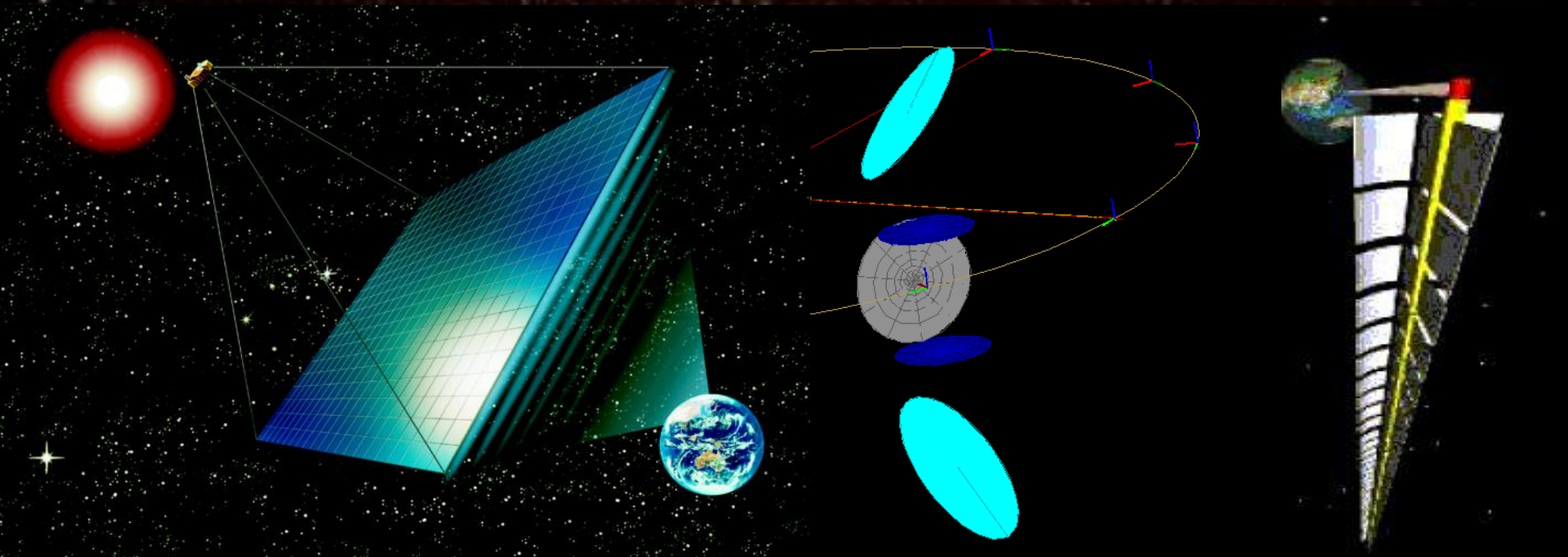
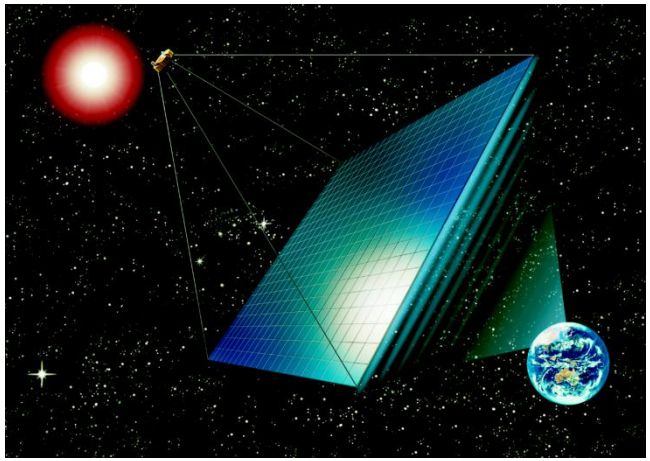
On-orbit Demonstration for SPS Wireless Power Transmission

- *Commercial SPS Models Currently Studied in Japan*
- *Roadmap towards Commercial SPS*
- *1 kW Class Wireless Power Transmission Experiment in Space*

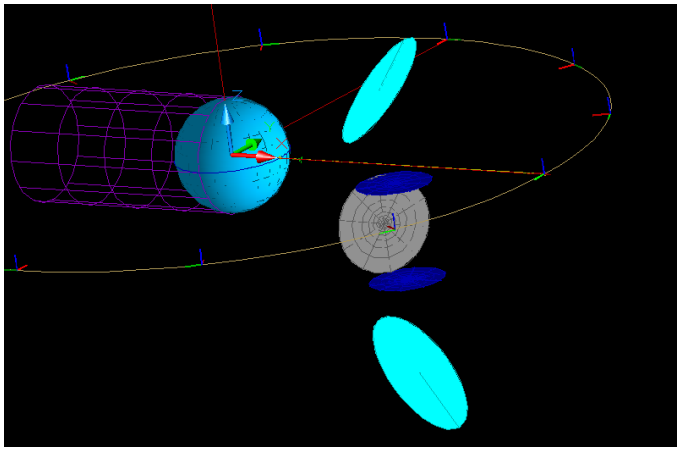


August 2010

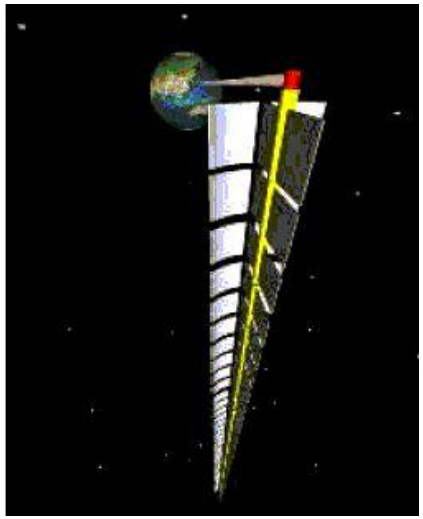
Commercial SPS Models Currently Studied in Japan



