Cosmic Microwave Background Anisotropy Measurements

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Special Thanks To:

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Cosmic Microwave Background-Introduction

Big Bang Cosmology: Expanding Universe- optically thick hot plasma at some time in the past.

Expanding plasma cools to ~3000K: Recombination (may) occurs and the Universe becomes transparent. This occurred at z~1000

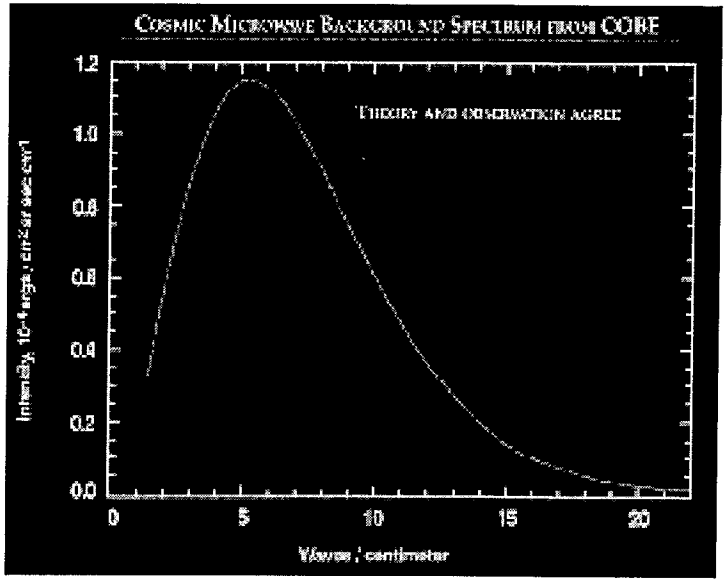
Photon background has spectrum characterized by a blackbody with a characteristic temperature which drops as 1/R.

Predicted in 1948 G. Gamow

Discovered 1965 Penzias & Wilson

Spectrum of the CMB traces the thermal history of the Universe:

COBE FIRAS- 1991



Anisotropy of the CMB

Why is it important: The CMB is a snapshot of the Universe at a time 300,000 years after the Big Bang.

The physics of the Universe at that time is relatively simple:

Linear regime - no messy details of structure formation

Simple physics

What can we learn from it:

Dipole Anisotropy- Our velocity in the Universe

Initial fluctuation spectrum- Large scale anisotropy (> a few degrees) is not effected by structure formation; traces the initial conditions (Planck scale) of the Universe.

Intermediate scales- horizon scale at decoupling - Ω_o

Smaller scales- matter content of the Universe

Polarization- Gravity wave background

Observation of the CMB is a rapidly evolving field

1948- Predicted by G. Gamow

1965- Discovered by Penzias& Wilson

1970- $\Delta T/T<10^{-3}$

1975- Dipole discovered, pol < 10^{-6}

1980s-$\Delta T/T<5x10^{-5}$

1991- COBE DMR $\Delta T/T=10^{-5}$

Early 1990s- $\Delta T/T=3x10^{-5}$

Mid 1990's- small scale maps

Late 1990's- larger maps-Boomerang

Early 2000's- MAP, Polatron, CBI, DASI etc

Late 2000's- Planck

<u>Detectors</u>

Schottky Mixers

Cooled Schottky

HEMT LNA, Bolometers

HEMT and Bolometer Arrays

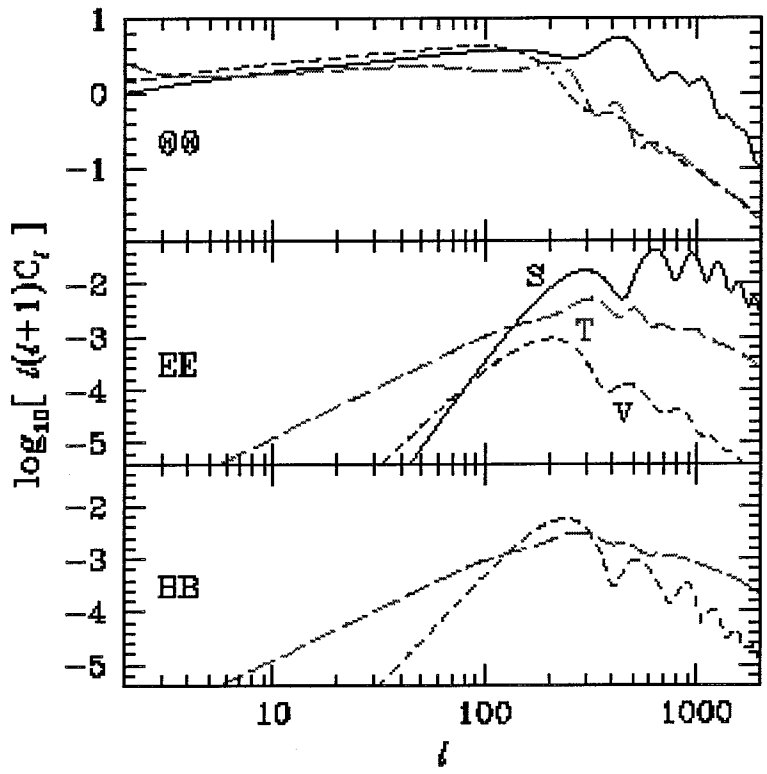
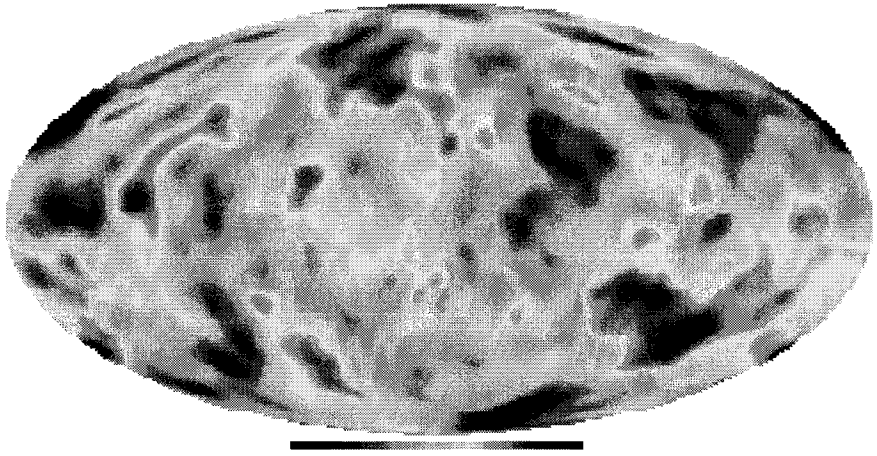


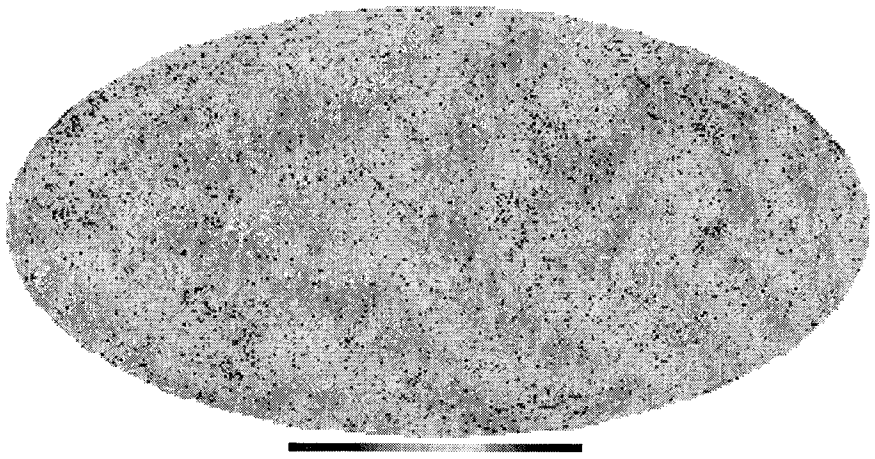
FIG. 8. Temperature and polarization power spectra for a scaling anisotropic stress seeds with the minimal characteristic time $B_1 = 1$ for scalars (S, solid), vectors (V, short-dashed), and tensors (T, long-dashed). Scalar temperature fluctuations at intermediate scales are dominated by acoustic contributions which then damp at small scales. B-parity polarization contributions are absent for the scalars, larger by an order of magnitude than E-parity contributions for the vectors and similar to but smaller than the E-parity for the tensors. Features in the vector and tensor spectra are artifacts of our choice of source and are unlikely to be present in a realistic model. The background cosmology is set to $\Omega_0 = 1$, $h = 0.5$, $\Omega_B h^2 = 0.0125$.

