A Solar Power Hybrid Sailor for A Jovian Orbiter and Trojan Asteroid Flybys

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A Solar Power Hybrid Sailor studied at JAXA

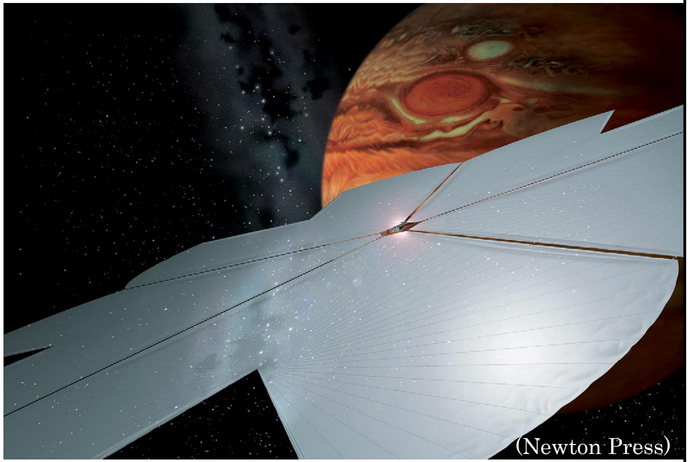
Solar Power Sail Working Group (WG) at ISAS/JAXA.

A Conceptual Study is summarized here.

The Mission aims at Technology Demonstration of A Combined Solar Electric/Photon Powered Sail to Jupiter for Science Mission.

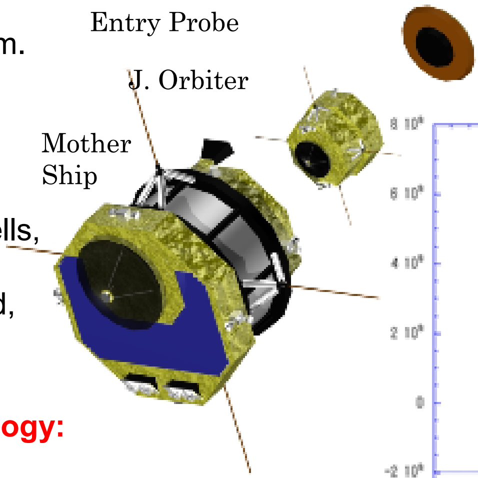
Solar Electric Hybrid Sailor to Jovian & Trojan System

Purpose Aiming at innovative new core technology requisite for future outer solar system, taking the advantage of large membrane deployment technology with the ultra high specific impulse propulsion means, the mission performs cruise demonstration, while it pursues the world's 1st class science observation.



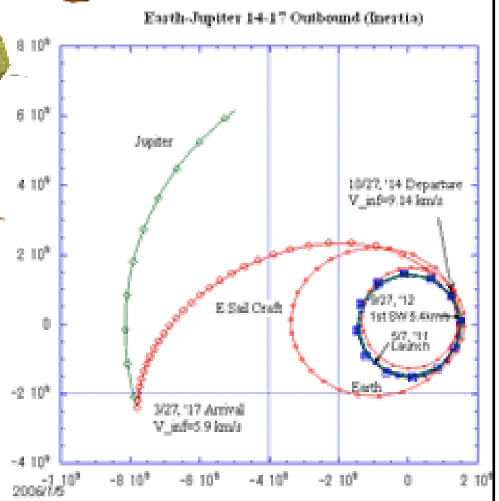
Seven News ushering Future Engineering & Science

1) 1st solar powered Jovian voyager,
2) 1st combined orbiter / flyby spacecraft,
3) Highest ultra-high specific impulse ion engines,
4) 1st hybrid propulsion,
5) 1st measurement of background emission free of zodiac dust,
6) 1st visit to Trojan asteroids,
7) 1st formation flying in the vicinity of Jovian system.



Accountability: toward social / economy

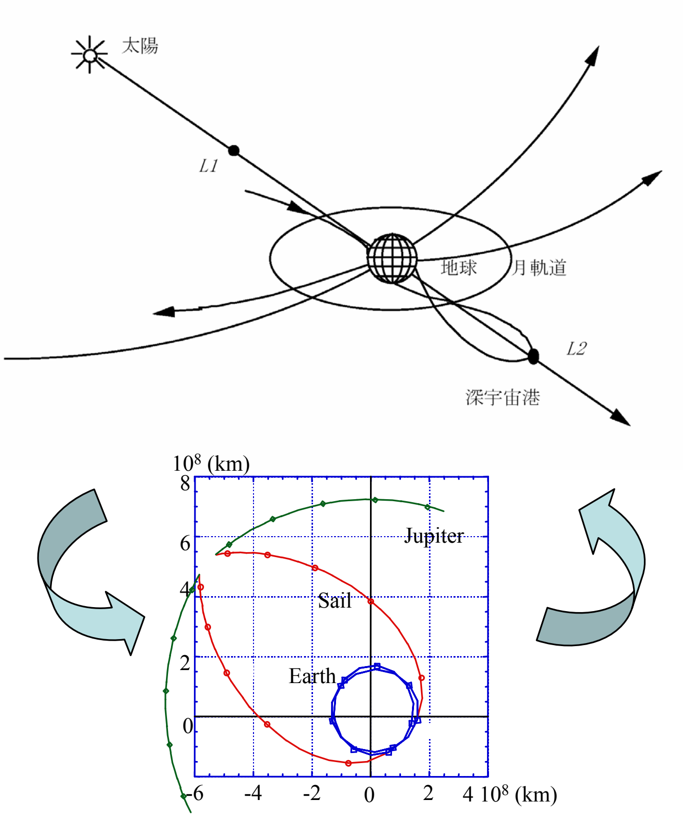
Large membrane structure technology,
Plasma reactor for advanced device fabrication,
Low cost and mass production of thin film solar cells,
Integrated power system using fuel cells,
Formation flight / robotic technology on the ground,
Anti-radiation devices / parts.



Leading the next generation Science & Technology:

Showing the legible way for the next generation.

Future Solar System Voyage
Deep Space Port, Infrastructures



Example: Round-Trip to Jupiter

(Outline) Deep Space Port built at L2, and Earth-to-Planetary Reusable Transportation System

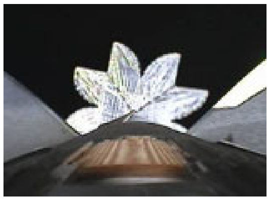
(Strategy) Large Spaceships are never launched from ground. Propulsion will be driven by nuclear power. Completely Reusable spaceships will be operated in future.

(Prospect) Flight/Voyage will fly through Relay Port (Deep Space Port) Multi-objective On-orbit Stations are constructed. The traffic infrastructure will include commuter craft between gravity-well to the Port.

Solar Sail
– Research & Development at JAXA

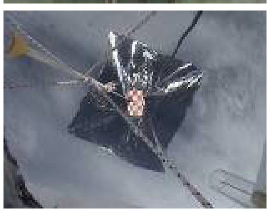
Solar Electric Hybrid Sailor – Roadmap (1/2)

What was attempted at JAXA:

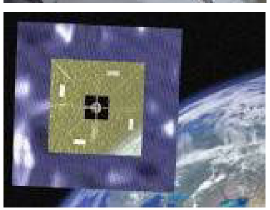


Aug. in 2003
Sounding Rocket (S310-34)
Dynamic Membrane Deployment (10m)
Spinner

Feb. 2006
Subpayload on M-V#8
Quasi-Static Membrane Deployment (10m)
Deployment resulted in Partial Success.



Aug. 2006
Balloon Experiment on B200-7
Quasi-Static Membrane Deployment (20m)
Deployment resulted in Success.

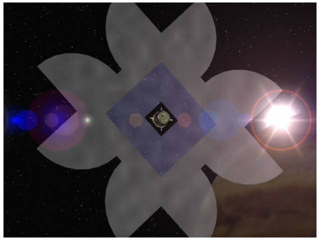


Sept. 2006
Piggy-back ultra-small satellite on M-V#7
Thin Film Solar Power Generation
Film Deployed. Functioned for 6 hrs using Battery.
Resulted in Failure.

