HUMANITY'S JOURNEY TO INTERSTELLAR SPACE

INTERSTELLAR PROBE

A Pragmatic Interstellar Probe for Launch in the 2030's

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The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA.

And almost 200 scientists and engineers worldwide.

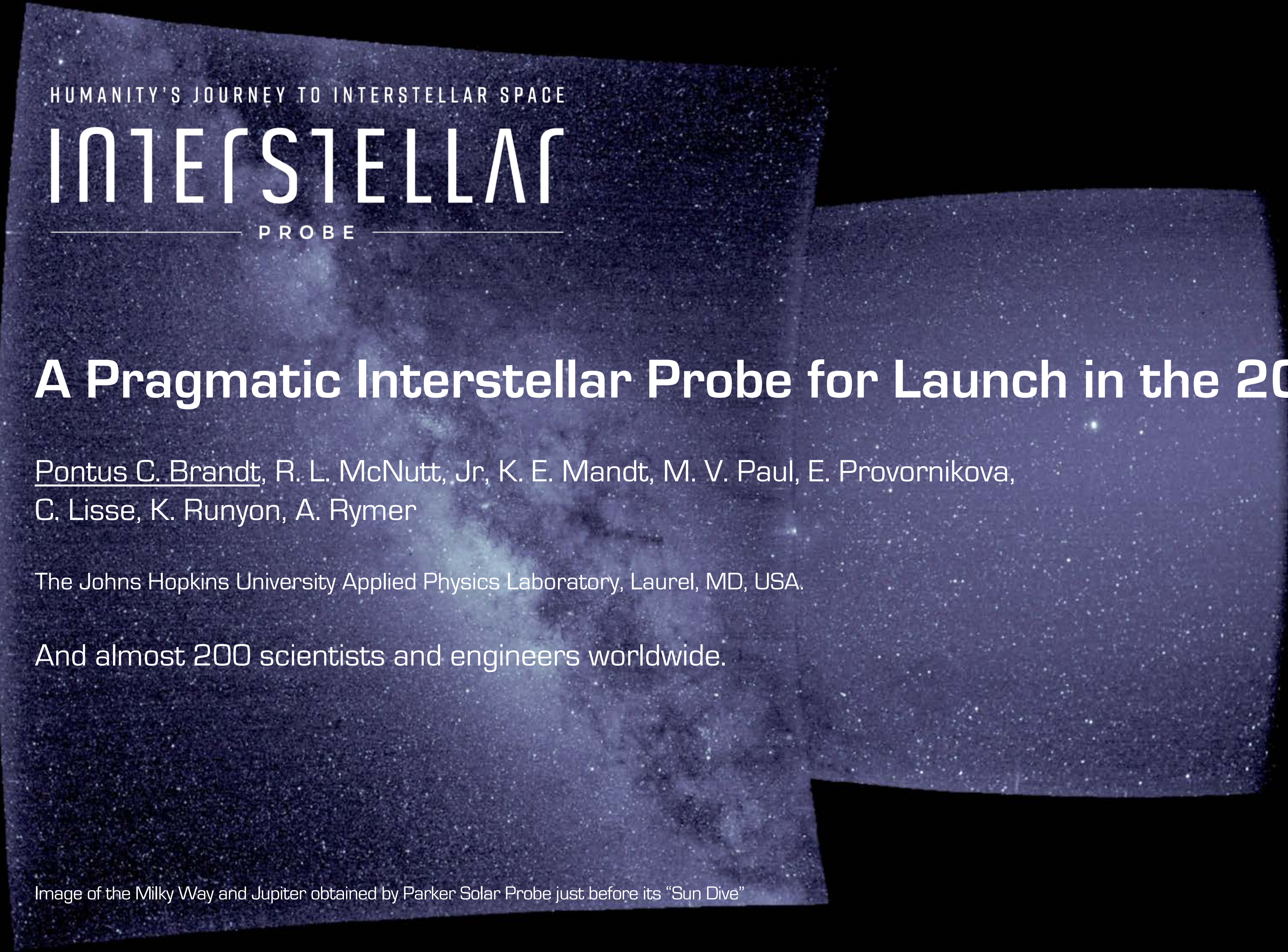


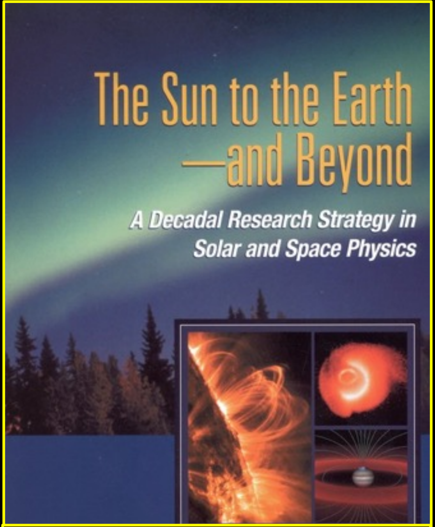
Image of the Milky Way and Jupiter obtained by Parker Solar Probe just before its "Sun Dive"

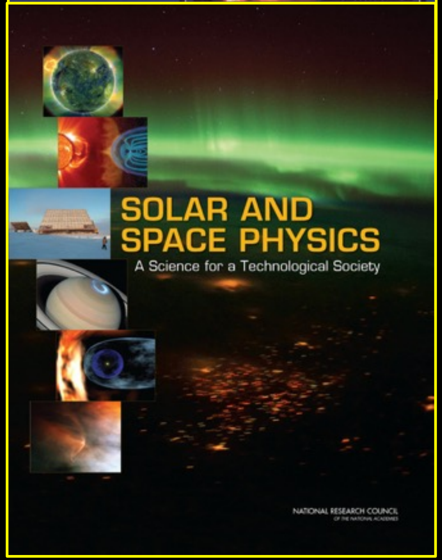
What is a "Pragmatic" Interstellar Probe?

- "Interstellar Probe" is a mission through the outer heliosphere and into the nearby "Very Local" interstellar medium or VLISM (0.01 parsecs = ~2,000 AU =~10 light days)
- Interstellar Probe uses today's technology to take the first explicit step on the path of interstellar exploration
- Interstellar Probe can pave the way, scientifically, technically, and programmatically for longer interstellar journeys that would require future propulsion systems

Context for This Effort

- Guidance from the science community for NASA's science program is provided every 10 years via "Decadal Surveys" for each of NASA's four science mission Divisions: Planetary Science, Astrophysics, Heliophysics, and Earth Science
- An "Interstellar Probe" has been discussed in the past two Heliophysics Decadals (2003, 2013) – and by the general community for long before
- This current study is being supported by NASA to provide technical input, which can be used for the deliberations of the next Heliophysics Decadal (to apply for the years 2023 – 2032)
- NASA has also asked this study to assess what science across all of the Divisions could be enable with such a mission
- This effort is to investigate what Interstellar Probe missions could be possible within the time period through 2032 – but not to select a specific set of science goals, target, or payload

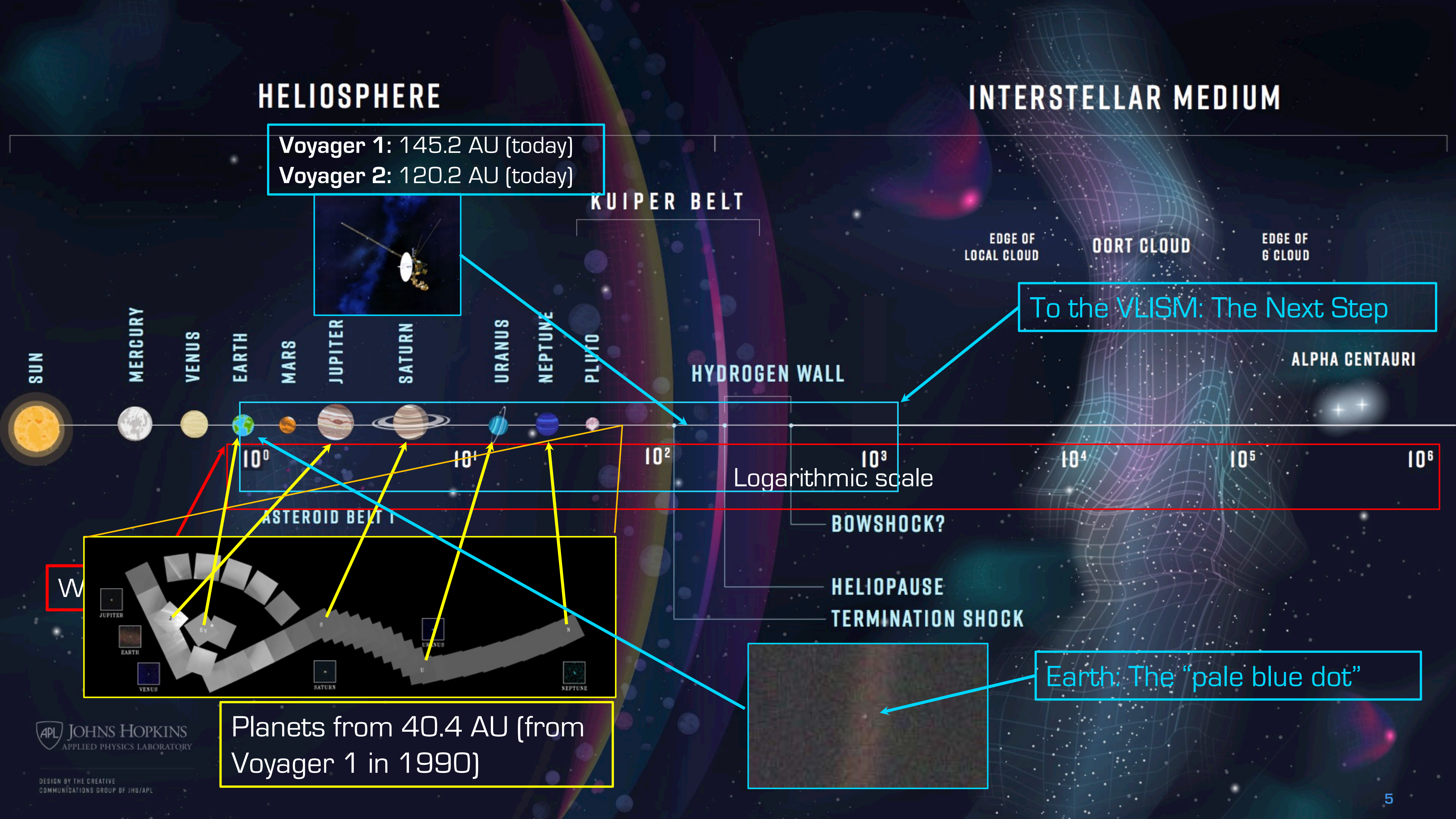




Study Team and Collaborators

- **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


HELIOSPHERE
INTERSTELLAR MEDIUM
Voyager 1: 145.2 AU (today)
Voyager 2: 120.2 AU (today)
KUIPER BELT
EDGE OF LOCAL CLOUD
OORT CLOUD
EDGE OF G CLOUD
To the VLISM: The Next Step
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
JUPITER
EARTH
VENUS
SATURN
URANUS
NEPTUNE
Earth: The "pale blue dot"
Planets from 40.4 AU (from Voyager 1 in 1990)
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY
DESIGN BY THE CREATIVE COMMUNICATIONS GROUP OF JHU/APL

