

# L'Univers révélé par le satellite Planck

Hervé Dole

au nom de la collaboration Planck

Institut d'Astrophysique Spatiale, Orsay, France

Université Paris Sud & CNRS

Institut Universitaire de France

<http://www.ias.u-psud.fr/dole/>



Comprendre le monde,  
construire l'avenir®



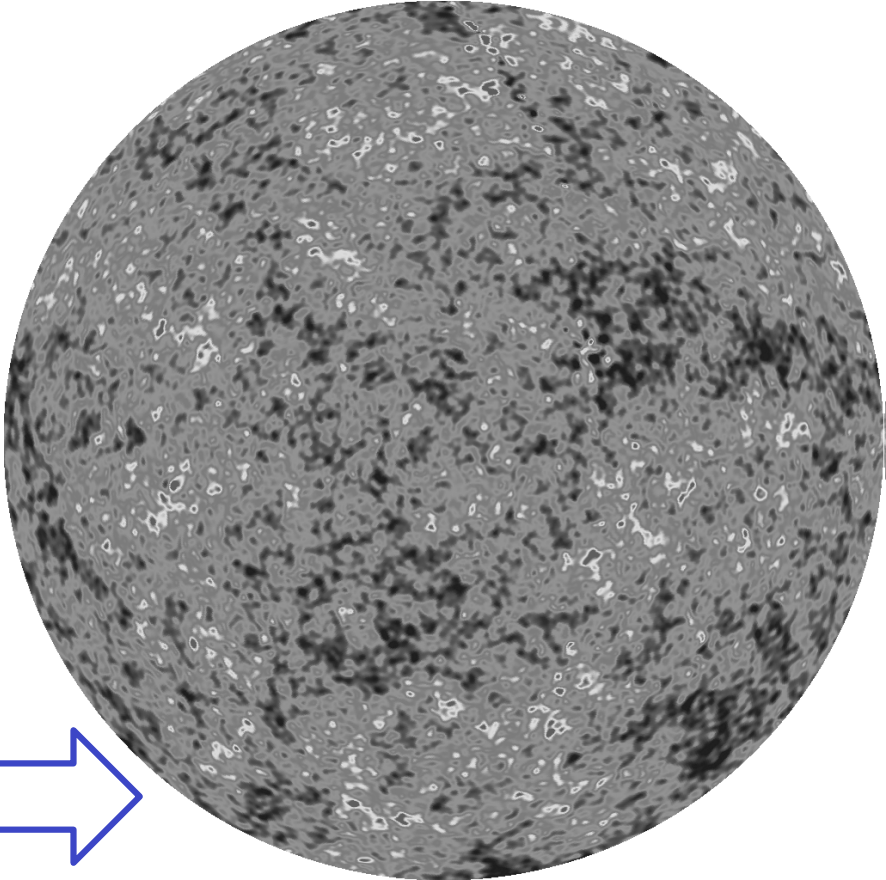
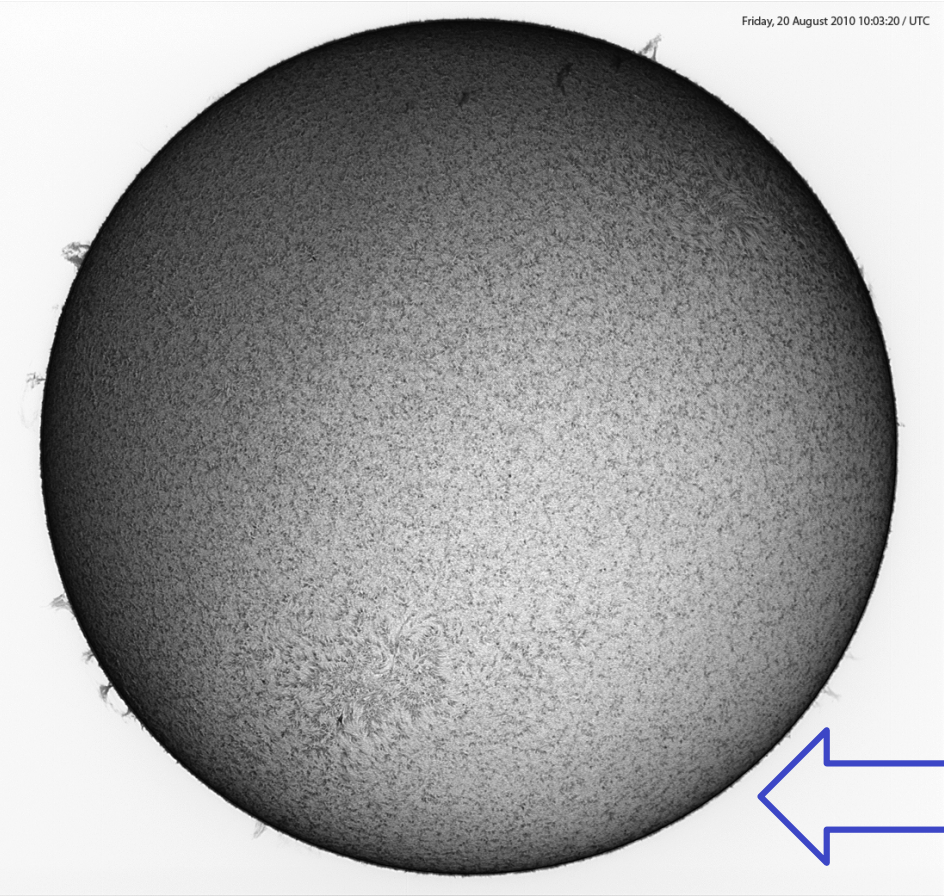
# notre ambition scientifique

---

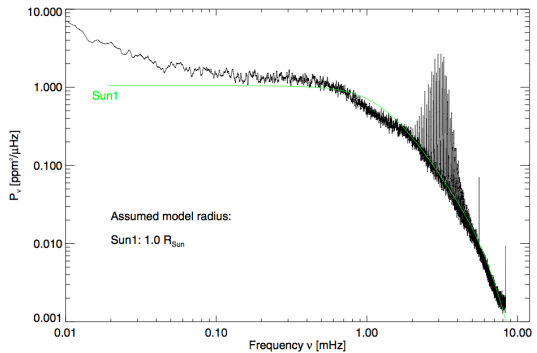
comprendre la **structure**, l'**évolution** et les **lois physiques fondamentales** régissant l'**univers** et ses **constituants**.

