ALBERT STEBBINS
FERMILAB

PUMA WORKSHOP
2020-08-18

Collaboration Authors

Many people have contributed to Tianlai - listed here only those which felt sufficiently involved to become co-authors

- **China** :

  Xuelei Chen PI, Zhiping Chen, Yanping Cong, Jingchao Geng, Jie Hao, Qizhi Huang, Jixia Li, Rui Li, Donghao Liu, Tao Liu, Yingfeng Liu, Chenhui Niu, Huli Shi, Lin Shu, Shijie Sun, Yafang Song, Haijun Tian, Fengquan Wu, Guisong Wang, Qunxiong Wang, Rongli Wang, Weixia Wang, Xin Wang, Yougang Wang, Yanlin Wu, Yidong Xu, Zijie Yu, Kaifeng Yu, Jiao Zhang, Juyong Zhang, Boqin Zhu, Jialu Zhu, Shifan Zuo

- **France** :

  Reza Ansari, Jean-Eric Campagne, Olivier Perdereau

- **South Africa** :

  Yichao Li

- **United States** :

  Santanu Das, John Marriner, Kiyoshi Masui, Calvin Osinga, Trevor Oxholm, Anh Phan, Jeffery Peterson, Gage Siebert, Albert Stebbins, Peter Timbie, Gregory Tucker
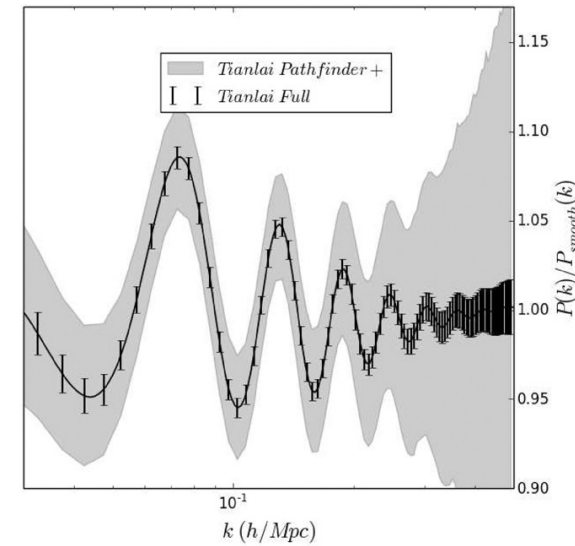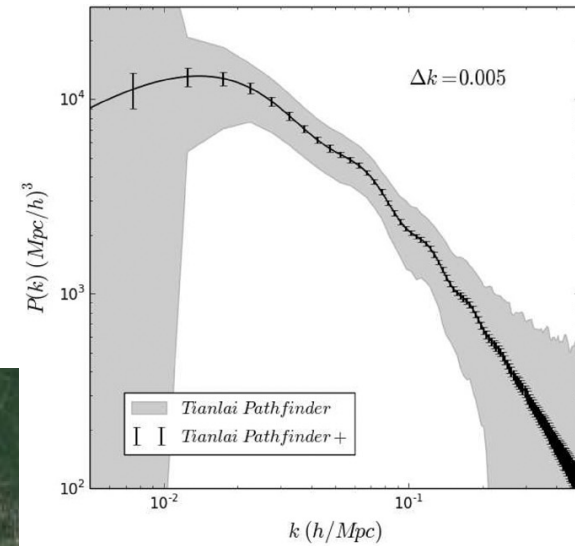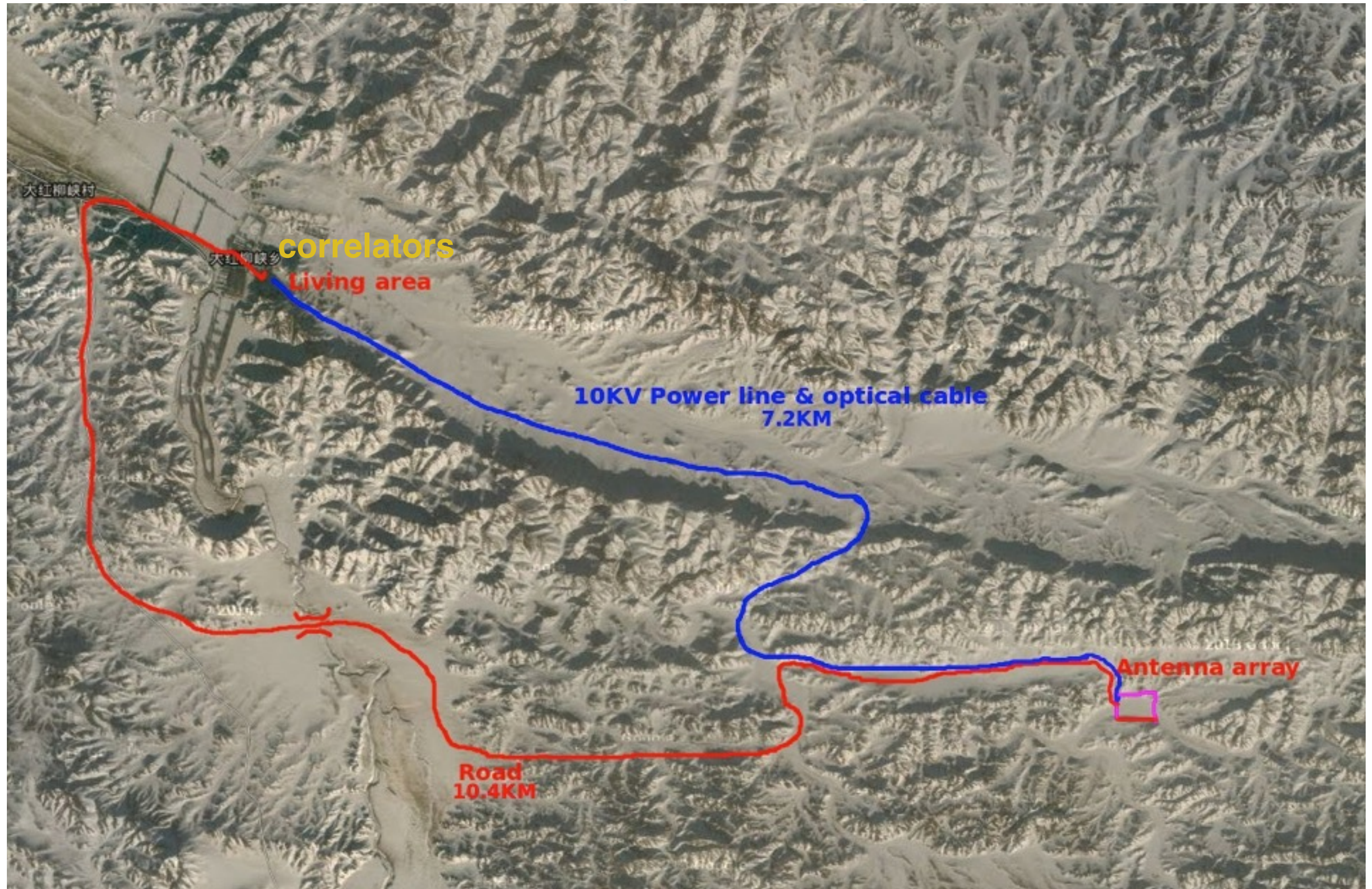
- **Canada** :

