

Space-based Neutron Lifetime Measurement & Update on Absolutely Calibrated Skymap at 310 MHz

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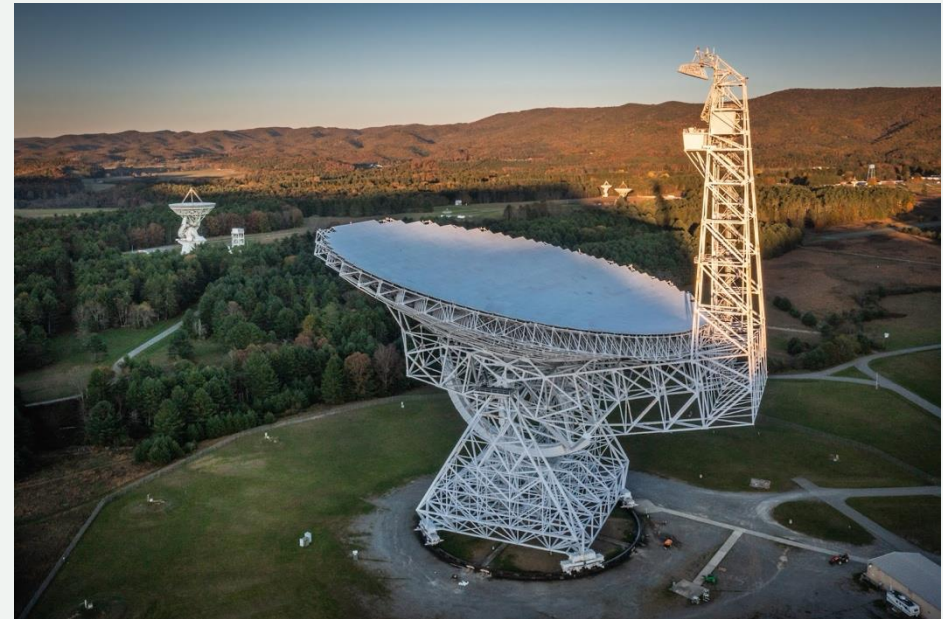
CETUP* 2026
Lead, SD
June 2026

Two focuses in this talk



NASA/JPL

Measurement of Neutron lifetime





NRAO

Excess Radio Background Studies:
Absolute sky map at 310 MHz

Systematic uncertainties in the measurement of the neutron lifetime using the Lunar Prospector neutron spectrometer

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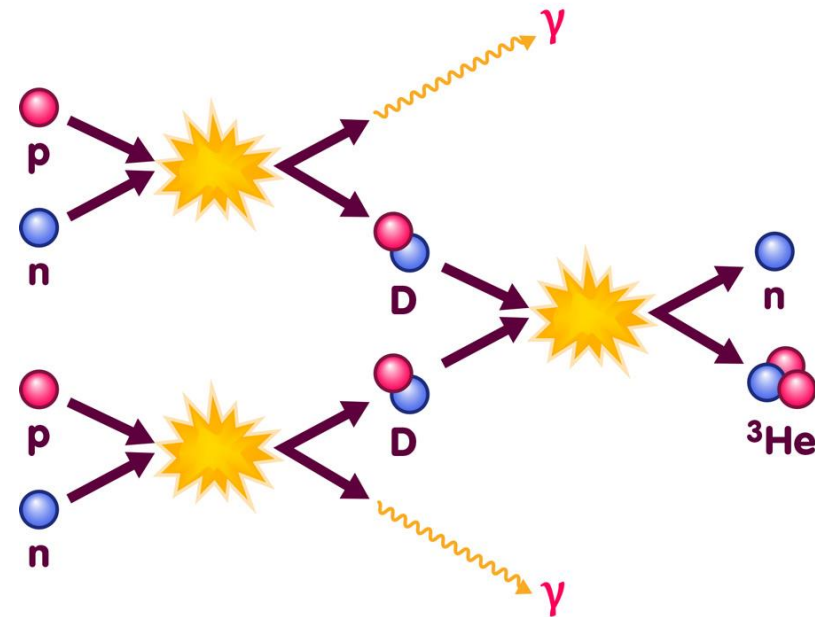
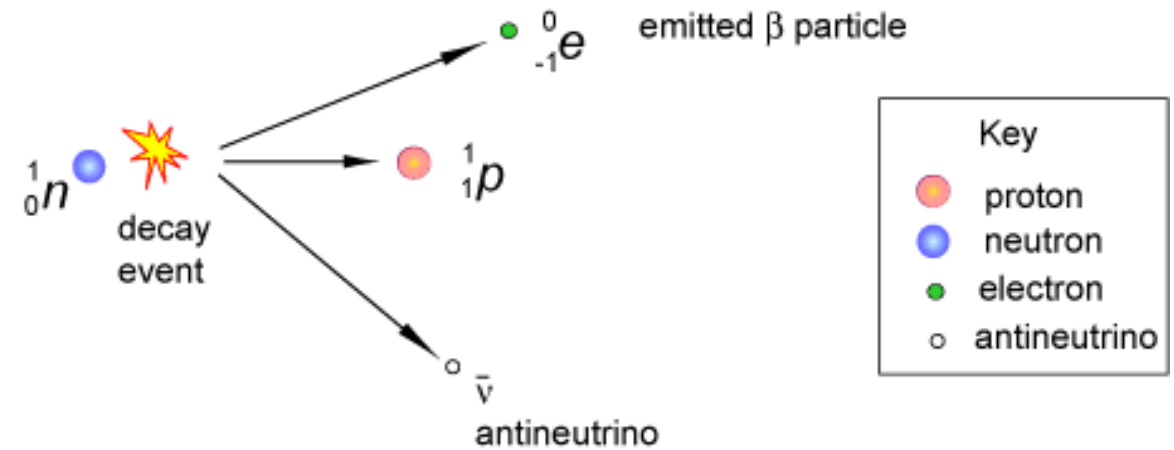
Neutron Lifetime

Free neutrons decay within ~15 min

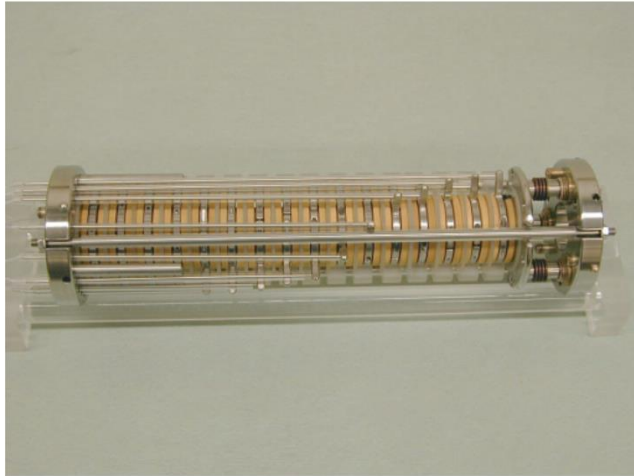
Precise τ helps:

- Measurement of axial and vector coupling constants – from β decay
- Place limits on physics beyond Standard model
- Big-bang nucleosynthesis \rightarrow Primordial abundance of He

Beta Decay of a Neutron



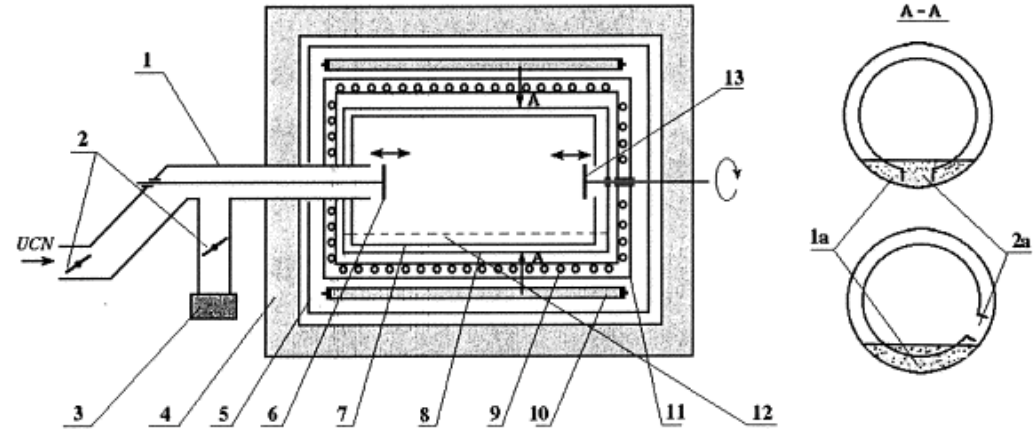
Long standing disparity: 9 seconds!



Beam method

Rate of beta decay products from a neutron beam

$$\tau_{\text{beam}} = 886.3 \pm 3.2 \text{ s}$$



Bottle method

Count the no. of neutrons in a container as a function of time

$$\tau_{\text{bottle}} = 878.5 \pm 0.7 \text{ s}$$

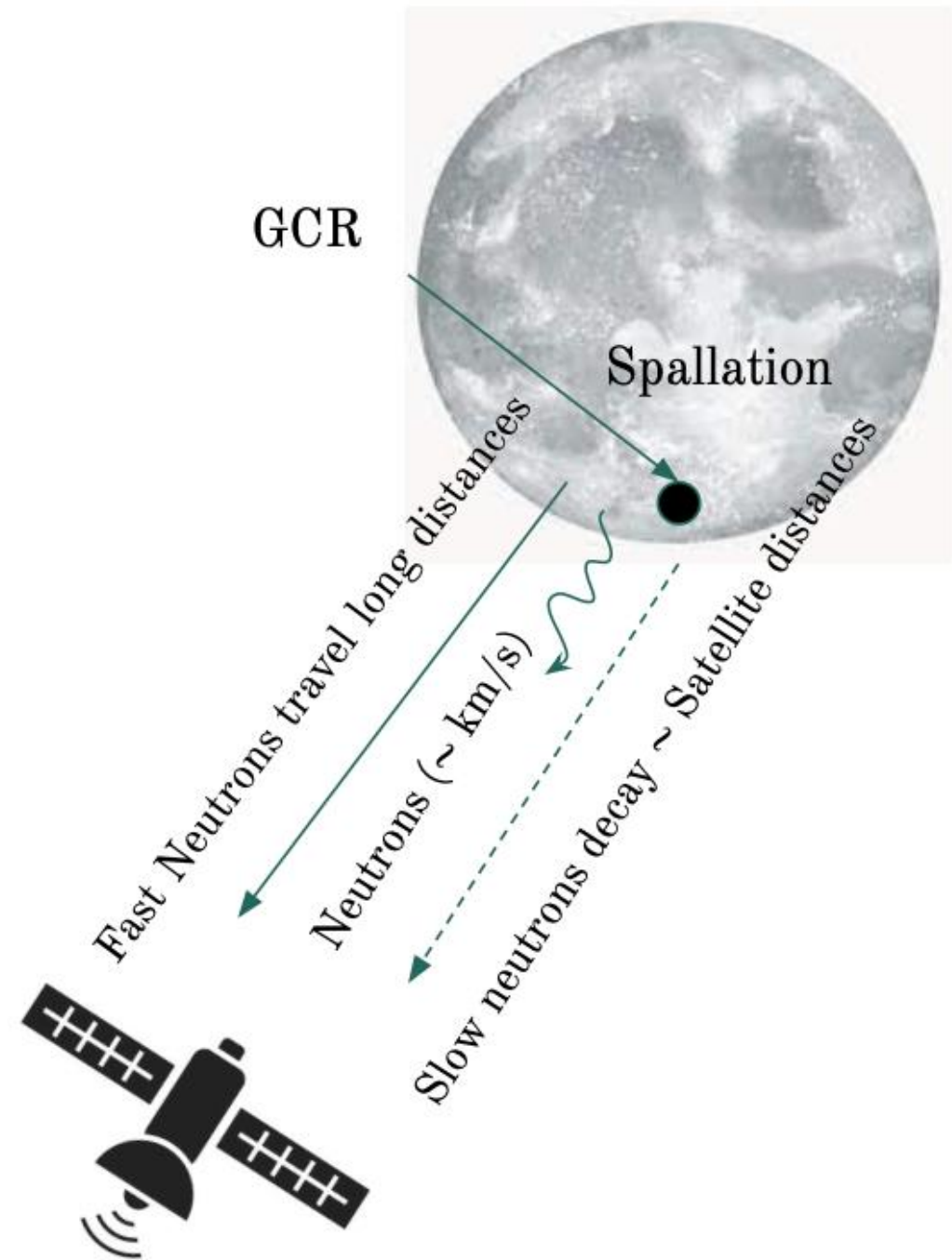
5 σ discrepancy!!

