21cm intensity mapping: the Tianlai Project

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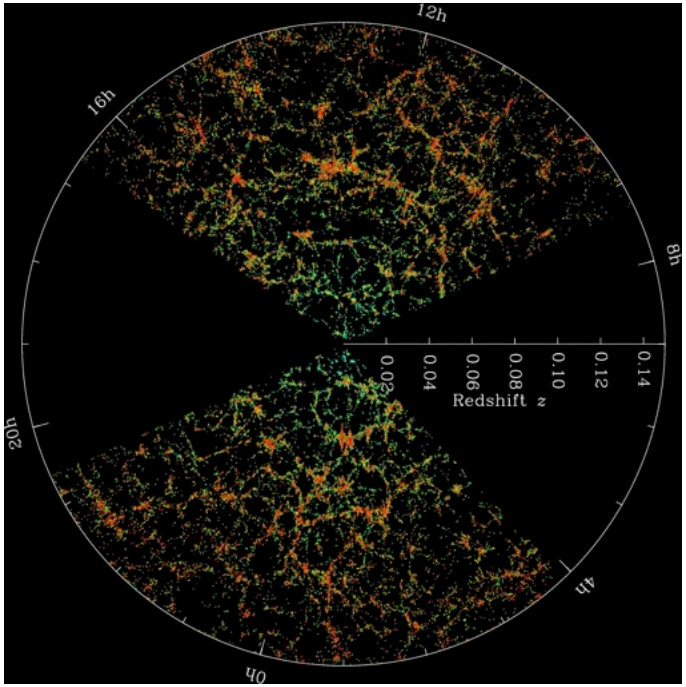
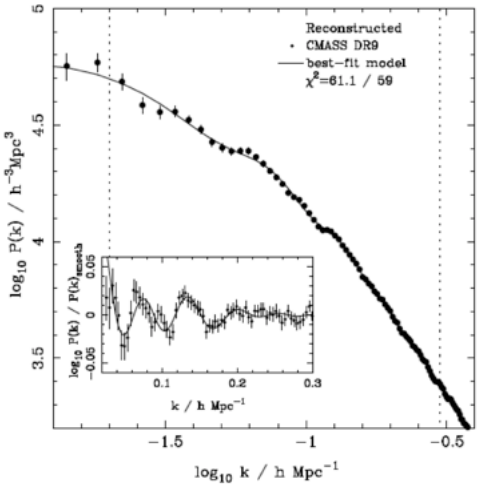
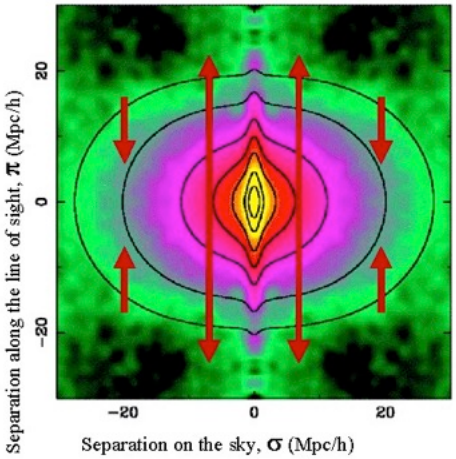
“Swiss SKA Days 2019”

Dark Energy from large scale structure





Baryon Acoustic Oscillation (BAO)

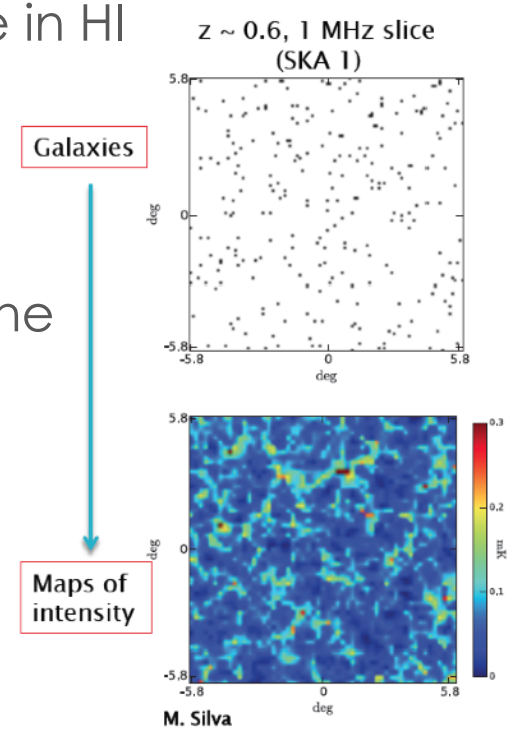


Redshift Space Distortion (RSD)

Why Intensity Mapping in Cosmology

- IM offers an alternative approach to map the 3D structure of the universe across redshift
- Galaxies get fainter with distance: hard to see individually at cosmological distance; hard to see in HI
- Large scale structure is large: degree scale; high resolution not needed; HI is visible
- Exciting potential to map all available modes in the universe - probe the LSS, EOR, dark ages …

Intensity Mapping (T. Chang et al. 2008): Map the intensity distribution with low angular resolution, individual galaxies are not resolved



The Tianlai (Heavenly Sound) Project

NAOC (PI: **Xuelei Chen**), Xinjiang Observatory, CETC-54, Institute of Automation, Hangzhou Dianzi U., SJTU

US: CMU(J. Peterson), U. Wisconsin (P. Timbie), Fermilab(A. Stebbins)

LAL/IN2P3 (R. Ansari, J.E Campagne, M. Moniez), Obs. Paris (J.-M. Martin, P. Colom) , IRFU-CEA(C. Magneville, C. Yeche), CITA(Pen), KASI (Song), ASIAA/JPL (Chang)

Monthly Teleconf and annual Collaboration Meeting since 2010

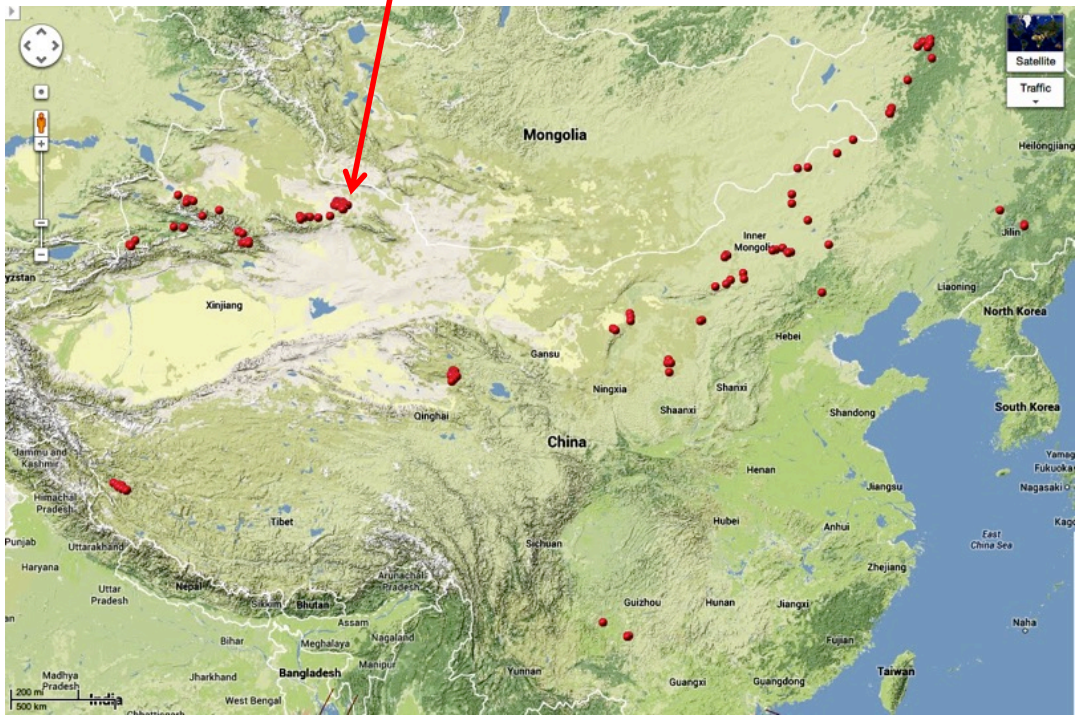
The word "Tianlai" means "heavenly sound" in Chinese, this phrase appeared first in the work of ancient Chinese philosopher Chuang Tzu (369BC-286BC).

