HUMANITY'S JOURNEY TO INTERSTELLAR SPACE

INTERSTELLAR PROBE

At The Intersection Of Heliophysics, Planetary Science, And Astrophysics

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Space Exploration Mission Formulation
Johns Hopkins Applied Physics Lab
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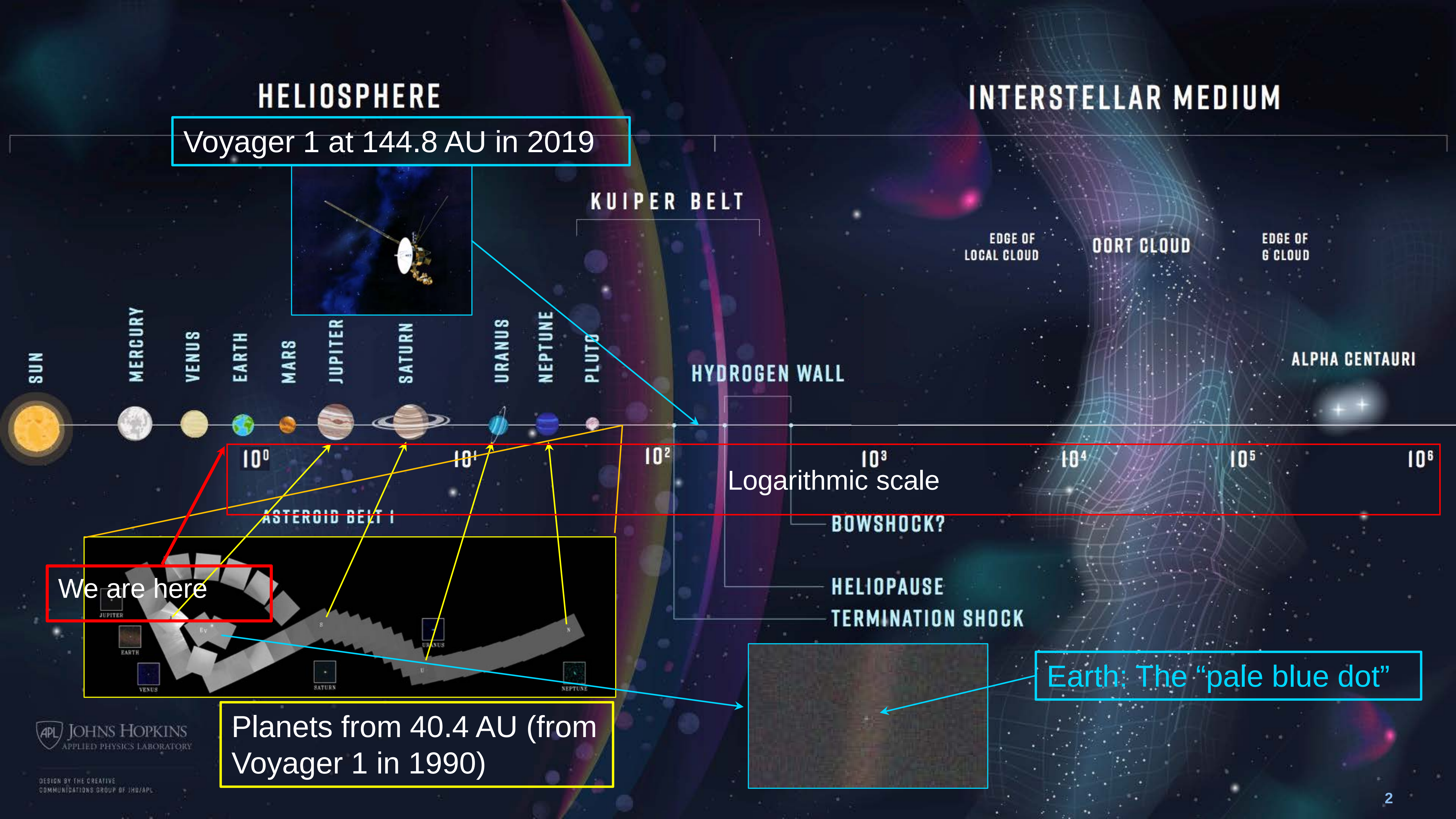
Space Science Week March 26-28, 2019--Washington, DC


HELIOSPHERE
INTERSTELLAR MEDIUM
Voyager 1 at 144.8 AU in 2019
KUIPER BELT
EDGE OF LOCAL CLOUD
OORT CLOUD
EDGE OF G CLOUD
SUN
MERCURY
VENUS
EARTH
MARS
JUPITER
SATURN
URANUS
NEPTUNE
PLUTO
HYDROGEN WALL
ALPHA CENTAURI
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Logarithmic scale
ASTEROID BELT
BOWSHOCK?
HELIOPAUSE
TERMINATION SHOCK
We are here
JUPITER
EARTH
VENUS
SATURN
URANUS
NEPTUNE
Earth: The "pale blue dot"
Planets from 40.4 AU (from Voyager 1 in 1990)
APL JOHNS HOPKINS APPLIED PHYSICS LABORATORY
DESIGN BY THE CREATIVE COMMUNICATIONS GROUP OF JHU/APL

Our Task

INTERSTELLAR PROBE

- The Heliophysics Division within NASA's Science Mission Directorate requests a proposal to study the first pragmatic *Interstellar Probe* mission concept. The *Interstellar Probe* would be NASA's first dedicated mission to venture into the unknown space between our star and other potentially habitable planetary systems.
- Tasks specific for JHU/APL include:
  - Host Mission Science Definition Workshop. **DONE**
  - Conduct engineering study to develop mission concept, including special studies on critical technologies. **DONE**

Study Team and Collaborators

- **R. L. McNutt, Jr** (Study Principal Investigator)
- **P. C. Brandt** (Study Project Scientist)
- **K. E. Mandt** (Deputy Study Project Scientist)
- **M. V. Paul** (Study Manager)
- **E. Provornikova** (Working Group Lead - Heliosphere/Local Interstellar Medium)
- **C. Lisse** (Working Group Lead - Circum-Solar Debris Disk/Astrophysics)
- **K. Runyon** (Working Group Lead - Kuiper Belt Objects/Planetary)
- **A. Rymer** (Working Group Lead - Exoplanetary Connections)

And almost 200 professional scientists and engineers world-wide actively working in support for Interstellar Exploration

Broad and Multi-Disciplinary Community Participation

88 active Fall 2018 AGU participants from a mailing list of 185:
United States, Germany, France, Sweden, Russia, and the People's Republic of China

INTERSTELLAR PROBE

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A Tale of Three Missions... and One Beginning

INTERSTELLAR PROBE

National Academy of Sciences
National Research Council
2101 Constitution Avenue
Washington 25, D. C.

INTERIM REPORT NO. 3

March 1960

to

Space Science Board

of

Committee 3

Physics of Fields and Particles in Space

I. Introduction

In Interim Reports to the Space Science Board of October 24, 1958 and February 10, 1959, the Committee proposed a wide range of experimental work to be conducted in its field of cognizance. These documents were approved by the Space Science Board and forwarded to the interested Government agencies - especially the newly formed National Aeronautics and Space Administration. At the same time and as a further assistance to the formulation of the NASA program, the Committee also reviewed all of the proposals submitted to it, recognizing, however, that such reviews would not in general constitute a continuing task of the Committee or the Board.

In this report the Committee turns to the matter of future programs in response to the SSB Memorandum 139 of 5 February 1960. Attention is devoted principally to the period of 1960-65; in addition, some observations are submitted concerning work which would be appropriate to the 1965-1975 period. This report was prepared as a result of a meeting held at the Enrico Fermi Institute for Nuclear Studies, University of Chicago on March 4-5, 1960. A list of those participating is given at the end of this report.

March 1960:
The "Simpson Committee"

Parker Solar Probe

Interstellar Probe

Ulysses

Special Probes

a. Solar probe: specially designed payload, capable of withstanding high temperatures; to be aimed close to the Sun.

Experiments:

Payload Group		1	(whole group)
"	"	2	part of the experiments
"	"	7a	nuclear processes
"	"	4a	gamma rays
"	"	4b	primary neutrons
"	"	6e	transport of particles and fields from the Sun
"	"	3c	solar magnetic field

Stabilization is required

b. Outer solar system probe: to be aimed away from the Sun in the plane of the ecliptic. (It is hoped that motion away from the Sun to the extent of 5 or 6 astronomical units per year could be accomplished by 1965)

Experiments:

Payload Group		6c	scale size of the 11 year cosmic ray modulation
"	"	6e	transport of particles and fields from the Sun
"	"	1	(whole group)
"	"	2	(whole group)

Stabilization is required

c. Probe "perpendicular" to the ecliptic. Here an increased velocity is needed and it may be necessary to compromise and accept a trajectory which has a strong component perpendicular to the field and thus moves in a spiral out of the plane of the ecliptic. This is probably the most difficult shot.

