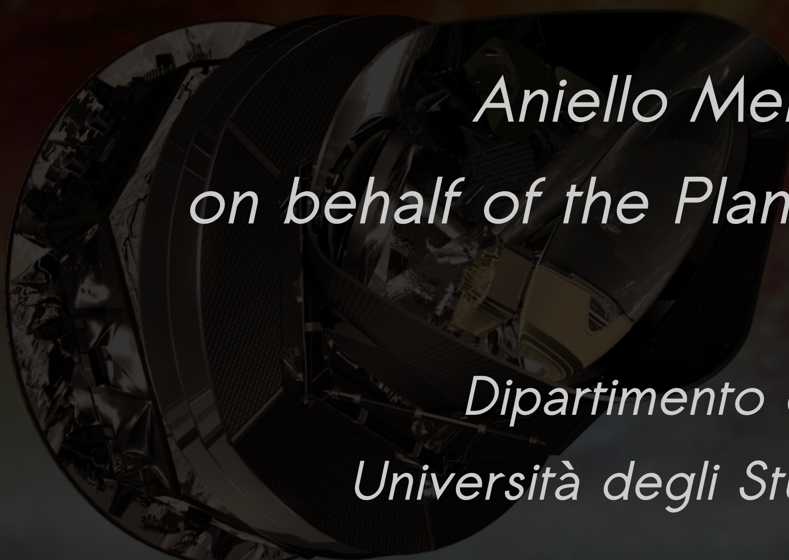
Planck: microwave glasses to study the Universe history



Aniello Mennella

on behalf of the Planck collaboration

Dipartimento di Fisica

Università degli Studi di Milano

2nd International Conference Frontiers in Diagnostic Technologies

Frascati, 28-30 November, 2011

Light travels at finite speed

Light takes more than 10 billion years to arrive to Earth

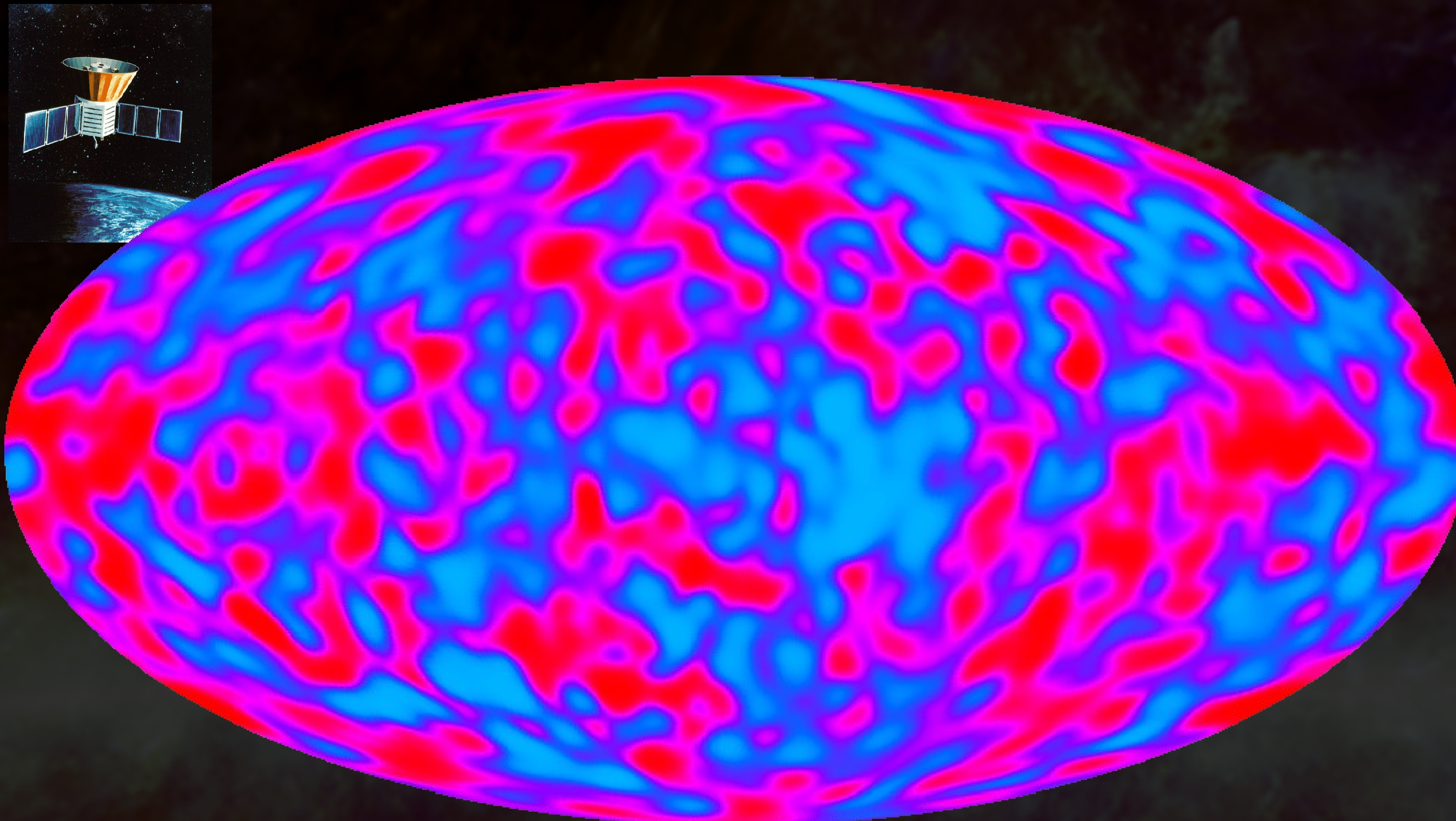
We see these galaxies as they were more than 10 billion years ago

Photons in the early universe

- Early universe is a hot and dense expanding plasma
- Photons are coupled to matter via Compton scattering
- At ~300000 yrs T falls below 3000 K and matter becomes neutral
- At that time photons freely travel carrying the “imprinting” of the “baby” universe
- We detect it today as a microwave signal, red-shifted by a factor ~1000

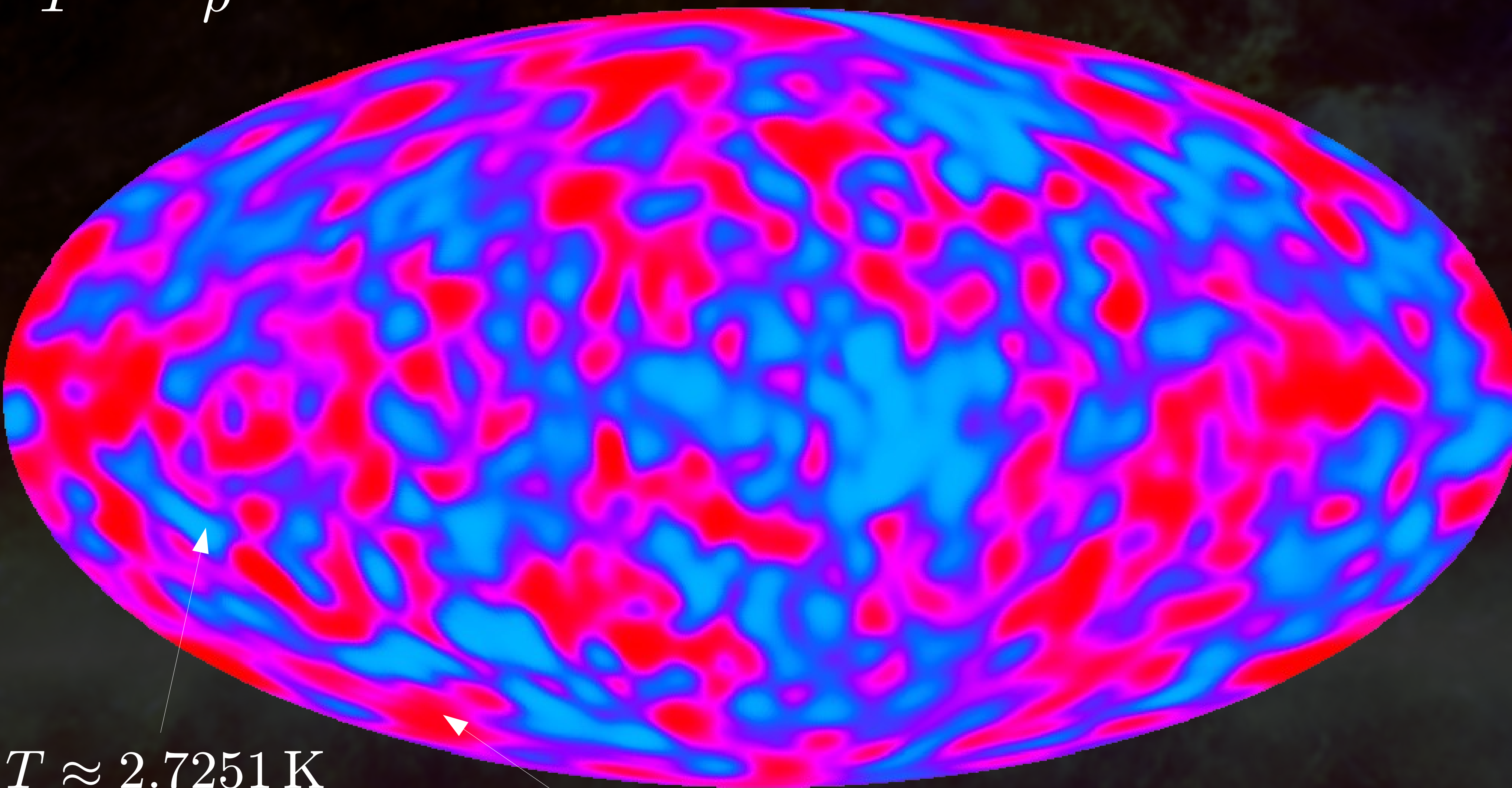
14 May 1964, 11:15 am

1989 - COBE space mission (NASA)



Tiny ripples

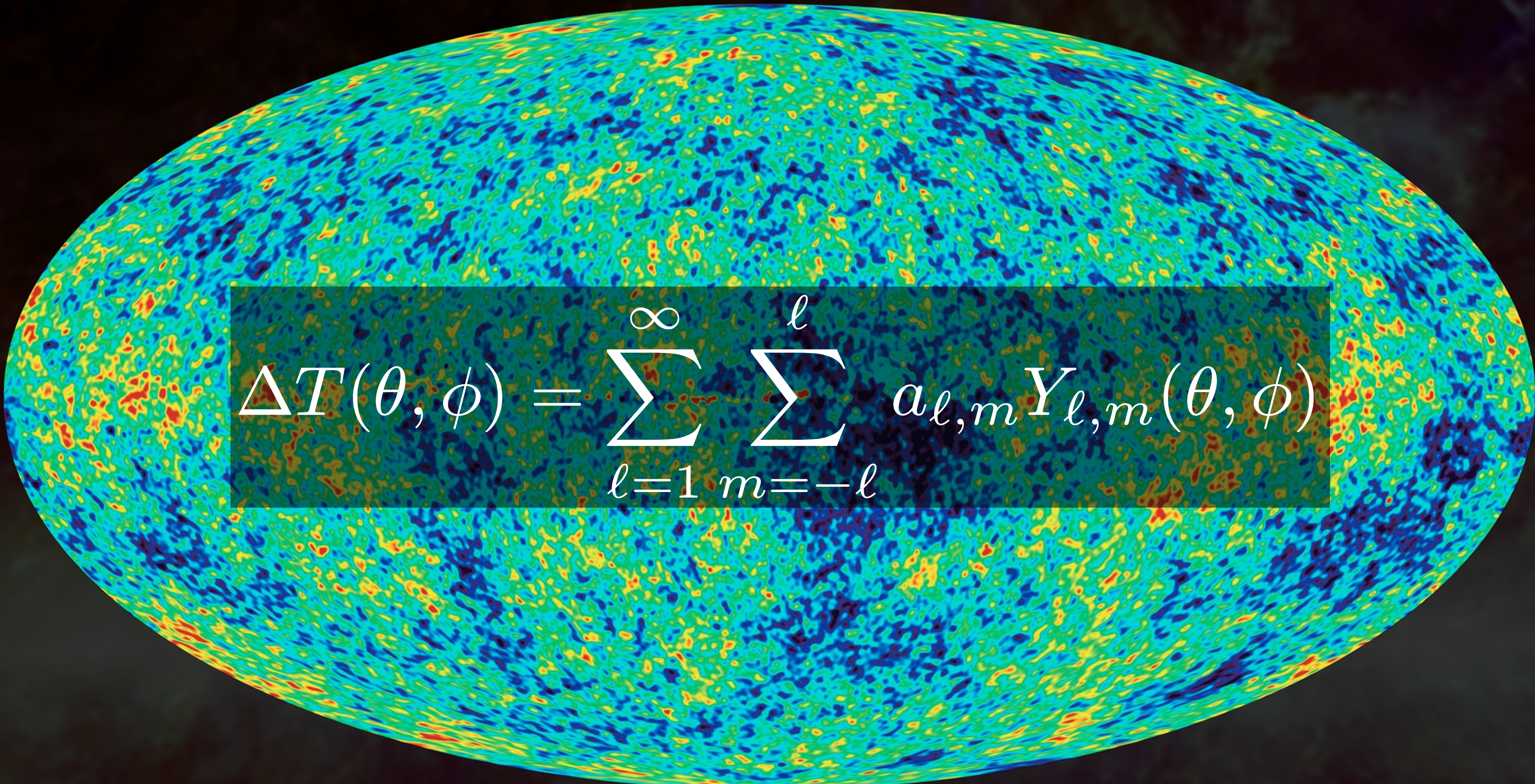
$$\frac{\Delta T}{T} \approx \frac{\delta\rho}{\rho} \approx 10^{-5}$$



