

Title: CHIME Radio Astronomy

Date: May 08, 2018 09:00 AM

URL: <http://pirsa.org/18050049>

Abstract:



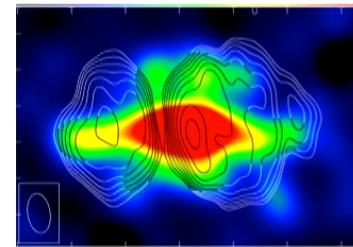
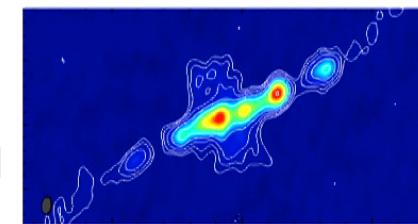
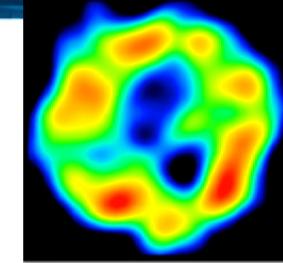
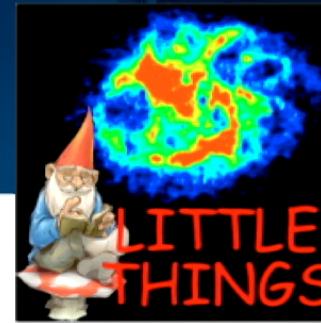
Outline

- The role of NRC Herzberg and DRAO
- Cosmology at DRAO: CHIME
- Cosmology at DRAO: CGEM
- Missing bits

Michael's science

I work on:

- The interstellar medium: HI, CO, and dust in nearby galaxies (with occasional bits of dynamics thrown in)
- Black hole, neutron star, and white dwarf binaries
- Supernovae, Fast Radio Bursts (FRBs), and other radio transients & variables
- Radio interferometers: correlation, imaging, and the like





NRC, HAA, & DRAO

6

NRC-CNR

- **Unique within Canada:**
 - Mandated by the NRC Act
 - Contributions support the development, construction, operations, and decommissioning of offshore telescopes operated in partnerships that include NRC
 - Observatory instrumentation developed with agencies/organizations that form our partnership – with representation from more than two dozen countries
 - Work closely with Canadian university labs and Canadian industry

NRC Act:

“operate and administer any astronomical observatories established or maintained by the Government of Canada”

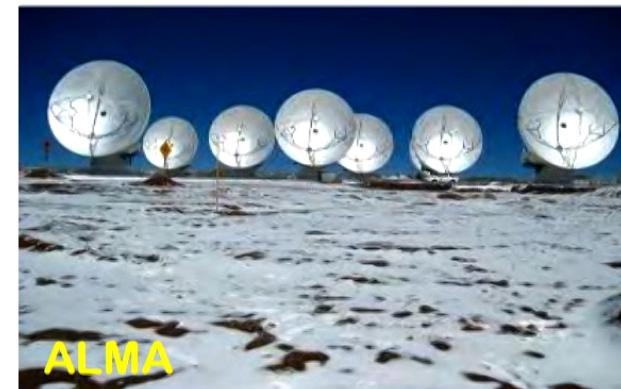
“A key characteristic of contemporary astronomy...is the importance of **international collaboration**, both on the facility side, where collaboration is now the norm for supporting new instruments, and on the research side.”

**Astronomy in Canada
HAL 2011**

- Main role: **national laboratory for the support and development of Canadian ground-based astronomy**
- Two sites:
 - Dominion Astrophysical Observatory (DAO) – Victoria, BC
 - **Dominion Radio Astrophysical Observatory (DRAO)** – Penticton, BC

What do we do?

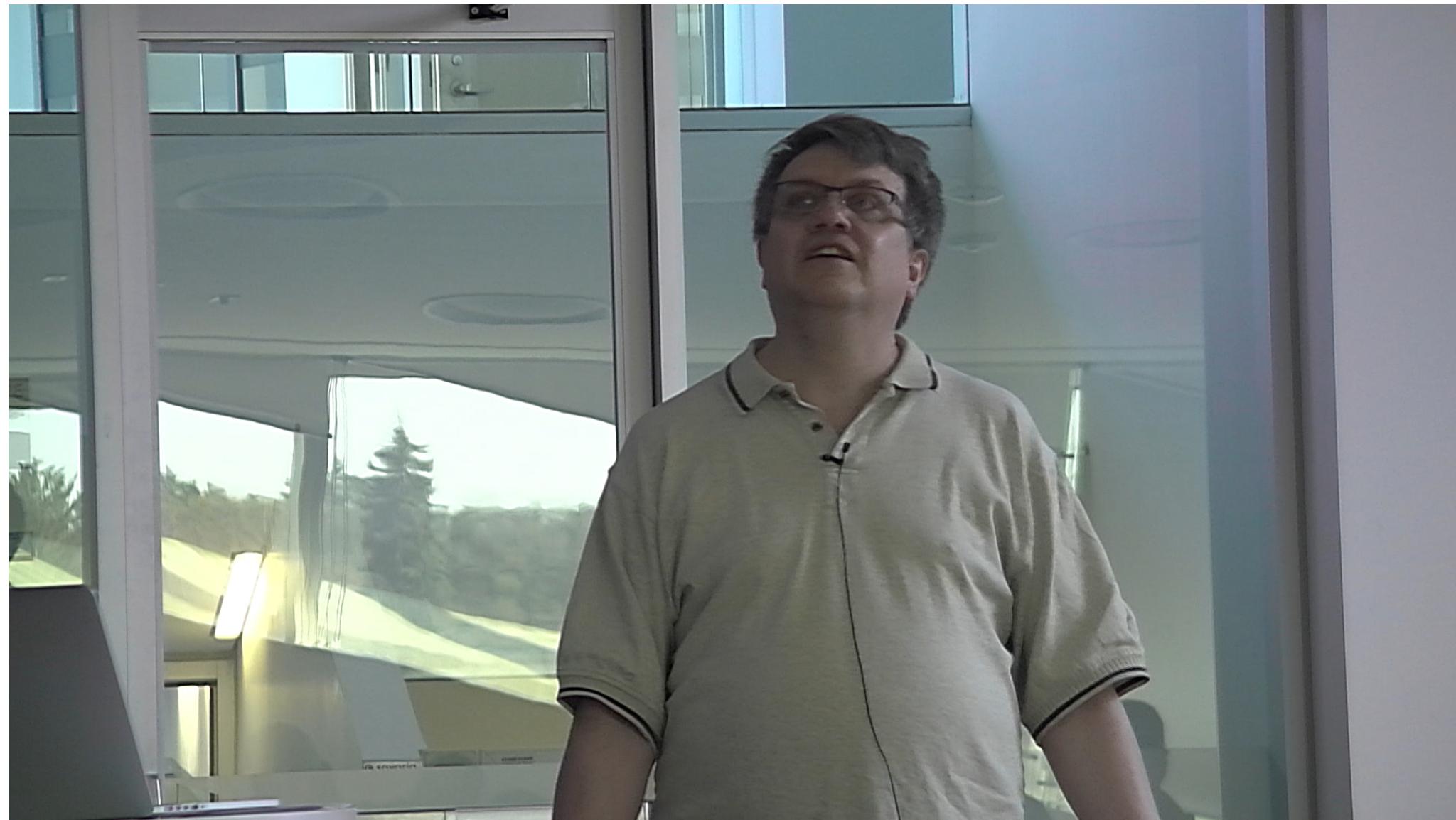
- **We conceive, design, build, and deploy things**
 - Combine scientific & technical expertise
- Past large-scale, long-term radio projects:
 - Jansky Very Large Array correlator (JVLA 2003-11): \$20M
 - Atacama Large Millimeter Array: receiver cartridges (ALMA 2003-12): \$1.5B (NRC: \$36M)
- Current large radio projects:
 - Square Kilometer Array: pre-construction detailed design phase: €120M (\$12M)
- Radio expertise:
 - LNAs, feeds, digital backends, composite dishes
 - Polarization, wide-field mapping, data archiving



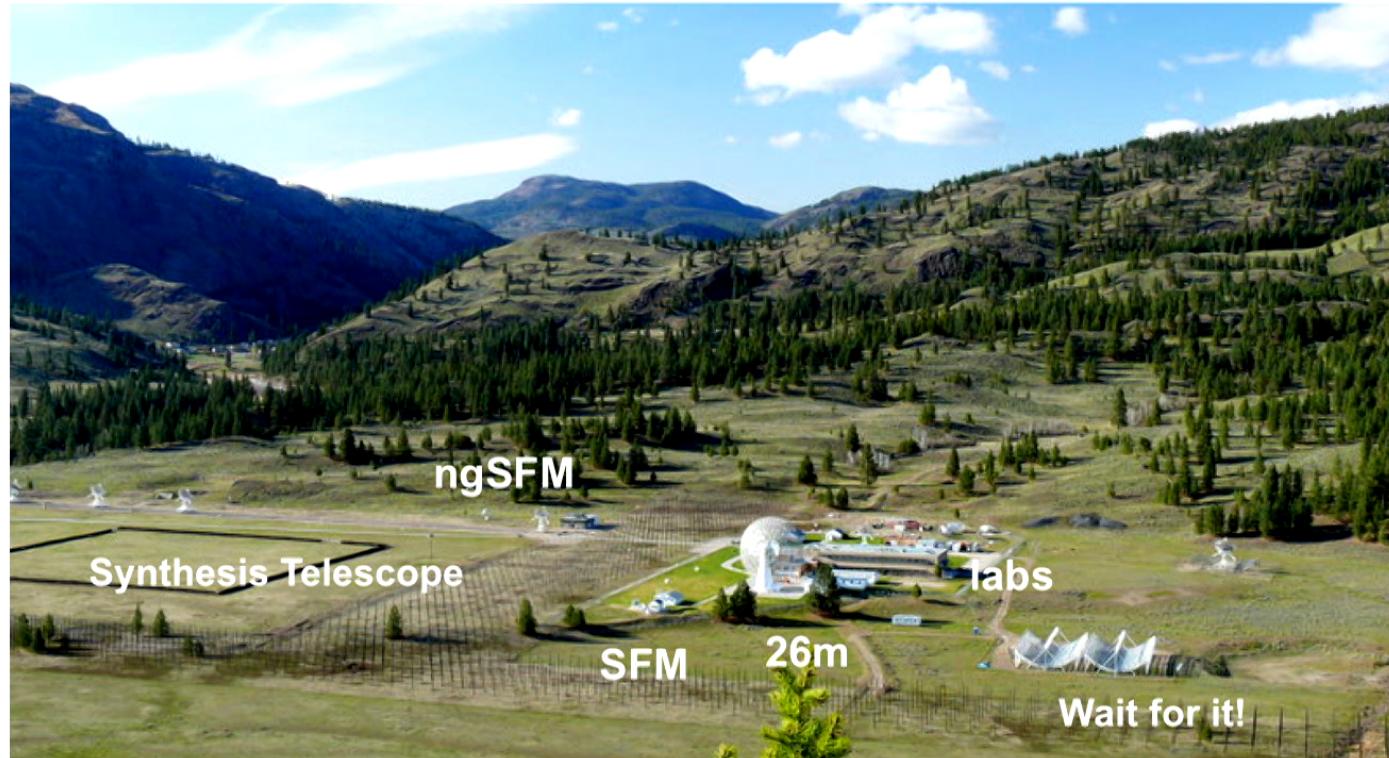


The role of HAA & DRAO

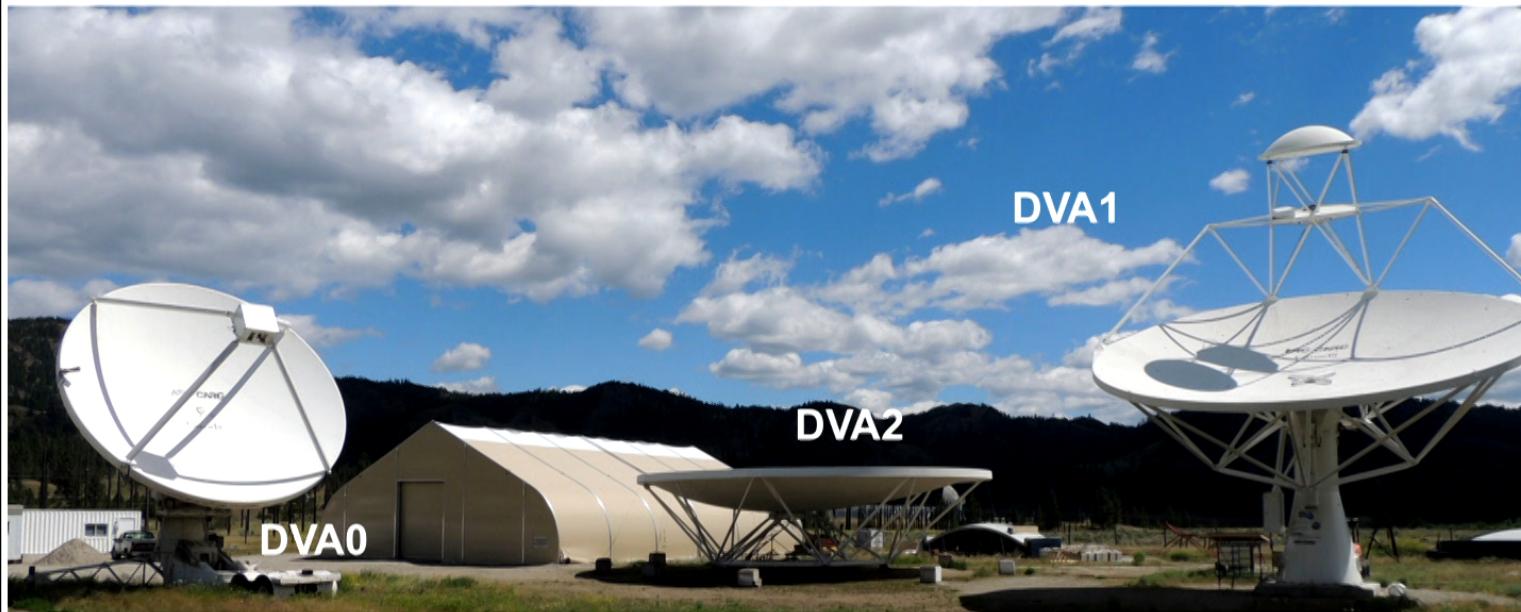
- NRC Herzberg is unique
 - Critical mass of scientific *and* technical staff (~60)
 - Consistent, long-term support
 - Ability to handle huge projects
 - *Radio-quiet site*
 - National, international, academic, and industrial connections (and reputation)
- Benefits to Canada
 - Access to cutting-edge instruments
 - Local telescopes: 26m, Synthesis Telescope, Solar Flux Monitor, CHIME, CGEM...
 - International projects: VLA, ALMA, SKA, ngVLA, ...
 - Training the next generation of astronomers & engineers
 - Active role in defining the biggest instruments on the planet



DRAO telescopes & site



DRAO telescopes & site



Composite dish development



Future prospects

- The next generation of radio telescopes
 - SKA (construction, regional centers, development funds)
 - ngVLA (dishes, small dishes, correlator, time distribution, ...)
 - ALMA (development funds)
- The next generation of radio questions
 - Fast Radio Bursts
 - Gravitational waves (big & small)
 - Dark energy
 - The time domain – cf. LSST
 - Extrasolar planets
 - Planetary formation
 - ...



A vision for DRAO

- Strategic, focused research
- Mix of big and small projects
 - Leveraged contributions to the “Great Radio Observatories”
 - Focused local instruments → internationally competitive in special areas
- Active scientific use & technical development
- Training
- Close relations with universities
- Lots of possibilities under study
 - Premier polarization telescope & interferometer
 - Technology Demonstrator Array
 - Wideband Solar Imaging Array
 - FRB localization instrument
 - Wideband variability instrument
 - SKA1 Regional Centre – post-processing training, support, development; special-purpose hardware
 - ...



Opportunities for collaboration

- Access to unique radio-quiet radio site
- Work collaboratively on projects of mutual interest, generally with in-kind labour support
- Advanced technology development in areas of mutual interest, with contract \$ support
- Co-sponsoring of graduate students
- Sabbatical visiting worker arrangements for faculty and postdocs
- Secondments of scientific and technical staff

Cosmology

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NRC·CNRC

Canadian Hydrogen Intensity Mapping Experiment



*(with thanks [and apologies] to Keith Vanderlinde & Mark
Halpern)*

¹⁷

A Very Brief History of Everything

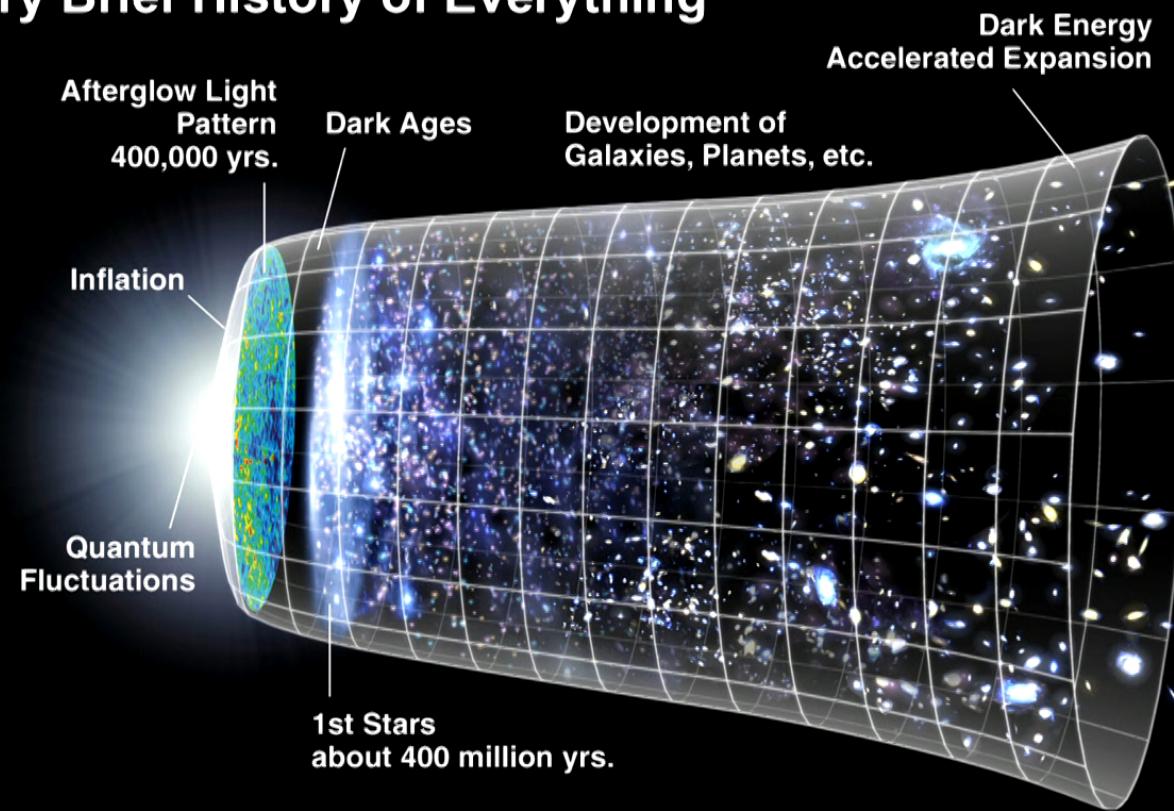


Image: NASA

Cosmological Principle: Homogeneous & isotropic

Only leaves 2 degrees of freedom in the metric:

$$ds^2 = -c^2 dt^2 + a(t)^2 [dr^2 + S_\kappa(r)^2 d\Omega^2]$$

↑ ↑
Scale Factor Curvature
(≈0)

