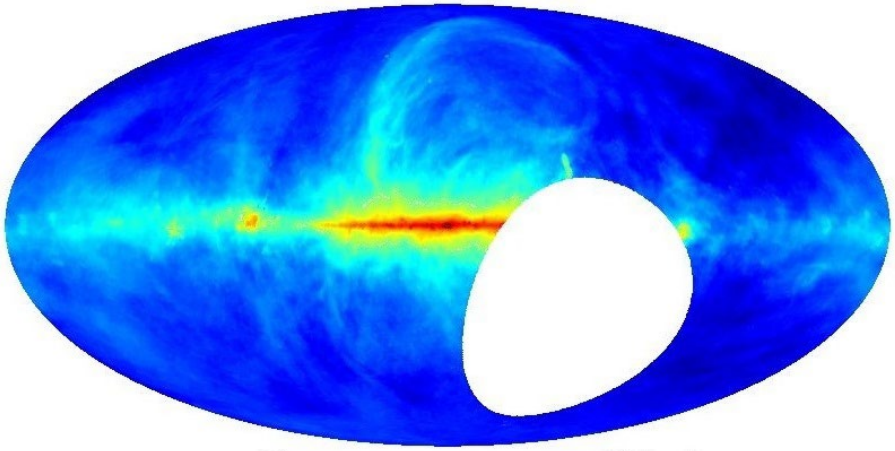
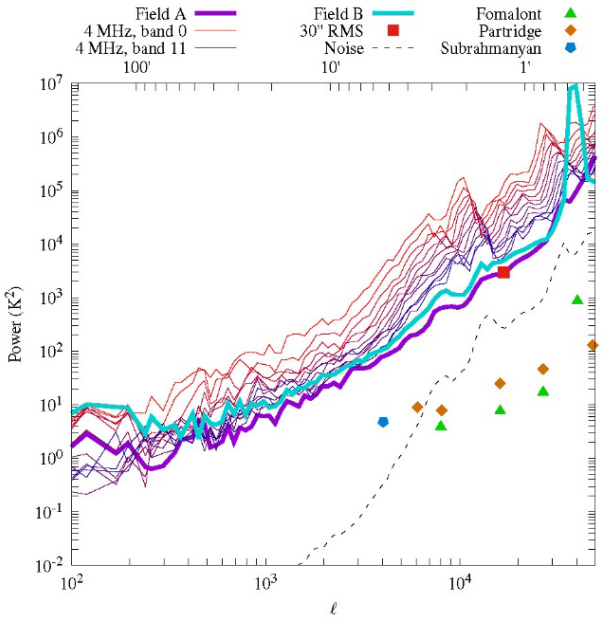
Jack Singal
University of Richmond, USA

