Project of Micro-Satellite Constellation for Earthquake Precursor Study

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Dr. T. Kodama (EORC/ JAXA), Mr. R. Misonoh (Tokyo Gakugei University)

Mitigation of Earthquake Disasters

- **Prevention**

O Well-developed

O Practical use

X Underneath strong earthquake

X Tsunami generated near the coast.

- **Prediction / Forecast**

Short-term Prediction
(days - hours in advance)

Holy grail of earth science!

Short-term Earthquake Prediction

- Prediction

  Where?

  When?

  How large?

- Precursor is needed !

Reported Precursors
Uyeda, Nagao &Kamogawa (2011)

- Animal behavior?
- Radon emission?
- Ground water?
- Geo-electric current?
- Ionospheric disturbance?

Some of them may be scientifically real,
but it is difficult to statistically prove it.

For precursor science …

- Physical mechanism (Deductive)

  So far, the mechanism of any precursor has not been found.

- Statistical method (Inductive)

  Epidemiology-like methodology

  Probabilistic earthquake forecast is possible.

Causation between EQ and Precursors

- Learning from epidemiology (Hill, 1965).

- A number of events is needed for statistics.

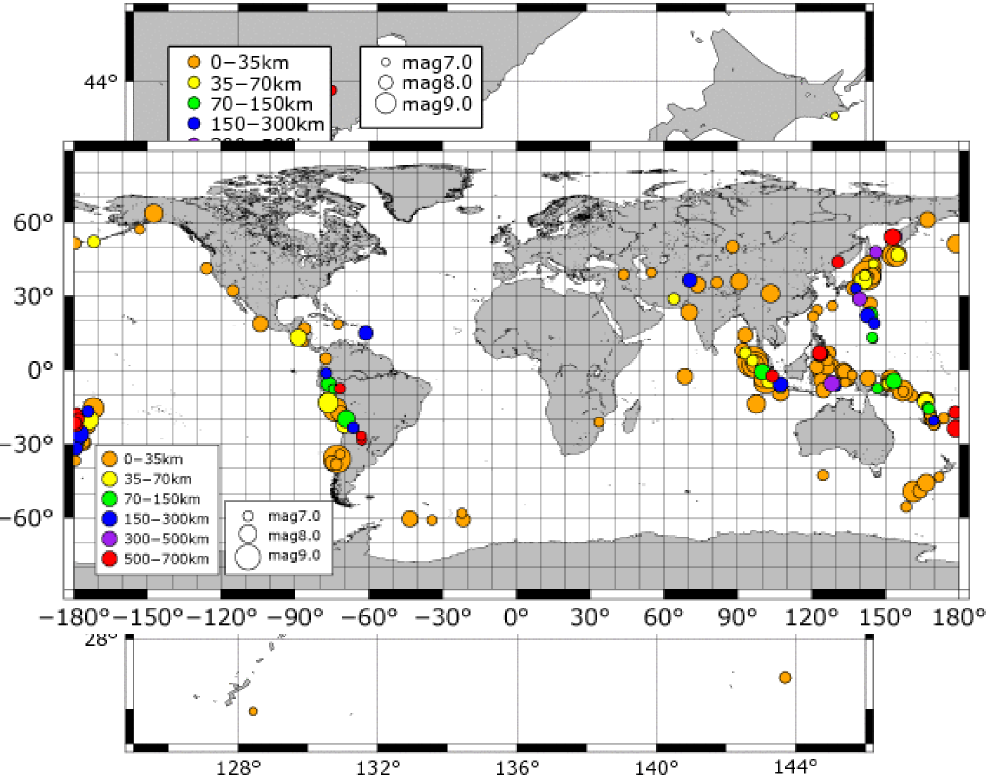
- Earthquake -> Precursor
- No earthquake -> No precursor

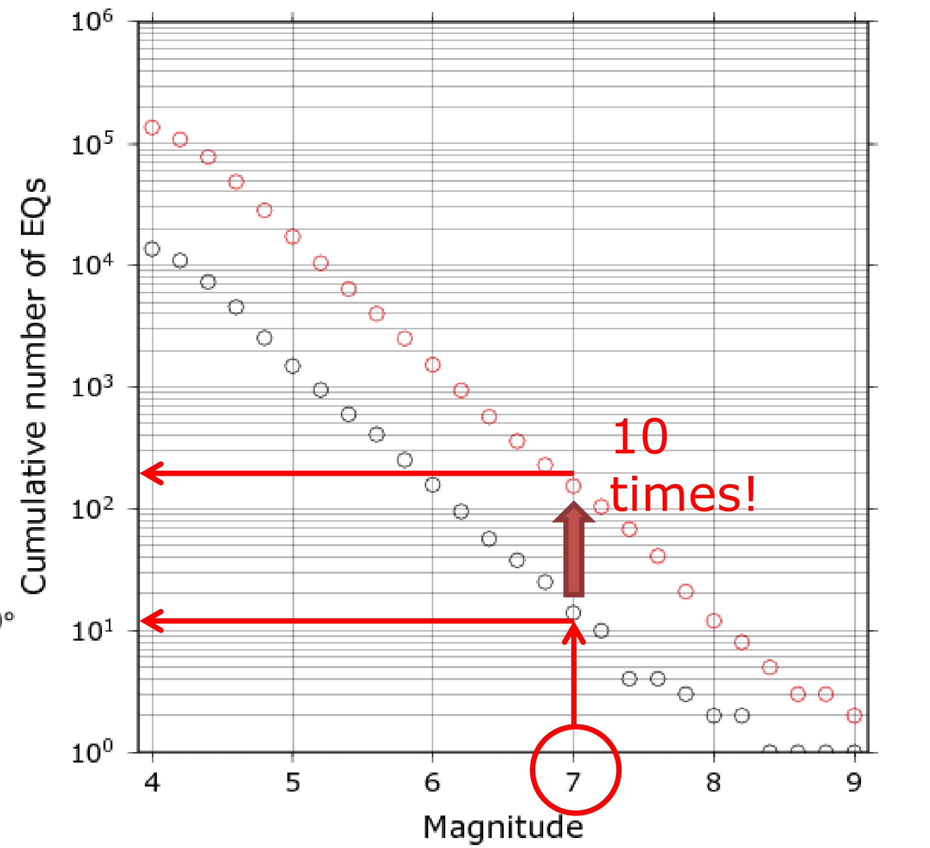
- Large (M>7) earthquake -> Large precursor

Most difficult issue!

The number of large earthquakes is small.
- Gutenberg Richter Law

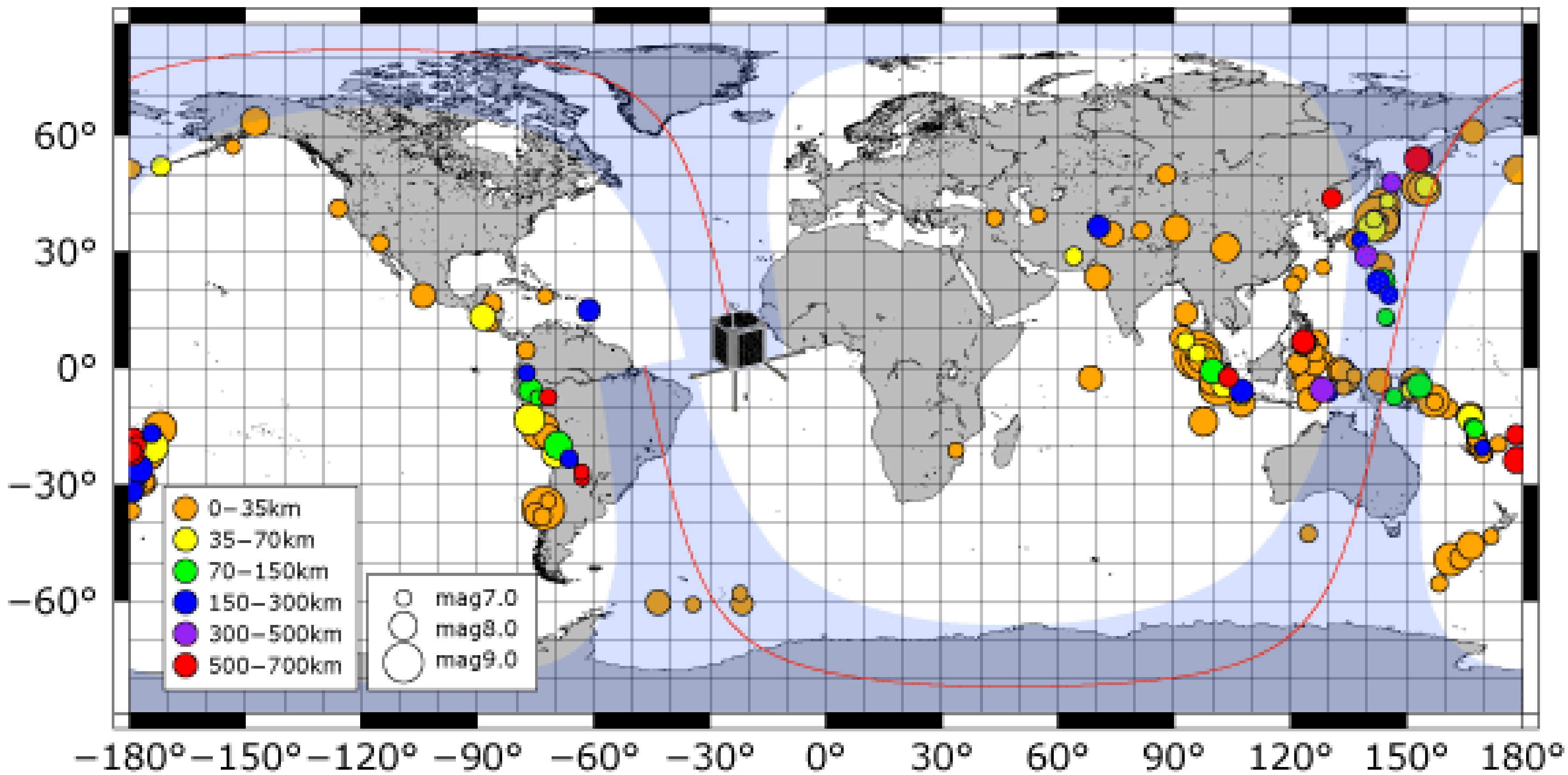
(USGS, 2000-2011)



