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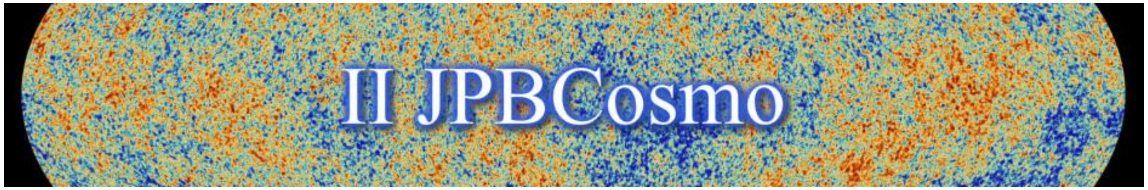

Brazilian participation in CMB measurements programs

Thyrso Villela

Instituto Nacional de Pesquisas Espaciais - INPE
(***National Institute for Space Research***)
Divisão de Astrofísica
(***Astrophysics Division***)

São José dos Campos, SP, Brazil

March 14, 2014

Cosmology...

Herman Bondi: *"the data in cosmology are so likely to be wrong that I propose to ignore them"…*

Ernest Rutherford: no one was allowed to use the word "Universe" in his lab…

Instruments to measure CMB:

- Anisotropies
  - Signal level: **milliKelvin, microKelvin**
- Polarization
  - Signal level: **microKelvin**
- Spectrum
  - Signal level: **Kelvin**
- Galactic foregrounds
  - Signal level: **microKelvin - Kelvin**

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CMB measurements programs

- experiments with Brazilian participation -

- **3mm (**COBE satellite DMR 90 GHz testbed)**:1982-1987**
- **ACME: 1987-1993**
- **ACME-Max, South Pole:1989-1994**
- **HACME: 1995-1997**
- **BEAST: 1998-2007**
- **WMPol: 2004-2006**
- **COFE: 2005-present**
- **ARCADE: 2005-present**
- **Planck satellite*: 2007-present**
- **GEM: 1991 – present**

*individual participation: Rodrigo Leonardi

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Theses...

- **Thyrso Villela**: **1987**
dipole measurement; quadrupole upper limit

- **Carlos Alexandre Wuensche: 1995**
intermediate-scale anisotropy

- **Angélica de Oliveira Costa: 1996**
topology

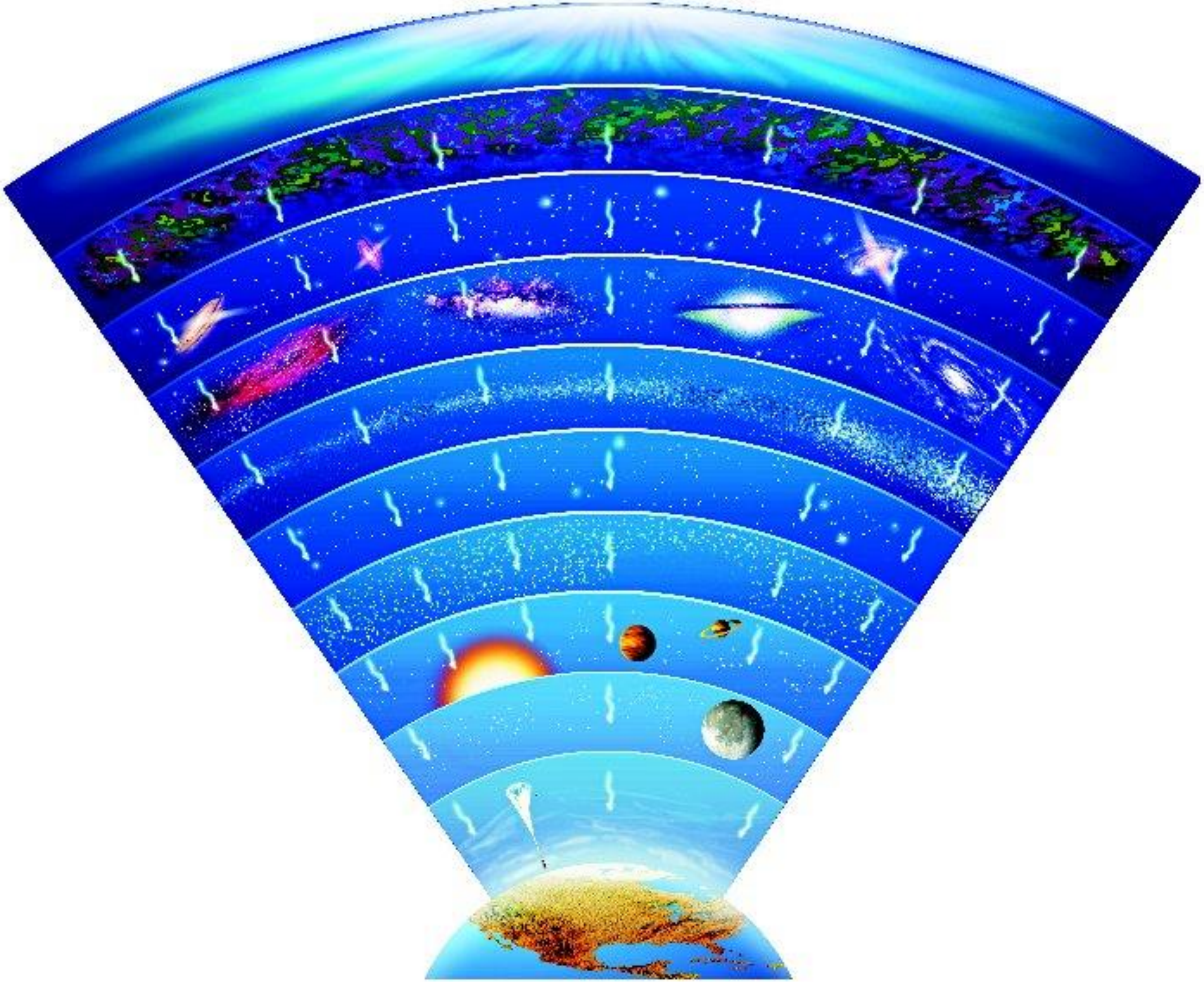
- **Newton Figueiredo: 1997**
intermediate-scale anisotropy; off-axis optics design

- **Camilo Tello: 1997**
1.465 GHz receiver development; foreground measurements

- **Agenor Pina da Silva: 2002**
intermediate-scale anisotropy

- **Rodrigo Leonardi: 2006**
polarimeter development; CMB polarization upper limit

- **Ivan Ferreira: 2008**
5 GHz polarimeter development; foreground measurements



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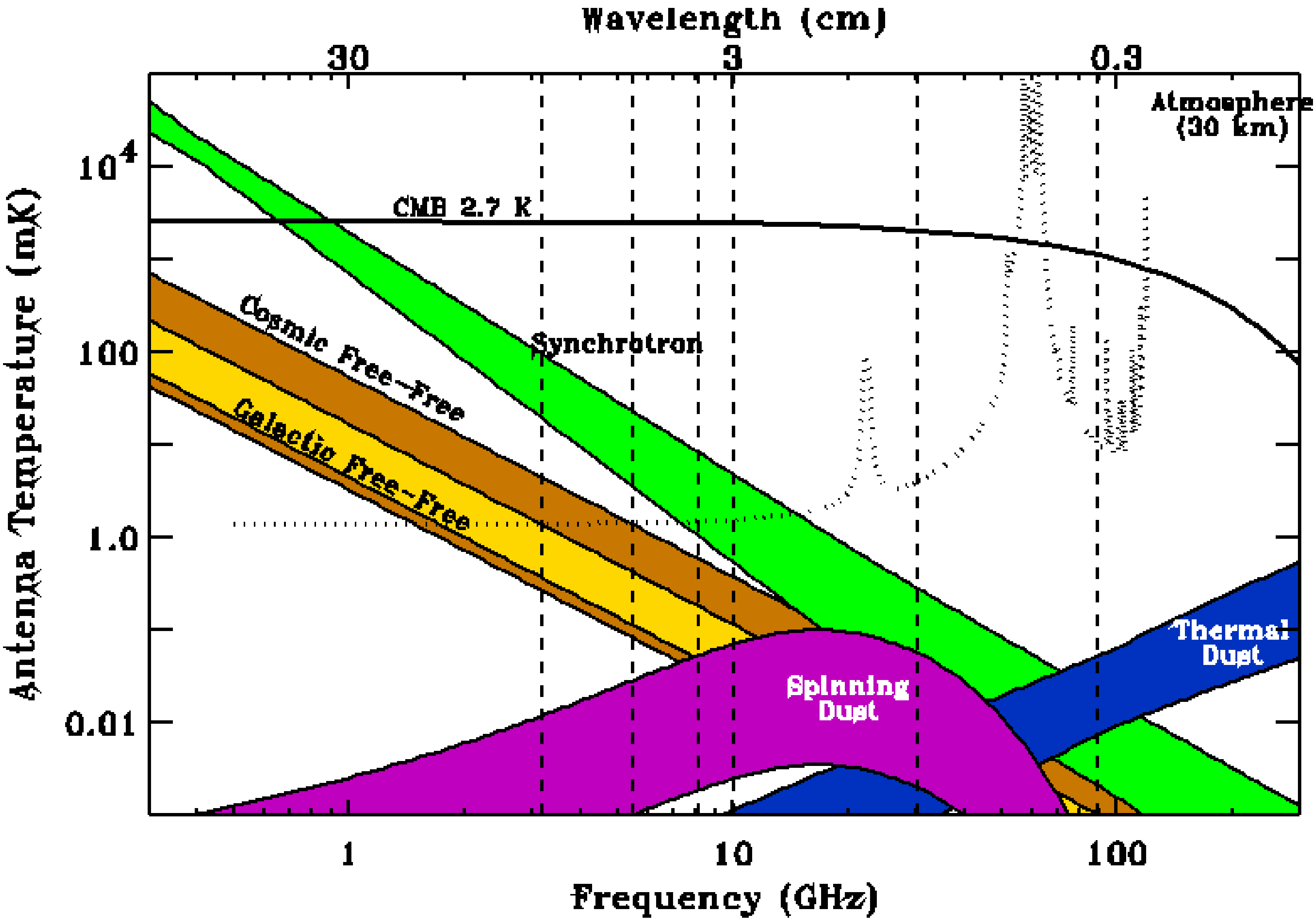
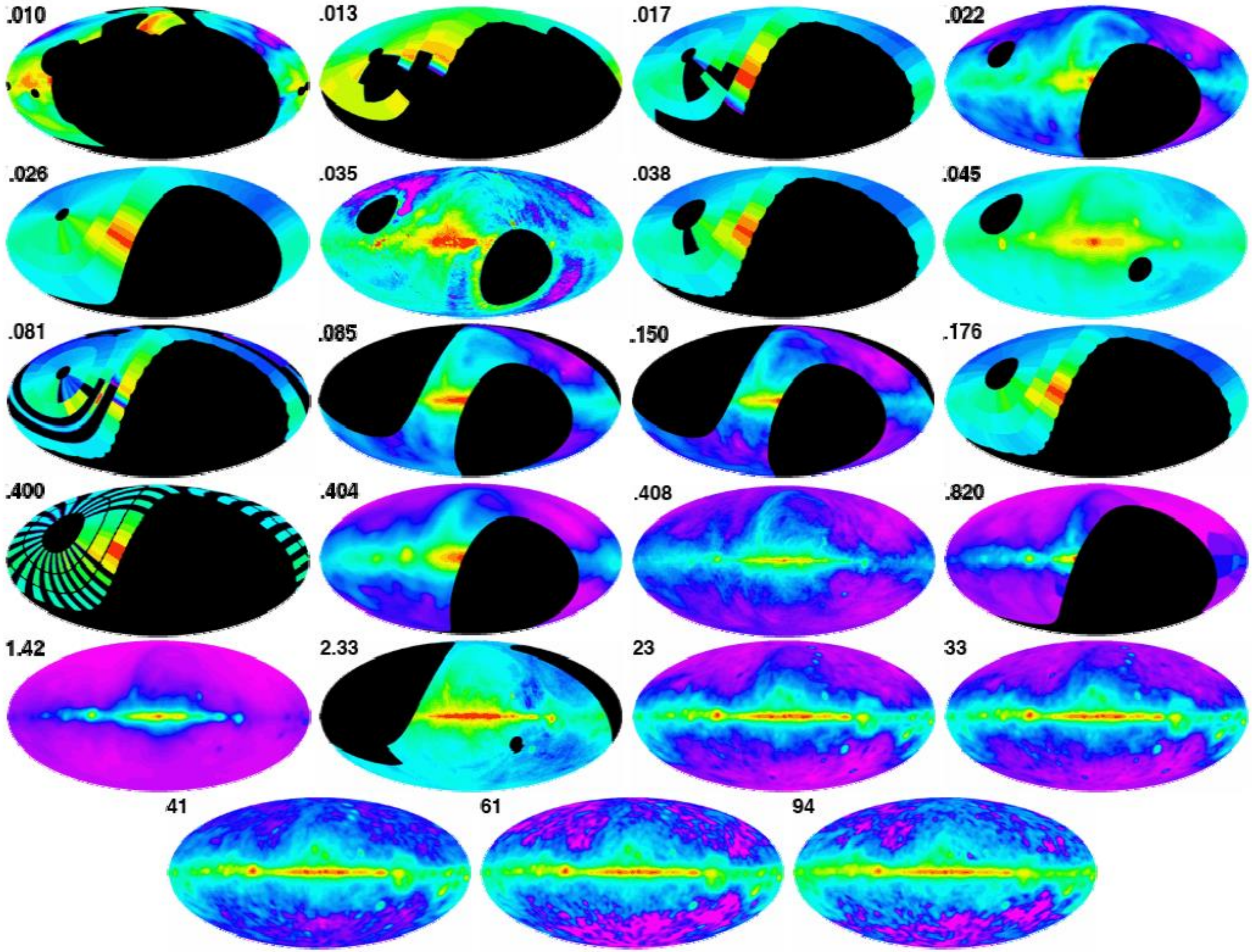
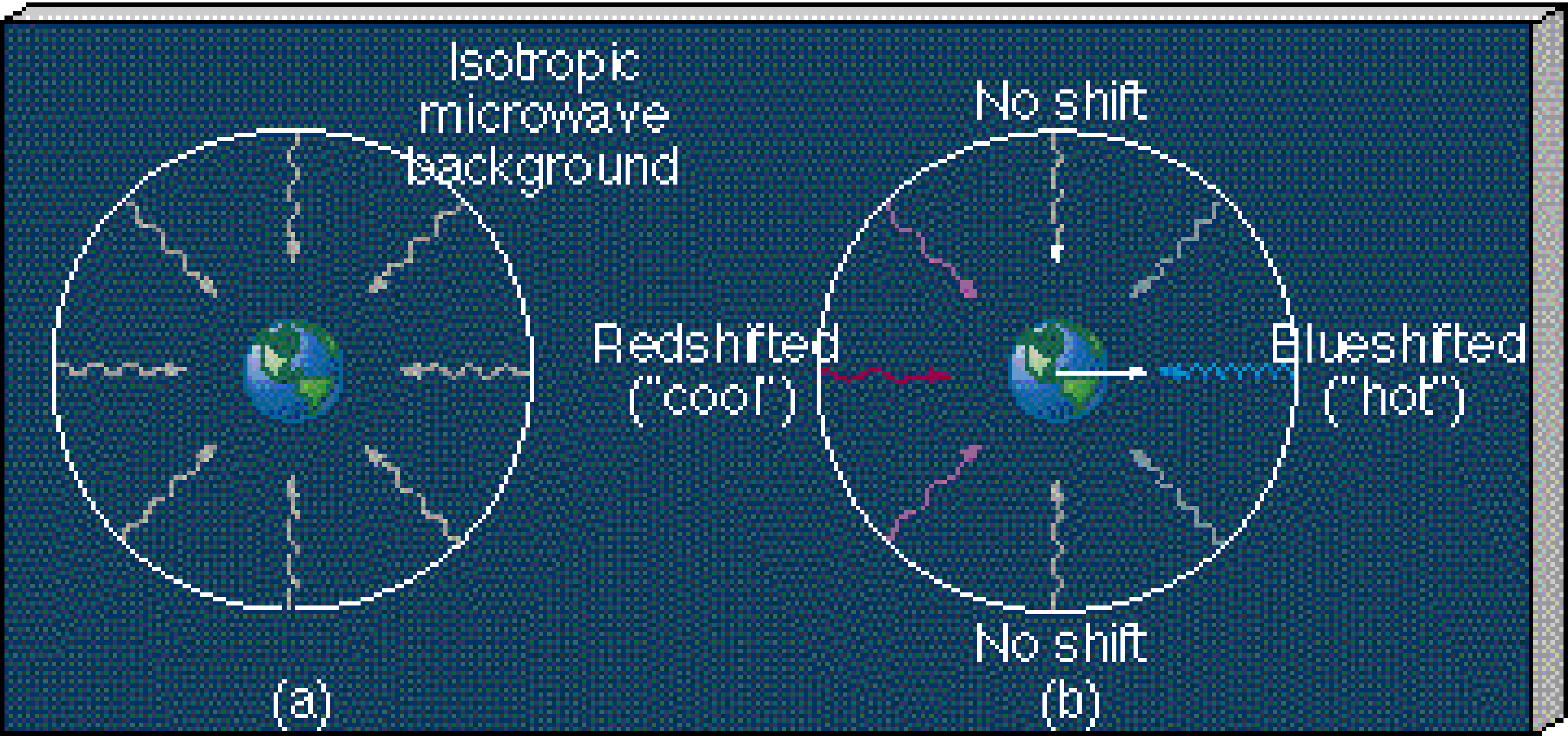




de Oliveira-Costa et al. 2008

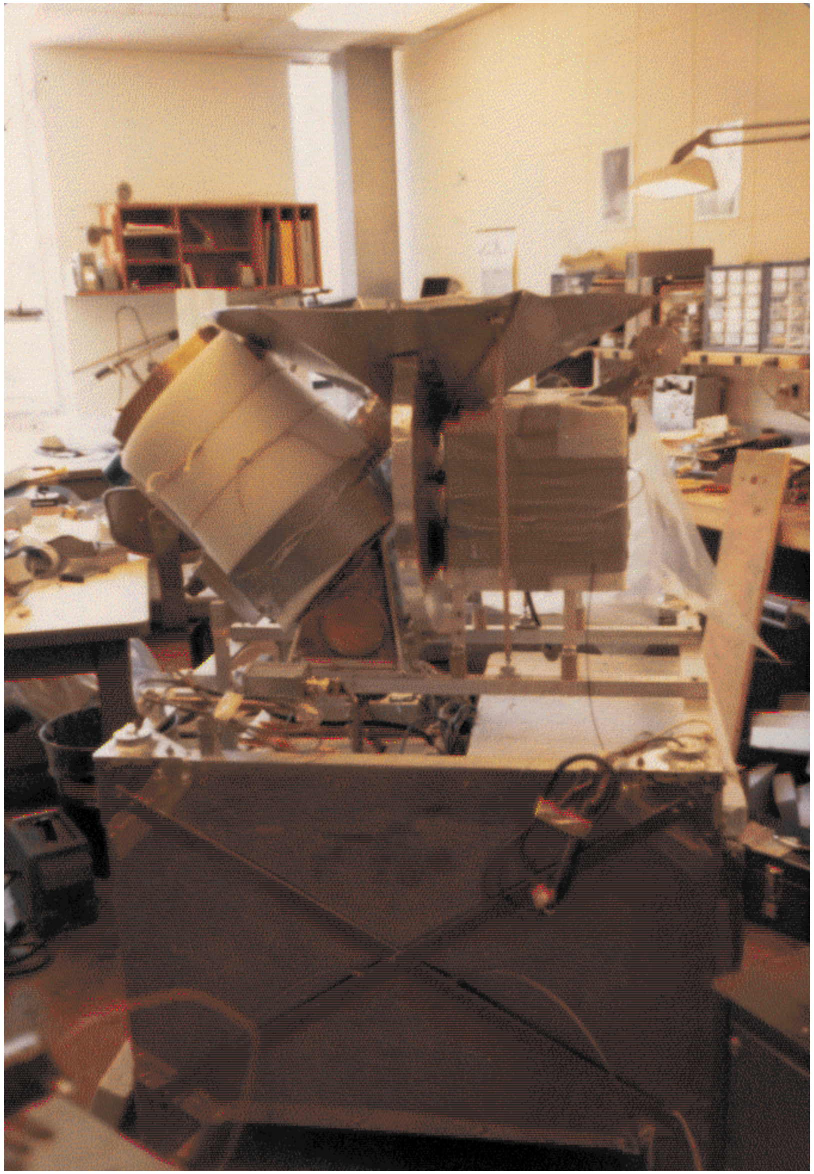
Dipole



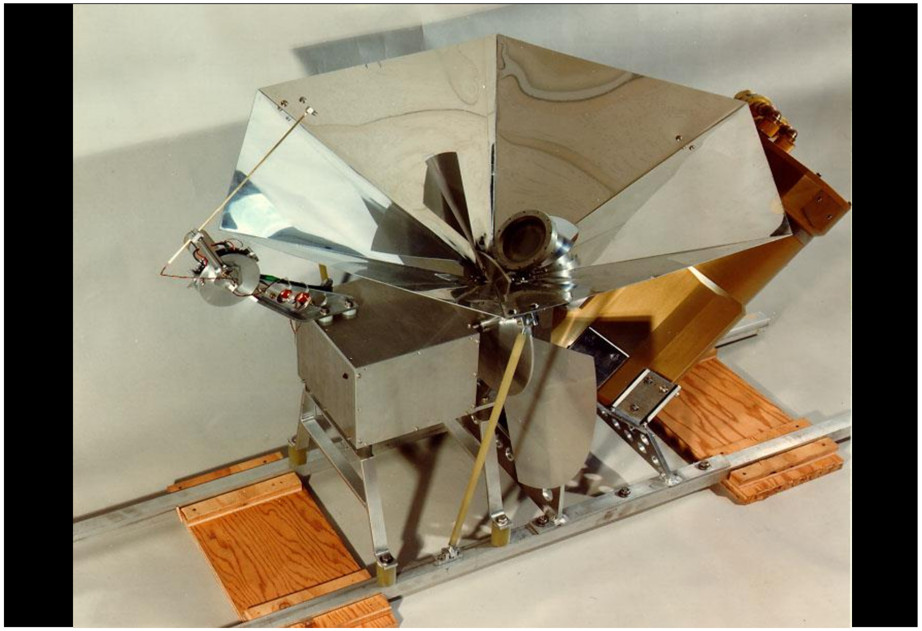
Isotropic
microwave
background
No shift
Redshifted
("cool")
Blueshifted
("hot")
No shift
(a)
(b)

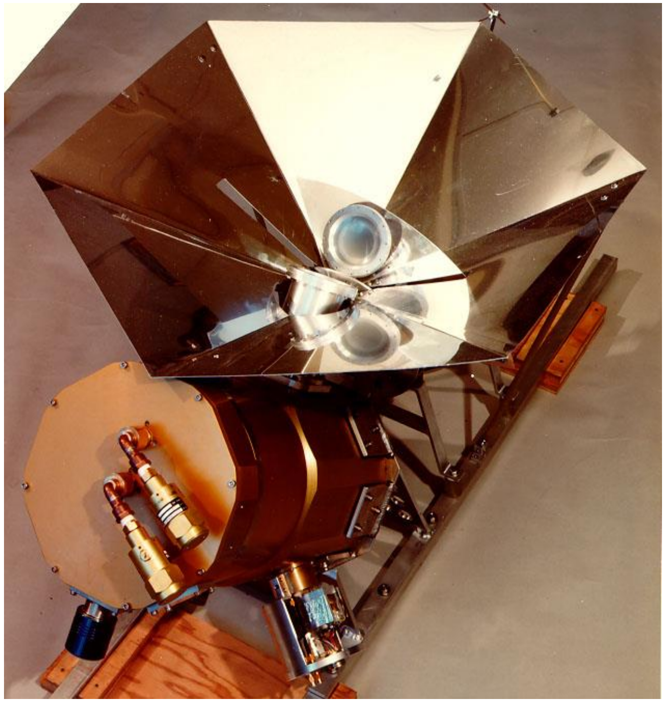
3 mm Experiment

Test bed and precursor for COBE 90 GHz DMR



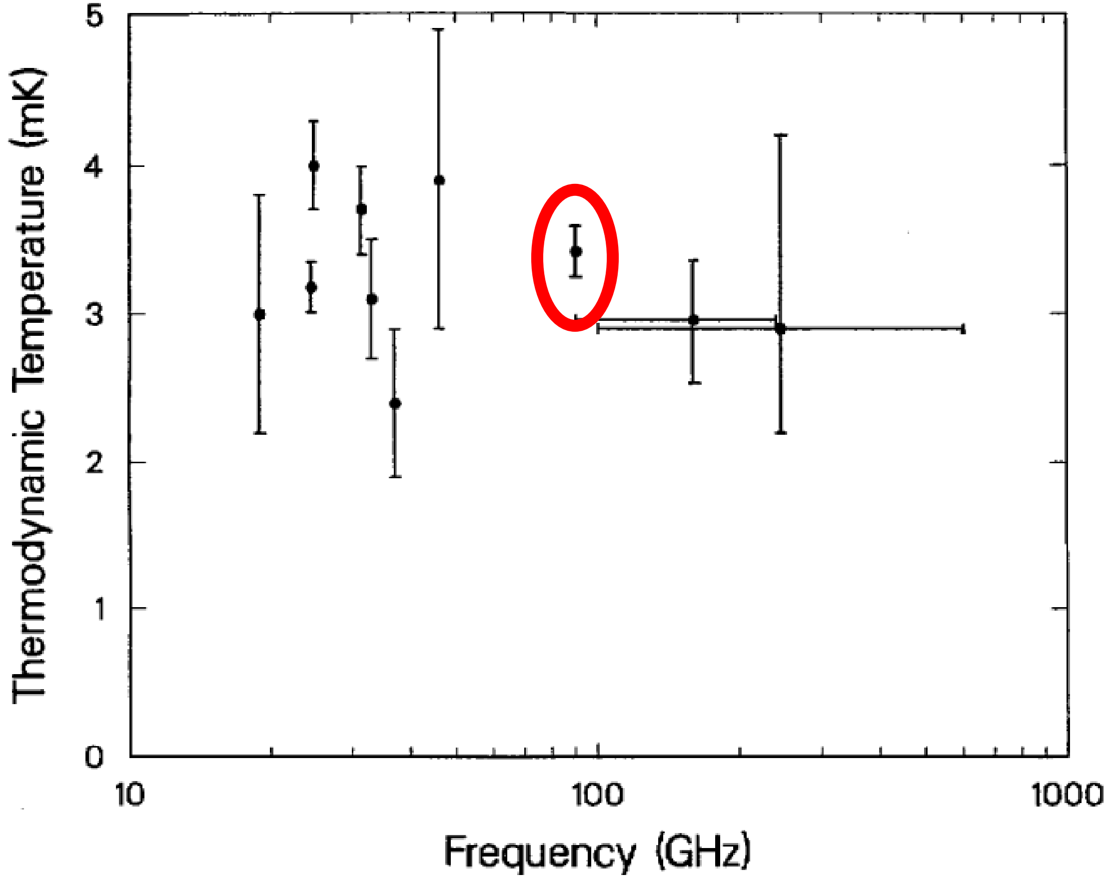
3 mm experiment – Berkeley, INPE





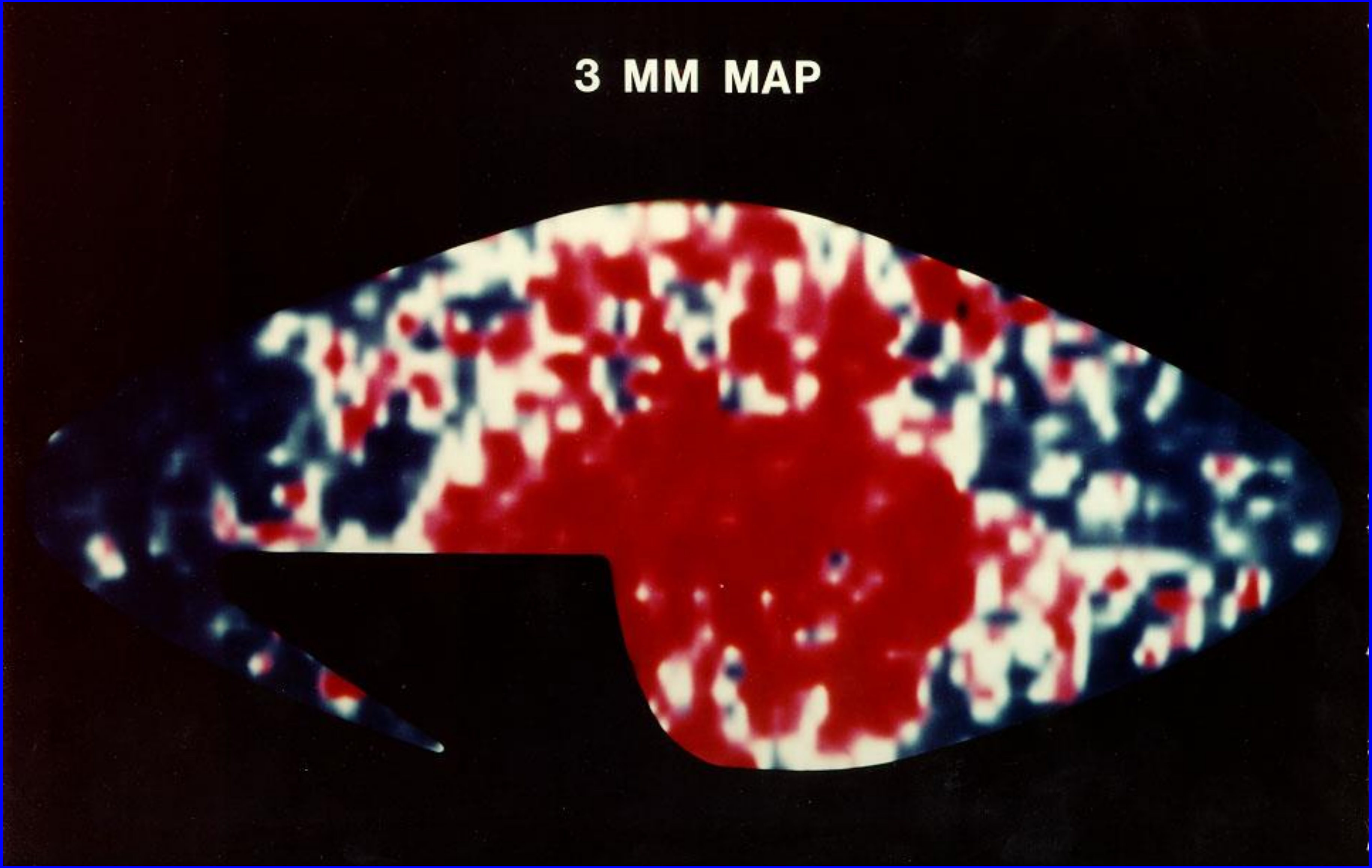
Noise temperature: 130 K
Bandwidth: 600 MHz
Gondola rotation period: 100 s
Beam width: 7º FWHM


