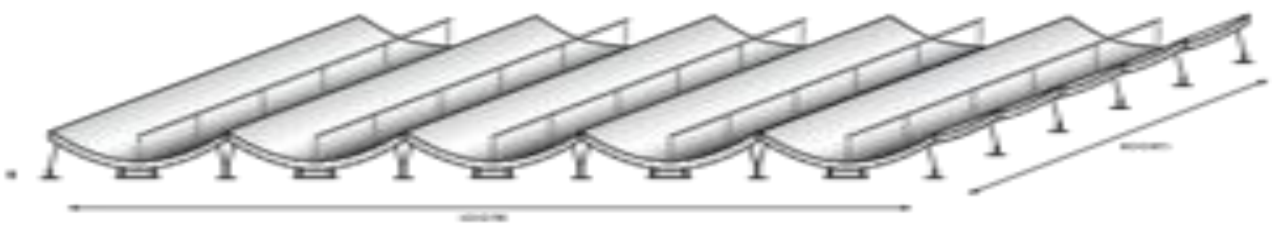
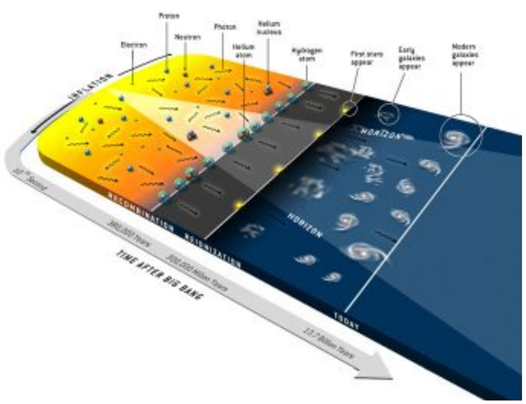
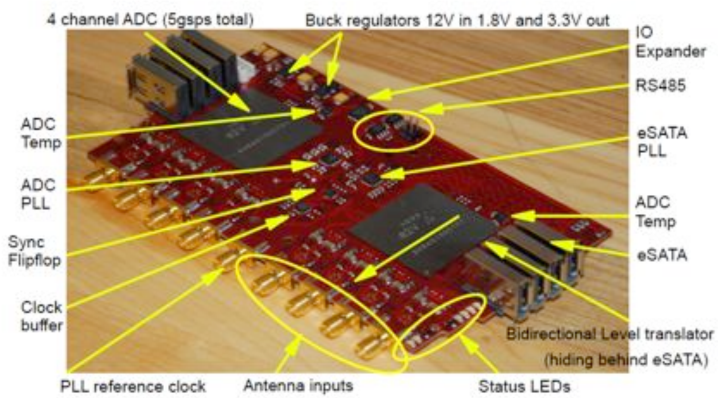
The Canadian Hydrogen Intensity Mapping Experiment

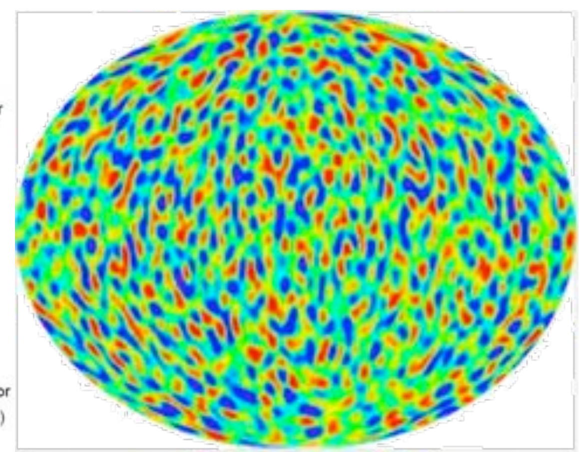
Matt Dobbs

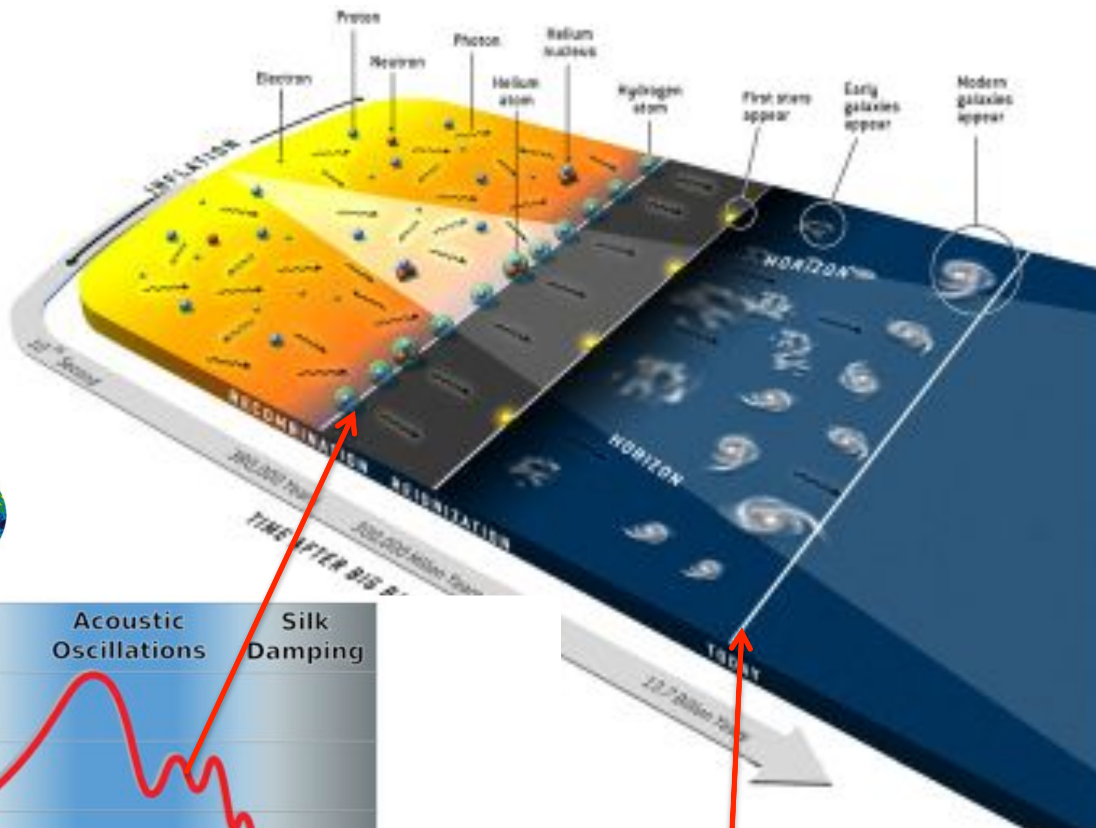
On behalf of the CHIME Collaboration

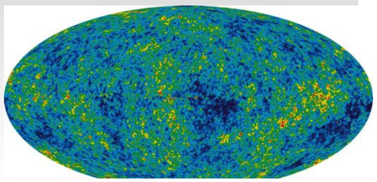


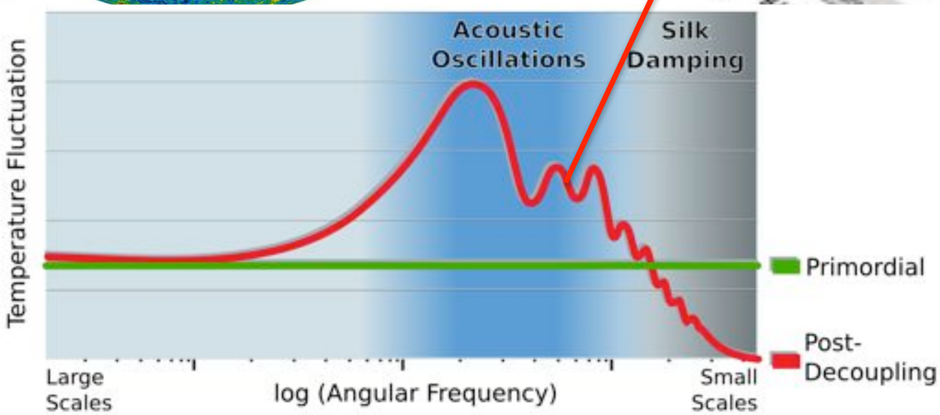




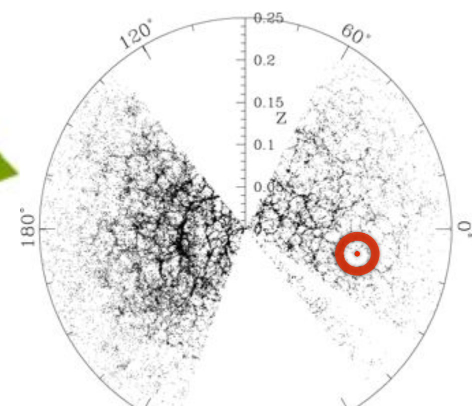








Baryon Acoustic Oscillations

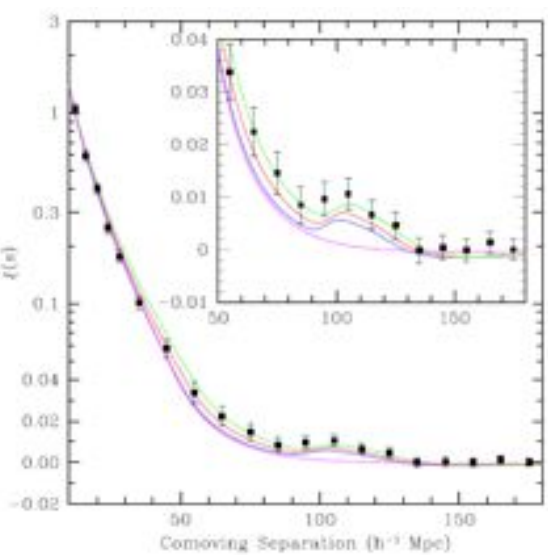


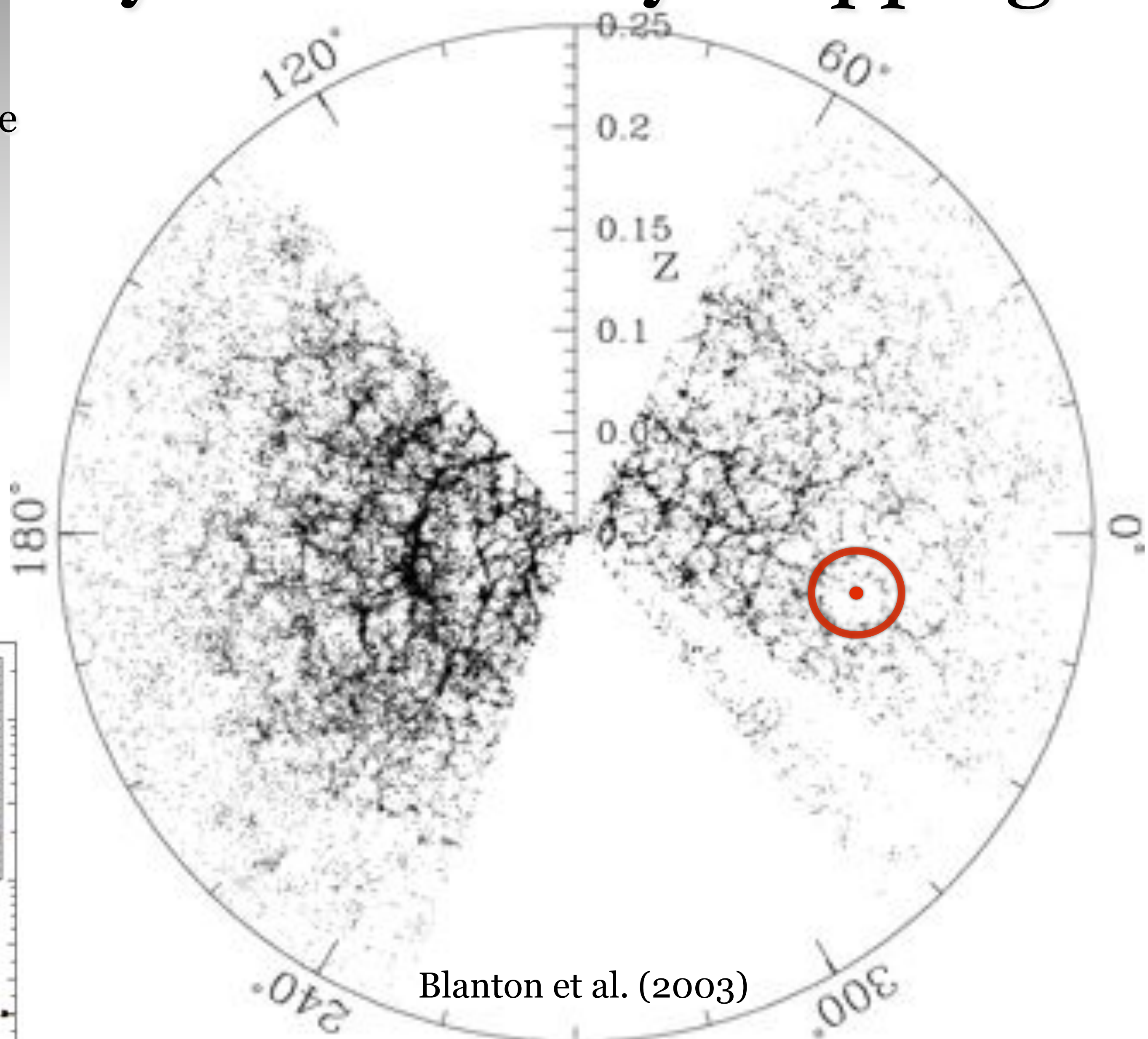
Blanton et al. (2003)

Galaxy Surveys vs. Intensity Mapping

Galaxy Surveys

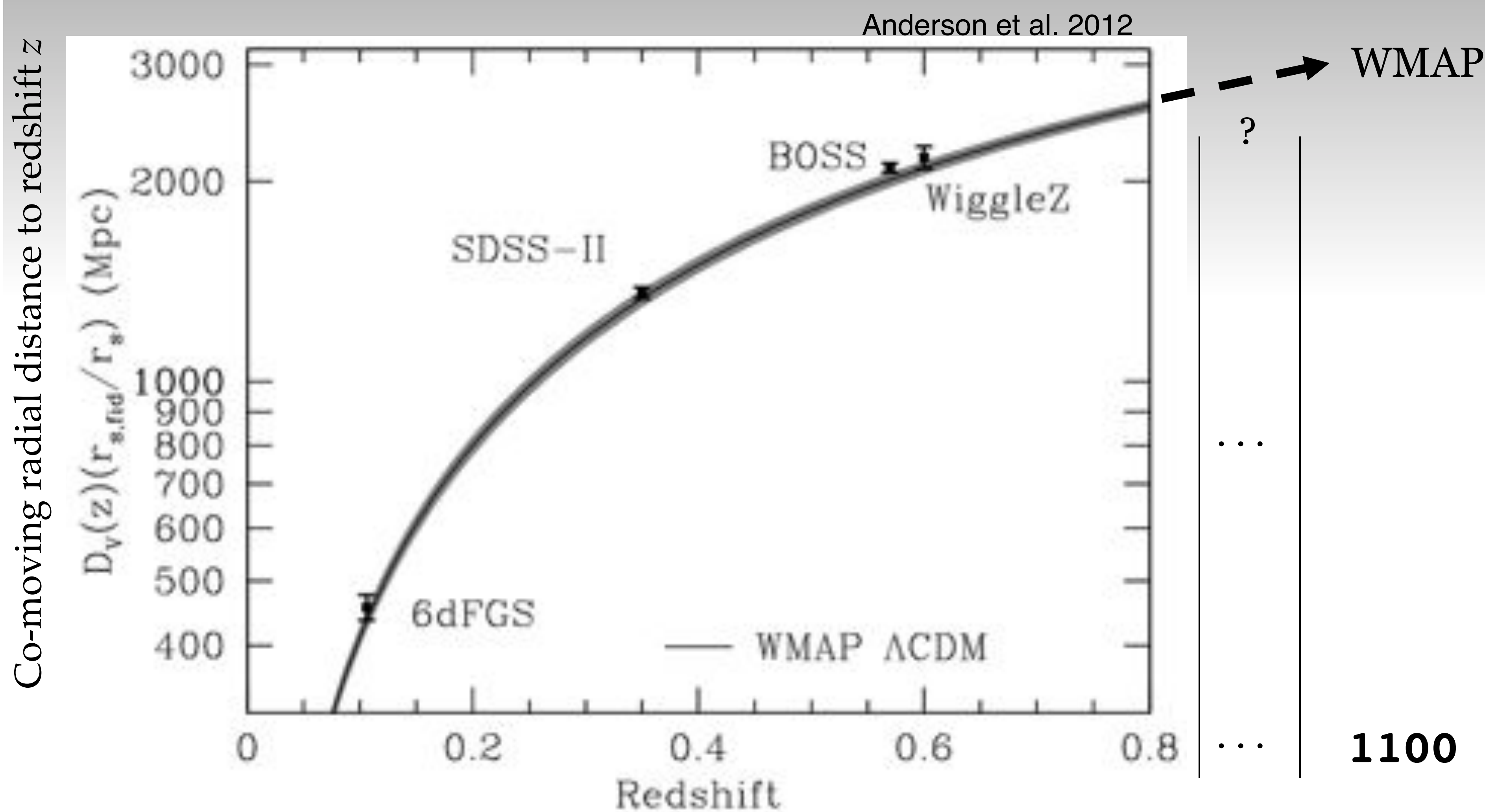
- ~1% (2 Gpc^3/h^3) of the universe has been mapped with optical light from galaxies.
- Galaxy surveys are expensive
- Rely on (non-linear) galaxies as tracers for BAO