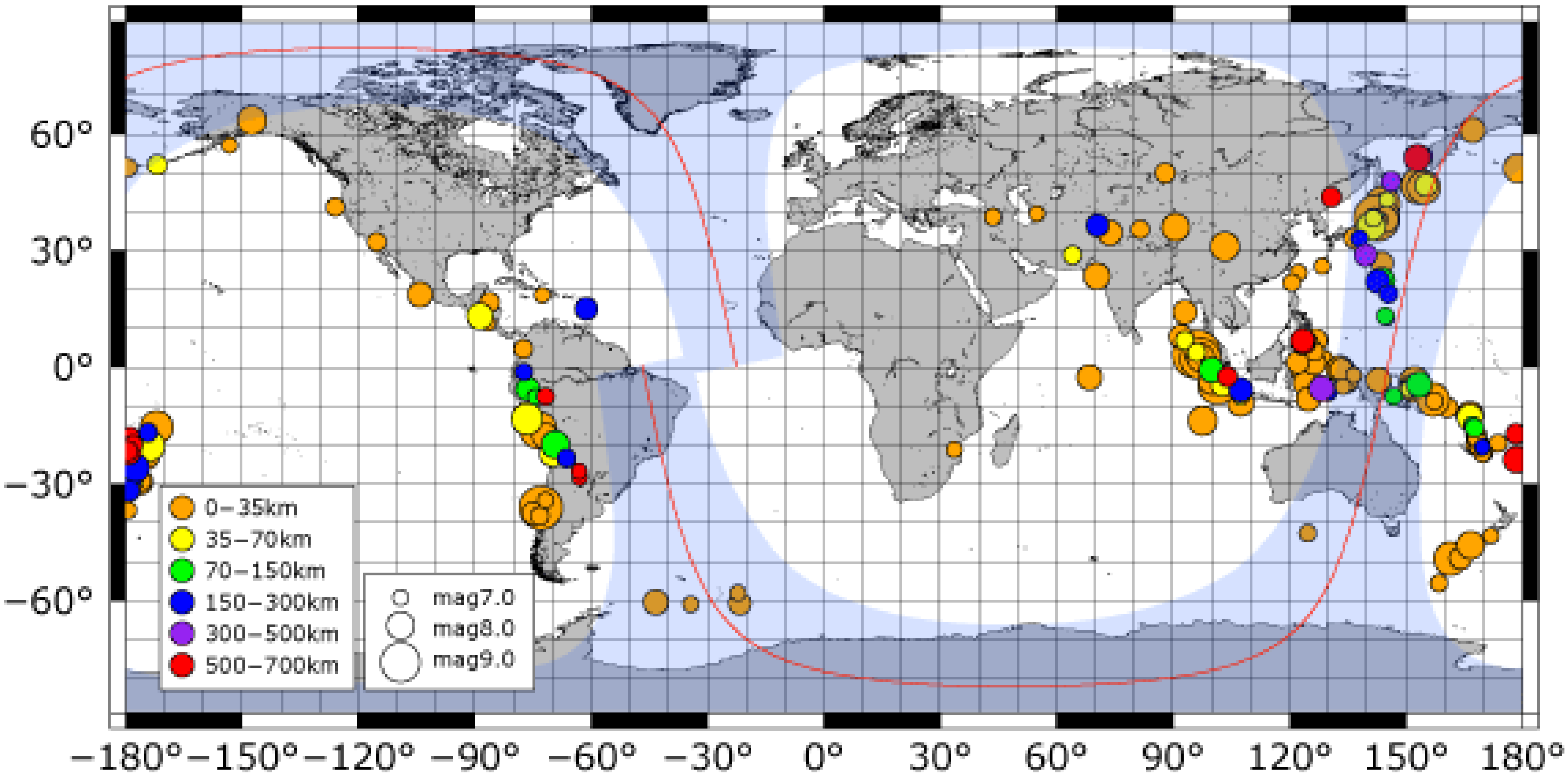


We focus on world earthquakes.

Satellite observation is useful!

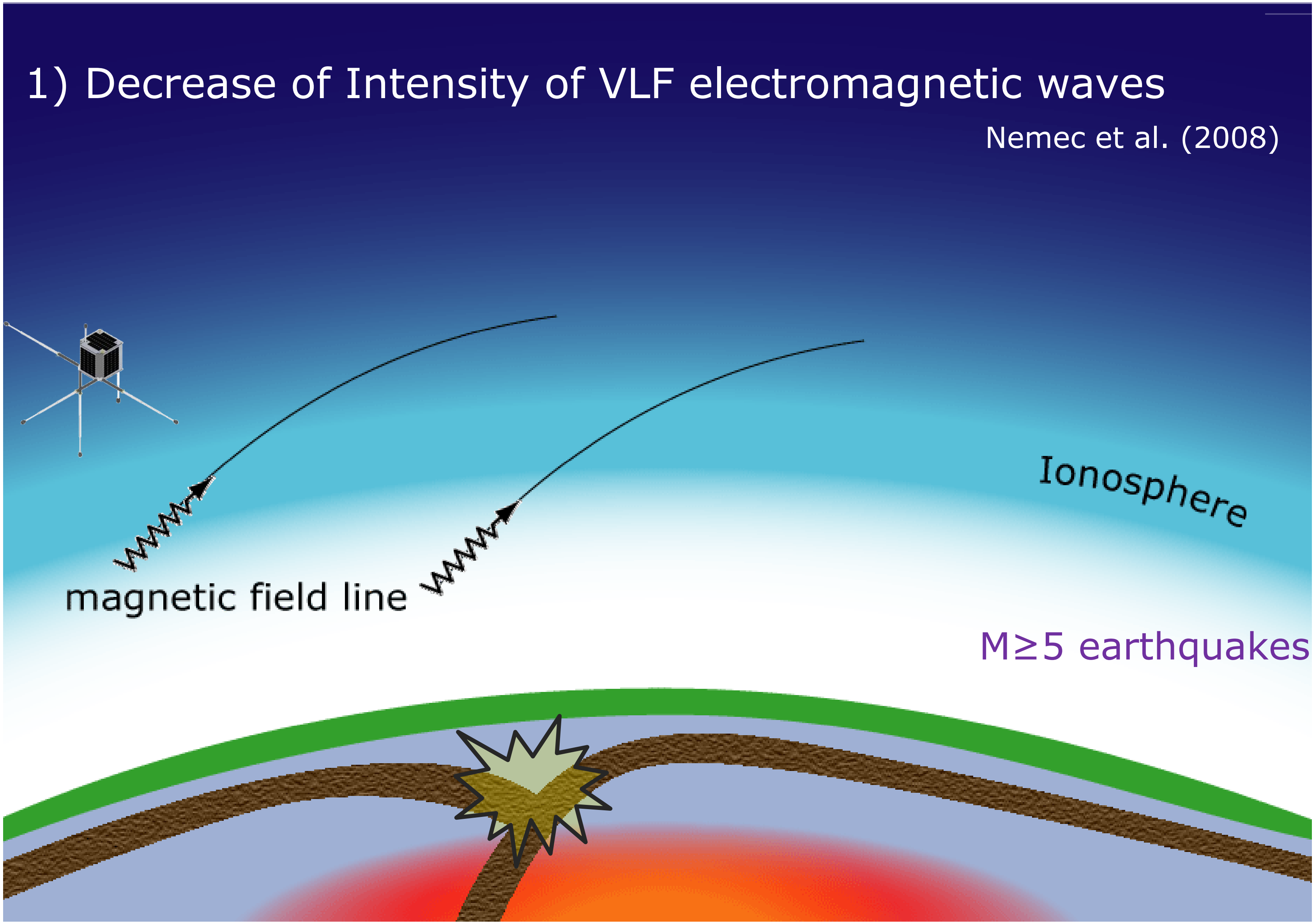


Before Earthquake



Plausible Ionospheric Precursors

(Kamogawa (2006) and later reviews)



Plausible Ionospheric Precursors

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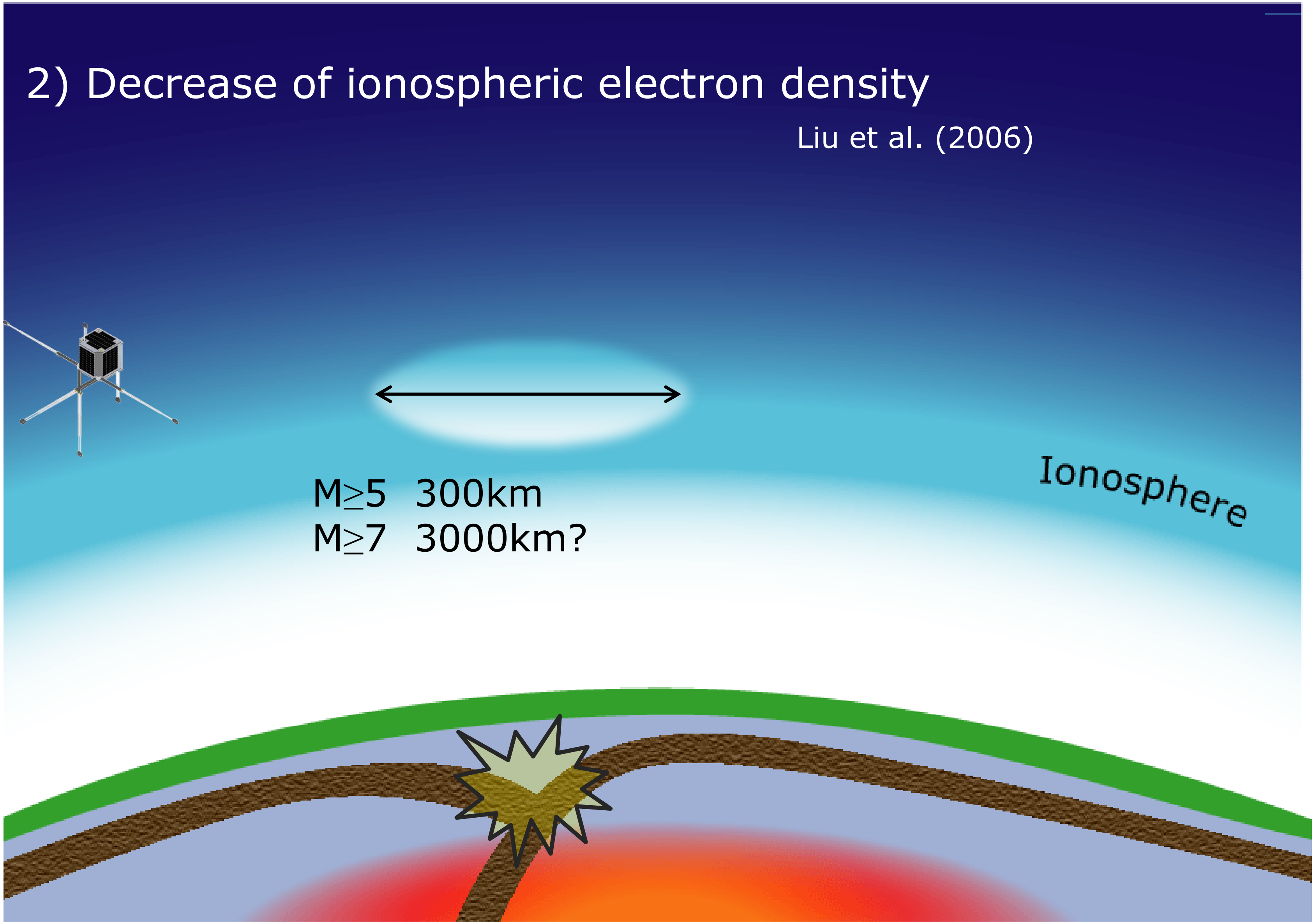