$T \approx 2.7251\,\mathrm{K}$

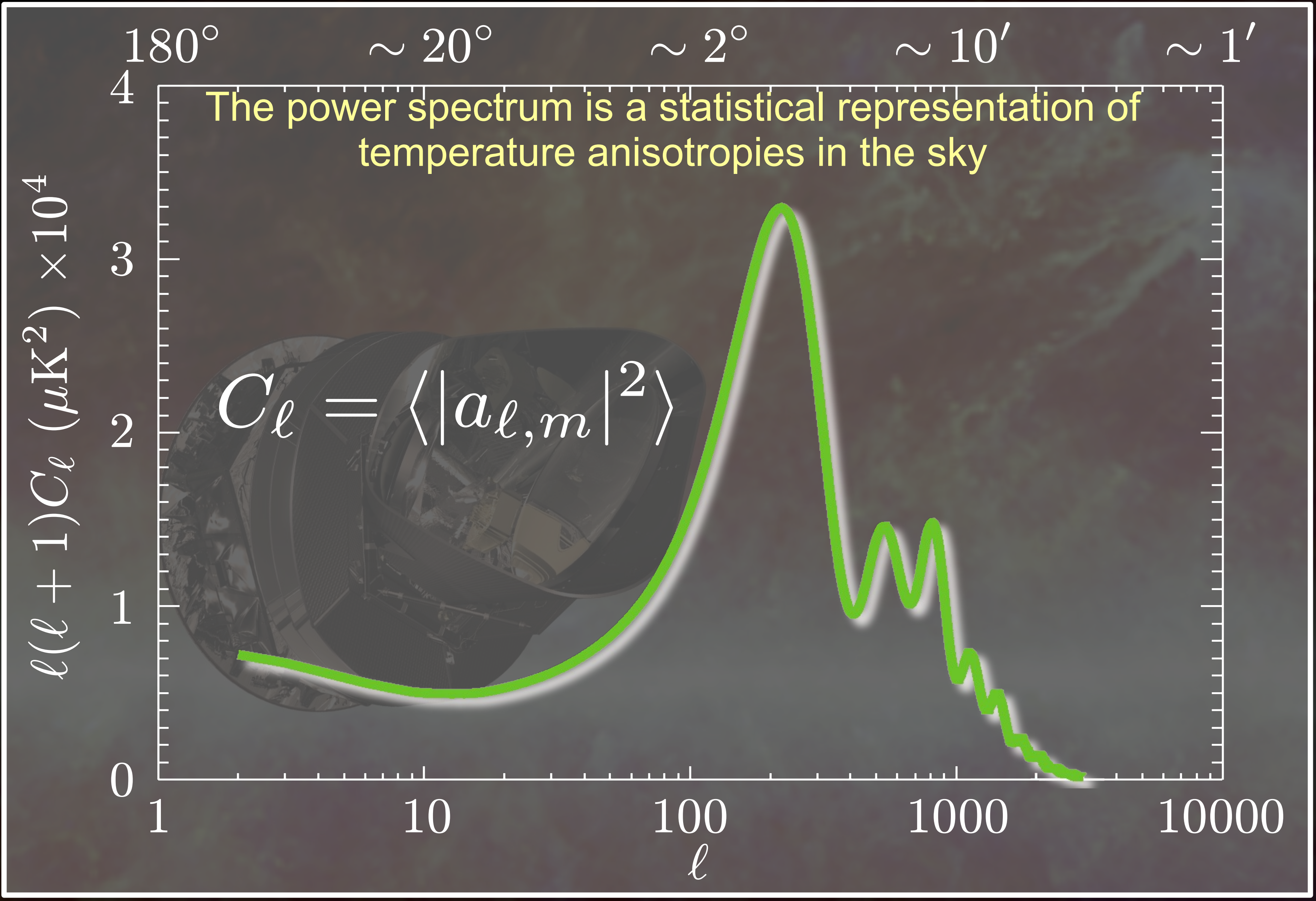
$T \approx 2.7252\,\mathrm{K}$

Spherical harmonics

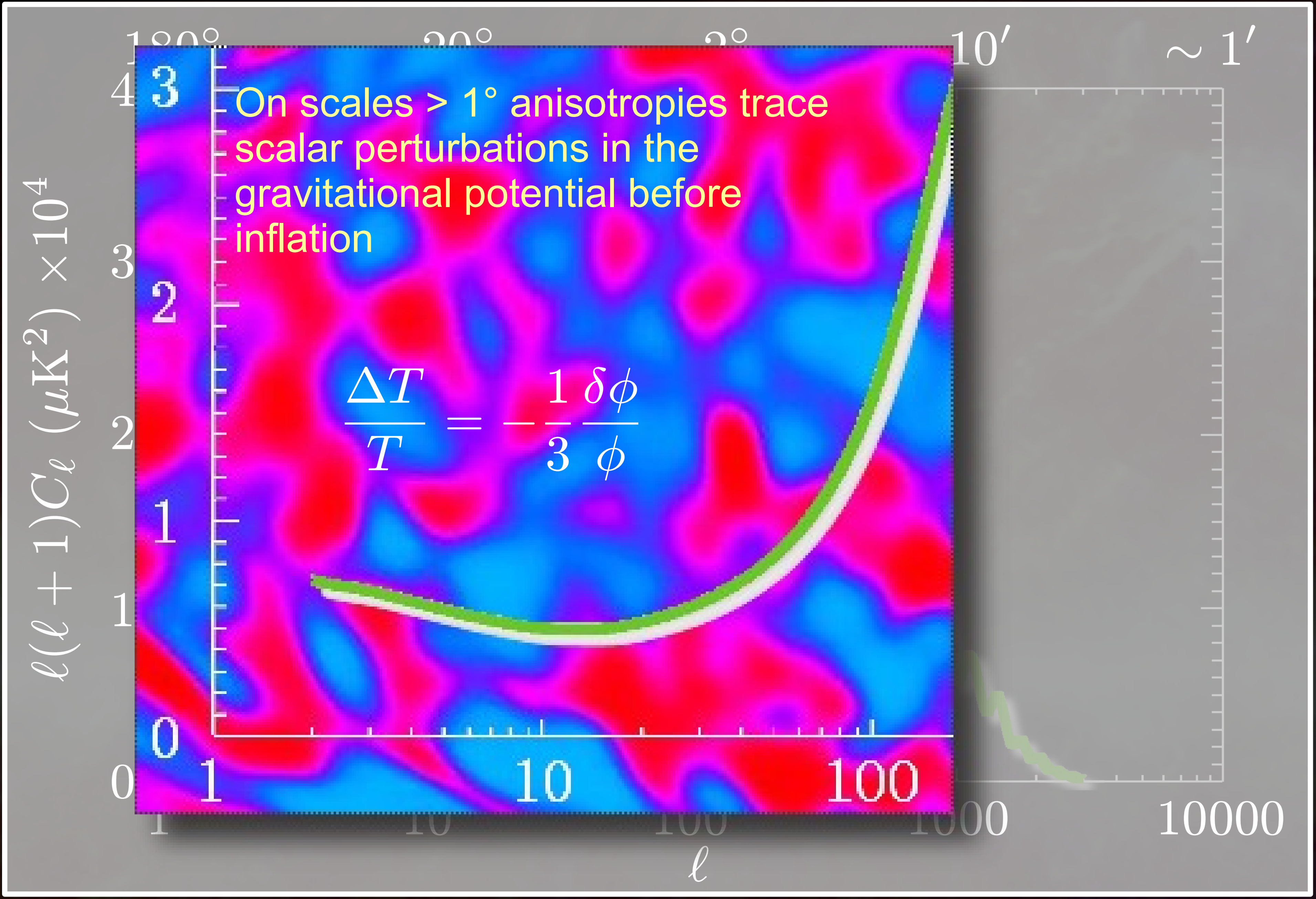


$$\Delta T(\theta, \phi) = \sum_{\ell=1}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell,m} Y_{\ell,m}(\theta, \phi)$$

Power spectrum



Large angular scales

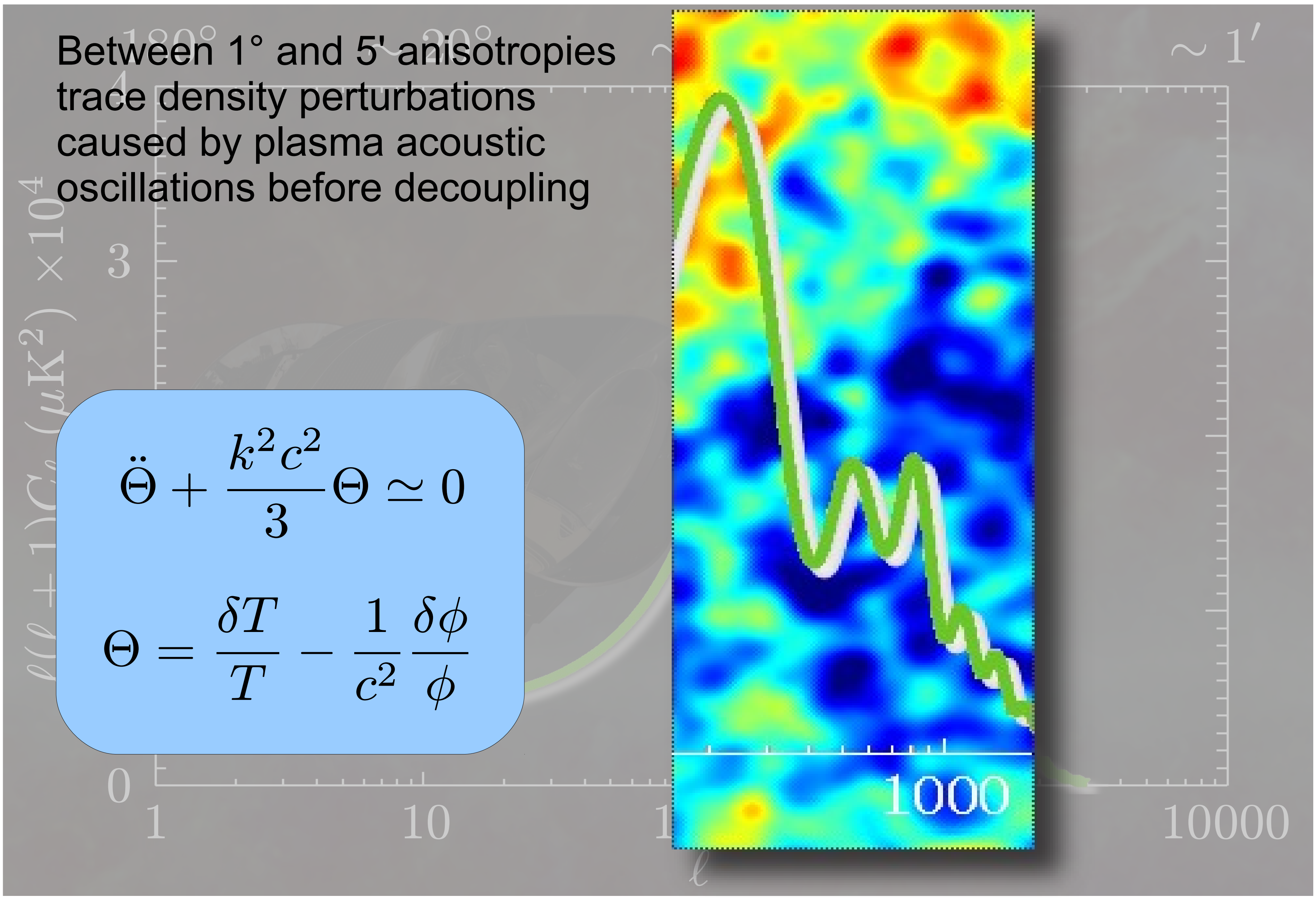


Medium angular scales

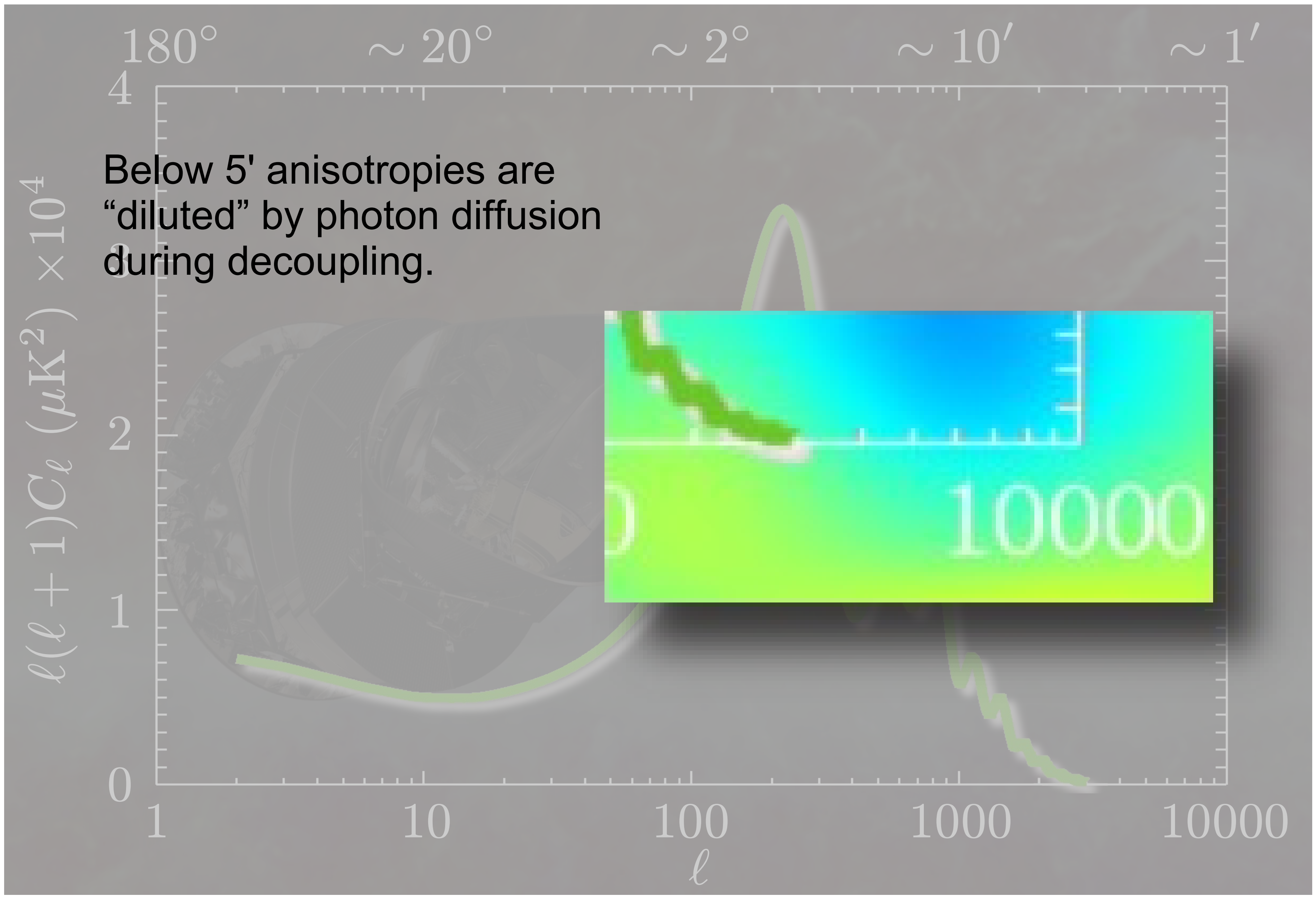
Between 1° and 5' anisotropies trace density perturbations caused by plasma acoustic oscillations before decoupling

$$\ddot{\Theta} + \frac{k^2 c^2}{3}\Theta \simeq 0$$

$$\Theta = \frac{\delta T}{T} - \frac{1}{c^2}\frac{\delta \phi}{\phi}$$

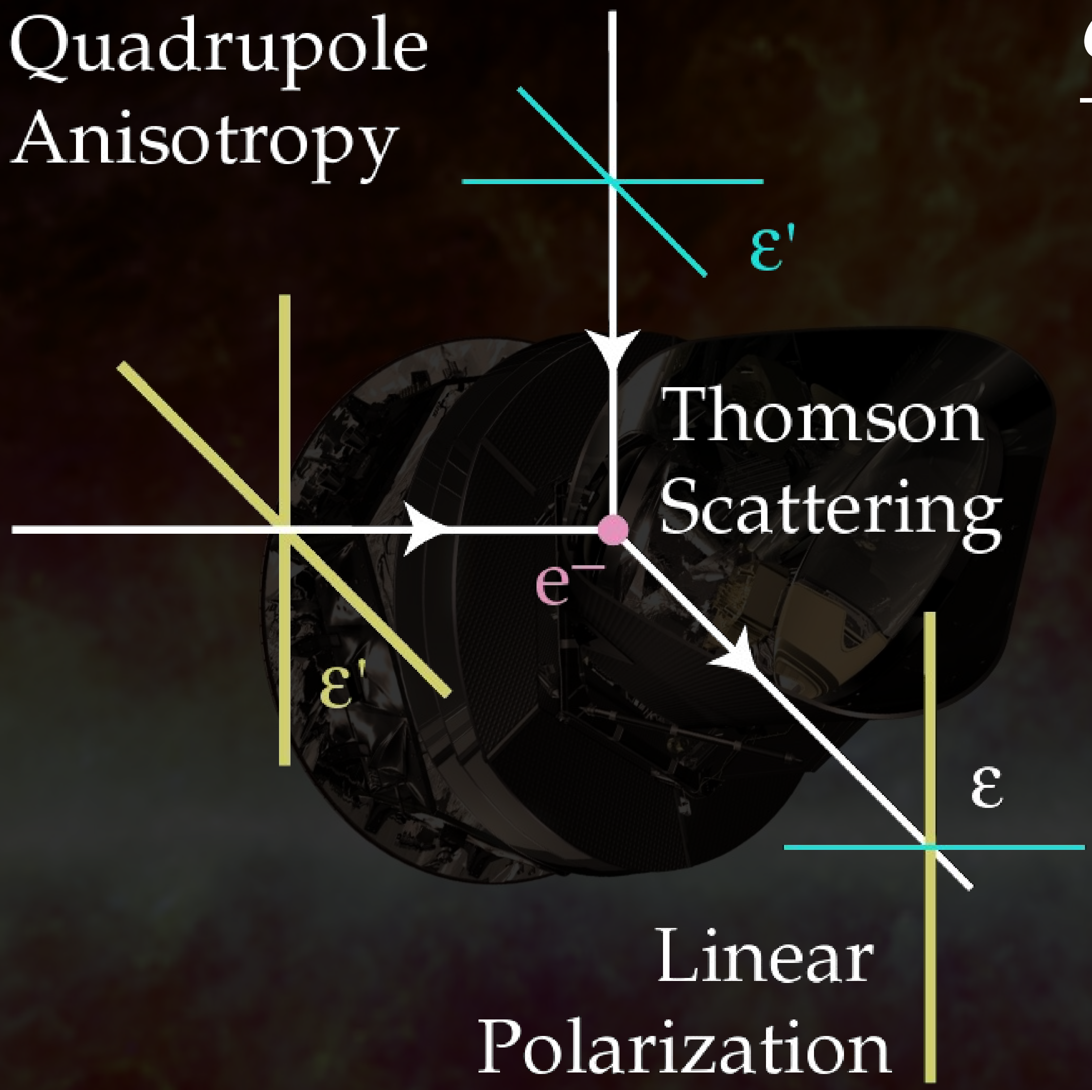


Small angular scales



Below 5' anisotropies are
“diluted” by photon diffusion
during decoupling.

