

# INTERSTELLAR PROBE

## Humanity's Journey to Interstellar Space

NASA Solar and Space Physics Mission Concept Study  
for the Solar and Space Physics 2024–2033 Decadal Survey

NASA TASK ORDER NNN06AA01C





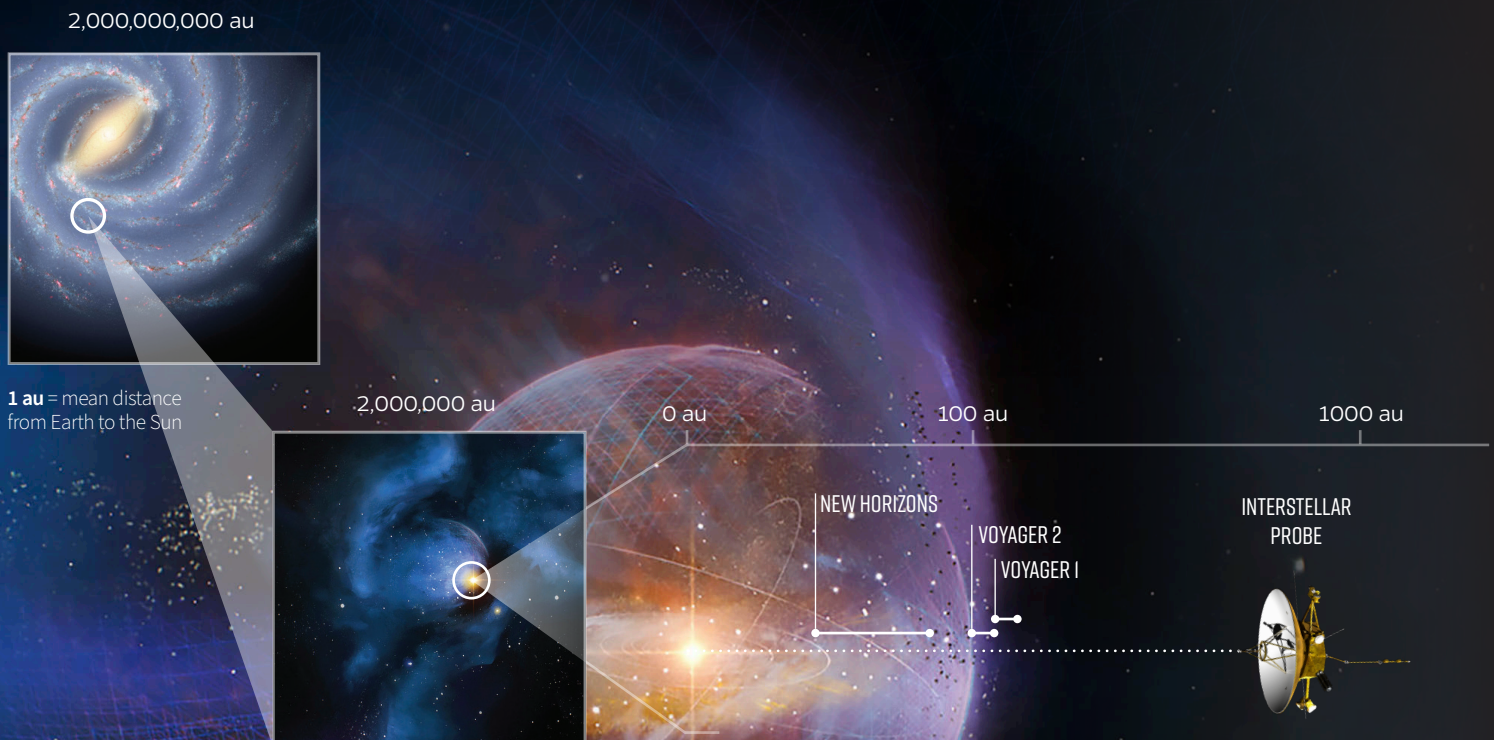
# HUMANITY'S JOURNEY TO INTERSTELLAR SPACE

**Traveling far beyond the Sun's sphere of influence, Interstellar Probe will be the boldest move in space exploration to date.** This pragmatic, near-term mission will enable groundbreaking science using technology that is near-launch-ready now. Flying the farthest and the fastest of any spacecraft ever launched, Interstellar Probe will represent humanity's first explicit step into the space between us and neighboring stars.

