Overview of KISS Workshop on the:

"Science and enabling technologies for the exploration of the Interstellar Medium (ISM)"

Leon Alkalai, Edward C. Stone, Louis Freedman

Keck Institute for Space Studies

Keck

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

KISS Proposal, December 2013

- *The Science and Enabling Technologies for the Exploration of the Interstellar Medium (ISM)*, Edward C. Stone, Leon Alkalai, Lou Friedman.
- Two workshops held: September 2014, January 2015 with ~ 32 participants
- KISS, September 30th 2015, "*The Science and Enabling Technologies for the Exploration of the Interstellar Medium (ISM), Final Report*" Alkalai L, Arora N, Arya M, Barnes N, Brashears T, Brown M, Cauley P W, Cesarone R J, Dyson F, Friedman L, Garber D, Goldsmith P, Jemison M, Johnson L, Liewer P, Lubin P, Maccone C, Males J, McDonough K, McNutt R L J, Mewaldt R, Michael A, Montgomery E, Opher M, Provornikova E, Rankin J, Redfield S, Shao M, Shotwell R, Strange N, Stone E, Svitek T, Swain M, Turyshev S, Werner M and Zank G P.

Goals

Capability Push:

- Can we reach the ISM in 10-15 years, rather than 36 (Voyager 1/2)?
- Can we achieve solar-system escape velocity of > 12 AU/Yr. and venture deep into the ISM, as a first step towards reaching to another star?
  - Voyager 1 ~3.6 AU/Yr.; Voyager 2 ~3.1 AU/Yr.; New Horizons ~ 2.75 AU/Yr.
- Can we build a low power, autonomous robotic systems to survive > 50 years?

Science Pull:

- What are the compelling science goals in exploring the ISM: 100 – 300 AU?
- Is there compelling science to be done on the way to the ISM?
- Is visiting a large KBO an option?

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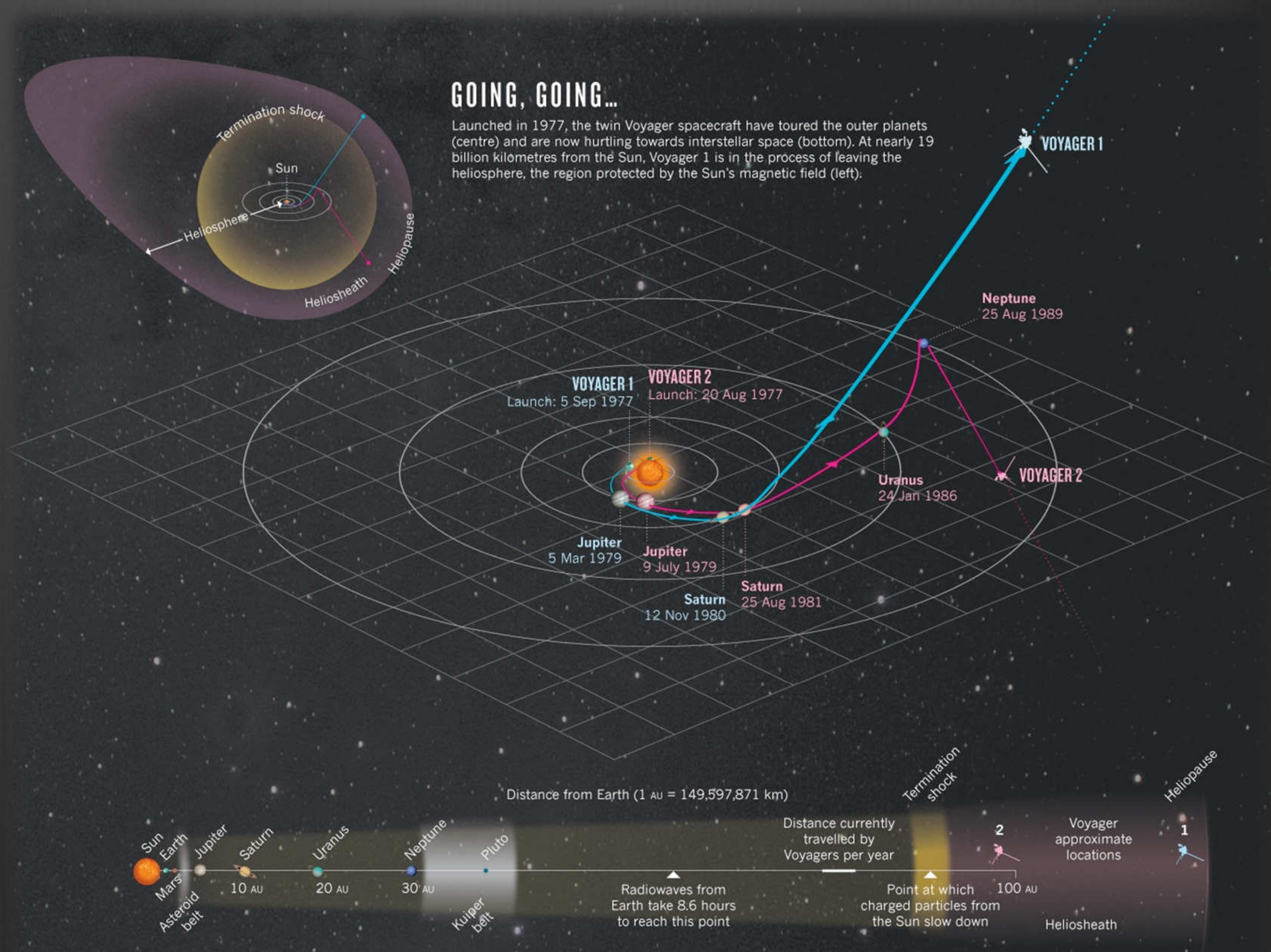
The Timing is Right…

Voyager and Kepler discoveries elucidate 2 end points of Interstellar Space or Interstellar Medium (ISM) between our star and ExoPlanets!