  Ue-Li Pen, Richard Shaw

- **NEW PARTICIPANTS WELCOME**

Hydrogen Intensity Mapping: The Tianlai Project

Tianlai ~ "*Heavenly Sound*"
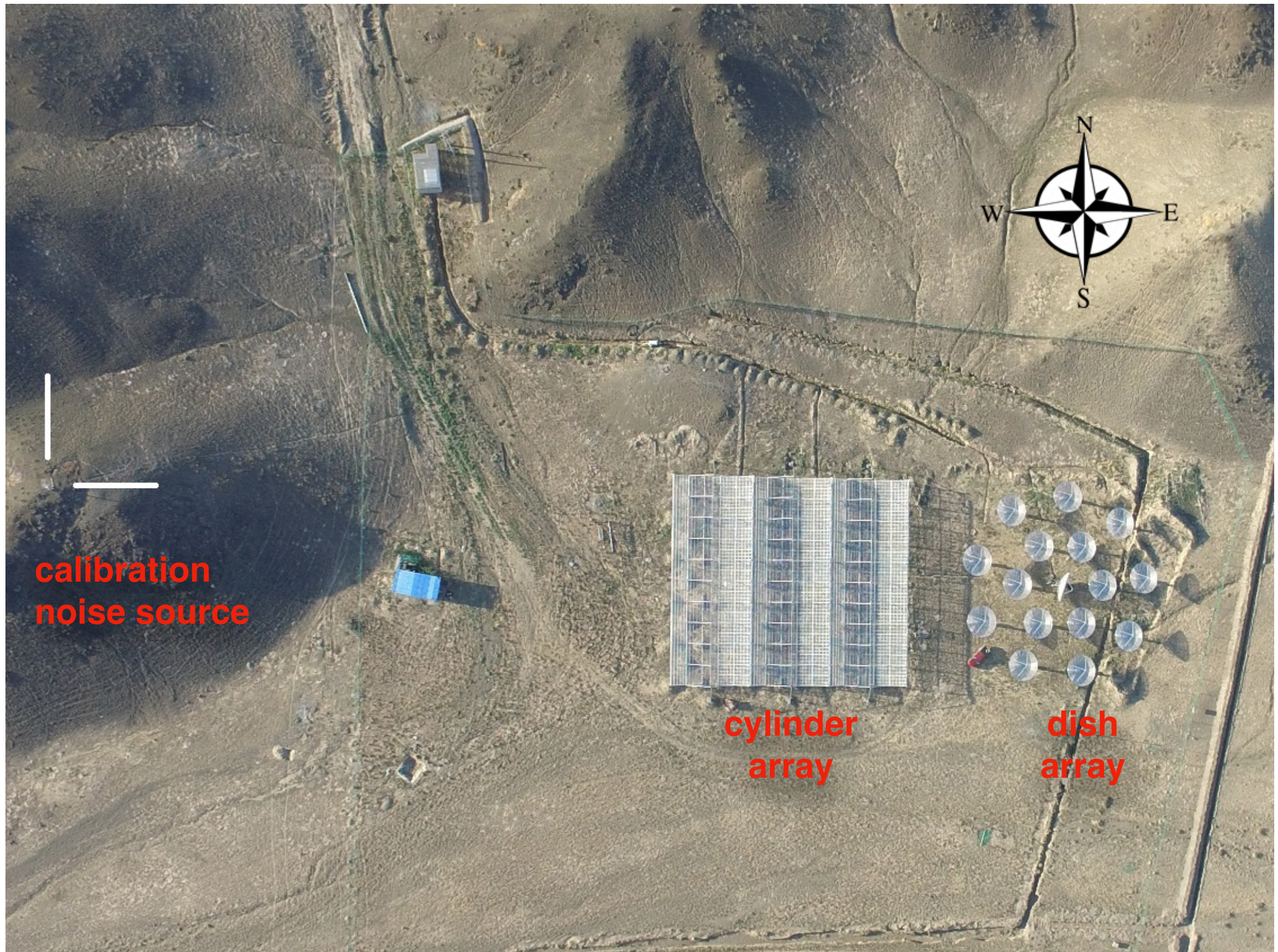
The Tianlai Project: Hongliuxia Site

correlators
Living area

10KV Power line & optical cable
7.2KM

Antenna array

Road
10.4KM

Hongliuxia Site (radio quiet)

Hydrogen Intensity Mapping: The Tianlai Pathfinder

demonstrates basic principles / encounters all issues rapidly

- **Bandwidth** Δν=125 MHz (tunable)
  685-810MHz (0.77<z<1.3) all observations so far
  tunable in 600-1420MHz (0<z<1.5)

- **Cylinder Array** 3 x 15m x 40m cylinders
  96 dual polarization feeds
  1024 frequency channels δν=122kHz
  (operate 576 frequency channels Δν=70MHz)
  4 sec sampling

- **Dish Array** 16 x 6m dishes
  16 dual polarization feeds
  512 frequency channels δν=244kHz
  1 sec sampling
  pointable alt-az