Solar Electric Hybrid Sailor – Roadmap (2/2)

Under Investigation for Proposal

Demonstrator



Launch : TBD
Small Demonstrator
Membrane Deployment + Electric Power Generation

Launch : TBD
Jovian Flyby / Orbiter + Trojan Flyby
Hybrid Propulsion
1st Class Space Science

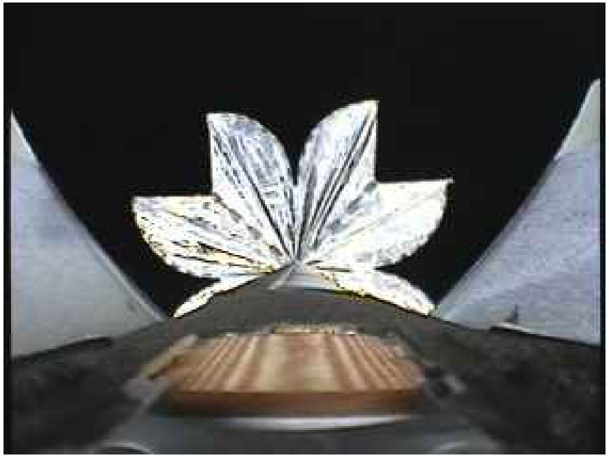
?

Beyond 2020:
New Solar System Transporter
Powered by Nuclear Reactor

Sail Deployment Experiment

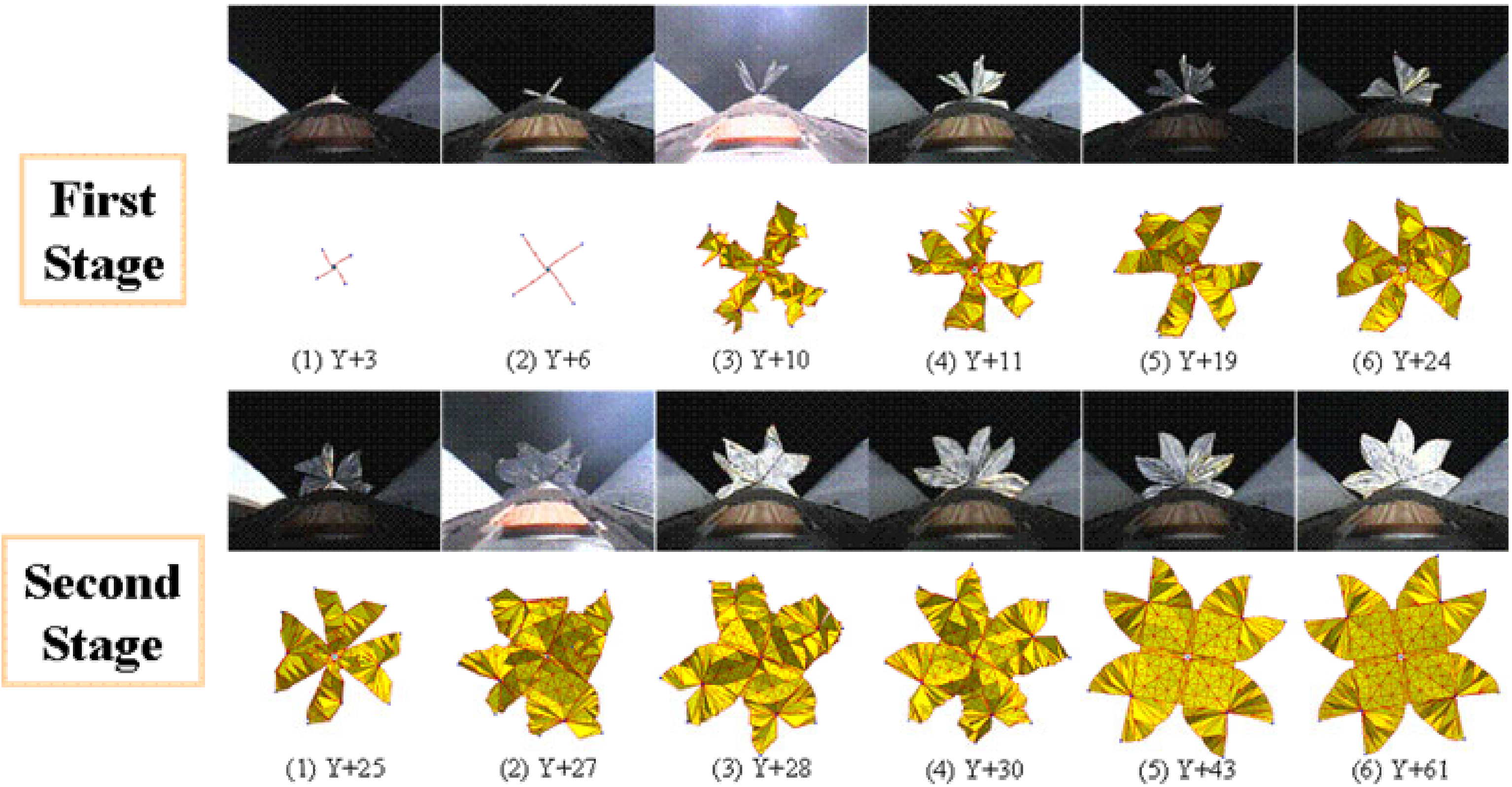
- ISA/JAXA conducted the sail deployment experiment in space via a sounding rocket via a sounding rocket S-310#34 that carried two types of sails whose diameter is 10m.

S-310#34 Sounding Rocket



Deployed Clover-Type Sail

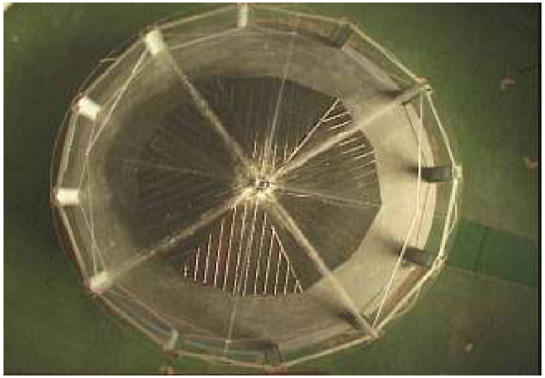
S310-34 Flight Results and Simulation



Membrane Deployment Experiments on the Ground

Clover Sail（ISAS）

Pseudo Logarithmic Sail（ISAS）

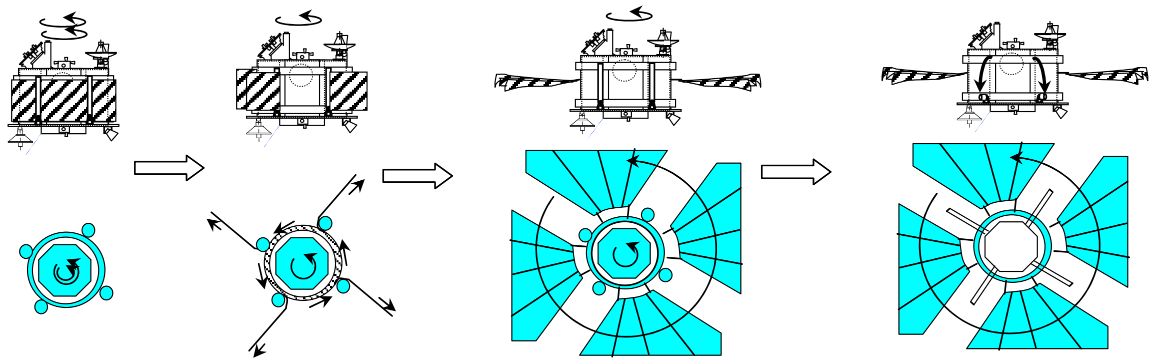


Double Accordion Sail (TMIT)

