CMB spectral distortion constraints from ground, sub-orbital, and space experiments

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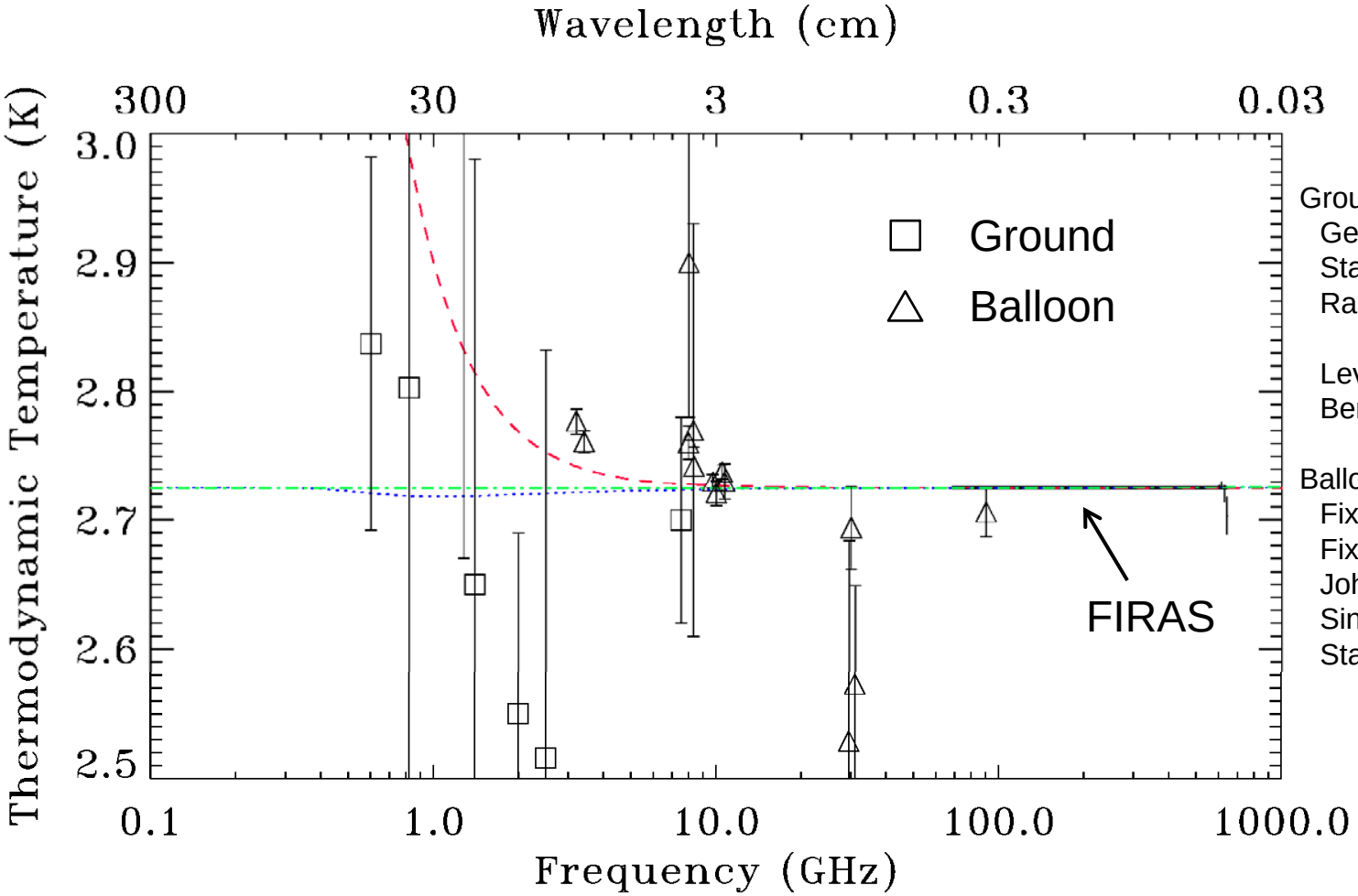
Keck Institute for Space Studies
The First Billion Years
Pasadena, August 2010

Current experimental constraints on CMB spectral distortions

Description of (some) of the experiments

What's next?

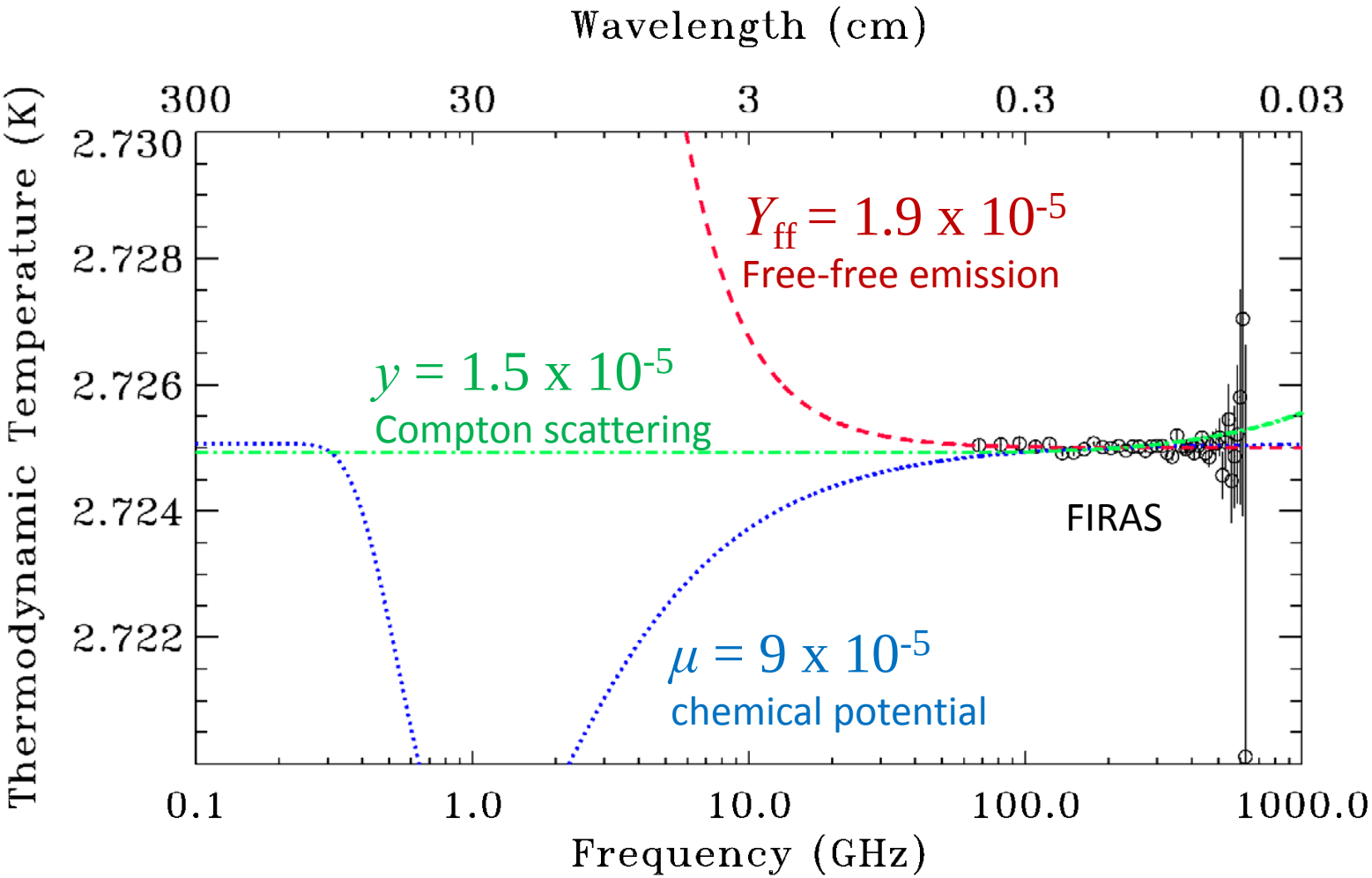
Recent, sensitive constraints on spectral distortions



Ground:
- Gervasi et al., '08
- Staggs et al., '96
- Raghunathan & Subrahmnayan '00
- Levin et al., '92
- Bersanelli et al., '94

Balloon:
- Fixsen et al., '04
- Fixsen et al., '10
- Johnson & Wilkinson '87
- Singal et al. '06
- Staggs et al. '96

