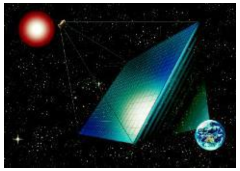
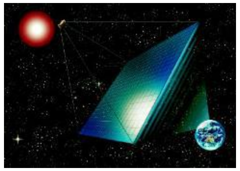


A New Type of Solar Power Satellite Using Microwave Power Transmission

- Comparison of Laser and Microwave Energy Transmission for SPS
- Examples of SPS using Microwave Energy Transmission
- Tethered-Solar Power Satellite (Our Study)

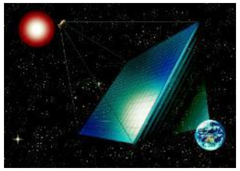
International Workshop on the Laser Energy Transmission for Space Exploration and Ground Applications

June 2004

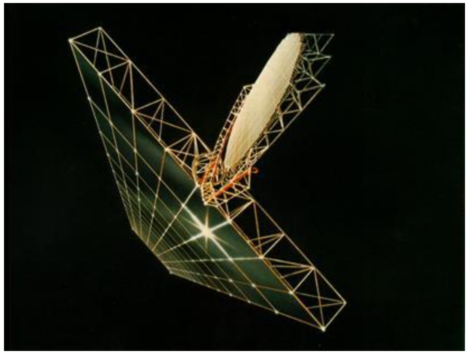


Comparison of Laser and Microwave Energy Transmission

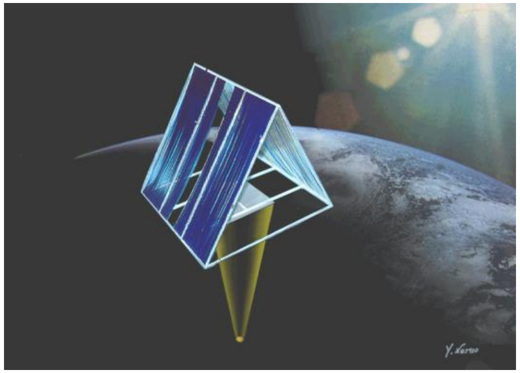
	Microwave	Laser
Frequency/Wave Length	~several GHz	~1 μm
Power Conversion	Solar-DC-RF･･･DC	Solar-Laser･･･DC
Conversion Efficiency	Higher	Lower
System Size	Larger	Smaller
Beam Energy Density	Lower(Safer)	Higher
Electromagnetic Compatibility	Lower	Higher
Weather Dependence	Smaller	Larger
Technology Maturity	Higher	Lower
Comment	Near term demonstration	Space-Space



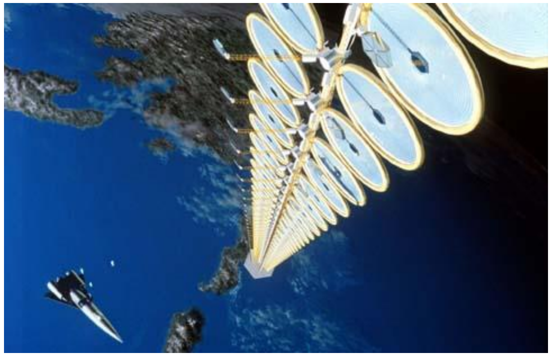
Examples of SPS using Microwave Energy Transmission



