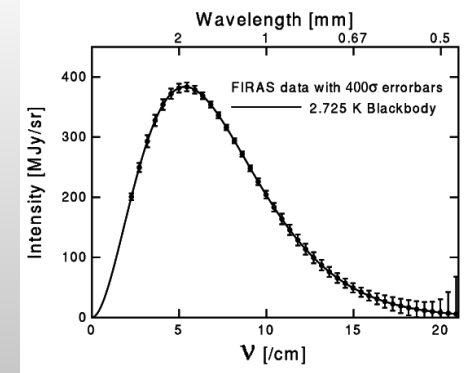




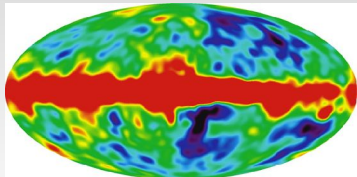
MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

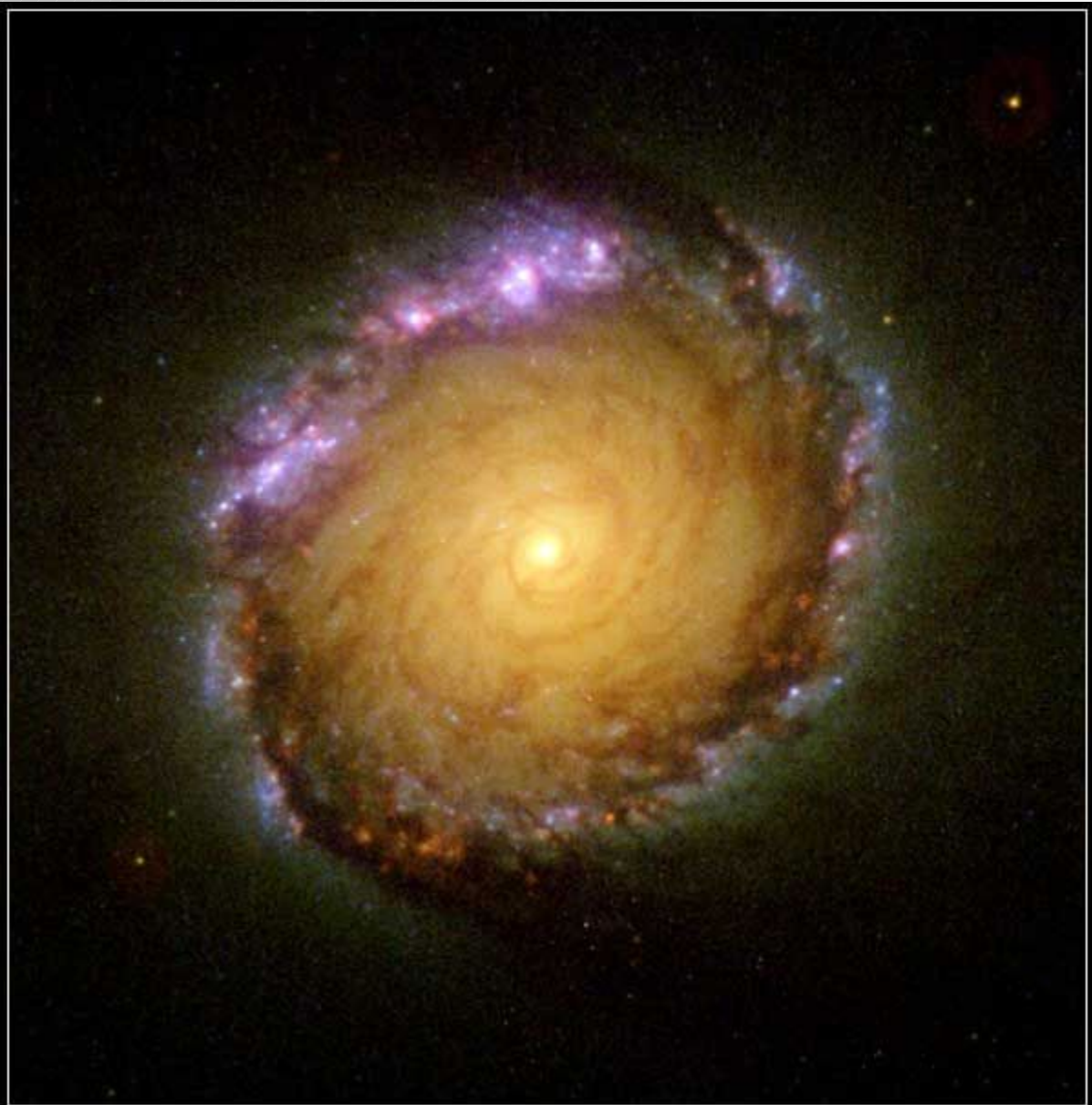


A Temperatura do Universo

Thyrso Villela

Instituto Nacional de Pesquisas Espaciais – INPE
Divisão de Astrofísica
São José dos Campos, SP

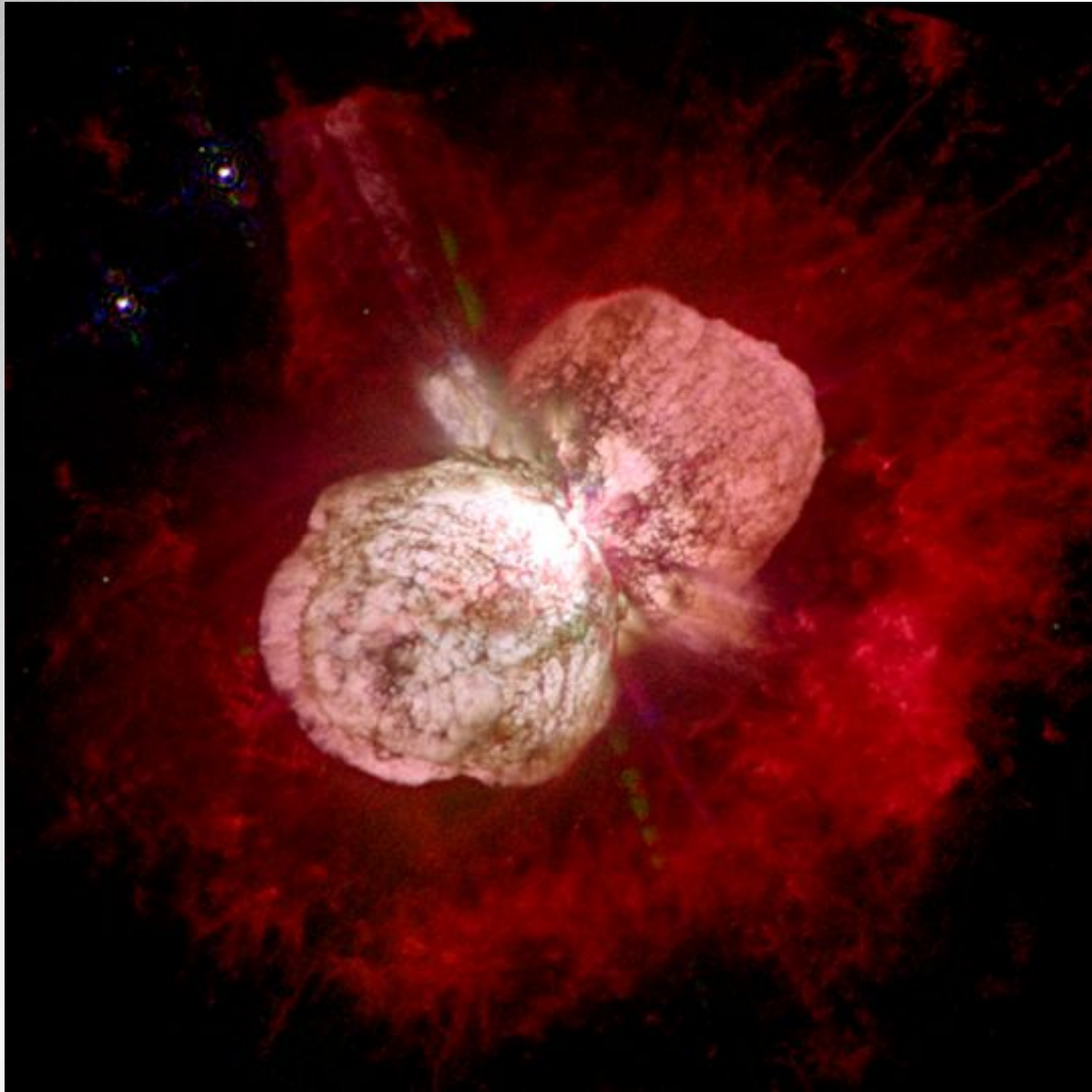


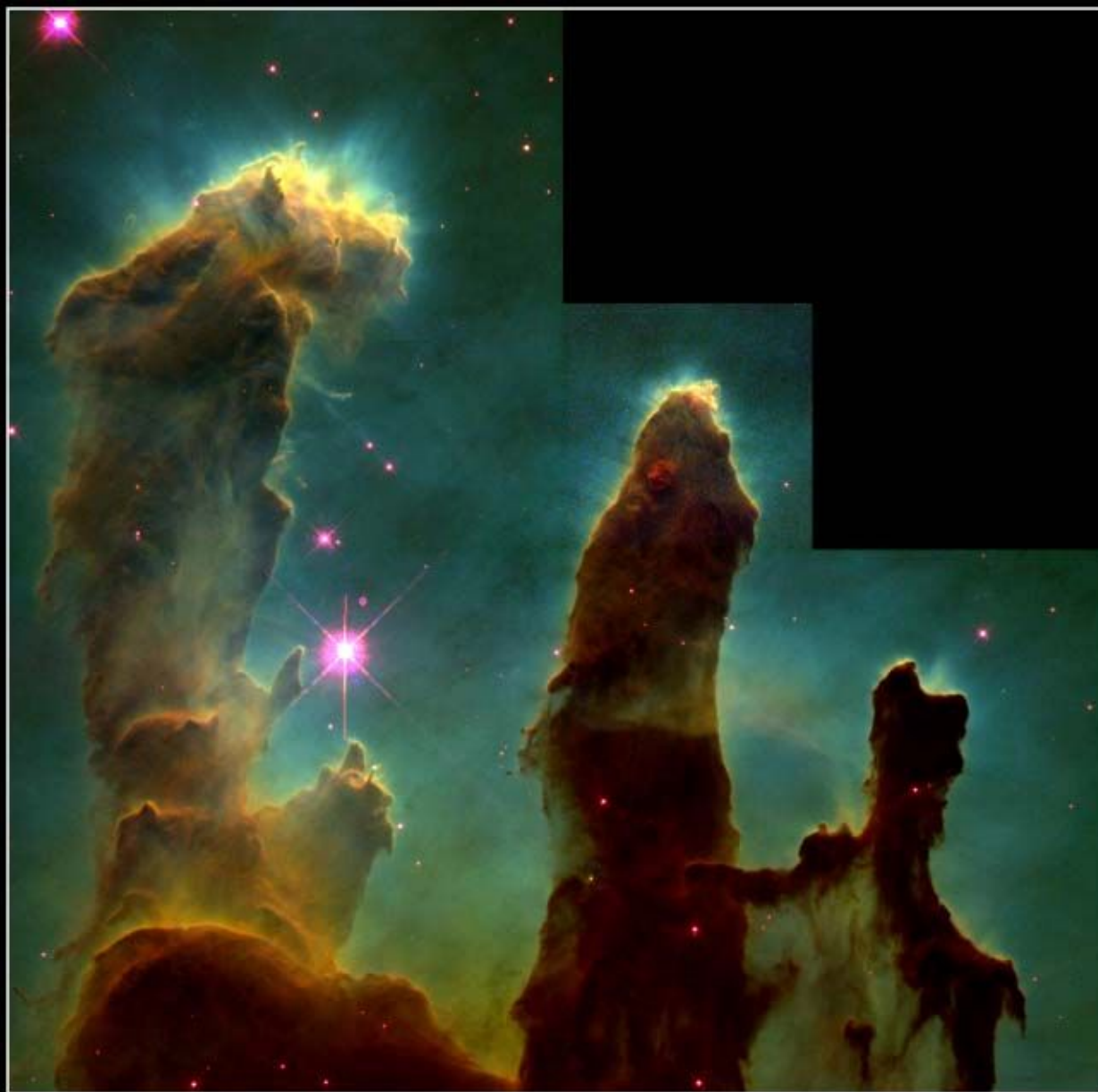


Galaxy NGC 1512

HST • FOC • NICMOS • WFPC2

NASA, ESA, and D. Maoz (Tel-Aviv University and Columbia University) • STScI-PRC01-16

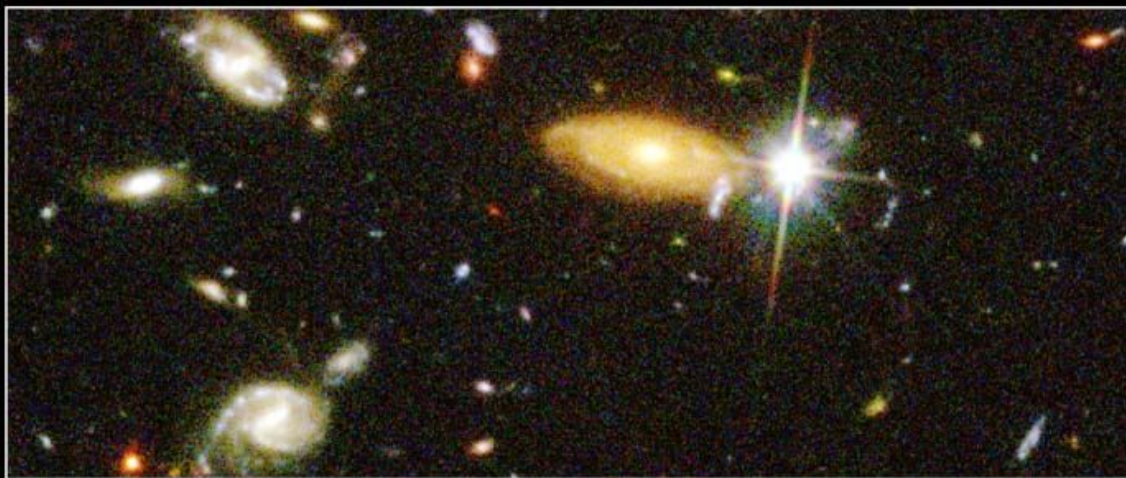
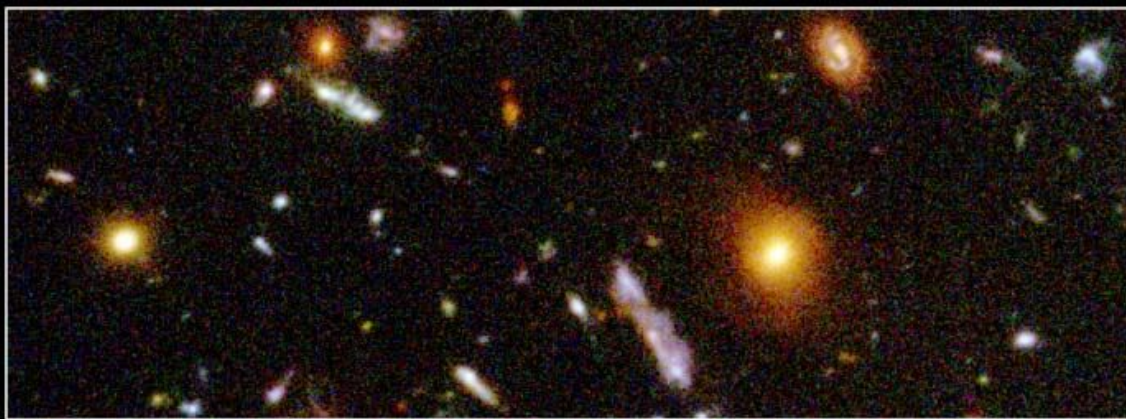




Gaseous Pillars · M16

HST · WFPC2

PRC95-44a · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA



Hubble Deep Field Details HST • WFPC2
PRC96-01b • ST Scl OPO • January 15, 1996 • R. Williams (ST Scl), NASA

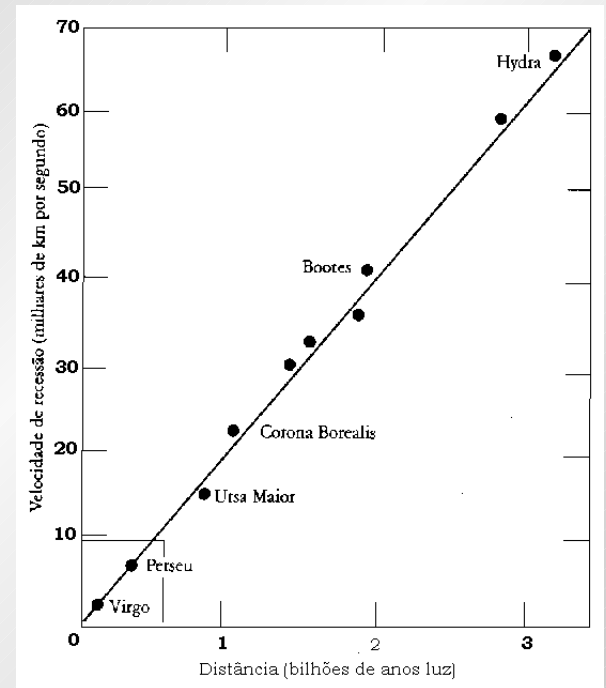
$$\frac{\Delta T}{T} \approx \frac{\Delta \rho}{\rho}$$

ΔT : flutuação de temperatura do céu

$\Delta \rho$ flutuação de densidade de matéria no Universo

Cosmologia moderna

Baseia-se nas seguintes observações:



Velocidade de recessão das galáxias: Lei de Hubble

Nucleossíntese primordial

Radiação Cósmica de Fundo em microondas (melhor observável)

MODELO COSMOLÓGICO PADRÃO (MCP)

(Very) Brief History

3 min 3×10^5 yrs

5×10^9 yrs

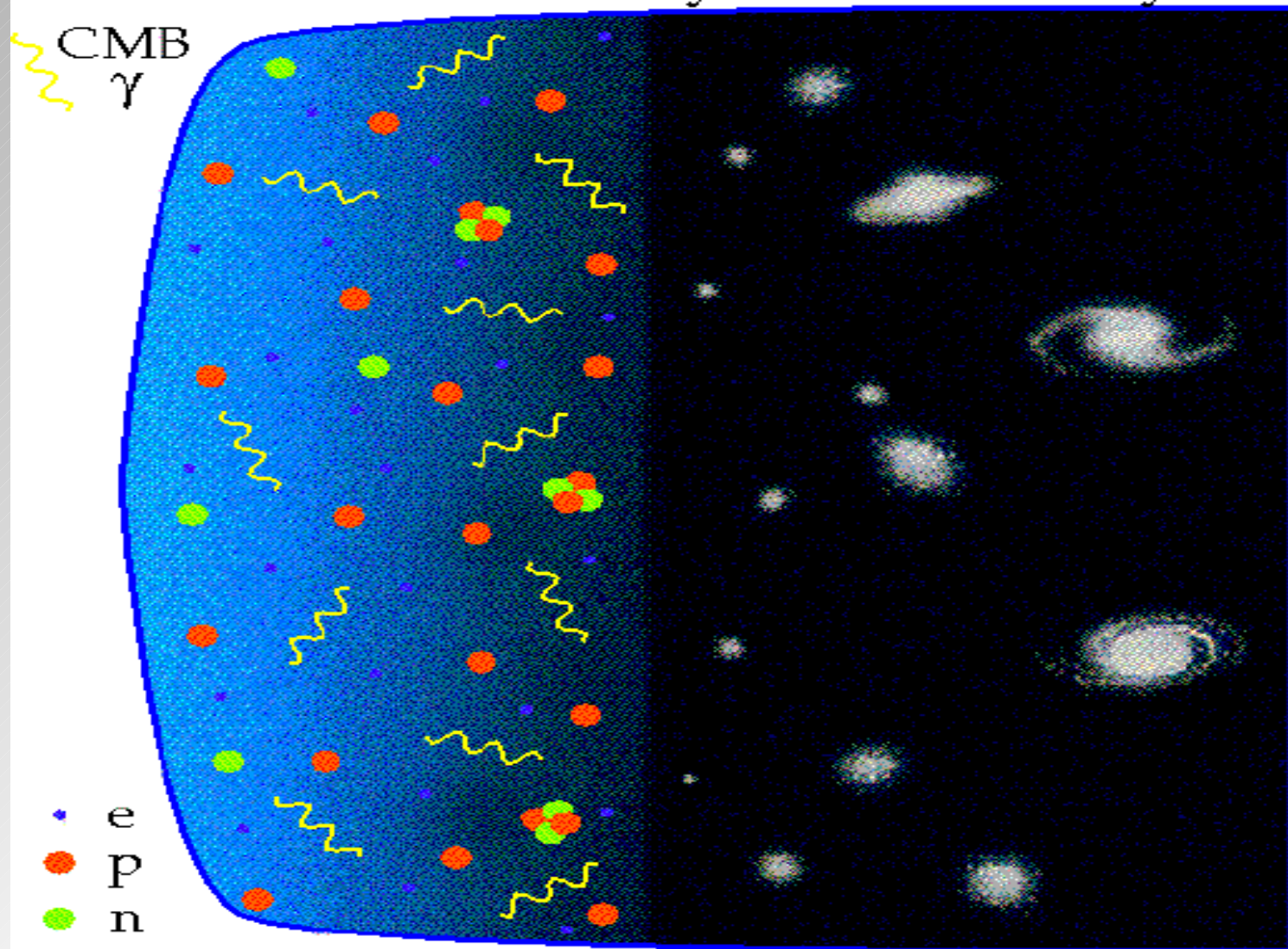
CMB
 γ

- e
- p
- n
- He

Nucleo-Synthesis

Last Scattering

Galaxy Formation



O que é a Radiação Cós mica de Fundo em Microondas?

