Canadian Hydrogen Intensity Mapping Experiment:
21 cm Intensity Mapping for Cosmology

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Gravity: Past, Present & Future

2017 Sep 4

THE UNIVERSITY OF BRITISH COLUMBIA

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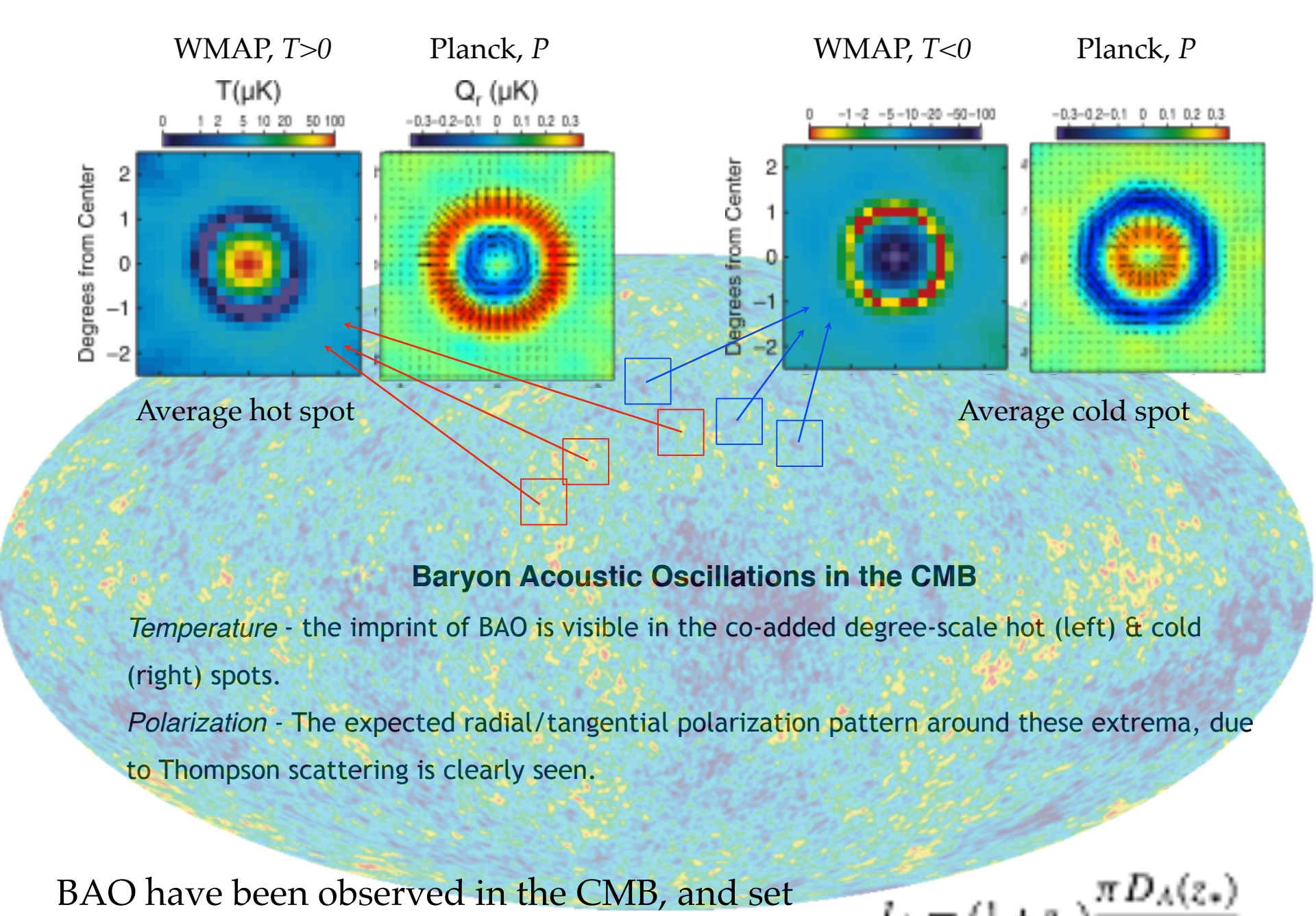
McGill



Baryon Acoustic Oscillations in the CMB

Temperature - the imprint of BAO is visible in the co-added degree-scale hot (left) & cold (right) spots.

Polarization - The expected radial/tangential polarization pattern around these extrema, due to Thompson scattering is clearly seen.

BAO have been observed in the CMB, and set the acoustic scale: $l_A = 302.35 \pm 0.65$ @ z_*=1091.

$$l_A = (1 + z_*)\frac{\pi D_A(z_*)}{r_s(z_*)},$$

Cosmological parameters

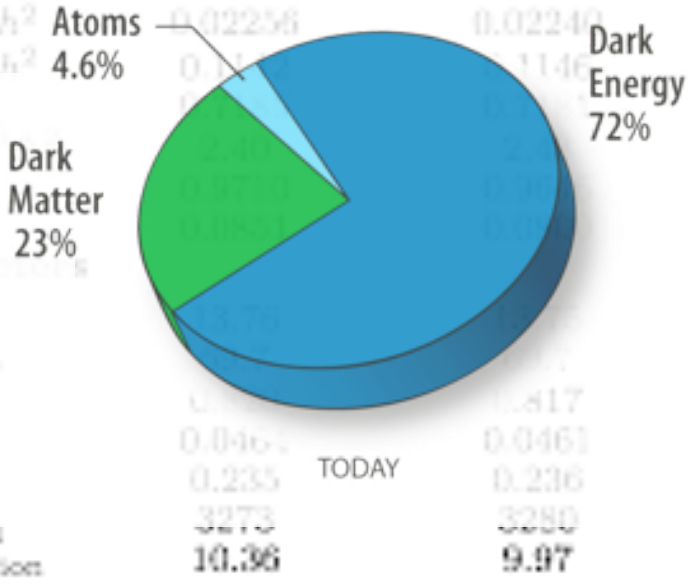
Hinshaw et al., arXiv/1212.5226

TABLE 2
MAXIMUM LIKELIHOOD ΛCDM PARAMETERS[a]

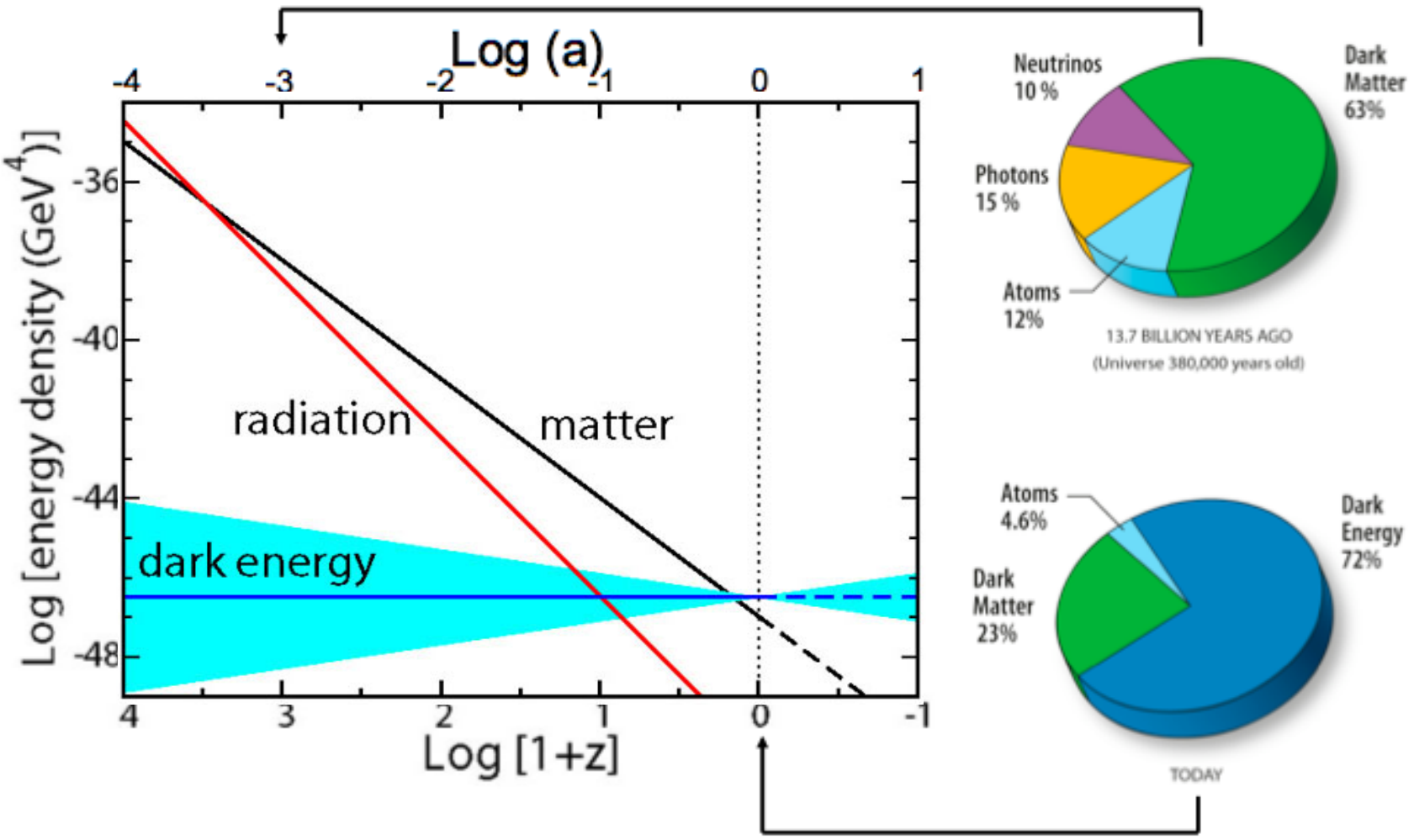
Parameter	Symbol	WMAP data	Combined data[b]
Fit ΛCDM parameters			
Physical baryon density	$\Omega_b h^2$	0.02256	0.02240
Physical cold dark matter density	$\Omega_c h^2$	0.1138	0.1146
Dark energy density ($w = -1$)	Ω_Λ	0.726	0.728
Scalar spectral index	n_s	0.9720	0.9705
Reionization optical depth	τ	0.0851	0.0813
Derived parameters			
Age of the universe (Gyr)	t_0	13.76	13.772
Hubble parameter, $H_0 = 100h$ km/s/Mpc	h	0.704	0.7081
Density fluctuations @ $8h^{-1}$ Mpc	σ_8	0.809	0.817
Baryon density/critical density	Ω_b	0.0456	0.0461
Cold dark matter density/critical density	Ω_c	0.235	0.236
Redshift of matter-radiation equality	$z_{\rm eq}$	3273	3280
Redshift of reionization	$z_{\rm reion}$	10.36	9.97

[a] The maximum-likelihood ΛCDM parameters for use in simulations. Mean parameter values, with marginalized uncertainties, are reported in Table 4.
[b] "Combined data" refers to WMAP+eCMB+BAO+H_0.

