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A VISION FOR PLANETARY AND EXOPLANETS SCIENCE: EXPLORATION OF THE INTERSTELLAR MEDIUM: THE SPACE BETWEEN STARS

IAC-17-D4.4.1x41640

Leon Alkalai, Nitin Arora, Slava Turyshev, Michael Shao, Stacy Weinstein-Weiss
Jet Propulsion Laboratory, California Institute of Technology

Merav Opher, Boston University, MA, USA

Seth Redfield, Wesleyan University, CT, USA

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POC: Leon Alkalai, leon.alkalai@jpl.nasa.gov

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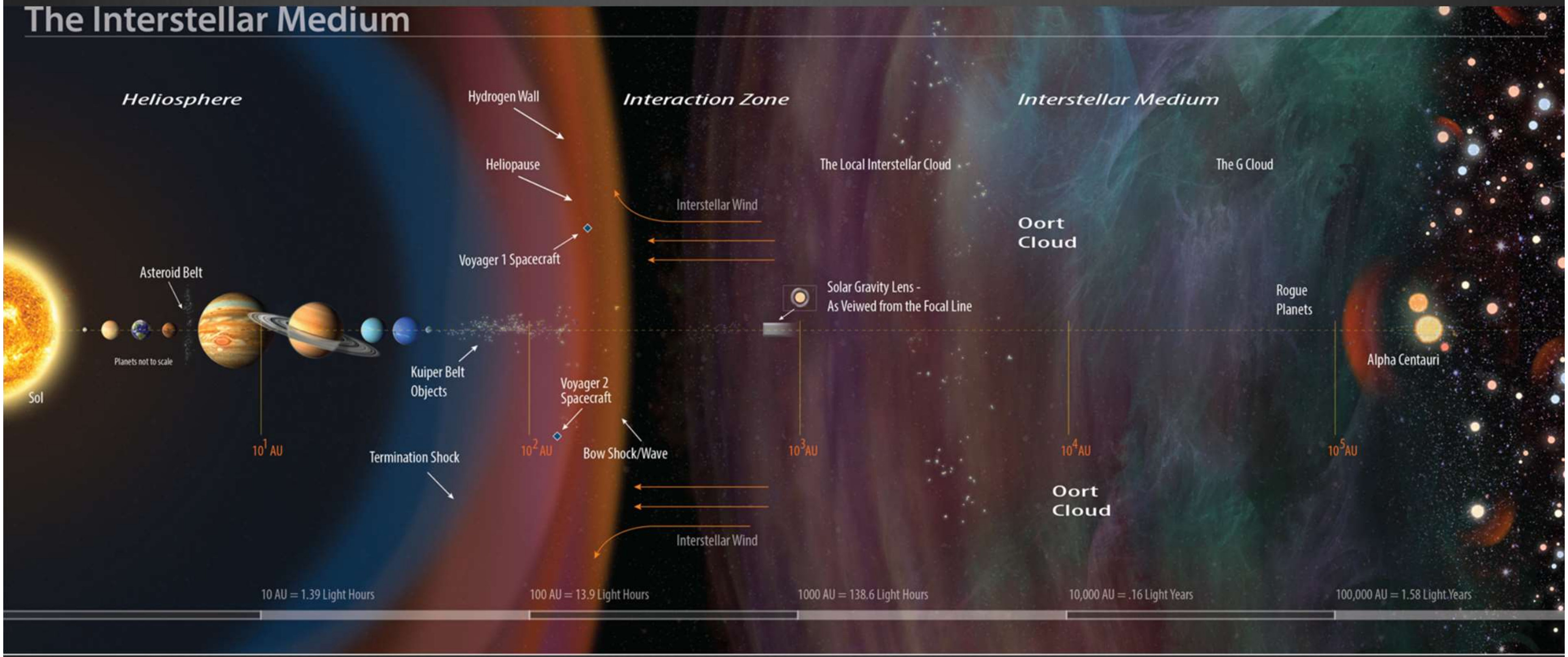
KISS Workshops on:

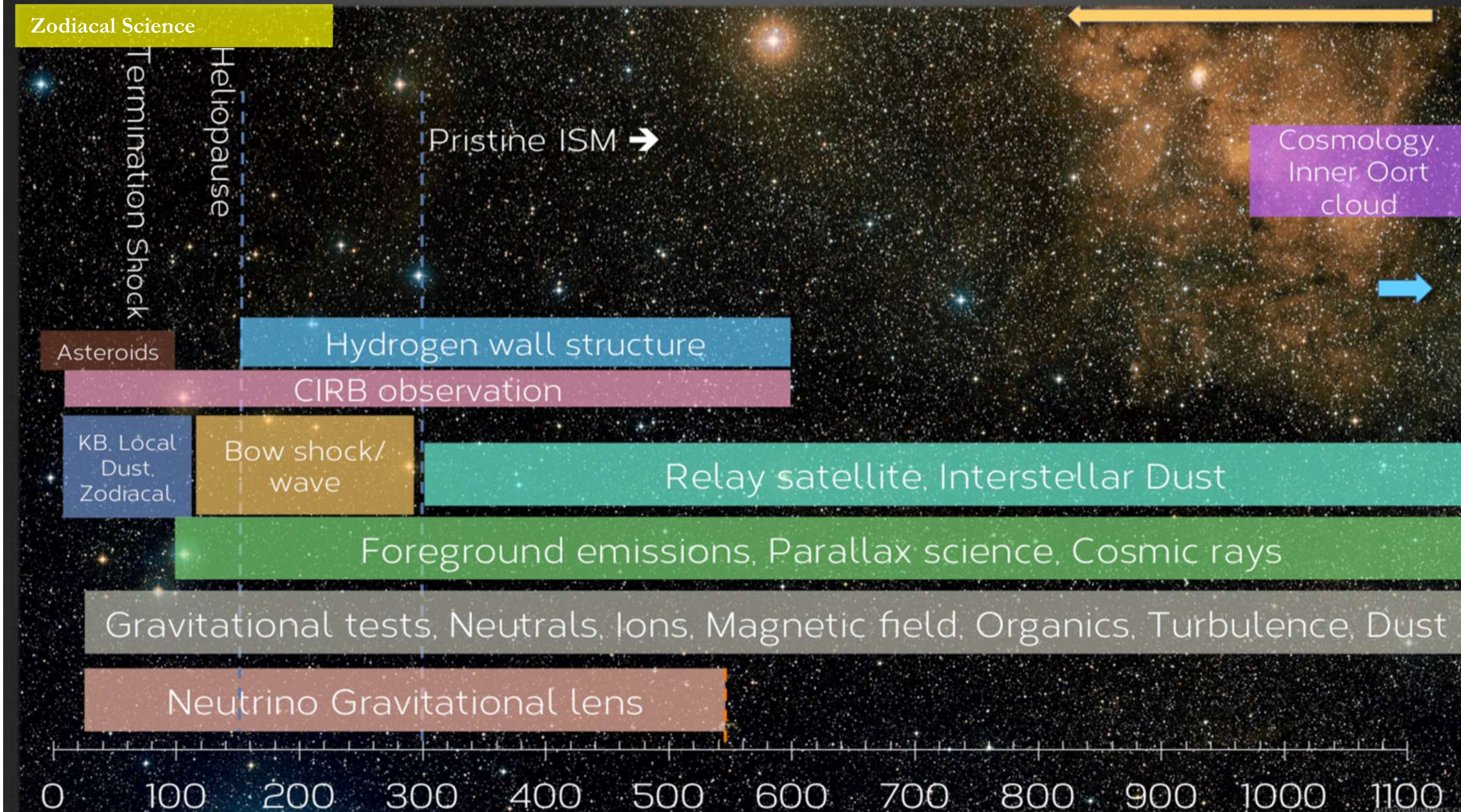
“*The Science and Enabling Technologies for the Exploration of the ISM*”, Stone, Alkalai, Friedman, 2015