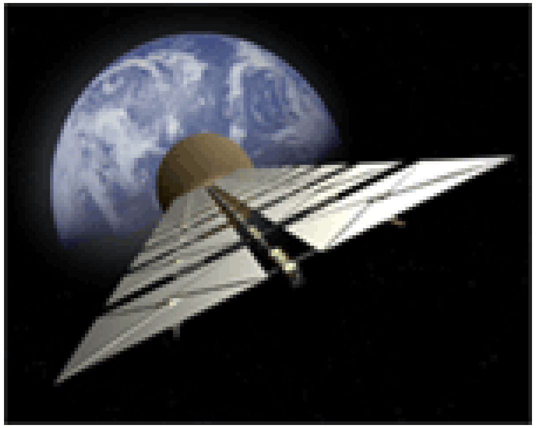
NASA Reference System



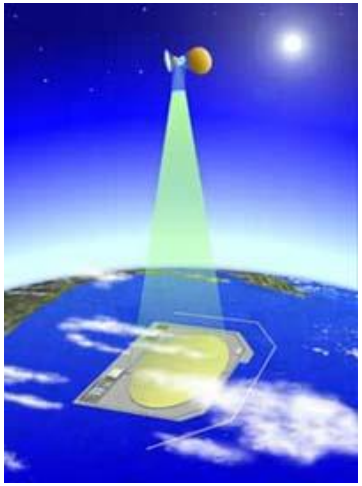
ISAS SPS 2000



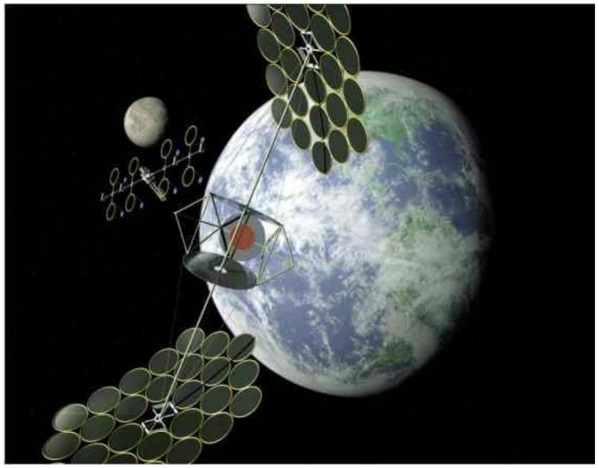
NASA Sun Tower



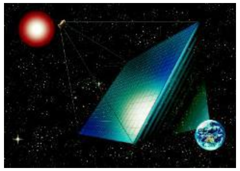
European Solar Sail Tower



NASDA SSPS Model

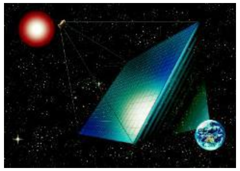


NASA Integrated Symmetrical Concentrator

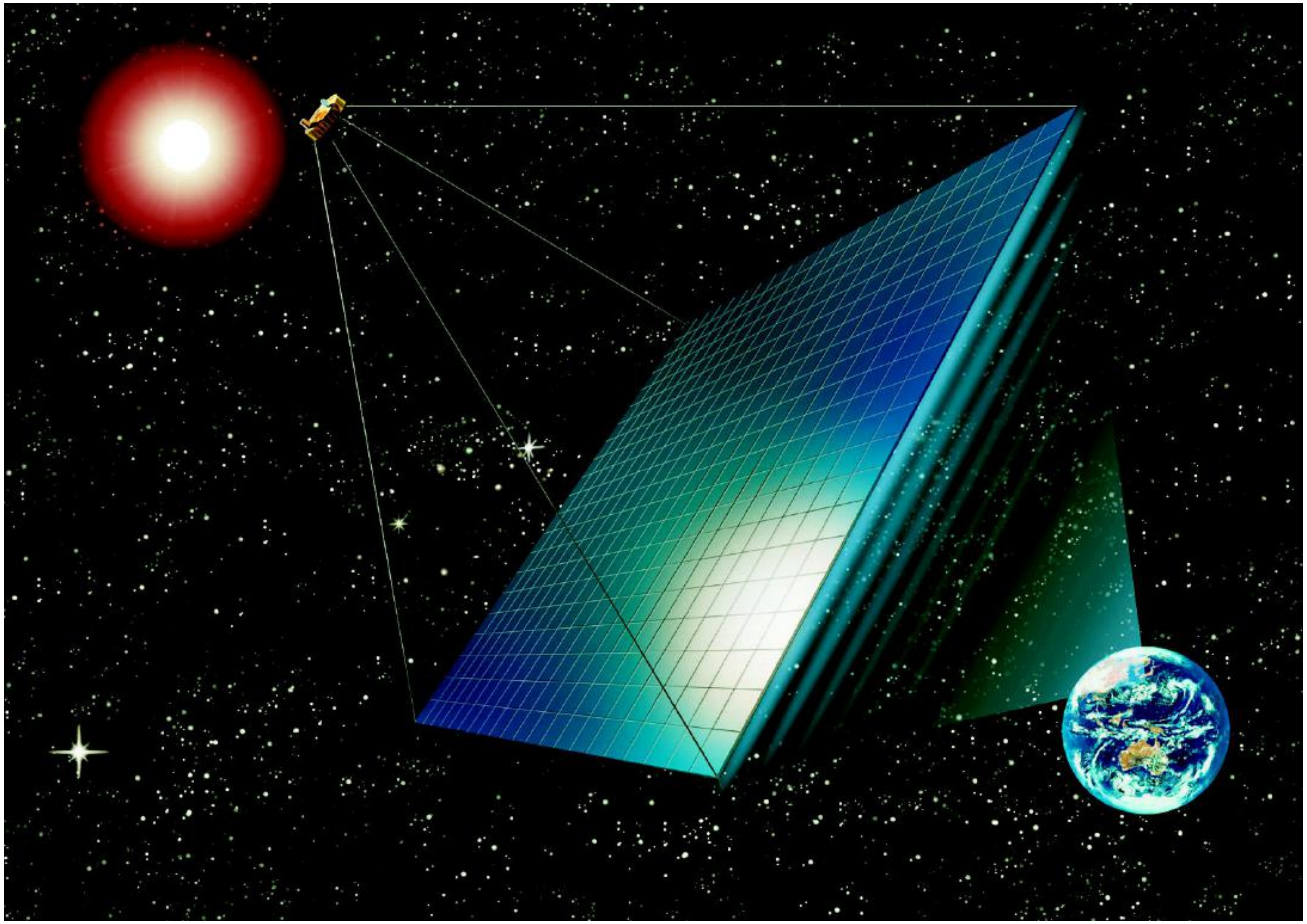


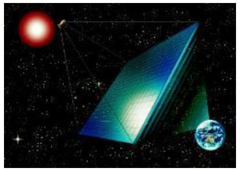
Problems in the Past SPS Models

Problem Area	Critical Problem
Rotary joint, Movable mechanism for rotation mirror	Lack of robustness (one-point failure gives total loss)
Power collection cable or super conduction cable	Non realistic weight Difficult implementation for SPS
Light condensing mirror	Serious problem in heat rejection from transmitter Non realistic technology in shape control of large thin film structure
Operation start after full construction	Hardly accepted as a large space infrastructure
Construction in LEO and transportation to GEO	Non realistic OTV Degradation of semi-conductors by radiation
Independent configuration between demonstration and practical SPS	Non consistent strategy in the road map to practical SPS



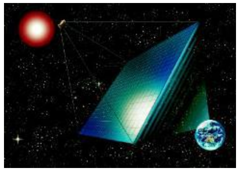
Tethered Solar Power Satellite (Our Study)





Design Policy for Tethered-SPS

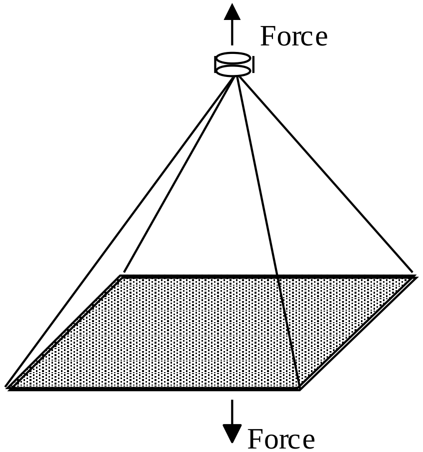
- Structure and mechanism be simple and robust:
  ⇨ no active attitude control and no movable mechanism in operation
  ⇨ attitude control by gravity gradient force using tethers
- Distributed power system :
  ⇨ power generation/transmission module(sandwitch power module), no power bus
- Concentration of information:
  ⇨ wireless LAN
- A large number of electrical parts (solar cells, microwave elements) required:
  ⇨ COTS(commercial off-the-shelf), high-technology, mass production, low-cost



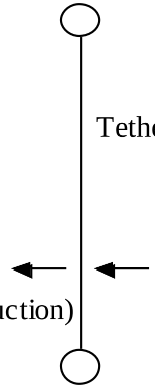
Stabilization by Gravity-gradient force Using Tether Wires

Why tether?

