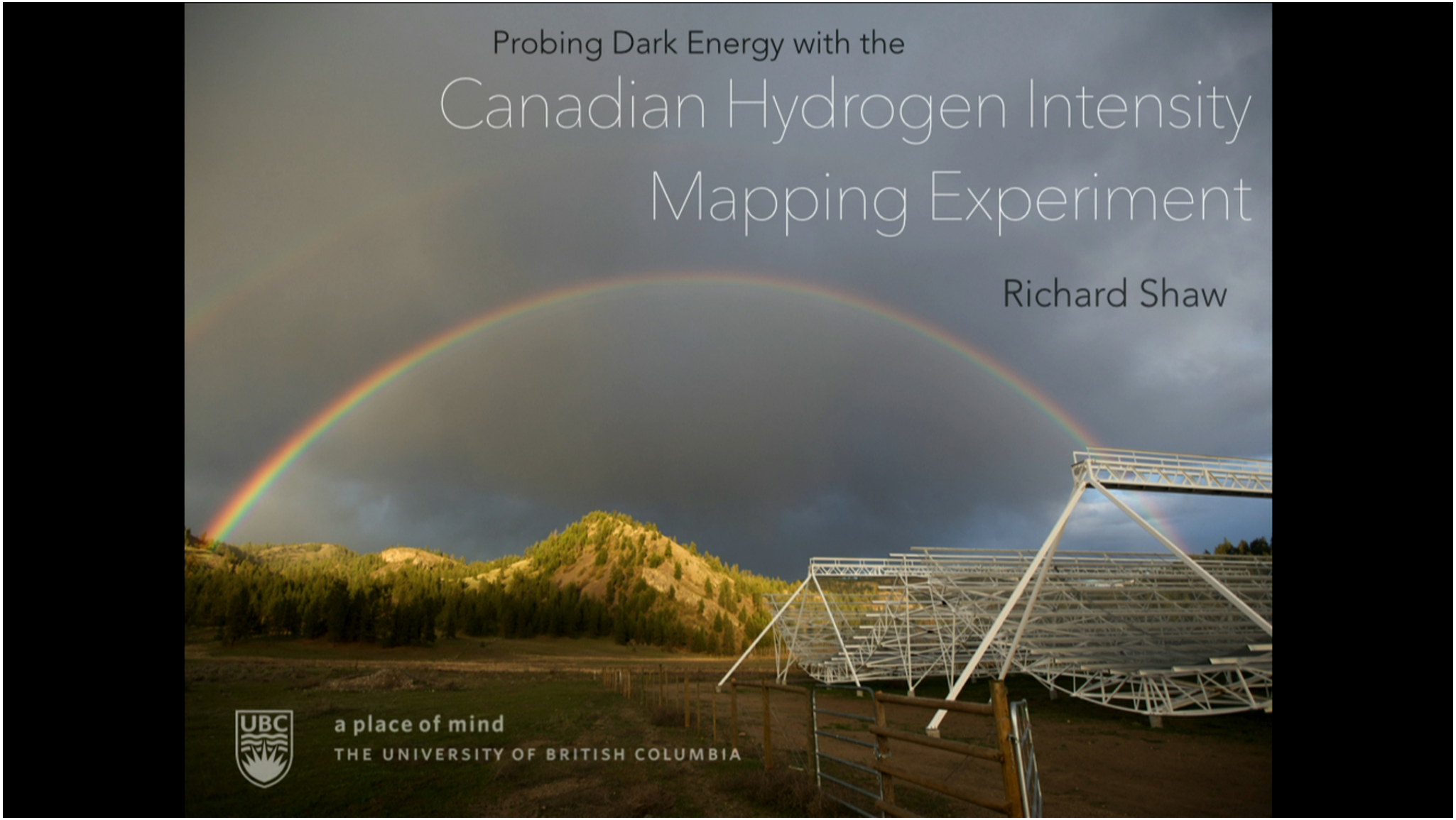
Title: Probing Dark Energy with the Canadian Hydrogen Intensity Mapping Experiment (CHIME)

Date: Aug 12, 2015 10:40 AM

URL: http://pirsa.org/15080002

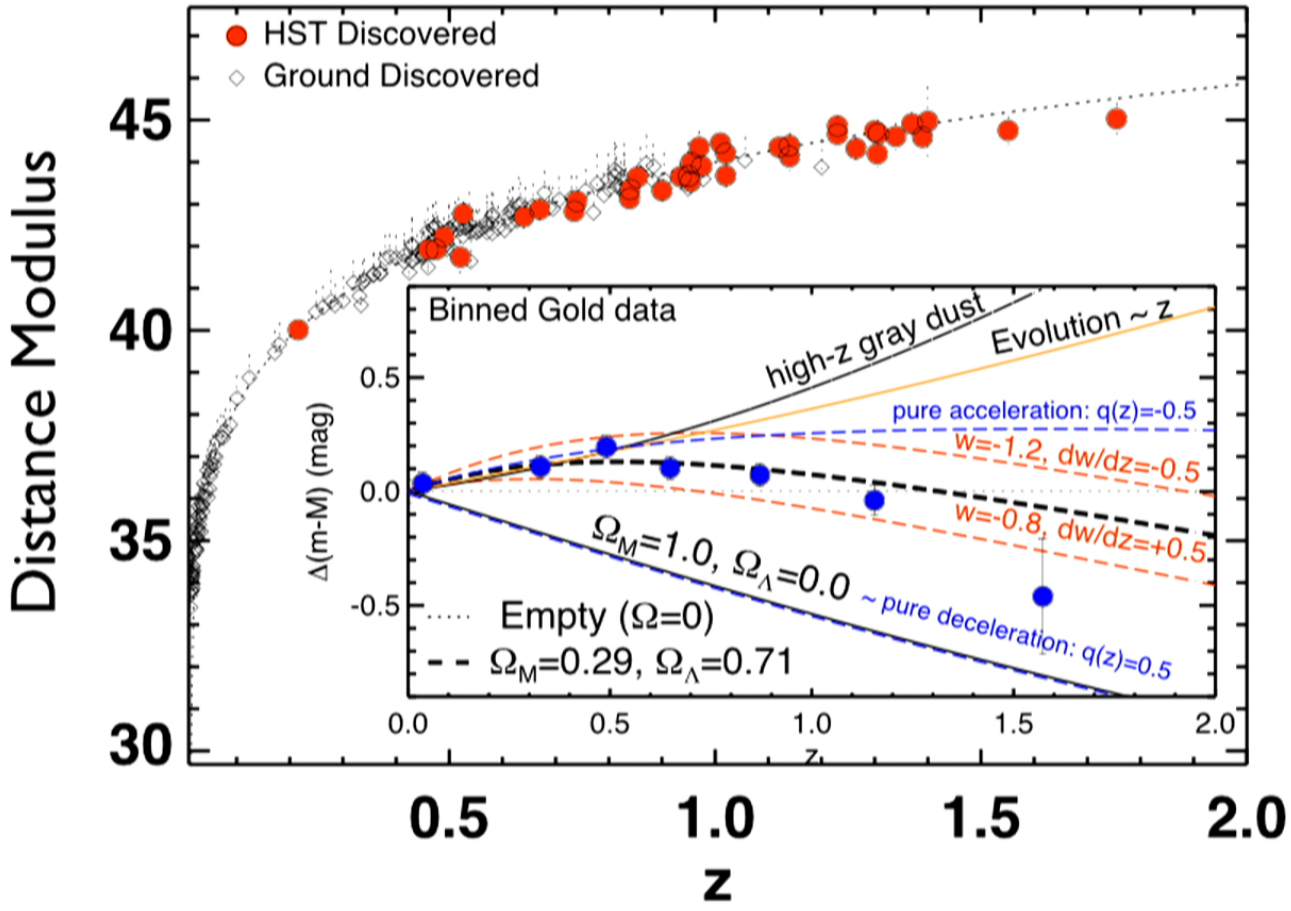
Abstract: CHIME will use the 21cm emission line of neutral hydrogen to map large-scale structure between redshifts of 0.8 and 2.5. By measuring BAO we will place constraints on the dark energy equation of state as it begins to dominate the expansion of the Universe, particularly at redshifts poorly probed by current BAO surveys.

In this talk I will introduce CHIME, a transit radio interferometer designed specifically for this purpose. I will discuss its goals and describe the powerful new analysis techniques we have developed to confront the many challenges of such observations, in particular removal of astrophysical foregrounds which are six orders of magnitude larger than the 21cm signal. A smaller 40m x 37m pathfinder telescope is currently operating at the DRAO in Penticton, BC, and the construction of the full-sized 80m x 100m instrument commenced in early 2015. I will report on current progress, and the lessons already learned.


