Keck

INSTITUTE FOR SPACE STUDIES

CALIFORNIA INSTITUTE OF TECHNOLOGY
JET PROPULSION LABORATORY

# Previous ISM Mission Studies


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Monday, September 8, 2014
Hameetman Auditorium – Cahill
California Institute of Technology
11:30 – 12:00

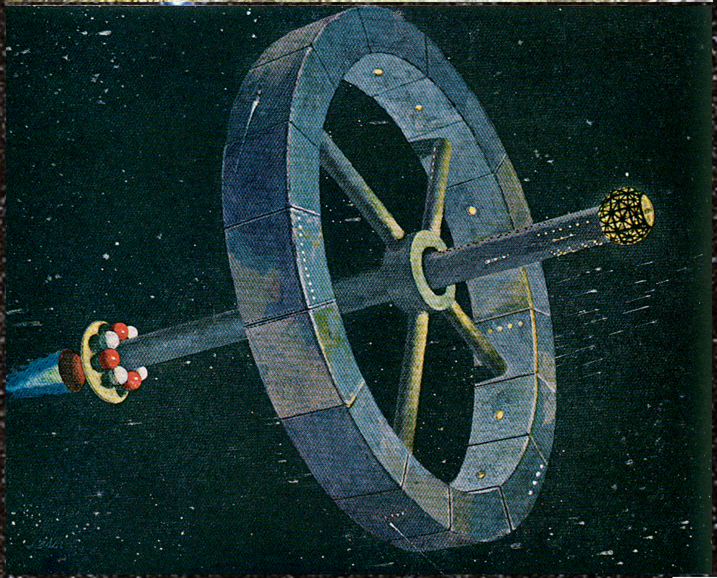

APL
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY
11100 Johns Hopkins Road, Laurel, MD 20723-6099

# This is *not* about "Interstellar Travel" ("Atlantic mode")

- Robert Goddard's "Great Migration" (14 January 1918)
- F. A. Tsander "Flights to Other Planets and to the Moon"
  - XIII. Slowing of life and possibility of returning to earth alive after millions of years, by flying at velocity near the speed of light, according to Einstein's theory of relativity. Possibility of flying through all of interstellar space. – notes 1920s
- Relativistic rocket mechanics, J. ACKERET, Zur Theorie der Rakete. Helvet. Physica Acta 19, 103 (1946)
- Photon rockets E. SANGER, Zur Flugmechanik der Photonenraketen. Astronaut. Acta 3,89 (1957). - Die Erreichbarkeit der Fixsterne. Proceedings of the VIIth International Astronautical Congress, Rome 1956. Roma: Associazione Italian a Razzi, 1956. - Zur Mechanik der Photonen-Strahlantriebe. Mtinchen: R. Oldenbourg, 1956.
- Reaching the nearer stars (<25 light years) W. PESCHKA,Über die tiberbrtickung interstellarer Entfernungen. Astronaut. Acta 2, 191 (1956).
- Interstellar fusion ramjets, R. W . BUSSARD, Galactic Matter and Interstellar Flight. Astronaut. Acta 6, 179 (1960).
- Ultimate limits, S. V. HOERNER, The General Limits of Space Travel. Science 187, 18 (1962).

# Or Colonization (!) ("Polynesian mode")

- J. D. Bernal "The World, The Flesh, and The Devil" (1929), Dandridge M. Cole and Roy G. Scarfo "Betond Tomorrow: The Next 50 Years in Space" (1965), Isaac Asimiov "How Far Will We Go in Space?" (1966)
- Stephen H. Dole "Habitable Panets for Man" (1964)
- "Interstellar Communication" A. G. W. Cameron, ed. (1963)
- "A Program for Interstellar Exploration" Robert L. Forward (1976)

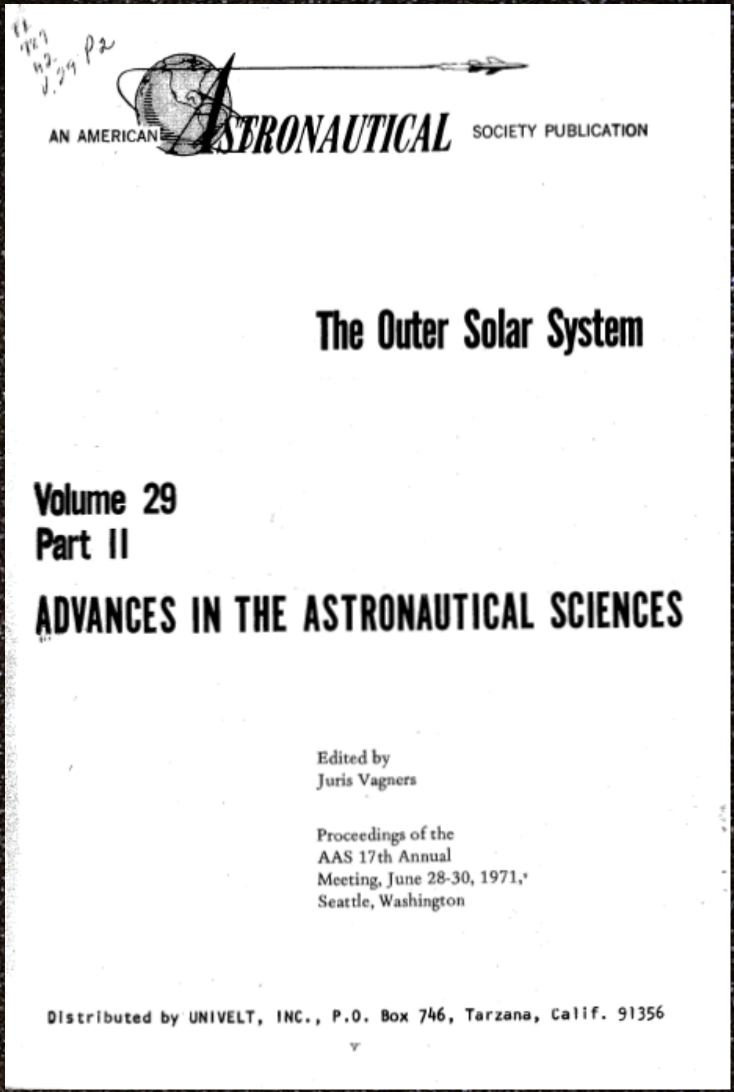


# 17th AAS Meetinng in Seattle, Washington, 28 – 30 June 1971

- **Scientific and technical bases for solar system escape missions were discussed**

THE FIRST STEP BEYOND THE SOLAR SYSTEM
A. J. Dessler
R. A. Park

The forthcoming flights of Pioneers F and G will see the launch from earth of the first spacecraft to leave the solar system. In this paper, we describe the solar wind and how it forms a region of interplanetary space called the heliosphere. There is little known about how (or even where) the solar wind interacts with the local interstellar medium. Our understanding of the plasma/magnetic-field interaction between the solar wind and insterstellar medium will be placed on a definitive basis by information obtained by the spacecraft that obtain data from penetration of the interaction region.


AN AMERICAN ASTRONAUTICAL SOCIETY PUBLICATION

The Outer Solar System

Volume 29
Part II

ADVANCES IN THE ASTRONAUTICAL SCIENCES

Edited by
Juris Vagners

Proceedings of the
AAS 17th Annual
Meeting, June 28-30, 1971,
Seattle, Washington

Distributed by UNIVELT, INC., P.O. Box 746, Tarzana, Calif. 91356

# The "Heliosphere" Defined (Dessler)

- "The solar wind will push aside the local interstellar medium. However as first noted as early as 1955[3] the solar-wind streaming pressure which decreases as $1/r^2$ , should become too weak to push aside the interstellar medium beyond some critical distance $r_h$. At this distance the solar wind should go through a shock transition[4] and slow to subsonic speeds before merging with the interstellar medium. where the solar wind is streaming supersonically is called the heliosphere[5]."


