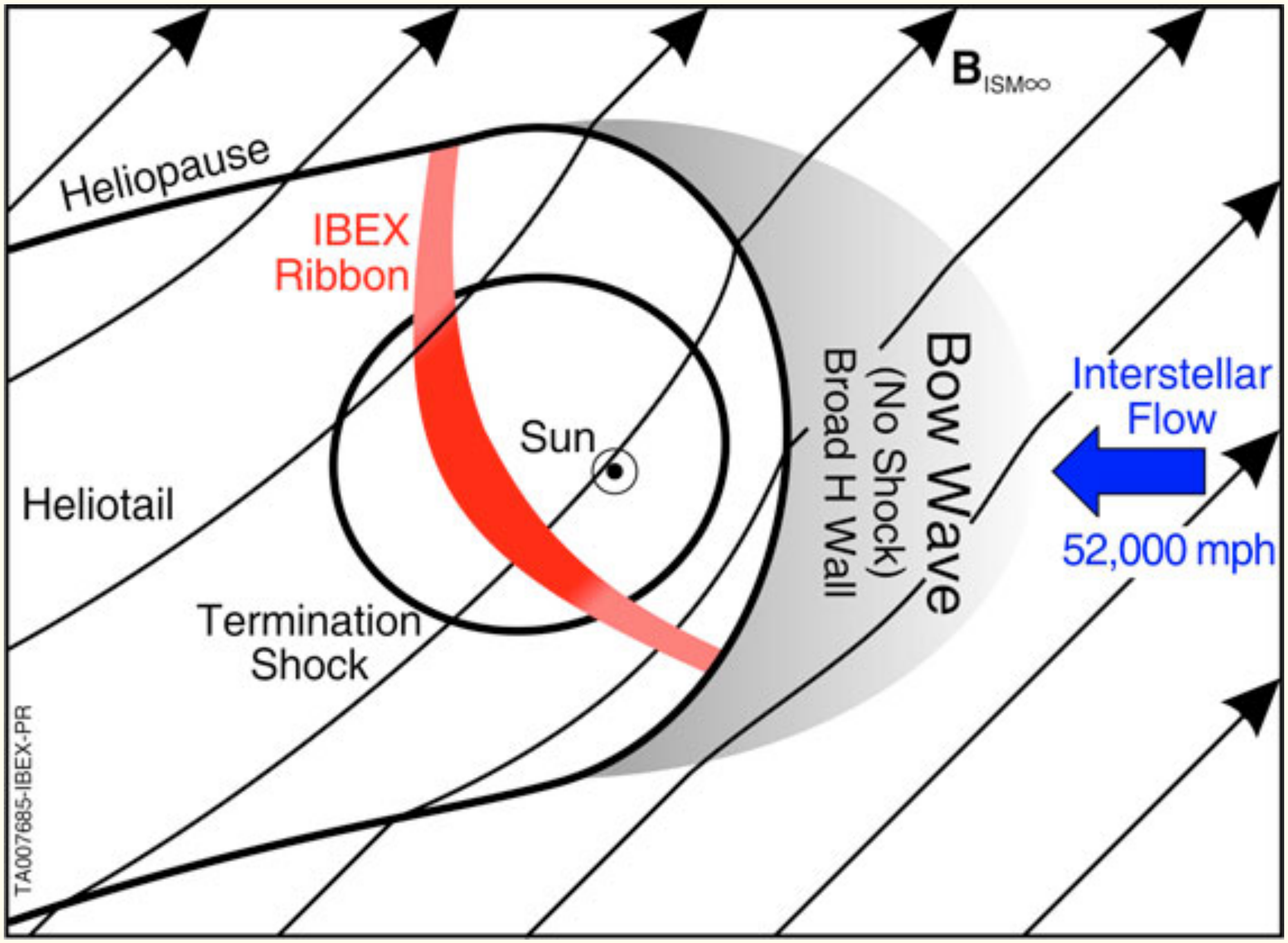


IBEX and Energetic Neutral Atoms (ENA)

- ENA imaging is the only way to globally observe the interaction between the solar wind and the interstellar medium (structures, dynamics, energetic particle acceleration, and charged particle propagation) in the complex region that separates our solar system from the galactic environment.

