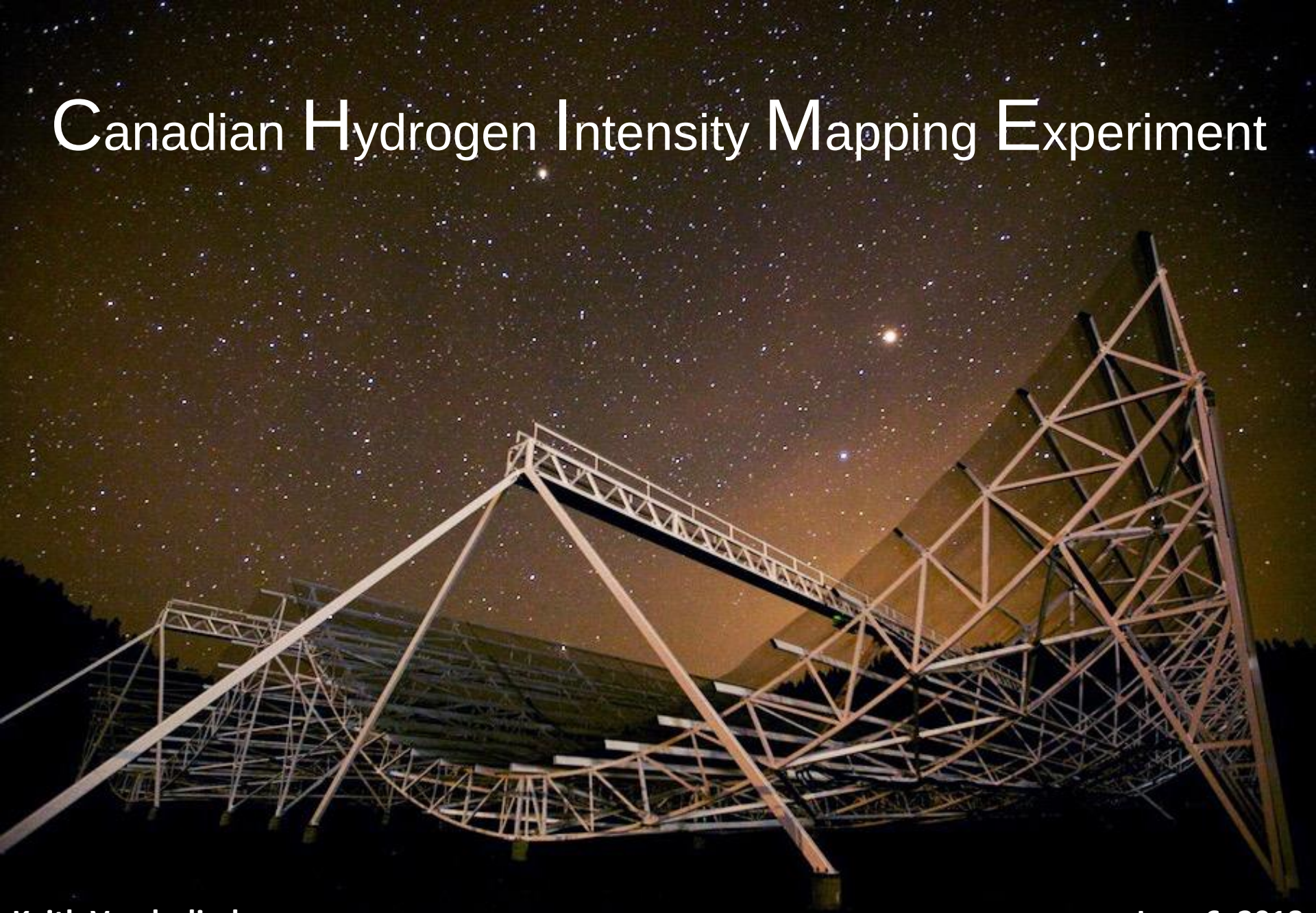
Canadian Hydrogen Intensity Mapping Experiment



Keith Vanderlinde
University of Toronto

June 6, 2018
Rencontres de Blois XXX

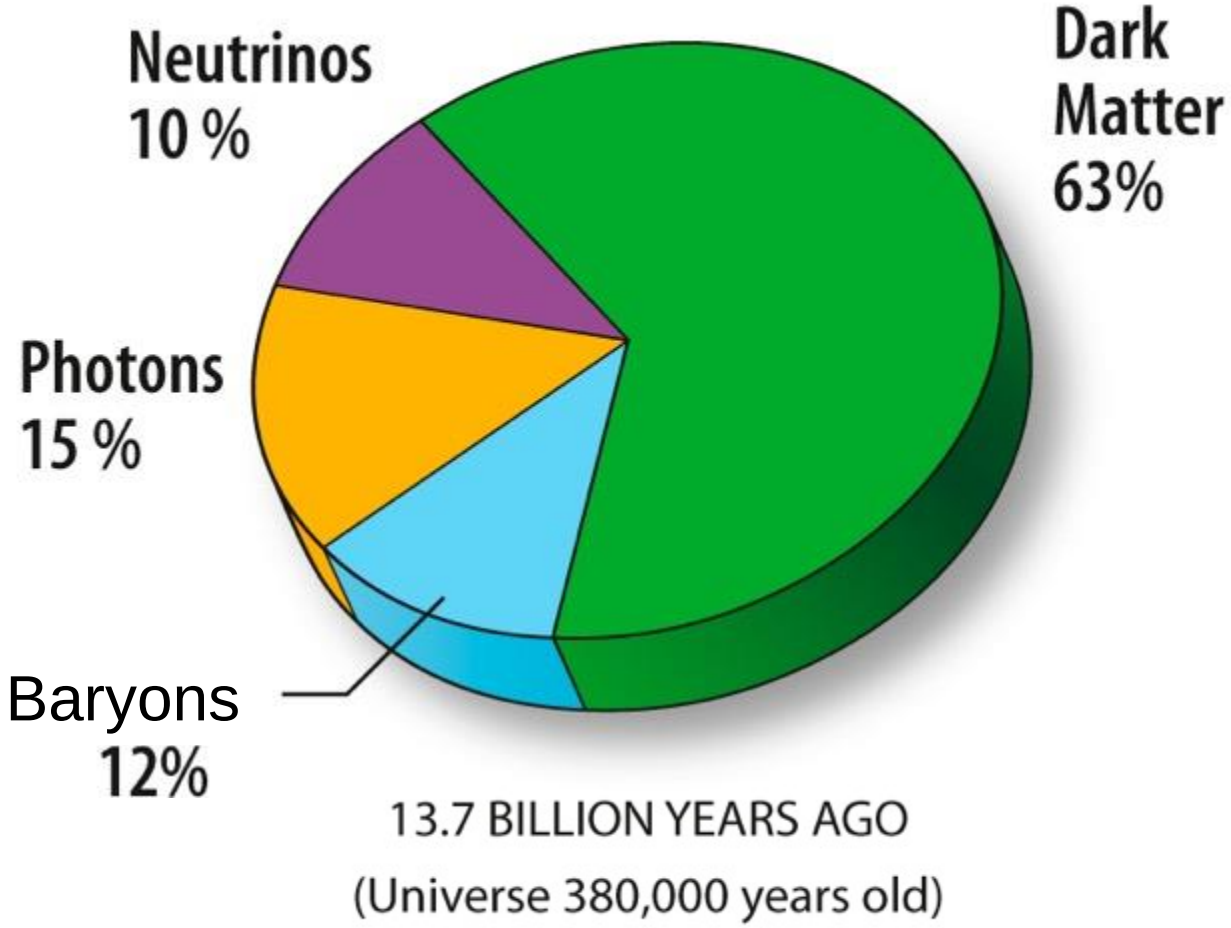
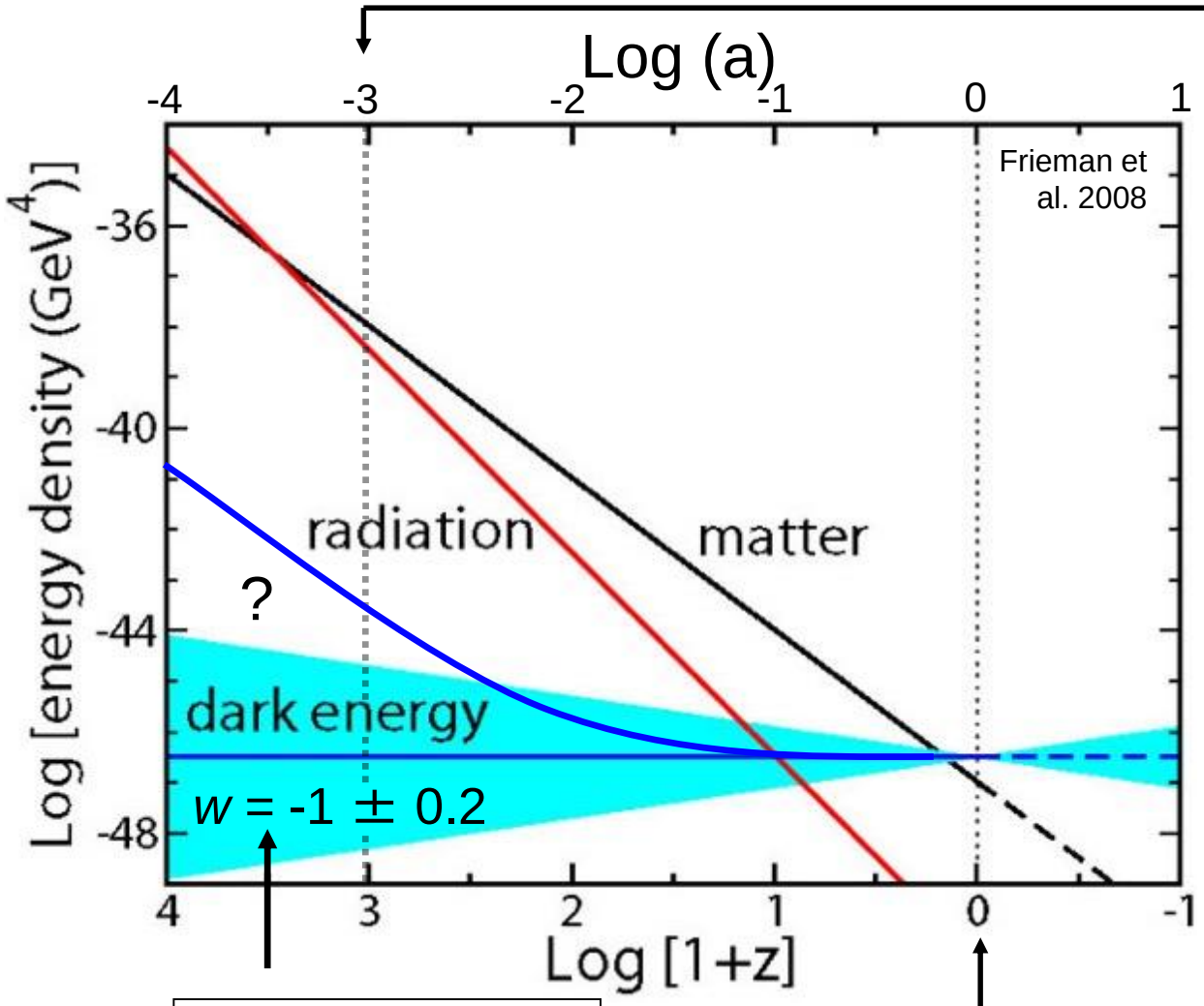
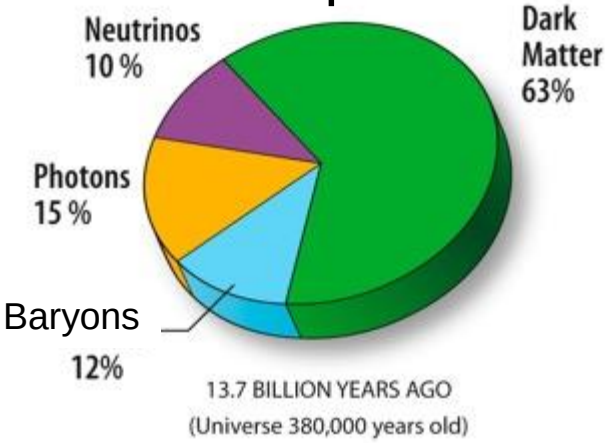
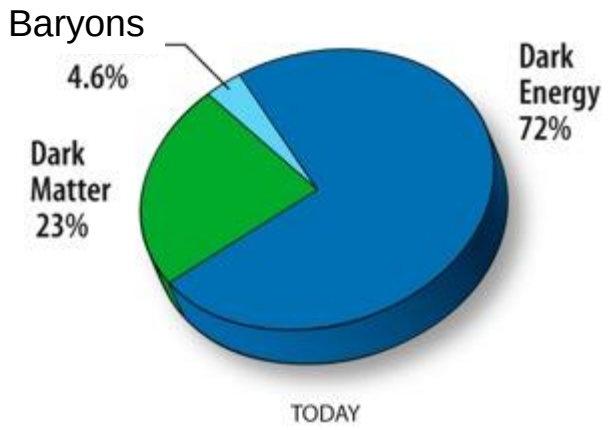


Image from
NASA / WMAP Science Team

The Evolution of Stuff







$P = w\rho$

$w(z) = \text{const}$?

Composition Images from
NASA / WMAP Science Team

Probing Dark Energy

Properties & existence inferred from expansion history.

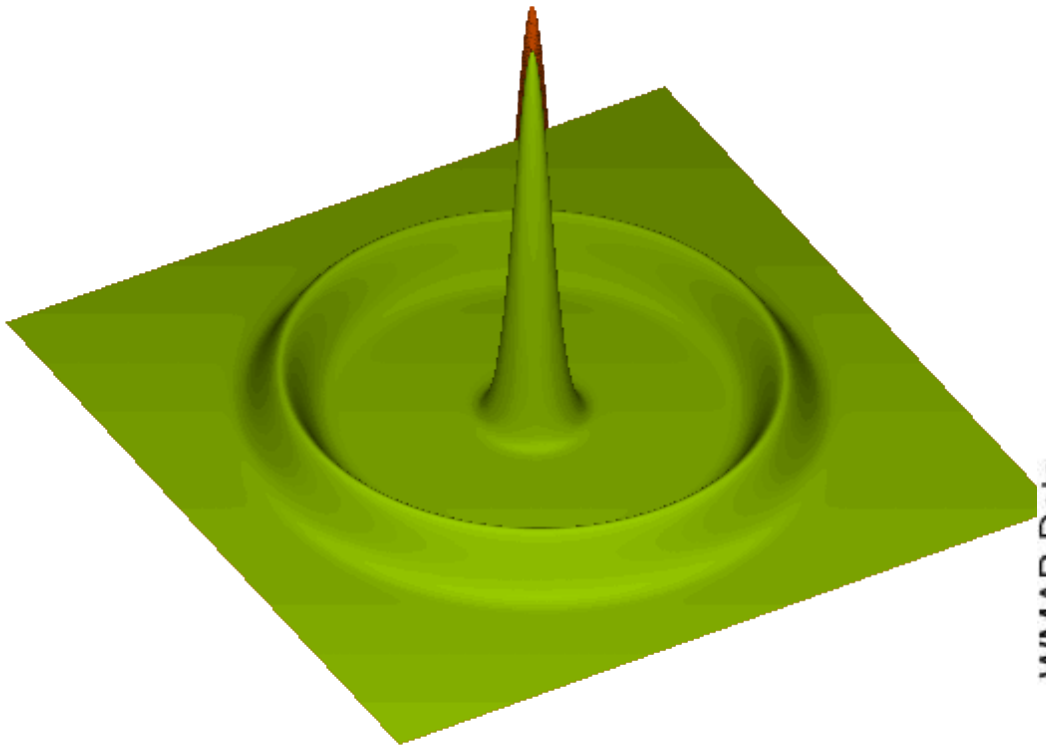
Many options to map the expansion:

- Standard candles → Supernovae
- Growth of struct → Galaxy Clusters
- Standard sirens → BBH Mergers & GW
- Standard rulers → BAO

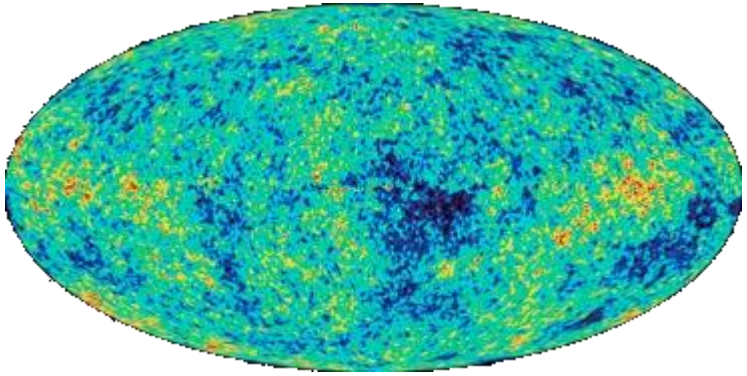
Can only probe in the nearby Universe, $z < \sim 2.5$.

Baryon Acoustic Oscillations

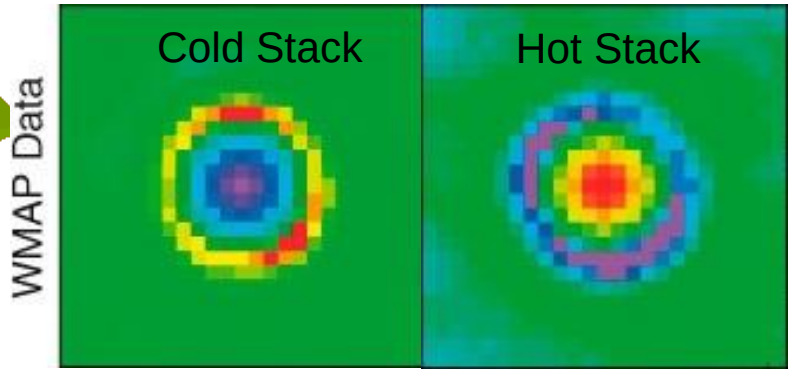
- random background of primordial fluctuations
- each fluctuation emits a pressure wave
- at decoupling, the size of this wave is frozen



(Eisenstein)

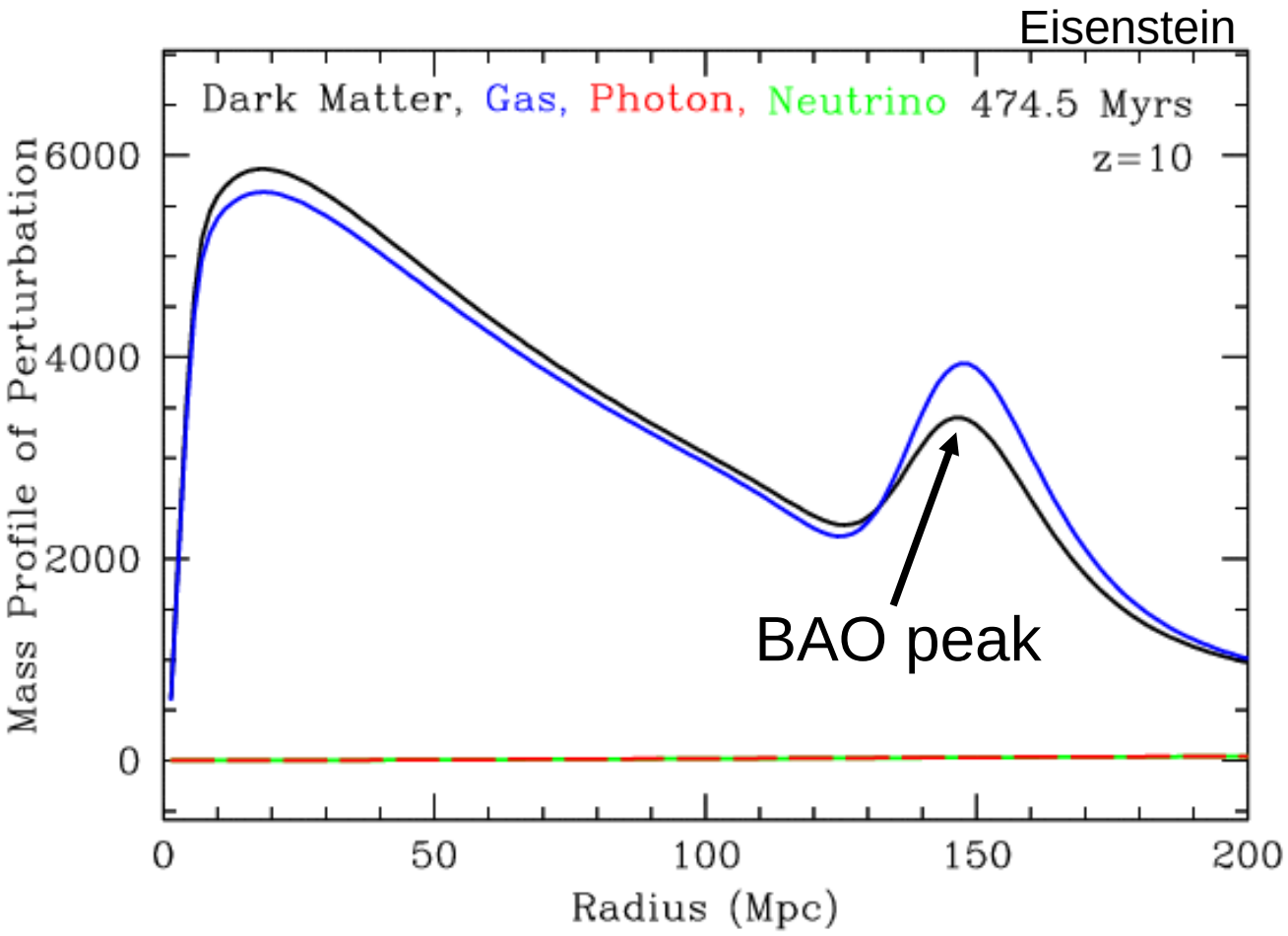


Measured in the CMB!



