Interference Mitigation for LFRS onboard Chang'e-4

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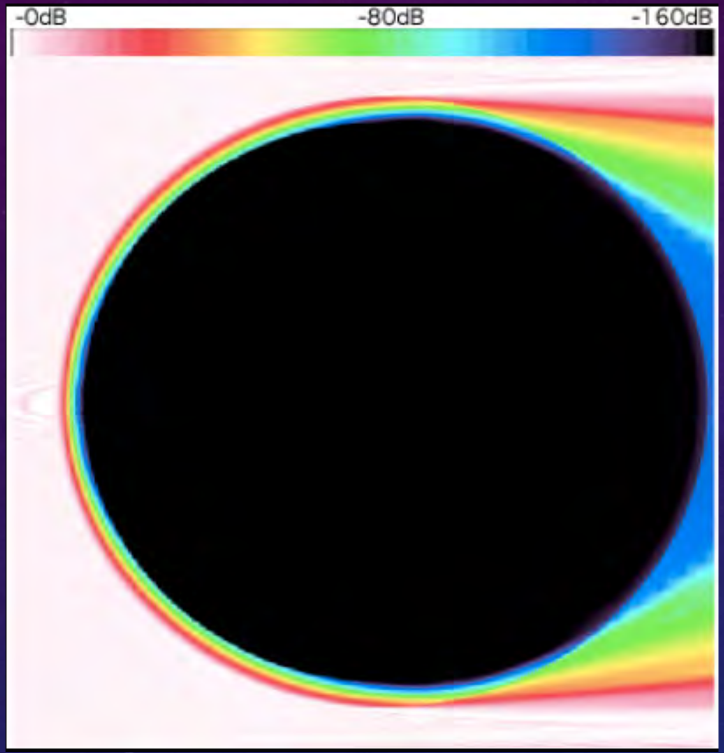
OUTLINE

- Low-frequency Radio Spectrometer (LFRS) onboard Change-4
- The Properties of LFRS's Interference
- Interference Mitigation Based on CLEAN
  - Basic Ideas
  - The CLEAN Algorithm
- Preliminary Results of LFRS
- Future Plans

Low-frequency Radio Spectrometer (LFRS) Onboard Chang'e-4



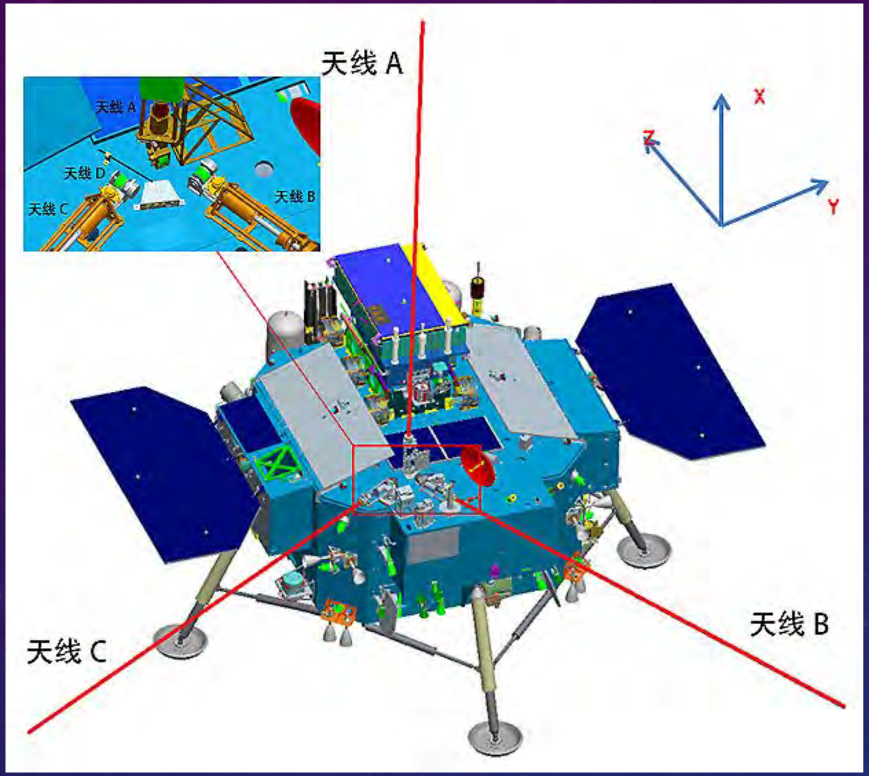
Far side of the moon

Lunar-based low-frequency radio projects in history

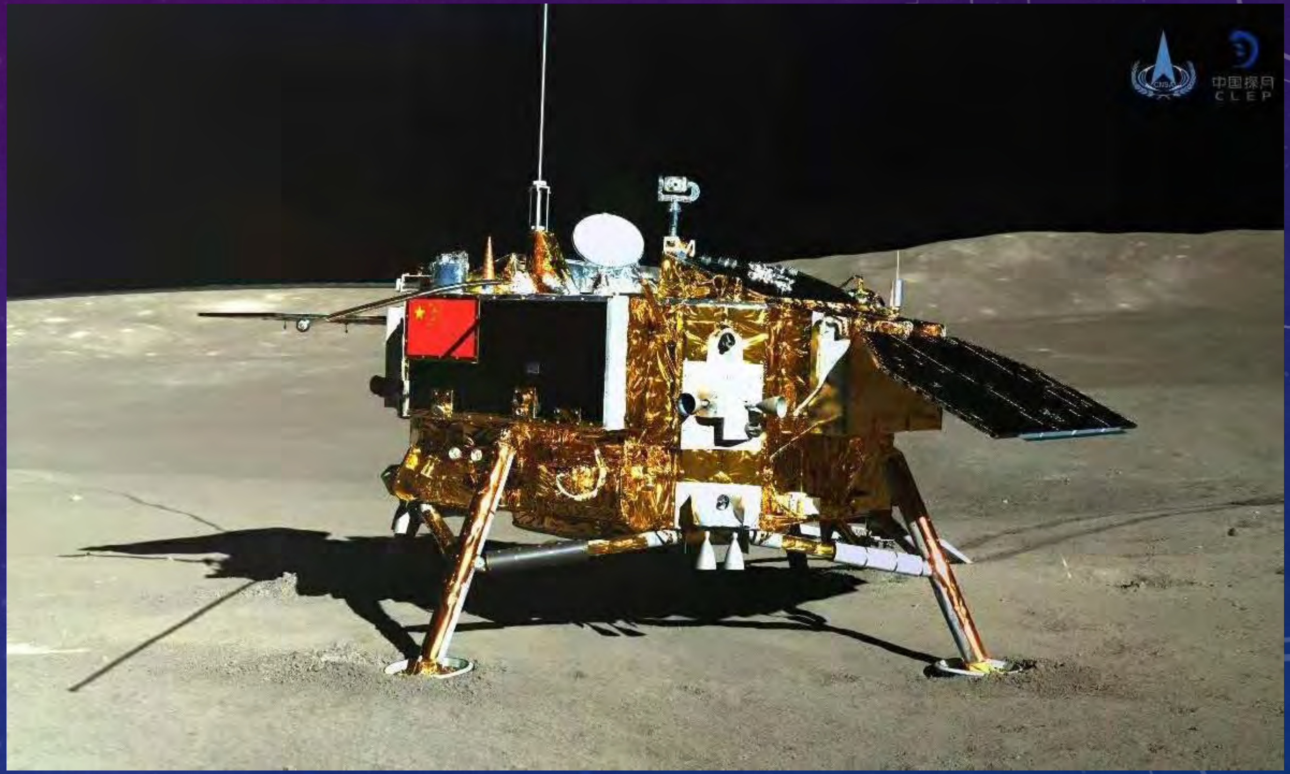
- In 1964, Gorgolewski proposed to build **a synthetic aperture array** on the moon and its orbit.
- In 1985, Burns proposed **long-baseline lunar-earth interferometry**.
- In 1990, Douglas and Smith proposed to establish **a 15*15Km square array**.
- Lunar Radio eXpriment (LRX) led by ESA.
- The Dark Age Lunar Interferometer (**DALI**) funded by NASA.
- Lunar Array for Radio Cosmology (**LARC**).
- ESA, Farside Explorer Project, Lunar Back in 2025, L2 relay star, **low-frequency radio interferometer**, solar system, outer space outside the solar system.
- NASA's FARSIDE plan to place a low-frequency interference array on the back of the moon.

Chang'e-4 was the first space probe landed on the far-side of the moon!

Low-frequency Radio Spectrometer (LFRS) Onboard Chang'e-4



Location of Antennas



Actual Photo

- Designed and made by Aerospace Information Research Institute
- Antennas A, B, C (5m)
- Antenna D (20cm)

