中国科学院国家空间科学中心
National Space Science Center . CAS

Progress on DSL and low-frequency experiments on Longjiang-2 Lunar satellite

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Introduction

What is DSL?

Discovering the Sky at Longest wavelengths

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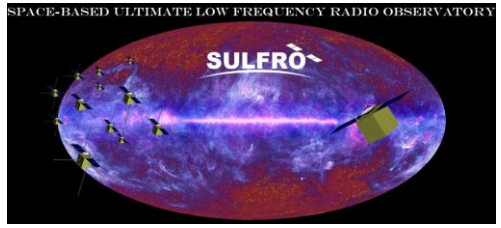

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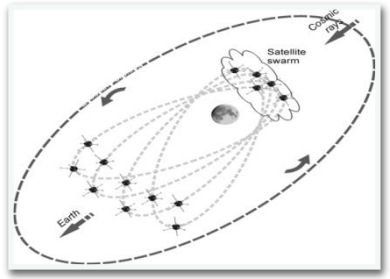
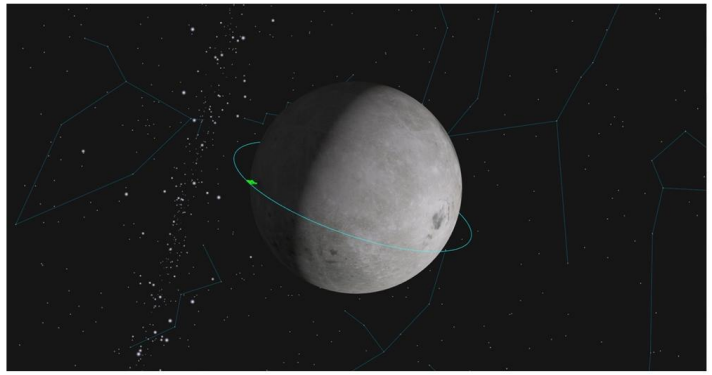


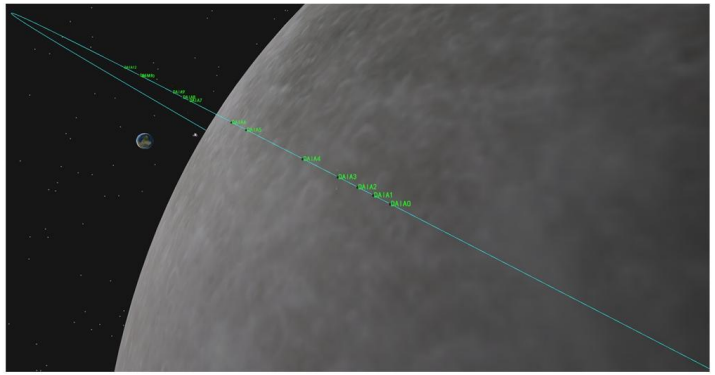
DSL history and contributors

- CAS-ESA joint space mission proposal: NSSC, SHAO, NAOC, PAS/PL, NL team, JIVE/EU, LESIA/FR
- DSL pathfinder LFIS: NSSC, HIT, NAOC
- DSL background study: NSSC, NAOC, IAMCAS, …

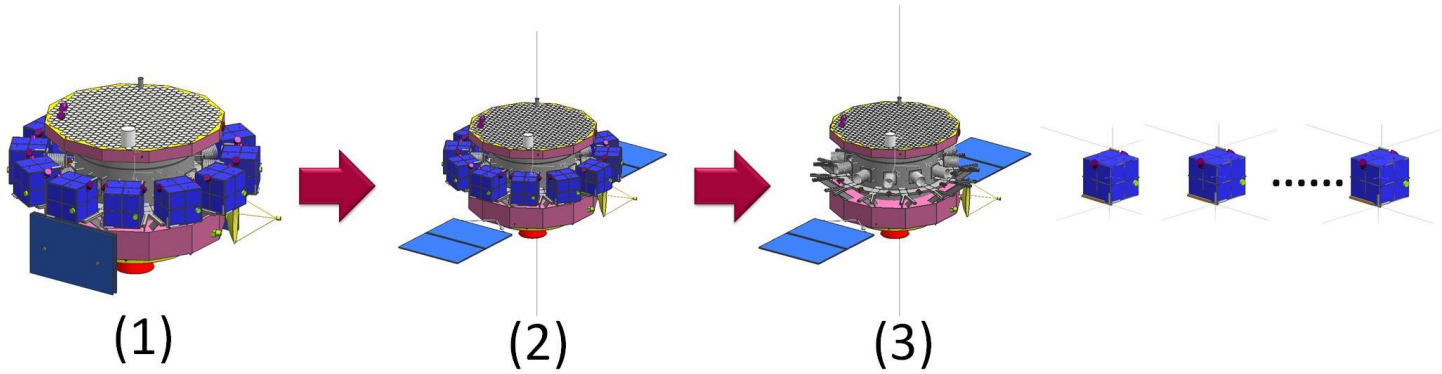
Jingye Yan; Ji Wu; Li Deng; Lin Wu; Li Zhou; Fei Zhao			**NSSC, CN**
Xuelei Chen; Maohai Huang; Yihua Yan; Yidong Xu;Fengquan Wu; Linjie Chen			NAOC, CN
Xiaoyu Hong; Tao An;			SHAO, CN
Jinpei Yu; Wen Chen; Xiaocheng Zhu			IAMCAS, CN
Xibin Chao; Xianren Kong; Limin Dong; Hui Li			HIT, CN
Albert-Jan Boonstra; Michael Garrett; Gert Kruithof, Michael Wise; Arnold van Ardenne			ASTRON, NL
Heino Falcke; Marc Klein-Wolt	Radboud University, NL	**Leonid Gurvits**	JIVE & TU Delft, EU/NL
Hanna Rothkael	SRC/PAS, PL	**Mark Bentum**	TU Eindhoven & ASTRON, NL
Eberhard K.A. Gill; Jian Guo	TU Delft, NL		
Leon Koopmans	University of Groningen, NL	**Philippe Zarka; Baptiste Cecconi**	LESIA, Observatory of Paris, FR

Initial Concept



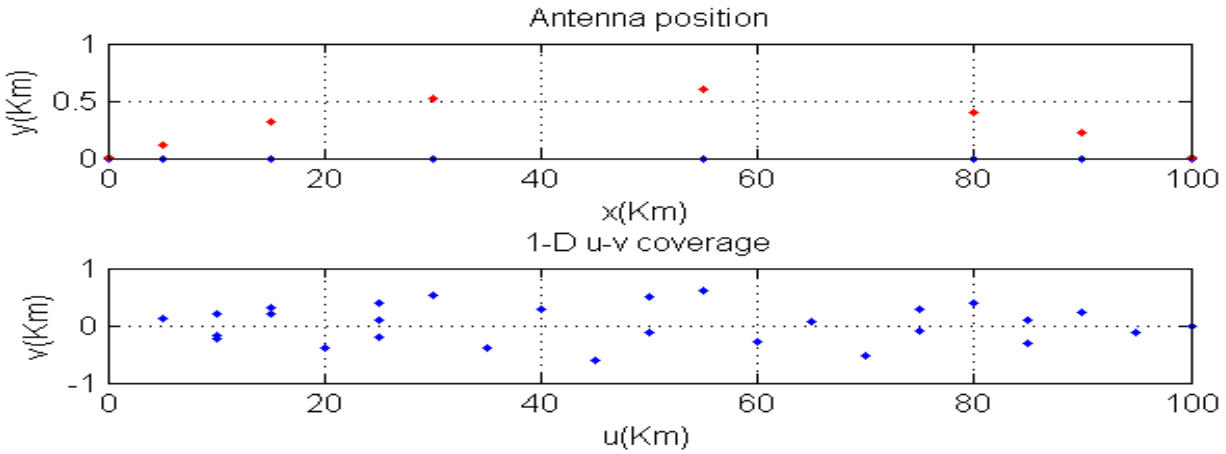


- 300km lunar orbit
- Linear formation flying.
- Active formation control
- Baselines coverage from 100km to 10m.

