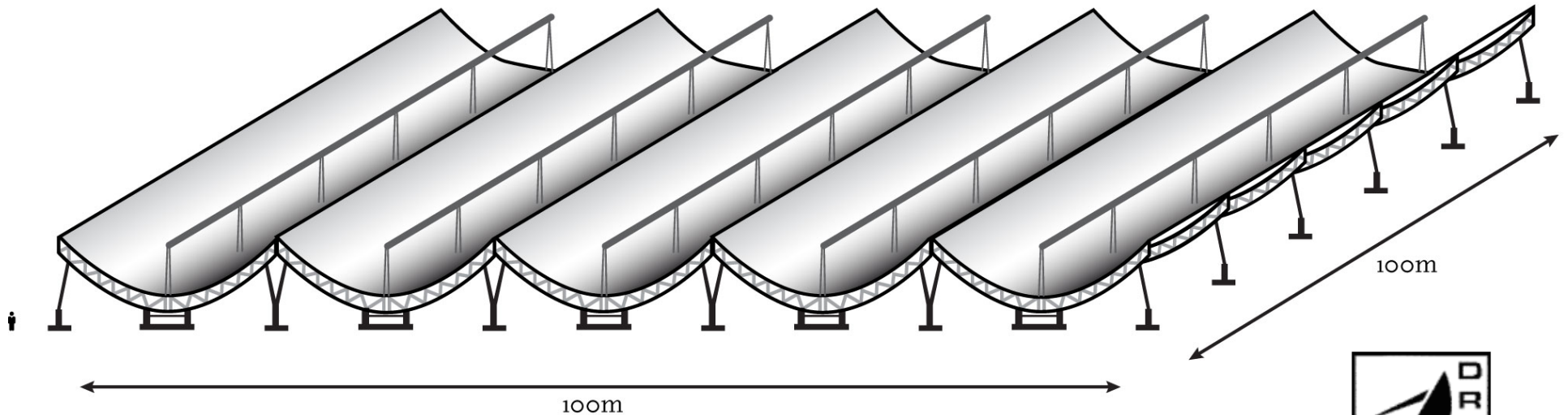


CHIME: Status Update



- 400-800MHz band
21cm from $z \sim 0.8 - 2.5$
- Resolution: 1MHz, 13-26'
3rd BAO peak resolved
- Drift scan, no moving parts
20,000 deg² coverage
- 1280 Dual-polarization feeds
Cosmic-variance-limited survey



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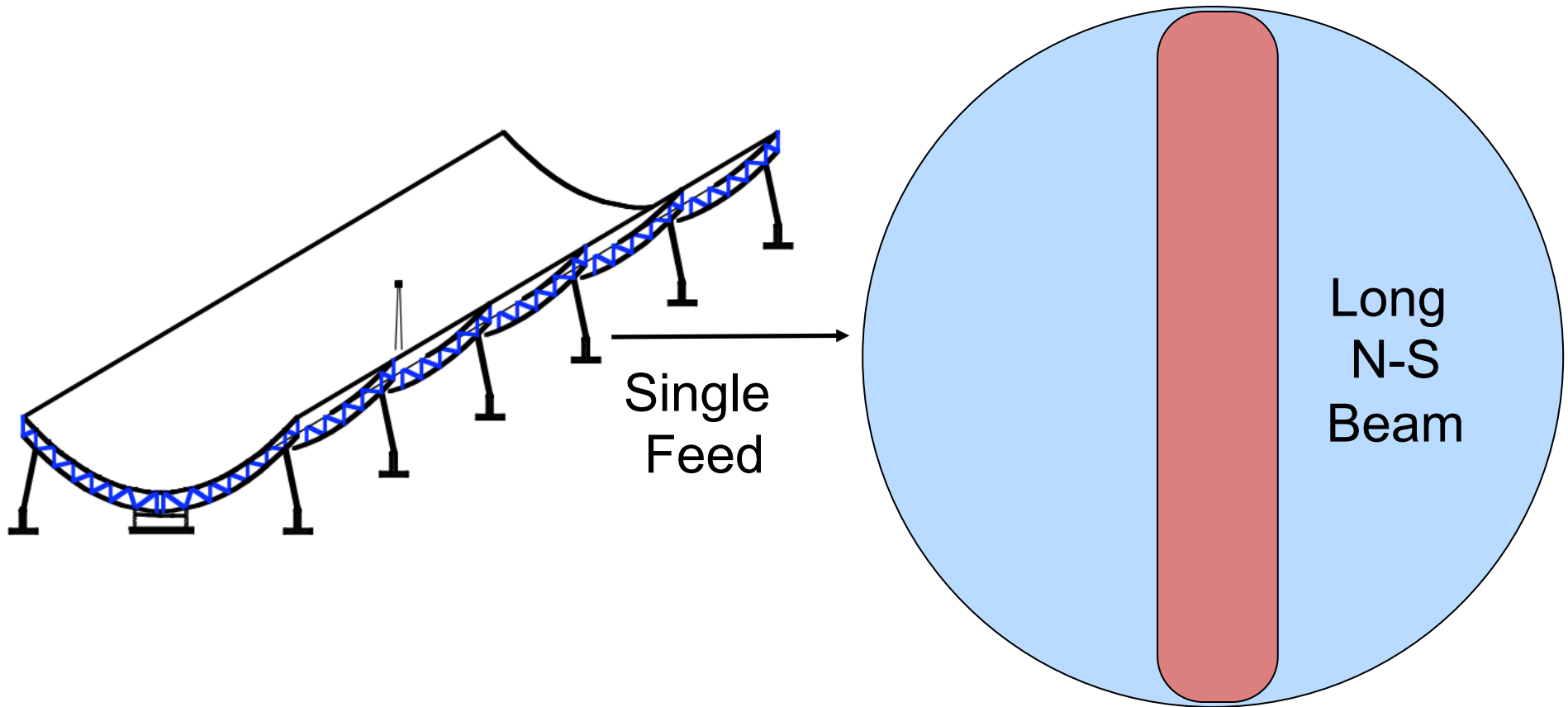