Project Wiki:
http://tianlai.bao.ac.cn/wiki

Site Surveys in China

- Low RFI (low population density, shielded by mountains)
- wide open terrain
- convenience in logistics, electricity,communication
- We checked for > 100 potential sites

Hongliuxia site in Balikun



Site Selection

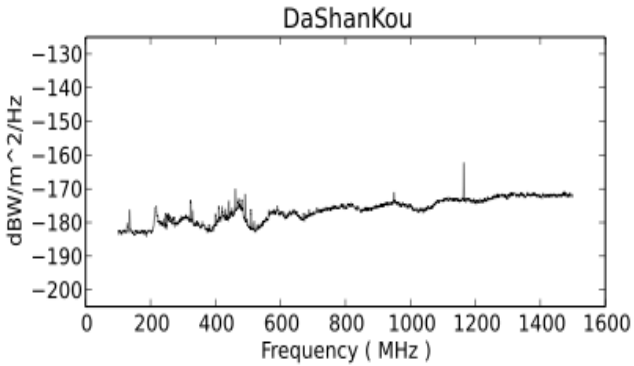
A site in Baiqi, Inner Mongolia

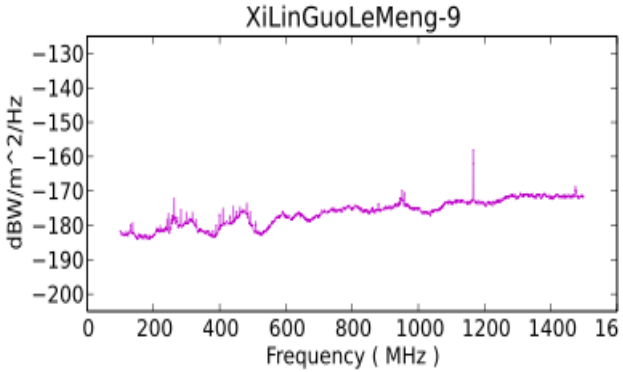
in Guizhou near FAST

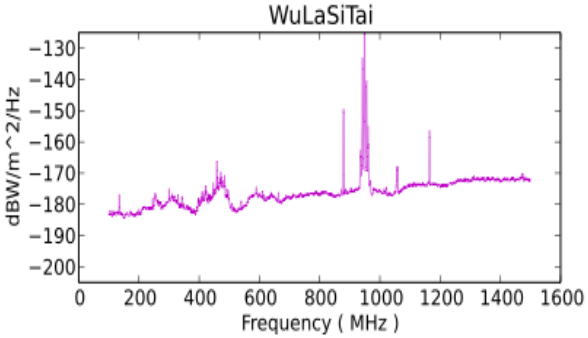
in Jiaohe, Jilin, NE China

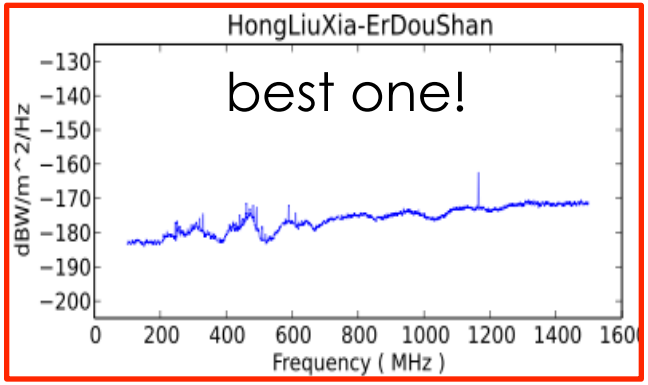
in Ali, Tibet

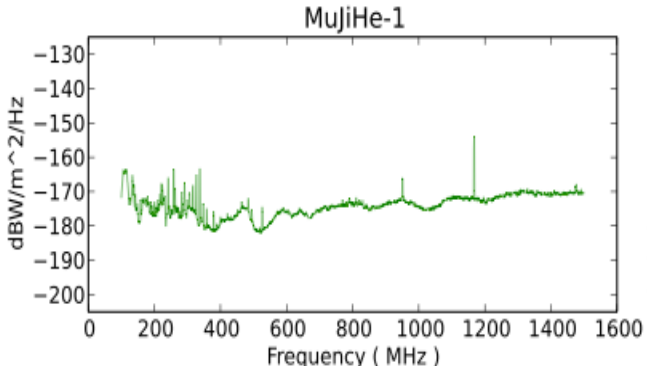
RFI measurements

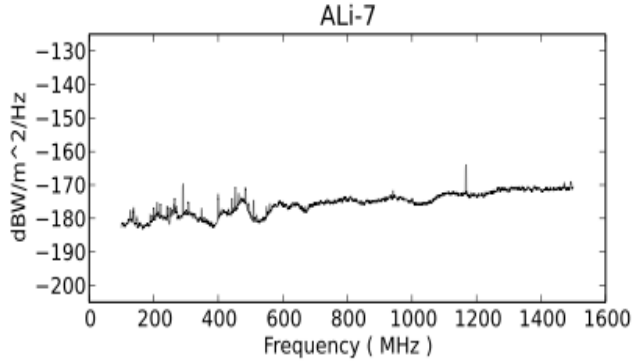


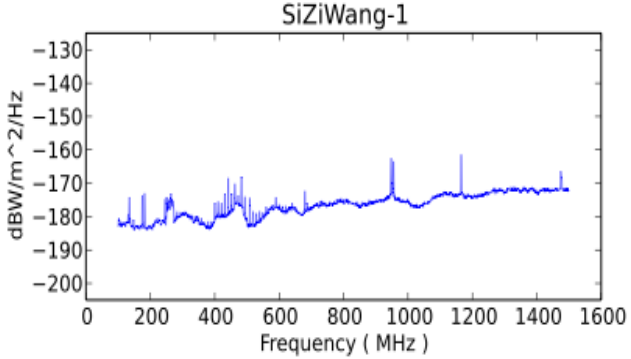


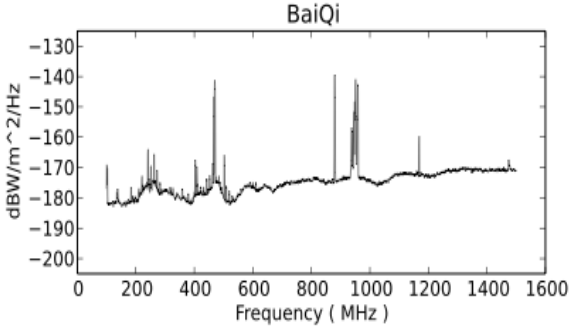








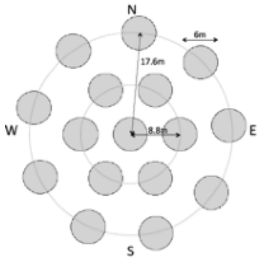




Tianlai pathfinder experiment

- A small pathfinder experiment to check the basic principles and designs, find out potential problems

