Tianlai experiments

Yougang Wang

National Astronomical Observatories, Chines Academy of Sciences

（on behalf of Tianlai collaboration)

Hangzhou Dianzi University

July 22, 2024

Outline

一 Introduction

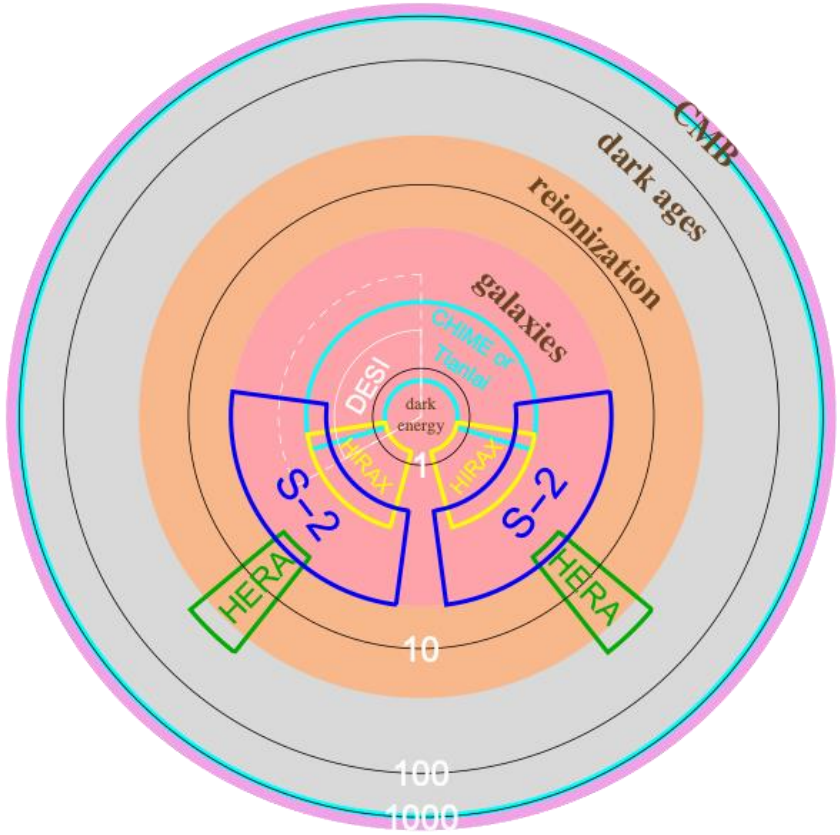
二 Tianlai experiment

三 Tianlai phase II

四 Next plan

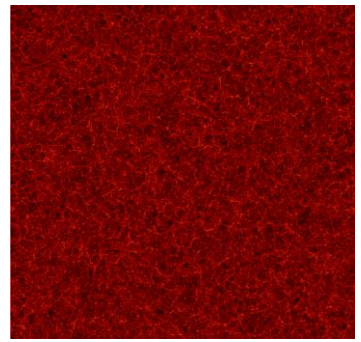
Introduction

21cm line—the ultimate cosmological probe

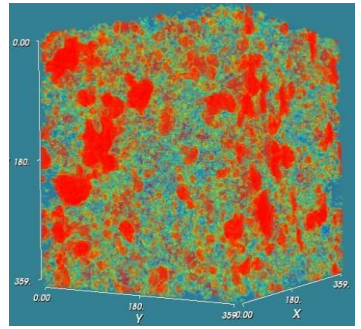


The observable Universe in comoving scale (Ansari et al. 2019)

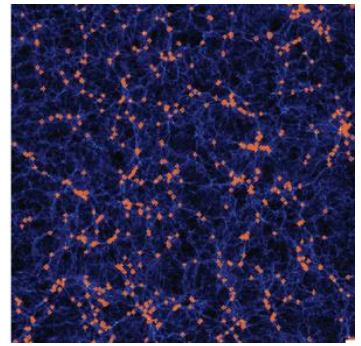
primordial fluctuation



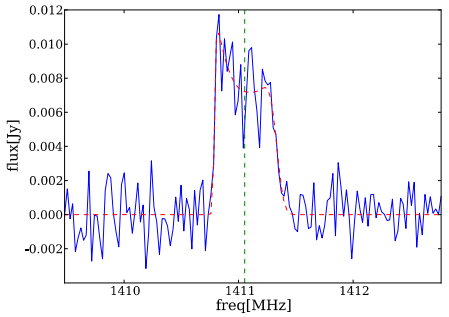
Epoch of Reionization (EoR)



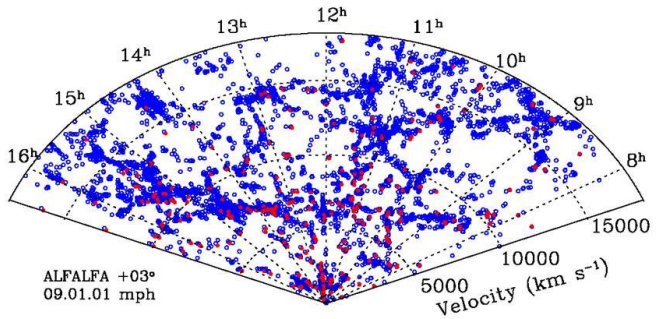
post-EoR



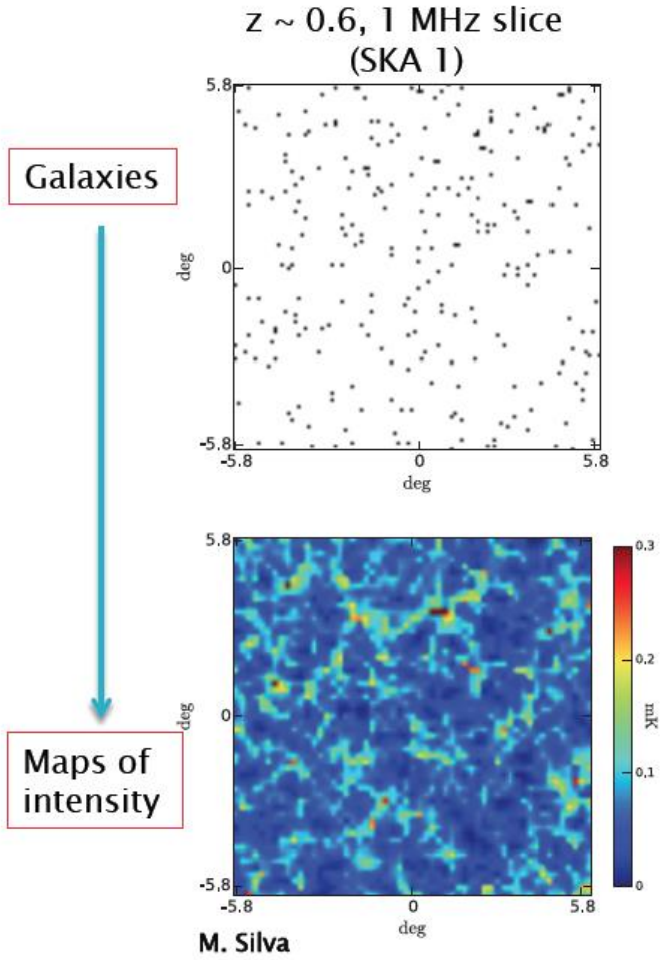
21cm Intensity Mapping

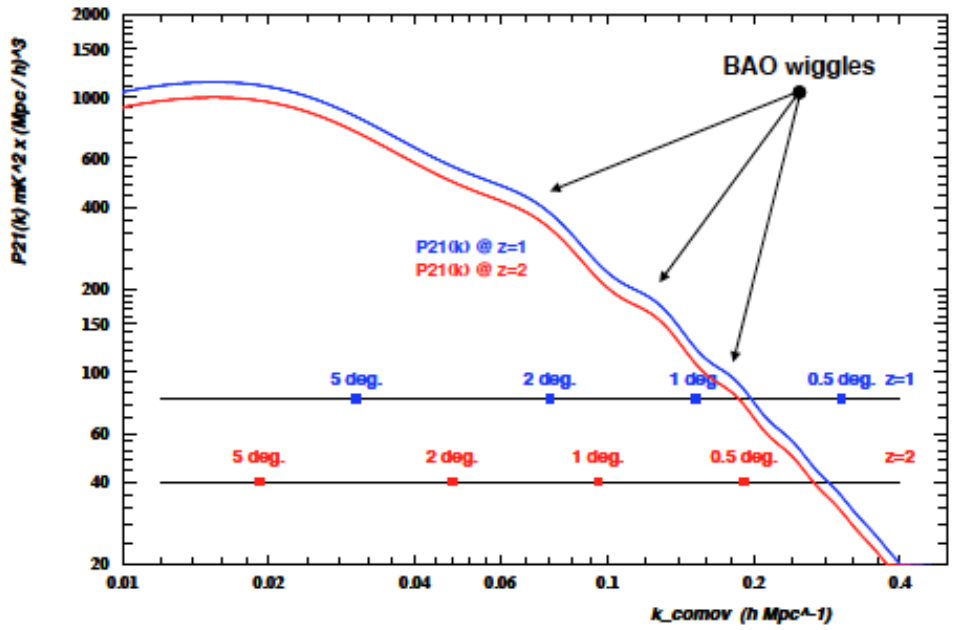


HI galaxy spectrum



HI galaxy survey

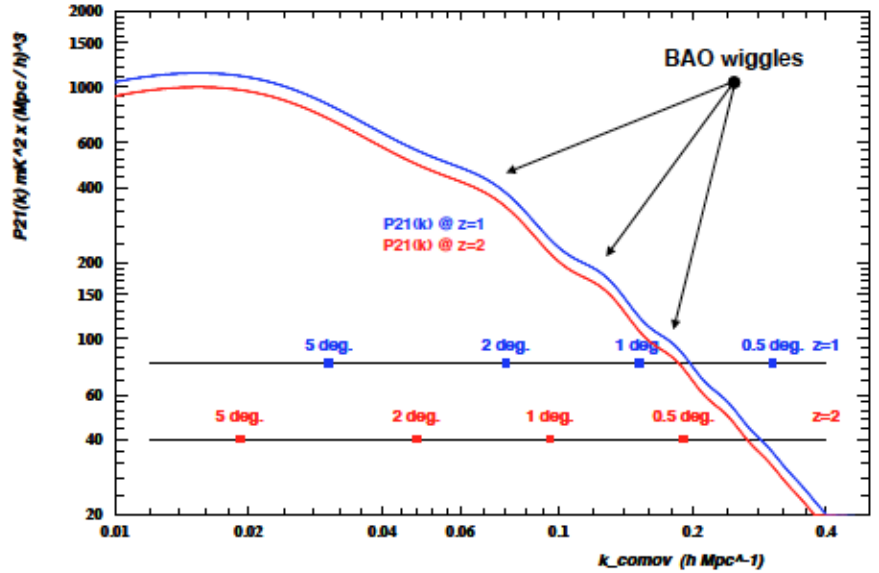




Ansari et al. 1108.1474

Tianlai (天籁) Array

- Intensity Mapping is potentially very powerful, a new technique, everyone on the same starting line
- An 21cm intensity mapping experiment in China
- Array Size: ~ 100 m for BAO



The concept of “tianlai”-- the heavenly sound was coined by ancient Chinese philosopher Zhuang-Zi (Chuang-Tzu, 369BC-286BC)

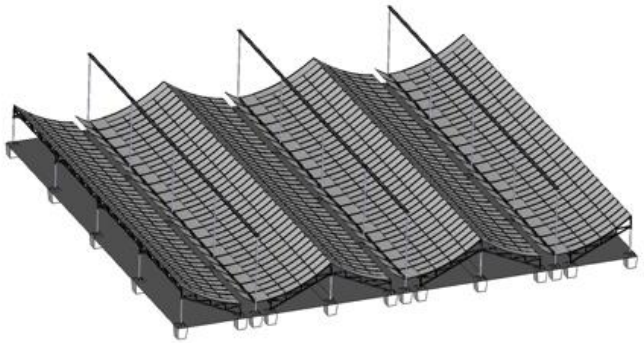
Realization

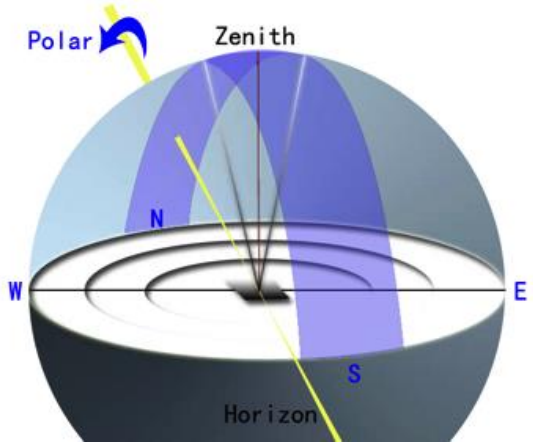
Cylinder Array:

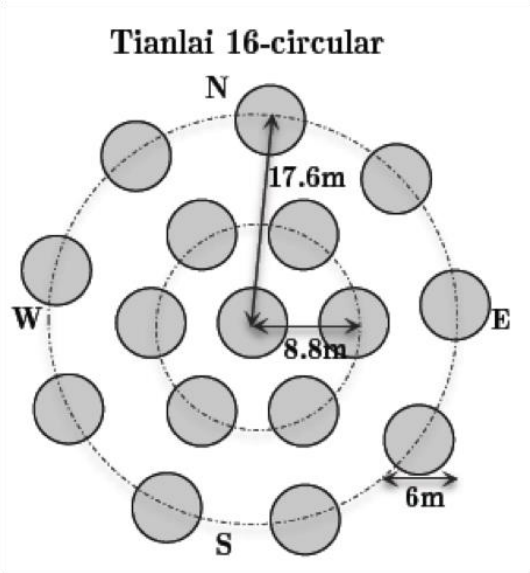
- large FoV, cheap
- design size: 40m
- actual size: 12.4m in center

Dish Array:

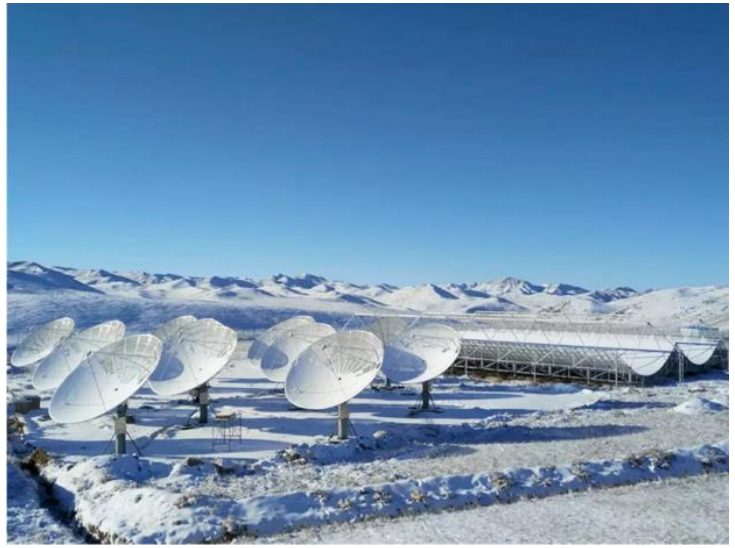
- dish array is historically more successful
- dense array to achieve complete uv coverage





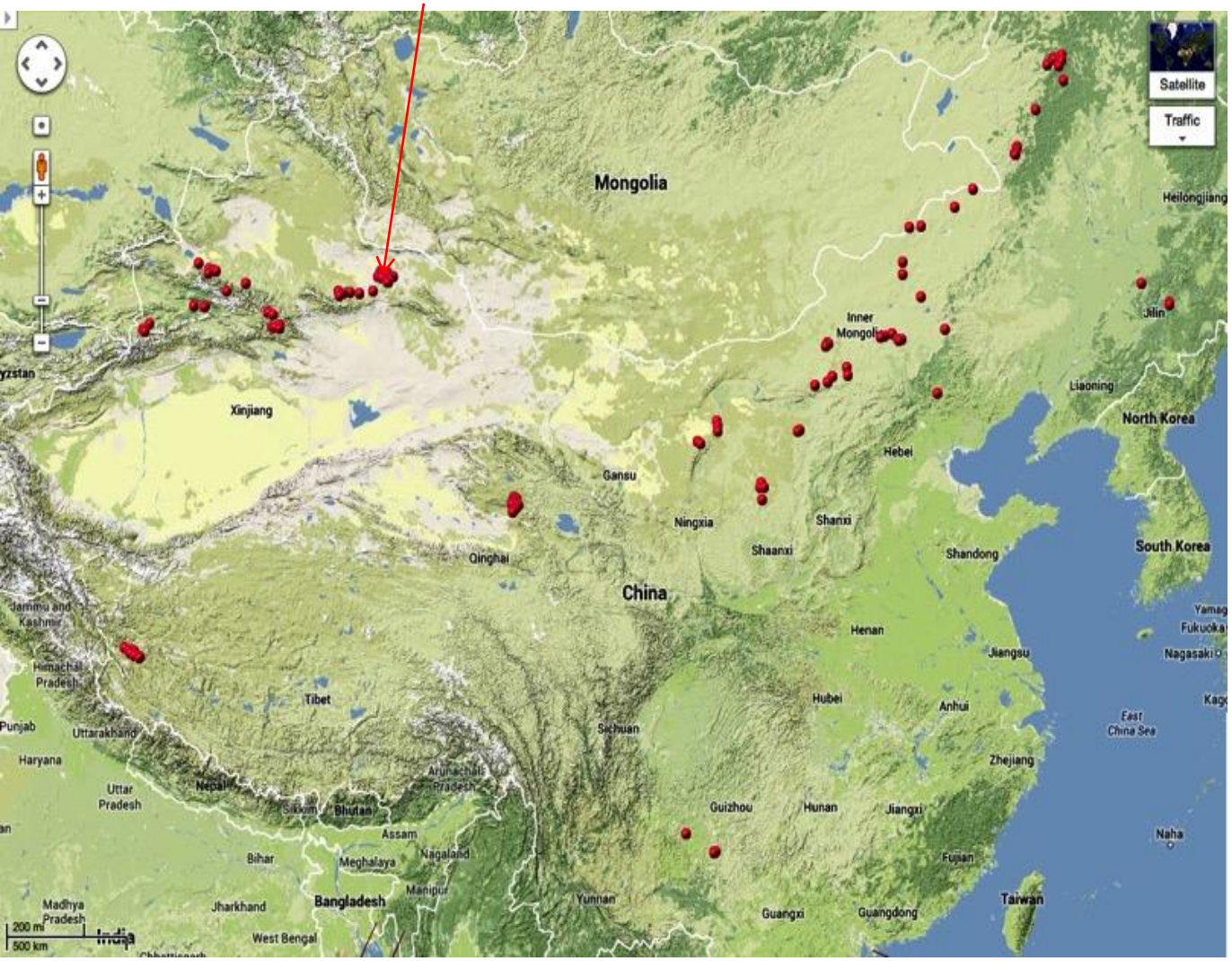


The Tianlai site and setup

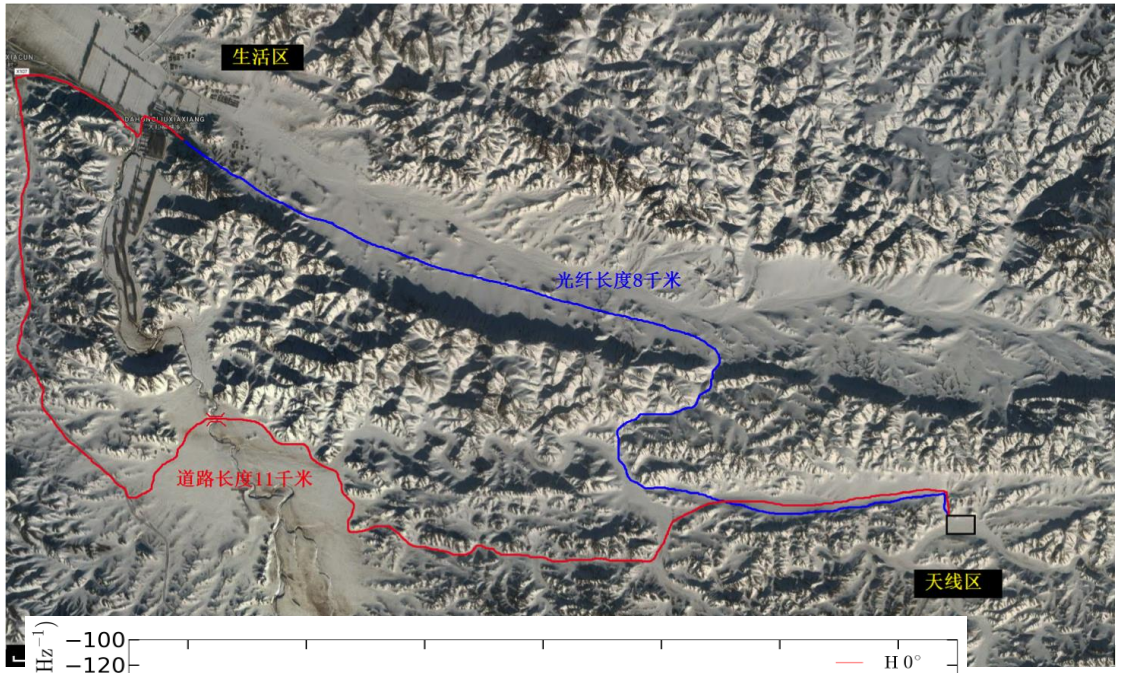


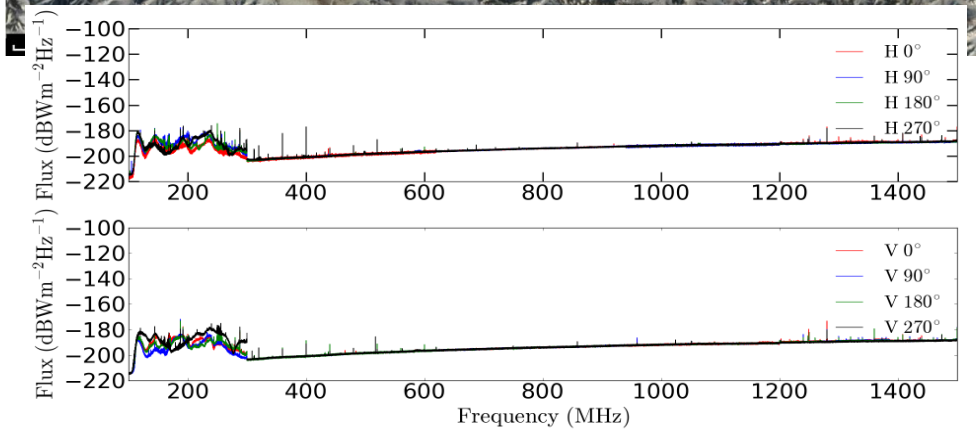
Site selection

Balikun County, Hami City, Xinjiang, China



天线阵和站房



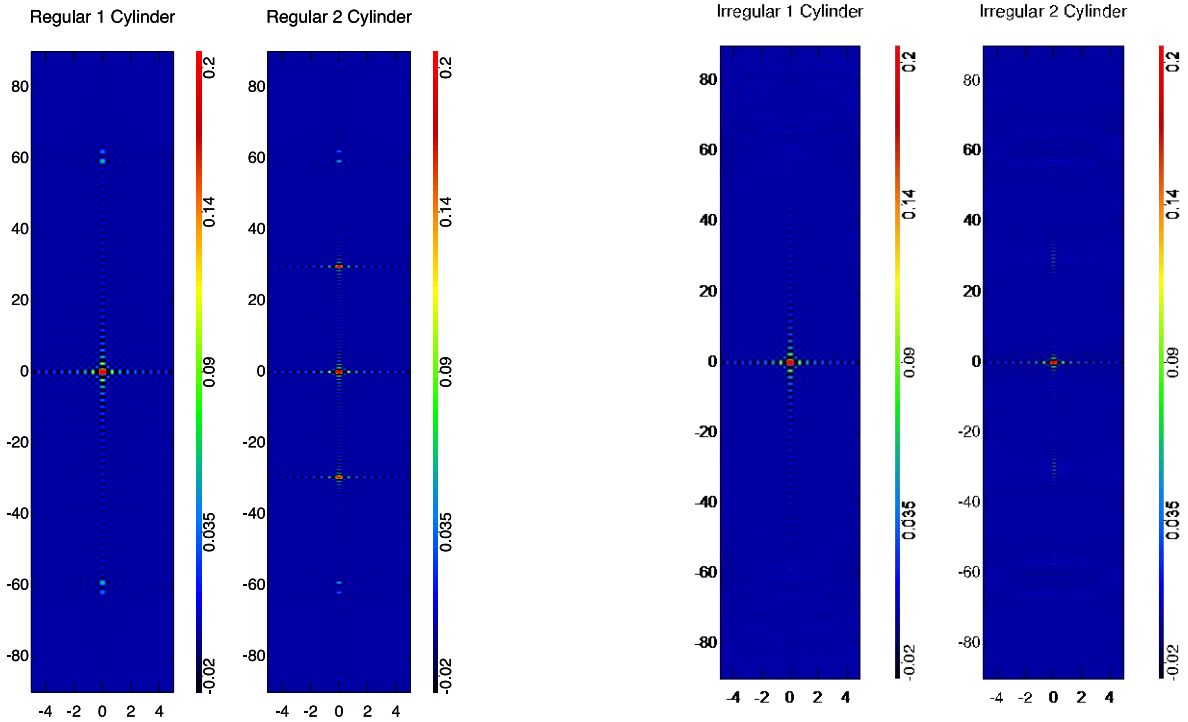


Array Configuration

Cylinder Array Jiao Zhang et al. 2016 MNRAS

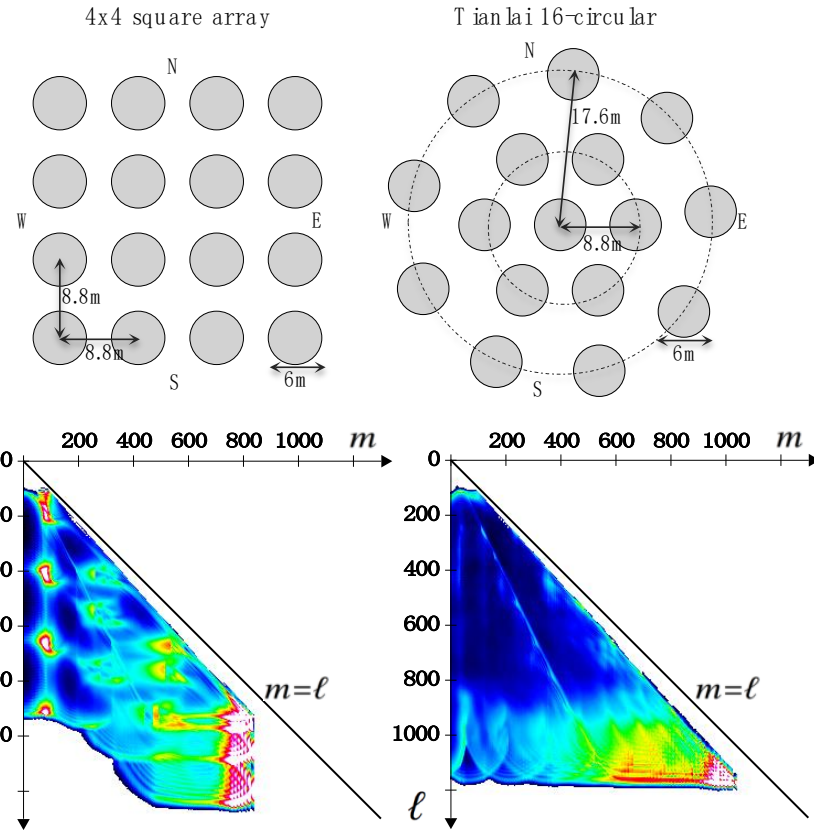
Regular: each cylinder 32 feeds
regular1: d=0.4m, total 12.4m
regular2: d=0.8m, total 24.8m

Irregular: 31,32,33 feeds
irregular1: <d>=0.4m, total 12.4m
regular2: <d>=0.8m, total 24.8m



