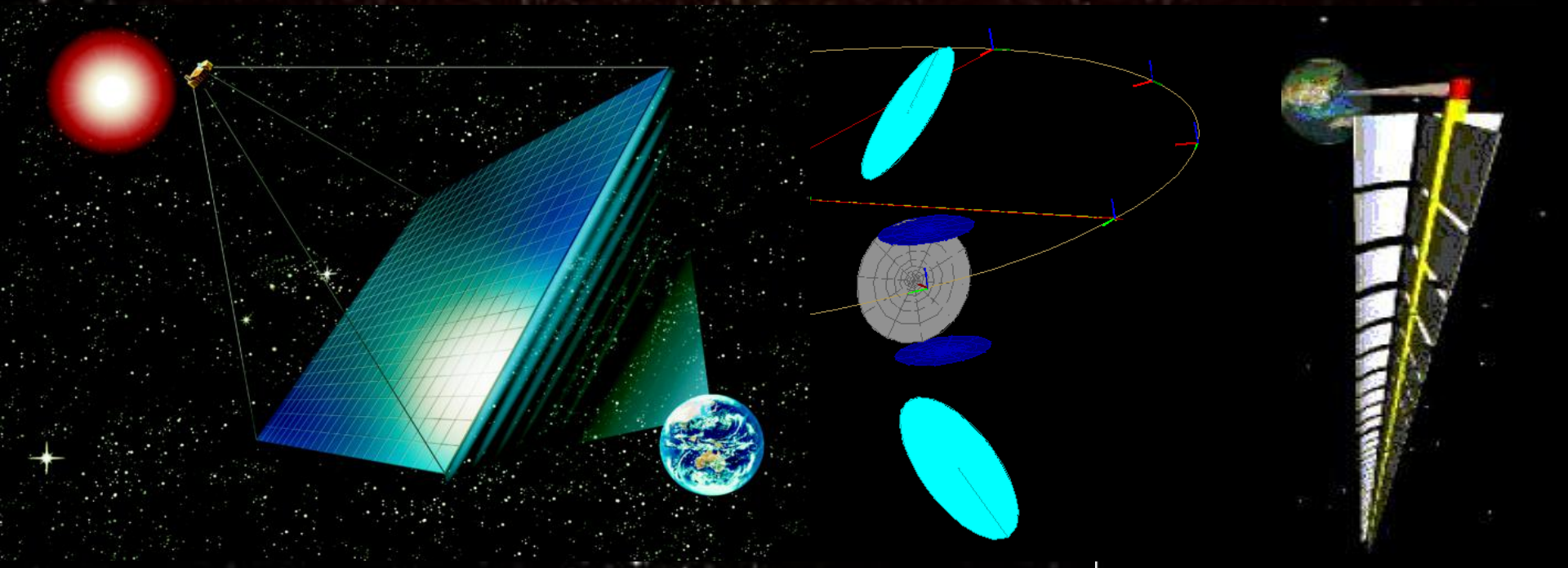
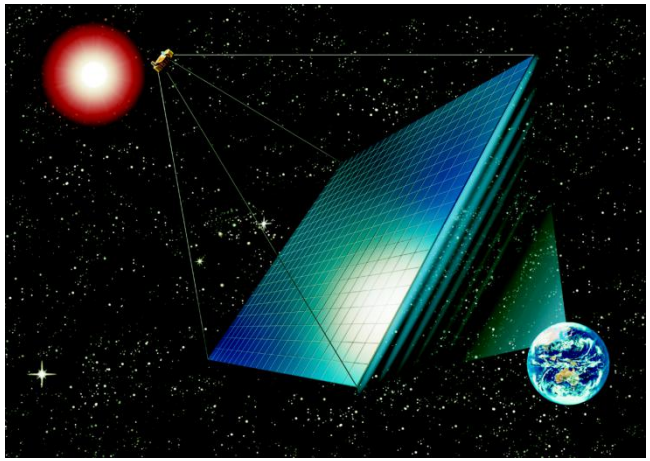
SSPS Technologies Demonstration in Space

- Roadmap towards Commercial SSPS
- 1 kW Class Microwave Power Transmission Experiment in Space
- 1 kW Class Laser Power Transmission Experiment in Space

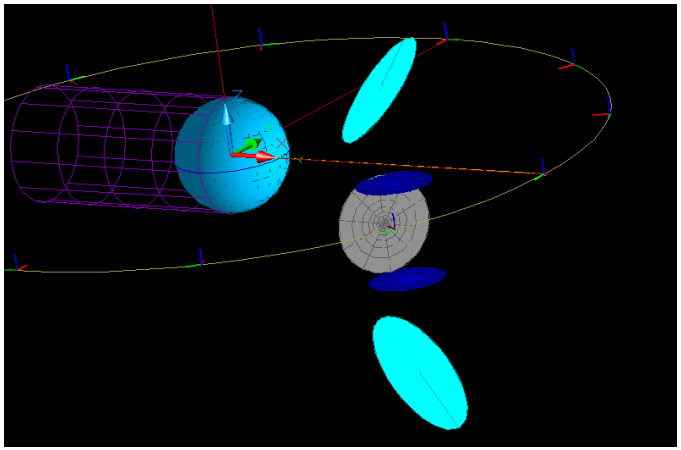


September 2010

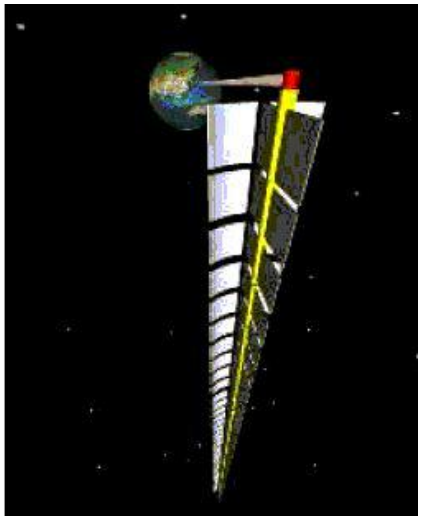
Examples of Commercial SSPS Models Currently Studied in Japan



