Lunar Low Frequency Astronomy Telescope LLFAST

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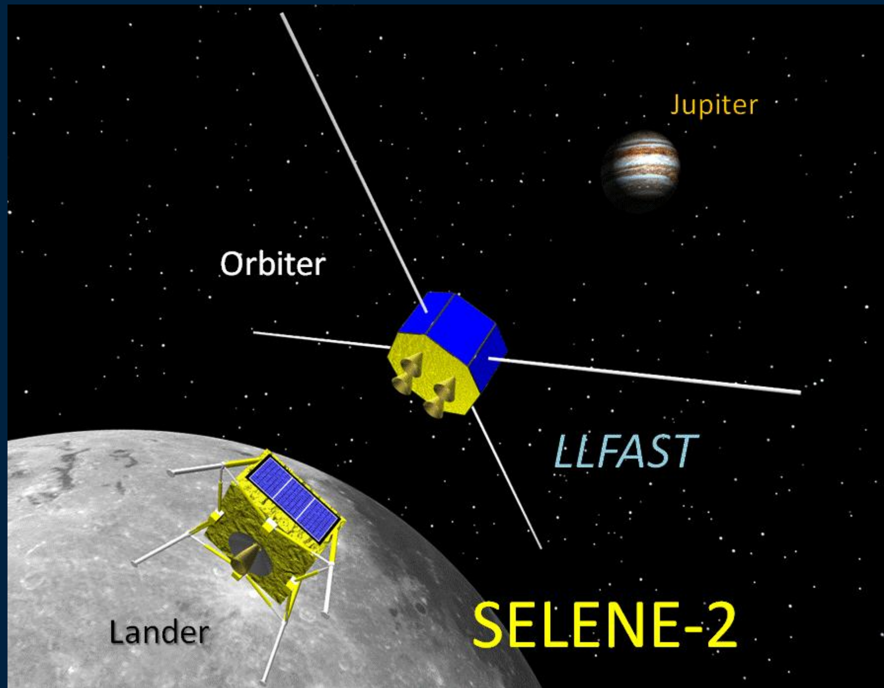
Future Plan

Lunar Low Frequency Astronomy Telescope
LLFAST

Space Jupiter Radio VLBI between Moon and Earth



LLFAST Team

PI: Dr. Iwata, JAXA

Sub-PI: Dr. Imai, KNCT

Future Plan

Japanese people used to believe that a rabbit was living and making a rice cake on the moon because the bright and dark on the moon surface made it look like a rabbit pounding on a rice cake with a mallet.

Mission flow for JAXA’s Candidate Lunar explorers

2005 2010 2015 2020 2025

SELENE series for Moon

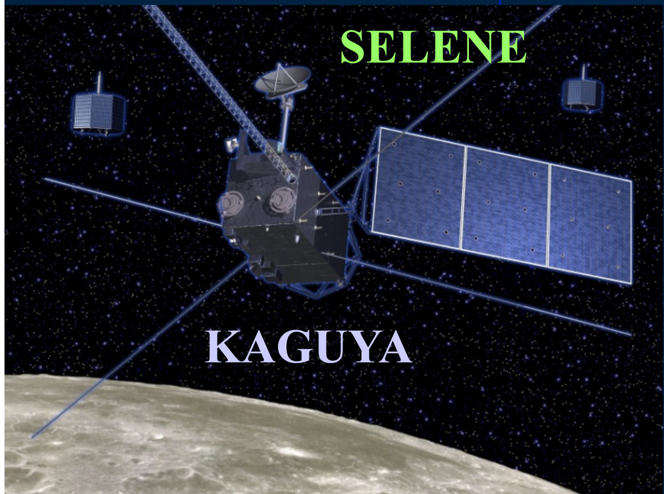
SELENE (KAGUYA)
three orbiters

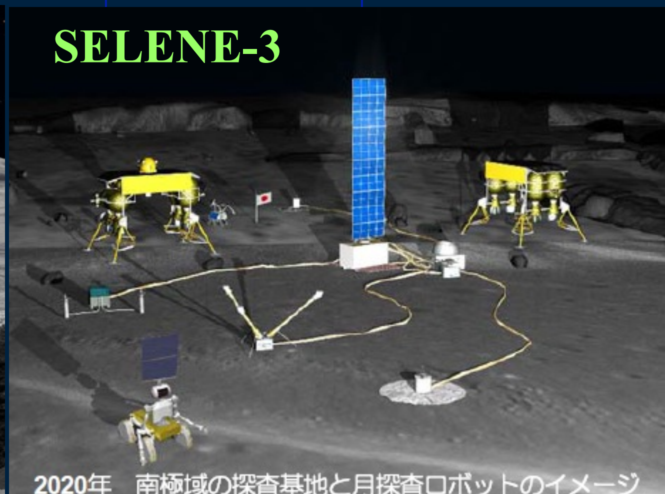
SELENE-2
lander, rover, and orbiter

SELENE-3
lander, rover, sample return

to be delayed

Launch year, name, and configurations are tentative for SELENE-2 and 3.