Irregular configuration reduced grating lobes

Dish Array Jiao Zhang et al. 2016 RAA



Circular Array have more uniform coverage in (l, m) space

Array Parameters

Cylinder Array:

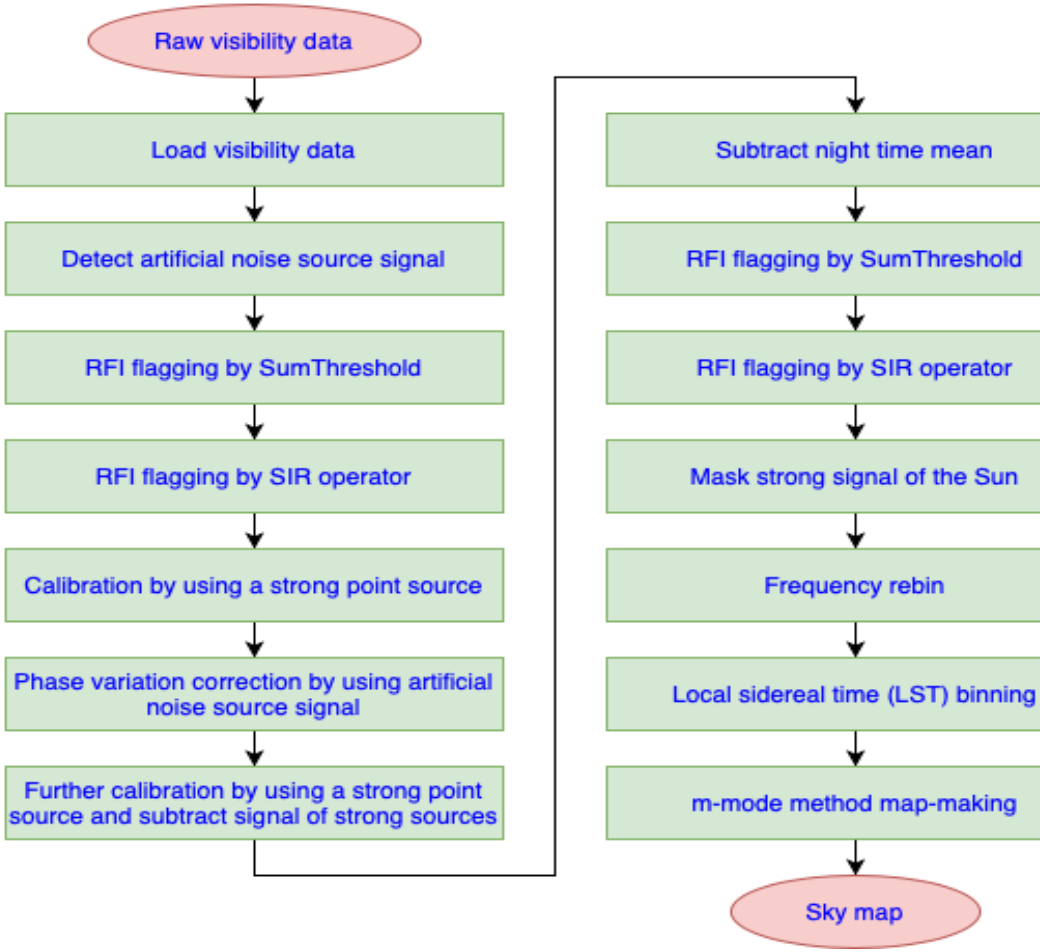
- cylinders: 3x40m (NS) x 15m(EW)
- Feeds per cylinder: 31(A), 32(B), 33(C)
- total number of channels: 192
- working frequency: 500-1500 MHz
- Current Frequency: 700-800 MHz
- Frequency Resolution: 0.122 MHz
- Location 91°48’ E, 44 °09’N

Dish Array:

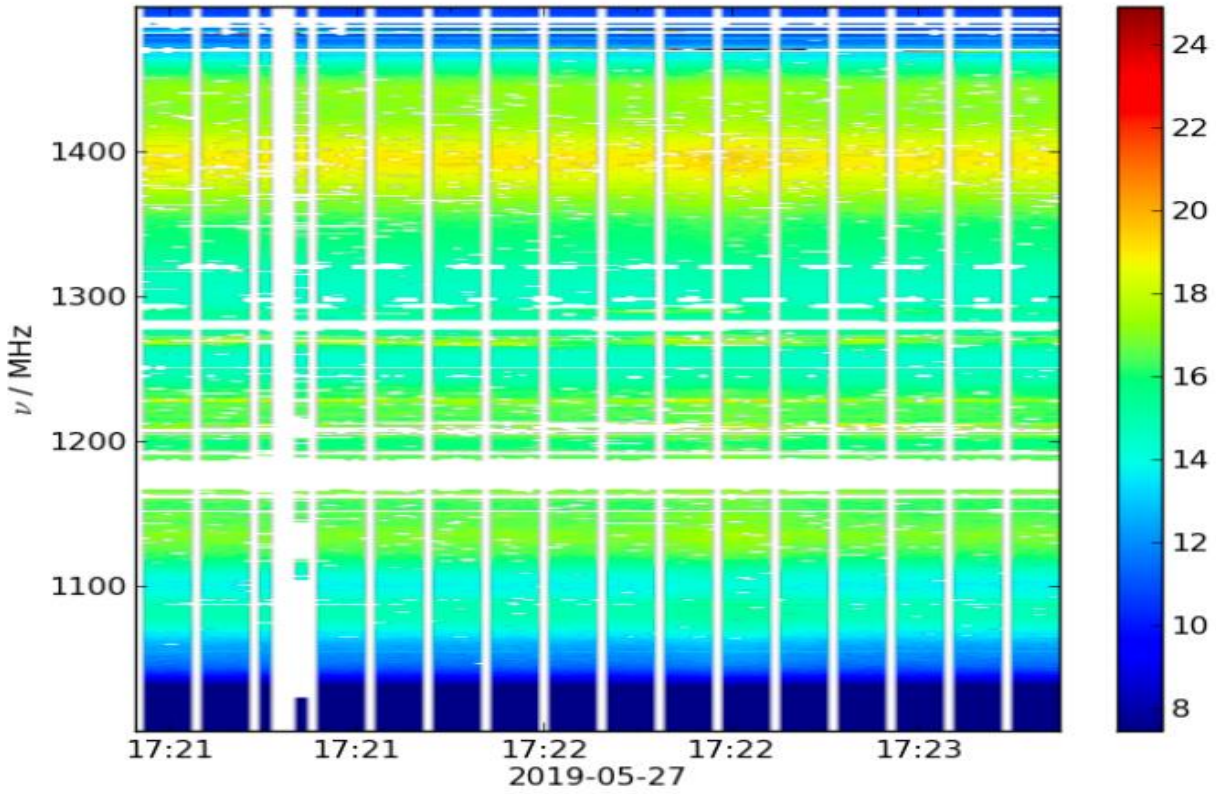
- dish: 6m
- Number: 16
- total number of channels: 32
- working frequency: 500-1500 MHz
- Current Frequency: 700-800 MHz
- Frequency Resolution: 0.122 MHz
- Location 91°48’ E, 44 °09’N

The dish array can pointing to different directions, but usually work in the drift scan mode

(Offline) Data Processing Pipeline



Sum Threshold Method+SIR

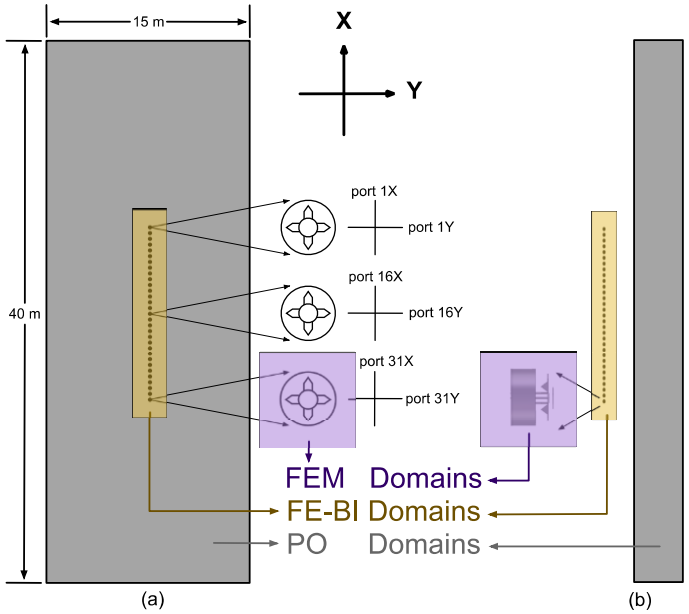


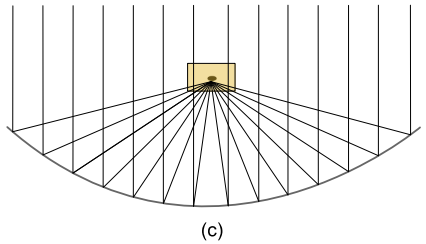
RFI masks

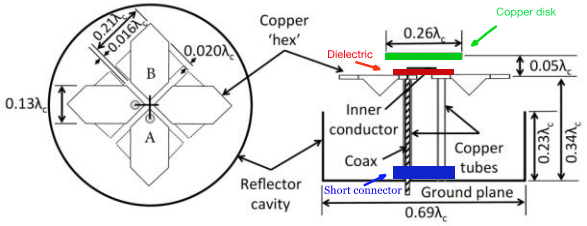
Tlpipe (Shifan Zuo et al. 2020): A python software package
http://tianlaiproject.github.io/tlpipe

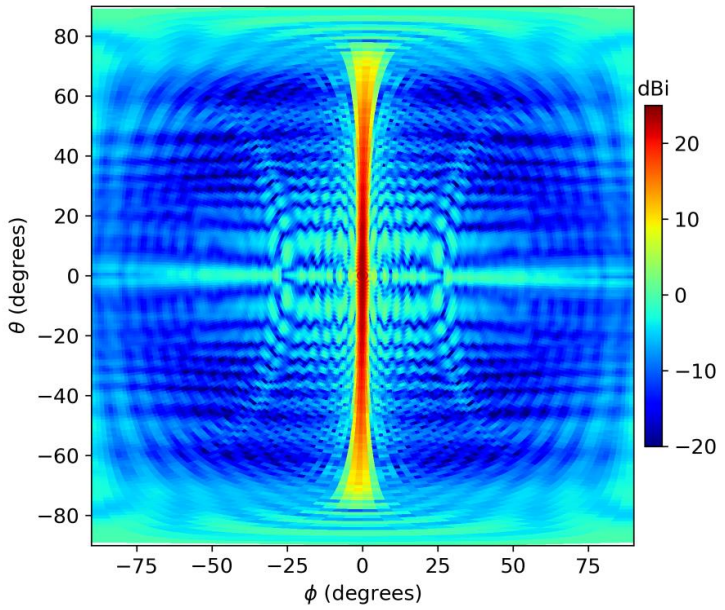
Beam Simulation

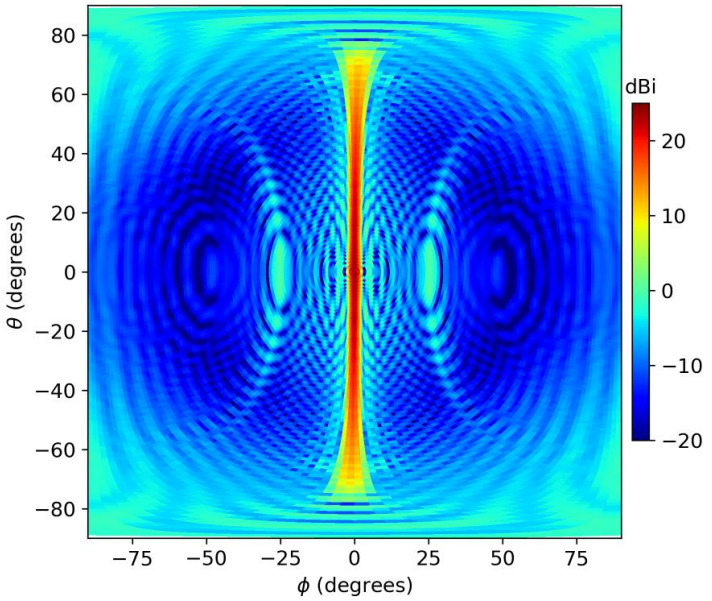
Shijie Sun et al. （2022, RAA)