(ALEXANDRA WITZE) Nature 497, 424–427 (23 May 2013); doi:10.1038/497424a

The Science of Exploring the ISM

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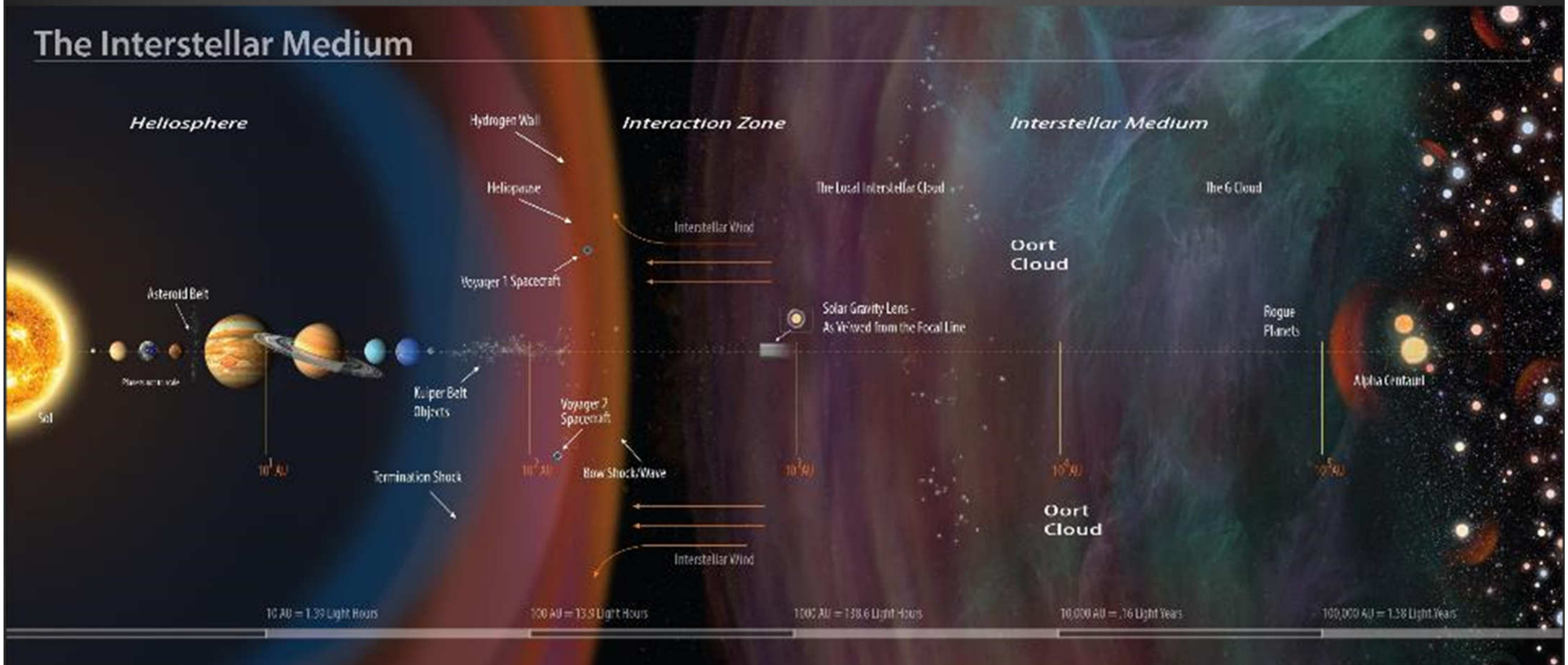
The New Frontier in Deep Space Exploration: The Interstellar Medium

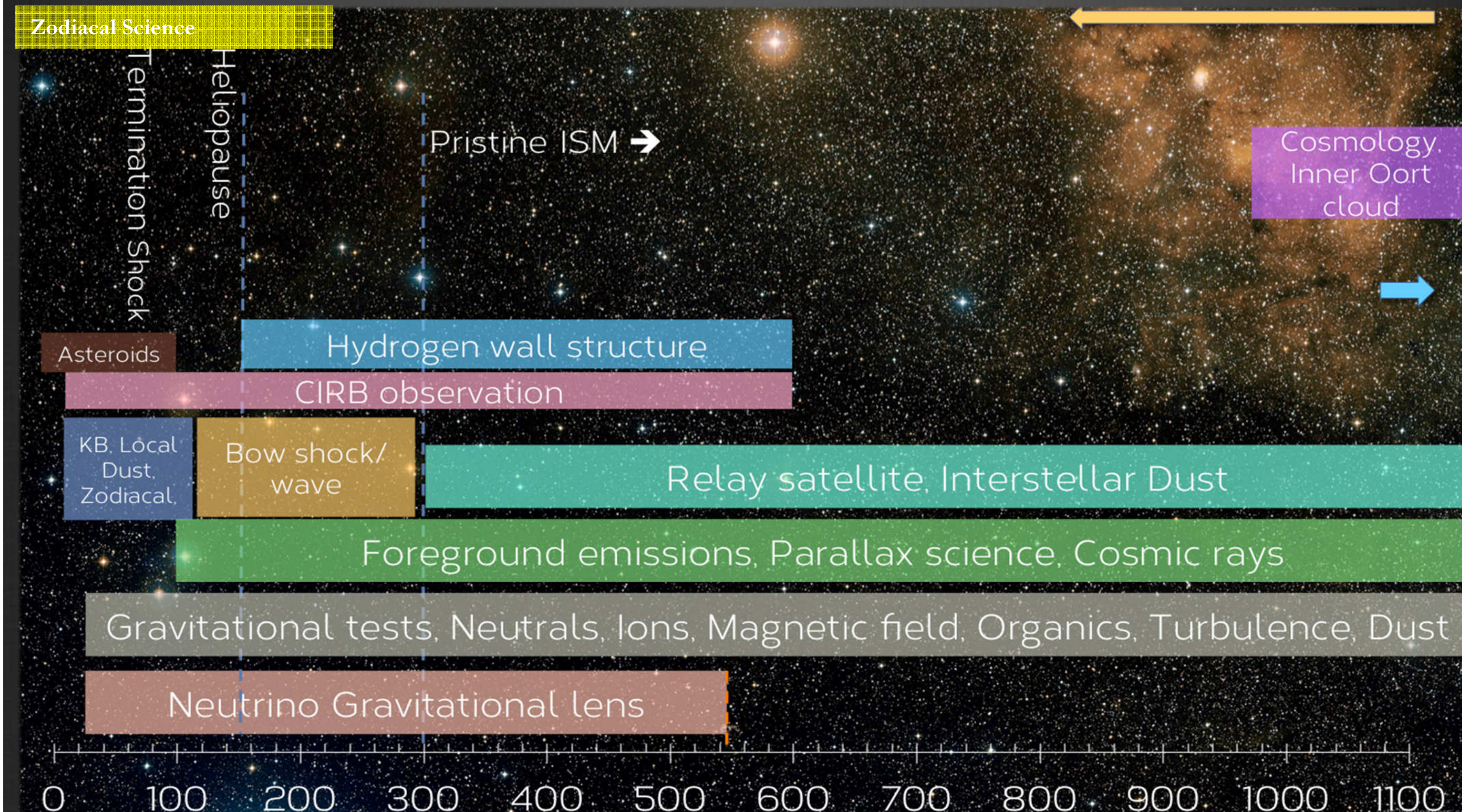


"Across the Sea of Space, the Stars are other Suns"

Carl Sagan

A Key Result of 2 KISS Workshops:

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



Distance from the Sun (AU) →

Key Heliophysics Science Questions

- What are the characteristics of the termination shock, the heliopause and the region in between?
- What is the influence of the interplanetary magnetic field on these structure?
- What are the transport and acceleration processes in these regions?
- How does the distribution functions of the ions and neutrals evolve along the trajectory of the spacecraft?
- Does the solar cycle influence the dynamics of these structures?
- How does the heliosheath shield against cosmic rays and neutral particles?
- and what role does it play in the interstellar-terrestrial relations?

Key Astrophysics Science Questions

- What is the nature of the Zodiacal background?
- What is the physical state of the interstellar medium, its composition and its magnetic field?
- What is the undisturbed interstellar spectrum of galactic cosmic rays?
- What can we learn from the composition and dynamics of interstellar dust grains?

