HUMANITY'S JOURNEY TO INTERSTELLAR SPACE

INTERSTELLAR

PROBE

Interstellar Probe: Overview

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APL JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

A “Pragmatic Interstellar Probe”…

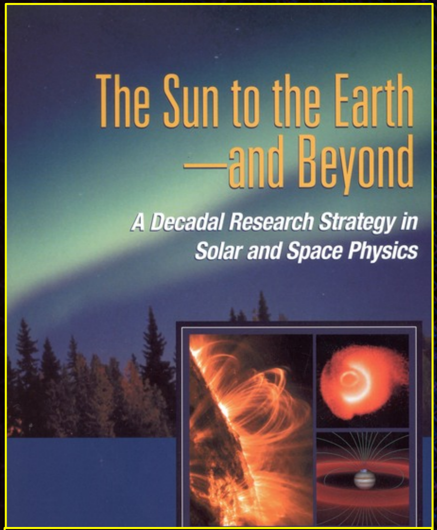
- … is a mission through the outer heliosphere and to the nearby “Very Local” interstellar medium (VLISM)

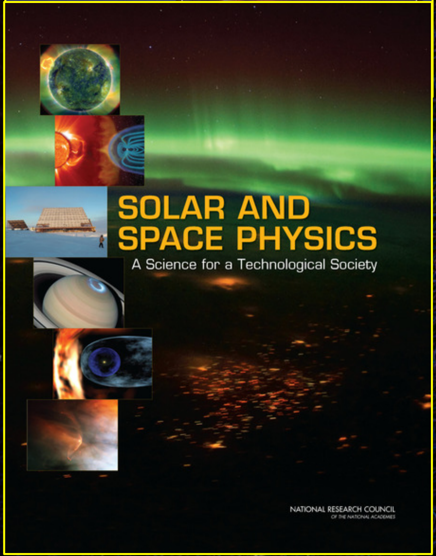
- … uses today’s technology to take the first explicit step on the path of interstellar exploration (faster than the Voyagers – on an SLS or commercial equivalent)

- **… can pave the way, scientifically, technically, and programmatically for more ambitious future journeys (and more ambitious science goals)**

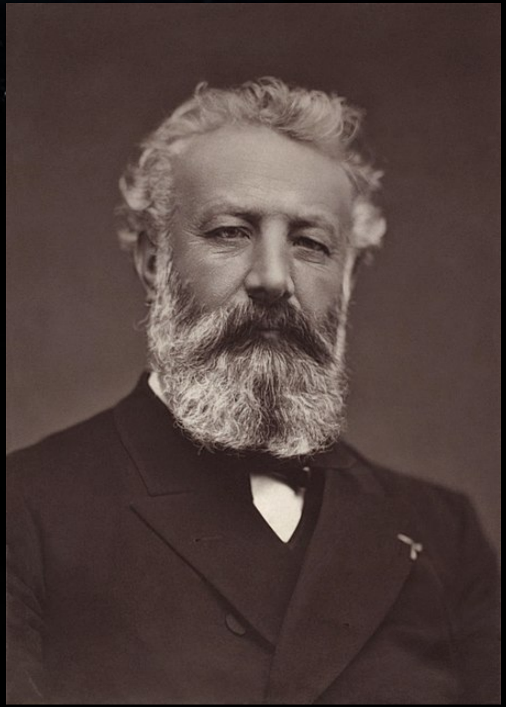
Study Status

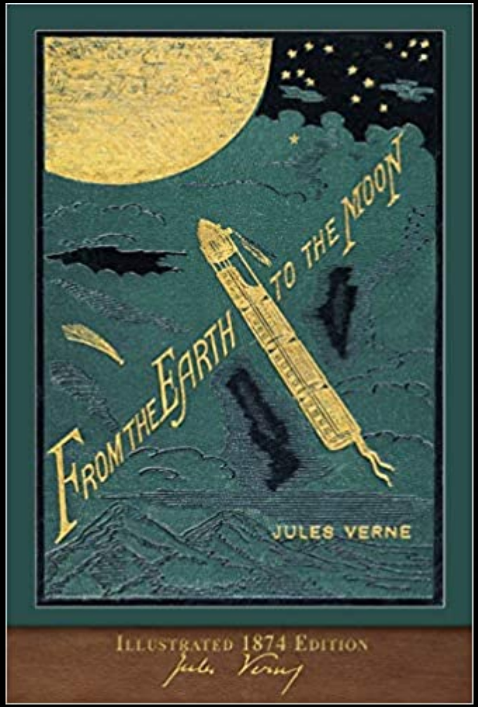
- The Johns Hopkins University Applied Physics Laboratory has been tasked by the NASA Heliophysics Division to (re-)study an Interstellar Probe mission
  - Phase 1: 13 June 2018 – 12 June 2019
  - Phase 2 “Next Phase Concept Development”: 25 July 2019 – 30 April 2022
- Technical Report to be delivered late 2021 for input to next Solar and Space Physics Decadal Survey

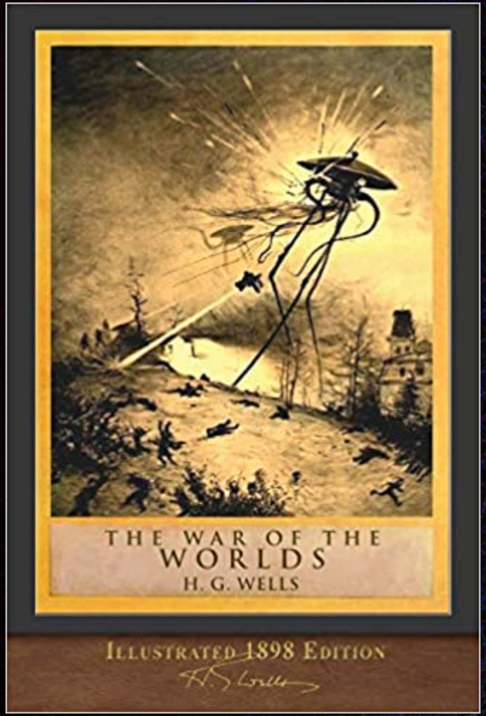




In the beginning, there is a confluence of ideas and people (TRL "0")…







Jules Verne (1828 – 1905):
From the Earth to the Moon 1865

H. G. Wells (1866 – 1946):
The War of the Worlds 1898

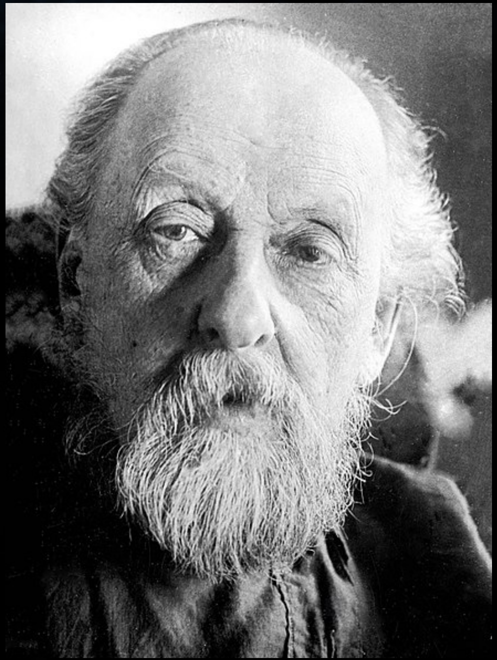
… and knowledge (TRL 1) …

Acc. 90-105 - Science Service, Records, 1920s-1970s, Smithsonian Institution Archives

Pierre Curie (1859-1906) and
Marie Sklodowska Curie (1867-1934)

Jointly awarded the Nobel Prize for Physics in 1903 for discovery of the radioactive elements polonium and radium

…which inspires those who follow (TRL 2)



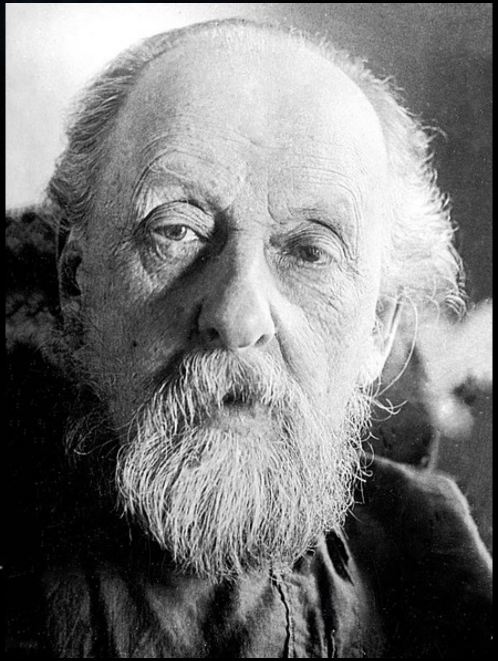
Konstantin Eduardovich Tsiolkovsky
Константин Эдуардович Циолковский
1857 - 1935

Robert Esnault-Pelterie
1881 - 1957

Robert Hutchings Goddard
1882 - 1945

Hermann Julius Oberth
1894 - 1929

The Idea of Travel to the Space Between the Stars … and the Stars Themselves … is not New



Konstantin Eduardovich Tsiolkovsky
Константин Эдуардович Циолковский
1857 - 1935

INVESTIGATION OF OUTER SPACES BY ROCKET DEVICES - 1911

…were it possible to accelerate sufficiently the disintegration of radium or other radioactive bodies, … then its use might give - in similar other conditions, … a velocity of the reactive device, by which access to the closest Sun (star) would come down to 10 – 40 years… a pinch of radium would be sufficient, to enable the rocket weighing a ton, to break all relations with the solar system."

"It may be, that with the help of electricity, it will be possible by and by, to impart tremendous velocity to the particles, being ejected from the reactive devices."

THE ULTIMATE MIGRATION – 14 January 1918

"Will it be possible to travel to the planets which are around the fixed stars, when the Sun and the Earth have cooled to such an extent that life is no longer possible on the Earth?
To answer this question, it is necessary to answer two others; first, will it be possible to unlock, and control, intraatomic energy?..."