# un exemple

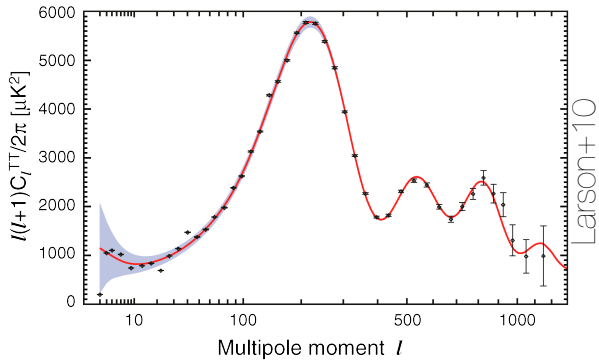
F. Noel - AAV 2010



WMAP



Ludwig+09



Hervé Dole, IAS

13 - Plaisir

Fig. 2. Power spectra of disk-integrated photometric fluctuations for the Sun: the predicted background signal of model Sun1 (green/grey solid line) and observational data from SOHO/VIRGO (black solid line)

# notre ambition scientifique

---

comprendre la **structure**, l'**évolution** et les **lois physiques fondamentales** régissant l'**univers** et **ses constituants**.

- conception, développement, réalisation, tests, étalonnage d'**instruments**
  - opération des **instruments**
  - analyse et interprétation des **données**
  - archivage, diffusion de **produits scientifiques** à haute valeur ajoutée
  - développement de **modèles**, simulations, avancées théoriques
  - confrontation **théorie+modèles** vs **données**
- 
- un des 5 grands laboratoires spatiaux en France
  - spécialisé dans **l'instrumentation spatiale**, **analyse de données**, **modélisation/théorie**

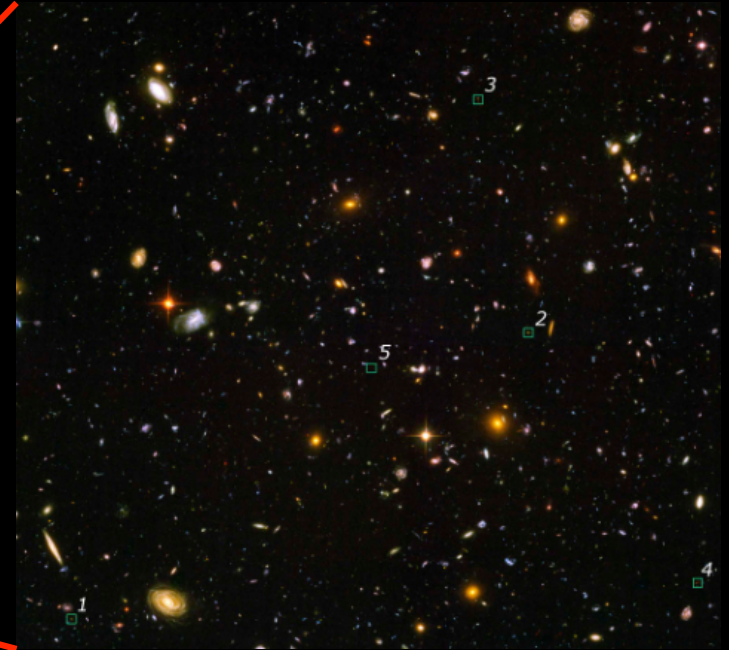
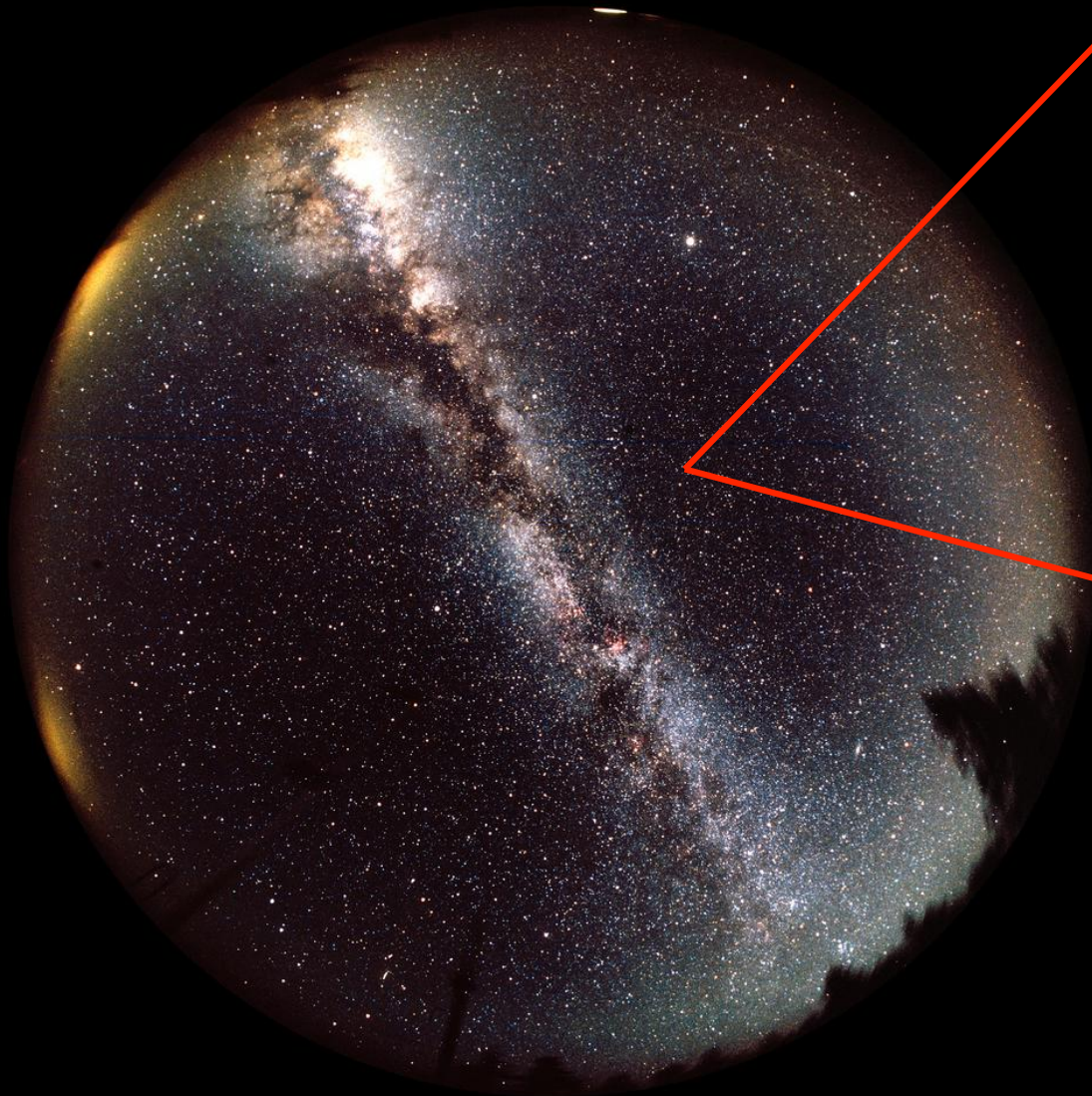
The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada



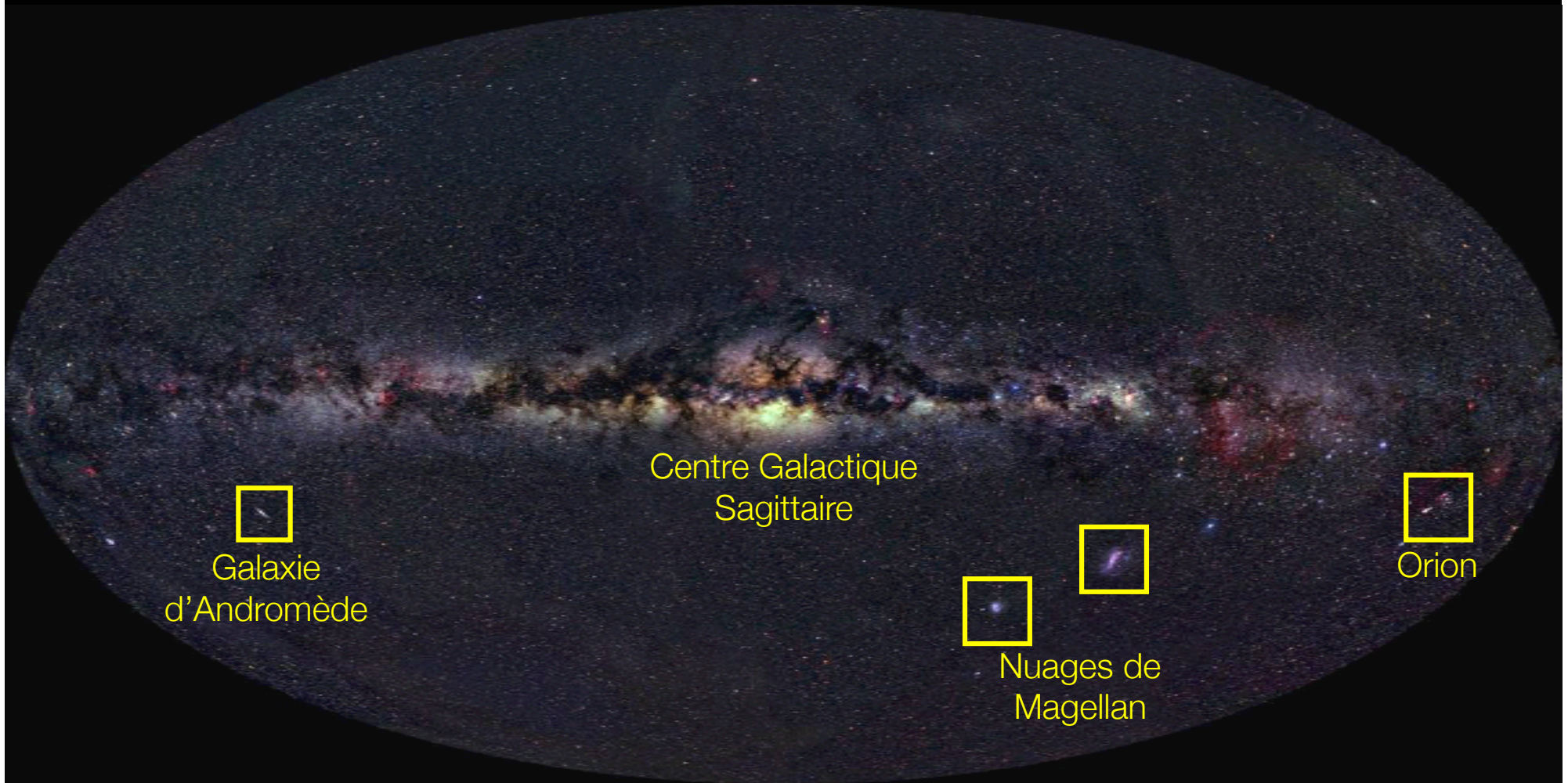
**Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.**