CMB dipole measurements



Experiment	Amplitude (mk)	l(º)	b (º)
Relikt (Strukov et al. 1987)	3.16 ± 0.07	266.4 ± 2.3	48.5 ± 1.6
3 mm (Villela 1987)	3.44 ± 0.17	264.3 ± 1.9	49.2 ± 1.3
COBE (Smoot at al. 1991)	3.3 ± 0.1	265 ± 1	48 ± 1

Pre-COBE era: Brazil, 1982
COBE-DMR (90 GHz) prototype



Lubin, Villela, Epstein & Smoot 1985; Lubin & Villela 1986; Villela 1987

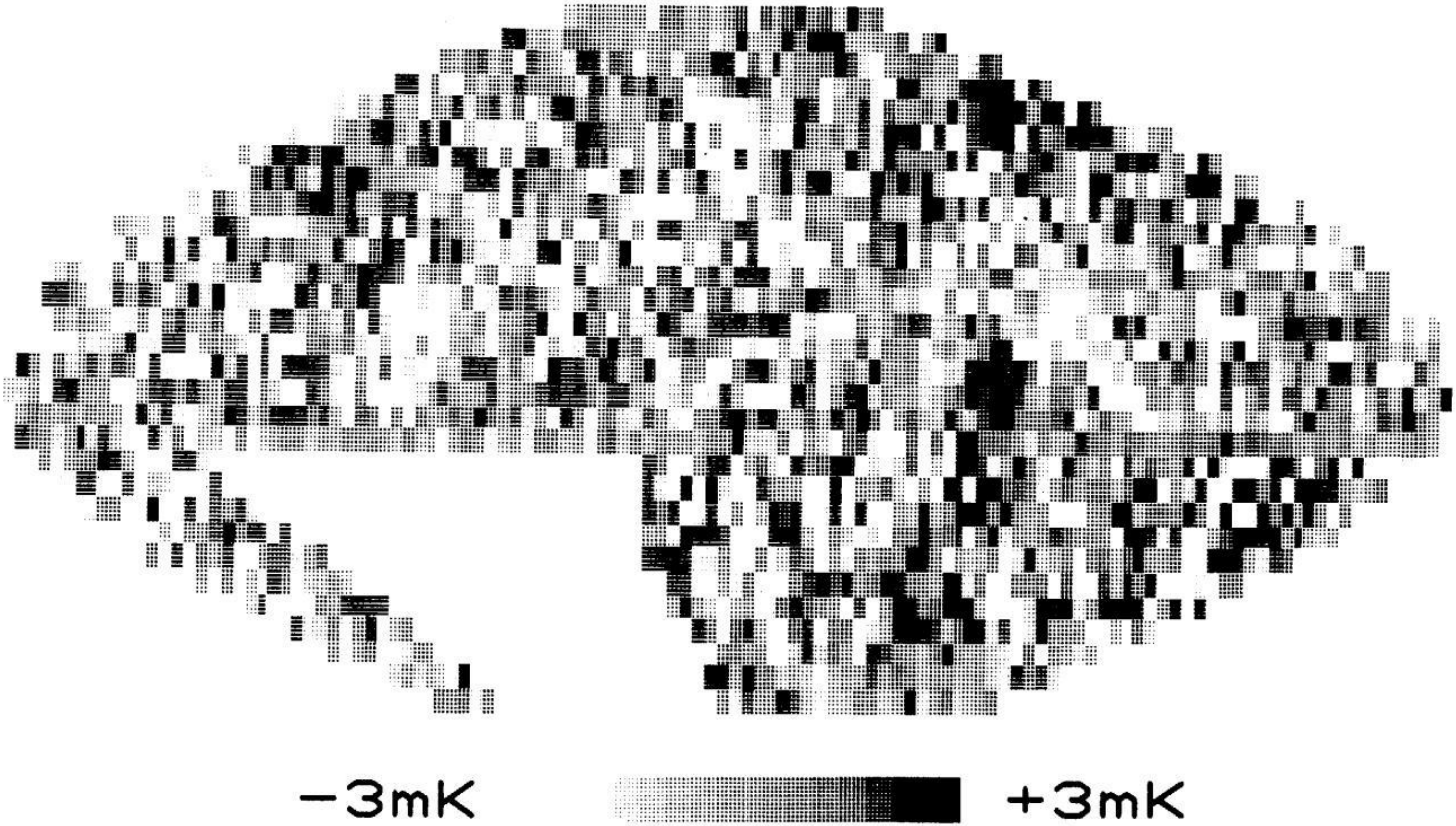
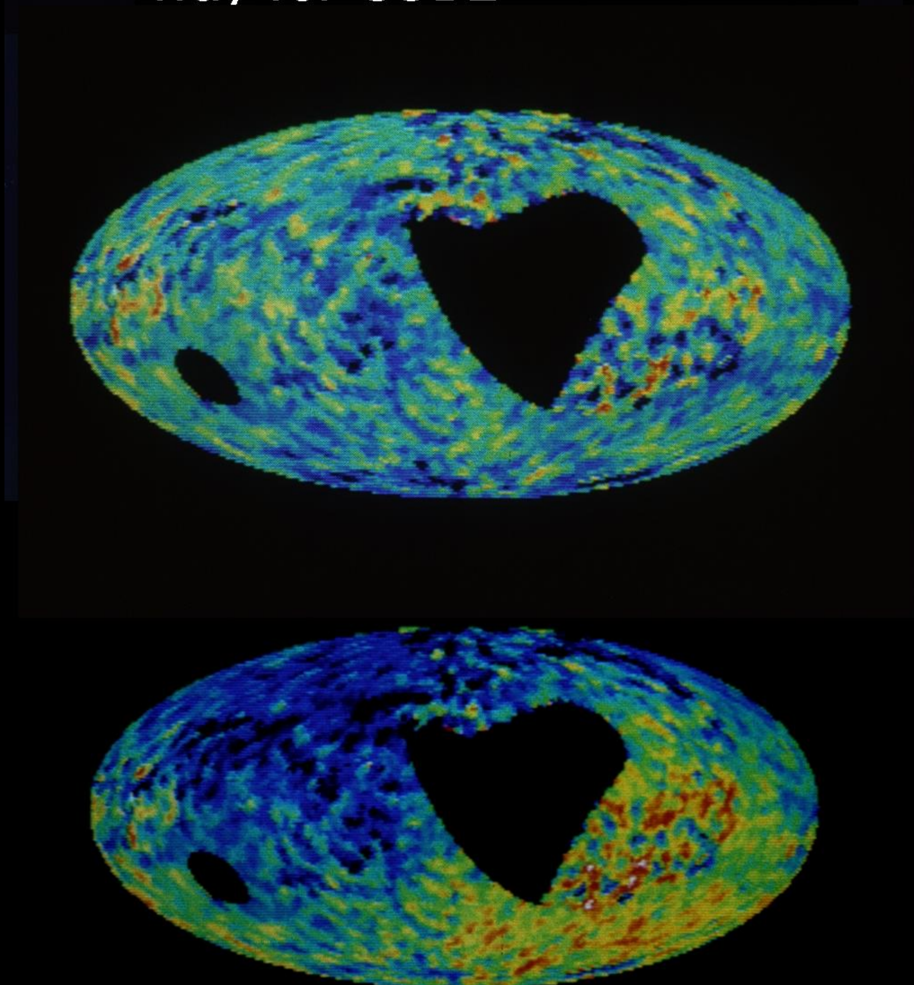


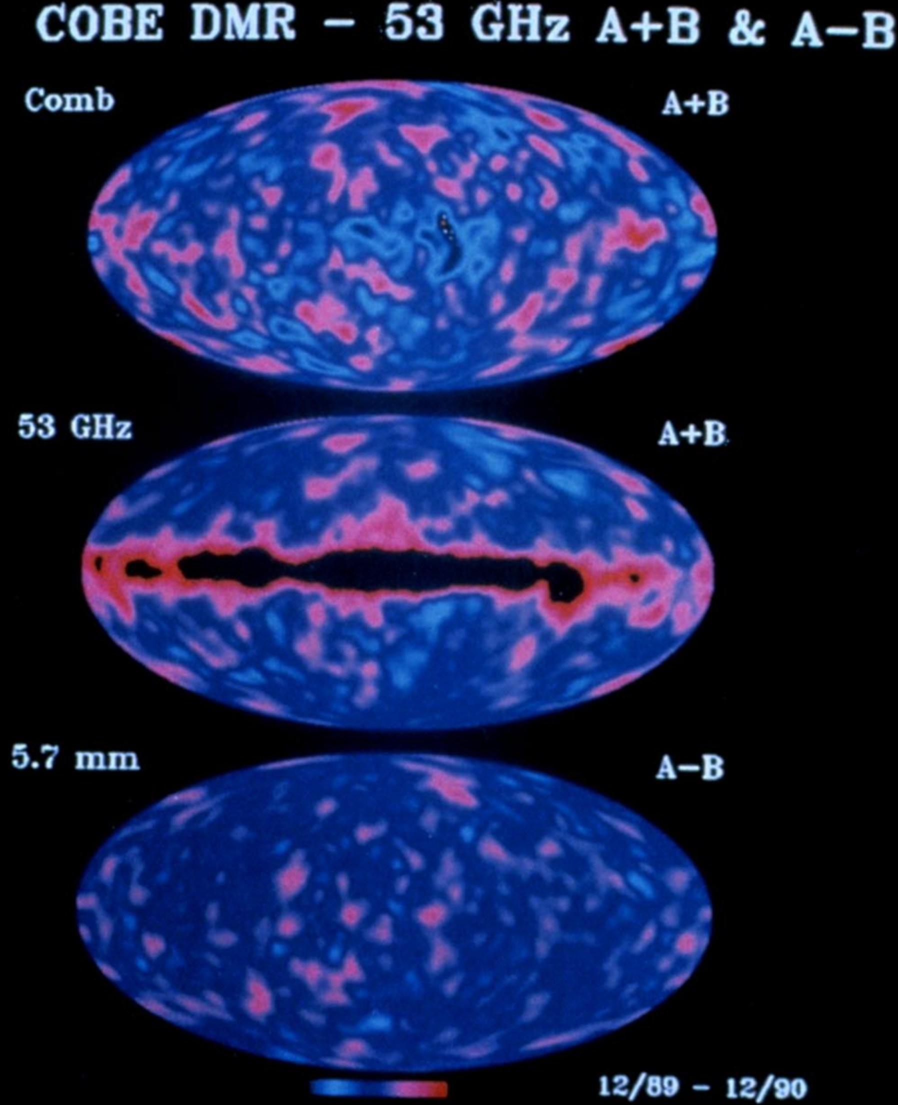
FIG. 4.—Residual map after subtraction of the dipole. Other parameters are same as Fig. 3.

LUBIN, VILLELA, EPSTEIN, AND SMOOT (*see* page L4)

Results from balloon-borne experiments that paved the way for COBE

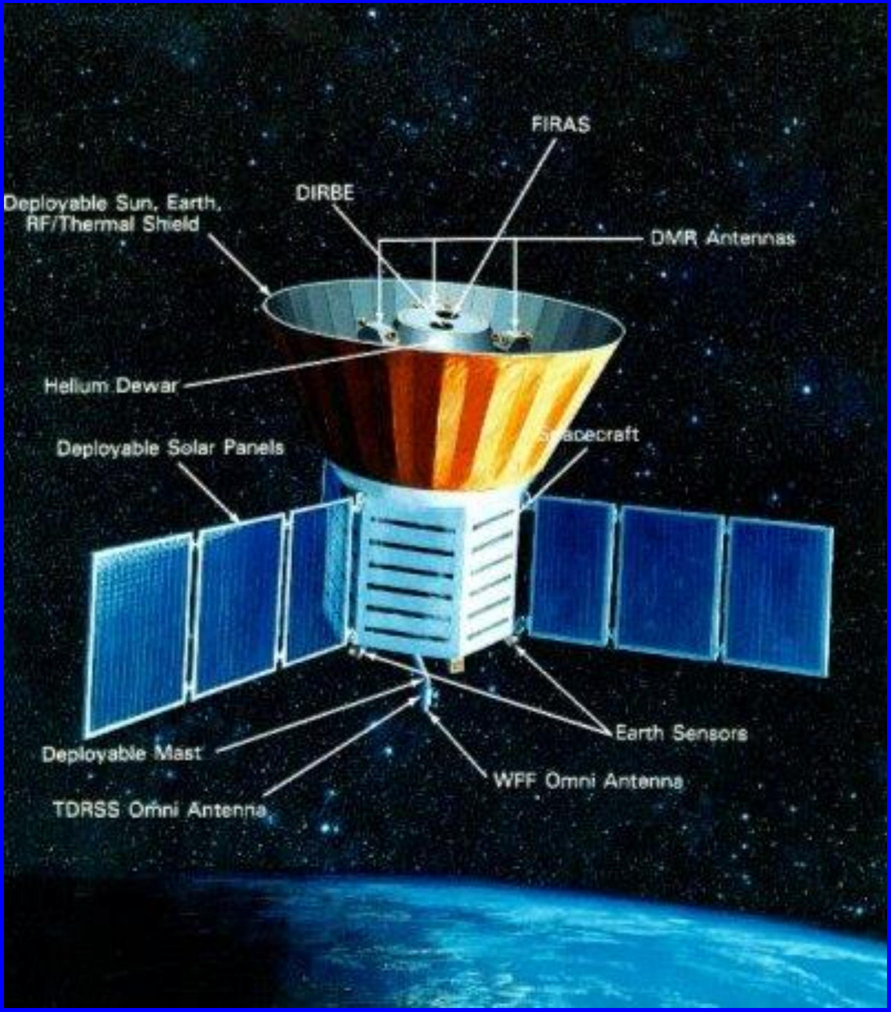


COBE Results

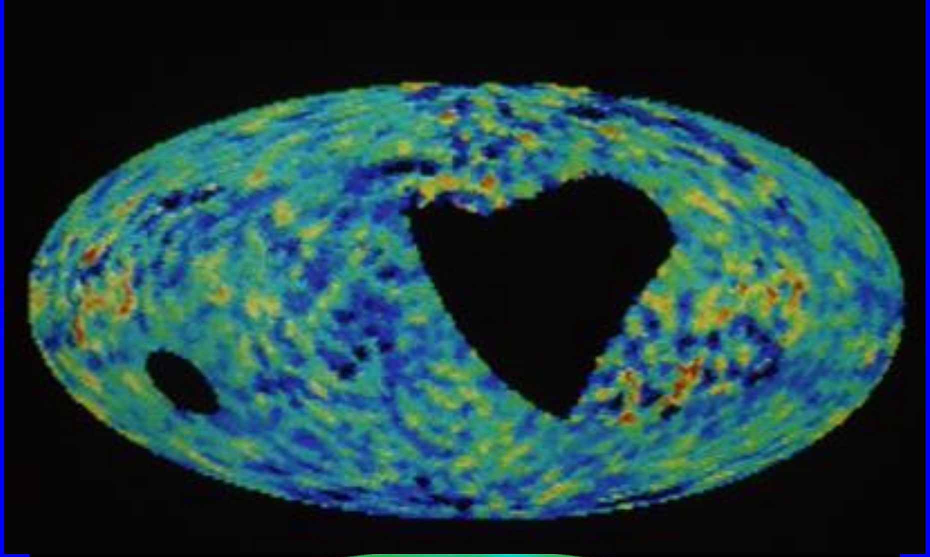


COsmic Background Explorer - COBE

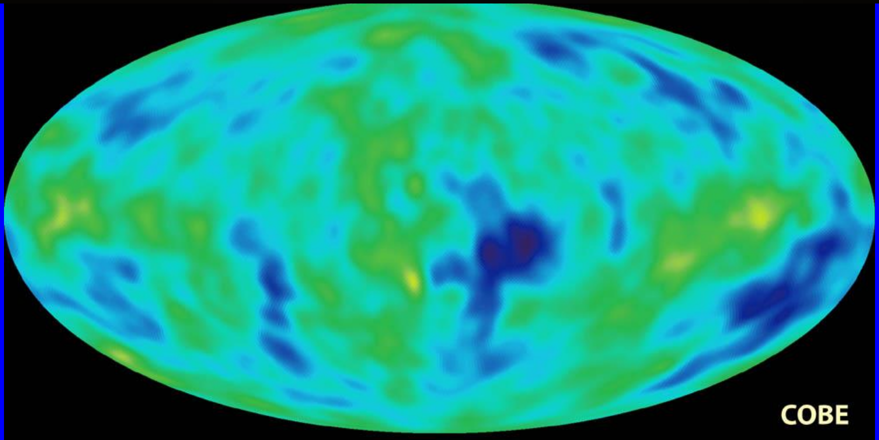
COBE 1989 (~2300 kg)



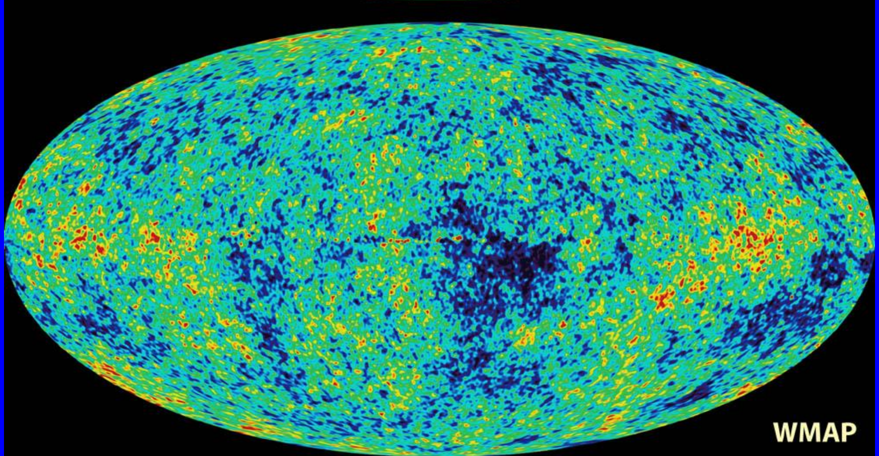
COBE 1986 (~5000 kg)



3 mm
1985, 1987



COBE
1992



WMAP
2003

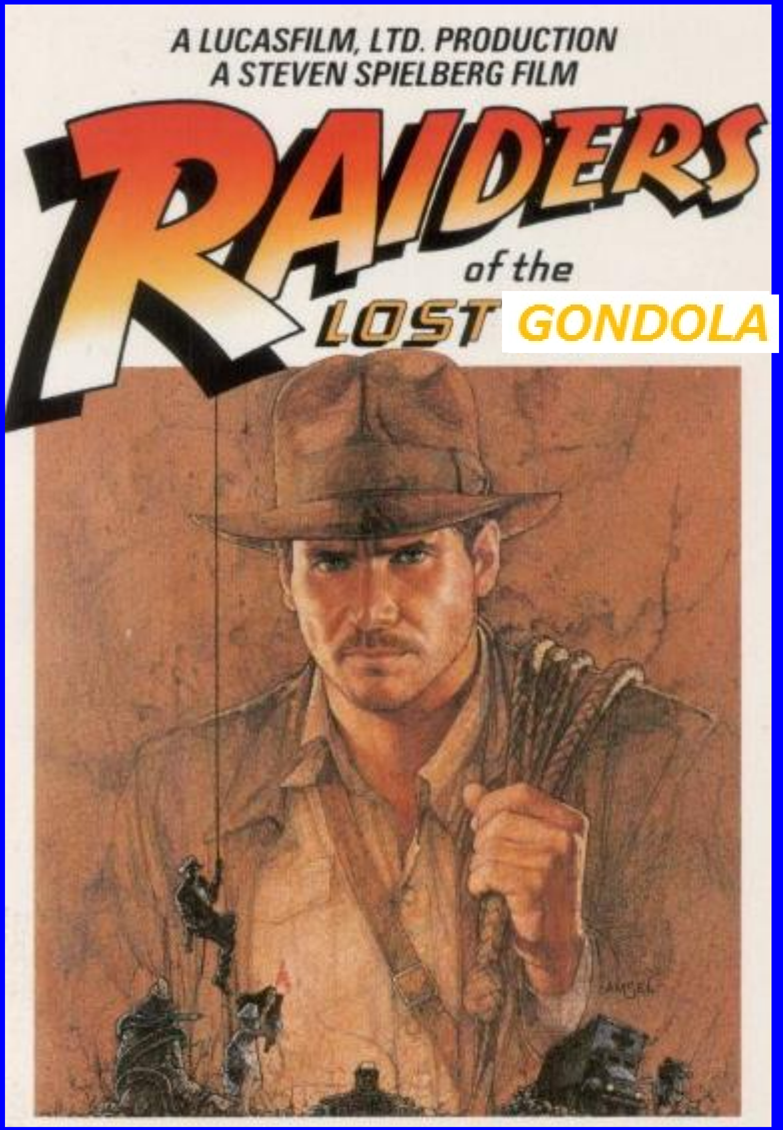

A LUCASFILM, LTD. PRODUCTION
A STEVEN SPIELBERG FILM
RAIDERS
of the
LOST GONDOLA

Figura 9 Destruição do experimento pela expedição de Tapiraí

Figura 10 João Mineiro

ACME – Advanced Cosmic Microwave Explorer

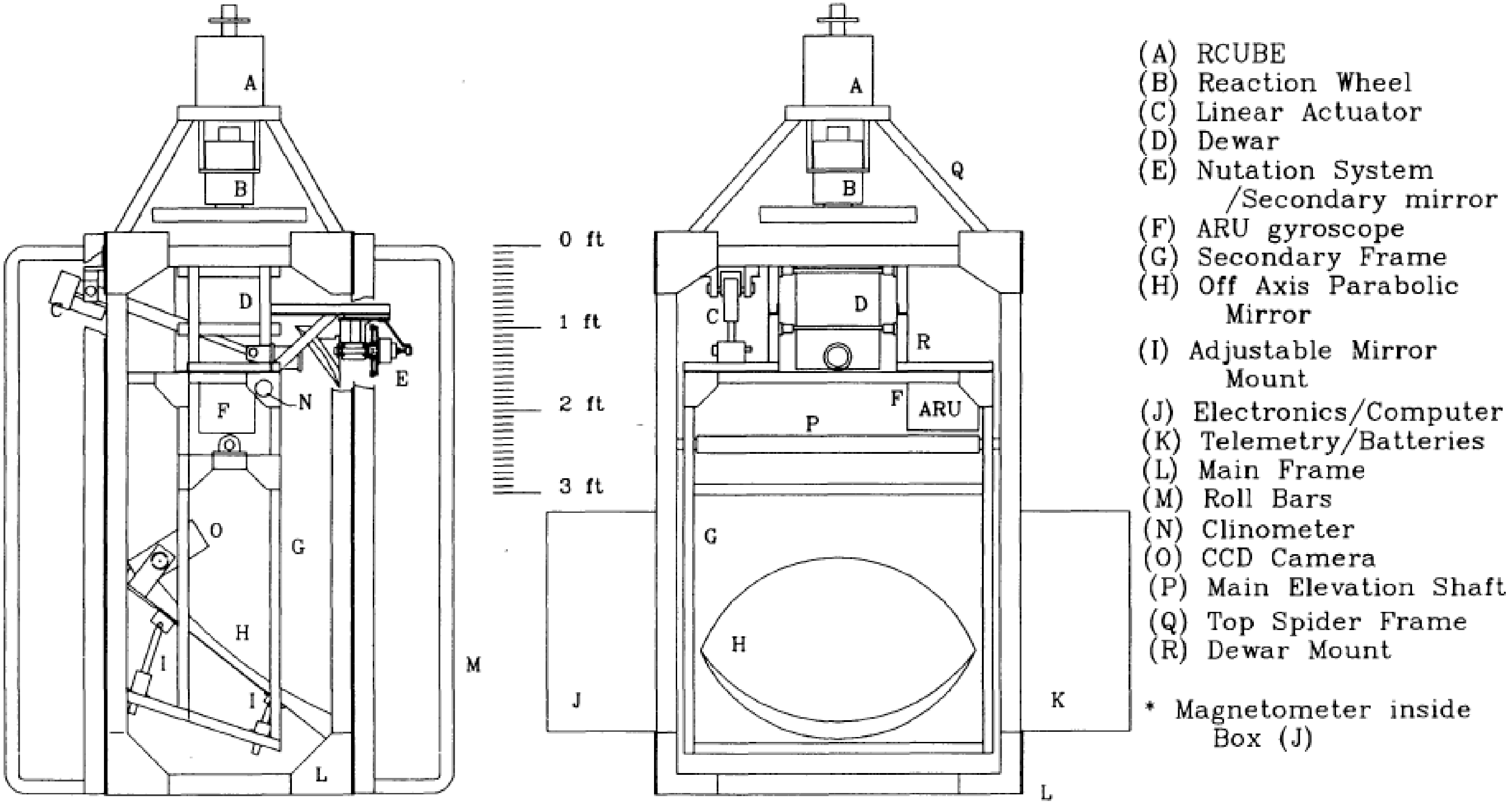


FIG. 8.—Scale drawing of gondola, including all major servo hardware and telescope elements

Meinhold et al.1993

ACME – Advanced Cosmic Microwave Explorer

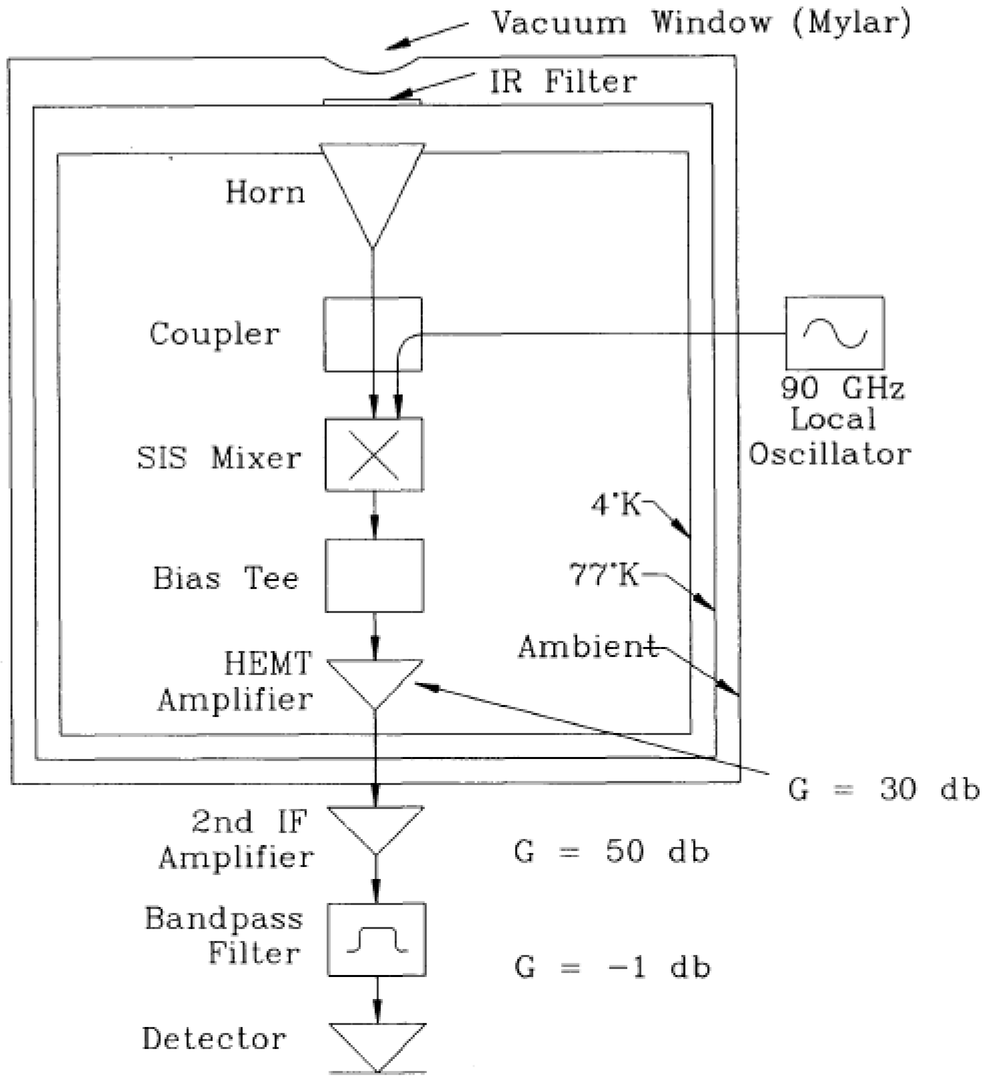


FIG. 12.—Schematic of the SIS receiver system

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ACME – Advanced Cosmic Microwave Explorer

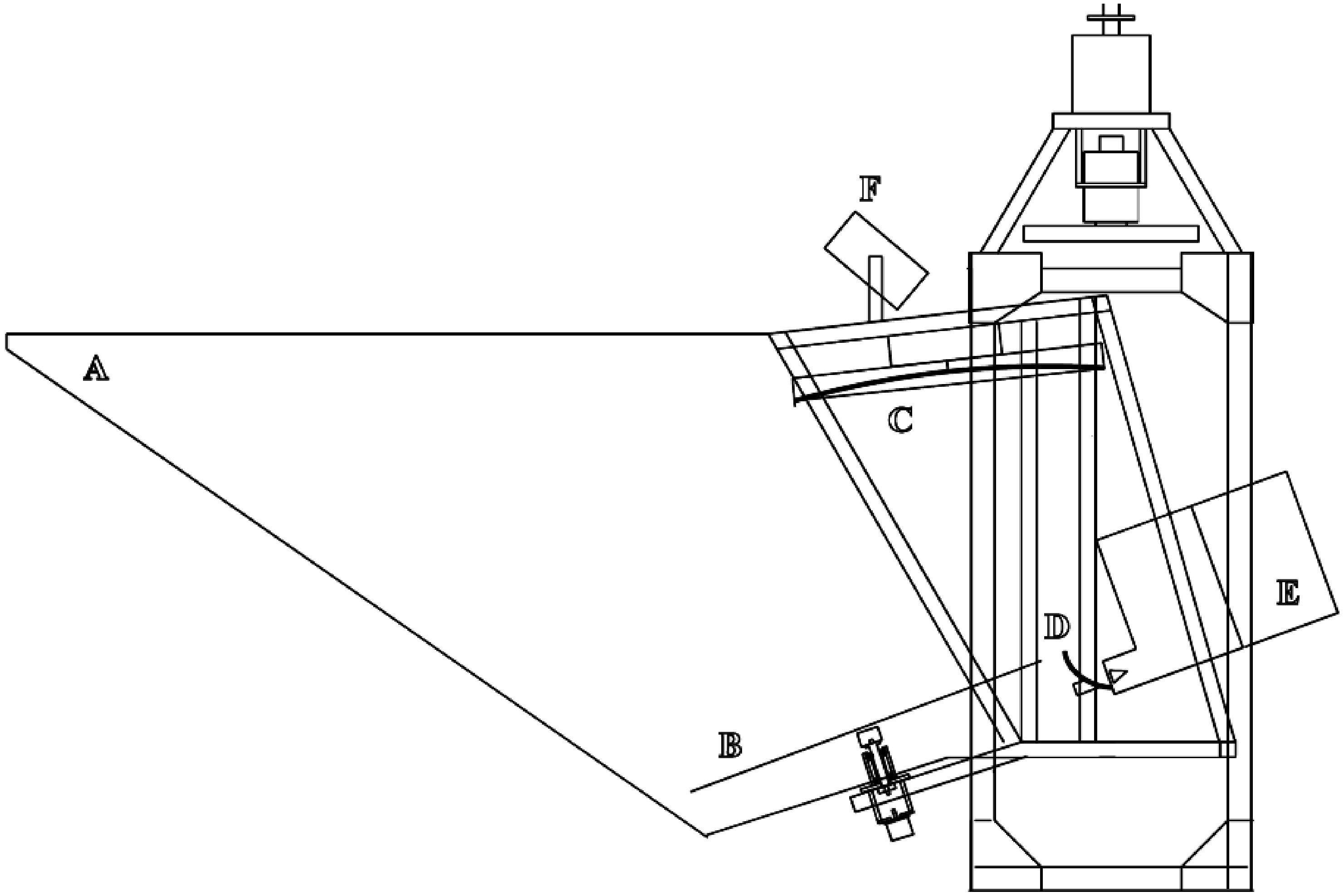


FIG. 1.—Schematic drawing of the major optical elements of HACME: A: Baffle; B: Canted spinning flat mirror; C: 1 m parabolic mirror; D: Ellipsoidal mirror; E: Dewar; F: CCD camera.