3. L. Davis, Jr., "Interplanetary Magnetic Fields and Cosmic Rays," Phys. Rev., vol. 100, 1955pp. 1440-1444
4. F. H. Clauser, "The Aerodynamics of Mass Loss and Mass of Stars," Laboratory Report, AFOSR TN 60-1386, The Johns Hopkins University, 1960
5. A. J. Dessler, "Solar Wind and Interplanetary Magnetic Field," Rev. Geophys., vol. 5, 1967 pp. 1-41

# Heliosphere Concept (1971)

A possible interaction configuration is sketched in Fig. 2. The subsonic plasma beyond the shock forms a boundary shell. Behond this shell lies the interstellar medium.

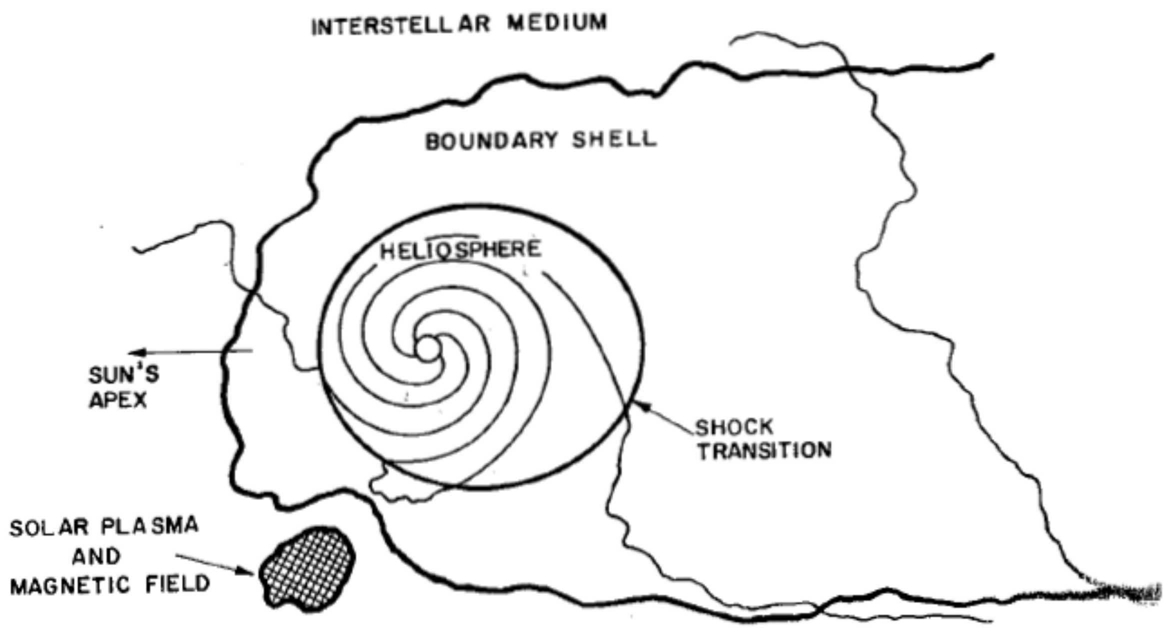



Fig. 2 Illustrative Sketch Showing Possible Interaction Between Interplanetary Medium (the Heliosphere) and the Interstellar Medium

- From Dessler and Park (1971)

# The "Grand Tour" was the grand motivator for thinking about the interstellar medium …

- **Starting with Gary Flandro in 1966 and the Grand Tour trajectories**

California Institute of Technology, Pasadena, Calif., U.S.A.

**Fast Reconnaissance Missions to the Outer Solar System Utilizing Energy Derived from the Gravitational Field of Jupiter[1]**

By

G. A. Flandro

With 16 Figures

*(Received April 18, 1966)*

- **The notion was extended to solar system escape and was articulated by Sergeyevsky in 1971**

The available spectrum of solar system escape trajectories, resulting from the 1977 Jupiter-Saturn-Pluto and 1979 Jupiter-Uranus-Neptune Grand Tour Missions, continued beyond the terminal planet is described in a parametric form …. The results indicate that the Grand Tour voyages could be so targeted as to escape solar space in a direction into the onrushing Galactic wind, with due regard for other mission objectives. As long as the spacecraft systems function, they could sample data on the properties of the outskirts of the solar system and their intercactions with the interstellar medium.

Early Solar System Escape Missions – An Epilogue to the Grand Tours , Paper AAS81 - 383

# Unlike Pioneer 10 and 11 trajectories, the direction of Grand Tour spacecraft would be good for such studies

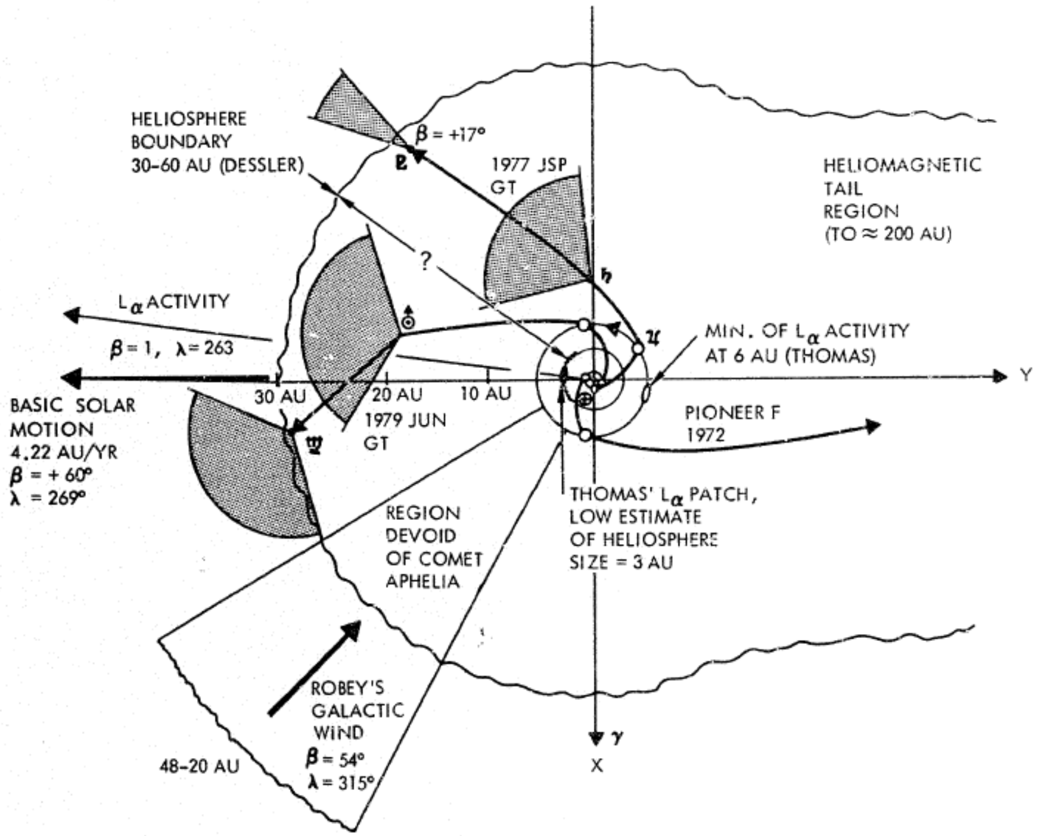



Figure 2. Heliosphere and Grand Tour Missions in an Ecliptic Projection

- "The immediate conclusion is solely that Grand Tour spacecraft escape into the forward part of the heliosphere is not only possible, but unavoidable, whereas, as pointed out in Reference 9 [], the earlier Pioneer F and G spacecraft are denied this opportunity (Figure 2) by their trajectory orientation, , a consequence of their departure in the early 1970's." [remedied for Pioneer 11 by its retrograde encounter with Juputer and subsequent flyby of Neptune]

9. A. J. Dessler, R. A. Park, The First Step Beyond the Solar System, Rice University, Houston, Texas, and TRW Systems Group, Redondo Beach, Calif., AAS 71-165, AAS 17th Annual Meeting, Seattle Wash., 1971.