How can we explain this? (some examples)

- Decay into dark matter with branching ratio of 1% (Bastero-Gil+2024)
- Neutron to mirror neutron oscillations (Battaglieri +2017)
 - Expt: Broussard+2022 at Oak Ridge Lab ruled this out
- Up scatter of ultra cold neutrons by the dark matter halo of the galaxy -> shorter lifetime observation than true value (Dawid+2022)

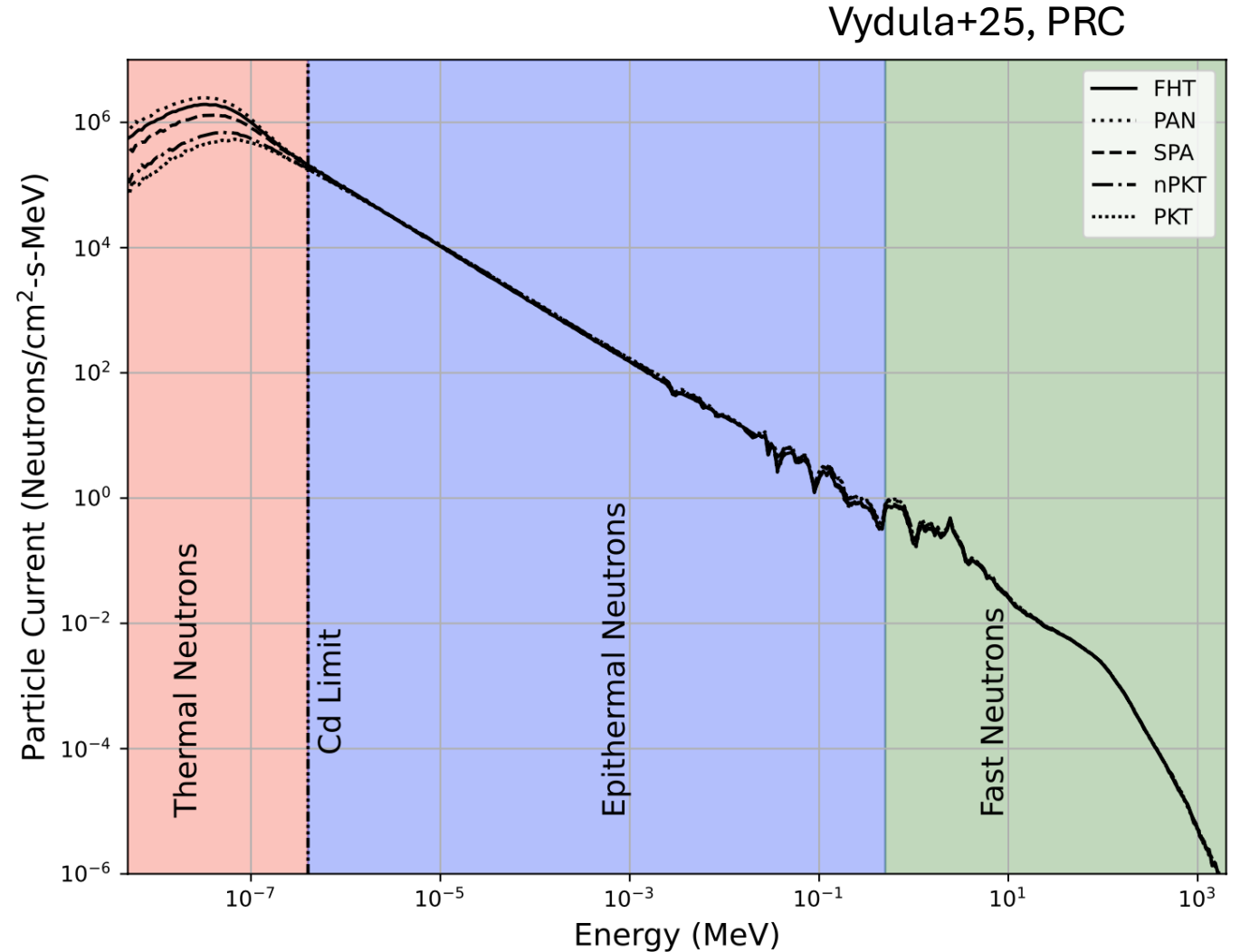
Space-based measurement technique

- Interaction b/w Galactic Cosmic rays and the low atmosphere planetary body (Eg: Moon, Mars or Venus)
- The disappearance of thermal neutrons as a function of distance can be used to measure the neutron lifetime



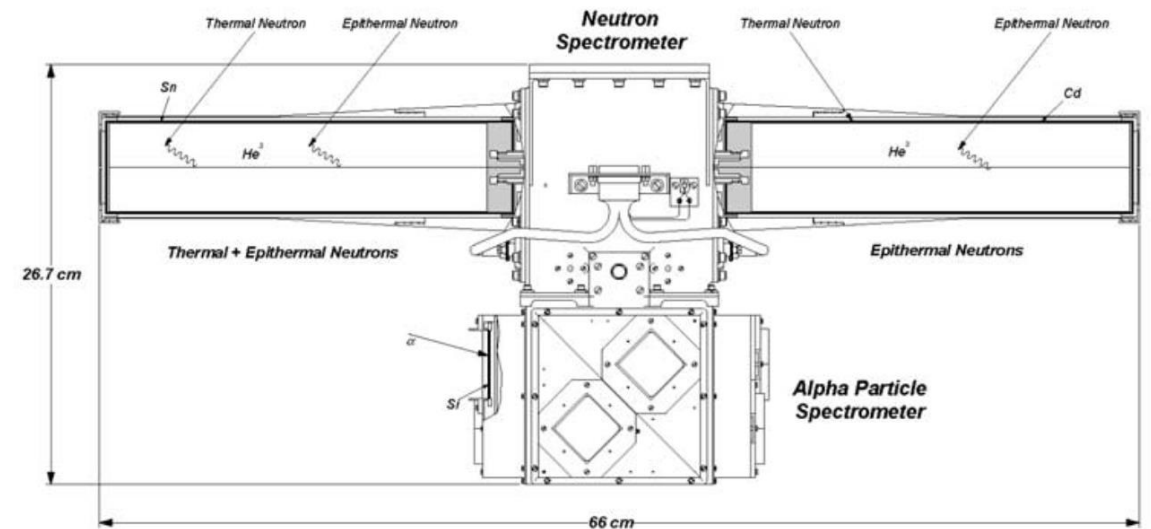
Modeling tool: MCNP

- MCNP - General-purpose Monte Carlo N-Particle code developed by LANL
- To track neutrons from GCR interactions
- Low energy thermal and epithermal neutrons are used



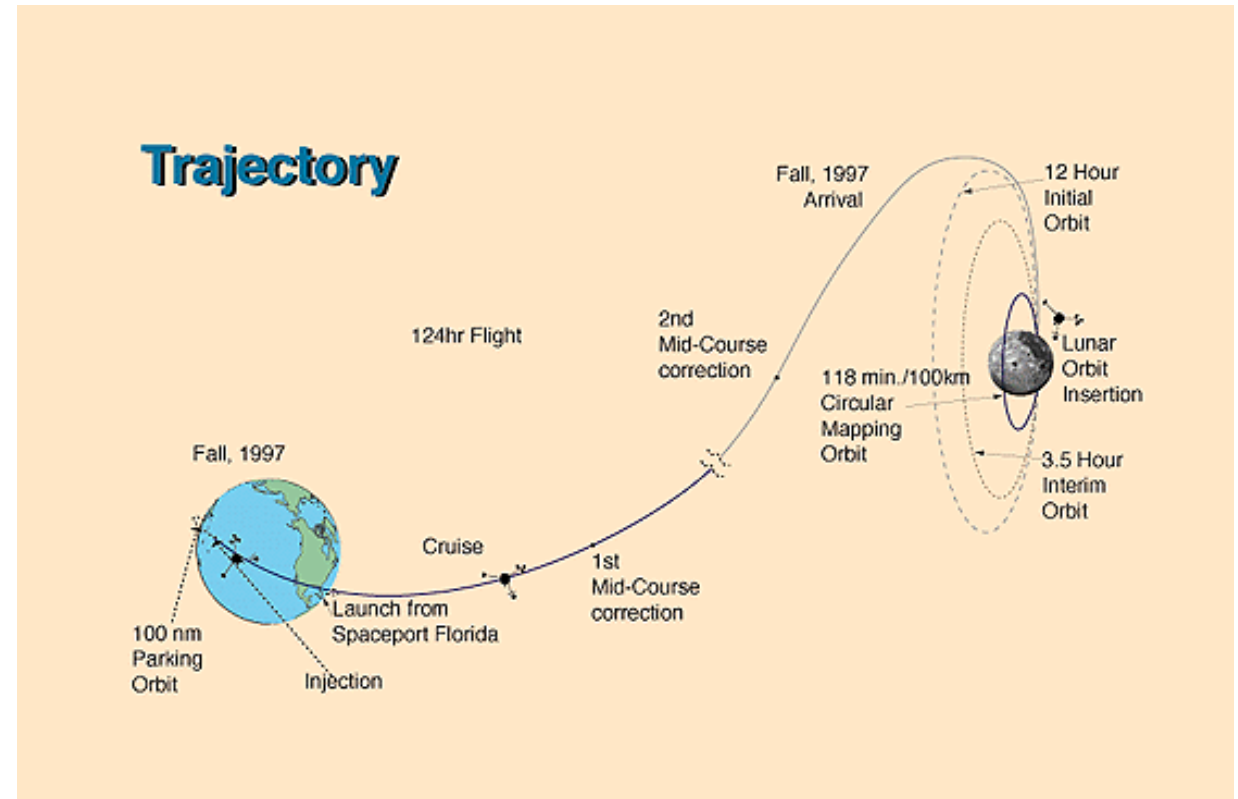
Data: The Lunar Prospector orbit insertion

- Detectors:
 - HeCd detector: Epithermal Neutrons
 - HeSn detector: Epithermal + Thermal(<0.4 eV)
- Spacecraft ephemeris data include position and velocity



