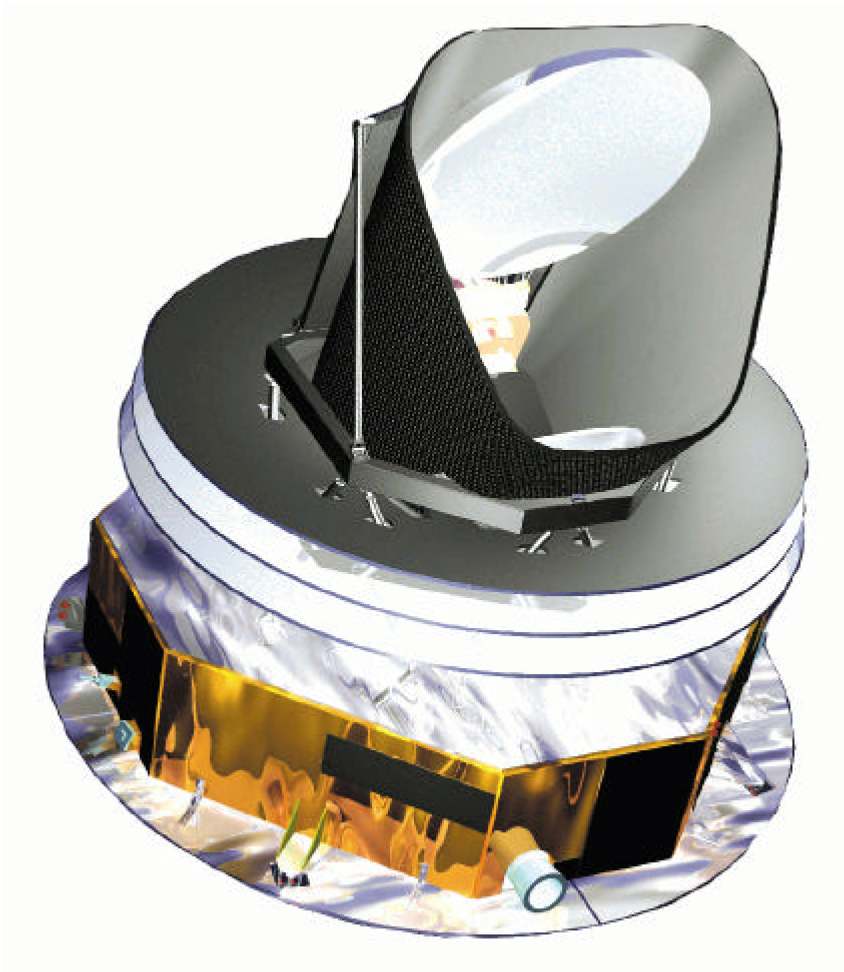
PLANCK



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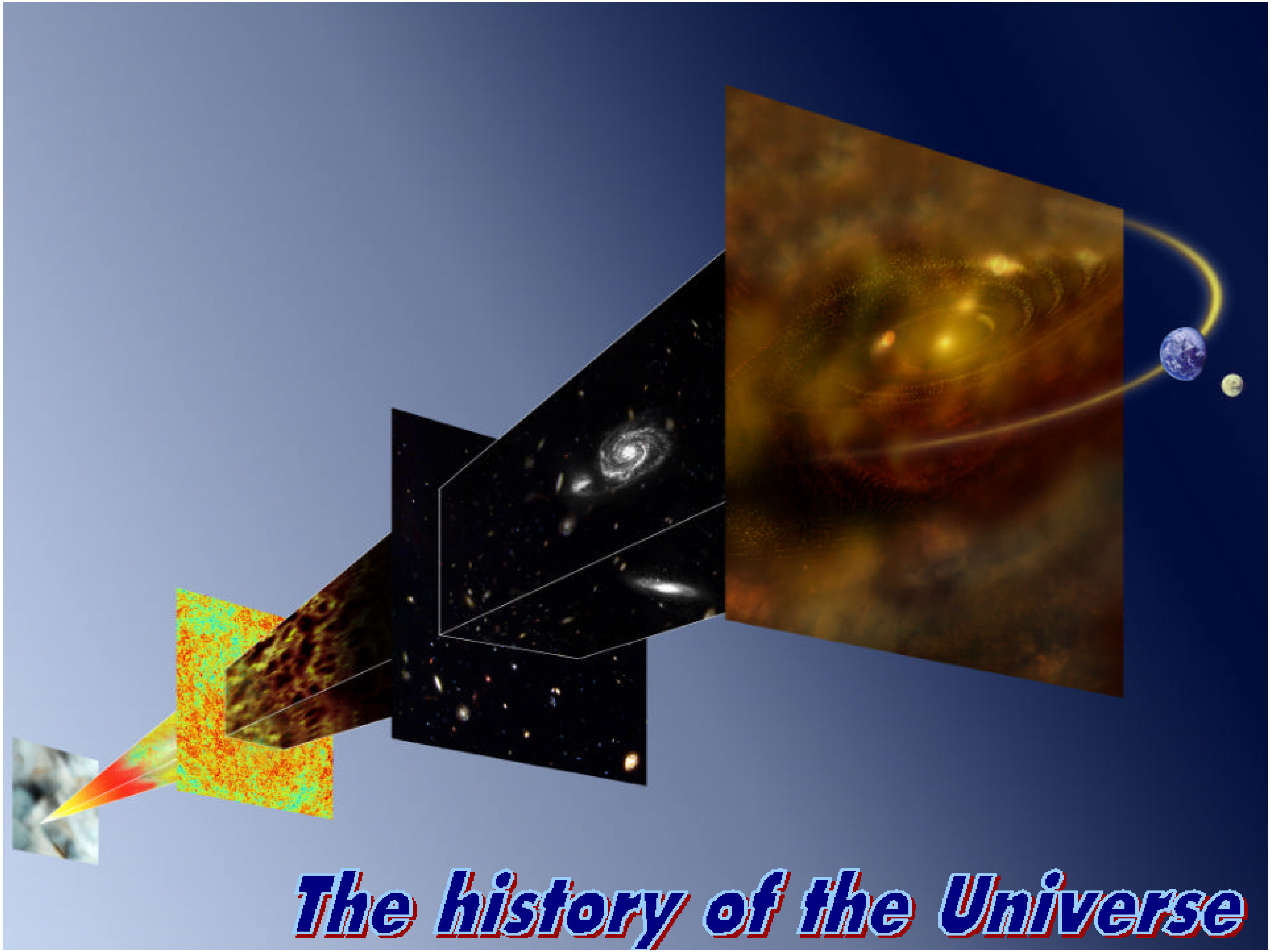
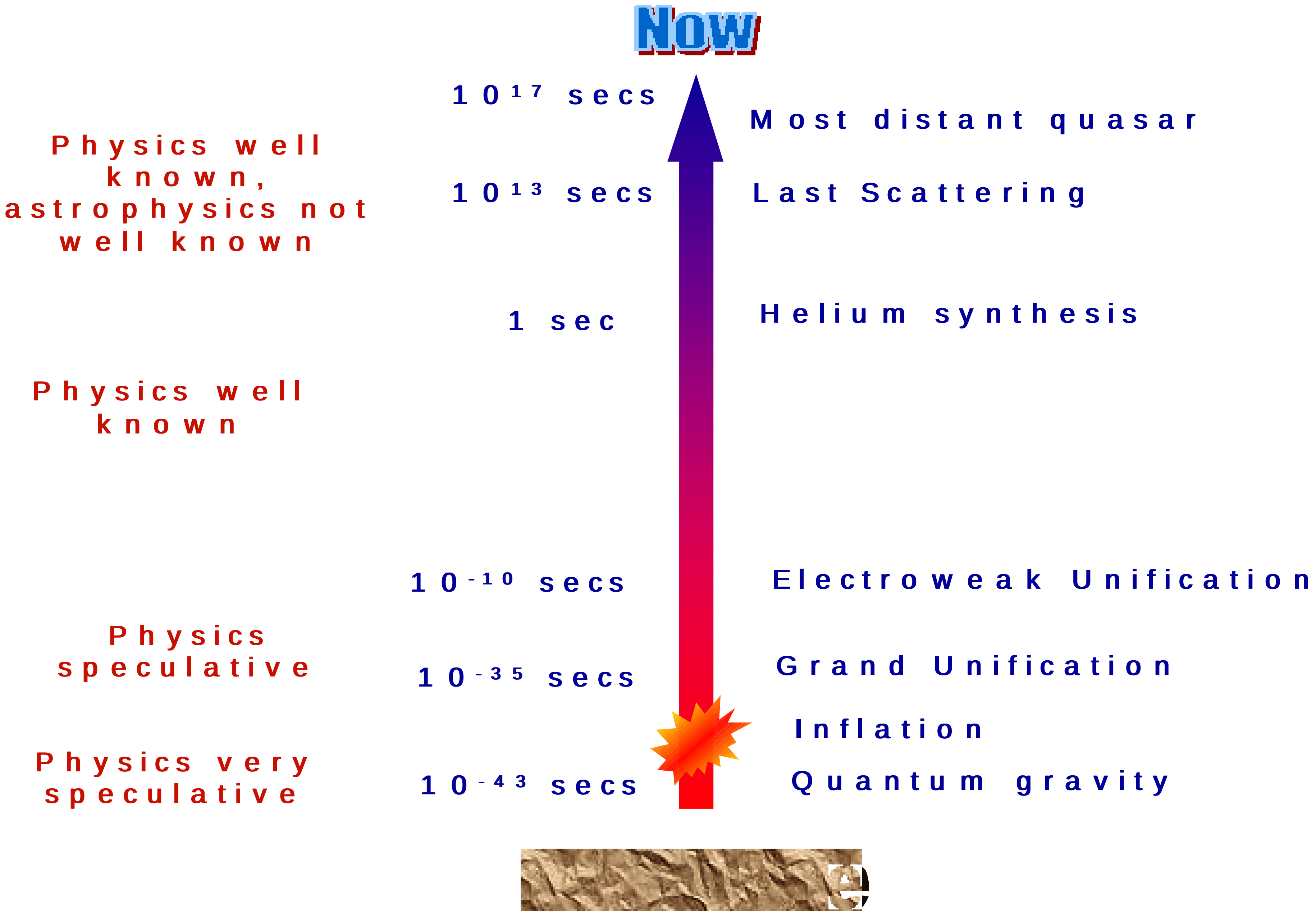
The European mission to map the Cosmic Microwave Background

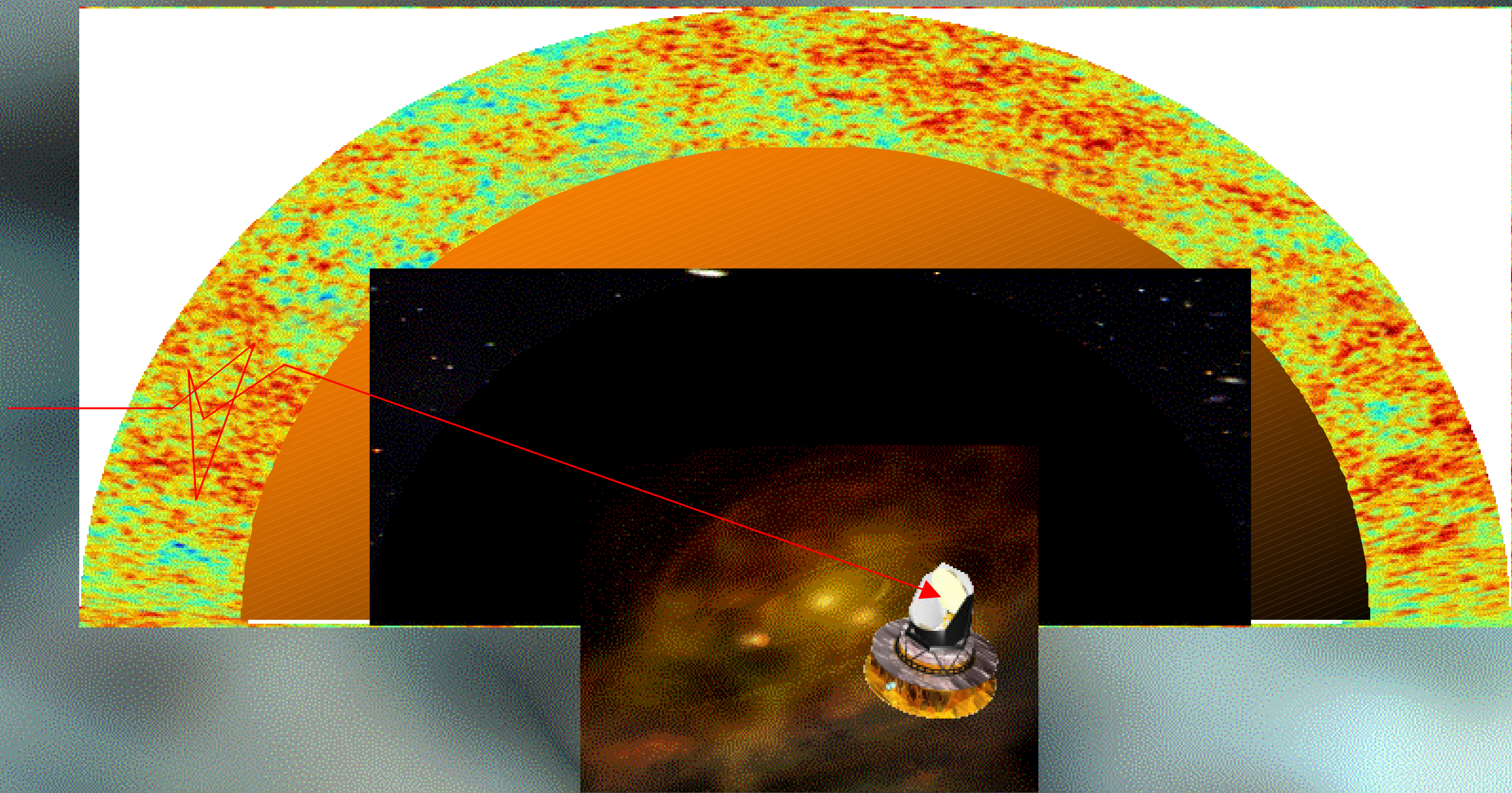
- Scientific context
- Current state of CMB experiments
- Planck payload and spacecraft

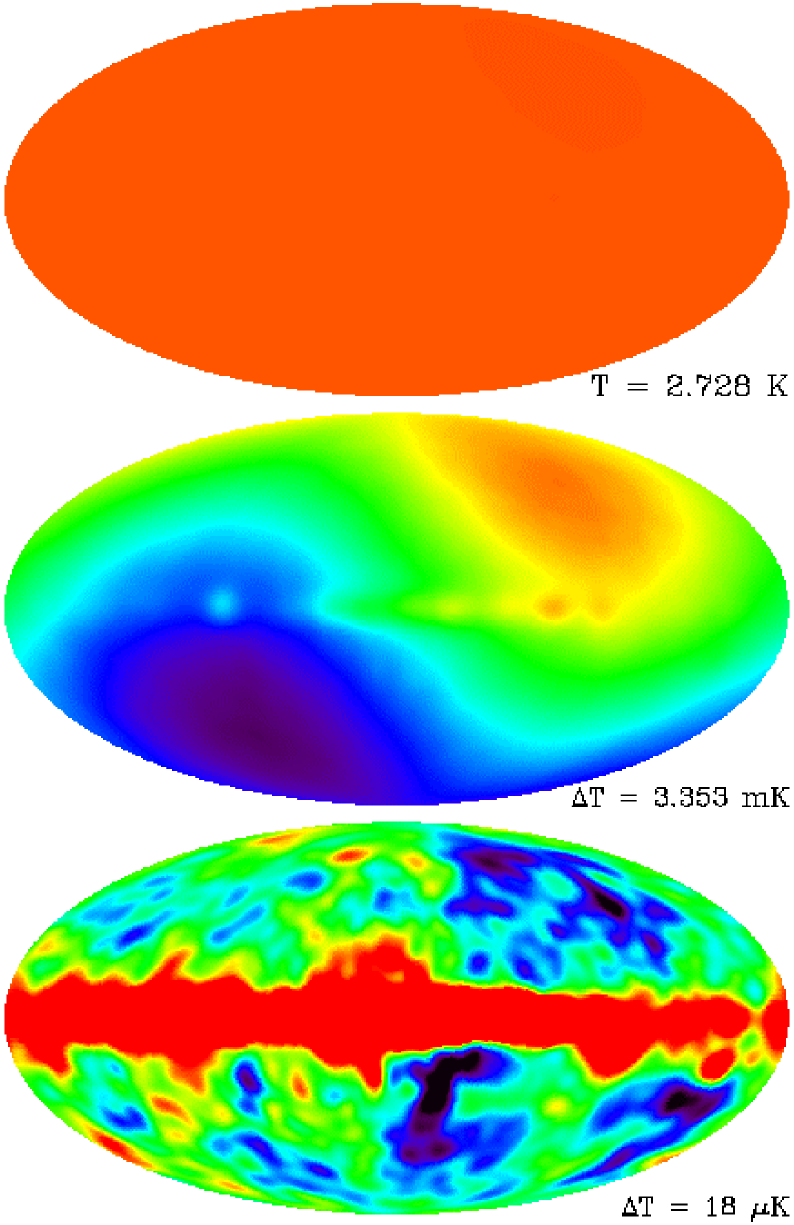
Science


The history of the Universe


Now
10^{17} secs
Most distant quasar
Physics well known, astrophysics not well known
10^{13} secs
Last Scattering
1 sec
Helium synthesis
Physics well known
10^{-10} secs
Electroweak Unification
Physics speculative
10^{-35} secs
Grand Unification
Inflation
Physics very speculative
10^{-43} secs
Quantum gravity