Basic Microwave-type Model (USEF/METI)

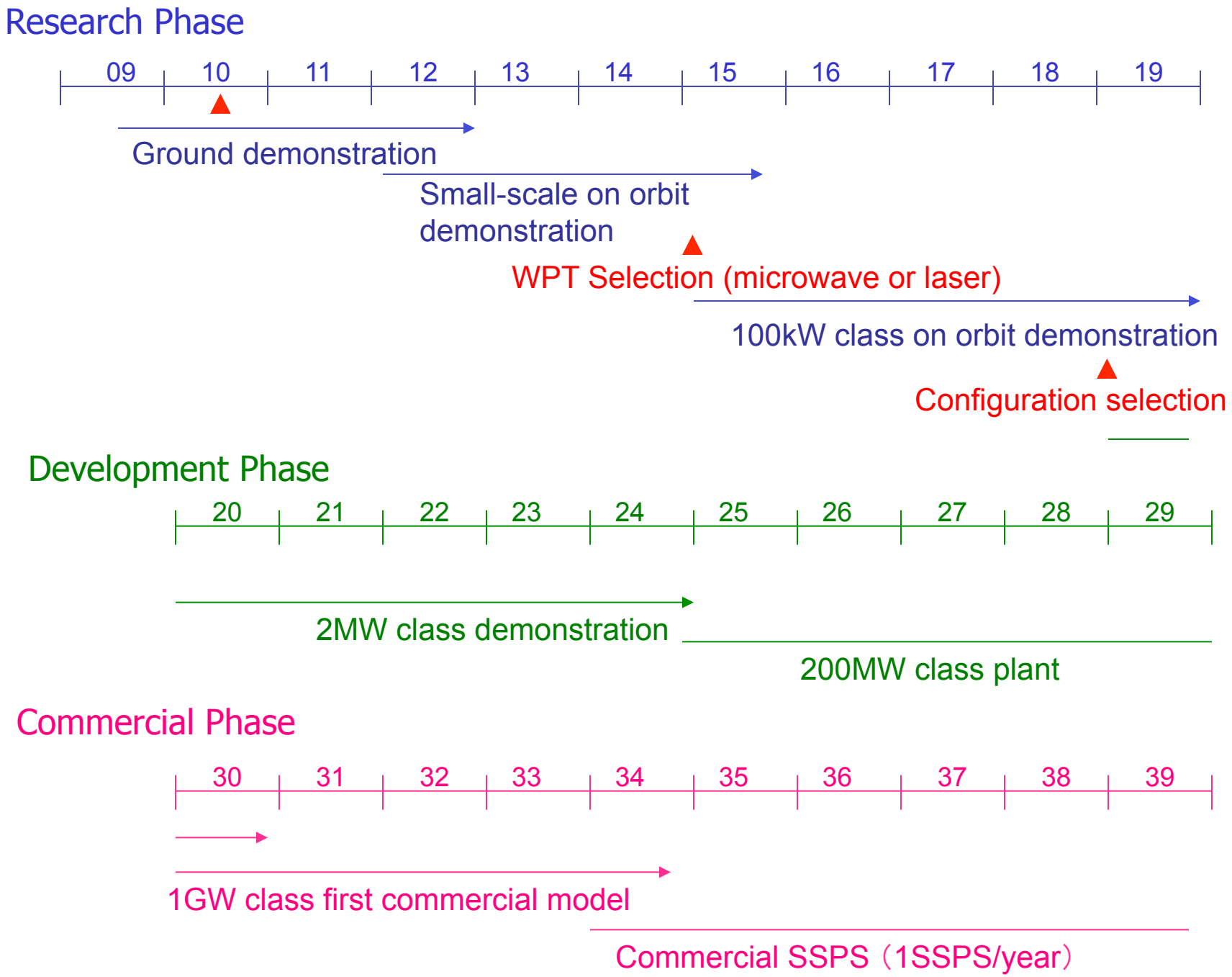


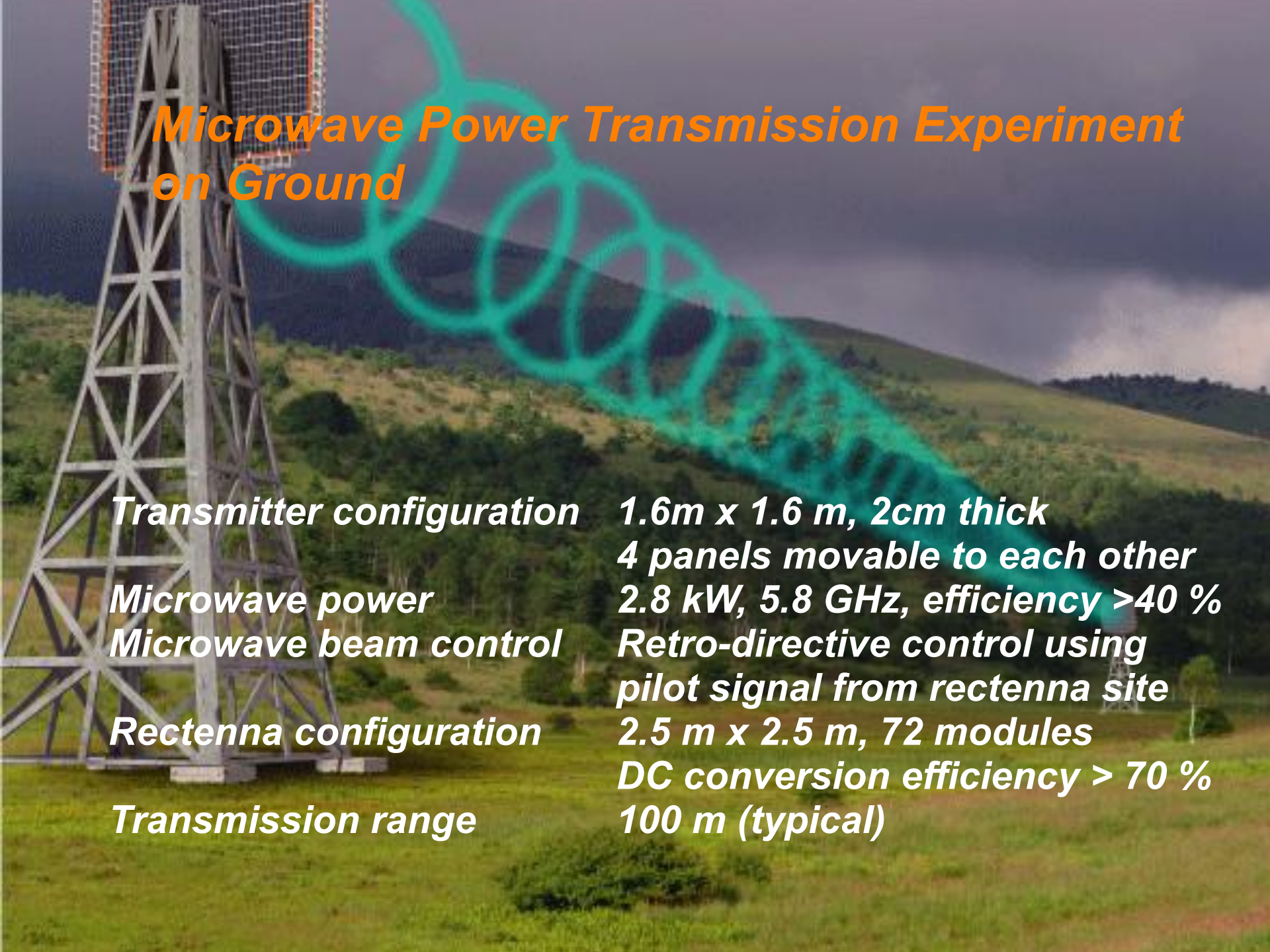
Advanced Microwave-type Model (JAXA/MEXT)



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）



Microwave Power Transmission Experiment on Ground

Transmitter configuration	1.6m x 1.6 m, 2cm thick 4 panels movable to each other
Microwave power	2.8 kW, 5.8 GHz, efficiency >40 %