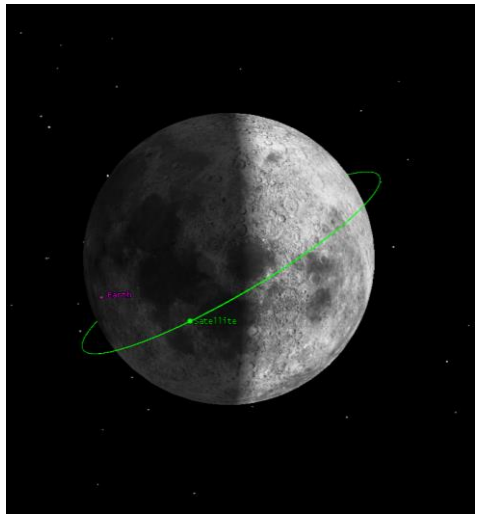


1. Satellites launch configuration.
2. Configuration in the transfer orbit from the Earth to the Moon.
3. Formation establishment.

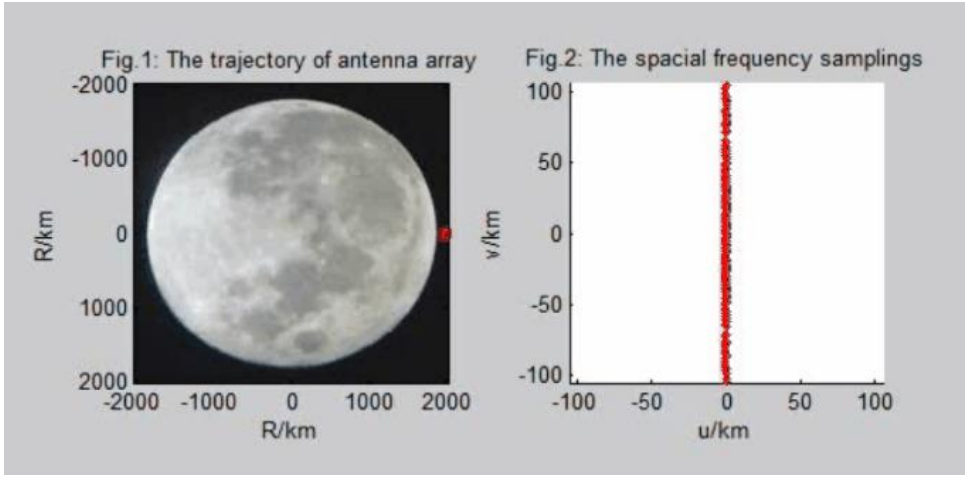
From snapshot up to precession cycle



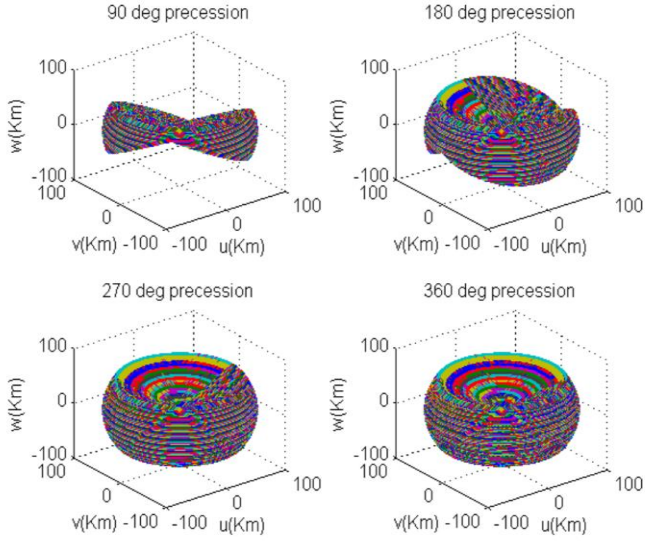
Quasi-linear coverage by snapshot



Using the precession of the orbital plane



Dish coverage of ½ orbit cycle (~75min)

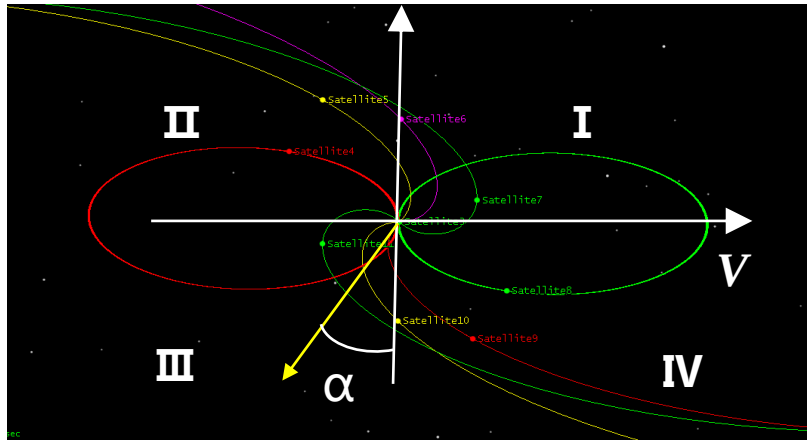


3D coverage up to 1.3yr

Super dense UVW coverage by linear “breath”

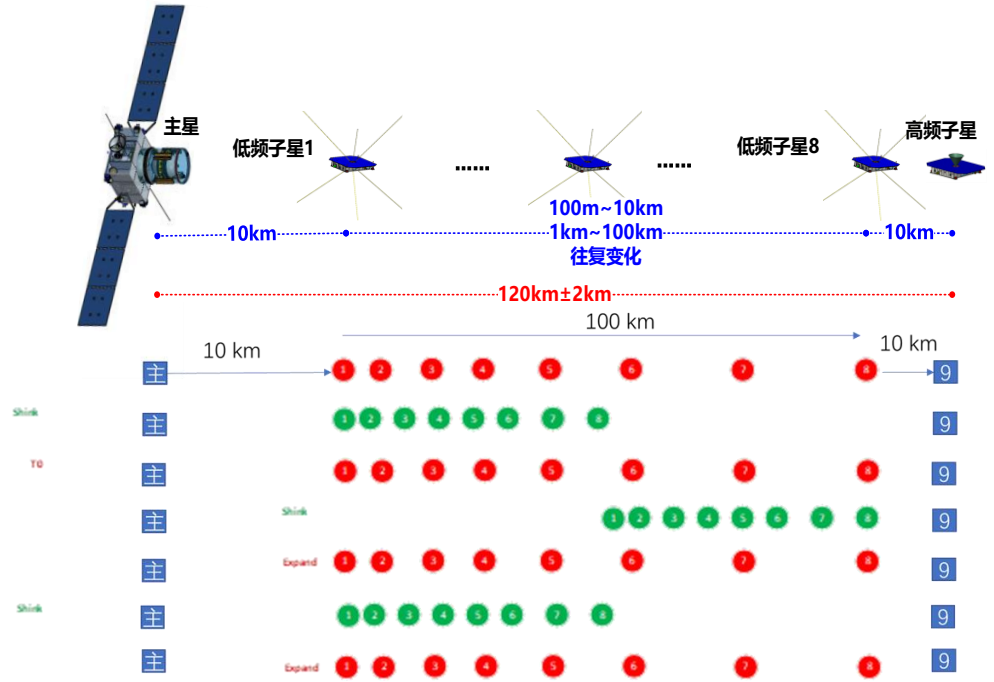
Deployment one after the other, slow drift