Probing Dark Energy with the
Canadian Hydrogen Intensity Mapping Experiment
Richard Shaw
UBC
a place of mind
THE UNIVERSITY OF BRITISH COLUMBIA

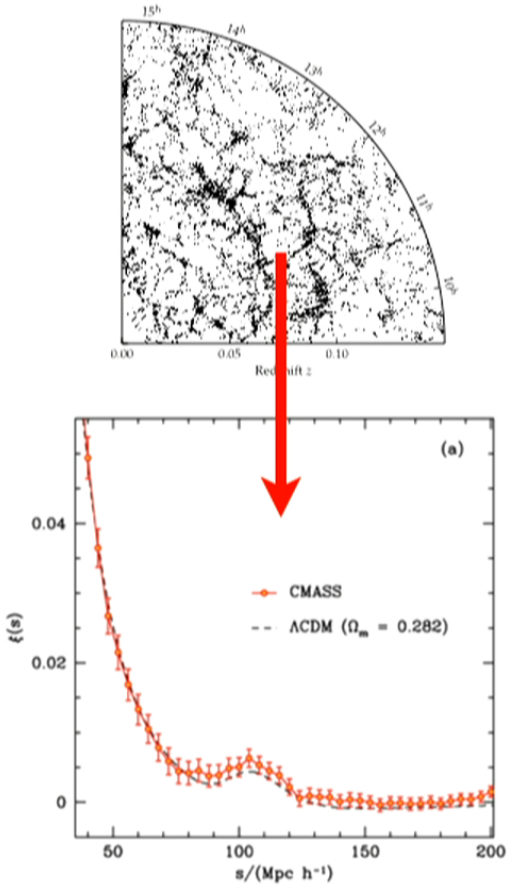
Dark Energy

$$d_L(z)^2 = L/4\pi F$$



Baryon Acoustic Oscillations

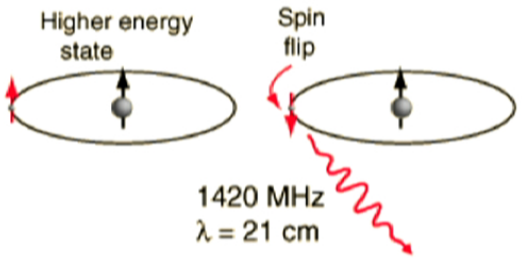
- Sounds waves propagating in the early Universe.
- Leave a weak imprint in the matter distribution
- Gives a standard (statistical) ruler
- Exact peak position tells you angular diameter distance and Hubble parameter at the redshift



Sanchez et al. 2012

21cm Intensity Mapping

Cosmological 21cm



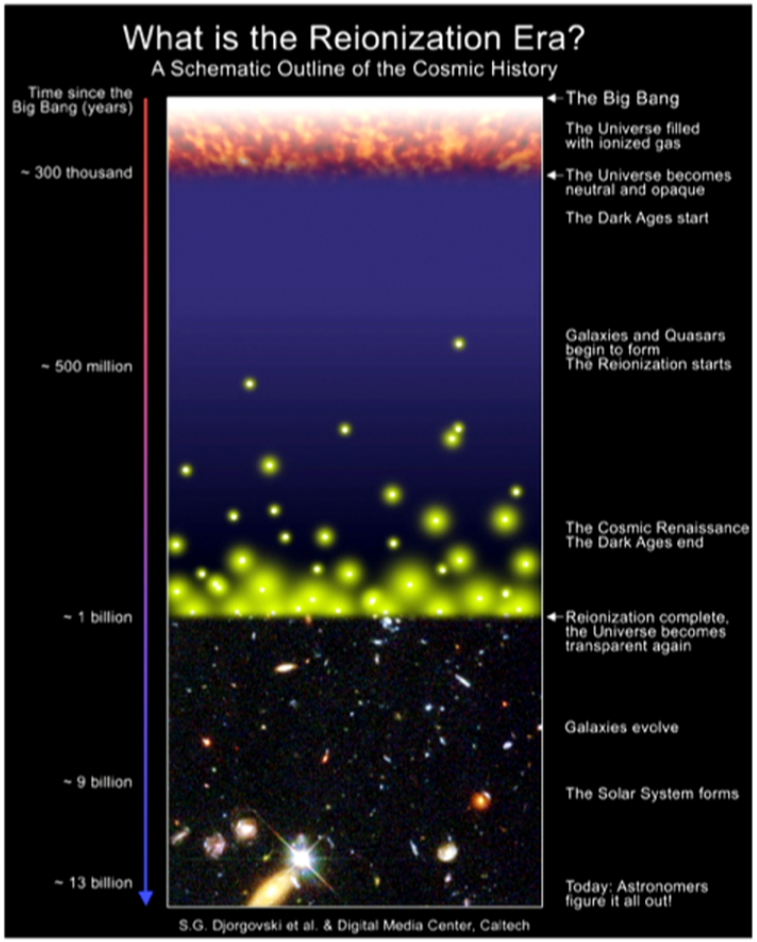
- 21cm line is the transition between parallel and anti-parallel spins of neutral Hydrogen
- The ratio between the two occupancies determines the spin temperature T_S

$$n_1/n_0 = (g_1/g_0)\exp(-T_*/T_S)$$

- We can observe the contrast relative to the CMB

$$\Delta T = 23.8\left(\frac{1+z}{10}\right)^{1/2}\left[1-\bar{x}(1+\delta_x)\right](1+\delta_b)(1-\delta_v)\left[\frac{T_S-T_\gamma}{T_S}\right]\ \mathrm{mK}$$

Hydrogen in the Universe

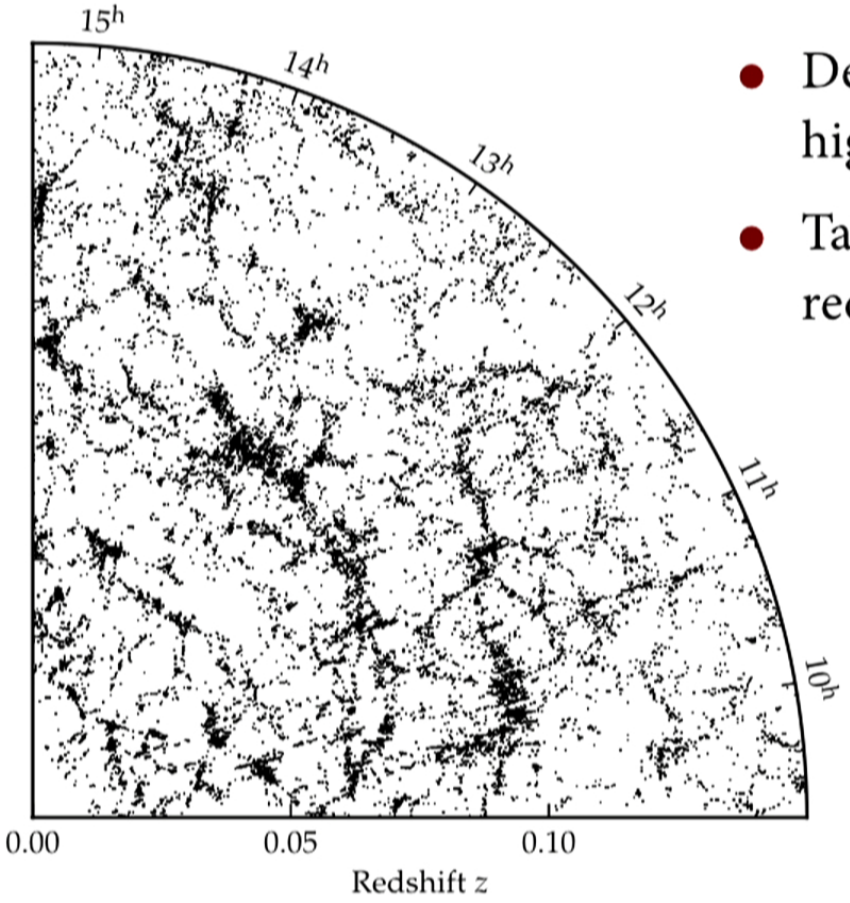


Dark ages

Reionisation

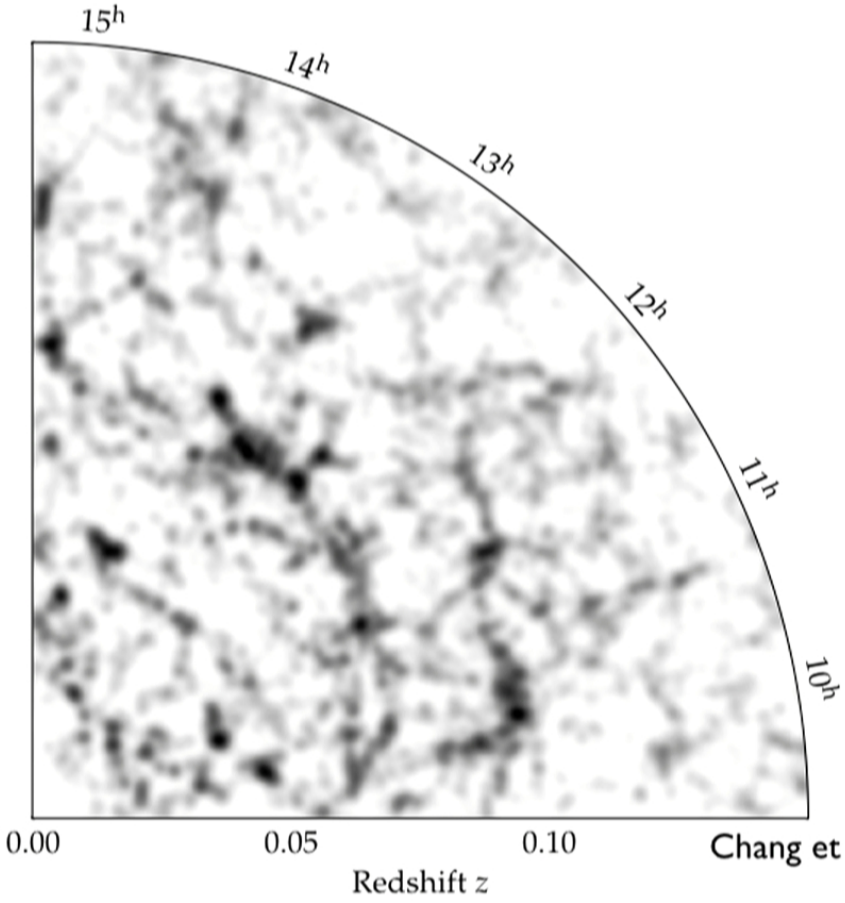
HI in galaxies

Galaxy Redshift Survey



- Detect all galaxies with high significance.
- Take spectra to determine redshift