Three “Special Probes”... One Beginning

... and One To Go

INTERSTELLAR PROBE

NASA Task Order NNN06AA01C

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

March 1960:
The “Simpson Committee”

Parker Solar Probe

Interstellar Probe

Ulysses

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.

Special Probes

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

" " 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

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

The Compelling Case: 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… Astro…

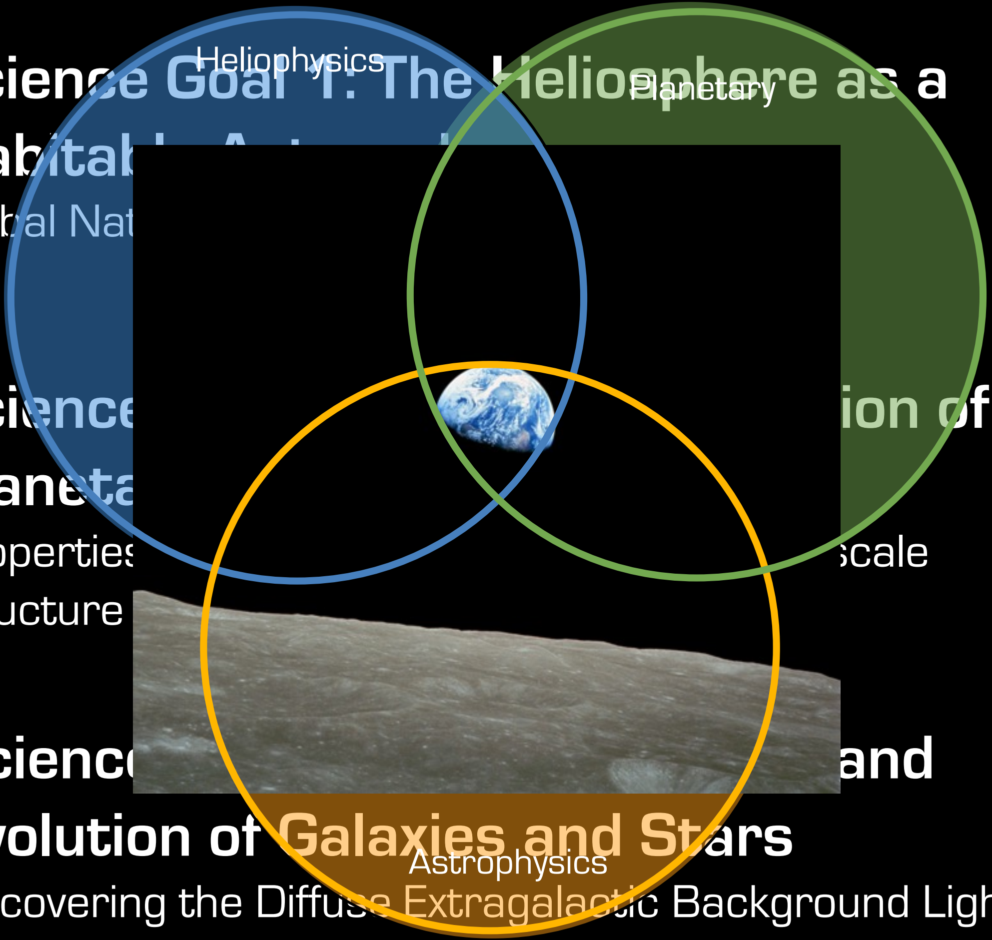
Global Nat…

Science … …ion of Planeta…

Properties … …scale structure

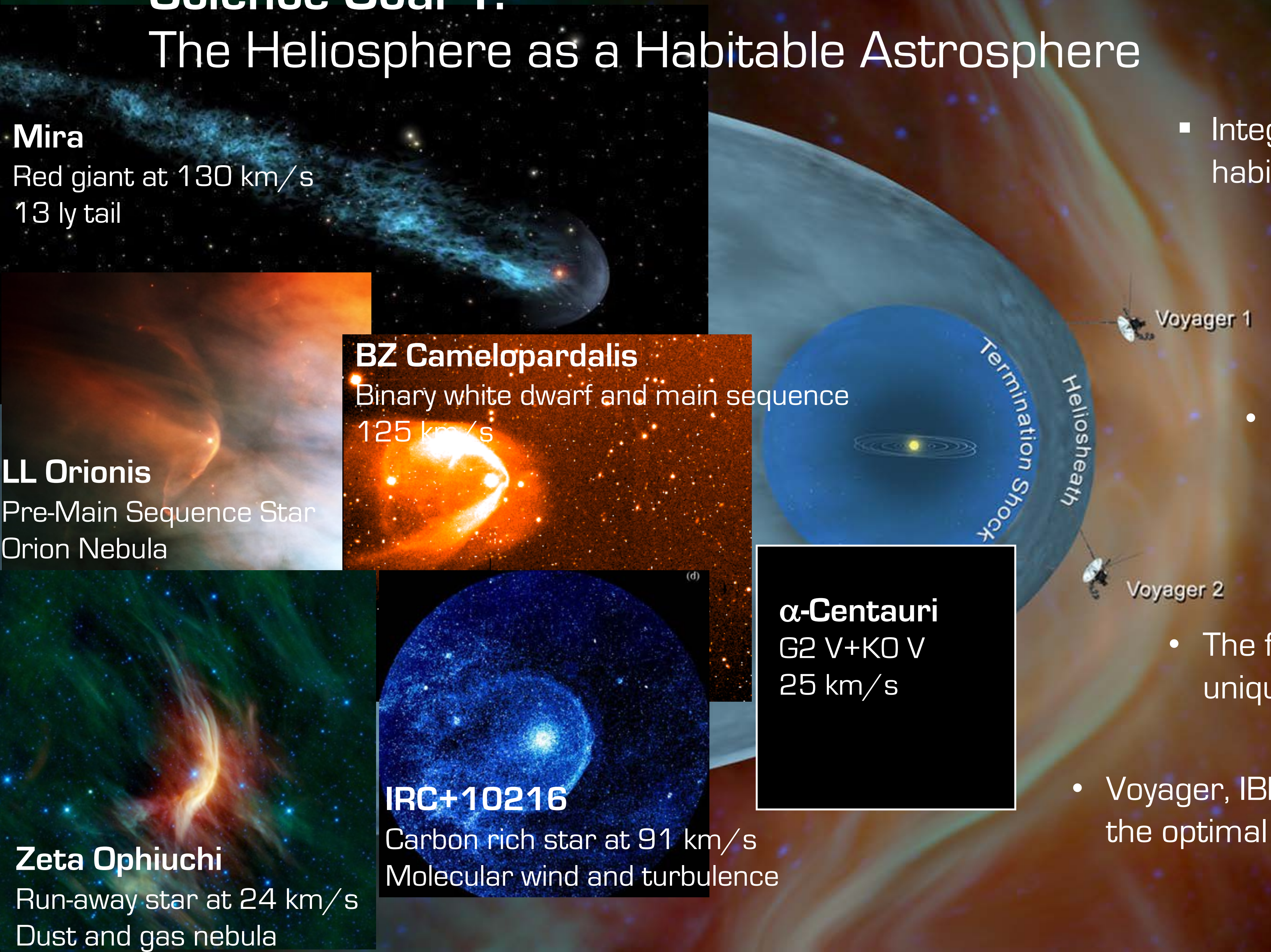
Scienc… …and Evolution of Galaxies and Stars

Uncovering the Diffuse Extragalactic Background Light



Science Goal 1:
The Heliosphere as a Habitable Astrosphere

INTERSTELLAR PROBE



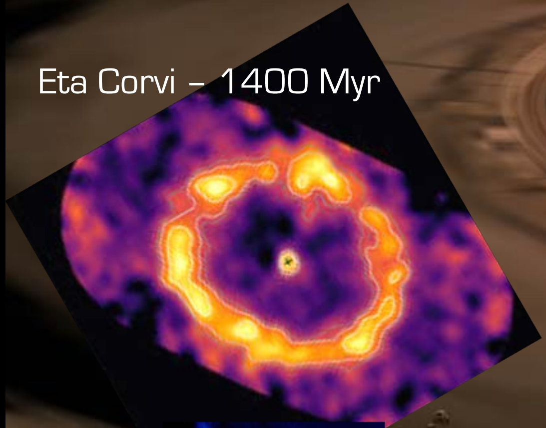
- Integral to evolution of habitable systems
  - Missing in the family portrait of Astrospheres
  - Dedicated measurements resolve the new physics uncovered by the Voyagers
  - The first ENA and UV images looking back uniquely determines the global nature
  - Voyager, IBEX, Cassini, JUICE and IMAP guide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