Data: The Lunar Prospector orbit insertion

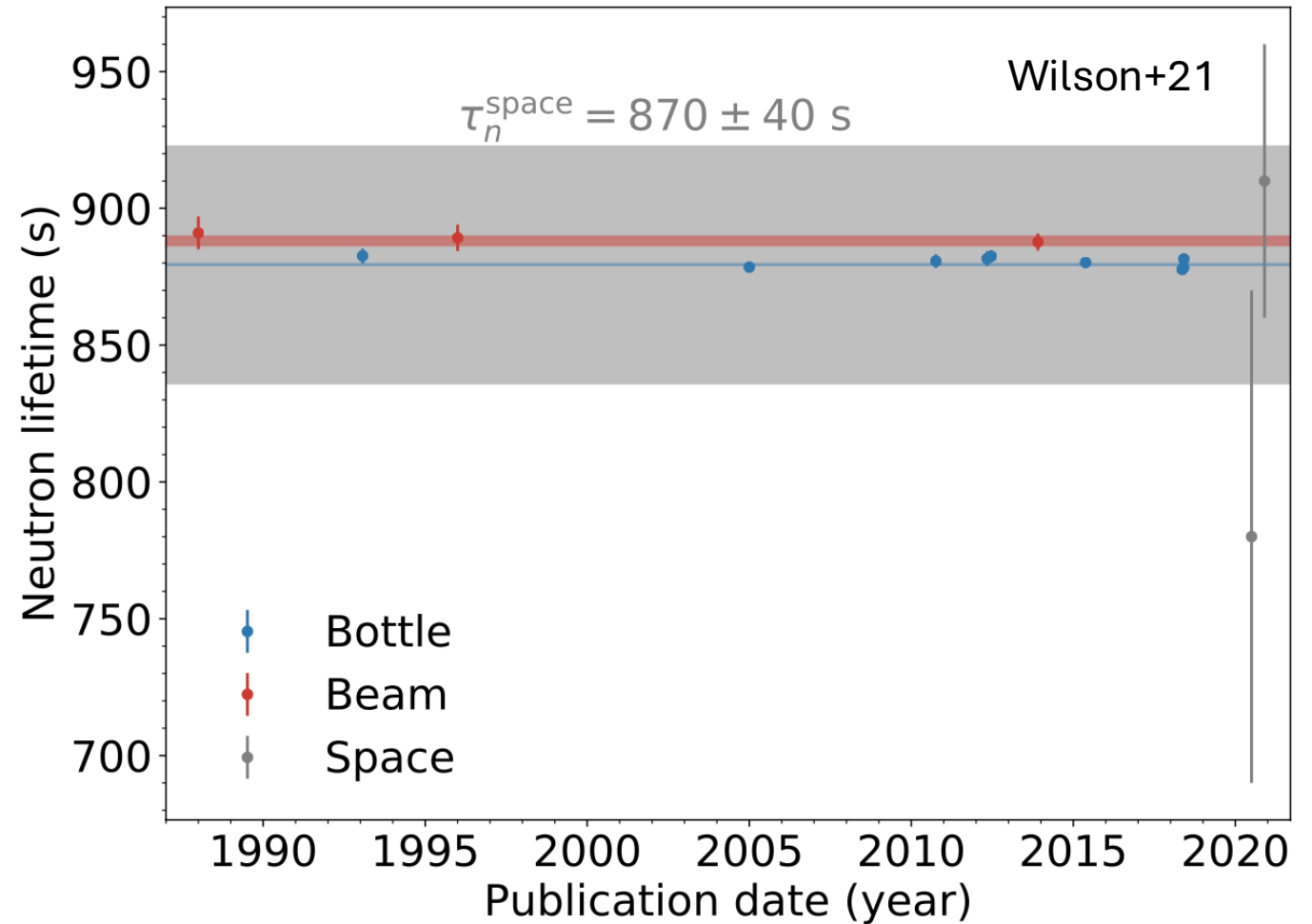
- ~4 days of elliptical orbit before the spacecraft was parked in its mission orbit
- Near circular lunar orbit: Jan-1998 to July-1999
- Closest approach: 126 km
- Farthest approach: 8400 km



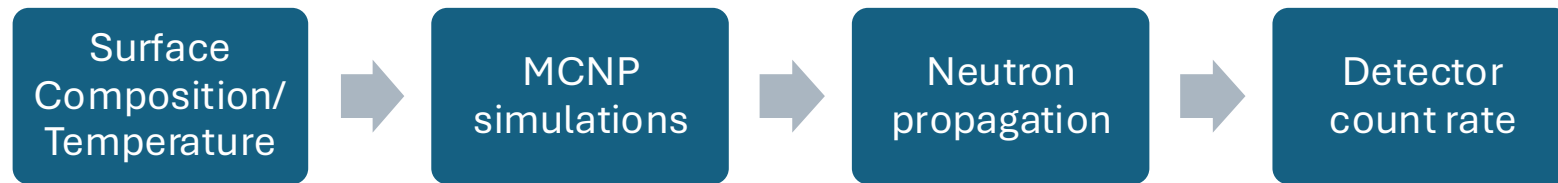
Credit: NASA

Existing space-based measurements

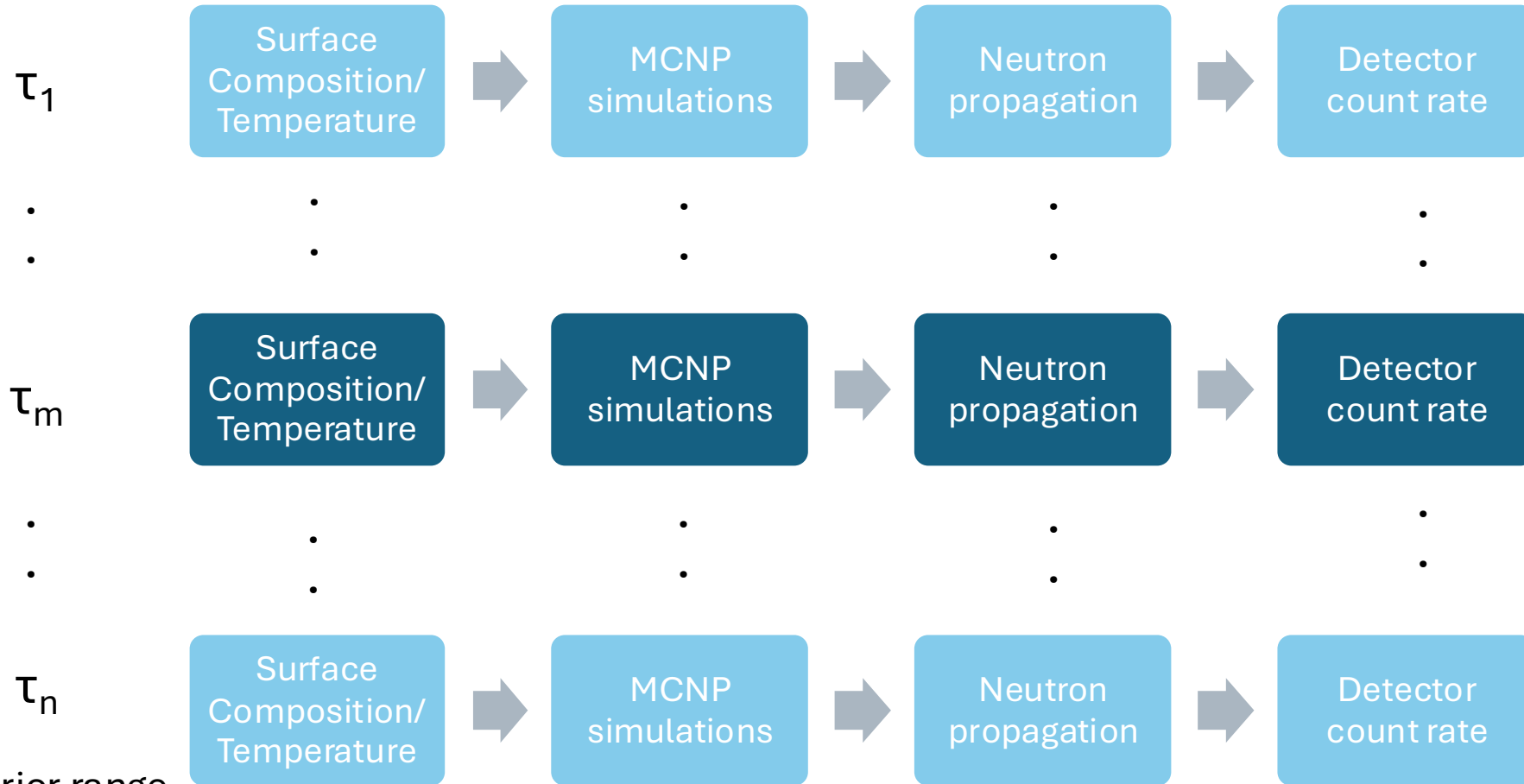
- MESSENGER flybys of Venus and Mercury: $\tau_n = 780 \pm 70$ s (Wilson et. al., 2020)
- Lunar Prospector: $\tau_n = 887 \pm 14$ s (Wilson et. al., 2021)
- Not competitive measurements



Analysis Design

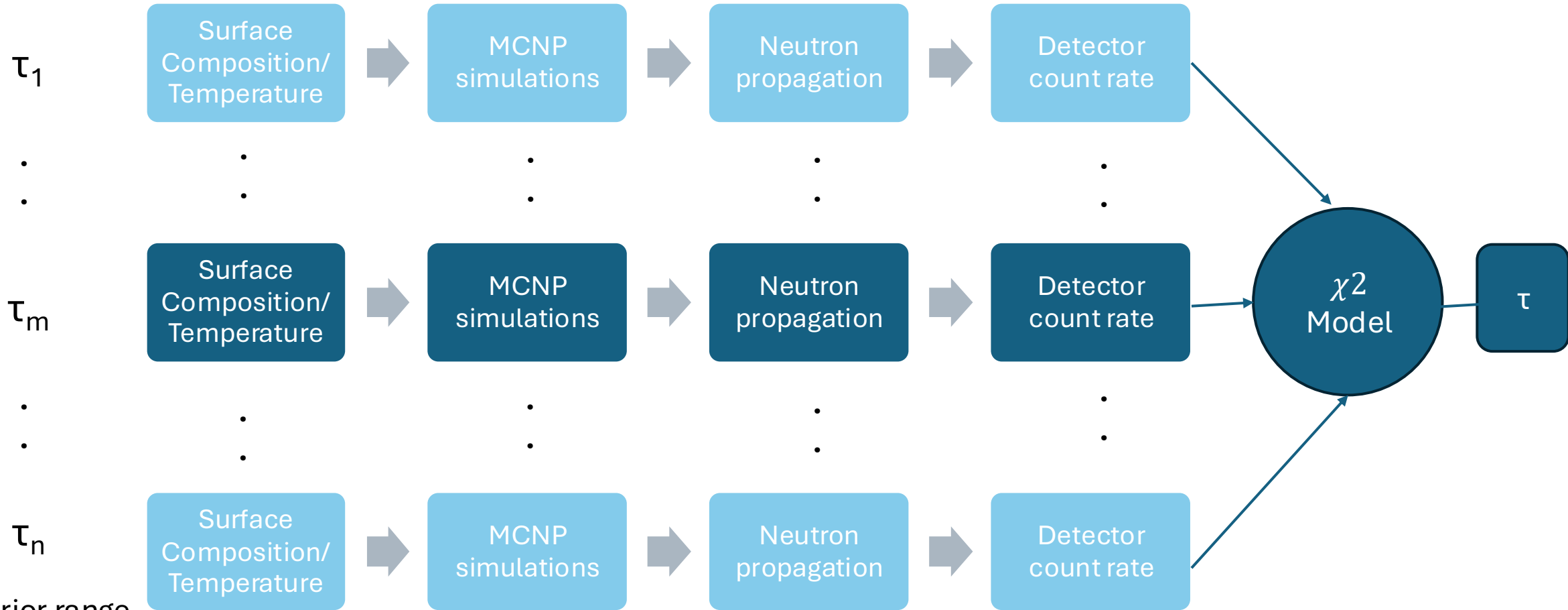


Analysis Design



Broad prior range
of 500-1600s

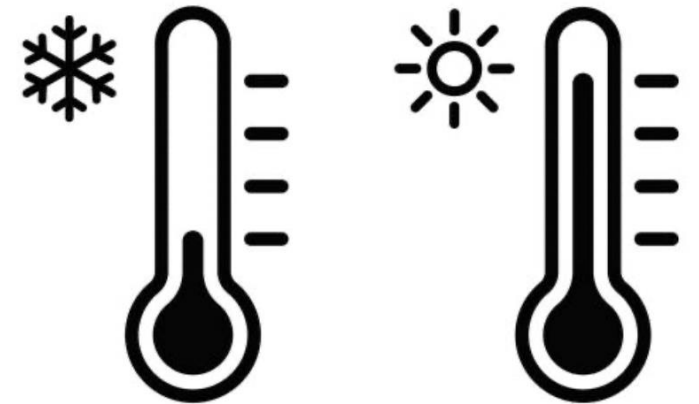
Analysis Design



Broad prior range
of 500-1600s

Systematics

- Surface composition
 - 5 Compositions, binned to 2 deg resolution (Apollo and LP approximations)
 - 114 Compositions binned to 20 deg resolution
 - 1790 Compositions binned to 5 deg resolution
- Surface Temperature
 - Latitude independent model
 - Latitude dependent model