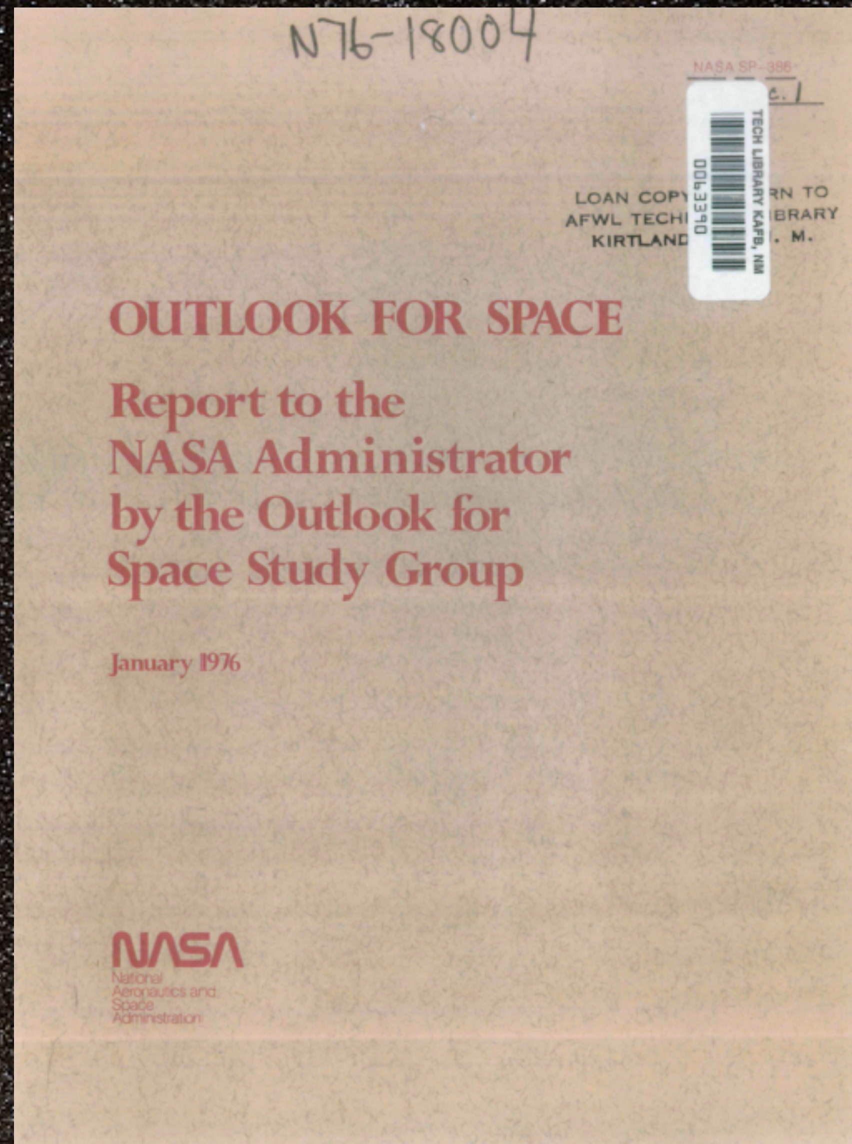
# Other discussions at the 1971 meeting

- THE SCIENTIFIC EXPLORATION OF NEAR STELLAR SYSTEMS
  - J . L. Archer and A. J. O'Donnell
- SCIENTIFIC GOALS OF MISSIONS BEYOND THE SOLAR SYSTEM
  - L.G. Despain, J.P. Rennest, and J . L. Archer
- THE ULTRAPLANETARY PROBE
  - Krafft A. Ehricke
- EXTENDED LIFETIME DESIGN IN RADIOISOTOPE THERMOELECTRIC GENERATORS
  - H. Jaffe and P. A. O'Riordan

# *Outlook for Space (January 1976)*

- **By 1976 A “modest” proposal had been incorporated in the massive NASA *Outlook for Space* report**

- **Item 1069:**
- **Small spacecraft with particles-and-fields instrumentation launched in 1980 by Titan-Centaur plus high-performance upper stages on a trajectory escaping solar system in general direction of solar apex. If mission launched in late 80's, electric propulsion, solar sailing, and/or Jupiter swingby could be used to reduce transit time to heliospheric boundary. Mission duration ten years or more.**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OUTLOOK FOR SPACE

Report to the
NASA Administrator
by the Outlook for
Space Study Group

January 1976

NASA
National
Aeronautics and
Space
Administration

# JPL "Ghost Conference" (August 1976)

- Perhaps motivated by this study an activity was appatently held at JPL in August 1976
- From Jaffe and Ivie (1979):
- "In a conference on "Missions Beyond the Solar System," organized by L. D. Friedman and held at the Jet Propulsion Laboratory in August 1976, the idea of a "precursor" mission out beyond the planets of the solar system, but not nearly to another star, was suggested as a means of elucidating and solving the engineering problems that would be faced in an interstellar mission. At the same time, it was recognized that such a precursor mission, even if aimed primarily at engineering objectives, could also have significant scientific objectives."
- While this connection is oft repeated in the literature, no other record of this "conference" has been found

# The 1976 – 1977 JPL effort had a significant science driver

ICARUS 39, 486–494 (1979)

## Science Aspects of a Mission Beyond the Planets

LEONARD D. JAFFE AND CHARLES V. IVIE

*Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California 91103*

Received July 26, 1978; revised April 10, 1979

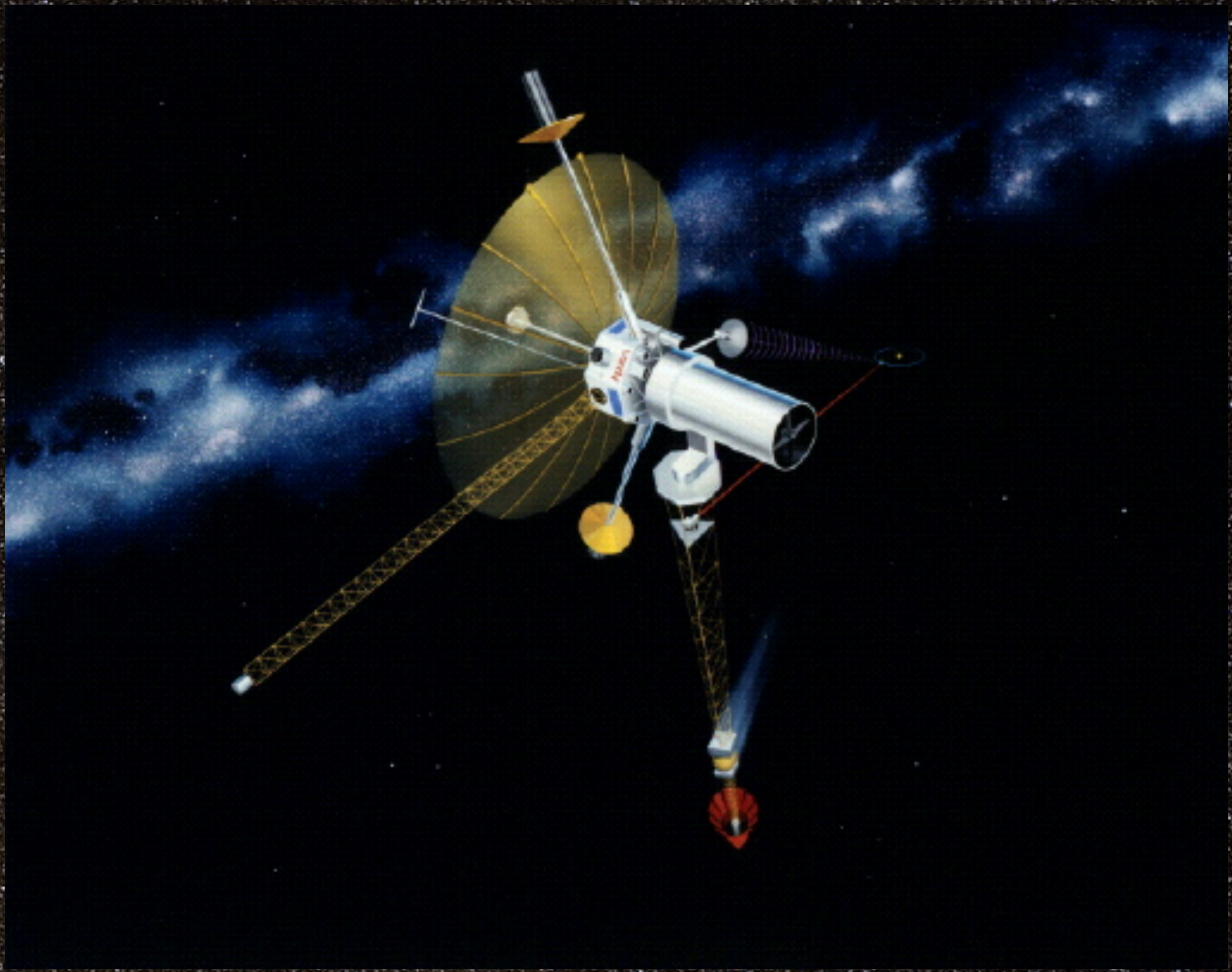
A mission out of the planetary system, launched about the year 2000, could provide valuable data concerning characteristics of the heliopause, the interstellar medium, stellar distances (by parallax measurements), low-energy cosmic rays, interplanetary gas distribution, and mass of the solar system. Secondary objectives include investigation of Pluto. Candidate science measurements, instruments, and instrument development needs are discussed. The mission should extend from 400 to 1000 AU from the Sun. A heliocentric hyperbolic escape velocity of 50–100 km/sec or more is needed to attain this distance within a reasonable mission duration (20–50 years). The trajectory should be toward the incoming interstellar gas. For a year 2000 launch, a Pluto encounter and orbiter can be included. A second mission targeted parallel to the solar axis would also be worthwhile.