ΛCDM: the model everyone loves to hate...

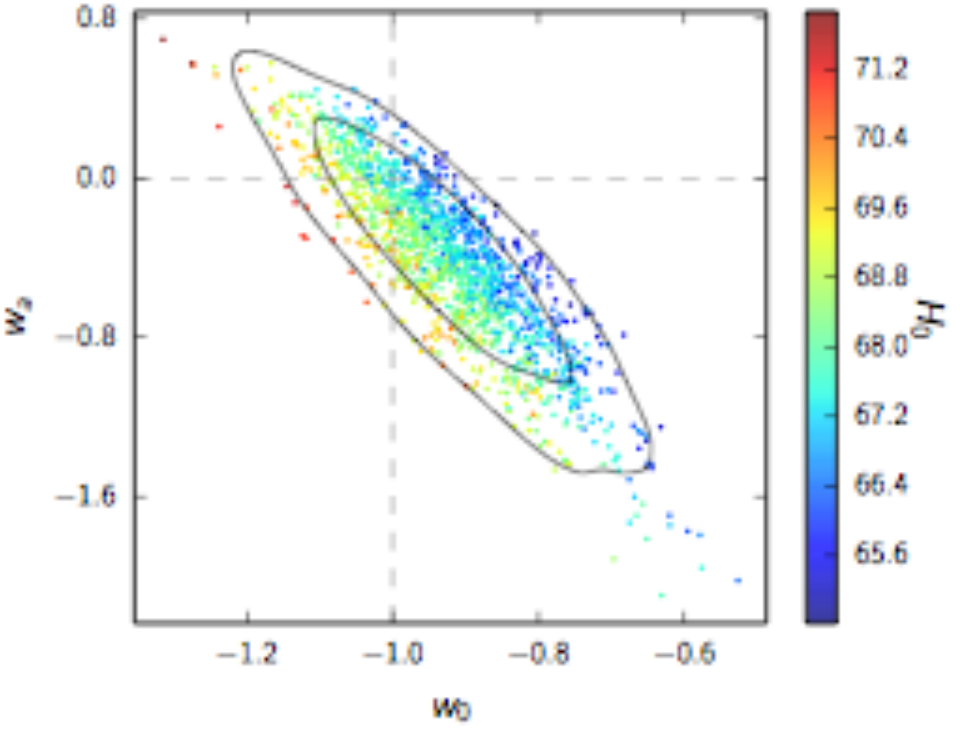


Energy density vs. scale factor



Composition - and hence expansion rate - changes with time (redshift), depending on density *and* pressure of constituents.

Testing Assumptions: Dark Energy



Planck 2015 + BAO + JLA (Sne)

Standard CDM constraints assume dark energy is cosmological constant, with

$$p = -\rho \quad (w = -1) \quad \rho = const.$$

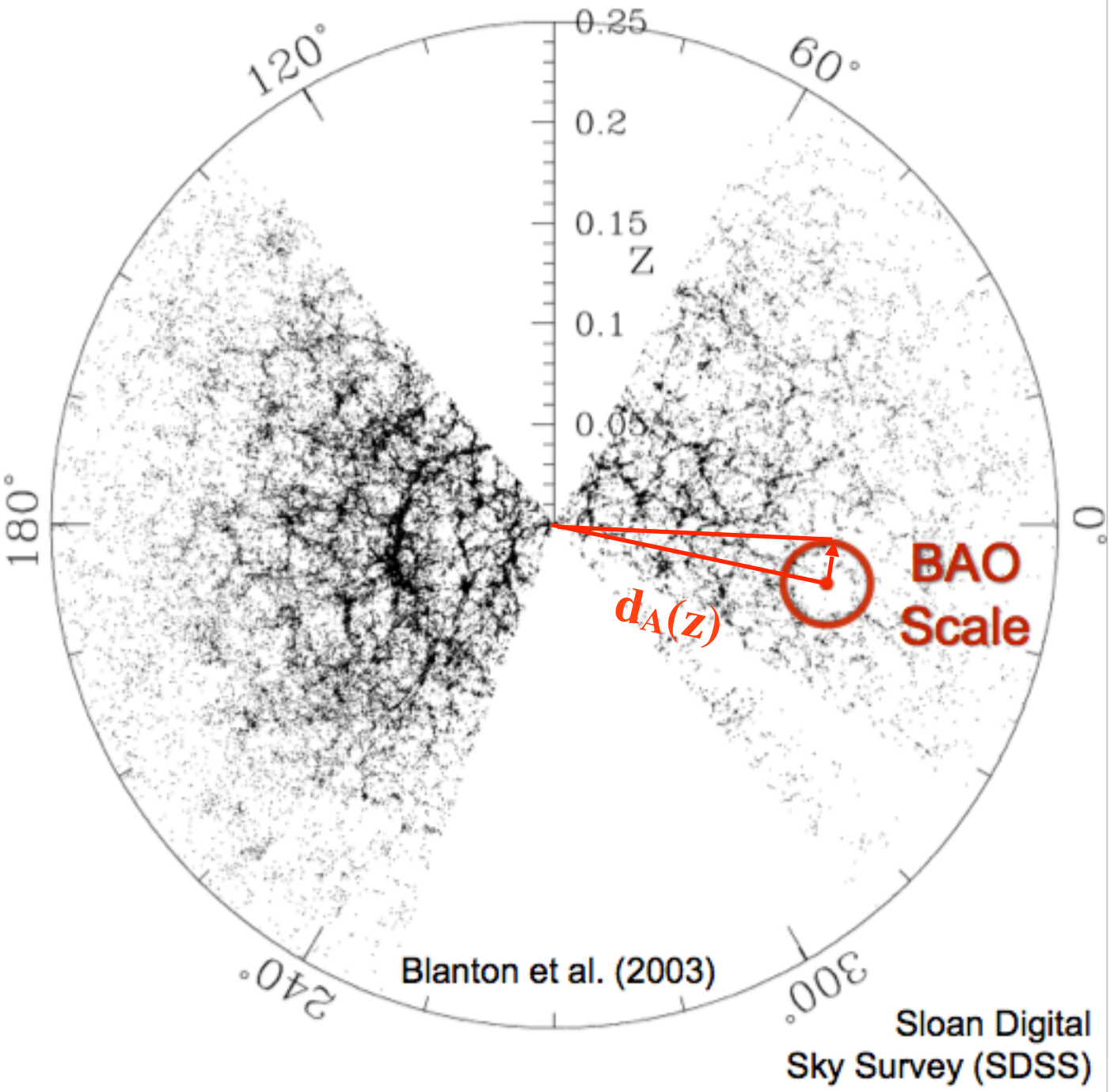
We wish to test this equation of state. Current constraints (left) are shown.

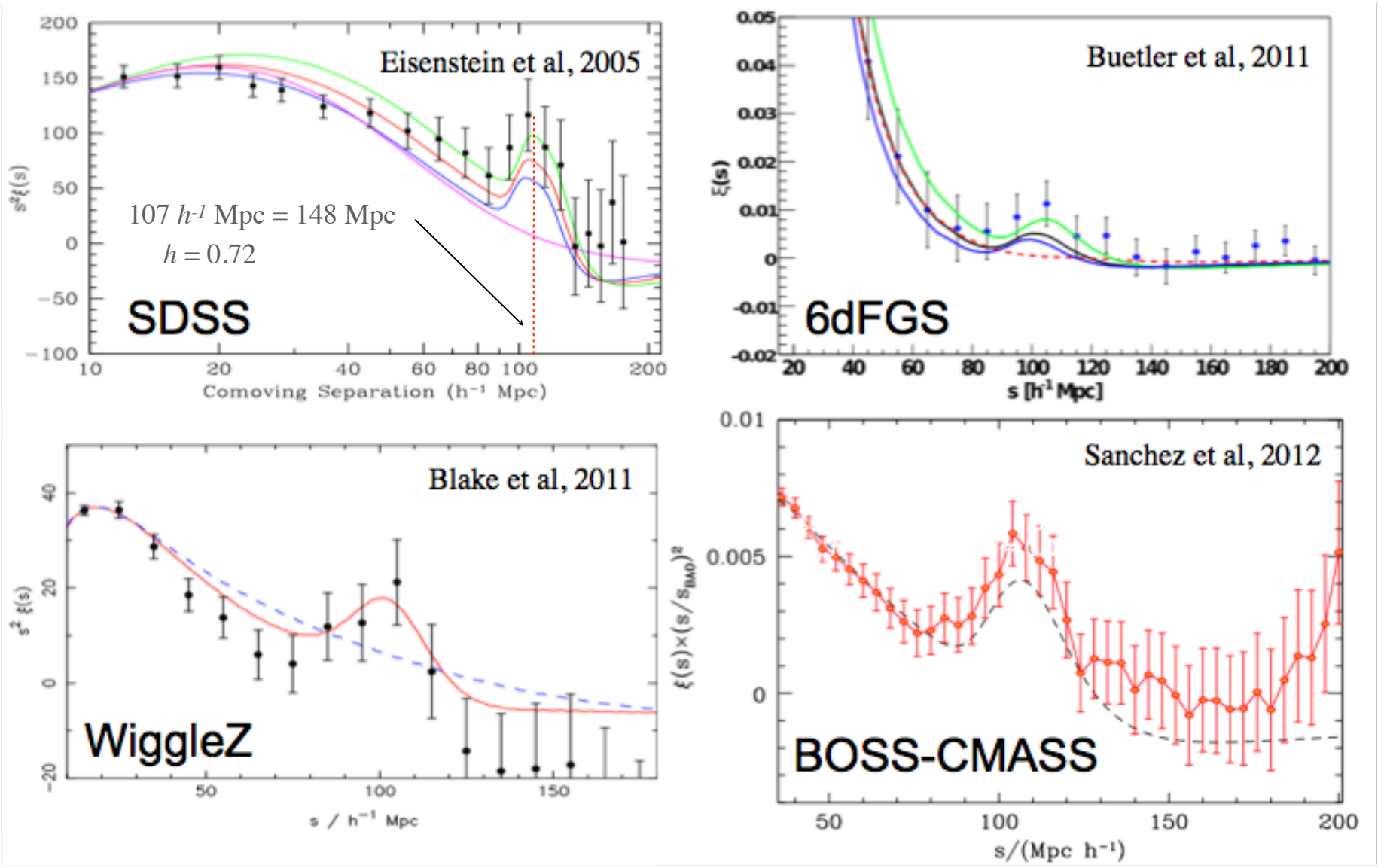
Further meaningful constraints require very accurate low redshift distance measurements, *d(z)*.