- **Pathfinder+ Cylinder Array**
  216 dual polarization feeds
  4 sec sampling

- **Proposed Full Cylinder Array** 8 x 15m x 120m
  2048 dual polarization feeds
  400-1420MHz
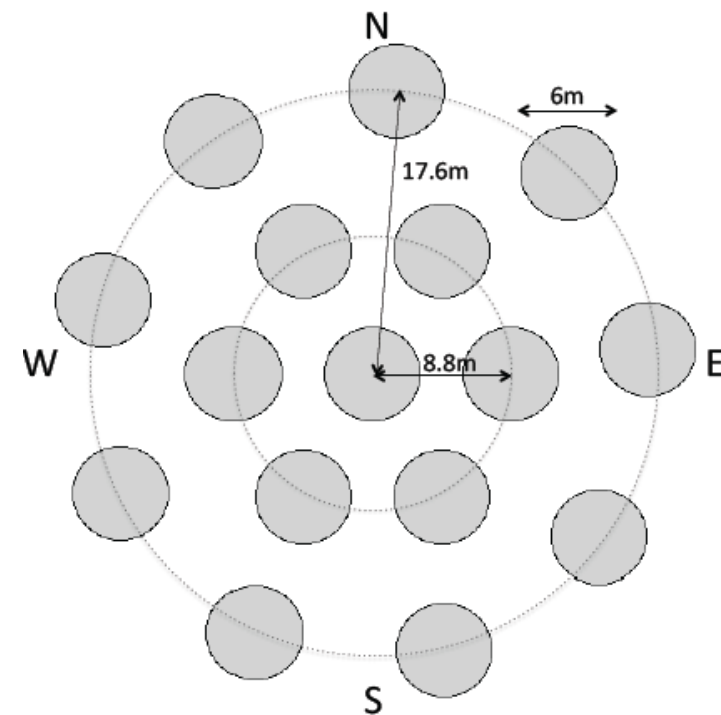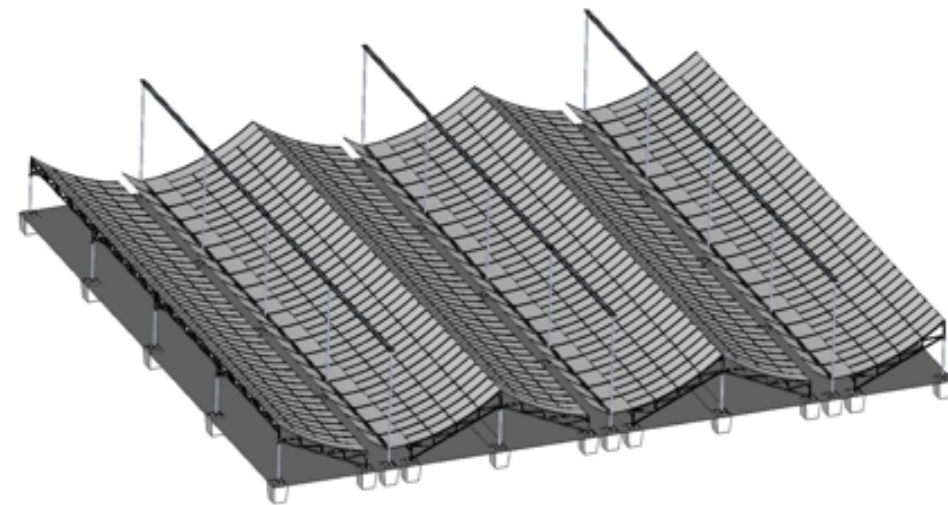
On Sky Observations

Correlator allows only observations with Dish Array **or** Cylinder Array
All feeds correlated / raw visibilities recorded for later analysis

- **Dish Array** : since May 2016
  operates in drift scan mode only - no tracking (RFI from motors)
  ~258 days including ~237 days pointed directly at NCP (North Celestial Pole)

- **Cylinder Array** : since October 2016
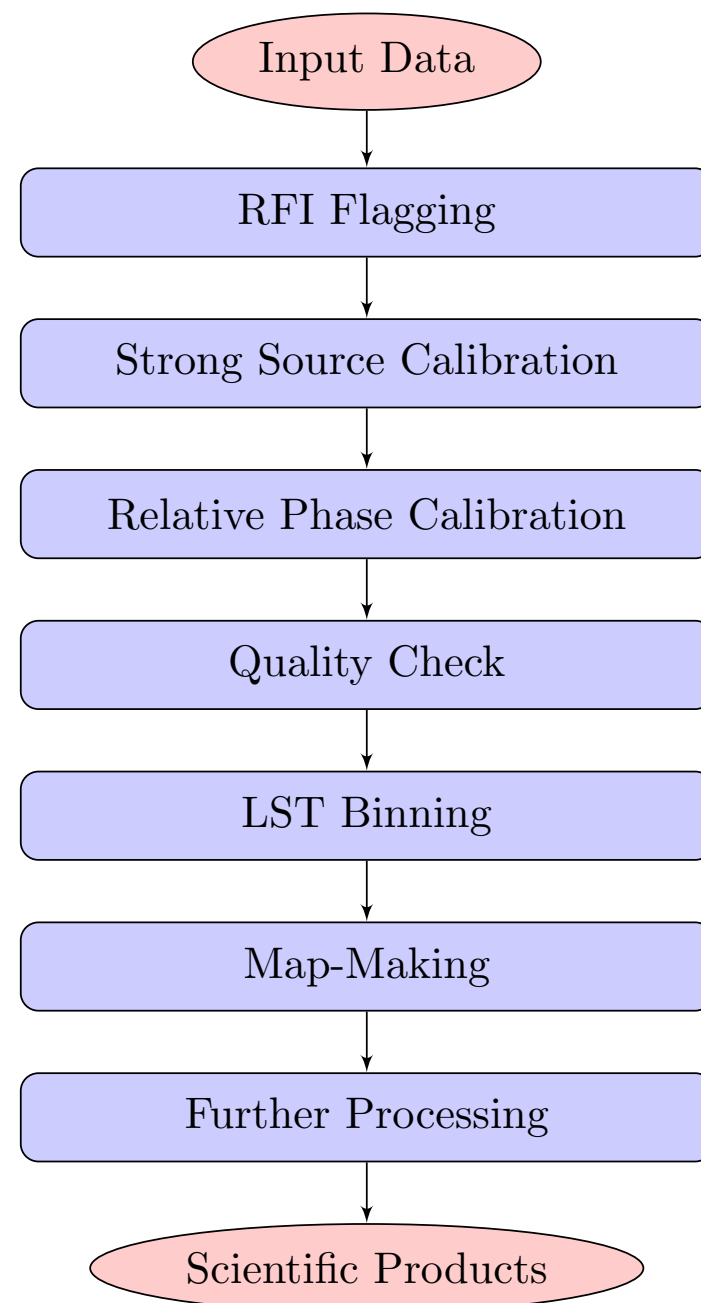 ~ 114 days

Recent Publications

- **Reflections and Standing Waves on the Tianlai Cylinder Array**
  submitted
- **The Tianlai Dish Pathfinder Array: design, operation and performance of a prototype transit radio interferometer**
  submitted to *MNRAS*