Komatsu et al. 2010

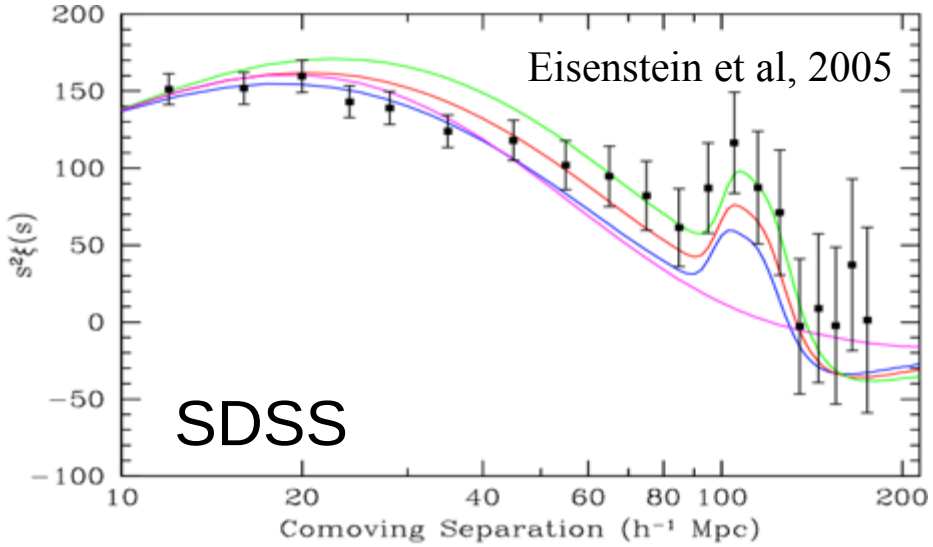
Late-Time Radial Profile

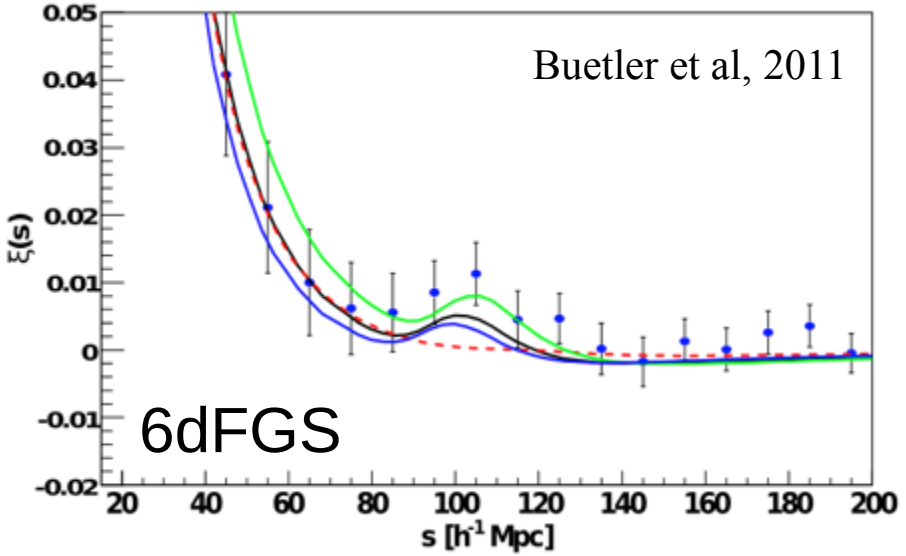


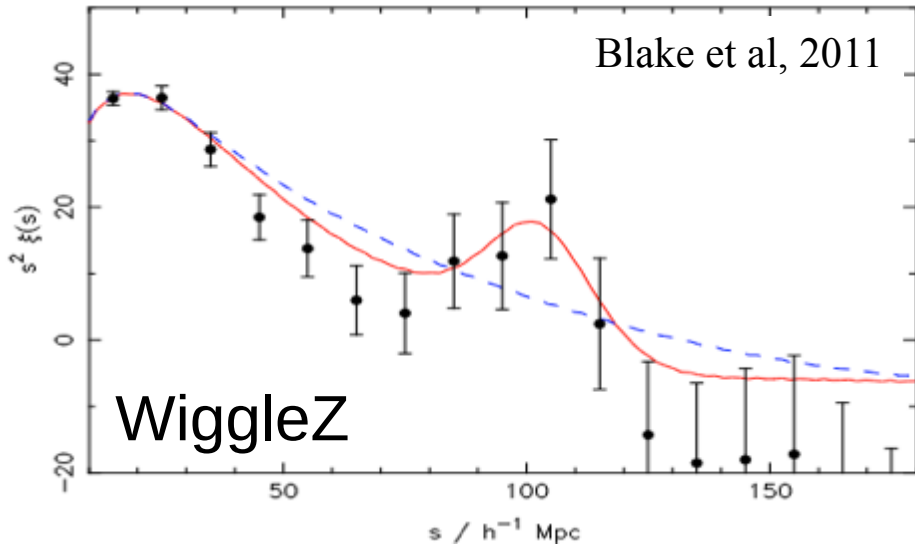
BAO are “frozen in” ≈150 co-moving Mpc.

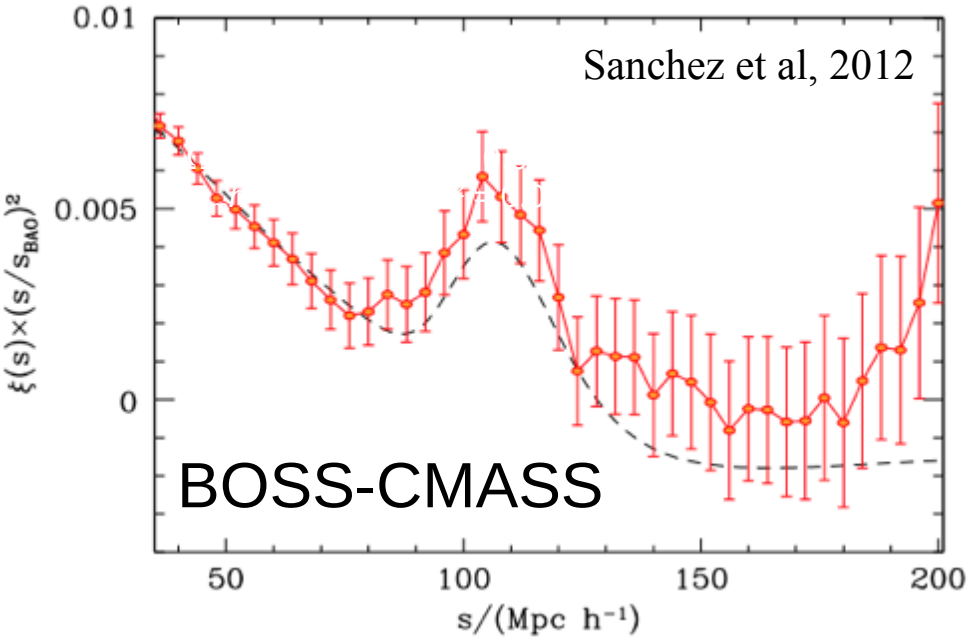
BAO Observations

Detected in galaxy correlations!

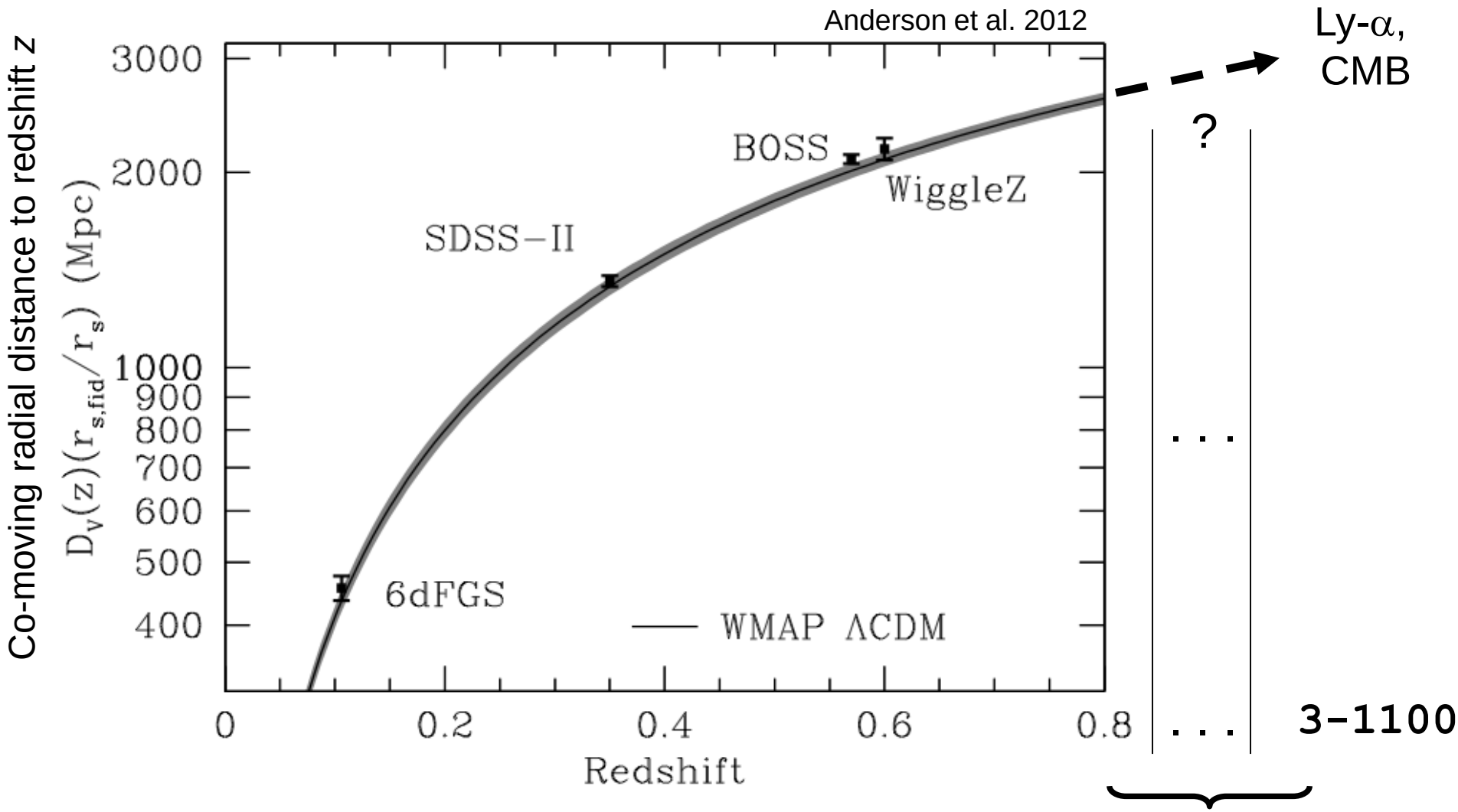








BAO as a standard ruler



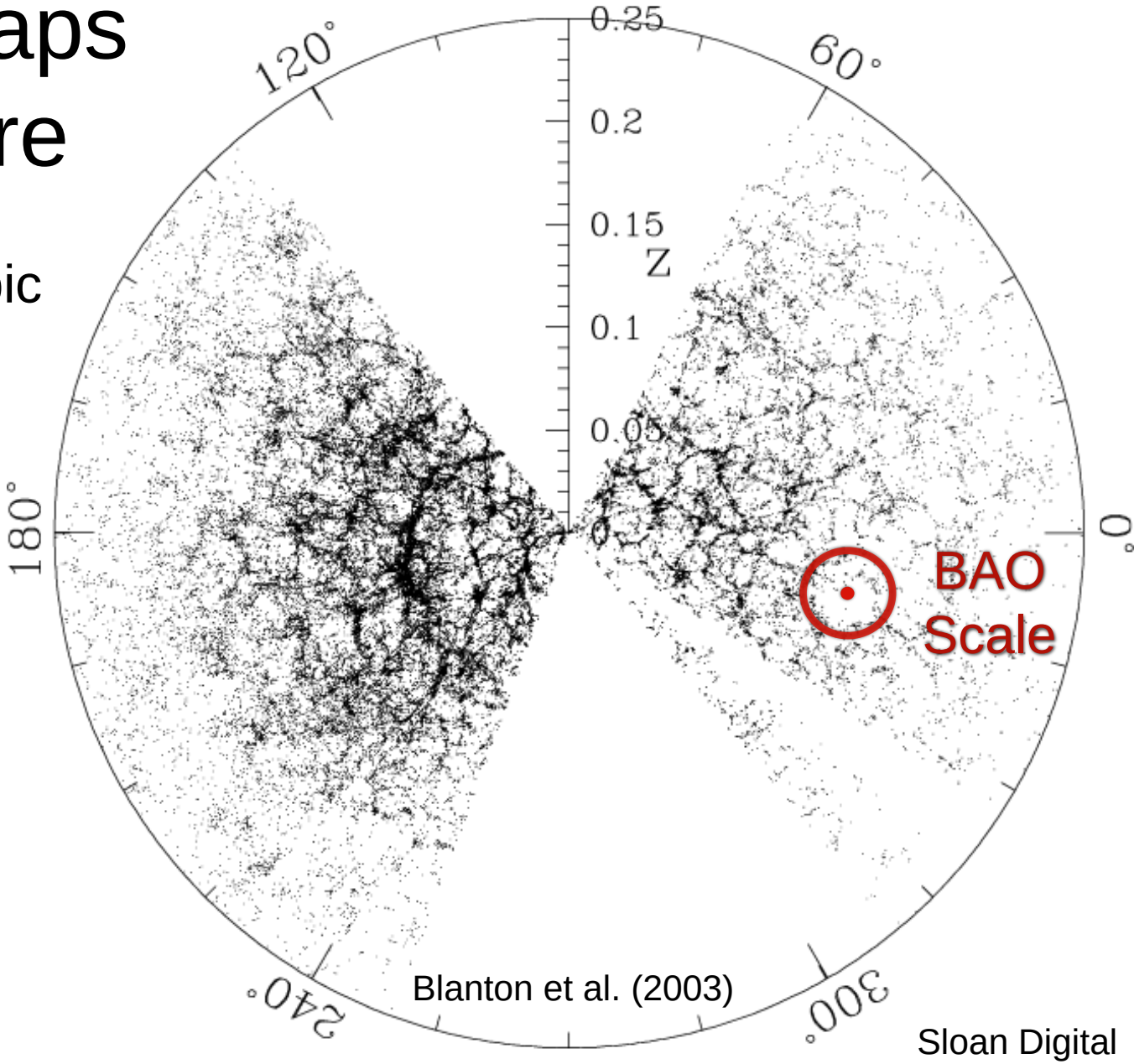
Blanton et al. (2003) (astro-ph/0210215)

Optical Maps of Structure

Get spectroscopic redshifts on lots of galaxies.

Works!

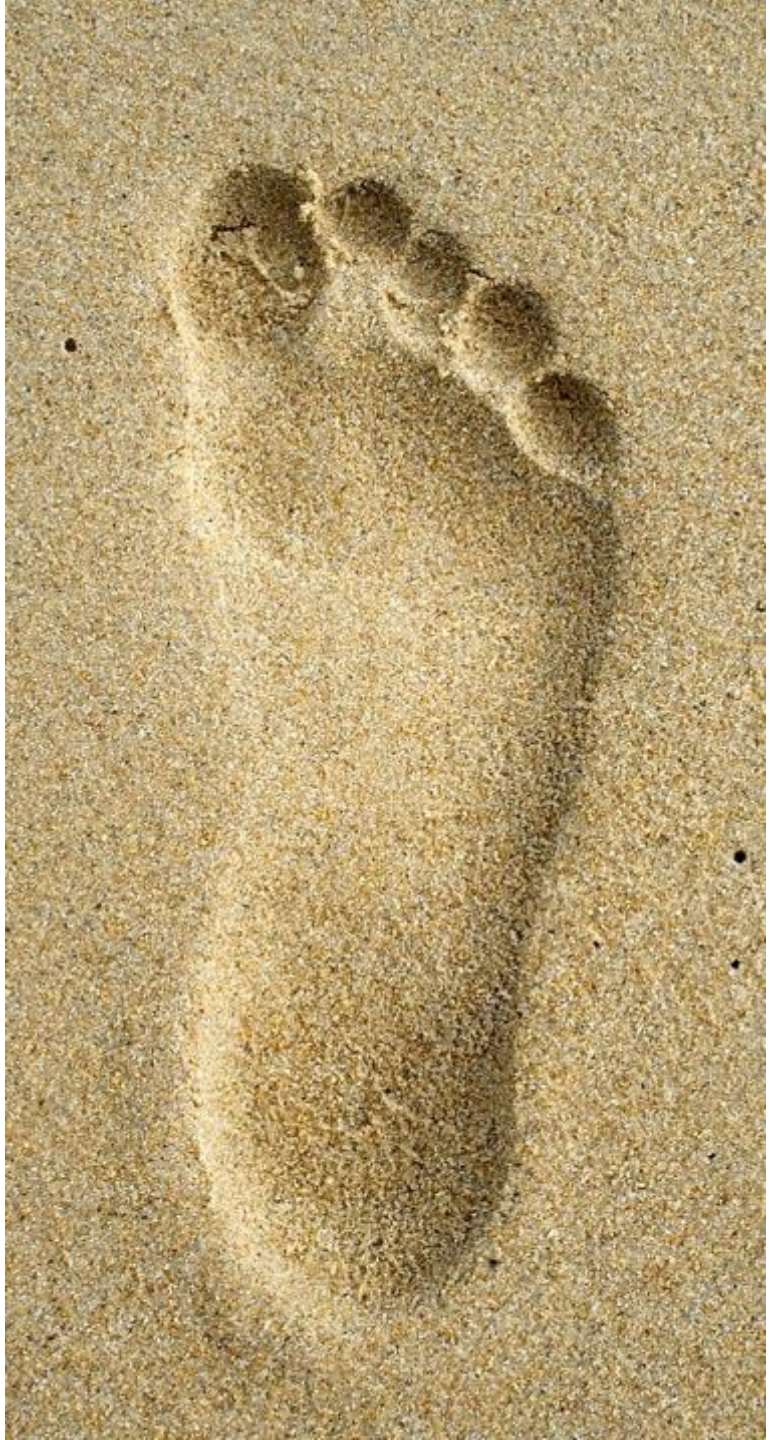
But:
- expensive
- hard at z ≈ 1-2



Blanton et al. (2003)

Sloan Digital Sky Survey (SDSS)

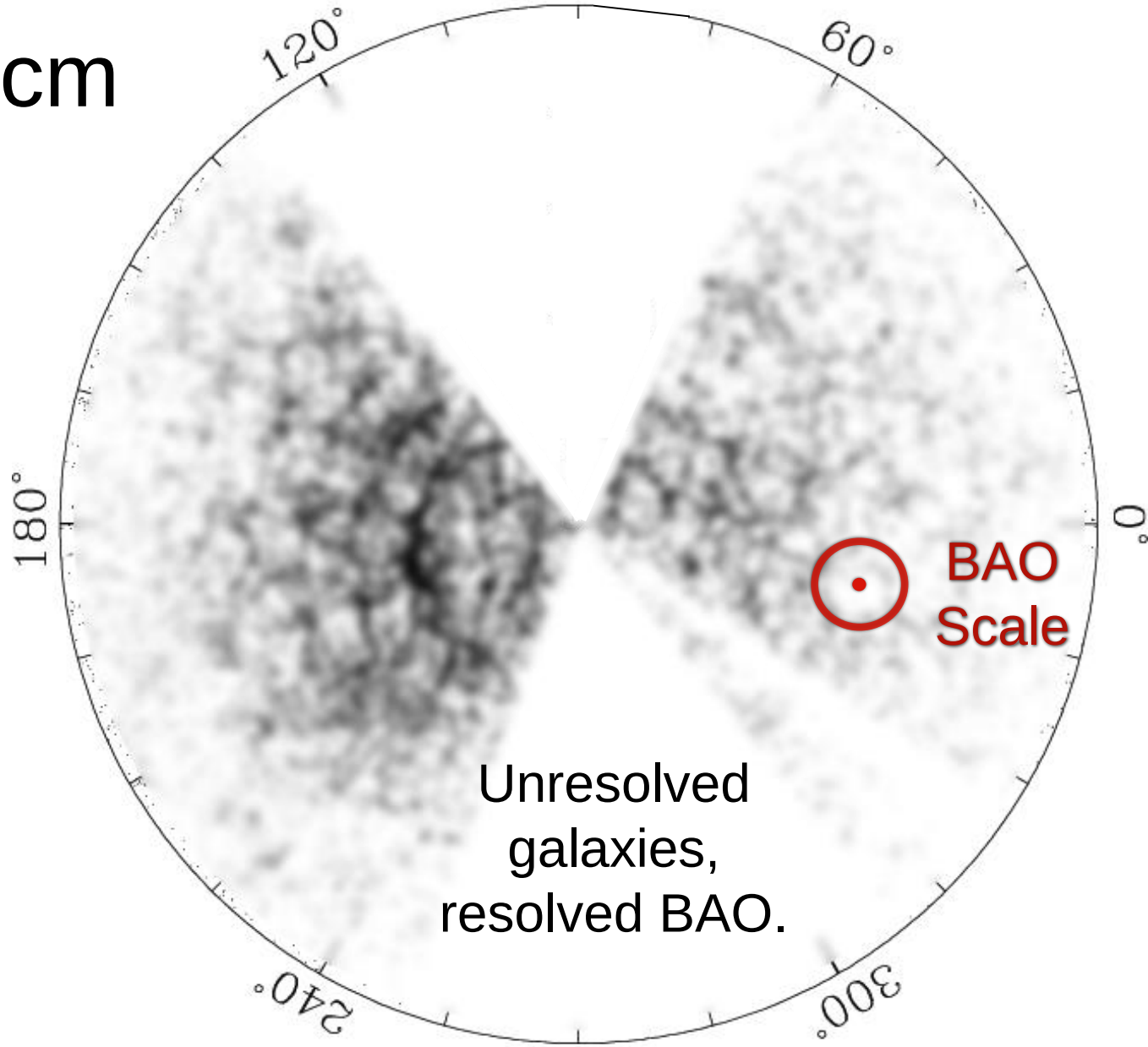
Large Scale Structure sample10



Tracing Structure through 21cm

To see BAO, no need to resolve galaxies individually.

