Previous ISM Mission Studies

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


Or Colonization (!) ("Polynesian mode")


- Stephen H. Dole “Habitable Planets for Man” (1964)

- “Interstellar Communication” A. G. W. Cameron, ed. (1963)

- “A Program for Interstellar Exploration” Robert L. Forward (1976)
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 interstellar medium will be placed on a definitive basis by information obtained by the spacecraft that obtain data from penetration of the interaction region.
The “Heliosphere” Defined (Dessler)

“The solar wind will push aside the local interstellar medium. However as first noted as early as 1955 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 and slow to subsonic speeds before merging with the interstellar medium. where the solar wind is streaming supersonically is called the heliosphere.”

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

Fig. 2 Illustrative Sketch Showing Possible Interaction Between Interplanetary Medium (the Heliosphere) and the Interstellar Medium.
The “Grand Tour” was the grand motivator for thinking about the interstellar medium …

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

- 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 interactions 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

“...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 Jupiter and subsequent flyby of Neptune]
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
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.
Perhaps motivated by this study an activity was apparently 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.
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.
**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 Implementations have been examined in some depth.

REP Implementation (IIE)

Solar Sail Implementation (IHP/HEX)

The following representatives comprised the study team:

<table>
<thead>
<tr>
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An ESA Technology Reference Study

Planetary Exploration Studies Section (54-AP)
Science Payload and Advanced Concepts Office (54-A)
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

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>Instruments</th>
<th>Spacecraft (dry) (kg)</th>
<th>Payload mass fraction %</th>
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<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Mass (kg)</td>
<td></td>
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<tr>
<td>Voyager</td>
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<td>104.32</td>
<td>721.90</td>
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<td>Ulysses</td>
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<tr>
<td>IIE</td>
<td>10</td>
<td>35.2</td>
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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)

Titan III E
Centaur: Voyagers

Atlas
Agena: Pioneers

Titan IV
Centaur - Cassini

Delta IV
Heavy

Ares V
Concept

Saturn V with Apollo IV

Science and Enabling Technologies to Explore the Interstellar Medium
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

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“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

Baselined single Jupiter flyby - prime opportunity every 12 years
Assembling the Pieces

- Figure is to approximate scale
- Earth Departure Stage is only partially fueled to optimize launch energy
- First iteration: $C_3 \sim 270 \text{ km}^2/\text{s}^2$
  - Corresponding asymptotic speed from the solar system is $\sim 19.0 \text{ km/s} \sim 4 \text{ AU}/\text{yr}$
  - New Horizons
    - Launched to $164 \text{ km}^2/\text{s}^2$
    - Pluto flyby at $13.8 \text{ km/s} = 2.9 \text{ AU}/\text{yr}$
  - Voyager 1 current speed = $3.6 \text{ AU}/\text{yr}$
  - Voyager 2 current speed = $3.3 \text{ AU}/\text{yr}$
- To reach $9.5 \text{ AU}/\text{yr}$ ($45 \text{ km/s}$) with only a launch from Earth would require $C_3 = 1,016 \text{ km}^2/\text{s}^2$
- Even with an Ares V, launch remains only one component
  
  Earth orbital speed = $29.79 \text{ km/s}$; $1 \text{ AU}/\text{yr} = 4.74 \text{ km/s}$
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
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

<table>
<thead>
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<td>The Decade of Discovery in Astronomy and Astrophysics (John N. Bahcall, chair)</td>
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<td>The Sun to the Earth - and Beyond: A Decadal Research Strategy in Solar and Space Physics, 2003</td>
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Science and Enabling Technologies to Explore the Interstellar Medium

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It is just a question of how and when...

L’Garde Solar Sail prototype (above)
Boeing SLS advanced concept (right)
And the background?

Alpha Centauri

Beta Centauri

[One can still dream]