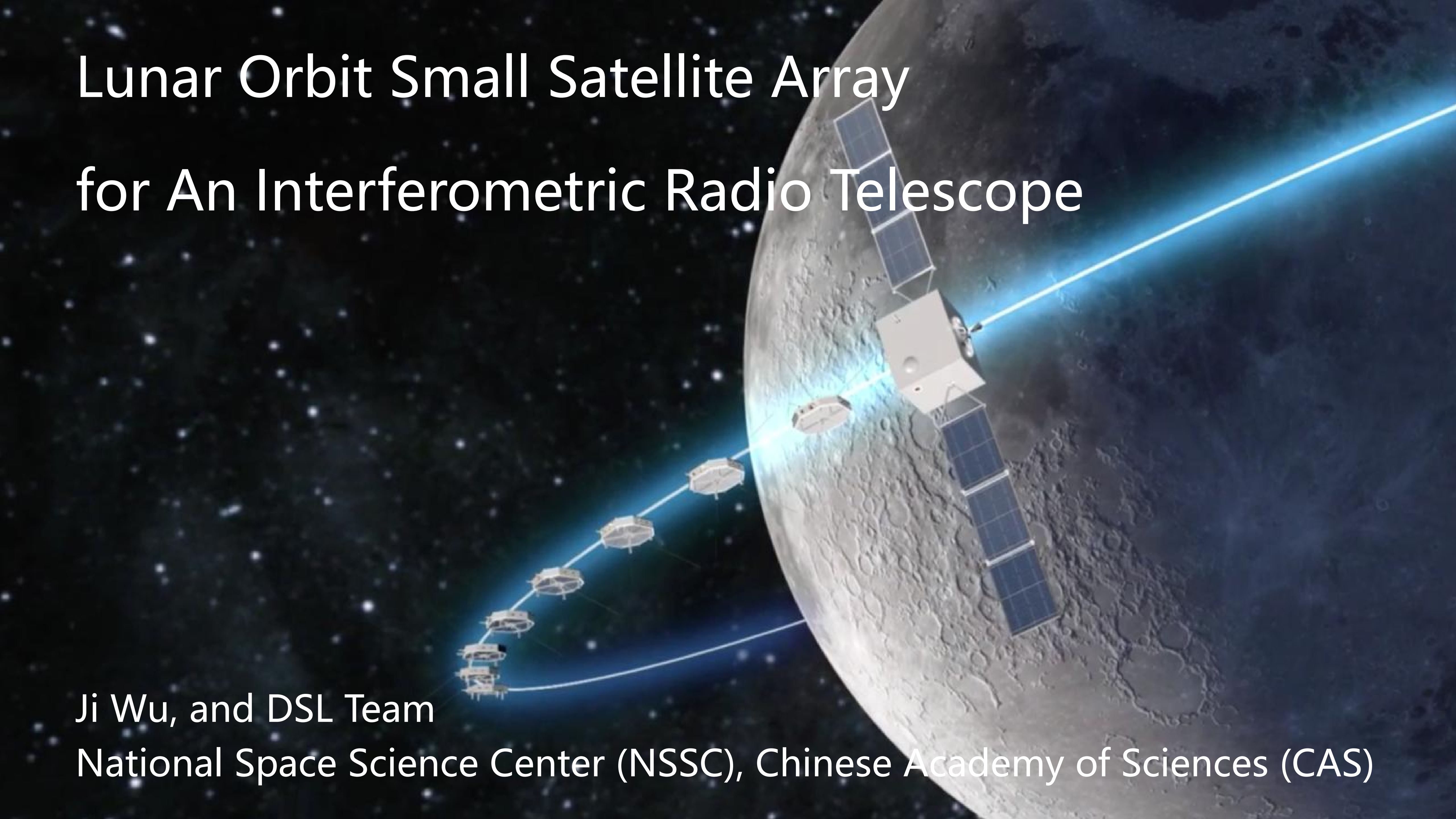


Lunar Orbit Small Satellite Array for An Interferometric Radio Telescope

Ji Wu, and DSL Team
National Space Science Center (NSSC), Chinese Academy of Sciences (CAS)

CONTENTS

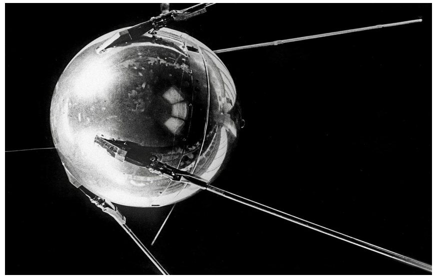
1

Small Satellite for Science

Small satellite for scinece

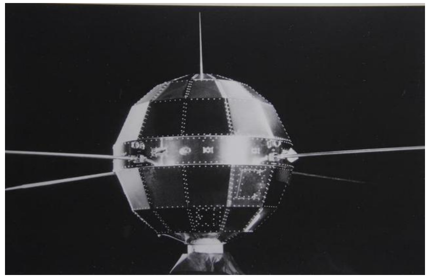
□ From small to large and then small again

Sputnik-1



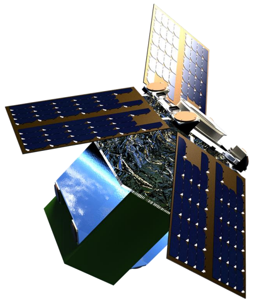
0.58m, 83.6kg, 1957

DHF-1



1.0 m, 173kg, 1972

Envisat: 12m, 7911kg, 1986-2002



SSTL Microsat: <1m, <100kg, 1990

Cubesat: 10cm, <1kg, 2010

Small satellite for scinece

□ In 2019 COSPAR issued a roadmap for small satellite

ELSEVIER

Advances in Space Research

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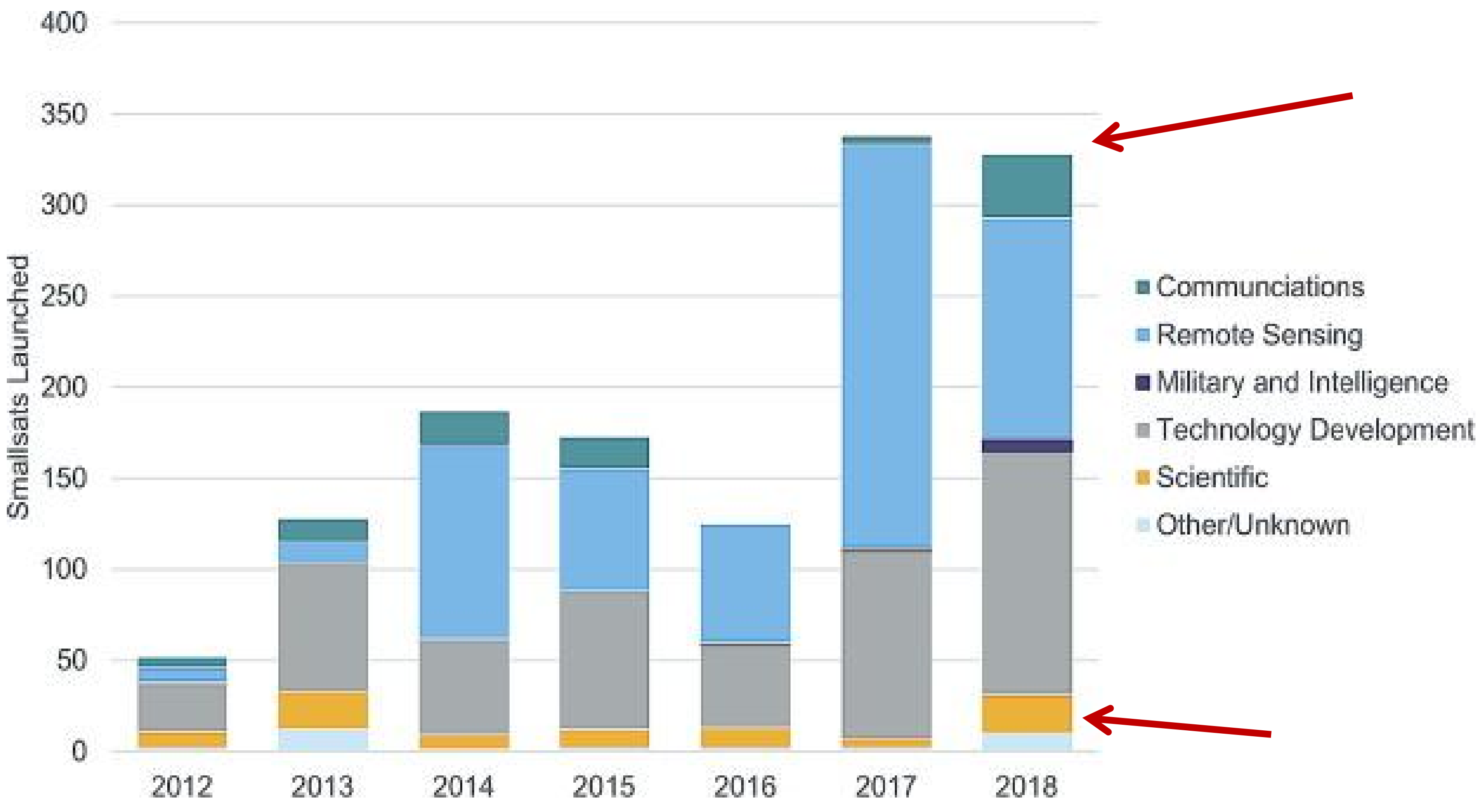
Review