4 flights and 2 South Pole campaigns

ACME – Advanced Cosmic Microwave Explorer

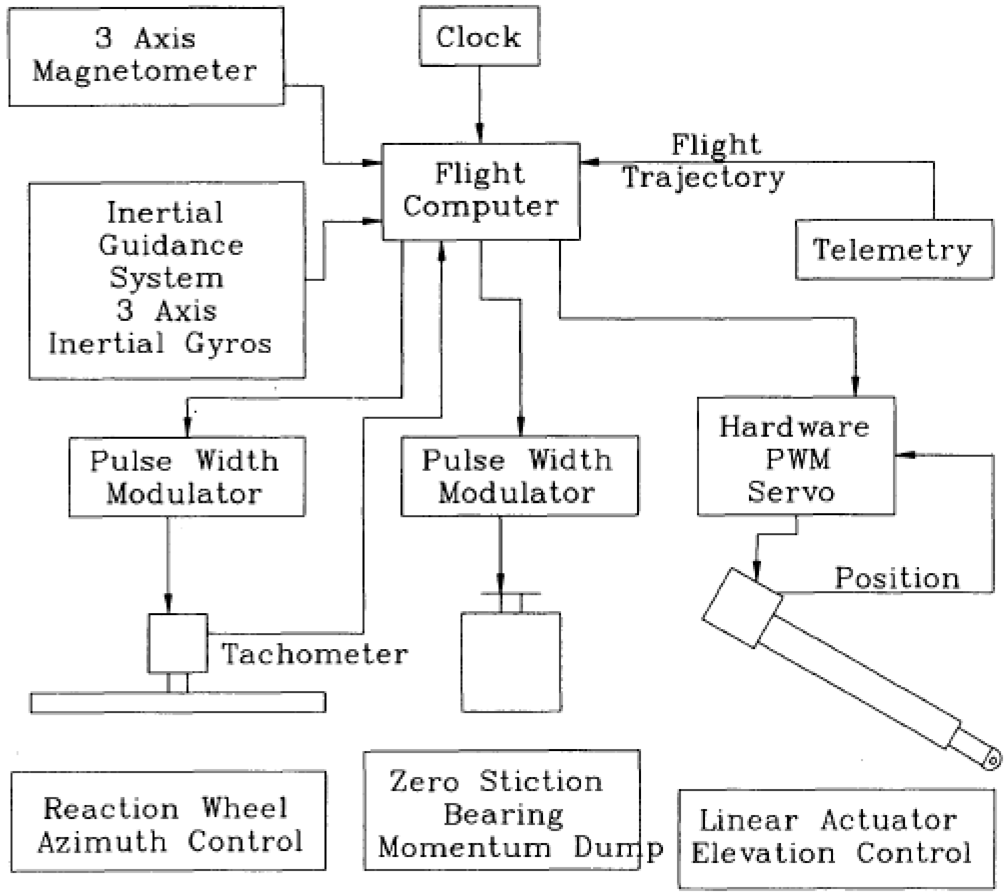
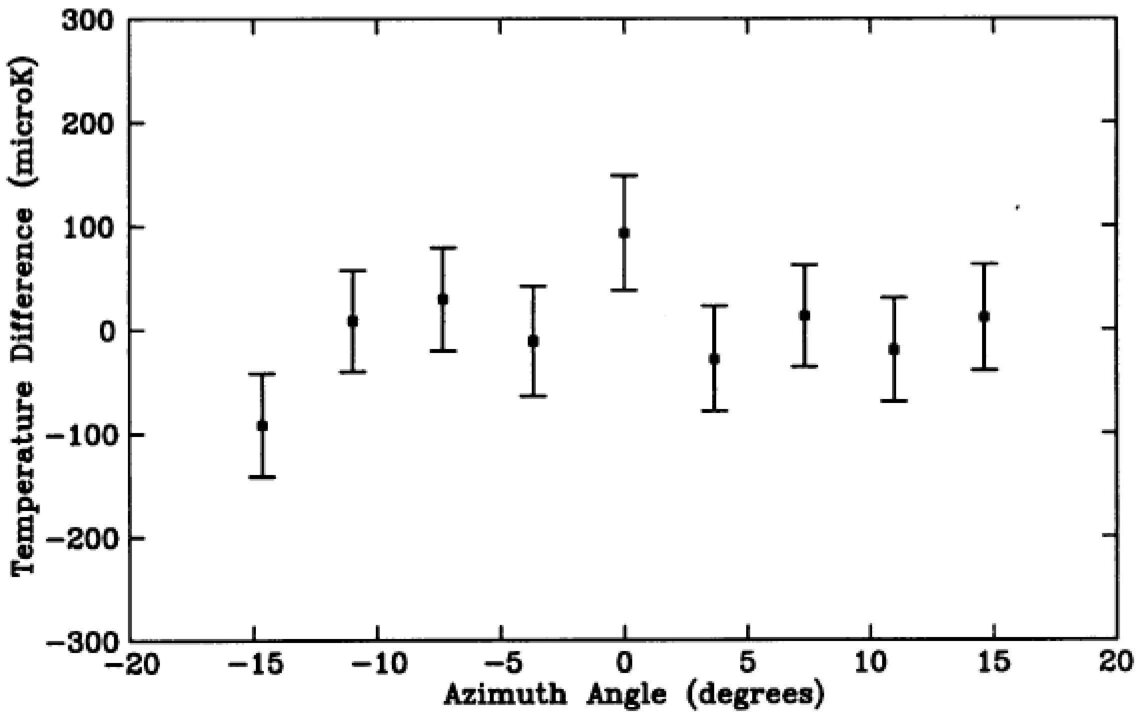


FIG. 9.—Diagram of the interaction between all portions of the servo system.

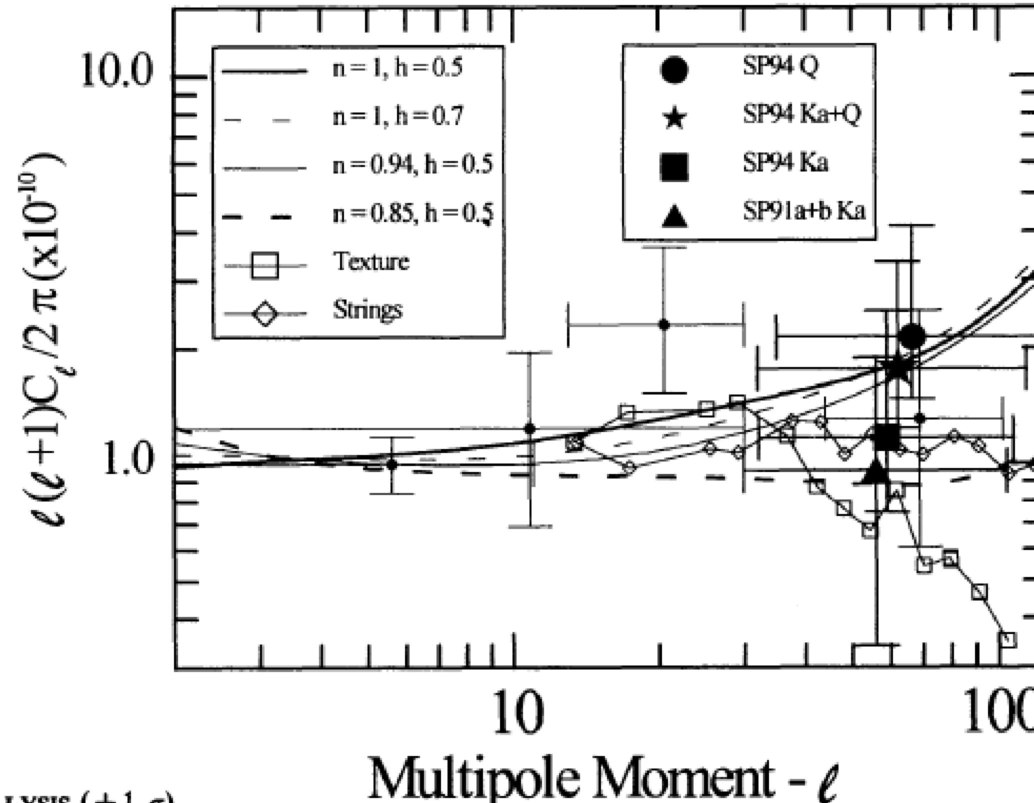
CBR MEASUREMENTS WITH THE UCSB PLATFORM

Date	Site	Detector System	Beam FWHM	Sensitivity
1988 Sep	Balloon (Palestine, TX)	90 GHz SIS receiver	0°5	6.5 mK $s^{1/2}$
1988 Nov–1989 Jan	South Pole	90 GHz SIS receiver	0.5	6.1
1989 Nov	Balloon (Fort Sumner, NM)	MAX photometer (3, 6, 9, 12 cm^{-1})	0.5	12, 2, 5.7, 7.1
1990 Jul	Balloon (Palestine, TX)	MAX photometer (6, 9, 12 cm^{-1})	0.5	0.7, 0.7, 5.4
1990 Nov–1990 Dec	South Pole	90 GHz SIS receiver	0.5	6.1
1990 Dec–1991 Jan	South Pole	4 Channel HEMT amp (25–35 GHz)	1.5	0.8
1991 Jun	Balloon (Palestine, TX)	MAX photometer (6, 9, 12 cm^{-1})	0.5	0.6, 0.6, 4.6



ACME South Pole

South Pole results



DERIVED PARAMETERS FROM LIKELIHOOD ANALYSIS ($\pm 1\ \sigma$)

Band (1)	$\Delta T_{\rm rms}$ (μK) (2)	β (3)	$\Delta T_{\rm rms}$ (μK) (4)	$\langle C_\ell \ell(\ell+1)/(2\pi)\rangle_B$ ($\times 10^{-10}$) (5)
Q-band	$43.1^{+16.9}_{-7.4}$	$1.7^{+1.5}_{-1.6}$	$49.6^{+19.4}_{-8.4}$	$2.14^{+2.00}_{-0.66}$
Ka-band......	$30.5^{+14.7}_{-5.7}$	$0.2^{+0.9}_{-1.4}$	$31.9^{+14.7}_{-6.4}$	$1.17^{+1.33}_{-0.42}$
Ka + Q	$31.3^{+11.3}_{-6.0}$	$0.9^{+0.3}_{-0.6}$	$41.2^{+15.5}_{-6.7}$	$1.77^{+1.58}_{-0.53}$

NOTE.—Cols. (2)–(3): The rms amplitude and spectral index β determined from the likelihood analysis using a "flat" radiation power spectrum given by $C_\ell \propto (f^k f^l)^\beta/[\ell(\ell+1)]$, where f^k is the center frequency of channel k normalized to the lowest frequency of the observation. Col. (4): The rms amplitude for $\beta = 0$. Col. (5): CMB band power estimates for $\beta = 0$.

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Results from the HACME / ACE balloon flight

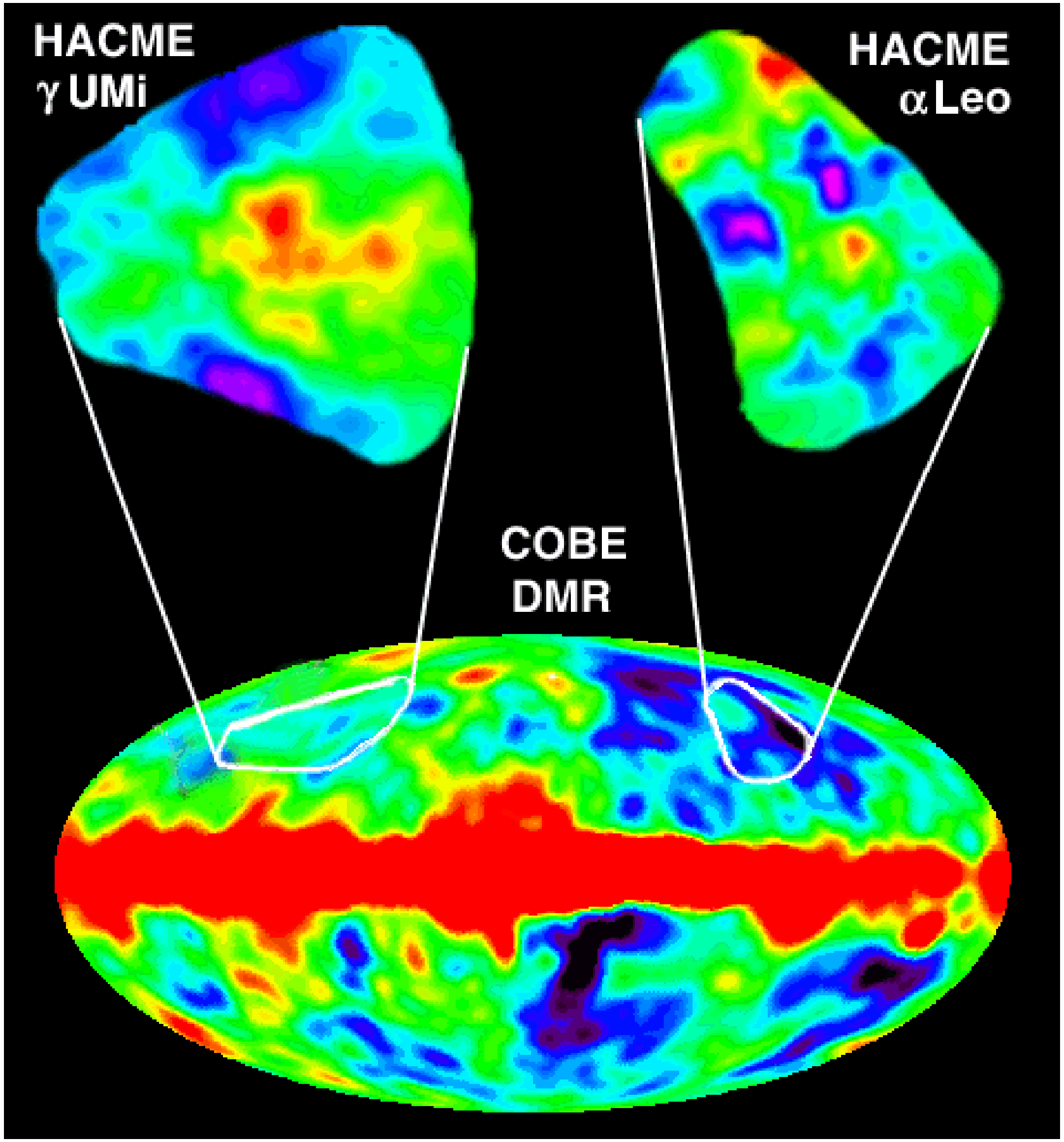
Observations covering 1150 square degrees near the stars γ Ursae Minoris and α Leonis

39, 41, 43 GHz

Beam FWHM ~ $0.^{0}77$

Frequencies: 39 GHz
41 GHz
43 GHz

Cosmic signal: < 77 microK



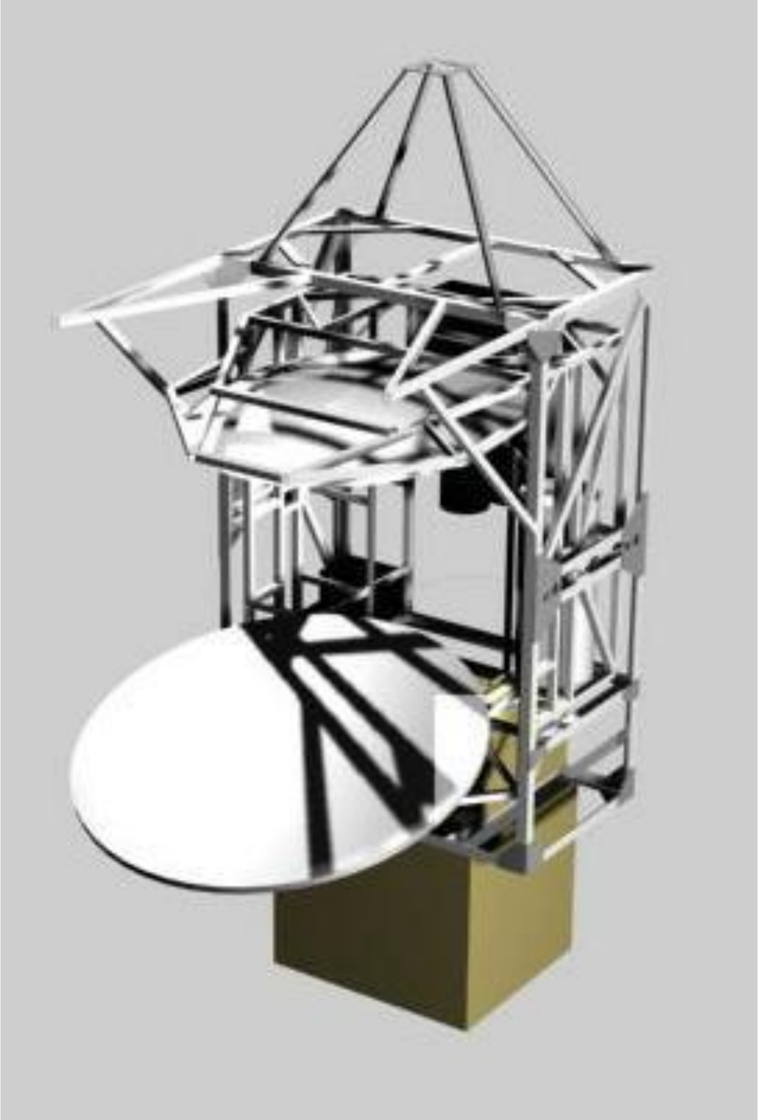
Staren et al. 2000

Tegmark et al. 2000

BEAST

Background Emission Anisotropy Scanning Telescope

UCSB
INPE
JPL/NASA
Unifei
Univ. Milano
Univ. Roma
IASF/CNR
Caltech
Univ. Illinois



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BEAST radiometers

Channel-band (GHz)		T_{sys} (K)	Band width (GHz)	Sensitivity (μK. s $^{1/2}$)	Beam size (arcmin.)
2 – Q*	(38 – 45)	24.3	4.54	670	23
3 – Q*	(38 – 45)	35.8	3.72	1100	23
4 – Q	(38 – 45)	27.8	4.37	725	23
6 - Ka	(26 – 36)	35.6	5.08	970	31
7 - Ka	(26 – 36)	23.1	4.56	810	31
8 – Q	(38 – 45)	31.0	3.58	940	23

* Channels 2 and 3 are the two polarization outputs from the single feed attached to the ortho-mode transducer

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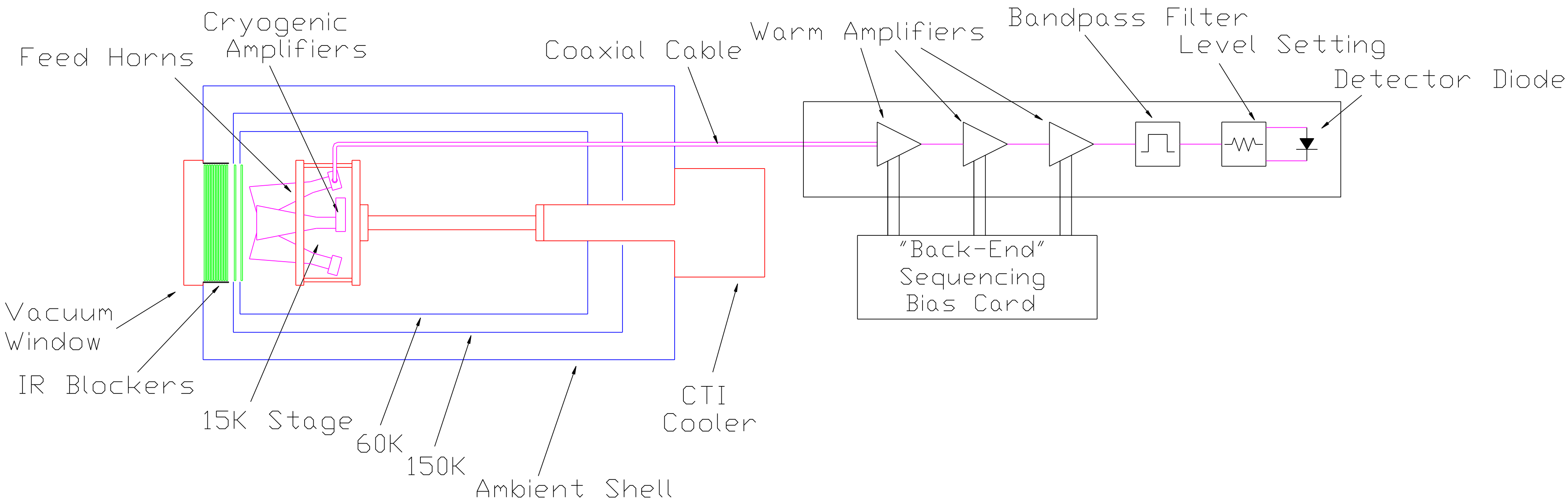
BEAST radiometer



CMB radiation enters through the vacuum window terminating into scalar feed horns. Cryogenic low noise amplifiers boost signal which is then sent to warm amplification stages via coaxial cable. After warm amplification, bandpass is defined and signal level is adjusted before termination onto the detector diode.

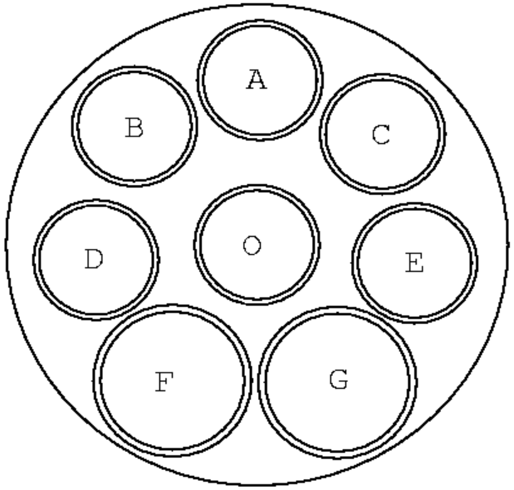
(Childers et al. 2005)

O Experimento BEAST

(Radiotelescópio gregoriano não axial)

Características do sistema de detectores do BEAST

Tipo de Receptor	Radiômetros	
Bandas	K_a	Q
Freqüências (GHz)	30	41,5
Largura de Banda (GHz)	8	7
Número de Cornetas	2	6
Resolução Angular (FWHM)	0,5°	0,35°
T_{sys} (K)	30	15
Sensibilidade por corneta ($\mu K \sqrt{s}$)	500	250



Parâmetros que definem o sistema óptico do telescópio.

Espelho Primário Paraboloidal	
Distância focal	1250,0 mm
Eixo maior	2200,0 mm
Abertura	1966,1 mm
Rugosidade (rms)	< 20 μm
Espelho Secundário Elipsoidal	
Distância Focal	170,0 mm
Semi-eixo maior	600,0 mm
Semi-eixo menor	575,4 mm
Abertura	800,0 mm
Excentricidade	0,2833
Rugosidade (rms)	< 20 μm
Espelho Plano	
Diâmetro	2600,0 mm
Rugosidade (rms)	< 100 μm

Figueiredo 1997

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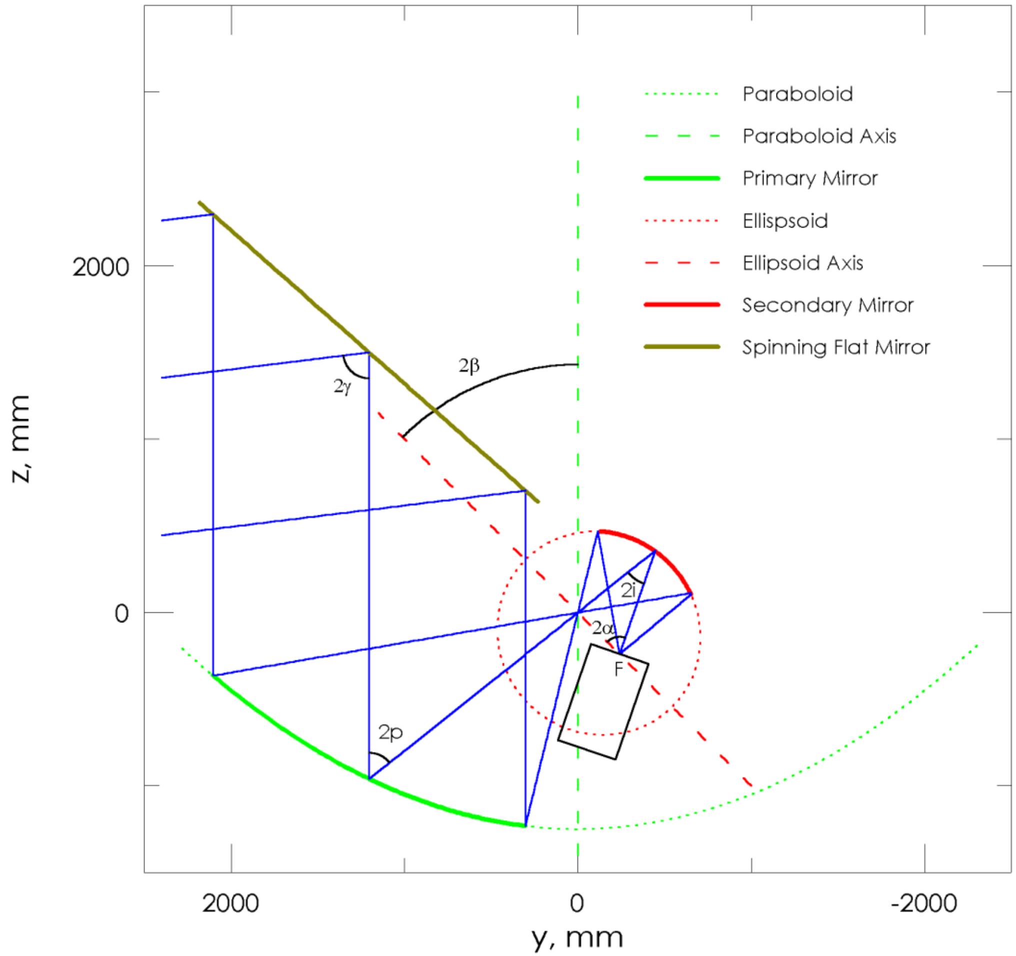
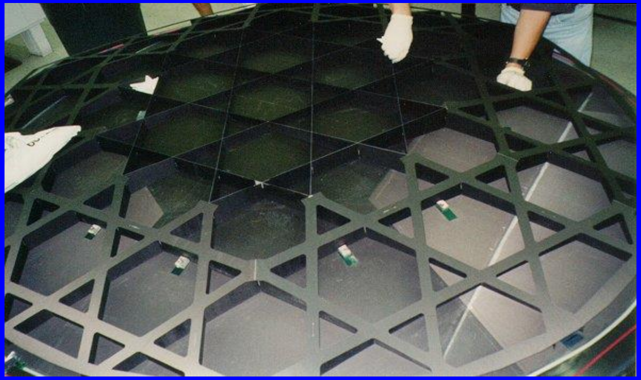
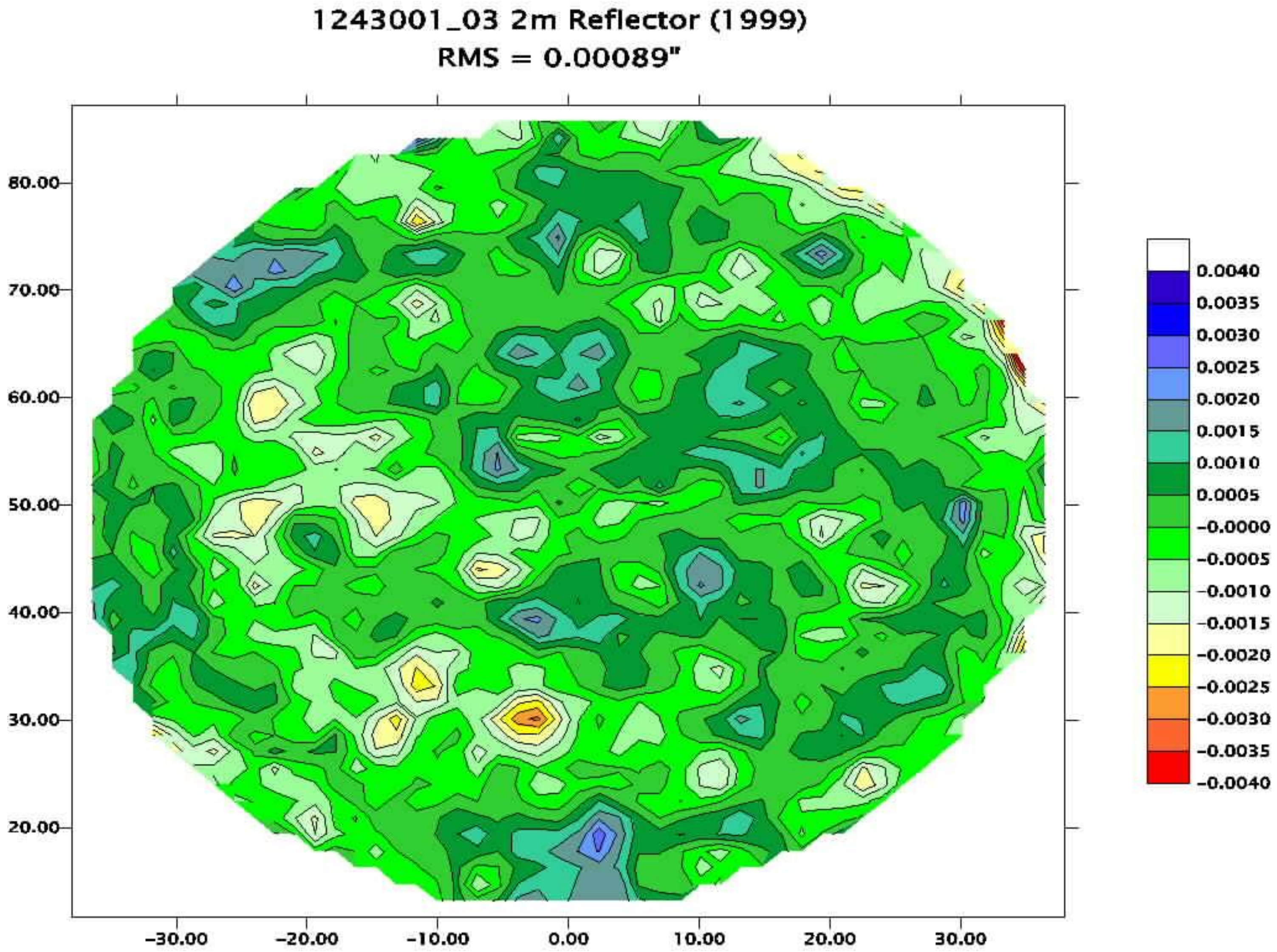
BEAST
Gregorian off-axis telescope optical parameters



