The Early Years: 1964 - 1974

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For further details, see *Finding the Big Bang*
Peebles, Page and Partridge, 2009

Summary:

The most profound consequence of the discovery of the CMB:

The Universe has a history

The most profound consequence of the discovery of the CMB:

The Universe has a **scientifically verifiable history**

The Context: 1964

Try to place yourself in 1964....

Willie Fowler (in a preface to a book on relativity and cosmology) “Cosmology is mostly a dream of zealots”

Herman Bondi's “Cosmology”

– more pages devoted to Mach's Principle than to observations

– models, not physics

– Steady State cosmology favored on philosophical grounds

The Context: 1964

Observations: Sandage and the “two numbers”

H_o and q_o (“deceleration parameter”)

Only Gamow, Alpher and Hermann asked about the **physical** consequences of an early dense state as $R \rightarrow 0$

– and their work was largely forgotten (and not considered part of “cosmology”)

1960s, The Princeton Gravity Group: Led by Bob Dicke & John Wheeler

Black Holes, wormholes and quantum foam (Wheeler)

Neutrino detection (DUMOND and later IceCube; Wheeler)

Testing Equivalence Principle: Eötvös experiment (Faller and Dicke), Mp = Ma (Kreuzer and Dicke), lunar ranging (*Alley* and Dicke)

Solar oblateness (later solar and stellar seismology; Goldenberg and Dicke)

Pulsar timing and starquakes (Boynton, Groth,Wilkinson & me)

Adaptive optics (then classified): Dicke

Cyclic Universe and the need for and consequences of a hot beginning (Dicke, Peebles, Roll & Wilkinson)

Context

Ask me about any of the above (coffee time?)

Context

Our concern: Cyclic Universe and the consequent need for and consequences of a hot beginning.

Discovery and Interpretation

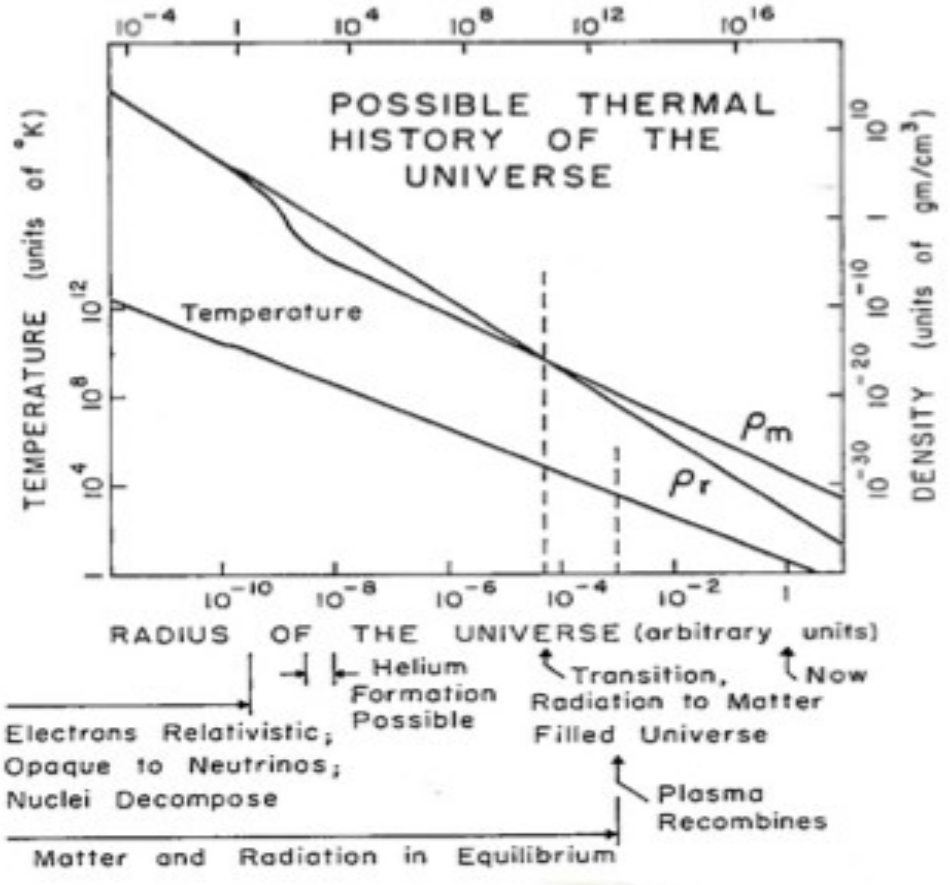
1964 (published May,1965) Penzias and Wilson: “excess antenna temperature”

Interpreted as cosmic

by Dicke, Peebles

Roll and Wilkinson

(in companion paper)



If It Is Truly Cosmic...

If the 3K radiation really is **cosmic**, then

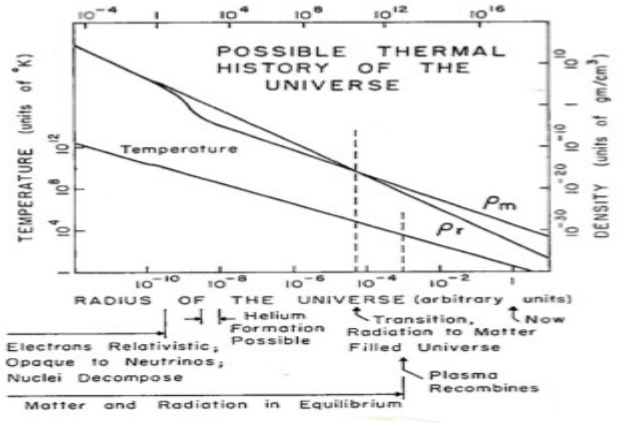
The Universe has a history

T(t) can be predicted

So can helium production

(Peebles, *Wagoner* and

Hegyi et al.)



Fluctuations are “seeds” of later galaxies (Peebles, Yu and *Zel'dovich*)

“Young Galaxies” must form and evolve (Peebles and Partridge)

But Is It Truly Cosmic?

THIS was the focus of much early work –

Was the 3K excess **cosmic** – or Galactic or radio sources or thermalized starlight or...?