1) initial velocity：0.3m/s;
2) deployment interval：2 days。



Array control： “breath” for much better coverage

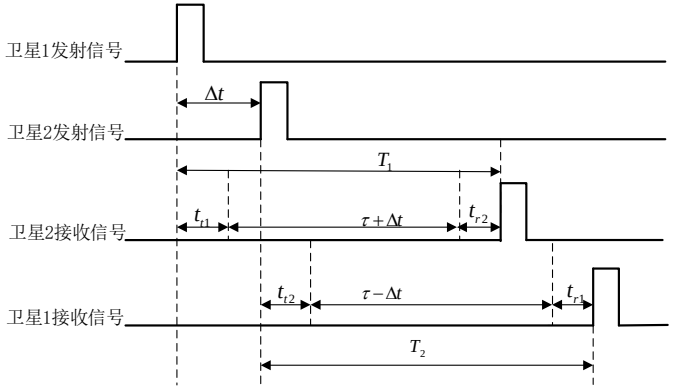
1) once every 7 days(14-days a cycle), $\Delta v \sim 1cm/s$
2) bidirectional compress, gas balance



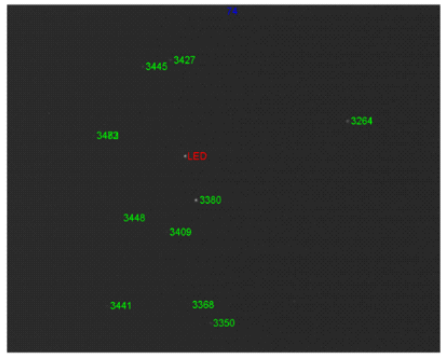
Key techniques

Baseline determination

- DOWR(dual-one-way ranging)