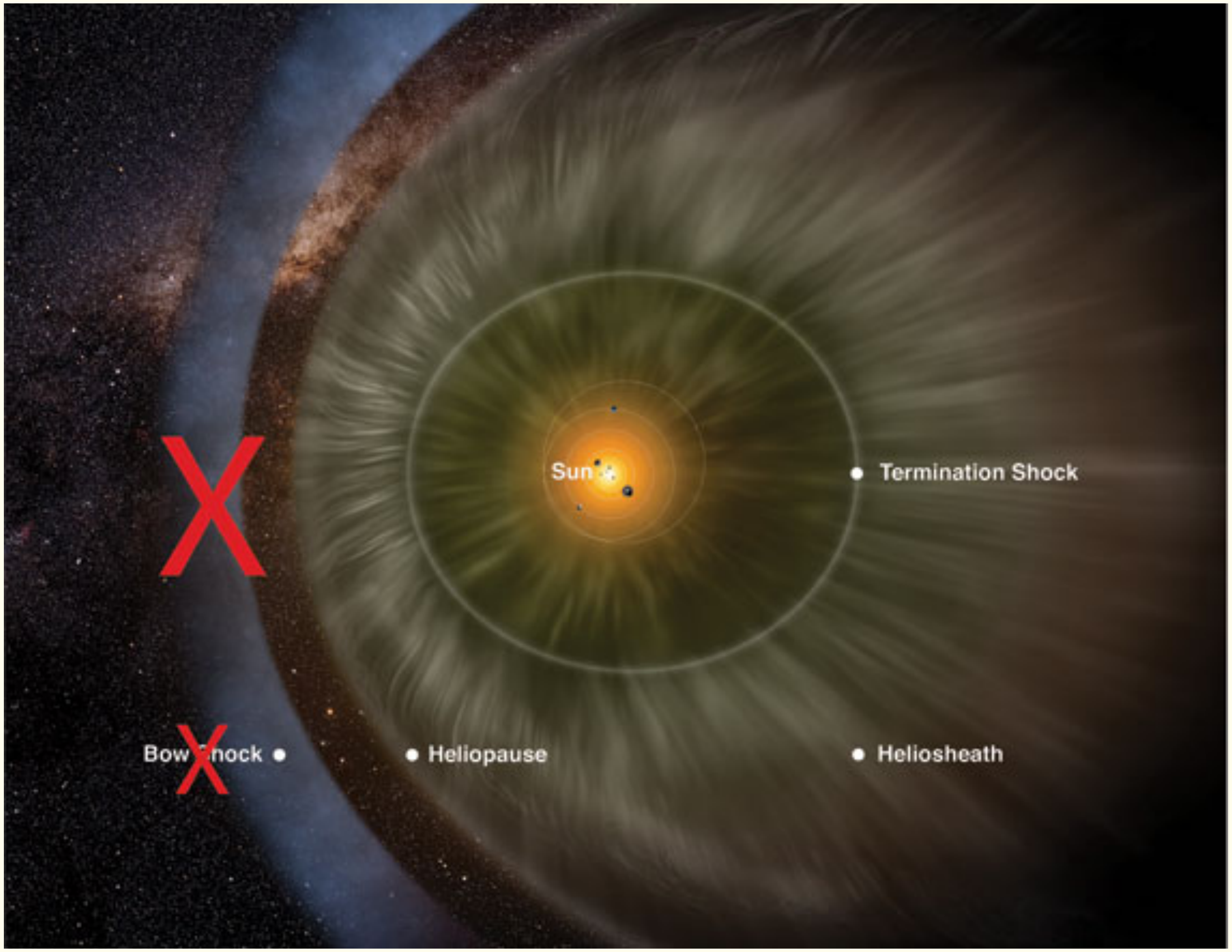


IBEX – News



B ISM∞
Heliopause
IBEX
Ribbon
Sun
Heliotail
Termination
Shock
Bow Wave
(No Shock)
Broad H Wall
Interstellar
Flow
52,000 mph
TA007685-IBEX-PR