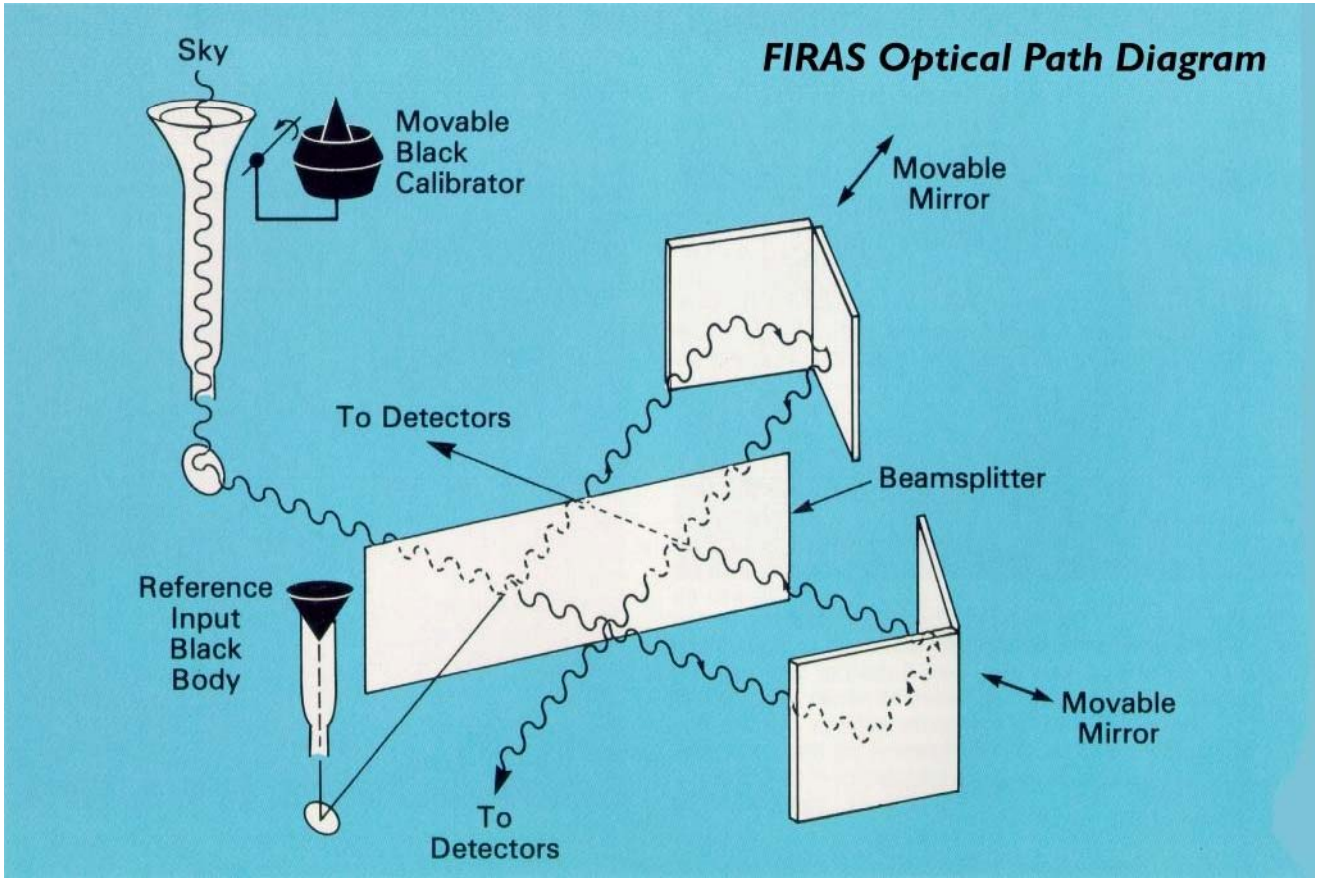
constraints on spectral distortions



COBE - FIRAS

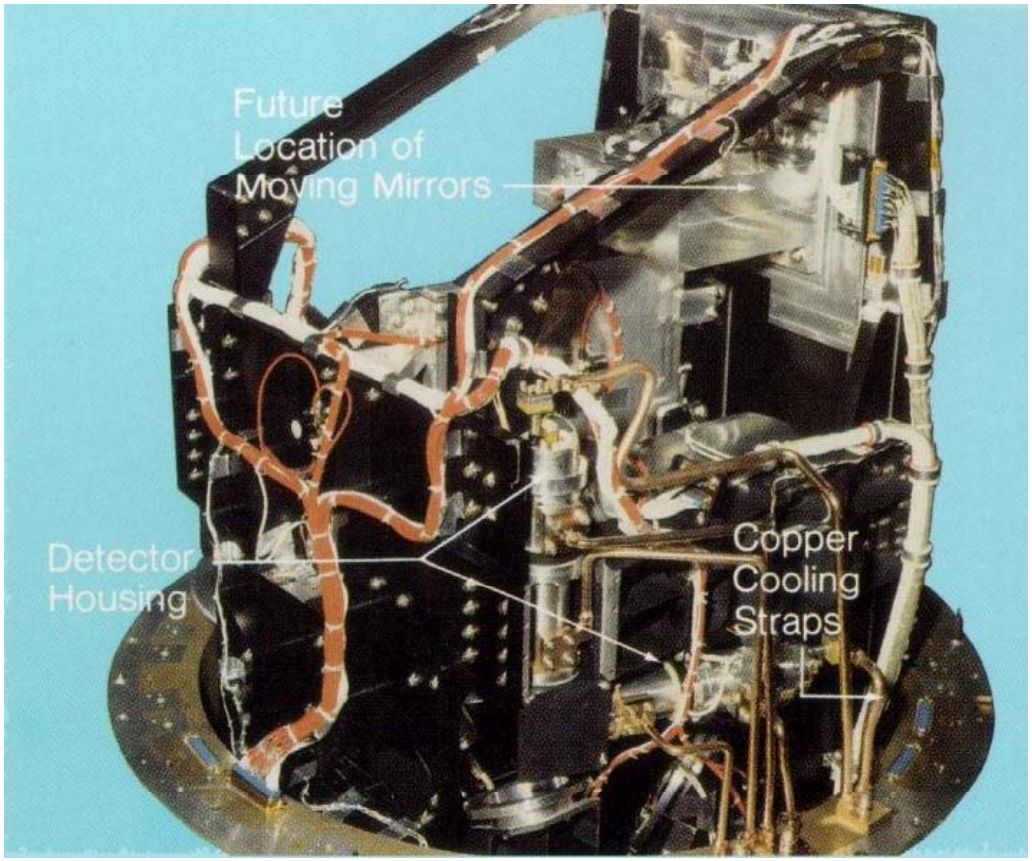
Far-Infrared Absolute Spectrophotometer
Polarizing Michelson interferometer
Measures the spectral difference between 7 deg sky patch and internal blackbody