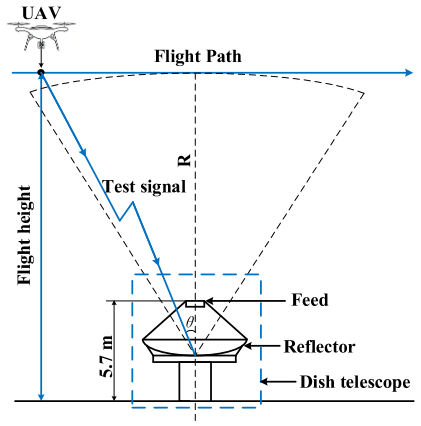


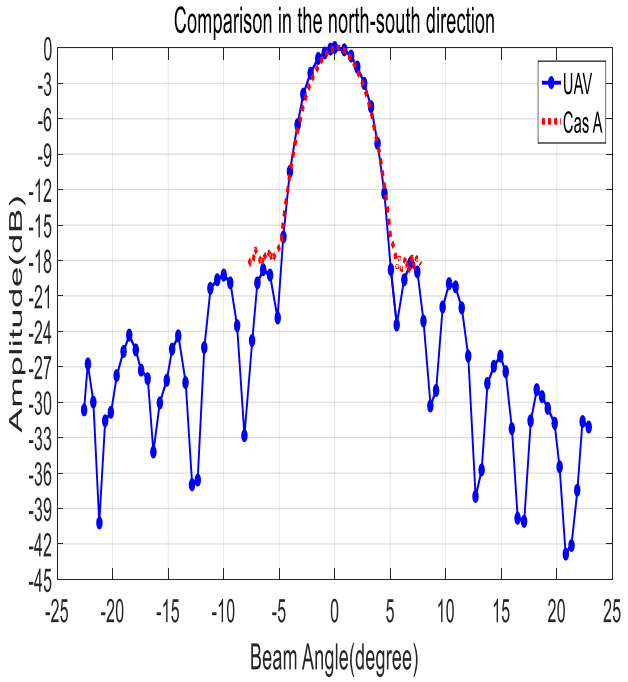


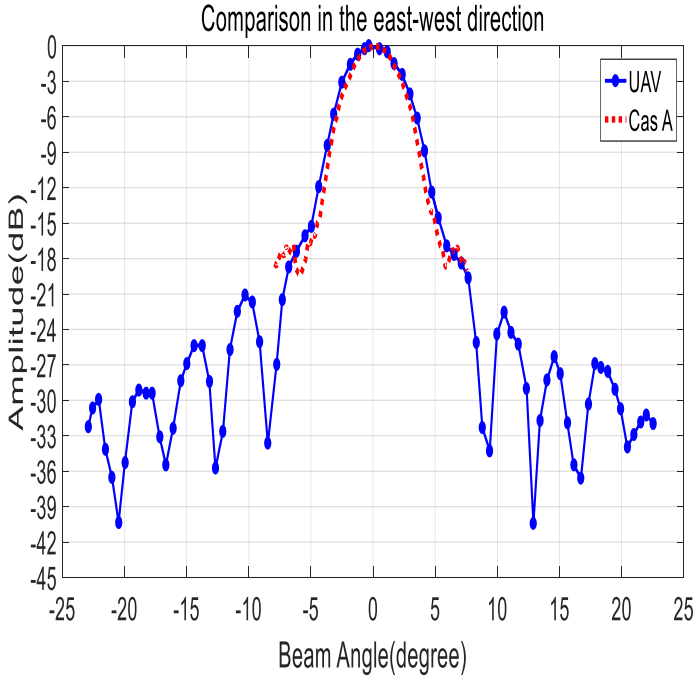




Array Calibration with Unmanned Aerial Vehicle



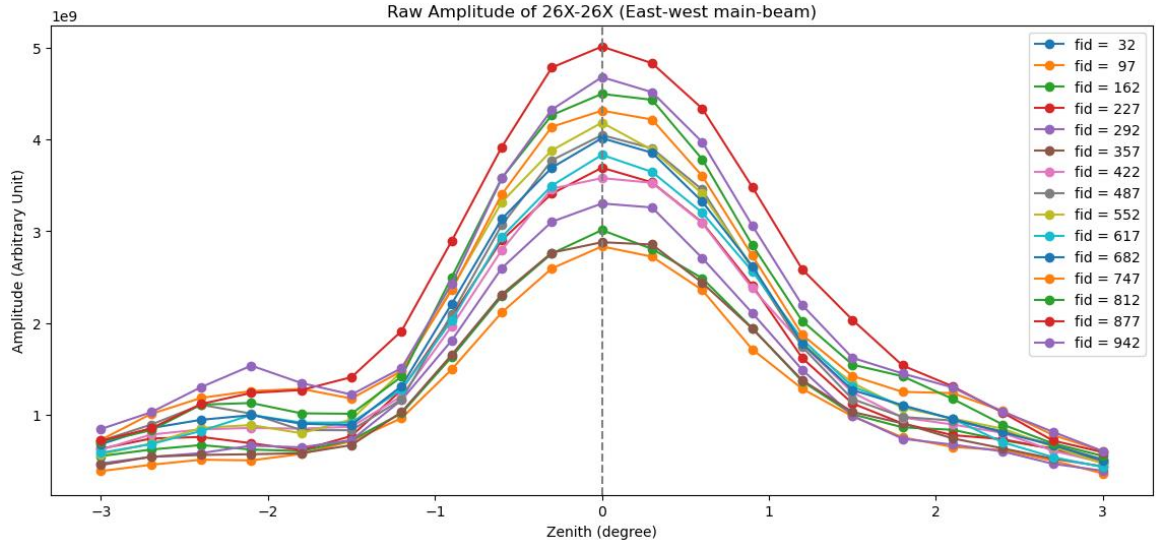


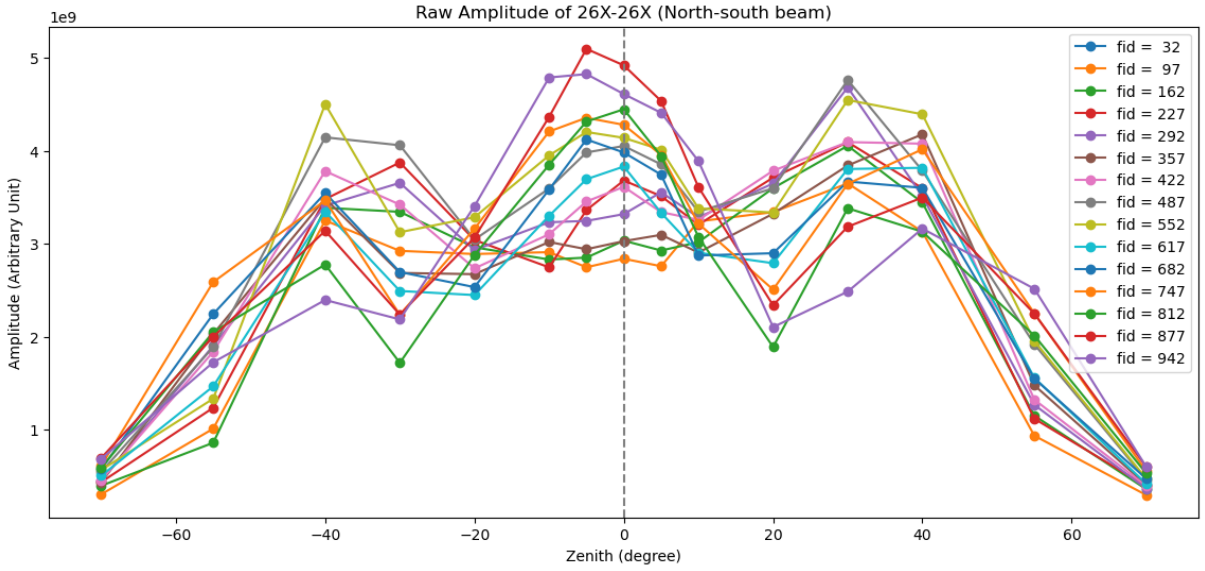


Juyong Zhang et al. (2021) IEEE Antenna & Propagation magazine

Far Field Condition: $d = \frac{2D^2}{\lambda}$

for cylinder this is not easy to satisfy


Raw Amplitude of 26X-26X (East-west main-beam)
1e9
Amplitude (Arbitrary Unit)
Zenith (degree)
fid = 32
fid = 97
fid = 162
fid = 227
fid = 292
fid = 357
fid = 422
fid = 487
fid = 552
fid = 617
fid = 682
fid = 747
fid = 812
fid = 877
fid = 942


Raw Amplitude of 26X-26X (North-south beam)
1e9
Amplitude (Arbitrary Unit)
Zenith (degree)
fid = 32
fid = 97
fid = 162
fid = 227
fid = 292
fid = 357
fid = 422
fid = 487
fid = 552
fid = 617
fid = 682
fid = 747
fid = 812
fid = 877
fid = 942

End-to-End Simulation

- Noise $\sigma_{noise} = \frac{\sqrt{2}T_{sys}}{\eta\sqrt{t_{int}\Delta\nu}}$

- Complex Gain Fluctuation: Gaussian Model

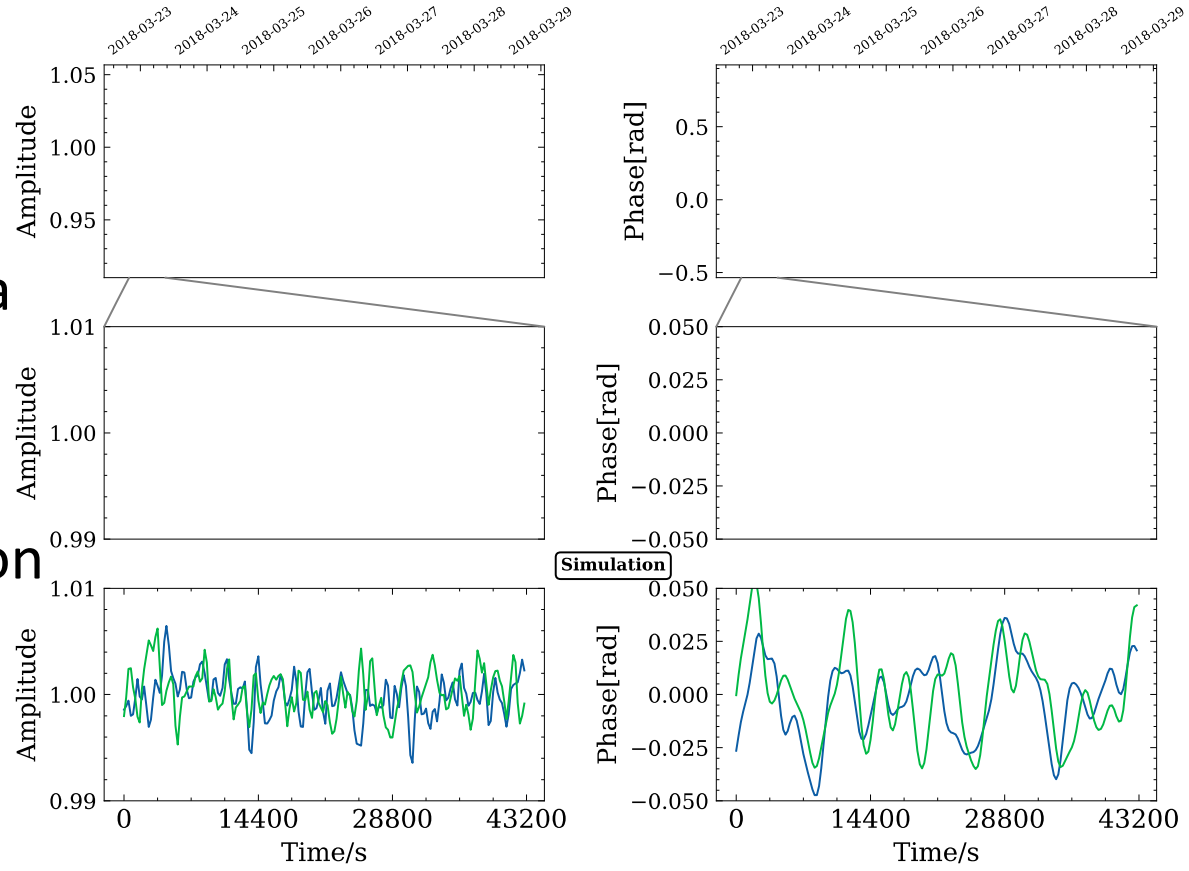
$$g(t) = (1 + \Delta g(t))\, e^{i2\pi\Phi(t)}$$

$$\Delta g \leftarrow N(0, \sigma_{amp}), \qquad \Phi \leftarrow N\left(0, \sigma_{phs}\right).$$