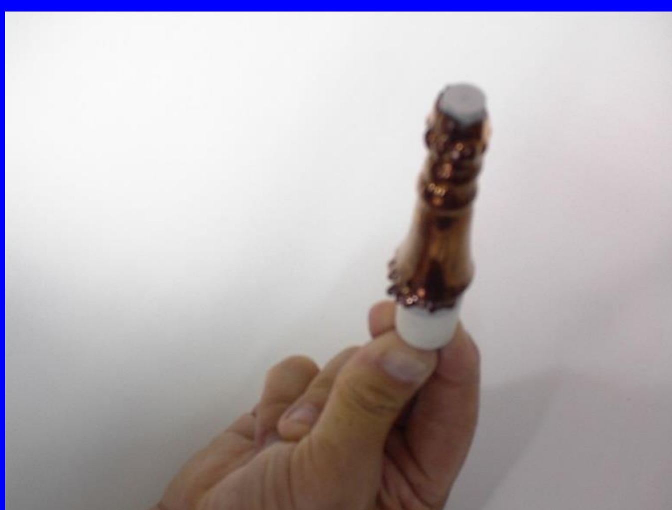
Primary Mirror	
Focal distance	1250.0 mm
Semi-major axis	2200.0 mm
Aperture	1966.1 mm
Secondary Mirror	
Semi-major axis	600.0 mm
Semi-minor axis	575.4 mm
Focal distance	170.0 mm
Eccentricity	0,2833
Flat Mirror	
Diameter	2600.0 mm

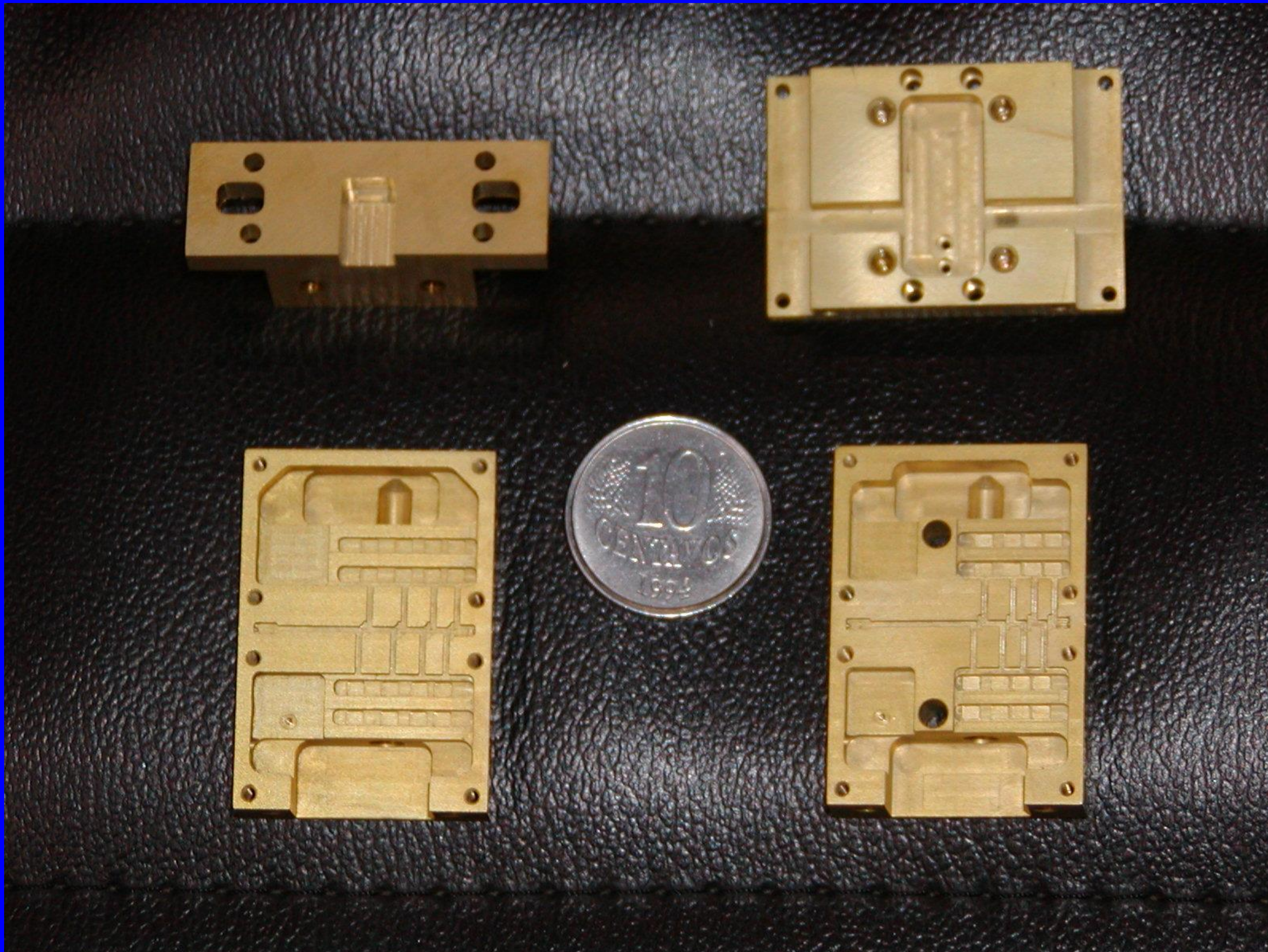
(Figueiredo et al. 2005)

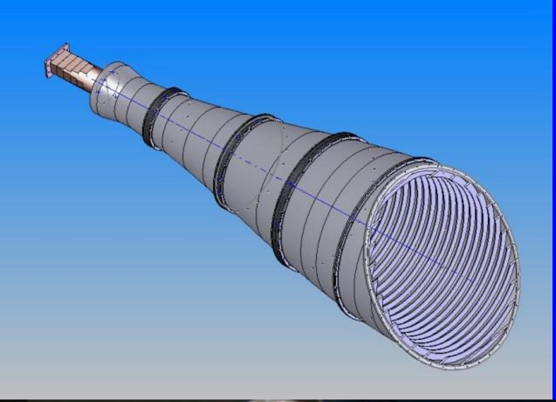
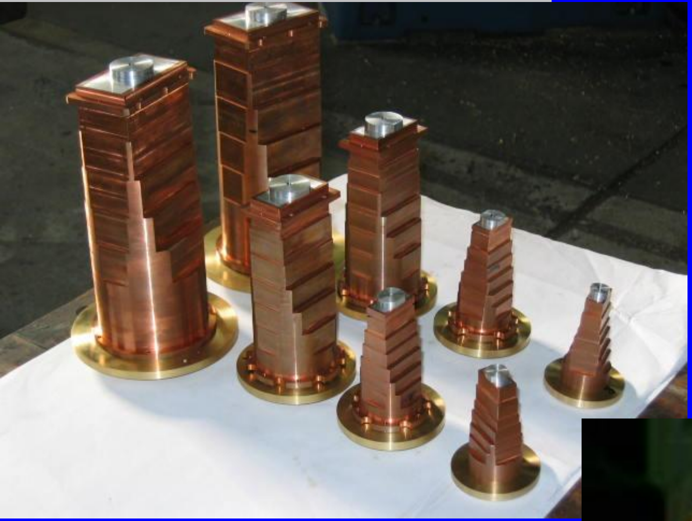


Error plot of primary reflector used for all BEAST campaigns. The 2.2-meter parabolic reflector has less than .001" rms error from the desired surface




10
CENTAVOS
1994

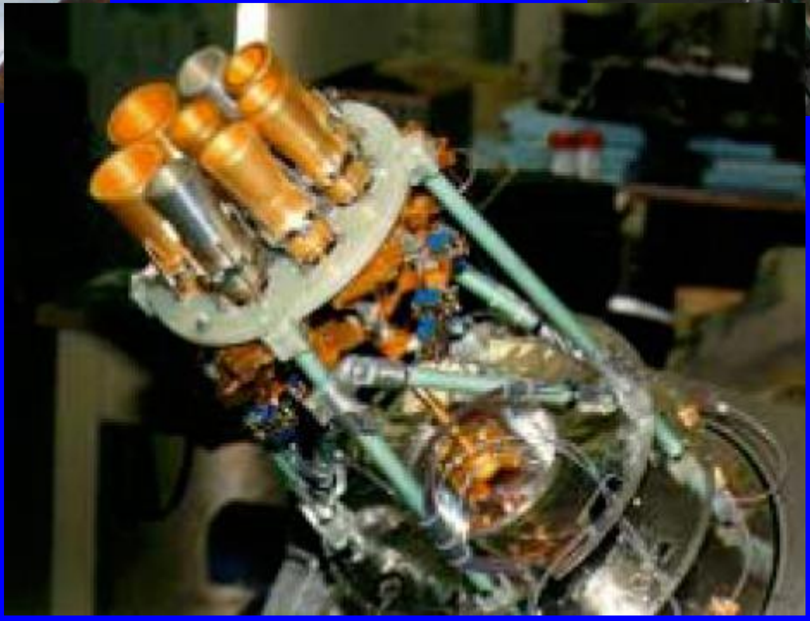


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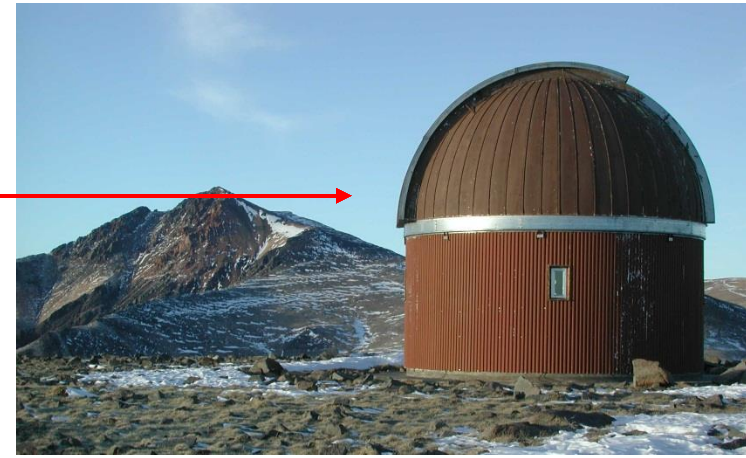
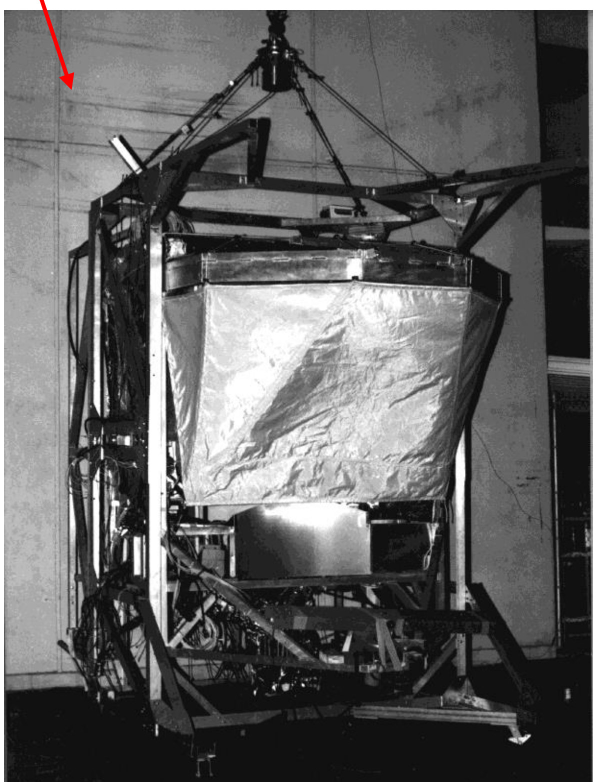
Figure 4

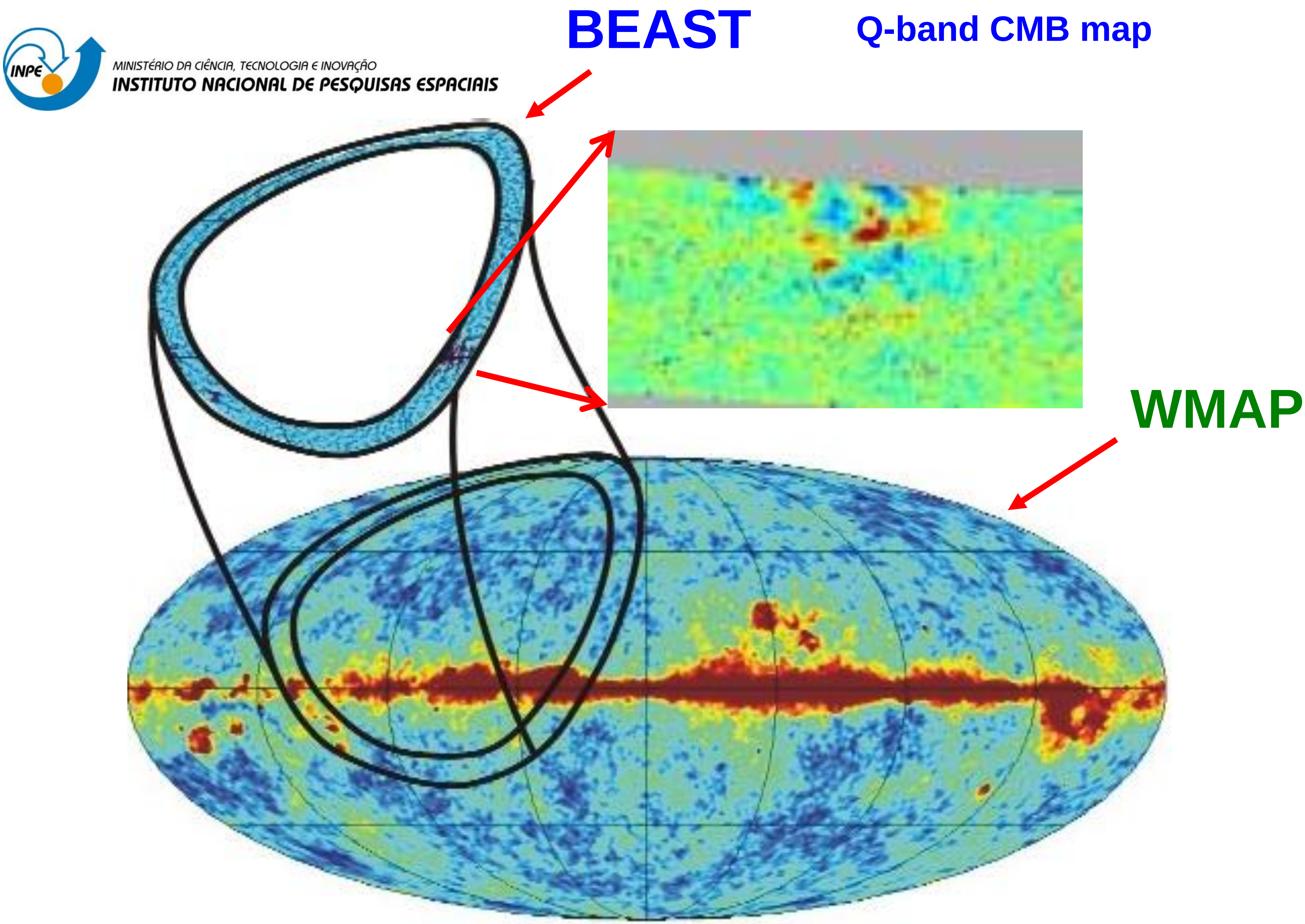
BEAST getting ready for flight
in Fort Sumner (USA), in October 2000.

BEAST collected CMB data from the ground at White Mountain Research Station (USA)

(altitude ~ 3800 m)







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BEAST
Q-band CMB map
WMAP

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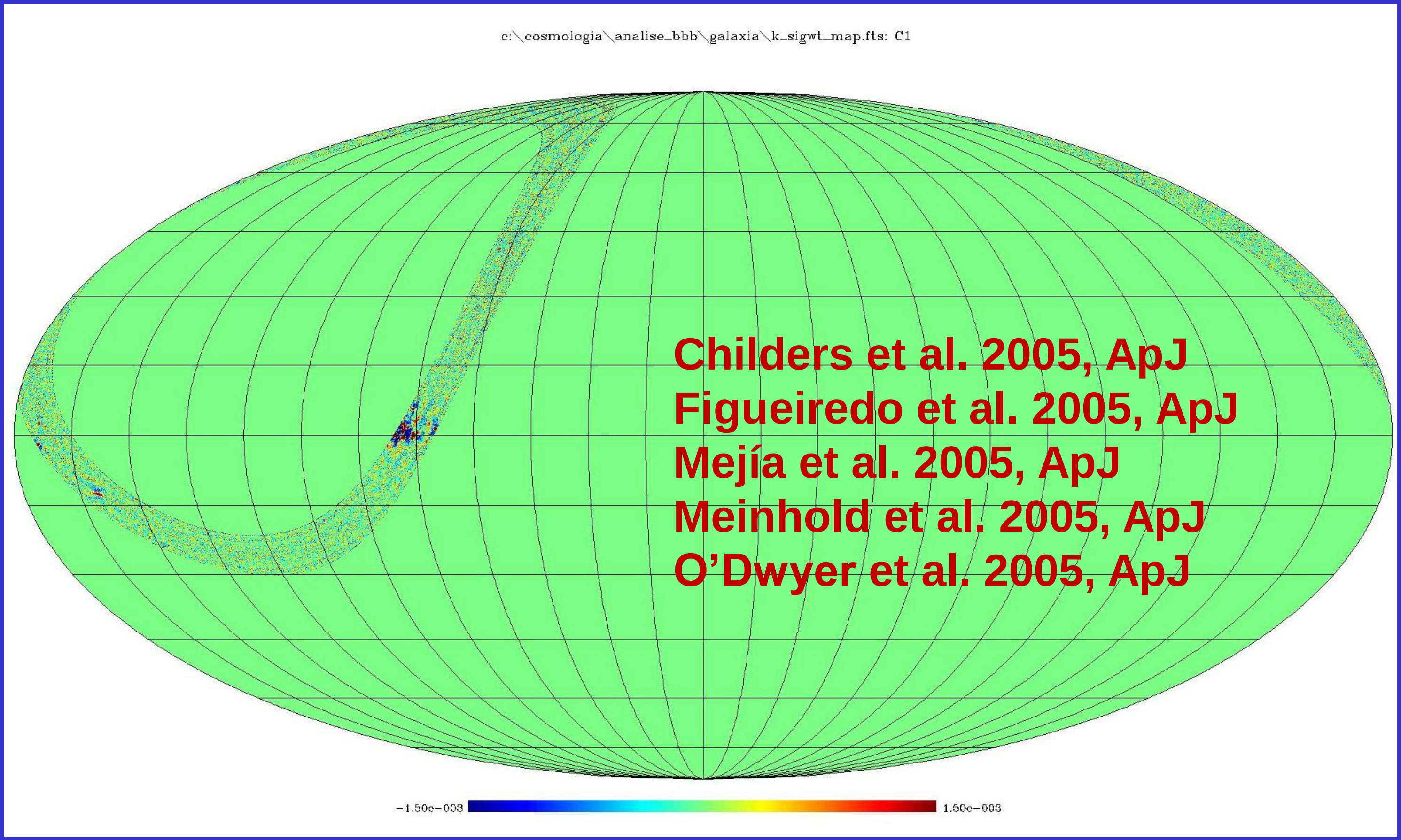
BEAST maps: ~ 2500 square degrees

$33^{o} \leq \delta \leq 42^{o}$
$0\ h \leq \alpha \leq 24\ h$

Ka band: 30' FWHM
Q band: 23' FWHM



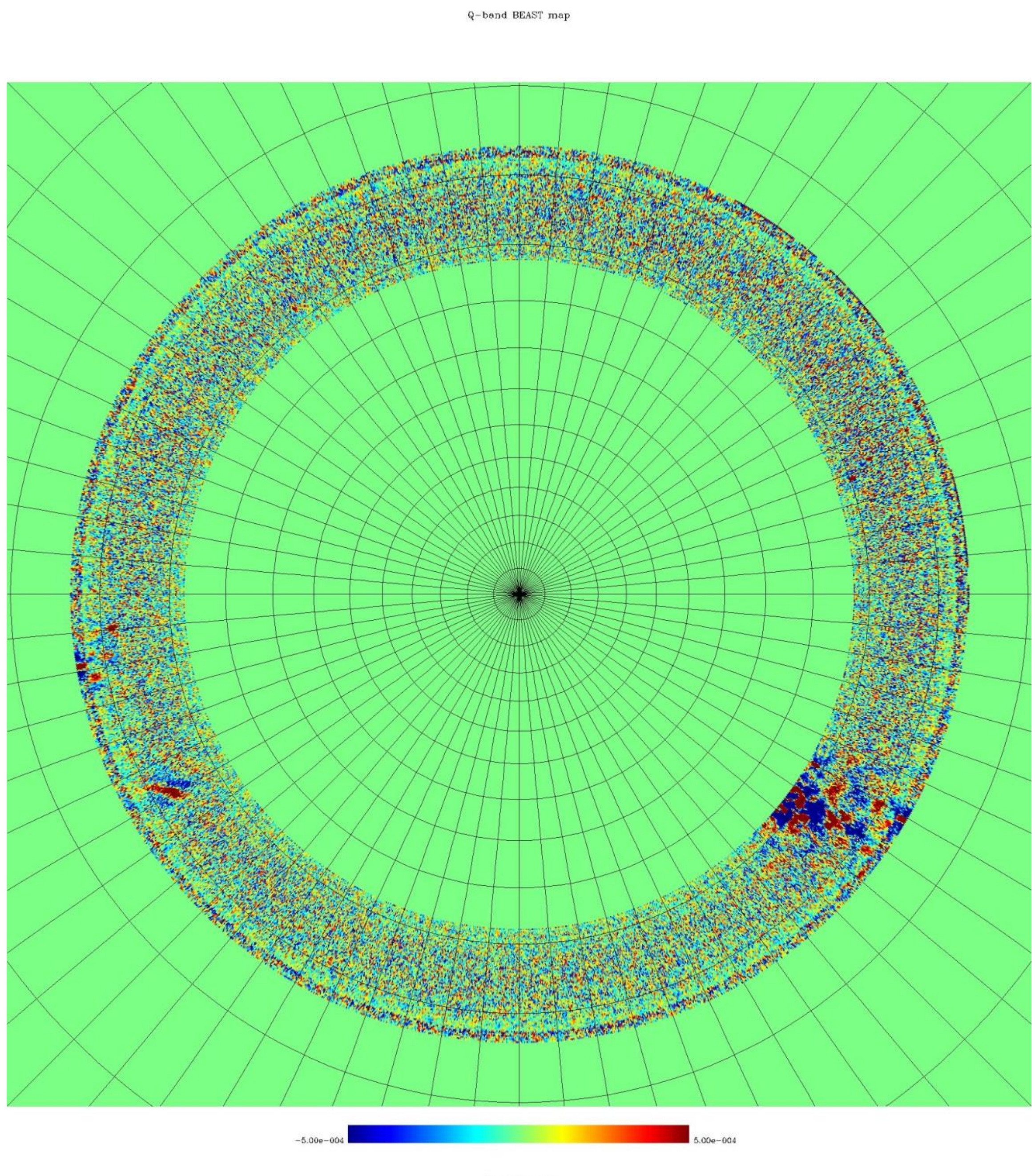
Childers et al. 2005, ApJ
Figueiredo et al. 2005, ApJ
Mejía et al. 2005, ApJ
Meinhold et al. 2005, ApJ
O'Dwyer et al. 2005, ApJ

BEAST
Q band
(40 GHz)

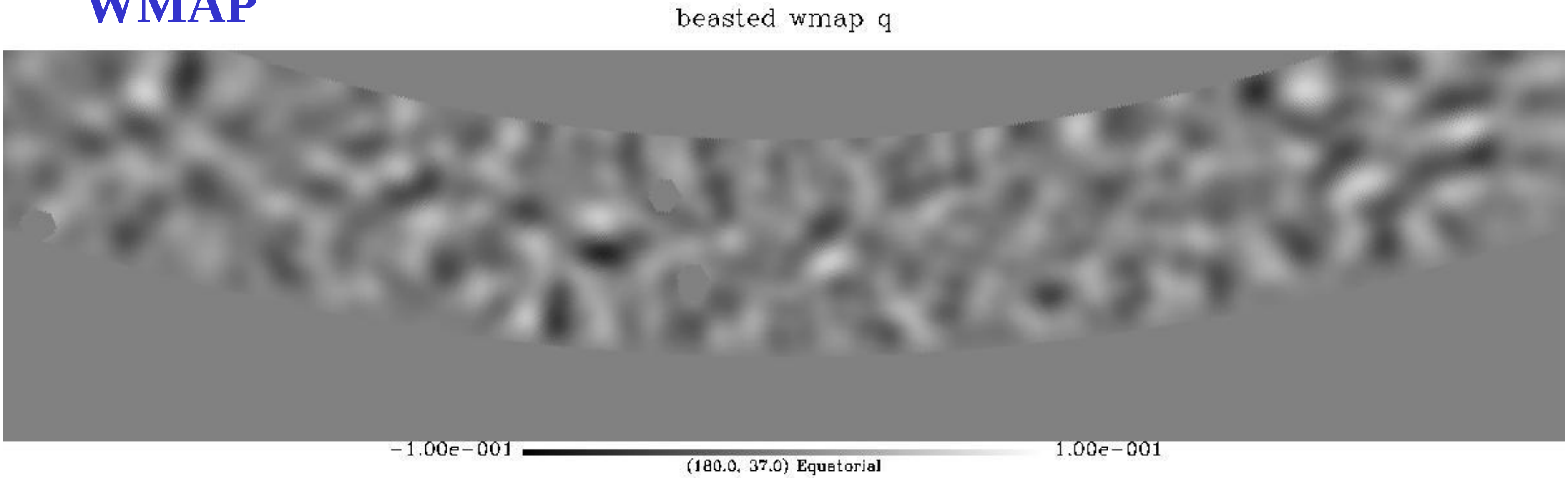
rms: 57 ± 5 μK
(noise, w/o Galaxy,
smoothed 30’)