**Our Sun is one of billions of stars in the galaxy that plows through the interstellar medium, journeying through remnants of supernovae.** With its dynamic solar wind, the Sun carves out the enormous habitable magnetic bubble harboring our solar system—the heliosphere.

**The unique interaction responsible for upholding the boundary of our heliosphere represents one of the most outstanding problems in space physics today.** Beyond the boundary of our solar system, the unexplored local interstellar medium presents a completely new territory that governs the heliospheric interaction and holds the key for understanding our evolutionary journey within the galaxy.

**By exploring processes from near the Sun through the heliospheric boundary, and out into the interstellar medium, Interstellar Probe will provide a snapshot of the current state of the heliosphere and its surrounding interstellar neighborhood, to ultimately understand where our home came from and where it is going.**



**In an epic 50-plus-year journey, Interstellar Probe will capture our place in the universe, enabled by multiple generations of engineers, scientists, and visionaries.**



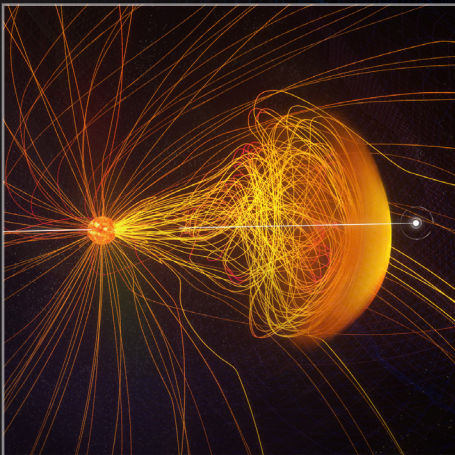
# OUR HABITABLE ASTROSPHERE

**How is our heliosphere upheld by the physical processes from the Sun to the very local interstellar medium?** The formation of our heliosphere begins near the Sun. Penetrating interstellar gas is picked up by the expanding solar wind that accelerates particles through poorly understood, complex processes across the solar system, upholding the entire heliosphere against the pressure of the interstellar medium.

**How do the Sun's activity as well as the interstellar medium and its possible inhomogeneities influence the dynamics and evolution of the global heliosphere?** Solar activity impacts the dynamics of the global heliosphere and its boundaries via mechanisms that are largely unexplained. As the Sun plows through the Local Cloud, the global heliospheric shape and interaction are dictated by changes in interstellar densities, flows, charge fractions, and fields that have never been sampled directly.

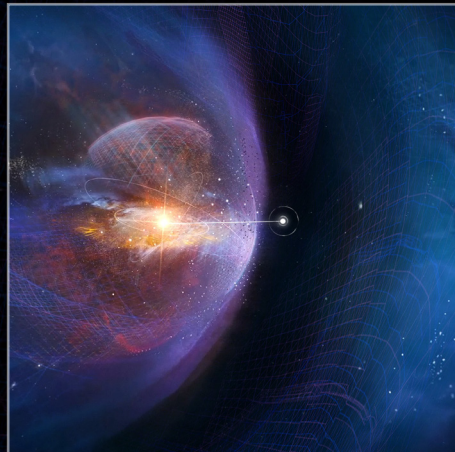
**How do the current interstellar medium properties inform our understanding of the evolutionary path of the heliosphere?** During its 4.6-billion-year journey around the galactic core, the solar system has evolved through encounters with dramatically different interstellar environments. Today, the Sun is about to leave the Local Cloud and enter the unknown environment of the G Cloud. The interaction between the heliosphere and interstellar medium remains an unexplored territory that guards the secrets to understanding the evolution of our habitable bubble and how the future will shape it.