McGill



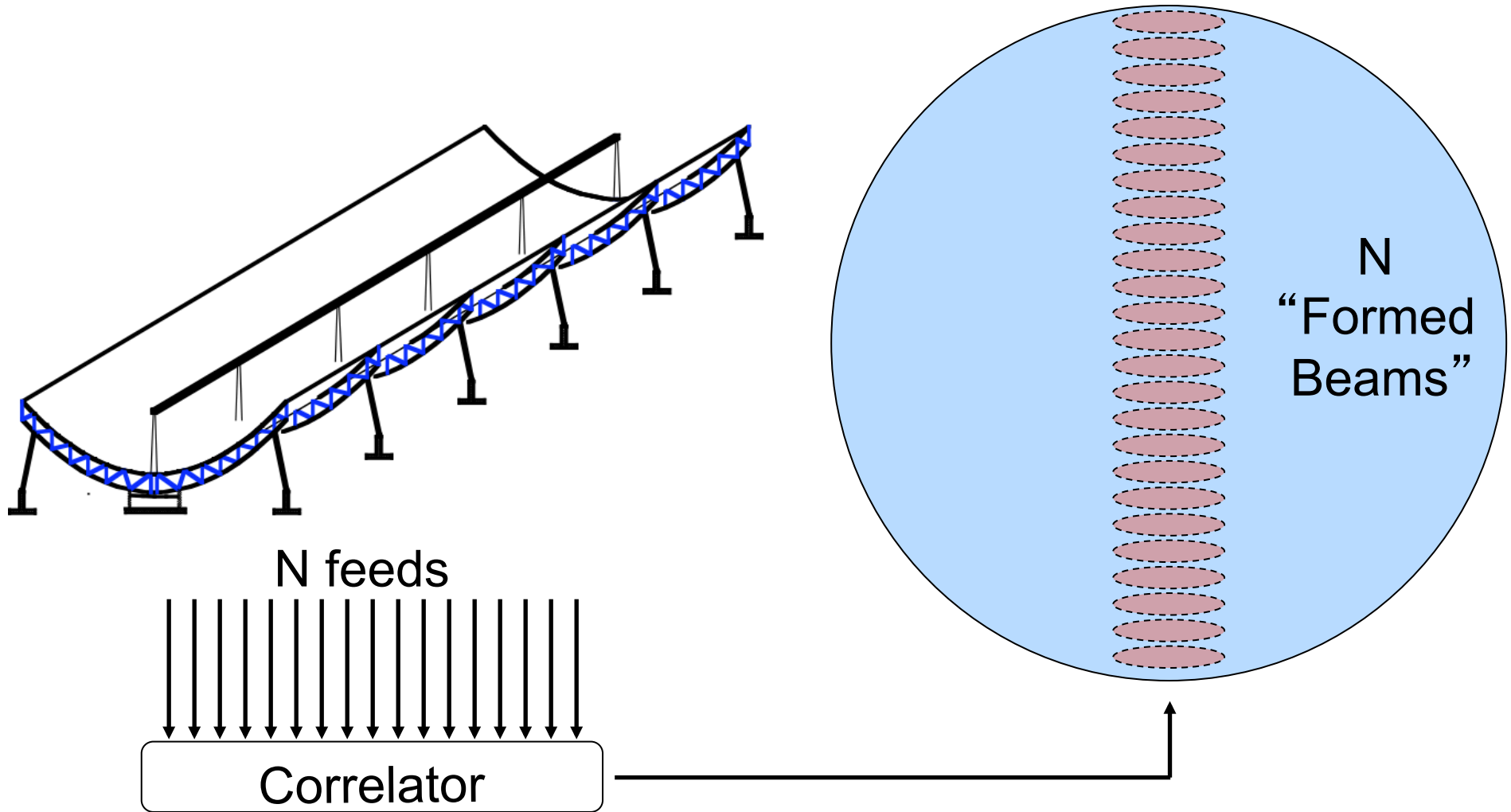
UNIVERSITY OF
TORONTO

Cylinder Antenna



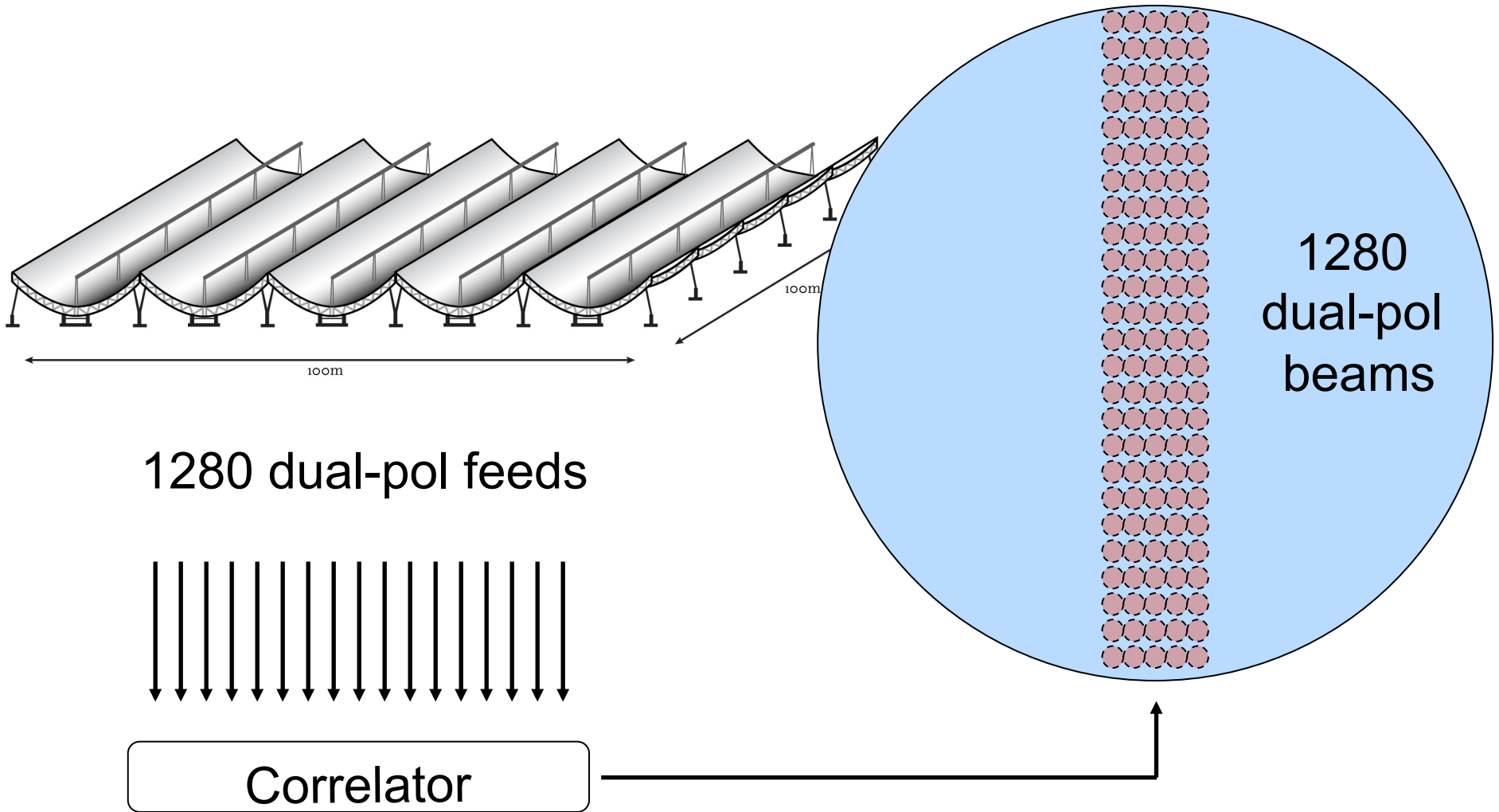
Cylinder Telescope

Hybrid: 1D Dish + 1D Interferometry



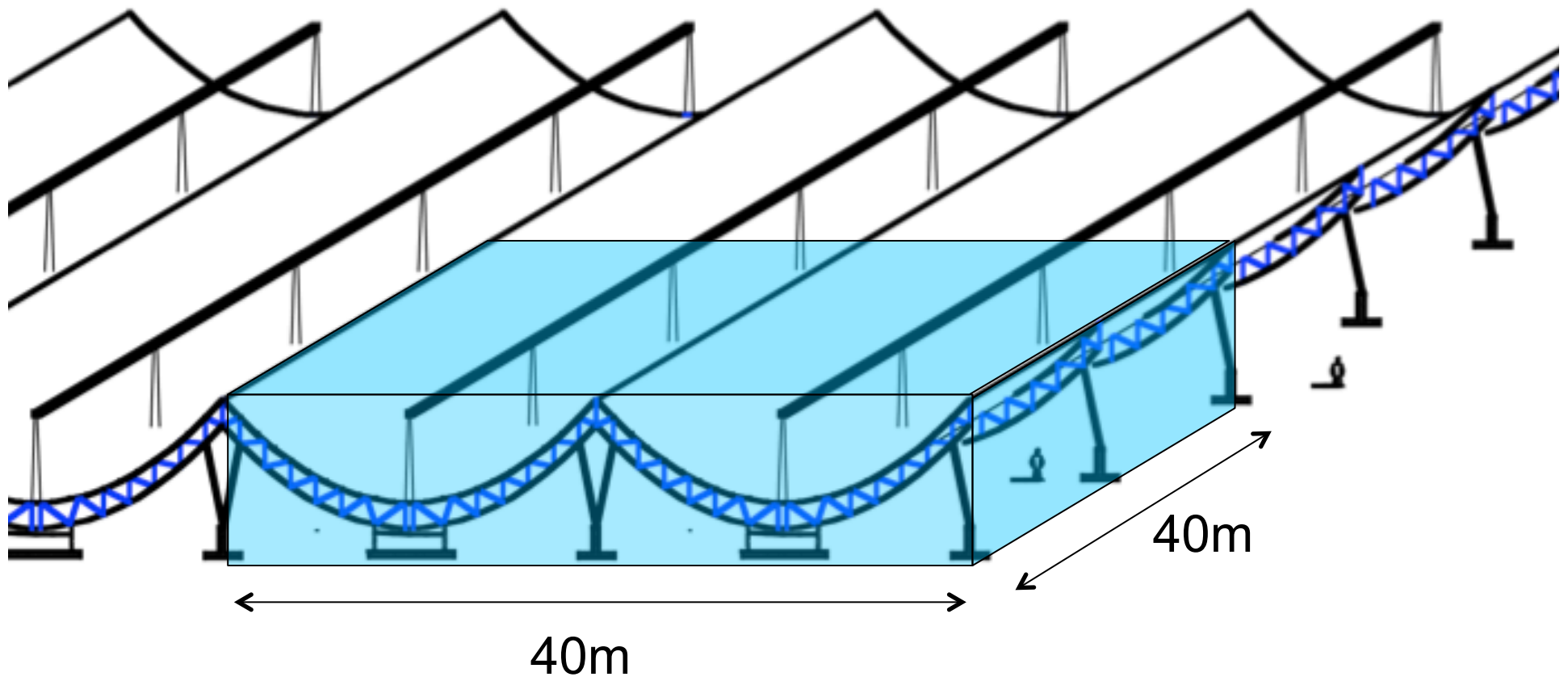
CHIME

1D Dishes + 2D Interferometry



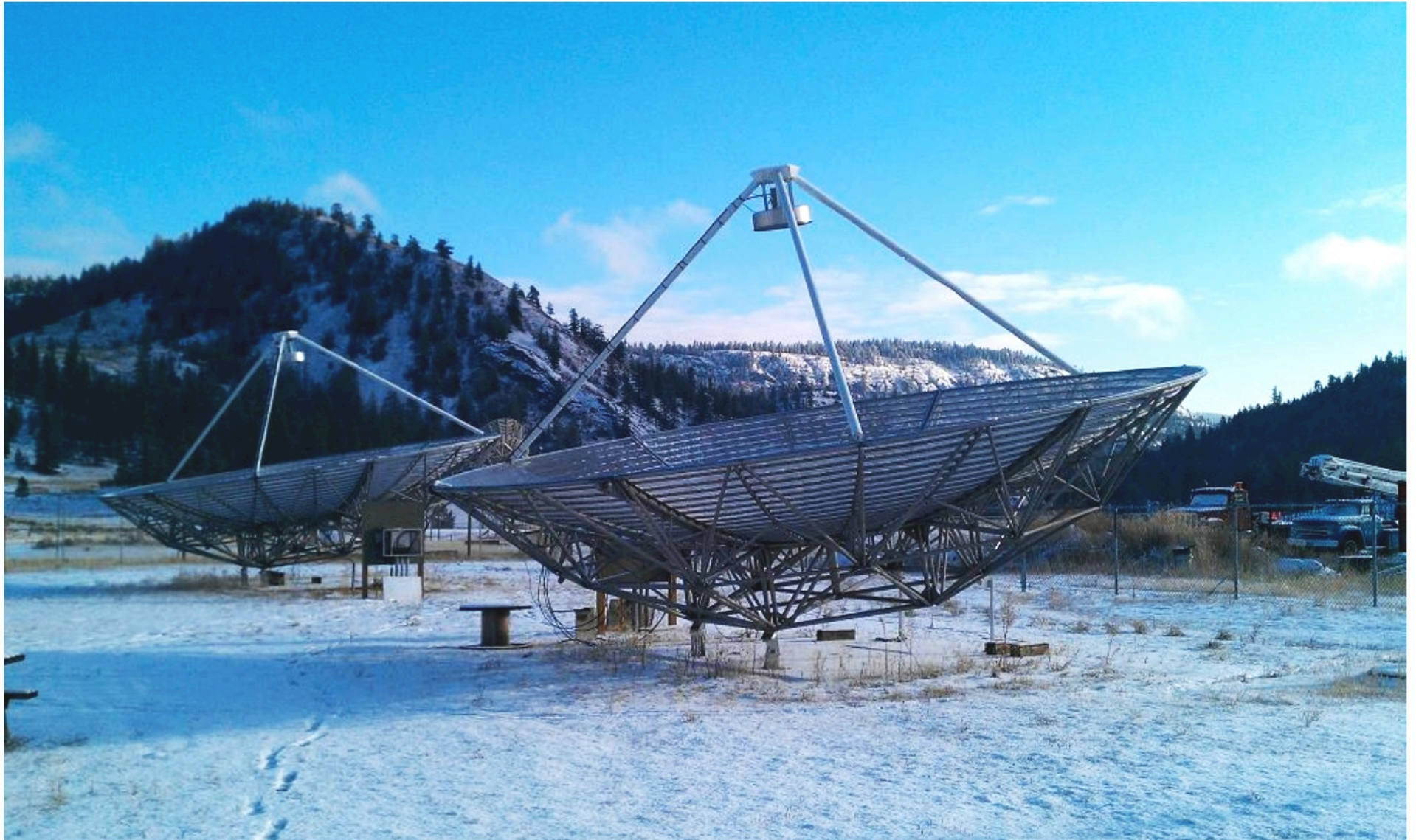
The CHIME Pathfinder

*An end-to-end hardware, calibration, foreground suppression,
and data analysis proof-of-concept for CHIME*



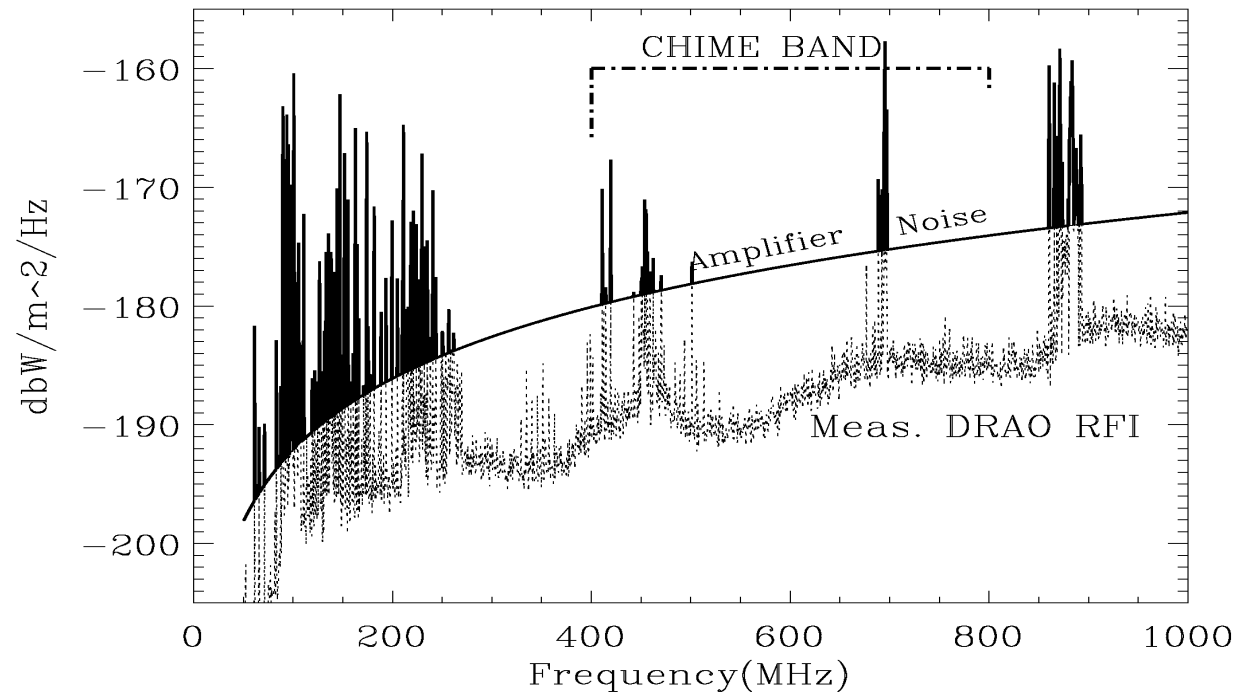
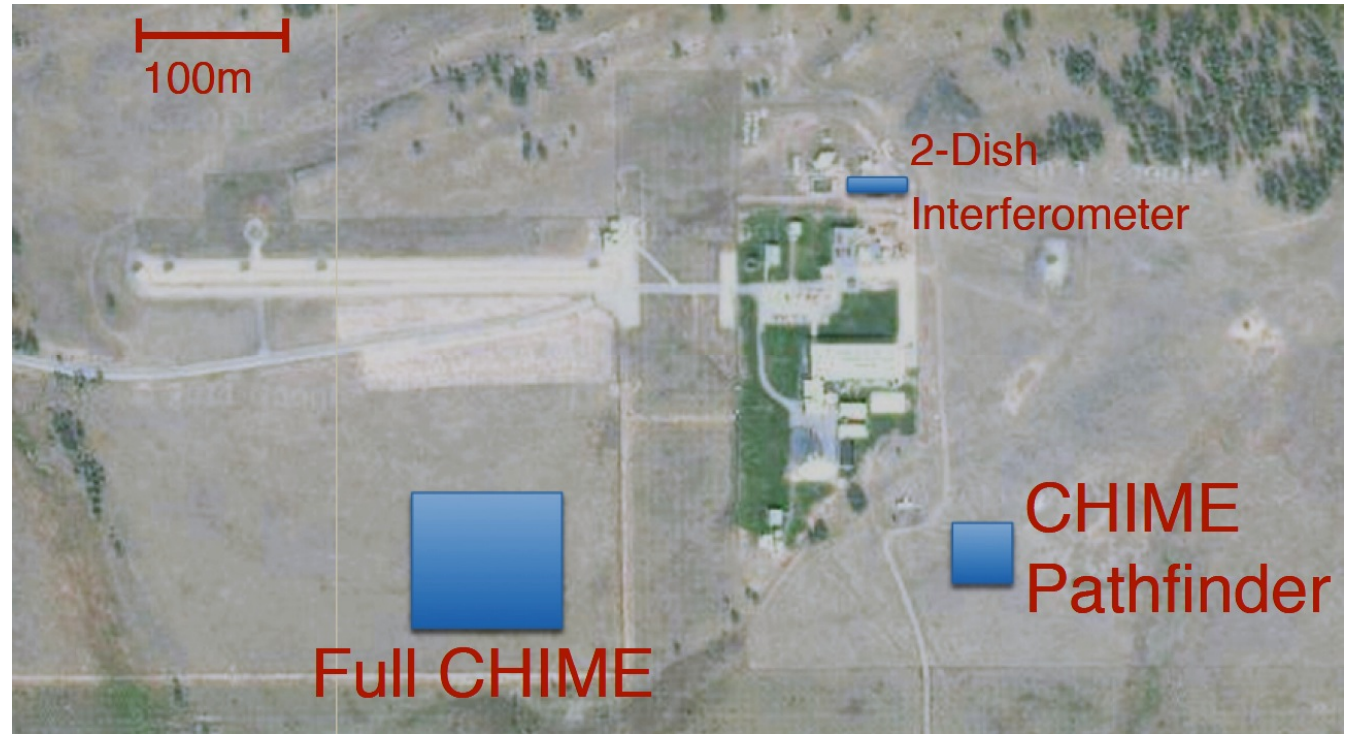
64 dual-pol antennas per cylinder (256 total channels)

Prototype Dishes at DRAO



2 x 8m dishes, propped in a field

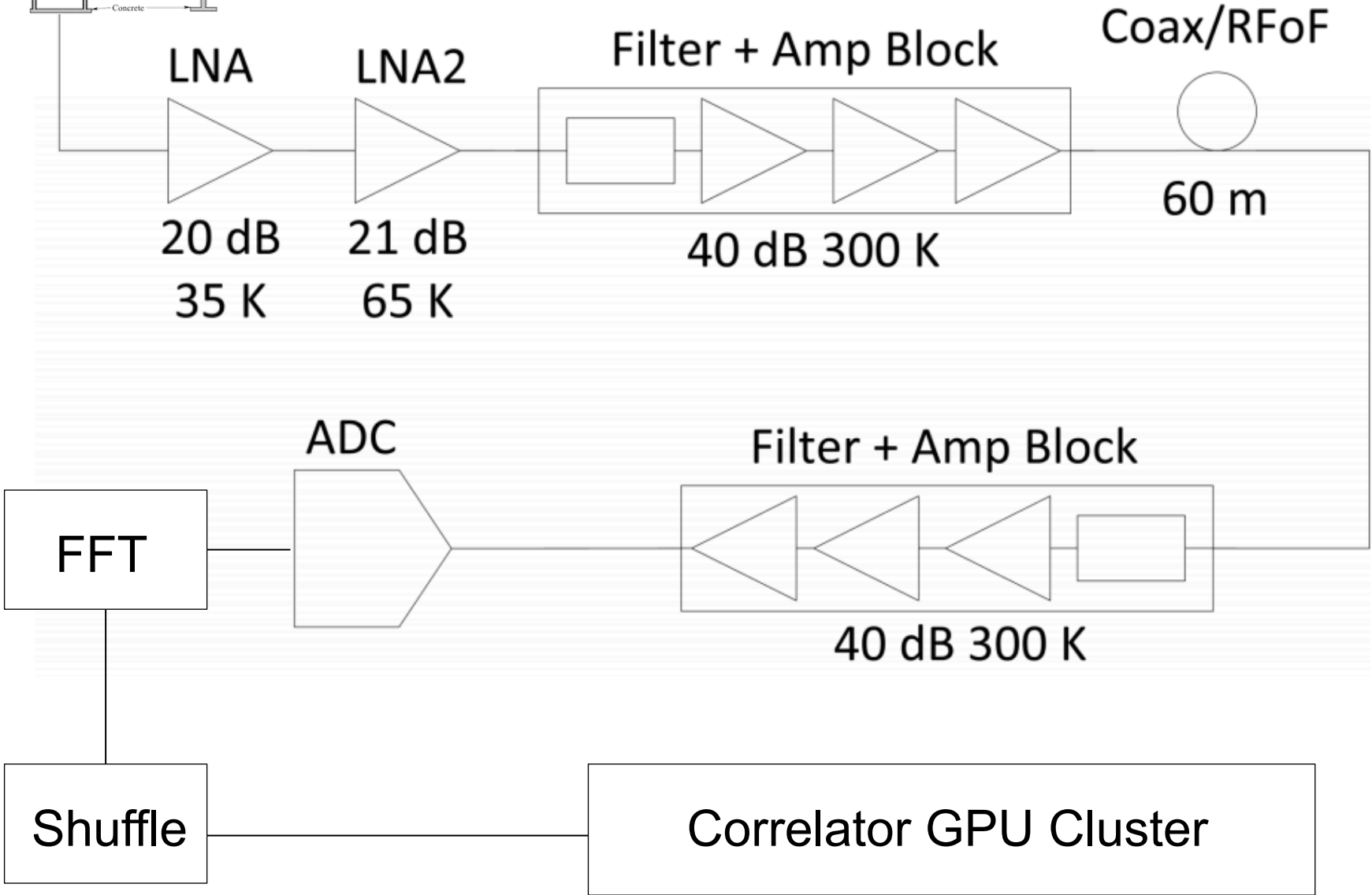
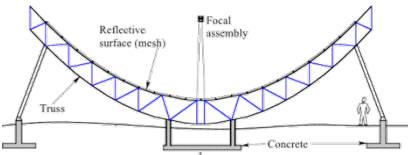
Site: DRAO



CHIME Site: DRAO



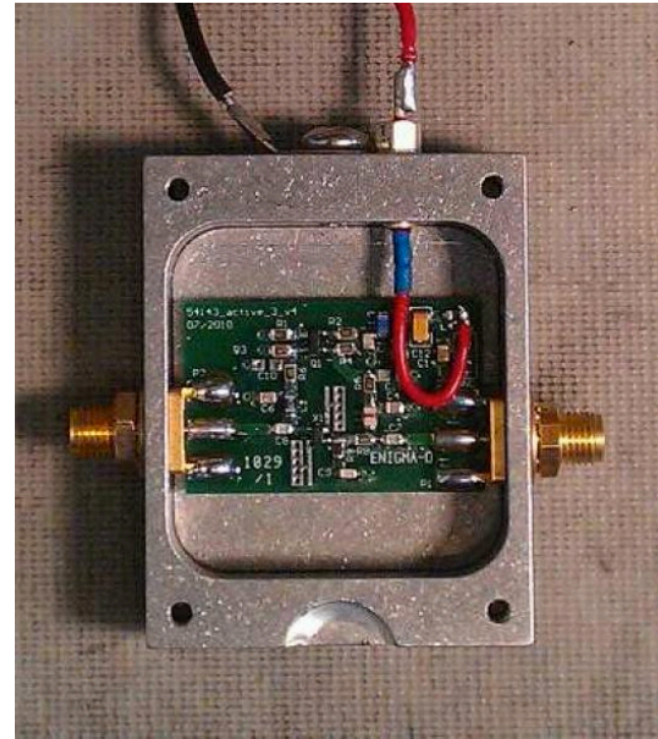
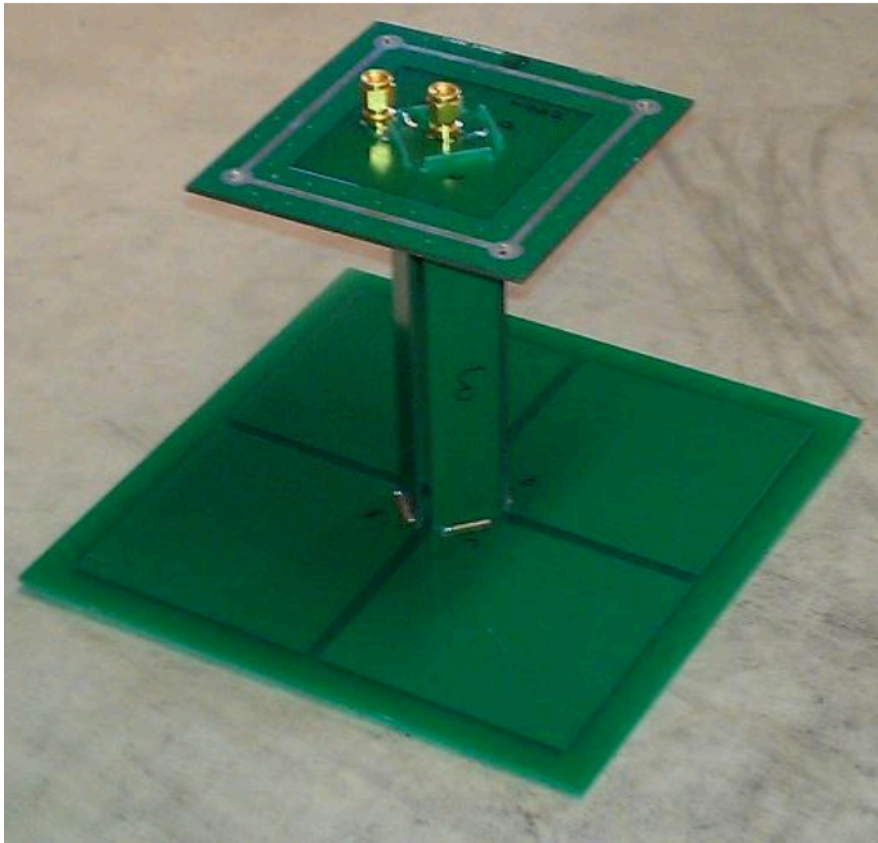
System Overview