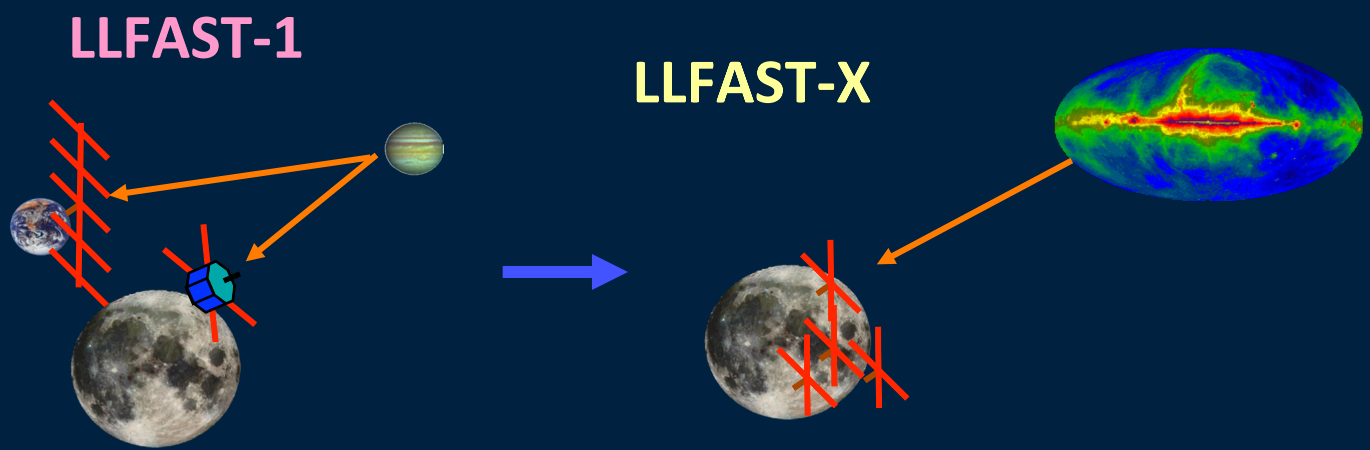


Characteristics of LLFAST

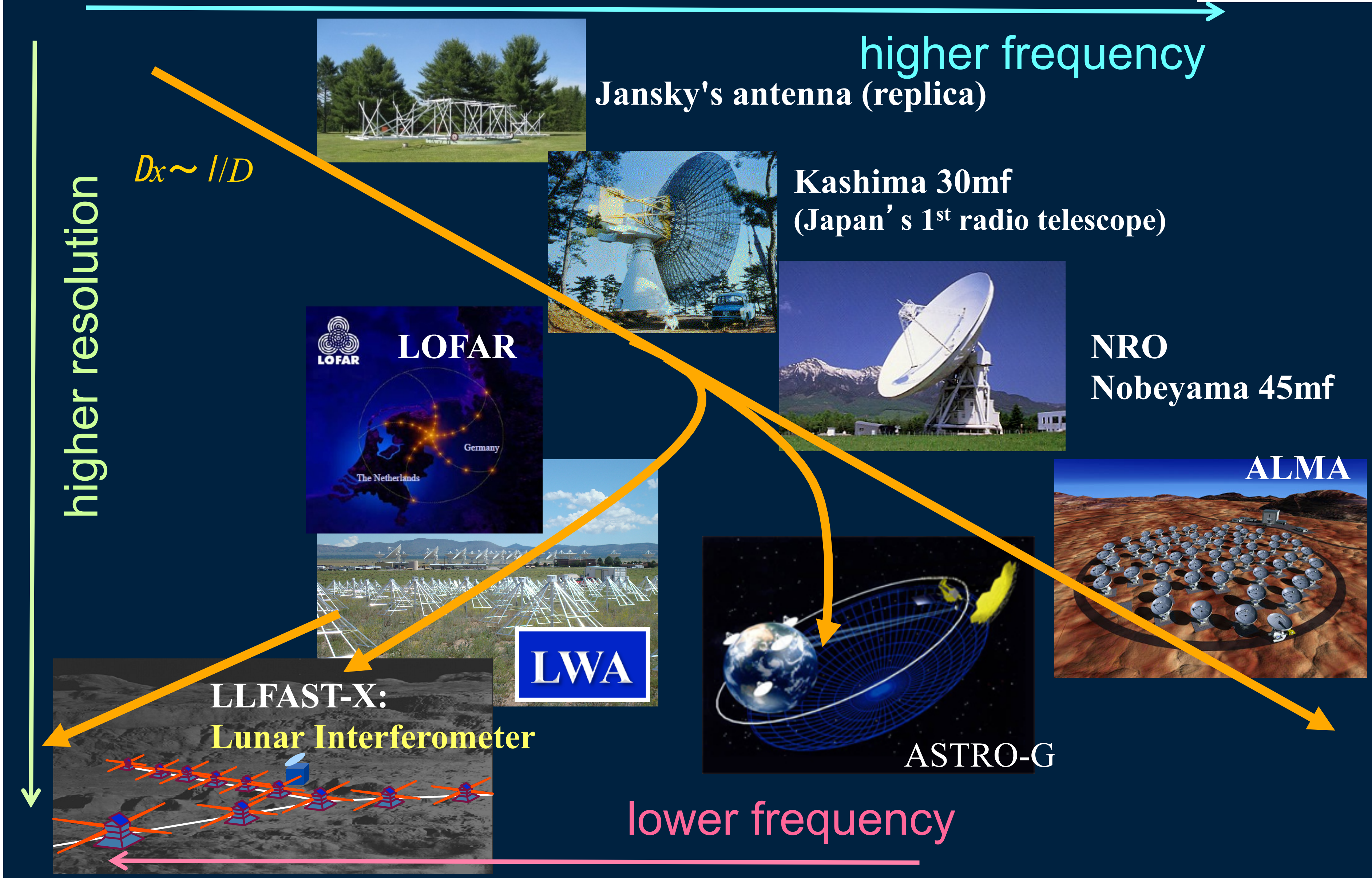
Lunar Low Frequency Astronomy Telescope :

- Series to achieve a large scale interferometer on the lunar far side to observe low frequency radio sources.

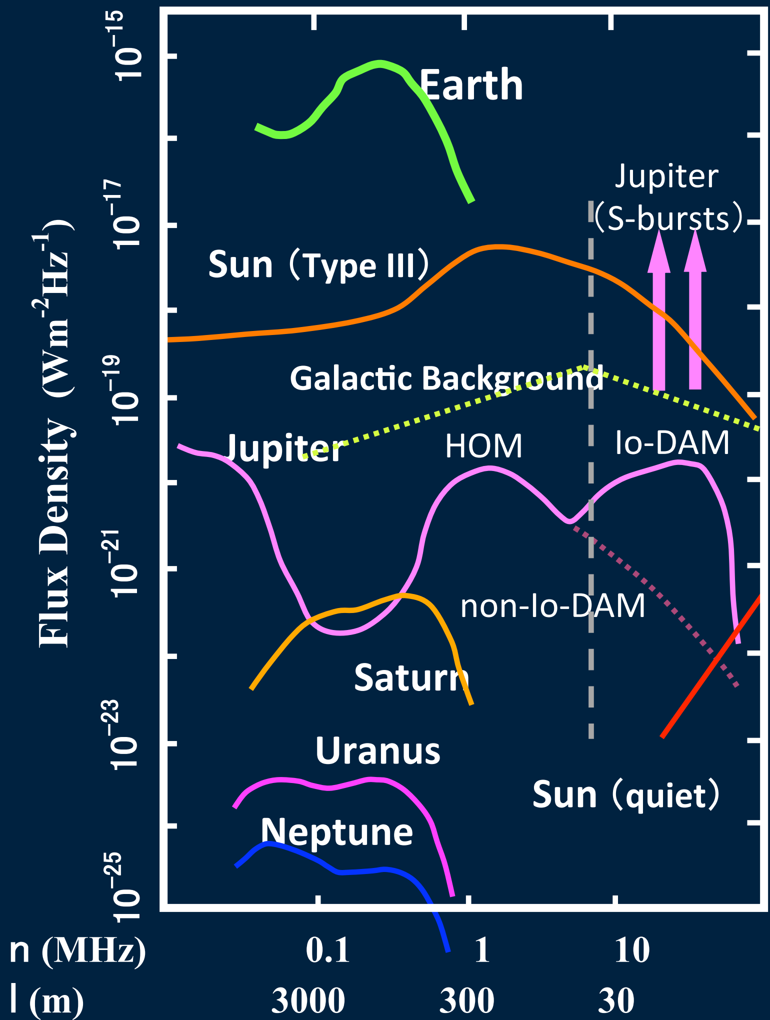
- The first step (LLFAST-1) is Moon (1 element)-Earth space VLBI to observe Jupiter.



Historical streams of radio telescope



Spectra at the Low Frequency on the Moon

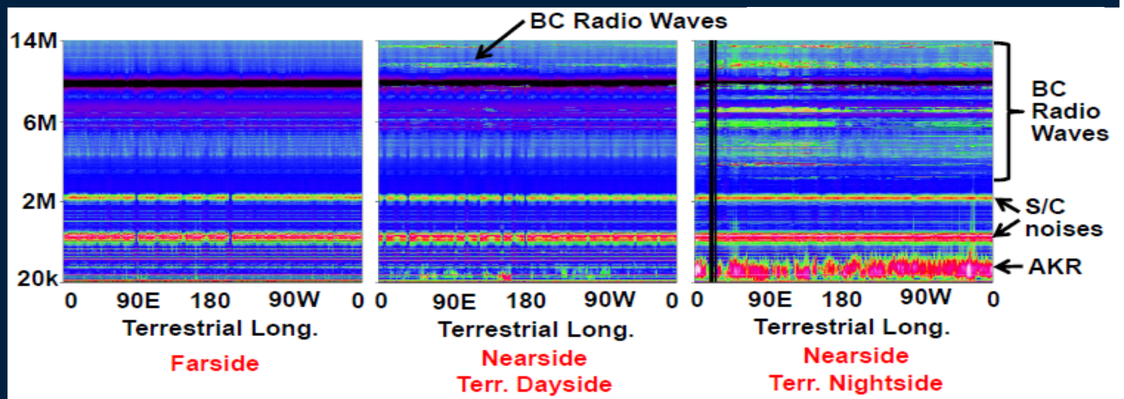


∧ Converted spectra
to be observed on the Moon
(after Zarka et al, 1997)

The lunar far-side is a suitable site for the low frequency astronomical observations, because noises from the Earth can always avoided.

Terrestrial interference observed by KAGUYA's Lunar Rader Sounder（LRS）
(Kumamoto *et al.* 2008)

↓far side ↓near side; day ↓near side; night



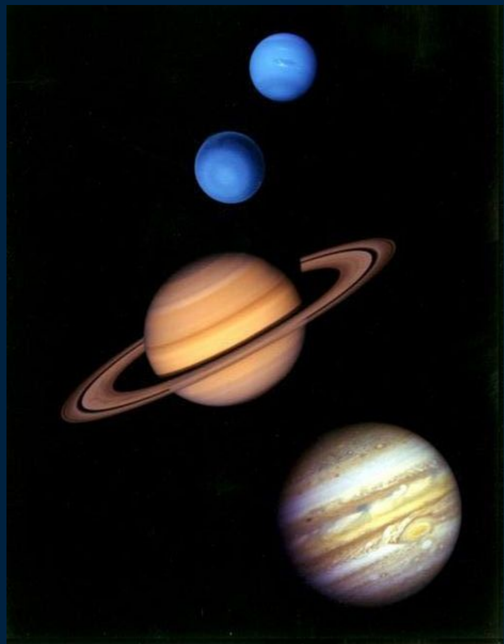
Low Frequency Planetary Science

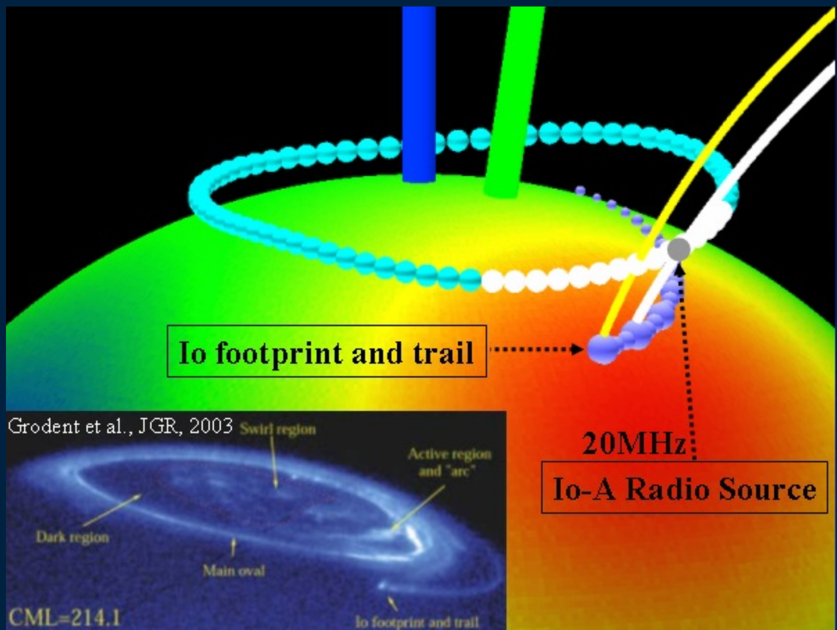
Our Solar System :

