Near-term Interstellar Probe: The First Dedicated Step

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Day 1, Session 2 - From representative missions to key technical requirements
11 September 2019

Coriolis Room, Observatoire Midi-Pyrénées, 14 avenue Edouard Belin, 31400 Toulouse, France
1705 – 1720 (15 minutes)
“Interstellar Probe”

• ... is a mission through the outer heliosphere and to the nearby “Very Local” interstellar medium (VLISM)

• ... uses today’s technology to take the first explicit step on the path of interstellar exploration (faster than the Voyagers – on an SLS or commercial equivalent)

• ... can pave the way, scientifically, technically, and programmatically for more ambitious future journeys (and more ambitious science goals)
We are here

Logarithmic scale

To the VLISM: The Next Step

Earth: The “pale blue dot”

Voyager 1 at 144.8 AU in 2019
Three “Special Probes”... One Beginning
... and One To Go

March 1960: The “Simpson Committee”

Parker Solar Probe

Interstellar Probe

Ulysses

Parker Solar Probe: 12 August 2018
3:31 a.m. EDT

Ulysses:
6 October 1990
11:47:16 UTC
(STS-41 launch)
The third one: **Interstellar Probe - A 59-year(+) Old Idea**

- **1960**: The Space Studies Board “*Outer solar system probe: to be aimed away from the Sun...*”
- **1965**: Eugene Parker advocates mission to heliospheric boundary region
- **1977**: Voyager-1 launch
- **1990**: The Interstellar Probe (*Holzer et al., 1990*)
- **1999**: JPL Study (NASA STDT)
- **2001**: NIAC Study, APL
- **2005**: Innovative Interstellar Explorer (*McNutt et al., 2005*) (“Vision Mission”)
- **2009**: The Interstellar Heliopause Mission (*Wimmer-Schweingruber et al., 2009*)
- **2015**: Keck Institute of Space Studies (KISS) Report
Two Distinct Questions

• **What should we do?**
  • The question for a future Science Definition Team or equivalent and the science community overall via Decadal Surveys

• **What could we do?**
  • The question at hand for this study
The Current Study

• The Johns Hopkins University Applied Physics Laboratory has been tasked by the NASA Heliophysics Division to (re-)study the mission (as of 13 June 2018)

• Provide input to help support the next round of “Decadal Surveys” in the United States
  - **Focus on the time frame** in the next Heliophysics Decadal: 2023 – 2032: Could we launch a scientifically compelling mission that decade? – **technical question but not without science implications**
The Compelling Case: Questions Span NASA Science Divisions

Potential for expanded science across all of NASA’s Science Mission Directorate

As we seek answers to the question of habitability

Science Goal 1: The Heliosphere as a Habitable Astrosphere
- Global Nature of the Heliospheric Interactions

Science Goal 2: Origin and Evolution of Planetary Systems
- Properties of dwarf planets/KBOs and large-scale structure

Science Goal 3: Early Formation and Evolution of Galaxies and Stars
- Uncovering the Diffuse Extragalactic Background Light

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Science Goal 1: The Heliosphere as a Habitable Astrosphere

- Integral to evolution of habitable systems
- Missing in the family portrait of Astrospheres
- Dedicated measurements resolve the new physics uncovered by the Voyagers
- The first ENA and UV images looking back uniquely determines the global nature
- Voyager, IBEX, Cassini, JUICE and IMAP guide the optimal exit
Science Goal 2: Formation and Evolution of Planetary Systems

Debris Disks: Signposts of terrestrial planet formation and evolution

- **IR imaging** reveals our unseen circum-solar debris disk
- **Flyby observations** provide leaps in understanding solar system formation and Kuiper Belt comparative planetology
- **Ground truth** for exoplanetary systems and disks

Dwarf Planets: Unexplored active worlds

KBOs: Fossils of solar system formation and composition

Eta Corvi - 1400 Myr

Fomalhaut - 440 Myr

HL Tauri - < 1 Myr

Pluto

Charon

Quaoar and Weywot

2014MU69

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**Science Goal 3:**
Uncover Early Galaxy and Star Formation

- Extragalactic Background Light (EBL) is all the light that has ever shined.
- Holds the collective knowledge of early formation: (1) starlight in $z = 2 - 5$ galaxies, (2) galactic dust re-emission, and (3) the light from the first stars.
- Uncover the EBL by going beyond the Zodiacal Cloud, which obscures the $1-100 \mu$m window by $10 - 100x$.
- EBL measurements provide Decadal-level cosmology science enabled by unique outside location.
Critical Trade-Offs Are Not New