Cosmological Principle: Homogeneous & isotropic

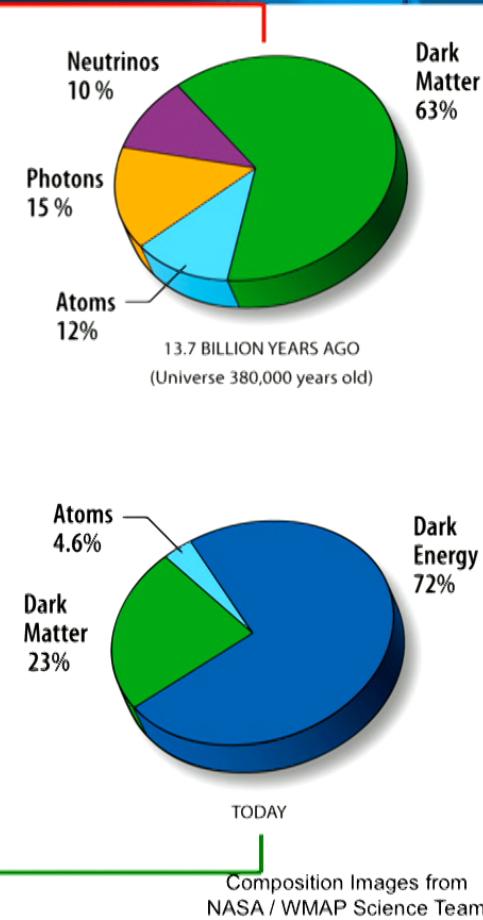
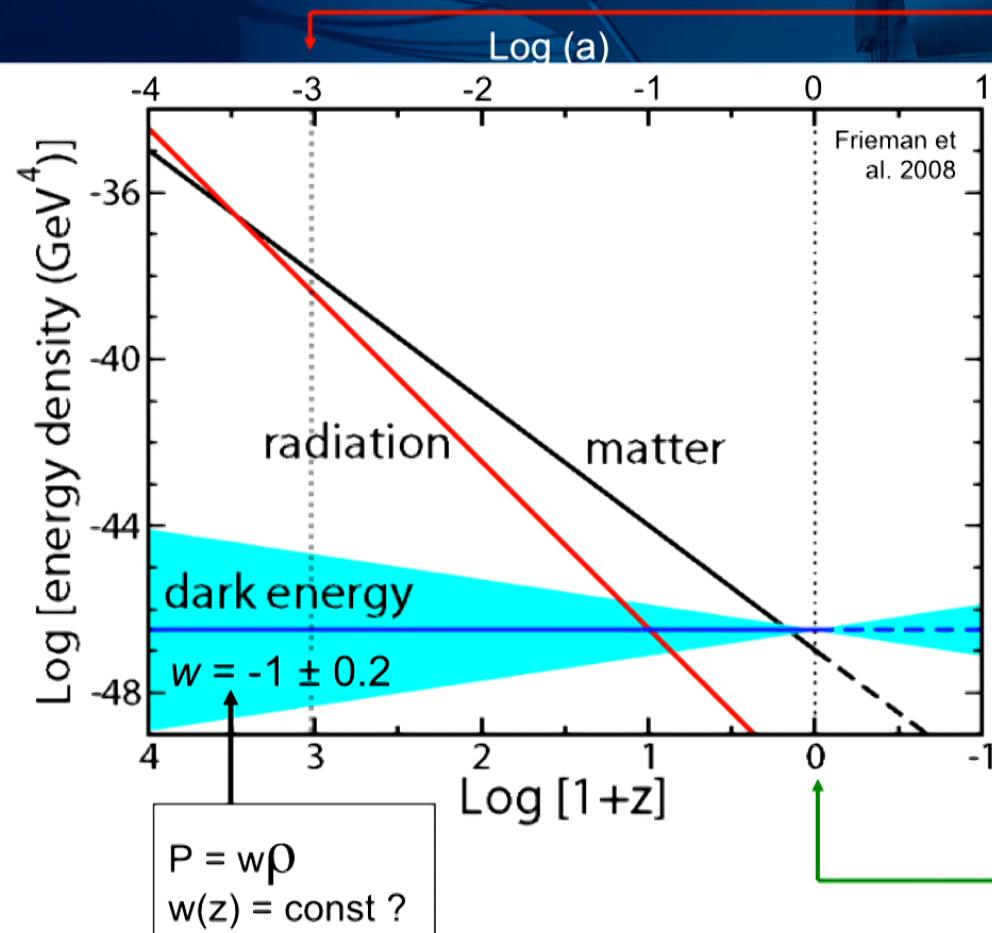
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Scale Curvature
Factor (≈ 0)

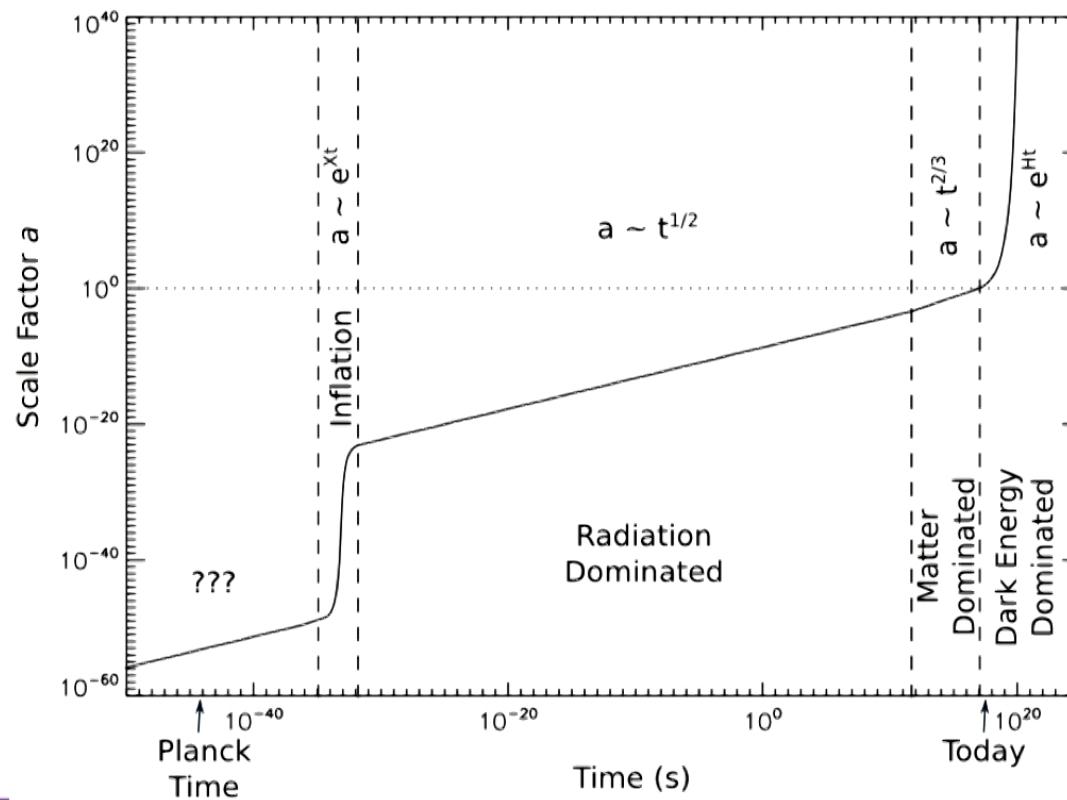
GR relates these to the stuff in the Universe,
& describes how $a(t)$ evolves over time.

The Evolution of Stuff



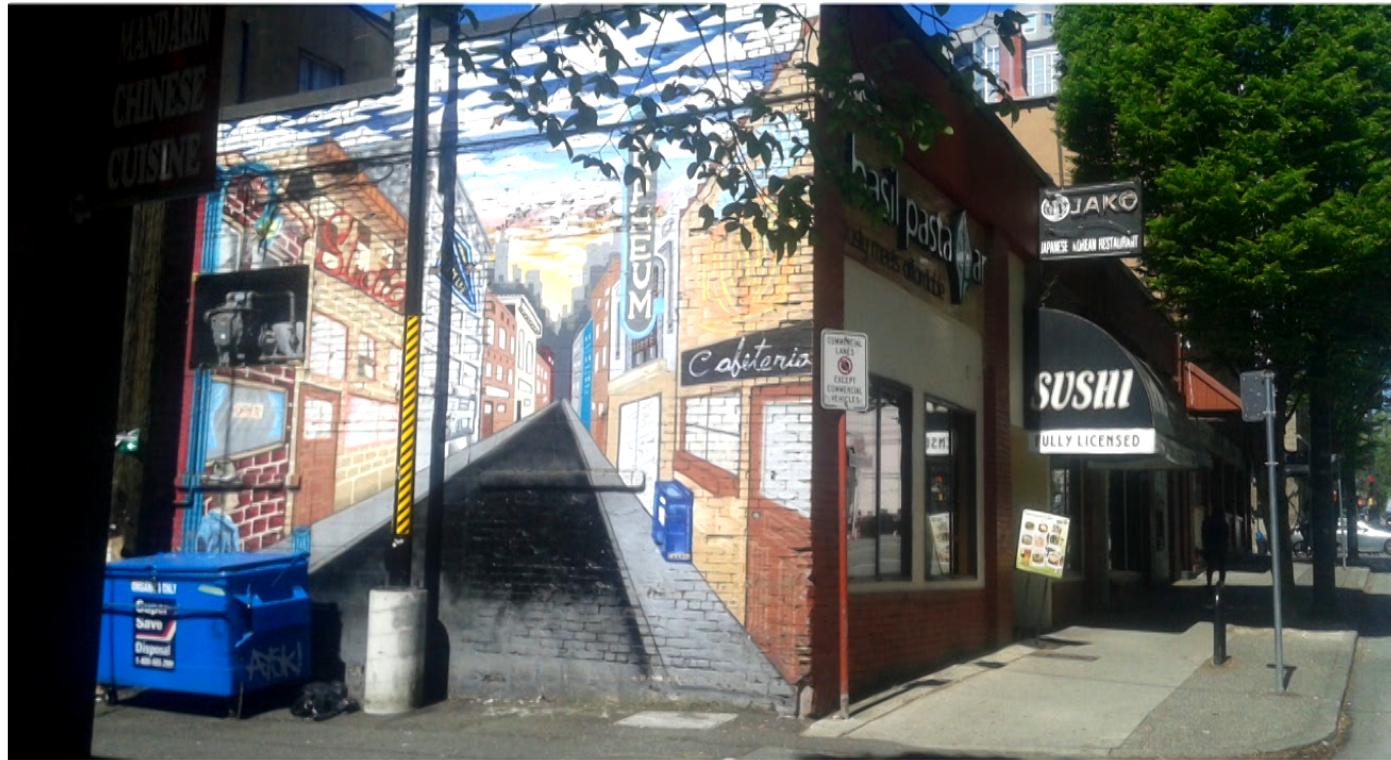
Expansion History

Scale vs. Time

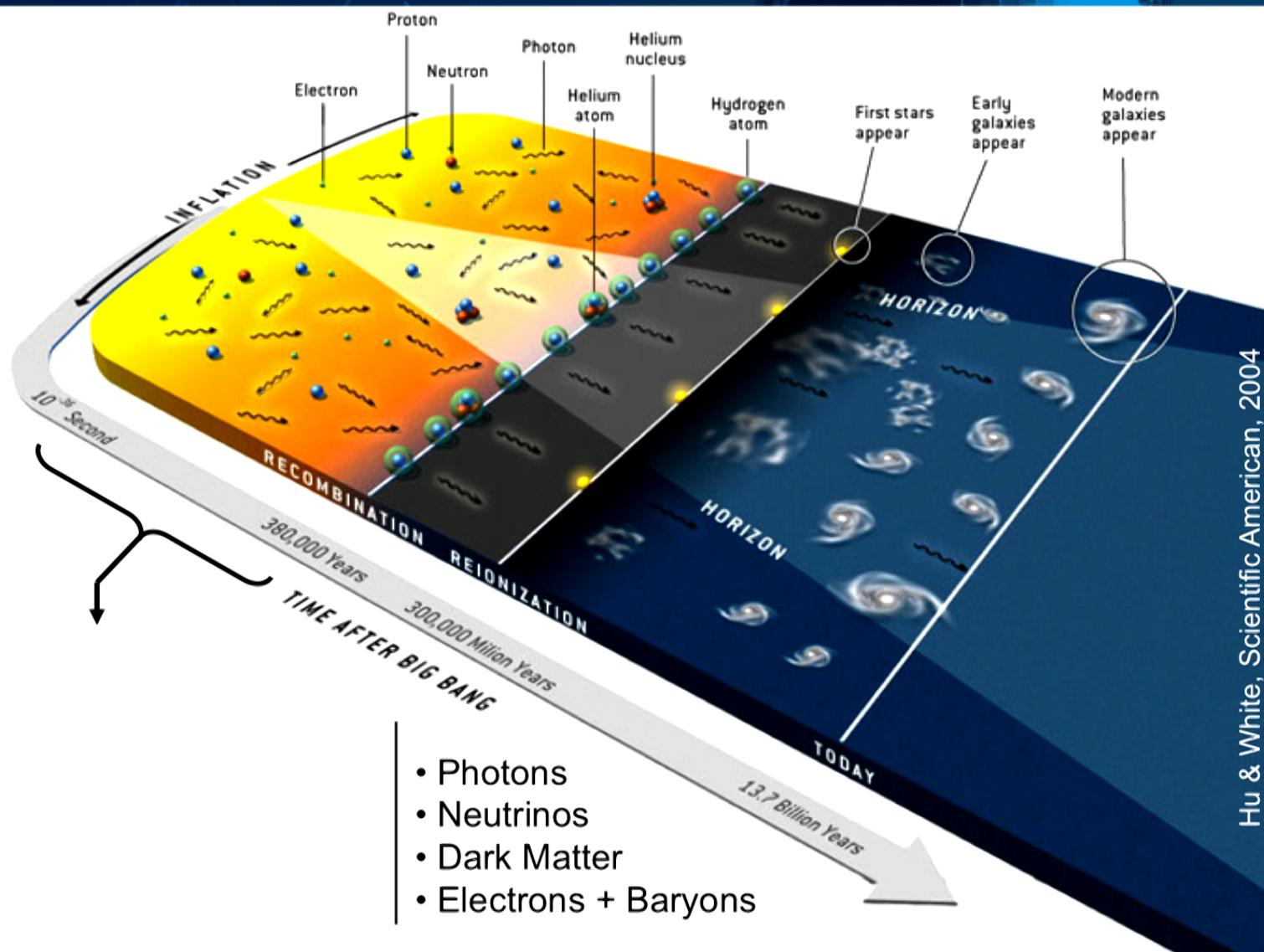


NRC-CNR

Measuring the metric: standard rulers

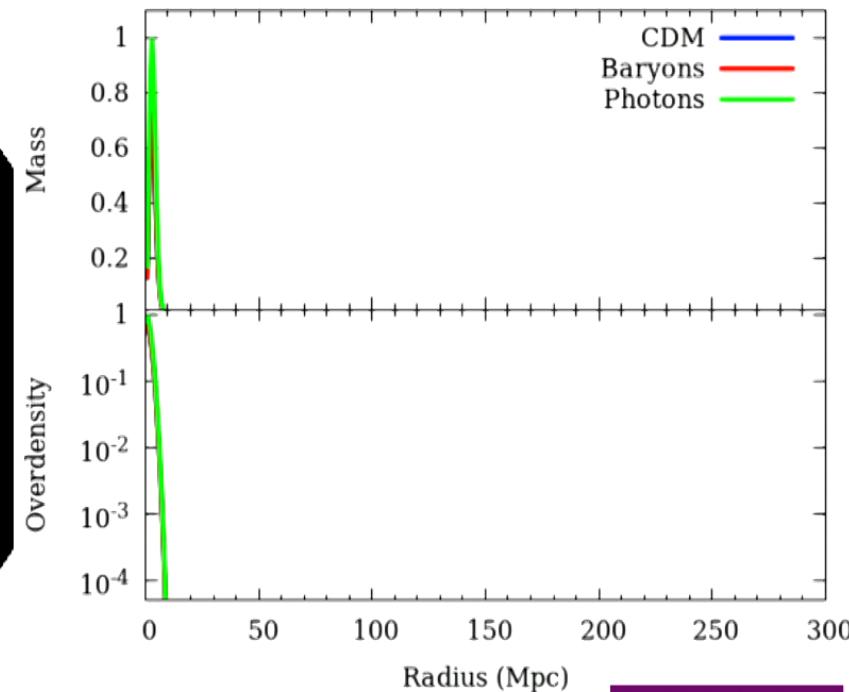


Hu & White, Scientific American, 2004



Baryon Acoustic Oscillations

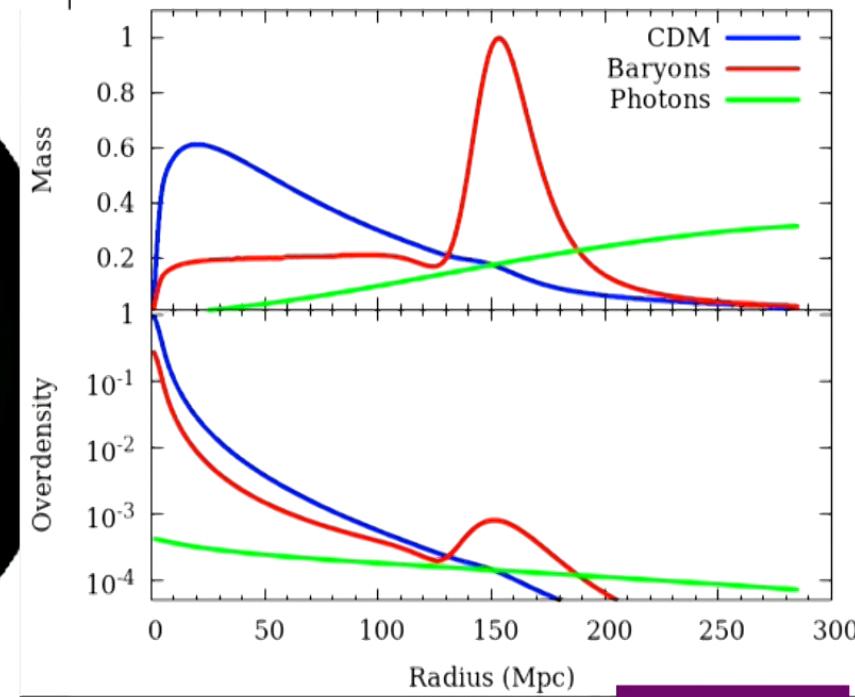
- random background of primordial fluctuations
- each fluctuation emits a pressure wave
- at decoupling (recombination), the size of this wave is frozen