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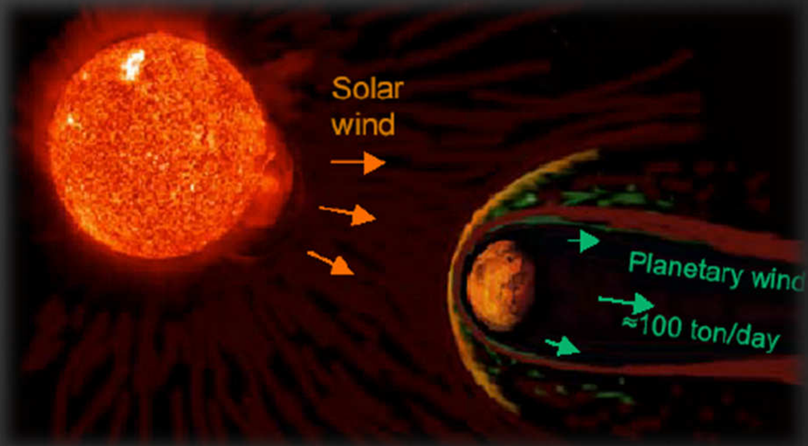
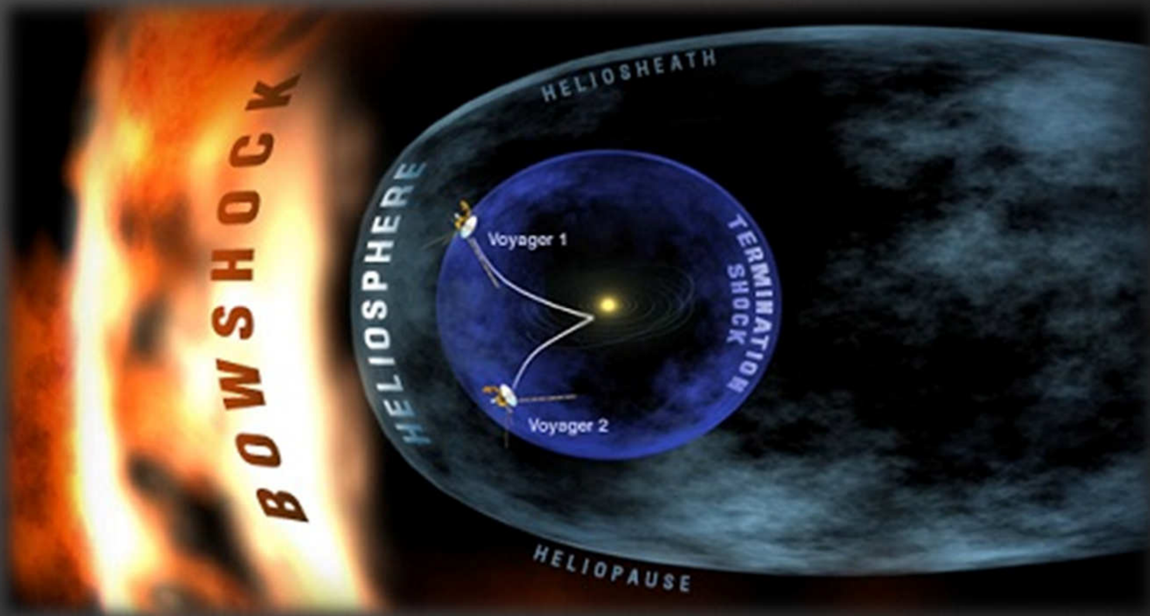
Science on the way to the ISM and within our solar system

- Zodiacal/Cosmic background science
- Solar-wind Science
- Parallax science, radio Science & astrometry
- Science close to the Sun



Science of the Local ISM (> 50 AU)

- Termination shock
- Heliopause
- Hydrogen Wall
- Bow-shock
- Bow-wave
- Organics
- Dust composition



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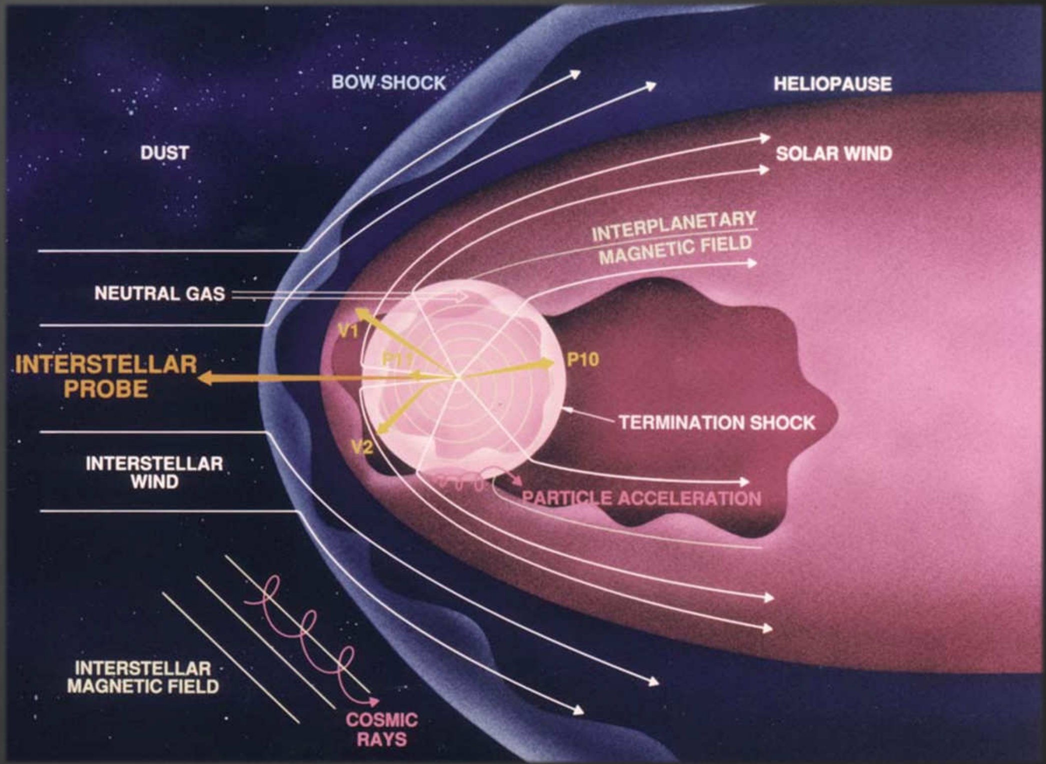
Science of the Pristine ISM (>200 AU)

- Interstellar magnetic field: direction, strength and turbulence
- Cosmic-ray science
- Interstellar winds
- Primordial Blackholes
- WIMS (weakly-interacting massive particles)
- Organics
- Dust composition of the Pristine ISM