**Mass:** Driven by flyout speed and payload (P/L) capability
- S/C range 300-800 kg (New Horizons 478.3 kg)
- P/L ~40-50 kg (New Horizons 30.4 kg)
- Thermal Protection System 150-900 kg (PSP 98.9 kg incl structure)

**Power:** GPHS RTG – life efficiency and lifetime for use *in vacuo*

**Communication:** Solid, near-term, tested engineering
- Ka-band at ~640 bps and more at 140 AU and beyond
- Optical laser comm might achieve ~10 kbps, but requires extreme pointing stability; lifetime needs investigation

**Trajectory/Propulsion/Launch Vehicle:** Keys for implementation
- In-depth trajectory analysis including accurate mechanical and thermal designs together with launch vehicle (LV) providers
- Propulsion technology and engineering assessment of what works and what does not
<table>
<thead>
<tr>
<th>Mission</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voyager</td>
<td>825.4 kg</td>
</tr>
<tr>
<td>Parker Solar Probe</td>
<td>643.0 kg</td>
</tr>
<tr>
<td>New Horizons</td>
<td>478.3 kg</td>
</tr>
<tr>
<td>Ulysses</td>
<td>366.7 kg</td>
</tr>
<tr>
<td>Pioneer 10</td>
<td>251.8 kg</td>
</tr>
</tbody>
</table>

**Notional Concepts:**
**825 kg to 250 kg**

Combine with SLS Launch vehicle and kick stages, e.g. Castor 30XL.

**Current example for study:**
Mission Concept(s)

• **Option 1:** Unpowered Jupiter Gravity Assist (JGA)
  - Burn all stages directly after launch
  - Follow with optimized prograde JGA

• **Option 2:** Active Jupiter Gravity Assist
  - Take one stage to Jupiter and burn it at optimized perijove
  - Opposite of orbit insertion maneuver

• **Option 3:** JGA + Oberth Maneuver Near the Sun
  - Reverse JGA to dump angular momentum
  - Fall in to the Sun without actually hitting the Sun, maximizing your incoming speed
  - Burn final stage(s) at (close) perihelion
Where We Could Go: Target Map

Positions from 2020 - 2031

Background based on IBEX-Hi 1.11 keV combined differential flux data – Release 4

Heliospheric features
Outer planets
KBOs

2015 TG387 (Goblin)
Neptune
Uranus
Eris
2012 VP113 (Biden)

“Tail”
Varuna
Makemake
Haumea
Voyager1

“Nose”
WISE 0855-0714
Orcus
Ixion
Voyager2

Barnard's Star
α Centauri

Eridani

ε Eridani

2018 VG18 (Farout)

KBOs

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Realities of Flight Near the Sun – Connecting with PSP...

• You can’t “go at night”
  - At end of Parker Solar Probe (PSP) mission (in seven years) we will be at a perihelion passage of 9.86 Rs

• Not close enough!

But PSP may be a pathfinder to solutions
Option 3: Shield Estimates (Star 48BV)

- Accommodate New Horizons – like Interstellar Probe: mass and layout as a model
- Options 1 and 2: Estimate performance
- Option 3: Estimate thermal shield for perihelia of 3 $R_S$, 4 $R_S$, and 5 $R_S$
  - Verify thermal performance
  - Estimate thermal shield mass
  - Estimate system performance

Umbra clearance checks made for each configuration

Thermal analysis at 5 $R_S$
~2200°C to 2600°C (hottest)
Designing for Different Perihelia: CASTOR 30XL

• Option 3 configuration with notional New Horizons – like spacecraft and CASTOR 30XL stage with thermal shields for 3 $R_S$, 4 $R_S$, and 5 $R_S$ perihelia.

Option 3 engineering studies in progress
Estimate is now $> 12$ AU/yr

Increasing temperature, shield mass $\rightarrow$

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Approaching the Sun: Materials and Mechanics – How close is possible?

Closest approach is set by melting point of Sun-facing front layer or its sublimation rate.

Lower Perihelion Does Not Always Lead To Higher Escape Velocity: thermal limit trades against mass.

Melting temperature of refractory metals

Sublimation vapor pressure of carbon
The real journey has only just begun…
... with a caveat:

• “Vision without execution is hallucination.”
  • — Thomas A. Edison

• Requirements must be commensurate with realistic cost estimates and funds – the key elements of any successful mission.
And all I ask is a tall ship and a star to steer her by…

- from *Sea Fever* by John Masefield

**AD ASTRA!**