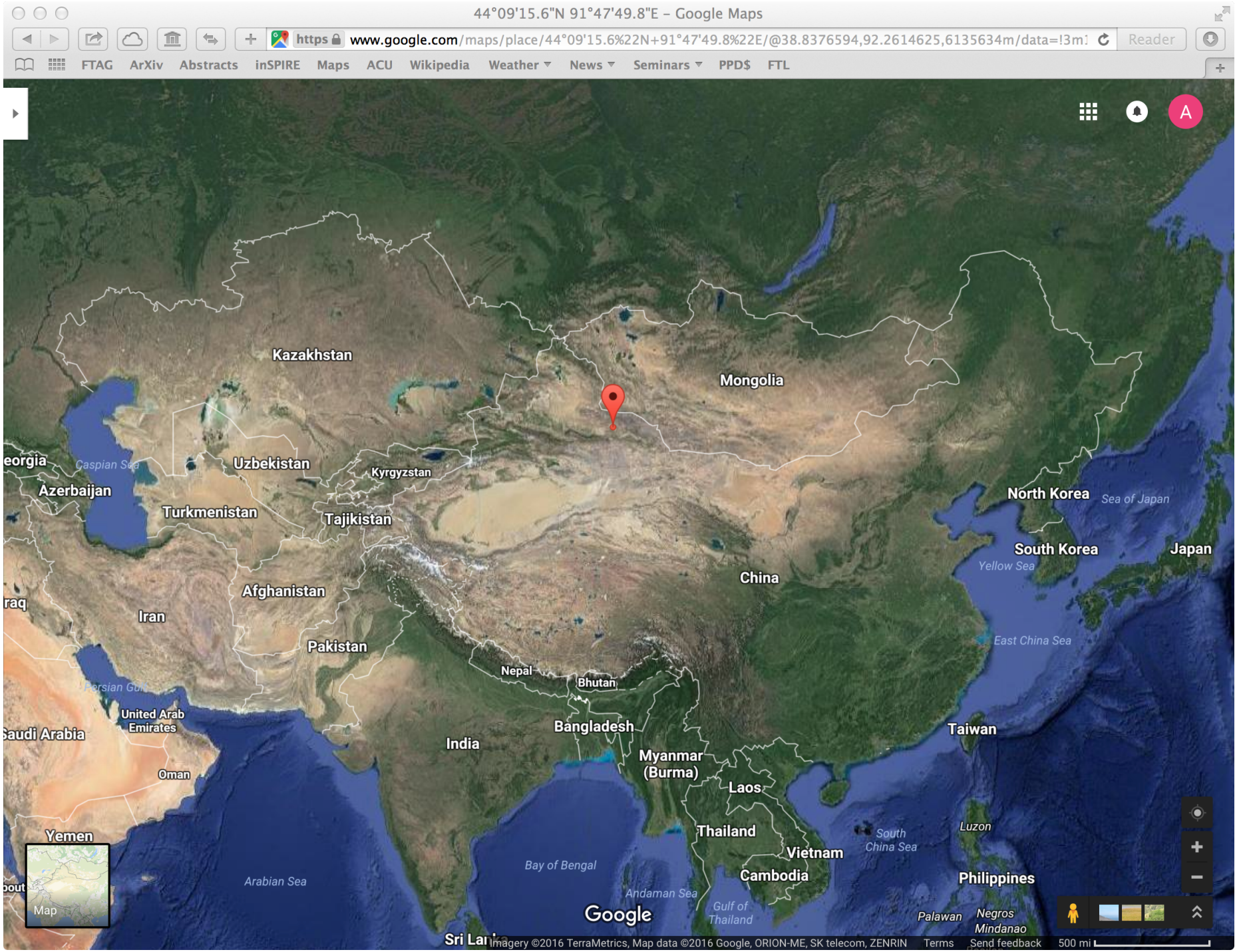
Tianlai

Peter Timbie
UW-Madison

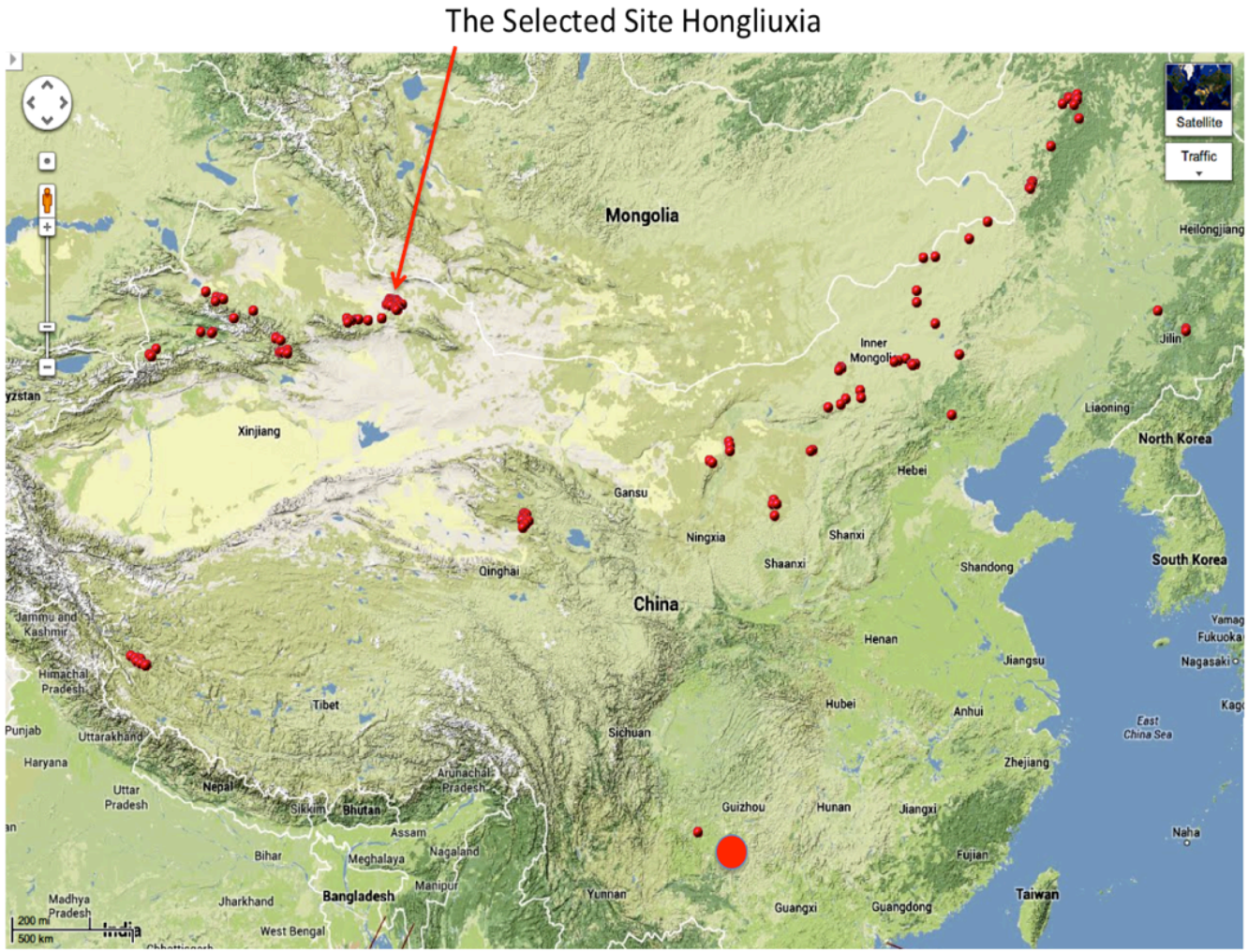
Tremendous Arrays Workshop
Brookhaven National Lab
July 30, 2018