BAM RSB Workshop
Barolo, Italy
June 15, 2022

Overview and New Measurements

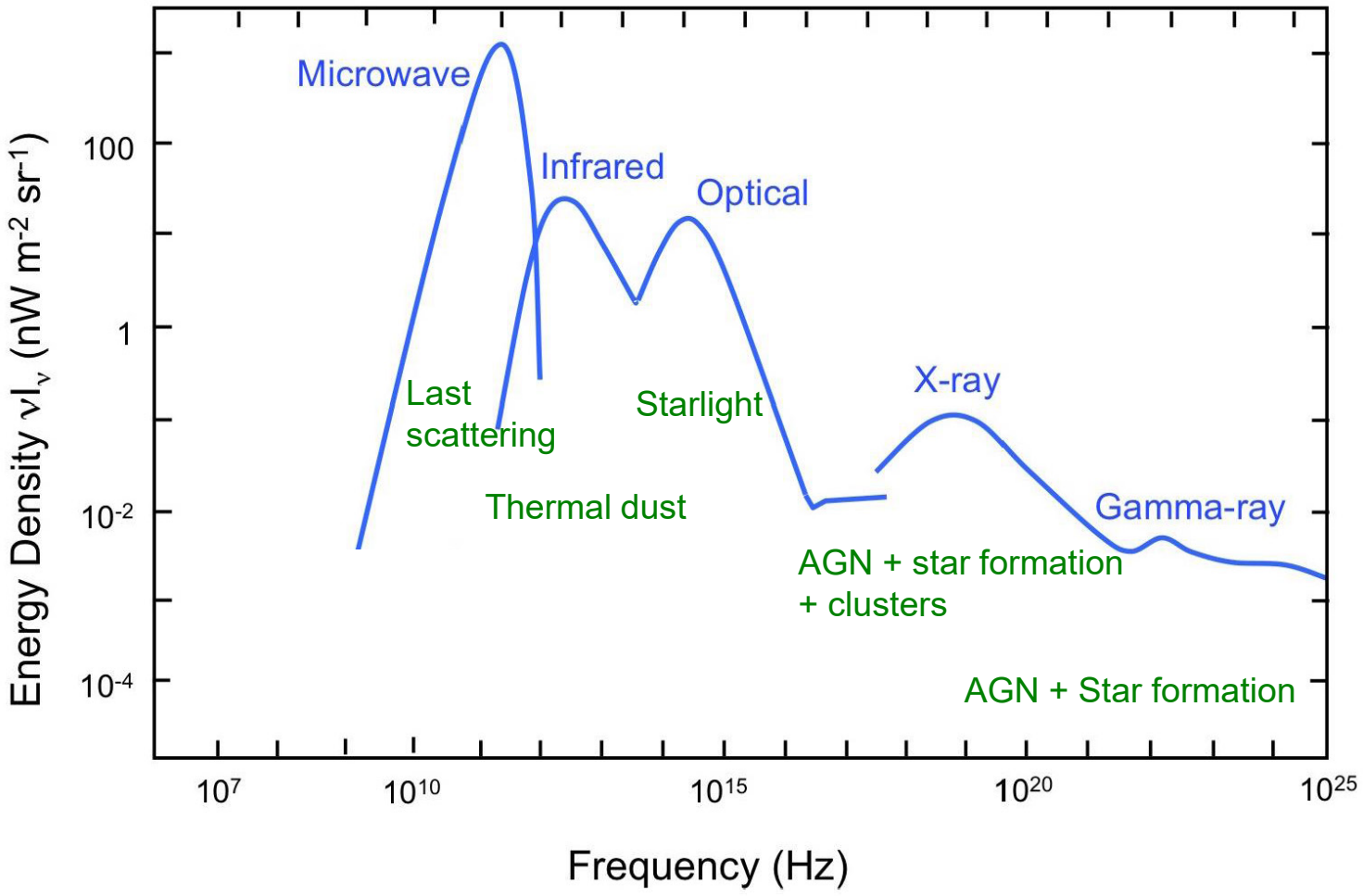




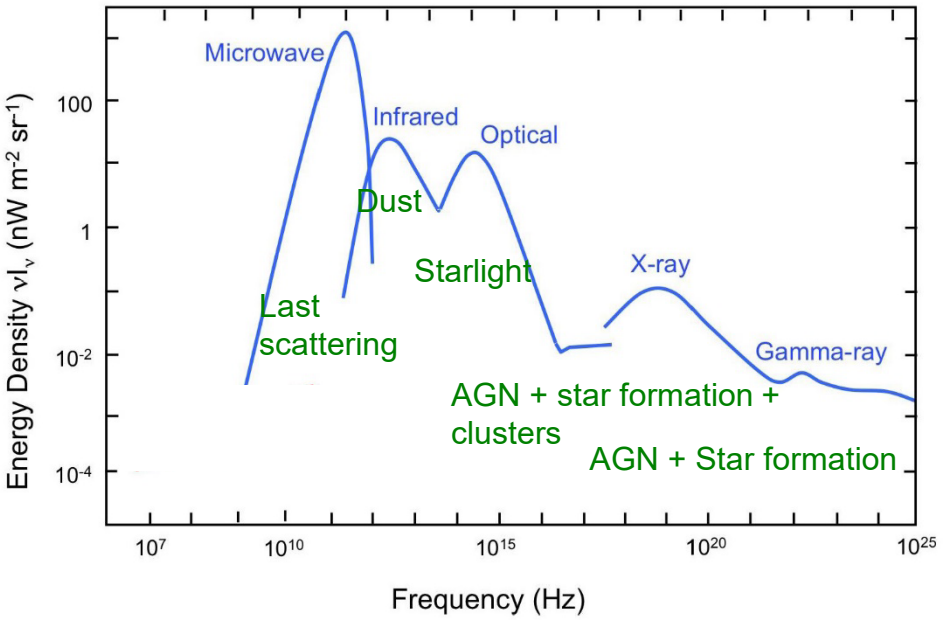
Light in the Universe

All the Light in the Universe

- All the light we receive from the Universe in a particular waveband



All the Light in the Universe

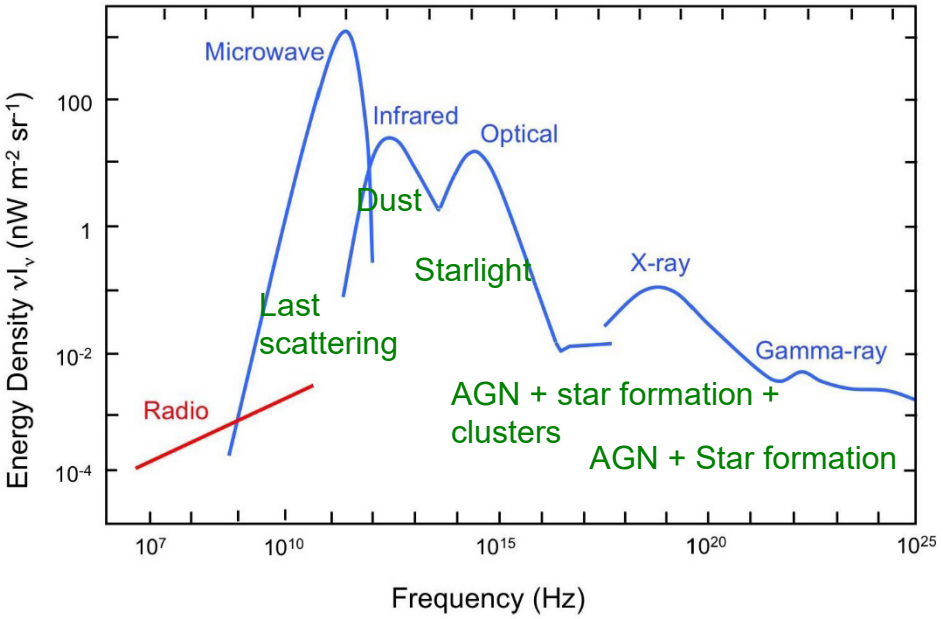


These photon backgrounds all:

- **Are at least roughly consistent with predicted the total emission of known source classes**
- **Have been resolved into the source class components when possible**
- **Have anisotropies which trace the large-scale distribution of optical sources in the universe**

All the Light in the Universe

None of these are true of the Radio Synchrotron Background!



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RSB!