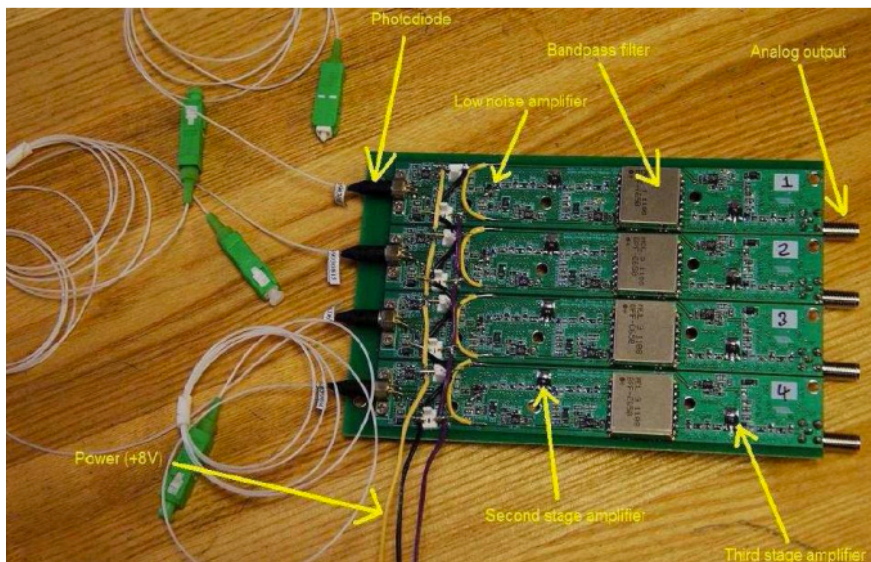
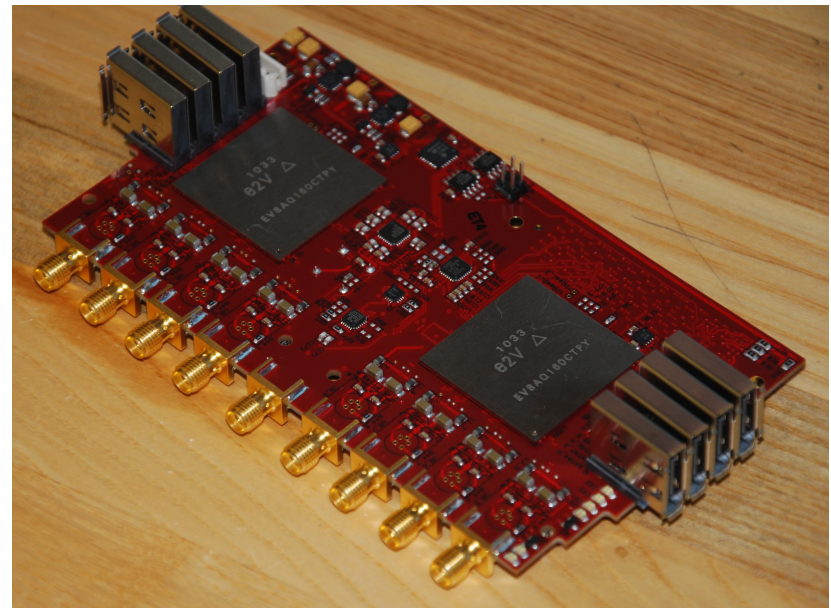
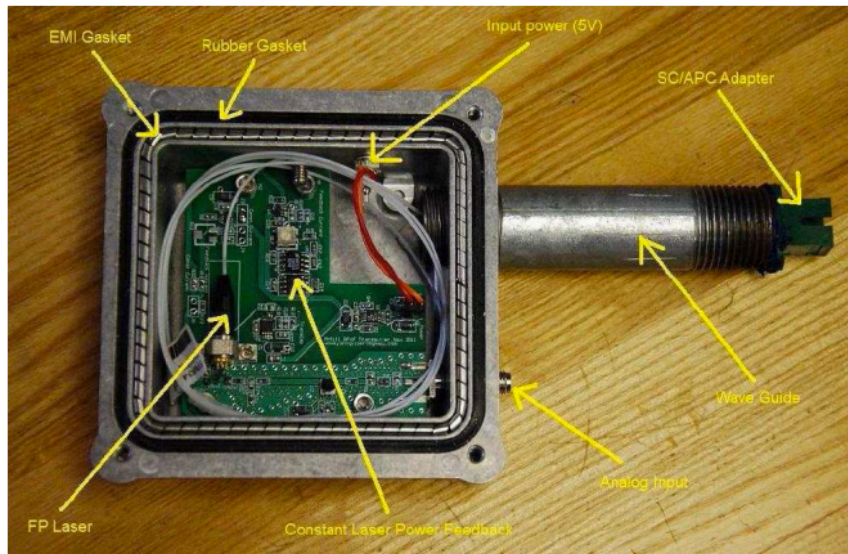
Pathfinder Cylinders: Metal in the Ground!



Feeds, LNAs, Filters



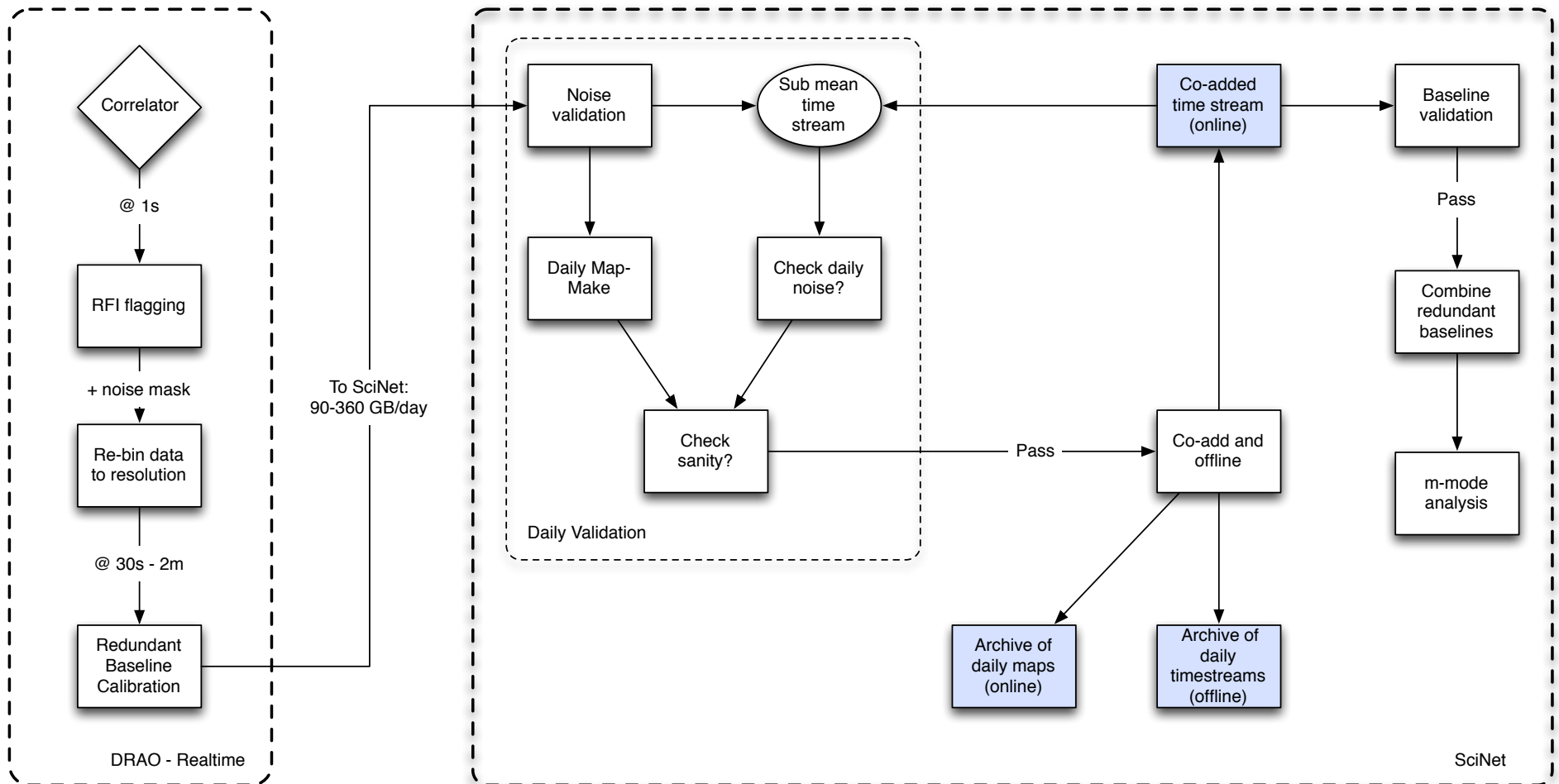
RF-over-Fiber, Digitization, Channelization, Correlation



The Hard Part

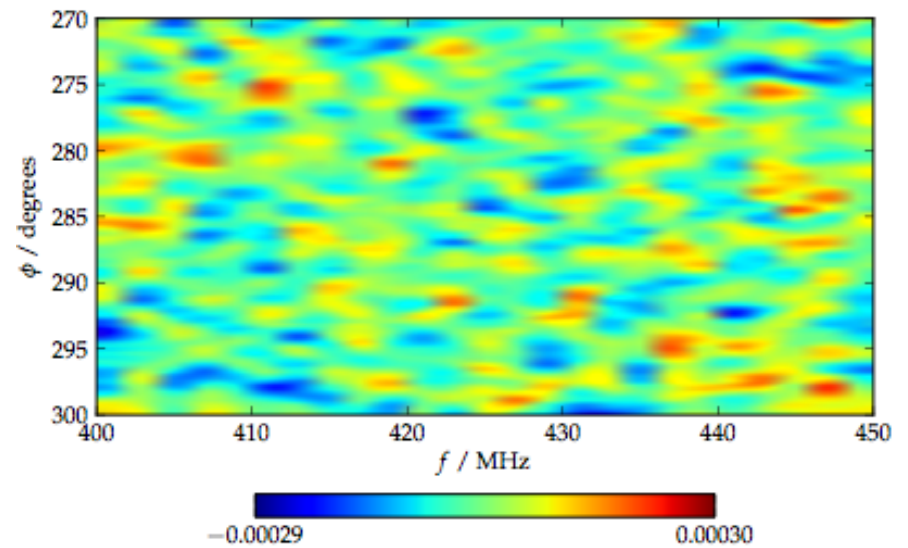
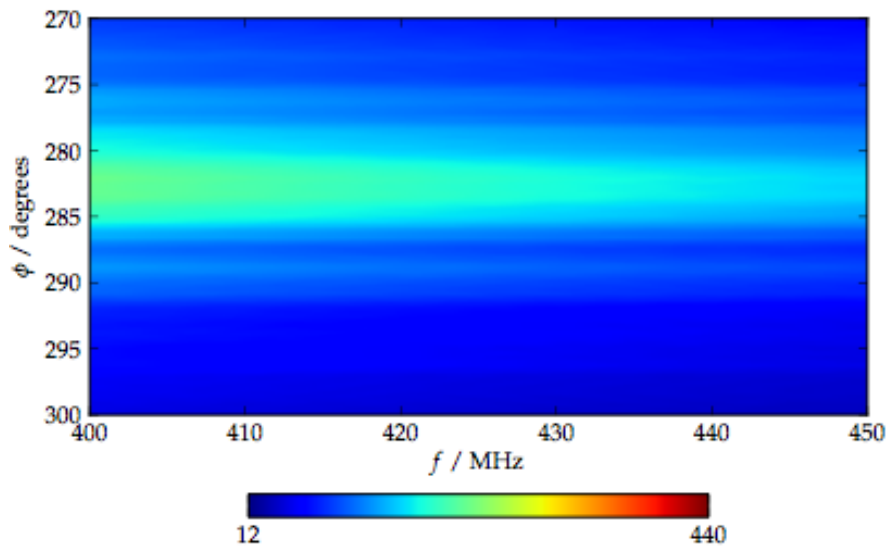
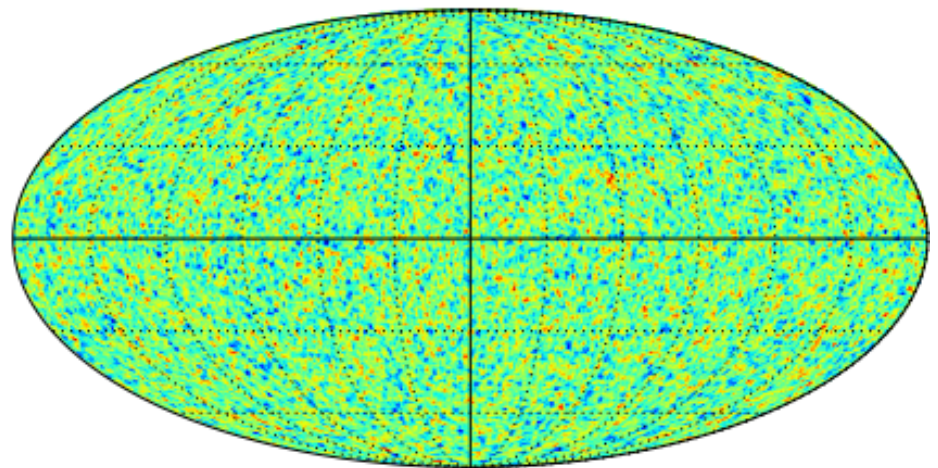
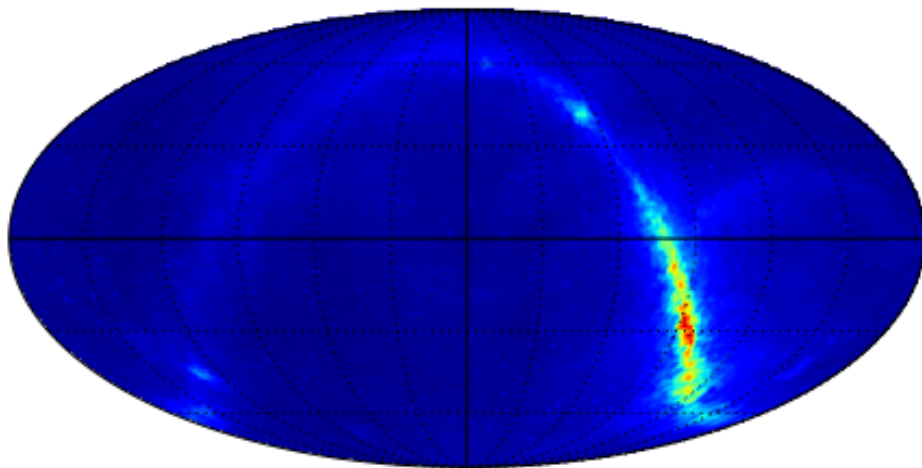
(calibrating, storing & analyzing 0.5 YB [5 x 10¹¹ TB] of data)

Correlation state: 256 channels
@ 256 freq = 128 MB



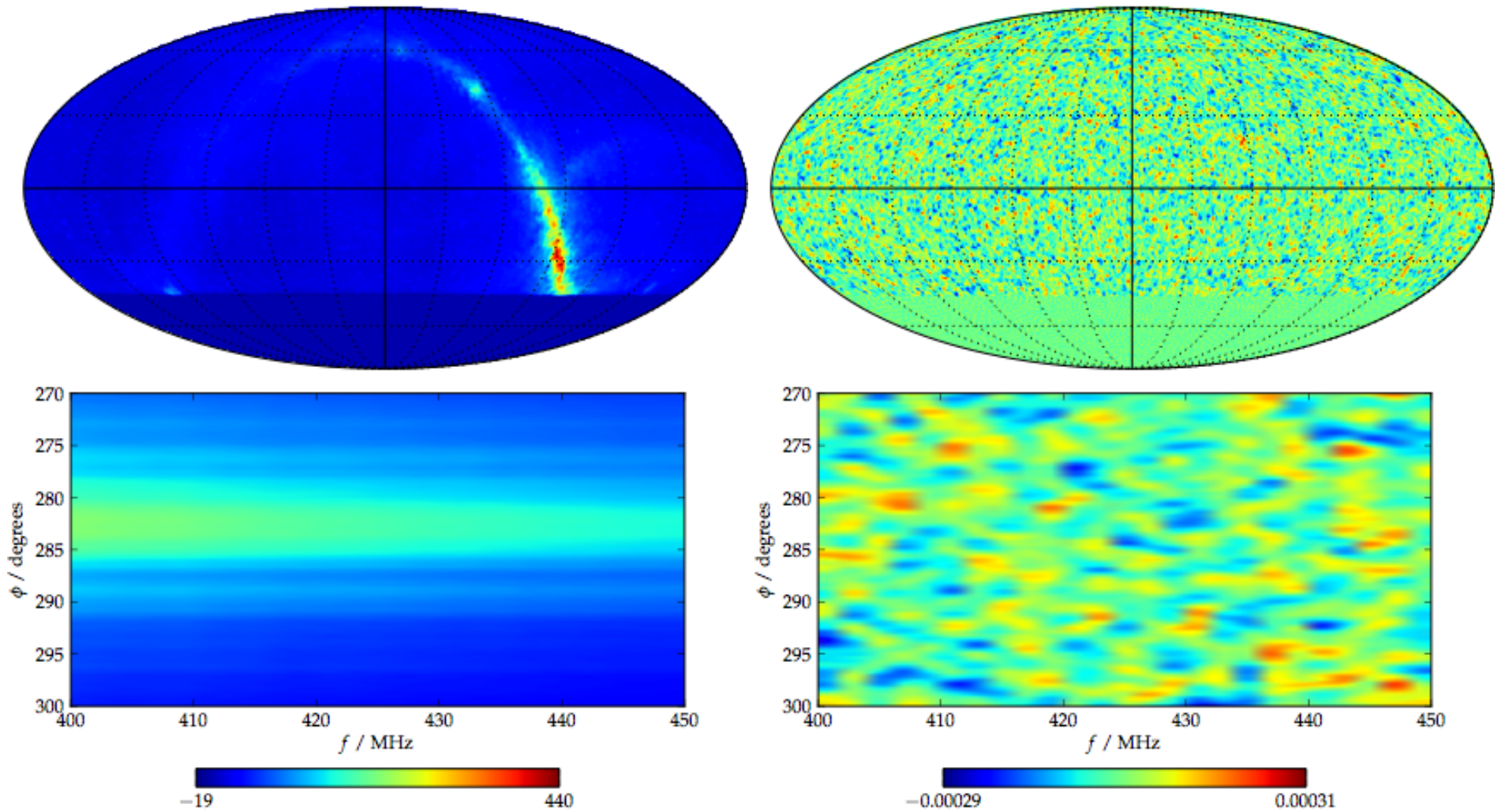
Foregrounds

21cm BAO



$\sim 10^6$ x brighter

Observed sky (from simulated time stream)