- Remanescente de uma fase de equilíbrio térmico por que passou o universo primitivo.
- Emitida pela *Superfície de Último Espalhamento* em $z \sim 1100$.
- Espectro de corpo negro a uma temperatura $T = (2,726 \pm 0,010)$ K.
- Distribuição aproximadamente isotrópica.

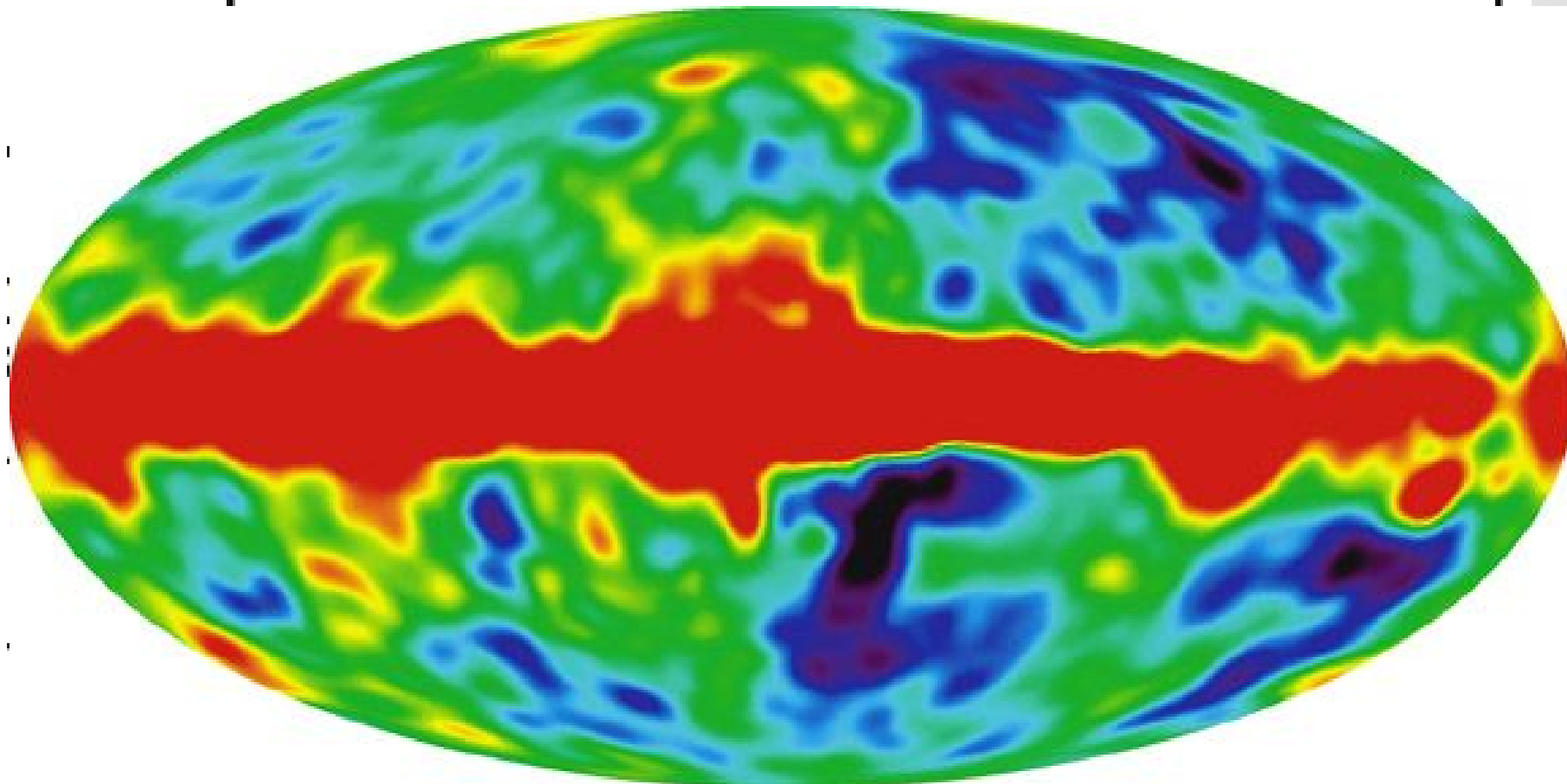
Wavelength [mm]

2

1

0.67

0.5



5

10

15

20

ν [1/cm]



Inside hot stars



10^9

Inside the sun



10^8

10^7

Nuclear explosion



10^6

10^5

Stellar nebulae



10^4

Melting point of iron



10^3

Melting point of ice (°C)



10^2

Highest known transition temperature for a superconductor



Nitrogen liquefies



10^1

Hydrogen liquefies



10^0

Outer space



10^0

^4He becomes superfluid



10^0

1 K

10^{-1}

10^{-2}

^3He becomes superfluid



10^{-3}

1 mK

Lowest temperature obtained for ^3He



10^{-4}

Lowest temperature for electrons in a metal



10^{-5}

10^{-6}

1 μK

10^{-7}

10^{-8}

Lowest temperature obtained for nuclei in a solid



10^{-9}

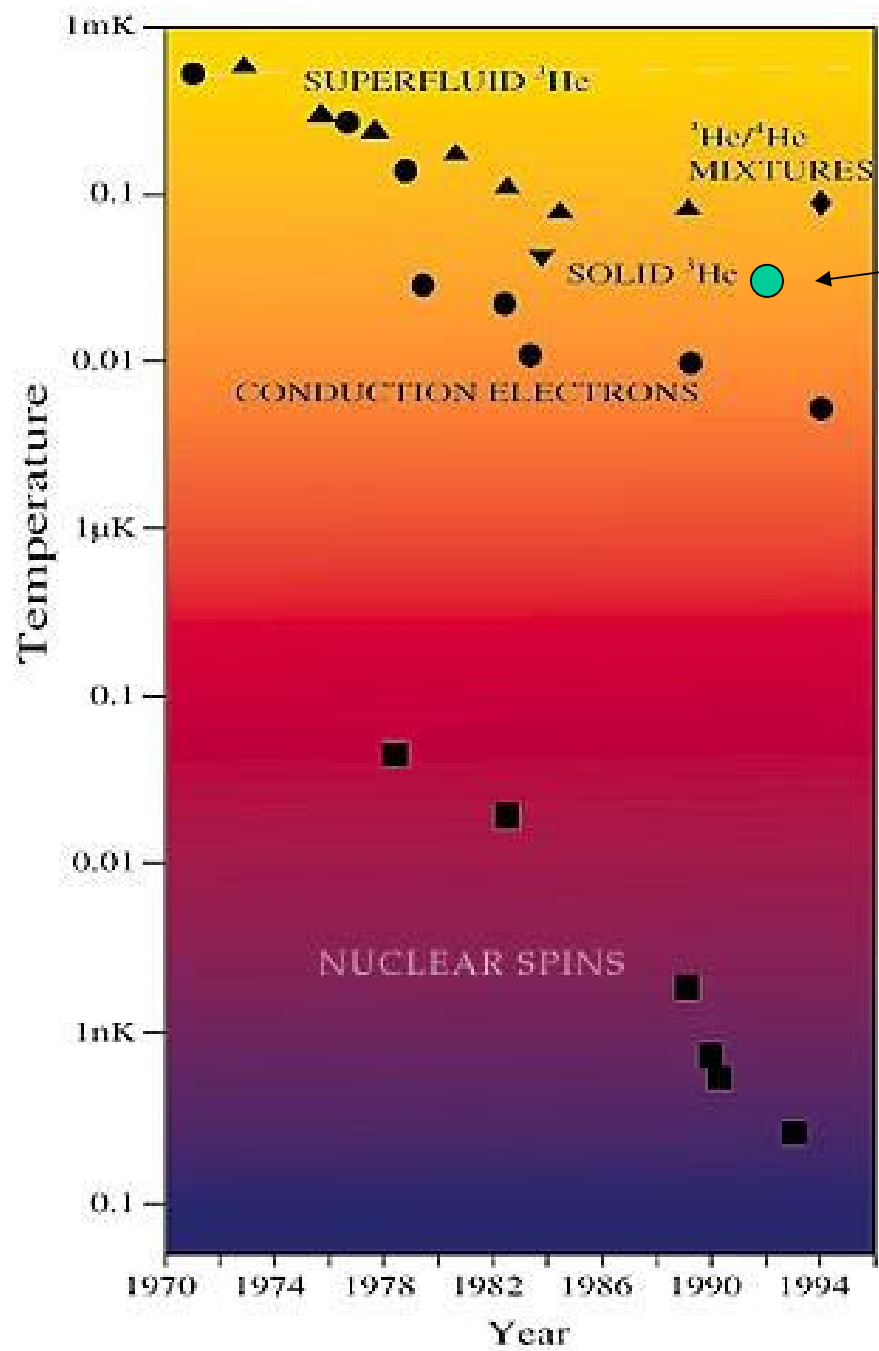
1 nK

absolute zero



Temperatura da RCFM

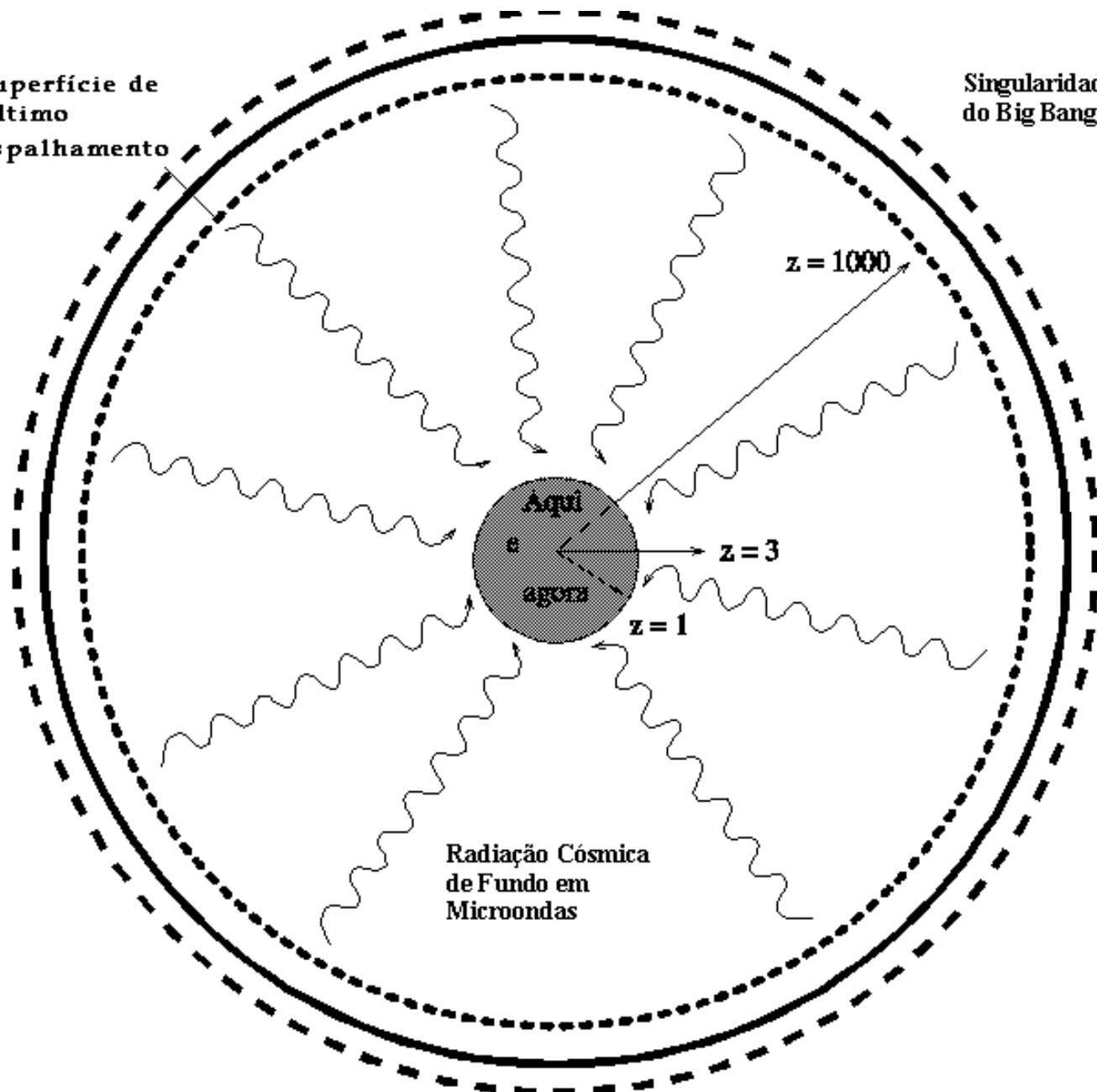
Anisotropia da RCFM



RCFM

Superfície de
Último
Espalhamento

Singularidade: época
do Big Bang



Anisotropias da RCFM

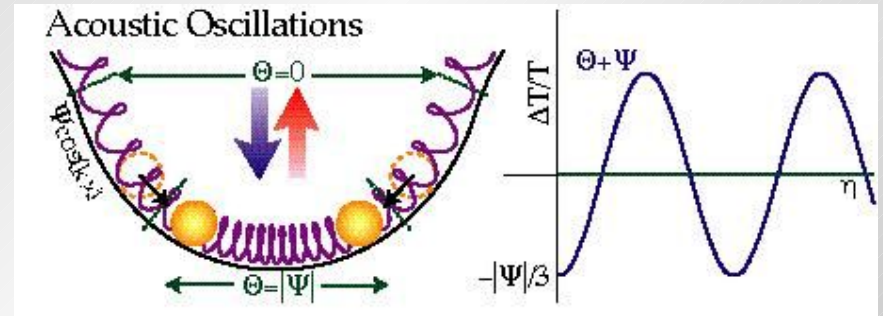
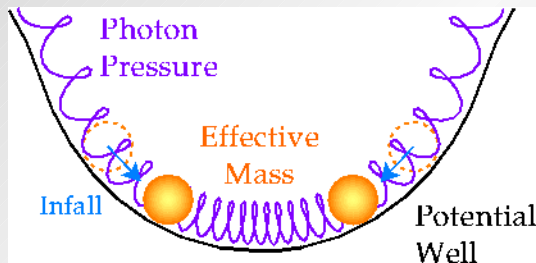
Caracterizam-se como flutuações na distribuição angular da temperatura da radiação e são descritas por uma expansão em harmônicos esféricos:

$$\frac{T}{T}(\vec{x}) = a_l^m Y_l^m(\theta, \phi)$$

Universo: fluido composto de fótons e bárions

Competição entre gravidade e expansão
⇒ oscilações ⇒ ondas acústicas

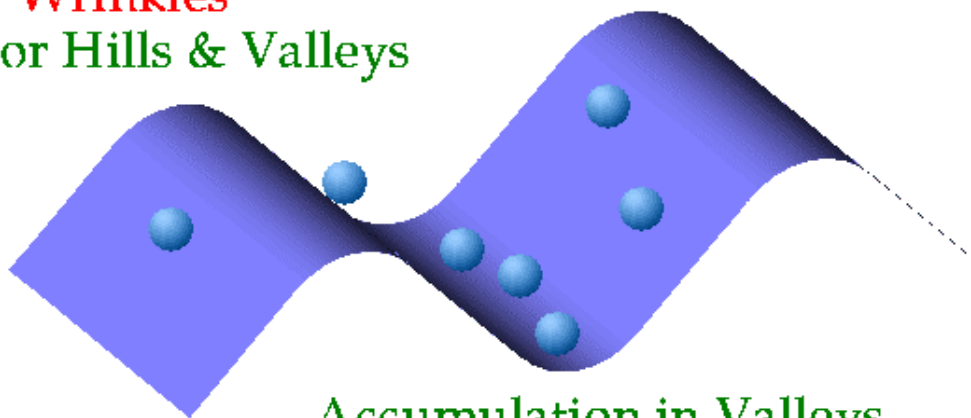
Matéria: pequeno oscilador harmônico
Bárions: massa ⇒ colapso
Fótons: resistência ao colapso



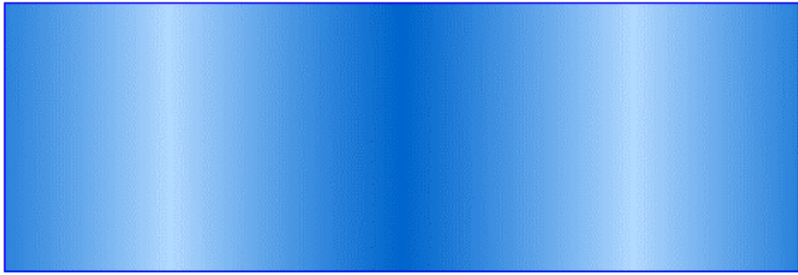
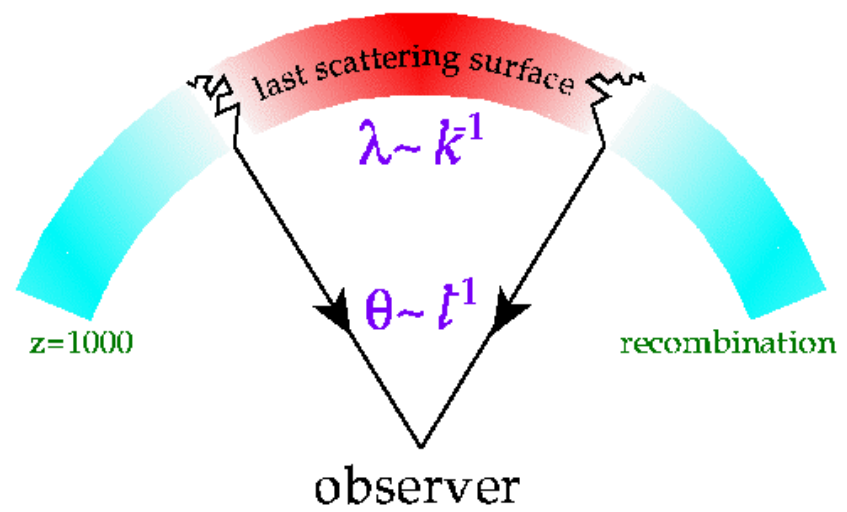
Oscilador harmônico amortecido

Densidade (não deslocamento): variável
Expansão (H_0): termo de amortecimento
Gravidade: força

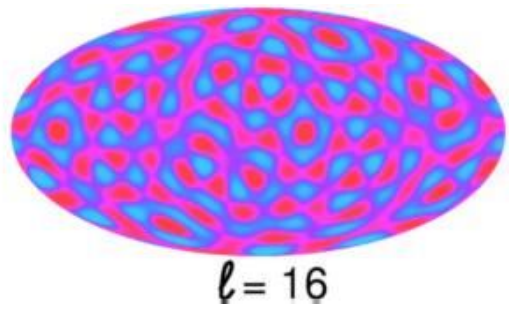
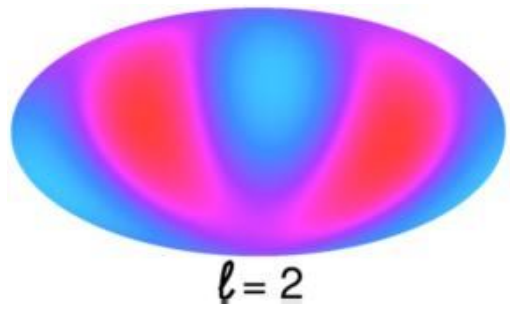
"Wrinkles"
or Hills & Valleys