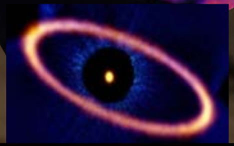
Science Goal 2:
Formation and Evolution of Planetary Systems

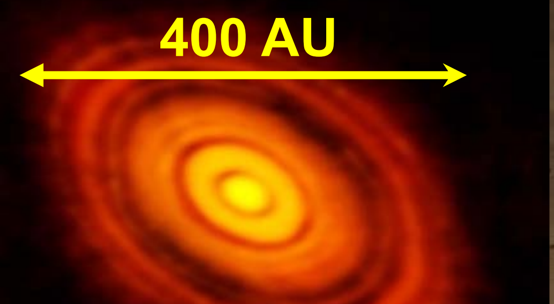
Debris Disks: Signposts of terrestrial planet formation and evolution

Dwarf Planets: Unexplored active worlds

KBOs: Fossils of solar system formation and composition

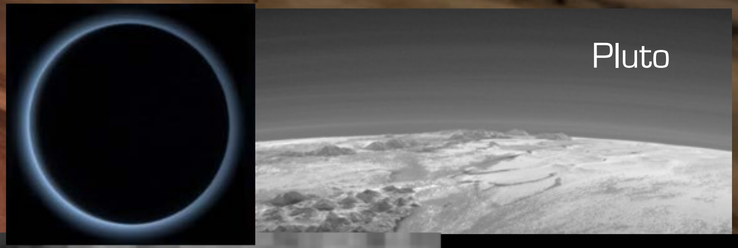

Eta Corvi – 1400 Myr


Fomalhaut – 440 Myr



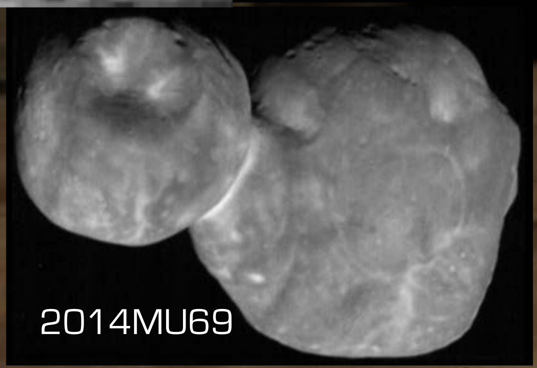
HL Tauri - < 1 Myr

- **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

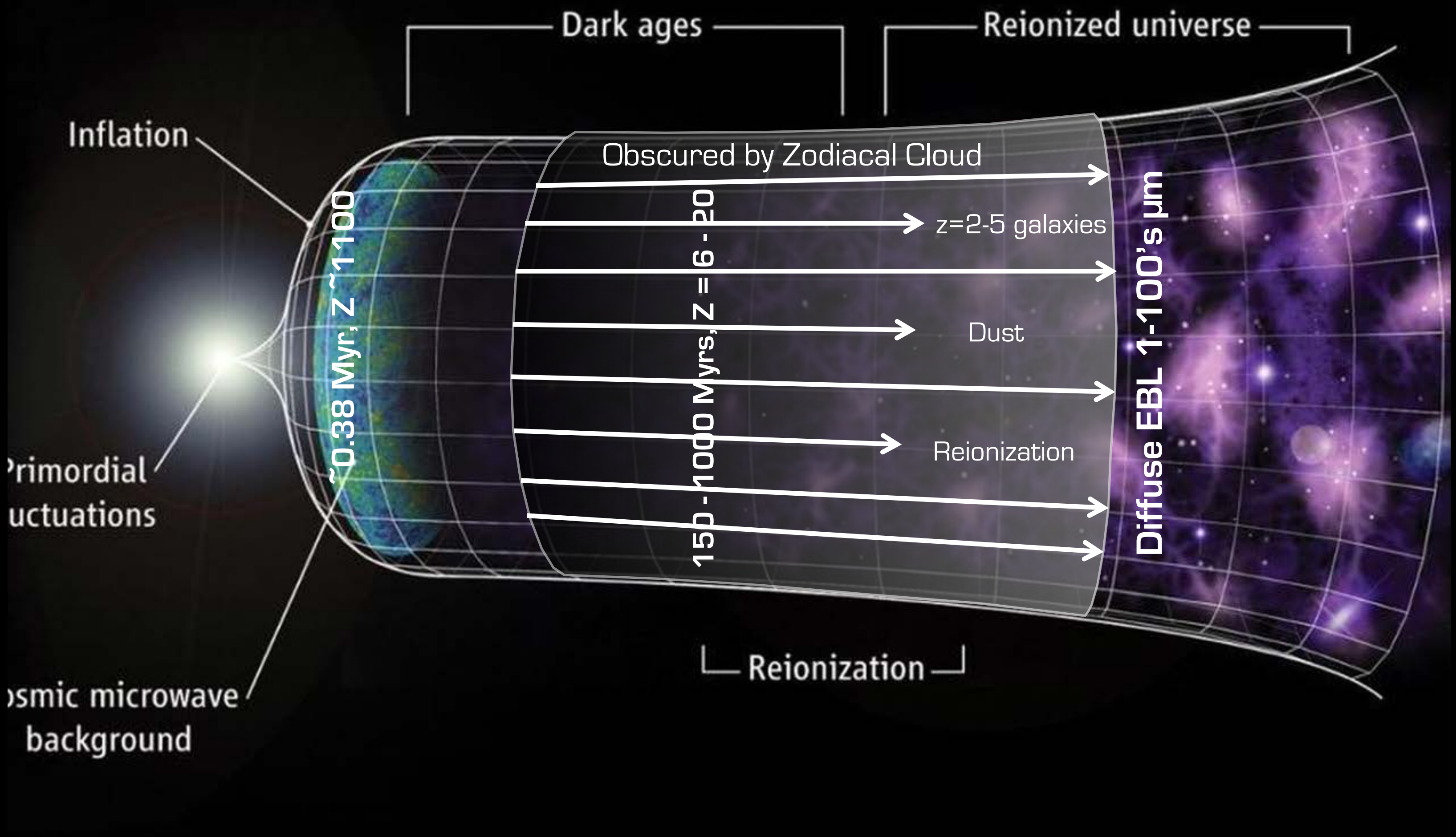

Pluto


Quaoar and Weywot


Charon


2014MU69

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 µm window by 10 - 100x
- EBL measurements provide Decadal-level cosmology science enabled by unique outside location

Example Payload "Box"

Define the "Box" Early, and Stick to it!

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Instrument	Mass (kg)	Power (W)	Data rate (bps)
Vector Helium Magnetometer	1	2	6
Fluxgate Magnetometer	5.6	2.2	1200
Plasma Wave Instrument	6	1.5	100
Solar Wind and PUI (combined with below)			
Suprathermals and Energetic Ions	6.1	10.8	1000
Cosmic-ray spectrometer	3	2	2
Dust Detector	14	25	579
Neutral Ion Mass Spectrometer	3.5	5	1
Low-Energy ENA	3	3	100
Medium-Energy ENA	7.37	0.65	99
High-Energy ENA	7.2	6.5	500
Ly-alpha Spectrograph	12.5	11.86	24
VisNIR Imager	8.6	15	16
VISNIR/FIR Mapper	4	3	10
Total	81.87	88.51	3637

- We know how to build all of this instrumentation
- No new technology required, but...
- Need to optimize mass and power!
- Box not yet defined, nor is it our job at this stage
- **New Horizons**: 29.9 kg
- **Voyager**: 104.4 kg

Notional Concepts Span 825 kg to 250 kg

Voyager 1 and 2 to Pioneer 10 and 11

- Voyager 825.4 kg

- Parker Solar Probe 643.0 kg

- New Horizons 478.3 kg

Current example for study

- Ulysses 366.7 kg

- Pioneer 10 251.8 kg

Baseline Existing or Near-Term Systems

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NASA Task Order NNN06AA01C

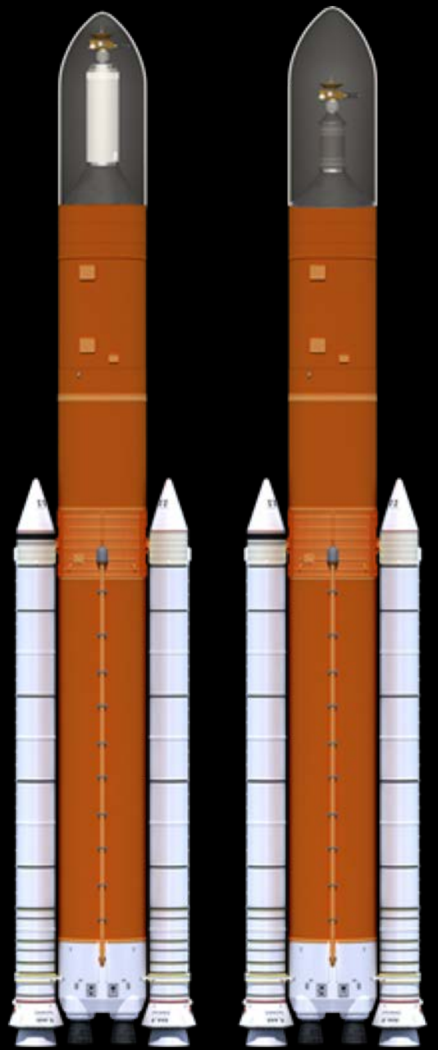
Stage and Motor Systems Considered					
#	Stage/Motor	Type	Propellant	Current Production Status	Manufacturer
1	STAR 48 BV	Solid Motor	Solid	In Production	Northrop Grumman
2	STAR 48 GXV	Solid Motor	Solid	Completed 1 successful static fire test	Northrop Grumman
3	Orion 50 XL	Solid Motor	Solid	In Production	Northrop Grumman
4	CASTOR 30B	Solid Motor	Solid	In Production	Northrop Grumman
5	CASTOR 30XL	Solid Motor	Solid	In Production	Northrop Grumman
6	Centaur D (Shuttle/Centaur)	Liquid Stage	LH_2/LO_2	Engineering development model components produced	United Launch Alliance
7	ACES	Liquid Stage	LH_2/LO_2	In Development	United Launch Alliance
8	Atlas V/Centaur 3	Liquid Stage	LH_2/LO_2	In Production	United Launch Alliance
9	ICPS (Delta IV stage)	Liquid Stage	LH_2/LO_2	In Production	United Launch Alliance
10	Vulcan/Centaur V	Liquid Stage	LH_2/LO_2	In Development	United Launch Alliance
11	European Service Module (Orion)	Liquid Stage	MON/MMH	Awaiting First Flight	Airbus