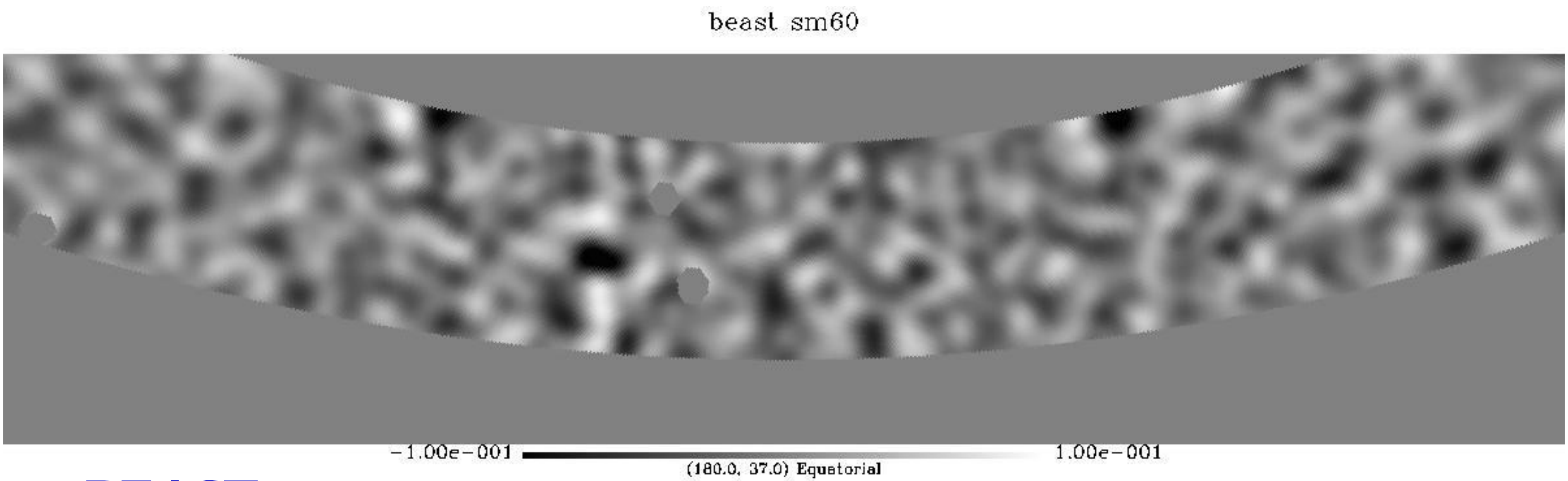
Cosmic signal: 30 ± 3 μK

Meinhold et al. 2005



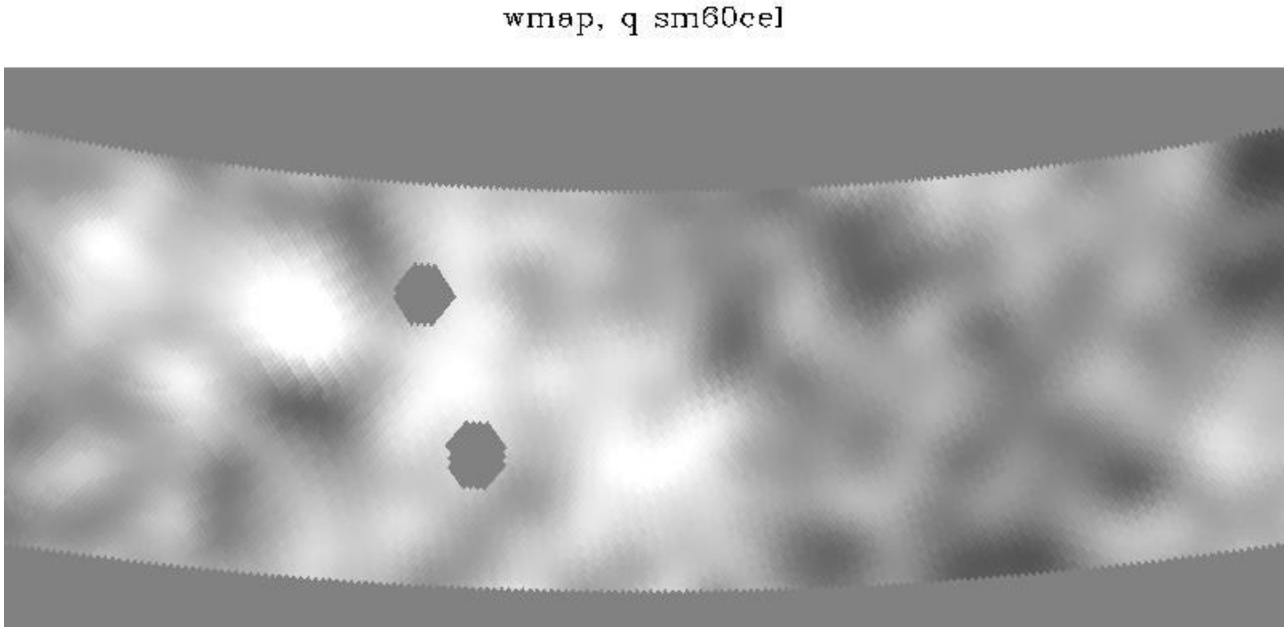
WMAP


beasted wmap q
−1.00e−001
1.00e−001
(180.0, 37.0) Equatorial

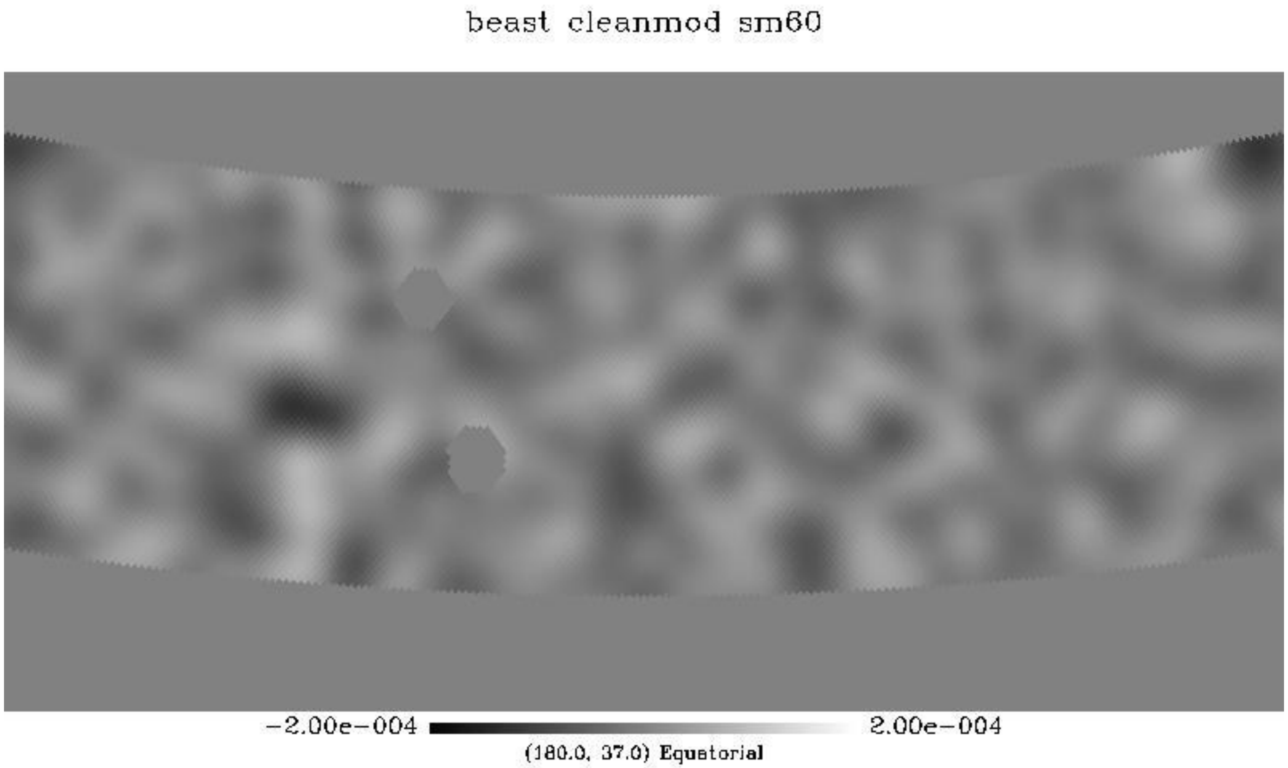

beast sm60
−1.00e−001
1.00e−001
(180.0, 37.0) Equatorial

BEAST

WMAP →


wmap, q sm60cel

BEAST →


beast cleanmod sm60
−2.00e−004
2.00e−004
(180.0, 37.0) Equatorial

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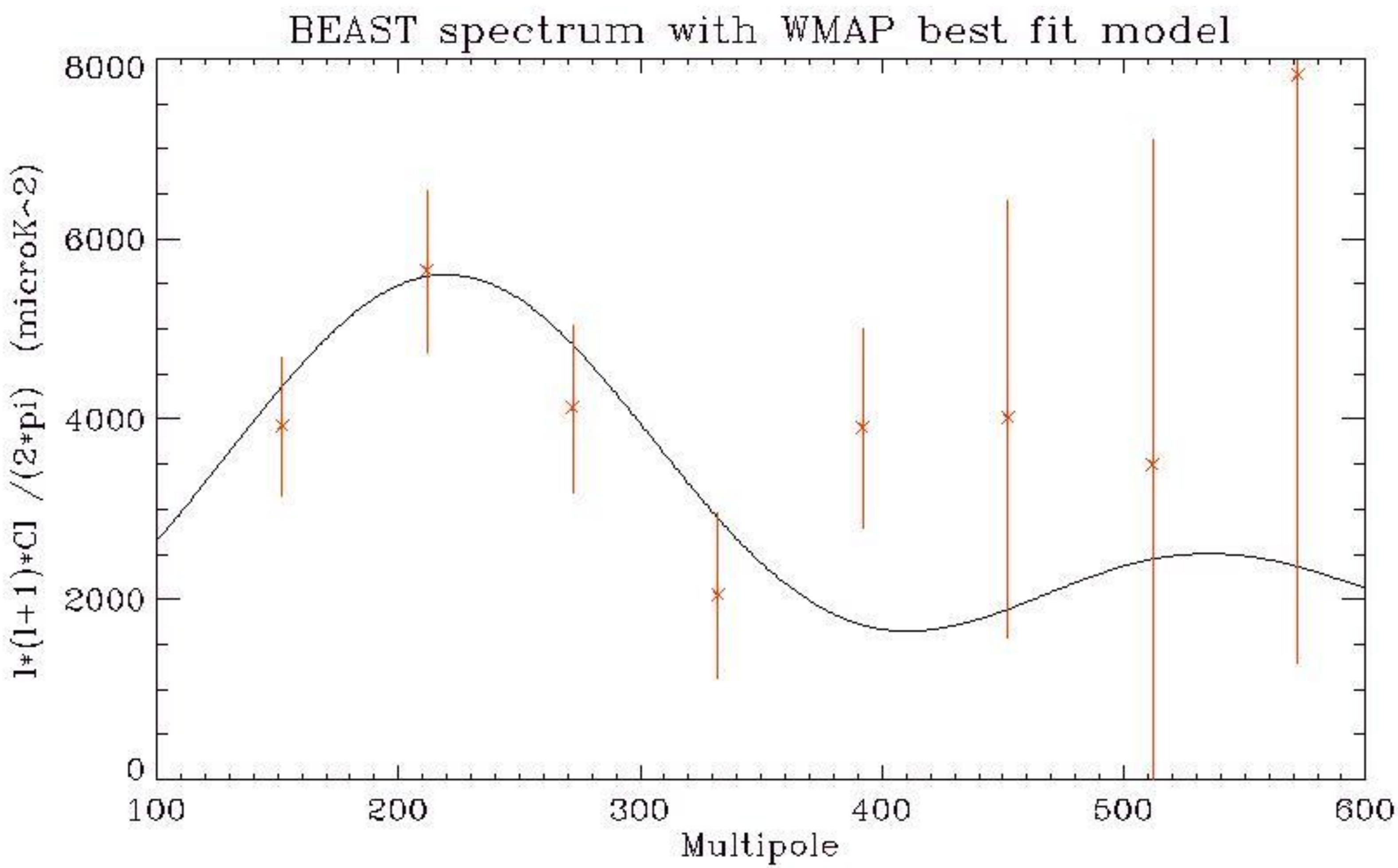
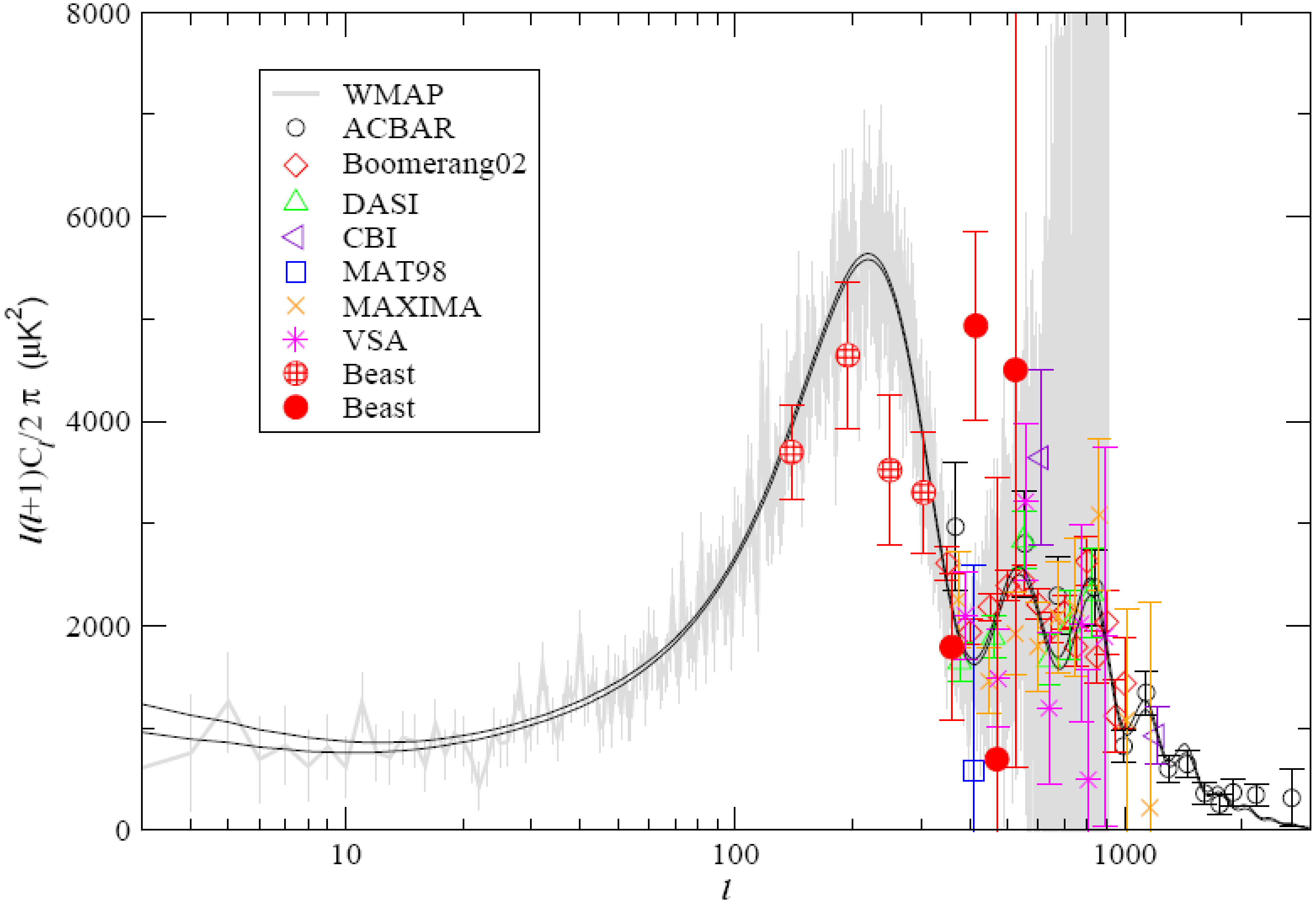
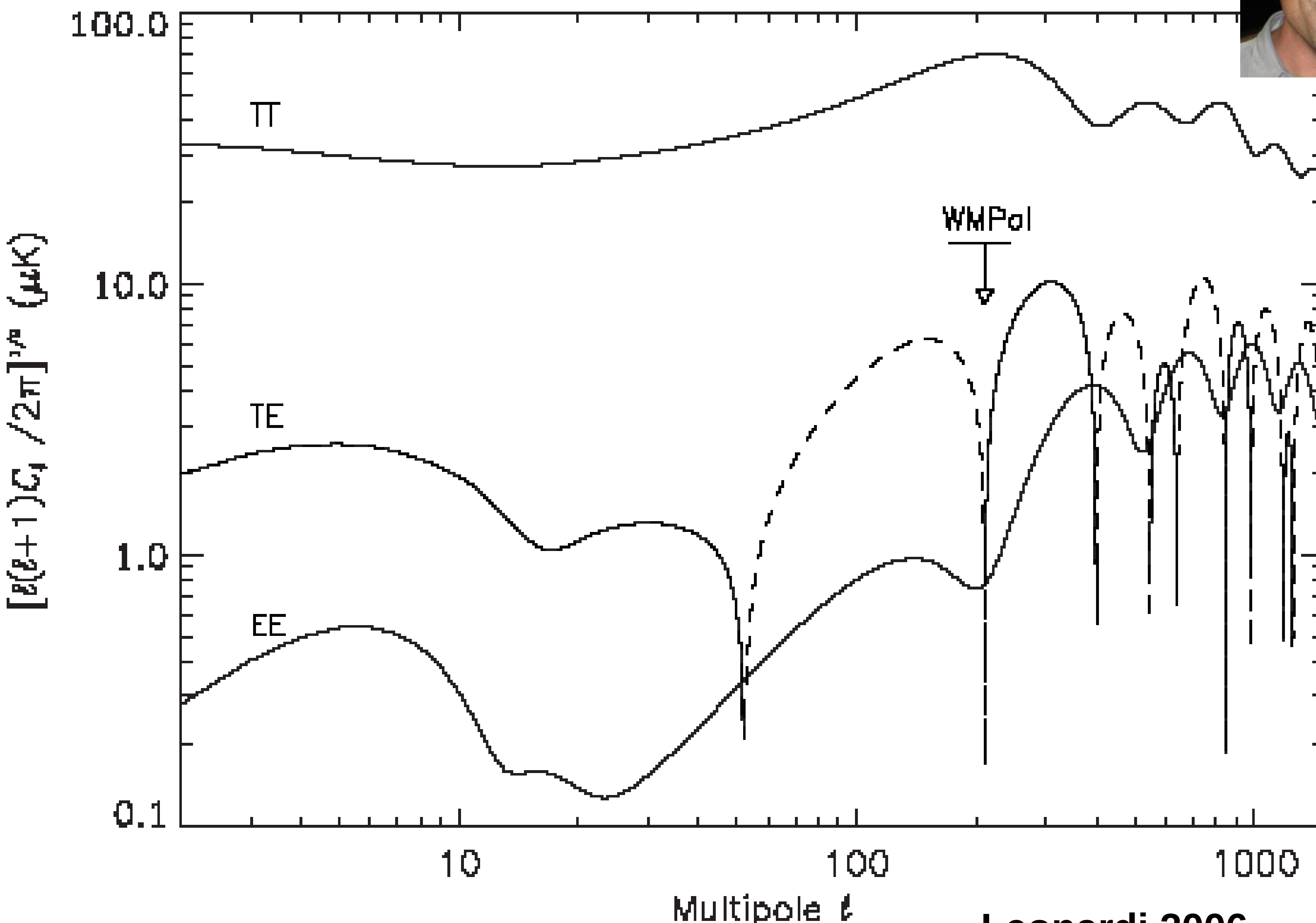
BEAST CMB power spectrum



Current BEAST measurement of the angular power spectrum of the CMB, based on 26 days of data. Our results are consistent with the current “best fit” cosmological model, and with the WMAP published power spectrum (O’Dwyer et al. 2005). Errors at high multipoles are limited by observation time, not beam size.


8000
6000
4000
2000
0
10
100
1000
l
$l(l+1)C_l/2\pi$ (μK^2)
WMAP
ACBAR
Boomerang02
DASI
CBI
MAT98
MAXIMA
VSA
Beast
Beast

WMPol



Leonardi 2006
Levy et al., ApJS, 2008

Multipole range	Frequency (GHz)	Main EE result	Experiment
$66 < \ell < 505$	90	$< 14\ \mu$K	PIQUE Hedman et al. (2001)
$2 < \ell < 20$	$26 - 36$	$< 10\ \mu$K	POLAR Keating et al. (2001)
$59 < \ell < 334$	90	$< 8.4\ \mu$K	PIQUE Hedman et al. (2002)
$30 \lesssim \ell \lesssim 900$	$26 - 36$	Detection	DASI Kovac et al. (2002)
$95 < \ell < 555$	$26 - 36$	$< 32\ \mu$K	COMPASS Farese et al. (2004)
$400 \lesssim \ell \lesssim 1500$	$26 - 36$	Detection	CBI Readhead et al. (2004)
$640 < \ell < 1270$	90	Detection	CAPMAP Barkats et al. (2005)
$446 < \ell < 779$ $930 < \ell < 1395$ $1539 < \ell < 2702$	$26 - 36$	$< 7\ \mu$K $< 12.8\ \mu$K $< 25.1\ \mu$K	CBI Cartwright et al. (2005)
$201 < \ell < 1000$	145	Detection	BOOMERANG Montroy et al. (2006)
$2 < \ell < 6$	$23 - 94$	Detection	WMAP Page et al. (2006)
$170 < \ell < 240$	42	$< 14\ \mu$K	WMPol This work

ARCADE

***A**bsolute **R**adiometer for **C**osmology, **A**strophysics, and **D**iffuse **E**mission*

Goddard Space Flight Center
NASA (EUA)

- Alan Kogut (PI)
- Dale Fixsen
- Michele Limon (Columbia)
- Paul Mirel
- Ed Wollack

University of California
Santa Barbara (EUA)

- Philip Lubin
- Jack Singal (Stanford)

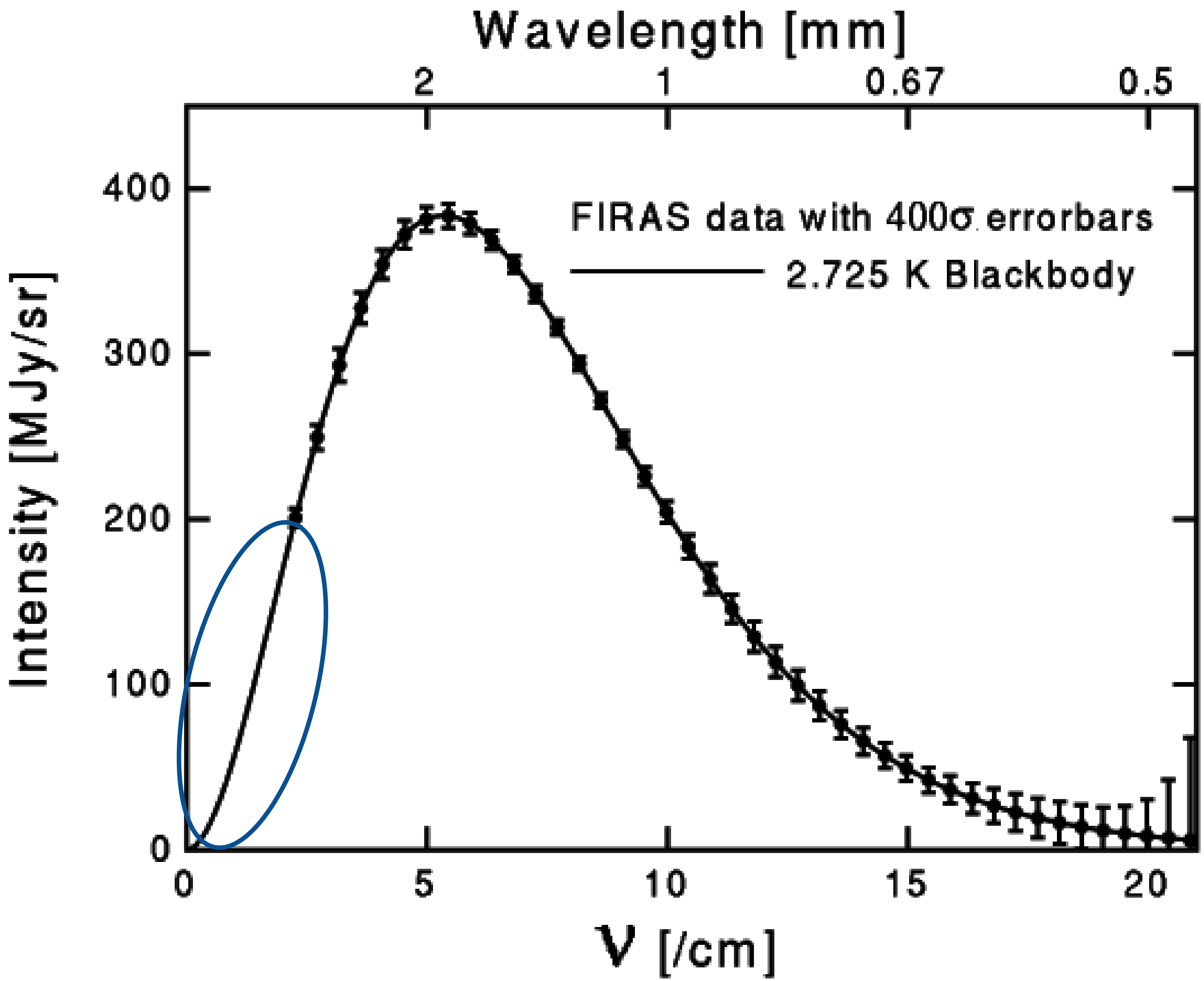
Instituto Nacional de Pesquisas Espaciais
INPE (Brasil)

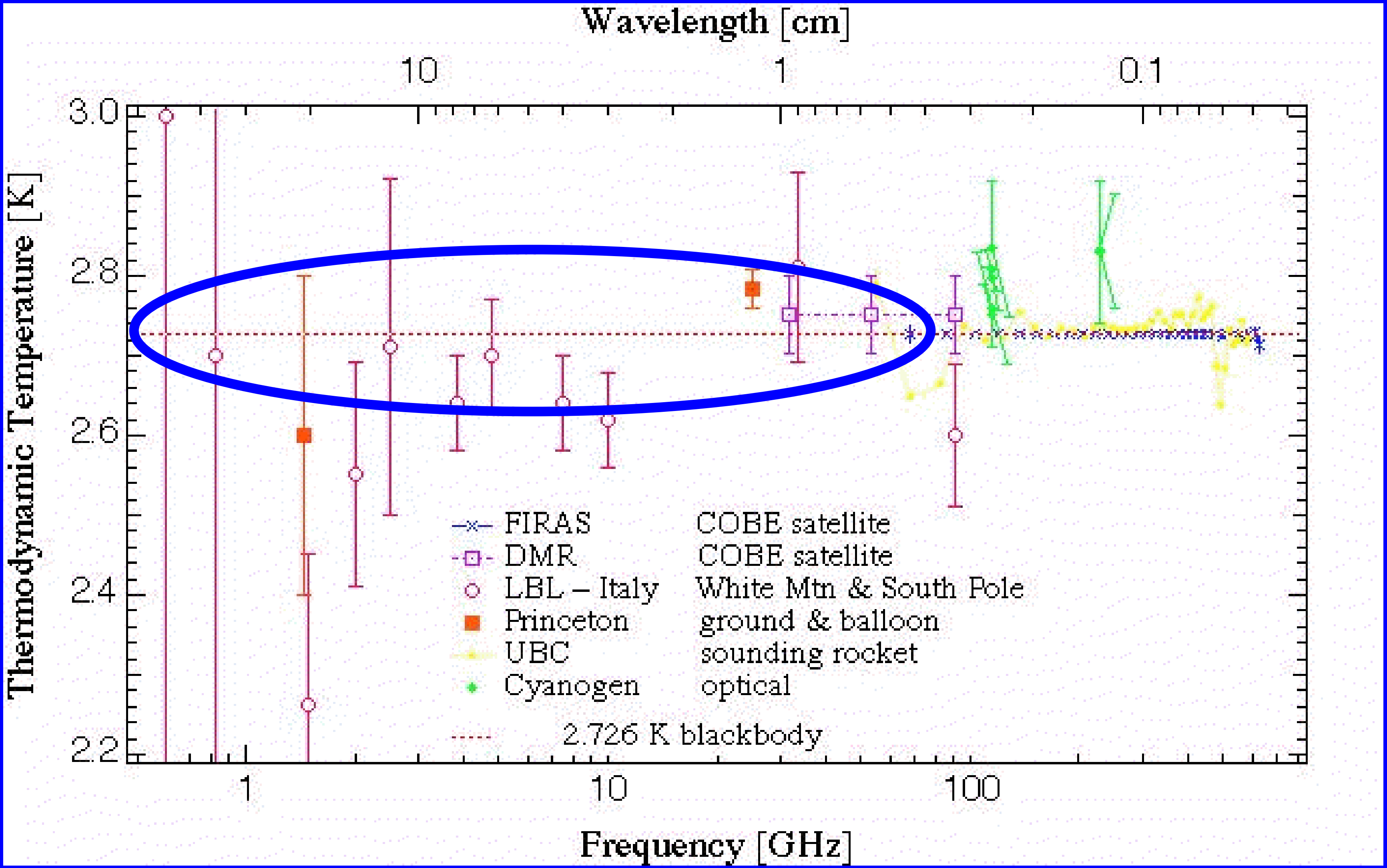
- Thyrso Villela
- Alex Wuensche

Jet Propulsion Laboratory
NASA (EUA)

- Steve Levin
- Michael Seiffert

- ***Apoiado pelo Programa Suborbital da NASA***
- ***INPE construiu as cornetas de 3, 8 e 10 GHz***


Wavelength [mm]
2
1
0.67
0.5
400
300
200
100
0
Intensity [MJy/sr]
FIRAS data with 400σ errorbars
2.725 K Blackbody
0
5
10
15
20
ν [/cm]



Wavelength [cm]
10
1
0.1
3.0
2.8
2.6
2.4
2.2
Thermodynamic Temperature [K]
FIRAS COBE satellite
DMR COBE satellite
LBL – Italy White Mtn & South Pole
Princeton ground & balloon
UBC sounding rocket
Cyanogen optical
2.726 K blackbody
1
10
100
Frequency [GHz]

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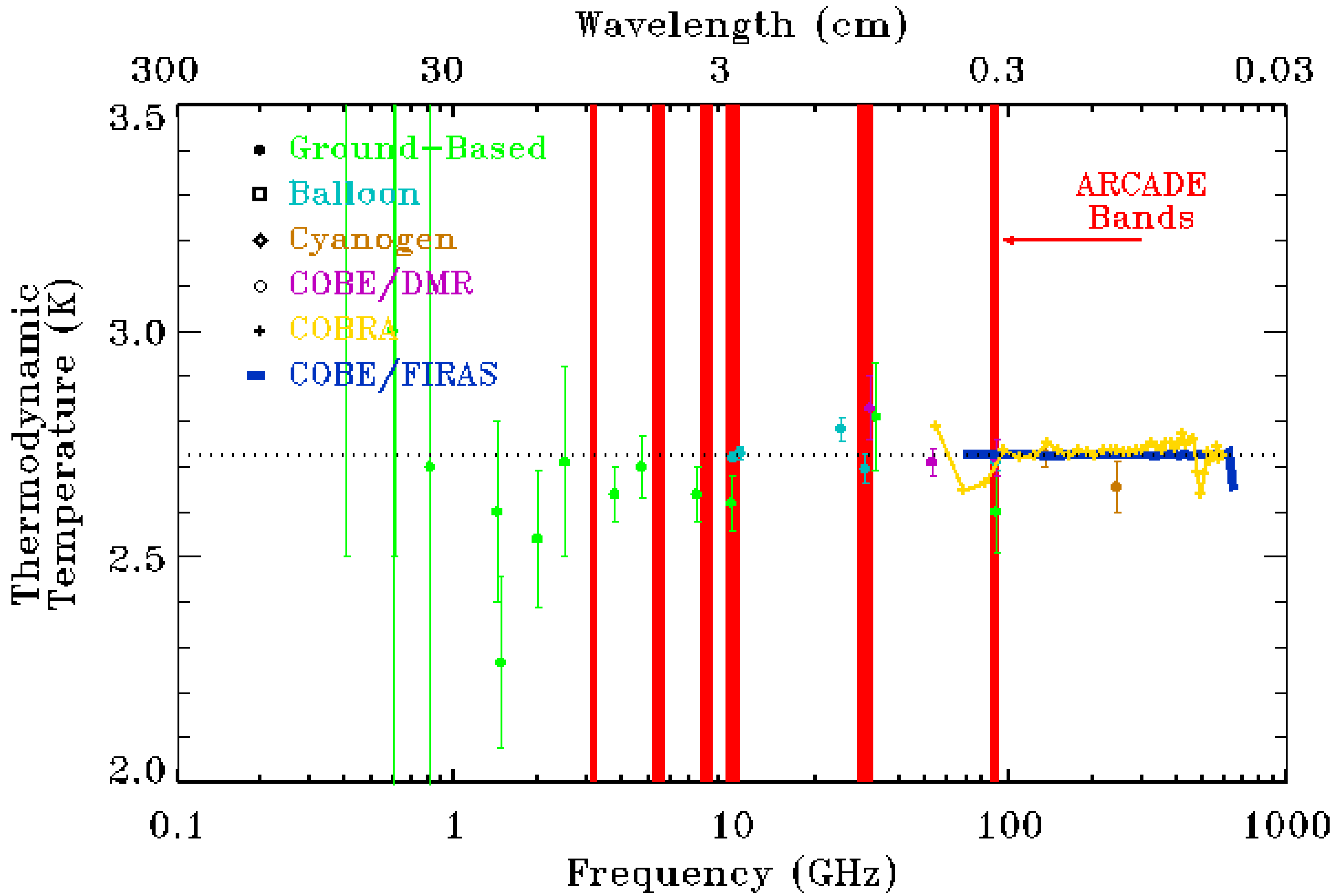