<u>Flight Experiments</u>

1) M-V#7 Sub-Payload (5m dia.)
2) H-IIA Piggy Payload? (10m dia)
3) Cruise Demoinstrator? (TBDm dia)

Drum Deployment Sequence



Spinning up

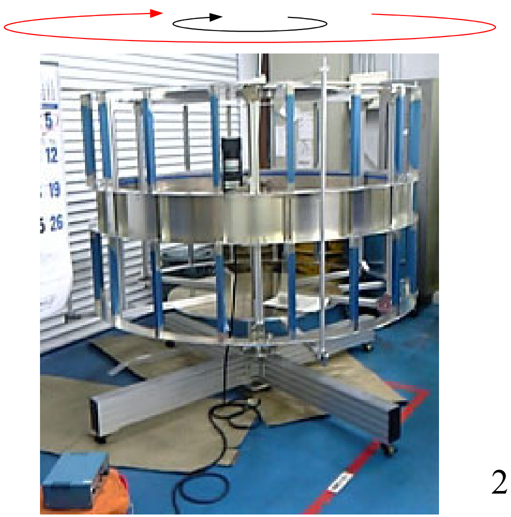
Deployment Start

Yo-Yo like Extension

Deployment End

2nd Deployment

Despinning Hub

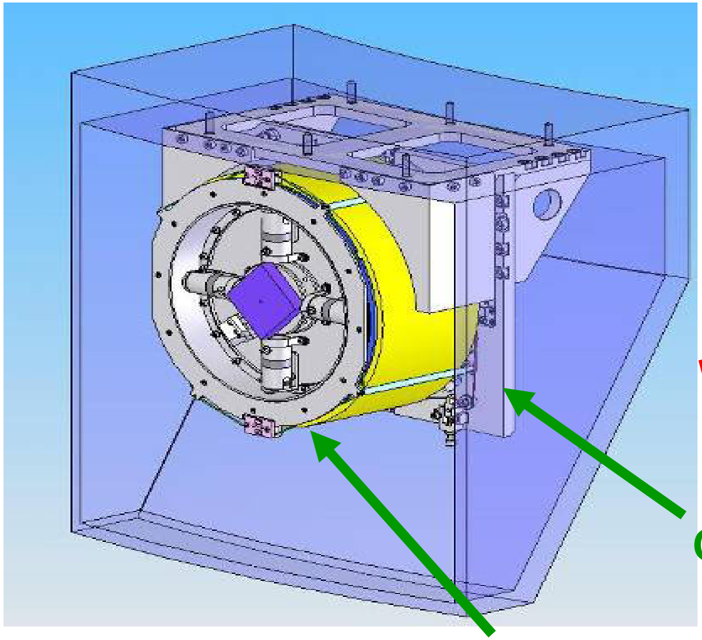


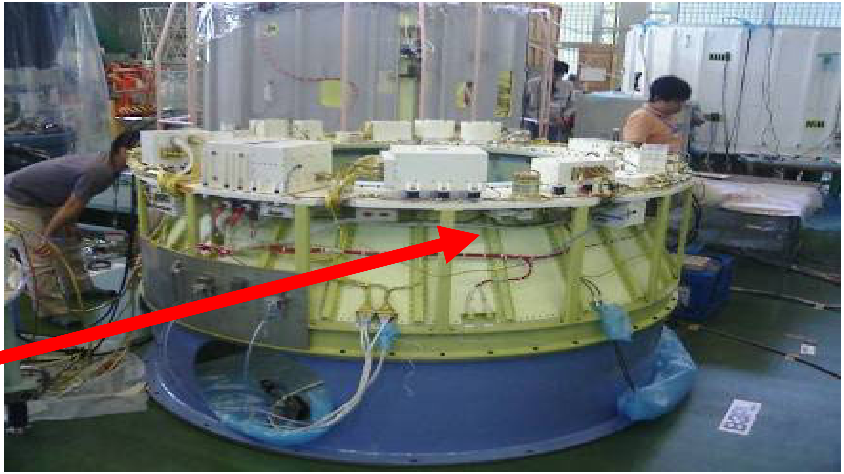
Power Feeder

5 Tracks

2.1 m diameter, 1.6 m Height.

Sub-Payload Experiment





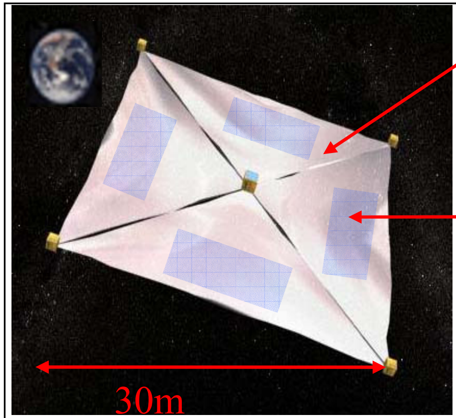
Cradle

Spacecraft

M-V#7 Sub Payload for Thin Film Solar Cell Satellite
5 kg ultra-small satellite deploying membrabe cell of 5 meter in diameter.

Demonstrator for Solar Electric Hybrid Sail

Purpose:
- Solar Electric Hybrid Sail spacecraft utilizes both photon and electric propulsion.
- The demonstrator aims at deploying a large membrane on which this film solar cells are.
- It also enables the steering technique for the sail spacecraft together with the guidance and navigation associated with this low thrust propulsion.



Thin Film Photon Sail
Photon Propulsion

Thin Film Solar Cell
Generation of solar electric power

Parameters	
Diameter:	30 m
Mass:	about 200 kg
Power:	a few kWs
Launch:	TBD
Mission :	1 year

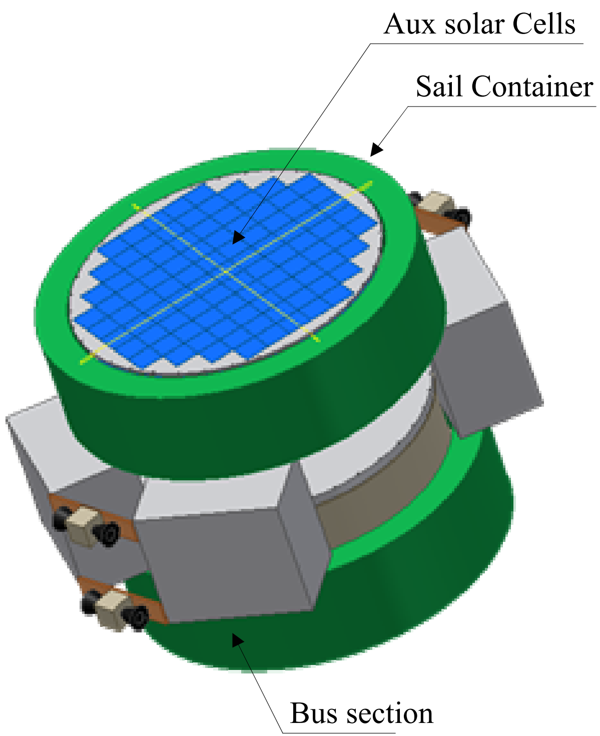
Demonstration of World's New technology:
(1) Deploying large membrane in space
(2) Generation / Use of solar power via thin film solar cells
(3) Demonstration of photon propulsion
(4) Cruise technology (Guidance, Navigation and Control)

What is expected?
- Developing innovative new propulsion and transportation capability in future.
- To expand the human's sphere of activity,
- To usher the new technology requisite for future transportation in solar system cruise.

Leads to the real mission still with the 1st class space science:
1. Jovian magnetosphere special observation,
2. 1st visit to unexplored Trojan asteroids.

Exploiting New Technology:
- Fabricating large Polyimide membrane is now within our reach,
- Electric propulsion is also within our hands.
- Future solar system cruise sooner or later tends to use nuclear power instead of solar power.
- Propulsion will start relying on high specific impulse means.
- Solar photon sail use is for limited use, in which only solar sail is essential.
- Cruise & rendezvous with other celestial bodies will still rely on the electric propulsion.
- Demonstrator looks at these views.