Use redshifted 21cm intensity as a bulk tracer for matter.



Green Bank 300 Foot Dish

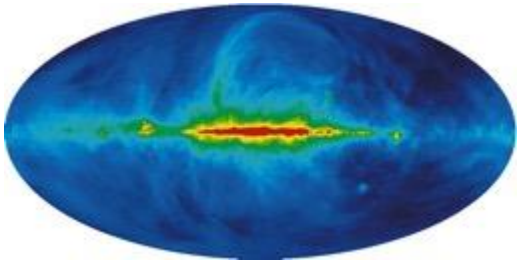
Green Bank 300 Foot Dish

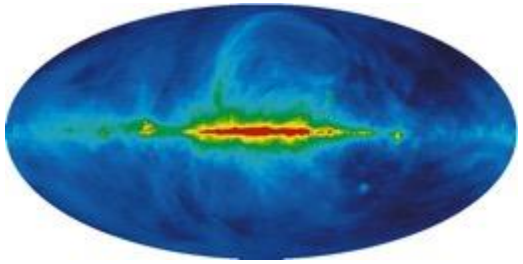
Collapsed: Nov 15, 1988

FFT Telescope

Haslam et al. 1982

Sky



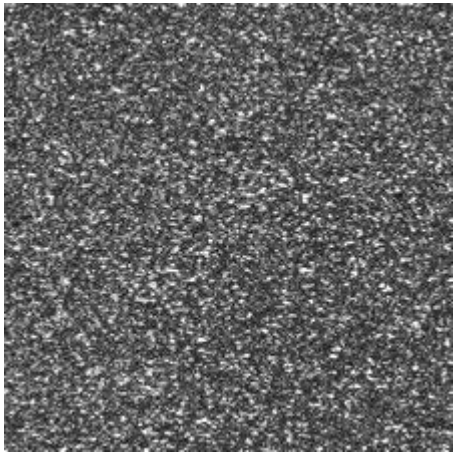


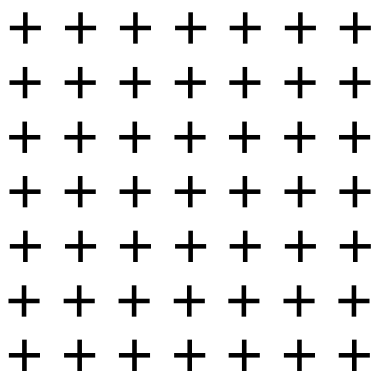
Measured Sky

$\mathscr{F}$

$\mathscr{F}$

Ground E

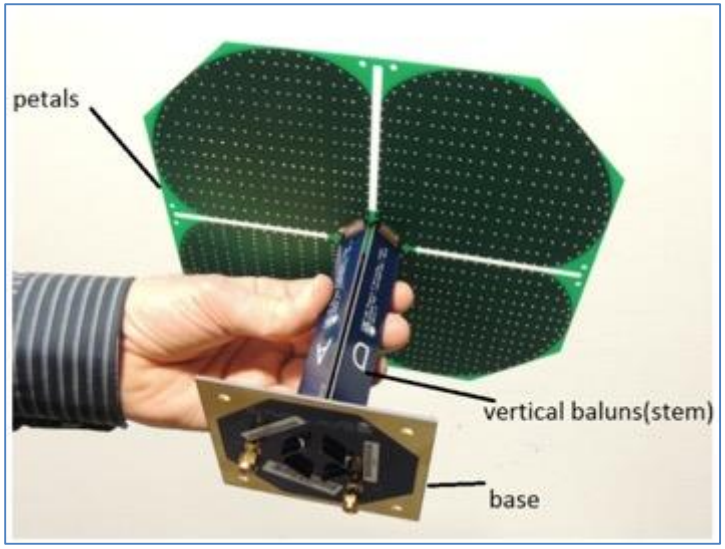


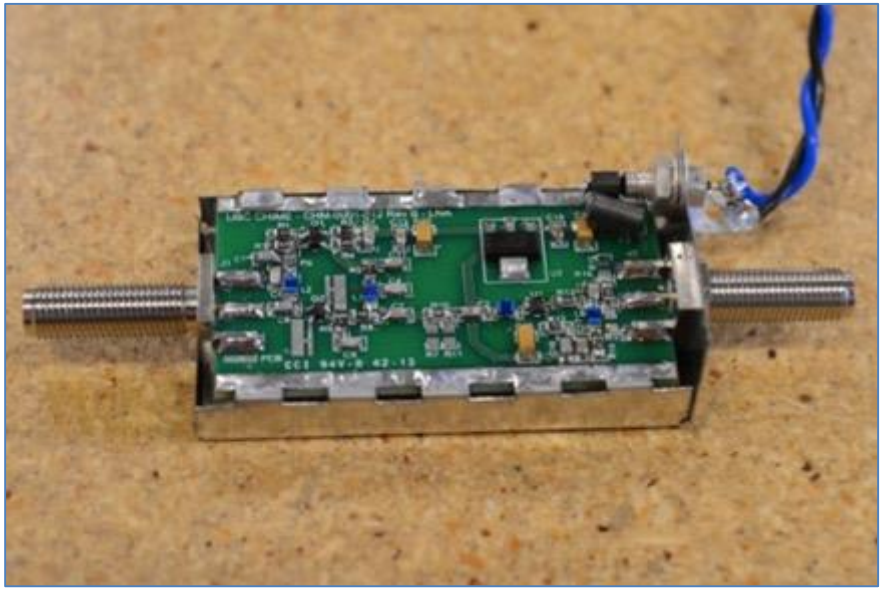


Sampled Ground

Computational Cost ~ N log(N) ~ D^2 log(D)

Consumer Electronics to the Rescue



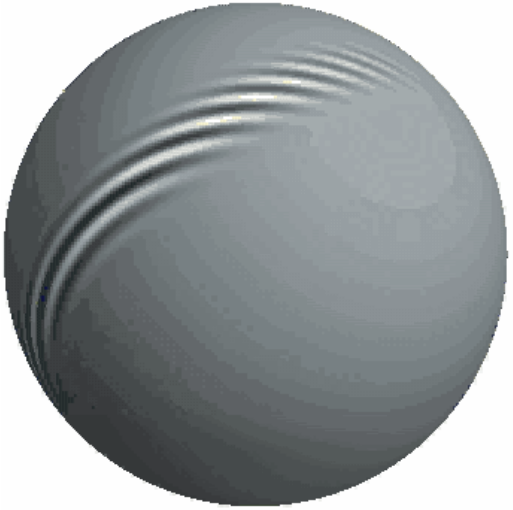


Supercomputer-in-a-Box

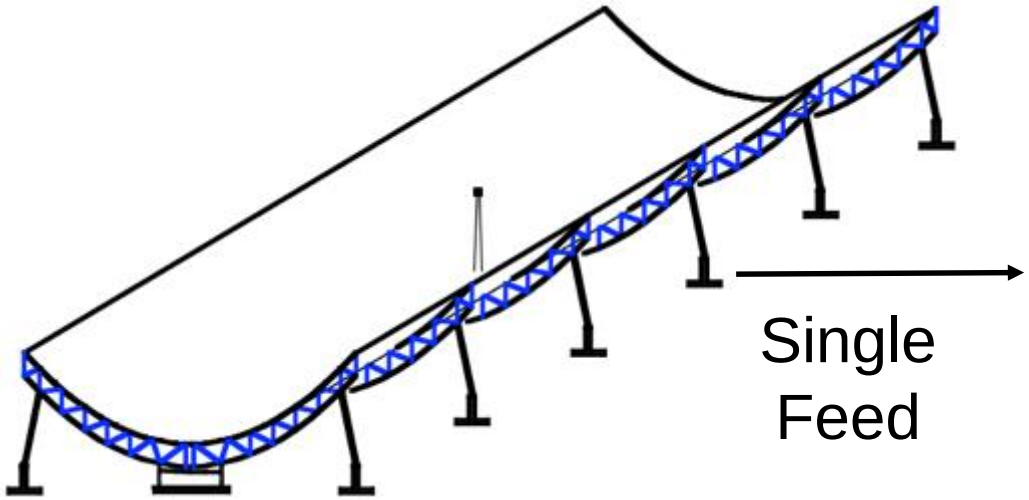
Spaceship Earth

- Large fields of view → many small elements.
- Small fields of view → many expensive dishes.

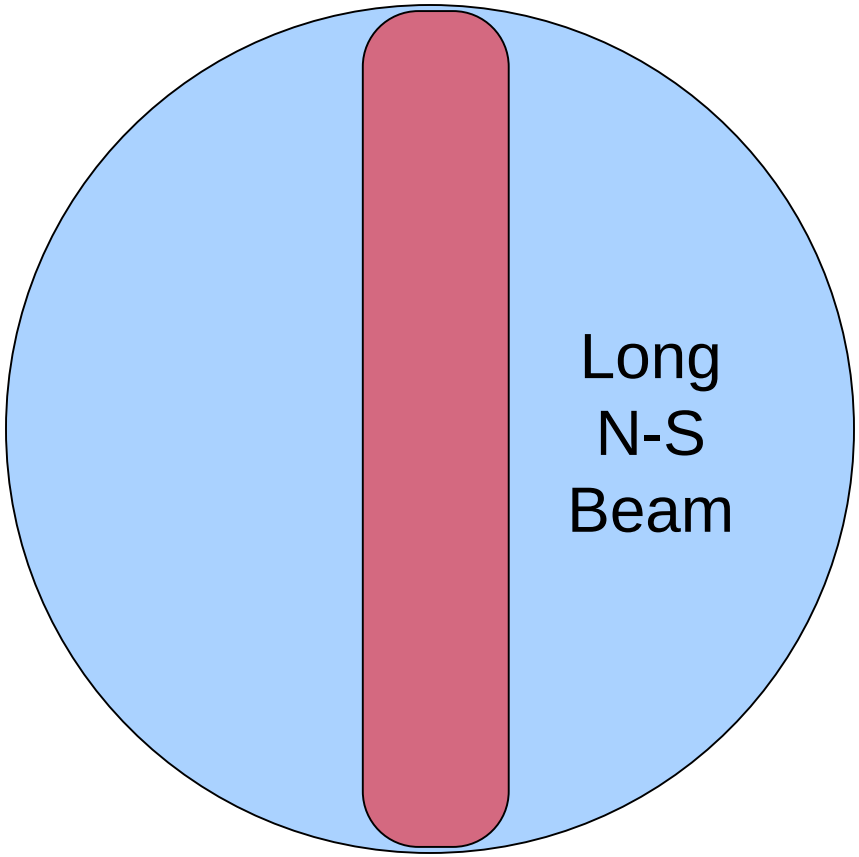
Satellite strategy: focus on a narrow N-S strip!



Cylinder Antenna

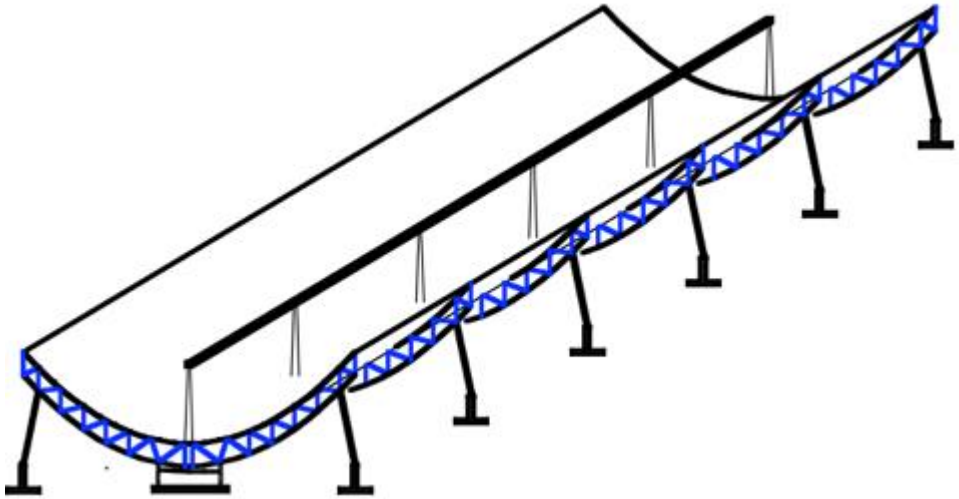


Single
Feed

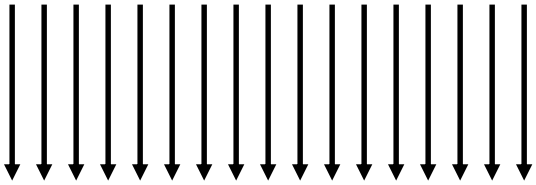


Cylinder Telescope

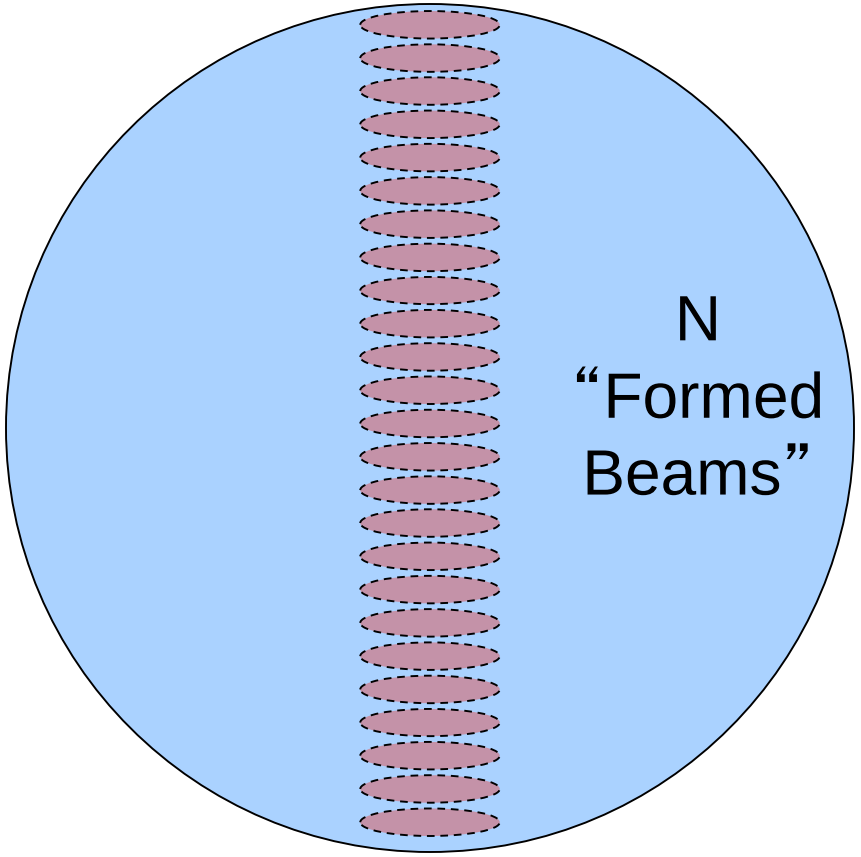
Hybrid: 1D Dish + 1D Interferometry



N feeds

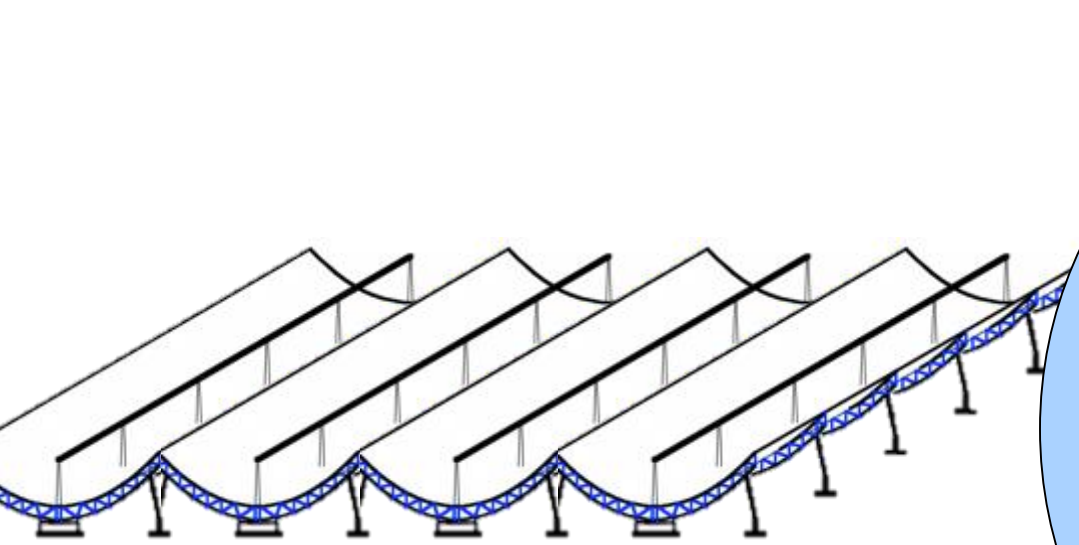


FFT / Beamforming Correlator

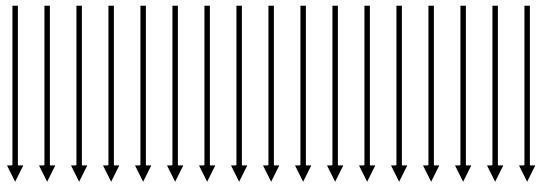


CHIME

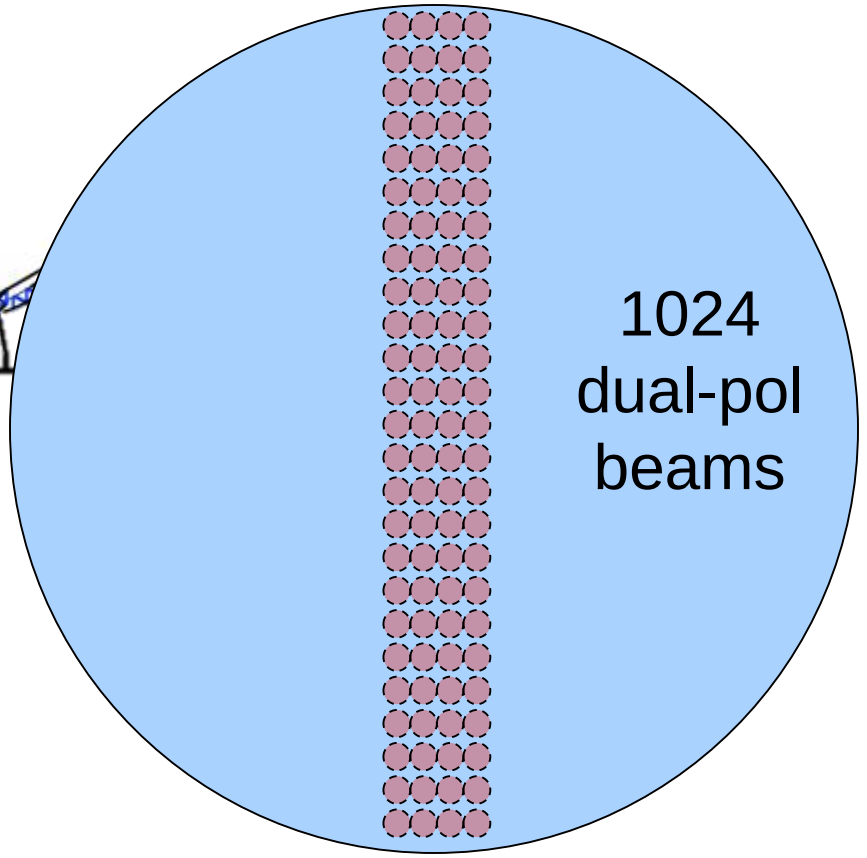
1D Dishes + 2D Interferometry



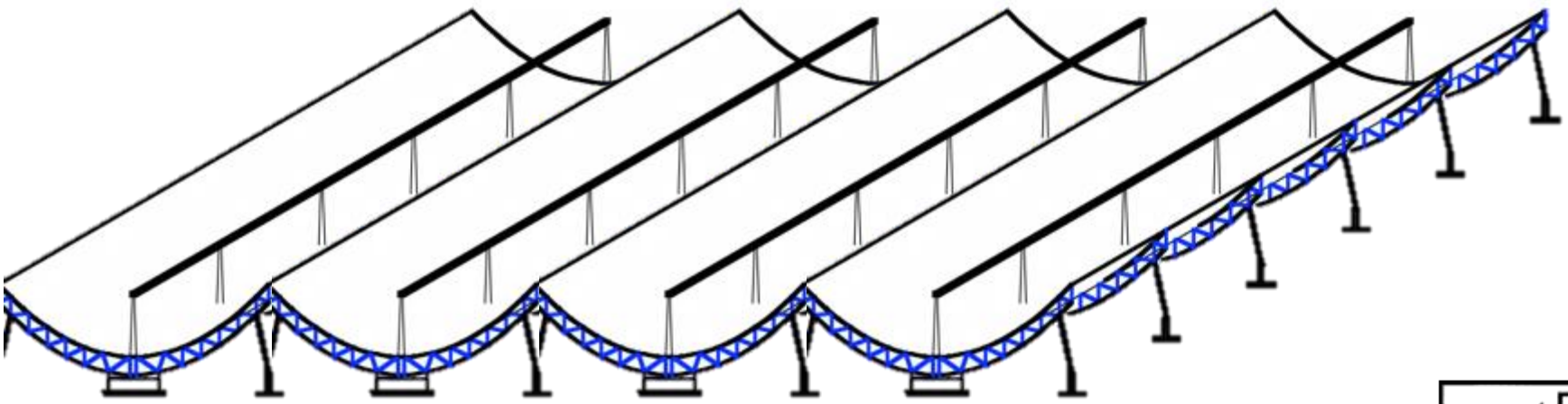
1024 dual-pol feeds



FFT / Beamforming Correlator



CHIME



- 400-800MHz band
  21cm from z ~ 0.8 - 2.5
- Resolution: 1MHz, 13-26’
  3rd BAO peak resolved
- Drift scan, no moving parts
  >20,000 deg^2 coverage
- 1024 Dual-polarization feeds
  Cosmic-variance-limited survey