Intensity Mapping



- Observe galaxies with a line transition
- Automatically gives redshift

Don't need to resolve individual galaxies

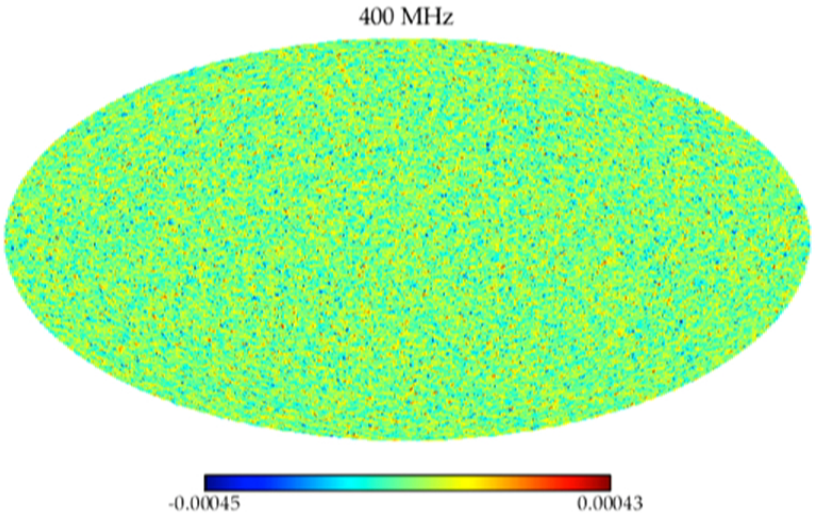
Chang et al, 2008; Wyithe and Loeb 2008

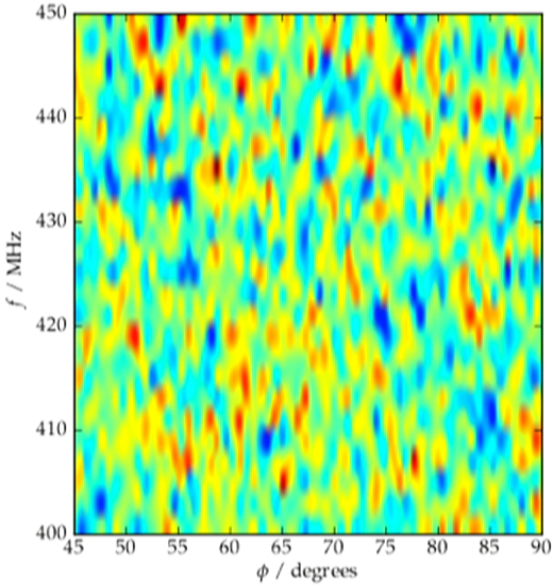
21cm Intensity Mapping

- In 21cm the frequency gives the redshift.
- Observe the diffuse emission from many unresolved galaxies
- Changes the game in telescope design:
  - Previously: large field of view, large collecting area, large angular resolution (SKA?)
  - Now: large field of view, large collecting area, modest angular resolution (compact arrays, single dishes).