# *Subsequent study details are described in JPL Publication 77-70* Interstellar Precursor Mission

- STUDY OBJECTIVE
  - The objective of the study was to establish probable science goals, mission concepts and technology requirements for a mission extending from outer regions of the solar system to interstellar flight. An unmanned mission was intended.
- STUDY SCOPE
  - The study was intended to address science goals, mission concepts, and technology requirements for the portion of the mission outward from the outer portion of the planetary system….
- The report was published 30 October 1977, less than 2 months after the Voyager 1 launch
- Propulsion was *the* issue and a nuclear electric propulsion (NEP) approach was eventually adopted as the baseline

# Large NEP Systems?

- Thousand AU Mission (TAU) (Nock, 1987)
- Nuclear Electric to 1000 AU
  - 1 MWe
  - 12.5 kg/kW specific mass
- 60 mt launch mass
- 10 mt dry mass
- 40 MT Xe
- 1000 AU in 50 years



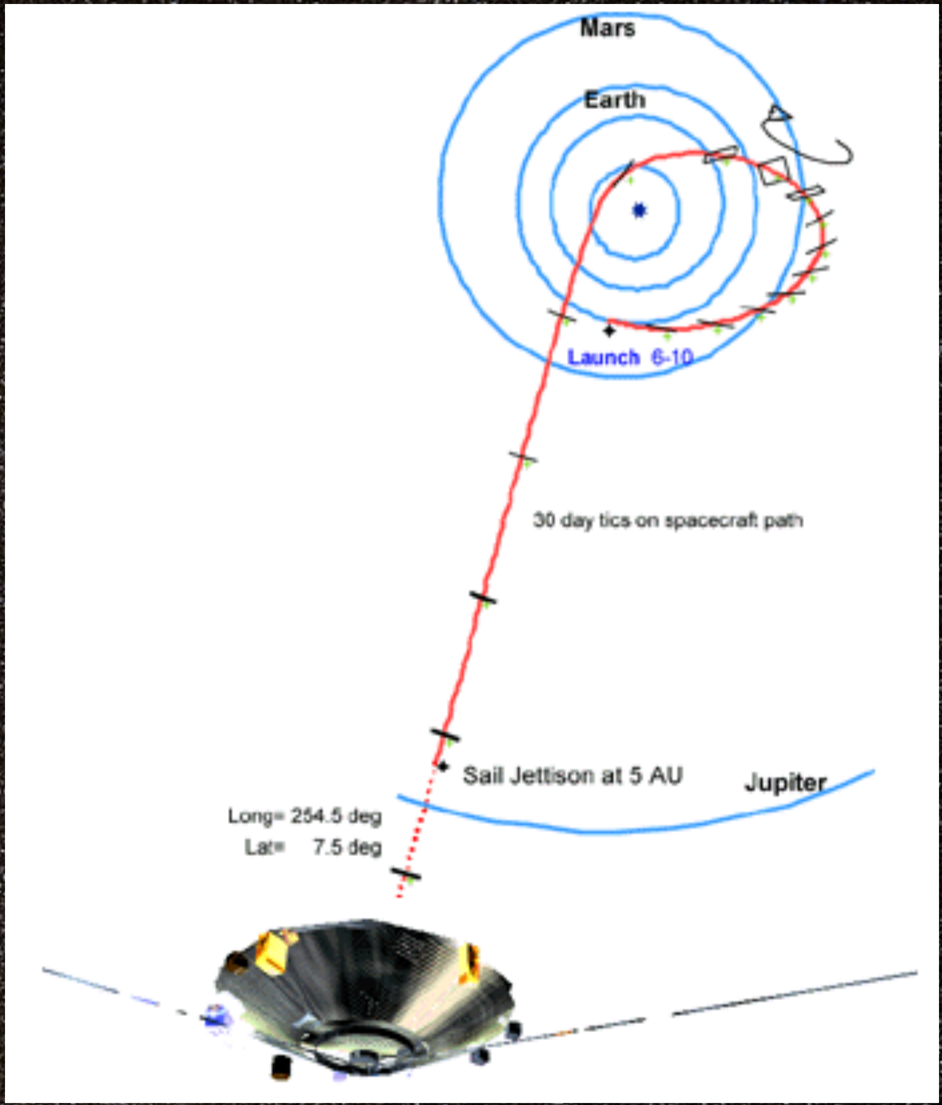
# Or back to small?

- **NASA Interstellar Probe Science and Technology Definition Team (IPSTDT) stood up in 1999 to relook at the precursor "problem"**

**A small spacecraft using a solar sail for propulsion and a near Sun encounter was baselined**

**To 200 AU in 15 years**

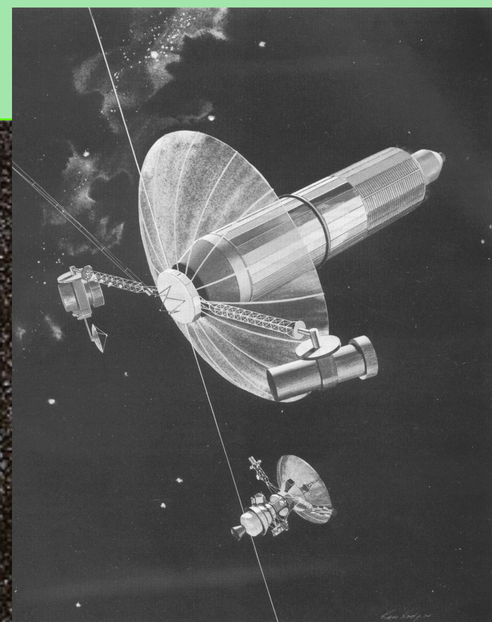
**Payload requirements similar to those of Pioneer 10**