## TRAVERSING THE HELIOSPHERE



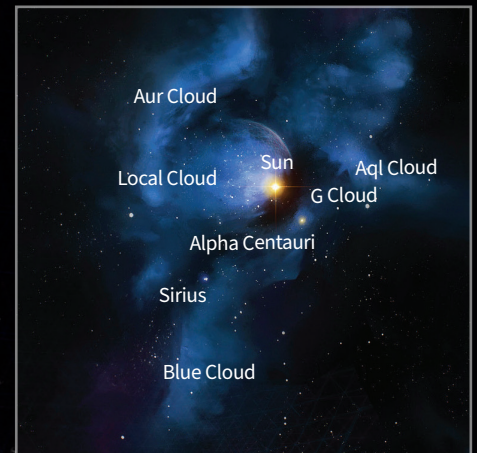
Launching on a fast trajectory, Interstellar Probe will reveal how the solar wind interacts with interstellar gas and how the heliosphere “breathes” under the influence of the Sun.

## THROUGH THE BOUNDARY



Crossing the boundary of the heliosphere, Interstellar Probe will explore the shield protecting our solar system, formed by the acceleration of particles yet to be directly observed.

## INTO UNKNOWN INTERSTELLAR SPACE



Free of the Sun's sphere of influence, Interstellar Probe will directly sample pristine interstellar material and uncover what lies ahead in the path of our habitable home.

**Interstellar Probe will explore our habitable astrosphere and its home in the galaxy, to understand ultimately where we came from and where we are going.**



# EXAMPLE MODEL BASELINE PAYLOAD

Payload Mass and Power

87.4 KG | 86.7 W

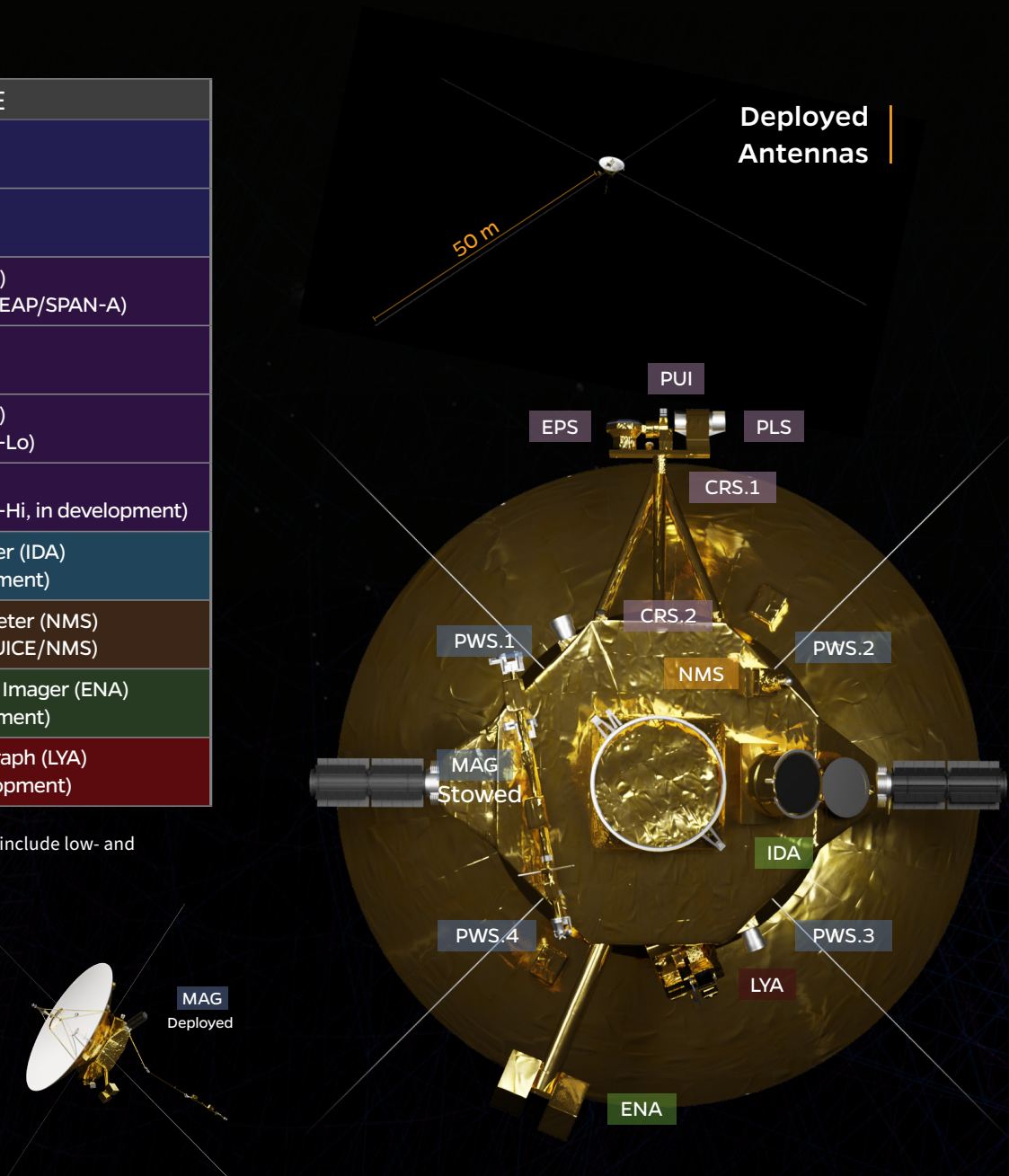
*To perform the required science, a final payload will be defined by a future science and technology definition team.* In this study, an example payload that can achieve the majority of the science was chosen from a menu of instruments and assembled within a 90-kg allocation to illustrate the feasibility and the types of necessary science trades that will have to be made. Other implementations exist and can achieve superior performance with associated mass and cost increases.