UBC THE UNIVERSITY OF BRITISH COLUMBIA

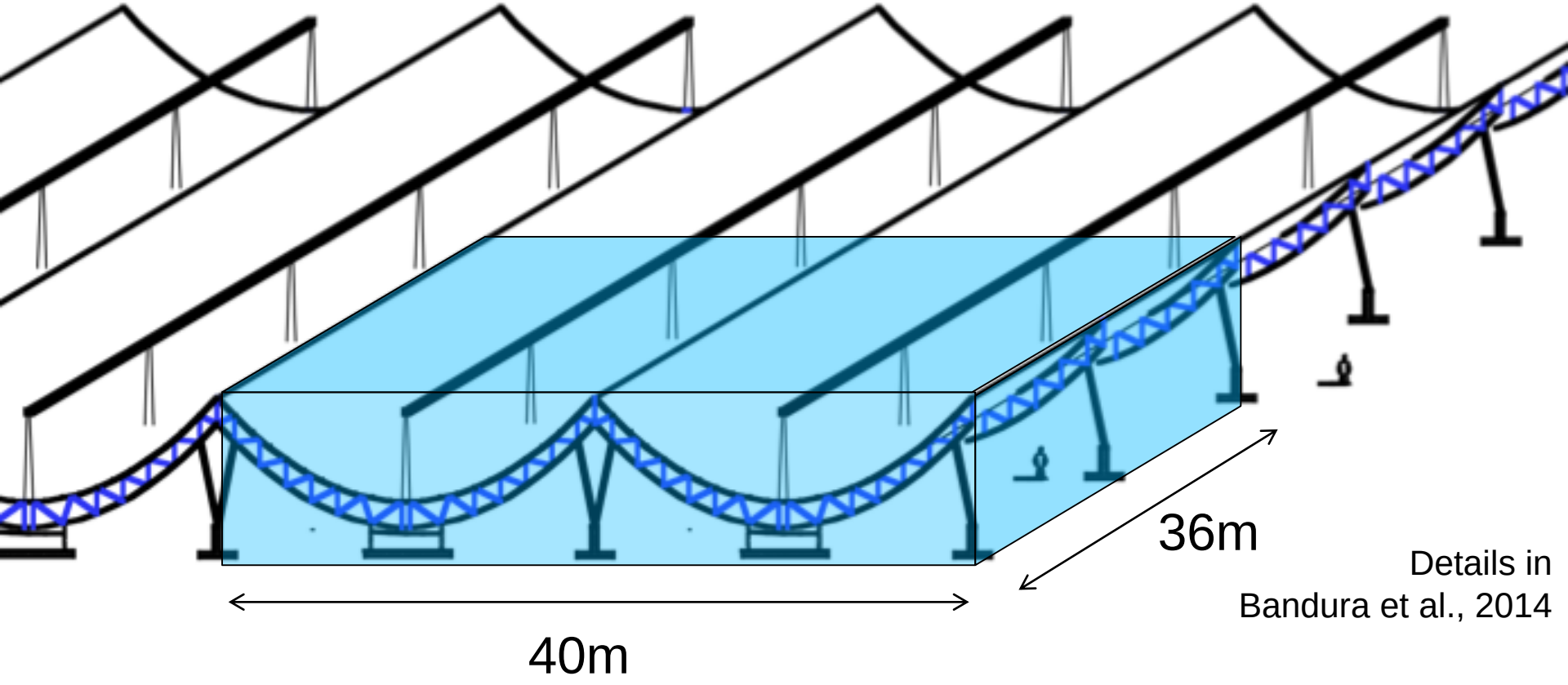
DRAO NRC · CNRC

McGill

UNIVERSITY OF TORONTO

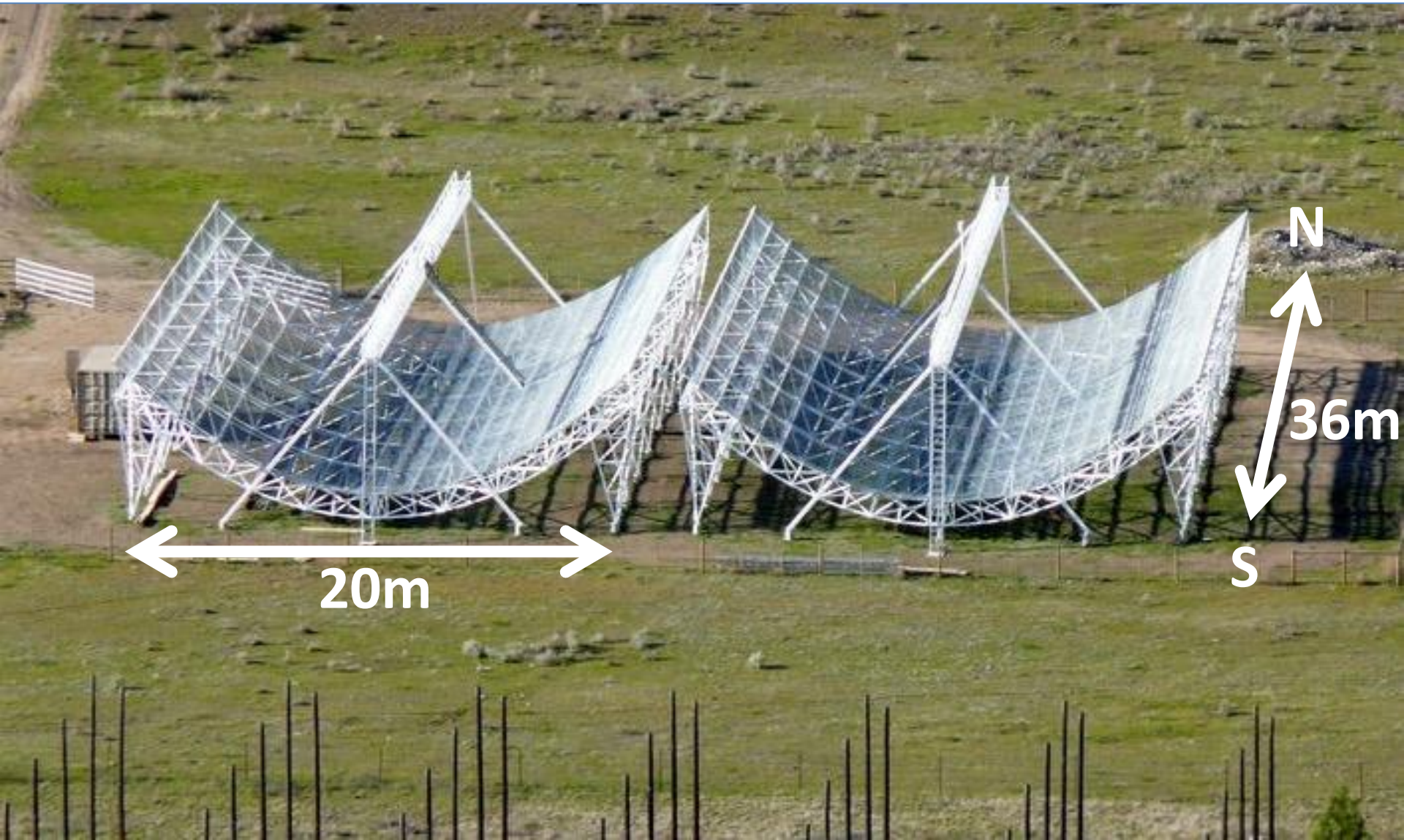
The CHIME Pathfinder

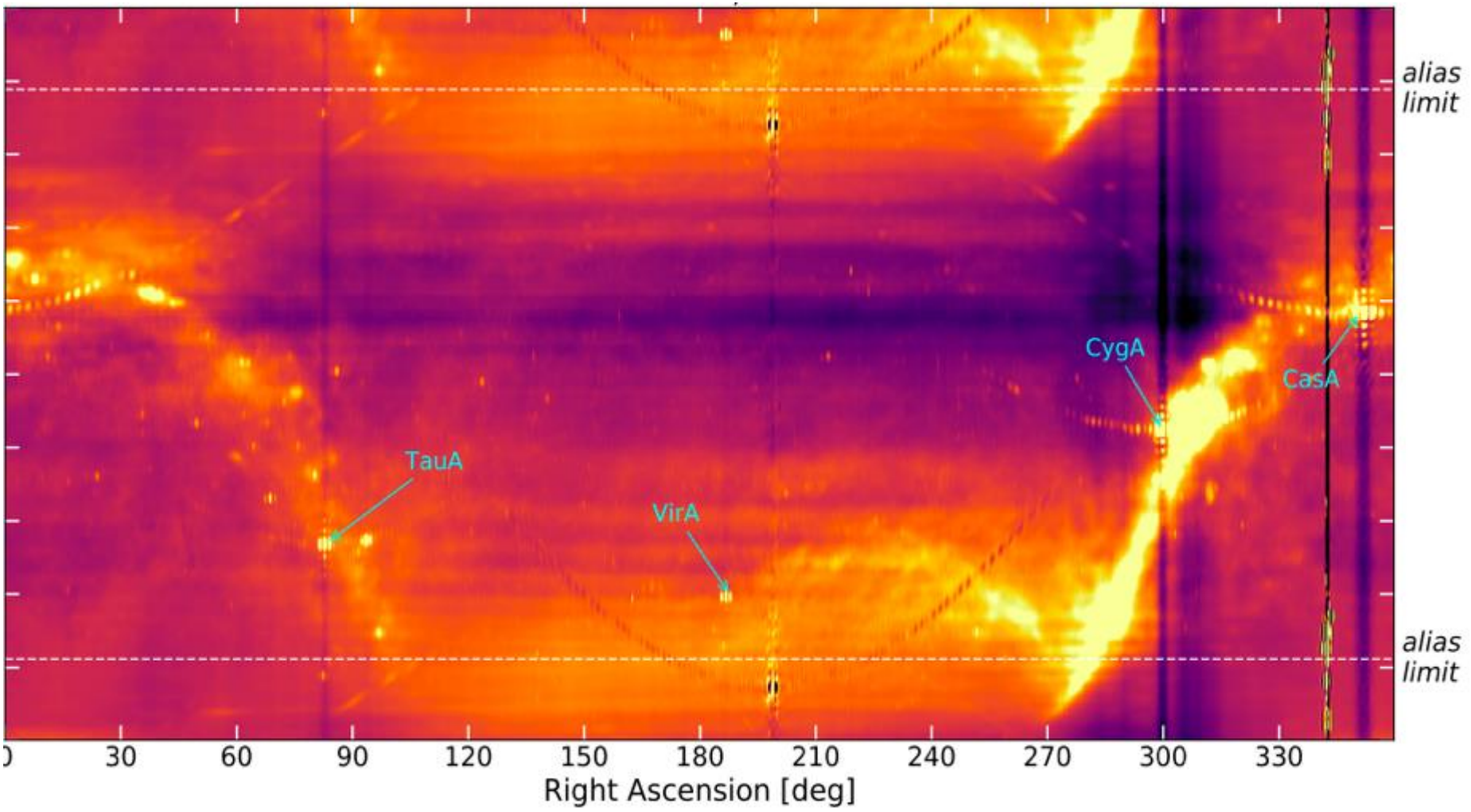
64 dual-pol antennas per cylinder (256 total channels)

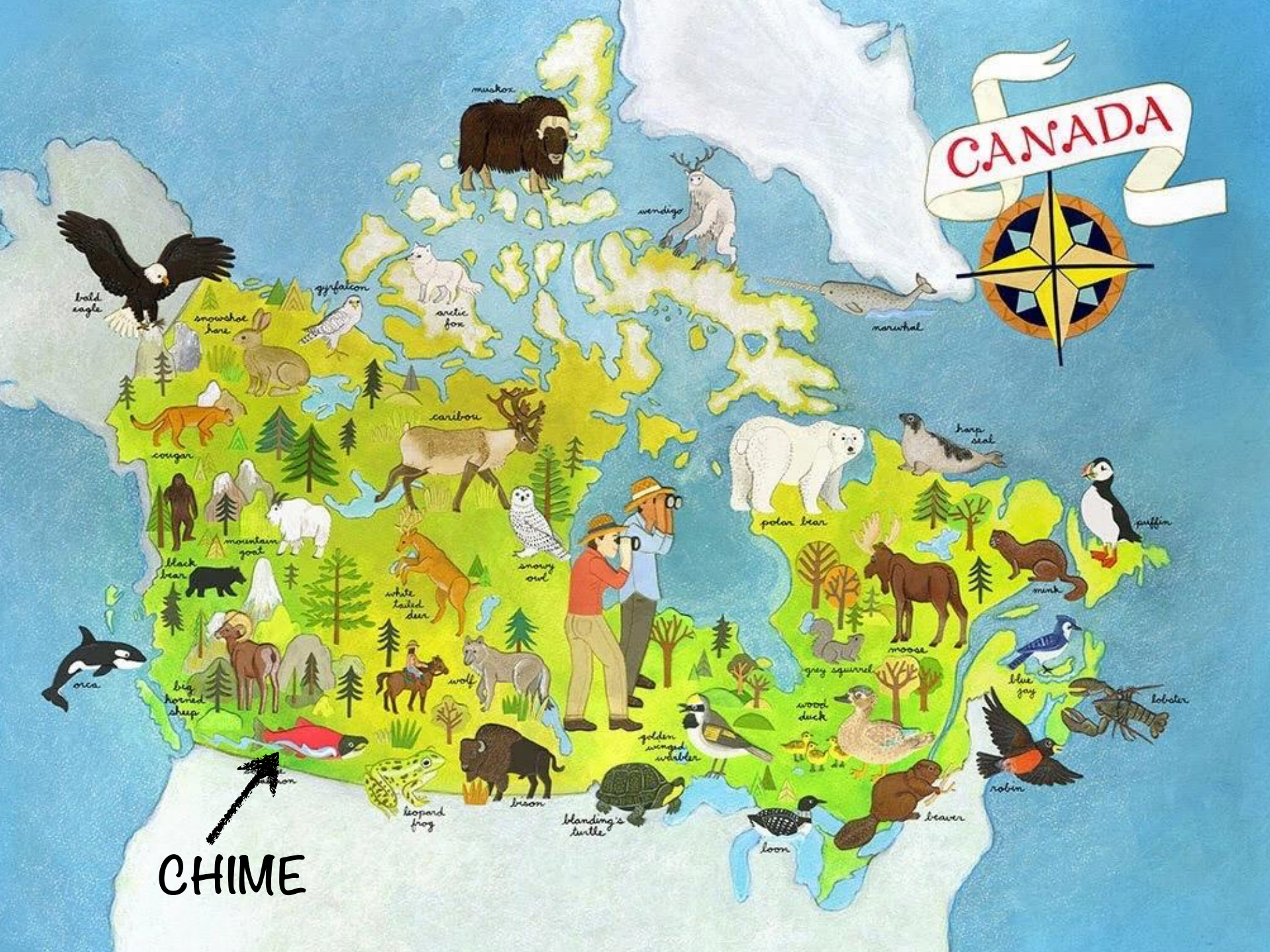


Details in
Bandura et al., 2014

Pathfinder Cylinders




alias
limit
CygA
CasA
TauA
VirA
alias
limit
0
30
60
90
120
150
180
210
240
270
300
330
Right Ascension [deg]

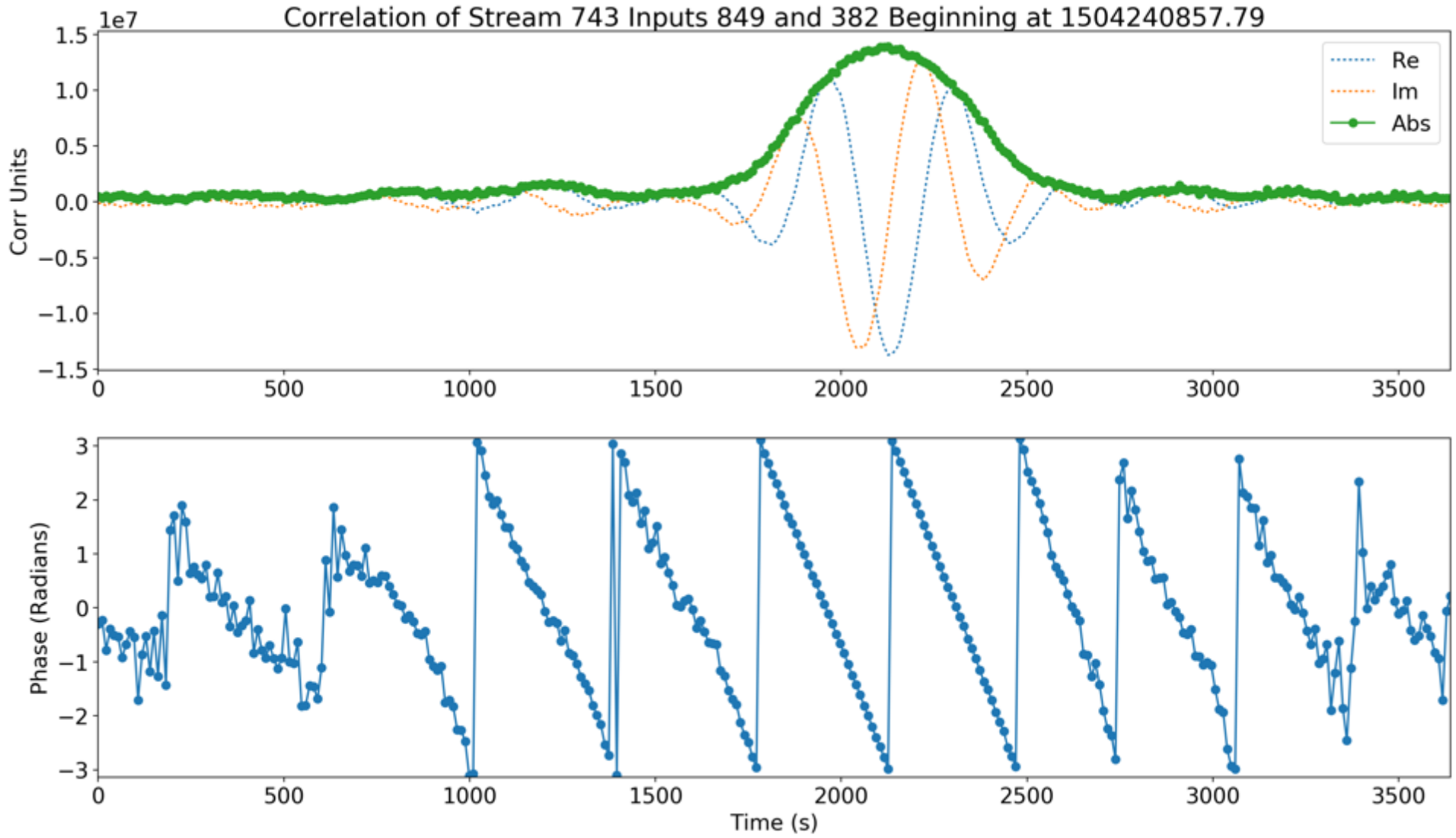

CANADA
muskox
wendigo
narwhal
bald eagle
gyrfalcon
snowshoe hare
arctic fox
cougar
caribou
harp seal
polar bear
puffin
mountain goat
black bear
snowy owl
white tailed deer
mink
moose
orca
big horned sheep
wolf
grey squirrel
blue jay
lobster
wood duck
golden winged warbler
robin
leopard frog
bison
blanding's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