- **The Tianlai Cylinder Pathfinder Array: System Functions and Basic Performance Analysis**
  arXiv:2006.05605
  December 2020 cover article: *Science China - Physics Mechanics and Astronomy*
- **Data Processing Pipeline For Tianlai Experiment** :
  Astronomy and Computing https://lss.fnal.gov/archive/2020/pub/fermilab-pub-20-141-a.pdf
- **An Eigenvector-Based Method of Radio Array Calibration and Its Application to the Tianlai Cylinder Pathfinder**
  Astronomical Journal MNRAS **157** 34 (2019)

tlpipe: the Tianlai data pipeline
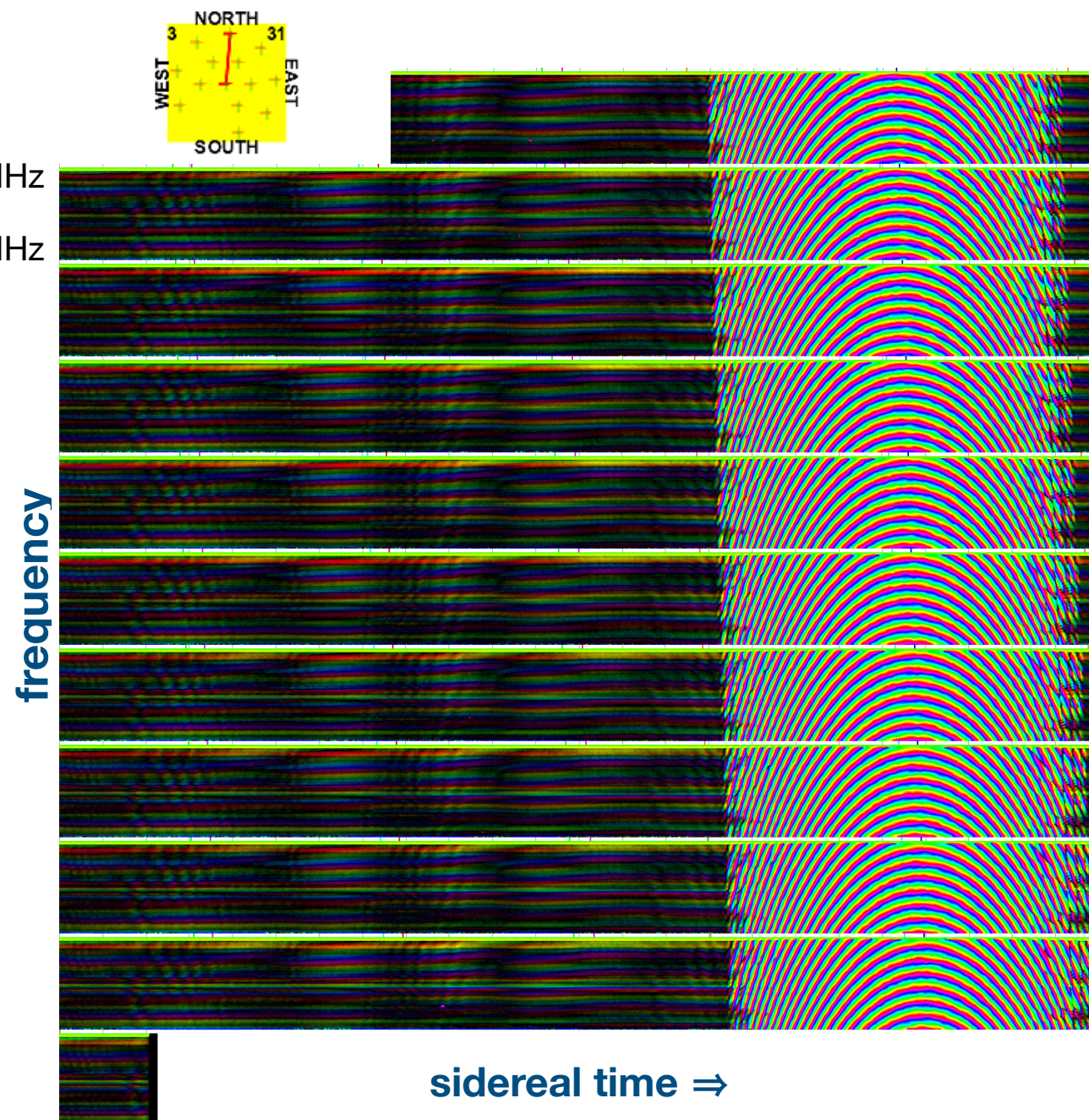
Publicly available: https://github.com/TianlaiProject/tlpipe

Incorporates novel and standard algorithms as well as general "plumbing"

Data structures based on HDF5 standard

```
            ( Input Data )
                  |
                  v
         [ RFI Flagging ]
                  |
                  v
    [ Strong Source Calibration ]        including injected signal
                  |
                  v
    [ Relative Phase Calibration ]
                  |
                  v
         [ Quality Check ]
                  |
                  v
          [ LST Binning ]
                  |
                  v
          [ Map-Making ]
                  |
                  v
       [ Further Processing ]
                  |
                  v
        ( Scientific Products )
```
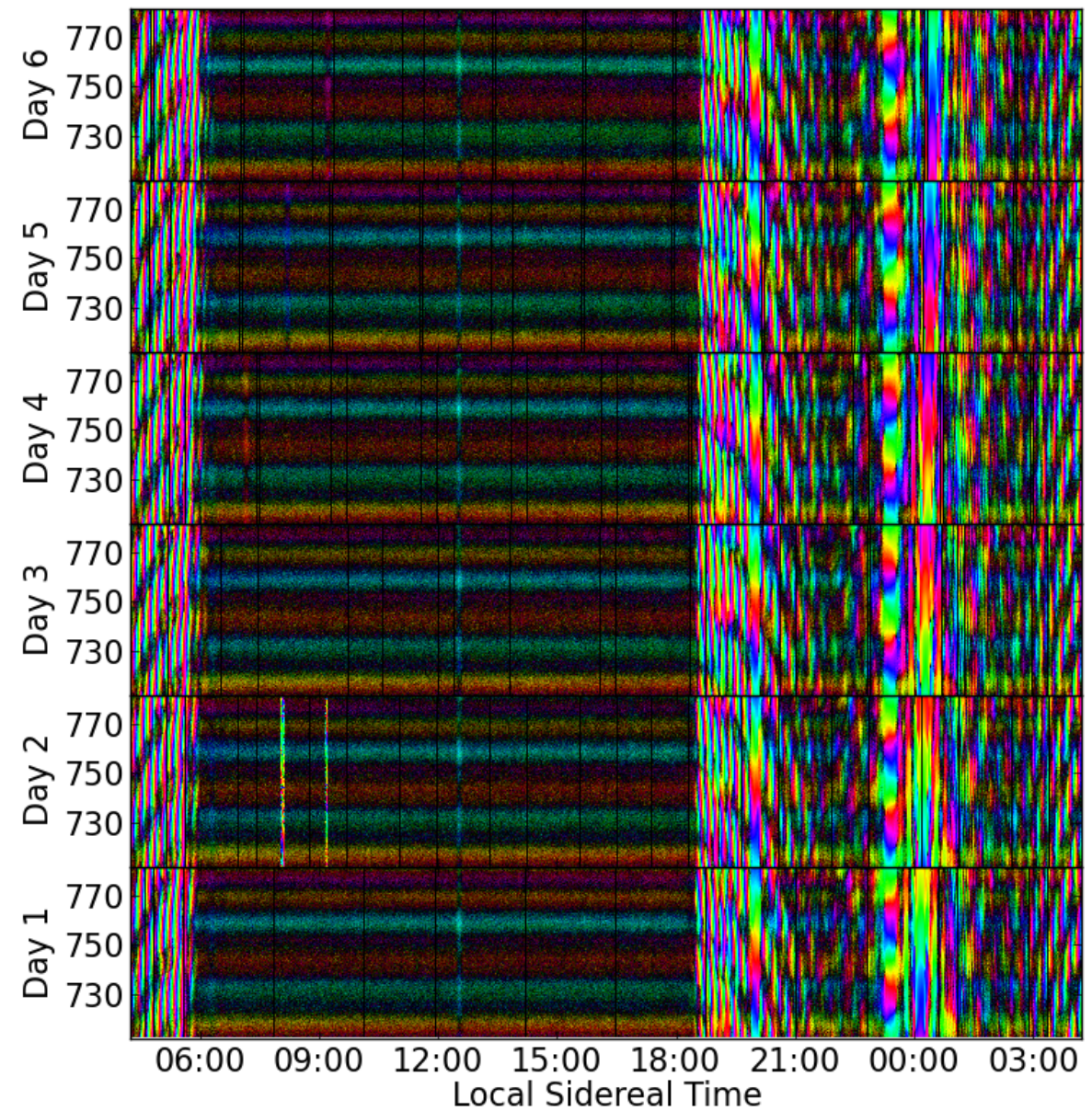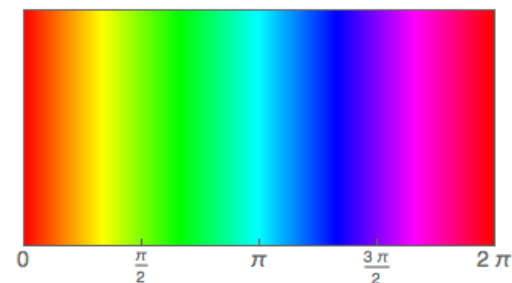
Typical Raw Visibilities