CMB polarisation



$$\frac{d\sigma_{\mathrm{T}}}{d\Omega} \propto \left|\hat{\epsilon} \cdot \hat{\epsilon}'\right|^2$$

- Thompson-scattered light is polarised | | to the incident polarisation
- To produce average polarisation in the CMB photon (and therefore matter) distribution must have a non zero quadrupole.

CMB polarisation

Three mechanisms can produce quadrupolar anisotropy

- **Scalar perturbations** (perturbations of the energy density at last scattering)
- **Vector perturbations** (matter vortical motions)
- **Tensor perturbation** (metric perturbations, i.e. gravitational waves)

$$\text{Stokes } Q, U \rightarrow E, B \text{ modes}$$

CMB polarisation

Three mechanisms can produce quadrupolar anisotropy

- **Scalar perturbations** (perturbations of the energy density at last scattering)
- **Vector perturbations** (matter vortical motions)
- **Tensor perturbation** (metric perturbations, i.e. gravitational waves)

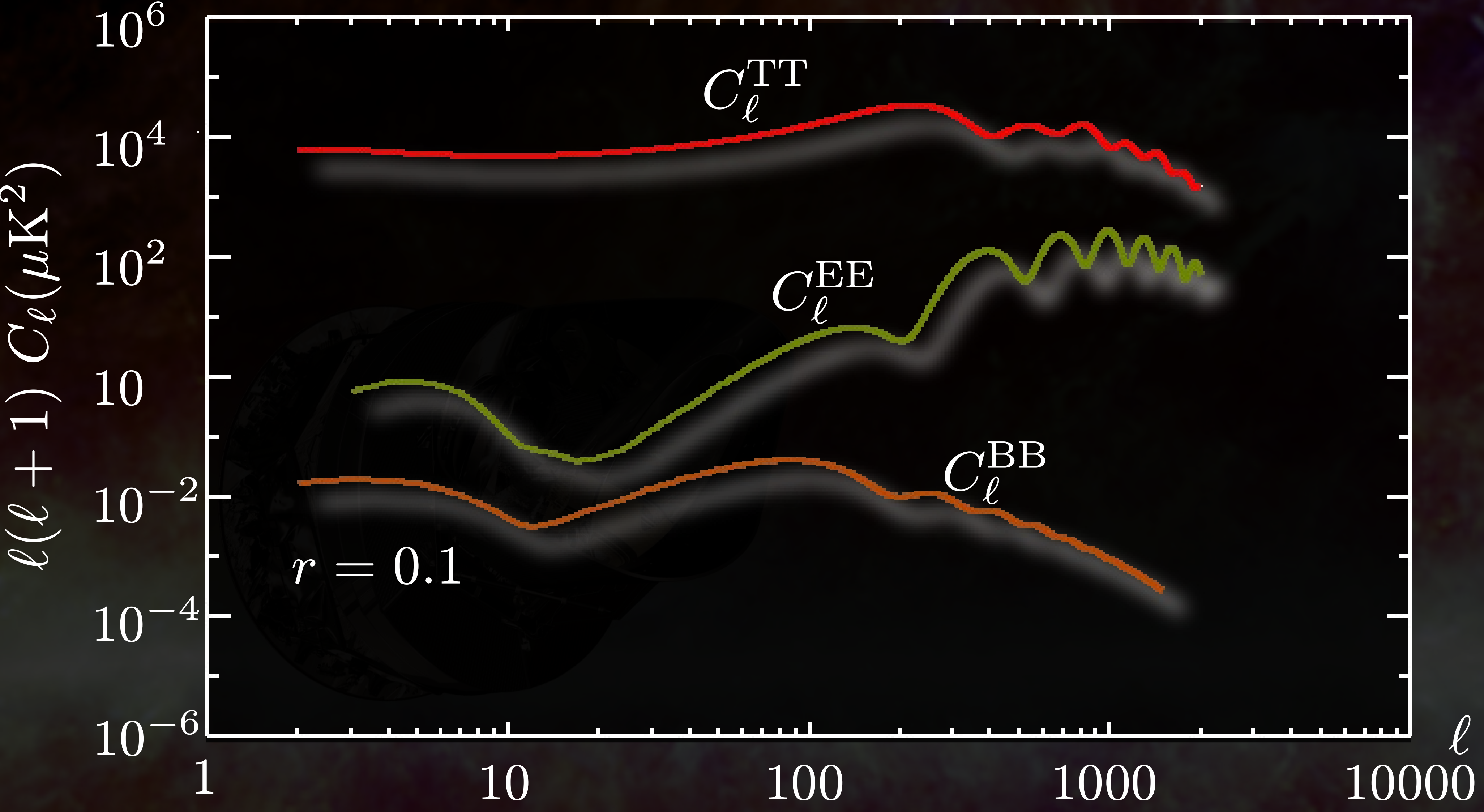
$$\text{Stokes } Q, U \rightarrow E, B \text{ modes}$$

CMB polarisation

Three mechanisms can produce quadrupolar anisotropy

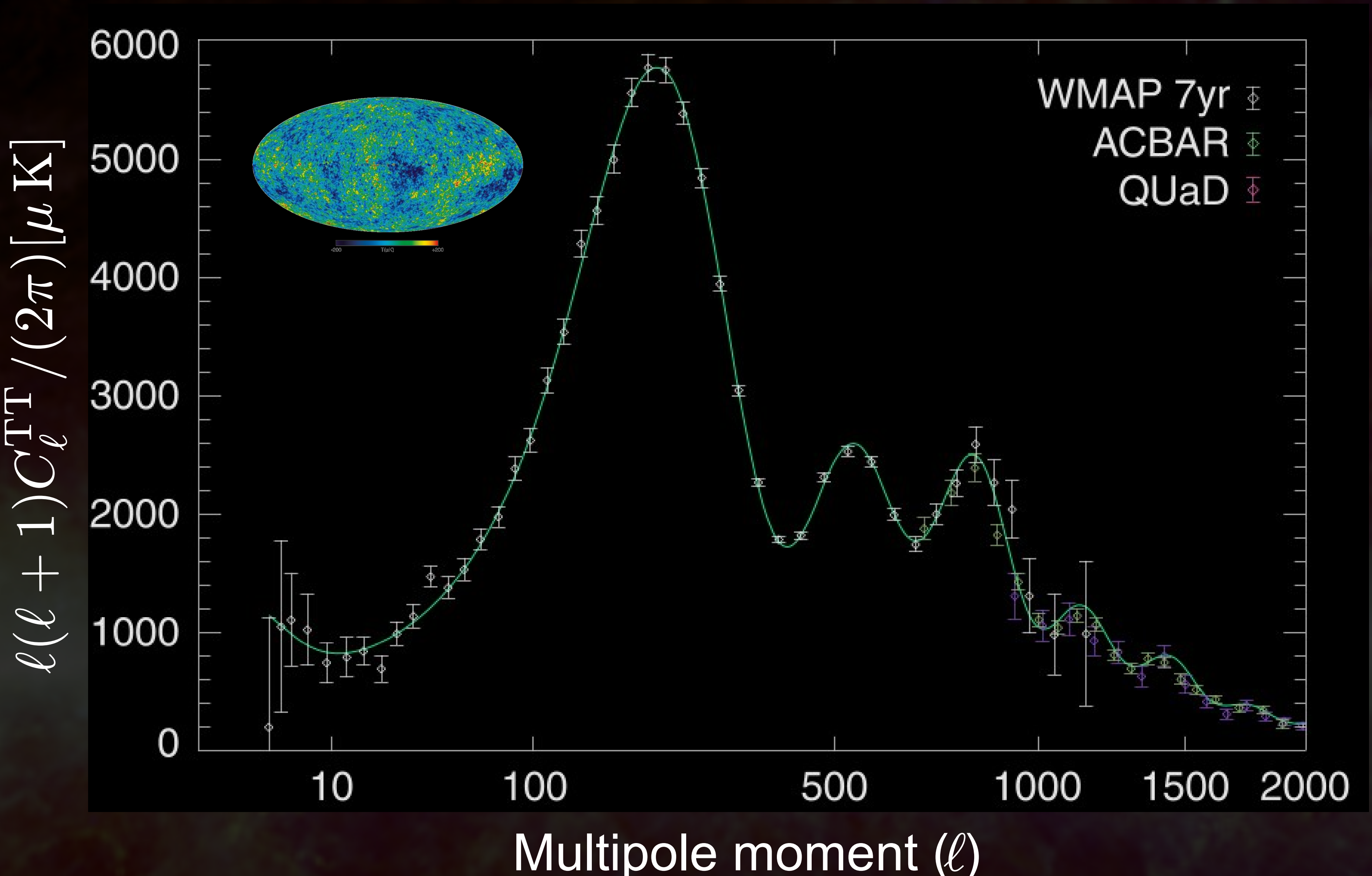
- **Scalar perturbations** (perturbations of the energy density at last scattering)
- **Vector perturbations** (matter vortical motions)
- **Tensor perturbation** (metric perturbations, i.e. gravitational waves)

$$\text{Stokes } Q, U \to E, B \text{ modes}$$

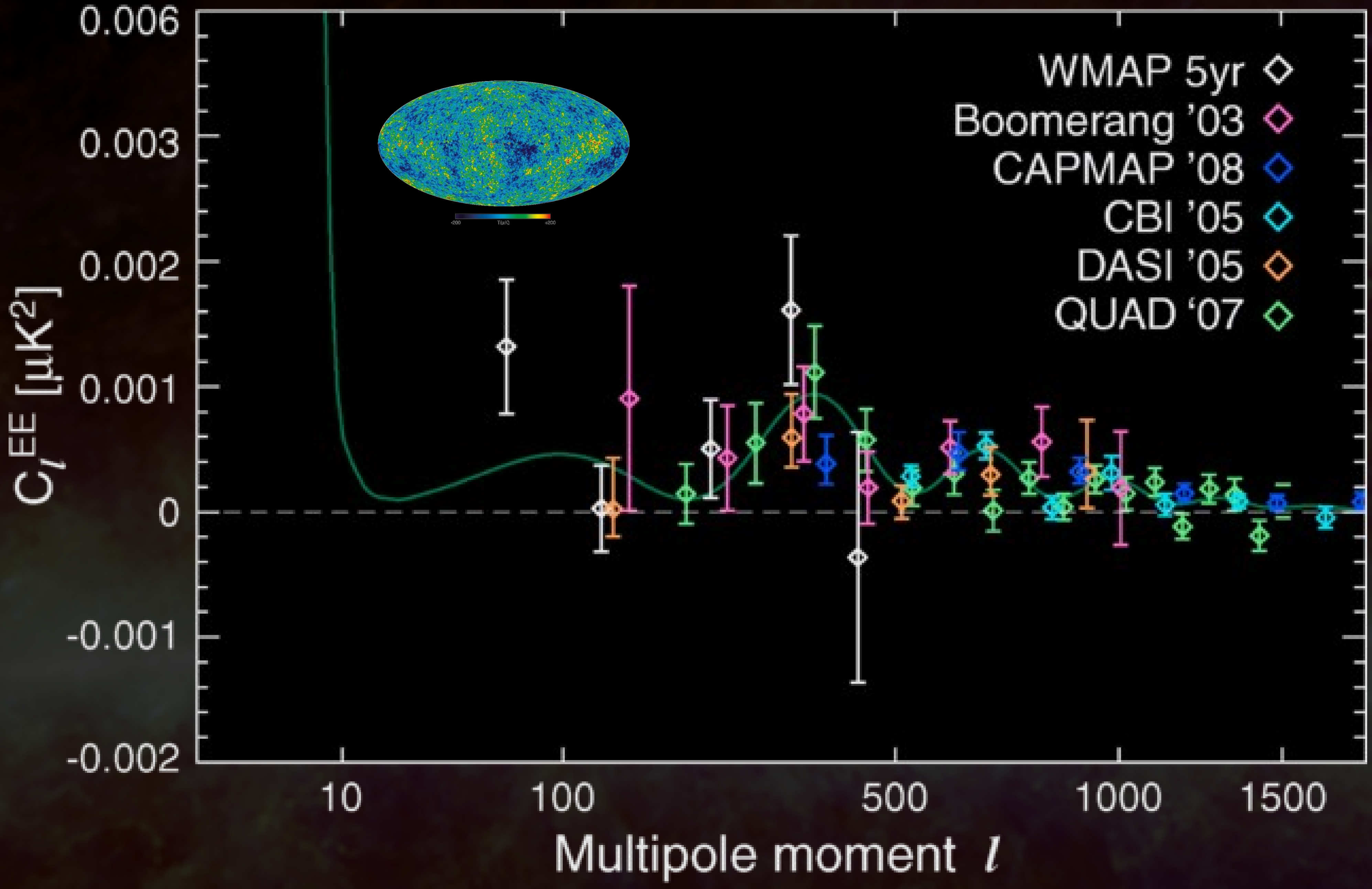


$\ell(\ell+1)\ C_\ell(\mu\mathrm{K}^2)$
10^6
10^4
10^2
10
10^{-2}
10^{-4}
10^{-6}
1
10
100
1000
10000
ℓ
C_ℓ^{TT}
C_ℓ^{EE}
C_ℓ^{BB}
$r = 0.1$