On-orbit Observations

1) Electric field of VLF electromagnetic waves

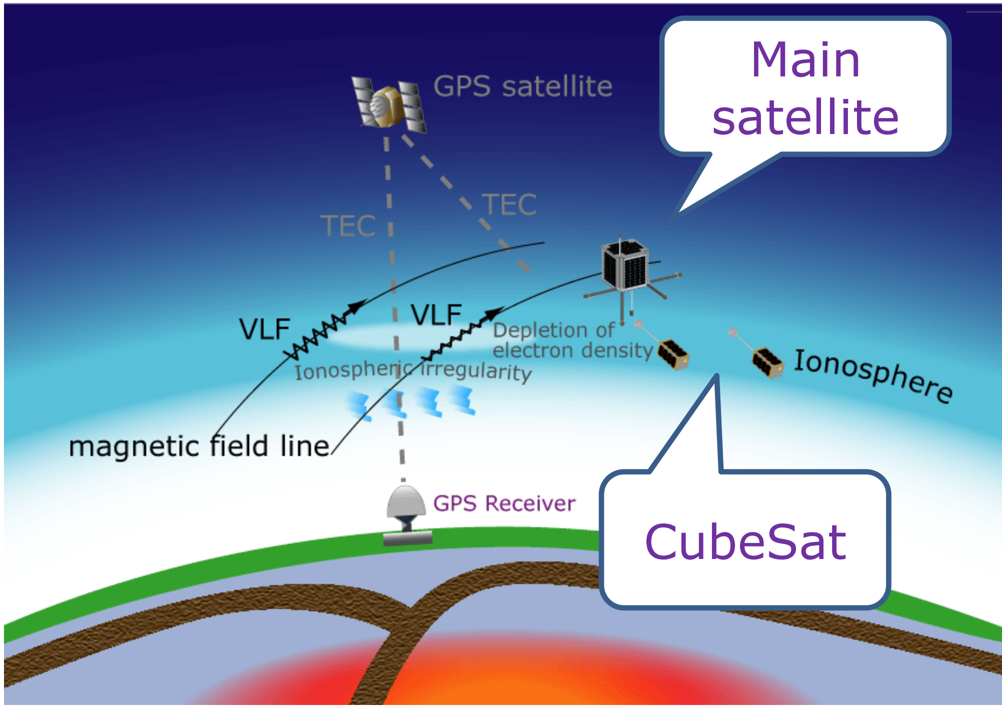
[EFM] Electric field measurement with Dipole antennas

[MFM] Magnetic field measurement

2) Electron density

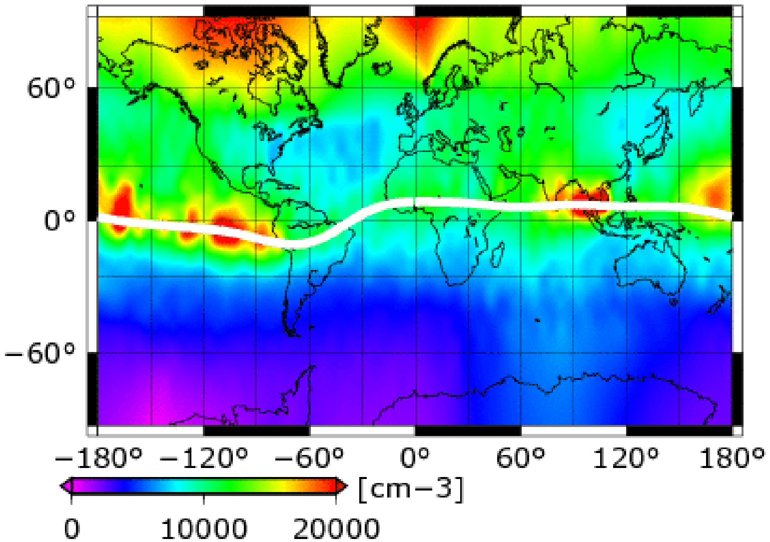
[EDTM] Electron density and temperature with Langmuir probe

[TEC] Total electron content with GPS receiver



How to identify a precursor?

We should know standard ionosphere .
So, we construct standard ionospheric model.



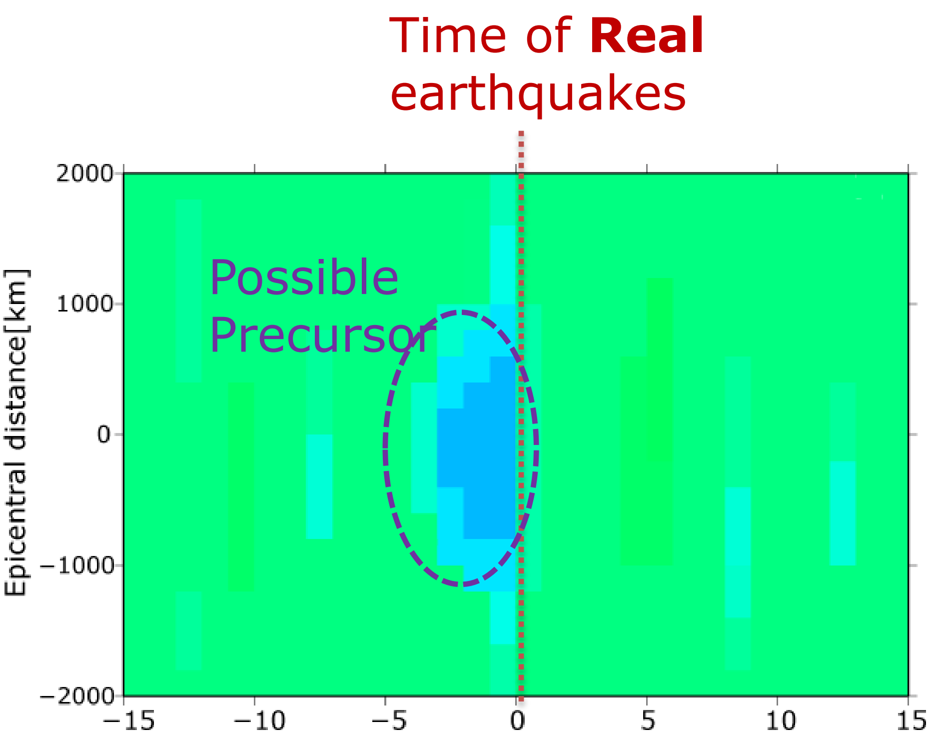
Example of electron density map
during geomagnetically quite period

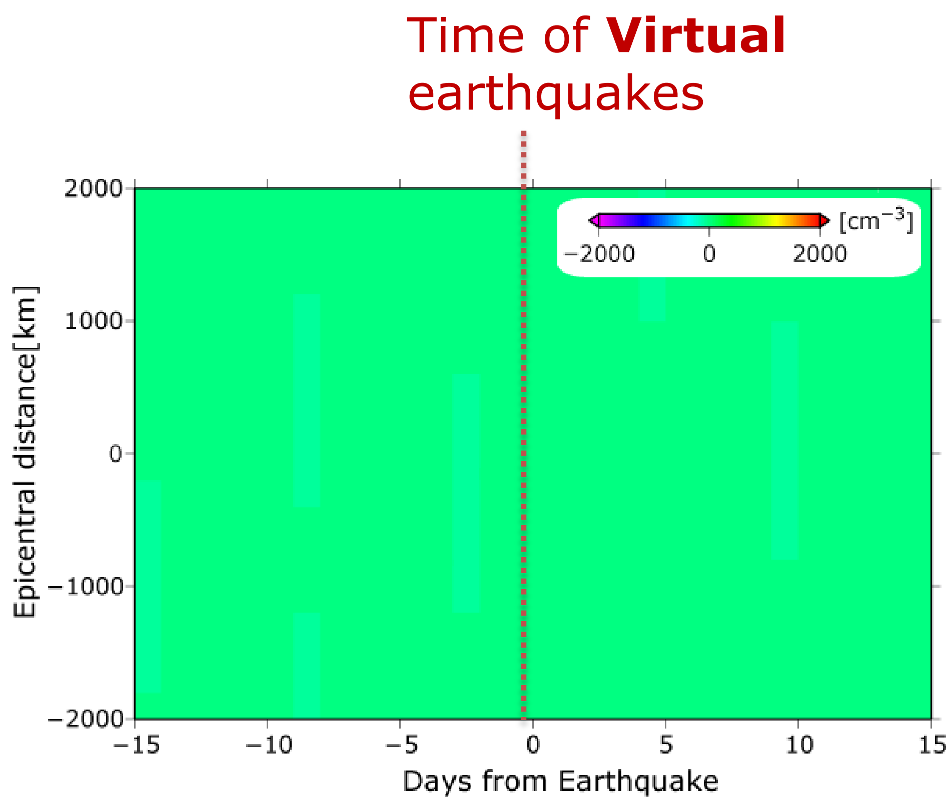
Model depends on..

Local time
Latitude
Longitude
Altitude
Solar flux
Geomagnetic activity
etc….