dish 11 days NCP

cylinder 6 days

Issues

- **Correlated Noise** :
  - cross talk between feeds
  - common ground pickup?
  - decreases with separation / much less between cylinders
  - seems to be very stable during a single night

- **Mis-Pointing** :
  - literally for dishes
  - feed alignment within cylinders

- **Complex Gain Drifts** :
  - improvement using external signal injection every 4 minutes
  - sky calibration: fast fringes from bright off-axis source always visible from dishes

- **Beam Calibration** : beams have lots of structure (e.g. cylinder standing waves)
  - drone
  - sky calibration:
    - bright off-axis source always visible from dishes
    - bright source transit regularly

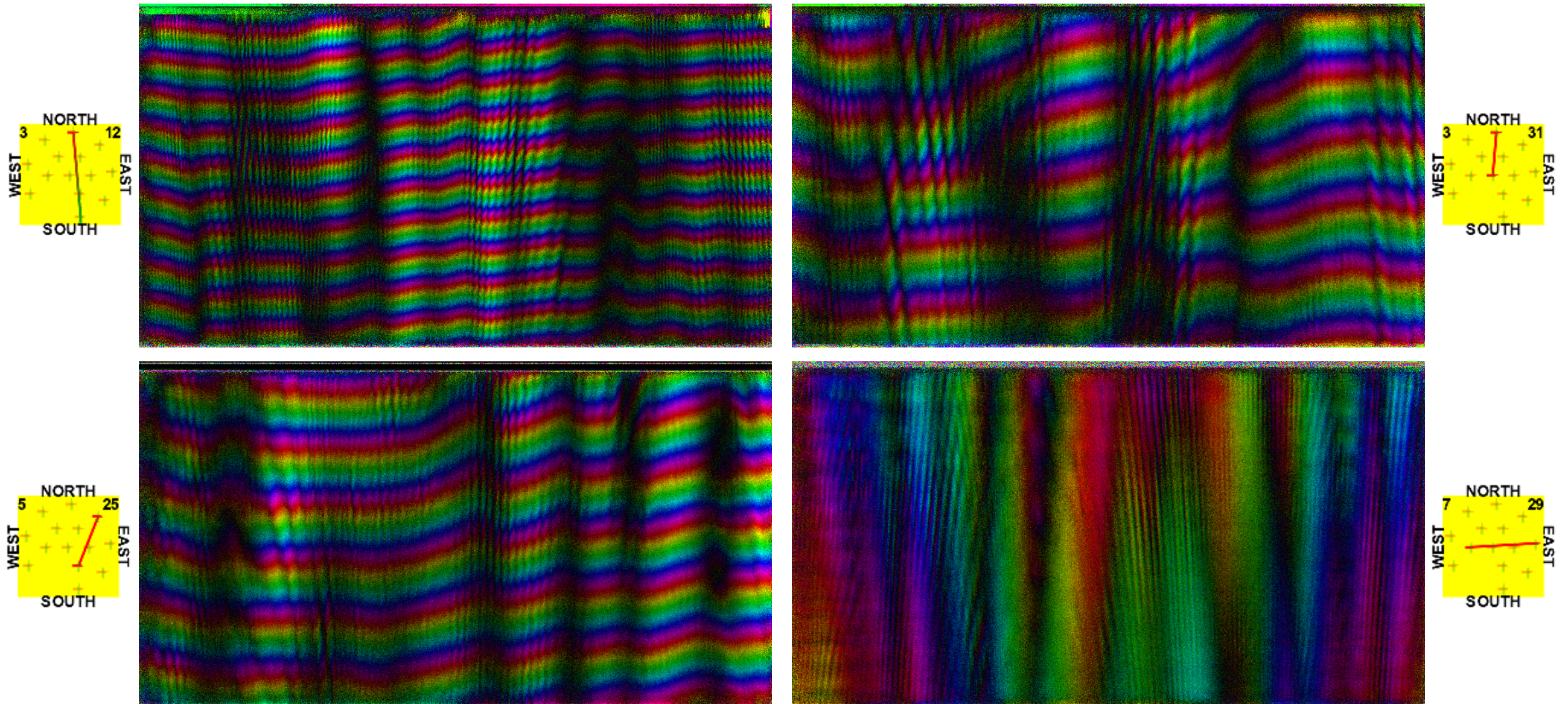- **RFI** :
  - it is infrequent and easily detected