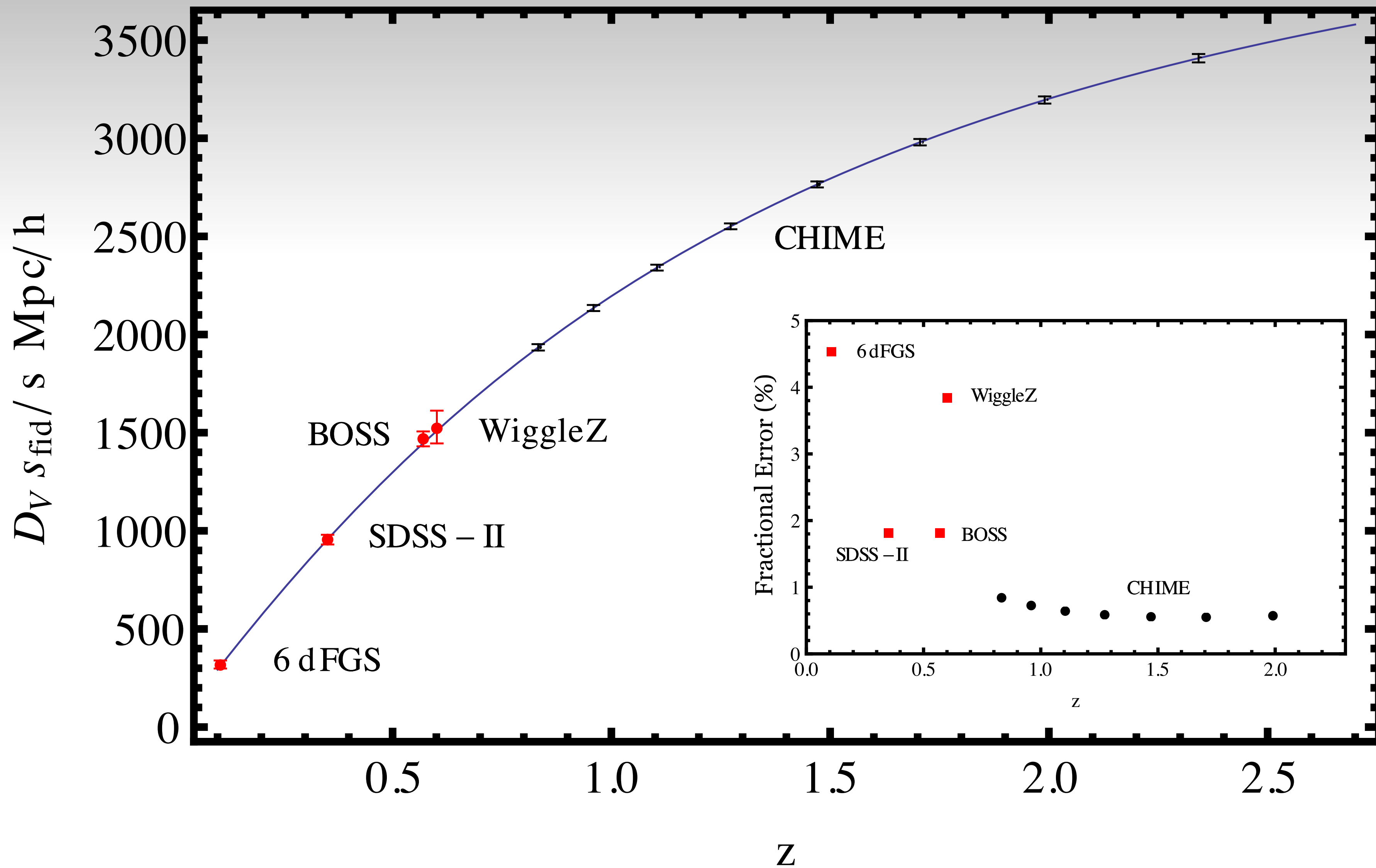


Blanton et al. (2003)

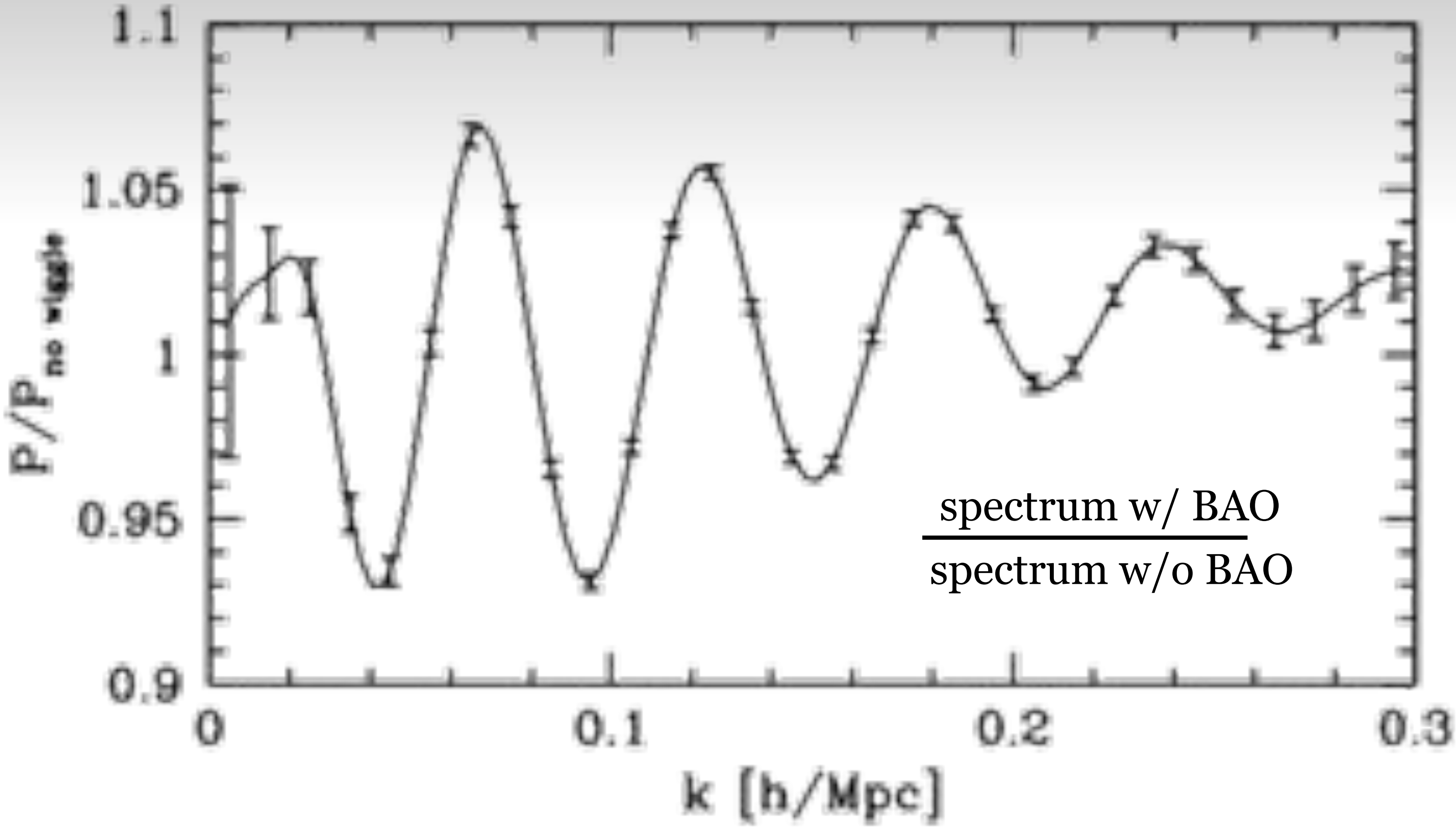
BAO as a standard ruler



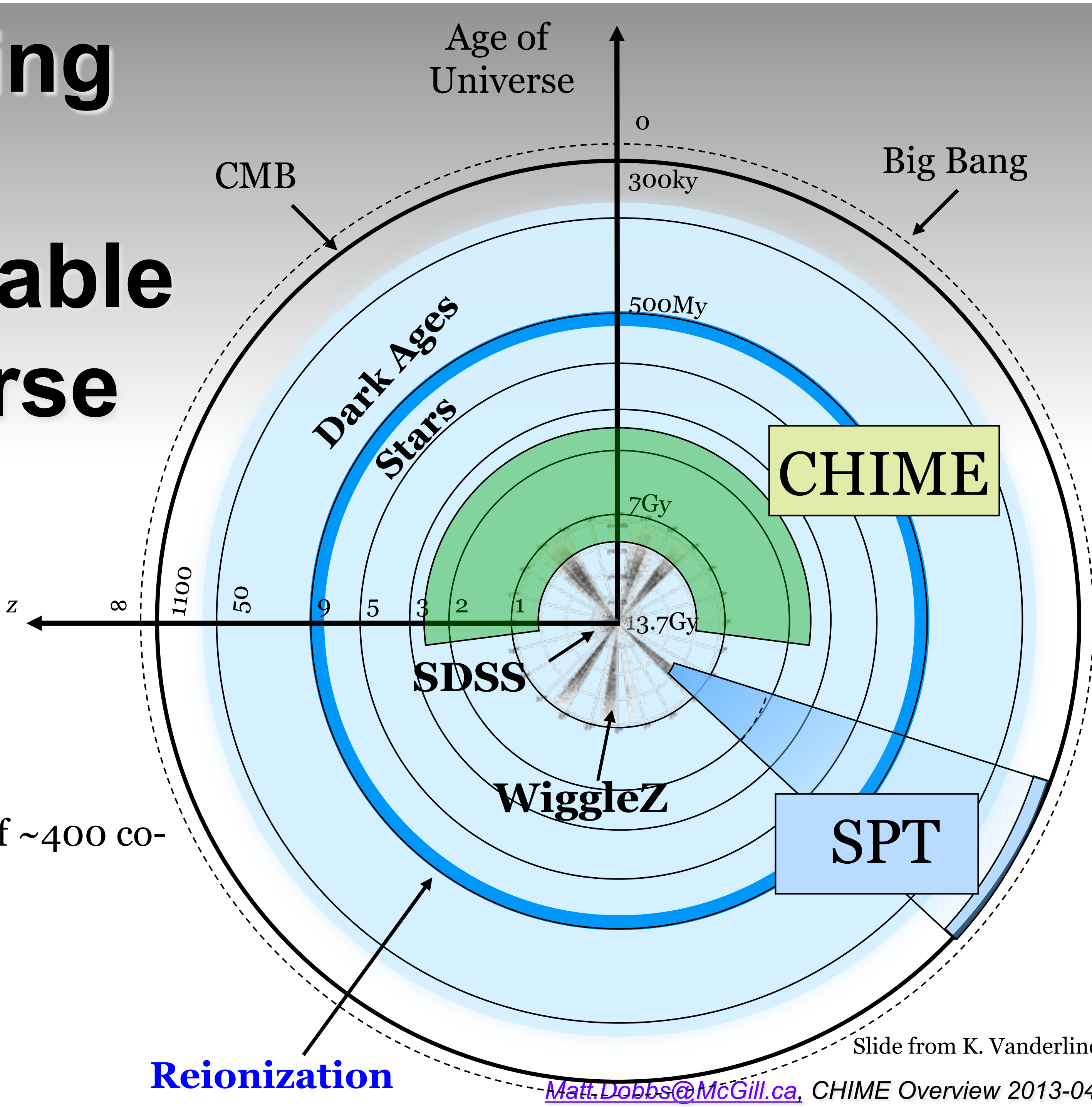
CHIME Cosmology Forecast



CHIME Cosmology Forecast



Mapping the Observable Universe



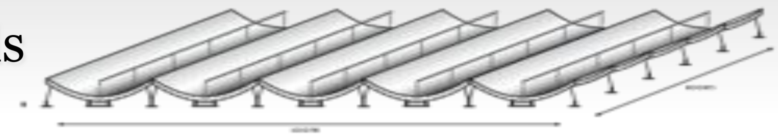
CHIME will:
- survey BAO
- measure the growth of space
- from 0.8<z<2.5
- over a volume of ~400 co-moving Gpc³

Slide from K. Vanderlinde

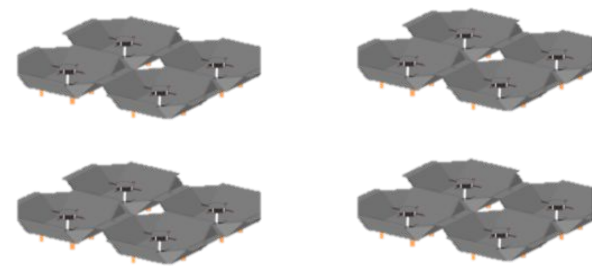
BAO Intensity Mapping

Future Experimenatal Strategies

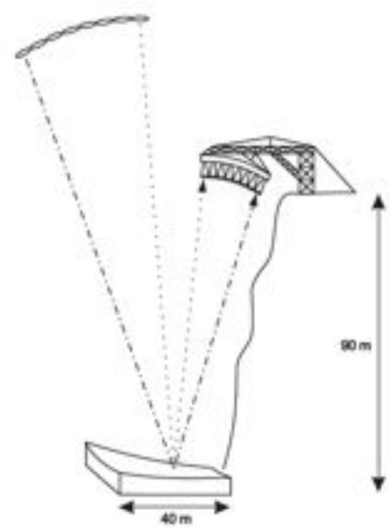
- (Existing – *i.e. GBT, GMRT)*
- CHIME – *drift scan cylinders*
  - Five 100 x 20m cylinders, 2560 channels
  - 400-800 MHz (z=0.8-2.5)
  - m-mode analysis, rigidization



- BAOBAB(*) – *redundant interferometer*
  - 32-128 tiles (2.6m²) of 4 PAPER-like antennas
  - 600-900 MHz (z=0.6-1.4)
  - Delay spectrum analysis

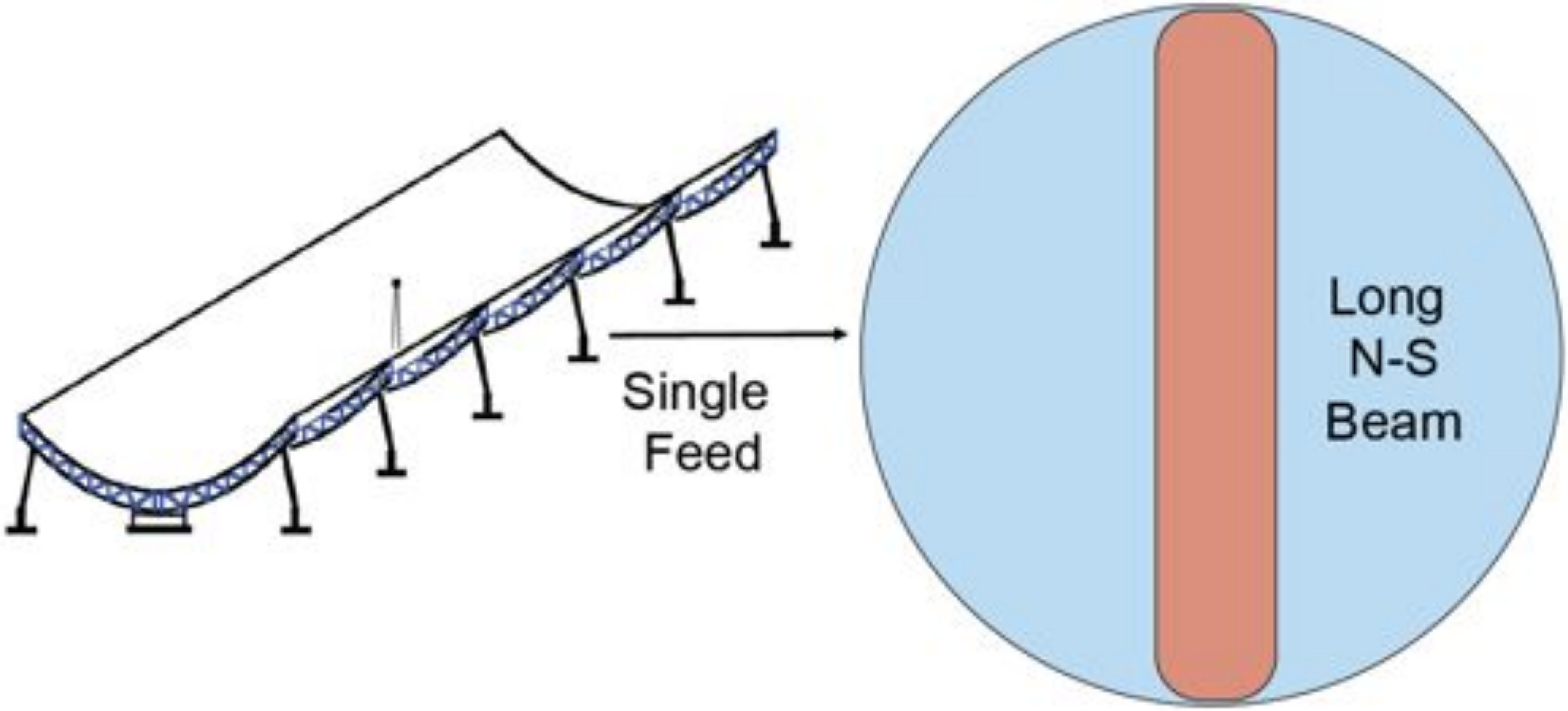


- Bingo(*) – *multi-beam, single dish*
  - 40m dish, 60 feeds
  - Low, clean sidelobes, ncp switching