https://kiss.Caltech.edu/interstellar/workshops/ism



Key Result of 2 KISS Workshops:

"There is compelling science on the way to the ISM, at the ISM, and from the ISM", Stone, Alkalai, Friedman



Distance from the Sun (AU) →

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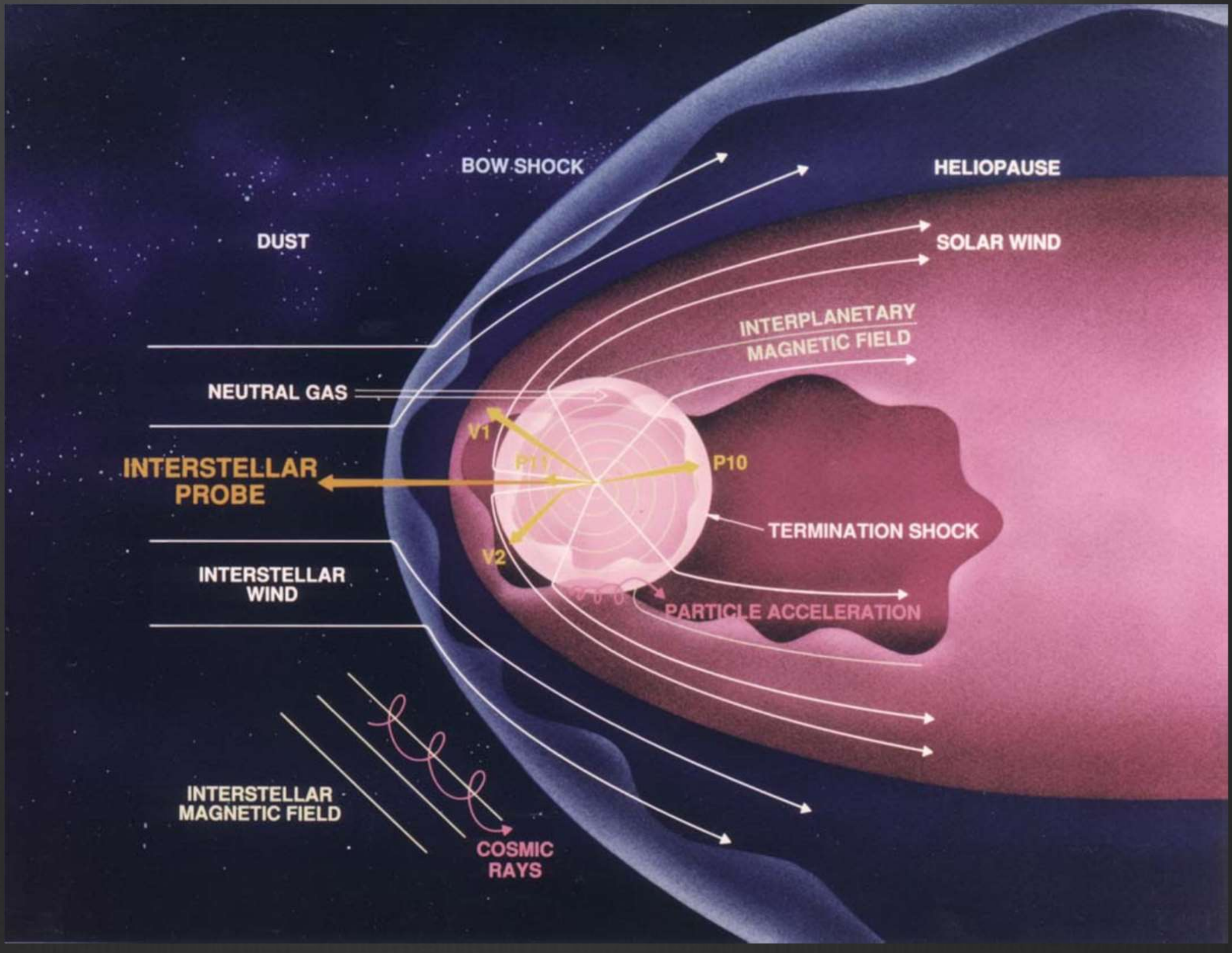
Local ISM elements

Structure of the region where solar wind interacts with the ISM.