- 3x15mx40m cylinders, 96 dual polarization receiver units

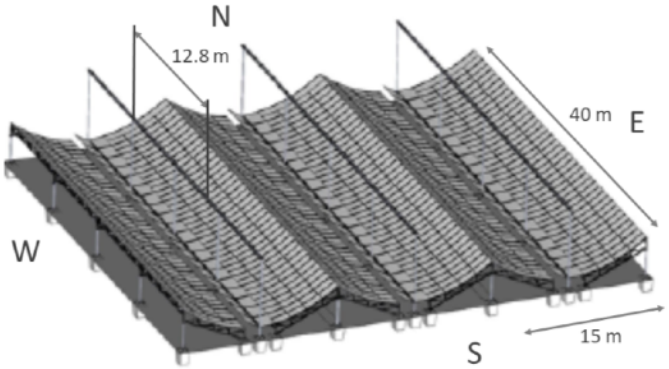


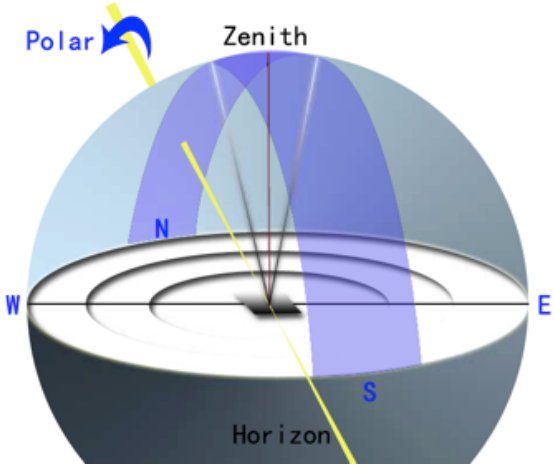
- 16 x 6m dishes

- observe 700-800MHz, can be tuned in 600-1420MHz

- If successful: expand to full scale 120mx120m, 2500 units

Long axes oriented along the N-S direction

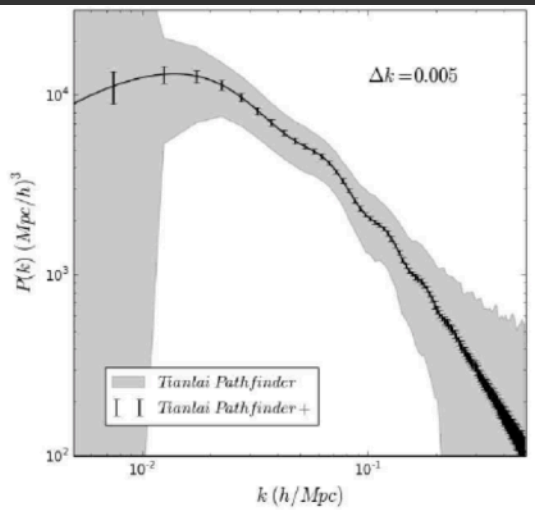


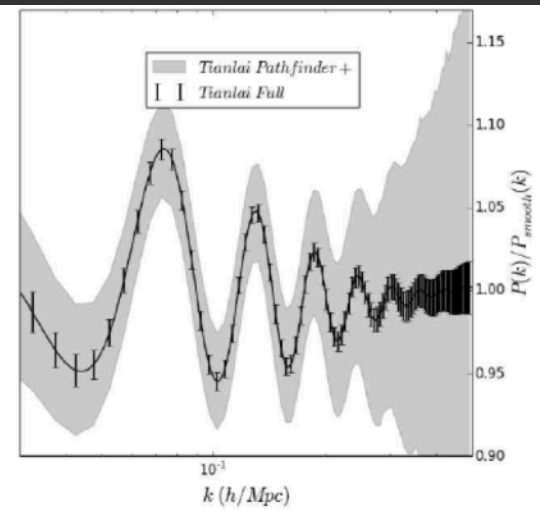


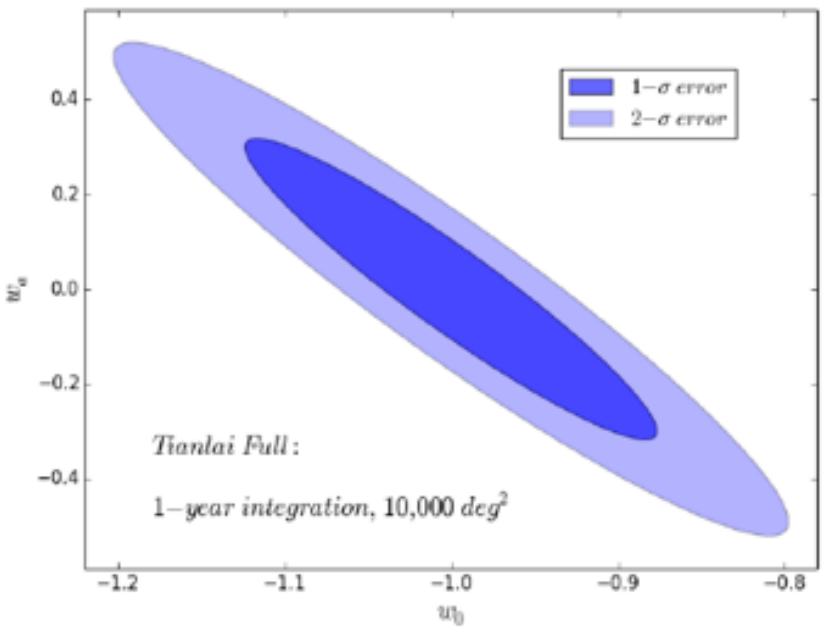
Dishes and Cylinders

Receiver and Correlator

BAO forecast







Xu, Wang & Chen, ApJ 2014

constraint on PNG from power spectrum (scale-dependent bias)

	pathfinder	pathfinder+	full scale
$N_{\rm feed}$ per cylinder	32	72	256
$\sigma_{f_{\rm NL}}^{\rm local}$	1504	161	14.1