$$\Sigma_{ij} = \sigma^2 \exp\left(-\frac{(t_i - t_j)^2}{2\xi^2}\right),$$

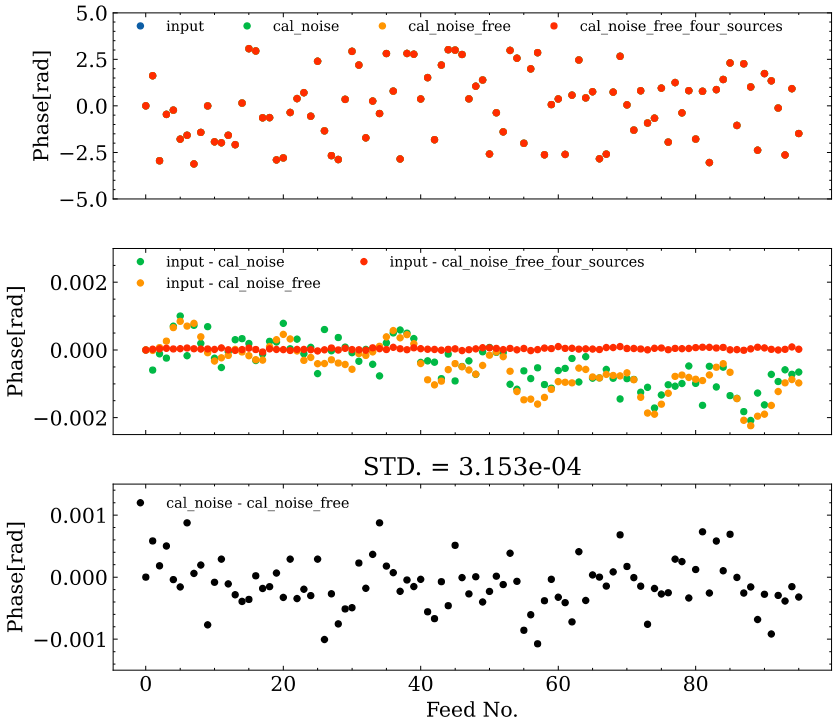
real data

simulation

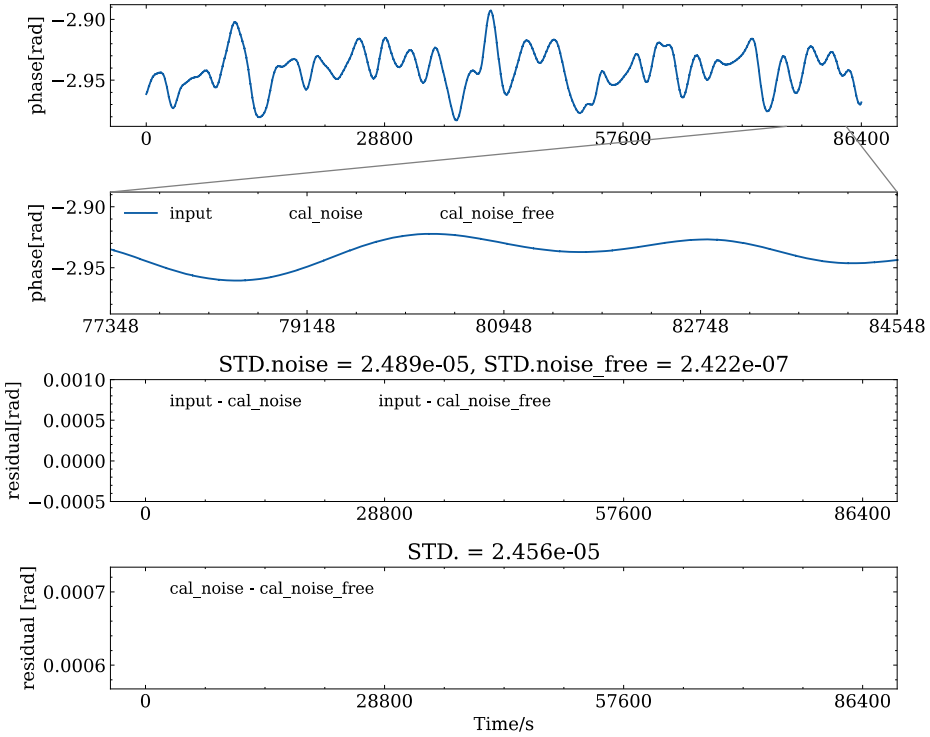


Calibration Errors from simulation

absolute calibration



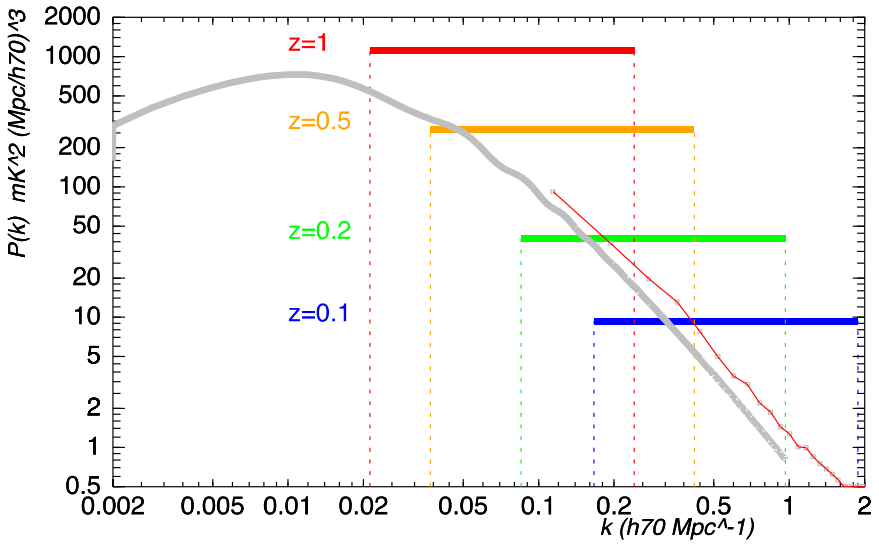
relative calibration



- even without noise, there is an error in absolute calibration ~ 10^{-3} rad
- noise induced error in absolute calibration ~ 10^{-4} rad
- noise induced error in relative calibration ~ 10^{-5} rad
- Origin of Error in Calibration: sky model—failure of single source dominance

Simulation-Dish

Perdereau et al. 2022 MNRAS



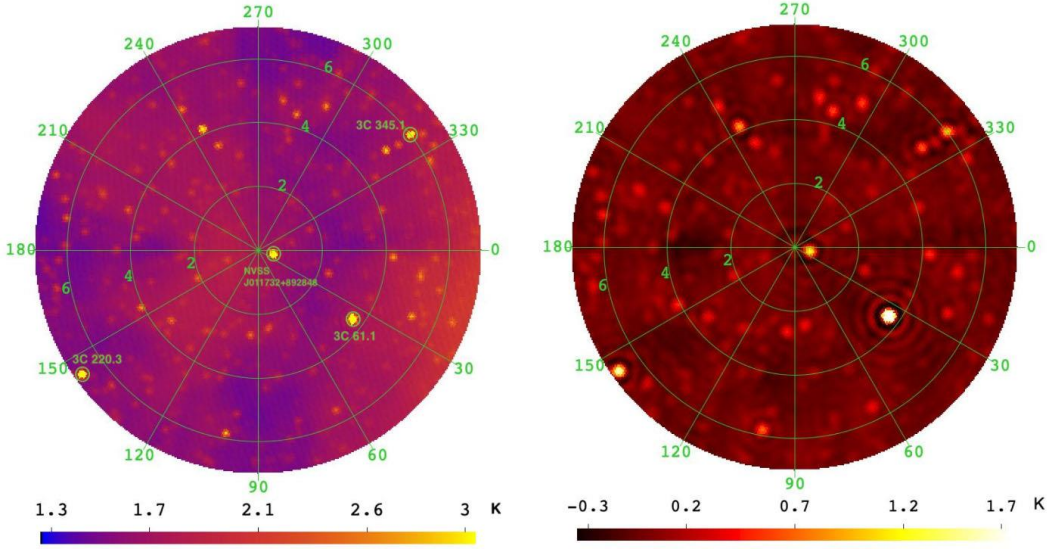
$$k_\perp(z) = \frac{\ell(z)}{d_M(z)}$$

$$\ell^{\min}(z=0) \simeq 75 \qquad \ell^{\max}(z=0) \simeq 850$$

$$k_\perp^{\min,\max} = \frac{1}{(1+z)\,d_M(z)} \times \ell^{\min,\max}(z=0)$$

$$P_{\rm noise}(z) \simeq (1+z)^2 d_M^2(z) \frac{c}{H(z)} \frac{\delta\nu}{\nu_{21}} (\delta\theta_0)^2 \times \left(\sigma_0^T\right)^2,$$

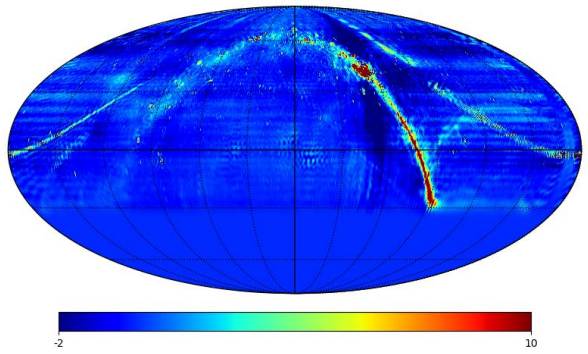
NCP region
(150 deg^2)



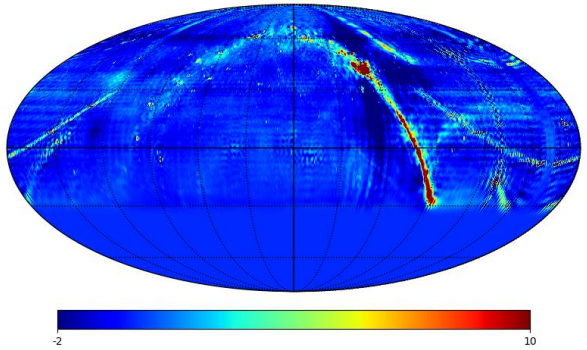
T_{sys}=80 K, σ_T(1MHz)=5mK
can be achieved by 2x1 month integration

The Tianlai collaboration is currently carrying out a Spectroscopic survey based on the NCCS photometric catalogue, performed with the WIYN telescope and HYDRA Spectrograph. A 4 degree radius disc around the NCP has been Targeted by the WIYN

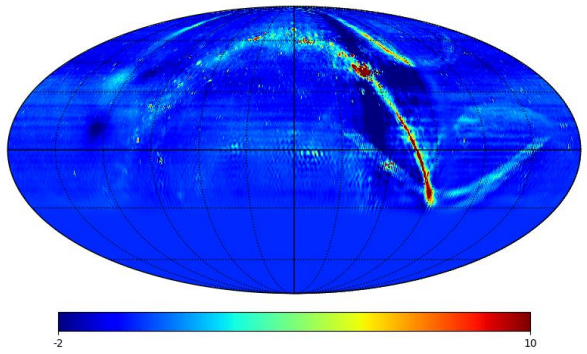
Maps in Equatorial Coordinates (single freq 750MHz)



