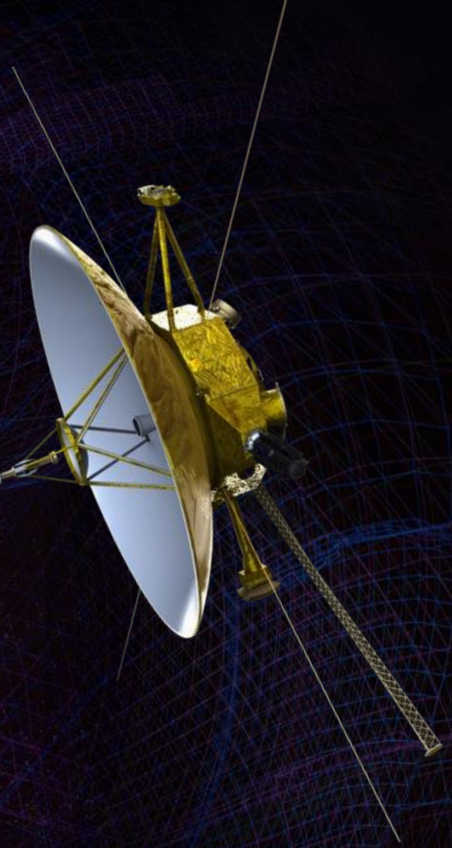
INTERSTELLAR

PROBE



Interstellar Probe: Humanity`s Journey to Interstellar Space Begins

Lecture at NASA Heliophysics Summer School, 25 June 2021

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and 476 experts and enthusiasts around the world

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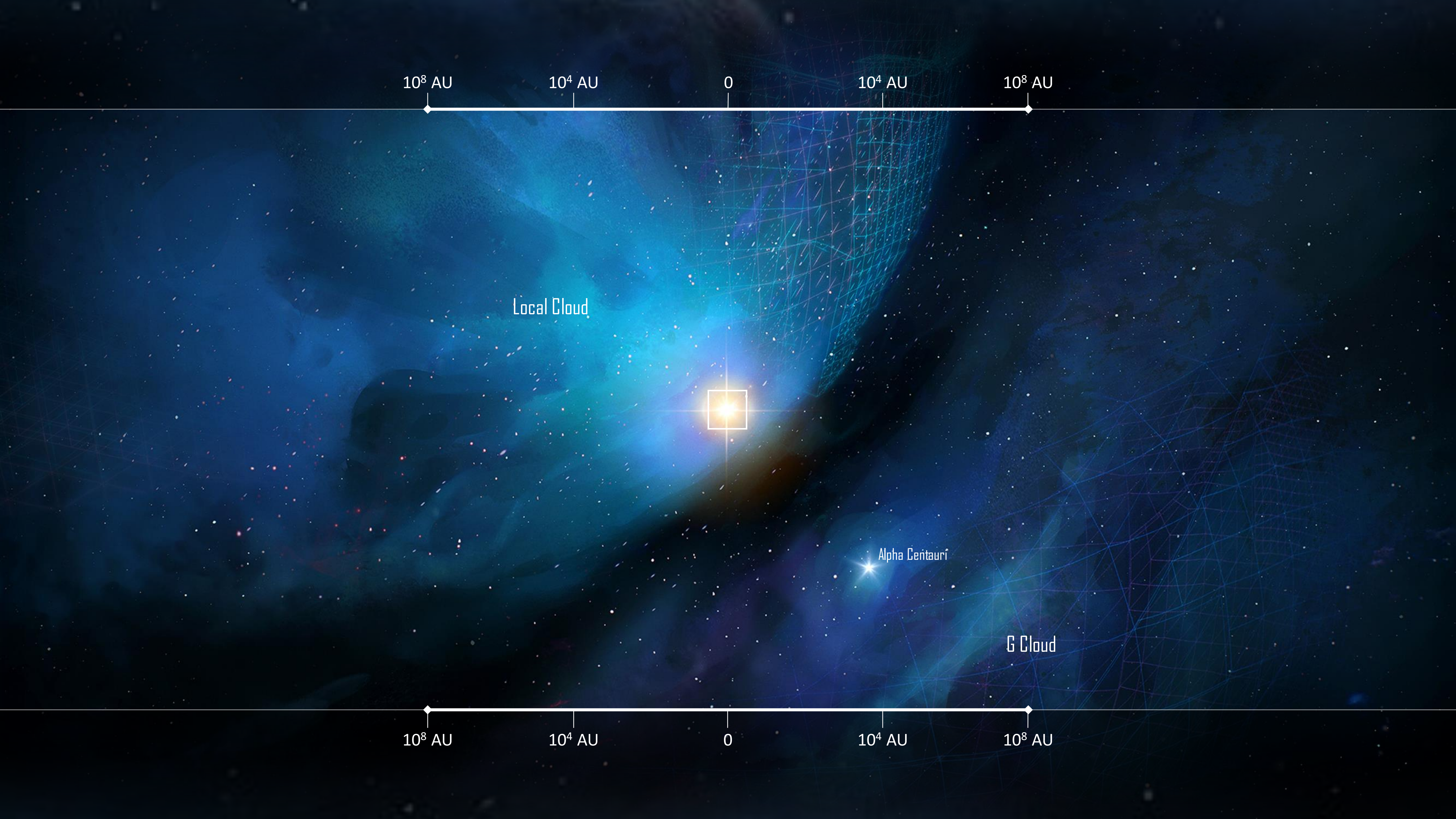
interstellarprobe.jhuapl.edu


Local Cloud
AQL Cloud
Alpha Centauri
G Cloud
Sirius
Blue Cloud


10^8 AU
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Local Cloud
Alpha Centauri
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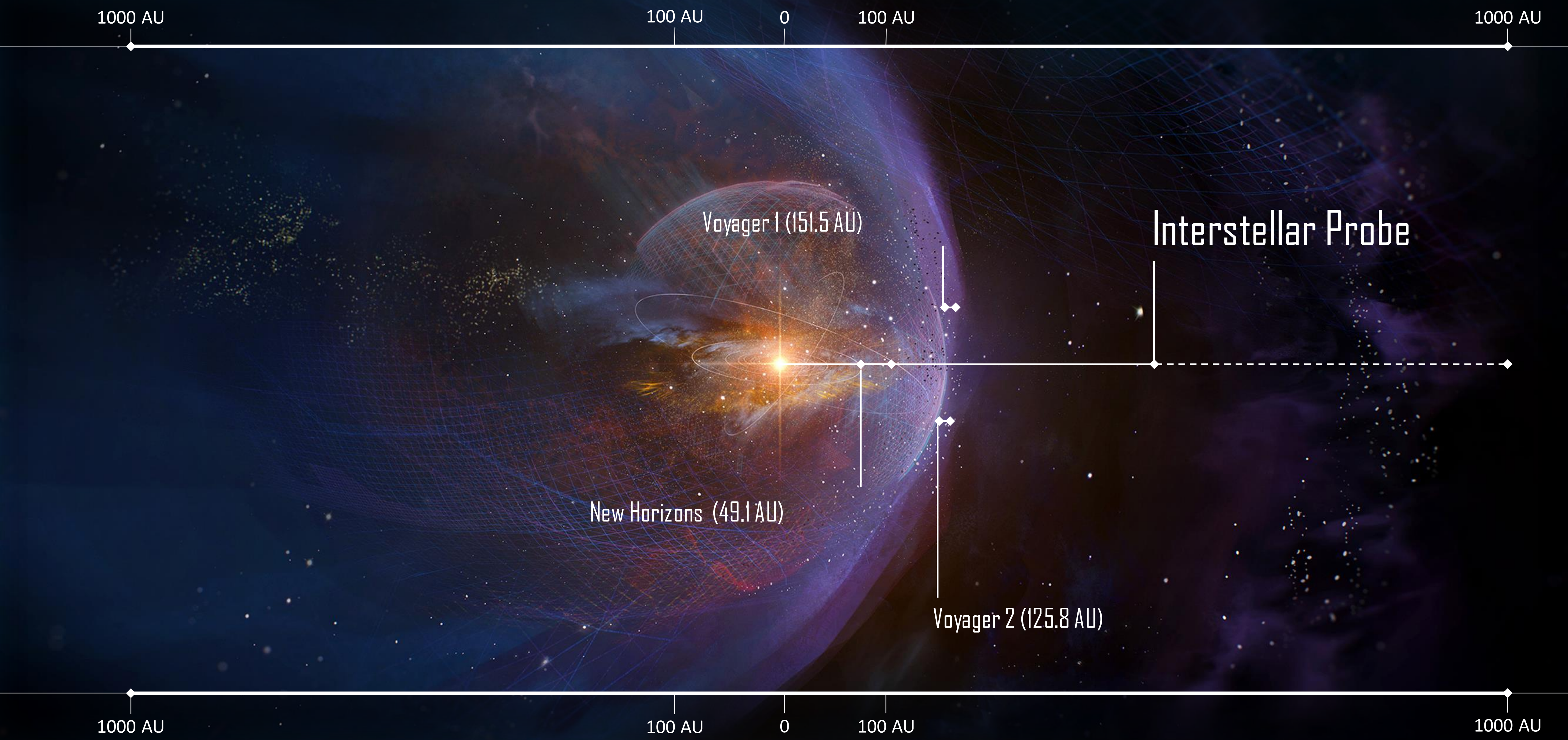
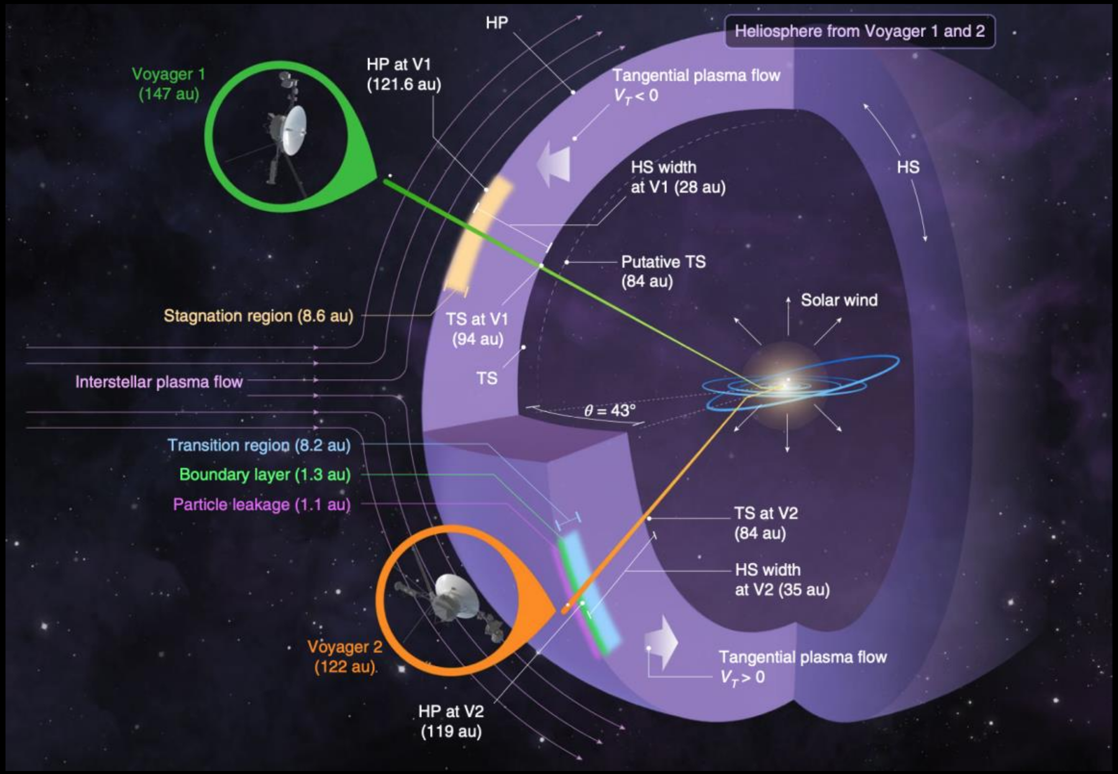