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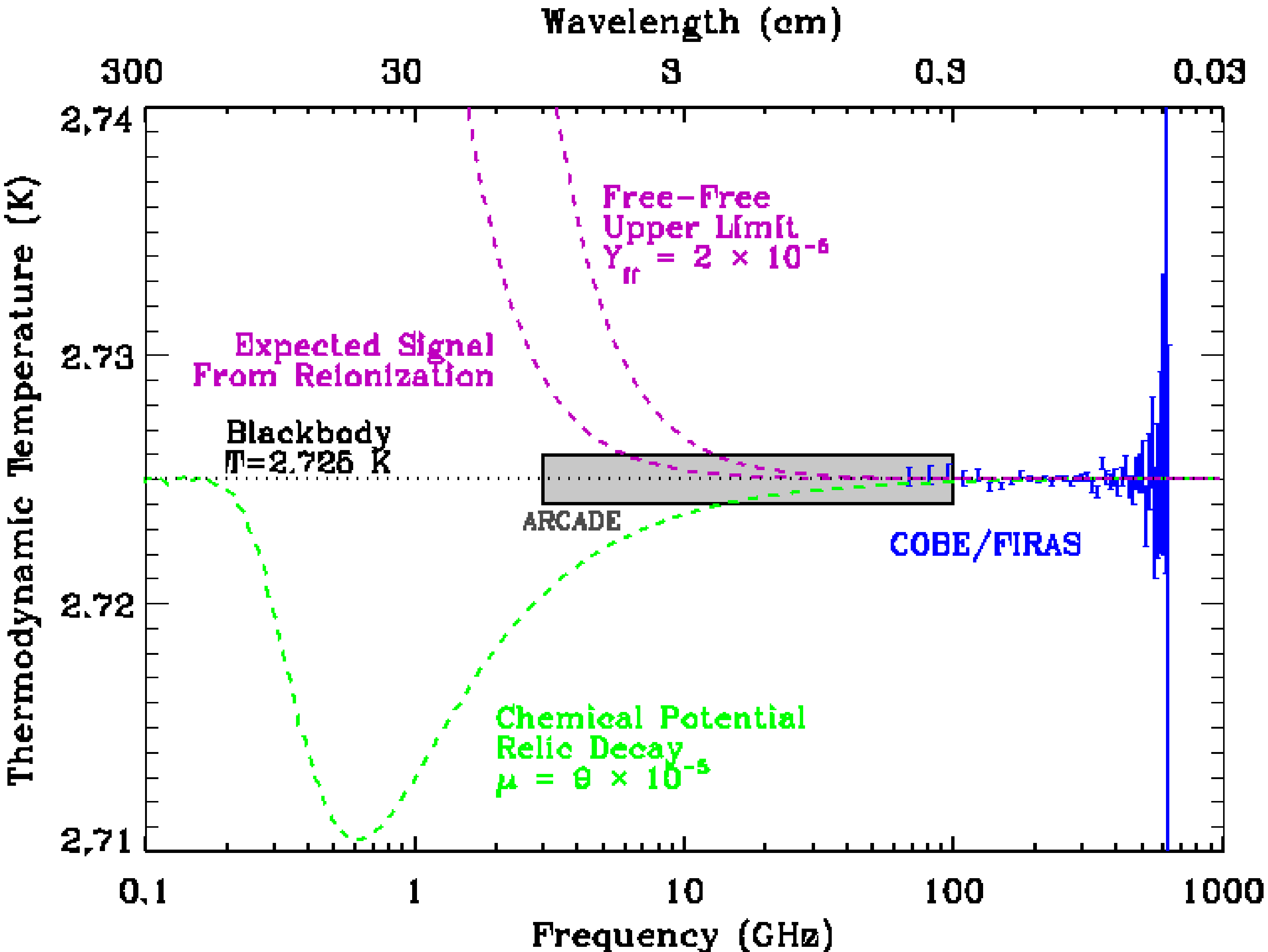
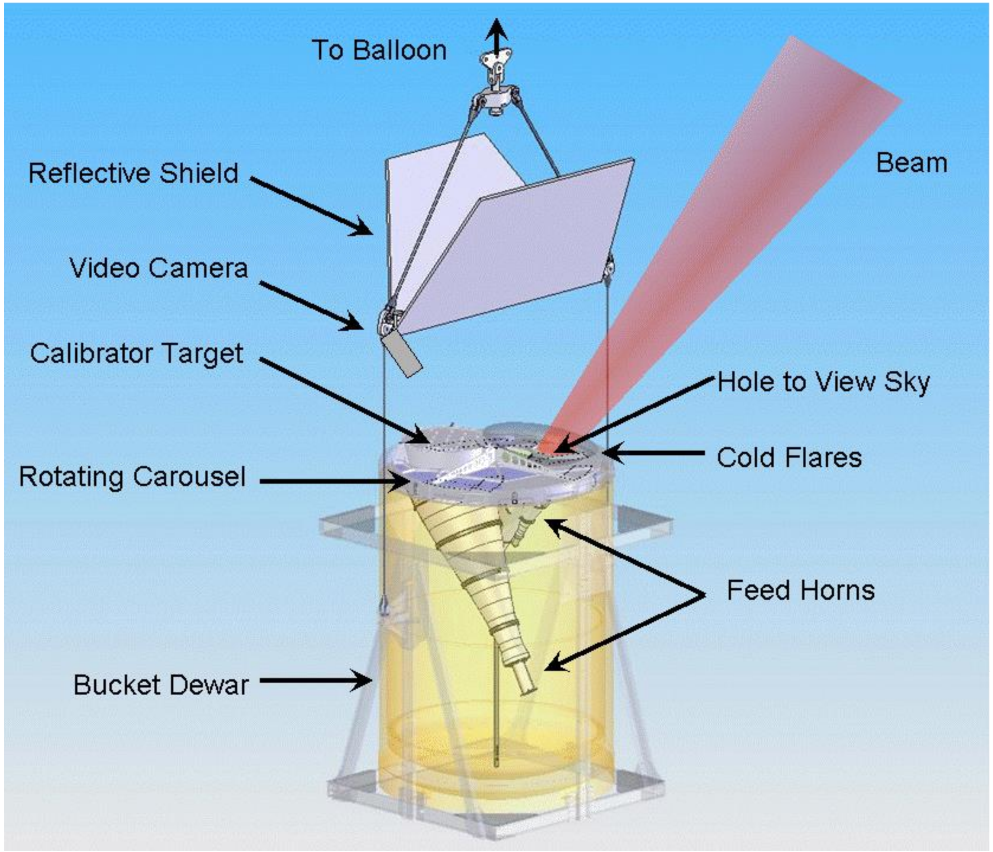
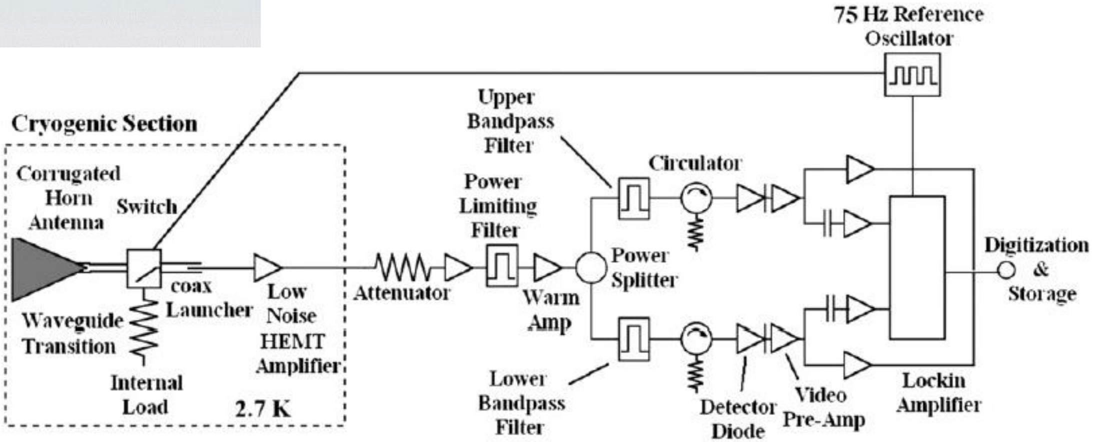
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS



Payload Schematic



- **7 radio receivers**
- **Cooled to -270º C**
- **~2000 l of superfluid liquid helium in ~3m tall "flying cold tub"**
- **Suspended below 100m diameter helium balloon**
- **Flight altitude: 37 km (120,000 ft)**
- **Science observations lasted 2.5 h**



Singal et al. , ApJ, 2011

Table of Selected Measured Radiometer Performance Specifications from the 2006 Flight

Channel	Cntr Freq (GHz)	Bandwidth (MHz)	T_{rcvr}[a] (K)	Offset[b] (mK)	Noise (pre-flt)[c] (mK$\sqrt{s}$)	Noise (rsduls)[d] (mK$\sqrt{s}$)	Noise (map)[e] (mK$\sqrt{s}$)
3 GHz Lo	3.15	210	5.5	180	7.1	9.3	11.8
3 GHz Hi	3.41	220	6.5	35	7.1	7.8	10.1
5 GHz Lo	5.33	340	6	−210	3.2	...	...
5 GHz Hi	5.67	330	6	−200	3.5	...	...
8 GHz Lo	7.97	350	10	6	1.4	5.5	5.5
8 GHz Hi	8.33	350	8	11	1.4	6.1	5.2
10 GHz Lo	9.72	860	13	180	6.8	3.7	3.0
10 GHz Hi	10.49	680	11	35	5.3	3.7	3.0
30 GHz Lo	29.5	2000	75	−30	21.5	208.2	206.9
30 GHz Hi	31.0	1000	72	−15	14.9	103.3	103.4
30# GHz Lo	29.5	2000	270	32	18	885.0	880.4
30# GHz Hi	31.0	1000	340	38	14	418.5	406.1
90 GHz Lo	88.2	1500	44	−75	5.2	50.5	42.0
90 GHz Hi	89.8	1500	38	−95	5.7	25.3	27.1

[a] T_{rcvr} is the receiver noise temperature of the amplifier, a figure of merit that is equal to the temperature that would be observed by a total power radiometer containing the amplifier and viewing a source at a temperature of absolute zero. These values presented here were measured in ground testing prior to the 2006 flight.
[b] The constant offset is the radiometer output when the internal reference load and the object being viewed are at the same temperature, multiplied here by the gain to be expressed as a temperature.
[c] This is the white noise as measured in ground testing prior to the 2006 flight.
[d] This is the white noise determined from the residuals of the data from the 2006 flight.
[e] This is the white noise as determined from the sky map variance in the 2006 flight.

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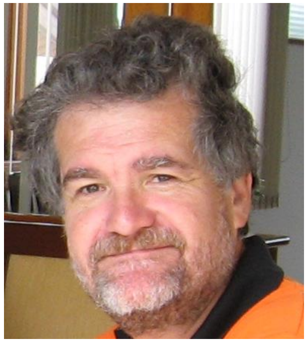
Transitions



Transitions provided by INPE for the ARCADE project:

90 GHz, 28-30 GHz, 10 GHz, 8 GHz, 5 GHz and 3 GHz

Material: **Copper**

Fabrication process: **eletrodeposition**

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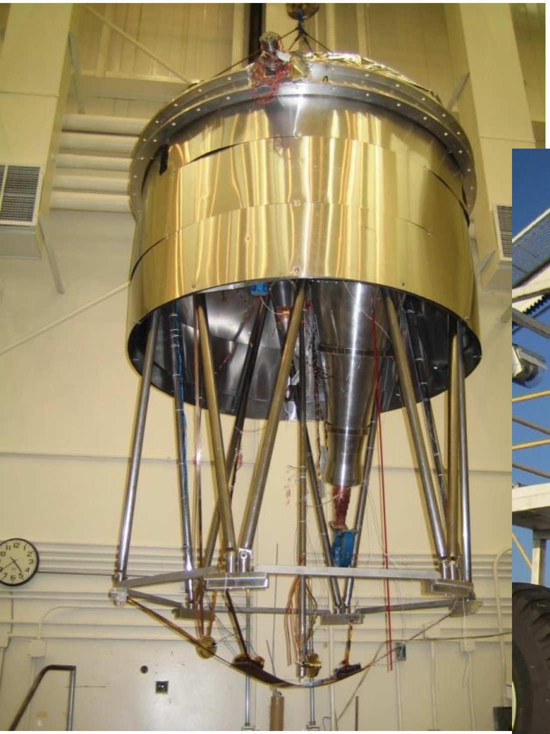
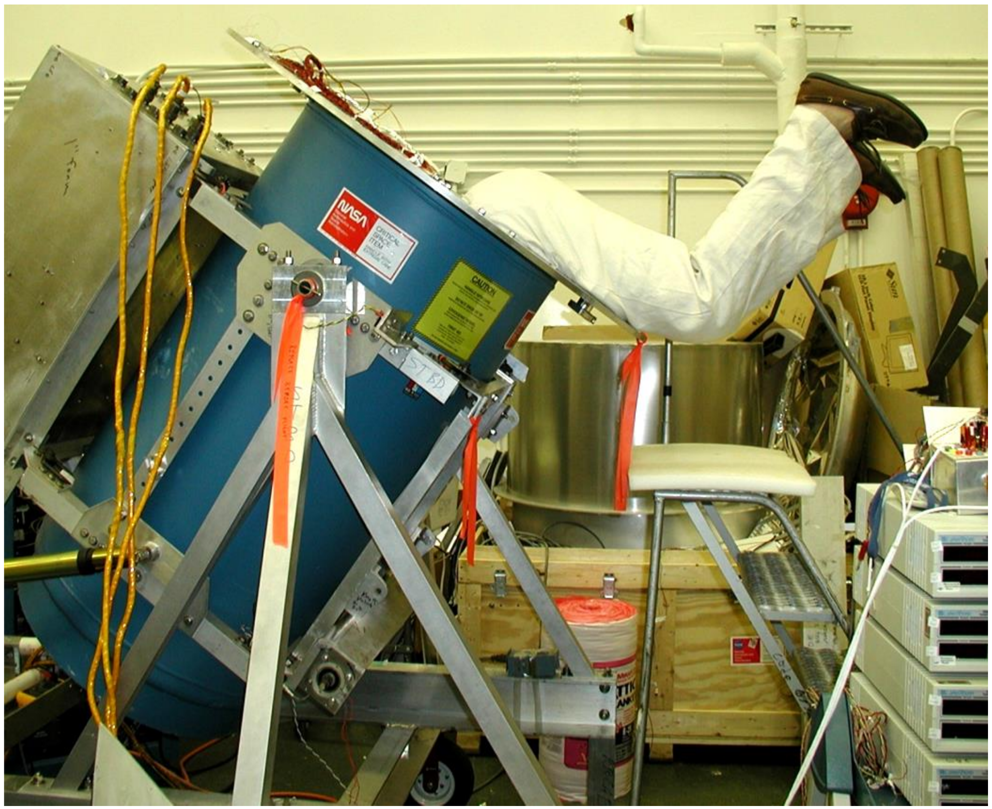
Horns provided by INPE for the ARCADE project

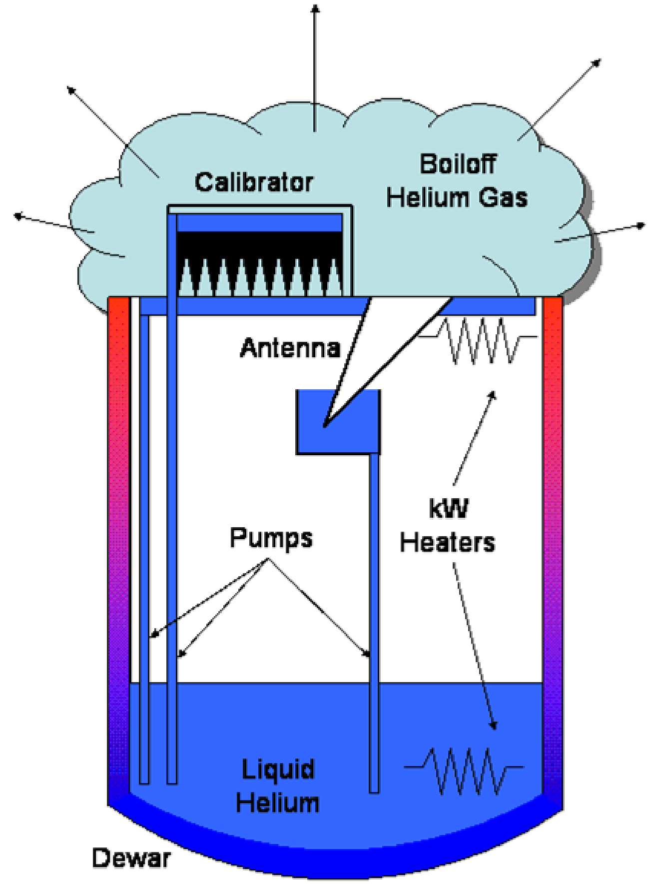
ARCADE



- Launched July 22, 2006
- Palestine, TX, USA
- 4 hours total at float

ARCADE

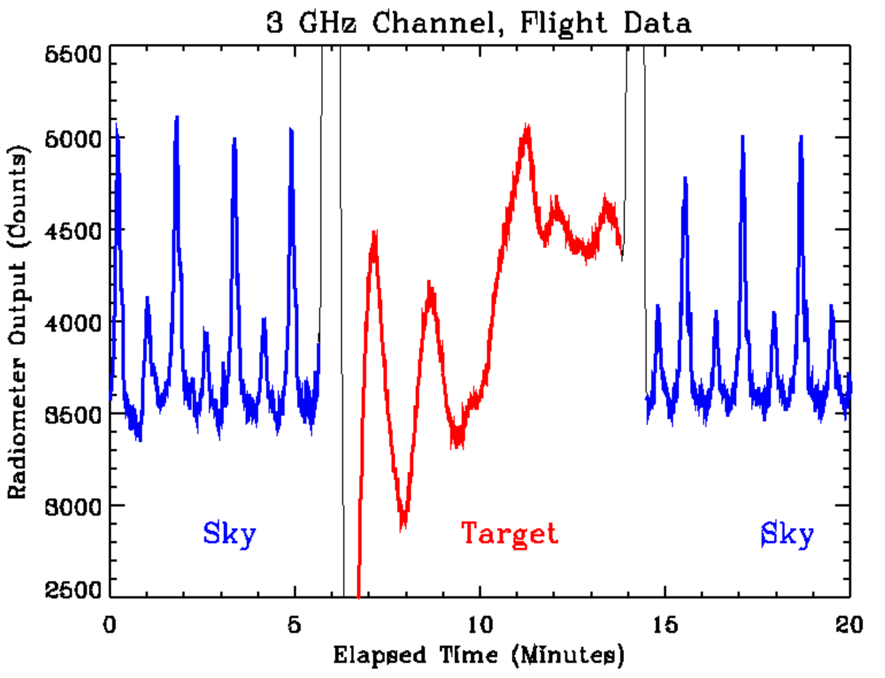




Instrument cooled to -270^{o} C

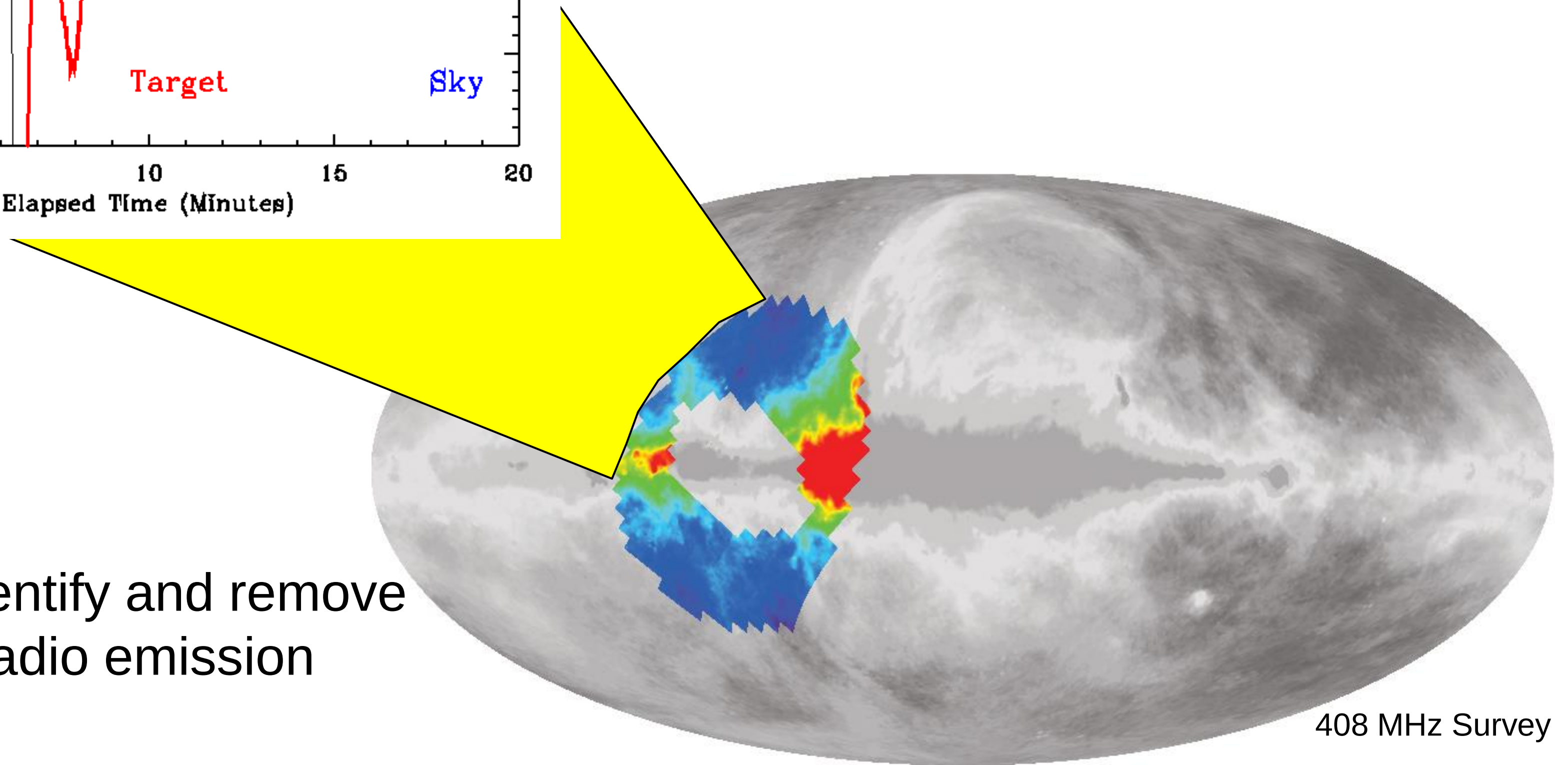
Radical thermal design puts cold components outside the dewar

Measuring the sky temperature



Successful thermal operations

- Compare sky to on-board target
- Maintain instrument within 0.1 K of sky
- Multiple sky/target comparisons

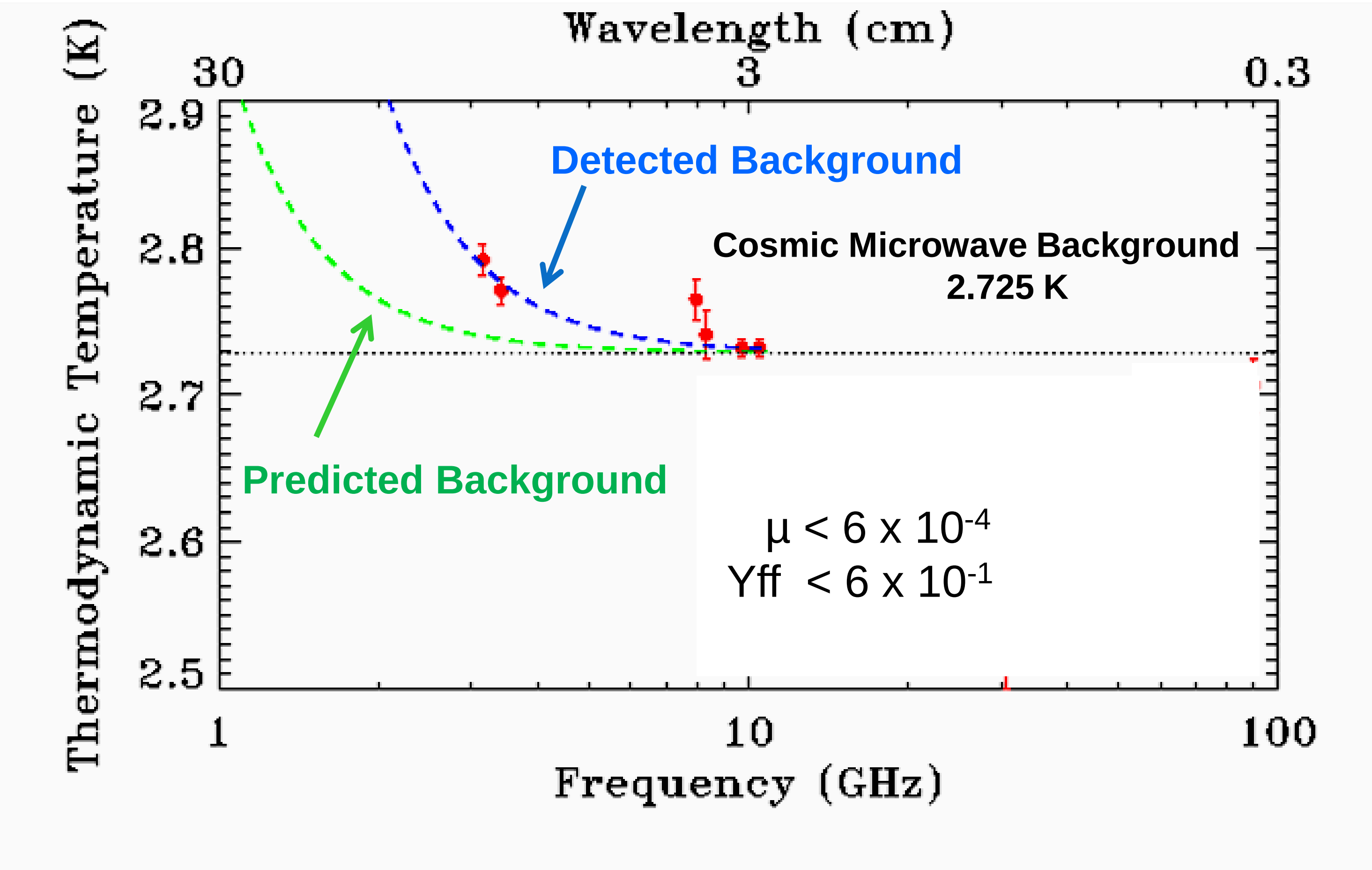


Challenge: identify and remove Galactic radio emission

408 MHz Survey

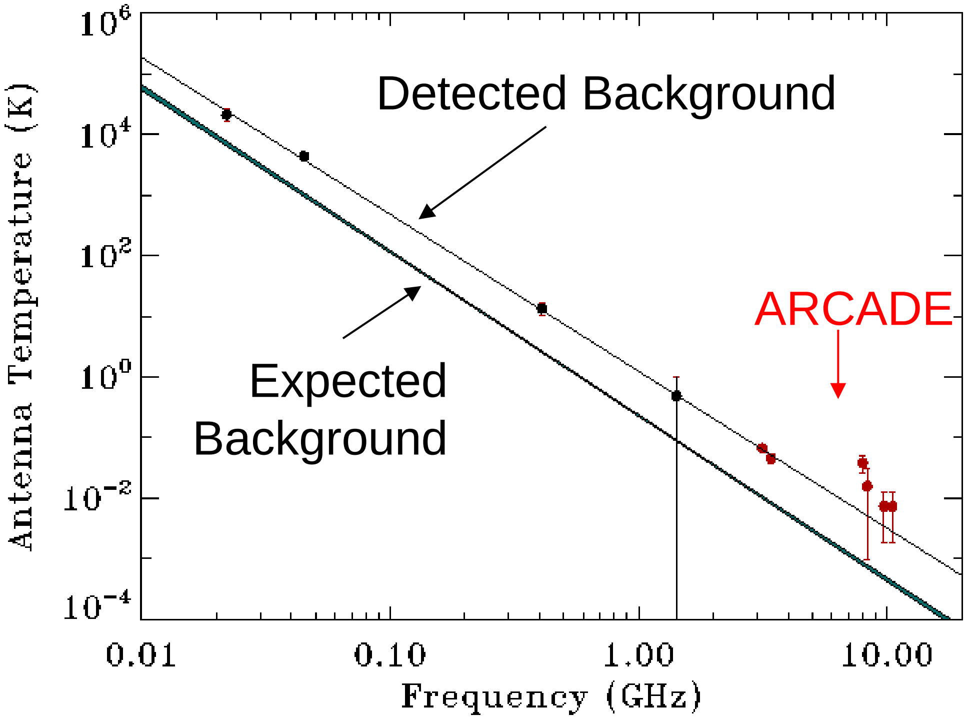
ARCADE Results

Kogut et al. , ApJ, 2011; Fixsen et al. ApJ. 2011, Seiffert et al., ApJ, 2011



Detection of bright radio background six times brighter than the expected contribution from radio galaxies

Cross-check: radio surveys



Perform identical analysis for full-sky low-frequency radio surveys

- **22 MHz (Roger et al. 1999)**
- **45 MHz (Maeda et al 1999, Alvarez et al 1997)**
- **408 MHz (Haslam et al. 1981)**
- **1420 MHz (Reich & Reich 1986)**

ARCADE is consistent with radio surveys, and has with much higher sensitivity

Looking for loopholes

Could the measurement be in error?

Not likely. ARCADE is designed to minimize the instrumental signature. Careful analysis of the data shows no evidence for instrumental errors. A re-analysis of other published data supports the ARCADE detection, reducing the likelihood of an ARCADE error.

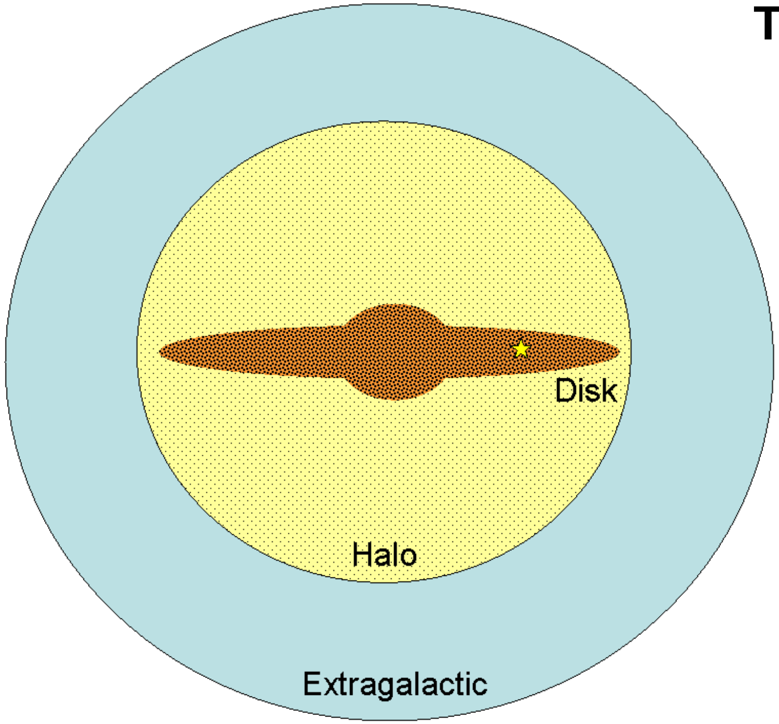
Could this be just be mis-identified Galactic emission?

Not likely. A Galactic origin would require a source that avoids the spatial distribution of the rest of the Galaxy, while also having no hydrogen, carbon, or dust. No such source is known or predicted.

Could there be more faint radio sources than we expect?

Not likely. Radio source counts are well known, and don't even come close to making up the detected background. New sources, too faint (10x) to observe directly, would have to vastly outnumber (100x) all the galaxies in the universe.

Galactic vs Extragalactic Emission



Two methods allow identification and removal of Galactic radio emission

I. Spatial Structure

- Dominant plane-parallel disk
- Compare radio emission to Galactic latitude

II. Line Emission

- Clean tracer of Galactic structure
- Compare radio to line emission

Consistent separation of Galactic vs Extragalactic emission leaves large, statistically significant extragalactic residual

ARCADE Results

- An unexpectedly bright radio background of unknown origin was found
- This radio “static” is six times brighter than the combined emission from all known radio sources

Maybe there is something new in the cosmos…

Some ideas...

- Lawson and Zhitnitsky, arXiv:1210.2400v2 [astro-ph.CO] 2013

“Isotropic Radio Background from Quark Nugget Dark Matter”

- Yang et al. PRD 2013

“The contribution of ultracompact dark matter minihalos to the isotropic radio background”

- Kellermann et al. 2013AAS...22132307K

“Is there a Population of Weak Radio Sources that Contributes to the Excess Sky Temperature Observed by Arcade 2?”