Little guidance from theory (until later)

TESTS of the cosmic origin

– 2 major tests

– 2 minor tests

Tests of the Cosmic Origin

Major: **Spectrum**

– thermalized early; thermal spectrum maintained

– black body spectrum, distinct from local sources

Major: **Isotropy**

– not coincident with Galaxy, ecliptic....

Minor: evidence of Doppler dipole

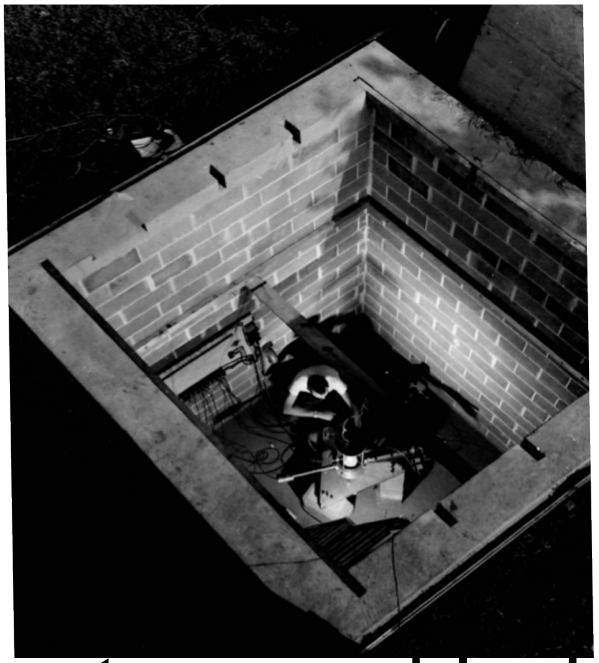
Minor: fine-scale isotropy

These tests inspired early observations

Detour: The Role of Null Experiments

Dicke was a master of null experiments

– example: the Eötvös experiment

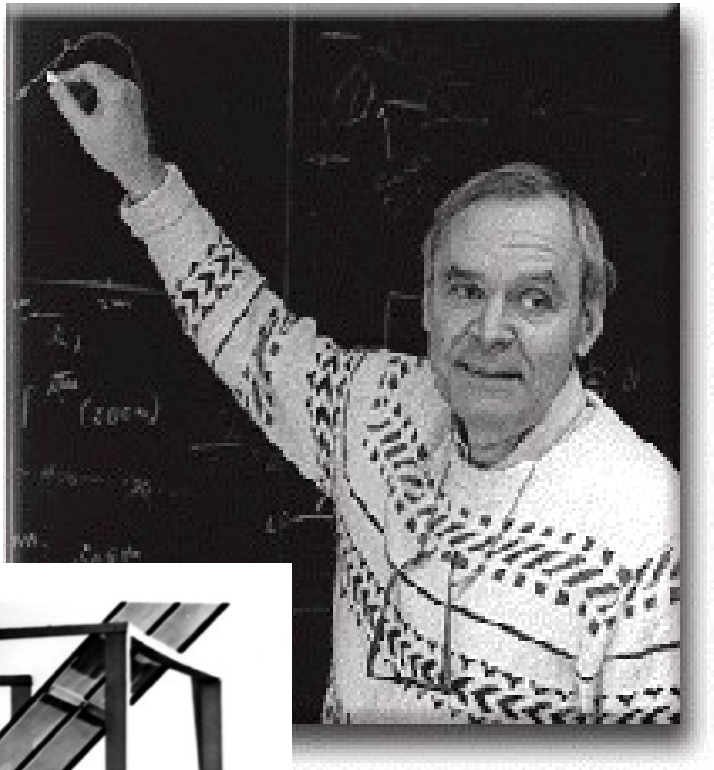


– cosmic tests could be viewed as null experiments:

any **departure** from isotropy or black body...

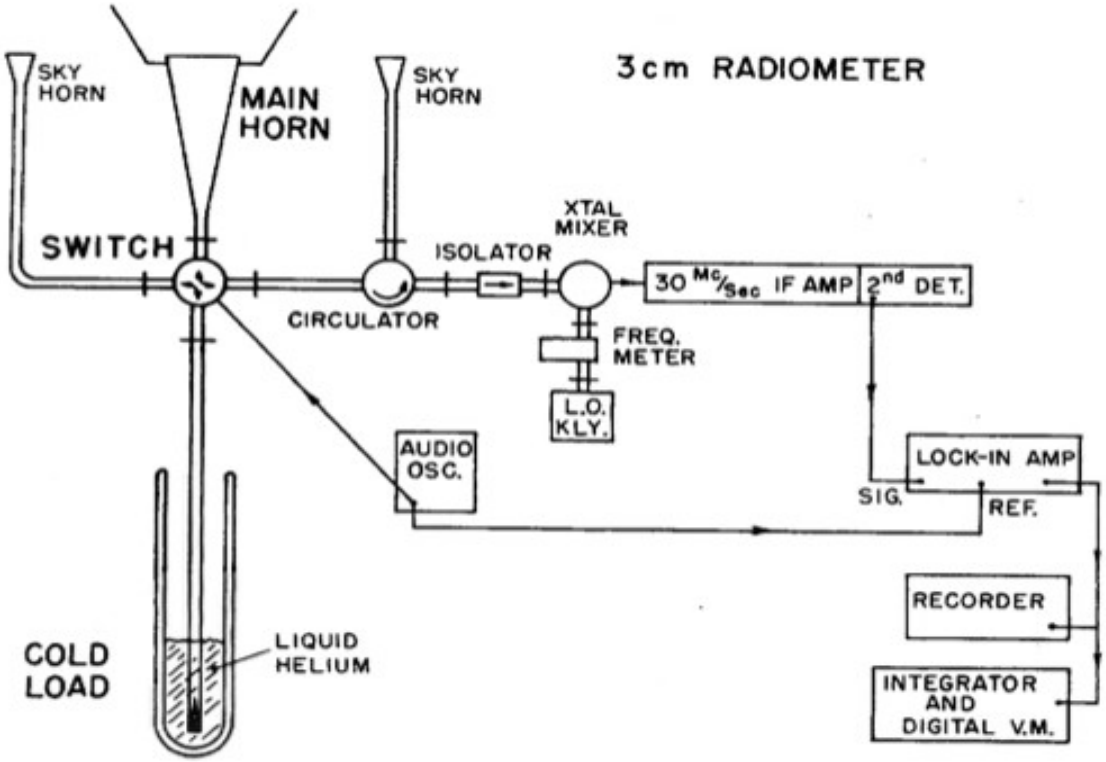
– and were approached that way

Peter Roll and Dave Wilkinson



Early Results: Spectrum

Roll and Wilkinson already at work
– more precise
– and crucially at a different wavelength (3 cm)