1000 AU
100 AU
0
100 AU
1000 AU
Voyager 1 (151.5 AU)
Interstellar Probe
New Horizons (49.1 AU)
Voyager 2 (125.8 AU)
1000 AU
100 AU
0
100 AU
1000 AU

Current understanding of the heliosphere

Unexpected discoveries that remain challenging to explain



- Voyager 1 and 2 are the only spacecraft to have traversed the Heliopause. With limited payload they left a range of mysteries.
- IBEX and Cassini have imaged the boundaries from inside and have brought the best global understanding to date, but still lack consistent interpretations
- SOHO, Ulyssses, New Horizons brought remote information on interstellar neutrals and their critical interaction with the heliosphere
- IMAP (launch 2025) will provide order-of-magnitude better ENA imaging capabilities from 1 AU and guide further formulation of the Interstellar Probe Science Investigation

What is Interstellar Probe?

Achieving a Dream: A mission to the Interstellar Medium has been discussed since 1960

The First Step: Interstellar Probe is a mission concept through the boundaries of the heliosphere, in to the Local Interstellar Medium

Not A Starship: Uses available or near-term technologies to achieve asymptotic speeds larger than those of past missions

The Science: Our heliosphere as a habitable astrosphere, the unexplored interstellar medium beyond, and opportunities for planetary science and astrophysics

Paving the Way: Interstellar Probe paves the way scientifically, technically and programmatically for longer interstellar journeys that would require future propulsion systems

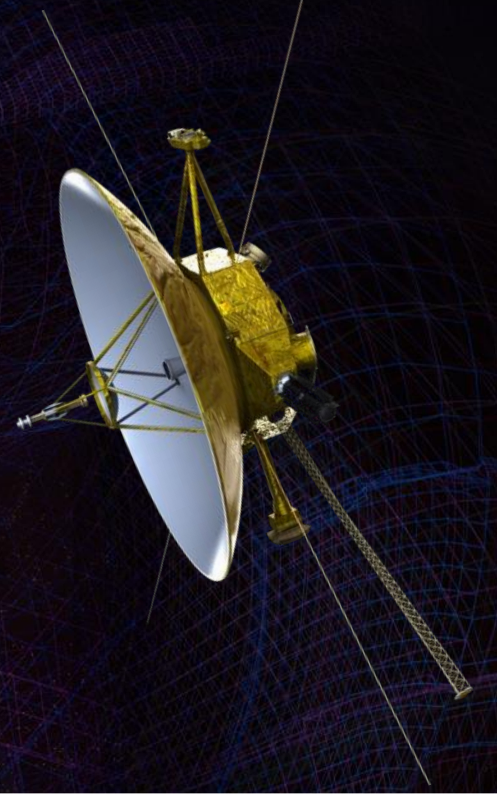
Interstellar Probe mission concept study

- 4-year study funded by NASA led by JHU APL and supported by more than 470 scientists, engineers and enthusiasts around the world
- “Pragmatic” mission concept
- Technology ready for launch by 2030
- Capability to operate and downlink out to 1000 AU
- Mission lifetime no less than 50 years
- “Menu” approach