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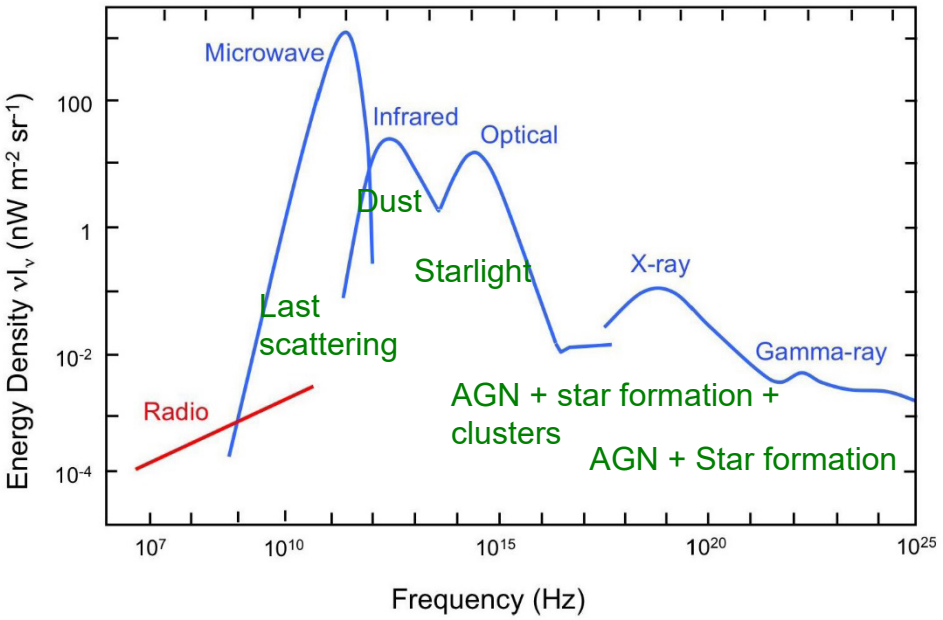
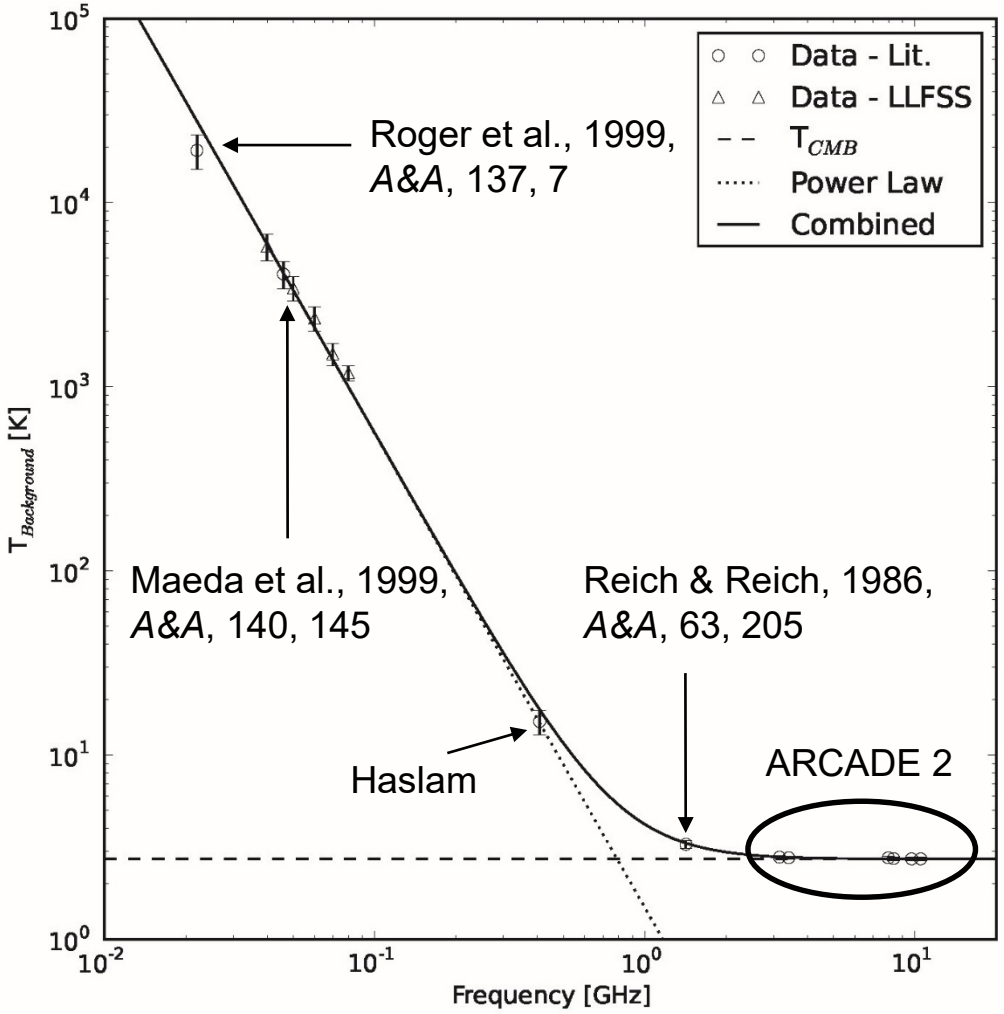
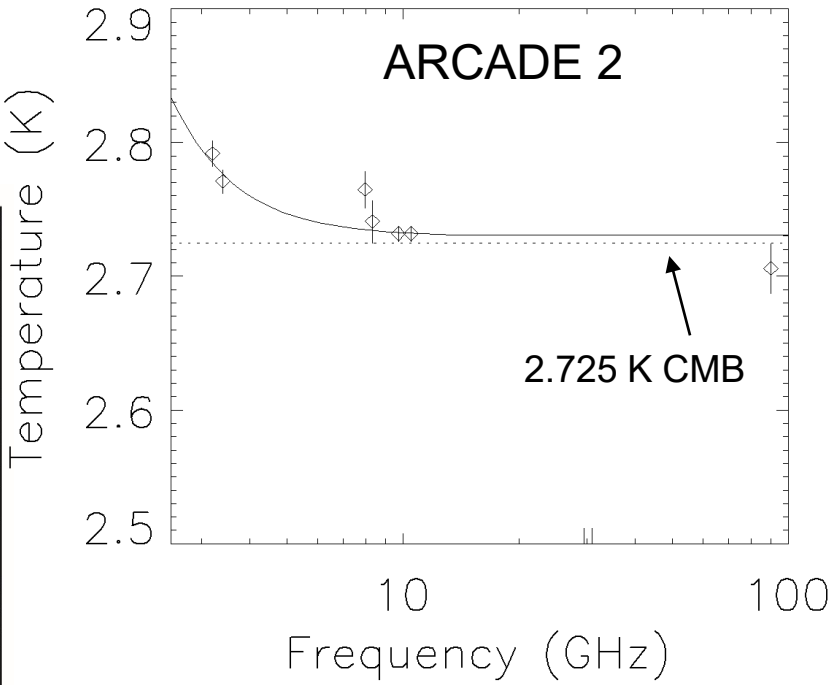


This is an interesting problem!

Reminder: RSB Level

Dowell & Taylor, 2018, *ApJL*, 858, 9





Available measurements have reported a high radio background level

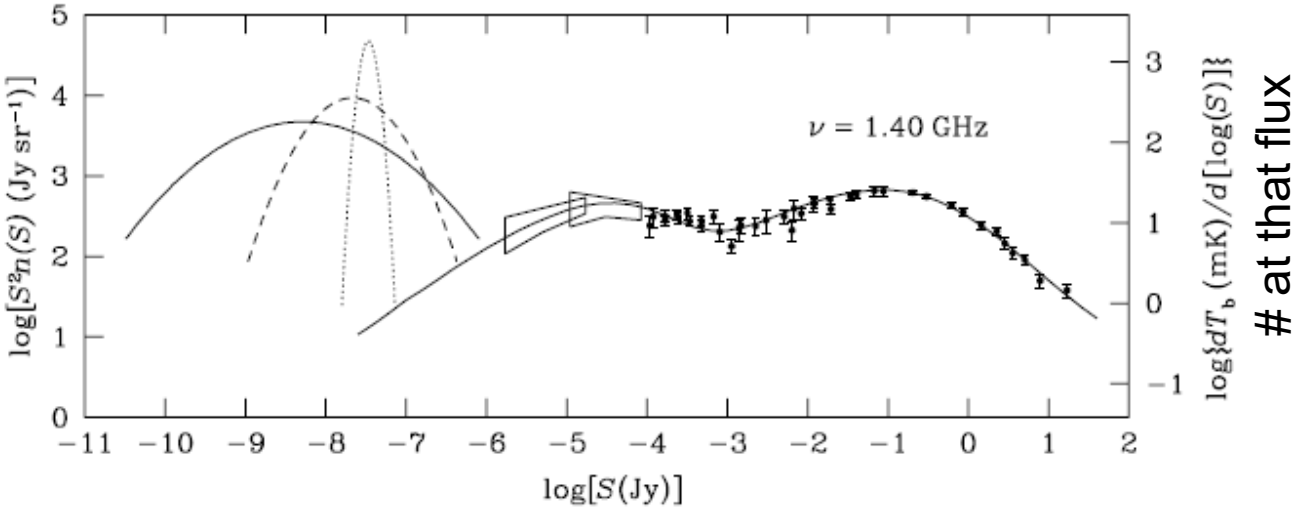
Reminder: RSB Level

Available measurements have reported a high radio background level

Known source classes added up give only ~1/5 of the claimed radio background level

J. Condon et al., 2012, *ApJ*, 758, 23
T. Vernstrom et al., 2014, *MNRAS*, 440, 2791
M. Hardcastle et al., 2021, *A&A*, 648, 10

Would need *huge (!)* # of low flux sources to make this brightness!