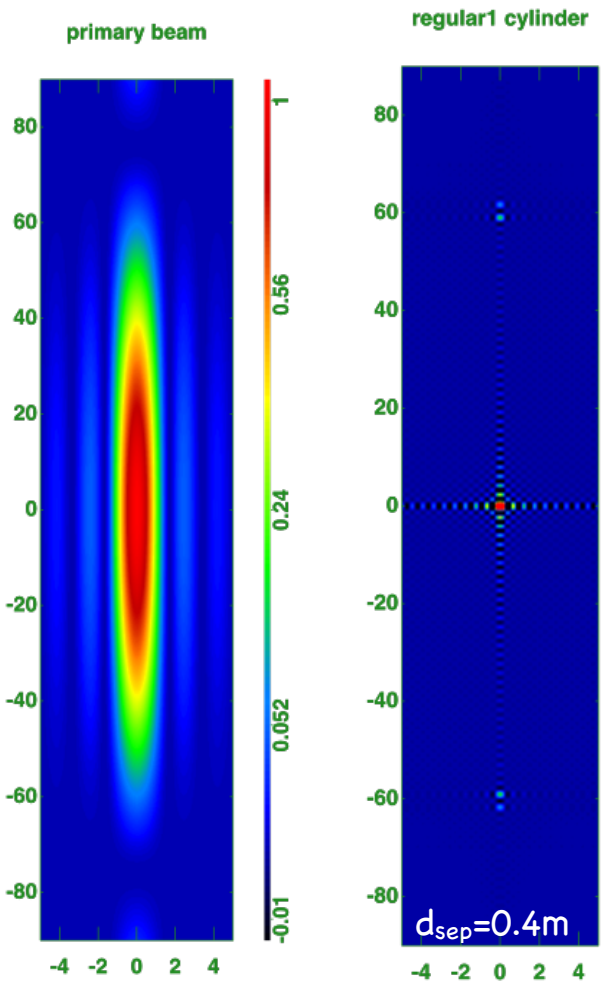
constraint on PNG from bispectrum

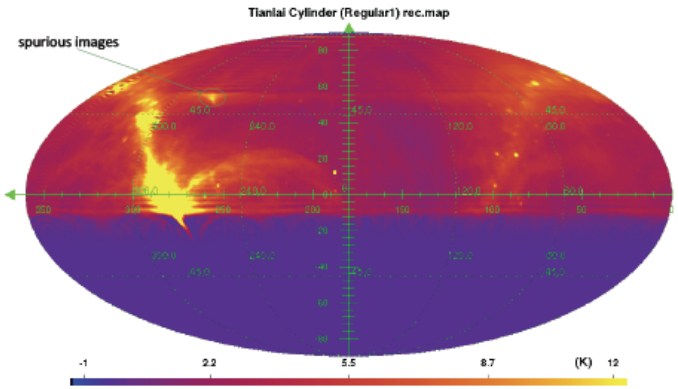
$N_{\rm feed}$ per cylinder	Pathfinder 32	Pathfinder+ 72	Full scale 256
$\sigma_{f_{\rm NL}}^{\rm local}$	70814	2272	21.7
$\sigma_{f_{\rm NL}}^{\rm equil}$	79427	2754	157

Brief status on site

- 2018 Aug: Begin Drone experiment
- 2018 Apr: Test using dish system to receive telemetry signal from HIT micro-satellites
- 2018 Apr: EM environment survey by French neutrino experiment group (GRAND)
- 2018 Mar: Linear power supply and some optical modules failed
- 2018 Mar: GPS receiver begin to record the data
- 2018 Jan: pulsar observation experiment for dish system
- 2017 Dec: Installed batteries of online UPS system
- 2017 Oct: completed 863 project review
- 2017 Aug: Fixed known problems in calibrator noise source
- 2017 Jul: re-installed all the DSP board and repare 32-chan correlator
- 2016 Dec: completed 863 technical review
- 2016 Sep: First Light