From: Hu&White '97

The Universe

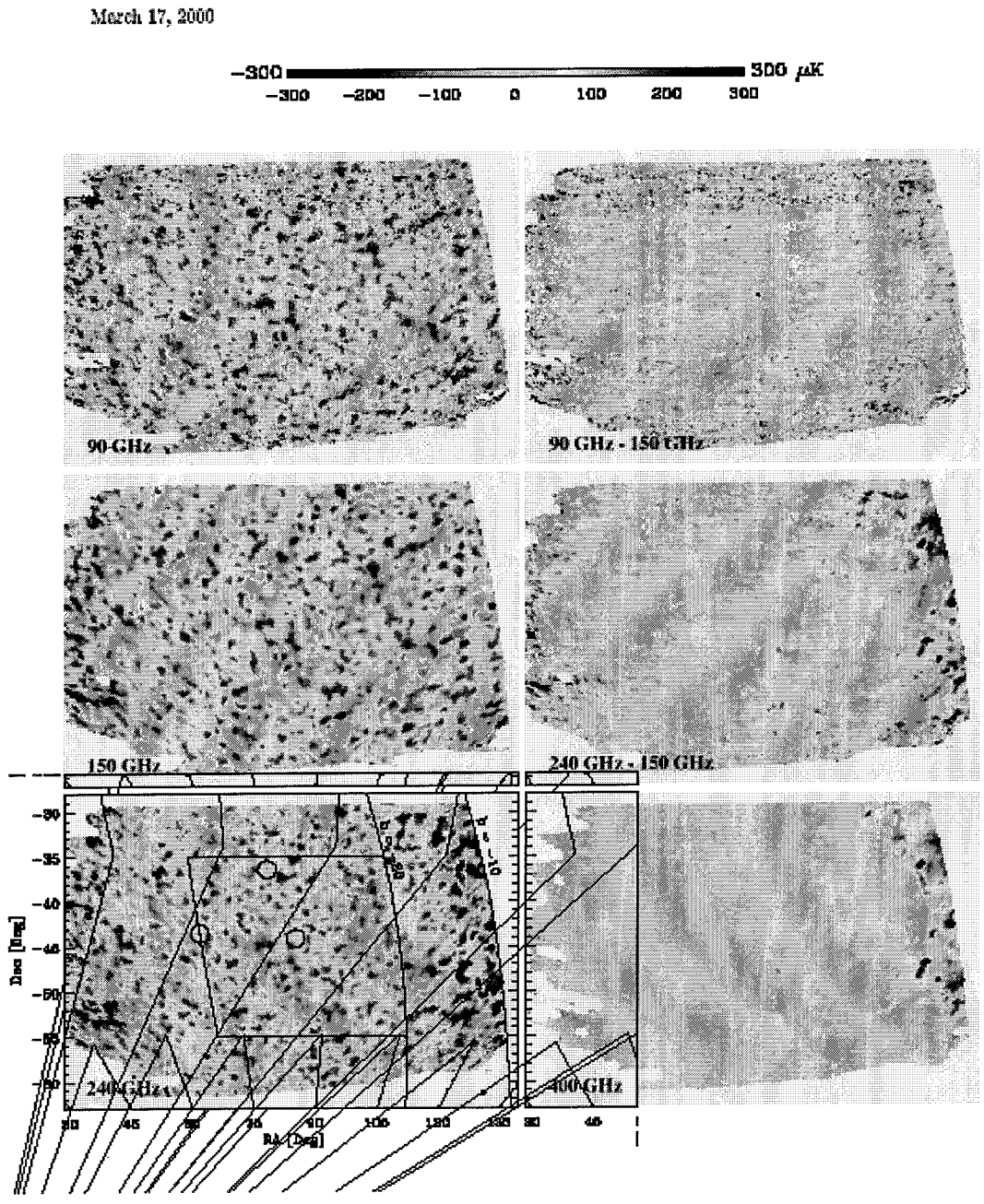


COBE Resolution



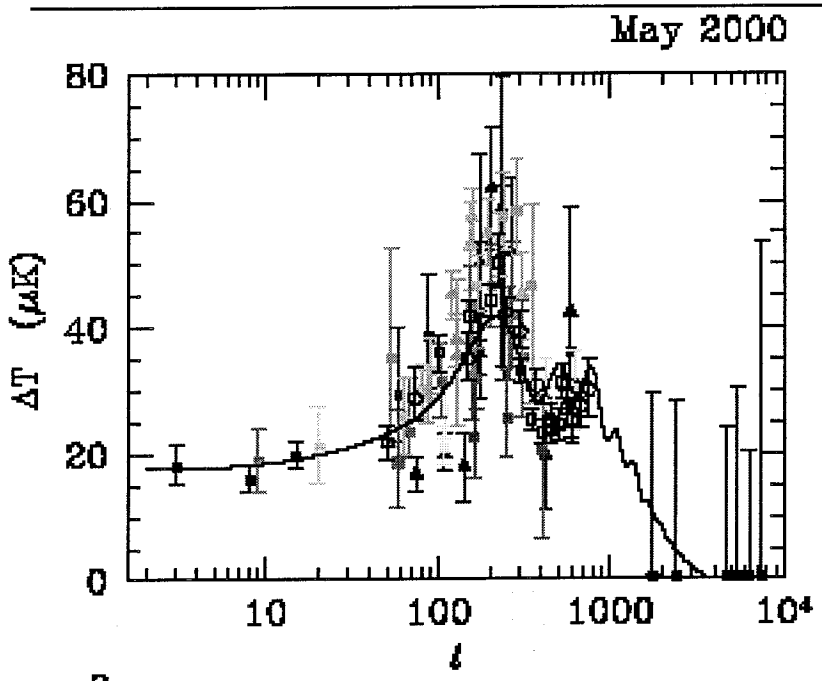
Planck Resolution

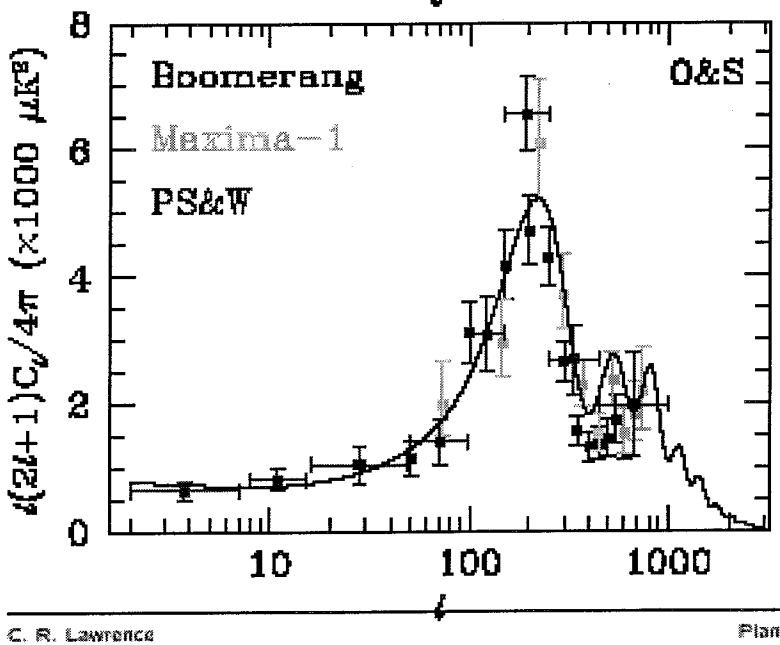
Boomerang Results

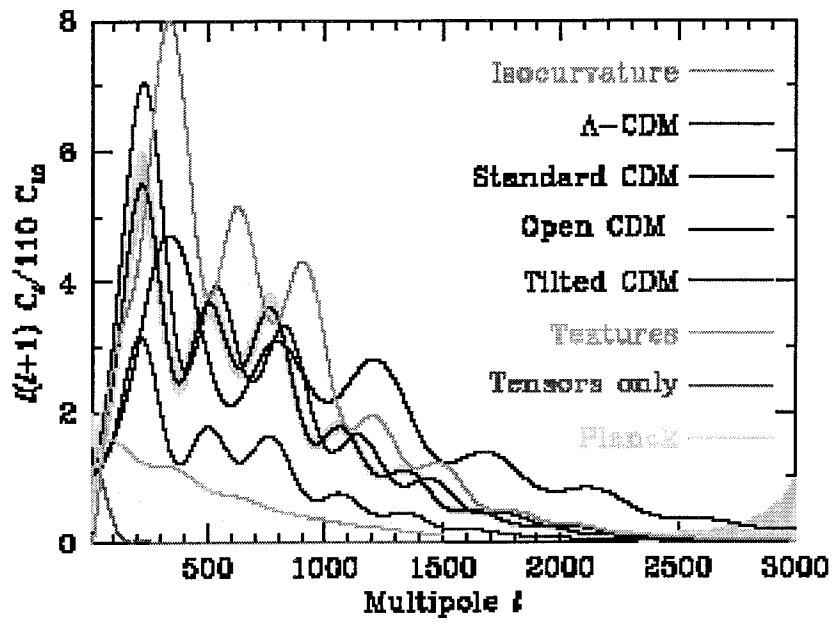


Nature June 00
Courtesy:A. Lange

Current Results and Planck Expectations







On angular scales greater than about 5′ the uncertainty in Planck's measurements of temperature anisotropies should be determined by the number of independent samples that the Universe provides, rather than by instrument noise.