Small Hybrid Sail Demonstrator (1)

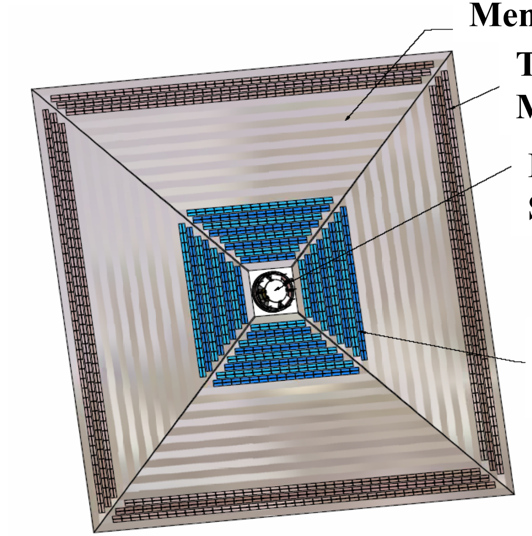


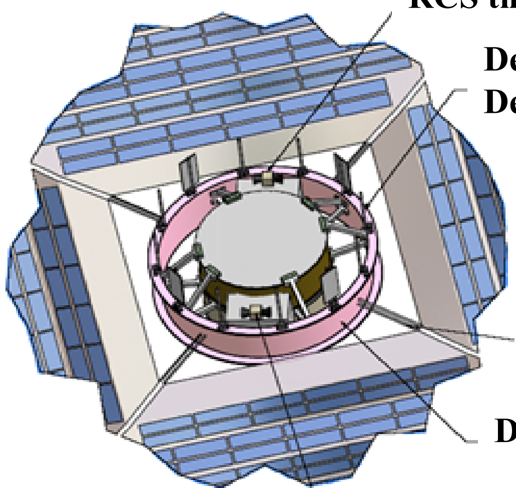
Overview

Items	Parameters
Sail	φ30m Solar Electric Sail
Spacecraft	Spinner, Attitude articulation via RCS
Mass	186 kg
Mission Life	1 year
Bus Power	150 W
Power generated	A few kWs
Vehicle	TBD
Launch	TBD
Orbit	Interplanetary
Station	UDSC/JAXA

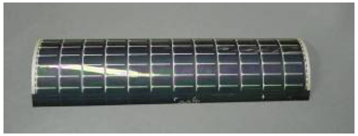
Small Hybrid Sail Demonstrator (2)

- Use of centrifugal force
- Diameter: 30m
- Sail made of Polyimide Film in view of Space Environment






Electric Sail Example


Film Solar Cell

Real Solar Power Hybrid Sailor

Seven News
in 'Solar Power Sail to Jupiter' Proposal

1. World's First Solar Powered Jovian Explorer,
2. World's First Combined Jovian Orbiter / Flyby Mission,
3. World's Highest Performance Ion Engines,
4. World's First Photon/Electric Hybrid Sail Propulsion,
5. World's First Background Emission Mapping,
6. World's First Access to Trojan Asteroids,
7. World's First Formation Flight in Jovian Magnetosphere.

A Prospect for Solar Sail Technology Utilization

1. Sooner or later, Nuclear Propulsion represented by Fission / Fusion Reactors will prevail for Large and Heavy Interplanetary Transportation in 21st century.

2. However, Nuclear Propulsion weighs heavy and not efficient for smaller spacecraft, and Solar powered electric propulsion continues to be sought for the time being.

3. Contemporary Ion Engines performance characterized in terms of specific impulse will shift for higher region dramatically. Ultra-High specific impulse era does come.

4. Pure Solar Photon propulsion is useless for rendezvous and orbiter missions and the applications will be confined to smaller flyby probes.

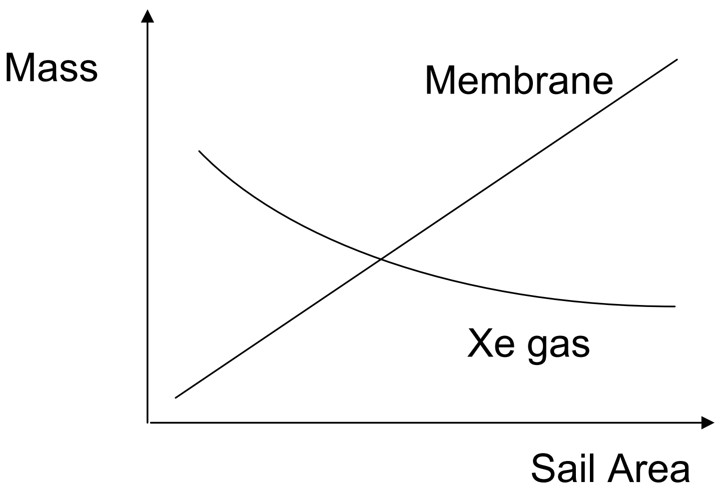
5. This Prospect infers : Solar powered high-specific-impulse Ion Engines combined with Solar photon propulsion will be utilized for medium-to-smaller missions in near future.

Nuclear Reactors Technology Prospect

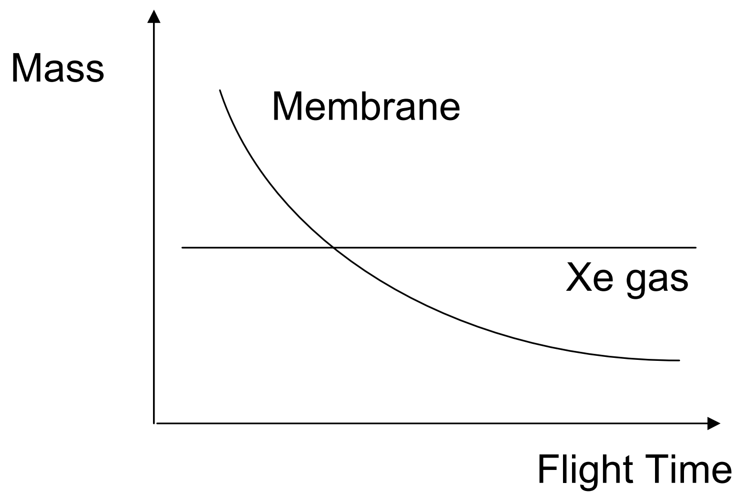
NASA's Prometeus Program / JIMO (Jovian Icy Moons Orbiter) Project is under intensive study. But JIMO was once canceled due to budgetary reason.

Fission Reactors that keep Uranium in dormant state seems much more safe than RTGs even at Launch.

Solar Electric Hybrid Sail - Concept



Flight-Time Fixed



Delta-V Fixed

Comparison : Proposed Solar Power Sail and Ulysses

Ulysses:

Mass: 370 kg, Powered by: RTG,

Launched by STS-41 with Double Upper Stage (1990),

Trajectory : ballistic.