Chang, Pen, Peterson and McDonald , 2008, http://arxiv.org/pdf/0709.3672

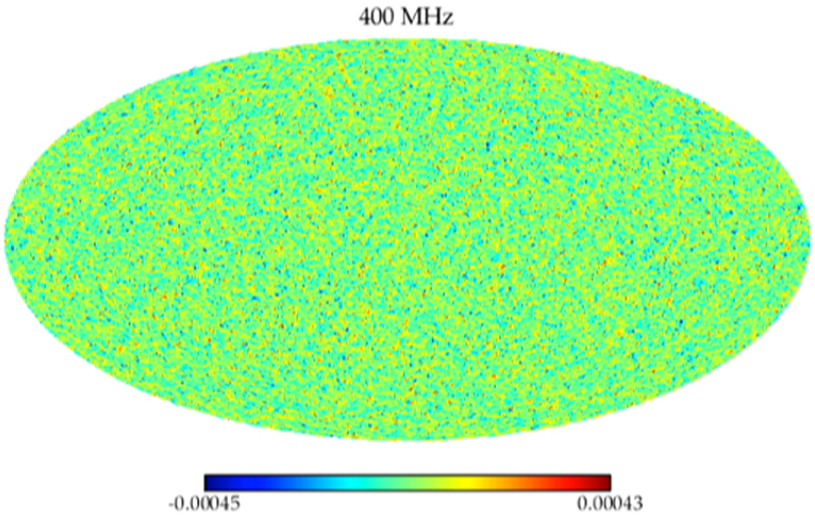
Foreground Challenges

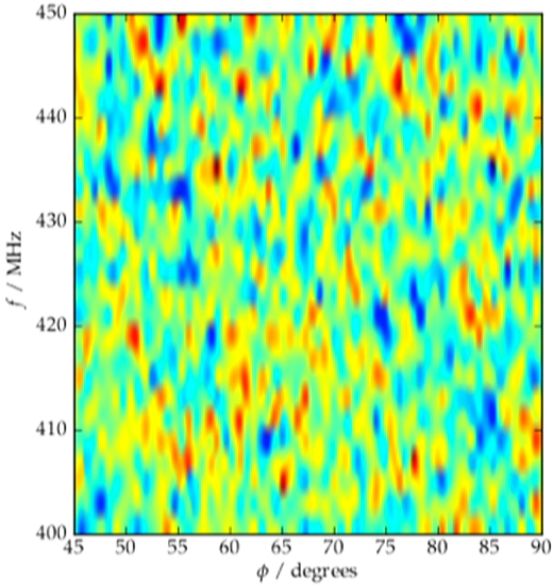




Cosmological 21cm Signal ~ 1mK

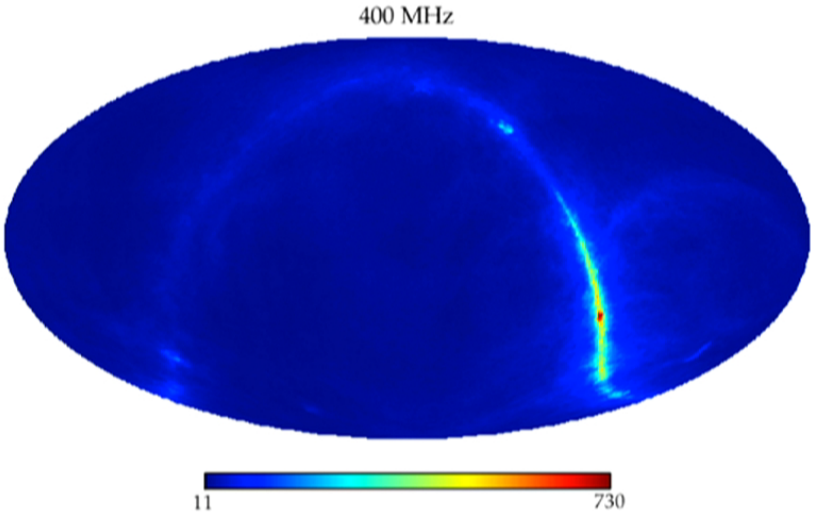
Foreground Challenges

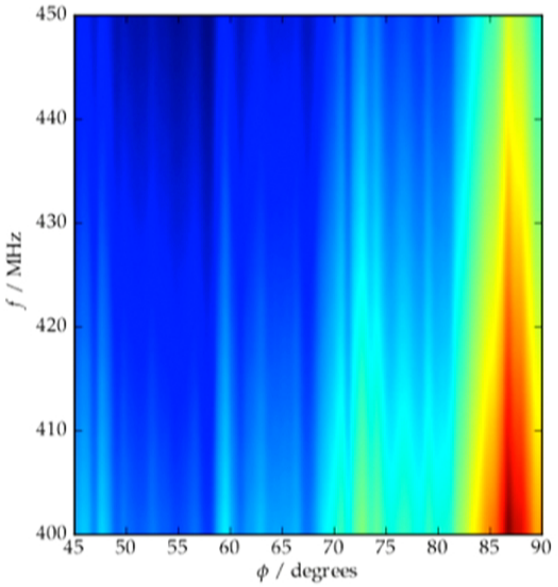




Cosmological 21cm Signal ~ 1mK

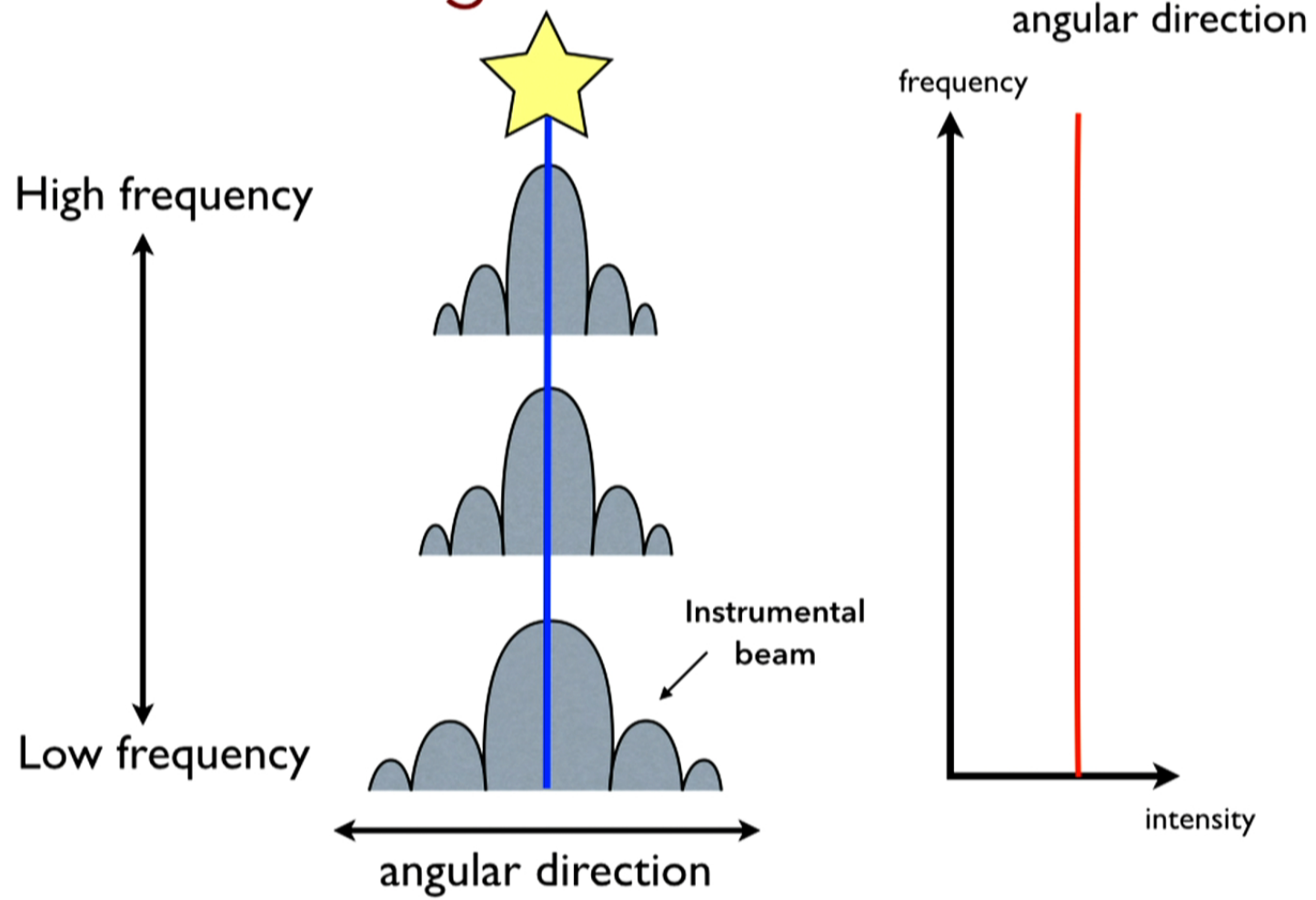
Foreground Challenges





Galaxy: up to 700K

Mode mixing


High frequency
Low frequency
Instrumental beam
angular direction
Sum along angular direction
frequency
intensity


Canadian Hydrogen Intensity
Mapping Experiment

CHIME Collaboration

McGill

Kevin Bandura
J-F Cliche
Matt Dobbs
Adam Gilbert
David Hanna
Juan Mena Parra
Graeme Smecher
Amy Tang

UNIVERSITY OF TORONTO

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Nolan Denman
Peter Klages
Laura Newburgh
Ue-Li Pen
Andre Recnick
Keith Vanderlinde

UBC

Mandana Amiri
Meiling Deng
Mateus Fandino
Kenneth Gibbs
Carolin Hofer
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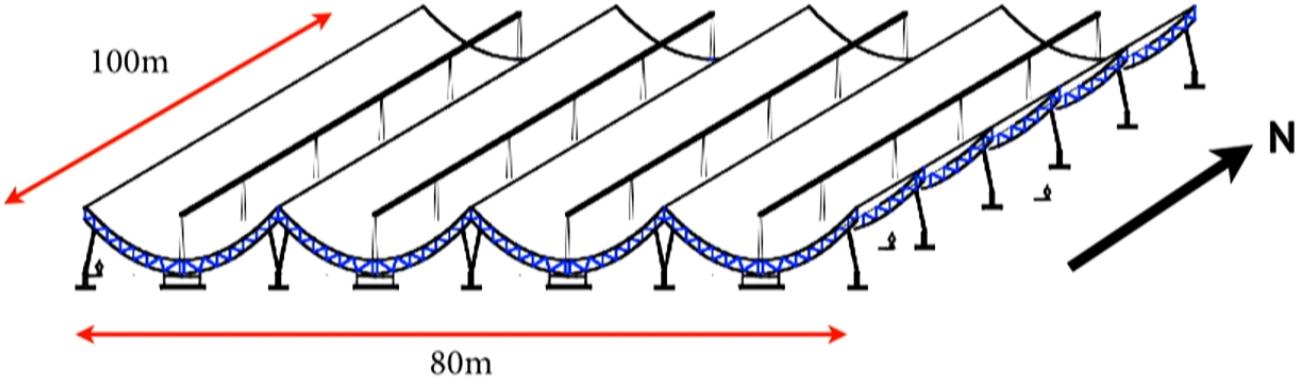
Adam Hincks
Gary Hinshaw
Kiyoshi Masui
Richard Shaw
Kris Sigurdson
Mike Sitwell
Rick Smegal
Don Wiebe