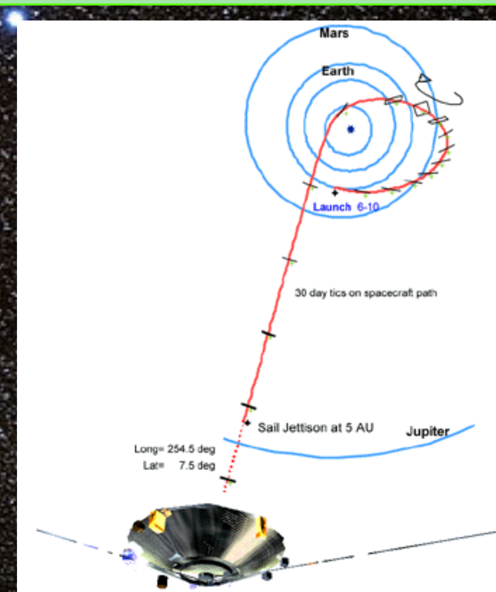
# All Approaches to an Interstellar Probe Mission Need Propulsion Development

- Ballistic (NIAC 2004)
  - optimized launch 20 Feb 2019
  - Jupiter flyby 19 June 2020
  - Perihelion maneuver 4 Nov 2021 at 4 RS
  - 1000 AU 17 Oct 2071
  - 12.16 kg science
  - 1.1 MT

- Nuclear Electric (JPL 1980)
  - 2015 departure 20 years to 200 AU
  - 30 kg science package
  - Bimodal nuclear propulsion
  - 11.4 MT



- Solar Sail (NASA 1999)
  - 200 AU in 15 years
  - Perihelion at 0.25 AU
  - Jettison 400m dia sail at ~5 AU
  - 25 kg science
  - 246 kg



# Radioisotope Electric Propulsion (REP) and Solar Sail Implementatins have been examined in some depth

## REP Implementation (IIE)

TEAM X
Jet Propulsion Laboratory

**ADVANCED PROJECTS DESIGN TEAM**
**INTERSTELLAR EXPLORER VISION MISSION**
**CUSTOMER: RALPH MCNUTT**
**REPORT ID #794**
**LEADER: CHARLES BUDNEY**
**5, 7, 8 APRIL 2005**

The following representatives comprised the study team:

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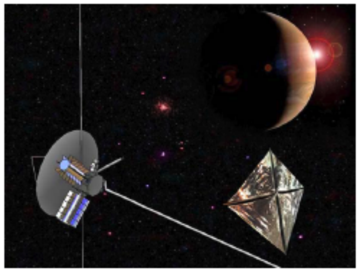
## Solar Sail Implementation (IHP/HEX)

esa

INTERSTELLAR HELIOPAUSE PROBE

**STUDY OVERVIEW OF THE INTERSTELLAR HELIOPAUSE PROBE**



AN ESA TECHNOLOGY REFERENCE STUDY

Planetary Exploration Studies Section (SCI-AP)
Science Payload and Advanced Concepts Office (SCI-A)


| | |
|---|---|
| prepared by/préparé par | A.E. Lyngvi, M.L. van den Berg, P. Falkner |
| reference/réference | SCI-A/2006/114/IHP |
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| Document type/type de document | Public report |

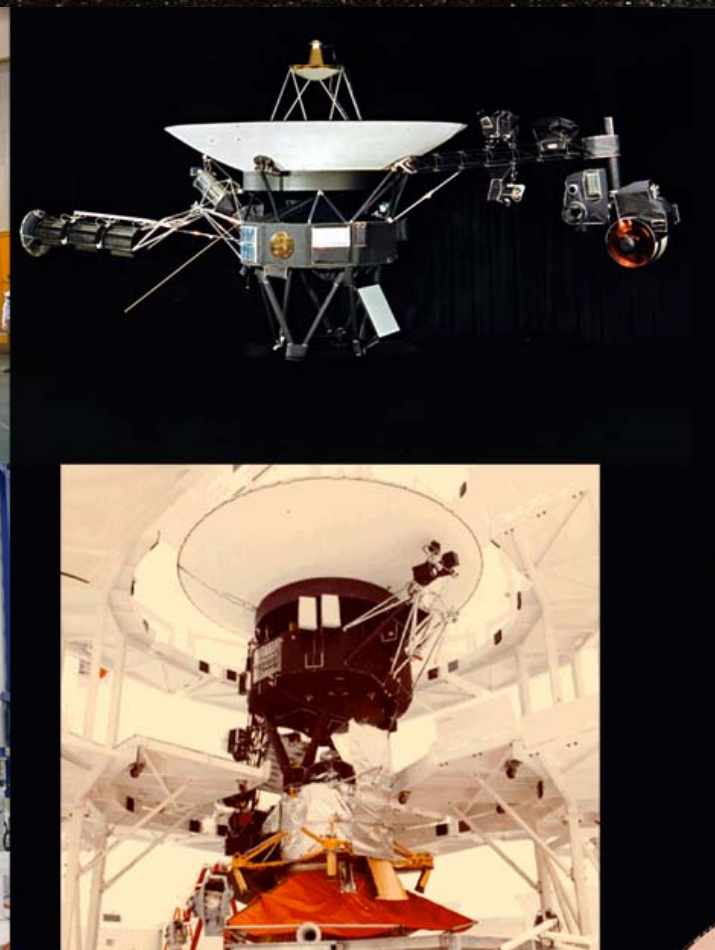


APL

# Historical and Conceptual Solar-System Escaping Spacecraft Are Dominated by High-Gain Antenna

Pioneer 10 and 11 Launched 1972 and 1973

New Horizons Launched 2006



Voyager 1 and 2 Launched 1977

IIE Concept

# Deep-space Spacecraft, Instruments, and Their Mass Fractions

| Spacecraft | Instruments | | Spacecraft (dry) (kg) | Payload mass fraction |
|---|---|---|---|---|
| | Number | Mass (kg) | | % |
| Voyager | 10 | 104.32 | 721.90 | 14.45 |
| Pioneer | 11 | 28.98 | 251.79 | 11.51 |
| New Horizons | 6 | 28.43 | 385.00 | 7.38 |
| Ulysses | 9 | 54.92 | 333.20 | 16.48 |
| IIE | 10 | 35.2 | 516.2 | 6.82 |

**Payload mass fractions are ~10% to 15% of system dry mass**

**The small mass fraction on IIE is driven by ~200 kg of dry mass associated with the REP power and propulsion system.**

# Propulsion "Contenders" Trade
# Technology Readiness Against Flight Time

- **Radioisotope Electric Propulsion (REP)**
  - Near-term technology
  - High-efficiency, low-specific mass radioisotope power supplies (RPS)
  - Work from 1 AU outward
  - Flyout time constrained by hardware