There is usually enough information in visibility data to correct for these

Beam Calibration: Dish: UAV / Cas A
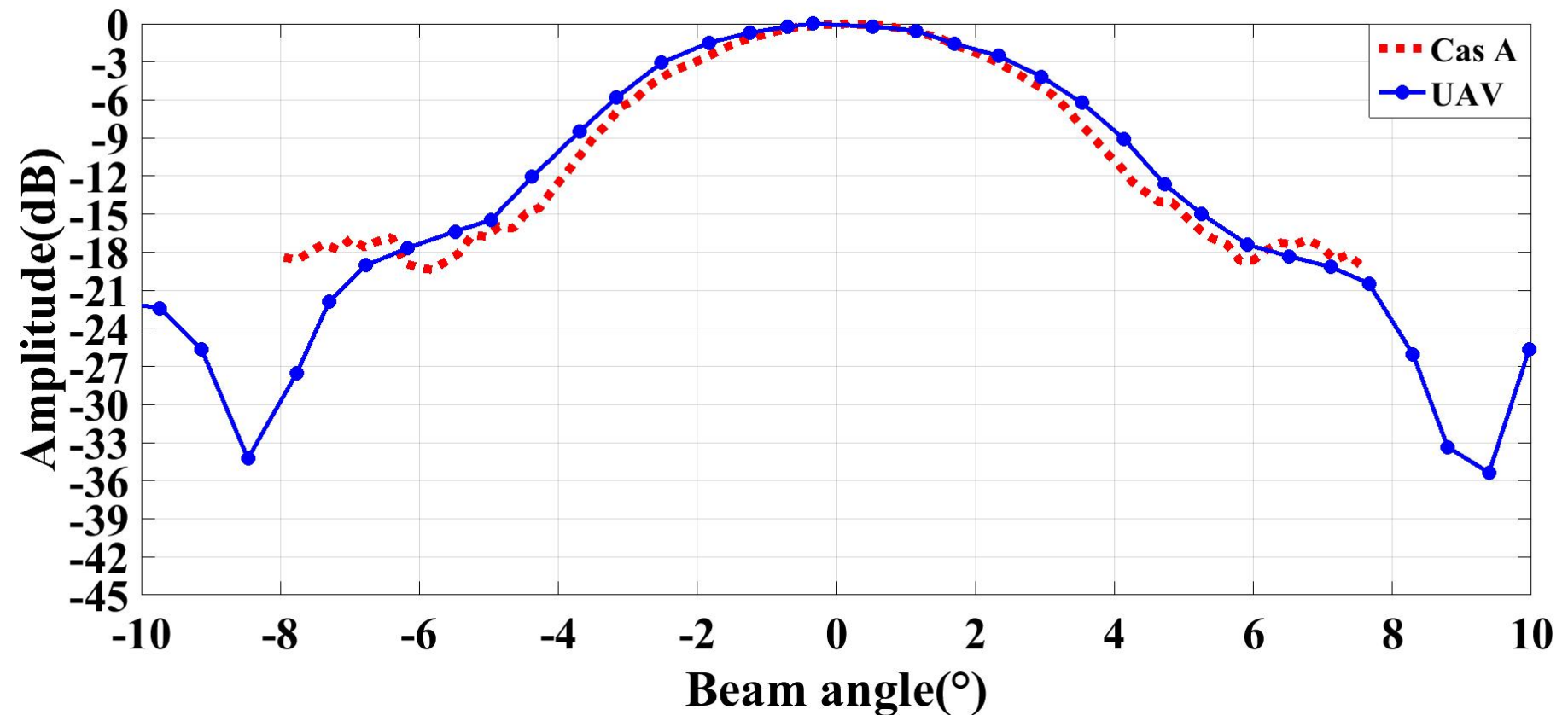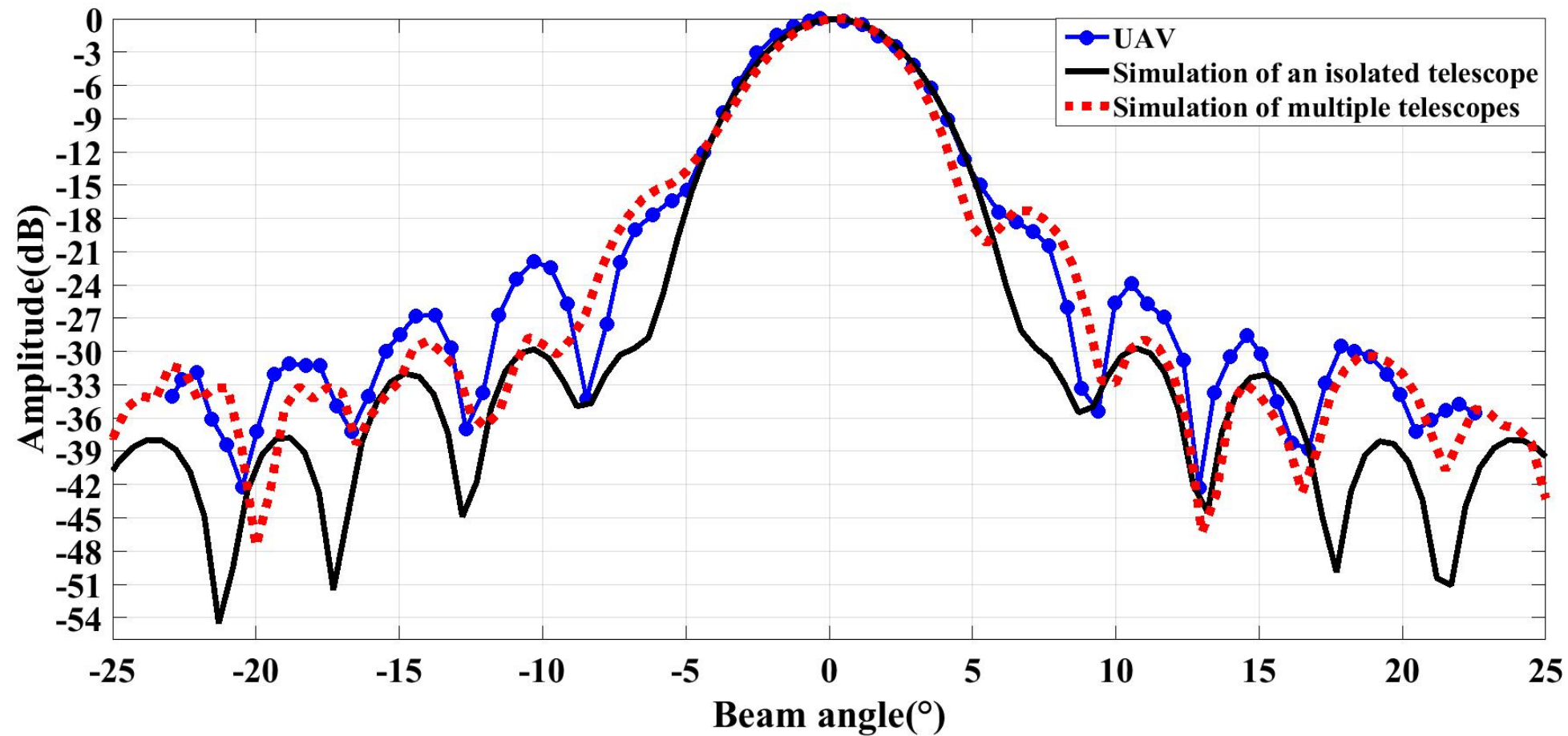
9 Night Median Averaging / Mean Nightly Subtraction

RFI removal unnecessary!