Can use the BAO in the nearby galaxy distribution as a standard ruler to probe *d(z)*.

The BAO scale schematically superposed on the SDSS galaxy distribution.

The feature is a standard ruler which can be used to measure distance vs. redshift, and therefore the Dark Energy equation of state.





BAO now detected in multiple large-scale structure surveys.

The BAO scale schematically superposed on the SDSS galaxy distribution.

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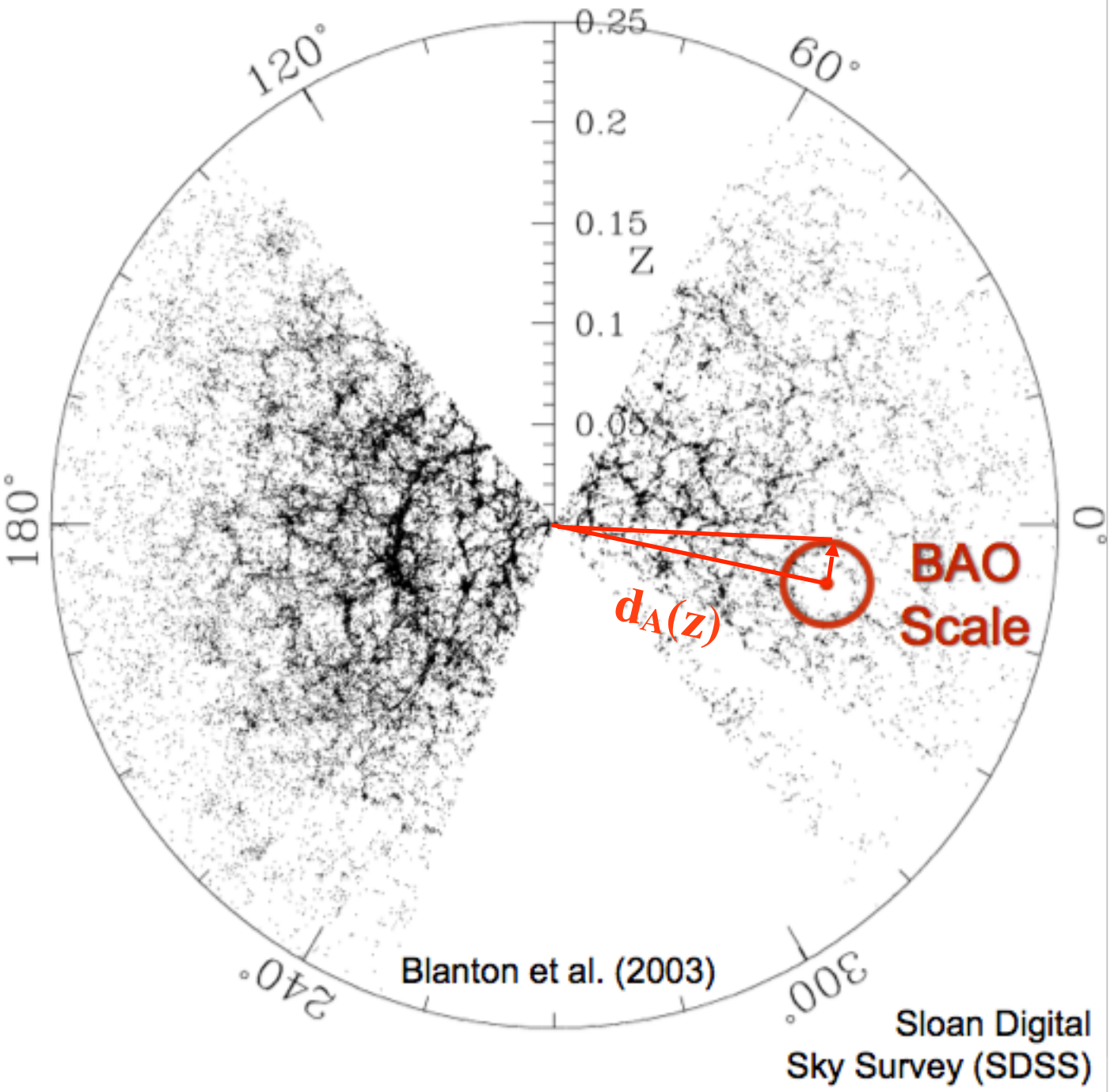
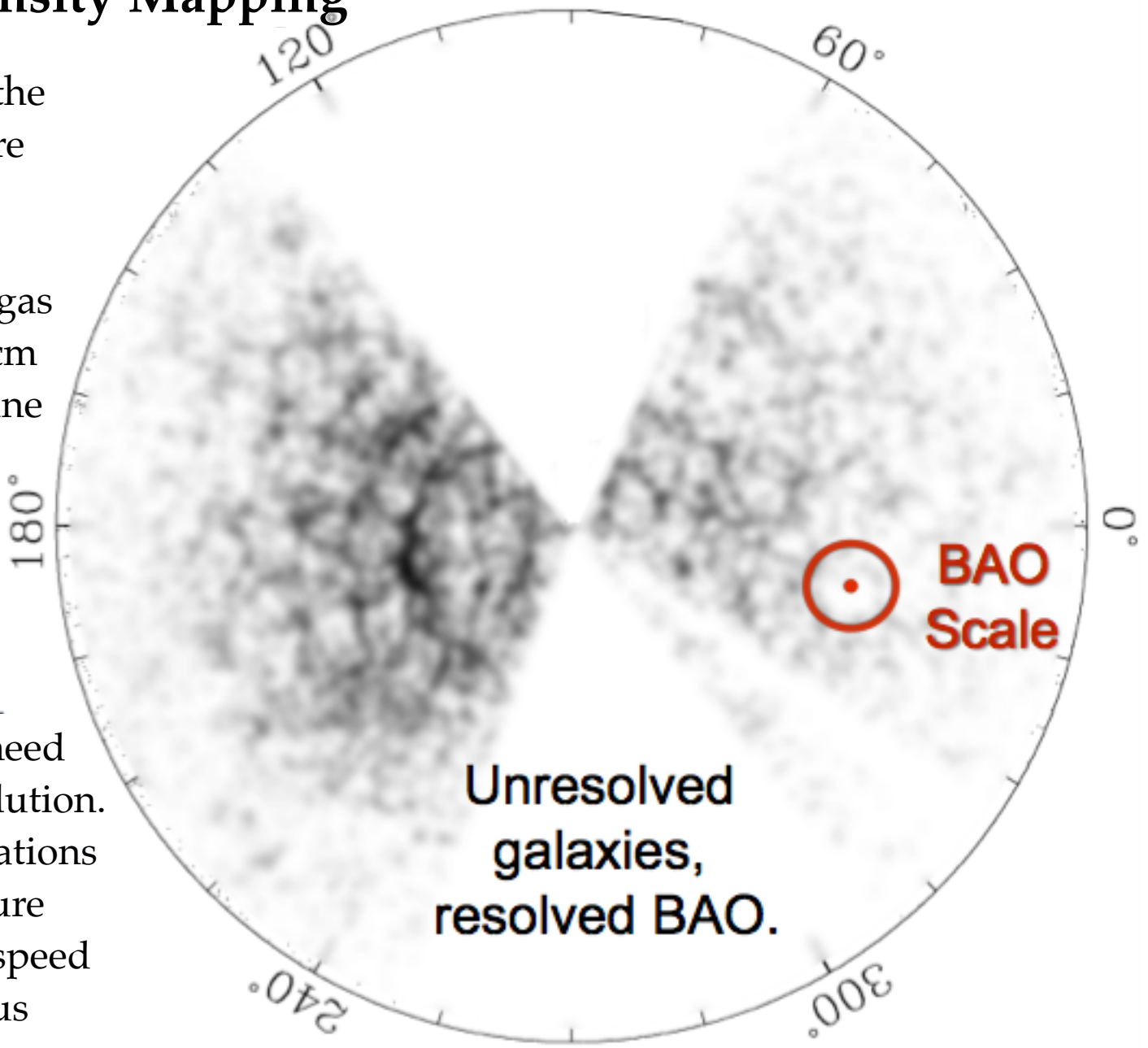