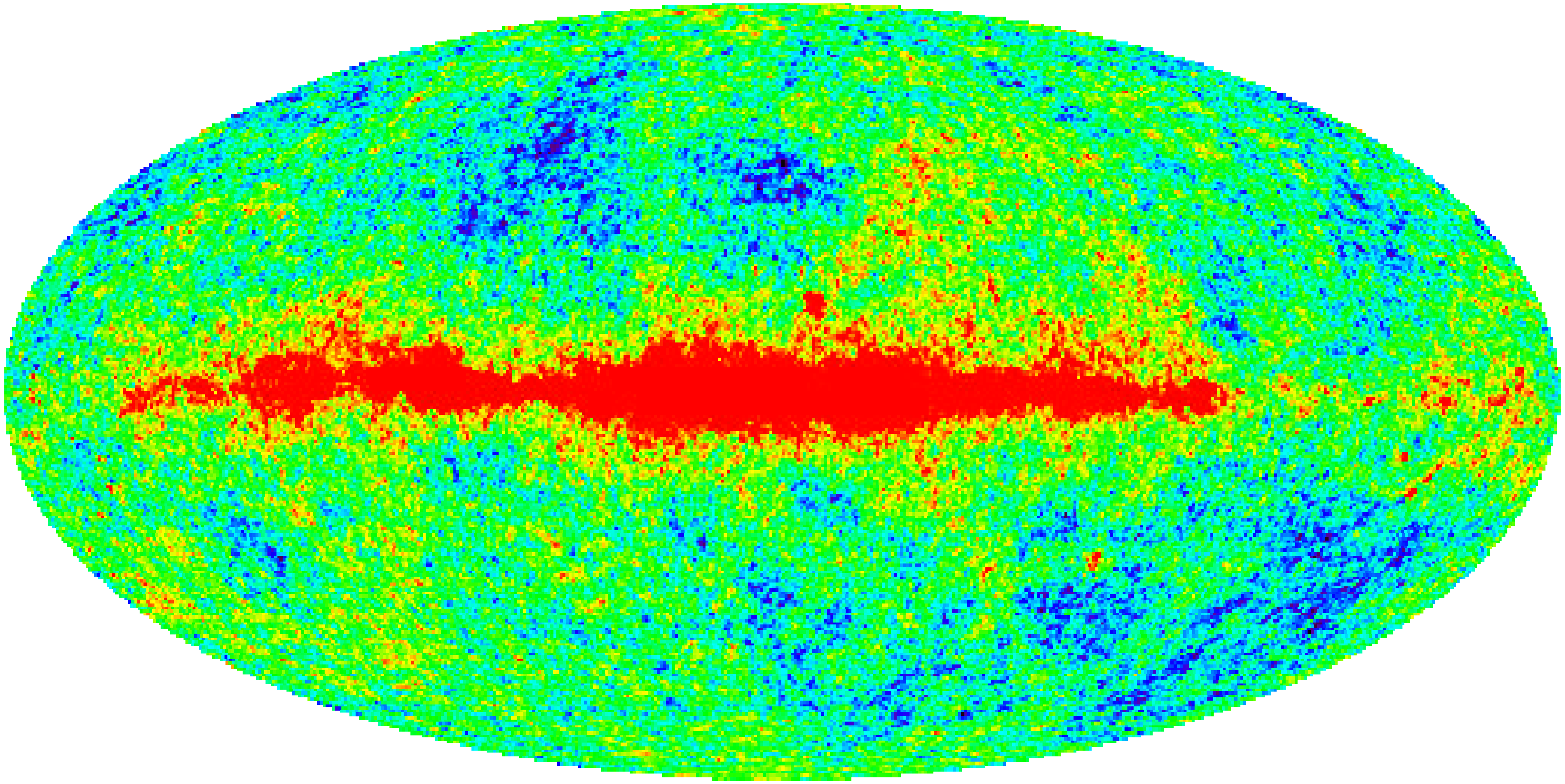
Looking back in time





The CMB as seen by COBE

The CMB as seen by Planck



Simulated CDM W=1 model,DQ=10', DT/T=2x10^{-6}

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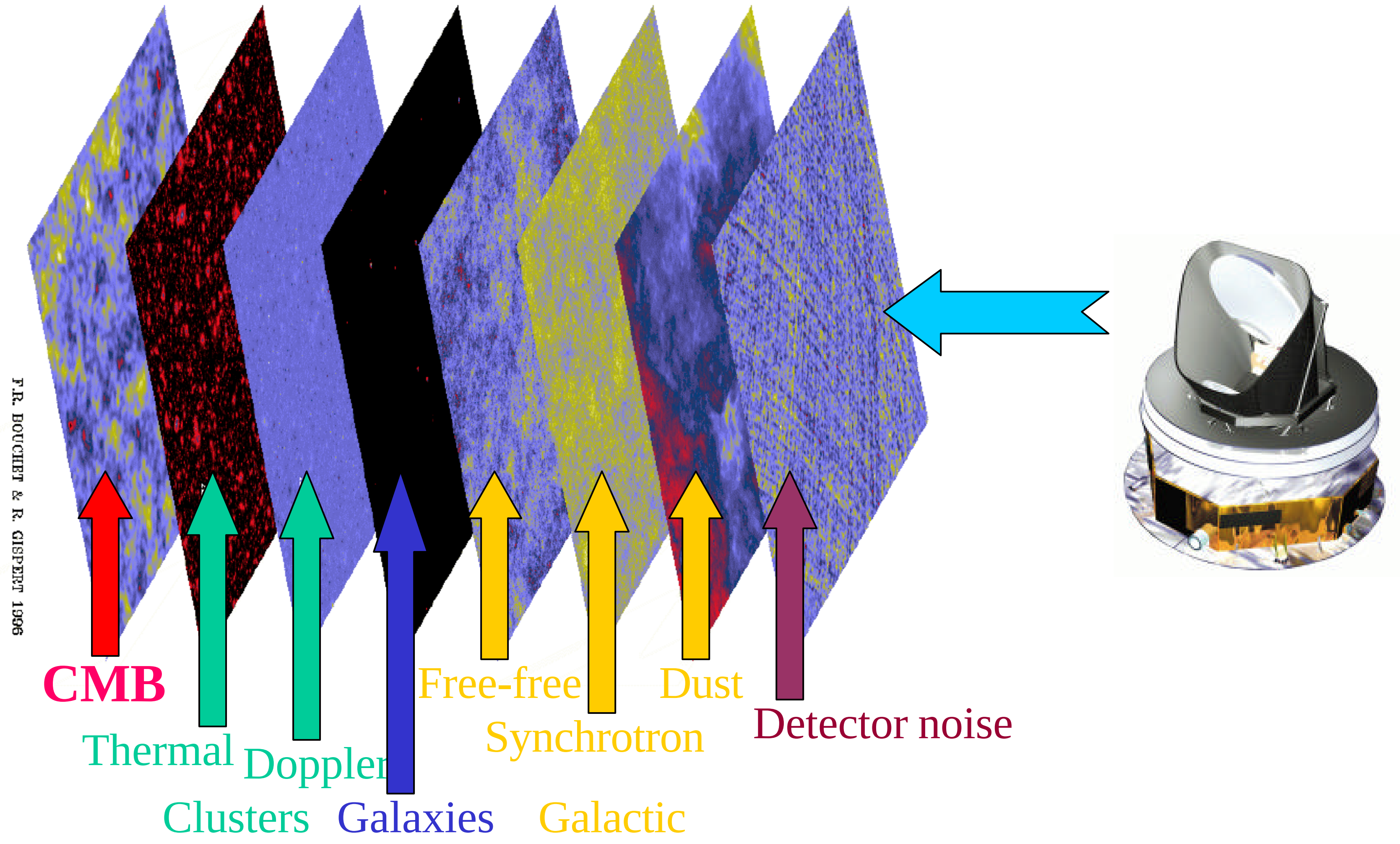
Foreground separation



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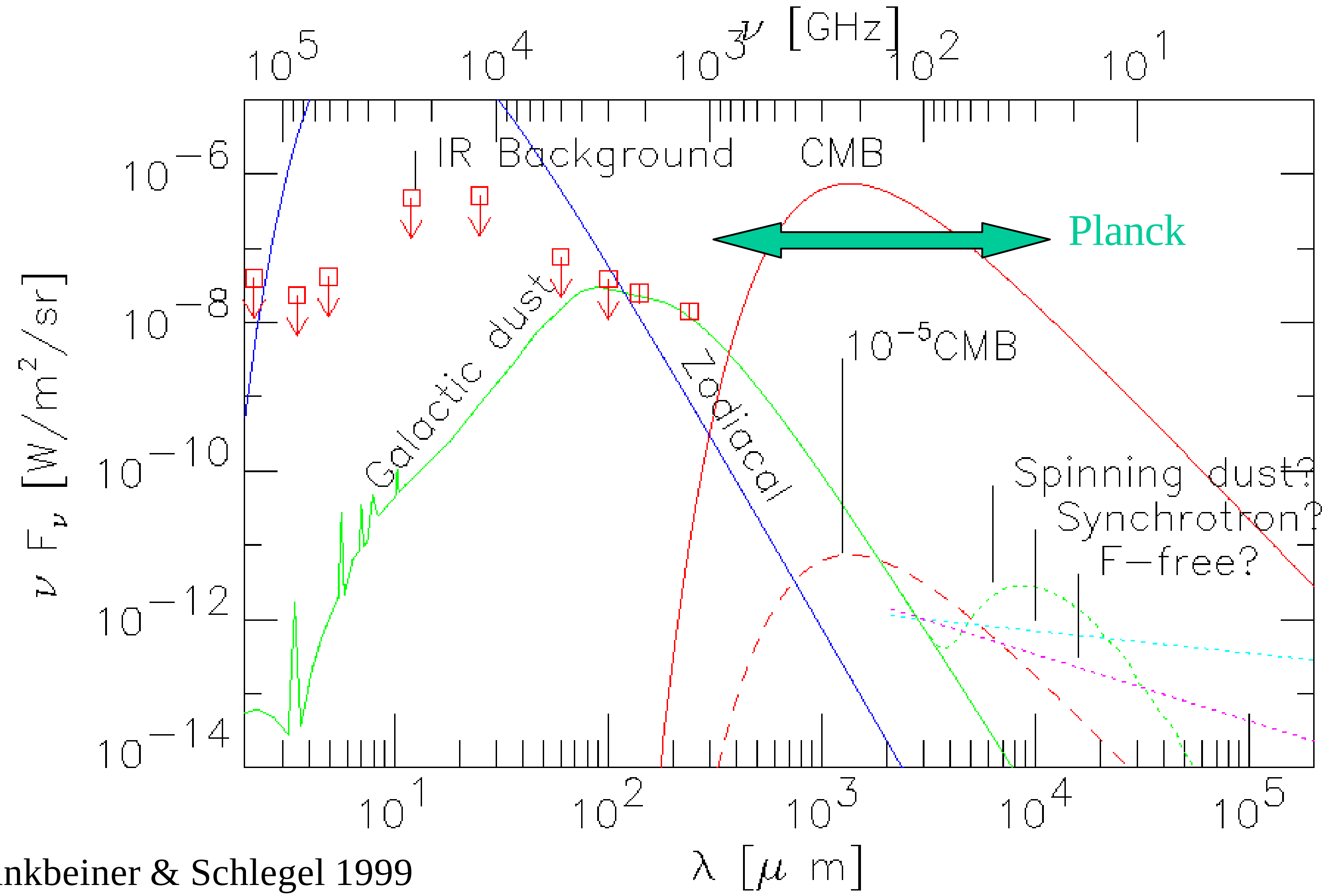
Sky emission components



Finkbeiner & Schlegel 1999

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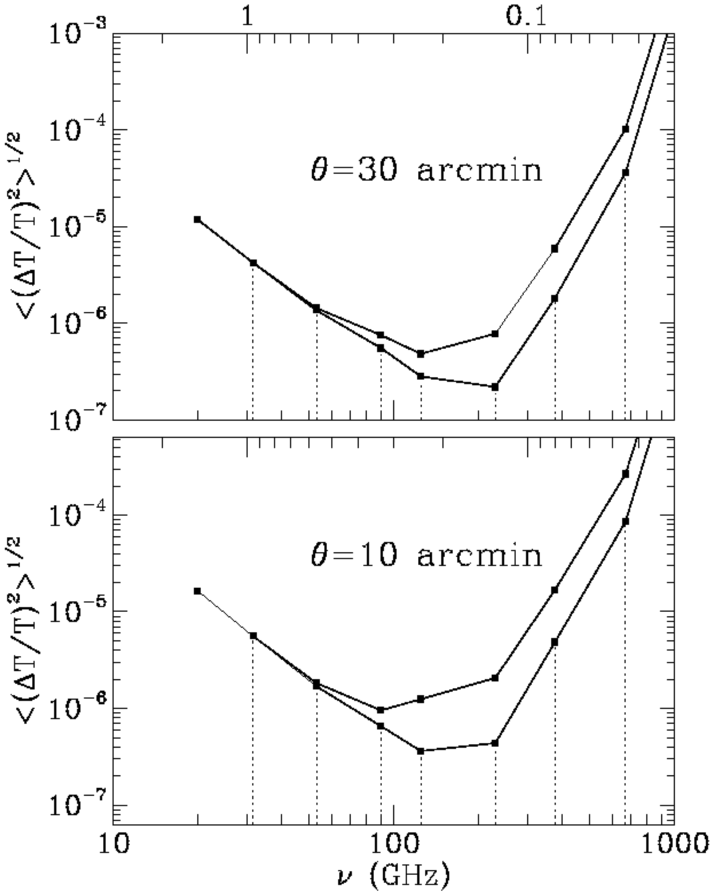
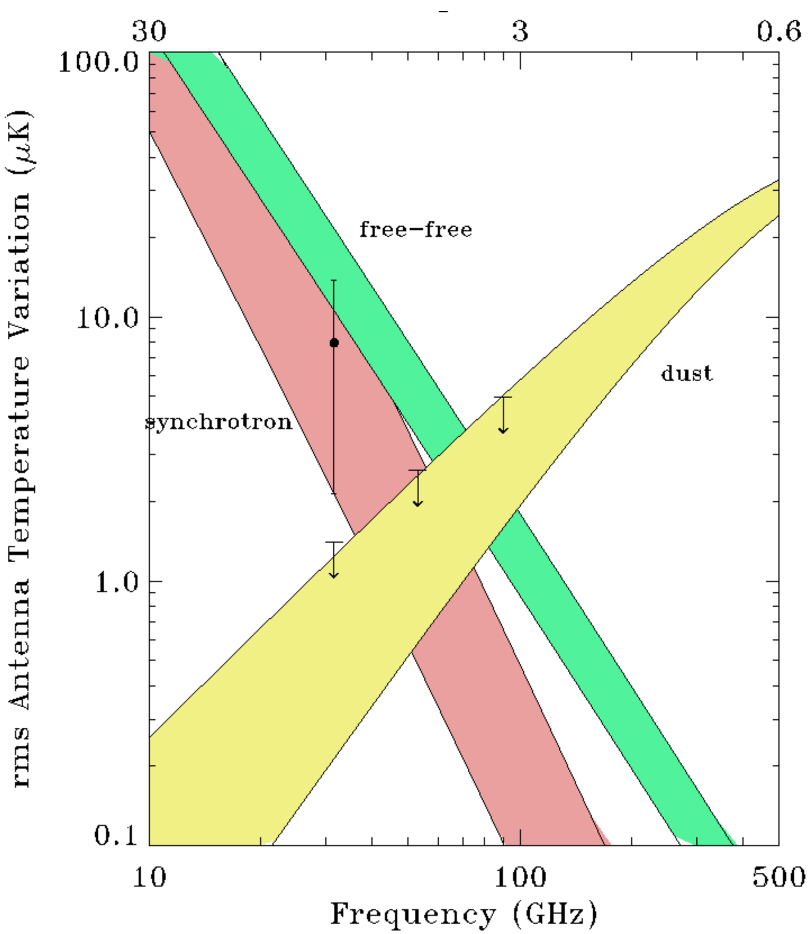
Foreground fluctuation levels

Extragalactic point sources



Galactic fluctuations at high latitudes



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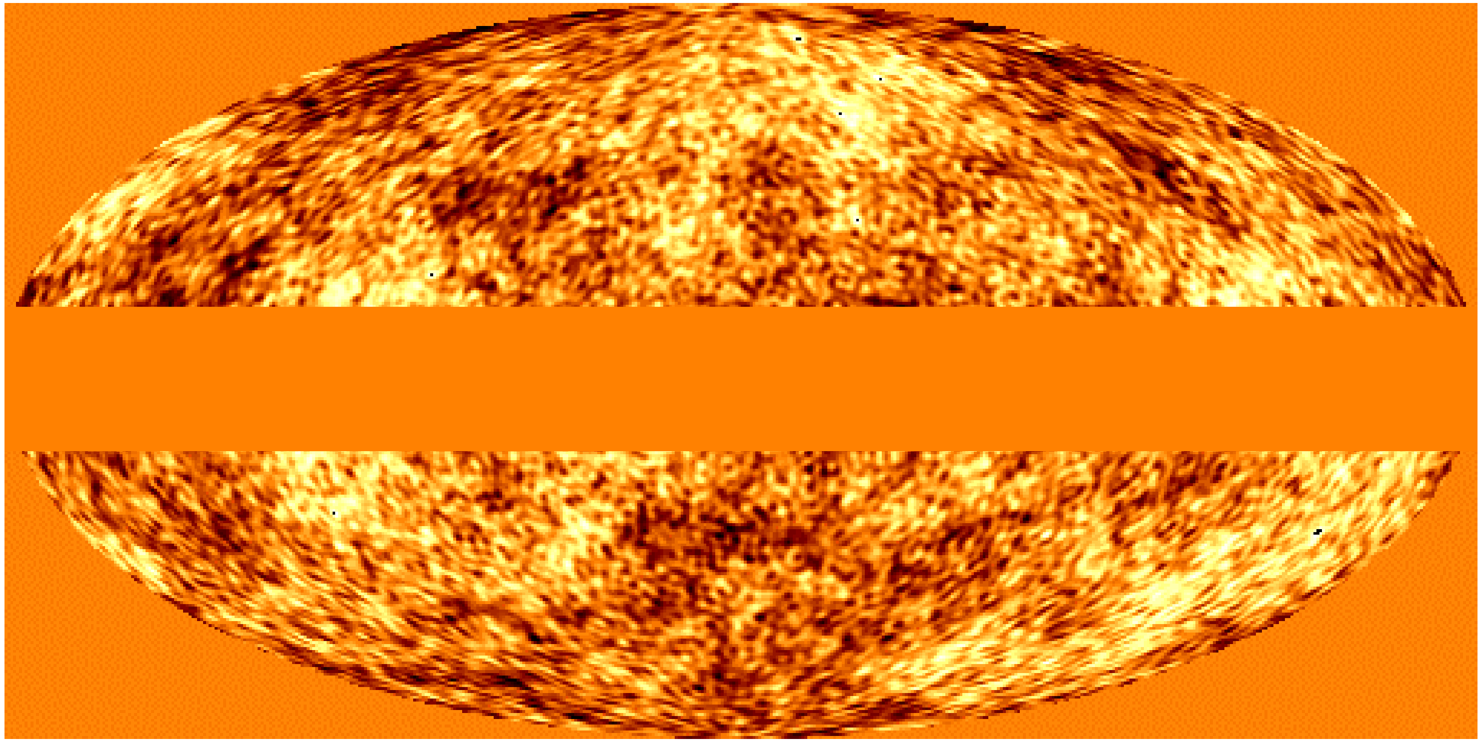
The CMB as seen by Planck