Measuring CMB Anisotropy

CMB measurements are difficult:

Signals ~ 100 μK (or 10 μK pol), Noise ~ 3-50 K-

systematics are critical

Atmosphere: ~ 20 K at sea level, < 1 K at balloon altitude, Lumpy

Optical: Diffraction limited optics, sidelobe response can contaminate measurements

Foregrounds: Galactic synchrotron, free-free and dust emission are all significant

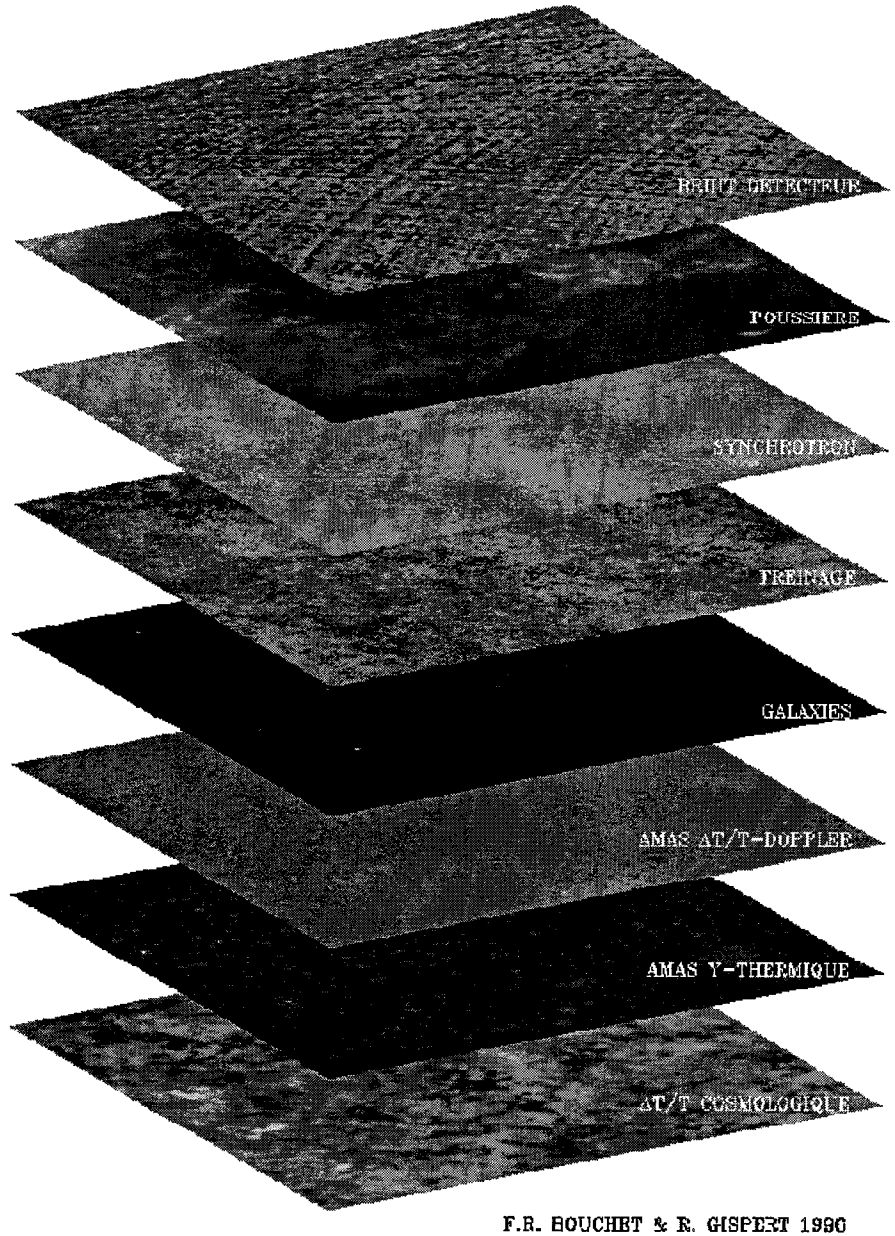
Extragalactic radio sources

Sunyaev-Zel'dovich effect as foreground

Lensing as confusion

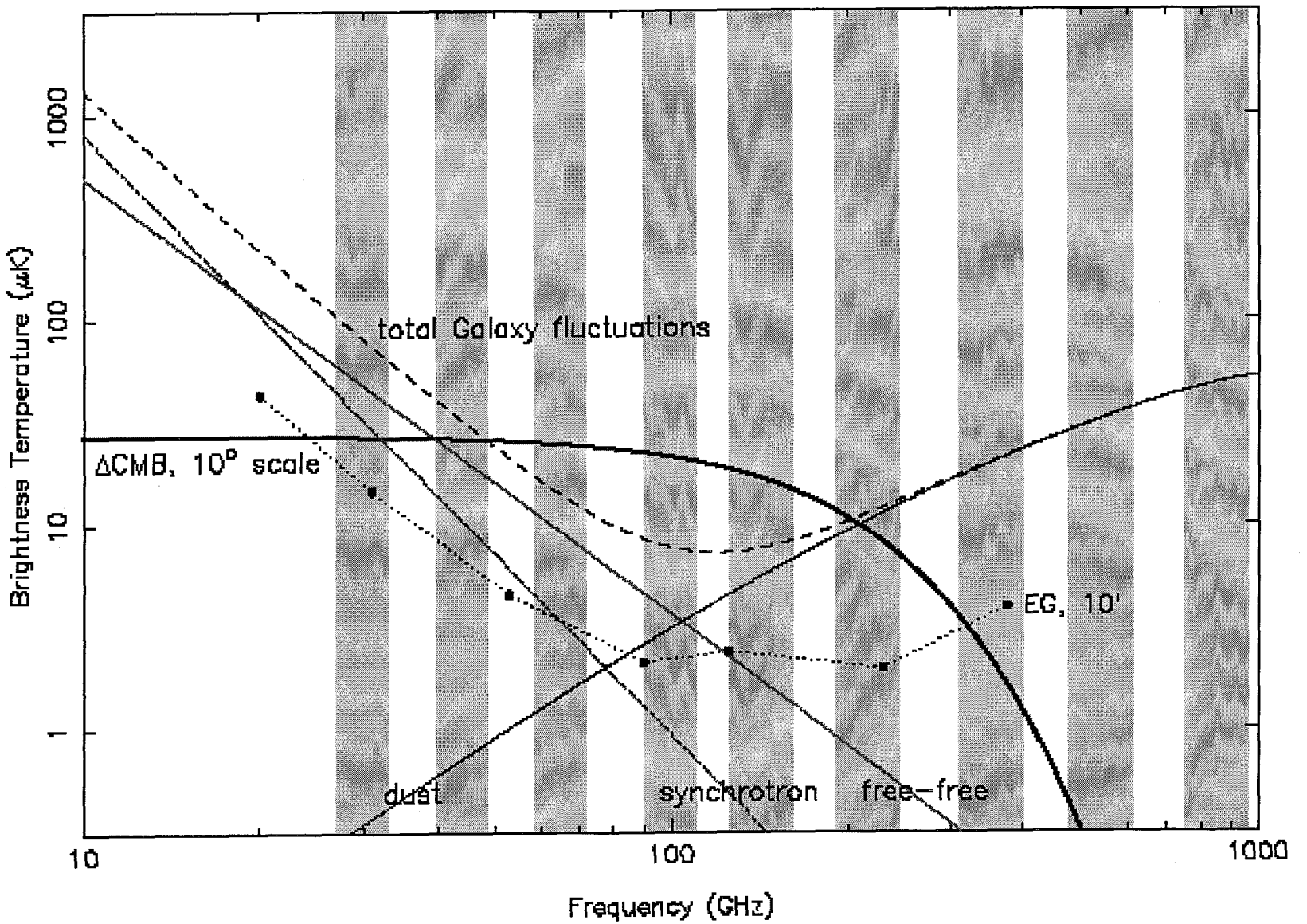
Multi-frequency measurements

Why Planck Needs 30–857 GHz: Foregrounds



F.R. BOUCHET & R. GISPERT 1990

Foregrounds and the CMB Have Different Spectra



Background Emission Anisotropy Scanning Telescope (BEAST)