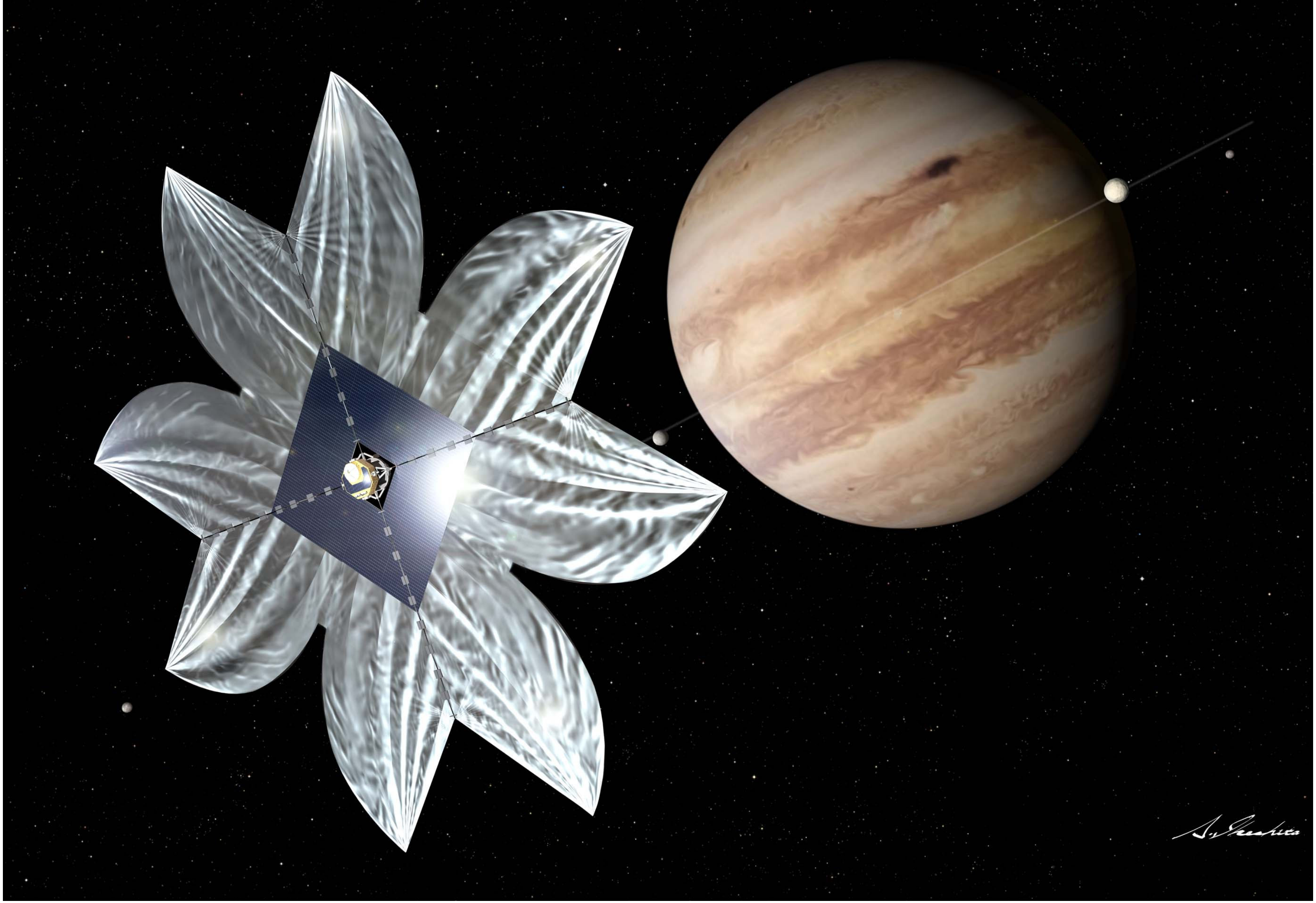
Proposed Solar Power Sail:

Mass: 650 kg including a Jovian Orbiter, Powered by Thin Film Cells,

Launched by M-V Smaller ELV,

Trajectory : Hybrid Combined SEP (Solar Electric Propulsion) with Photon

Solar Power Hybrid Sailor Approaching to Jupiter

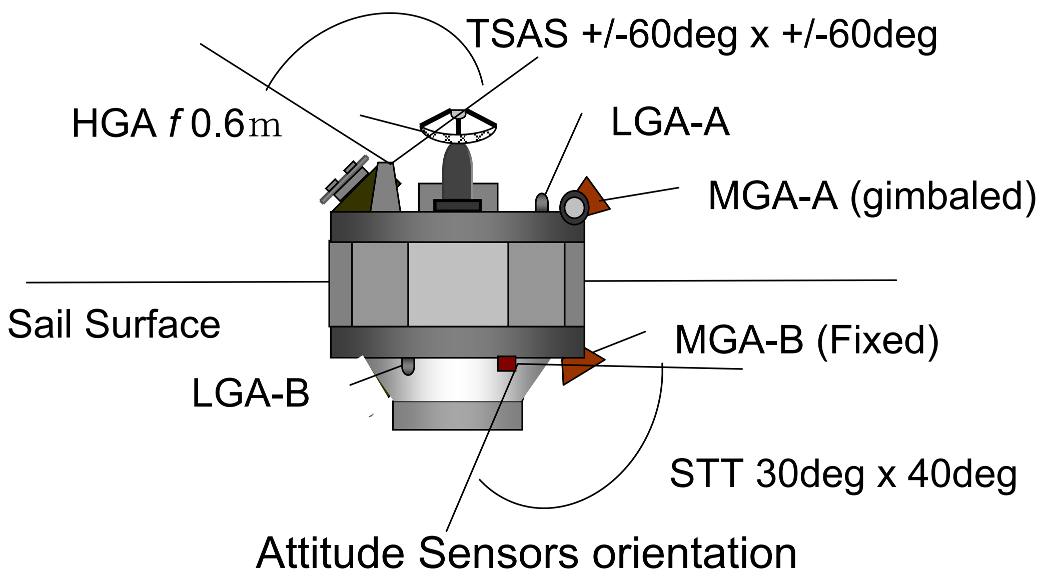


Spacecraft Outline

A Rotor / Stator stabilized spacecraft, with a Thin Film Cell Sail deployed,

Sail size : 50m in diameter,

A Hybrid propulsion using both Photon and Electric (Ion Engines).



Technology Demonstration

1. A Large Membrane Space Structure including Deployment strategy,
2. A Hybrid Propulsion using both Photon and High Performance Ion Engines,
3. Thin Film Solar Cells,
4. Reaction Control System (Jet) functioning at very Low Temperature,
5. An Integrated Propulsion/Power System using Fuel Cells.
6. Formation Flight in Jovian system,
7. Electric Delta-VEGA technique departing for outer solar system,
8. Ultra Stable Oscillator for 1-way range or VLBI orbit determination,
9. Ka-band for Interplanetary Missions,
10. Radiation-Resistant Technology for Jovian Orbiter,

* Ultra High Speed Entry Probe for Jovian Atmosphere. (optional)

Scientific Objectives in Solar Power Sail Mission

1. A Mapping Observation of Background Emission,
2. Jovian Science :
   Magnetosphere, Jovian Satellites, Jovian Atmosphere (option)
3. Flybys with Trojan Asteroids and Main-belt Asteroids, (Extended Flighjt Segment)
4. Gamma-Ray Bursts Detectors,
5. A Large Area Dust Counter.

Baseline Science Instruments Aboard

1. Visible / Near IR Background Emission and Zodiacal Dusts Detectors 7 kg
2. Gamma-Ray Burst Detector 1~2 kg
3. A Large Area Dust Counter 1~2 kg
4. Optical Navigation Cameras (included in Bus)
5. Jovian Orbiter 93 kg
6. Atmospheric Entry Probe 40 kg

Example : Major Mission Events

Launch Window :

Enough long launch windows are assured for 2011 and 2012 and further.

