SSP Workshop
8 November 2013

Mission design of WPT Space Demonstration Experiment using Small Scientific Satellite toward SPS

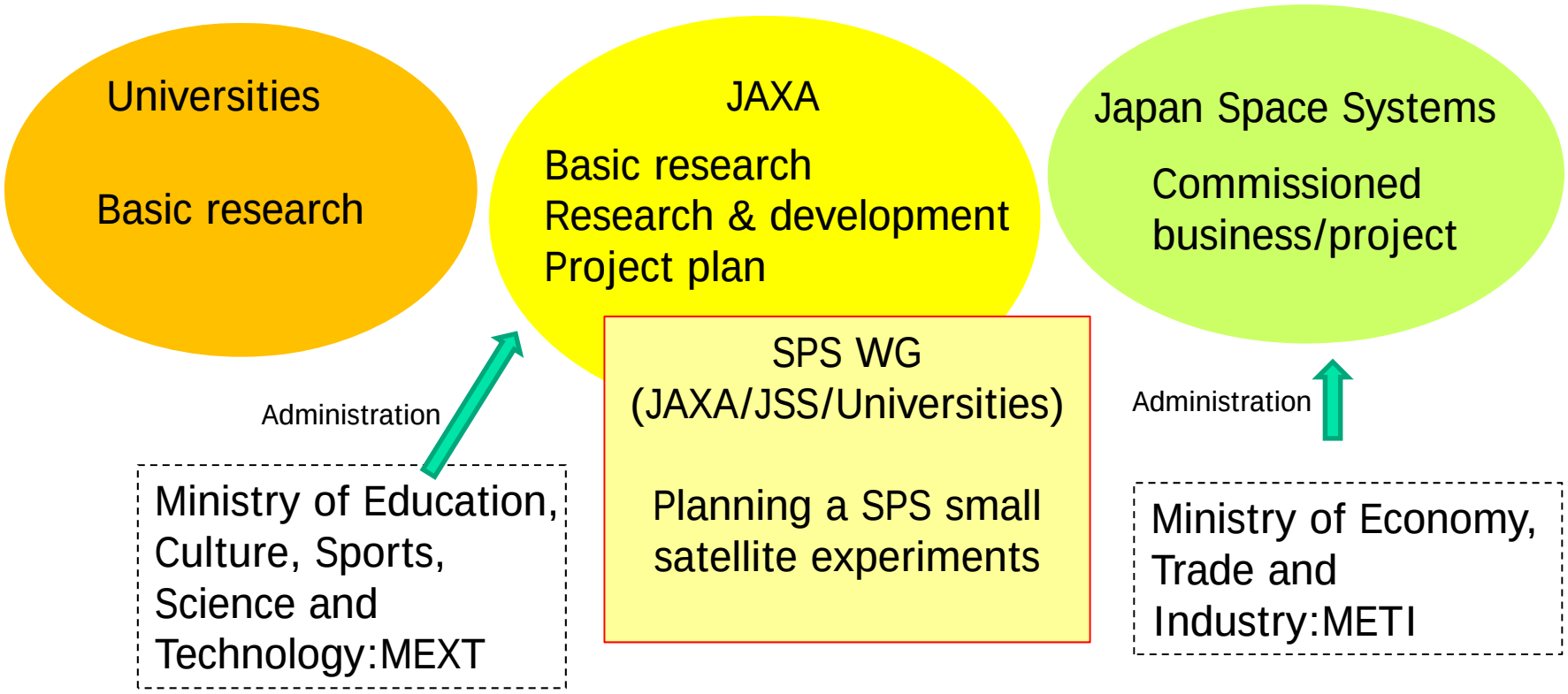
K. Tanaka, S. Sasaki, SPS WG
ISAS/JAXA, Tokyo

Contents

- Japanese activity for SPS
- Principle of the SPS and current study in JAPAN
- Purpose of the WPT demonstration in space
- Outline of the small satellite experiments
- Summary and Conclusion

Japanese Activities for SPS

Basic Plan on Space Policy



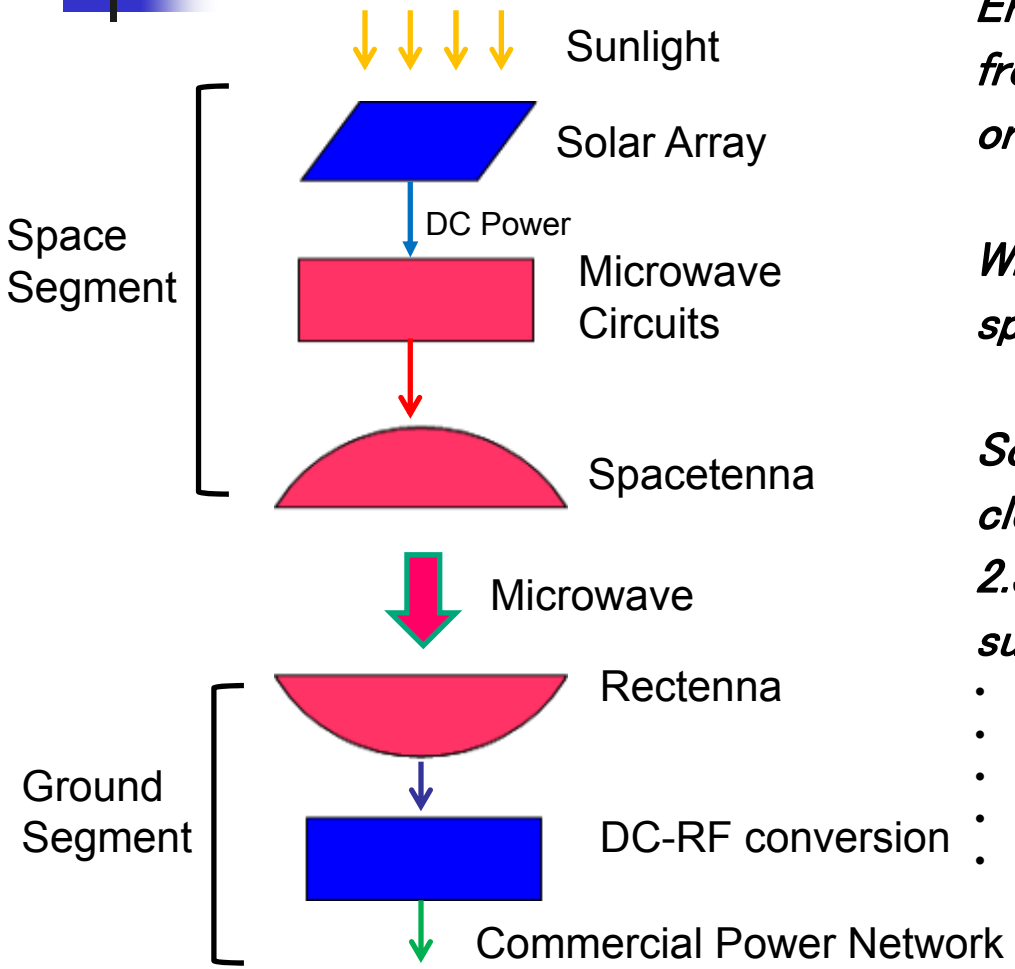
Small Scientific Satellite Program in ISAS/JAXA