Hydrogen Intensity Mapping

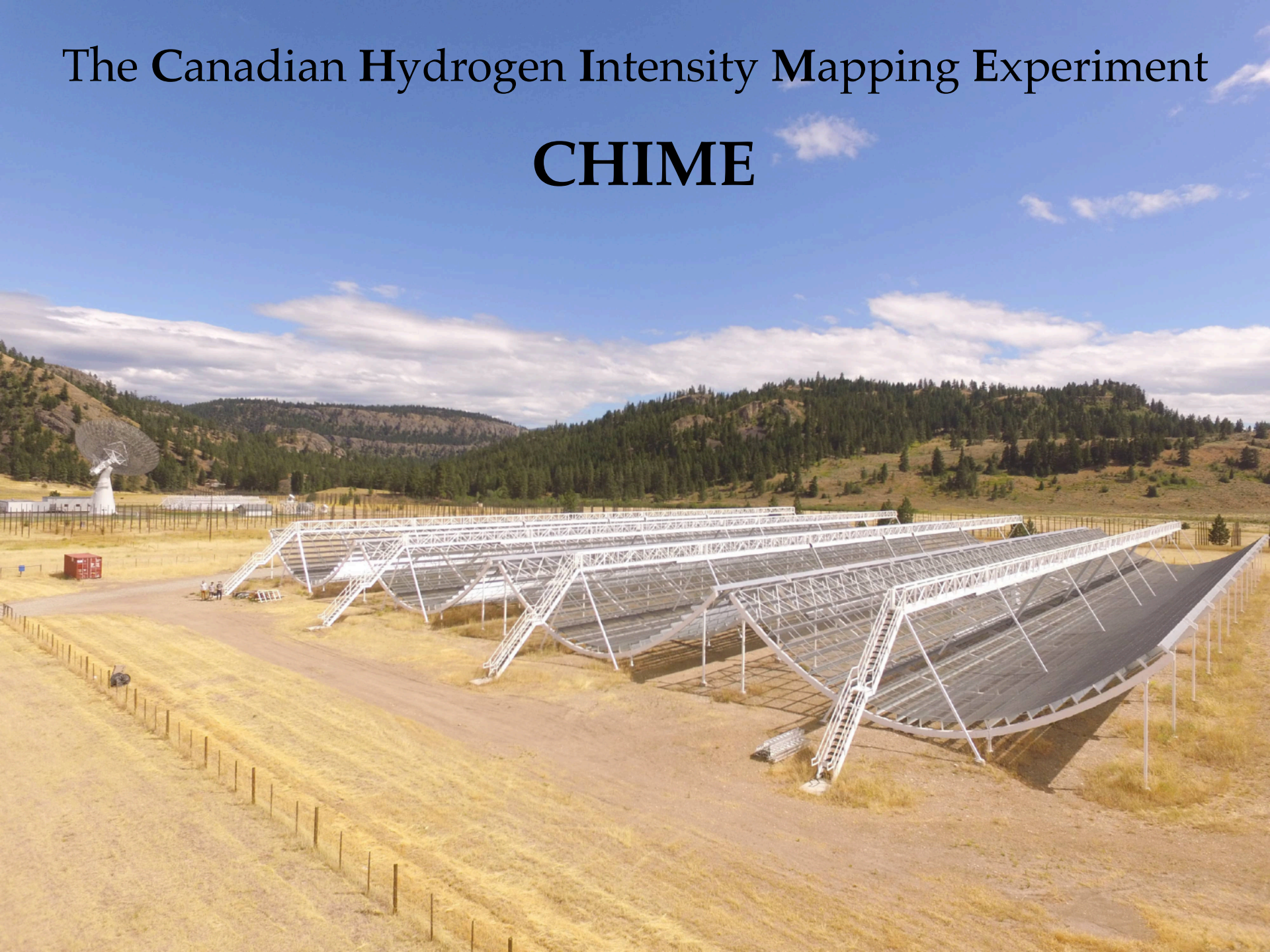
To measure BAO in the gas distribution, there is no need to resolve individual galaxies. Map intensity of HI gas using redshifted 21 cm emission along the line of sight.



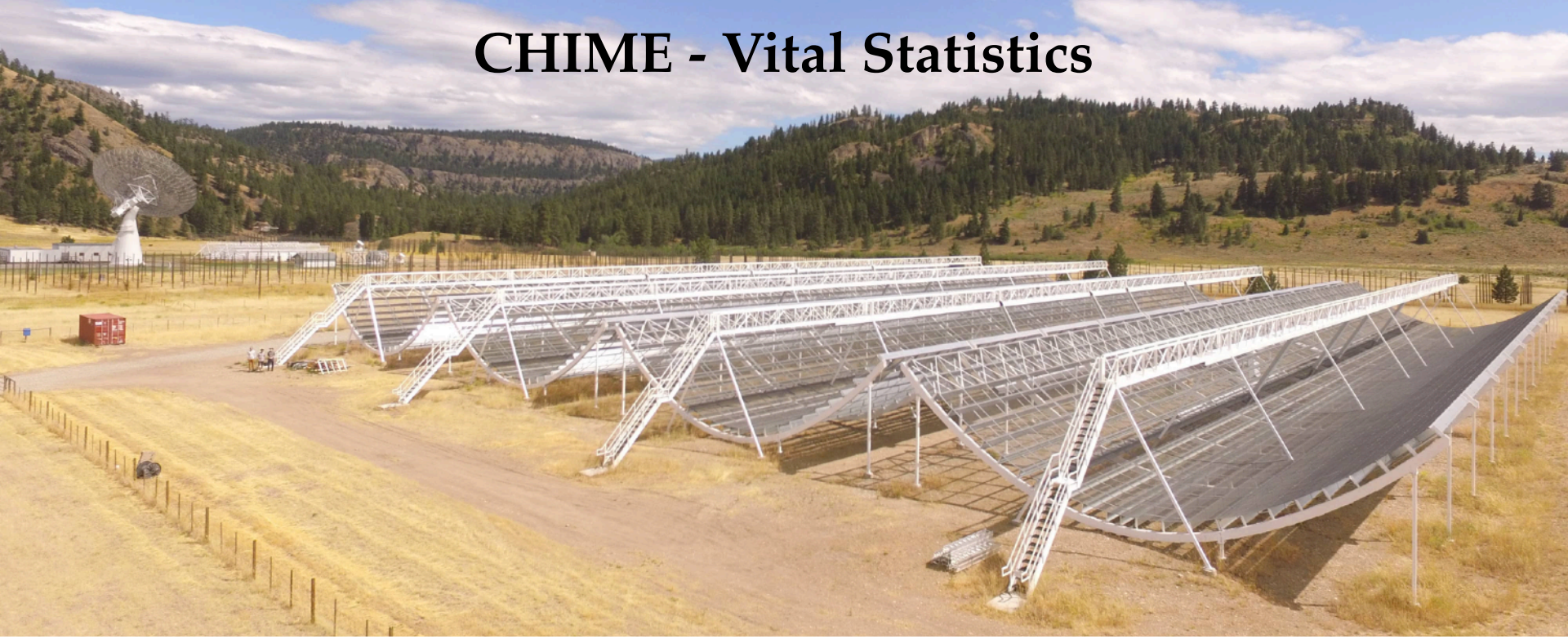
For 15 Mpc spatial resolution at z~1-2, need ~15-25′ angular resolution. This requires observations with a ~100 m aperture and a **fast** mapping speed in a nearly continuous 400-800 MHz band.

The Canadian Hydrogen Intensity Mapping Experiment

CHIME



CHIME - Vital Statistics



CHIME consists of four 20 m x 100 m N-S cylindrical reflectors with 256 antennas along each 100 m focal line. (Drift scan telescope with no moving parts).

Frequency: 400-800 MHz (21 cm radiation, z~0.8 - 2.5).

Coverage: 20,000 sq.deg. of sky; 5% of the observable co-moving volume.

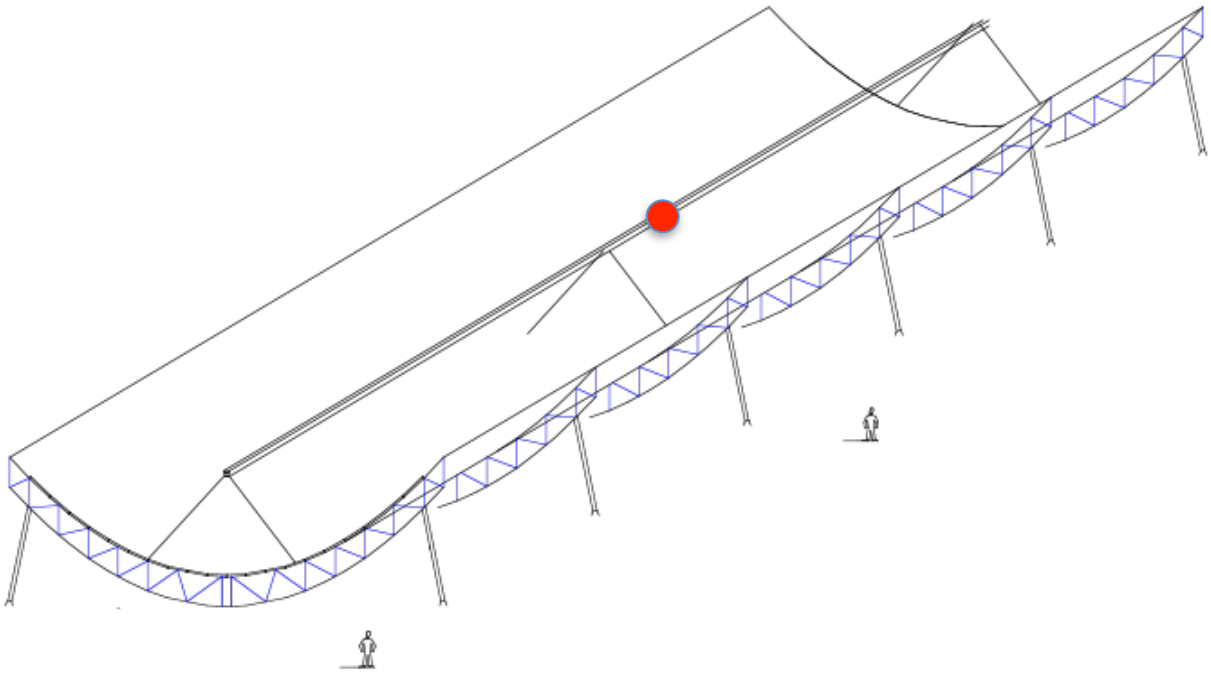
Resolution: 0.39 MHz bandwidth; 13-26 FWHM beam.