- Gravity gradient force to stabilize attitude（~ML²）
- Dynamically robust.
- Analogy with suspension bridge on ground (km scale structure)

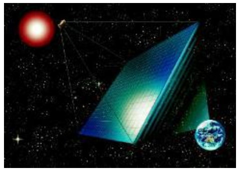


Grabity gradient stabilization
(No active control required)



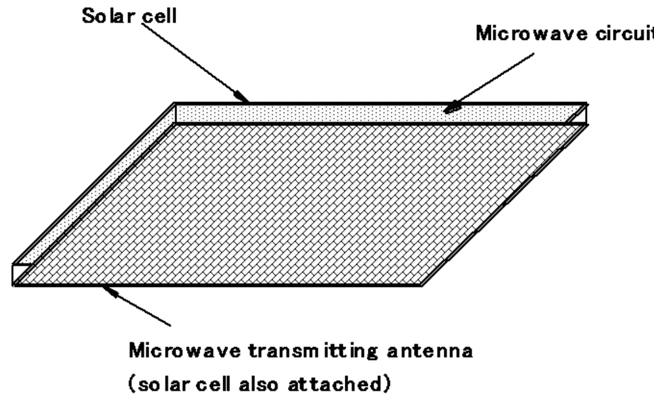
Dynamically Robust

Suspension Bridge
1,600mx34m

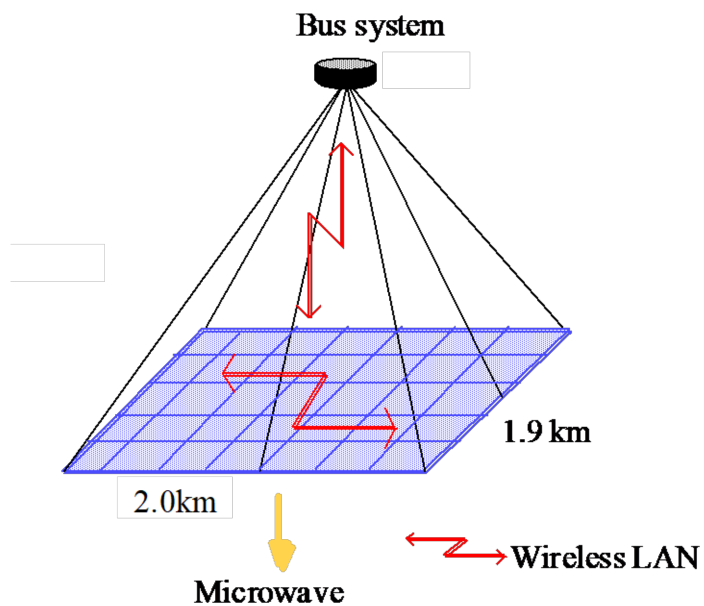


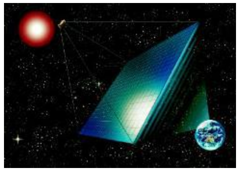
Concept of power generation and transmission module (Sandwich Panel)

- Module including power generation and transmission
- Wireless interface between modules



- easy attachment and detachment as a module
- robust as a power system
- easy fabrication, test, integration, and maintenance





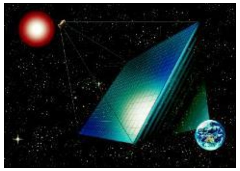
Characteristic features of Tethered SPS

Advantages

- No active attitude control
- No movable mechanism
- No thermal problem
- Smaller rectenna

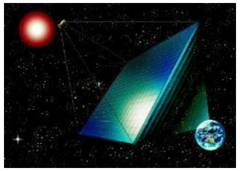
Disadvantages

- The power efficiency is 64% as compared with the sun-pointing type SPS.
- Variation of power transmission depending on local time(sun angle)