Basic Microwave-type Model (USEF/METI)



Advanced Microwave-type Model (JAXA/MEXT)



Laser Model (JAXA/MEXT)

USEF/METI:Unmanned Space Experiment Free Flyer/ Ministry of Economy, Trade and Industry
JAXA/MEXT:Japan Aerospace Exploration Agency/ Ministry of Education, Culture, Sports, Science and Technology

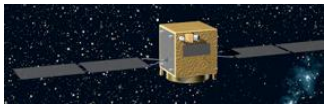
Research Phase

09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19

Ground demonstration

Small-scale on orbit demonstration

WPT Selection (microwave or laser)



100kW class on orbit demonstration

Configuration selection

Development Phase

20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29

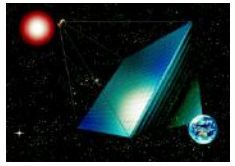
2MW class demonstration

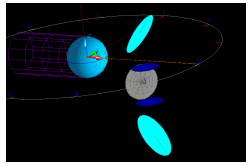
200MW class plant

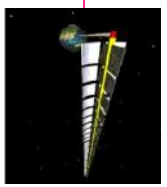
Commercial Phase

30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39

1GW class first commercial model







Commercial SSPS（1SSPS/year）

Two Possible Platforms for SSPS Wireless Power Transmission Experiment in the Near Future

Epsilon Launch Vehicle for small satellite
Next-generation solid propellant rocket to reduce the cost by a third of that for the former M-V launch vehicle. First flight will be in 2013.

Japanese Experiment Module Kibo on the International Space Station (ISS), for science and technology research. Mission extended for 5 years.

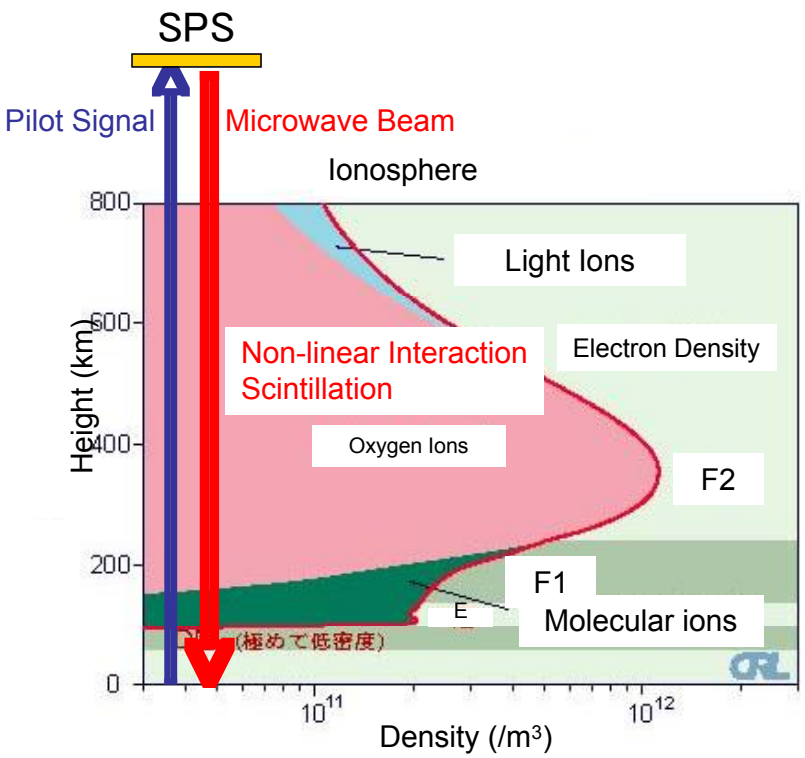
Microwave Transmission Experiment in Space

(1) demonstration of the microwave beam control precisely to the target on the ground from the antenna in orbit,P

(2) verification of microwave power transmission (~kw/m^2) through the ionosphere,

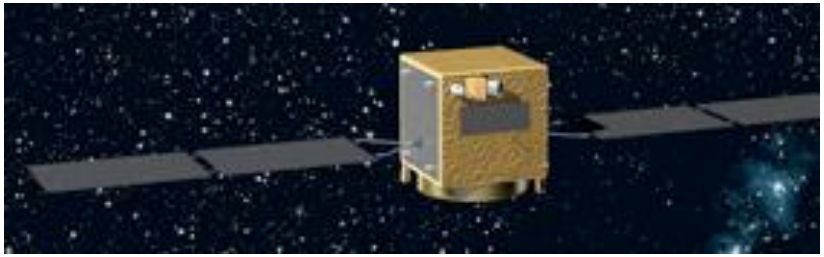
(3) evaluation of the over-all power efficiency as an energy system,P