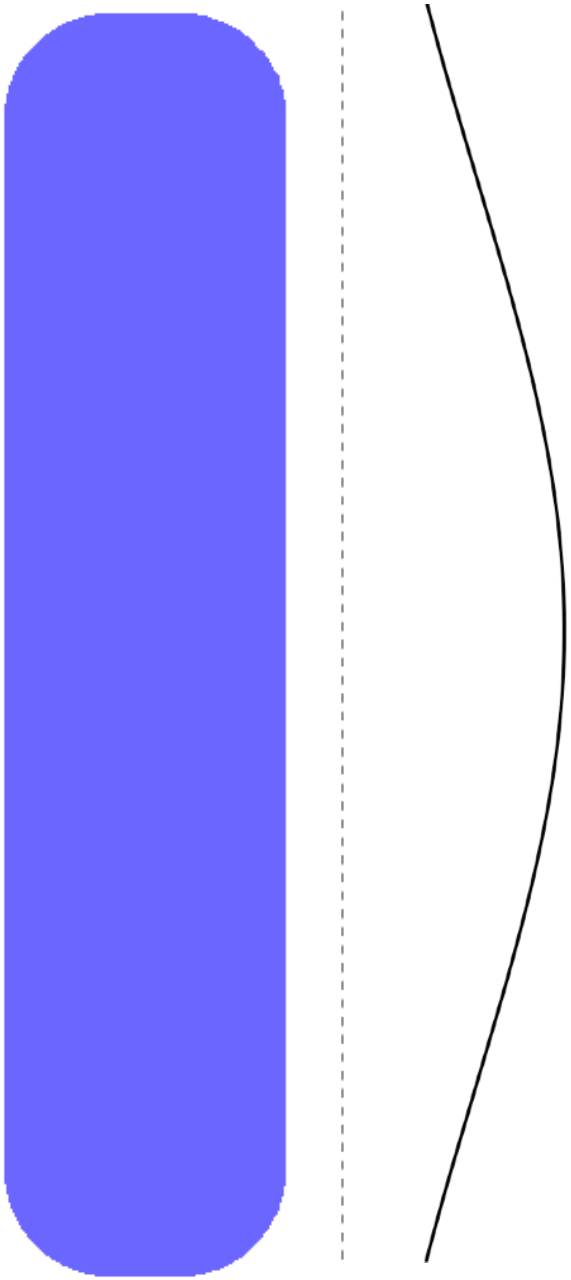
Receivers: 1024 dual polarization feeds, cosmic variance limited in ~2 years.

Dominion Radio Astrophysical Observatory

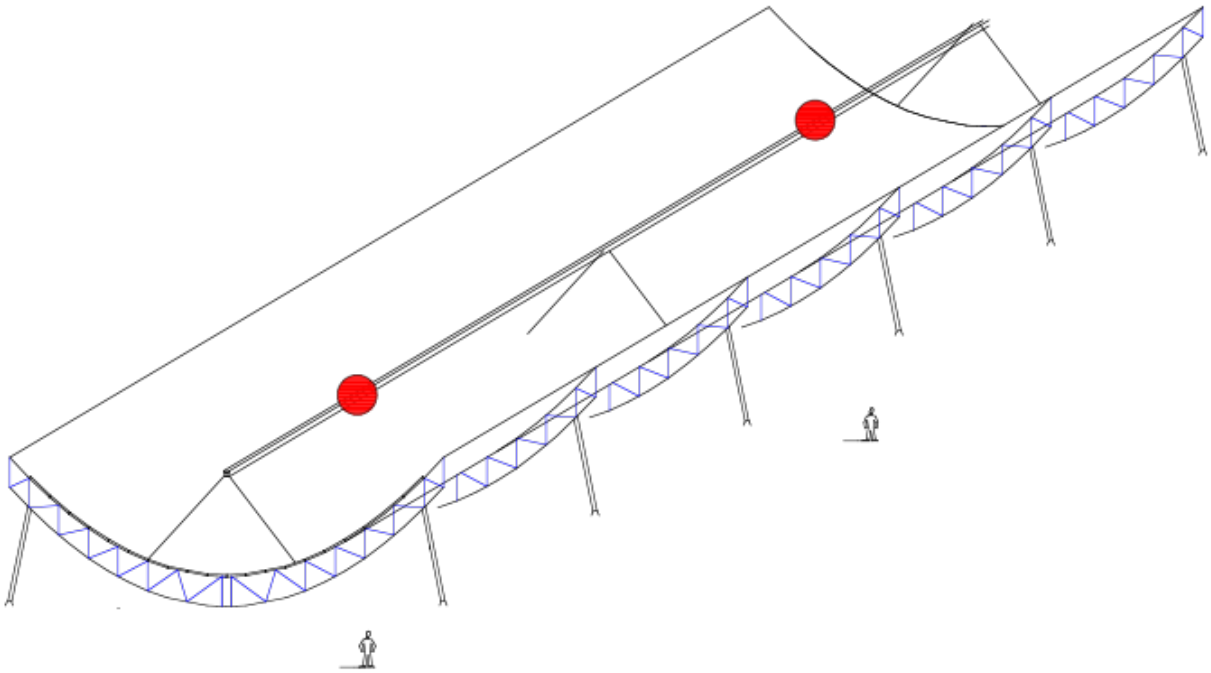
Penticton

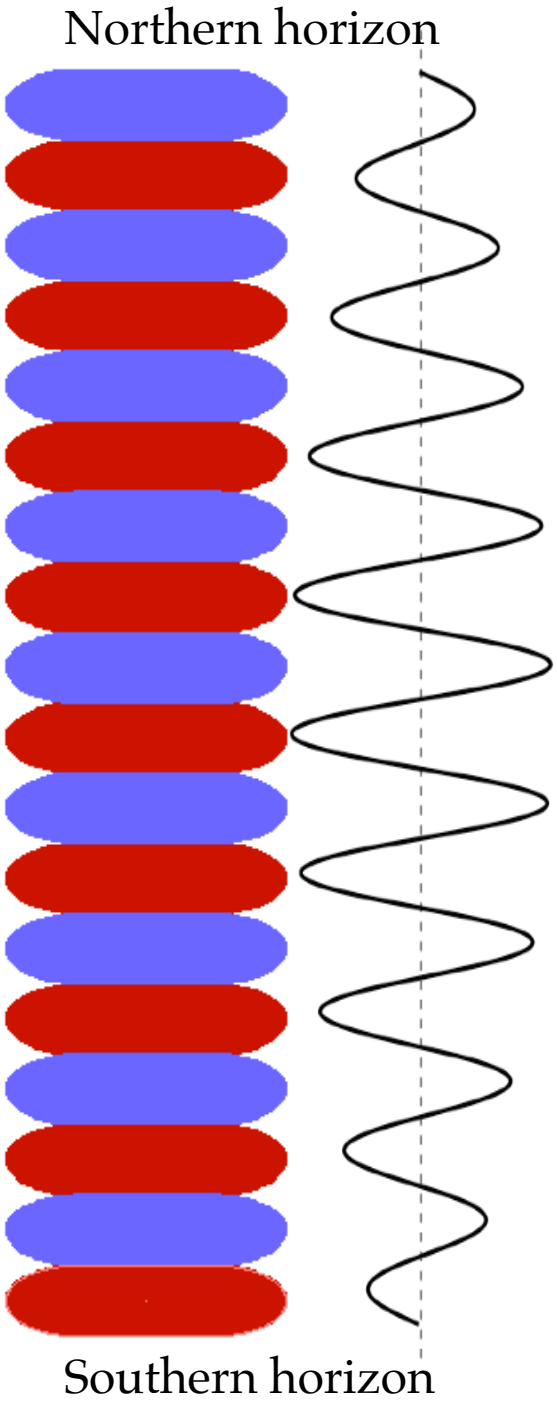
Google



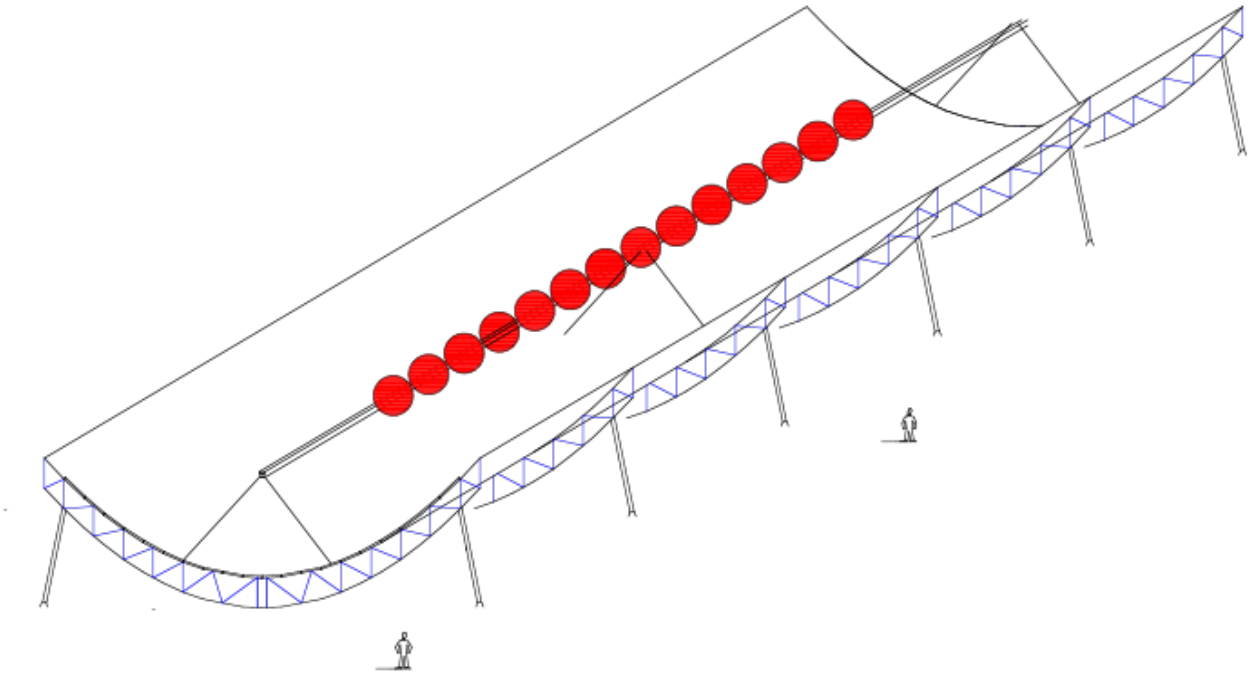


A single feed at the focus of a parabolic/cylindrical reflector sees a north-south stripe of sky.