DRAO
NRC · CNRC

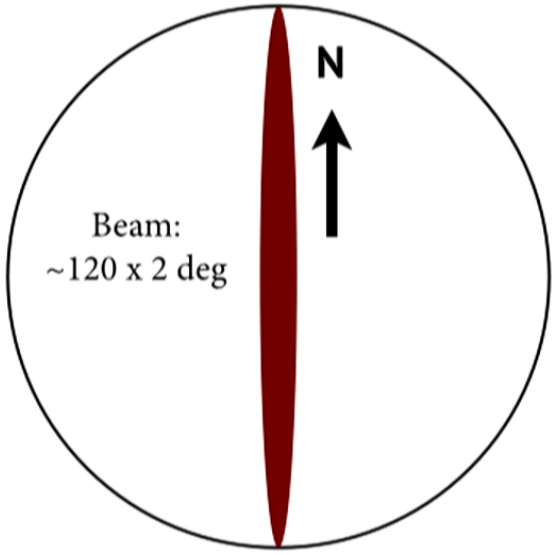
Tom Landecker

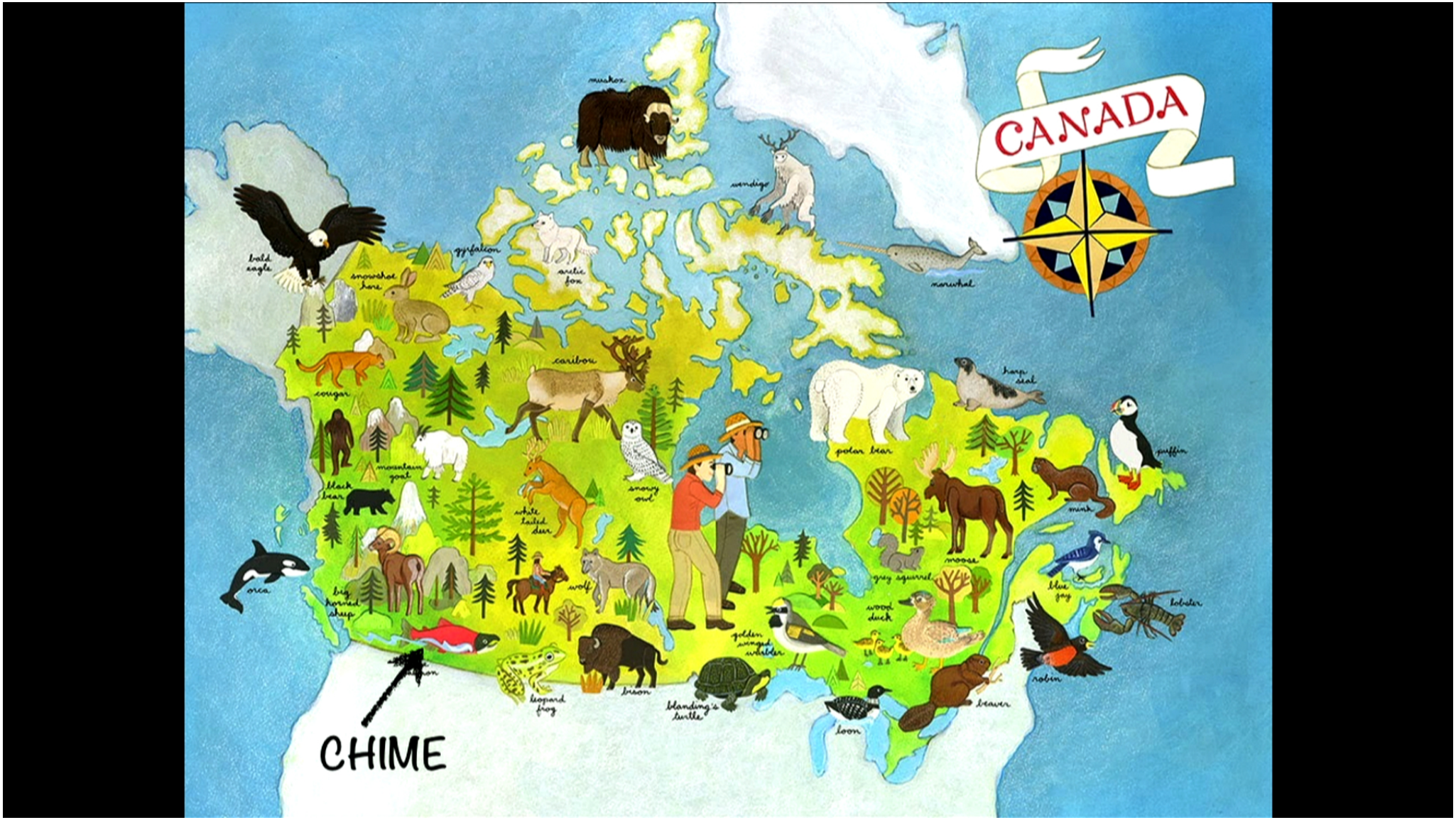
Kendrick Smith (Perimeter)
Jeff Peterson (CMU)

CHIME Overview



- Located at DRAO in BC
- Transit radio interferometer
  - Observe between 400-800 MHz
  - 0.4 MHz spectral resolution
  - 1024 dual pol antennas (T_{recv} = 50K)
- 120 x 2 degree FoV




CANADA
CHIME
musk ox
wendigo
narwhal
bald eagle
gyrfalcon
snowshoe hare
arctic fox
caribou
cougar
harp seal
polar bear
puffin
mountain goat
black bear
snowy owl
white tailed deer
mink
moose
orca
wolf
grey squirrel
blue jay
big horned sheep
wood duck
lobster
golden winged warbler
robin
leopard frog
bison
blanding's turtle
beaver
loon


BAFFIN SEA
Banks Island
Somerset Island
Prince of Wales Island
BEAUFORT SEA
Victoria Island
Baffin Island
Davis Strait
King William Island
NUNAVUT TERRITORY
Foxe Basin
ARCTIC CIRCLE
YUKON TERRITORY
NORTHWEST TERRITORIES
Great Bear Lake
Great Slave Lake
Hudson Bay
Labrador Sea
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUÉBEC
NEWFOUNDLAND
Queen Charlotte Islands
Vancouver Island
PACIFIC OCEAN
Lake Winnipeg
Calgary
Regina
Winnipeg
Vancouver
Seattle
Portland
Minneapolis
Milwaukee
Toronto
Montréal
Québec
OTTAWA
Detroit
Chicago
Cleveland
Pittsburgh
Boston
New York
NOVA SCOTIA
Nova Scotia
ATLANTIC OCEAN
UNITED STATES
CHIME
CANADA
0 km 300 600 900 km
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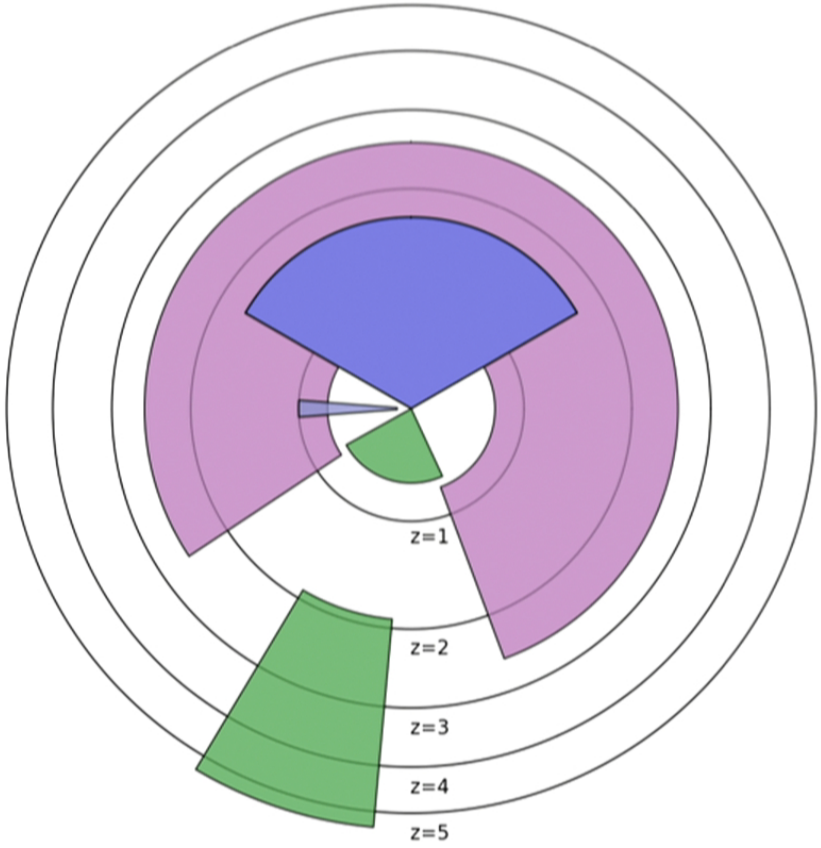
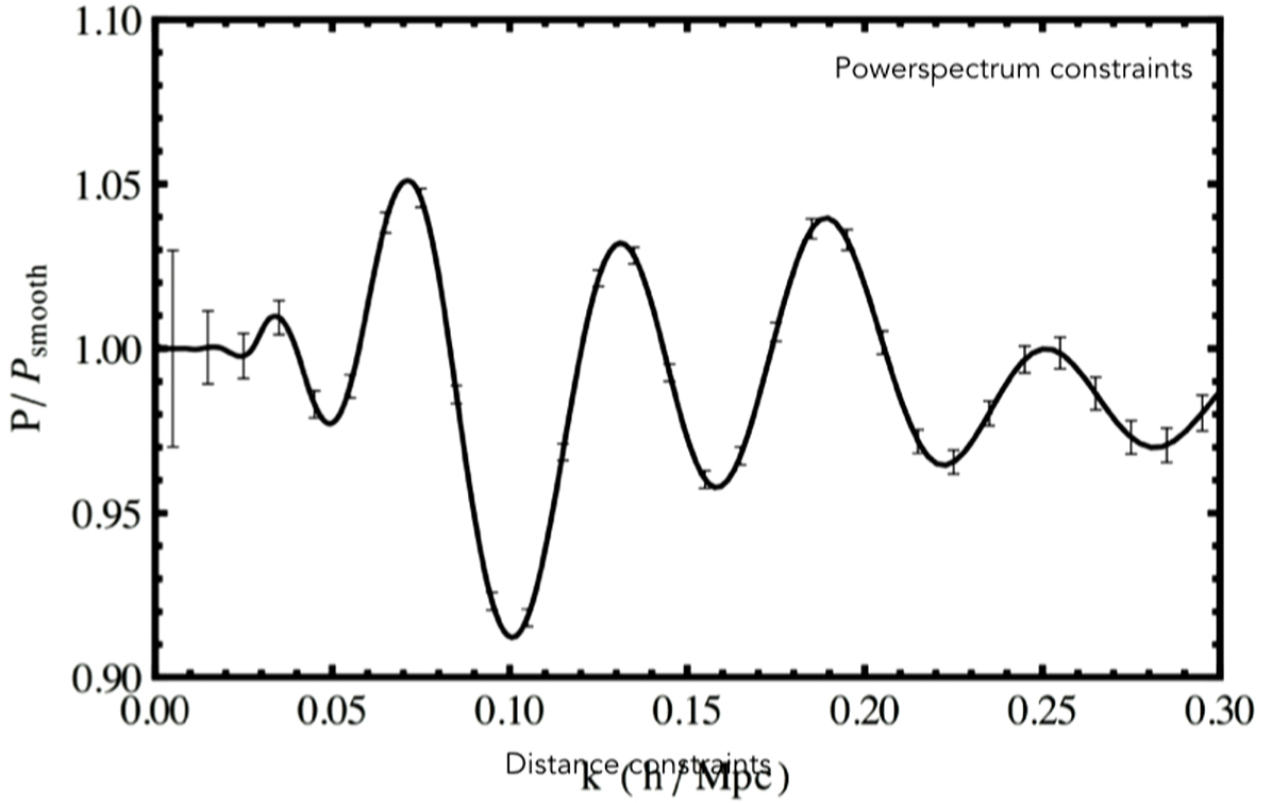
Survey Volume