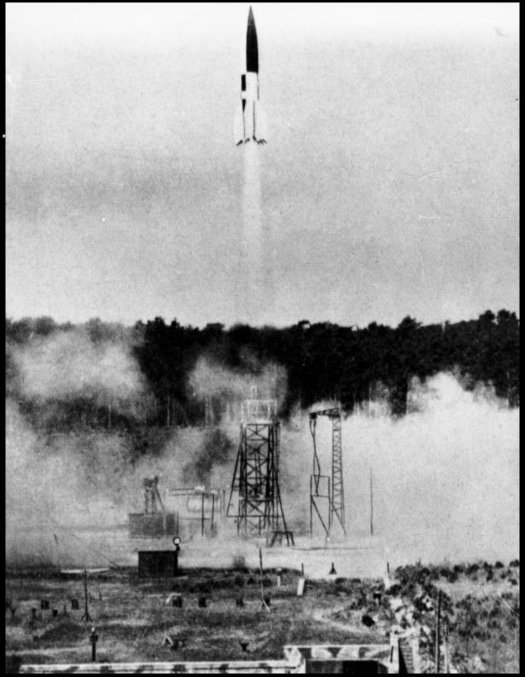
"If it is possible to unlock, and to control, intra-atomic energy, or even to store up to great quantities of energy in artificial atoms, the transportation can be a comparatively simple matter."

Robert Hutchings Goddard
1882 - 1945

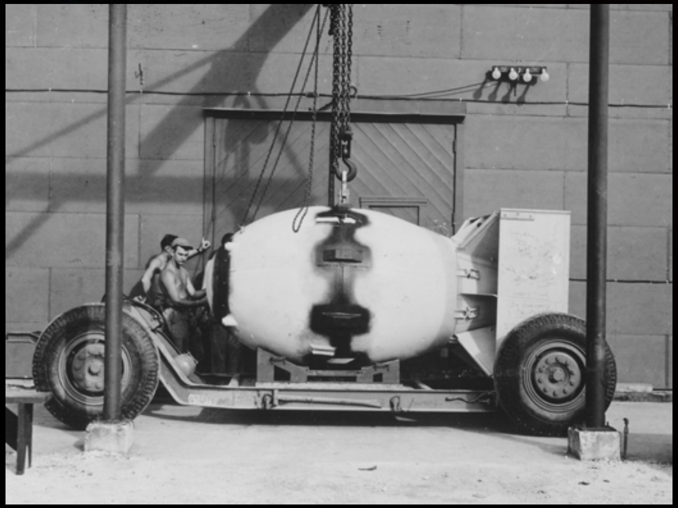
Mission Need + Demonstrated prototypes Led to Funds to go to the Next Level (TRL 3) – Space Nuclear Power

Parts from World War II

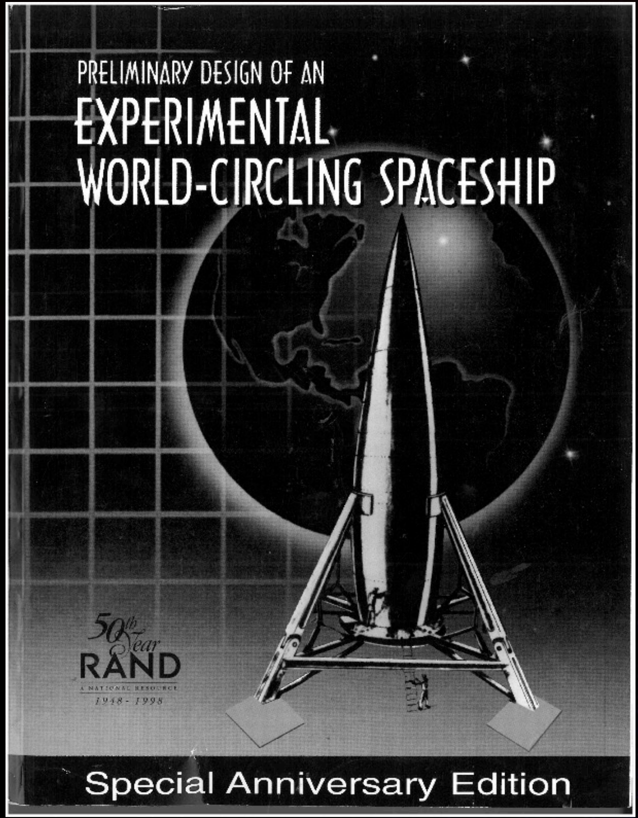
Mission need for "Cold War"
500 W electric power supply for satellite (SNAPs for Project Feed Back)

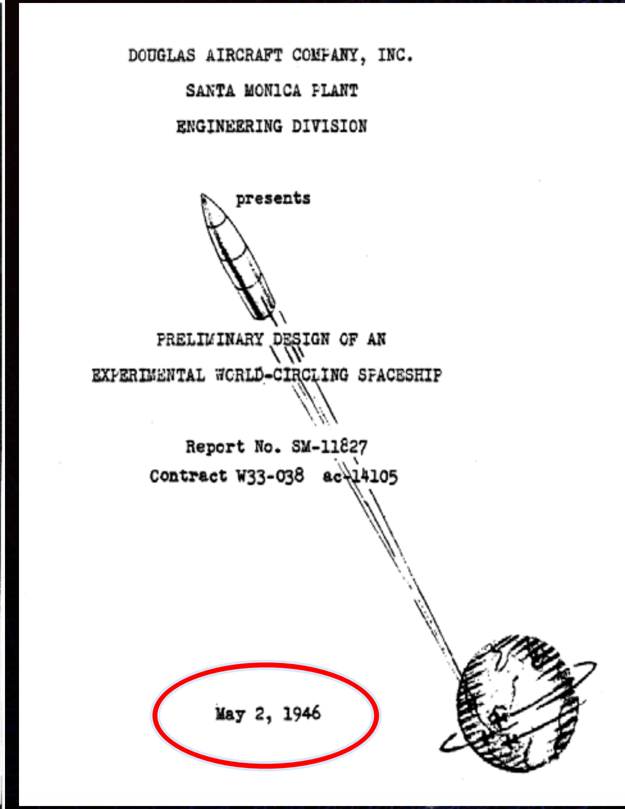


V2 (1943)
German



"Fat Man" (1945)
American





DOUGLAS AIRCRAFT COMPANY, INC.
SANTA MONICA PLANT
ENGINEERING DIVISION

presents

PRELIMINARY DESIGN OF AN
EXPERIMENTAL WORLD-CIRCLING SPACESHIP

Report No. SM-11827
Contract W33-038 ac-14105

May 2, 1946

One of Three "Special Probes" … in March 1960

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

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.

March 1960

Parker Solar Probe

Interstellar Probe

Ulysses

Special Probes

a. Solar probe: specially designed payload, capable of withstanding high temperatures; to be aimed close to the Sun.

Experiments:

Payload Group	1	(whole group)
" "	2	part of the experiments
" "	7a	nuclear processes
" "	4a	gamma rays
" "	4b	primary neutrons
" "	6e	transport of particles and fields from the Sun
" "	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
" "	1	(whole group)
" "	2	(whole group)

Stabilization is required

c. Probe "perpendicular" to the ecliptic. Here an increased velocity is needed and it may be necessary to compromise and accept a trajectory which has a strong component perpendicular to the field and thus moves in a spiral out of the plane of the ecliptic. This is probably the most difficult shot.

The Rationale Has Not Changed

"There seem to be several critical objectives of space-flight operations.

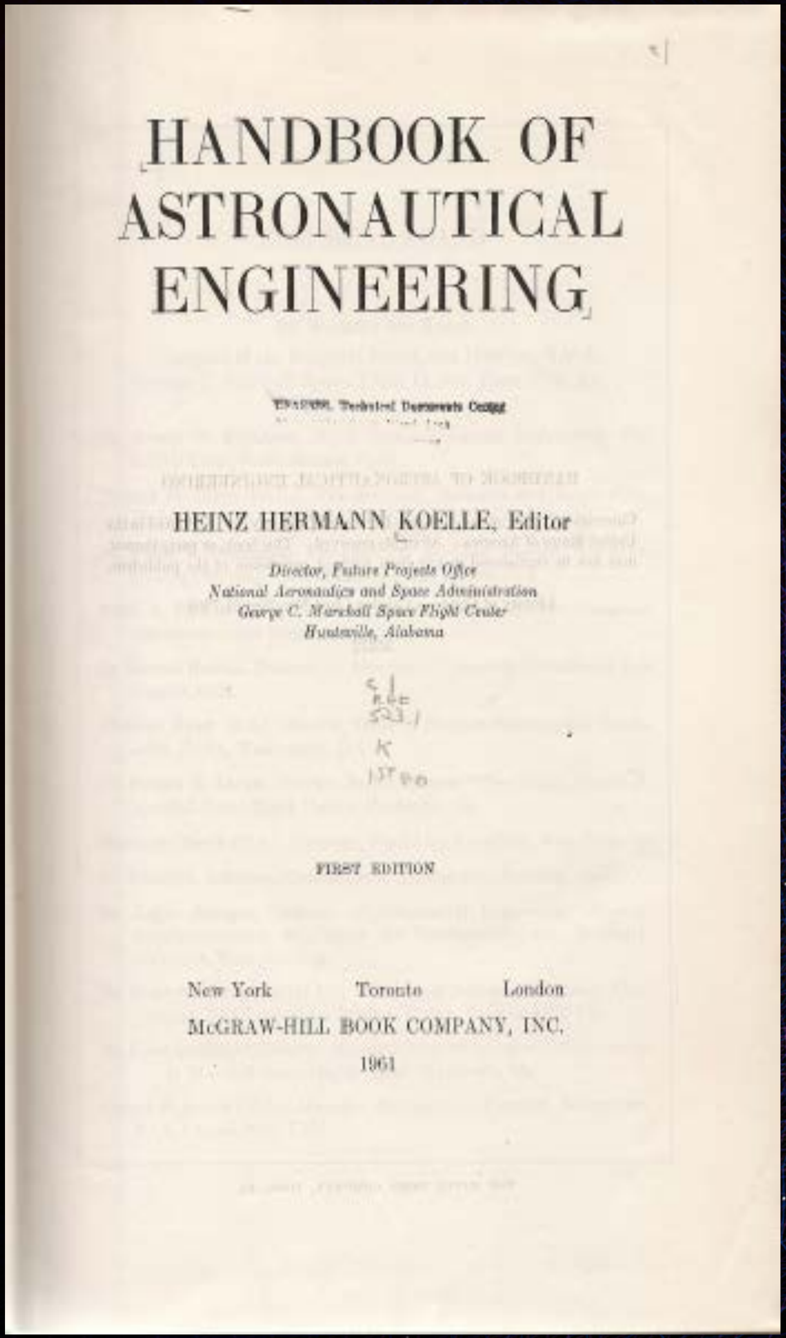
"The first principal objective is the ***scientific exploration of space***, the planets, and later, the stars.