- Jupiter ; Mechanism of Jupiter-Io Decameter wave
- Sun ; Mechanism of Type III burst
- Saturn, Uranus, Neptune

Extra Solar System :

- Jovian Planet Survey



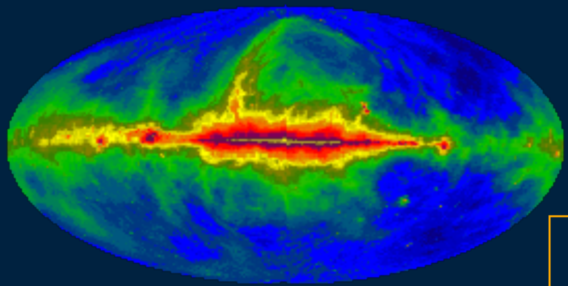


← **Distribution of 20 MHz radio sources and the UV aurora at Jupiter** (Imai *et al.*)

Low frequency astronomy

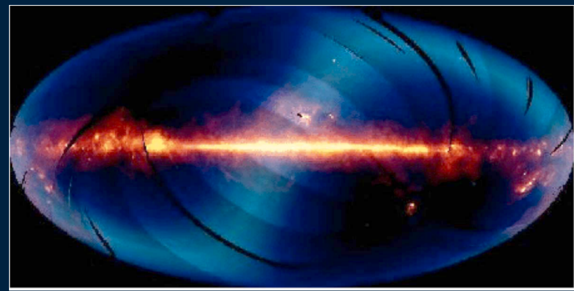
← lower frequency / energy

higher frequency / energy →



$DE = h \ n$

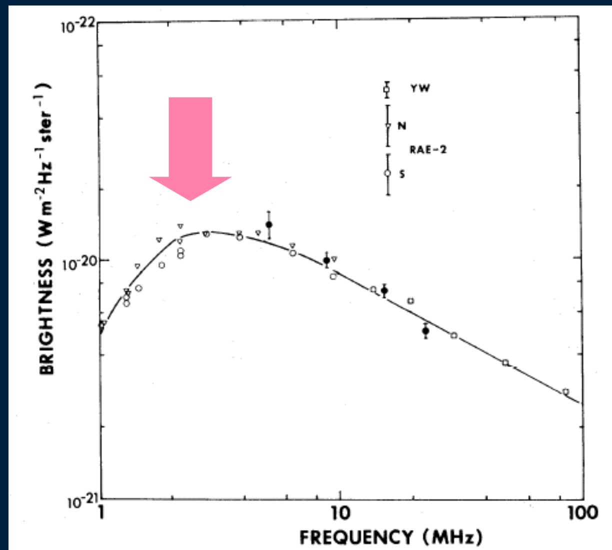
Bonn 408 MHz Survey (Haslam *et al.*, 1982)



IRAS Survey (Beichman *et al.*, 1988)

physical processes

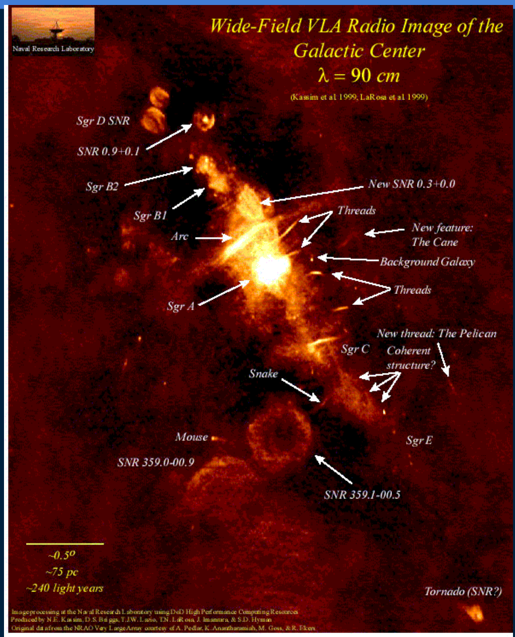
- Low temperature/density
- Absorption by cold electron
- Synchrotron self absorption
- free-free absorption



Galactic Background spectrum (Cane, 1979):
- Free-free absorption by low temperature / low density plasmas in the galactic plane ?
  Te = 6000[K], *Ne* = 0.1[cm^{-3}] ?

Future astronomical targets

SNR survey →
at 330MHz toward
Galactic Center
(La Rosa *et al.* 2000)