- WiggleZ: 1.2 $(h^{-1}\ Gpc)^3$
- BOSS
  - LRG: 5.3 $(h^{-1}\ Gpc)^3$
  - Lyα: 37 $(h^{-1}\ Gpc)^3$
- CHIME: 203 $(h^{-1}\ Gpc)^3$
- DESI ELG: 50 $(h^{-1}\ Gpc)^3$

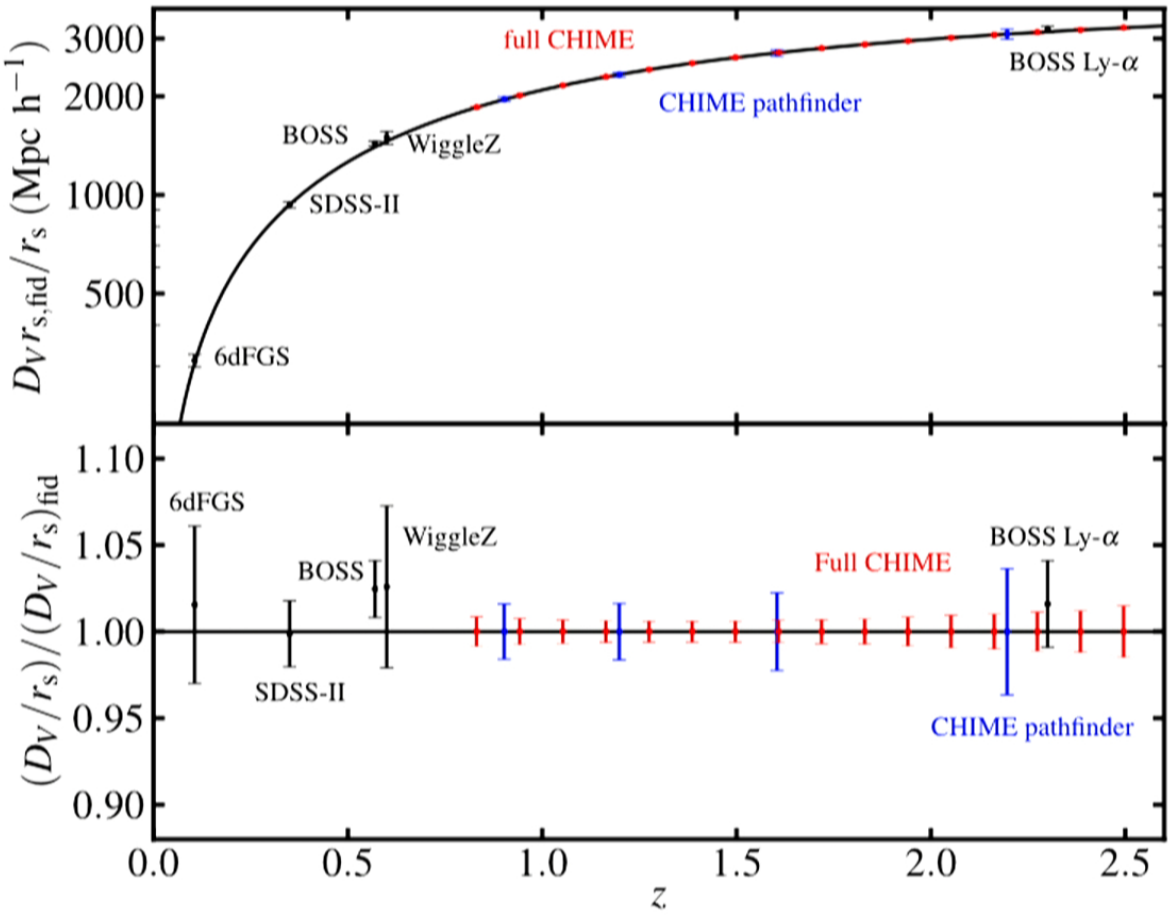


Scaled such that:
area of patch=volume of survey

BAO Forecasts



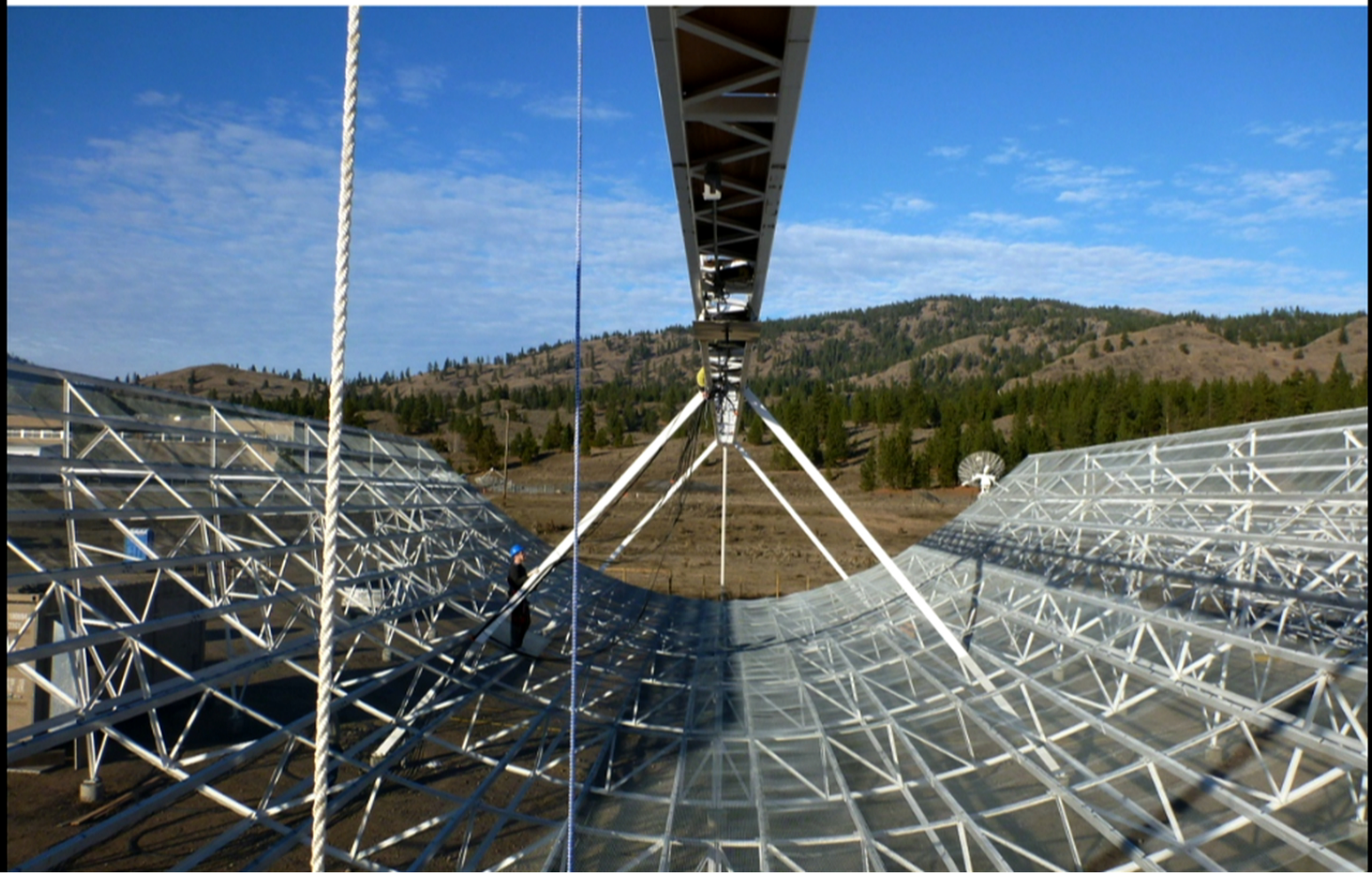
BAO Forecasts



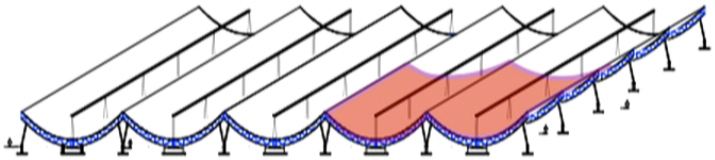
CHIME Status

- Construction completed!