- The "Small Satellite" program recently started in the institute of space and astronautical science (ISAS)/JAXA is designed to provide opportunities for demonstration experiments. Announcement of opportunity (AO) for Small Satellite III that utilizes epsilon rocket and the standard bus of the small scientific satellite is opened.
- SPS WG was organized in ISAS/JAXA. This group consists of researchers of JAXA, JSS, Universities.
- We are planning space experiments using a small scientific satellite toward SPS in preparation for the AO.

Epsilon launch Vehicle

Small Satellite I

Basic Configuration of SPS



Energy conversion system in space is from 5 to 10 times more efficient than on ground.

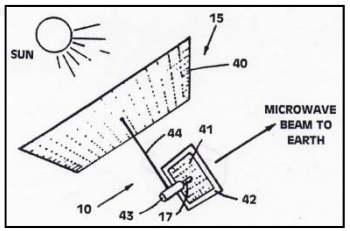
WPT efficiency of more than 50 % from space to the ground will be achieved.

So, SPS possesses great potential of a clean and stable energy supply with from 2.5 to 5 times more efficient than the sunlight utilities on the ground.

- *Available energy : unlimited*
- *Stability : HIGH (without weather and day and night)*
- *EPT(Energy Payback Time): less than several years,*
- *Cost: 10～30 (JP Yen)／kwH*
- *CO_2 Load: less than several tenth part of the thermal power plant.*