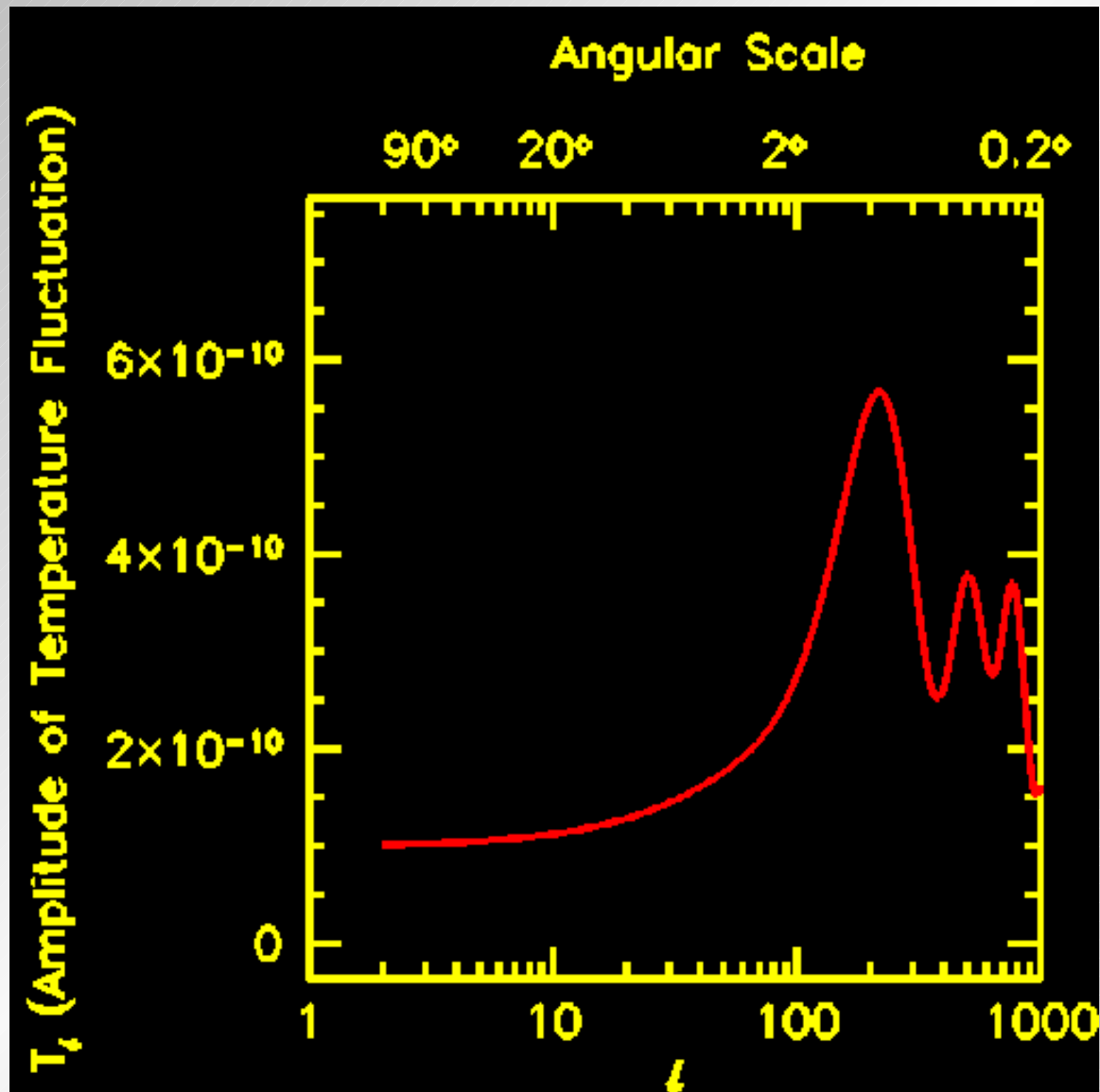
Accumulation in Valleys



"Top View"

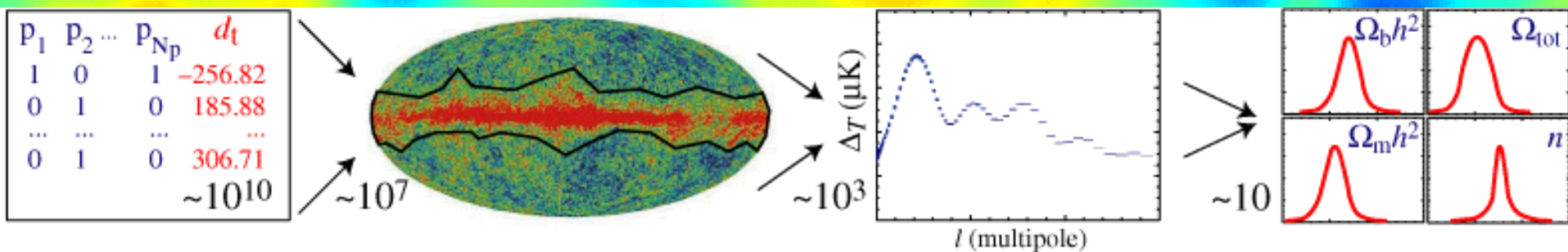


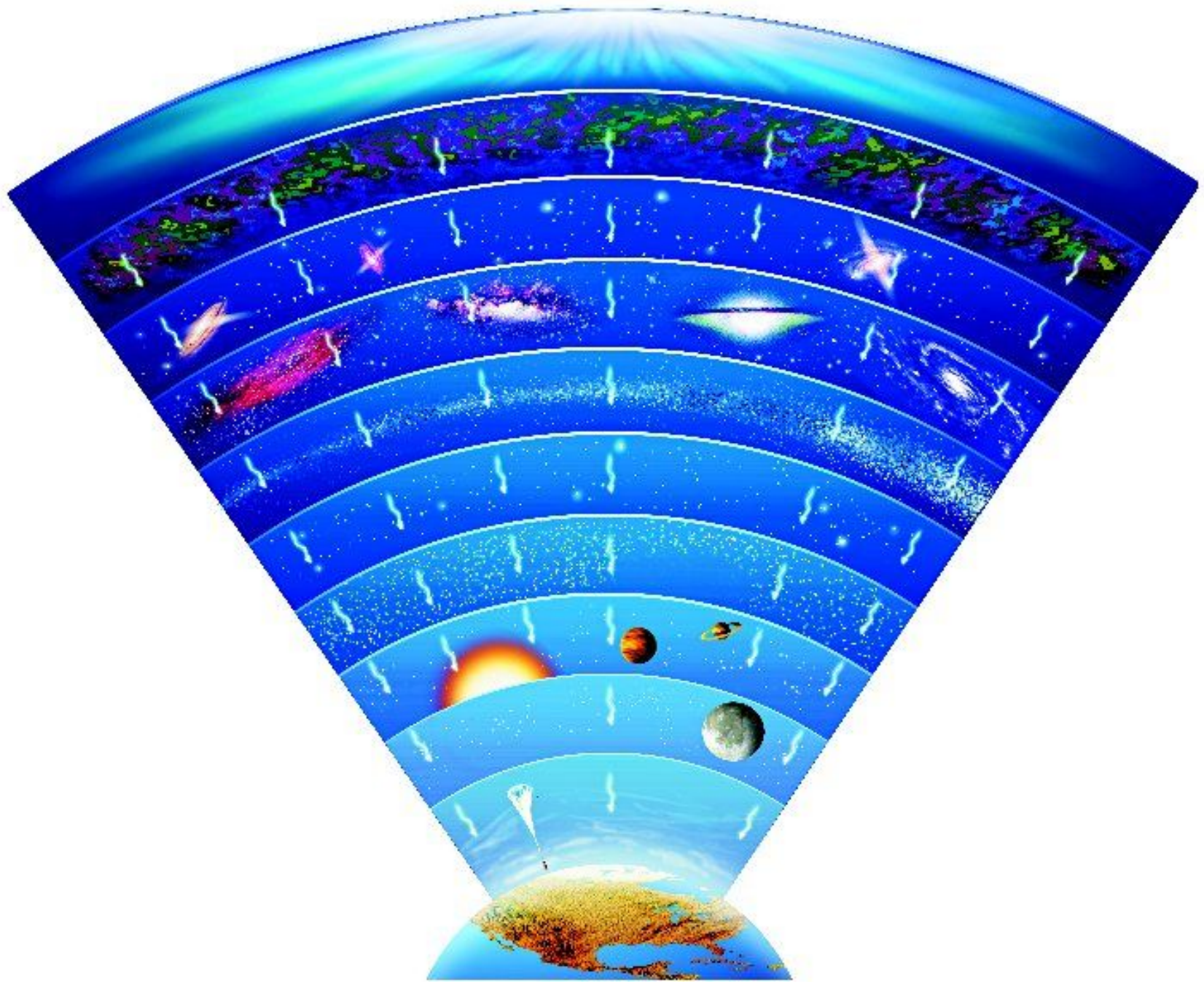
Espectro de Potência Angular

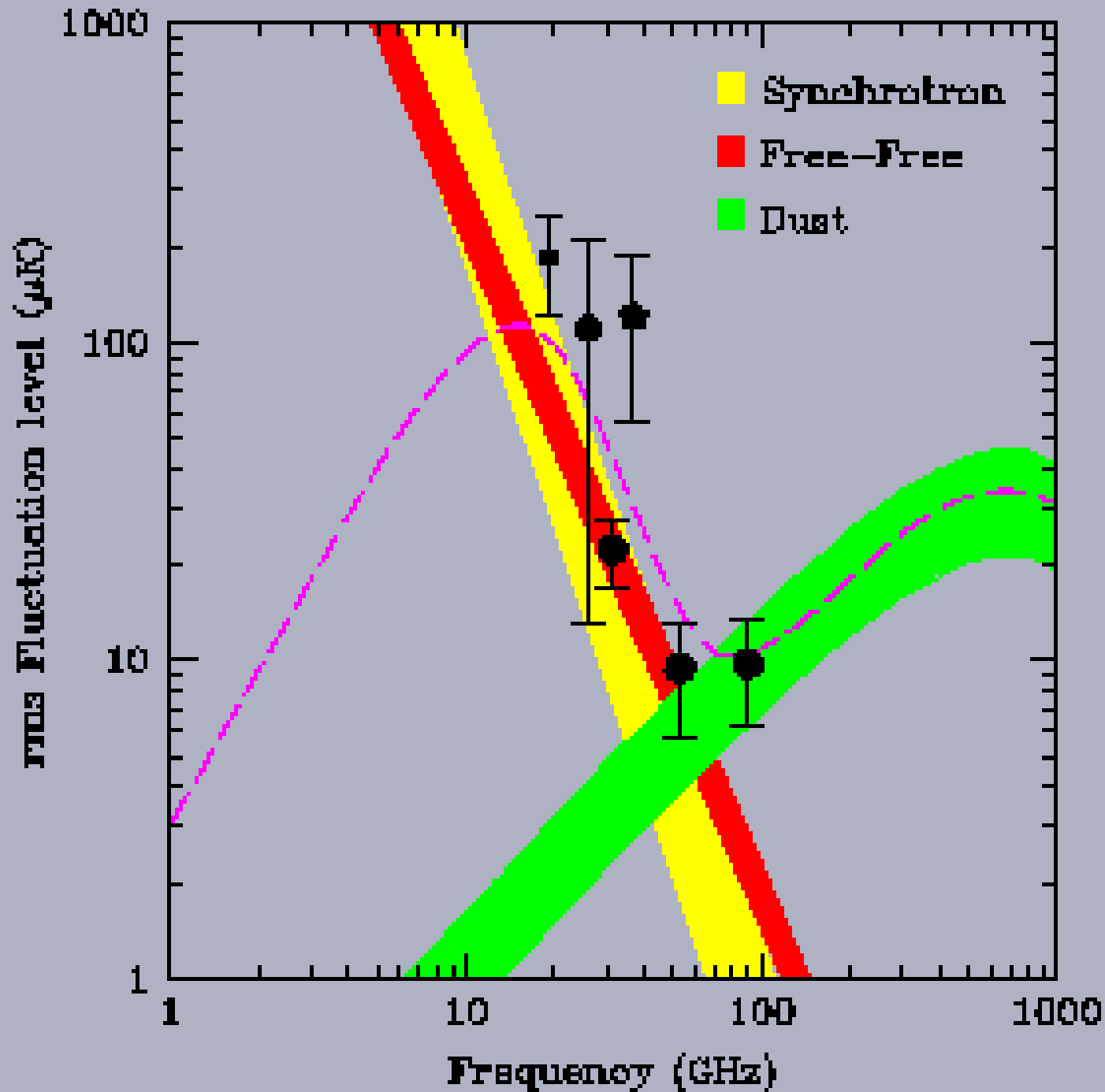


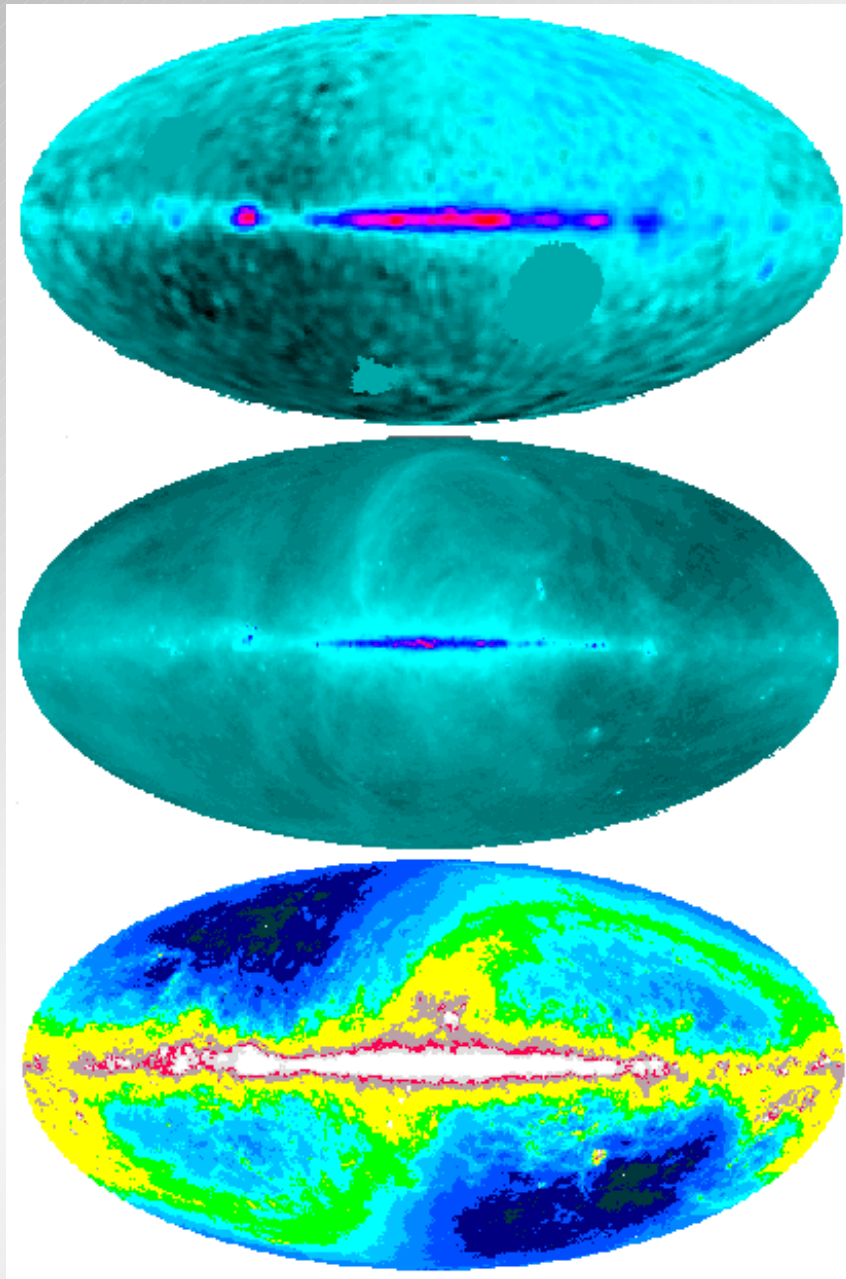
PROBLEMA

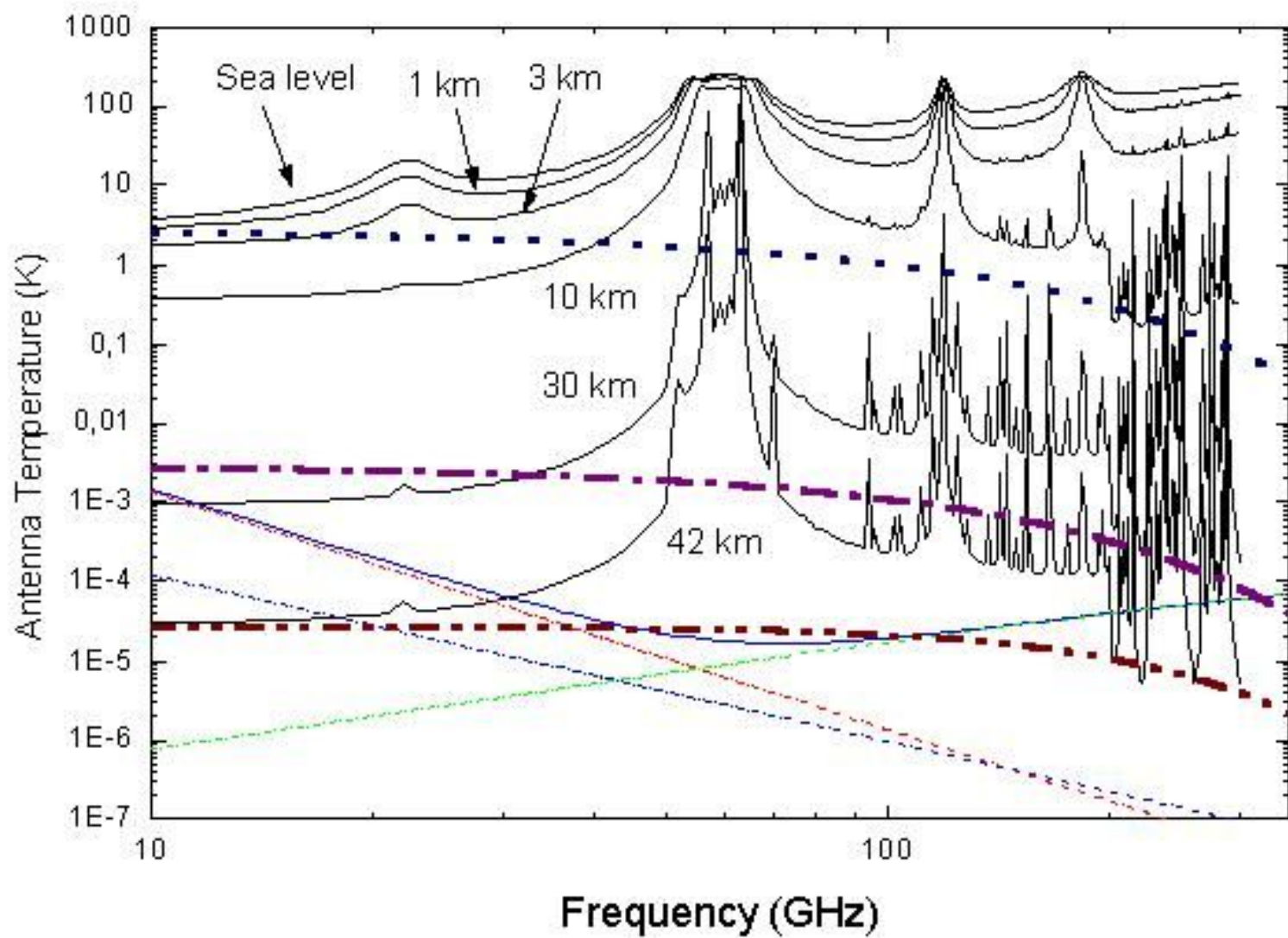
Produção de mapas de anisotropia da RCFM a partir de STD constituída de M medidas diferenciais de temperatura da RCFM proveniente de N regiões do céu.