IBEX - News

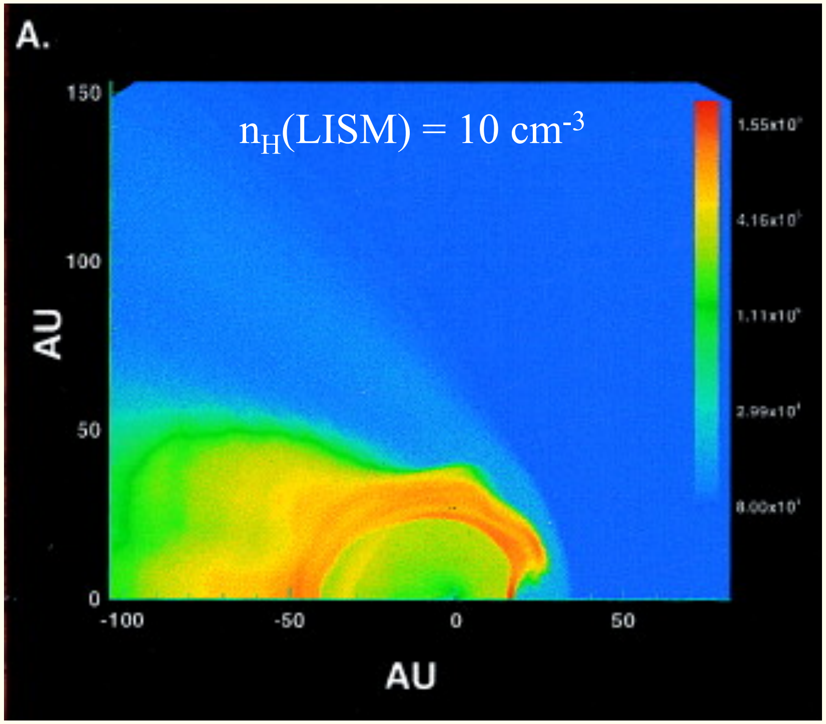


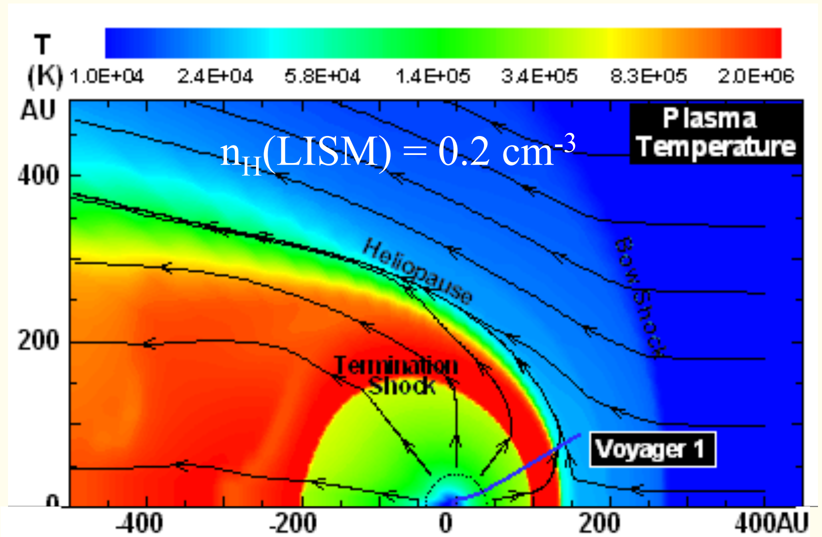
ISM Effects on Planets

- About 98% of diffuse material in heliosphere is interstellar gas
- Solar wind and interstellar gas densities are equal near Jupiter, or at ~6AU
- At 1AU (at Earth) in $10cm^3$ there is 1 atom of interstellar gas and 10 ions of solar wind
- Inner versus outer planets
- Cosmic rays:
  - Anomalous Cosmic Rays (ACRs) require neutral ISM
  - Galactic Cosmic Rays (GCRs) are sensitive to the heliospheric magnetic field
- In principle, core samples on inner versus outer planets would sort solar variations from interstellar variations

Interstellar Medium Impact on the Heliosphere

Zank & Frisch (1999)





Müller (2004)

- **How large of a density increase in the ISM is needed to significantly alter the structure of the heliosphere?**

- Increase the density of the surrounding LISM by only a factor of 50 (n_H from 0.2 to 10 cm^{-3}) and the termination shock (TS) shrinks from 100 AU to 10 AU.