Microwave beam control	Retro-directive control using pilot signal from rectenna site
Rectenna configuration	2.5 m x 2.5 m, 72 modules DC conversion efficiency > 70 %
Transmission range	100 m (typical)

Laser Power Transmission Experiment on Ground

Laser output	1 kW
Wave length	1.06 μm
Transmission	500 m
Beam control	several μrad
Receiver output	0.2 kW

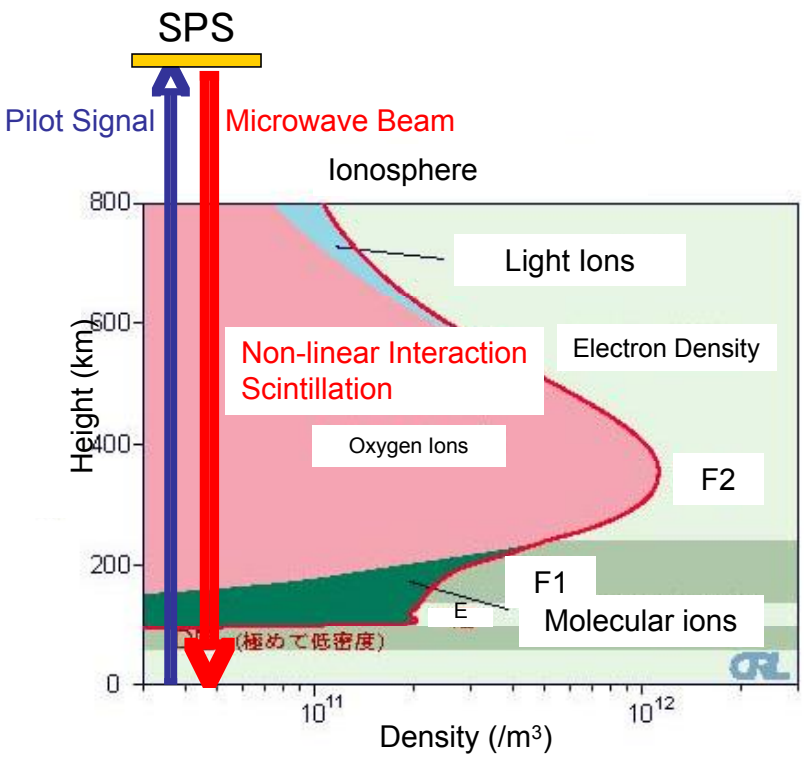
Microwave Transmission Experiment in Space