Adam Hincks

Baryon Acoustic Oscillations

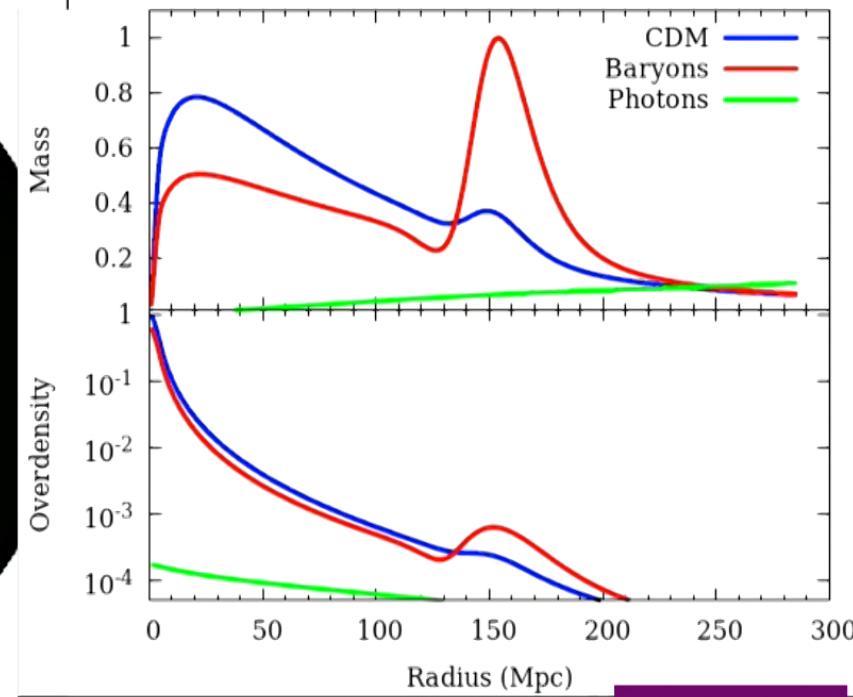
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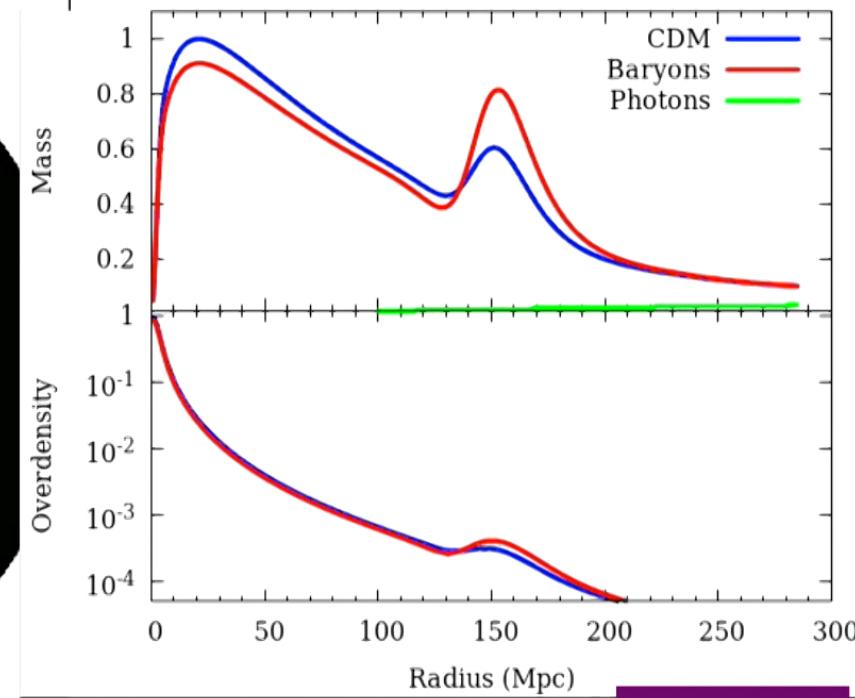
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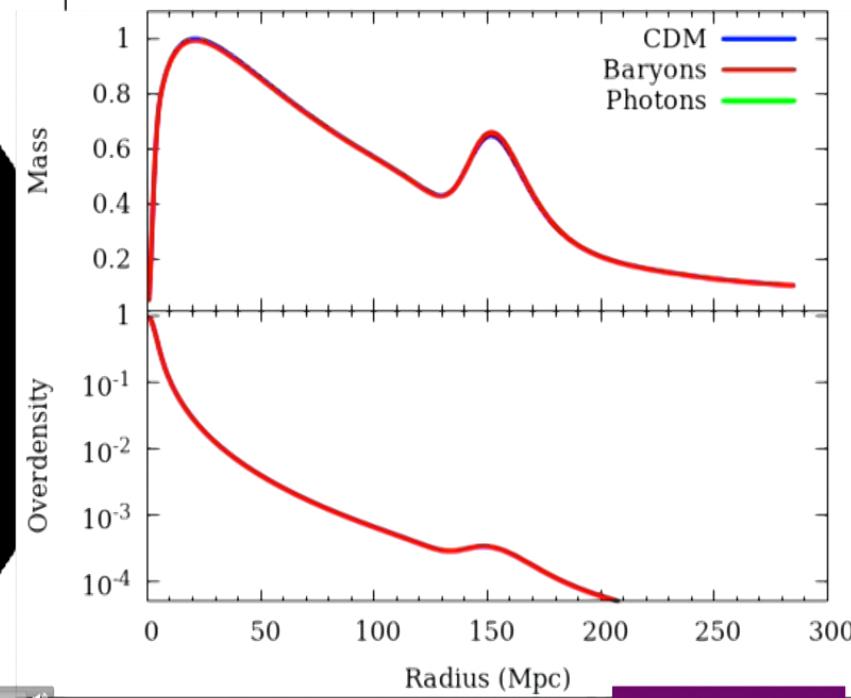
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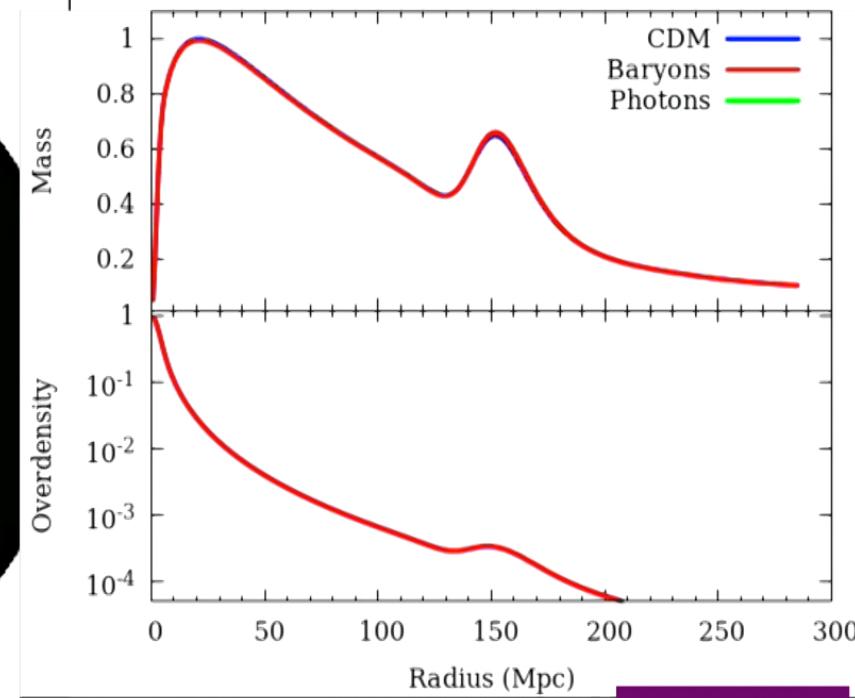
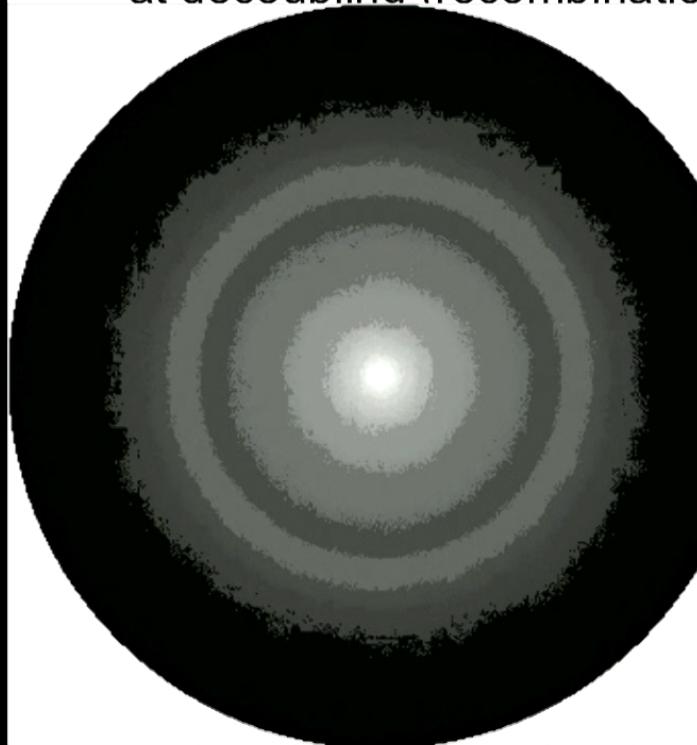
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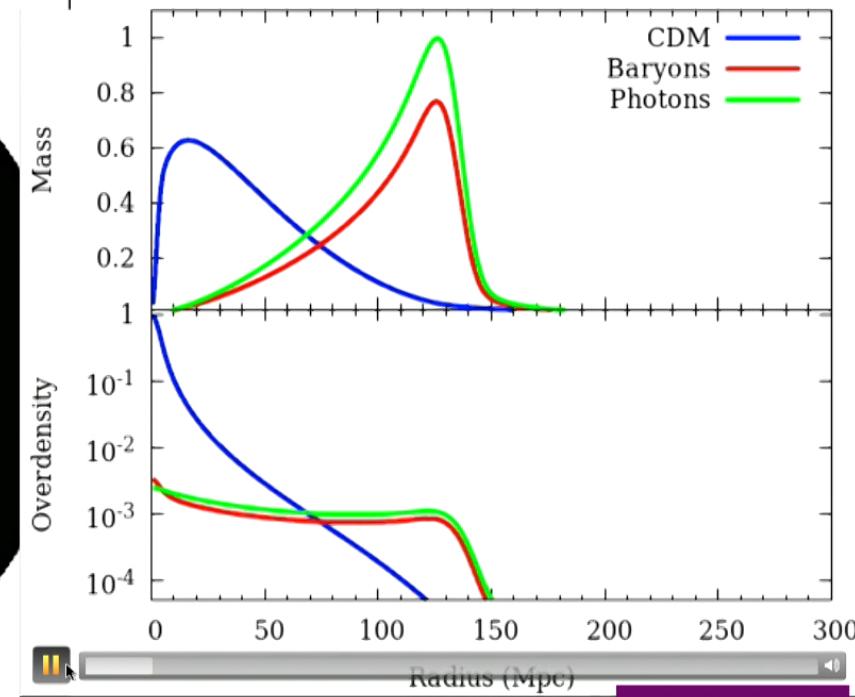
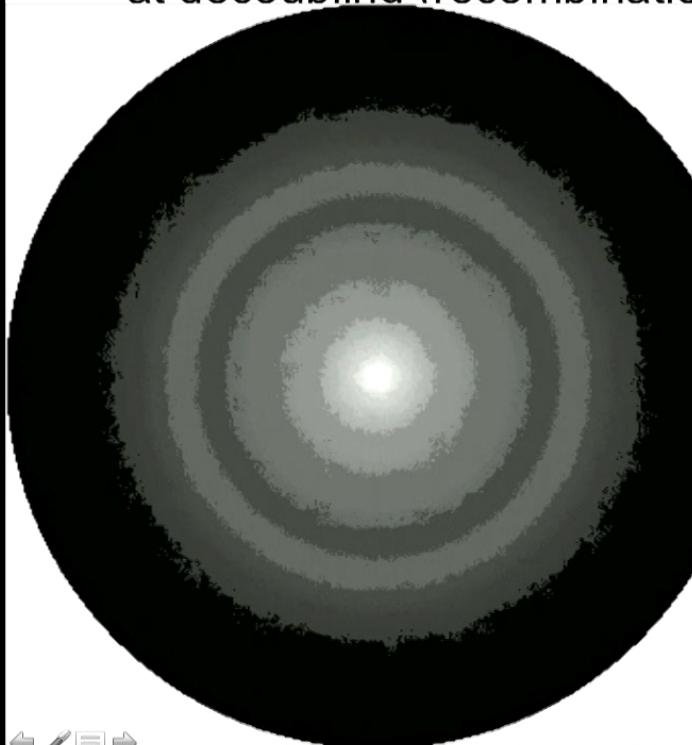
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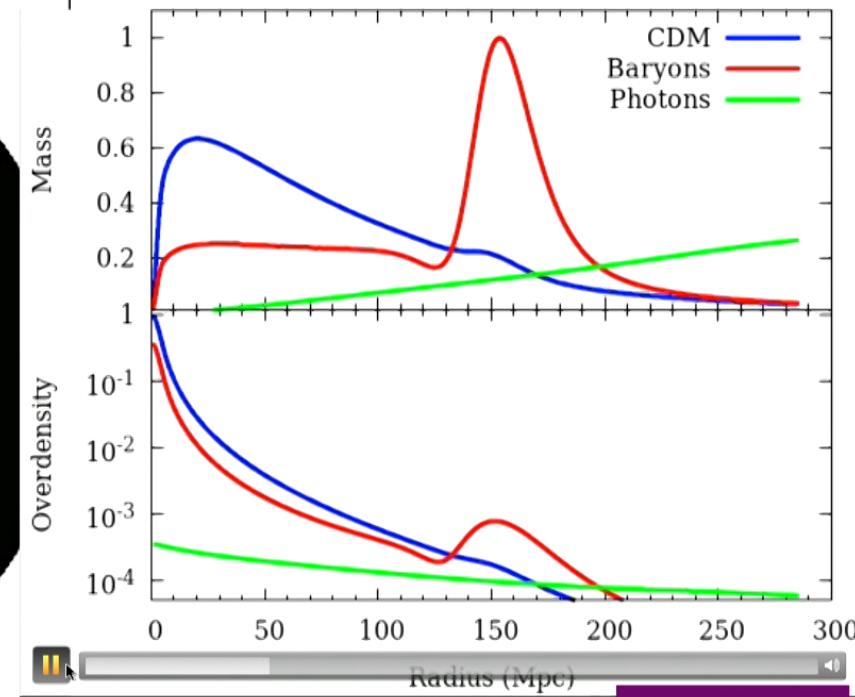
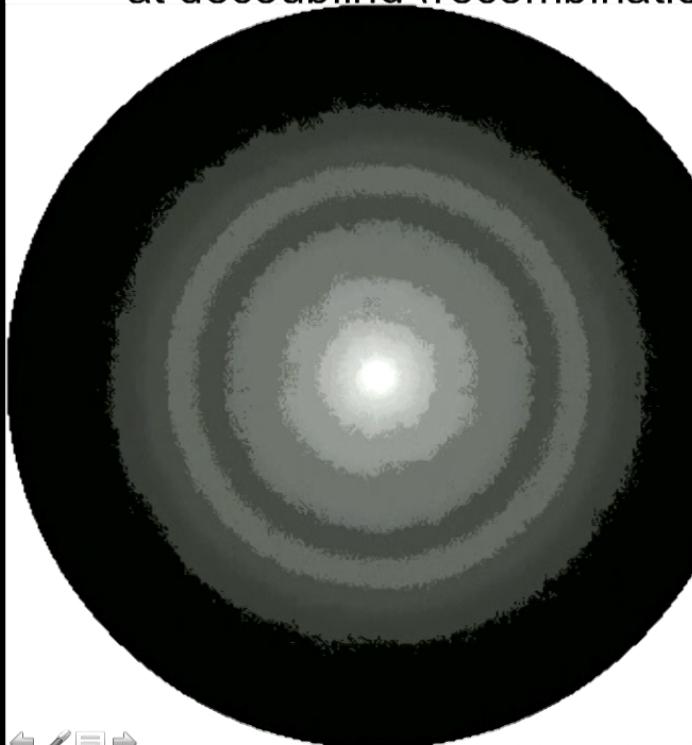
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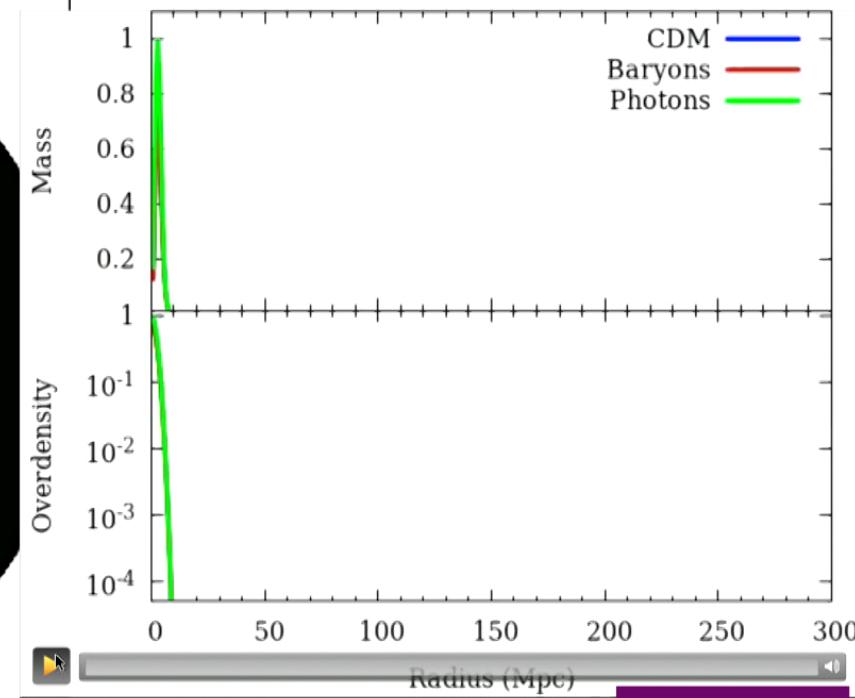
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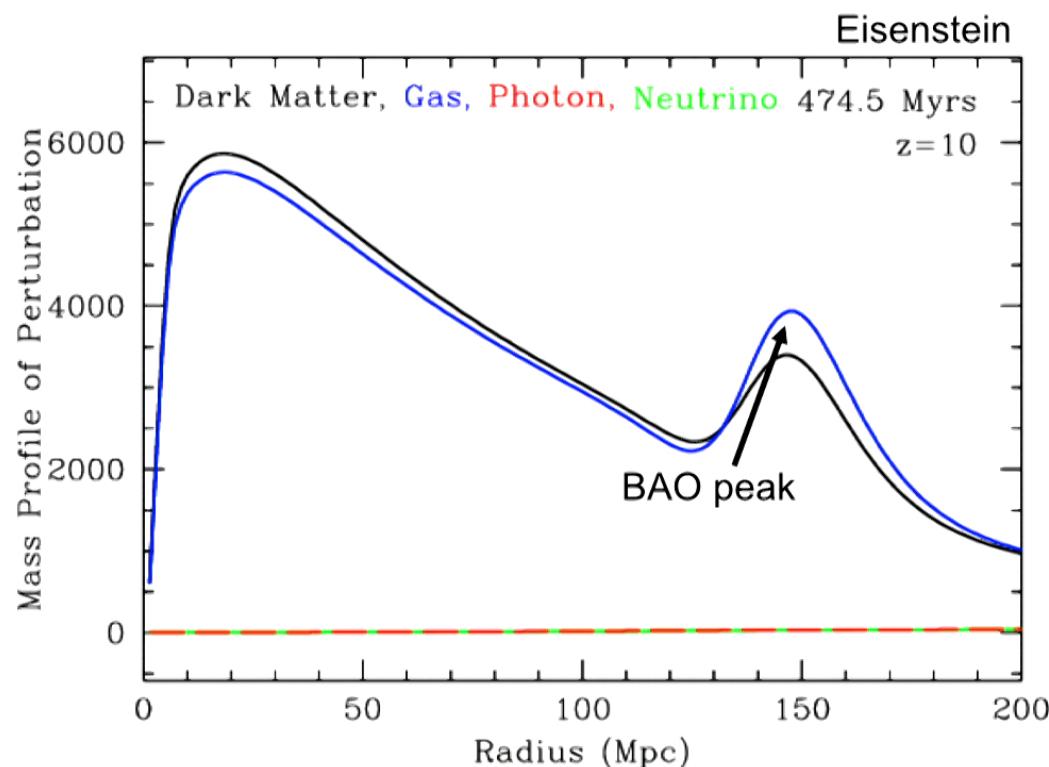
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Adam Hincks