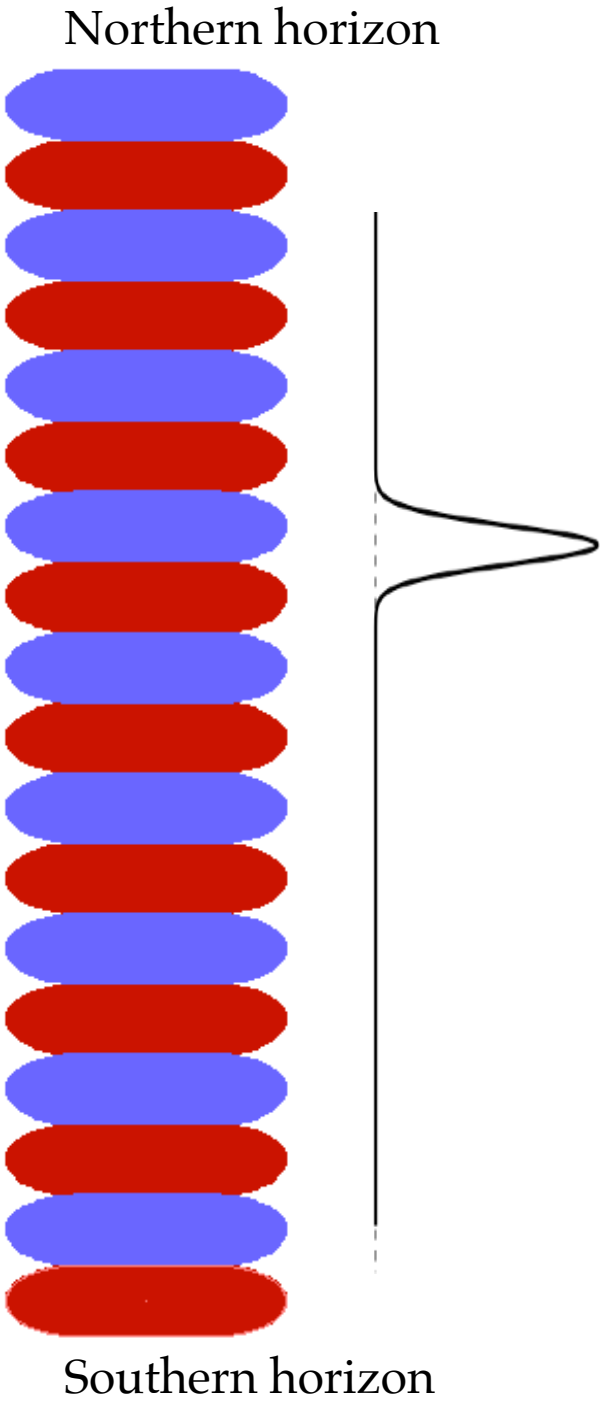


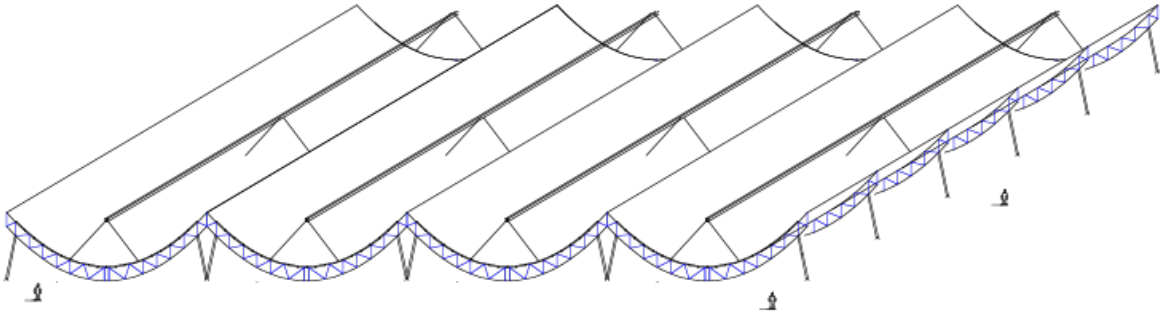


Two feeds on the focal line of the cylinder would see N-S interference fringes.

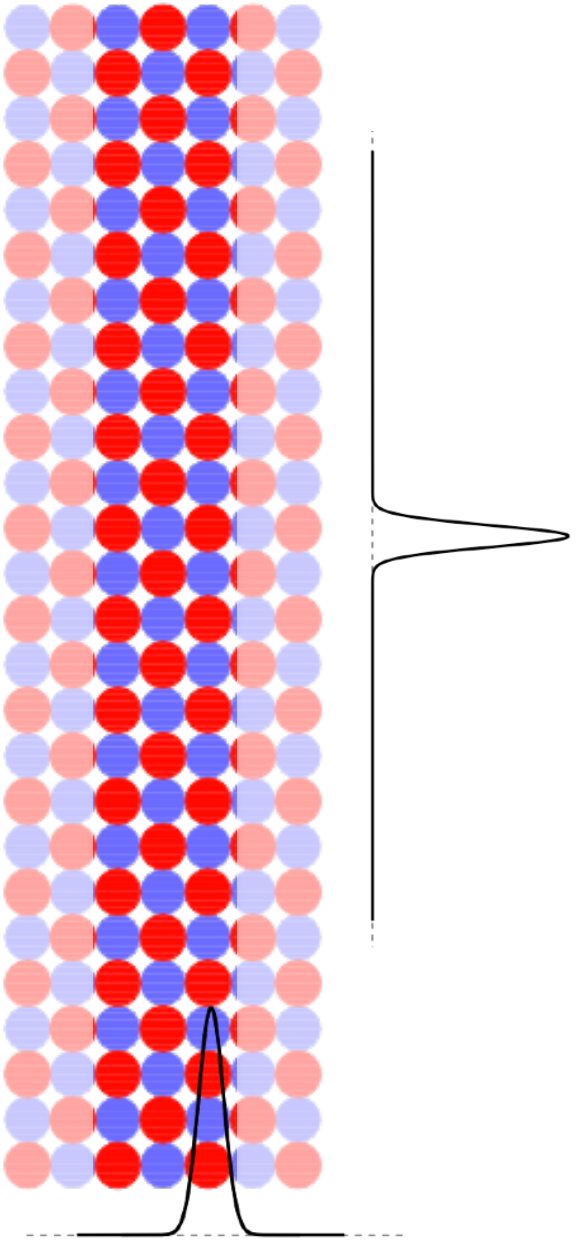


Many feeds in a linear array fully sample the sky along a N-S stripe and provide high sensitivity.

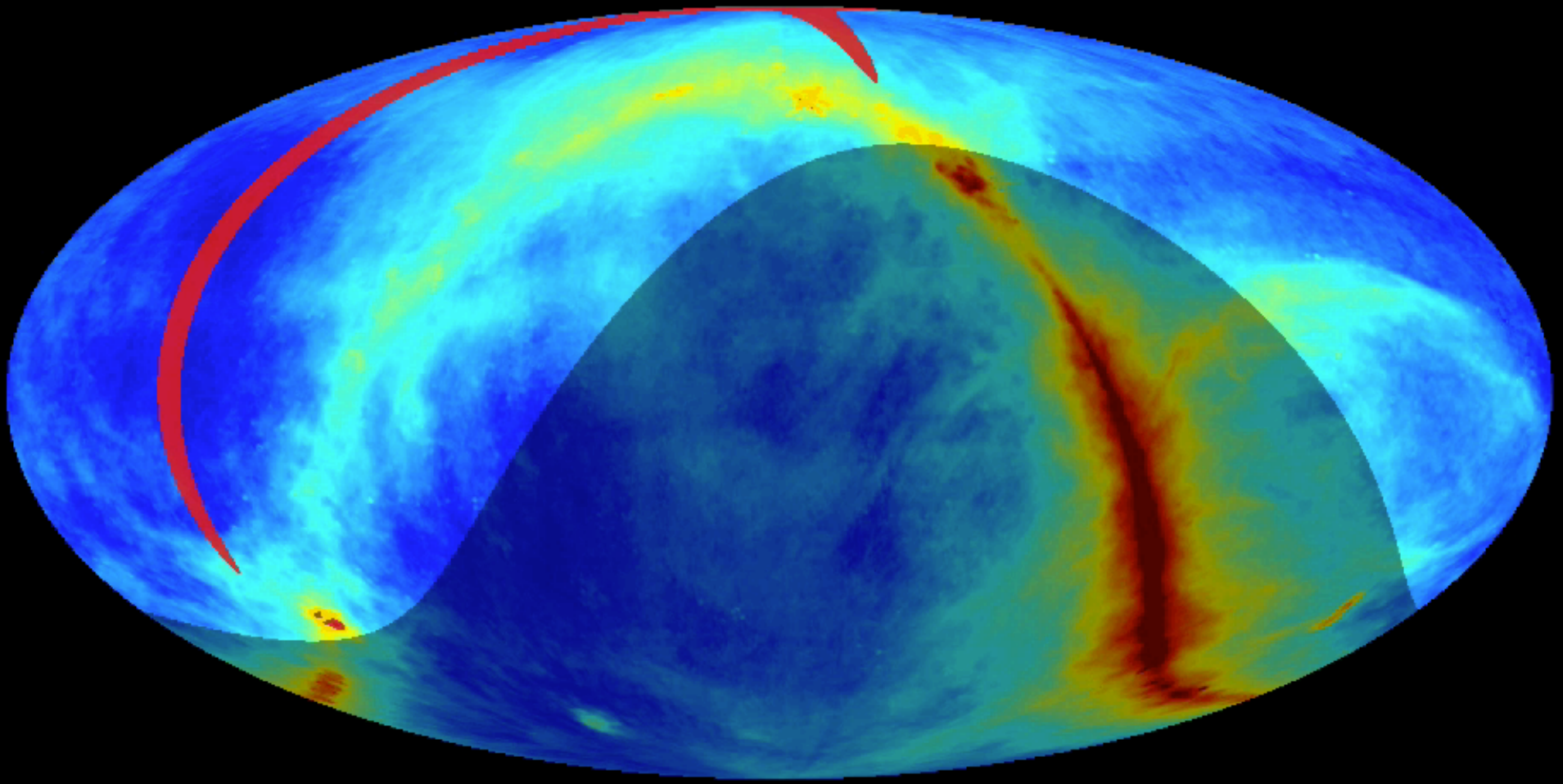




An east-west array of parabolic/cylindrical reflectors, with a linear array of feeds on each, resolves a two dimensional image of the overhead N-S stripe at each frequency.