Absolute calibration provided by moveable external calibrator

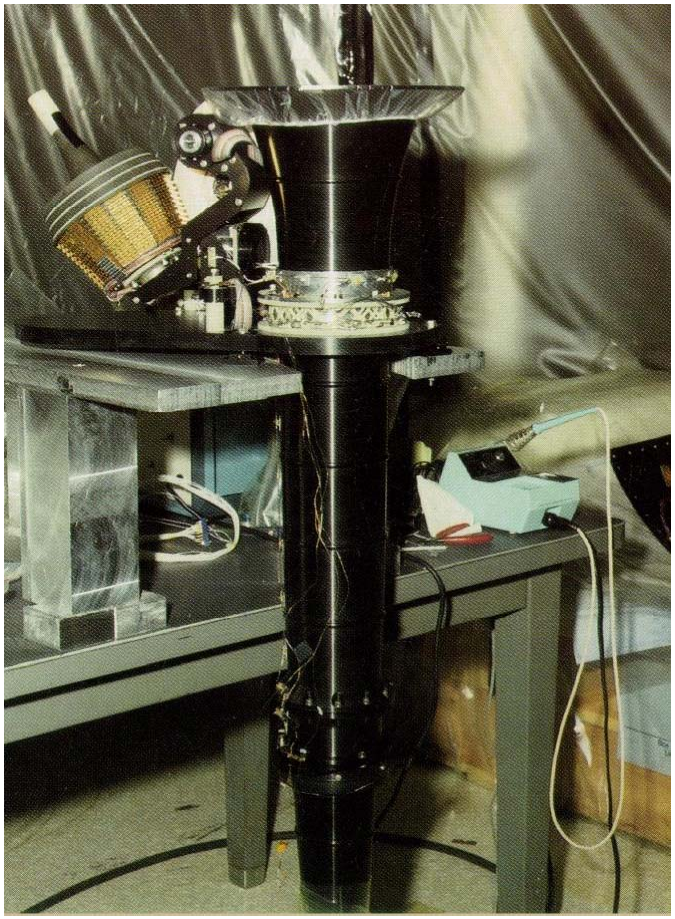


Credit: COBE team

FIRAS



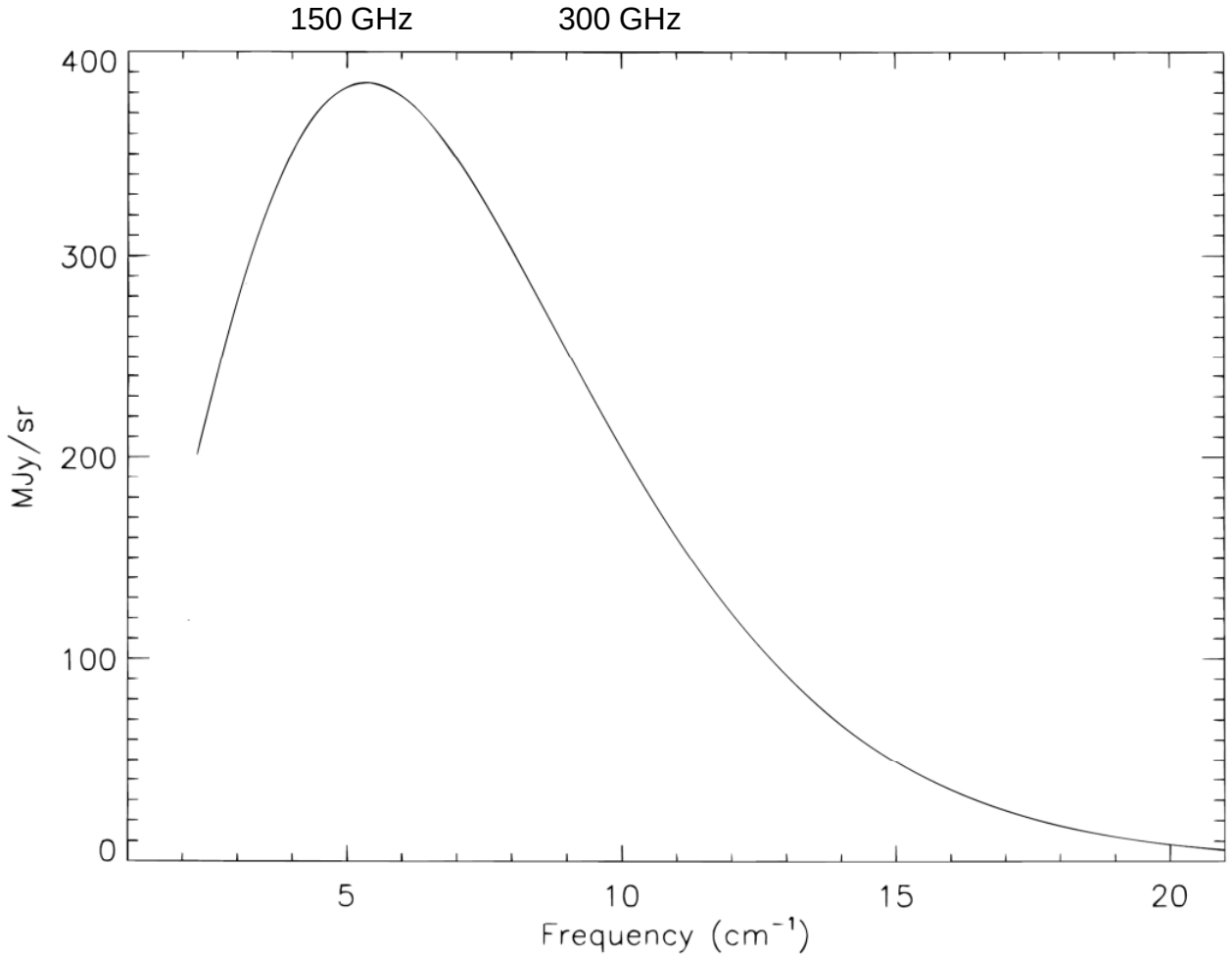
FIRAS test unit



FIRAS horn

Credit: COBE team

FIRAS results



Errors on this curve are of order 1 part in 10^4

Conventional to show results this way, but what the experiment is actually measuring is something closer to zero.

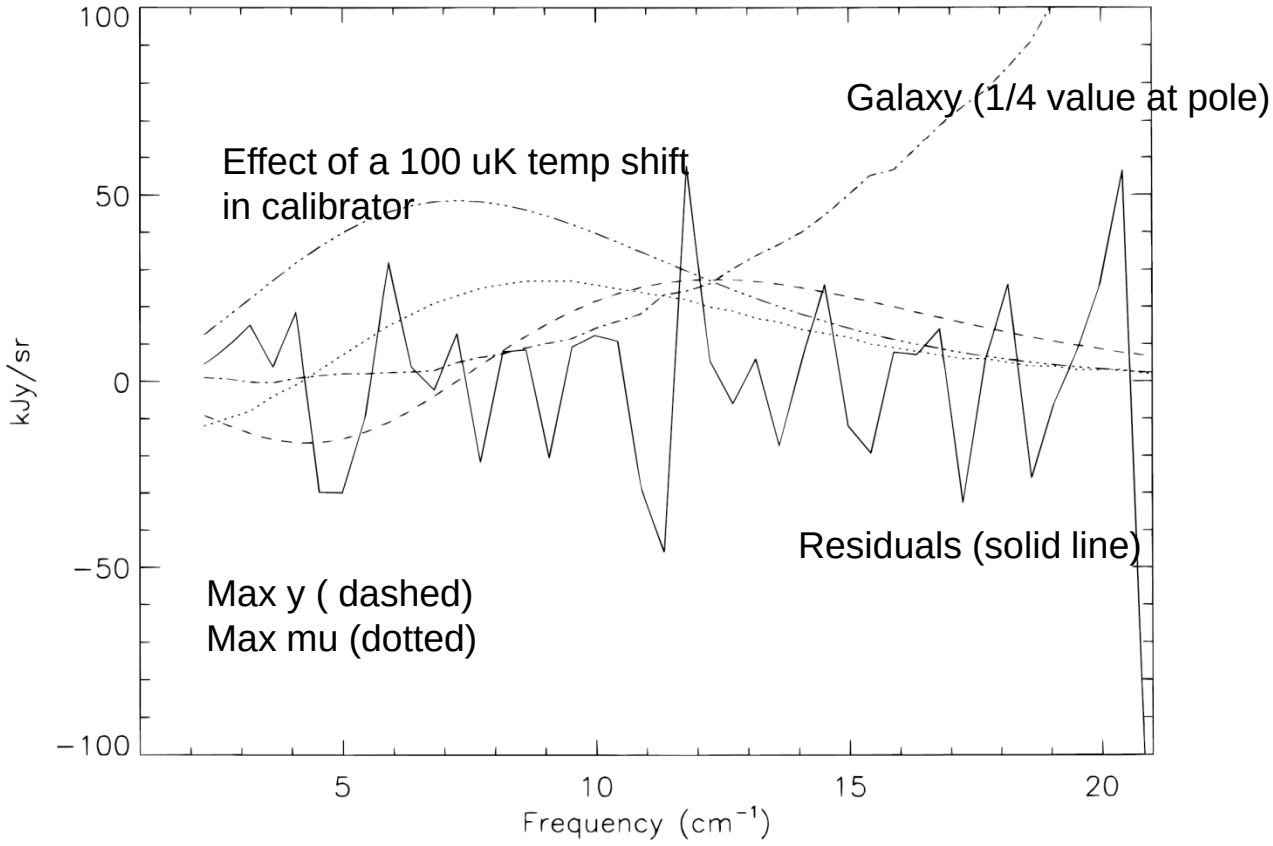
Fixsen et al., ApJ, 473, 585 (1996)

FIRAS CMB distortion constraints and residuals

$|y| < 1.5 \times 10^{-5}$

$|\mu| < 9 \times 10^{-5}$

(95% CL)



$$I_0(\nu) = B_\nu(T_0) + \Delta T \frac{\partial B_\nu}{\partial T} + G_0\, g(\nu) + p \frac{\partial S_c}{\partial p}$$

blackbody cal offset residual galaxy spectral distortion

Fixsen et al., ApJ, 473, 585 (1996)