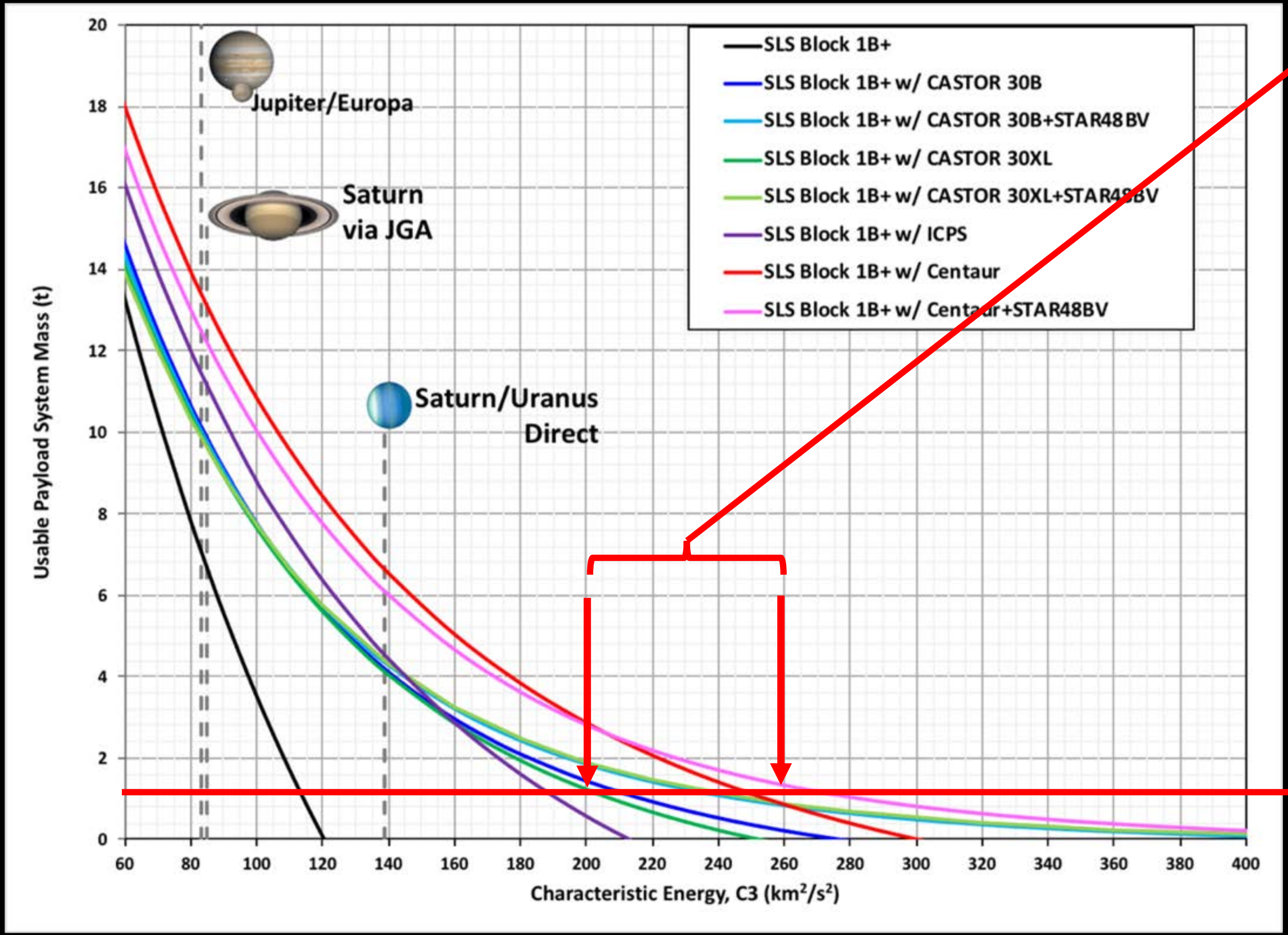
- Eleven stages / motor systems evaluated for functionality and propulsive scenarios across 31 configurations

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

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





Region of interest
$200 \leq C_3 \leq 260$ km²/s²

The "region of interest" is here defined by twice the maximum Earth-launch energy per unit spacecraft mass that an SLS Block 1B could deliver to New Horizons using multiple upper stages using available technology

$$C_3 \equiv v_\infty^2$$

478.3 kg

Where We Could Go: Target Map

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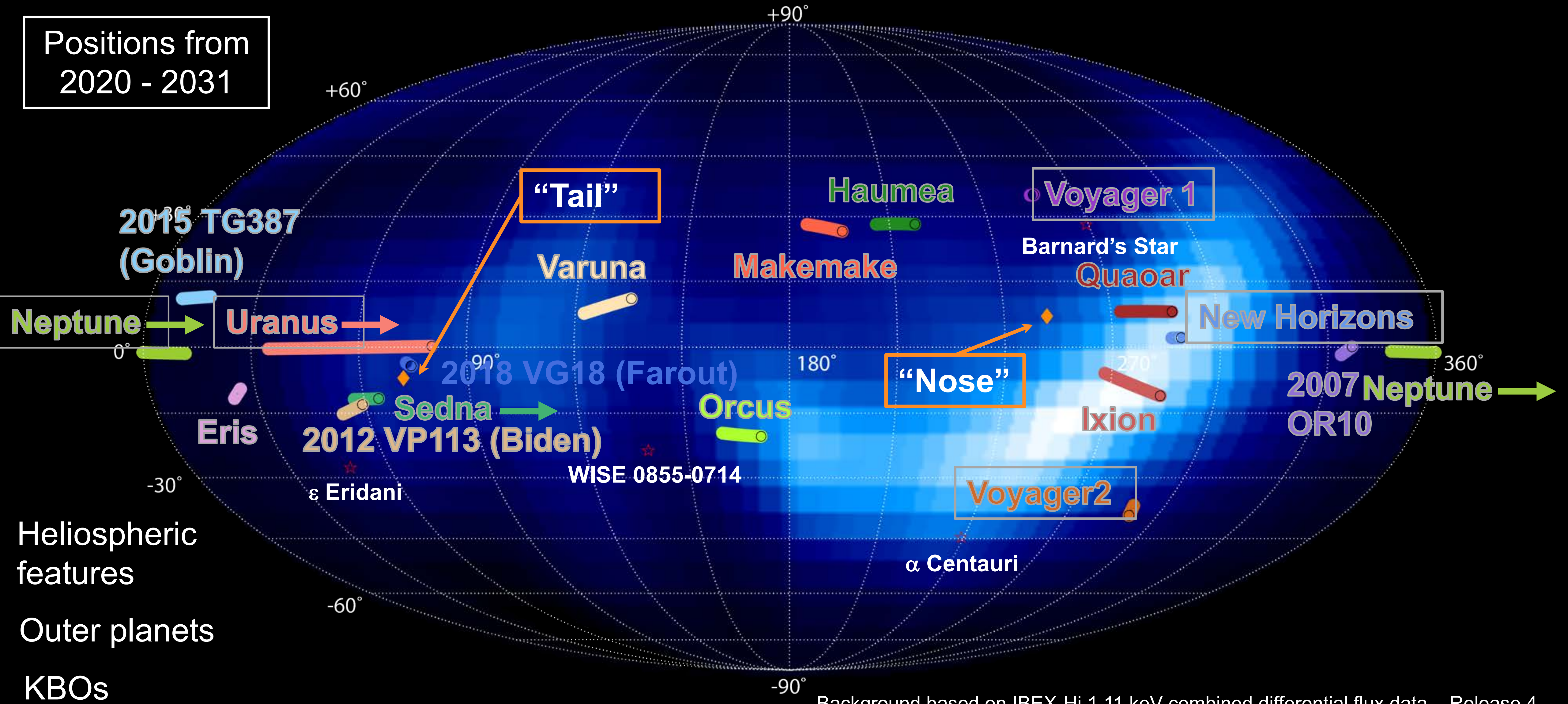
Positions from 2020 - 2031