Importance of the Heliosphere

- Heliosphere is the **first defense** in the three-layer shield system of the Earth against high-energy galactic cosmic rays, which consists of:

1. **Heliosphere** with the Sun's magnetic field carried out by the solar wind
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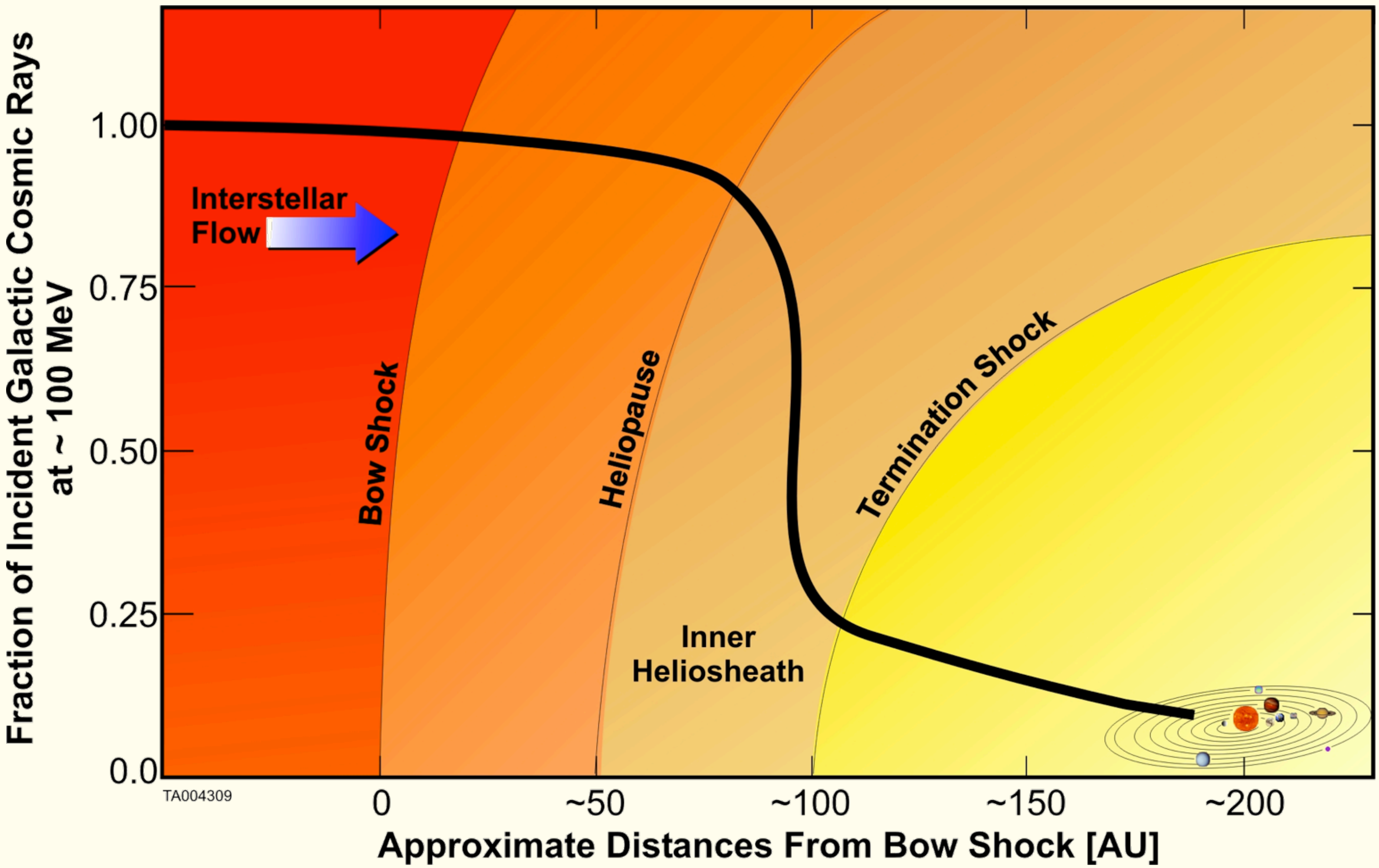
Galactic Cosmic Ray Shielding