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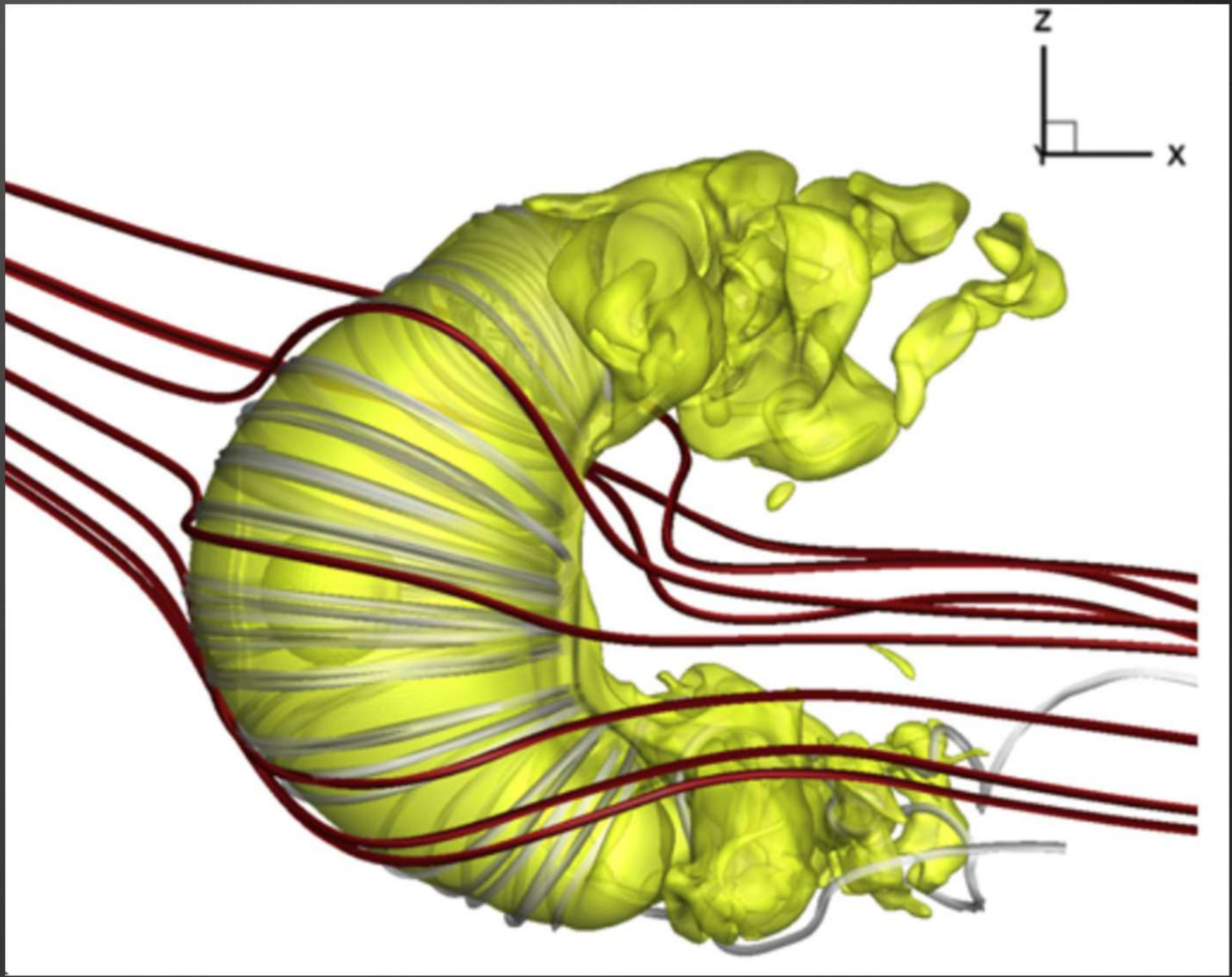
LISM Magnetic Field

Key elements of the interaction between the solar wind and the ISM, including the Termination Shock, Bow Shock, Galactic Cosmic Rays, etc.

Simulation by Opher Merav et. al



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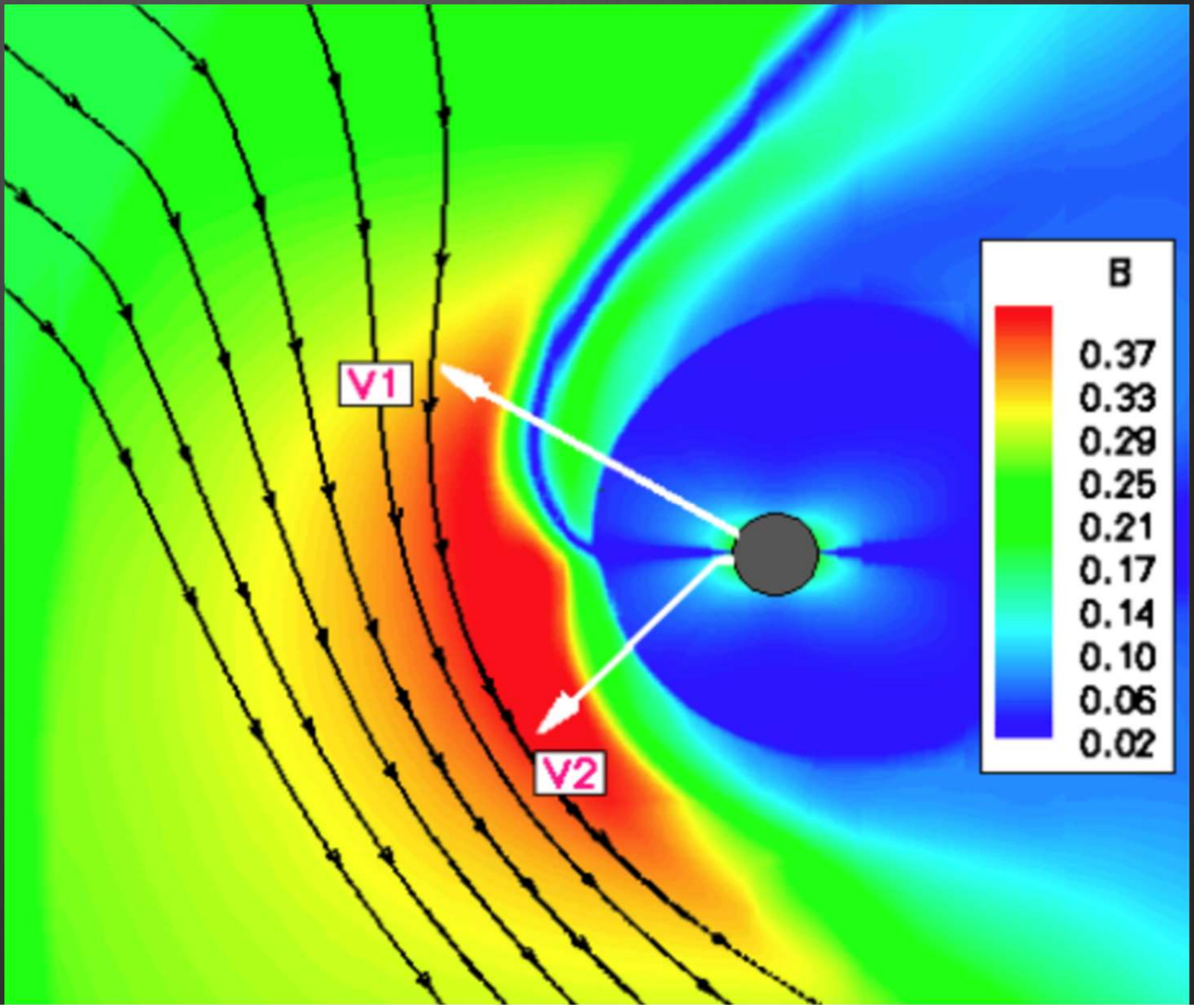
LISM Magnetic Field

Tilted interstellar magnetic field (black curves) creates asymmetric heliosphere. Trajectories of Voyager 1 and 2 are shown by white arrows.