44°09'15.6"N 91°47'49.8"E - Google Maps
https www.google.com/maps/place/44°09'15.6%22N+91°47'49.8%22E/@38.8376594,92.2614625,6135634m/data=!3m1
Reader
FTAG ArXiv Abstracts inSPIRE Maps ACU Wikipedia Weather News Seminars PPD$ FTL
A
Kazakhstan
Mongolia
Uzbekistan
Kyrgyzstan
Azerbaijan
Turkmenistan
Tajikistan
North Korea
Sea of Japan
South Korea
Japan
Yellow Sea
China
Afghanistan
Iran
Pakistan
East China Sea
Nepal
Bhutan
Bangladesh
India
Taiwan
Myanmar (Burma)
Laos
Thailand
Vietnam
Cambodia
Philippines
Luzon
South China Sea
Oman
Yemen
Arabian Sea
Bay of Bengal
Andaman Sea
Gulf of Thailand
Palawan
Negros
Mindanao
Google
Map
Imagery ©2016 TerraMetrics, Map data ©2016 Google, ORION-ME, SK telecom, ZENRIN
Terms
Send feedback
500 mi

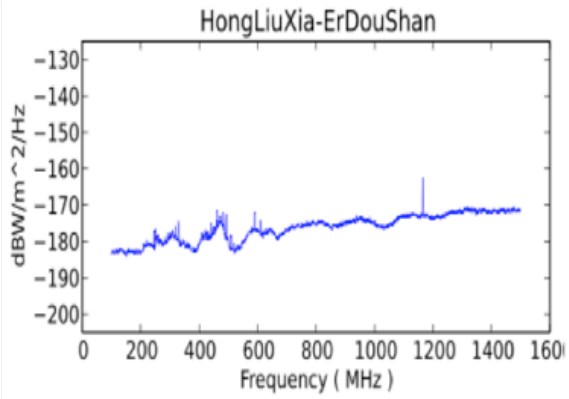
Site Selection

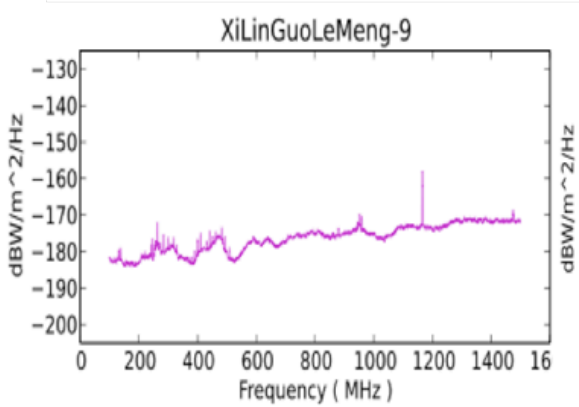
Site Requirements:

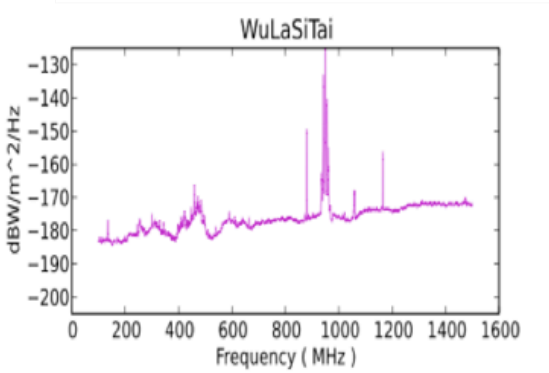
To minimize radio frequency interference (RFI), typically sparsely populated area, surrounded by mountains and hills