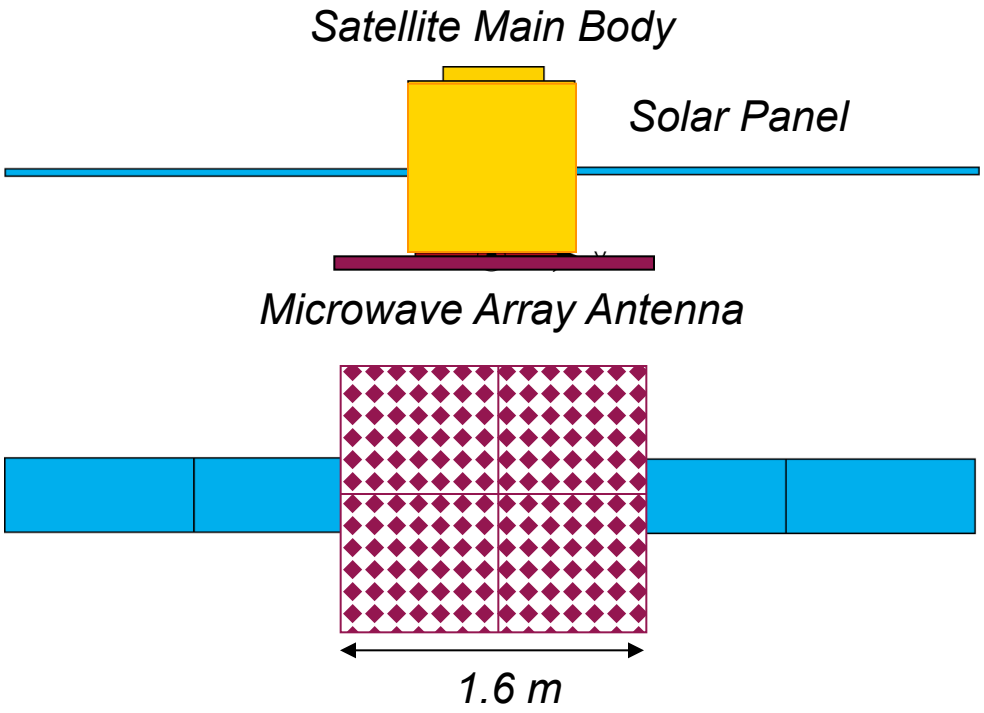
(4) demonstration of the electromagnetic compatibility with the existing communication infrastructure.



Experiment on Small Satellite

Orbit: Low Earth Orbit (370 km)
Satellite Weight: 400 kg
Mission Weight: 200 kg
Attitude Control: 3-axis Stabilization
Transmission Power: 3.8 kW