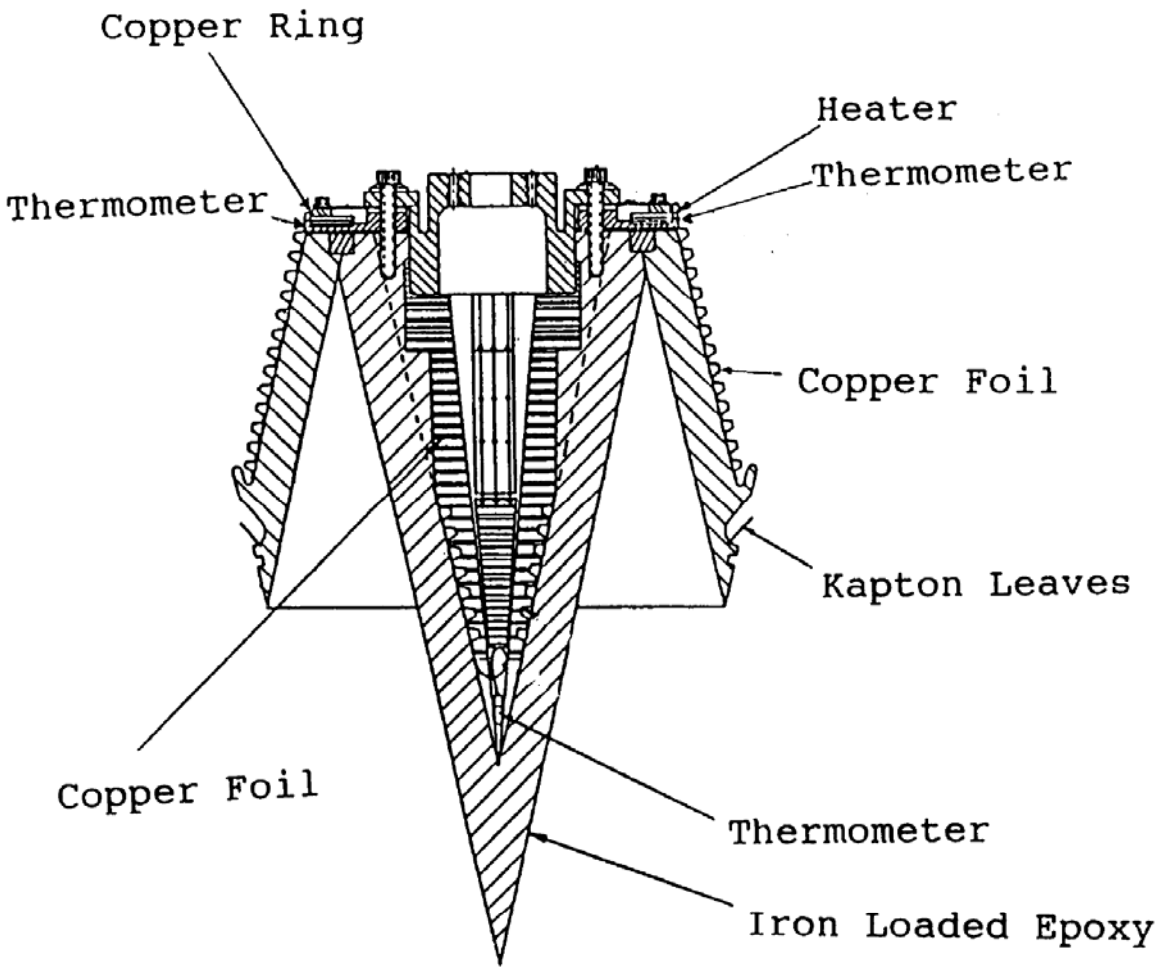
FIRAS galaxy modeling

Galactic emission modeled using template fits from DIRBE 140 and 240 μm.

FIRAS residual emission includes a fit of emissivity and temperature to a $\nu^2 B(T)$ model