(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,

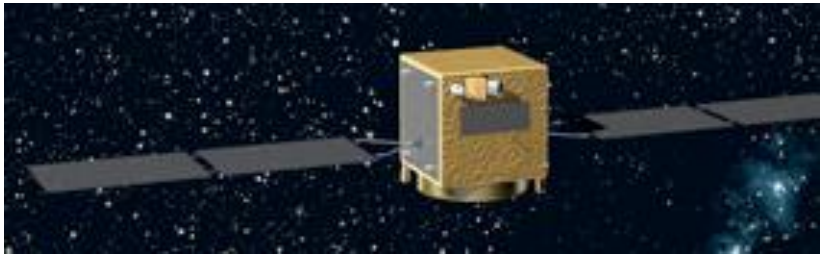
(3) evaluation of the over-all power efficiency as an energy system,P

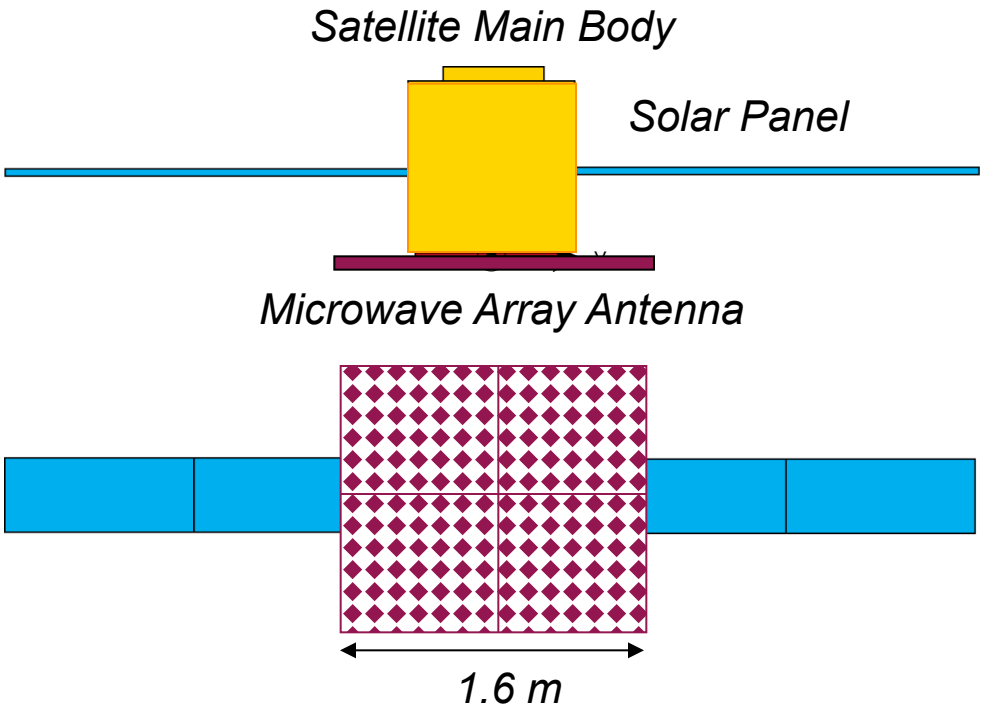
(4) demonstration of the electromagnetic compatibility with the existing communication infrastructure.