Solution of problems by the tethered-SPS

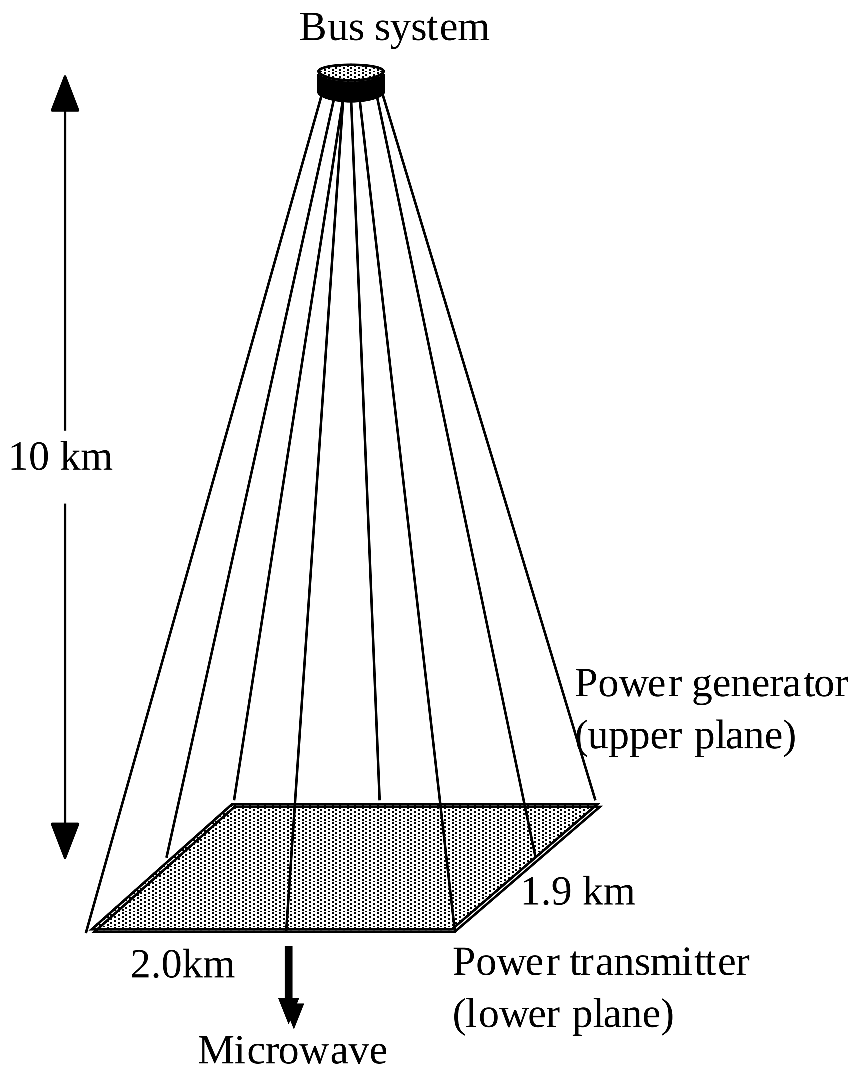
Problem Area	Critical Problem	Tethered-SPS
Rotary joint, Movable mechanism for rotation mirror	Lack of robustness (one-point failure)	No movable mechanism
Power collection cable or super conduction cable	Non realistic weight Difficult implementation for SPS	No power collection cable (power generation/ transmission panel)
Light condensing mirror	Serious problem in heat rejection from transmitter Non realistic technology in shape control of thin film structure	No light condenser
Operation start after full construction	Hardly accepted as a large space infrastructure	Phased construction from low to high power system
Construction in LEO and transportation to GEO	Non realistic OTV Degradation of semi-conductors by radiation	Construction in GEO
Independent configuration between demonstration and practical SPS	Non consistent strategy in the road map to practical SPS	Demonstration model = a part of practical SPS