Typical SPS Models

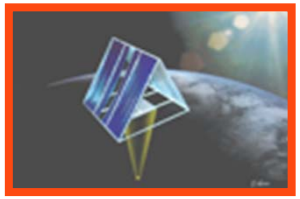
Solar Power Satellite



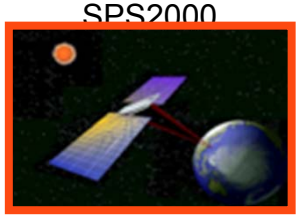
Non-concentrator

Bus Power

NASA Reference Model

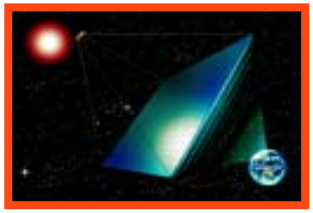


SPS2000



NEDO Grand Design

Distributed Power

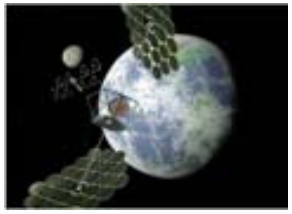


USEF Tether SSPS

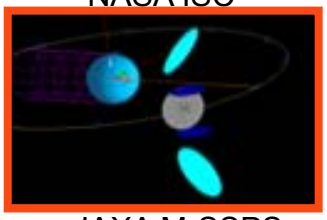
Concentrator

Bus Power

NASA Sun Tower



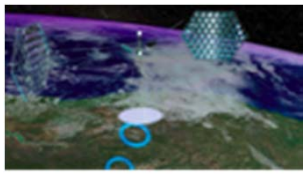
NASA ISC



JAXA M-SSPS

Distributed Power

NASDA 2001



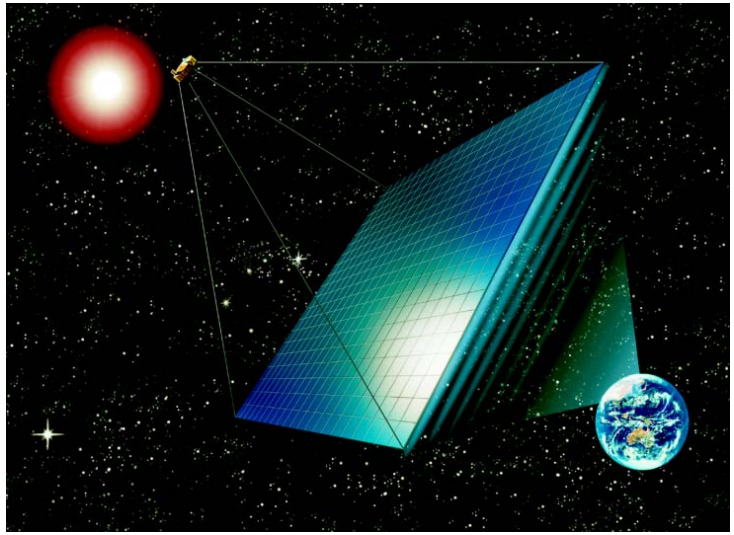
IAA Study Model

Laser Direct Excitation

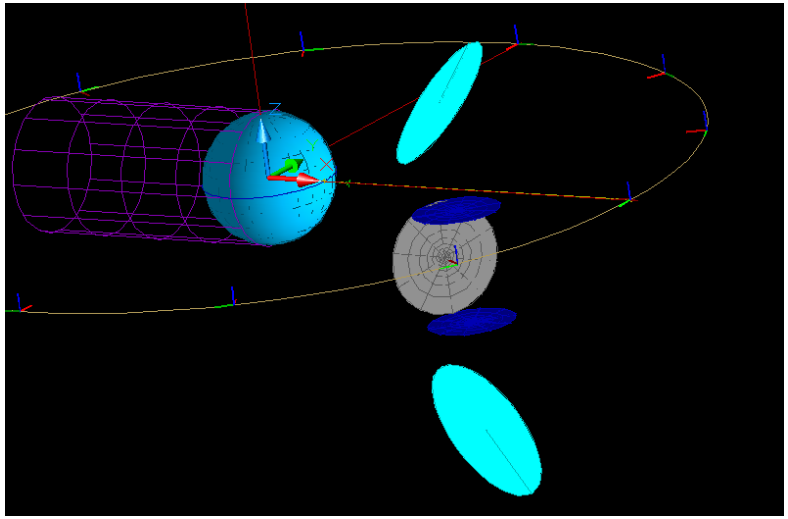
JAXA L-SSPS

Designed in Japan

Commercial SPS Models Currently Studied in Japan



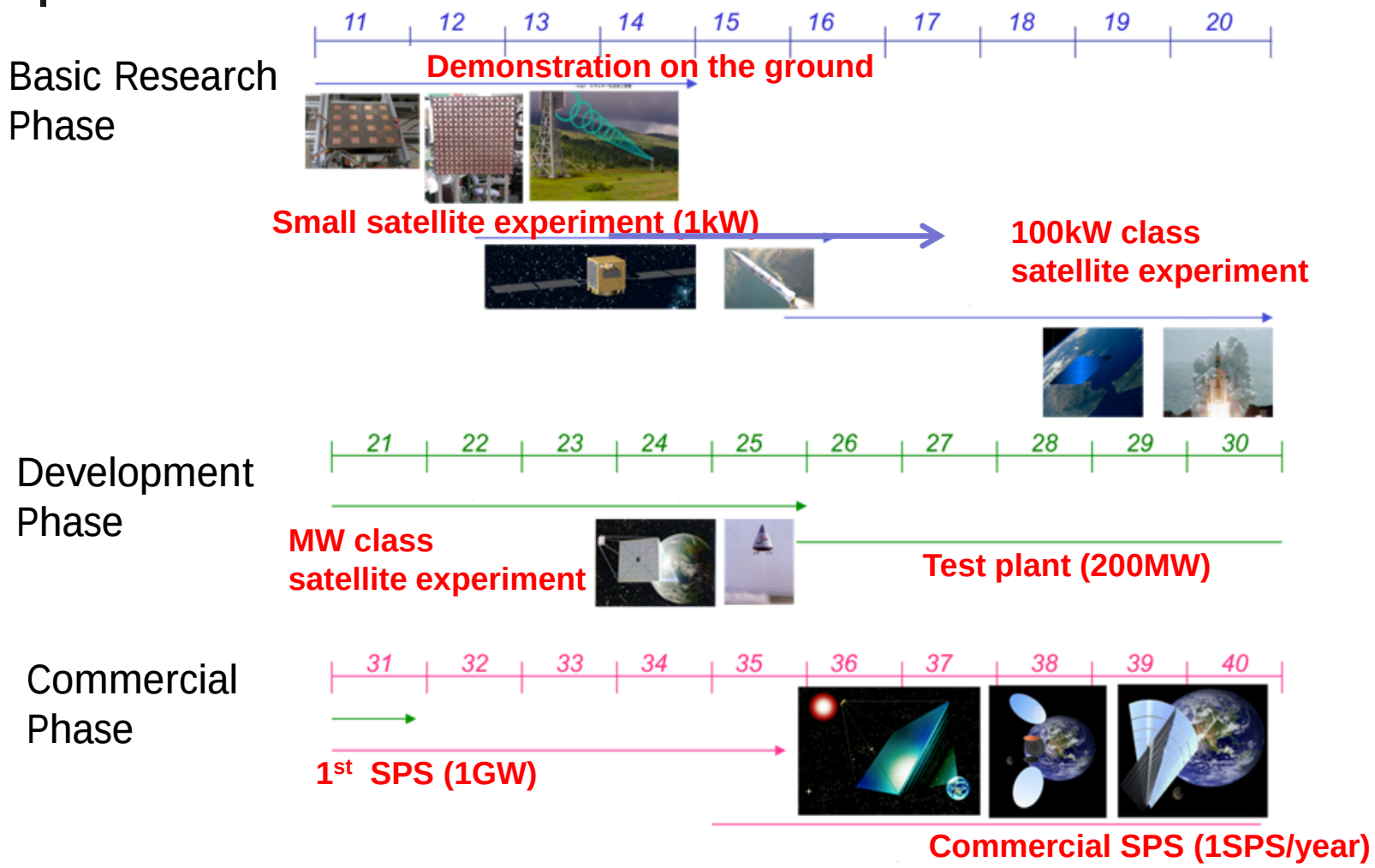
Basic Microwave-type Model (Jspacesystems/METI)



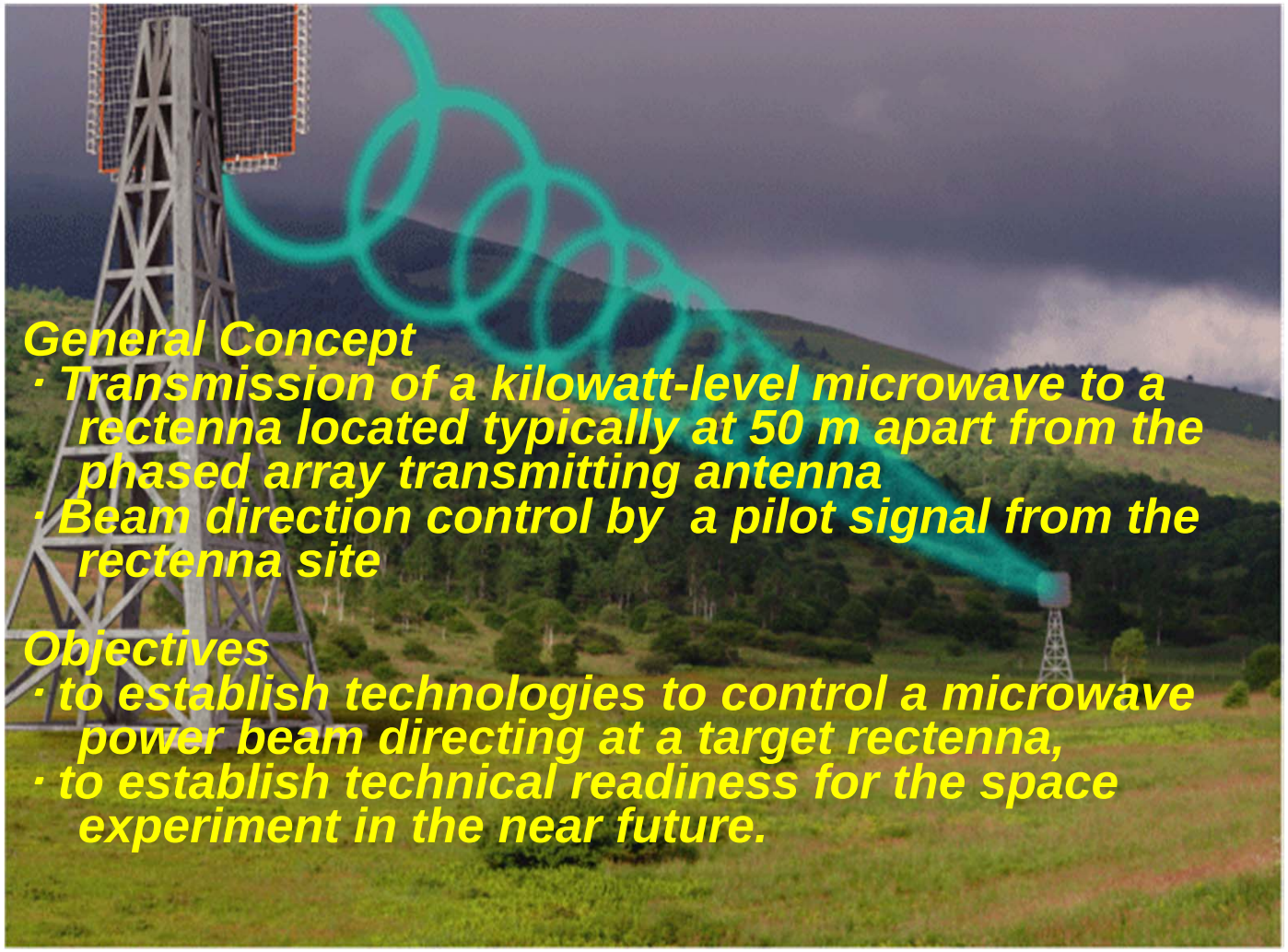
Advanced Microwave-type Model (JAXA/MEXT)