Synchrotron, free-free, extra-galactic radio sources not included

FIRAS external calibrator



Approximation to an ideal black body that fills the beam of the instrument

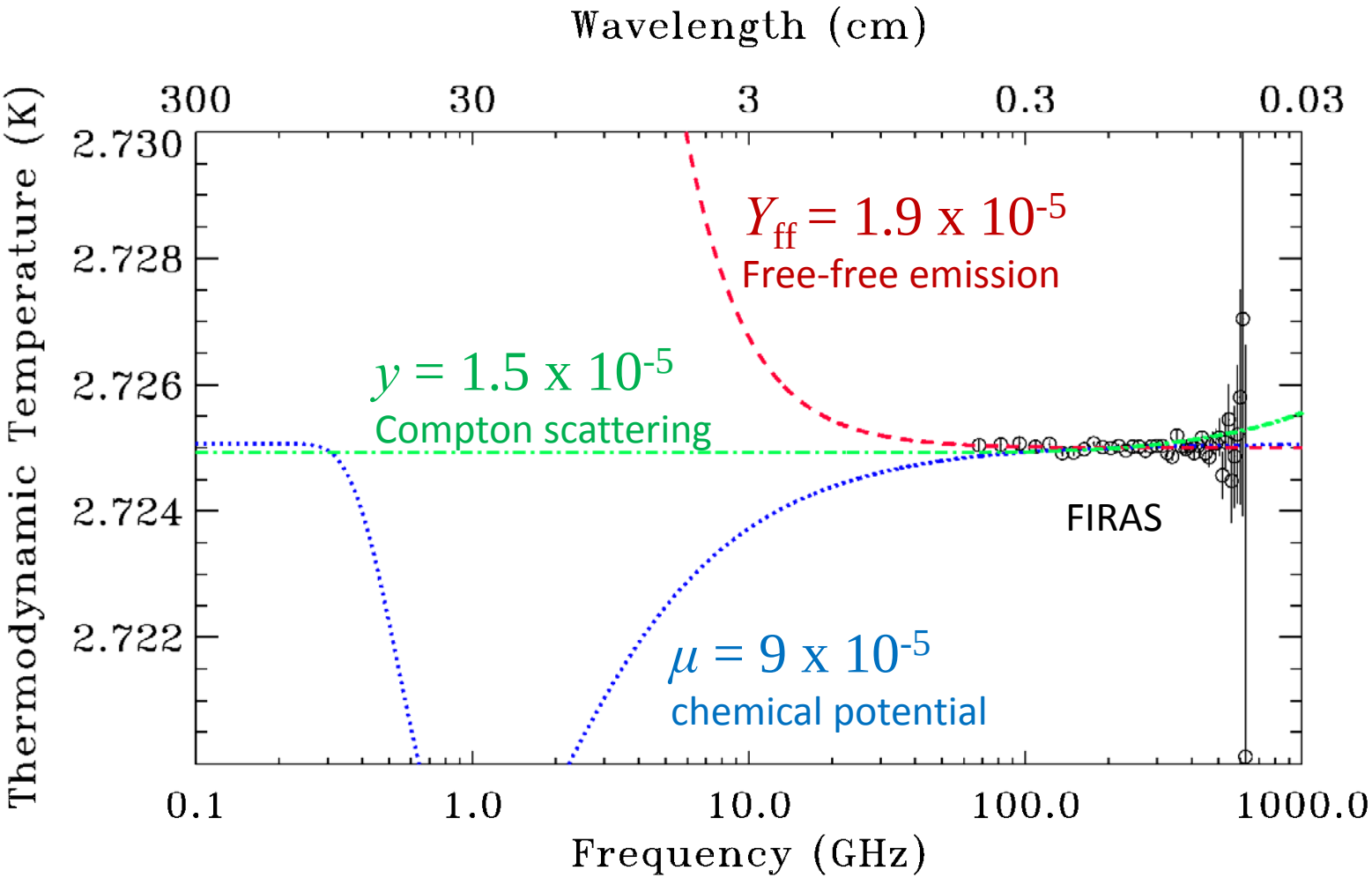
20 cm diameter

Gradients < 1 mK

Reflectivity < 3×10^{-5}

Thermometry:
- precision ~ 0.2 mK
- accuracy ~ 1 mK

constraints on spectral distortions



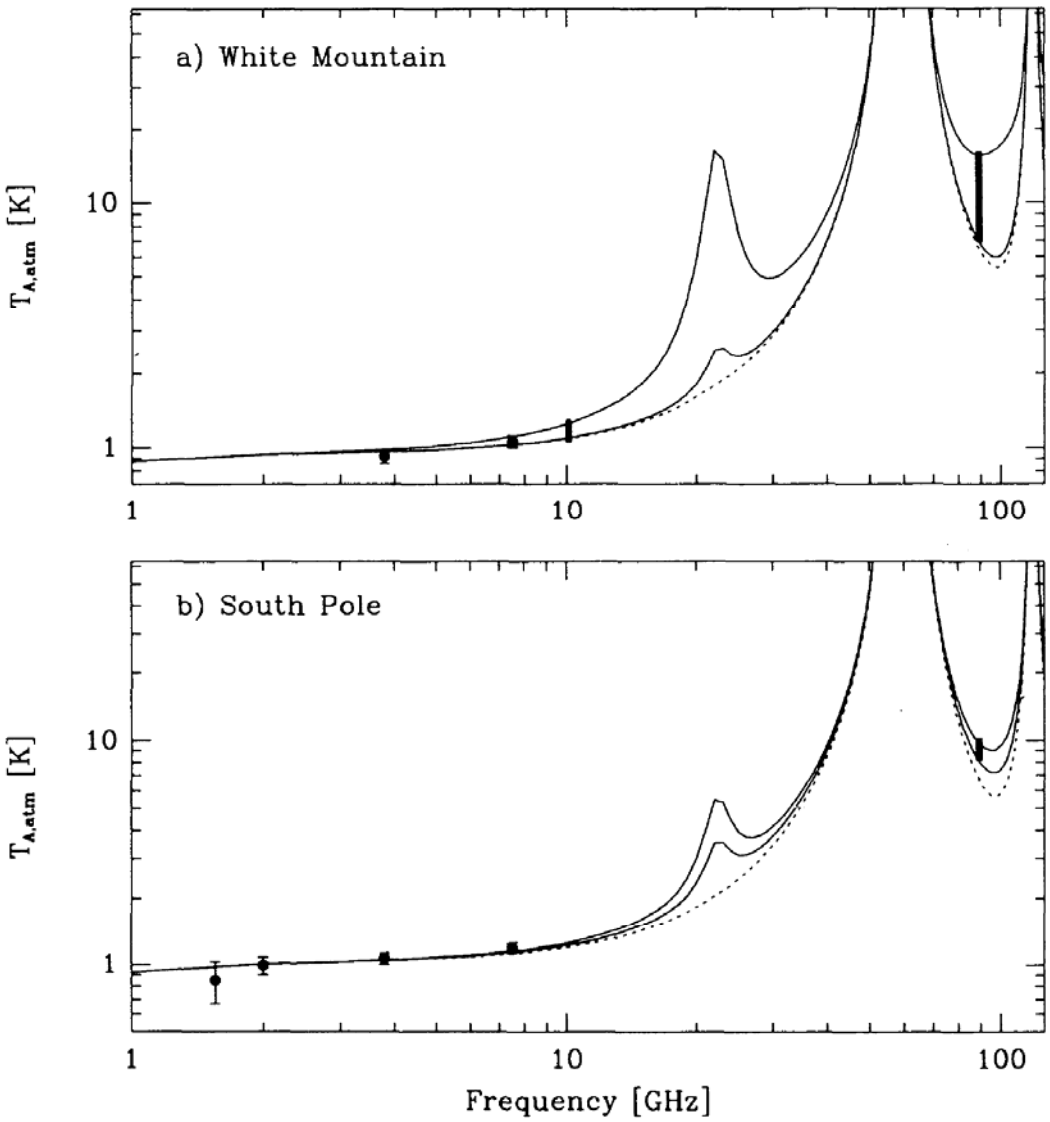
Ground experiments

South Pole

Ground experiments typically require a window

Must look through bulk of the atmosphere

Atmospheric contribution limits ground-based measurements



Measured and modeled atmospheric emission.

Dashed line is dry atmosphere emission model.

Solid lines represent range of water vapor contributions.

Bersanelli et al., ApJ, 448, 8 (1995)