"This is an effort to learn the basic physics, chemistry, medicine, or biology of these new places.

"It includes the invention, research, and development of new instruments and scientific devices.

G. P. Sutton - § 1.391 of "Trends in Astronautical Developments" in Handbook of Astronautical Engineering, ed. H. H. Koelle, 1961.

(5 September 1920 – 15 October 2020)



HANDBOOK OF ASTRONAUTICAL ENGINEERING

HEINZ HERMANN KOELLE, Editor

Director, Future Projects Office
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama

FIRST EDITION

New York Toronto London

McGRAW-HILL BOOK COMPANY, INC.

1961

For Any Mission There Are Four Key Elements

• The case for going	Science/Politics
• The means to go	Technology
• Agreement to go	Strategy
• Funds in place	Policy

A well-thought-out systems approach incorporating all key elements is required to promote and accomplish a successful exploration plan

The Questions are not new…

JPL study of 1976 – 1977 (the eve of Voyager):

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

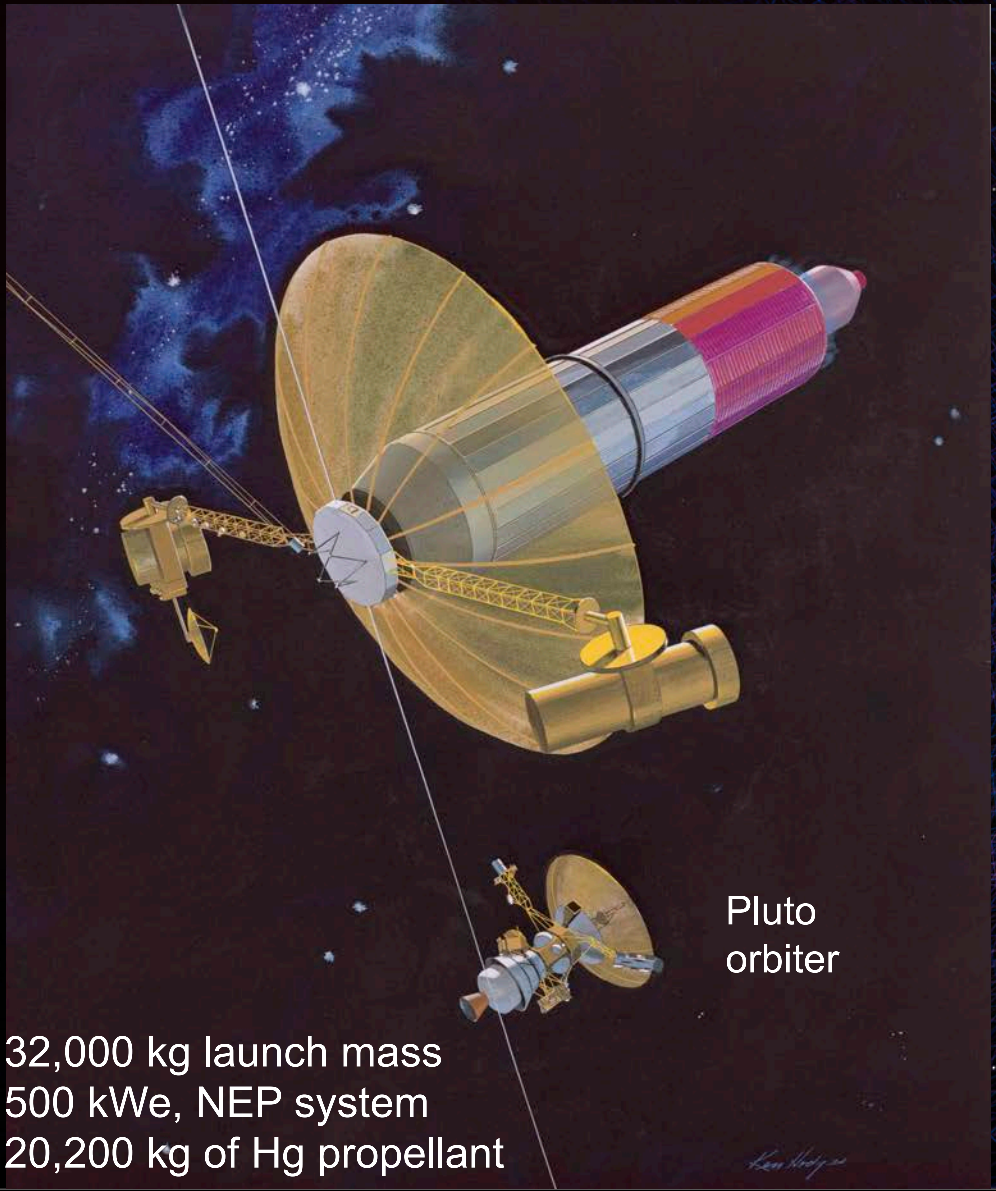
Received July 26, 1978; revised April 10, 1979

Primary Objectives

(1) Characterize the heliopause
(2) Determine characteristics of the interstellar medium
(3) Improve the stellar and galactic distance scale
(4) Determine characteristics of cosmic rays
(5) Determine characteristics of the solar system as a whole

Secondary Objectives

(1) Determine characteristics of Pluto and its satellites and rings, if any.
(2) Determine characteristics of distant galactic and extragalactic objects
(3) Evaluate problems of scientific observations of another solar system from a spacecraft



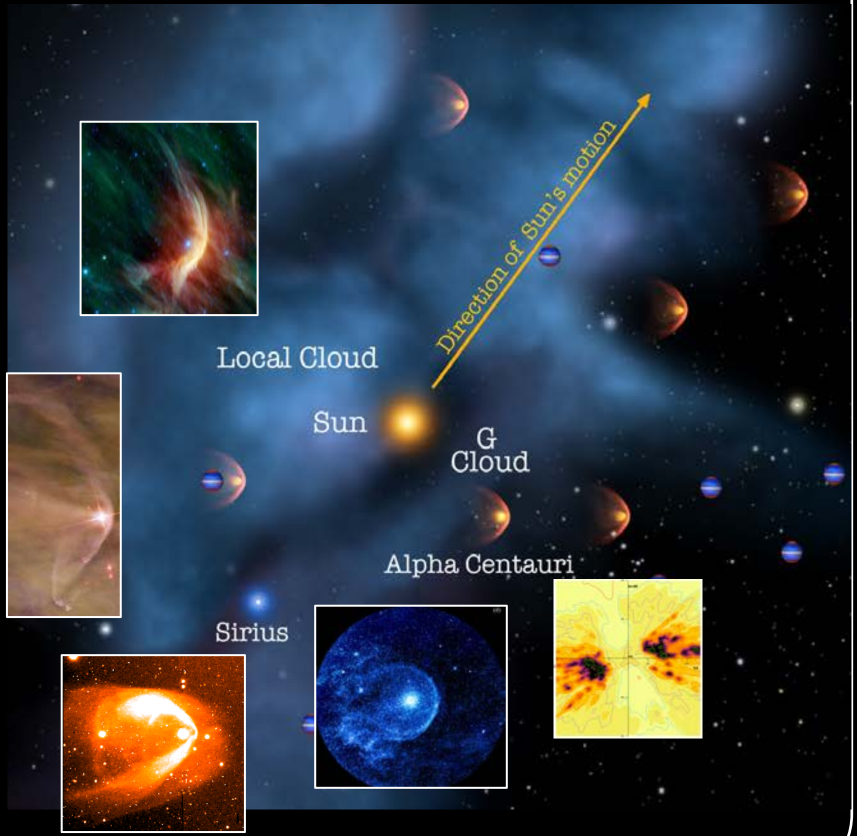
32,000 kg launch mass
500 kWe, NEP system
20,200 kg of Hg propellant

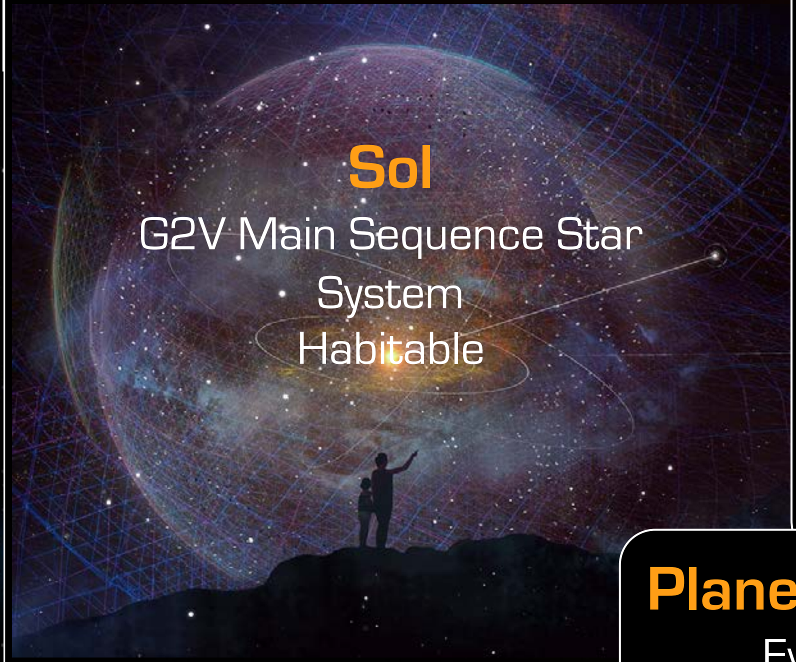
Interstellar Probe Science Goals and Opportunities