Simulations by Opher Merav et. al



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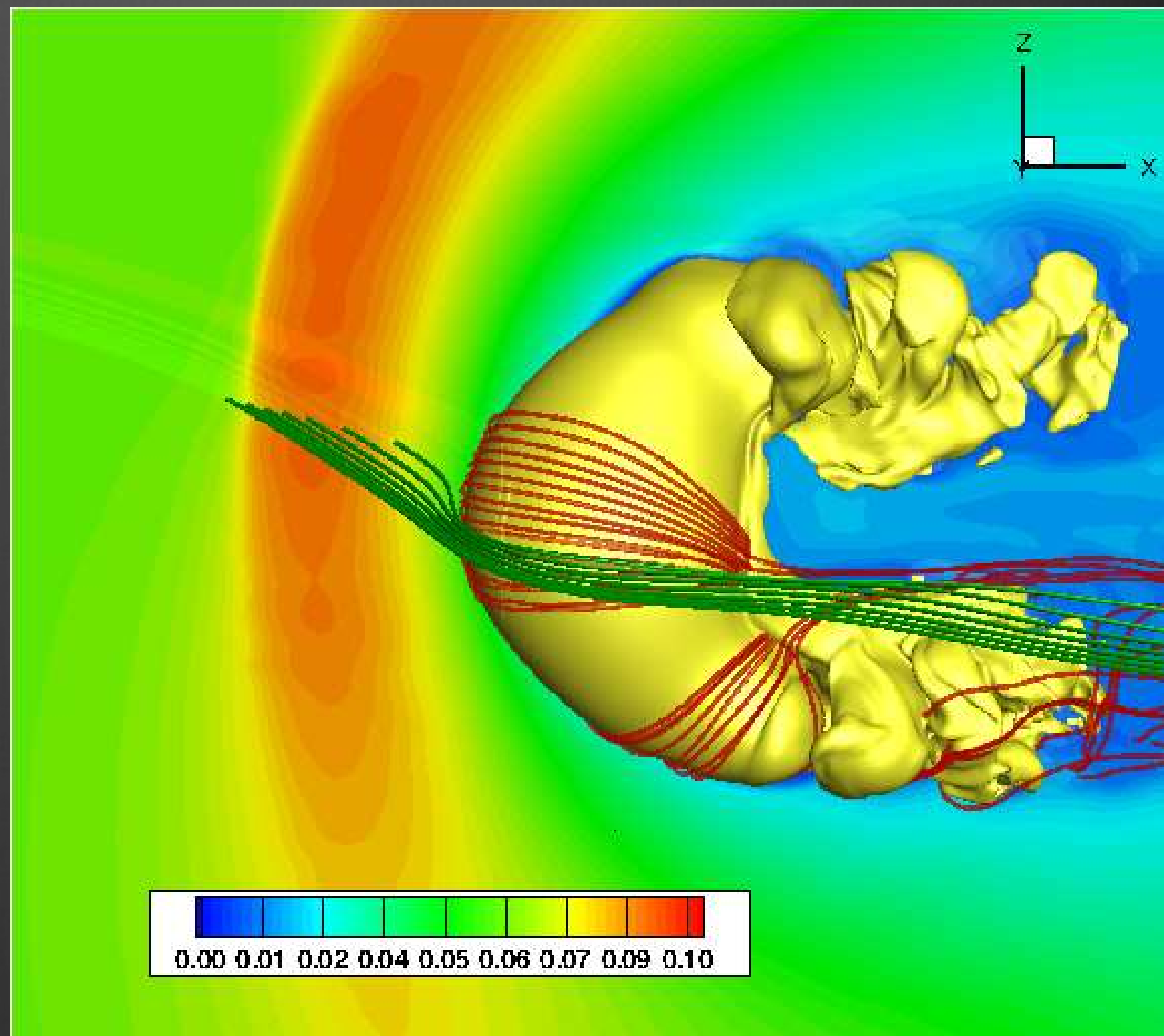
LISM: H, Magnetic Field

Complex interaction of the interstellar neutral Hydrogen atoms (color contours in #/cm3) and the interstellar magnetic field (red and green lines) coming into contact with the solar wind protons and magnetic fields in the Heliosphere (yellow surface).

Picture courtesy of Opher Merav.

Opher et al. The Astrophysical Journal Letters, Volume 800, Issue 2, article id. L28, 7 pp. (2015)



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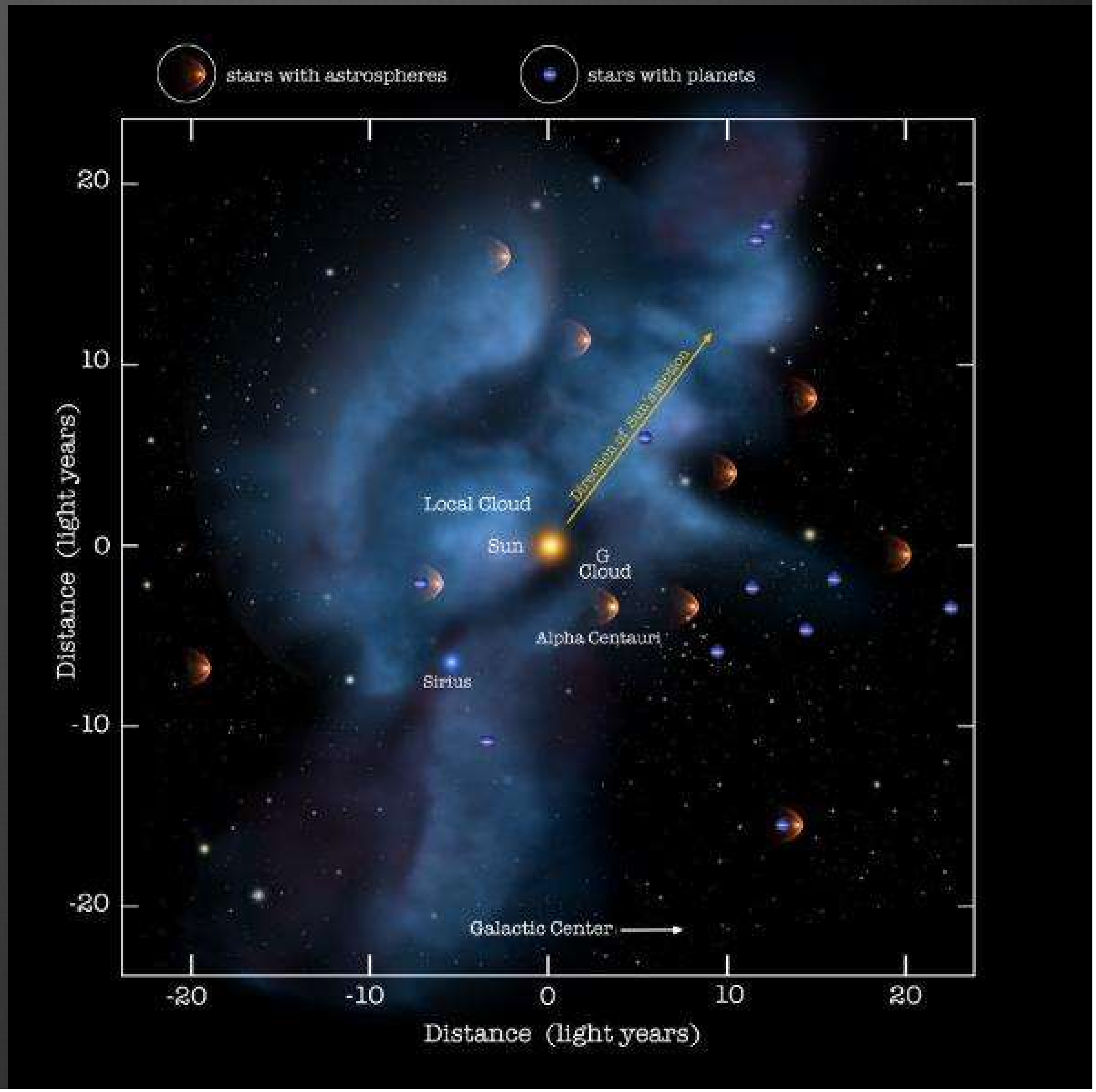
Pristine ISM