Small satellites for space science: A COSPAR scientific roadmap

Robyn M. Millan [a], Rudolf von Steiger [b c], Meir Ariel [d], Sergey Bartalev [e], Maurice Borgeaud [f], Stefano Campagnola [g], Julie C. Castillo-Rogez [g], René Fléron [h], Volker Gass [i], Anna Gregorio [j k l], David M. Klumpar [m], Bhavya Lal [n], Malcolm Macdonald [o], Jong Uk Park [p], V. Sambasiva Rao [q], Klaus Schilling [r], Graeme Stephens [g], Alan M. Title [s], Ji Wu [t]

Small satellite for scinece

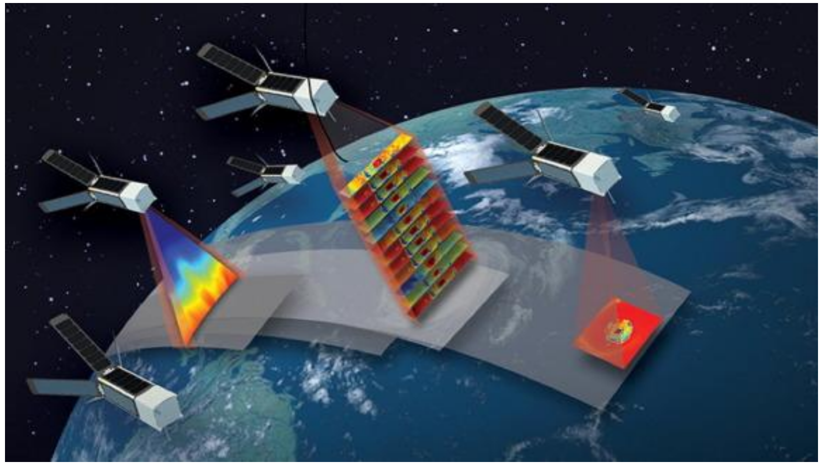
□ In 2019 COSPAR issued a roadmap for small satellite



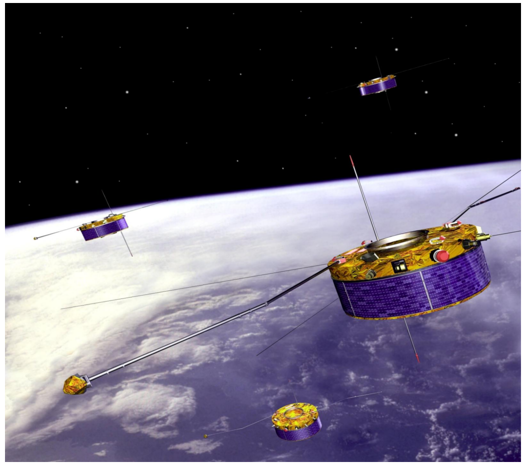
However, science is not the main user of small satellite, although the totol number of launches were already more than 300 per year.

Small satellite for scinece

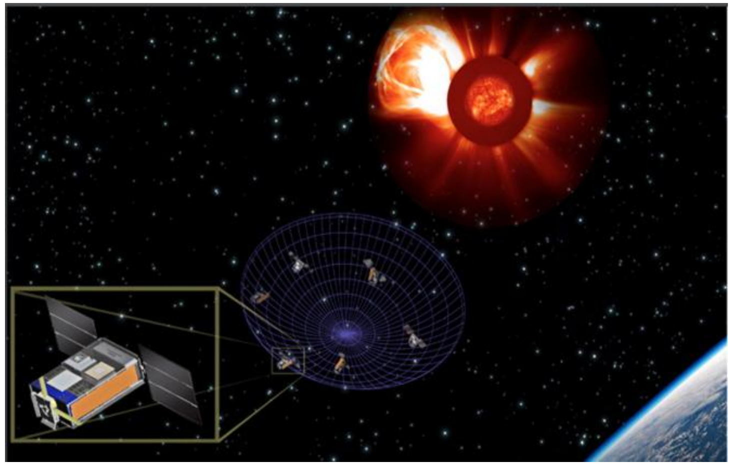
◻ Most science missions using small satellite are clusters



TROPICS mission for Earth remote sensing, NASA



CLUSTER mission for space physics, ESA

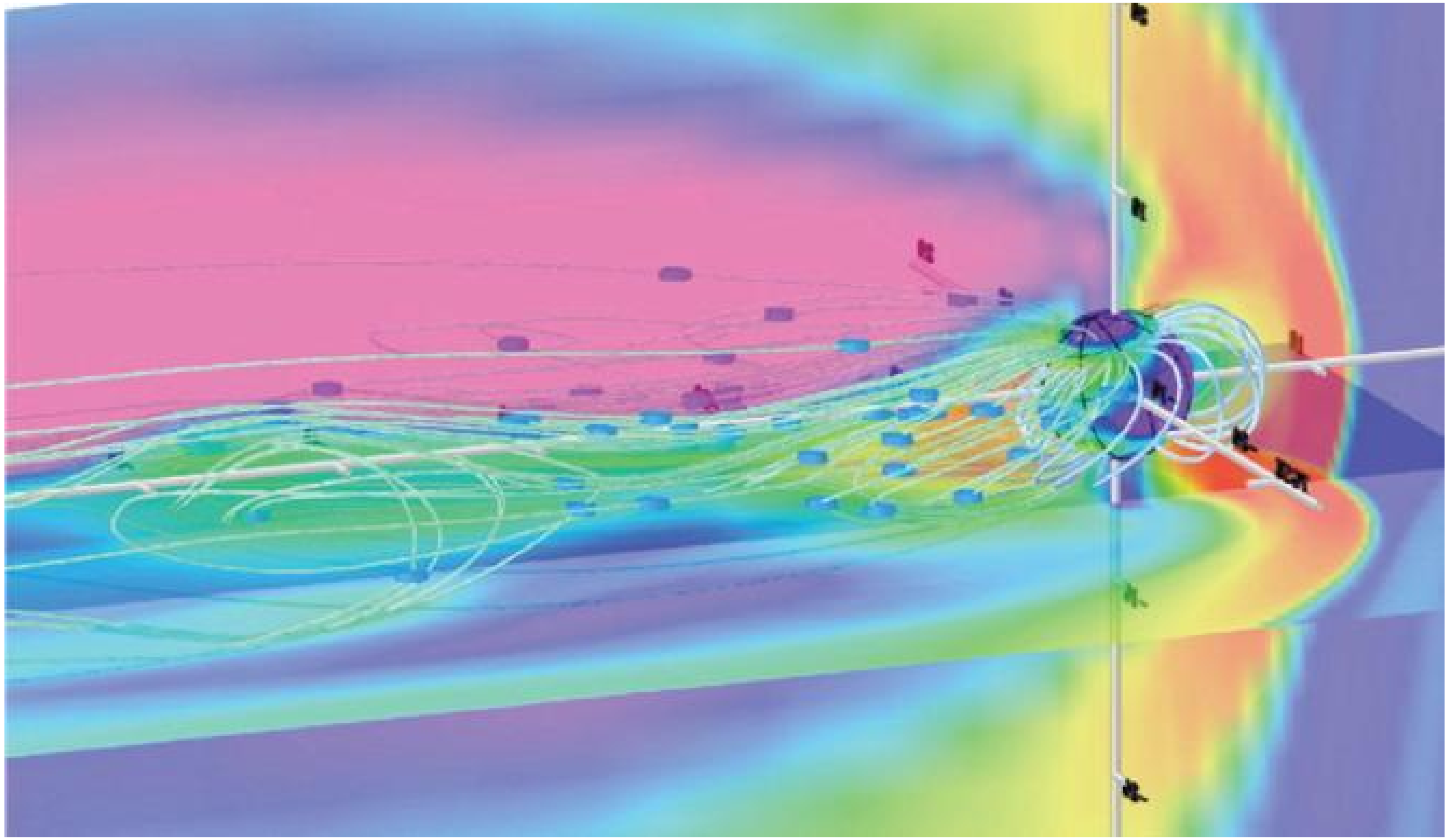


SUNRise mission for solar physics, NASA

A group of small satellites can reach a better observation result than a single large satellite, or forming up a larger aperture that even a large satellite cannot realize.

Small satellite for scinece

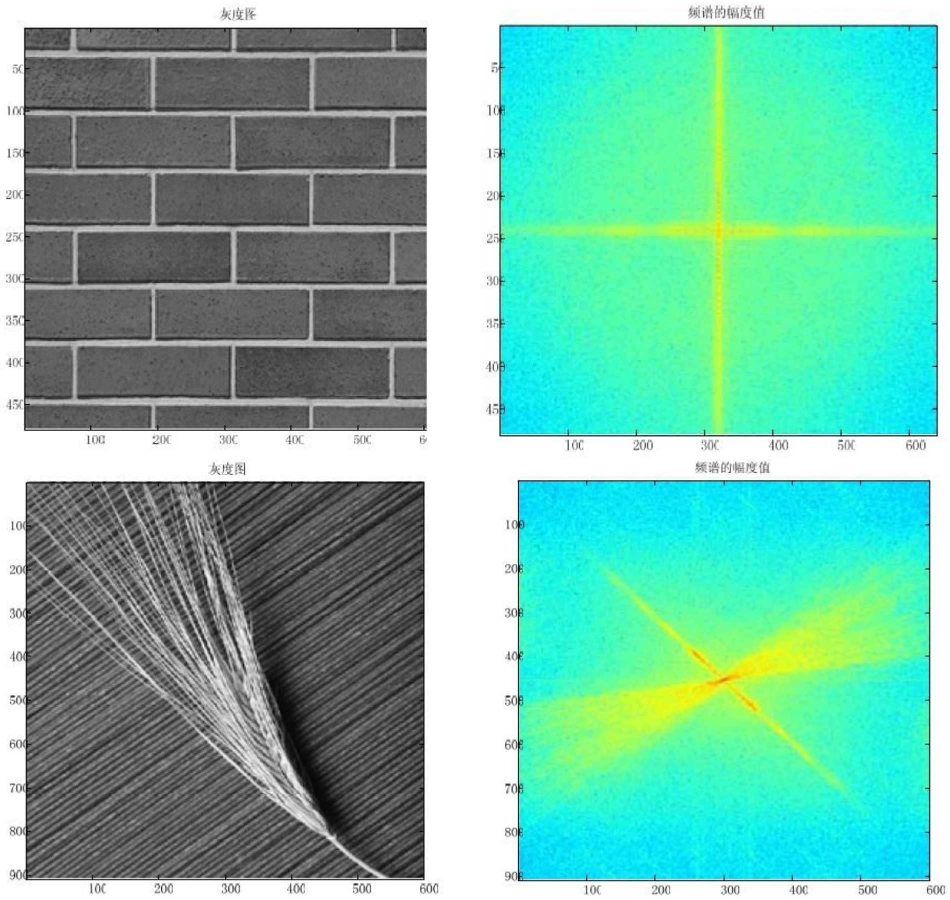
□ How large an apertue can they form up?