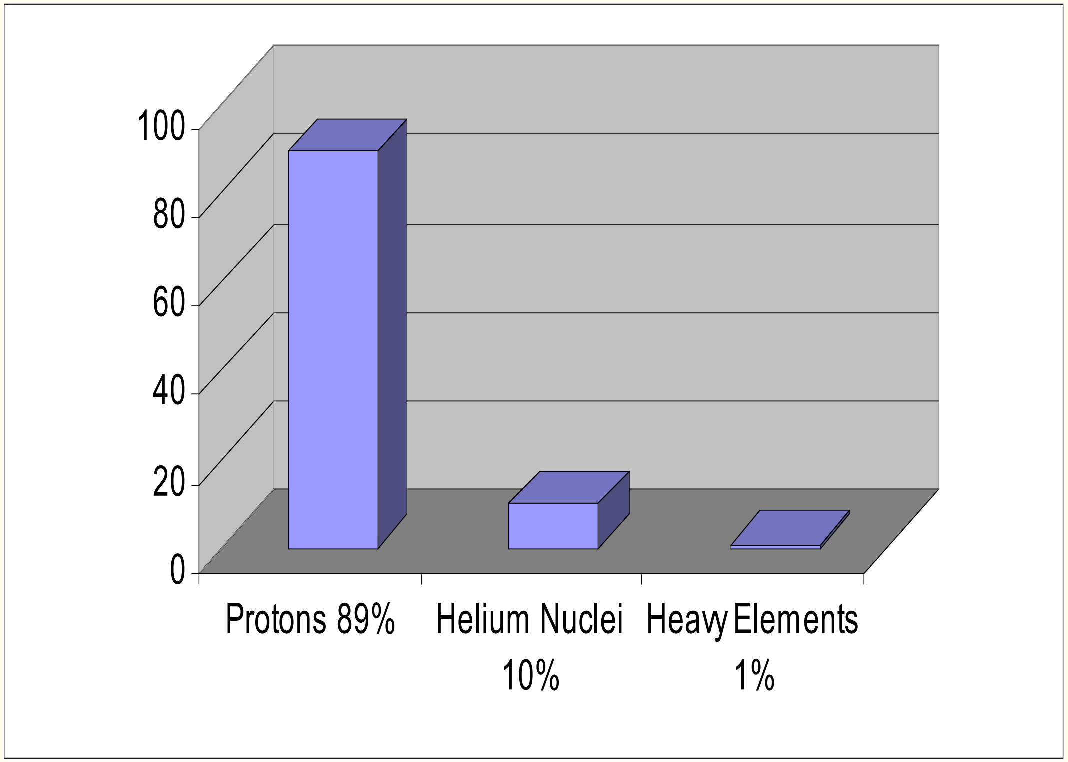


Galactic Cosmic Rays (GCRs)

- Most GCRs have energies between 100Mev (0.43 c) and 10Gev (0.996 c)
- GCRs originates in sources outside the solar system, but inside the Milky Way
- Most GCRs are probably accelerated in the blast waves of supernova remnants
  - Once a supernova explodes, its remnants (expanding clouds of gas and associated magnetic fields) can last for thousands of years and can accelerate cosmic rays by bouncing them back and fourth in the magnetic field of the remnant
  - Eventually GCRs build up enough speed to escape to the Galaxy