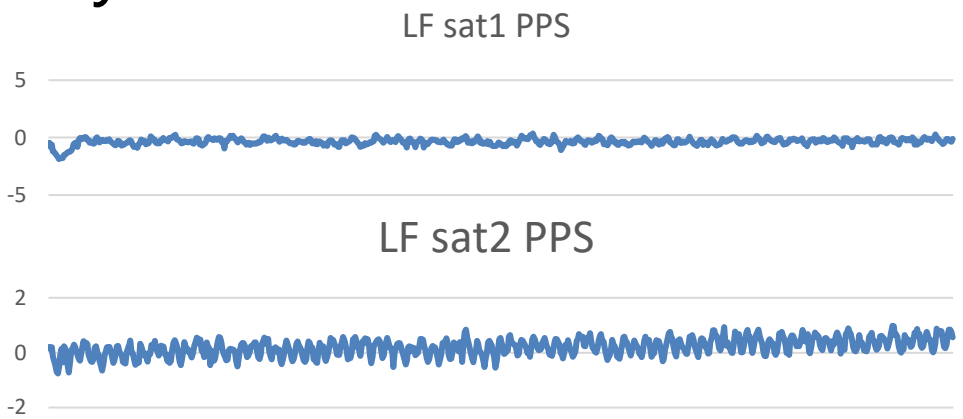


- Direction: angular distance by star tracker

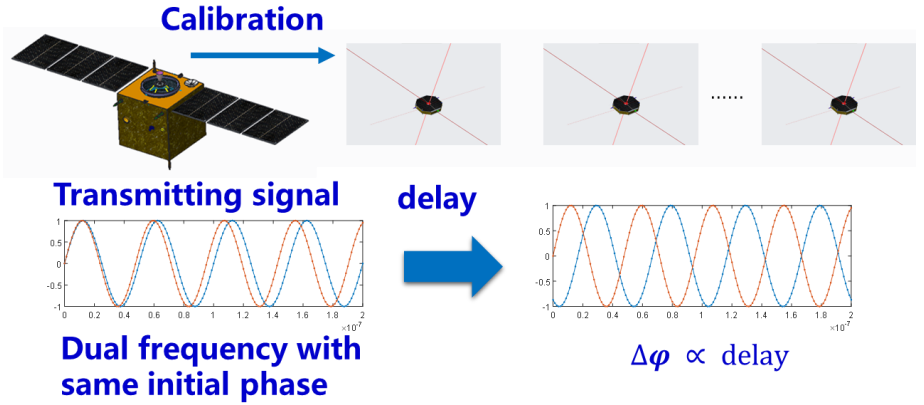


Visibility measurement

- Synchronization： PLL + DOWR

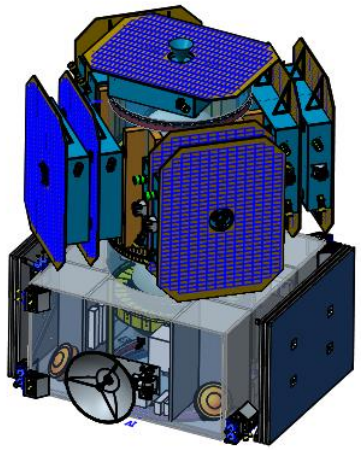


- Internal and external calibration

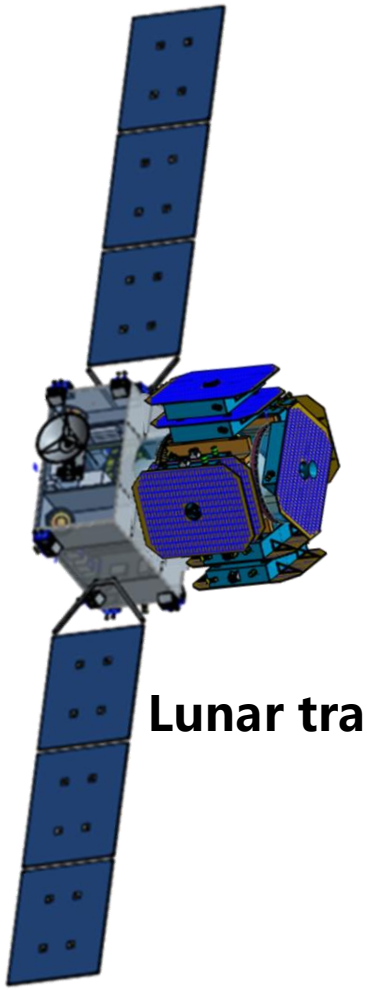


Recent progress

Newest configuration: improved reliability

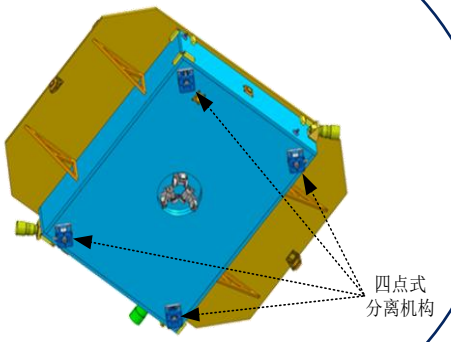


launch

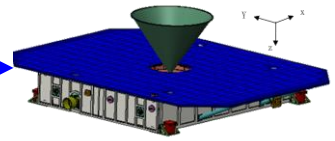


Lunar transfer

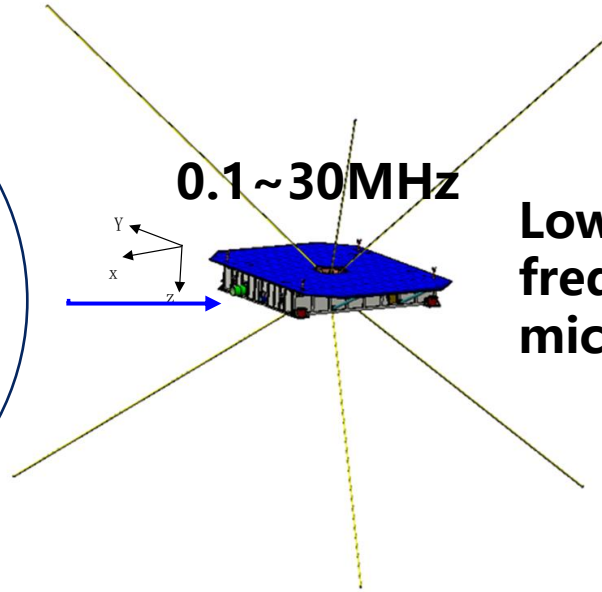
Deployment
At lunar orbit



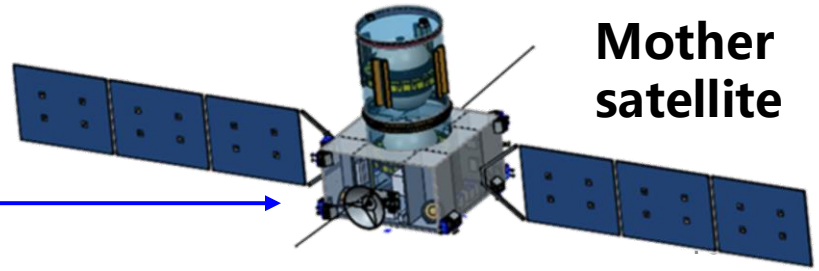
30~120MHz



High frequency microsat



Low-frequency microsat



Mother satellite

payload

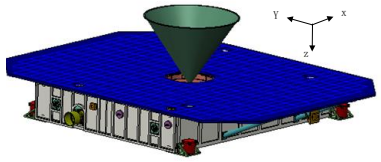
scientific objectives

1：high accuracy global spectrum

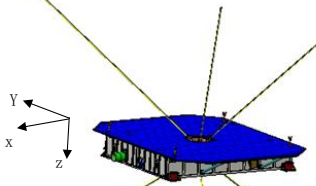
2：ULW all sky map, open up new window

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

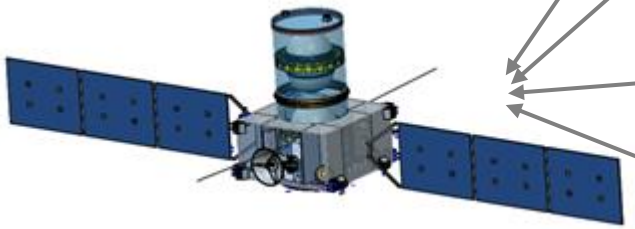
satellite



HF sat ×1



LF sat ×8



Mother satellite

payload

1 HF spectrometer

2 LF interferometer & spectrometer

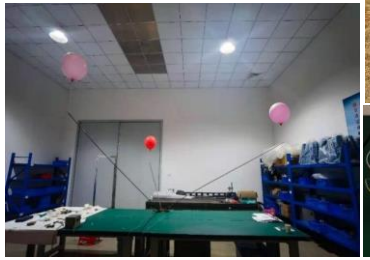
3 communication，ranging and synchronization