← z ~10
reionization

z = 1 ; 1420 MHz
↓
z = 13 ; 100 MHz
z = 130 ; 10 MHz

← z ~1000; recombination

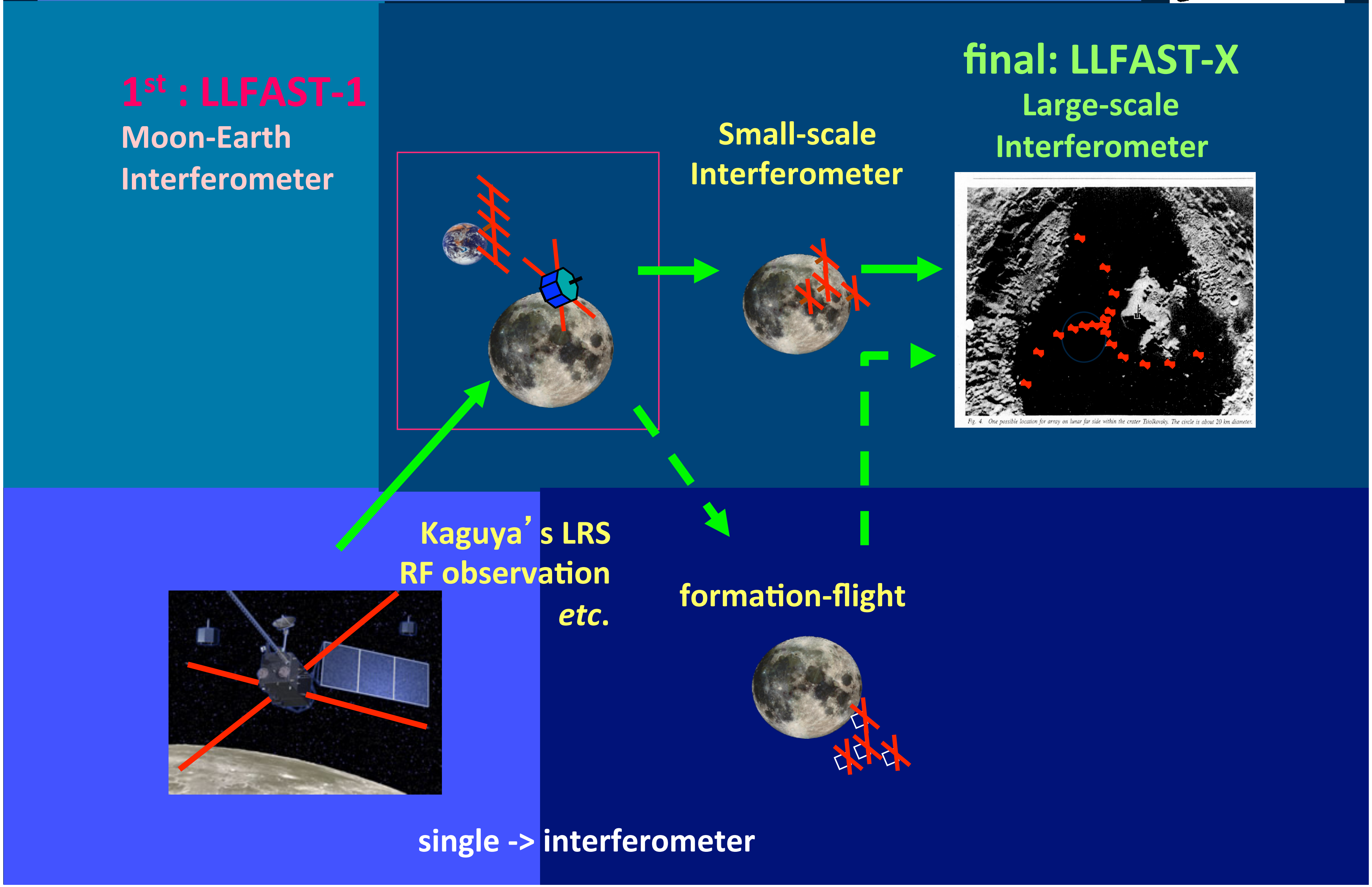
← Big Bang

after Djorgovski *et al.*

targets

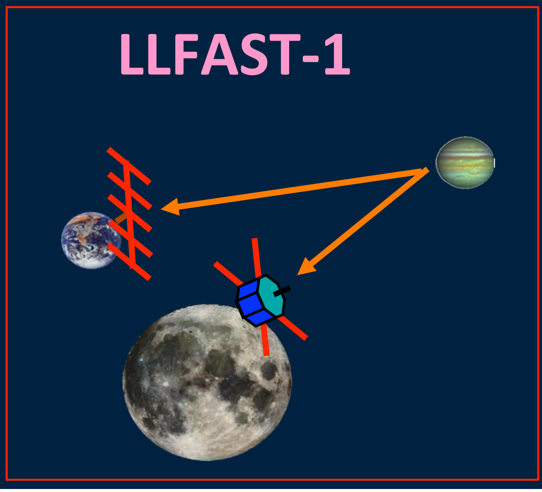
- Lower-energy SNR (super nova remnant)
- Spatial distribution of lower-energy materials in our galaxy, inter-galactic space
- Large scale distribution of cosmic web structures

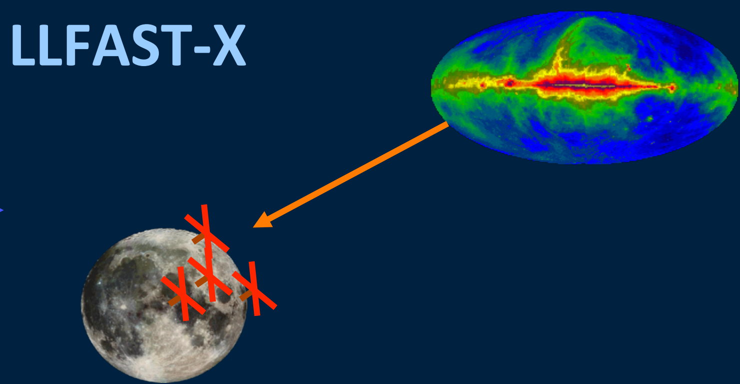
Road-map of LLFAST



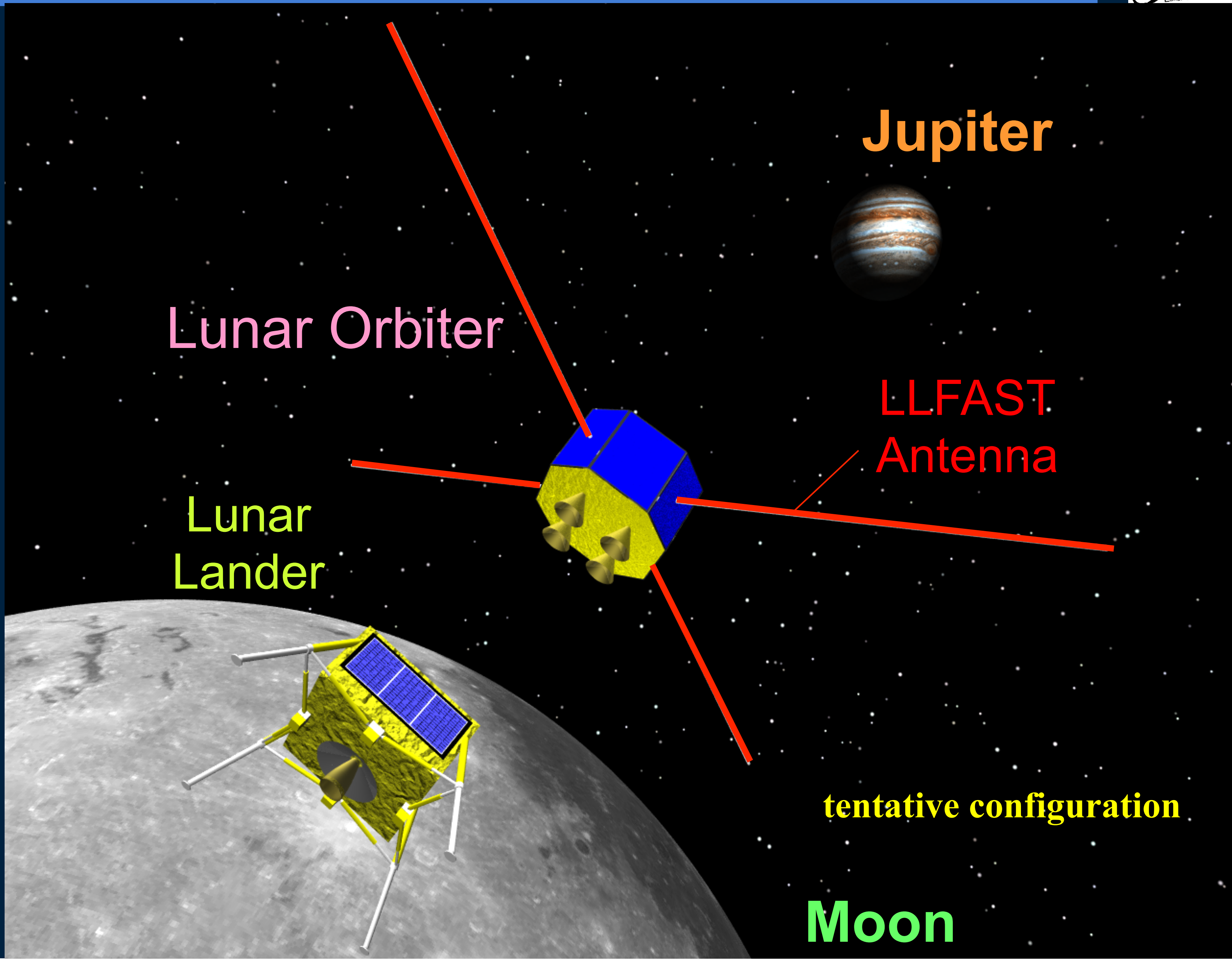
Comparison of 1st and final observatory

	1st ; LLFAST-1	final ; LLFAST-X
configuration	Moon (1 element)-Earth interferometer	Interferometer on the Moon (~100 elements)
site	**lunar orbit (SELENE-2/3 Orbiter)**	**far side**
frequency	**15 - 25 MHz**	**0.1 – 20 MHz**
targets	**Jupiter**, Sun	galactic and extra-galactic objects, etc.





A configuration of LLFAST on SELENE-2/3



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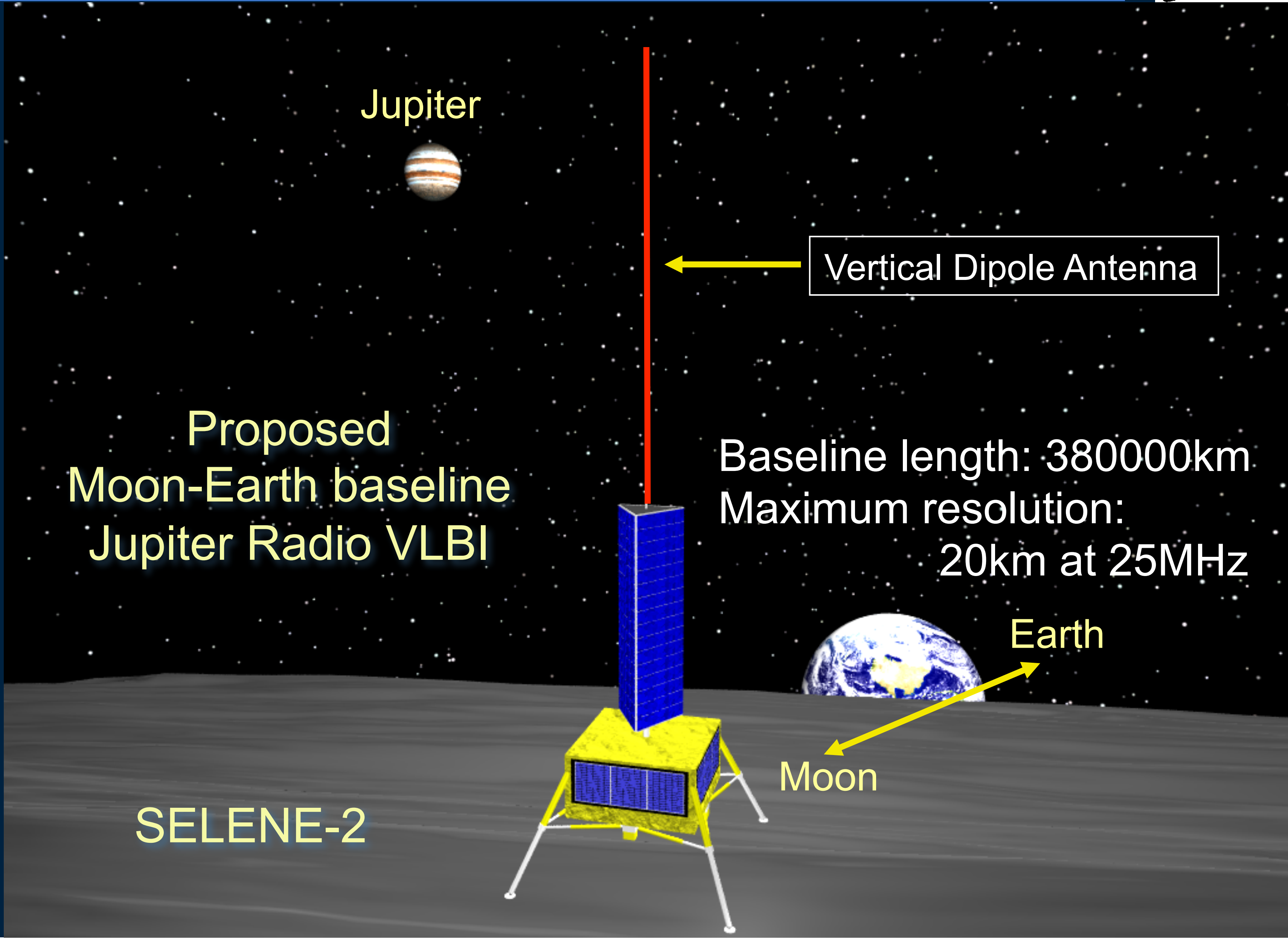