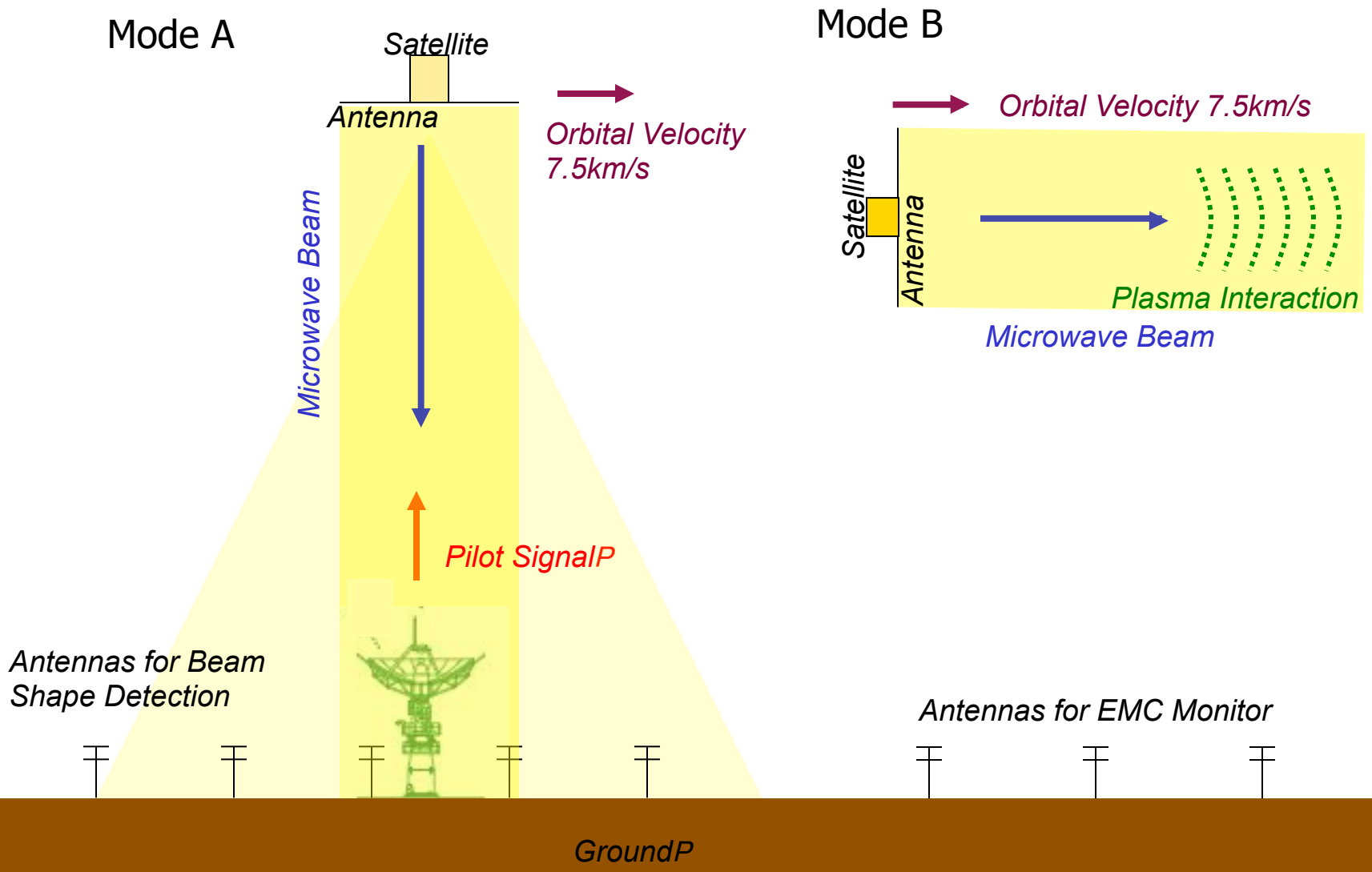




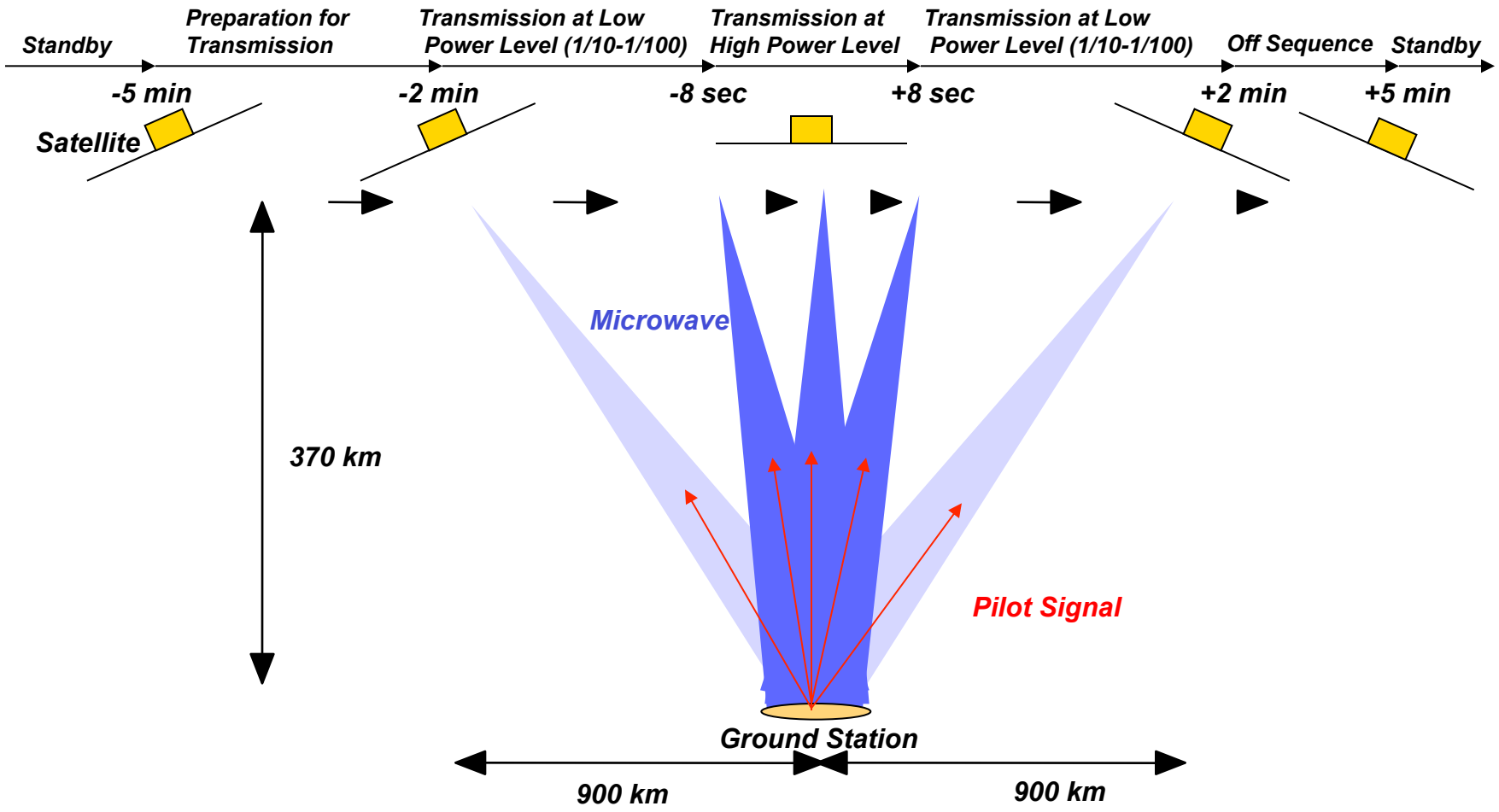
System Characteristics of Demonstration Model (Typical Example)