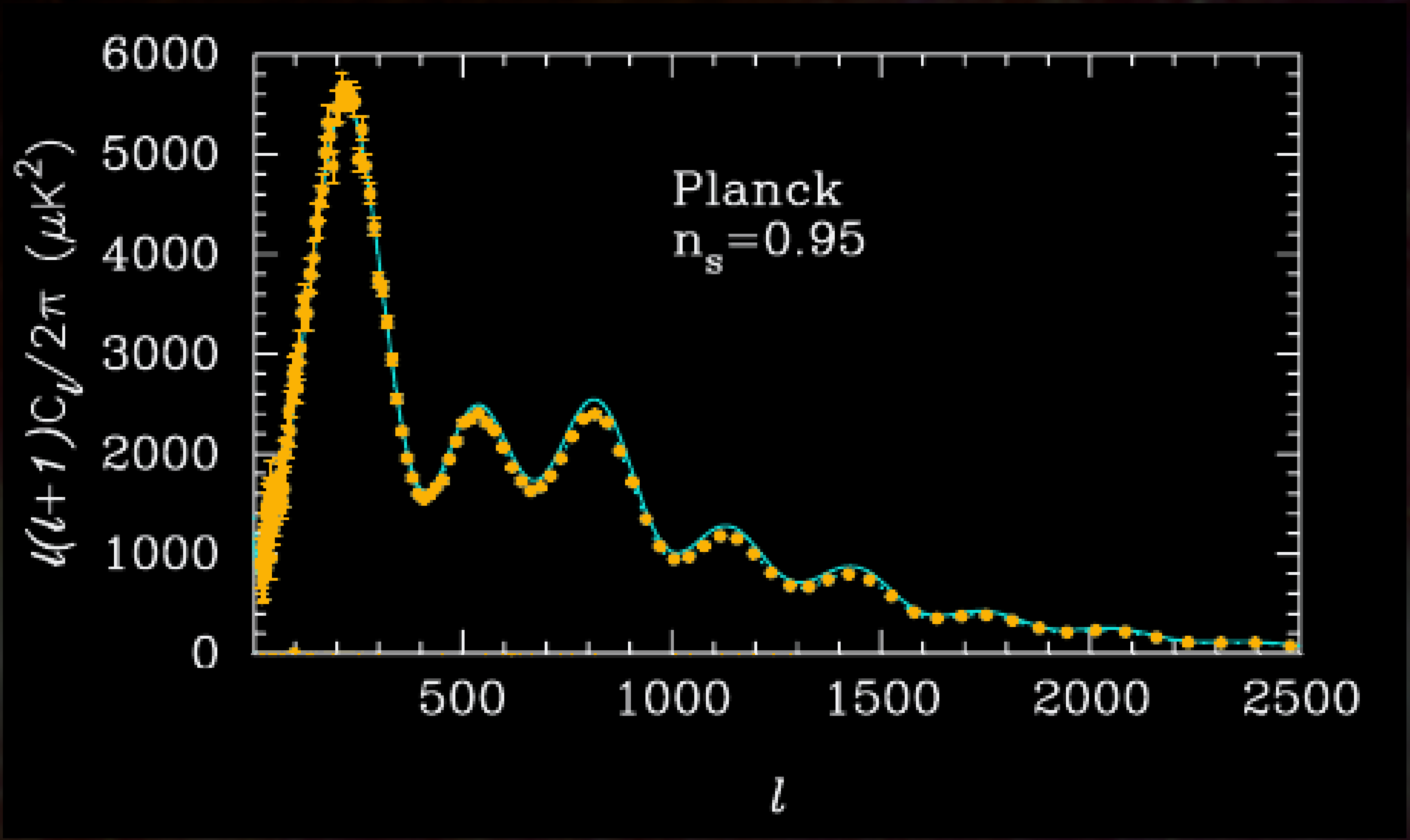
State-of-the-art



State-of-the-art

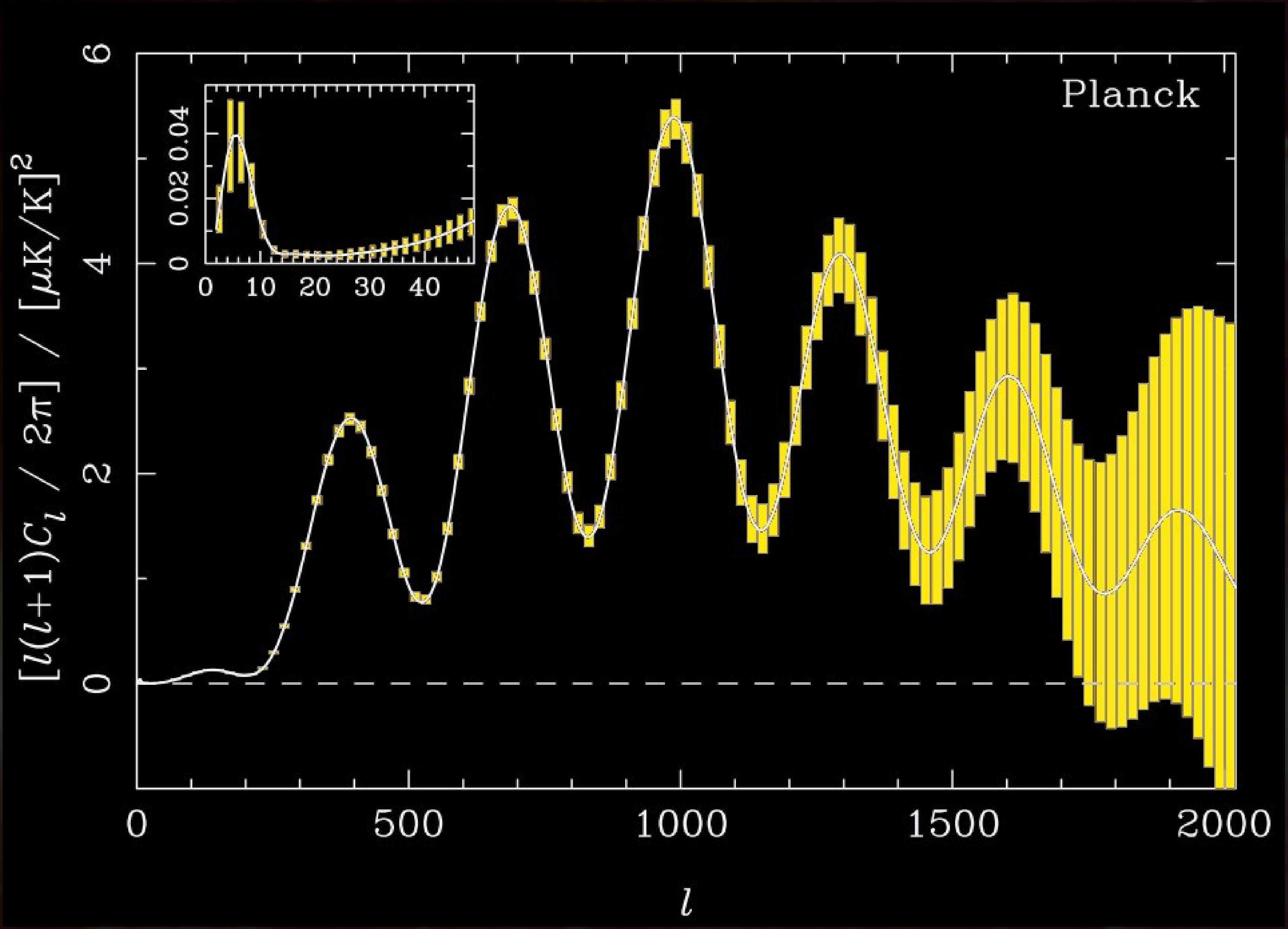


Near future



6000
5000
4000
3000
2000
1000
0
500
1000
1500
2000
2500
$l(l+1)C_l/2\pi$ (μK^2)
l
Planck
n_s=0.95

Near future


Planck
$[l(l+1)C_l \ / \ 2\pi] \ / \ [\mu K/K]^2$
0
2
4
6
0
500
1000
1500
2000
l
0
0.02
0.04
0
10
20
30
40

