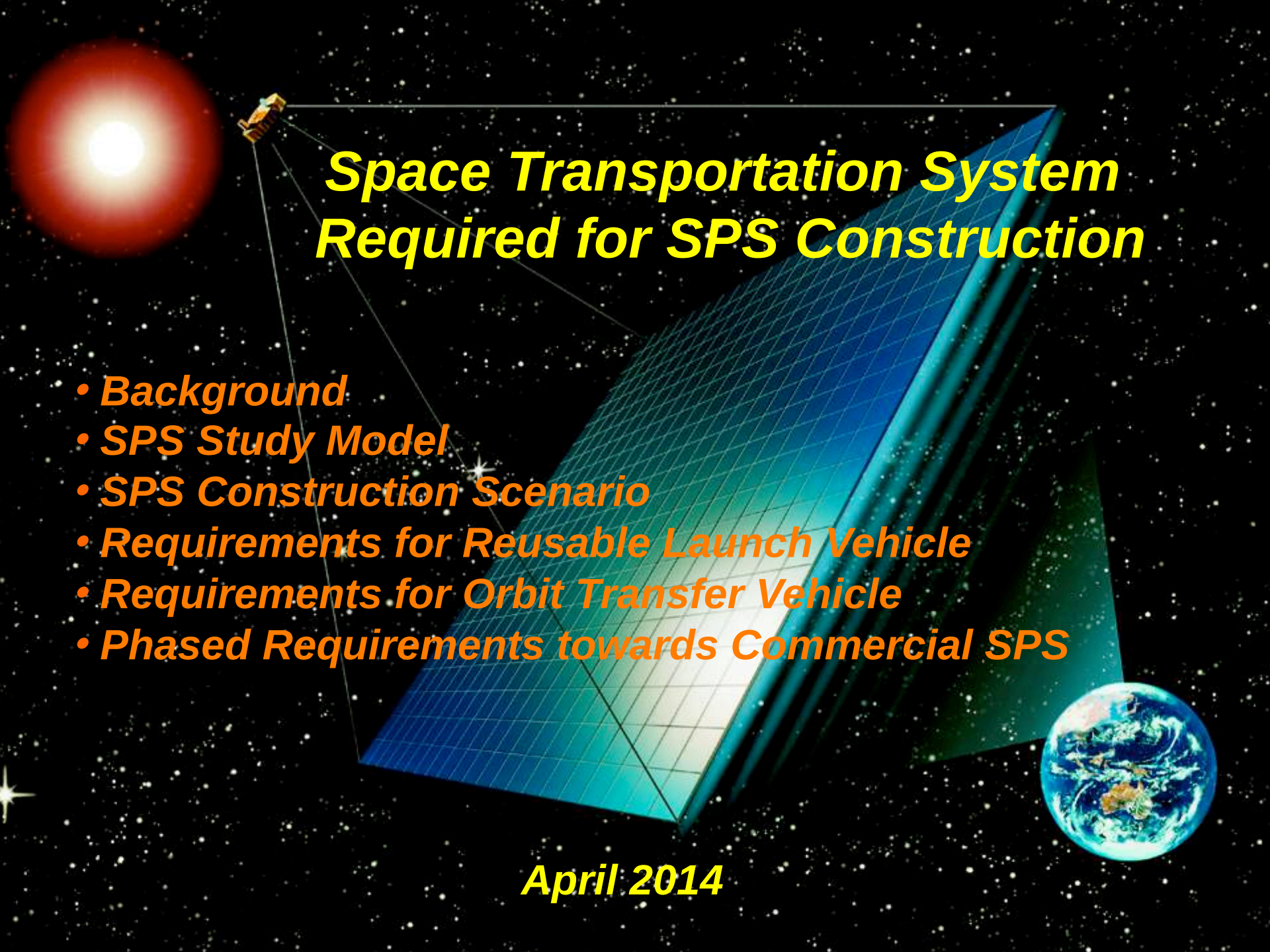


Space Transportation System Required for SPS Construction

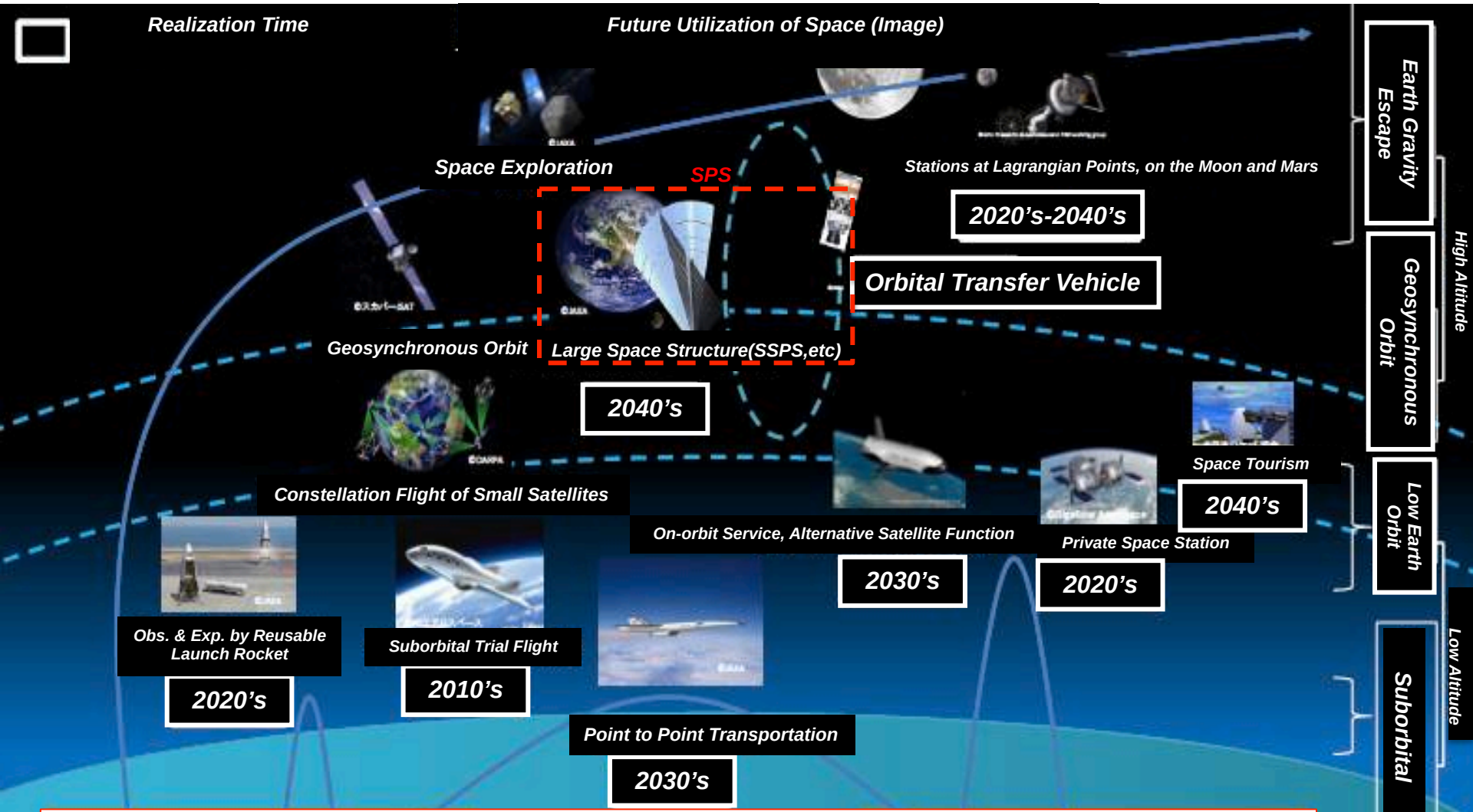
- Background
- SPS Study Model
- SPS Construction Scenario
- Requirements for Reusable Launch Vehicle
- Requirements for Orbit Transfer Vehicle
- Phased Requirements towards Commercial SPS

April 2014

Background

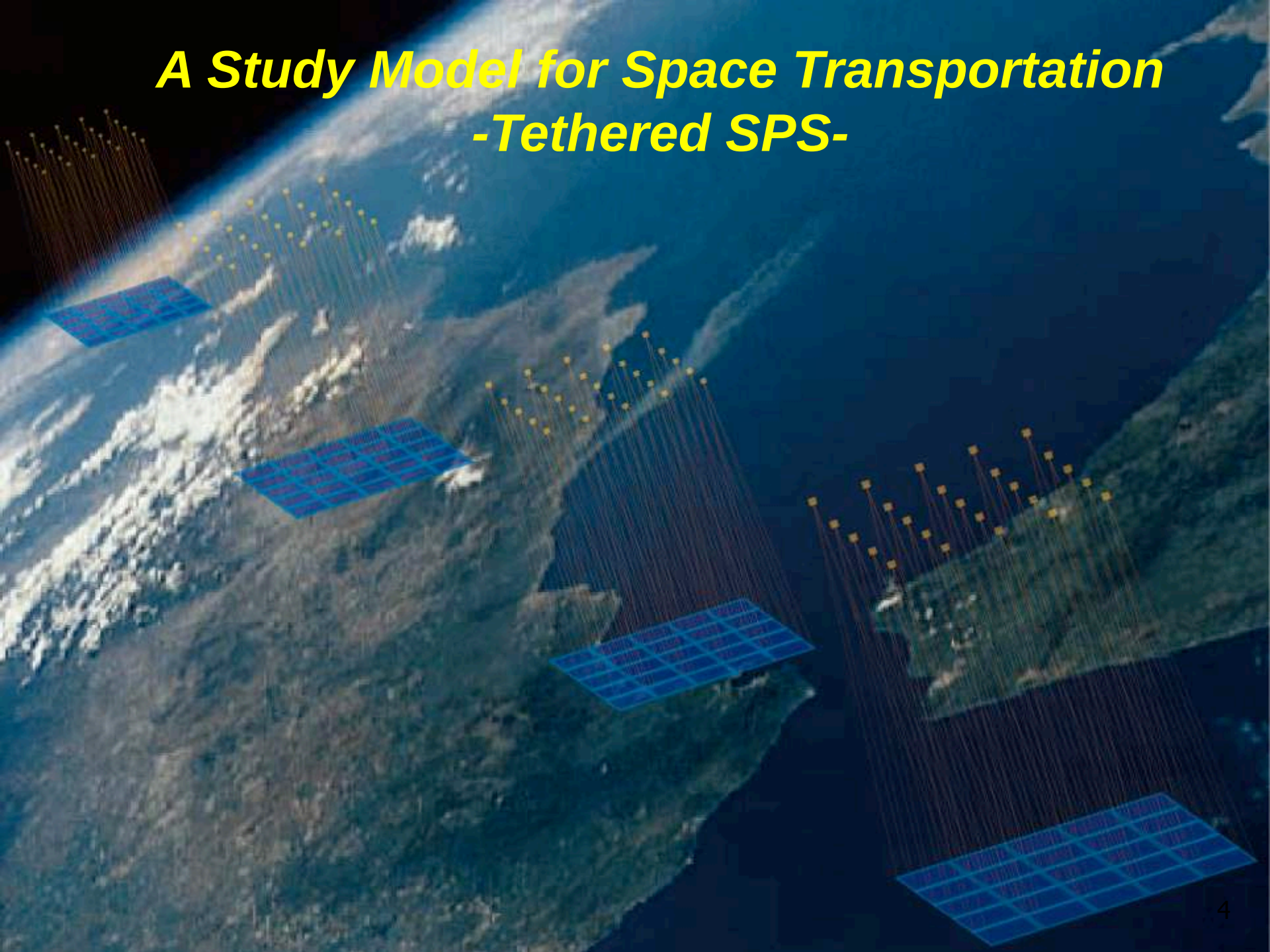
- Space transportation is one of the crucial issues to realize SPS.
- However, the space transportation system for SPS has not been well defined, except for the cost requirement to be reduced to 1/100-1/50 of its current level.
- Actually, the space transportation community has no specific information on the design and operation requirements for SPS construction, even though recognizing SPS as a potential customer in their roadmap.