Jspacesystems/METI:Japan Space Systems/ Ministry of Economy, Trade and Industry
JAXA/MEXT:Japan Aerospace Exploration Agency/ Ministry of Education, Culture, Sports, Science and Technology

Development Scenario toward Commercial SPS



Microwave Power Transmission Experiment on Ground



General Concept

- Transmission of a kilowatt-level microwave to a rectenna located typically at 50 m apart from the phased array transmitting antenna
- Beam direction control by a pilot signal from the rectenna site

Objectives

- to establish technologies to control a microwave power beam directing at a target rectenna,
- to establish technical readiness for the space experiment in the near future.

Verification Matrix toward Commercial SPS

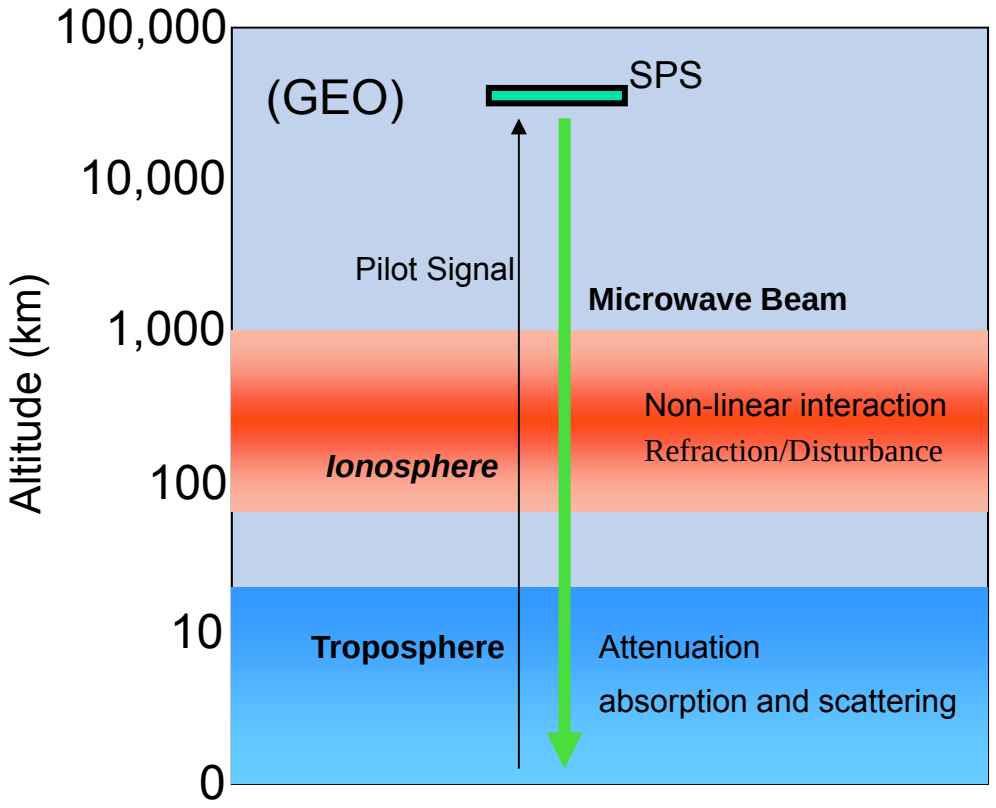
Phase / Verification	Ground Demonstration	Small Satellite or JEM on Space Station	Large Satellite	Small Plant	Verification Plant
	kW Ground	kW Low Earth Orbit	100kW Low Earth Orbit	2MW 1000 km Altitude	200 MW Geostationary Orbit
Beam Control	**100m**	**～400km**	**～400km**	**1000km**	**36000km**
Ionosphere/ 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

Interaction between microwave and both ionosphere and troposphere

Propagation in troposphere.

- Attenuation by the gases.
  - water vapor
  - oxygen

- Absorption and Scattering
  - by hydrometeors,
    - rain,
    - snow,
    - hail.



Interaction between Ionospheric Plasma and Microwave

Influence	Mechanism	Evaluation
refraction effect	Refraction by plasma (total electron content)	This gives no problem by using the pilot signal.
Faraday rotation	Rotation by the magnetic field	Influence for the transmission efficiency is small.
Scintillation	Phase variation caused ionosphere irregularity	In case of the active scintillation : N_r'=5x10^{16} electrons/m^2 ΔP=0.34m(2.78 times the wavelength (2.45 GHz ） ΔP=0.06m(1.16 times the wavelength (5.8 GHz ） This effect on the pilot beam and microwave power beam can not be ignored.
Non-linear interaction	parametric instability excitation, electron thermal runaway in the lower ionosphere, and thermal self-focusing of the microwave beam in the ionospheric F-region.	These phenomena is expected to be small impact. Confirmation will be needed using a microwave with the comparable power density as a practical SPS.

