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A New Vision of Science and Strategy for an Interstellar Probe Mission

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ABSTRACT

The recent in situ and remote observations from the Voyager Interstellar Mission (VIM), the Interstellar Boundary Explorer (IBEX), and the Ion and Neutral Camera (INCA) on Cassini have revealed the interaction of the heliosphere with the very local interstellar medium (VLISM) to be much more complex than described by our present-day concepts. These discoveries call for a major revision of the strategy for the Interstellar Probe, a mission to explore the interstellar medium surrounding the Solar System. Voyager 1 and Voyager 2 continue to reveal unanticipated flow patterns and significant fluxes of energetic particles in the heliosheath (beyond the solar wind termination shock) while pointing to a more remote location for the modulation region and source of the anomalous cosmic rays (ACRs). Remarkably, over the past year Voyager 1 has been reporting near-zero plasma flows (tens of kilometers per second) beyond 115 AU.

One implication of this flow stagnation is that Voyager is already in a "transition layer" that could lead to the interstellar plasma. Consequently, an Interstellar Probe Mission may "punch out" into the deflected interstellar plasma flow at a much smaller distance than previous models had predicted. Global imaging observations by IBEX and INCA of energetic neutral atoms (ENAs) originating from the interaction region(s) of the solar wind and the VLISM show unexpected structure and possible time dependence on a variety of scales. In addition to the general "glow" of the sky in ENAs, IBEX revealed a relatively narrow "ribbon" of enhanced atomic hydrogen emission from ~200 eV to ~6 keV. The neutrals from both the glow and ribbon are also characterized by nonthermal distribution functions. In addition, INCA sees a "belt" of emission in ENAs, broader than the ribbon and tilted significantly away from it, at even higher energies (tens of kiloelectron volts). This evidence supports the idea that the bulk of the energy density in the heliosheath plasma resides in a nonthermal component that extends to very high energies. We have never sampled such a huge and dynamic plasma regime that is dominated by nonthermal pressure, but this regime must be representative of the astrospheres of stars similar to our Sun.

These new quantitative and qualitative implications for the overall heliospheric structure already call for a new generation of measurements to understand the global nature of our Sun's interaction with the local galactic environment. An interstellar probe with modern instruments and measurement requirements better defined by these recent observations will certainly advance our understanding of the heliospheric interaction and the VLISM. New launch vehicles in the evolving fleet, including the Atlas V, Delta IV and Falcon Heavy, offer new capabilities that can enable such a mission with an acceptable development and launch cost.

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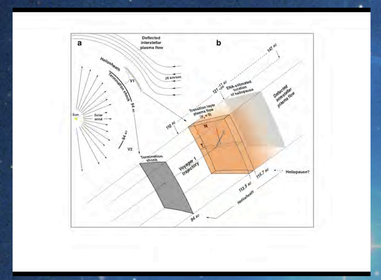
An Unexpected Plasma Regime

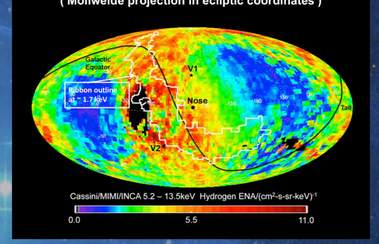
- **Key question for Interstellar Probe:** ***What is the structure of the heliosphere?***
- **New observations show the problems with the old answers:** Voyager 1 entered (at 113.5 AU) a "transition layer" to the heliopause, within which all three components of the plasma flow are small (~10s of km/s)

Reference: Krimigis, S. M., E. C. Roelof, R. B. Decker, and M. E. Hill, Zero outward flow velocity for plasma in a heliosheath transition layer, *Nature*, **474** (7351), 359–361, 2011.

Also: Voyager Special Session SH13C (This Conference)

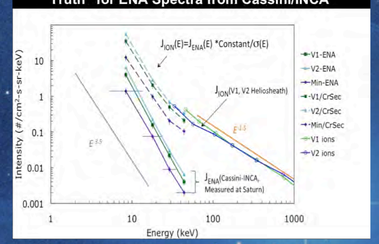


Heliospheric ENA Image Obtained with Cassini/ MIMI/INCA (Mollweide projection in ecliptic coordinates)



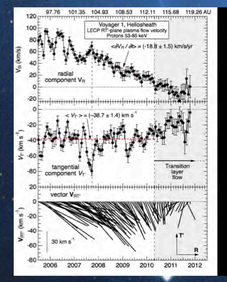
Energetic Neutral Atoms Observed by Cassini at 10 AU Ions Observed *in situ* by Voyager 1 and Voyager 2

Ion Intensities at Voyagers 1 & 2 Provide "Ground Truth" for ENA Spectra from Cassini/INCA