Ulysses (1990) and Solar Probe (2018): "Checking" two of the three "boxes"

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Ulysses:
6 October 1990
11:47:16 UTC
(STS-41 launch)

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

Meetings, Workshops, and Presentations Under This Study

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- COSPAR 42nd Assembly: 14 - 22 July 2018, Pasadena, CA
- 1st Explorers Club Workshop: 10 - 12 October 2018, New York, NY
- AGU Fall Meeting: 10 - 14 December 2018, Washington, D.C.
- 2nd Explorers Club Workshop: TBD October 2019, New York, NY 70th
- IAC, 21-25 October 2019 Washington, D.C. (Session proposed)
- COSPAR 43nd Assembly: 15 - 23 August 2020, Sydney, Australia

https://explorers.org/events/detail/the_next_step_on_humanitys_journey_to_the_stars_interstellar

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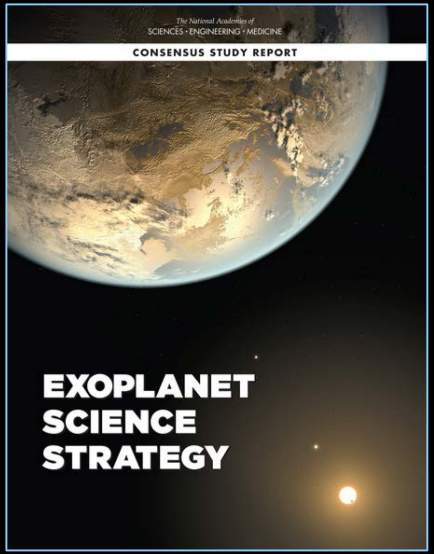
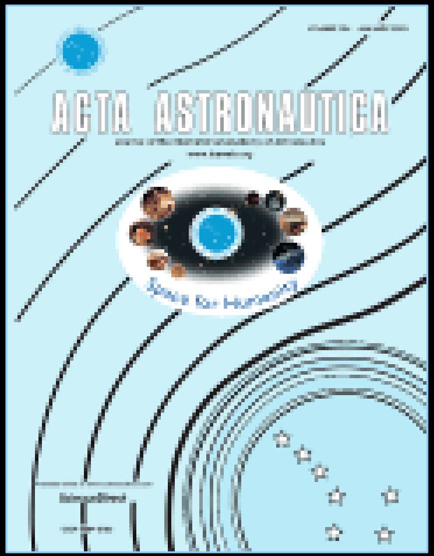
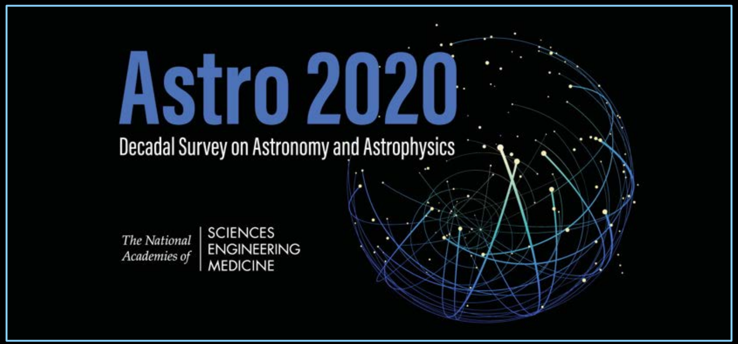
Papers

- McNutt et al., 2018, Acta Astronautica.
- Brandt et al., 2019, J. of British Interplanetary Society.
- Brandt et al., 2019, White Paper to Plasma 2020.
- Brandt et al., 2018, White Paper to Committee on Exoplanet Science Strategy, National Academies of Sciences.
- Mandt et al., 2019, White Paper to Astro 2020.
- Zemcov et al., 2019, White Paper to Astro 2020.







Expanded Questions Span NASA Science Divisions

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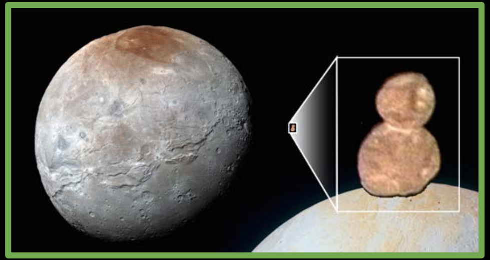
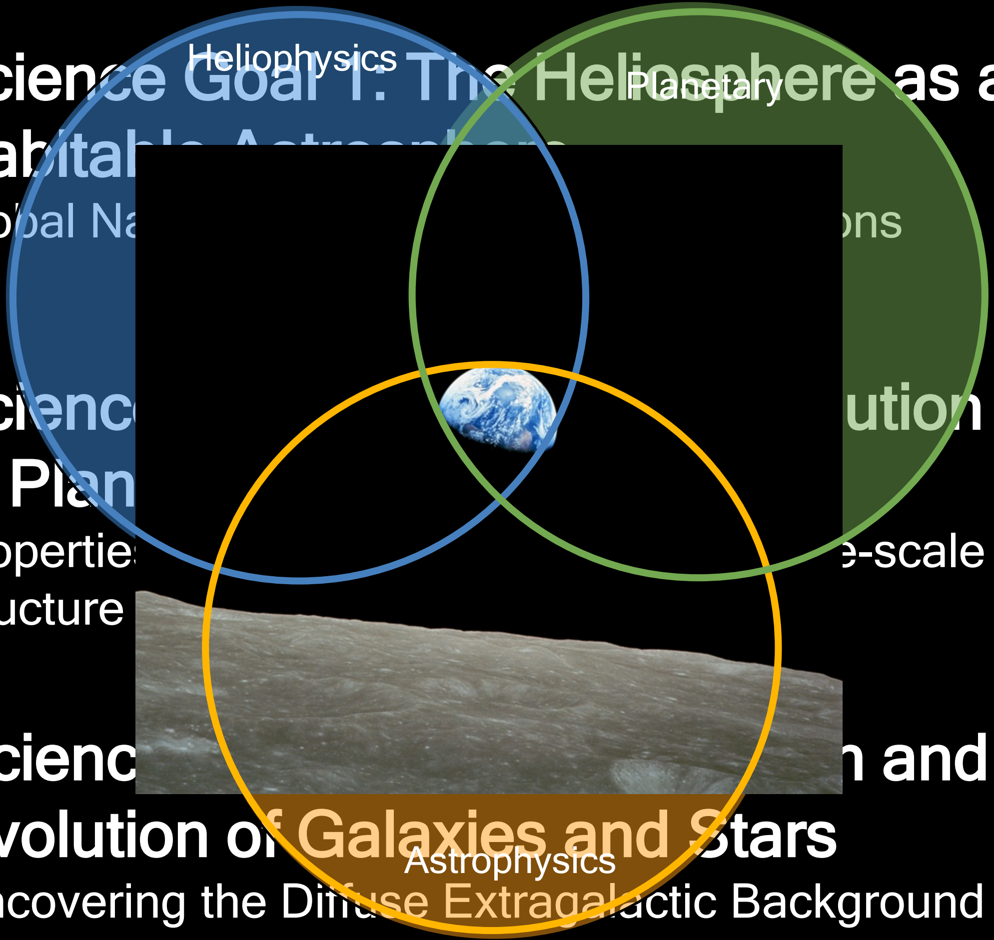
Potential for expanded science across all of NASA's Science Mission Directorate

As we seek answers to the question of habitability





Science Goal 1: The Heliosphere as a Habitab

Global Na ... ons

Scienc ... ution of Plan

Propertie ... e-scale structure

Scienc ... n and Evolution of Galaxies and Stars

Uncovering the Diffuse Extragalactic Background Light

Science Goal 1:
The Heliosphere as a Habitable Astrosphere

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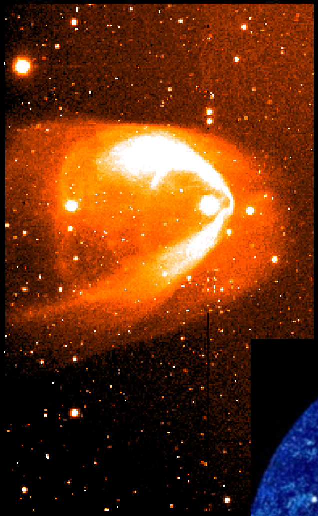
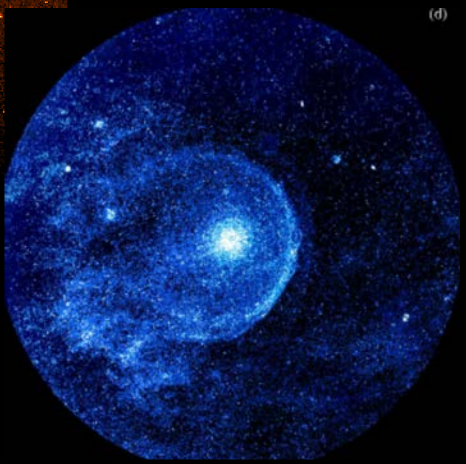
Mira
Red giant at 130 km/s
13 ly tail

LL Orionis
Pre-Main Sequence Star
Orion Nebula



BZ Camelopardalis
Binary white dwarf and main sequence
125 km/s

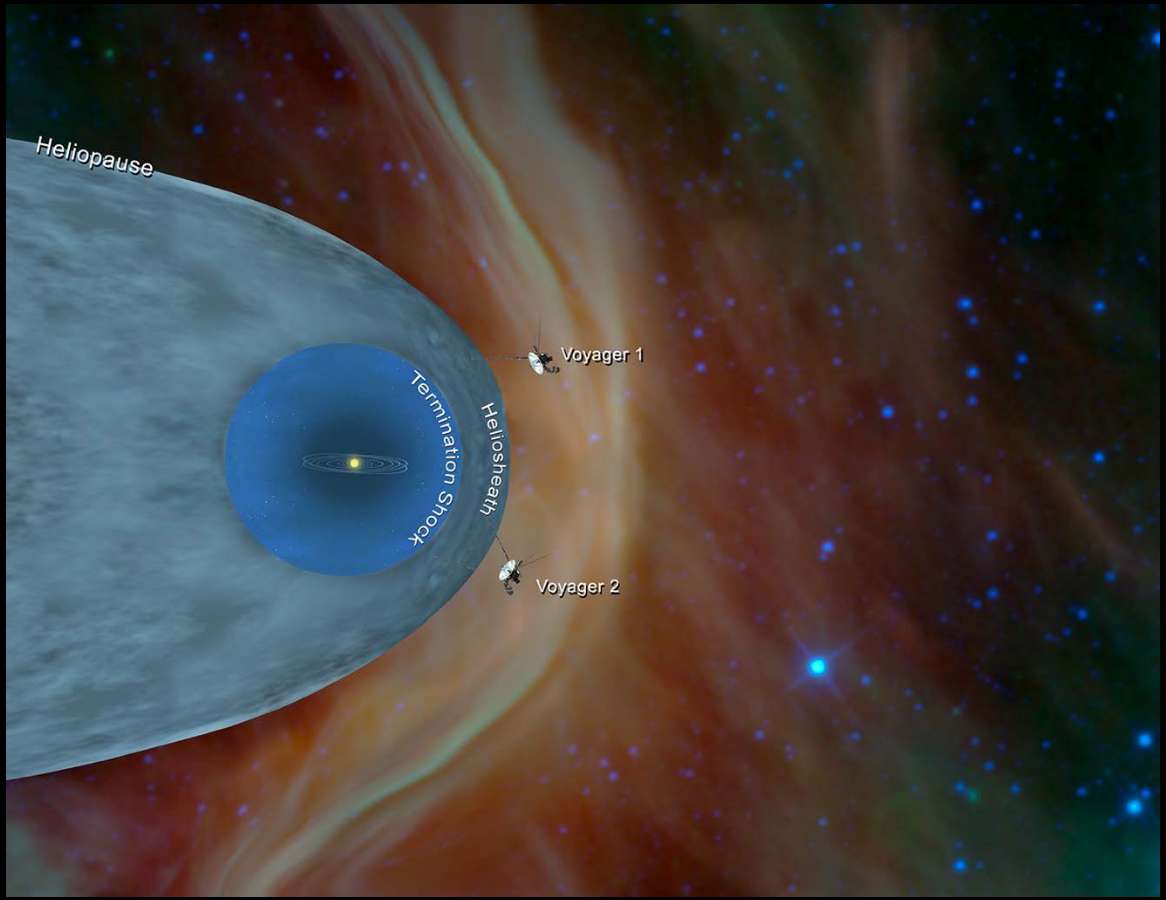
Zeta Ophiuchi
Run-away star at 24 km/s
Dust and gas nebula