- Magnetospheric Constellation (MagCon) mission concept from a NASA mission definition study showing 36 spacecrafts
- Which in fact is not an aperture but a distribution of indevidual satellites that doing measurement on their own.

Small satellite for scinece

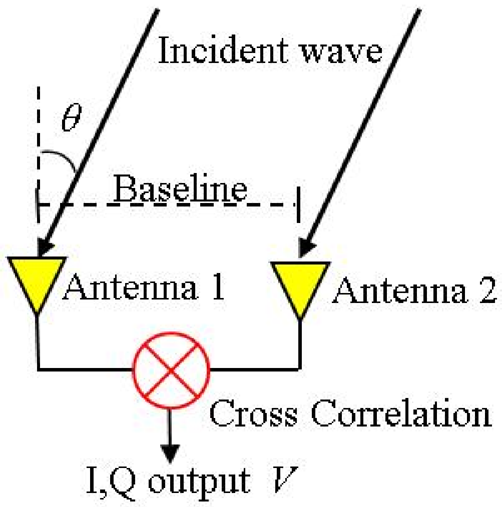
□ How large an apertue can they form up?



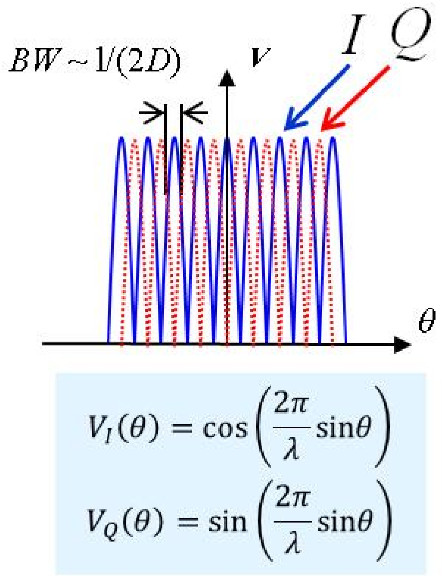
spatial domain (XY) image

spatial frequence (UV) domain image

Spatial resolution of retrieved image using interfeometric technology depends on its longest baseline



Interferometer



Grating lobes pattern

Small satellite for scinece

- ◻ However a single long baseline cannot retrieve a good image, we need full coverage on the spatial frequence domain or the UV plane

VLA, 1-50GHz, New Mexico, USA

SSRT, 5.7 GHz, Siberia, Russia

DART, 150-450MHz, Daocheng, China

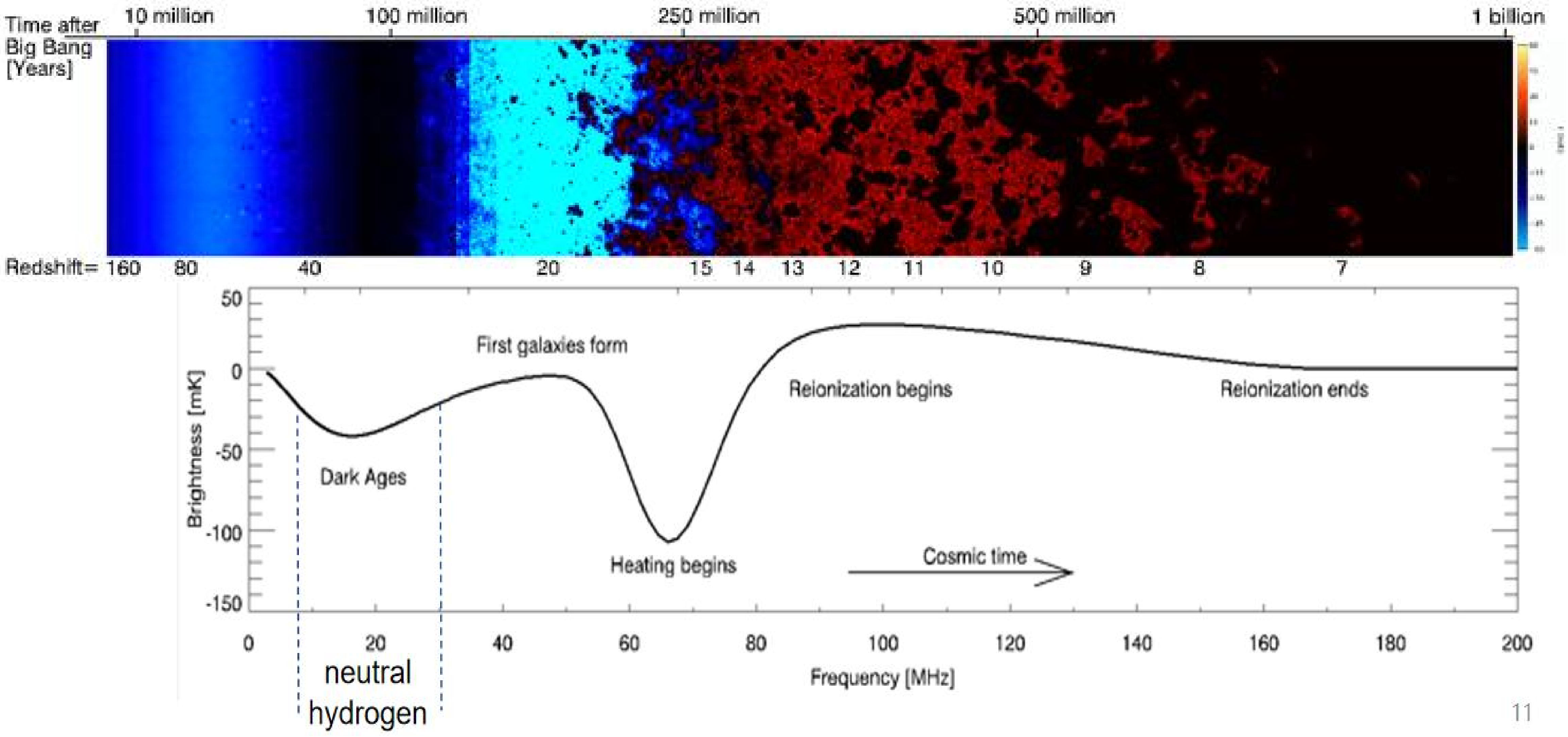
- ◻ In space, it is difficult to reach a full coverage on the UV plane!