Simulated CDM W=1 model,DQ=10', DT/T=2x10^{-6}

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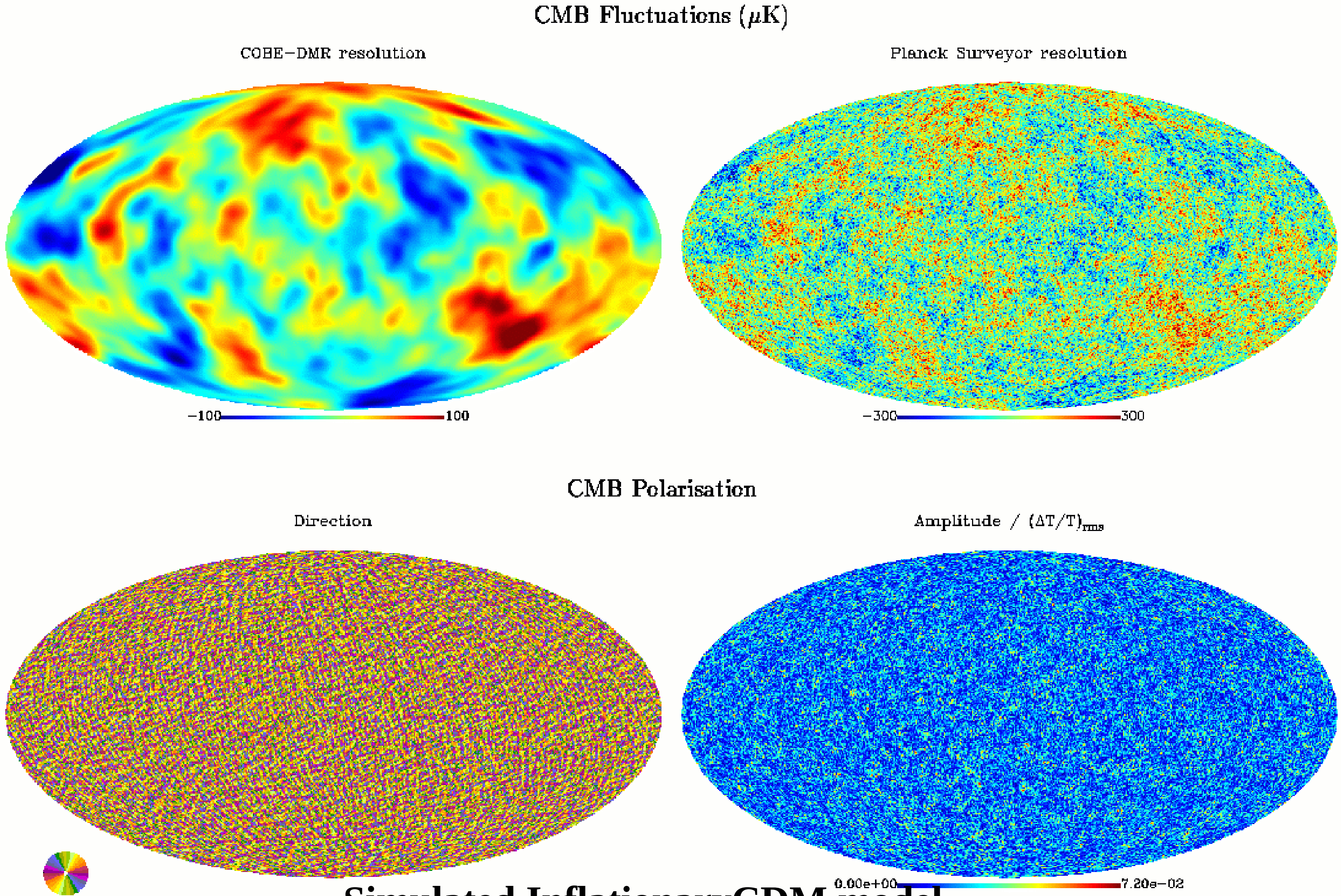
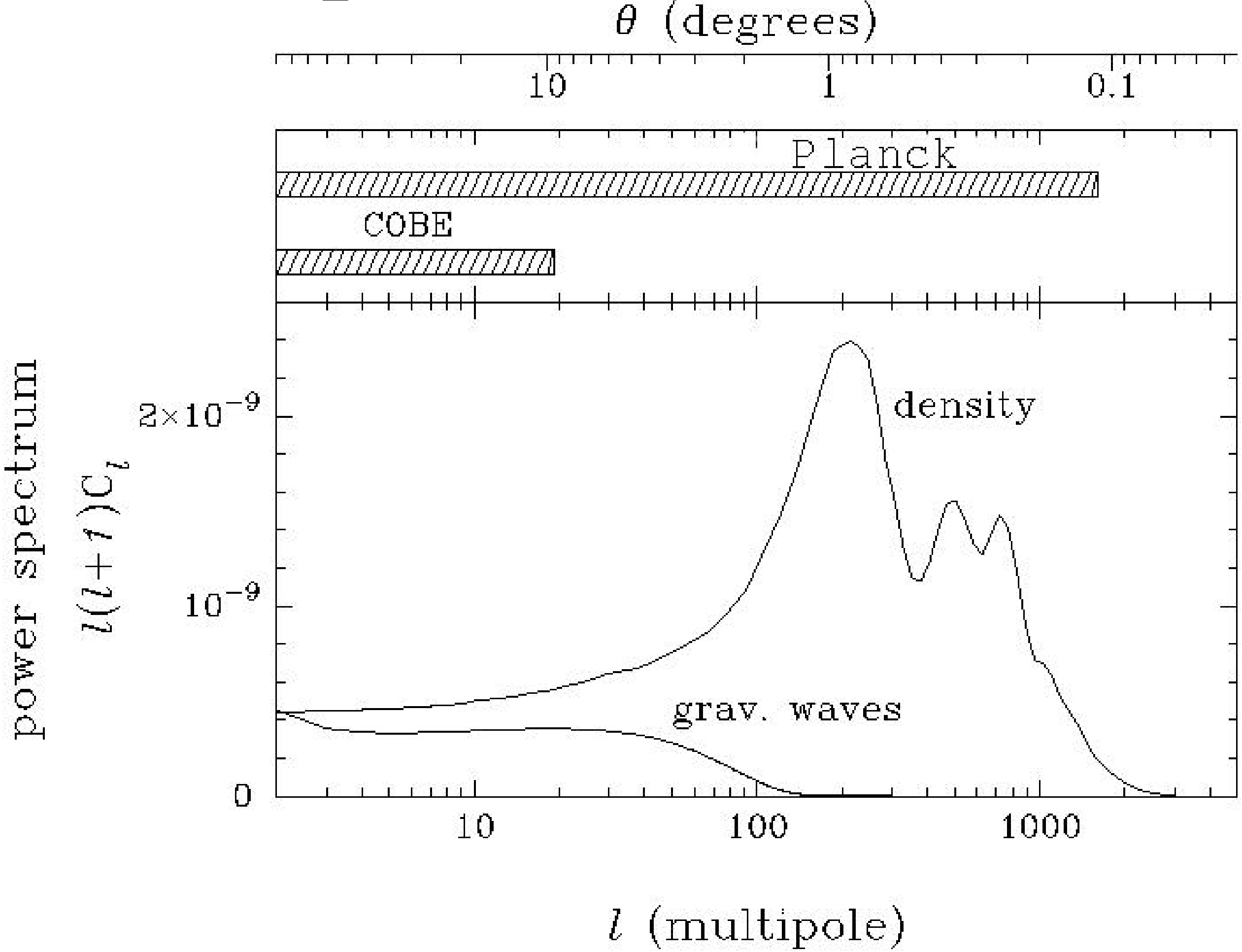
The CMB as seen by Planck



Simulated InflationaryCDM model

Theoretical angular power spectrum of the CMB



$$\frac{\Delta T}{T} = \sum_{l,m} a_l^m Y_l^m(\theta, \varphi)$$

$$C_l = \langle |a_l^m|^2 \rangle$$

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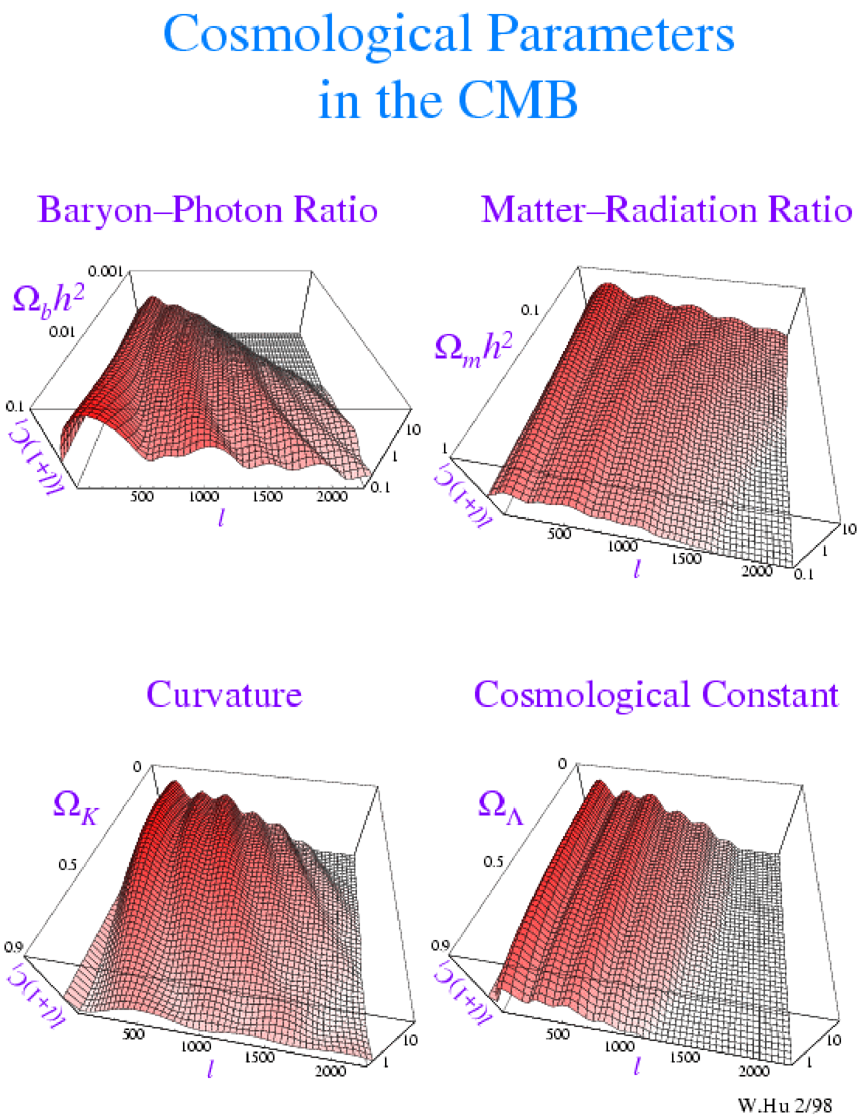
Main Cosmological Parameters

- Ω_o Cosmological total density parameter
- H_o Hubble constant
- Ω_b Baryon density
- Ω_c Cold dark matter density
- Λ Cosmological constant
- n_s Spectral index of scalar perturbations
- Q Amplitude of fluctuation spectrum
- r Ratio of Gravitational wave to density perturbations
- τ_r Residual optical depth due to reionisation

The shape of the power spectrum depends sensitively on the value of cosmological parameters



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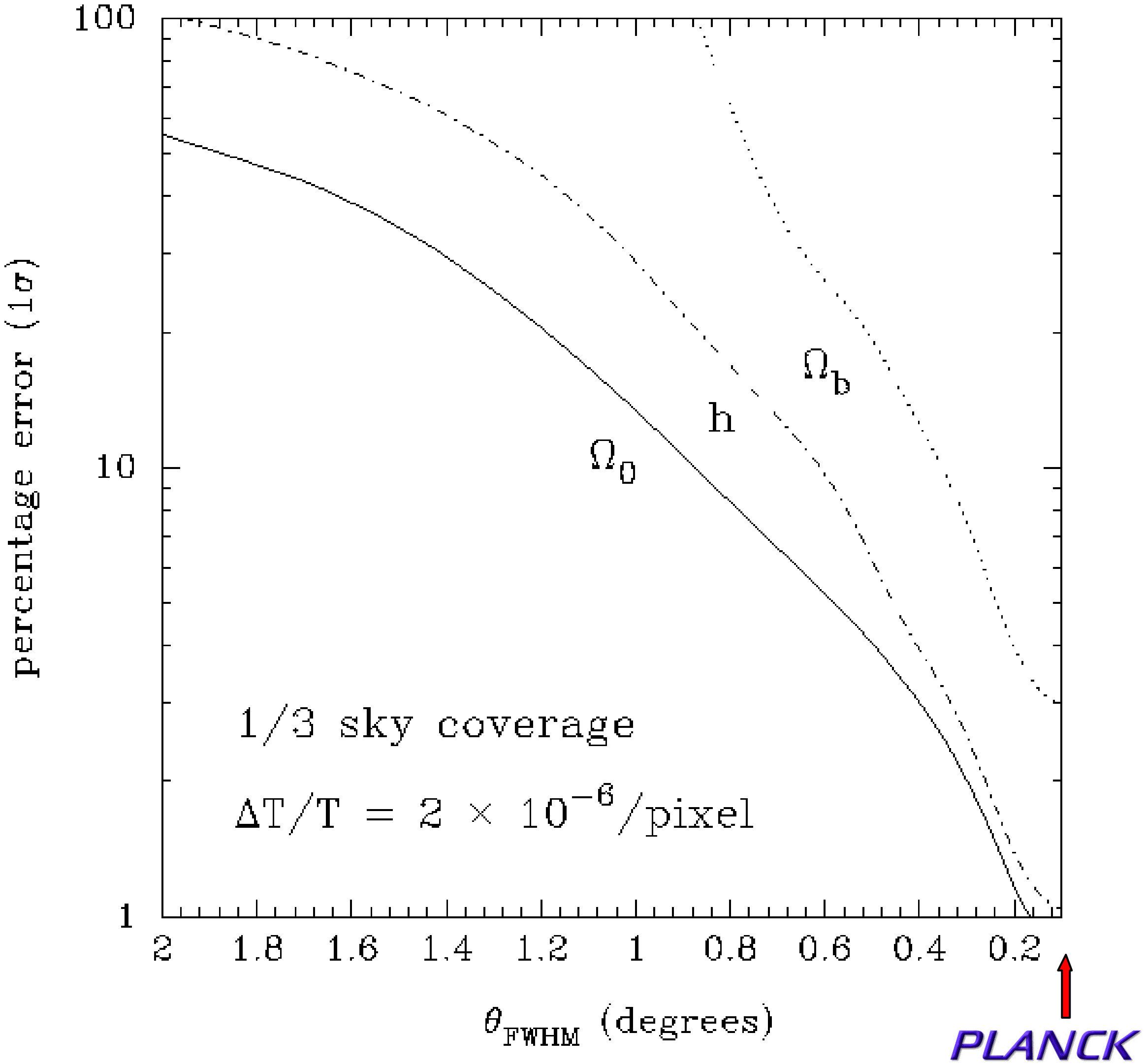
Science with accurate cosmological parameters

- Geometry of Universe
- Age of Universe, H_o, Ω_o, Λ, & stellar evolution
- Primordial nucleosynthesis:
  - abundance determinations
  - chemical evolution of galaxies
- physics beyond standard model
- Evolution of structure and nature of dark matter
- Dynamical estimates of Ω_o
- Galaxy redshift surveys

Accuracy of recovery of fundamental parameters



Maximum likelihood estimates in an eight dimensional parameter space (Ω_0, h, Ω_b, n_s, Q_{rms}, n_s/n_t, Λ, τ_{reion})

Efstathiou 1997

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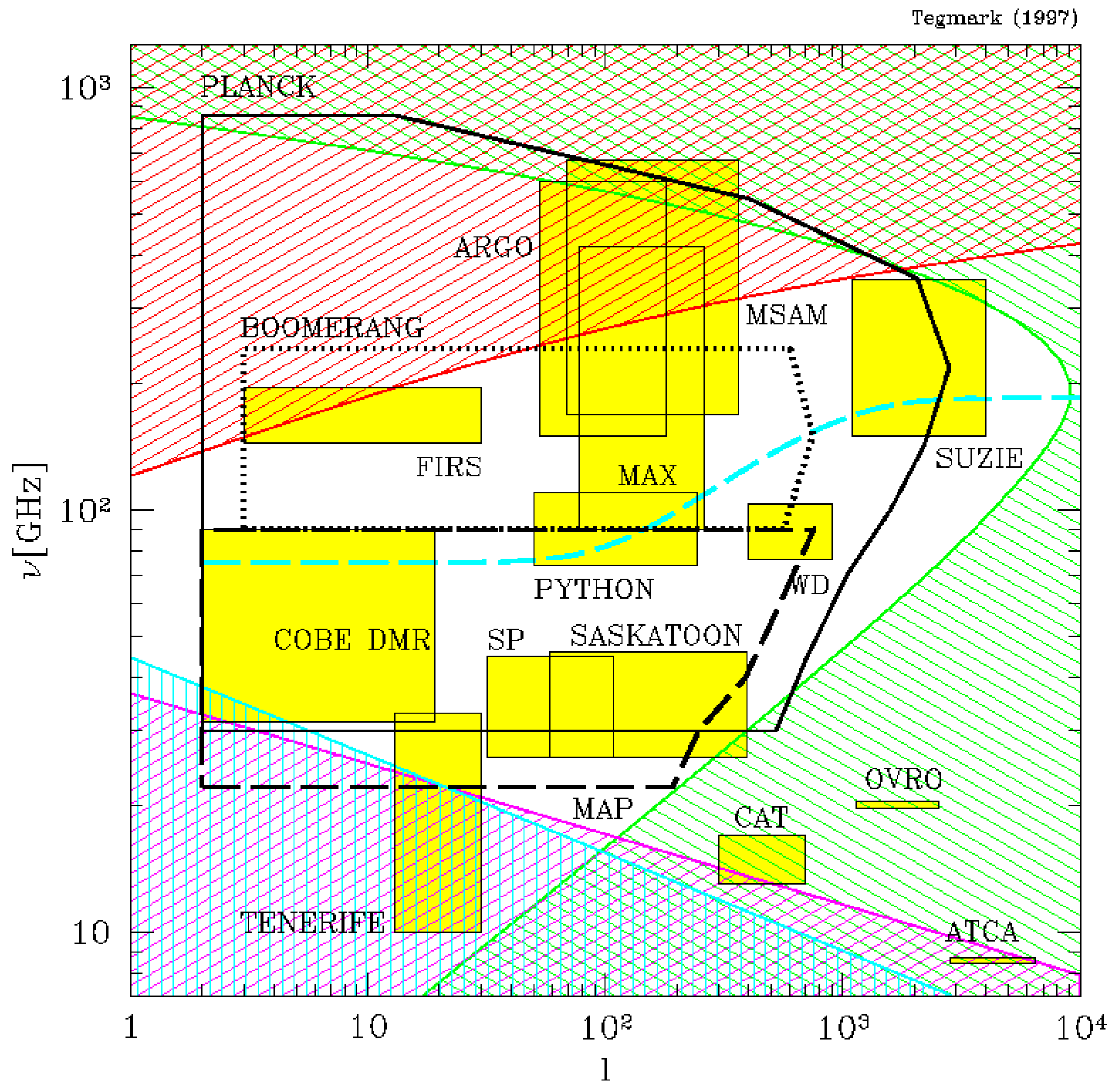
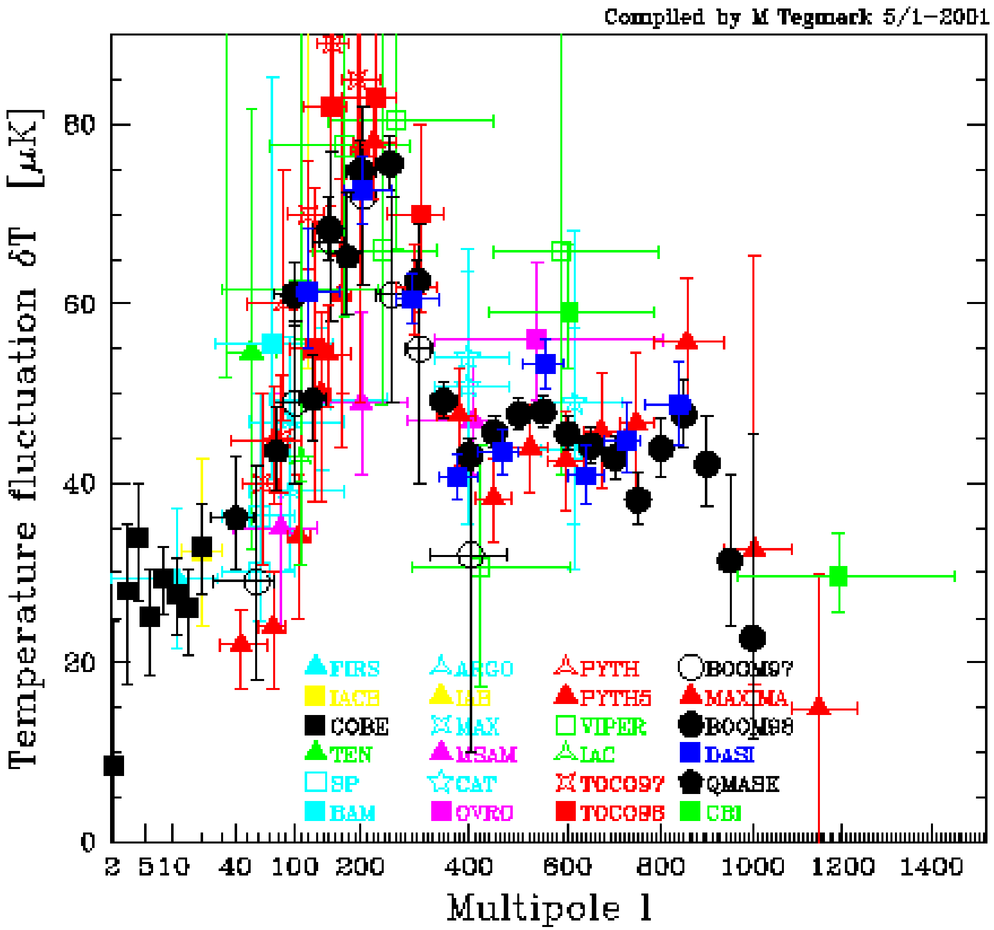
CMB anisotropy experiments

- Ground-based: single-dish, interferometers
- Balloon-based: BOOMERANG, MAXIMA, TOPHAT, ...
- Space-based: COBE, MAP, Planck