IRC+10216
Carbon rich star at 91 km/s
Molecular wind and turbulence

- Integral to evolution of habitable systems
- The Heliosphere is missing in the family portrait of Astrospheres
- Perhaps the most outstanding problem of space physics today
- Dedicated in-situ exploration would uncover the astrophysical mechanisms at work
- First remote imaging from an external vantage point would uniquely determine the global nature

Science Goal 1:
Voyager 1 and 2 at the Doorstep to the LISM



- The limited Voyager payloads uncovered new mysteries to modern plasma science
- Force balance not understood and dominated by energetic particles not measured by Voyager
- Anticipated acceleration site of the Anomalous Cosmic Rays (ACR) remains elusive
- Solar disturbances propagating well beyond the HP
- Irreproducible Heliopause structure and location
- Unexpected interstellar magnetic field direction

Science Goal 1:
First Glimpses of Unexplained Structure

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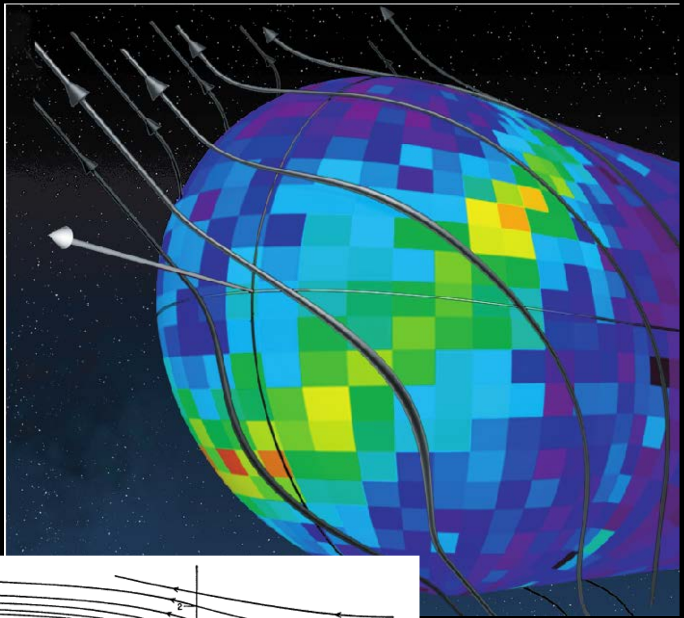
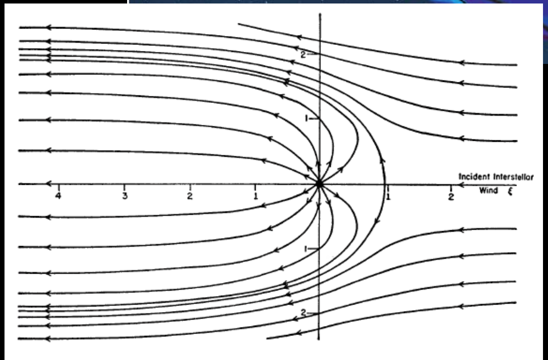
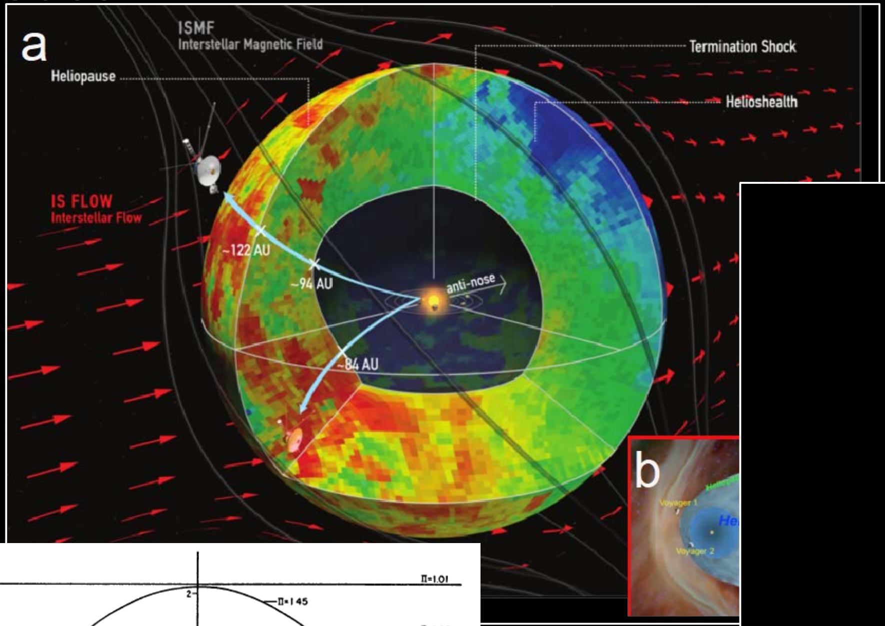
IBEX: Comet-like

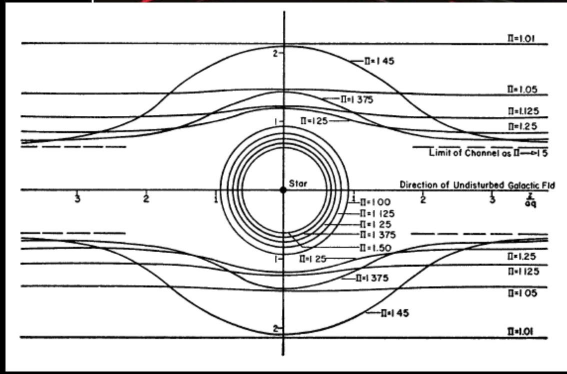




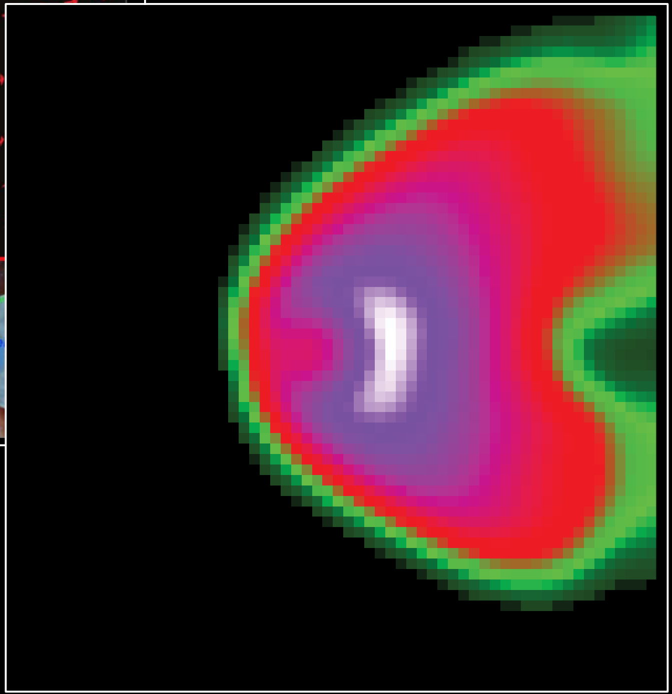
Parker 1961: Weak ISM Field

Cassini: Bubble-like





Parker 1961: Strong ISM Field



Remote imaging beyond the heliopause. ENA simulations at 250 AU (79 keV).