http://interstellar.jpl.nasa.gov/

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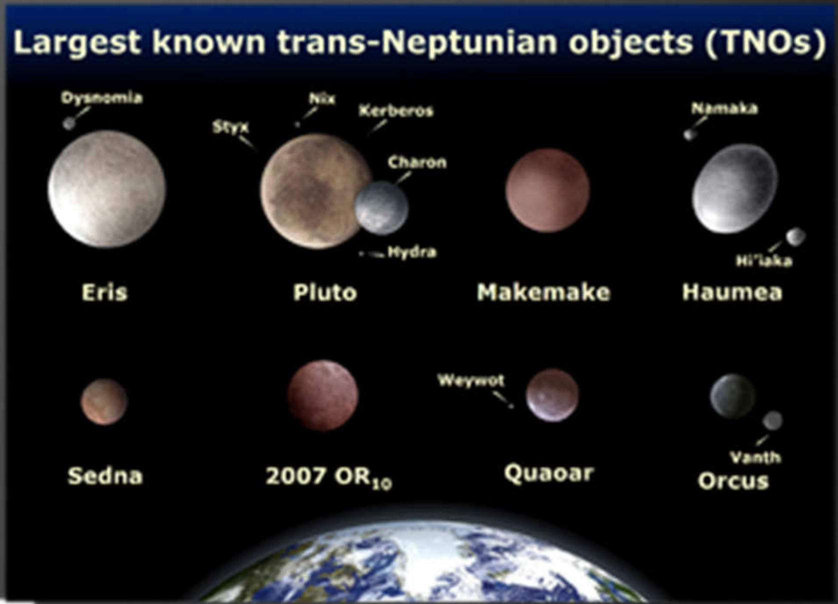
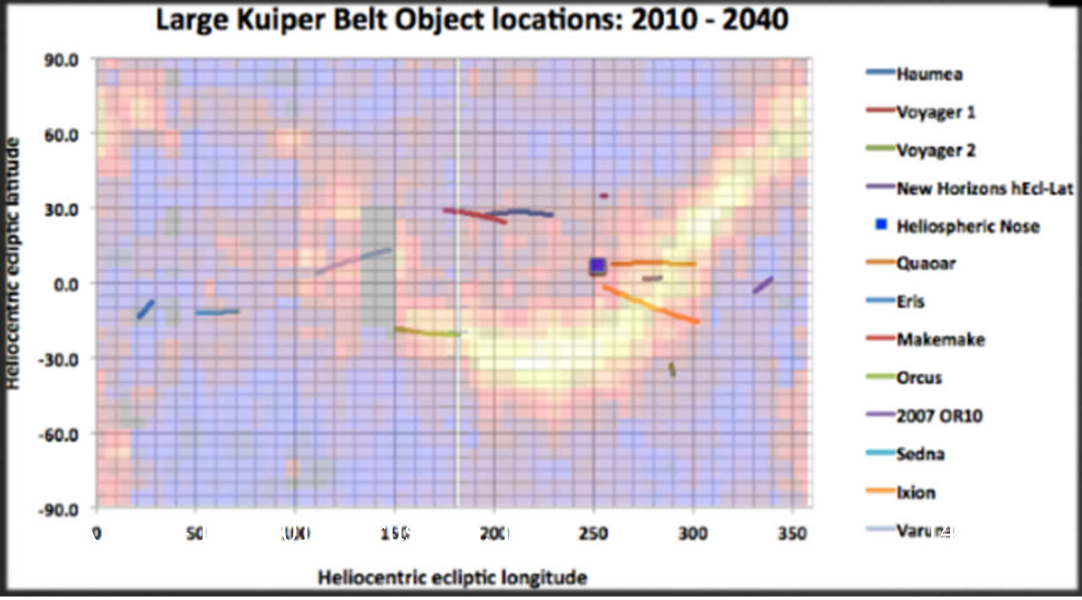
KBO Science (~ 30-50 AU)

KBO science with very fast flyby

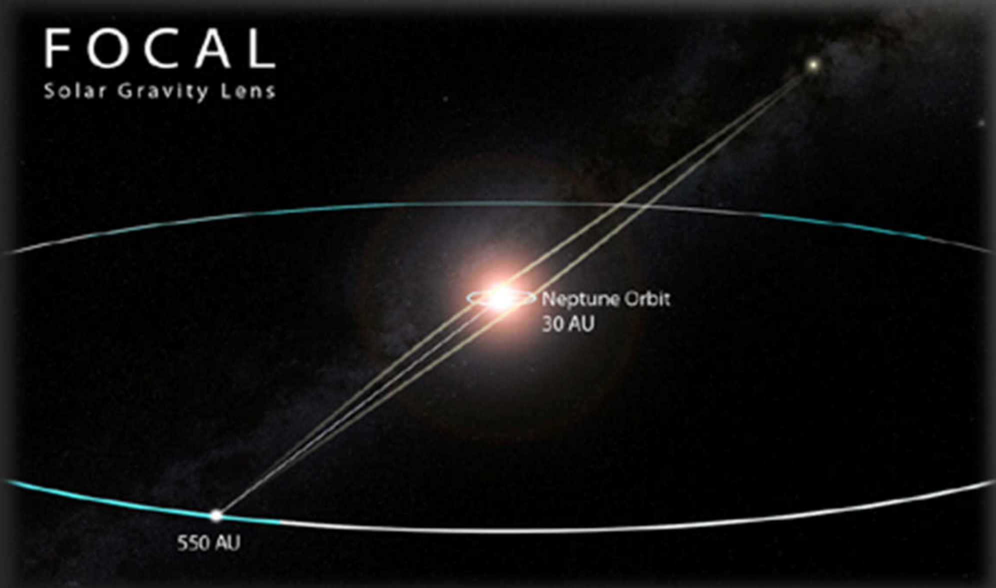
- Flyby speed > 60 km/s
- Cubesat impactor

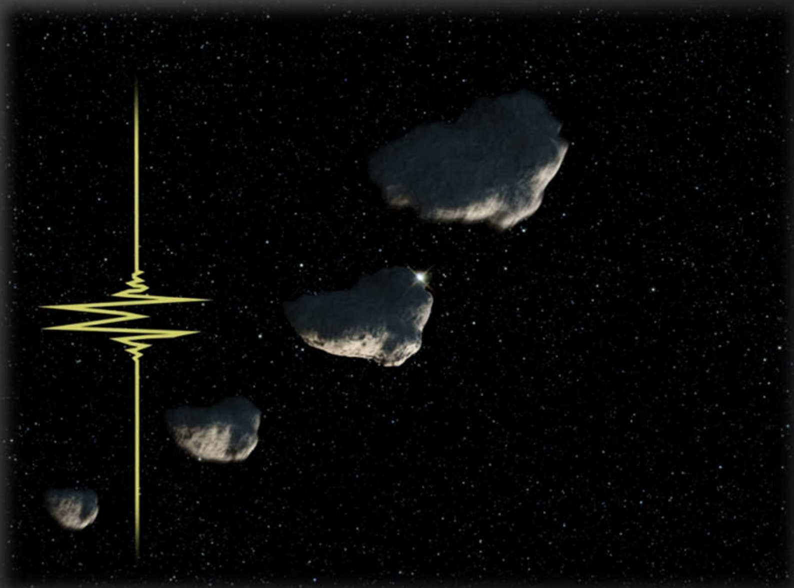




Science from the ISM (>50 AU)

- Radio Science
- Solar gravity lens focus (550 AU and beyond)
- Exoplanets and KBO detection detection





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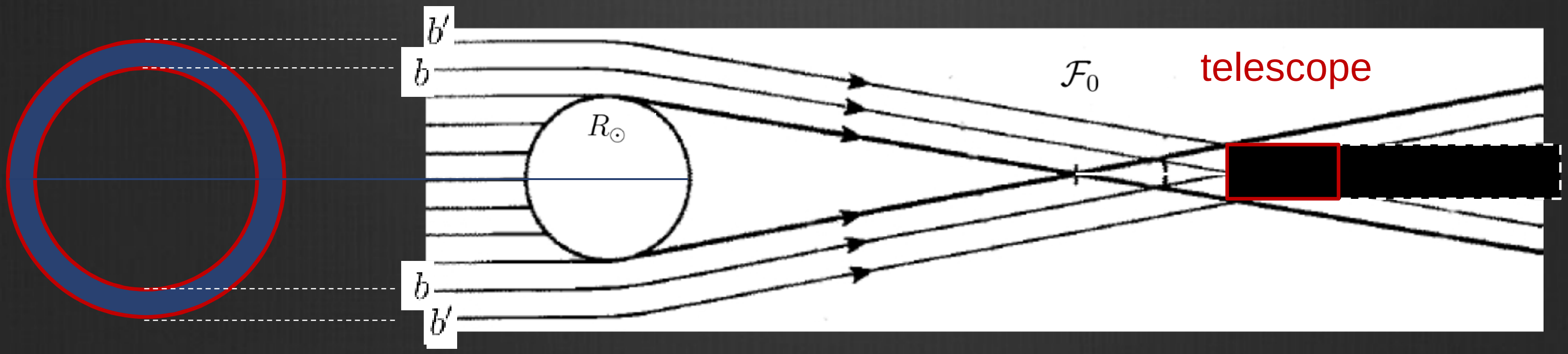
Beautiful reason for a mission to The Solar Gravity Lens

Possible (1000 × 1000) multipixel image of an exo-Earth at ~30 pc away from the Sun with resolution of (3 x 3) km.