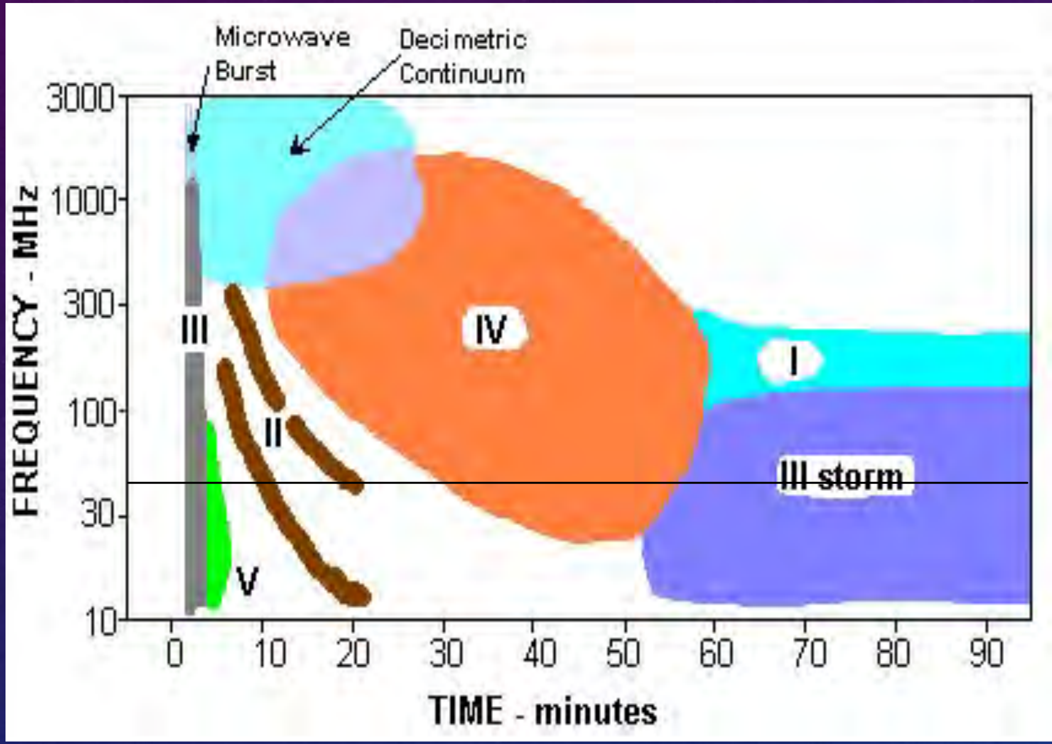
LFRS

Low frequency ： 0.1-2MHz

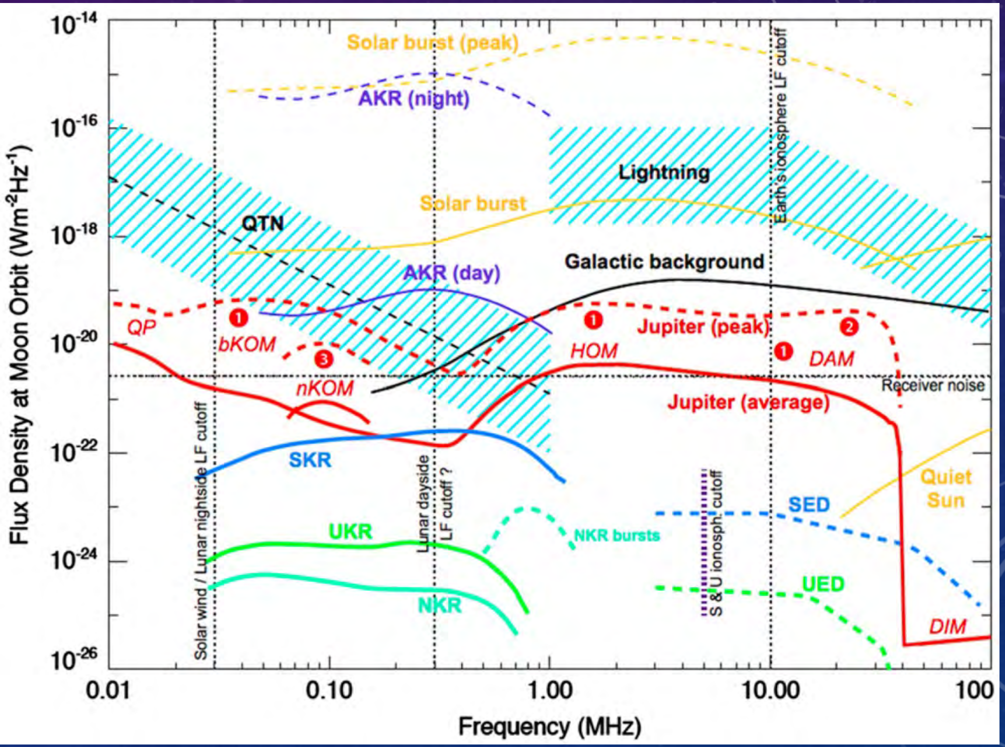
High frequency ： 1-40MHz

Low-frequency Radio Spectrometer (LFRS) Onboard Chang'e-4

Scientific Goals



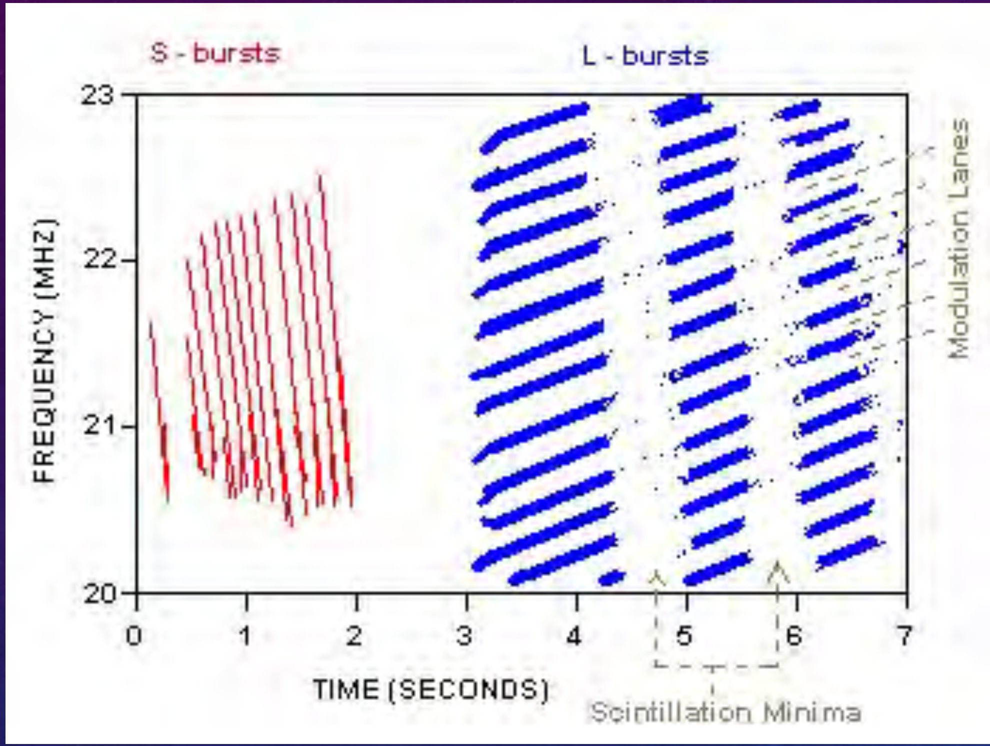
Solar Radio Bursts



Solar Burst Intensity
Peak intensity： $10^{-15}\mathrm{Wm}^{-2}\mathrm{Hz}^{-1}$

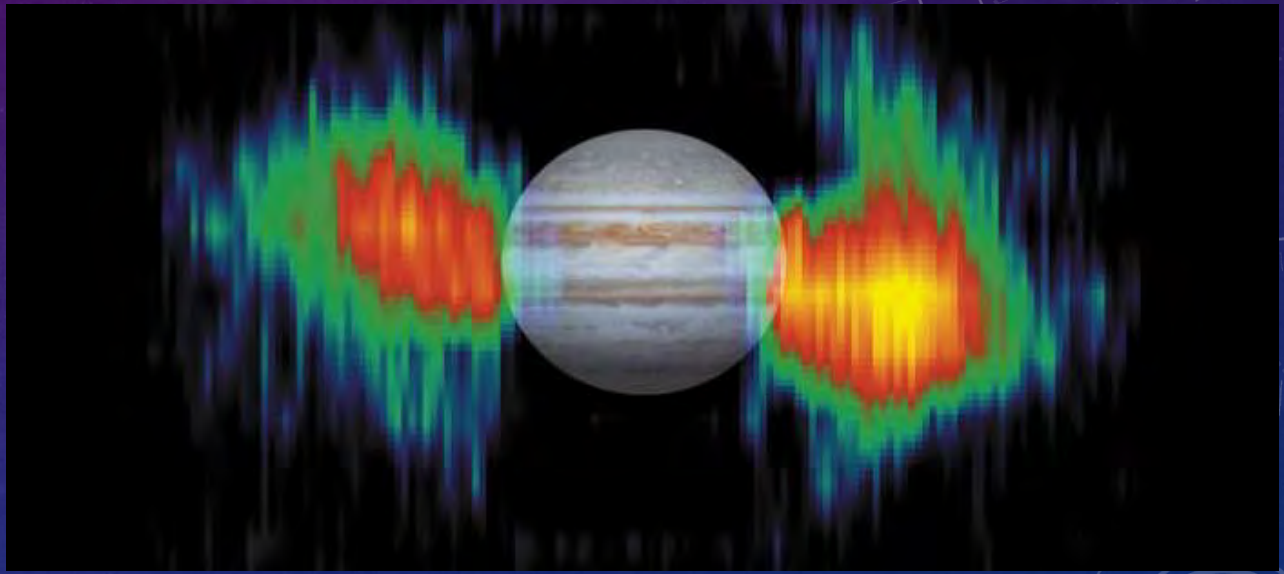
Low-frequency Radio Spectrometer (LFRS) Onboard Chang'e-4

Scientific Goals



Jupiter's radio burst

- 1955, 22.2MHz
- L burst 、 S burst
- Cyclotron radiation

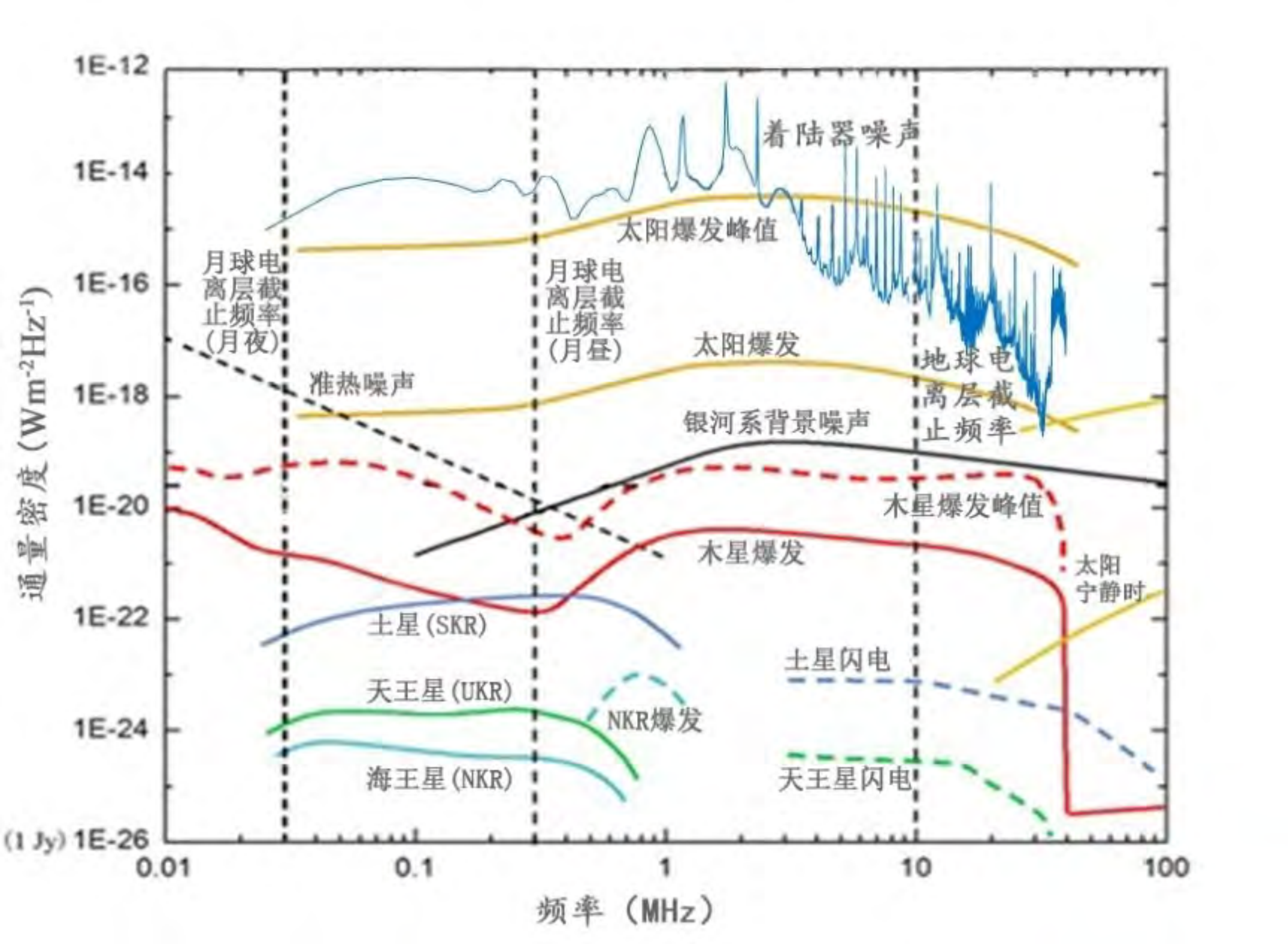


Jupiter: radiation belts

- Bernard Burke and Kenneth Franklin found
- $S = 1.21 \times 10^{-20}\, W/(m^2 \cdot Hz)$

Burke, B. F. and K. L. Franklin, *Observations of a variable radio source associated with the planet Jupiter.*

The Properties Of LFRS's Interference



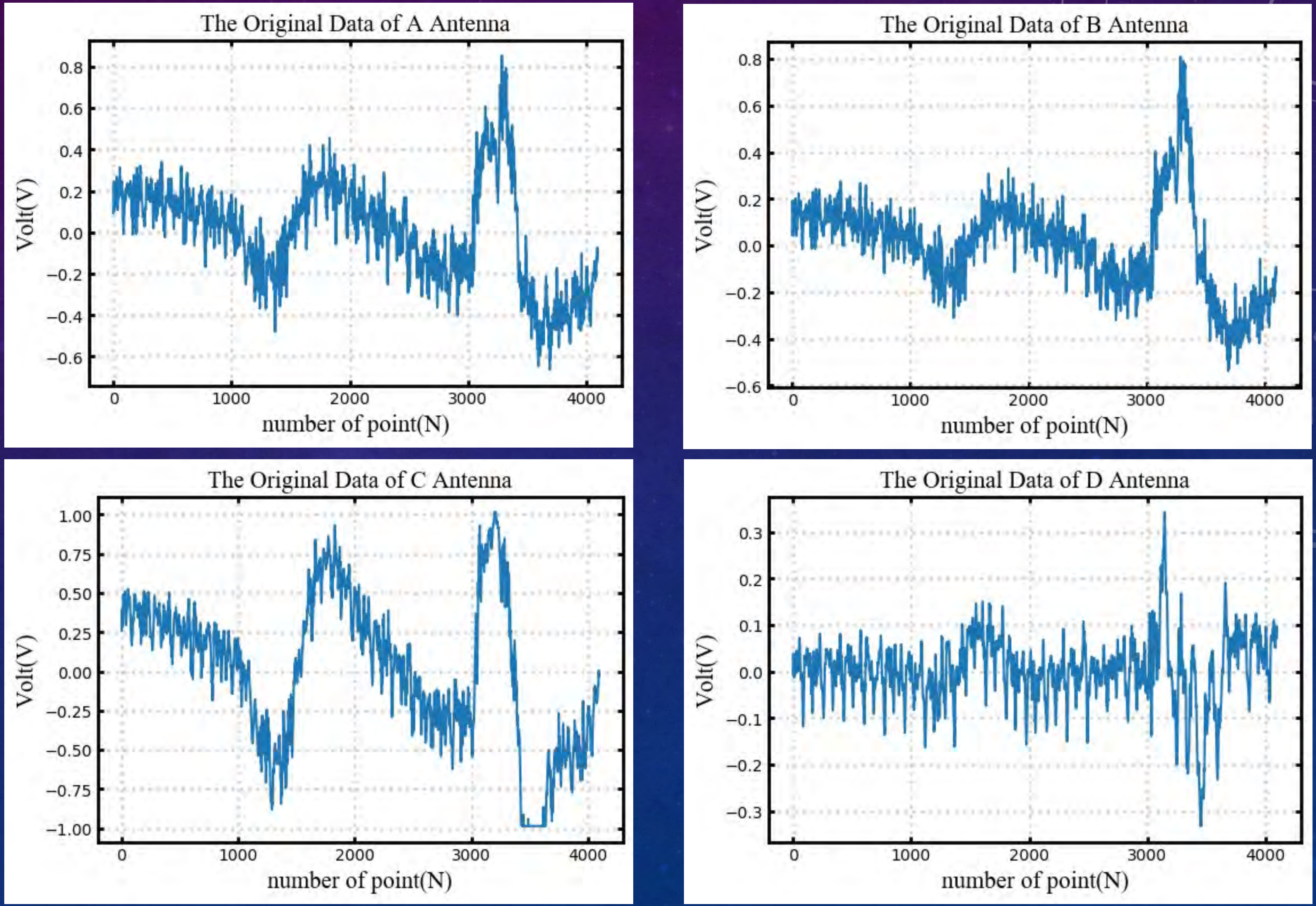
The Properties Of LFRS's Interference

The 4th trace on the 23rd moon day

Each trace has :

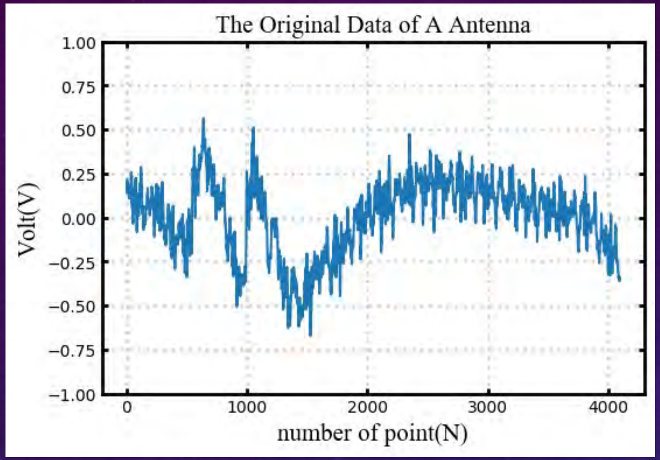
- **4096 points**,
- sampling rate **100MHz**,
- total length **40.96us**.

