

The Canadian Hydrogen Intensity Mapping Experiment

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Overview

- CHIME Goals
- CHIME (Canadian Hydrogen Intensity Mapping Experiment) Design
 - Cylinder Structure
 - Analog electronics design
 - Digital electronics design
- Challenges
 - Calibration
 - Stability
 - Beam
 - RFI
- CHIME FRB
- CHORD

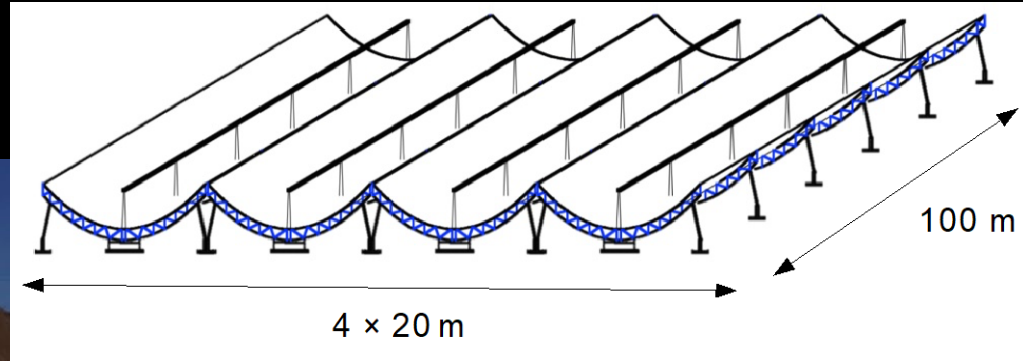




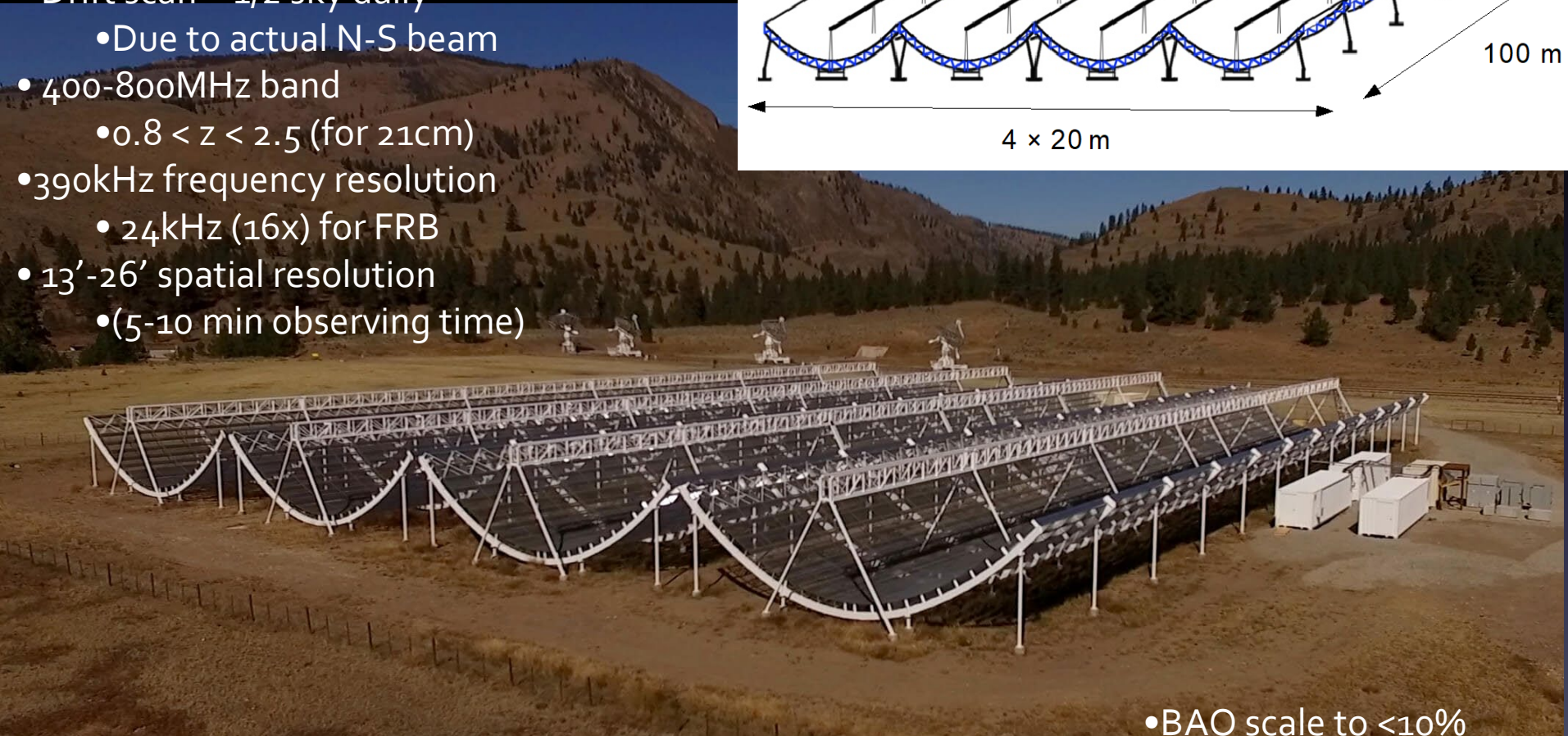
- Drift scan = 1/2 sky daily, Due to actual N-S beam
- 400-800MHz band, $0.8 < z < 2.5$ (for 21cm)
- 390kHz frequency resolution, 24kHz (16x) for FRB
- 13'-26' spatial resolution, (5-10 min observing time)

CHIME

The Canadian Hydrogen Intensity Mapping Experiment



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• BAO scale to $< 10\%$

- w_0 to ± 0.05 ($w_0 \sim 1$)
- w_a to ± 0.2 ($w_a \sim 0$)

Cylinder Telescopes

Illinois 400' ~1959



Ooty, India,
1970

Recently
upgraded



STE Lab,
Japan, 1980s



Northern Cross,
Italy, 1980s

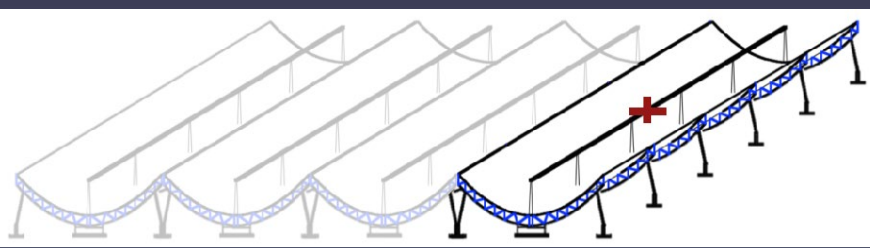
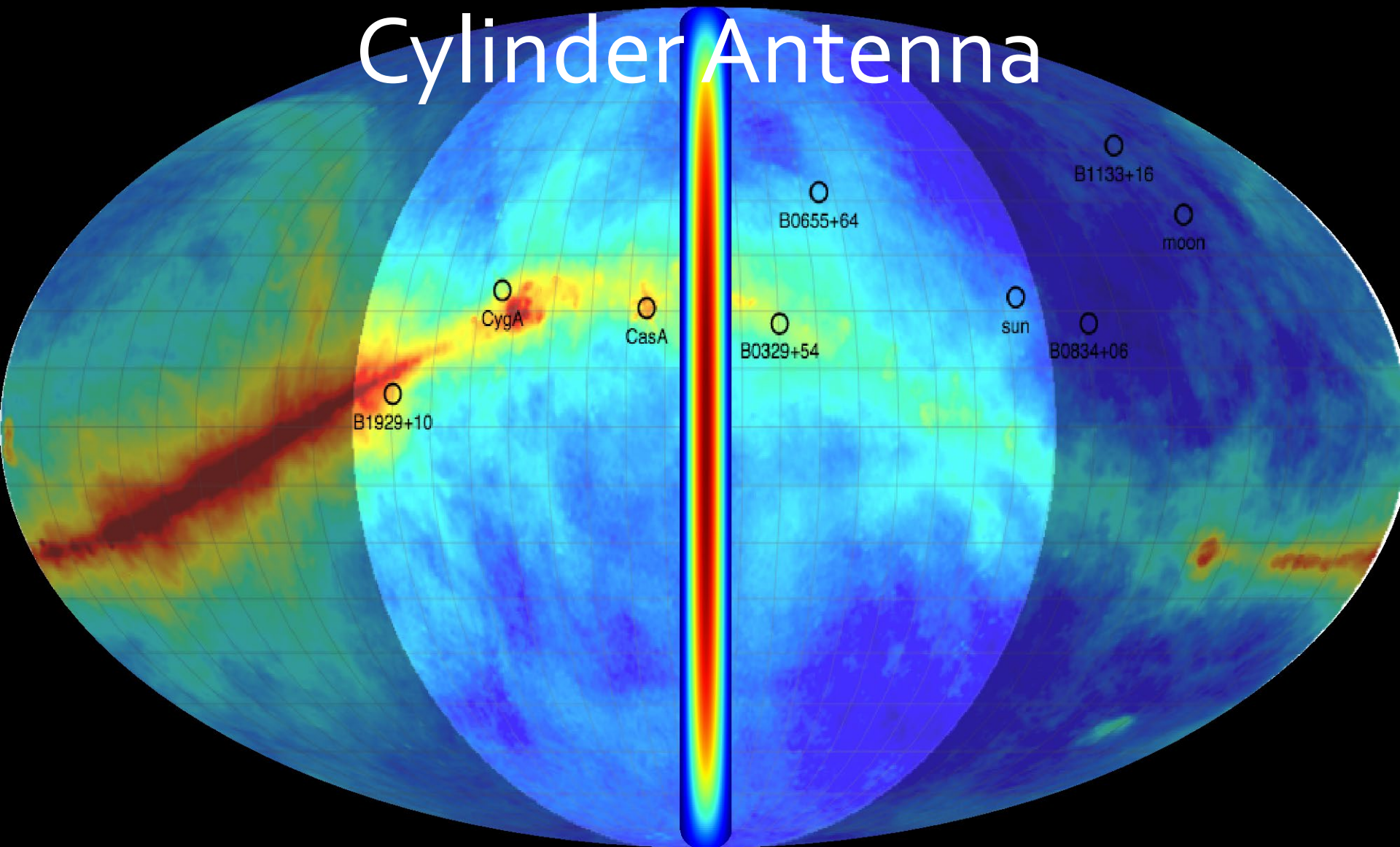


UTMOST, Australia,
Built ~1960

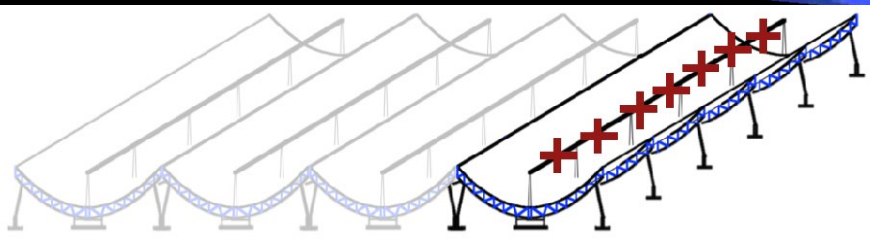
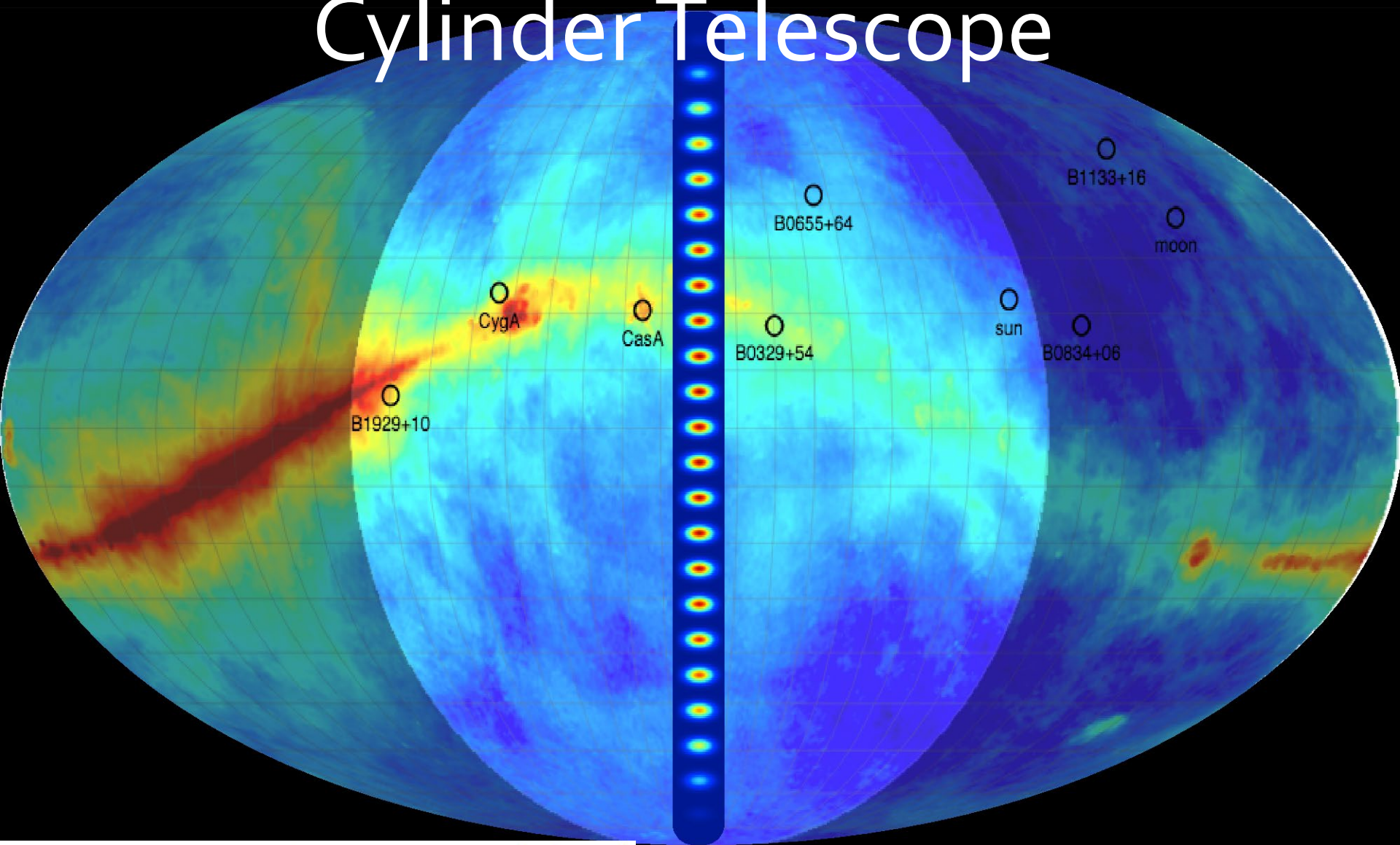
Recently upgraded



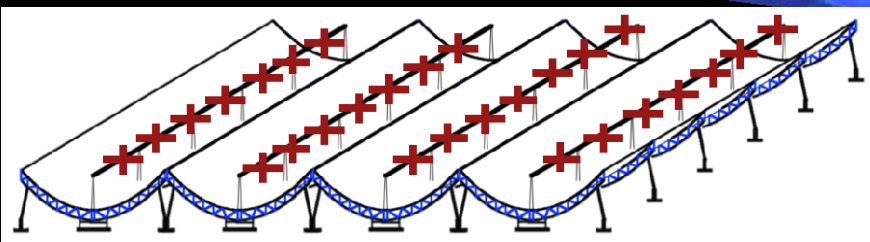
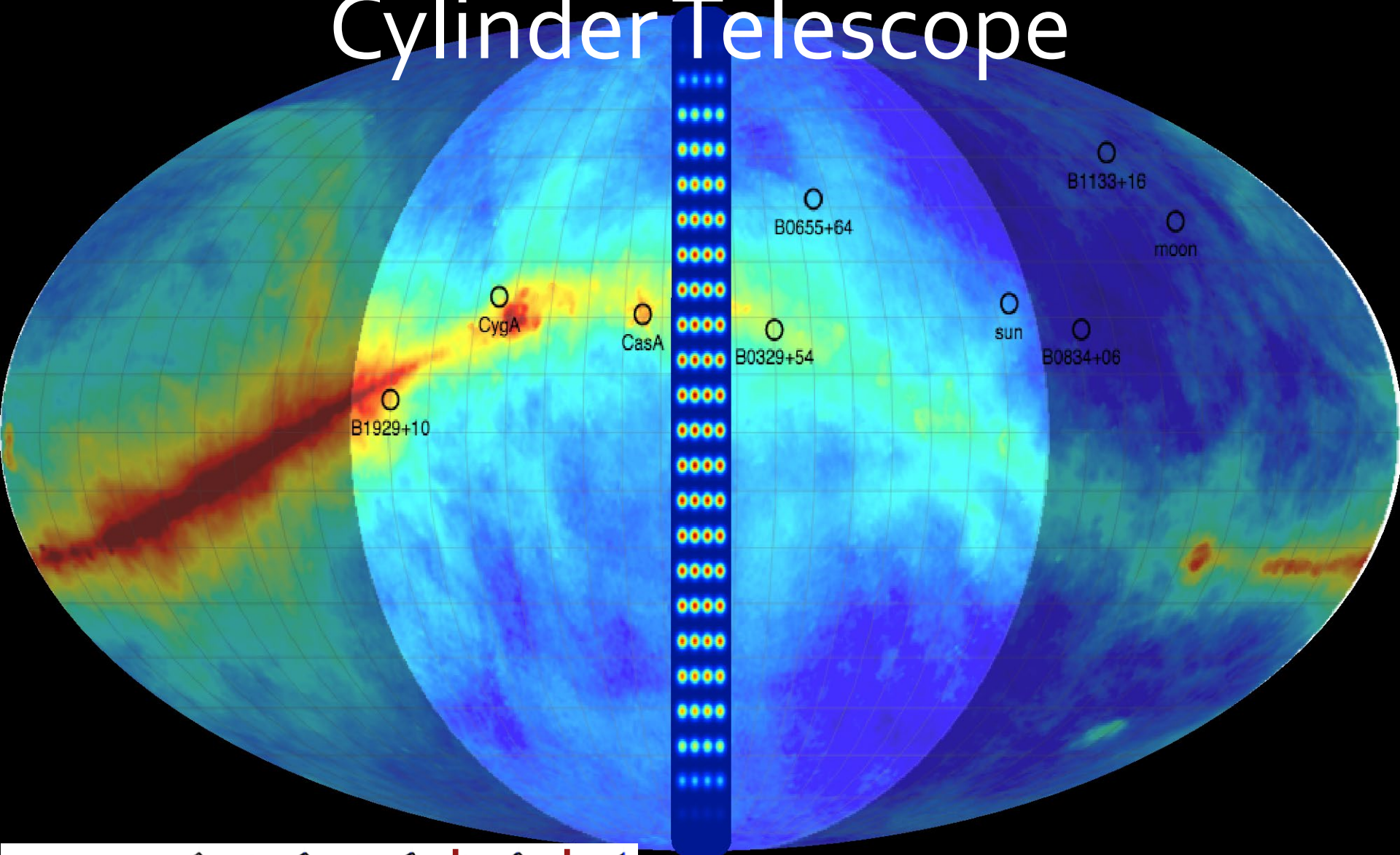
Cylinder Antenna