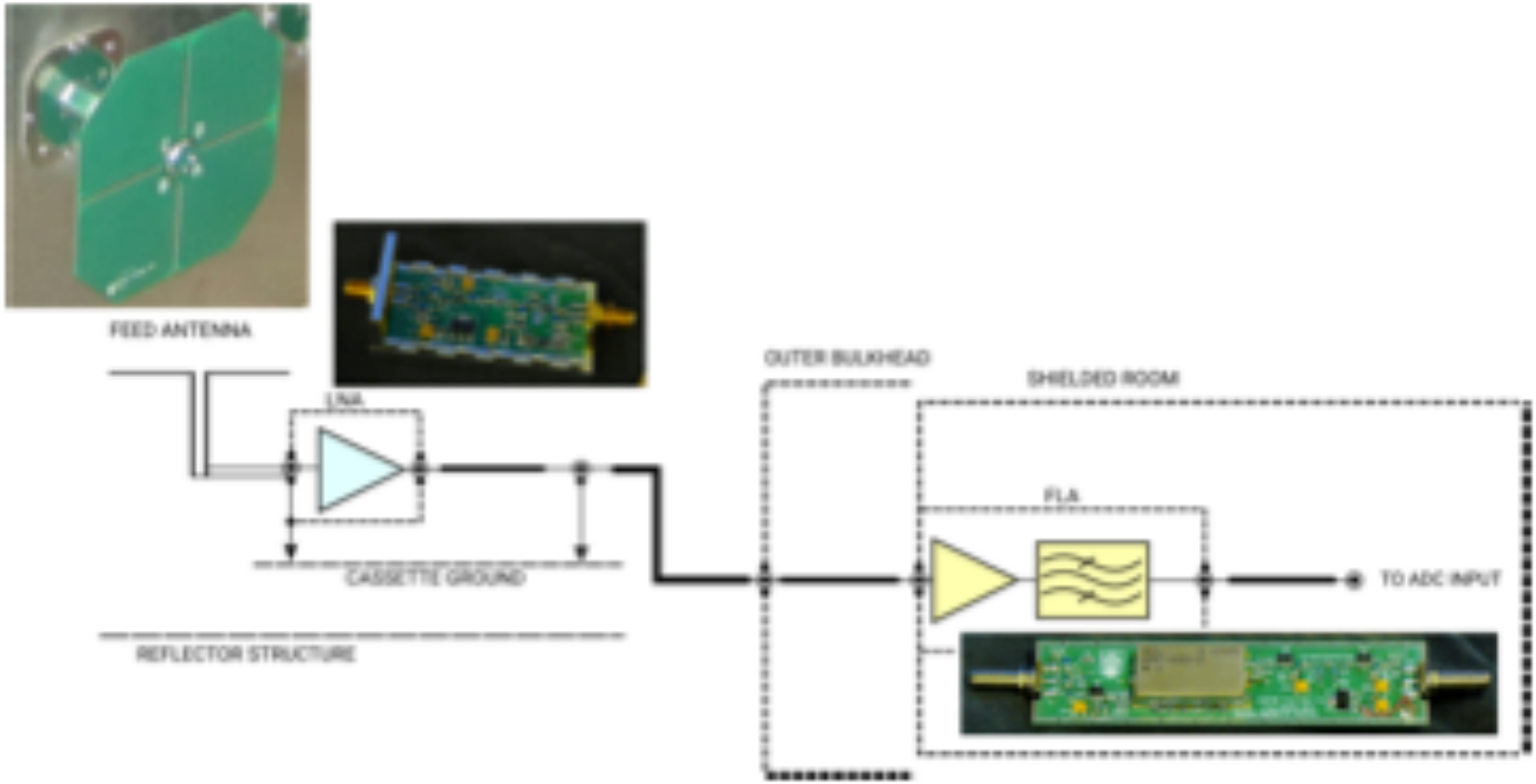
CHIME observes over half the sky each day as the sky transits.



CHIME Focal Line (Assembly)

1024 dual-polarization antennas (256 per cylinder)

CHIME Analog Signal Chain



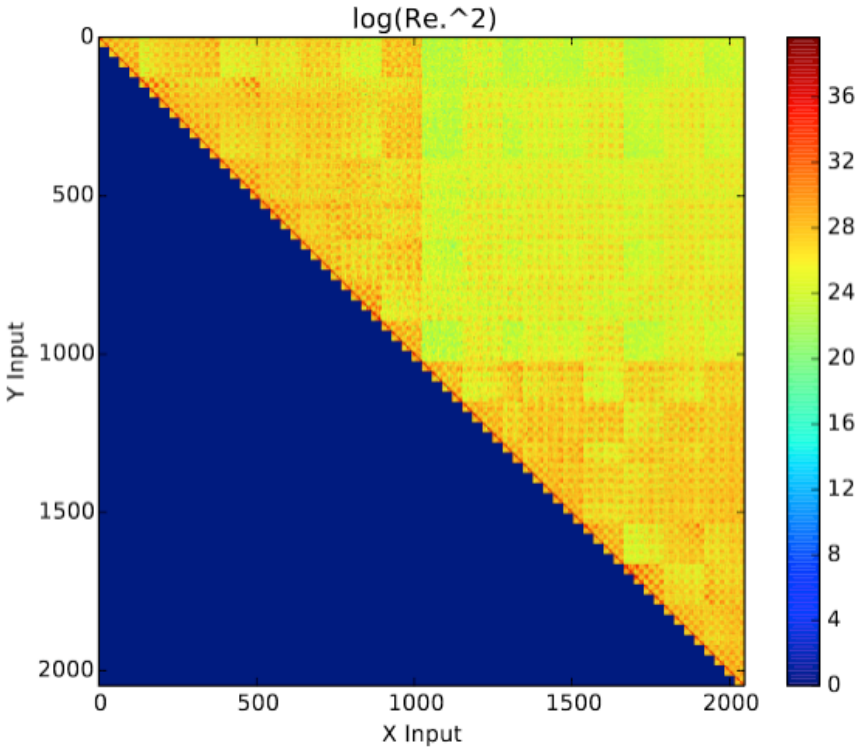
Dual-polarization antennas; low-noise amplifiers (~35 dB gain); 50 m co-ax signal cable; filter amplifier; a/d converter.

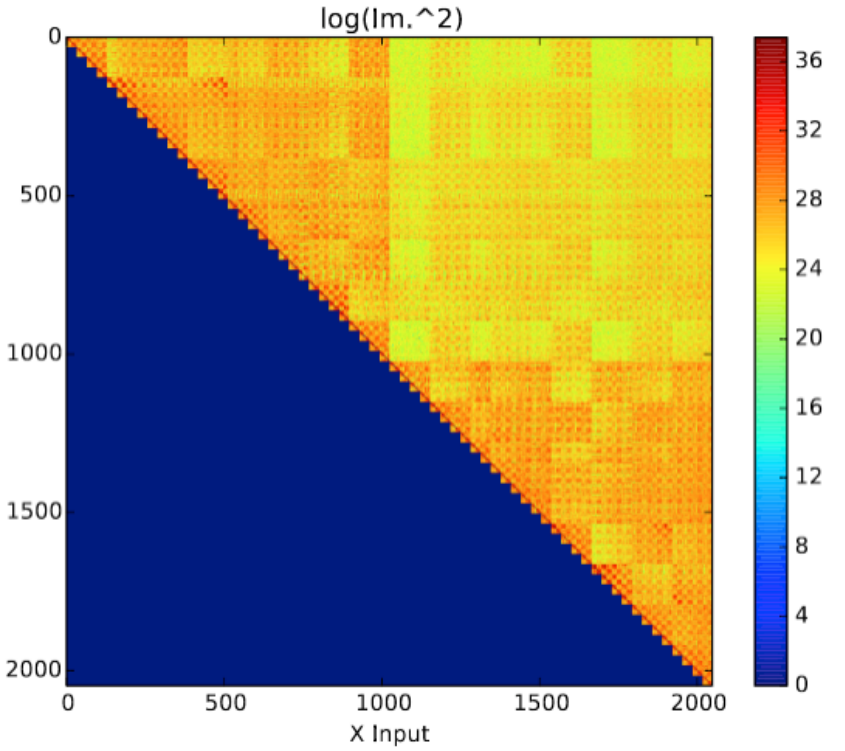
CHIME F-Engine

- Housed in two shielded 20-foot shipping containers.
- One cylinder's worth of analog inputs shown, at left.
- Each input sampled @ 800 MHz.
- 2048 time samples FFT'ed into 1024-element frequency spectrum.
- All 2048 spatial inputs for each frequency bin re-packaged and sent to X-Engine.
- Raw data rate processed: 13 Tb/sec!