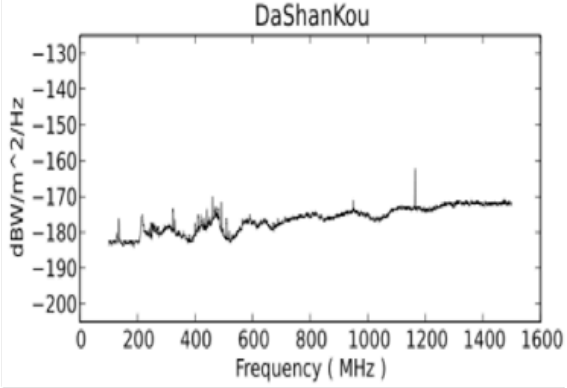


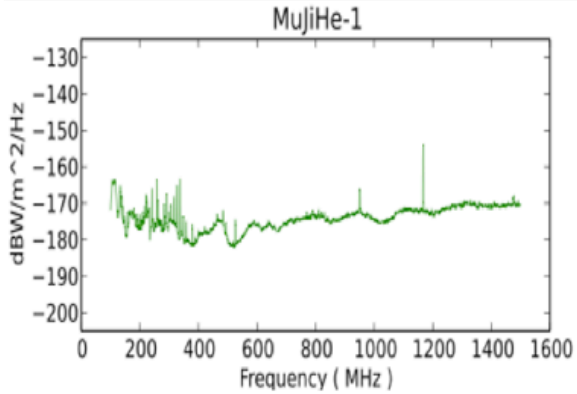
RFI spectra for some sites

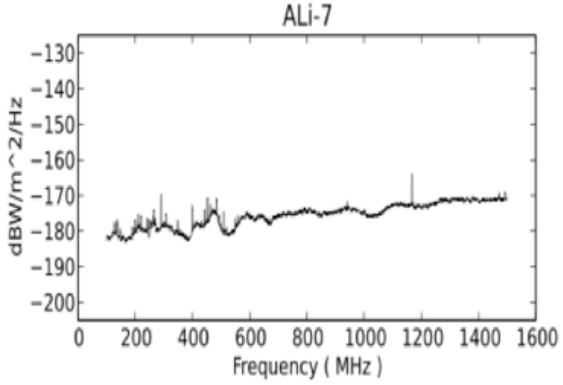


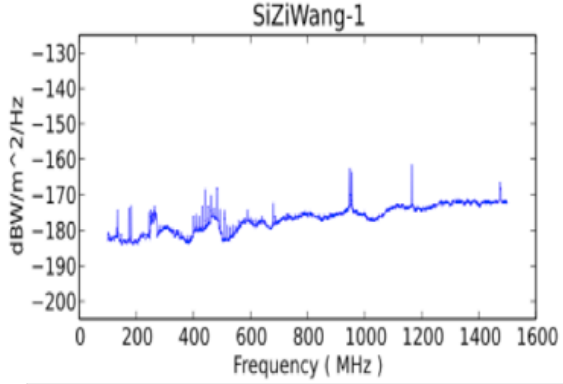


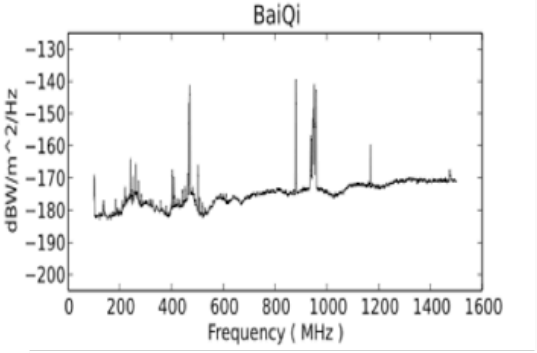


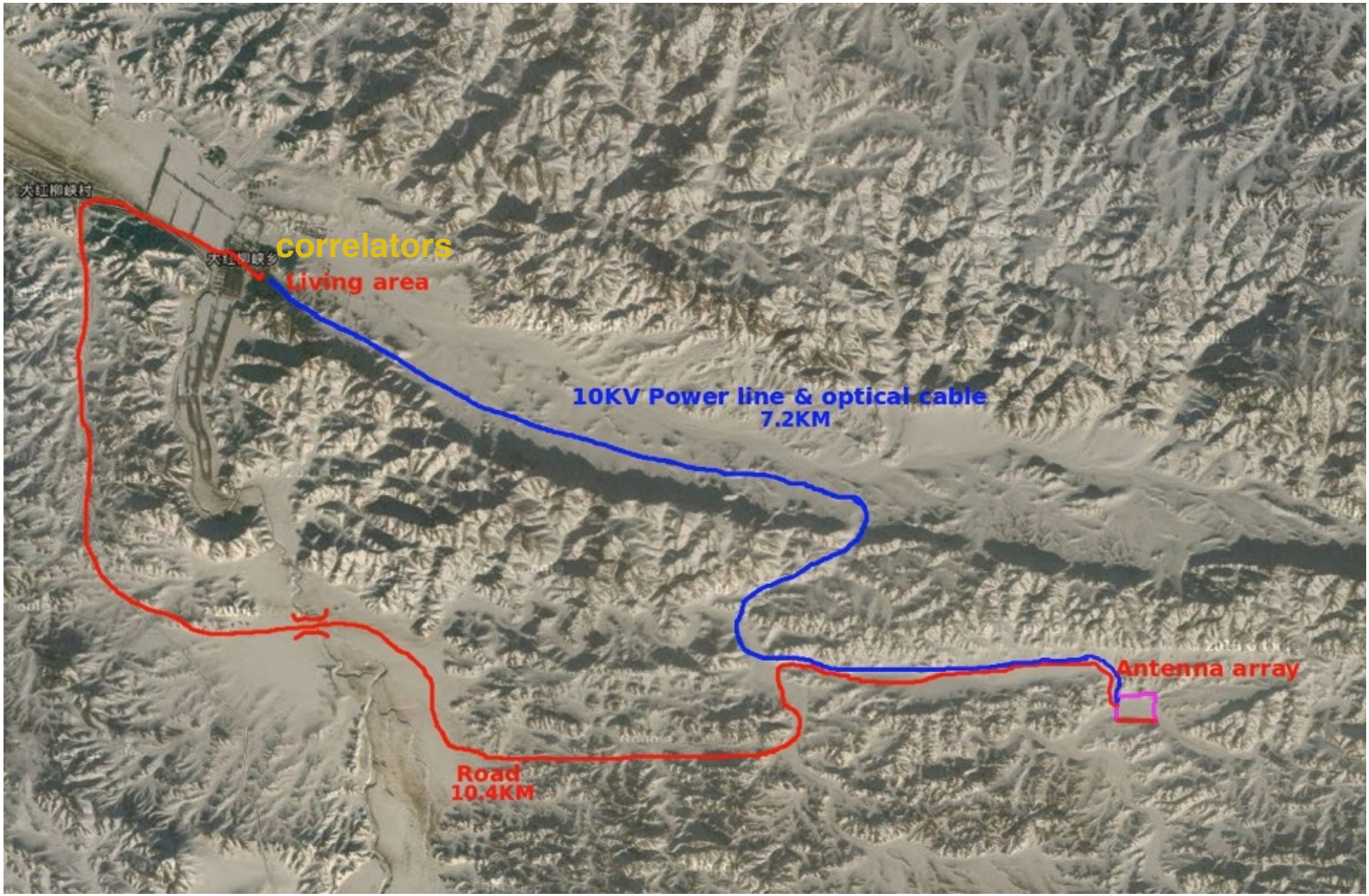




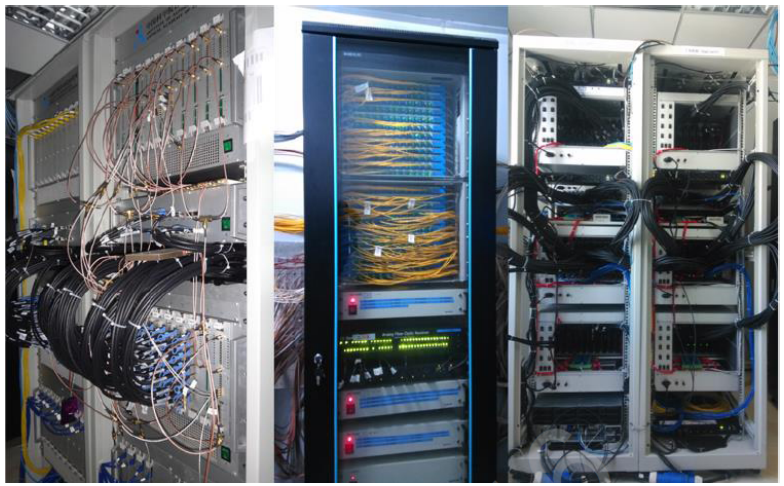







correlators
Living area
10KV Power line & optical cable
7.2KM
Antenna array
Road
10.4KM

Tianlai Facility



Receiver and Correlator

Tianlai Participants

China: Xuelei Chen (PI at NAOC), CETC-54, Institute of Automation, Hangzhou Dianzi U., XAO

US: J. Peterson (CMU)
P. Timbie, S. Das (Wisconsin)
A. Stebbins, J. Marriner (Fermilab),
G. Tucker (Brown)

France: R. Ansari, J.E Campagne,
M. Moniez (LAL/IN2P3)
J.-M. Martin, P. Colom (Obs. Paris)

Song (KASI), L. Wolz (Melbourne),
T-C. Chang (JPL), U-L. Pen (CITA)

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

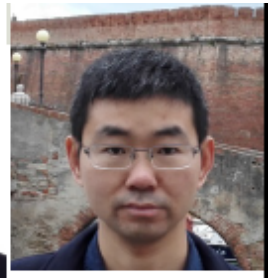

Changjun.Gao


Fengquan Wu

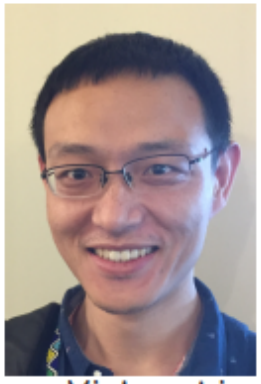

Huli Shi


Xin Wang


Yan.Gong

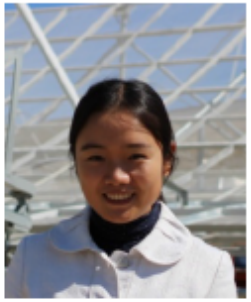