WPT Demonstrations

- 1964 Microwave-powered helicopter demonstration (USA)
- 1975 Transmission of 30 kW of power over 1.6 mile (managed by JPL:USA)
- 1983-SHARP project (Canada)
  Airplane powered 500kW of energy beamed at 5.8GHz
- 1983 MINIX (JAPAN) -Sounding Rocket Experiment-
  Interaction between microwave and ionosphere
- 1993 ISY-METS(JAPAN) -Sounding Rocket Experiment-
  A rocket experiment of the first microwave energy transmission experiments in the ionosphere
- 2006 Retro-Directive Demonstration Experiment (JAPAN)
  – Sounding Rocket Experiment-
  - Microwave beam control
- 2009- WPT experiment on ground (JAPAN)

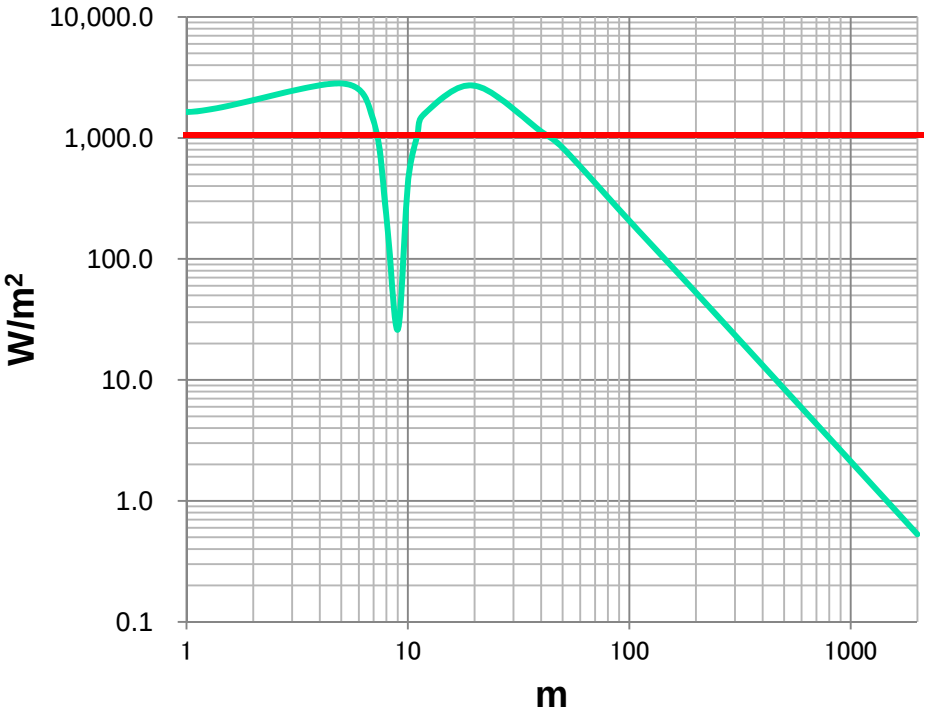
Microwave Power Requirement of Space Experiment

Large transmitting antenna and high power microwave radiation will be required for space experiments. Microwave power density of 1,000 W/m^2 will be needed for confirmation of interaction between microwaves and plasma.