ARCADE I

Absolute Radiometer for Cosmology and Diffuse Emission

JPL

Steve Levin

Mike Seiffert

GSFC

Al Kogut –PI

Dale Fixsen

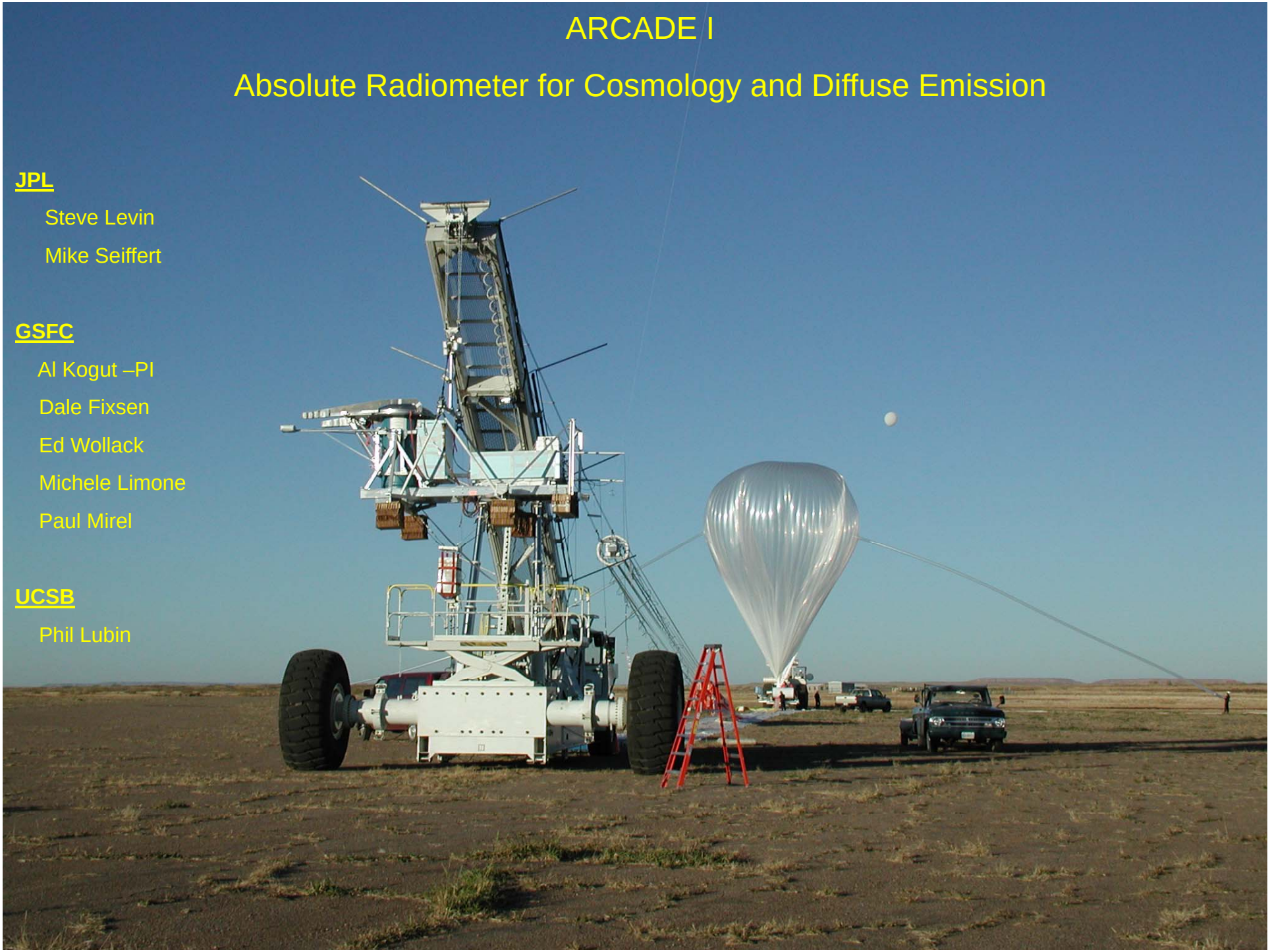
Ed Wollack

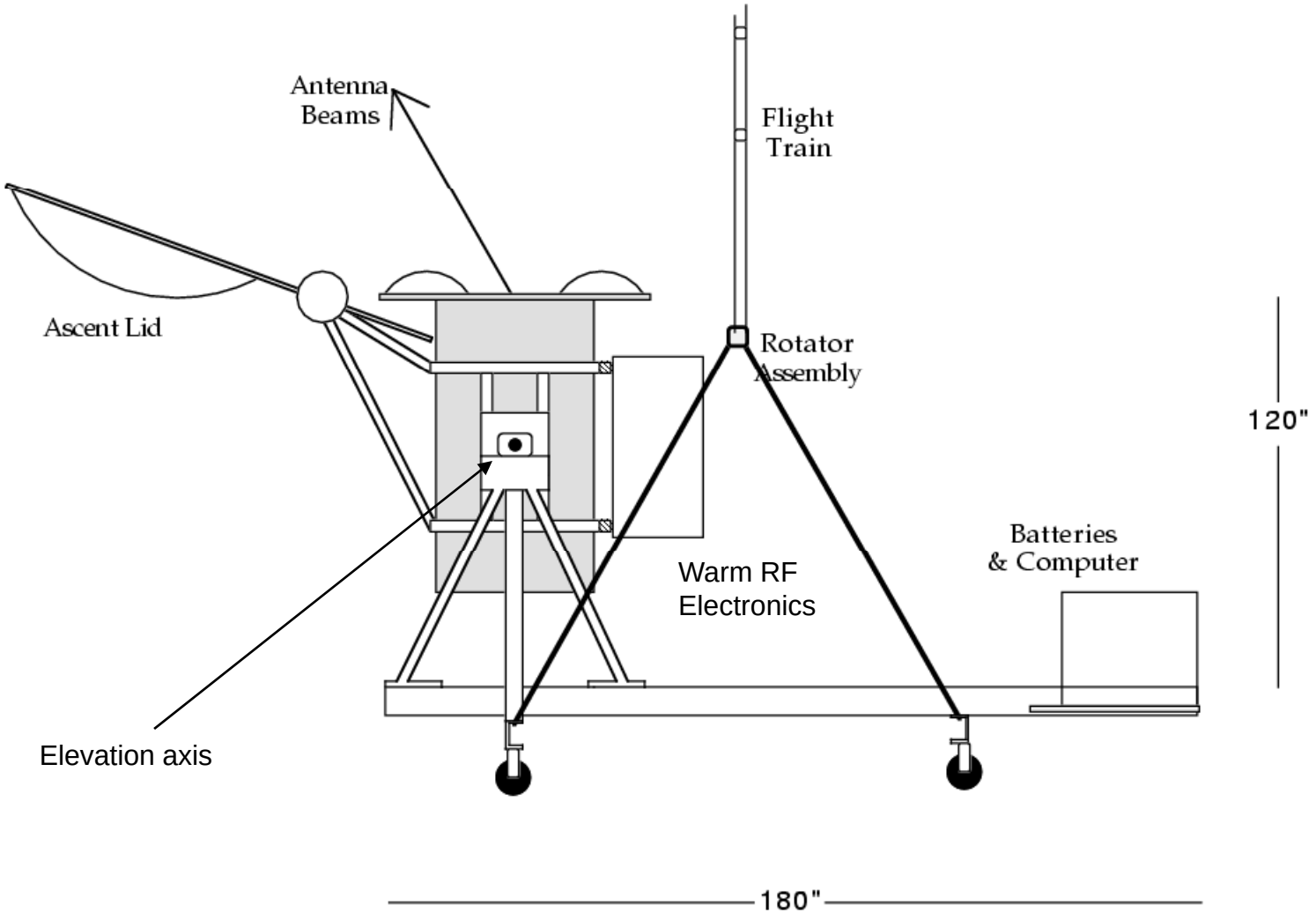
Michele Limone

Paul Mirel

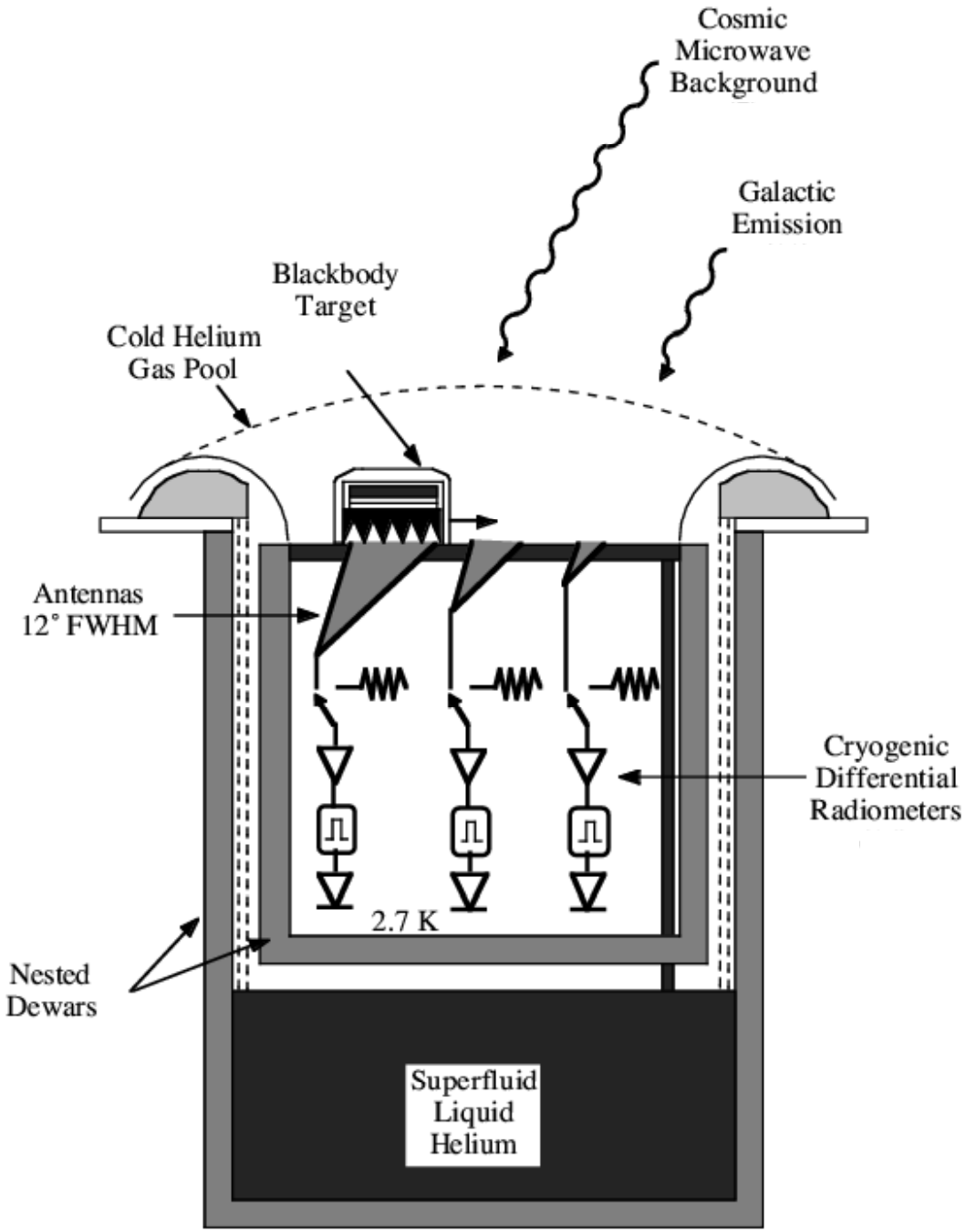
UCSB

Phil Lubin





ARCADE Gondola Schematic Diagram



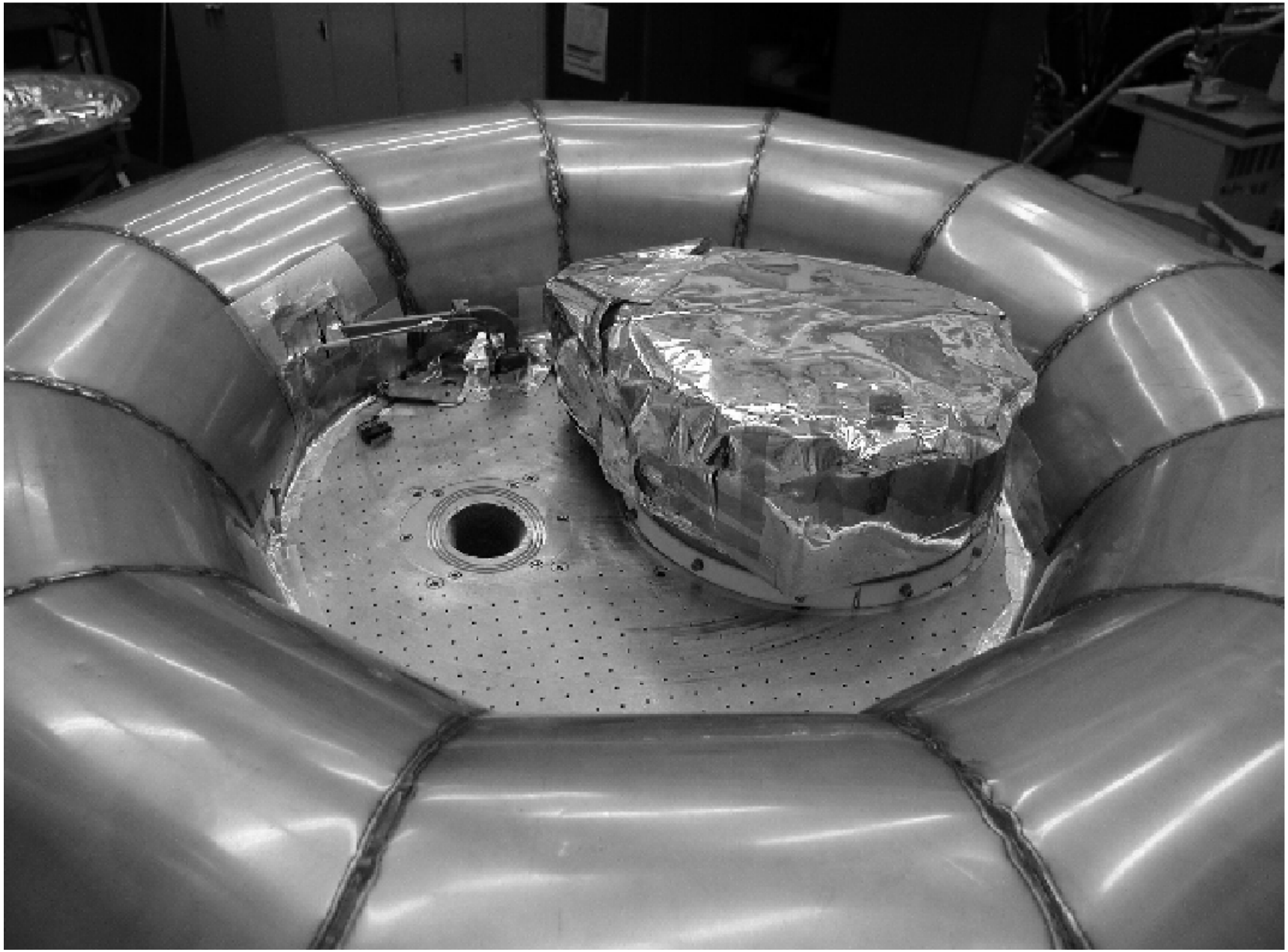
ARCADE Cryostat

Multiple levels of differencing

No window

Instrument regulated at 2.725 K

ARCADE I instrumented with 10 GHz and 30 GHz receivers



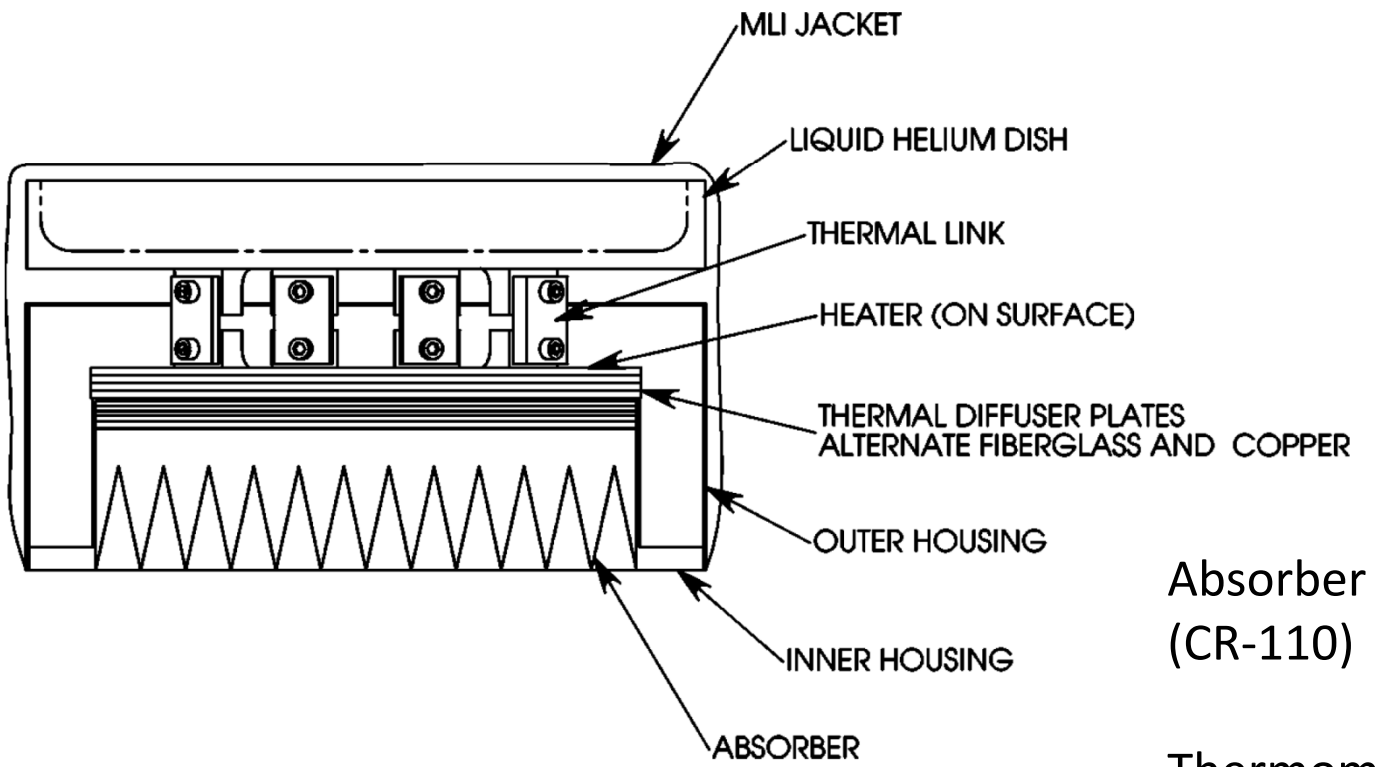
ARCADE 1 results

10 GHz : 2.721 ± 0.010 K
30 GHz : 2.694 ± 0.032 K

Fixsen et al., *ApJ*, 612, 86 (2004).

No improvement on spectral distortion limits over FIRAS, but rather validation of measurement technique for more ambitious experiment.

ARCADE I Calibrator