Heliospheric features

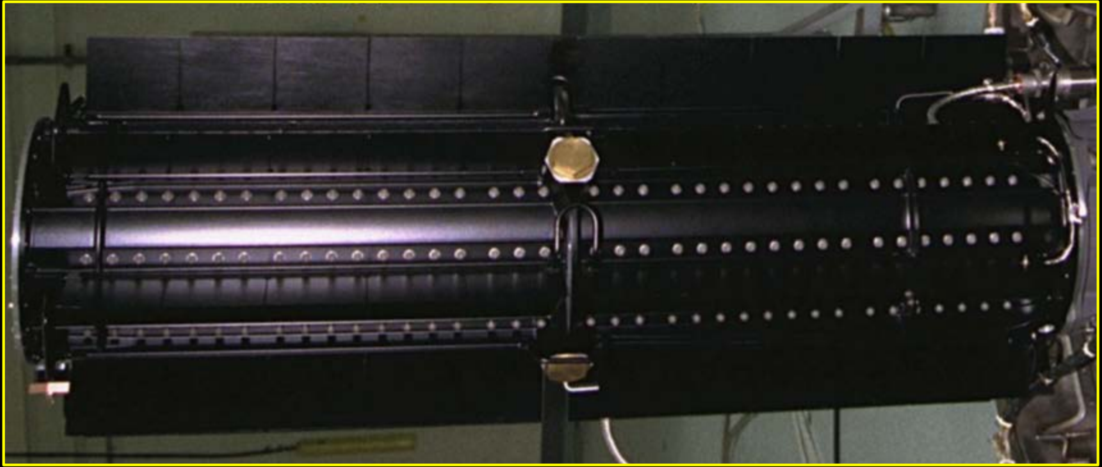
Outer planets

KBOs

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

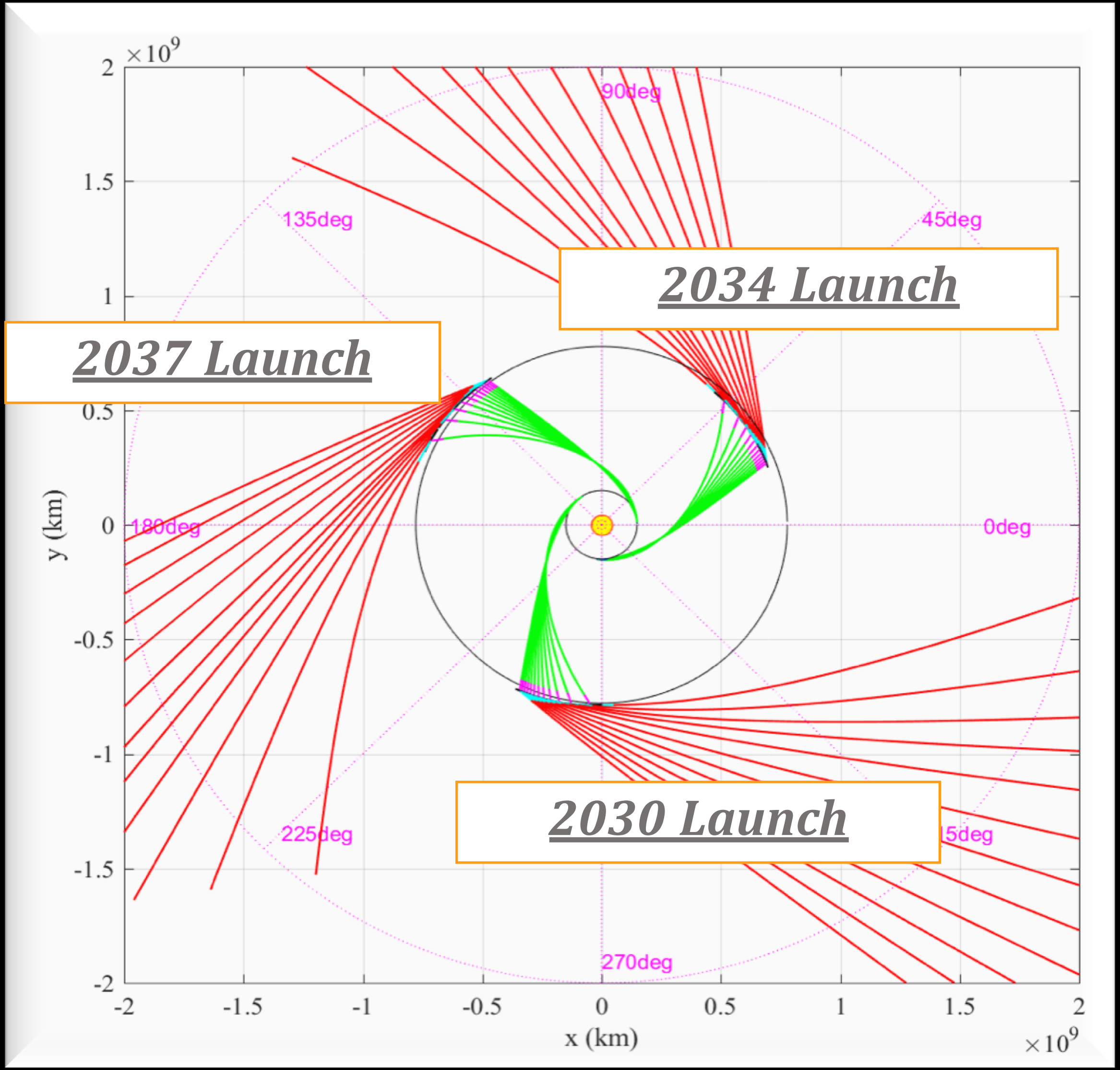
Critical Trade-Offs Are Not New

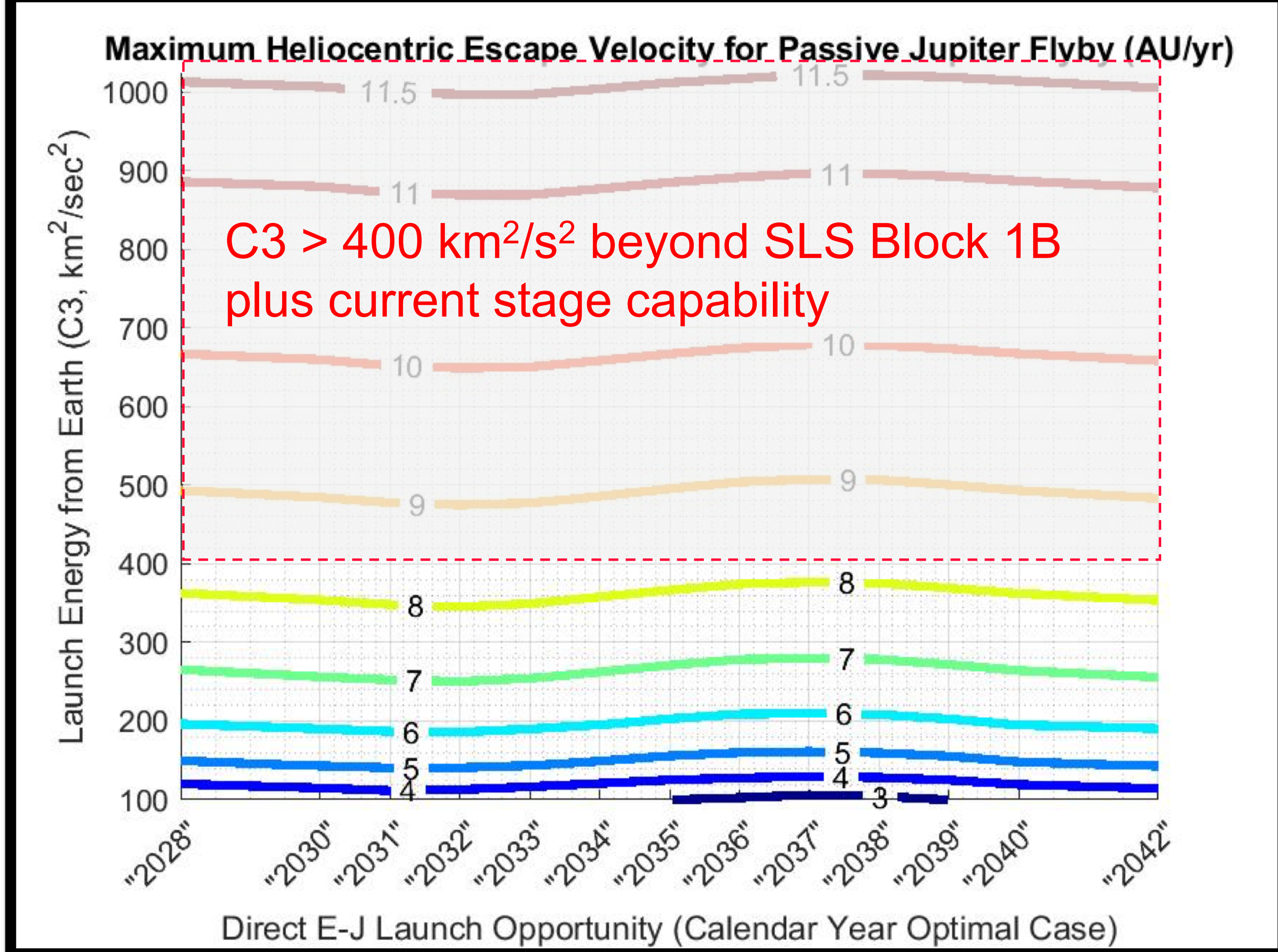
- **Mass:** Driven by flyout speed and payload (P/L) capability
  - S/C range 300-800 kg (New Horizons 478.3 kg)
  - P/L ~40-50 kg (New Horizons 30.4 kg)
  - Thermal Protection System 150-900 kg (PSP 98.9 kg incl structure)
- **Power:** GPHS RTG – life efficiency and lifetime for use *in vacuo*