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Taking a first step towards another star:

Explore the local environment first!

Reference Mission Goals

Send a spacecraft to the interstellar medium, capable of:

1. Reaching ~200 AU in ~20 years from launch

2. Travelling at high solar system escape velocity (13 AU / Yr.)
    - > 500 AU in 50 years
    - Voyager 1 ~ 3.5 AU/Yr., New Horizons ~2.5 AU/Yr.

3. Survivability
    - Design for 20 years; good to last for 50 years

4. Cost ~ $ 1 Billion or less (Team-X cost estimates)
    - Excluding launch vehicle and phase E cost

5. Fit on an SLS Block 1B

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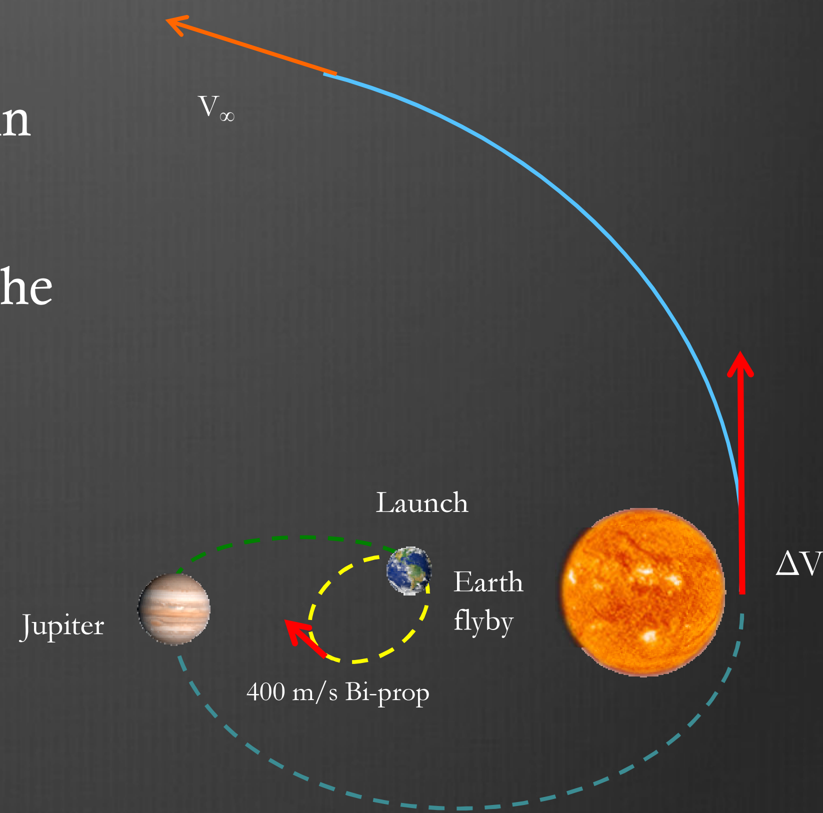
Mission Overview

- A reference mission was designed between the two KISS workshops, in conjunction with Team-X (JPL)
- KBO flyby was not considered for the Team-X design. Simpler problem.

Options	Launch energy ($C3$, km^2/s^2)	Launch mass (Metric Ton)
E-J-Sun-Escape	116	7.3
E-ΔV-E-J-Sun-Escape	47.3	16.8



Enabling Features:

- Perihelion burn provides breakthrough escape velocity of > 13 AU/Yr.
- Low launch C3 ‘banks’ delta-V for use at perihelion
- Launch on a near term SLS-1B

Mission Design Overview

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1.a Launch V_∞ = 6.875 km/sec
1.b Launch Date = Feb-19-2027

2.a DSM date = Dec-27-2028
2.b DSM ΔV = ~0.4 km/sec
2.c Post DSM Earth Flyby date = Jan-12-2030

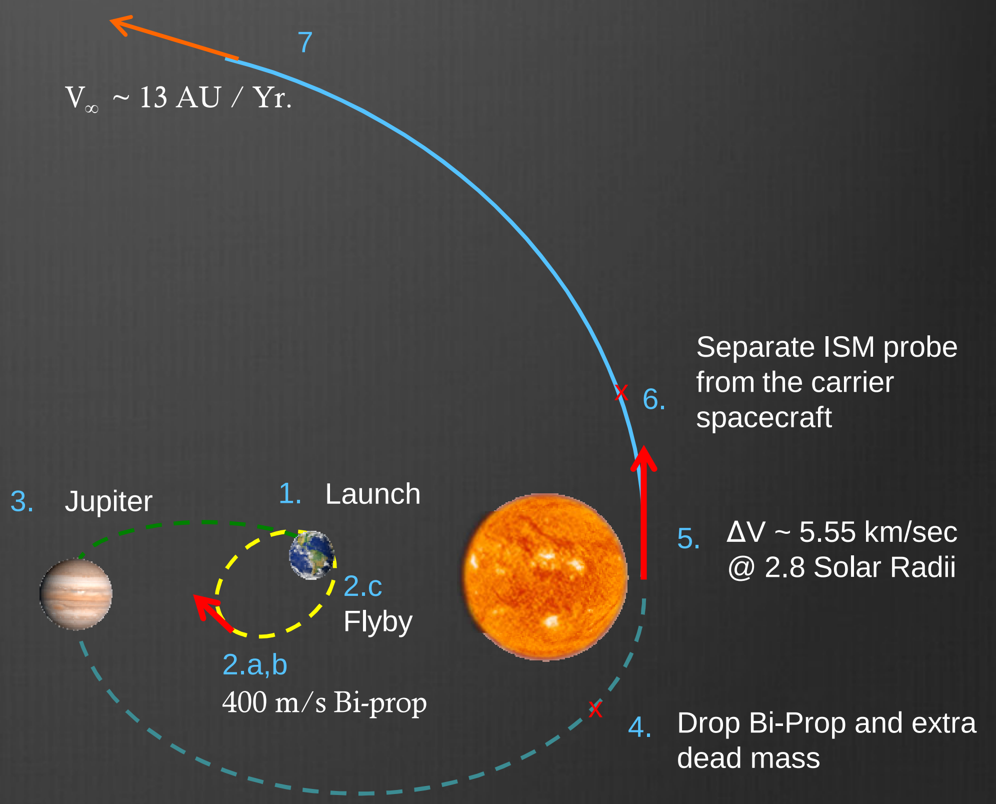
3.a Jupiter Arrival date = July-15-2031
3.b Jupiter Flyby alt. (km) = 621781
3.c Jupiter Flyby V_∞ (km/s) = 12.01

4.a Drop Bi-prop stage and associated mass
4.b Drop off distance = before perihelion

5.a Solar Encounter date = June-22-2033
5.b Perihelion distance = 2.8 solar radii
5.c SRM ΔV (km/s) = ~5.55
5.d Time from launch to perihelion= ~6.34 yrs.

