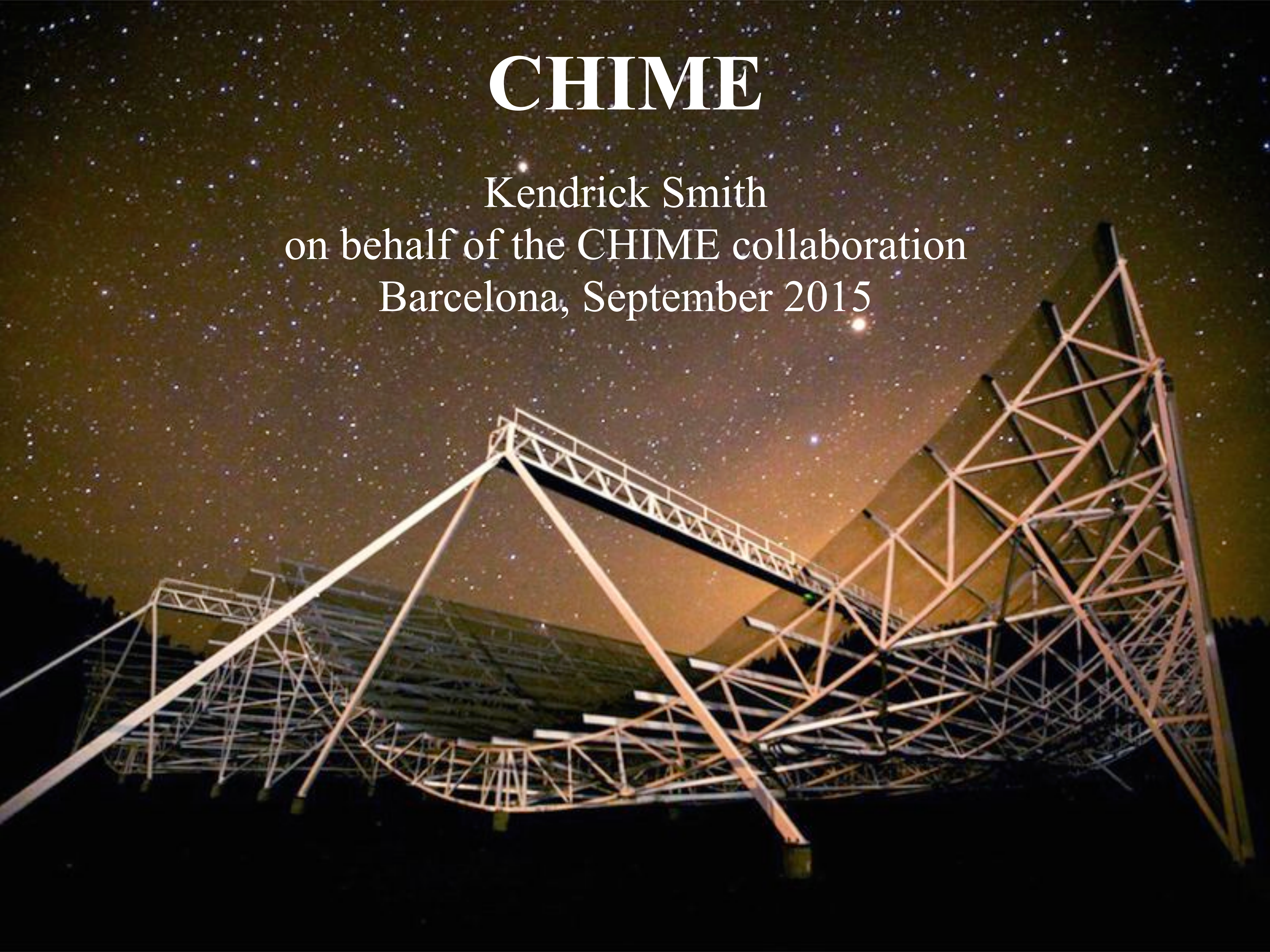
CHIME

Kendrick Smith
on behalf of the CHIME collaboration
Barcelona, September 2015



chime

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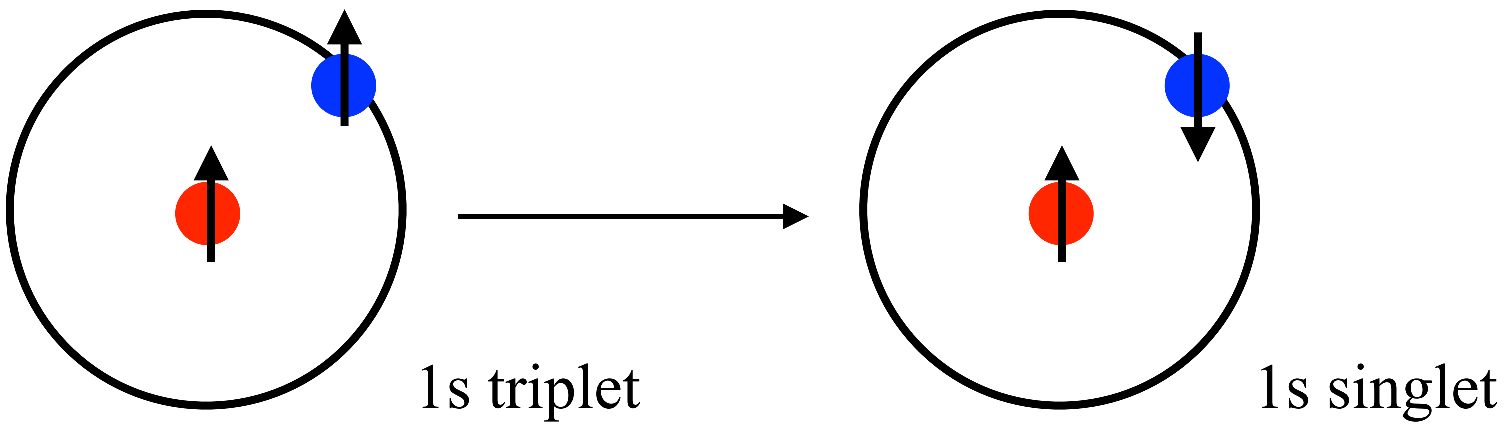
21-cm emission as a tracer of large-scale structure

Neutral hydrogen (HI) has a long-lived emission line at λ_0=21cm



21-cm emission as a tracer of large-scale structure

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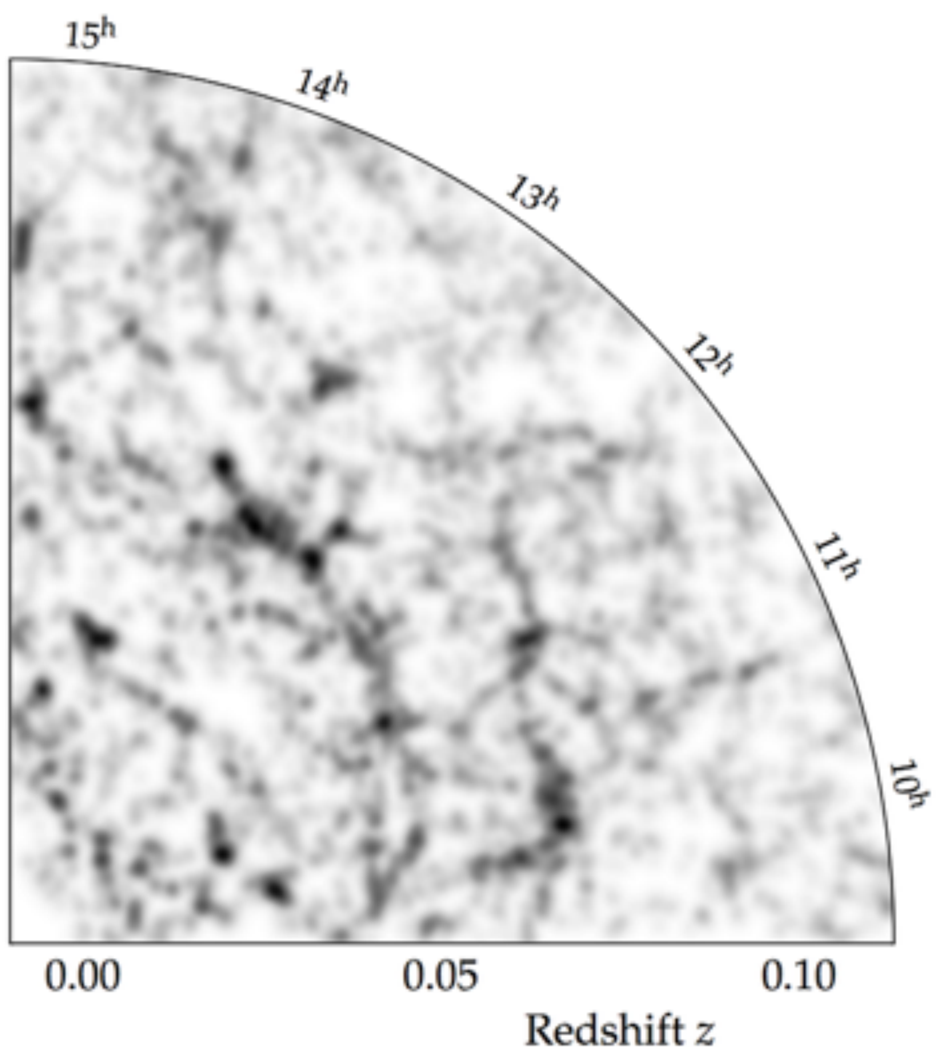
Intensity mapping: by observing the radio sky as a function of angle θ,ϕ and wavelength λ, make a 3D map of fluctuations in HI density (or HI thermal state).



Chang et al 2008,
Wyithe and Loeb 2008

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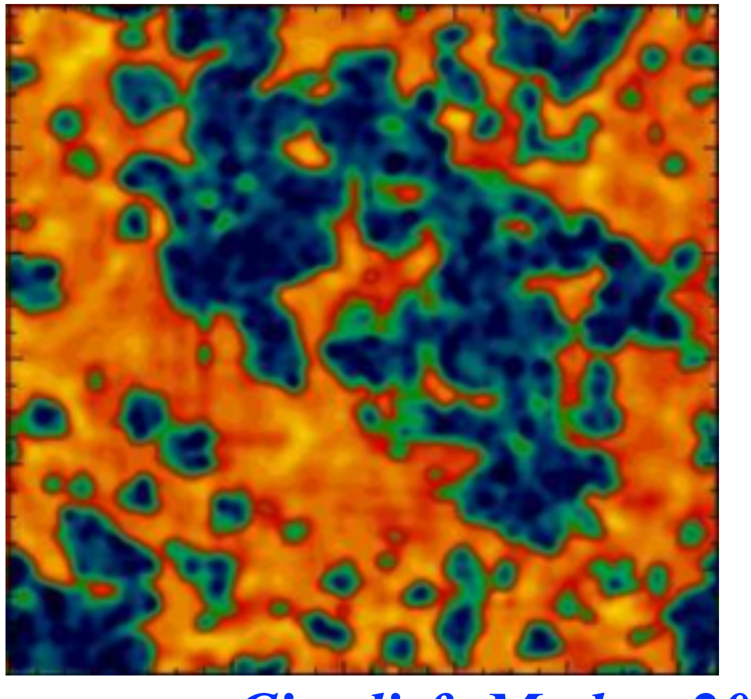
At high redshifts ($5 \lesssim z \lesssim 12$), HI fluctuations are mainly sourced by reionization bubbles; we get a map of patchy reionization.