## PERCENTAGE OF PAYLOAD MASS

Charged Particles	Fields and Waves	ENA Imaging	Dust	Neutrals	Lyman-Alpha
30%	19%	14%	12%	11%	14%

INSTRUMENT HERITAGE
Magnetometer (MAG) (MMS/DFG)
Plasma Waves (PWS) (Van Allen Probes/EFW)
Plasma Subsystem (PLS) (Parker Solar Probe/SWEAP/SPAN-A)
Pick-up Ions (PUI) (Ulysses/SWICS)
Energetic Particles (EPS) (Parker Solar Probe/EPI-Lo)
Cosmic Rays (CRS) (Parker Solar Probe/EPI-Hi, in development)
Interstellar Dust Analyzer (IDA) (IMAP/IDEX, in development)
Neutral Mass Spectrometer (NMS) (Luna-Resurs/NGMS, JUICE/NMS)
Energetic Neutral Atom Imager (ENA) (IMAP/Ultra, in development)
Lyman-Alpha Spectrograph (LYA) (MAVEN/IUVS, in development)

\*Other instruments considered include low- and high-energy ENA telescopes.





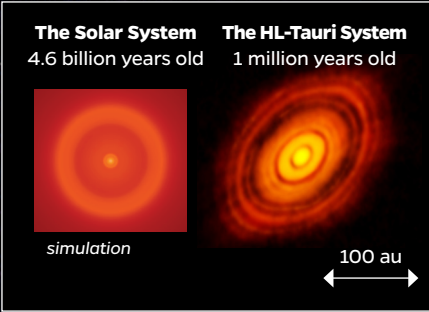
# OPTIONAL CROSS-DIVISIONAL SCIENCE GOALS

## DWARF PLANETS AND KBOS



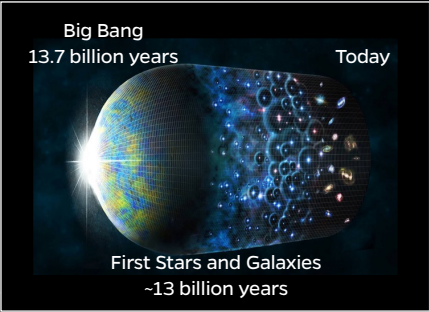
Any direction defined by heliophysics offers at least one compelling flyby of a dwarf planet or Kuiper Belt object (KBO).

## CIRCUMSOLAR DUST DISK



An infrared detector can reveal the disk structure critical for understanding the evolution of planetary systems.

## EXTRAGALACTIC BACKGROUND LIGHT



Infrared observations can uncover the extragalactic background spectrum missing from our understanding of early galaxy formation.