Late-Time Radial Profile

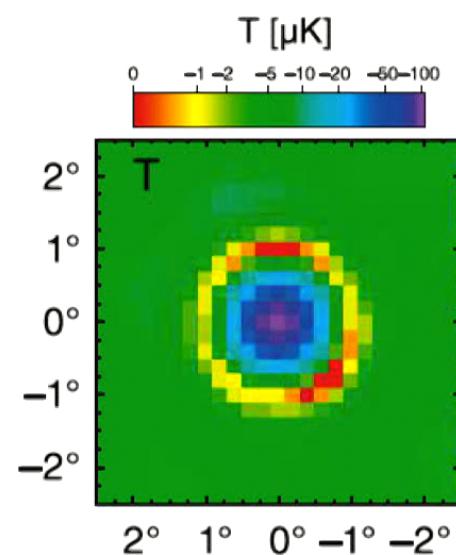
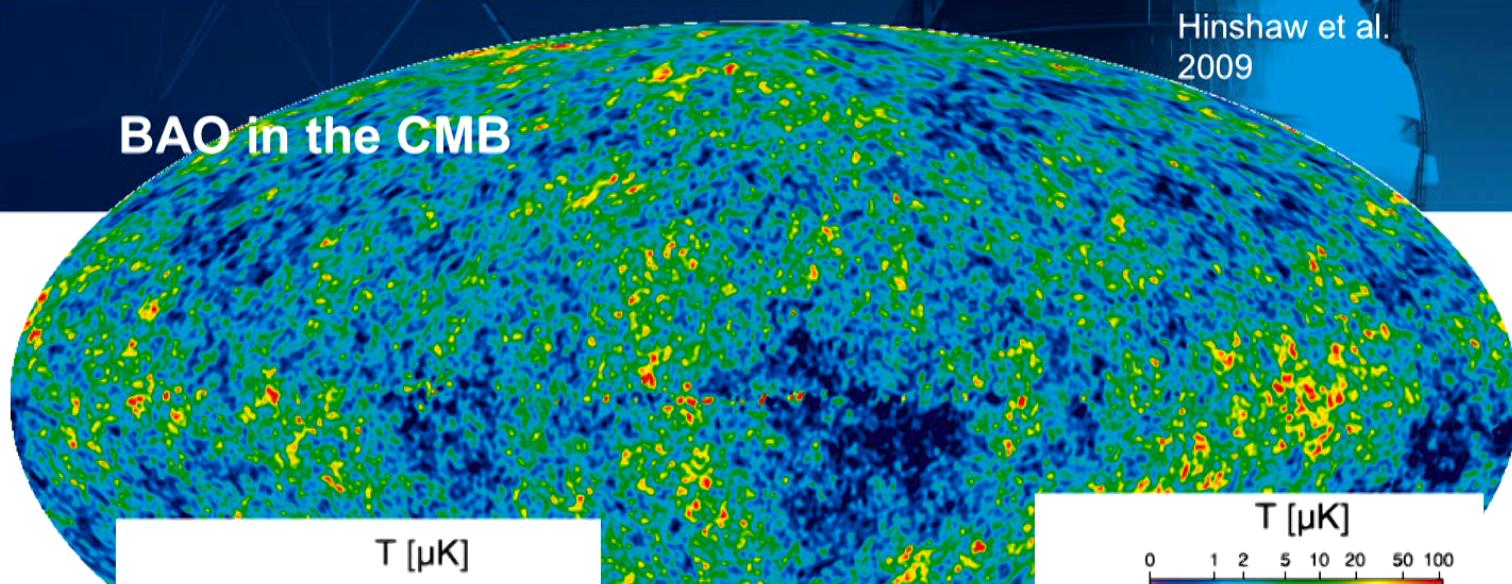


BAO are “frozen in” ≈ 150 co-moving Mpc.

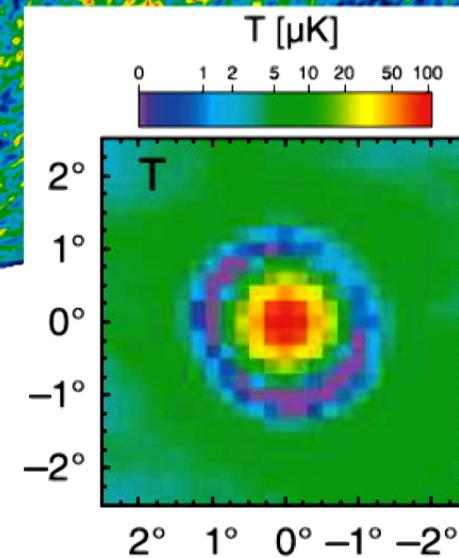
NRC-CNR

BAO in the CMB

Hinshaw et al.
2009

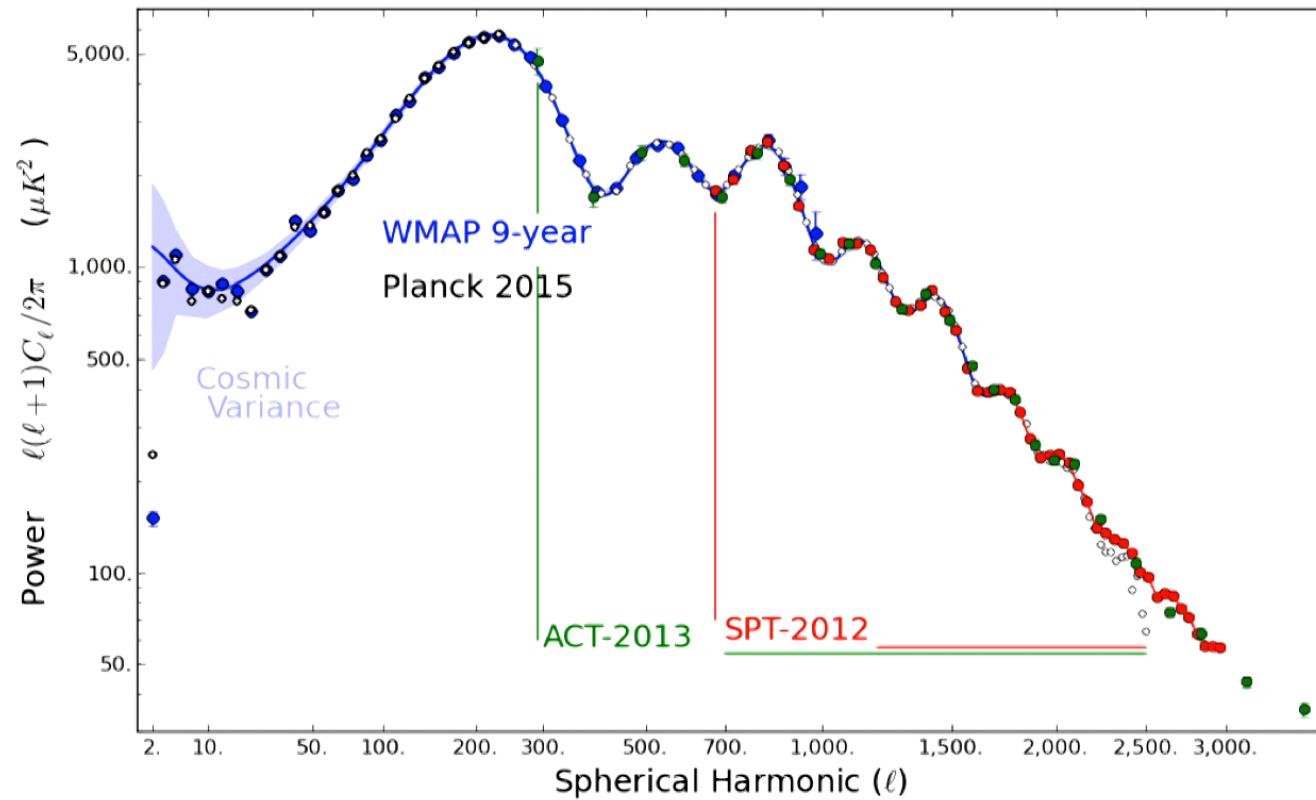


Komatsu et al. 2010



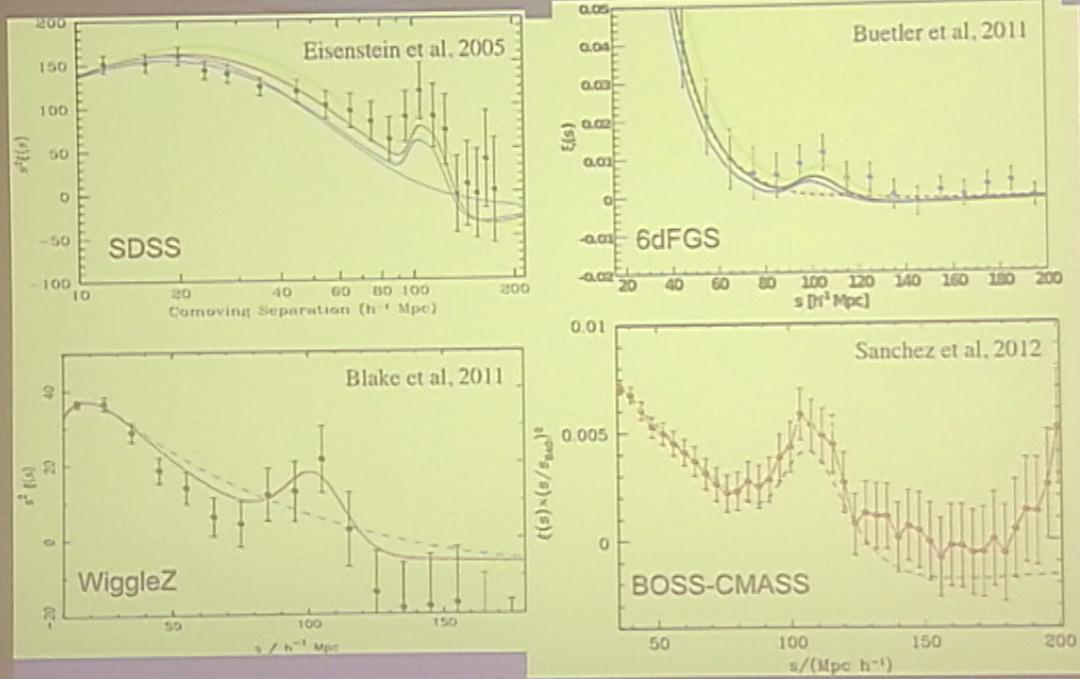
ARC-CRC

BAO in the CMB

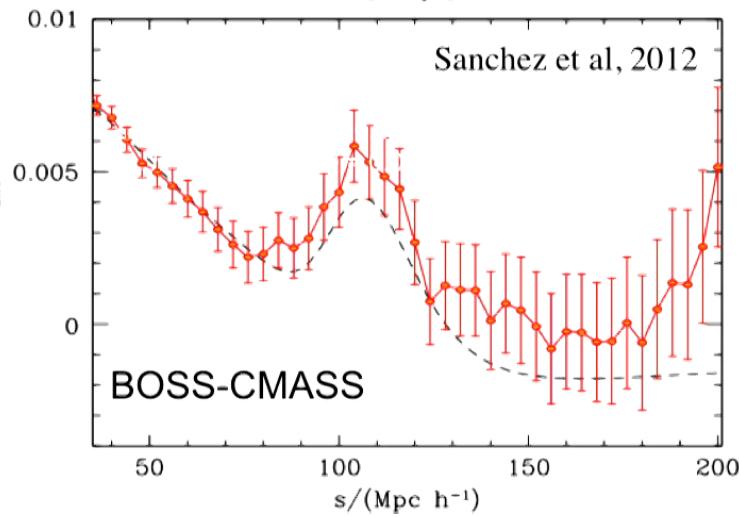
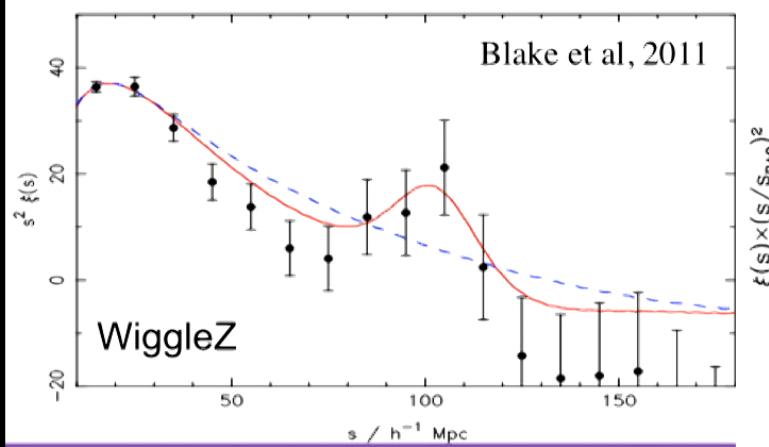
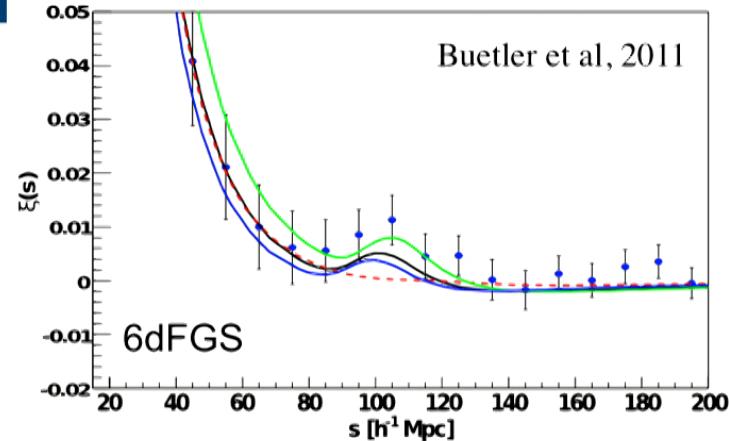
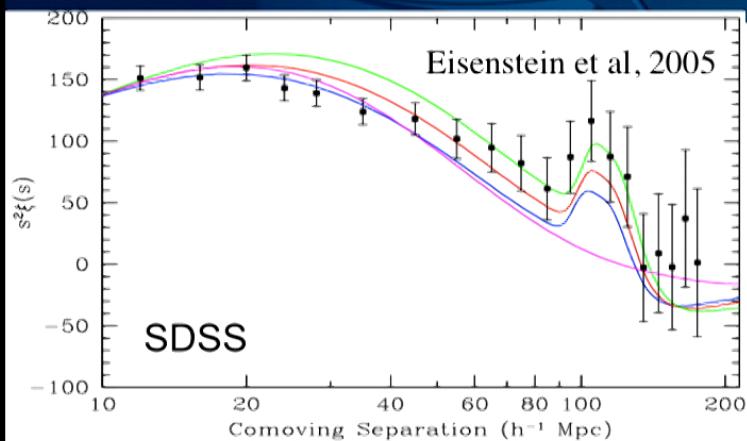


