Proposal to ISSI for a Team to Address the Physics of the Heliopause

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ABSTRACT

This proposal is for an ISSI team to study the physics of the heliopause in the context of the Voyager observations, with the goal of maximizing the science return from the mission. The team consists of the Principal Investigators or their representatives from each of the functioning instruments on Voyager and a broad selection of theorists/modelers. The two Voyager spacecraft are exploring a totally uncharted region of space and will make the first crossings of the heliopause and enter interstellar space.

This proposed team is timely because of the likelihood that the Voyagers will soon see (or may already be) seeing phenomena associated with the heliopause. Because the phenomena are new it is desirable to have a team diverse team try to understand and predict the physical processes which occur and how these be observed with the Voyager instruments. We have commitments to participate on the team from:

- Rob Decker and Tom Krimigis from the LECP instrument (one will attend)
- Don Gurnett from the Radio-Wave instrument
- Norm Ness from the Magnetometer
- John Richardson from the plasma instrument
- Ed Stone from the CRS instrument
- Jim Drake, a theorist
- Vladimir Florinski, a theorist.
- Vladimir Izmodenov, a theorist
- J. R. Jokipii, a theorist
- Merav Opher, a theorist
- Roma Ratkiewicz, a theorist
- Nathan Schwadron, who is a theorist and who also represents the IBEX mission

We will schedule three four- or five-day meetings beginning as soon as practicable after proposal approval and extending over a period of 12-18 months. In addition to the benefit to the scientific return from the Voyagers, we expect a number of scientific papers with predictions for characteristics of the heliopause boundary to result from our studies. The only facilities required are a meeting room at ISSI and internet access. We ask for the standard support, which includes living expenses while in Bern for each of the participants and travel support for the team coordinator.

ISSI is the ideal venue for this study for a number of reasons, it provides a venue conducive to studying these issues, it facilitates the attendance of European investigators and ISSI has a history of enabling such studies.

1. Scientific Rationale

The outermost frontier of the heliosphere is the heliopause (HP), the boundary between solar and interstellar plasma. The two Voyager spacecraft are now in the heliosheath, the region between the termination shock and the heliopause, and will hopefully cross the heliopause in the next several years. Observations from the Voyagers and model predictions suggest that we may be quite close to this boundary.

We at present know very little about the heliopause. In an ideal hydromagnetic fluid, the heliopause would be a very thin contact surface separating quite distinct fluids. However, some work suggests that the heliopause is much thicker, with a transition regions as thick as 10 AU (e.g., Fahr and Neutsch, 1986).