Surface Composition

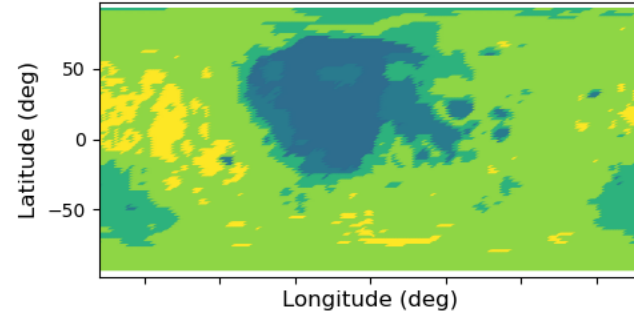
Three surface composition maps

5 Compositions, binned to 2° resolution (Apollo and LP approximations)

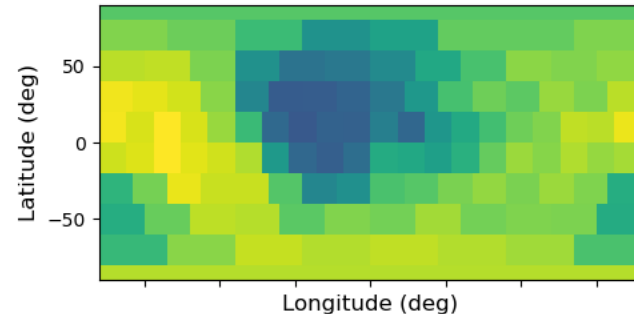
114 Compositions binned to 20° resolution

1790 Compositions binned to 5° resolution

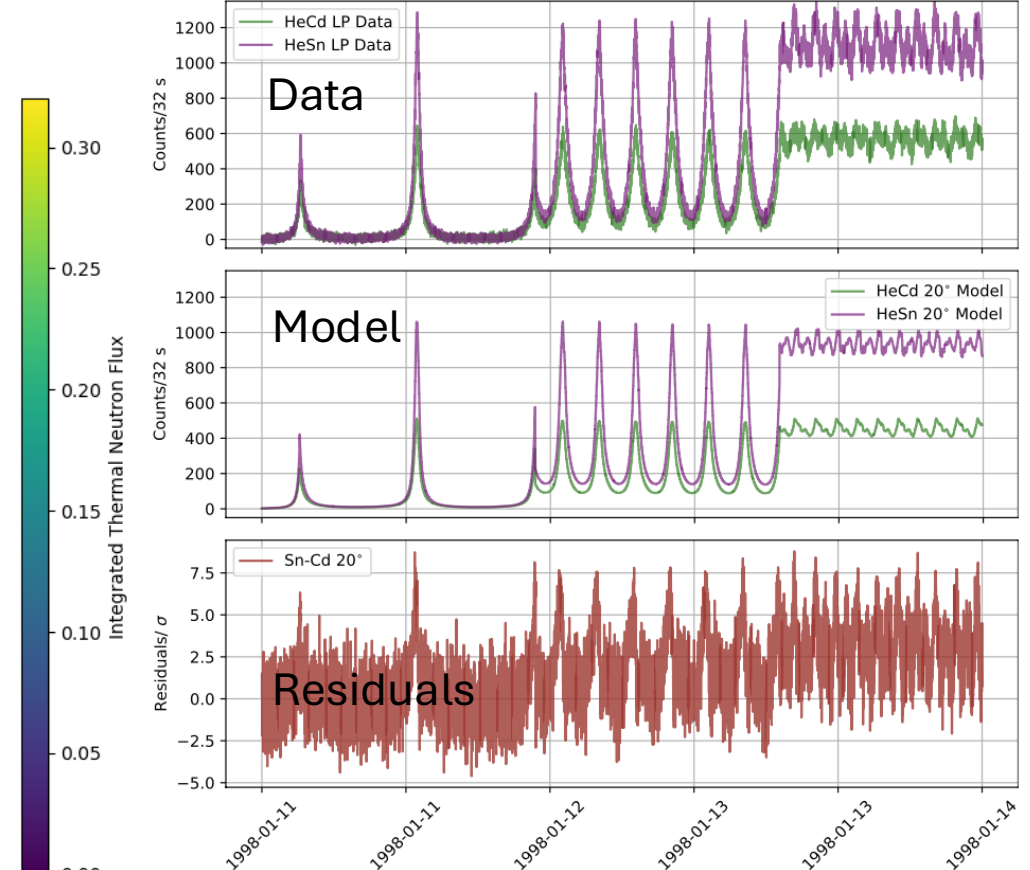
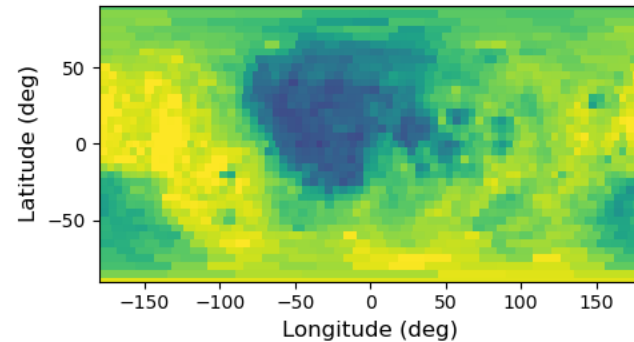
Wilson rebinned 2 deg map (5 compositions)



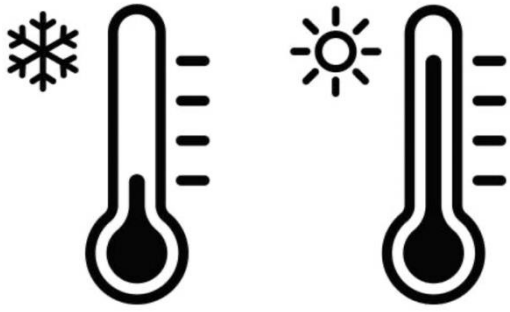
Prettyman 20 deg map (114 compositions)



Prettyman 5 deg map (1790 compositions)

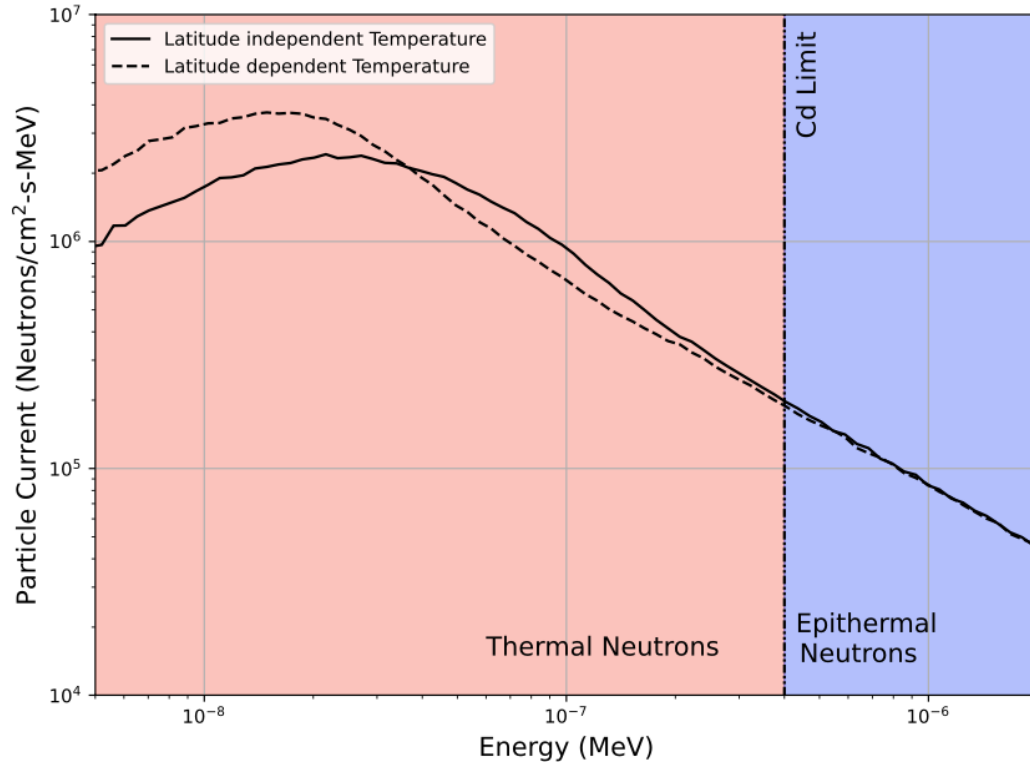


Vydula+25, PRC

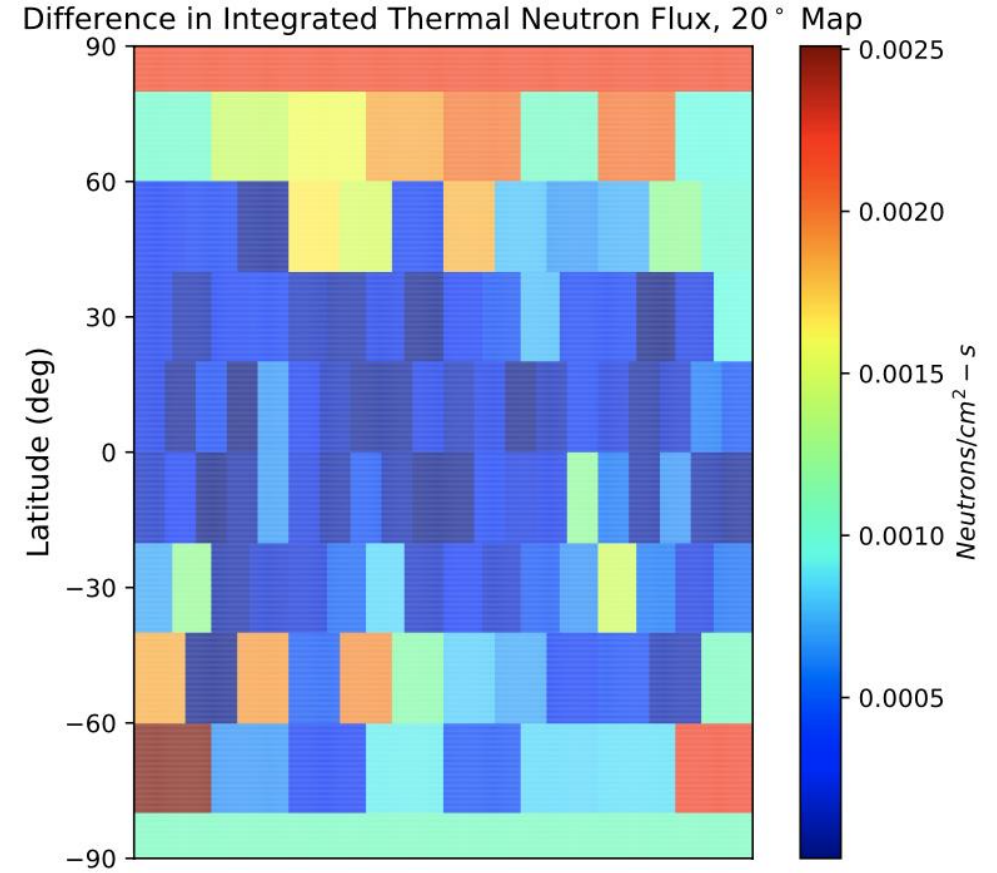


Surface Temperature

1. Constant equatorial temperature of 250 K
2. Latitude dependent temperature model: colder at the poles, 250 K at the equator