The Team Journey

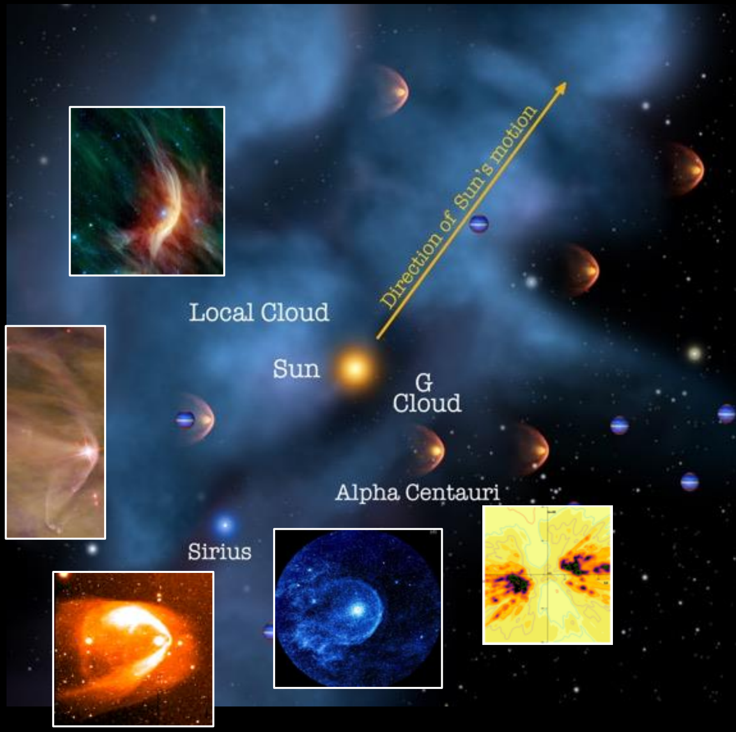
Interstellar Probe

Humanity's Exploration of Interstellar Space Begins



Primary Goal

Our Habitable Astrosphere and its Home in the Galaxy



Planetary Supporting Goal

Evolution of Planetary Systems

KBOs

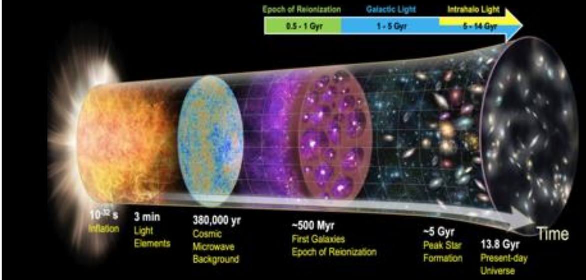
Dwarf Planets

Dust Disk

Astrophysics Supporting Goal

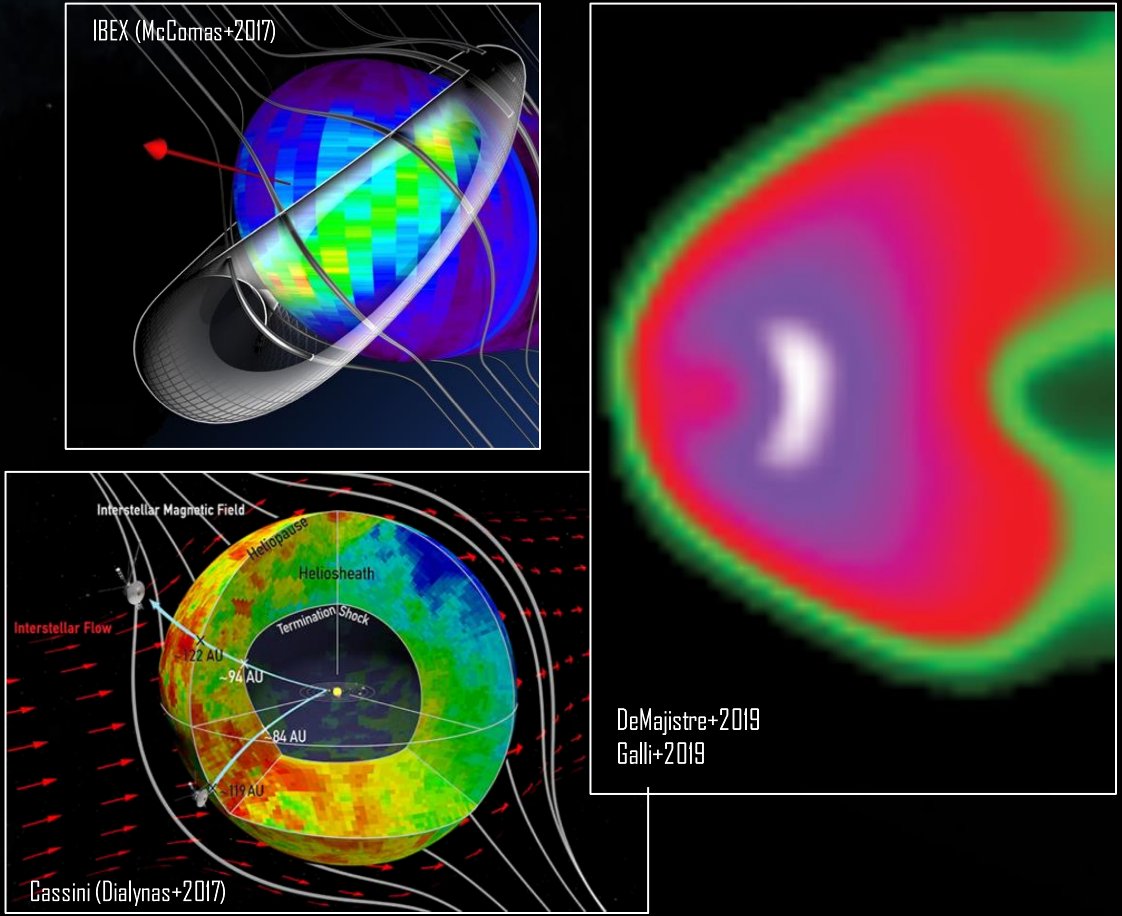
Formation of Early Galaxies and Stars

Extragalactic Background Light



Goal 1: Objective 1: A Heliosphere Shaped by the Sun

Unknown Global Structure

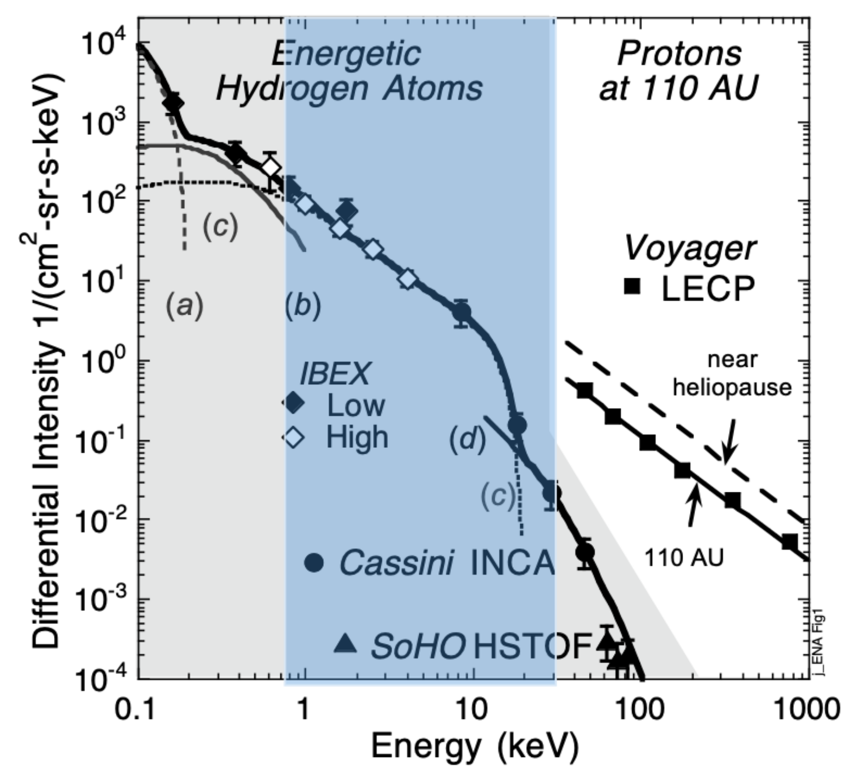


IBEX (McComas+2017)

DeMajistre+2019
Galli+2019

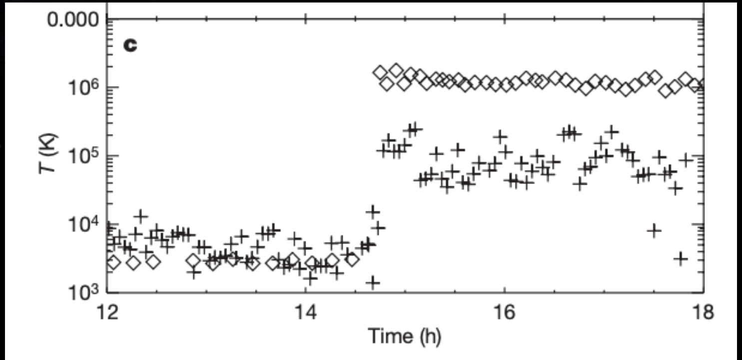
Cassini (Dialynas+2017)

Processes Upholding the Heliosphere: gap in understanding the critical pick-up-ion population



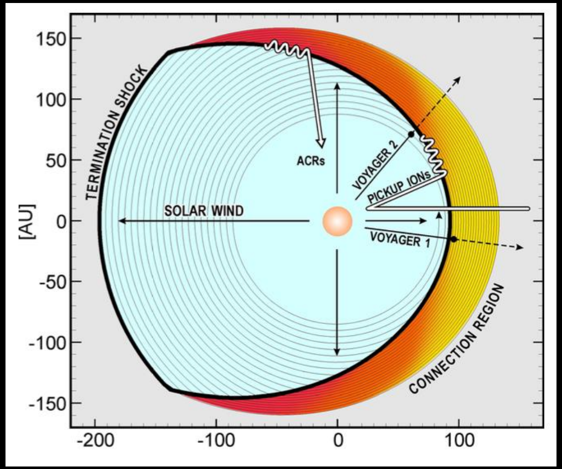
Goal 1: Objective 1: A Heliosphere Shaped by the Sun