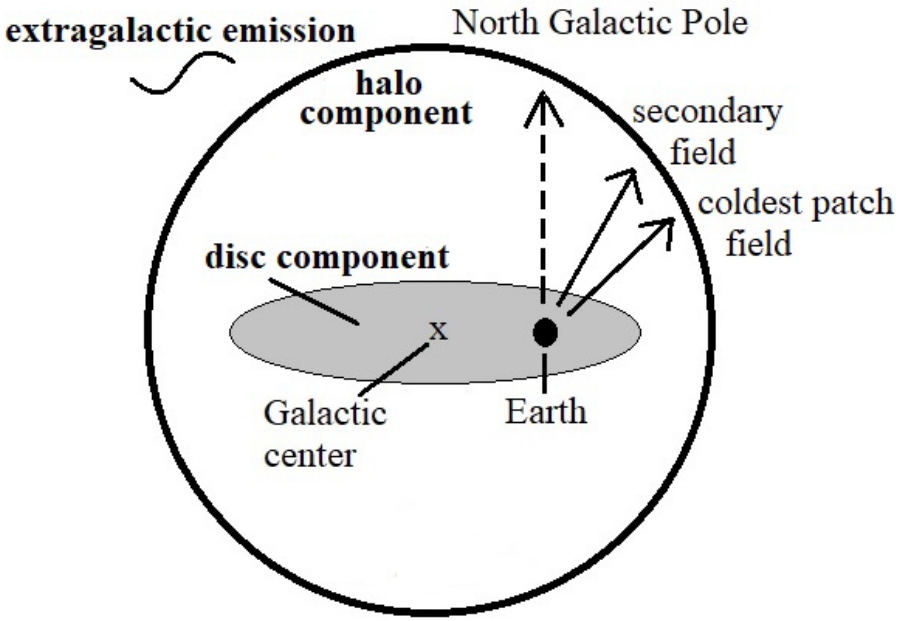


Flux (measured brightness)

Reminder: RSB Level

It is tough to stuff into a giant Galactic halo

- Other nearby edge-on spiral galaxies do not show bright spherical halo morphology
- Overall Galactic emission structure is well-fit by simple csc|b| model
- Corelates of galactic radio emission such as 158 μm C+ line suggest low level at poles



Singal et al., 2015, *ApJL*, 799, L10
Kogut et al., 2011, *ApJ*, 734, 4

A Tale of Two Meetings

1st RSB Workshop

1st RSB Workshop

Publications of the Astronomical Society of the Pacific, 130:036001 (21pp), 2018 March https://doi.org/10.1088/1538-3873/aaa6b0

The Radio Synchrotron Background: Conference Summary and Report

J. Singal[1], J. Haider[1], M. Ajello[2], D. R. Ballantyne[3], E. Bunn[1], J. Condon[4], J. Dowell[5], D. Fixsen[6], N. Fornengo[7], B. Harms[8], G. Holder[9], E. Jones[1], K. Kellermann[4], A. Kogut[6], T. Linden[10], R. Monsalve[11,12,13], P. Mertsch[14], E. Murphy[4], E. Orlando[15], M. Regis[7], D. Scott[16], T. Vernstrom[17], and L. Xu[16]

The workshop reached a strong consensus on the importance of having at least one new, purpose-built, absolutely calibrated zero-level measurement to confirm (or dispute) the level of the radio synchrotron background obtained from ARCADE 2 and the low frequency radio surveys. The options for such a measurement can be broadly classified into the following categories:

(2) A measurement at around 300 MHz, consisting of a purpose-built receiver mounted on the Green Bank Telescope, which features an unblocked aperture. At this frequency the effect of tropospheric water vapor fluctuations is not important and the location in the National Radio Quiet Zone provides protection against radio frequency interference. Such a setup would only take a

Previous Barolo Astroparticle Meeting

Discussions came up with the idea of using LOFAR to measure the anisotropy of the RSB

New Measurements to talk about

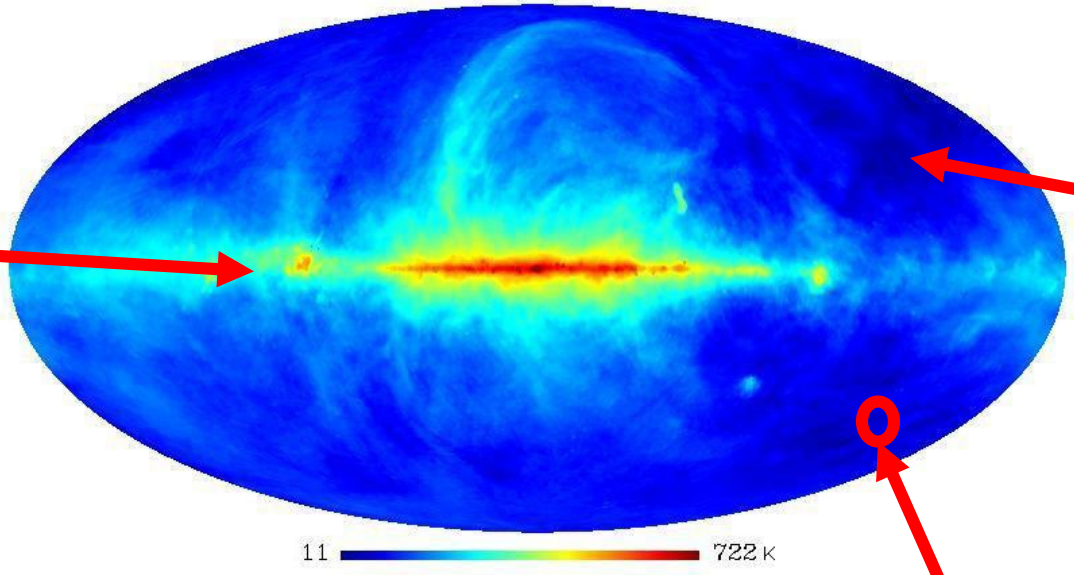
1) 310 MHz Absolute Map (in progress)

2) Arcminute scale anisotropy power spectrum at 140 MHz (done)

310 MHz Absolute Map

Haslam Map - 1980s
(> 1000 citations)

Plane structure of our Galaxy



Some combination of Galactic and extragalactic

Resolution (~1 deg) is such that these temperature levels are due to the integrated surface brightness of many sources and/or a diffuse glow from the Galaxy

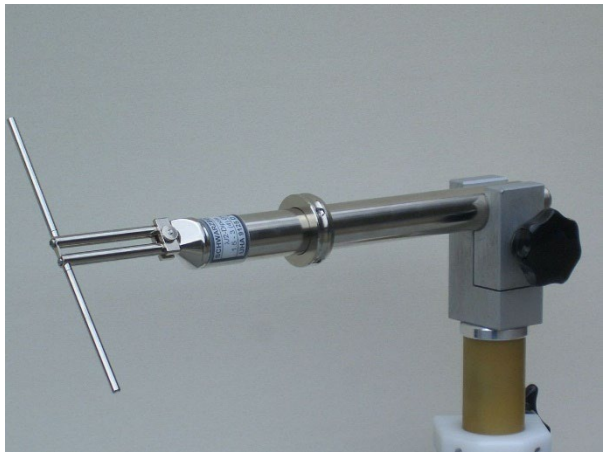
What (supposed) absolute radio measurements do we have?