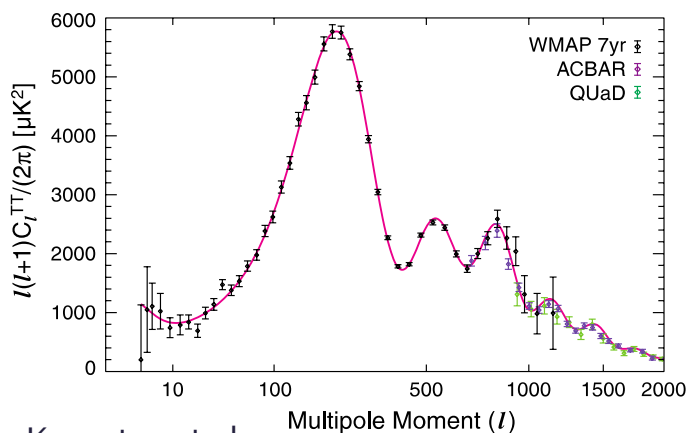
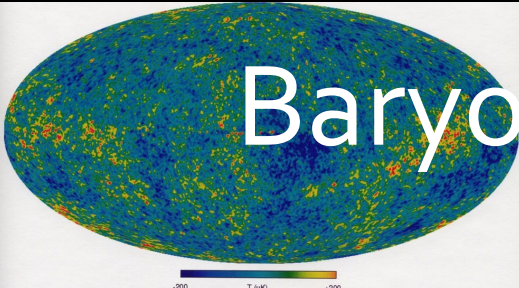
Cylinder Telescope



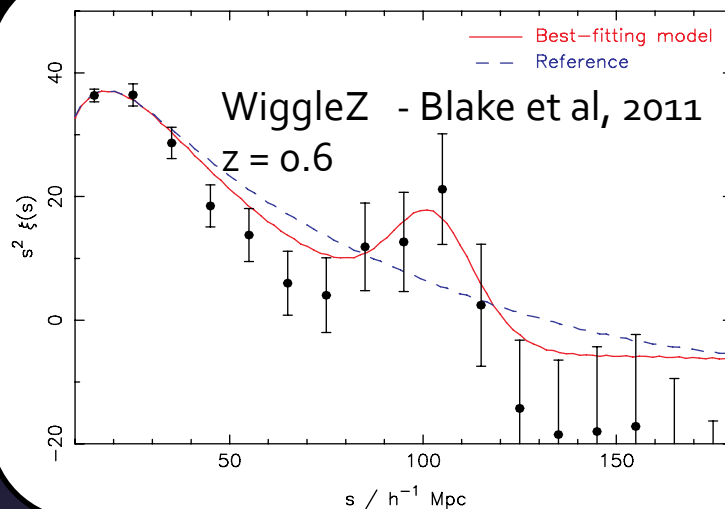
Cylinder Telescope



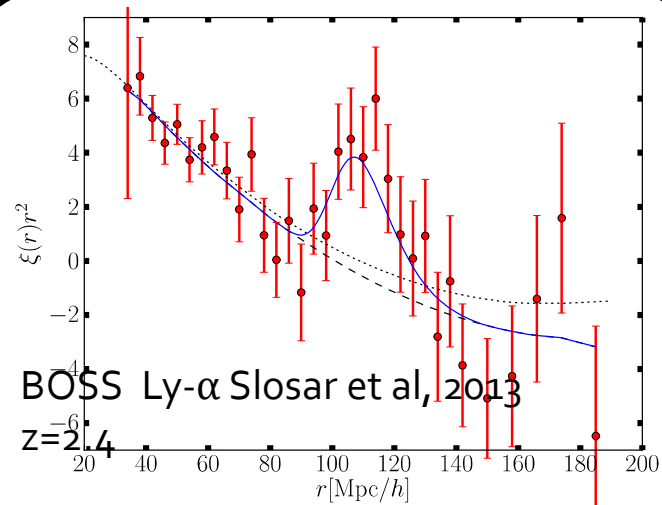
Baryon Acoustic Oscillations as Dark Energy Probe



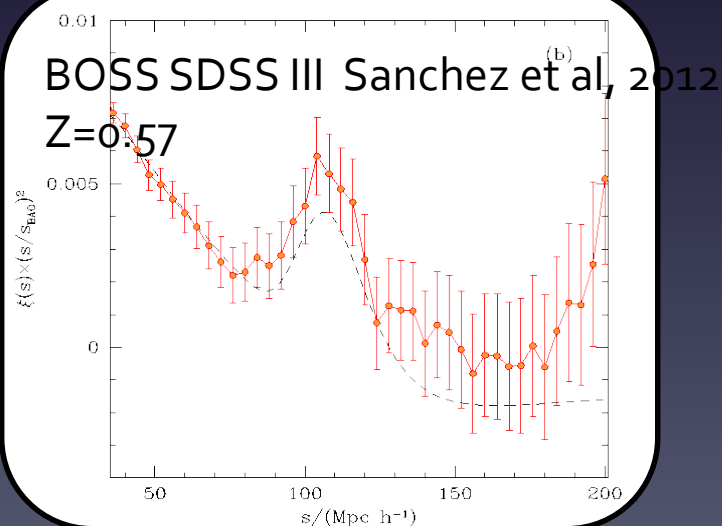
Komatsu et al. 2011



WiggleZ - Blake et al, 2011



BOSS Ly- α Slosar et al, 2013



BOSS SDSS III Sanchez et al, 2012

Galaxy Surveys vs. Intensity Mapping

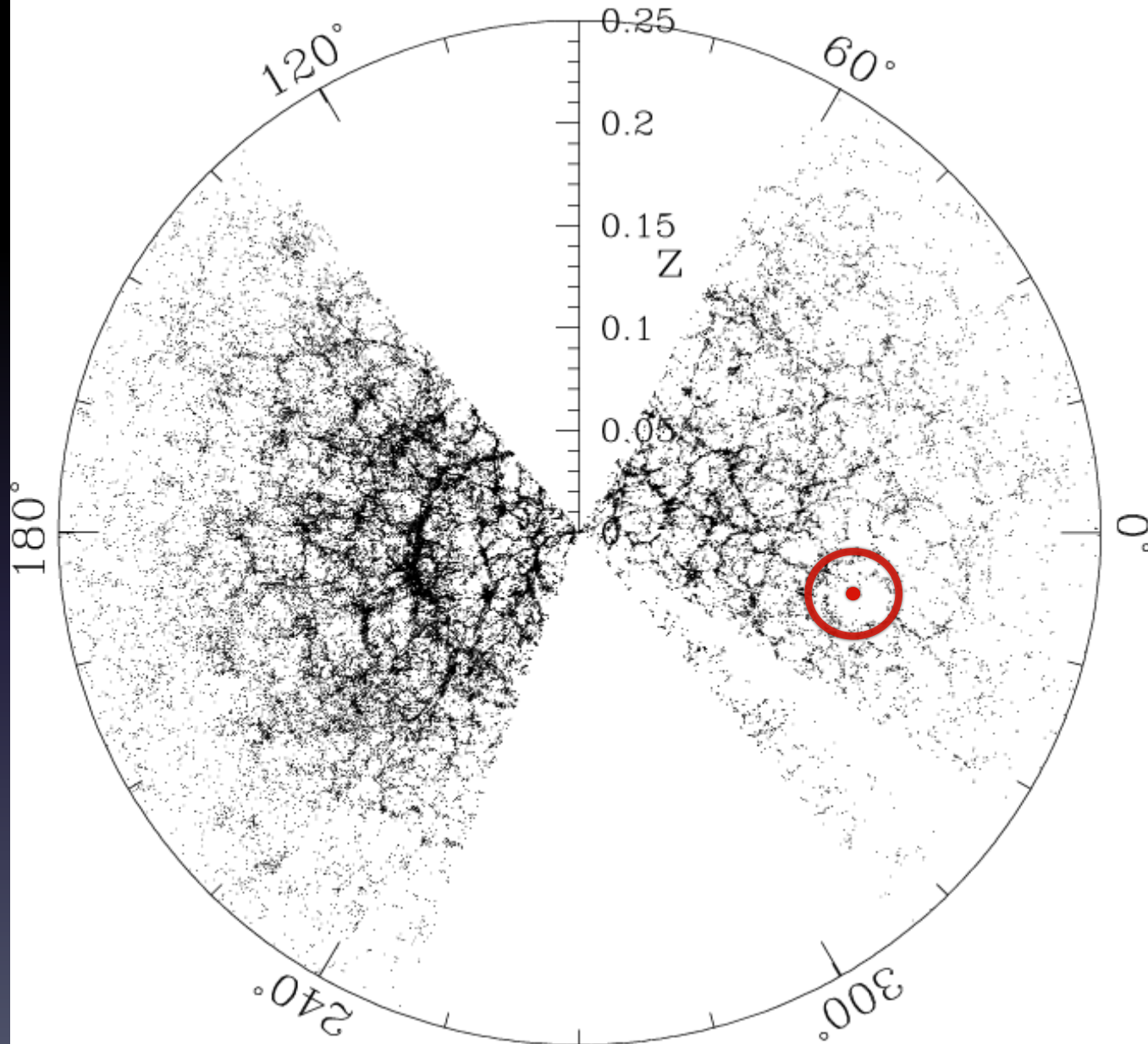
- Galaxy Surveys (SDSS shown)

- Lack of spectral lines from redshift 1-2.

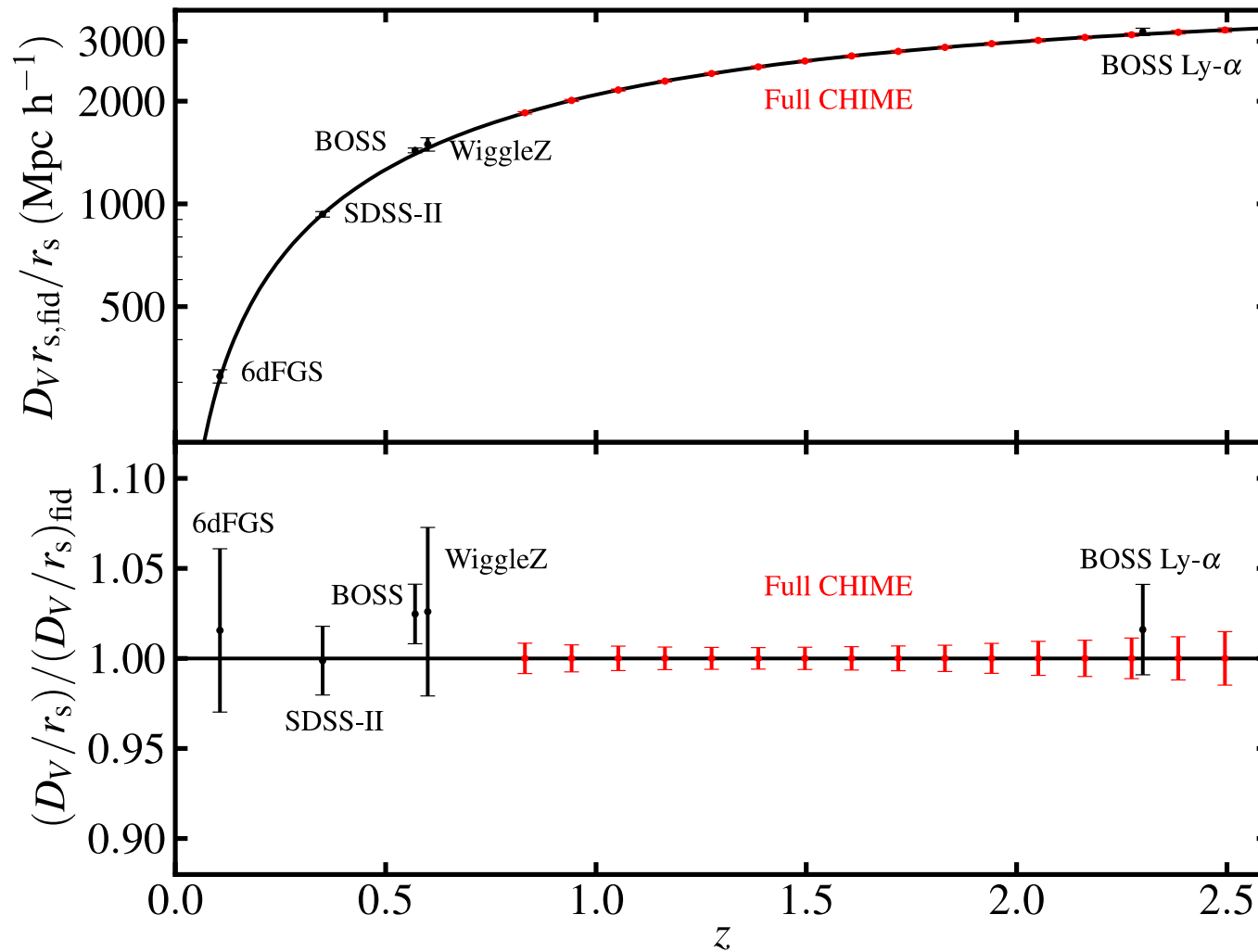
- Galaxy surveys are expensive

- Intensity Mapping:

- Resolve only largest Scales
- Still Need Redshift information \rightarrow 21cm
- Until recently Neutral Hydrogen not measured to high redshift
- Has been detected at Green Bank $z=0.8$