Cold load as reference; rapid (Dicke) switching

Early Results: Spectrum

Roll and Wilkinson:

An audacious and prescient graph

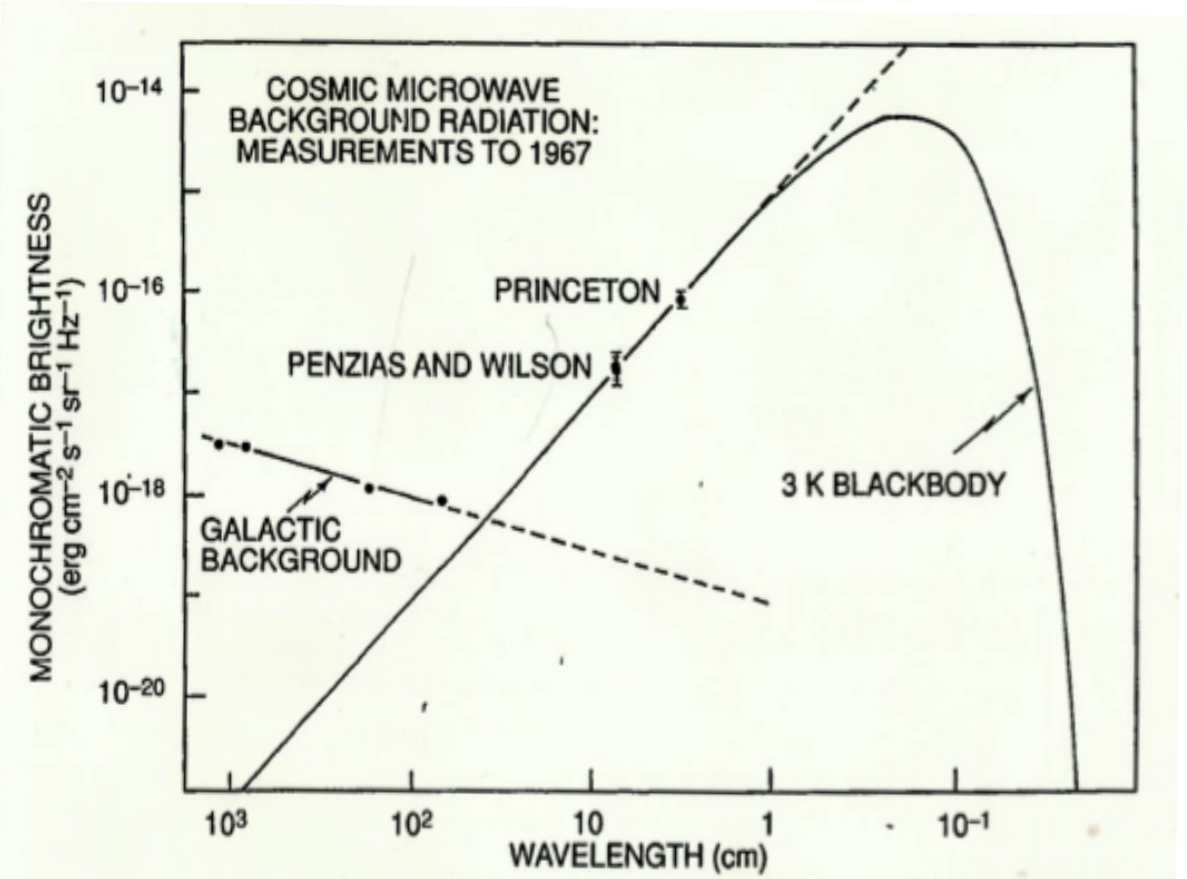


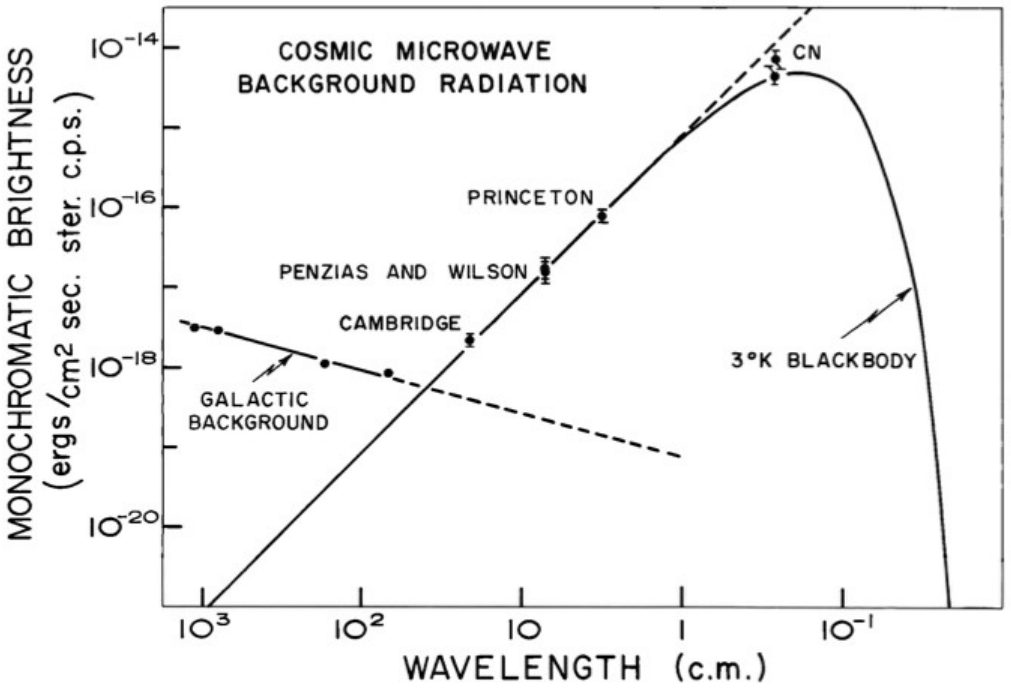
Fig. 2.5 A second measurement of the CBR at 3.0 cm (Roll and Wilkinson, 1966) confirms the discovery of a thermal background and refines the value for T_0.