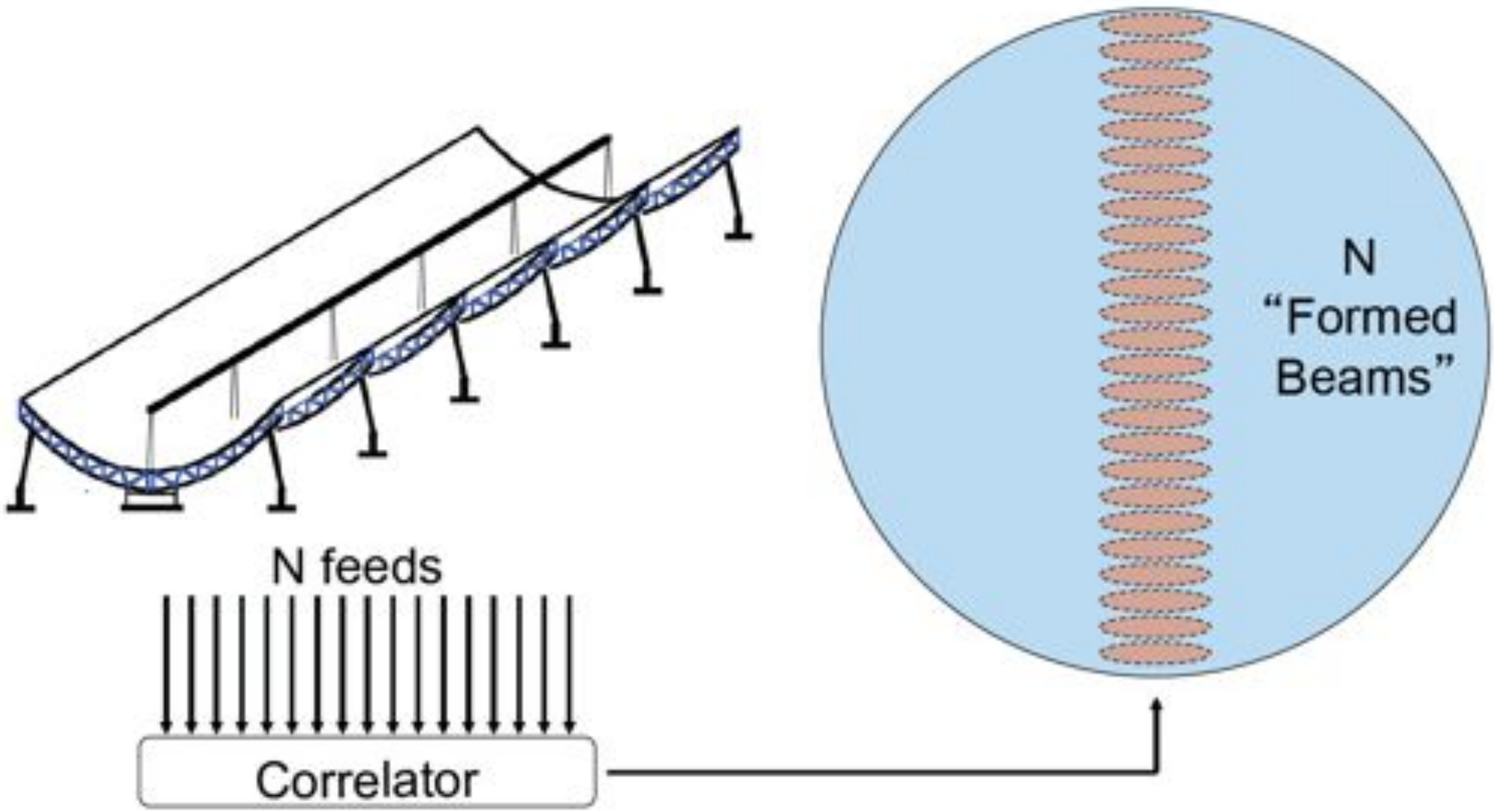
(*) proposed but not yet funded

Cylinder Antenna



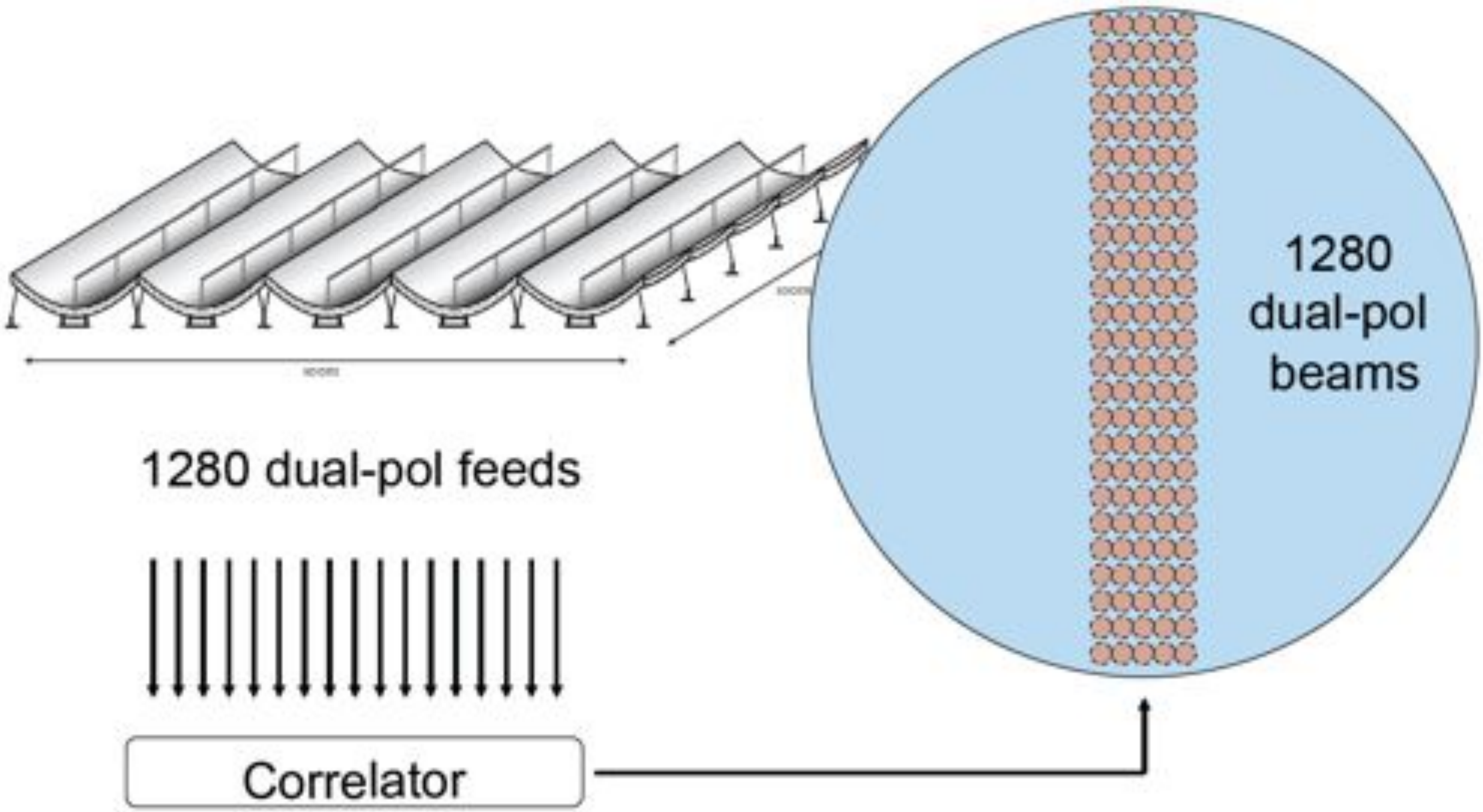
Cylinder Telescope

Hybrid: 1D Dish + 1D Interferometry

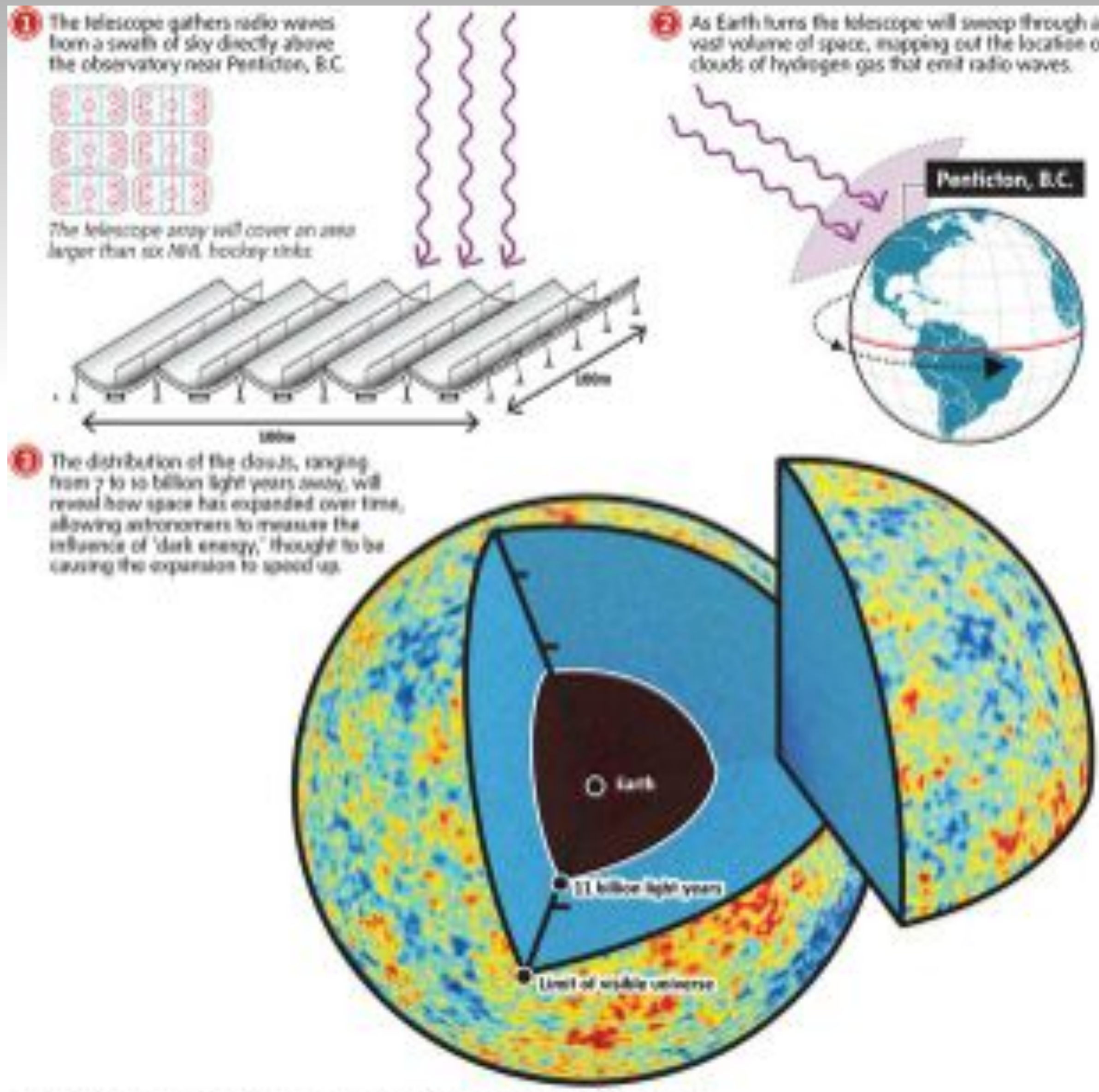


CHIME

1D Dishes + 2D Interferometry



3-D Intensity Mapping



THE GLOBE AND MAIL ■ SOURCE: UNIVERSITY OF BRITISH COLUMBIA; CHIME; DEUS CONSORTIUM

Cylindrical Telescopes

Illinois 400' (120x180m) 1959

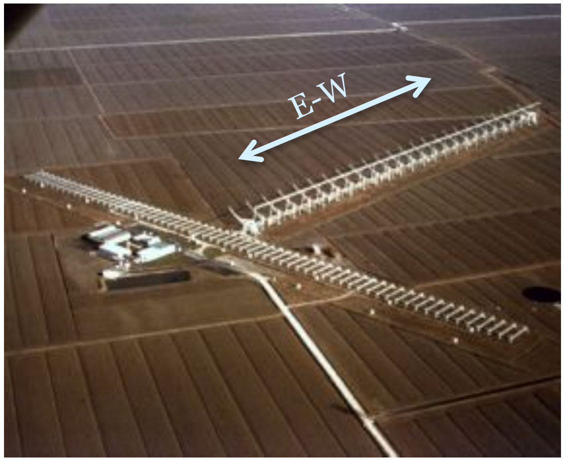
- 610 MHz
- BW ~ 5 MHz

MOlonglo Synthesis Telescope (Australia 1960)

- Steerable 778 x 12m
- SKA Molonglo Prototype
  - 30 MHz BW near 840 MHz
  - 96 input FPGA correlator

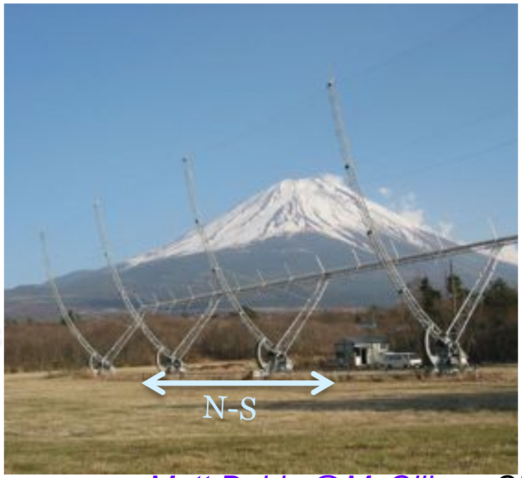
Ooty (India 1970)

- Steerable 530 x 30m N-S
- 326 MHz, 15 MHz BW
  - Inclined at 11 degree = latitude
  - 1056 half dipoles (1 pol)
  - 12 analog-formed beams



Northern Cross (Italy 1980s)

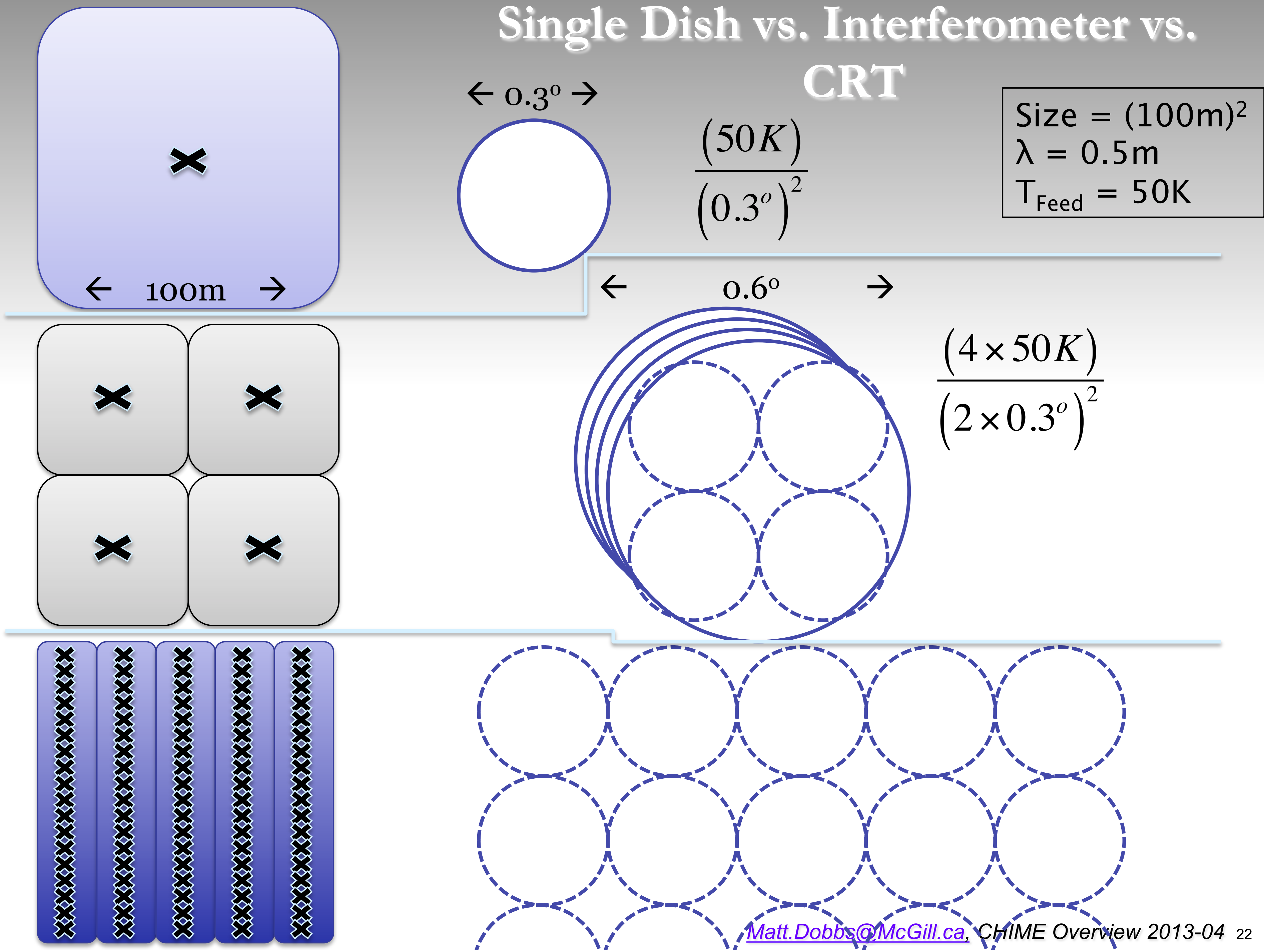
- Steerable 564 x 35m E-W, w/ 1536 dipoles
- Sixty-four 24 x 7.5m, w/ 64 dipoles
- 400-416 MHz, T_{sys}=120K
- BEST (SKA Path)