2

Most Important Science

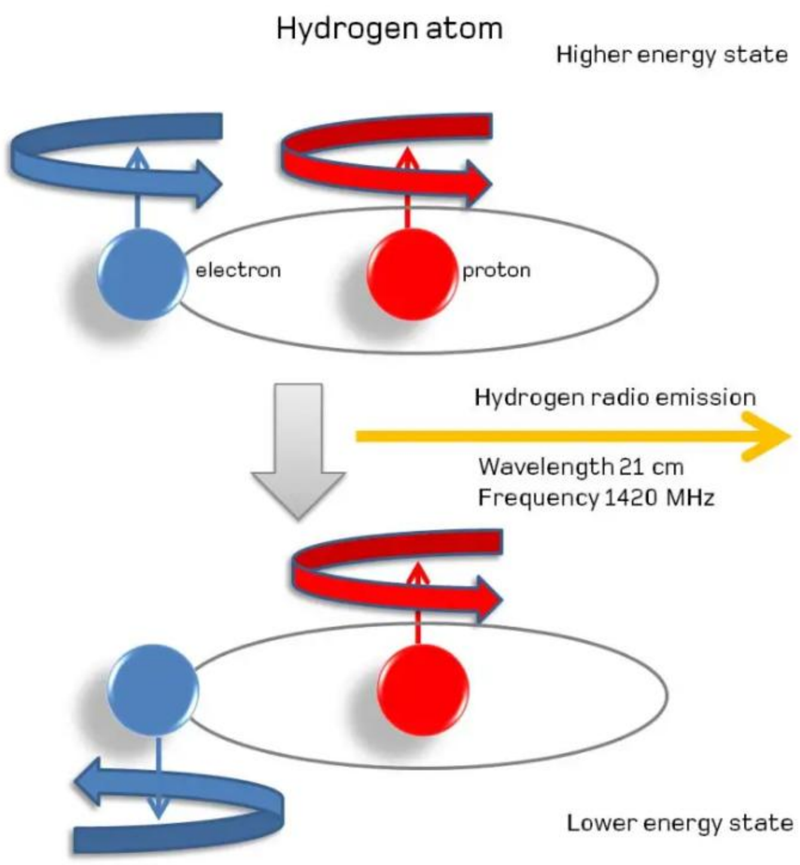
Most Important Science

□ Dark Ages and Cosmic Dawn, the only unkown period of Universe



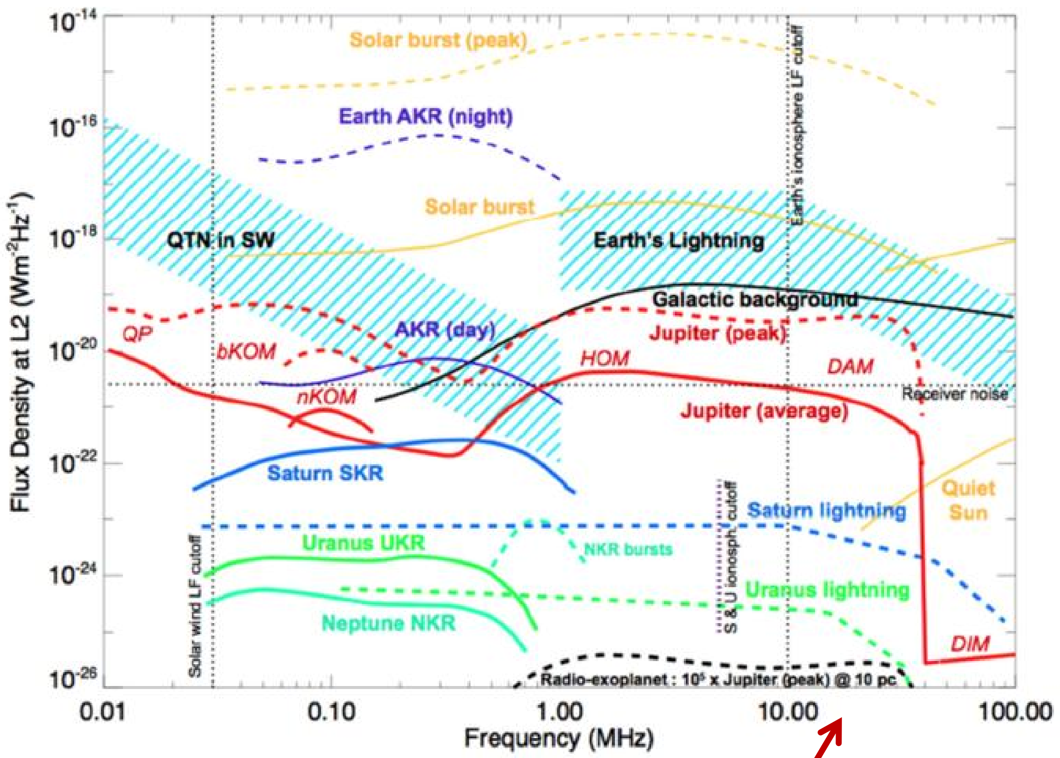
Most Important Science

□ How can we measure the Dark Ages if it is all dark?



Redshift

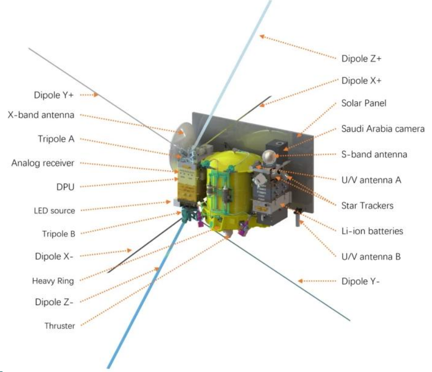
10-30MHz



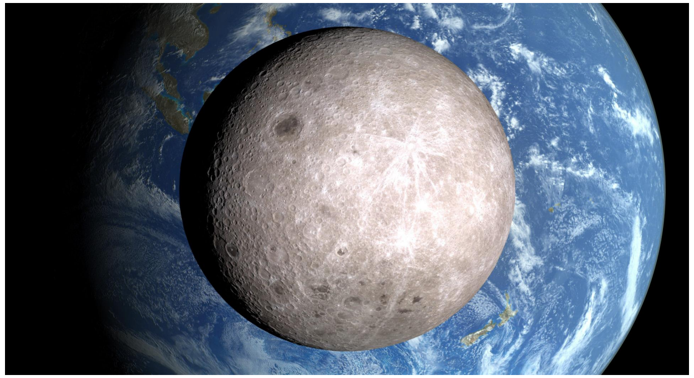
Hendrik Christoffel van de **Hulst** predicted theoritically and measured by Harold **Ewen** in 1951 in the lab.

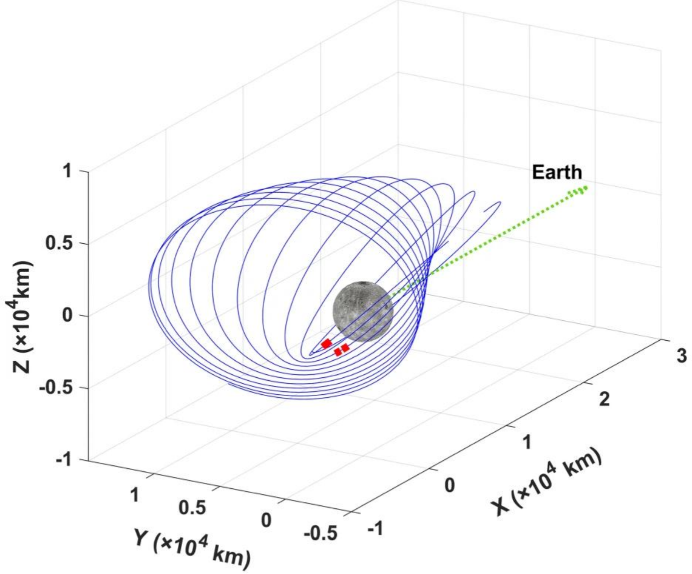
Difficult to measure such low frequence on the earth

Most Important Science



□ Advantage of the far side of the Moon





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Ultra-low-frequency radio astronomy observations from a Seleno-centric orbit

First results of the Longjiang-2 experiment

Original Article | Published: 27 January 2023

Volume 56, pages 333–353, (2023) Cite this article

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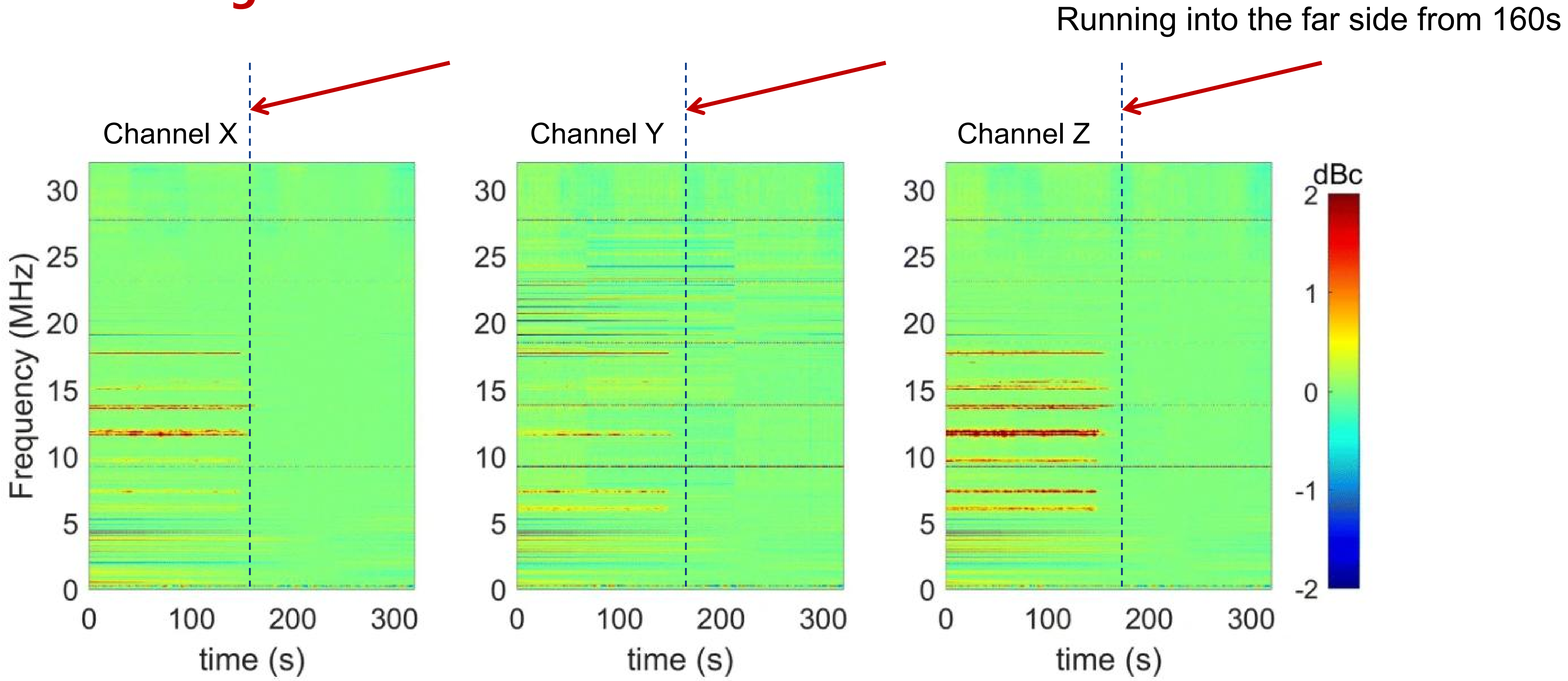
Jingye Yan, Ji Wu, Leonid I. Gurvits, Lin Wu, Li Deng, Fei Zhao, Li Zhou, Ailan Lan, Wenjie Fan, Min Yi, Yang Yang, Zhen Yang, Mingchuan Wei, Jinsheng Guo, Shi Qiu, Fan Wu, Chaoran Hu, Xuelei Chen, Hanna Rothkaehl & Marek Morawski