The interval between two adjacent traces is about **1.0 second**.

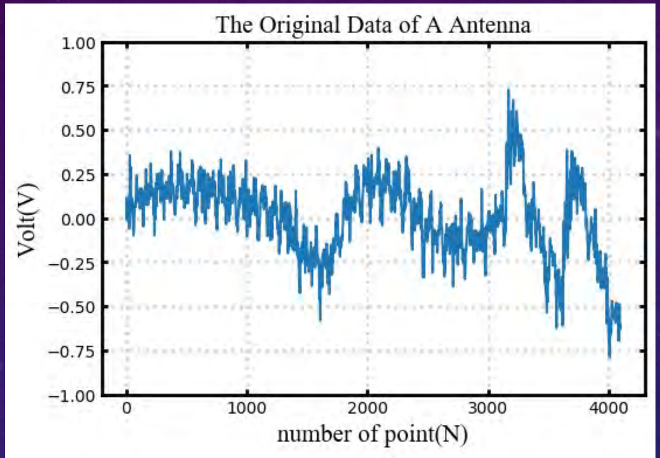


The Properties Of LFRS's Interference

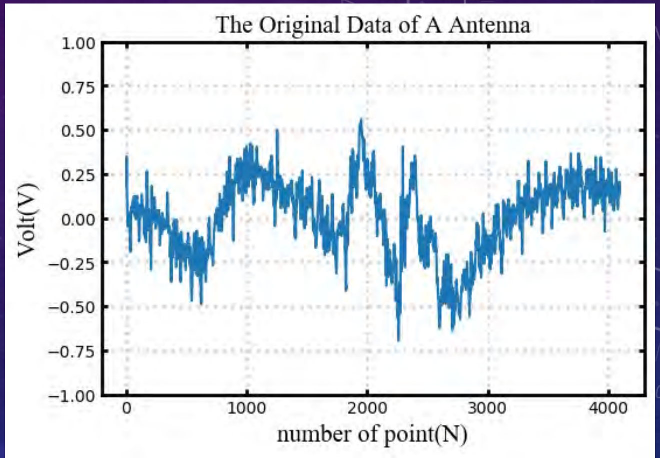
The signals of A antenna on different moon days



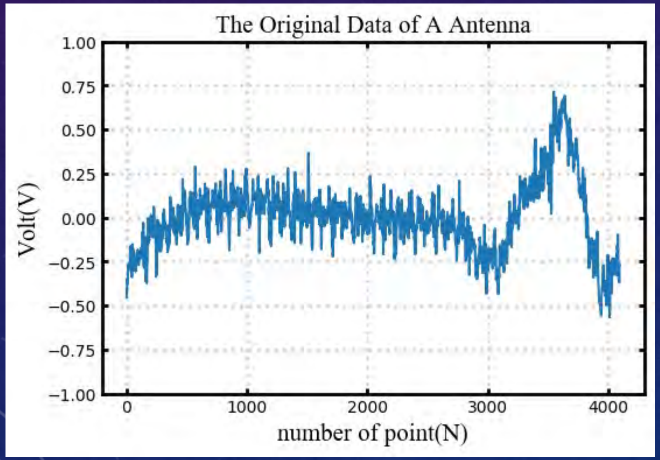
2nd trace, 3rd moon day



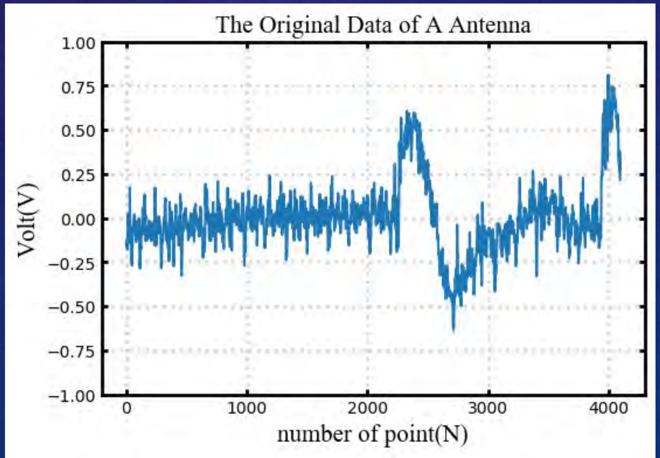
2nd trace, 5th moon day



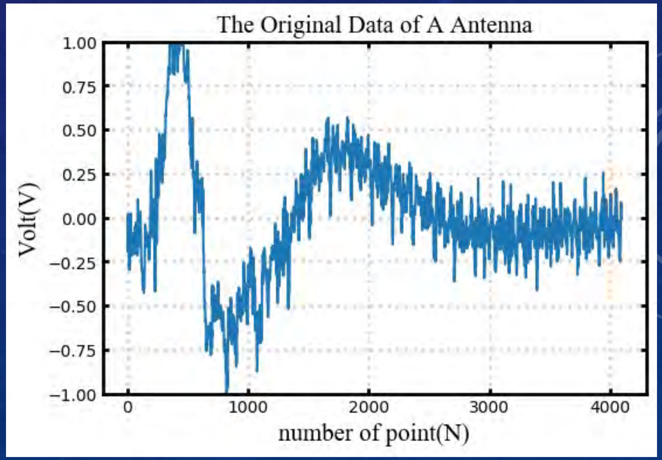
2nd trace, 10th moon day



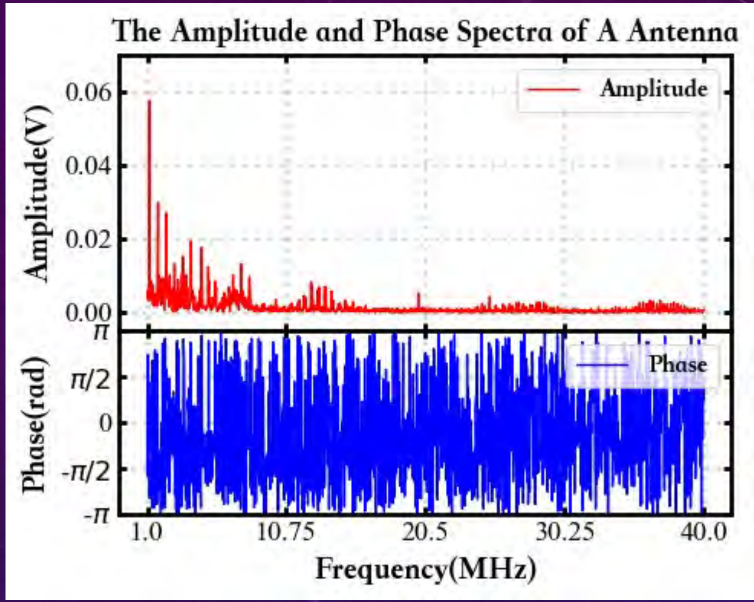
2nd trace, 15th moon day

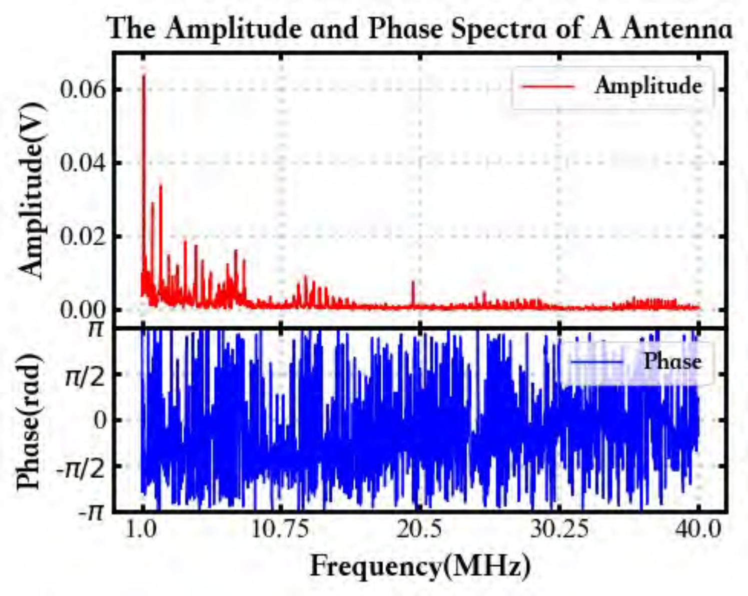


2nd trace, 20th moon day



2nd trace, 24th moon day


The Amplitude and Phase Spectra of A Antenna
Amplitude
Phase
Amplitude(V)
Phase(rad)
0.06
0.04
0.02
0.00
π
π/2
0
-π/2
-π
1.0
10.75
20.5
30.25
40.0
Frequency(MHz)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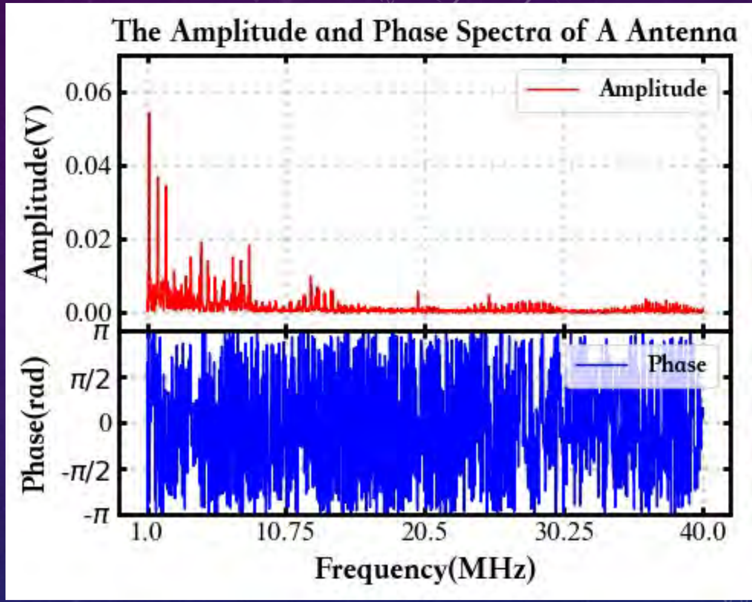
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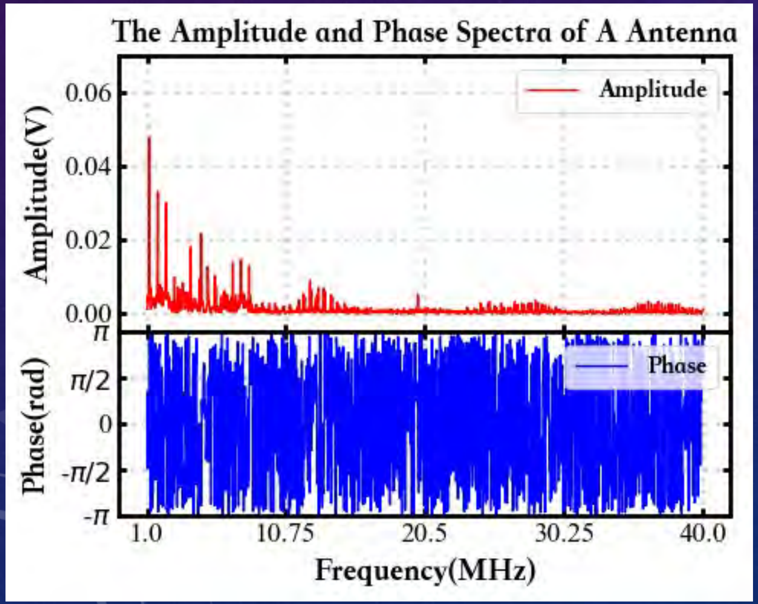
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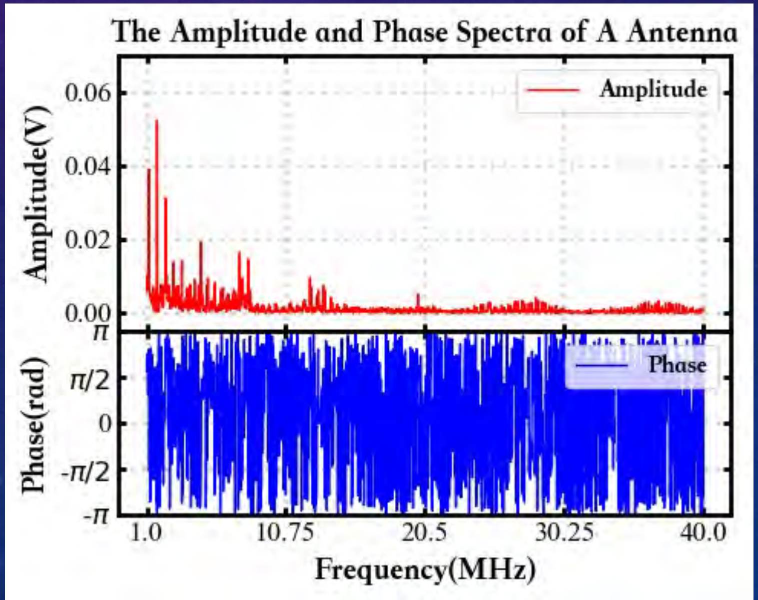
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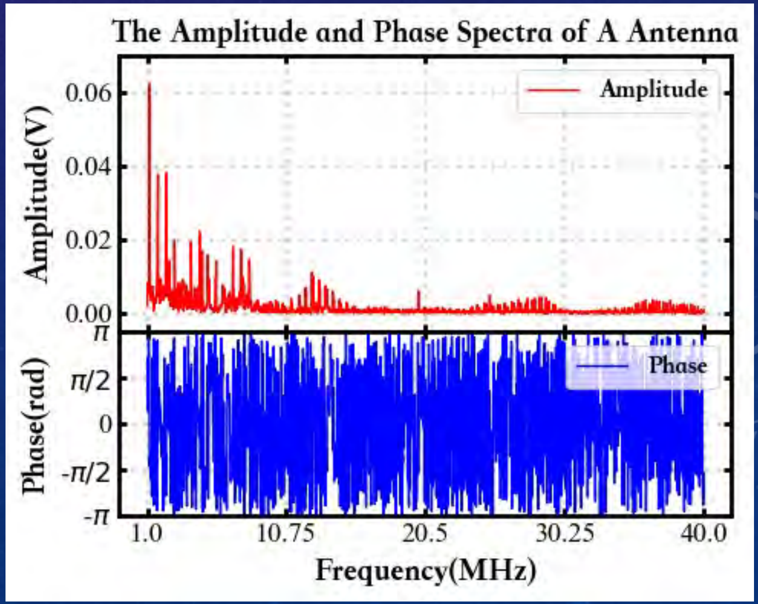
Frequency(MHz)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40.0
Frequency(MHz)