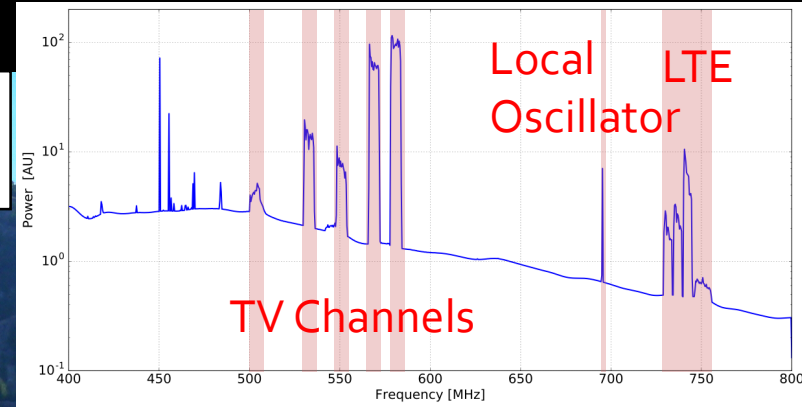
Forecasted Sensitivity



CHIME Site



30% of band currently masked due to RFI



CHIME Pathfinder

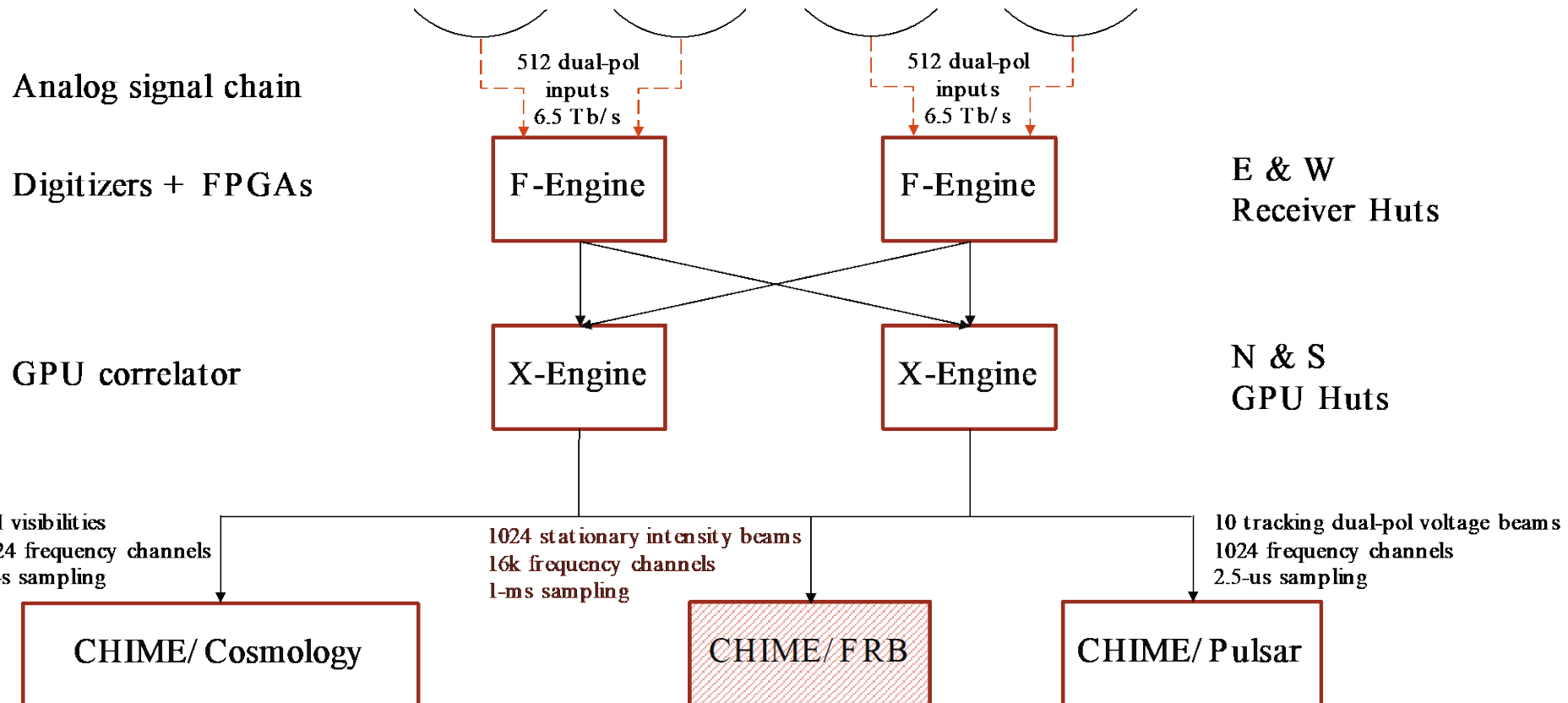
CHIME



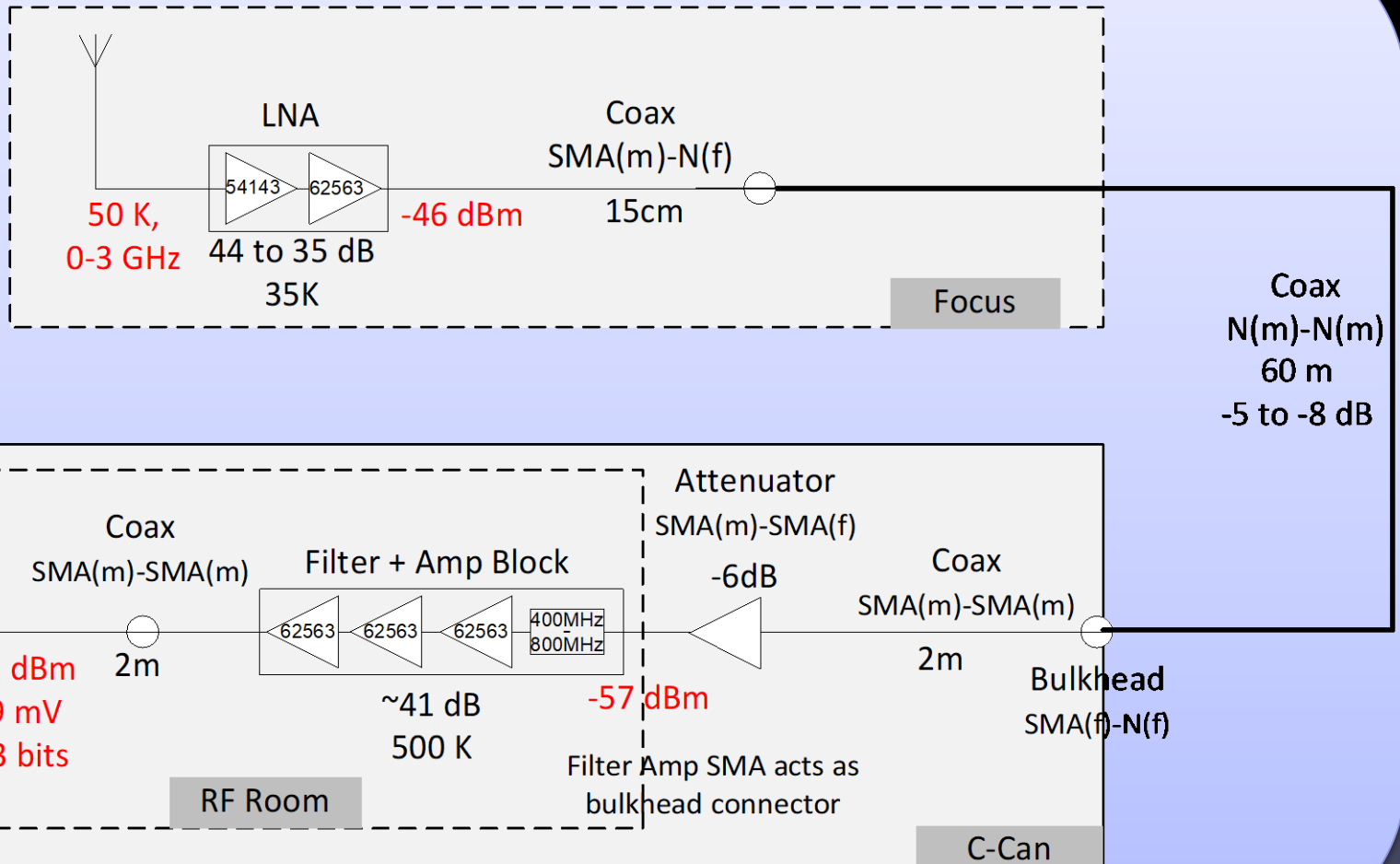
Photo: The CHIME Collaboration

- Dominion Radio Astrophysical Observatory (DRAO)
- Penticton, BC
- Legally Protected Valley

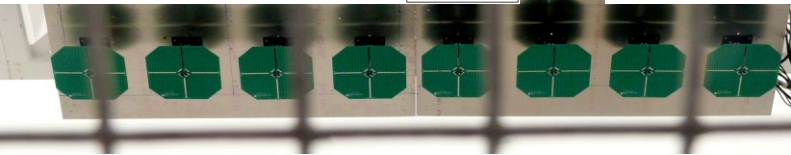
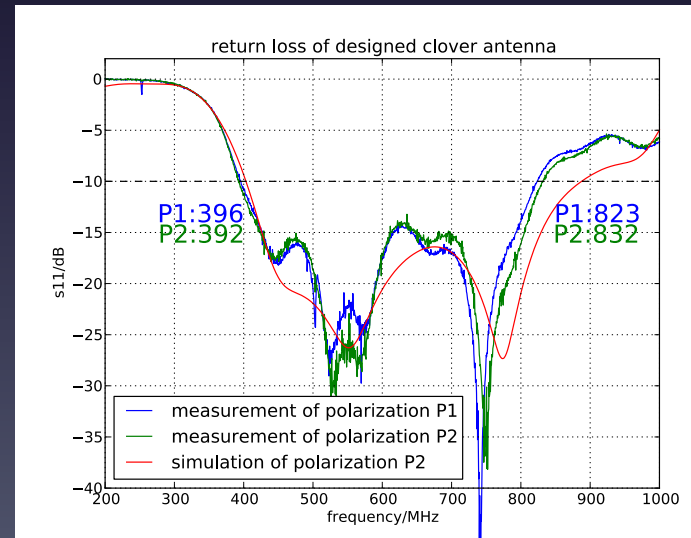
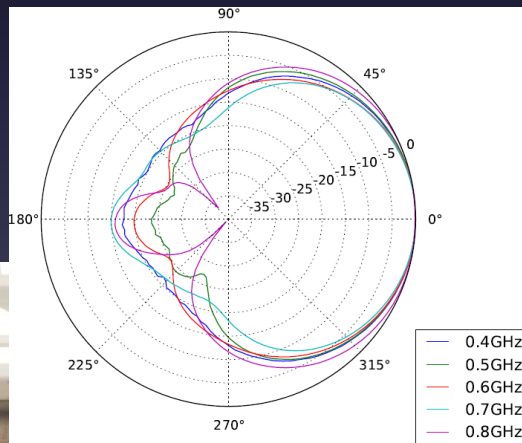
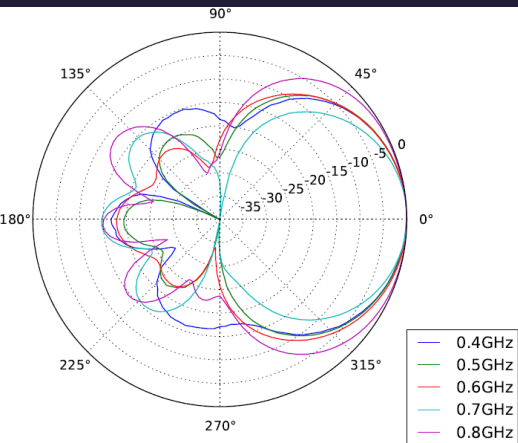
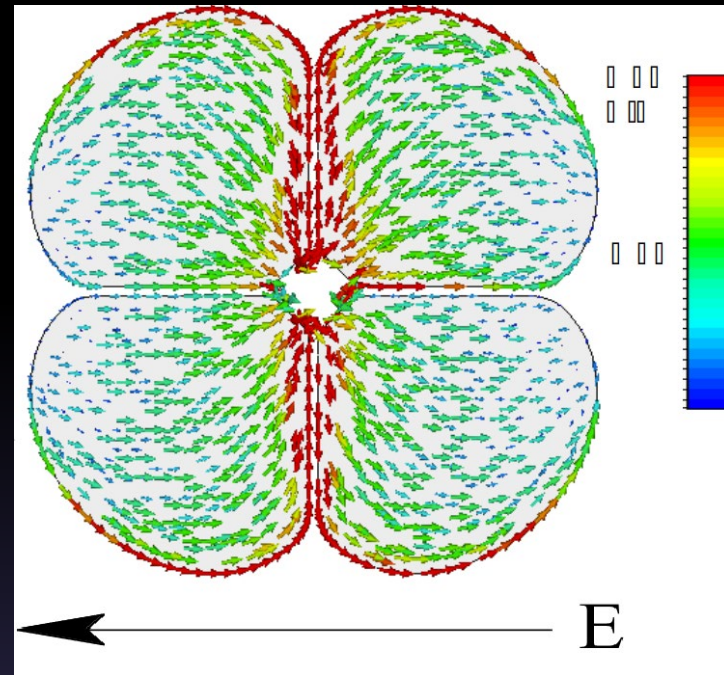
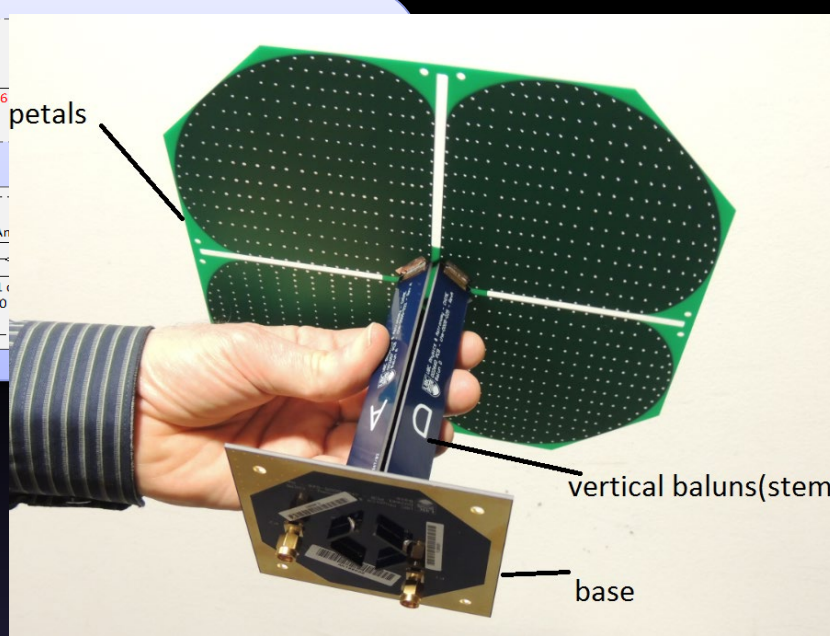
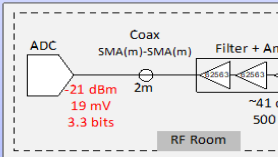
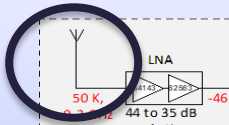
CHIME System



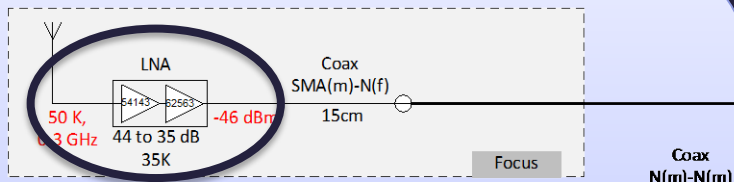
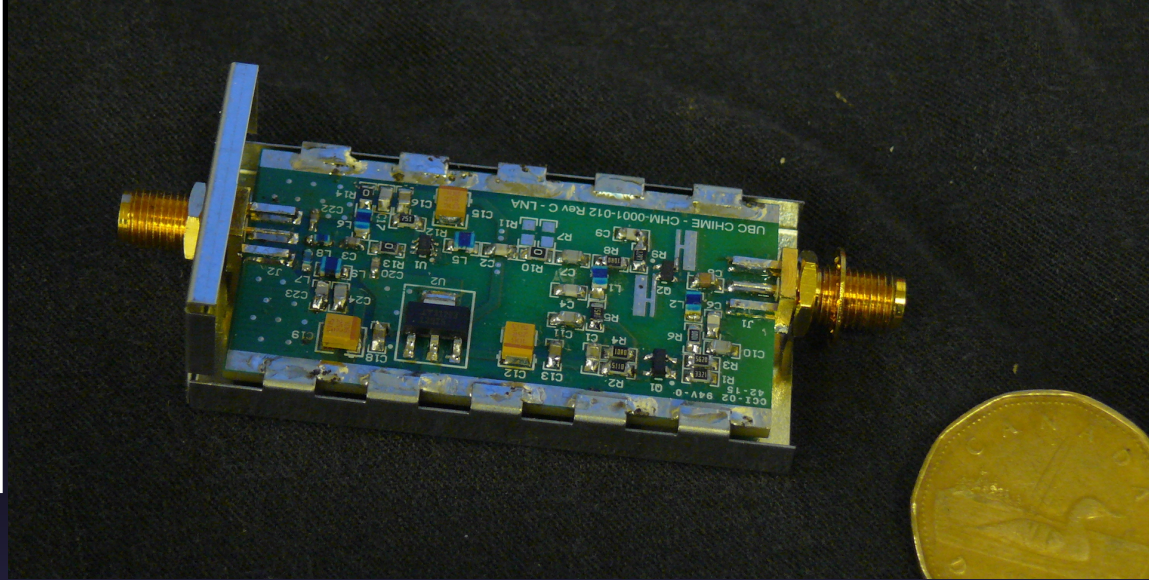
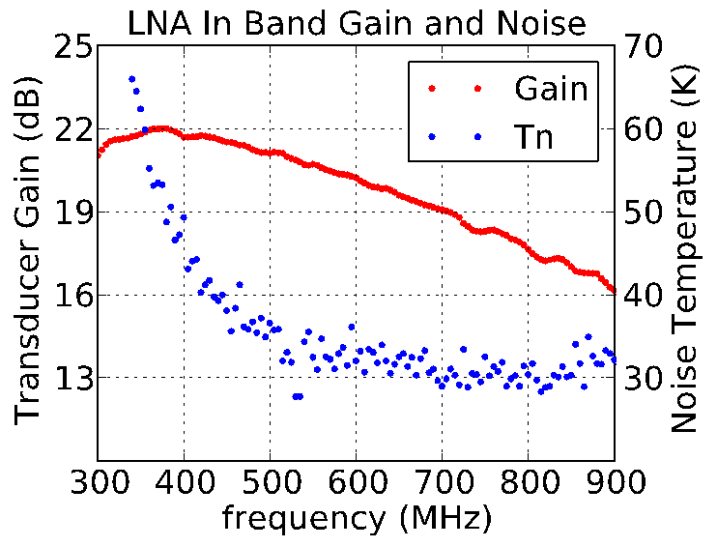
Analog System Overview



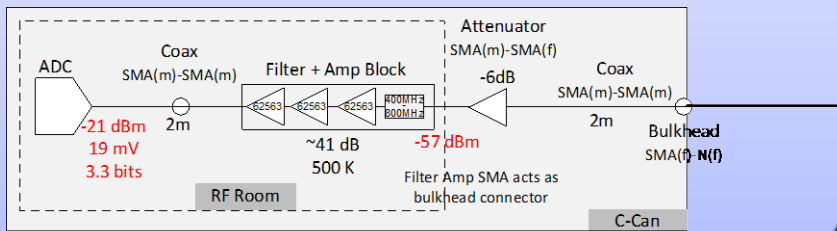
Antenna



LNA



Coax N(m)-N(m)
60 m
-5 to -8 dB

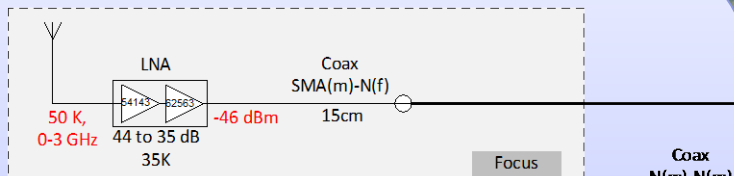
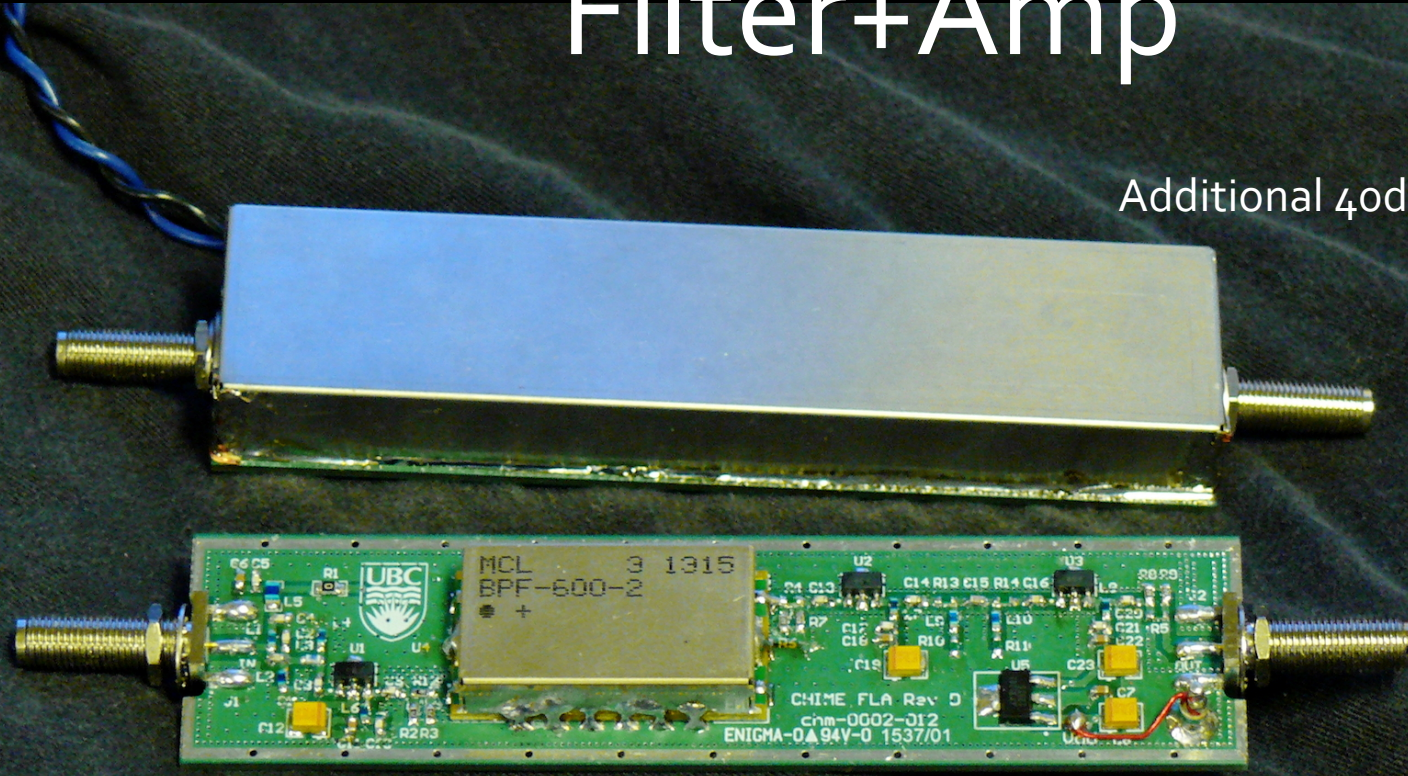