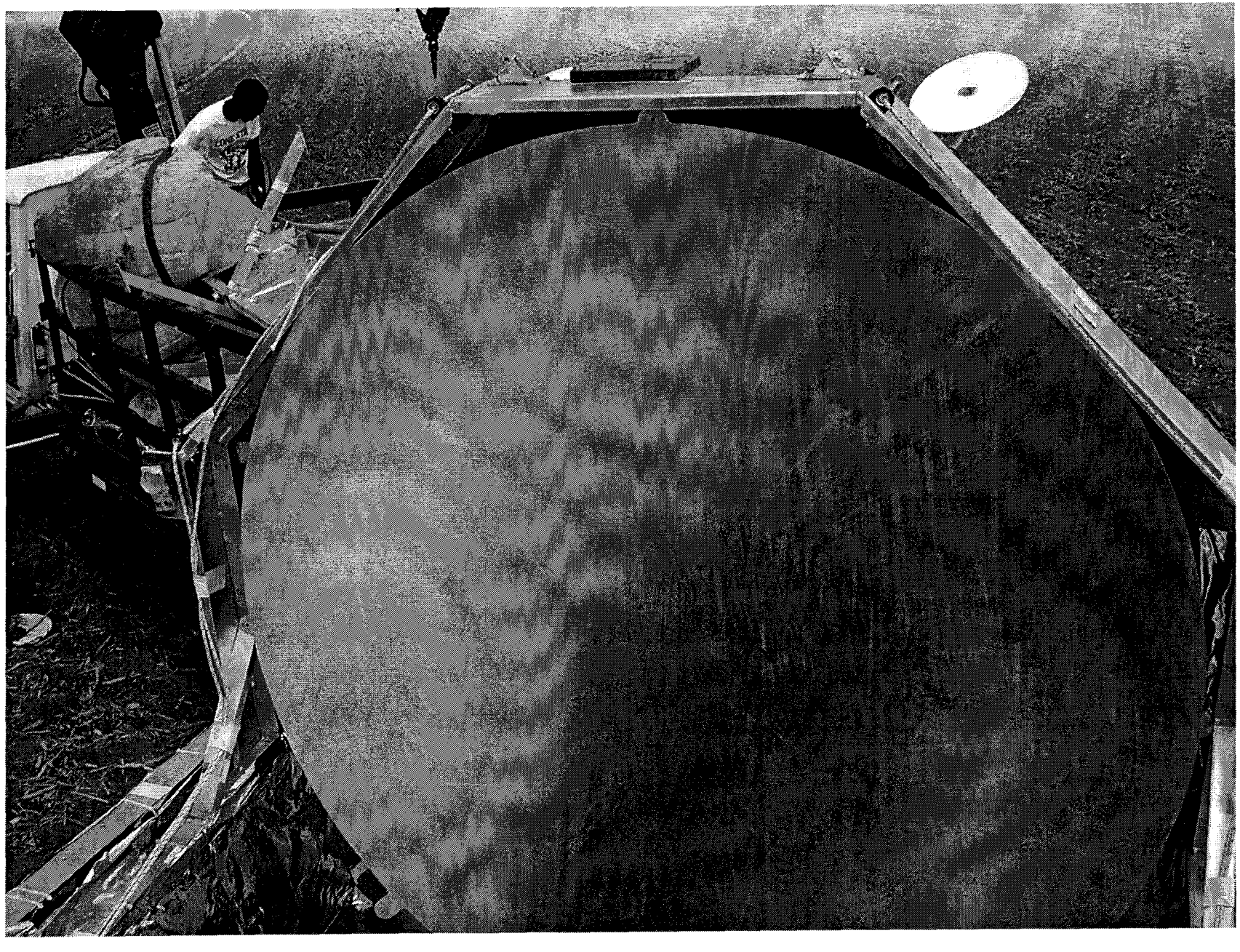
Instrument Parameters:

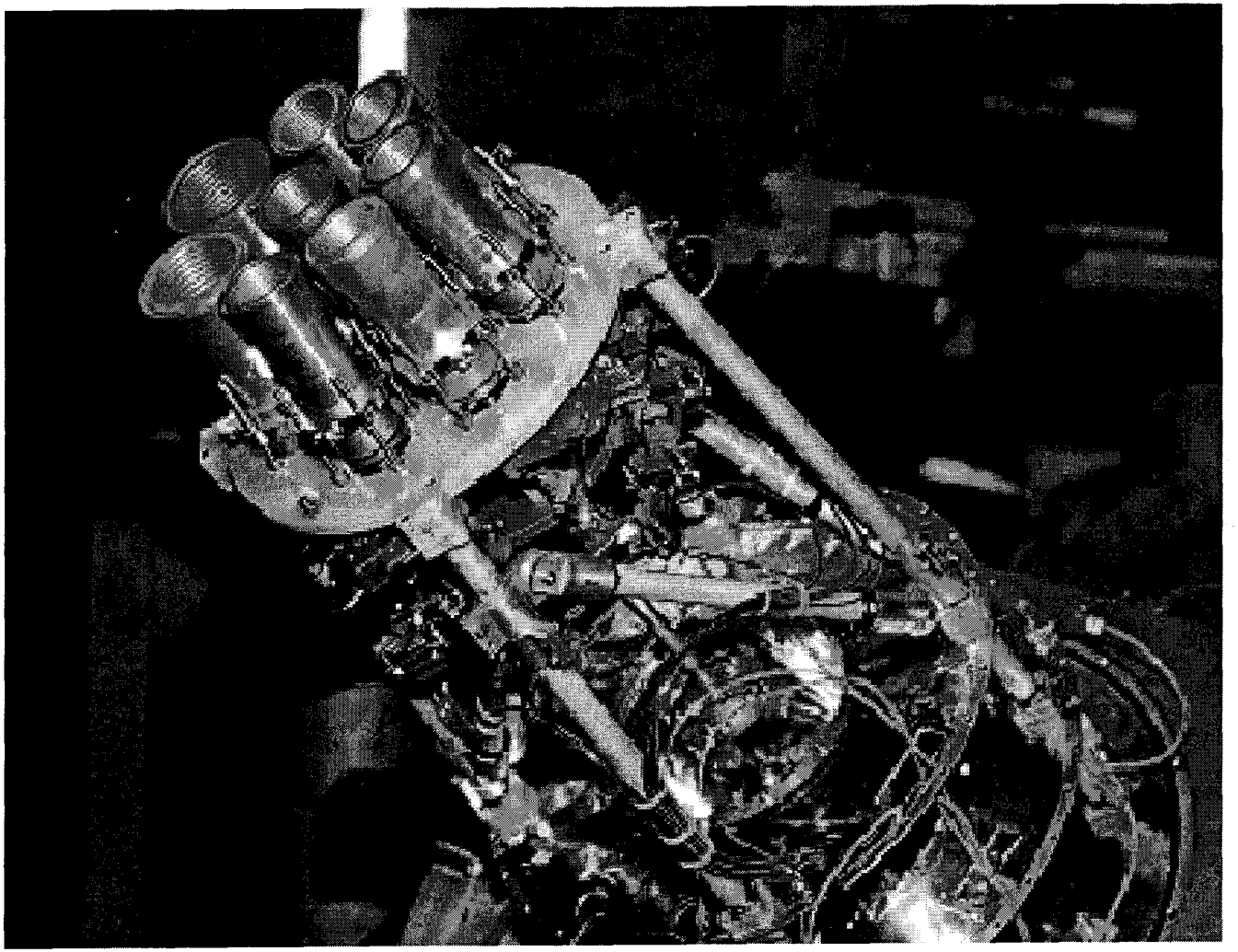
2.2 meter diameter CFRP optimized off axis Gregorian telescope

Focal Plane array of InP High Electron Mobility Amplifiers (HEMT) at 30, 40 and 90 GHz

Detectors cooled to 12 - 20K via LHe storage tank

2.5 meter diameter rotating flat allows a 2-D raster scan of the sky – highly interconnected data – typically 10 degree diameter "circle"