ICRC

BAO in galaxy correlations

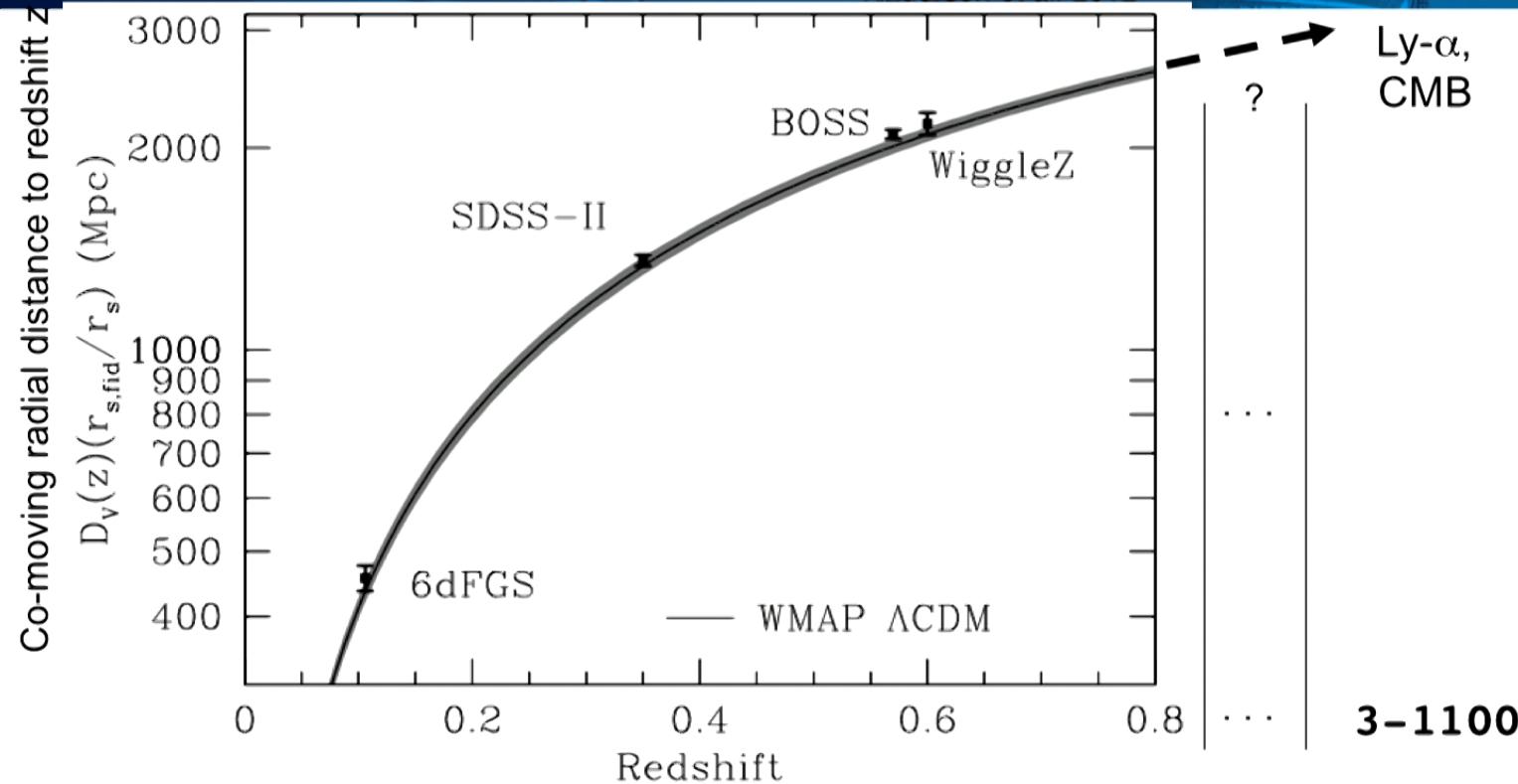


BAO in galaxy correlations



BAO as a standard ruler

Anderson et al. 2012



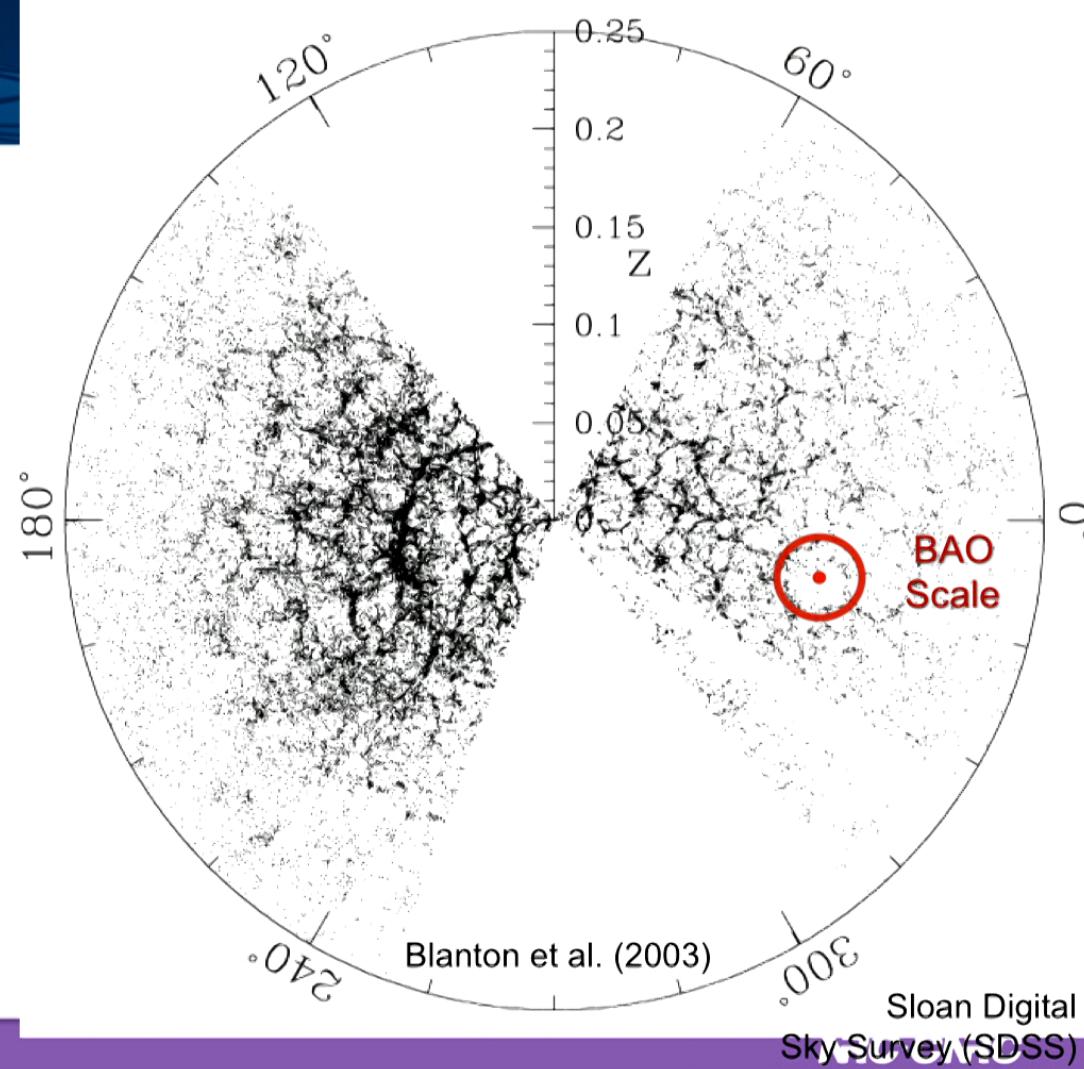
3-1100

NRC-CNR

Galaxy surveys

Get spectroscopic redshifts on lots of galaxies.

OK, but painful:
• expensive
• hard at $z \approx 1-2$

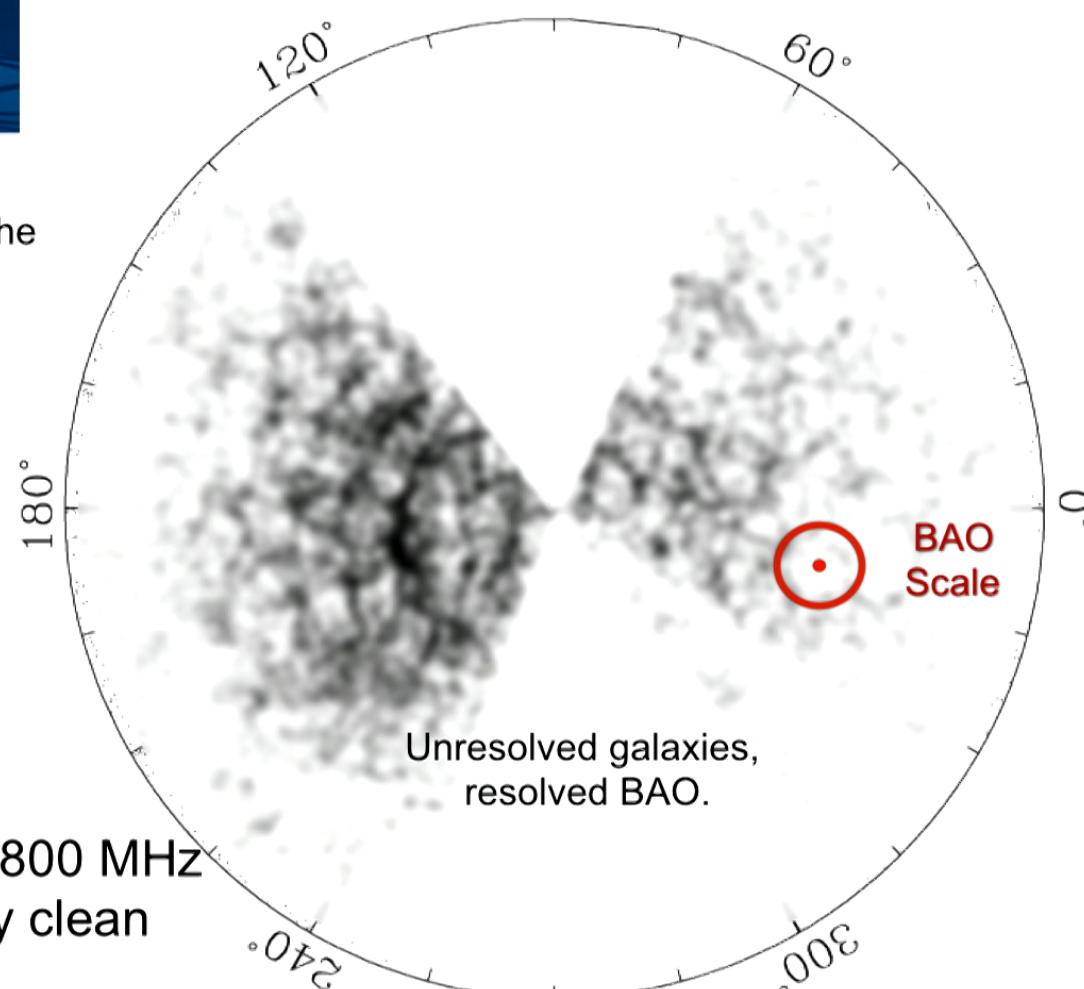


Hydrogen Intensity Mapping

Don't bother resolving the galaxies

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

$0.8 < z < 2.5 = 400-800 \text{ MHz}$
is also a relatively clean radio window



ARC-CRC

Nominal Design: Resolution & Sensitivity

- Driven by $z=2.5$ (400MHz)
 - worst resolution
 - least sensitivity
 - smallest size structures
- Aperture $\approx 80m$

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Problems: Universe ionized, forbidden transition, faint signal

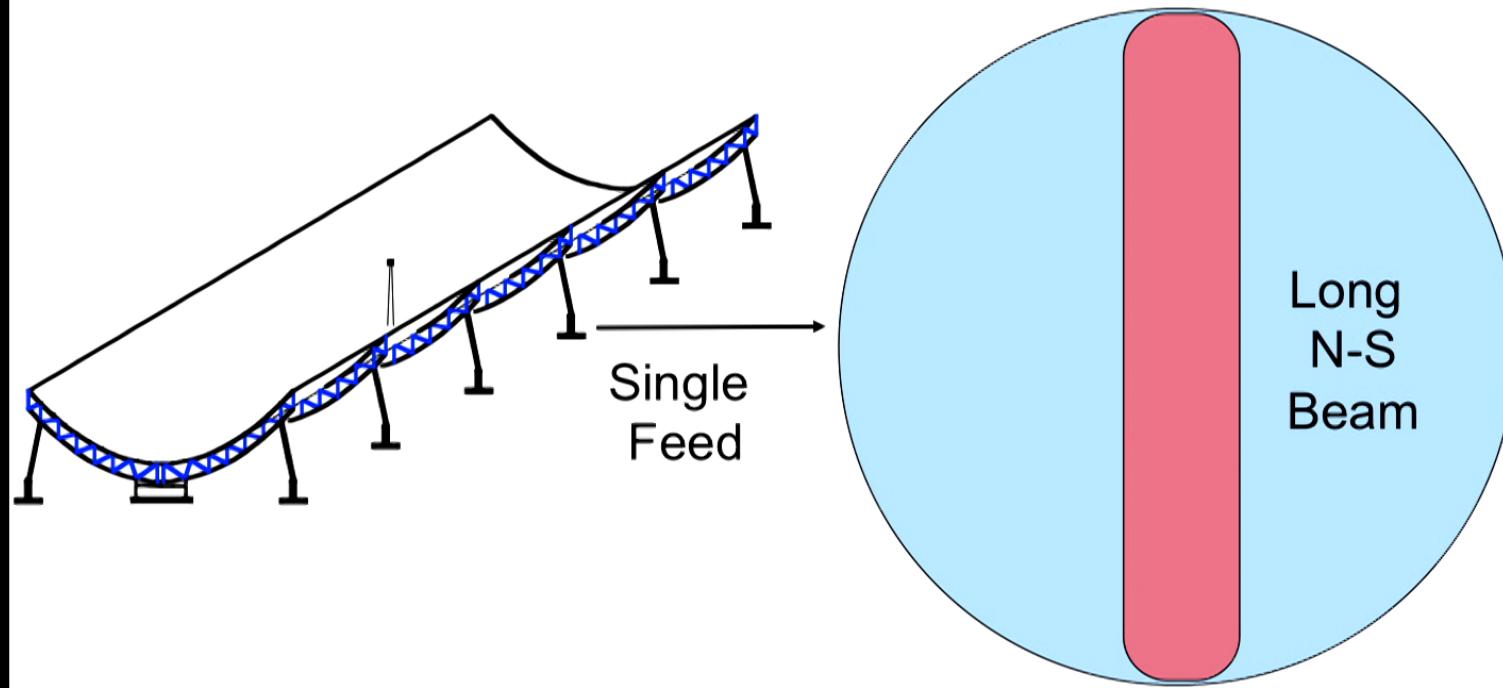
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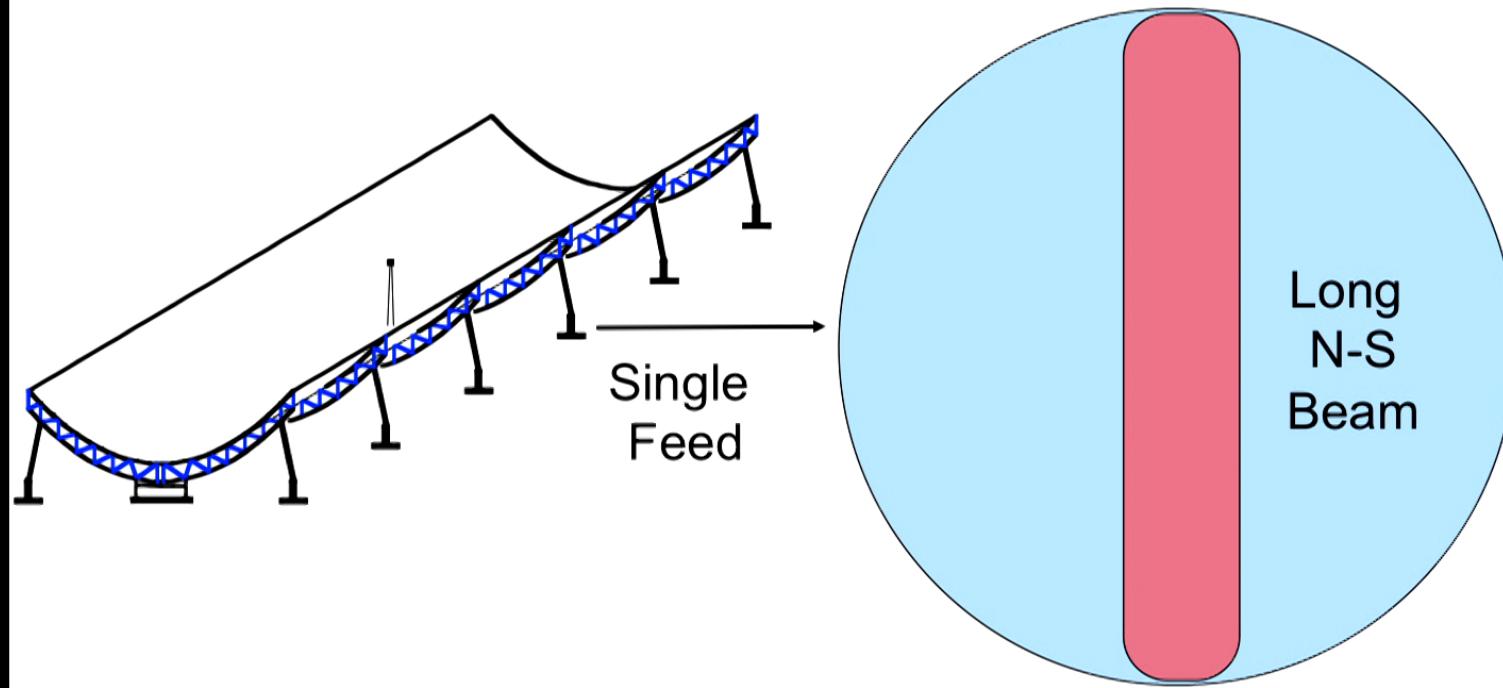
➔ Need a big light bucket, lots of pixels, long integration