Scientific goals of LLFAST-1

Jupiter-Io Decametric radio emission (Io-DAM):
- the strongest in our solar system
- the mechanism has not been confirmed;
    * low spatial resolution (ground VLBI ; 1,000 km)
    * narrow field of view (in-situ observations)

1) Mechanism of radio sources:
conical-sheet beam (Dulk 1967) or search-light beam (Imai *et al*. 2008).

2) Distribution of energy transfer along longitude suggested by modulation lane methods (Imai *et al*. 2002).

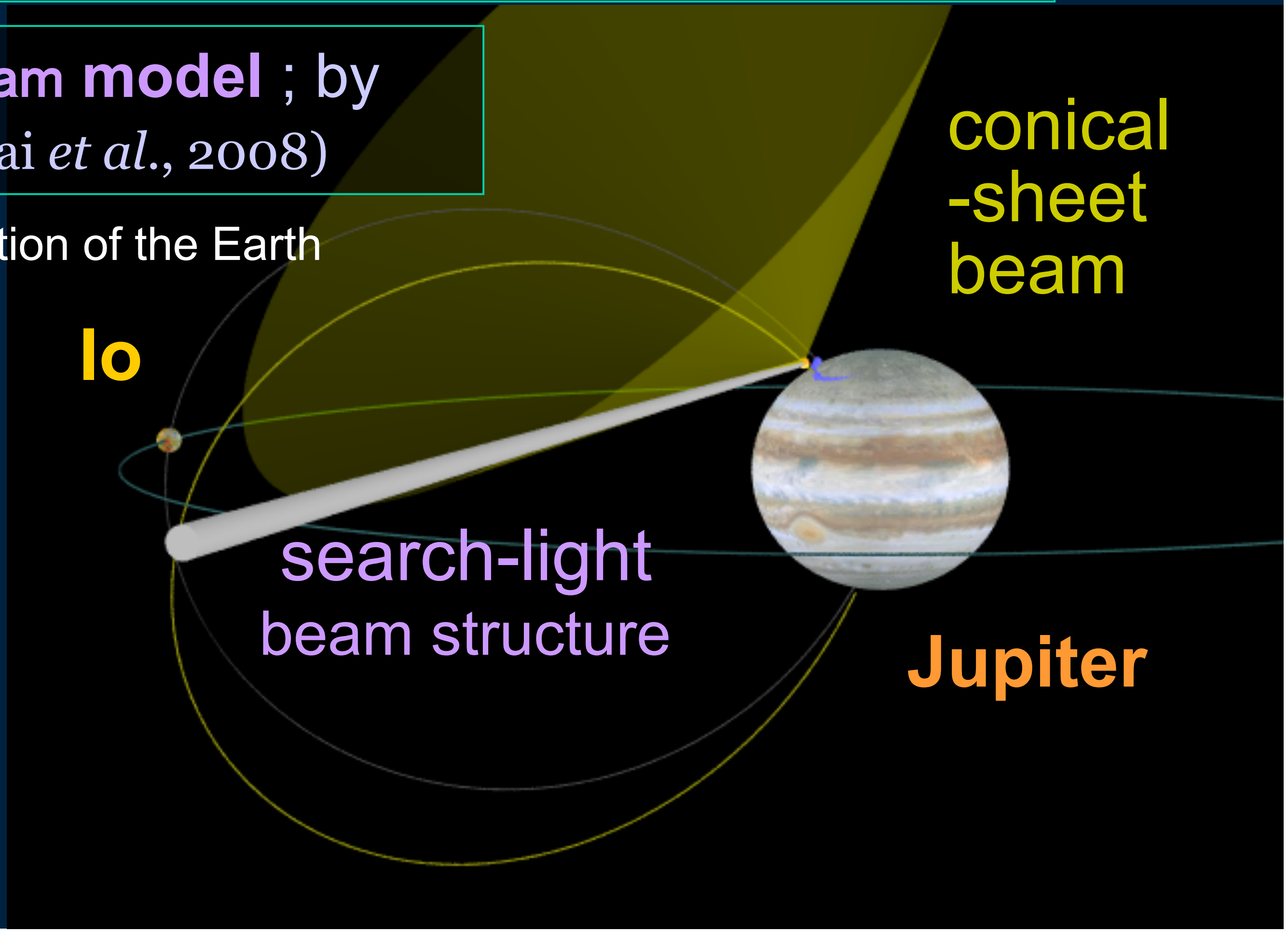
3) Wave-particle interaction mechanism:
Cyclotron Maser Instability (CMI) mechanism (Wu & Lee, 1979) and / or Mode Conversion (MC) mechanism (Oya 1971).

1) Two models for Io-DAM beam structure

1) **conical–sheet beam (emitting cone) model** ; by
- variations of signal power (*ex*. Dulk, 1967)
- in-situ observation results

2) **search–light beam model** ; by
+ **De effects** (Imai *et al*., 2008)

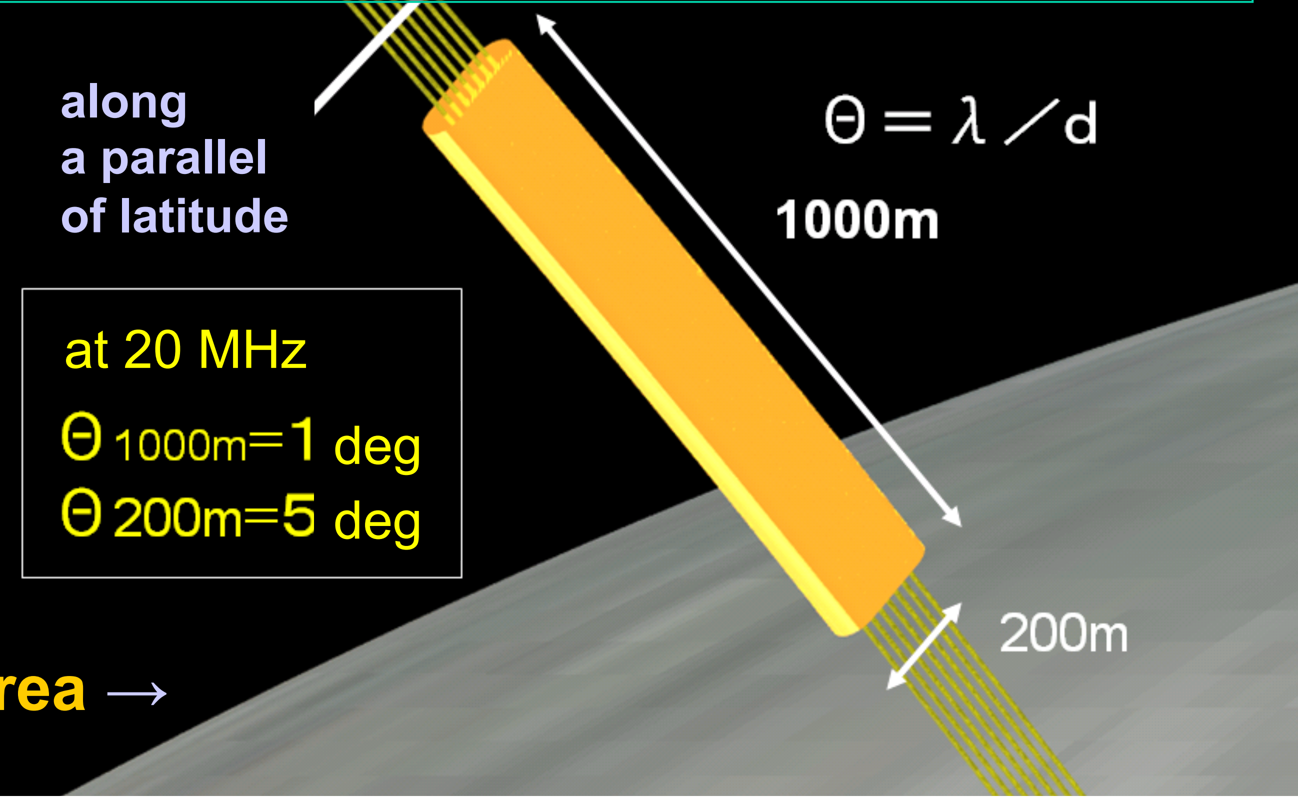
De: Jovicentric Declination of the Earth