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

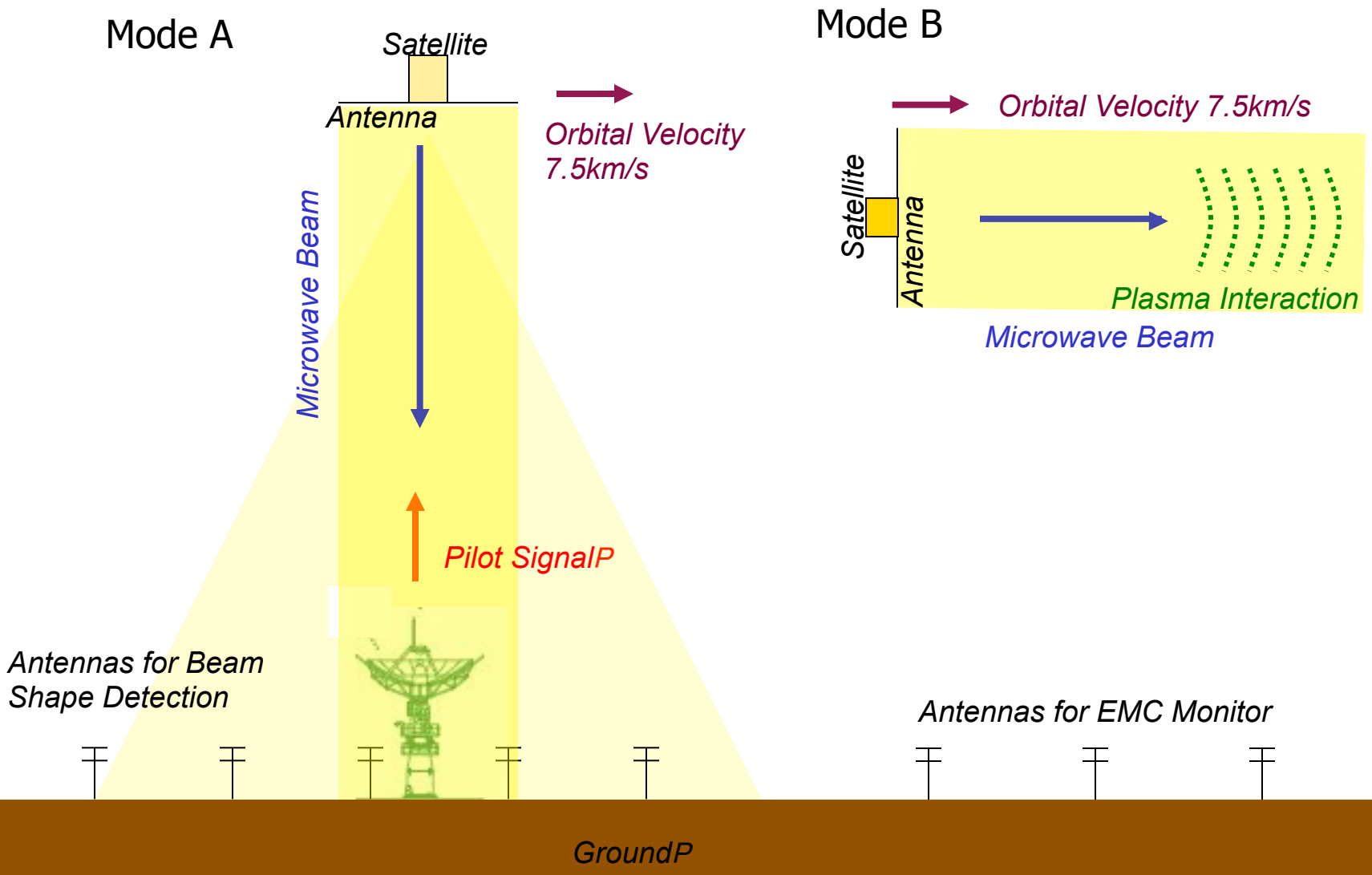




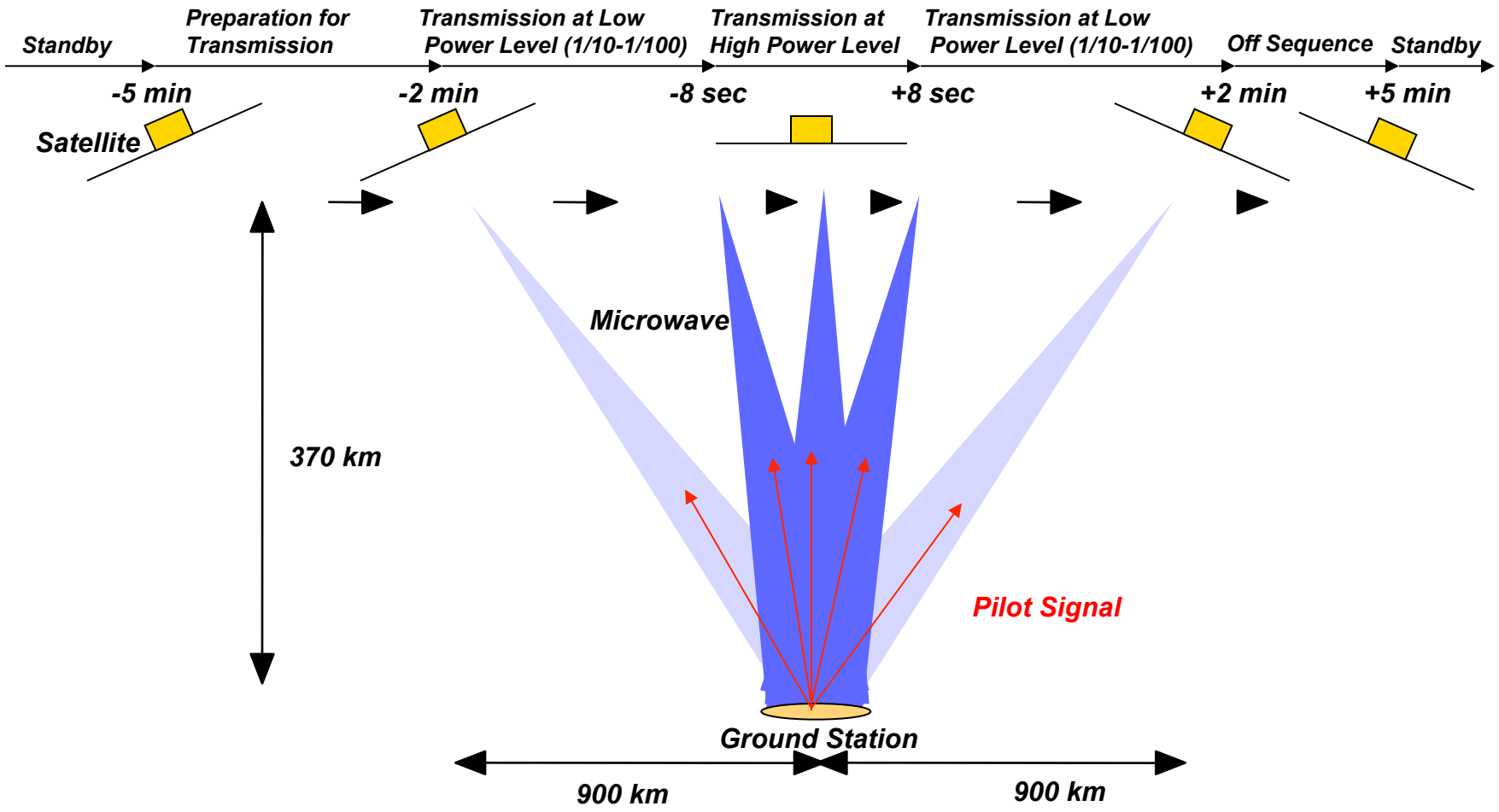
System Characteristics of Demonstration Model (Typical Example)

Mission	*Period*	*1 year*
System	*Configuration*	*Power generation/transmission panel suspended by 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*