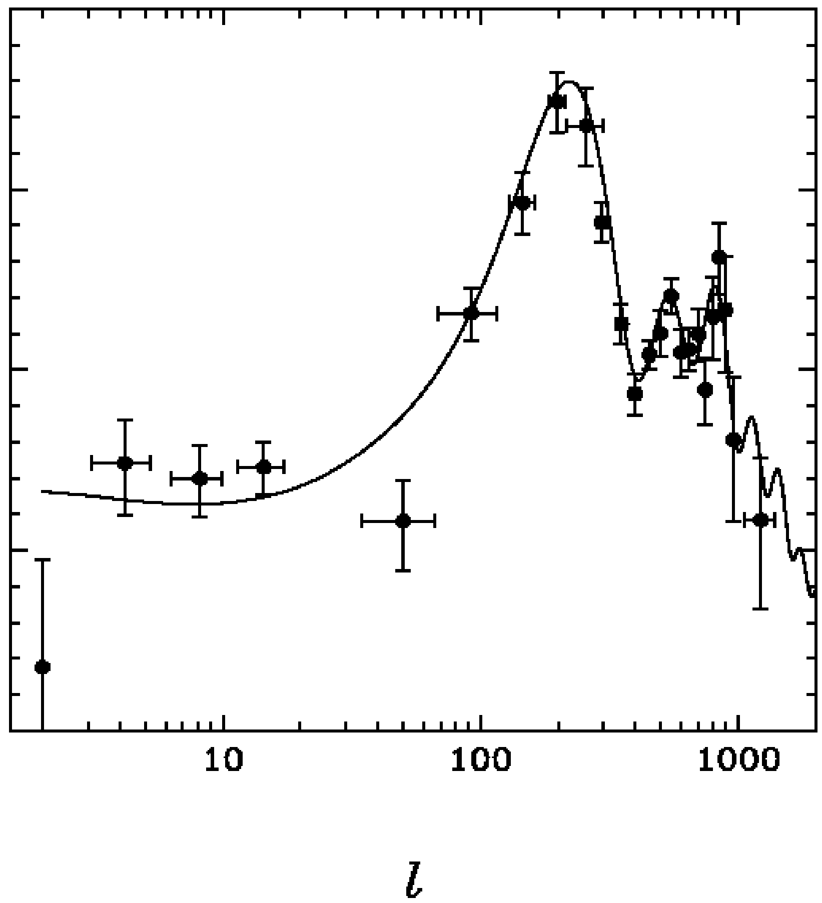
Experiments and foregrounds



Observational status



Wang, Tegmark, and Zaldarriaga 2001



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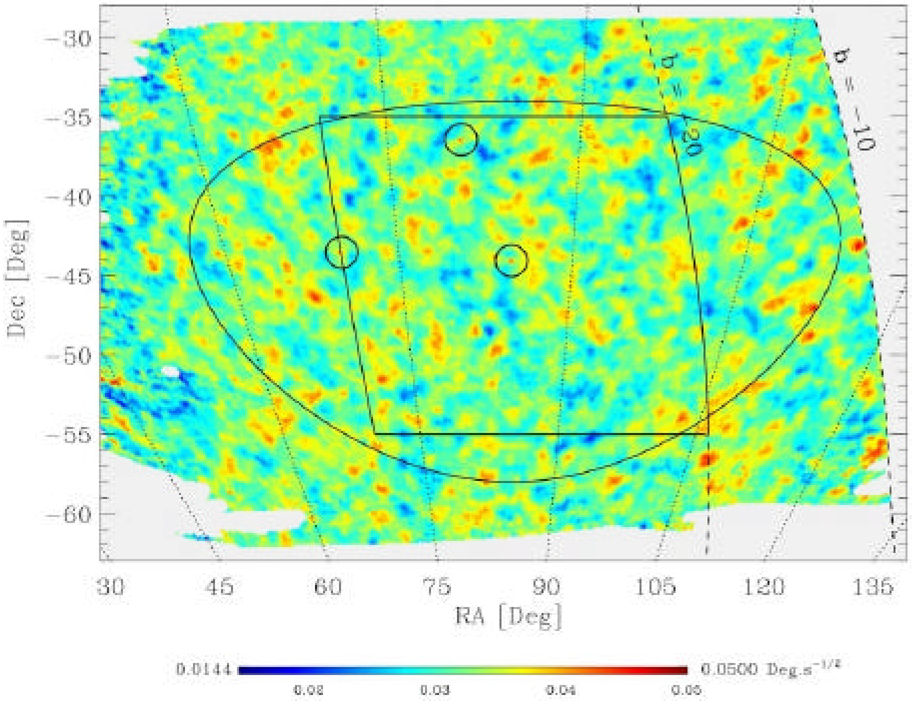
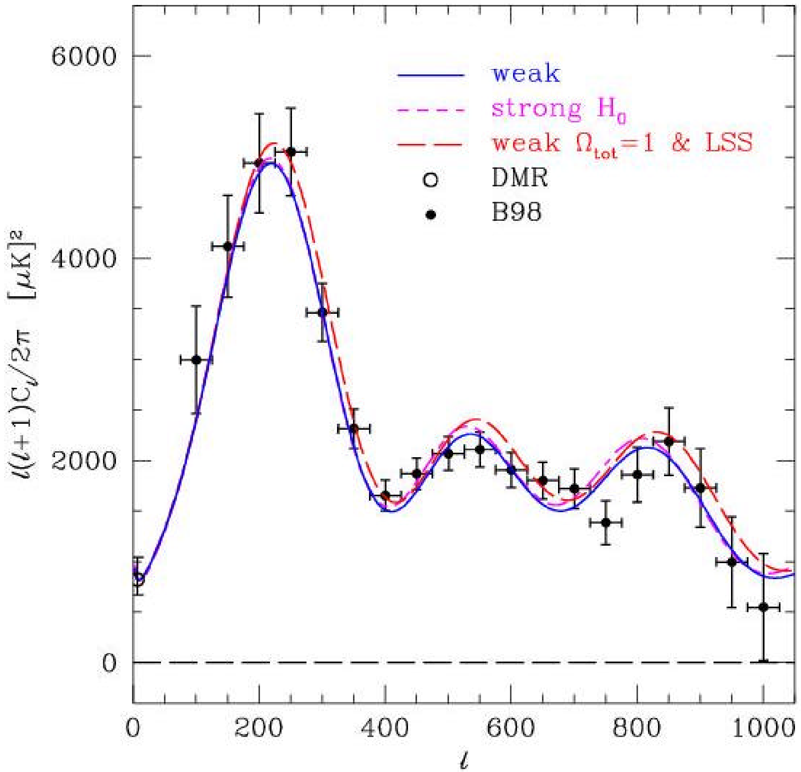
Observational status





BOOMERANG: Netterfield et al 2001

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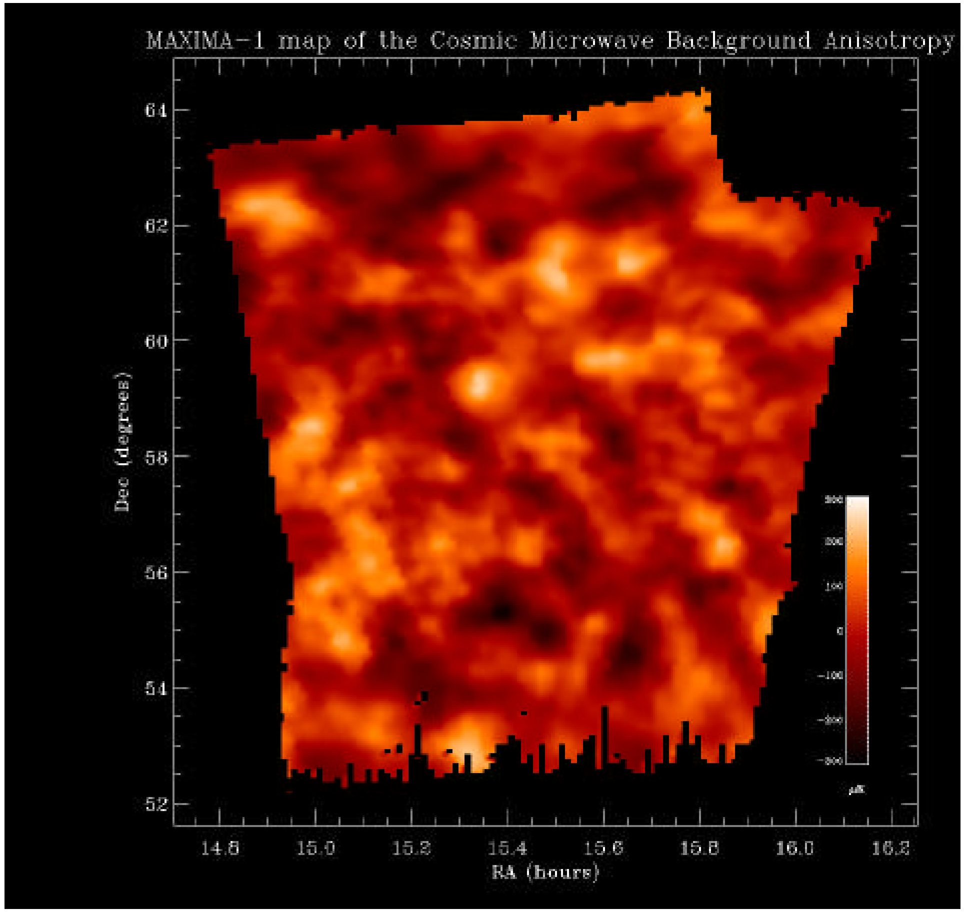
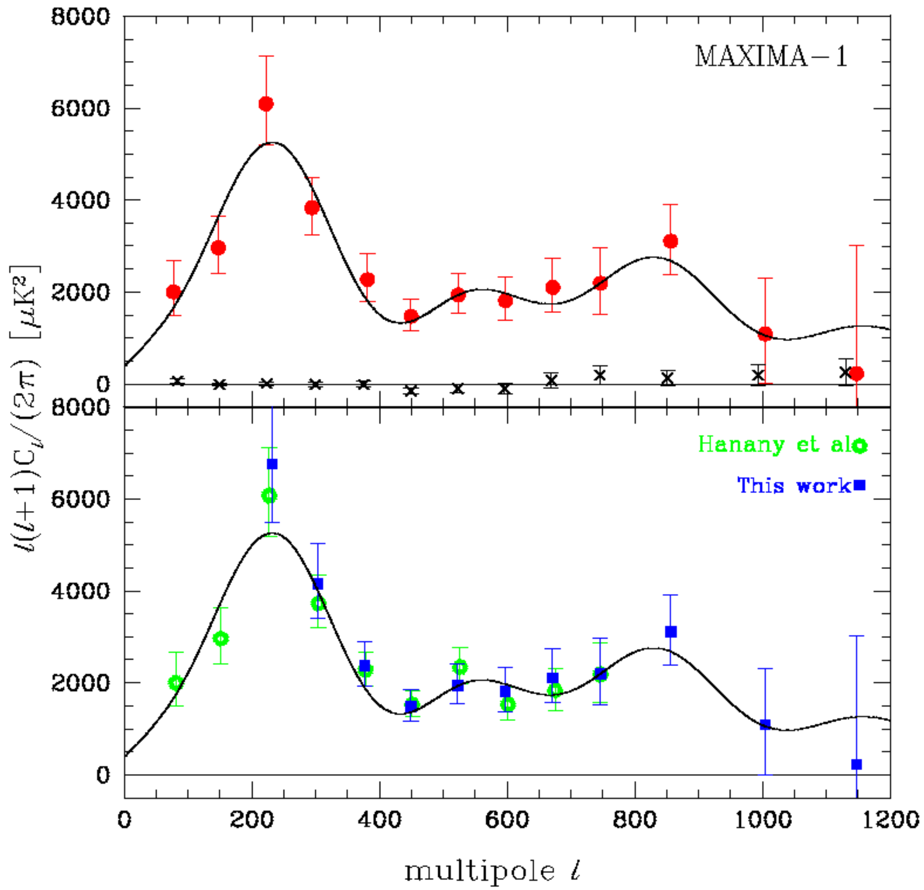
Observational status





MAXIMA: Lee et al 2001

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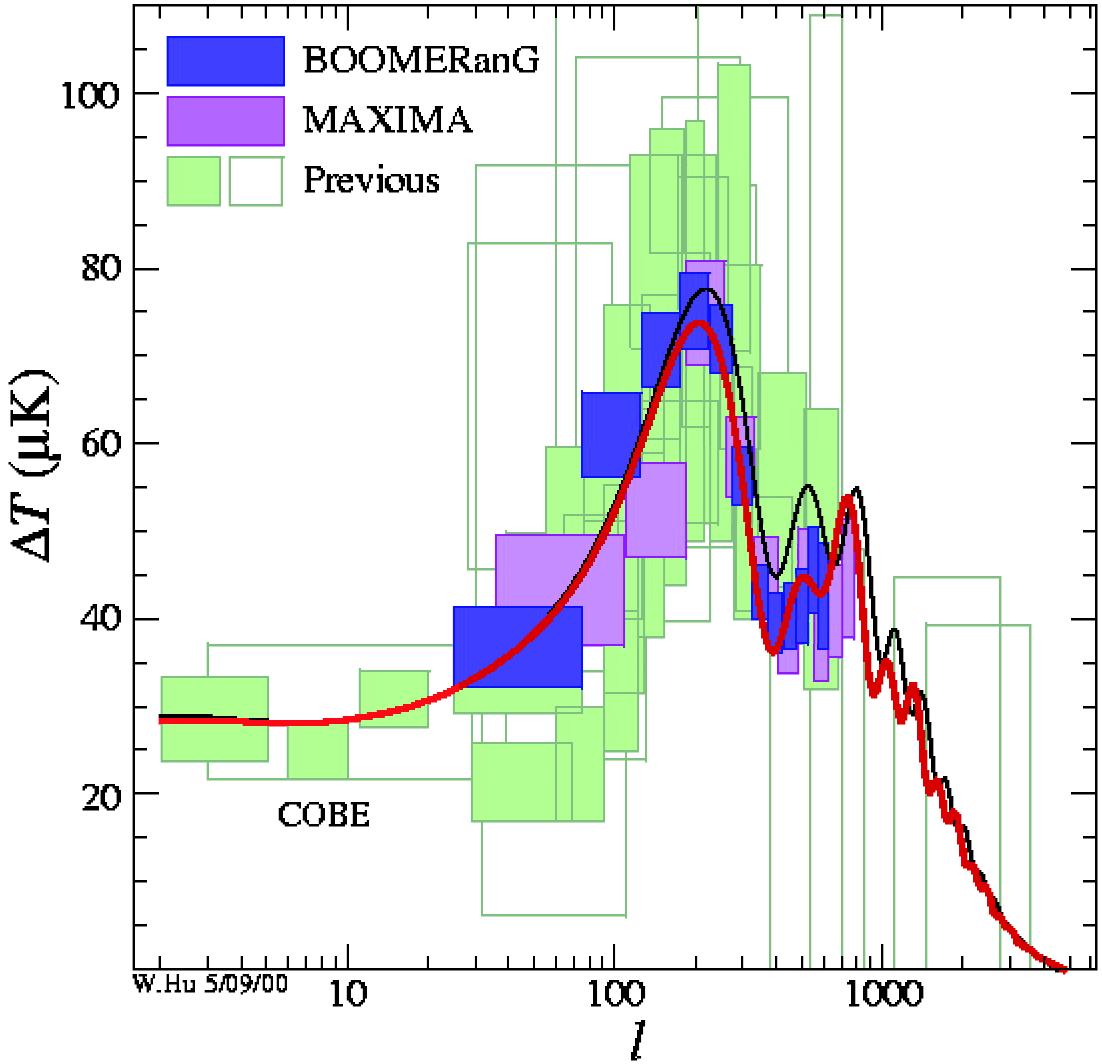
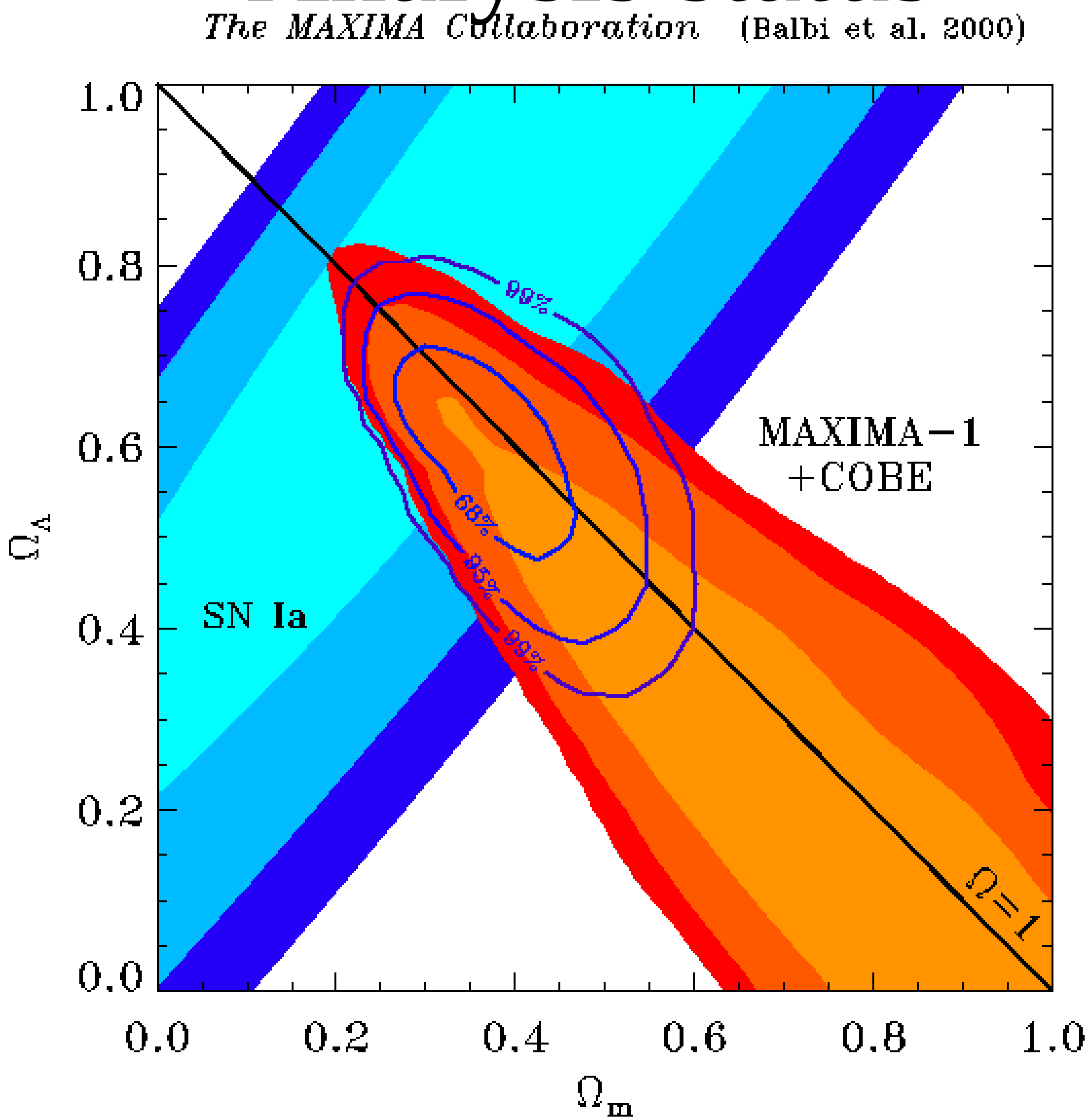
Observational status



From: W. Hu 2001

Analysis status



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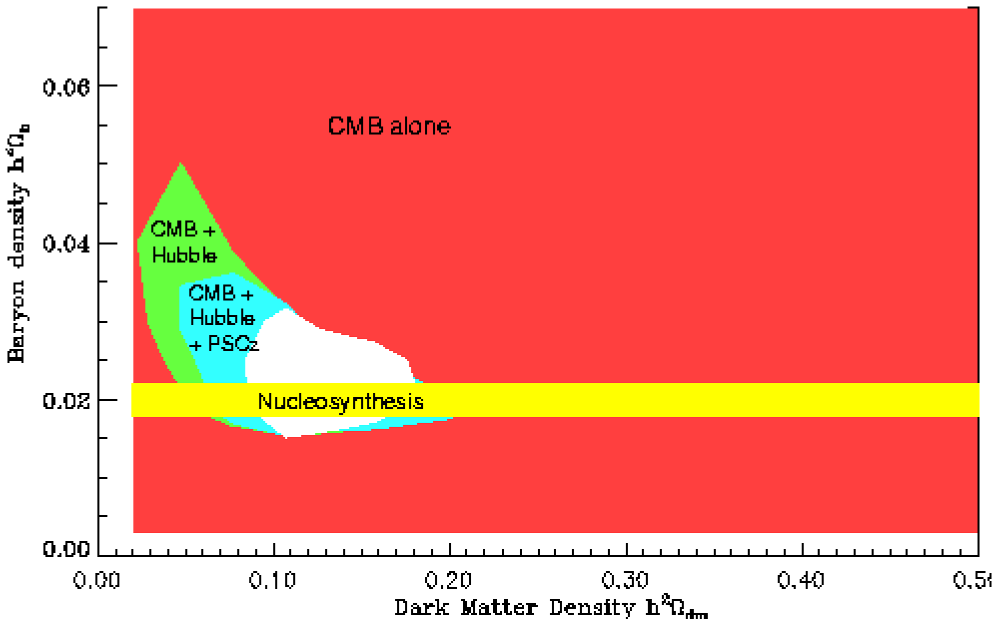
Analysis status