Precise model requires one solar cycle (11 years) observation.

Accumulate residual values between model and observed data.





Note: This is a conceptual view.

Mission Objectives

- Investigate two plausible ionospheric precursors
- Observe 100 M≥7 earthquakes
- Sustain 11-year observation

- Satellite successive operation and constellation

Orbit and Constellation Design

Observation:

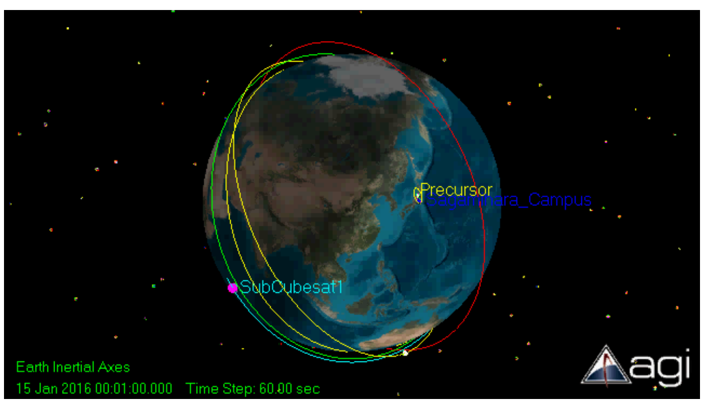
- Global coverage w/ instrument cross calibration
- Continuous operation for one solar cycle
- Capture both reduced parameter and time dependent dynamics of ionosphere

both SSO and non-SSO assets, in a sustained constellation

Operation:

- Exploit high-latitude GS for frequent downlink

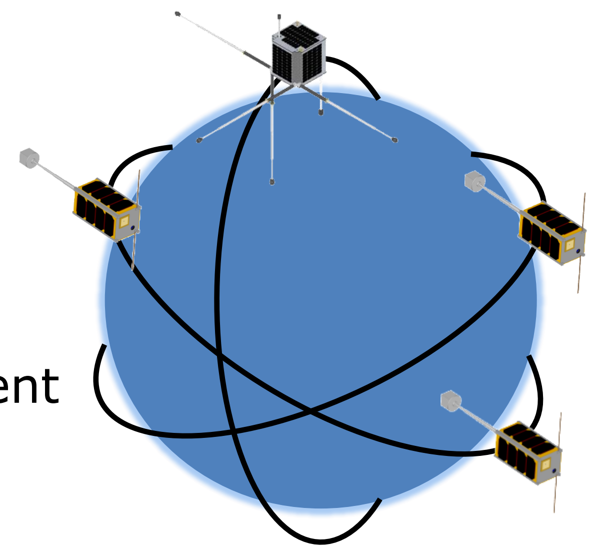
high-inclination for Main Satellite



1 SSO Main Satellite

+ non-SSO CubeSats

@ 2 year replenishment cycle

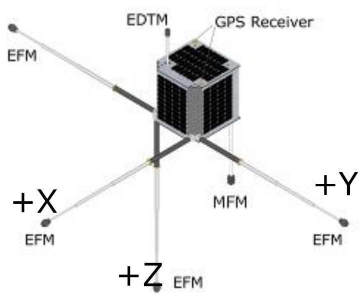


Flight Segment Description

Design Concept

1. To use mature technology except extension boom system
2. Main-satellite and Sub-satellite are composed with similar architecture
3. Power Interface and Communications Interface are common for each components in order to be able to upgrade components on its own

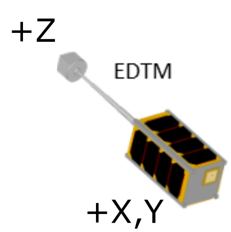
Main Satellite

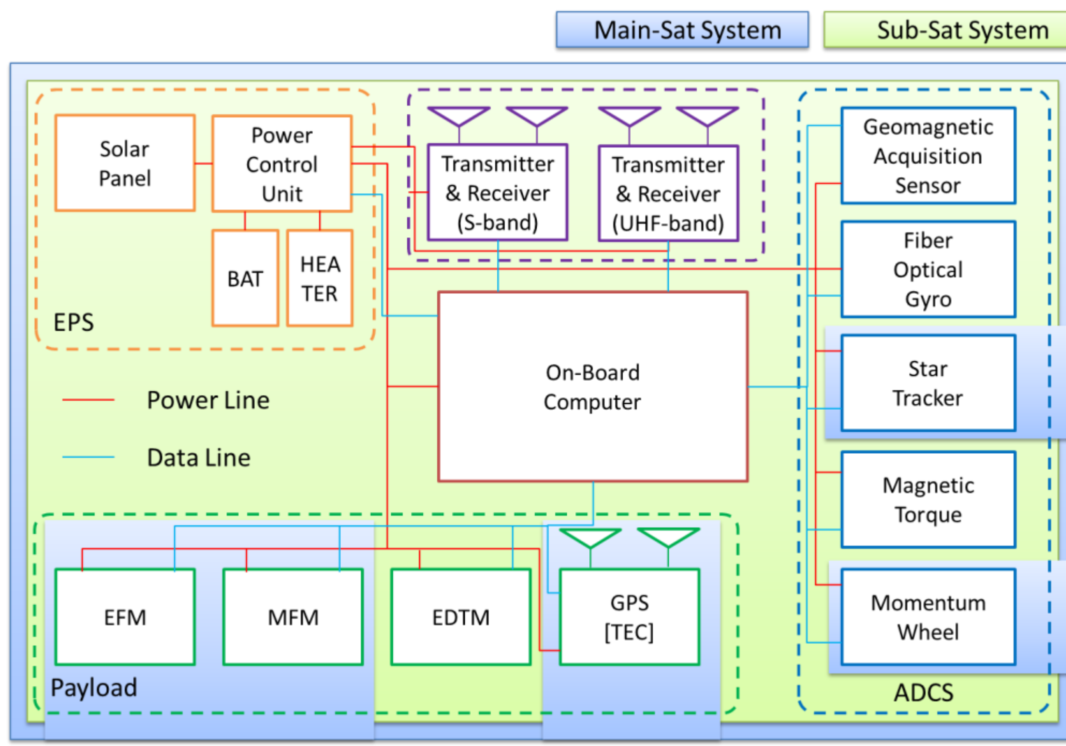


50 kg satellites to treat with a large amount of Mission Data on sun-synchronous orbit.

Sub Satellite

CubeSats to treat with only EDTM on non-sun-synchronous orbit.





Candidate: Extension Boom System

IEM system has heritage in small size, so it is currently under consideration for selection.

	Inflatable Extension Mast (IEM)	Telescopic Extension Mast (TEM)	Deployment Boom (DB)
size	△	○	○
weight	○	△	△
heritage	○	△	△

spec

Inflatable Extension Mast (IEM):

	SIMPLE	This Satellite
Number of booms	1	4
Length[mm]	1500	1500
Diameter[mm]	120	40
Mass[kg]	0.389	TBD
Storage size[mm]	210x268 x468	100x115 x210

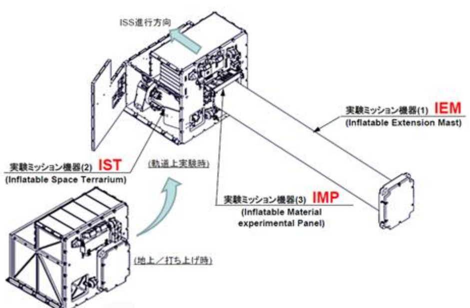
Telescopic Extension Mast (TEM):

Parameter	
Material	Aluminum
Extension Length[mm]	1410
Side Length[mm]	30
Mass[kg]	0.68x4=2.72
Storage size[mm]	30x30x500

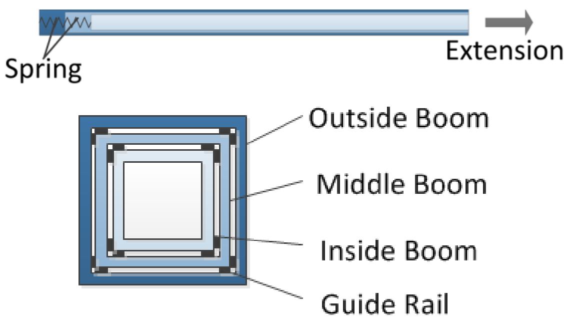
Deployment Boom (DB):

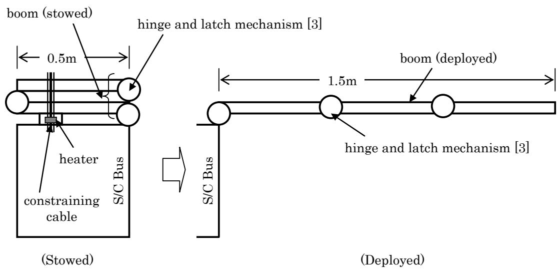
Parameter	
Material	Aluminum
Extension Length[mm]	1500
Side Length[mm]	30
Mass[kg]	0.6x4=2.4
Storage size[mm]	20x50x500