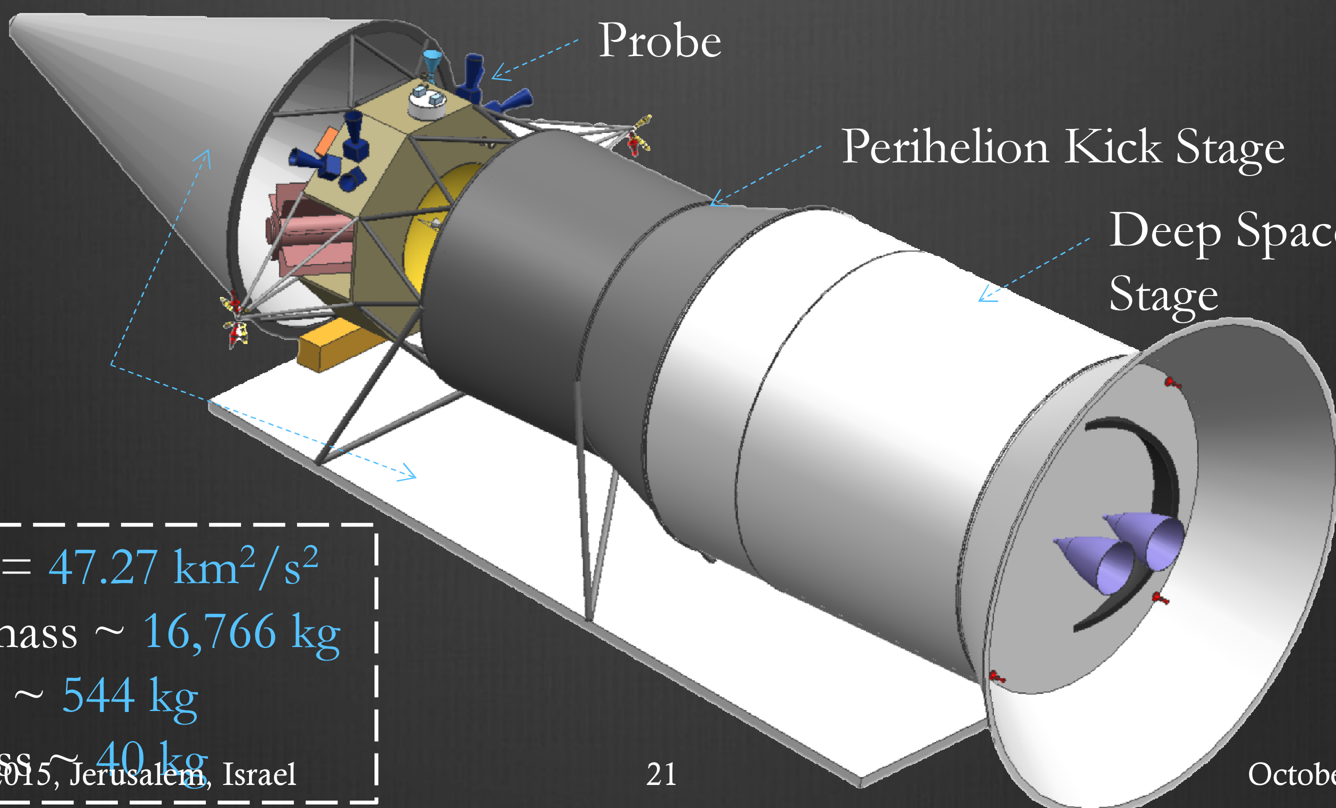
6.a Distance from Sun = 1 AU
6.b Separate ISM probe

7.a Solar system escape V_∞ =~13 AU/Yr. (~62 km/s)
7.b Time to 200 AU = ~21.5 Years



Spacecraft Overview

One probe with a single solid rocket motor "Perihelion Kick Stage" and another bi-propellant "Deep Space Maneuver" stage for ~500m/s of Delta-V prior to the perihelion burn.

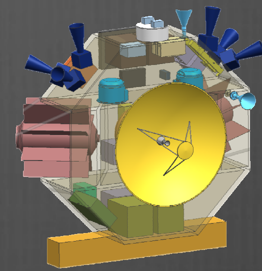


Launch C3 = $47.27\ km^2/s^2$
Total S/C mass ~ 16,766 kg
Probe mass ~ 544 kg
Payload mass ~ 40 kg

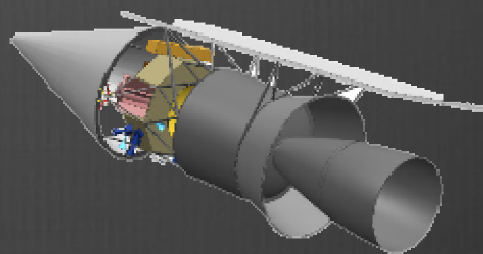
Flight System Elements

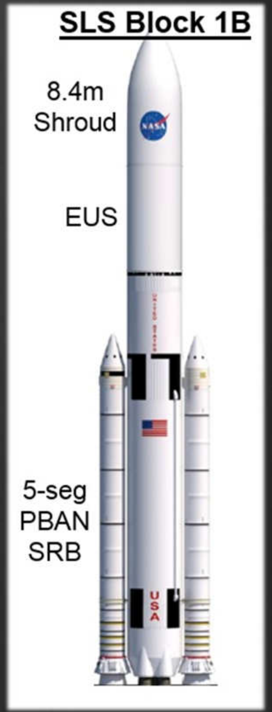
Three Stages

1. ISM Probe
   - Spinner
   - Big ACS (22N and 0.9N thrusters)
   - ~500 KG

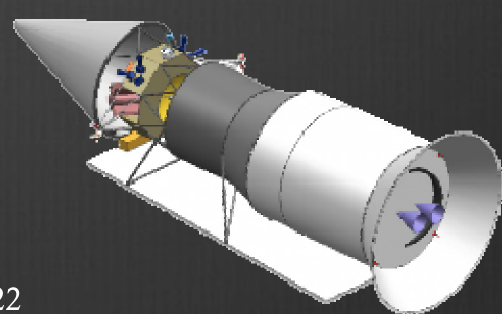


2. Perihelion Kick Stage
   - 3 axis stabilized
   - Heat shield
   - Truss and support structure
   - SRM (deployed)





3. Deep Space Maneuver stage
   - 3 axis stabilized
   - Bi-Prop system
   - Load bearing structure (one of the mass and cost drivers)