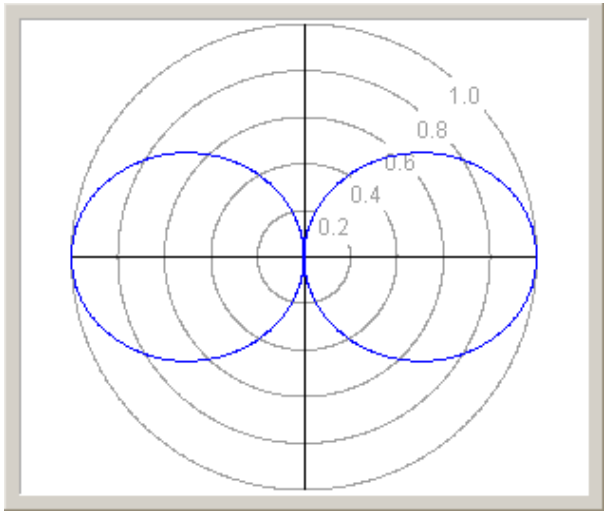
Table 1: All Relatively Recent Radio Maps Reporting an Absolute Zero-Level Calibration

Frequency (MHz)	*Map*	*Instrument*	*Source of Absolute Zero-Level Calibration*
22	Roger et al. (1999)	Dipoles above reflecting screen	Scaling relative to 408 MHz Haslam et al. (1982) map at Zenith applied to other elevations
45	Maeda et al. (1999)	Phased array Yagi dipoles	Overlap with Alvarez et al. (1997), itself based on small region overlap with unspecified pedigree
40,50,60,70,80	Dowell & Taylor (2018)	240 dipole array with synthesized beam	Flux calibrator sources and instrument gain modeling
408	Haslam et al. (1982)	Jodrell Bank 75 m clear aperture dish	Overlap with blocked-aperture, 7.5° resolution dipole measurement of Pauliny-Toth & Shakeshaft (1962)
1420	Reich & Reich (1986)	Stockert 25 m blocked aperture dish	Small overlap with wide beam horn-based measurment of Howell & Shakeshaft (1966)
2300	Tello et al. (2013)	blocked aperture dish	Total power radiometer calibrated with observations of moon
2326	Jonas et al. (1998)	HartRAO 26 m blocked aperture dish	Small overlap with horn-based south celestial pole measurement of Bersanelli et al. (1994)

What (supposed) absolute radio measurements do we have?

Bare Dipoles?





→ Large sidelobes coupling extra radiation from other places than the intended place on the sky

- Bright Galactic plane
- Ground
- Anything else

Brighter than or of comparable brightness to what we are trying to measure

What (supposed) absolute radio measurements do we have?

Blocked Aperture Dishes?

→ Reflections and emissions off of giant structures right in the beam

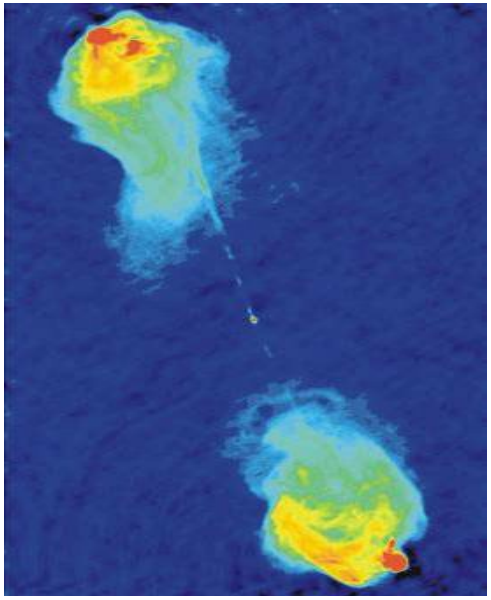
- How much of the signal is actually from the intended point on the sky?

What (supposed) absolute radio measurements do we have?

Flux calibrators and gain modeling?

Use a bright source(s) that has been measured well and interpolate / extrapolate a function for output vs. brightness

- Is the instrument gain linear over orders of magnitude in brightness?
- Does the bright source observation include the (unknown) amount of diffuse background



We don't actually know (confidently) the level of diffuse radio emission in the universe

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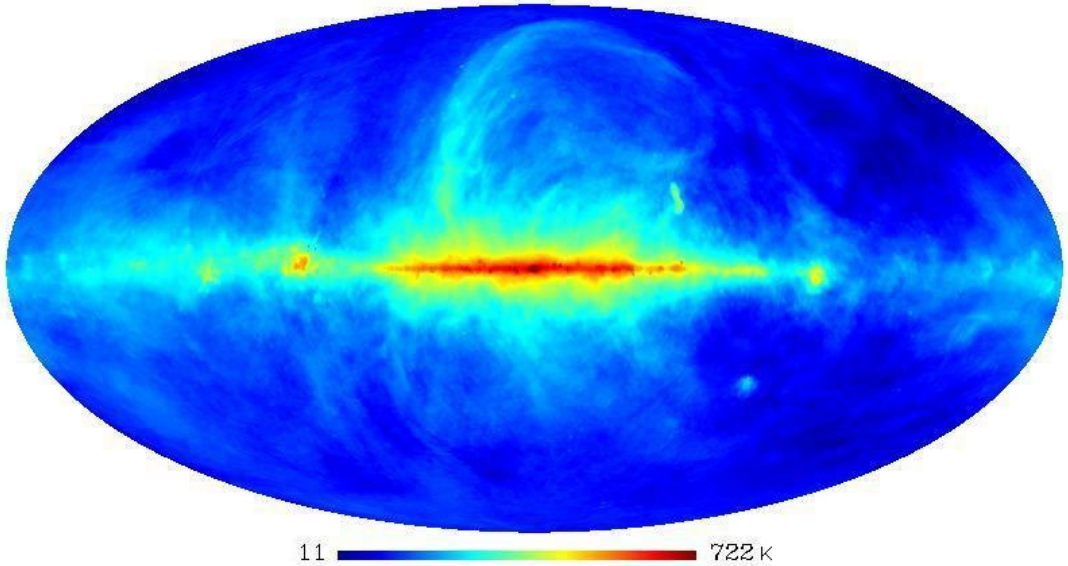
- Absolute zero-level calibration not a primary goal of these measurements
- These measurements are (mostly) old and/or rely on old ones

Absolute Maps - Extremely Important

The Haslam all-sky survey 408 MHz from the 1980s is *still* the gold standard - Cited over 1000 times and citation rate is *increasing*

Important for understanding and constraining almost all Galactic and extragalactic phenomena that manifest in diffuse radio emission



Examples (not exhaustive):