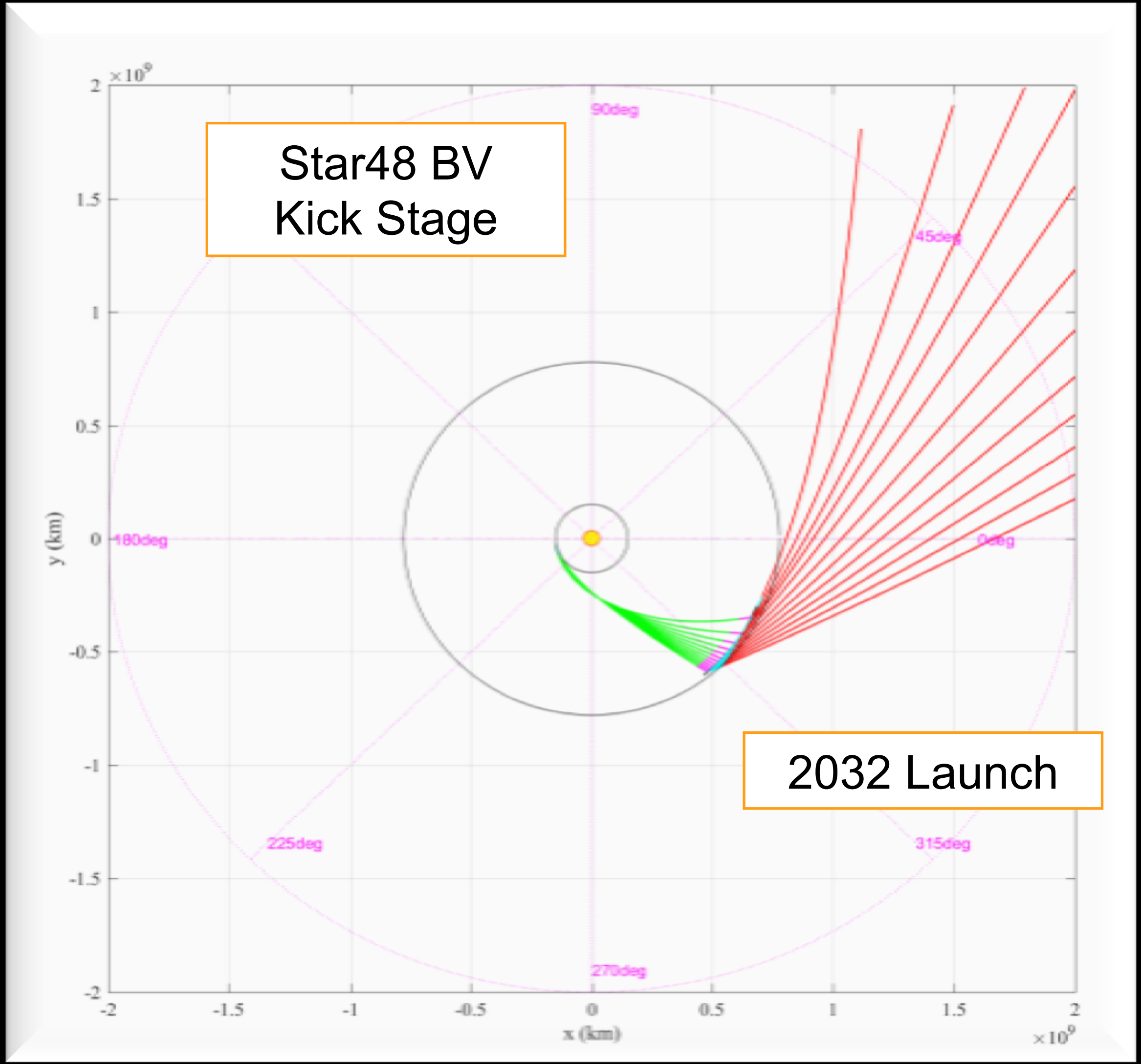
- **Communication:** Solid, near-term, tested engineering
  - Ka-band at ~640 bps and more at 140 AU and beyond
  - Optical laser comm might achieve ~10 kbps, but requires extreme pointing stability; lifetime needs investigation
- **Trajectory/Propulsion/Launch Vehicle:** Keys for implementation
  -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

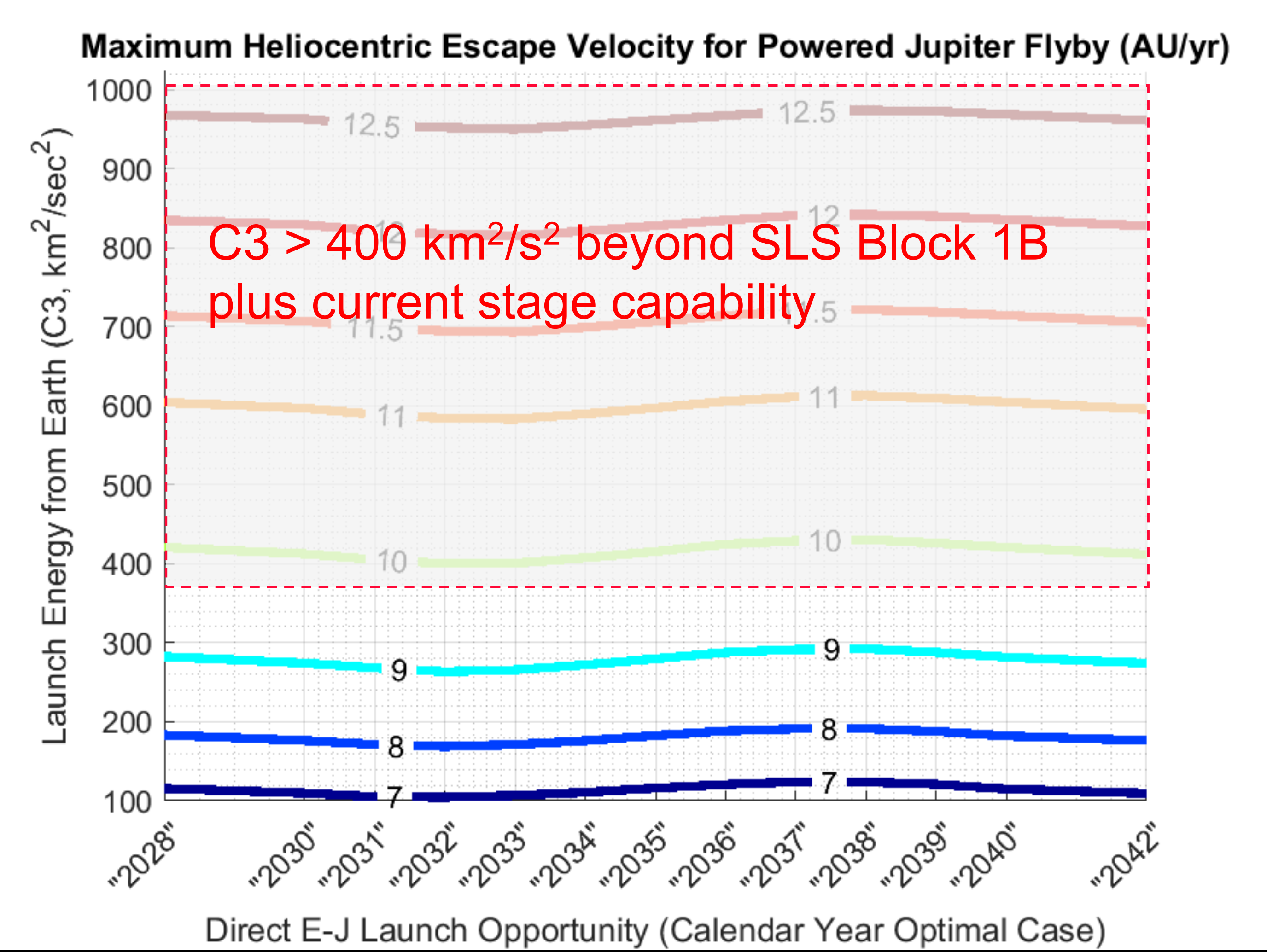
Option 1: Passive Jupiter Gravity Assist





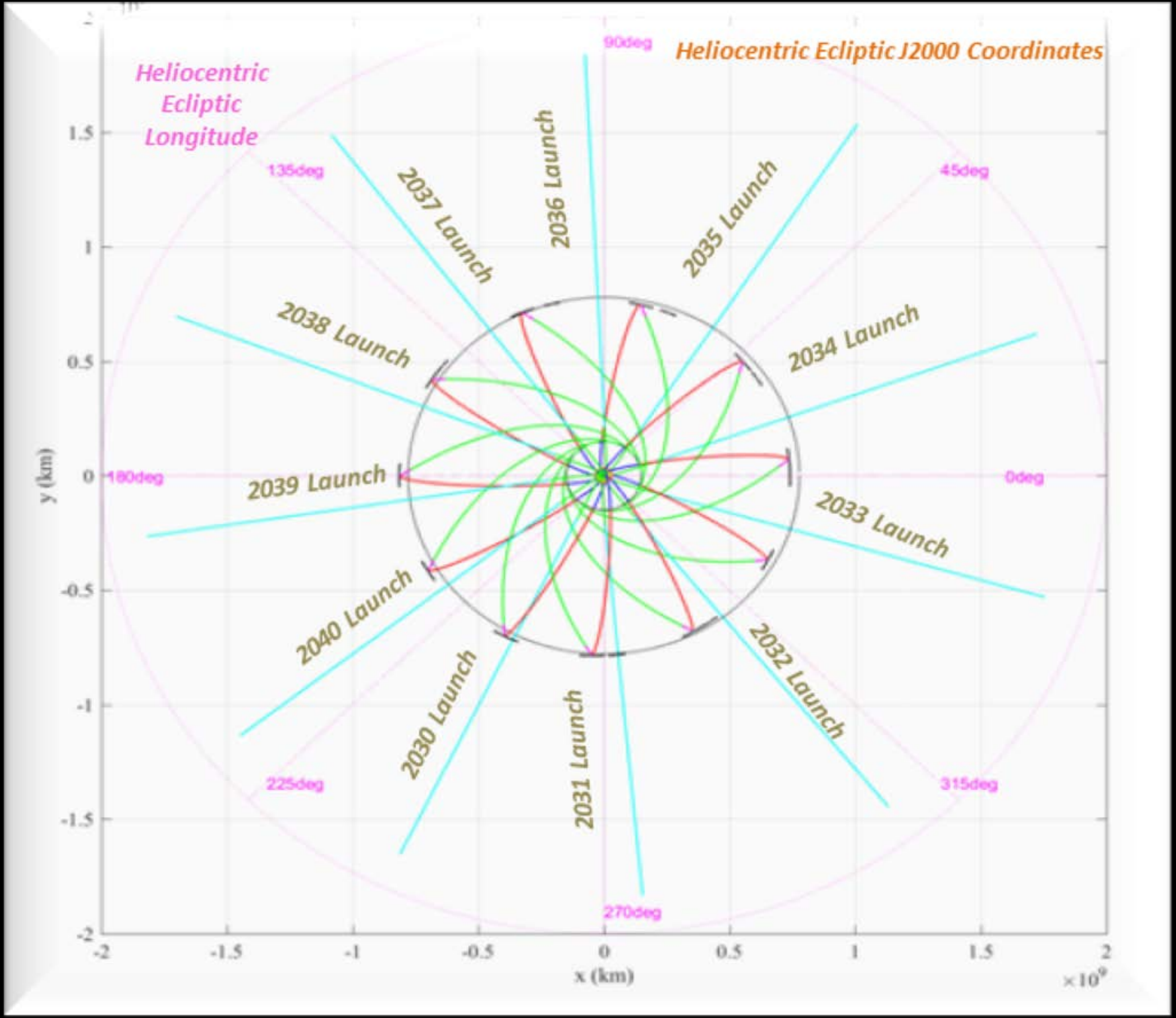
Option 2: Powered Jupiter Gravity Assist