Bin.Yue

Juyong Zhang


Yichao Li

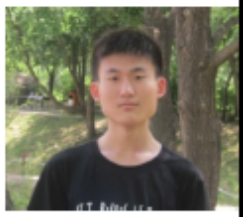

Yougang.Wang


Shifan Zuo


Yidong.Xu


Jialu.Zhu


Donghao Liu


Gong.Cheng


Rongli.Wang


Boqin Zhu


Wang Weixian


Tiantian Li


Jingyu Zhang

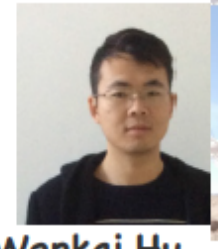

Jixia.Li


Zhiping Chen

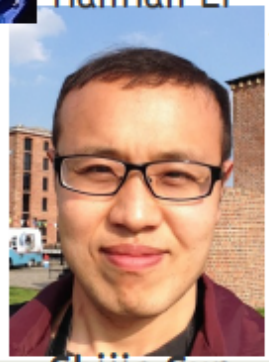

Qizhi Huang


Chenhui .Niu

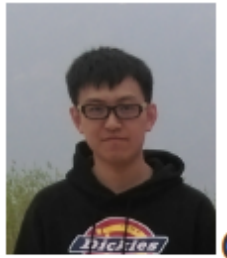

Kaifeng.Yu


Wenkai.Hu

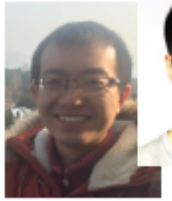

Wenxiao.Xu


Shijie.Sun


Yanping.Cong


Jiawei.Li


Qunxiong. Wang


Ye.Cao


Tianxian Mao

U.S. Participation in Tianlai

- In addition to large Chinese / French participation
  - Peter Timbie / Santanu Das / Trevor Oxholm & UG's - University of Wisconsin
  - Albert Stebbins / John Marriner - Fermilab
  - Jeff Peterson - Carnegie Mellon
  - Greg Tucker - Brown
  - open to new participants

- NSF grant: reduce/analyze 1st 3 years of data
  - Timbie (PI) / Stebbins received NSF-AAG Grant (2016 - 2019)
  - **Tianlai Analysis Center**
    - computing/storage @ FNAL & Open Science Grid