The Termination Shock: the largest shock in the heliosphere and not like others



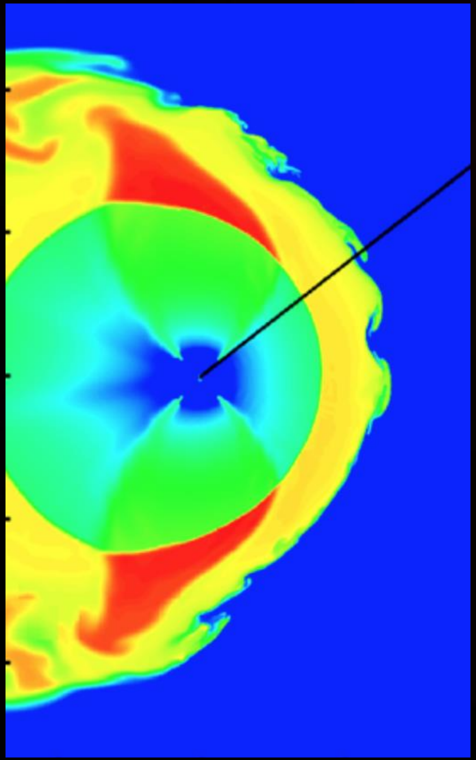
Richardson et al. 2008

Acceleration of Anomalous Cosmic Rays: still unsolved

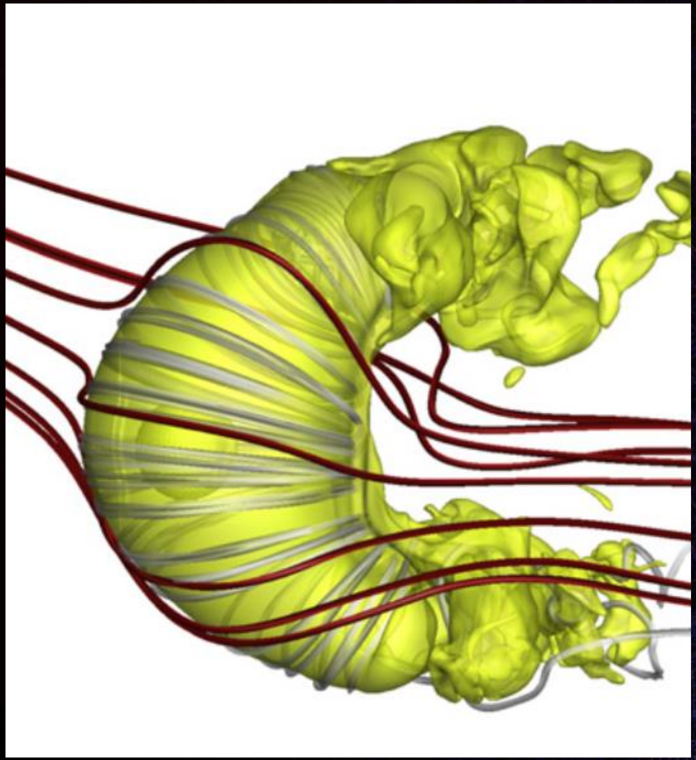


McComas and Schwadron 2006

Instabilities at the Heliopause and Magnetic Draping



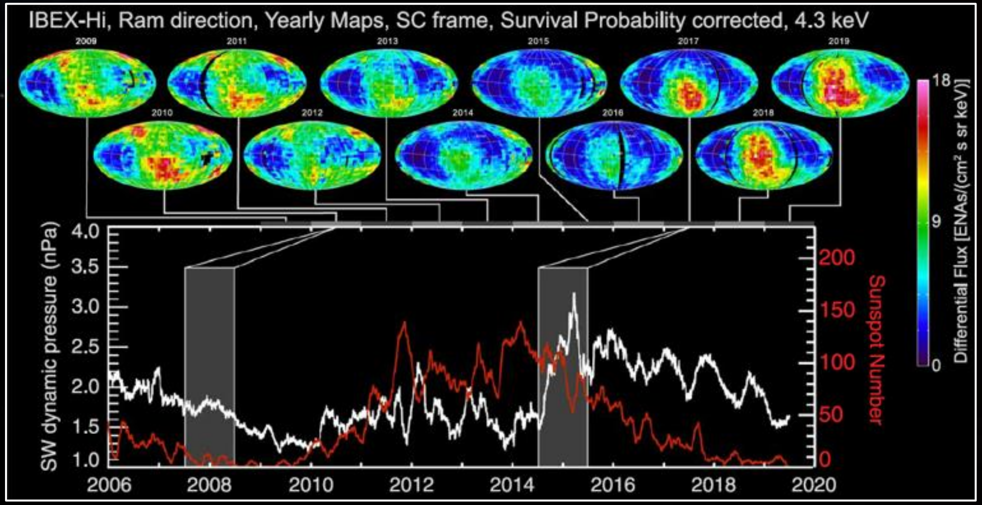
Pogorelov et al. 2017



Opher et al. 2015

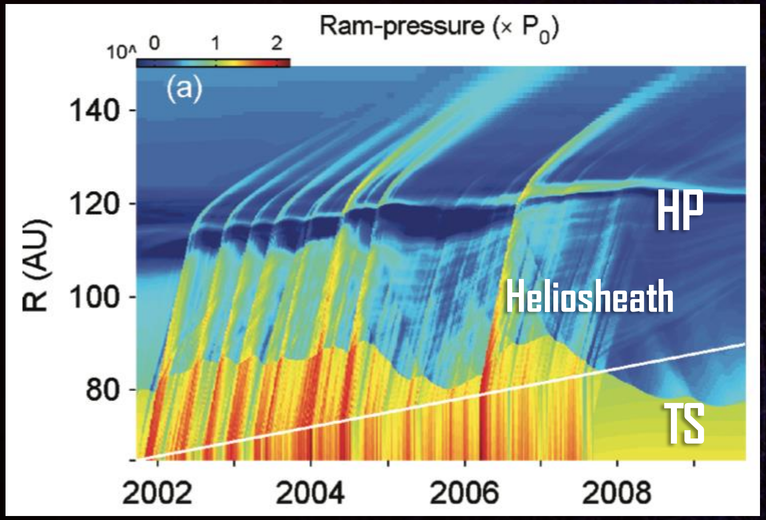
Goal 1: Objective 2: A Variable Sun in a Changing Interstellar Environment