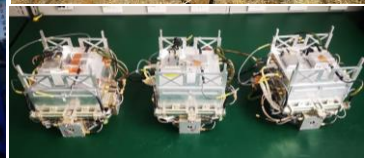
4 sky camera

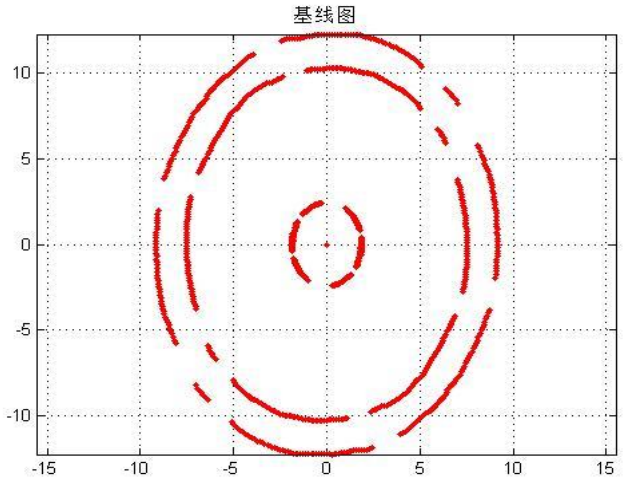
5 correlator

6 Calibrator

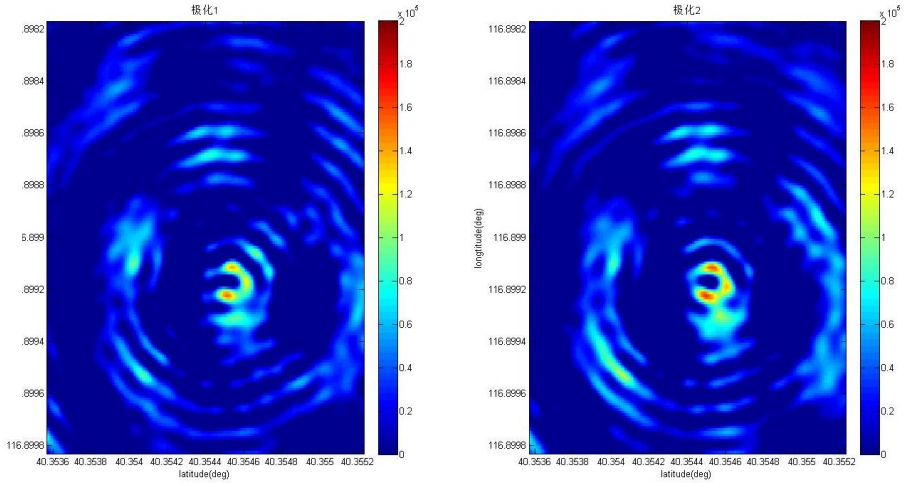
Formation flying with drones



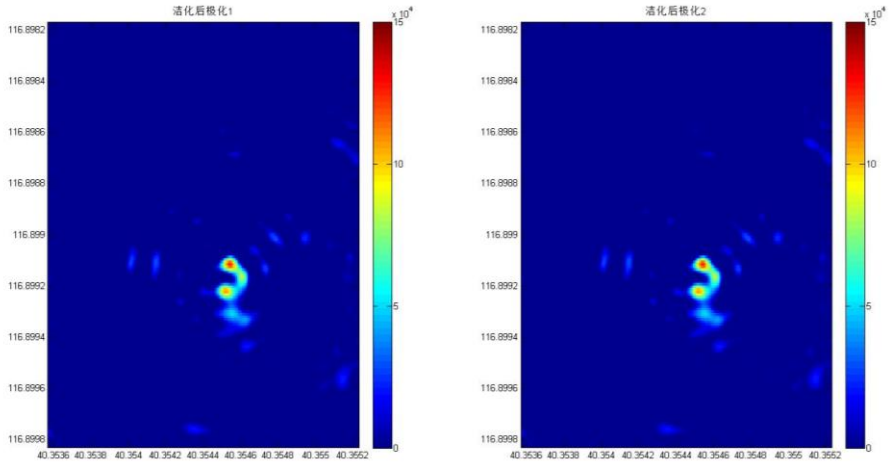




Retrieved image



After CLEAN

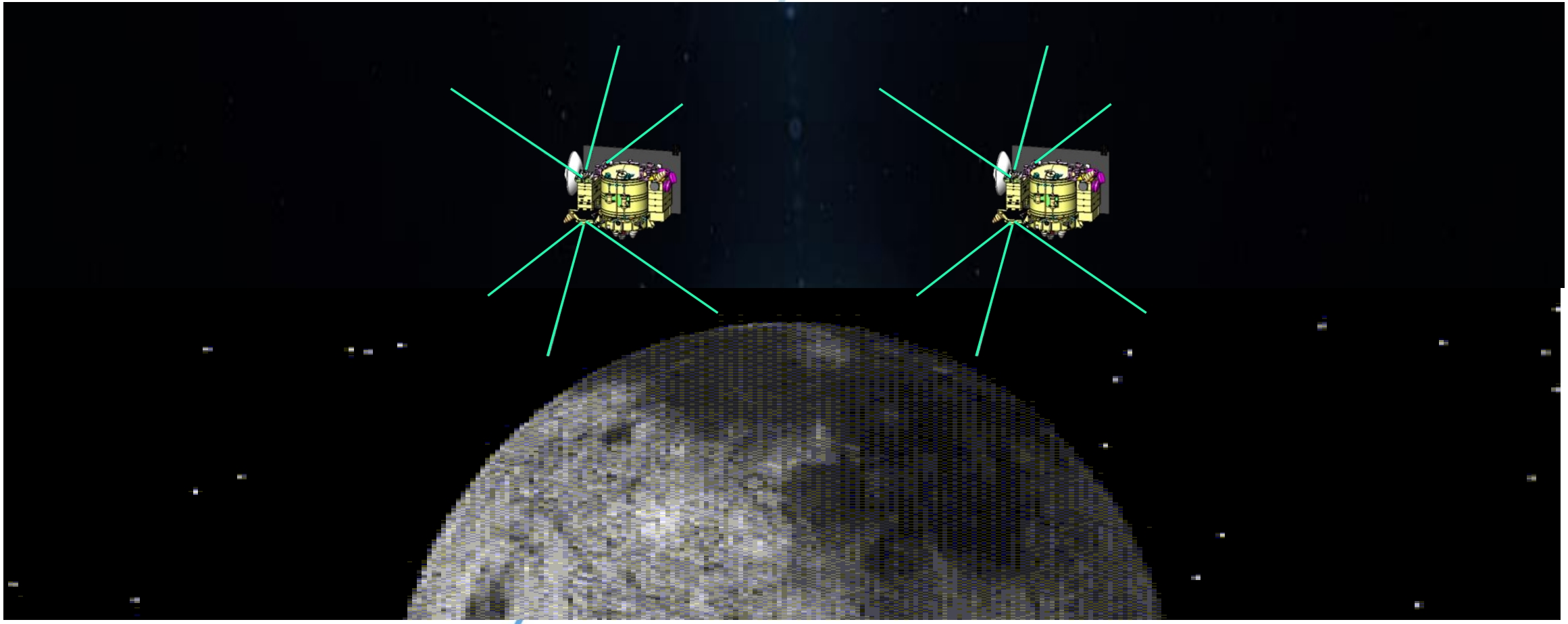


Major parameters (verified by lab/field/air/space test)

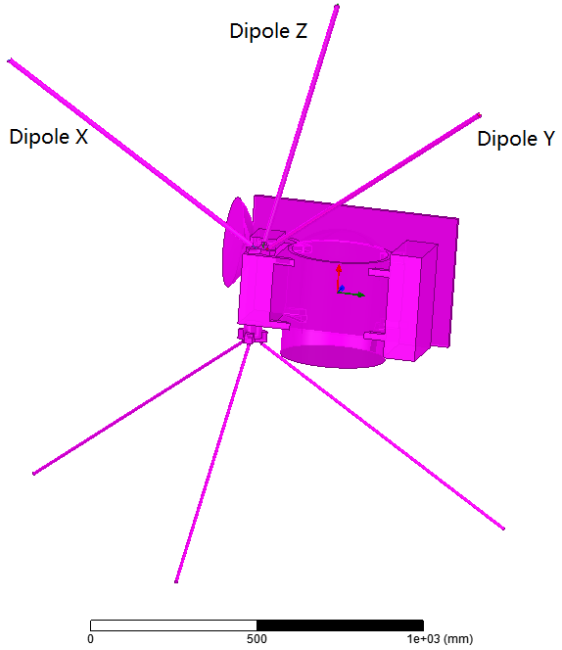
- Interferometric imaging with formation flying (first ever?)
- Range accuracy: <0.8m (1/12.5 λ @30MHz)
- Direction determination: $<25\ \mathrm{urad}\ (5'')$ (independent on satellite attitude)
- Synchronization: <1.5ns
- Single receiver sensitivity: $< 2.93nV/\sqrt{Hz}$
- Amplitude similarity: <0.02dB
- Phase similarity: <0.1°