# EXAMPLE MODEL AUGMENTED PAYLOAD

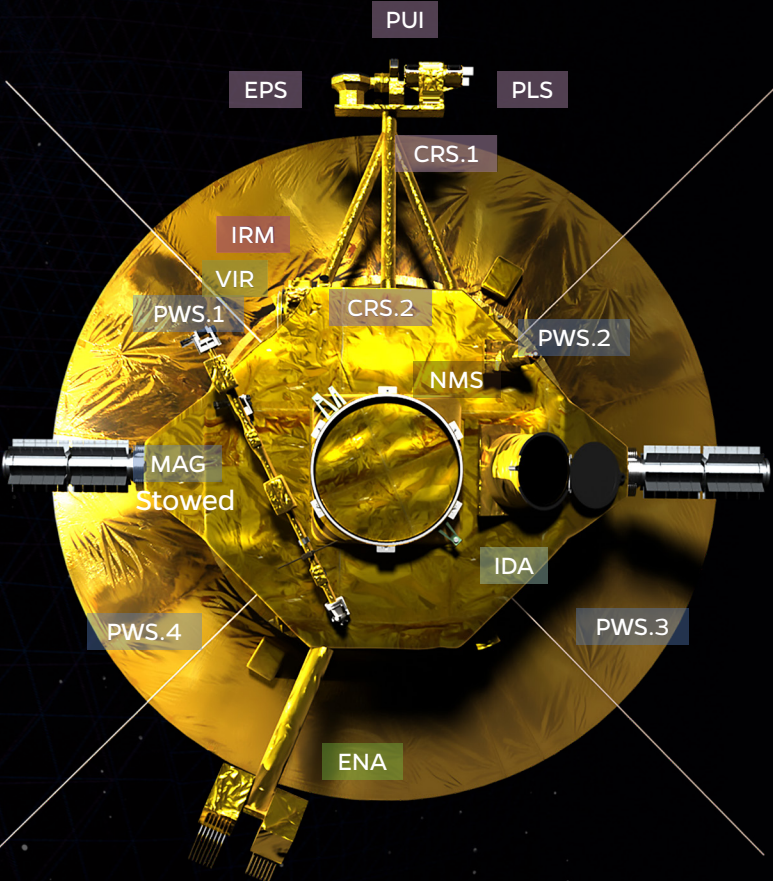
*An example augmented payload was also assembled that accomplishes the baseline heliophysics science and addresses cross-divisional science goals.* Including many of the same instruments as the baseline example, it requires that the PWS be converted to shorter rigid stacers. The two additional flyby cameras are offset by the removal of LYA.

## Payload Mass and Power

89.1 KG

90.2 W

INSTRUMENT HERITAGE	
Magnetometer (MAG)	(MMS/DFG)
Plasma Waves (PWS)	(STEREO/SWAVES)
Plasma Subsystem (PLS)	(Parker Solar Probe/SWEAP/SPAN-A)
Pick-Up Ions (PUI)	(Ulysses/SWICS)
Energetic Particles (EPS)	(Parker Solar Probe/EPI-Lo)
Cosmic Rays (CRS)	(Parker Solar Probe/EPI-Hi, in development)
Interstellar Dust Analyzer (IDA)	(IMAP/IDEX, in development)
Neutral Mass Spectrometer (NMS)	(Luna-Resurs/NGMS, JUICE/NMS)
Energetic Neutral Atom Imager (ENA)	(IMAP/Ultra, in development)
Visible-Near-IR (VIR)	(New Horizons/Ralph)
Visible-IR Mapper (IRM)	(New Horizons/LEISA; CIBER-2, in development)





## BASELINE MISSION CHARACTERISTICS

### ESTIMATED COSTS (FY25\$)

Launch	Mass	Peak Exit Speed
2036	860 KG	7.0 AU/YEAR

Phases A-D without launch costs  
\$1689M\*

Phase E  
~\$230M/DECADE\*  
\*without reserves

## Telecommunication

X-band with 5-m fixed antenna capable of sufficient downlink ( $\sim 10$  Mbit/week) at 1000 au using Next Generation Very Large Array or equivalent resource

## Power

Two Next Generation Radioisotope Thermoelectric Generators for 300 W (electric) at end of mission, provided as Government-Funded Equipment