The Breathing Heliosphere Harboring a Variable Sun



McComas+2020

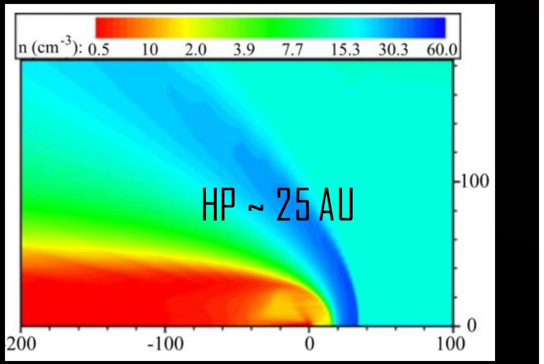
Highly Dynamic Heliosheath



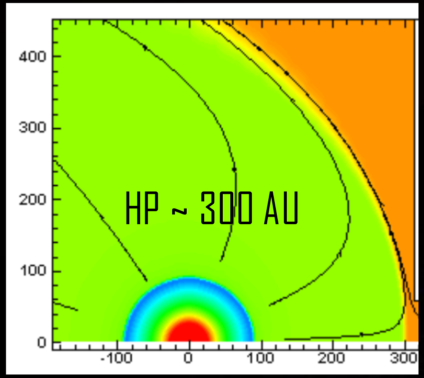
Washimi et al. 2011

The Changing Heliosphere Through an Inhomogeneous ISM

Tiny heliosphere in a dense interstellar cloud

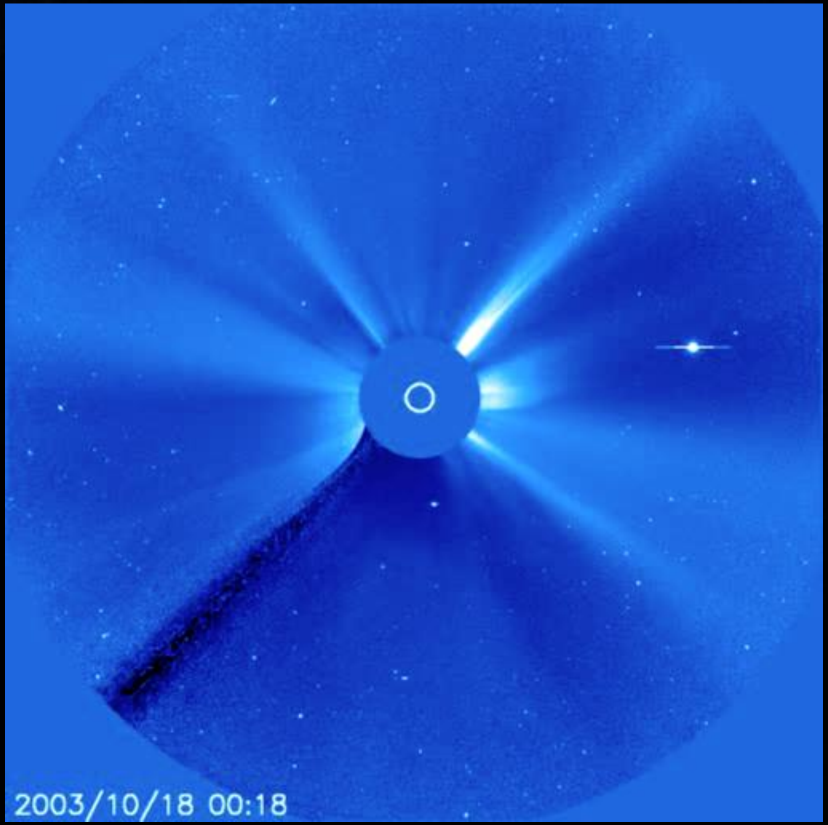


Large heliosphere in Local Bubble plasma



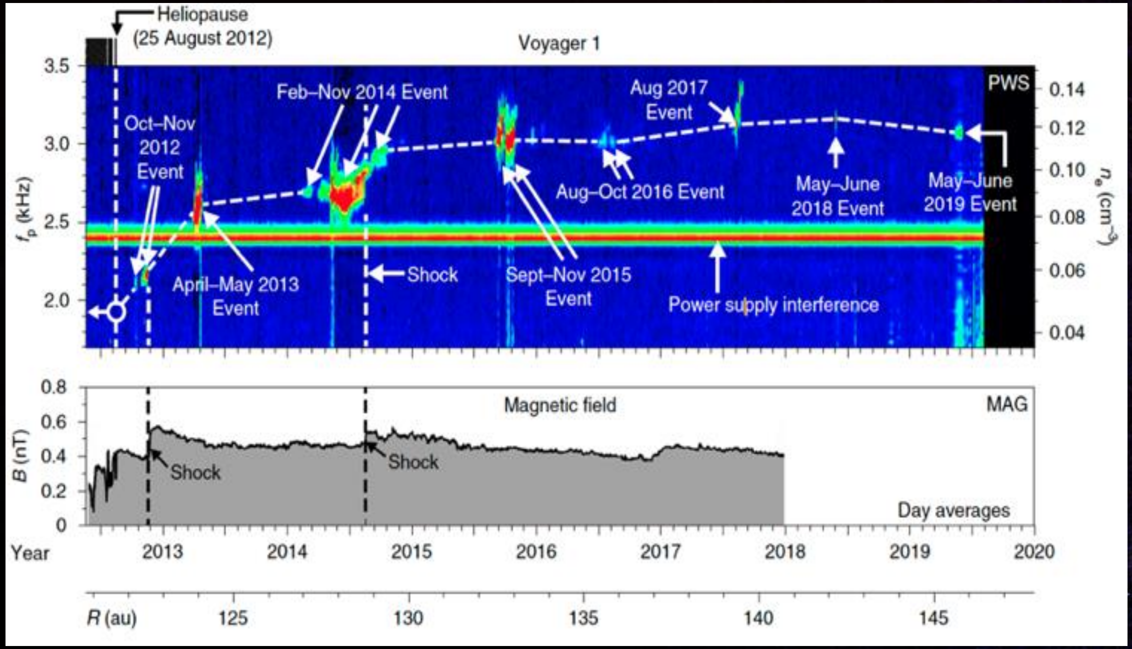
Muller et al. 2008

Goal 1: Objective 2: A Variable Sun in a Changing Interstellar Environment



SOHO/LASCO

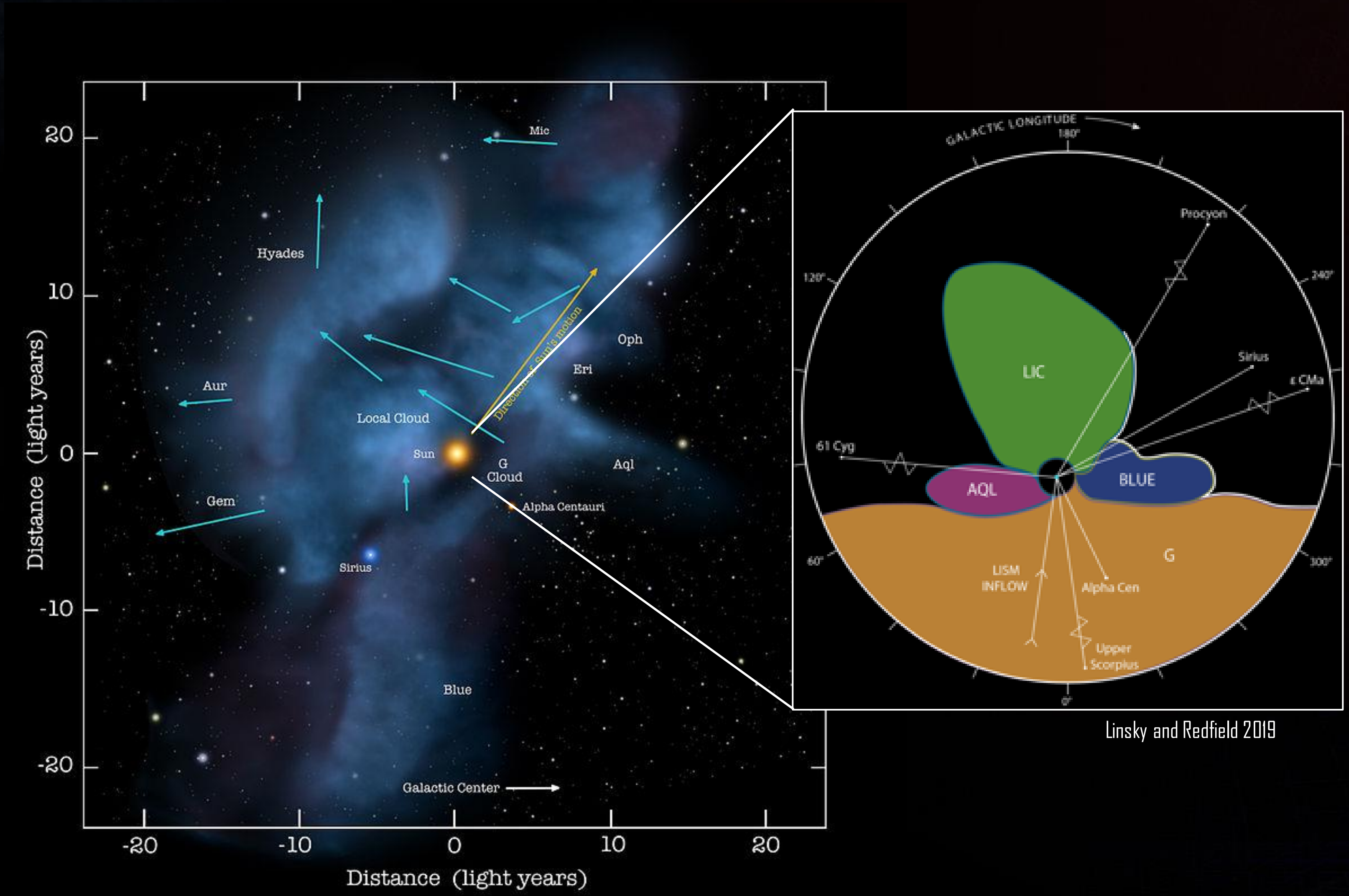
Connecting the dynamic Sun with shocks in the interstellar medium



Gurnett & Kurth (2019)

How far does the influence of our Sun extends into the interstellar space?

Goal 1: Objective 3: Into the Unknown Local Interstellar Cloud

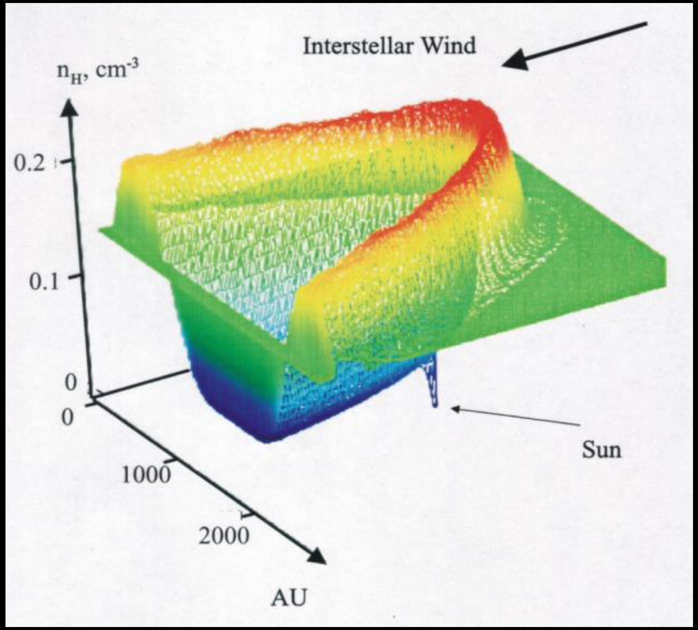


Linsky and Redfield 2019

The first direct sampling of density, temperature, ionization, state, composition and fields beyond the heliopause would provide decisive information on the heliospheric interaction, and also on the chemical evolution of the galaxy.

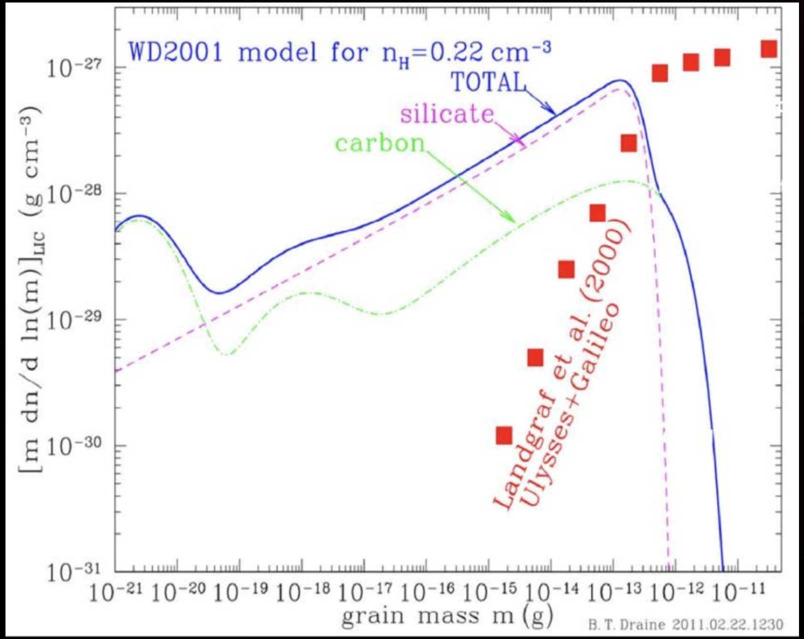
Goal 1: Objective 3: Into the Unknown Local Interstellar Cloud

Hydrogen Wall: Discovered remotely but unexplored

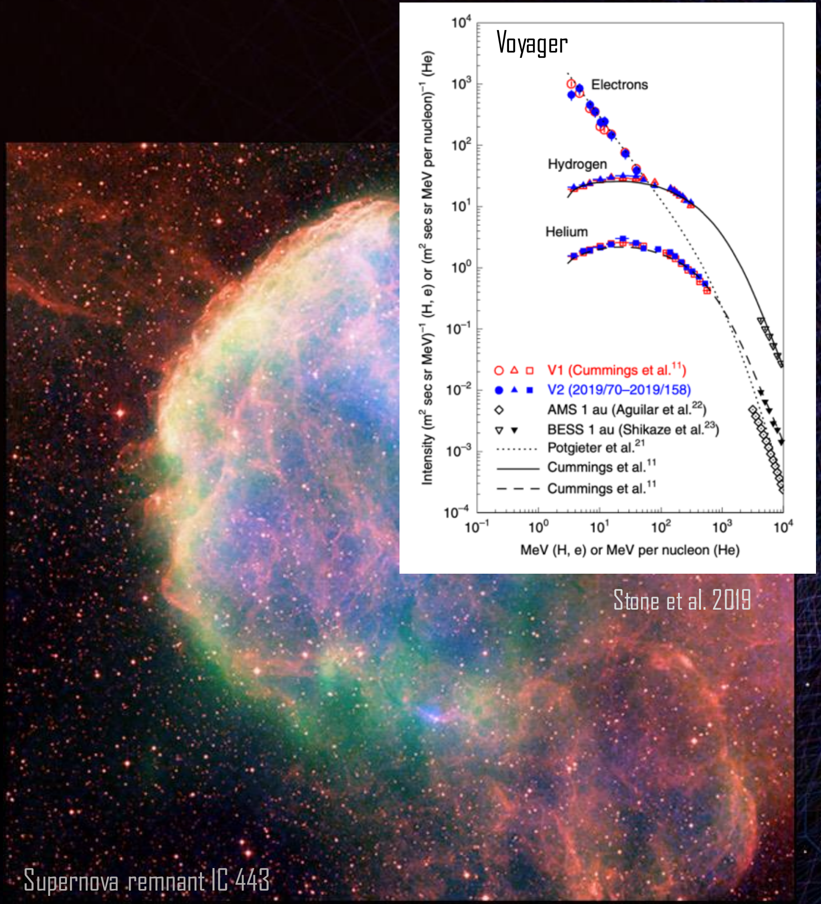


Gruntman et al. 2001

Interstellar Dust: disconnect between ISM dust measurements from remote sensing and in-situ measurements