Longjiang-2 and LFIS

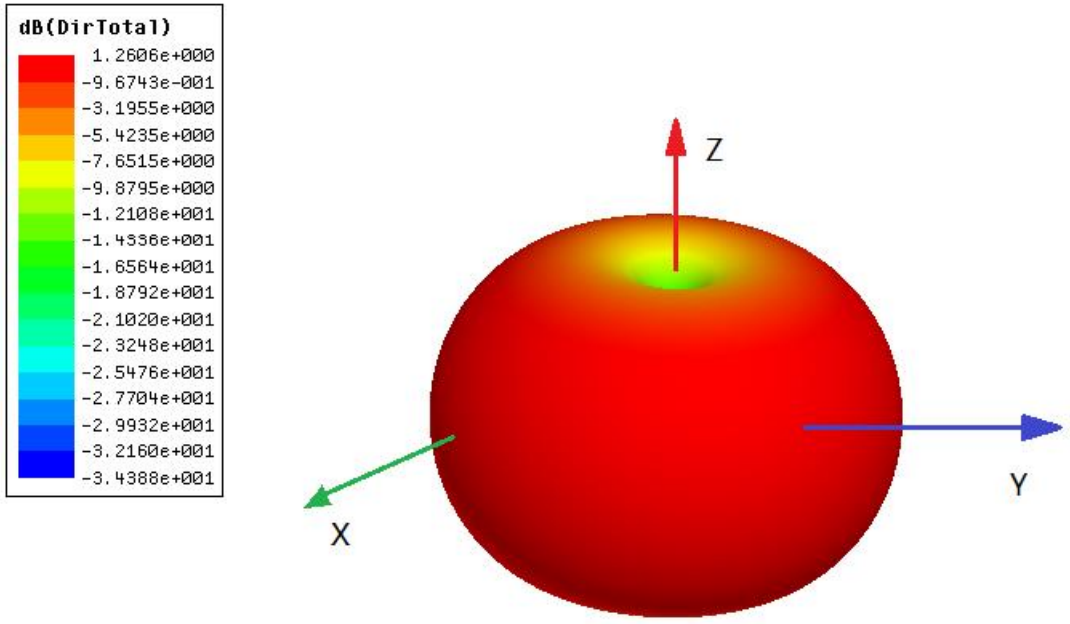
Longjiang satellite: DSL pathfinder



Antenna

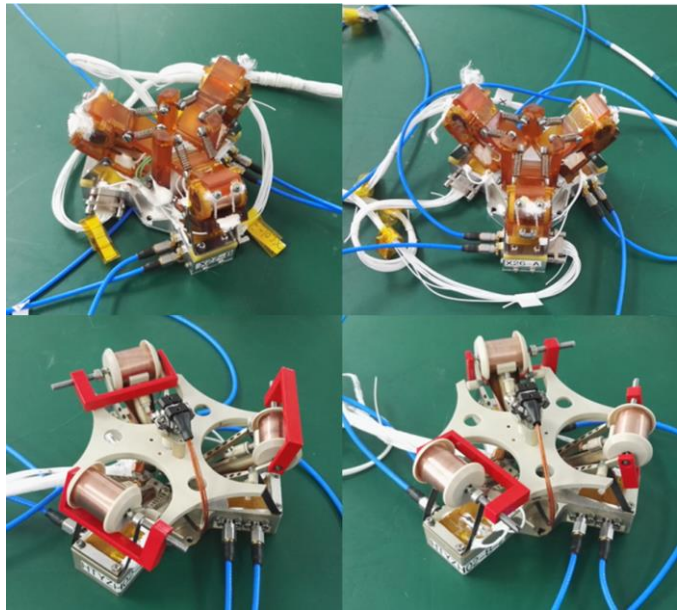


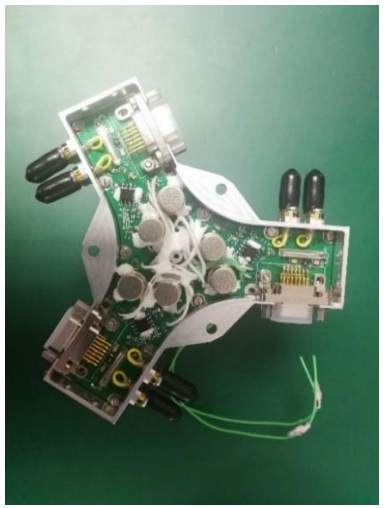
Satellite model

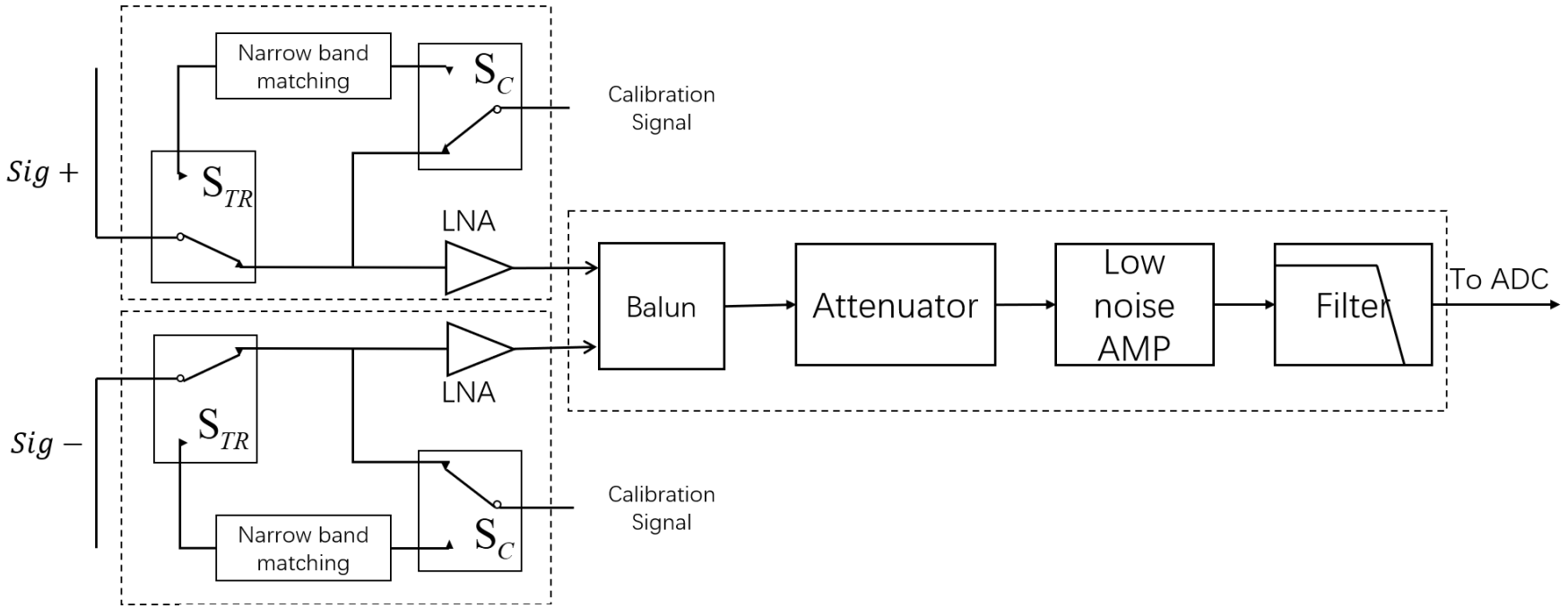


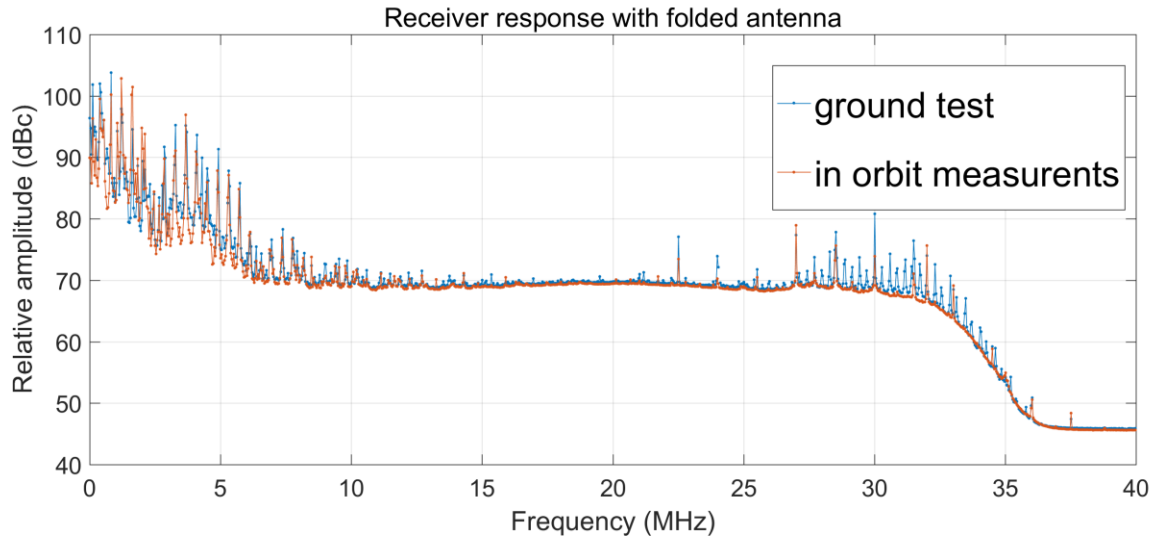
Simulated pattern

Receiver

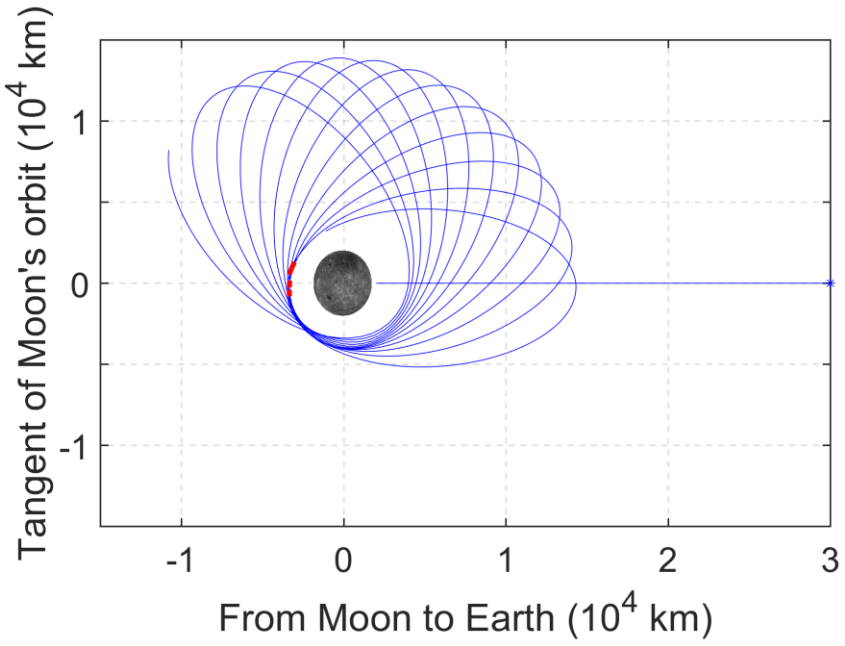