Early Results: Spectrum

Low frequency checks

– Cambridge and Penzias and Wilson

Rediscovery of CN



First rocket experiments

– at first discordant

Confirming the Black Body Spectrum

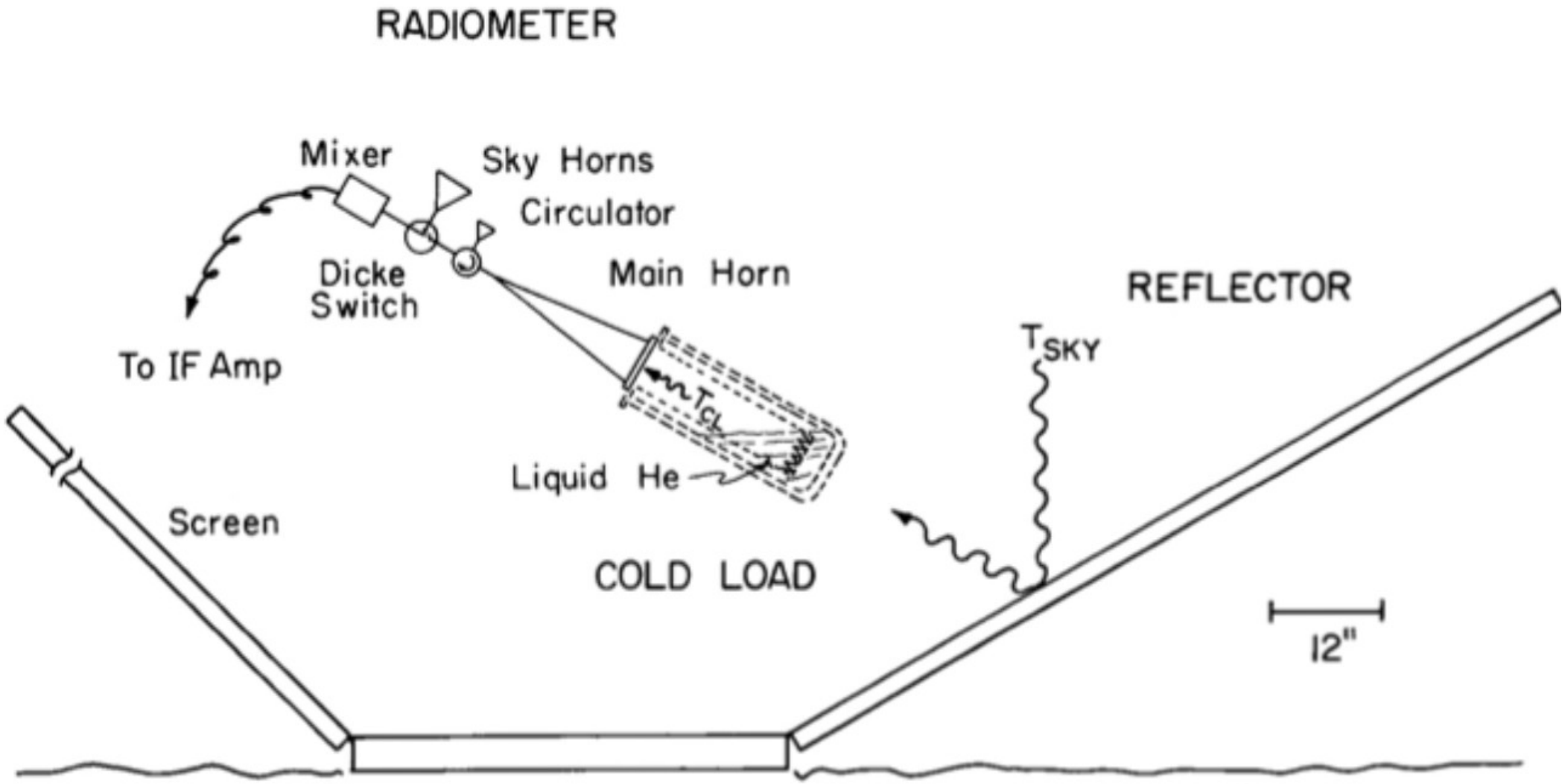
White Mountain Experiment (Stokes, Partridge, Boynton and Wilkinson 1967)