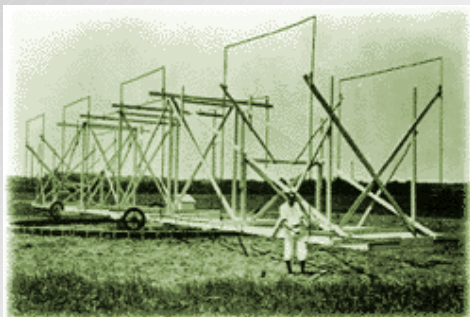
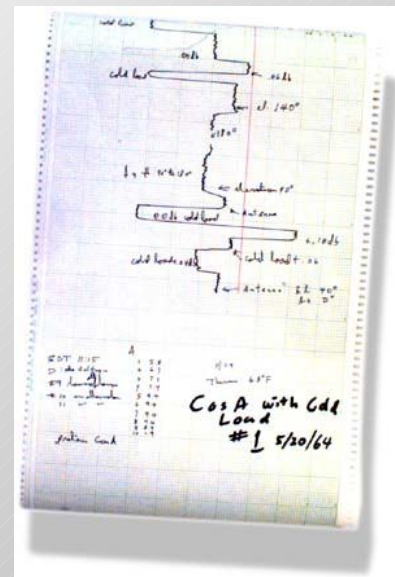
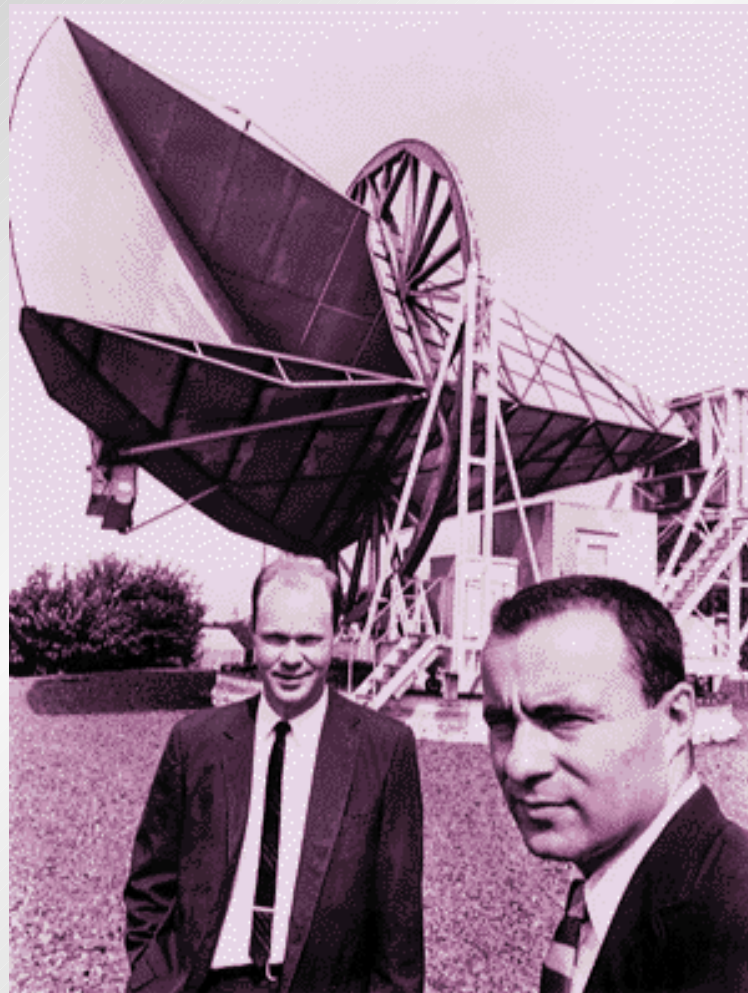


História da Descoberta da RCFM

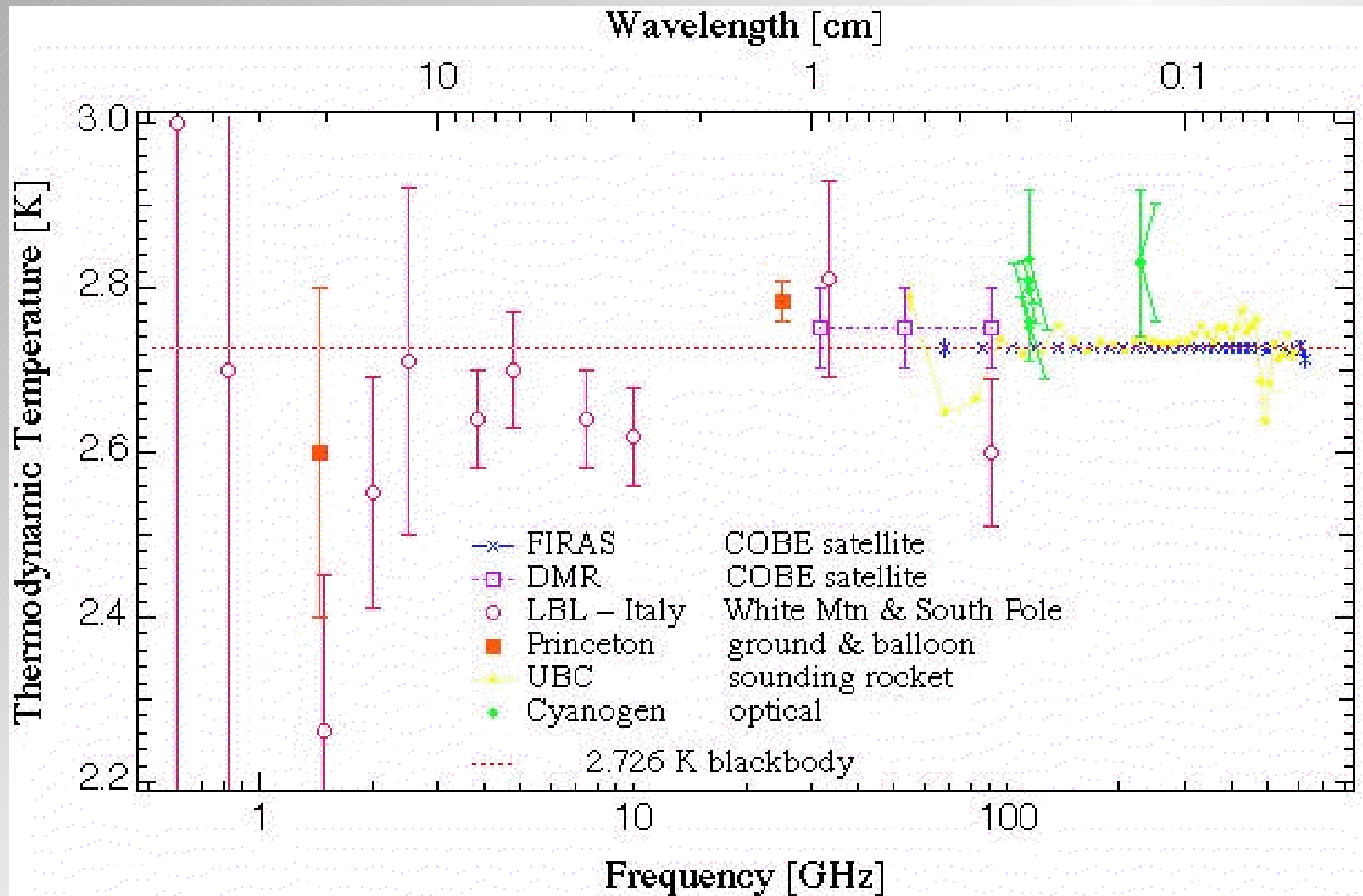
1933



1964

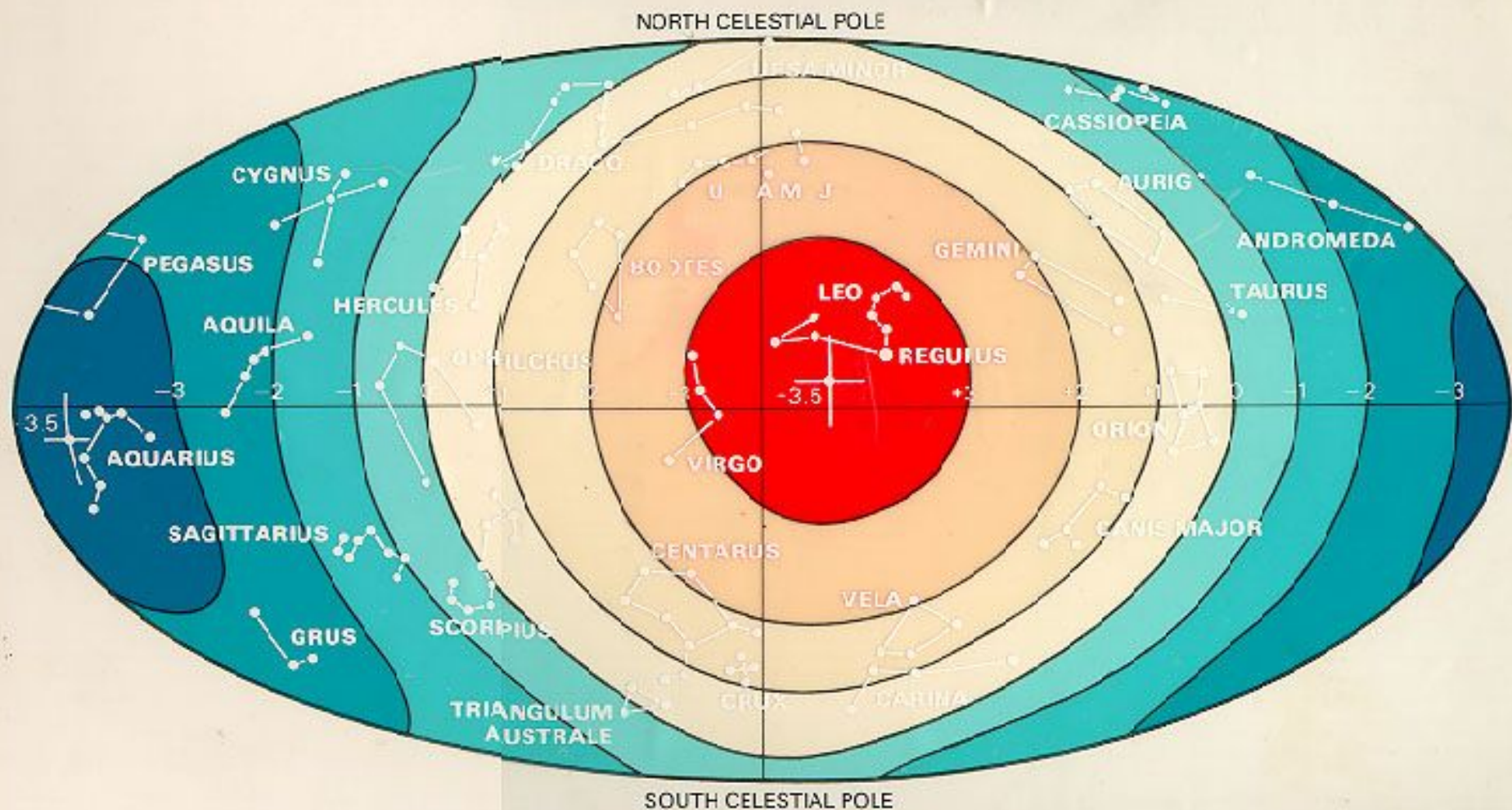








U2 em Lima, Peru - Aeroporto Jorge Chavez.



Hidra-Centauro

Grupo Local

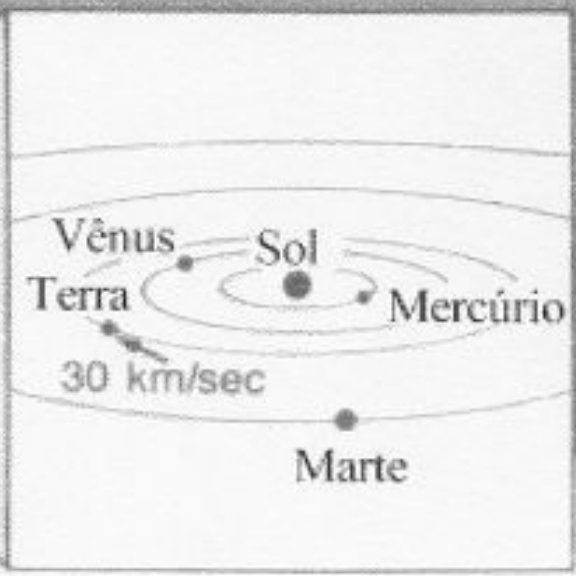
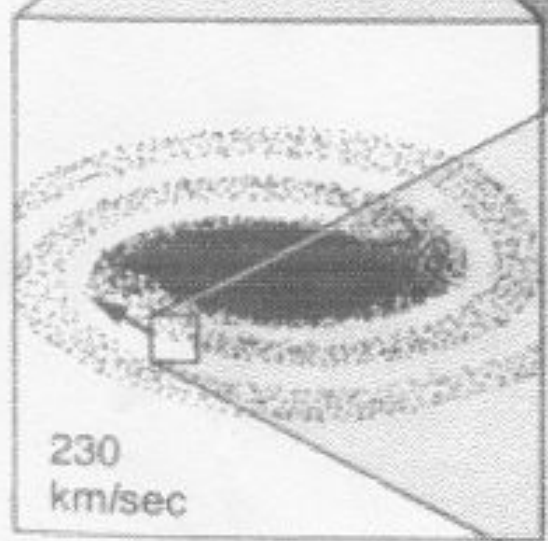


600 km/sec

Virgem

SISTEMA SOLAR

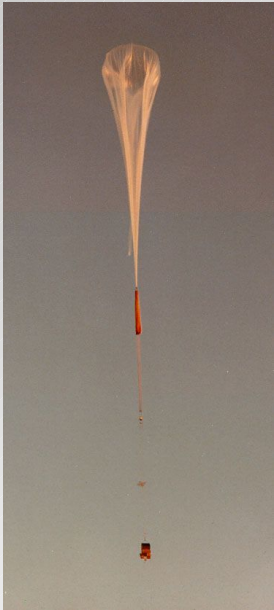
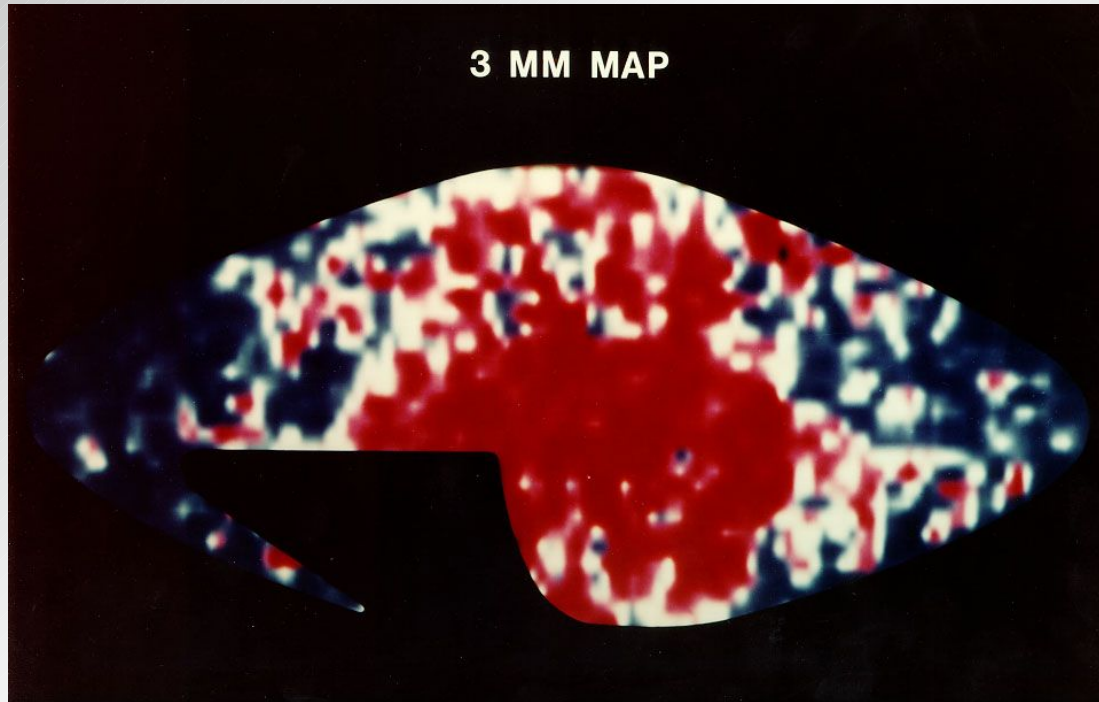
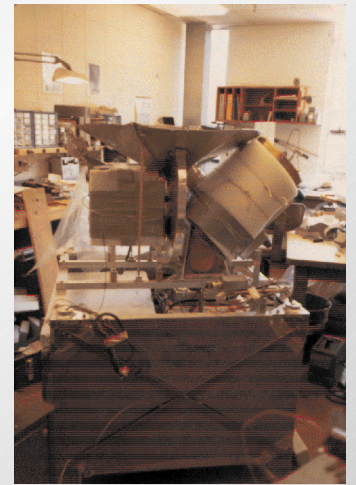
GRANDE ATRATOR

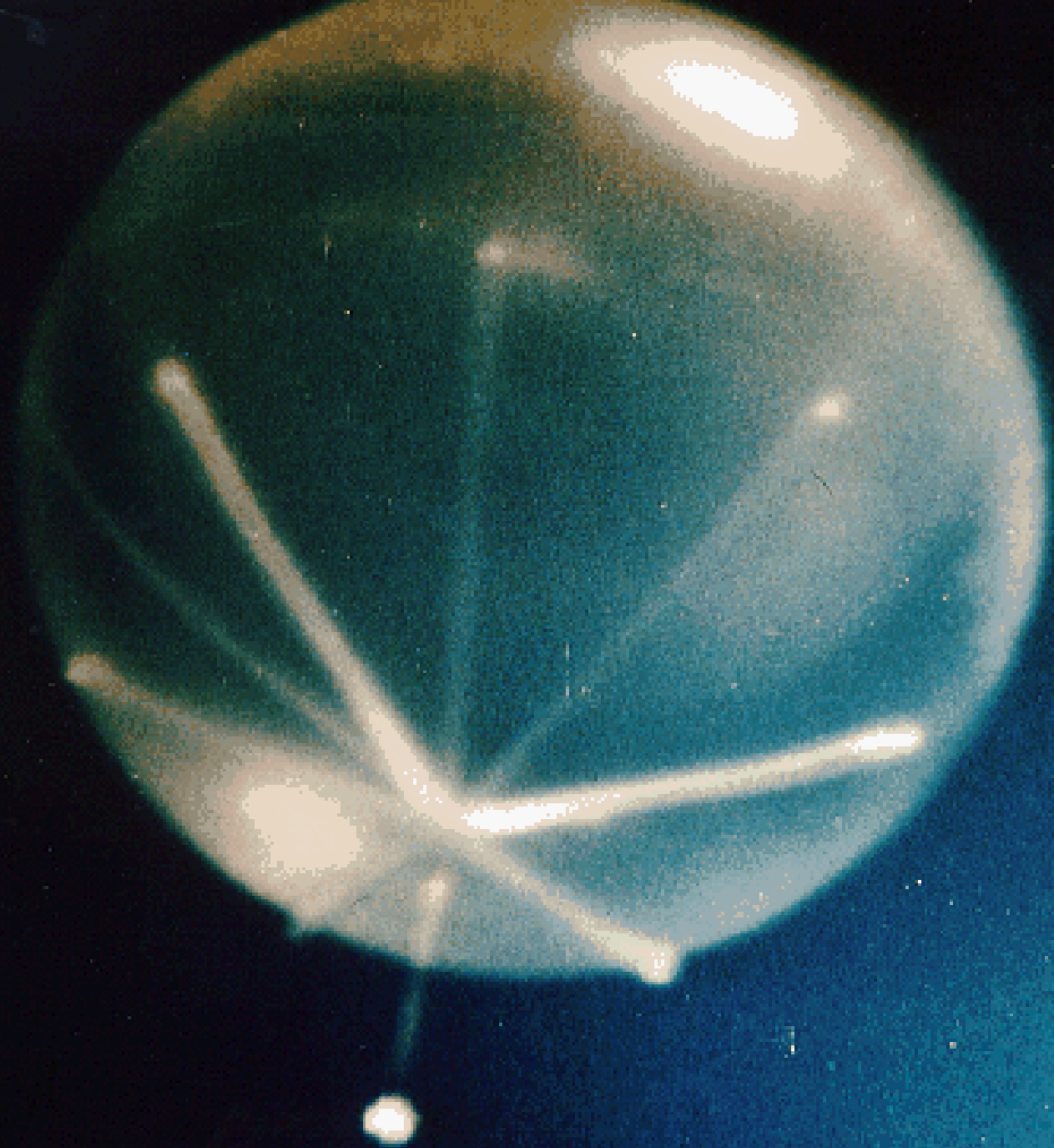


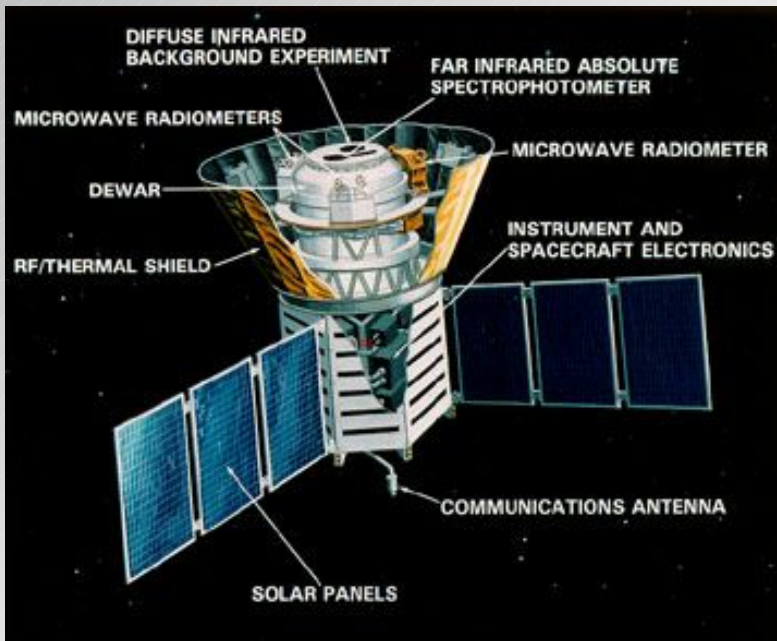
?