Cylinder Antenna



NRC-CNR

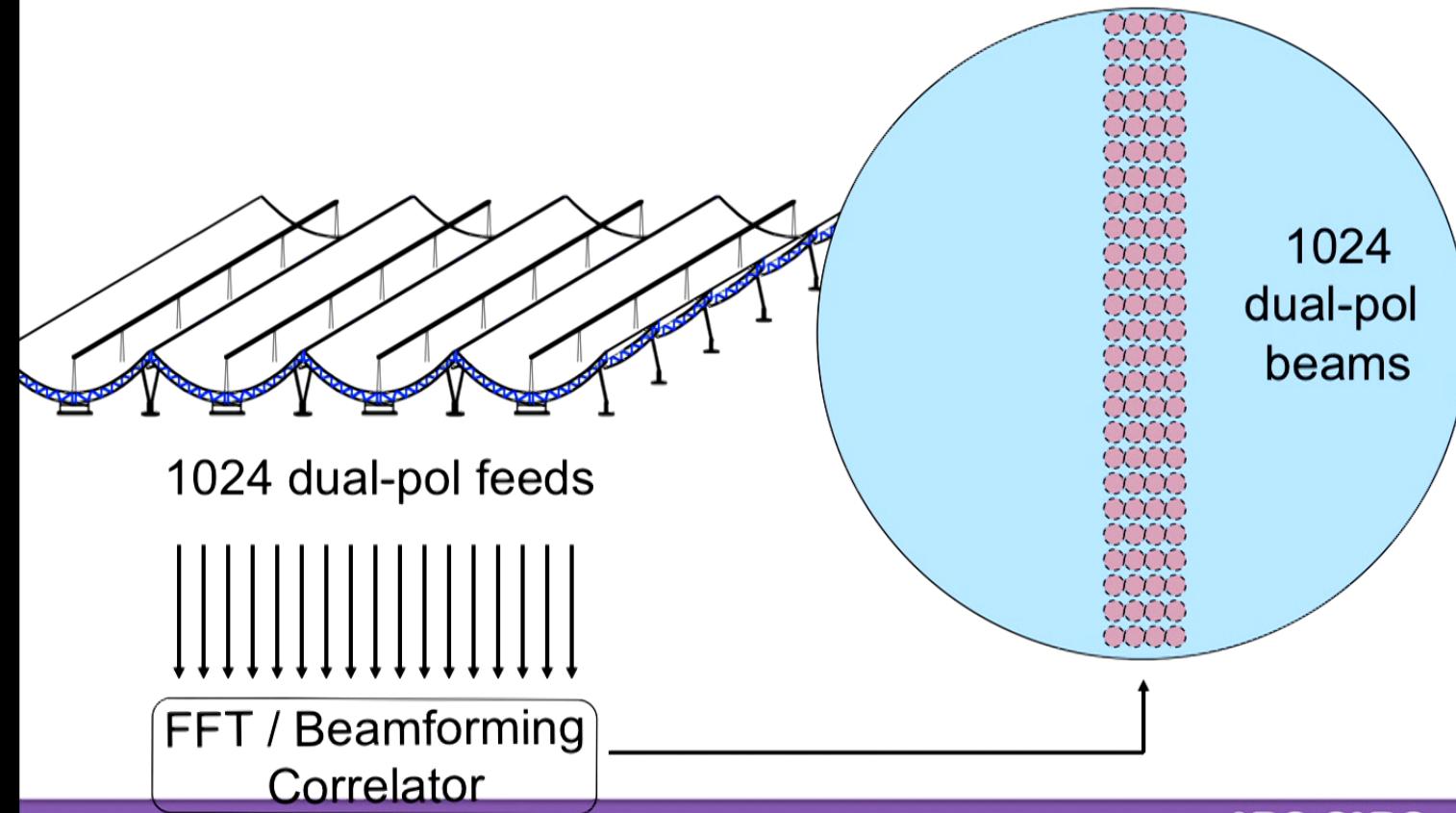
Cylinder Antenna



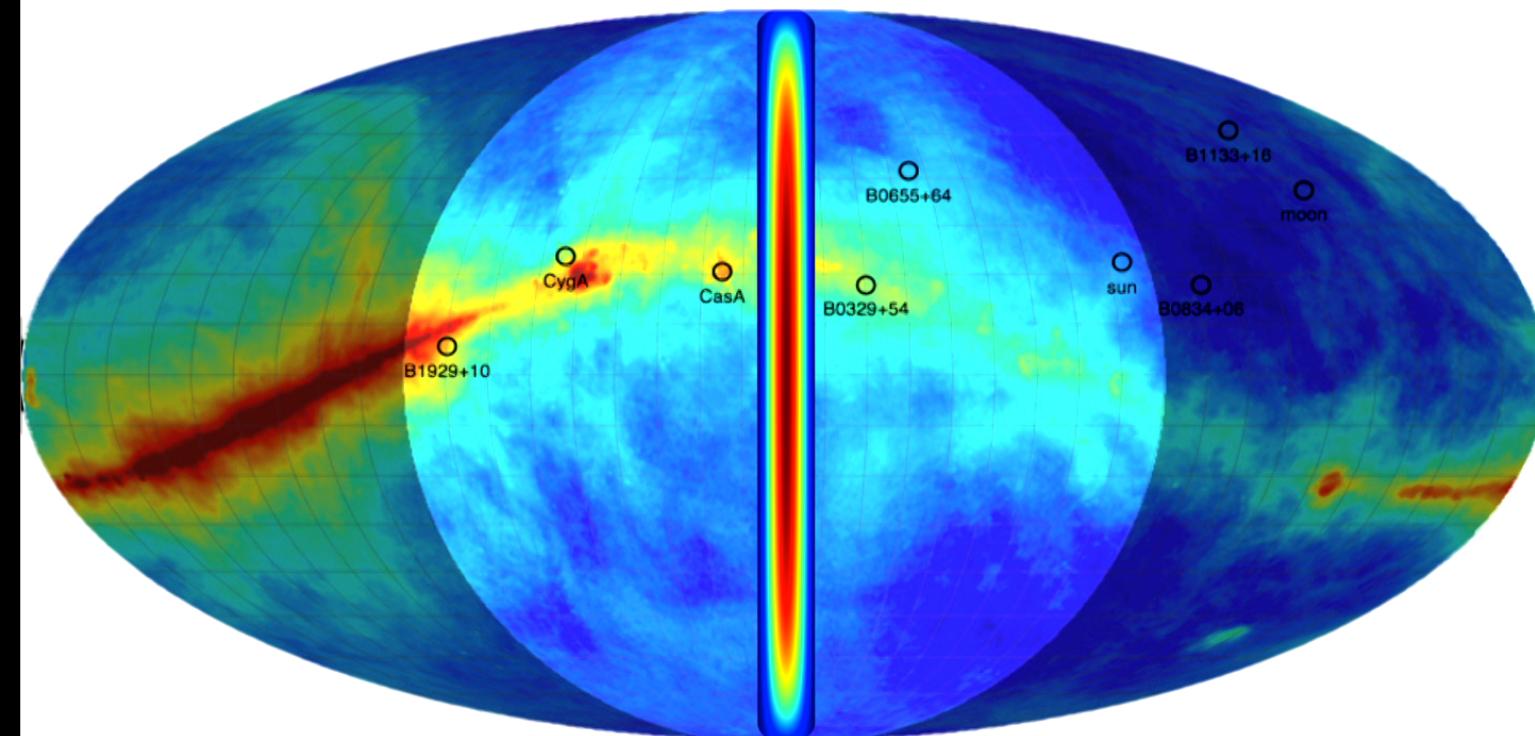
NRC-CNR

CHIME

1D Dishes + 2D Interferometry

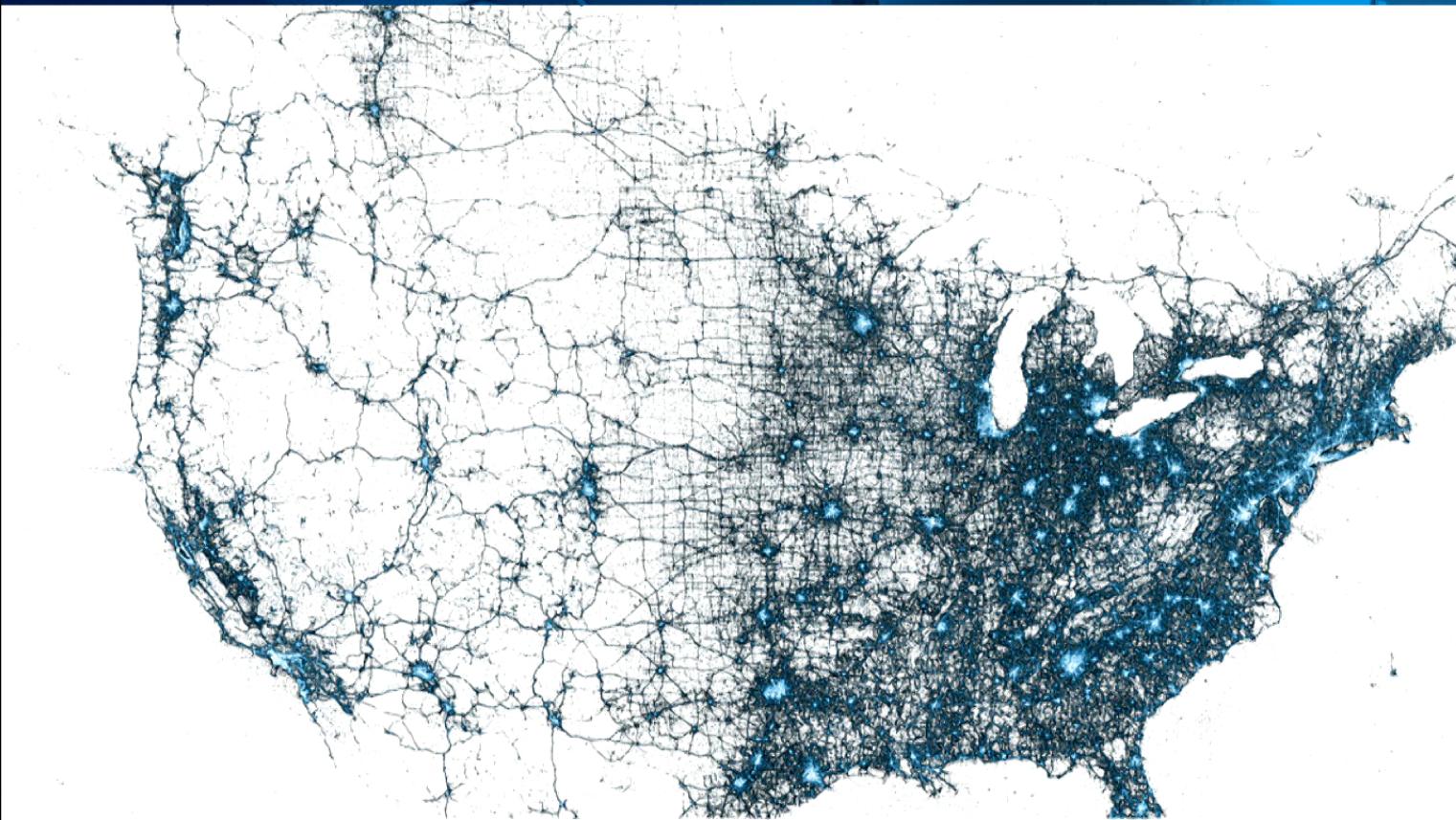


CHIME observes half the sky every day as the earth turns



NRC-CNRCC

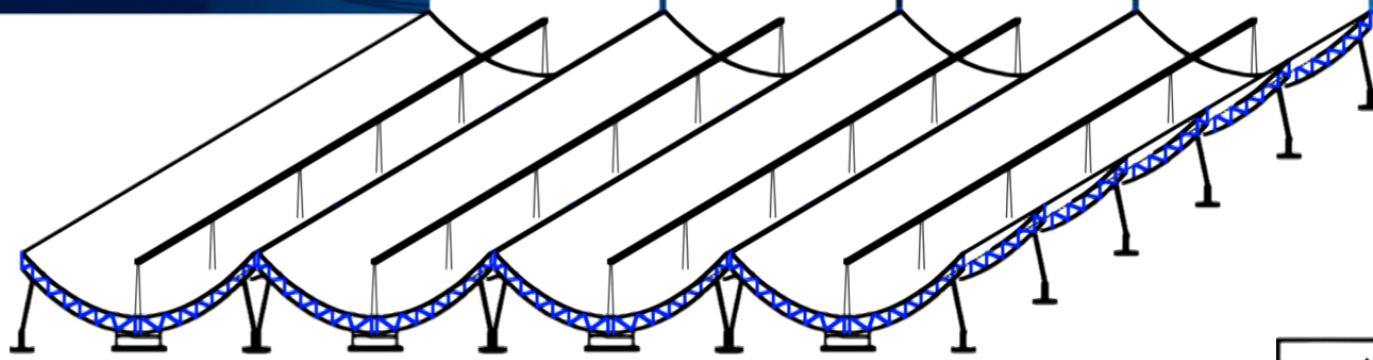
An ounce of prevention...



Twitter feeds ~ RFI

NRC-CNR

CHIME



- 400-800 MHz
21cm from $z \sim 0.8 - 2.5$
- Resolution: 1 MHz, 13-26' (~15 Mpc)
3rd BAO peak resolved
- Drift scan, no moving parts
>20,000 deg² coverage
- 1024 Dual-polarization feeds
Cosmic-variance-limited survey