– 4 wavelengths

– correct for atmosphere and systematics

– better cold load calibration

Confirming the Black Body Spectrum



Relevance to Current Work

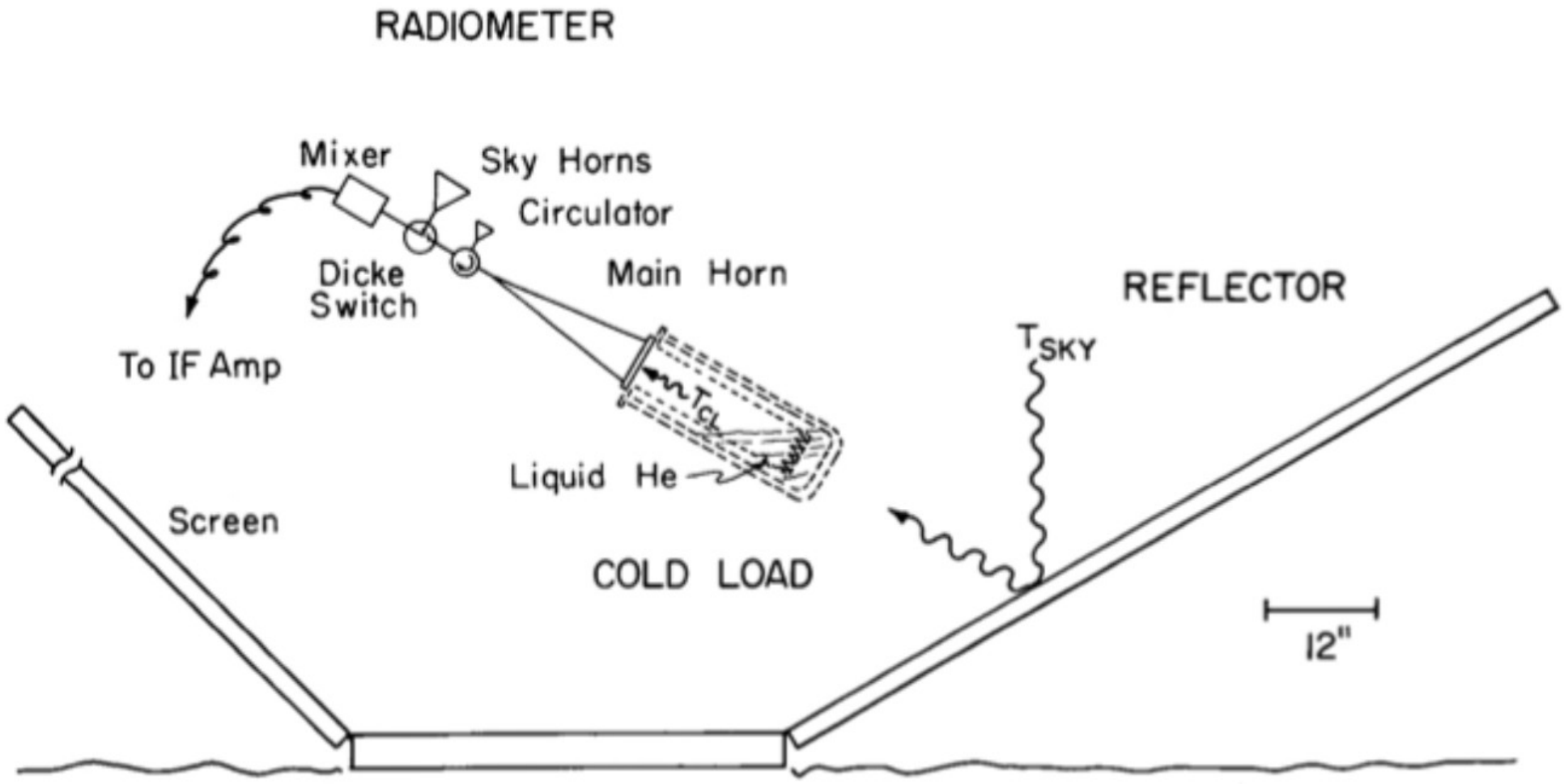
Emphasis on calibration (crucial for absolute T measurements) and control of systematics

- the role of the (over-moded) cold load
- better “symmetry” with the sky

Direct measurements of foregrounds (atmosphere)

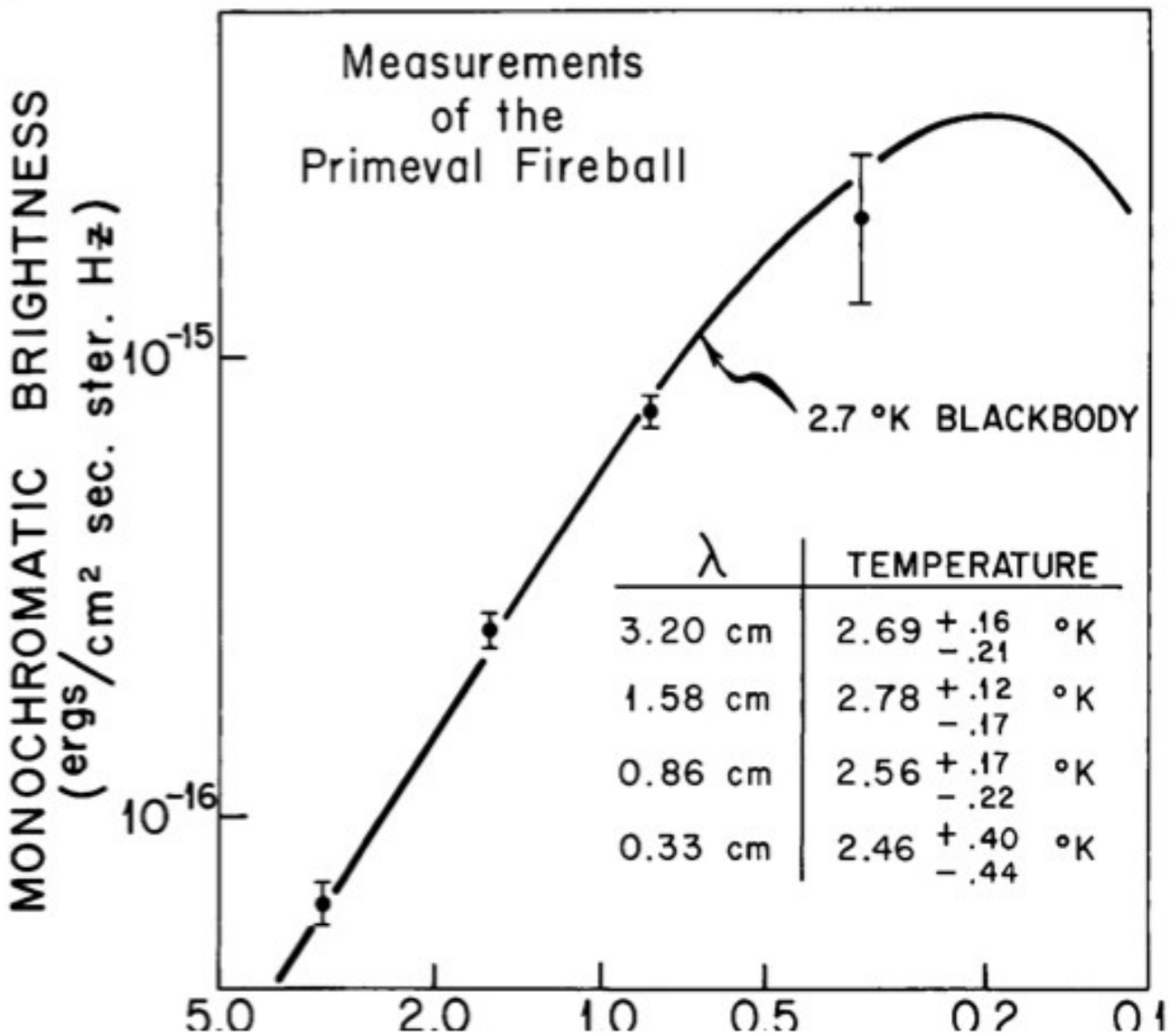
And mitigation of others (side lobes)