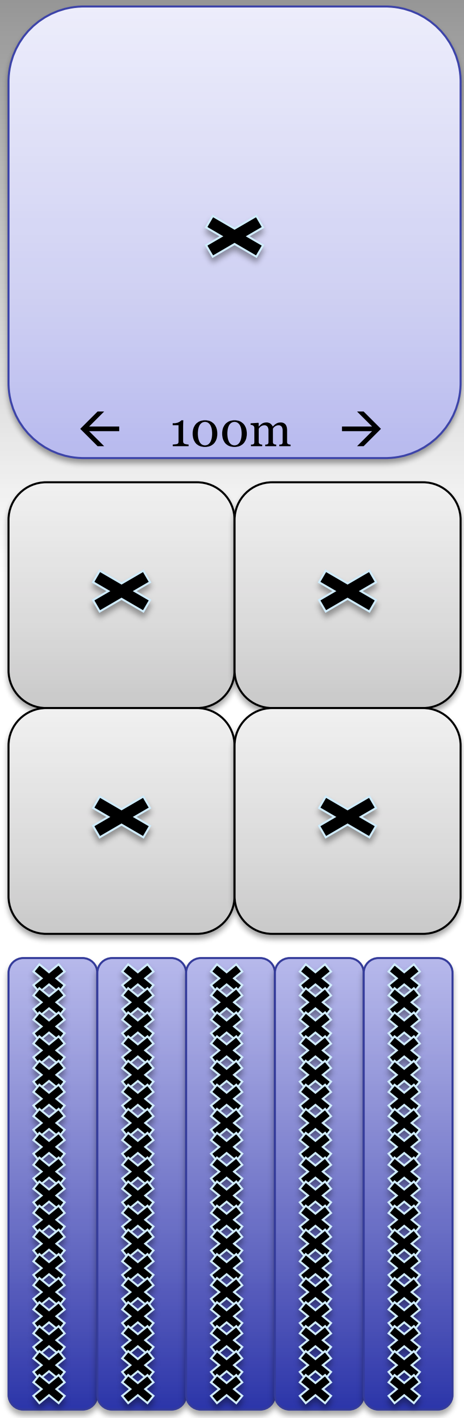
STE Lab (Japan 1980s)

- Study Solar wind
- 4 steerable cylinders, up to 100m x 20m
- ~ 320-330 MHz
- T_{sys}= 150 K, 1 pol

Single Dish vs. Interferometer vs. CRT



Single Dish vs. Interferometer vs. CRT



	Single Dish	Four-Dishes	Five Cylinders
Total Number Feeds	1	4	1280
Feed Noise Equivalent Temperature	50 K	50 K	50 K
Dish Size	one 100m ×100m	four 50m ×50m	five 100m ×20m
Field of View $\approx \frac{\lambda}{D}$	$(0.29°)^2$	$(0.57°)^2$	74°×1.4°
Collecting Area	100m×100m	100m×100m	100m×100m
Angular Resolution	0.57°	0.57°	0.57°
NET per square degree [K/degree^2]	594	154	0.48
Time to Integrate Pointed Unresolved Source [Collecting Area/T_{sys}]	$(100m)^2$/50 K	$(100m)^2$/50 K	$(100m)^2$/50 K

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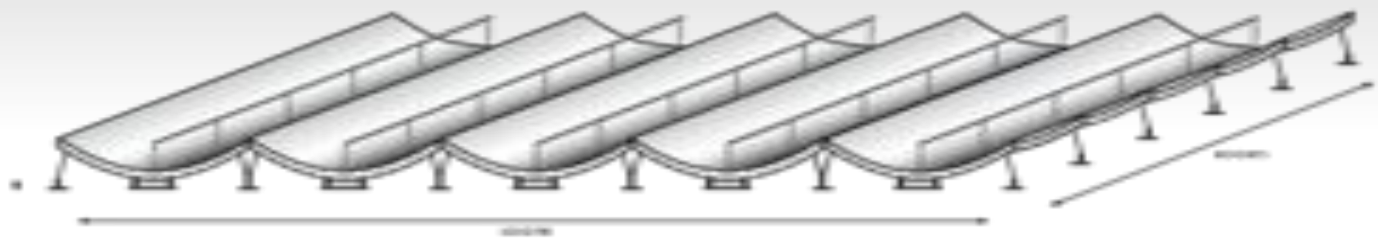


<u>UBC</u>

- *Mandana Amiri*
- *Greg Davis*
- *Meiling Deng*
- Mark Halpern
- Gary Hinshaw
- Kris Sigurdson
- *Mike Sitwell*

<u>McGill U</u>

- *Kevin Bandura*
- *Jean-Francois Cliche*
- Matt Dobbs
- *Adam Gilbert*
- David Hanna
- *Juan Mena Parra*

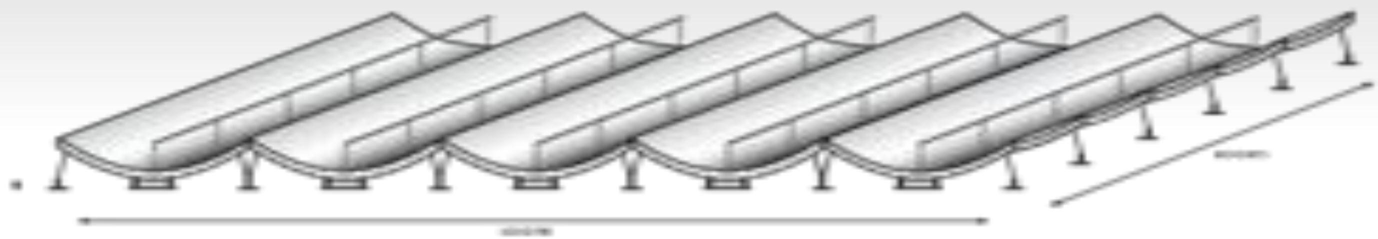
<u>U Toronto / CITA</u>

- Dick Bond
- Ue-li Pen
- *Richard Shaw*
- Keith Vanderlinde
- *Ivan Padilla*

<u>HIA, DRAO</u>

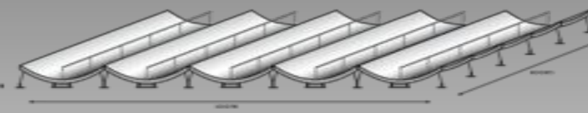
- Tom Landecker

The Canadian Hydrogen Intensity Mapping Experiment



- a transit telescope
- no moving parts
- one scan strategy
- 24/7 observations
- no TAC

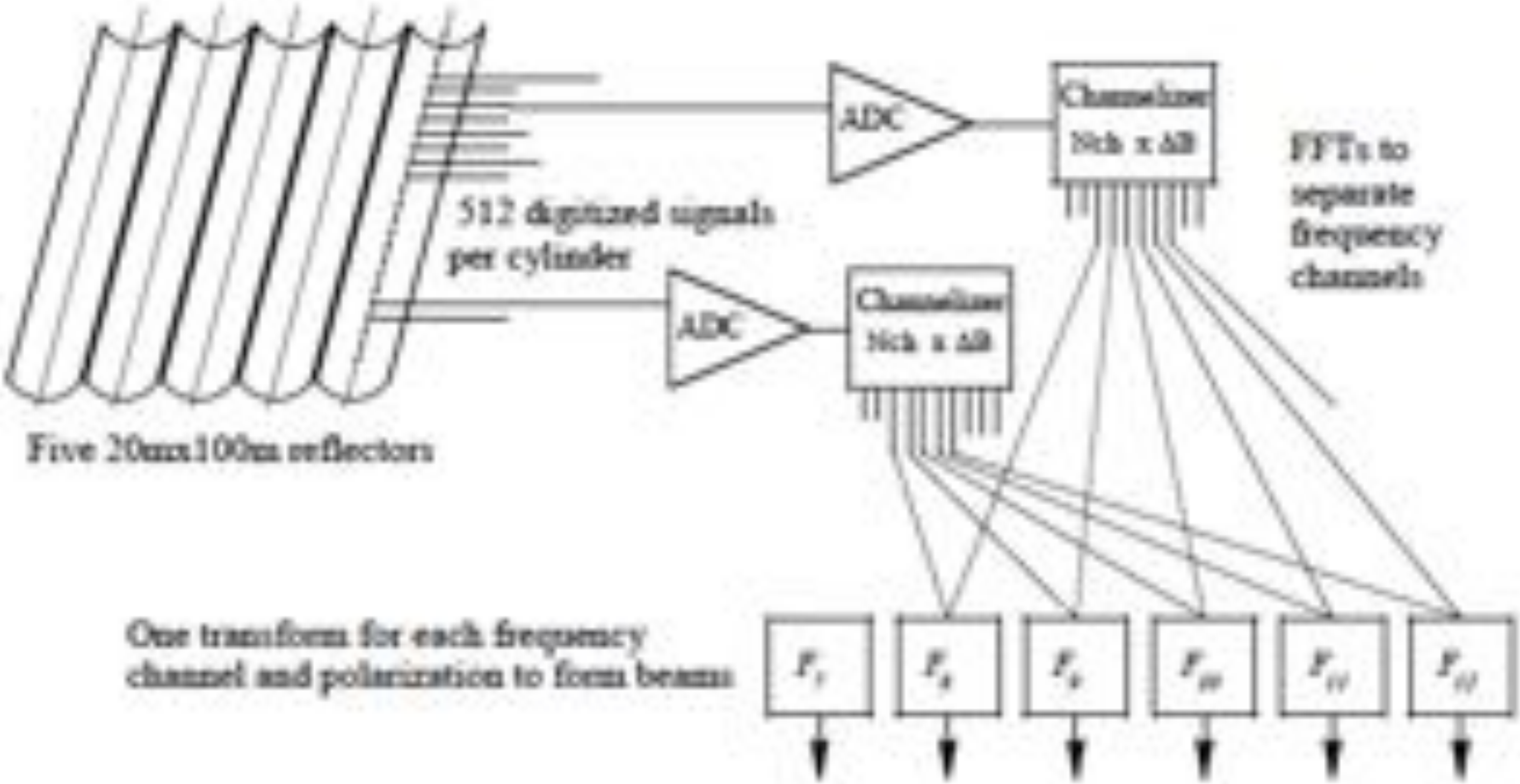
Full CHIME Specs



Full CHIME Layout		
Structure	5 cylinders, 100m x 20m each	
Bandwidth	400-800 MHz	*Digitize 8bits at 800 MSPS*
Number Feeds/cylinder	256 dual pol feeds per cylinder (2560 digitizers total)	~31cm spacing
Frequency Channels	512 frequency channels, 781 kHz wide (1.28 µs)	(for cosmology, you can channelize further!)
Data Rate	$2N_{FEEDS}$ x 3.2 Gbit/s = 8 TeraBit/s	(assumes 4bit truncation)

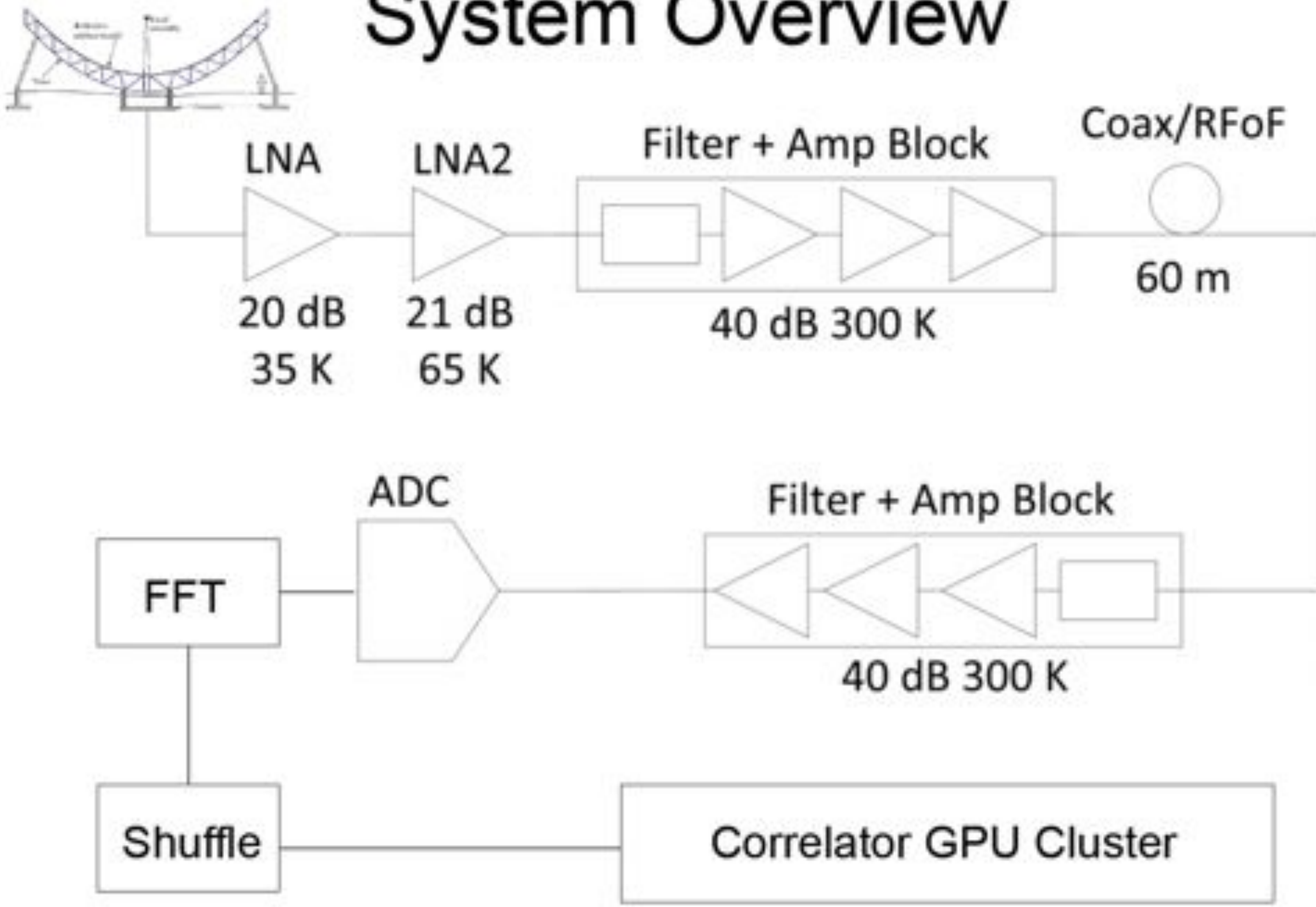
Observing Frequency	**400 MHz** to	**800 MHz**
Wavelength	75 cm	37 cm
21cm Redshift	z=2.5 *(11 Gyr ago)*	z=0.8 *(7 Gyr ago)*
Beam Size	0.52^{o}	0.26^{o}
E-W FoV	2.5^{o}	1.3^{o}
N-S FoV	-45^{o} to $+135^{o}$ (max possible) 0^{o} to $+90^{o}$ (more likely)	
Time/pixel/day	10min, 14min, 24hrs equator, 45deg, ncp	5min, 7min, 24hrs equator, 45deg, ncp
Receiver Noise Temperature Flux Conversion Daily Sensitivity Final Survey	50k ~2K / Jy ~50 µJy / pixel ~1.5 µJy/pixel *(Approximate – for planning purposes only)*	