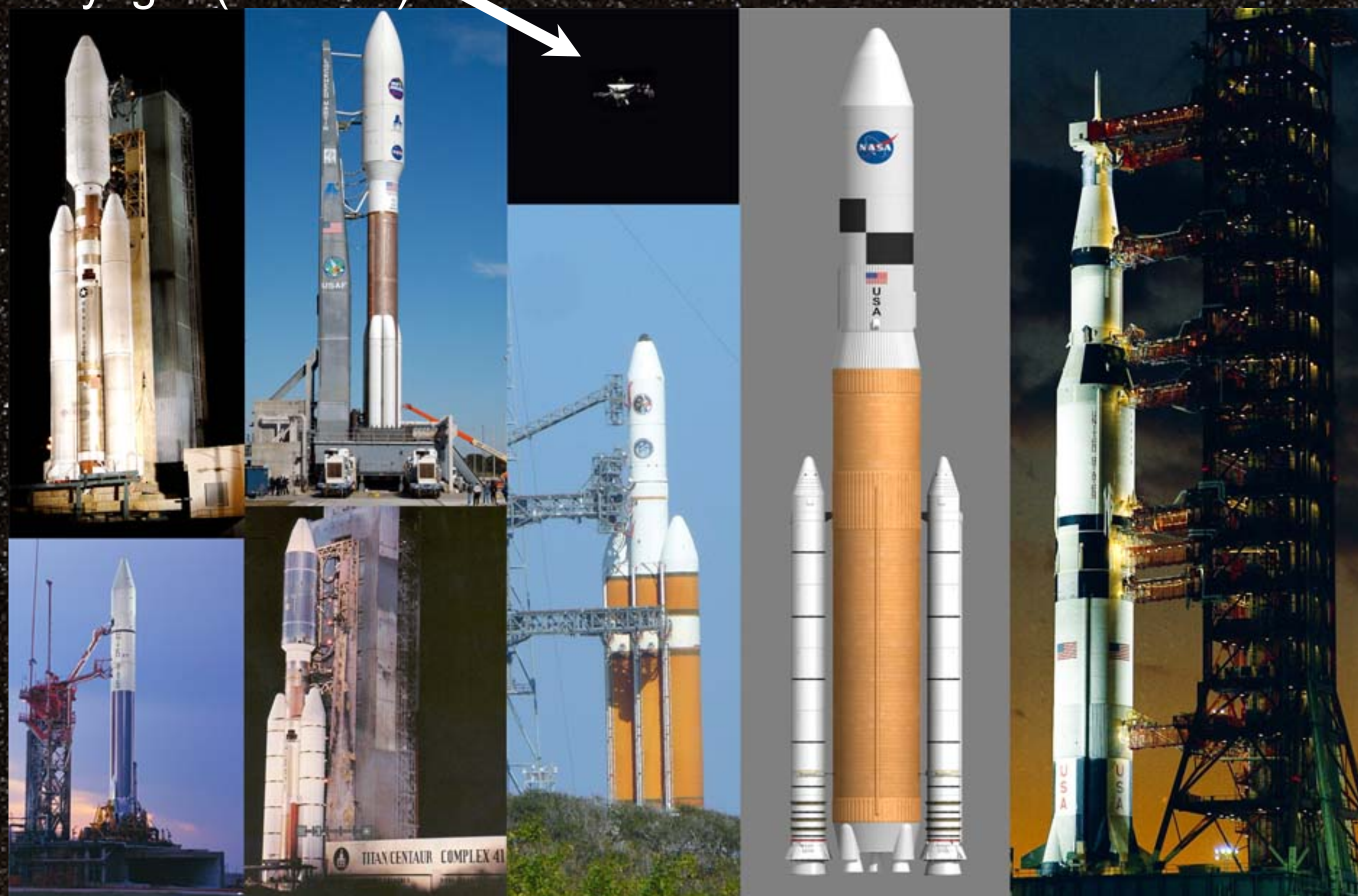
- **Solar Sail (IHP/HEX)**
  - Needs low areal mass density (~1 g $m^{-2}$ or less)
  - Needs to deal with high temperature
  - Work from ~0.25 AU outward
  - Current technology RPS sufficient for power

# *Launch Vehicles: Historical, Operational, Conceptual (to scale)*

Voyager (to scale)

Titan III E Centaur: Voyagers

Atlas Agena: Pioneers




Titan IV Centaur - Cassini

Delta IV Heavy

Ares V Concept

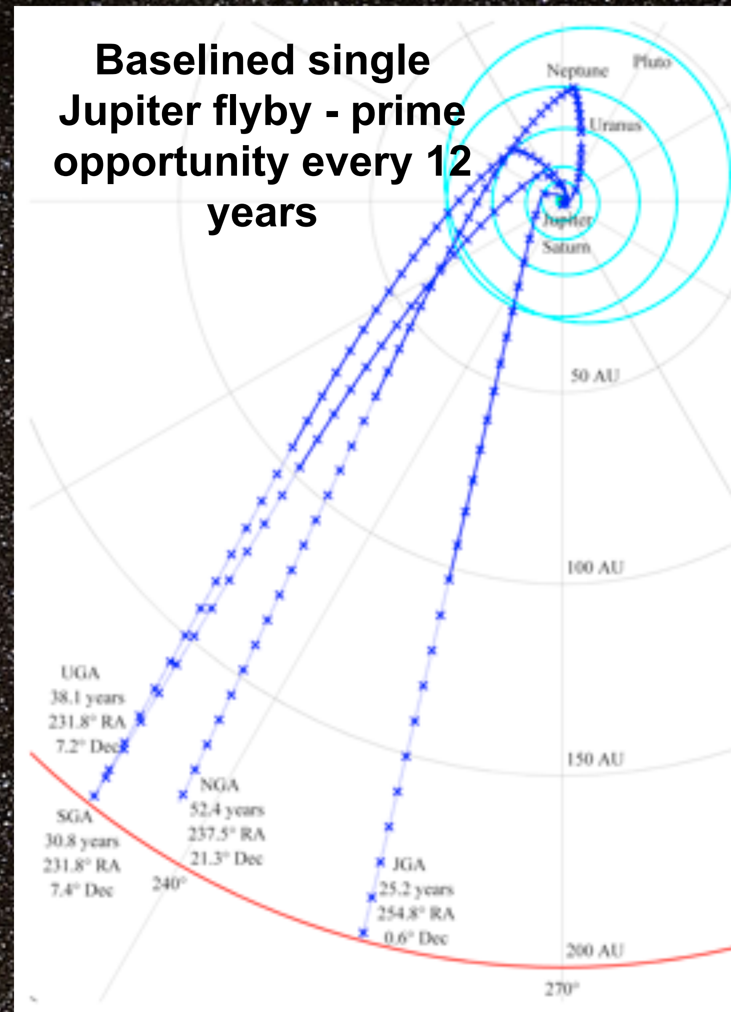
Saturn V with Apollo IV

# *Enablers for ANY Architecture*

- "Affordable" launch vehicle including high-energy stage
- kWe power supply with low specific mass
  - Pu-238 is REQUIRED
- Reliable and sensitive deep, space communications at Ka-band
- Mission operations and data analysis (MO&DA)
  - $10 M per year for 30 years at 3% per annum inflation ~$500M

# "Vision Mission" REP Mission Design Options

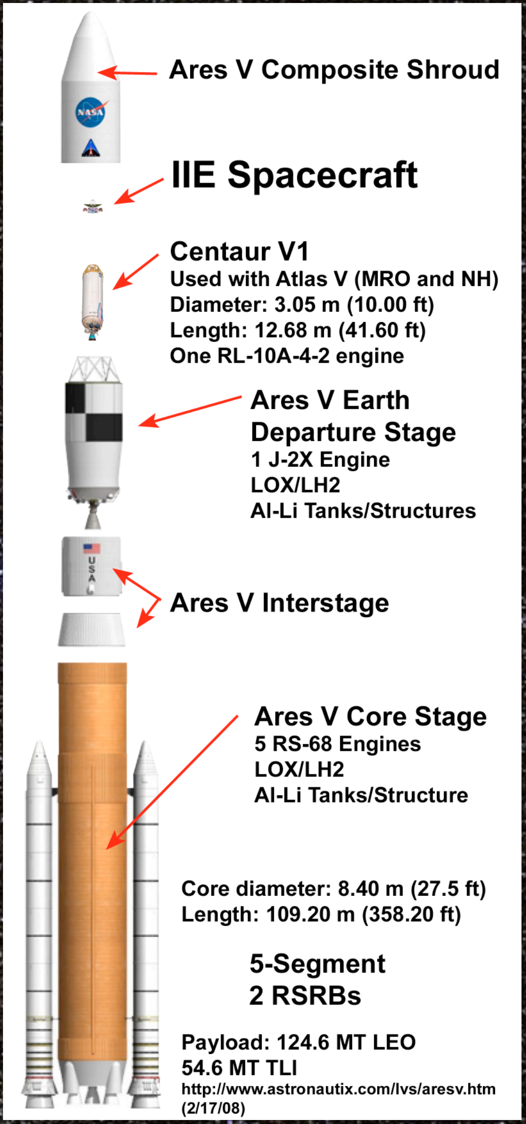
- Various upper stage options for Delta IV H were studied
- Investigated 12 existing and conceptual upper stages
- Final system was too heavy for Star 48 + Star 37 upper "stage"
- Went to a Star 48A "double stack" with custom interfaces