# pourquoi la nuit est-elle noire ?

---



# the sky: visible wavelengths



Galaxie  
d'Andromède

Centre Galactique  
Sagittaire

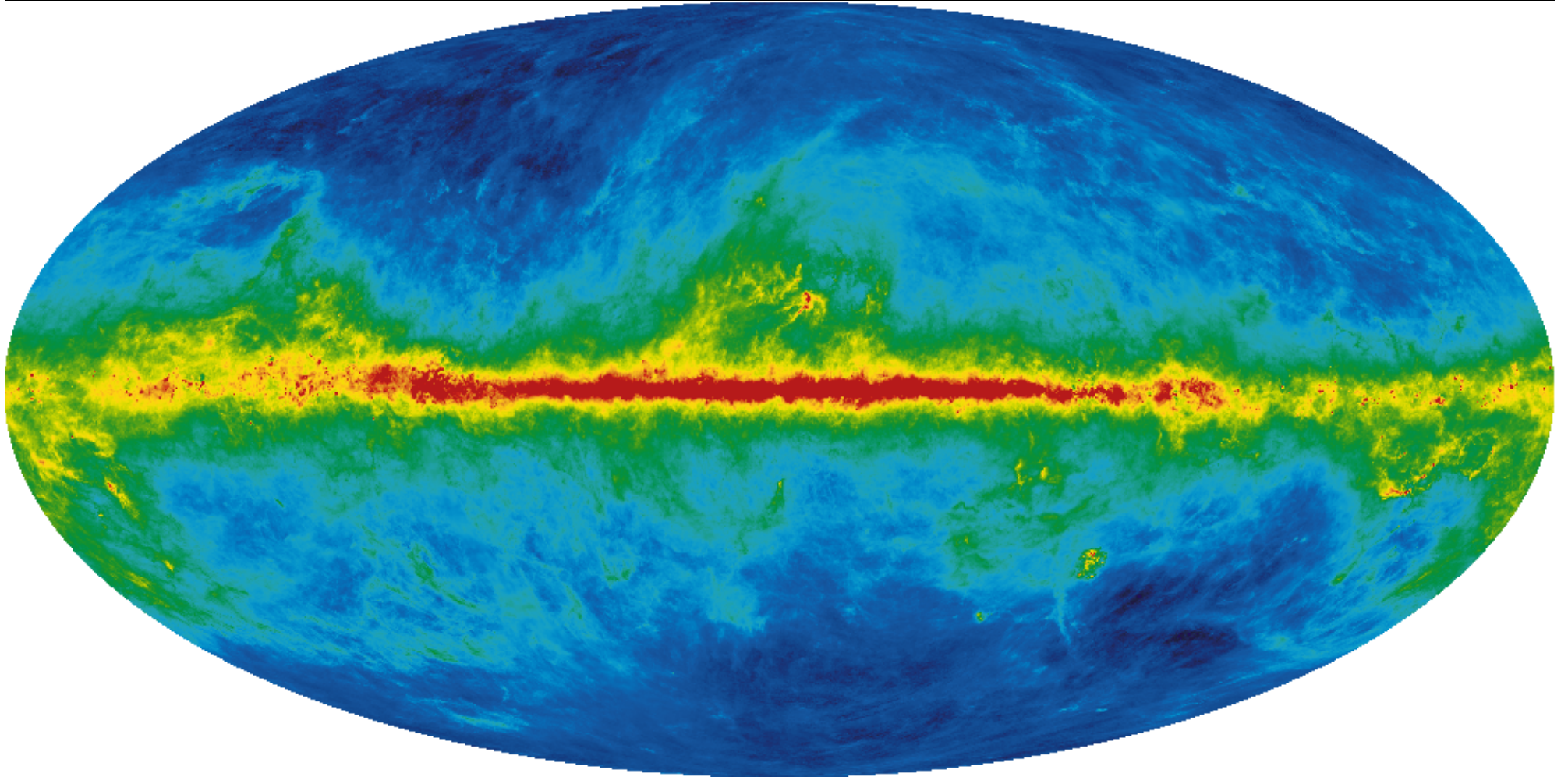
Nuages de  
Magellan

Orion

Axel Mellinger

[http://canopus.physik.uni-potsdam.de/~axm/mwpan/mwpan\\_web.html](http://canopus.physik.uni-potsdam.de/~axm/mwpan/mwpan_web.html)