CHIME



512 digitized signals
per cylinder
ADC
Channelizer
Nch x Δf
ADC
Channelizer
Nch x Δf
FFTs to
separate
frequency
channels
Five 20mx100m reflectors
One transform for each frequency
channel and polarization to form beams

System Overview



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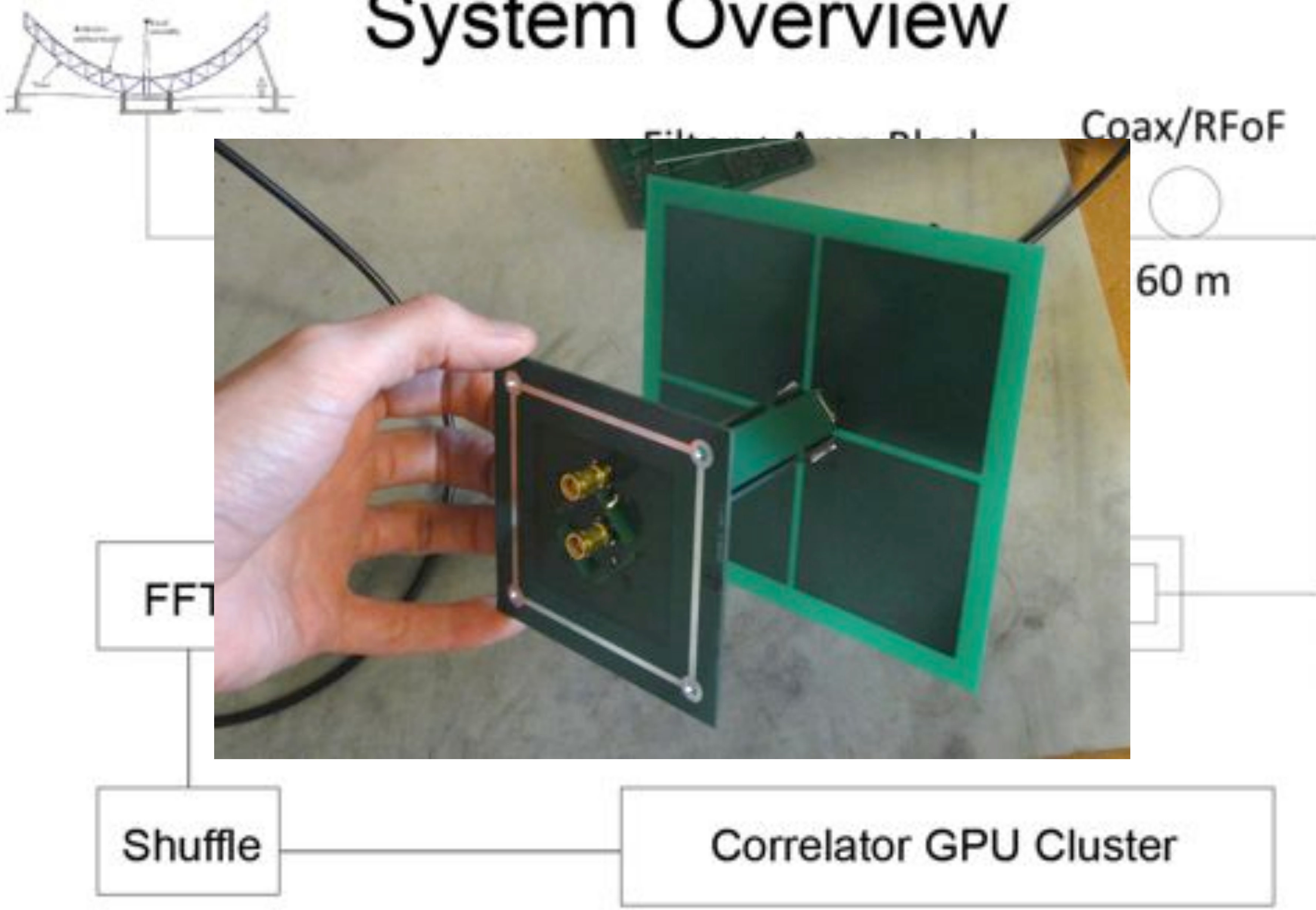

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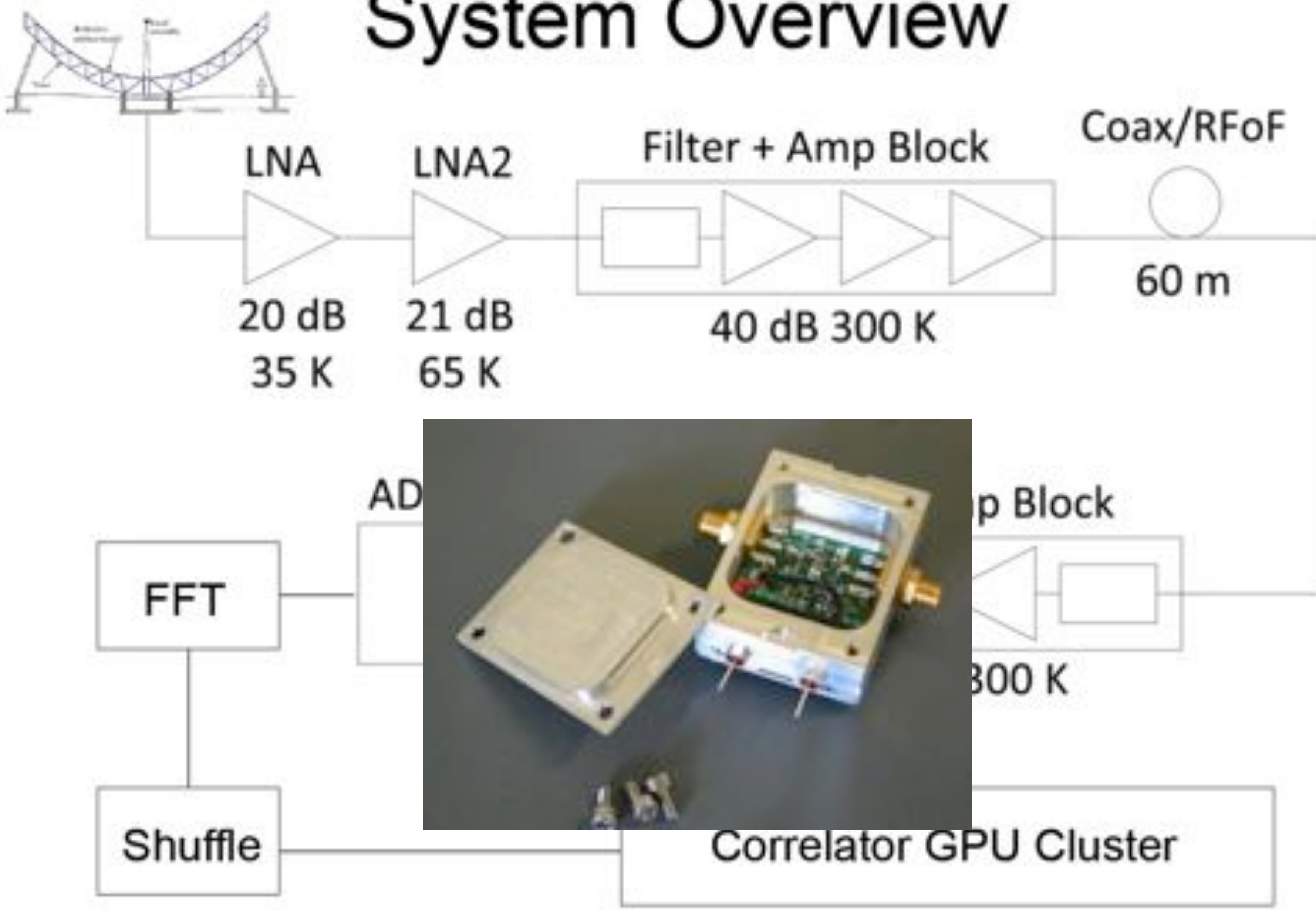

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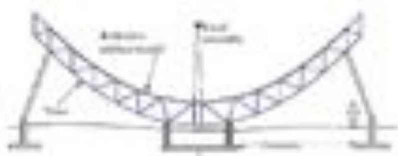