Long-term Vision for Space Transportation System (Draft)
Office of National Space Policy (Dec.2013)

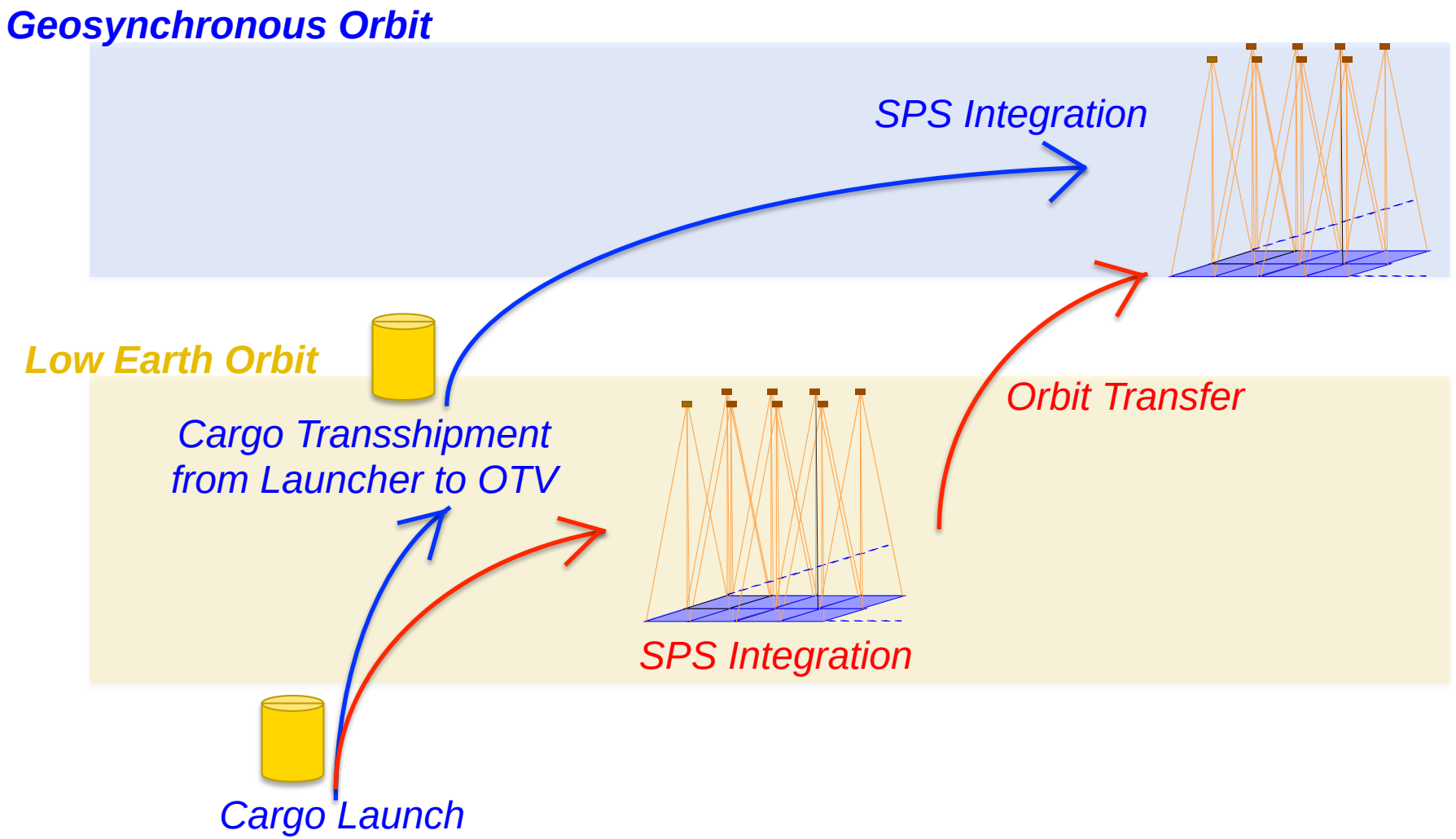


Space transportation community recognizes SPS as one of their future missions, but SPS requirements on space transportation are not well specified yet