The clouds of the pristine Interstellar Medium

Source: Seth Redfield



Solar Gravity Lens - Telescopes

- Solar gravity lens line (> 550 AU)
- Unprecedented exoplanet imaging capability and SNR for spectroscopy (SGL magnification is ~2E+11 at 1 μm)
- Target has to be known a priori

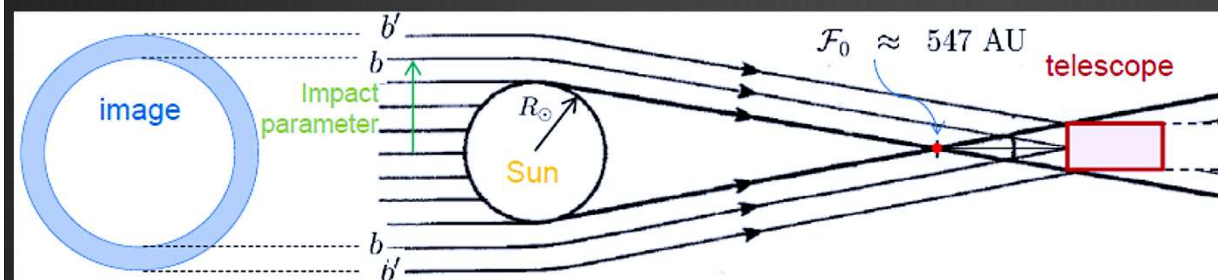


Image of earth in 1000 X 1000 pixel resolution

Source: Slava Turyshev, JPL

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ISM Exploration Program:

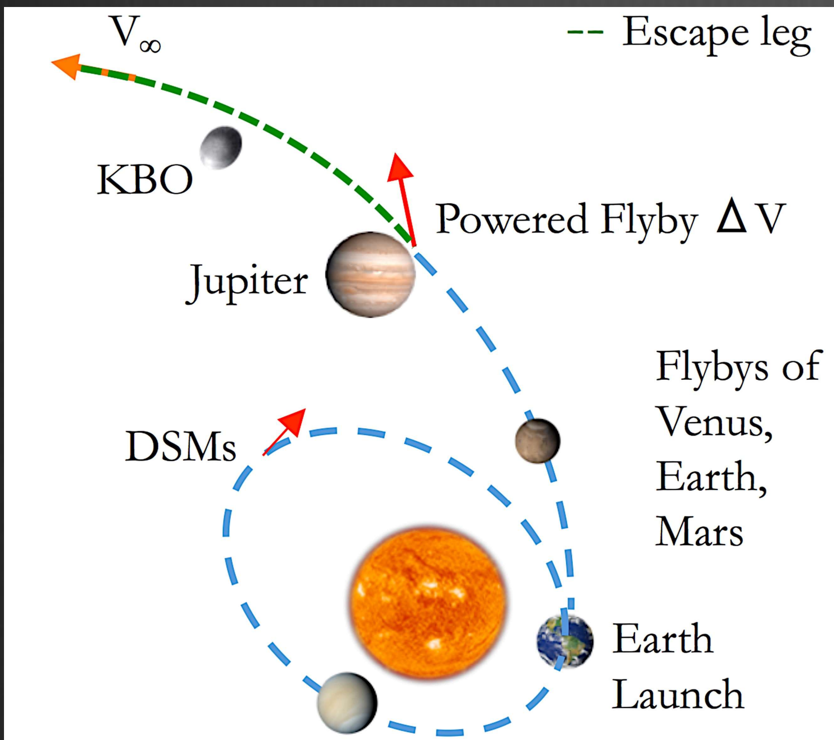
1. Probes to explore and sense the Local Interstellar Medium (LISM):
   8 - 10 years from launch at 100 – 200 AU

2. Probes to explore Pristine ISM:
   10 – 20 years from launch; 200 – 400 AU

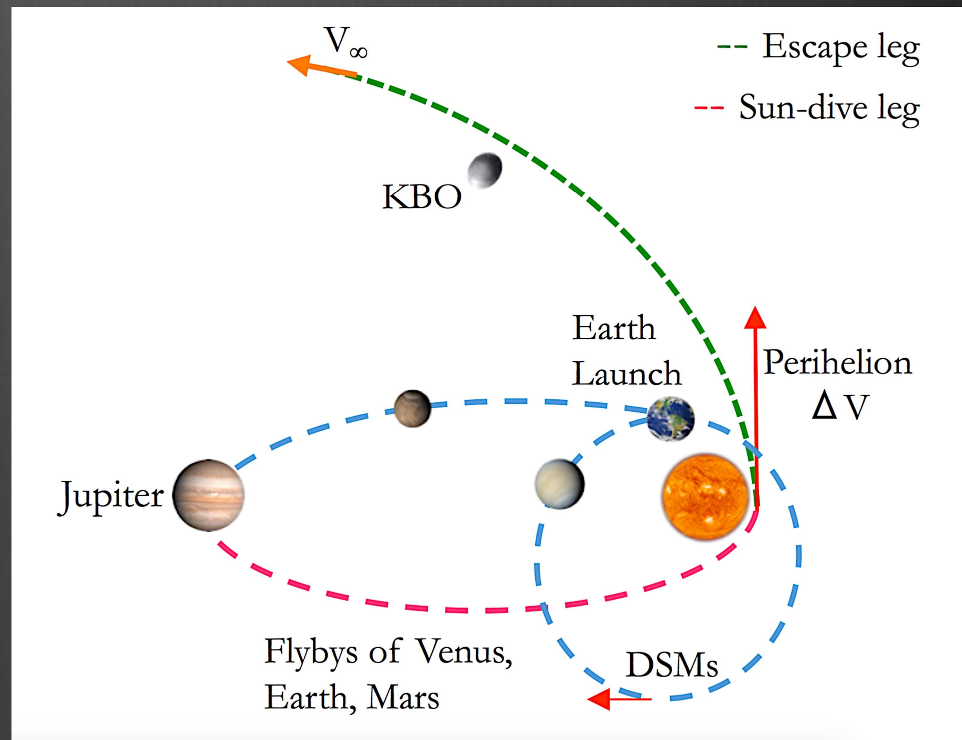
3. Deploy imaging telescopes to the SGL to image exoplanets:
   25 – 30 years from launch; 500 – 800 AU