- Manpower limited

Tianlai Configuration(s)

- **Band** 700-800MHz (0.58<z<1.05)

1024 frequency channels
(δν=100kHz δz=0.0002)
tunable in 600-1420MHz

- **Cylinder Array** 3 x 15m x 40m cylinders

96 dual polarization feeds
4 sec sampling

- **Dish Array** 16 x 6m dishes

16 dual polarization feeds
1 sec sampling

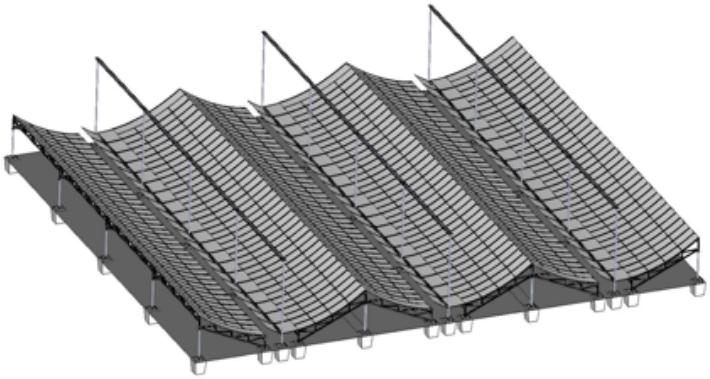
- **Pathfinder+ Cylinder Array**

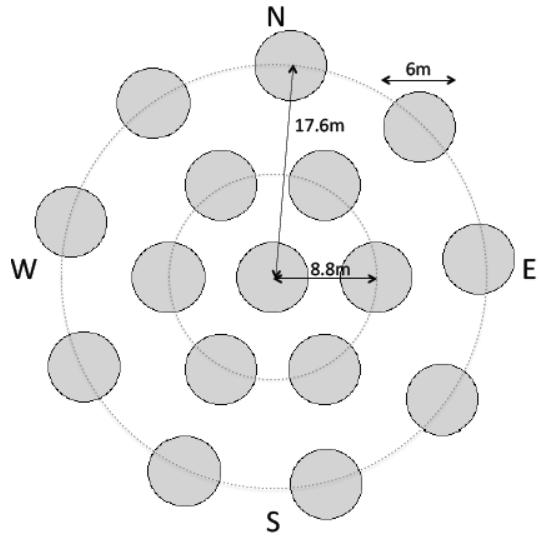
216 dual polarization feeds
4 sec sampling

- **Full Cylinder Array** 8 x 15m x 120m

2048 dual polarization feeds
400-1420MHz

Pathfinders to demonstrate basic principle and encounter issues rapidly





Pathfinder Highly Configurable Transit Telescope

- Tuneable:
  - 600 < v < 1420MHz (0<z<1.36) [fixed 100 MHz bandwidth]
- Cylinders:
  - equal/unequal spacing of feeds on cylinder
  - feed placement on cylinders may be same or different
    - redundancy vs broader u-v coverage (less mode mixing)
- Dishes:
  - pointable / tracking
  - arrangeable in any ground configuration

R&D: plan to play with all the knobs

Tianlai *Long Term* Goals

With **lessons learned** from current pathfinder arrays fill out and expand arrays …

- make lower noise / higher resolution images of Northern sky.
- make HI maps, $P_{HI}[k]$ for cosmological parameters e.g. BAO/DE.

Bull et al. ApJ 2015

Table 2
Telescope Configurations Used in This Paper

		Experiments	T_{inst} [K]	$N_d \times N_b$	D_{dish} [m]	D_{min} [m]	D_{max} [m]	ν_{crit} [MHz]	ν_{max}^{IM} [MHz]	ν_{min}^{IM} [MHz]	$\Delta\nu^{IM}$ [MHz]	z_{min}	z_{max}	S_{area} [deg^2]
Targeted IM	•	BAOBAB-128	40	128 × 1	1.6	1.6	26.0	…	900	600	300	0.58	1.37	1,000
		BINGO	50	1 × 50	25.0	…	…	…	1260	960	300	0.13	0.48	5,000
	◊	CHIME	50	1280 × 1	20.0	…	…	…	800	400	400	0.77	2.55	25,000
		FAST	20	1 × 20	500.0	…	…	…	1000	400	600	0.42	2.55	2,000
	•	MFAA	50	3100 × 1	2.4	0.1	250.0	950	950	450	500	0.49	2.16	5,000
	◊	Tianlai	50	2048 × 1	15.0	…	…	…	950	550	400	0.49	1.58	25,000

Table 4
1D Marginal Constraints (68% CL) on the Extended ΛCDM Model, Including the Planck Prior

Experiments	A / 10^{-2}	h / 10^{-3}	Ω_K / 10^{-4}	Ω_{DE} / 10^{-3}	n_s / 10^{-4}	σ_8 / 10^{-3}	γ / 10^{-2}	w_0 / 10^{-2}	w_a / 10^{-2}	FOM
BAOBAB-128	24.3	50.2	71.3	36.6	38.5	8.1	9.0	33.3	71.4	8.0
BINGO	25.8	30.8	90.0	16.1	38.5	8.2	2.8	44.1	172.5	7.8
CHIME	3.0	8.7	9.7	7.1	30.2	5.2	3.4	5.0	15.1	288.1
FAST	7.5	13.5	16.0	10.1	33.5	6.4	3.2	7.1	18.5	144.7
MFAA	5.7	11.9	14.1	9.1	32.2	6.0	3.1	6.3	17.2	165.7
Tianlai	3.6	8.0	11.9	6.3	28.7	4.9	2.4	4.0	12.0	383.3

Tianlai *Pathfinder* Goals

- Implement large interferometric **arrays** in a quiet site in western China to obtain a high fidelity 3D image of Northern Sky w/ 100MHz bandwidth. Accurate **beam calibration** is essential.
- Compare cylinder arrays with dish arrays (also cross correlate dish/cylinder)
- Experiment with cylinder feed arrangements / dish placements.
- Experiment with different calibration schemes: artificial calibration sources on ground and in air; natural calibrations sources: Sun and other bright sources, pulsars, holography; numerical modeling of beam.
- Deep imaging of North Polar Cap (NPC) with dish array.
- Optimize algorithms **and** telescope arrangement for best foreground removal.
- Construct redshift space HI emission maps especially in NPC.
- Vary frequency band up to 1.4GHz (lo-z 21cm) so as to make maps to compare with LSS with optical redshift surveys SDSS and NCCRS