RF Room

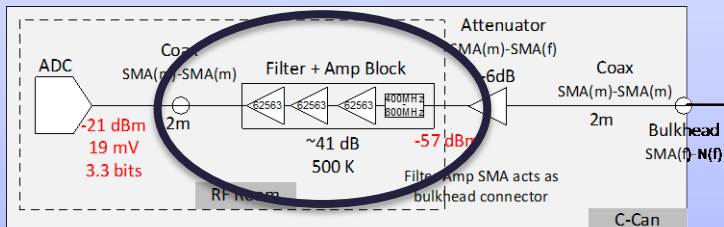
C-Can

Filter+Amp

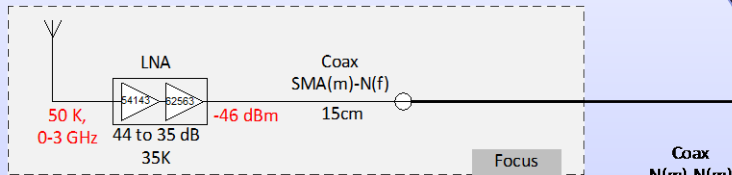
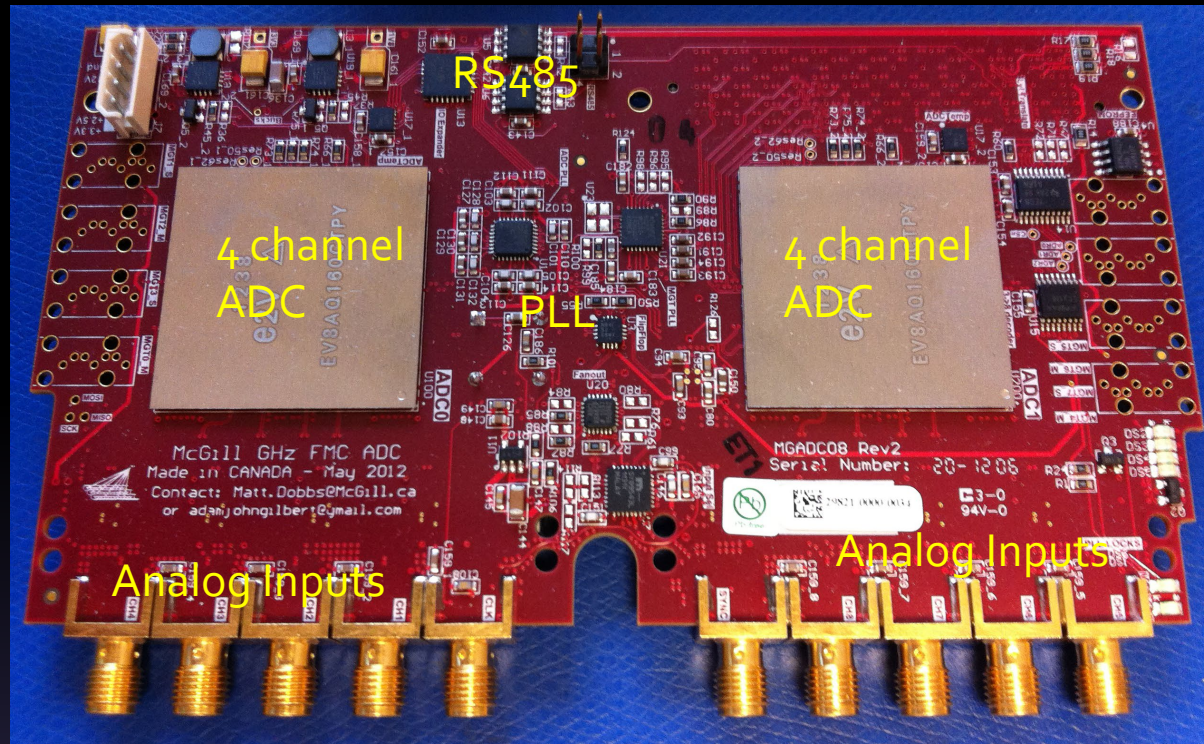
Additional 40db gain+filtering



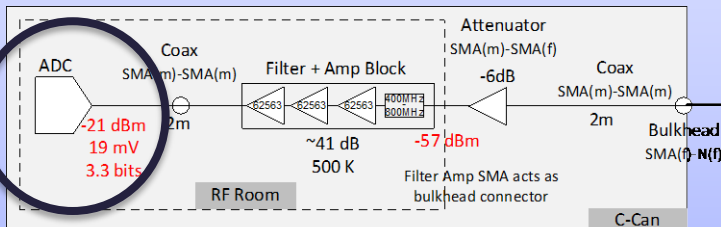
Coax
 N(m)-N(m)
 60 m
 -5 to -8 dB



ADC



Coax
N(m)-N(m)
60 m
-5 to -8 dB



Correlator F-Engine

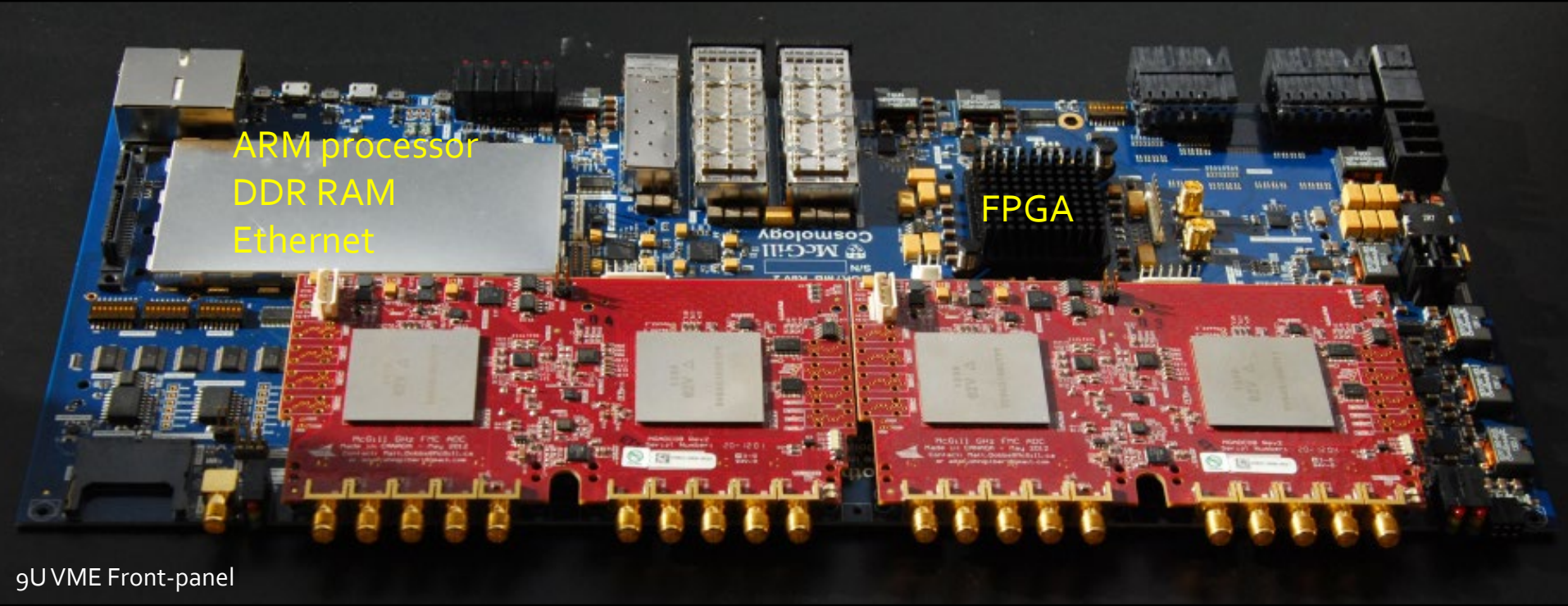
Two Gbit
Ethernet

Digital signals come in/out the back

Custom Backplane
Power, clock, timestamp
Board inter-connect

ARM processor
DDR RAM
Ethernet

FPGA

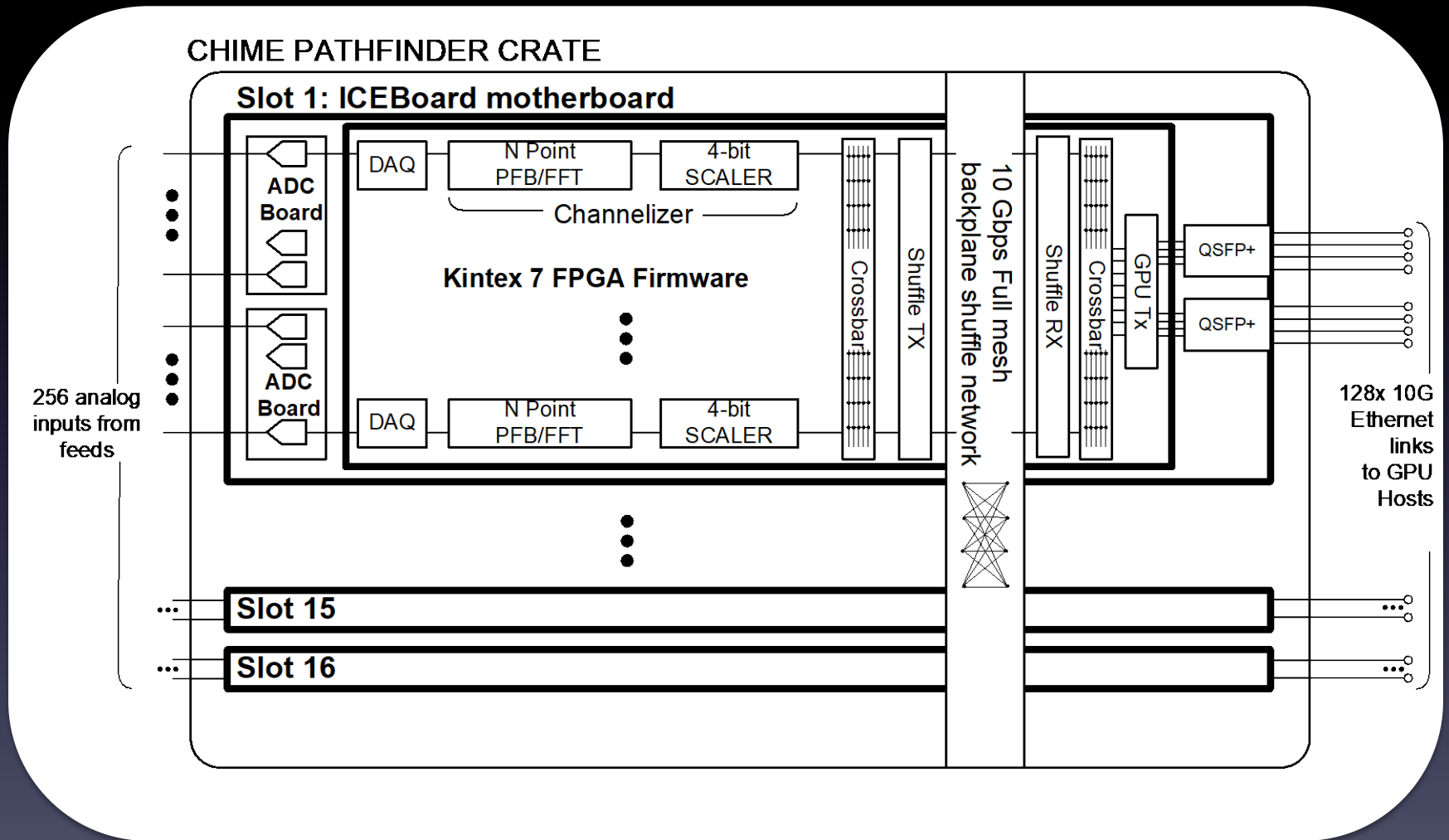


9U VME Front-panel

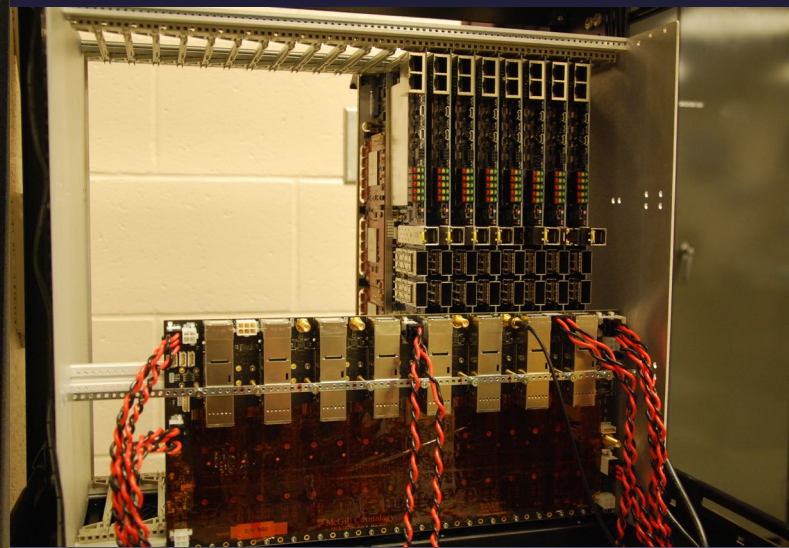
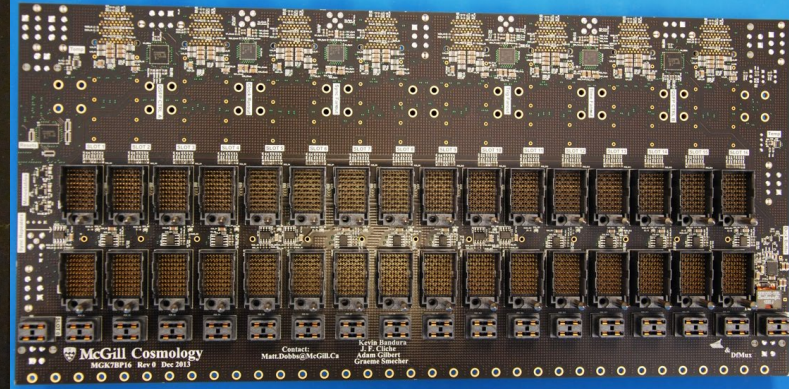
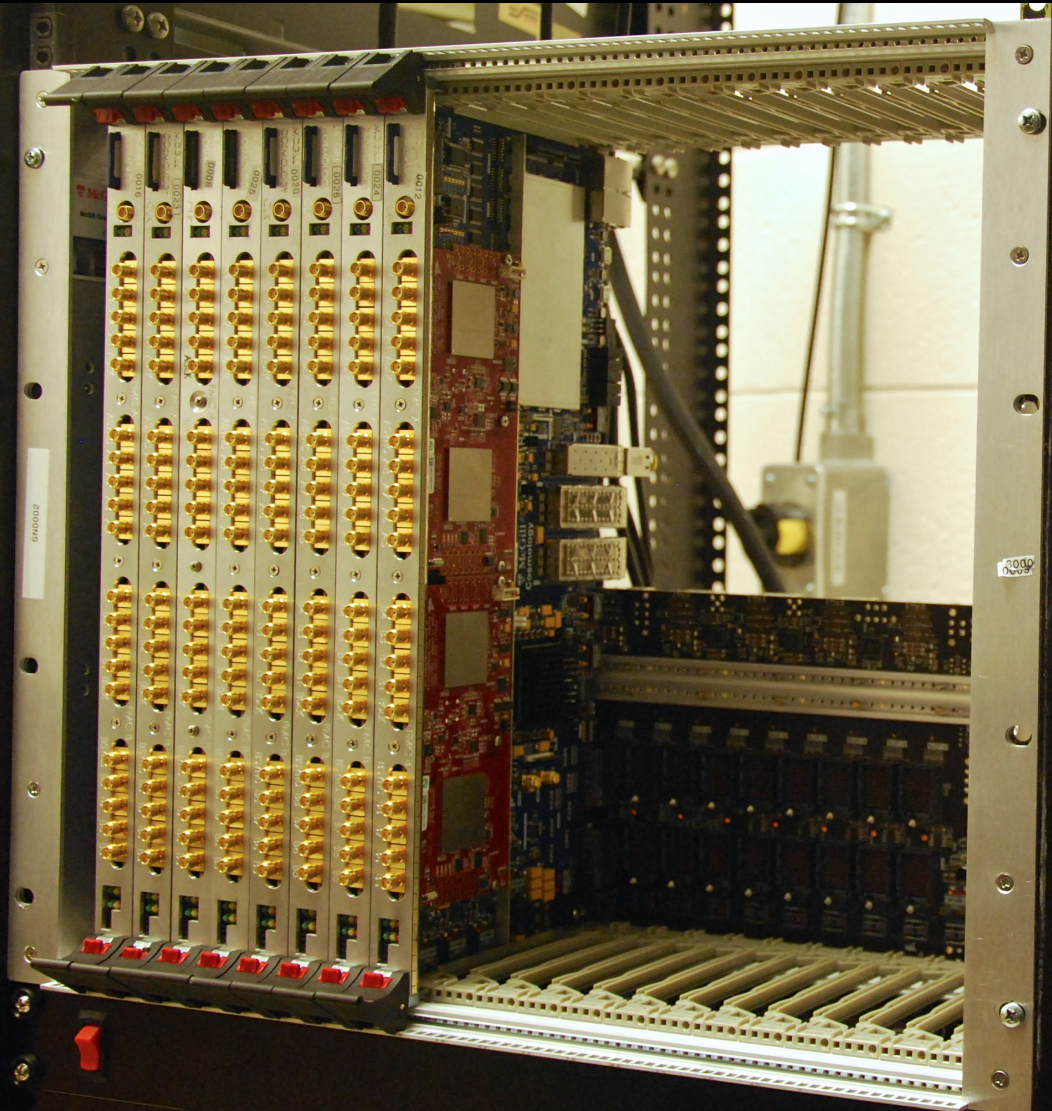
Two FMC Mezzanines