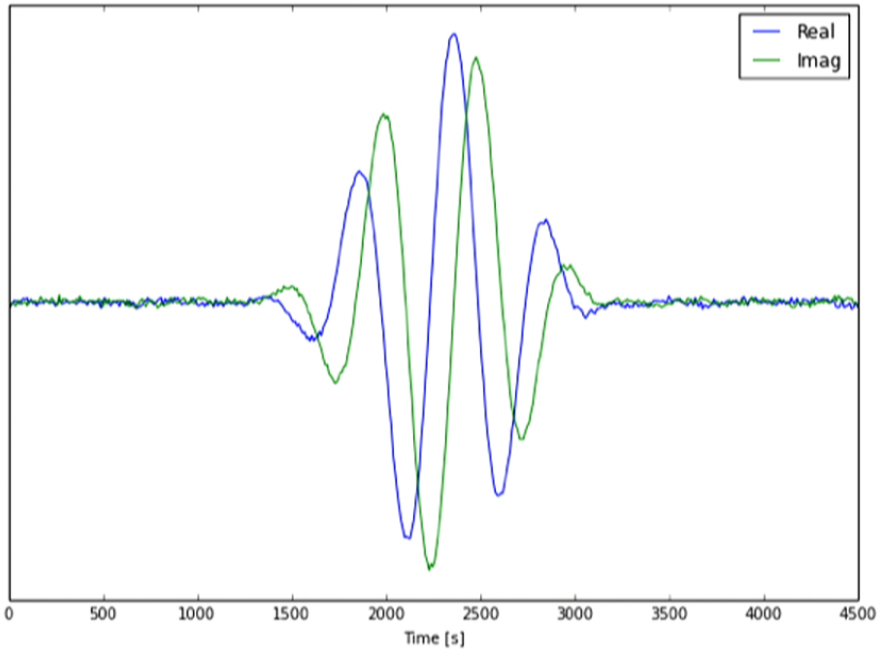
CHIME Pathfinder



CHIME Pathfinder



- 2x20m cylinder, 40m long
- First light was late 2013
- Pathfinder analysis ongoing



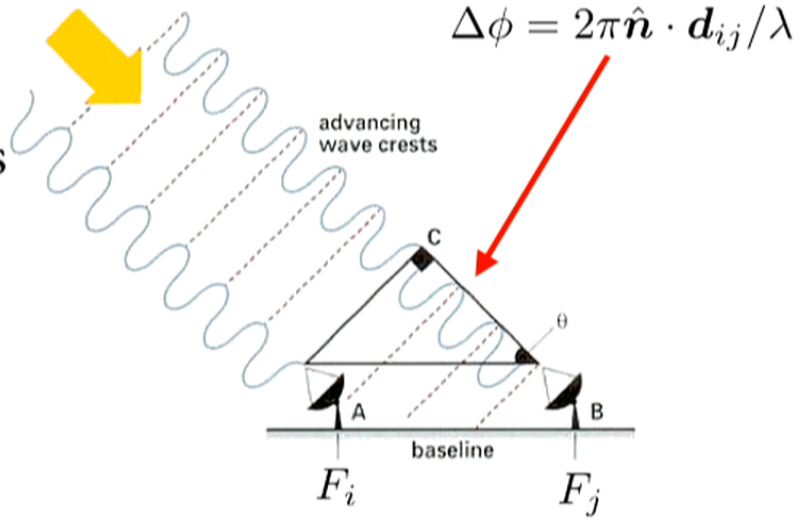
Data Analysis with the m-mode formalism

arXiv:1302.0327; arXiv:1401.2095

Data Analysis

- Analysis is challenging:
  - Wide field at given instant *(~ 120 x 2 degrees)*
  - Effectively an all sky survey *(3π sr)*
  - Data volume *(>~ 1 TB/day for pathfinder)*
  - Polarisation leakage
  - **Foreground removal** *(> 10^6 times brighter)*

Interferometers



- Visibility is instantaneous correlation of 2 antennas

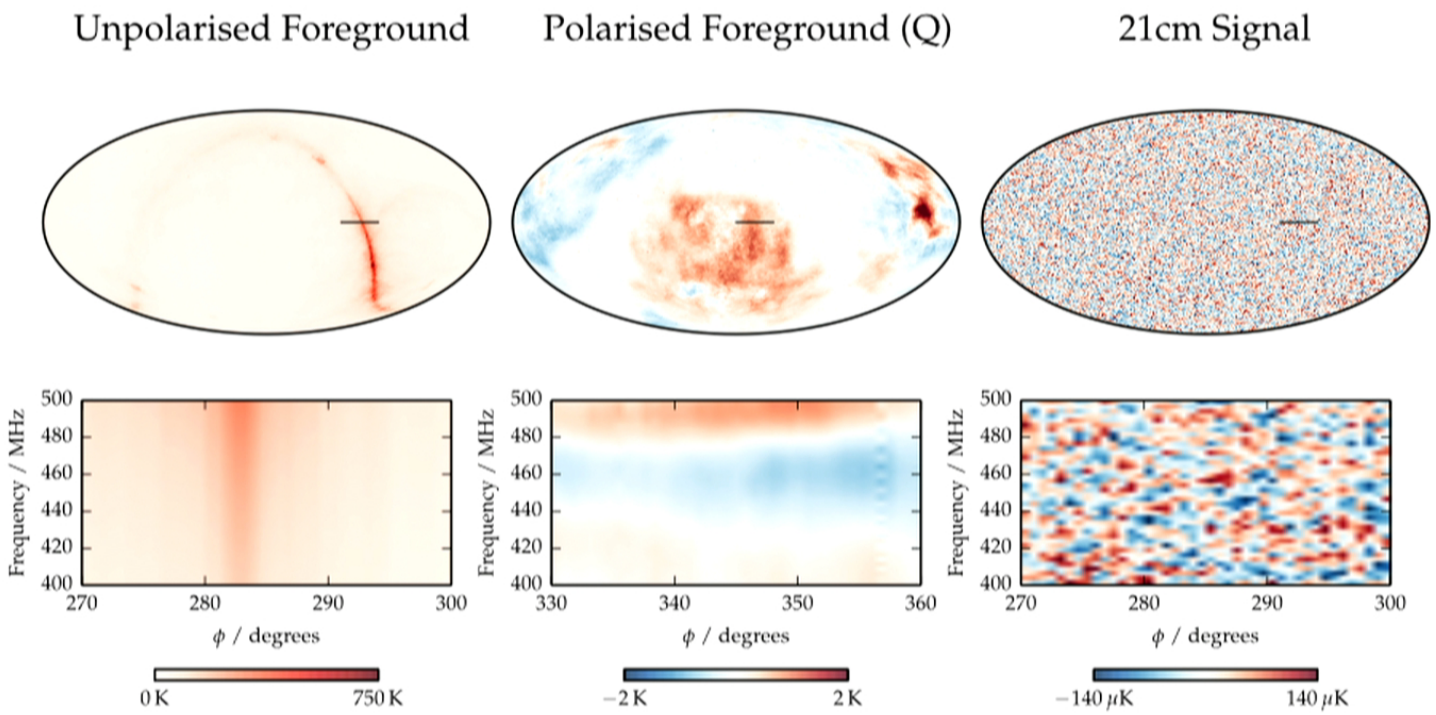
$$V_{ij} = \langle F_i F_j^* \rangle$$

- Written explicitly:

$$V_{ij}(t) = \frac{1}{\Omega_{ij}} \int d^2\hat{\mathbf{n}}\, A_i(\hat{\mathbf{n}};t) A_j^*(\hat{\mathbf{n}};t) e^{2\pi i \hat{\mathbf{n}}\cdot\mathbf{u}_{ij}(t)} T(\hat{\mathbf{n}})$$