Planck space mission

ESA mission

Launched on May 14th, 2009

Scheduled until Jan 2012

Extension approved through 2012

PLANCK

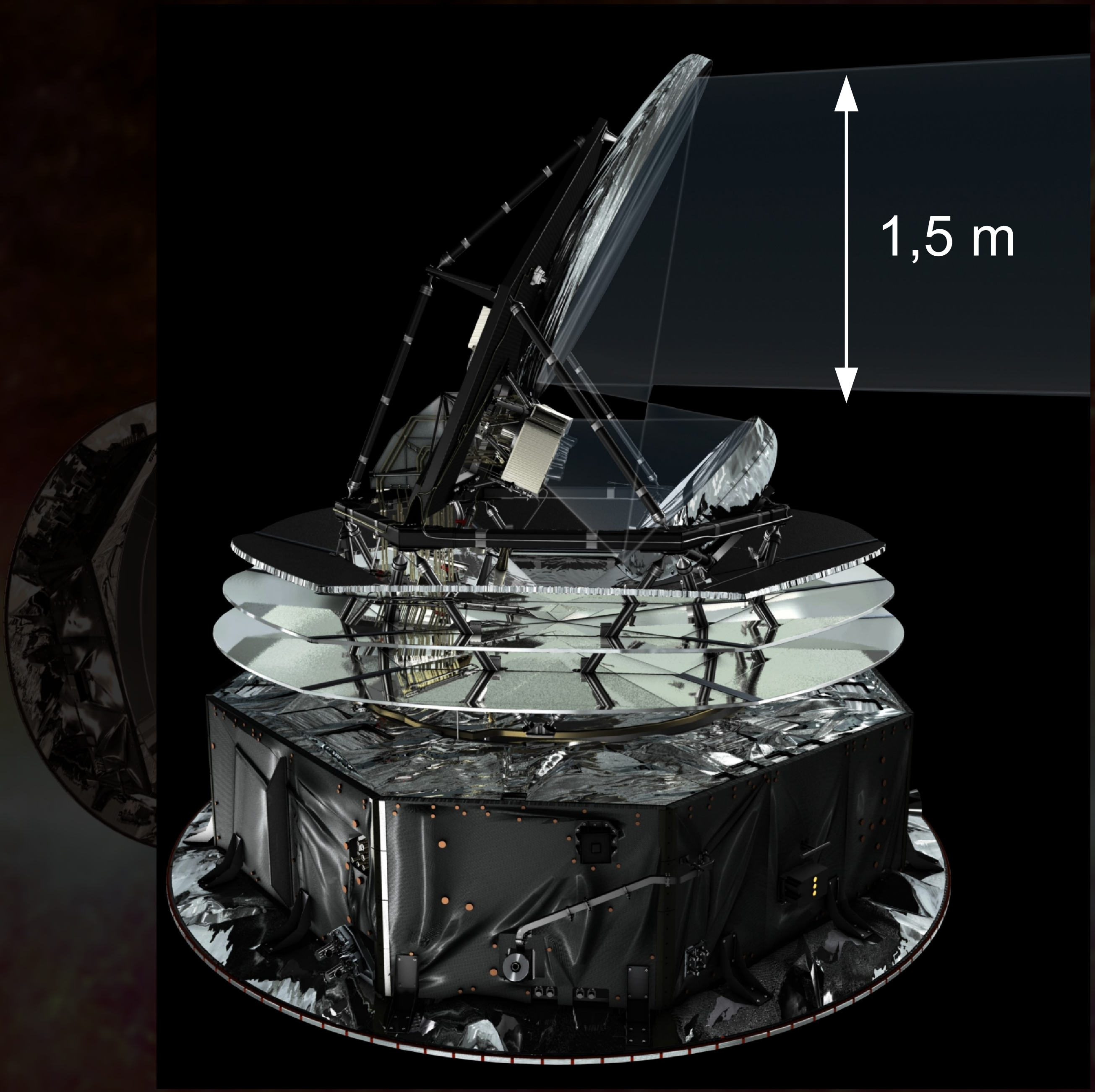
esa

asi agenzia spaziale italiana

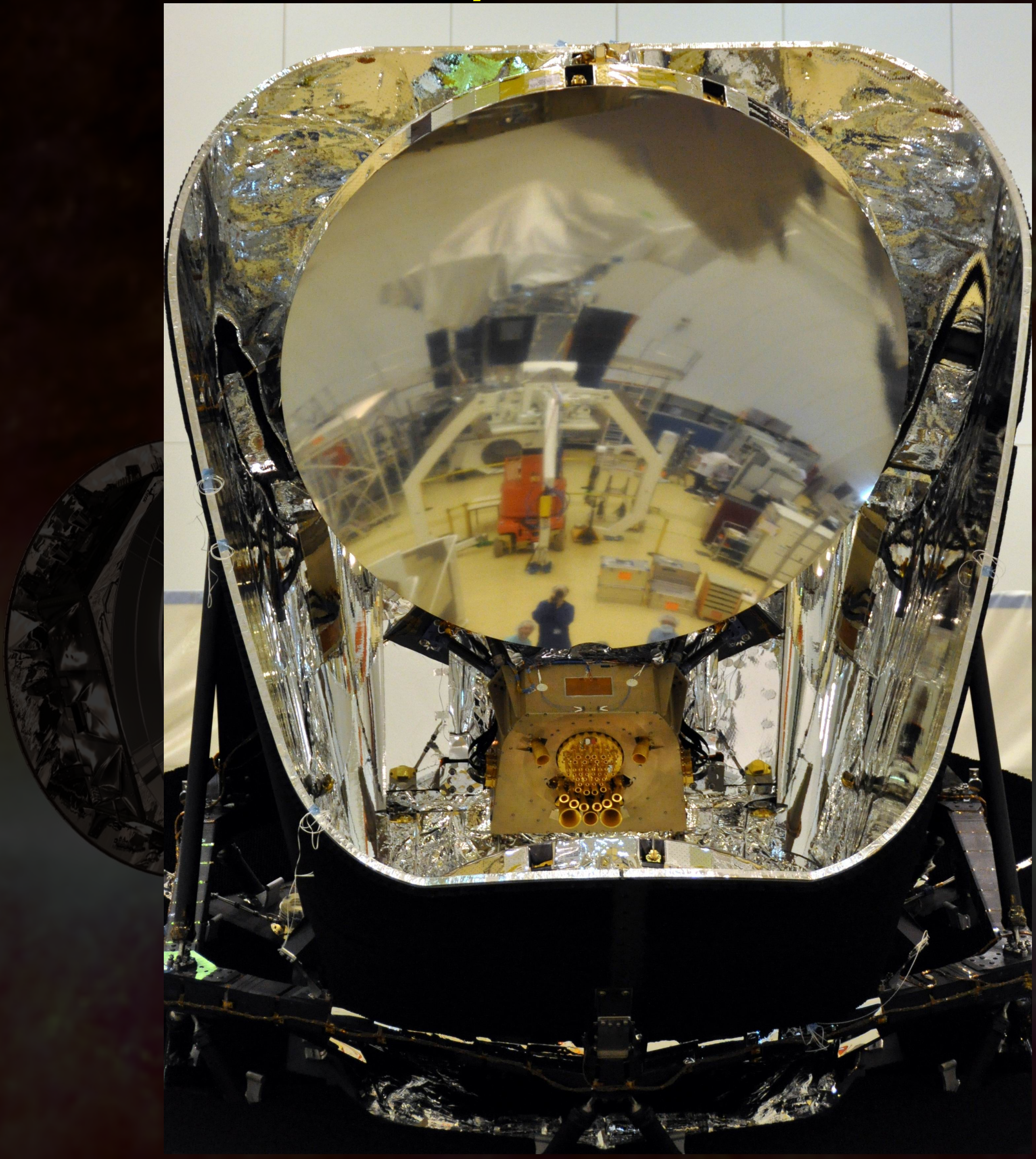
cnes CENTRE NATIONAL D'ÉTUDES SPATIALES

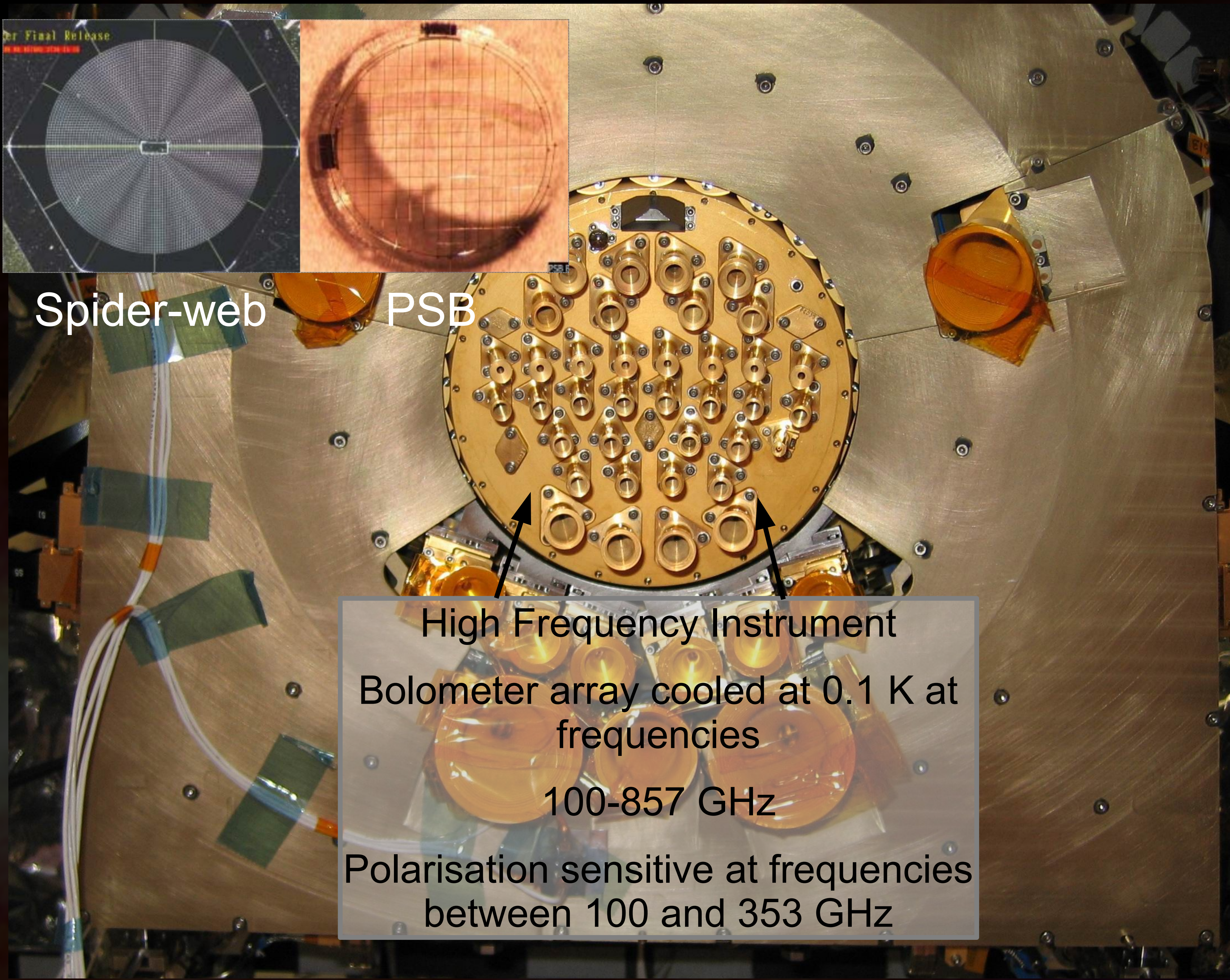
Orbit: L2 Lagrangian point

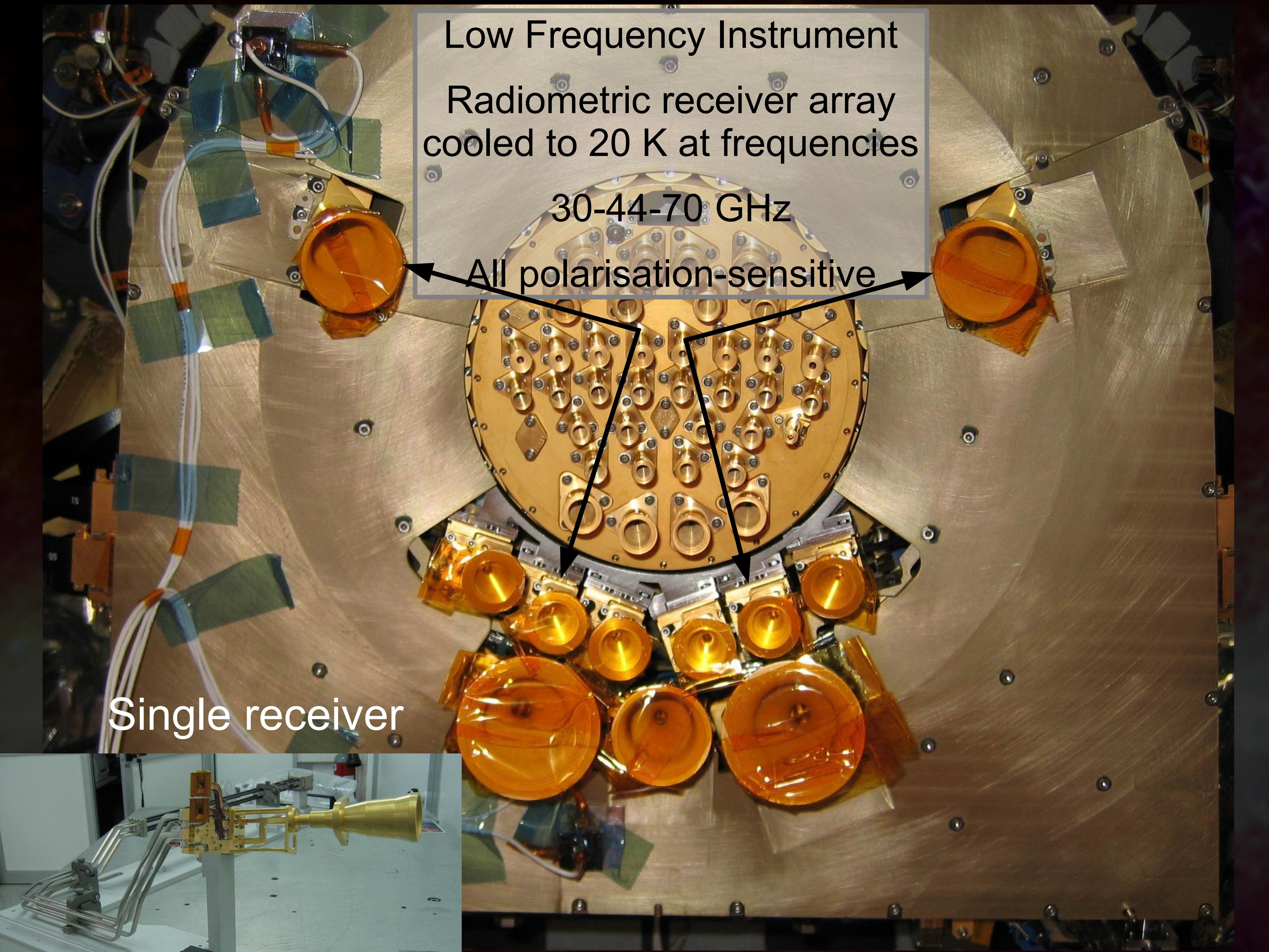
The eye of Planck



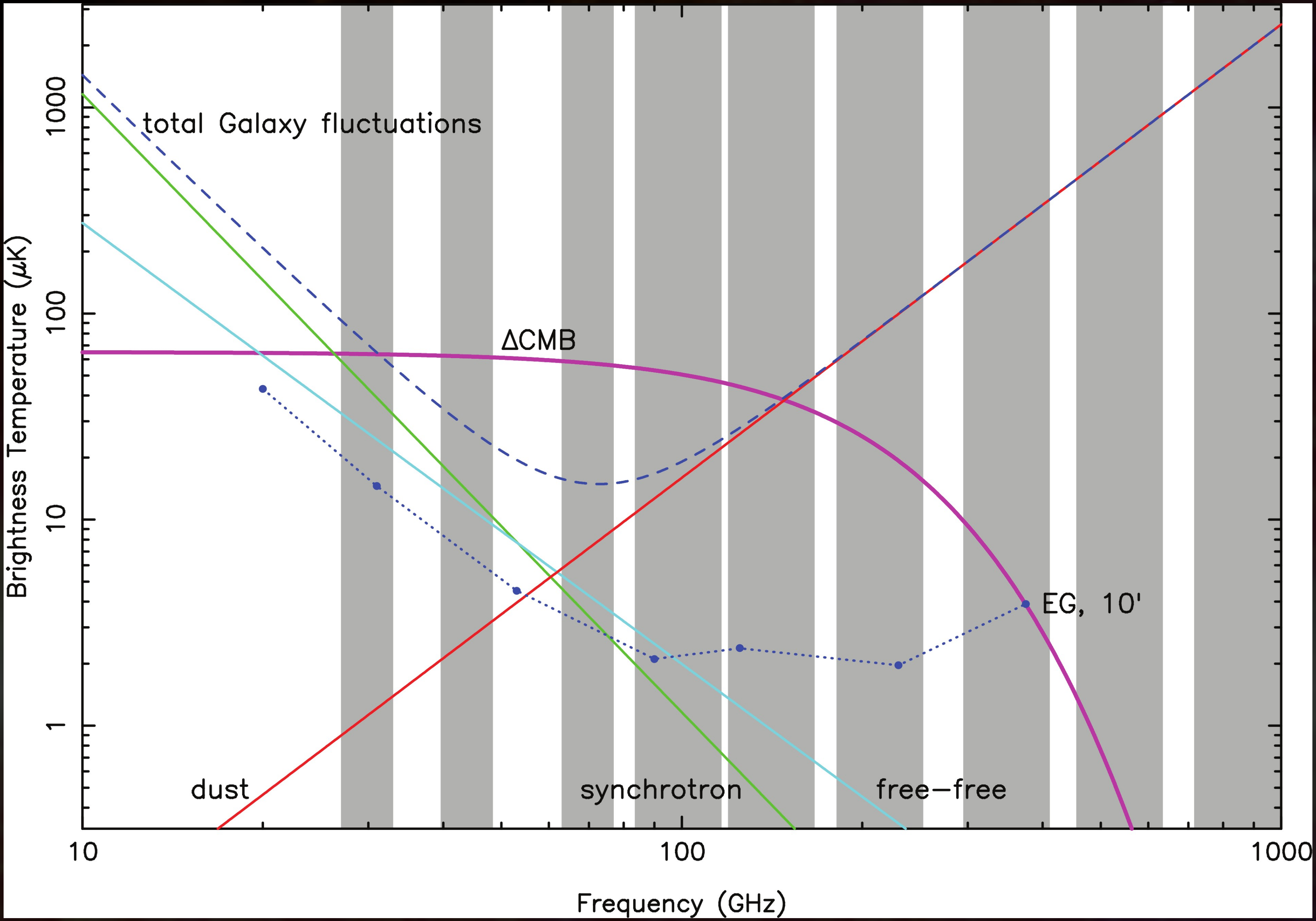
The eye of Planck

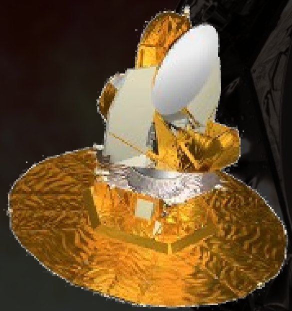



Spider-web
PSB
High Frequency Instrument
Bolometer array cooled at 0.1 K at frequencies
100-857 GHz
Polarisation sensitive at frequencies between 100 and 353 GHz

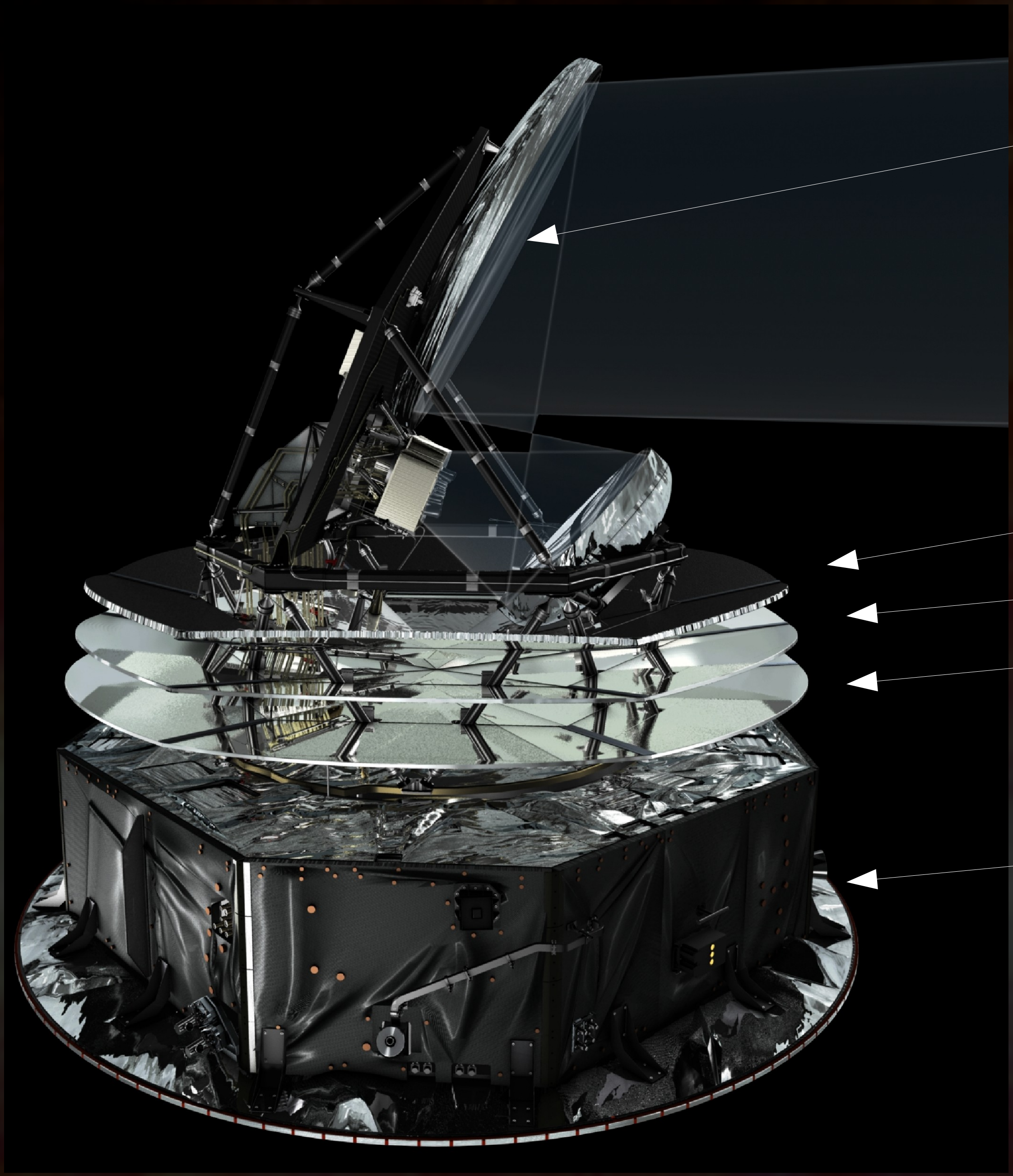

Low Frequency Instrument
Radiometric receiver array cooled to 20 K at frequencies
30-44-70 GHz
All polarisation-sensitive
Single receiver

Why so many frequencies?

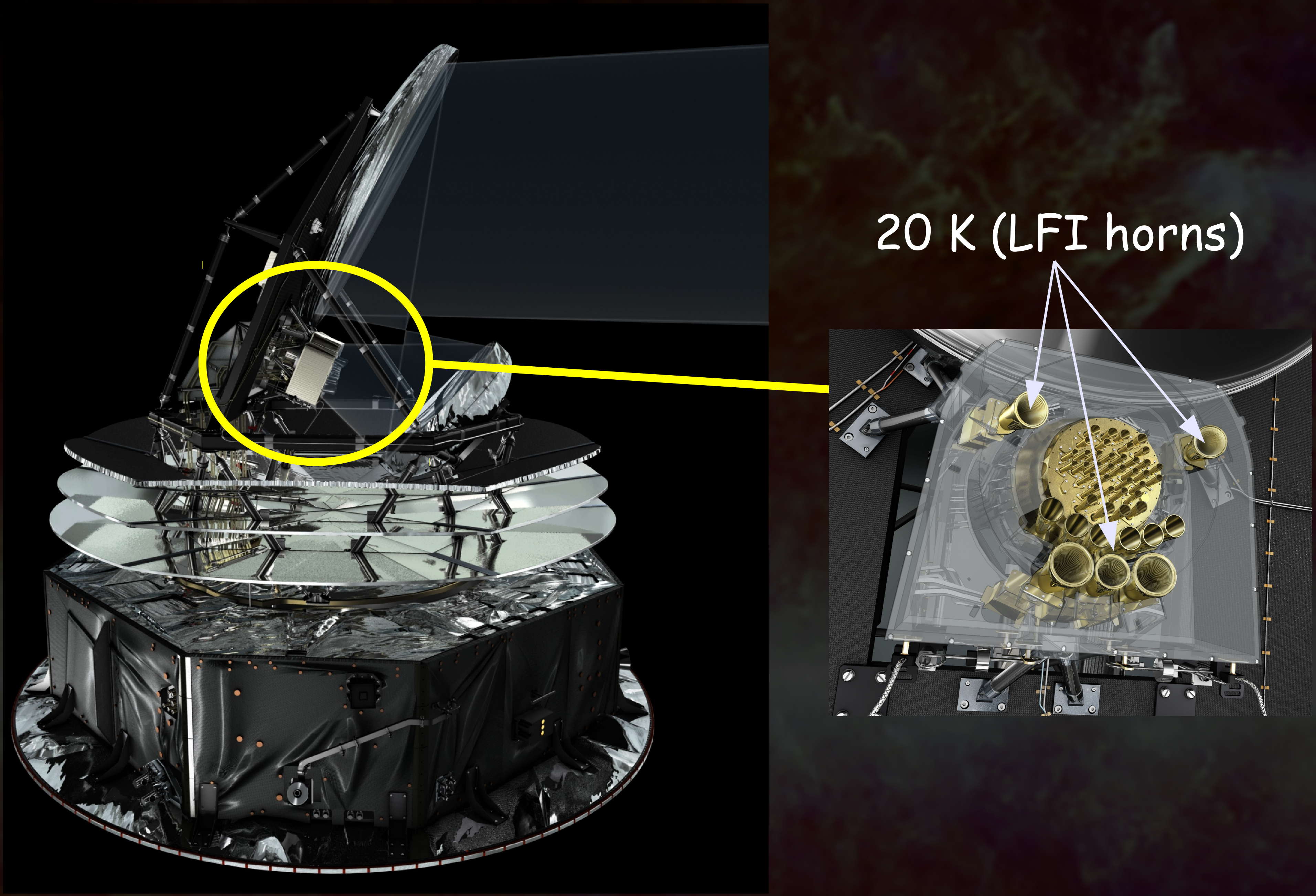


	Angular resolution	Sensitivity	Component separation
	7°	140 μK (0.5 deg pixel)	31.5–90 GHz 3 channels
	0.22°	13 μK (0.5 deg pixel)	22–90 GHz 5 channels
	0.08°	1 μK (0.5 deg pixel)	30–857 GHz 9 channels

Cold is "cool"

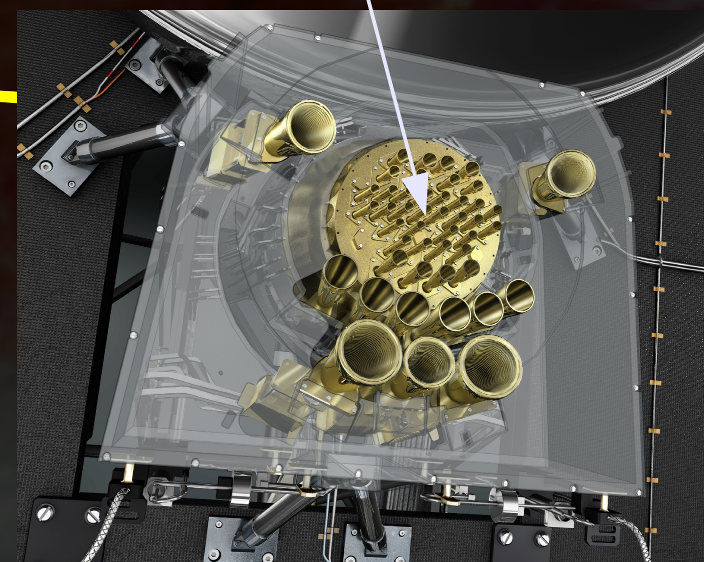


Cold is “cool”