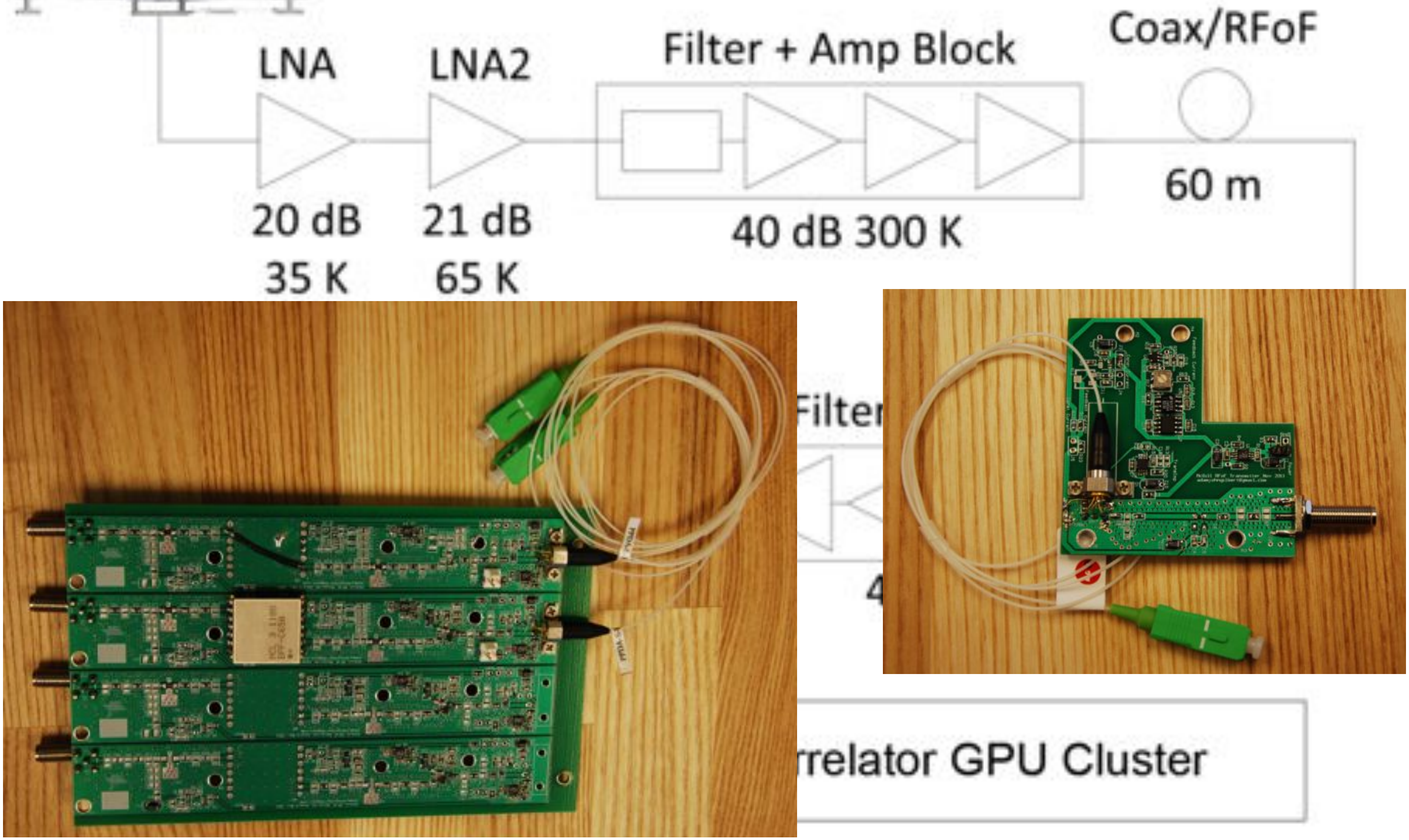

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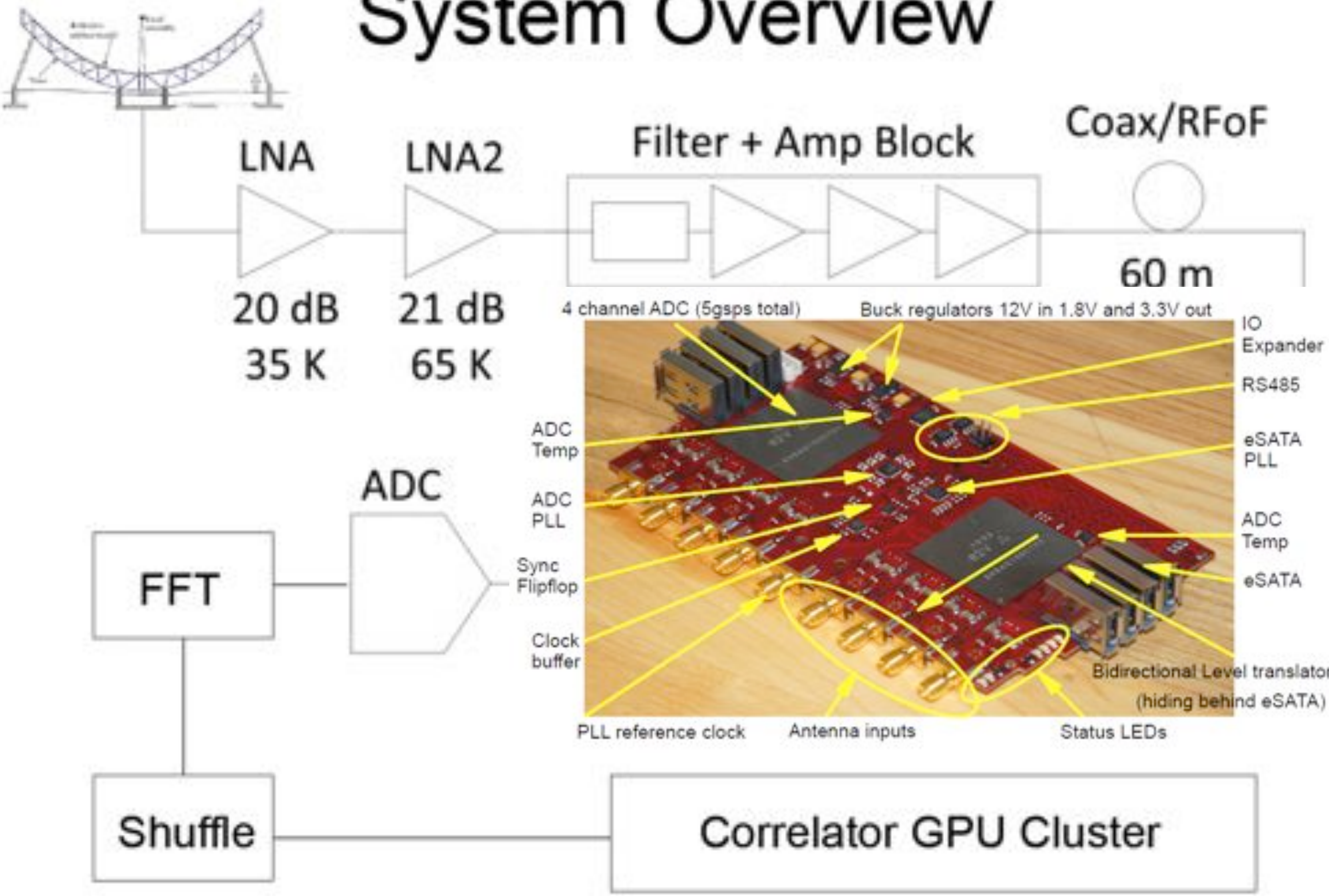
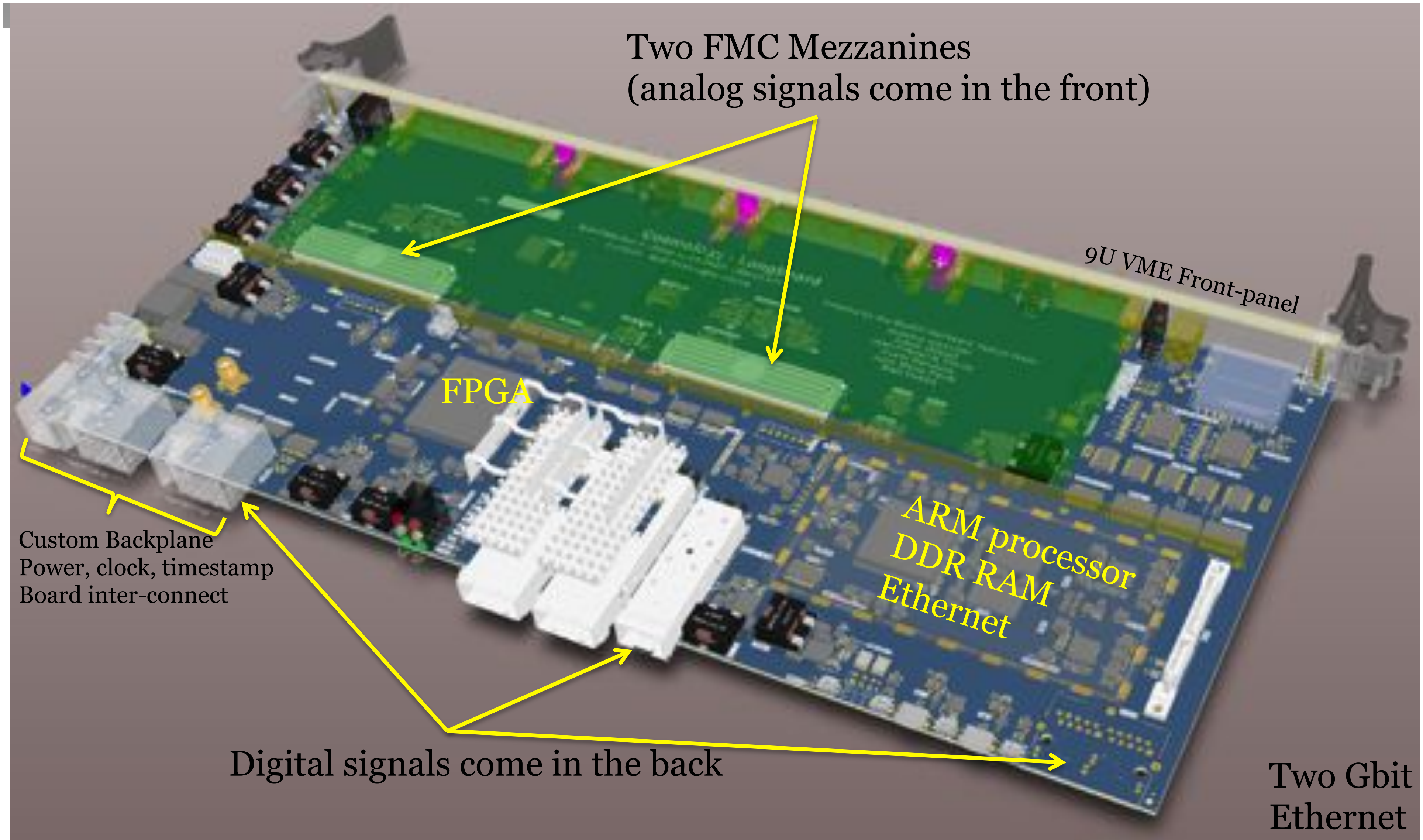
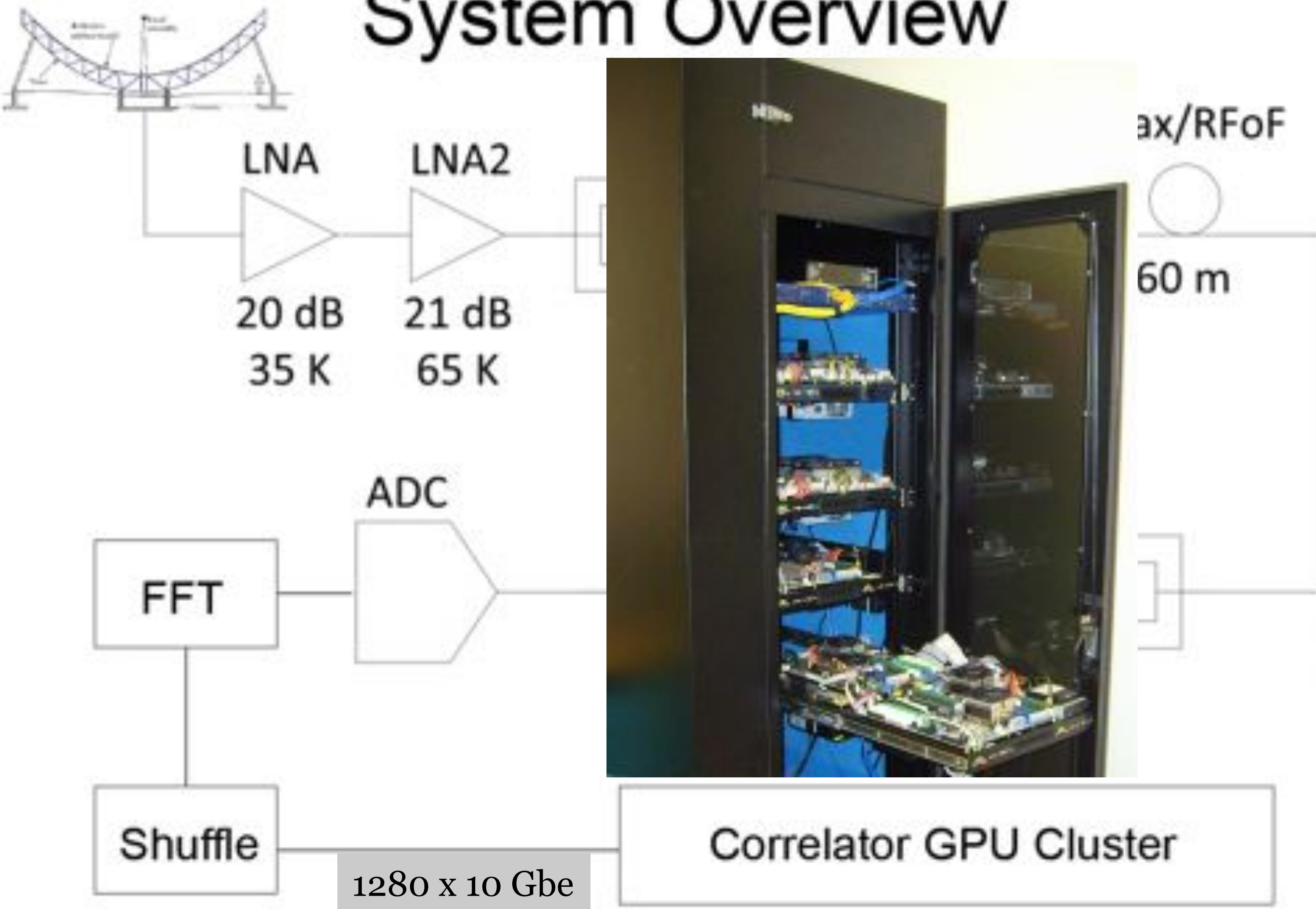




Shuffle

Correlator GPU Cluster

System Overview



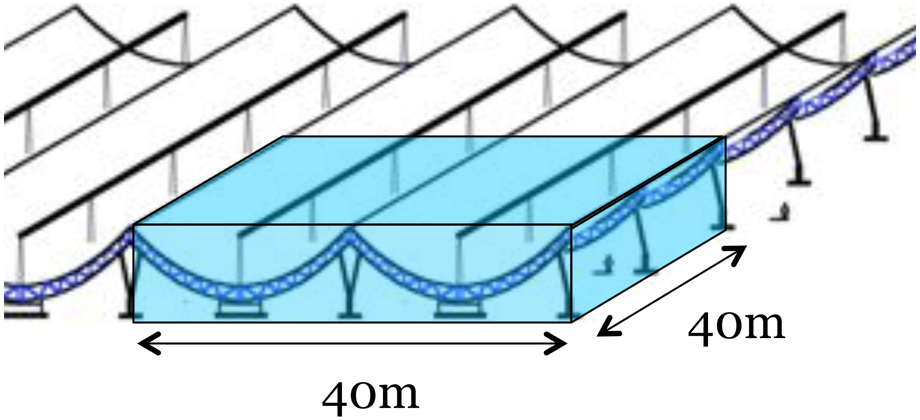
CHIME Development

Prototype, two 8m Dishes

- 4 channels
- running since March 2011

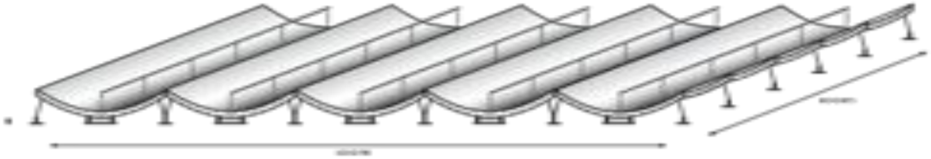
Pathfinder, two 20m x 40m Cylinders

- 256 channels
- under construction



Full CHIME, five 20m x 100m Cylinders

- 2560 channels
- FUNDED by CFI. Operating in 2016.



DRAO – CHIME Site

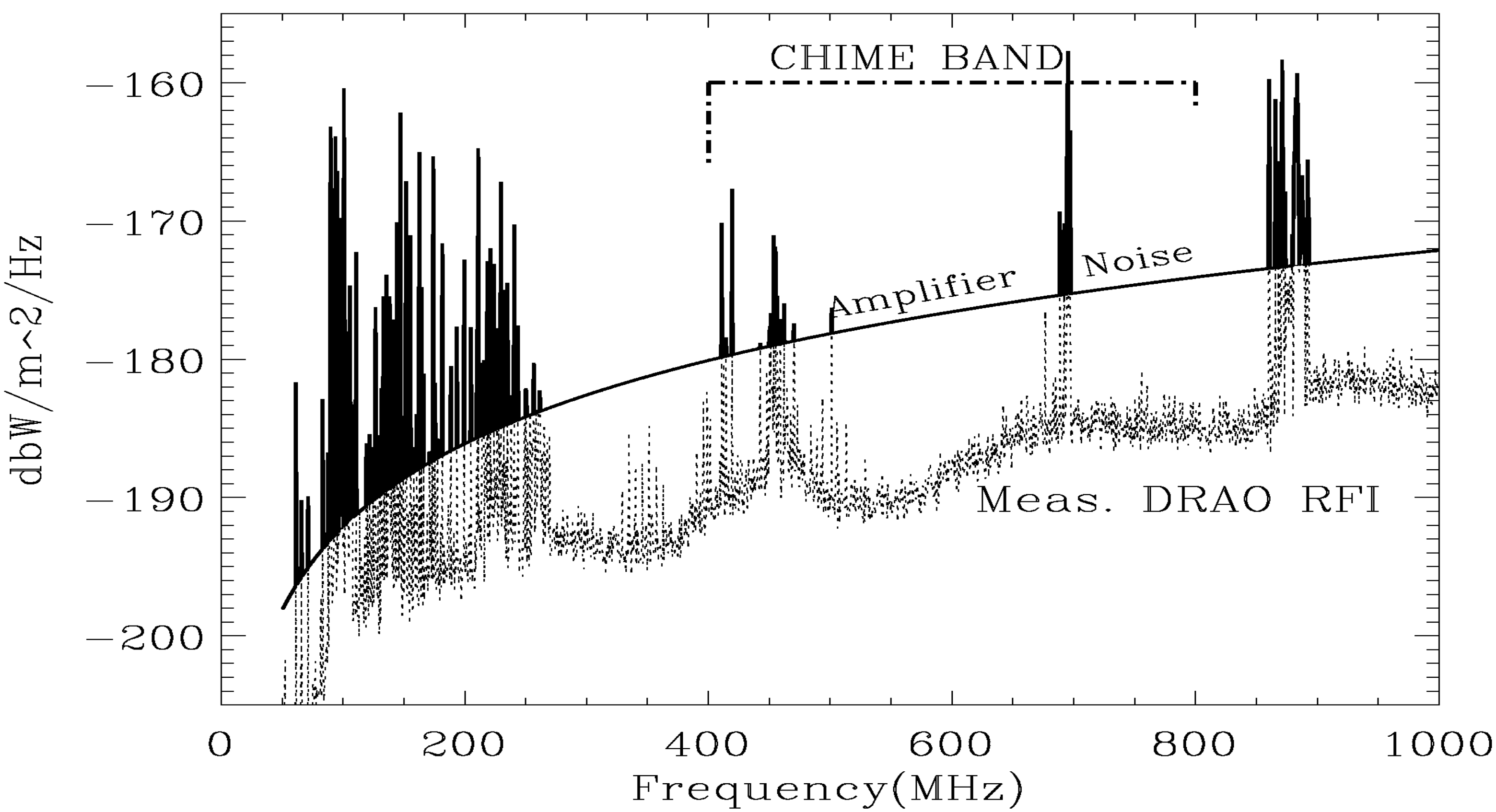
Jan 2013: Construction of CHIME Pathfinder

DRAO – CHIME Site

Pathfinder construction, April 14, 2013

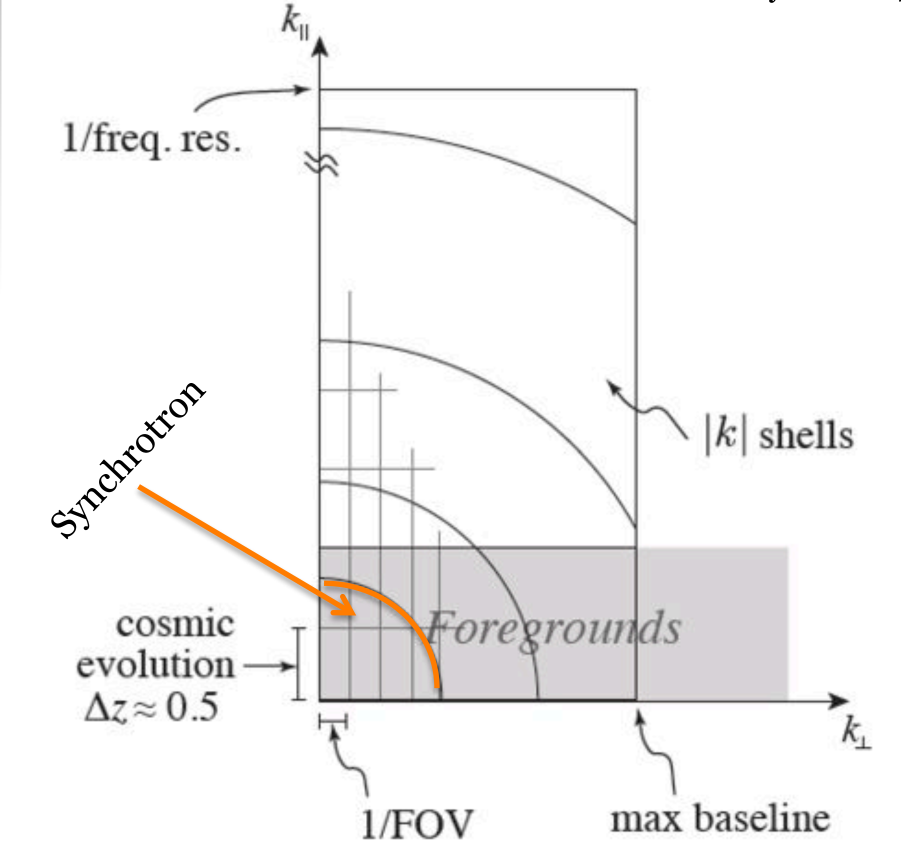
DRAO RF Environment

Measured RF Interference at the proposed CHIME site at the DRAO in Penticton. Measurement resolution is 10 kHz.The cell phone band at 850 GHz defines CHIME's top frequency. Test noise floor is 400K.

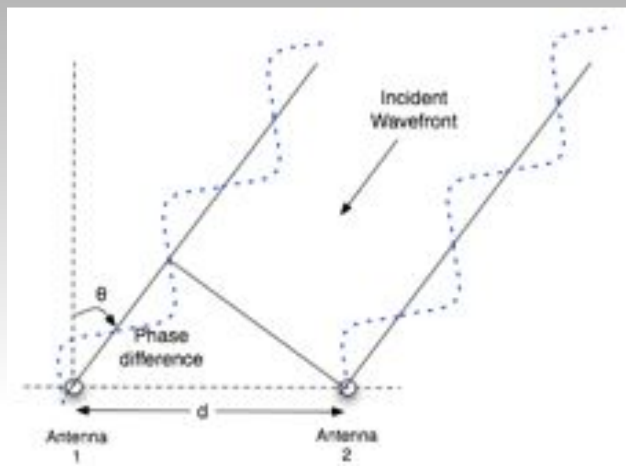


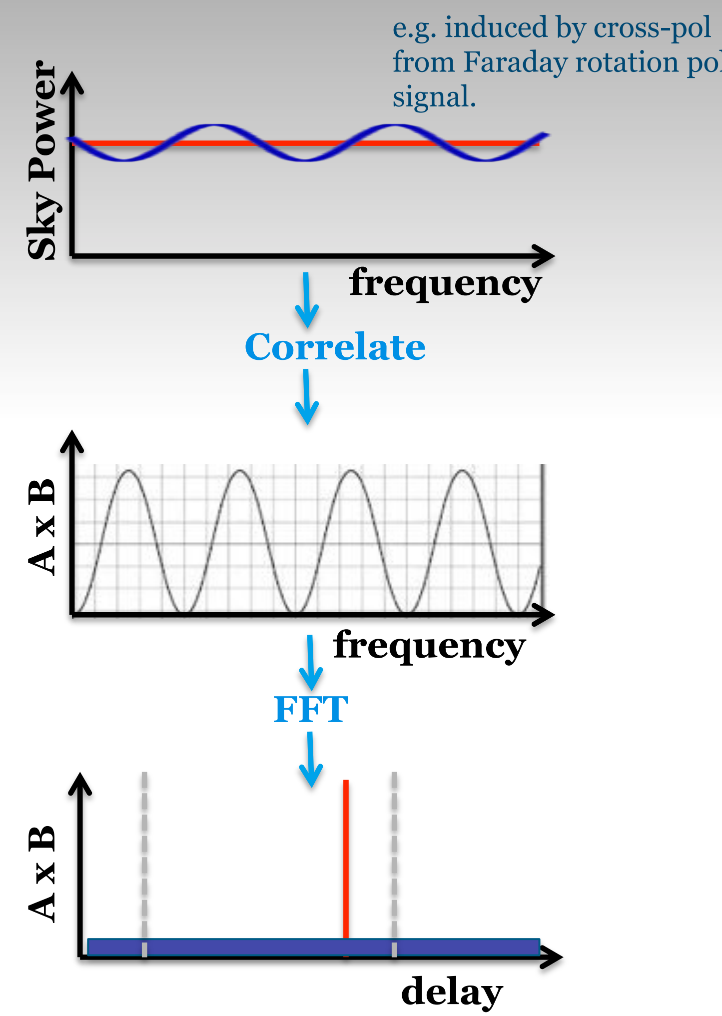
Foreground Separation

- Traditional wisdom:
  - Synchrotron foregrounds are smooth → throw away long kpar-modes
  - Point source foregrounds contaminate k_{perp} only → throw away
- Frequency dependence of the instrument response complicates this.