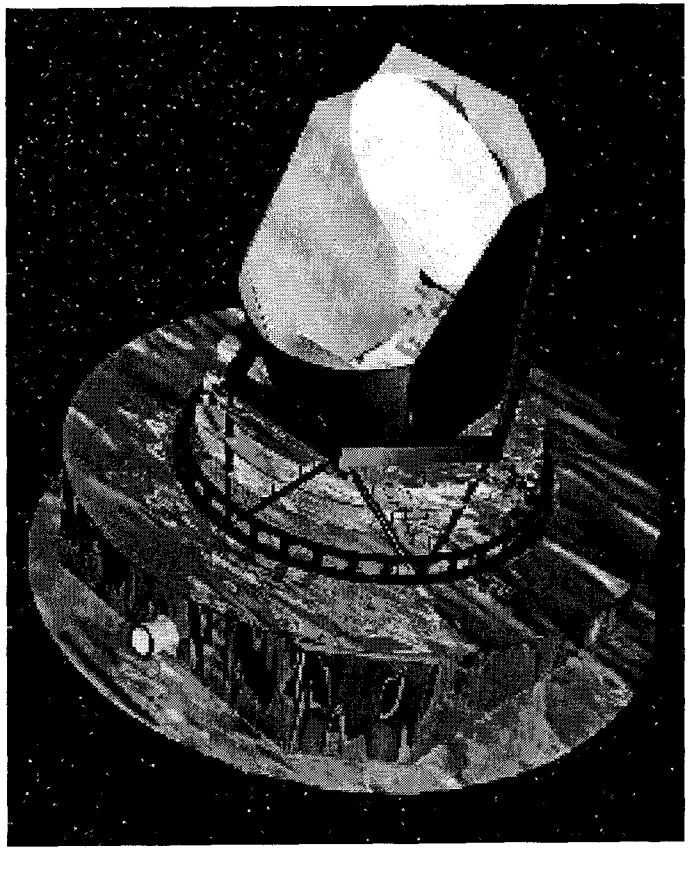


Planck Mission Overview

- Third generation space CMB mission
- Launch 2007 (was 2004) with FIRST
- Main objective: image over the whole sky the temperature anisotropies of the CMB, with FWHM as small as 5′ and sensitivity per resolution element of 5–12 μK
- L_2 Lissajous orbit
- Spin axis pointed at Sun, 1 rpm spin
  - Optical axis ≈perpendicular to spin axis
- Single, continuous, observing mode
- Two instruments
  - Low Frequency Instrument (30–100 GHz)

    56 channels of HEMT amplifiers cooled to 20 K by the H_2 sorption cooler
  - High Frequency Instrument (100–857 GHz)

    48 channels of bolometers cooled to 0.1 K by three coolers: sorption + 4 K ^{4}He JT + ^{3}He^{4}He dilution



Planck Mission Parameters

Launch: 2007
Optical System: 1.5 m off-axis Gregorian providing 5'-25' beams

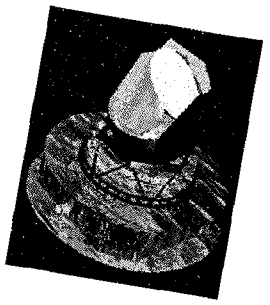
Low Frequency Instrument:

20 K InP HEMT amplifier based pseudo-correlation receivers

Frequency (GHz)	Fractional BW	# Channels	Sys Noise (K)	Sensitivity ($\mu K\sqrt{s}$)
30	0.2	4	10	90
44	0.2	6	15	100
70	0.2	12	23	90
100	0.2	34	32	80

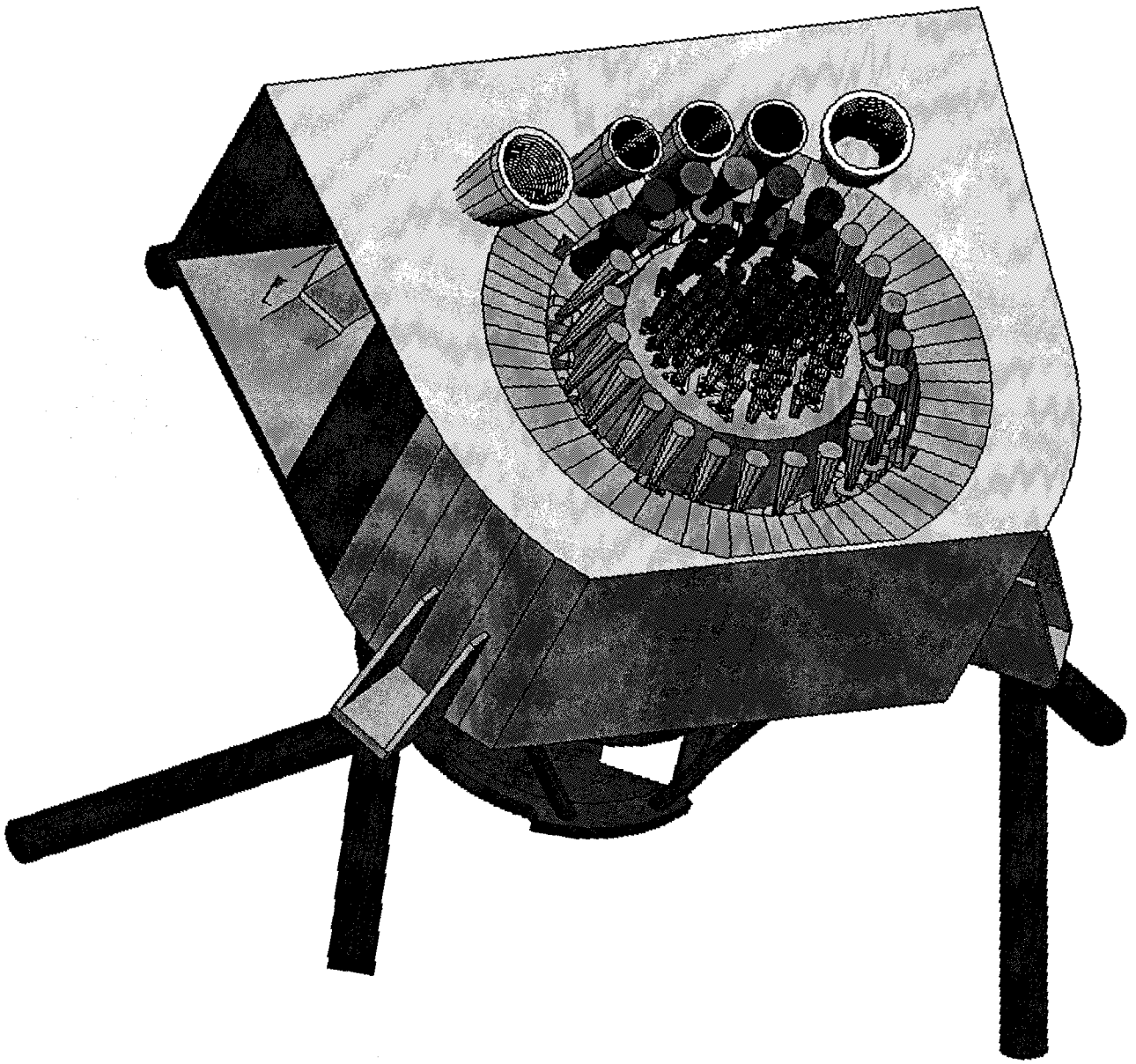
High Frequency Instrument
0.3 K Bolometers

Channel central frequency (ν)	**Ghz**	**100**	**143**	**217**	**353**	**545**	**857**
Beam FWHM	**(arcmin)**	**9.2**	**7.1**	**5**	**5**	**5**	**5**
Number of Unpolarised detectors		**4**	**5**	**6**	**6**	**/**	**6**
Number of polarised detectors		**/**	**7**	**8**	**/**	**8**	**0**
ΔT/T Channel NEDT (Intensity)	**(μK/K)Hz$^{-1/2}$**	**13.1**	**11.2**	**12.7**	**50.8**	**/**	**24000**
ΔT/T Channel NEDT (U and Q)	**(μK/K)Hz$^{-1/2}$**	**/**	**21.3**	**29.4**	**/**	**508**	**/**
ΔT/T Sensitivity (Intensity)	**(μK/K)**	**2.0**	**2.2**	**3.5**	**14**	**/**	**6600**
ΔT/T Sensitivity (U and Q) Polarised	**(μK/K)**	**/**	**4.2**	**8.1**	**/**	**140**	**/**