Antenna Size : ϕ 1.9m
Power : 2kW
Frequency : 5.8 GHz

1,000W/m^2 (JAXA model): ～40 m
230W/m^2 (NASA model): ～80 m
100W/m^2 : ～100 m

Power density on the ground:
16 μ W/m^2

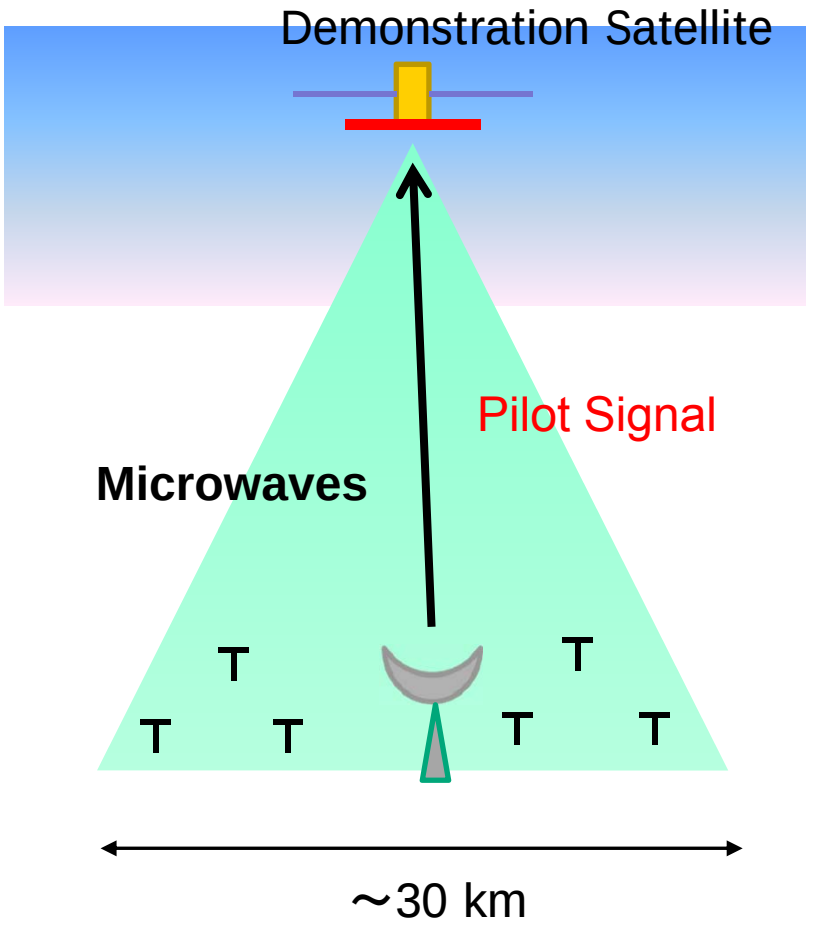


Purposes of the Space Demonstration using Small Scientific Satellite

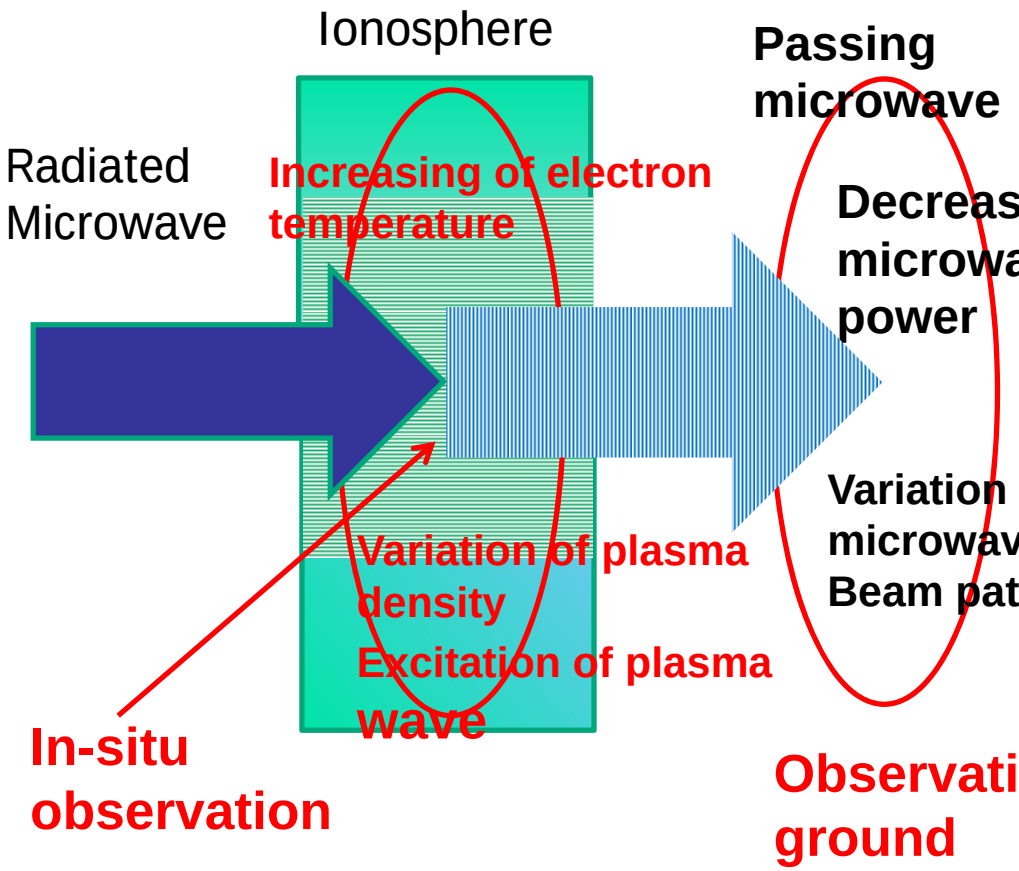
Main Subjects

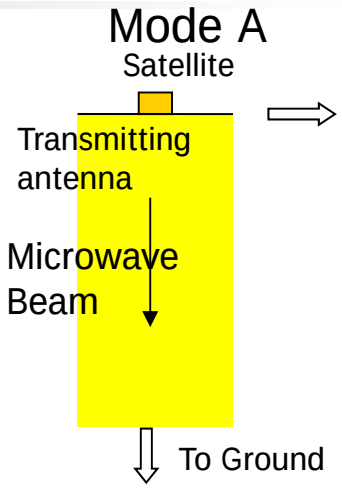
(1) demonstration of the accurate microwave beam control to the target on the ground from the antenna in orbit,

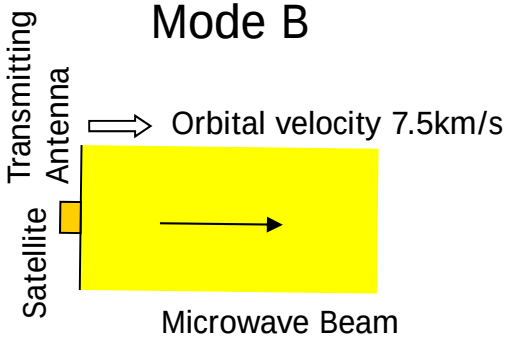
(2) verification of microwave power transmission (~kw/m^2) through the ionosphere and the atmosphere.



Space Experiments







In the direction of forward movement

Experimental Method I

Beam steering experiment from space to the ground.	Detection of the direction of the site using the pilot signal → Amplitude monopulse direction finding Beam steering by the phased array antenna → 5 bit phase shifters, 512 sub-array antenna Target value : 0.5 degrees (TBD)
Beam Forming Experiment	・Phase synchronization method Confirmation of the basic function of the REV (Rotating-element Electric-field Vector) Method 4 modules. Each module includes phase shifter for the rev method. Target value:11.25deg.(1bit accuracy of 5bit phase shifter)
	Power monitor and Beam pattern measurement using receiver groups on the ground located within a 15 km radius..

Experimental Method II

Transmission loss	・Confirmation of the transmission loss with an accuracy of 1% (TBD). ✓For the atmosphere Power monitor under a variety of the weather conditions at various area → international cooperation (TBD) ✓For the ionosphere On board instrument Plasma parameters will be measured with an accuracy of 10%. Wave receiver Excited wave (several kHz to 10MHz) ・Evaluation of the applicability of the WPT for the power system.