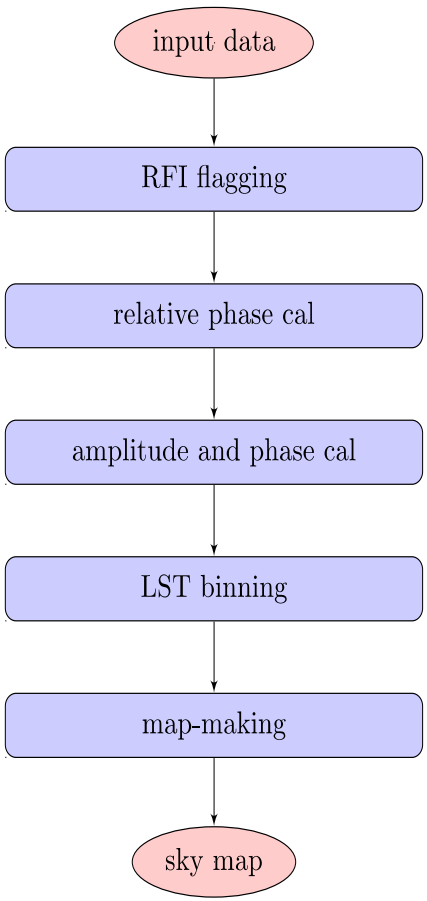
Cylinder Array simulation - Beam



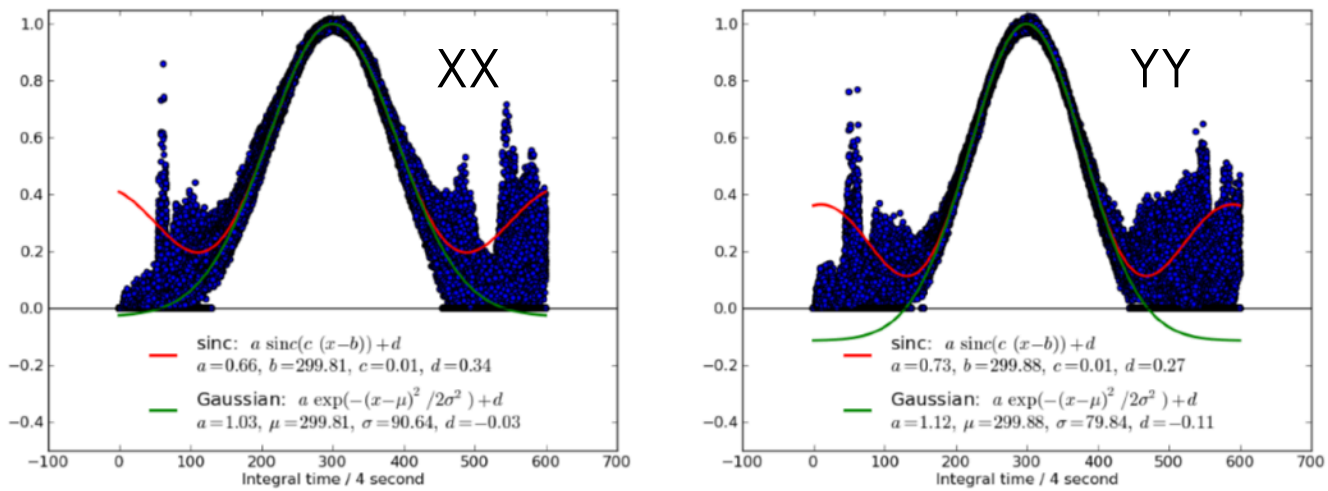


Wide primary beam - NS direction
Narrow primary beam - EW direction

Preliminary Analysis: calibration



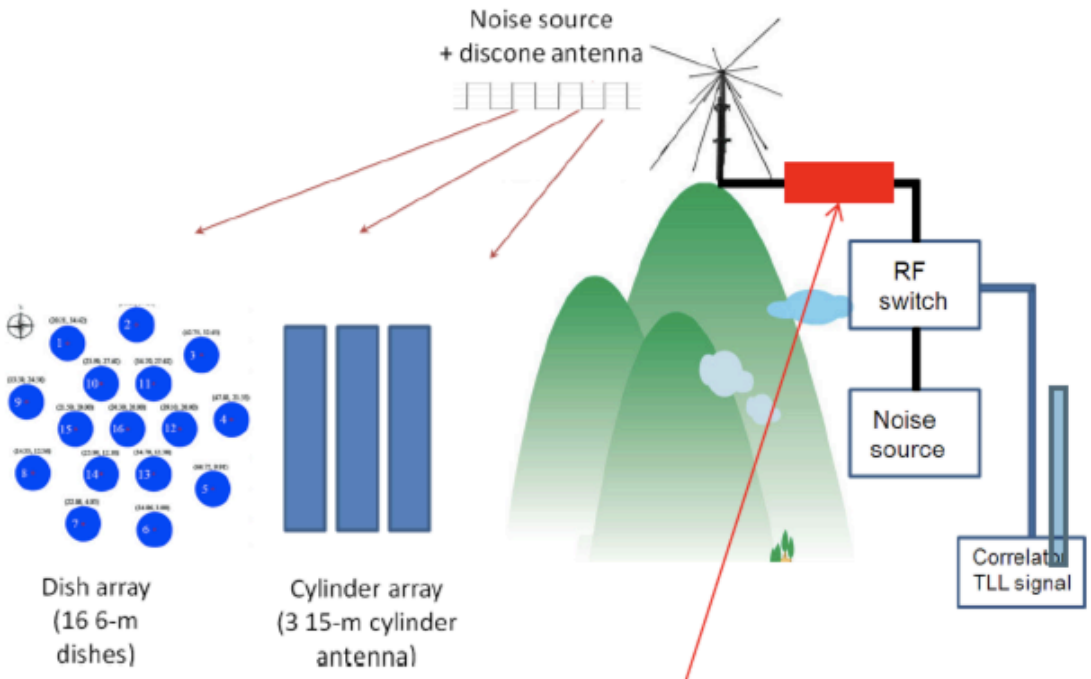
Cygnus A as a calibrator:

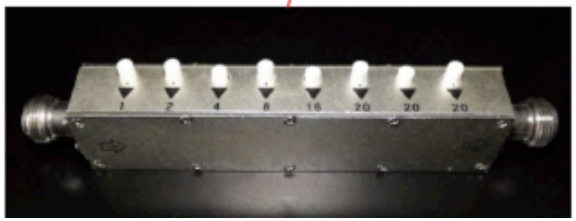


East-West beam profile along the transit track of the point source at 750 MHz

- Beam pattern: sinc-like function
- Sidelobes of the beam vary significantly with frequency