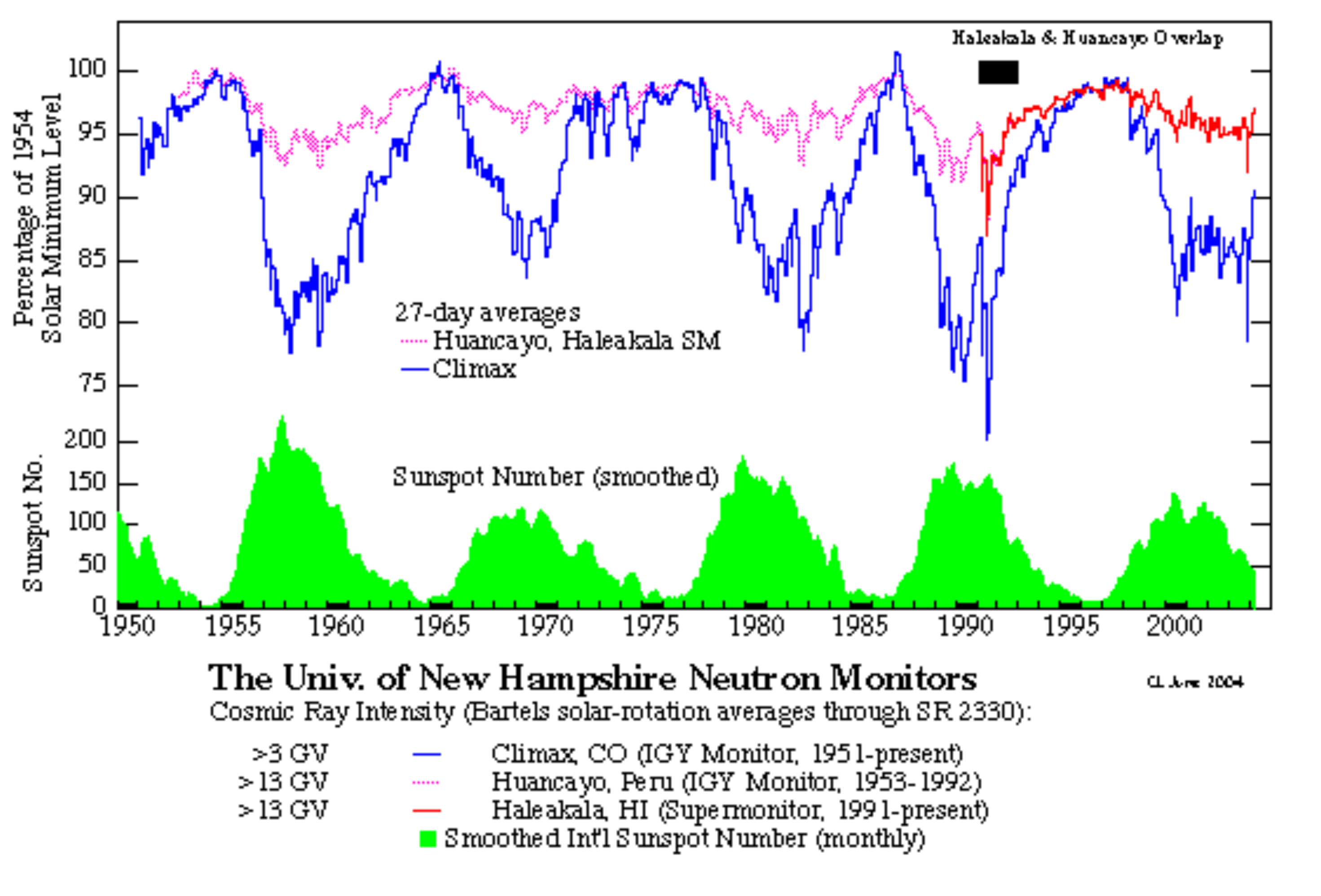
Galactic Cosmic Ray Composition

- They include essentially all of the elements in the periodic table. About 89% of GCRs are hydrogen (single protons), 9% helium nuclei, and about 1% heavier nuclei - in fact, all of the elements in the periodic table.
- GCRs for the most part are fully ionized atoms, i.e. bare nuclei.