Interference Mitigation Based On CLEAN

Basic ideas

The composition of the raw signals： Platform interference $I(t)$; Astronomical signal $C(t)$; Receiver noise $N(t)$; Projection coefficients α_A, α_B, α_C, β_A, β_B, and β_C.

$$S_A(t) = \alpha_A(t)I(t) + \beta_A(t)C(t) + N_A(t)$$

$$S_B(t) = \alpha_B(t)I(t) + \beta_B(t)C(t) + N_B(t)$$

$$S_C(t) = \alpha_C(t)I(t) + \beta_C(t)C(t) + N_C(t)$$

1. Platform interference： **Coherent** (High correlation), Relatively strong.
2. Astronomical signal： **Coherent** (High correlation); Relatively weak.
3. Receiver's noise： **Incoherent** (No correlation).

Decompose raw signals into coherent **CLEAN Model Signals** and partially coherent **Residual Signals**!

Interference Mitigation Based On CLEAN

Basic ideas

Demonstration of CLEAN by Simulated Data

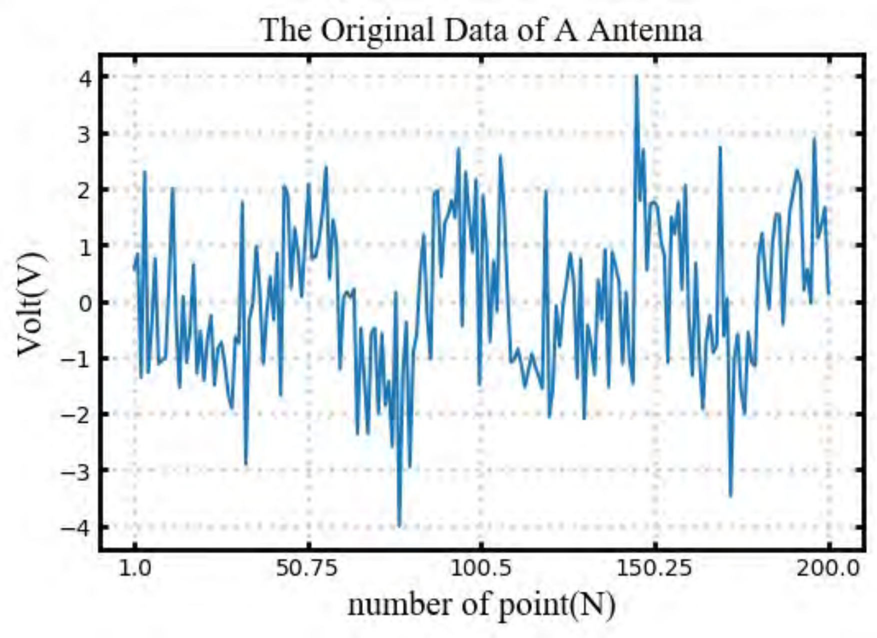
$f_1 = 4.137$ Hz

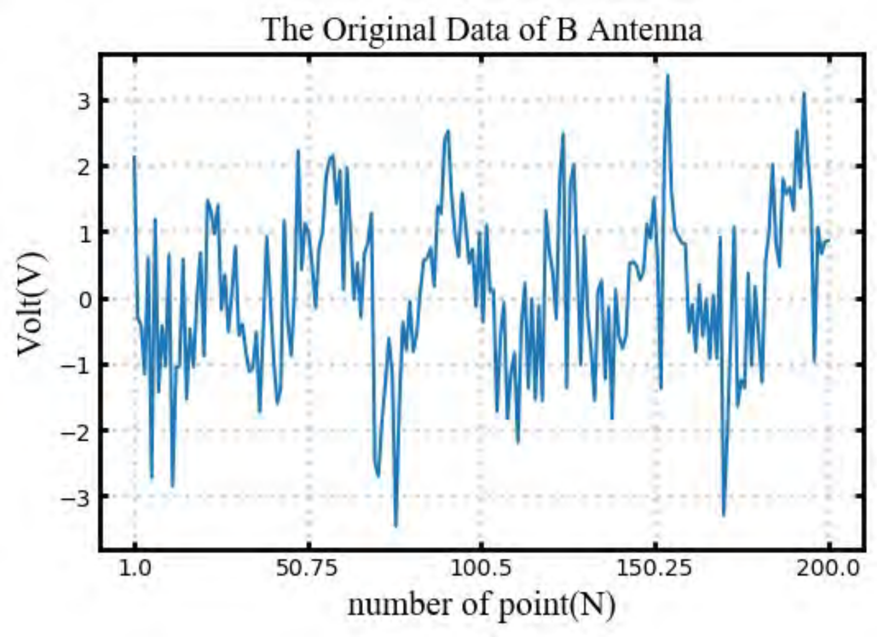
$f_2 = 6.124$ Hz

$$A(t) = 1.0\cos(2\pi f_1 t) + 0.5\cos\left(2\pi f_2 t + \frac{\pi}{2}\right) + N_1(t),$$

$$B(t) = 0.5\cos(2\pi f_1 t) + 1.0\cos\left(2\pi f_2 t + \frac{\pi}{2}\right) + N_2(t)$$

$N_1(t)$ and $N_2(t)$ are independent random Gaussian noises, with $\sigma = 1.0$.



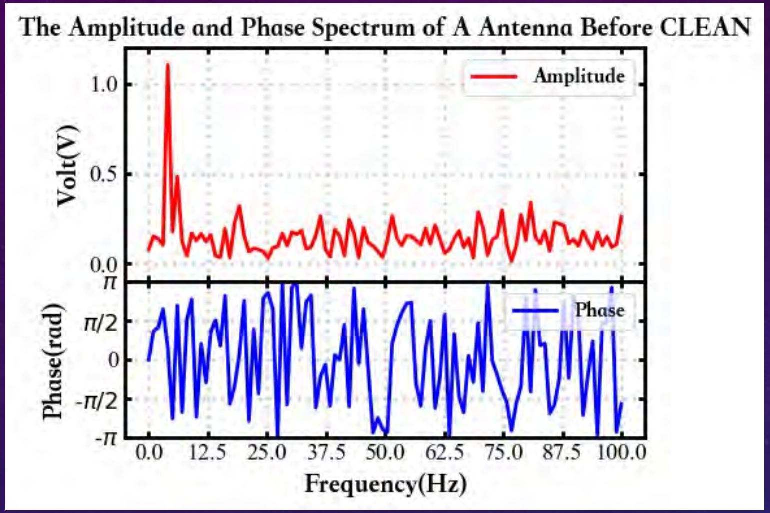


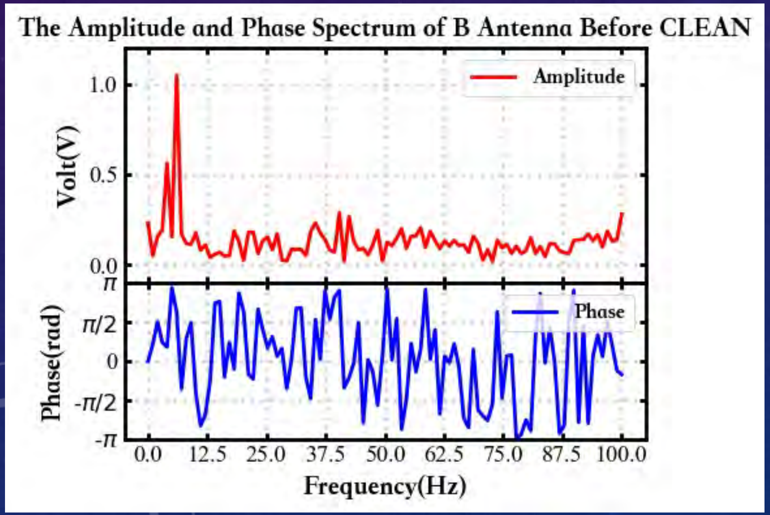
Interference Mitigation Based On CLEAN

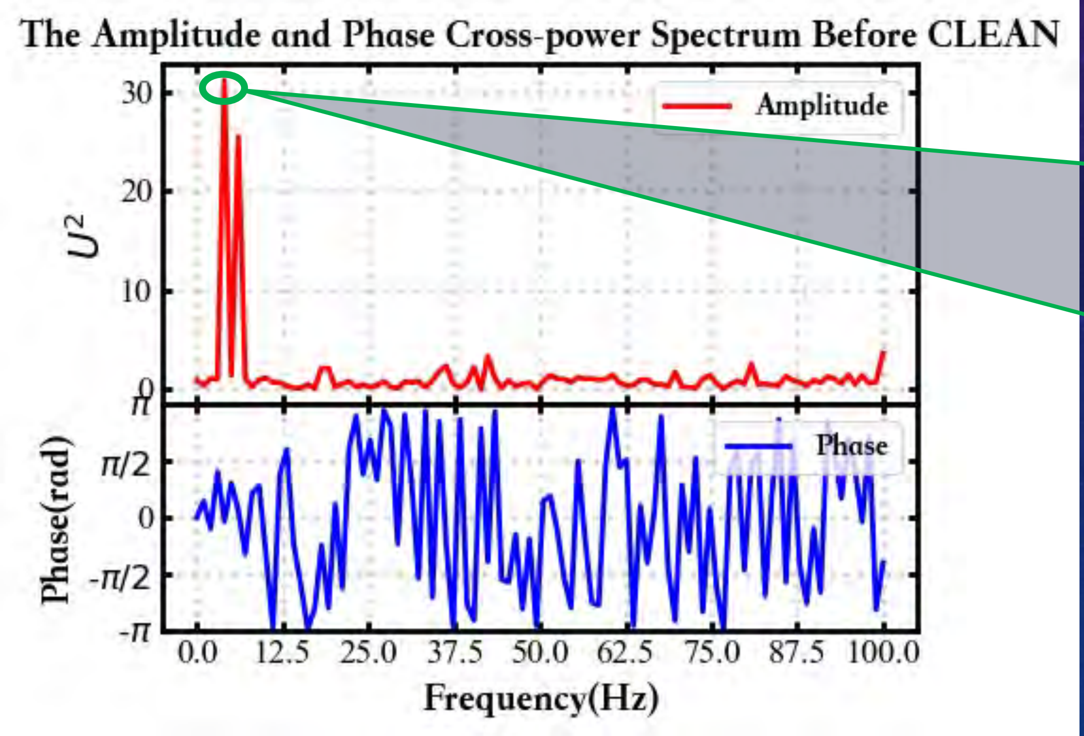
Basic ideas

Demonstration of CLEAN by Simulated Data

1st iteration







$\omega_m = 2\pi \cdot 4.185Hz$

$M_m^A = 1.267$
$M_m^B = 0.607$
$\varphi_m^A = -0.08$
$\varphi_m^B = -0.08$

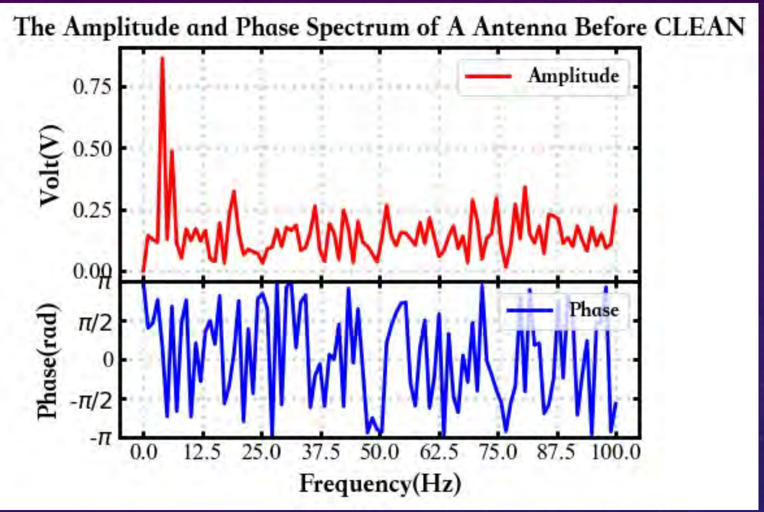
$\delta M_m^A \cos(\omega_m t + \varphi_m^A)$
$\delta M_m^B \cos(\omega_m t + \varphi_m^B)$
CLEAN Gain δ=0.2.