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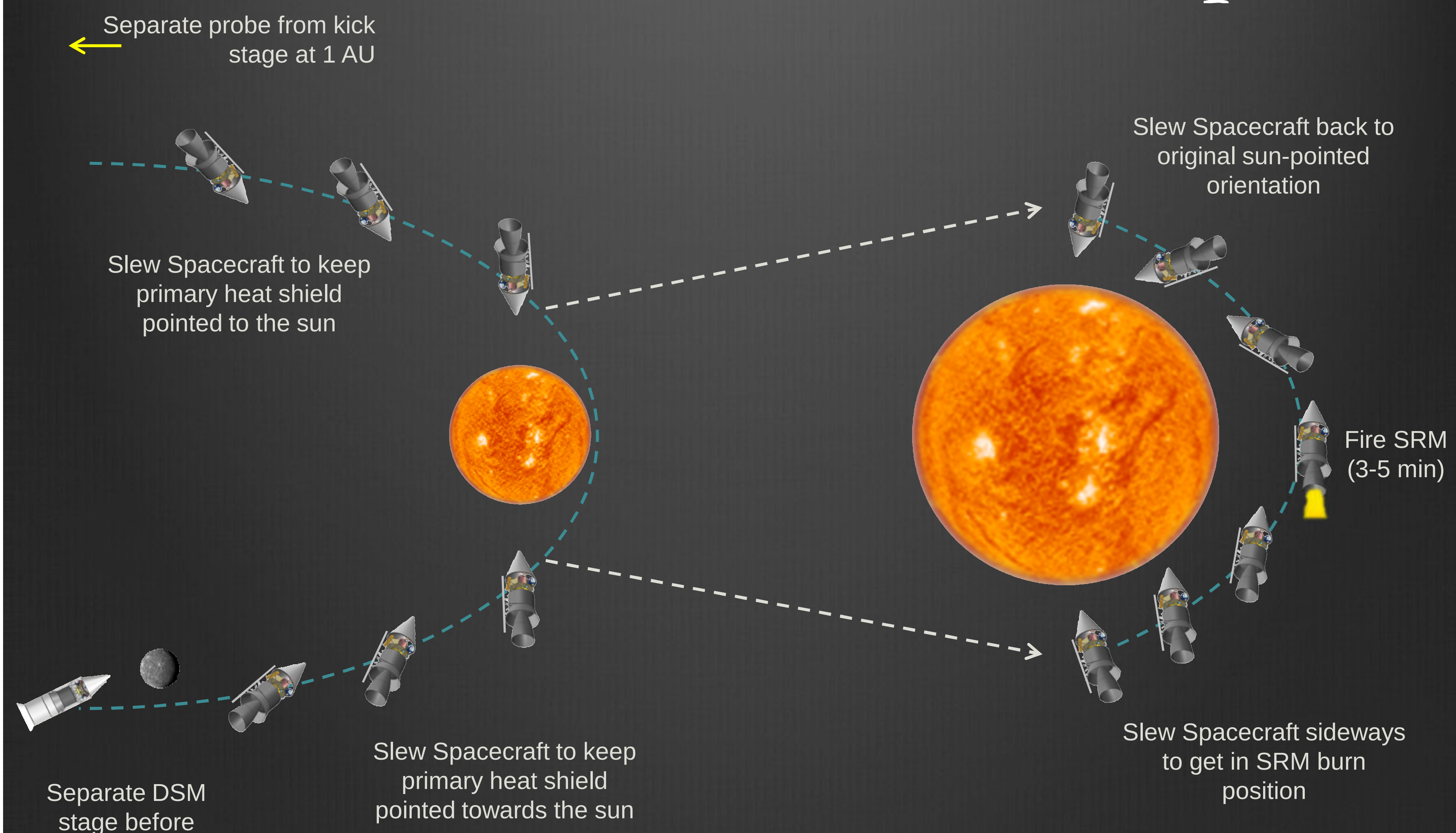
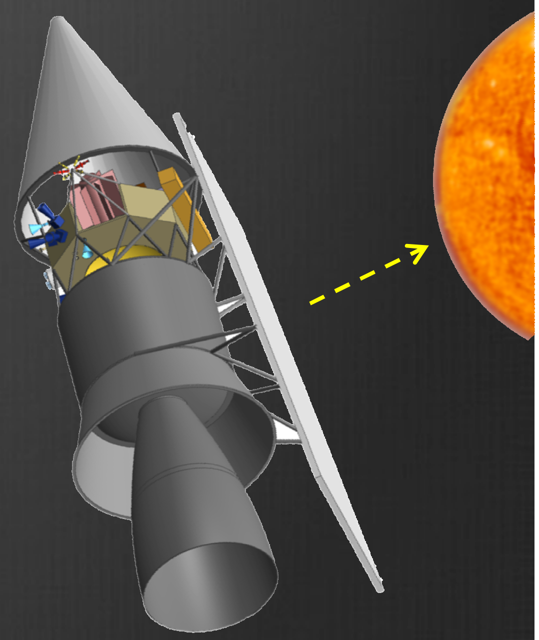
Solar Encounter Con-Ops



Enabling Technologies for Ref. Mission

- Thermal protection system for low solar perihelion burn
- Vector + extended nozzle Star or hybrid motors
- Multi use Optical Instrument:
  1. Optical Science instrument:
     - KBO Imager at high velocities
     - Zodiacal background science instrument
  2. Optical navigation and communication terminal



- Advanced RTG power source
  - eMMRTG already under development
  - ARTG will be better
- Low power spacecraft systems and operations
- Miniaturized instruments, deployable systems (telecom), autonomy & quick hibernation

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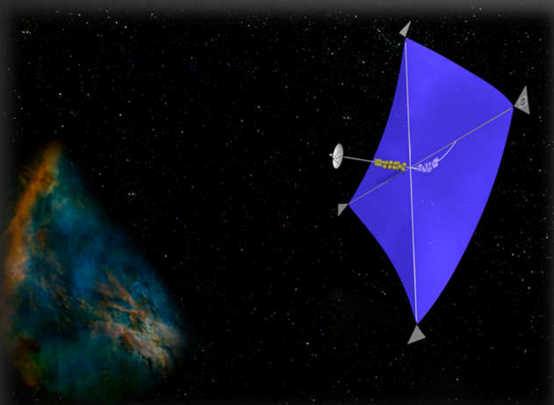
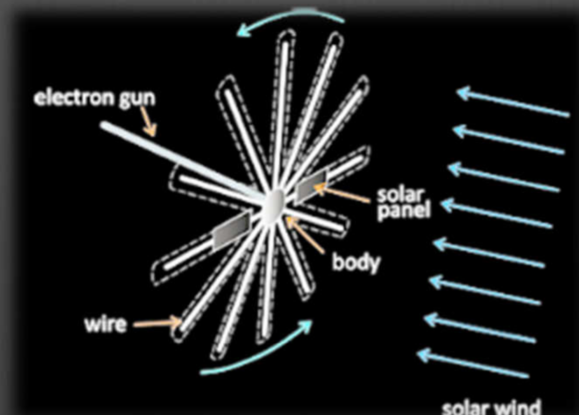
Reaching to another star