Ciardi & Madau 2003

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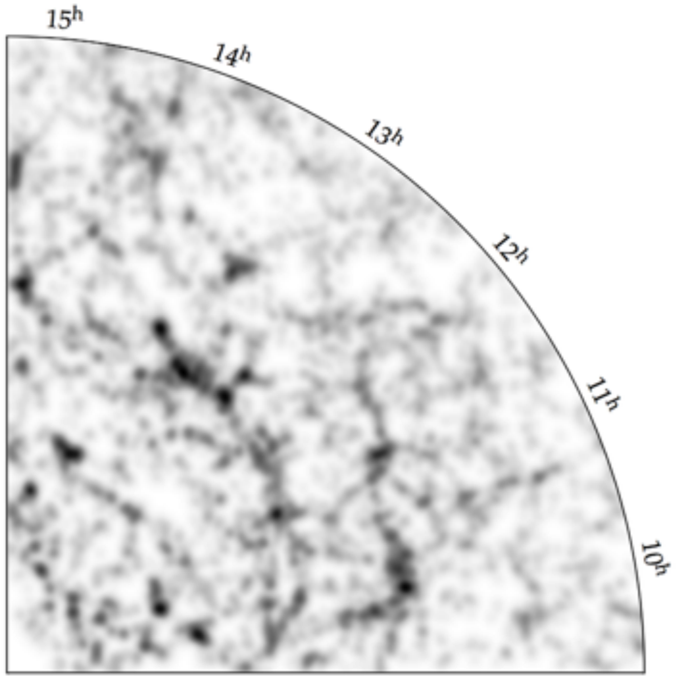
At low redshifts, hydrogen is mostly ionized.
Some HI survives in "self-shielding" systems.
(CHIME: $0.8 \leq z \leq 2.5$)



21-cm emission as a tracer of large-scale structure

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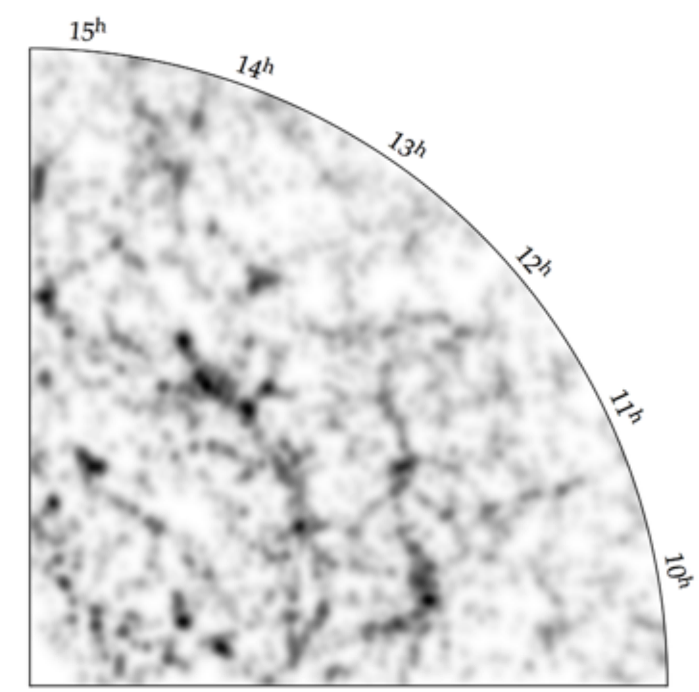
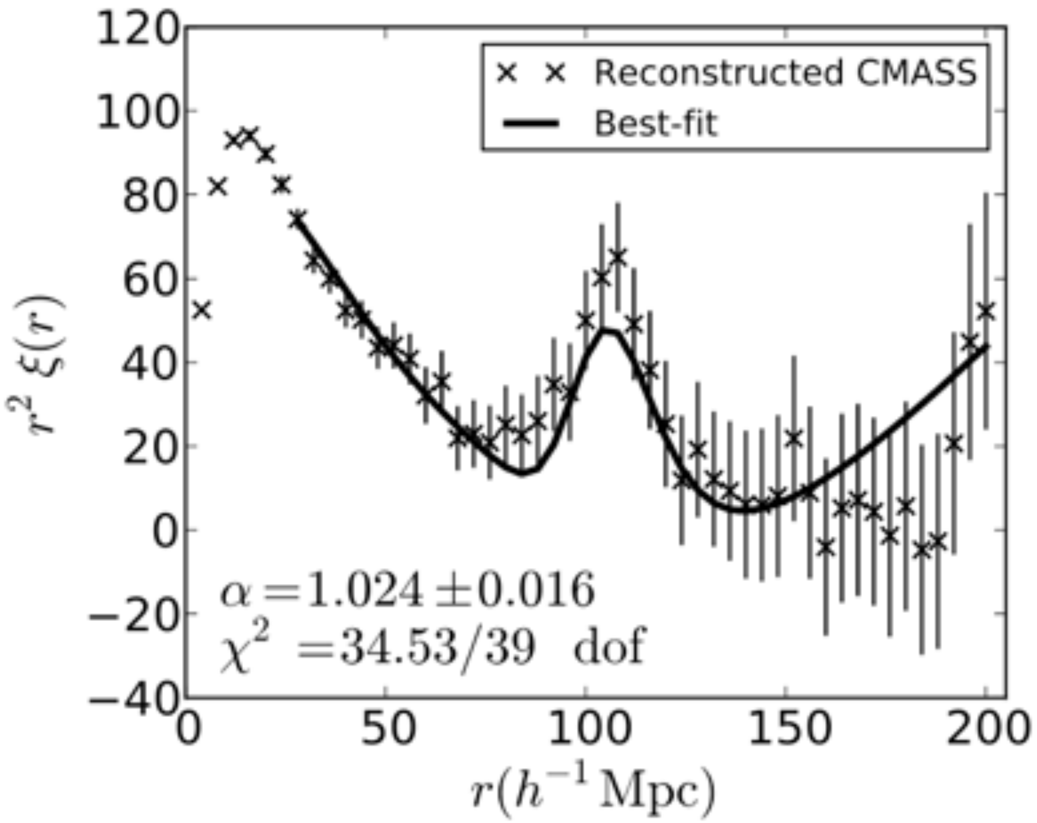
Since HI systems trace large-scale structure, we get a 3D map of the cosmological density field (individual HI systems unresolved)



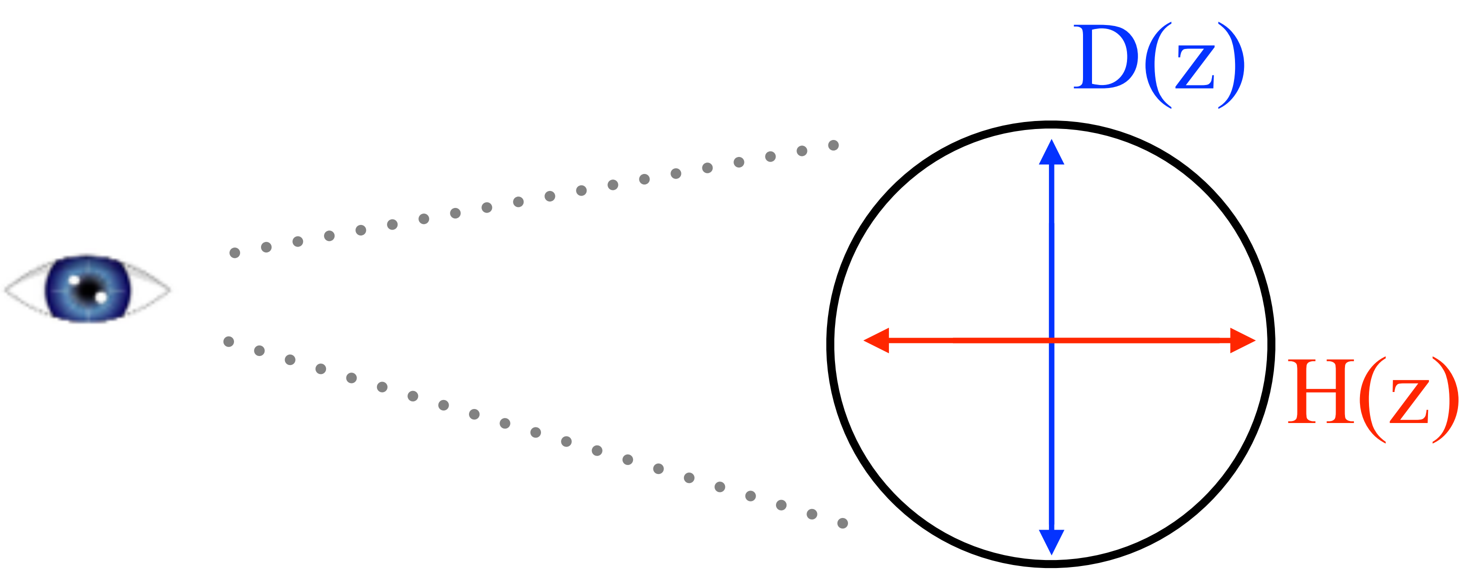
21-cm emission as a tracer of large-scale structure

Can use this 3D map to do large-scale structure: baryon acoustic oscillations, lensing, redshift-space distortions, etc.

Main goal of CHIME is to measure the BAO "standard ruler"

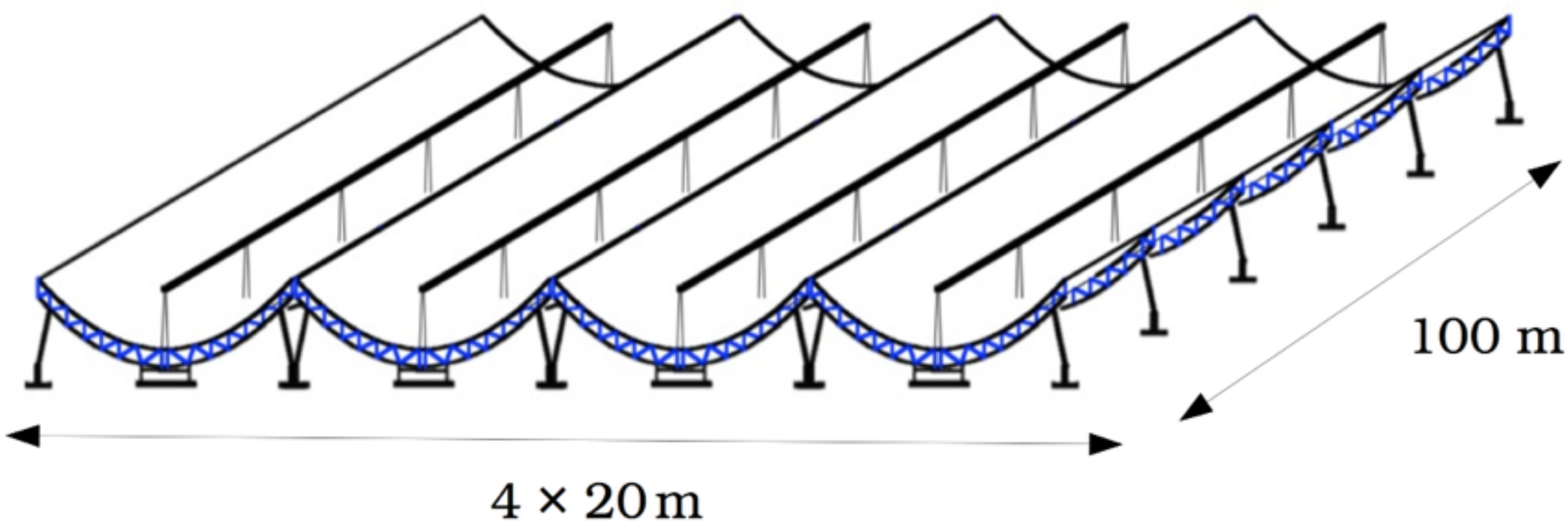


SDSS (2012)