image

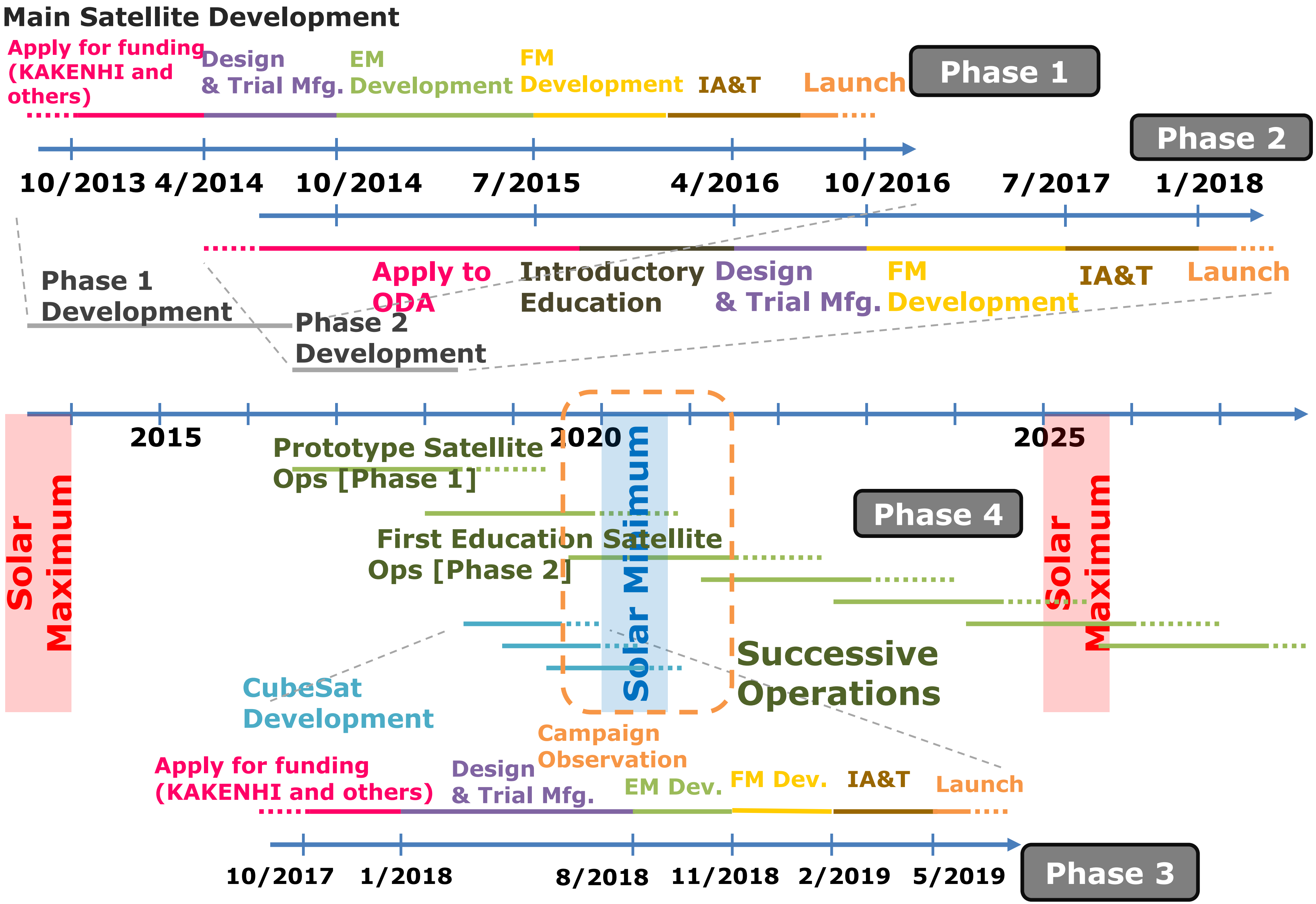


Reference：
http://iss.jaxa.jp/kiboexp/news/120821_simple.html

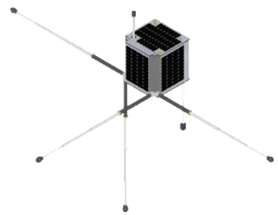


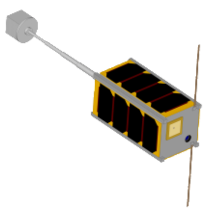


Project Schedule



Cost Estimate & Funding





	Main Satellite (FY14 KJPY)	CubeSat (FY14 KJPY)
Total	**150,000**	**30,000**
Mission Payloads	20,000	12,000
Satellite Bus	70,000	6,000
IA&T	10,000	4,000
Ground Systems	5,000	2,000
Project Management & SE	45,000	6,000

Phased Funding Approach

Grant-in-Aid for Scientific Research (KAKENHI)
Prototype Satellite

Official Development Assistance (ODA)
Educational Satellite

International EQ Satellite Network
Replenishment Satellites

Funding Sources

Grant-in-Aid for Scientific Research (KAKENHI)

- Up to 300 M JPY expected
- Funded Tohoku University's SPRITE-SAT

Official Development Assistance (ODA)

- First case: 40 B JPY to Vietnam
- Especially for countries participating in UNISEC's CanSat Leadership Training Program

Proposal will be submitted to JSPS (KAKENHI) **this month** by Prof. Kamogawa for next fiscal year funding.

Funding Sources

- International Microsatellite Network for EQ Prediction
  - Following DMC’s successful model
  - Leverage space development funding across the world
  - Members “buy in” to the EQ satellite network…

Join our Ponzi scheme

(Nezumi-kou)?

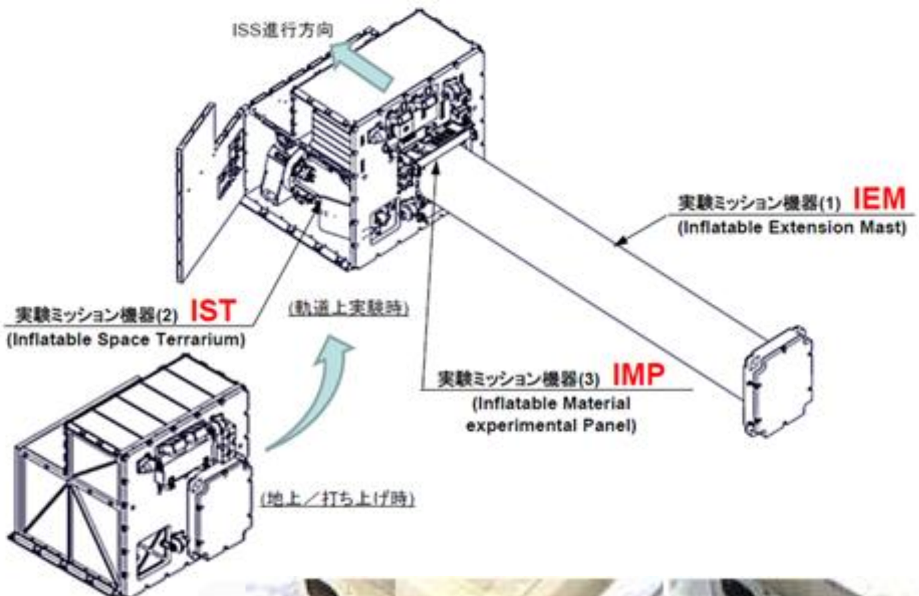
Back slide

Trade off: Extension boom system

	Inflatable Extension Mast (IEM)	Inflatable Extension Mast (IEM)	Spring Loaded Mast (SLM)
pro	1. This technology was developed originally in Japan and have high hopes for the future 2. This extension way is used and validated in JEM, so there is high reliability. 3. We hold promise from development team.	1. Easy to stow 2. Can decrease the opening shock with calibrating the damper 3. The boom is rigid	1. Don’t need an active extension mechanism 2. Spring extensions are well used as a space technology
con	1. Too big to use for 50x50x50 cm size satellites 2. Weak for disturbance	1. Need a boom extension control mechanism 2. take an ingenuity in fear of failing to deploy	1. High cost 2. Too big size

Methods of Extension Booms

Plan A : Inflatable Extension Mast (IEM)



	SIMPLE	This Satellite
Number of booms	1	4
Length[mm]	1500	1500
Diameter[mm]	120	40
Mass[kg]	0.389	TBD
Storage size[mm]	210x268 x468	100x115 x210

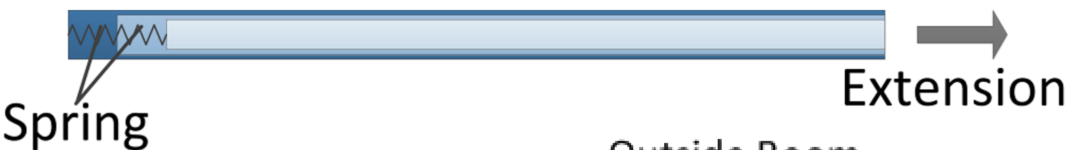
The appearance of extension

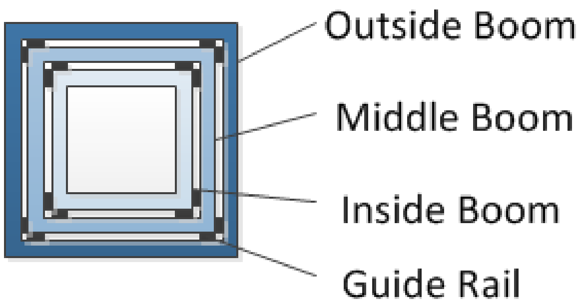
Reference：http://iss.jaxa.jp/kiboexp/news/120821_simple.html

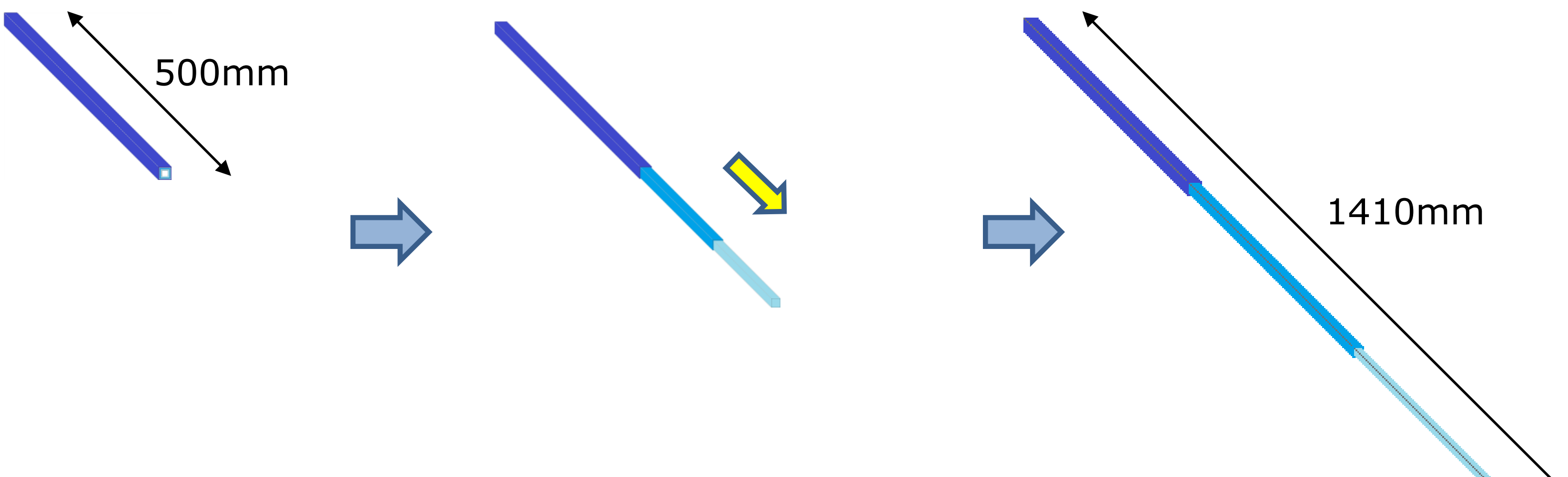
Methods of Extension Booms

Plan B : Triple Extension Rod(TER)