- Holder, arXiv:1207.0856v1 [astro-ph.CO] 2012

“The unusual smoothness of the extragalactic unresolved radio background”

- Hooper et al. arXiv:1203.3547v1 [astro-ph.CO] 2012

“The Isotropic Radio Background and Annihilating Dark Matter”

- Draper et al. arXiv:1110.0453 [astro-ph.CO] 2011

“Are Active Galactic Nuclei the Solution to the Excess Cosmic Radio Background at 1.4 GHz?”

- Fornengo et al. Phys. Rev. Lett. 107, 271302 (2011)

“Possibility of a Dark Matter Interpretation for the Excess in Isotropic Radio Emission Reported by ARCADE”

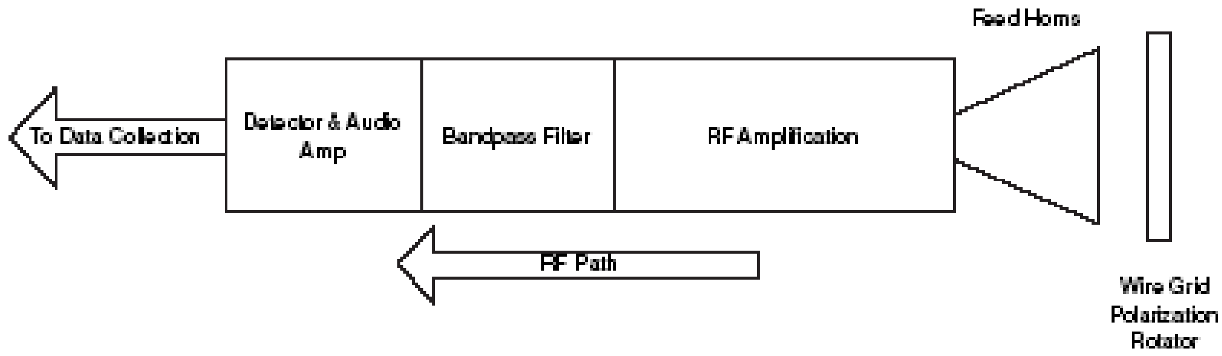
COsmic Foreground Explorer:

a balloon-borne microwave polarimeter to characterize CMB polarized foregrounds

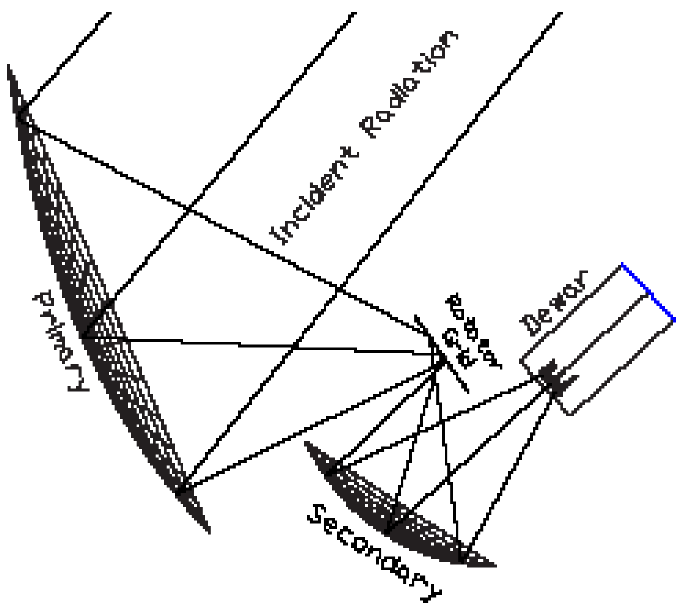
Instrument parameters

	COFE			Prototype	
Central frequency (GHz)	10	15	20	31	41.5
FWHM beam (arcmin)	83	55	42	28	20
T_{sys} (K)	8	10	12	25	27
T_{sky} (K) at target altitude	2.5	2.4	2.3	6.4	13.0
Bandwidth (GHz)	4	4	5	10	7
Number of receivers	3	6	10	2	6
Sensitivity per receiver ($\mu\mathrm{K}\sqrt{\mathrm{s}}$)	261	308	318	493	751
Aggregate sensitivity ($\mu\mathrm{K}\sqrt{\mathrm{s}}$)	151	126	100	348	307

Radiometer layout



Optics



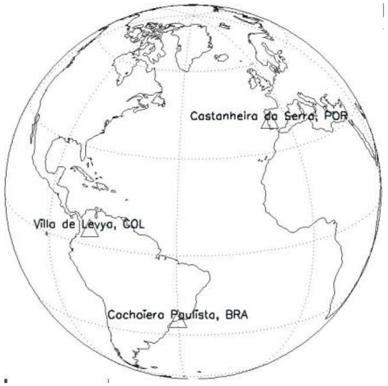
COFE

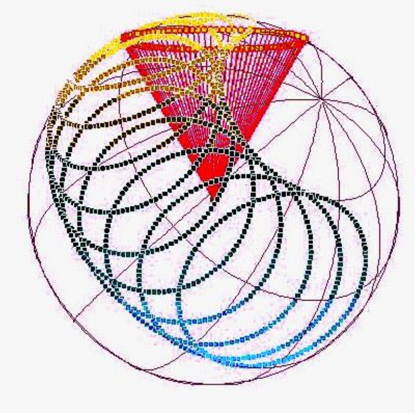
GEM – Galactic Emission Mapping

(Univ. California, Berkeley – INPE – Univ. Milano – IT Lisboa)

D = 5.5m

(9m with extension panels)





GEM Observing Sites
(portable 5.5 m-diameter dish)

Villa del Leyva, Colombia

Tenerife, Canary Islands, Spain

White Mountain Research Station, USA

South Pole

Frequencies:
408 MHz,
1.465 GHz
2.3 GHz
5 GHz
10 GHz

Cachoeira Paulista, Brazil

Galactic Emission Mapping

Cachoeira Paulista, SP

Cachoeira Paulista site: declinations between –52º 23' 14.1" and +7º 8' 50.98" (33% of the sky)

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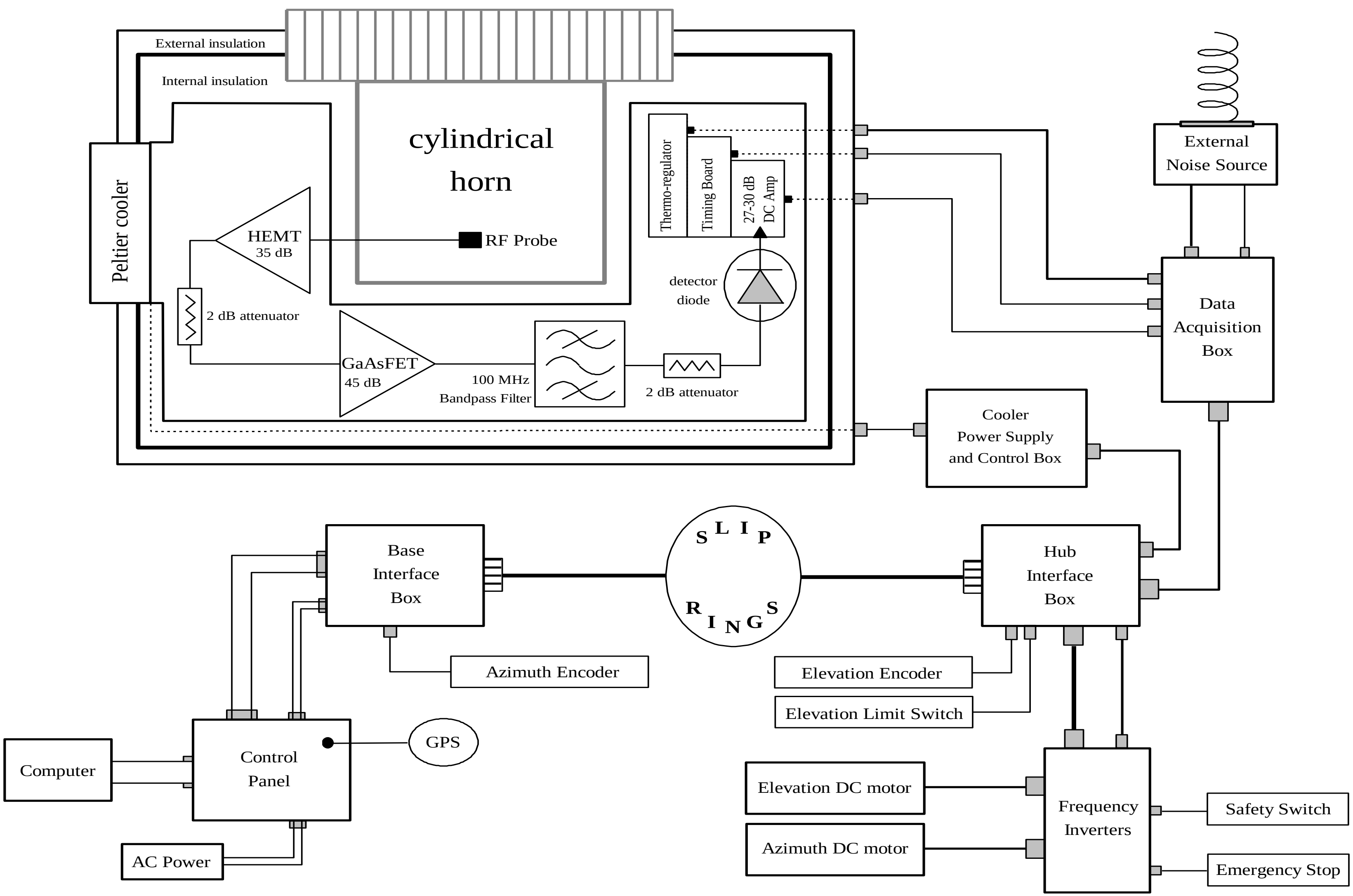
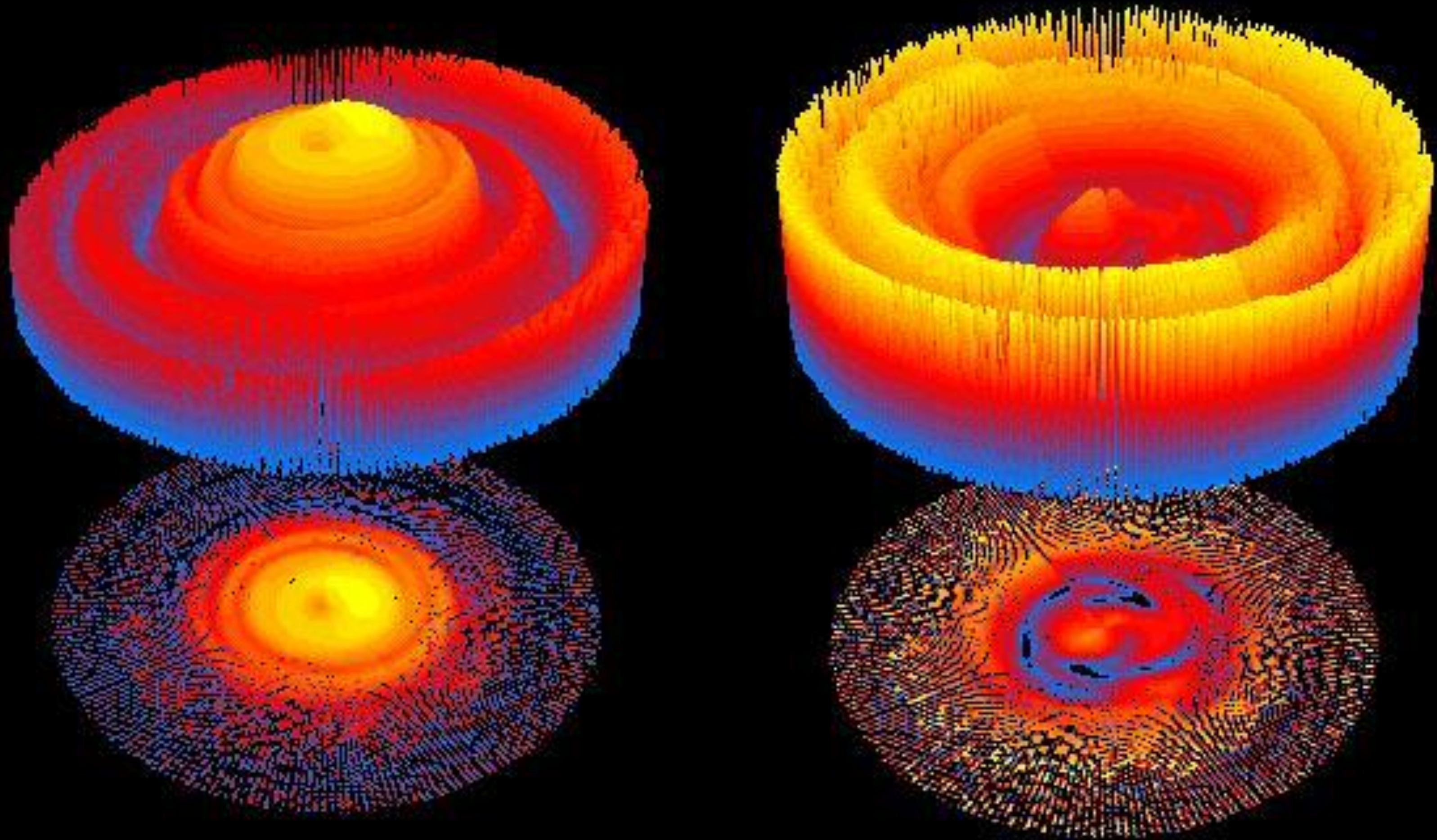


The *GEM* backfire helical feed antenna at 408 MHz



0° → 180°	Polar Angle Range	180° → 0°
-30 dB	Minimum Power Level	-30 dB

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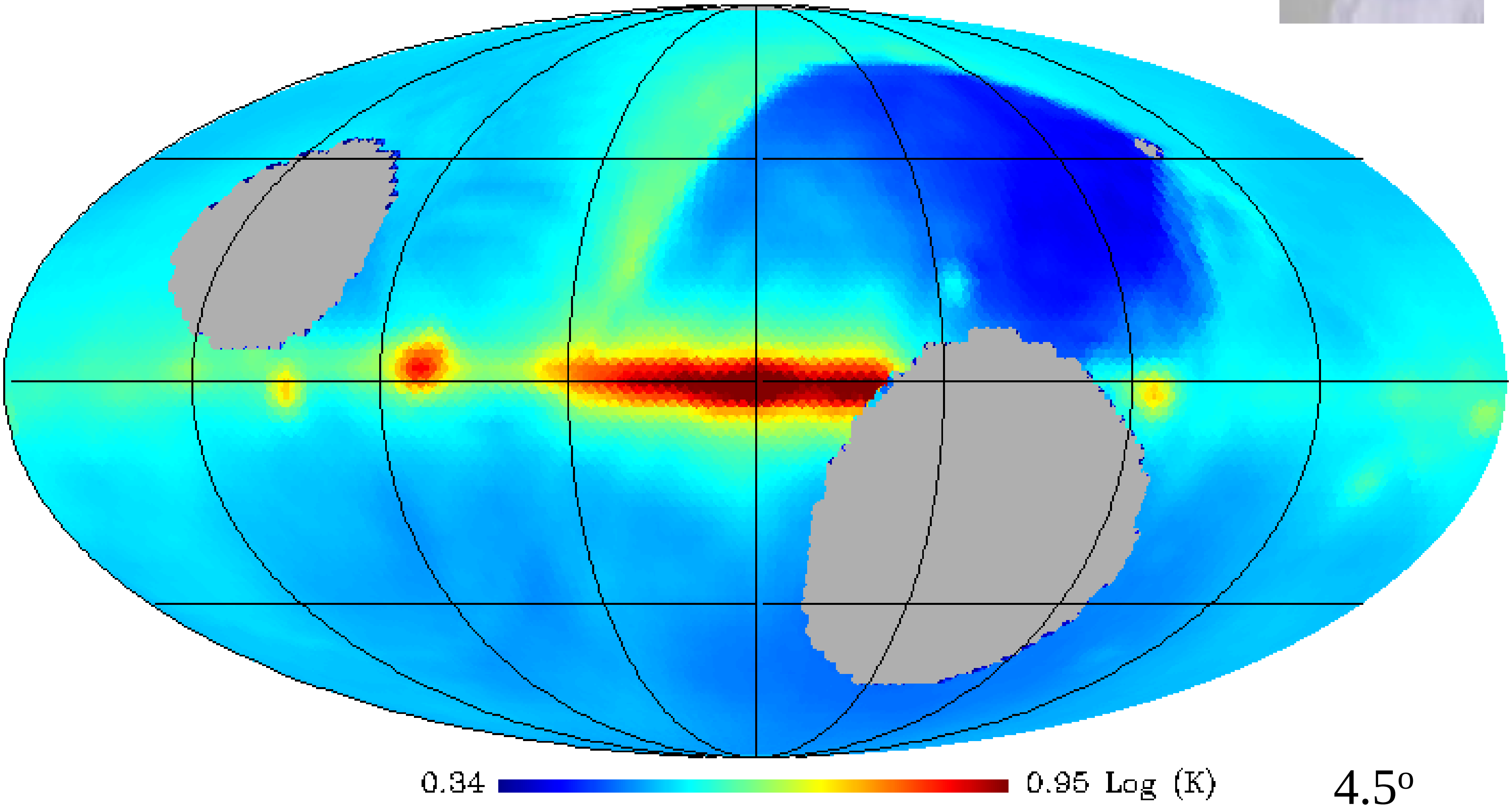
1.465 GHz map



4.5°

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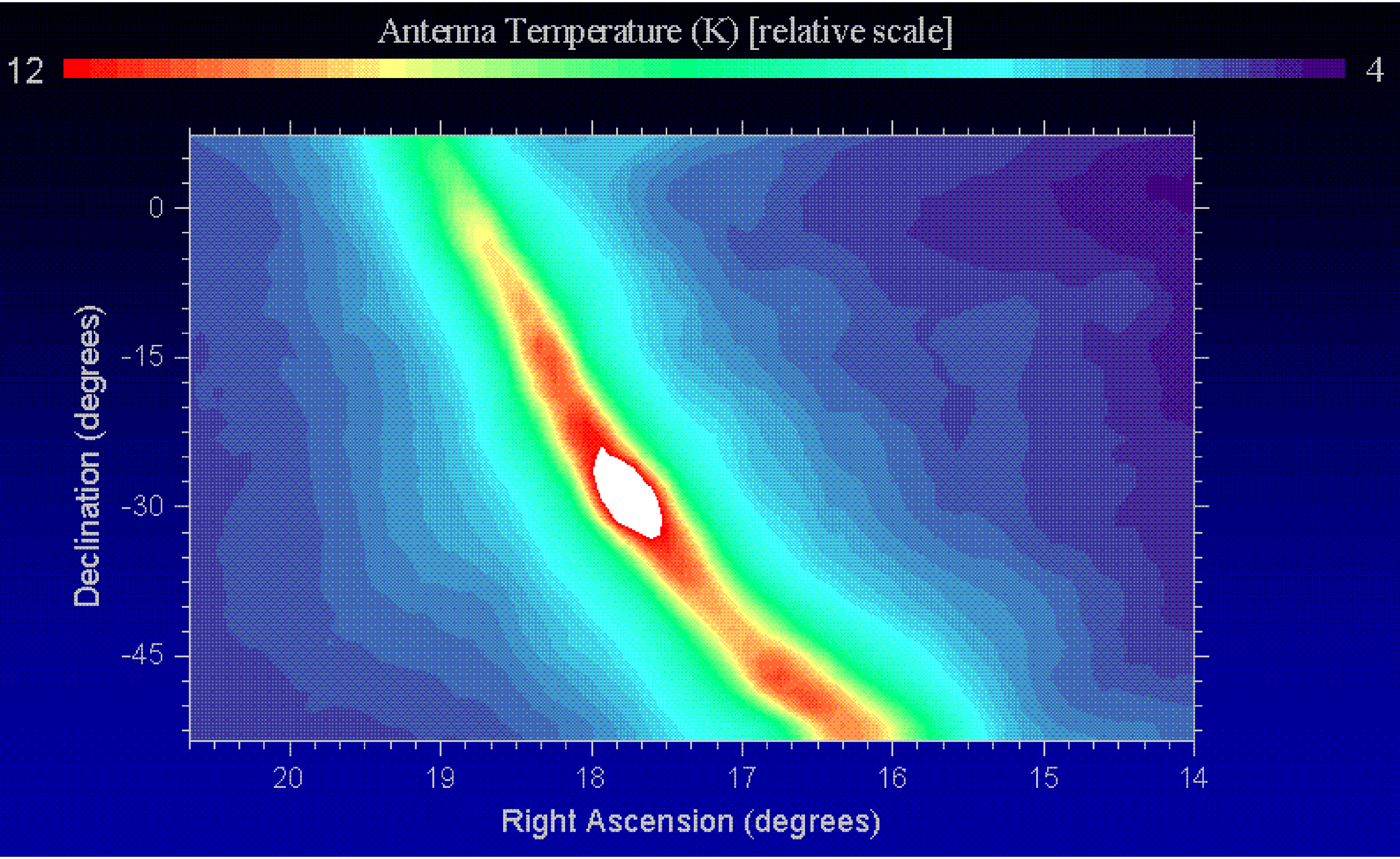

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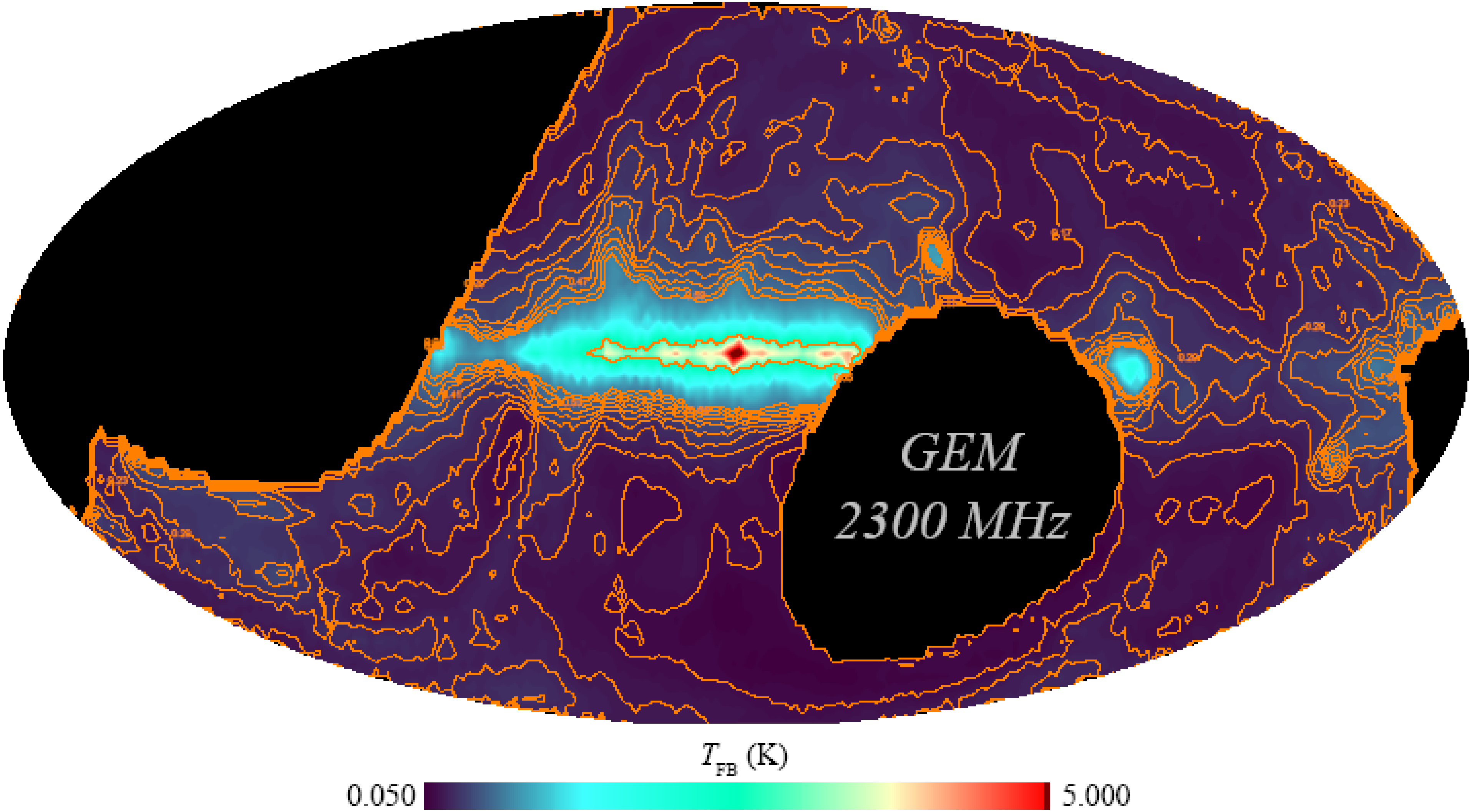
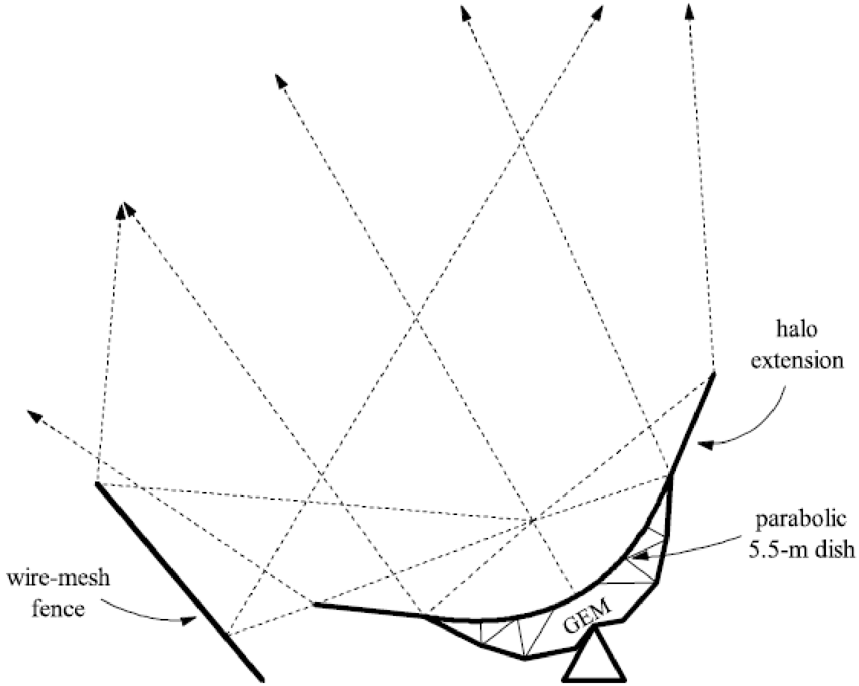
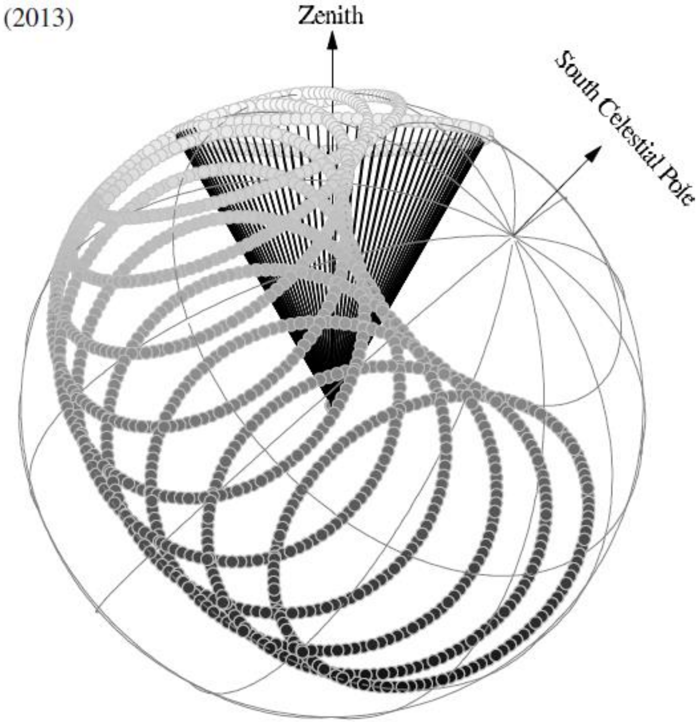
Galactic emission map at 2.3 GHz
GEM experiment
(Tello, Villela et al., A&A 2013)



(2013)





Frequency (MHz)	*HPBW* (degrees)	Sky coverage (degrees)	Duration (hours)	Observational campaign
408	10.5	$+07\overset{\circ}{.}2 < \delta < +67\overset{\circ}{.}5$	40	Bishop, CA, USA 1994 (1)
1465	4.2	$+07\overset{\circ}{.}2 < \delta < +67\overset{\circ}{.}5$	70	Bishop, CA, USA 1994 (2)
408	11.3	$-24\overset{\circ}{.}4 < \delta < +35\overset{\circ}{.}6$	447	Villa de Leyva, Colombia 1995 (3)
2300	3.7	$-24\overset{\circ}{.}4 < \delta < +35\overset{\circ}{.}6$	231	Villa de Leyva, Colombia 1995 (4)
1465	4.2	$-52\overset{\circ}{.}1 < \delta < +06\overset{\circ}{.}7$	709	Cachoeira Paulista, SP, Brazil 1999 (5)
2300	$2\overset{\circ}{.}30 \times 1\overset{\circ}{.}85$	$-51\overset{\circ}{.}73 < \delta < +06\overset{\circ}{.}36$	532	Cachoeira Paulista, SP, Brazil 1999 (6)
1465	4.2	$-52\overset{\circ}{.}1 < \delta < +06\overset{\circ}{.}7$	510	Cachoeira Paulista, SP, Brazil 2004–2005 (7)
1465	4.2	$-52\overset{\circ}{.}1 < \delta < +06\overset{\circ}{.}7$	417	Cachoeira Paulista, SP, Brazil 2009 (7)

Description	Colombia	Brazil
Observational site	Villa de Leyva	Cachoeira Paulista
Longitude (WGS84)	$-73°35'0.53''$	$-44°59'54.34'$
Latitude (WGS84)	$+5°37'7.84''$	$-22°41'0.74''$
Altitude (m.a.s.l.)	2173	572
Observing runs	1995-Jun-1–18	1999-May-18–Jun-17 1999-Oct-11–26
Antenna mounting	altazimuthal	altazimuthal
Azimuth scanning speed (rpm)	0.99632 ± 0.00036	1.00290 ± 0.00063
Sky coverage (%)	46.3	46.8
Pointing accuracy	$6\overset{'}{.}84$	$5\overset{'}{.}26$
Center frequency (MHz)	2300	2300
Pre-detection BW (MHz)	100	100
Gain (K V^{-1})	54.675	50.928
Gain susceptability (K^{-1})	-0.02381 ± 0.00028	-0.02164 ± 0.00006
System temperature (K)	85.466	61.644
RMS sensitivity (mK)	11.42	8.24
RF plate T_{cal} (K)	310.572	308.031
Horizontal *HPBW* (°)	2.30 ± 0.13	2.31 ± 0.03
Vertical *HPBW* (°)	1.92 ± 0.18	1.82 ± 0.12
Beam efficiency (%)	75.0 ± 3.5	75.0 ± 3.5
Aperture efficiency (%)	38.0	39.9
PSS (Jy K^{-1})	306	291