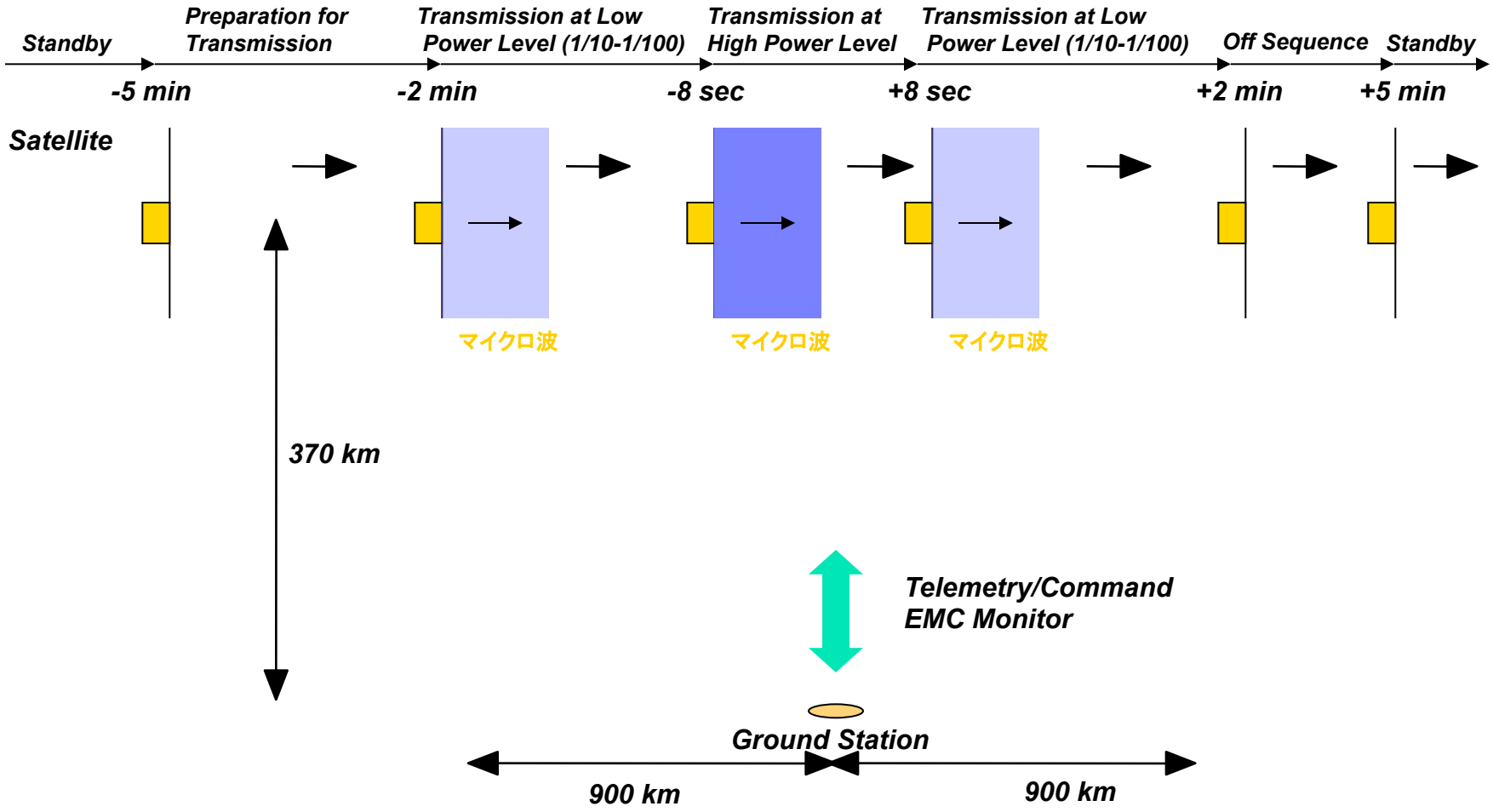
Experiment Configuration



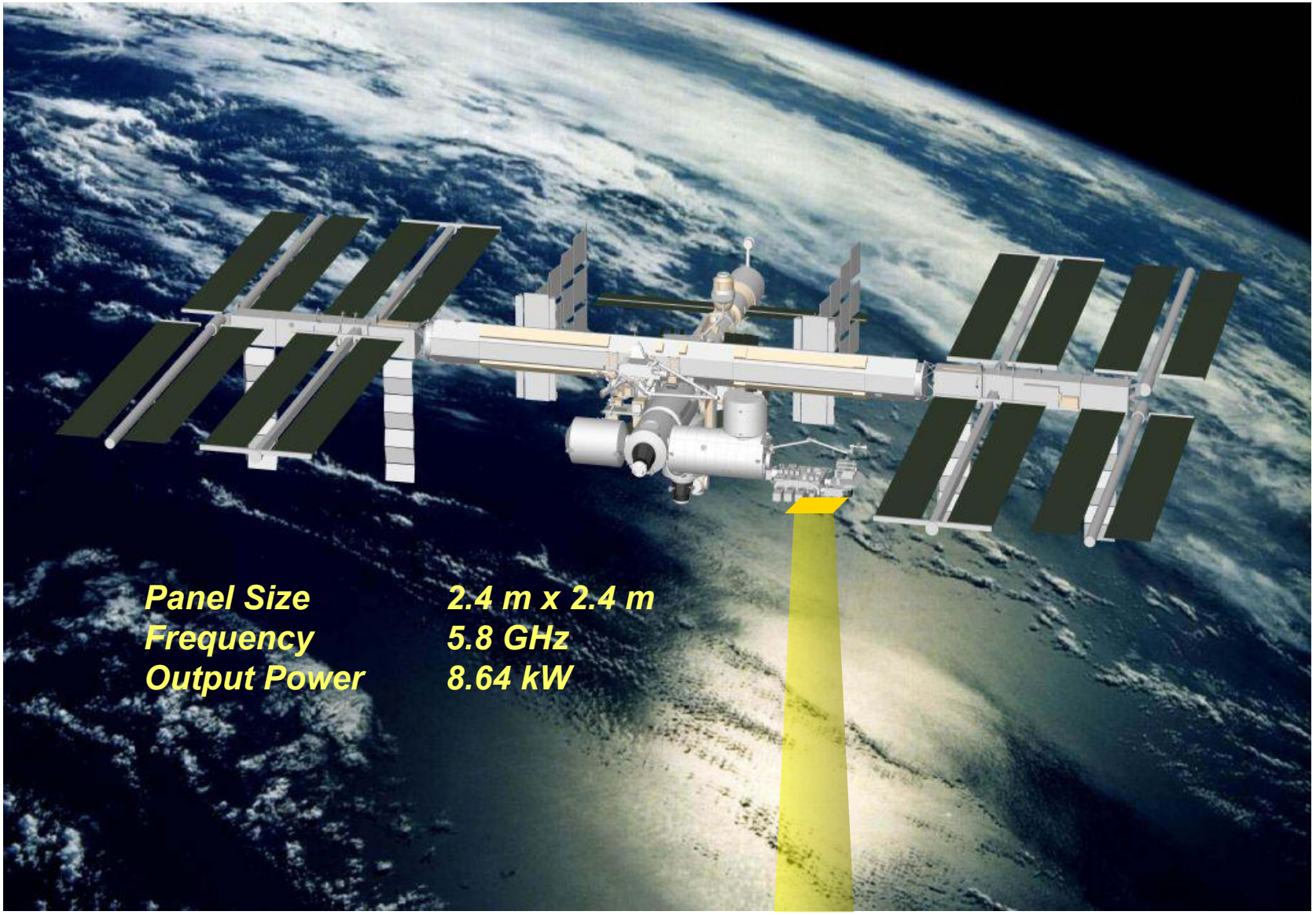
Experimental Sequences (Mode SA)P



Experimental Sequences (Mode B)