A Study Model for Space Transportation -Tethered SPS-



Two Major Construction Scenarios



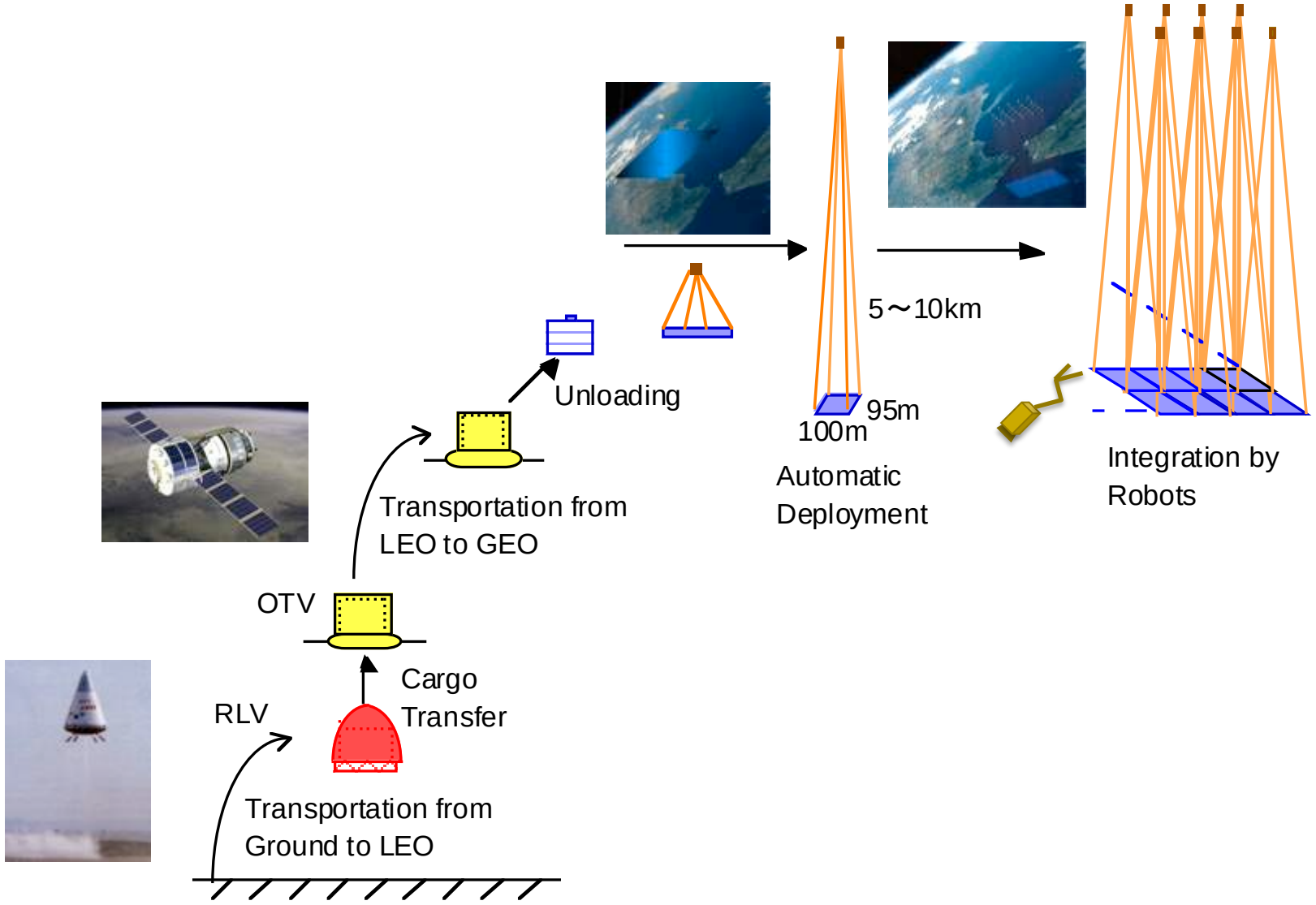
Trade-off Study between GEO and LEO Construction

Total Mass (One SPS)	20,000 Mtons	
Construction Period	One year（construction） ＋Three months（LEO-GEO transportation）	
Construction Orbit	GEO	LEO
OTV Cargo	50 Mtons	20,000 Mtons
OTV System	100N class thruster x 200 (three times per year))	40,000N class thruster (once per year)
Attitude Control and Orbit Maintenance during Construction	Lower gravity force No drag force	Higher Gravity force Drag force
Transportation and Construction	Higher robustness, consisting of individual events	Lower robustness, consisting of sequential events
System Verification during Integration	Transmission test is not possible in the early phase.	Transmission test is possible from the early phase.
Manned Construction	Difficult	Possible

Preferable

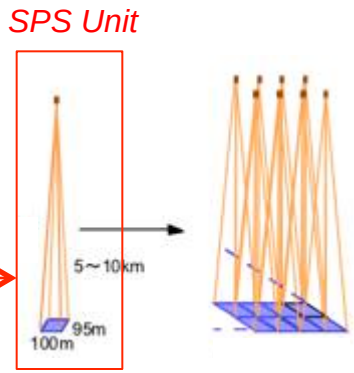
Advantage

GEO Construction Scenario for Tethered SPS



Requirements for Space Transportation

Operation/Construction orbit	*Geosynchronous Orbit*
SPS class	*1GW*
Total weight	*26700 Mtons (Latest Model)*
Construction/replacement	*1 year*
Payload mass	*50 Mtons ,1 SPS unit*
Reusable Launch Vehicle (RLV)	*50 Mtons payload capability* *Ground to LEO (500km)*
Orbit Transfer Vehicle (OTV)	*50 Mtons payload capability* *LEO to GEO* *4 months round trip*