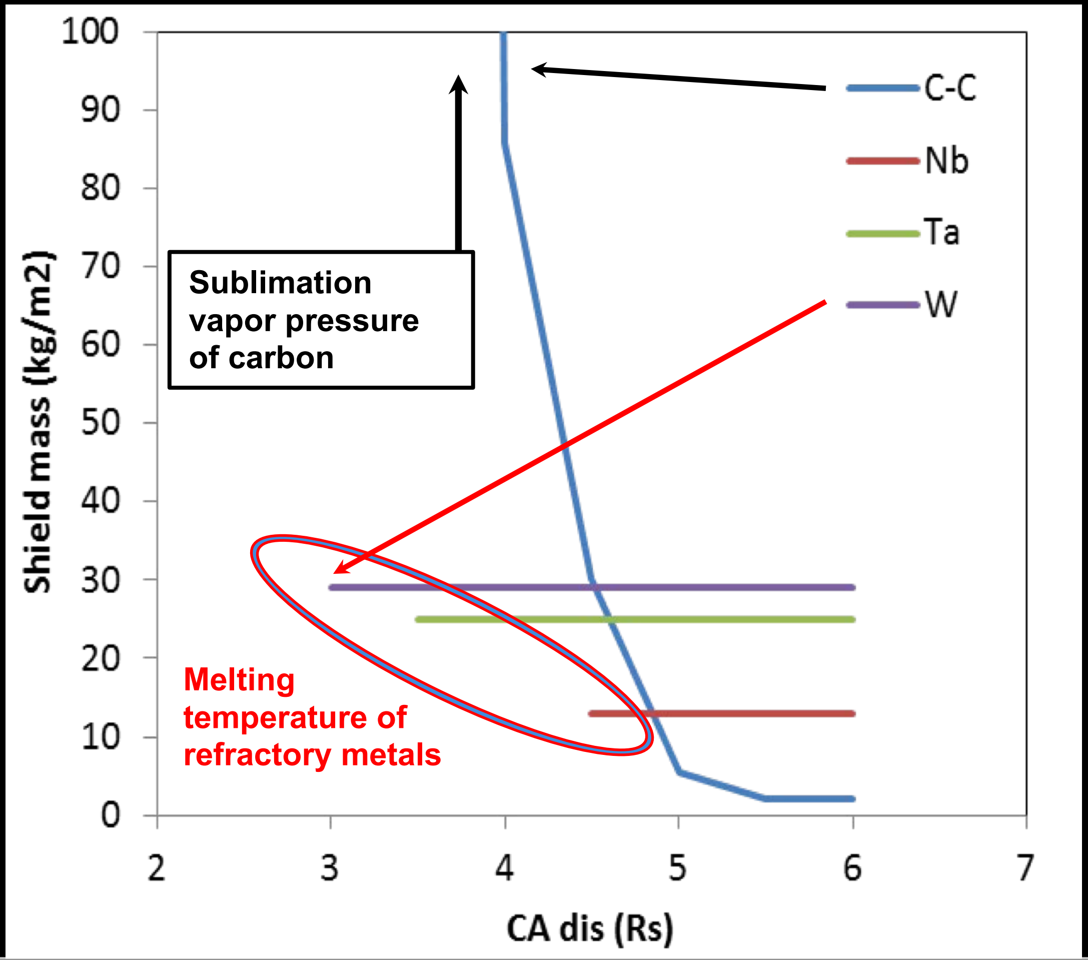
Option 3: Solar Oberth Maneuver and Pushing the Limits

- Explicit launch dates for 2030 to 2040 shown
- Trajectory asymptotes lag those of options 1 and 2 by ~120° - modulated by launch details
- All options cover 360° of heliolongitudes over an ~12-yr period
- Flyout speed depends on exact launch direction, launch conditions, and spacecraft/stack configuration

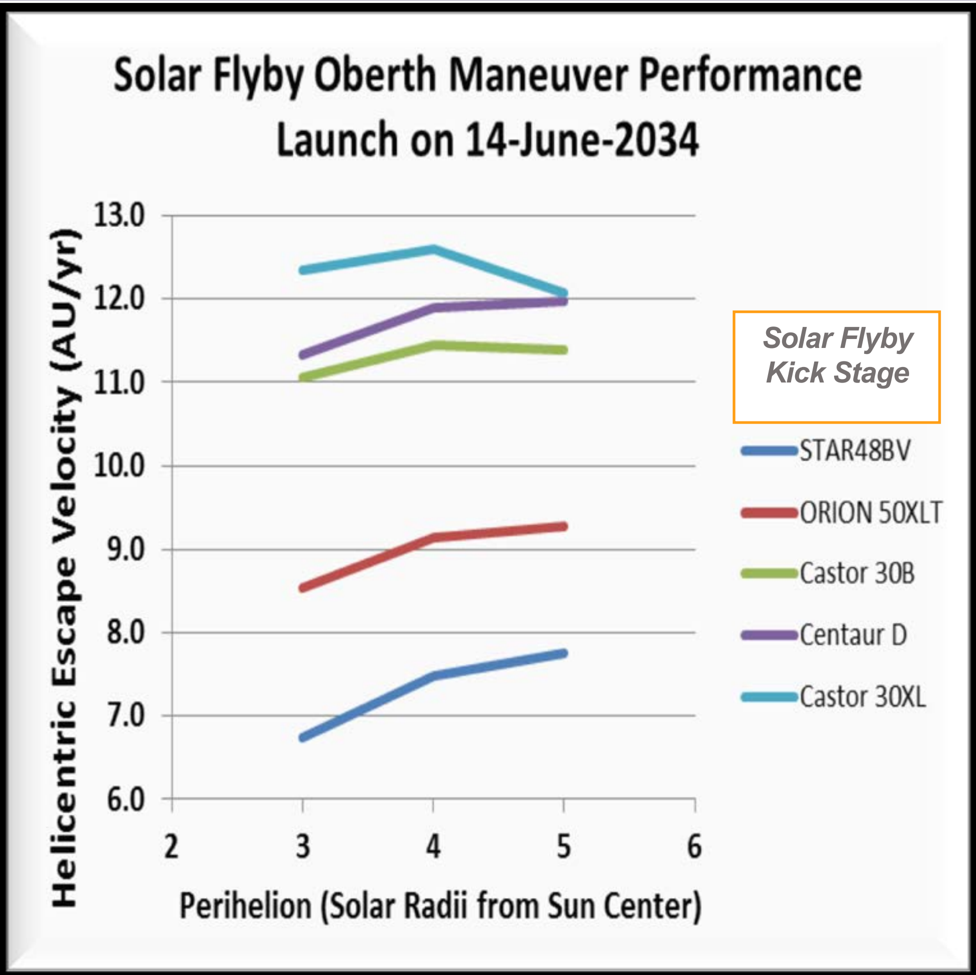


Approaching the Sun: Materials and Mechanics

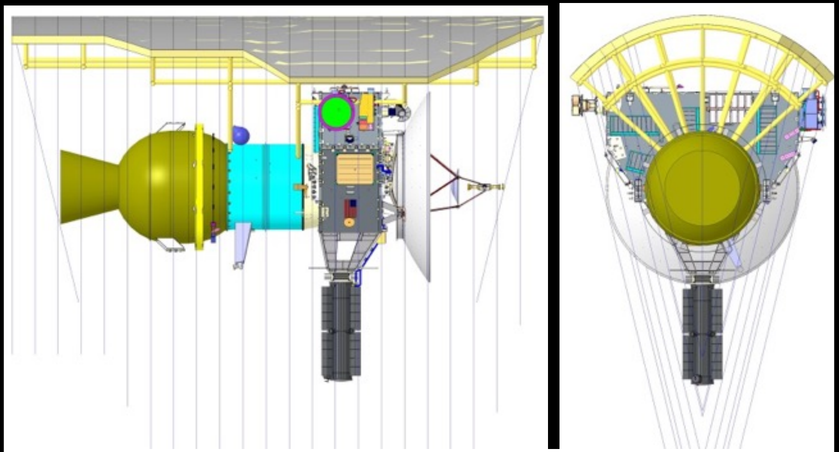
Closest approach is set by melting point of Sun-facing front layer or its sublimation rate



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

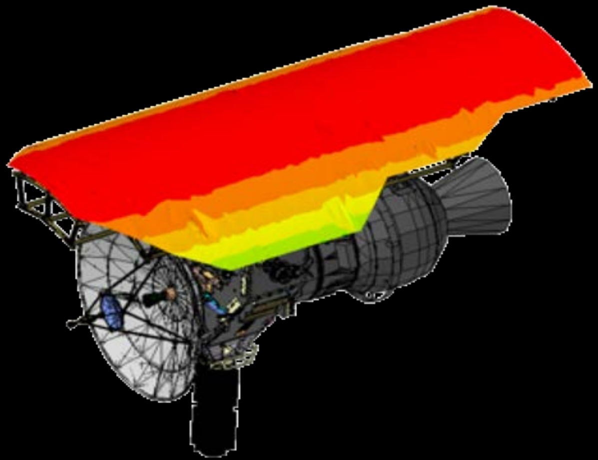


Option 3: Shield Estimates (Star 48BV)