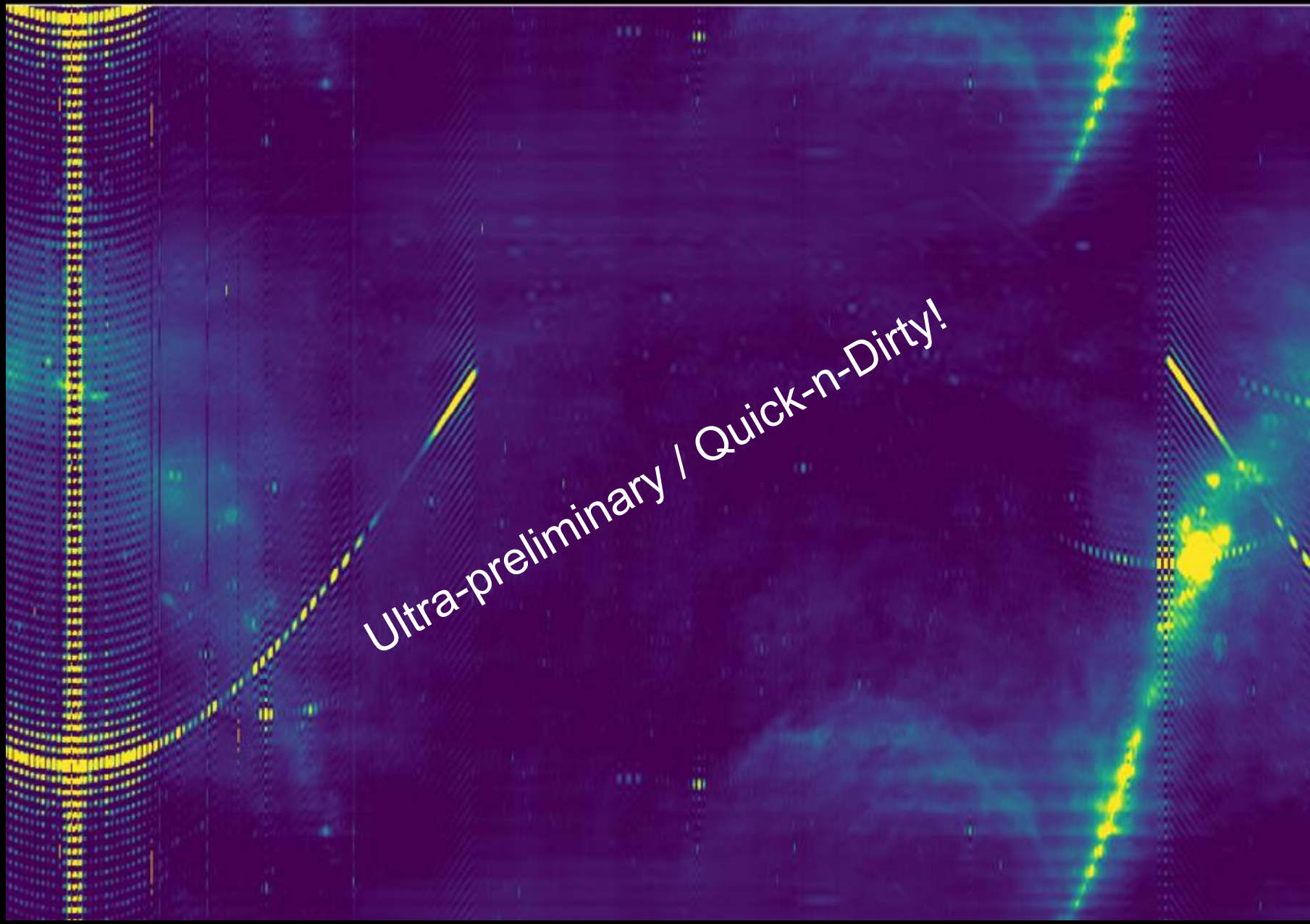

BEAUFORT SEA
BAFFIN SEA
Banks Island
Victoria Island
Somerset Island
Prince of Wales Island
King William Island
Baffin Island
Davis Strait
NUNAVUT TERRITORY
Foxe Basin
ARCTIC CIRCLE
YUKON TERRITORY
NORTHWEST TERRITORIES
Great Bear Lake
Great Slave Lake
Hudson Bay
Labrador Sea
Gulf of Alaska
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUÉBEC
NEWFOUNDLAND
Queen Charlotte Islands
Vancouver Island
PACIFIC OCEAN
Lake Winnipeg
Calgary
Regina
Winnipeg
OTTAWA
Montréal
Québec
Toronto
Seattle
Minneapolis
Chicago
Detroit
Cleveland
Boston
New York
Pittsburgh
Milwaukee
NOVA SCOTIA
Nova Scotia
Cape Breton Island
ATLANTIC OCEAN
UNITED STATES
CHIME
CANADA
0 km 300 600 900 km
2009 Ezilon.com All Right Reserved


20m
N
S
100m

First Light!

Sept, 2017




N-S Angle
RA
Ultra-preliminary / Quick-n-Dirty!

Extra Capabilites

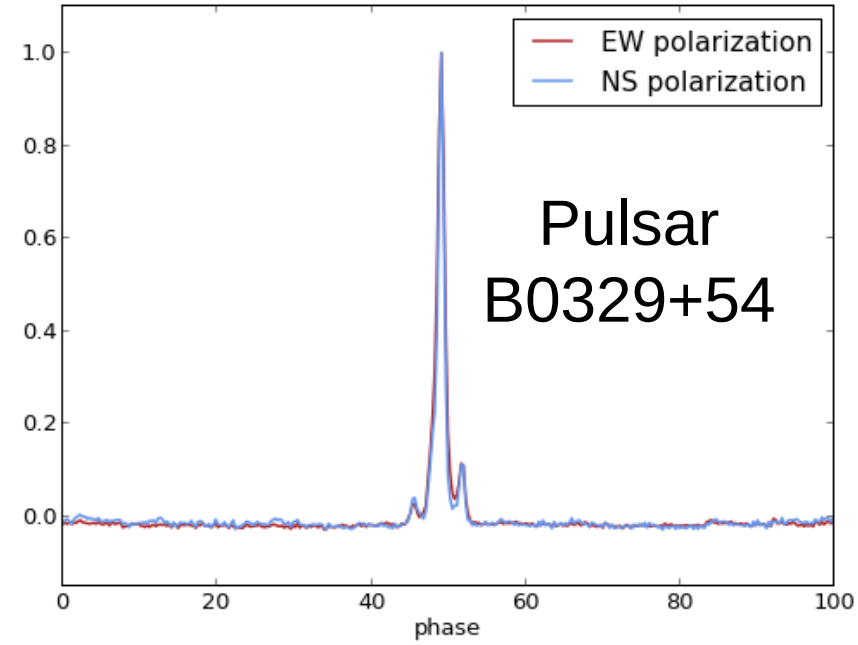
Digital telescope → trivially fork the data

CHIME/pulsar
- monitor every known northern pulsar ~daily

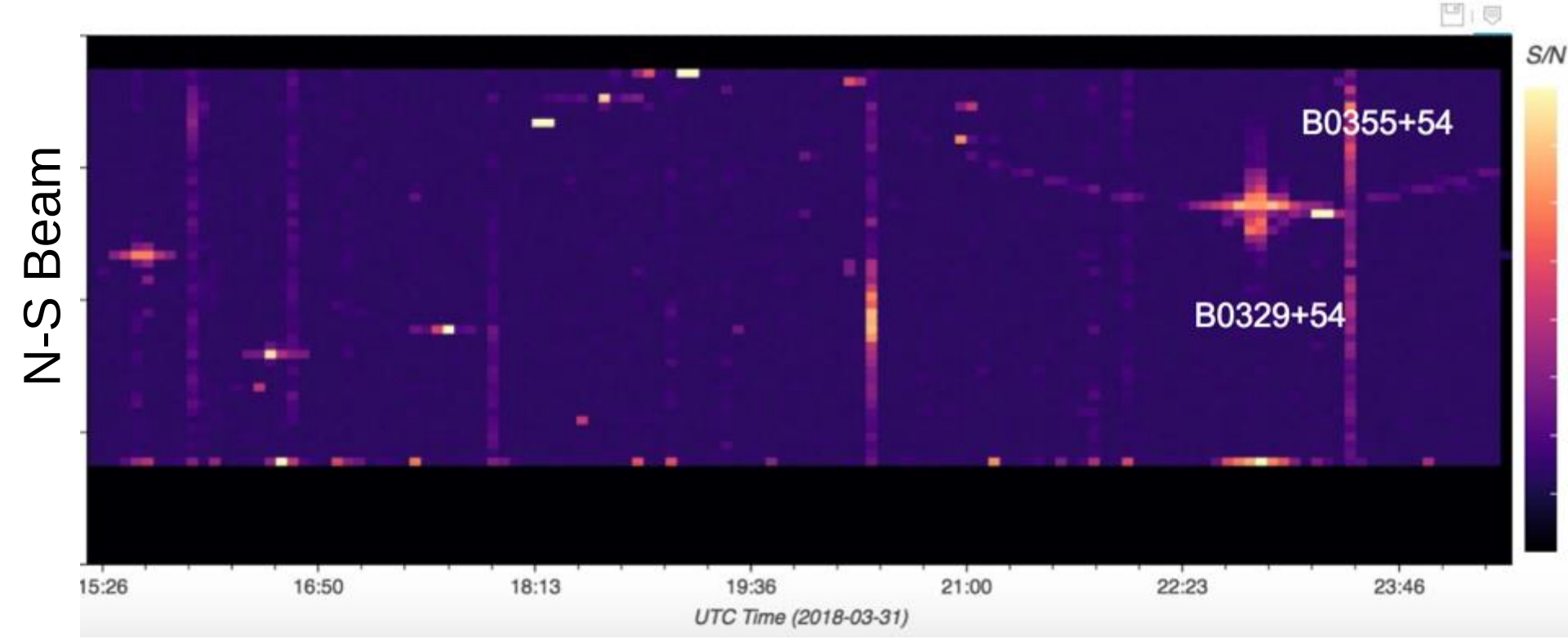
CHIME/VLBI
- combine with remote stations for source localization

CHIME/FRB
- search for dispersed single-pulse events, e.g. Fast Radio Bursts

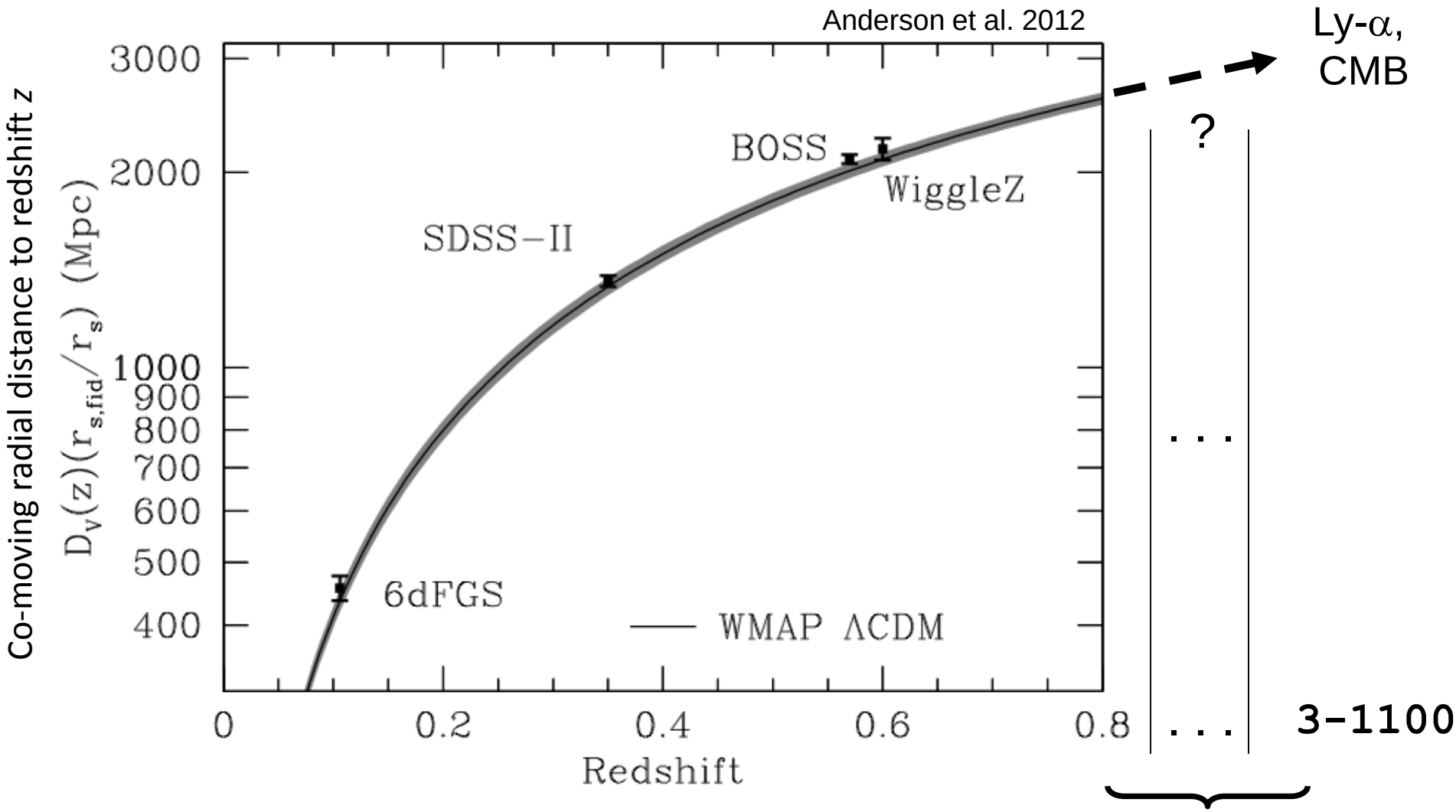
…



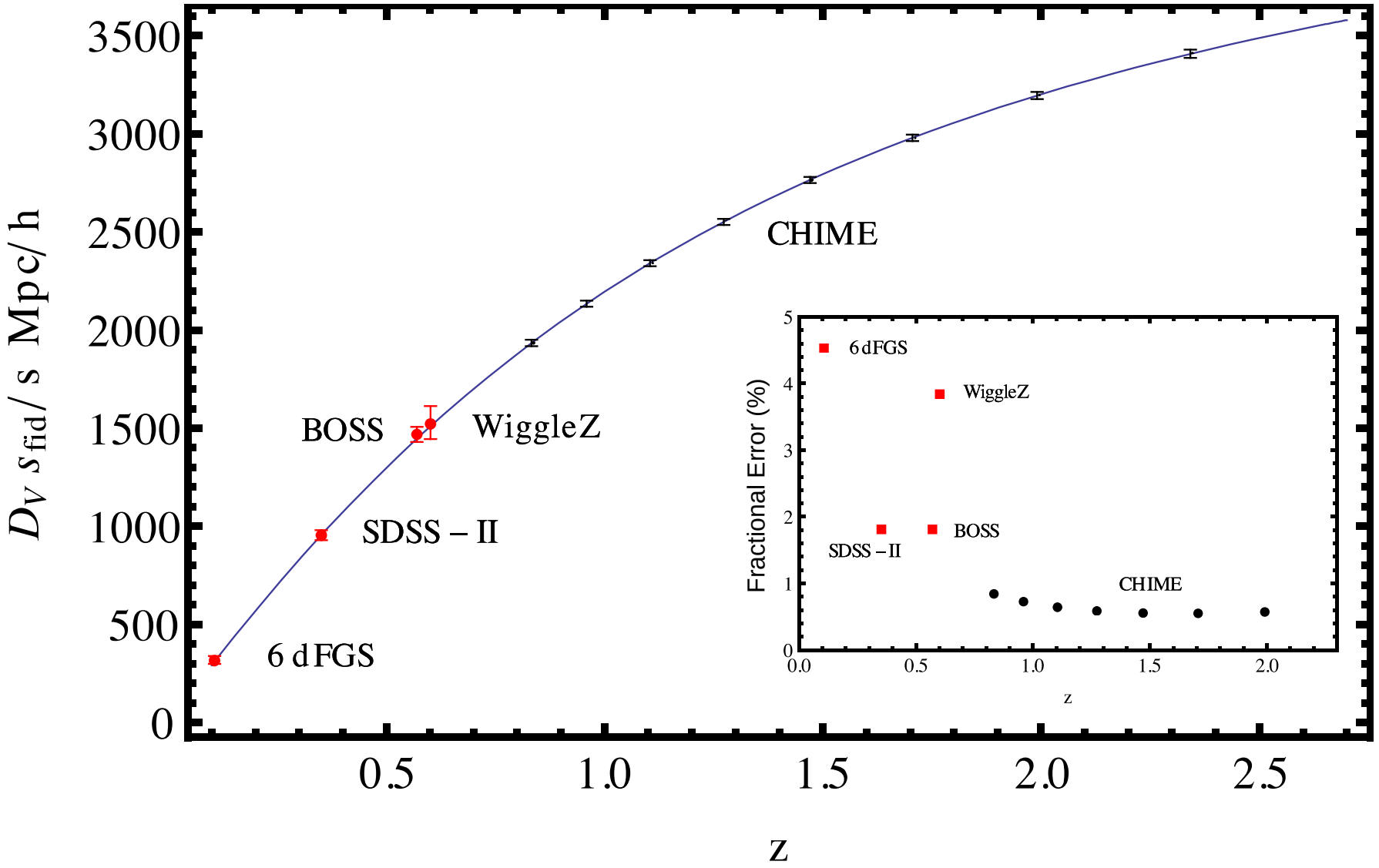
Commissioning
← CHIME/pulsar & CHIME/FRB
↓