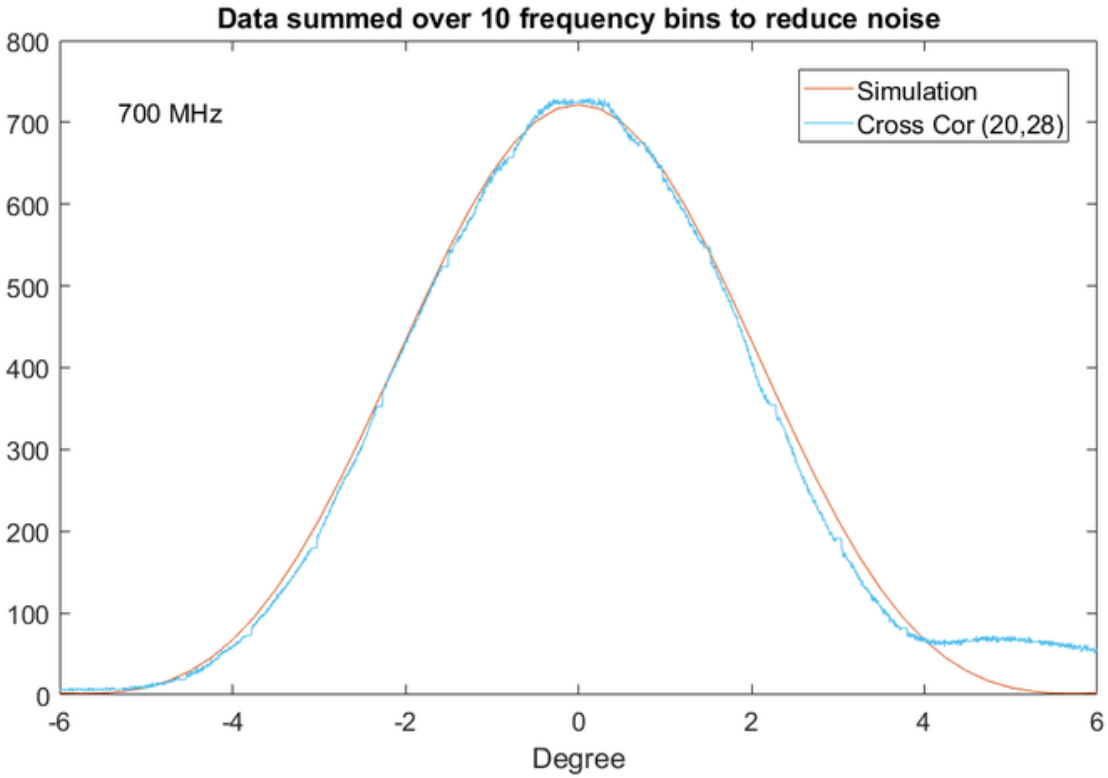
Timeline

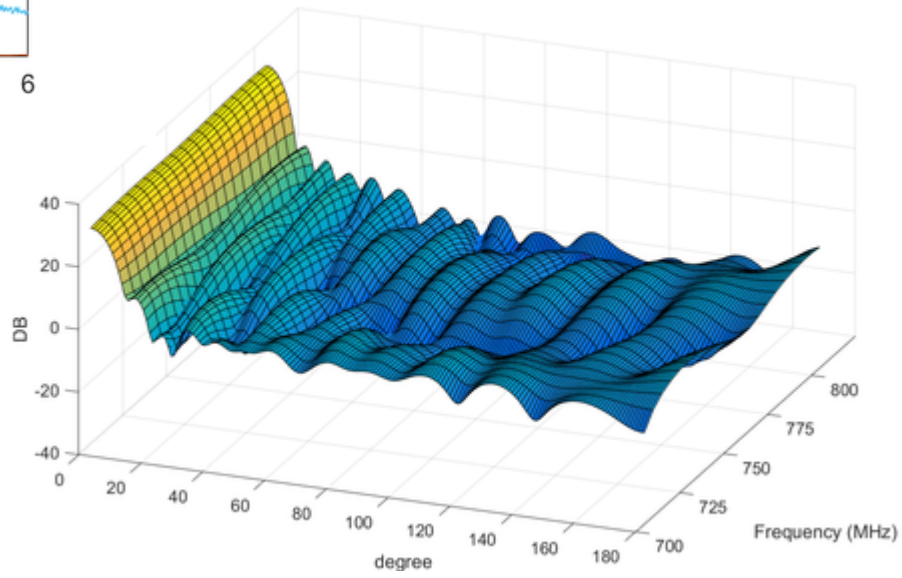
- **2014:**
  - basic infrastructure: roads, buildings, power, optical fibers
  - electronics design
- **2015:**
  - scientific infrastructure: reflectors finished
  - much of electronics installed
  - first fringe
  - engineering / debugging
- **2016:**
  - engineering / debugging
  - astronomical imaging of bright sources
  - several runs with dish array : mostly NCC
  - 1 run with with cylinders
- **2017:**
  - fix hardware issues (some down time)
  - develop test calibration methods (mostly offline analysis development while taking data)
  - cylinder+dish runs
- **2018:**
  - production runs
- **2019:**
  - production runs
  - tune dishes to lo-z
  - transient backend / outriggers?