Size of Jovian radio sources

Both of beam structure models predict the existence of coherent structure sized < 1km, which cannot be confirmed by ground VLBI*.
ex. search–light beam model (Imai *et al.*, 2008)
→ ~ 1 km x 200 m

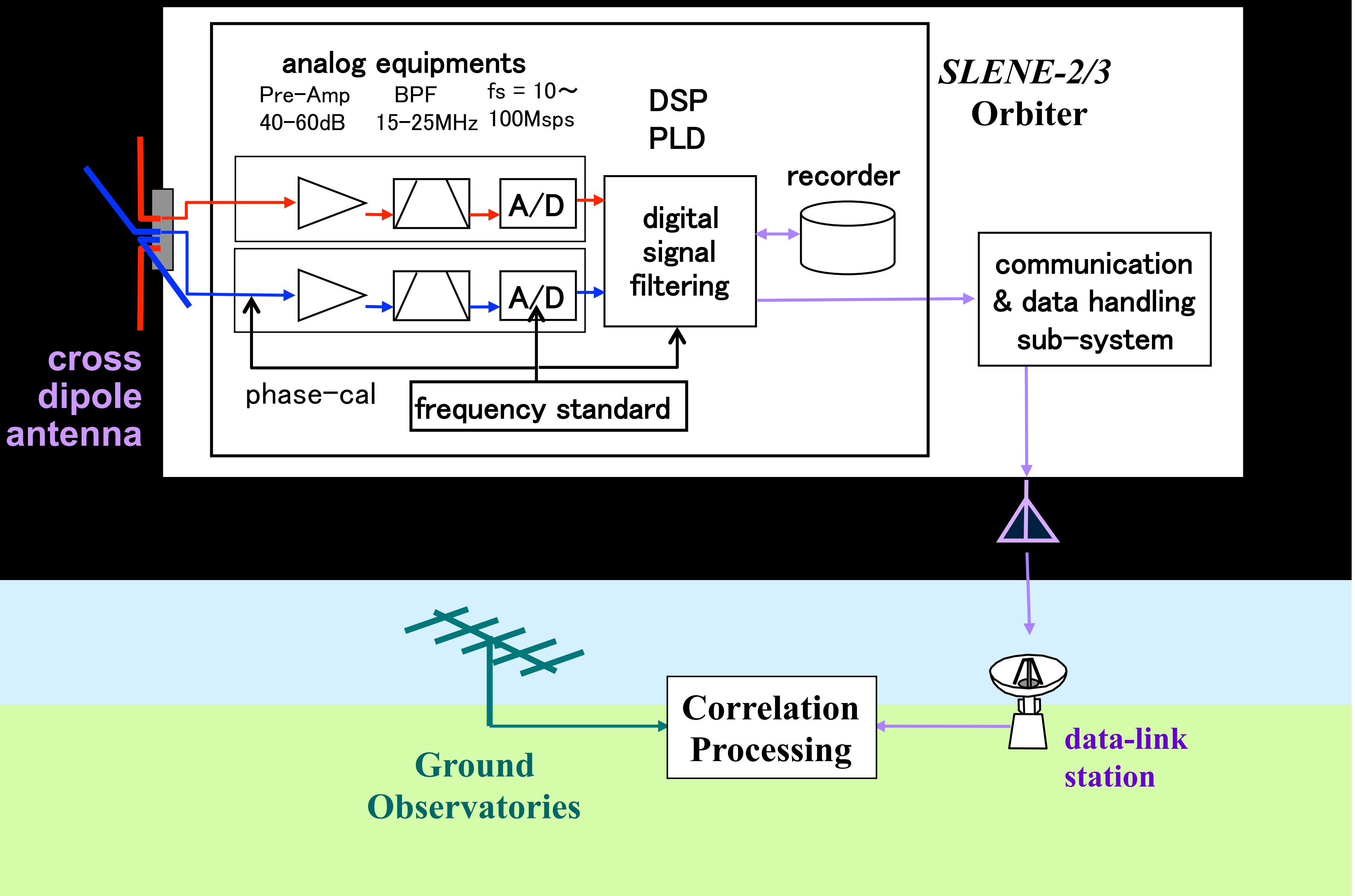
*) resolution; 1,000 km



coherent beam area →
(Imai *et al.* 2008)