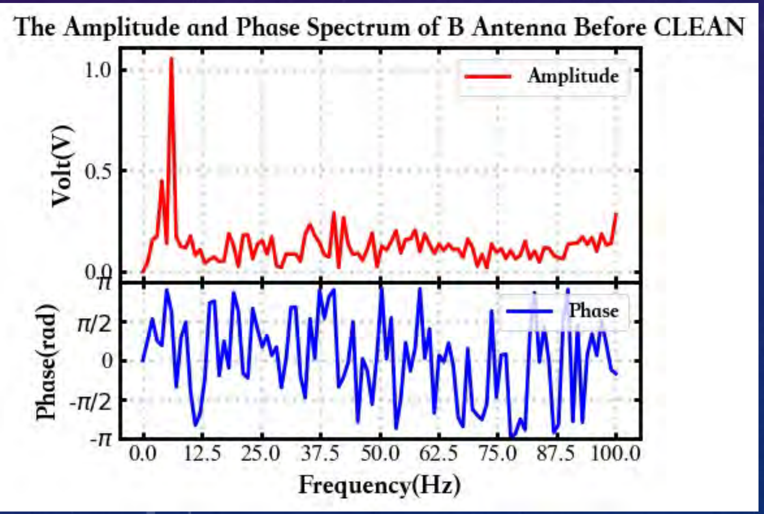
Interference Mitigation Based On CLEAN

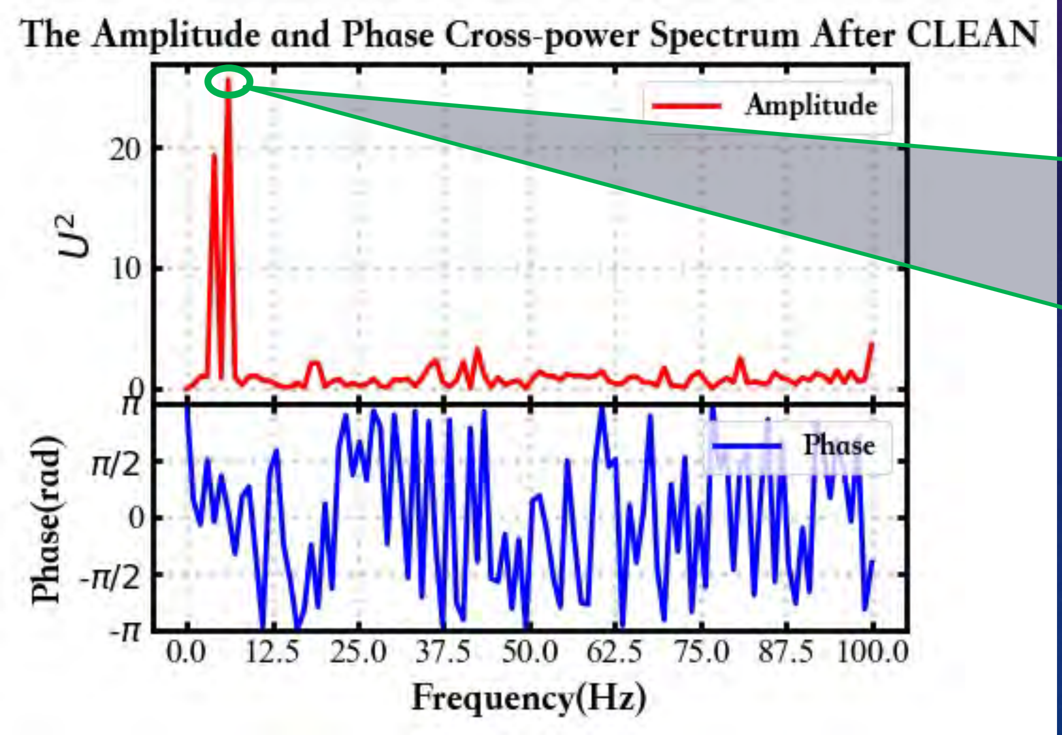
Basic ideas

Demonstration of CLEAN by Simulated Data

2nd iteration







$\omega_m = 2\pi \cdot 6.083Hz$

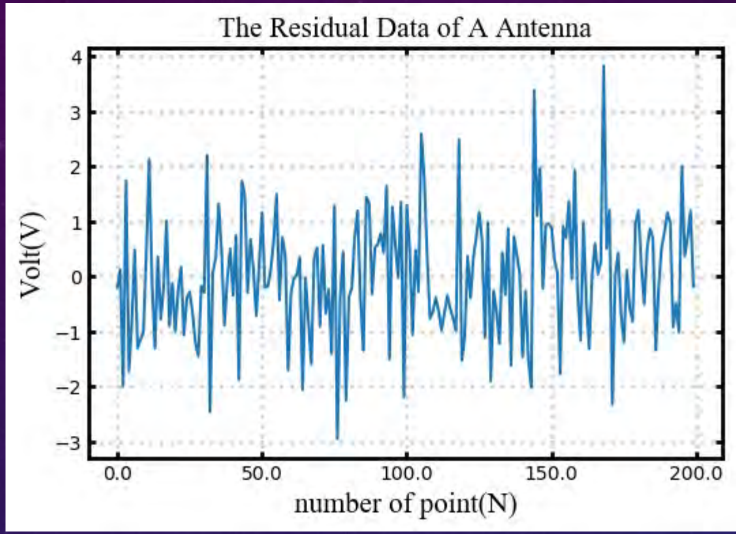
$M_m^A = 0.574$
$M_m^B = 1.185$
$\varphi_m^A = 1.705$
$\varphi_m^B = 1.675$

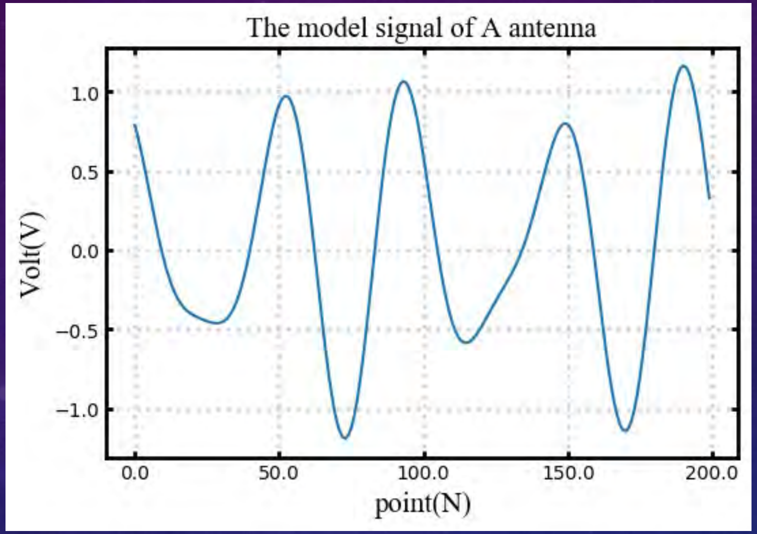
$\delta M_m^A \cos(\omega_m t + \varphi_m^A)$
$\delta M_m^B \cos(\omega_m t + \varphi_m^B)$
CLEAN Gain δ=0.2.

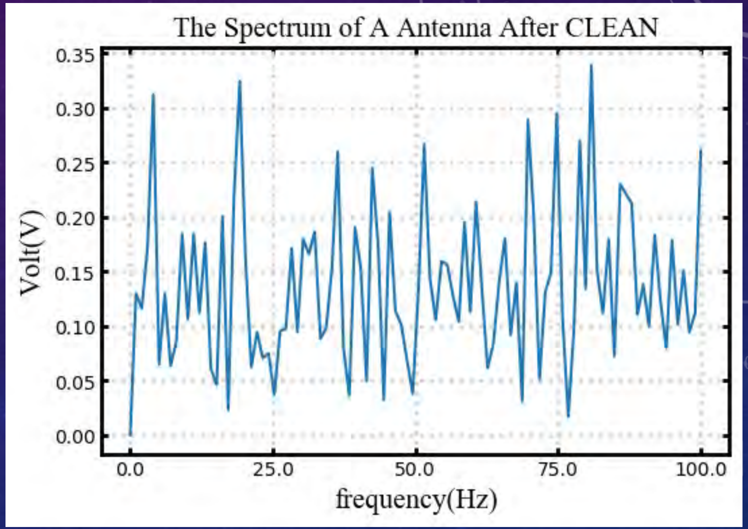
Interference Mitigation Based On CLEAN

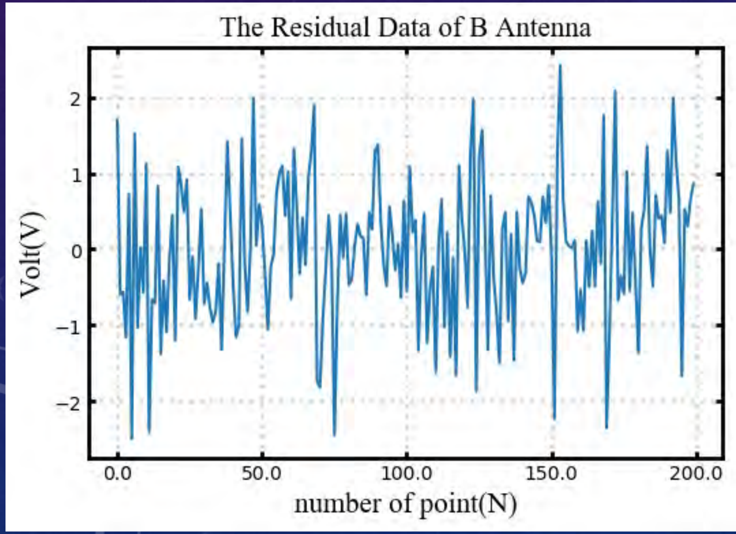
Basic ideas

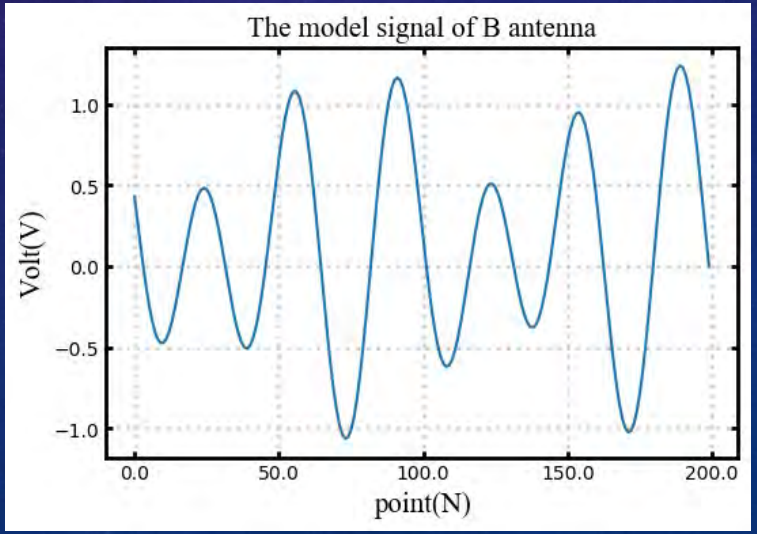
Demonstration of CLEAN by Simulated Data