## Mechanical

## Spin-stabilized, 50-m PWS wire antennas

## Lifetime

50-year lifetime drives reliability and longevity, requiring that a multigenerational approach to staffing be built in from the beginning

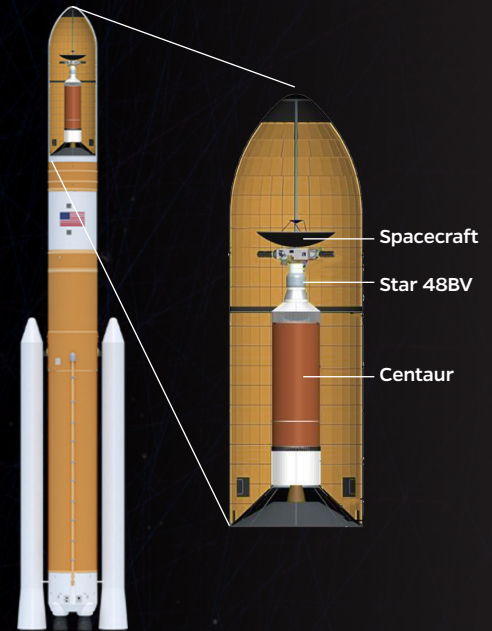
## Technology Horizon

Could be ready to launch by 1 January 2030 (independent of funding and policy constraints)

## SPACECRAFT MASTER EQUIPMENT LIST SUMMARY

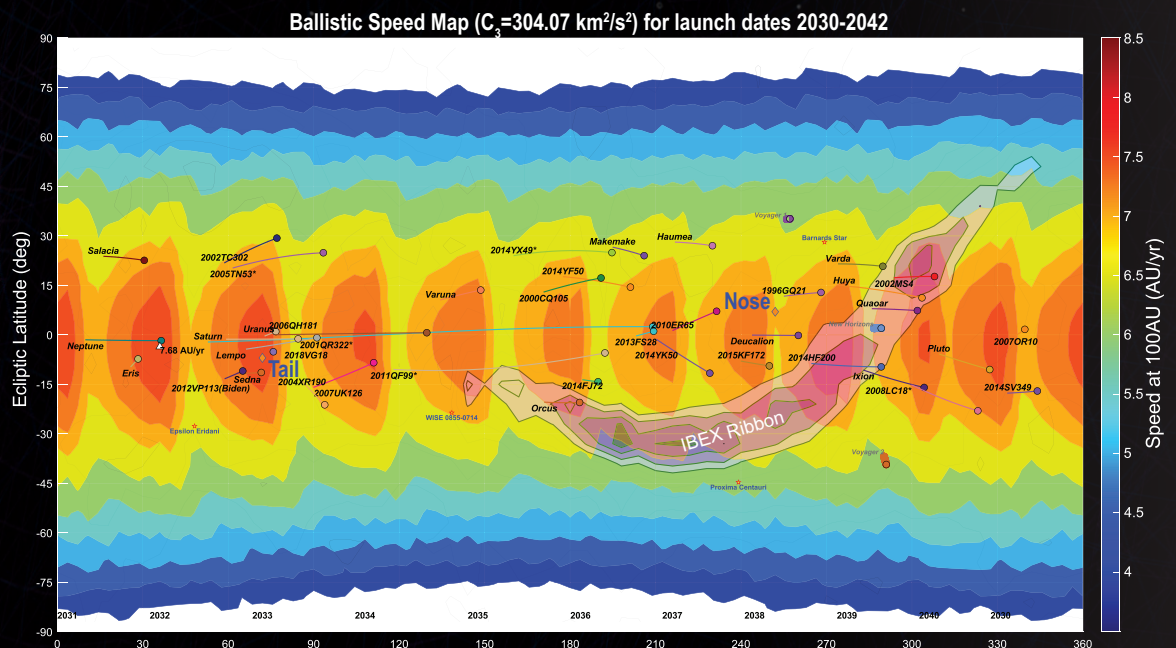
Equipment	Mass (kg) (includes contingency)
Payload (including accommodation hardware)	100.5
Telecommunications	83.4
Guidance and Control (G&C)	16.8
Power	169
Thermal Control	70.8
Avionics	12.8
Propulsion	37.2
Mechanical/Structure	150
Harness	29.3
Propellant	106
Total	776
Margin	84
Launch Mass	860