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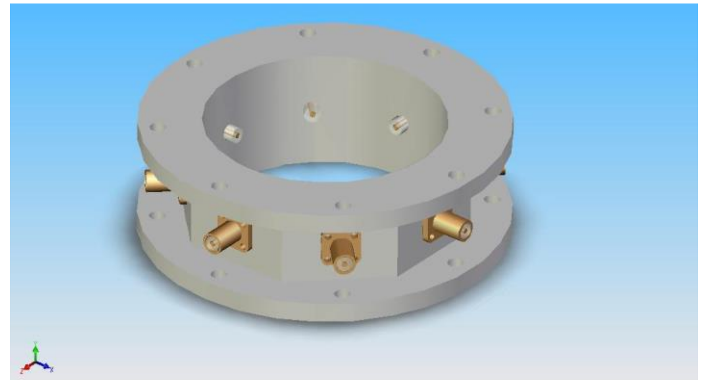
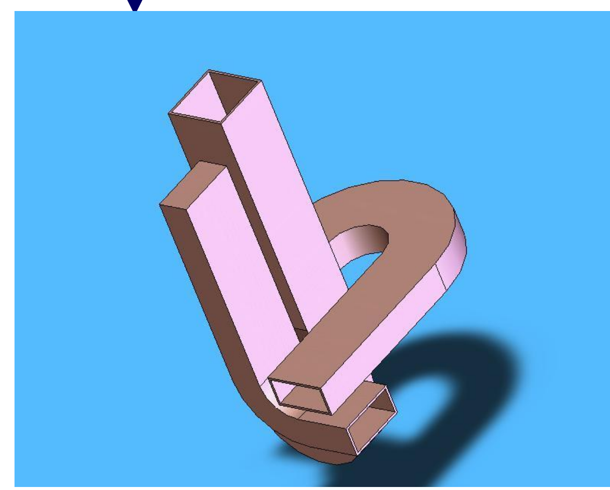
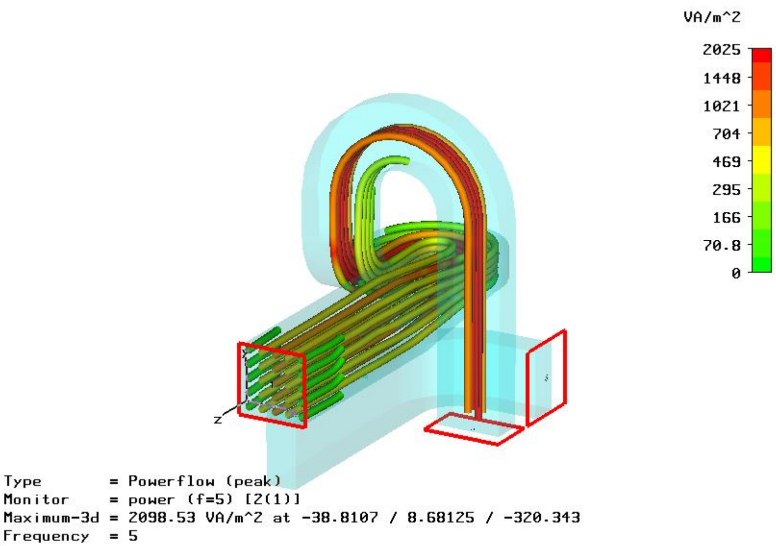
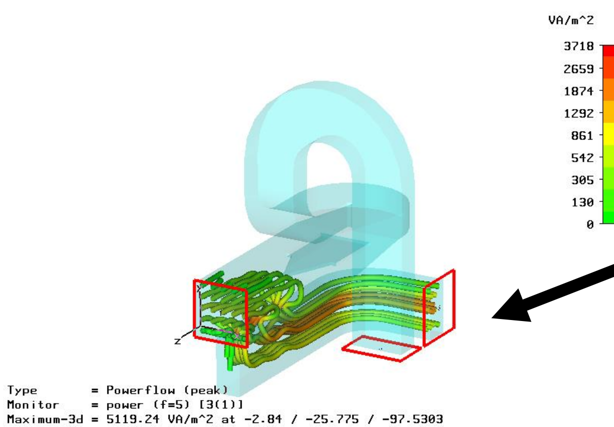
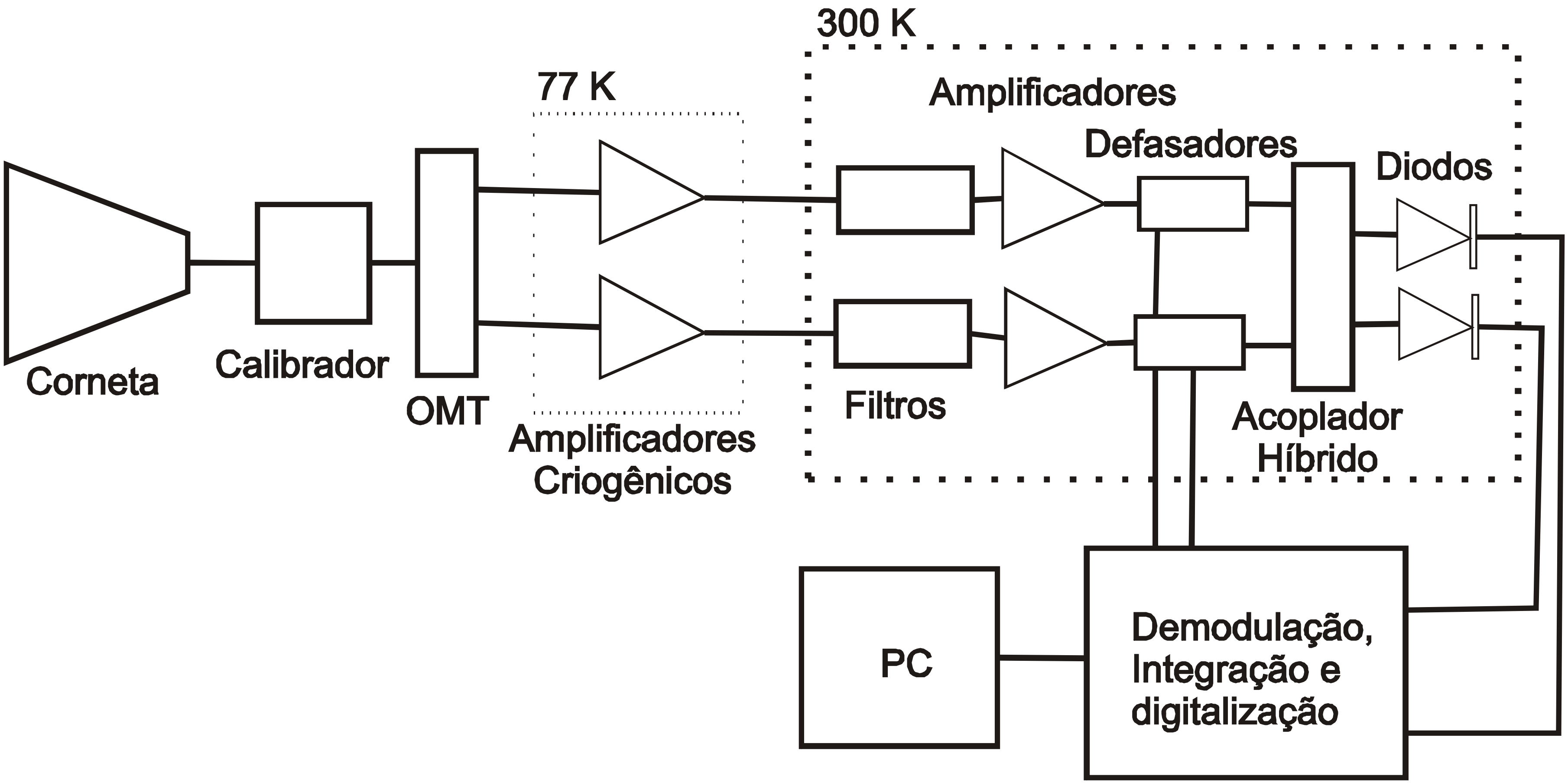
5 GHz polarimeter



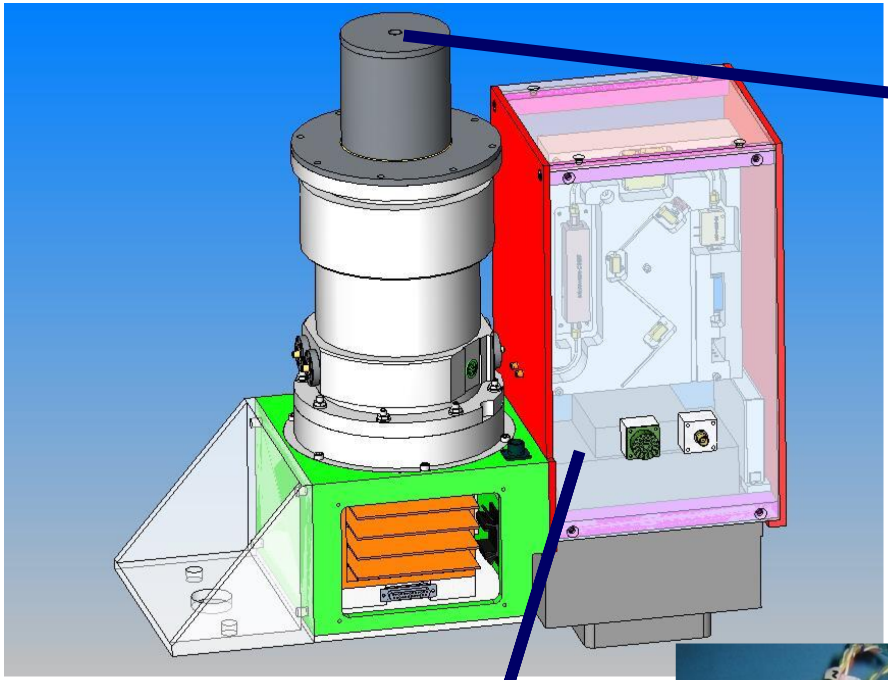


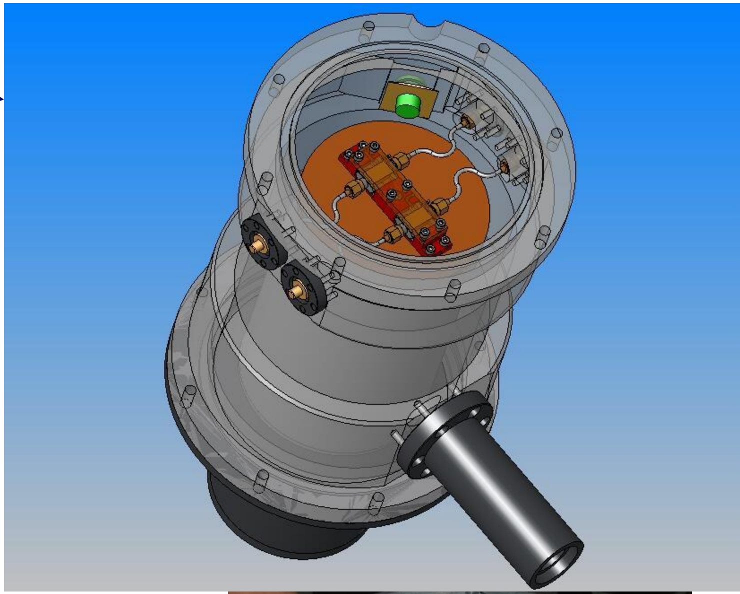


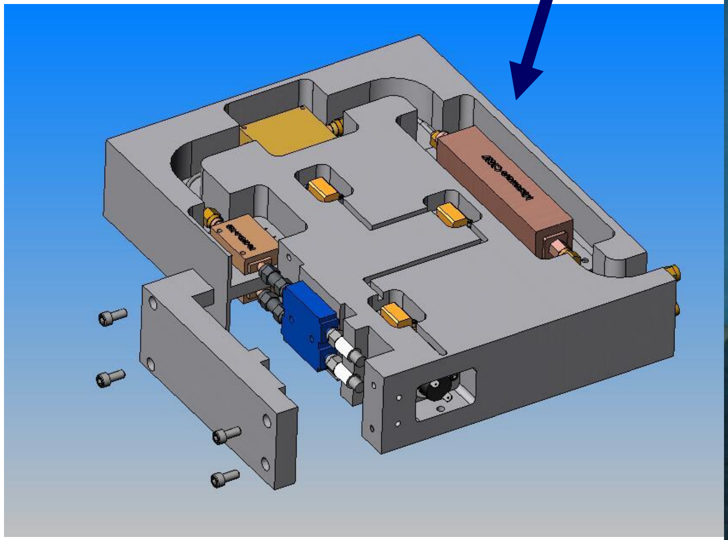


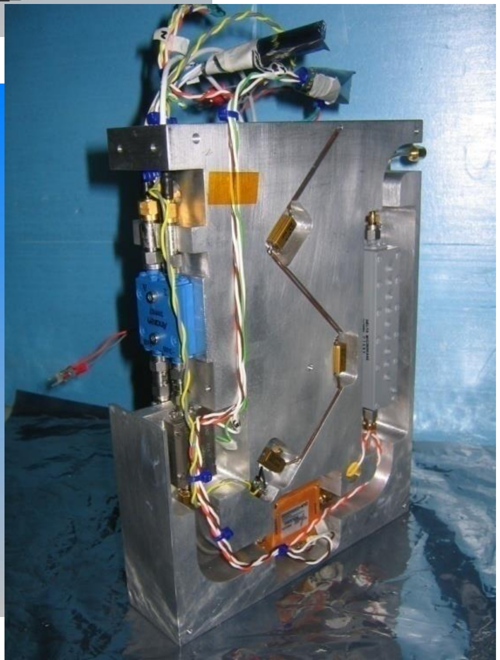

300 K
77 K
Amplificadores
Defasadores
Diodos
Corneta
Calibrador
OMT
Amplificadores
Criogênicos
Filtros
Acoplador
Híbrido
PC
Demodulação,
Integração e
digitalização

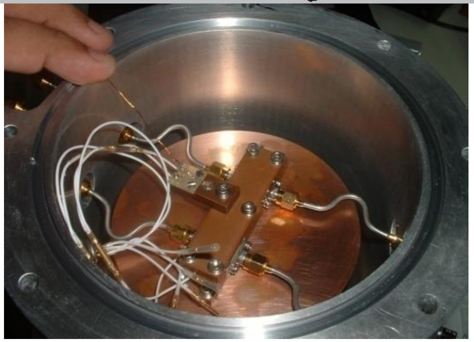
5 GHz polarimeter





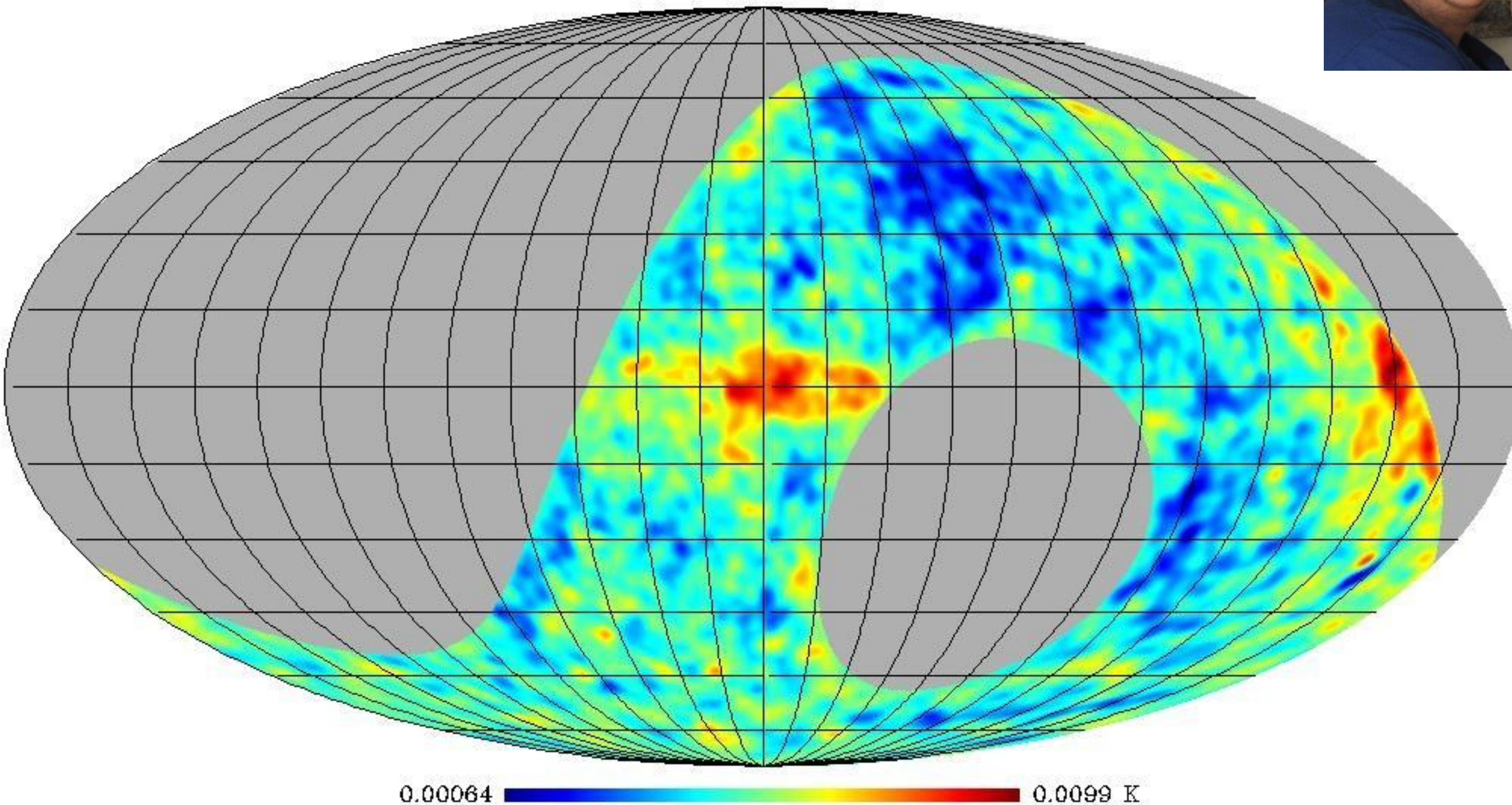




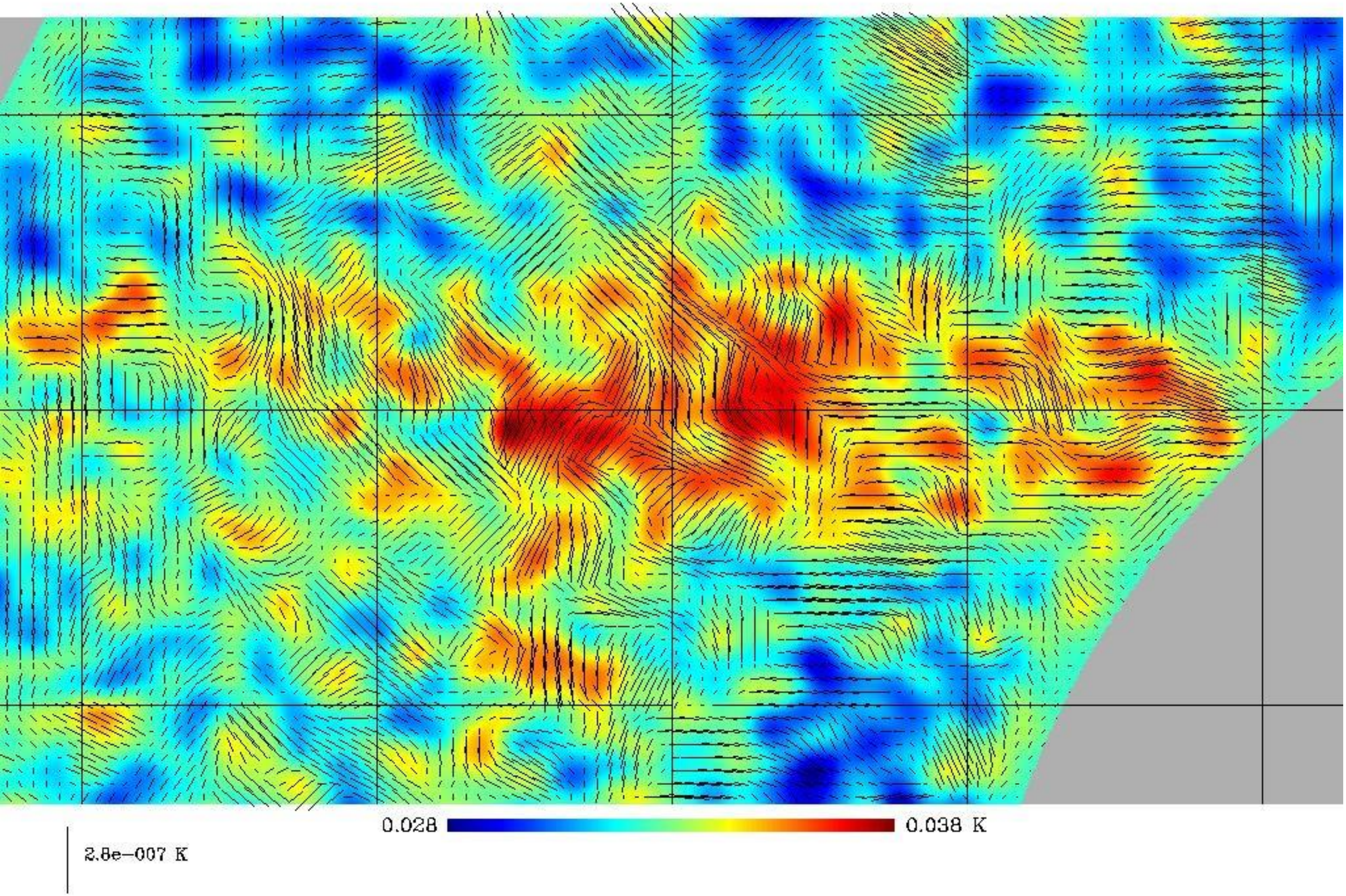


5 GHz polarimeter

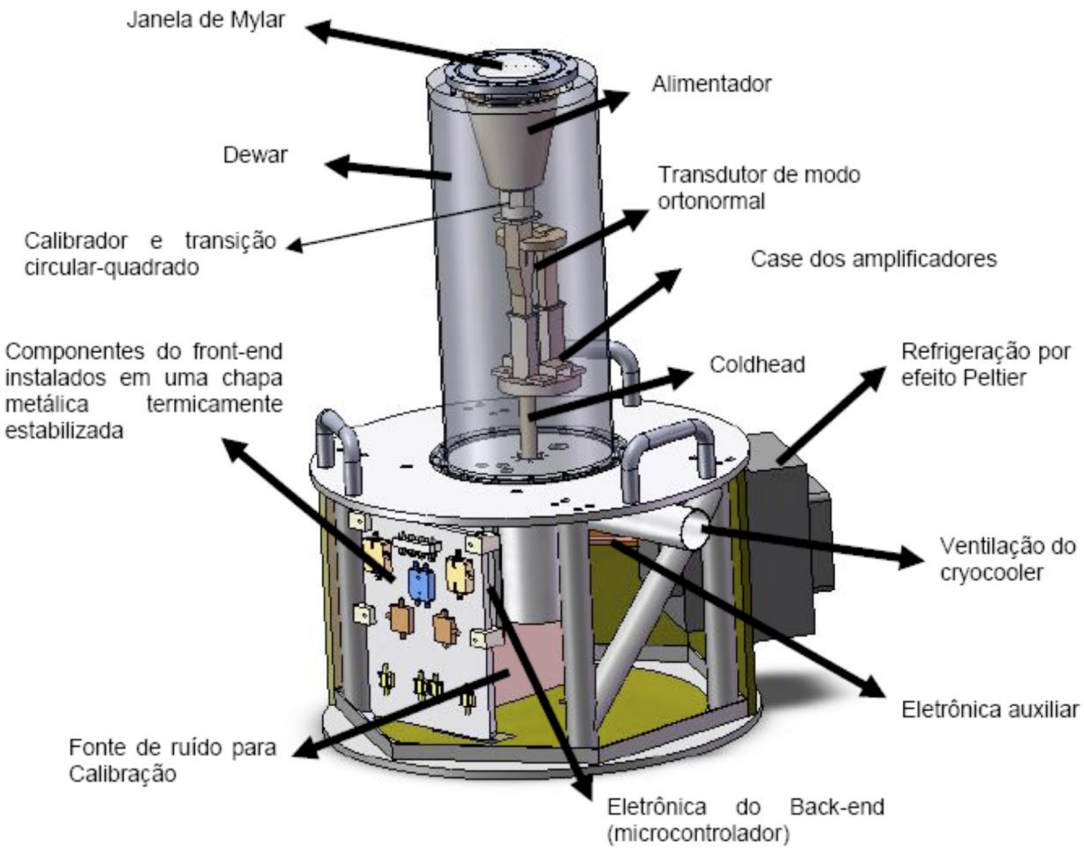
GEM – 5 GHz polarized map

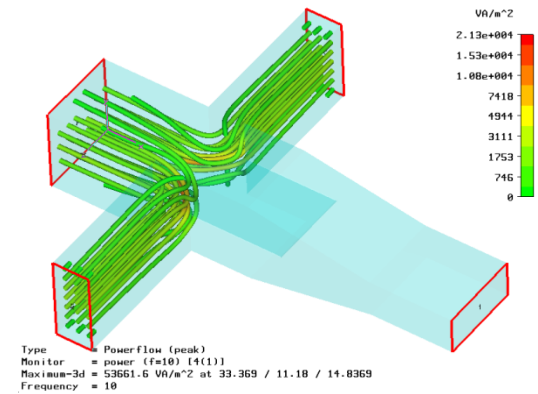


GEM – 5 GHz Galactic Center region polarized map

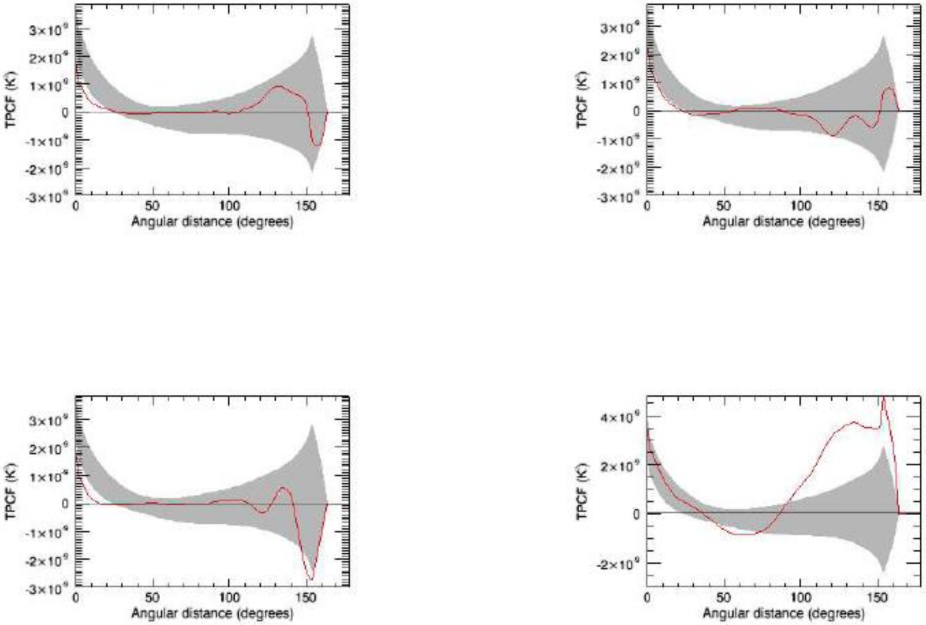


10 GHz


Janela de Mylar
Alimentador
Dewar
Transdutor de modo ortonormal
Calibrador e transição circular-quadrado
Case dos amplificadores
Componentes do front-end instalados em uma chapa metálica termicamente estabilizada
Coldhead
Refrigeração por efeito Peltier
Ventilação do cryocooler
Eletrônica auxiliar
Fonte de ruído para Calibração
Eletrônica do Back-end (microcontrolador)

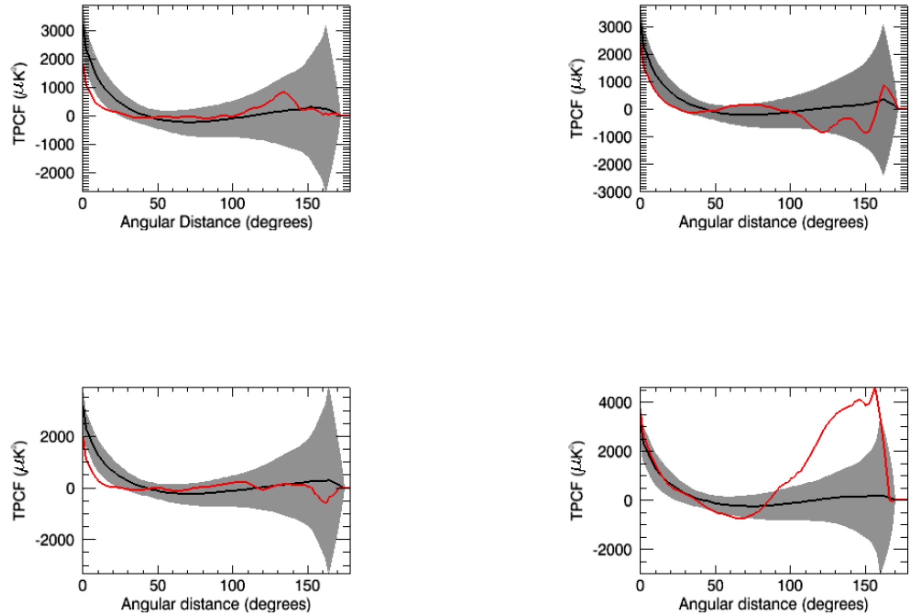

VA/m^2
2.13e+004
1.53e+004
1.08e+004
7418
4944
3111
1753
746
0
Type = Powerflow (peak)
Monitor = power (f=10) [4(1)]
Maximum-3d = 53661.6 VA/m^2 at 33.369 / 11.18 / 14.8369
Frequency = 10

WMAP



Santos, Villela and Wuensche, A&A 2012

Planck



Santos, Cabella, Villela, Balbi, Vittorio, Wuensche, 2014

Some People...


Rodrigo Leonardi


Camilo Tello


Philip Lubin


Agenor Pina


Alex Wuensche

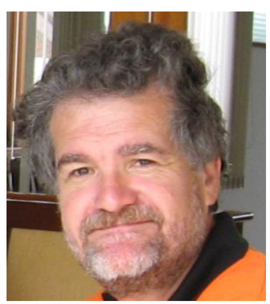

Peter Meinhold

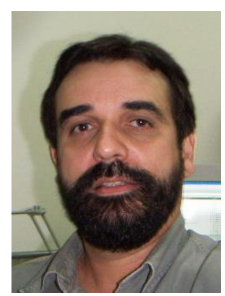

Jorge Mejía


Angélica Costa


Ivan Ferreira


George Smoot


Luiz Reitano


Thyrso Villela


Newton Figueiredo