Mission	*Period*	*1 year*
System	*Configuration*	*Power transmission panel attached to satellite main body*
	Panel size	*1.6 m x 1.6 m x 0.02 m*
	Total weight	*200 kg*
	Attitude stability	*±1°*
Power transmission	*Frequency*	*5.8 GHz*
	Phase control	*5 bit*
	Number of module	*4*
	Beam control	*Retro-directive/Computer control, ±10°*
	Output power	*950 W/module, 3.8 kW(total)*
	Power density	*1500,1000, 500, 100 W/m^2 (at antenna)* *24 μW/m^2(max, on ground)*
Ground stations		*JAXA ground stations* *International experiment sites*

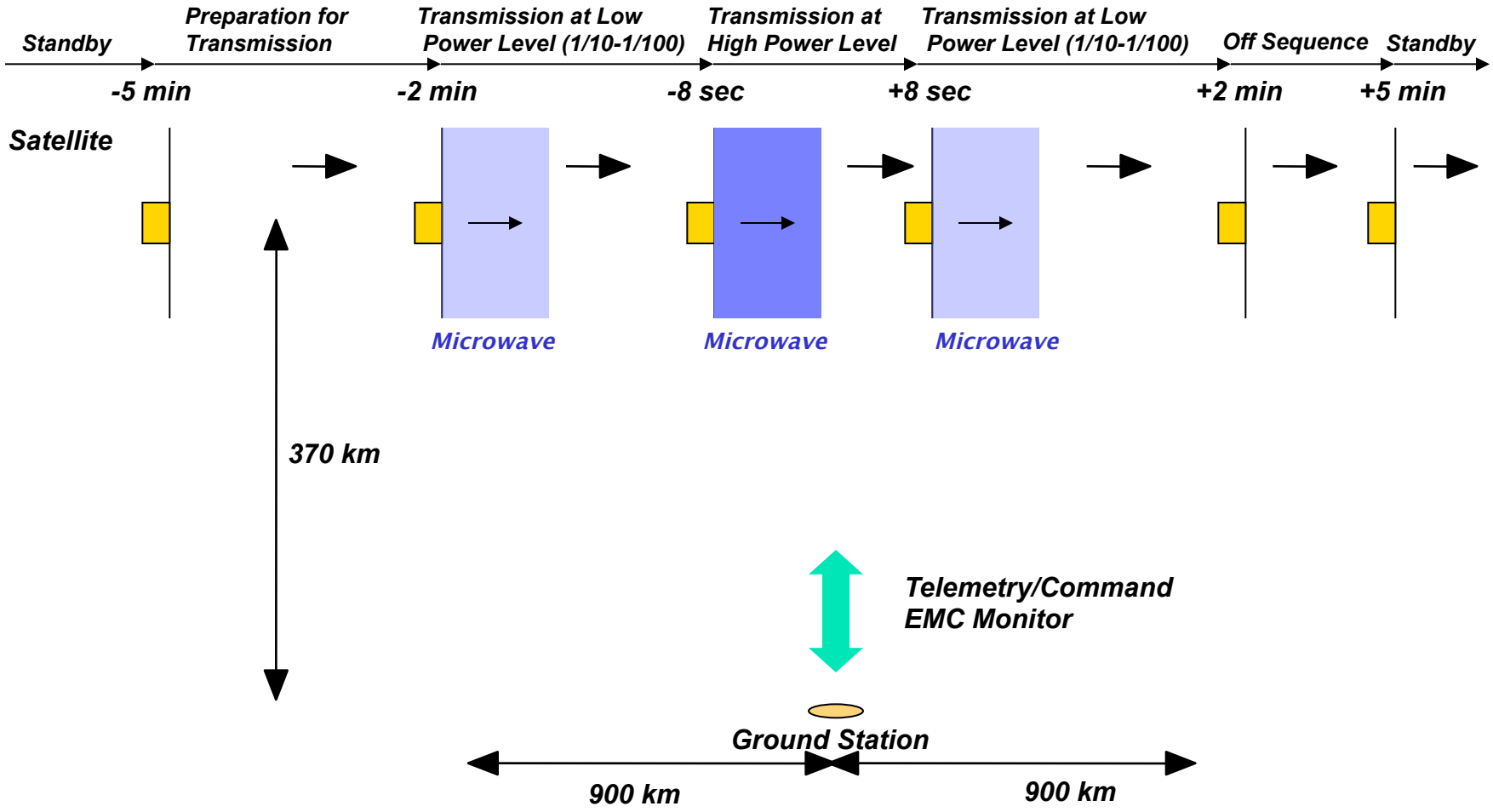