System testing using calibrator noise source

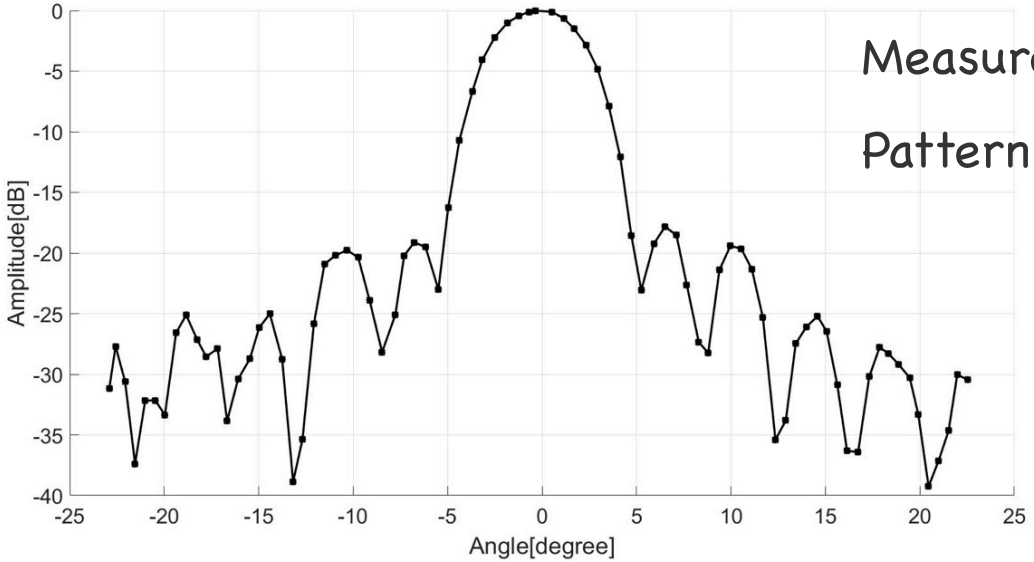




Adjustable Attenuator

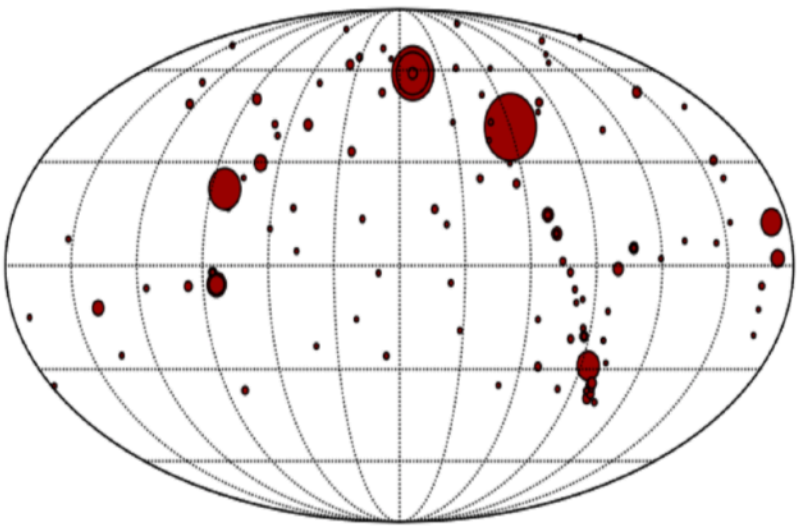
Drone experiment for beam

It can reach an altitude of 2500 m with positional accuracy of ~ 1 cm



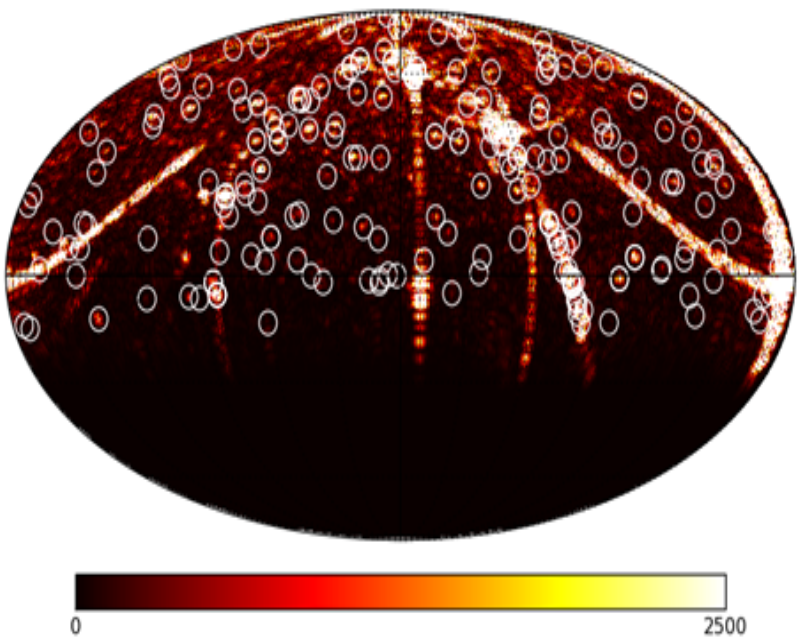
Measured Dish Antenna Pattern at 730MHz

Comparison with NVSS sources



NVSS (1.4GHz) bright sources

First light image

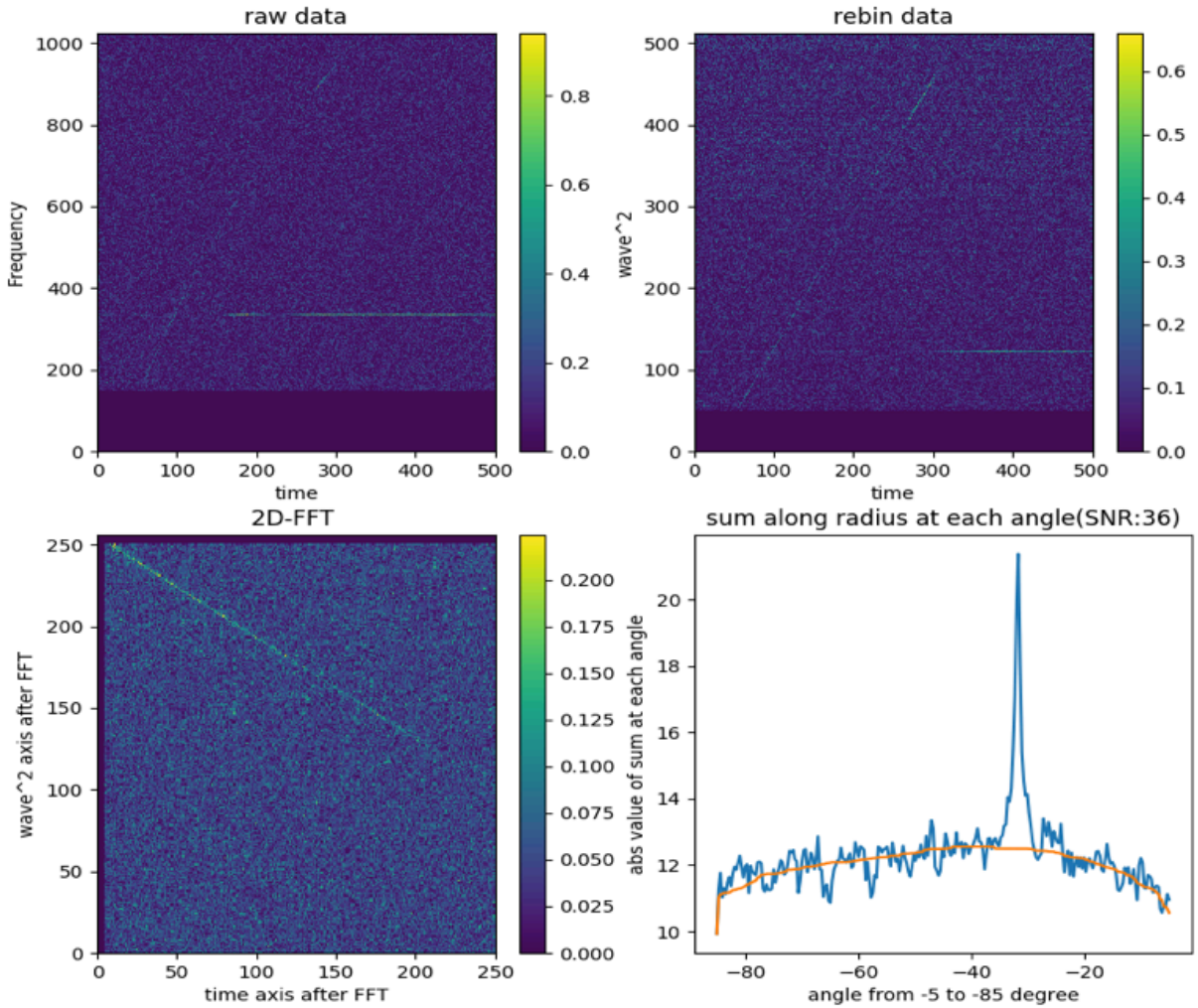


First Light Map
5 frequency average for observation of Sept. 27-30, 2016

S. Zuo et al., in preparation

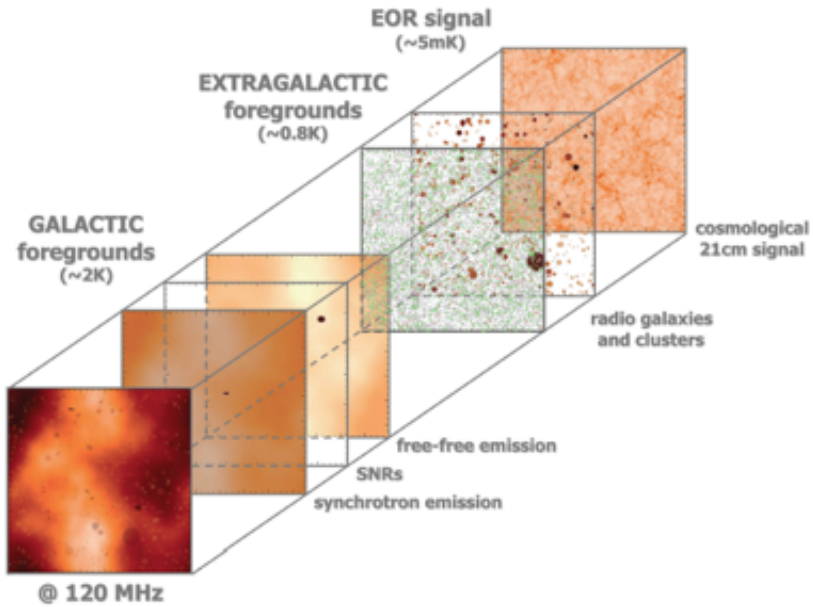
New algorithm on Transient search

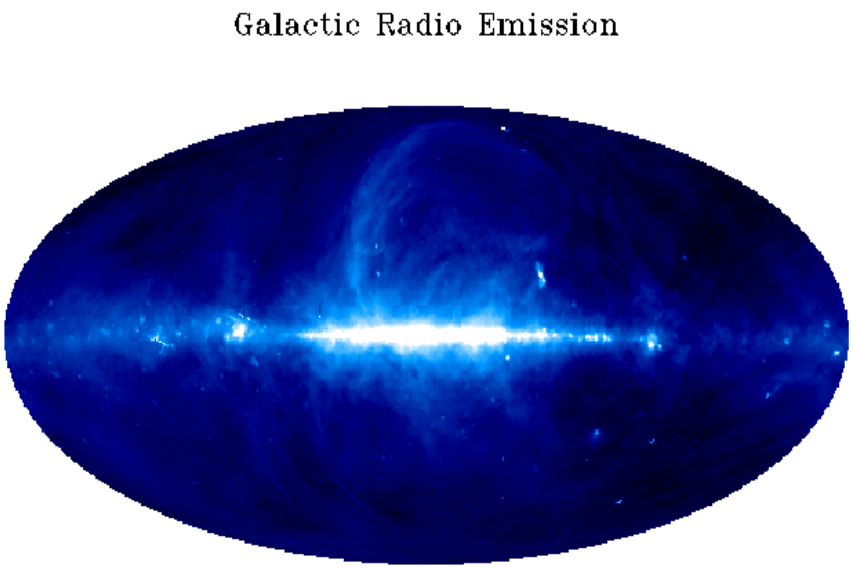
- Develop a new FRB search algorithm (2DFFT)