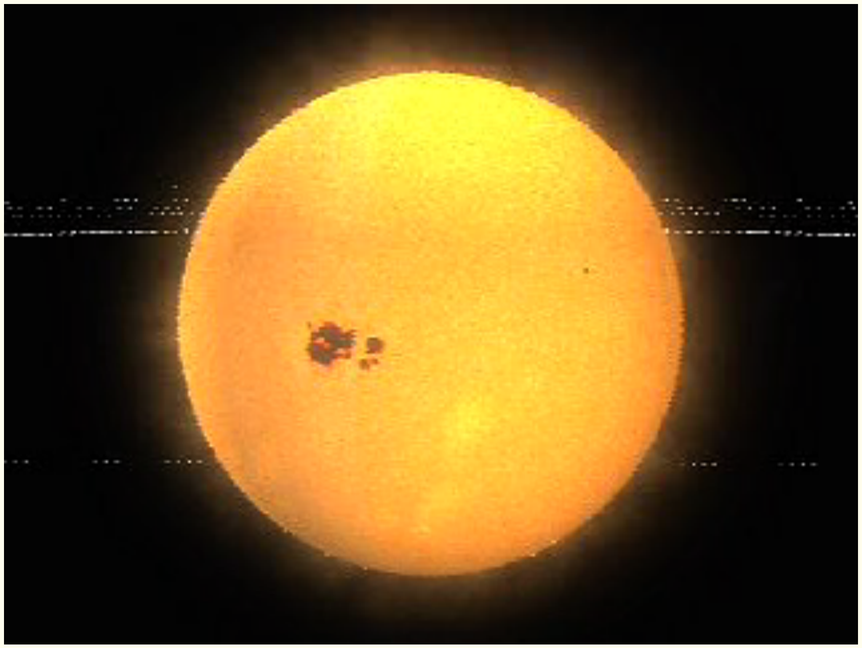


GCR Intensities Measured at Earth

- GCRs arrive at Earth after traveling through the Galaxy for several million years



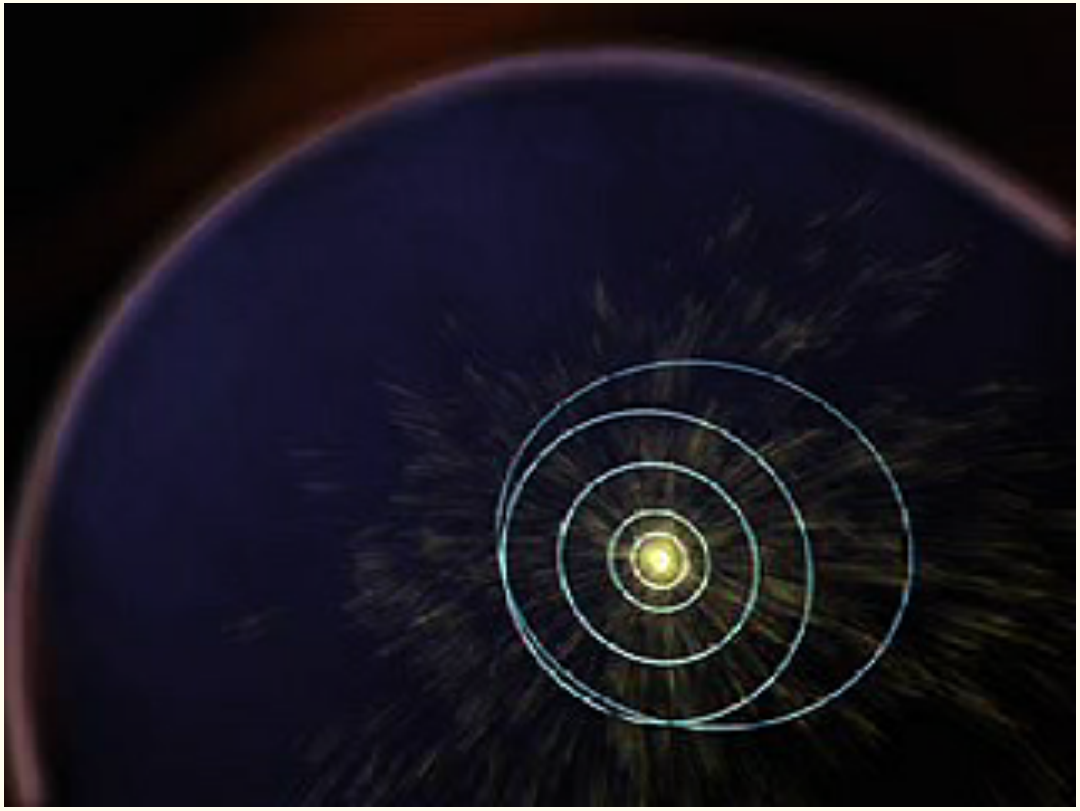
CME Impact on the Heliosphere



- In a period of about two weeks starting at the end of 17 October 2004 major flares erupted on the Sun. One was the most powerful ever recorded.
- The series of events and their effects were observed by spacecraft throughout the heliosphere.
- Ulysses was very near Jupiter, Cassini was near Saturn, and Voyager 1 and 2 were approaching the Termination Shock when the events occurred.

The CME Interaction with the Heliopause

- Even beyond the Termination Shock, the CME blast waves will continue to have effects.
- The CMEs may push the heliopause outwards by about 400 million miles (~3AU).
- It will likely take a year or two for the heliopause to settle back to it's normal position.



Mahalo!