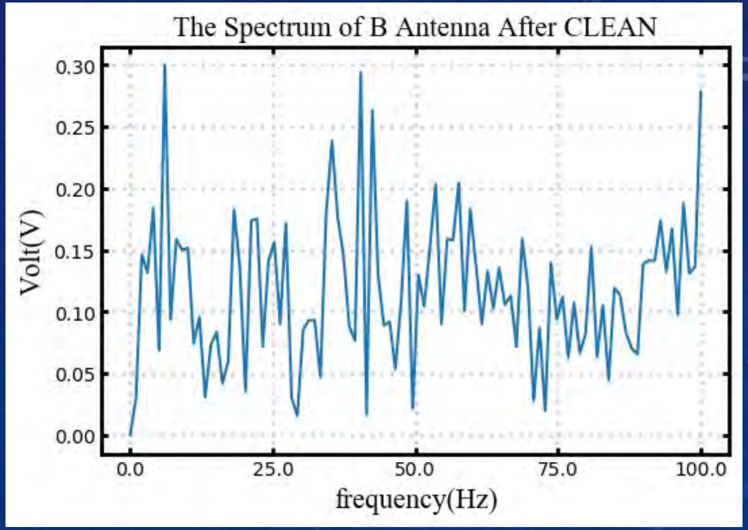






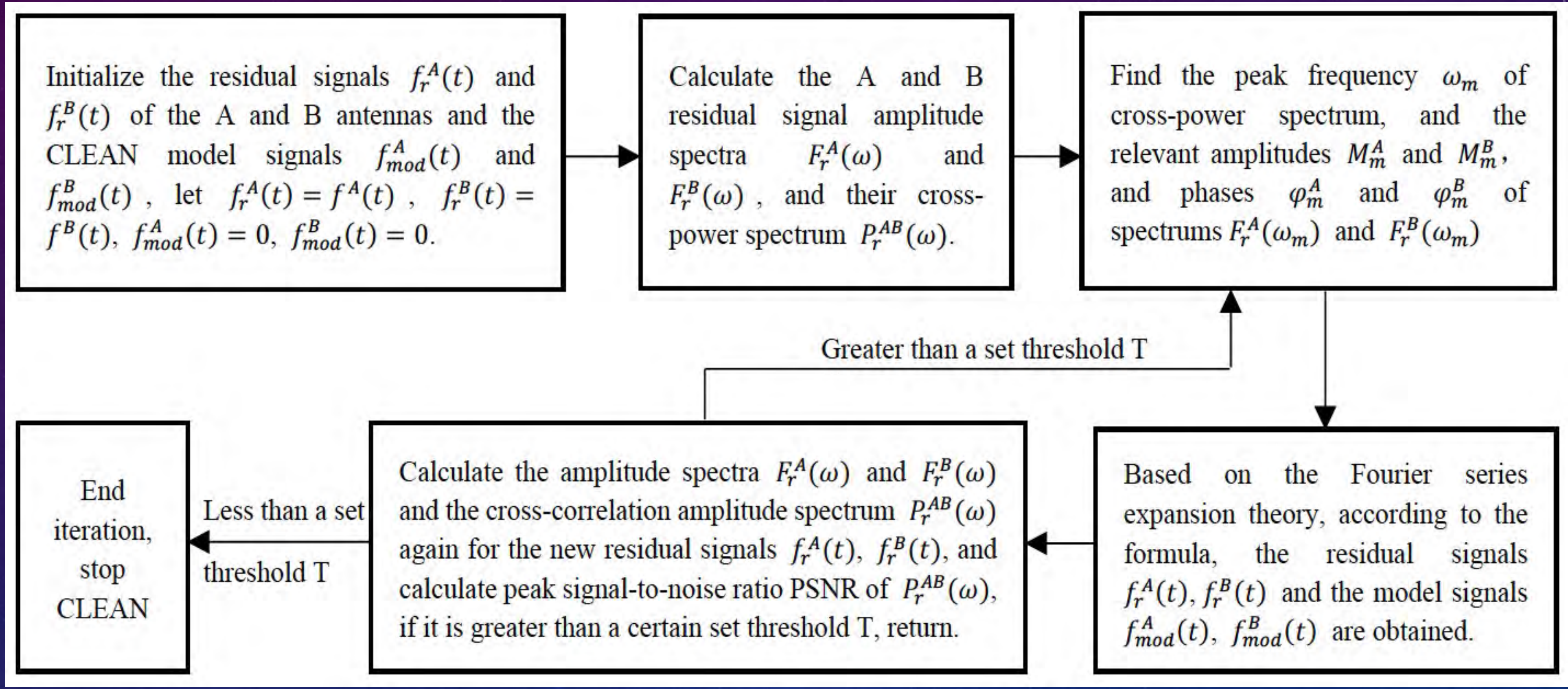






Interference Mitigation Based On CLEAN

The CLEAN Algorithm



$$f_r^A(t) = f_r^A(t) - \delta M_m^A \cos(\omega_m t + \varphi_m^A)$$

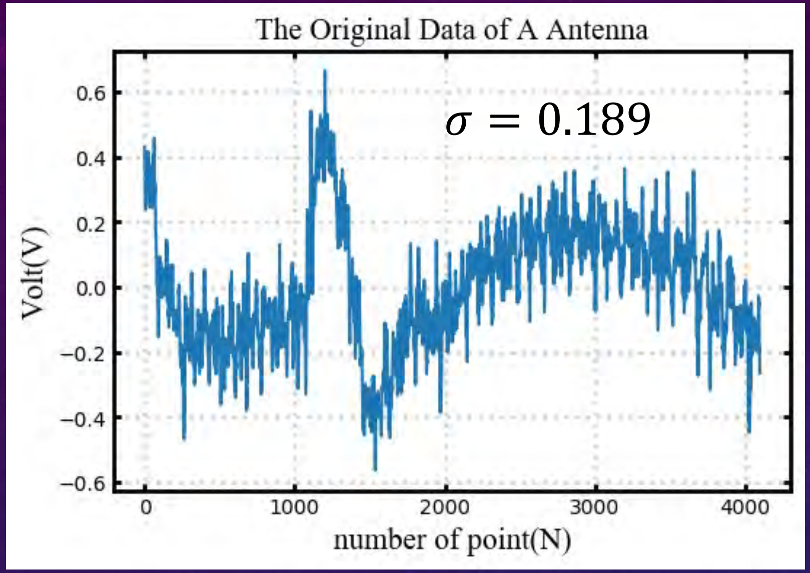
$$f_{mod}^A(t) = f_{mod}^A(t) + \delta M_m^A \cos(\omega_m t + \varphi_m^A)$$

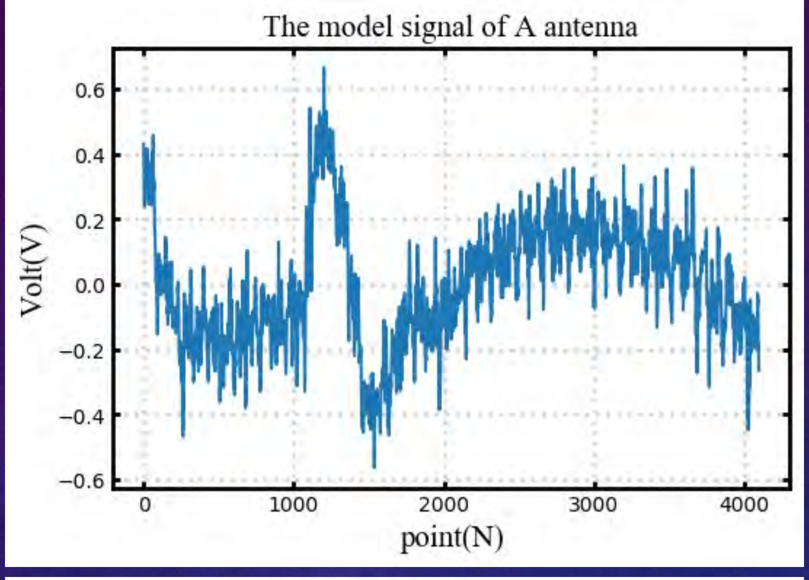
$$f_r^B(t) = f_r^B(t) - \delta M_m^B \cos(\omega_m t + \varphi_m^B)$$

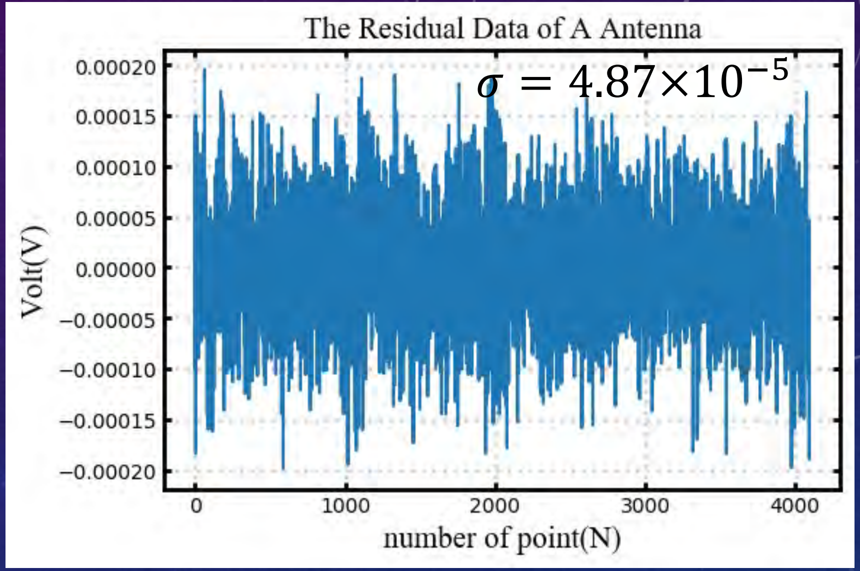
$$f_{mod}^B(t) = f_{mod}^B(t) + \delta M_m^B \cos(\omega_m t + \varphi_m^B)$$