Instruments of LLFAST-1

Block diagram of LLFAST-1 observation system



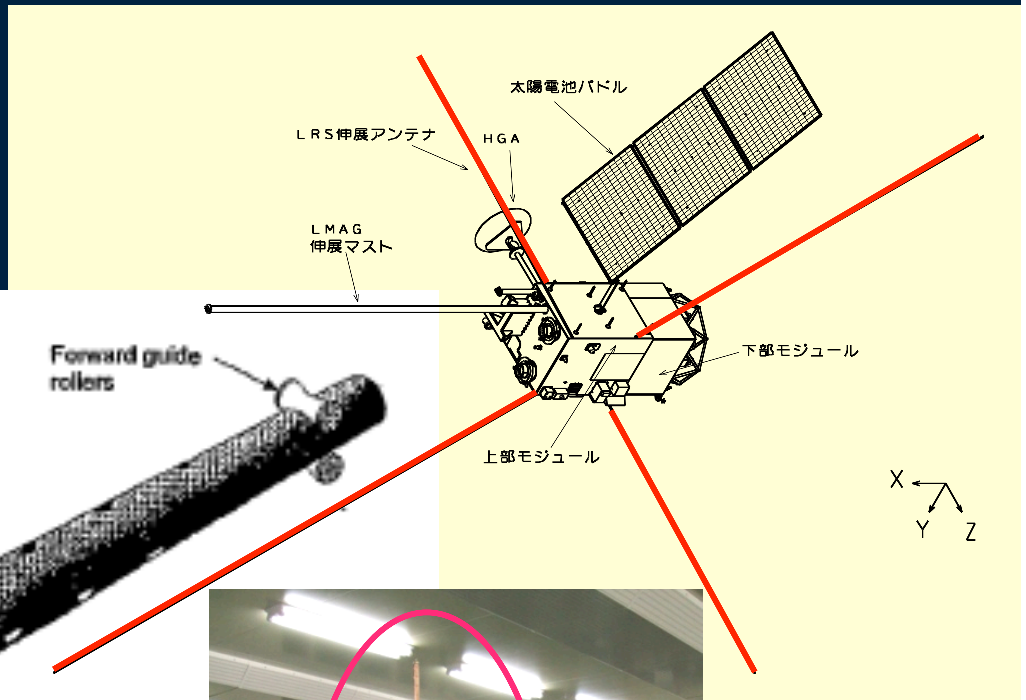
Expanding bi-stem antenna candidate

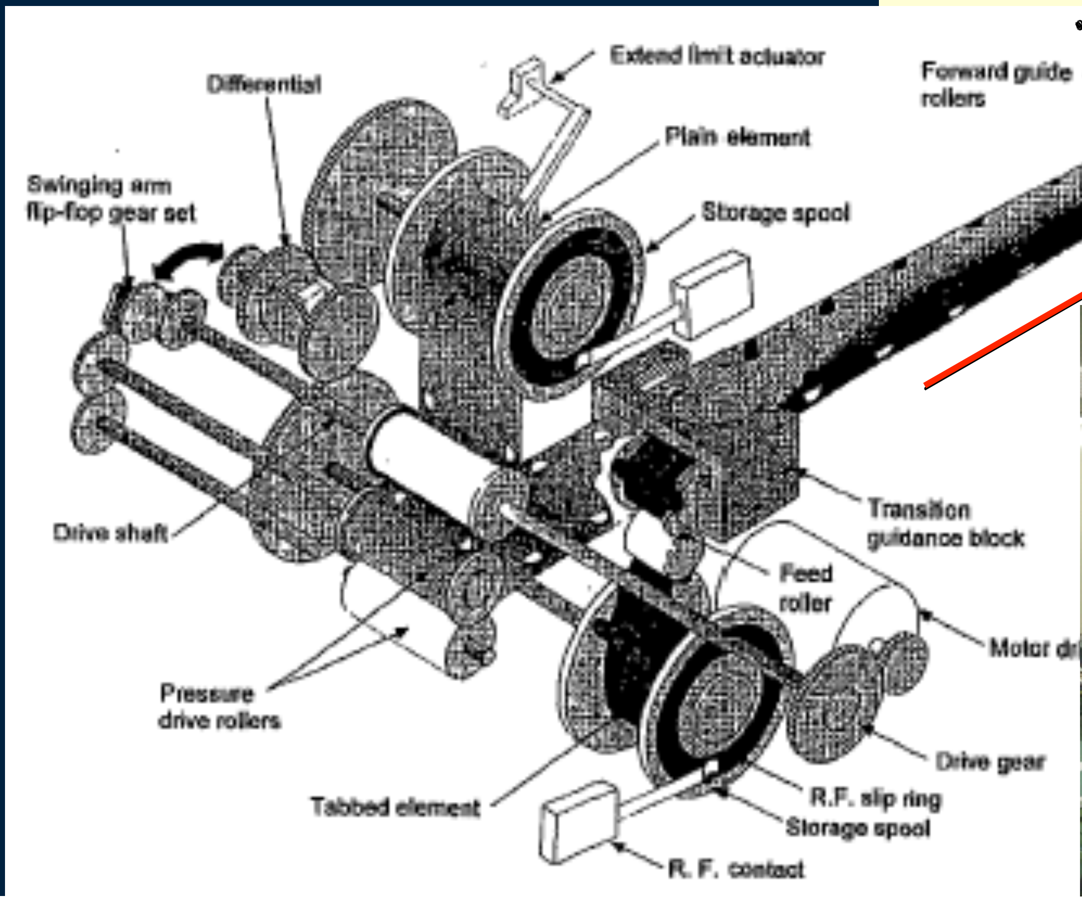
based on **LRS** antenna on Kaguya

30 m cross dipole adjusted for **5 MHz**

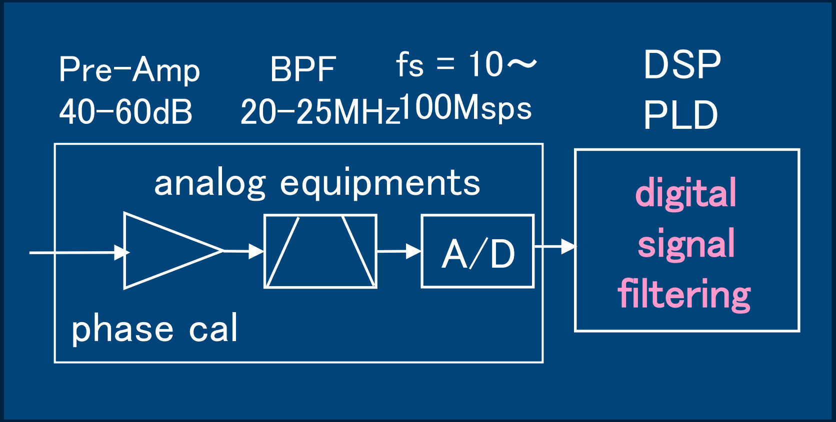
↓ **LLFAST**

3.35 m for **15-25 MHz**

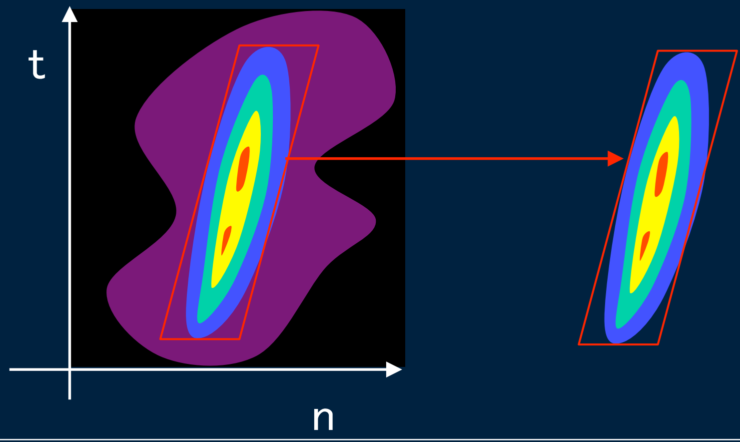




Properties of LLFAST on-board instruments



concept of digital filtering



data handling	sampling; 60 MHz >> 10MHz re-sampling, 8 bit, 2 ch, digital filtering >> 160 Mbps, 220 GB/week down-link; 200 kbps
component; mass	- 3.35m cross dipole antenna; 9 kg (antenna + exp. mechanism) - electronics; 10 kg (amplifier, sampler, recorder, freq. stand.) - frequency standard of $<10^{-11}$
power	12.8 W (max. in observation)

Technical key problems for future LLFAST on the Moon

1) Survivability during the lunar nights

- electricity supplying
- endurance for low temperature

Thermal Cycle Test have been executed;

+80 ~ -200 ^{o}C, 6 cycles for Amplifier, AD Converter, *etc*.

2) Performances of Frequency standard

USO: Ultra Stable Oscillator of $<10^{-13}$ stability

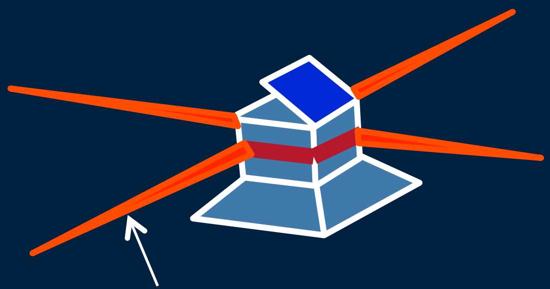
with low electric power / mass

3) Development of antenna expanding system

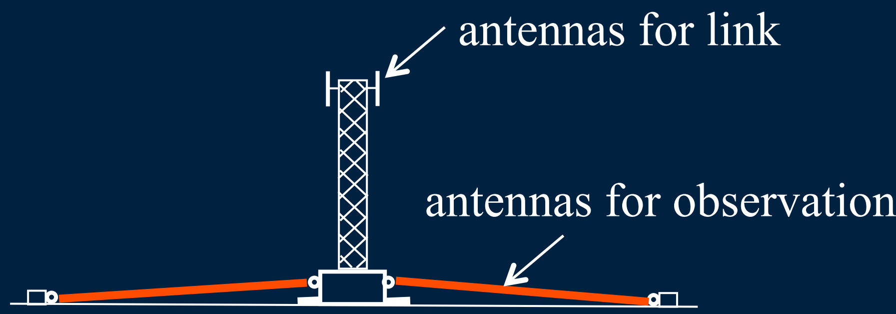
expanding bi-stem (LRS, LLFAST-1)

-> examining; expanding wire, inflatable, whale harpoon, *etc*.

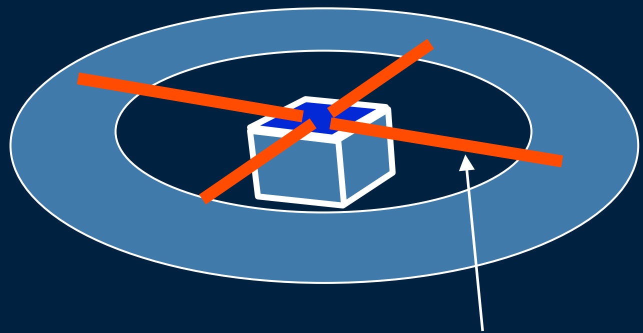
examples of antenna expanding system



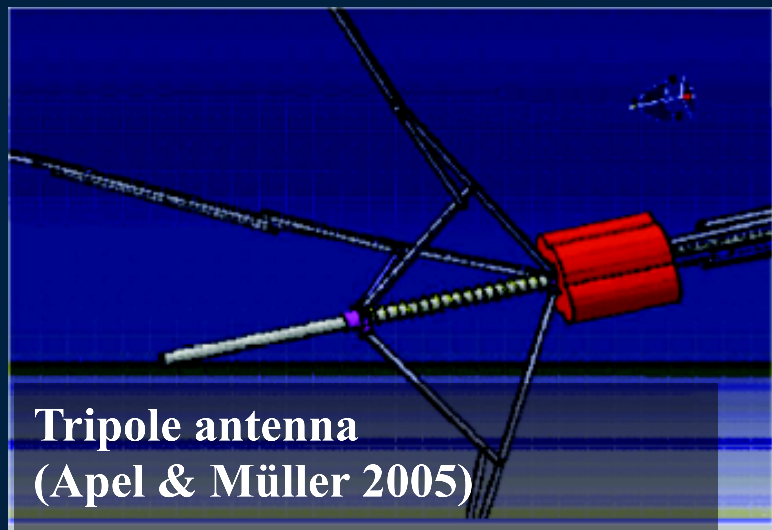
expanding bi-stem
(ESA Report, 1997)



expanding wire
(Kuiper *et al*., NASA, 1990)



one example of inflatable
(Iwata *et* . 2004)