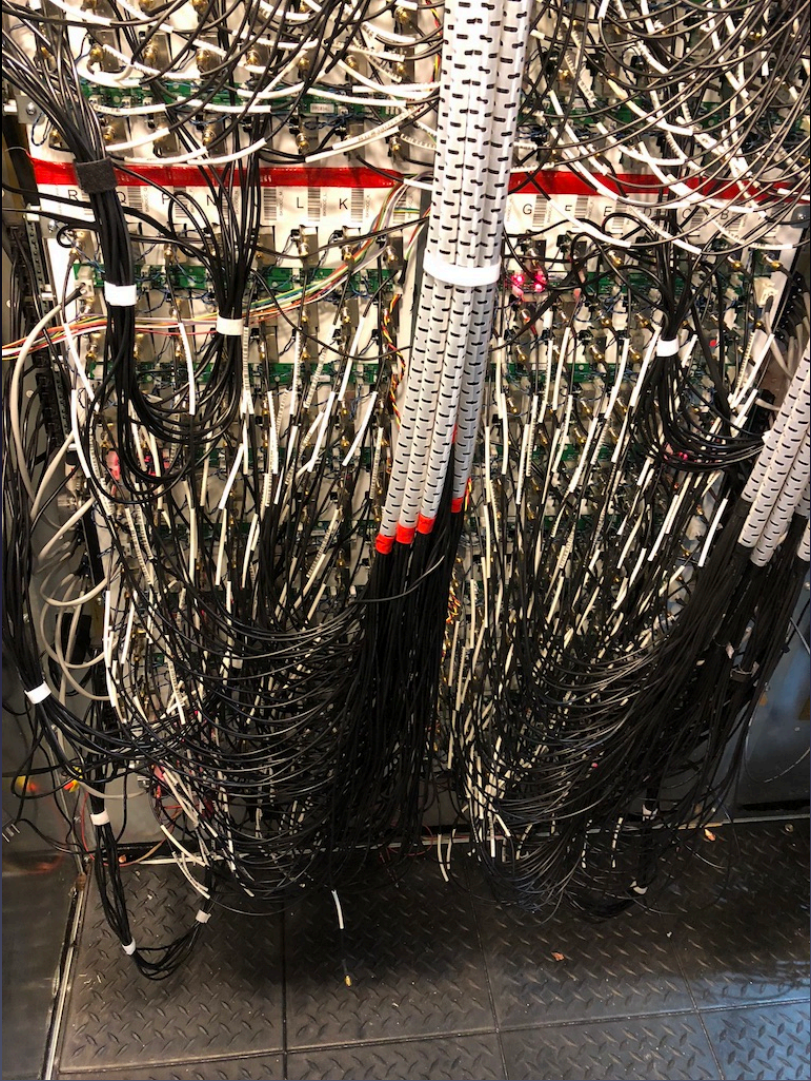
ICE System

Correlator F-Engine and Networking



FPGA Crate



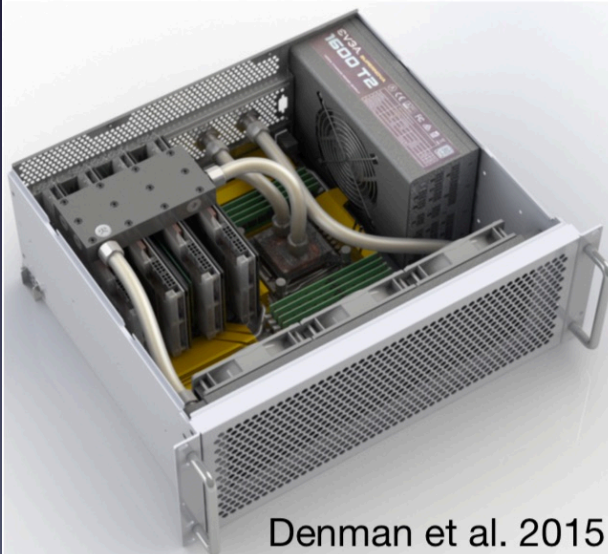


Correlator –X Engine

GPU

- FRB FFT Beamformer
- Pulsar Beamformer

Pathfinder: 13T complex MAC/s
CHIME: 840 TcMAC/s



Denman et al. 2015

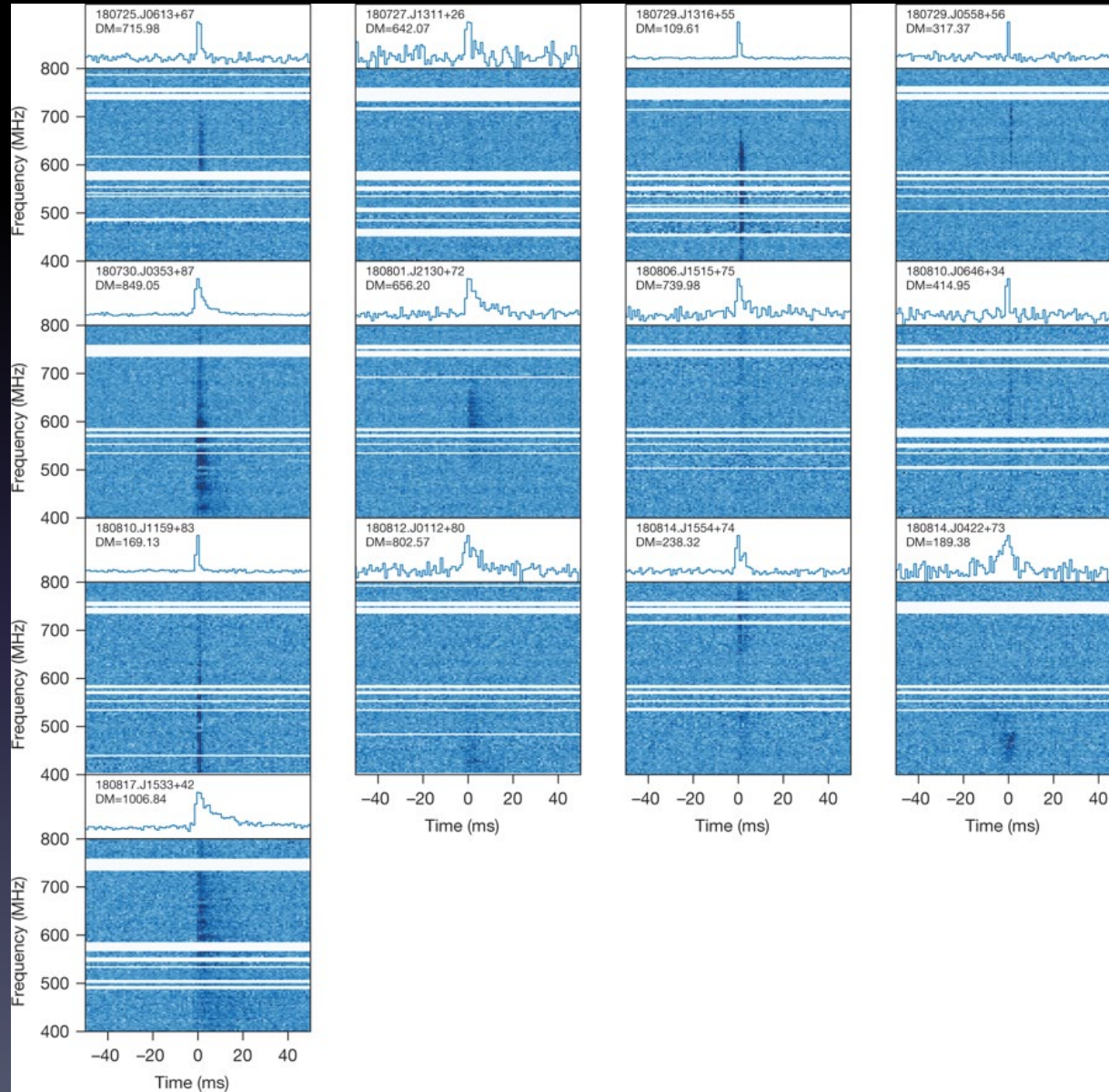


AMD 59300x2

History and Current Status

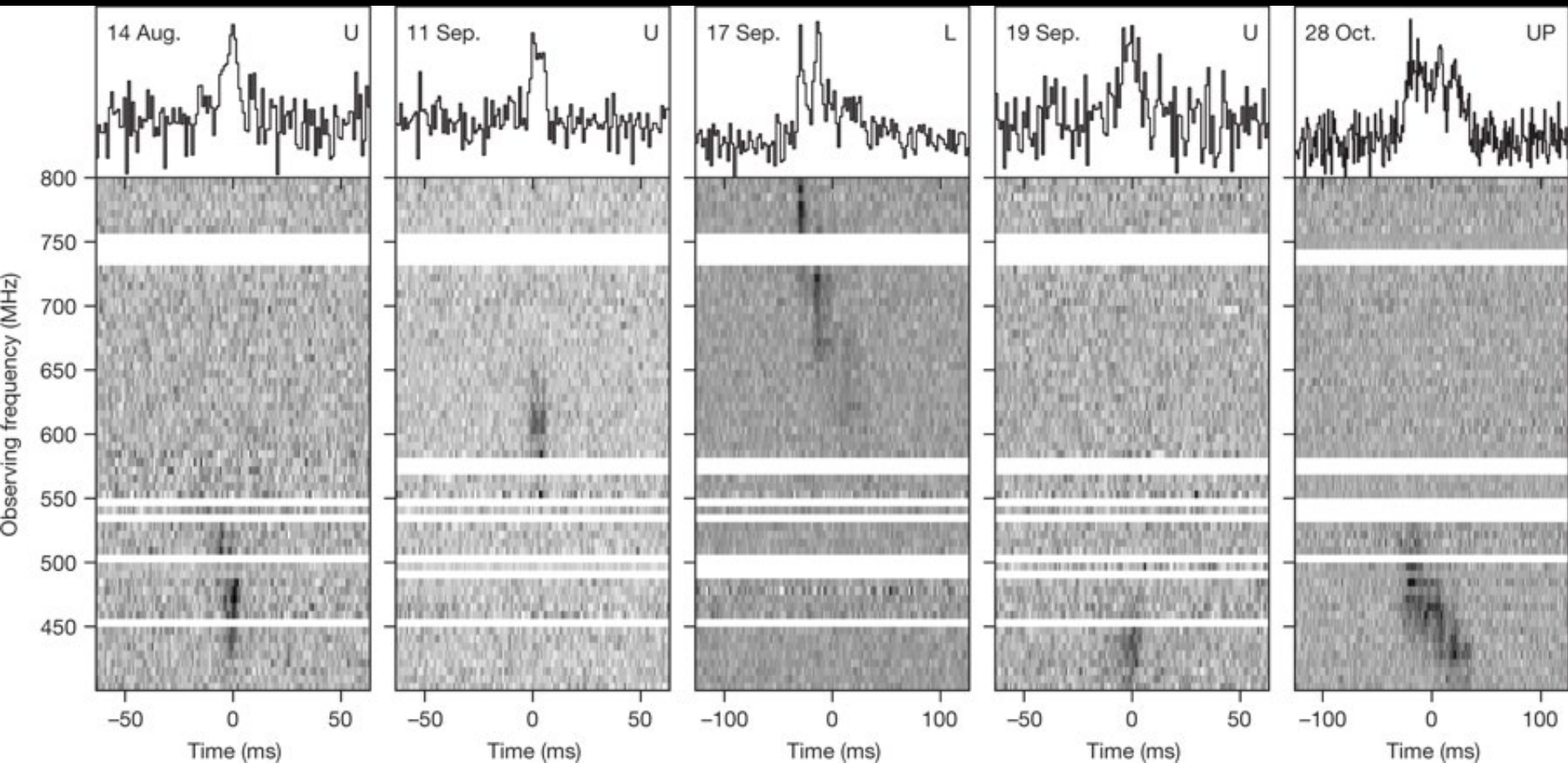
- September 7, 2017: First light ceremony
- September 2018: Reached full capacity
 - Compression through averaging redundant baselines.
 - Have had ~75% uptime
- Ongoing:
 - RFI, calibration, systematics
 - Foreground removal
 - Without beam model
 - Attempts at SVD in Frequency-Pixel
 - Quasar cross-correlation

CHIME/FRB Detections



13 New FRBs with emission detected down to 400MHz (CHIME/FRB Nature 2019)

CHIME/FRB Detections

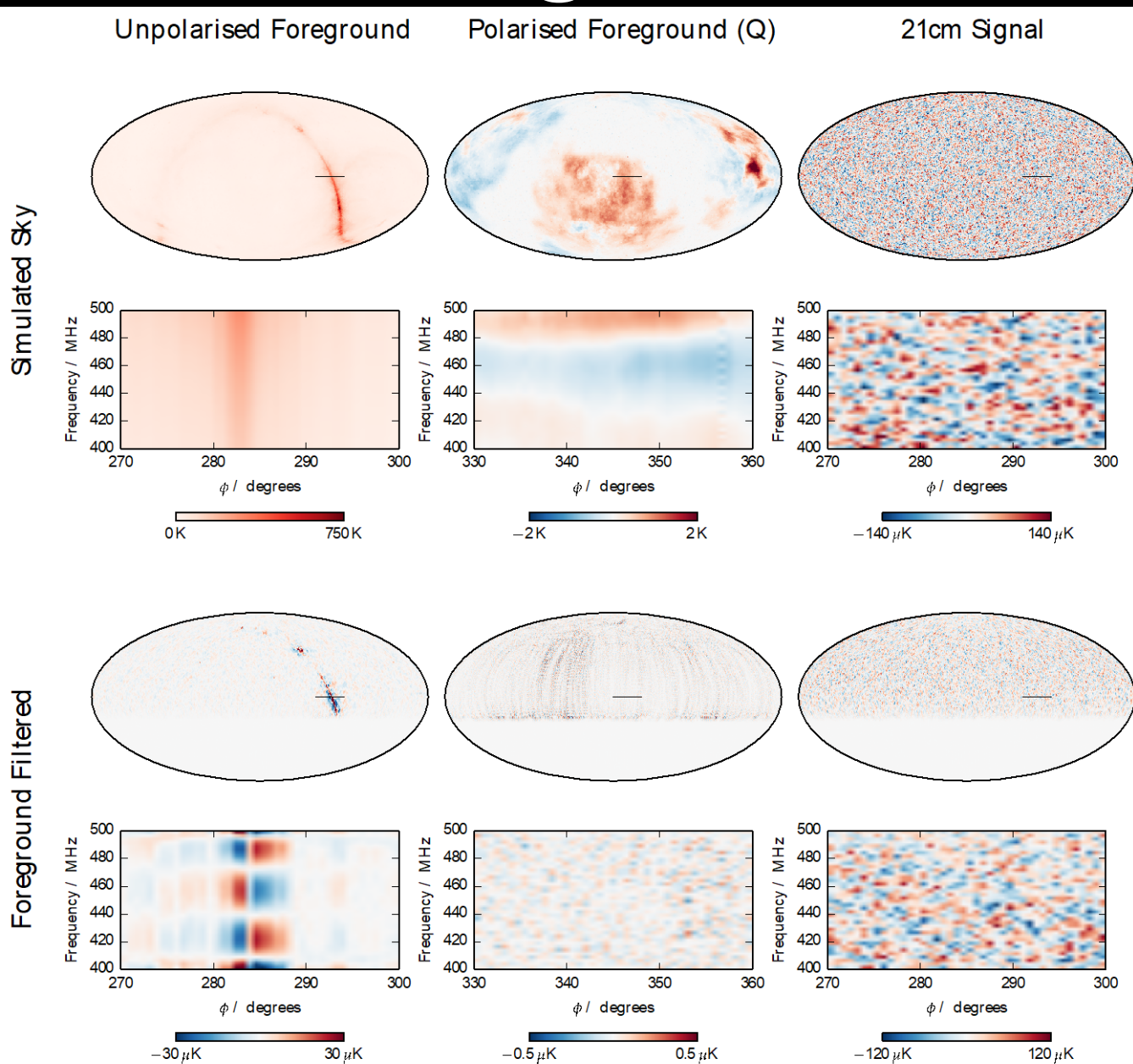


Repeating FRB 180814.J0422+73 with emission detected down to 400MHz
DM 189 pc/cm³
(CHIME/FRB Nature 2019)

CHIME Challenges

- Calibration for Spherical Harmonic - KL transform technique
 - Need to know Gains to $\sim 0.3\%$ amplitude and ~ 0.003 Radian phase.
 - Beams to 0.1%

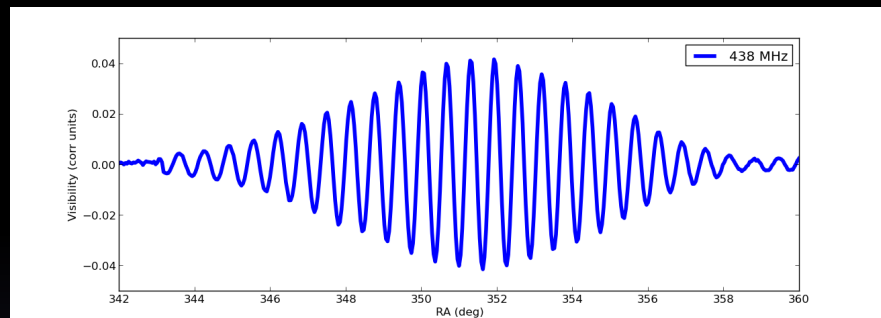
Foreground Removal



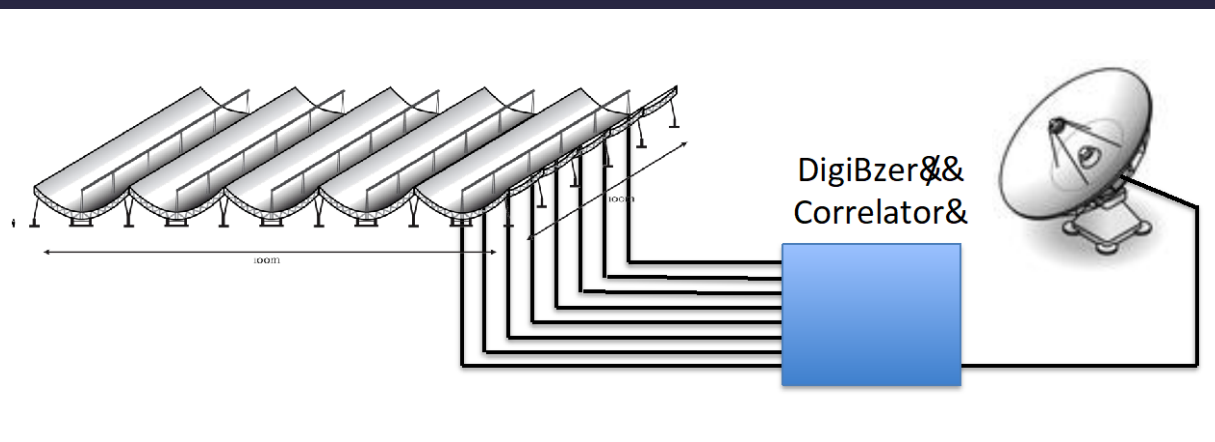
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Beams to 0.1%