Through Our Habitable Astrosphere and Into The Unknown

Primary Goal

Our Habitable Astrosphere and The Unexplored Interstellar Medium

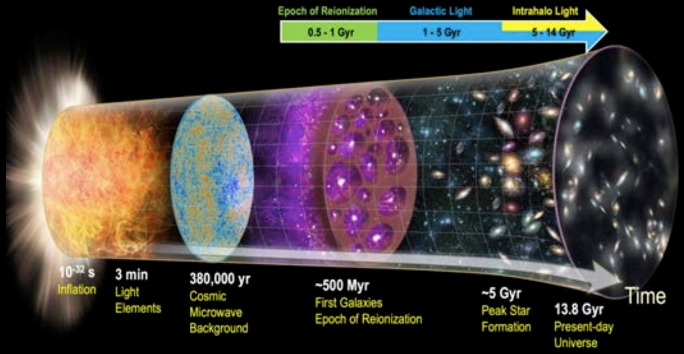




Astrophysics Opportunity

Formation of Early Galaxies and Stars

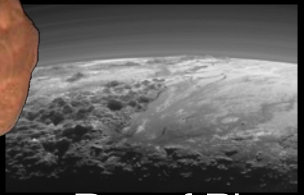
Extragalactic Background Light



Planetary Science Opportunity

Evolution of Planetary Systems

KBOs



Dwarf Planets

Dust Disk

Notional Science Traceability Matrix

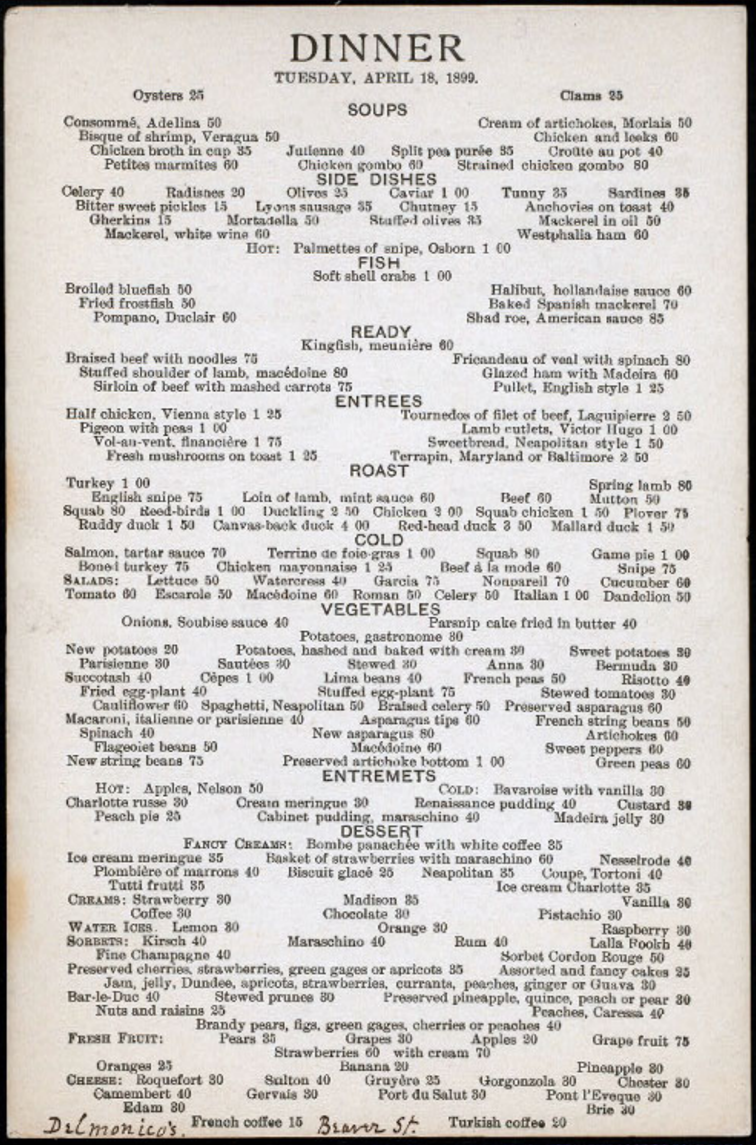
Identifying Requirements for Mission Designs

Goal	Questions	Objectives	Measurements	Mission Requirements
Our Habitable Astropshere in Interstellar Space	What is the Global Dynamical Nature of the Heliosphere as it plows through the ISM?	Global Structure	Particles, fields, waves, ENA	Spinning, external view, ≥200 AU
		Ribbon/Belt	ENA, particles, fields	Spinning, image, in-situ ribbon, ≥200 AU
		Force Balance	Particles, fields, ENA	Spinning, 90-300 AU
		Astrophysical Shock Acceleration	Particles, fields	Spinning/multiple heads, flanks, ≥90 AU
		Nature and dynamics of Heliopause	Particles, fields, waves	Spinning, wire/rigid, ≥100 AU
		GCR Shielding	Particles, fields	Spinning/multiple heads, ≥100 AU
		Solar perturbations in LISM	Particles, fields	Spinning/multiple heads, ≥300 AU
		Bowshock	Particles, fields, nanodust	Spinning, ≥150 AU
		Hydrogen Wall	UV, particles, fields, neutrals	Near ram, spinning, ≥300 AU
	What are the properties of the Interstellar Cloud surrounding the Heliosphere and what does it teach us about our place in the galaxy?	Cloud properties	Particles, fields, neutrals	Near ram, ≥200 AU
		Gas and dust flows	Particles, neutrals, dust	Near ram, ≥200 AU
		Boundary region	UV, particles, neutrals	Near ram, ≥400 AU
		Governing processes of ionization	UV, particles, neutrals	Near ram, ≥200 AU
		Galactic Evolution and Nucleosynthesis	Elements, isotopes, dust	Near ram, ≥400 AU
		Building blocks of planetary systems	Dust	Near ram, ≥200 AU

Version 4.0

A “Menu” Approach

- **Engage** the science and technical communities
- **Assemble a “Menu”** of what has been done and what can be done
- **“Ordering” from the menu** will be a charge to a future Science Definition Team – at NASA’s discretion
- But one always would like the **assurance about what orders can be placed** – and **delivered** – and what they would **cost**



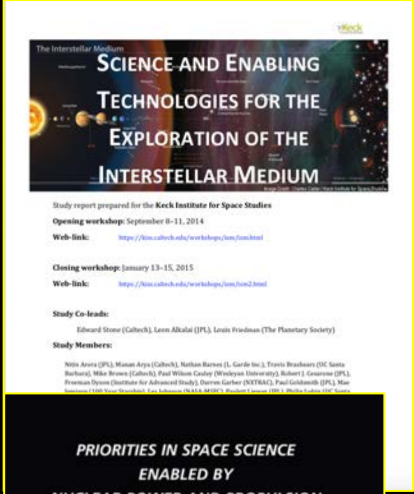
DINNER
TUESDAY, APRIL 18, 1899.
Oysters 25 Clams 25
SOUPS
Consommé, Adelina 50 Cream of artichokes, Morlais 50
Bisque of shrimp, Veragua 50 Chicken and leeks 60
Chicken broth in cup 35 Julienne 40 Split pea purée 35 Croûte au pot 40
Petites marmites 60 Chicken gombo 60 Strained chicken gombo 80
SIDE DISHES
Celery 40 Radishes 20 Olives 25 Caviar 1 00 Tunny 35 Sardines 35
Bitter sweet pickles 15 Lyons sausage 35 Chutney 15 Anchovies on toast 40
Gherkins 15 Mortadella 50 Stuffed olives 35 Mackerel in oil 50
Mackerel, white wine 60 Westphalia ham 60
HOT: Palmettes of snipe, Osborn 1 00
FISH
Soft shell crabs 1 00
Broiled bluefish 50 Halibut, hollandaise sauce 60
Fried frostfish 50 Baked Spanish mackerel 70
Pompano, Duclair 60 Shad roe, American sauce 85
READY
Kingfish, meunière 60
Braised beef with noodles 75 Fricandeau of veal with spinach 80
Stuffed shoulder of lamb, macédoine 80 Glazed ham with Madeira 60
Sirloin of beef with mashed carrots 75 Pullet, English style 1 25
ENTREES
Half chicken, Vienna style 1 25 Tournedos of filet of beef, Laguipierre 2 50
Pigeon with peas 1 00 Lamb cutlets, Victor Hugo 1 00
Vol-au-vent, financière 1 75 Sweetbread, Neapolitan style 1 50
Fresh mushrooms on toast 1 25 Terrapin, Maryland or Baltimore 2 50
ROAST
Turkey 1 00 Spring lamb 80
English snipe 75 Loin of lamb, mint sauce 60 Beef 60 Mutton 50
Squab 80 Reed-birds 1 00 Duckling 2 50 Chicken 3 00 Squab chicken 1 50 Plover 75
Ruddy duck 1 50 Canvas-back duck 4 00 Red-head duck 3 50 Mallard duck 1 50
COLD
Salmon, tartar sauce 70 Terrine de foie-gras 1 00 Squab 80 Game pie 1 00
Boned turkey 75 Chicken mayonnaise 1 25 Beef à la mode 60 Snipe 75
SALADS: Lettuce 50 Watercress 40 Garcia 75 Nonpareil 70 Cucumber 60
Tomato 60 Escarole 50 Macédoine 60 Roman 50 Celery 50 Italian 1 00 Dandelion 50
VEGETABLES
Onions, Soubise sauce 40 Parsnip cake fried in butter 40
Potatoes, gastronome 30
New potatoes 20 Potatoes, hashed and baked with cream 30 Sweet potatoes 30
Parisienne 30 Sautées 30 Stewed 30 Anna 30 Bermuda 30
Succotash 40 Cèpes 1 00 Lima beans 40 French peas 50 Risotto 40
Fried egg-plant 40 Stuffed egg-plant 75 Stewed tomatoes 30
Cauliflower 60 Spaghetti, Neapolitan 50 Braised celery 50 Preserved asparagus 60
Macaroni, italienne or parisienne 40 Asparagus tips 60 French string beans 50
Spinach 40 New asparagus 80 Artichokes 60
Flageolet beans 50 Macédoine 60 Sweet peppers 60
New string beans 75 Preserved artichoke bottom 1 00 Green peas 60
ENTREMETS
HOT: Apples, Nelson 50 COLD: Bavaroise with vanilla 30
Charlotte russe 30 Cream meringue 30 Renaissance pudding 40 Custard 30
Peach pie 25 Cabinet pudding, maraschino 40 Madeira jelly 30
DESSERT
FANCY CREAMS: Bombe panachée with white coffee 35
Ice cream meringue 35 Basket of strawberries with maraschino 60 Nesselrode 40
Plombière of marrons 40 Biscuit glacé 25 Neapolitan 35 Coupe, Tortoni 40
Tutti frutti 35 Ice cream Charlotte 35
CREAMS: Strawberry 30 Madison 35 Vanilla 30
Coffee 30 Chocolate 30 Pistachio 30
WATER ICES. Lemon 30 Orange 30 Raspberry 30
SORBETS: Kirsch 40 Maraschino 40 Rum 40 Lalla Rookh 40
Fine Champagne 40 Sorbet Cordon Rouge 50
Preserved cherries, strawberries, green gages or apricots 35 Assorted and fancy cakes 25
Jam, jelly, Dundee, apricots, strawberries, currants, peaches, ginger or Guava 30
Bar-le-Duc 40 Stewed prunes 30 Preserved pineapple, quince, peach or pear 30
Nuts and raisins 25 Peaches, Caressa 40
Brandy pears, figs, green gages, cherries or peaches 40
FRESH FRUIT: Pears 35 Grapes 30 Apples 20 Grape fruit 75
Strawberries 60 with cream 70
Oranges 25 Banana 20 Pineapple 30
CHEESE: Roquefort 30 Salton 40 Gruyère 25 Gorgonzola 30 Chester 30
Camembert 40 Gervais 30 Port du Salut 30 Pont l'Eveque 30
Edam 30 Brie 30
Delmonico's French coffee 15 Beaver St. Turkish coffee 20