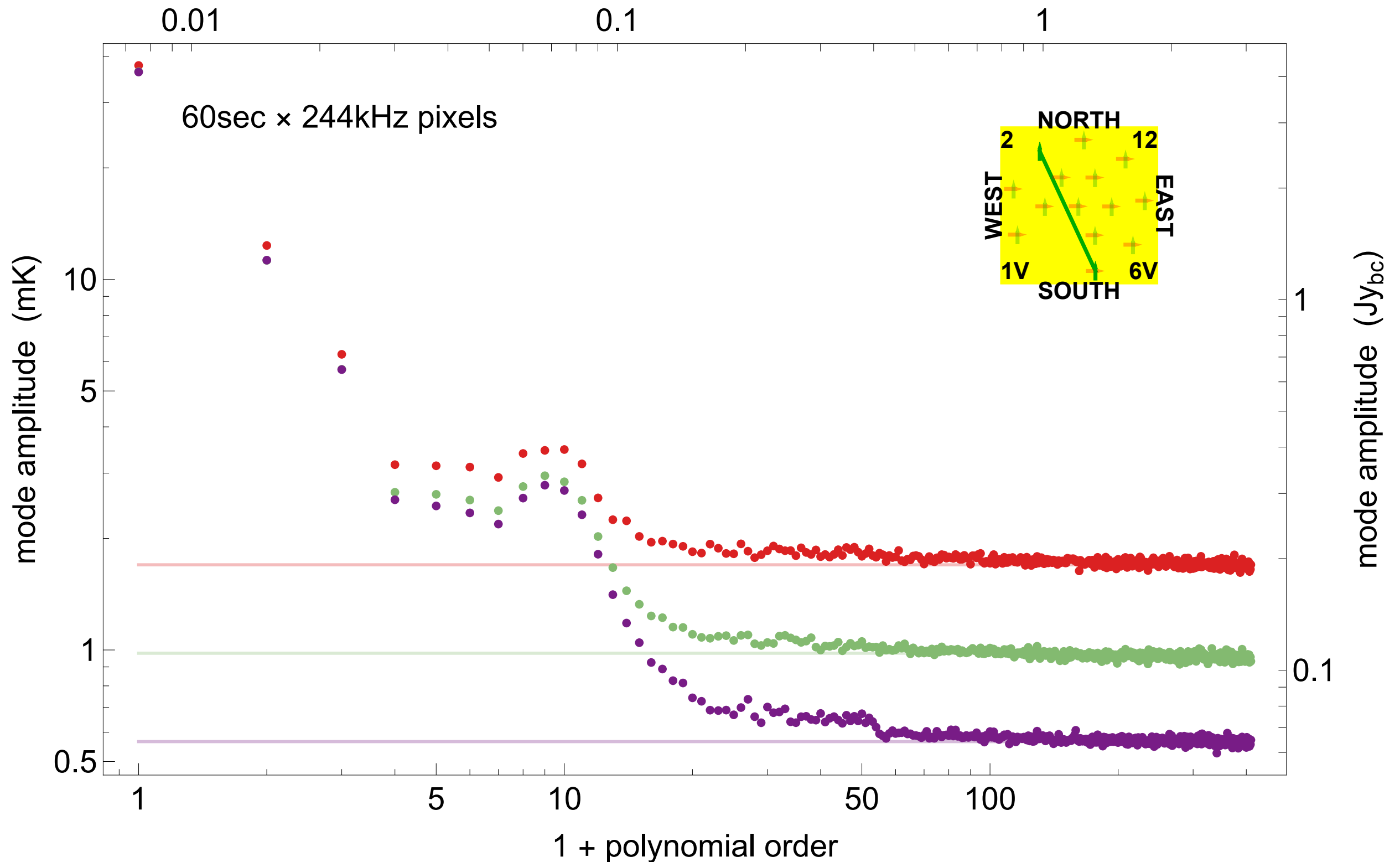have good measure of visibilities from foreground sources