Importance of LEO Transportation Cost

Power Cost vs Launch Cost (LEO)

	NASA Reference Model	NEDO 1993 Model	JAXA 2003 Model	USEF 2002 Baseline Model
Mass	50,000 Mtons	20,000 Mtons	10,000 Mtons	26,600 Mtons
Power	5GW	1GW	1GW	1GW
Cost	26500 M$ (1996$)	23610 M$	12929 M$	17081 M$
Life	30 years	30 years	30 years	40 years
Transportation cost	32.8%（G to LEO $100/kg, LEO to GSO$30/kg)	7,250 M$(G to LEO 250$/kg、LEO to GSO 25$/kg)	2,795 M$ (G to LEO 170$/kg、LEO to GSO 10$/kg)	7,785 M$ (G to LEO 100$/kg, LEO to GSO 175$/kg)
Transportation Cost Ratio	33%	31%	22%	46%
Power Cost	8.5¢/kWh	23¢/kWh	8.9¢/kWh	13.4¢/kWh
G to LEO 10K$/kg	2.2$/kWH	279¢/kWH	112¢/kWh	257¢/kWh
* G to LEO 5K$/kg	1.14$/kWH	148¢/kWh	60¢/kWh	134¢/kWh
G to LEO 1K$/kg	28¢/kWh	42¢/kWh	18¢/kWh	35¢/kWh

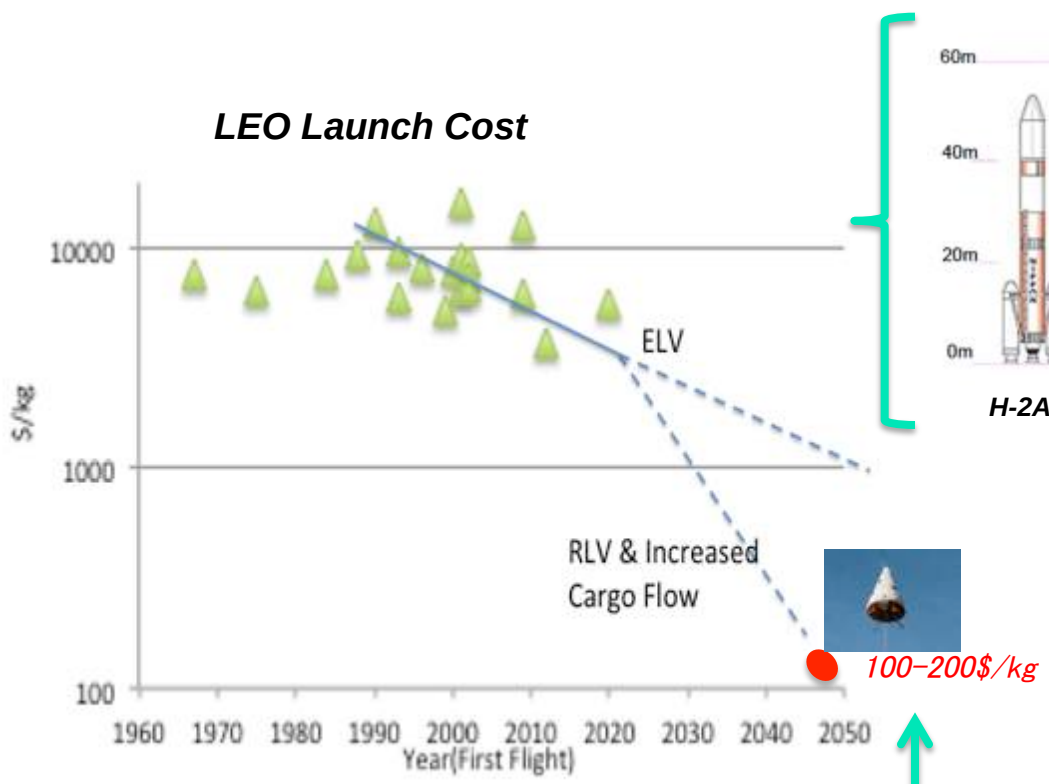
* Assuming that all construction cost targets are achieved except for LEO transportation cost.

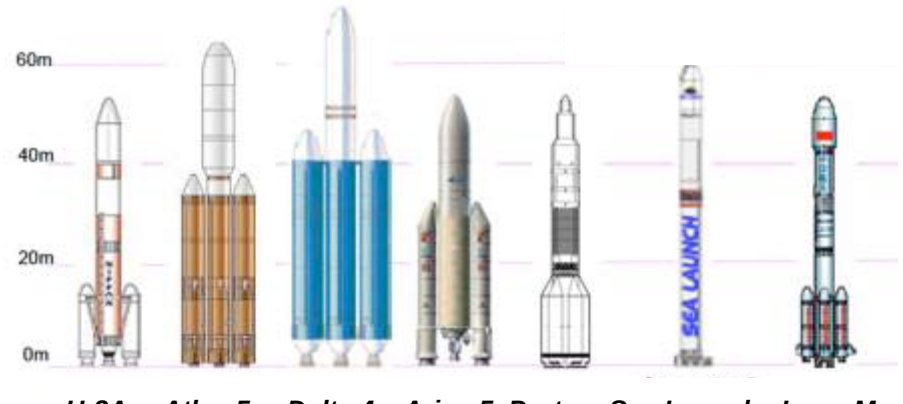
Space Transportation to LEO
- Current technology level and target level for SPS -