Parameter	
Material	Aluminum
Extension Length[mm]	1500
Side Length[mm]	30
Mass[kg]	0.6x4=2.4
Storage size[mm]	20x50x500







Before Extension While Extending After Extension

Mission Orbit Requirement

~Main Satellite Requirement~

- Mission Observation Requirement (EFM MFM TEC)

  Periodic/Quasi-static measurement

  Area

  : 1500km radius from the epicenter near the equator
- Large amounts of mission data

  Polar Region Ground Station
- Piggy-back Launch Opportunities

  -> Sun Synchronous sub-recurrent orbit

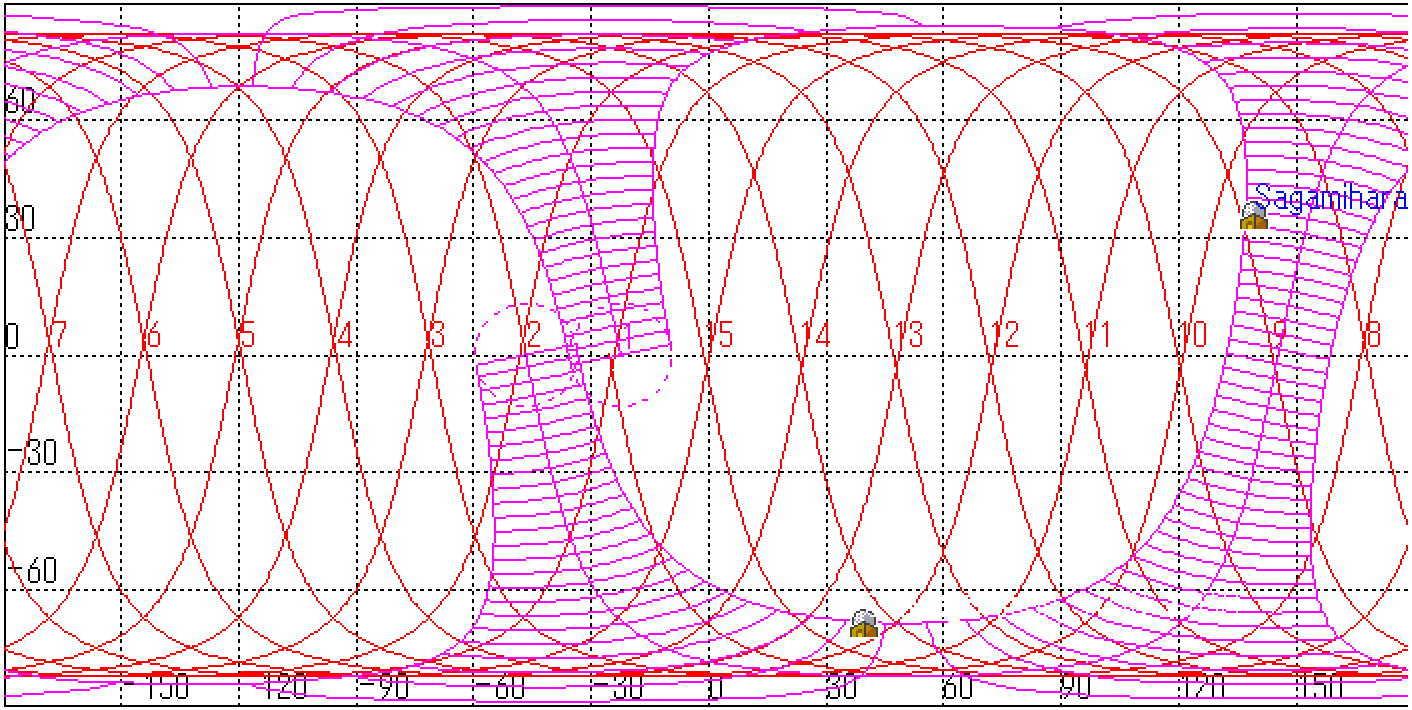
~Sub Satellite Requirement~

- Mission Observation Requirement (EDTM)

  Temporal and Spatial Variability measurement

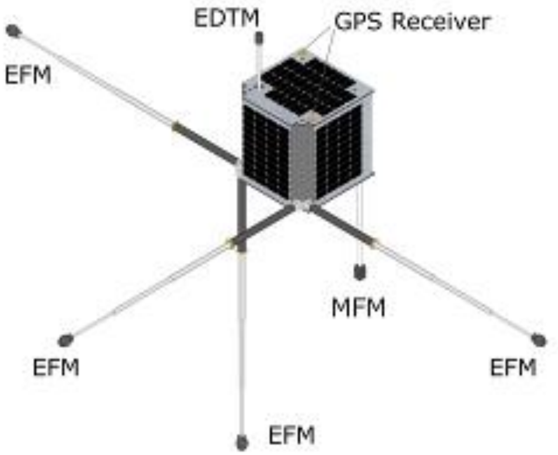
  - ->Non-Sun-Synchronous Orbit

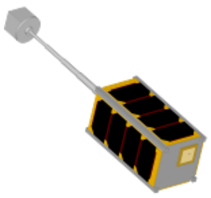
Main Satellite Orbit

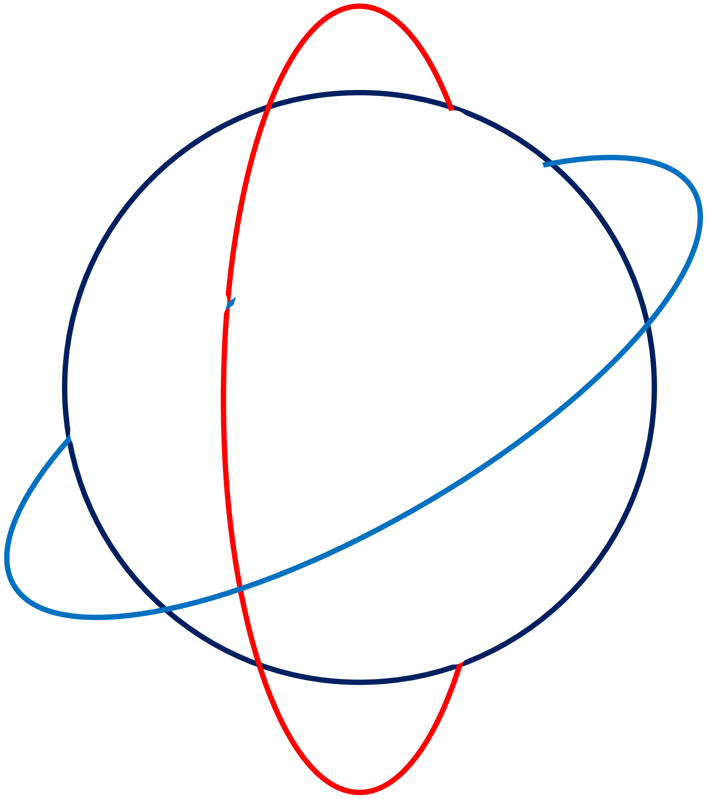


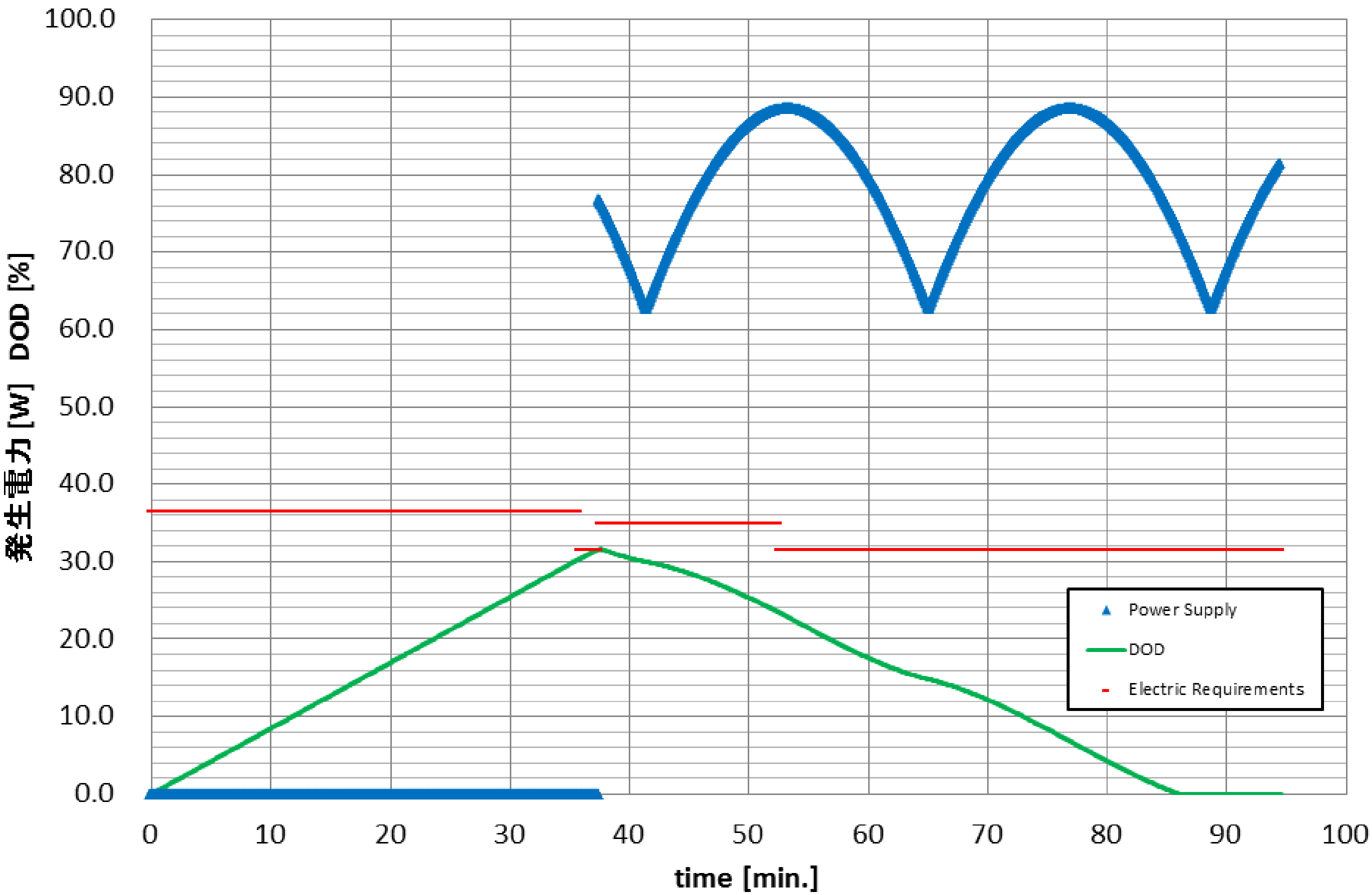
Sun Synchronous sub-recurrent orbit
LTDN: 1030
-> Orbital Period : 90 min / Path Interval 22.5 deg