Vydula+25, PRC



This results in four composition and temperature models

Map Resolution	Temperature
Five compositions re-binned to 2°	Latitude independent
20°	Latitude independent
20°	Latitude dependent
5°	Latitude dependent

} Temperature effects

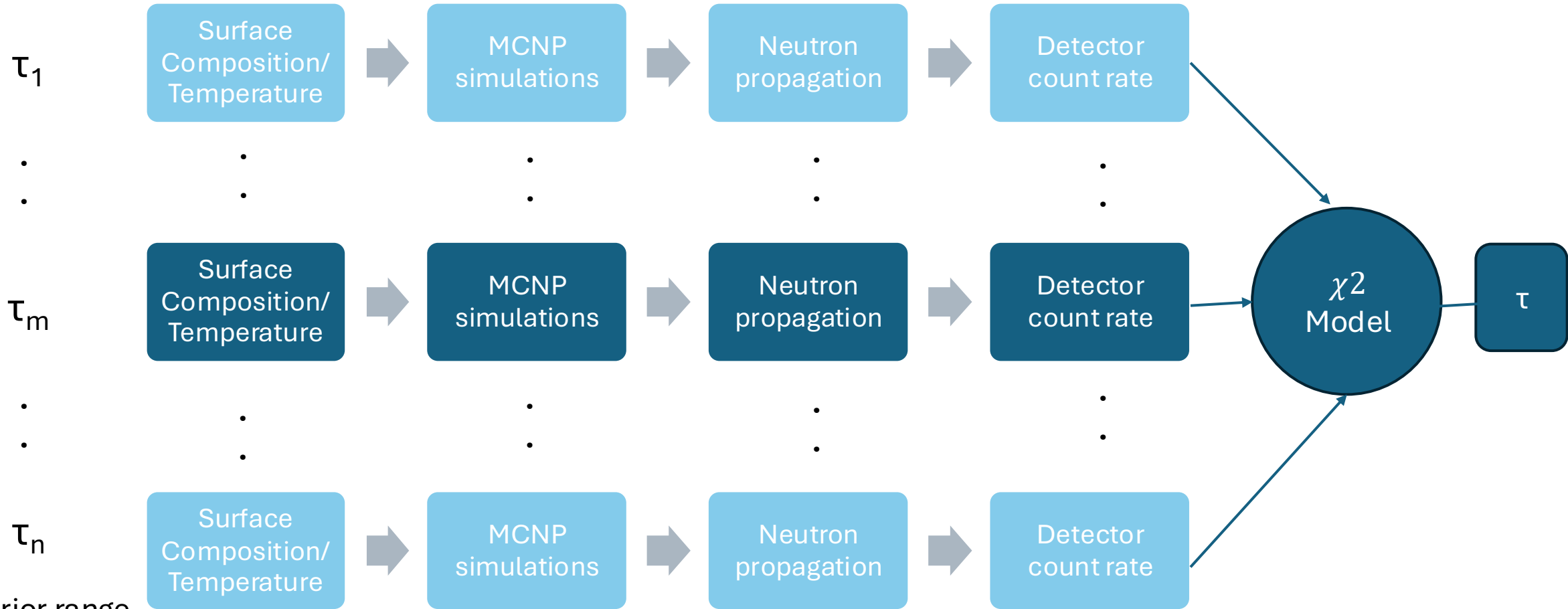
This results in four composition and temperature models

Map Resolution	Temperature
Five compositions re-binned to 2°	Latitude independent
20°	Latitude independent
20°	Latitude dependent
5°	Latitude dependent

} Composition effects

Analysis Design

Repeat for all four models

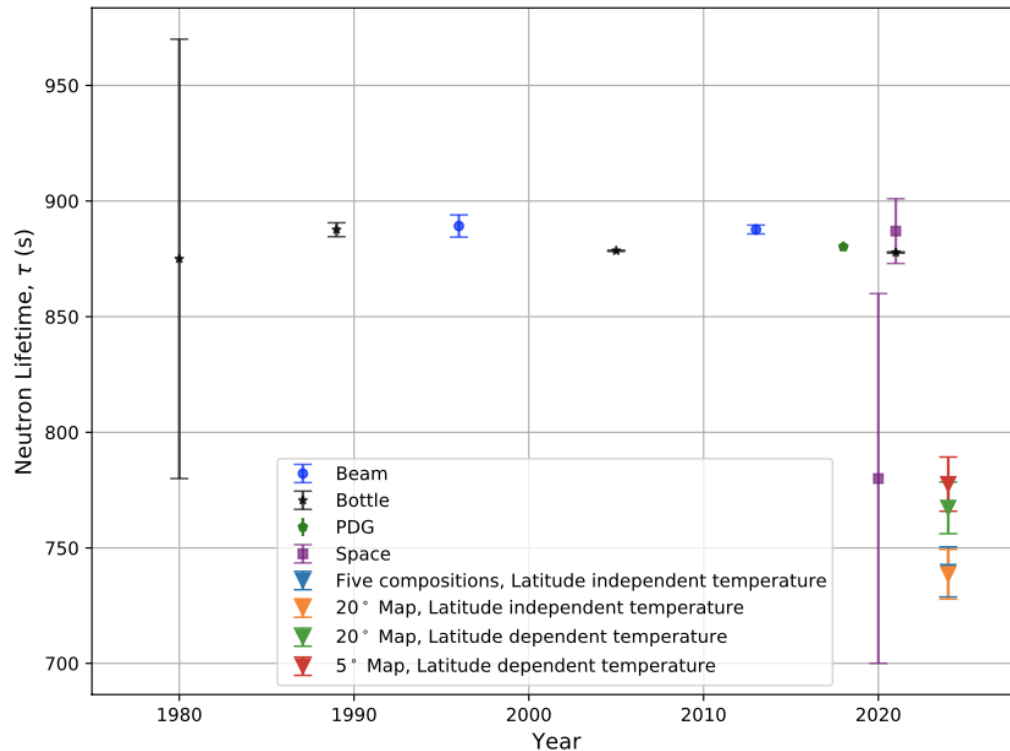


Broad prior range of 500-1600s

Results

- Choice of temperature model: 28.7 ± 15.5 s
- Choice of compositional map: 10.3 ± 12.2 s

Not in agreement with PDG results \Rightarrow other large unknown systematics!



Vydula+25, PRC

TABLE III. Computed τ_n values along with 1σ statistical errors for each of the cases capturing lunar surface composition and temperature effects.

Map resolution	Temperature	τ_n (s)
Five compositions re-binned to 2°	Latitude independent	739.6 ± 10.8
20°	Latitude independent	738.6 ± 10.8
20°	Latitude dependent	767.3 ± 11.2
5°	Latitude dependent	777.6 ± 11.7

Future of this measurement

- Planetary bodies: Earth, Moon, and Venus
 - Venus is ideal due to higher statistical precision and simpler surface composition; non-trivial orbit insertion
 - Earth's composition is complex, but relatively easier orbit insertion
- In orbit: Neutron detectors with neutron lifetime specific orbits
- Landers/Rovers: Moon is a great test bed in the near future, surface analysis adds to the existing composition data

Follow-up on:

Jack Singal
University of Richmond, USA

CETUP* Workshop
Lead, SD
June 16, 2025

The Radio Synchrotron Background – New Particle Processes?