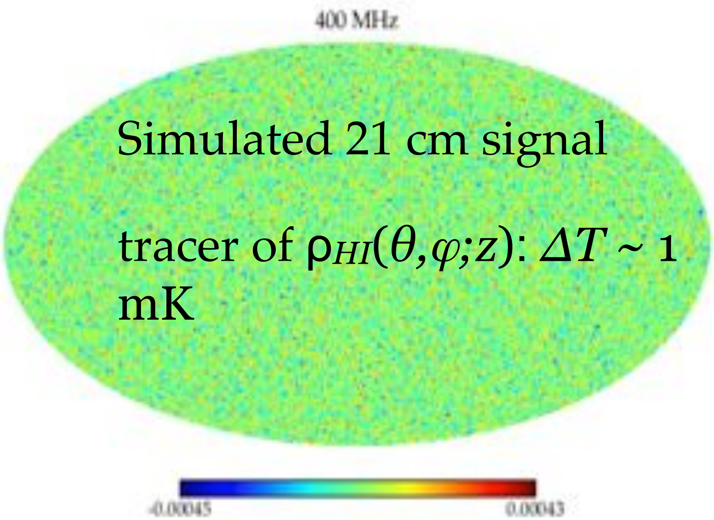
Delay Spectrum Foreground Technique





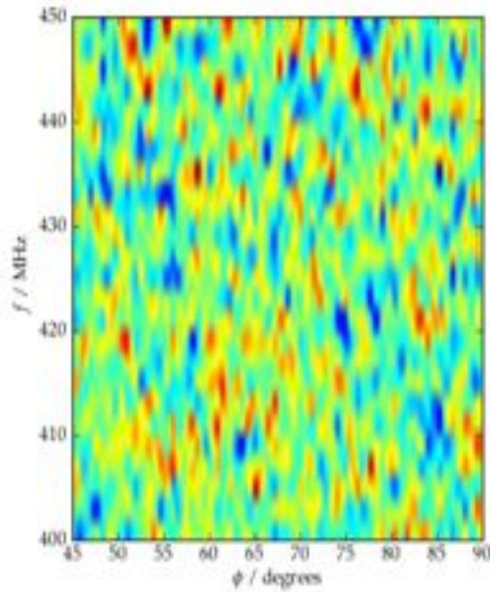
- Flat-spectrum foregrounds are confined to one location in delay space
- But need to know polarized beam vs. frequency perfectly in all directions.

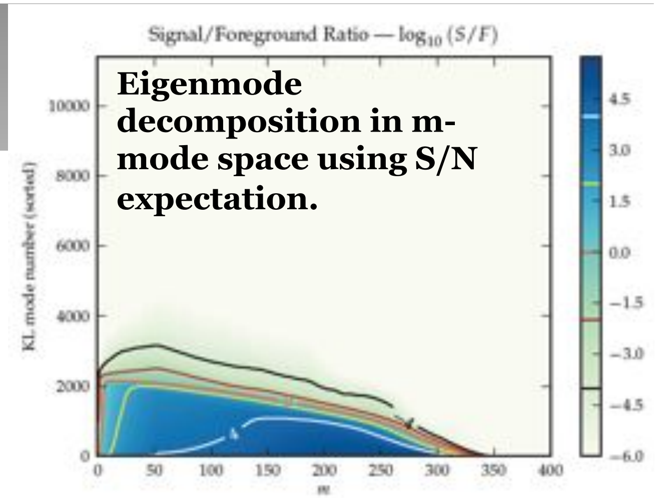
CHIME m-mode Analysis



Simulated 21 cm signal

tracer of $\rho_{HI}(\theta,\varphi;z)$: $\Delta T \sim 1$ mK

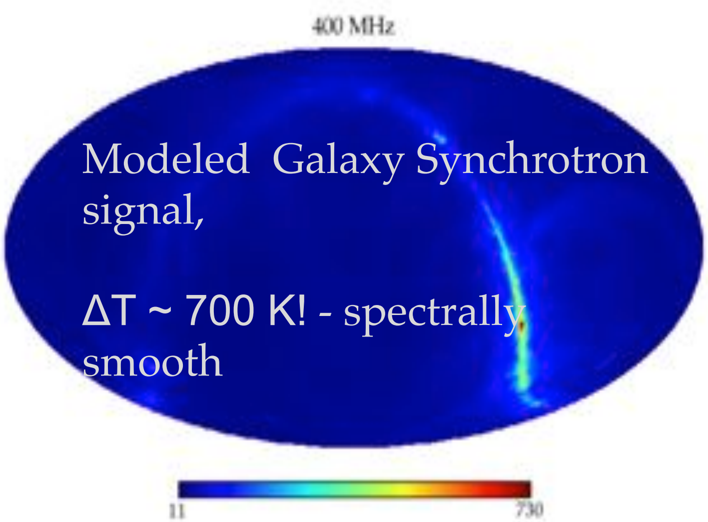




Eigenmode decomposition in m-mode space using S/N expectation.

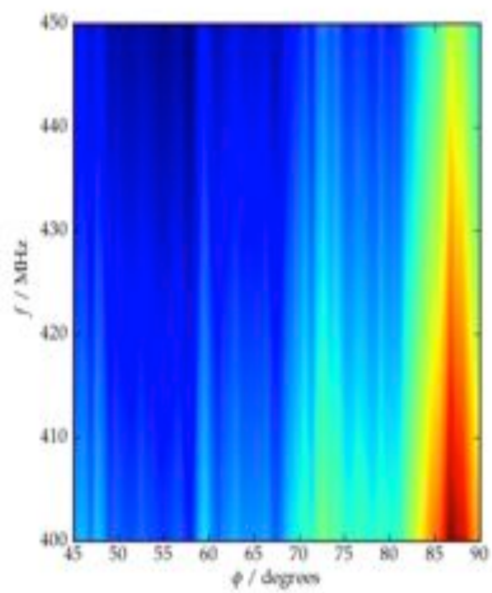
left - over full sky at 400 MHz

right - over 50 MHz at 1 declination



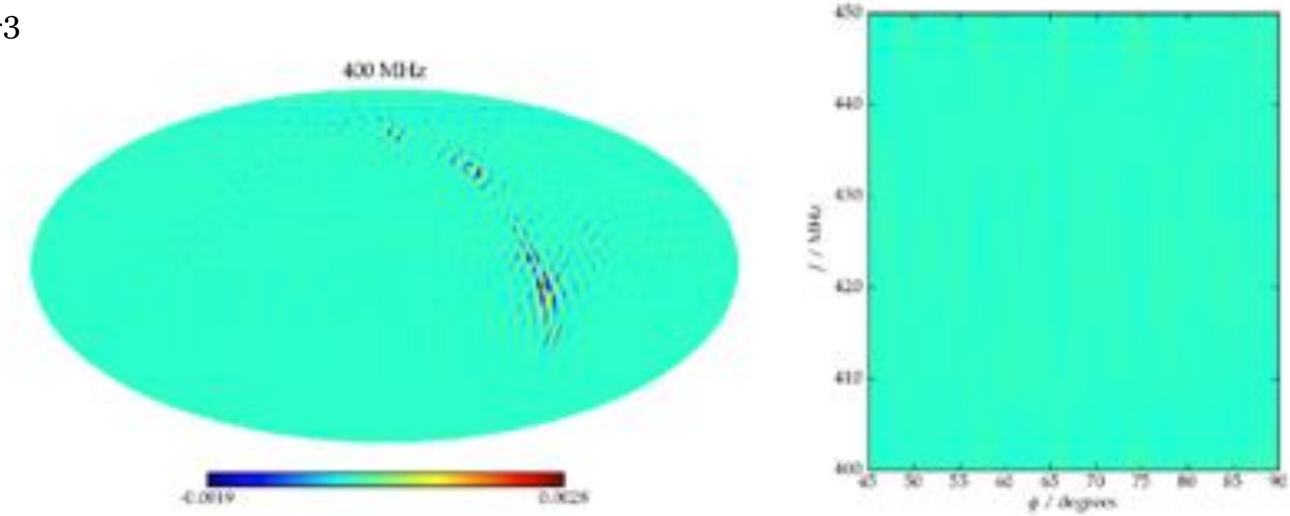
Modeled Galaxy Synchrotron signal,

ΔT ~ 700 K! - spectrally smooth

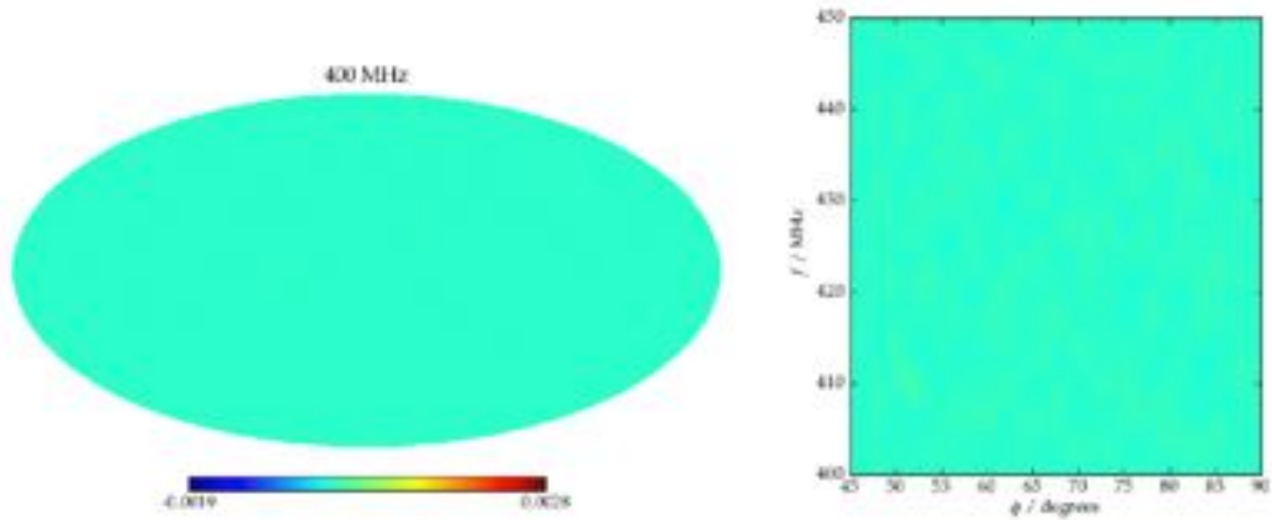


Shaw, Sigurdson, Pen, Sitwell, et al. (2013)

$S/F > 10^{-3}$

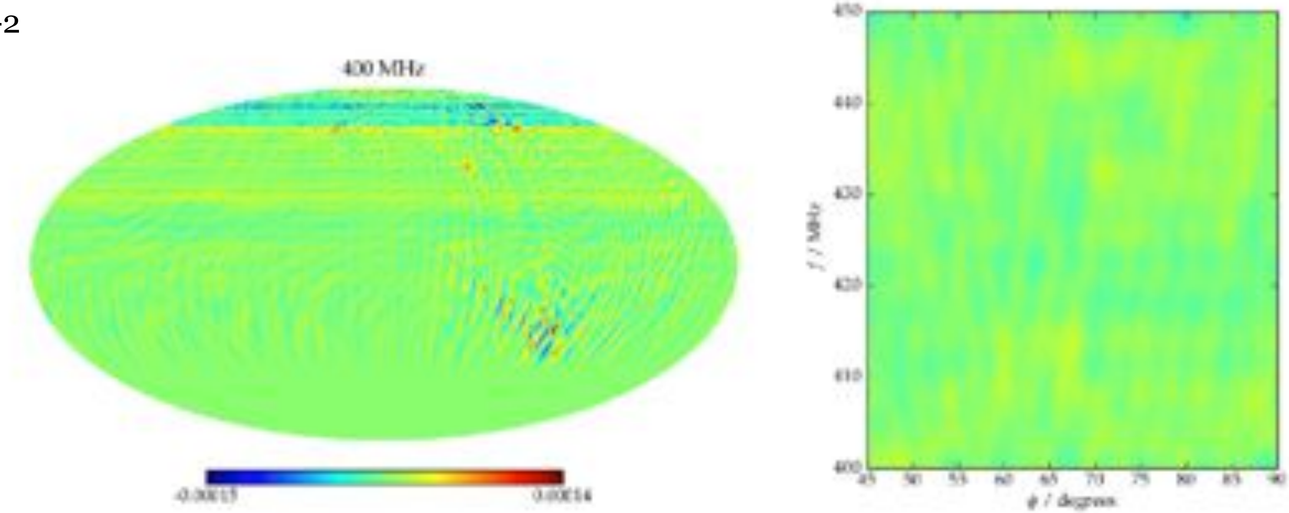


Reconstruction of galaxy signal as more S/F modes are employed.

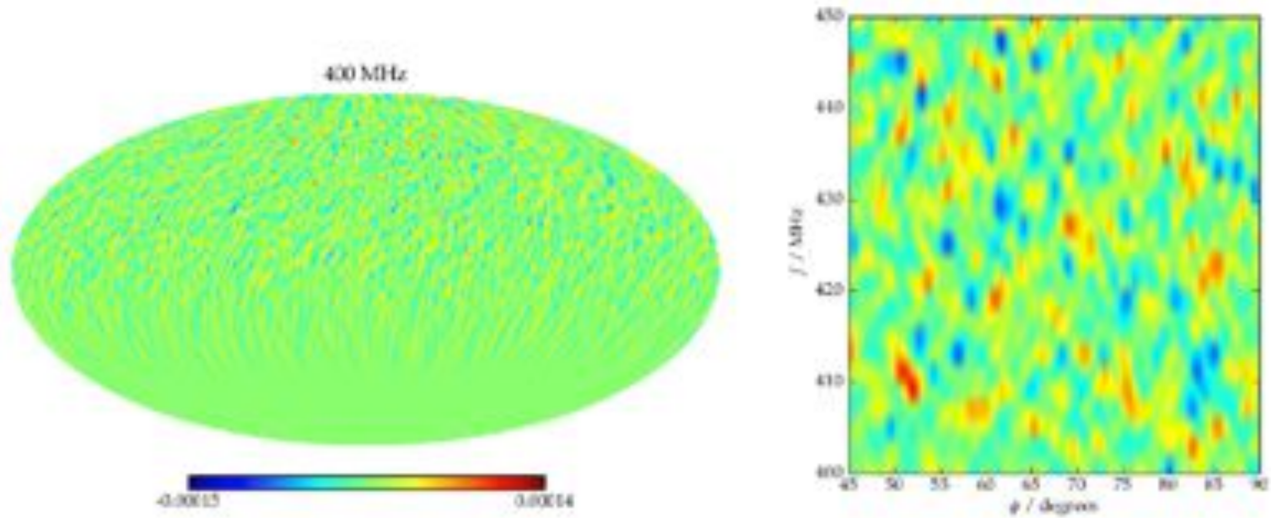


Reconstruction of HI signal as more S/F modes are employed.