Major Event :

[2011] about 6 years

Launch:	2011 5
1st Earth Swing-by:	201210
2nd Earth Swing-by:	2014 9
Jupiter Arrival:	2017 3

[2012] about 6 years

Launch:	2012 6
1st Earth Swing-by:	201311
2nd Earth Swing-by:	201510
Jupiter Arrival:	2018 4

*** H-IIA (C_3=35 km^2/s^2) may make the flight period shortened one year.**

Launch Windows Example in ‘2011 & ‘12

Launch Window in ‘2011 : **Totally 2.5 months**

Type-I :4/28 to 6/11 arriving in March of 2017

Type-II:6/12 to 7/11 arriving in November of 2017

Launch Window in ‘2012 : **Totally 2 months**

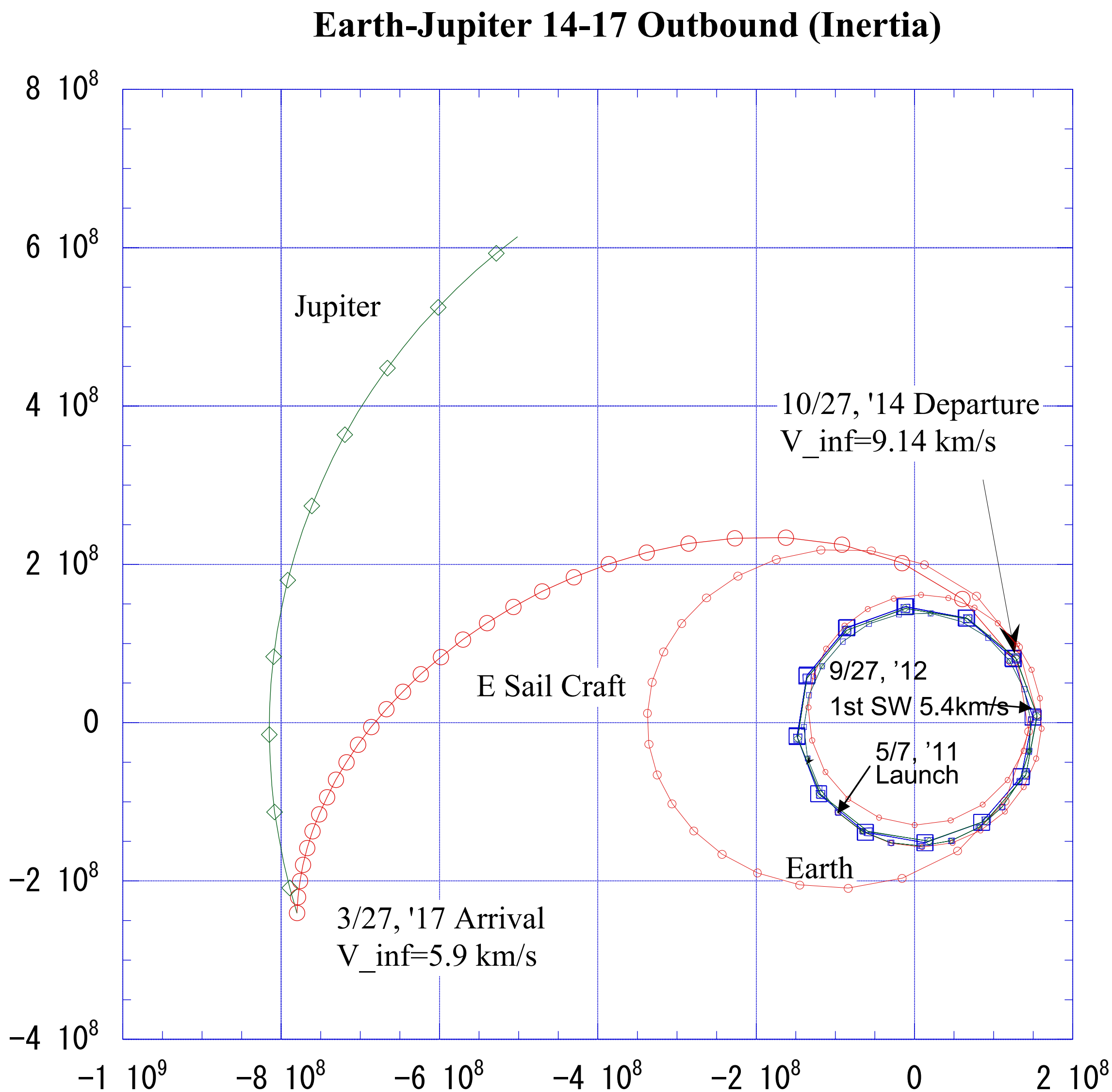
Type-I: 6/2 to 7/15 arriving in April of 2018

Type-II:7/16 to 8/5 arriving in December of 2018

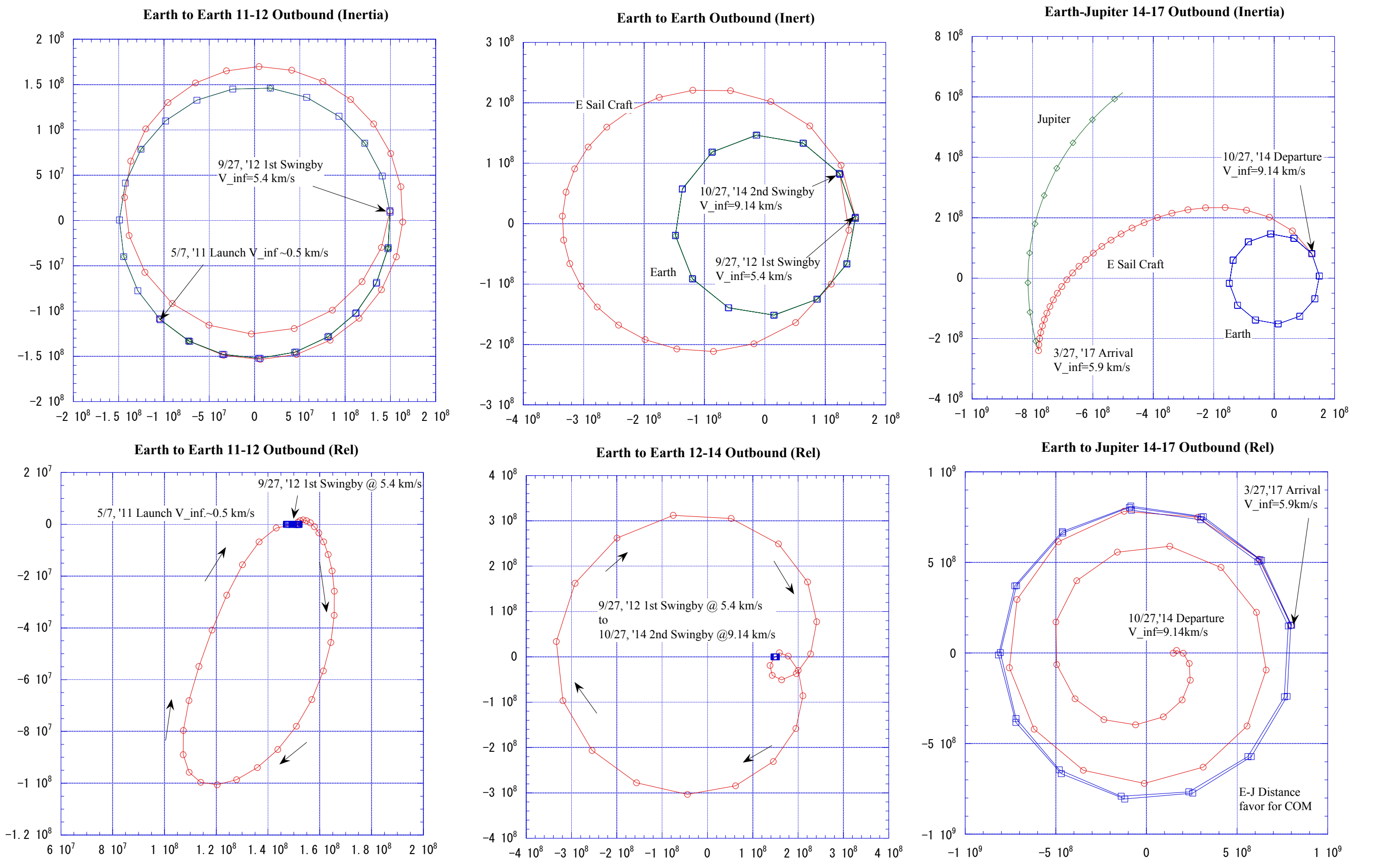
***Type-I : Outbound Departure with less flight time (less than 6 years)**

Type-II : Inbound Departure will more flight time (more than 6 years)

Typical Transfer Sequence



Flight Plan Example : Launch in ‘2011 Type-I (Outbound)



EDVEGA-1 ’11-’12

EDVEGA-2 ’12-’14

Trans-Jupiter ’14-’17 (March)

Launch Window : 4/28, ’11 to 6/11, ’11 with V_inf=~0.5 km/s.