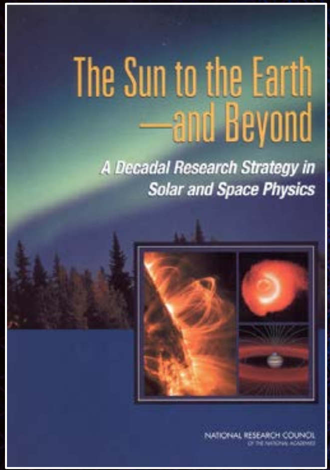
Delmonico’s – 18 April 1899
“Tournedos of filet of beef… $2.50” (!!)

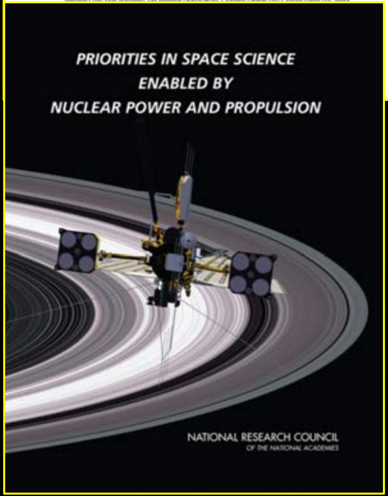
The Central Technical Question Has Always Been Propulsion

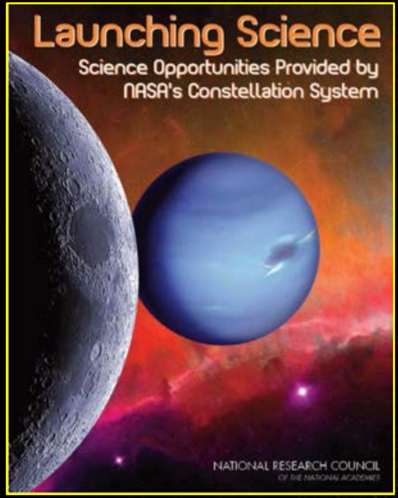
- “Near-future” capabilities have always been the backdrop for defining requirements

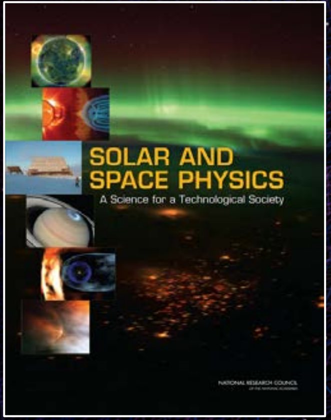
- ***The real issue:* unite** compelling science **with** engineering and technical **reality**