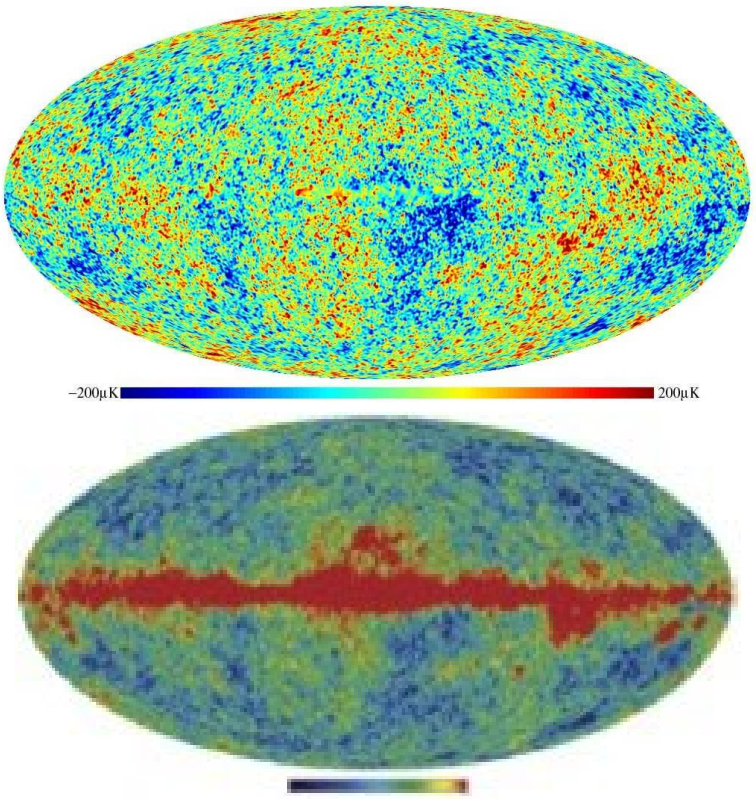
- cosmic ray propagation (e.g. Orlando & Strong 2013; Orlando 2017)
- magnetic field structures (e.g. Sun et al. 2008)
- supernova remnant and pulsar searches (e.g. Surnis et al. 2018; Bhat et al. 2018)
- composition of the interstellar medium (e.g. Nguyen et al. 2018)
- finer scale radio structure (e.g. Mertsch & Sarkar 2013)
- tracers for Galactic phenomena at other wavelengths (e.g. Kogut et al. 2011)
- cosmic microwave background (CMB) studies (e.g. Adam et al. 2016)
- 21-cm cosmology (e.g. Bowman et al. 2018)
- Constraints on the radio synchrotron background (e.g. Singal et al. 2018)

Absolute Maps - Extremely Important

Case study: CMB foregrounds

"... Lack of robustness with respect to systematics; any systematic error that may be present in the 408 MHz and 857-2 channels can and will propagate into the respective foreground amplitude maps. In order to improve on this situation in the future… incorporating additional low-frequency observations is critical."

(Planck 2015 Results. X. Adam et al 2016, *A&A*, 594, A10, "Diffuse component separation: Foreground maps")

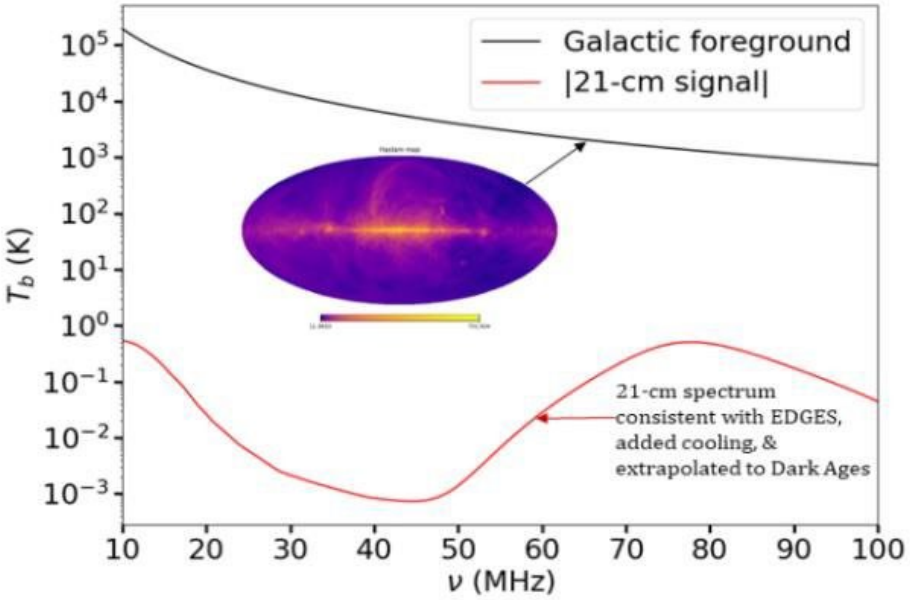


Absolute Maps - Extremely Important

Case study: 21-cm foregrounds and interpretation

"Broadband foreground sources are expected to be roughly four orders of magnitude larger than any cosmological signals, so precise foreground models will be necessary"

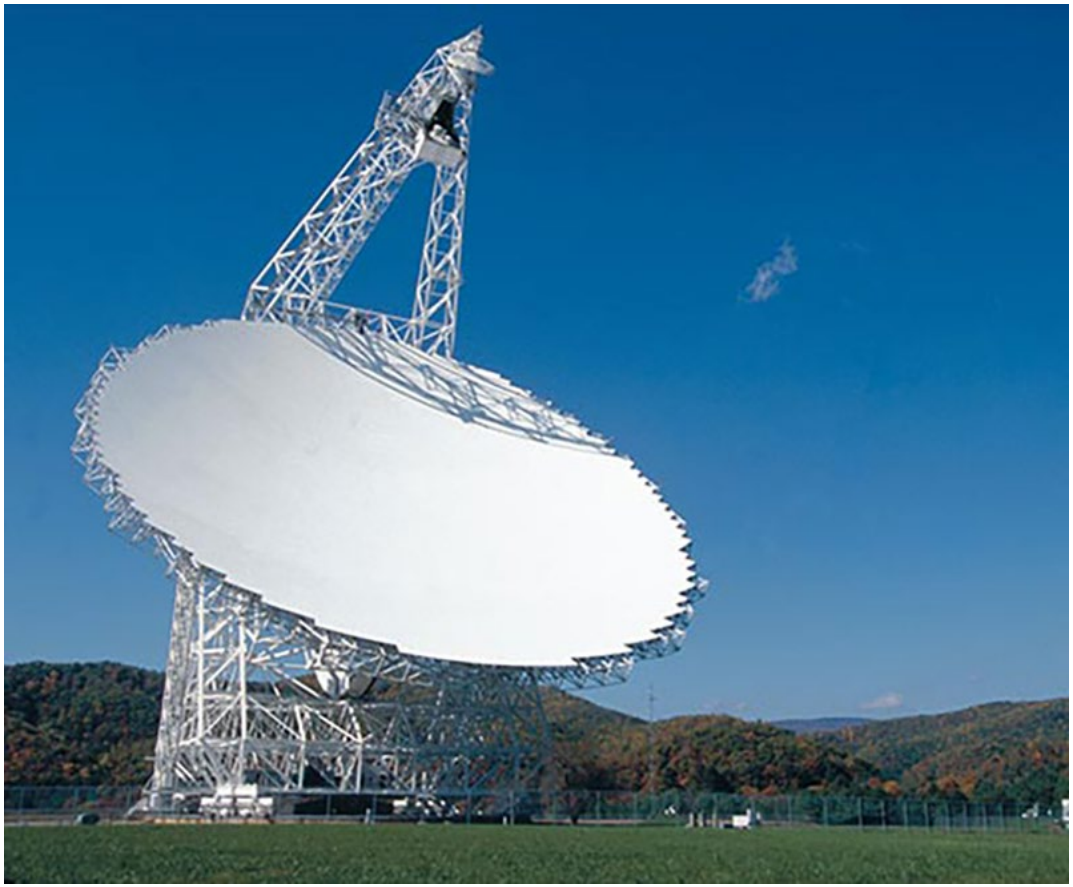
- Liu & Tegmark, 2012, *MNRAS*, 419, 3491



(figure from Jack Burns' Astro2020 white paper)