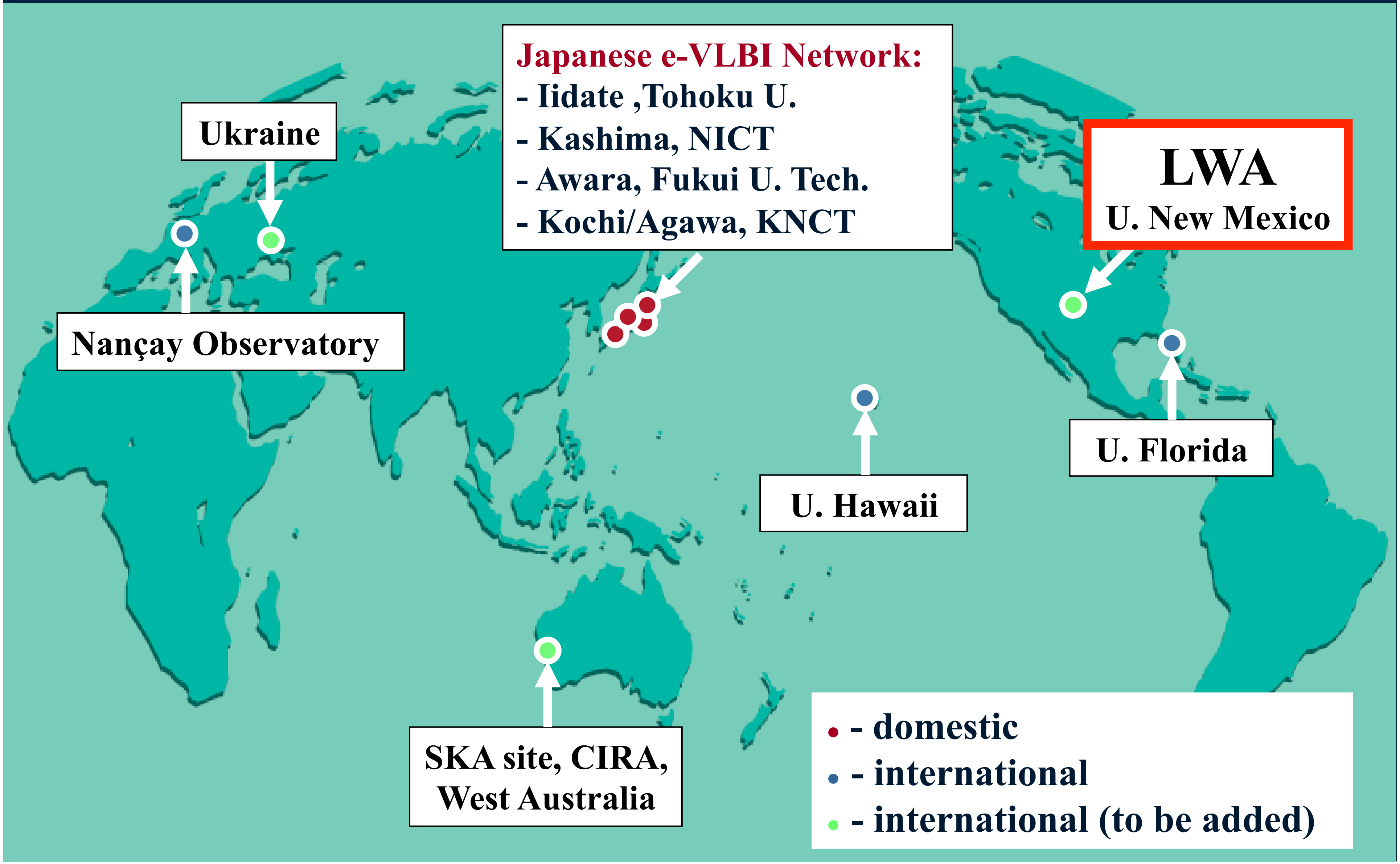


Tripole antenna
(Apel & Müller 2005)

expanded by “whale harpoon”

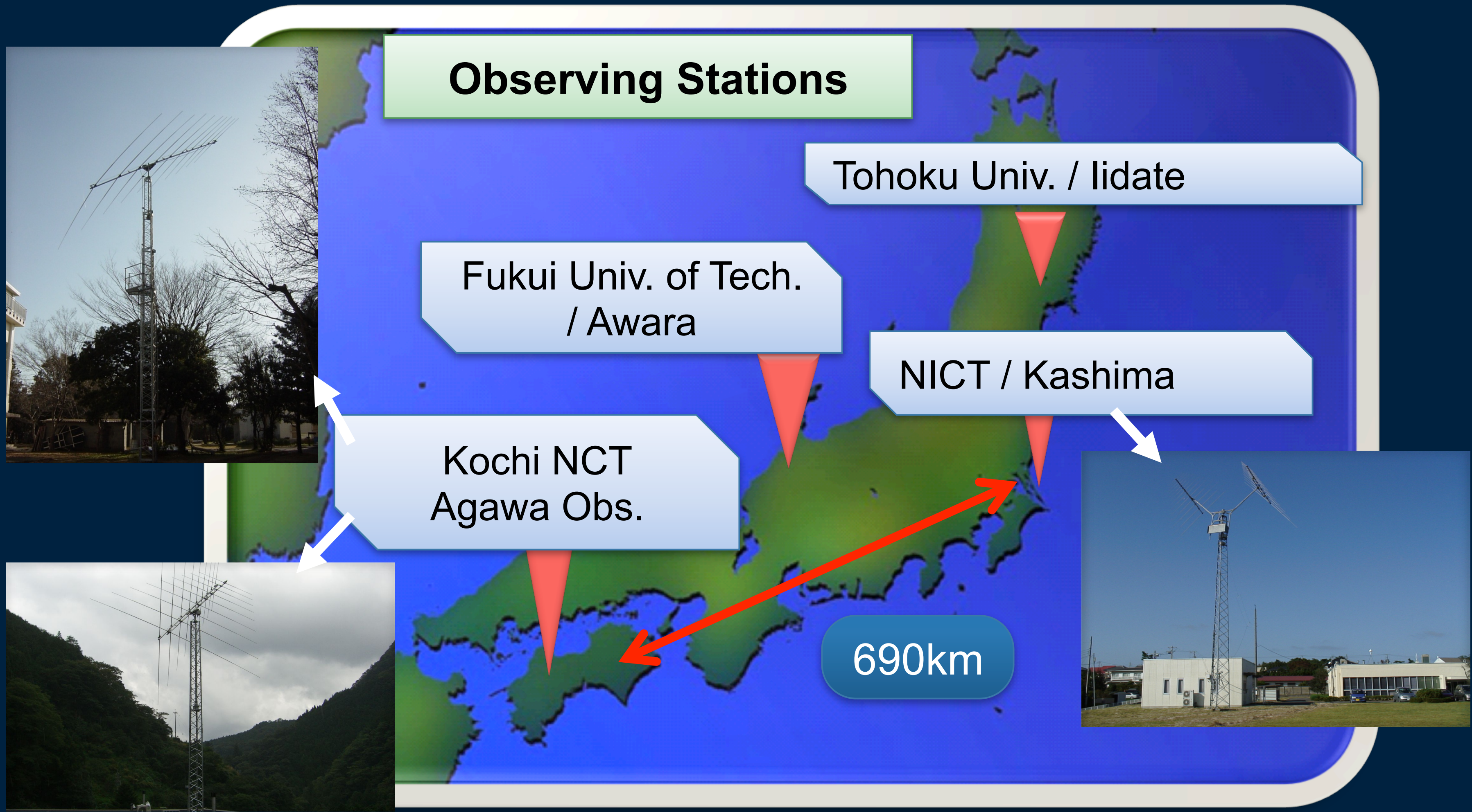
ground stations for LLFAST-1

Candidate Ground Stations



Japanese e-VLBI network

Present Observing frequency: 26～28MHz



Summary of LLFAST

LLFAST-1:
- Moon (1 element)-Earth space VLBI
- elucidation for the Mechanism of Io-DAM

Key items for future LLFAST series:
- developments for
  * survivability during the lunar nights
  * performances of frequency standard
  * antenna expanding system

Collaboration:
- International collaboration for ground stations
- many planetary scientists, but a few astronomers
  -> Please join us !

Thank you!