Tianlai Analysis Center

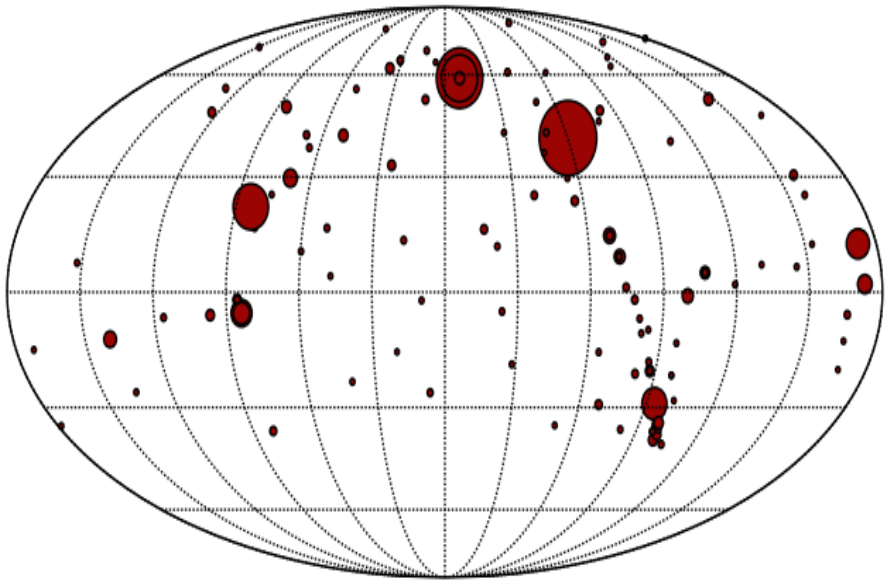
- software development
- computer resources / data storage
- data reduction
- data visualization tools/repository
- feedback for instrumentation / observational strategy
- EM simulations and modeling of beams
- beam calibration techniques
- transient detections