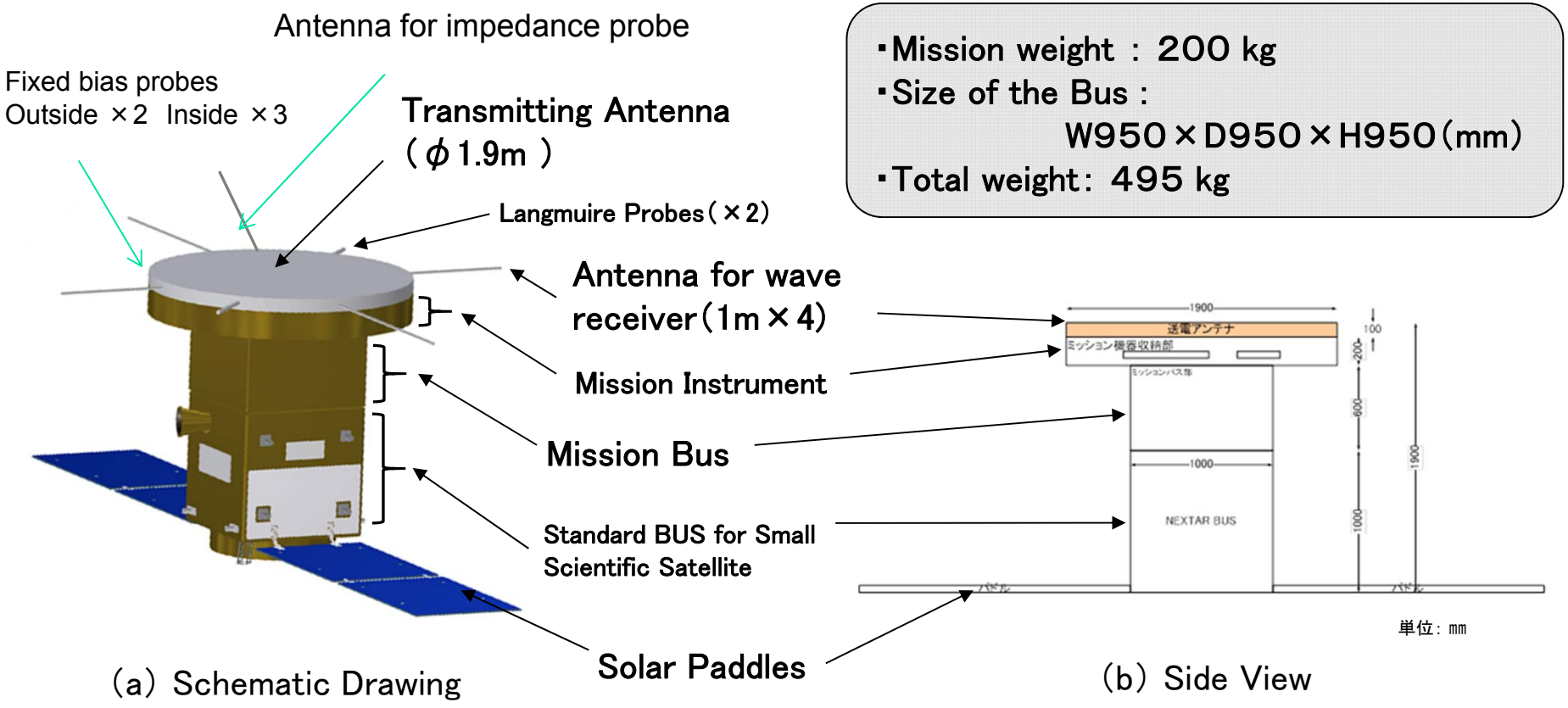
Operation Scenario

Phase	*Terms*	Small Satellite
Launch Vehicle	—	Epsilon
Initial Operation	*1 Week*	Initial Checkout, Sap deployment, System checkout
Normal Operation	*1 year*	Experimental operation: three times per day. Once every three days: mode A (Satellite pass directly above the station.) Other path : mode B（Plasma interaction experiments)
Attitude		Sun tracking control (non-experiments mode) 3-Axis control（Transmitting experiments, mode A/B)

System Characteristics

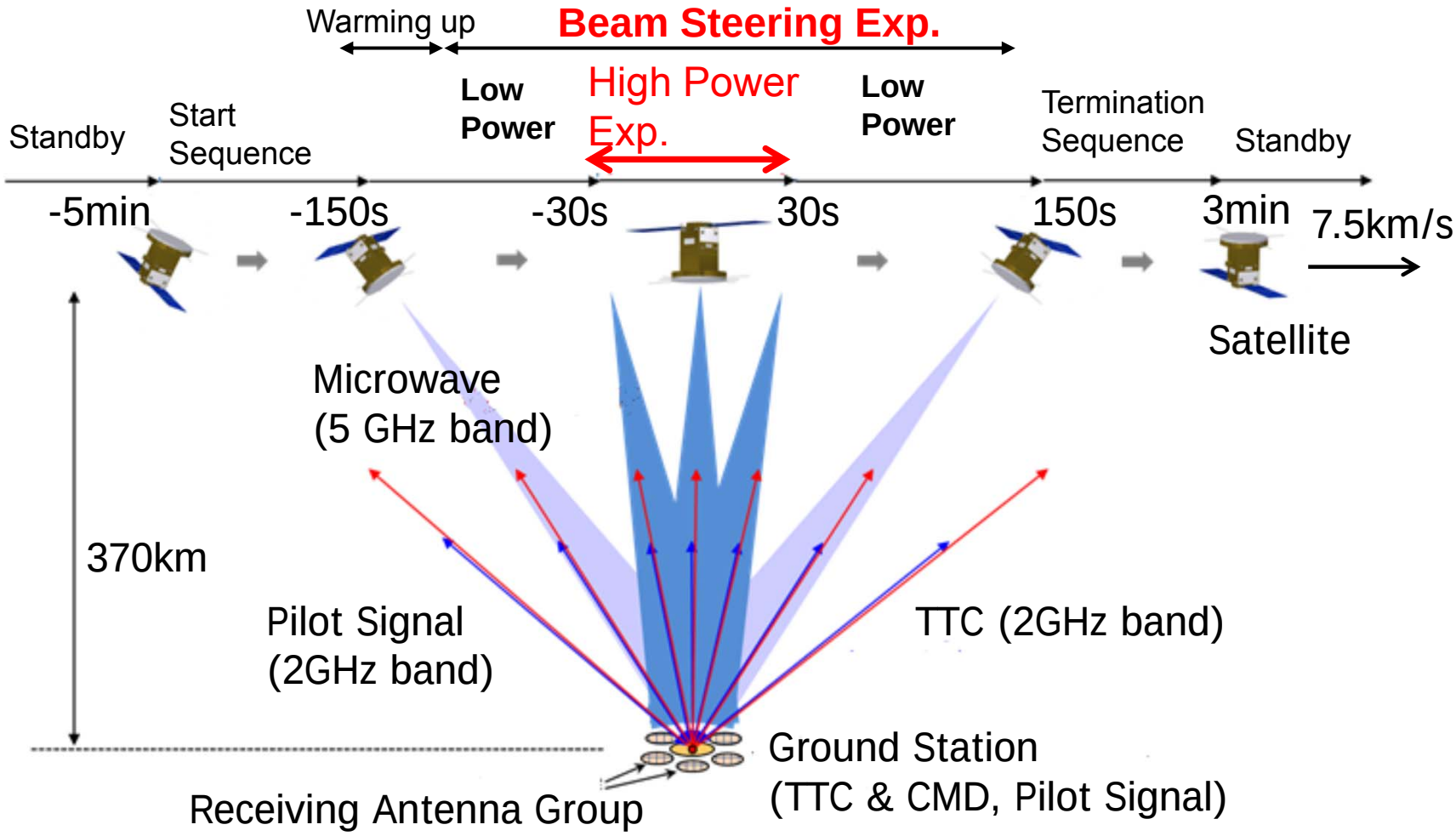
Altitude/Orbit	*370km (sub recurrent orbit)*
Mission Weight	*200kg*
Mission Instruments	
Transmitting Antenna with a diameter of Φ1.9m, 4 module configuration	
Plasma measurements instruments	
Langmuir probe, impedance probe :electron density : 10^3-10^7/cc,	
electron temperature:500-5000° K	
Wave receiver	*100kHz-10MHz、1kHz-30kHz (wide band)*
Control Unit, Power Units for High power transmission experiment	
Transmitting Power	*Typ. 2kW (1kW ～ 4kW)*
Attitude Control	*3-axis control*
Orbit maintenance	*Thruster (3N)*
frequency	*5.729 GHz (TBD)*
Beam Control	*Software Retro-directive method by onboard CPU*
Ground Station	JAXA ground stations
	International experiment sites
Power density at the ground	*16μW/m^2 (MAX)*
Beam width on the ground	*φ ～30km*