Science Goal 2:
Formation and Evolution of Planetary Systems

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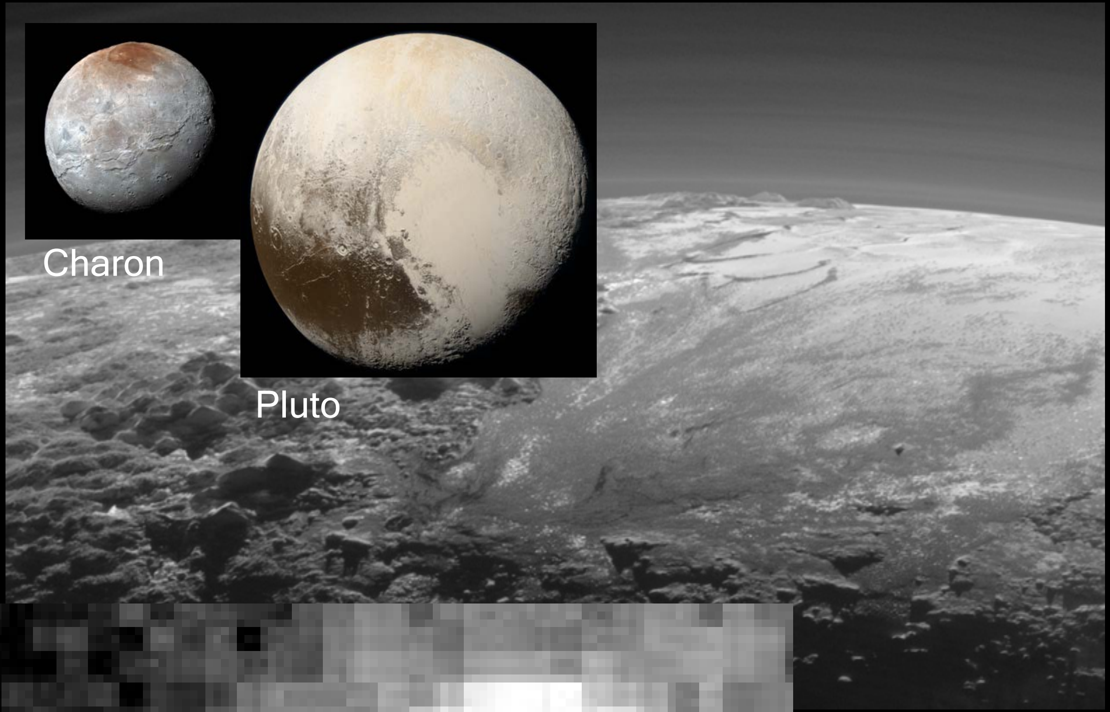

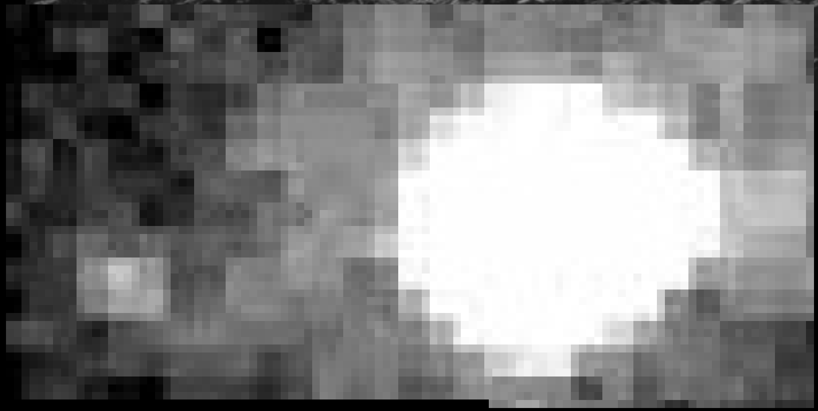

Quaoar and Weywot

- **Dwarf Planets:** Unexplored active worlds
- **KBOs:** Fossils of solar system formation and composition
- **Flyby observations** provide leaps in understanding solar system formation and Kuiper Belt comparative planetology

2014MU69 1 January 2019 at 43.3 AU

Science Goal 2:
Formation and Evolution of Planetary Systems

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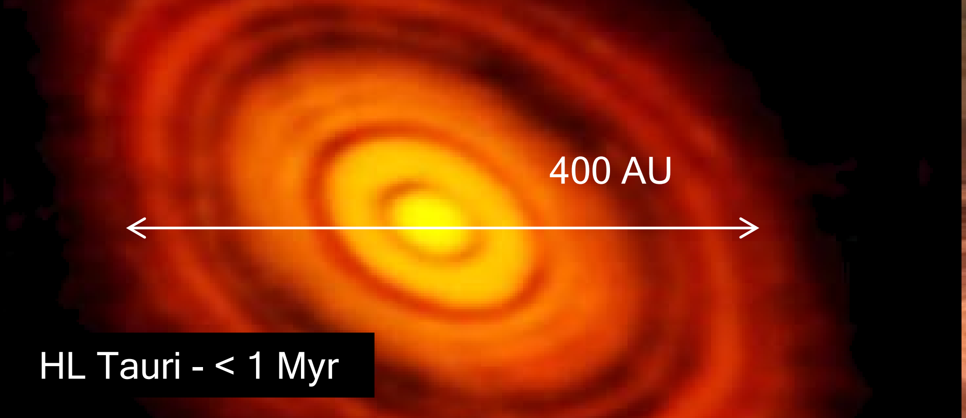
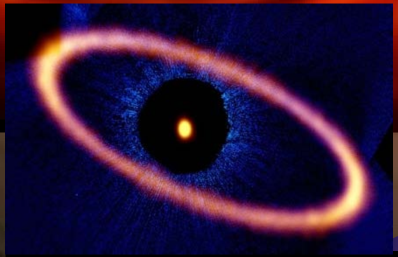
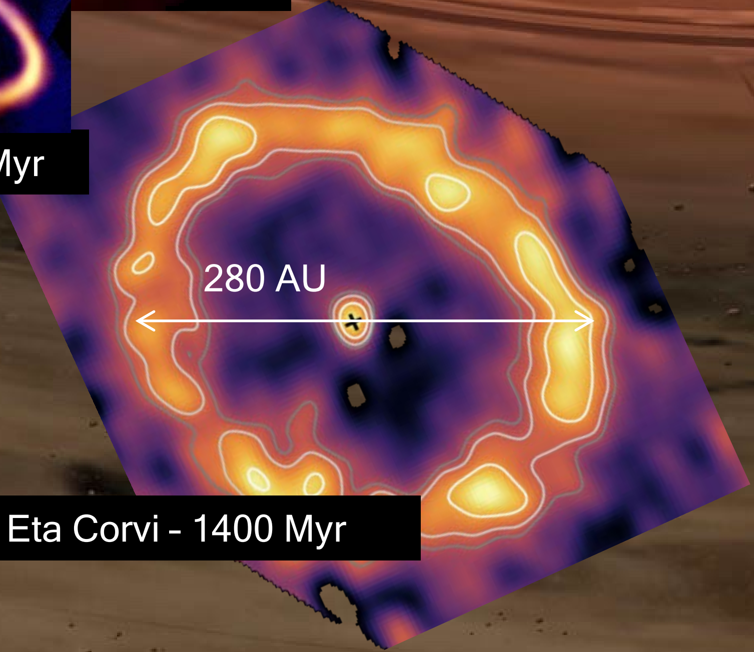