4. Technology Development Program:
   Propulsion, Power, Avionics, Telecommunications, Navigation

Two General Class of Trajectories For Solar-System Escape



Type 1



Type 2

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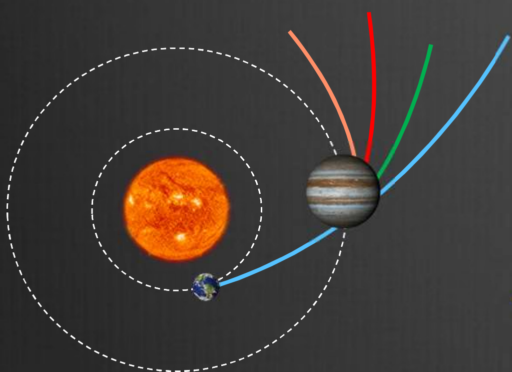
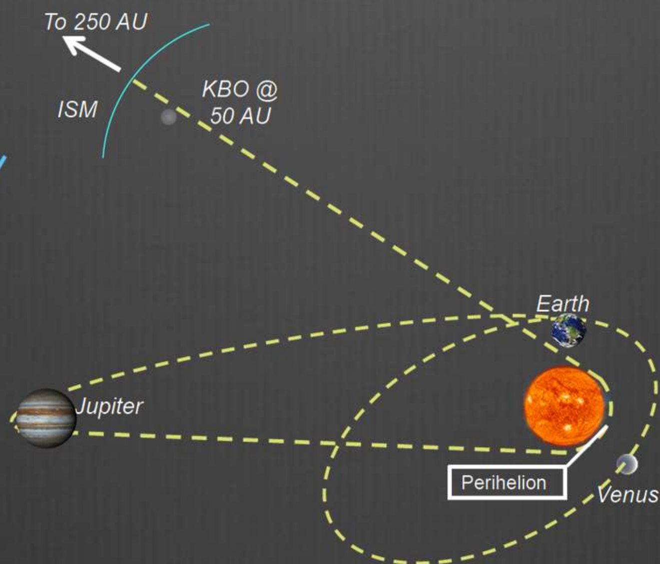
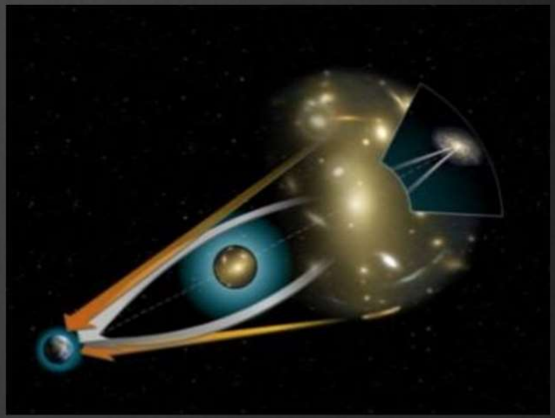
Three Pronged Approach for ISM / SGL Exploration







Credit: Martin Kornmesser & Lars Lindberg Christensen, ST-ECF.

Small Spacecraft (3-6) for near-term rapid exploration of the Local ISM (<150 AU)

A deep ISM probe (>250 AU), travelling at ~20 AU/Yr., flying-by major KBO and reaching target ISM distance in < 20 years

A mission to SGLF for deploying a 0.5-2m telescope, travelling at > 20 AU/Yr., reaching SGLF in < 40 years from launch

Mission Concept Requirements

Note: Voyager escape velocity ~3.5 AU/Yr., New Horizons ~2.5 AU/Yr.

FOM	Local ISM Small Probes	Deep ISM Explorer	SGLF Telescope
Solar-system escape velocity (AU/Yr.)	< 10 AU/Yr.	< 20 AU/Yr.	> 20 AU/Yr.
Mission Time of Flight (years)	15	20	40
Distance at End of Mission (AU)	~150	250 - 300	> 600
# of Spacecraft	3-6	1	1
Typical probe wet mass	< 160 kg	< 550 kg	< 600 kg
Typical number of instruments	1 – 2	3 - 6	1 (telescope)

Propulsion Options

Option	Fuel Type	ISP	Usage	Other comments
Solid Rocket Motor (SRM)	Solid	308s	Perihelion or Powered flyby	High ISP is available via deployed nozzle
Nuclear Thermal Propulsion (NTP)	H2	850s -940s	Perihelion or Powered flyby	H2 tank is heavy and needs to be cryocooled. Nuclear Fission based reactor results in large dry-mass
Solar Thermal Propulsion (STP)	H2	1200s -1350s	Perihelion	Utilizes heat from proximity to the Sun to heat up the H2 (at 3400k) and expel it at high velocity using engine nozzles. This concept requires a heat-exchanger
RTG powered EP (REP)	Xenon	~1800s	Probe	Propellant is carried on the probe and used during the escape phase
Electric or Solar Sail	-	-	Probe	Sail deployed on the probe beyond 0.1 AU

- Local ISM Armada ➔ SRM or NTP
- Deep ISM ➔ STP + REP or STP + E-Sail
- SGLF Mission ➔ STP + REP or STP + E-Sail