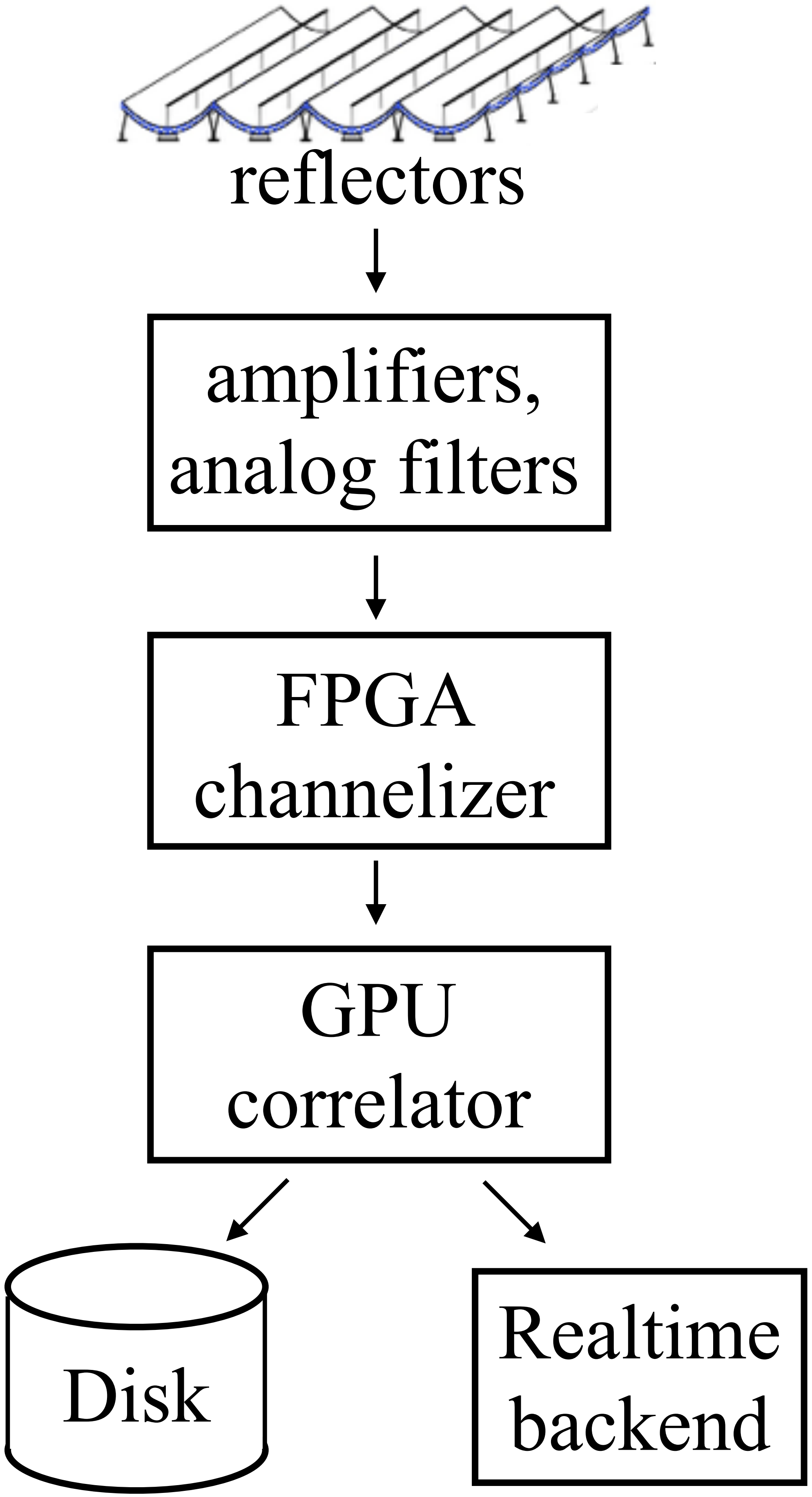


CHIME

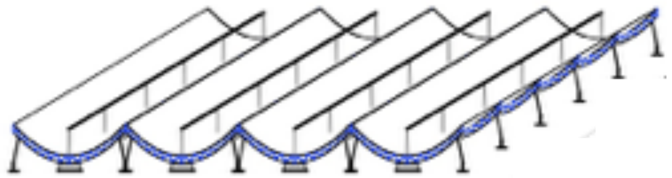
- No moving parts, sky is surveyed via Earth rotation
- Frequency range 400-800 MHz (redshift $0.8 \leq z \leq 2.5$)
- "Pathfinder" instrument running! (128 dual-pol feeds, 40x25 m^2)
- Full instrument under construction (1024 feeds, 80x100 $m^{2)}$



CHIME


reflectors
amplifiers, analog filters
FPGA channelizer
GPU correlator
Disk
Realtime backend

CHIME



reflectors

↓

amplifiers, analog filters

↓

FPGA channelizer

↓

GPU correlator

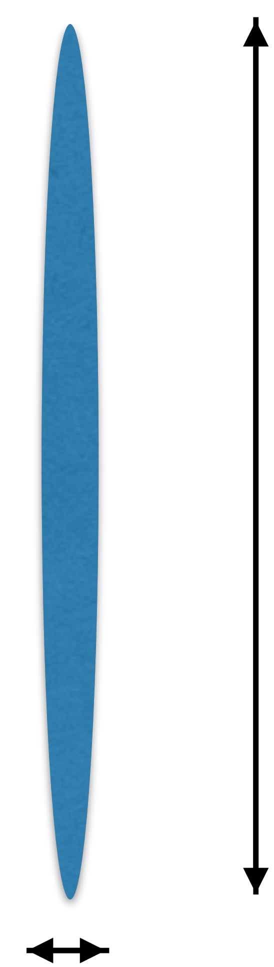
↙ ↘

Disk

Realtime backend

Reflectors:

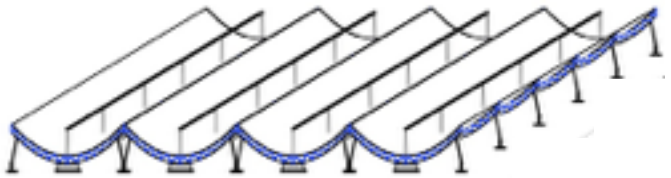
- instrumented with 1024 (4x256) feeds
- each feed "sees" narrow primary beam
- Earth rotation gives full sky coverage