Constellation with two types satellite



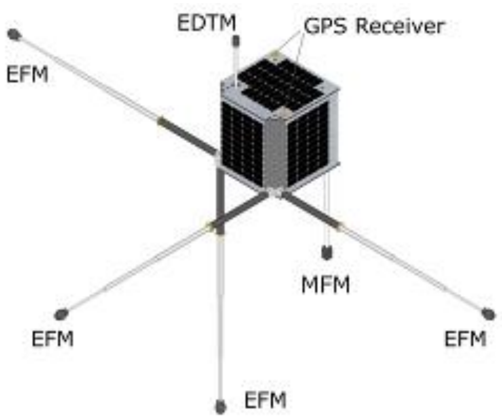






100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
発生電力 [W]　DOD [%]
0
10
20
30
40
50
60
70
80
90
100
time [min.]
Power Supply
DOD
Electric Requirements

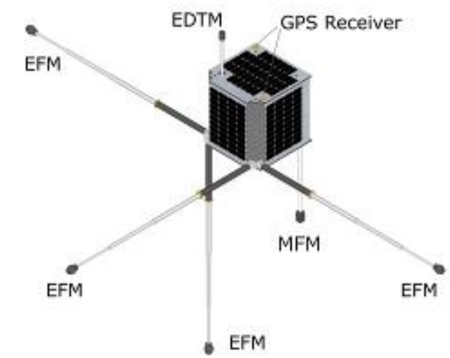
Main satellite



Main-satellite to treat with a large amount of Mission Data with sun-synchronous orbit.

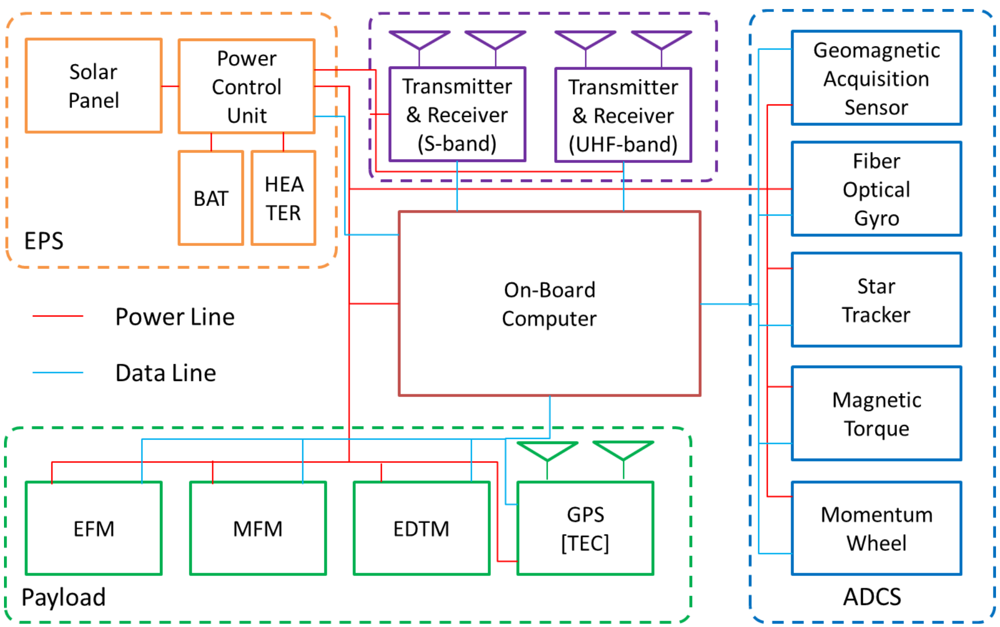
Size	< 50 x 50 x 50 cm
Mass	< 50 kg
Mission Payloads	EFM × 4
	MFM × 1
	EDTM × 1
	TEC × 1
Communication	S-band Transmitter & Receiver / Antenna × 2
	(HK/Mission Downlink)300kbps (receiver) 4kbps
	UHF-band Transmitter / Antenna × 4
	(Mission Downlink) 9600 bps
Power	Max Generation > 90 W
	Solar Array: Indium Tin Oxide cell
	Body Mount × 6
	Max Consumption > 40W
	Li-ion Battery: 8 series × 2 parallel
	2.5 ~ 4.2 × 8 = 20 ~ 33.6 V
	2.9 × 2 = 5.8 Ah
Orbit Determination Accuracy	< 1 km
Attitude Determination Accuracy	< 0.1 deg.

System diagram



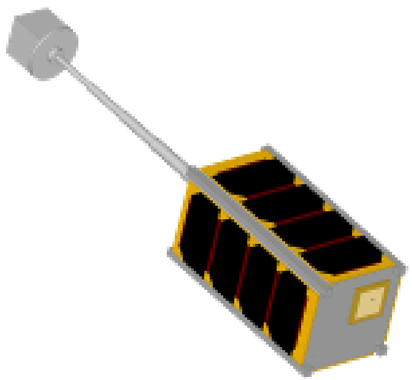
(→)Main satellite’s power and mass budget

(↓)Bus and payload system for Main-satellite



	Components	Qty.	Power [W]	Mass [kg]
Mission	EFM	4	4	2.4
	MFM	1	2	0.8
	EDTM	1	3	0.8
	TEC	1	see GPS-R	see GPS-R
DH	OBC	1	5	2.5
COM	U-Tx	1	4	0.06
	S-TRx	1	3.5	0.7
AOCS	MW	1	0.7	1
	GPS-R	1	1.6	0.06
	GPS-ANT	1	0.3	0.06
	MTQ	3	1.05	1.5
	STT	2	4	1
	GAS	1	0.25	0.25
	FOG	1	3	2.5
Power	PCU	1	3	1.5
	SAP	6		0.6
	BAT	1		1.5
STR /THRM	THERMAL (Heater)	2	4	1
	STRUCTURE	1	N/A	17
	Boom (long)	4	N/A	2.4
	Boom (short)	2	N/A	0.8
Total			39.4	38.43

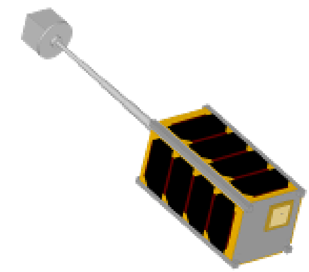
Sub satellite



Sub-satellite to treat with only EDTM with non-sun-synchronous orbit.

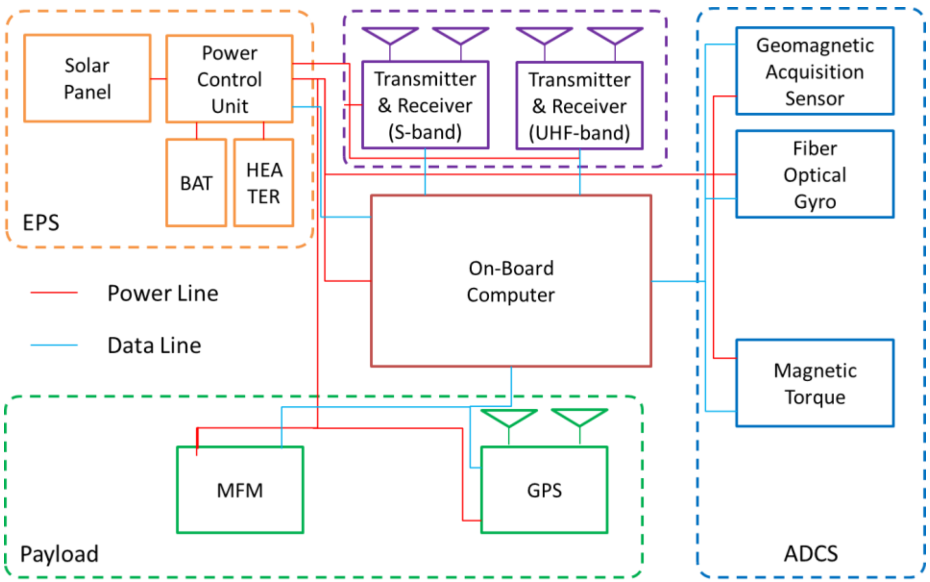
Size	< 10 x 10 x 20 cm
Mass	< 3 kg
Mission Payload	EDTM: × 1
Communication	S-band Tx & Rx / Antenna × 2
Power	Max Generation > 3.4 W
	Solar Array: Indium Tin Oxide cell
	Body Mount × 5
	Max Consumption > 2.9W
	Li-ion Battery: 1 series × 2 parallel
	2.5 ~ 4.2 × 1 = 2.5 ~ 4.2 V
	2.9 × 2 = 5.8 Ah
Control Method	Gravity-gradient stability