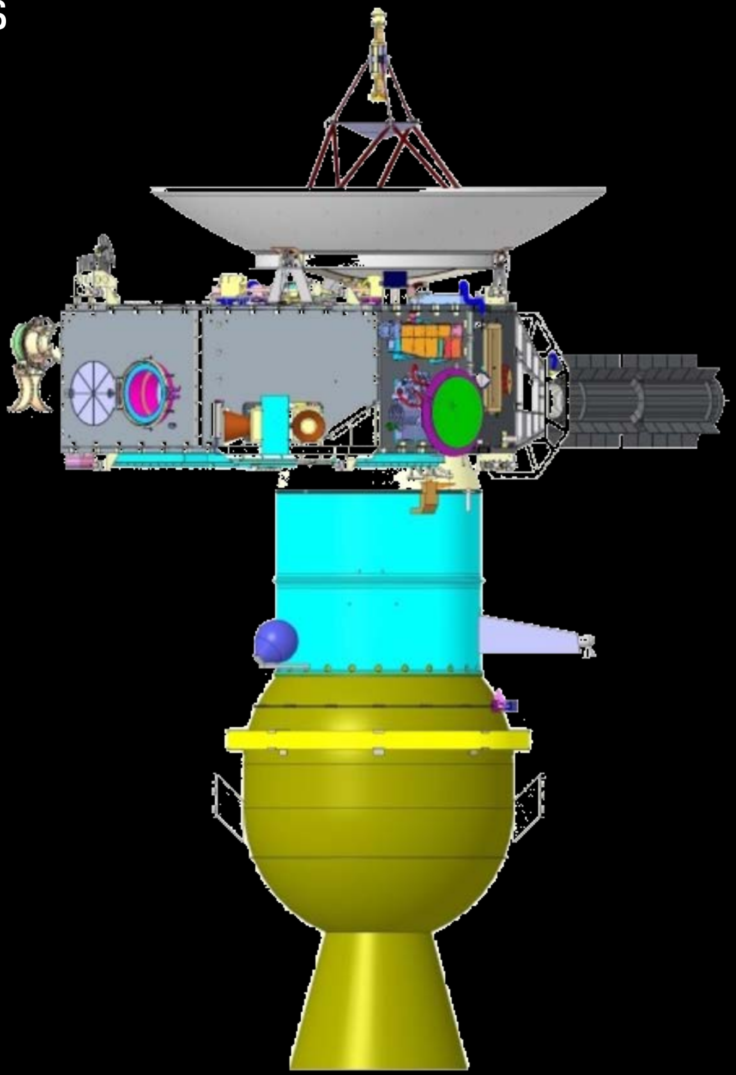


Umbra clearance checks made for each configuration

Thermal analysis at 5 R_s ~2200°C to 2600°C (hottest)



- 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

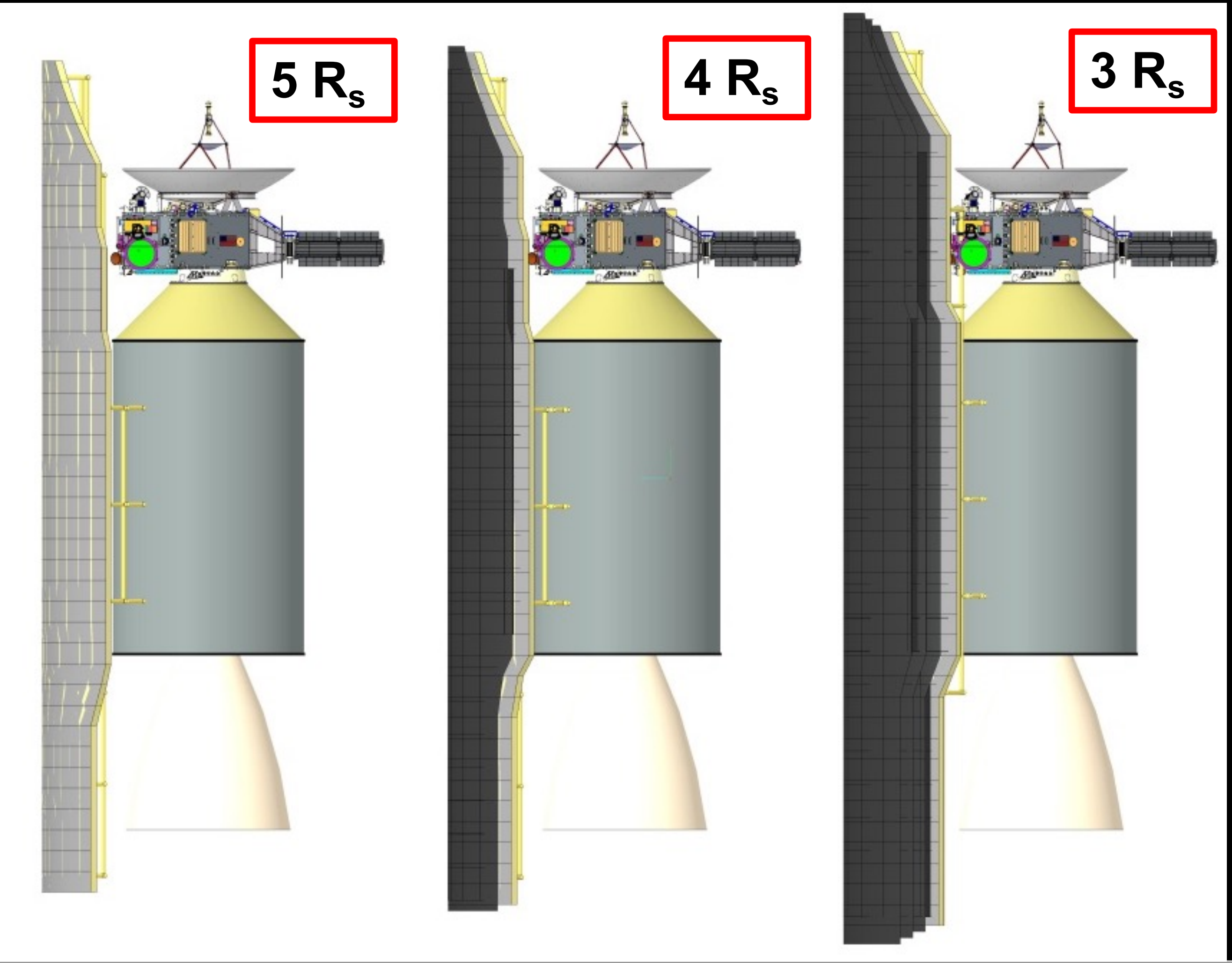


Designing for Different Perihelia: CASTOR 30XL

- 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 →

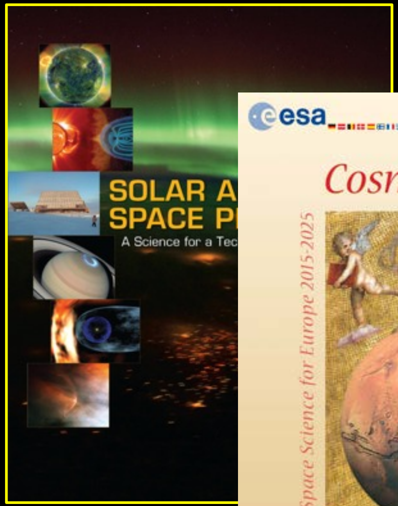


Next Key Events 2019

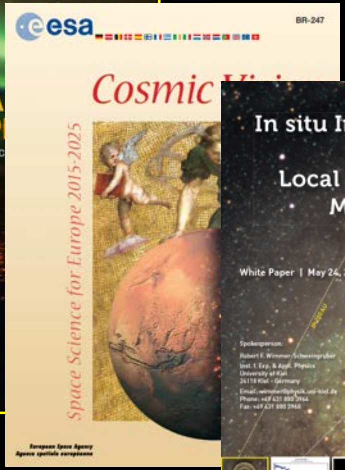
INTERSTELLAR PROBE
NASA Task Order NNN06AA01C

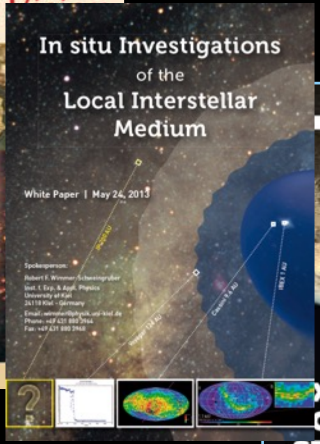
- **June 2019:** Submission of Phase 1 Study Report
- **July 2019:** Study Phase 2 begins
- **16-20 September 2019:** Interstellar Probe Special Session, EPSC-DPS, Geneva.
- **16-18 or 28-30 October 2019:** 2nd Interstellar Probe Exploration Workshop, Explorer's Club, NYC.
- **21-25 October 2019:** Interstellar Probe Special Session, 70th International Astronautical Congress, Washington, DC.
- **29-31 October 2019:** Voyage 2050, Madrid.
- **7-8 November 2019:** ISSI-Beijing Forum on "Exploration of Outer Heliosphere and Nearby Interstellar Medium".
- **9-13 December 2019:** 3rd Interstellar Probe Special Session, Fall AGU, San Francisco, CA.

White Papers



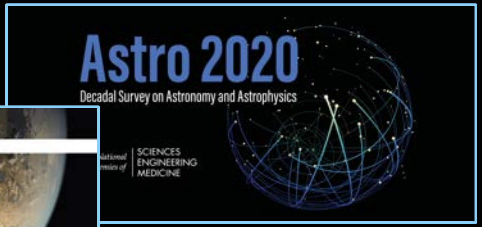
Mcnutt+2012





Wimmer+2013

Brandt+2018



Mandt+2018
Zemcov+2018

Brandt+2019

Voyage 2050

5 Aug 2019

NAS/Planetary Decadal

Q1 2020

NAS/Solar and Space Physics Decadal

Q1 2022

Please submit!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INTERSTELLAR
PROBE
Gravity Assist here
Begin.