New Galactic Cosmic Ray science: sources and origin of GCRs <1 GeV



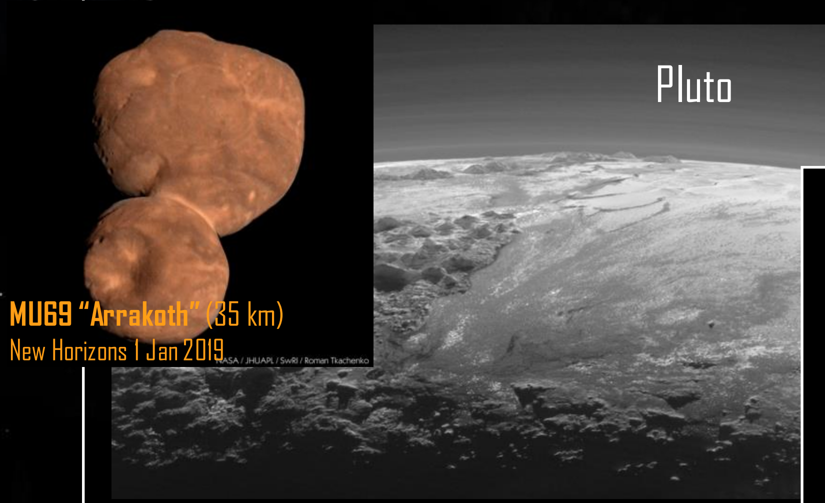
Stone et al. 2019

Supernova remnant IC 443

Unique Opportunities for Planetary Science and Astrophysics

The Origin of Planetary Systems

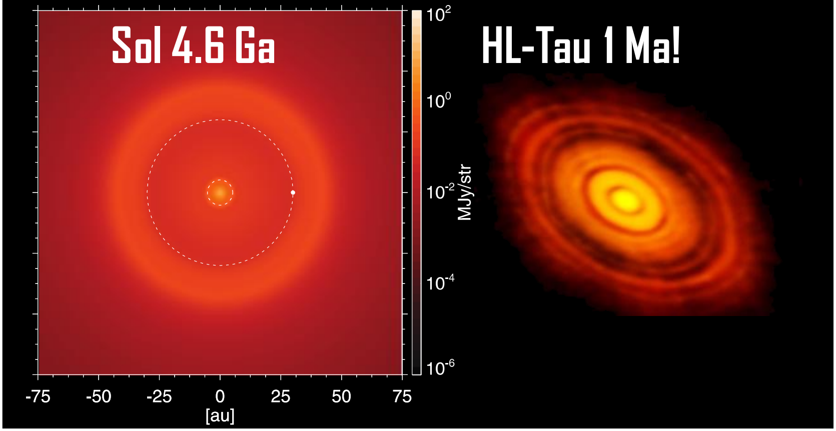
Dwarf Planets and KBOs



130 dwarf planets and over 4000 KBOs. Any direction defined by Heliophysics offers at least one compelling flyby.

Imprint of Solar System Evolution

Circum-Solar Dust Disk



Discovery of the solar dust disk is critical for understanding the evolution of planetary systems.

Understand Galaxy and Star Formation

Extragalactic Background Light (EBL)

Uncovering the Extragalactic Background spectrum, a key in our understanding of early galaxy formation.

Notional Operations Scenario

Driving Mission Architecture Designs

Baseline Scenario

(concluding now)

- Spin stabilized
- 50m PWS wire antennas

Inner Heliosphere Phase

1-90 AU

- In-situ measurements of magnetic fields, solar wind and PUI
- ENA and Ly-a imaging from a changing vantage point
- PWS observations of 2.5 kHz emission

Heliosheath Phase

90-120 AU

- In-situ measurements through boundary region
- ENA and LYA imaging
- PWS Observations

Interstellar Phase

>120 AU

- In-situ measurements of ISM gas, neutrals and dust
- External ENA and Ly-α imaging
- In-situ measurements of ribbon

Baseline: Goal 1 (Primary)

Goal	Science Objectives	Specific Questions	Measurement Objectives	Measurements (Supporting)	Mission Requirements
1. Understand Our Habitable Astrosphere and in its Home in the Galaxy	Physical Processes and Global Manifestation	Global Structure; Force Balance	In-situ particle spectra and fields across HS and into LISM, flows; Remote wave, Ly-a and ENA imaging.	MAG, PLS, PUI, EPS, CRS, ENA, PWS, LYA	Spinning; imaging from ~250 AU
		Ribbon/Belt	ENA imaging; In-situ within ribbon.	ENA, PLS	Spinning; trajectory through ribbon to ~300 AU
		ACRs, shocks, reconnection, TS, HP	Fields, e/ion plasma to ACRs across TS, HS; Fields, waves, particle spectra for HP instabilities	MAG, PLS, PUI, EPS, CRS, PWS	Spinning; through HP ~130 AU; spend sufficient time in HS
		Neutrals in the Heliosphere	LOS velocity and temperature of H	LYA, NMS	Through HP ~130 AU
	Dynamics and Evolution	Solar Wind Effects on the Boundary	In-situ ~day variations in HS; ENA and wave variations remotely	MAG, PLS, PUI, EPS, CRS, ENA, PWS	Spinning; spend sufficient time in HS
		Shock Propagation and Turbulence	Fields, e/ion plasma to GCR anisotropies; fields turbulent spectra Earth to LISM	MAG, PLS, PUI, EPS, CRS, PWS	Spinning; sufficient time beyond HP out to ~400 AU
		GCR Modulation/Shielding	GCR e/ion composition, fields out to LISM	MAG, CRS	Spinning; sufficient time beyond HP out to ~400 AU
	Properties of the Unexplored VLISM	Nature of Bow Shock	In-situ fields, plasma, PUI for sound speed	MAG, PLS, PUI	Spinning; ≤300 AU
		Hydrogen Wall	LOS H; In-situ H and composition	LYA, NMS	≥300 AU
		Neutrals/Dust Filtration	In-situ elemental and isotopic out to LISM	NMS, IDA	~400 AU
		LISM gas and plasma	Density, temp., composition, ionization	MAG, PLS, NMS	Spinning; ~400 AU
		LISM Inhomogeneities	Variability of properties on 100's AU	MAG, PLS, NMS	Spinning; ~400 AU
		Origin of GCRs	Elemental/isotopic abundances, spectra	MAG, CRS	Spinning; sufficient time beyond HP

v12.0

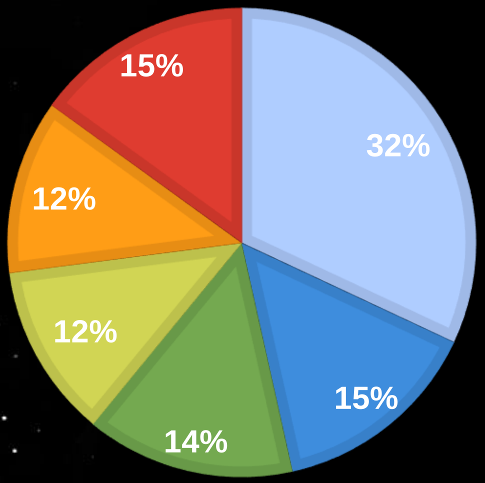
MAG	Magnetometer	**EPS**	Energetic Particle System	**PWS**	Plasma Wave System	**IDA**	Interstellar Dust Analyzer	**NMS**	Neutral Mass Spectrometer
PLS	Plasma System	**CRS**	Cosmic Ray System	**ENA**	Energetic Neutral Atoms	**IDC**	Interstellar Dust Counter	**LYA**	Ly-Alpha Spectrograph