Map making efforts using Green Bank Telescope
at 310 MHz

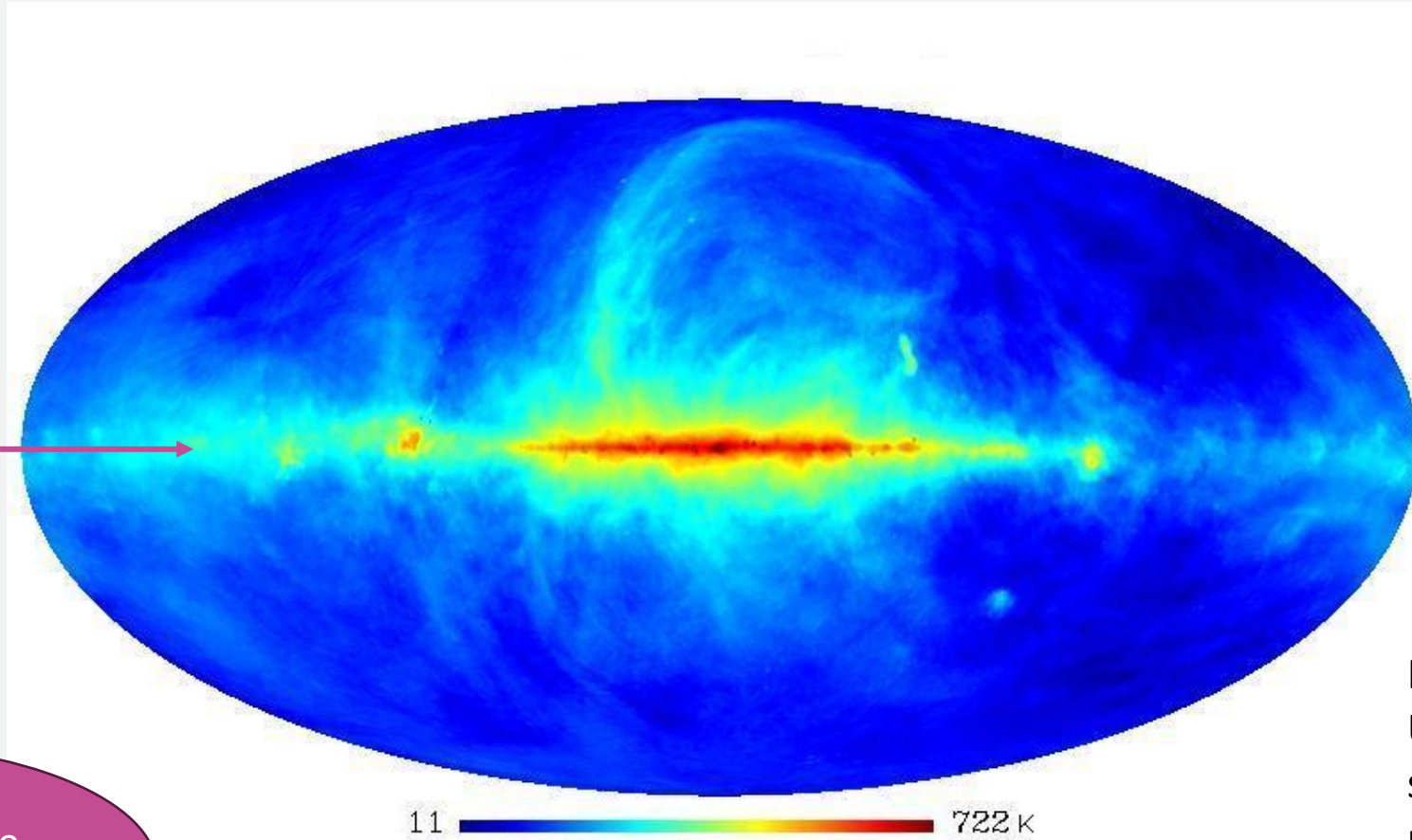
Motivation

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

clear about the existence of the radio (non) zero-level

requires correction of ARCADE excess

Galactic Plane



Some combination of Galactic and extragalactic

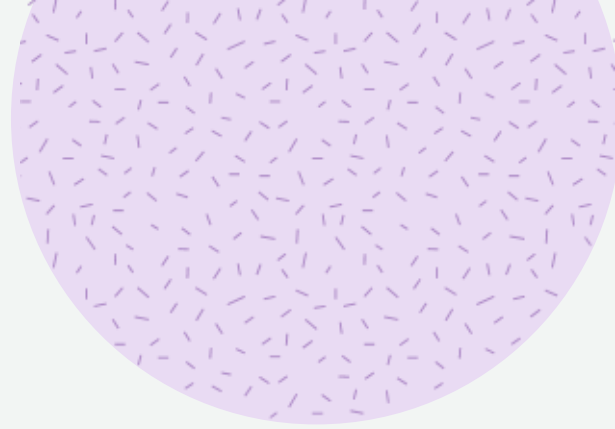
Resolution: 1deg;
Uncertainties of $\sim K$: while spatial variations are reliable, the absolute temperature scale is not

We need absolute measurements!

Haslam Map 408 MHz, 1981

But what is absolute measurement?

- Most observations in radio astronomy are *differential*, meaning comparing the brightness of one region or source to another
 - Eg: VLA, OVRO-LWA, LOFAR, HERA etc
 - Lower calibration burden
 - Typically used in imaging/sky surveys
- Absolute measurements are sensitive to absolute total power
 - Eg: ARCADE, COBE, EDGES
 - Higher calibration burden
 - Can access cosmological signals and diffuse backgrounds



Current absolute measurements

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

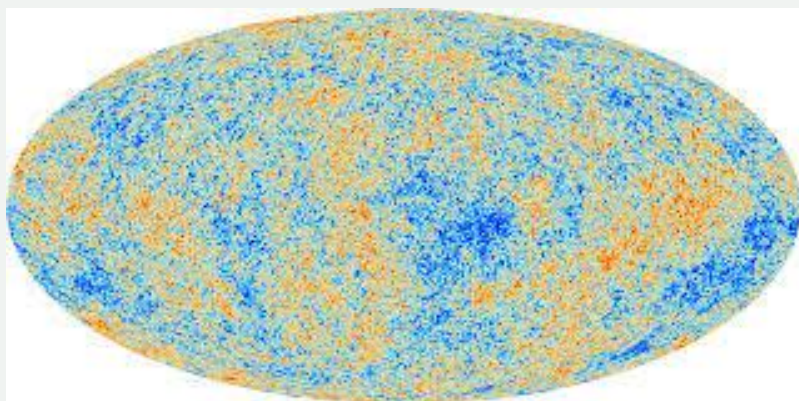
<i>Frequency (MHz)</i>	<i>Map</i>	<i>Instrument</i>	<i>Source of Absolute Zero-Level Calibration</i>
22	Roger et al. (1999)	Dipoles above reflecting screen	Scaling relative to 408 MHz Haslam et al. (1982) map at Zenith applied to other elevations
45	Maeda et al. (1999)	Phased array Yagi dipoles	Overlap 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 measurement 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)

Simple dipoles, blocked aperture, and calibration using astrophysical sources all have an uncertain absolute zero level

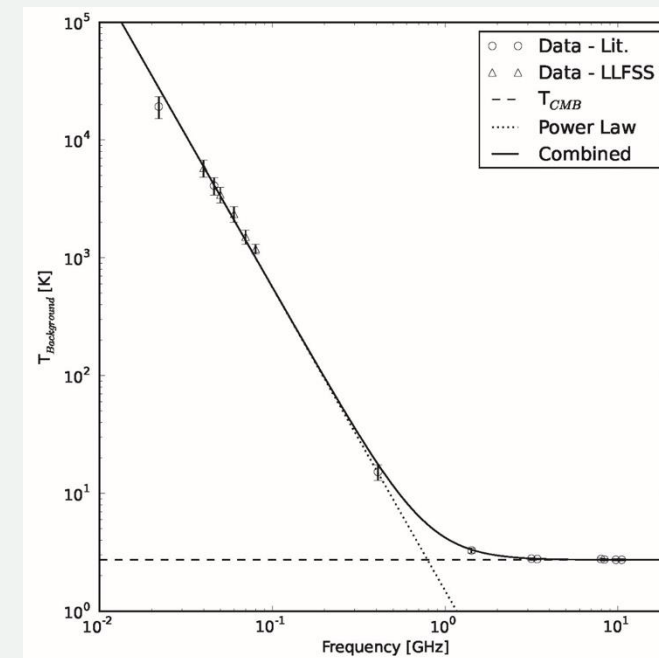
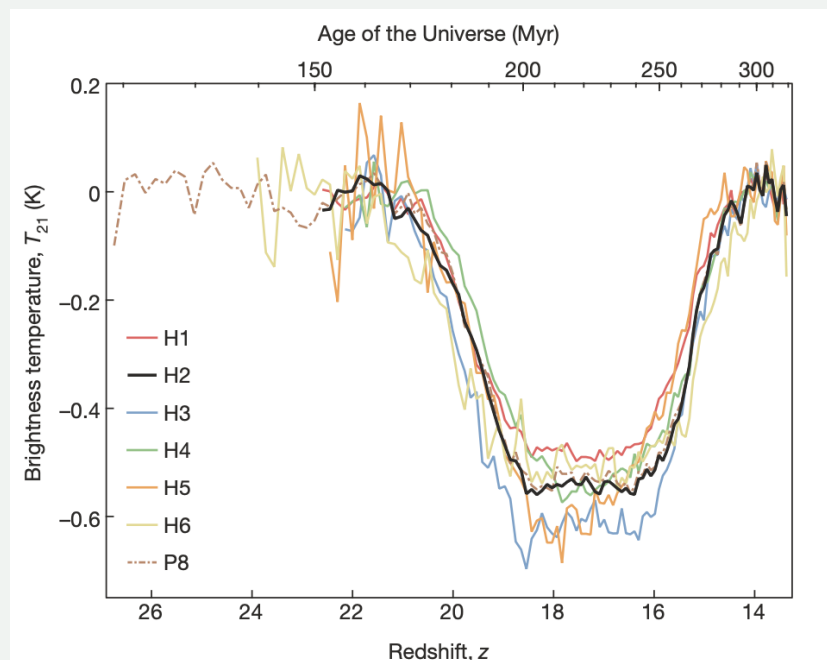
We Need a Definitive Absolutely Calibrated Map!

We Need a Definitive Absolutely Calibrated Map!

Better interpretation of 21cm observations (esp EDGES)



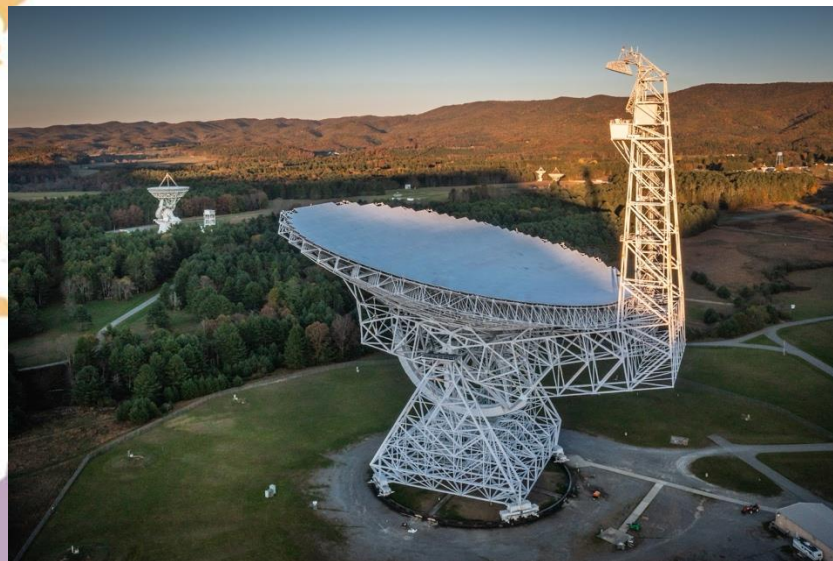
Better understanding of CMB foregrounds (uncertainties in 408 MHz map will propagate to Plank)