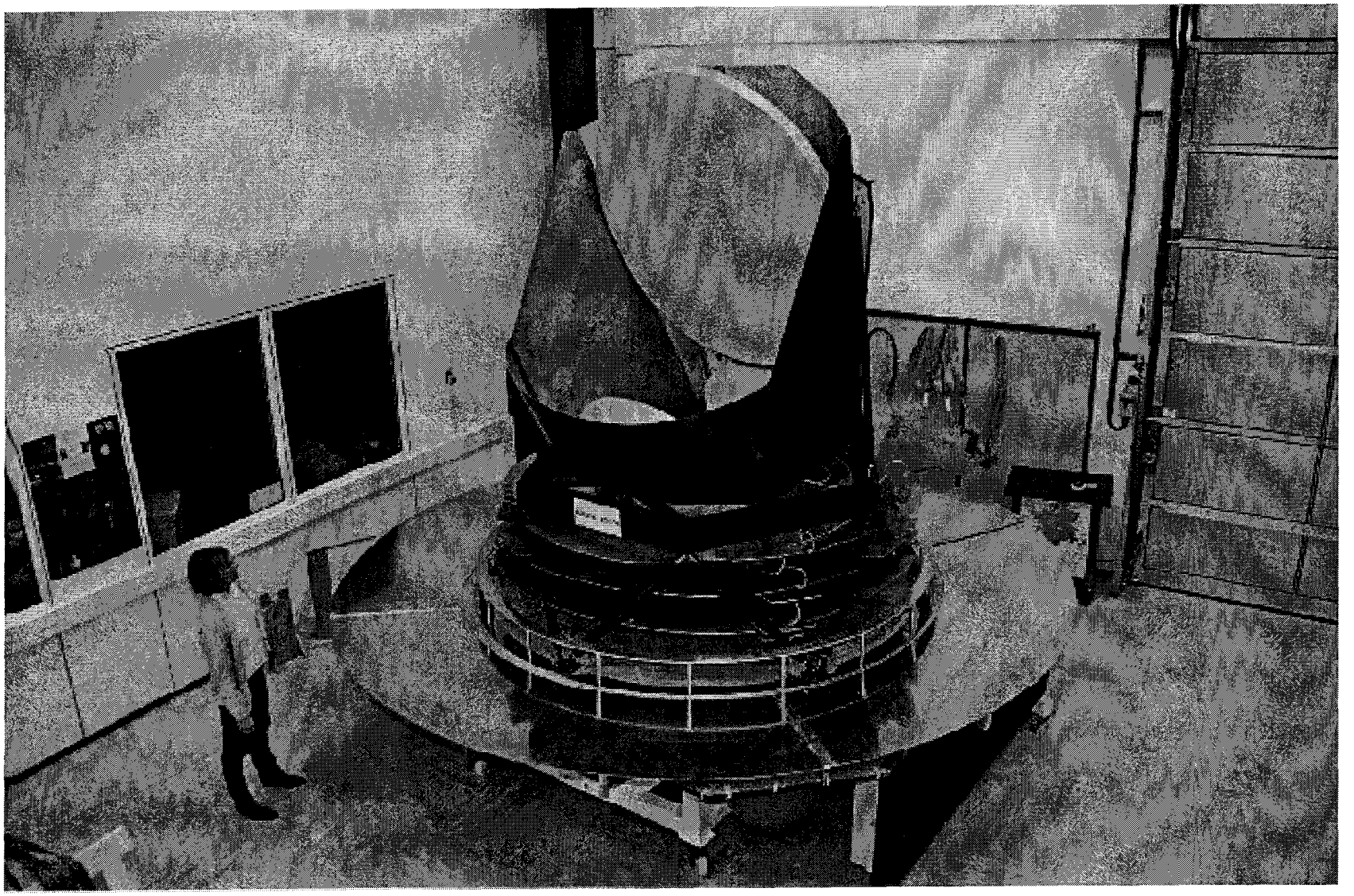
First / Planck Payload Review
23 May, 2000