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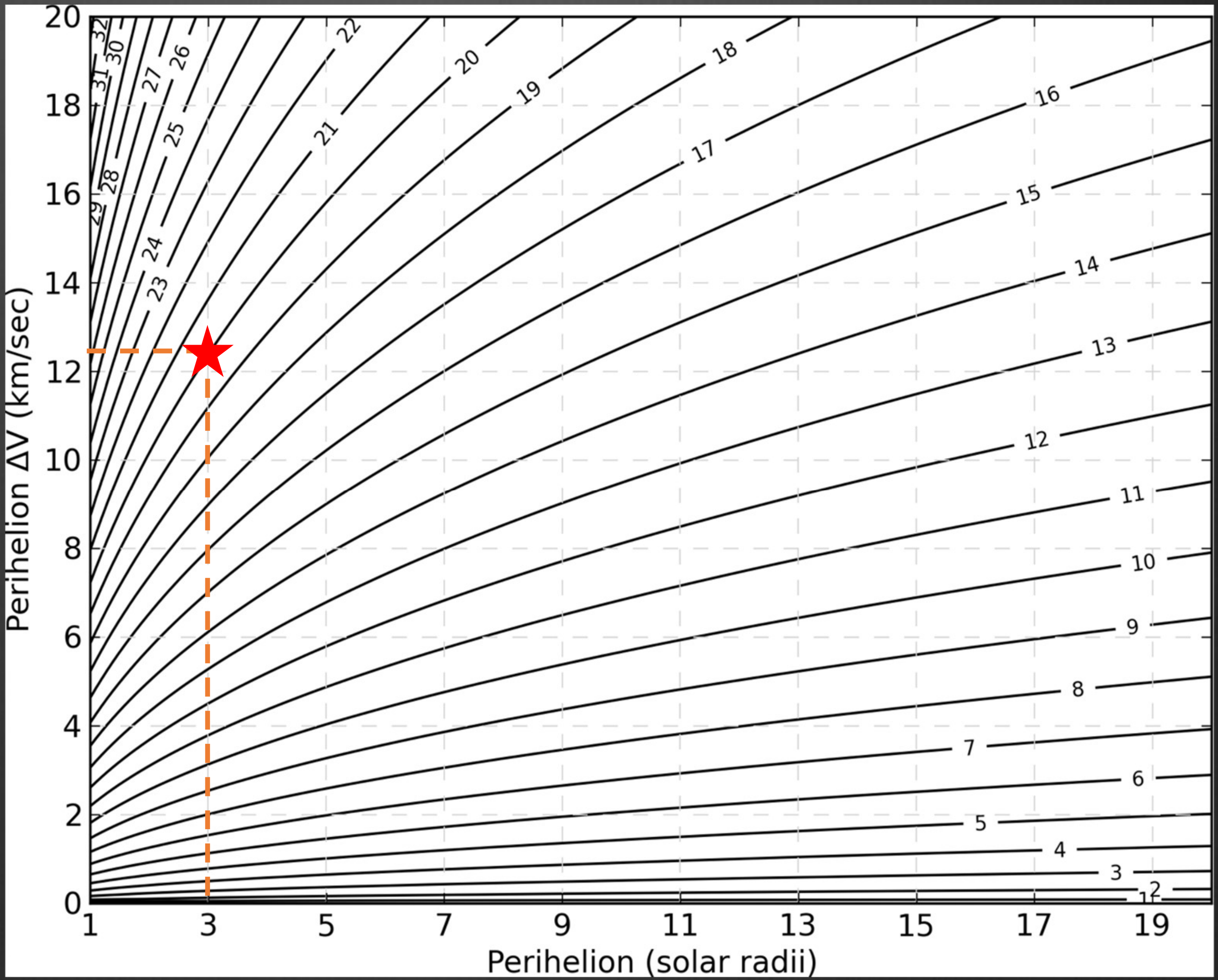
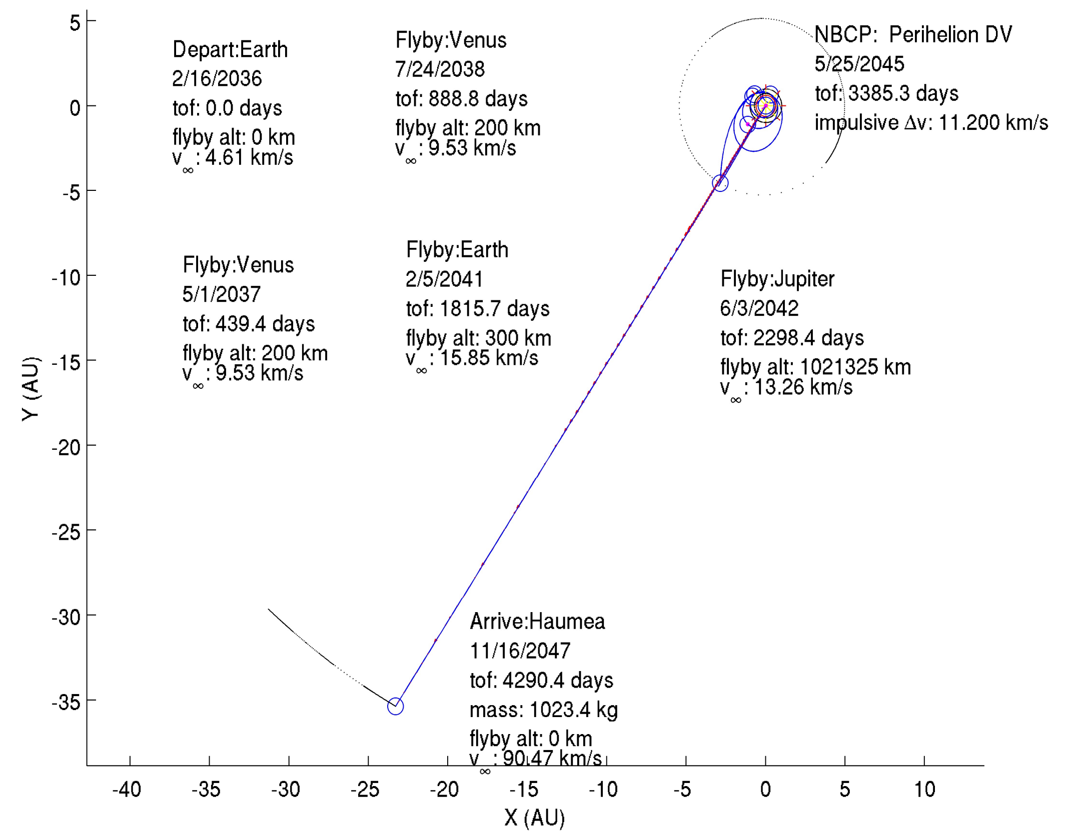
Type 2 Perihelion Maneuver

Escape Velocity Contours in AU/Yr.



STP Baseline Mission Design (Deep ISM Explorer)

- E-V-V-E-J-Perihelion-KBO-ISM four flyby sequence
- Launch in mid 2030s (early launches are possible)
- Flyby KBO Haumea in ~11 years
- No deep space maneuvers
- STP Perihelion burn ~11.2 km/s
- REP provides ~4 km/s ΔV
- Escape (KBO flyby) velocity > 90 km/s or > 19 AU/Yr.