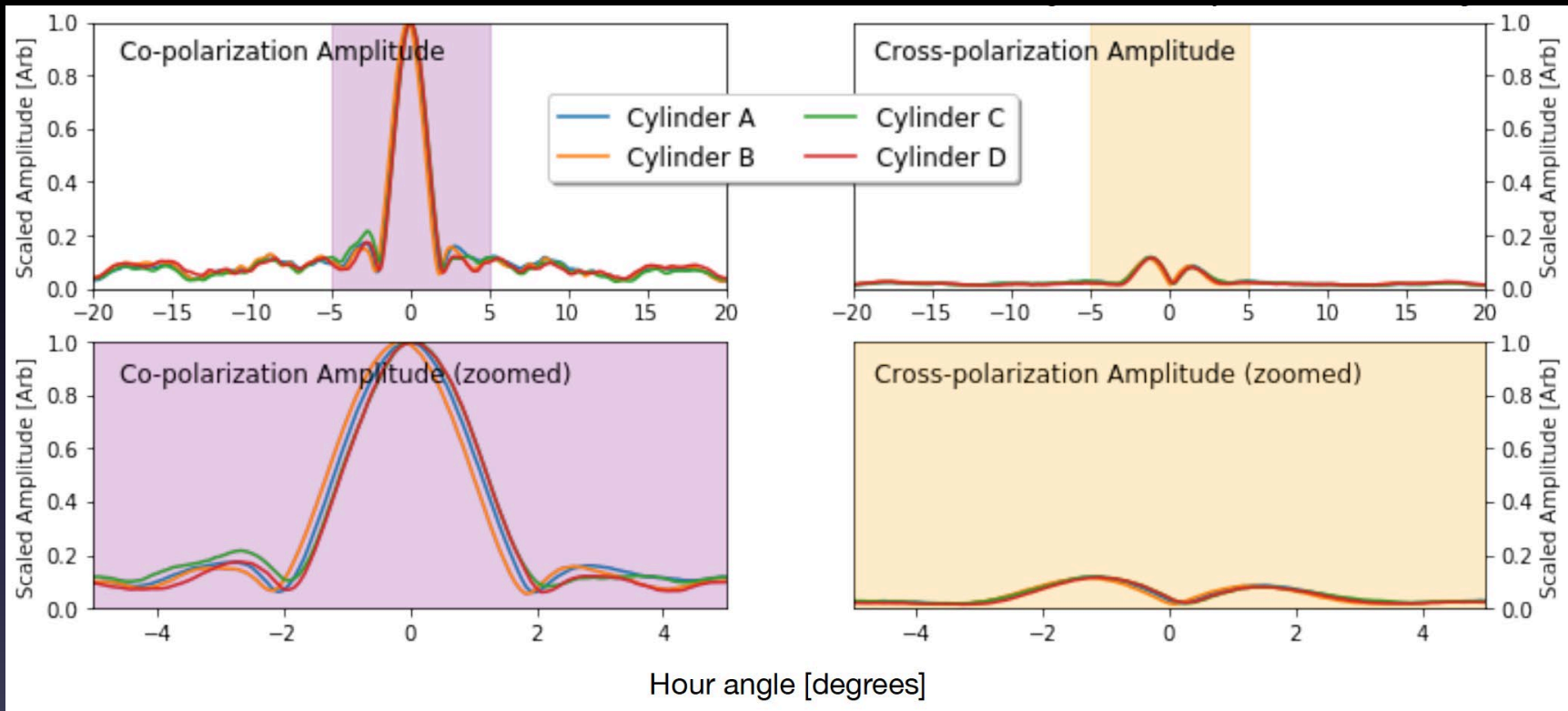
Holography Beam Calibration

- Source Holography to map out Telescope Beams
 - Track with DRAO 26m and correlate
- Pulsar Polarization Calibration



26m and CHIME pathfinder fringes as Cassiopeia A passes overhead

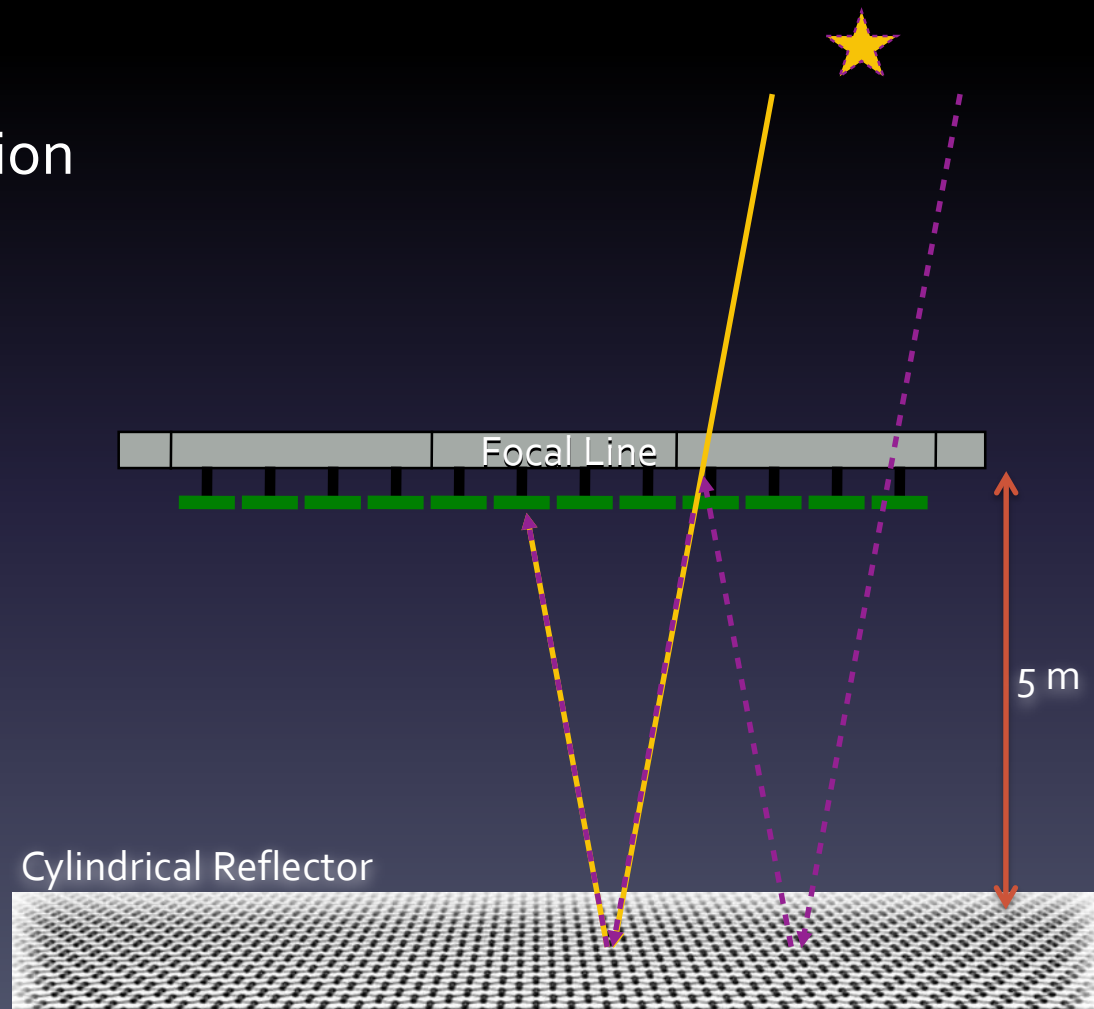




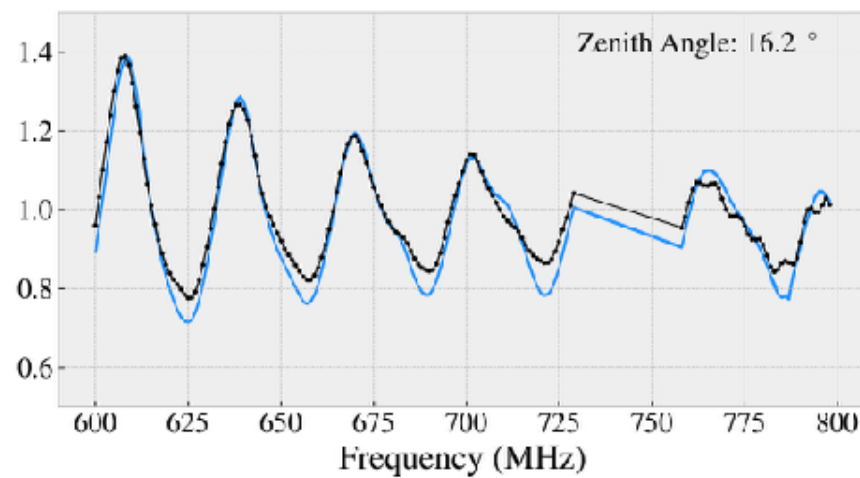
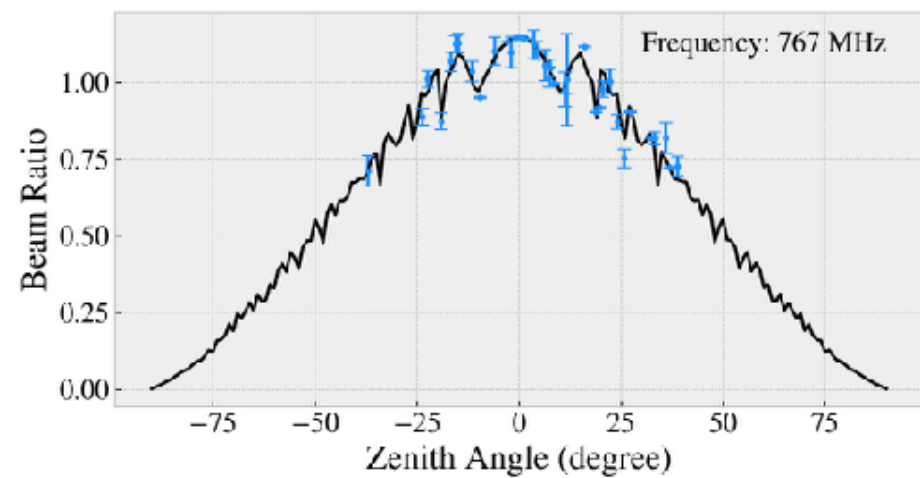
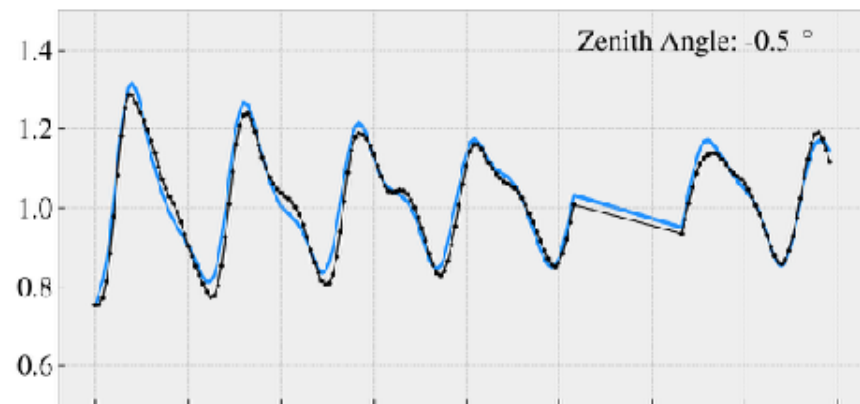
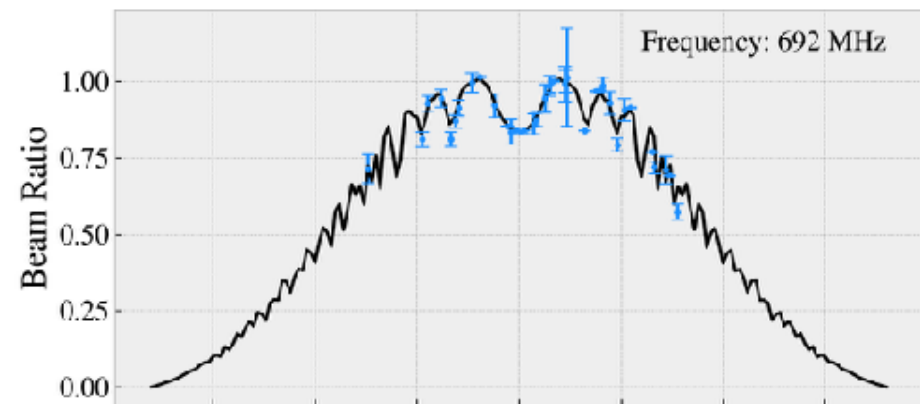
717MHz measurement of Y polarization beam using Cygnus A

Cylinder Beam N-S direction

- Model coupling as a function of frequency and position
- Fit to bright radio sources