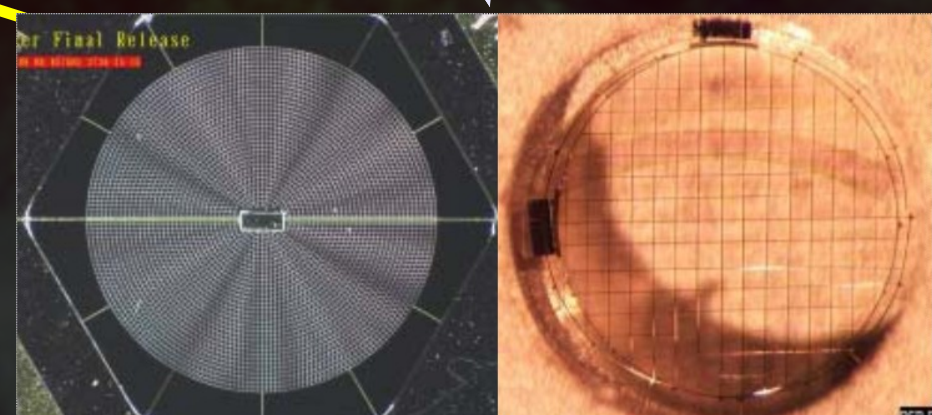


Cold is “cool”

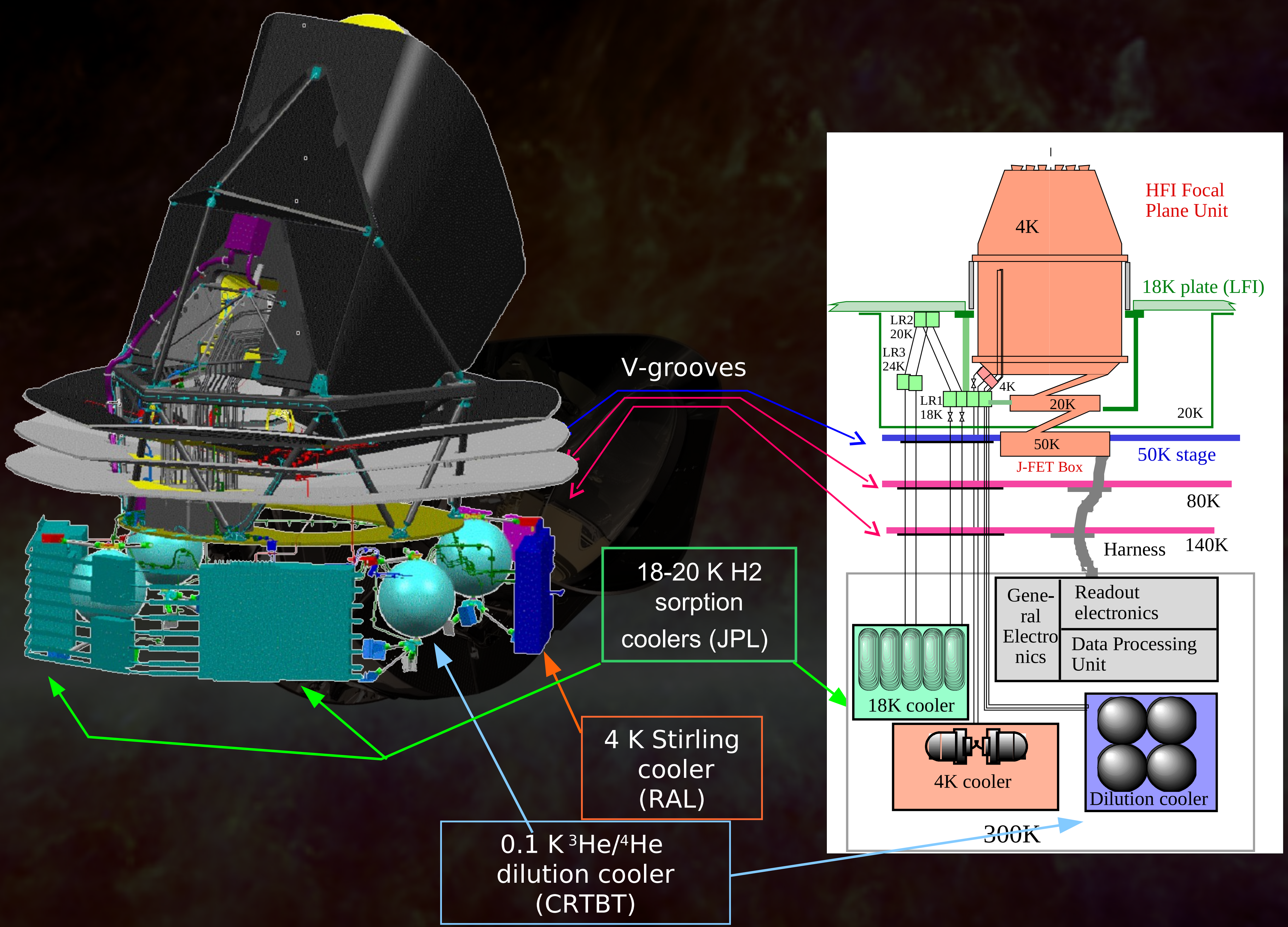
4 K (HFI horns)

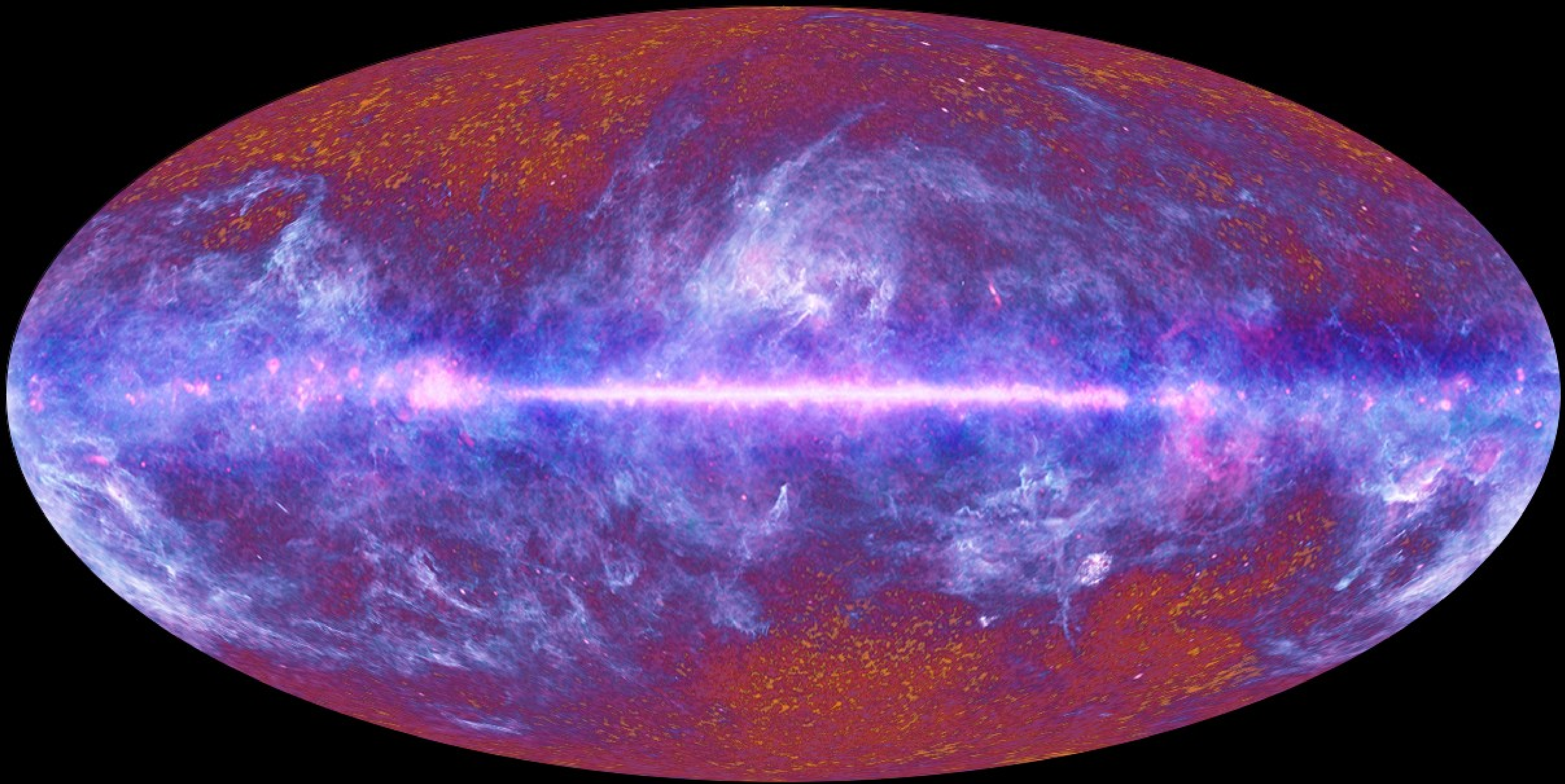


The coldest object in space



The Planck cryogenic system

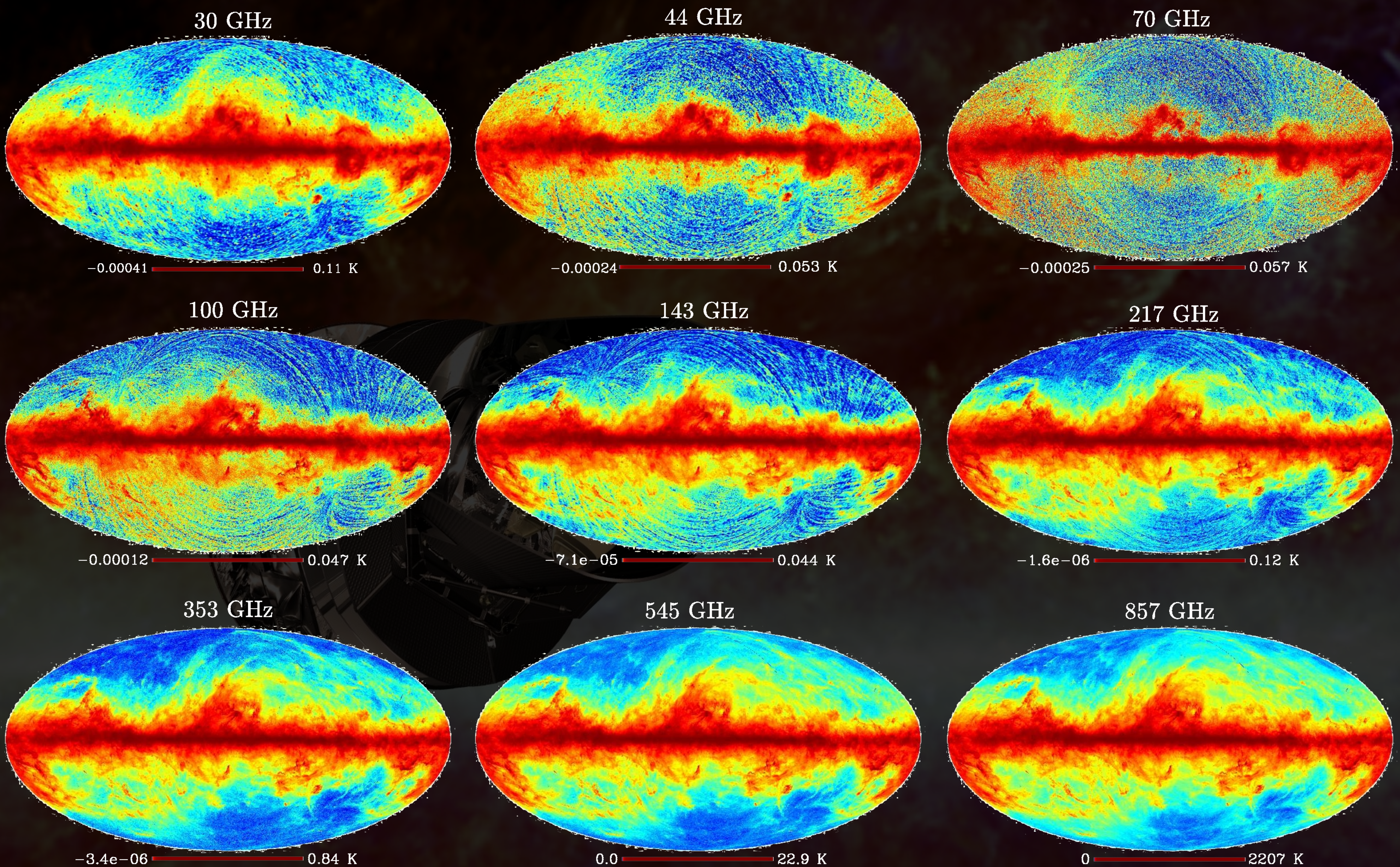




The Planck one-year all-sky survey

esa

The first year Planck maps (no CMB)

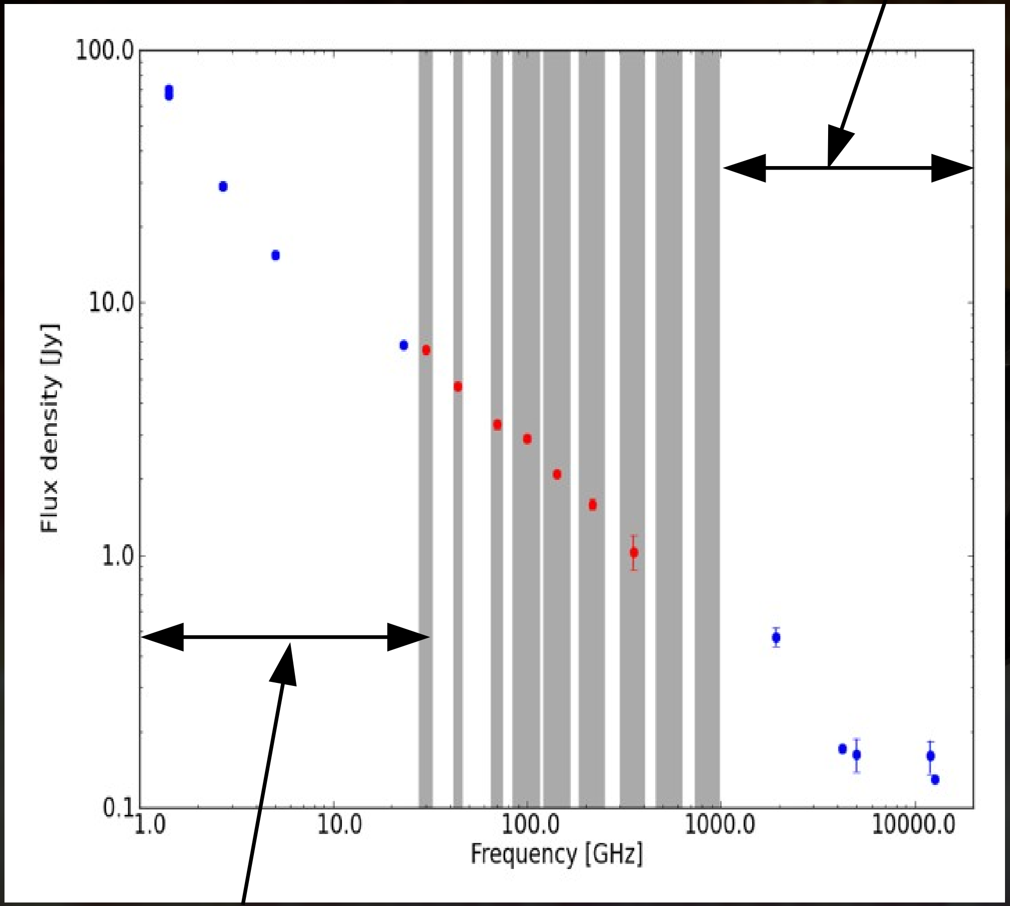


January 2011 - release of the Planck ERCSC

- Widest frequency coverage of any catalogue produced by a single telescope
- More than 15,000 compact sources (both galactic and extra-galactic, radio and infra-red luminous galaxies)
- Includes sample of 189 galaxy clusters
- Early Cold Core Catalogue (915 clouds cooler than 14 kelvin)
- ~ 25 papers in Astronomy & Astrophysics