Example Model Payloads

Heliophysics Baseline

87.4 kg
86.7 W

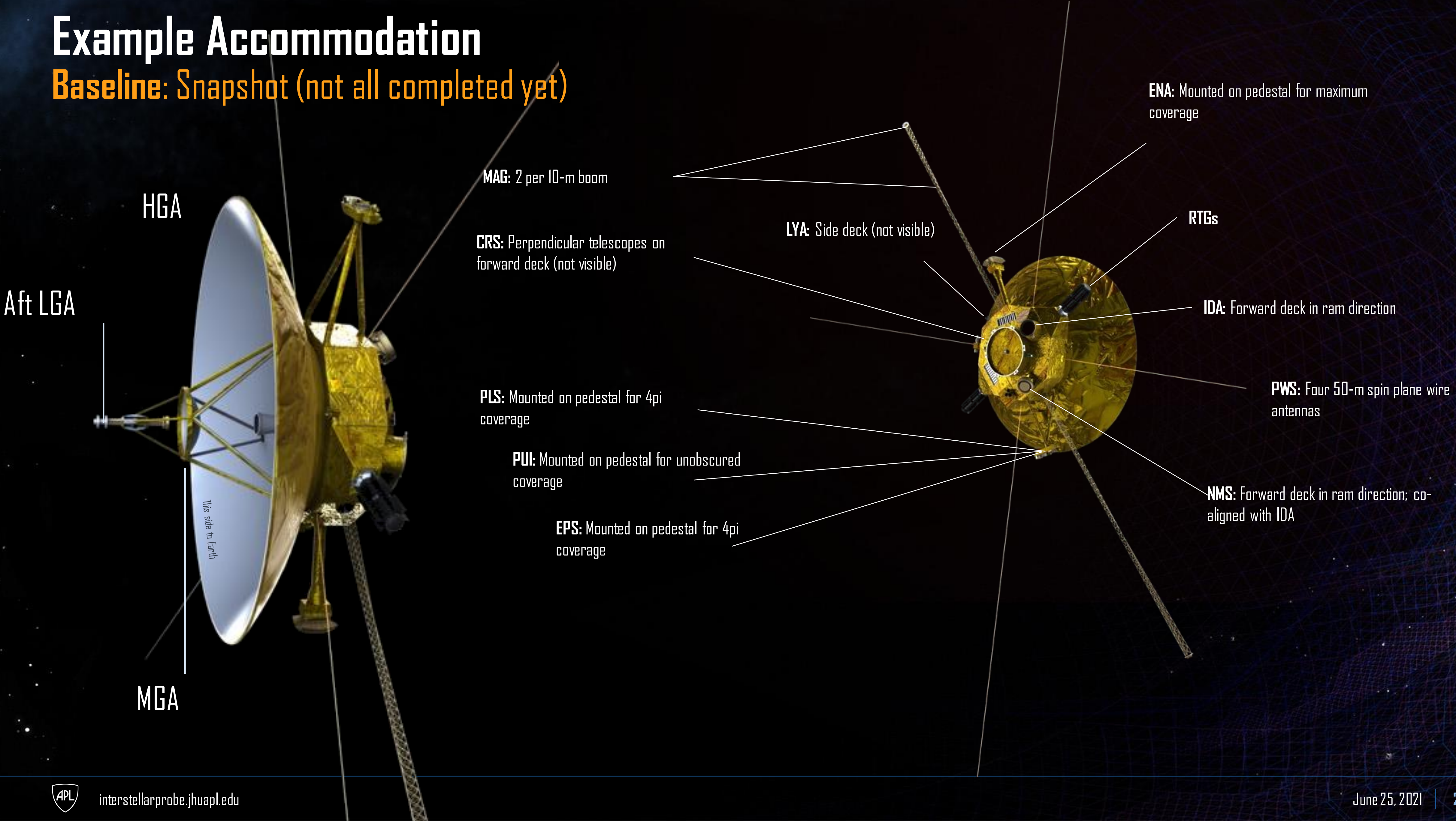
- ◻ Charged Particles
- 🟦 Fields and Waves
- 🟩 ENA Imaging
- 🟨 Dust
- 🟧 Neutrals
- 🟥 Ly-alpha



Instrument (Heritage)	Measurement Requirements		Mission Requirements	Science Driver
Magnetometer (MAG) (MMS/DFG)	0.01 - 100 nT; 0.01 nT (10^{-8} nT^2/Hz turb.)	≤60 s; (100 Hz)	Two FG, 10m boom	LISM (turbulence)
Plasma Waves (PWS) (Van Allen/EFW)	~1 Hz – 1 MHz; Δf/f≤4% ≤0.7 µV/m @ 3 kHz	≤60 s (≤ 4 s at TS)	4x50 m wire; spin plane	LISM n$_e$, T$_e$ (QTN), turbulence
Plasma Subsystem (PLS) (PSP/SWEAP/SPAN-A)	~eV to 10's keV e, H+, He+, C+, N-O+	~4π; ≤60 s	Spinning	Flows, n$_e$, T$_e$, n$_i$, T$_i$ Force balance
Pick-up Ions (PUI) (Ulysses/SWICS)	0.5-78 keV/q H, ^{3}He, ^{4}He, C, ^{14}N, ^{16}O, ^{20}Ne, ^{22}Ne, Mg, Si, Fe (charge states)	iFOV: 60°	Spinning	Interstellar, inner PUI Force balance
Energetic Particles (EPS) (PSP/EPI-Lo)	10's keV – 1's MeV H, ^{3}He, ^{4}He, C, O, Ne, Mg, Si, Fe (Li/BeB)	~4π; ≤60 s	Spinning	S/W, HS and ACRs Force balance
Cosmic Rays (CRS) (PSP/EPI-Hi, new development)	H to Sn; ≤1 GeV/nuc; Δm= 1 amu electrons; ≤10 MeV	≥2 directions; daily	Spinning	ACRs, GCRs LiBeB cosmic story
Interstellar Dust Analyzer (IDA) (IMAP/IDEX, new development)	1-500 amu; **m/Δm:** ≥ 200	iFOV: 90°	Ram direction Co-boresighted NMS	ISDs, galactic heavy ion composition
Neutral Mass Spectrometer (NMS) (LunaResurs/NGMS, JUICE/NMS)	H to Fe, m/Δm > 100 (1σ) 1 – 300 u/e	iFOV: 10°; weekly	Ram direction Co-boresighted IDA	LISM composition
ENA (ENA) (IMAP/Ultra, new development)	~1-100 keV; H (He, O goal)	iFOV: 170° x 90°	Spinning, 2 heads	Shape, force balance, ribbon/belt
Lyman-Alpha Spectrograph (LYA) (MAVEN/IUVS, new development)	120-130 nm; 0.004nm	iFOV: 5°; 140° monthly	Spinning	LISM and heliosheath H

Example Accommodation

Baseline: Snapshot (not all completed yet)



MAG: 2 per 10-m boom

CRS: Perpendicular telescopes on forward deck (not visible)

PLS: Mounted on pedestal for 4pi coverage

PUI: Mounted on pedestal for unobscured coverage

EPS: Mounted on pedestal for 4pi coverage

LYA: Side deck (not visible)