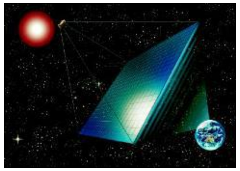


System Characteristics of Tethered SPS

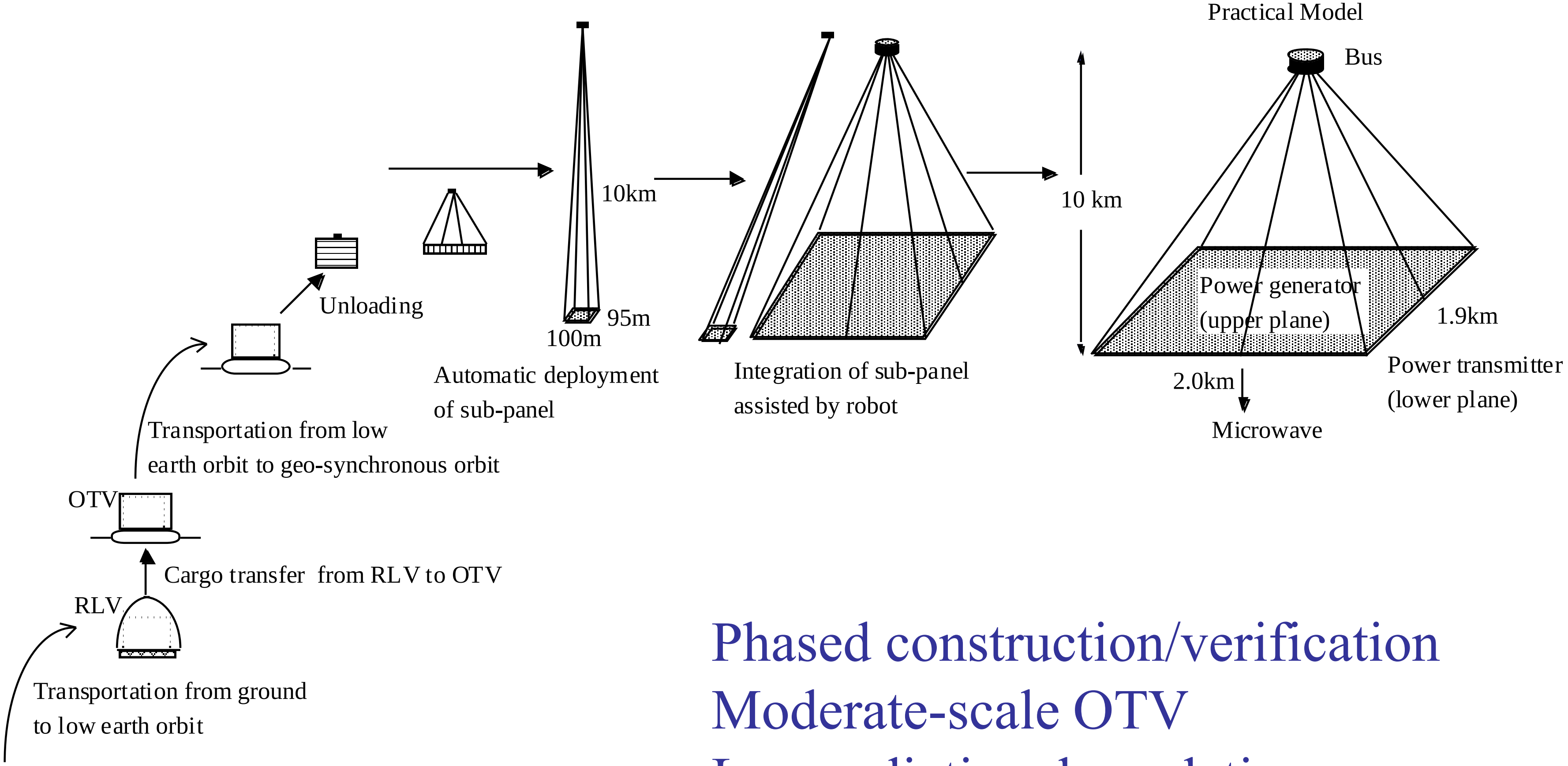
Total weight:
20,000 MT

Output power:
1.2 GW maximum,
0.75 GW on average

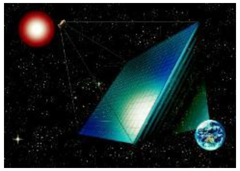




Construction Scenario

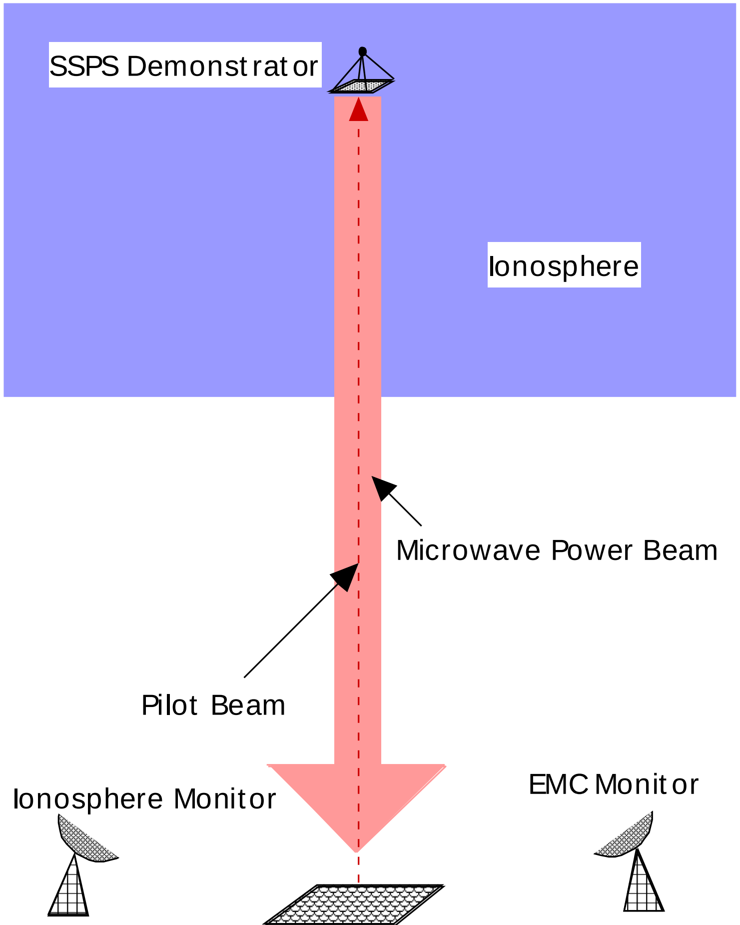


Phased construction/verification
Moderate-scale OTV
Low radiation degradation



Objectives of Demonstration Experiment

Most important subject at this stage towards the practical SPS is a verification of power transmission from space to ground.

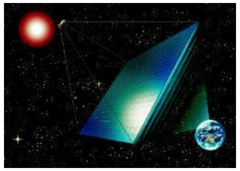


(1) Demonstration of microwave beam control, pointing precisely to a rectenna on ground from a large antenna dynamically-moving in orbit.

(2) Evaluation of over-all power efficiency as an energy system.

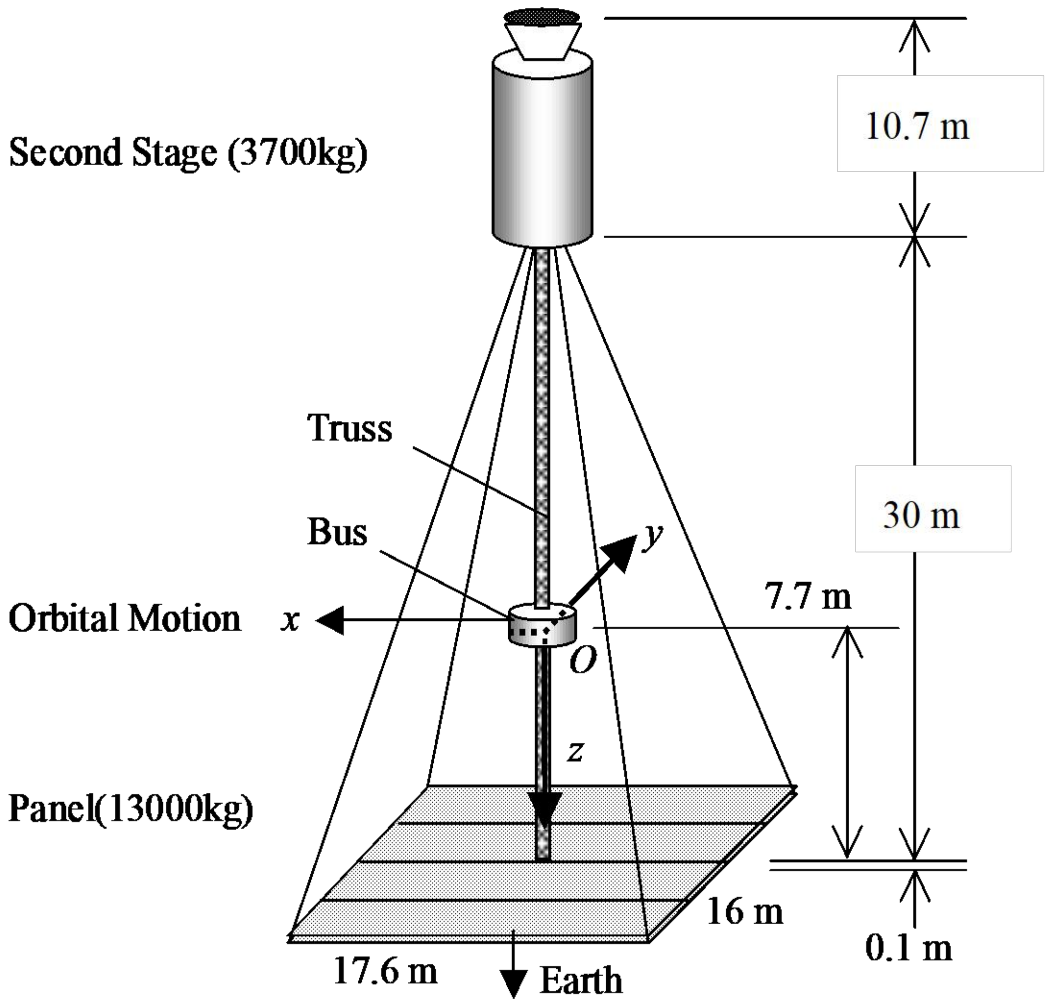
(3) Demonstration of electromagnetic compatibility with existing communication infrastructure.