Relevance to Current Work



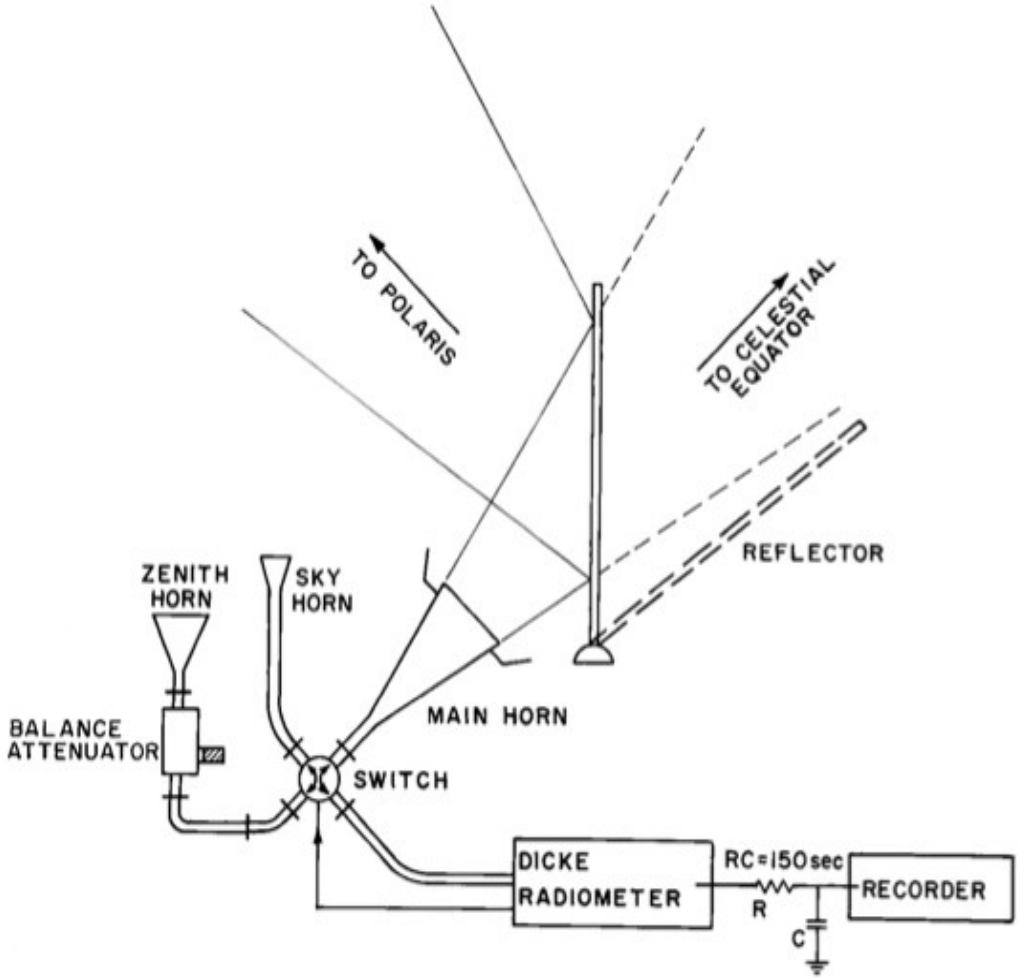
Confirming the Black Body Spectrum

Suggestion of curvature in spectrum: **not** RJ



Early Results: Isotropy

Partridge and Wilkinson



Denver Post
July 24, 1967
p. 13
Harold and
Thelma
Wilkinson
happened upon
this article
at the Brass
Lantern Restau-
rant in Kimball,
Nebraska while
travelling.

DRS. BRUCE PARTRIDGE, LEFT, AND DAVID WILKINSON OF PRINCETON
They are holding part of a device used to measure radiation from outer space.