Pictor-A radio galaxy

- IRAS
- SPITZER

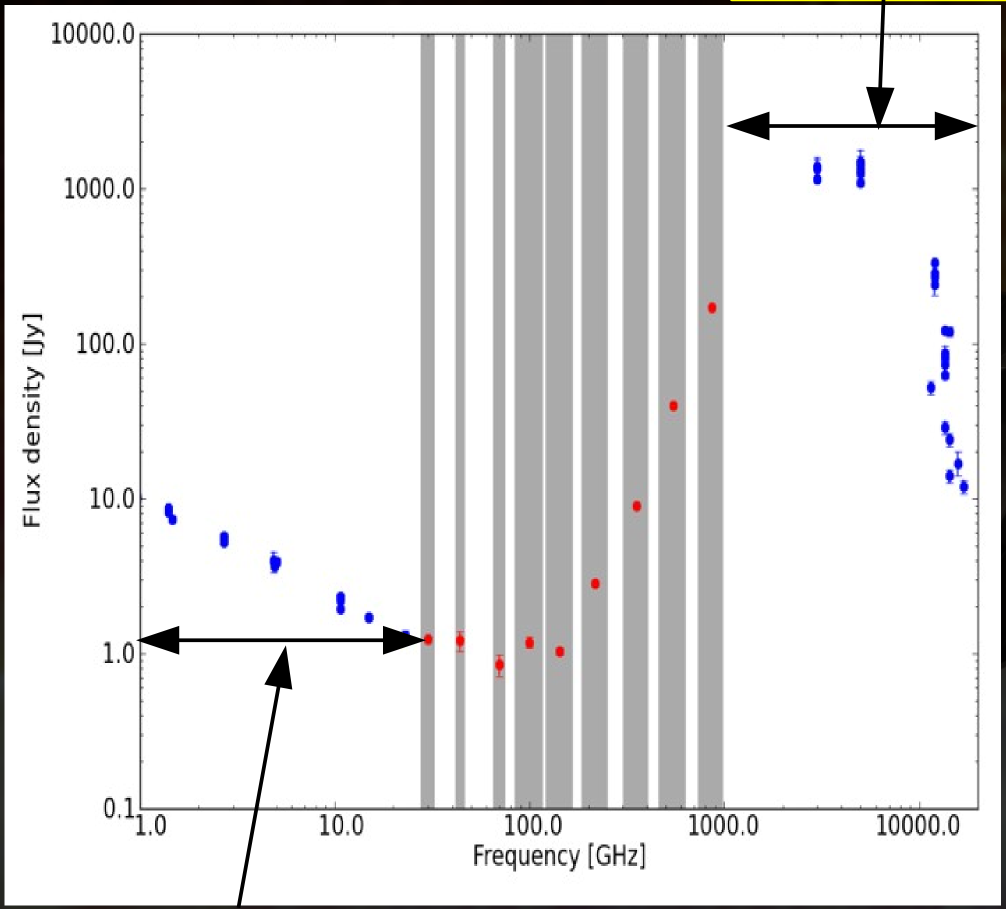


- 64-m Parkes radio telescope (Australia)
- 100-m MPA radio telescope (Germany)
- 43-m NRAO Telescope (USA)
- WMAP

- Bright, nearby radio-galaxy
- Typical power-law spectral distribution due to synchrotron emission from high energetic particles
- Good fit with existing data

M82 starburst galaxy

- IRAS and ISO infrared space telescopes
- 2.3-m Bok Telescope (USA)
- NASA 61-inch Mount Bigelow telescope

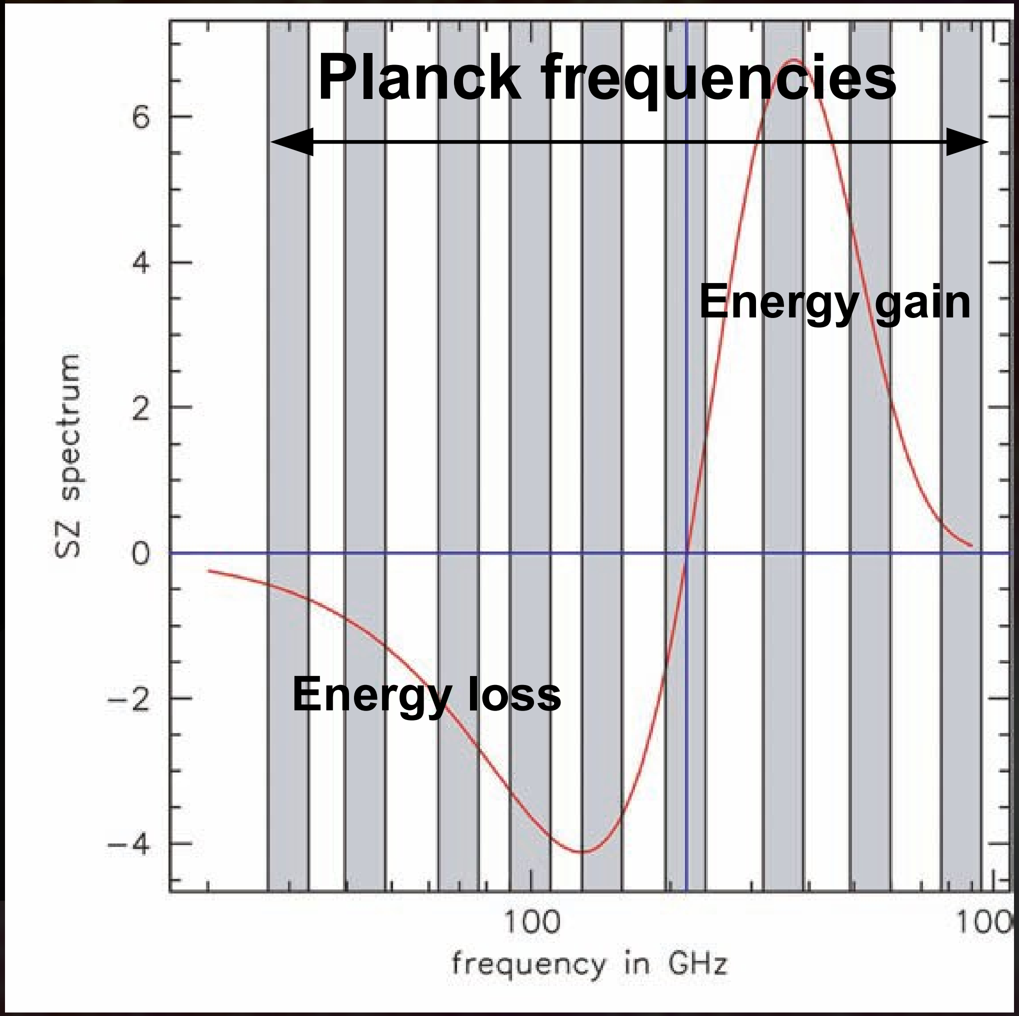


- MRAO interferometer (UK)
- NRAO 43-m, 91-m Robert, 65-m telescopes (USA)
- 100-m MPA radio telescope (Germany)
- TRAO interferometer
- 76-m MKIA Radio Telescope (JBO, UK)
- NRAO Very Large Array (USA)
- WMAP

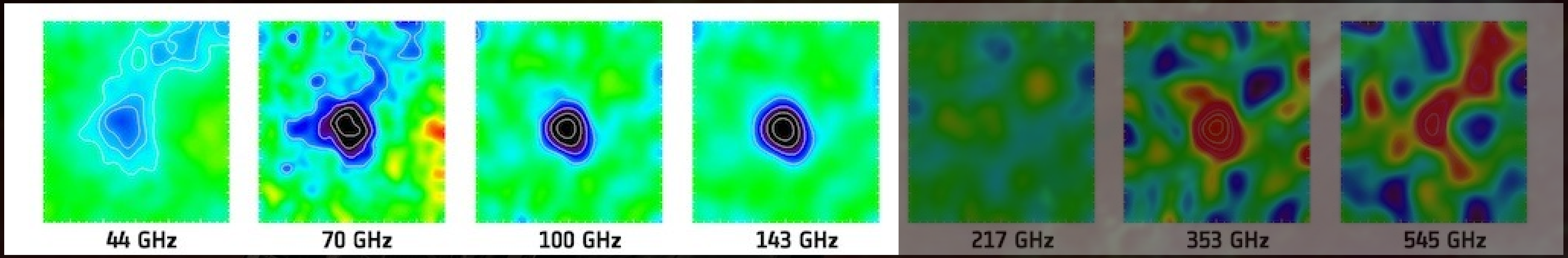
- Galaxies with high stellar formation rates
- Typical bump at high frequencies due to interstellar dust
- Low frequency power-law radio spectrum
- Extremely good fit of the overall shape

Galaxy clusters (SZ effect)

- Galaxy clusters are immersed in hot, rarefied gas (~ 10^6 K)
- CMB photons interact with electrons by inverse Compton scattering
- Photons gain energy at high frequencies and loose energy at low frequencies
- 189 candidate clusters detected with one year of Planck data

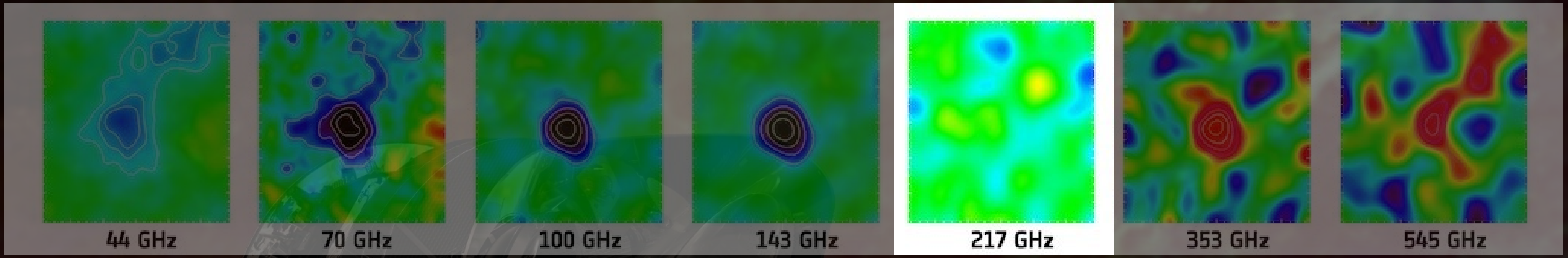


Galaxy clusters (SZ effect)



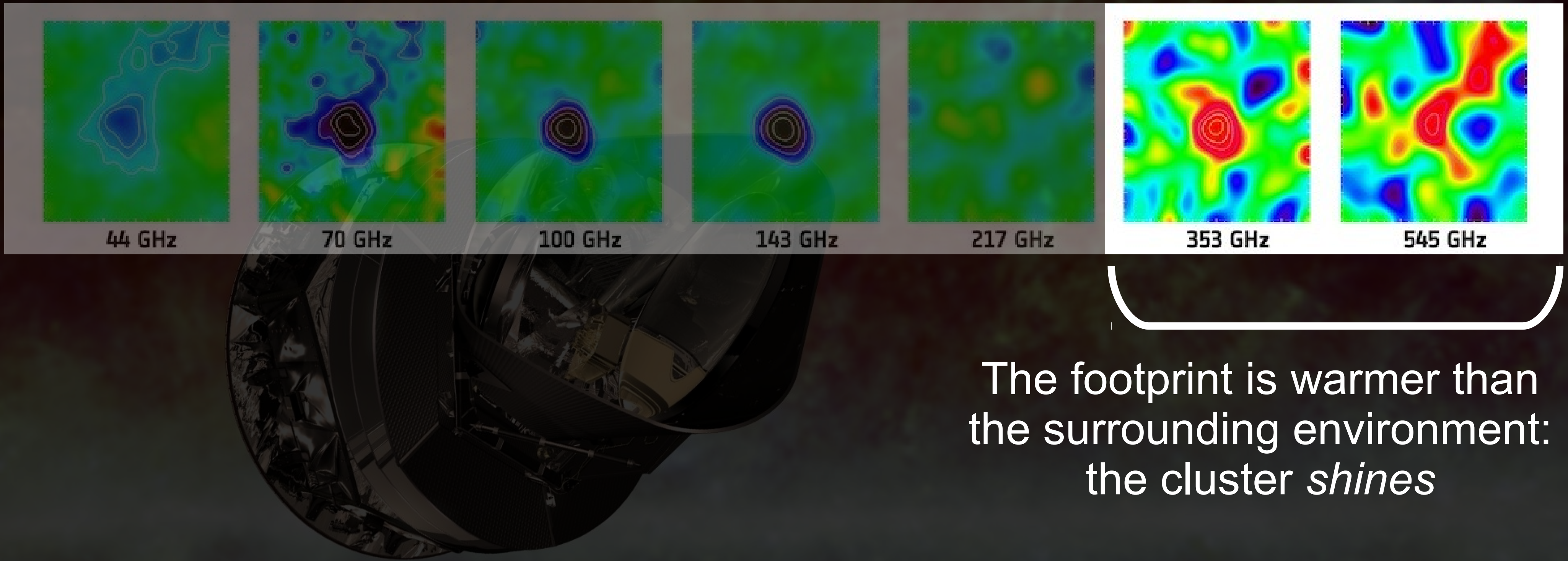
The footprint is colder than the surrounding environment: the cluster casts a *shadow*

Galaxy clusters (SZ effect)



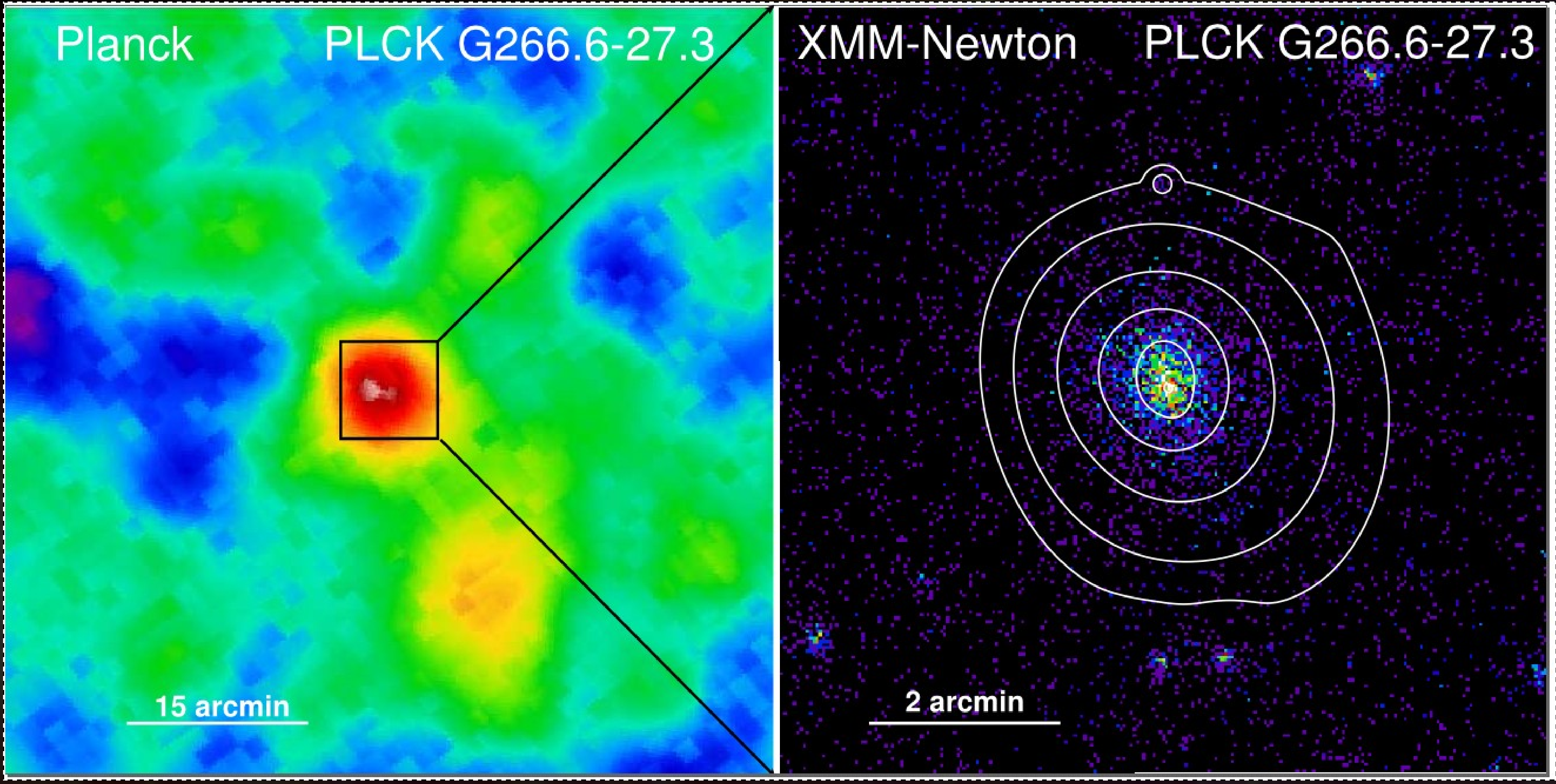
A 217 GHz the cluster is *invisible*

Galaxy clusters (SZ effect)

