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Investigating the heliosphere and ISM - a European perspective

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Abstract

After the exciting in-situ observations of the termination shock and the entry of the Voyager 1 spacecraft into the inner and possibly outer heliosheath, there is a growing awareness of the significance of the physics of the outer heliosphere. Its understanding helps to clarify the structure of our immediate interstellar neighborhood, contributes to the clarification of fundamental astrophysical processes like the acceleration of charged particles at a stellar wind termination shock and beyond, and also sheds light on the question to what extent interstellar–terrestrial relations are important for the environment of and on the Earth and of exoplanets. In order to explore the boundary region of the heliosphere, it is necessary to send a spacecraft to perform advanced in-situ measurements particularly in the heliosheath, i.e. the region between the solar wind termination shock, and the heliopause, as well as in the (very) local interstellar medium. Solar activity is decreasing to 'normal values' below those of the Grand Solar Maximum which was typical of the space age so far. This is likely to reduce the size of the heliosphere and allows us to study a 'normal' heliosphere by launching an Interstellar Probe (IP) which will also provide within a shorter time than previously believed the first comprehensive measurements of key parameters of the local interstellar environment such as its composition, state, and magnetic field. Together with an accurate determination of the state of the heliospheric plasma across the heliosphere, these quantities are crucial to our understanding of how the heliosphere, and, much more generally, astrospheres, are formed and how they react to varying interstellar environments.

1. Introduction

After the exciting in-situ observations of the termination shock and the entry of the Voyager 1 spacecraft into the inner and possibly outer heliosheath, there is a growing awareness of the significance of the physics of the outer heliosphere. Its understanding helps to clarify the structure of our immediate interstellar neighborhood contributes to the clarification of fundamental astrophysical processes like the acceleration of charged particles at a stellar wind termination shock and beyond, and also sheds light on the question to what extent interstellar–terrestrial relations are important for the environment of and on the Earth and of exoplanets. In order to explore the boundary region of the heliosphere, it is necessary to send a spacecraft to perform advanced in-situ measurements particularly in the heliosheath, i.e. the region between the solar wind termination shock, and the heliopause, as well as in the (very) local interstellar medium.

Figure 1: Image of LL Orionis the astrosphere, as a visualization of our heliosphere. Credit: Hubble

As discussed in above and in section 2, there are a number of reasons for an interstellar mission. There are also a number of "places to go", as discussed in section 3. Because such a mission will take a long time to reach the heliosheath and the very local interstellar medium and it will therefore also need to return science results “on its way out there”.

2. Why again after the Voyagers?

After the already extremely successful Voyagers have reached and passed the termination shock, one may legitimately ask why one would want to fly another mission towards our heliosphere's boundary and on into interstellar space. Some of the most important reasons are listed below:

- **New physical understanding:** Our understanding of the shape of the heliosphere has undergone substantial changes in the past 50+ years. This is partially due to our constantly improving understanding of the boundary conditions involved, but also by our increased ability to model the very complex physics involved in shaping the heliosphere. The instrumentation on the two Voyagers was not primarily designed to measure the physical conditions in the heliosphere and so our understanding of them would improve in a giant leap if we knew them better.

- **New enabling instrumentation:** Improved instruments are key to a better understanding, especially new, enabling technologies such as imaging of energetic neutral atoms (ENAs) hold the promise to revolutionize our understanding of the heliosphere.

- **New observations:** New enabling technologies, especially those of ENA imaging, would allow us to image the structure of the heliosphere in 3D as we acquire such images along our trajectory out to interstellar space. IBEX has shown how this can be done from one point, only one AU from the Sun, but an interstellar probe would revolutionize this technique by providing a constantly increasing baseline.

- **New solar-system targets:** Our understanding of potential flyby targets has changed enormously in the past decades and an interstellar probe could (and should) increase our knowledge of the huge variety of bodies in our solar system

3. Where to aim?

The heliosphere is big and we can't go everywhere. There are other mission proposals, especially by China, and a close coordination in choosing “where to aim” the spacecraft is imperative to optimize the science that can be done with an interstellar probe. Apart from the technical implementation, several scientific factors should be considered:

- **Nose:** The shortest path out into the VLISM may be to fly to the nose of the heliosphere. This obviously would allow for the shortest mission time, but is constrained by the planetary alignment with Jupiter which in turn put strong constraints on the mission schedule.

- **Poles:** A mission to the heliospheric poles would be a first and allow us to discriminate between different models of the heliosphere. This suggestion, however, requires an extremely high Δv which is - to our knowledge - currently no available. A lower inclination with respect to the ecliptic plane is of course possible.

- **Tail:** A mission to the heliotail would be new and has the potential to see different plasma-physical regimes (due to mass loading by pickup ions) than previous missions.

- **Side:** A mission “to the side” of the heliosphere would also be new and has the potential to obtain the best estimate of the overall shape of the heliosphere, especially using ENA imaging.

- **Ribbon:** Pointing the interstellar probe towards the ribbon has been discussed at many meetings but needs to be weighed against other potential science gains.

- **Planetary objects:** A key point for consideration is the location and accessibility of planetary objects along the missions orbit. Because of the long duration of the mission, we will be in dire need of new science results every decade or so. Only so can scientific interest in the mission be maintained in the wider science community which in turn is required to ensure the funding of such a long-term project.

4. Summary and Conclusions

An interstellar probe, or better even, a sequence of coordinated missions of international cooperation would greatly enhance our understanding of our local interstellar neighborhood.