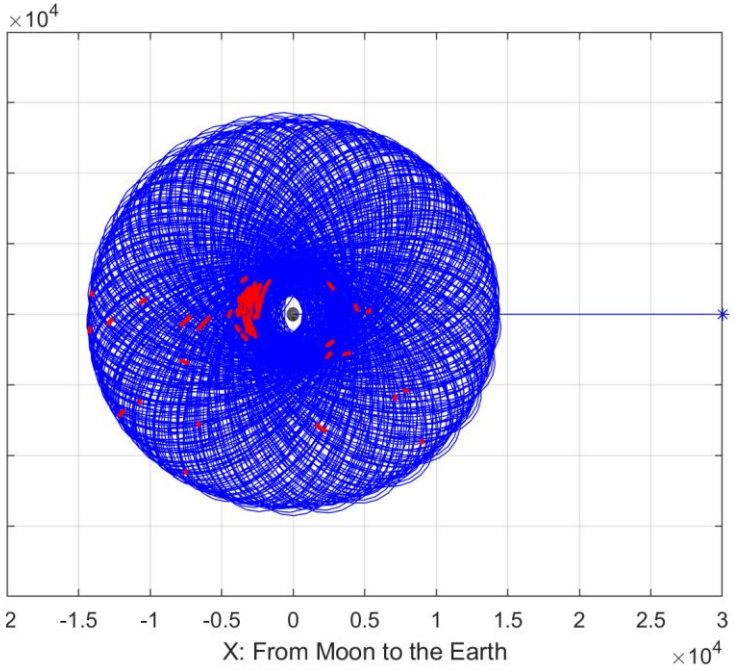

Narrow band matching
S_C
Calibration Signal
$Sig+$
S_{TR}
LNA
Balun
Attenuator
Low noise AMP
Filter
To ADC
LNA
$Sig-$
S_{TR}
Calibration Signal
Narrow band matching
S_C


Receiver response with folded antenna
Relative amplitude (dBc)
Frequency (MHz)
ground test
in orbit measurents
110
100
90
80
70
60
50
40
0
5
10
15
20
25
30
35
40