HL Tauri - < 1 Myr



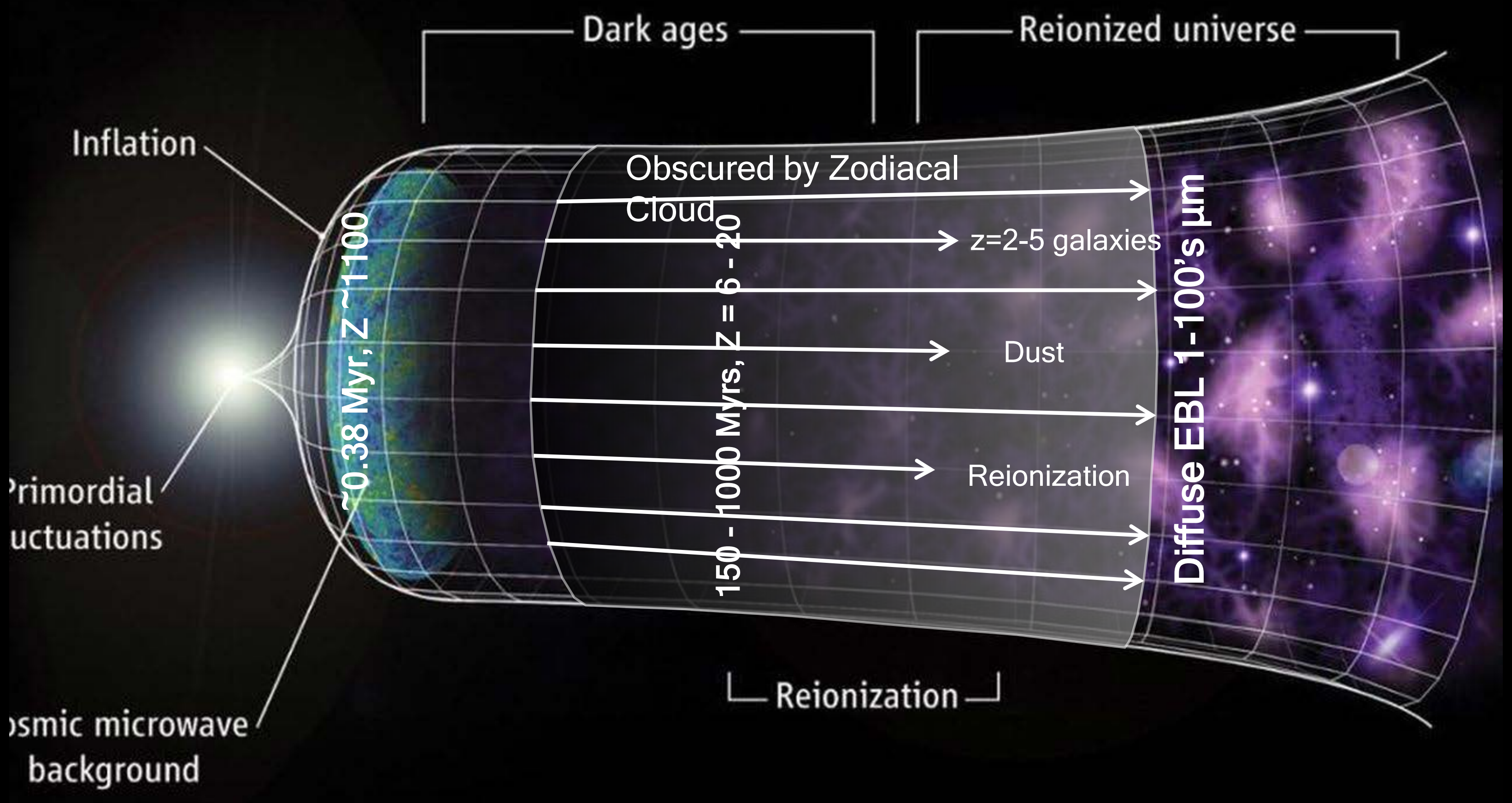
Fomalhaut - 440 Myr



Eta Corvi - 1400 Myr

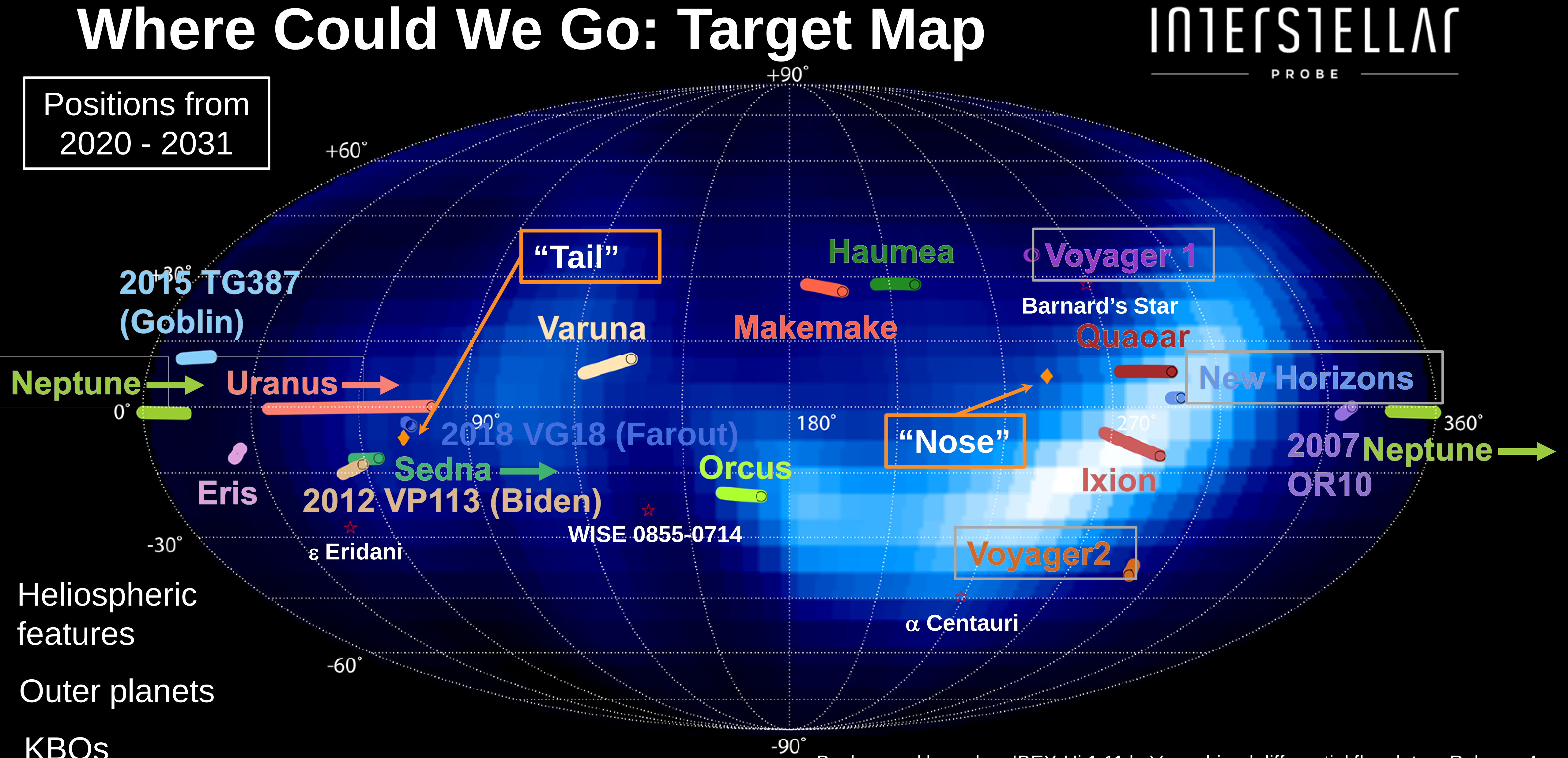
- **Circumstellar Disks**: Signposts of terrestrial planetary formation and evolution
- Global structure of our own debris disk sourced by asteroids, comets, & KBOs & stirred by planets is largely unknown
- VISIR spectral imaging through & beyond our disk will uncover its structure & provide ground truth for exoplanetary disk systems

Science Goal 3:
Uncover Early Galaxy and Star Formation



- Diffuse Extragalactic Background Light (EBL) is all the light that has ever shined, including major contributions from
  - Starlight in z=2-5 galaxies
  - Galactic dust re-emission
  - The first stars in the Universe that created today's reionized plasma-dominated cosmos
- The EBL holds all the collective knowledge of early formation, not just the brightest individual objects
- The Sun's Zodiacal Cloud obscures the 1-100 µm window by 10 - 100x
- EBL measurements provide Decadal-level cosmology

Where Could We Go: Target Map



Heliospheric features

Outer planets

KBOs

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

These are not actually separable questions

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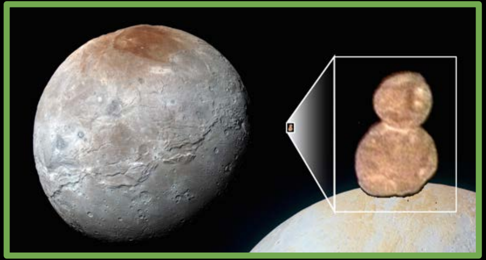
Science Goal 1: The Heliosphere as a Habitable Astrosphere

Global Nature of the Heliospheric Interactions



Science Goal 2: Origin and Evolution of Planetary Systems

Properties of dwarf planets/KBOs and large-scale structure of the circum-solar debris disk

Science Goal 3: Early Formation and Evolution of Galaxies and Stars

Uncovering the Diffuse Extragalactic Background Light

System Trades For Better Science

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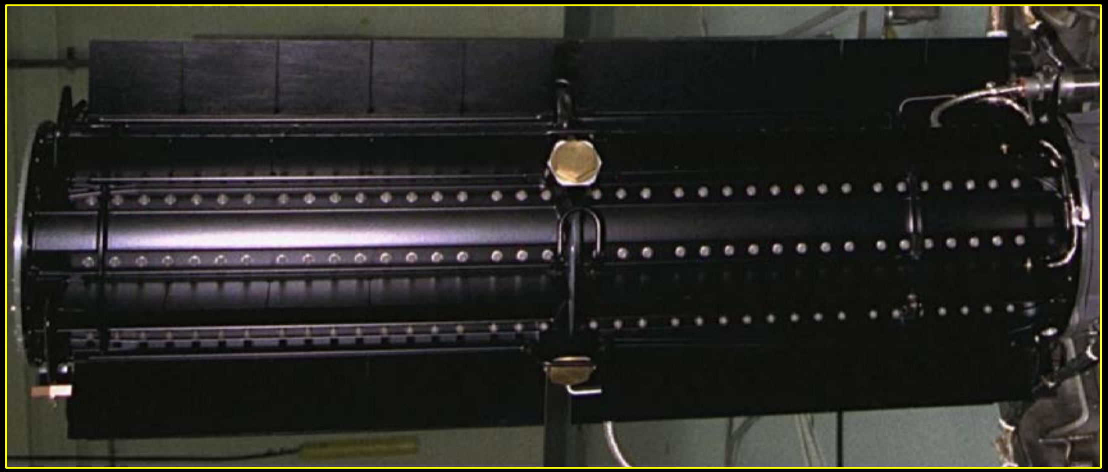
- **Mass:** Driven by flyout speed and payload capability
  - S/C range 300-800 kg (New Horizons 478.3 kg)
  - P/L ~40-50 kg (New Horizons 30.4 kg)
  - Thermal Protection System 150-900 kg (PSP 98.9 kg incl structure)
- **Power:** GPHS RTG Galileo, Cassini, Ulysses
  - Voyager (MHW RTG) will last to mid-2020's
  - Pu-238 production restored



- **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

Spinning Versus Three-Axis: How To Maximize Science?

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- **Spinning platform:**
  - Maximizes angular coverage of in-situ particle measurements and ENA, UV imaging
  - Plasma wave antennas need to be ≥10 m, which can be achieved with wire antennas (more challenging with rigid)
  - Line-of-sight IR measurements perpendicular to the spin-axis advantageous to do “MRI” of the debris disk
- **3-axis platform:**
  - Flyby imaging
- **A possible solution:**
  - 3-axis stabilized until KBO flybys are completed, which is well before termination shock
  - Spin up and deploy wire antennas and magnetometer boom
  - Trade-off: sacrifices optimal inner heliospheric science

Mission Concept(s)