PLANCK
HFI

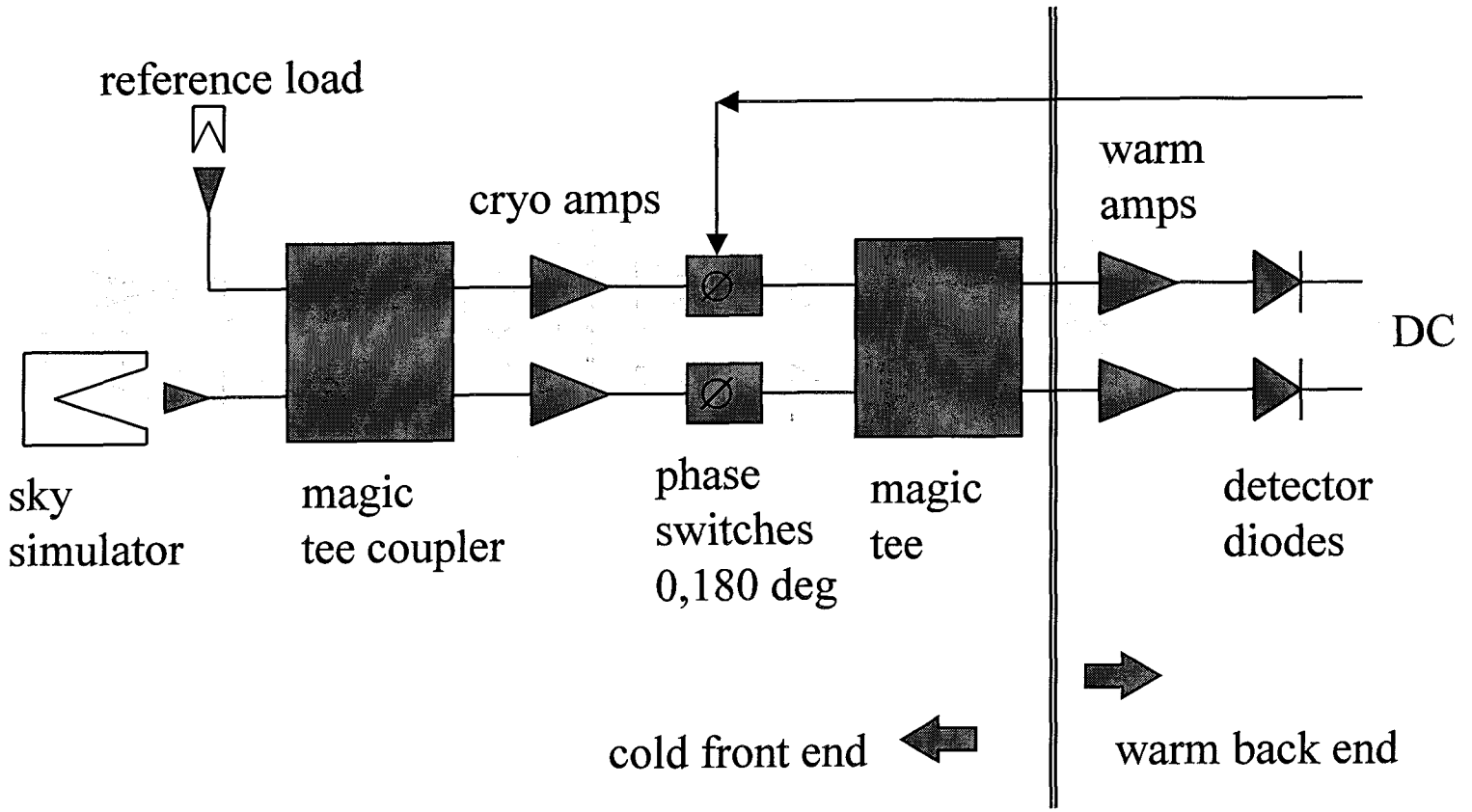


I.A.S. / J-L. Puget

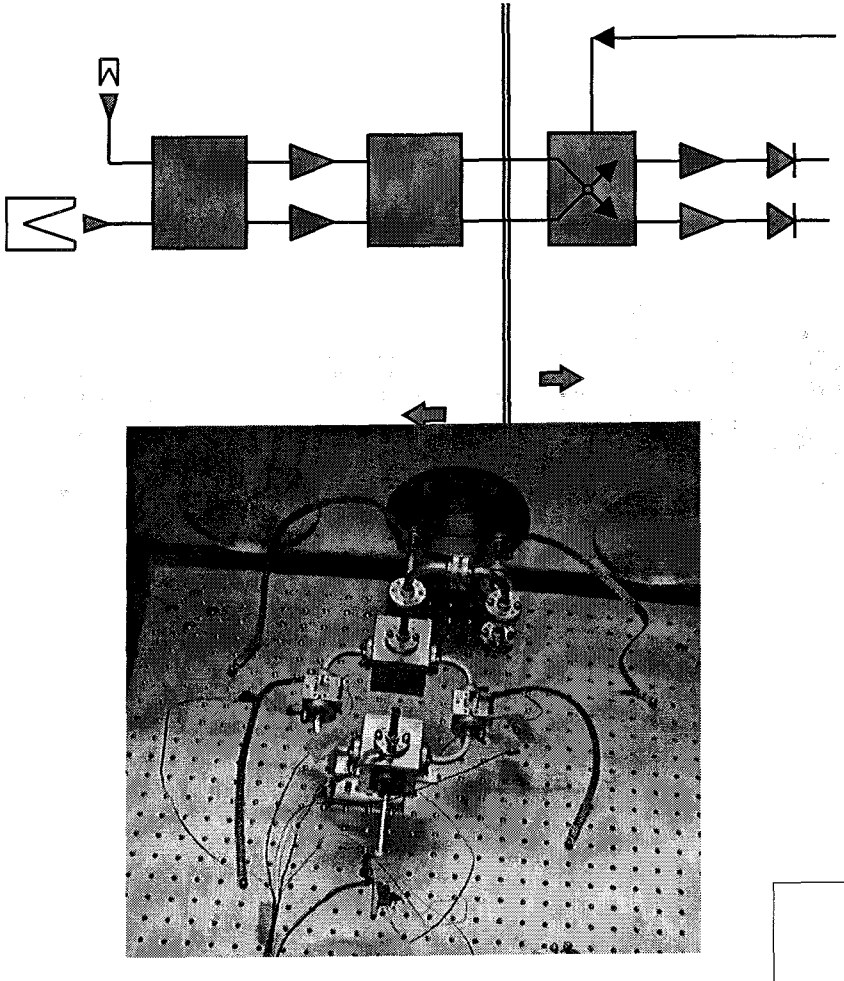
Planck Mock-Up

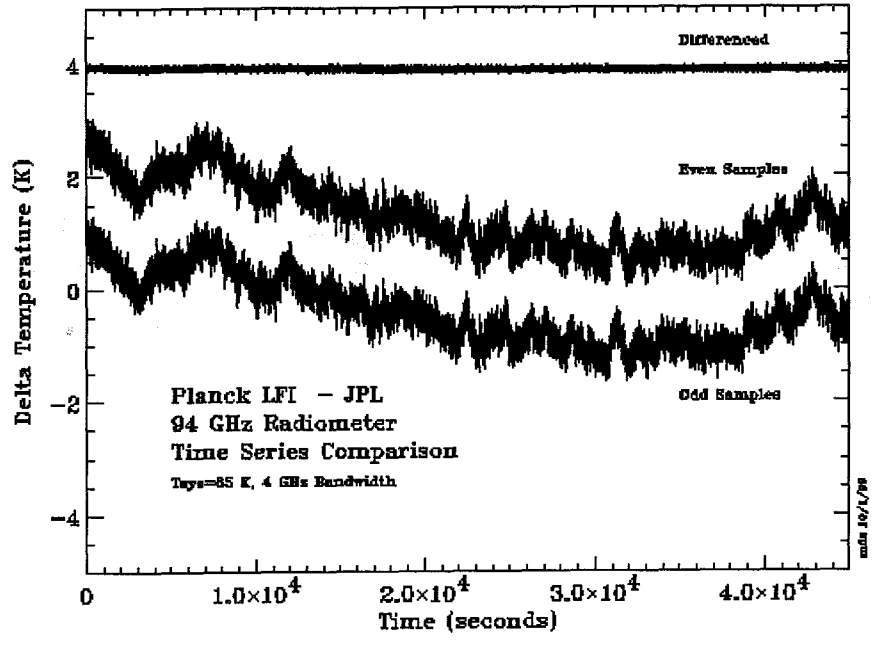


LFI 100 GHz Block Diagram - Baseline



JPL Prototype Demonstrator





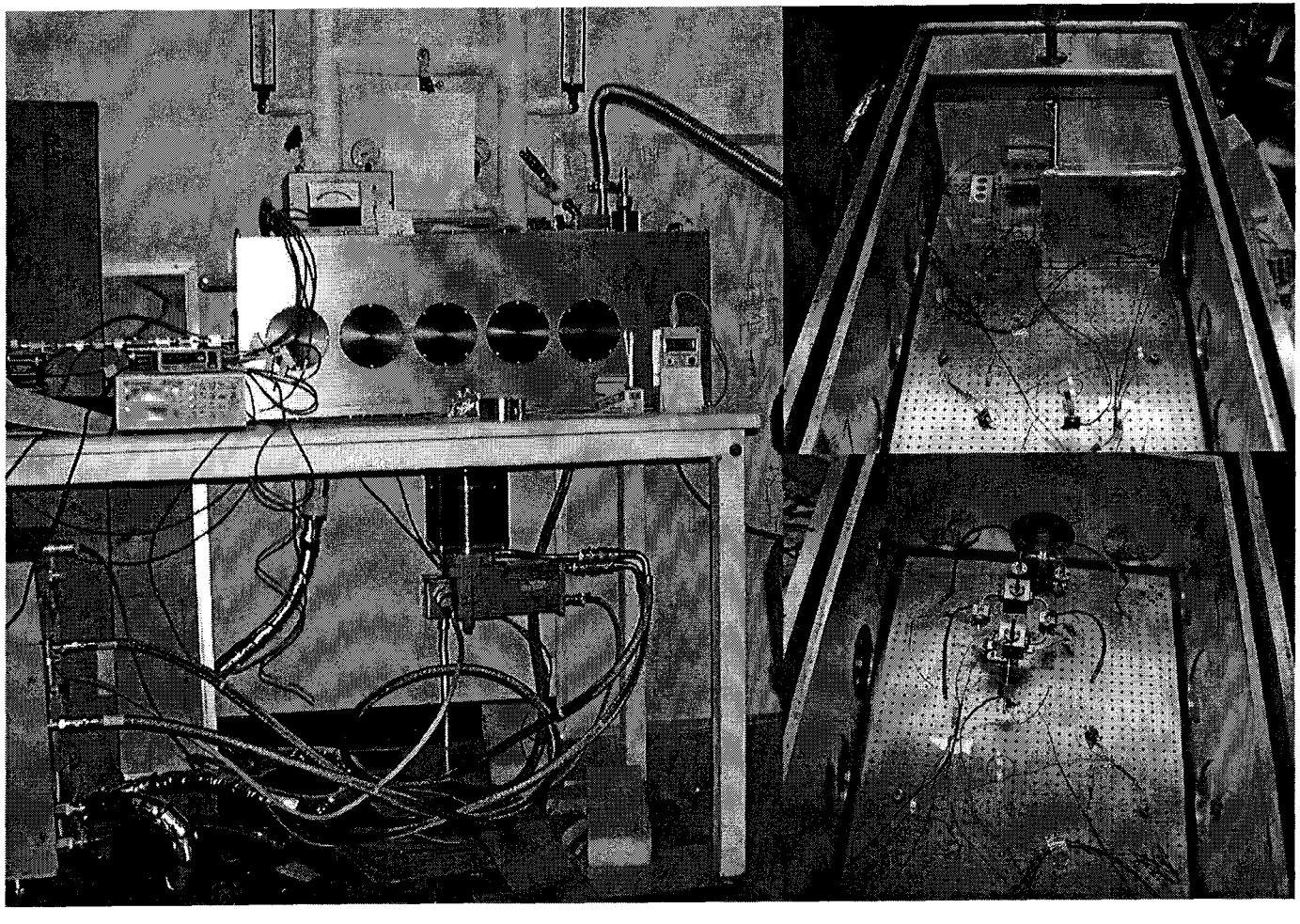
JPL

NASA

esa

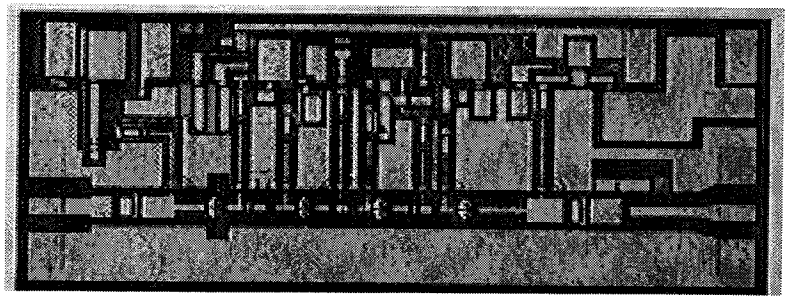
PLANCK

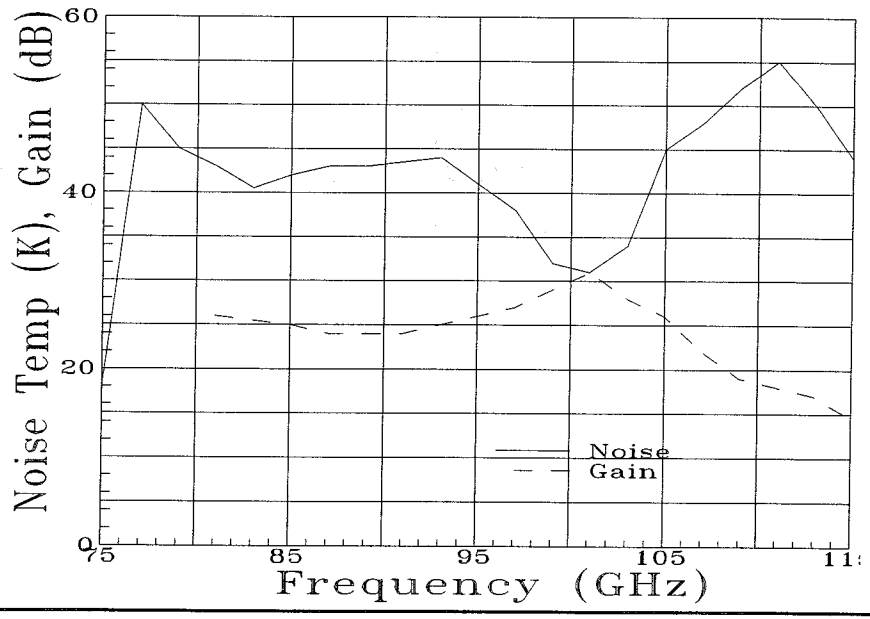
Cryostat



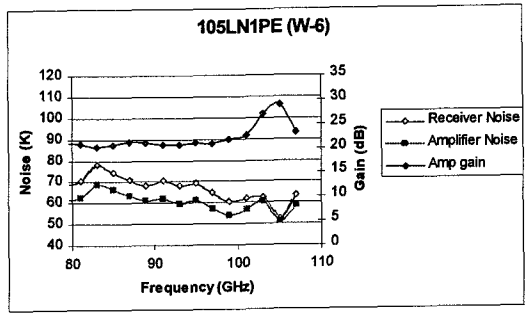
TRW 4-Stage CPW 80-115 GHz Amplifie

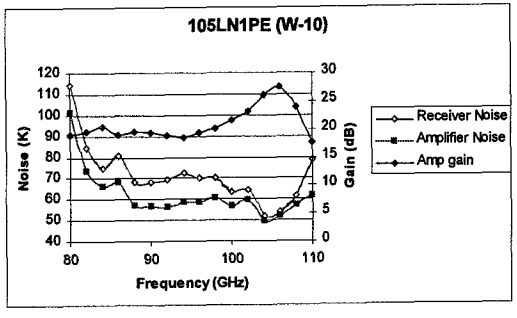
- Design by S. Weinreb
- 80-115 GHz >17 dB gain
- NF~ 3-4 dB at room temp
- Record low noise at cryo temps:
  - → < 45 K from 85-105 GHz
  - → < 40 K from 96-104 GHz
  - → 30 K noise at 100 GHz
- Yield:105 chips per wafer