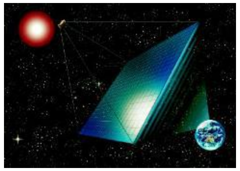
(4) Study of operation procedure as an solar power satellite.



System Characteristics of Demonstration Experiment

Size	40.8m x 17.6m x 16.0m
Total Weight	18,100 kg
Power Generation	36 kW max
Power Transmission	420 kW～140 kW
Beam Control	retrodirective control
Microwave Frequency	5.8 GHz
Operation	full power for 16 sec 10% power for 4 min
System Configuration	panel, truss, tether, weight mass
Panel Configuration	80 foldable panels 400 power modules 250,000 antennas
Attitude Control	gravity gradient force
Altitude	370 km
Rectenna type	parabola collector
Rectenna output	30 kW～10 kW (500 m diameter)

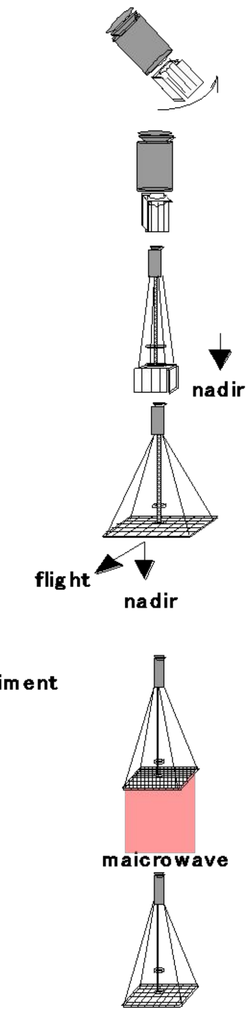


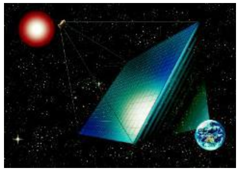


Launch and Mission Operation

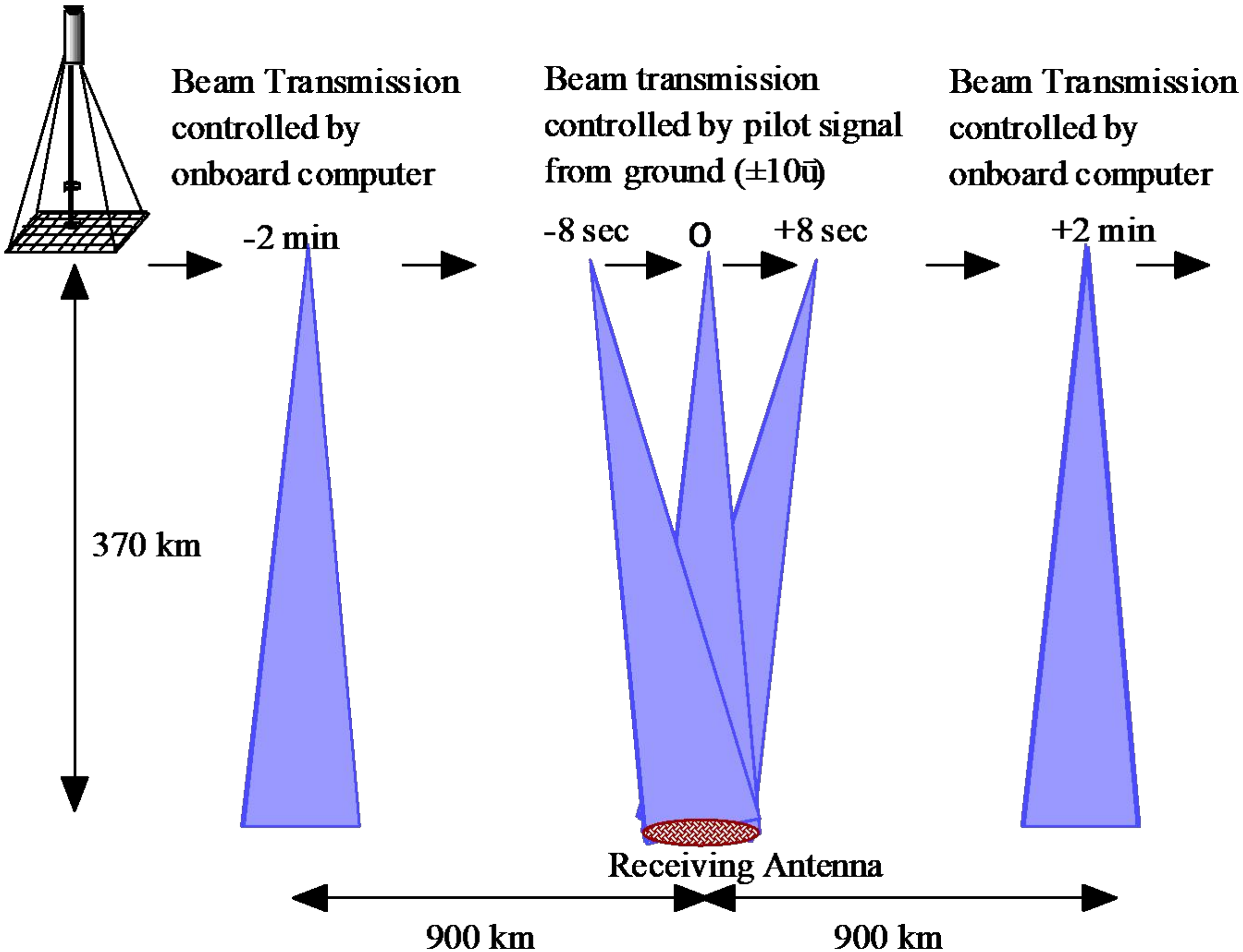
H2-A Launch Vehicle

MET 0	Launch Orbit (370km altitude) despin
MET 1	bus system checkout earth pointing
	truss deploment
MET 2	panel deployment
MET 3 ~	orbit adjustment
MET 30	experiment checkout
MET 31 ~	power transmission experiment
	standby