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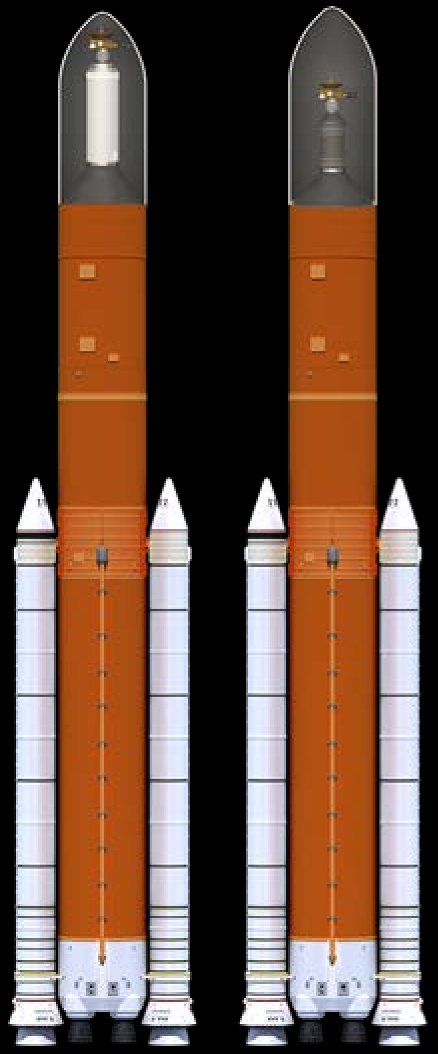
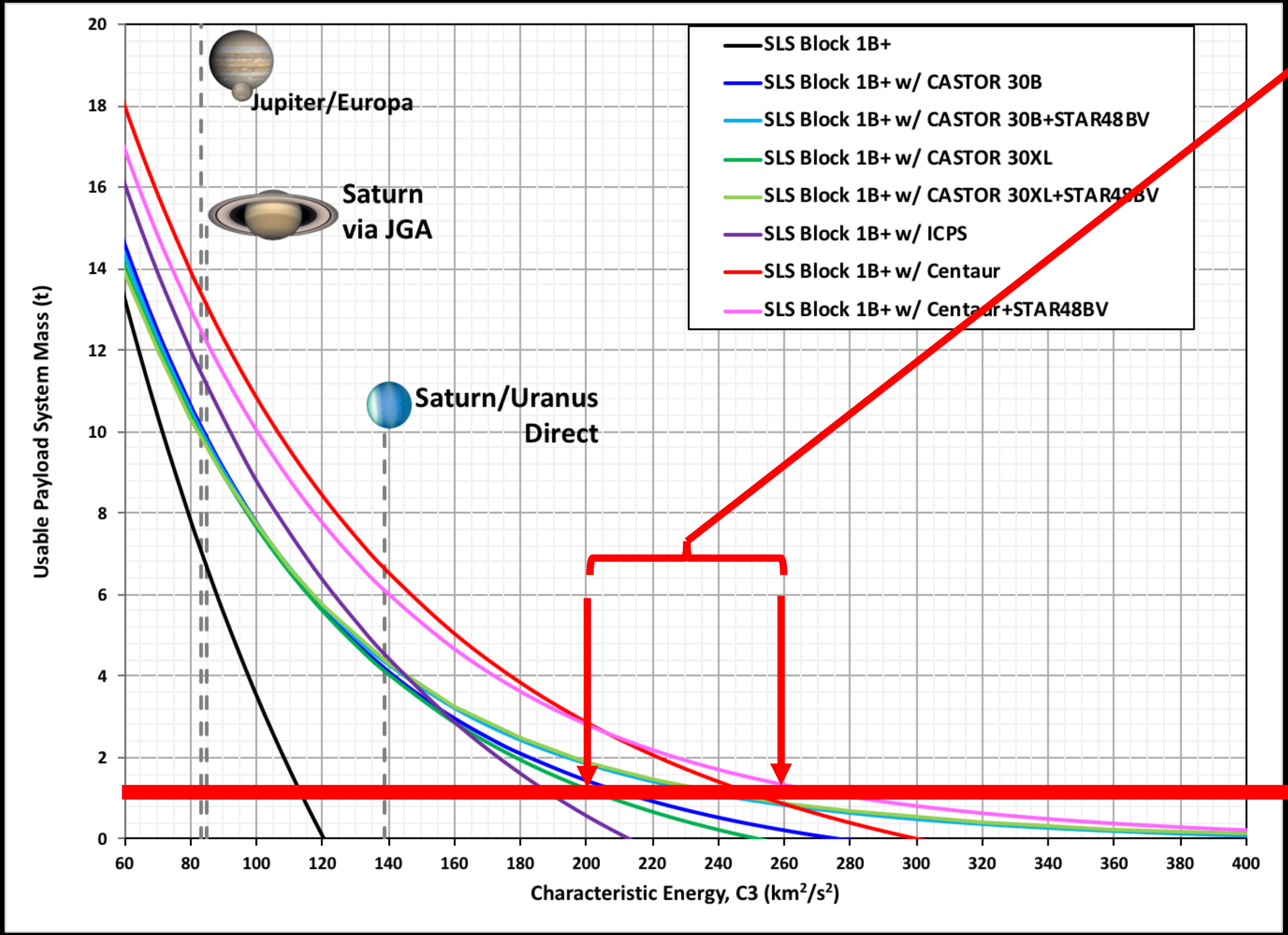
- **Option 1:** Unpowered Jupiter Gravity Assist (JGA)
  - Burn all stages directly after launch
  - Follow with optimized prograde JGA
- **Option 2:** Active Jupiter Gravity Assist
  - Take one stage to Jupiter and burn it at optimized perijove
  - Opposite of orbit insertion maneuver
- **Option 3:** 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 <u>final stage(s)</u> at (close) perihelion

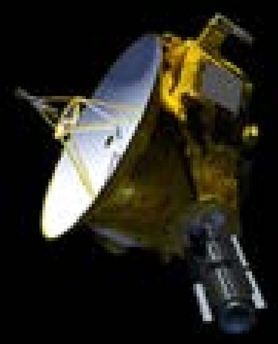
Space Launch System (SLS) Offers Possibilities – with Upper Stages