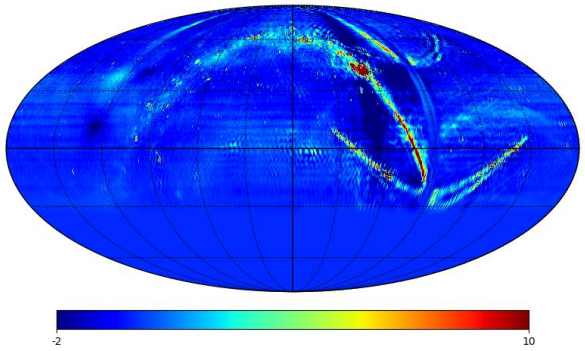
2016/9/27, 5 days



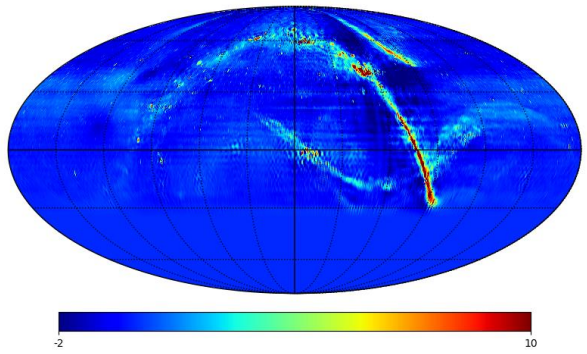
2016/10/11, 5 days



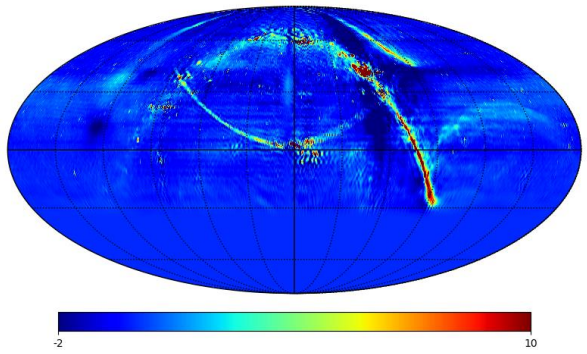
2017/12/9, 9 days



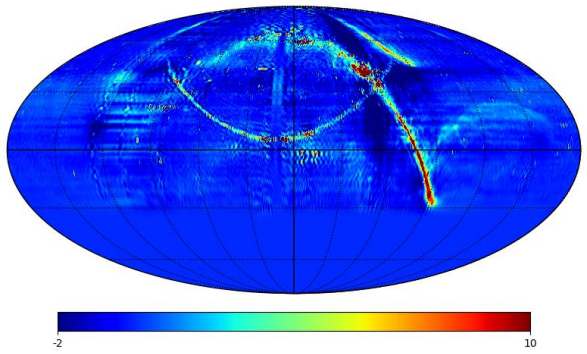
2017/12/20, 3 days



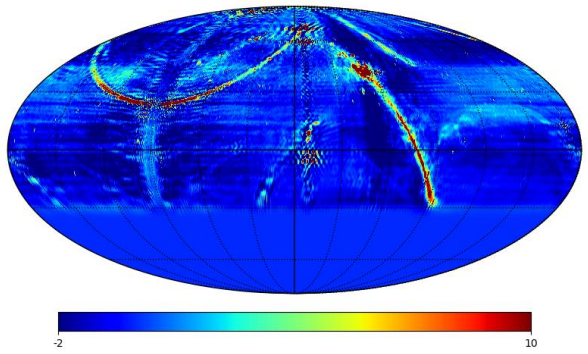
2018/1/21, 14 days



2018/3/22, 6 days

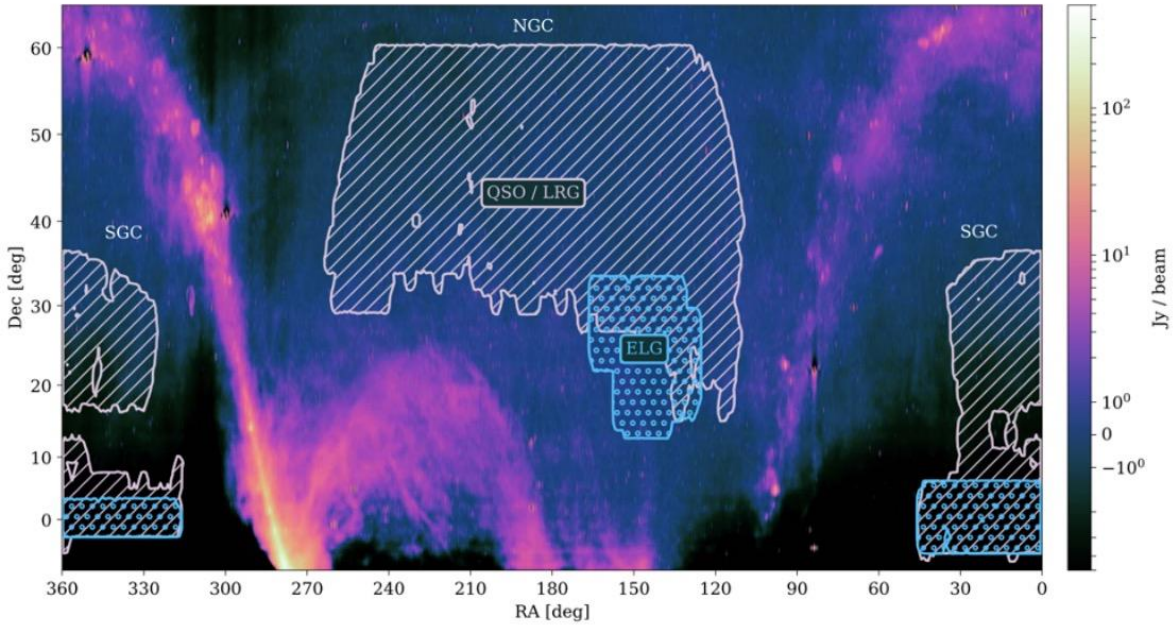


2018/3/31, 3 days

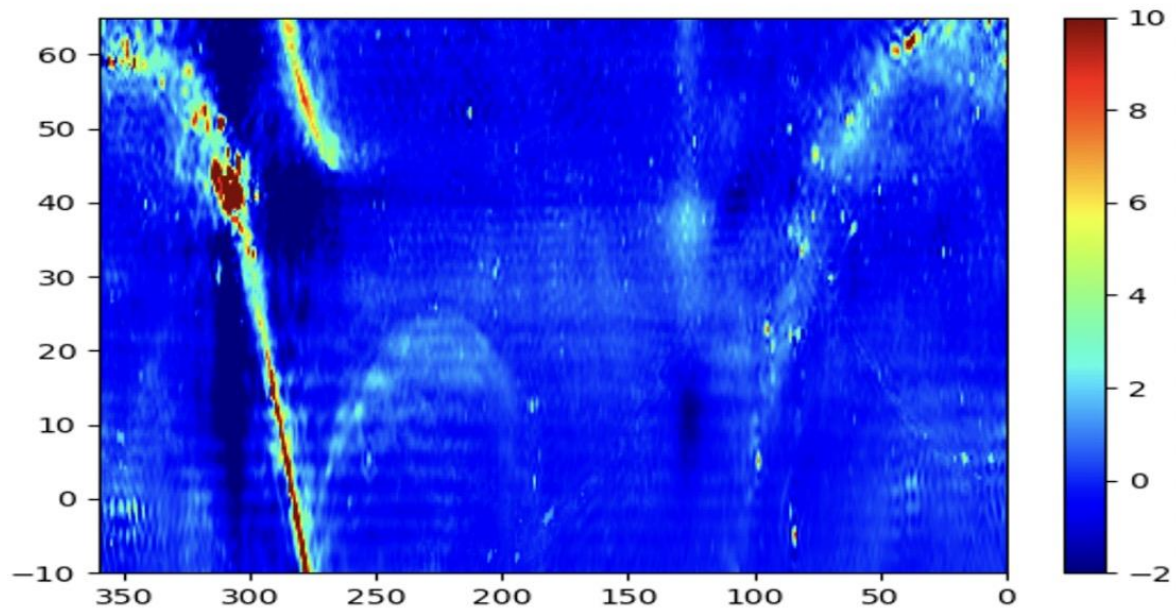


2023/6/21, 5 days

Stacking Analysis



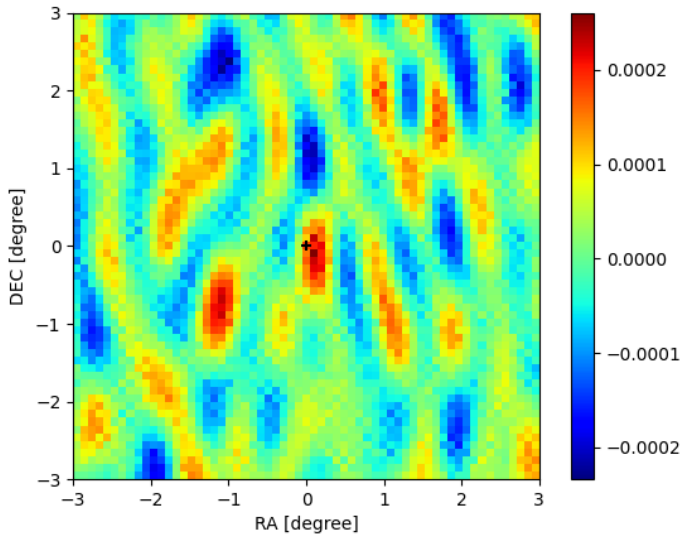
CHIME map



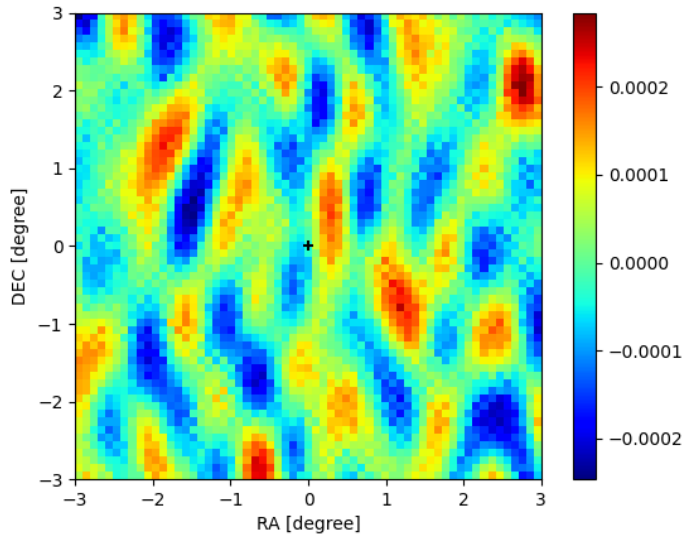
Tianlai map

Stacking Analysis

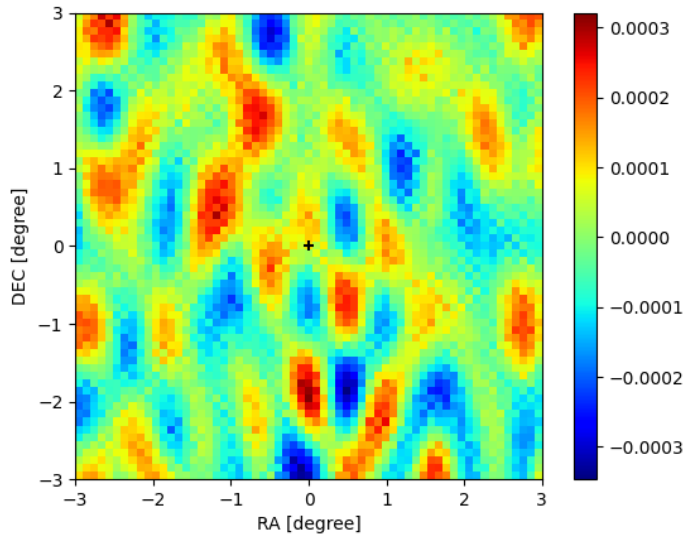
ELG

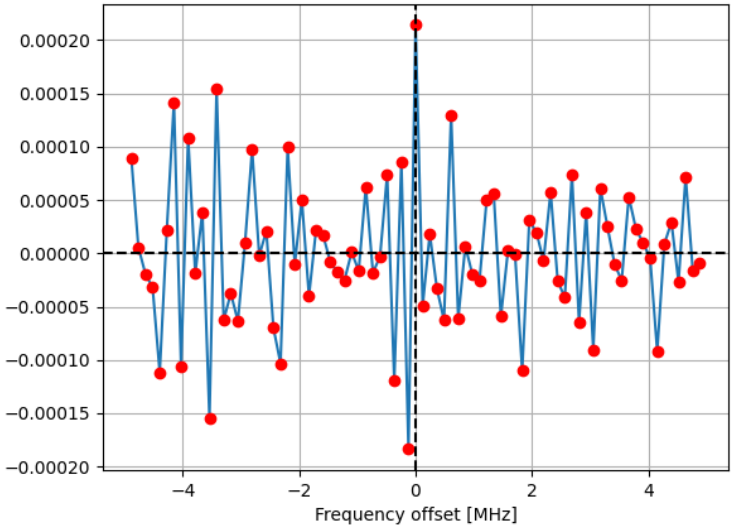