Most Important Science

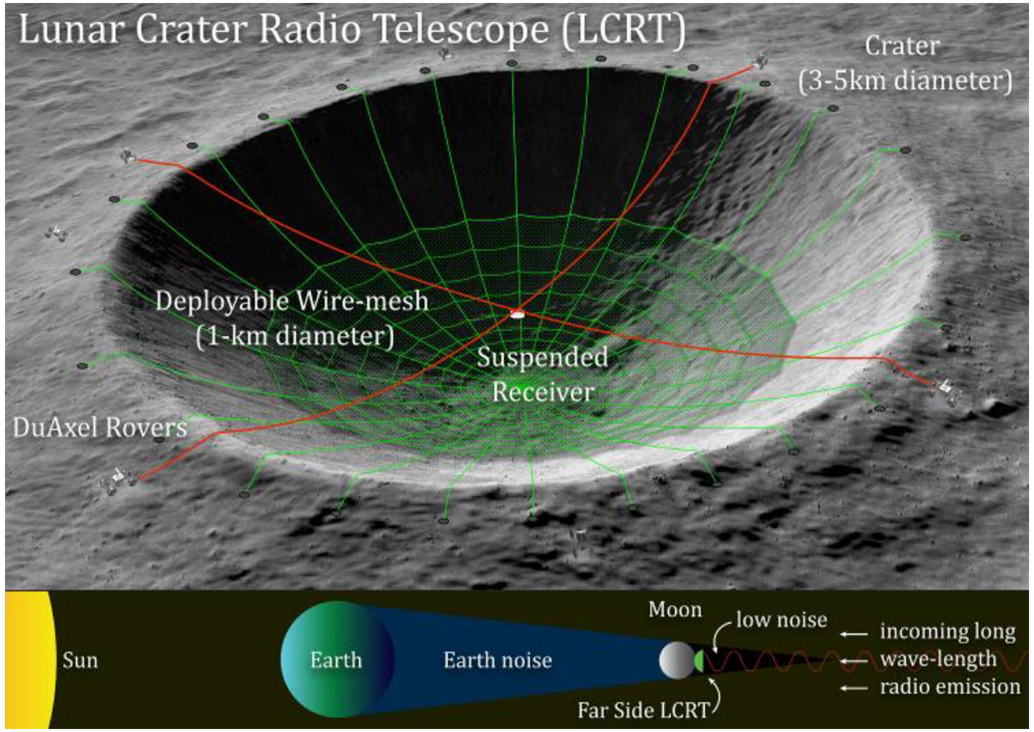
□ Advantage of the far side of the Moon



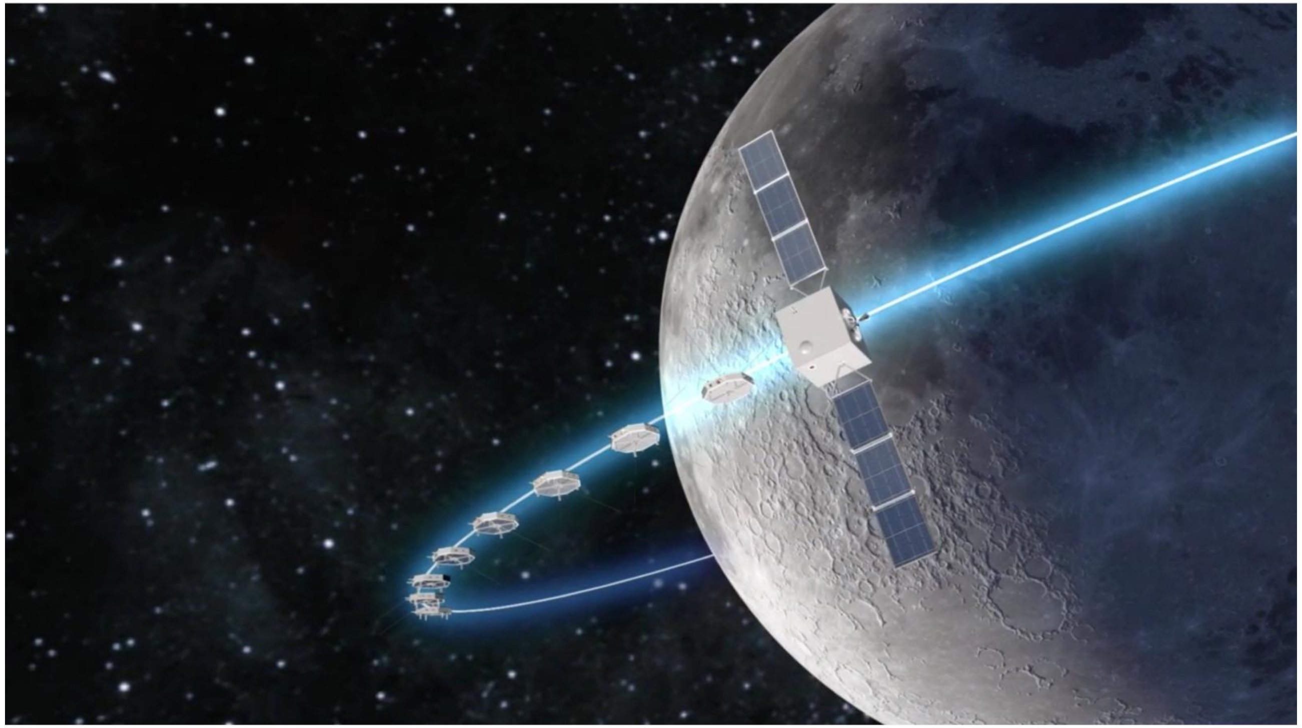
Measurements from lunar orbit by Longjian-2, 2018

Most Important Science

□ Solid aperture v.s. synthetic aperture



Solid aperture



Synthetic aperture by a liner array

3

DSL Proposal

DSL (Discovering the Sky at the Longest Wavelengths)

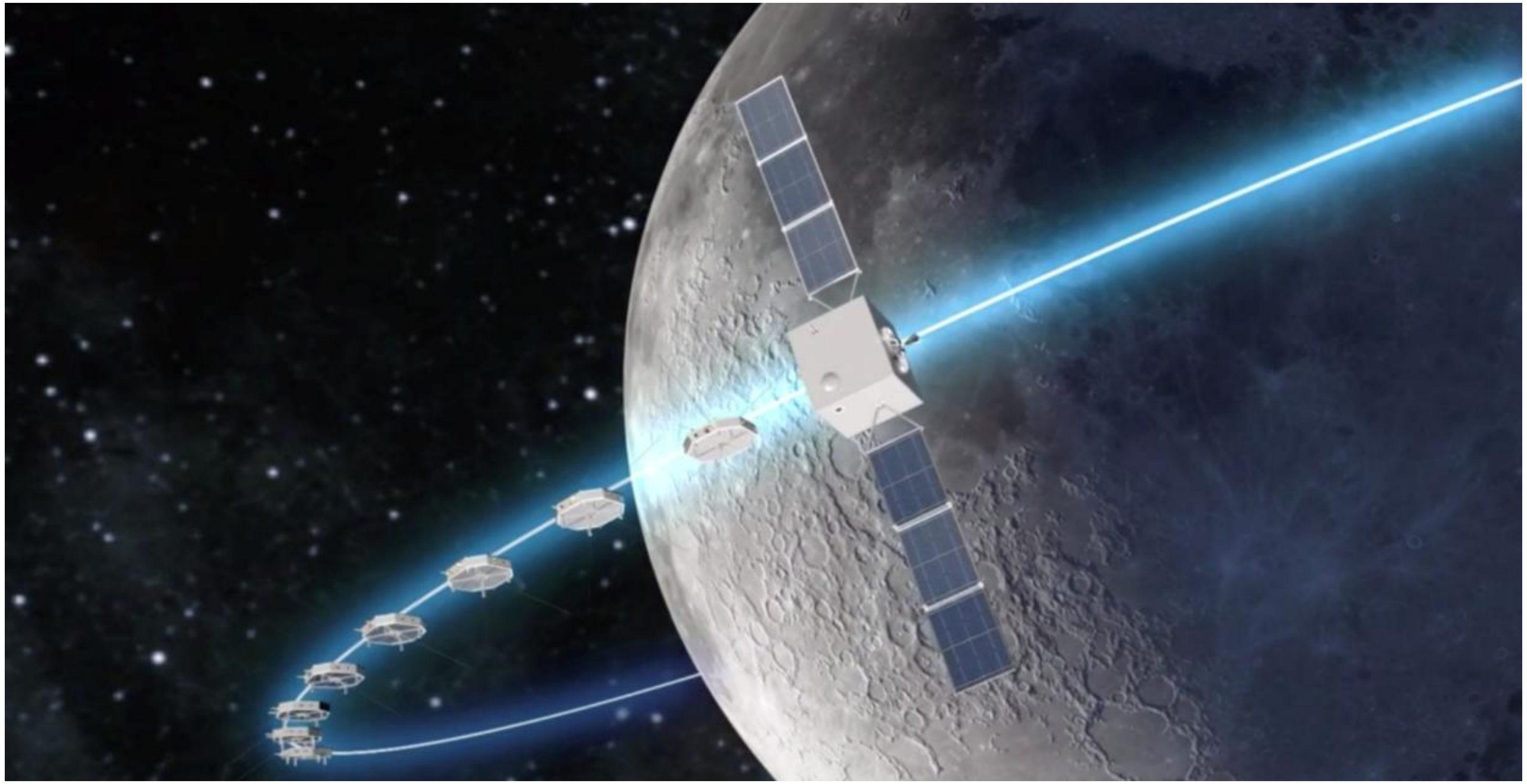
2014: Concept study by NSSC;