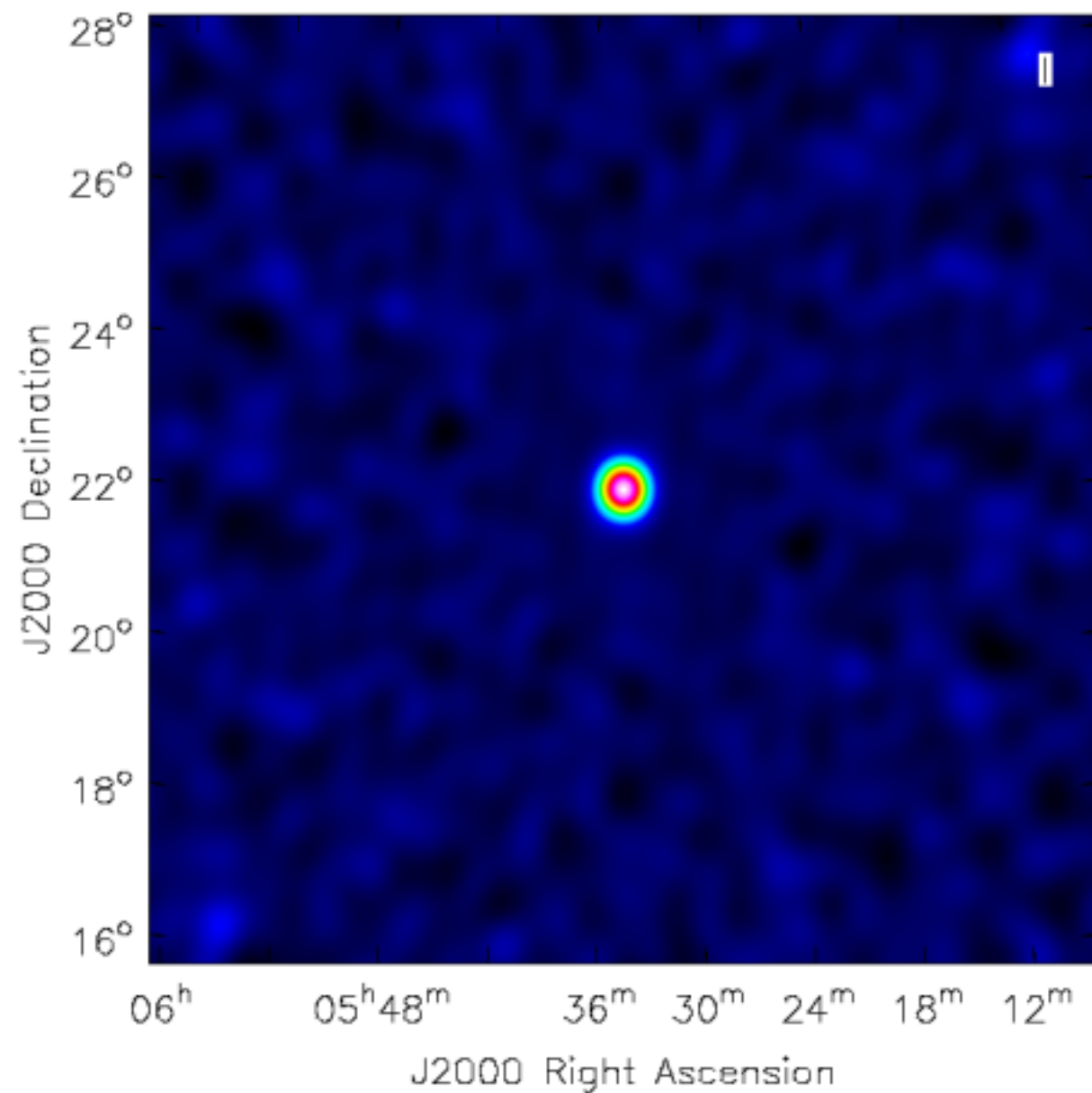# Spectral Polynomial / Temporal Fourier Decomposition

Power Distribution 03x31 Dish

←**pseudo-m**→

n

n=0

n=472

m=−470

m=0

m=+471

log of power in 1min × 244kHz pixels

pseudo-m because not entire sidereal day

Smooth of Spectrum of Visibilities

Combining Baselines: Map Making

M1 transit dish (CASA)
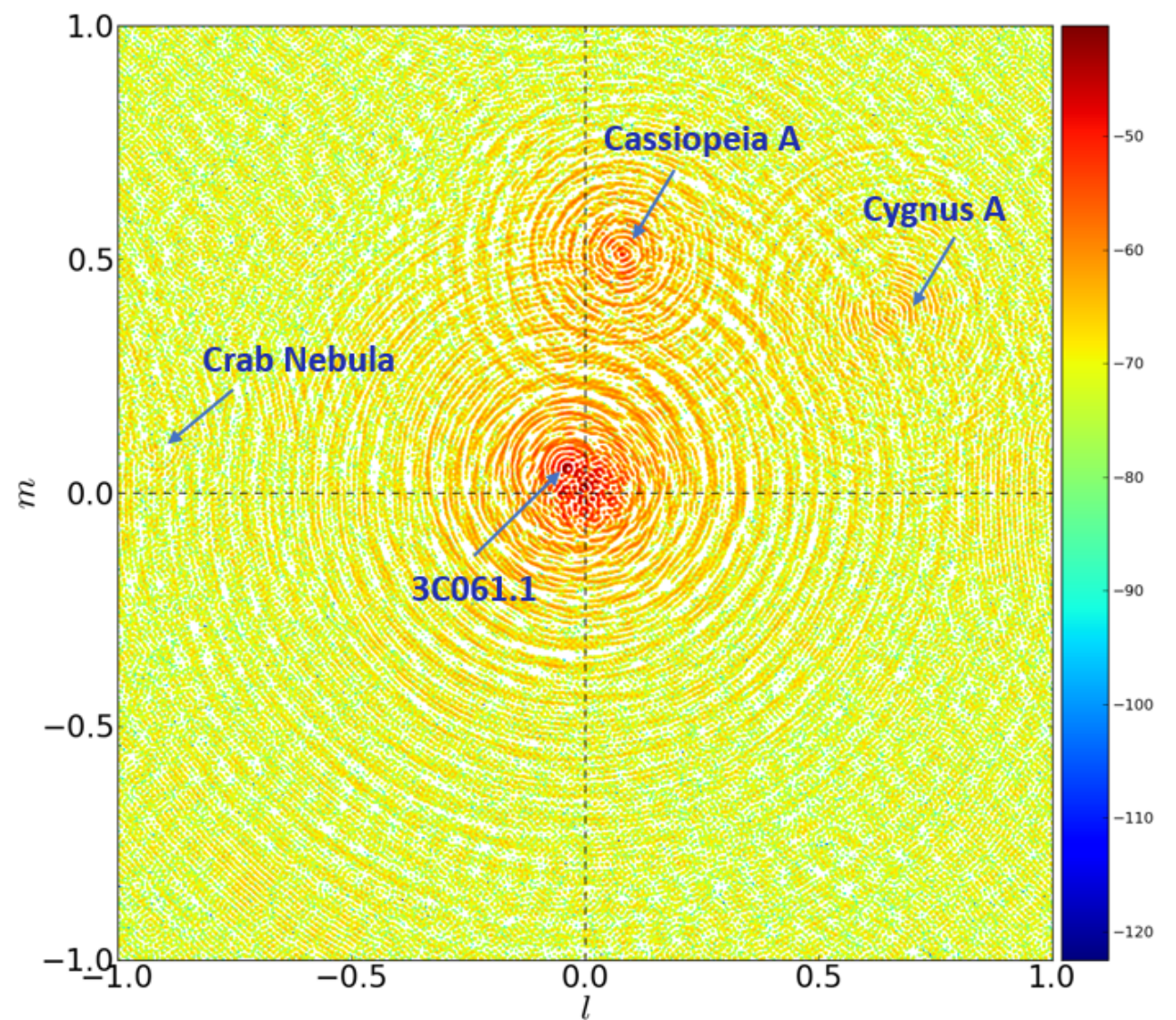
Northern Sky from NCP - dish

need better beam modeling

What's Going On Now / Soon

- **Transient Back-End Installed** :

- **Analysis of ~200 days of NCP dish data** :

- **Retune to z~0** :
  - Correlate with optical galaxy redshift surveys
    - North Celestial Cap Survey photometric survey: taking spectra w/ WIYN
    - SDSS

QUESTIONS??