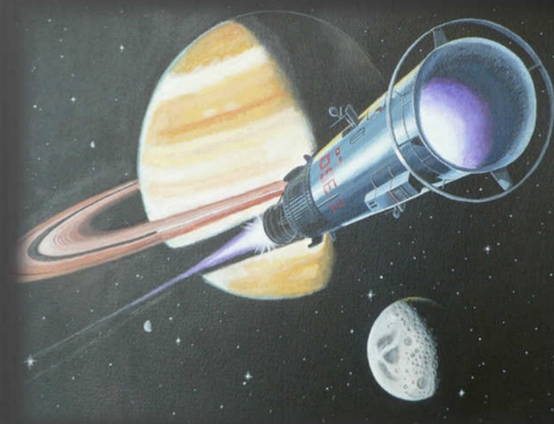
Long Term Technology Options



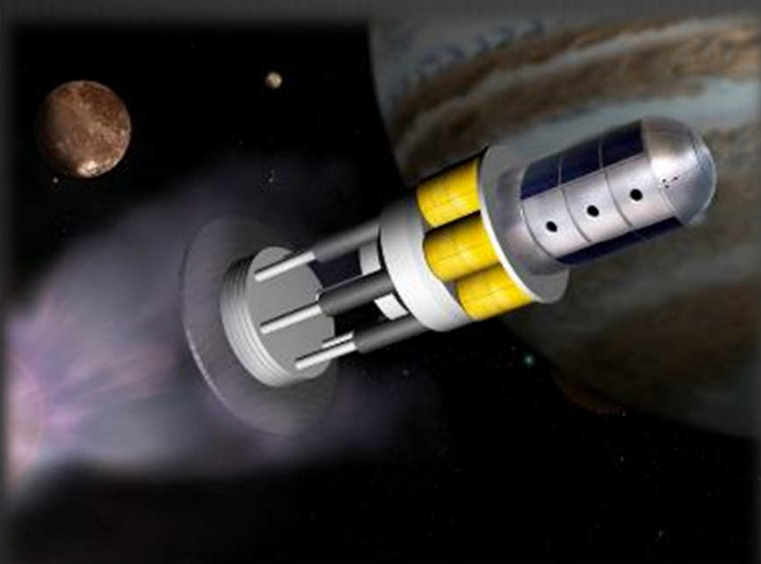
Large solar sails



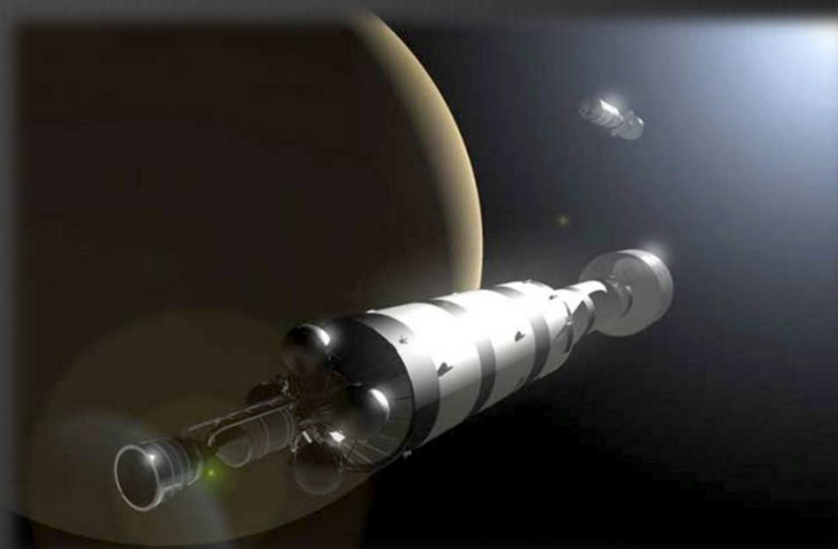
Very Large Electric sails



Laser Beamed Propulsion



Orion (Nuclear Pulsed Propulsion)



Nuclear Thermal Rocket

KISS Workshop final report

"*The Science and Enabling Technologies for the Exploration of the Interstellar Medium (ISM),*" Alkalai L, Arora N, Arya M, Barnes N, Brashears T, Brown M, Cauley P W, Cesarone R J, Dyson F, Friedman L, Garber D, Goldsmith P, Jemison M, Johnson L, Liewer P, Lubin P, Maccone C, Males J, McDonough K, McNutt R L J, Mewaldt R, Michael A, Montgomery E, Opher M, Provornikova E, Rankin J, Redfield S, Shao M, Shotwell R, Strange N, Stone E, Svitek T, Swain M, Turyshev S, Werner M and Zank G P.

2015 Keck Institute for Space Studies, 30 Sept. 2015. Web.

1 Great Study Team

KISS Workshop Study Members

Nitin Arora (JPL), Manan Arya (Caltech), Nathan Barnes (L. Garde Inc.), Travis Brashears (UC Santa Barbara), Mike Brown (Caltech), Paul Wilson Cauley (Wesleyan University), Robert J. Cesarone (JPL), Freeman Dyson (Institute for Advanced Study), Darren Garber (NXTRAC), Paul Goldsmith (JPL), Mae Jemison (100 Year Starship), Les Johnson (NASA-MSFC), Paulett Liewer (JPL), Philip Lubin (UC Santa Barbara), Claudio Maccone (IAA), Jared Males (University of Arizona), Kyle McDonough (UC Santa Barbara), Ralph L. McNutt, Jr. (JHU/APL), Richard Mewaldt (Caltech), Adam Michael (Boston University), Edward Montgomery (Space and Missile Defense Command), Merav Opher (Boston University), Elena Provornikova (Catholic University of America), Jamie Rankin (Caltech), Seth Redfield (Wesleyan University), Michael Shao (JPL), Robert Shotwell (JPL), Nathan Strange (JPL), Thomas Svitek (Stellar Exploration, Inc.), Mark Swain (JPL), Slava Turyshev (JPL), Michael Werner (JPL), Gary Zank (University of Alabama)

Further Information about KISS

- http://kiss.caltech.edu/
- Sign up to get monthly updates of current KISS events
- Michele Judd, Managing Director
- Tom Prince, Center Director

3 Study Leads: Campus/JPL/TPS

Public Lecture at Beckman Auditorium (~ 600 attendees) generates exciting *Interstellar Conversation*

September 9, 2015

562 Lecture Attendees

Recent Related Studies

- "Key Technologies to enable near-term interstellar scientific precursor missions", Claudio Bruno, Gregory Matloff, Editors, IAA, January 2013.
- P. C. Liewer, R. A. Mewaldt, J. A. Ayon, C. Gamer, S. Gavit, and R. A. Wallace, "Interstellar probe using a solar sail: Conceptual design and technological challenges," *COSPAR Colloquium on The Outer Heliosphere: The Next Frontiers COSPAR Colloquia Series*, Vol. 11, 2001, pp. 411–420.
- "Deep-Space Probes To the Outer Solar System and Beyond", Gregory L. Matloff, 2005, Springer-Verlag.
- R. L. McNutt Jr, R. E. Gold, T. Krimigis, E. C. Roelof, M. Gruntman, G. Gloeckler, P. L. Koehn, W. S. Kurth, S. R. Oleson, D. I. Fiehler, et al., "Innovative interstellar explorer," 2006.
- L. Johnson and S. Leifer,"Propulsion options for interstellar exploration,"*AIAA Paper*,Vol.3334, 2000.
- L. Alkalai and N. Arora, "The Interstellar Medium (ISM) the Next Frontier in Space Science and Exploration," *IAA Symposium on the Future of Space Exploration*, Torino, Italy, July 2015.
- N. Arora, N. Strange and L. Alkalai, "Trajectories for a Near Term Mission to the Interstellar Medium", AIAA/AAS Astrodynamics Specialist Conference, Vail, CO 2015.
- R. L. McNutt Jr, M. S. Elsperman, M. Gruntman, K. K. Klaus, S. M. Krimigis, and e. a. E. C. Roelof, "Enabling Insterstellar Probe with the Space Launch System (SLS)," 2014.
- R. F. Wimmer-Schweingruber, R. L. McNutt Jr, *et al.*, "The Interstellar Heliopause Probe/Heliospheric Explorer: IHP/HEX," *Twelfth International Solar Wind Conference*, Vol. 1216, AIP Publishing, 2010, pp. 655–658.
- R. McNutt, G. Andrews, J. McAdams, R. Gold, A. Santo, D. Oursler, K. Heeres, M. Fraeman, and B. Williams, "Low-cost interstellar probe," *Acta Astronautica,* vol. 52, pp. 267-279, 2003.

Thank you !

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