# the sky: far-infrared

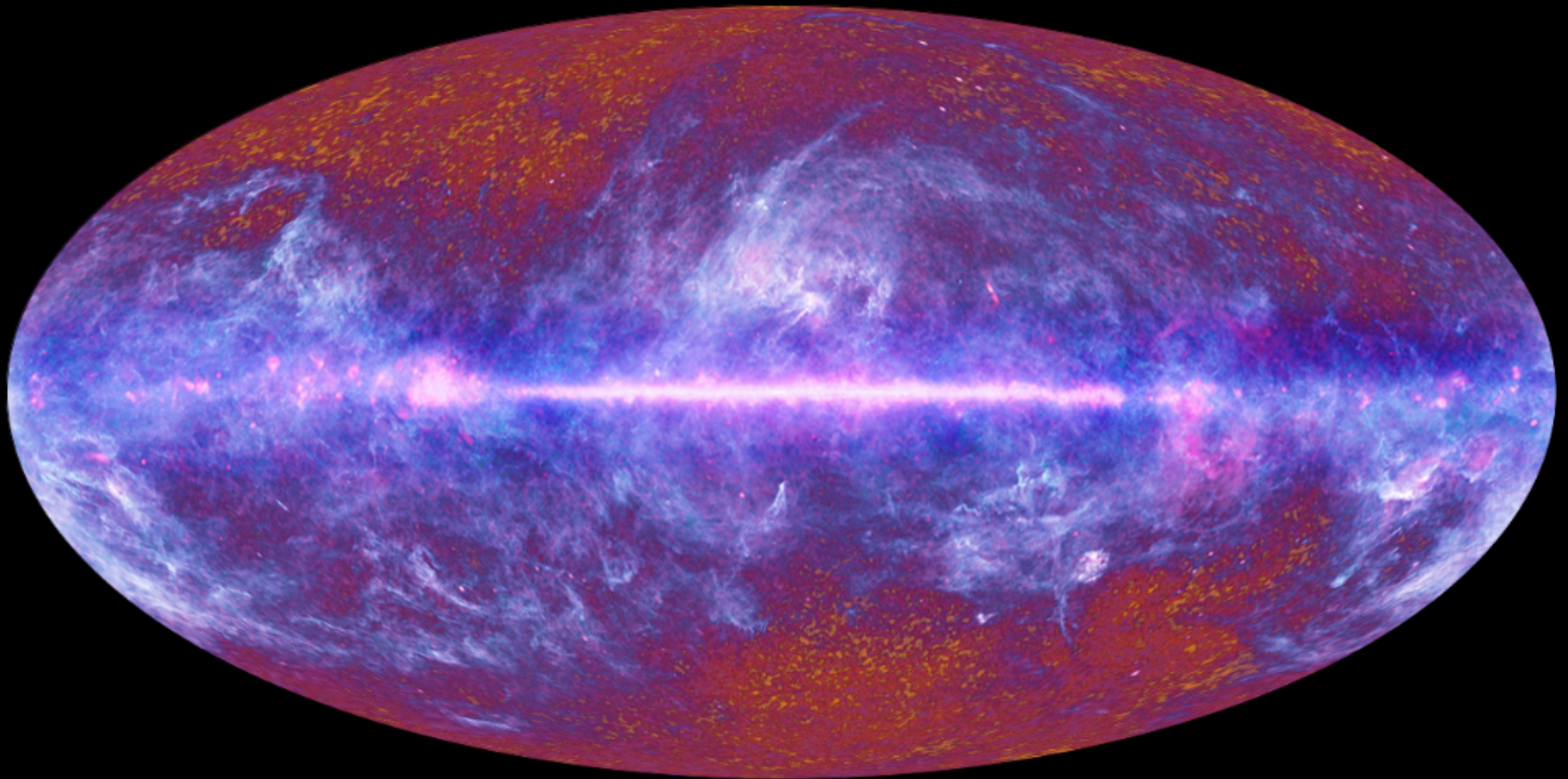


IRAS 100um IRIS



# the sky: microwaves

---



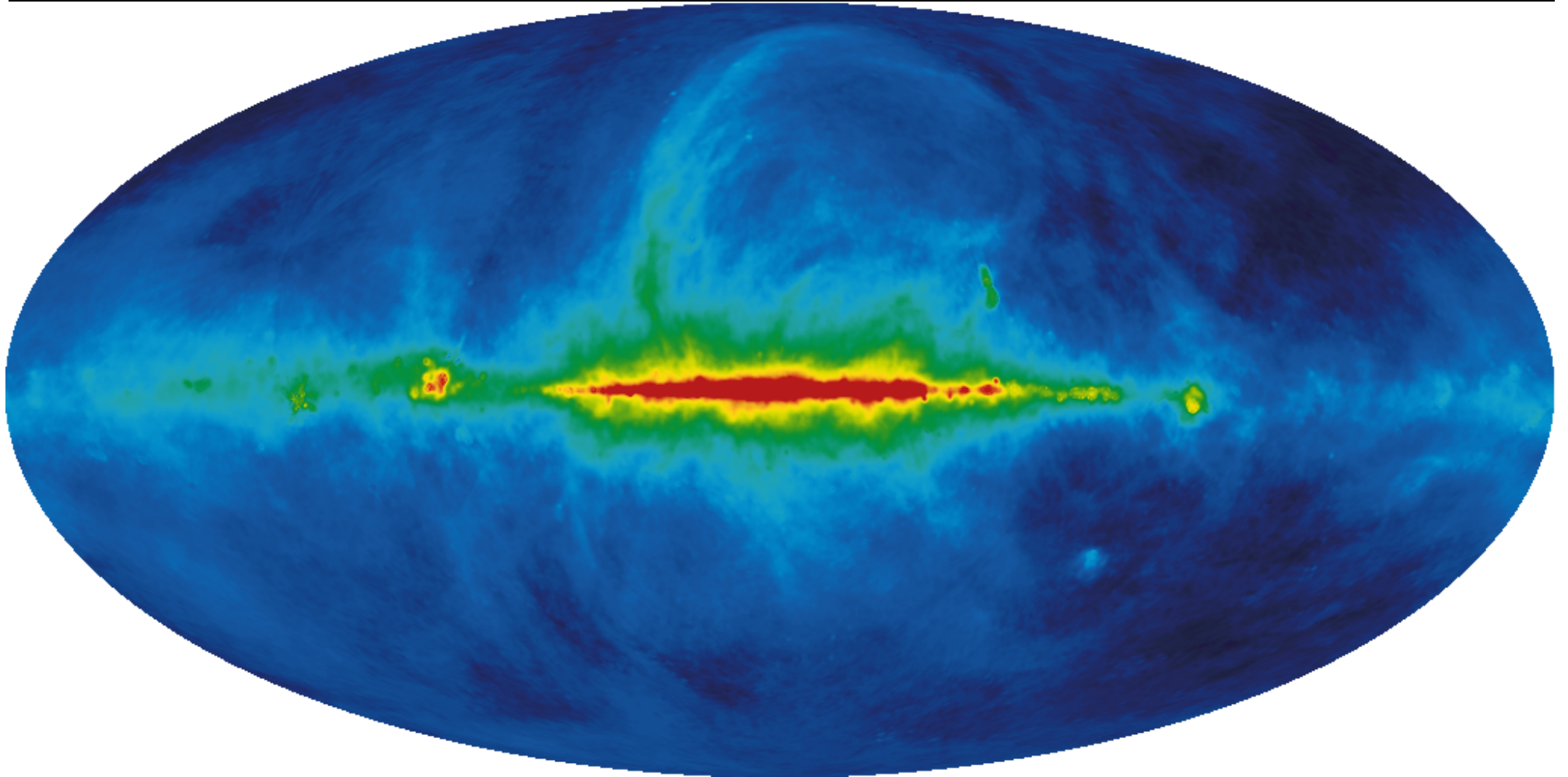
The PLANCK one-year all-sky survey