Experiment Configuration



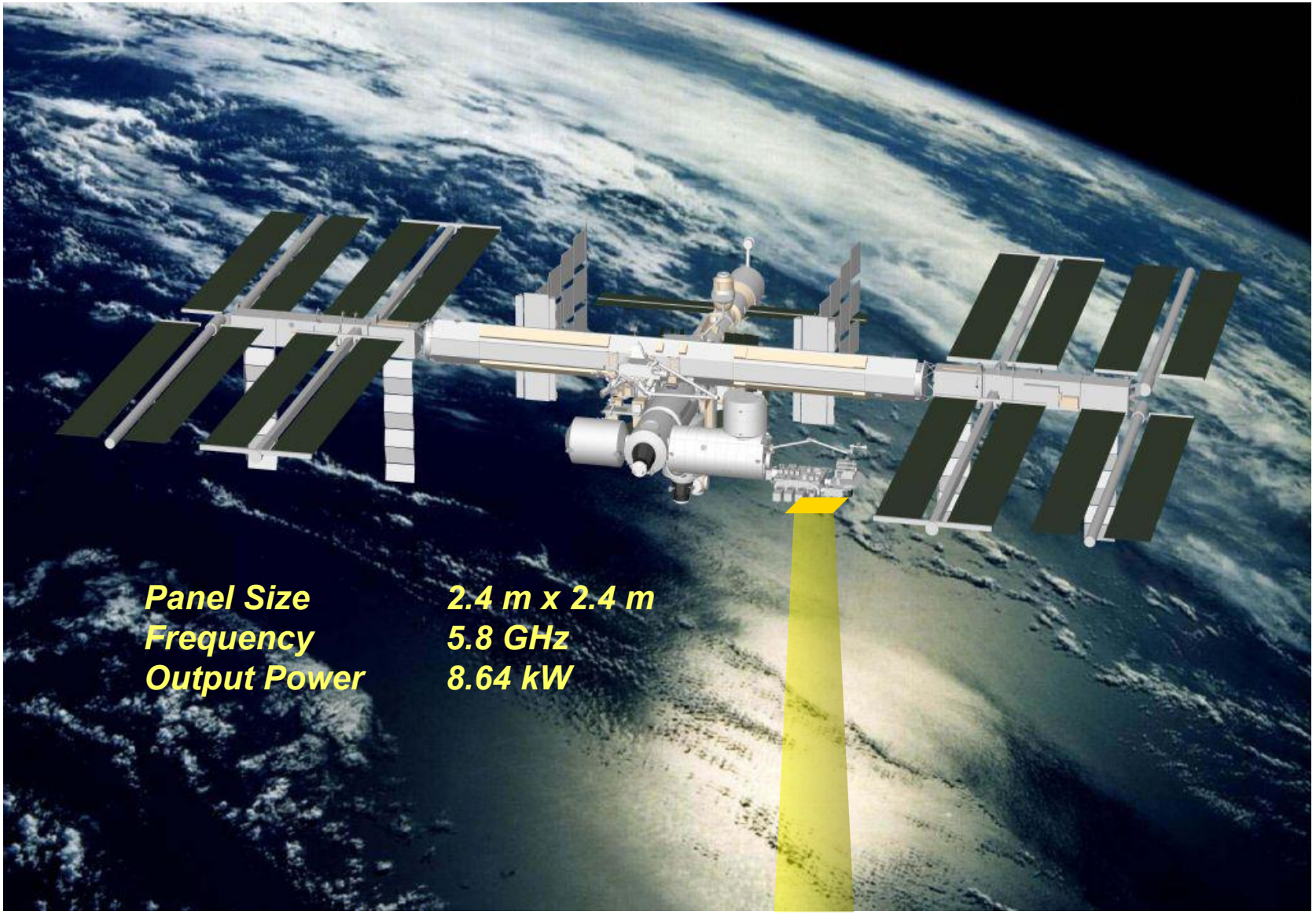
Experimental Sequence (Mode A)P



Experimental Sequences (Mode B)P

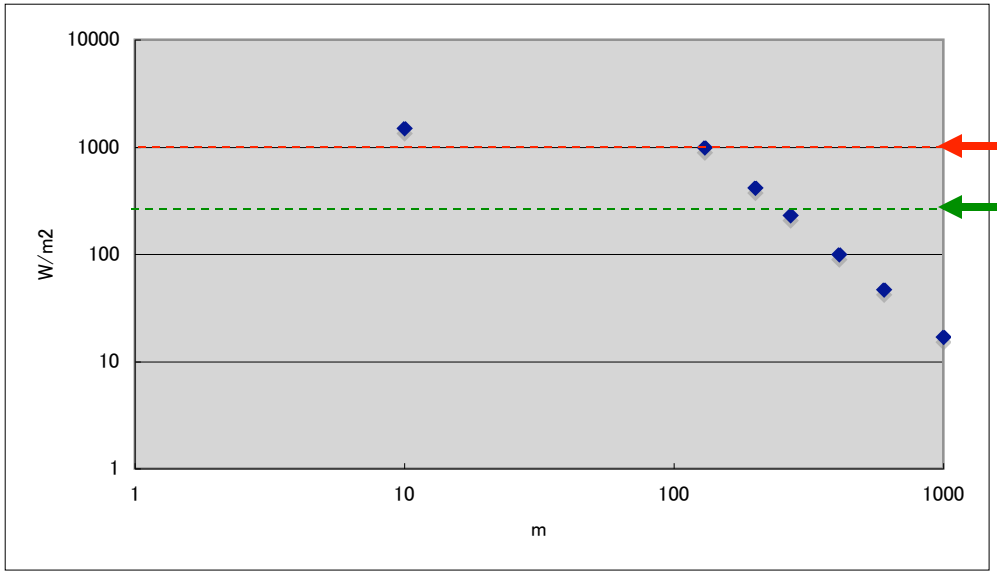


Microwave Power Transmission Experiment from JEM

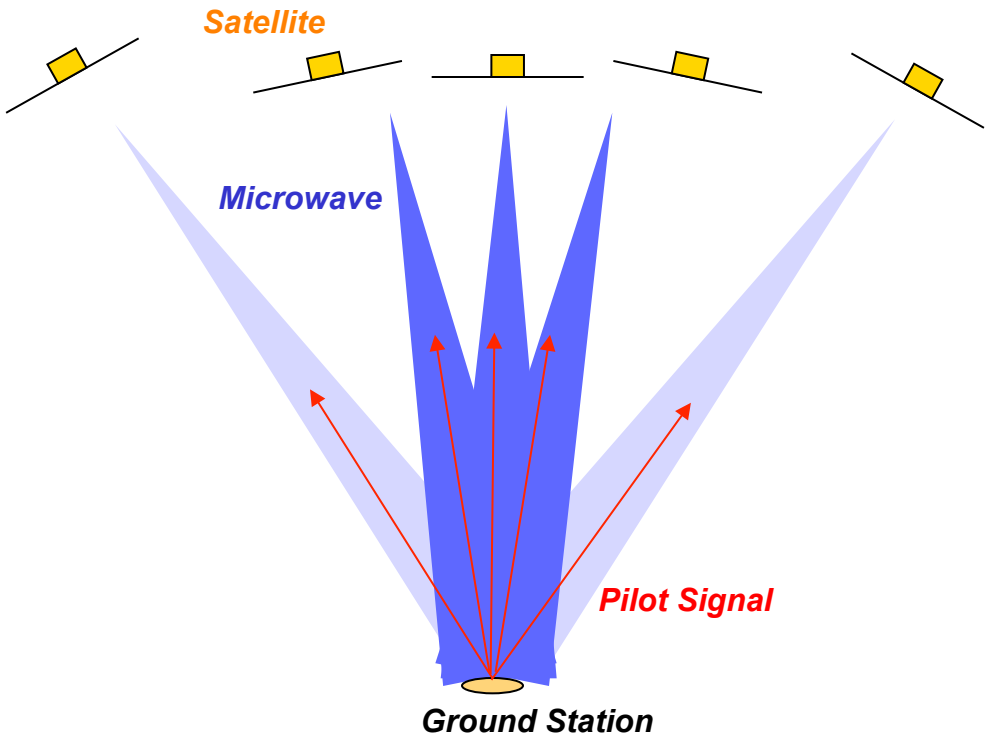


Microwave Power DensityS

Panel Size（9 panels）	*2.4 m x 2.4 m*
Frequency	*5.8 GHz*
Output Power	*8.64 kW、1.5kW/m²*
Power Density (>1000W/m²)P	*130 m*
Power Density (>230W/m²) P	*270 m*
Power Density(>100W/m²)	*410 m*
Power Density(on ground)	*136μW/m²*

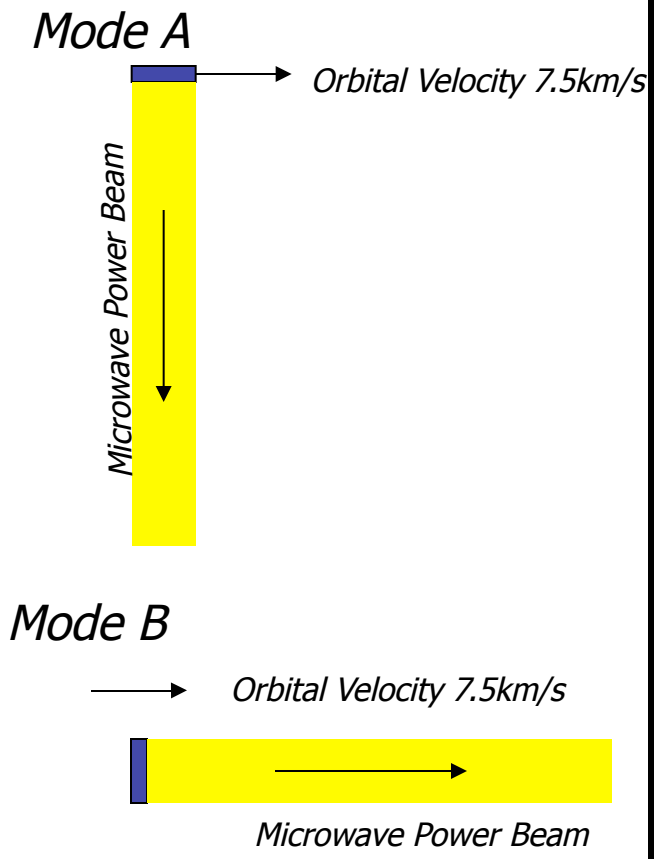


Verification of Beam Forming and Control



- *Beam forming according to array antenna theory (diffraction limit, beam width 3 degrees (null-to-null)) will be verified.*
- *Beam control accuracy according to retro-directive control theory (0.5 degrees accuracy (TBD)) will be verified.*
- *With experimental results, beam forming and beam control from geo-stationary orbit to ground can be evaluated quantitatively. P*

Verifications of Microwave/Plasma Interaction



Observation
Ground Beam power density profile
In-situ Electrons temperature,
Plasma density,
Plasma waves,
Back-scatter waves