- Ultra-low power operation
  - 20 dB gain at 1.4 mW
  - 15 dB gain at 0.54 mW
- Excellent Gain and Phase match (5 deg typ)

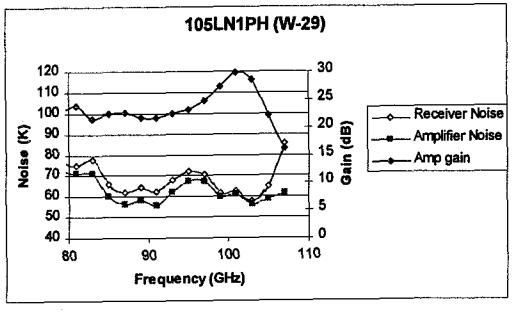


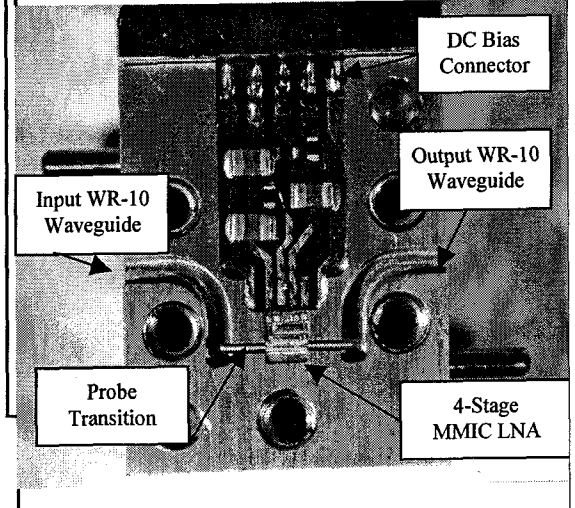


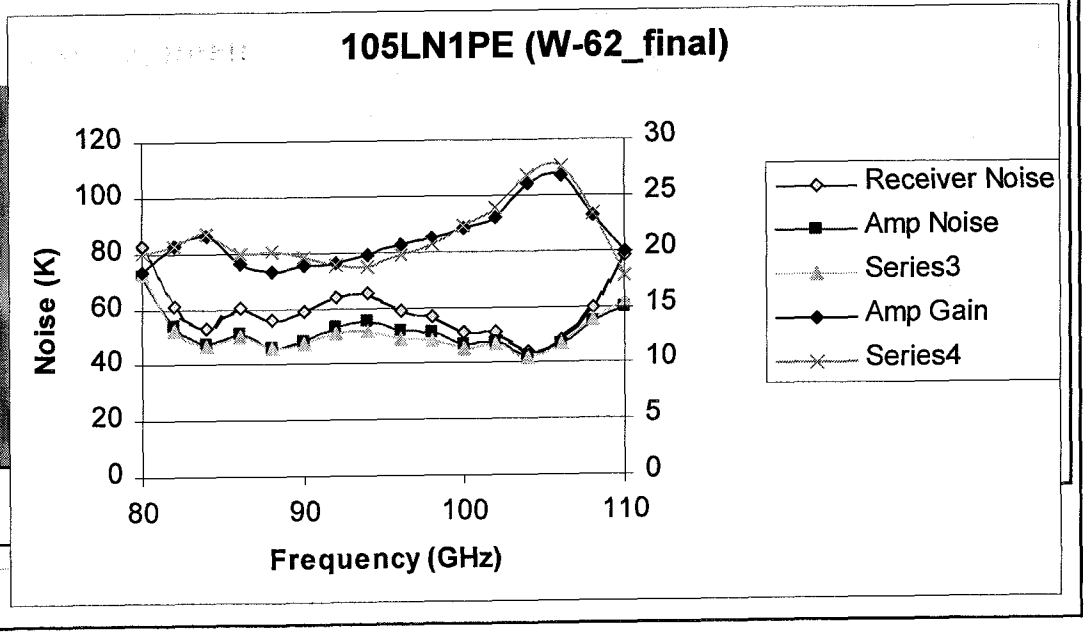
InP MMIC Module Fabrication



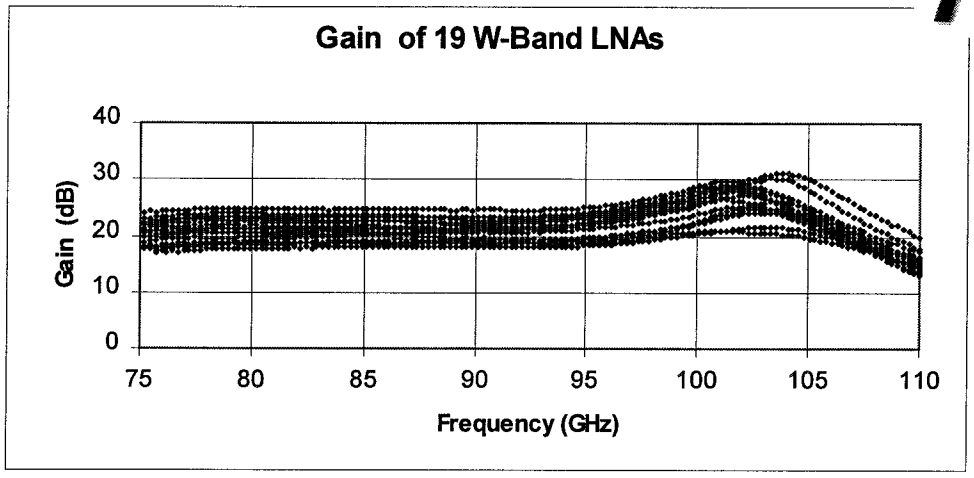


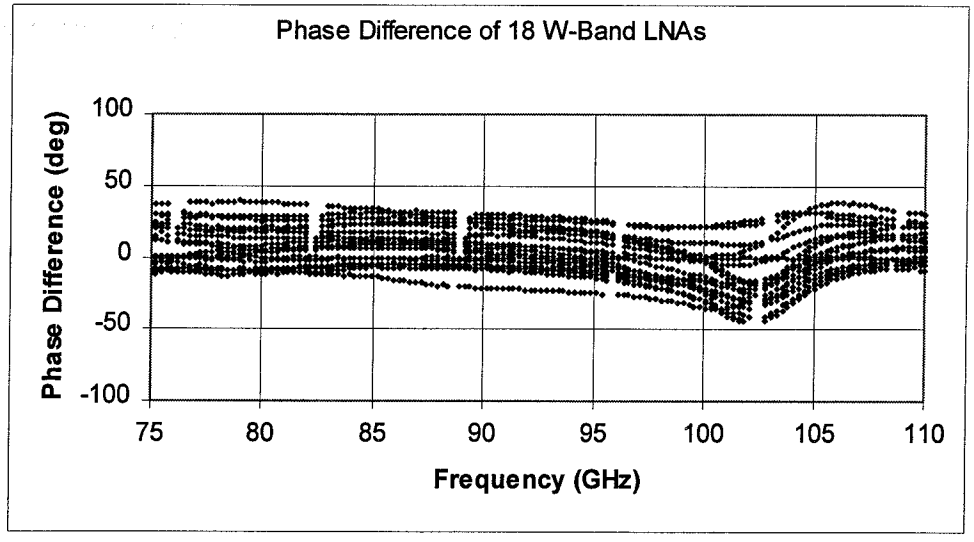






MMIC Module Repeatability





Summary

- CMB research is a dynamic rapidly evolving field
- Current experiments have made fundamental contributions to our understanding of the Universe
- Future experiments are being built and planned to make even greater advances in the field
- CMB research will remain a fertile research area for a decade or longer