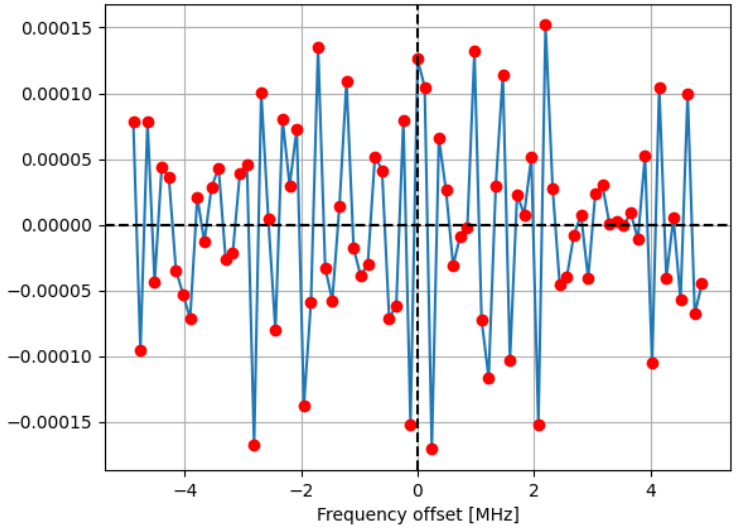
LRG

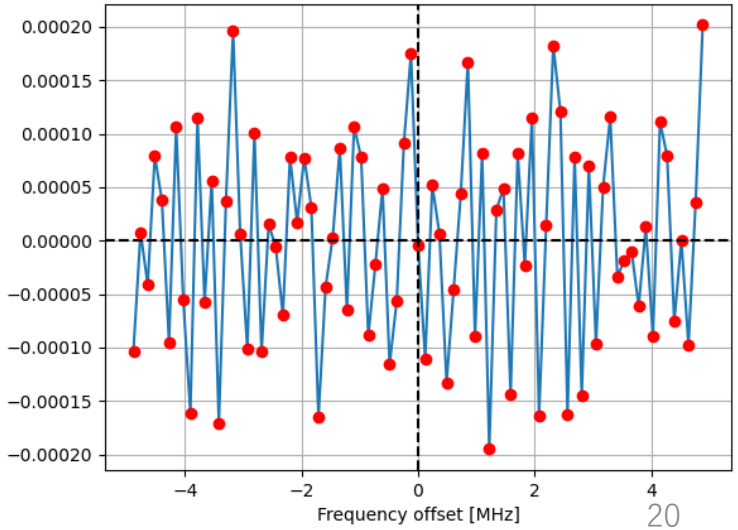


QSO

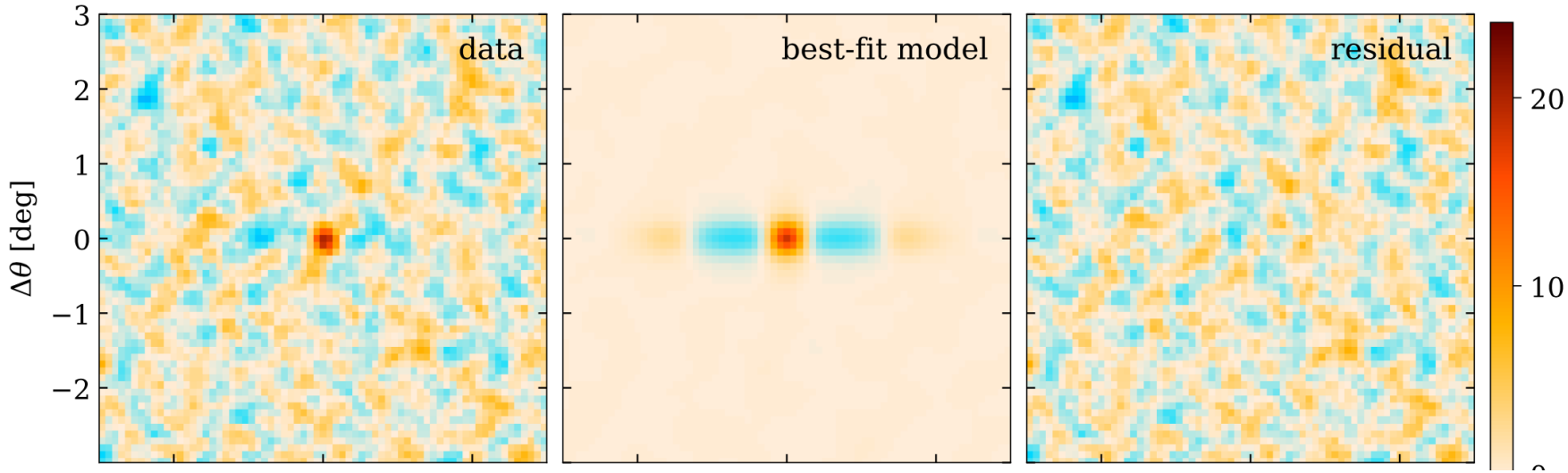


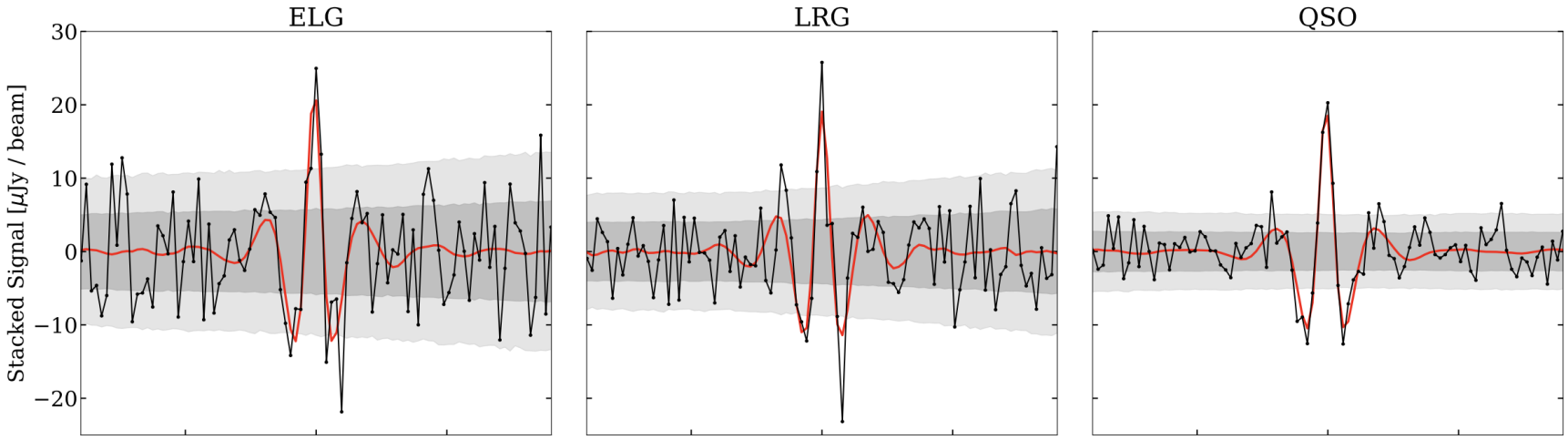




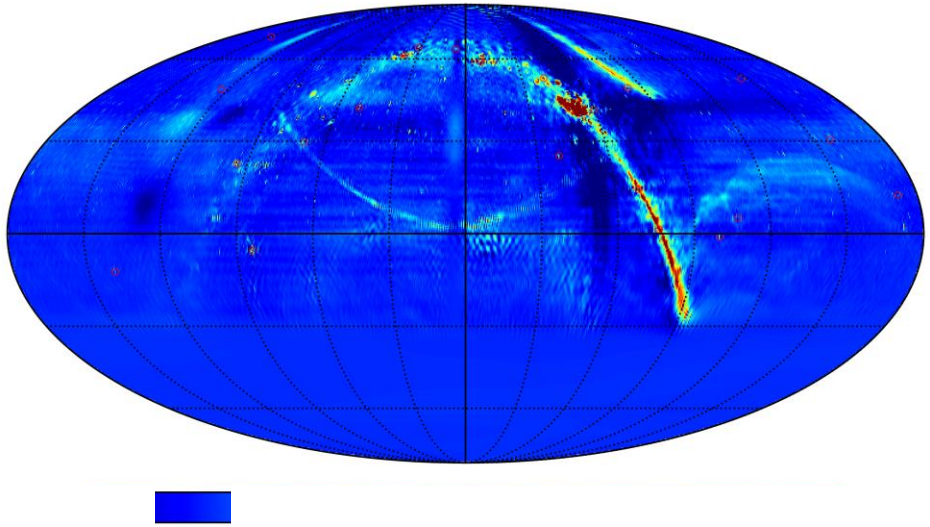


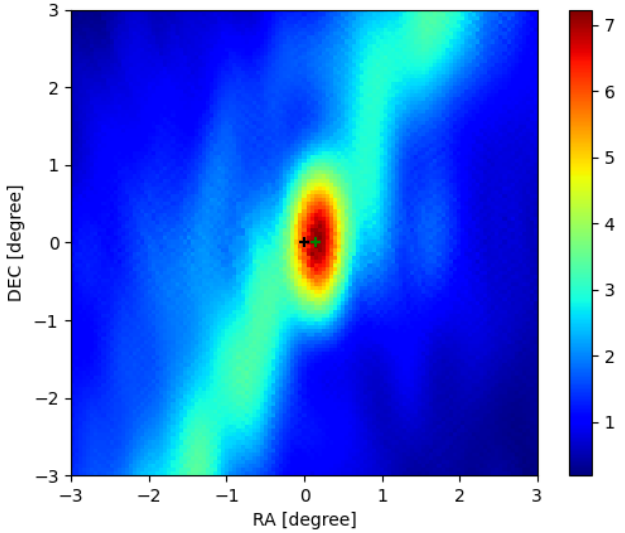
Stacking Analysis---CHIME Restults



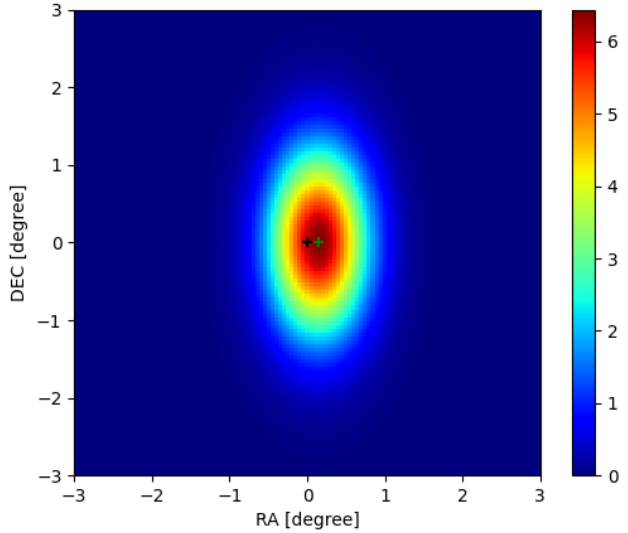


Stacking Analysis on Strong Sources

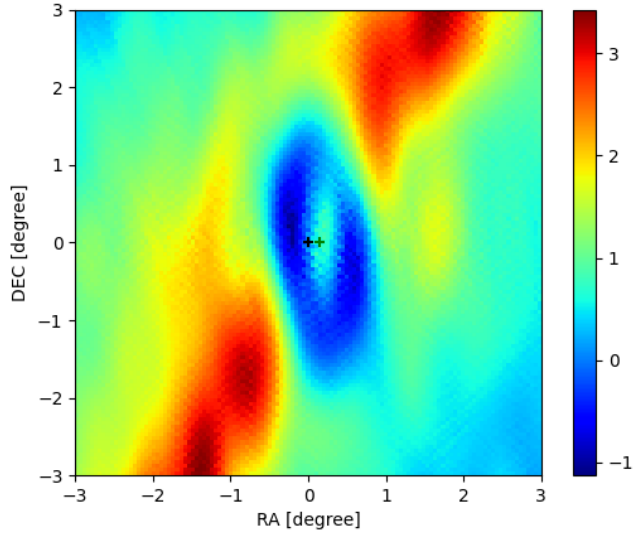




Stacked image



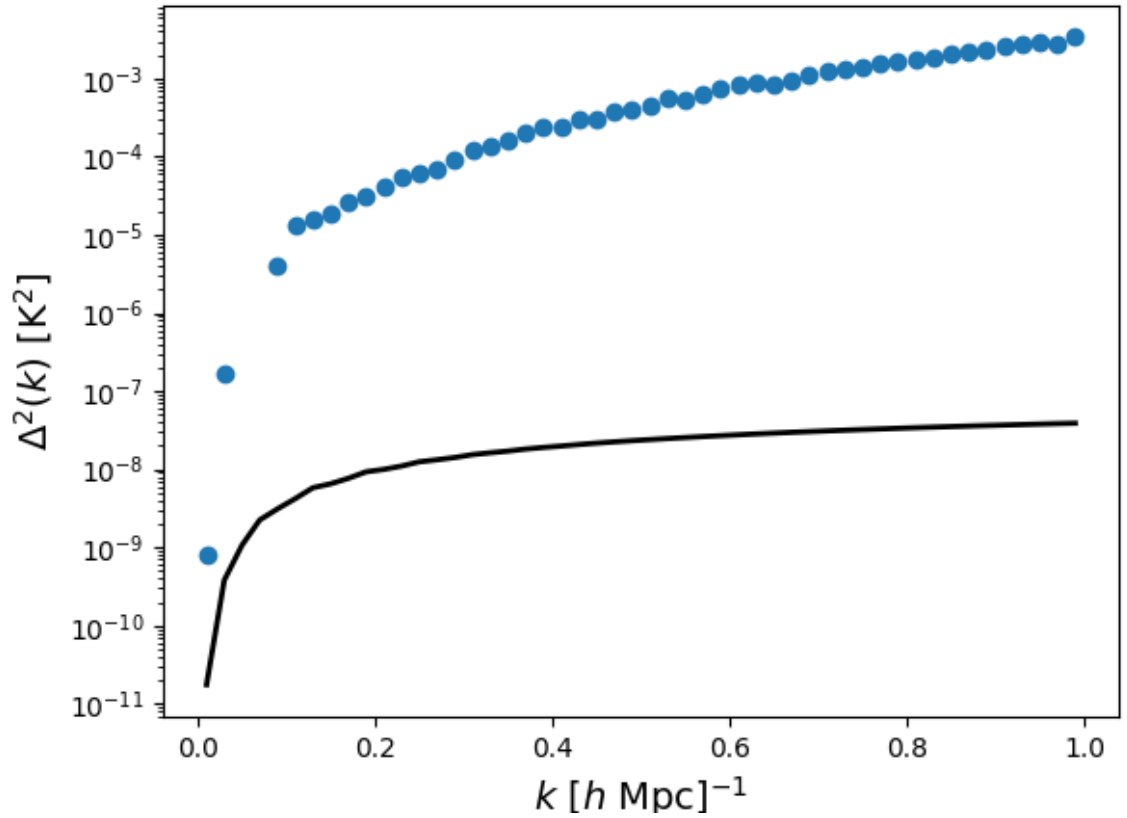
2D Gaussian fit



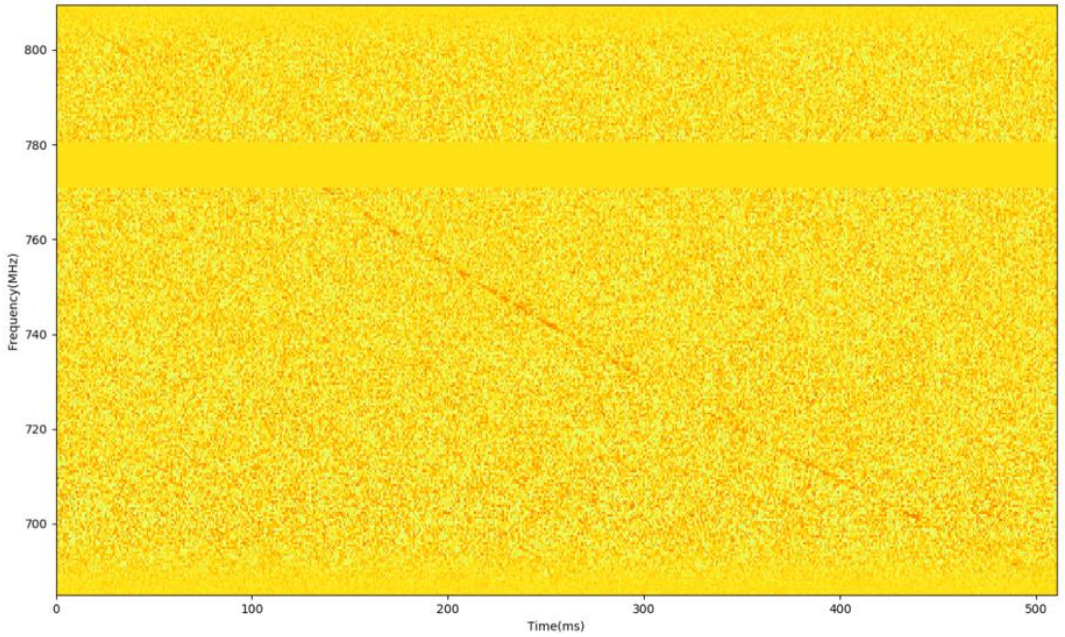
Residue

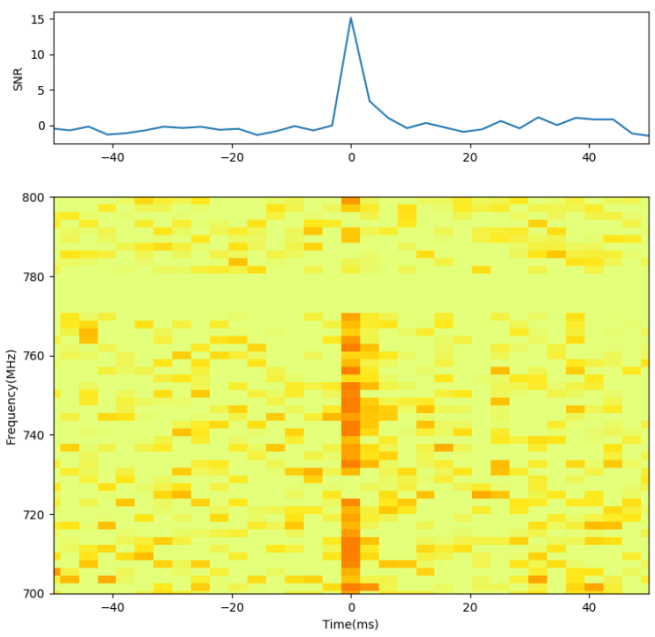
Power Spectrum

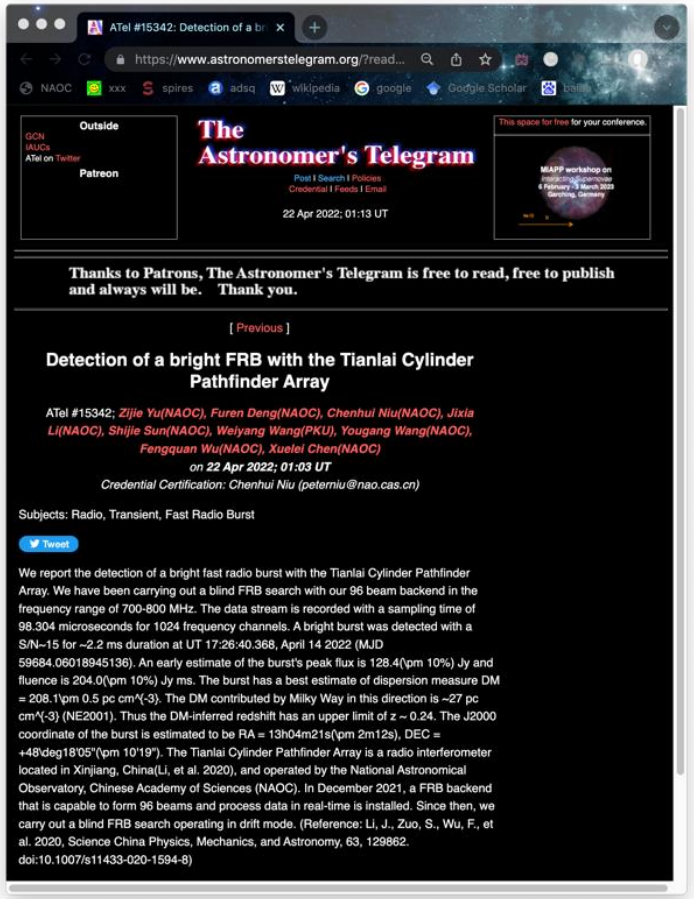
$\Delta^2(k) = k^3 P(k)/2\pi^2$ from 20160927 + 20180322