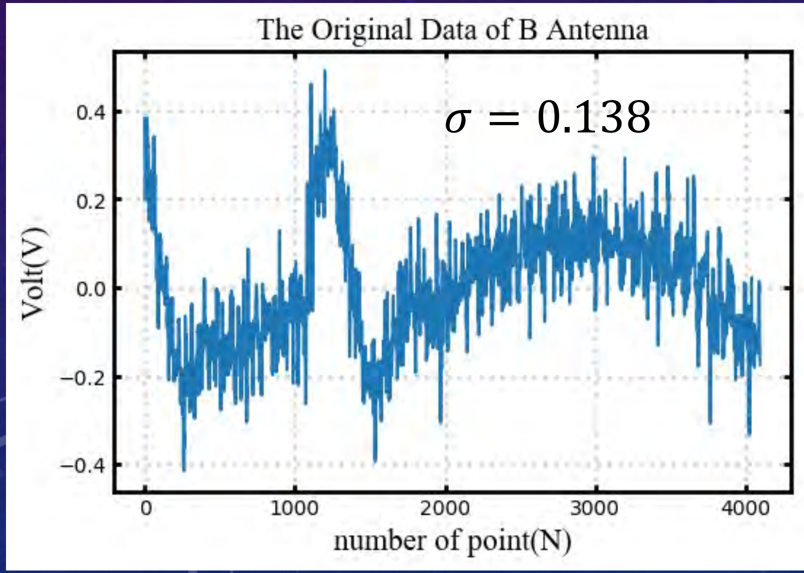
Preliminary Results Of LFRS

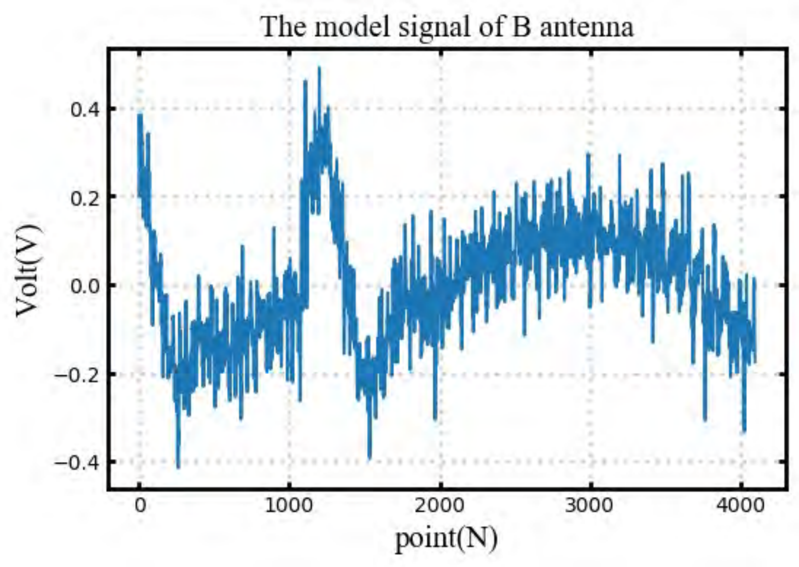
The 1st trace on the 23rd moon day

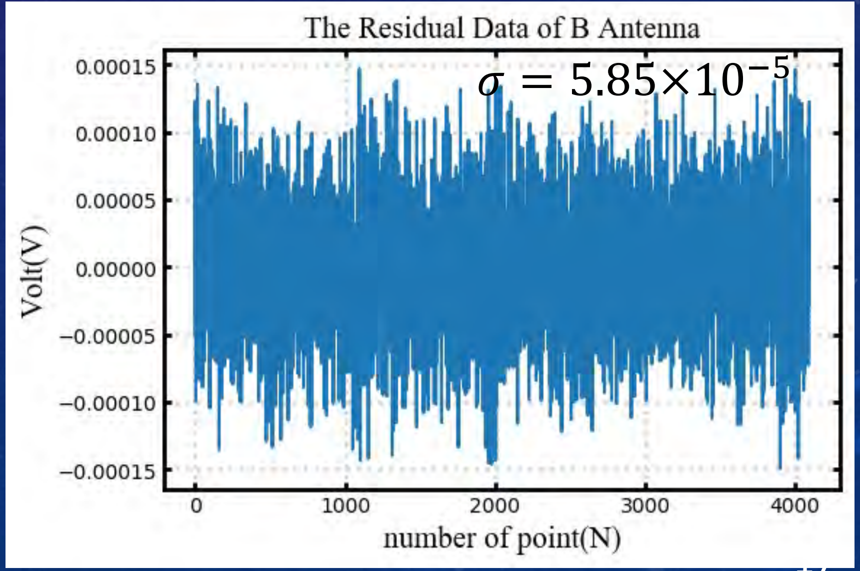






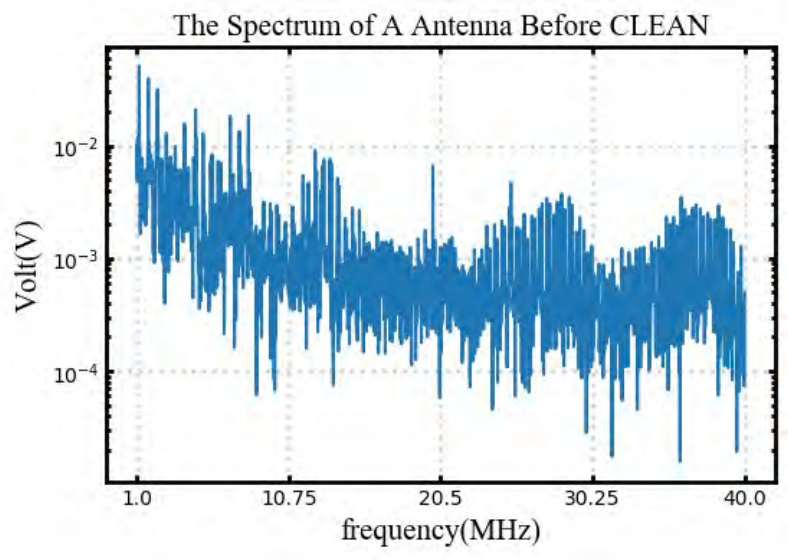


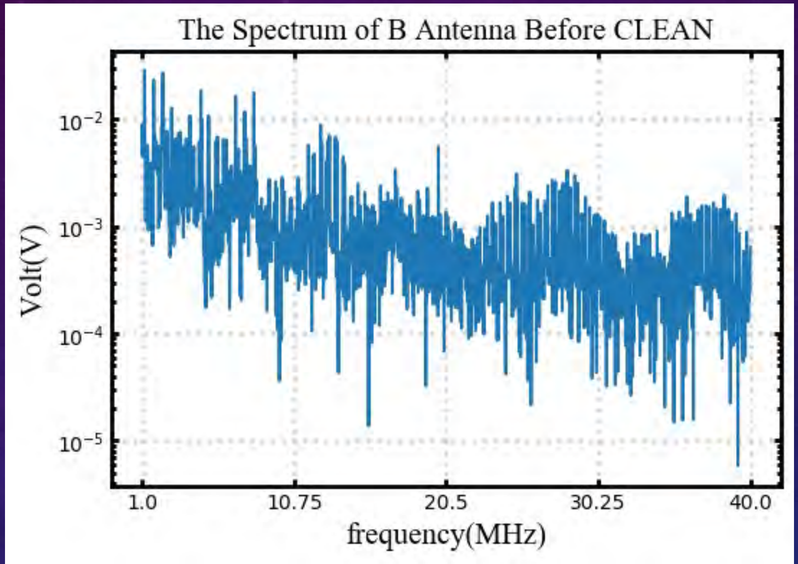


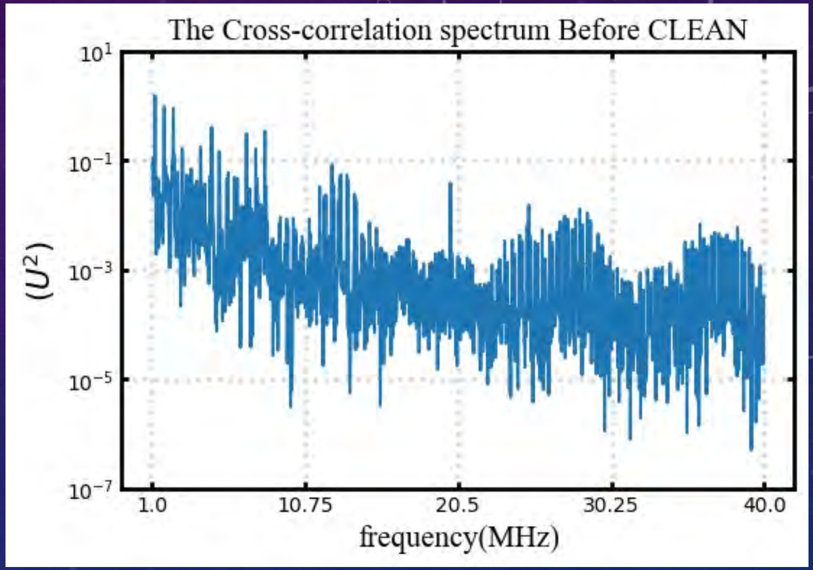


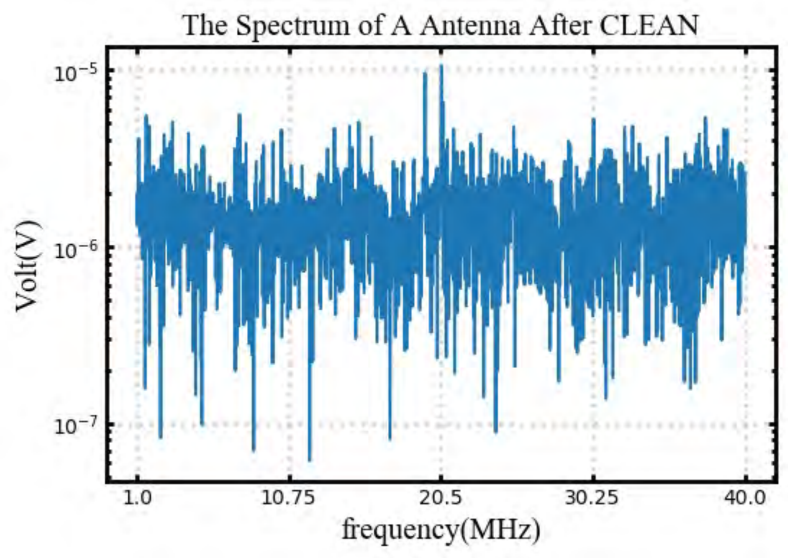
Preliminary Results Of LFRS

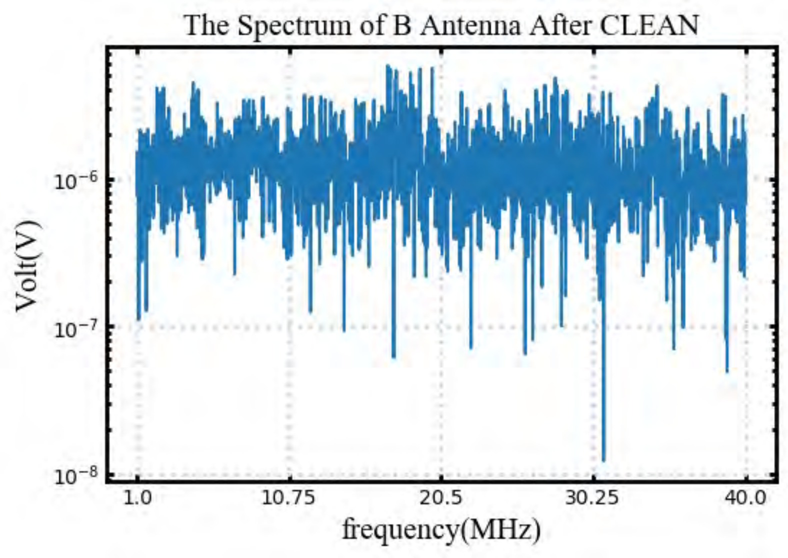
The 1st trace on the 23rd moon day

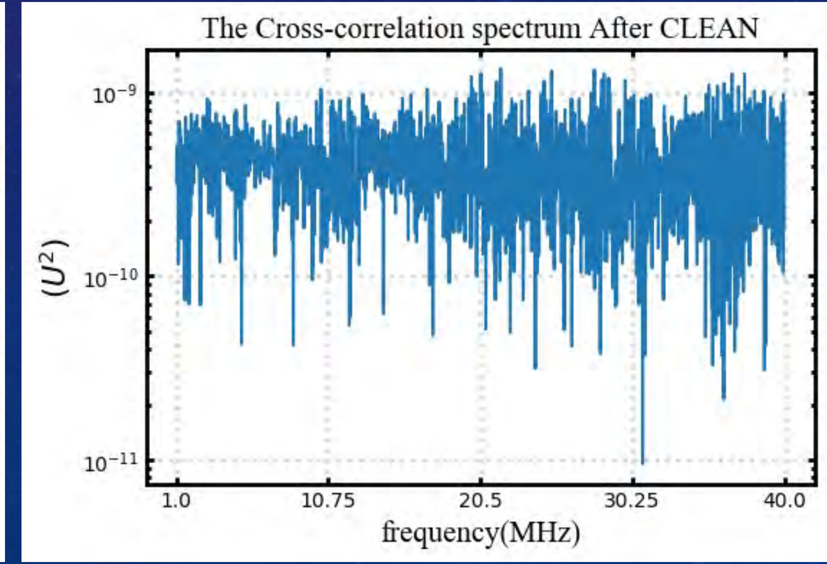






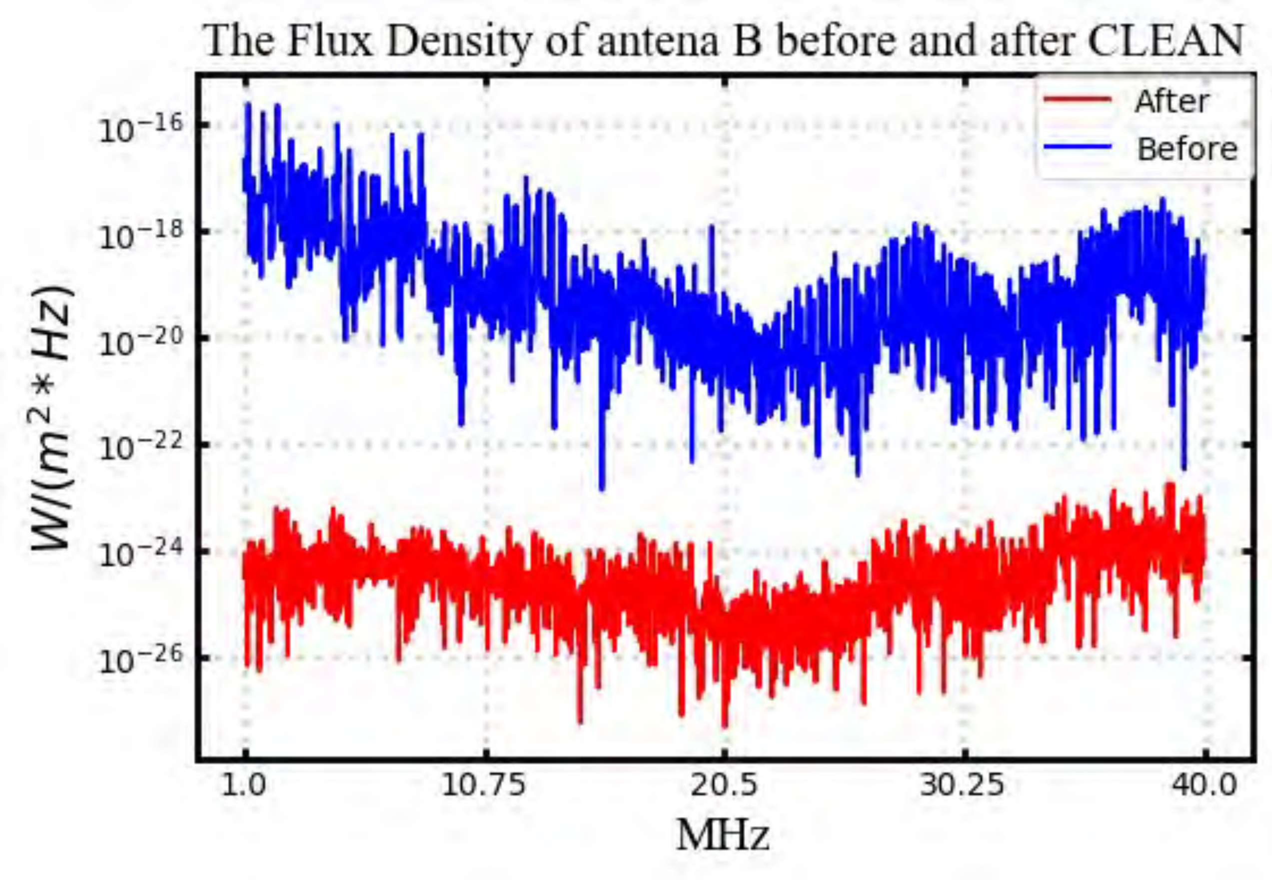


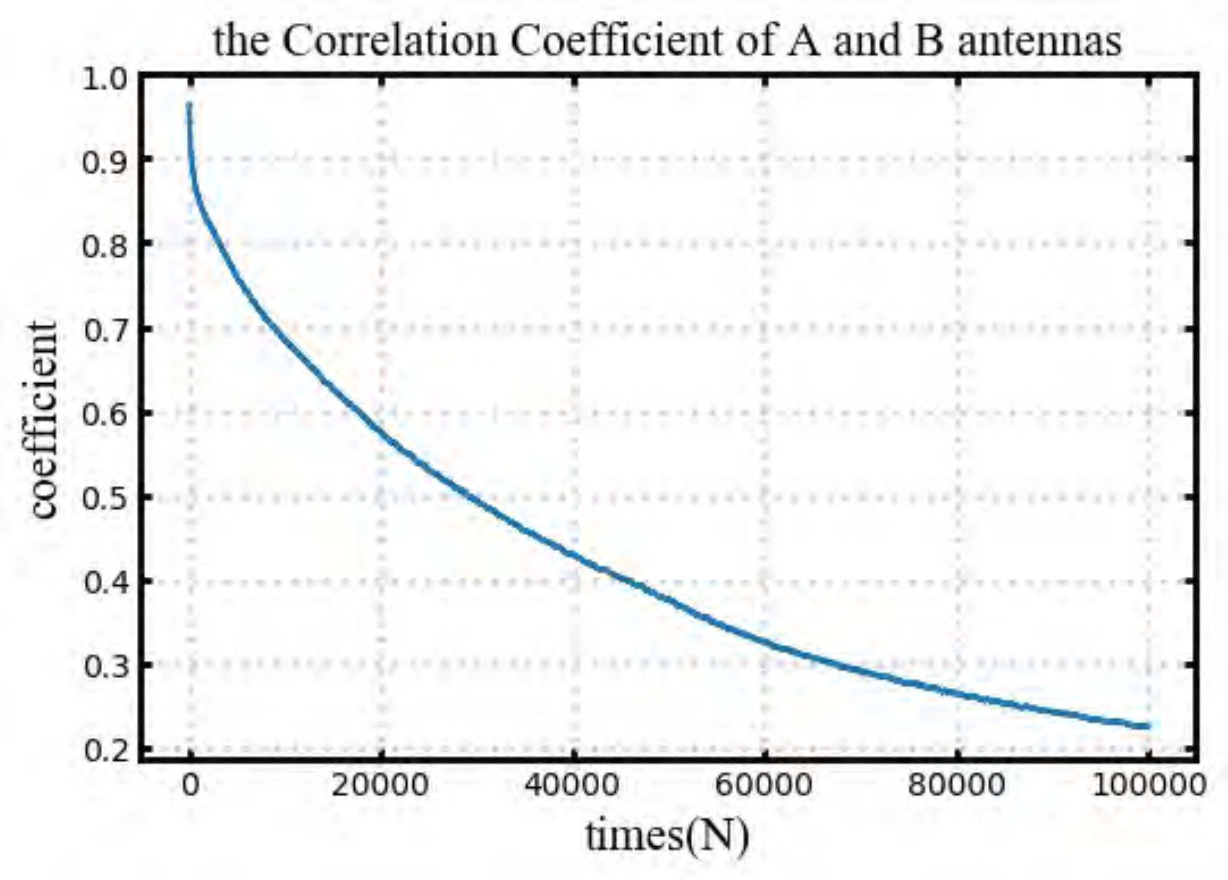




Preliminary Results Of LFRS

The 1st trace on the 23rd moon day



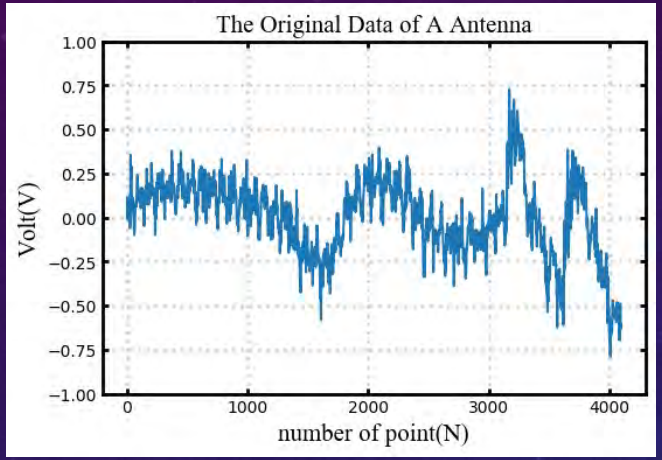


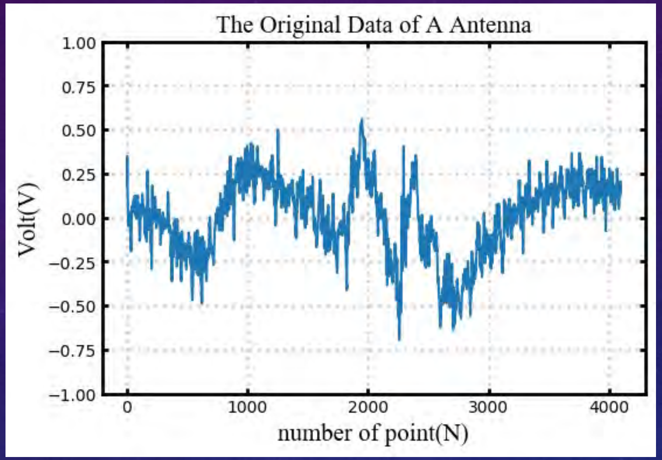
After CLEAN, the sensitivity of the residual signal is improved by about **8 order of magnitude**!

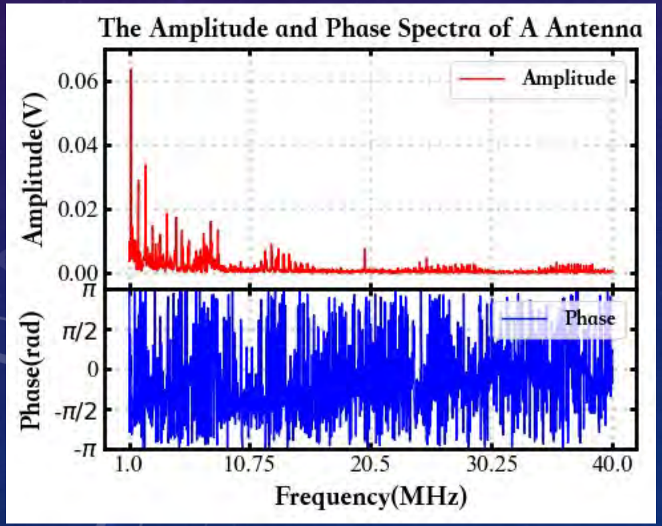