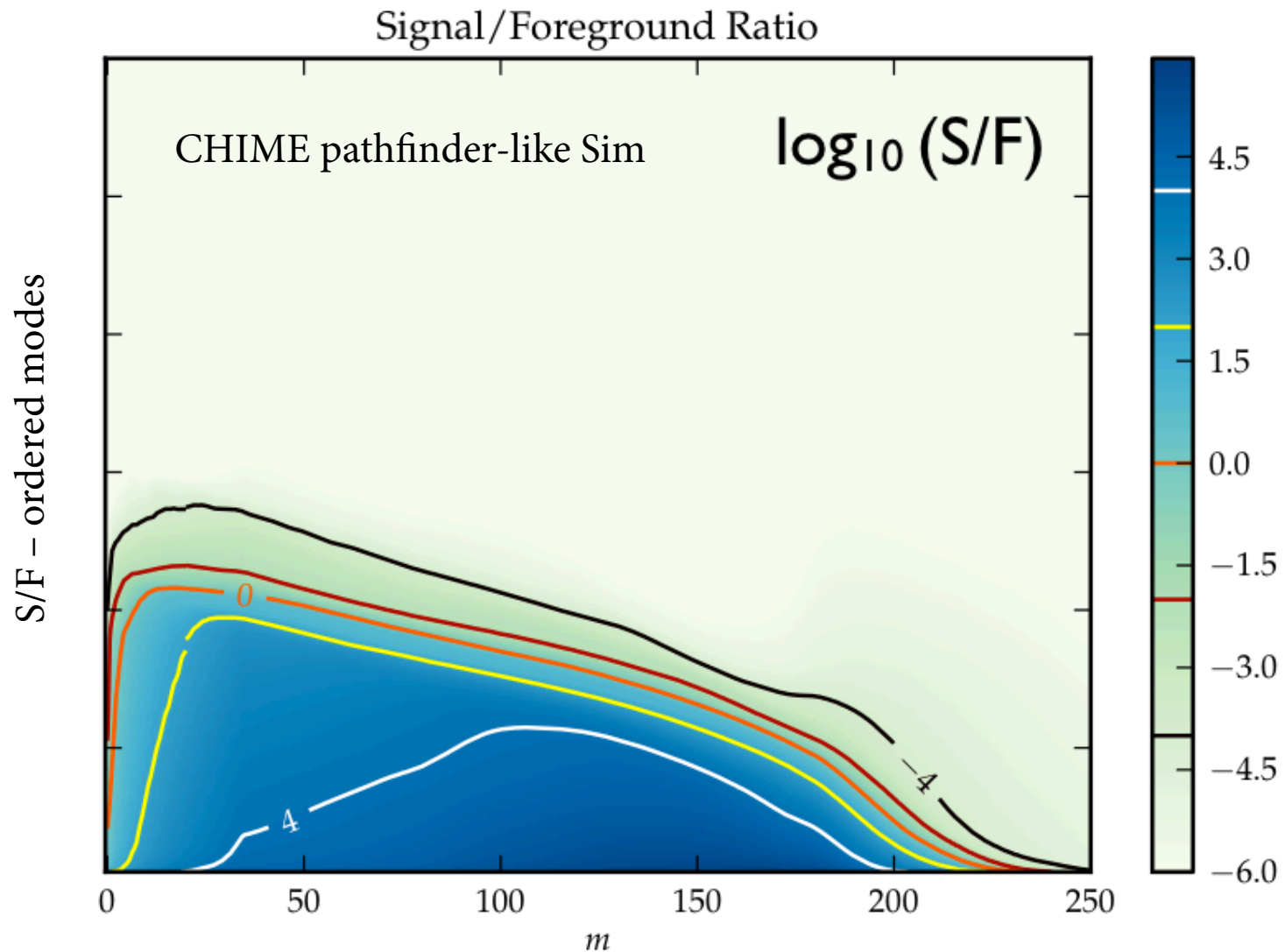


$\sim 10^6$ x brighter

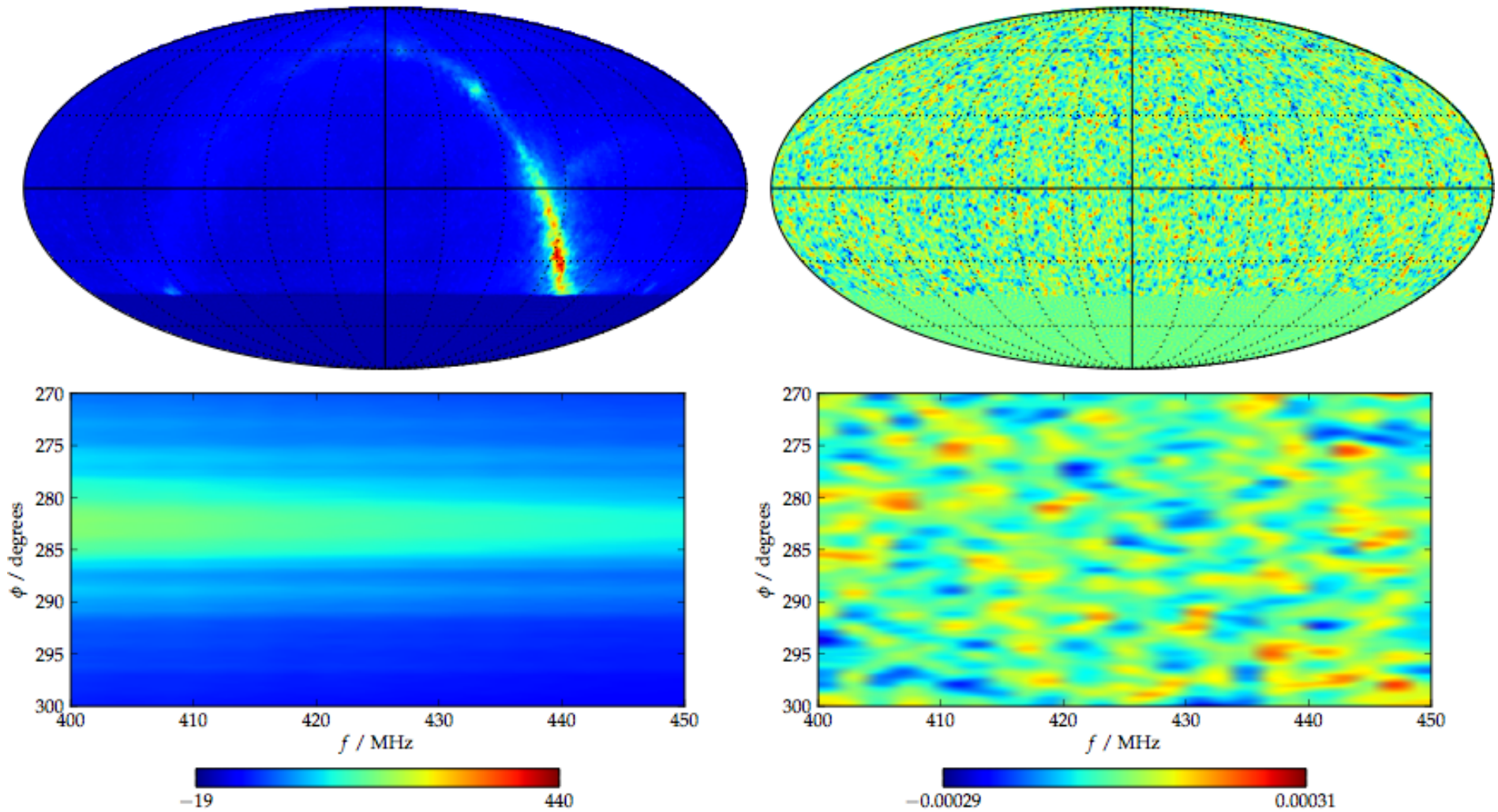
Signal/Foreground Filtering

ALL-SKY INTERFEROMETRY WITH SPHERICAL HARMONIC TRANSIT TELESCOPES

J. RICHARD SHAW^{1,†}, KRIS SIGURDSON², UE-LI PEN¹, ALBERT STEBBINS³, AND MICHAEL SITWELL²

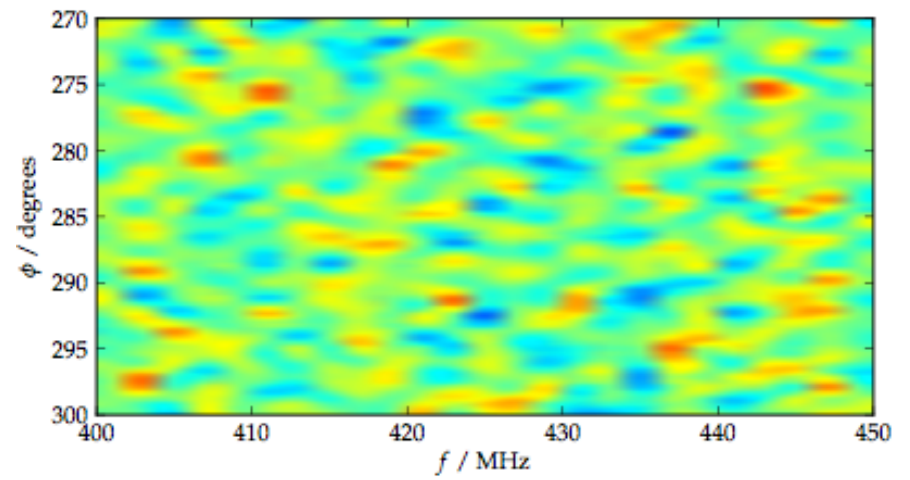
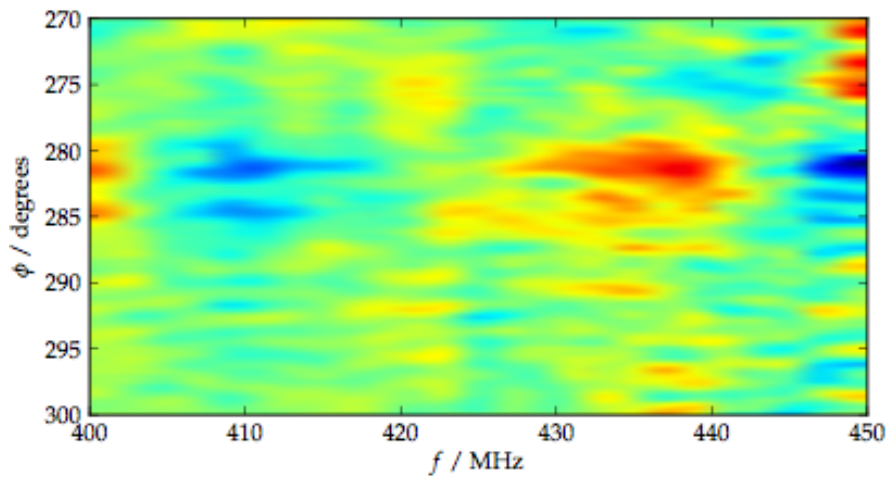
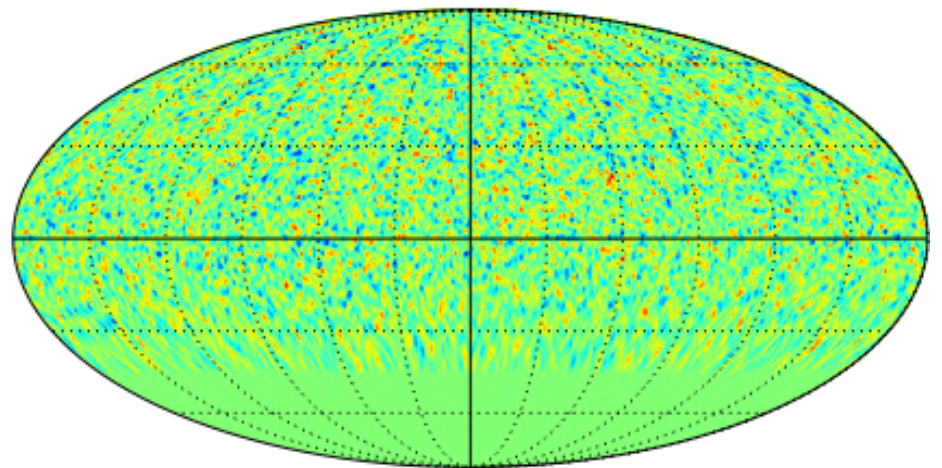
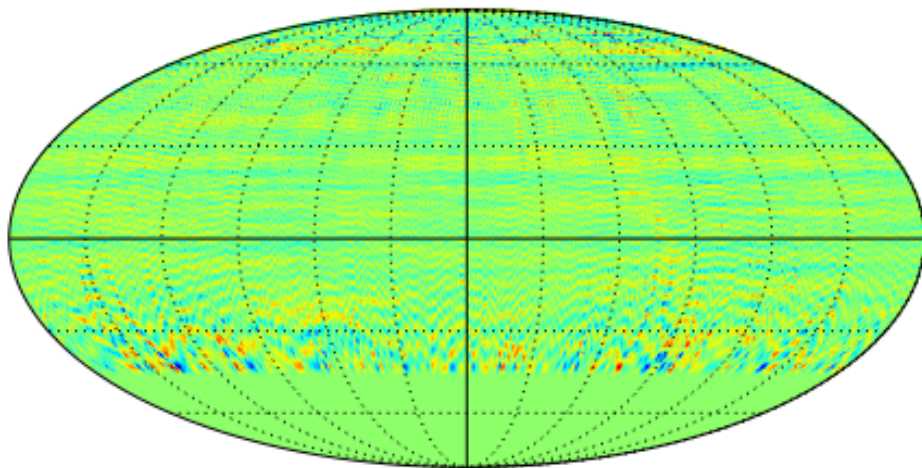


Observed sky (from simulated time stream)



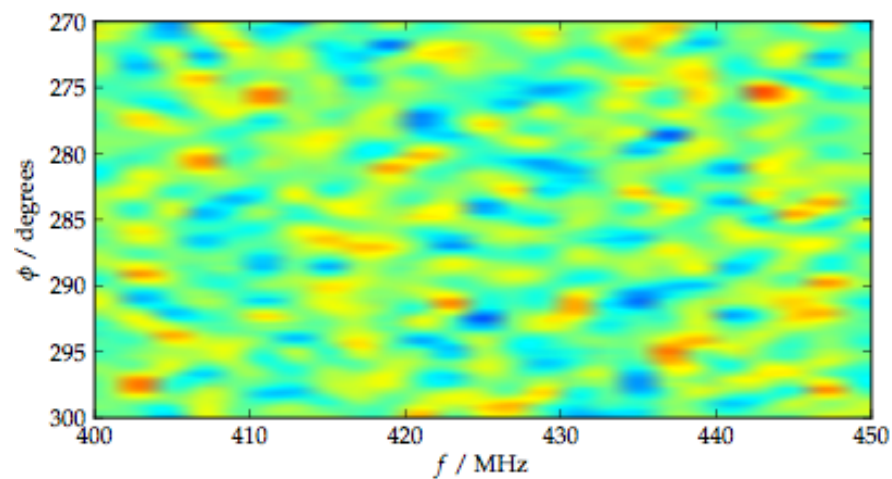
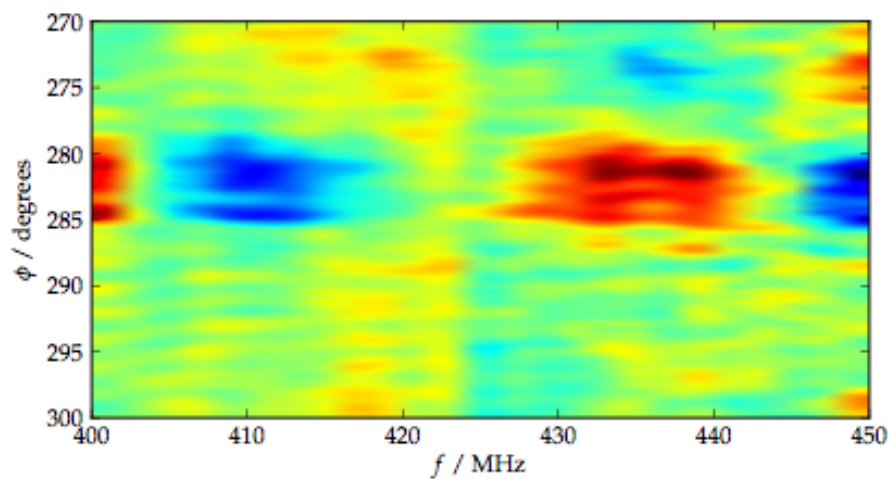
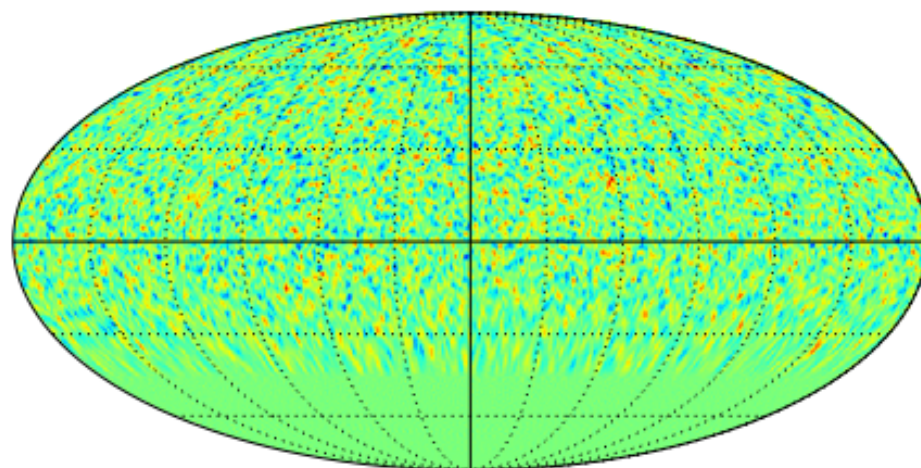
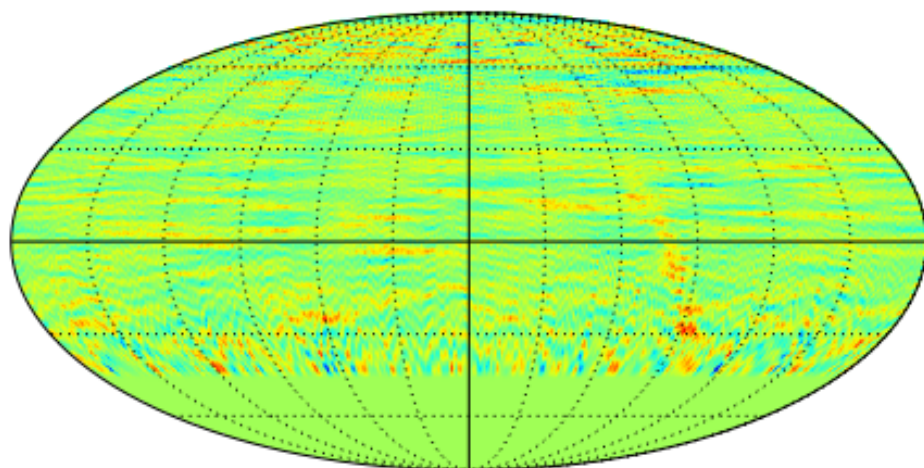
$\sim 10^6$ x brighter