North-South: ~100 deg

East-West: ~1.3 deg

CHIME



reflectors

↓

amplifiers, analog filters

↓

FPGA channelizer

↓

GPU correlator

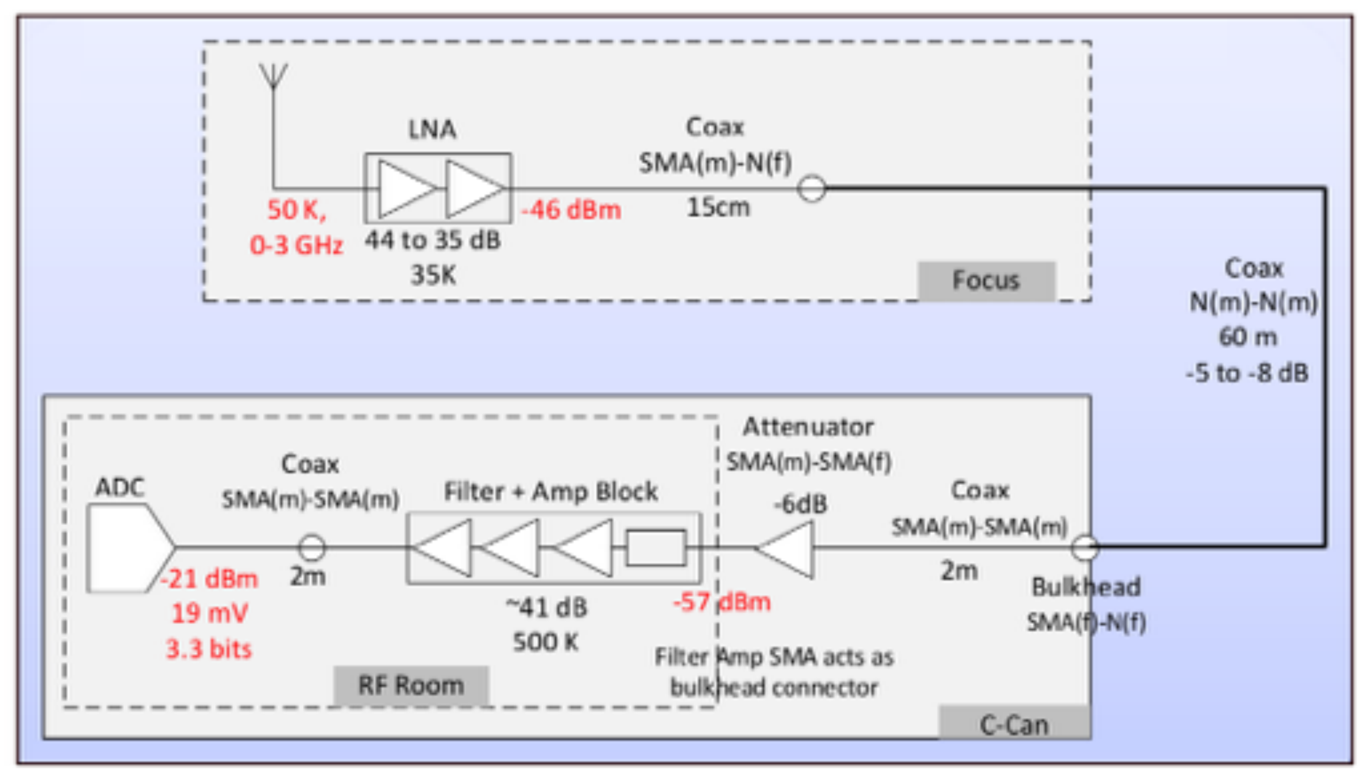
↙ ↘

Disk

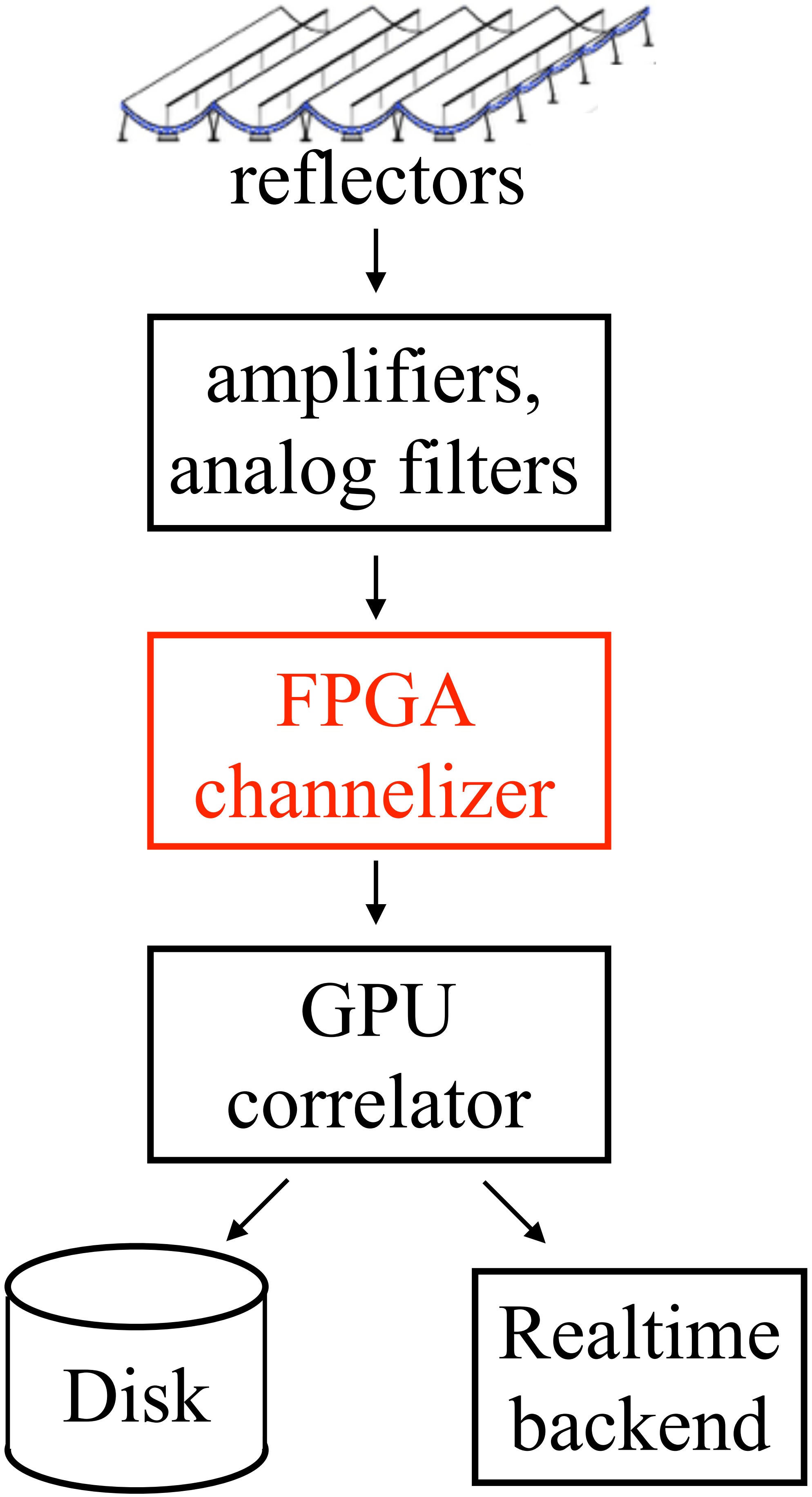
Realtime backend

Analog chain:

- amplifies signal and bandlimits to $400 < \nu < 800$ MHz.
- output of this stage is two analog signals (polarizations) for each feed

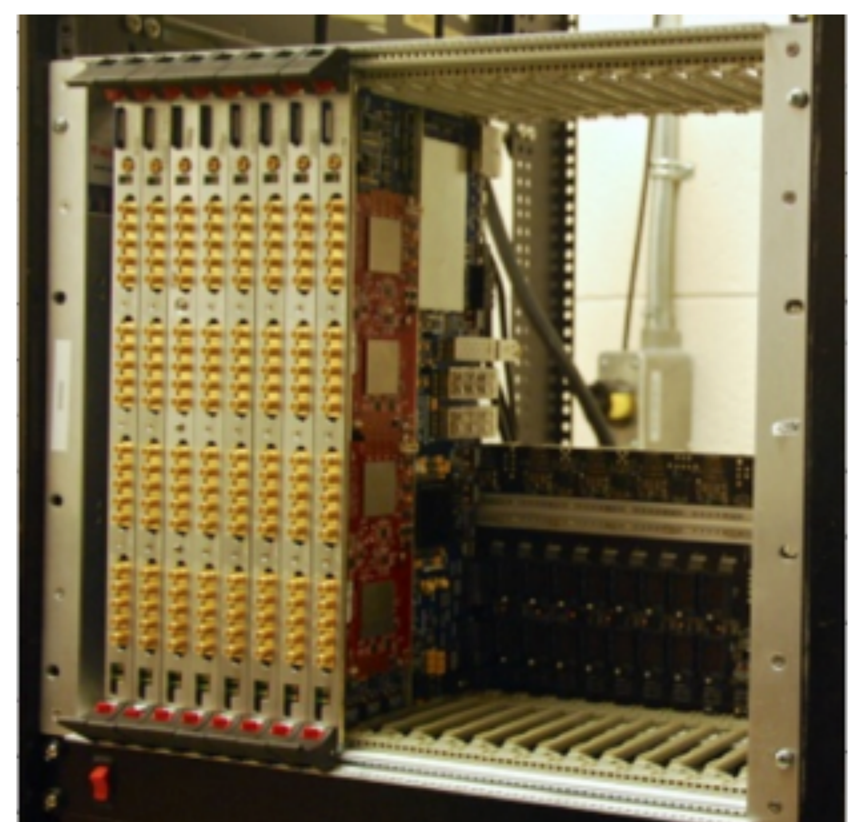


CHIME

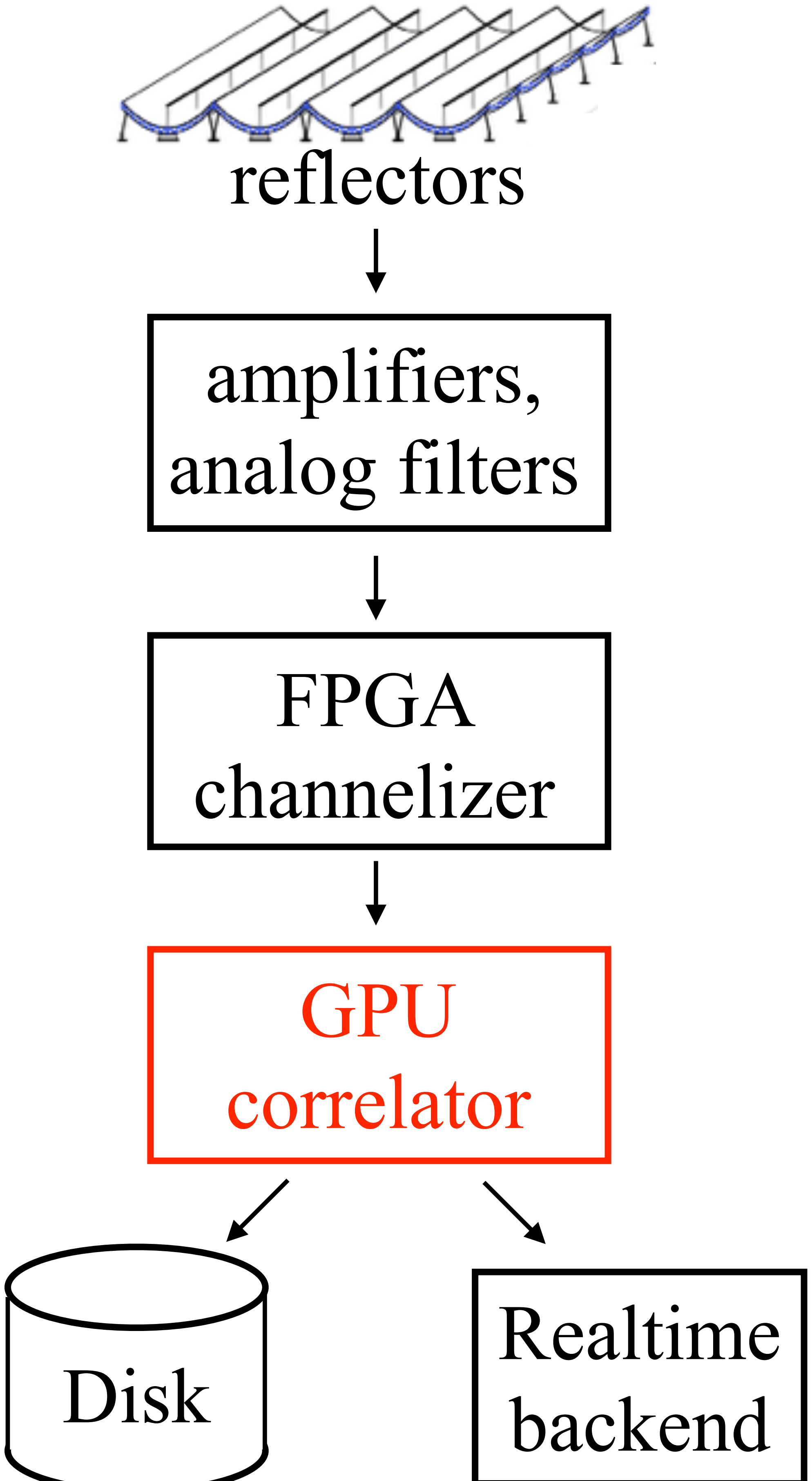


FPGA channelizer:

- analog to digital conversion
- digital channelization into 1024 frequency bands ($\Delta\nu$ = 380 kHZ)
- output of this stage is 1024 digital timestreams per polarization per feed

