# Global Heliosphere:
# Processes Responsible for Shape and Structure

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# Outline

- List of processes responsible for the shape and structure of the heliosphere
- Three important  comments (quoting from the White Paper 4060)
- Questions still open (quoting from the White Paper 4060)
- A cure for the above questions as suggested by the White Paper 4060
- The question how does the heliosphere look like?
- Why still we do not know the shape and structure of the heliosphere?
- Solution?
- Solution

# Processes Responsible for Shape and Structure of the Heliosphere

- new data from Parker Solar Probe of the solar wind (SW)
- interplanetary (IMF) and interstellar (ISMF) magnetic fields
- ionized and neutral components of Local InterStellar Medium (LISM)
- energetic neutral atoms (ENAs)
- pick-up ions (PUIs)
- anomalous cosmic rays (ACRs)
- galactic cosmic rays (GCRs)
- time-dependent phenomena

# Processes Responsible for Shape and Structure of the Heliosphere

- latitudinal dependence of the SW
- Sun’s effective magnetic dipole tilt with respect to the spin axis
- heliospheric current sheet (HCS)
- reconnection at the heliopause
- dissipative processes
- instabilities
- turbulence
- circum-solar dust

# Three important comments

## First

„Our heliosphere is the only astrosphere accessible to us to explore in detail how a star's wind interacts with its interstellar neighborhood, and what interplanetary environment such interaction creates for star system planets"

**Our Global Heliosphere:**
**Toward Understanding Astrospheres Around Other Stars**
**Provornikova et al. White Paper 4060**

## Second

„The Voyager mission discovered that our heliosphere shields solar system planets from galactic cosmic rays (GCR). Modulation of GCR flux in other astrospheres is a fundamental, open question and critical to assess the habitability of exoplanets"

## Third

„Understanding how dust flows through the heliosphere is the key for using observed dust traces in other astrospheres to unravel interactions between stellar winds and ISM"

Provornikova et al. White Paper 4060

In the light of our knowledge today, „the following fundamental science questions (top-level) on the nature of the heliosphere remain open:

- *How are galactic cosmic rays modulated in the heliosphere?*
- *What pressure components uphold the heliosphere boundary?*
- *Does the heliosphere have an open or closed tail?*
- *How is interstellar dust filtered through the interaction region at the heliosphere boundary?*
- *How do shock waves propagate through the heliospheric boundary, and what is their role in particle acceleration?*
- *What is the structure of the hydrogen wall, and how does it relate to similar structures in other astrospheres?*
- *What are the properties of the local interstellar medium?"*

Provornikova et al. White Paper 4060

# A cure for the above questions

It is obvious, „to answer these questions and fill the gaps in our understanding requires the near-term (2030-2050) investigation of the heliospheric boundary and local ISM by making new both in-situ measurements of charged and neutral particles, magnetic fields and dust, and remote observations in energetic neutral atoms (ENAs) and backscattered hydrogen Lyman-α emission"

Provornikova et al. White Paper 4060

# The question of what  the heliosphere looks like?

The recipe above is definitely a good one. But this, on the other hand, still does not answer the question of what the heliosphere looks like?
To answer this question and fill the gap in our modeling, we have to accept the following fact:
there is a long series of publications in which numerical models of the heliosphere are validated by observations and  measurements, but there are still problems with fitting all key observations into one numerical solution at once.

# The reason of above difficulties

The magnetohydrodynamic approach to the description of the SW-LISM interaction is not a good enough numerical tool to obtain the correct shape and structure of the heliosphere.

The MHD code does not imitate nature, and the simplifications introduced into the models distort the real picture of the heliosphere

# SOLUTION?

Therefore we need the numerical methods that allow us to fully cover the physics of the problem being solved.

This is guaranteed by the use of fully kinetic Particle-In-Cell (PIC) code that rigorously solves for everything: Debye-scale plasma oscillations, electron and ion Larmor-scale physics, the propagation of electromagnetic waves, collective macroscale dynamics, etc.

But existing computers are unable to cope with this task.

# SOLUTION ☺

A promising compromise is the hybrid-kinetic model. Non-relativistic electrons are taken to be a massless, neutralizing, MHD-like fluid, while the ions are treated kinetically. This eliminates Debye-scale physics, plasma oscillations, and the speed of light, while guaranteeing scale separation and capturing crucial microscale phenomena. Consequently, the resulting system of equations are much cheaper to solve numerically. This is the approach which Kunz et al. (2014) have adopted in building Pegasus, which solves the hybrid-kinetic equations using the PIC approach.

# Even better Solution ☺ ☺

Or code created with the use of artificial intelligence AI