The challenge: foreground removal

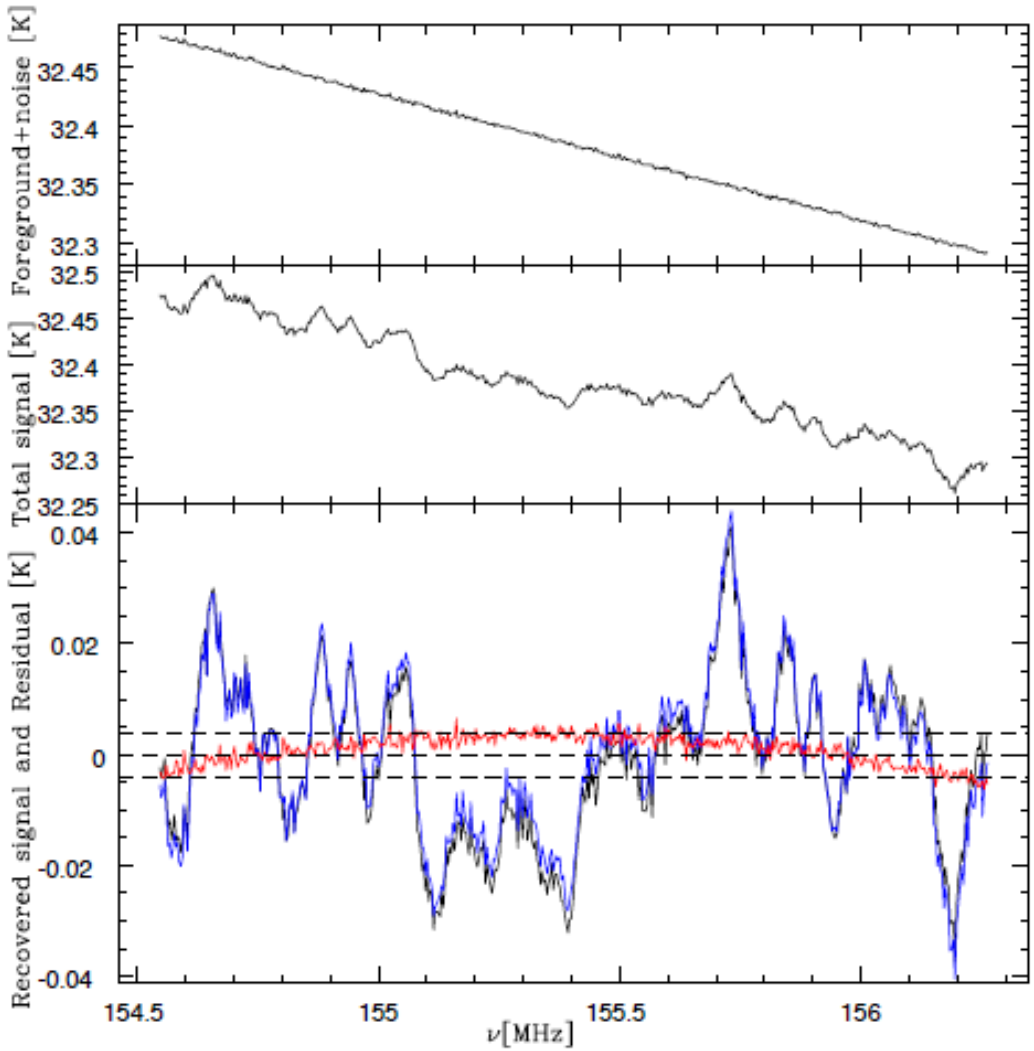
raw signal to noise ration (SNR) ~ 10^{-5}