Configuration of the Satellite

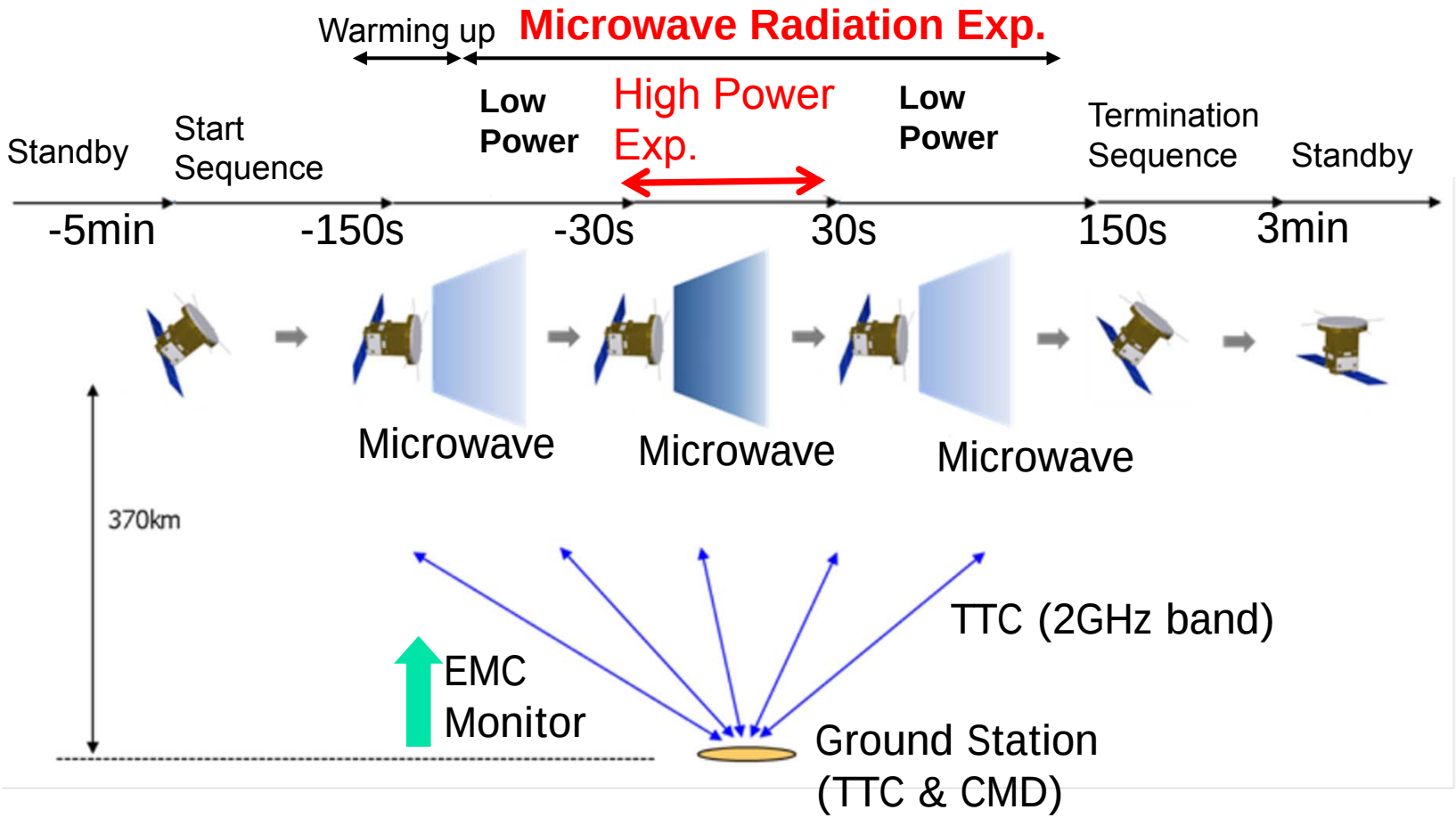


- Mission weight : 200 kg
- Size of the Bus :
  W950×D950×H950(mm)
- Total weight: 495 kg

Operation Sequence
（from space to the ground：mode A）



Operation Sequence
（Interaction between Plasma and Microwave：mode B）



Summary and Conclusions

- We are considering a space demonstration experiment on the WPT from space to the ground and on the interaction between high power microwaves and ionospheric plasma using a small scientific satellite.

- Interaction mechanism between ionospheric plasma and high power microwave were summarized.

- Microwave power density around ionospheric region is designed around several hundred W/m^2 for the future commercial base SPS. These effects should be confirmed by the space experiments.

- We plan to measure the electron temperature, the electron density and excited waves under the microwave irradiated conditions using plasma probes, wave receiver or some observation equipment.

- This WPT demonstration using a small satellite is expected to solve basic and critical issues of SPS, and to lead towards a follow-up project using a larger satellite that will aim to perform a high-power transmission experiment over 100 kW.