Ion Engines Duty & Thrust/Power Assumed

	'11 Type-I A	'11 Type-I B	'11 Type-II A	'11 Type-II B	'12 Type-I A	'12 Type-I B	'12 Type-II A	'12 Type-II B
E-J	1947	925	487	77	1947	950	974	643
E-E 2yr EDVEGA	6810	3312	6171	2931	6575	3187	5942	3236
E-E 1.4yr EDVEGA	5726	5440	7129	6773	5704	5419	6760	6422
Total (hrs)	14483	9677	13787	9781	14226	9556	13676	10301

A: Simply Sum of On Time (Hours)
B: Flow rate Weighted Sum of On Time (Hours)

- Weighted Nominal Duty : 10,000 hrs : as low as 'Hayabusa' Mission.

*** Spec for 'Hayabusa' (MUSES-C) : 18,000 hrs.**

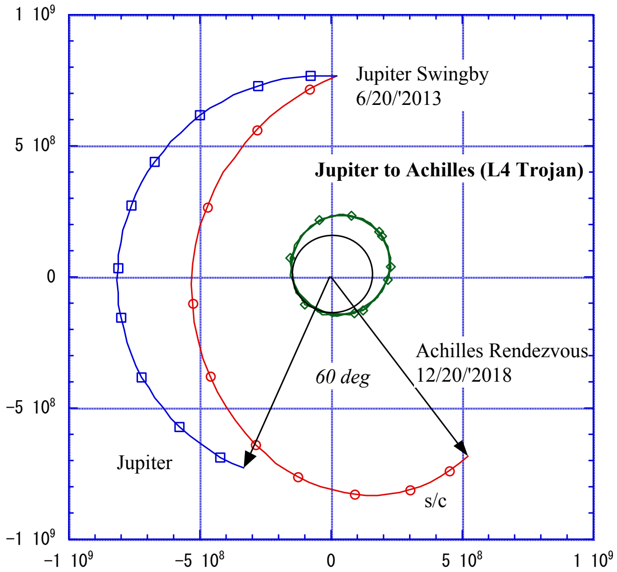
- Power to Thrust Parameters assumed :

9mN / kW, with 130W heat out / kW, and with the Isp of 10,000 sec.

Solar Electric Hybrid Sail Design Point (8kW class)

Sail Area (m2)	0	500	1000	2000	3000	4000	5000	6000	10000	20000
wet (kg)	0	480	542	648	648	648	648	648	648	648
Xe		50	50	40	37	34	32	30	27	22
IES sys (kg)		75	75	75	75	75	75	75	75	75
Sail (12.5μm) (kg)	imide photon sail	7.5	15	30	45	60	75	90	150	300
Sail (7.5μm) (kg)	imide photon sail	5	10	20	30	40	50	60	100	200
Spin-up Fuel (12.5μm) (kg)		0.12	0.47	1.9	4.2	7.5	11.7	16.88	46.88	187.5
Spin-up Fuel (7.5μm) (kg)		0.06	0.235	0.95	2.1	3.75	5.85	8.44	23.44	98.875
Steering Fuel (12.5μm) (kg)	<- 4π rad	1.5	5	20	45	80	125	180	500	2000
Steering Fuel (7.5μm) (kg)	<- 4π rad	0.75	2.5	10	22.5	40	62.5	90	250	1000
Criterion (12.5μm) (kg)		346	400	481	442	392	329	256	-151	-1937
Criterion (7.5μm) (kg)		349	404	502	481	455	423	385	173	-748

Beyond Jupiter Swingby to Trojan Asteroids Region



An Example to Achilles

Targeting Trojan Asteroids at L4.

At least Two Flybys with Trojan Asteroids.

First Glimpse of Trojan Asteroids.

A Typical Flyby Example

16 Flight Cases are found for Double Trojan Asteroids Flybys with less than 30 m/s delta-V.

Example) Delta-V=23.9 m/s

Asteroids	1973SA2(Laertes)	1930BH(Odysseus)
Magnitude	10.7	7.93
Flight Days after Jupiter Swingby	1577	1786
Phase Angle (deg)	107.6	105.35

*** 32 Flight Cases found with less than 50 m/s delta-V**

*** 3 Flight Cases are found for Triple Trojan Asteroids Flybys with less than 500 m/s delta-V**

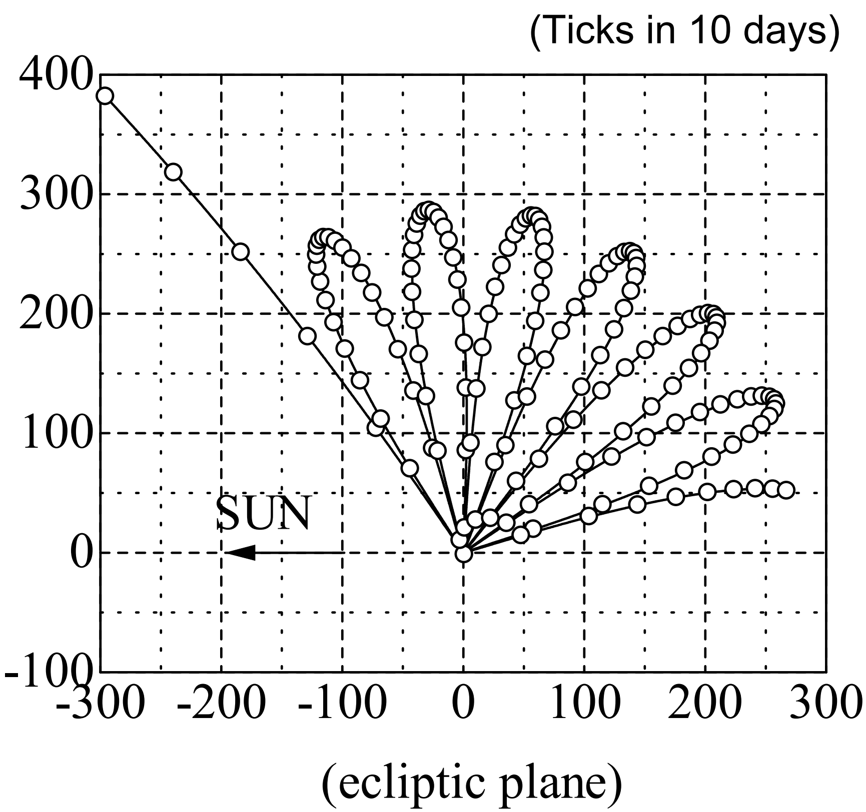
Chances in flying-bys with 1 main-belt and 2 Trojan asteroids

Best Opportunity : ⊿V=143.8 m/s

	1 (Main-belt)	2 (Trojan)	3 (Trojan))
ID	2003FK110	1996TS49 Augeias	1996TN49
H(Mag)	14.6	10.8	11.9
Flight Days after J. SW	989	1478	1647
Rel. Speed (km/s)	6.3808	6.8108	7.7859
□1(deg)	80.54	138.86	151.64
□2(deg)	101.72	110.44	109.78

*** 16 Flying-bys chances are found for 1 Main-belt and 2 Trojan Asteroids with delta-V less than 300 m/s.**

Orbiter Trajectory
(Jupiter-Sun FixedCoordinate)



Phase Angle in Approach is 110 degrees.

Flight Plan for Orbiter and Entry Probe

Jovian Orbiter Trajectory :

Separated 100 days before the Jupiter Swingby.

Polar Elliptic Orbiter. 1.5 RJ x 300 RJ.

Jupiter Atmosphere Entry Probe

The Orbiter carries an Entry Probe.

An Entry probe released at a distance to Entry.