V. Jelic et al. (2010)

Subtract the Foreground: polynomial fitting



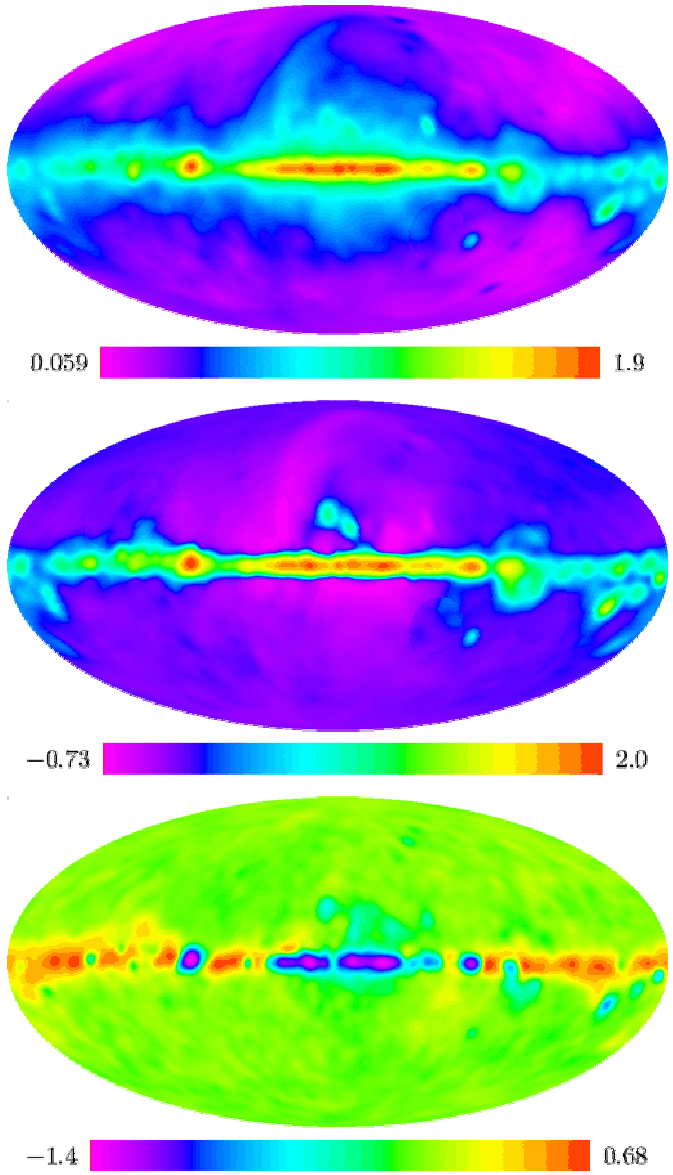
smooth foreground

foreground+21cm signal

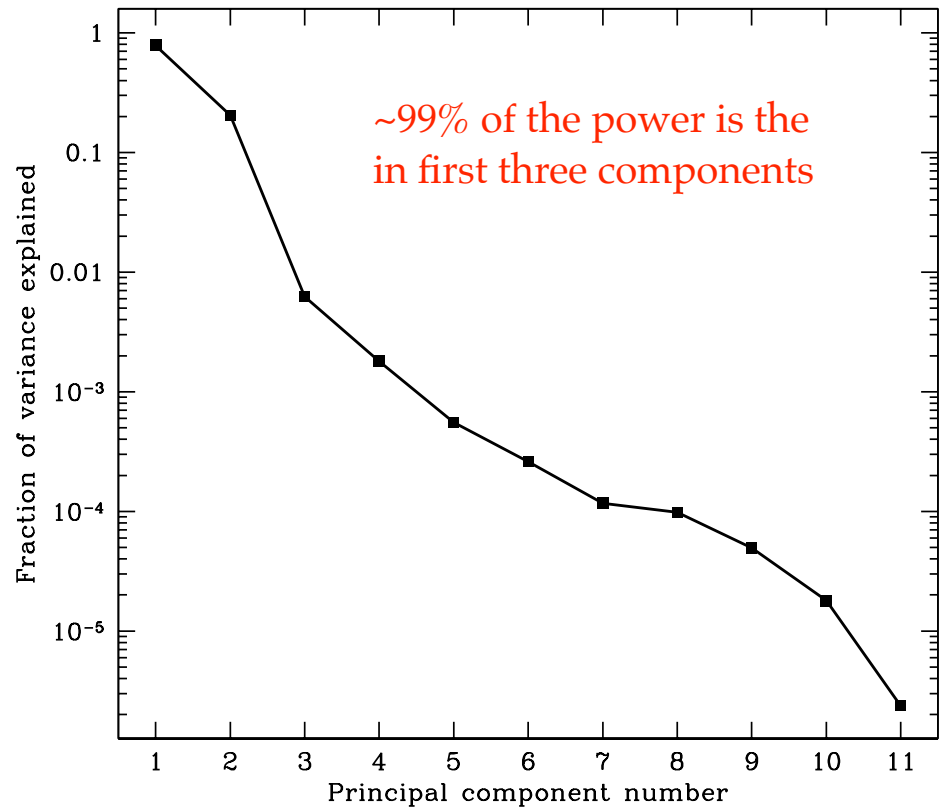
black: original 21cm signal
blue: reconstructed signal
red: residues

X. Wang et al. (2006)

SVD/PCA method

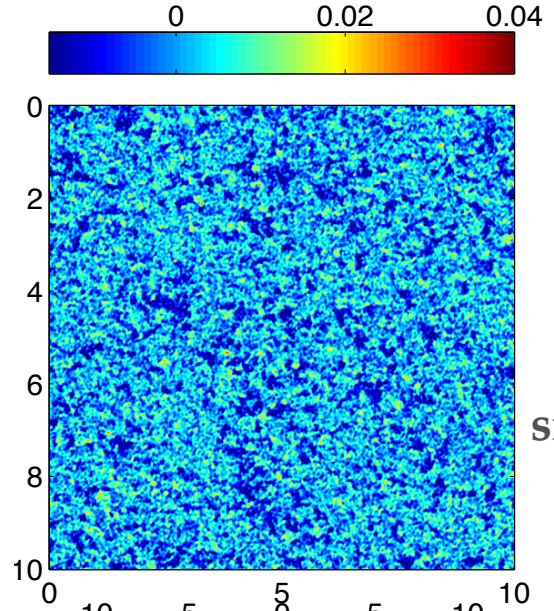


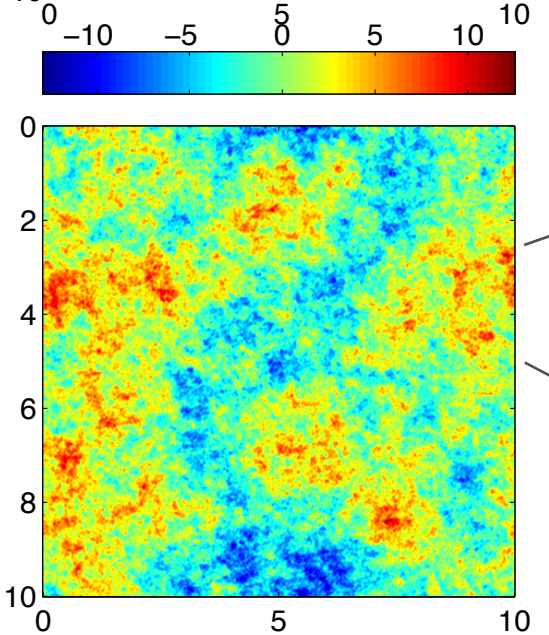
The first three principal components, which can be crudely interpreted as maps of total "stuff", synchrotron fraction and thermal dust fraction.

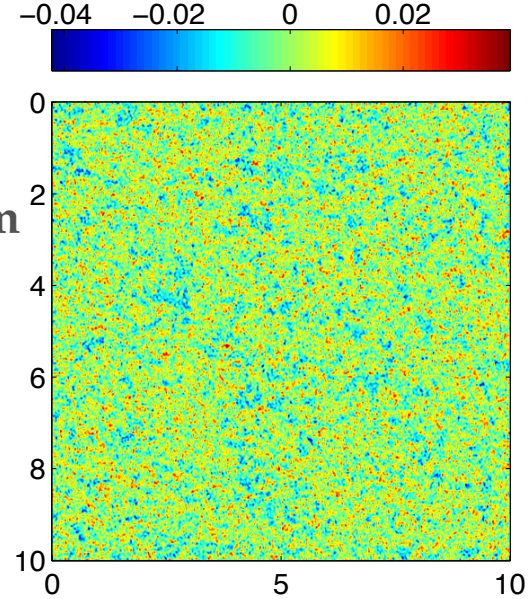


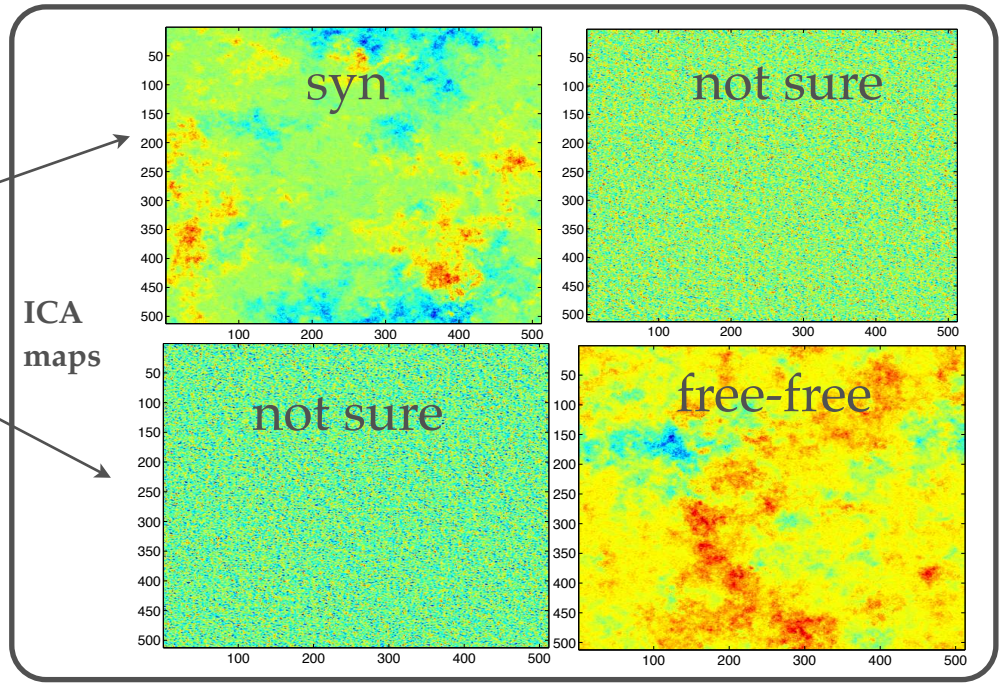
SIGNAL LOSS?

Independent component analysis









The Future Plan

- Improve on the Data Analysis, with more careful analysis of the data quality and RFI removal
- Polarization calibration
- conduct all sky survey
- FRB search: online beam-forming to search for FRB


Thanks !