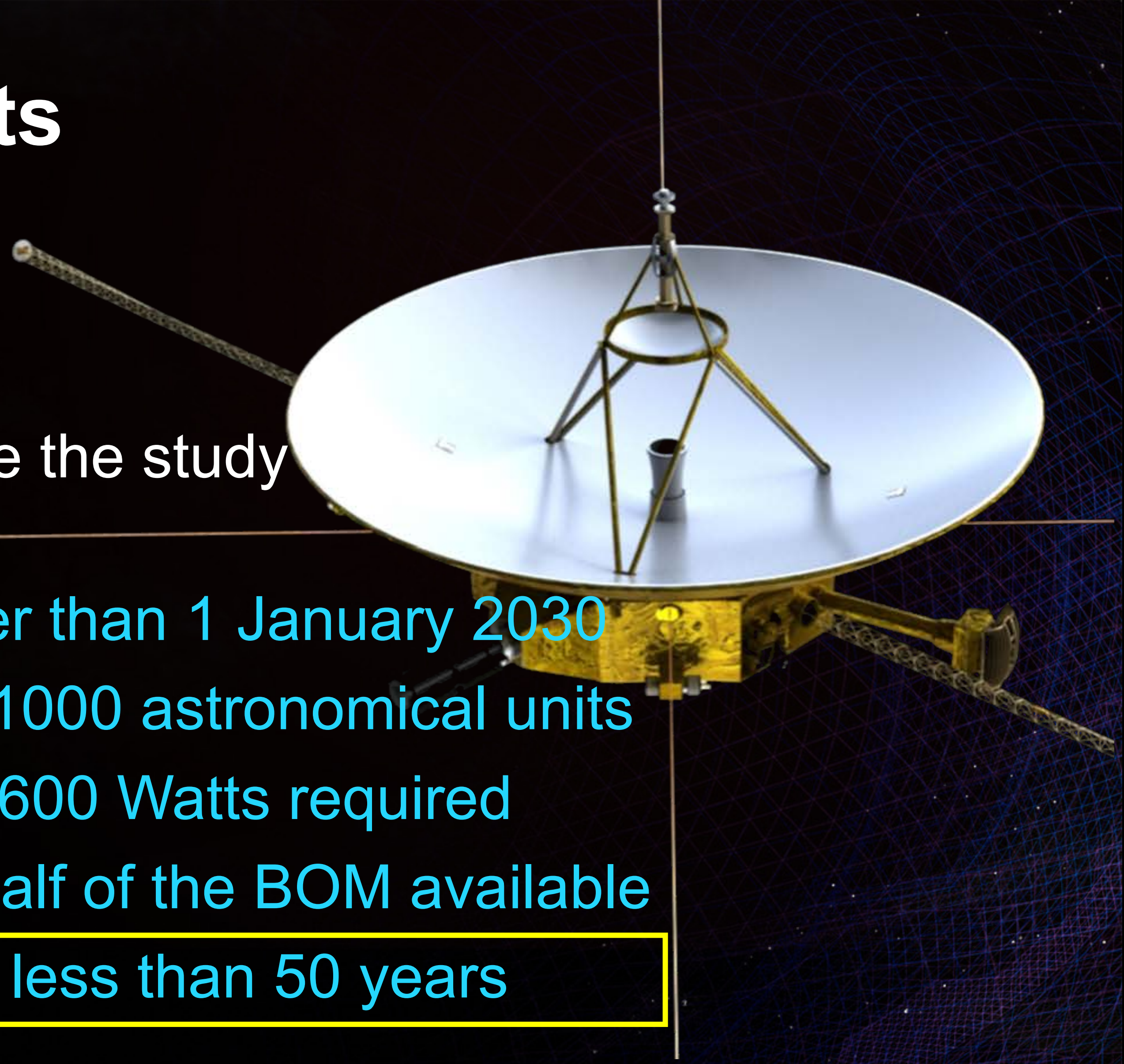








Engineering Requirements



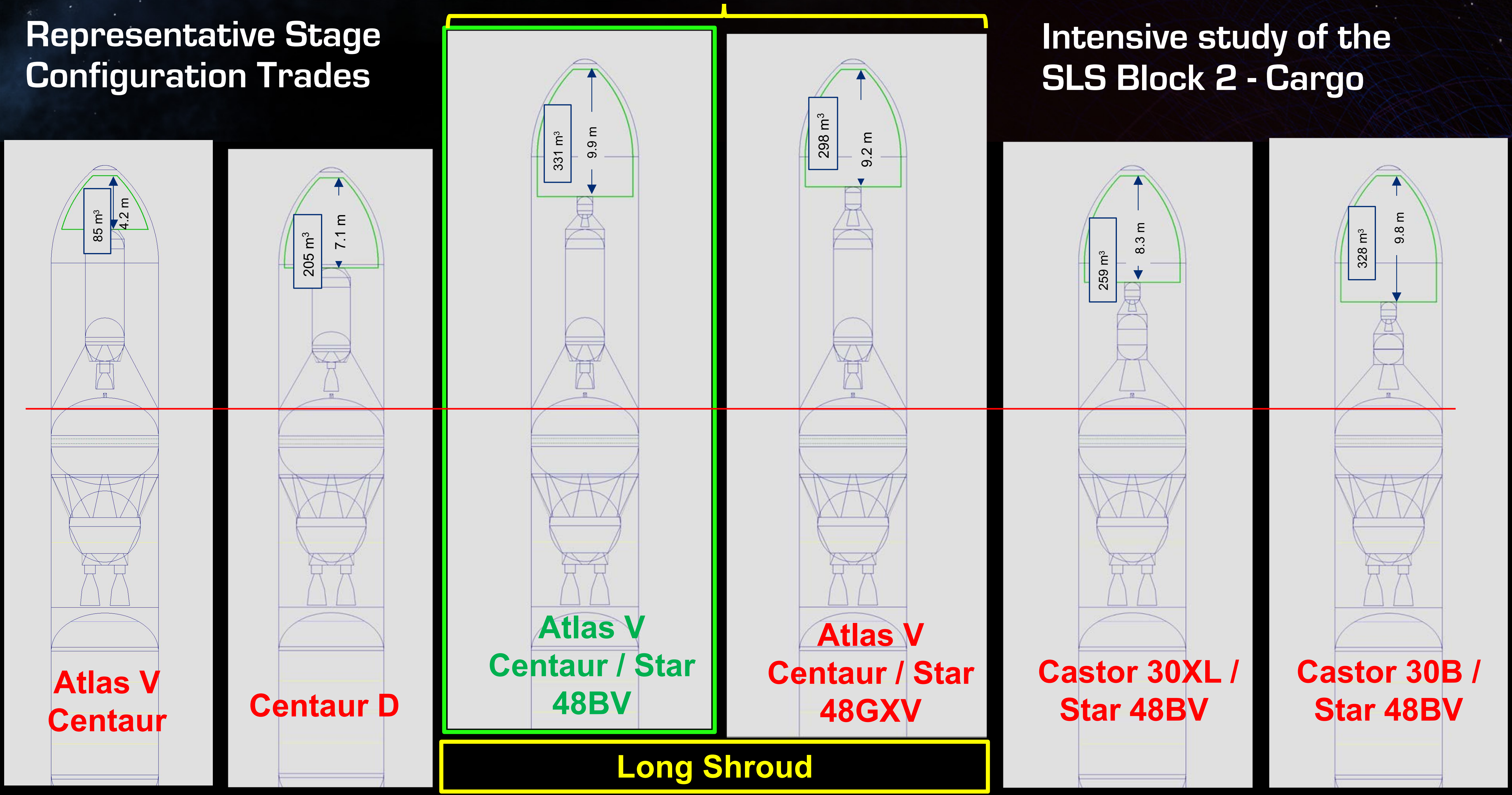
- Broad engineering requirements frame the study

(1)	Readiness:	Launch no later than 1 January 2030
(2)	Downlink:	Operate from 1000 astronomical units
(3)	Power (BOM):	No more than 600 Watts required
	(EOM):	No less than half of the BOM available
(4)	Longevity:	Lifetime of not less than 50 years

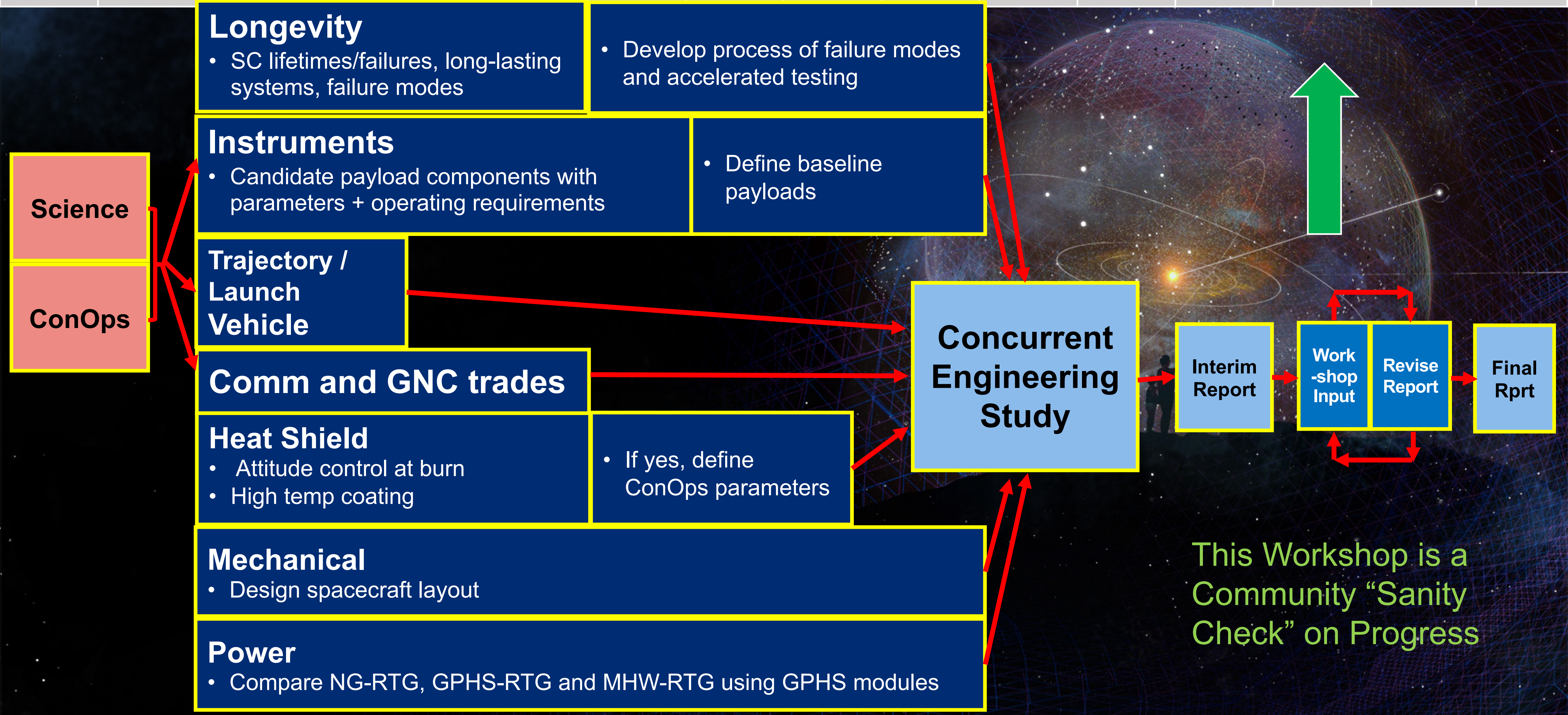
These are *INDEPENDENT* of each other – the starting point

Representative Stage Configuration Trades

Intensive study of the SLS Block 2 - Cargo



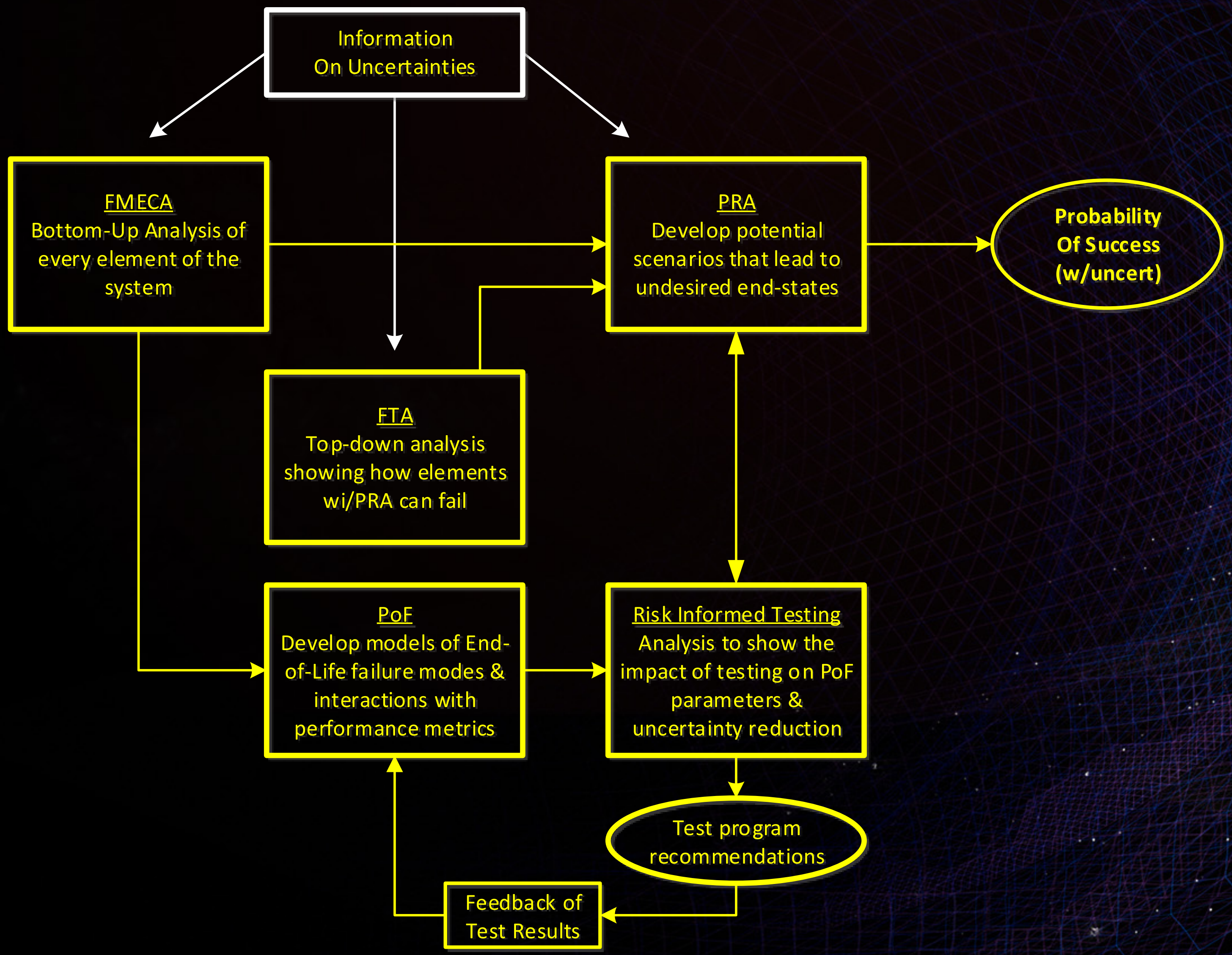
…	Oct 19	Nov 19	Dec 19	Jan 20	Feb 20	Mar 20	Apr 20	May 20	Jun 20	July 20	Aug 20	…	Nov 20	…	Dec 21
	Wksp 2019								Prelim Results	Trade Study		Interim Report	Wksp 2020		Final Report