WAVES FROM FIREBALL

'Snow' on TV Linked To Universe Creation

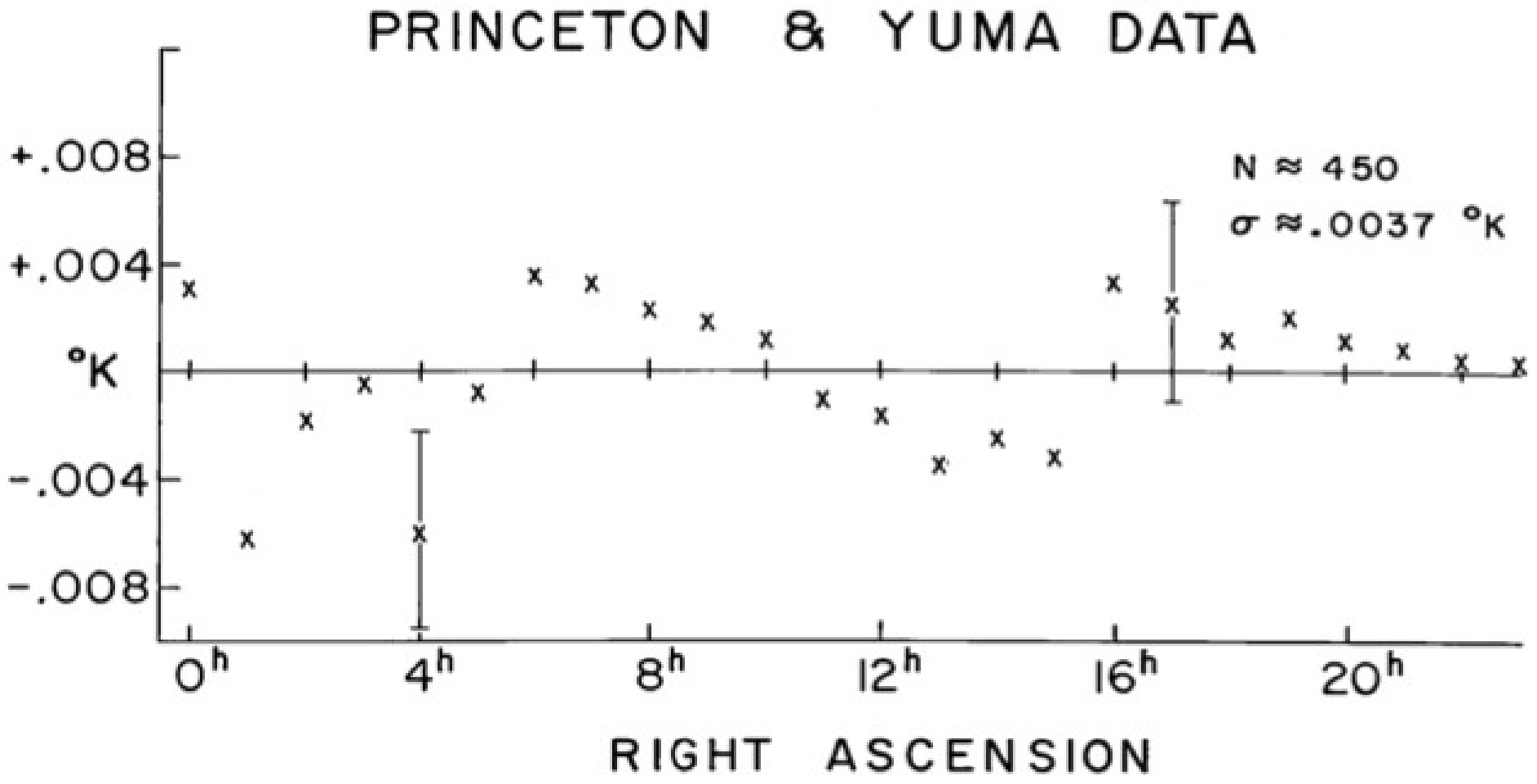
The Yuma Experiment

Drier atmosphere

More rapid switching

Ran remotely for 2 years

Early Results: Isotropy



Isotropic to ~0.2%

Relevance to Current Work

Comparative measurements easier than absolute

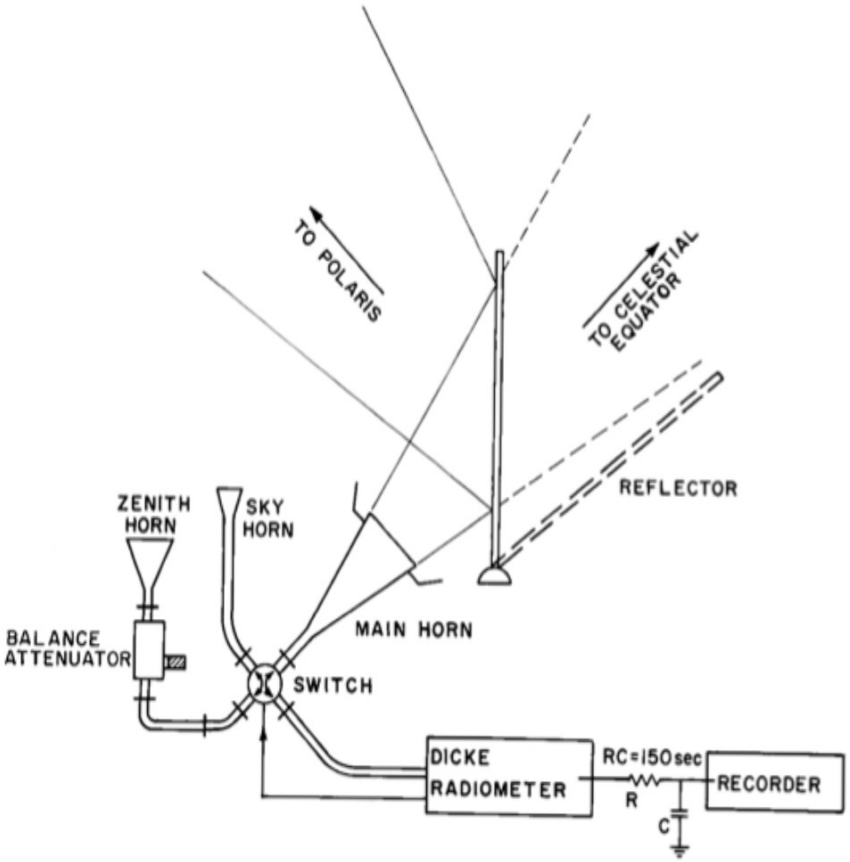
But still need a reference:

three steps

– Dicke switch to zenith

– (Slow) switching to North Pole sky

– Rotation of Earth (dipole = 24h)



Relevance to Current Work

Sky as reference – U2, COBE-DMR, WMAP

– OK for comparative measurements

Cold load as reference

– Required for absolute measurements – COBE-FIRAS

– Adapted for *Planck*

Modern standard reference: CMB dipole

Early Results: Doppler Dipole

At Princeton, Wilkinson, Henry, Corey and Cheng (balloons)

At Stanford, Conklin (ground)

Smoot et al. (U2 aircraft)

Contested *discovery*, but clear *evidence*

--amplitude now known to 0.1% – a new "reference"