# Assembling the Pieces

- Figure is to approximate scale
- Earth Departure Stage is only partially fueled to optimize launch energy
- First iteration: $C_3$~270 $km^2/s^2$
  - Corresponding asymptotic speed from the solar system is ~19.0 km/s ~ 4 AU/yr
  - New Horizons
    - Launched to 164 $km^2/s^2$
    - Pluto flyby at 13.8 km/s = 2.9 AU/yr
  - Voyager 1 current speed = 3.6 AU/yr
  - Voyager 2 current speed = 3.3 AU/yr
- To reach 9.5 AU/yr (45 km/s) with only a launch from Earth would require $C_3$ = 1,016 $km^2/s^2$
- Even with an Ares V, launch remains only one component

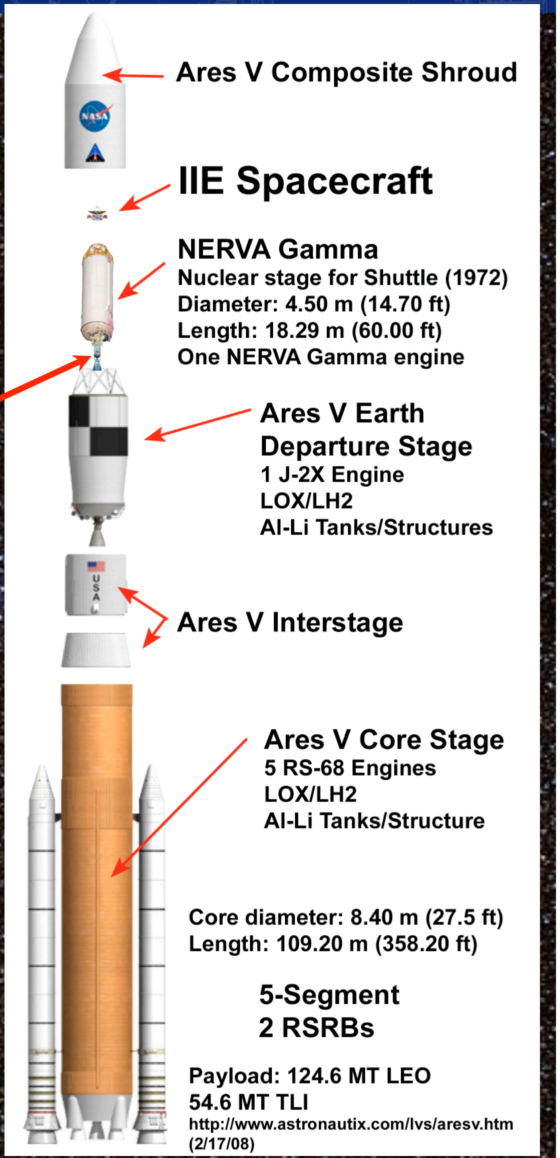
Earth orbital speed = 29.79 km/s; 1 AU/yr = 4.74 km/s



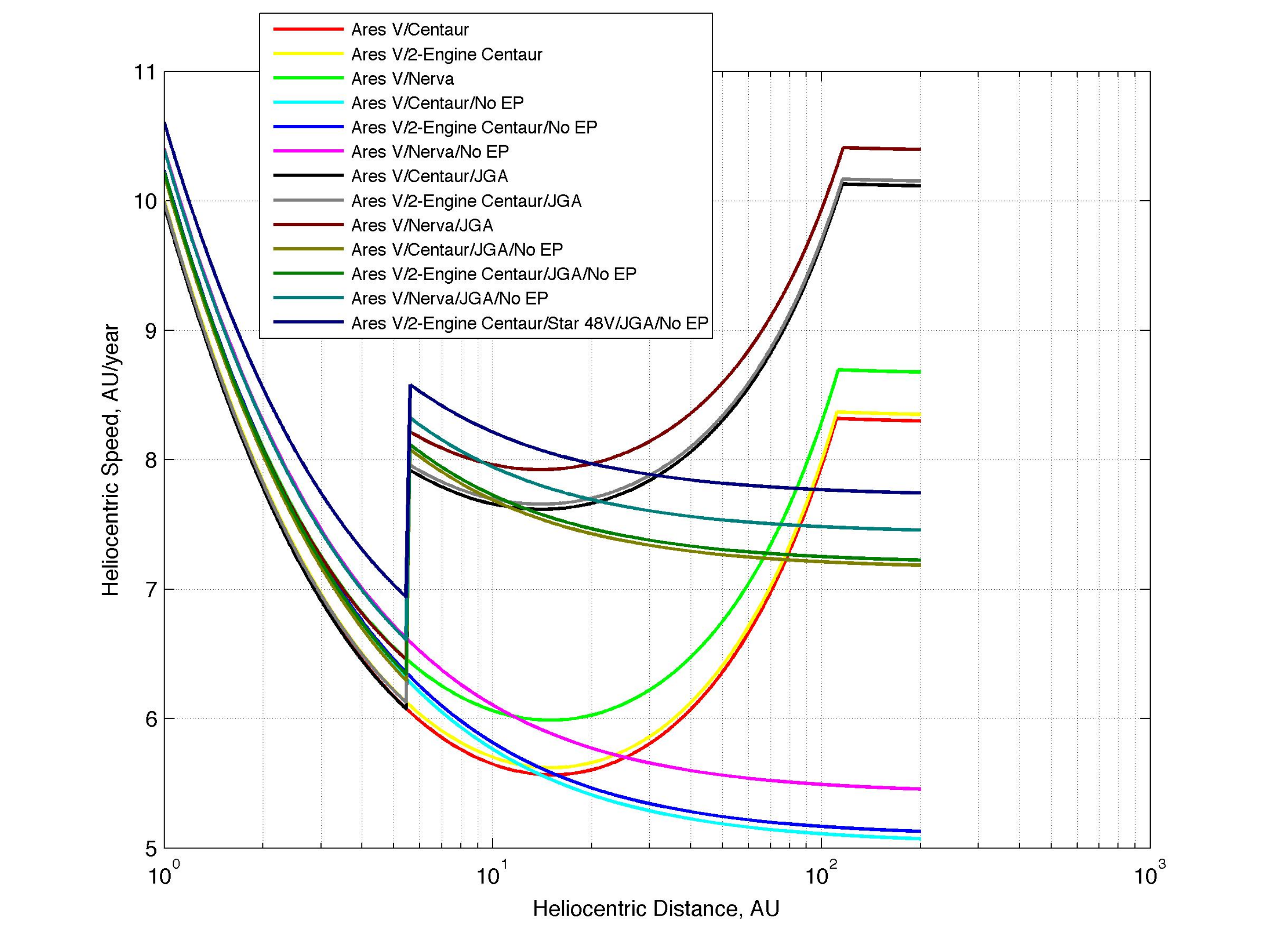
# Nuclear Upper Stage ?