2015: Joint proposal by CAS and European team;

2018: Longjiang -1 and -2 microsats were launched;

2018: Phase A was approved by CAS

2024: Selected as one of four in the next round of space missions

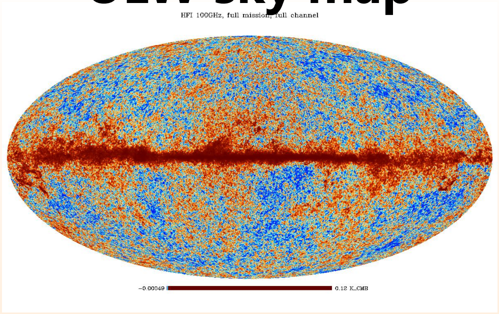


DSL (Discovering the Sky at the Longest Wavelengths) mission consists of 1 mother satellite and 9 daughter satellites flying around the Moon and forming a space virtual radio observatory to survey the sky with a high-resolution.

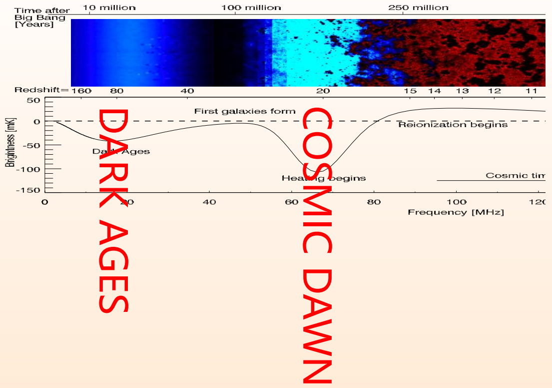
Mission profile

Scientific objectives

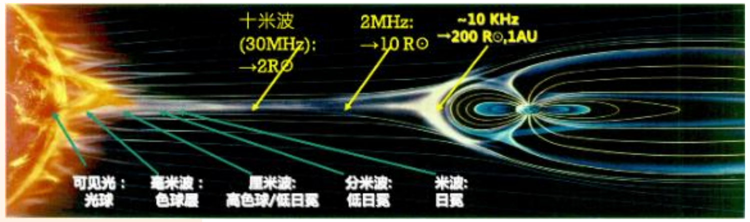
ULW sky map



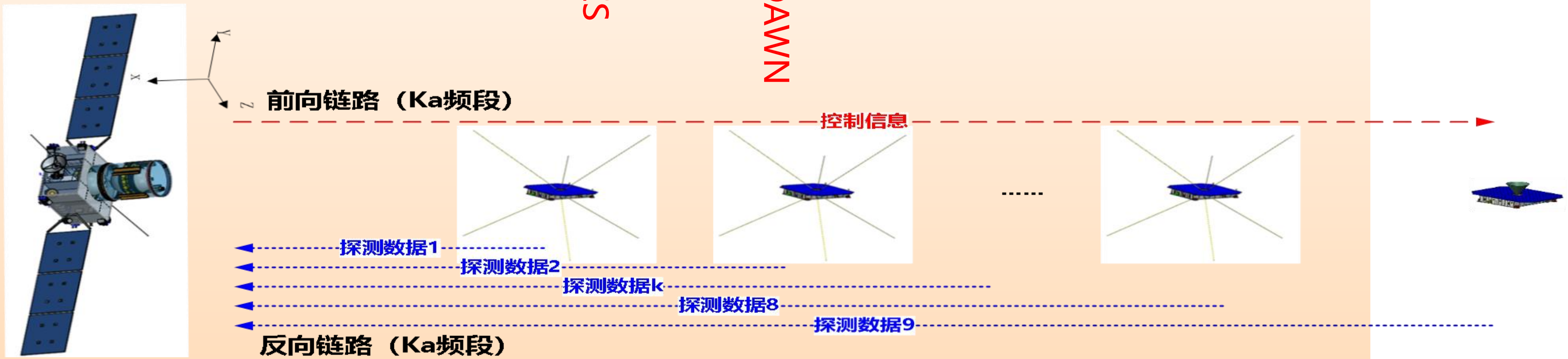
ULW global spectrum



ULW in solar system

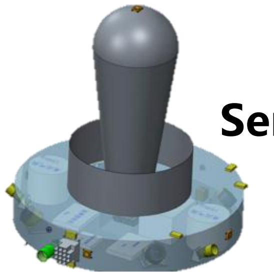


Satellites



Payloads

A 100km aperture radio telescope
8 LF (0.1~30MHz) interferometric polarimeters
1 HF (30~120MHz) spectrometer
9 inter-satellites units for CRS

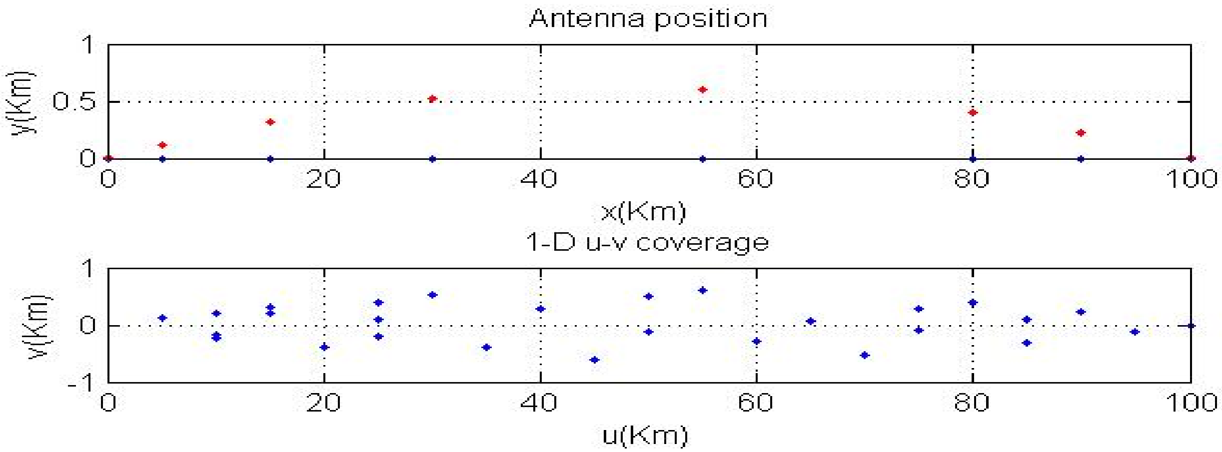


Sensitivity:10^{-4}

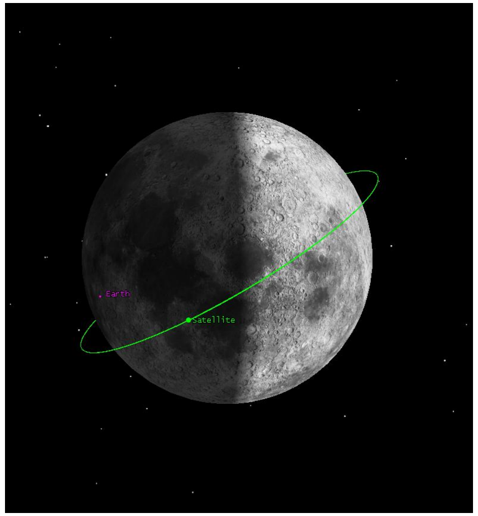
LF: Distributed interferometric imager/spectrometer