THE
UNIVERSITY OF
BRITISH
COLUMBIA



NRC-CRBC



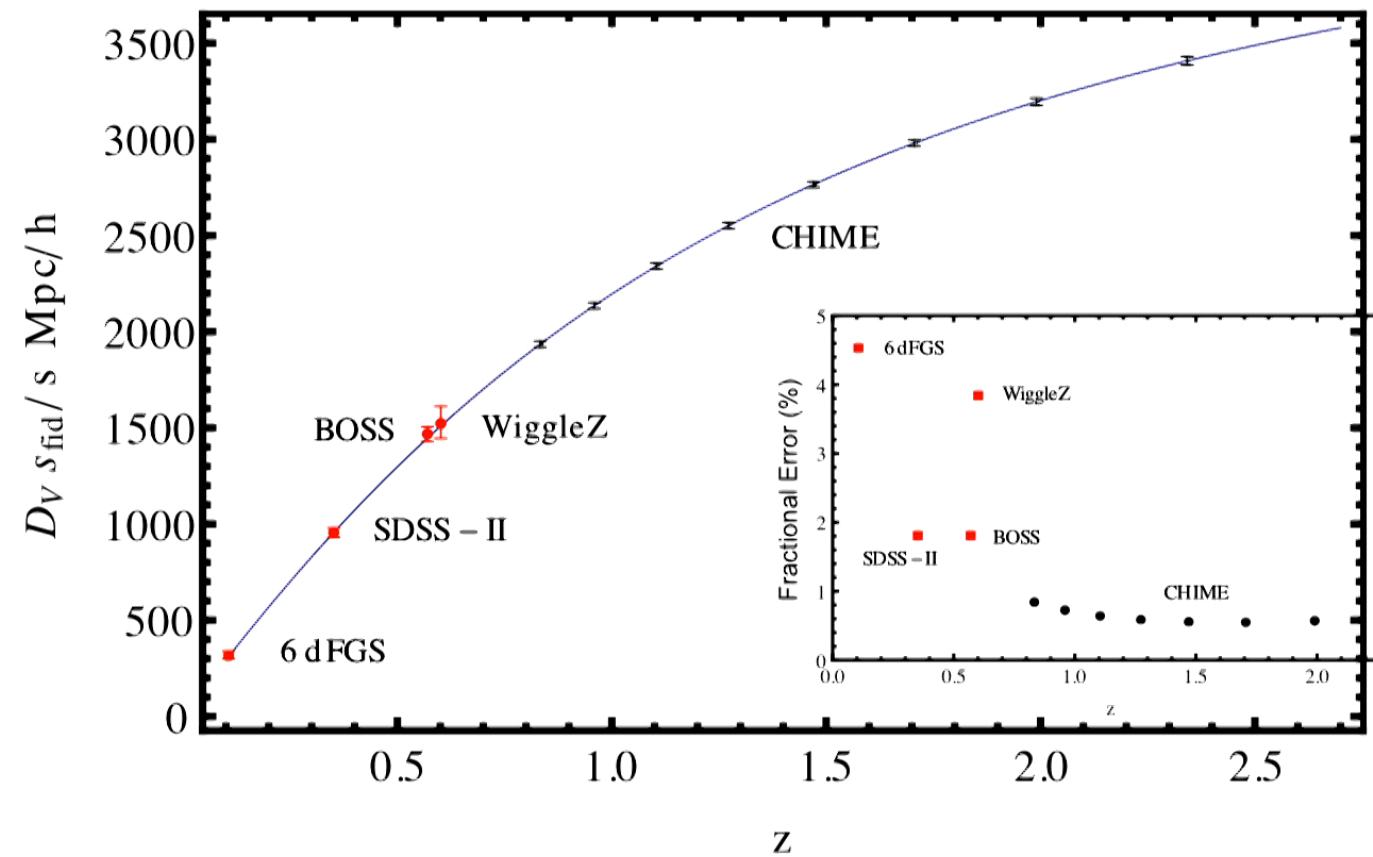
McGill



UNIVERSITY OF
TORONTO

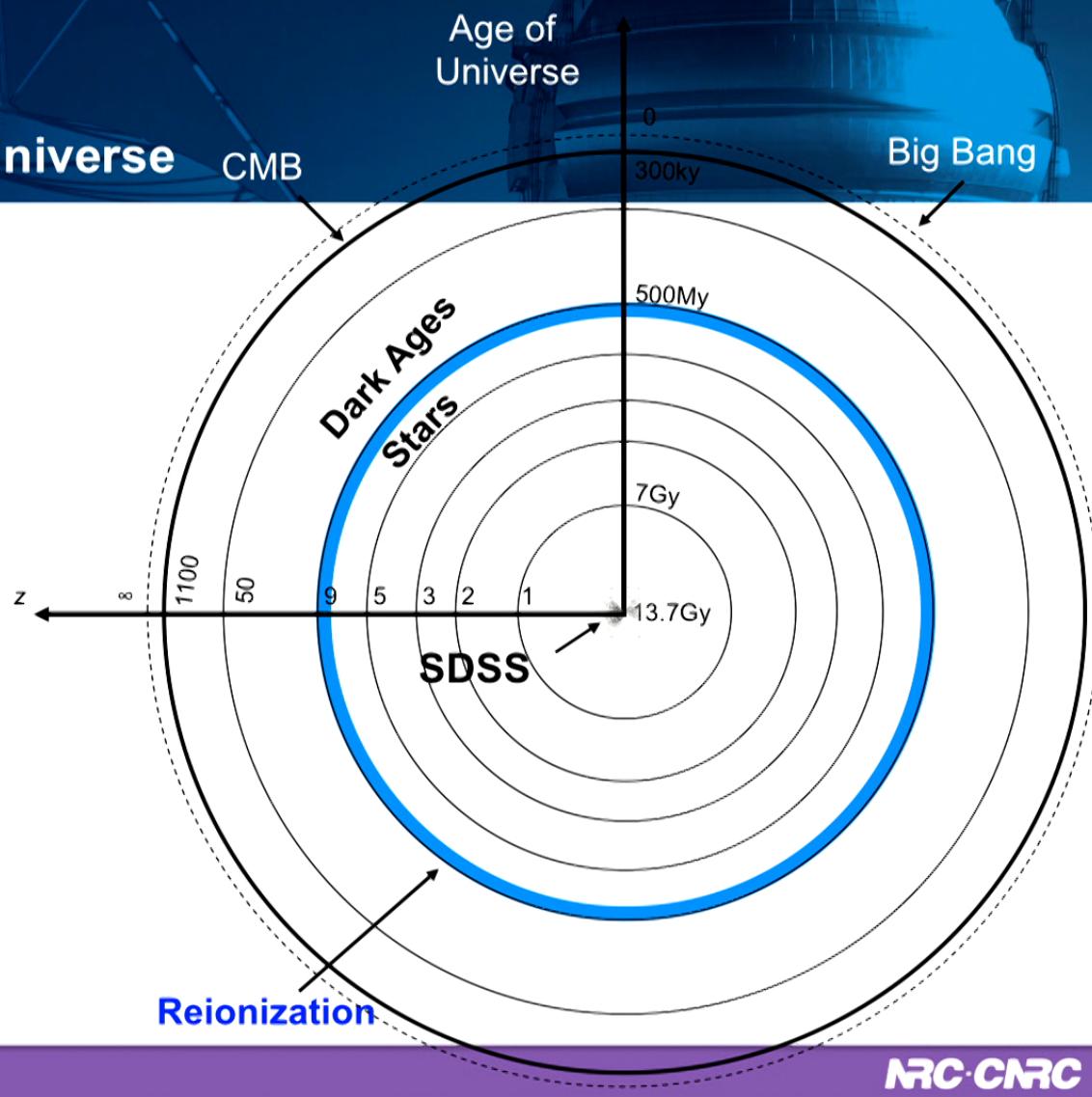
NRC-CRBC

Nominal sensitivity to scale factor



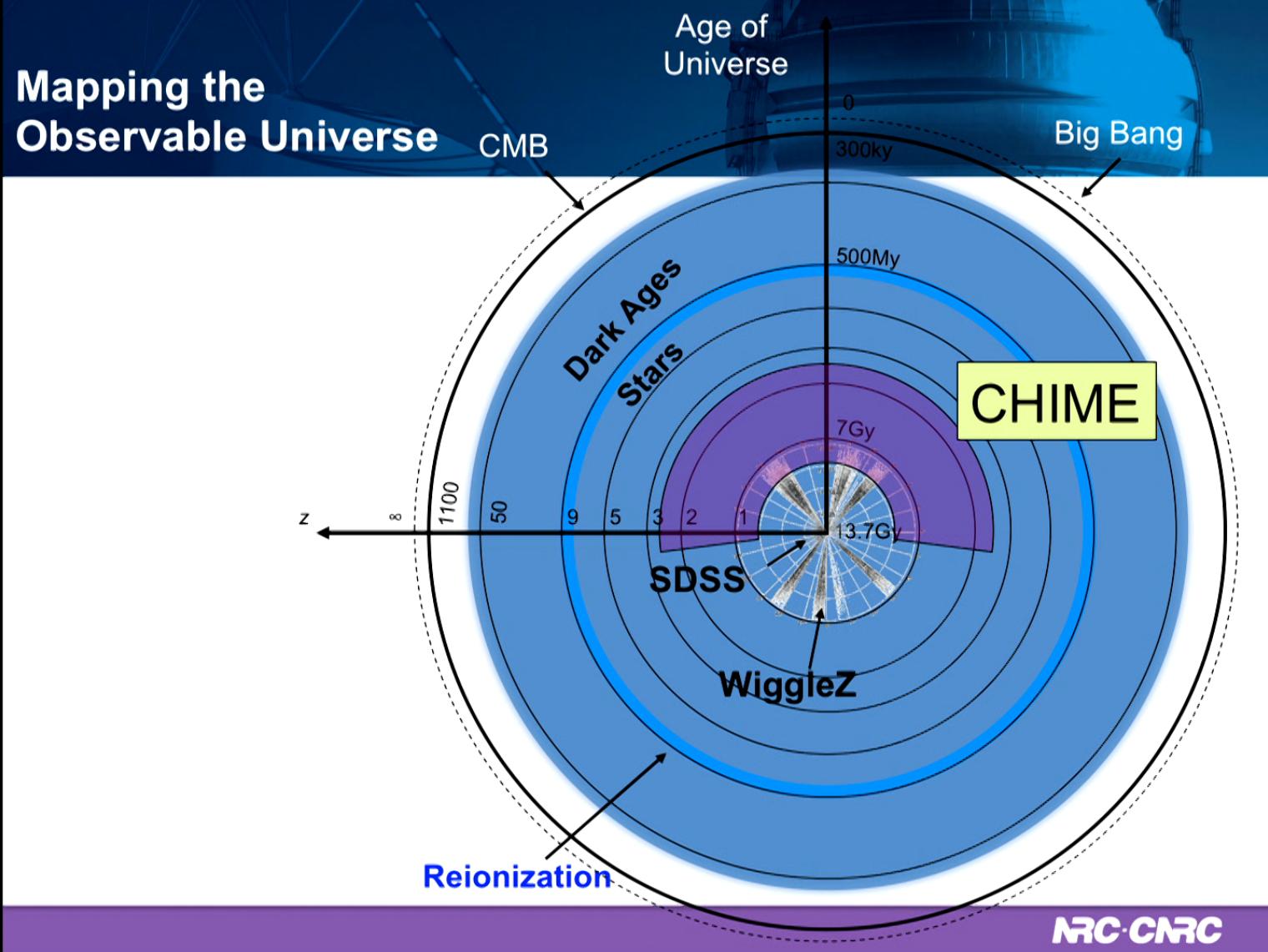
NRC-CNR

Mapping the Observable Universe



NRC-CNR

Mapping the Observable Universe



NRC-CNRC

CHIME: Fast Radio Bursts

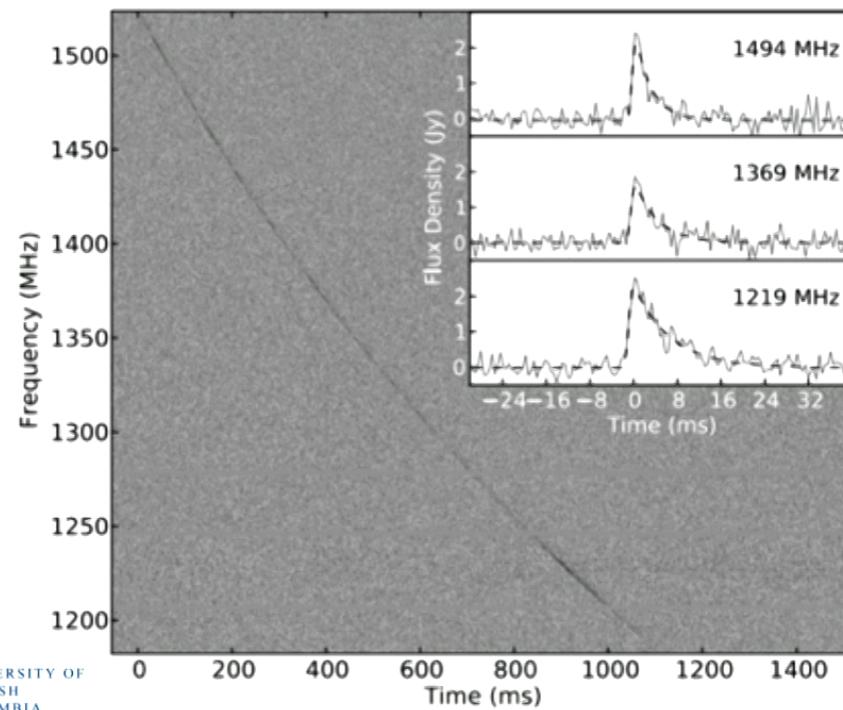
(Mostly) non-repeating, ms-duration, unpredictable, unknown origin, huge chromatic dispersion

Siphon off data stream of:

- 1024 FFT/Fan Beams
- Stokes-I, $\Delta\tau=1\text{ms}$, $\Delta\nu=24\text{kHz}$
- $8,000\text{m}^2$ collecting area
- 400-800MHz bandwidth

Feed into search cluster, search everywhere in CHIME, always.

Should see 1-10 / day



CHIME: Fast Radio Bursts

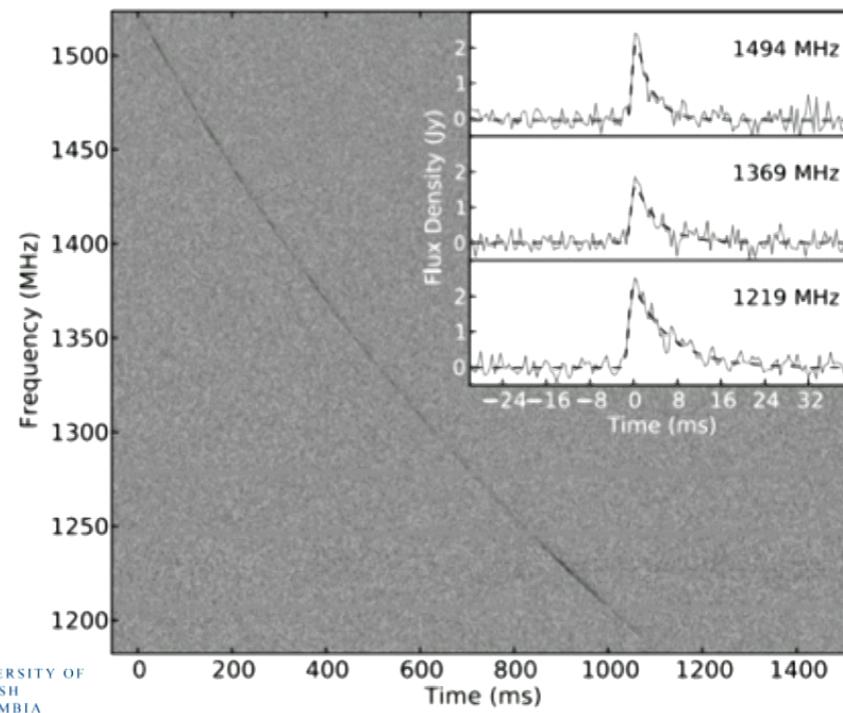
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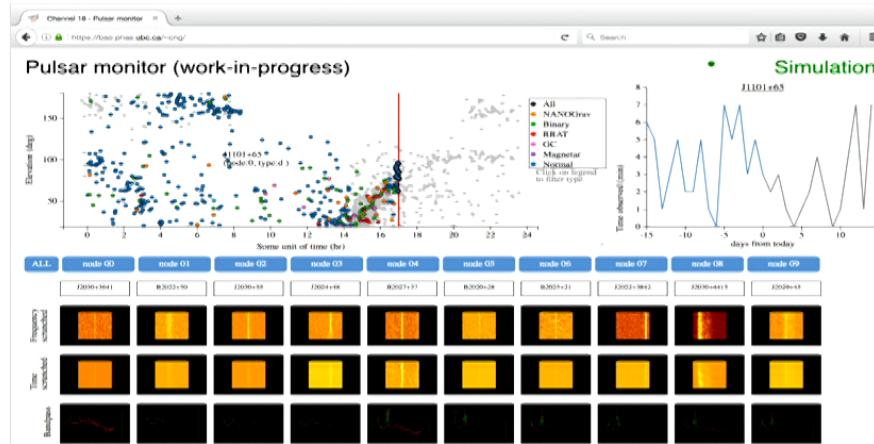
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CHIME/Pulsars

- Time all northern hemisphere pulsars, cycling through over ~10 days
- Track changes in DM, scattering → improve nanoGrav (PTA) timing precision by 25-50% (gravitational waves!)



Status



CHIME

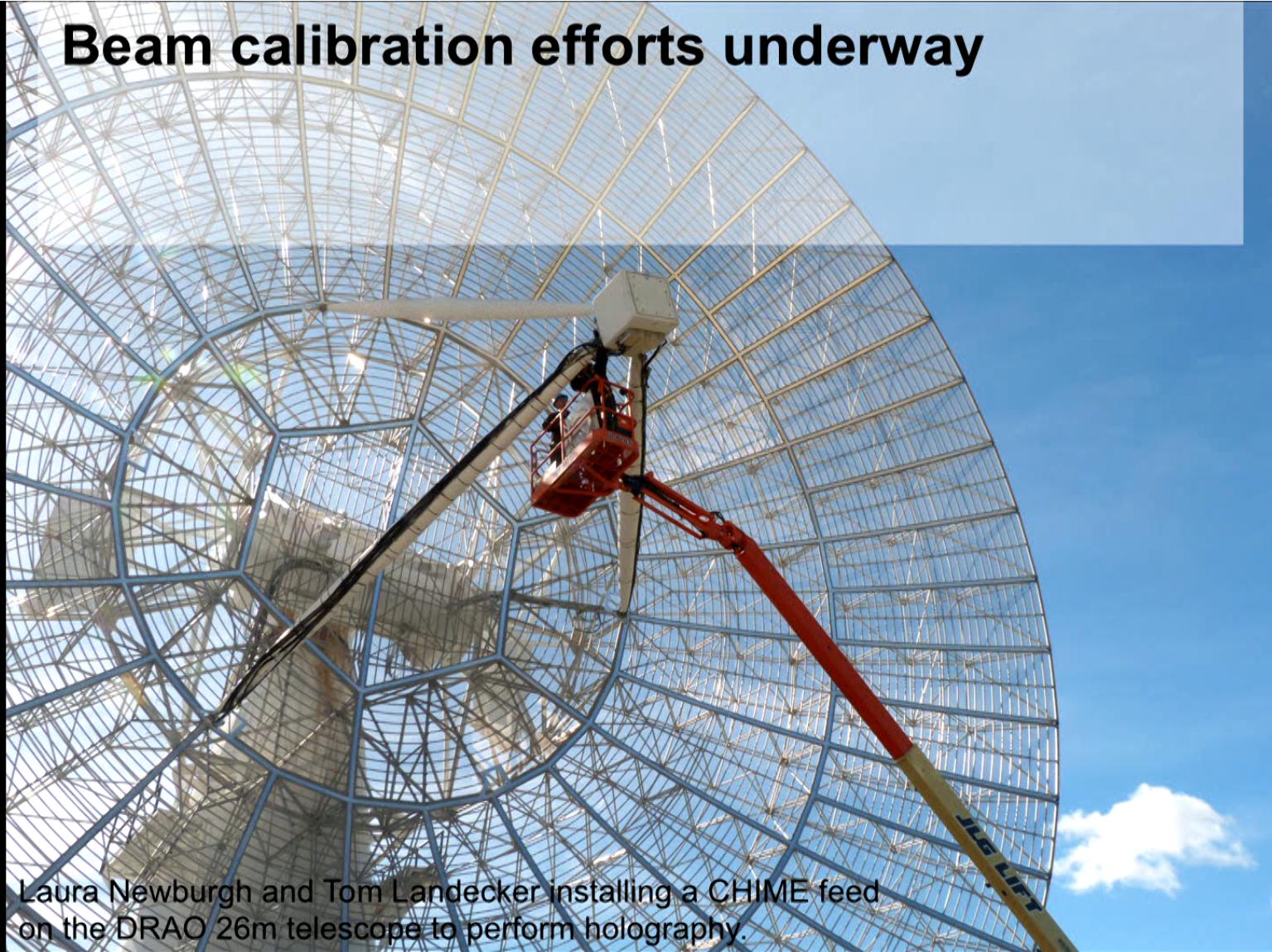


NRC-CNR

Construction timeline

- Cylinders completed 2015-09
- Power available in huts 2016-08
- Focal lines instrumented 2017-08
- F-engine to sky channels 2017-08
- X-engine completed 2017-08
- First light ceremony 2017-09
- Backend computing installed 2017-11
- Two-month science run
 - $\frac{1}{4}$ of the bandwidth (100 MHz)
 - Subset of baselines2018-03 to -05 (now!)

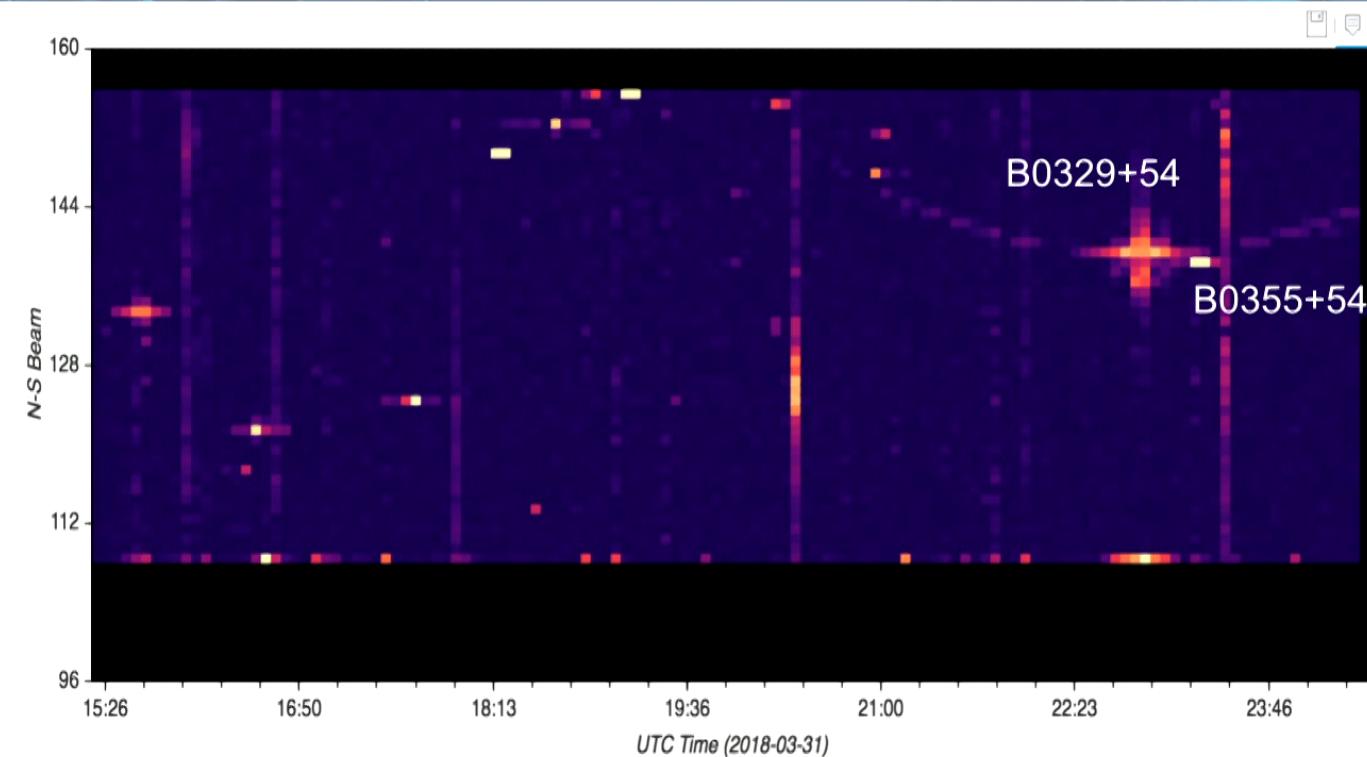
Beam calibration efforts underway



CHIME/FRB: On-sky and collecting data

NRC-CNR

Current status 48 coherent beams + 1 incoherent beam.
Imminent 760 coherent beams + 1 incoherent beam.
Goal 1024 coherent beams + 1 incoherent beam.