Detection of FRB by Tianlai Cylinder







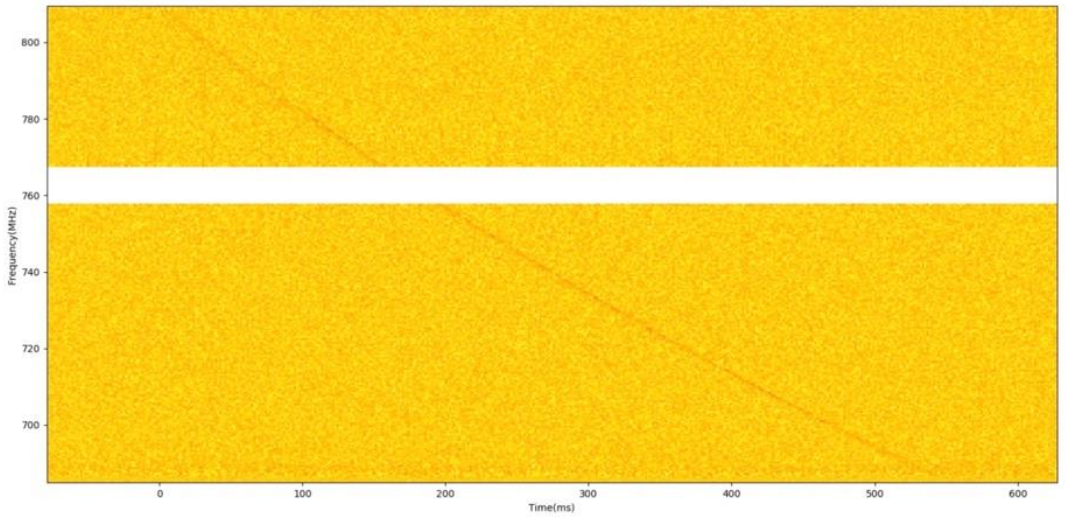
Blind Search 2022.04.14, 17:26:40.368 UT

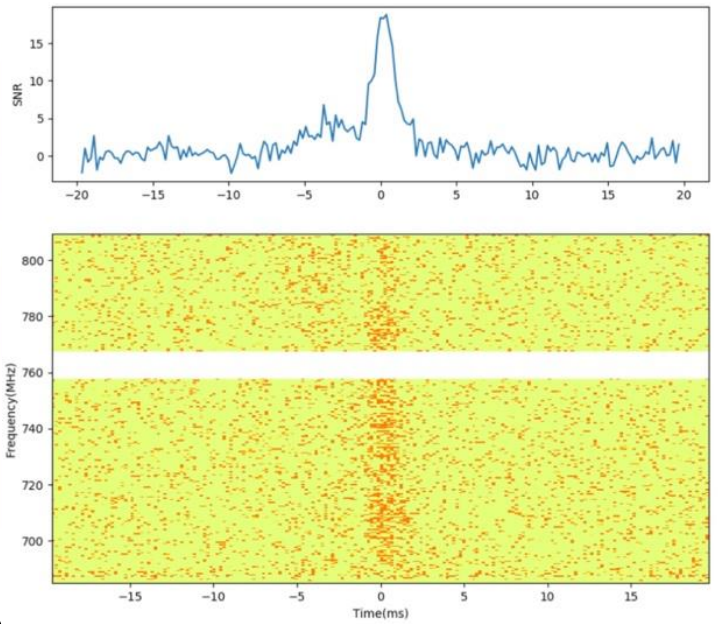
DM=208.1±0.5 pc cm^{-3}

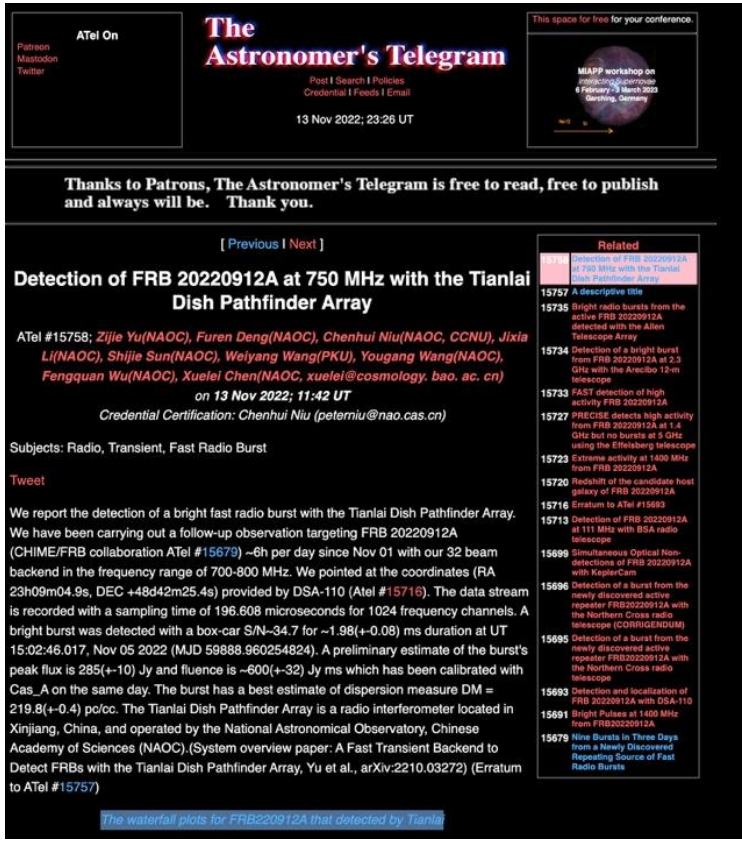
S_{peak} = 128.4 Jy, fluence = 204 Jy ms, z<0.24

Prediction：0.5/month

Detection of FRB by Tianlai Dish







ATel On
Patreon
Mastodon
Twitter

The Astronomer's Telegram
Post | Search | Policies
Credential | Feeds | Email

13 Nov 2022; 23:26 UT

This space for free for your conference.

Thanks to Patrons, The Astronomer's Telegram is free to read, free to publish and always will be. Thank you.

[Previous | Next]

Detection of FRB 20220912A at 750 MHz with the Tianlai Dish Pathfinder Array

ATel #15758; *Zijie Yu(NAOC), Furen Deng(NAOC), Chenhui Niu(NAOC, CCNU), Jixia Li(NAOC), Shijie Sun(NAOC), Weiyang Wang(PKU), Yougang Wang(NAOC), Fengquan Wu(NAOC), Xuelei Chen(NAOC, xuelei@cosmology. bao. ac. cn)*
on 13 Nov 2022; 11:42 UT
Credential Certification: Chenhui Niu (peterniu@nao.cas.cn)

Subjects: Radio, Transient, Fast Radio Burst

Tweet

We report the detection of a bright fast radio burst with the Tianlai Dish Pathfinder Array. We have been carrying out a follow-up observation targeting FRB 20220912A (CHIME/FRB collaboration ATel #15679) ~6h per day since Nov 01 with our 32 beam backend in the frequency range of 700-800 MHz. We pointed at the coordinates (RA 23h09m04.9s, DEC +48d42m25.4s) provided by DSA-110 (Atel #15716). The data stream is recorded with a sampling time of 196.608 microseconds for 1024 frequency channels. A bright burst was detected with a box-car S/N~34.7 for ~1.98(+-0.08) ms duration at UT 15:02:46.017, Nov 05 2022 (MJD 59888.960254824). A preliminary estimate of the burst's peak flux is 285(+-10) Jy and fluence is ~600(+-32) Jy ms which has been calibrated with Cas_A on the same day. The burst has a best estimate of dispersion measure DM = 219.8(+-0.4) pc/cc. The Tianlai Dish Pathfinder Array is a radio interferometer located in Xinjiang, China, and operated by the National Astronomical Observatory, Chinese Academy of Sciences (NAOC).(System overview paper: A Fast Transient Backend to Detect FRBs with the Tianlai Dish Pathfinder Array, Yu et al., arXiv:2210.03272) (Erratum to ATel #15757)

The waterfall plots for FRB220912A that detected by Tianlai

Related

15758 Detection of FRB 20220912A at 750 MHz with the Tianlai Dish Pathfinder Array
15757 A descriptive title
15735 Bright radio bursts from the active FRB 20220912A detected with the Allen Telescope Array
15734 Detection of a bright burst from FRB 20220912A at 2.3 GHz with the Arecibo 12-m telescope
15733 FAST detection of high activity FRB 20220912A
15727 PRECISE detects high activity from FRB 20220912A at 1.4 GHz but no bursts at 5 GHz using the Effelsberg telescope
15723 Extreme activity at 1400 MHz from FRB 20220912A
15720 Redshift of the candidate host galaxy of FRB 20220912A
15716 Erratum to ATel #15693
15713 Detection of FRB 20220912A at 111 MHz with BSA radio telescope
15699 Simultaneous Optical Non-detections of FRB 20220912A with KeplerCam
15696 Detection of a burst from the newly discovered active repeater FRB20220912A with the Northern Cross radio telescope (CORRIGENDUM)
15695 Detection of a burst from the newly discovered active repeater FRB20220912A with the Northern Cross radio telescope
15693 Detection and localization of FRB 20220912A with DSA-110
15691 Bright Pulses at 1400 MHz from FRB20220912A
15679 Nine Bursts in Three Days from a Newly Discovered Repeating Source of Fast Radio Bursts

Observation of repeat FRB 20220912A detection on 2022.11.05 15:02:46.017 UT

DM =219.8

S_{peak}=285 Jy, fluency=600 Jy ms

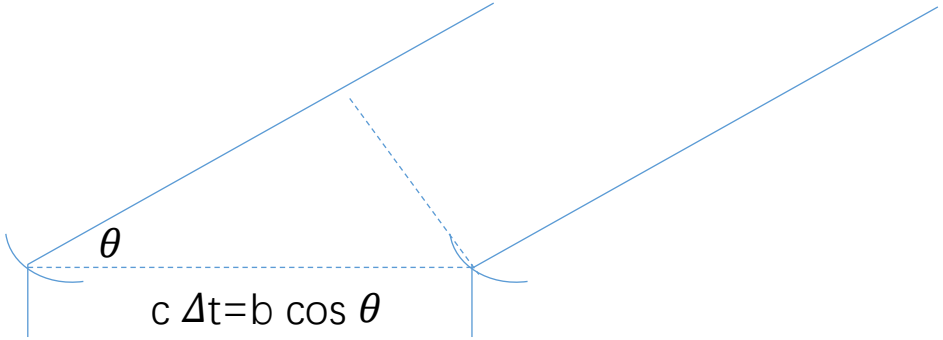
Prediction：0.27/month

Locating FRB with Outtrigers

current Tianlai FRB locating precision is

beam size ~ λ/b ~ 0.4m/30m ~ 0.75°

Too coarse! Need better locating precision



Use outtriger to improve precision:

c Δt=b cos θ

Error: $\delta\theta = \frac{c\,\delta(\Delta t)}{b\,\sin\theta}$

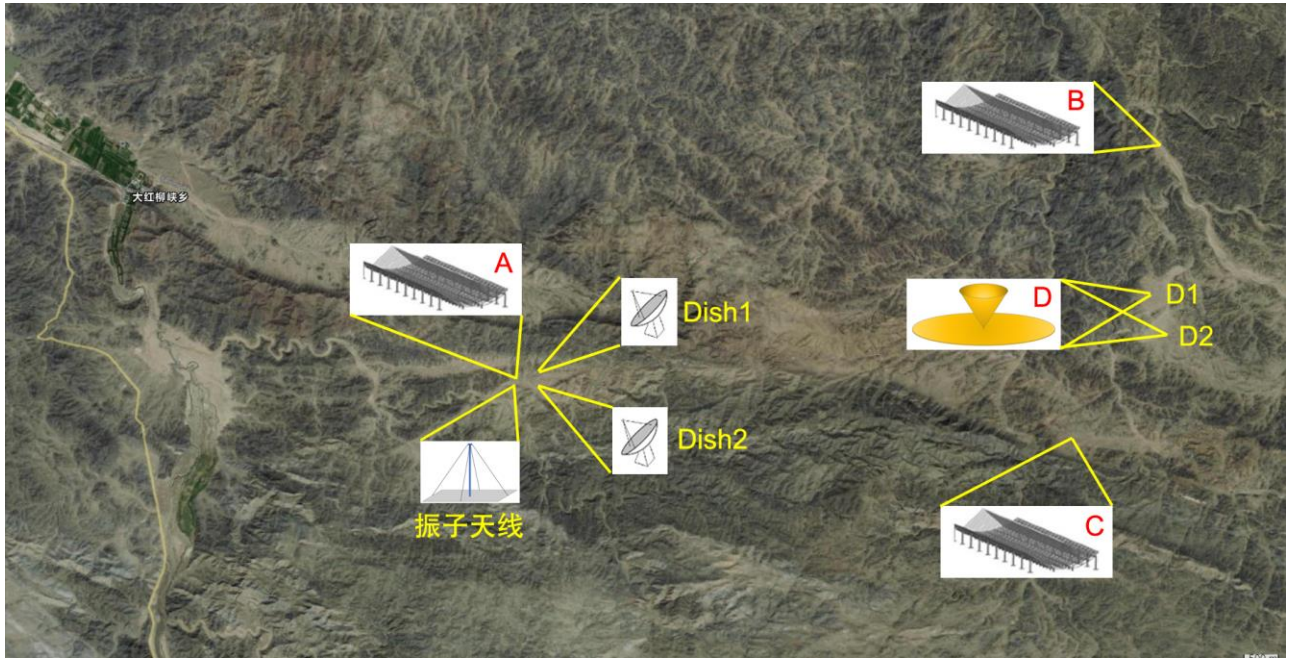
- Outtrigers store raw voltage data for some time (e.g. 1 min.)
- Do the FRB search with the main array
- FRB candidate detected—with direction, time, DM value
- Search the same FRB event in the outtrigger data, using cross correlation to measure c Δt, determine θ

$\delta(\Delta t)<1/(250\ \mathrm{MHz})=4$ ns

$$\delta\theta = 24.75\,\frac{10\ \mathrm{km}}{b\,\sin\theta}\ \mathrm{arcsec}$$

Tianlai phase II project

- Cylinder at A for imaging
- Cylinder B,C as FRB outtriger
- Dishes are for better calibration
- Global Spectrum Experiment at D1, D2
- Dipole antenna experiment



Collaboration with Northeastern University to construct the FRB outtriger

AB：9.518KM　　BC：4.186KM　　AC：7.863KM

Next plan

- Conduct the survey (continuous observation)
- Beam Mapping with Holography
- Polarization Analysis
- Foreground subtraction and 21cm power spectrum improvement

Thanks!