Via Láctea

“Era pré-COBE”: Brasil 1982

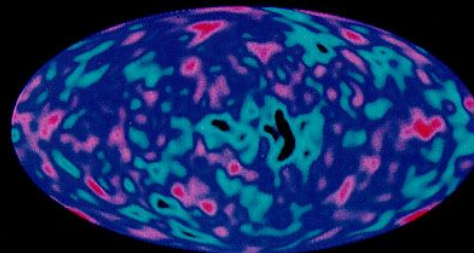
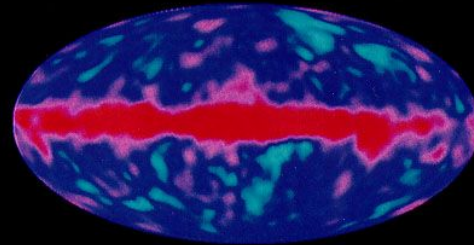
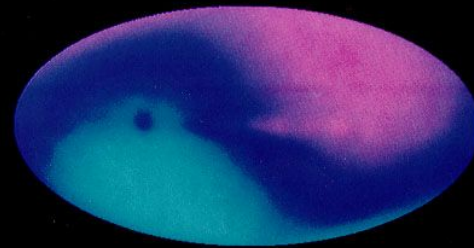




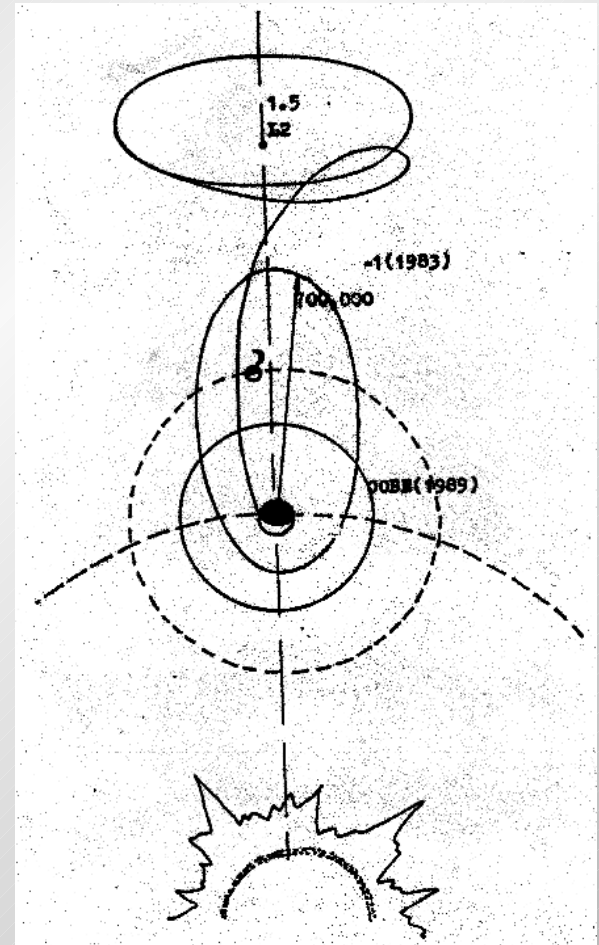
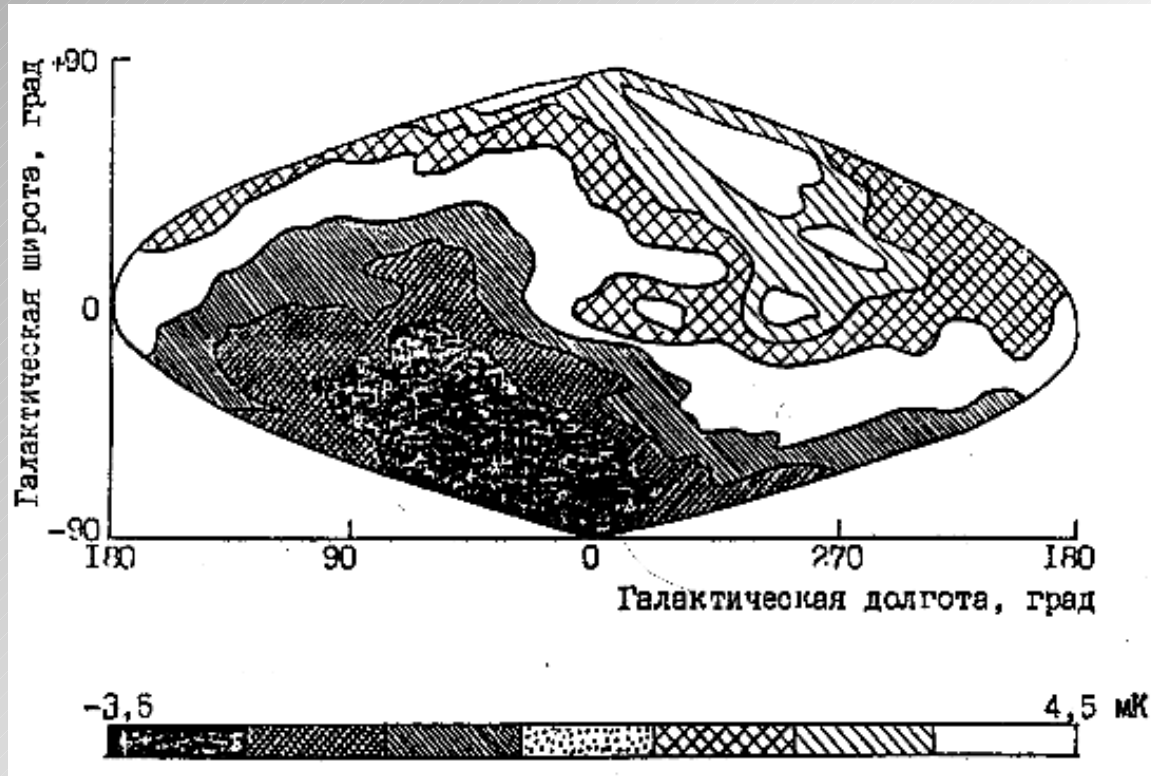


PHYSICS TODAY

JUNE 1992



Satélite Relict: 1983 !



Strukov et al. 1992 (*Relict-1 Experiment - New Results*)

$\nu = 37$ GHz

detecção de uma “região fria” ($\Delta T = -71 \pm 43 \mu\text{K}$, área ~ 1 strad)

centrada em $\alpha = 1\text{h}30$, $\delta = -10^\circ$

Saskatoon – experimento no solo

Netterfield et al.

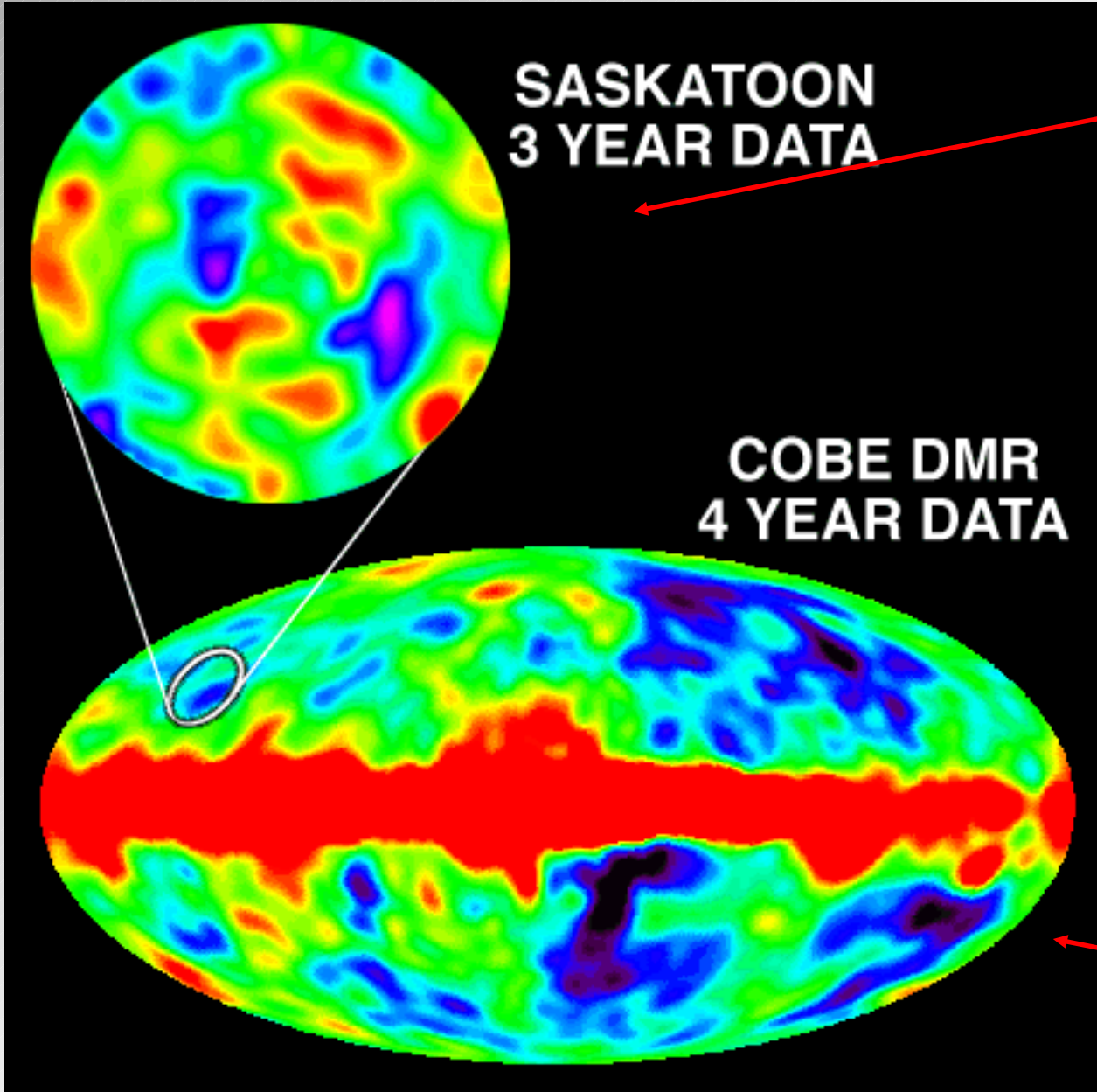
1997

SASKATOON
3 YEAR DATA

COBE DMR
4 YEAR DATA

Bennett et al.

1996



HACME (UCSB + INPE + EFEI)

HEMTs on **Advanced Cosmic Microwave Explorer**

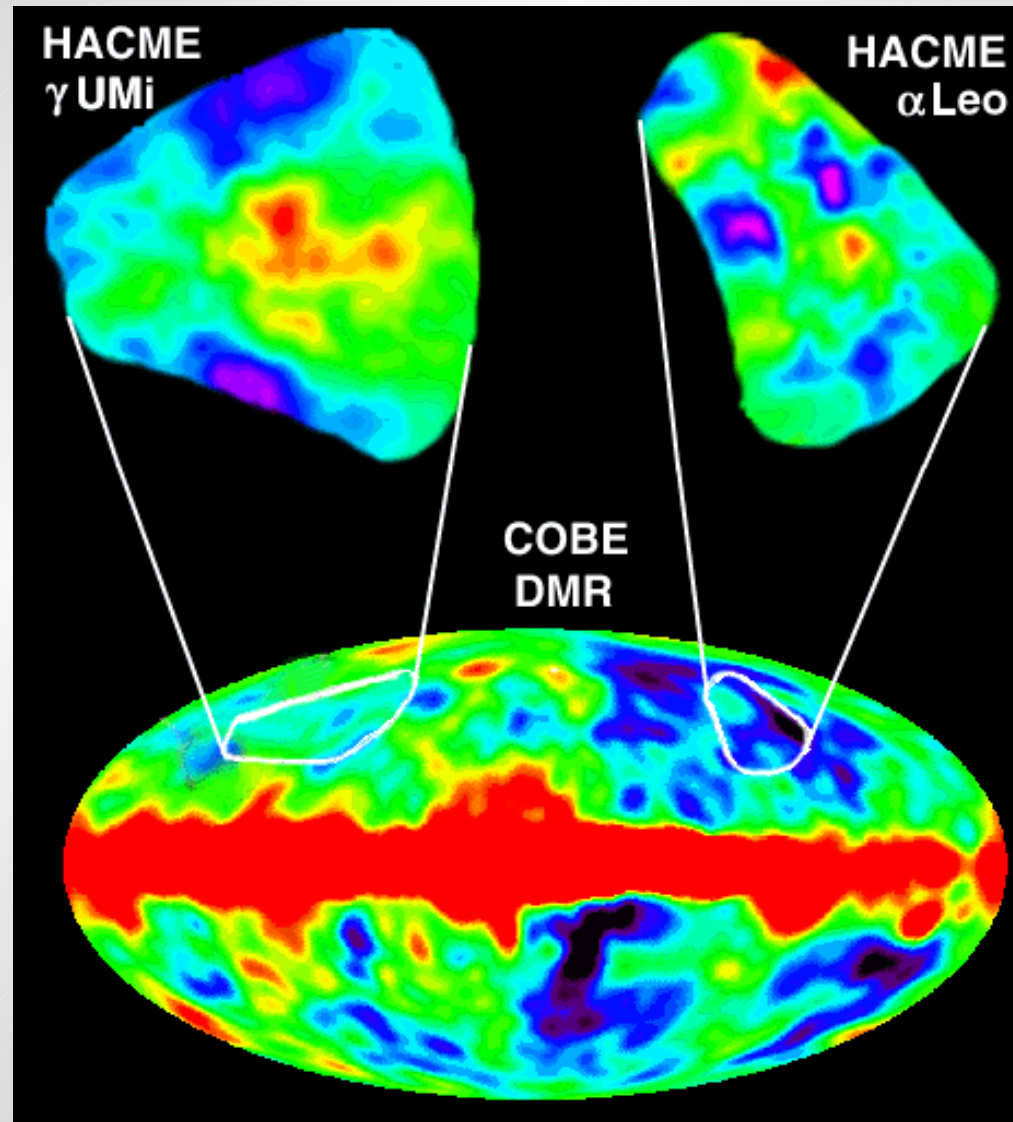
Óptica gregoriana off-axis +
espelho plano giratório

Detectores: HEMT (15 K)

Frequências: 30 e 45 GHz

Sensibilidade: $\sim 350 \mu\text{K}/\text{s}^{1/2}$

Tempo de observação: 8 h



MAXIMA

Millimeter Anisotropy eXperiment IMaging Array

Telescópio gregoriano off-axis (1,3 m)

Detectores: 16 bolômetros (0,1 mK)

Frequências: 150, 240, e 410 GHz

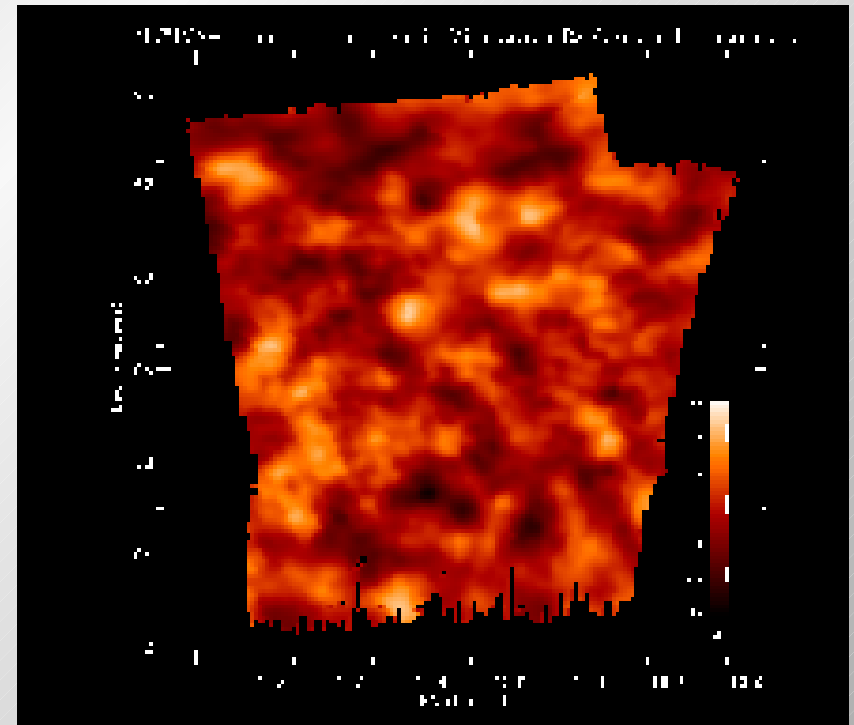
Sensibilidades: 90, 120 e 2050 $\mu\text{K}/\text{s}^{1/2}$