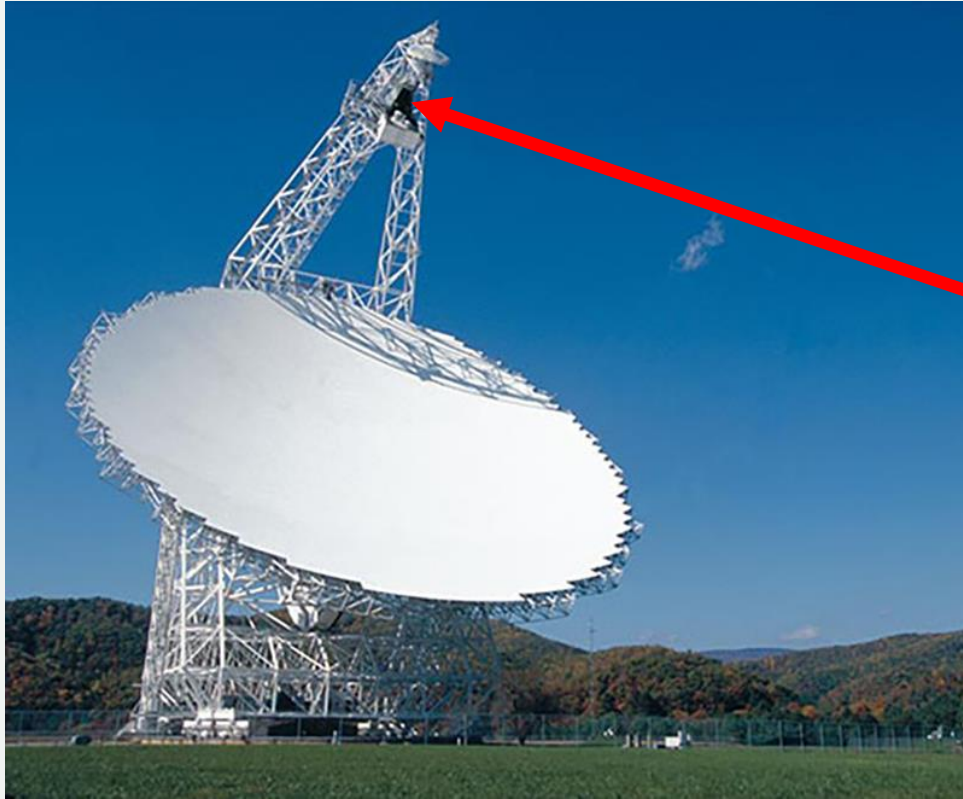
Understand Radio Synchrotron Background



Greenbank Telescope, WV



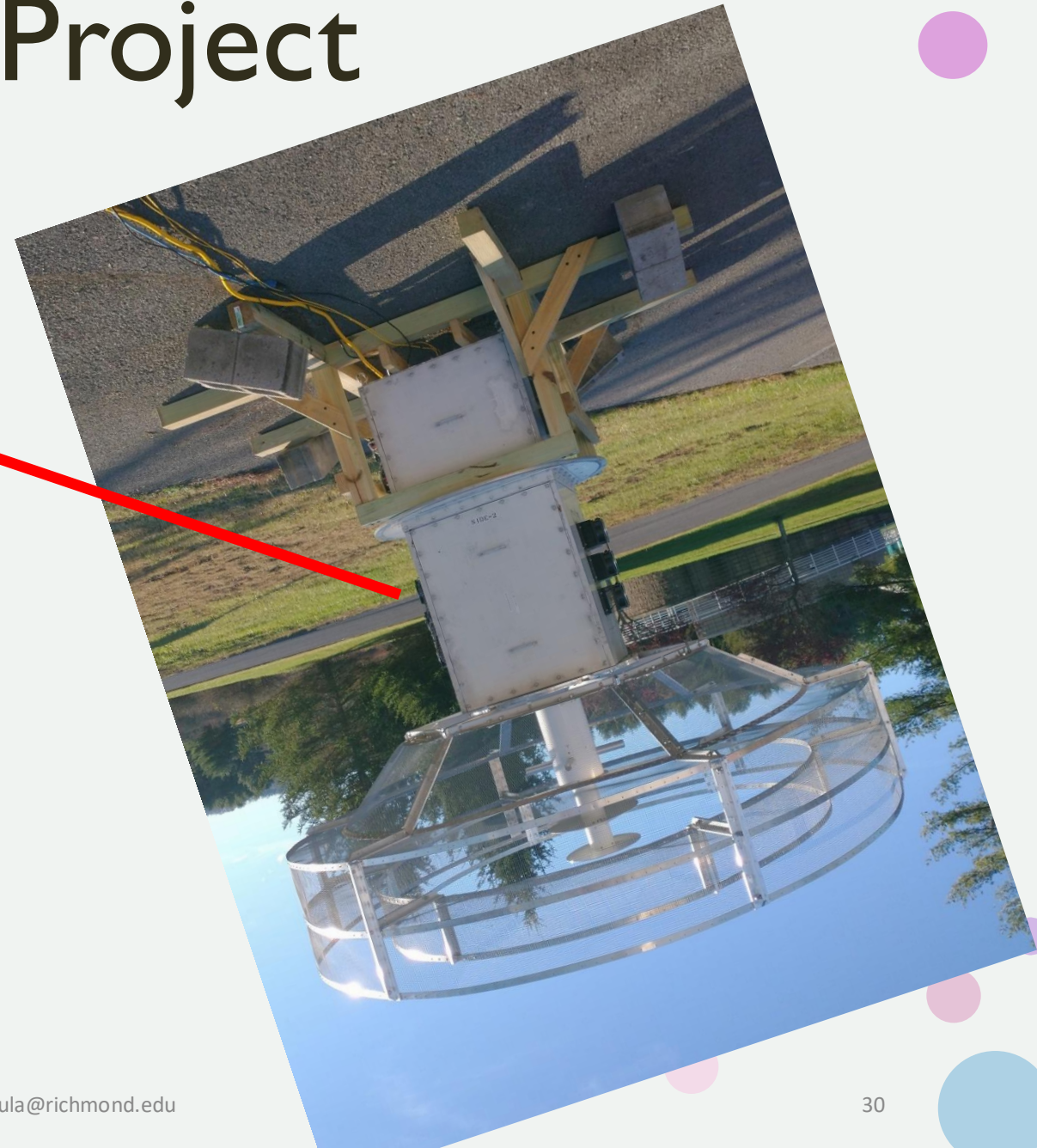
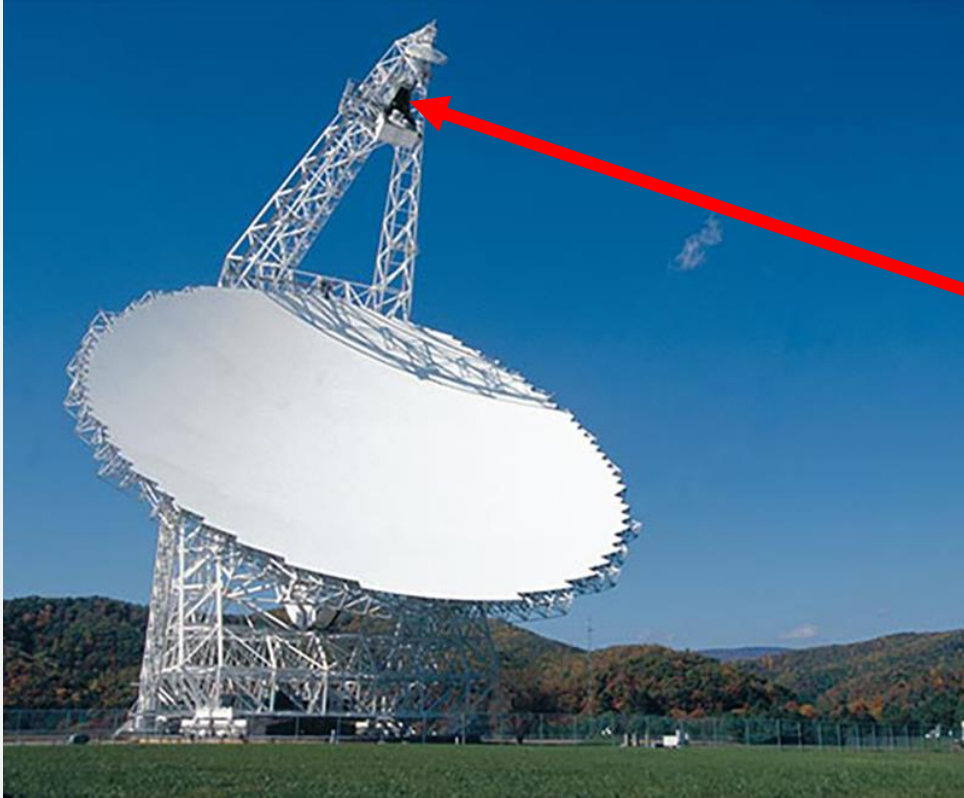
GBT Absolute Map Project



- Custom antenna (“feed”) to “under-illuminate” and suppress sidelobes
- Custom absolutely calibrated receiver



GBT Absolute Map Project



- Custom antenna (“feed”) to “under-illuminate” and suppress sidelobes
- Custom absolutely calibrated receiver

How do we achieve absolute calibration?

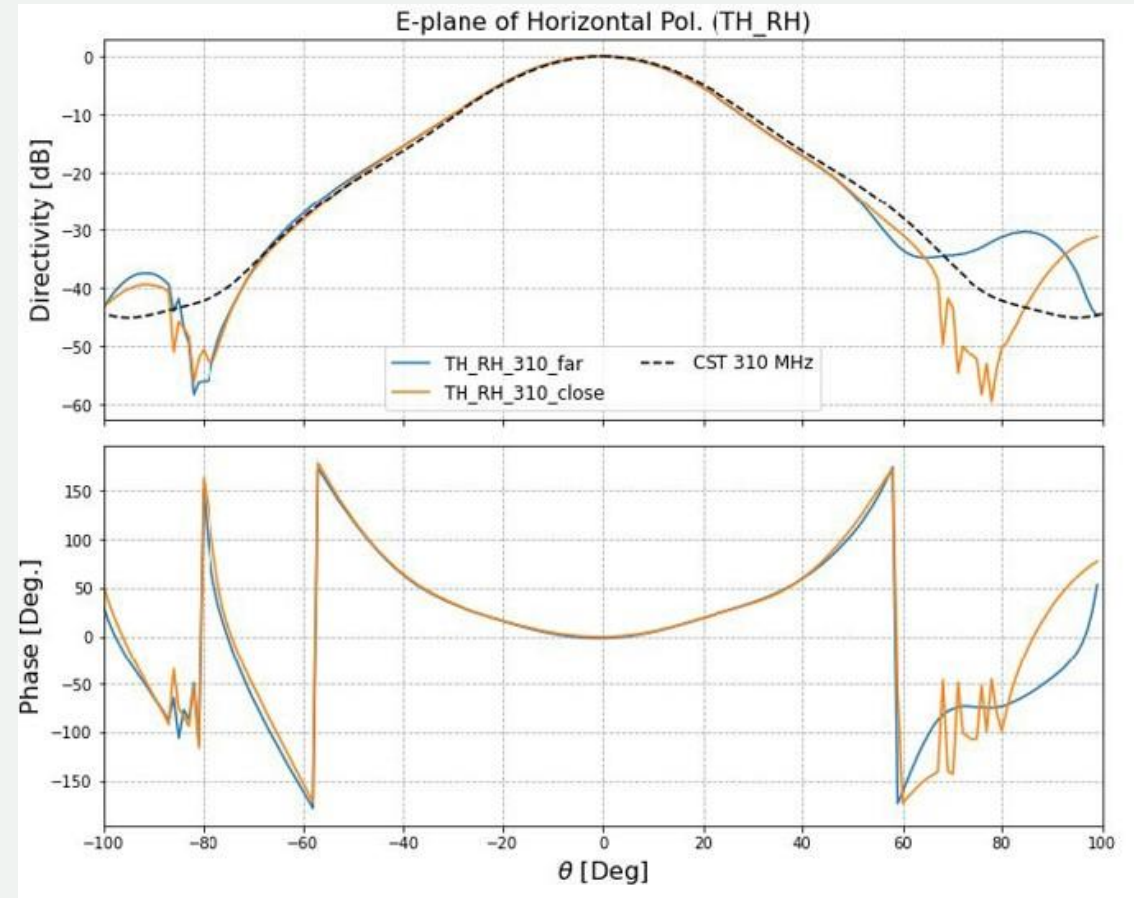


Custom Receiver, developed at Central Development Laboratory

Custom Feed



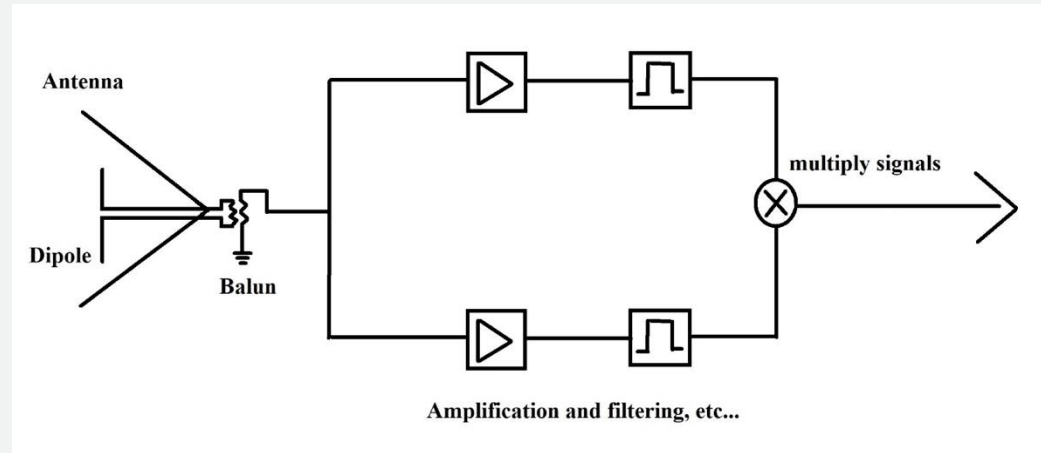
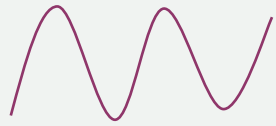
Lightweight wire mesh designed to break in the off chance of weather-motivated automatic stow sequence; no damage to GBT