## Example Stack Configuration



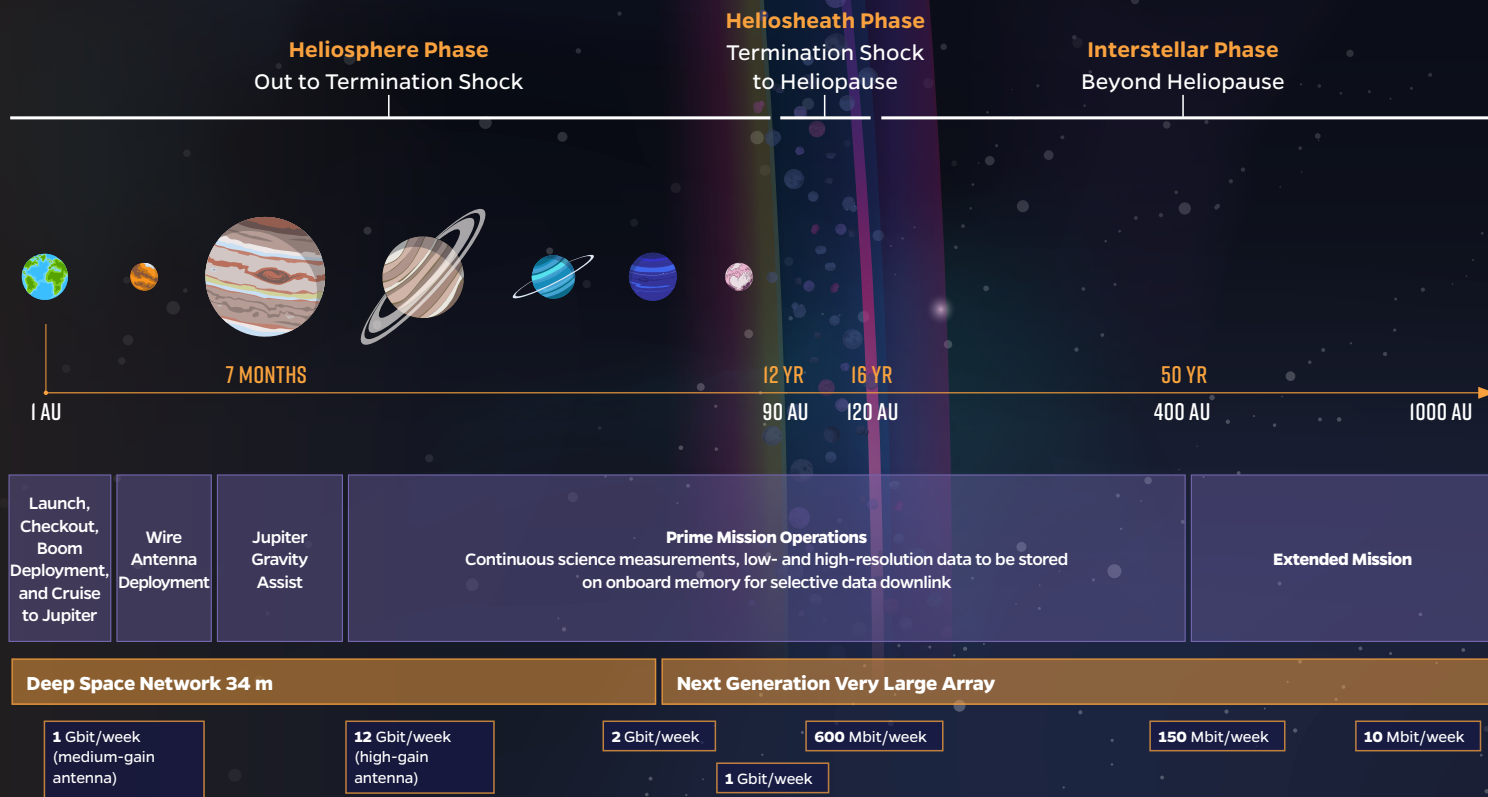
Interstellar Probe will require a super heavy-lift launch vehicle, currently under development by both the government and the private sector. An example stack configuration is shown here with NASA's SLS Block 2.