National Research
Council Canada

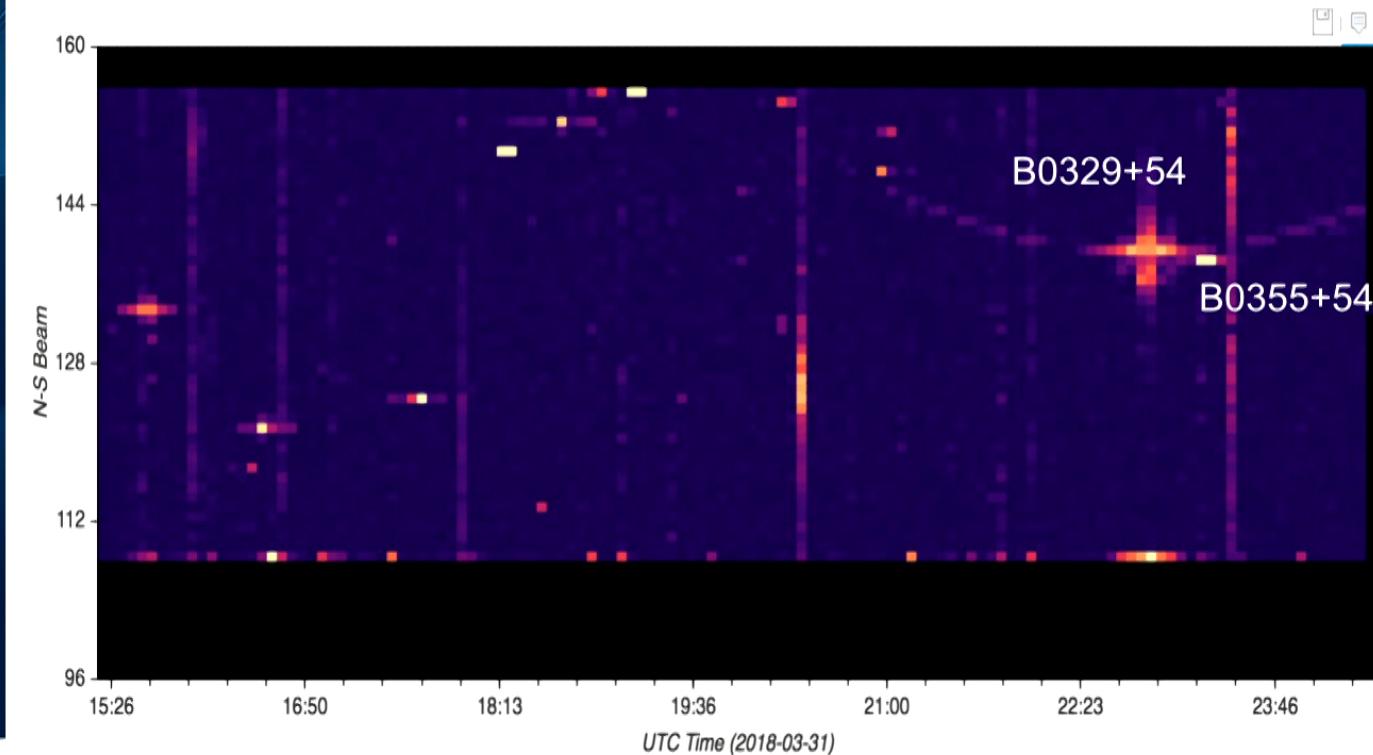
Conseil national de
recherches Canada

Canada

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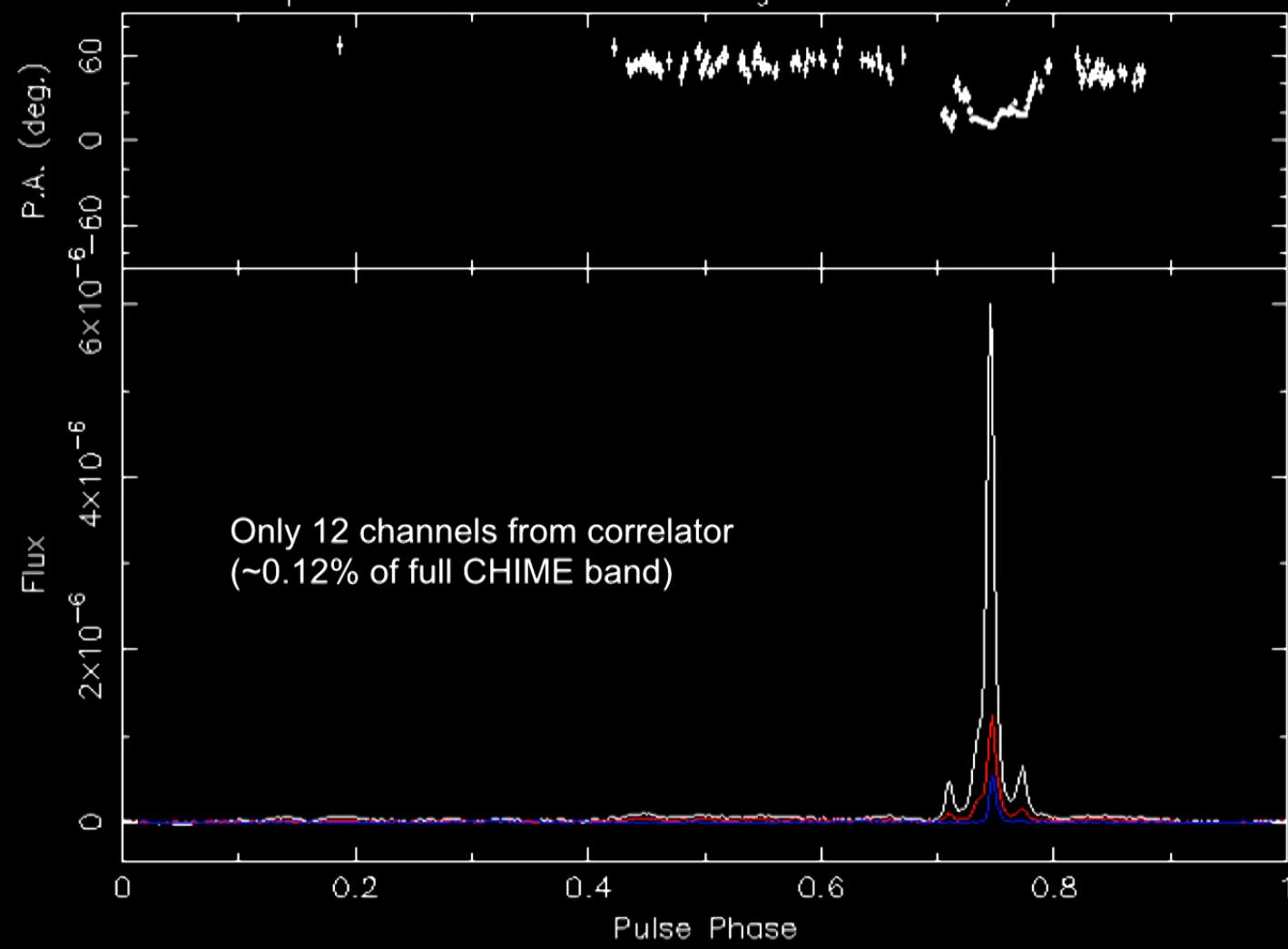


National Research
Council Canada

Conseil national de
recherches Canada

Canada

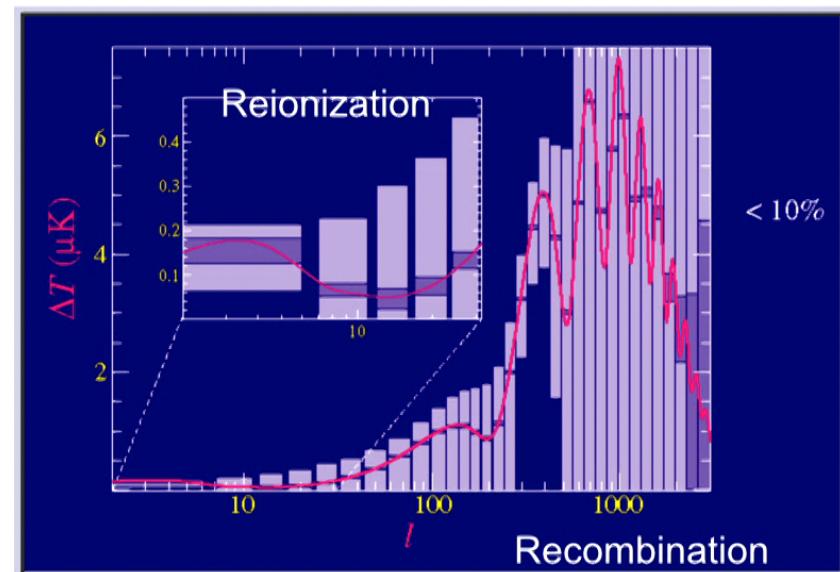
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Freq: 600.000 MHz BW: -400 Length: 2039.999 S/N: 259.917



Canadian Galactic Emission Mapper

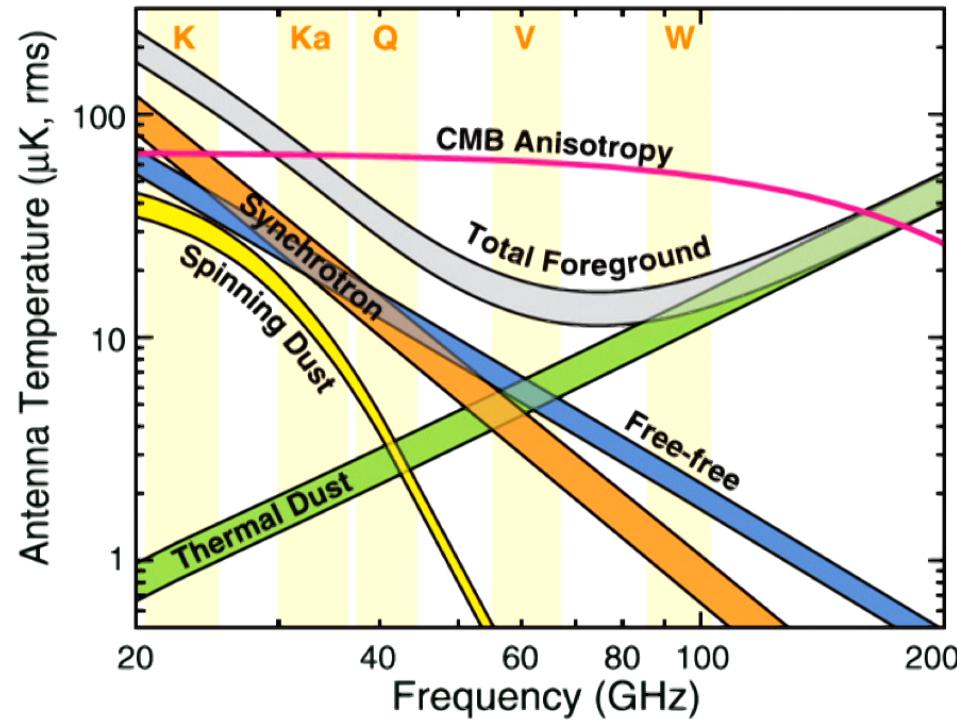
CMB Polarization

- Quadrupole moment → generated by scattering
- Probes last scattering surface of photons: recombination & re-ionization
- Clear check on acoustic oscillations
- **Gravitational waves during inflation** uniquely predict *B-mode polarization*



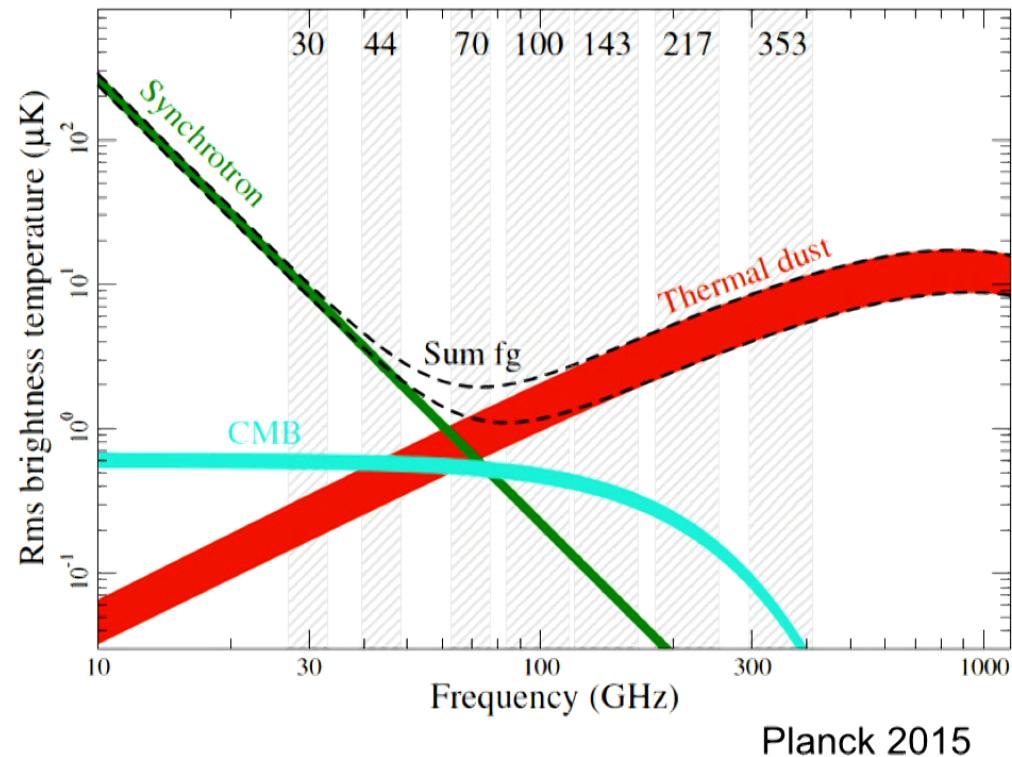
CMB Foregrounds

- Shape & pol'n fraction of foregrounds complex and not predictable

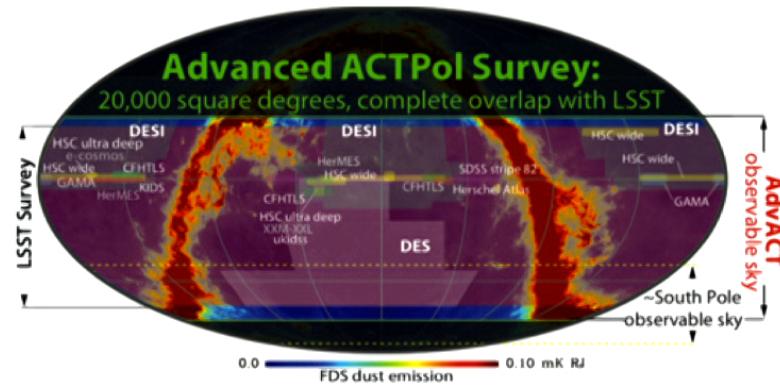


CMB Foregrounds: polarized emission

- B-mode pol'n is *sub-dominant*
- Requires excellent foreground removal

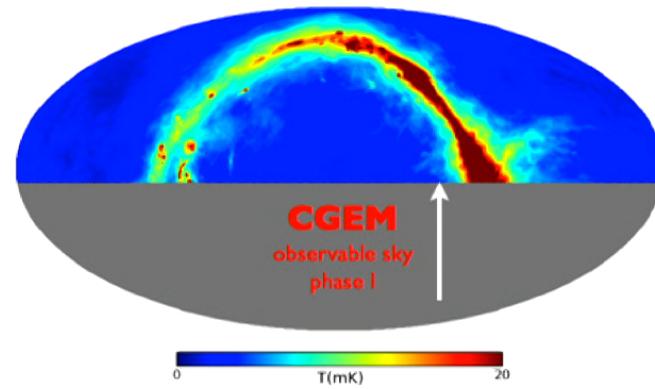


CGEM: sky coverage



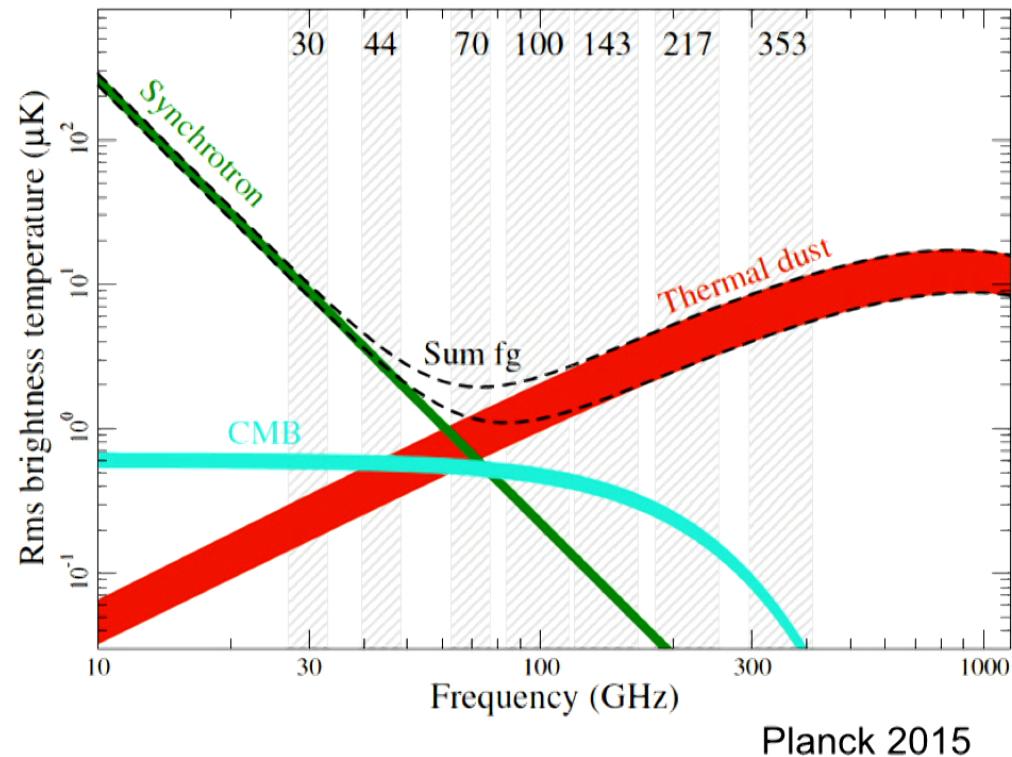
ACTPol, CLASS: 28-230 GHz
Keck Array: 35-270 GHz

CGEM: 10 GHz
Separate dust & synchrotron emission

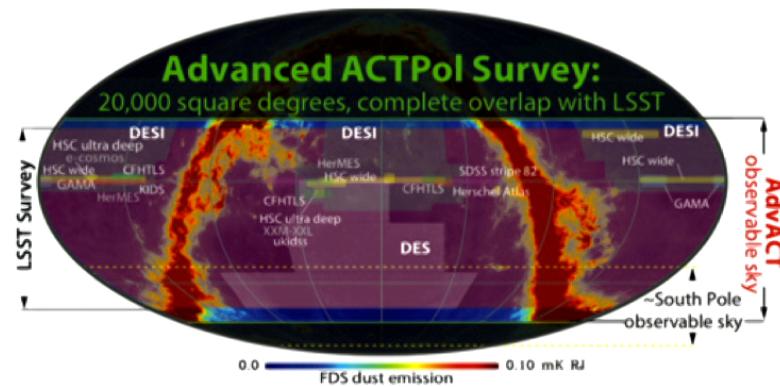


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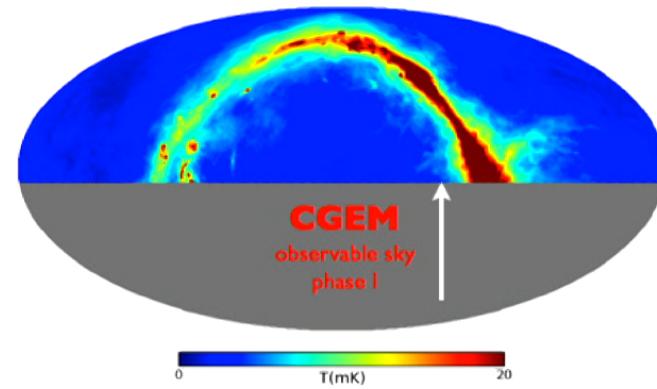


CGEM: sky coverage

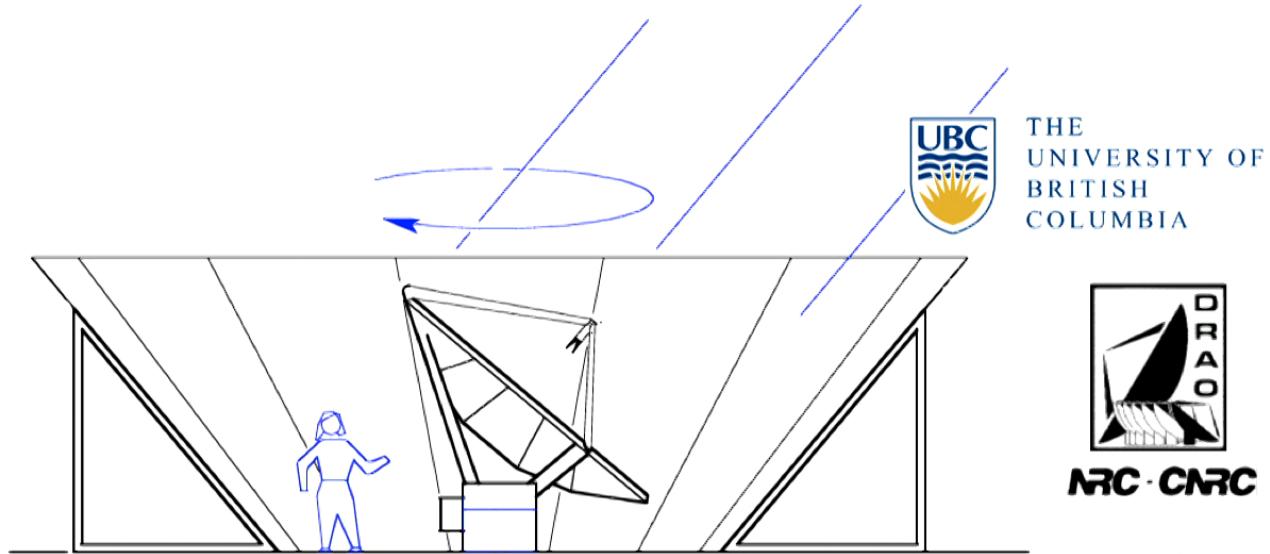


ACTPol, CLASS: 28-230 GHz
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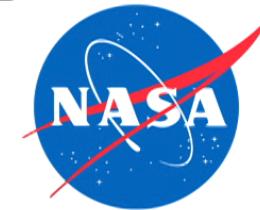
CGEM: 10 GHz
Separate dust & synchrotron emission



CGEM: the instrument



- 4m, f/10.4 dish + reflective ground screen
- 4 rpm @ constant elevation
- Begin work this fall-ish





Some of what I didn't cover

- GMIMS & other polarization work
- ALMA
- Square Kilometre Array
- Technical developments (correlators, beamformers, composite dishes, RFI excision, post-processing, fast transients, ...)
- Future instruments (ngVLA, ngCMB, ...)

Many opportunities (and challenges) ahead!





Thank you

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