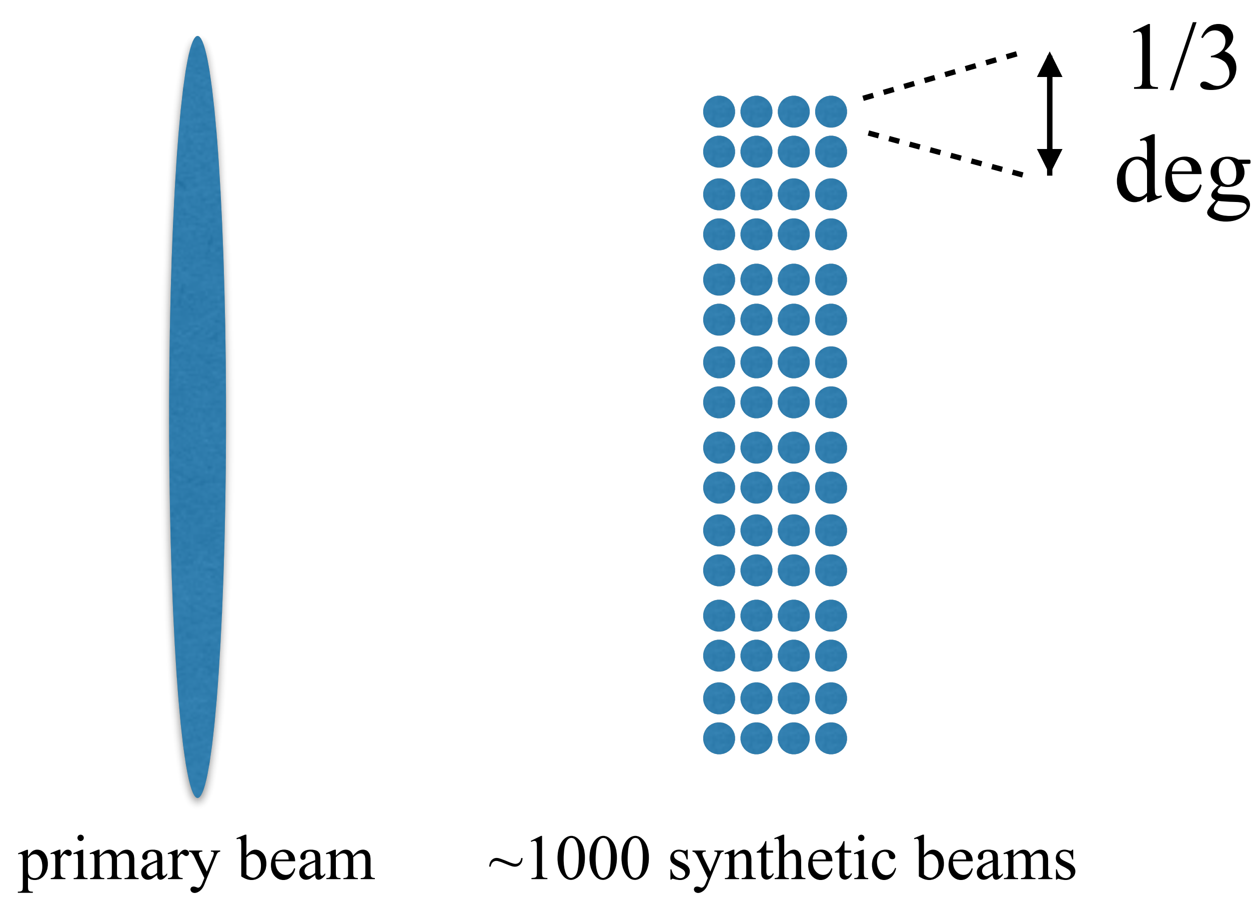


CHIME

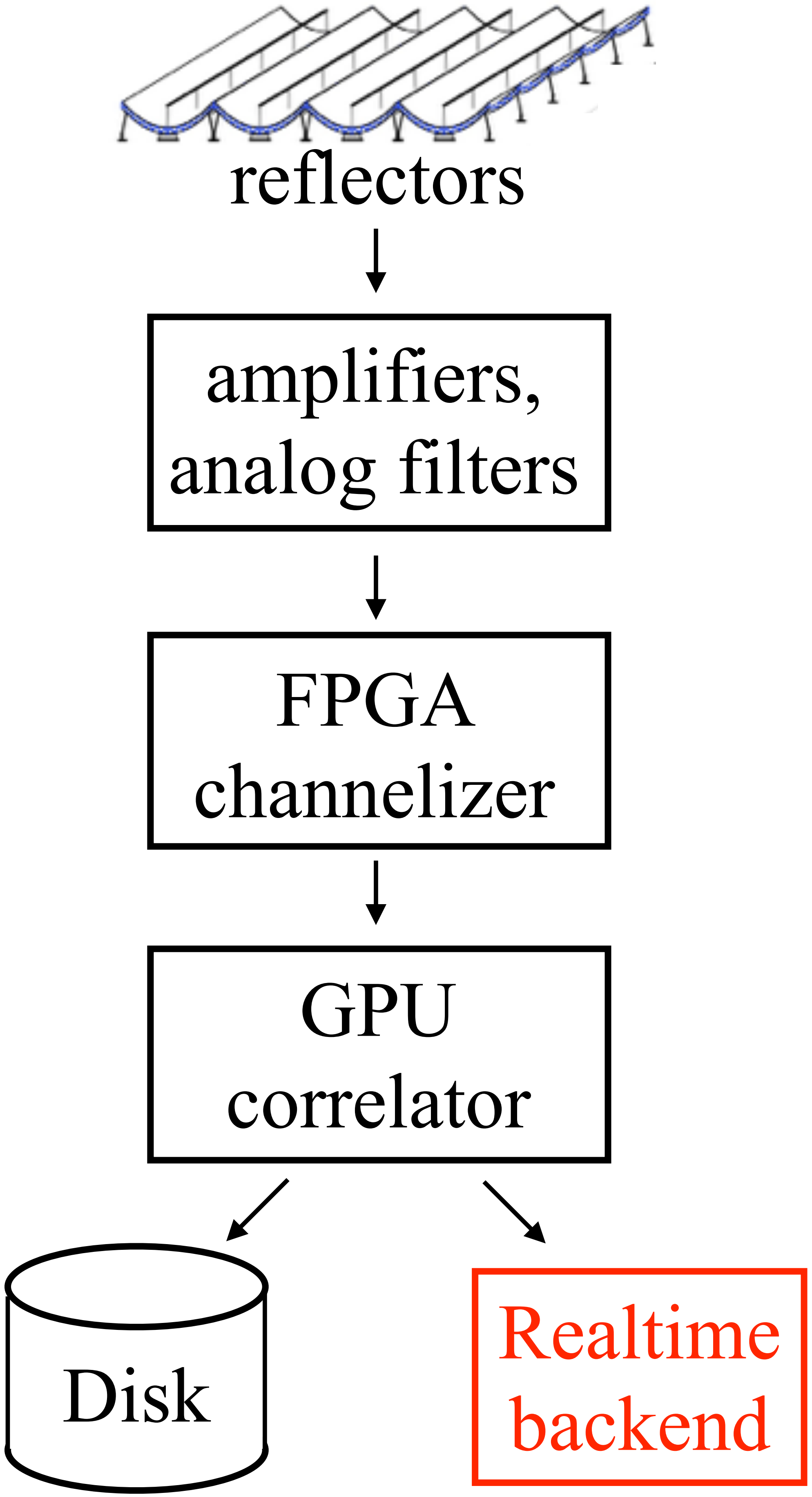


GPU correlator:

- correlates different feeds/polarizations in same frequency channel
- output roughly consists of an I,Q,U,V measurement for every synthetic beam and frequency channel



CHIME



Realtime backend:

- Transient searches have data volumes too large to write to disk, must search in real time.

- E.g. fast radio bursts: duration ~1 ms, data volume is ~1 petabyte/day!

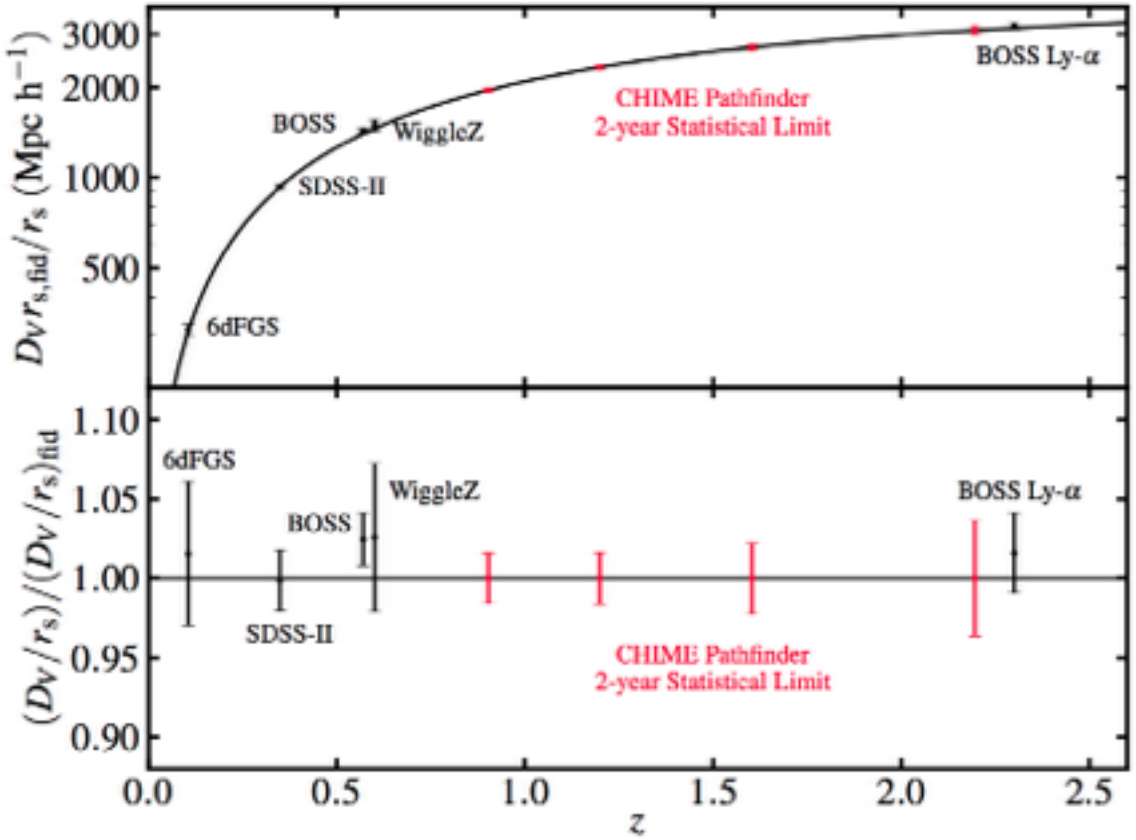
- Backend recently funded, currently in design stage

BAO forecasts

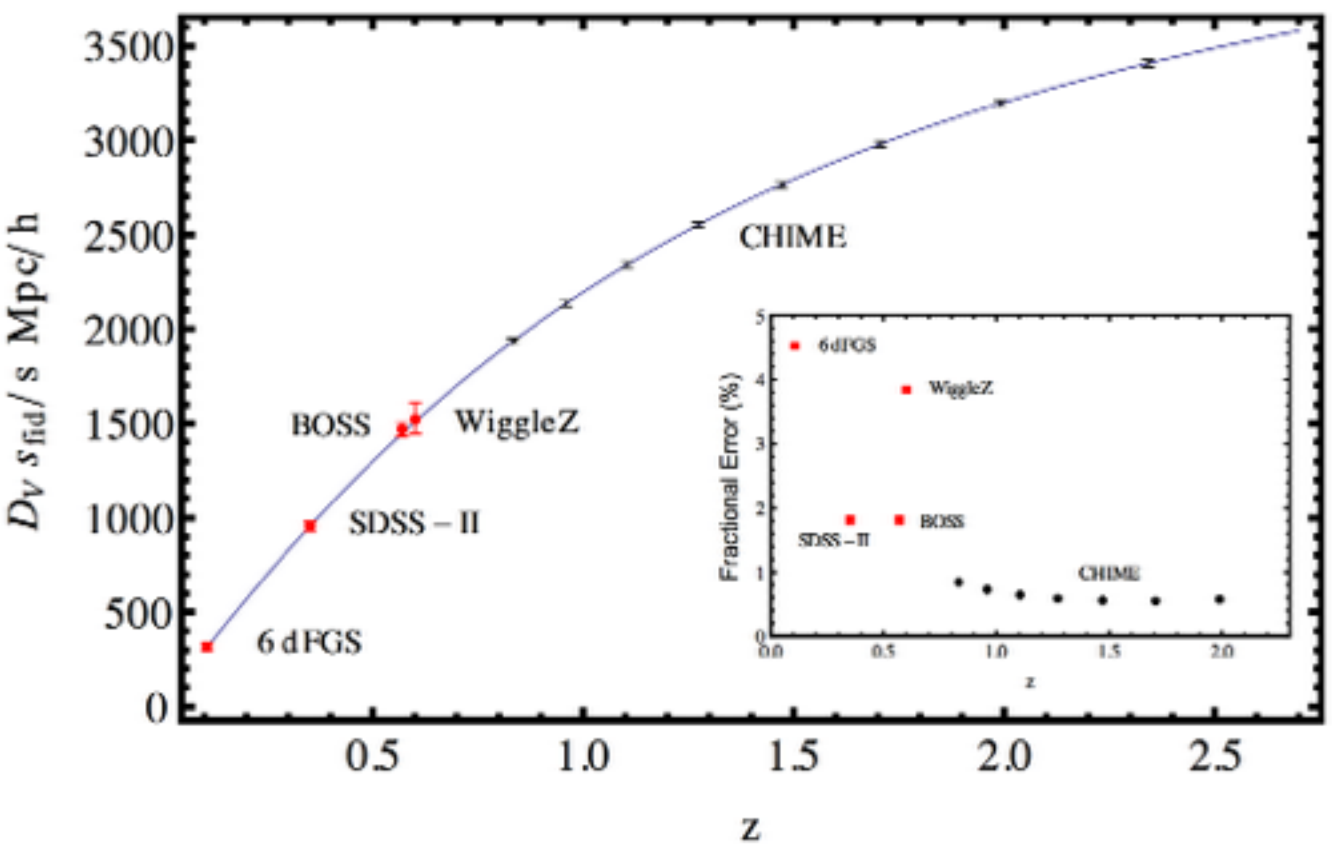
The CHIME pathfinder is an interesting BAO experiment, comparable to current surveys.