Tempo de observação: ~ 3 horas

Área coberta: 124 graus quadrados

Posição do pico acústico: $l = 197 \pm 6$

Amplitude do pico acústico: $\Delta T_{200} = 69 \pm 4 \mu\text{K}$



Hanany et al., ApJ, 2000

Matéria “normal” ~ 5 %
Matéria escura: ~ 30 %
Energia escura: ~ 65 %

BOOMERANG

Balloon Observations Of Millimetric Extragalactic Radiation AND Geophysics

Detectores: 16 bolômetros no plano focal resfriados a 0,3 mK

Freqüências: 90 (18'), 150 (10'), 240 (14'), 400 (13') GHz

Sensibilidades: 140, 170, 210 e 2700 $\mu\text{K}/\text{s}^{1/2}$

Tempo de observação: ~ 10 dias

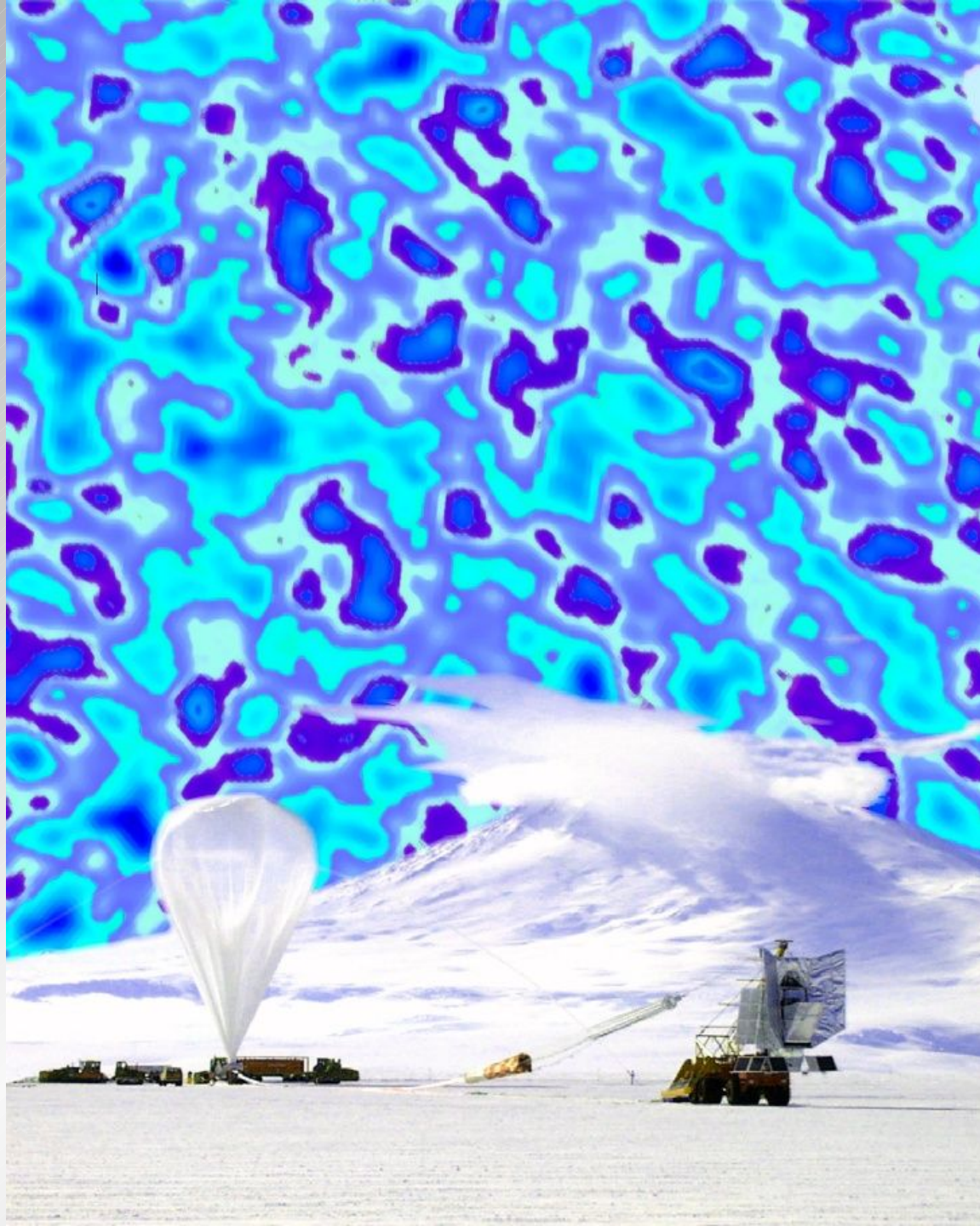
Área coberta: ~ 1500 graus quadrados

Posição do pico acústico: $l = 197 \pm 6$ (1 sigma)

Amplitude do pico acústico: $\Delta T_{200} = 69 \pm 4 \mu\text{K}$

de Bernardis et al., Nature, **404**, abril 2000



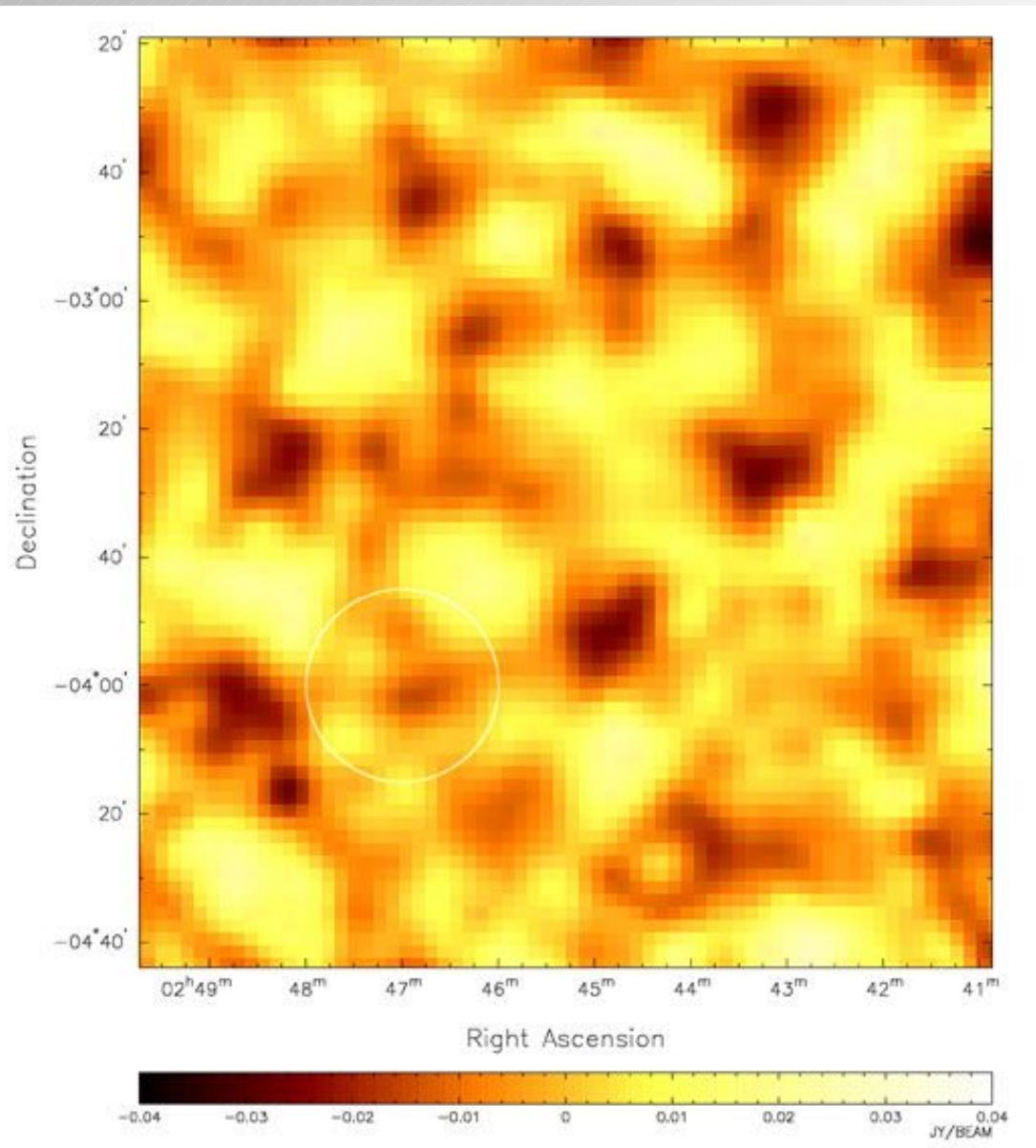


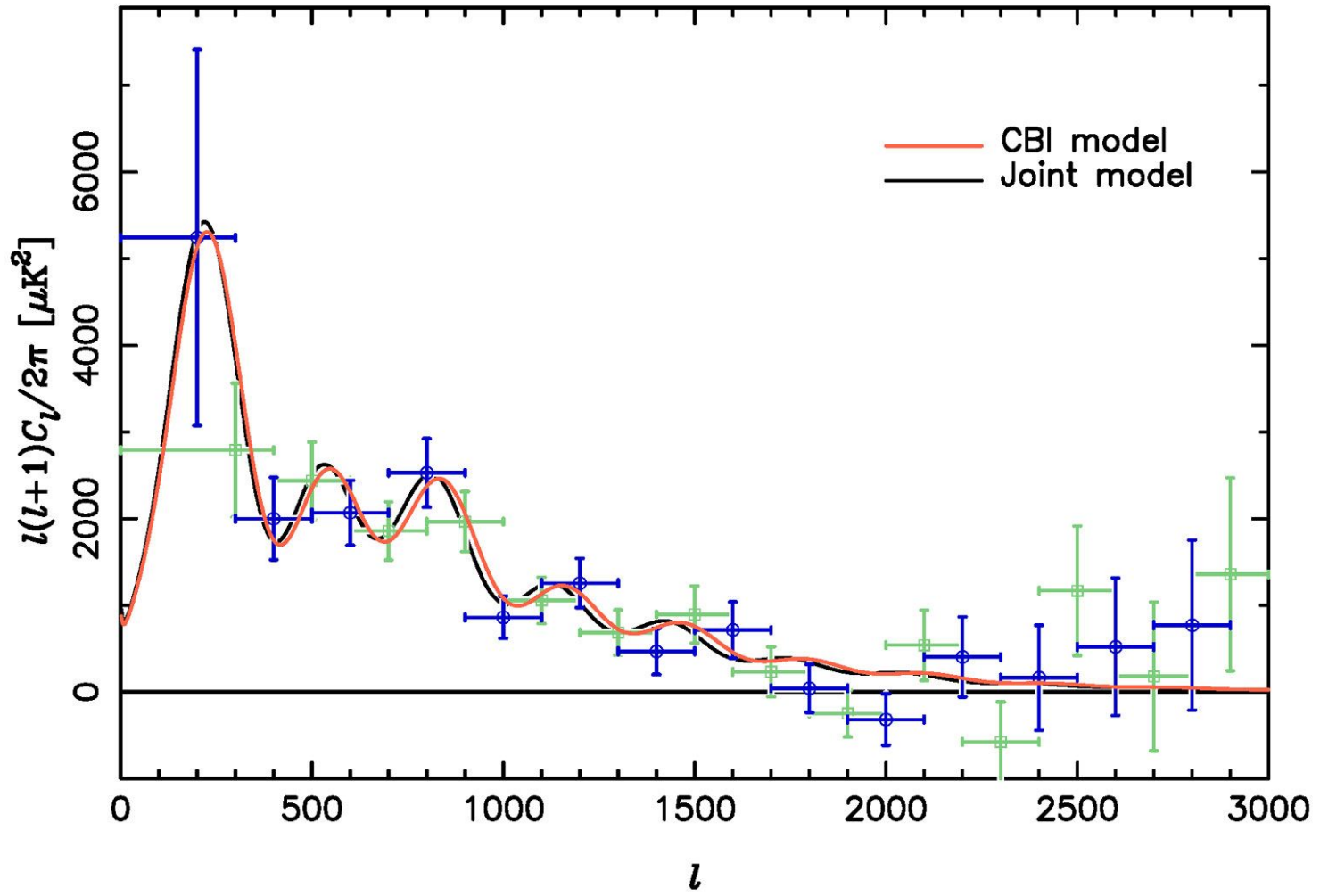
BOOMERANG



*Cosmic
Background
Imager*

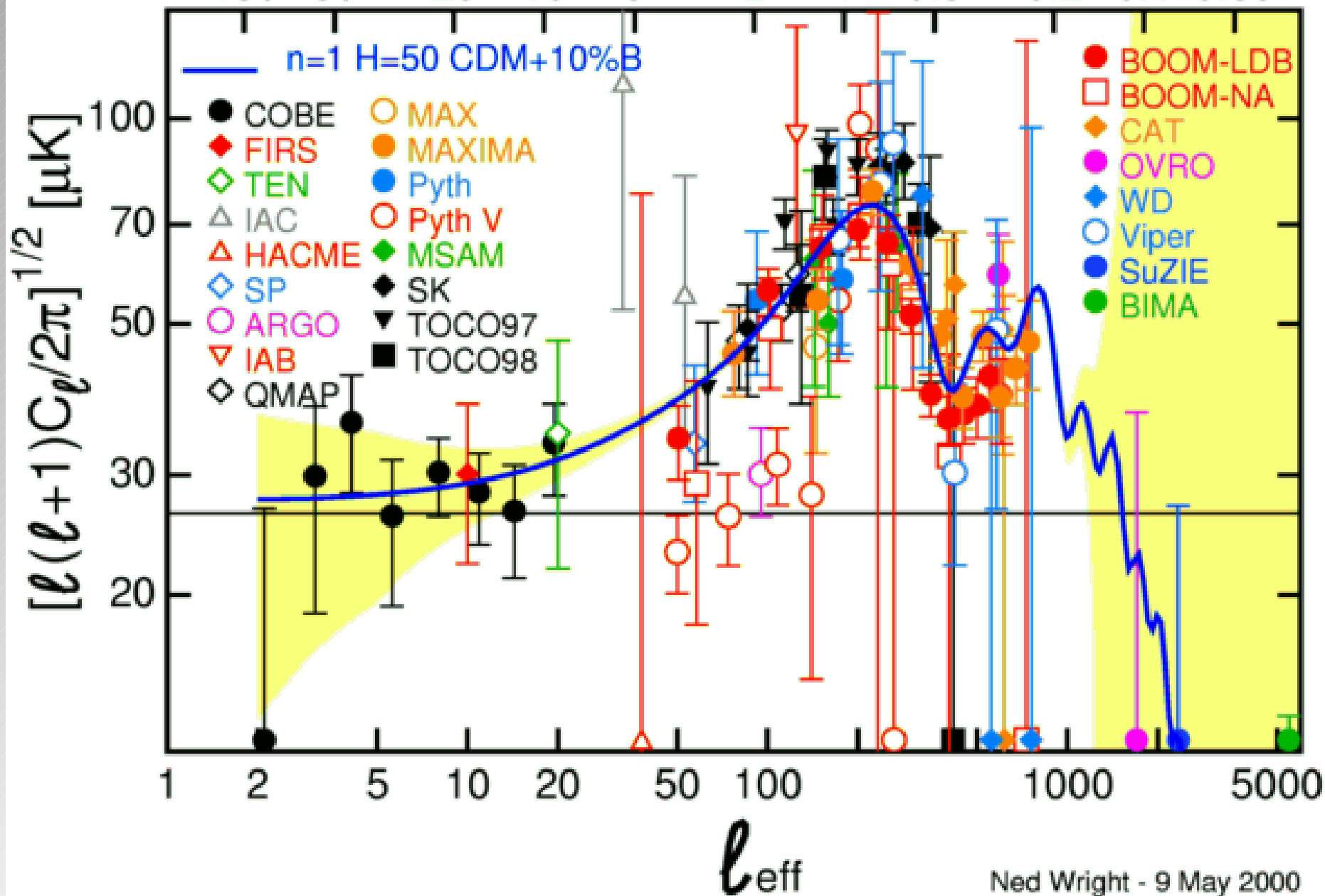






Angular Scale [Degrees]

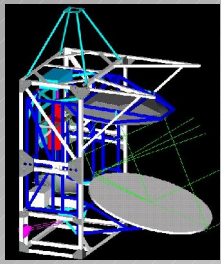
100 50 20 10 5 2 1 0.5 0.2 0.1 0.05



Projeto ACE

- Advanced Cosmic Explorer -

- Colaboração UCSB + INPE + EFEI + JPL + Univ. Roma + Univ. Milão
- Experimentos:
 - ACME/MAX (1989-1994)
 - HACME (1995-1997)
 - BEAST (1998-2004) + BOOST + TUPI
 - ACE (2005-2010)
- Financiamento:
 - FAPESP – CNPq (Brasil) + NASA – NSF (EUA)



BEAST

Background **E**mission **A**nisotropy **S**canning **T**elescope

Óptica gregoriana off-axis

Detectores: 8 HEMT (0,3 mK)

Frequências: 30, 41 e 90 GHz

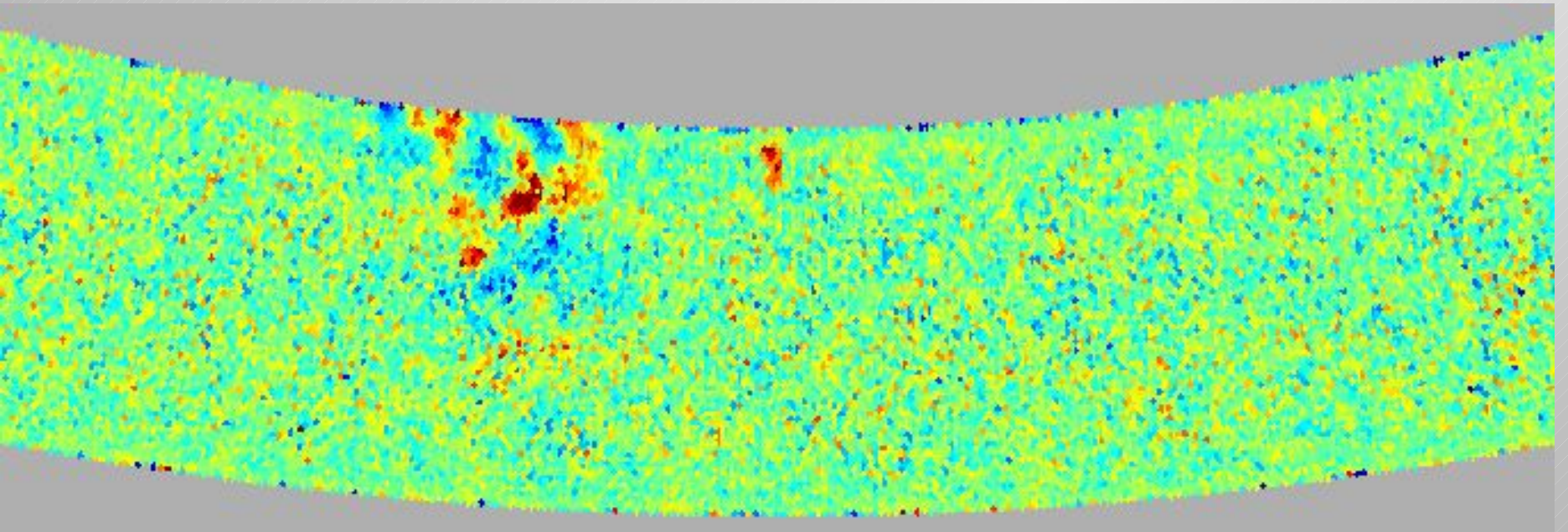
Sensibilidade: $\sim 230 \mu\text{K}/\text{s}^{1/2}$







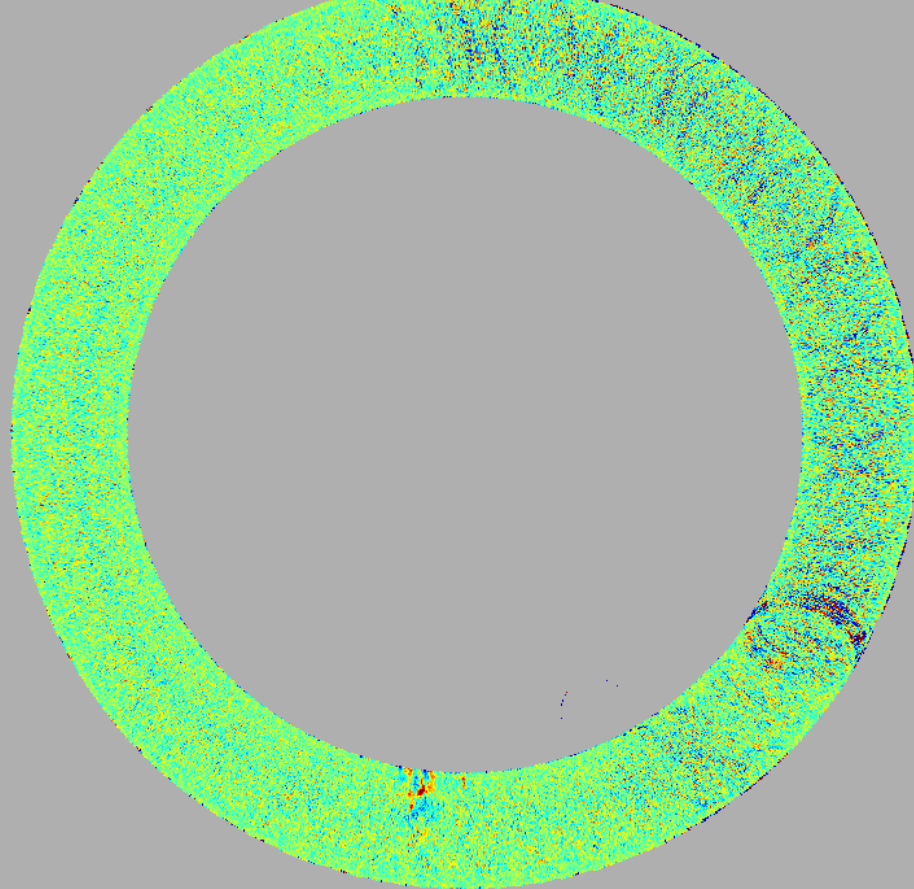
BEAST: Resultados preliminares



30 GHz, 28'

Meinhold et al. 2002; Childers et al. 2002; Seiffert et al. 2002;
Figueiredo et al. 2002; Villela et al. 2002