	Current	*SPS Target*
Cargo Weight	*30 Mton*	*50 Mton*
Cargo Flow to Space	*Several hundreds Mtons/year*	*10,000 Mtons/year*
Transportation Cost (Ground to LEO)	*5-10 k$/kg*	*Several 100 $/kg*
Launch Vehicle	*Expendable*	*Reusable*

Falcon Heavy
Commercial, low cost, heavy weight lifting

LEO Transportation Cost (LEO)

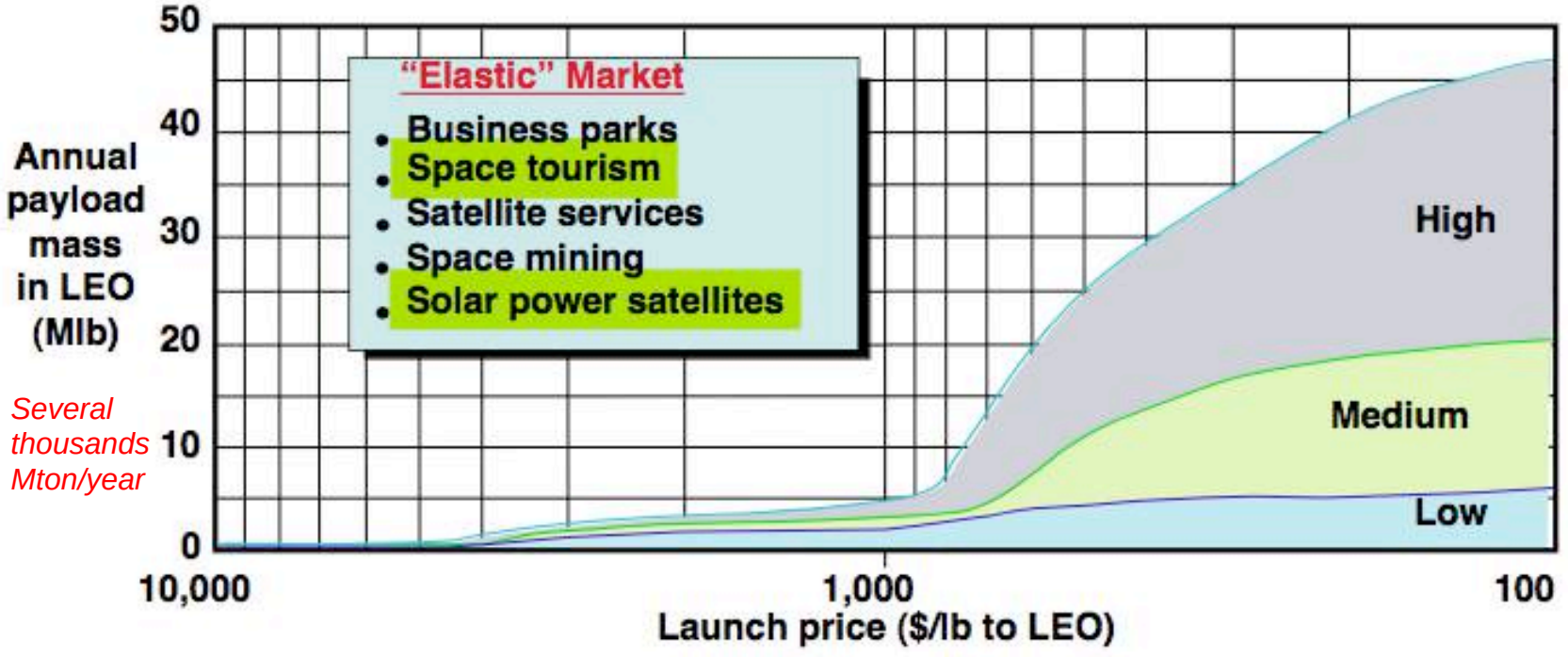




Reusable launch Vehicle
Total Weight: 2000 tons
Payload: 50 Mtons
Fuel: 1800 tons (Hydrogen250tons, Oxygen 1550 Mtons)