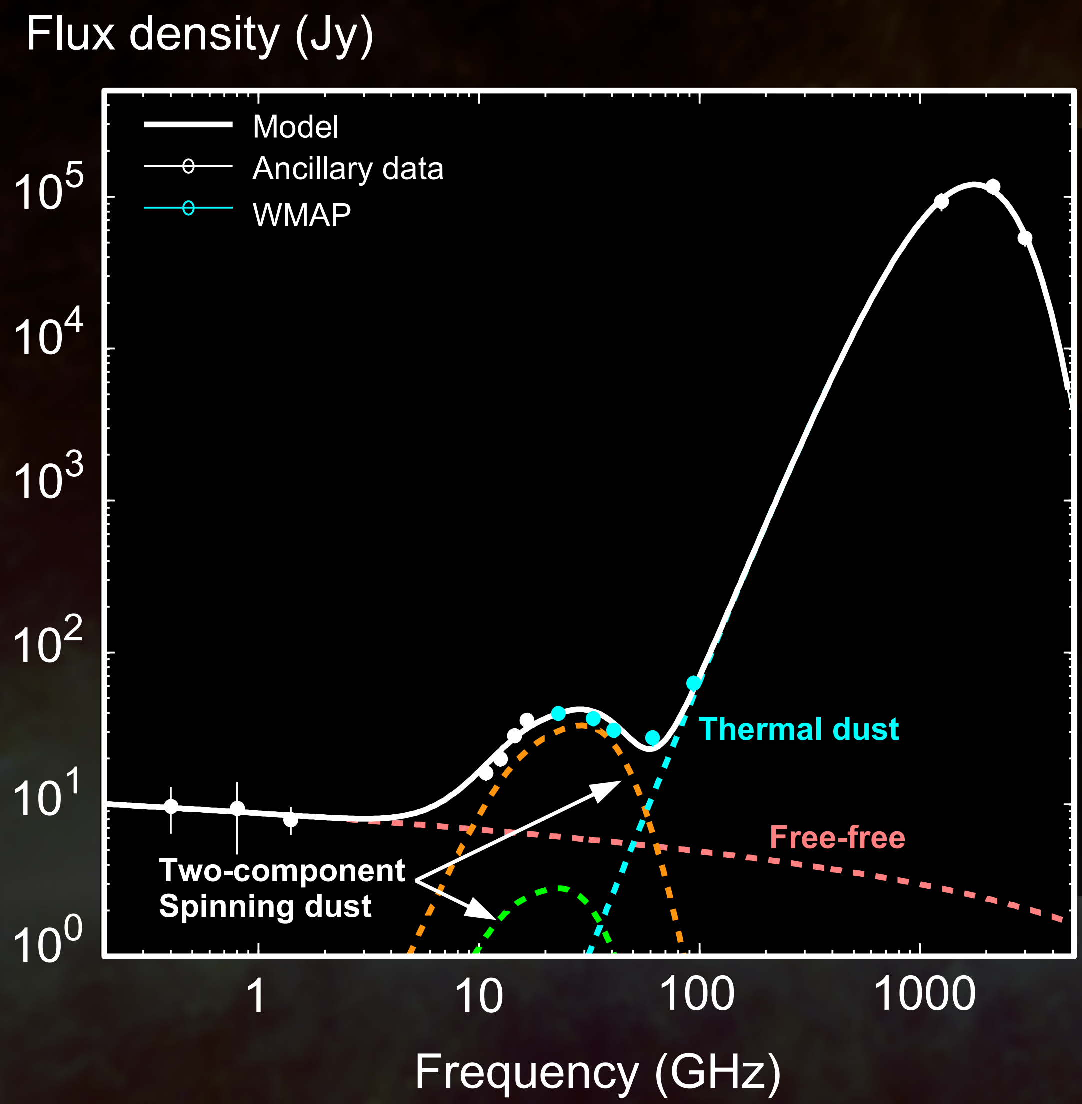


The footprint is warmer than the surrounding environment: the cluster *shines*

PLCK G266.6−27.3
A massive galaxy cluster at z~1

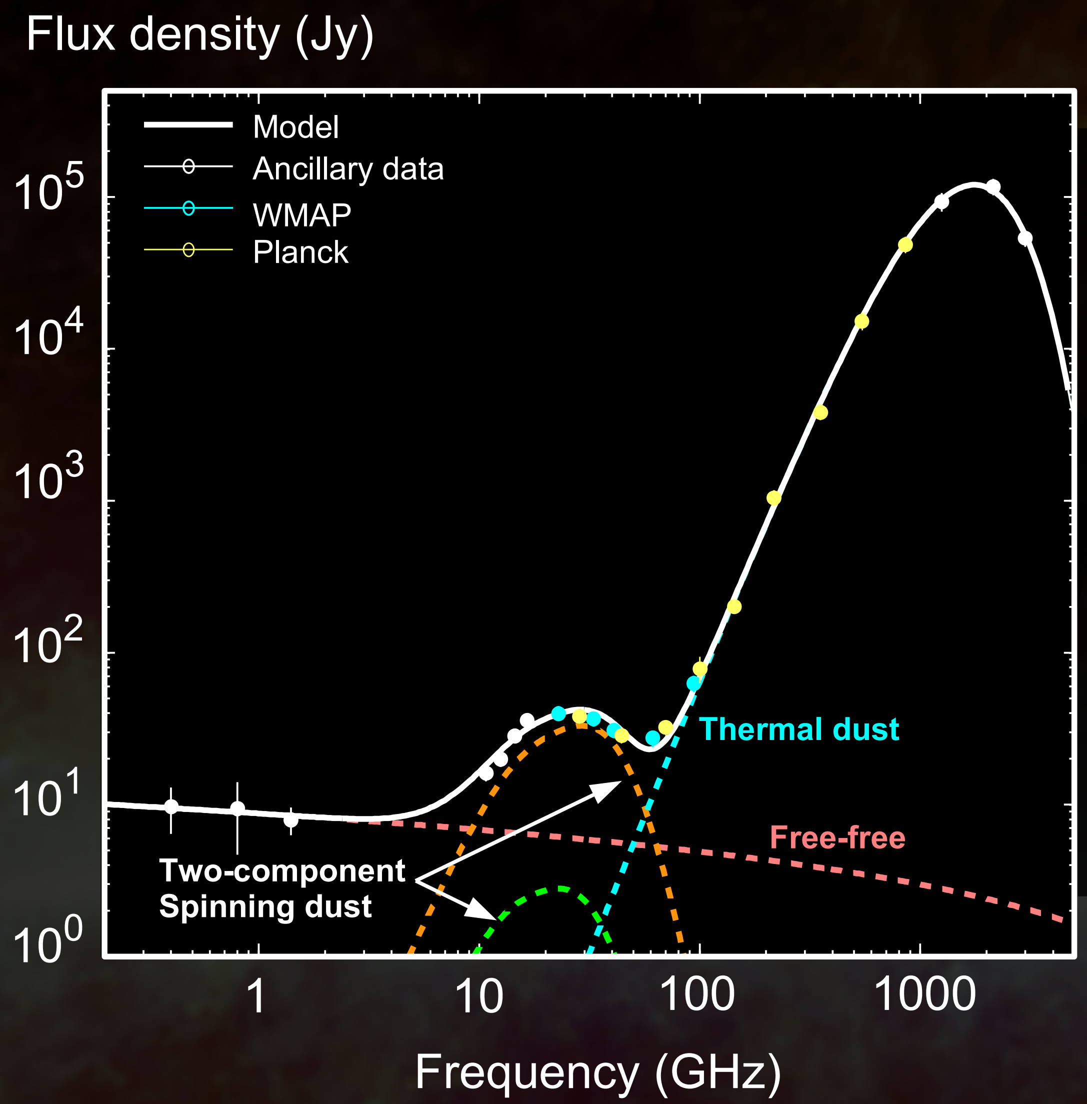


Anomalous microwave emission



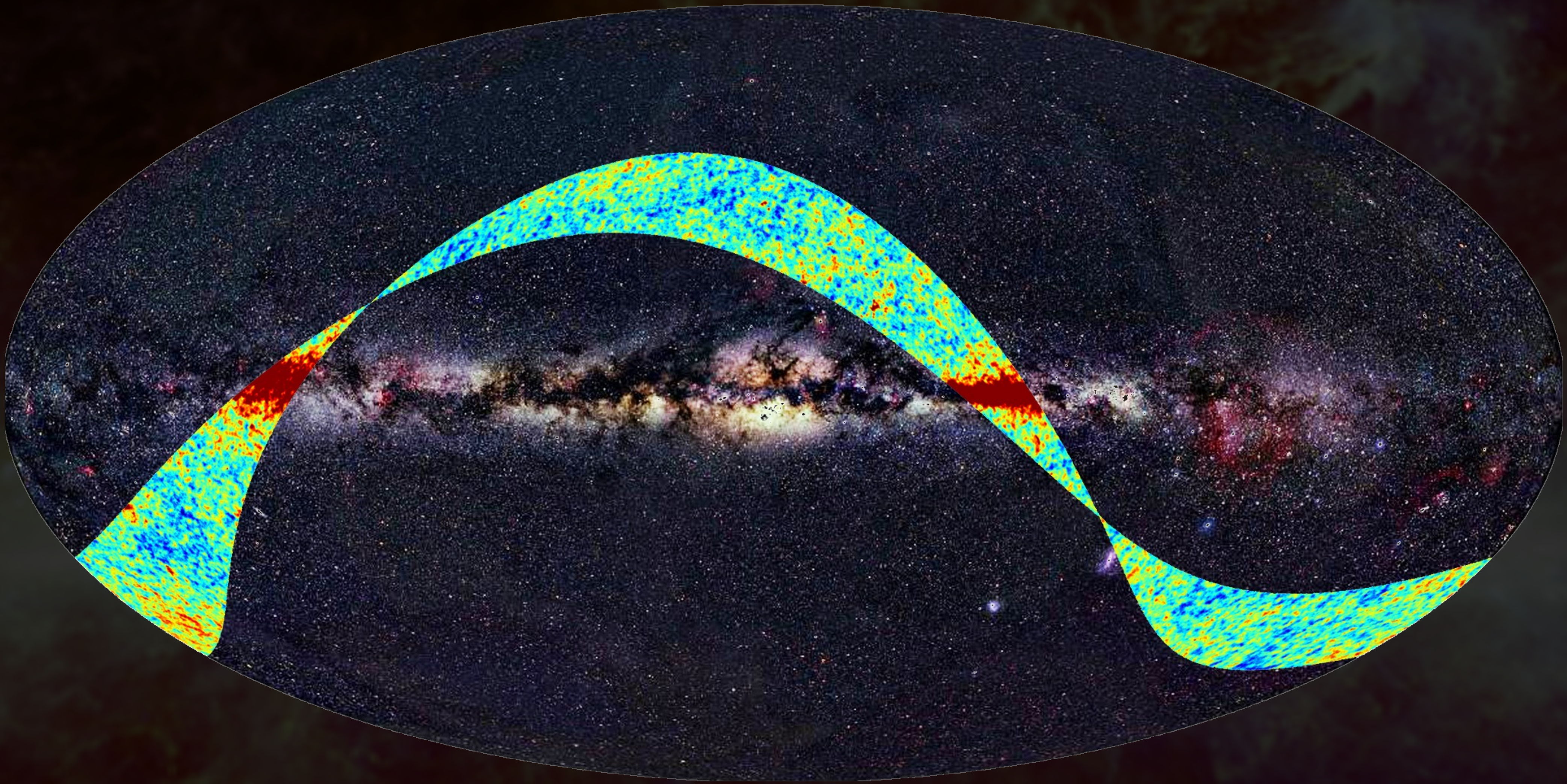
- Anomalous microwave emission: not explained by synchrotron, free-free, or thermal dust emission
- correlated with far infrared (FIR) emission associated with thermal emission from dust grains
- “Spinning dust hypothesis: electric dipole radiation from small rapidly spinning dust grains
- Theoretical models predict a peaked spectrum, in the range 10–150 GHz

Anomalous microwave emission

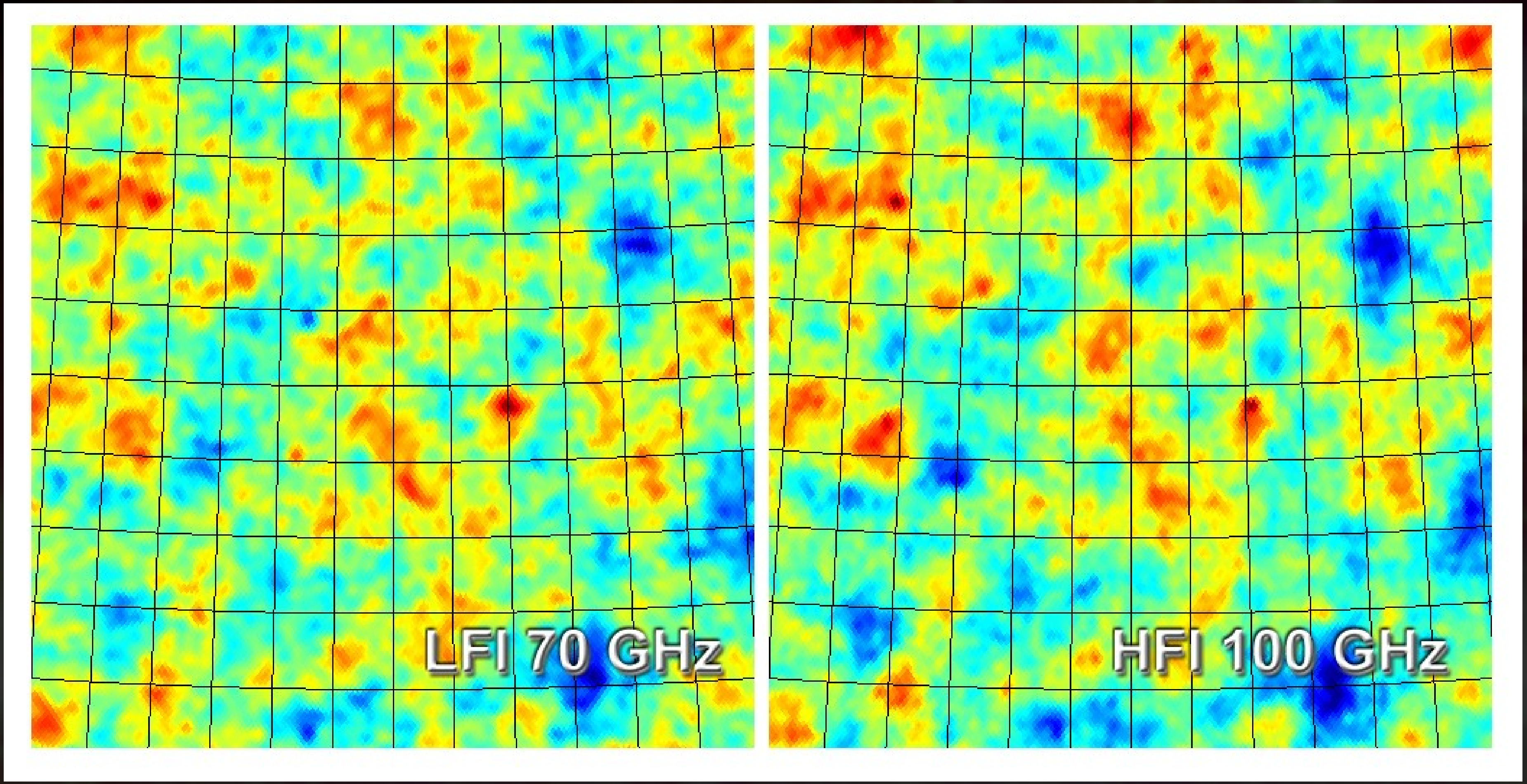


- Anomalous microwave emission: not explained by synchrotron, free-free, or thermal dust emission
- correlated with far infrared (FIR) emission associated with thermal emission from dust grains
- “Spinning dust hypothesis: electric dipole radiation from small rapidly spinning dust grains
- Theoretical models predict a peaked spectrum, in the range 10–150 GHz

The Planck "first light"
(the first 14 days)



The Planck "first light"
(the first 14 days)



Full sky in January 2013

Conclusions

- Planck has started its fifth sky survey as we write. Its focal plane instruments have confirmed and maintained their predicted performance.
- The first public data release has provided a full-sky catalogue of compact, unresolved sources in a largely unexplored frequency range.
  - New galaxy clusters,
  - Stellar formation in cold gas regions
  - Anomalous microwave emission
- First release of cosmological data and results is foreseen by January 2013, and a second one, based on the complete Planck dataset, will happen in early 2014.
- The best still has to come.

Planck Collaboration: ~400 scientists!

Planck Core Team