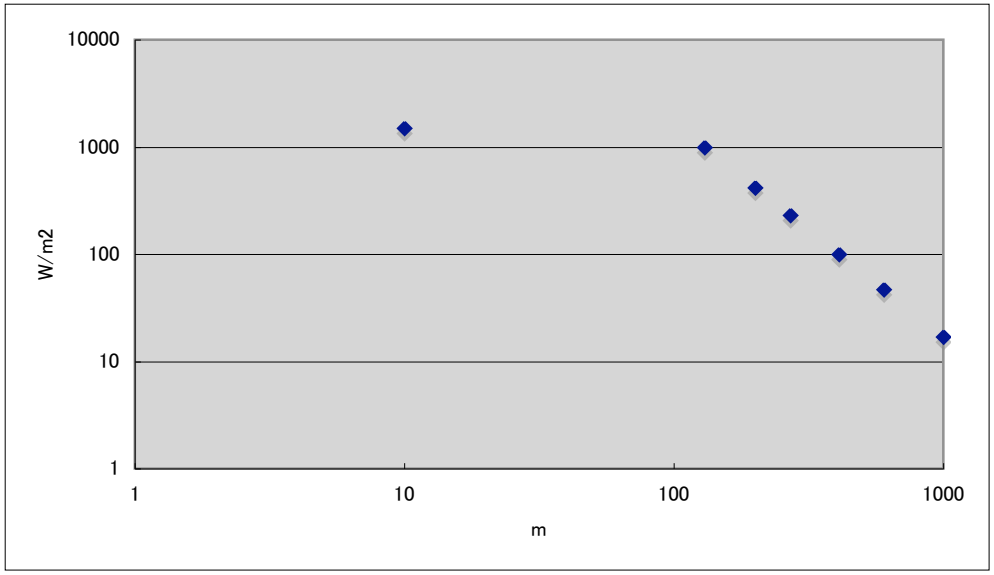


Microwave Power Transmission Experiment from JEM

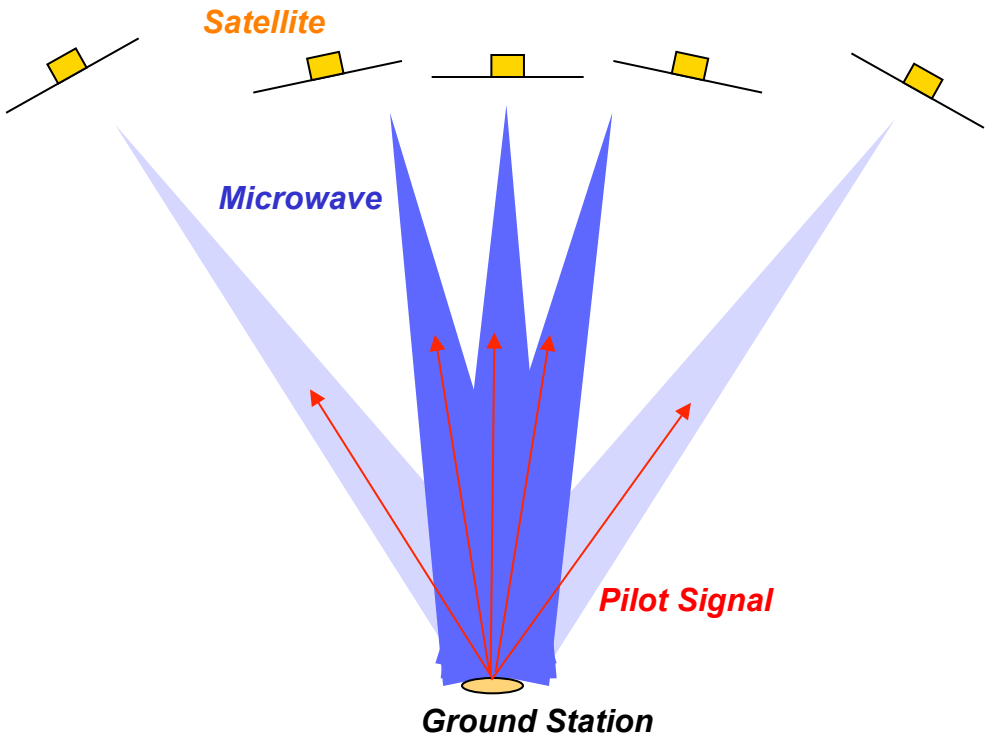


Microwave Power DensityS

Panel Size（9 panels）	2.4 m x 2.4 m
Frequency	5.8 GHz
Output Power	8.64 kW、1.5kW/m^2
Power Density (>1000W/m^2)P	130 m
Power Density (>230W/m^2） P	270 m
Power Density(>100W/m^2)	410 m
Power Density(on ground)	136μW/m^2

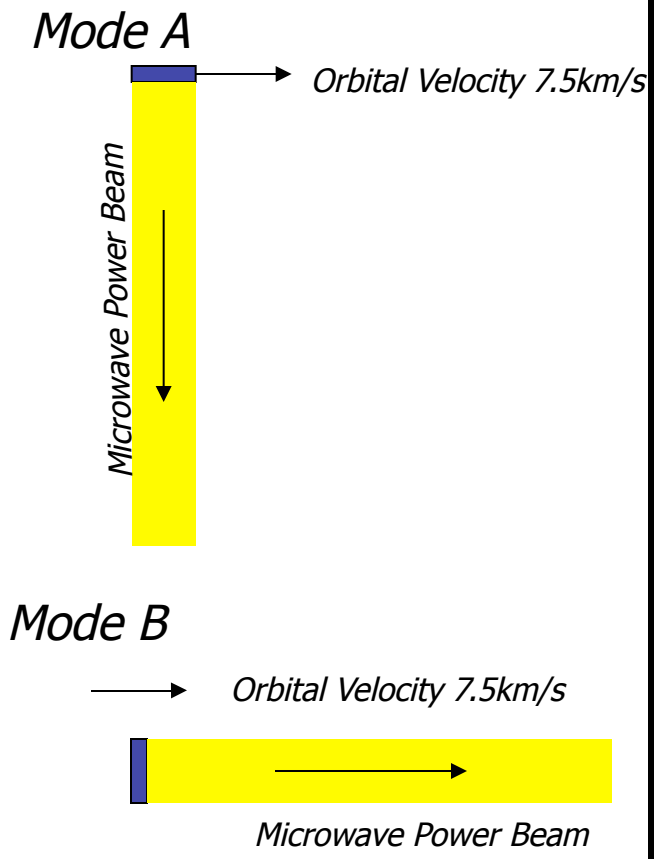


Verification of Beam Forming and Control



- *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