….a surprise – not in expected direction

– evidence for peculiar motion of our Galaxy

Early Results: Fine-scale Isotropy

Conklin

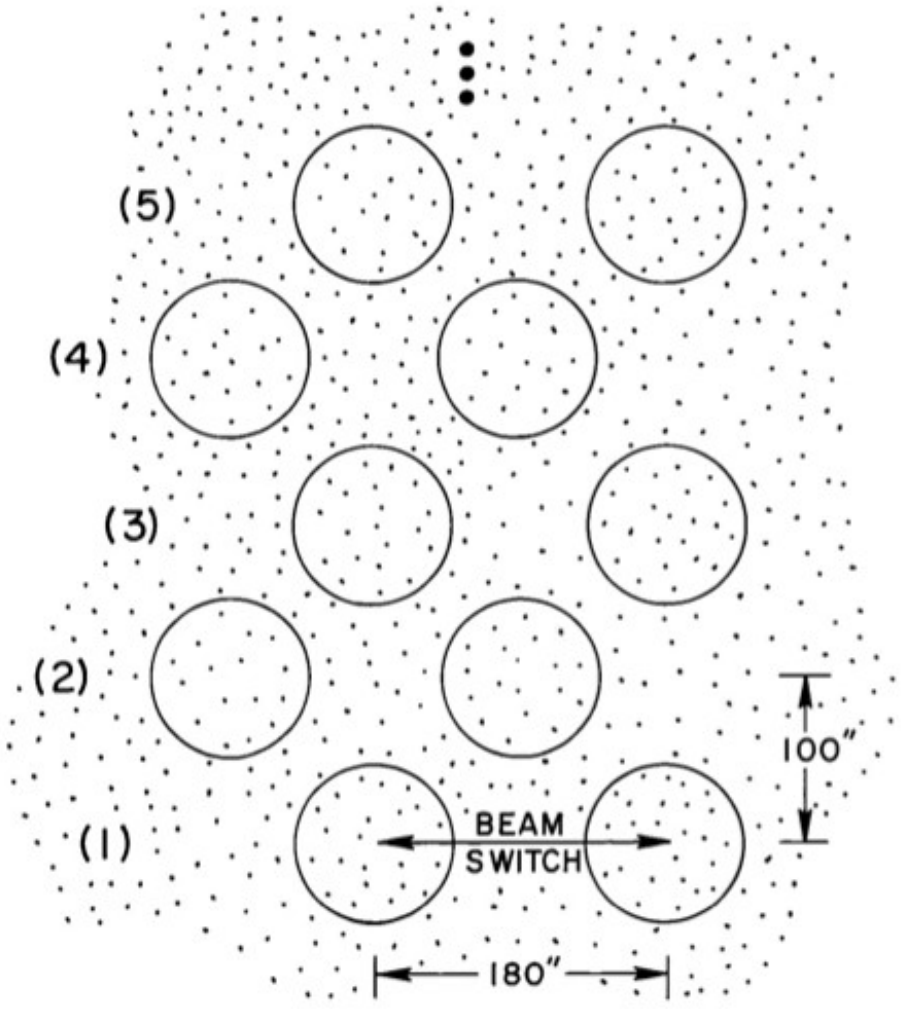
Penzias, Schraml

and Wilson

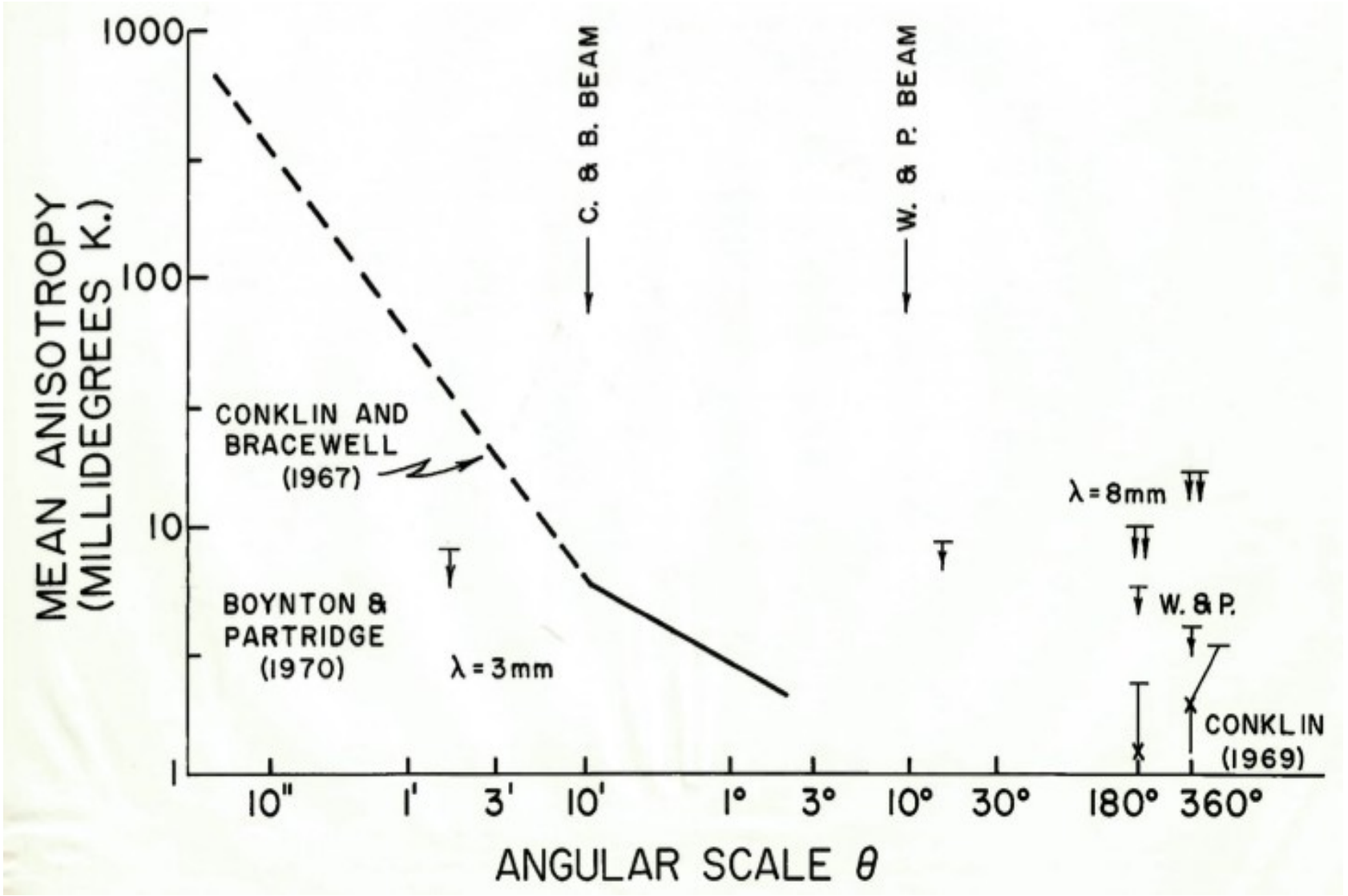
Smith and Partridge

CMB is too “smooth”

to be radio sources



Better and Better Upper Limits on Anisotropy



Summary

By ~1969, all tests were passed

3K background generally accepted as *cosmic*

(For contemporary review, see my “The Primeval Fireball” in *American Scientist*,” 1969)

A Fateful Trip to Moscow

I've summarized where CMB studies stood in ~1968

That summer,

I went to Russia

...and

again

in 1981

A Pause in the 70's

A lull in interest and results --

Waiting for the theorists

Waiting for better

equipment (and space)

Planning for COBE

But the CMB is **cosmic**: the Universe does have a **history.**

Remembering the good old days....