$S/F > 0.01$



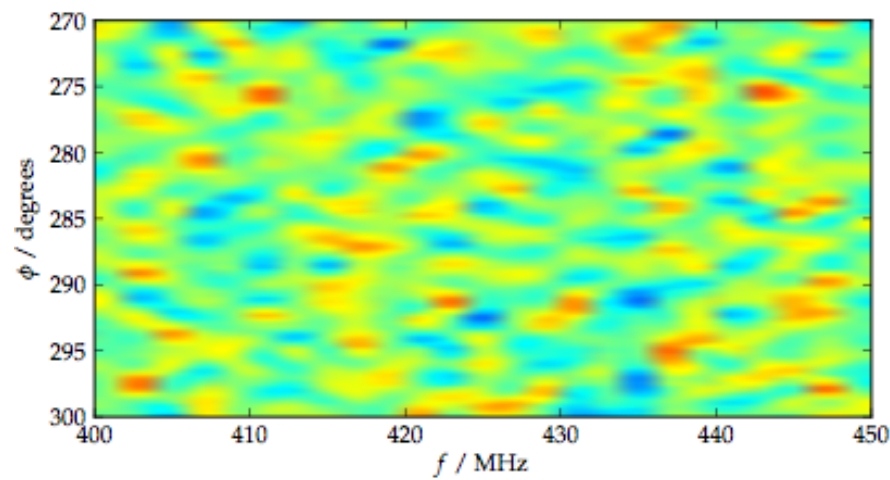
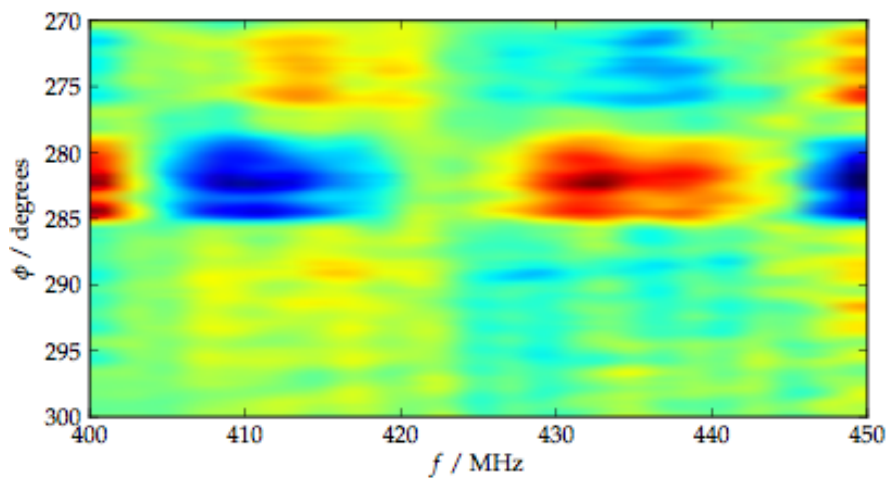
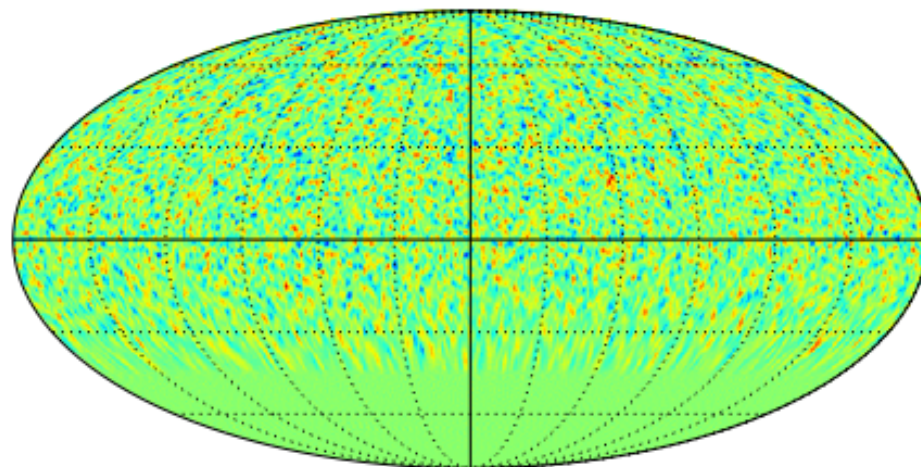
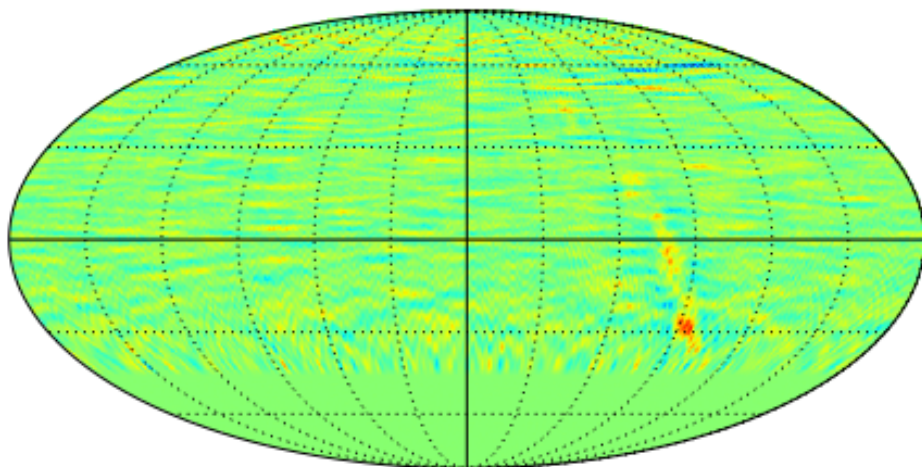
~ same brightness

$S/F > 0.1$



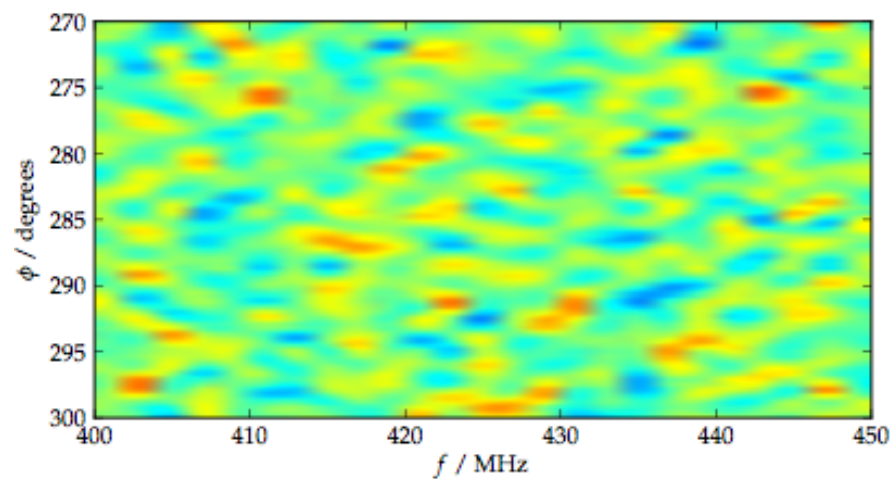
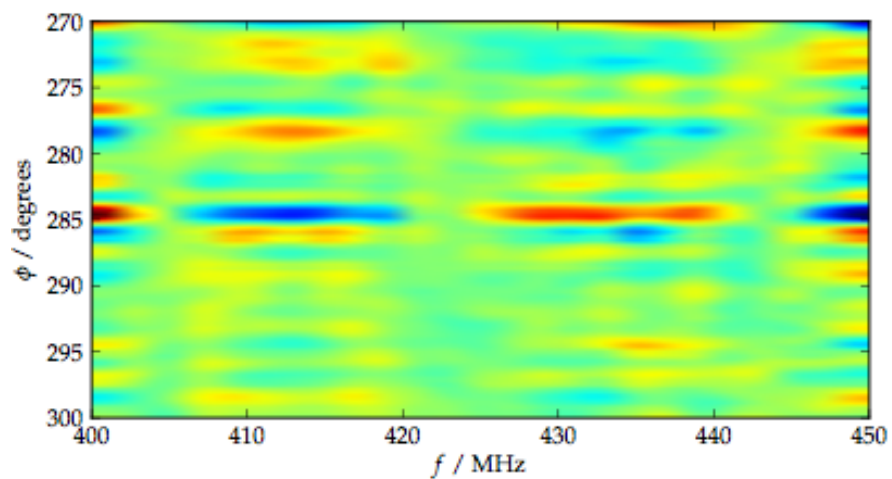
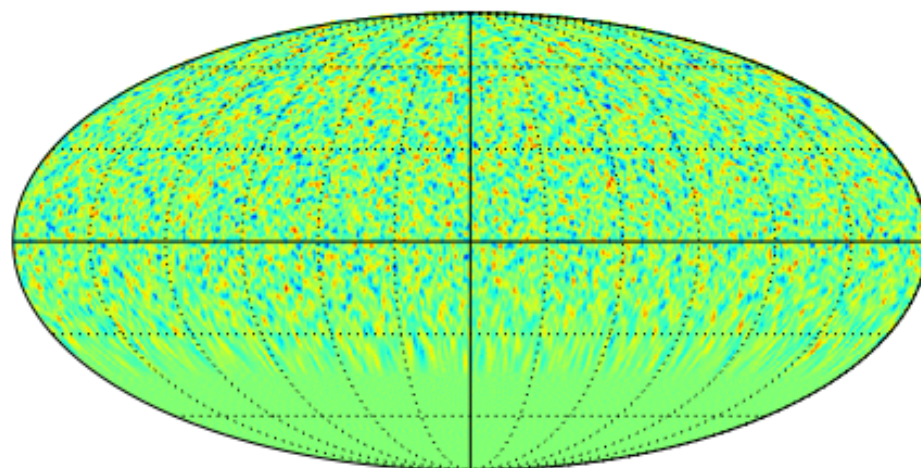
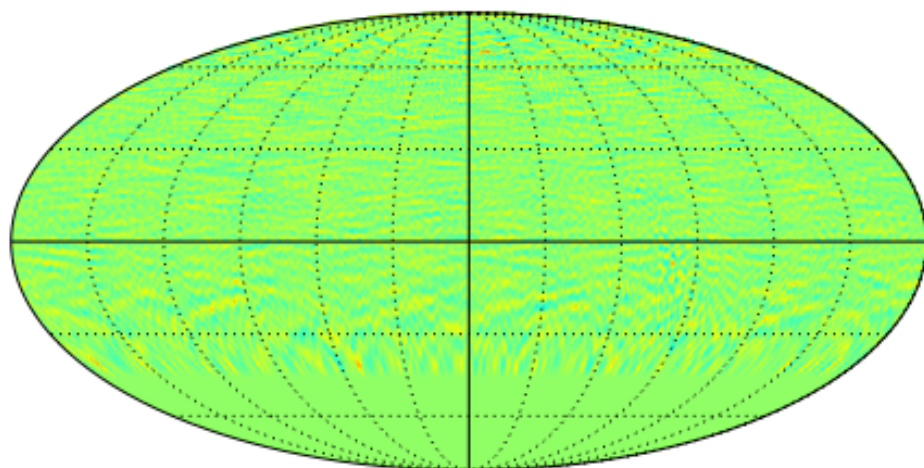
$\sim 3x$ dimmer

$S/F > 1$



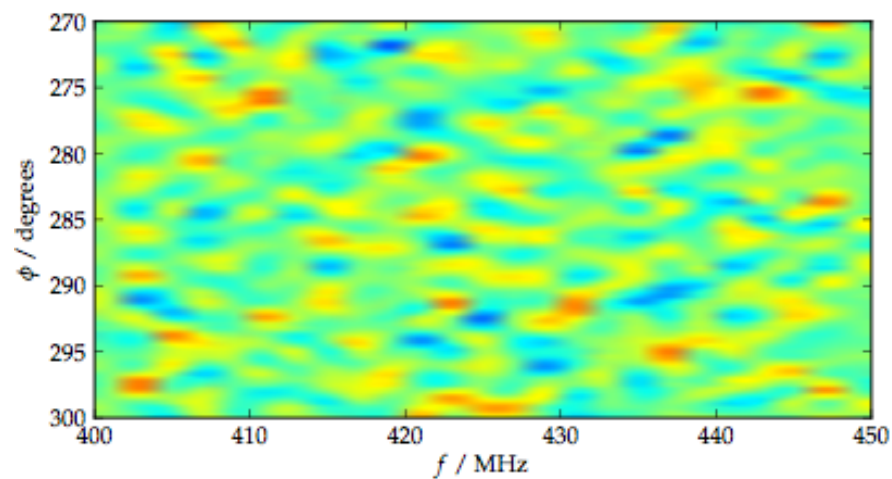
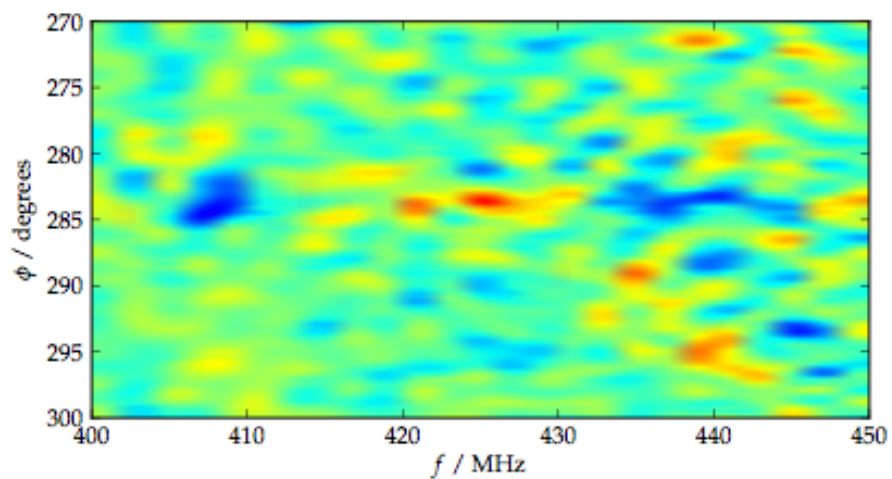
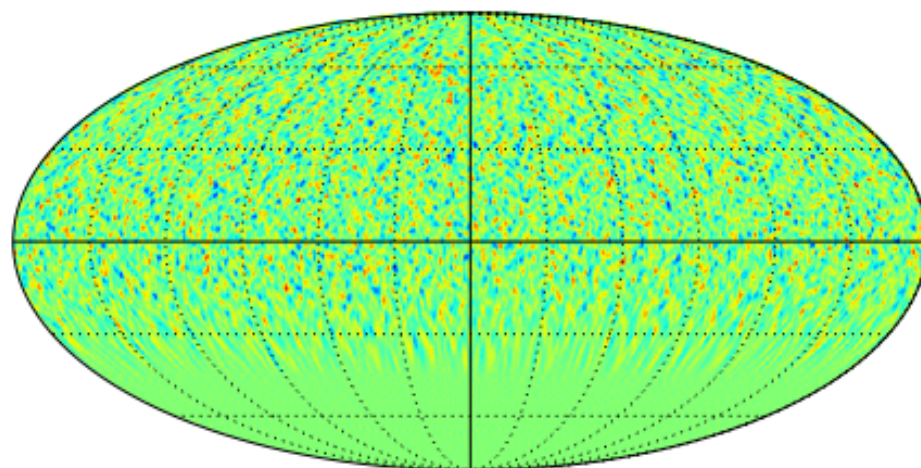
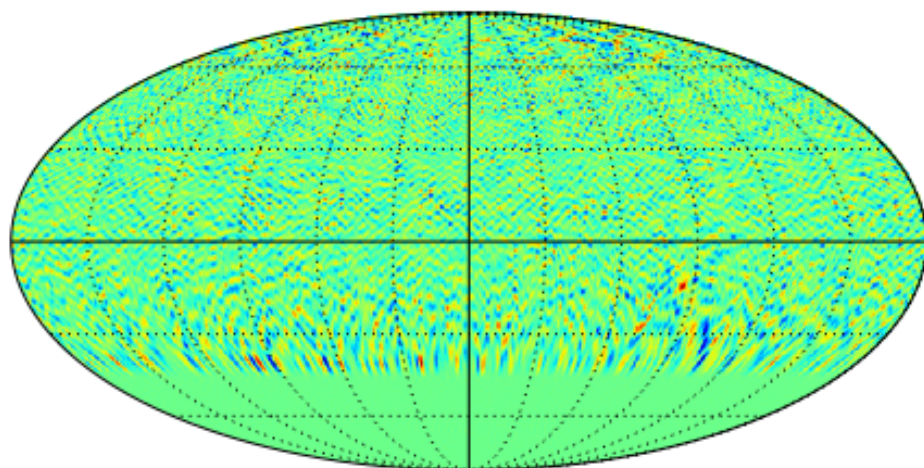
$\sim 5x$ dimmer