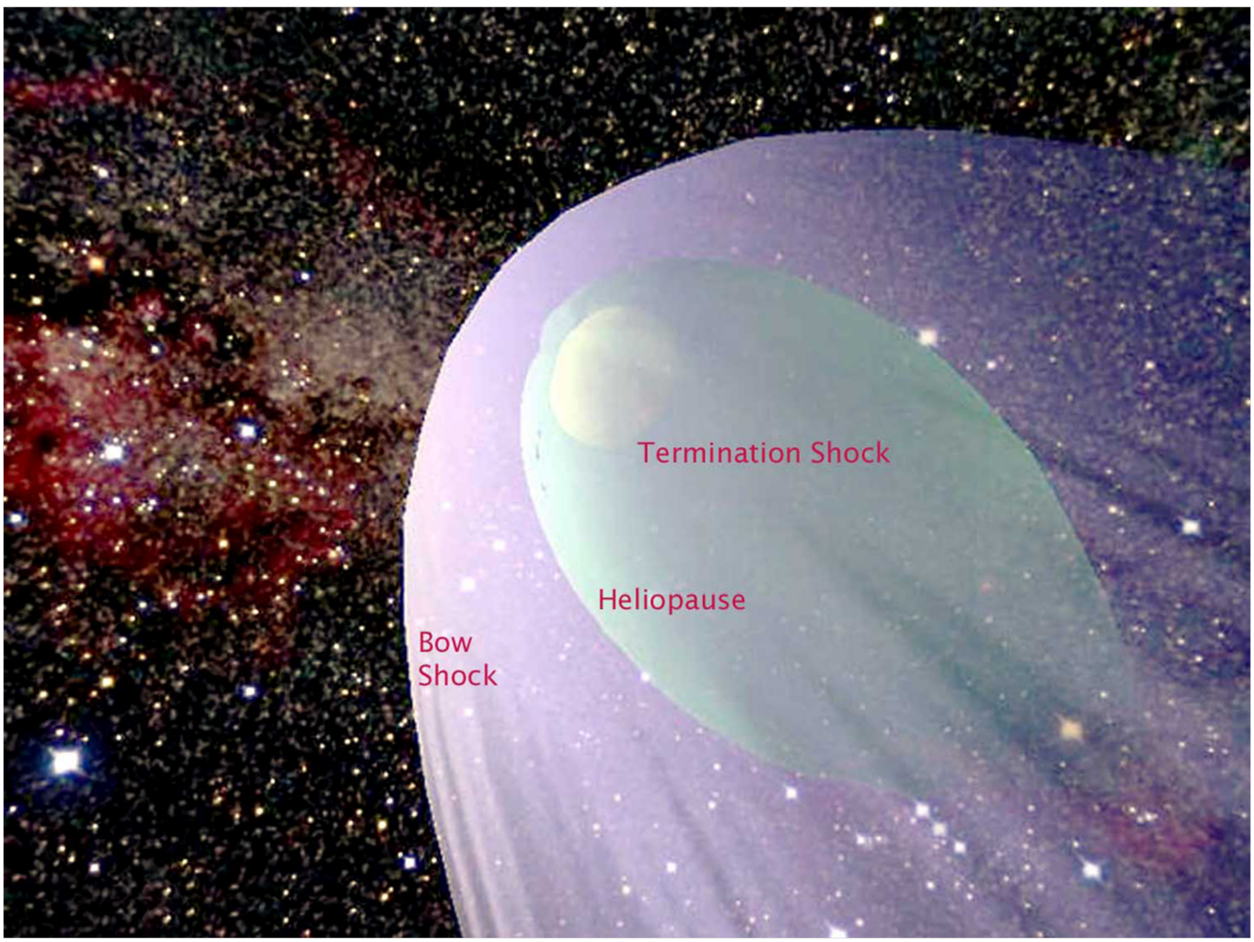

Fig. 1.— Schematic view of the heliosphere, illustrating the termination shock and heliopause. The Sun is near the center of the smallest spheroidal surface.

1.1. Background

The two Voyager spacecraft were launched in 1977 on a trajectory toward the giant planets, which serendipitously was also toward the nose of the heliosphere. After the successful planetary encounters, the renamed Voyager Interstellar Mission continued outward with the goal of making the first *in-situ* observations of the local interstellar medium (LISM). The Voyager spacecraft have both crossed the termination shock and are in the heliosheath, making the first in situ observations of this region of shocked solar wind. The heliosheath extends to the heliopause; beyond the heliopause is the LISM. The goal of the Voyager Interstellar Mission, as the name implies, is to make the first in situ observations of the region outside our heliosphere.

The Voyager spacecraft are relatively healthy. The active instrument teams are the Plasma Science experiment (PLS) which measures thermal plasma, the Low Energy Charged Particle experiment (LECP) which detects particles in the tens of keV to tens of MeV range, the Cosmic Ray subsystem (CRS) which measures GCRs and ACRs, the magnetometer experiment (MAG), and the Plasma Wave subsystem (PWS) which observes plasma and radio waves. The V1 PLS experiment failed soon after the Saturn encounter in 1980-, but the V2 PLS experiment is returning excellent data from the heliosheath. The V2 PWS returns valuable data in many channels and detected emissions at the TS crossing; however, the wide band receiver failed in 2003, the 17.8 Hz channel is intermittent, and the upper 8 channels (1 kHz to 56 kHz) have decreased sensitivity. The V2 MAG experiment has a continuing problem with noise generated by the spacecraft and other instruments which makes reliable analysis very difficult, but the higher magnetic field strengths in the heliosheath have made that problem more tractable. Otherwise the instruments work well and all have the sensitivity to continue observations in the environments expected in the heliosheath and in the LISM.

As the Voyagers proceed outward, they are making measurements of totally unexplored regions of the heliosphere. The Voyager crossings of the TS provided the first concrete information on the scale size and the shape of the heliosphere. Voyager 1, in the northern hemisphere of the heliosphere, crossed the TS at 94 Astronomical Units (AU) while V2, in the southern hemisphere, crossed it at 84 AU. Based on these TS distances and model predictions, the HP and LISM are probably 30-50 AU further out. The asymmetry in the TS crossing distances verifies that the southern hemisphere of the heliosphere is pushed inward, probably by the interstellar magnetic field. Although the uncertainties in the HP position are large, the Voyager spacecraft have a good chance of reaching this boundary in their operational lifetimes. The observed asymmetry may allow V1 and V2 to cross the HP at roughly the same time and provide simultaneous observations of the LISM.