Full CHIME is a Stage-IV dark energy experiment!

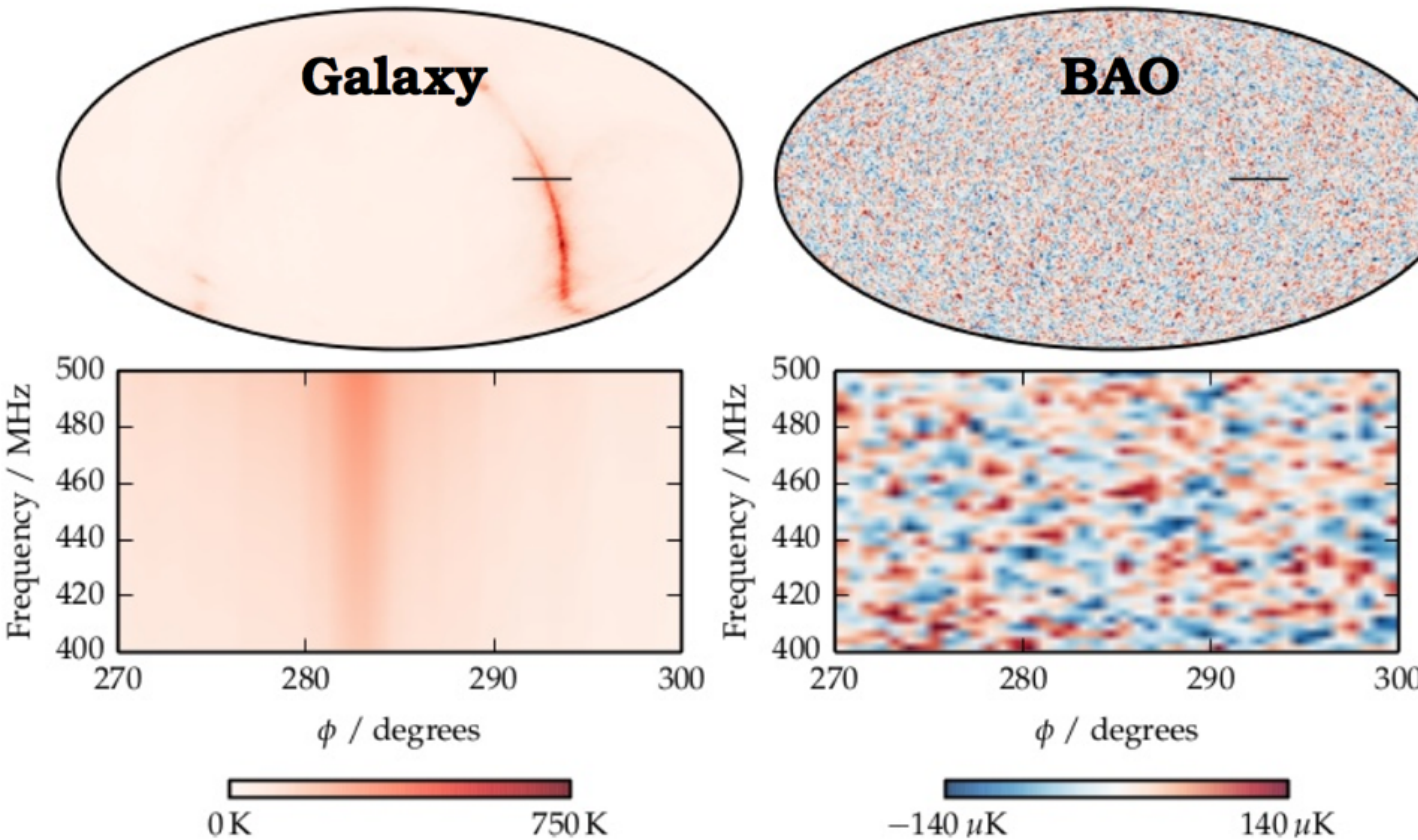
CHIME pathfinder



Full CHIME



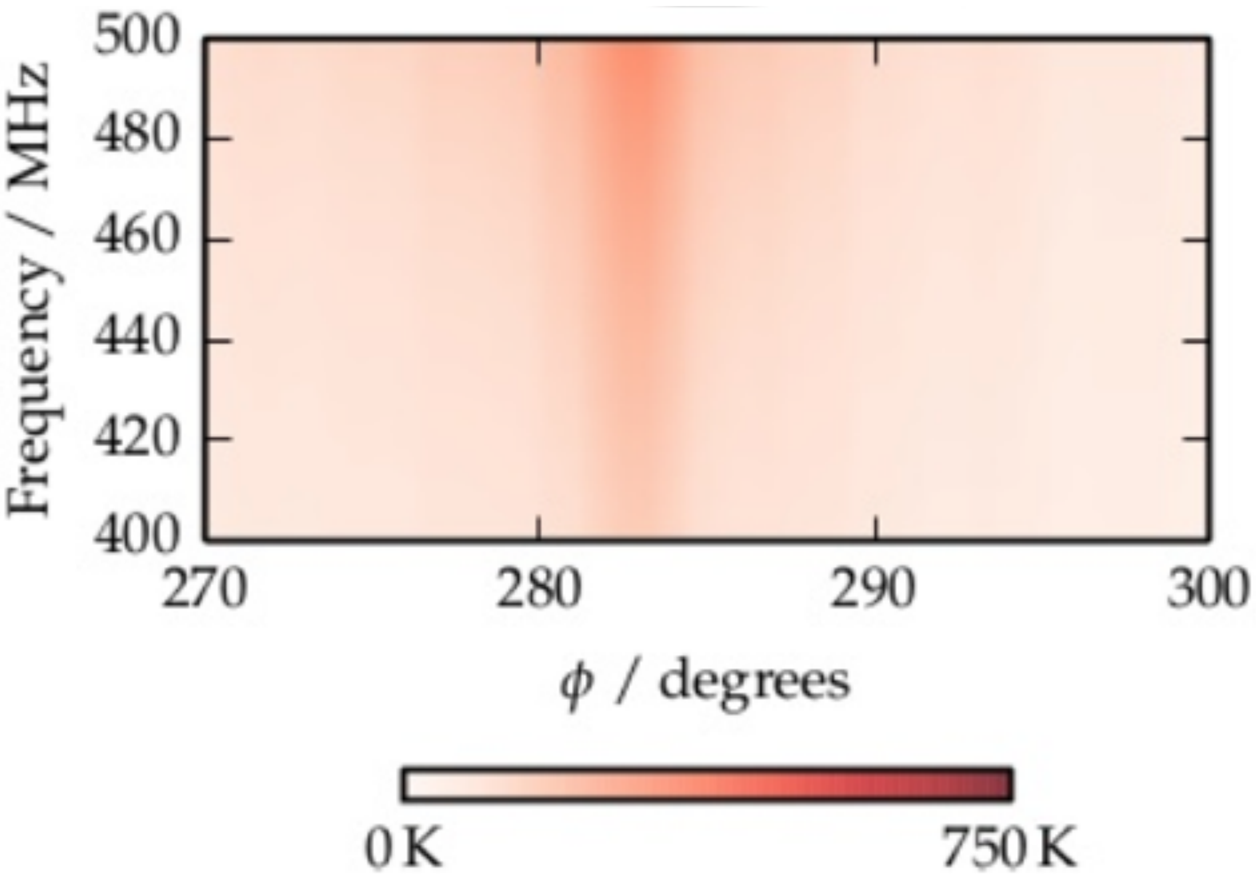
Foregrounds: the reason this is hard

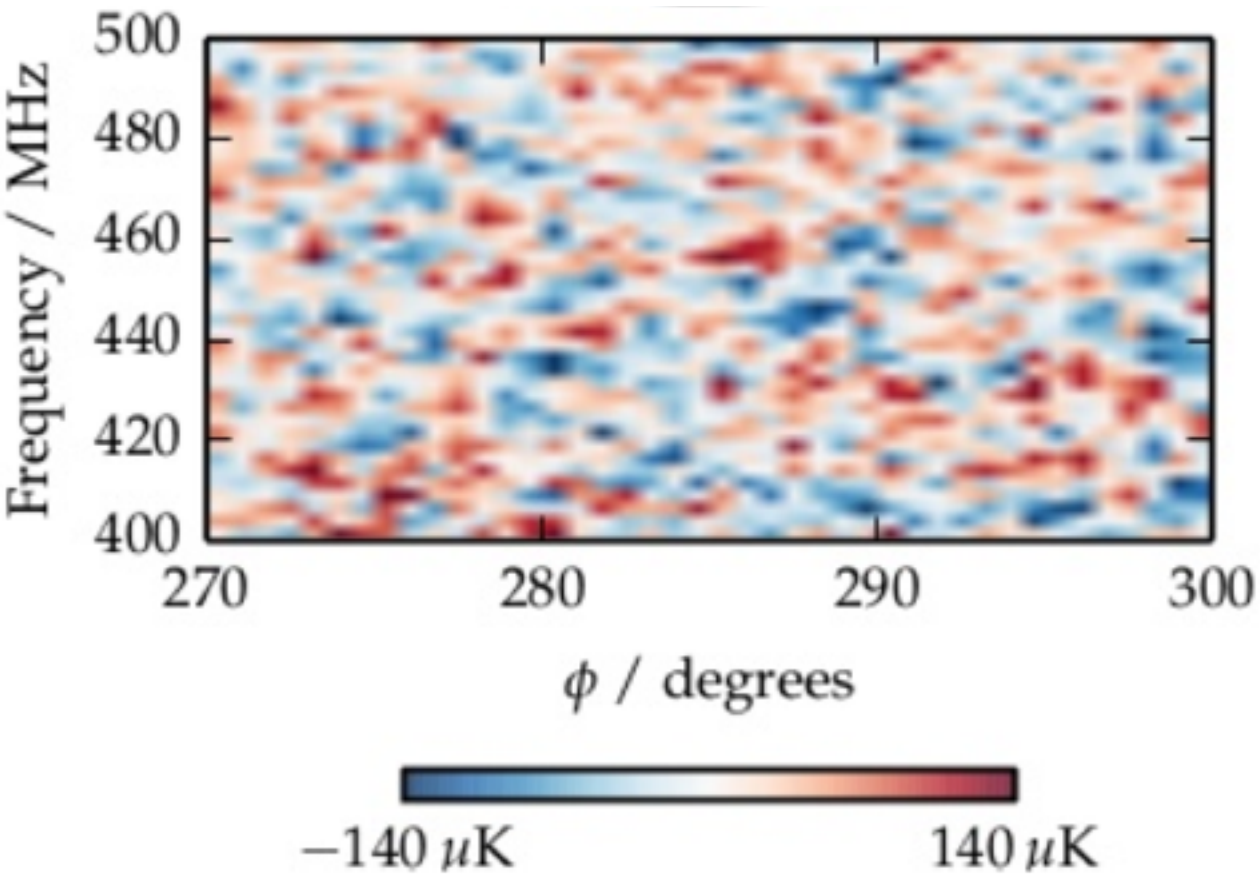


Foregrounds: the reason this is hard

Strategy: radio foregrounds are very spectrally smooth, whereas 21-cm anisotropy has small-scale power in the frequency (radial) direction.