$S/F > 10$



$\sim 10x$ dimmer

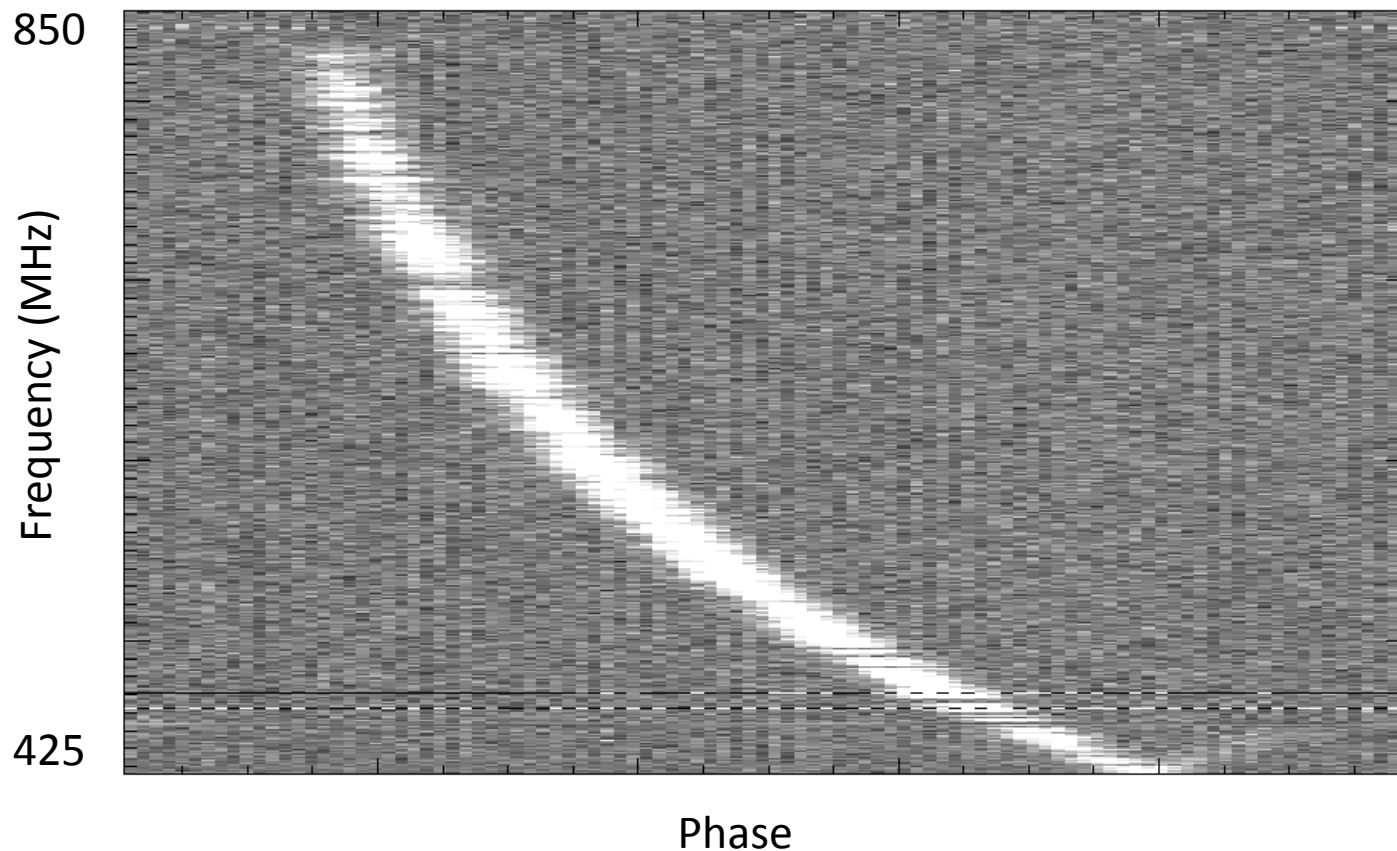
$S/F > 100$



$\sim 70x$ dimmer

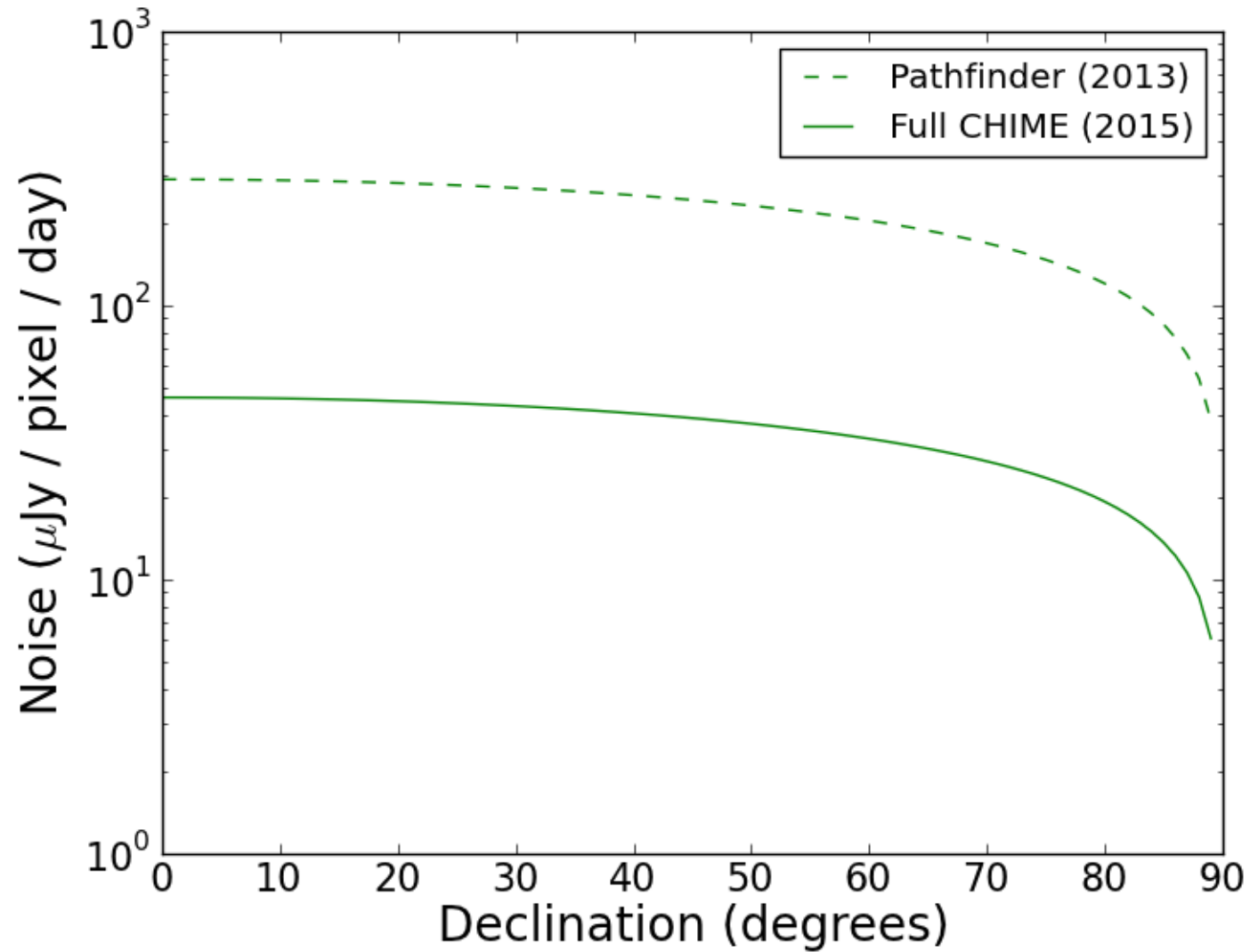
Calibration: Pulsar Holography

- Track pulsars with large dish
- Correlate each feed against those
- Map primary beams & sidelobes

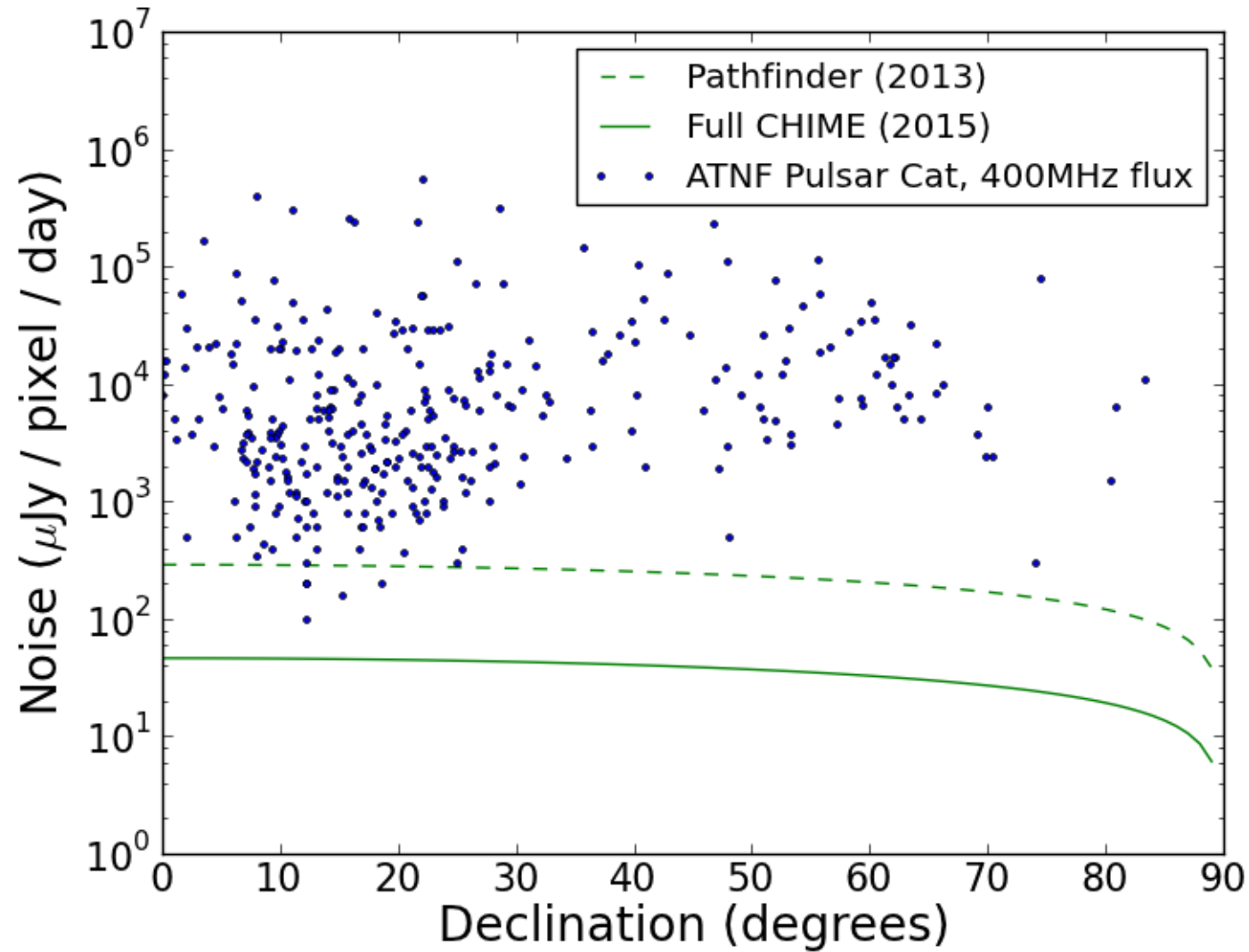


Trial Drift-
Scan Pulsar
Observation
on 8m dishes

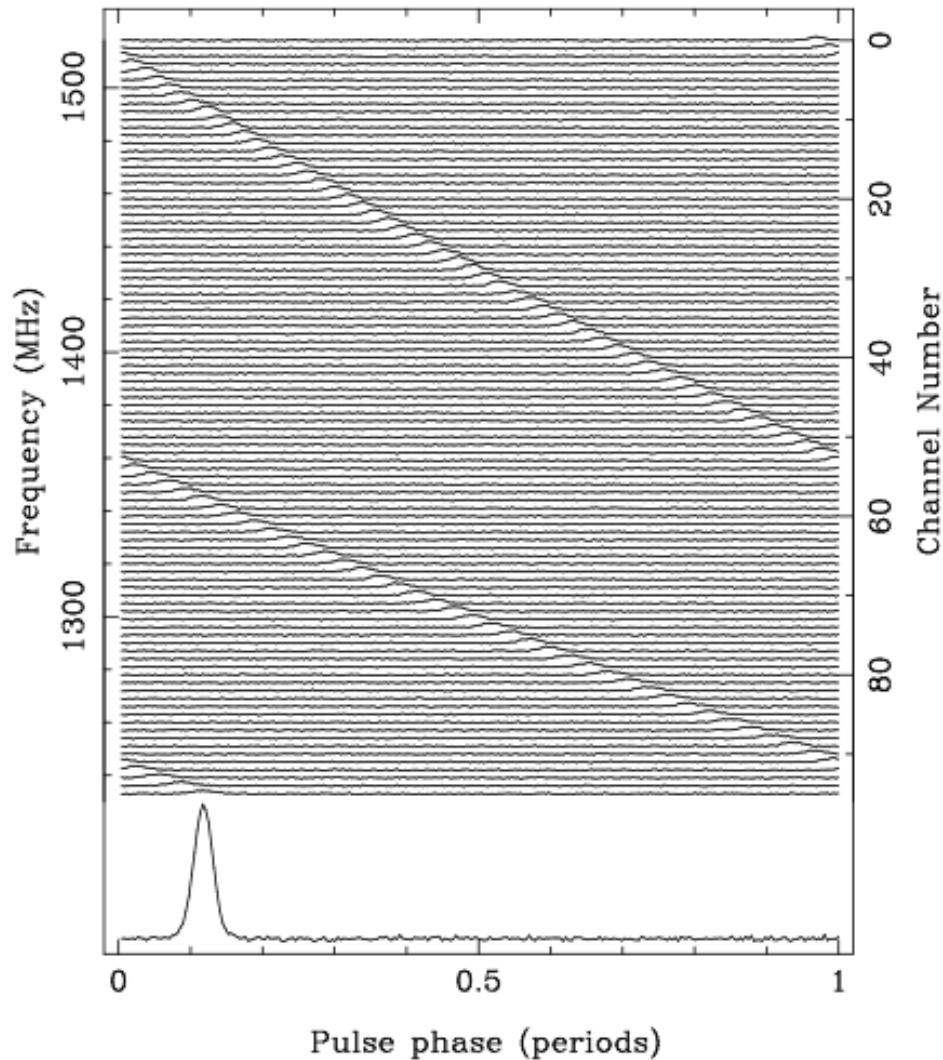
(Daily) Survey Sensitivity



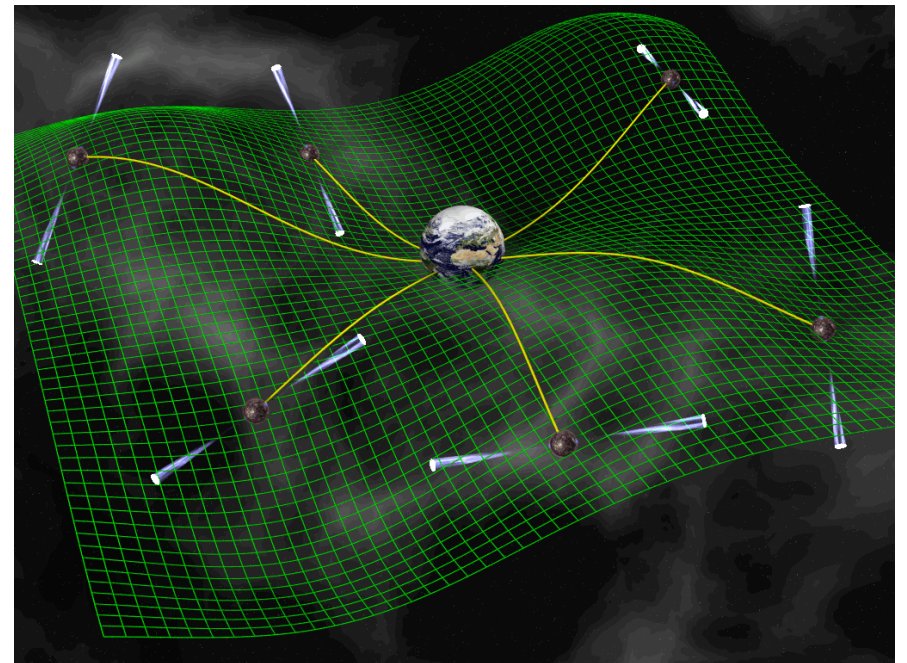
(Daily) Survey Sensitivity



Pulsar Monitoring & Detection



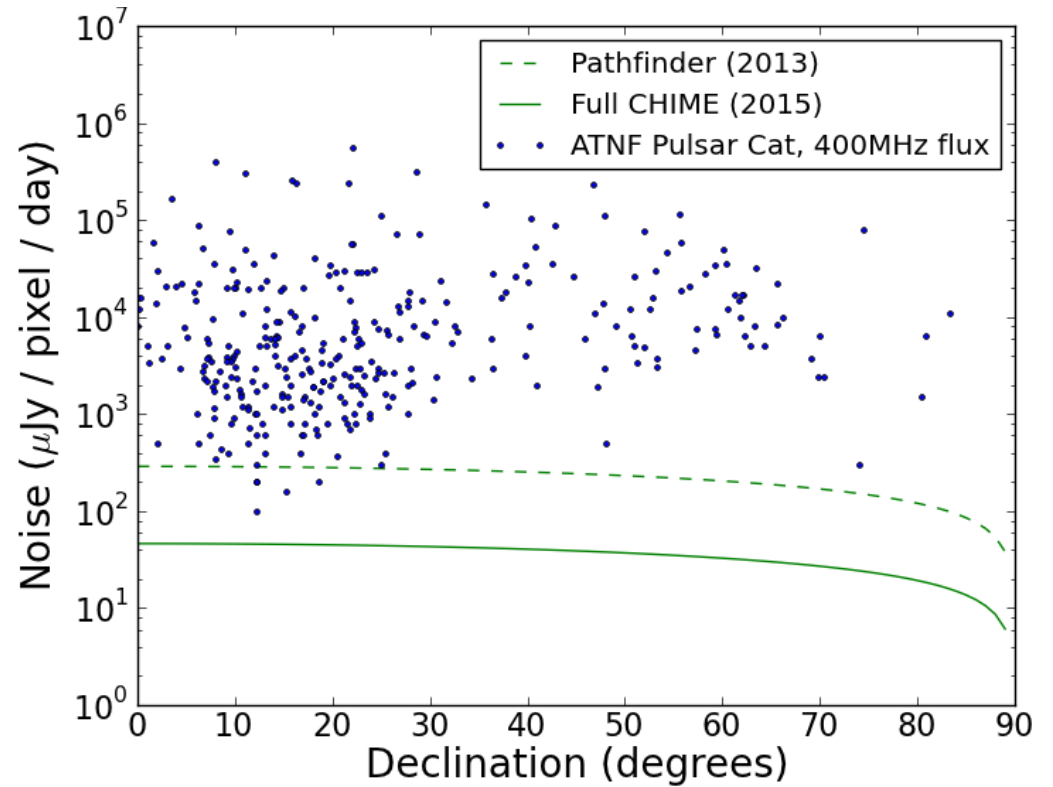
- Daily coverage of $\sim 1/2$ sky
- Monitor known pulsars for residuals or dispersions