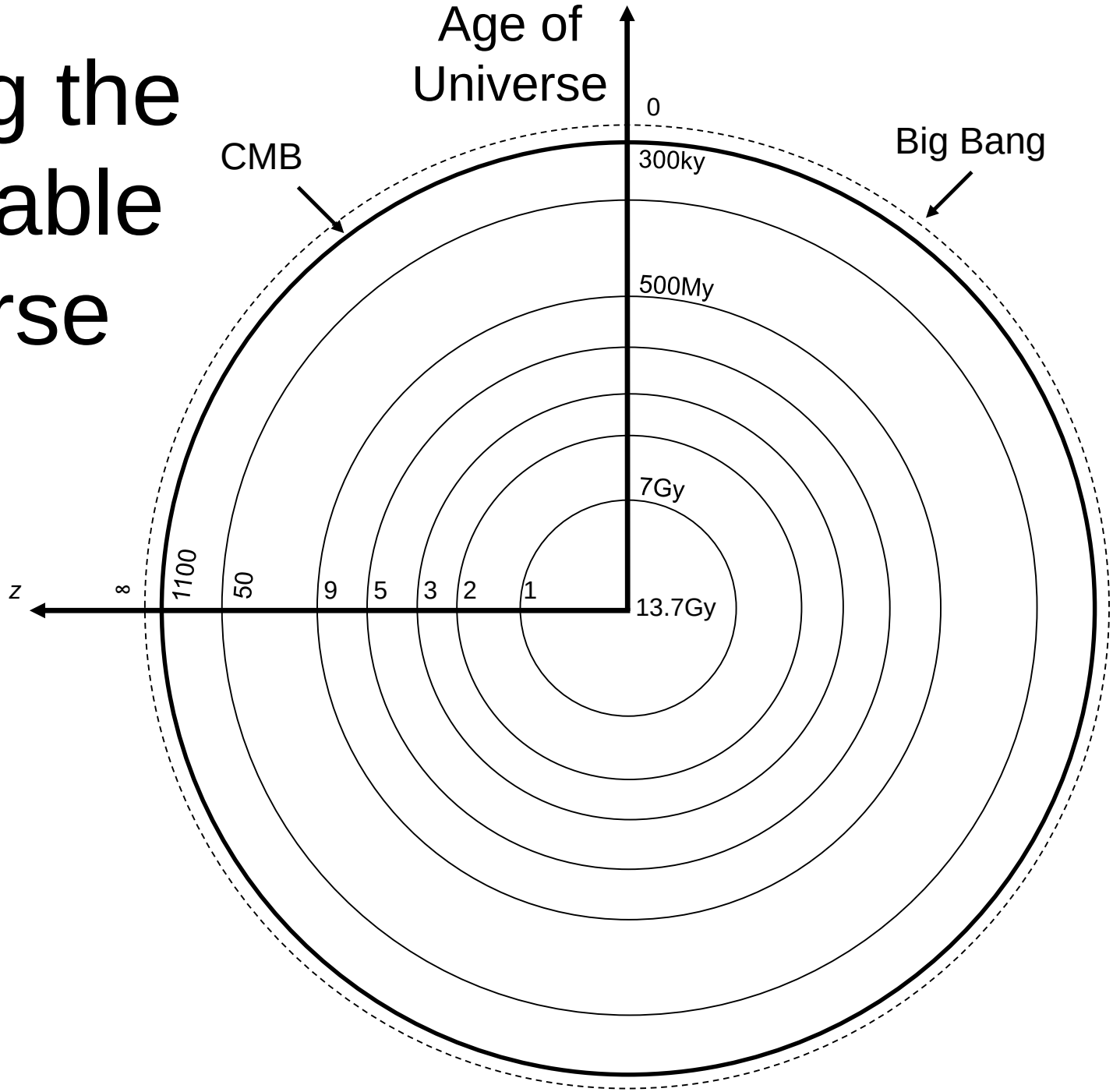
BAO as a standard ruler



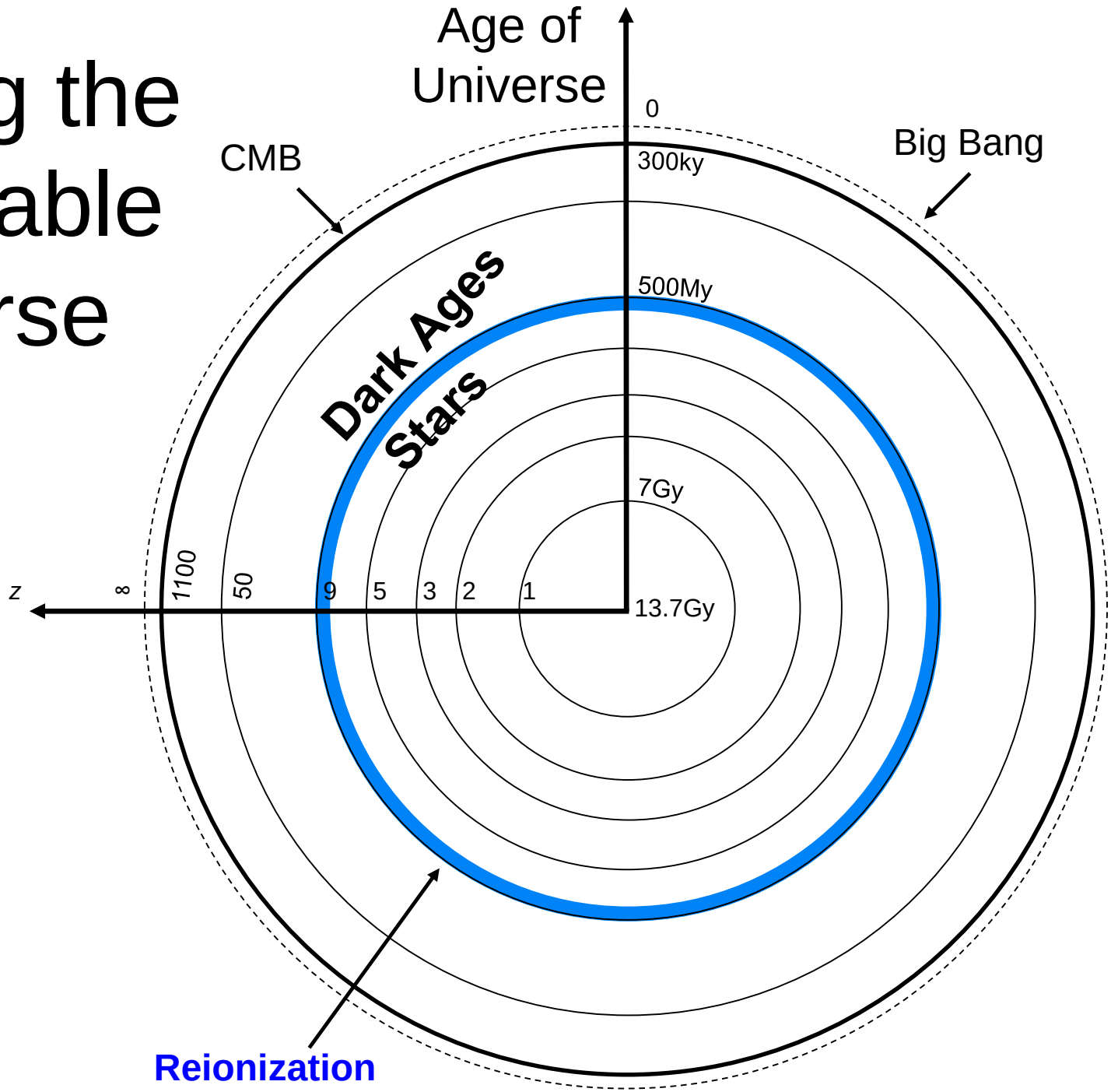
CHIME Cosmology



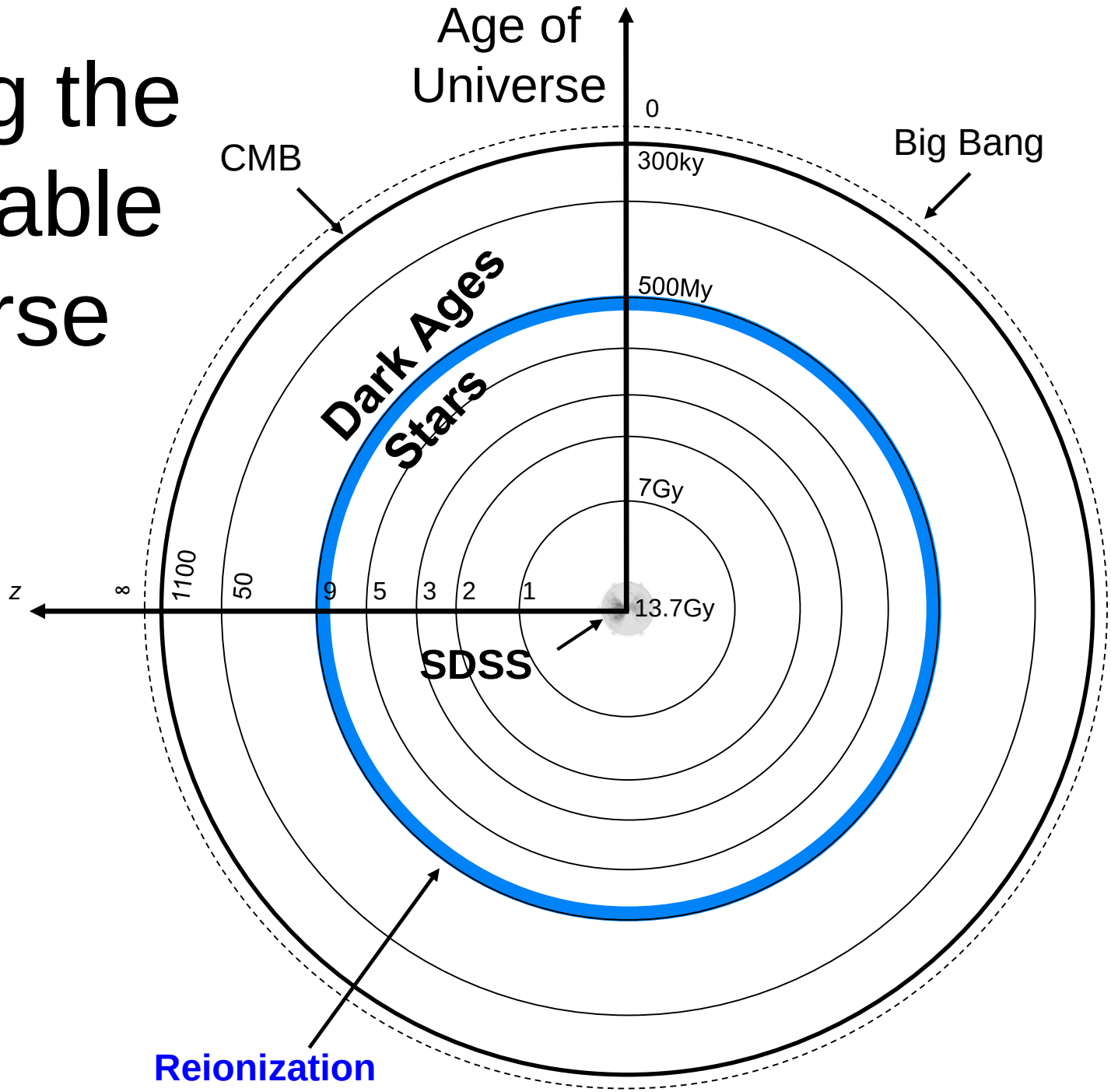
Mapping the Observable Universe



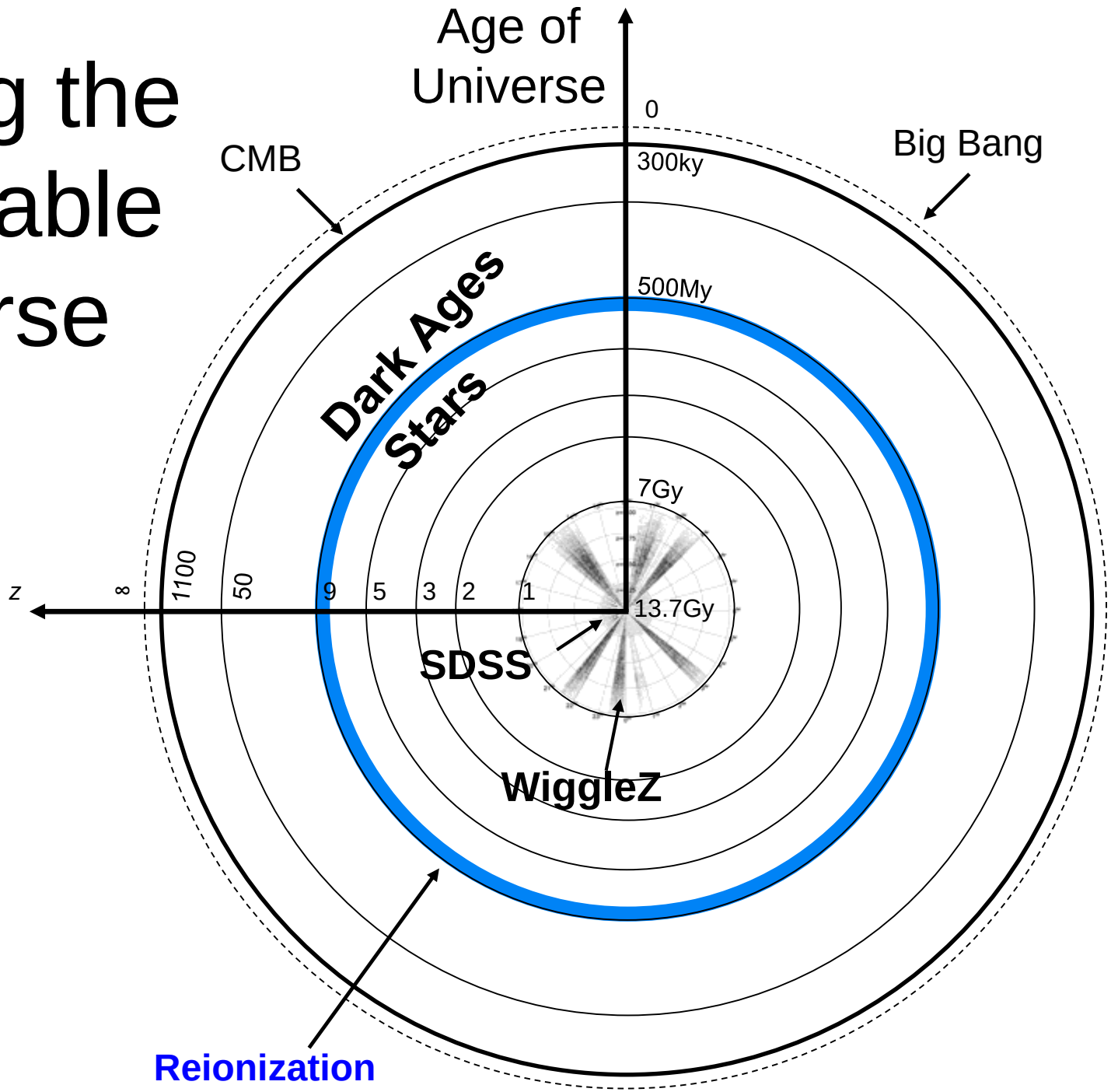
Mapping the Observable Universe



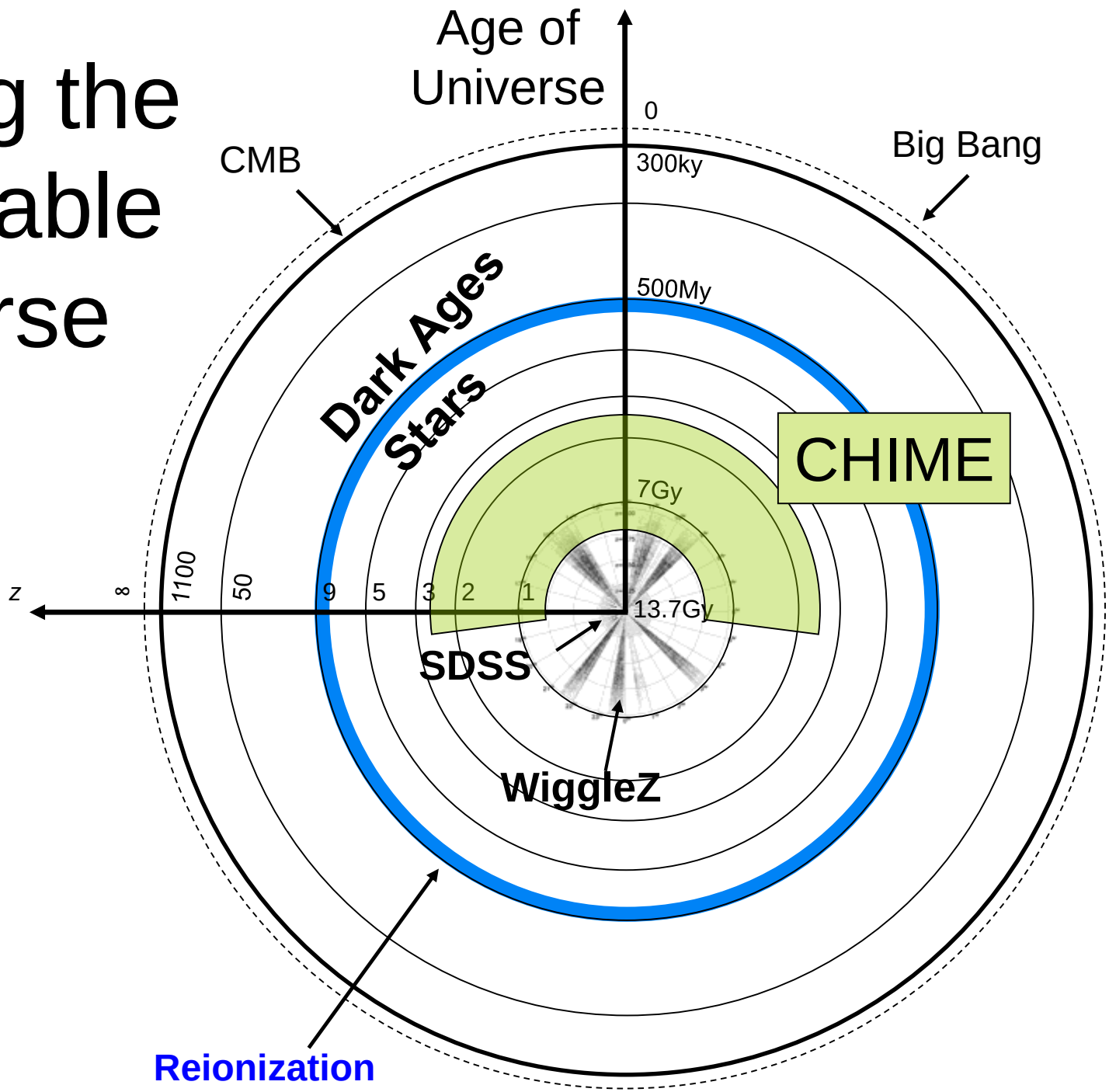
Mapping the Observable Universe



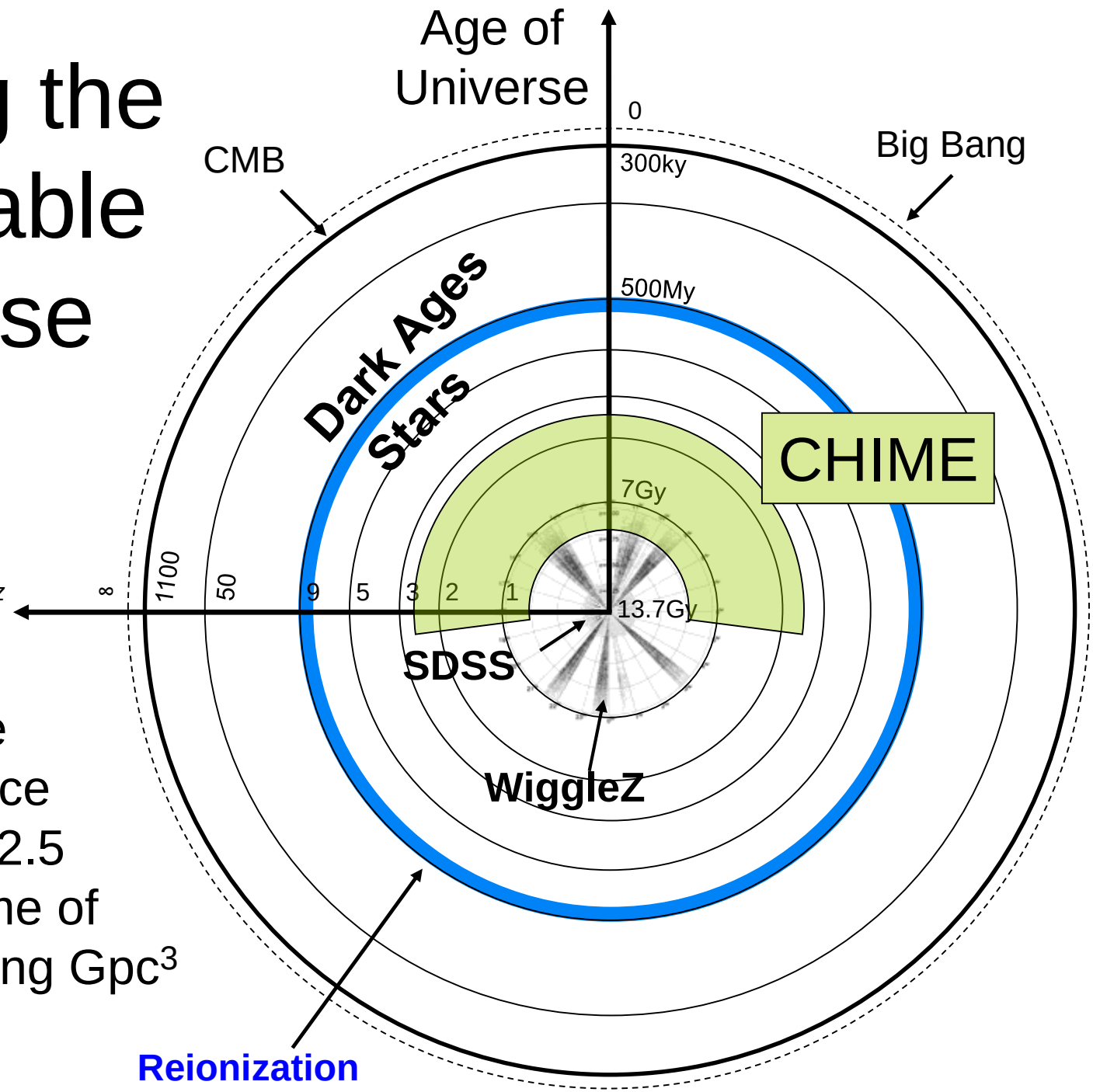
Mapping the Observable Universe



Mapping the Observable Universe



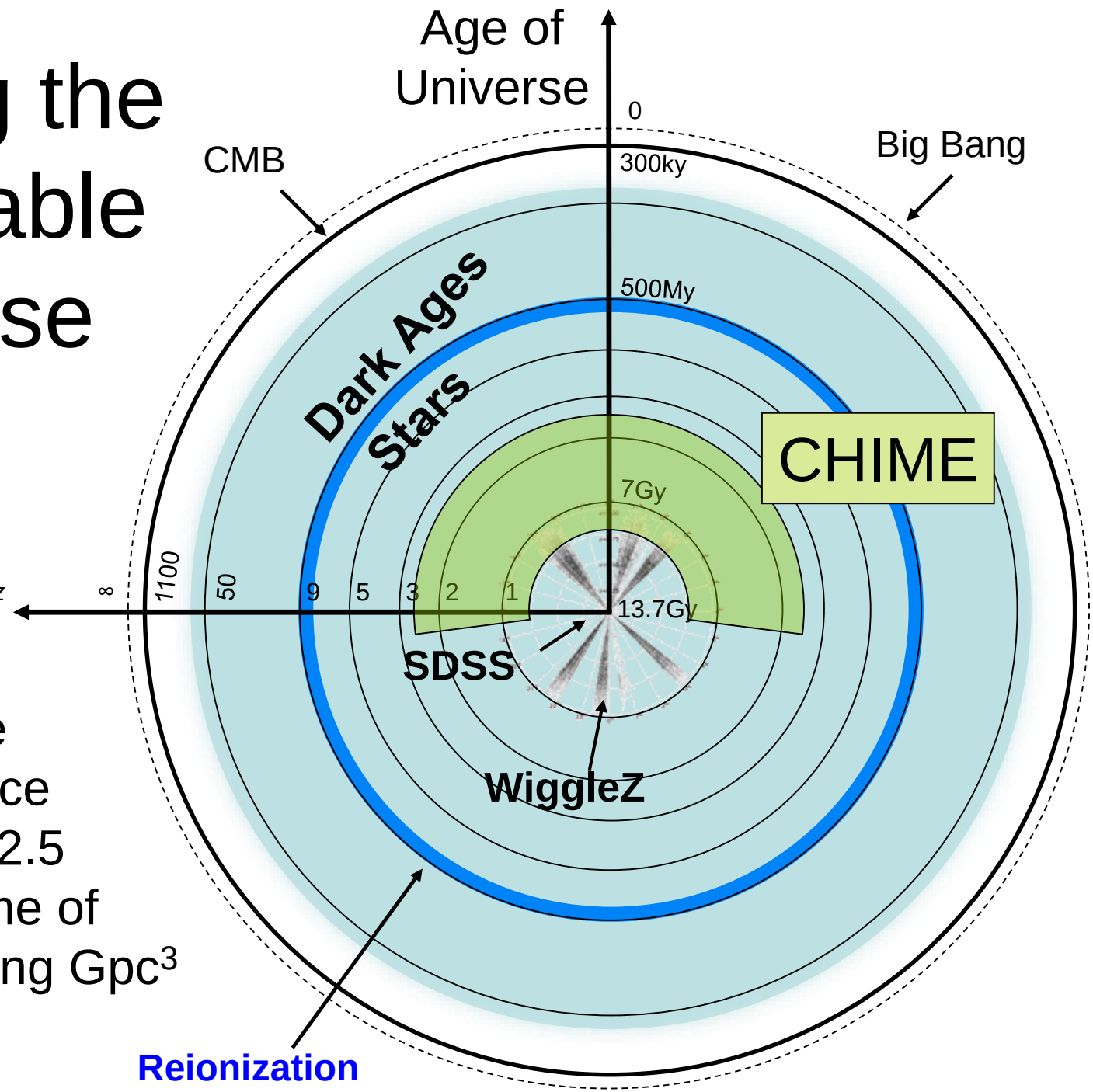
Mapping the Observable Universe



CHIME will:

- survey BAO
- measure the growth of space
- from 0.8<z<2.5
- over a volume of ~400 co-moving Gpc^3

Mapping the Observable Universe



CHIME will:

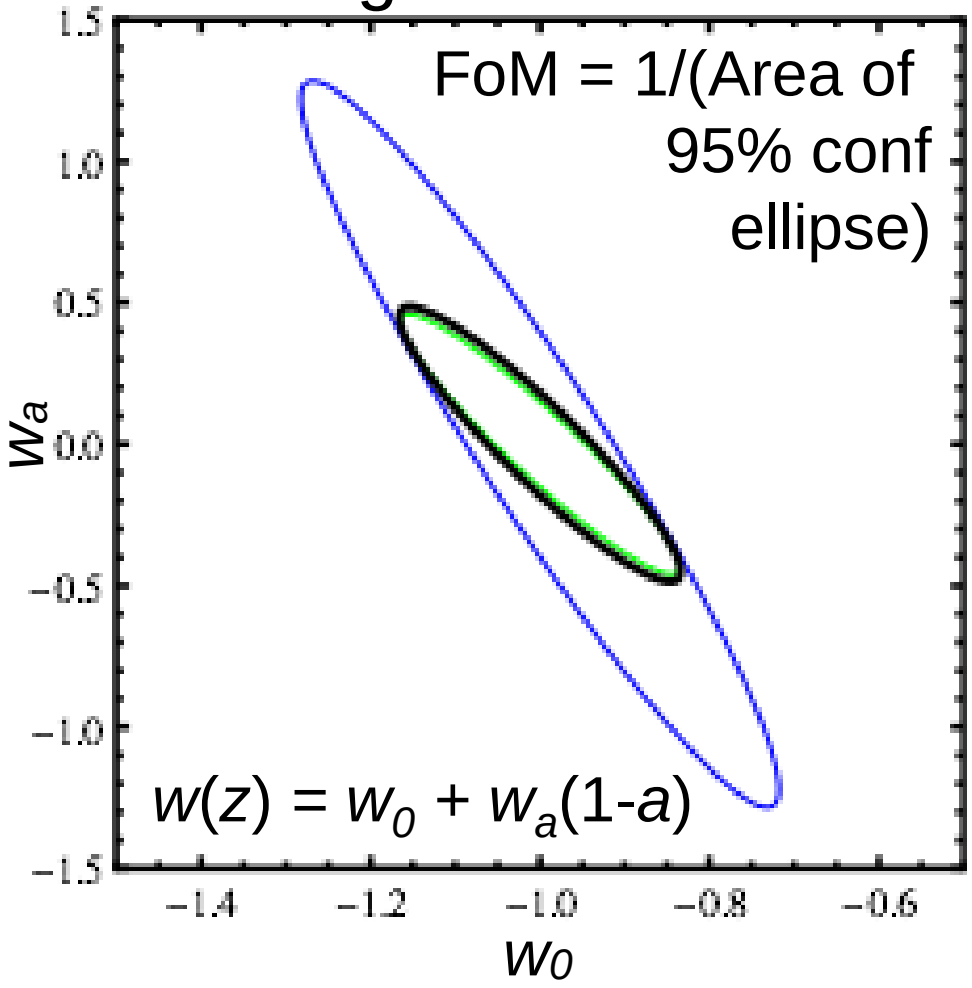
- survey BAO
- measure the growth of space
- from 0.8<z<2.5
- over a volume of ~400 co-moving Gpc^3

The End

Extra Slides Follow

Dark Energy Task Force

Figure of Merit



Stages I-IV (def'n 2006)

I. Known → foundations

II. Underway → complete

III. Near-term → ongoing

IV. Large (>G$) → 2020s?
   i. LSST
   ii. JDEM / WFIRST
   iii. SKA

GPU Backend

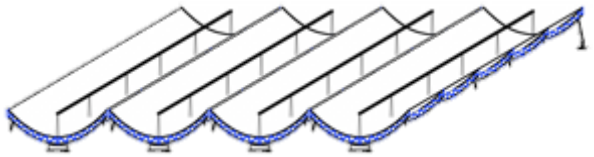
Graphics Processing Units (GPUs) are powerful & cheap

~1000x more computational power per $ than CPUs

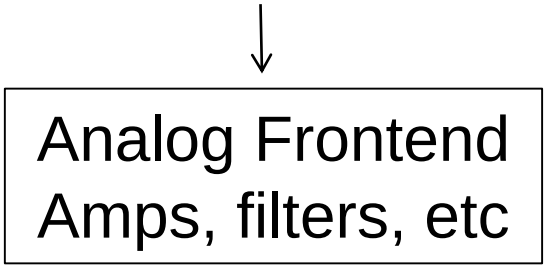
Consumer parts → *very* robust.

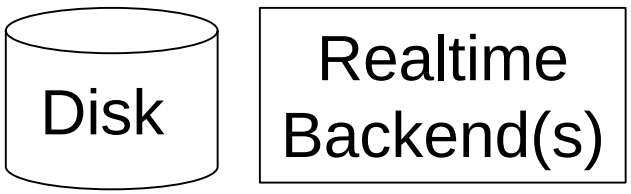
Relatively simple to program, very easy to update code.