This Workshop is a Community “Sanity Check” on Progress

Spacecraft Reliability / Longevity

- Defining success with robustness in science requirements
- Modeling spacecraft configurations
- Mining historical record of long-lived missions
- Examining Physics-of-Failure methods for key technologies



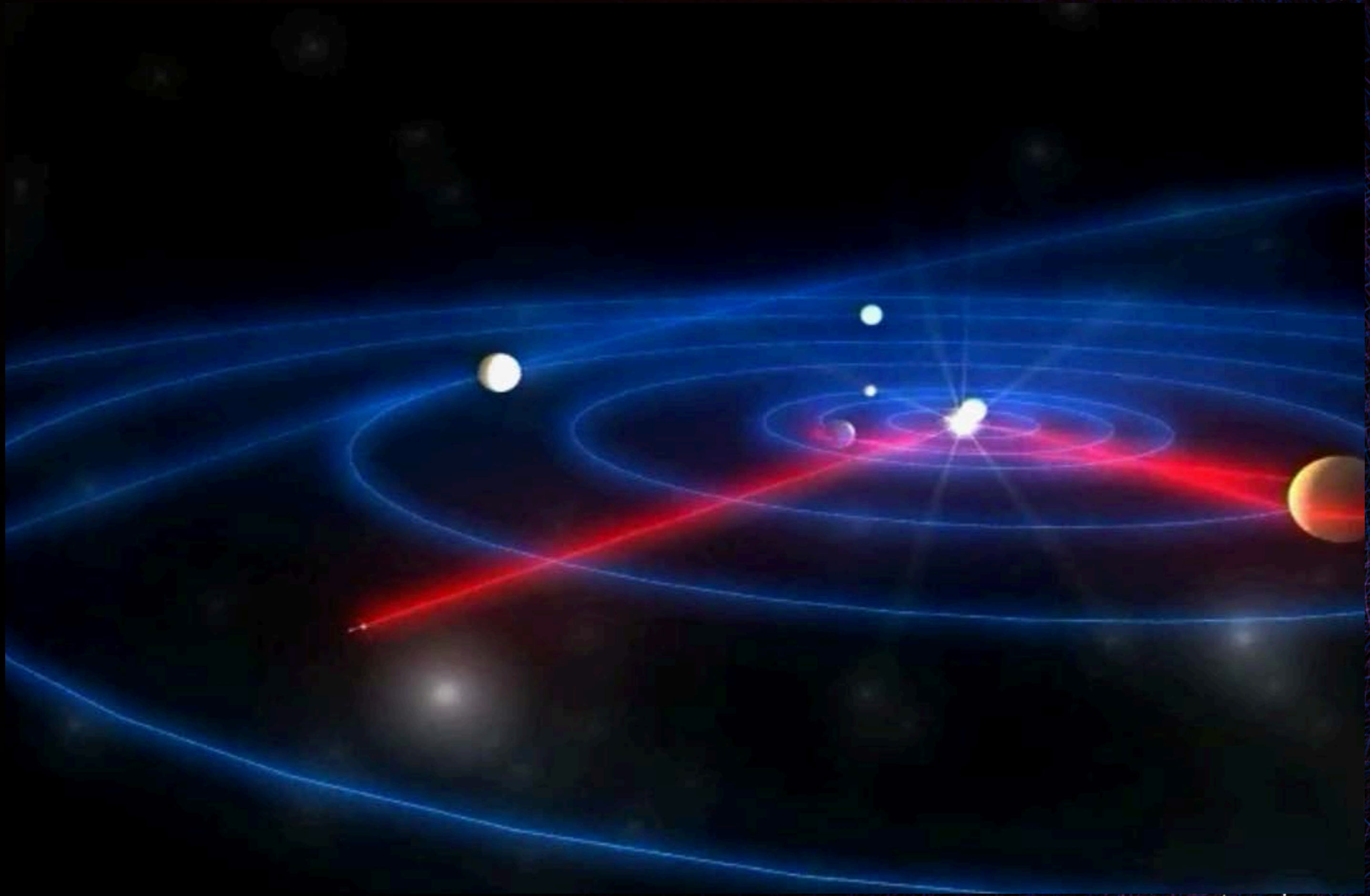
Review of Instrument Possibilities

Spacecraft → / Instrument	Interstellar Probe 1990	Small Interstellar Probe 1994	A Sole/Ad Astra 1997	IPSTDT 1999	NIAC fII (2004)	IIE Vision (2005)	IIE (TRL 9) (2005)	NEP Vision (2008)	IHP (2007)	Helios (1974)	Pioneer (1972)	Voyager (1997)	ACE (1997)	New Horizons (2006)	Ulysses (1986)	IBEX (2008)	STEREO (2006)	Van Allen Probes (2012)	IMAP (Decadal)
Magnetometer (type not specified)	4	1	0.25	0.5	1.89			1.8										20.9	3
Vector helium magnetometer						8.81			1.5	4.40	2.7				2.332				
Fluxgate magnetometer							5.6			4.75	0.3	5.6	4.1		2.4		0.27		
Plasma wave sensor	11	3	2.25	0.5	1.48	10.0	7.17	7	5.8	NA		9.1			7.4		13.23	27.4	
Plasma	20	10	2	8.5	0.97	2.00	6.2	16	2	15.696	5.5	9.9	6.8	3.3	6.7		2.37	65.6	7
Plasma composition	17						5.97	8	1.5				14.6		5.584		11.4		
Energetic particle spectrometer	8	3	0.5	1.5	0.80	1.50	37.4	15	3.0	3.50	3.3	7.5	60.2	1.5	5.8		1.63	6.6	10
Cosmic-ray spectrometer: anomalous and galactic cosmic rays	22			2.5	0.84	3.50	51.1	12	3.5		3.2	7.5	54.0		14.6		1.92		5
Cosmic-ray spectrometer: electrons/positrons, protons, helium	10	2.5		2.4		2.30	14.6	4	1.5	7.15	1.7		12.8				1.98	9.2	3
Geiger tube telescope											1.6								
Meteoroid detector										8.93	3.2								
Cosmic dust detector	8	1.5		1.5	0.70	1.75	16.36	25	1.1		1.6			1.6	3.8				8
Solar X-rays and gamma-ray bursts		0.5			2.05										2.0				
Neutral atom detector	4	3		2.3		2.50	20.75	8								12.09			15
Energetic neutral atom detector				3.5		2.50	13.9	7	4.5						4.3	7.70			27
Lyman-alpha detector / UV measurements	1	0.5	2	0.4	3.43	0.30	6.6	5	1.2		0.7	4.5		4.4					4
Infrared measurements	20			3			34	15			2.0	30.2							
Imaging photopolarimeter											4.3	4.4		8.6					
Imaging system								30		8.93		38.2		10.5			48.1		
Common electronics, harness, boom, etc.		2	3					20					3.9			5.42	19.1		24
Totals	**125**	**27**	**10**	**26.6**	**12.16**	**35.2**	**219.65**	**173.8**	**25.6**	**73.2/76.5**	**30.1**	**116.9**	**156.4**	**29.9**	**54.9**	**25.21**	**100.0**	**129.7**	**106**
Spacecraft wet mass	**N/A**	**~200**	**311.9**	**~246**	**147.15**	**549.5**	**N/A**	**N/A**	**517**	**370.0/376.5**	**252.1**	**825.4**	**756.54**	**478.3**	**366.7**	**104.9**	**623/658**	**665.4**	**N/A**
Payload / Wet mass (fraction)	**--**	**0.135**	**0.032**	**0.108**	**0.083**	**0.064**	**--**	**--**	**0.049**	**0.198/0.203**	**0.119**	**0.142**	**0.207**	**0.063**	**0.150**	**0.240**	**0.160/0.152**	**0.195**	**--**
B – as built; N - notional	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**B**	**B**	**B**	**B**	**B**	**B**	**B**	**B**	**B**	**N**

Mission Concepts are ALL Ballistic

Low-thrust, in-space concepts limited by their mass-to-power ratios

- Option 1: Unpowered Jupiter Gravity Assist (JGA)
- Option 2: Active Jupiter Gravity Assist
  - Final stage burn at Jupiter
- Option 3: JGA + Oberth Maneuver Near the Sun



22 staging cases with the SLS studied; guidance and control and thermal studies ongoing for solar Oberth scenario

Telecommunications Trade Space

Pointing Control	Frequency	Aperture Size	Ground Station	Transmit Power
Body-Fixed: dependent on S/C	X-band	Solid	Current DSN Capability	Total RTG power limited
Active Pointing: independent of S/C	Ka-band	Mesh / Membrane	ngVLA Capability	Failed RTG power limited/Extended Mission
	Optical		Telescope (e.g. Hale)	