[c] ESA, HFI and LFI consortia, July 2010

# the sky: radio

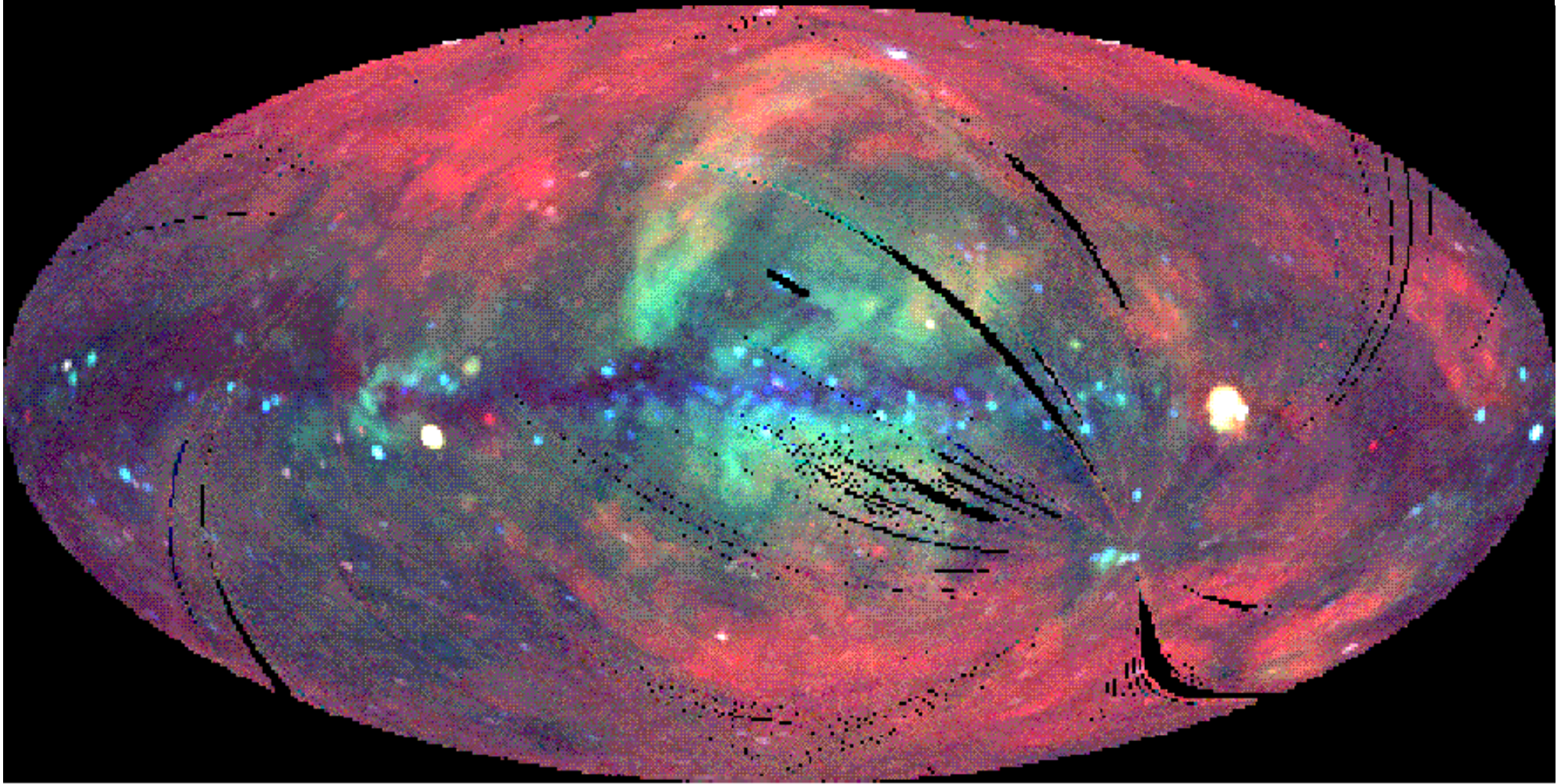
---



21 cm Leiden/Parkes

# the sky: X-rays

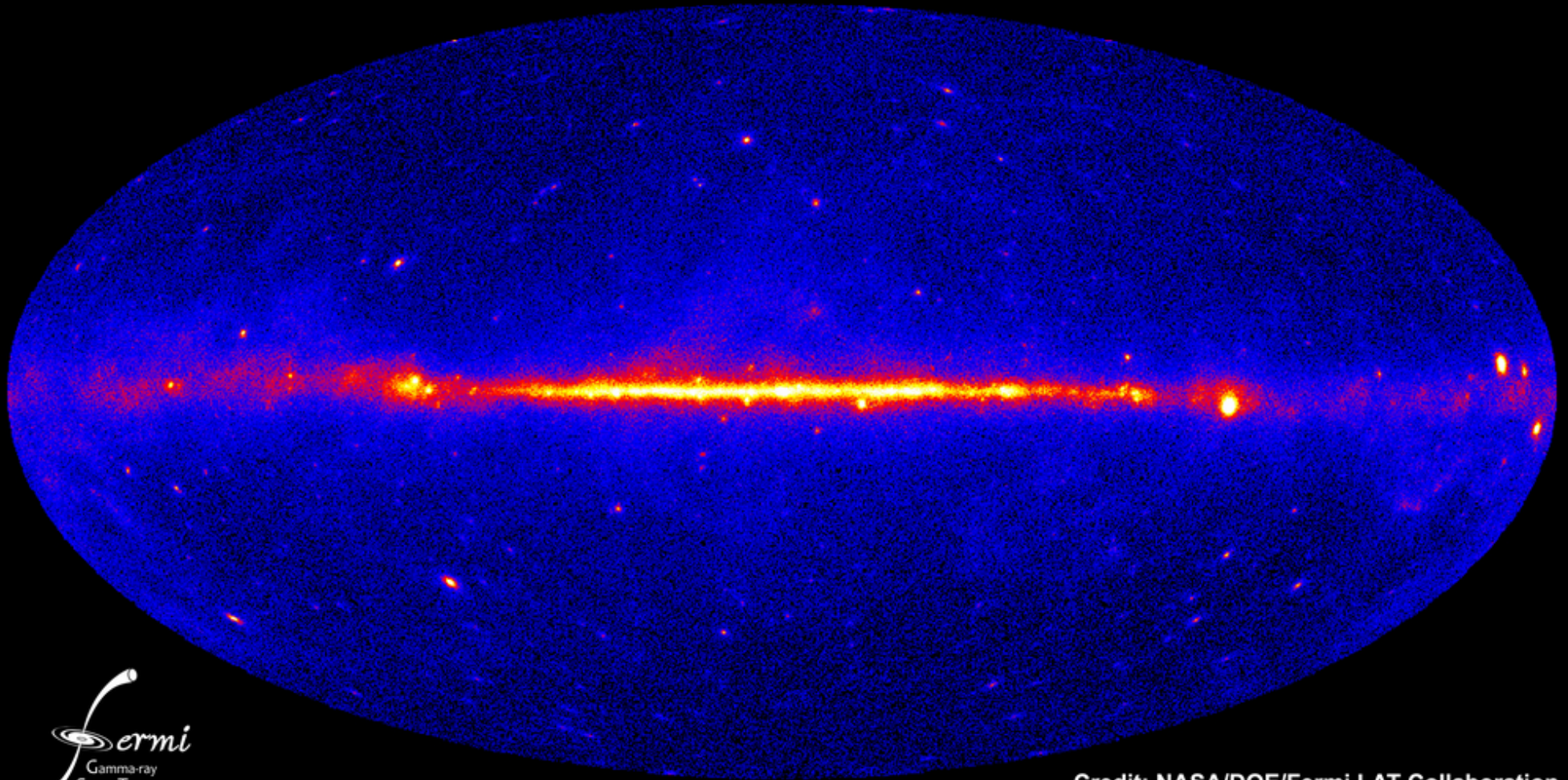
---



ROSAT

# the sky: gamma-rays

---