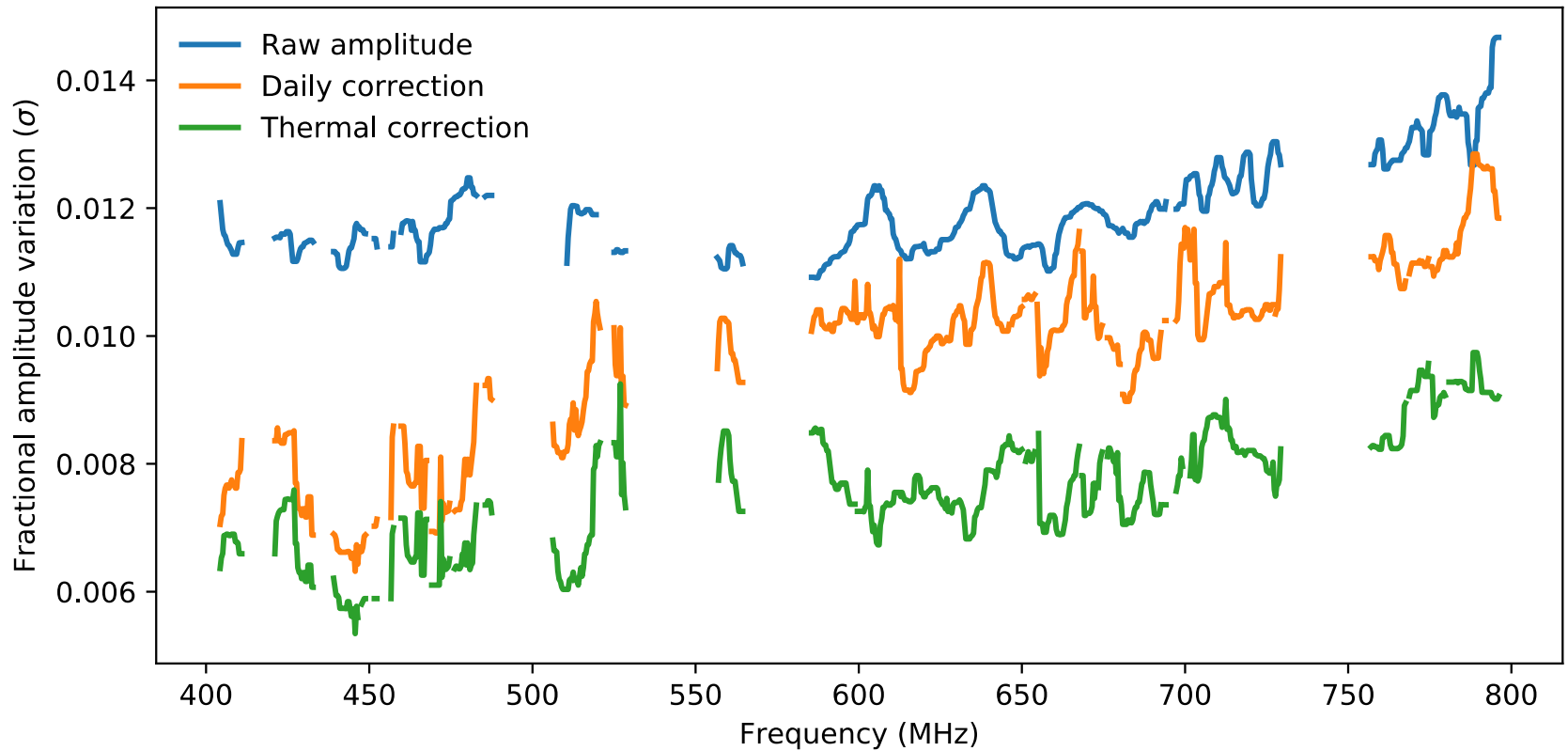
Cylinder Beam



Beam as a function of angle

Beam as a function of frequency

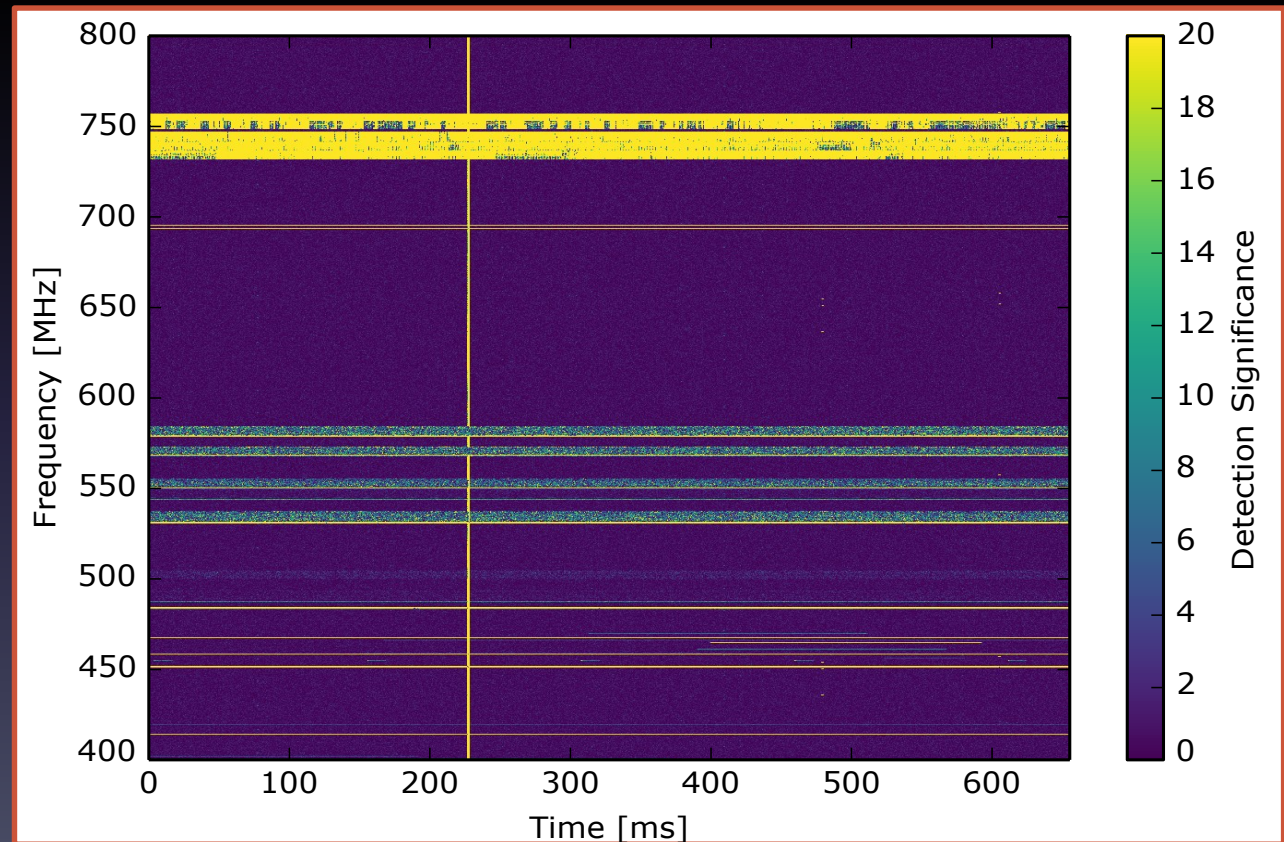
Gain Calibration



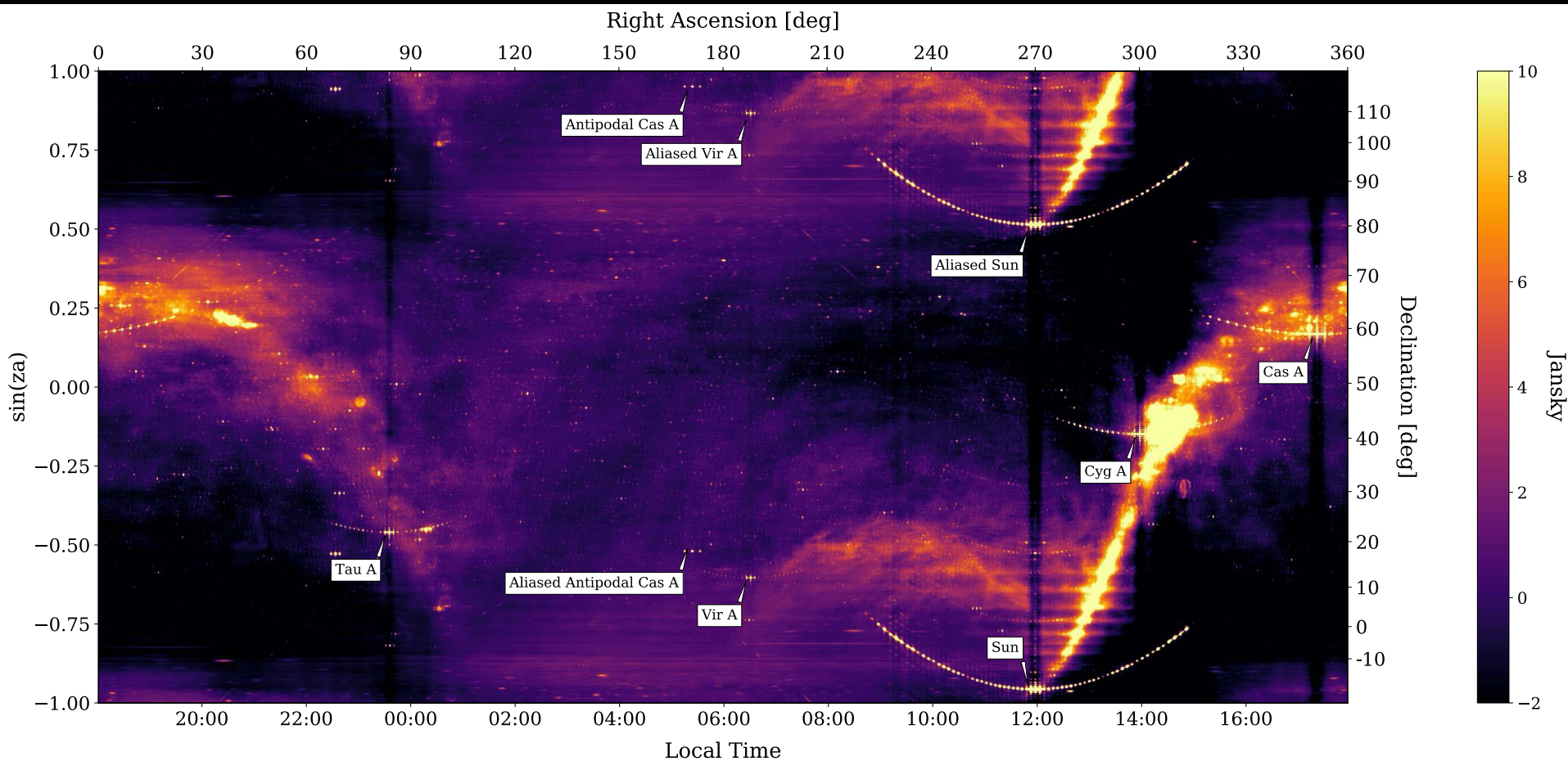
Instrument common-mode stability

RFI mitigation

- Spectral Kurtosis Based RFI Mitigation for CHIME

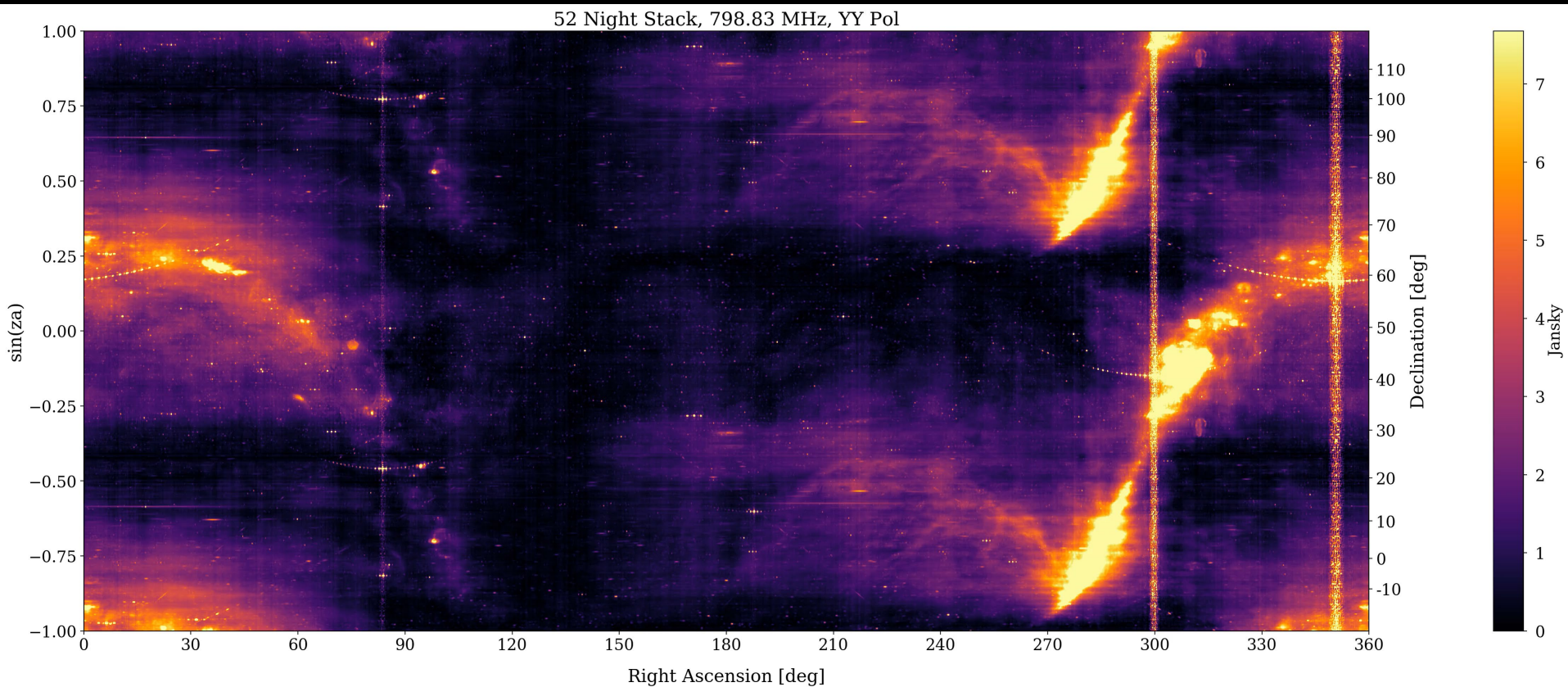


Single Day Sky Map



Dirty map. 670MHz, YY polarization

52 Night Stack



CHORD

- 512 CORE 6m dishes
- 64 dishes per outrigger station
 - 2 Stations
- 300MHz – 1500MHz
- FRB Localization
- 21cm Mapping

Summary

- Path Toward BAO Measurement
 - CHIME (Canadian Hydrogen Intensity Mapping Experiment) Design
 - Cylinder Structure
 - Analog electronics design
 - Digital electronics design
 - Challenges
 - Calibration
 - Stability
 - Beam
 - RFI
 - CHIME FRB
 - CHORD
- 
- A large, complex metal structure, likely the CHIME radio telescope, is under construction in a field. The structure consists of a dense network of white metal beams forming a cylindrical shape. In the background, there are rolling hills covered in green trees under a dark, cloudy sky. A vibrant rainbow arches across the sky, passing behind the structure. In the foreground, there is a wooden fence and a dirt path.



chime

a collaboration between



THE
UNIVERSITY OF
BRITISH
COLUMBIA



UNIVERSITY OF
TORONTO



McGill



Dominion
Radio
Astrophysical
Observatory

NRC · CNRC



West Virginia University®



Yale University

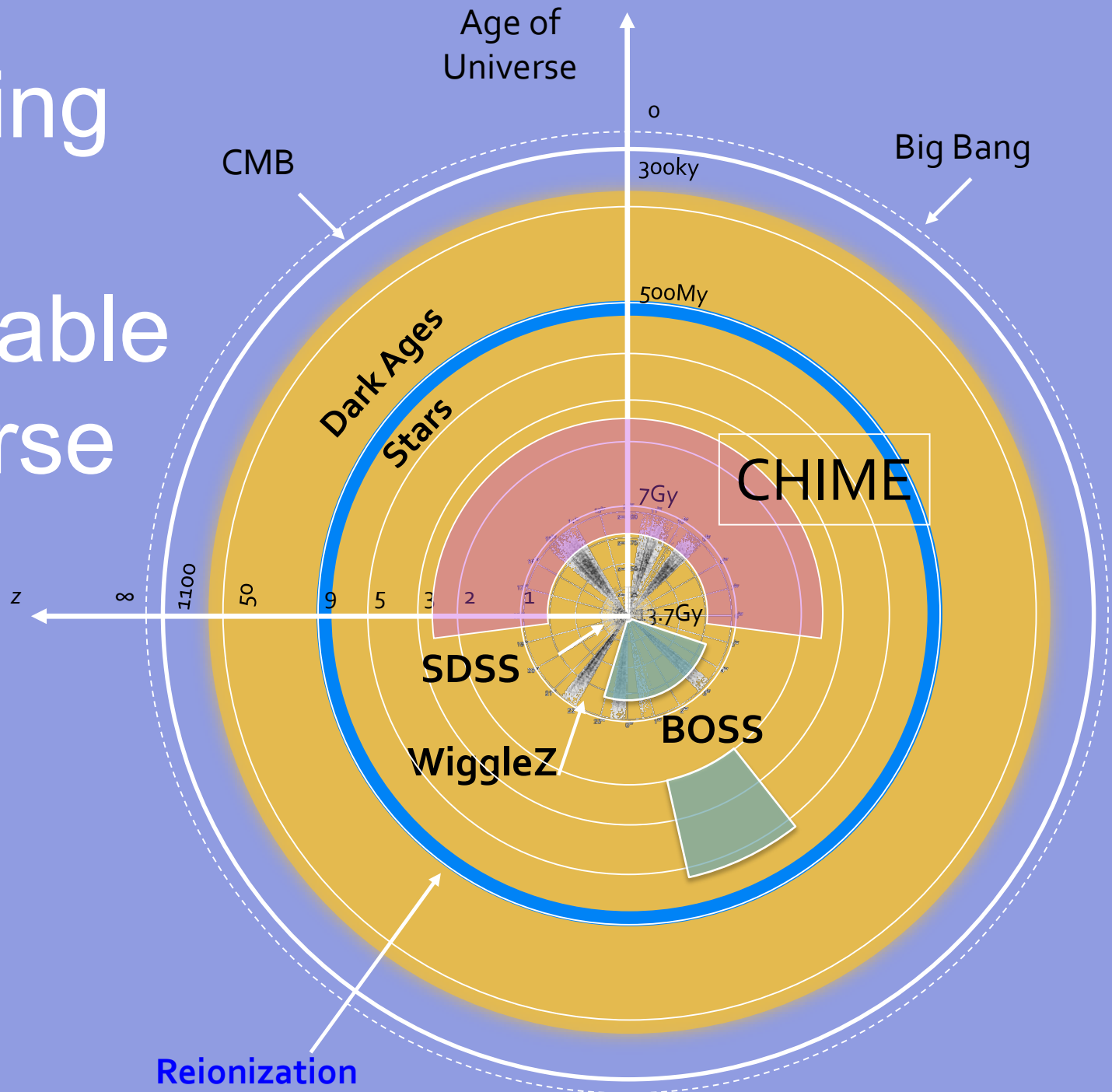


**Massachusetts
Institute of
Technology**

Mapping the Observable Universe

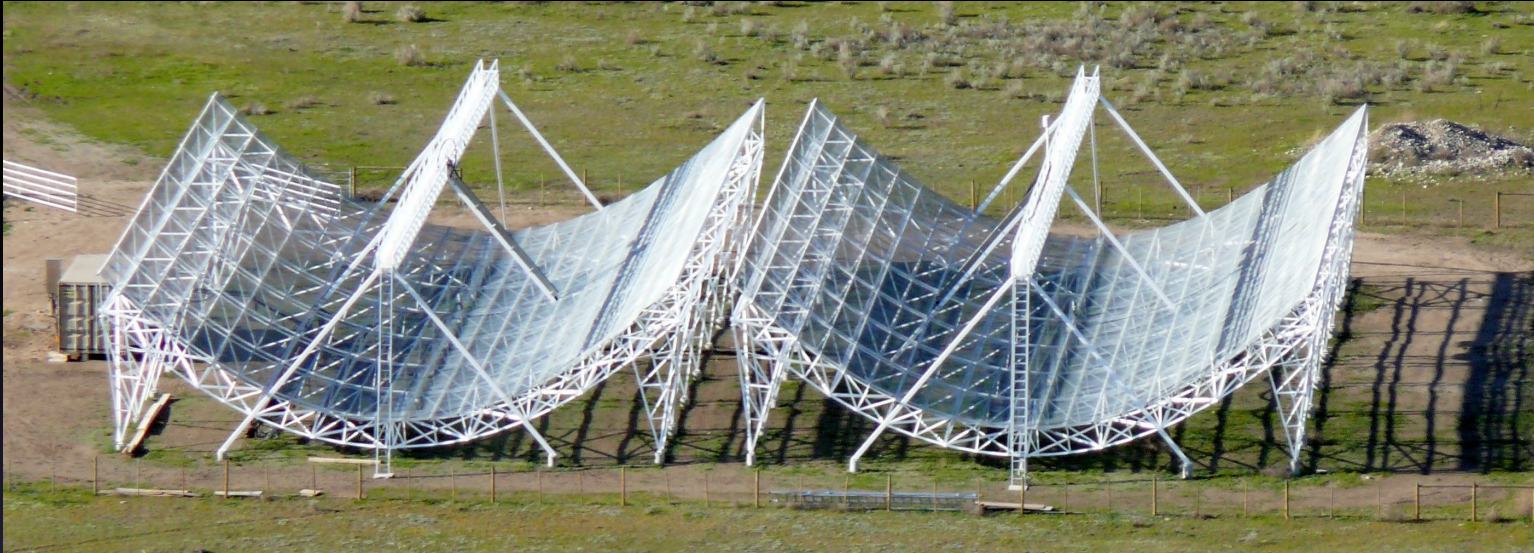
CHIME will:

- survey BAO with $z \sim 1$
- measure the growth of space
- redshift $0.8 < z < 2.5$
- over a volume of ~ 200 co-moving Gpc^3



The CHIME Pathfinder

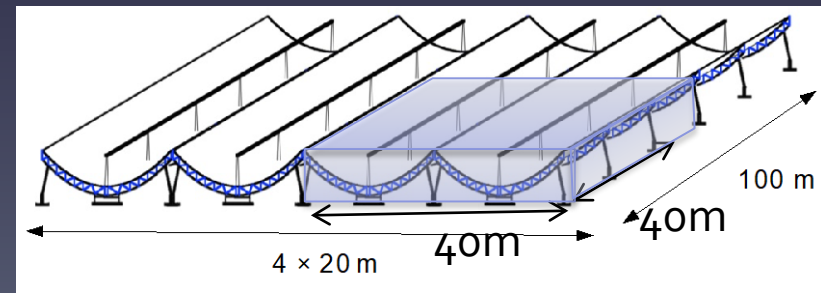
"an end-to-end hardware, calibration, foreground suppression, and data analysis proof-of-concept for CHIME"



- 64 dual-pol antennas per cylinder (256 total analog signals)
 - 100's Gpc³ Survey volume
- *Initial data began in 2013*
- Test CHIME hardware
- Test Calibration Techniques
- Test Foreground Removal
- Preliminary BAO Measurement