Verification items			Mode A	Mode B
Direction of microwave power beam			Ground	Orbit parallel
Ionospheric plasma irradiation time			0.2ms	10ms
Research subject			Observation	
Ionosphere interaction	Heating	F-layer electrons heating	partially	yes
		F-layer plasma density reduction	no	yes
		Lower ionosphere electrons heating and plasma density increase	no	no
	Thermal self-focusing	Electrons heating	partially	yes
		Plasma density reduction	no	yes
	Beam gradient self-focusing	Electrons heating and density reduction	yes	yes
		Plasma reduction	no	yes
	3-wave interaction	Back-scatter waves, plasma waves, electrons heating	yes	yes
Beam control	Transmission to ground station		yes	no

Issues for the Microwave Power Transmission Experiment in Space

(1) Frequency assignment for the microwave power transmission experiment has not been negotiated yet,P

(2) Diagnostic instruments have not been well defined to study the microwave-plasma interaction,

(3) It is hard to see yet how to meet EMC regulations in case of JEM experiment.

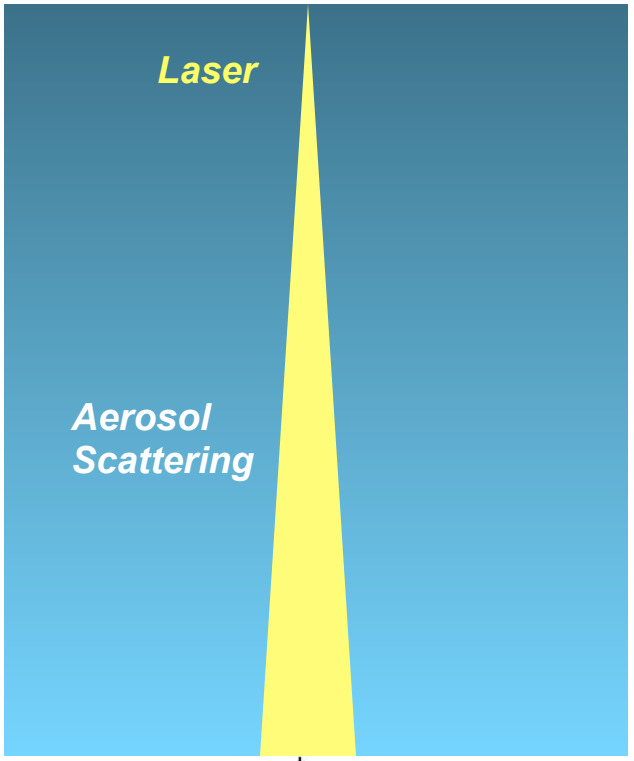
Laser Transmission Experiment in Space

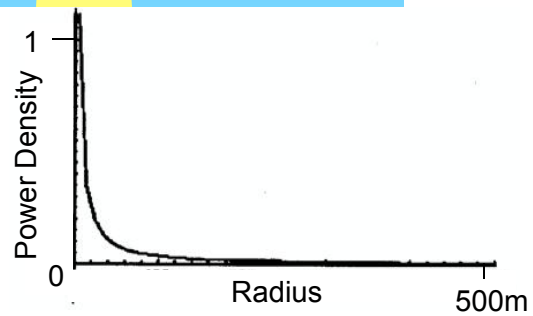
(1) demonstration of the laser beam control precisely to the target on the ground from the transmitter in orbit,P

(2) verification of laser power transmission through the atmosphere,

(3) evaluation of the over-all power efficiency as an energy system,P

(4) demonstration of laser safety for public acceptance.





Laser Power Transmission Experiment from JEM (an example)

International Space Station JEM

Transmitter
1 kW, 1.06 μm
20 cmΦ Optics

Laser Beam

Divergence 15 μrad
Pointing 1 μrad

Pilot Beam

Receiver
10 mΦ Area
200 W Output

Photovoltaic Cell Array

Issues for the Laser Power Transmission Experiment in Space

(1)Beam pointing technologies to assure the μ-radian accuracy while tracking at 1 degree/sec have not been established yet (1 degree/sec tracking is not required for commercial SSPS in the geo-synchronous orbit),P

(2) It is hard to see yet how to guarantee "eye safety" requirement in case of system failure.

Verification Matrix towards Commercial SSPS

Phase / Verification	Ground Demonstration	Small Satellite or JEM on Space Station	Large Satellite	Small Plant	Verification Plant
	kW Ground	kW Low Earth Orbit	100kW Low Earth Orbit	2MW 1000 km Altitude	200 MW Geostationary Orbit
Beam Control	100m	400km	400km	1000km	36000km
Ionosphere/ atmosphere transmission	-	1kW/m²	1kW/m²	1kW/m²	1kW/m²
Power Transmission	(Test Rectenna kW)	-	Small Rectenna 10kW	Large Rectenna 2MW	Large Rectenna 200MW
SPS Total Function	-	-	10kW	2MW	200MW
Power for Practical Use	-	-	-	2MW	200MW

Near Term Target

Summary and Conclusion

- *SKW-class wireless power transmission systems with 100-500 m range , both for microwave and laser, are now under development and will be completed within three years.*
- *Following the ground demonstration experiments, we will start a small-scale experiment in orbit to transmit a 1 kW class microwave power and/or laser power to the ground.*
- *After an assessment of the results from the ground and space experiments, we propose to conduct a larger-scale experiment of 100 kW class in orbit, using microwave or laser.*
- *This approach is in accordance with the basic plan on space development by the government's space development strategy headquarter in Japan.*