JAXA/ISAS RTV Reusable vehicle testing

Cargo Flow
LEO Transportation Cost vs Annual Payload Mass

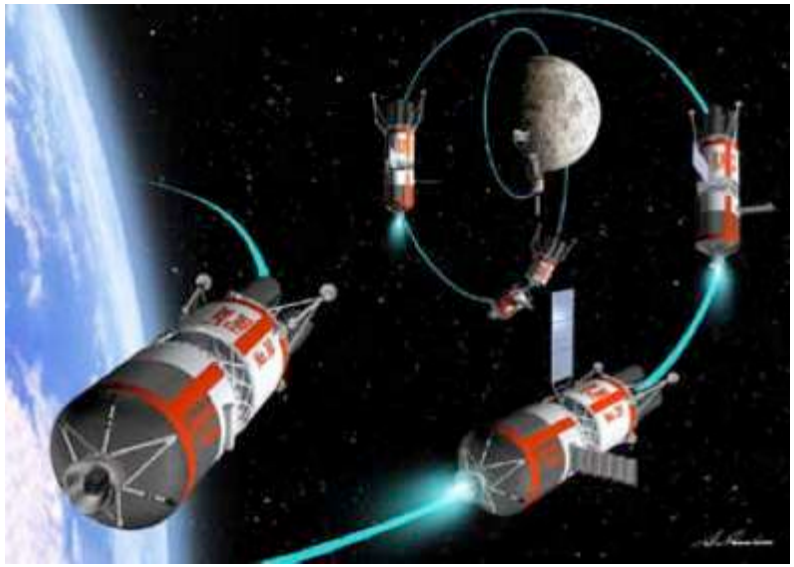


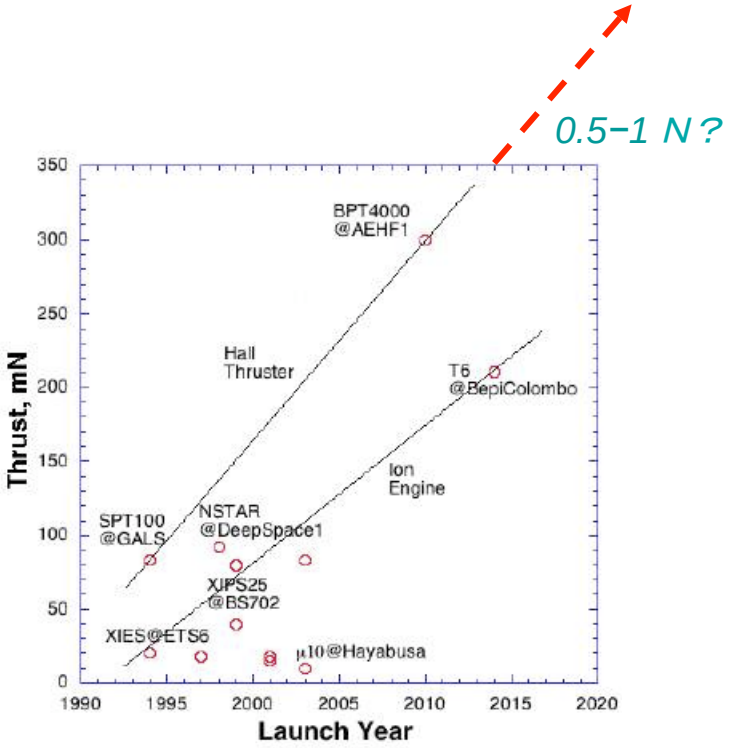
Several thousands Mton/year

ina-lab.isas.jaxa.jp/documents/the_next_goal_for_rockets.pdf

Electric Propulsion for Orbit Transfer Vehicle
-Current technology level and target level for SPS -

	Current	SPS Target
Cargo Weight	Several Mtons (orbit maintenance, GTO/GEO transition, planetary exploration)	50 Mton
Cargo Flow	Several Mtons/year	10,000 Mtons/year
Thrust Level	100 mN Level	100 N Level
Transportation Cost (LEO to GEO)	No specific data	50-100 $/kg

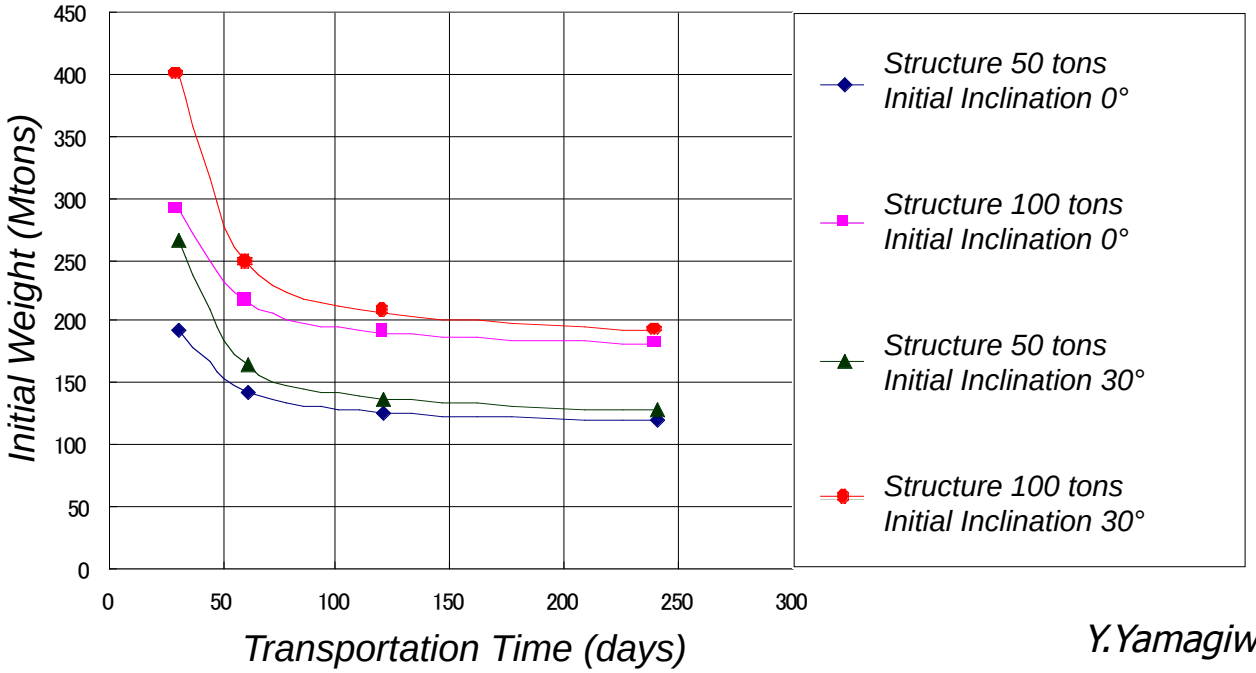




Development History of Electric Propulsion (Kuninaka, 2011)

OTV Transportation Time from LEO to GEO

Payload: 50 tons,Specific Impulse:3000 sec、Working Gas: Argon, Power Specific Mass:10kg/kW、Thruster Specific Mass:2kg/kW



Y.Yamagiwa, 2005

Transportation time longer than 60 days is desirable, considering the initial weight (fuel).