The V1 and V2 TS and heliosheath observations have provided many surprises that we are still working to understand. A major outstanding problem is the source of the anomalous cosmic rays (ACRs). Before the Voyager TS crossings, the ACRs were thought to be accelerated at the TS. The ACR source was not found at either Voyager TS crossing; new hypotheses place the source either in the flanks of the TS or nearer to the heliopause. Plasma flows in the heliosheath are also a puzzle, with radial flows at V2 a factor of two greater than at V1 and flows at V2 more tangential than meridional, both contrary to predictions. The heliosheath magnetic field is highly variable on time scales of tens of minutes to hours, showing that this region is very dynamic. None of the foregoing observations were anticipated. These and future revelations of the unexpected nature of the heliosheath, HP, and LISM will continue to drive theoretical modeling leading to improved understanding of the physics of the heliosheath.

Recent observations show that the radial solar wind flow observed at V1 has decreased to zero and that the other flow components are small [Krimigis et al., 2011]. This speed reduction suggests the exciting possibility that the Voyagers are nearing the HP and could be entering a transition regions between the solar wind and LISM.

In addition an exciting new scientific opportunity is presented by the Interstellar Boundary Explorer (IBEX) mission. This spacecraft observes neutral atoms generated by charge exchange in the inner and outer heliosheaths and its goal is to understand the global properties of the heliosphere, making all-sky maps of the energetic neutral atoms every six months. Voyager in situ observations of the plasma and particle distributions are critical for the understanding the source of the neutrals observed by IBEX and IBEX gives us a chance to put the Voyager observations into a global perspective.

2. Schedule and Discussion Points

The first part of the first meeting will be devoted to discussion of the Voyager instruments, their most-recent observations and their capabilities for making measurements in the LISM.

Subsequent to the instrument discussions we anticipate that there will be a discussion of other relevant observations, such as those from IBEX.

The third part of the discussion will involve discussions of the results of modeling and theory of relevant physical processes in the outer heliosheath and heliopause.

Possibilities for the latter include:

- Discussions of the latest global modeling of the three-dimensional heliosphere and the results of fitting the most-recent data to models. This will include the effects of the change from principally radial flow outward from the Sun to a tangential flow, more aligned with the heliopause surface.

- Some recent models proposed for the acceleration of anomalous cosmic rays suggest that the acceleration will increase near the heliopause, and these models will be discussed.

- The effects of the decrease in radial flow velocity in compressing considerably the distance between the oscillations in the heliospheric current sheet. This latter effect is playing an increasing role in considerations of the physics.

- Similarly, the small distance between successive folds in the interplanetary current sheet may well result in considerable reconnection between the oppositely directed magnetic fields. This will distort and make more turbulent the magnetic field and also possibly accelerate charged particles.

- The radial flow velocity as determined from the LECP instrument on V1 has recently become very low, which may indicate that V1 is now very close to the heliopause. This important observation will also be the subject of discussion.

- The basic nature of the boundary, whether it is an extended layer or a sharp boundary analogous to a magnetopause, is not known and will be discussed.

- Observational predictions and tests for these models will be developed and discussed

The character of energetic particle transport in the distant heliosheath and especially in the vicinity of the heliopause could be quite distinct from the other regions of the heliosphere. The magnetic field structure is dominated by a tightly wrapped oscillating heliospheric current sheet which is transported to higher latitudes by the non-radial heliosheath flows. Because of the solar cycle, the Voyagers are bound to eventually enter a region dominated by the sector field formed during the preceding solar maximum. As the plasma flow slows down on approach to the heliopause, the distance between the folds of the current sheet decreases to the point where it becomes comparable to the cyclotron radius of an energetic ion, such as a galactic cosmic ray. Then, a charged particle can effectively drift across a stack of magnetic sectors with a speed comparable with the particle's velocity. Particles should also be able to efficiently diffuse across the mean magnetic field if the distance between sector boundaries varies randomly. The region of the heliopause could thus be much more permeable to cosmic rays than previously thought. This proposed transport mechanism could explain the very high intensities (approaching the model interstellar values) of galactic cosmic rays measured by Voyager 1 during 2010-2011. A

The schedules of the subsequent team meetings will be decided upon after the end of the previous meeting.

REFERENCES

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This preprint was prepared with the AAS LaTeX macros v5.2.