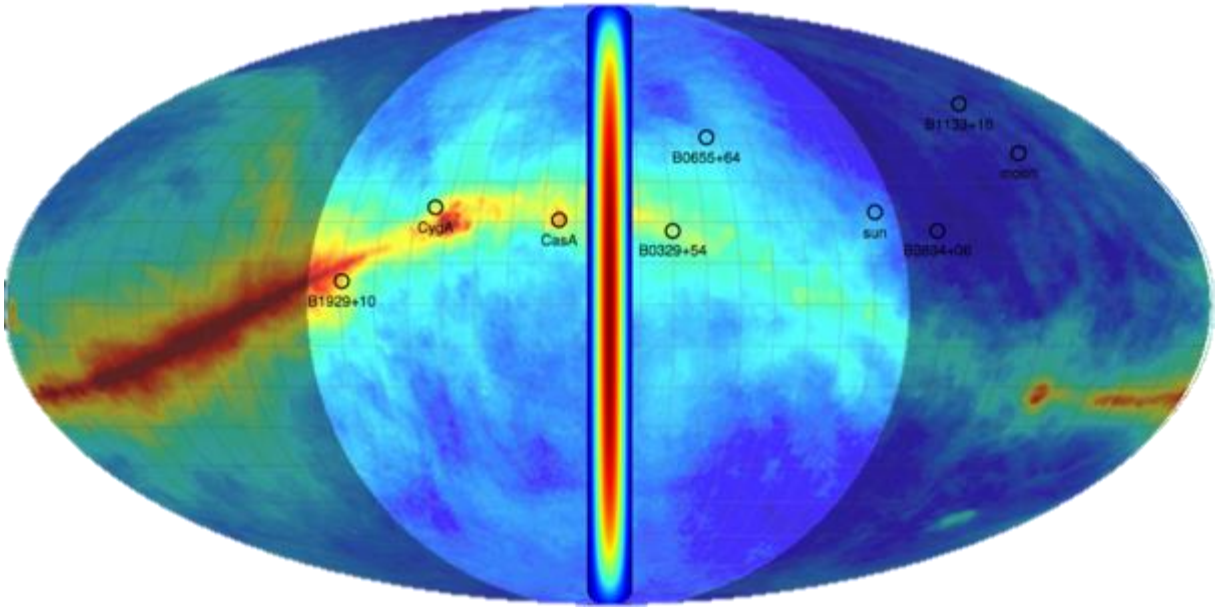
System Overview



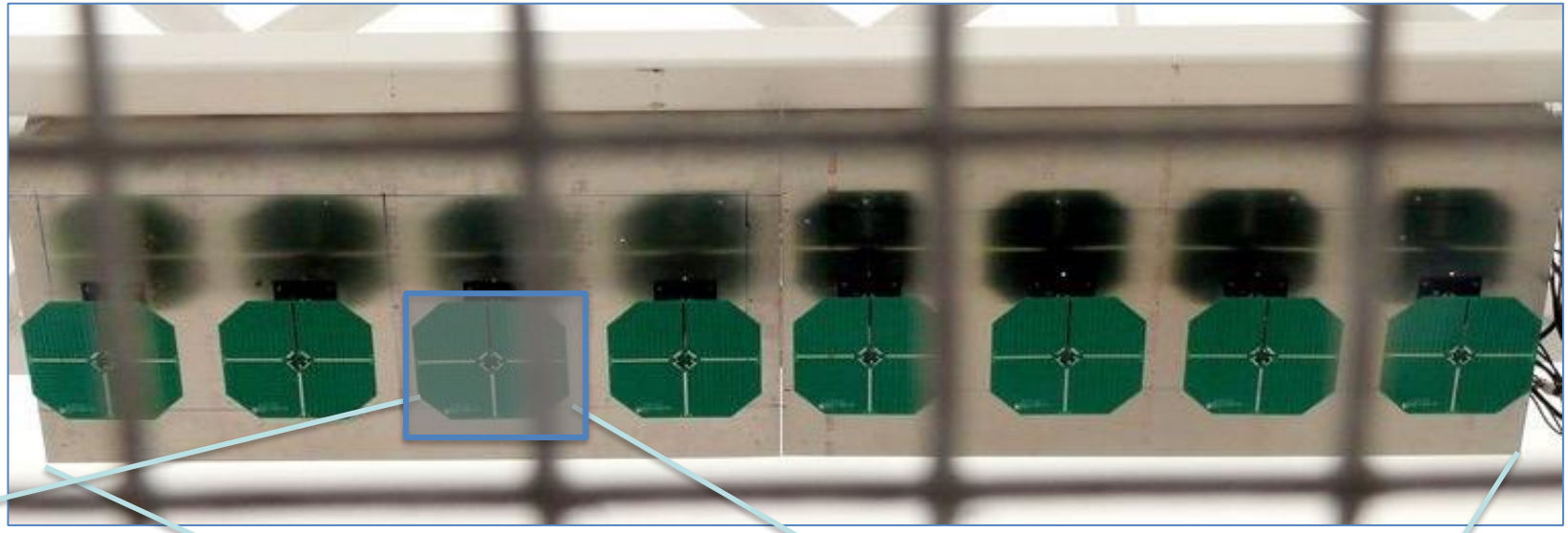
Reflectors

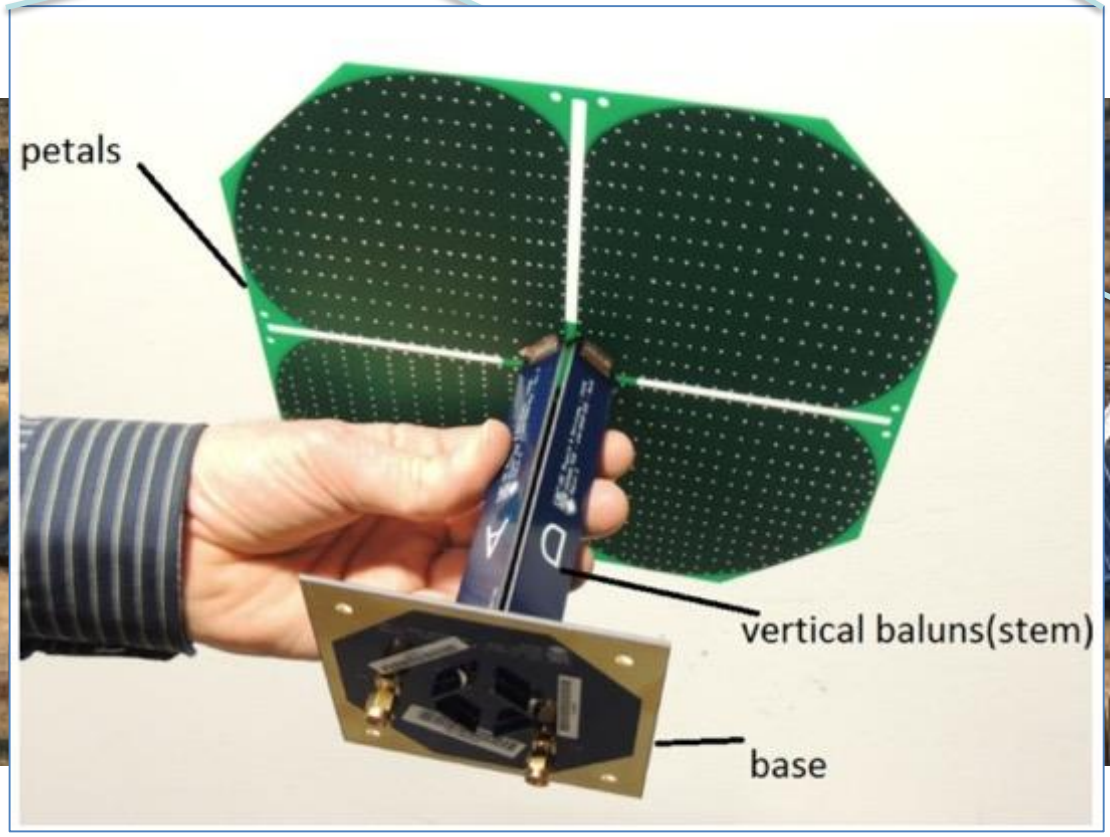




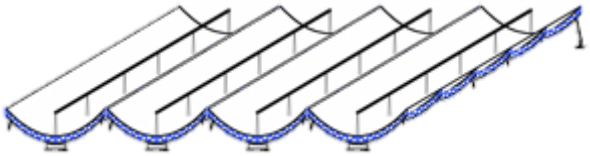


- 1024 dual-polarization feeds
- each sees a broad N-S band

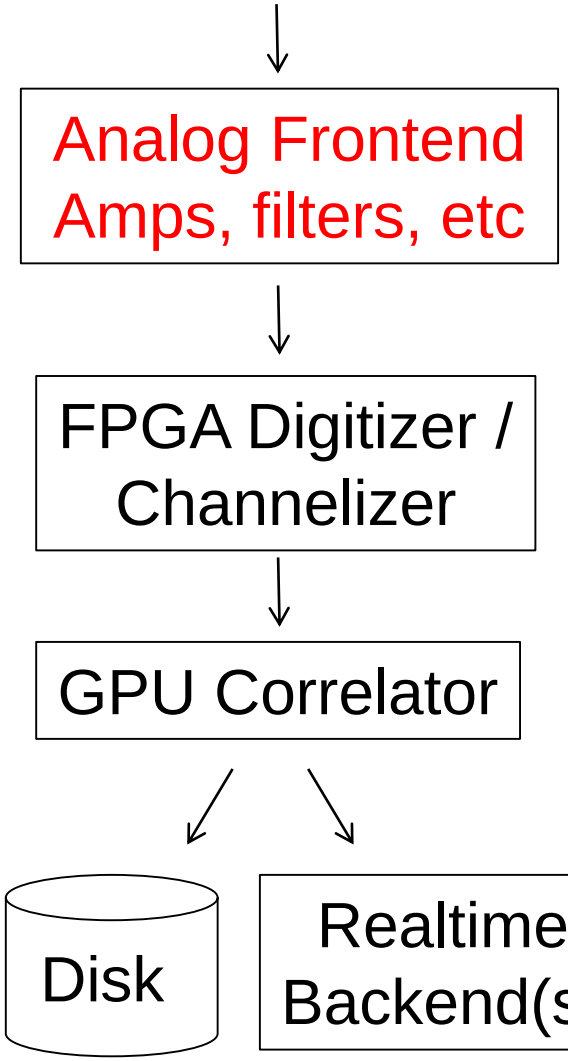


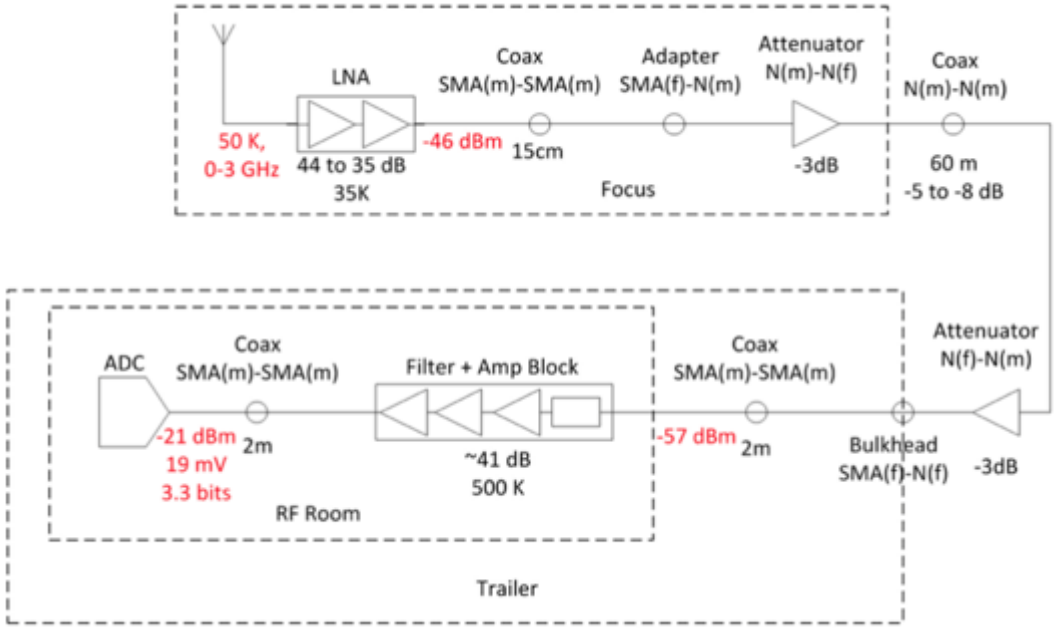

petals
vertical baluns(stem)
base

System Overview



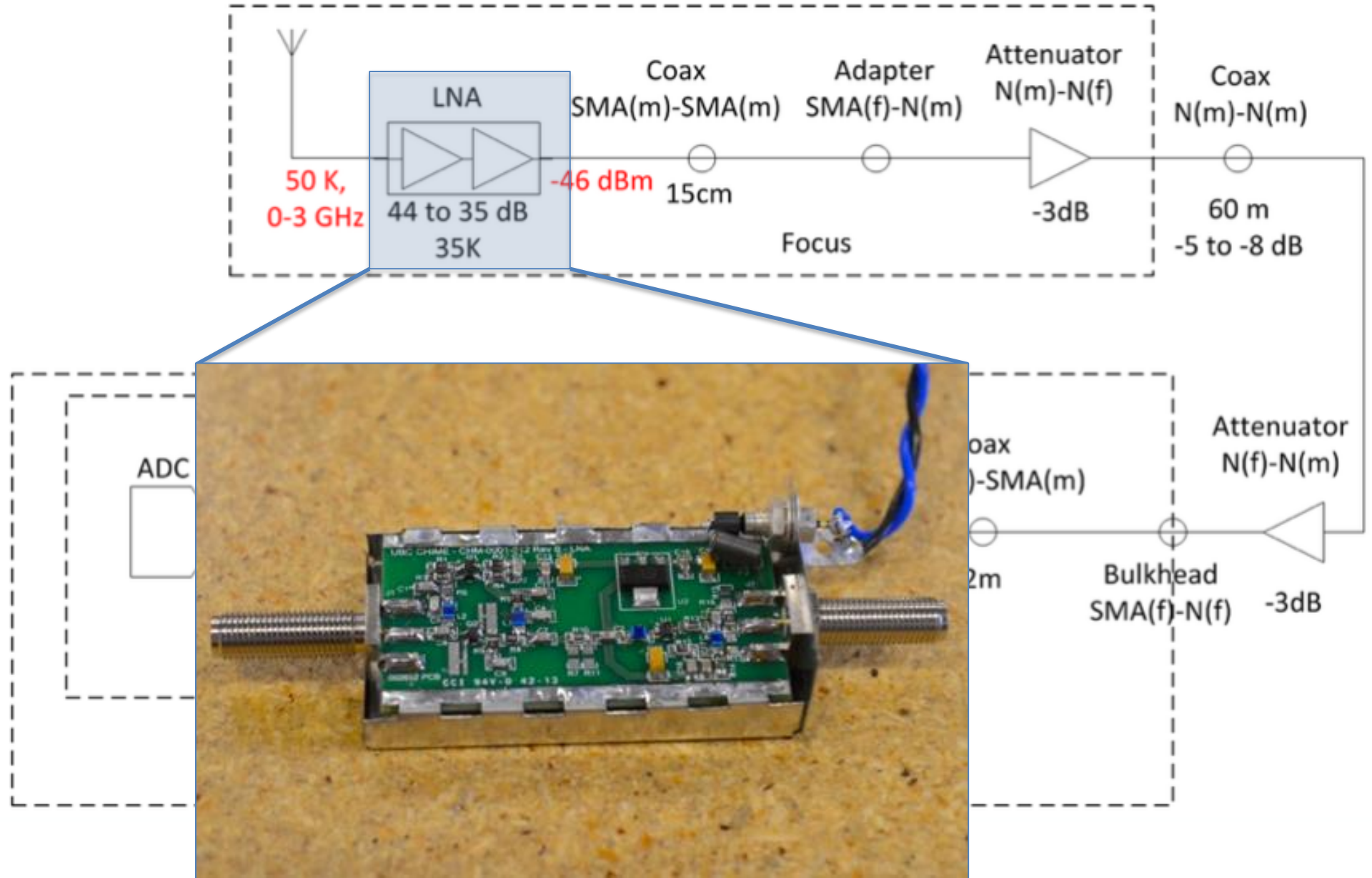
Reflectors



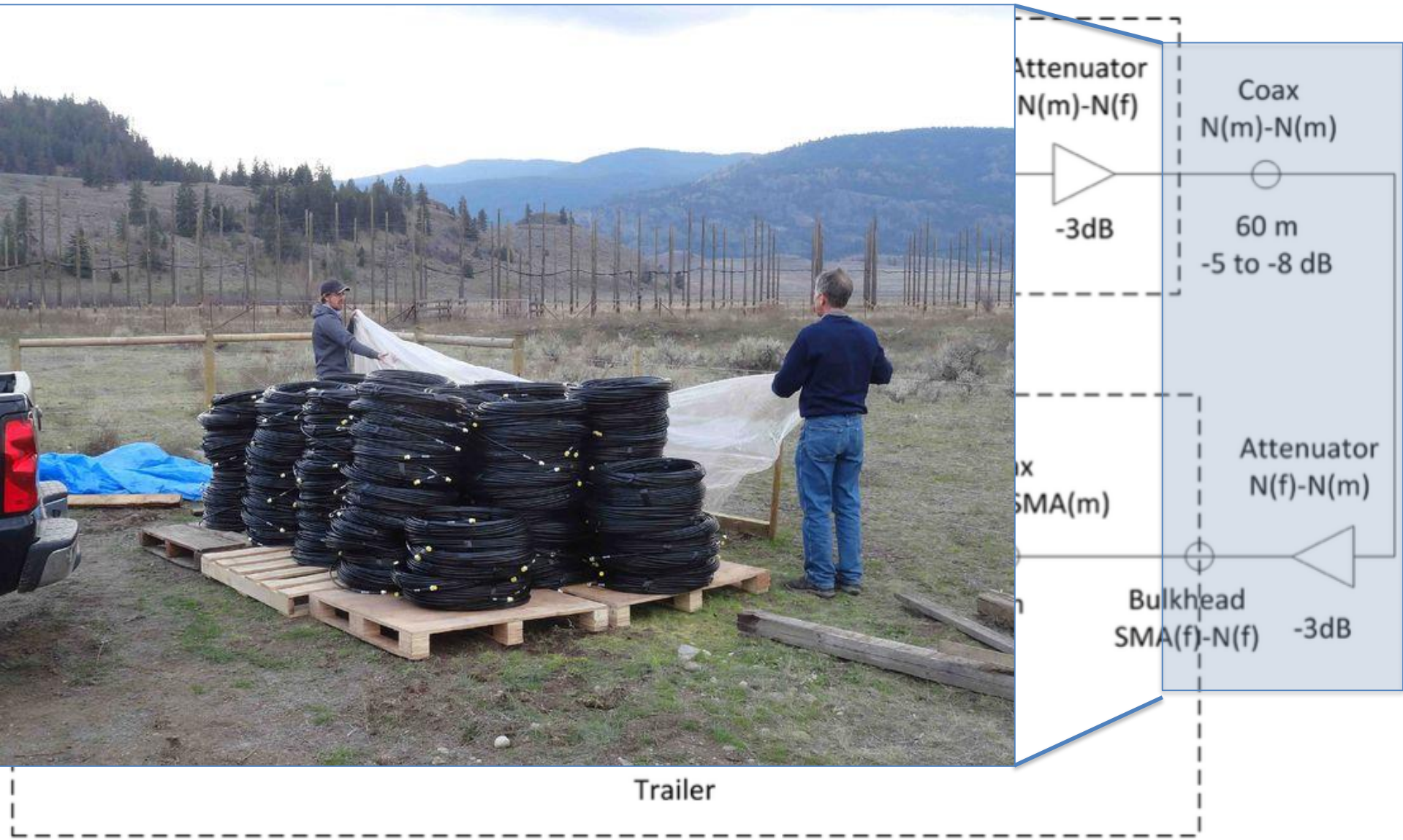


Custom analog frontend, possible largely due to communications tech.

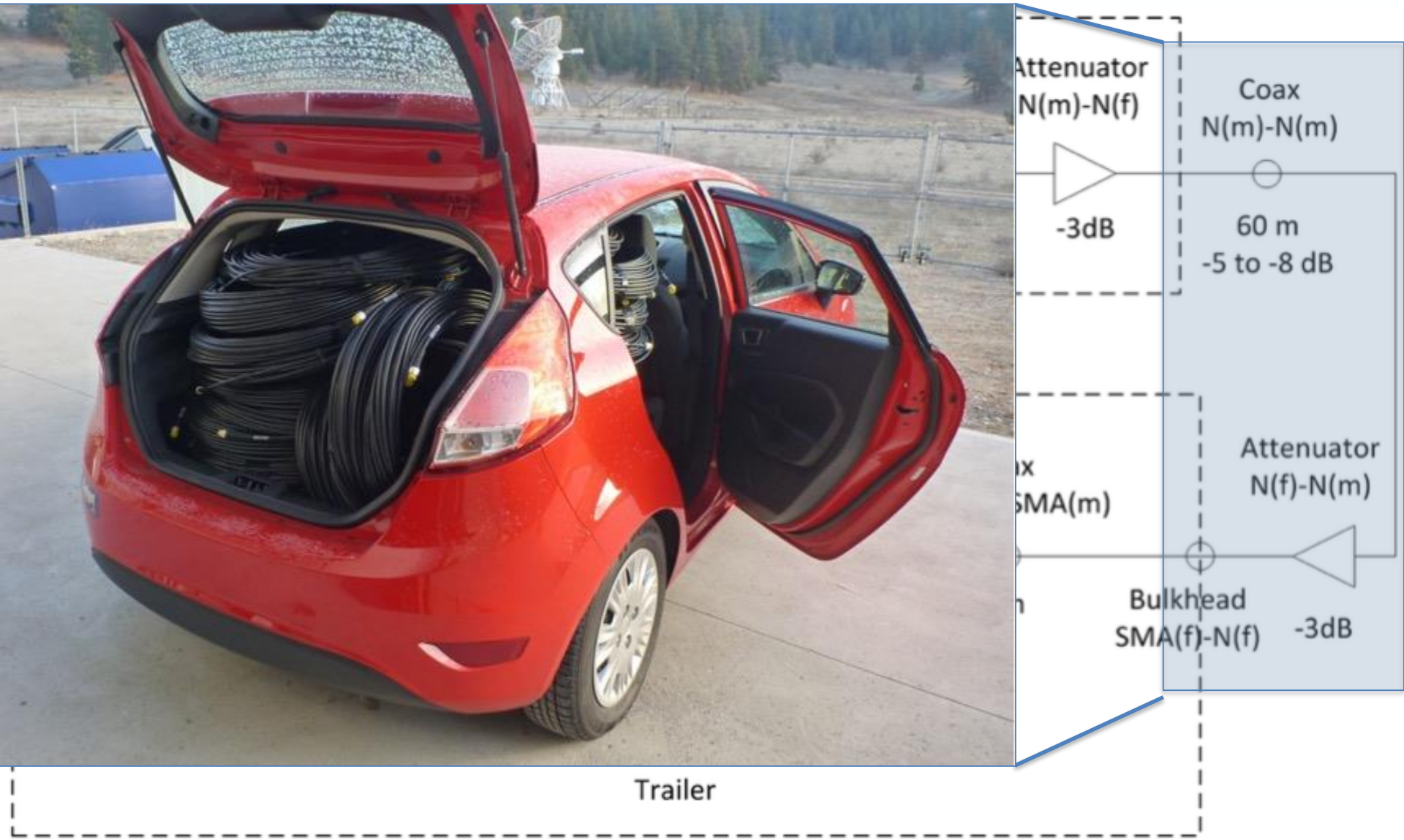
Analog System Overview



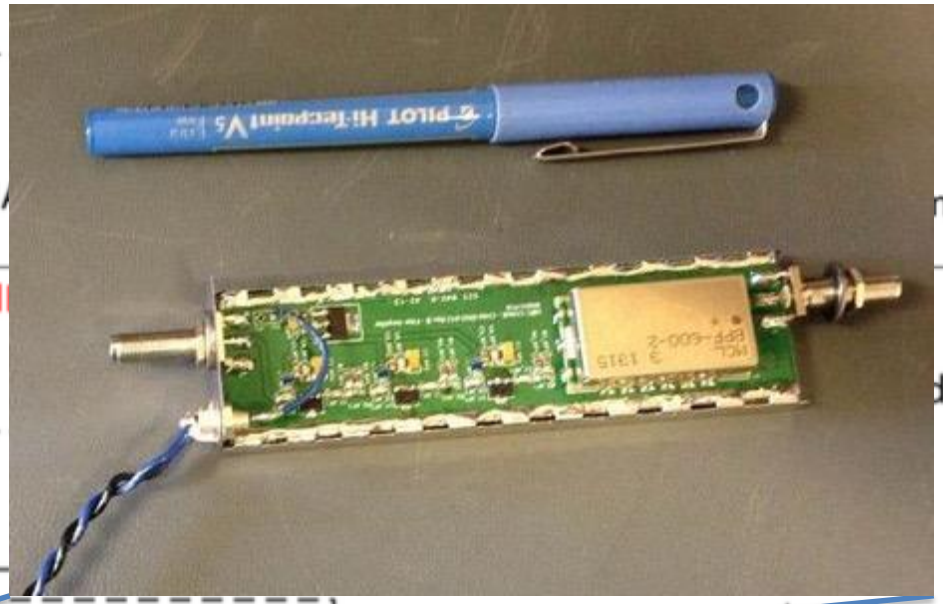
Analog System Overview



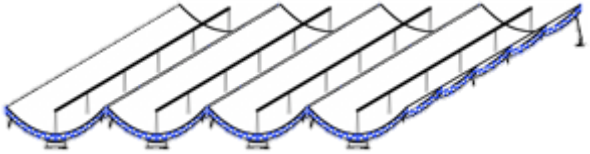
Analog System Overview



Analog System Overview



System Overview



Reflectors

↓

Analog Frontend
Amps, filters, etc

↓

FPGA Digitizer /
Chanelizer

↓

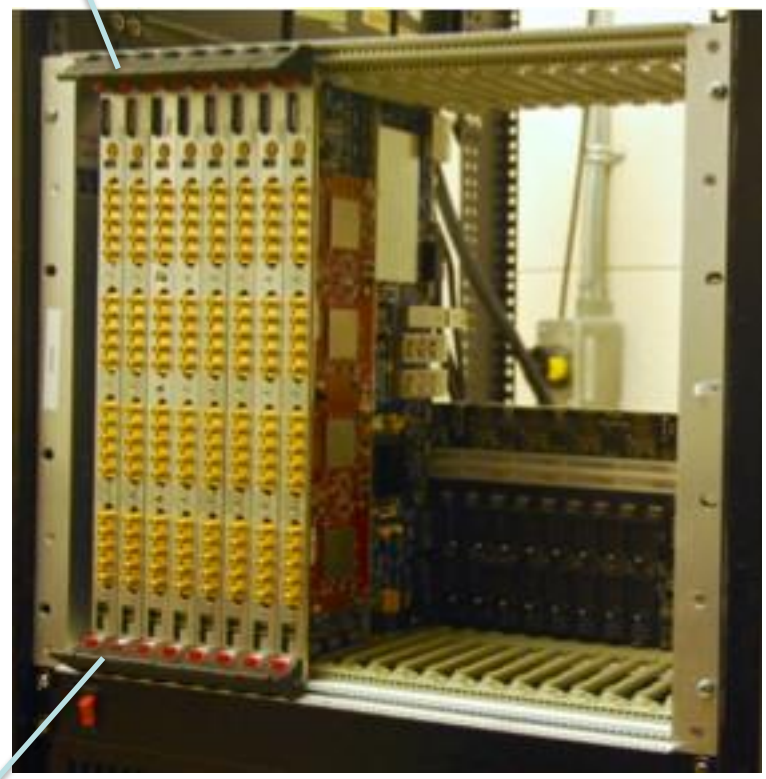
GPU Correlator

↓

HDD

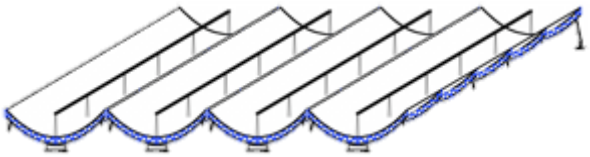
Bandura et al, 2016

Digitizes at 800MHz
Splits into 1024 freqs
via 4-tap PFB



16 / crate, 8 crates

System Overview



Reflectors

↓

Analog Frontend
Amps, filters, etc

↓

FPGA Digitizer /
Chanelizer

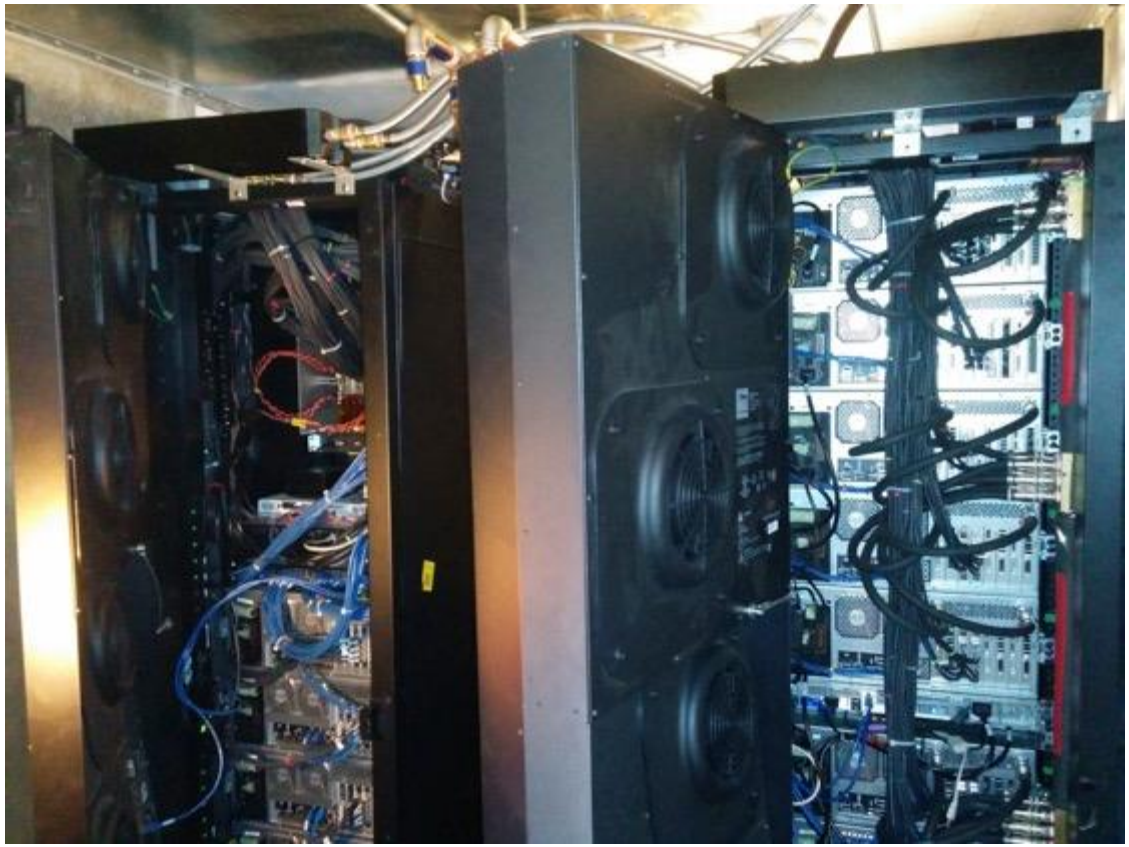
↓ ≈Tbps

GPU Correlator

≈Gbps ↙ ↘

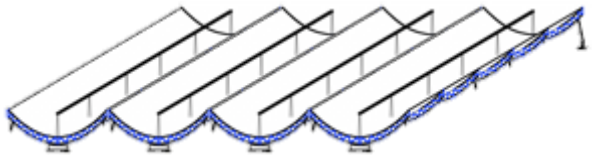
Disk

Realtime
Backend(s)



Consumer-level supercomputer
Process data, raw → imaging
Flexible: software telescope!

System Overview



Reflectors

↓

Analog Frontend
Amps, filters, etc

↓

FPGA Digitizer /
Chanelizer

↓ ≈TBps

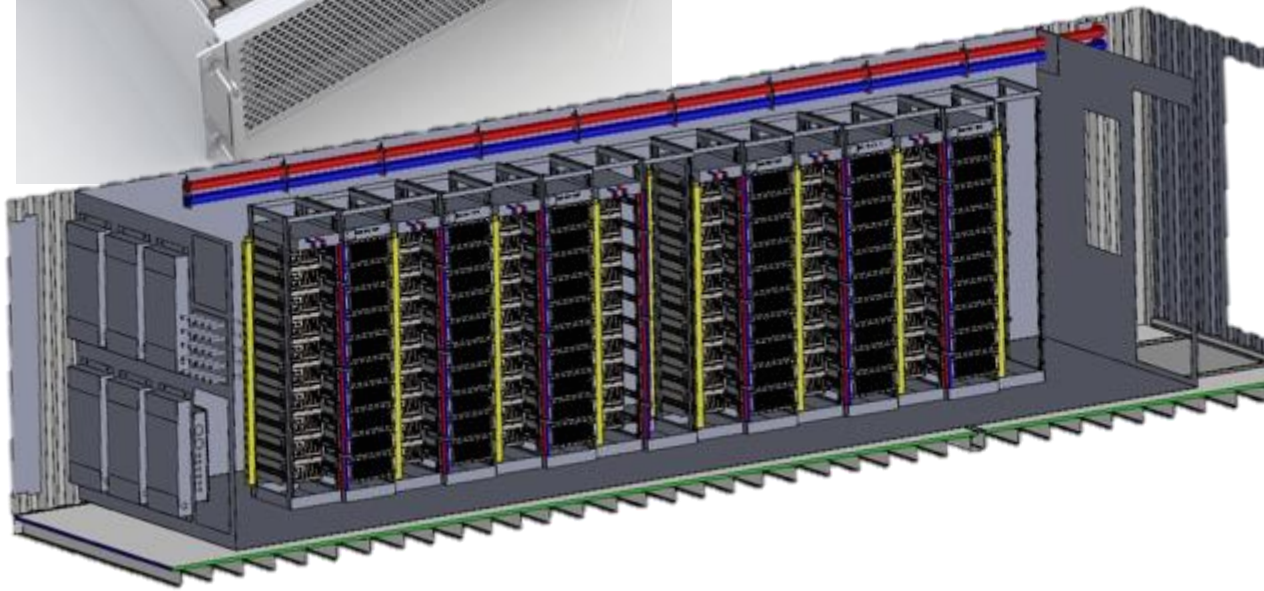
GPU Correlator

≈GBps ↓

HDD

AMD GPU-based X-Engine

- GPUs outdid Moore's Law
  ➔Full N^2 corr
- Fits in a SeaCan



Full N^2 ≈10^{15} cMAC/s ≈ 8 PFLOP/s