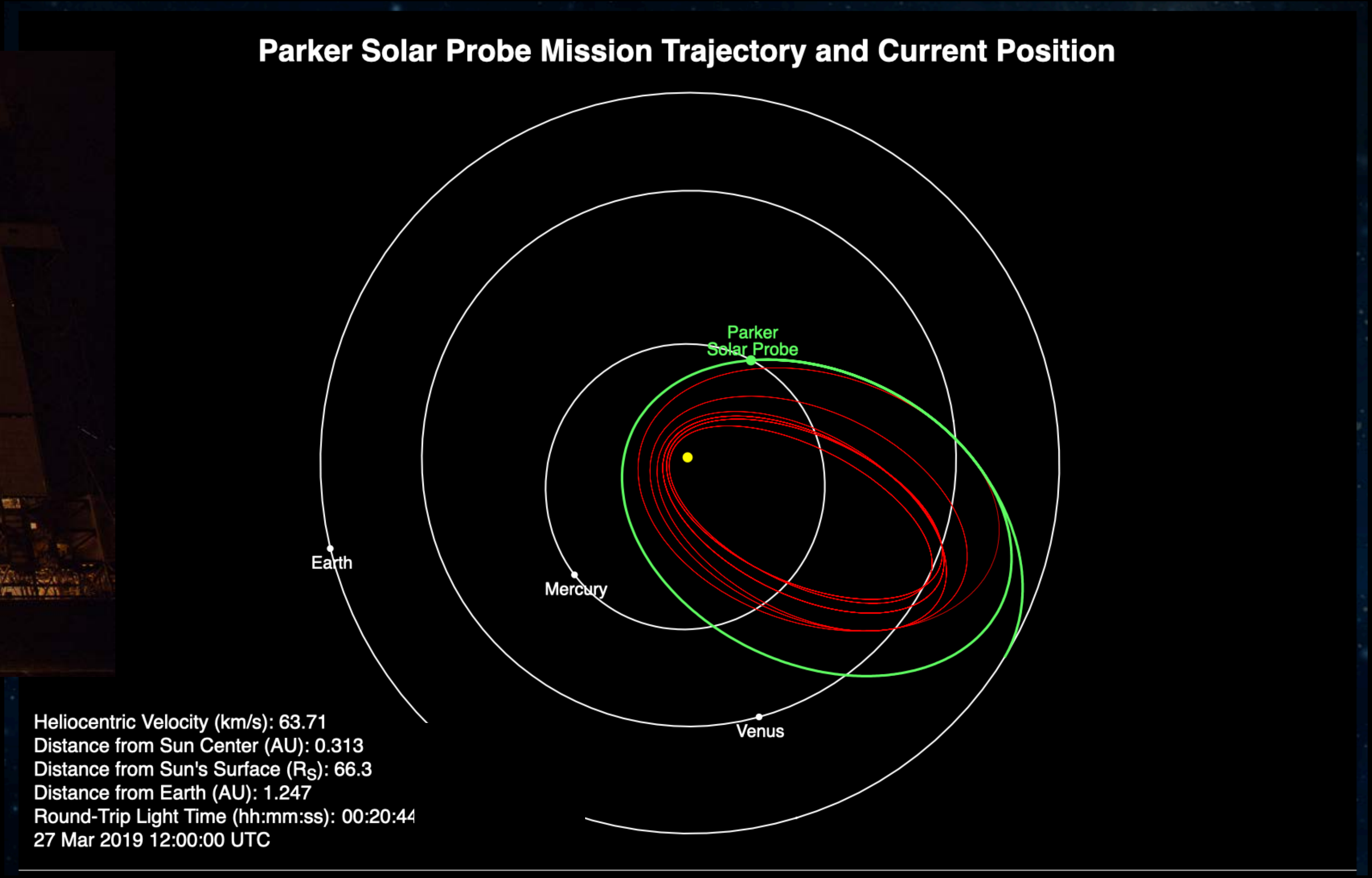


Region of interest
$200 \le C_3 \le 260$ km^2/s^2

478.3 kg

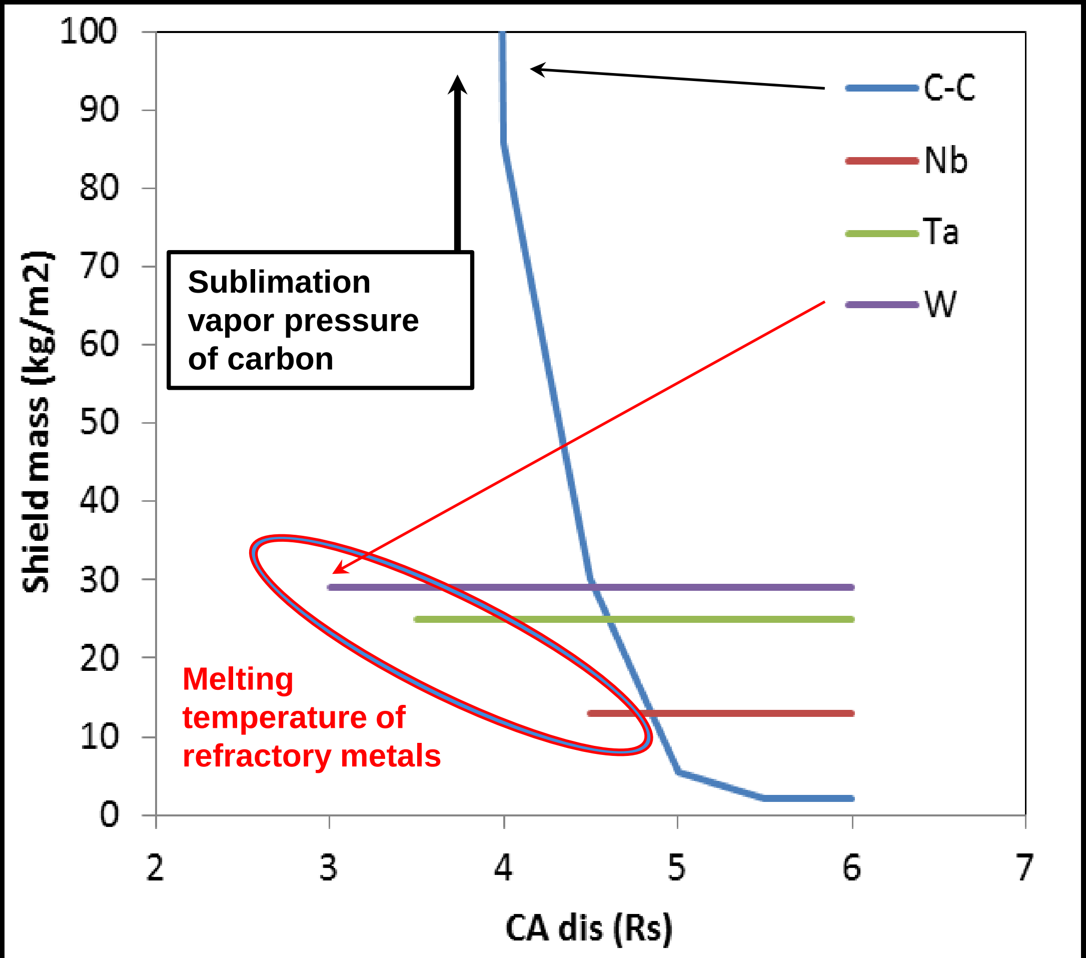


Realities of Flight Near the Sun – Connecting with PSP…

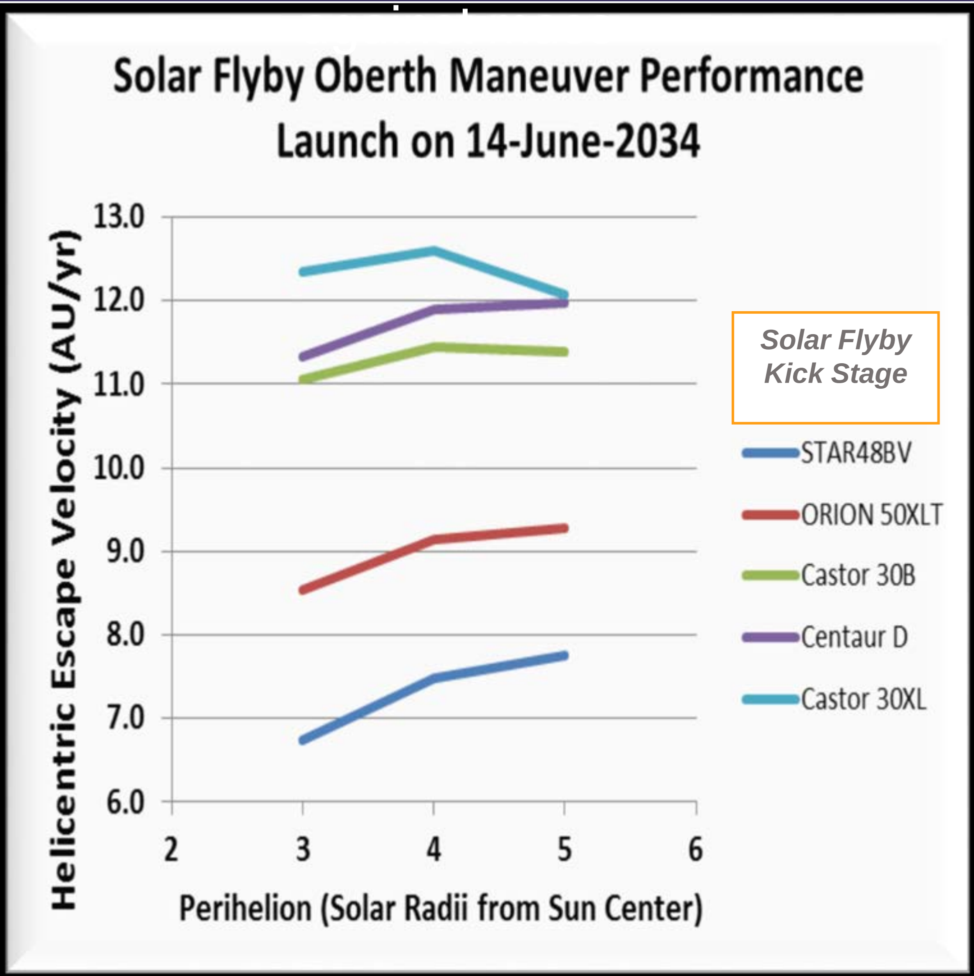


Approaching the Sun: Materials and Mechanics

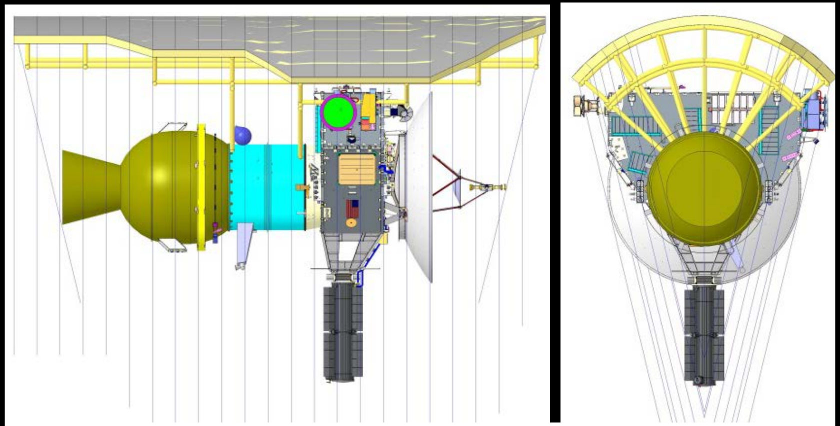
Closest approach is set by melting point of Sun-facing front layer or its sublimation rate



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



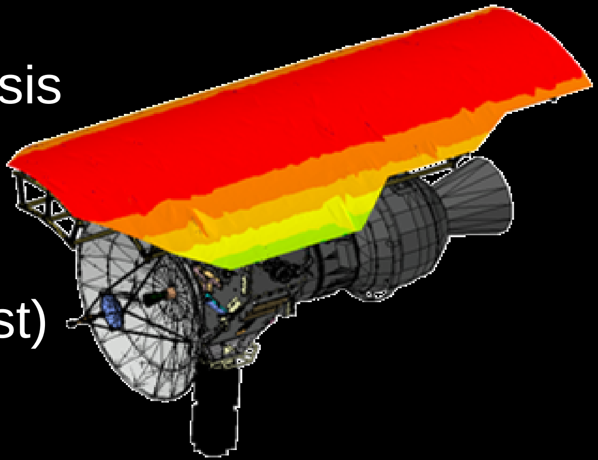
Solar Oberth Maneuver: Thermal Shield Estimates

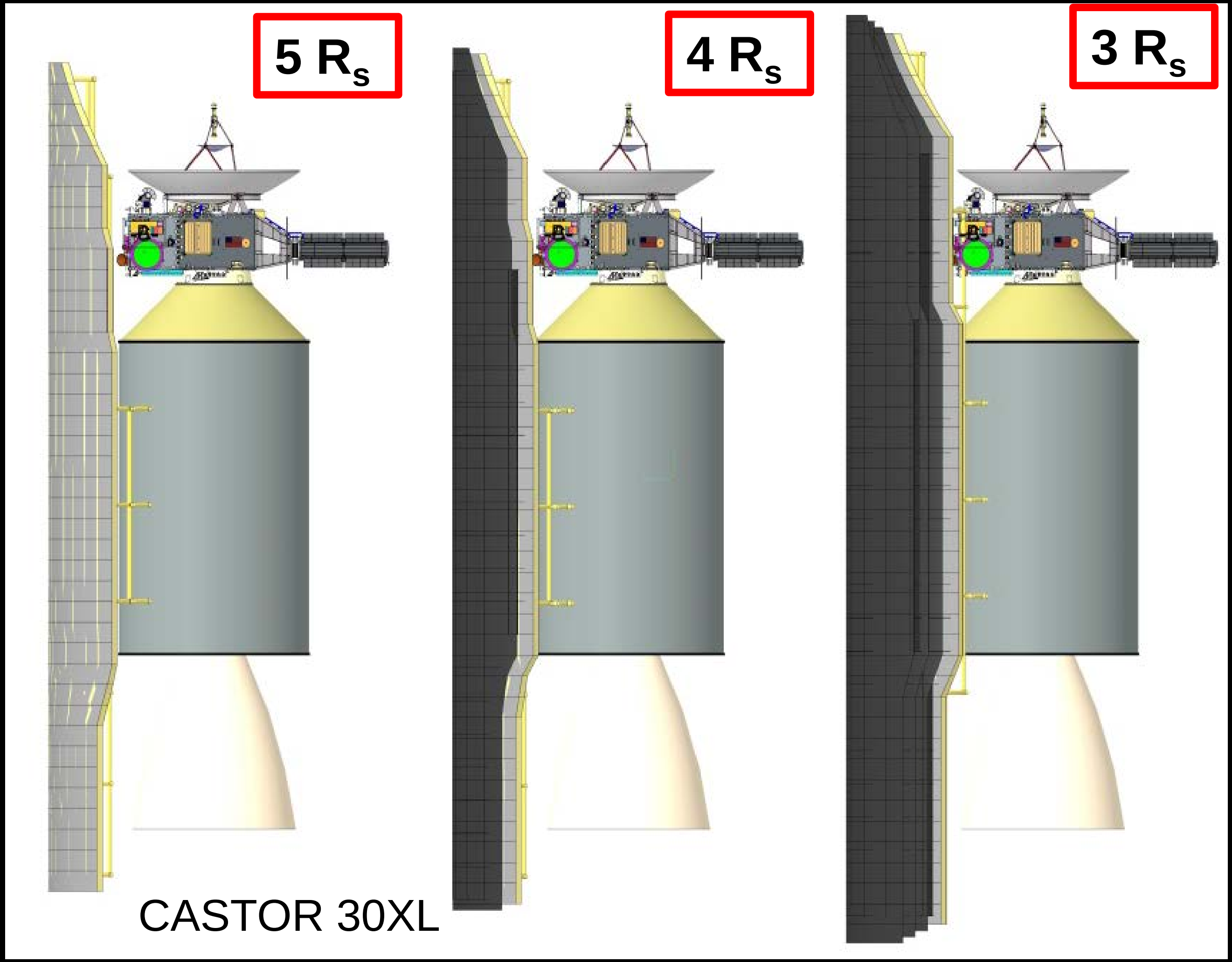


Umbra clearance checks made for each configuration

Thermal analysis at 5 R_s

~2200°C to 2600°C (hottest)