Enabling Features:

- STP Perihelion burn + REP provides breakthrough escape velocity of >19 AU/Yr.
- Low launch C3 'banks' delta-V for use at perihelion
- Launch on NASA's SLS

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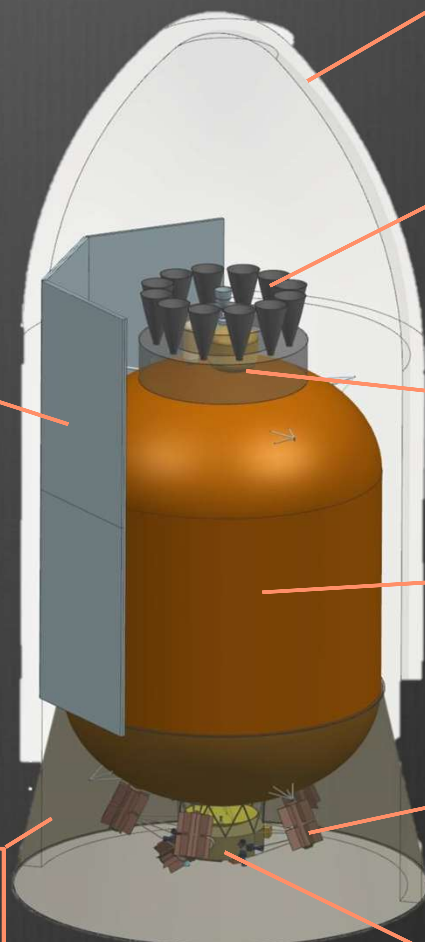
Pristine ISM Probe

Launch Mass = 28 Tons
LH2 mass ~ 15.8 Tons
Probe mass ~ 560 kg
Payload mass ~ 54 kg



Probe Design: Deep ISM Explorer

Sub-system	MEV (kg)	Comments
Power (without SMRTG)	47	Ref. bus + batteries
Propulsion	17	Monoprop
Telecomm.	30	Iris level radio, 1m - 2 m deployable HGA
Mechanical	177	Light weight, multi-functional structures
Thermal	29	RTG + RHU and Louvers
Attitude & Control	34	RWA, MIMU
C&DH	15	3U JPL Avionics
Science Payload	42	Fields and Particles + Camera
Propellant	25	Can be Xenon or can be extra mass for an E-Sail
System Level Margin	**74.4**	According to JPL DP
2x SMRTG	**52**	No margin needed for RTGs
Total Allocation	**542**	**Wet mass / probe**

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LISM Probe Mass Breakdown

Sub-system	MEV (kg)	Comments
Power (without SMRTG)	11	"right-sized" SMRTG
Propulsion	20	REP or E-Sail
Telecomm.	4	Iris level radio, 1m - 2 m deployable HGA
Mechanical	20	Light weight, multi-functional structures
Thermal	6	RTG + RHU and Louvers
Attitude & Control	3	Monoprop + small-sat ACS
C&DH	1	SmallSat Avionics
Science Payload	9	1-2 instruments
Propellant	25	Can be Xenon or can be extra mass for a bigger E-Sail
System Level Margin	**21**	According to JPL DP
SMRTG mass	**40**	No margin needed for RTGs
Total Allocation	**160**	**Wet mass / probe**

Probe Design: SGLF Telescope

Sub-system	MEV (kg)	Comments
Power (without SMRTG)	47	Ref. bus + batteries
Propulsion	17	Monoprop
Telecomm.	30	Iris level radio, 1m - 2 m deployable HGA
Mechanical	177	Light weight, multi-functional structures
Thermal	29	RTG + RHU and Louvers
Attitude & Control	34	RWA, MIMU
C&DH	15	3U JPL Avionics
Telescope	50	0.5-1m Telescope
Propellant	25	Can be Xenon or can be extra mass for a bigger E-Sail
System Level Margin	**80**	According to JPL DP
2x SMRTG	**52**	No margin needed for RTGs
Total Allocation	**556**	**Wet mass / probe**

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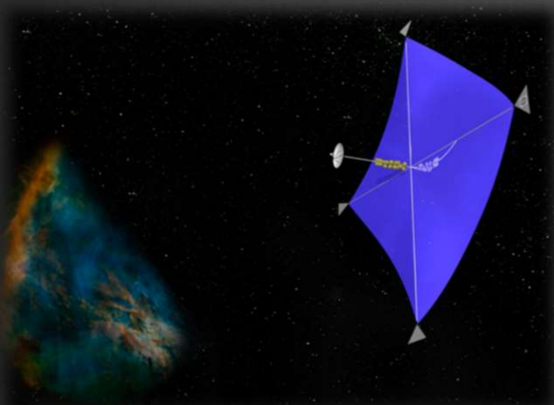
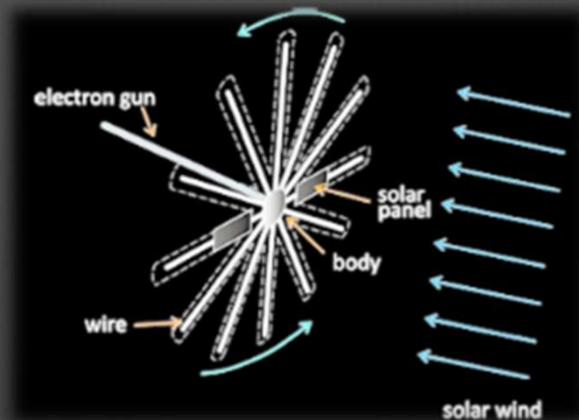
Propulsion: Technology Development Options



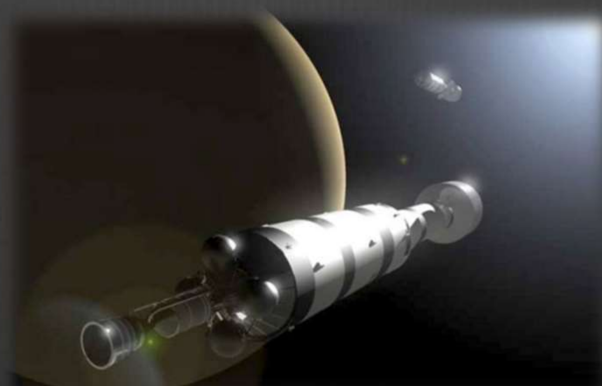
Very Large solar sails



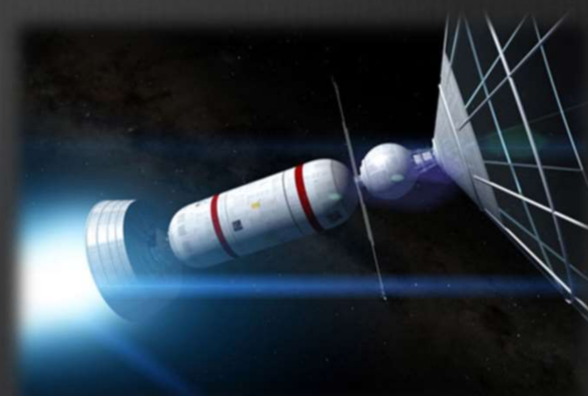
Very Large Electric sails

Beamed Propulsion

Orion (Nuclear Pulsed Propulsion)



Nuclear Fusion Rocket



http://www.daviddarling.info/encyclopedia/I/interstellar_ramjet.html

Bussard Ramjet

Summary of proposed ISM Program

Interstellar Program Elements

- Probes carrying telescope to the SGL: 500 – 800 AU
- Deep ISM Probes to the Pristine ISM: 200 – 400 AU
- Small Satellite Probes to the Local ISM: 100 – 200 AU
- Technology Development Program: Propulsion, Power, Telecom., Autonomy

All Paths to Exoplanets go through the ISM