Absorber is iron loaded epoxy (CR-110)

Thermometry:
- precision 0.15 mK
- accuracy 2 mK

Gradients: 720 mK

Kogut et al., Rev Sci Instr. 75, 5079 (2004), [astro-ph/0402580]

Arcade 1 foregrounds

Observations at Galactic latitude $13 < b < 83$, majority at $b > 35$.

Foreground contribution estimated using models of the synchrotron, free-free, and dust emission derived from the Wilkinson Microwave Anisotropy Probe (WMAP) (spectral index) with zero point constraint from Haslam 408 MHz map.

10 GHz : $1.4\ \text{mK} \pm 2\ \text{mK}$
30 GHz : $< 0.5\ \text{mK}$

Uncertainty driven by uncertainty in the spectral index.

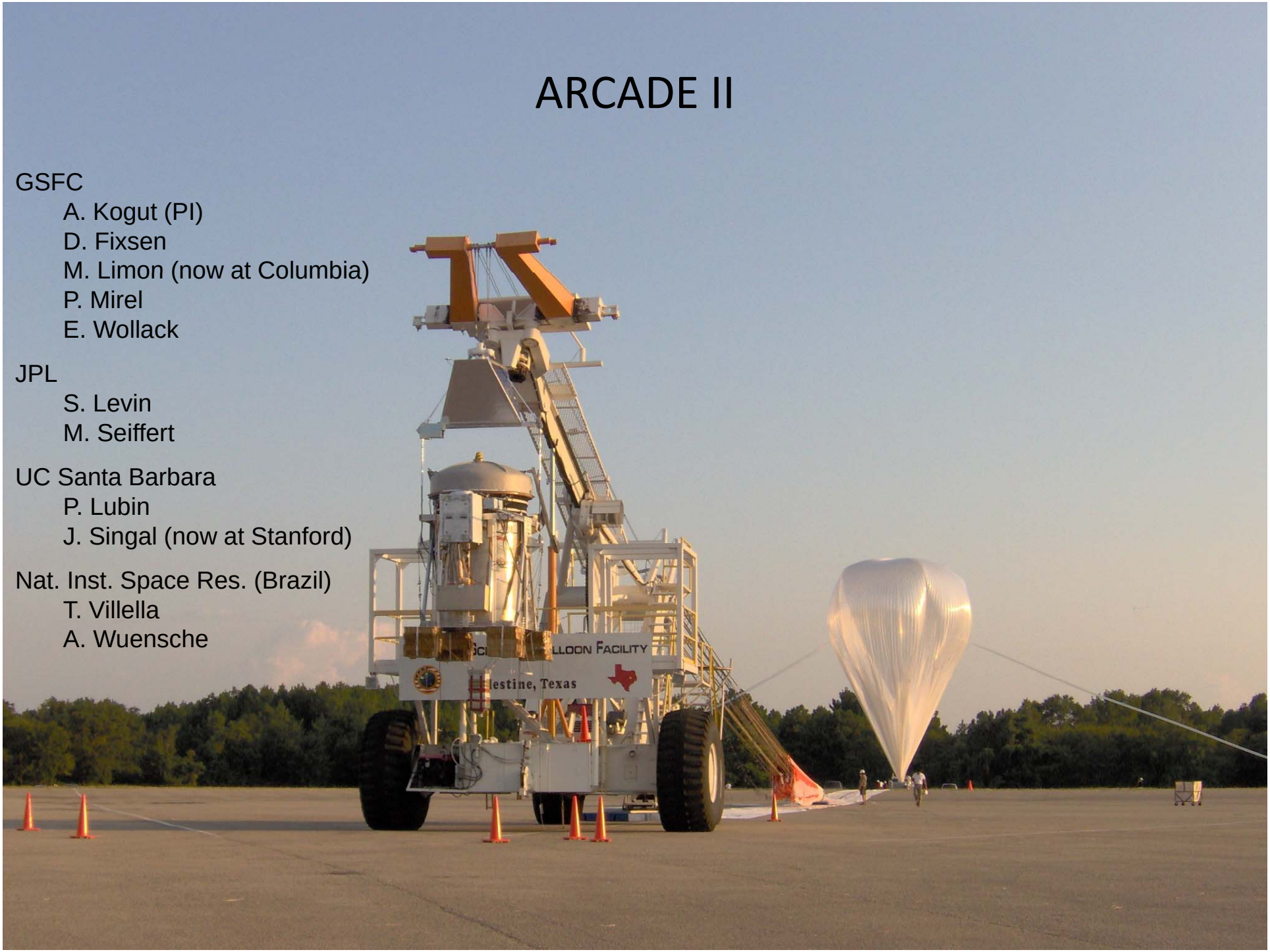
ARCADE II

GSFC
- A. Kogut (PI)
- D. Fixsen
- M. Limon (now at Columbia)
- P. Mirel
- E. Wollack

JPL
- S. Levin
- M. Seiffert

UC Santa Barbara
- P. Lubin
- J. Singal (now at Stanford)