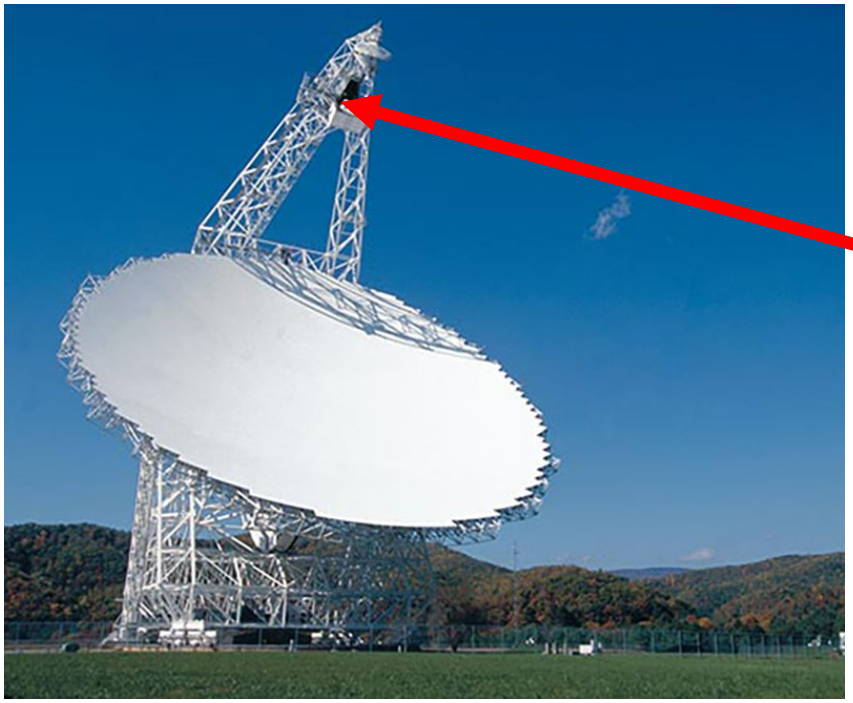
Can we make a new, modern, believable, absolutely calibrated radio map?

The Green Bank Telescope



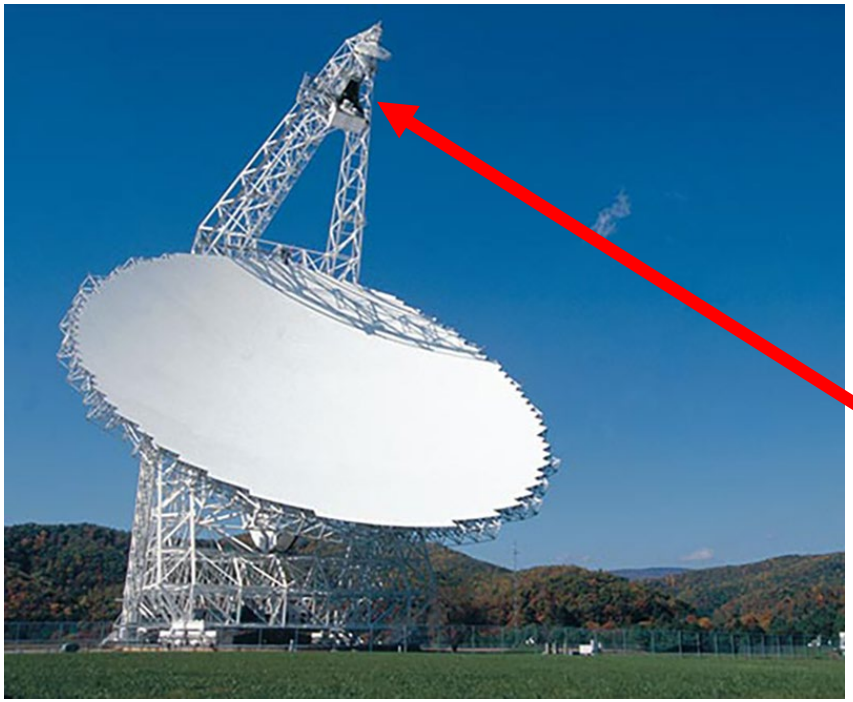
- World's largest clear aperture telescope
- Located in rural West Virginia in National Radio Quiet Zone
- Could be utilized for absolute map if done properly

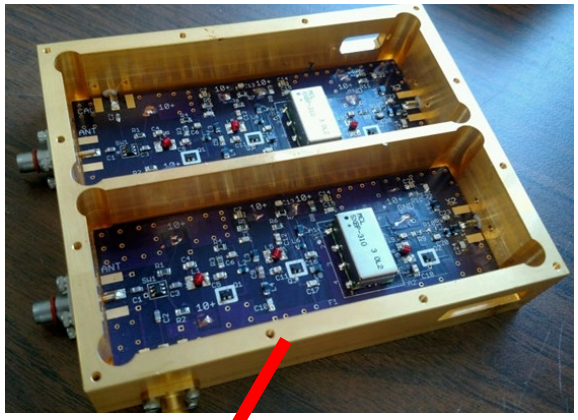
GBT Absolute Map Project

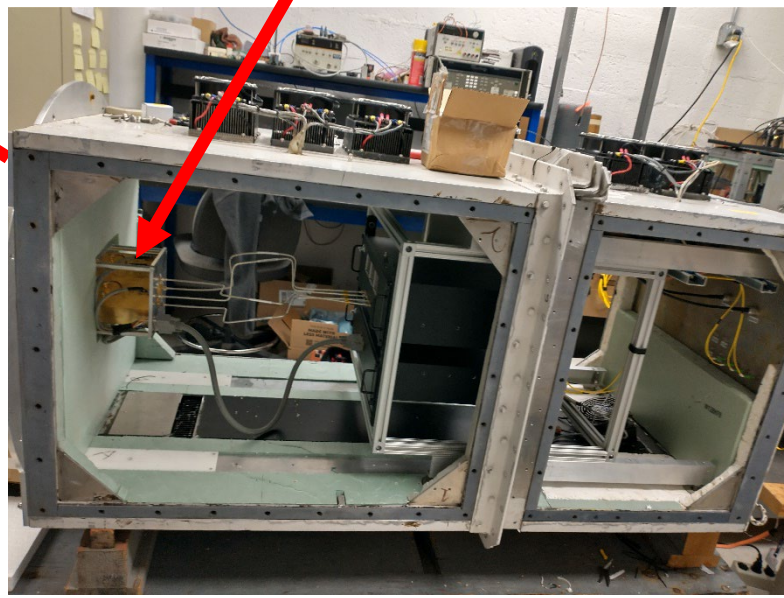


1) Custom antenna (“feed”) to “underilluminate” (less power spilling over the edge of the dish to the ground)