The correlation coefficient between the residual data of A and B antennas.

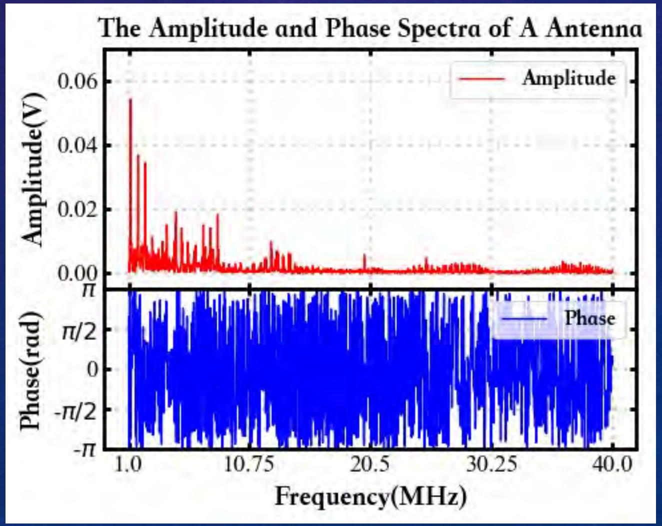
Future Plans

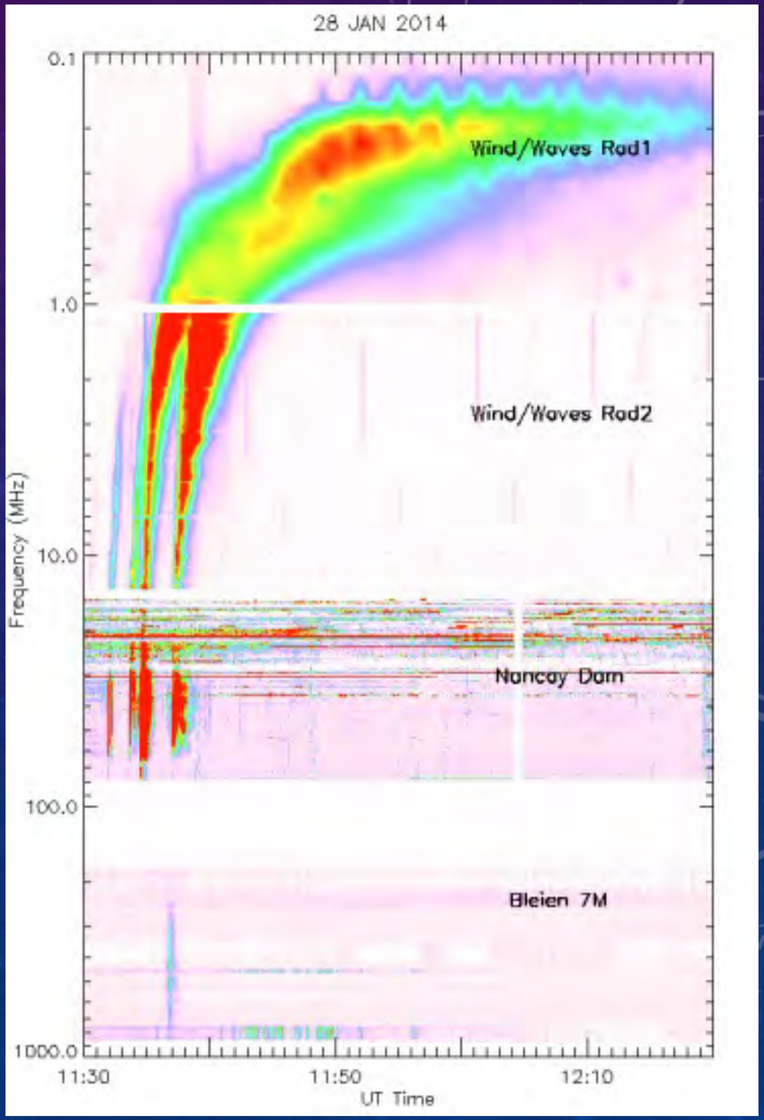
For CLEAN Model Signals : Modeling, Calibrating and Subtracting the interference!







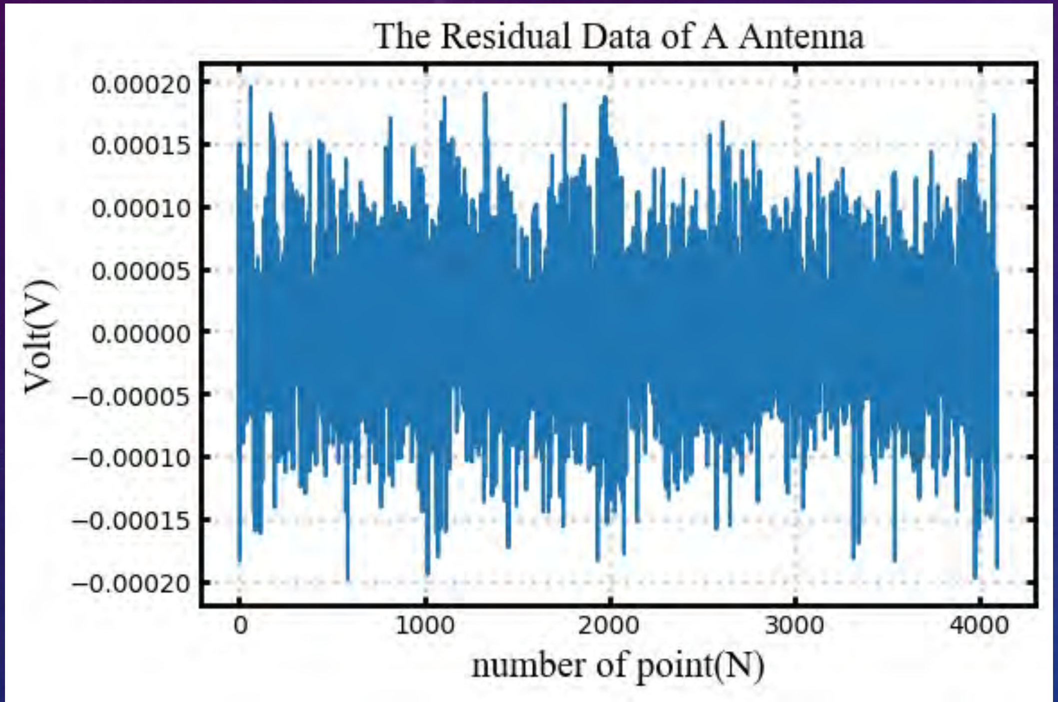




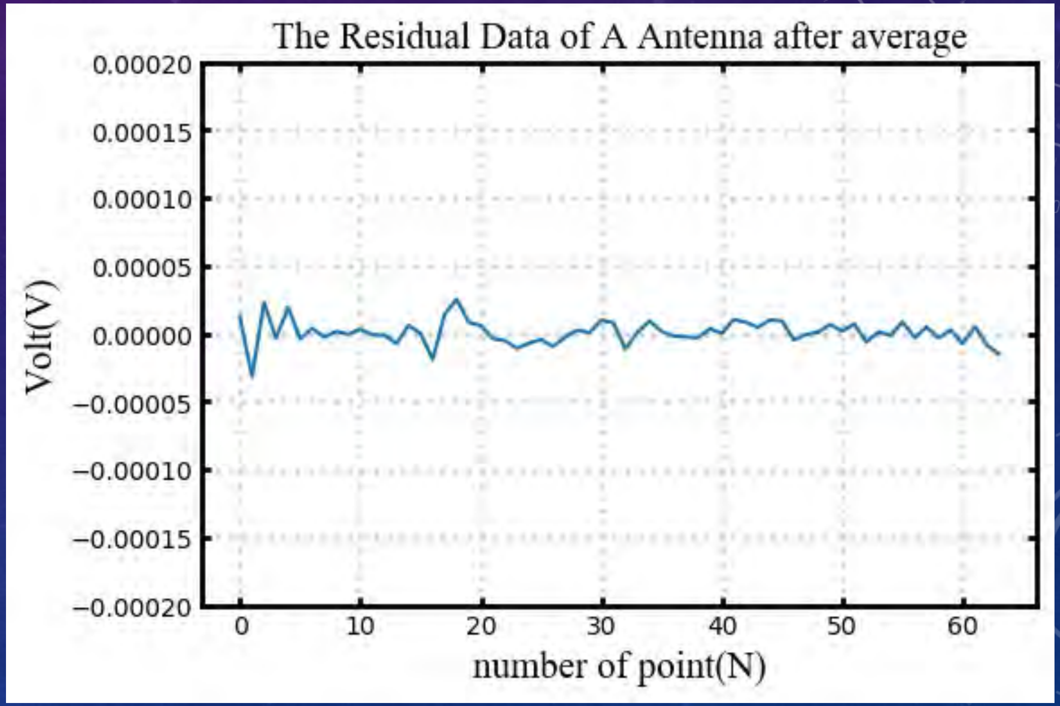
Solar radio bursts

Future Plans

For Residual Data : Averaging(Radiometer), Model fitting and Deconvolution!



The residual data of A antenna.



64-point averaging of the residual data of A antenna.

Summary

1. We decomposed the raw signals of LFRS into **coherent CLEAN Model Signals** and **partially coherent Residual Signals** by using **CLEAN algorithm**!

2. After CLEAN, the sensitivity of the residual signal is improved by about **8 orders of magnitude**!

3. Further astronomical analysis will use both **CLEAN Model Signals** and **Residual Signals**.