Detecting new Pulsars & Radio Transients

Every day, CHIME surveys:

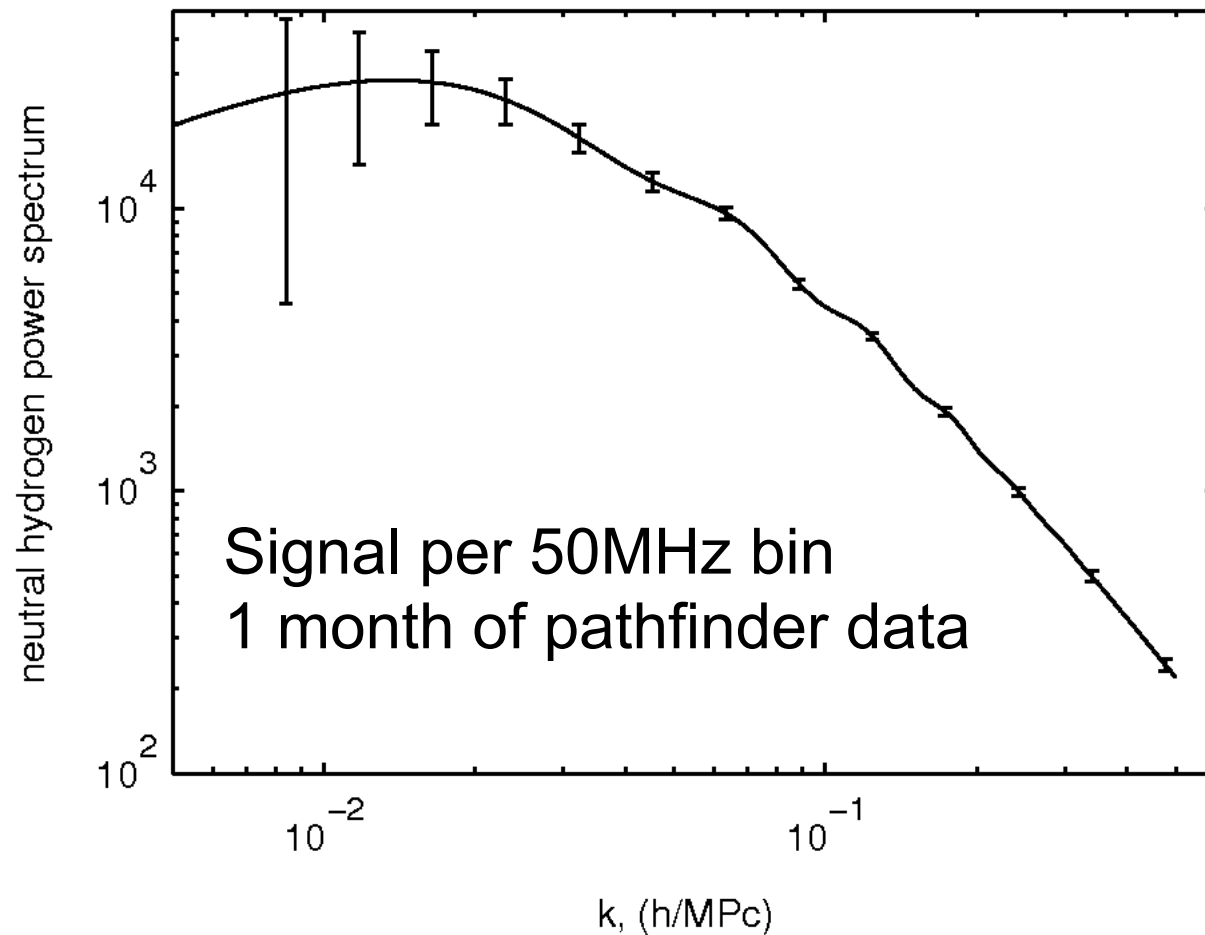
- 20,000 deg²
- from 400-800MHz
- for > 10 minutes
- with μs timing
- to $< 50 \mu\text{Jy}$ noise



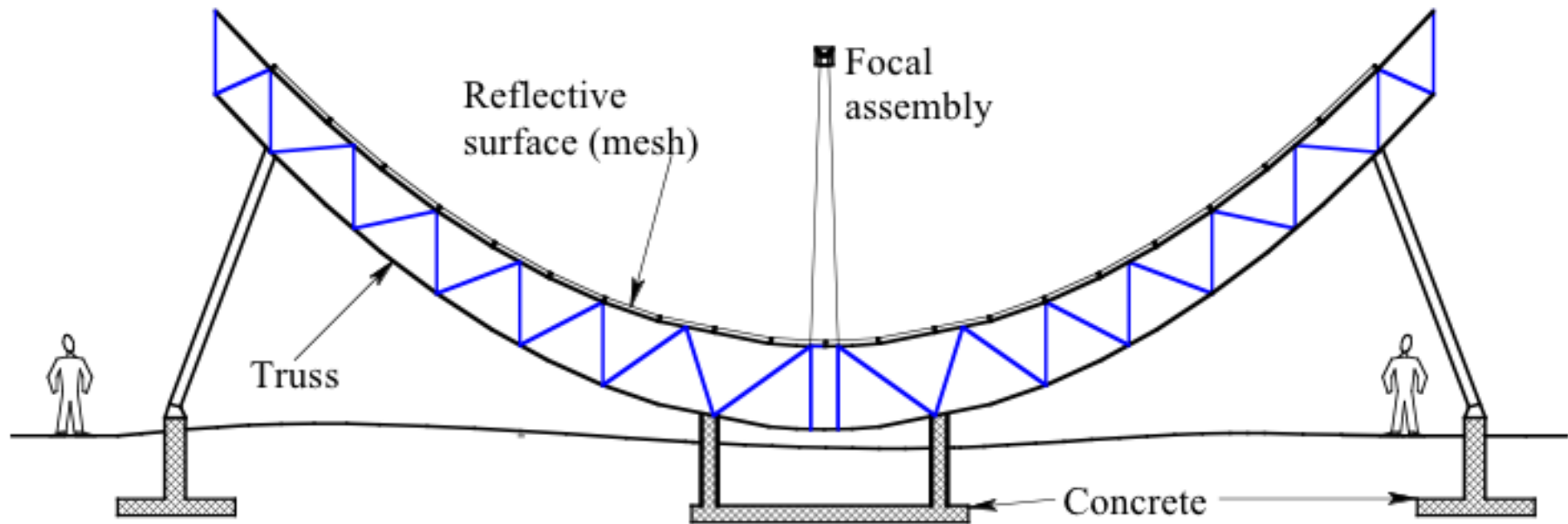
Someone who knows what they're doing should really hang a pulsar / transient detection engine off CHIME...

Pathfinder Science

- Will measure HI power spectrum with high S/N in a short period of time
- Should yield the most precise measurement of the BAO scale to date



The End



Spare slides follow

Data Processing

ALL-SKY INTERFEROMETRY WITH SPHERICAL HARMONIC TRANSIT TELESCOPES

J. RICHARD SHAW^{1,†}, KRIS SIGURDSON², UE-LI PEN¹, ALBERT STEBBINS³, AND MICHAEL SITWELL²

<http://arxiv.org/abs/1302.0327>

- Observations are periodic in ϕ
- Noise stationary \rightarrow m-modes independent
- Map-making can be on m-by-m basis
- Standard max-likelihood estimator

$$\hat{\mathbf{a}} = (\mathbf{B}^\dagger \mathbf{N}^{-1} \mathbf{B})^{-1} \mathbf{B}^\dagger \mathbf{N}^{-1} \mathbf{v}$$

- Signal-to-noise Eigenmodes also on m-by-m
- Jointly diagonalize **S**ignal, **F**oreground covariances
- Generalized Eigenmode problem

$$\mathbf{S} \mathbf{x} = \lambda \mathbf{F} \mathbf{x}$$

Correlation

Correlation is fundamentally a matrix multiplication.
3D -> 2D projection is also a matrix multiplication.

Graphics Processing Units (GPUs) are correlators!

100-1000x more computational power per \$ than CPUs

As Implemented for a 256-input Pathfinder:

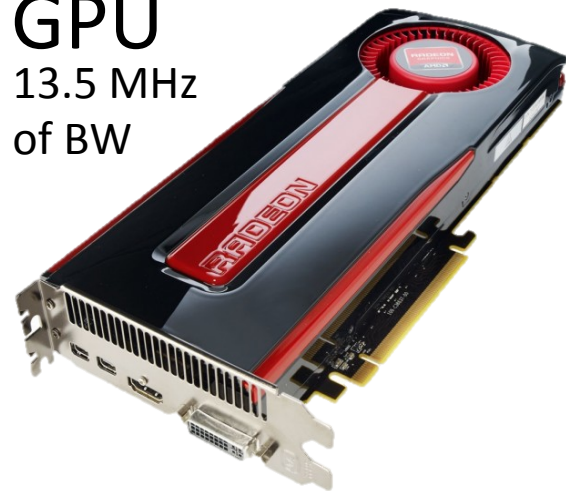
CPU

14 kHz
of BW



GPU

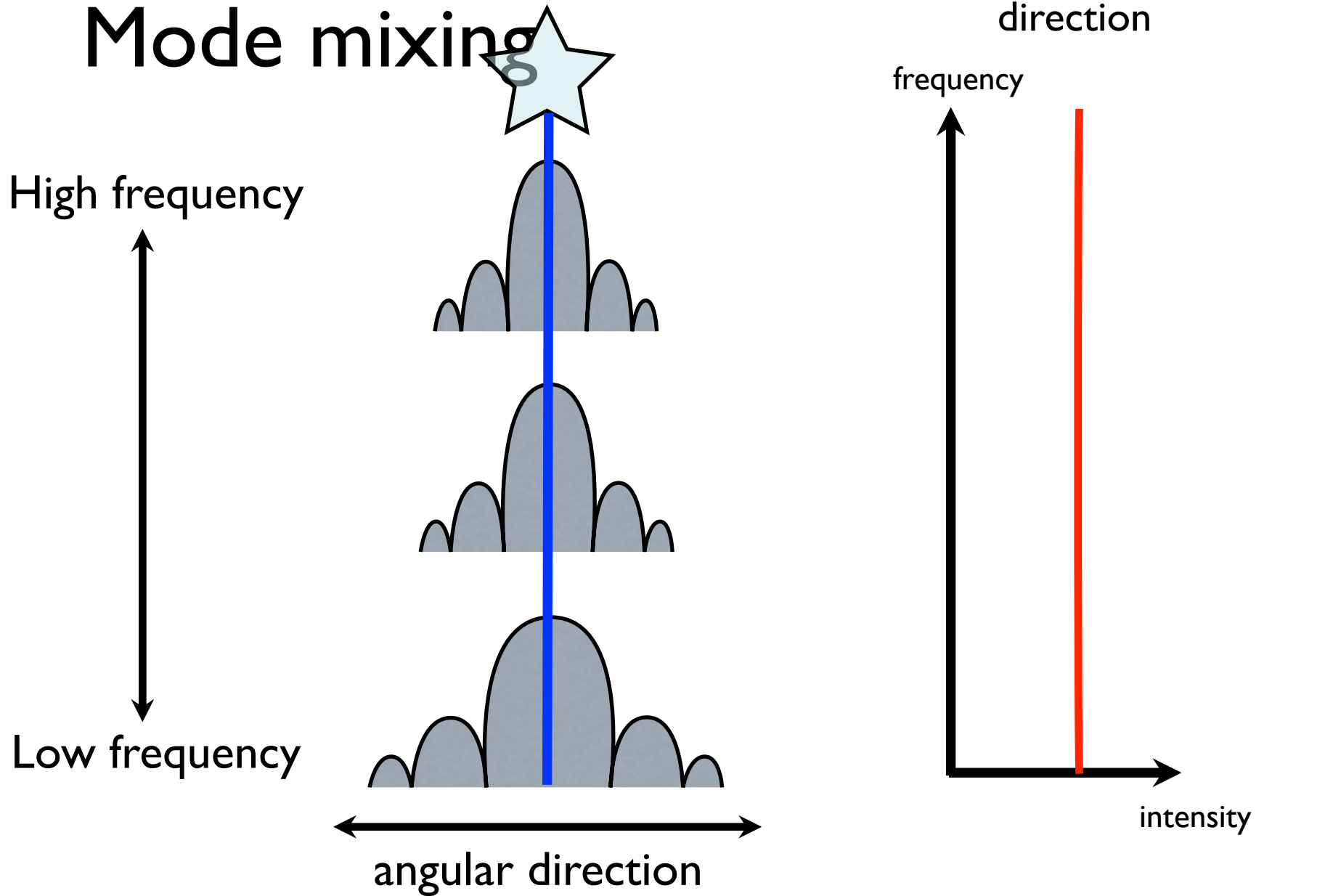
13.5 MHz
of BW



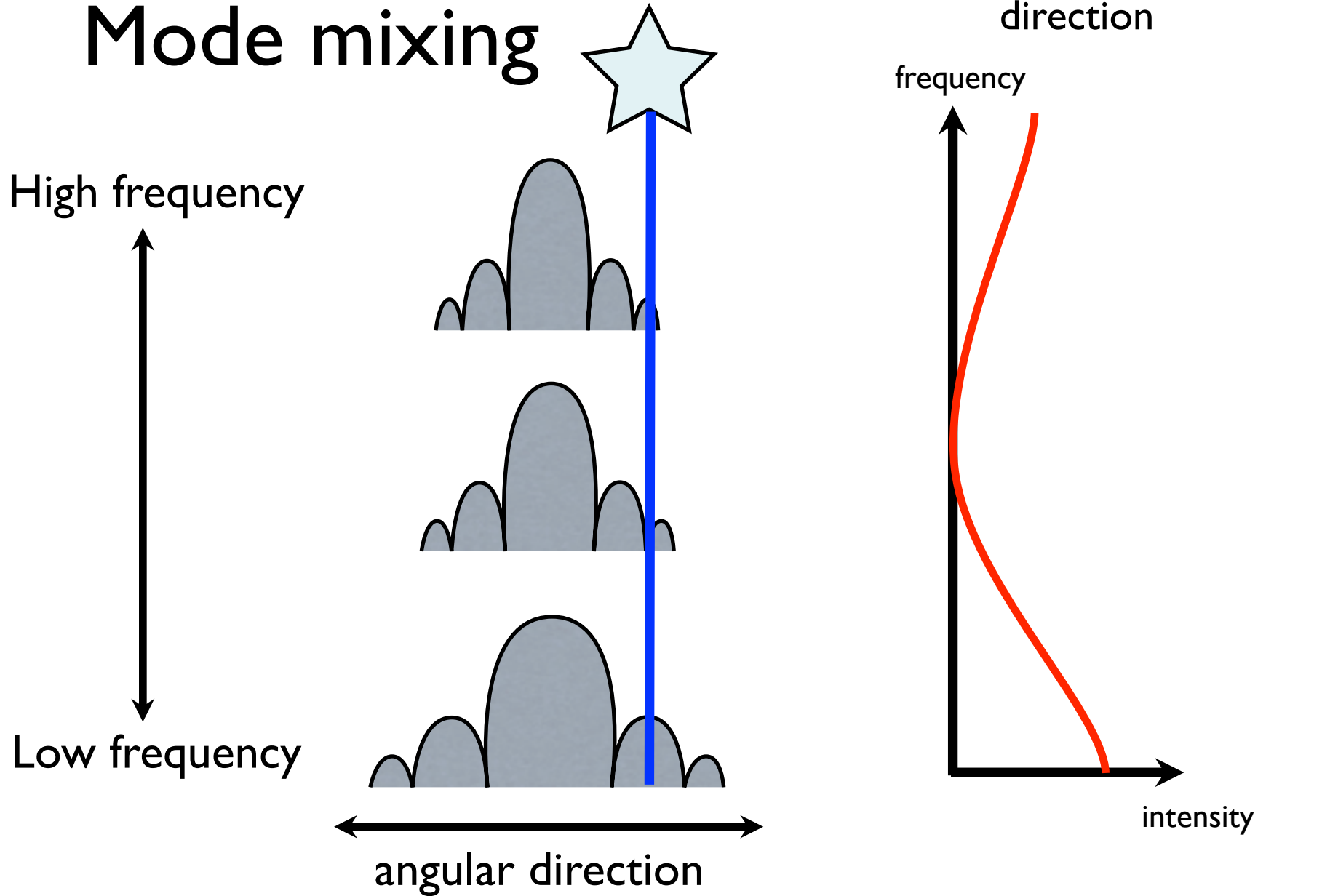
Pathfinder Cylinders: Holes Dug!