Wang, Tegmark and Zaldarriaga 2001

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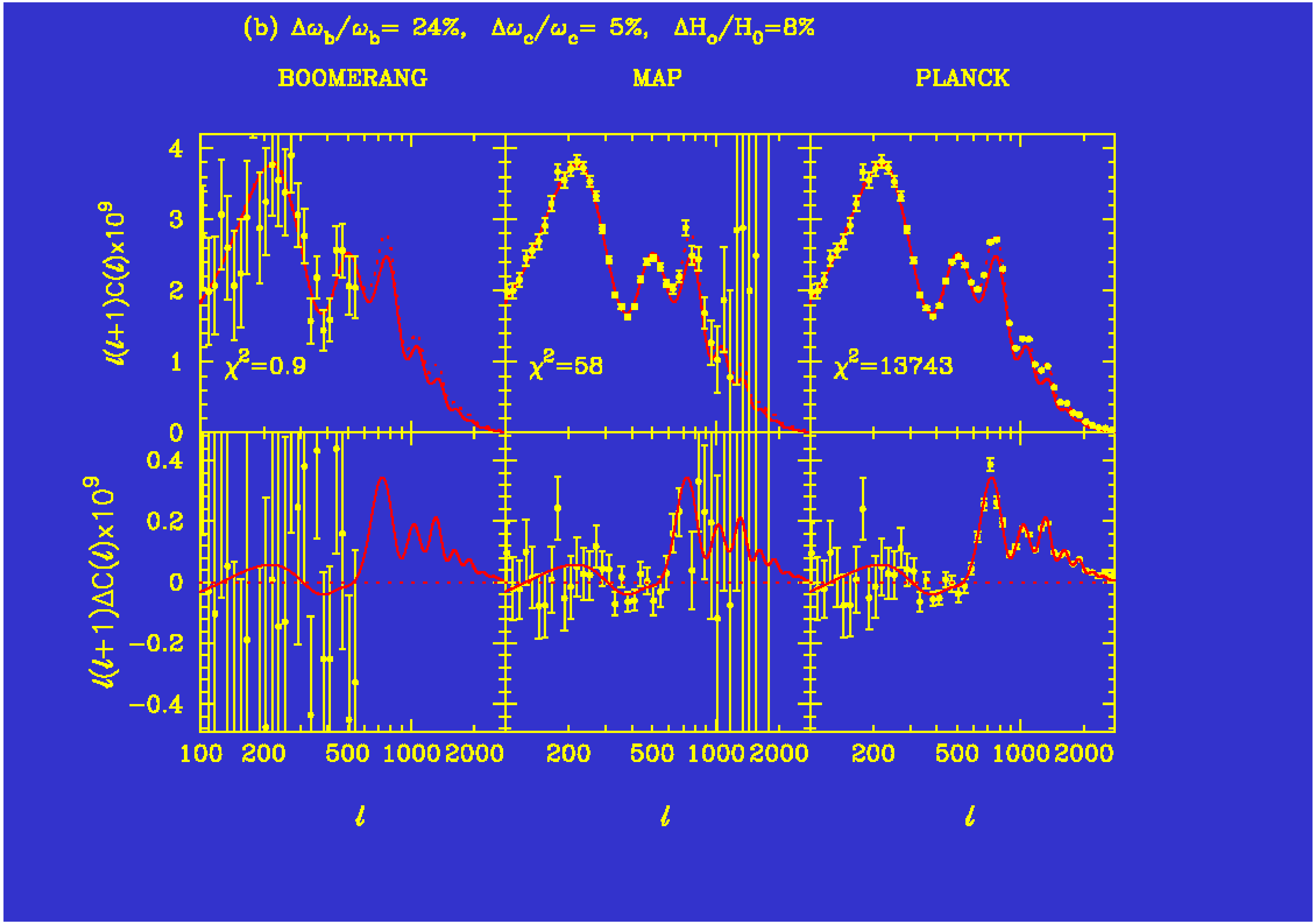
The need for accuracy

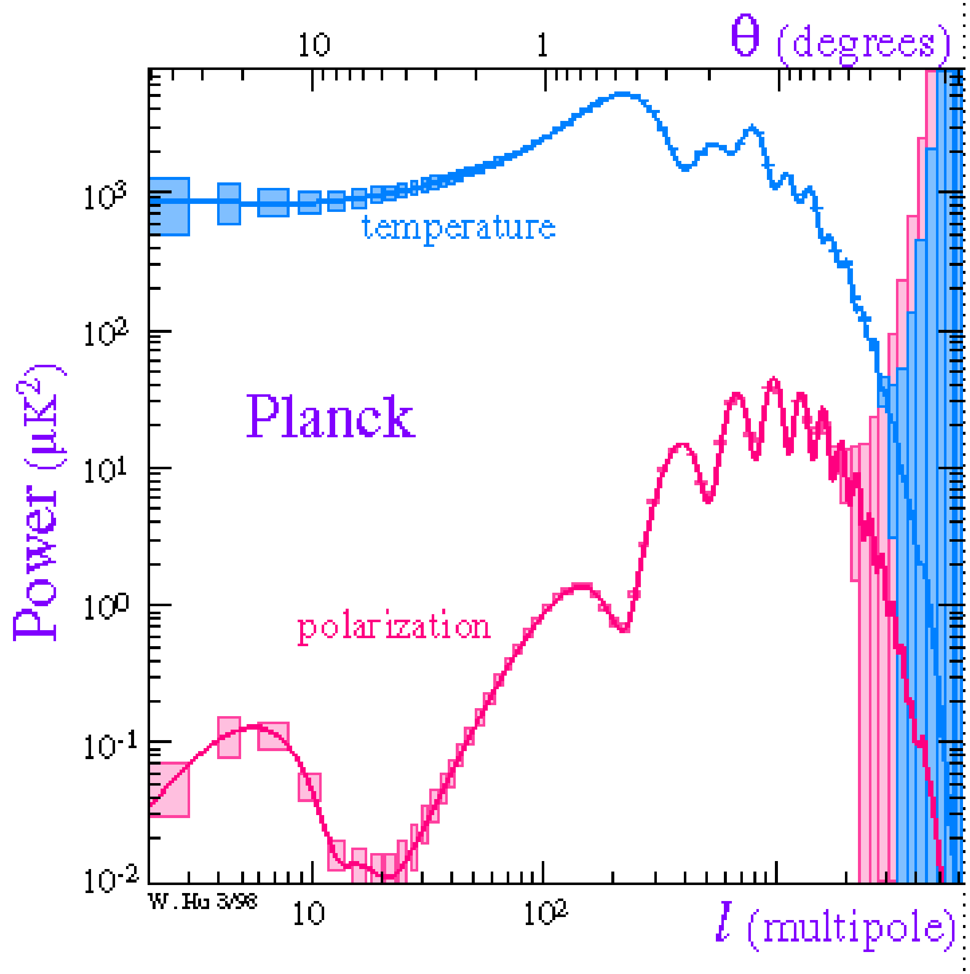
Efstathiou et al 2001



Main Observational Objective of PLANCK

To image the whole sky at wavelengths near the peak of the spectrum of the Cosmic Microwave Background Radiation Field (CMB), with an instrument sensitivity $\Delta T/T \sim 10^{-6}$, an angular resolution ~5 arcminutes, wide frequency coverage, and excellent rejection of systematics .

Predicted power spectrum recovery



Both the temperature and the polarisation angular power spectra are accurately recovered

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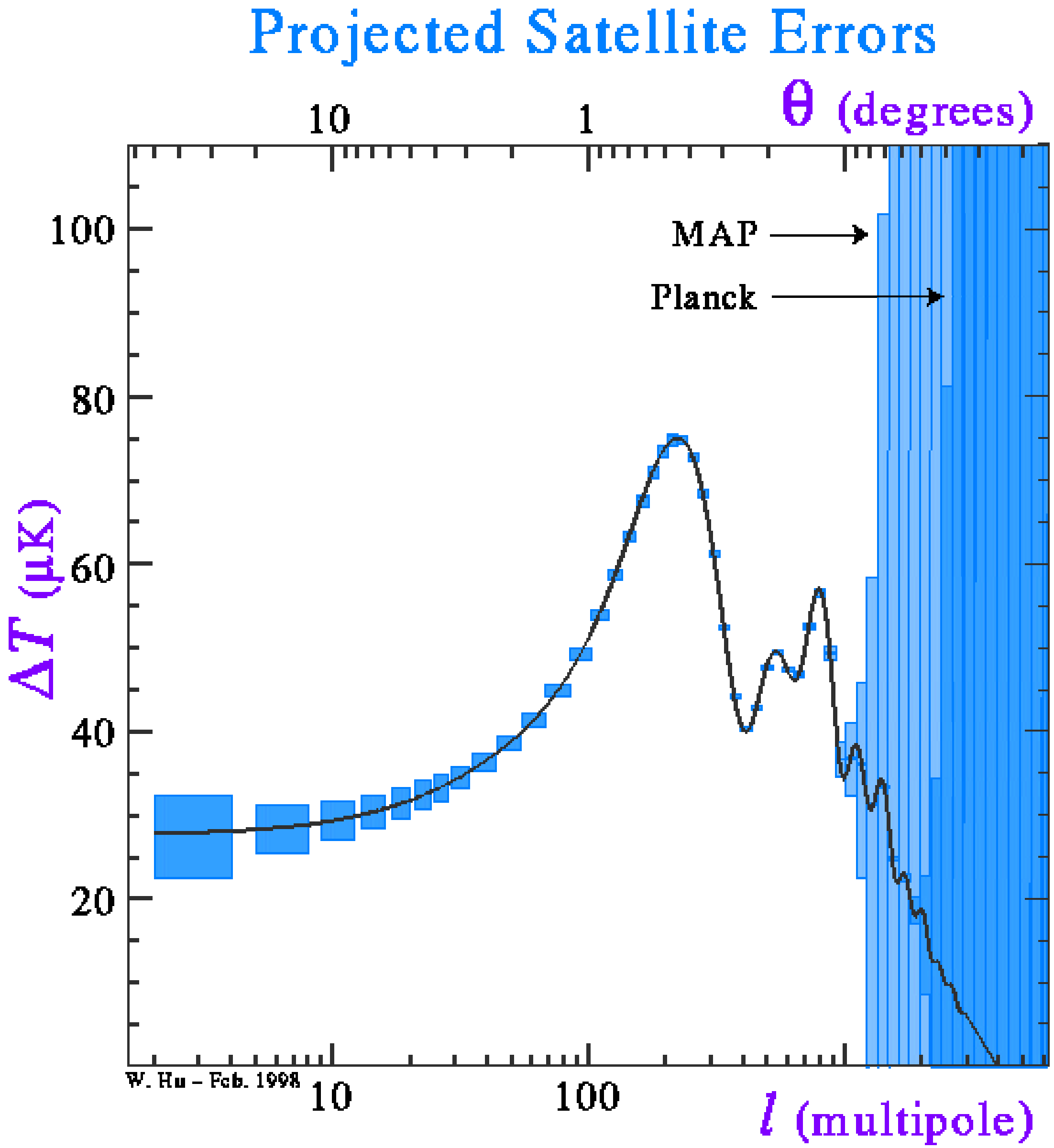
Predicted power spectrum recovery



From: Hu 2001

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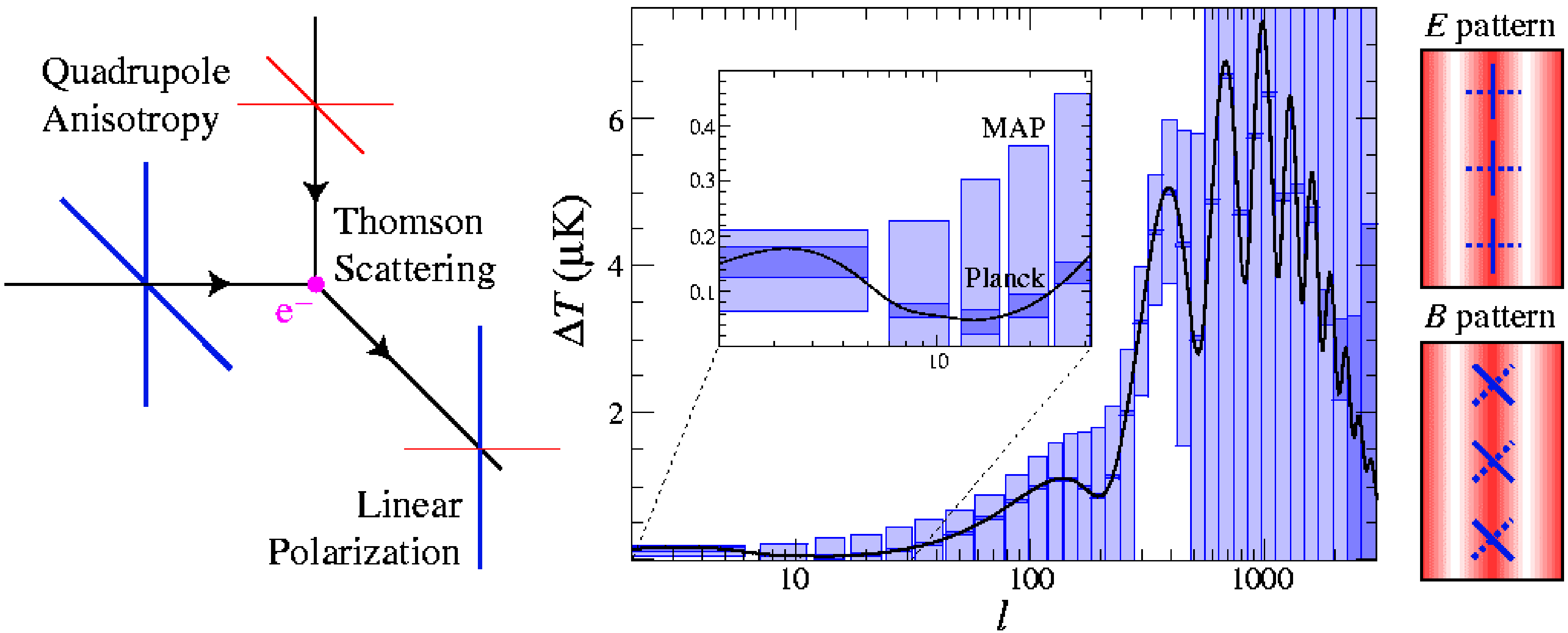
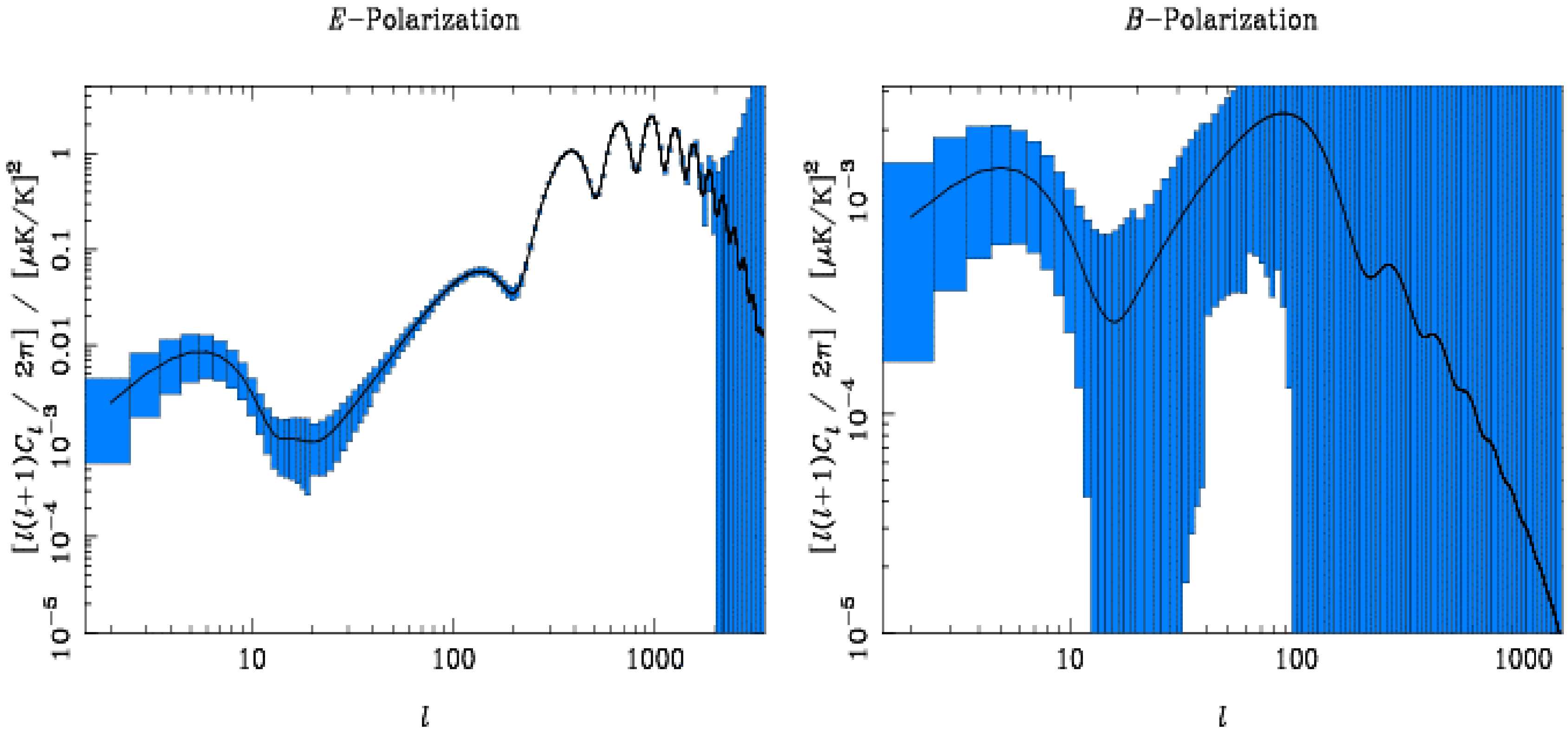
Polarisation power spectrum recovery



From: Hu 2001

Polarisation power spectrum recovery



From: Challinor 2001

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Recovery of cosmological parameters

Marginalised errors for LCDM

Parameter	Temp. only	Temp. & Pol.
h	1.1	0.13
Ω_m	1.2	0.14
Ω_Λ	0.96	0.11
$\ln(\Omega_B h^2)$	0.035	0.01
n_S	0.041	0.0008
T/S	0.35	0.012
τ	0.59	0.004

Target model: LCDM with $h=0.65$, $\Omega_m=0.35$, $\Omega_\Lambda=0.65$, $\Omega_B=0.05$, $n_S=1$, $T/S=0$, $\tau=0.05$;