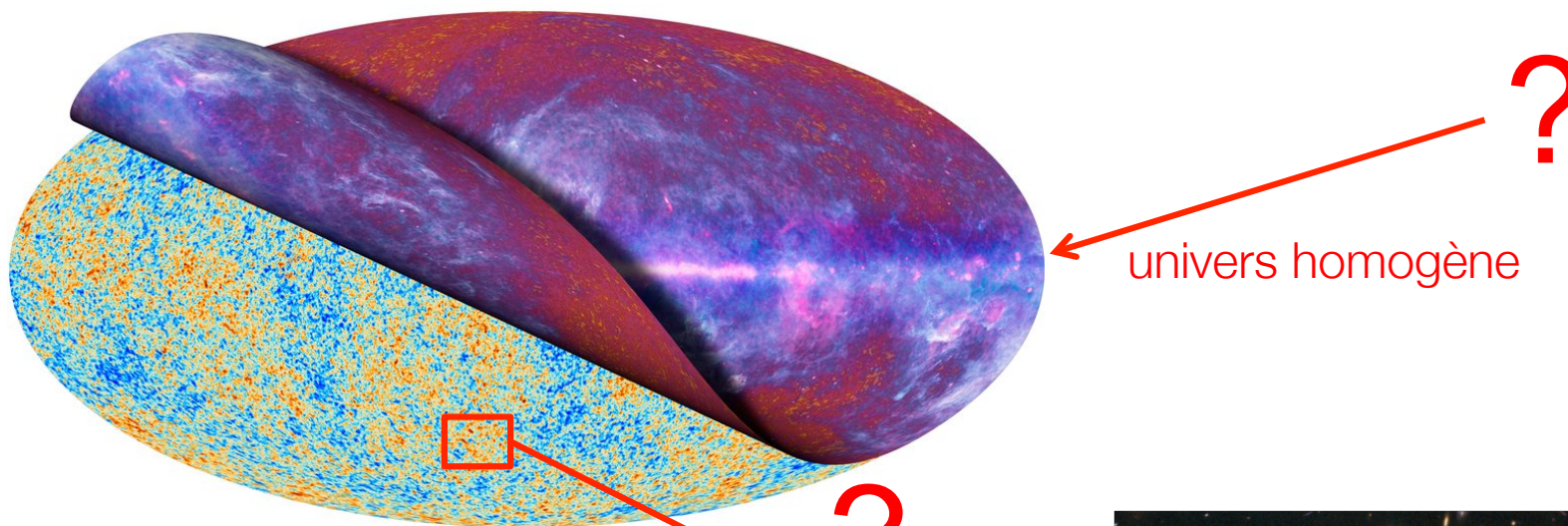


Credit: NASA/DOE/Fermi LAT Collaboration

FERMI LAT

# les deux grandes questions

---

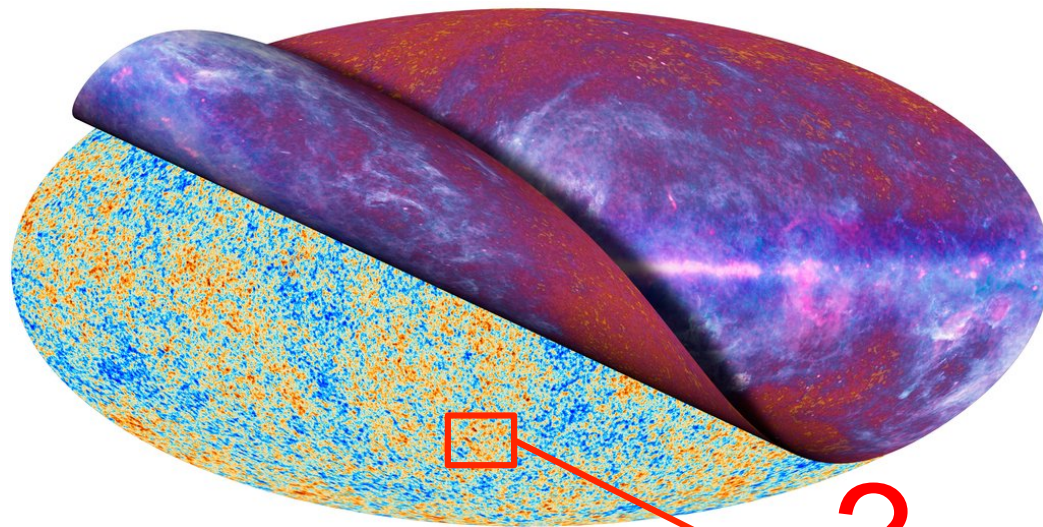


univers homogène