ENA: Mounted on pedestal for maximum coverage

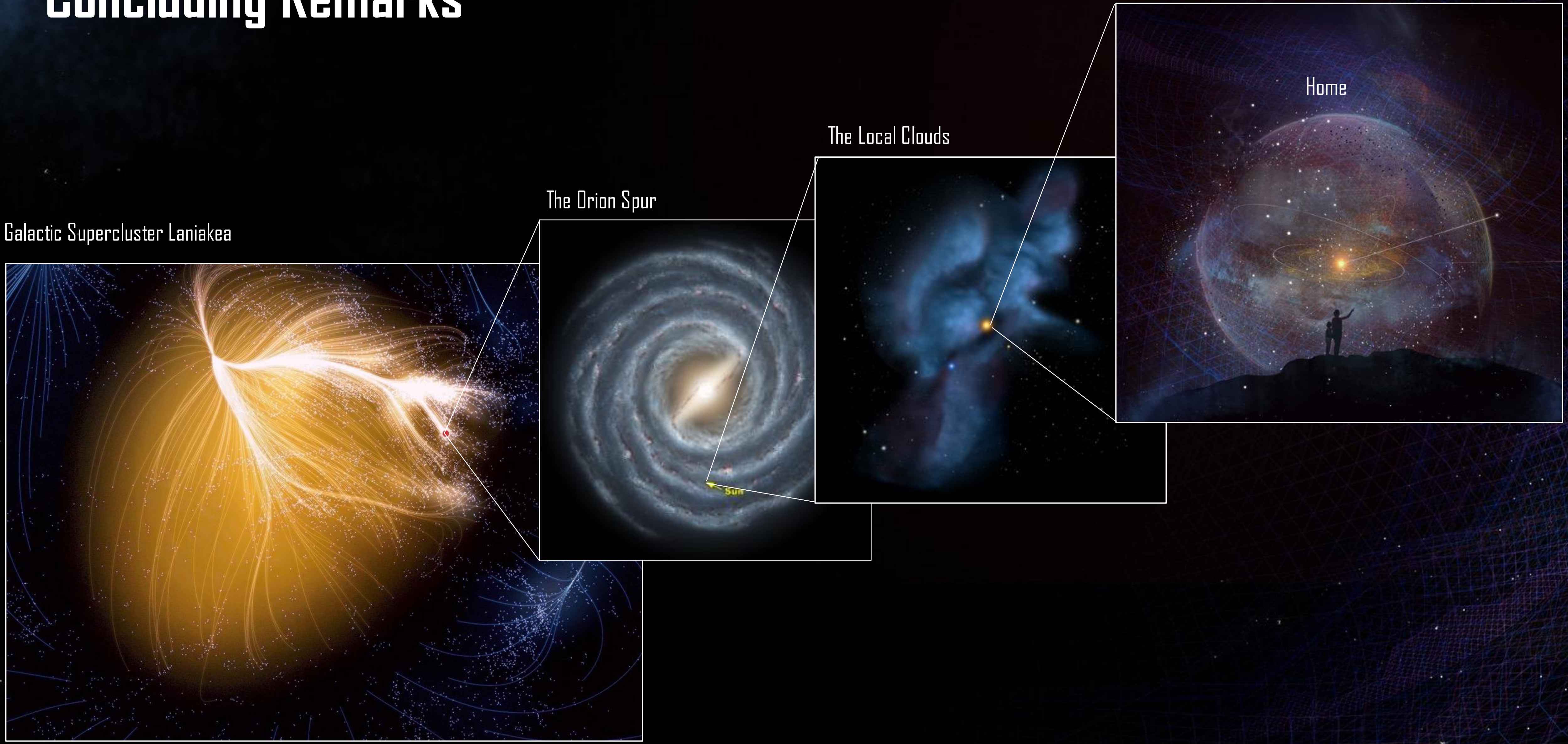
RTGs

IDA: Forward deck in ram direction

PWS: Four 50-m spin plane wire antennas

NMS: Forward deck in ram direction; co-aligned with IDA

Concluding Remarks

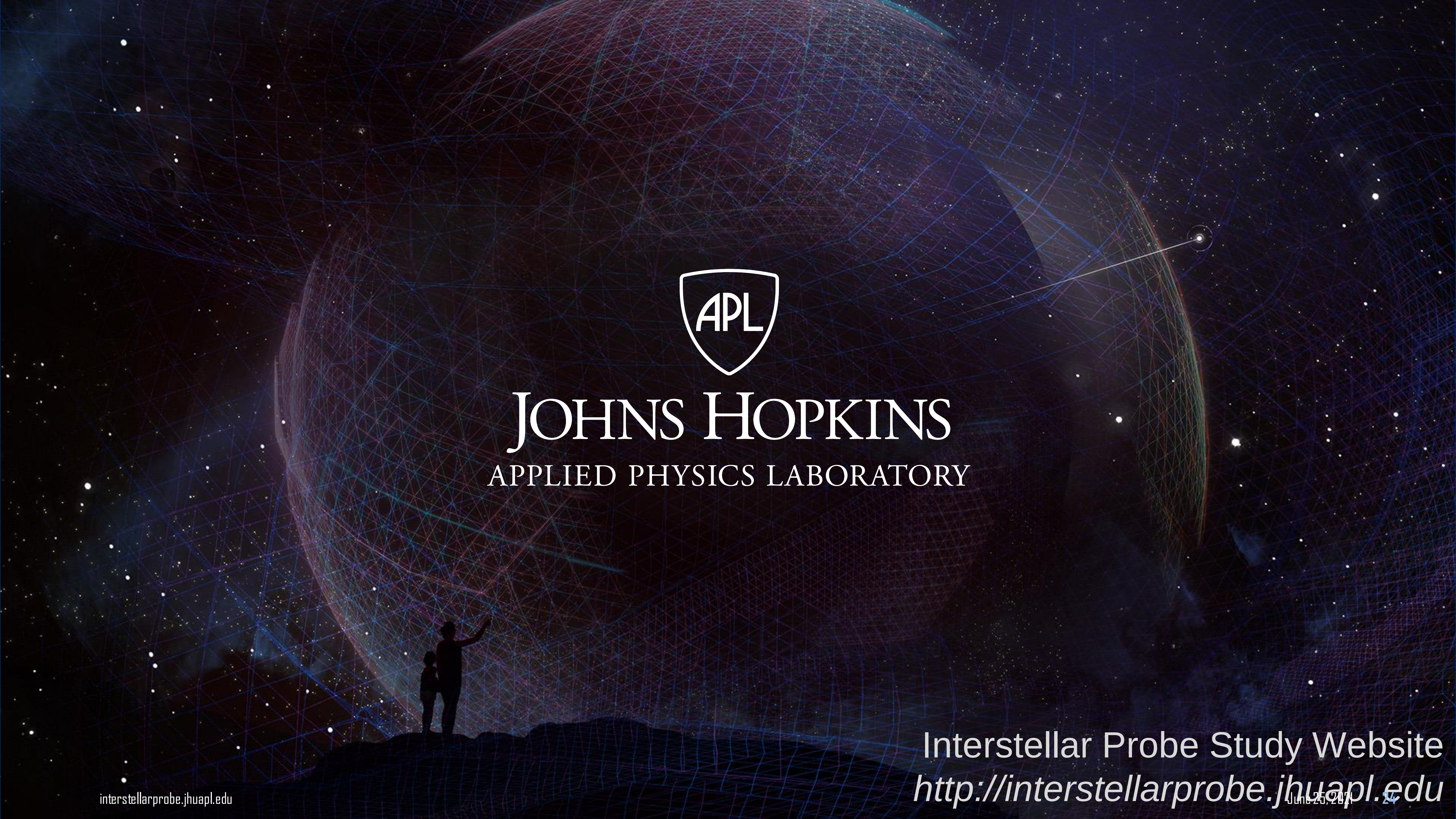


Engage

- Join the team at interstellarprobe.jhuapl.edu
- Student Program is under development
- White Papers for the Heliophysics Decadal
- https://www.lpi.usra.edu/decadal_whitepaper_proposals/heliophysics/

To join the journey: interstellarprobe.jhuapl.edu

Question and Answer Session



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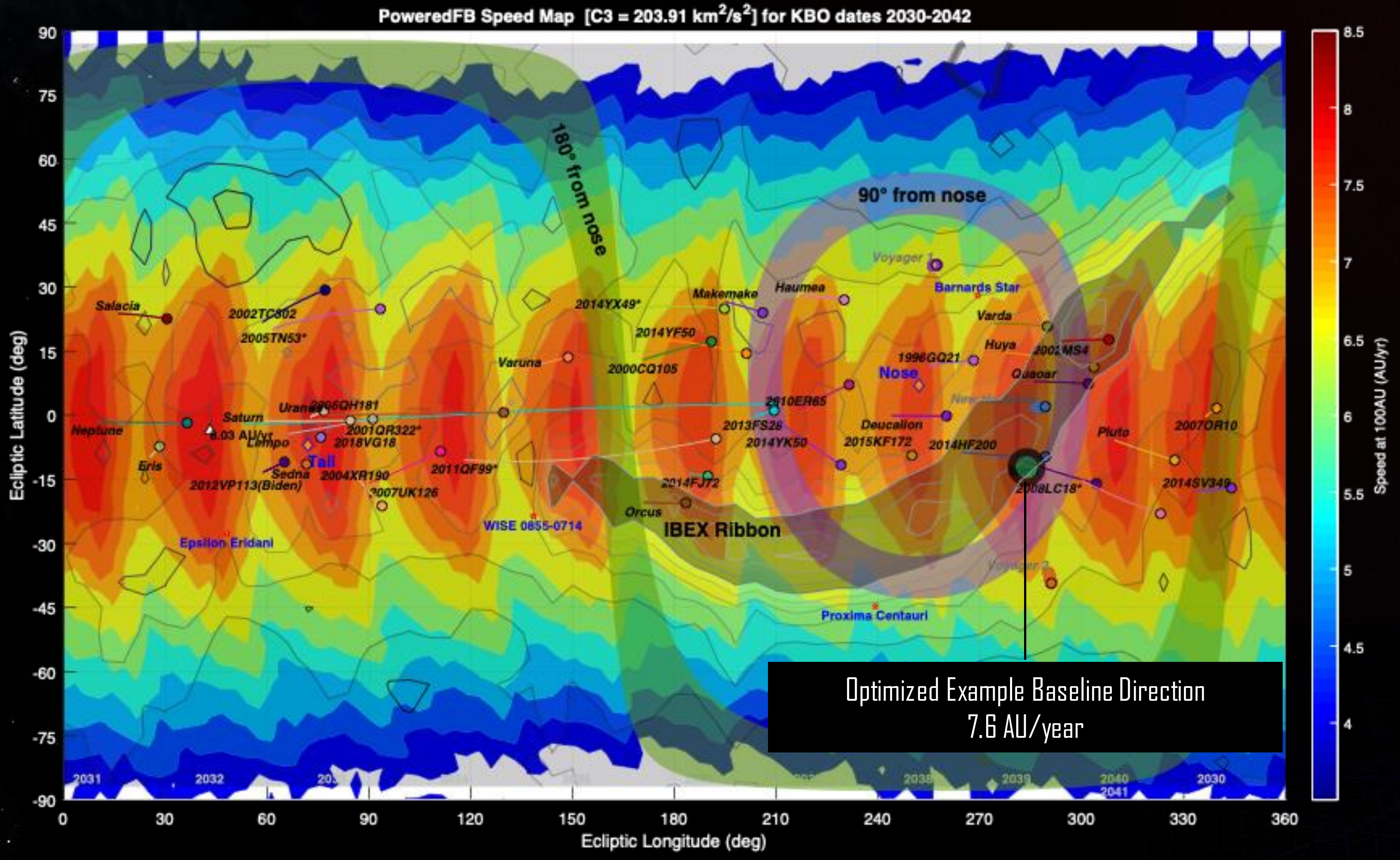
Interstellar Probe Study Website
http://interstellarprobe.jhuapl.edu

Baseline Trajectory



Optimized Example Baseline Direction
7.6 AU/year

Direction Trades from 2019 Workshop

Direction	Heliophysics Trades
~45° off nose	• Through ribbon (~285° ELON) • Good for imaging from outside • Good for ISD
Nose	• Fast way to LISM • Stagnation, high-pressure region, force balance • Good for ISD • Not through max ribbon • Not optimal for imaging from outside
Flank (~90°)	• HP data point important for shape • ACR acceleration • May be longer to reach LISM • Not in the ribbon • Dust duty cycle limited
~135° off Nose	• Problematic for dust • Sufficiently close to the direction of CMA • Maximum outbound speed area
Tailward	• Problematic for dust • Sufficiently close to the direction of CMA
Off Ecliptic (U/N)	• Jets, turbulence • Towards EUV ionizing stars (CMA) • Not through ribbon (tailward)