Eisenstein, Hu & Tegmark 1998

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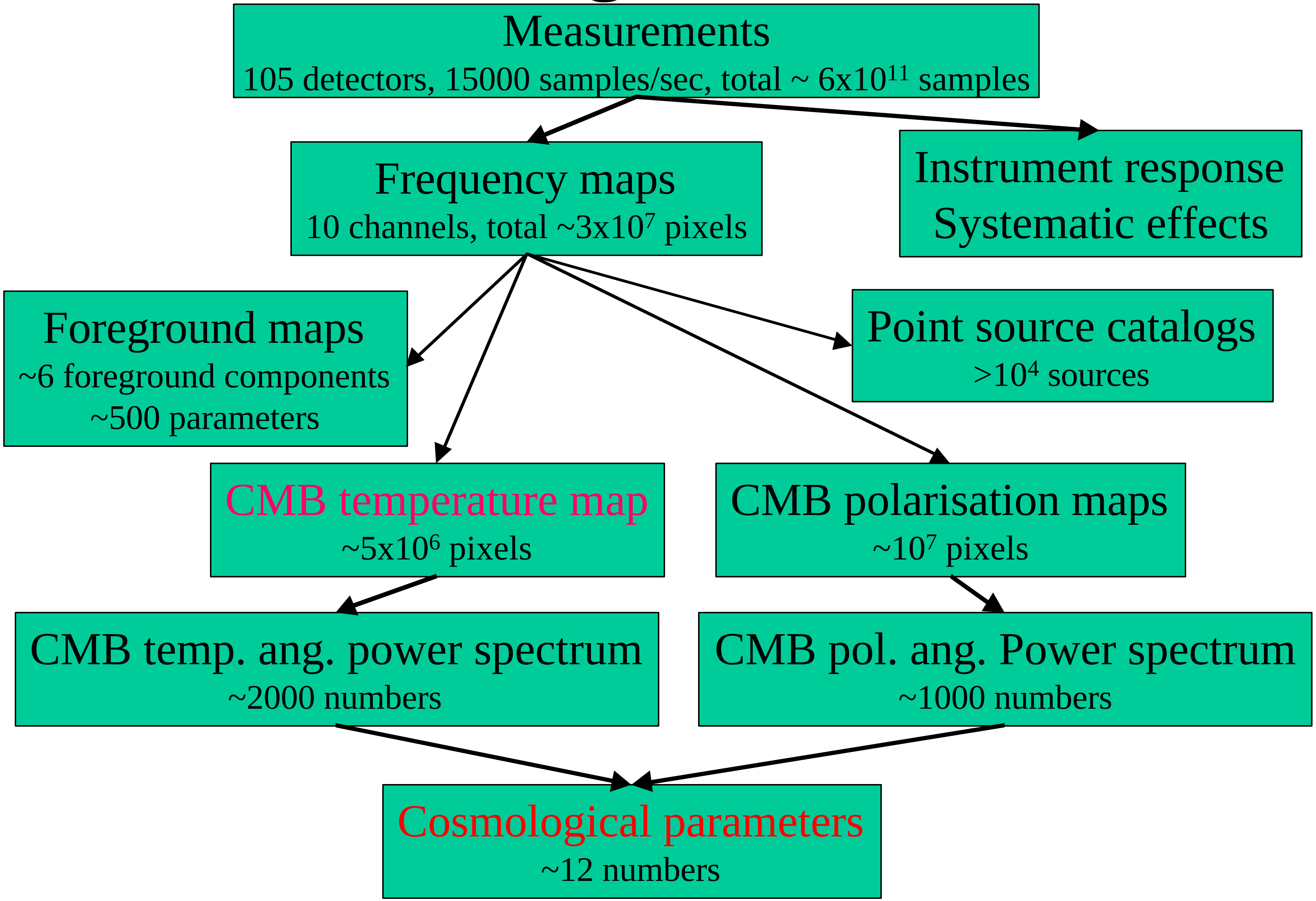
Recovery of cosmological parameters

Efstathiou and Bond 1999

	MAP			**Planck**		
Param.	No const.	$r = -7n_t$	$r = 0$	No const.	$r = -7n_t$	$r = 0$
$_b/ \quad _b$	0.052	0.028	0.030	0.0064	0.0056	0.0056
$_c/ \quad _c$	0.097	0.028	0.031	0.0042	0.0042	0.0039
Q	0.0066	0.047	0.005	0.0013	0.0010	0.0011
r	0.49	0.043	---	0.33	0.023	---
n_s	0.03	0.0061	0.0098	0.0049	0.0032	0.0042
n_t	0.56	0.0061	---	0.40	0.0032	---
h/h	0.082	0.02	0.028	0.0045	0.0045	0.0041
	0.16	0.049	0.068	0.012	0.012	0.011

Extracting the science



Key Scientific Objectives (1)

- CMB anisotropy maps to an accuracy $\Delta T/T \sim 10^{-6}$, on angular scales larger than 10 arcminutes
- Cosmological parameters, H_o, Ω_o, Ω_b, ... to a precision of a few percent
- Tests of inflationary models of the early Universe
- Search for non-gaussianity/topological defects
- Initial conditions for formation of large-scale structure
- Nature of dark matter

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Key Scientific Objectives (2)

- A wide spectrum of non-CMB science:
  - Detection of Sunyaev-Zeldovich effect in thousands of rich clusters of galaxies
  - Extragalactic sources and backgrounds
  - Maps of Galaxy at frequencies 30 - 1000 GHz

Non-CMB Science highlights (1)

- Sunyaev-Zeldovich effect
  - Measurement of y in > 10^4 clusters
  - Cosmological evolution of clusters to z > 1
  - H_o and X-ray measurements, gas properties
  - Bulk velocities on scales > 300 Mpc
- Extragalactic sources
  - IR and radio galaxies
  - AGN's, QSO's, blazars
  - Evolution of galaxy counts to z > 1
  - Far-IR background fluctuations

Non-CMB Science highlights (2)

- Galactic studies
  - Dust properties
  - Cloud and cirrus morphology
  - Star forming regions
  - Cold molecular clouds
  - Maps of free-free and synchrotron emission
  - Cosmic ray distribution
  - Galactic magnetic field

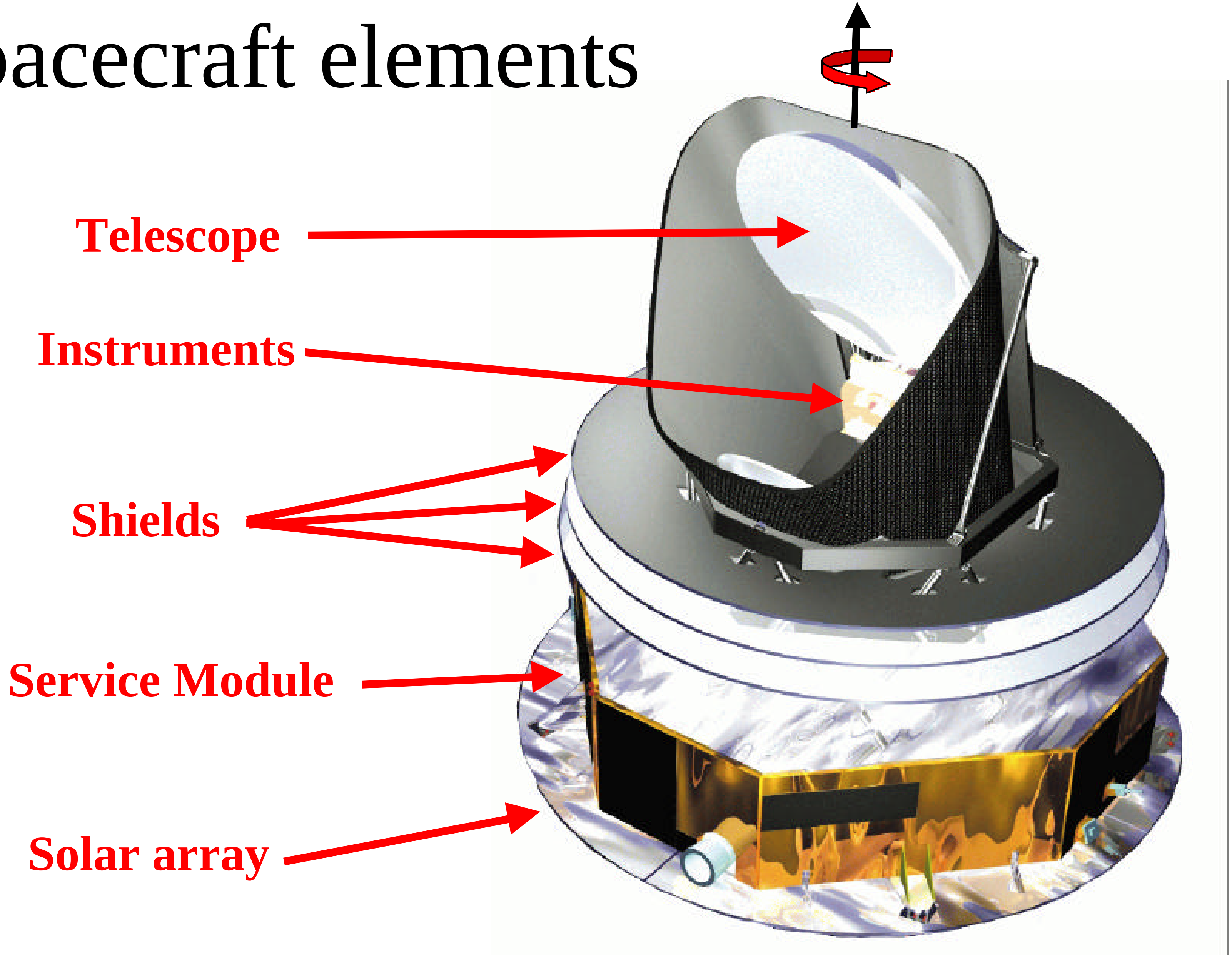
Payload and Spacecraft

Netscape Hypertext Document

Observational Strategy

- Two successive all-sky surveys
- 1.5 metre aperture telescope
- wide frequency coverage (25 GHz - 950 GHz)
- State-of-the-art detectors
- extreme attention to systematic effects

Spacecraft elements



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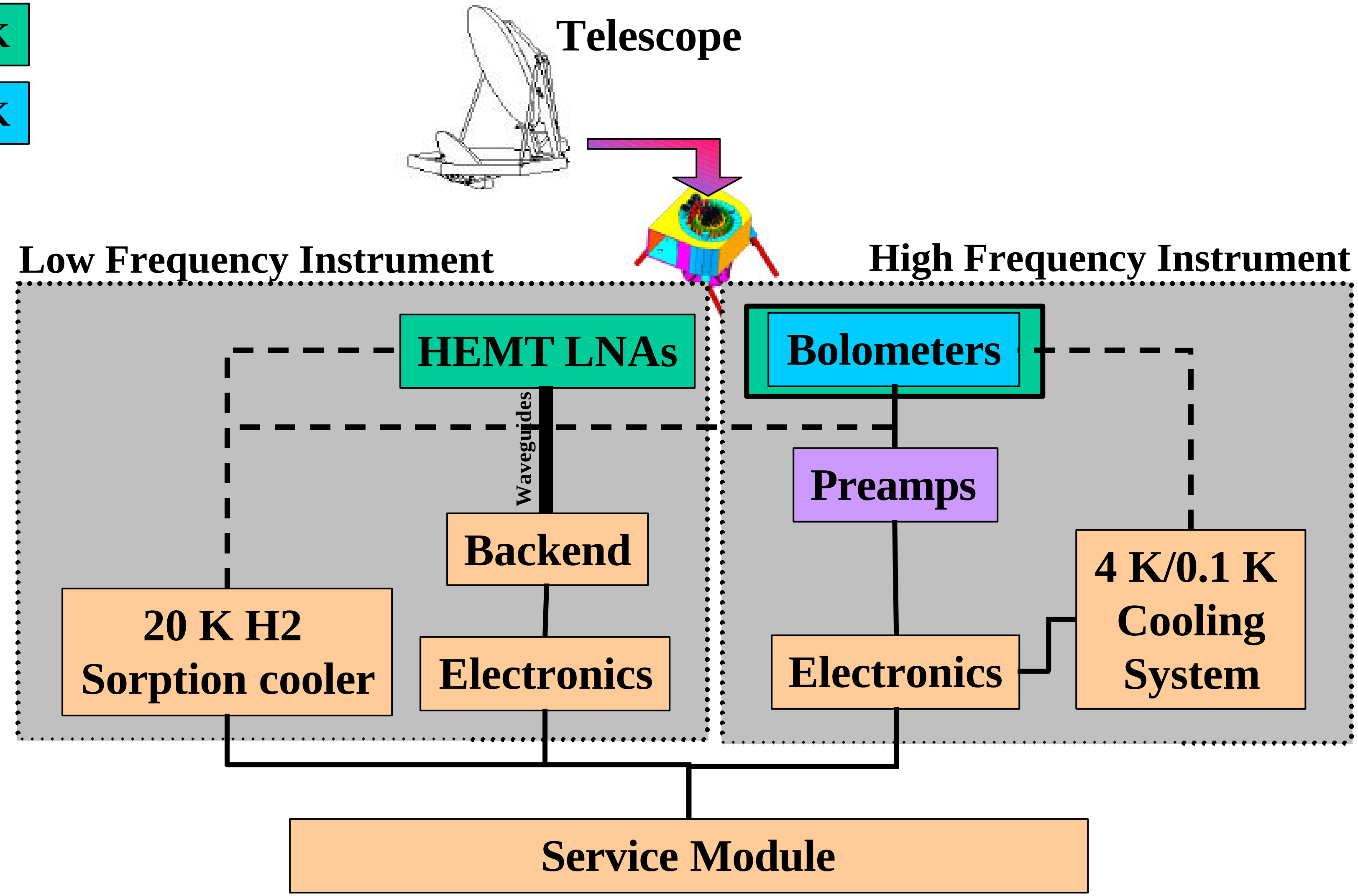
Instrument elements

300 K

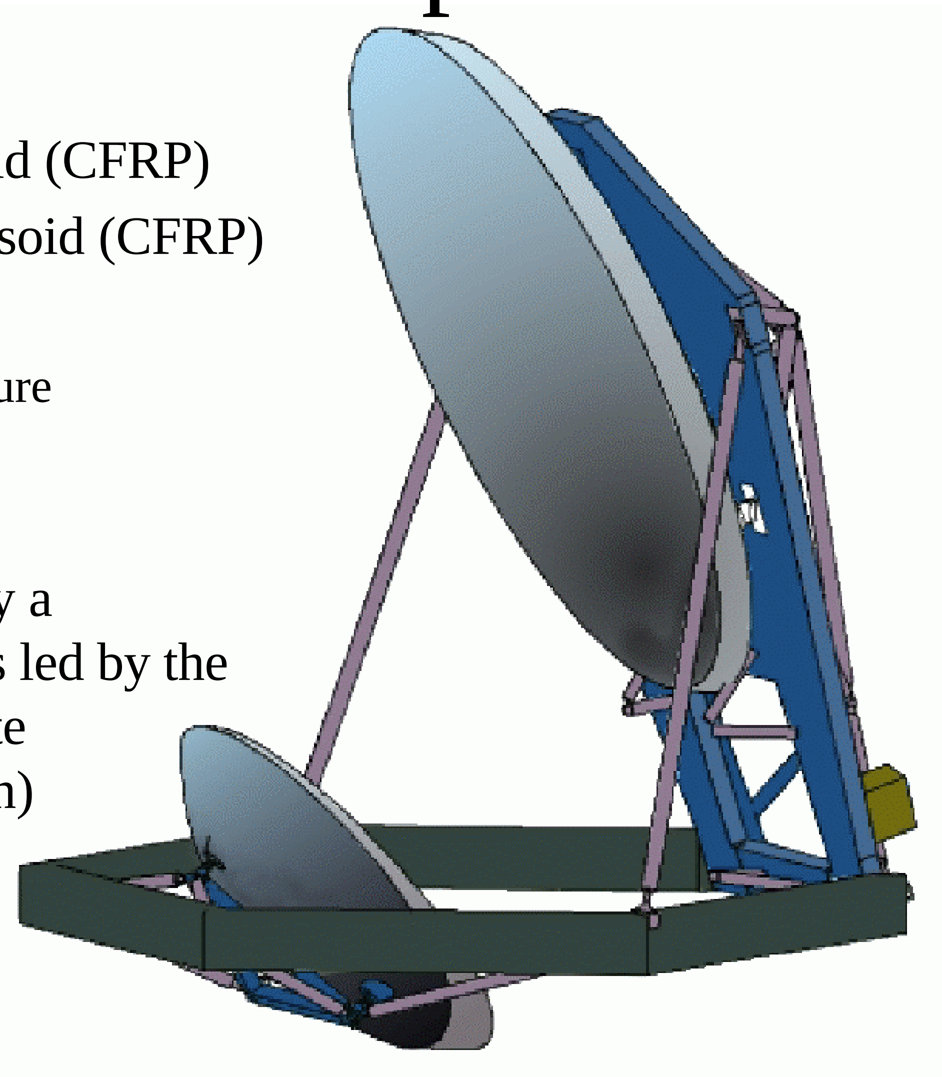
20 K

0.1 K



Planck Telescope

- Primary: 1.50 x 1.89 m ellipsoid (CFRP)
- Secondary: 1.02 x 1.04 m ellipsoid (CFRP)
- System:
  - 1.5 m circular projected aperture
  - Total MWFE<40 μm rms
  - Total ε <0.01
- Reflectors will be developed by a Consortium of danish institutes led by the Danish Space Research Institute (PI: Dr. H.U. Norgaard-Nielsen)



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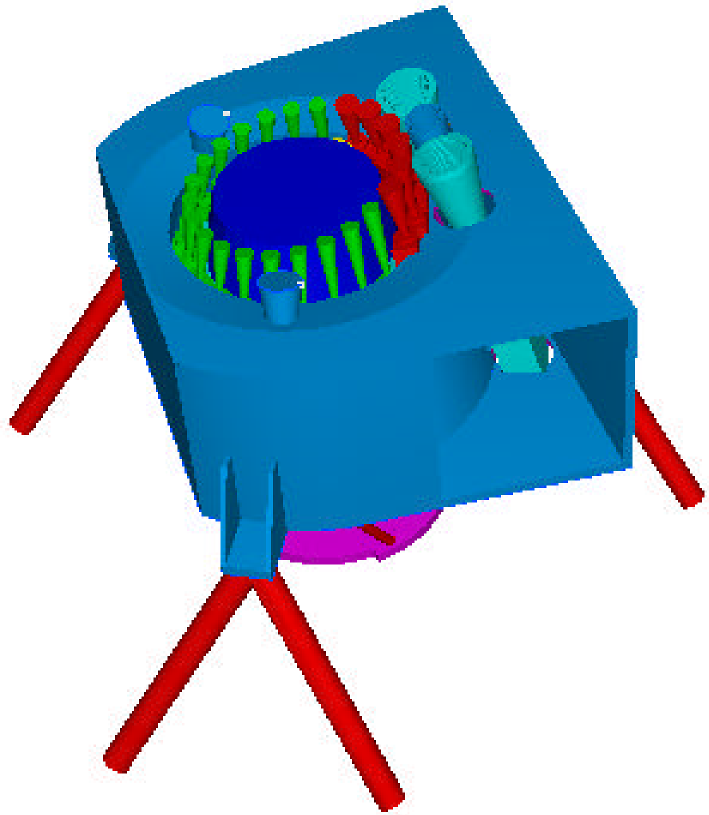
Low Frequency Instrument

- Freq.: 30 -100 GHz
- Techn.: HEMT correlation receivers (56)
- Temp.: 20 K (Front-end), 300 K (Back-end)
- Ang. res.: 10' (100 GHz) to 33' (30 GHz)
- Temp. sens. (@100 GHz): ~12 μK
- PI: N. Mandolesi (CNR - Bologna)