HF: spectrometer

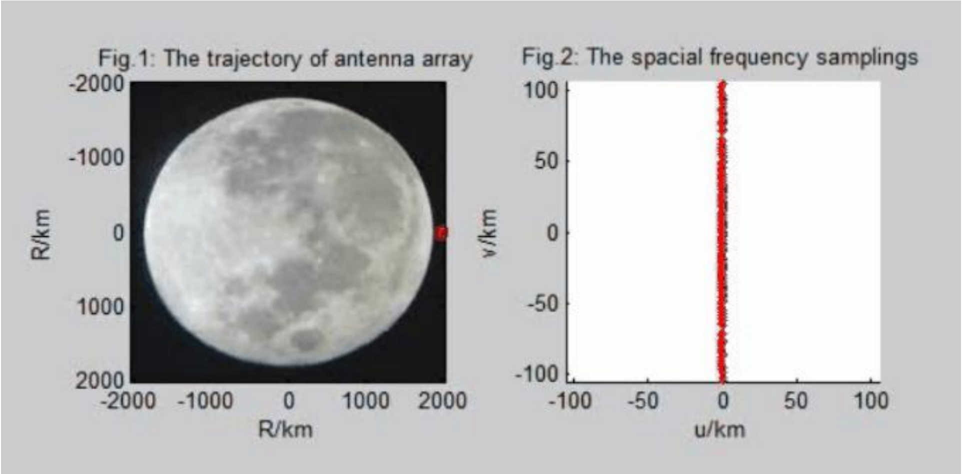
Using orbital movement and precession



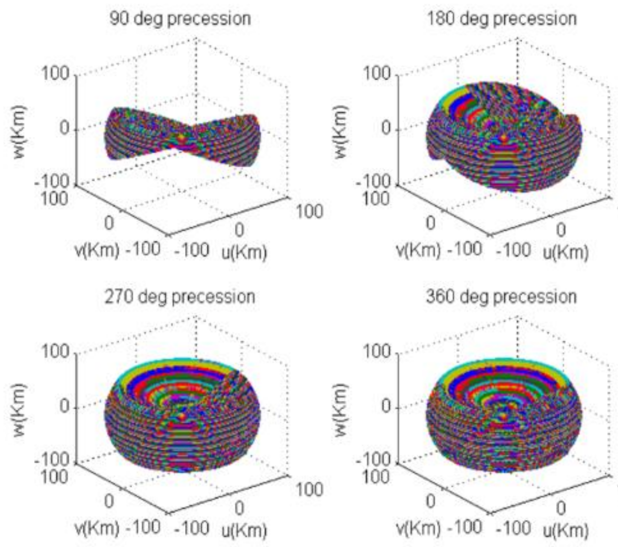
Quasi-linear coverage by snapshot



Using the precession of the orbital plane



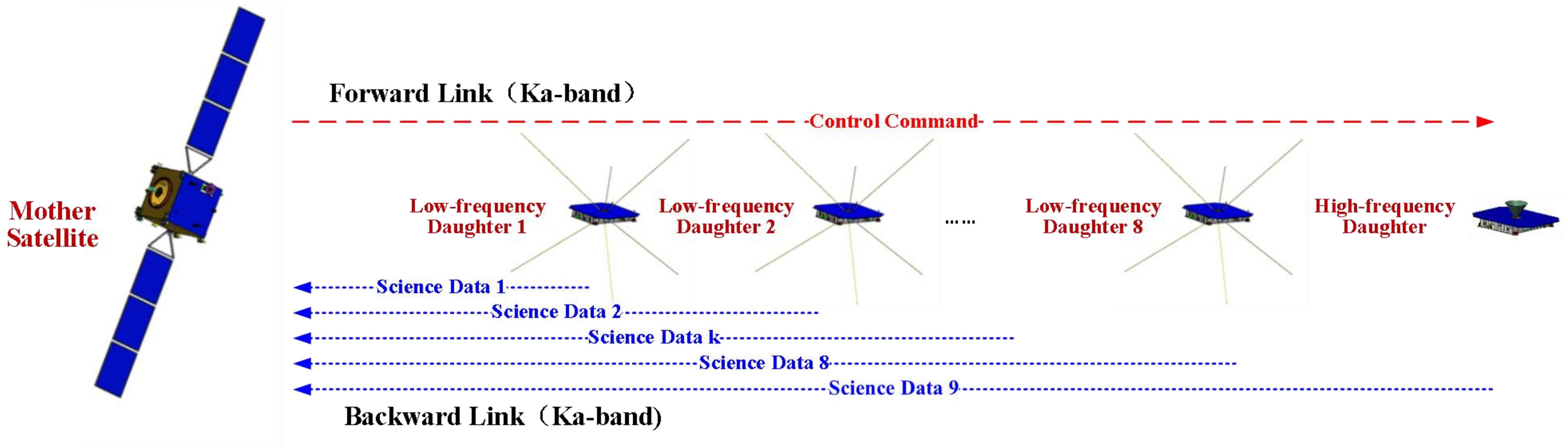
Dish coverage of ½ orbit cycle (~75min)



3D coverage up to 1.3yr

Baseline determination and clock synchronization

Distinguish "array" from "constellation"