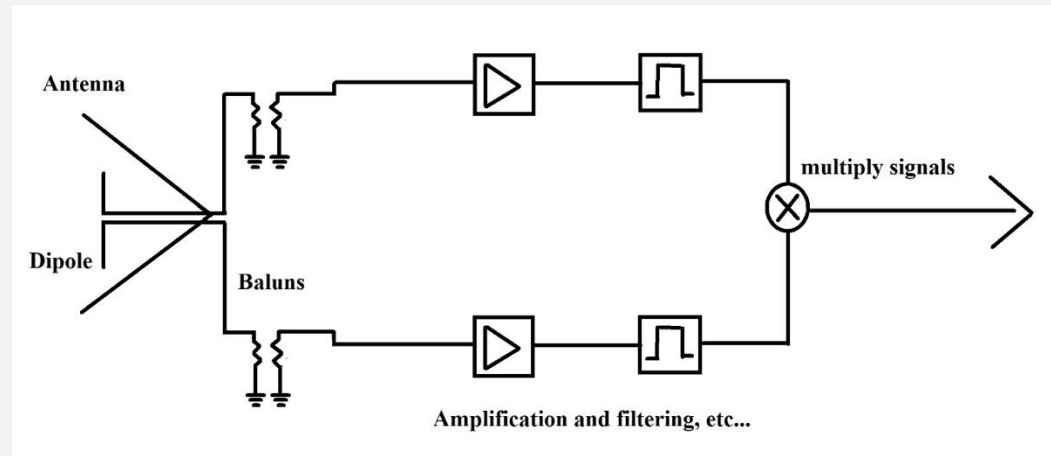
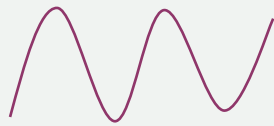
Custom narrow beam feed that under-illuminates the dish and suppresses sidelobes

Custom Receiver Design

(conventional) Correlation receiver: noise after signal divider is uncorrelated in the two arms and therefore reduced upon multiplication



Balanced correlation receiver: noise in transmission lines from antenna and baluns is also uncorrelated because two separate signals are taken from antenna



Mapping strategy

- Azimuth scans at 38 deg elevation to pass through NCP every 30 min
- Repeat scans at different times of the year to cover declinations north of -13 deg
 - Roughly every other month
- Basketweave technique gives northern sky coverage
- RFI within the observation band is minimal/manageable
- 104 h of GBT time (approved)

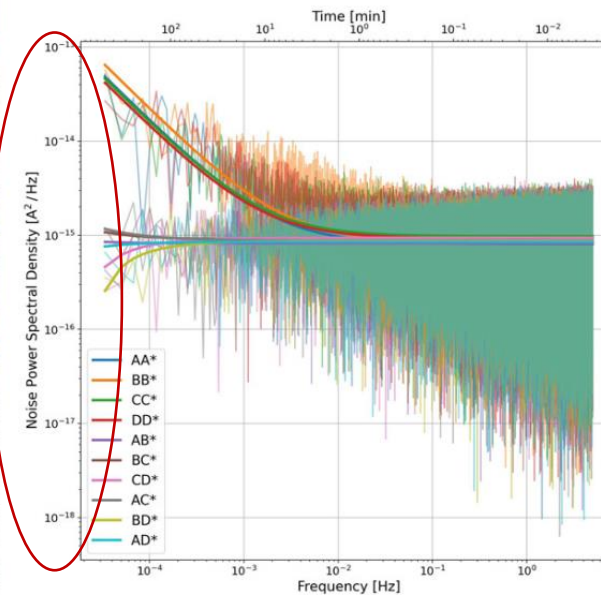
+custom receiver + custom
feed = Absolute sky map!

Current Status

- Fully-integrated system has been deployed for testing



Measured noise spectra of four auto and six cross-correlations

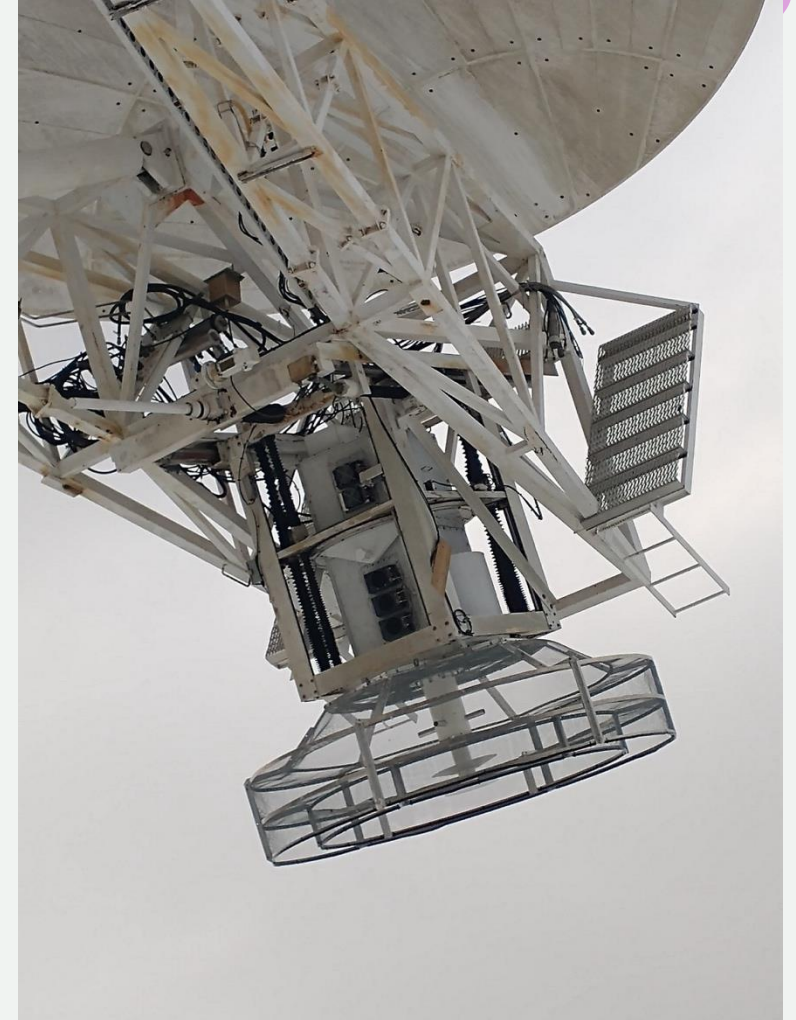


~Near zero noise in cross powers

Current Status

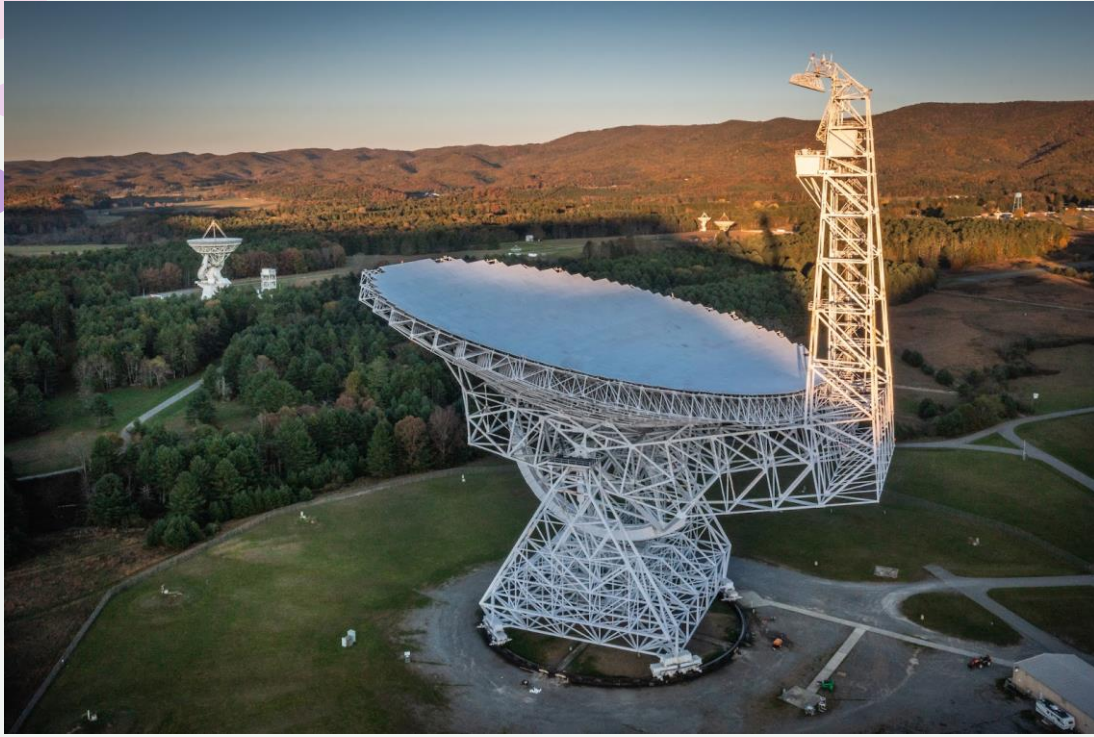
- Fully-integrated system has been deployed for testing
- Successful mechanical and connection tests
- Successful Beam map observations of 3C353 in Jan 2026!

Science Obs expected in Fall 2026



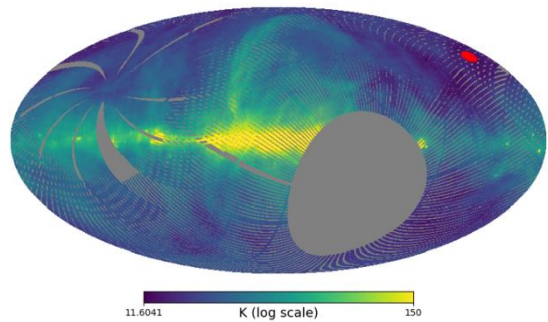
Potential of 310 MHz map

- Coldest patch measurements will help understand the radio synchrotron background levels
 - Currently known extragalactic source classes add up only $\sim 1/5$ of the claimed radio background level
- Constraints on:
 - FIR background (using radio FIR correlations)
 - Inverse-Compton Constraint
 - Galactic Halo Constraint
 - Source populations
- 21cm cosmology (50-200 MHz)
 - Could help explain EDGES signal (Bowman 2018)
- Decaying / Annihilating Dark Matter to charged particles to synchrotron
- Decaying Dark Matter to dark photons which decay to RSB photons



310 MHz sky map
coming soon...
(circa 2027)

100° Azimuth with 90° Tips



Total	74.0%
Reachable	85.8%
Square Degs	30,527