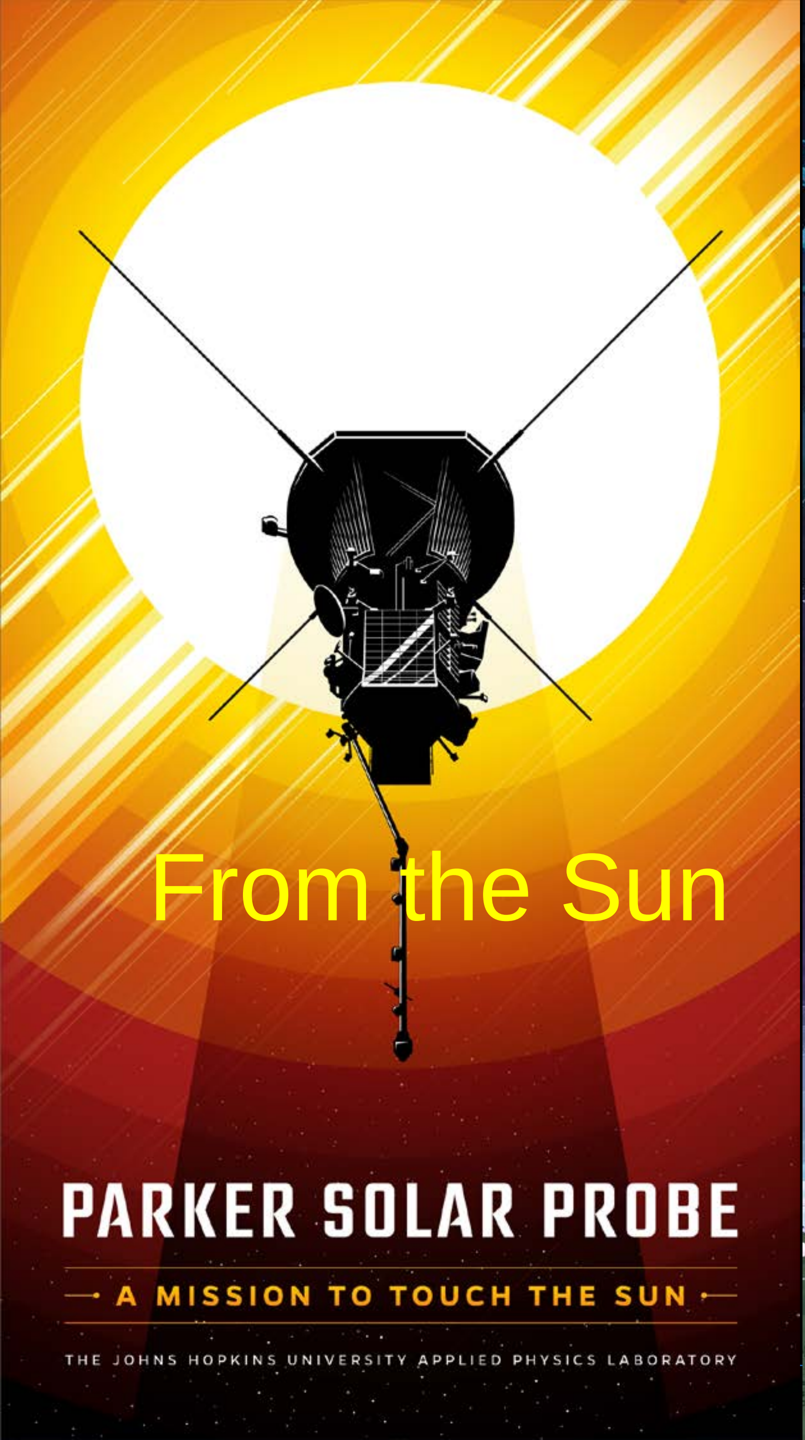




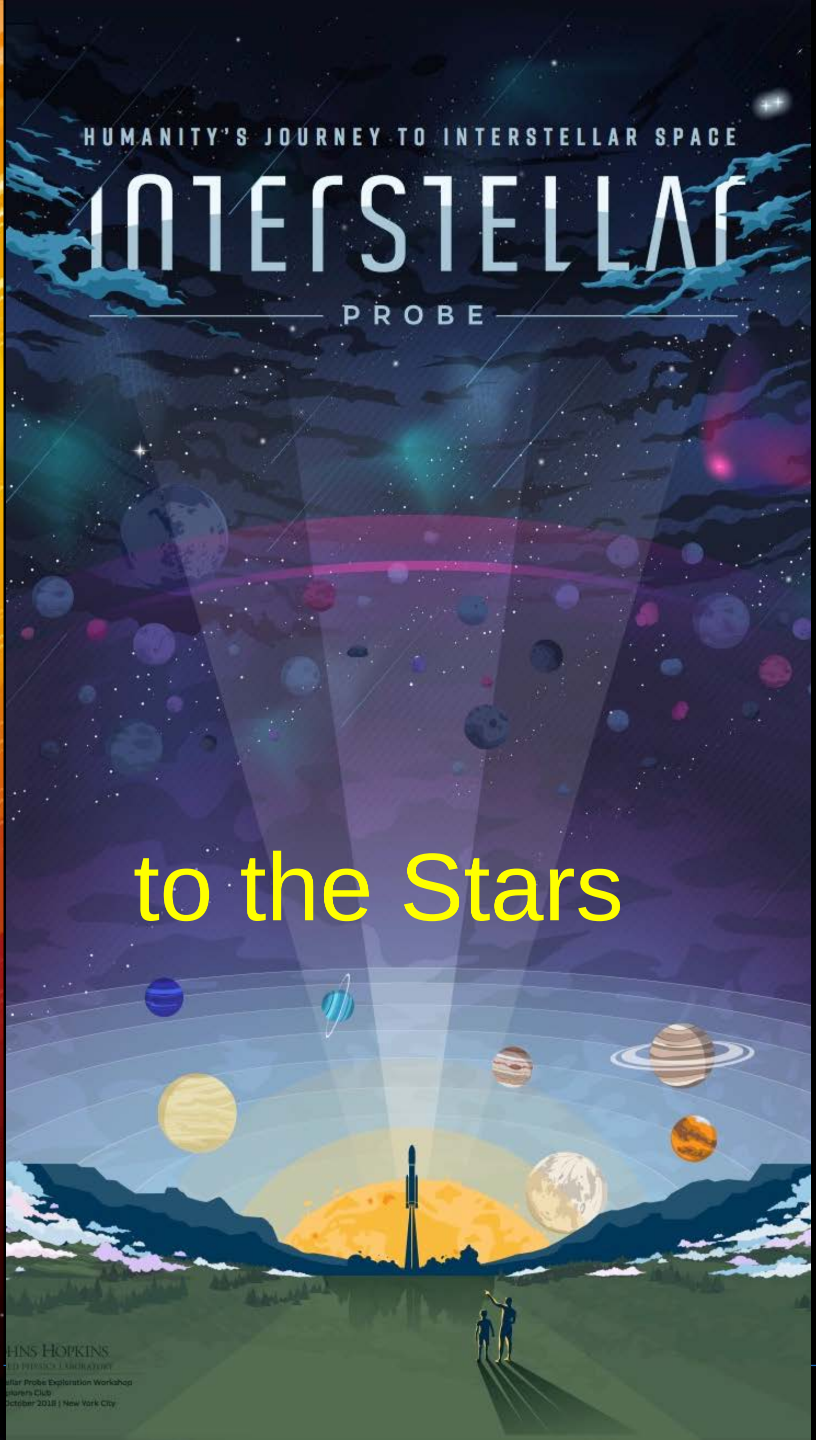
Where Do We Go From Here?

INTERSTELLAR PROBE

Accomplishments	➢	What's Next?
1st Interstellar Probe Explorers Club Workshop	➢	Strong interest from community: call for annual event
Diverse viewpoints informing mission science	➢	Expand call for participation to give more voice to contributors in advance of upcoming decadal surveys
Study Report: Preparing for May release	➢	Delve deeper Into engineering implications, solutions, options
Trajectory classes identified	➢	Trade off payload mass vs. speed vs. mission complexity
Notional payload identified	➢	Refine synergy between observations; solicit additional options from community; develop CONOPS by phase
Solar Oberth maneuver limitations framed	➢	Explore enhancements to TRL 9 Parker Solar Probe thermal protection system to open up the envelope
SLS High-C_3 capabilities understood	➢	Refine upper stage options; investigate other launch vehicle options, e.g., commercial providers



From the Sun



to the Stars

INTERSTELLAR PROBE

The real journey has only just begun…