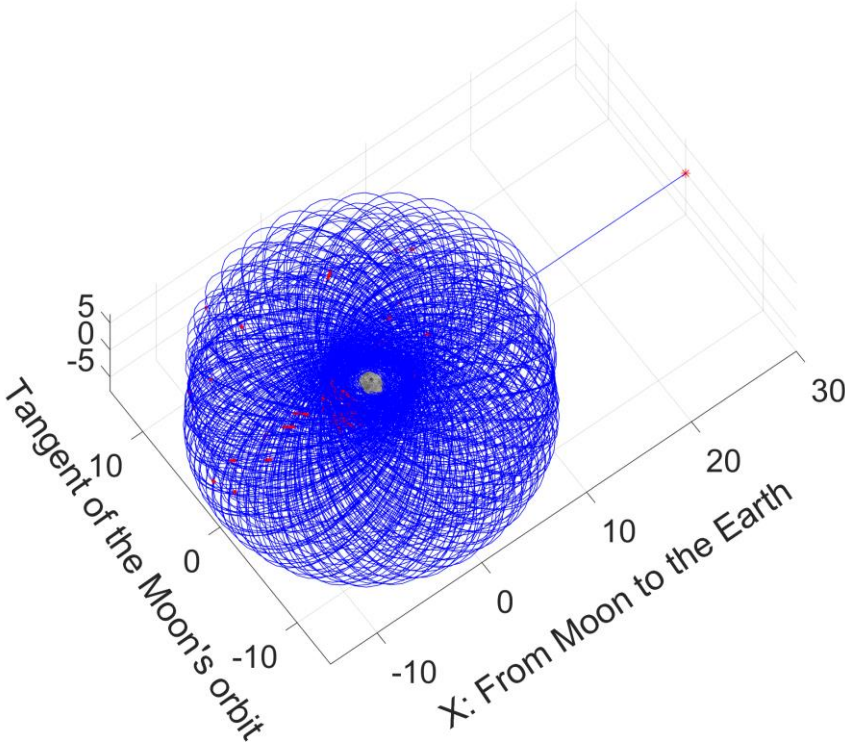
Large elliptical orbit 357×13, 704 km



10 cycles

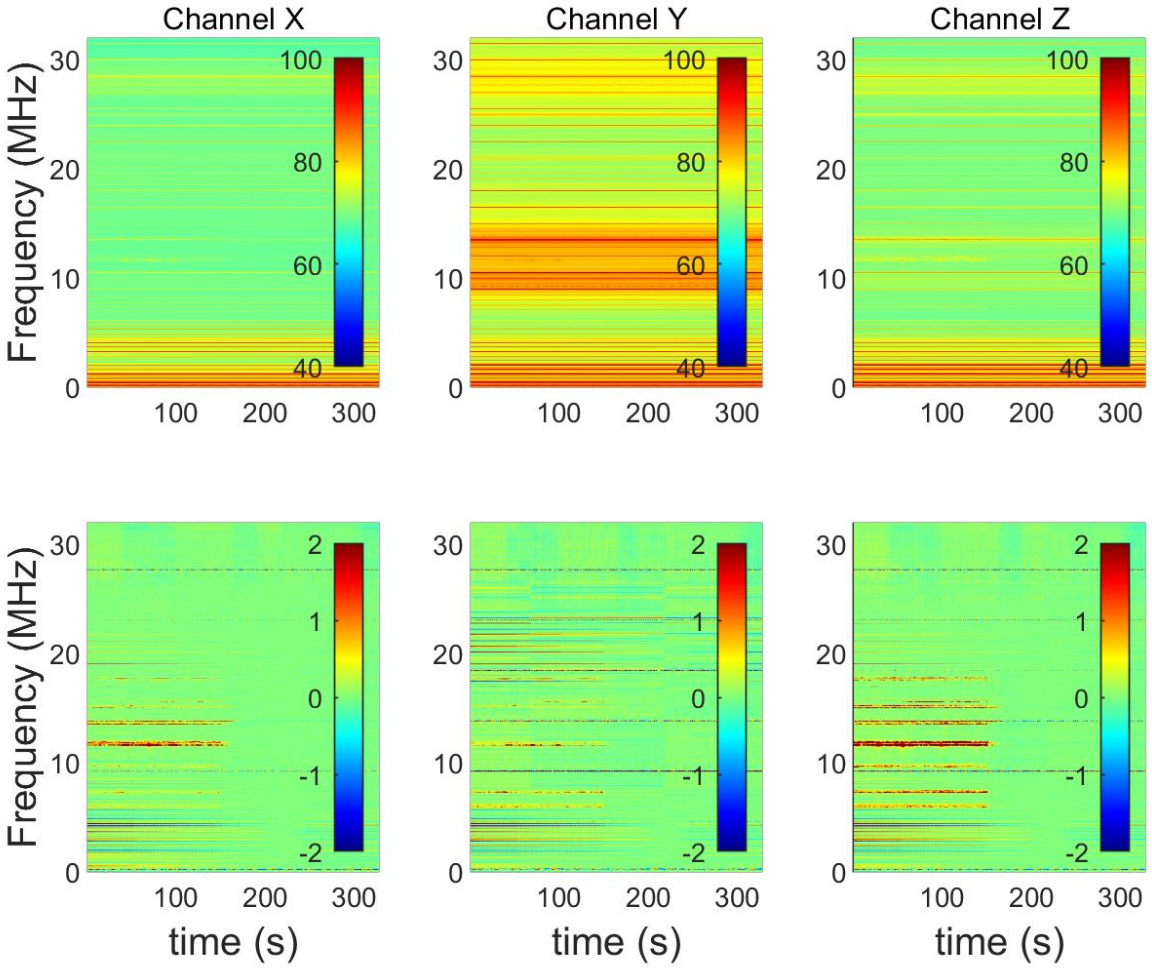


Top view from celestial north pole

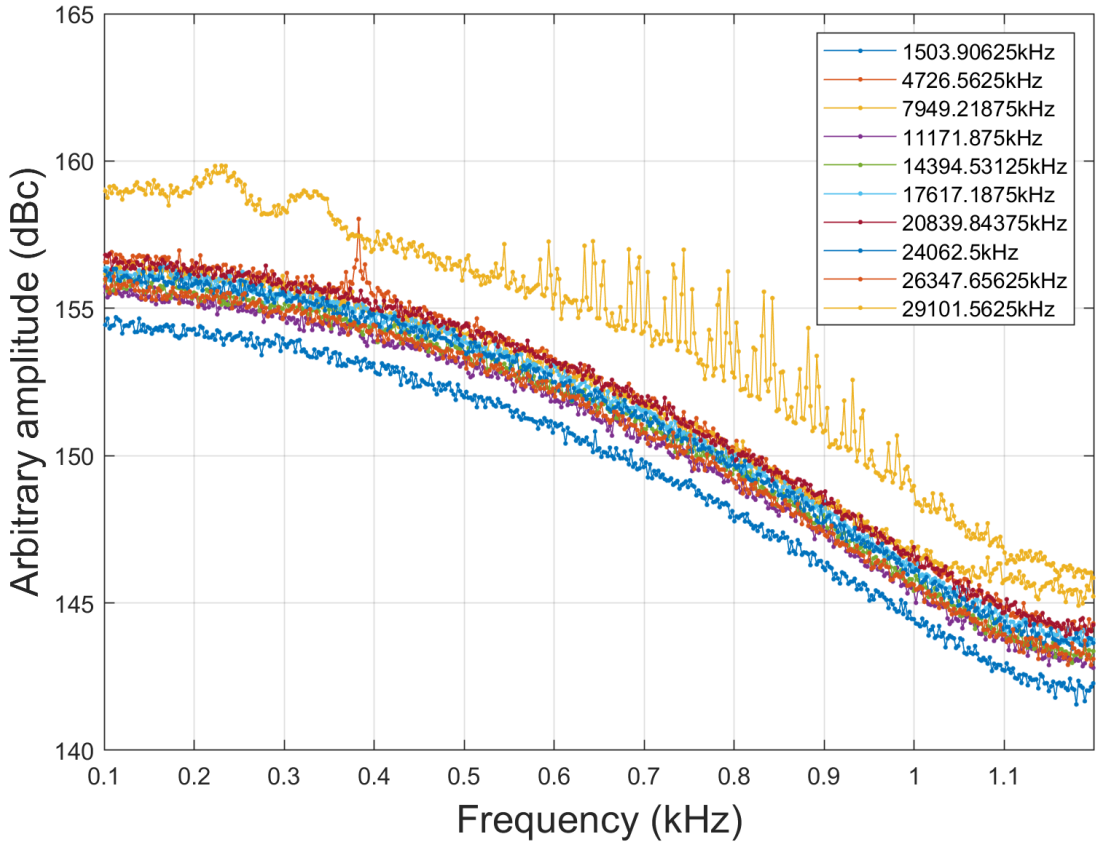


3D view

Typical observation



Default spectrum (19kHz resolution)



Ultra fine spectrum of narrow band signal

Conclusion from Longjiang-2

- It is advisable to have ability to downlink digitized raw signal for in-depth high resolution spectrum analysis for EMI analysis.
- The terrestrial RFI is a few dB higher than the system temperature, and sharp cutting after the shielding transition, ULW behind the Moon is working.
- A simple subtraction algorithm allowed us to mitigate the satellite-originated RFI to an acceptable level, lunar orbiter has advantages.

Summary

Summary

1、Moon blockage, orbital movement, orbital plane precession, all together helps the DSL to improve the uvw coverage;

2、Linear array makes all techniques feasible;

3、Longjiang-2 verified many techniques in lunar orbit;

DSL is READY to shift into engineering phase!

Welcome cooperation on all aspects.

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