Nat. Inst. Space Res. (Brazil)
- T. Villella
- A. Wuensche



ARCADE II

1.5 m open aperture with 1800 liters LHe at launch

Launch in July 2006 from Palestine, TX

4 hours observation at float

ARCADE II results

First flight:

8.0 GHz : 2.90 ± 0.12 K

8.3 GHz : 2.77 ± 0.16 K

Singal et al., *ApJ*, 653, 835 (2006)

Second flight:

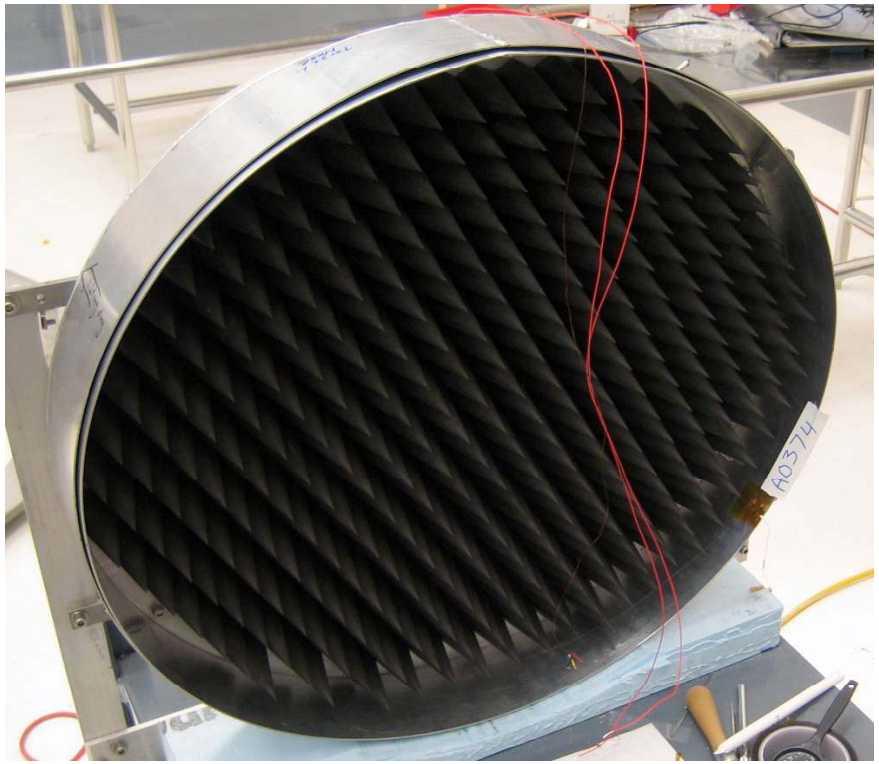
3.20	2.777 ± 0.010
3.41	2.761 ± 0.008
7.98	2.761 ± 0.013
8.33	2.742 ± 0.015
9.72	2.730 ± 0.005
10.49	2.738 ± 0.006
29.5	2.529 ± 0.155
31	2.573 ± 0.076
90	2.706 ± 0.019

Instrumental systematics

Singal et al., *ApJ* accepted

Component	3L	3H	8L	8H	10L	10H	30L	30H	90L	90H
Balloon	0.1	0.1	0.2	0.2	0.3	0.3	1.9	2.0	14.8	14.8
Reflector shield	1.5	0.9	4.2	4.5	0.5	0.5	0.8	0.8	0.8	0.7
Lights[a]	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spreader bar	8.5	4.3	31.4	36.6	1.7	1.1	1.3	1.7	1.3	1.1
Upper Suspension[b]	0.1	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Lower Suspension[b]	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Cold Flare[c]	0.3	0.3	0.3	0.5	0.3	0.3	0.3	0.3	0.3	0.3
Total	10.8	5.8	36.6	42.2	2.9	2.3	4.4	4.8	17.2	16.9

ARCADE II calibrator



Absorber cones cast onto aluminum core

Temperature is adjustable

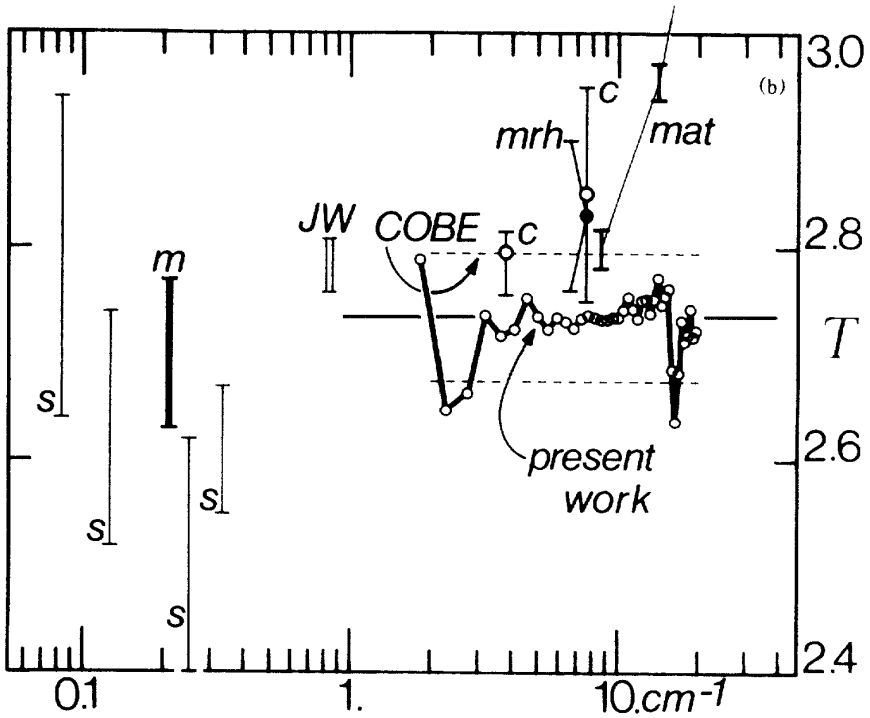
Reflectivity varies with frequency
1×10^{-4} at 3 GHz
3×10^{-6} at 90 GHz

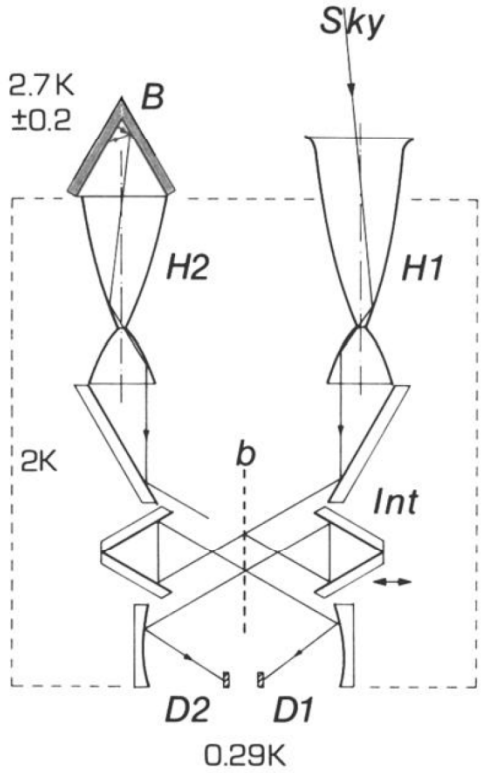
26 RuO thermometers embedded
Precision 0.15 mK
Accuracy 1 mK

Gradients in flight:
600 mK front-to-back
20 mK transverse

Fixsen et al., *Rev. Sci. Instrum*, 2005, 77, 064905

Sounding rockets …





Freedom from the atmosphere
Short flights
Concern about residual environment

Polarizing interferometer
External calibration on the ground, but not in flight

Gush, Halpern, & Wishnow, PRL, 65, 537 (1990)

Conclusion - What's next?

Raw Sensitivity is not a fundamental limit

Important ingredients:
- Foregrounds
- Calibration
- Instrumental systematics

Approach of proposed space experiments will be discussed this week

FIRAS II
Fixsen & Mather '02

Diffuse Microwave Emission Survey

R.A. Shafer, J. Mather (GSFC), A. Kogut, D.J. Fixsen (HSTX), M. Seiffert, P.M. Lubin (UCSB), S.M. Levin (JPL)

1996BAAS...28S1289S

Measurements of the CBR Frequency Spectrum at Low Frequencies: Ground and Space Observations

G. SIRONI *Physics Department, University of Milano, Milano*
G. BONELLI *Istituto IFCTR/CNR-Milano*
G. DALL'OGLIO *Physics Department-III,University of Rome, Roma*
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M. PERELLI *IMT, Roma*

The Primordial Inflation Explorer (PIXIE) Mission

Alan J. Kogut*[a], David T. Chuss[a], Jessie L. Dotson[b], Dale J. Fixsen[a], Mark Halpern[c], Gary F. Hinshaw[a], Stephan M. Meyer[d], S. Harvey Moseley[a], Michael D. Seiffert[d], David N. Spergel[f], Edward J. Wollack[a]