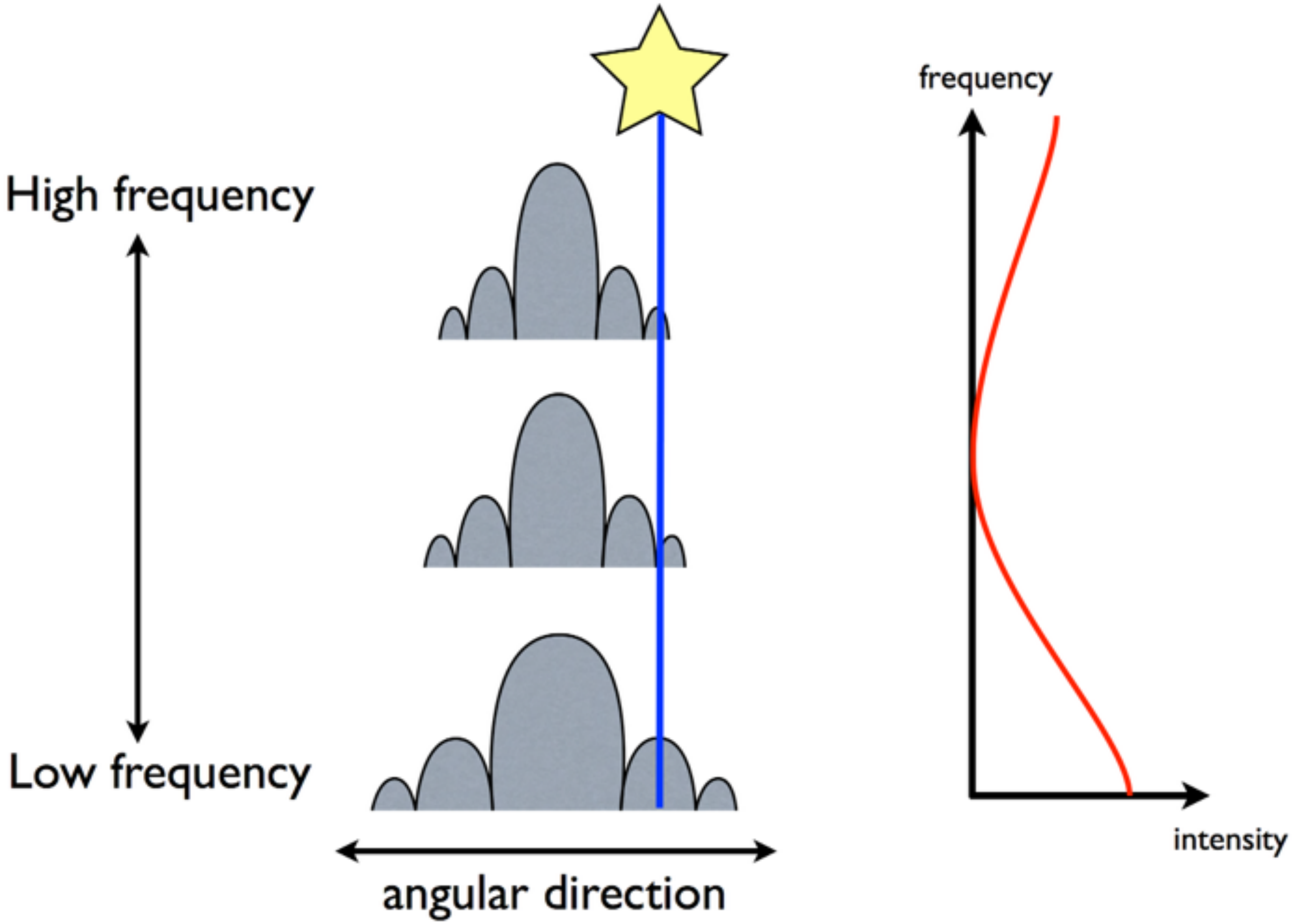
So foregrounds and 21-cm can be separated by high-pass filtering along the frequency axis.





Foregrounds: the reason this is hard

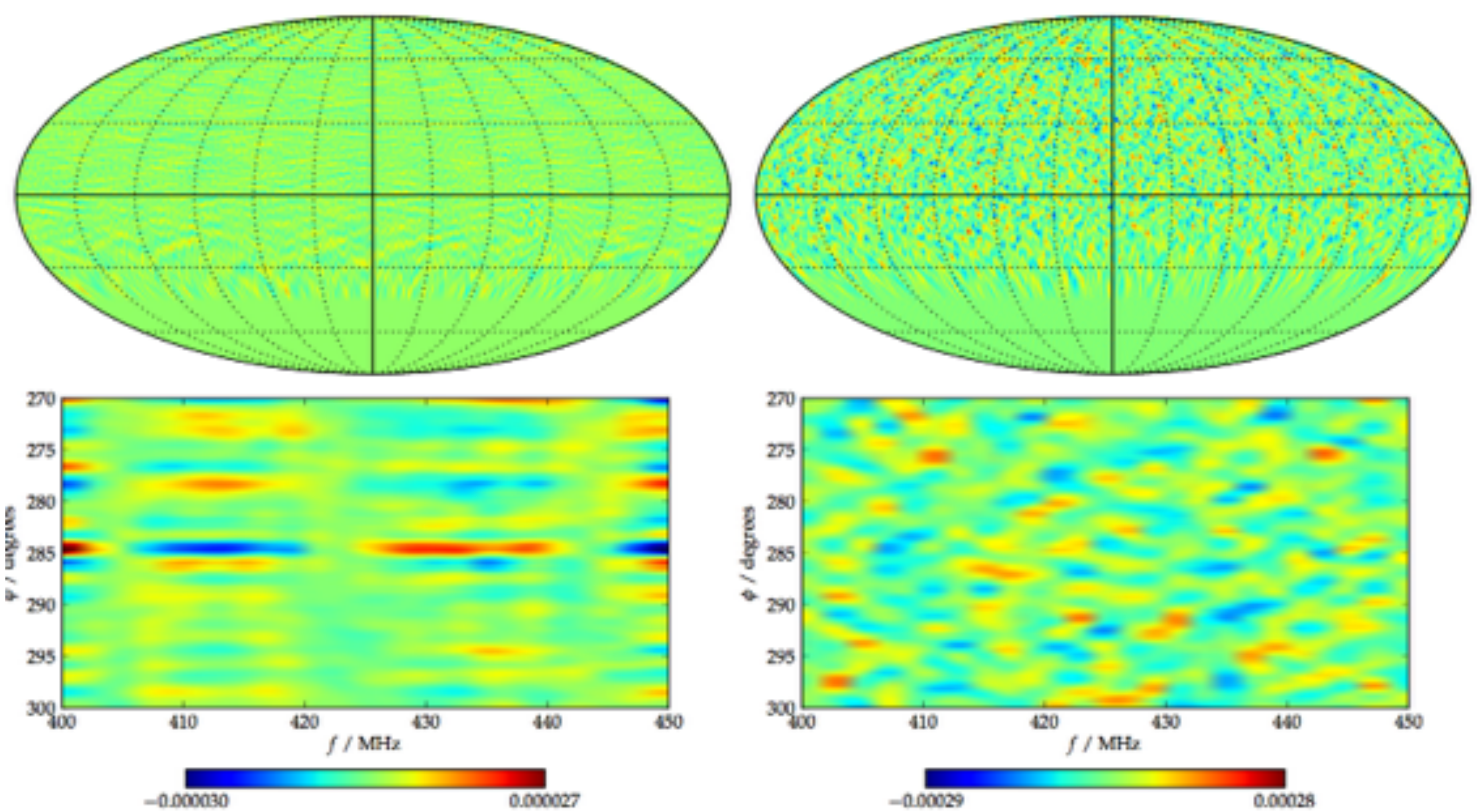
Problem: beam is frequency-dependent (diffractive) which leads to mode mixing. Naive high-pass filtering doesn't work.



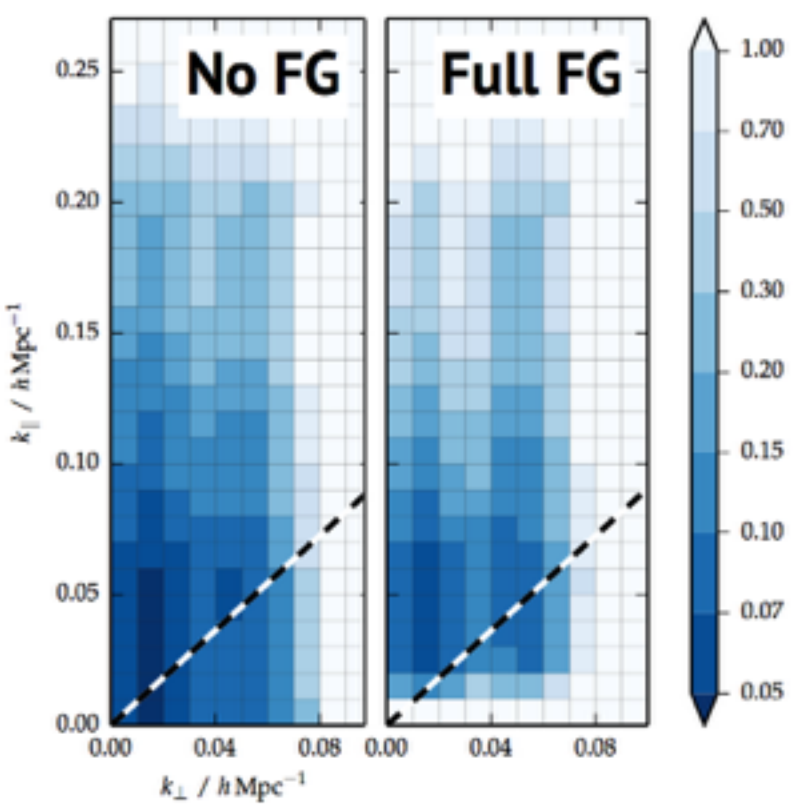
Foregrounds: the reason this is hard

Shaw et al 2013, 2014: can separate foregrounds and 21-cm by linear algebra tricks if the instrument is perfectly characterized. (Key idea: use block diagonality in m)

Galaxy 21-cm



Fractional powerspectrum errors (blue is better)