EM Simulations



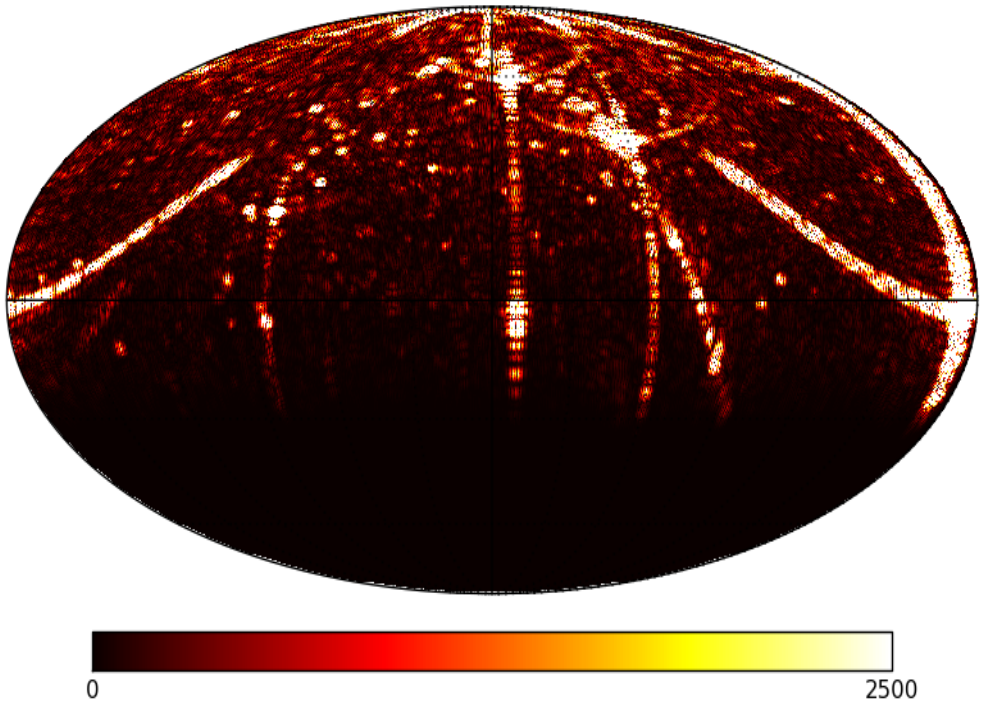


First Light: sky maps with cylinders



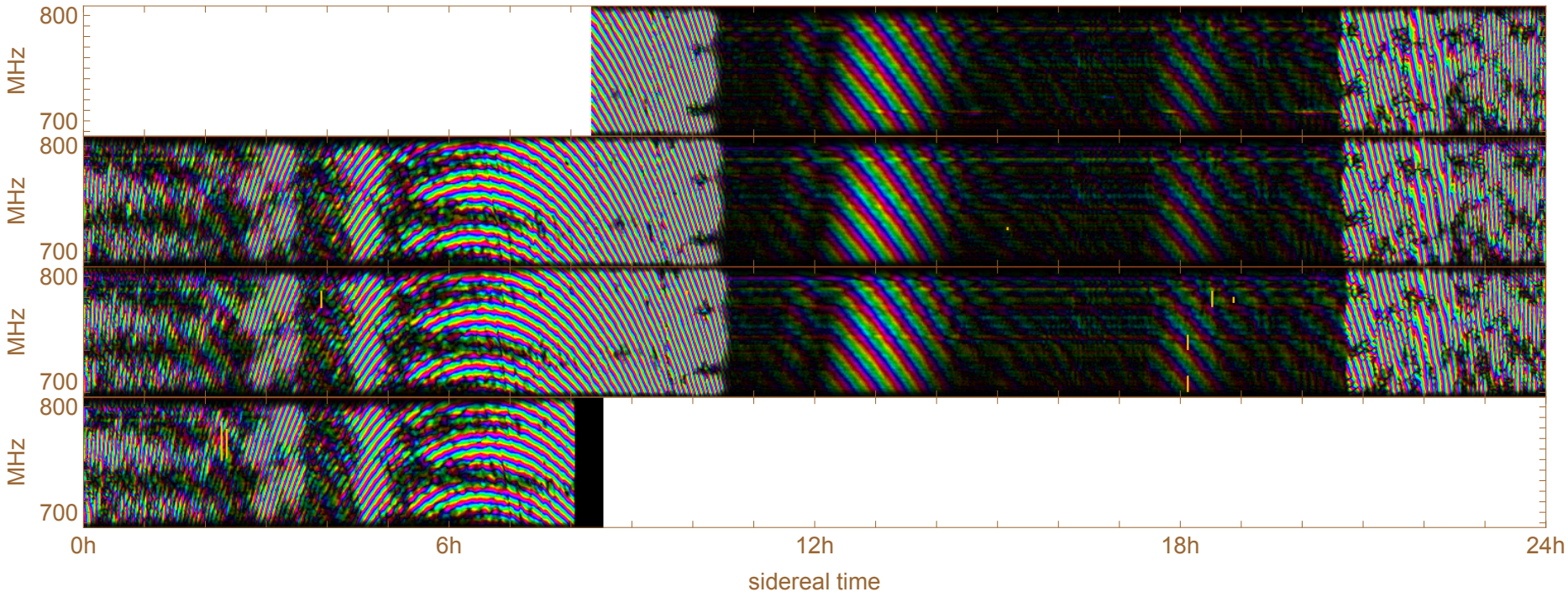
NVSS（1.4GHz）bright sources

S. Zuo et al., in preparation



First light image with 5 frequency channels (0.1 MHz each) from data taken during first light 2016.09.27-2016.09.30

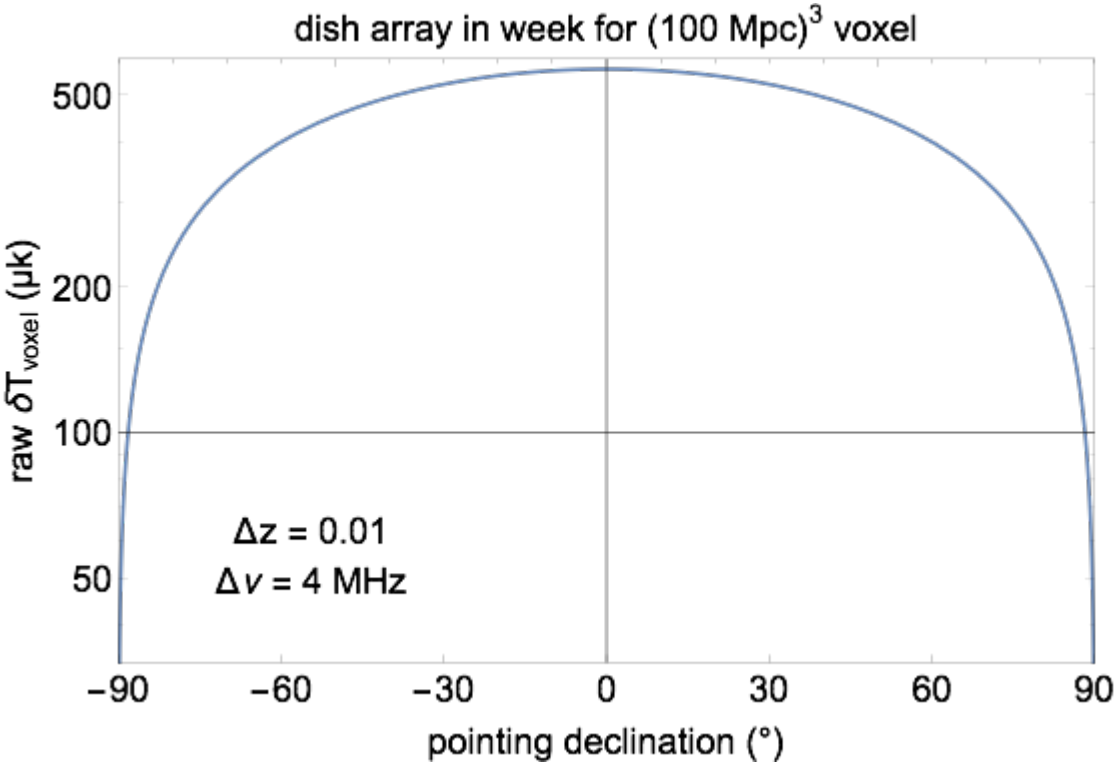
First Light: waterfall plots from dish array



A. Stebbins'
visibility visualizer

- Visibility for one of 528 baselines in dish array
- Pointed at NCP for 4 days, June 2016
- Data avg'd over 1 minute, 1 MHz
- Intensity is magnitude of visibilty, color is phase

Planned North Polar Survey with Dish Array

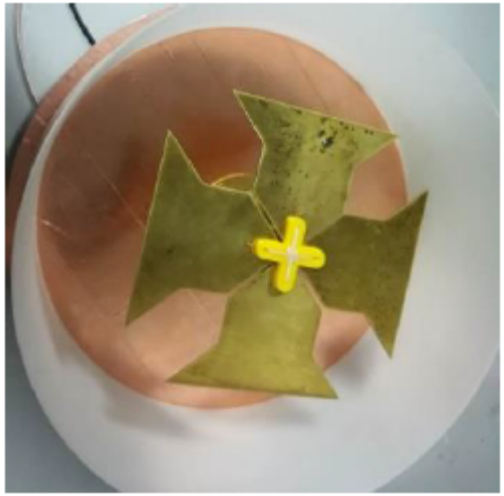


- By pointing dish array toward pole will integrate down to low map noise temperature rapidly.

- **WANTED**: NCC optical spectroscopic survey of existing photometric survey to compare to

Beam Mapping with Drone

1.6 m



- Matric-600 Pro
- 18 min. flight for 5.5 kg payload
- 2500 m max altitude (but 500 m regulations)
- Lightweight dish feed as transmitter
- First tests with broadband noise source

Tianlai Target Of Opportunity

- Tianlai Analysis Center NSF Grant ends in 2019!
- **but** Tianlai will continue and expand.
- continued/expanded US participation after 2019?
- most flexible developmental machine for HI intensity mapping
- excellent site wrt RFI.
- Tianlai buildout $\gtrsim$ CHIME $t_{Tianlai} > t_{CHIME}$
- low entry costs relative to a new scope
- Chinese lead in funding

21 cm Cosmology workshop and Tianlai Collaboration Meeting

2018-09-17--2018-09-21 **Pingtang**

Important Deadlines

- Deadline for the registration: August 5, 2018