Spatial-Spectral Mode mixing



Spatial-Spectral Mode mixing

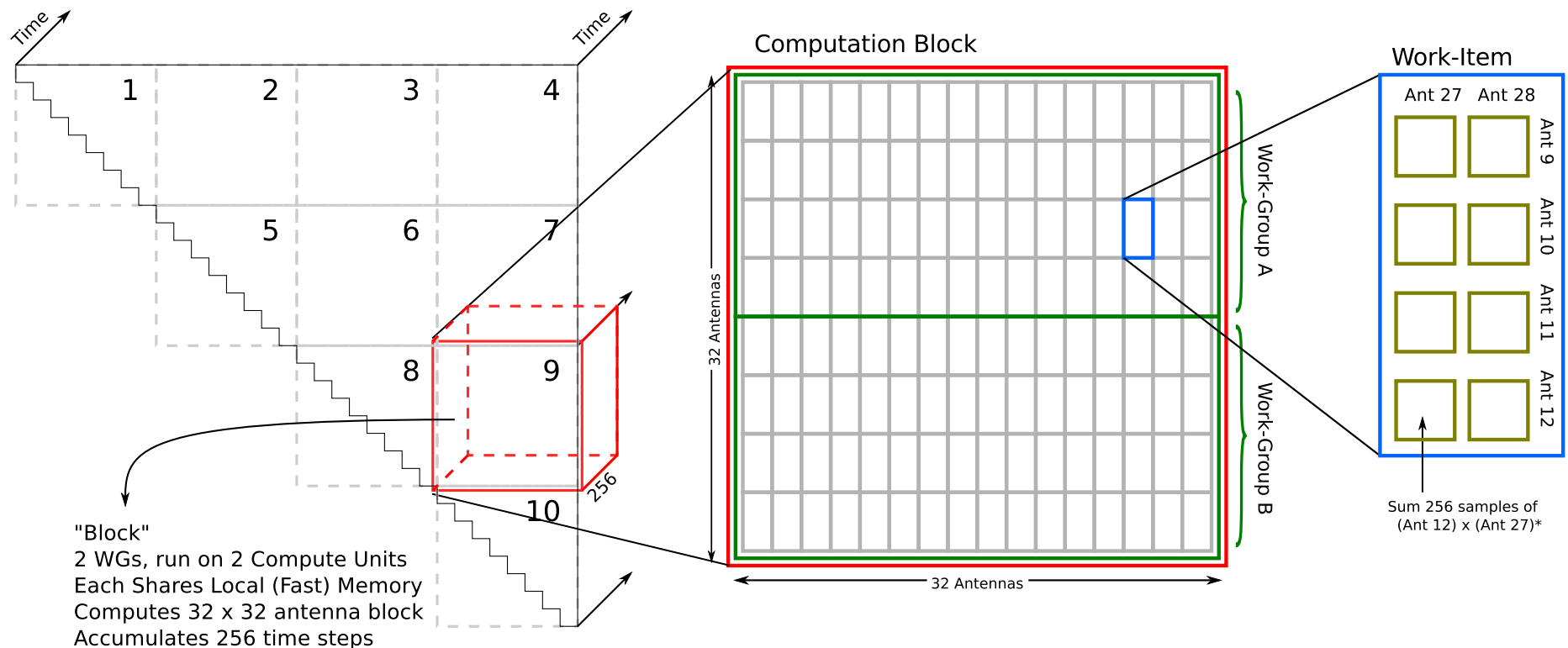


GPU Correlator

Correlation is fundamentally a matrix multiplication.
3D -> 2D projection is also a matrix multiplication.

Graphics Processing Units (GPUs) are correlators!

100-1000x more computational power per \$ than CPUs, ~8GFLOPs/\$

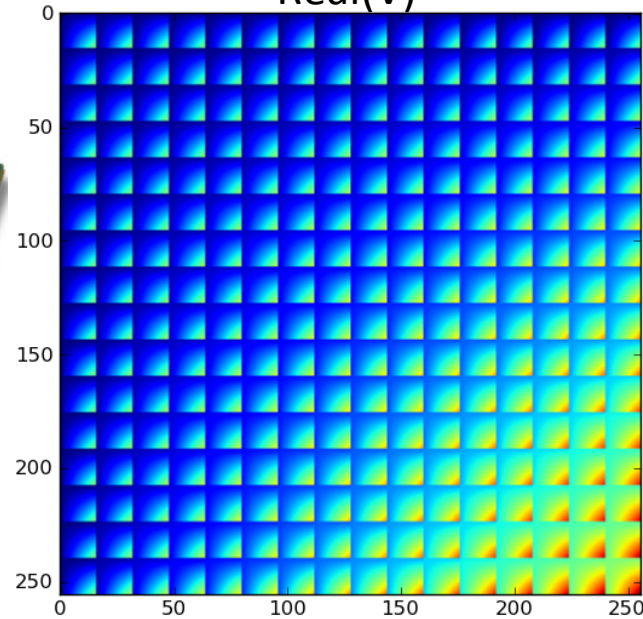


N^2 Correlator Implemented ($N=256$)

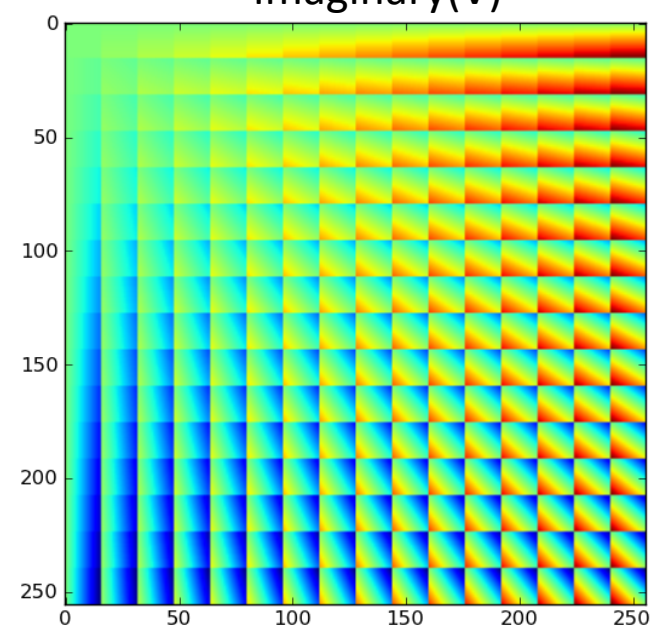
CPU
14 kHz
of BW



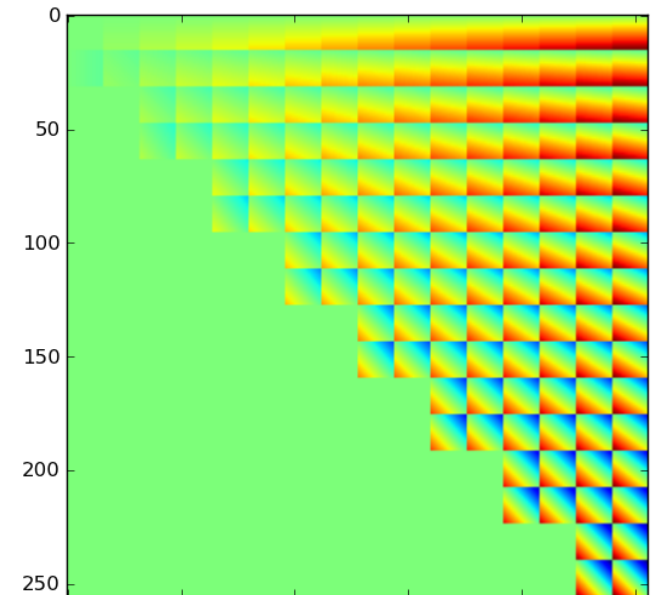
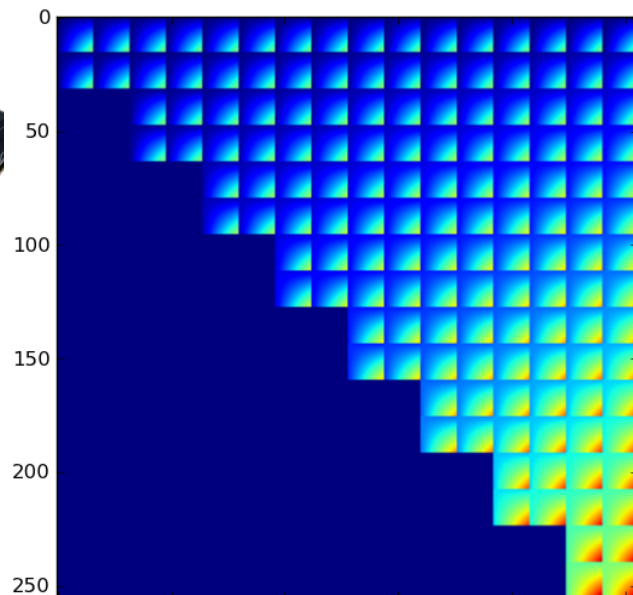
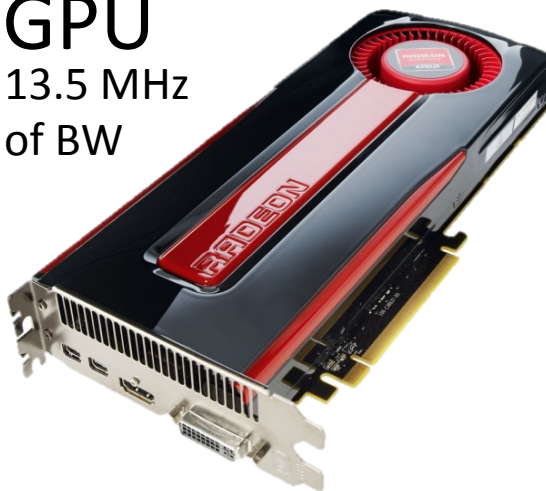
Real(V)



Imaginary(V)

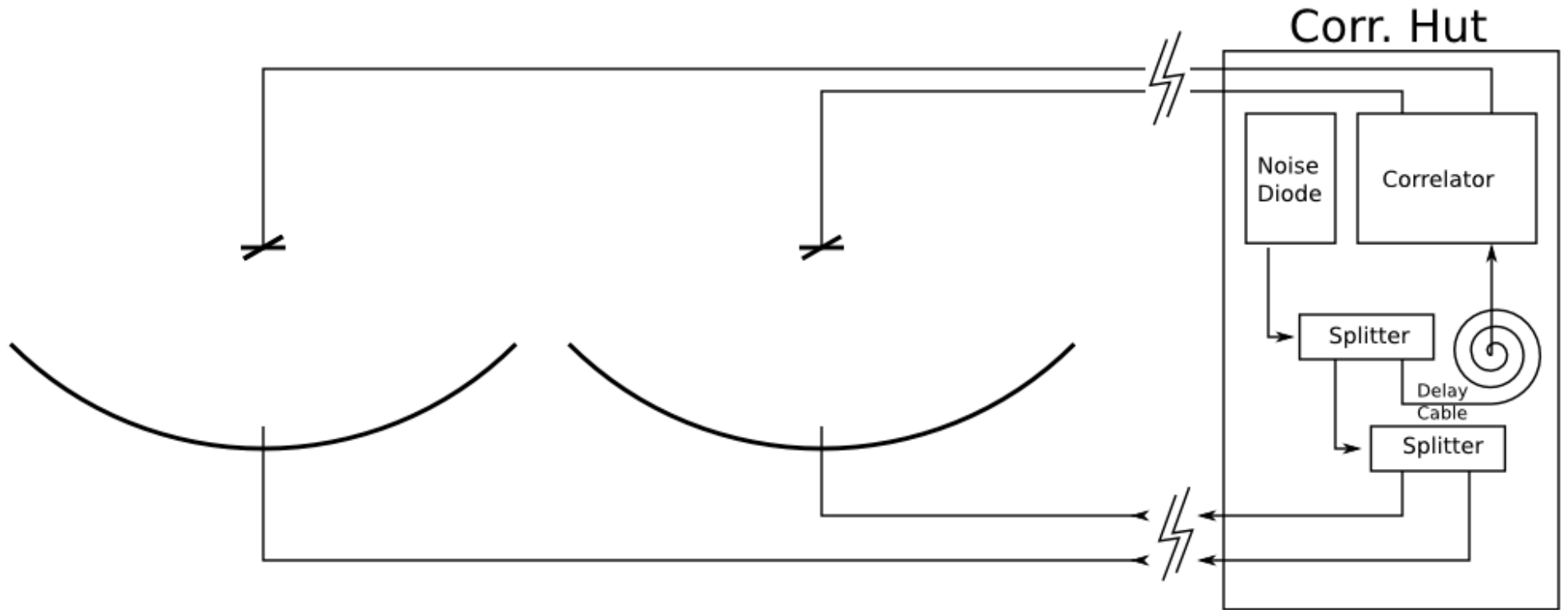


GPU
13.5 MHz
of BW



Calibration: “Rigidization”

(noise injection)



Correlate against sampled noise to fix relative gains *in realtime*.

Correlation is expensive

Performance Highlights of the ALMA Correlators, 2012:

Defining the ability of a single correlation machine to process many independent antenna pairs, N , and the bandwidth BW as the product $N \times BW$, the 64-antenna correlator is clearly the largest machine ever built for radio astronomy. With $N = 2096$ and $BW = 16$ GHz (see Table 1) this product is about 3.35×10^4 GHz while the current mm-wave interferometers are about 100 to 10 times less powerful. Only the future first design correlator stage of the SKA project with 250 antennas and 1 GHz bandwidth will rival ALMA when it is built.

2012	ALMA	3.35×10^4 GHz
2020 (?)	SKA	3.13×10^4 GHz
2013	Pathfinder	1.31×10^4 GHz
2015	CHIME	1.31×10^6 GHz

CHIME Status

Prototype, 2 x 8m Dishes

- running since March 2011

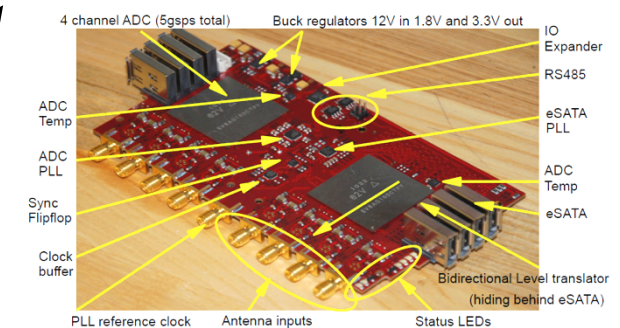
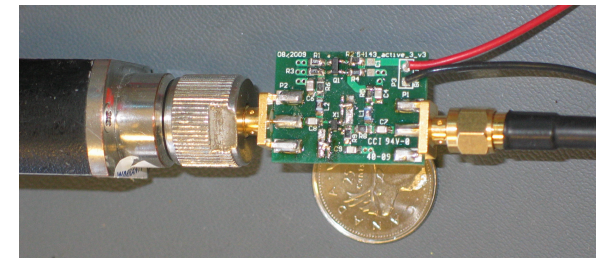
Pathfinder, 2 x 20m x 40m Cylinders

- under construction

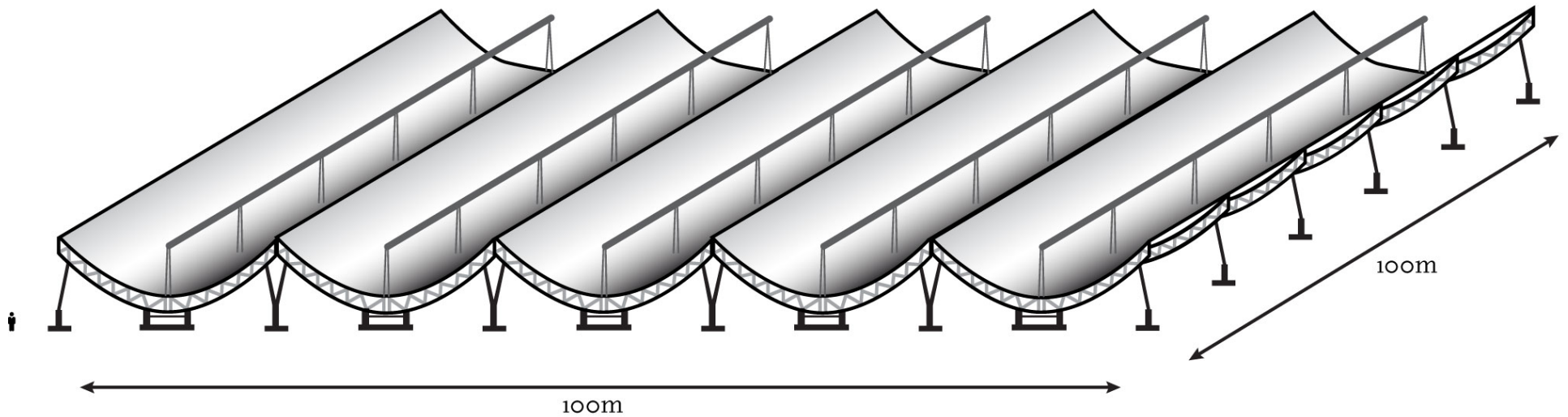
Full CHIME, 5 x 20m x 100m Cylinders

- **CFI FUNDED**

- Low-noise Amplifiers built
- GHz ADCs built
- Antennas under R & D
- Cylinders under construction
- Correlators prototyped
- Simulation/Analysis ongoing
- RF-over-Fiber exists



CHIME: Status Update



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BRITISH
COLUMBIA



McGill



UNIVERSITY OF
TORONTO



NRC · CNRC

Keith Vanderlinde
Cifar C&G 2012 AGM

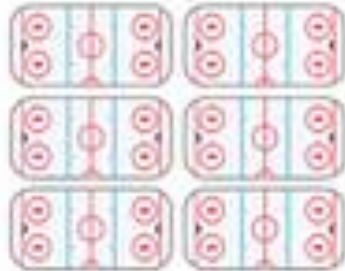
Minimalist Outline

- CHIME specs
- Hardware
- Status
- Calibration
- Pipeline
- Ancillary



Canadian Units of Measurement

The telescope gathers radio waves from a swath of sky directly above the observatory near Penticton, B.C.



The telescope array will cover an area larger than six NHL hockey rinks