S/F > 10

Foregrounds: the reason this is hard

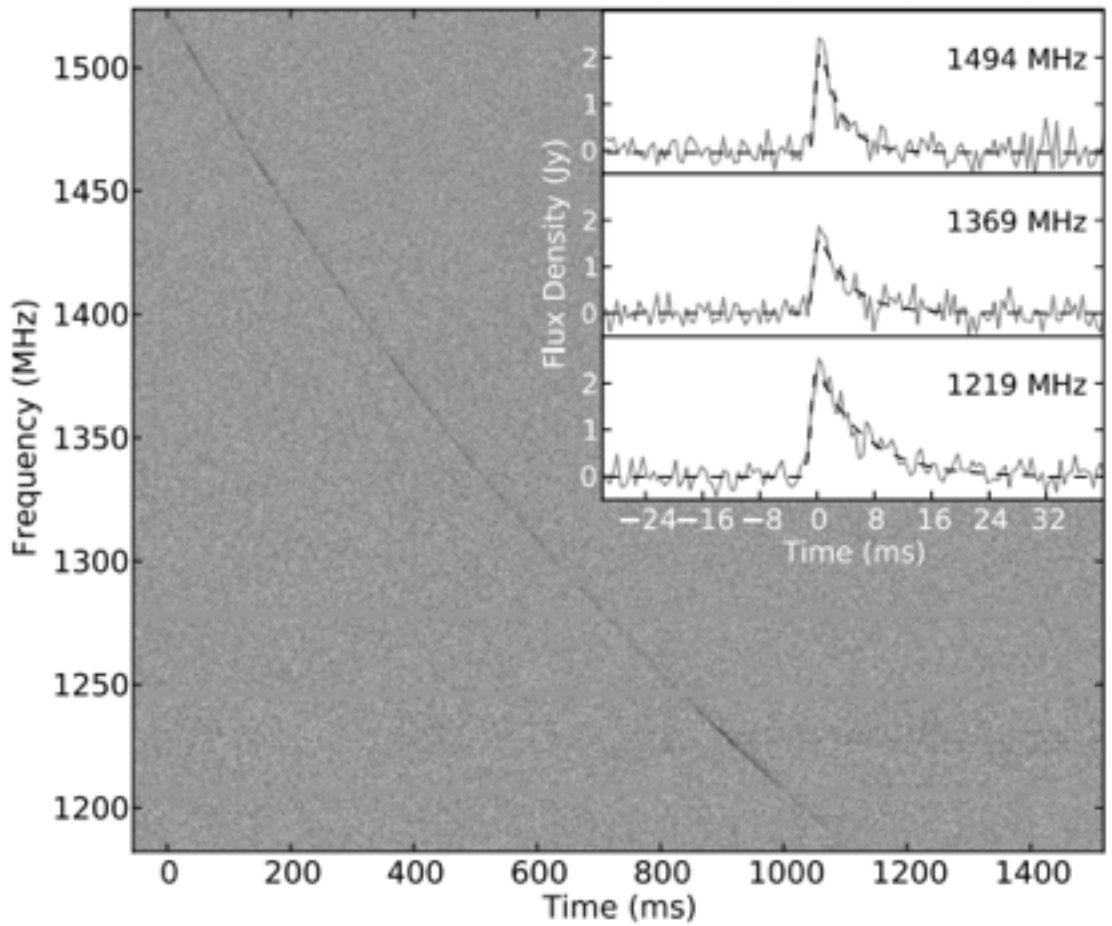
Instrument must be very well-characterized. From sims:

- Calibration requirement (complex gains) ~1%
- Beam modeling requirement ~0.1%

Other ideas which filter more aggressively may also be useful:

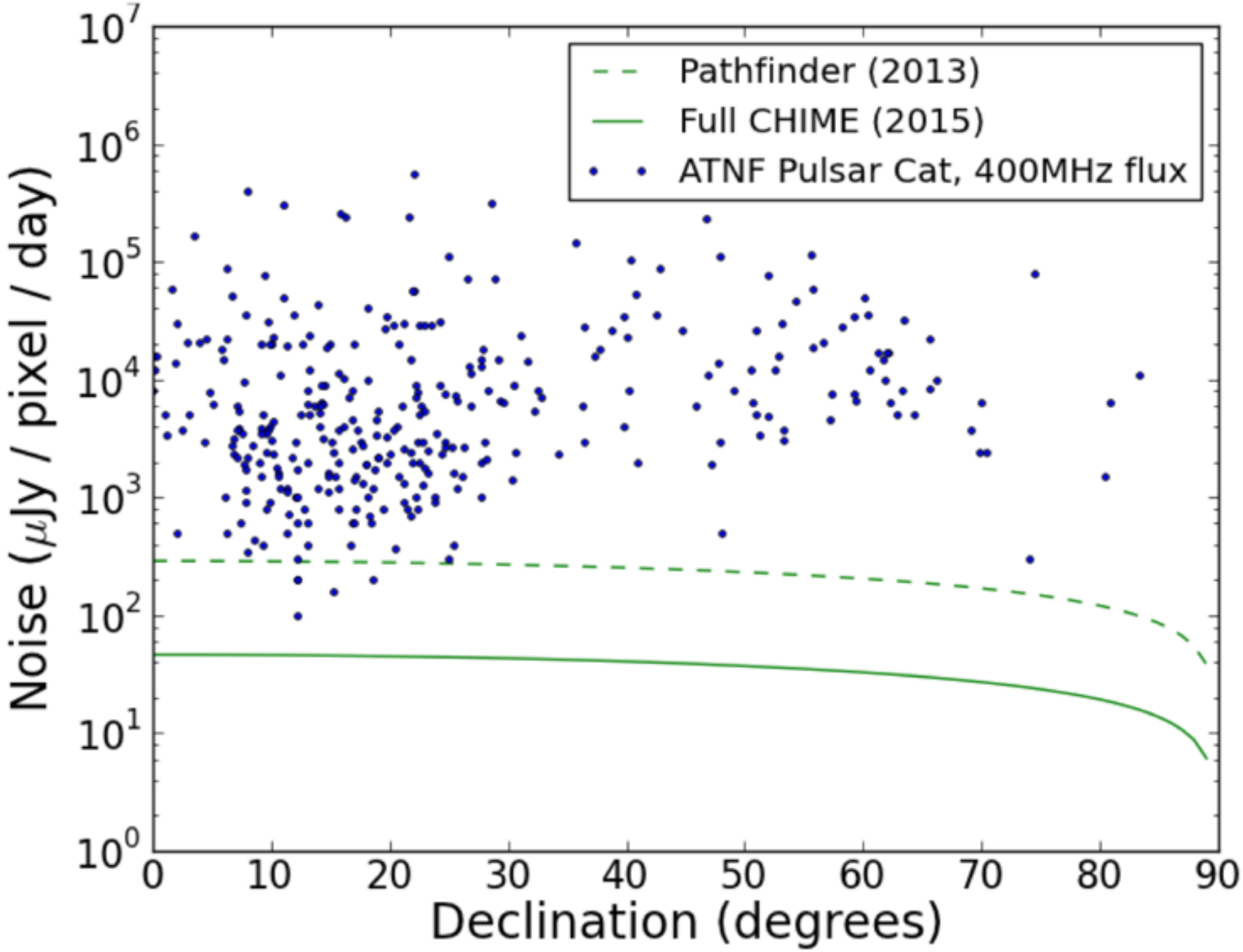
- Foreground “wedge”?
- Delay-space filtering?

Fast radio bursts



	DM (pc cm	z
FRB0102	375	~0.3
FRB1102	944	~0.81
FRB1106	723	~0.61
FRB1107	1103	~0.96
FRB1201	553	~0.45
FRB1211	557	~0.26

Pulsars?



Pathfinder (2013)
Full CHIME (2015)
ATNF Pulsar Cat, 400MHz flux
Noise (μJy / pixel / day)
Declination (degrees)

CHIME is an enormous computation:

- Total bandwidth 6.4 Tbps (global internet: ~250 Tbps!)
- Correlator is ~7 petaflops (achieved by bit-packing tricks)
- Reduced data is tens of TB per day

Moore's law: key computing parameters (e.g. flops/watt, network speed, memory bandwidth) increase exponentially with doubling time $T_{Moore} \sim 24$ months.

Building an instrument like CHIME has just become possible (on a reasonable budget) recently:

- cheap teraflop gaming GPU's
- cheap 10Gbps ethernet

The 21cm (auto) power spectrum hasn't been detected yet, but we hope to measure it well enough to be a stage-IV dark energy experiment! (CMB analog: pre-COBE→Planck in one experiment?)

Great promise: if CHIME works well, cost of scaling up the collecting area A is either

- proportional to A, or (e.g. reflector)
- proportional to A $\exp(-T/T_{Moore})$! (e.g. correlator)

Most scalable way to measure more large-scale structure modes

A huge volume is potentially measurable

Can try to map

(1) low-z

(2) reionization

(3) dark ages

… although foreground temperature varies as $T \sim (1+z)^{2.5}$

At high z, the power spectrum goes out to very high k, so there is essentially no fundamental limit on how many modes we might measure

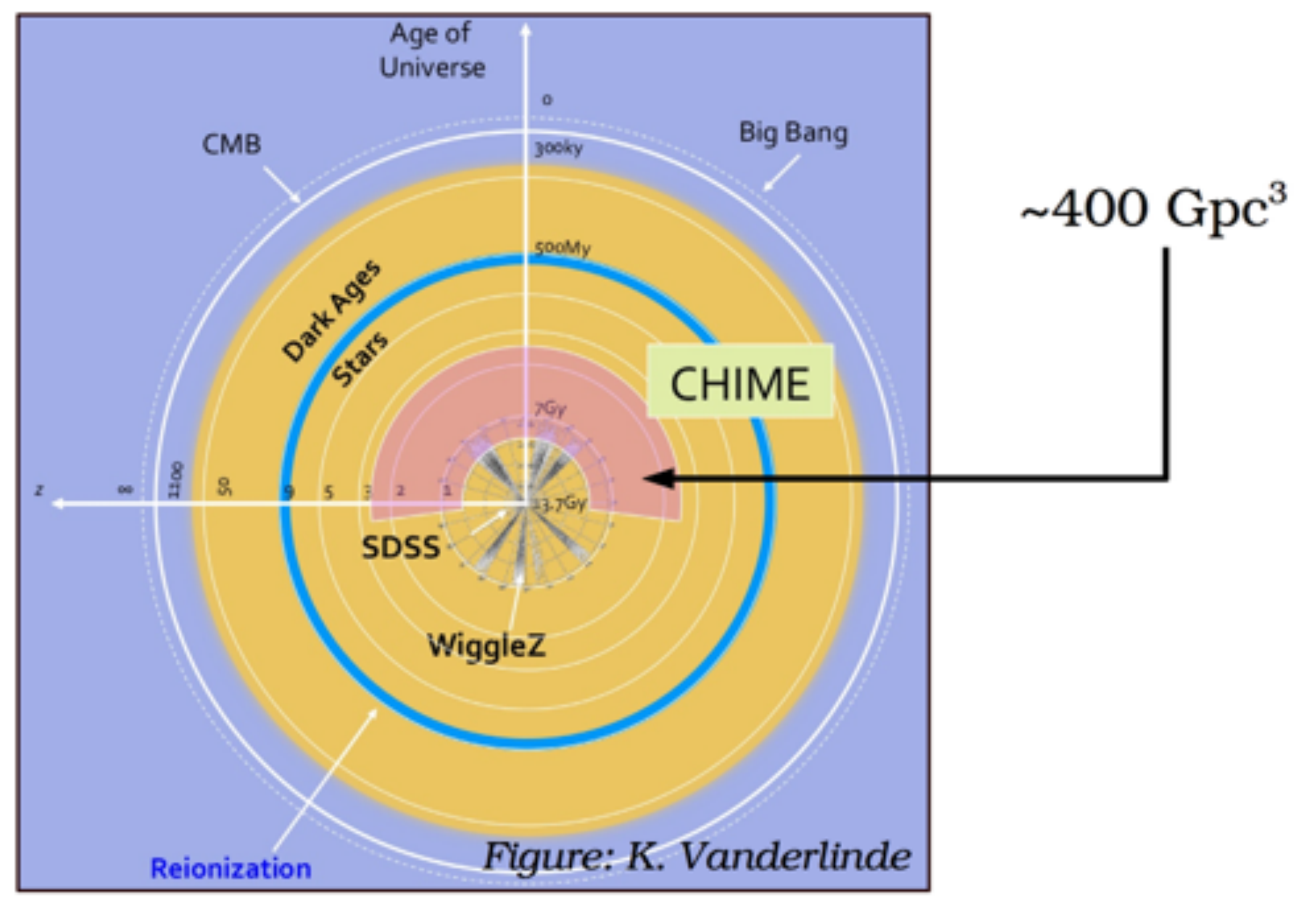


Figure: K. Vanderlinde


Thanks!