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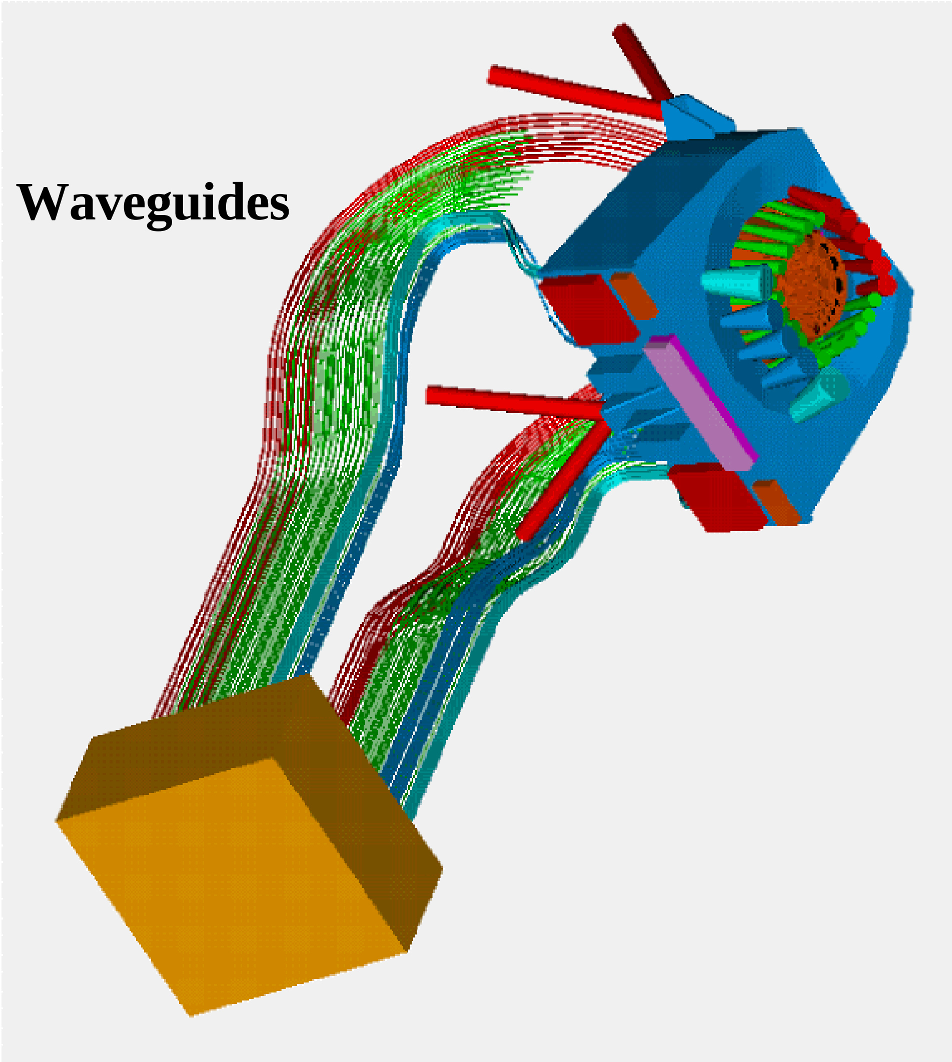
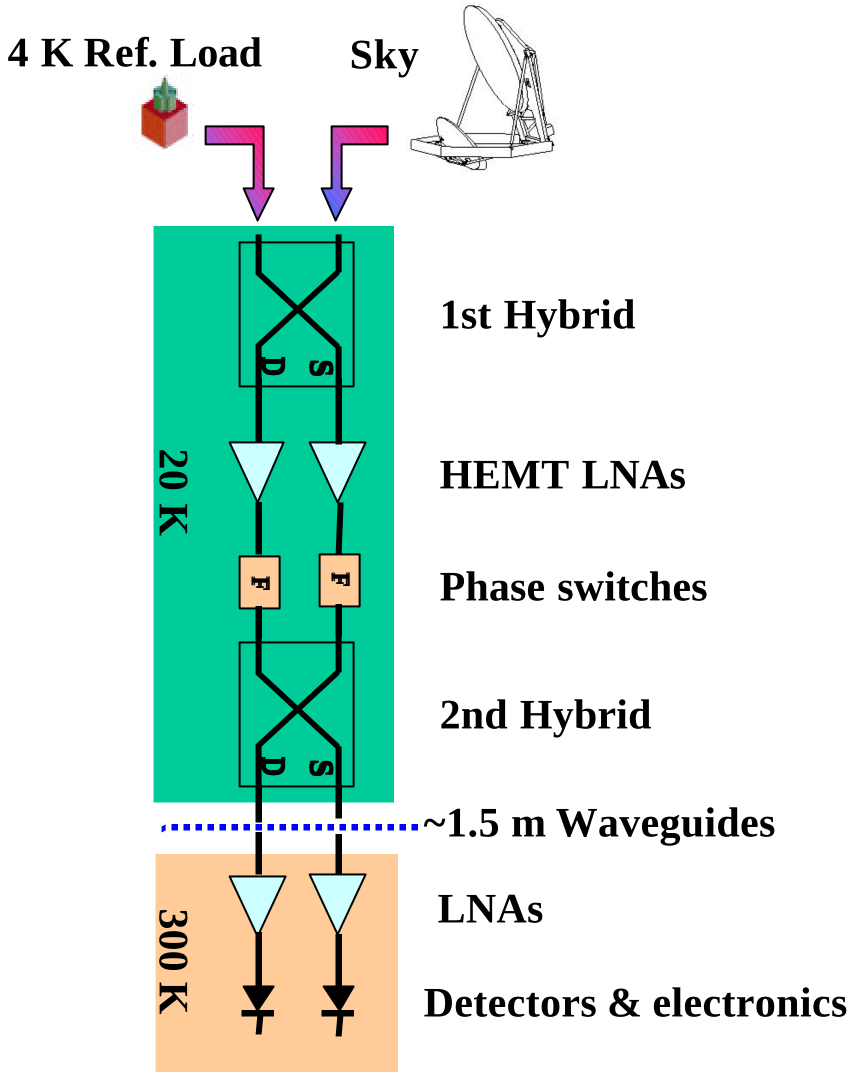
Low Frequency Instrument





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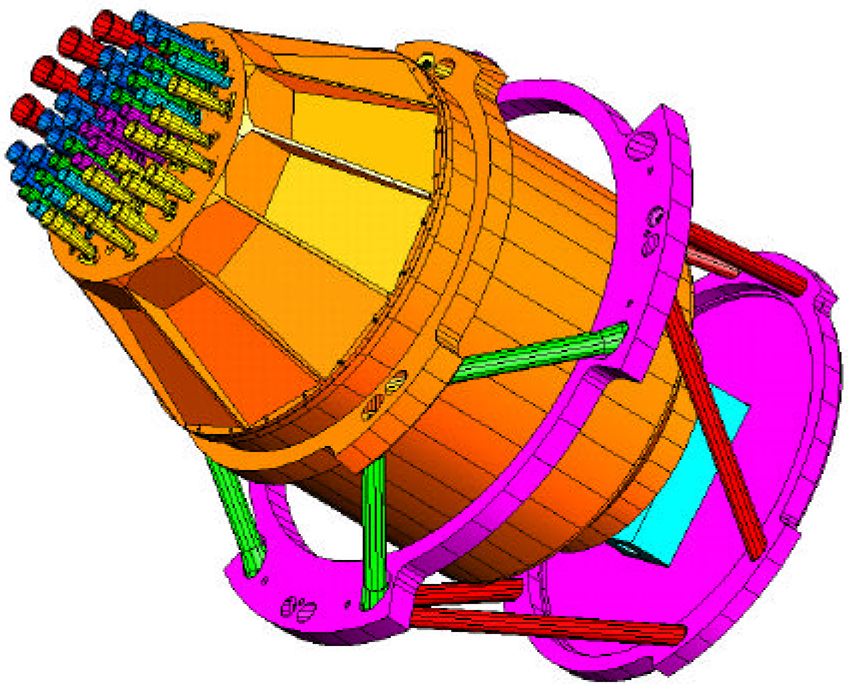
High Frequency Instrument

- Freq.: 100 -850 GHz
- Techn.: spider-web bolometers (50)
- Temp.: 0.1 K
- Ang. res.: 9.2' (100 GHz) t 5' (850 GHz)
- Temp. sens. (@100 GHz): ~5 μK
- PI: J.L. Puget (IAS - Orsay)



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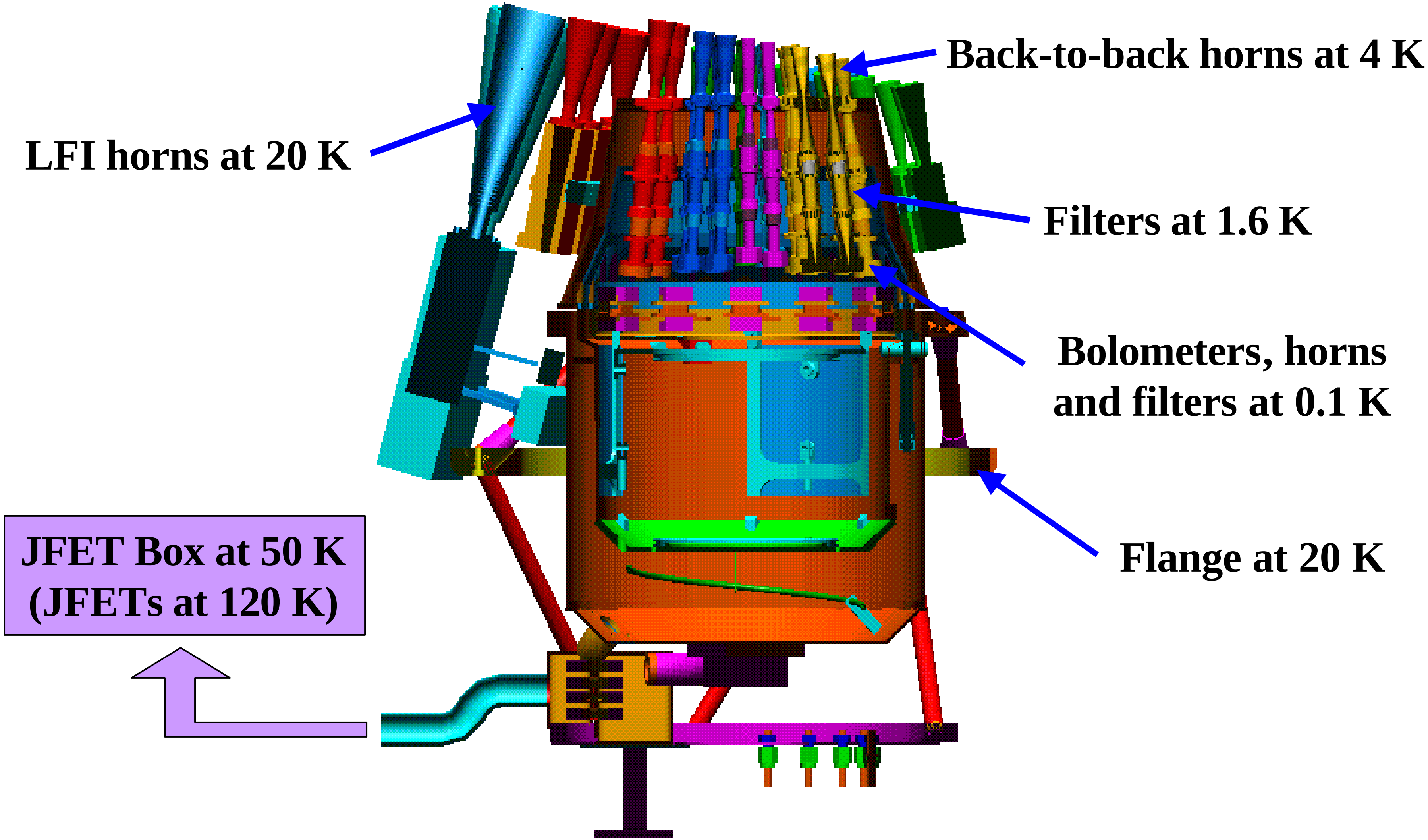
High Frequency Instrument



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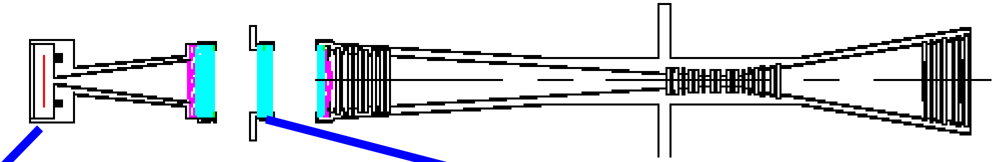
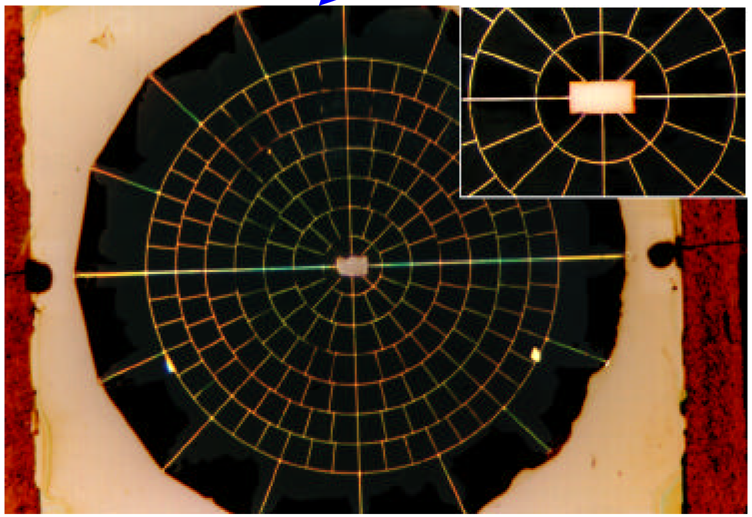
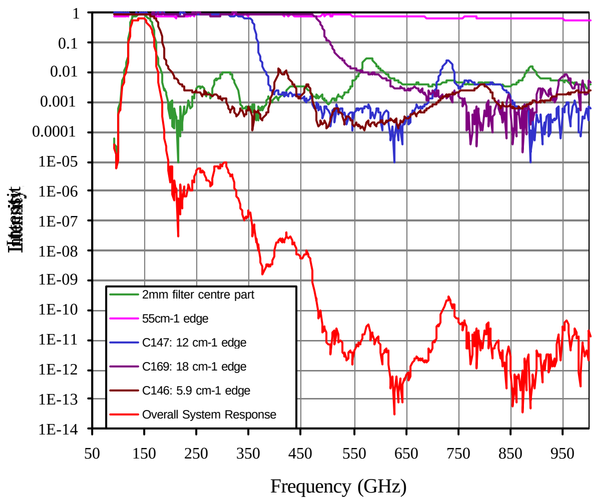
High Frequency Instrument

Back-to-back horns







Spider-web bolometers (CalTech/JPL)

Filters (QMW)

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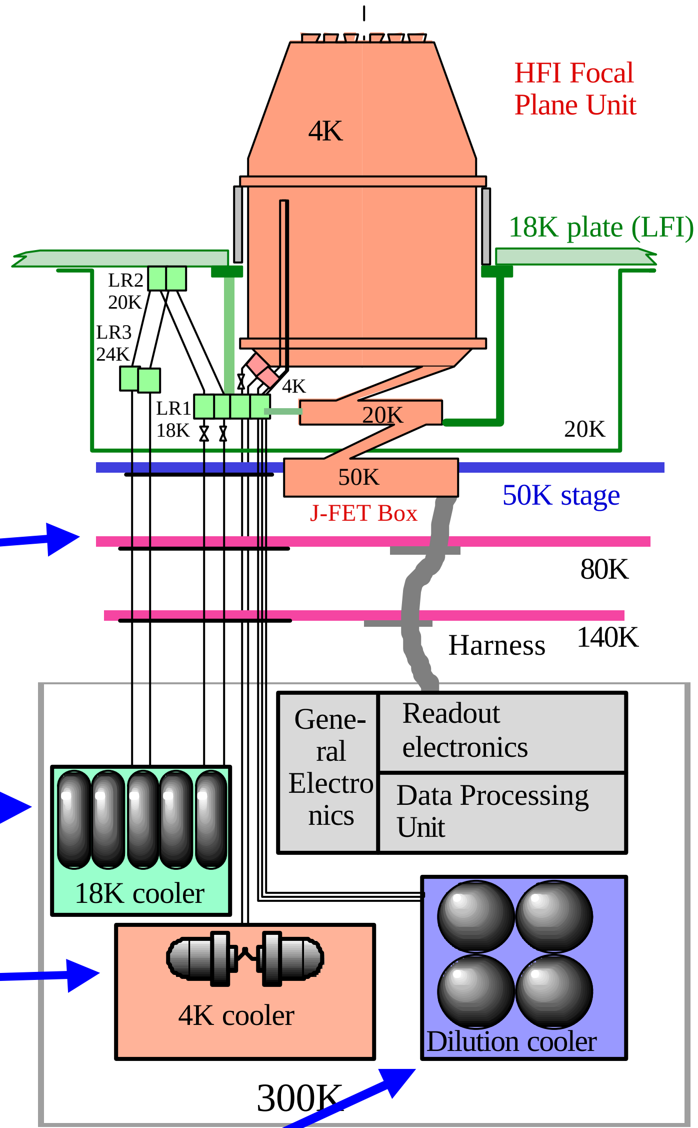
Cooling system



V-groove radiators (to 60 K)

20 K H_2 sorption coolers (JPL)

4 K Stirling cooler (RAL/MMS)

0.1 K $^3He/^4He$ dilution cooler (CRTBT)

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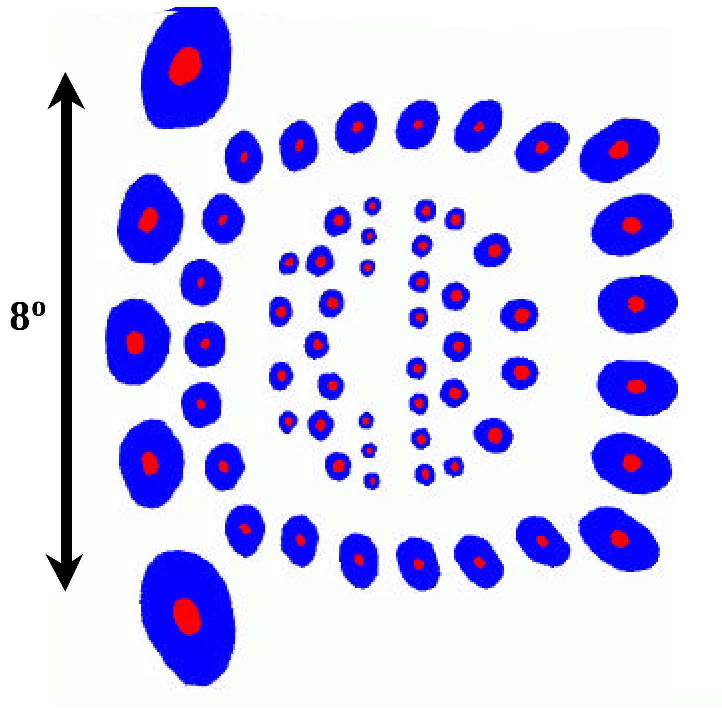
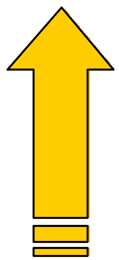
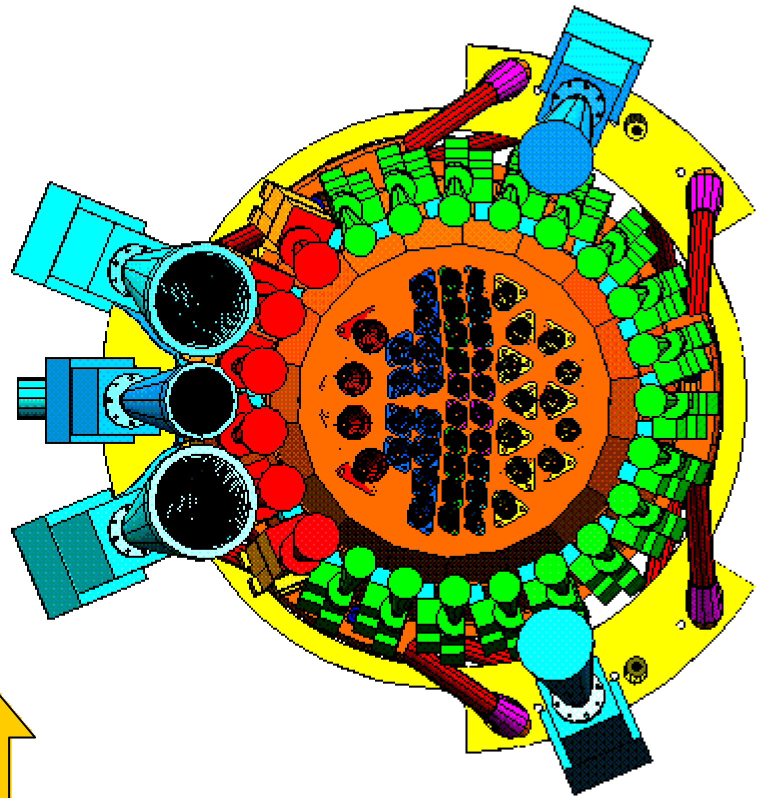
Optical configuration