Launch opportunities exist every 13 months, from 2036 to 2042, exiting the forward hemisphere of the heliosphere at a similar speed to the baseline trajectory, ranging from 7 to 8 au/year.





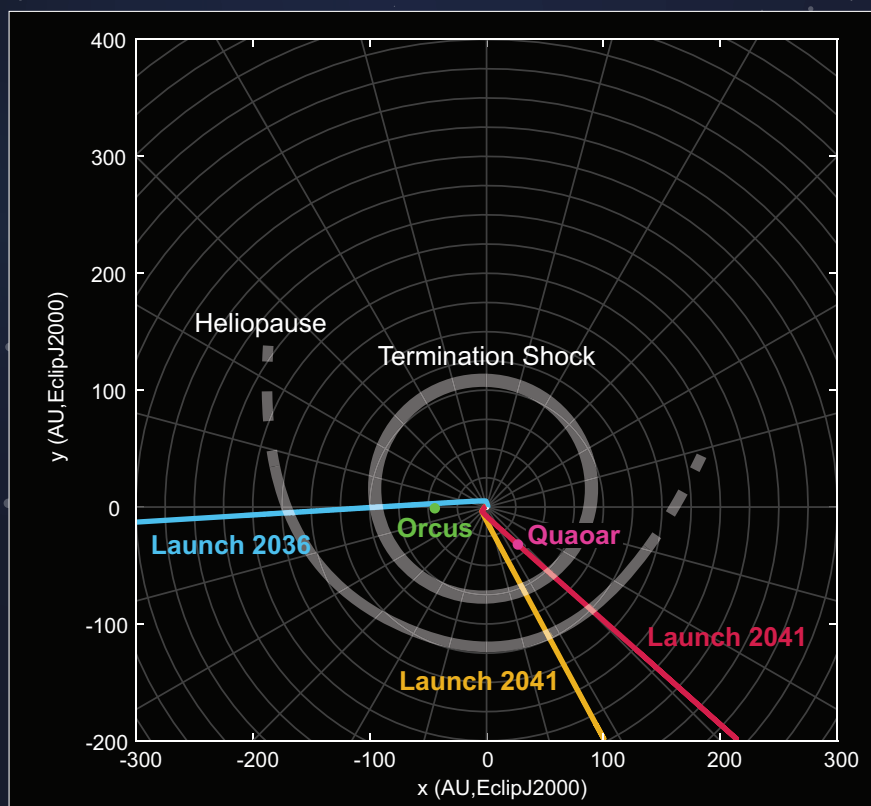
# MISSION DESIGN



A few example trajectories are shown, each involving a passive Jupiter gravity assist. Other options through 2042 can also be explored. If a planetary flyby is desired, the trajectory could be altered to pass by a number of targets. The trajectory launching in 2036 (blue) has an untargeted flyby near Orcus, while the trajectory launching in 2041 (red) has a targeted Quaoar flyby. The trajectory launching in 2041 (yellow) is targeted closer toward the heliospheric nose but does not include any flybys. Each trajectory exits the solar system in a different direction, where an estimate of the nominal location of the termination shock and heliopause is marked on the plot.

## STUDY OVERVIEW

This NASA-funded Johns Hopkins Applied Physics Laboratory (APL) study was led by Principal Investigator Ralph L. McNutt Jr., Program Manager Michael V. Paul, Project Scientist Pontus C. Brandt, and Mission Systems Engineer James D. Kinnison.



With contributions from over 500 people at over 170 institutions located in over 30 countries, including 190 authors and collaborators on the final report, 146 talks at 46 events, 38 posters at 48 events, and several submitted white papers to the National Academies, this has truly been a science-community effort.





HUMANITY'S JOURNEY TO INTERSTELLAR SPACE

# INTERSTELLAR

— PROBE —

*"We shall not cease from exploration  
And the end of all our exploring  
Will be to arrive where we started  
And know the place for the first time."*

**—T.S. Eliot**