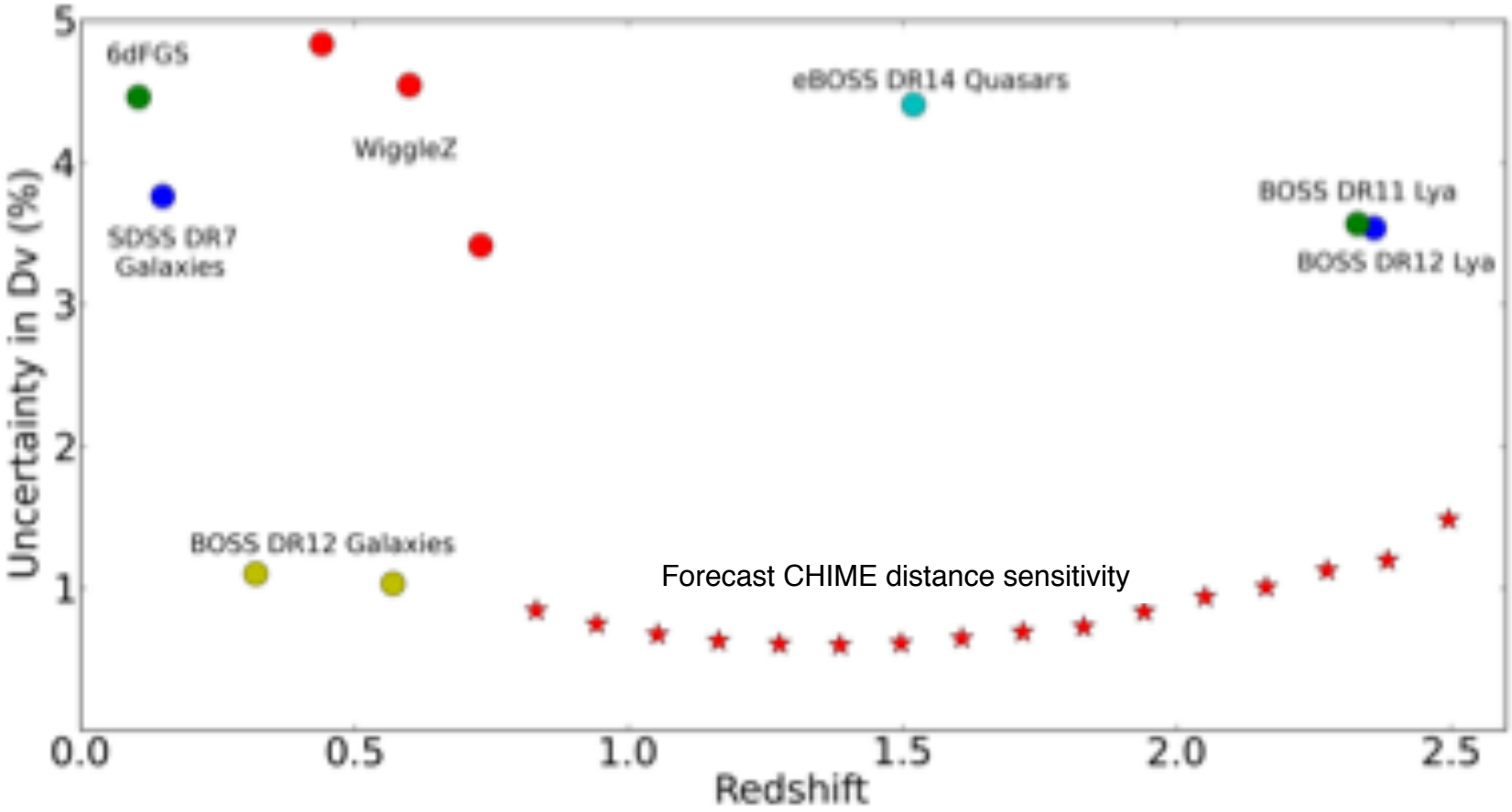
CHIME X-Engine

First full correlation matrix from CHIME: 2017 Aug 31!





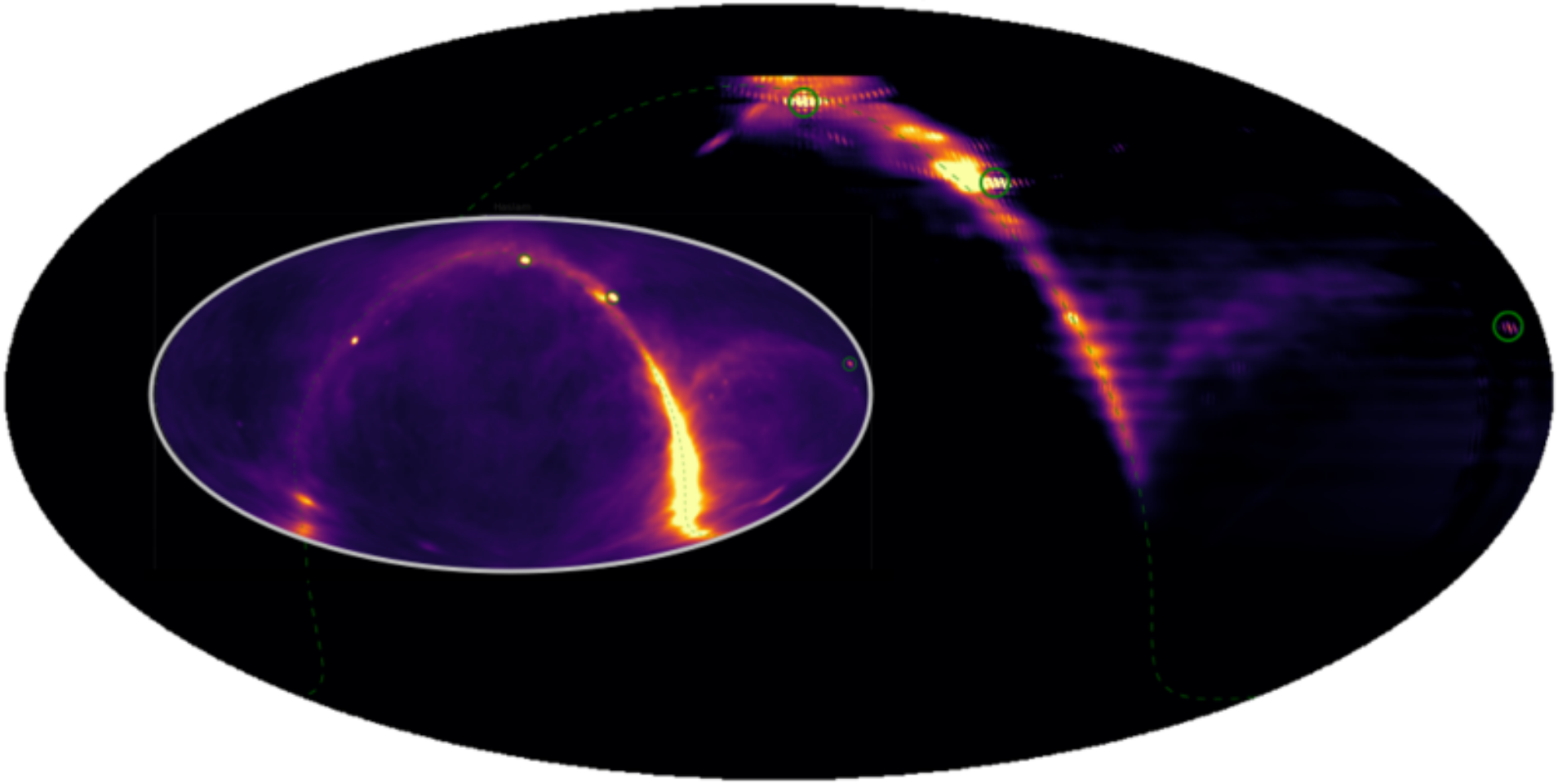
CHIME Sensitivity Forecast



CHIME is expected to reach the cosmic variance limit with a two-year survey.

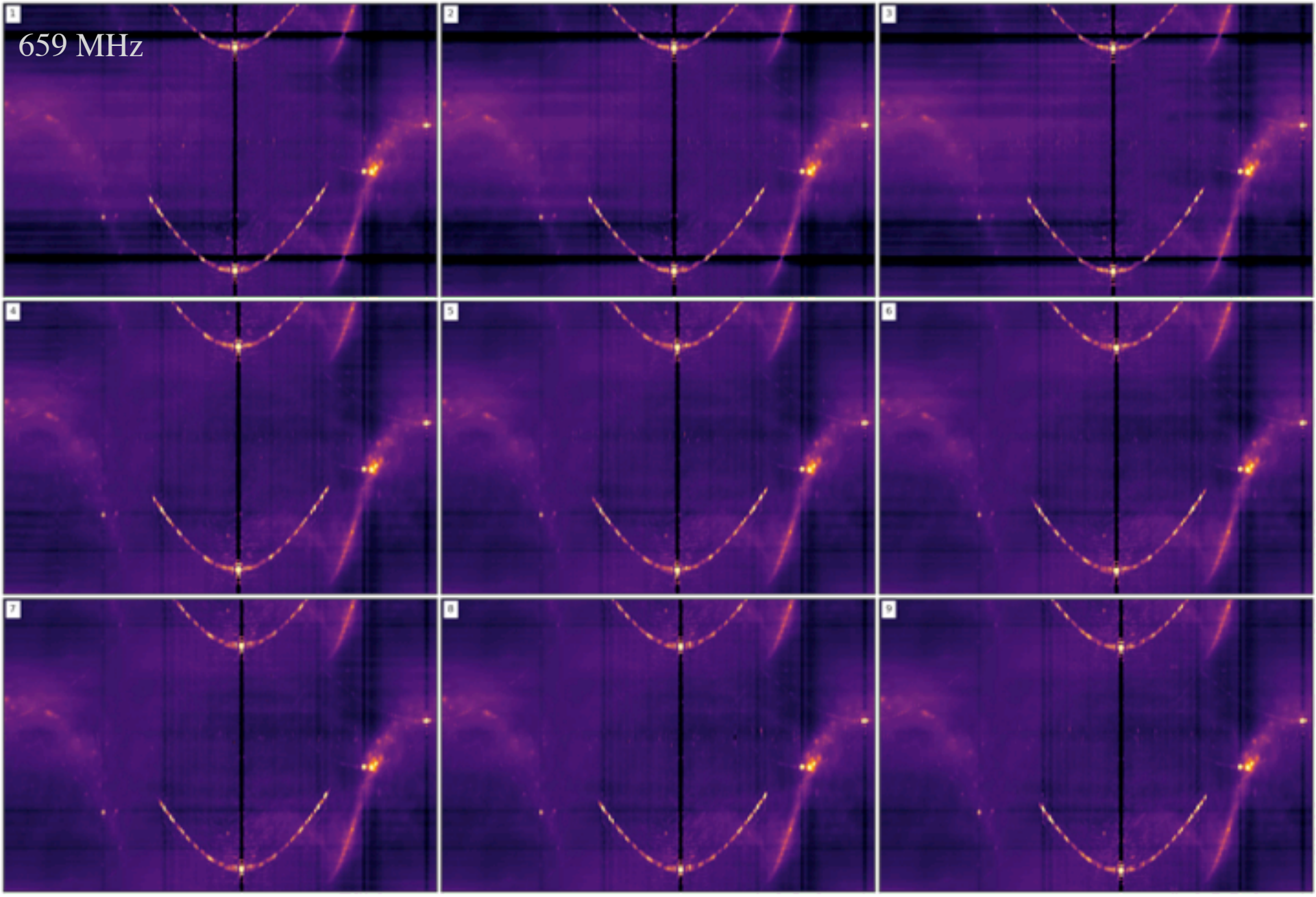

CHIME Pathfinder

First map from CHIME Pathfinder data taken summer 2015



A partial sky map covering -10° ≲ δ ≲ +60° at 614 MHz from three nights of CHIME Pathfinder data taken in summer 2015. The inset shows a full-sky map at 408 MHz from Haslam et al. for comparison. This map has been processed with a very preliminary pipeline and still exhibits artifacts that will require additional

Daily maps from the CHIME Pathfinder data, c. 2016



Full CHIME Status:

- Telescope construction completed summer 2015,
- Assembly of receiver components completed this summer,
- First light ceremony at DRAO this Thursday: 2017 Sep 7!