OTV Capabilities Required for SPS Construction

	Capabilities and Requirements	Note
Cargo	A unit of tethered SPS, fuel, and miscellaneous items	A unit of SPS consists of sandwich panel and bus system Fuel is for SPS orbit maintenance and construction robots.
Cargo Weight	50 Mtons	45 Mtons (unit) and 5 tons (miscellaneous)
Cargo Volume	10mx5mx4m	
Operation Time	4 months	Round trip between LEO and GEO
Shield Container	less than 10 krad inside container	Requirement from photovoltaic cells
Manipulator	Transshipment from launcher to OTV at LEO Unloading and loading at GEO	Loading and unloading of cargo Construction support
Optional Function	Deployment of SPS unit Thrusting for SPS orbit maintenance	

OTV System (example)
Total Weight: 182.2 tons、Structure:50 tons、Fuel:37.6 tons、Thruster:4.3 tons、Power Generation System: 21.5 tons、Payload:50 tons、Thrust 118.4N、Electric Power: 2150 KW、Round trip(LEO/GEO) :118 days

Requirements of RLV and OTV

Construction	*every year (steady construction)*
Payload mass	*50 Mton (1 SPS unit)*
Reusable Launch Vehicle (RLV)	*Ground to LEO (500km)* *15 RLVs* *Turn around 5 days* *2.83 launch/day* *1000 launch life* *1 RLV* manufacturing/year
Orbit Transfer Vehicle (OTV)	*LEO to GEO* *206 OTVs* *4 months round trip* *1000 round trip life* *0.6 OTV* manufacturing/year

Image

Ferris wheel

Development Roadmap towards Commercial SPS

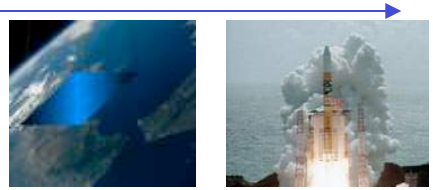
Research Phase

11 12 13 14 15 16 17 18 19 20

Ground demonstration

Small-scale on orbit demonstration

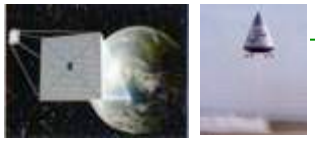
100kW class on orbit demonstration



Development Phase

21 22 23 24 25 26 27 28 29 30

2MW class demonstration

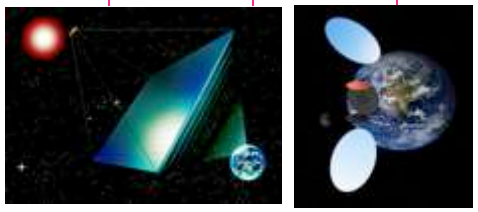


200MW class plant

Commercial Phase

31 32 33 34 35 36 37 38 39 40

1GW class first commercial model



Commercial SSPS（1SSPS/year）

Space Transportation Required for SPS Development

Phase	Small scale demonstration	Large scale demonstration	Small plant	Large plant	First commercial model	Commercial
Target year	～2017	～2020	～2025	～2030	～2035	2035～
Orbit	LEO	LEO	1000 km	GEO	GEO	GEO
Power level	1～5kW	100 kW	2 MW	200 MW	1 GW	1 GW
System weight	500 kg	15 Mtons	42.5 Mtons	5300 Mtons	26600 Mtons	26600 tons
Construction	NA	NA	6 months	3 years	5 years	1 year
Payload weight	500 kg	15 Mtons	10 Mtons	50 Mtons	50 Mtons	50 tons
Launch vehicle	Small ELV LEO	Large ELV LEO	1 RLV 1000km 5 Round trips 1 launch/month	1 RLV 500 km 207 round trips 1 launch/5 days 5 days turn around	3 RLV 500 km 345 round trips 1 launch/2 days 5 days turn around	15 RLV 500 km 69 round trips 2.8 launch per day 5 days turn around
Orbit transfer vehicle	NA	NA	NA	14 OTV 500 km-GEO 9 round trips*	42 OTV 500 km-GEO 15 round trips*	206 OTV 500 km-GEO 3 round trips*

Epsilon Launch Vehicle

H-II Launch Vehicle

Reusable Sounding Rocket

OTV(Image)

*:fuel 38 tons for a round trip

Summary and Conclusion

- *Based on the current SPS model (Tethered SPS/ Basic Model), the requirements on the RLV and OTV are defined.*
- *50 Mtons cargo capability and 5 days turn around time are required for RLV, and 50 Mtons cargo capability and 4 months round trip are required for OTV.*
- *RTV is required early 2020's and OTV is required around 2025 for the SPS plant level verification.*