System diagram



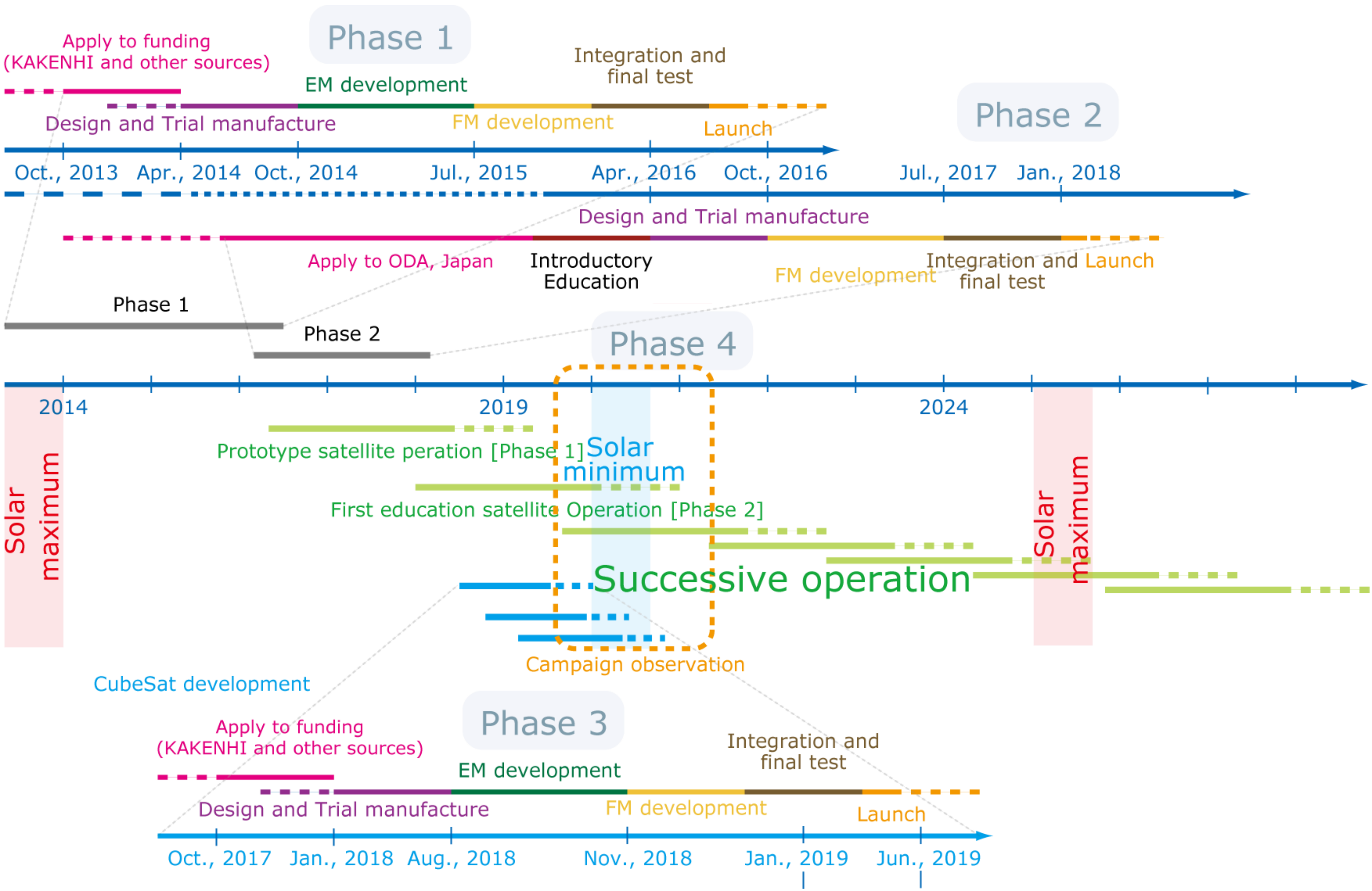
(→)Main satellite's power and mass budget

(↓)Bus and payload system for Main-satellite



	Components	Qty.	Power [W]	Mass [kg]
Mission	EDTM	1	3	0.8
DH	OBC	1	1	0.1
COM	U-Tx	1	1	0.06
	S-TRx	1	3.5	0.3
AOCS	MTQ	3	0.35	0.3
	GAS	1	0.25	0.1
	SS	3	0.2	0.1
Power	PCU	1	0.5	0.1
	SAP	6		0.4
	BAT	1		0.2
STR /THRM	THERMAL (Heater)	2	2	0.1
	STRUCTURE	1	N/A	0.6
	Boom	1	N/A	0.4
Total			10.8	3.46

Schedule and budget



Mission requirement

1. Observe ionospheric precursors continuously during the solar cycle
   1. Observe whole day long
   2. Launch on non-sun-synchronous orbit during solar minimum for a campaign o
2. Bus system satisfy Table1's requirements.

Table1. mission requirements

Payloads	Sampling rate	Data size		Power	Bus requirement	Weight
		S-band	UHF			
		Full data[/day]	Trend data [/90 min]			
EFM	1 Hz*	138.2 MB	216.0 kB	4.0 W	0.1 deg. of altitude determination accuracy	2.4 kg for 4 booms
MFM	1 Hz	0.5 MB	32.4 kB	2.0 W		0.8 kg
EDTM	1 Hz	0.7 MB	21.6 kB	3.0 W	-200V power dispatching for ion spattering	0.8 kg
TEC**	1 Hz	63.7 MB	N/A	1.6W	Dual frequency GPS signal reception	0.06 kg

Link design

(a) Syowa station, Antarctic

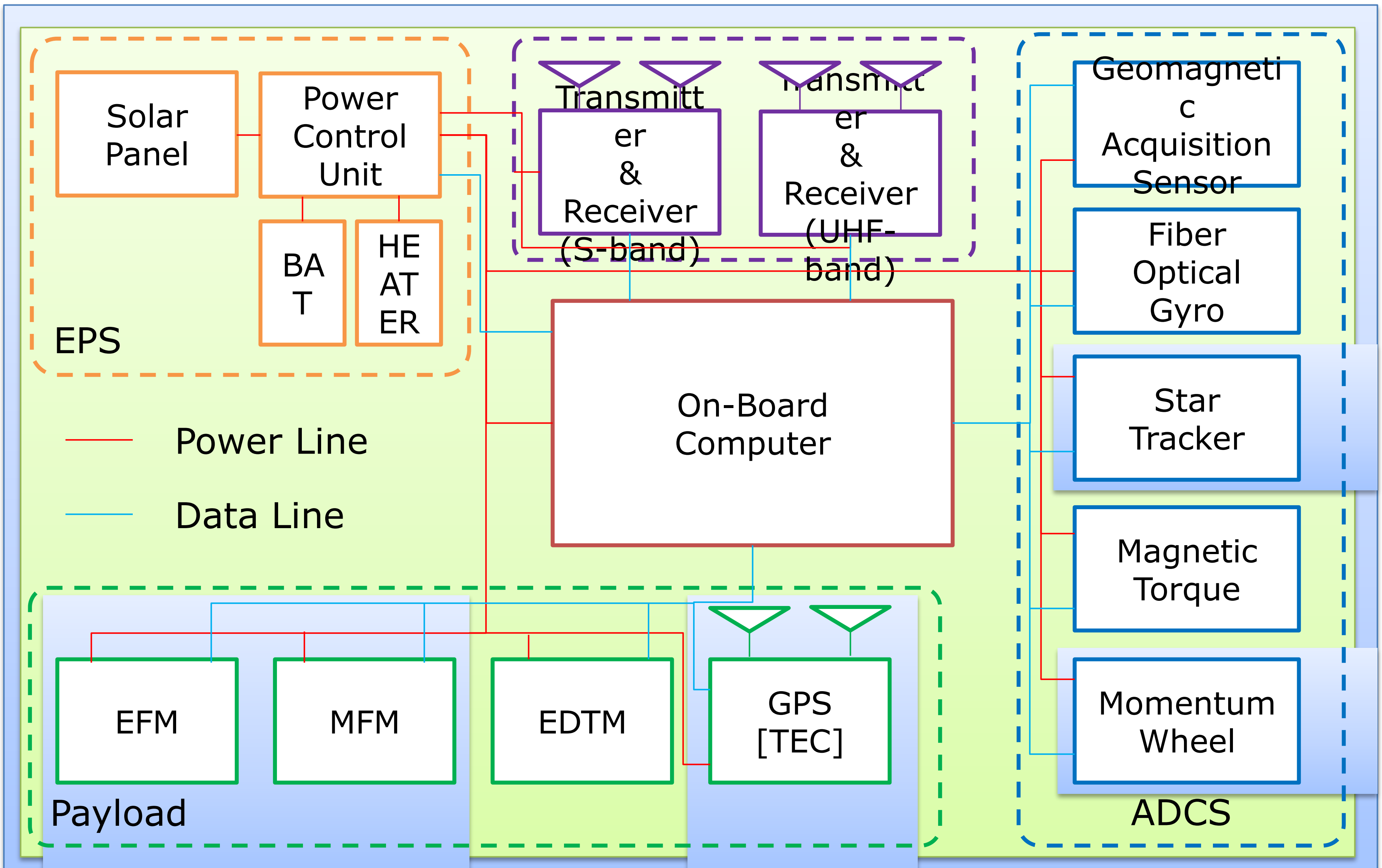
	Path [/Day]	Duration [sec./path]	Duration [Sec./Day]
Maximum	12.0	777	7981
Average	11.7	666	7675
Minimum	10.0	180	6323

(b) Tokyo, Japan

	Path [/Day]	Duration [sec./path]	Duration [Sec./Day]
Maximum	6.0	769	3429
Average	5.7	618	2977
Minimum	4.0	191	1893

	S-band downlink	S-band uplink		UHF downlink
		Command	Carrier	
Frequency [GHz]	2263.6	2084.4		460
Transmitter power [dBW]	-6.99	10		-20.0
Transmit Antenna Gain [dBi]	2	35.13		0
Line Loss [dB]	-5	-1		-1
Transmit Antenna Pointing Loss [dB]	0	0		0
Free Space Loss [dB]	-166.70	-166.16		-148.9
Atmosphere Absorption Loss[dB]	-0.5	-0.5		-0.5
Polarization Loss [dB]	0	0		0
Rain Fades [dB]	-0.61	-0.61		-0.12
Receive G/T [dB/K]	23.80	-45.45		2.32
Receive C/No [dBHz]	74.60	60		60.32
Modulation Type	BPSK	PCM-PSK-PM	PCM-PSK-PM	GMSK
Required Eb/N_O [dB]	6	10.34	N/A	3.2
Required S/No[dB]	N/A	N/A	10.00	N/A
Bit Rate [kbps]	300	4	4	9.6
Coding type	Reed Solomon	BCH	No Coding	Convolution
Hardware loss	-1.5	-1.5	-1.5	-1.5
Modulation Loss (1.0rad) [dB]	N/A	-1.5	-5.35	N/A
Margin [dB]	12.33	11.64	5.64	12.8

System Diagram



System Diagram