map-sum.fits: WHITE

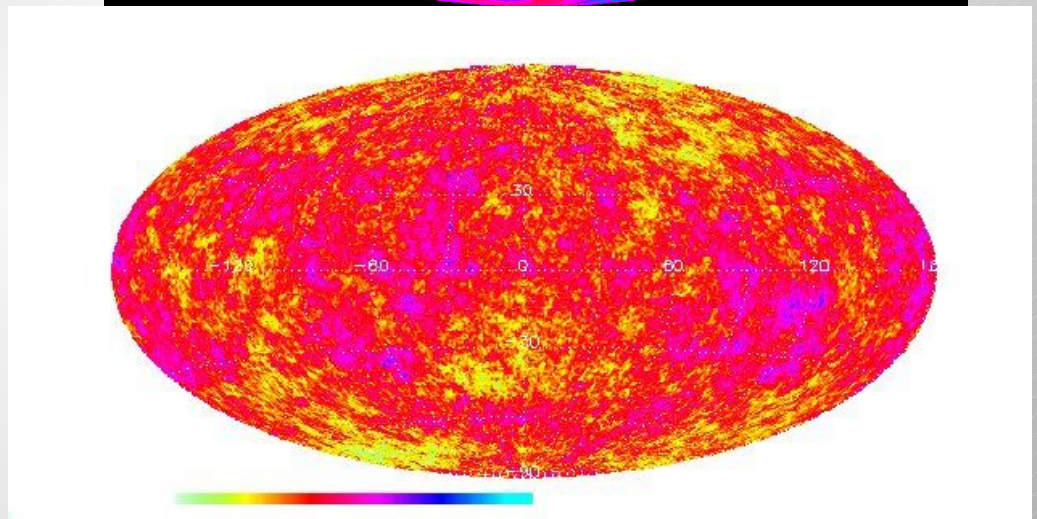
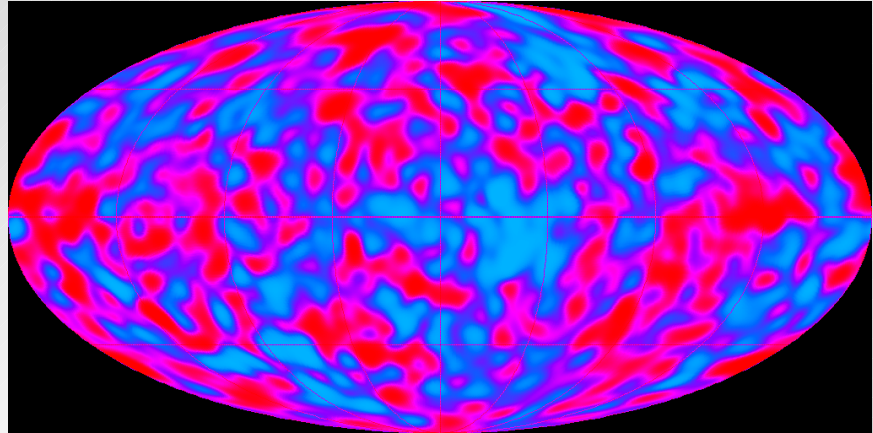
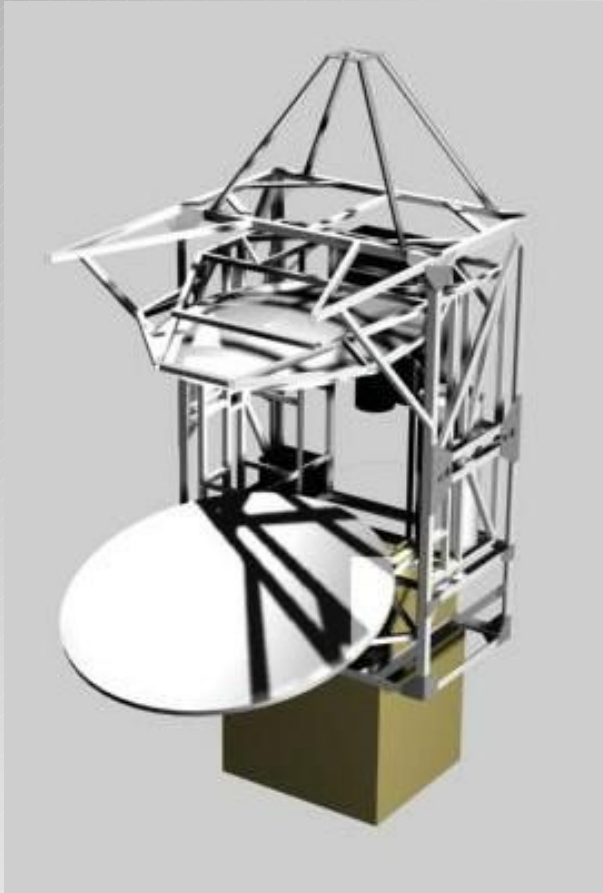


-5.00e-03 5.00e-03

(300.0, 90.0) Equatorial

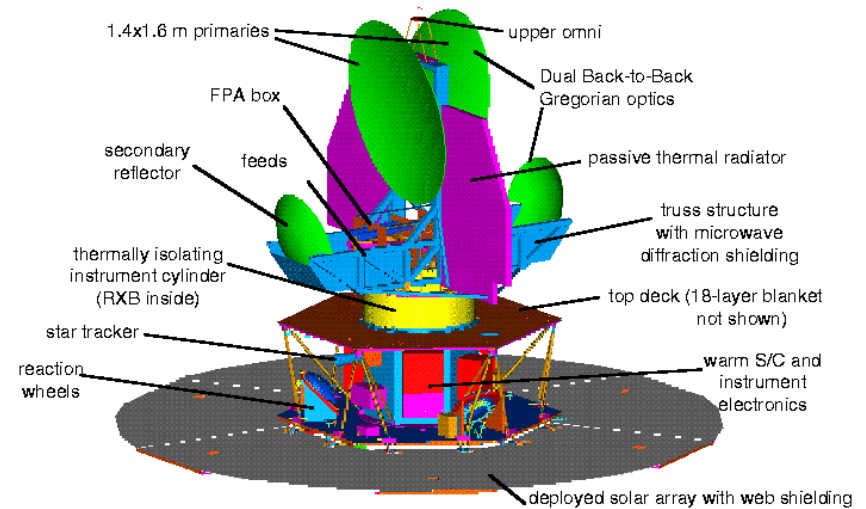
BEAST (UCSB + INPE)

Background Emission Anisotropy Scanning Telescope



$$\Omega_{\text{CDM}}=0,3, \Omega_{\Lambda}=0,65, \Omega_{\text{b}}=0,05, h=0,69$$

Satélite MAP



Telescópio gregoriano (1,6 m x 1,4 m)

Detectores: arranjo de 40 radiômetros (HEMT)

Frequência: 22, 30, 40, 60 e 90 GHz

Temperatura: ~ 20 K (3 estágios)

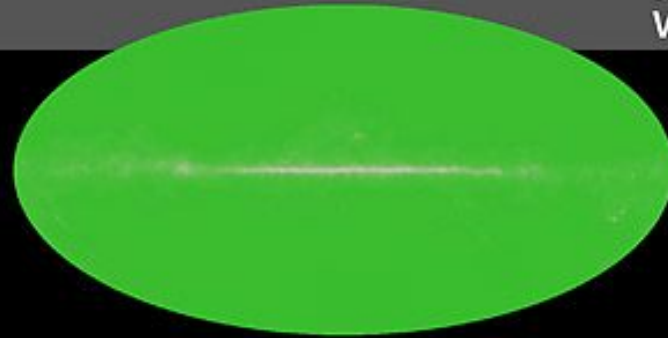
Resolução (°): 0,93; 0,68; 0,53, 0,35 e < 0,23

Sensibilidade média (24 meses, μK): ~ 35/pixel

1965



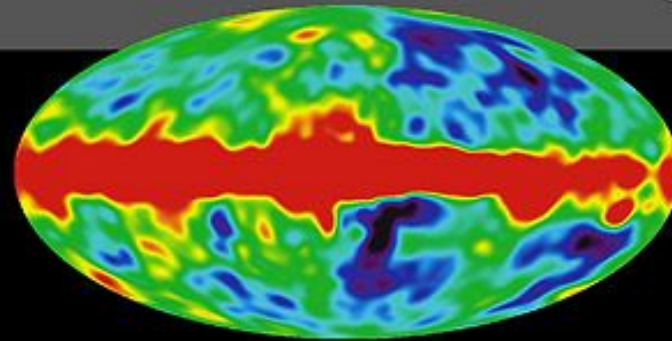
Penzias and
Wilson



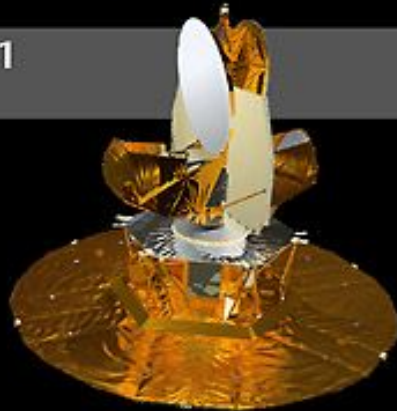
1992



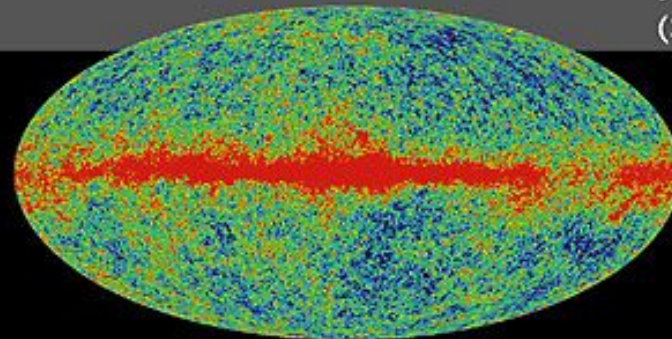
COBE

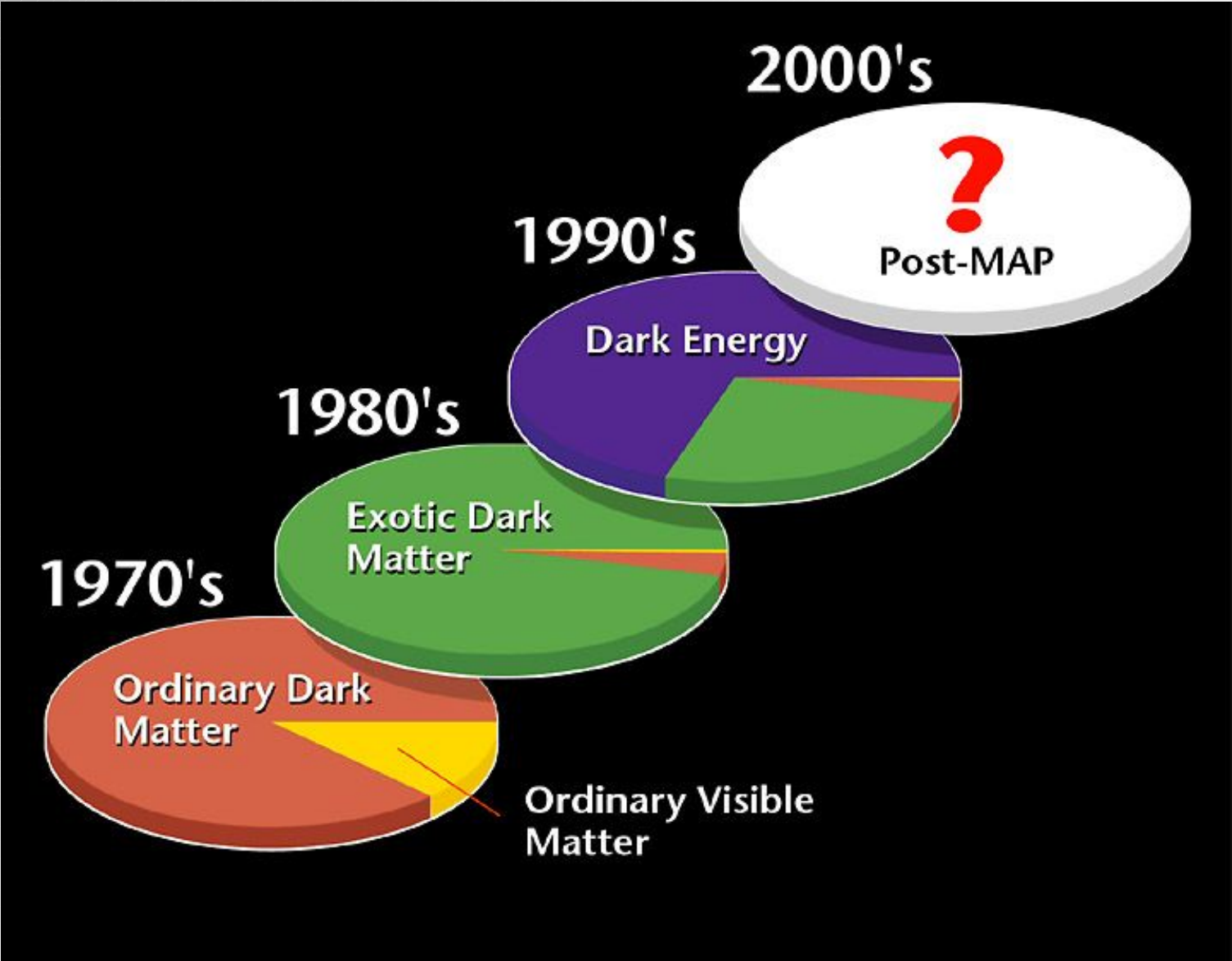


2001

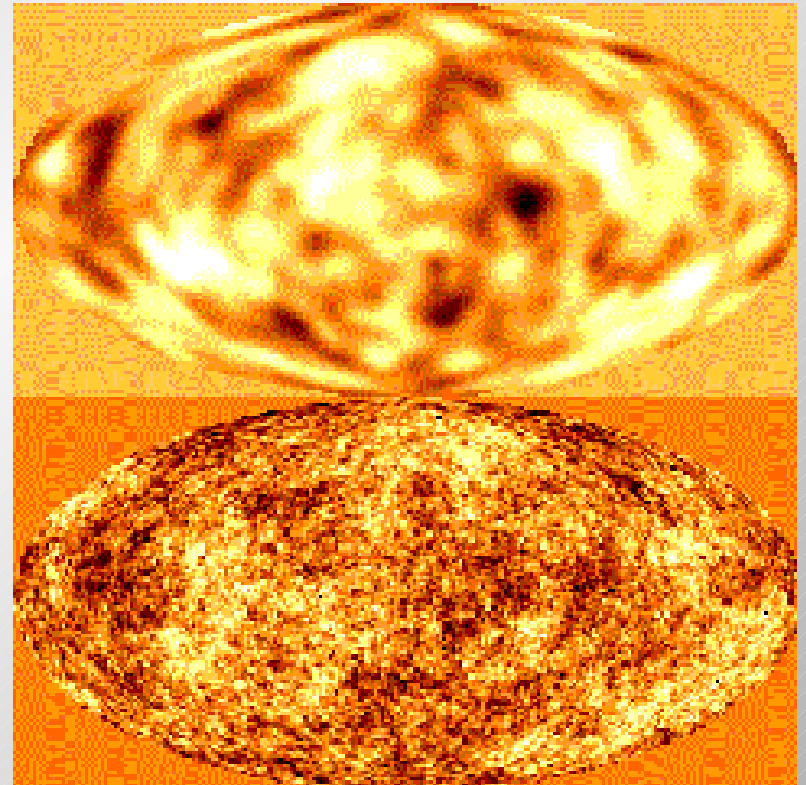
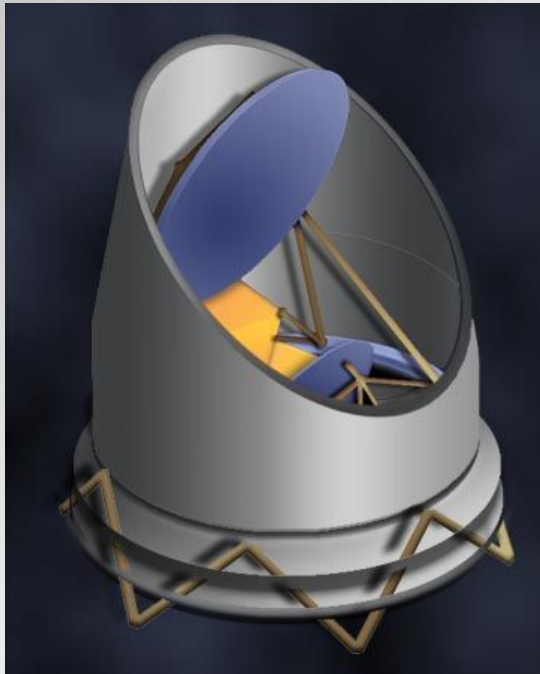


MAP
(Simulated)





Satellite Planck



Satélite Planck

Telescópio gregoriano “off axis” (1,5 m)

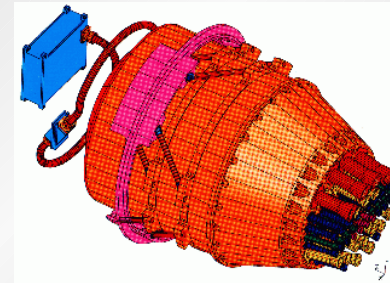
Detectores: arranjo de 48 bolômetros

Frequências: 100, 143, 217, 353, 545 e 857 GHz

Temperatura: ~ 0,1K (3 estágios)

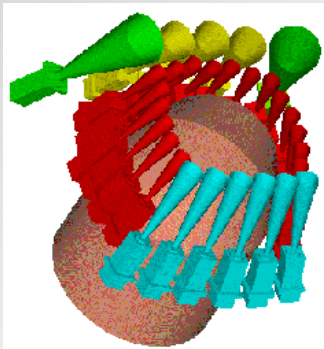
Resolução angular ('): 10,7; 8,0; 5,5; 5,0; 5,0; 5,0

Sensibilidade média/pixel (12 meses, μK): 1,7; 2,0; 4,3; 14,4; 147 e 6670



HFI

LFI



Detectores: arranjo de 56 diodos HEMT

Frequências: 30, 44, 70 e 100 GHz

Temperatura: ~ 20 K (3 estágios)

Resolução angular ('): 33, 23, 14, 10

Sensibilidade média/pixel (12 meses, μK): 1,6; 2,4; 3,6; 4,3

Cosmologia com a RCFM na era pós-Planck...

Polarização

Observações multifrequência em escalas $\sim 1^\circ$

RCF “Deep Field”

Contaminantes

Efeito Sunyaev-Zel’dovich

Nova física?