On the sky



Scan direction



In the focal plane

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Calibration

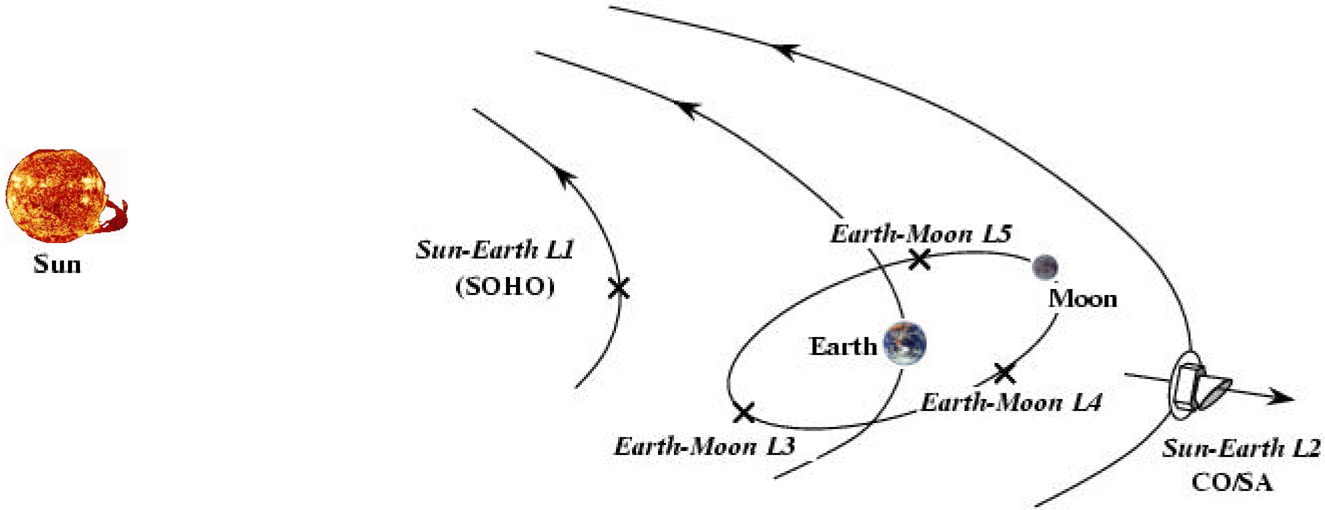
- No on-board standards
- External calibrators:
  - FIRAS (0.1% on CMB temperature)
  - CMB dipole (~3 mK amplitude, known to ~10 mK)
  - CMB dipole modulation with orbital motion (~0.3 mK amplitude)
  - celestial sources
- Precise determination of beam patterns:
  - main beam using outer planets
  - mid- and far- side lobes using Sun, Moon, Earth, and Milky Way
- Goal: 1% photometric calibration

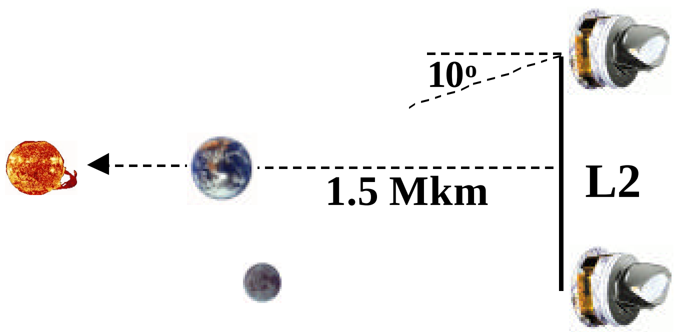
Predicted instrument characteristics

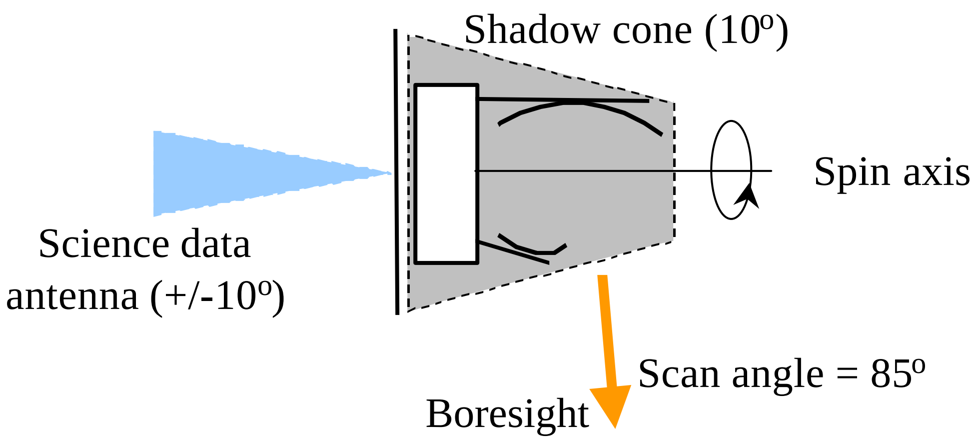
Telescope	**1.5 m (projected aperture) aplanatic; shared focal plane; system emissivity 1%**									
	Viewing direction offset 85^o from spin axis									
Center Freq. (GHz)	**30**	**44**	**70**	**100**	**100**	**143**	**217**	**353**	**545**	**857**
Detector Technology	**HEMT LNA arrays**				**Bolometer arrays**					
Detector Temperature	**~20 K**				**0.1 K**					
Cooling Requirements	**H_2 sorption cooler**				**H_2 sorption + 4 K J-T stage + Dilution cooler**					
Number of Detectors	**4**	**6**	**12**	**34**	**4**	**12**	**14**	**6**	**8**	**6**
Angular Resolution (')	**33**	**23**	**14**	**10**	**9.2**	**7.1**	**5**	**5**	**5**	**5**
$\Delta T/T$ Sensitivity per res.element (12 months, 1σ, 10^{-6} units) *	**1.6 (P)**	**2.4 (P)**	**3.6 (P)**	**4.3 (P)**	**2.0**	**2.2 (P)**	**3.5 (P)**	**14.0**	**140 (P)**	**6600**

*** (P) indicates sensitivity to linear polarisation**

Choice of orbit







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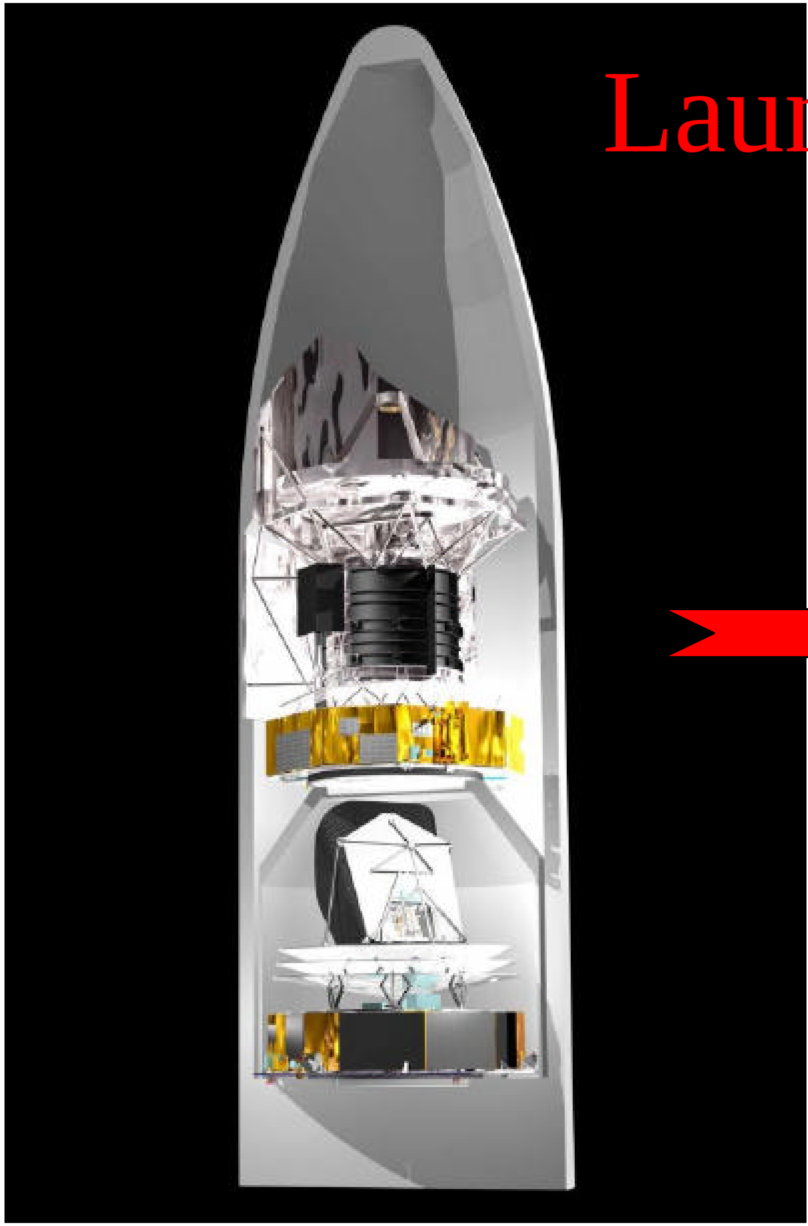
Launch in 2007



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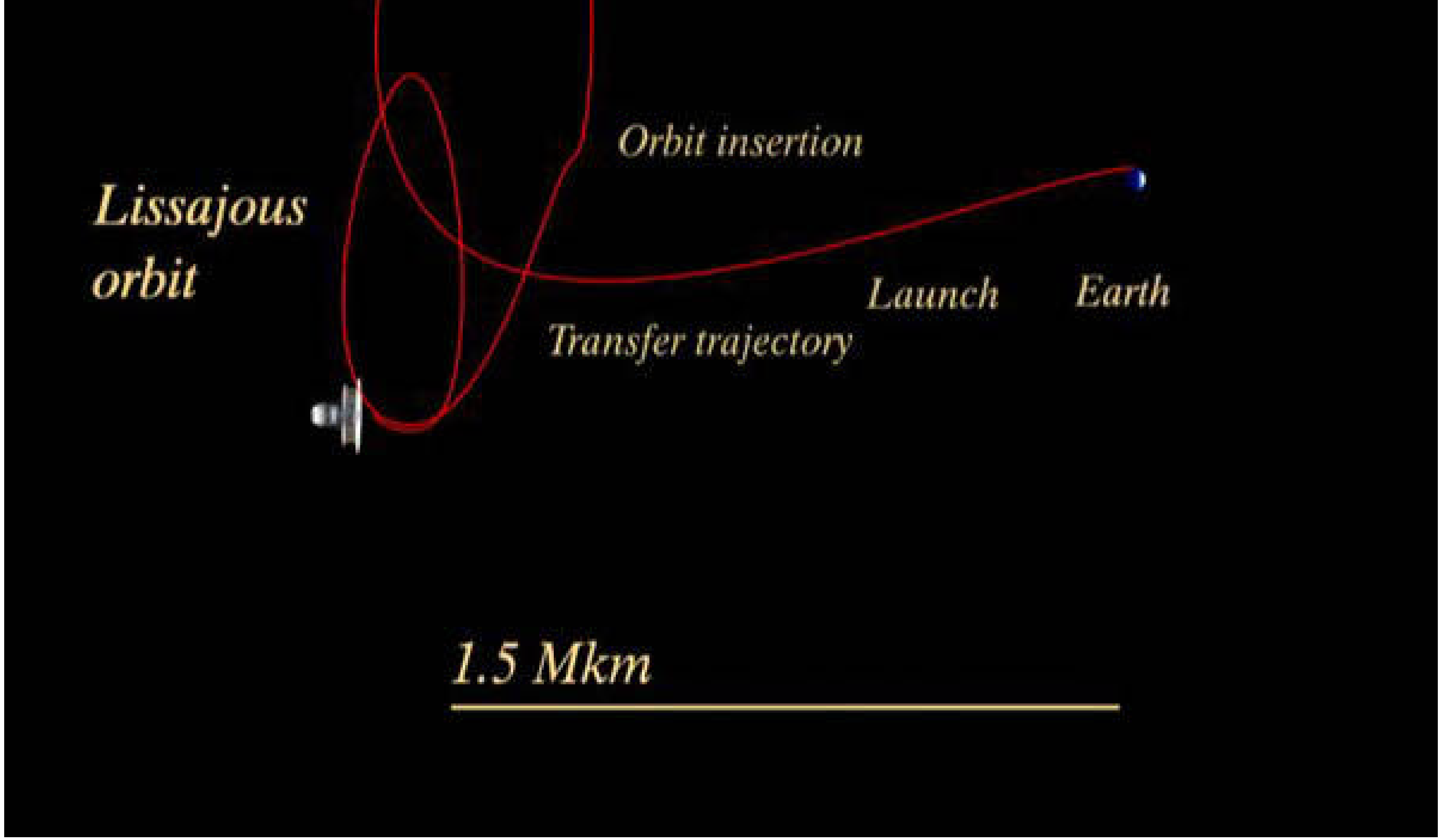
Transfer to orbit



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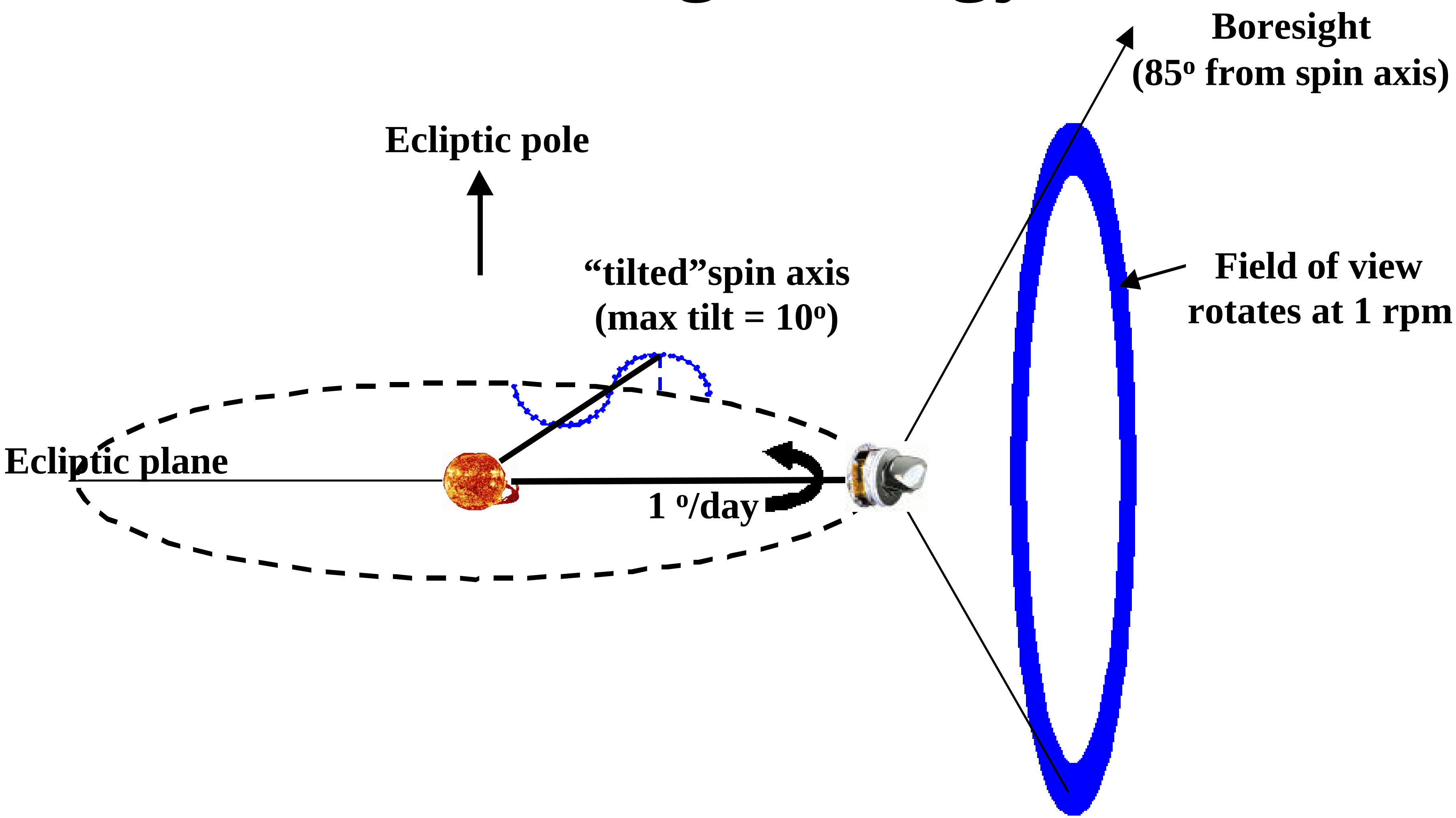
Observing strategy



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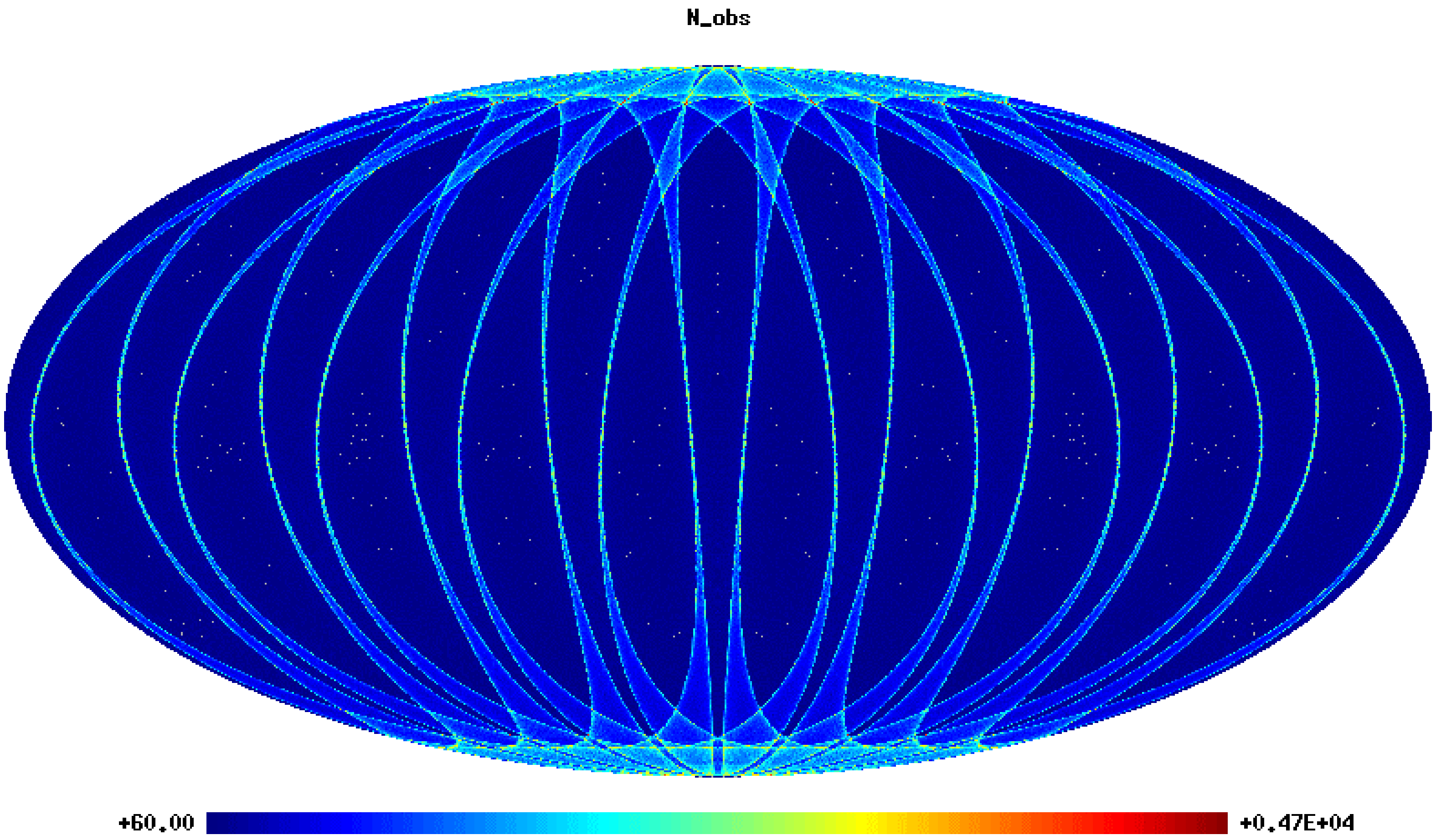
(Possible) distribution of integration time



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Key dates

- Start of spacecraft Phase B: mid-2001
- Start of spacecraft Phase C/D: end-2002
- Payload model deliveries: 2003-2004
- Launch: February 2007
- Insertion into orbit: June 2007
- Operations: 2007-end 2008
- Scientific product delivery: 2010