An Orbiter tracks an Entry probe in formation flight for magnetosphere observation.

Mass Breakdown for Baseline Spacecraft

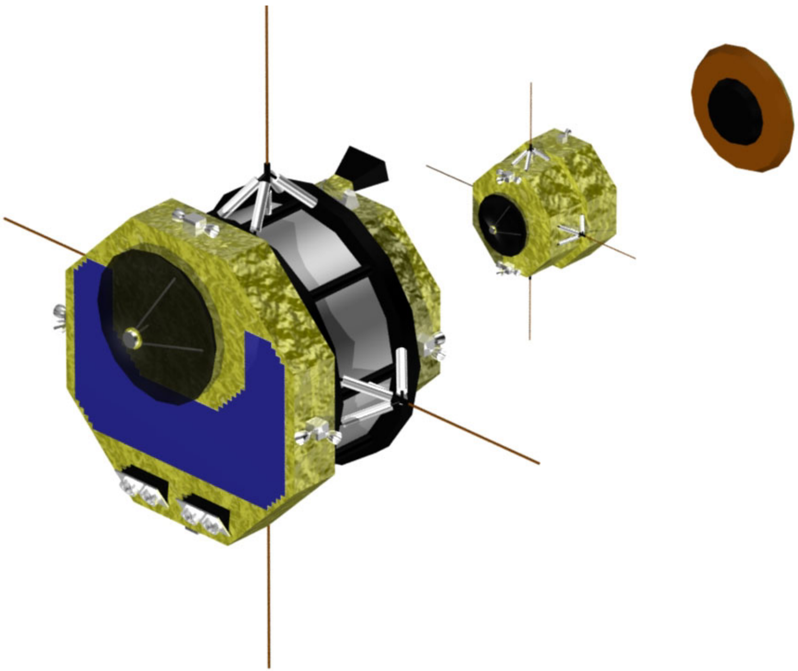
Overall :

Launch :	**650 kg**	**(V_inf.=1.0km/sec) Direct Ascent**
Xe loaded :	**65 kg**	
Bi-Prop Fuel :	**60 kg**	**(NH3/N2O or MON) Isp=260sec(cont.)**

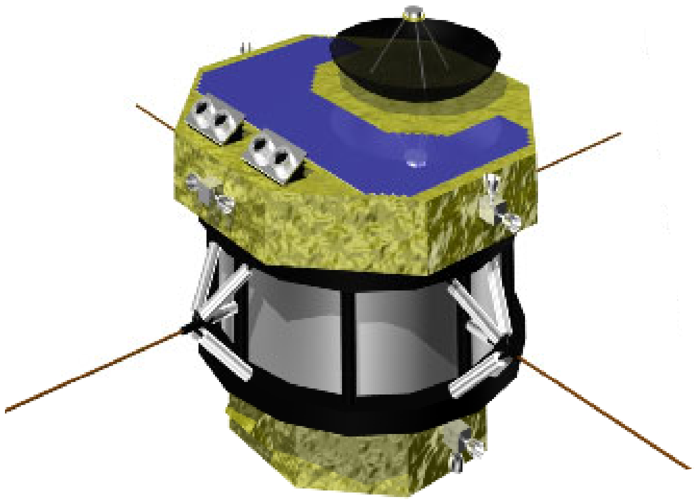
Break-Down

Wet Mass	**=**	**650 kg**	
SCP WEIGHT	**=**	**68**	**Thin-film Cell（a-Si38kg）+30kg Drum, etc.**
EP XE TOTAL	**=**	**65**	
EP S/S WEIGHT	**=**	**65**	**(PPU PS)**
BP F/O TOTAL	**=**	**60**	**(Isp=260s.cont.)**
BP S/S WEIGHT	**=**	**35**	
STR+HRNS+THRML	**=**	**110**	
Science Payload	**=**	**28**	
Jupiter Orbiter	**=**	**128**	**(option : Entry Probe 40kg included.)**

Spacecraft Outline

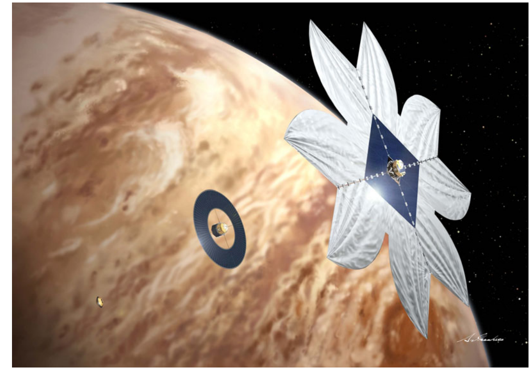


Mother ship, Orbiter and an Entry Probe



Mother ship Configuration

Jovian Small Orbiter Outline



Orbiter : Spin-Stabilized

Size : 700mmϕ in diameter.
Operational Temperature : -30degC (243degK)
Heater power : 80W assumed.
Power required : 150W (no- communication),
250W.(with communication XPA: 20W)
Cells Film : 60m². (~9mϕ) No Drum Structure required.
Ka-band TLM via HGA fixedly mounted.

Routine operation assumes 0.5 hr/day.
Heavy duty period is backed up by Fuel Cells aboard.

Aero-probe: 30~40kg :
Heat-shield 20kg, Drogue (Parachute): 2.5kg, Bus-Instrument: 1.5kg,
Bus structure : 4kg, Science Instruments: 2kg.

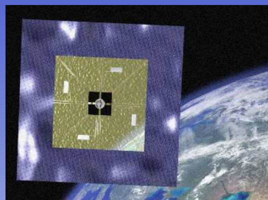
Solar Sail Demonstration Roadmap

2003

Centrifugal Force Deployment in Space (S310#34)

Suceeded in deploying 10m diameter Sail in space.

Contributed to updating accurate model.



2006

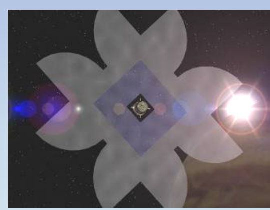
Solar Power Sail Test (M-V#7 subpayload)

Thin Film Solar Cell is actually used in space.

TBD

Photon Sail Demonstration (Piggy)

Attempting Photon Propulsion



TBD

Solar Power Sail Demo in Interplanetary Field

Guidance and Navigation Demonstration via 30m diameter Sail Craft.

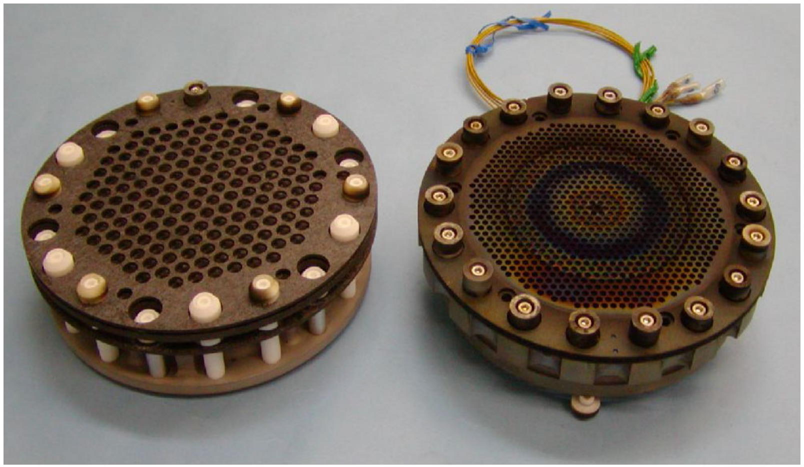
TBD

Solar Power Hybrid Sail Craft to Jupiter

Hybrid Propulsion to Jupiter with Ultra High-Isp Ion Engine and 50m diameter Photon Sail.

Microwave-driven μ10 engine to μ10HIsp

μ10(Hayabusa Heritage) to μ10HIsp(15kV, Isp 10,000sec, 2.5kW)



μ10HIsp Grid μ10 Grid