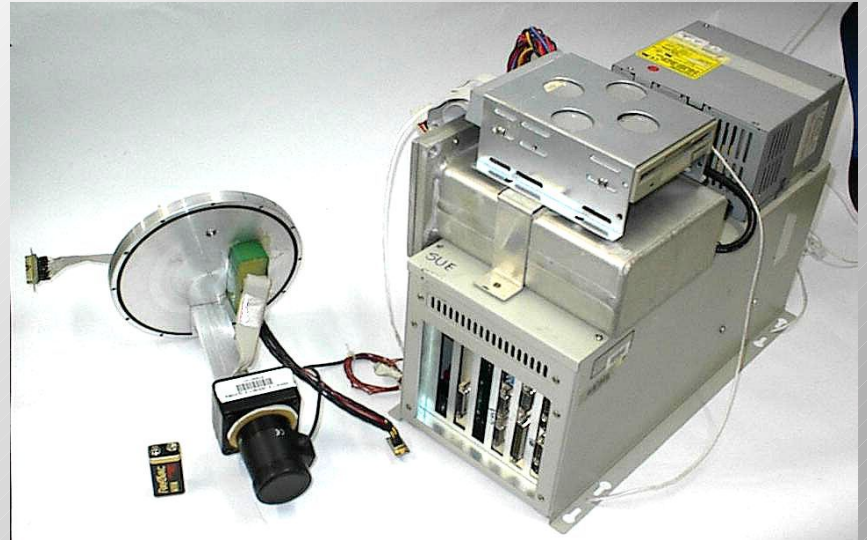
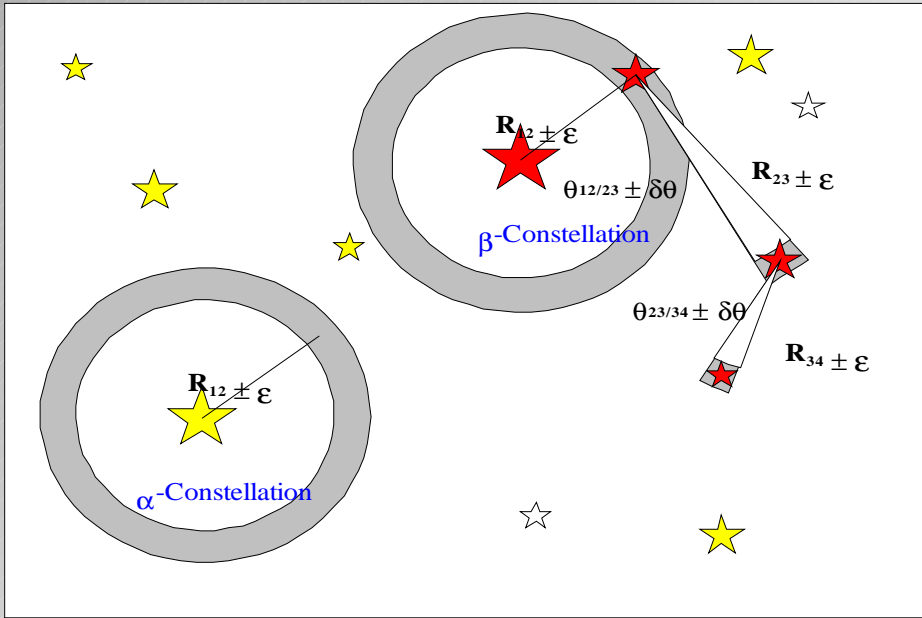
MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

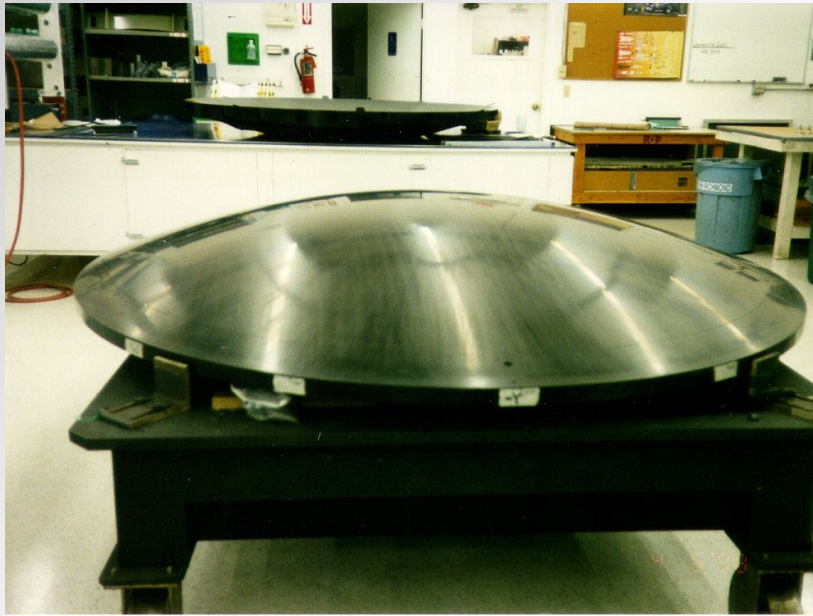
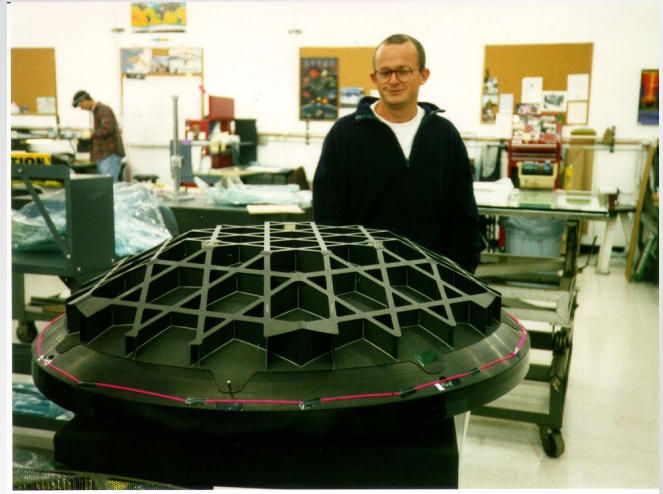
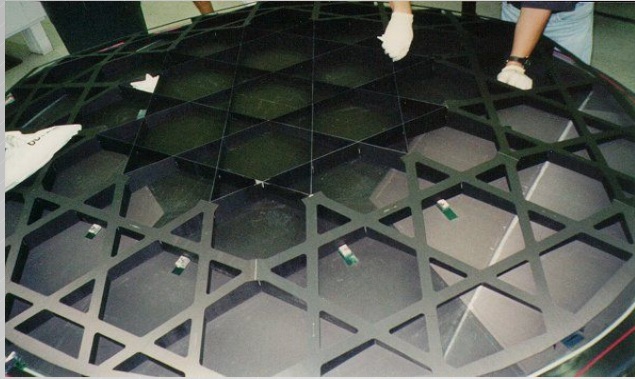
Desenvolvimentos Tecnológicos

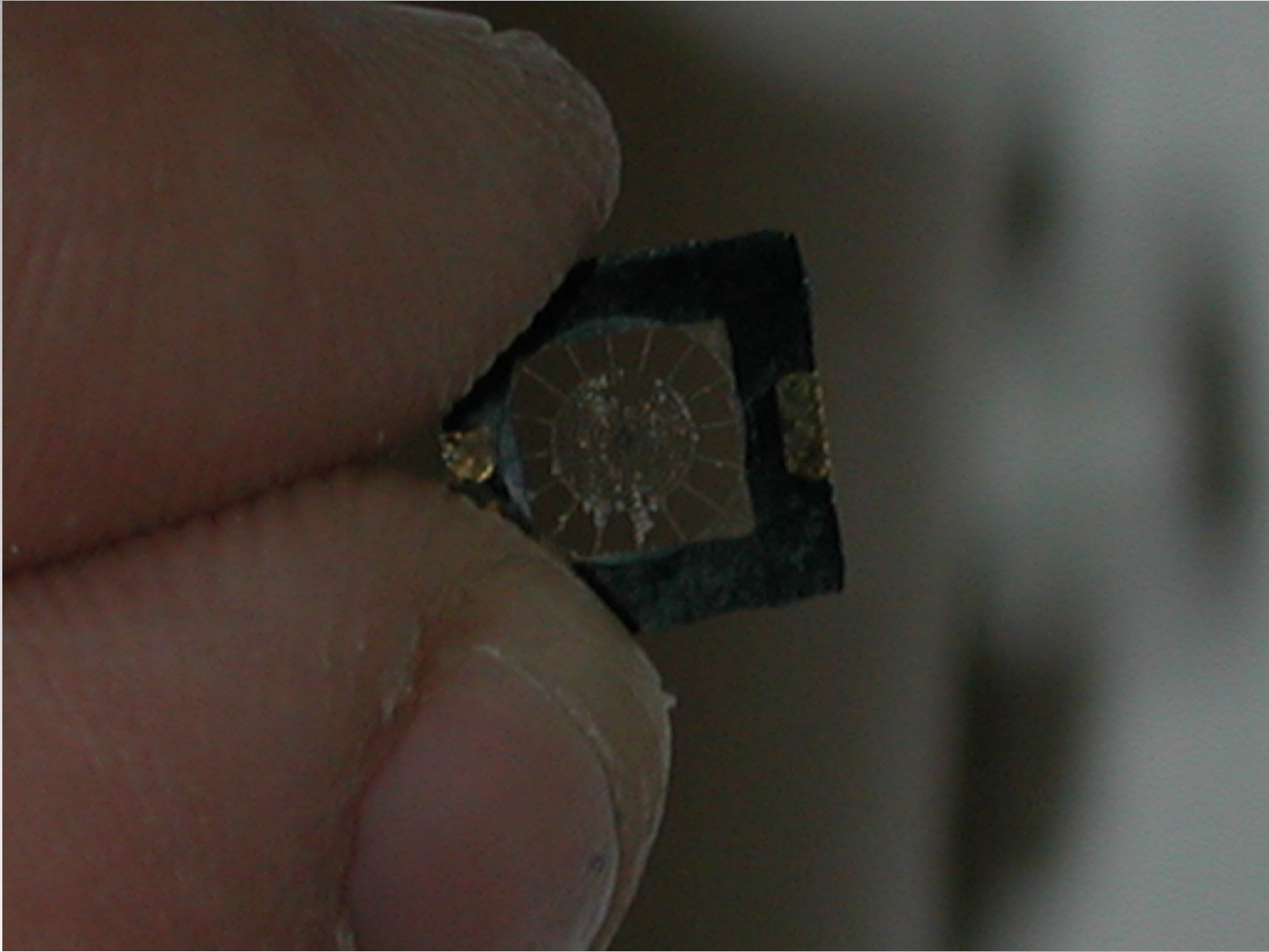
- Sensor estelar CCD
- Sistema de controle de atitude
- Detectores de microondas (HEMT)
- Mecânica de precisão
- Técnicas utilizadas em telecomunicações
- Criogenia
- Interferência eletromagnética
- Análise de dados

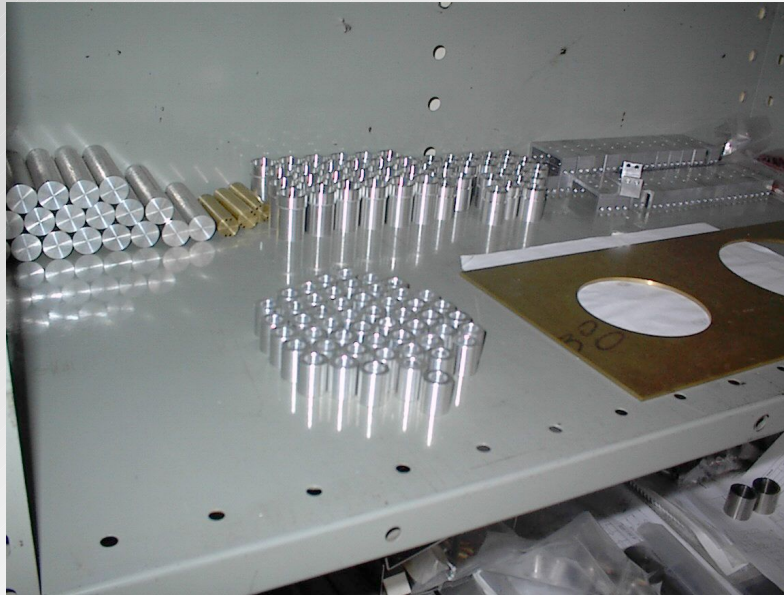
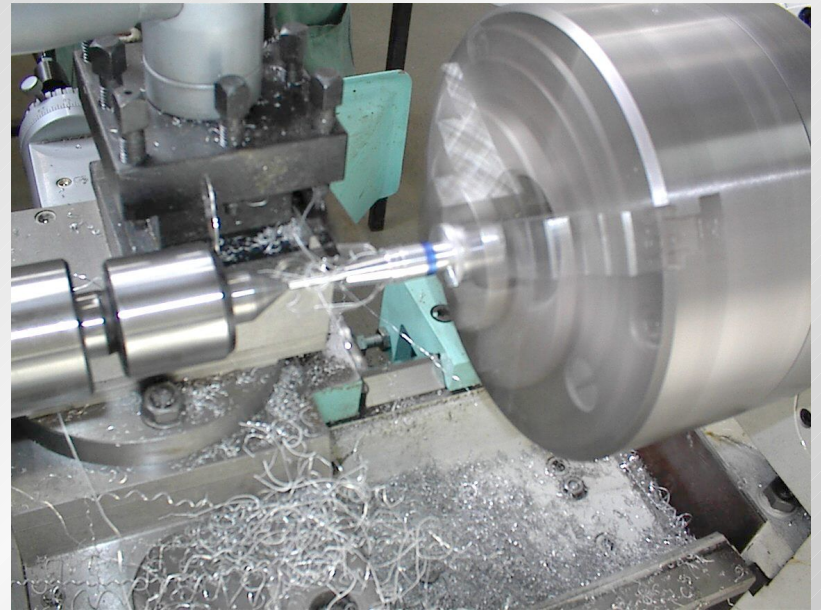
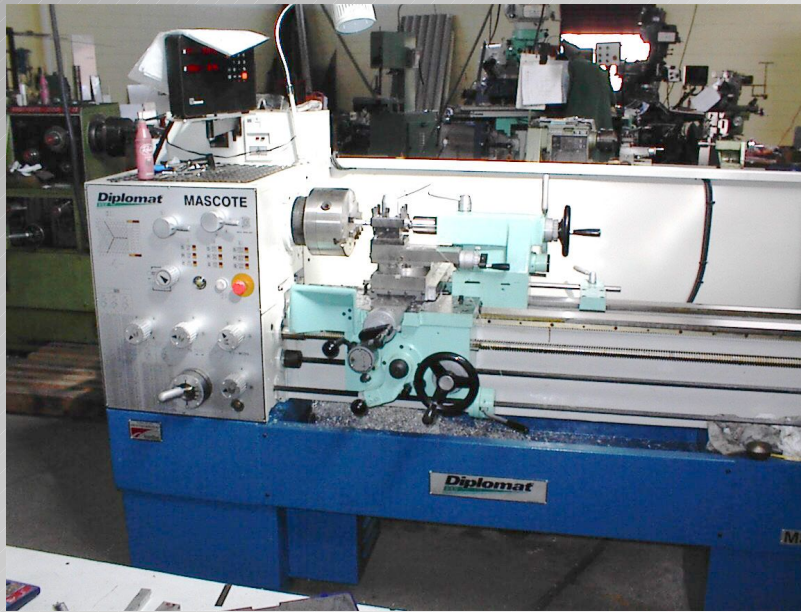
Rastreador Solar



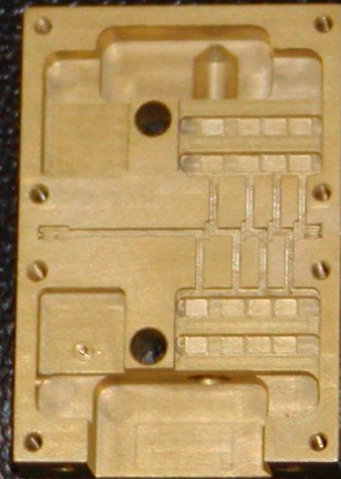
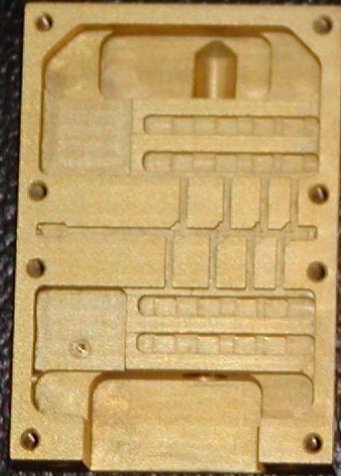
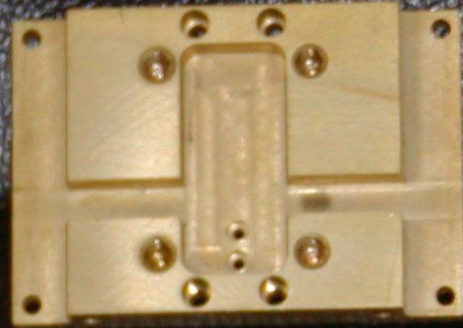
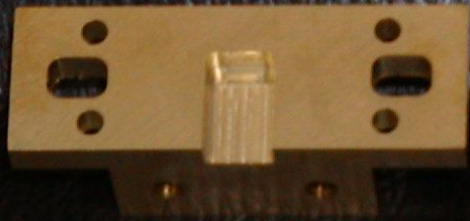




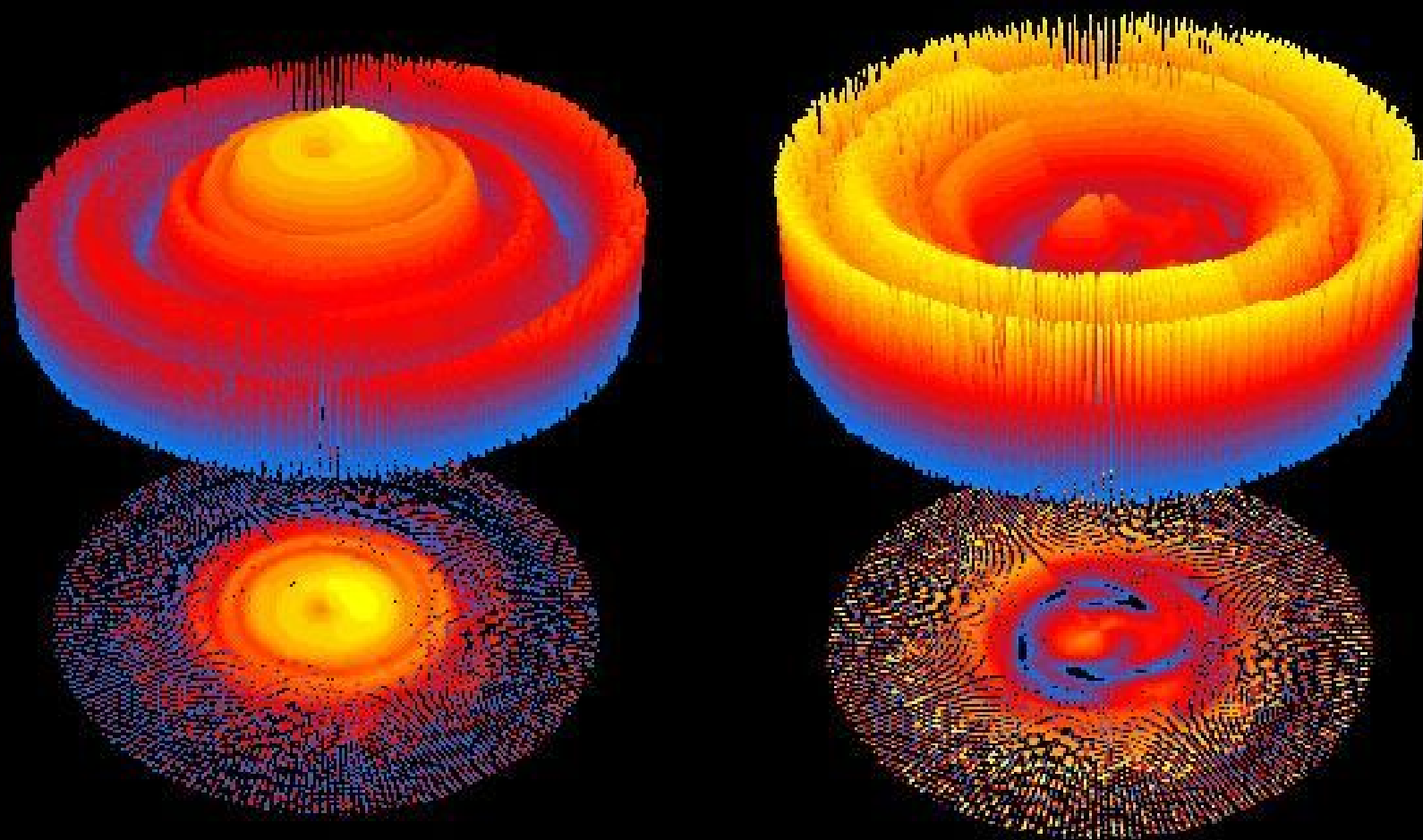








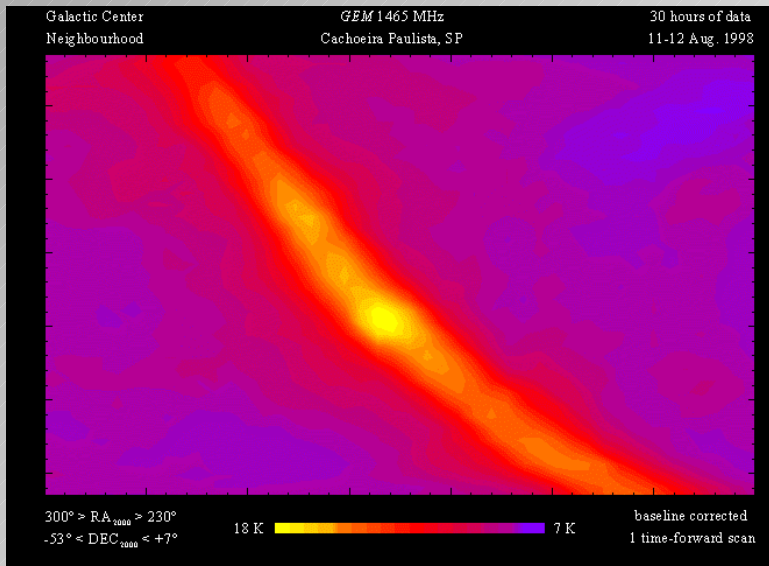
The *GEM* backfire helical feed antenna at 408 MHz



$0^\circ \rightarrow 180^\circ$
-30 dB

Polar Angle Range
Minimum Power Level

$180^\circ \rightarrow 0^\circ$
-30 dB



Telefonia celular