GBT Absolute Map Project

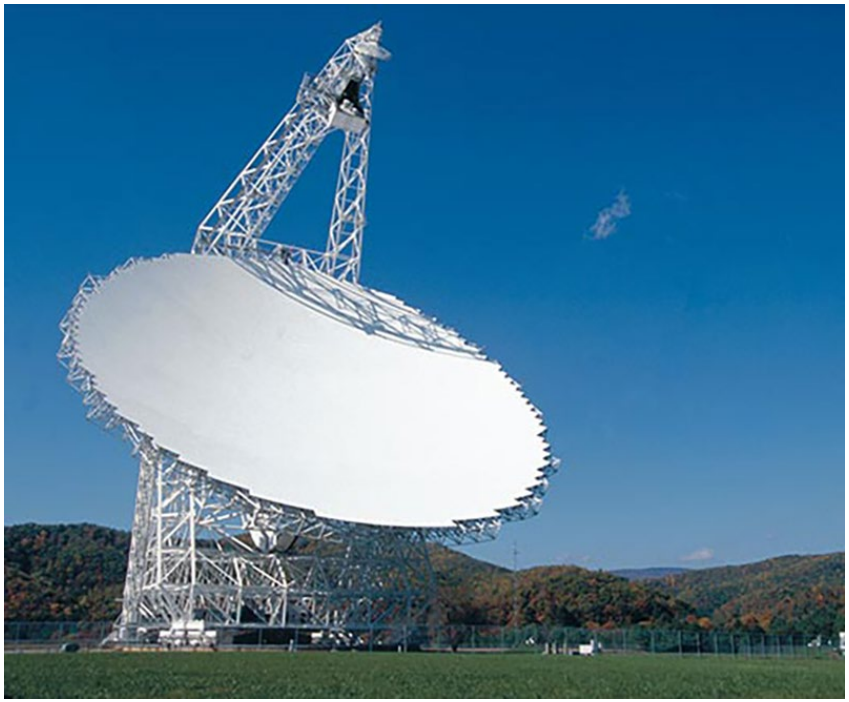






2) Custom absolutely calibrated receiver designed for this purpose

GBT Absolute Map Project



3) Scans in circles of constant elevation of 38° to pass through unchanging NCP every 15 minutes

Tip scans up and down to estimate residual ground pickup and get lower elevations

Do this in ~every month to map entire sky (north of -48° dec)

GBT Absolute Map Project

Approved for 24 hours of observing in October to make preliminary porous map

Will involve mount and de-mount of custom antenna, front-end box, etc…

Will propose for 162 hours of observing in 12 sessions for full-sky map

<u>UR</u>
Jack Singal

<u>NRAO CDL</u>:
Rich Bradley
Sivasankaran Srikanth
Bang Nhan
Krishna Makhija
David Bordenave

<u>NRAO Jansky Lab</u>:
Jim Condon
Ken Kellermann
Eric Murphy

<u>Green Bank Observatory</u>:
Chris Salter

More to come in David's Talk!

LOFAR Anisotropy Measurement

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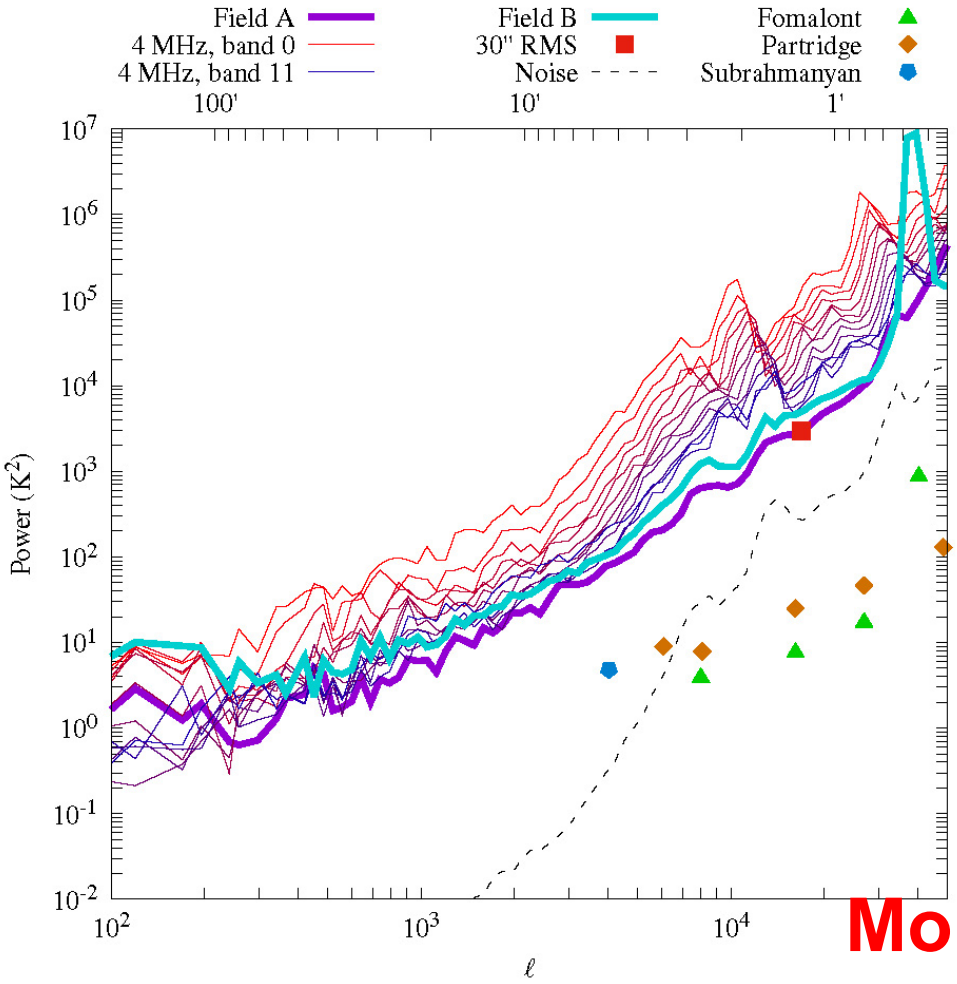
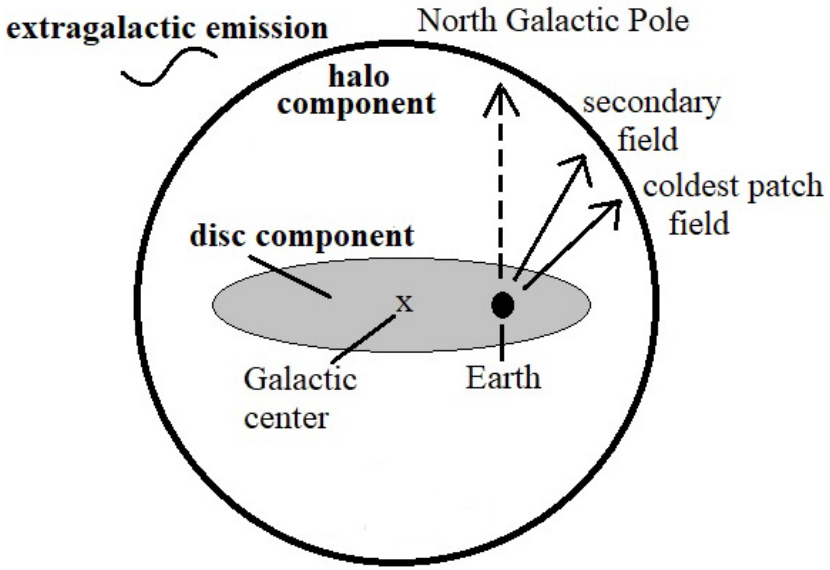
The anisotropy on arcminute scales is weird…



A. Offringa, J. Singal, et al., 2021 *MNRAS*, 509, 114



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