$S/F > 10^{-2}$

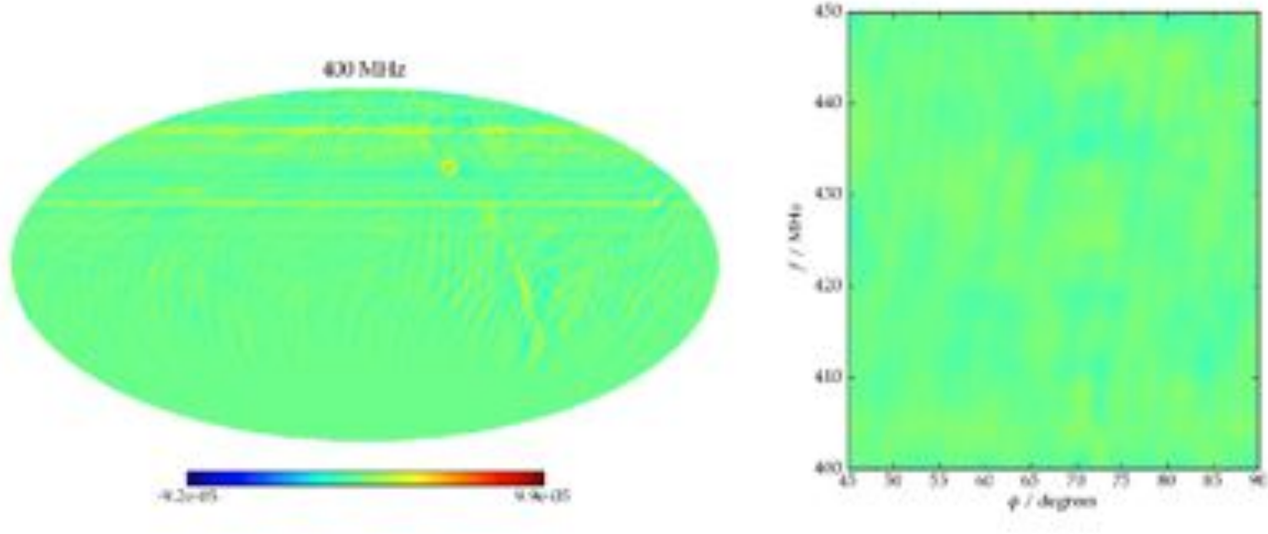


Reconstruction of galaxy signal as more S/F modes are employed.

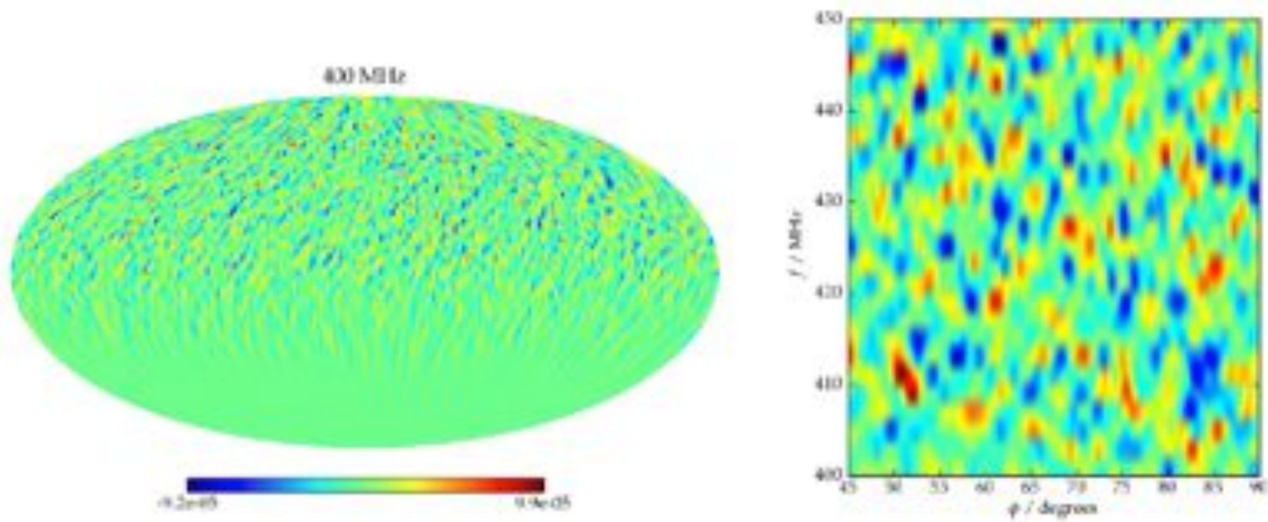


Reconstruction of HI signal as more S/F modes are employed.

$S/F > 10^{-1}$

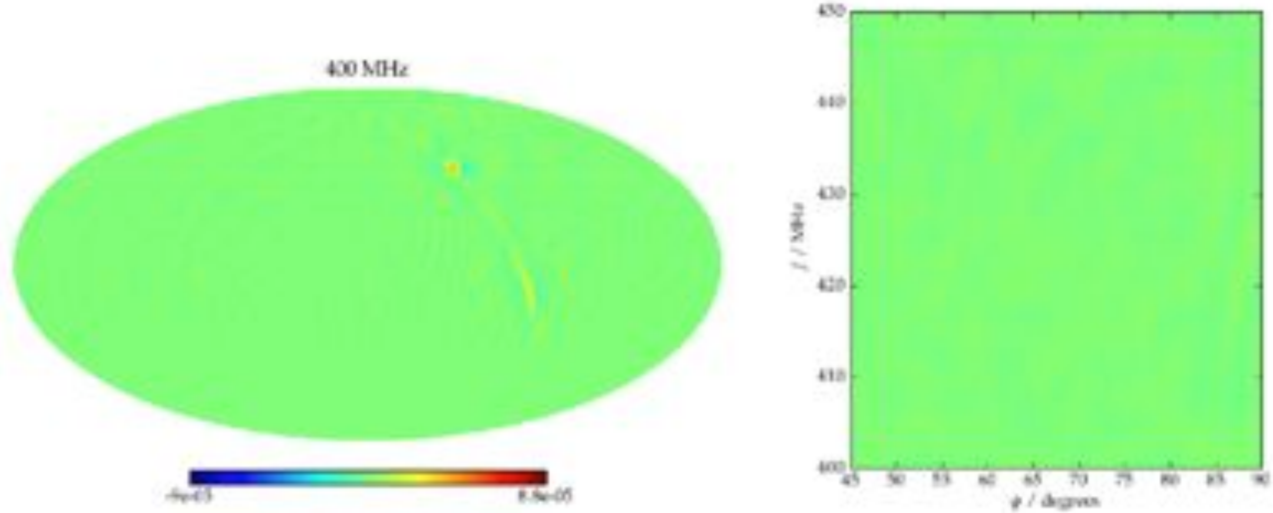


Reconstruction of galaxy signal as more S/F modes are employed.

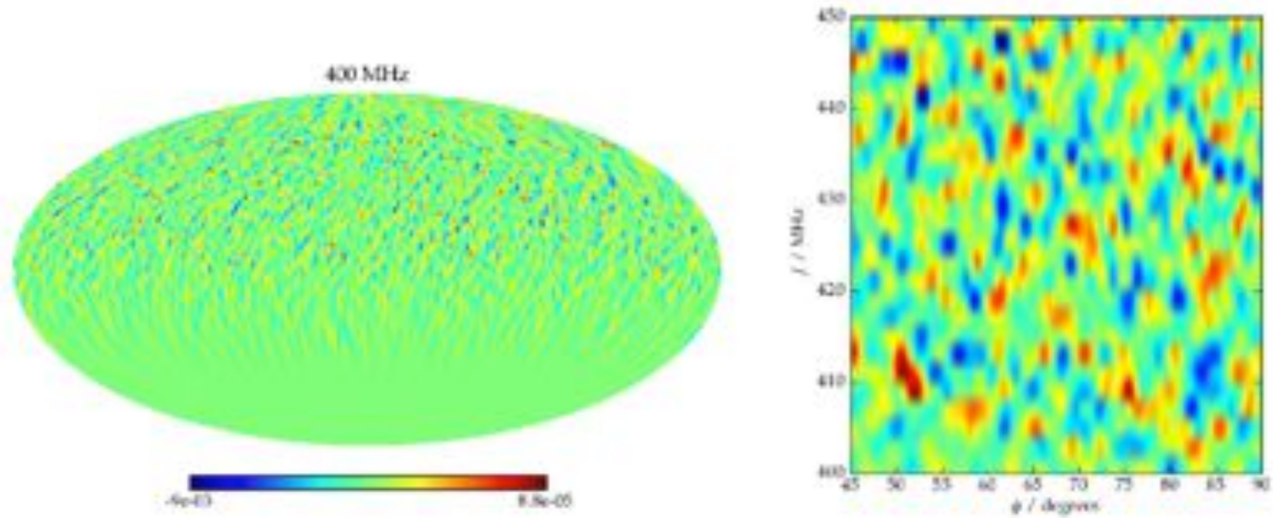


Reconstruction of HI signal as more S/F modes are employed.

$S/F > 1$

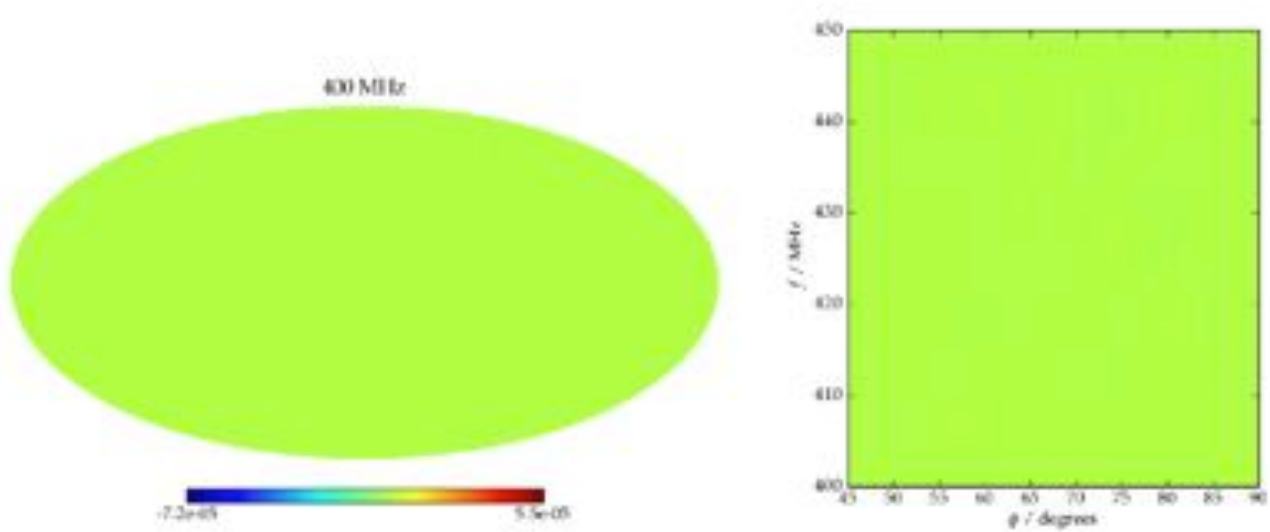


Reconstruction of galaxy signal as more S/F modes are employed.

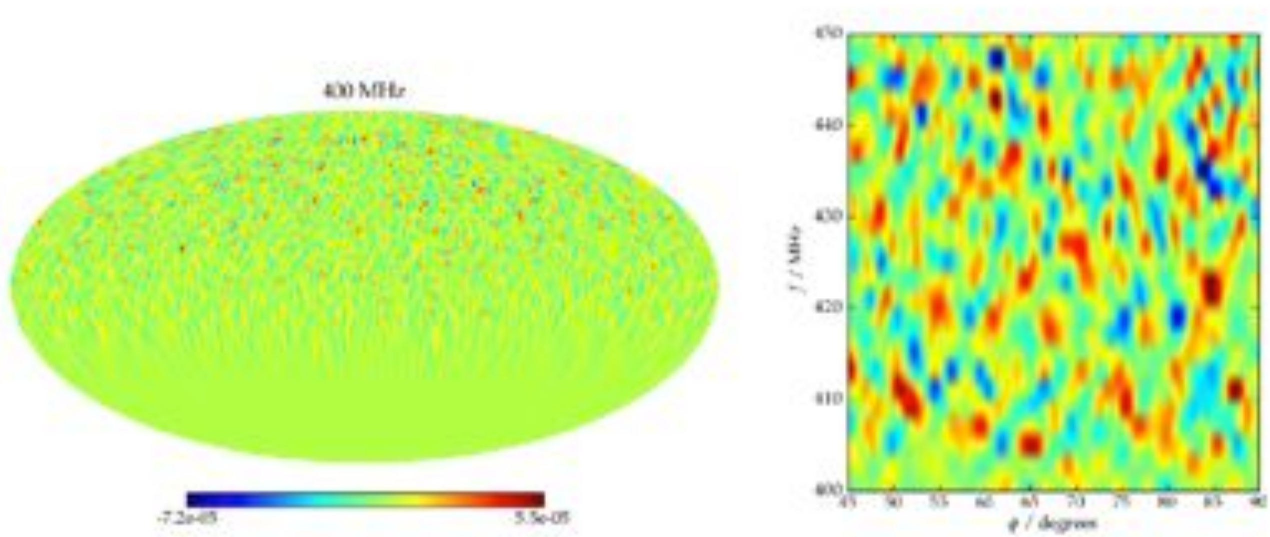


Reconstruction of HI signal as more S/F modes are employed.

$S/F > 10$



Reconstruction of galaxy signal as more S/F modes are employed.

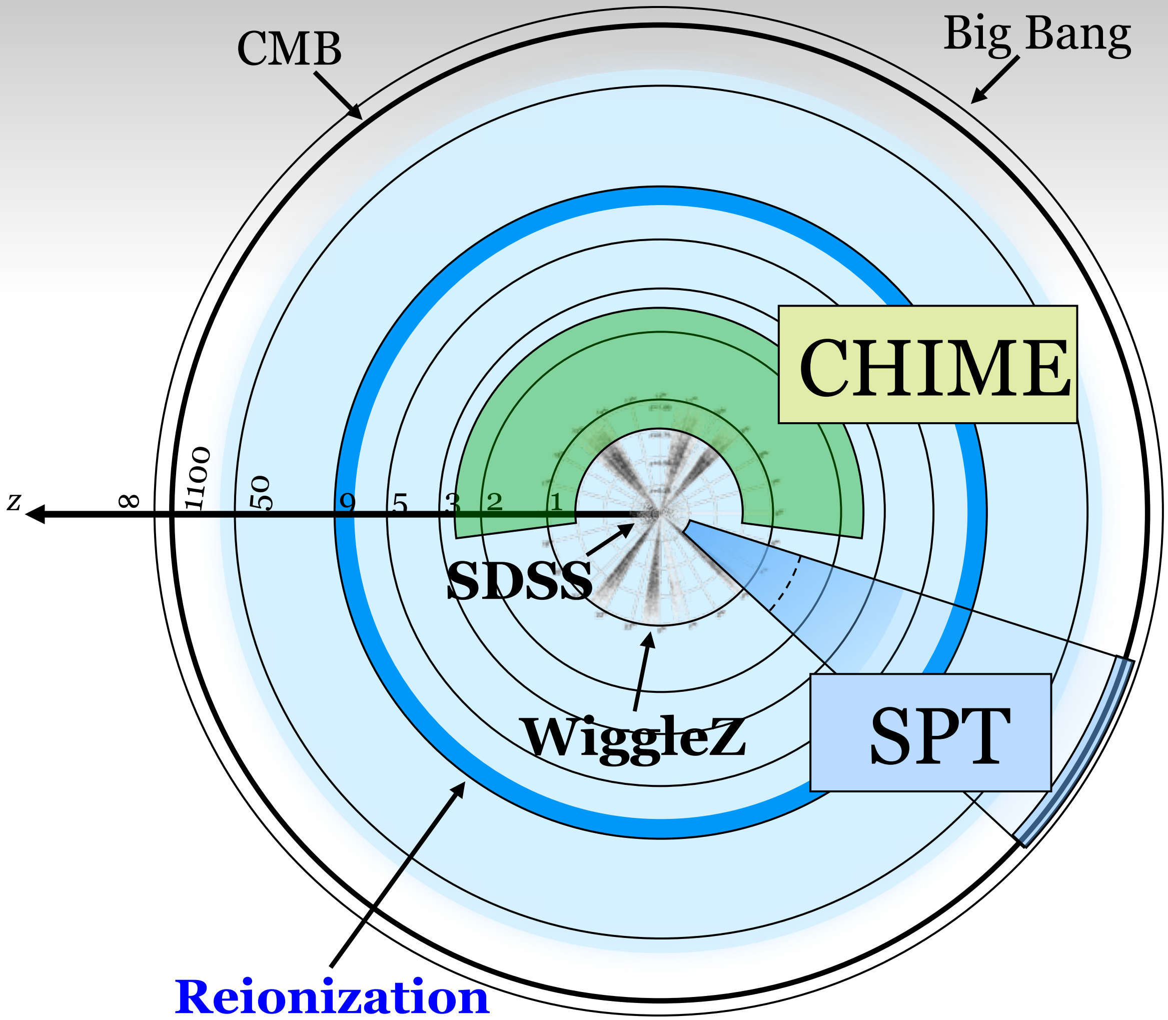


Reconstruction of HI signal as more S/F modes are employed.

Beyond Cosmology

- *Chime will map the polarization and intensity of 40% of the sky with great sensitivity in a poorly explored frequency band.*
- Pulsar monitoring
  - Nightly all-sky monitoring for Pulsar Timing Arrays
  - Monitor "space weather", to correct observations at higher frequency.
- Pulsar search
  - Detect new pulsars, then monitor them daily.
- Radio transient phenomena
  - New ground.
  - Surprisingly bright and distant radio events have been reported recently. CHIME is an ideal all-sky monitor.
- Galactic Magnetic Fields

End



CMB
Big Bang
CHIME
z
∞
1100
50
9
5
3
2
1
SDSS
WiggleZ
SPT
Reionization