- Nuclear stage advantages
  - More performance than Centaur V1
  - Lower mass
  - Earth escape trajectory
  - Fully flight qualified
- Nuclear stage disadvantages
  - More expensive than Centaur
  - Larger (low LH2 volume)
  - Not solar system escape trajectory
  - Requires development
    - Gamma engine thrust 81 kN (18,209 lbf)
    - BNTR engine thrust 66.7 kN (15,000 lbf)
    - 3 BNTR's baselined for Mars DRM 4.0 of 1999
- Nuclear Earth Departure Stage not acceptable
  - Not Earth-escape trajectory
  - Comparable thrust engine to NERVA 2
    - 867.4 kN (195 klbf)
    - Stage mass: 178,321 kg wet, 34,019 kg dry
    - Compare S IVB: 119,900 kg wet, 13,300 kg dry; J-2: 486.2 kN (109.3 lbf)
  - No development plans or identified requirements

15 klbf BNTR engine

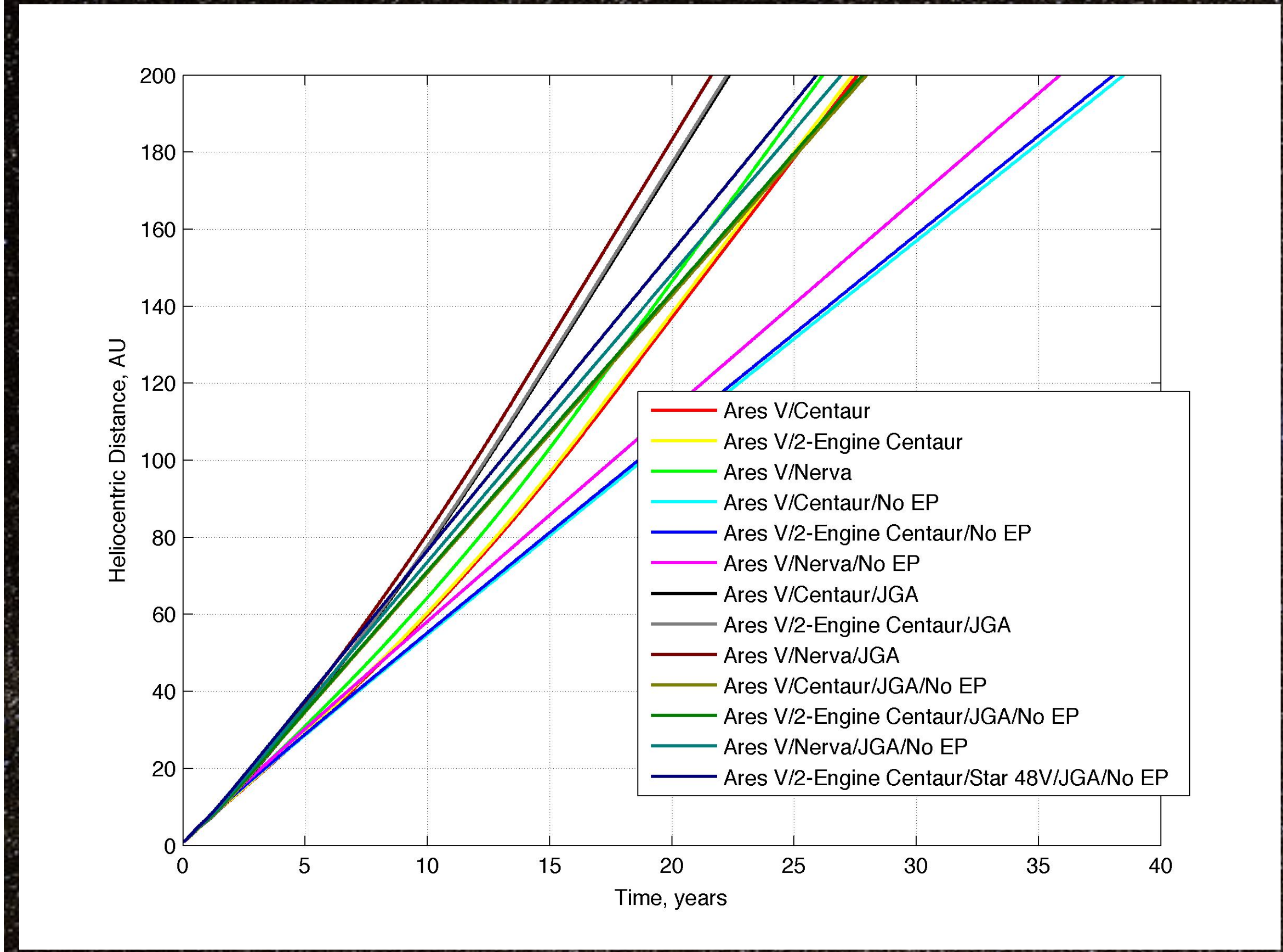


# Comparing the Options: Speed to 200 AU and Beyond




- Probe speed versus heliocentric distance
  - To 200 AU
  - Log distance
  - JGA is the discontinuity

# Comparing the Options: Time to 200 AU

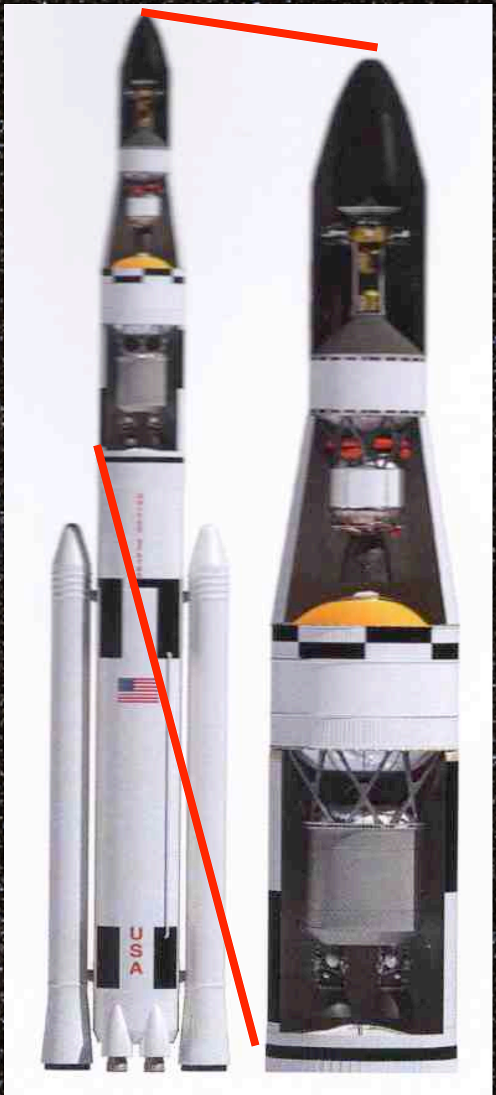



- Spread among options is ~22 to 38 years to 200 AU
- Widens in going to even larger distances
- Initial goal had been 15 years to 200 AU

# An Interstellar Probe Has Been Advocated for Over 30 Years…and Continues to Be Advocated

| NASA Studies | National Academy Studies |
|---|---|
| Outlook for Space, 1976 | Physics through the 1990's - Panel on Gravitation, Cosmology, and Cosmic Rays (D. T. Wilkinson, chair), 1986 NRC report |
| An implementation plan for solar system space physics, S. M. Krimigis, chair, 1985 | Solar and Space Physics Task Group Report (F. Scarf, chair),1988 NRC study Space Science in the 21st Century - Imperatives for the Decade 1995-2015 |
| Space Physics Strategy-Implementation Study: The NASA Space Physics Program for 1995-2010 | Astronomy and Astrophysics Task Group Report (B. Burke, chair), 1988 NRC study Space Science in the 21st Century - Imperatives for the Decade 1995-2015 |
| Sun-Earth Connection Technology Roadmap, 1997 | The Decade of Discovery in Astronomy and Astrophysics (John N. Bahcall, chair) |
| Space Science Strategic Plan, The Space Science Enterprise, 2000 | The Committee on Cosmic Ray Physics of the NRC Board on Physics and Astronomy (T. K. Gaisser, chair), 1995 report Opportunities in Cosmic Ray Physics |
| Sun-Earth Connection Roadmaps, 1997, 2000, 2003 | A Science Strategy for Space Physics, Space Studies Board, NRC, National Academy Press, 1995 (M. Negebauer, chair) |
| NASA 2003 Strategic Plan | The Sun to the Earth - and Beyond: A Decadal Research Strategy in Solar and Space Physics, 2003 |
| The New Science of the Sun - Solar System: Recommended Roadmap for Science and Technology 2005 - 2035, 2006 | Exploration of the Outer Heliosphere and the Local Interstellar Medium, 2004 |
| Heliophysics: THE SOLAR AND SPACE PHYSICS OF A NEW ERA; Recommended Roadmap for Science and Technology 2009–2030, May 2009 | Priorities in Space Science Enabled by Nuclear Power and Propulsion, 2006 |

# It is just a question of how and when…




L'Garde Solar Sail prototype (above)
Boeing SLS advanced concept (right)

# And the background ?