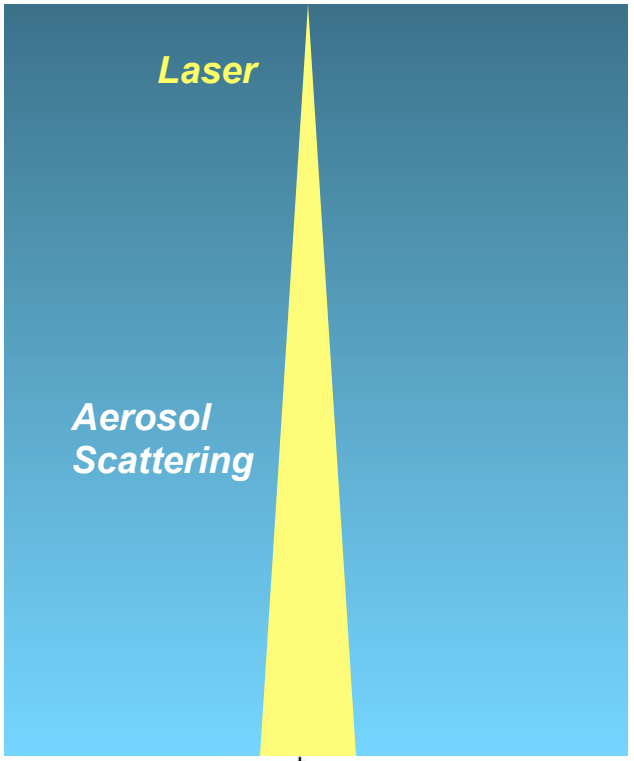
Laser Transmission Experiment in Space

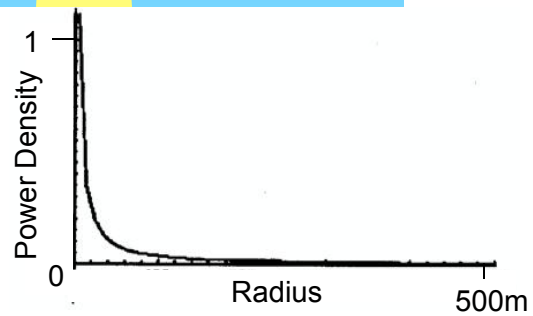
(1) demonstration of the laser beam control precisely to the target on the ground from the transmitter in orbit,P

(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

Verification Matrix towards Commercial SPS

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/m^2	1kW/m^2	1kW/m^2	1kW/m^2
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

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.*