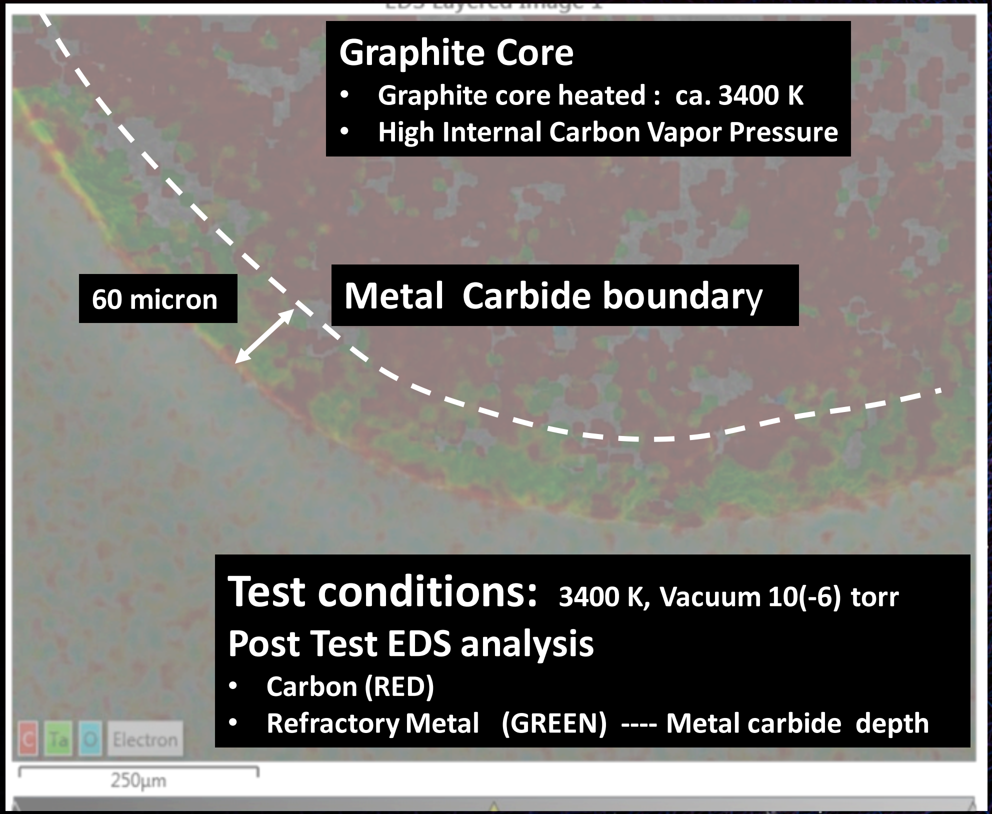
Beam Pointing Control	Frequency Band	Aperture Size/ Technology	Ground Station Capability	Transmit Power Scaling
Body-Fixed: dependent on S/C	**X-band**	**Solid**	Current DSN Capability	**Total RTG power limited**
Active Pointing: independent of S/C	Ka-band	**Membrane**	**ngVLA Capability**	Failed RTG power limited

Determine Thermal Limits of Shield Material for an Oberth Maneuver

Carbon fiber: lightweight with high strength

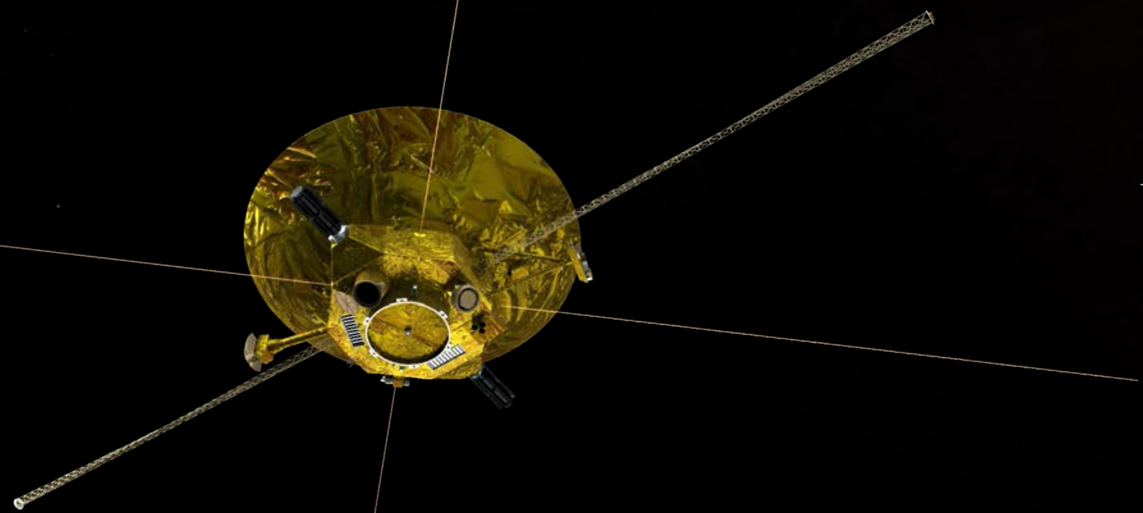
ADVANCED CERAMIC FIBERS, LLC
TRANSFORMING THE REINFORCED MATERIALS MARKETPLACE

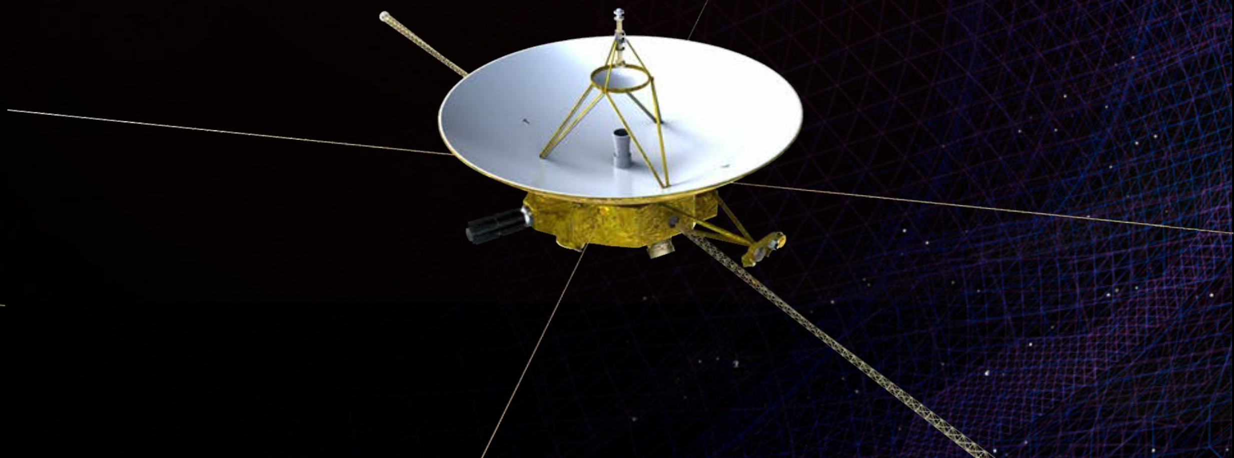
- High vapor pressure limits
- High density of refractory metals problematic
- Advanced Ceramic Fibers, LLC (ACF) working with Project to develop metal carbide (MC) layers on carbon cores (MC/C) to provide ultra high temperature (UHT) shield materials



Mechanical Layout

- Developing all heliospheric science, large payload with Option 1 trajectory (passive Jupiter Gravity Assist) as baseline
- Alternate payloads and Option 2 trajectory (powered Jupiter Gravity Assist)
- Option 3 – Solar Oberth maneuver to be studied next year (after thermal limits study completed)





Preliminary concept for slow spinner – all heliospheric science, 2 RTGs, 5-m diameter HGA

Power Requirements – Close to Historical

- **NG-RTG:** GPHS/MHW derivative RTG – efficiency and lifetime for use *in vacuo*

GPHS–RTG

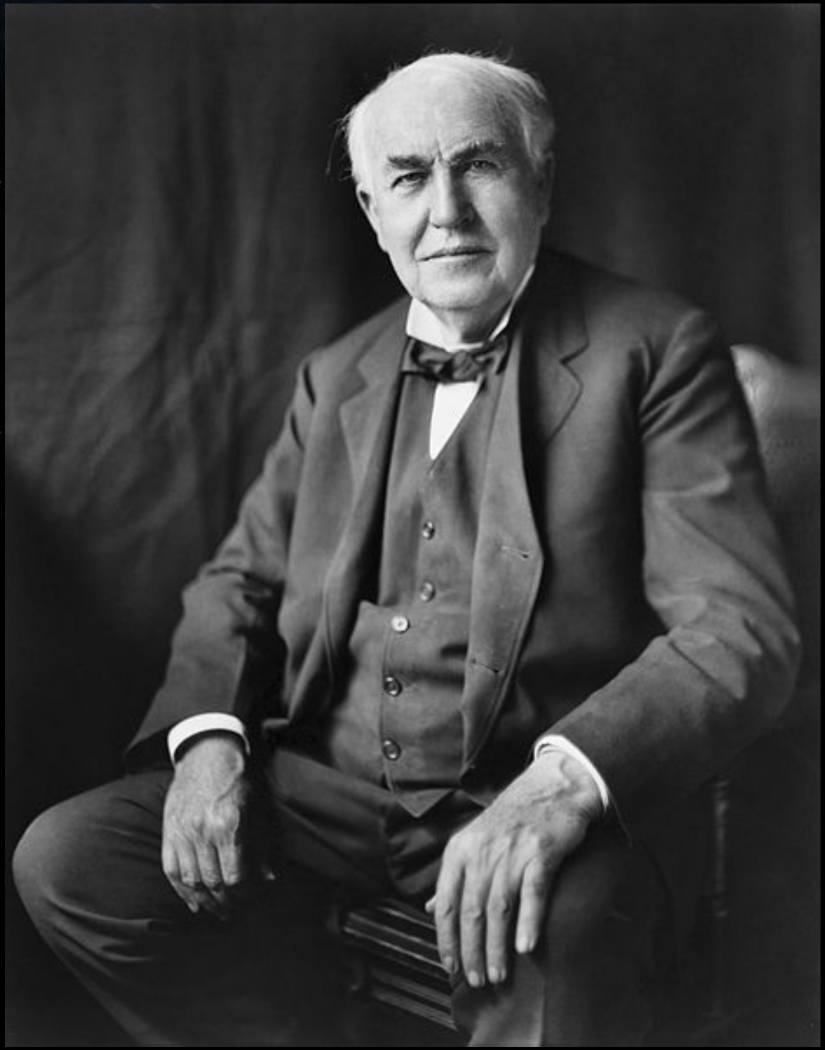
MHW–RTG

New Horizons with GPHS-RTG – Now in 14th year
Voyager MHW-RTGs now in 43rd year

One scenario: 24 February 2030…


AD ASTRA

… with a caveat:



- "Vision without execution is hallucination."
    - — Thomas A. Edison

- Requirements must be commensurate with realistic cost estimates and funds – the key element of any successful mission


HUMANITY'S JOURNEY TO INTERSTELLAR SPACE
INTERSTELLAR
PROBE