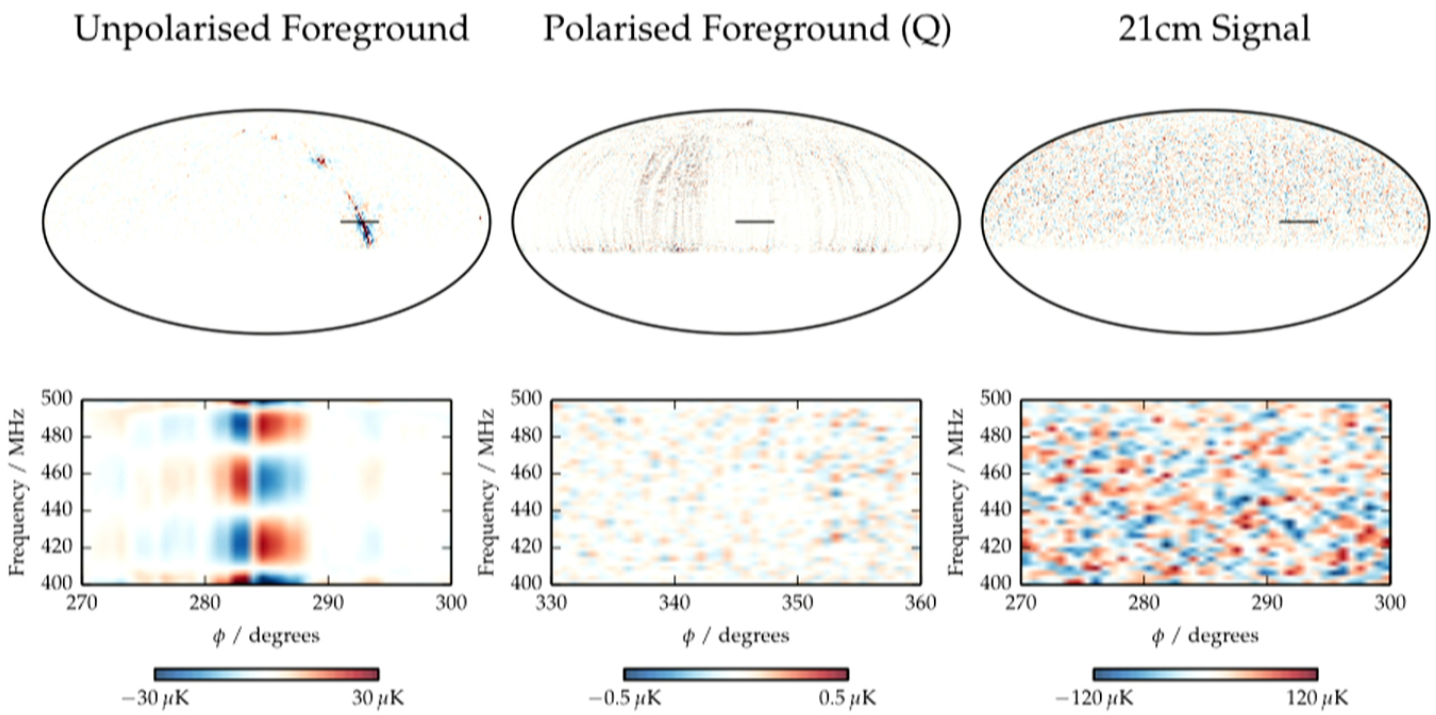
- Traditional analysis approximates this to a 2D Fourier transform and proceeds from there.

Foreground Cleaning



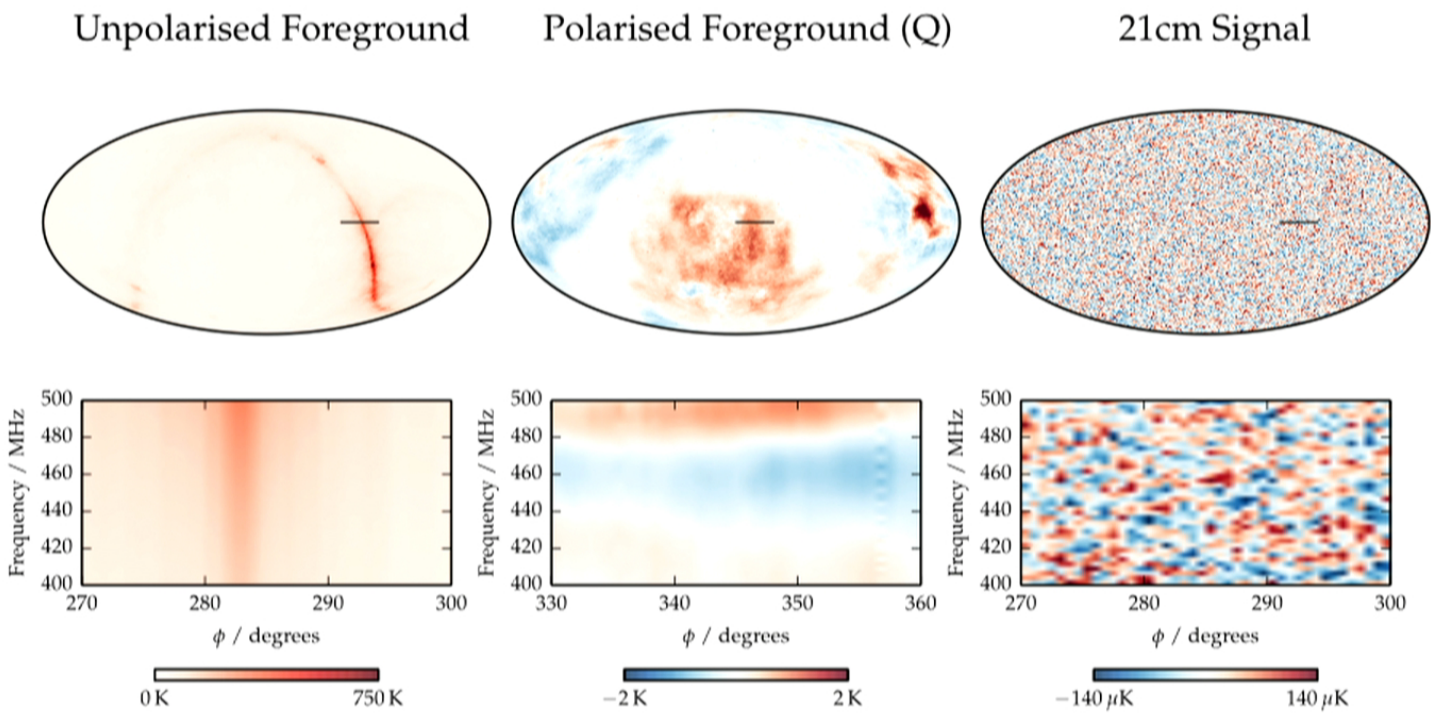
Foregrounds 10^6 times larger than signal

Foreground Cleaning



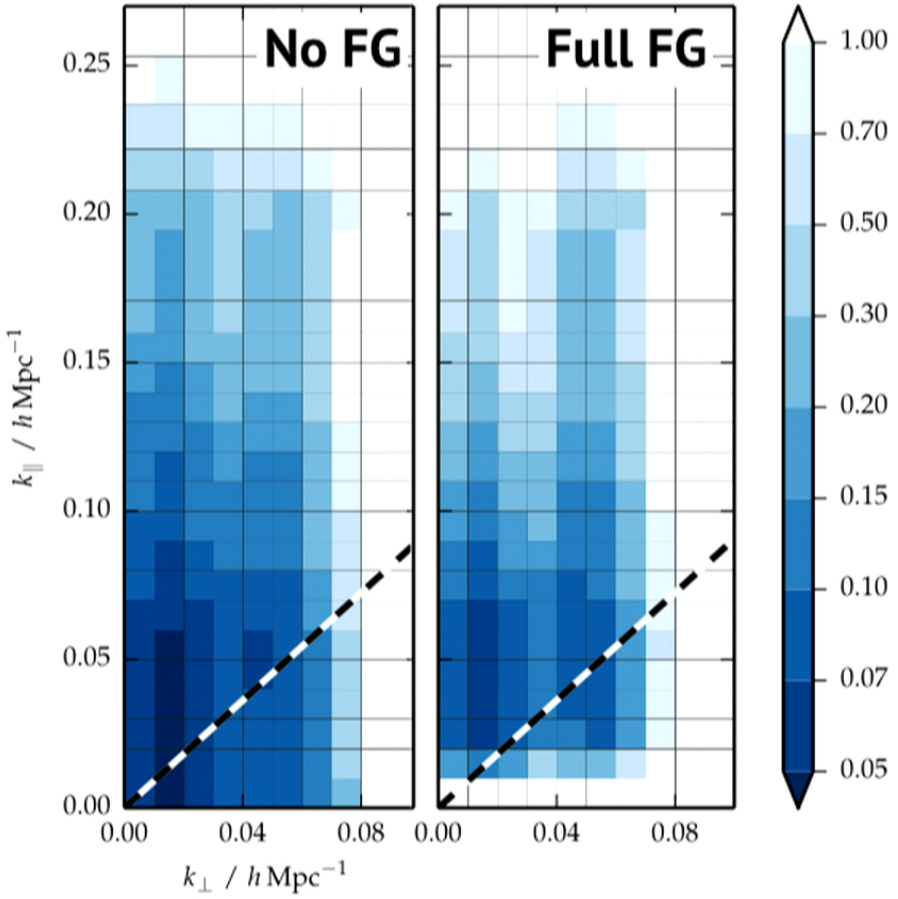
Foreground residuals significantly smaller than signal

Foreground Cleaning



Foregrounds 10^6 times larger than signal

2D Power spectrum Estimation



Fractional powerspectrum errors (blue is better)

Subtraction works well into foreground wedge

Summary

- BAOs are an alternative probe of dark energy
- 21cm Intensity Mapping is a promising technique for mapping the Universe and measuring BAOs - foregrounds are challenging
- CHIME Pathfinder is operating, full instrument construction finished summer 2015
- Analysis is fun! Polarised radio sky simulation and 21cm data analysis code all available at:

http://github.com/radiocosmology/