Inter-satellite link between mother satellite and daughter satellites

payload

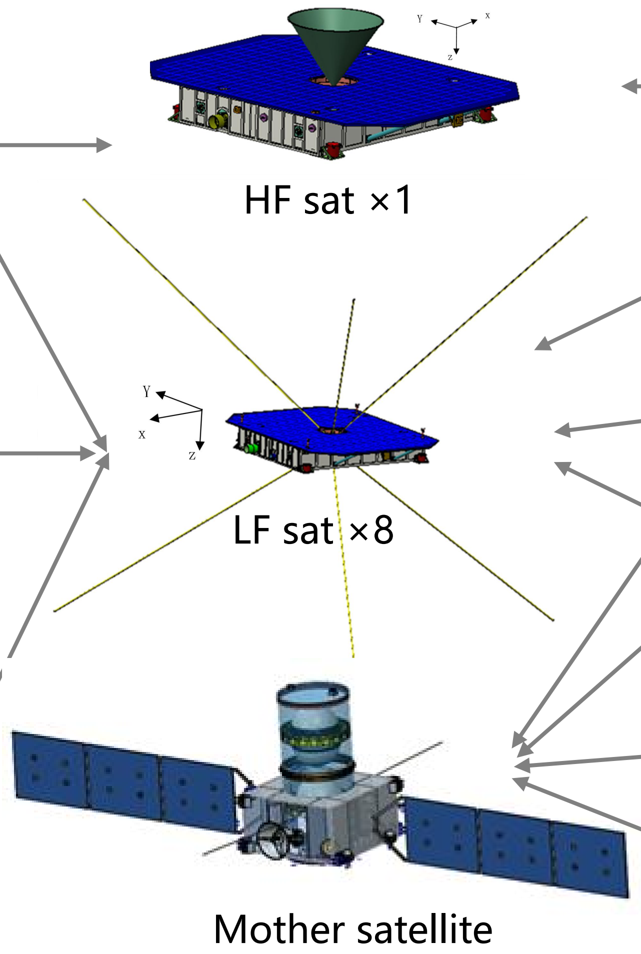
scientific objectives

1. high accuracy global spectrum

2. ULW all sky map, open up new window

3. radio burst of the Sun and planets, study space environment

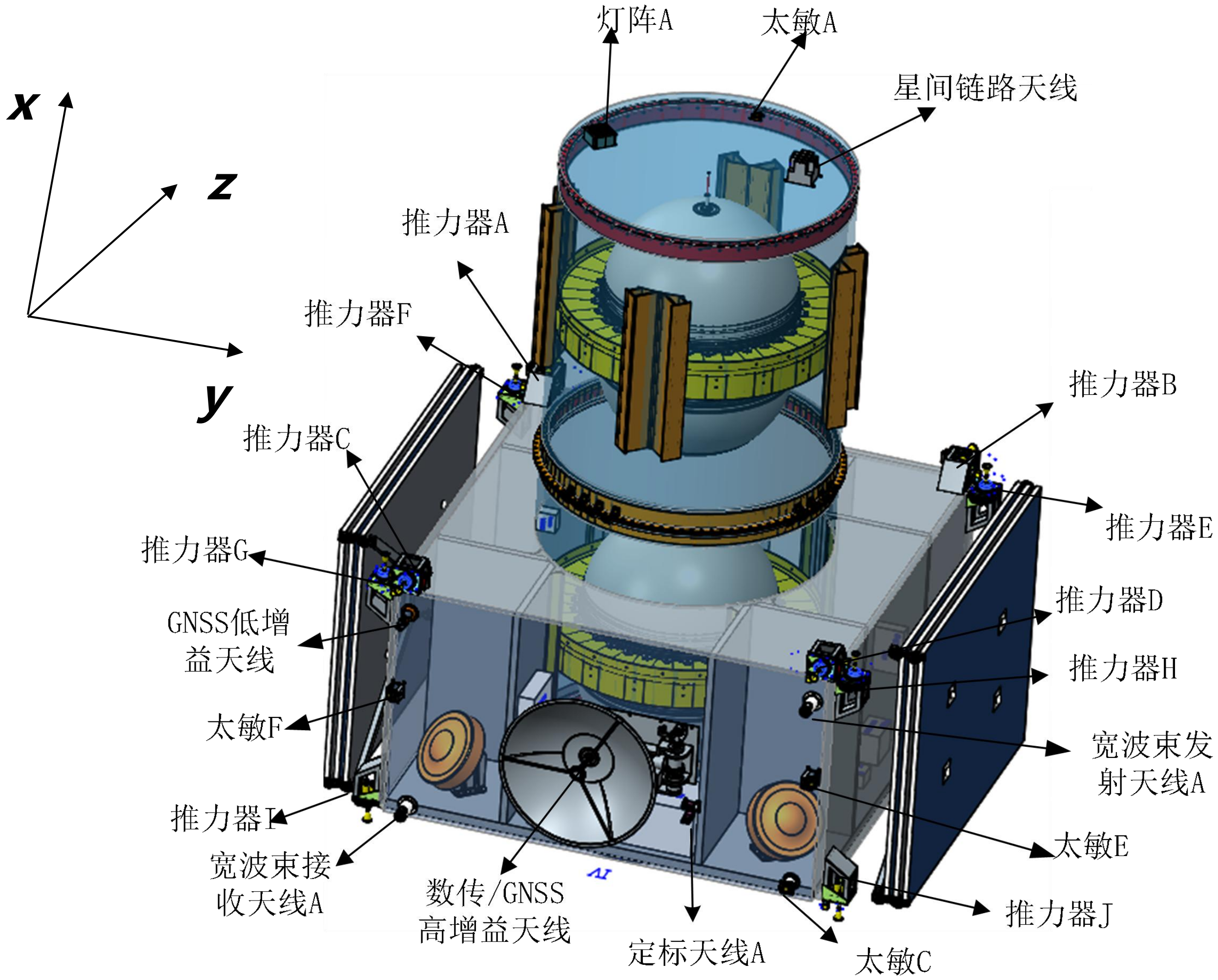
satellite



payload

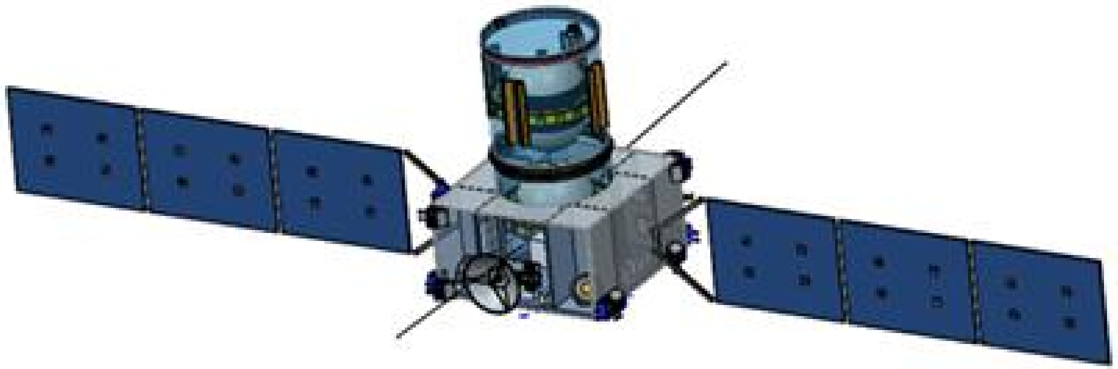
1. HF spectrometer
2. LF interferometer & spectrometer
3. Communication， ranging and synchronization
4. Sky camera
5. Correlator
6. Calibrator

Mother satellite



Mother configuration

- **Dry mass： 723kg**
- **Propellant: 854kg**
- **Power: 480W**



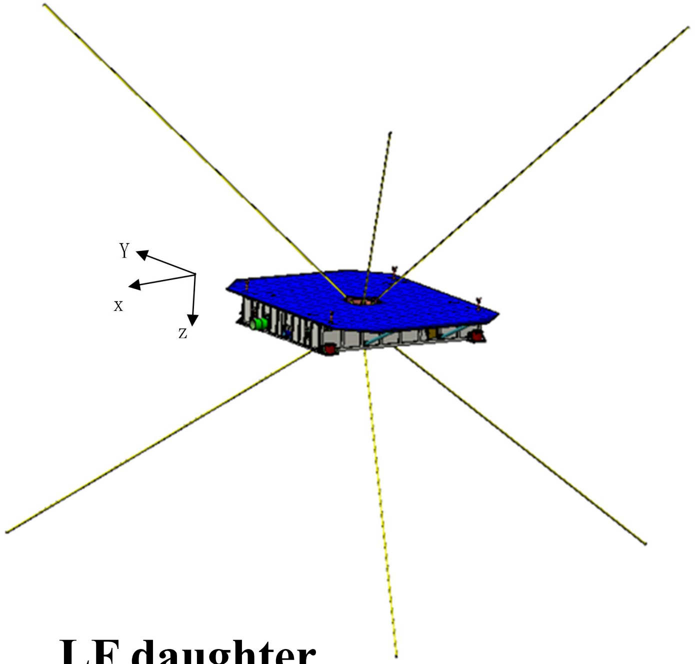
Operation mode

Daughter satellite

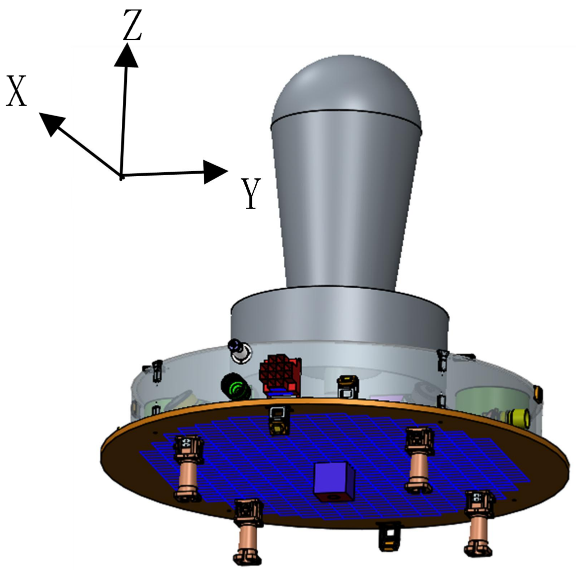
- “flate” configuration

  Low frequency interferometric spectrometer: 85kg，90W；

  High frequency spectrometer: 95kg，90W。



LF daughter



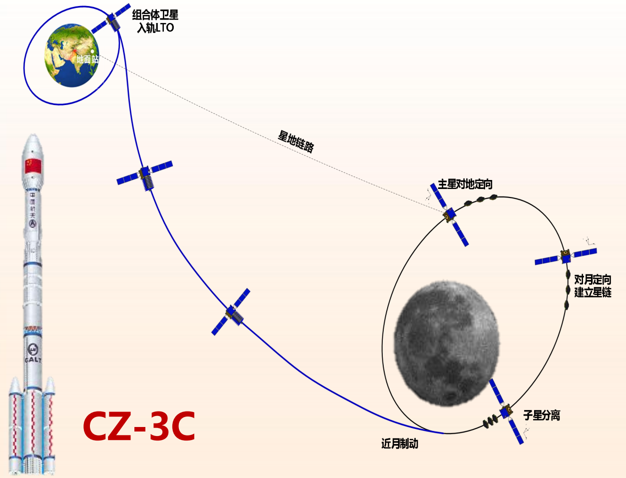
HF dauther

Specifications (verified by lab/field/air/space test)

- □Interferometric imaging with formation flying
- □Baseline ranging accuracy: <1m (1/10 λ @30MHz)
- □Baseline direction: ＜10 μrad（5as）(independent on satellite attitude)
- □Clock synchronization: <3ns
- □Single receiver sensitivity: $< 2.93nV/\sqrt{Hz}$
- □Amplitude calibration accuracy: <1dB
- □Phase calibration accuracy: <1/10 λ

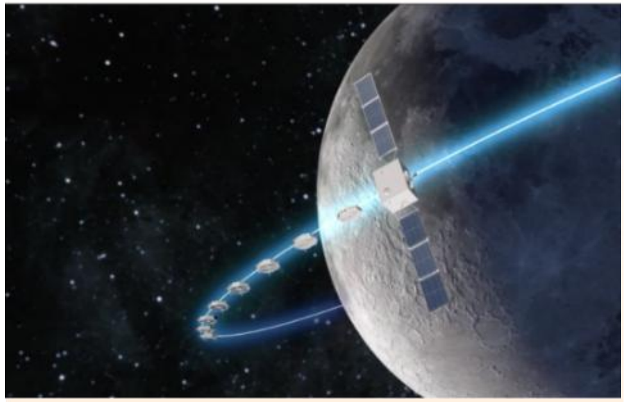
DEVELOP SCHEDULE

Launch in 2027



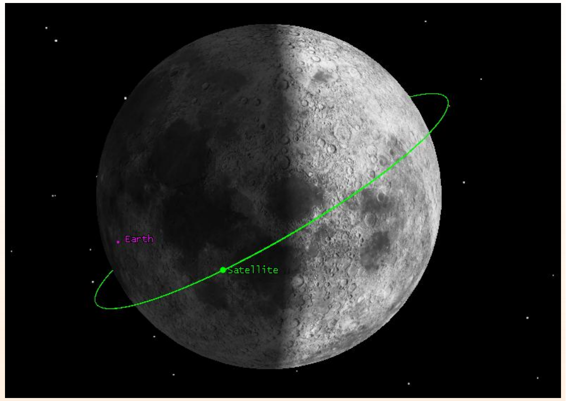
1. Lift by a single launcher
2. Transfer to the Moon as a combination of 10 satellites
3. Insert into the lunar orbit as a combination together

Commissioning in a half year



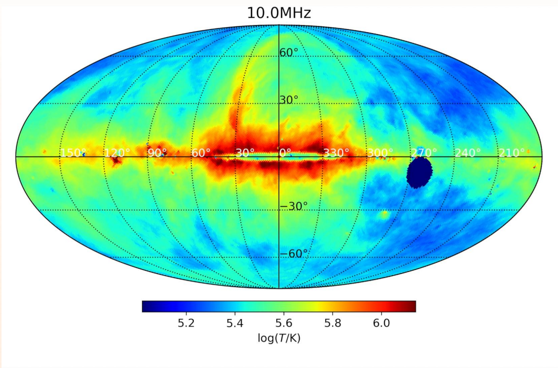
1. Deploy into a circular orbit of 300km height and 30° inclination angle
2. Baseline: 100m to 100km
3. Changing baselines lengths by array "breath"

Operational In 3 years



1. Orbital period ≈ 2.3h
2. Precession period ≈ 1.3 yr
3. Super dense sampling in spatial frequency domain
4. All sky map of very high quality

Scientific outputs Since 2028



1. Global spectrum of increasing sensitivity
2. High resolution sources in the normal of the dish after a few orbital periods.
3. All sky map of high resolution
4. ICME between the Sun and Earth

Summary

1. Small satellite can do good science as long as its performance can surpas what the large satellite can do.

2. Aiming at the most important science of universe evolution, to measure the low radio frequency band from far side of the Moon is the solution.

3. DSL is a mission proposal dedicated to explore the dark age of the universe at the low radio frenquenc band with a fleet of small satellites.

4. Baseline formation and complete UV coverage is the innovative characterastice of this proposal

5. DSL is now ready to go to the engineering phase and will be launched in later 2027 or first half of 2028.

Thanks for attention!