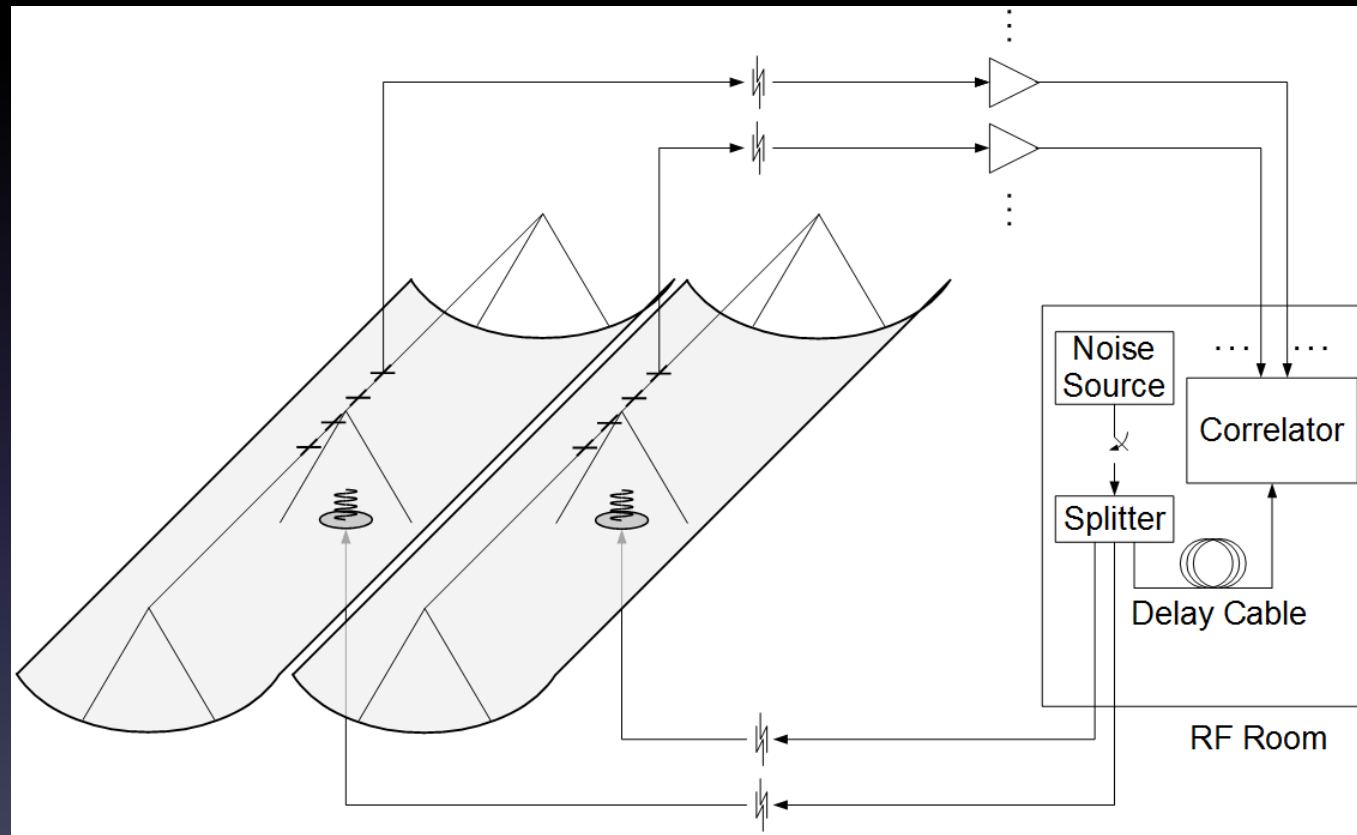
CHIME

- 4 cylinders 20m by 100m (100x100m total)
- 1024 dual-pol antennas

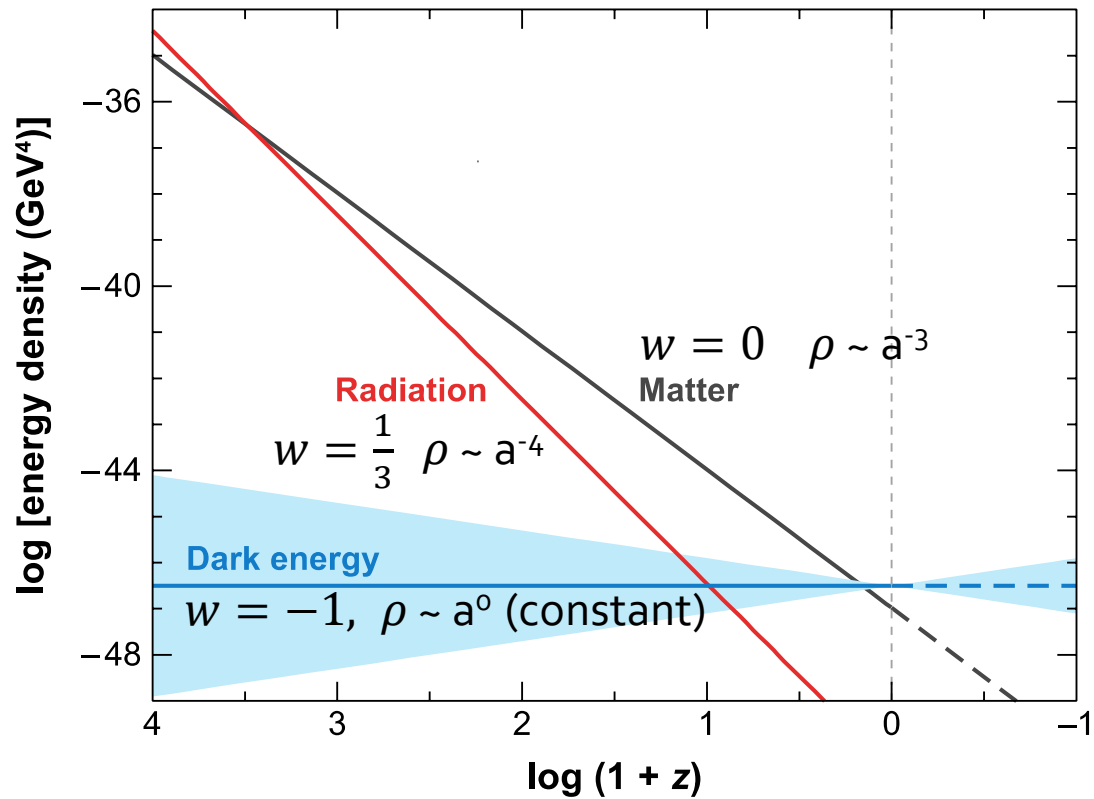


Gain Calibration

- Broadband Injected Signal
- Measured by Correlator
- Thermal Model

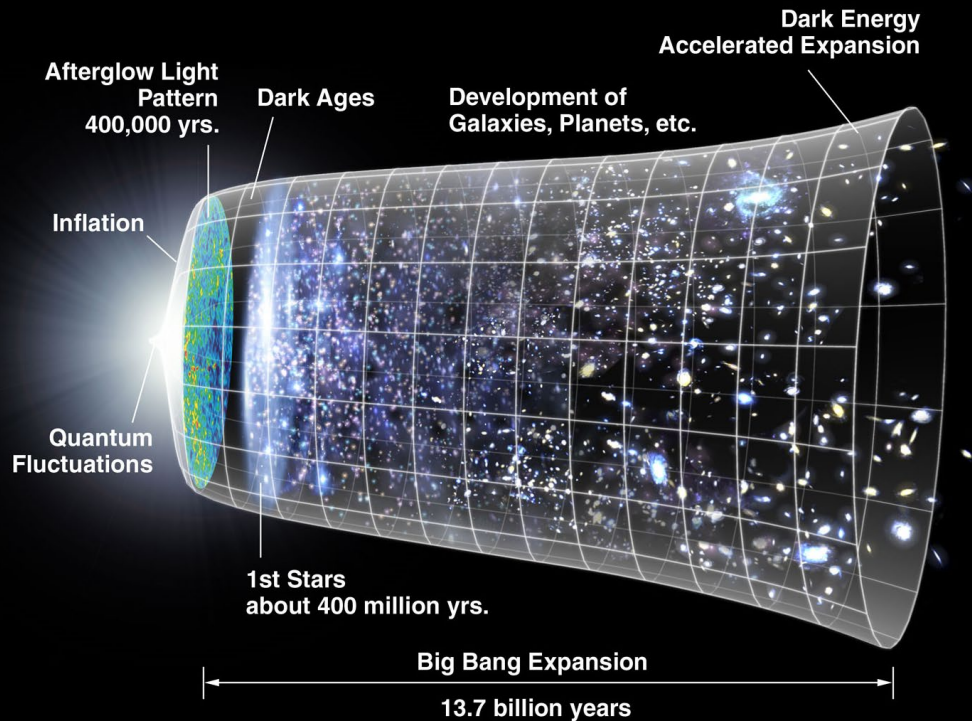
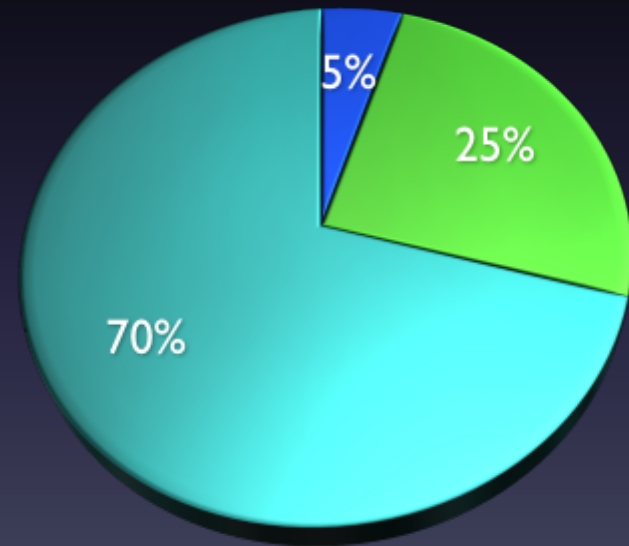


Λ CDM Cosmology

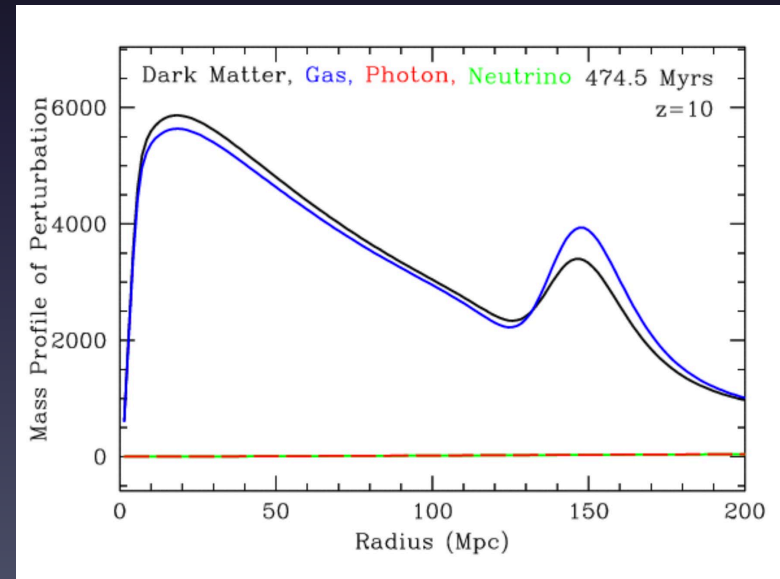
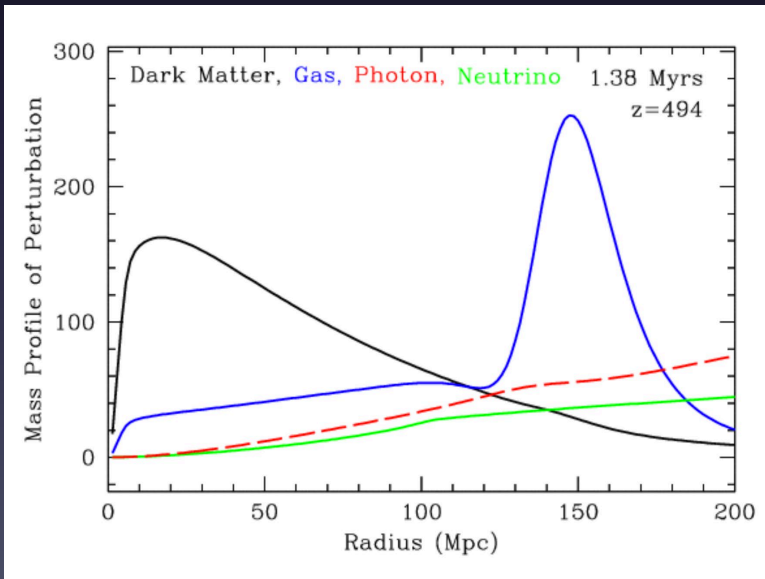
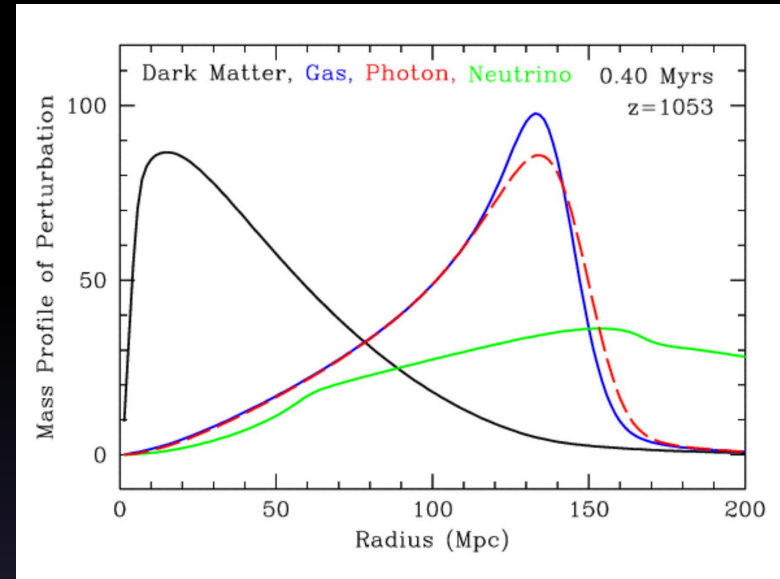
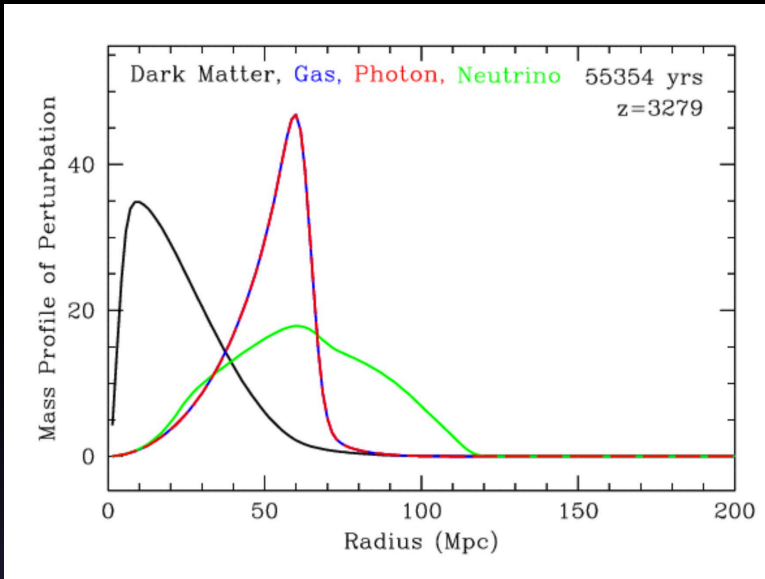


Λ CDM Cosmology

- Baryons
- Dark Matter
- Dark Energy

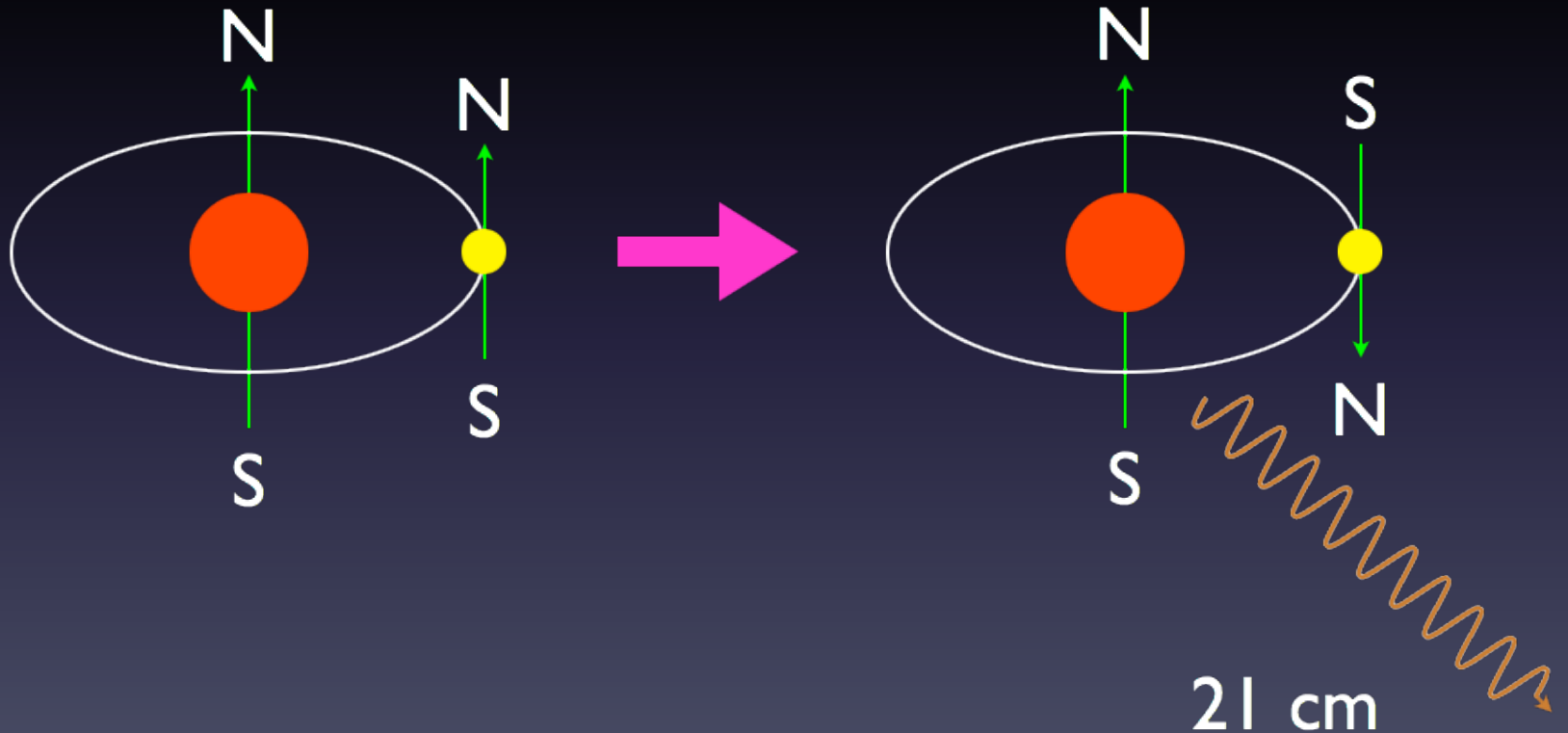


Baryon Acoustic Oscillations



Wavelength = 21 cm

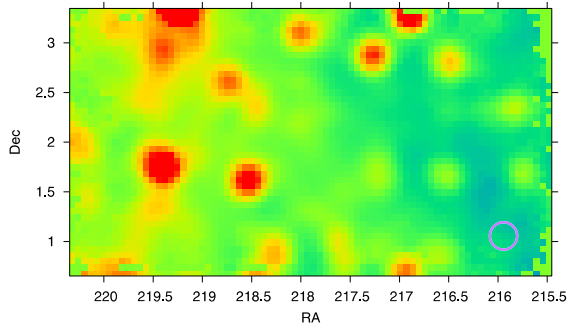
Hydrogen Emission





WiggleZ Cross-Correlation

GBT 15hr field (800.4 MHz, $z = 0.775$)



Masui et al. 2013

- $\Omega_{\text{HI}} b_{\text{HI}} r = [0.43 \pm 0.15(\text{stat.})] \times 10^{-3}$