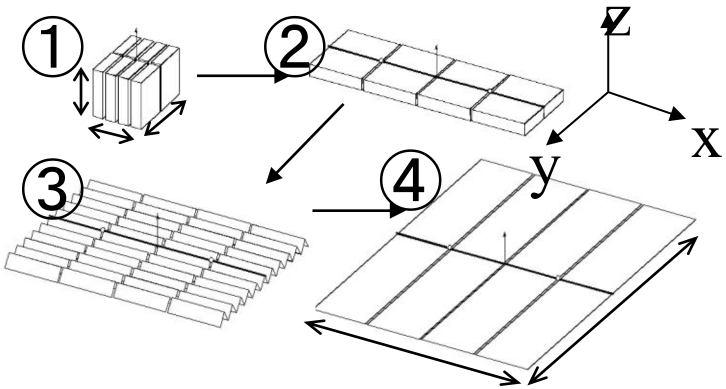


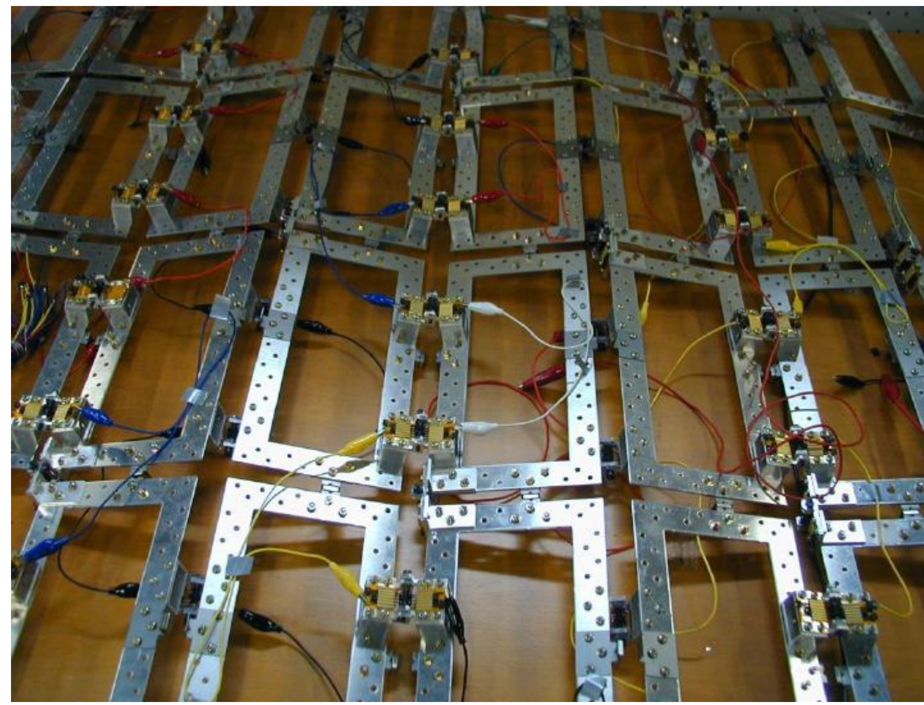


Experiment Sequence of Microwave Power Transmission

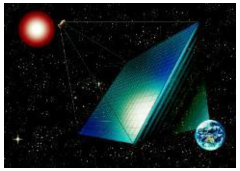


Two Dimensional Panel Deployment

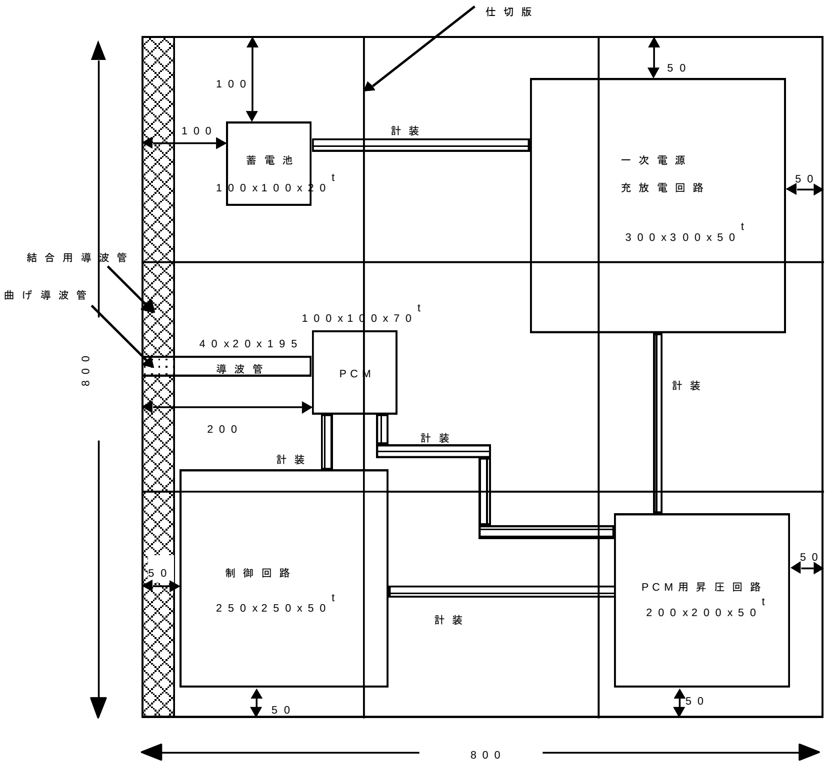


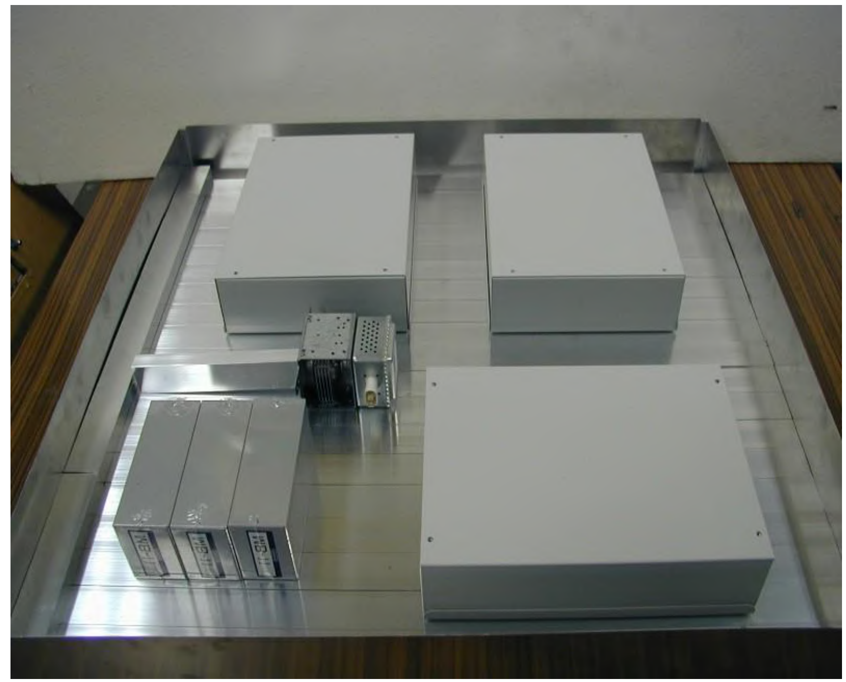


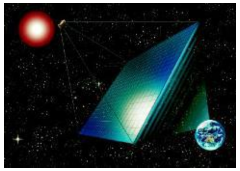
Shape memory alloy actuator
for two dimensional deployment



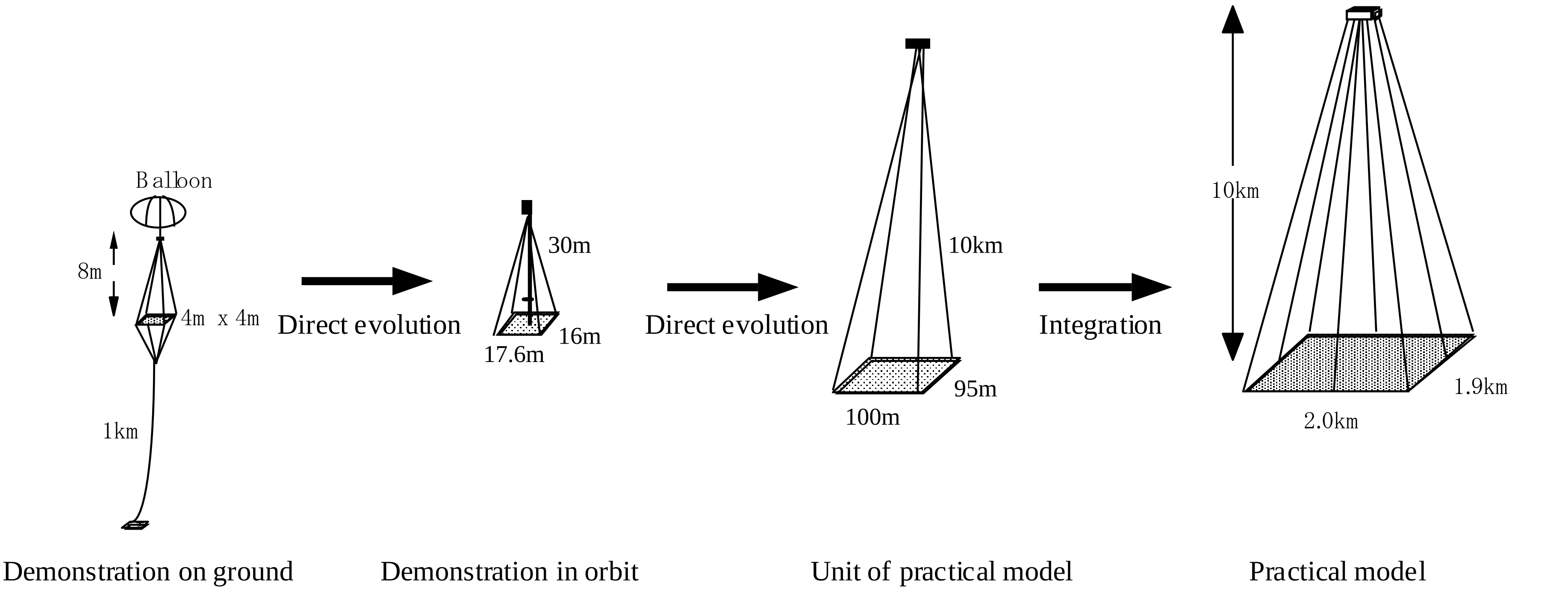
Power Generation and Transmission Panel

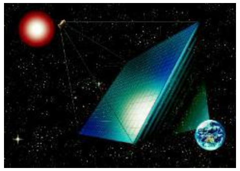






Evolution Strategy from Demonstration to Practical Model

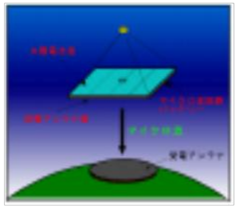




Road Map for SPS Research and Development

2000 2010 2020 2030 2040 2050 2060（年）

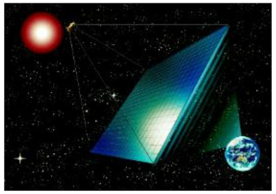
Basic Research → Reserach and Development → Commercial



100kW Experiment

10MW Demonstration

100MW Demonstration



Commercial SPS

Initial 1GW

Total 1000GW