Plasma Flow at Voyager 1 in Heliosheath

- Compton−Getting analysis of 26-day average angular distributions from three ion channels 40−139 keV reveals unexpected behavior
- Radial component of flow V_R (inertial frame)
  - **In 2007.7−2010.3 decreased −5 to −6 km/s/AU**
  - **Since 2010.3 has been ≈0 km/s or *negative***
- Approximate tangential component of flow (inertial frame)
  - **Varied ±20 km/s about average ≈ −40 km/s**
  - **Recent decrease to $-20 < V_T < 0$ km/s**
- Normal component V_N has always been variable but small (±10s of km/s) in the heliosheath and transition layer (AGU Special Session SM13C)

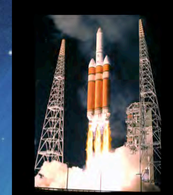


Energetic ion measurements show radial plasma flow velocity in the heliosheath decreasing to zero (and going negative) in a "transition layer" as Voyager 1 appears to be approaching the heliopause boundary with the interstellar medium.

Propulsion "Contenders" Trade Technology Readiness Against Flight Time

- **Radioisotope Electric Propulsion (REP)**
  - Near-term technology
  - High-efficiency, low-specific mass radioisotope power supplies (RPS)
  - Work from 1 AU outward
  - Flyout time constrained by hardware
- **Solar Sail (IHP/HEX)**
  - Needs low areal mass density (~1 g m^{-2} or less)
  - **Needs to deal with high temperature**
  - **Work from ~0.25 AU outward**
  - Current technology RPS sufficient for power

Delta IV H-Class is Required for REP Implementation Falcon Heavy *MAY* Suffice at High C_3



http://en.wikipedia.org/wiki/File:Delta-4H_DSP-23_2.jpg

http://www.universetoday.com/84638/spacex-unveils-launch-of-falcon-heavy-worlds-most-powerful-rocket-by-2013/

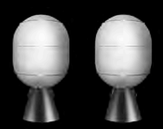
Even Larger Boosters are Better – But Likely Not Affordable for a Robotic Science Mission

Ares V – 188,000 kg to LEO−cancelled 71,100 kg to trans-lunar injection

Space Launch System (SLS) – Startup 2011 70,000−130,000 kg to LEO; 1st flight ~2018

Upper Stages Are a Driver for either Delta IV H/ Falcon H or Heavy Lift Launch Vehicles

- Current approach: Stack two Star 48A stages on Delta IV H
- Other "solutions" are not promising
- Fregat is too heavy



Delta IV H with Cryogenic 3rd Stage?

Standard 4-m Fairing

Standard 5-m Fairing Outline (reference)

Standard 4-m Stage* (Isp = 462 s; Propellant = 20,000 kg; Burnout = ~4000 kg) - may be modified for longer mission (more boil-off &/or thermal control)

Standard 5- to 4-m Interstage

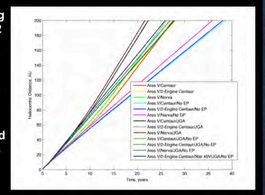
Standard 5-m Stage* (Isp= 462 s; Propellant = 27,000 kg; Burnout = ~5000 kg)

- Existing stage is too heavy
- A Delta IV H can deliver only ~23,000 kg to LEO

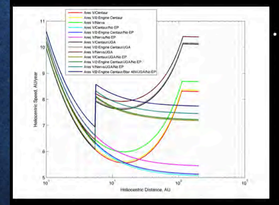
Propellant offloading will be required if 3rd stage is burned in LEO – not the most efficient approach

Comparing the Options to "Bound the Box": Time to 200 AU with an Ares V

- Spread among options is ~22 to 38 years to 200 AU
- Widens in going to even larger distances
- Initial goal had been 15 years to 200 AU



Comparing the Options: Speed to 200 AU and Beyond with an Ares V



- Probe speed versus heliocentric distance
  - To 200 AU
  - Log distance
  - Discontinuity is Jupiter gravity assist

Enablers – Rather than the spacecraft – Drive the Cost for *ANY* Implementation

- "Affordable" launch vehicle
  - Delta IV H-class or larger for REP
  - Existing components for high-energy stage as needed
- Kilowatt-electric power supply with low specific mass
  - Six ASRGs for REP; one or two for solar sail
  - Sufficient Pu-238 is **REQUIRED in any case**
- Reliable and sensitive deep, space communications
- Mission operations and data analysis (MO&DA)
- **Not unlike needs for deep-space planetary missions**

Continuing Steps

- Inform the scientific and technical communities of the mission: its new science and its technical challenges
- Educate stakeholders that this mission is not "far term" – a launch in the near future is possible
- Propulsion/speed trades remain key and require further exploration and discussion in the science community
  - Examine thermal requirements for use with a solar sail
    - What technology precursors are and when they are required
  - Plan on using a close Jupiter gravity assist for an REP-enabled mission–too helpful to ignore
    - The next opportune launch window opens ~2024

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