univers inhomogène,  
structuré



# les deux grandes questions



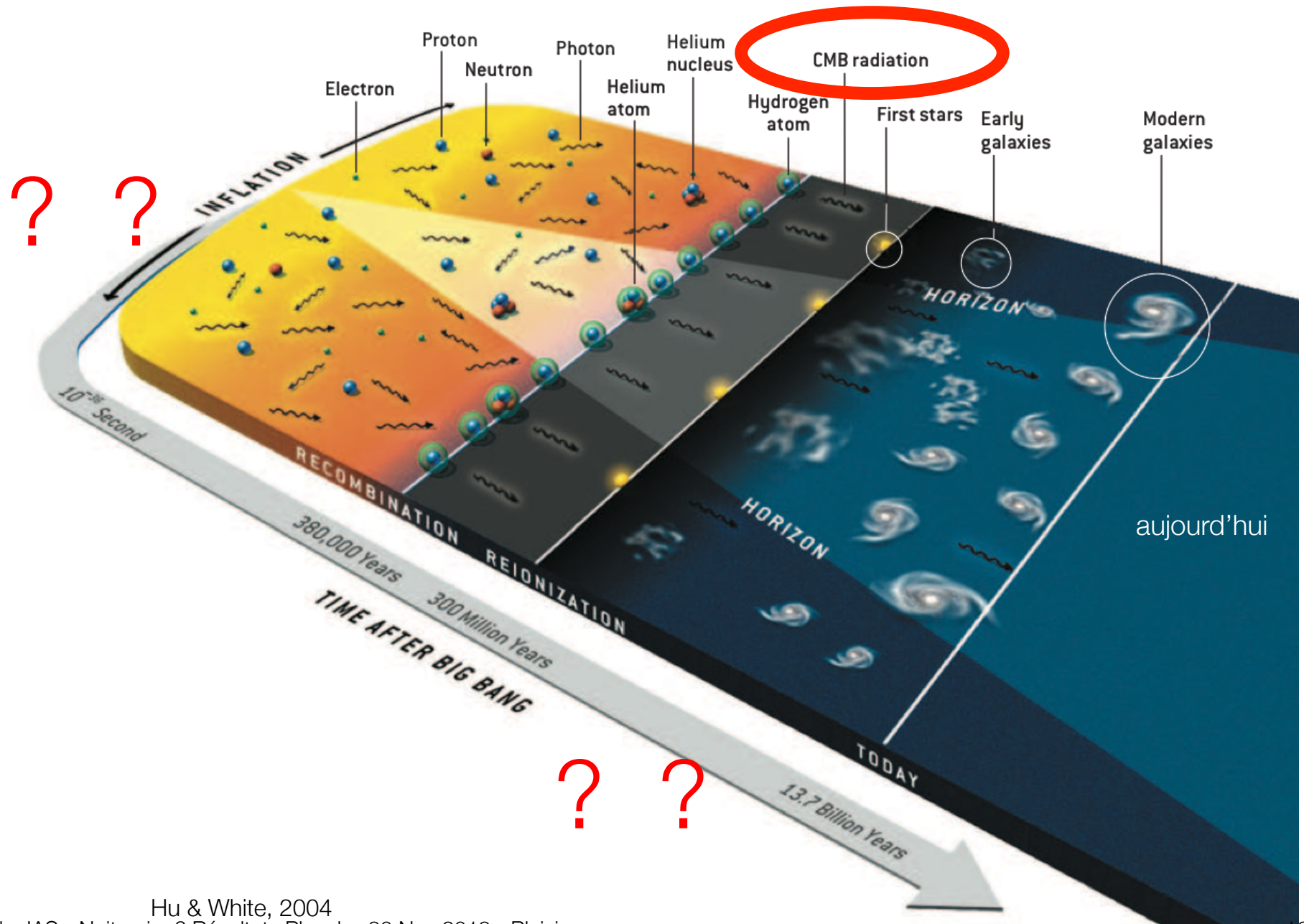
?  
univers homogène  
modèles d'inflation ?

?  
univers inhomogène,  
structuré

formation  
des structures



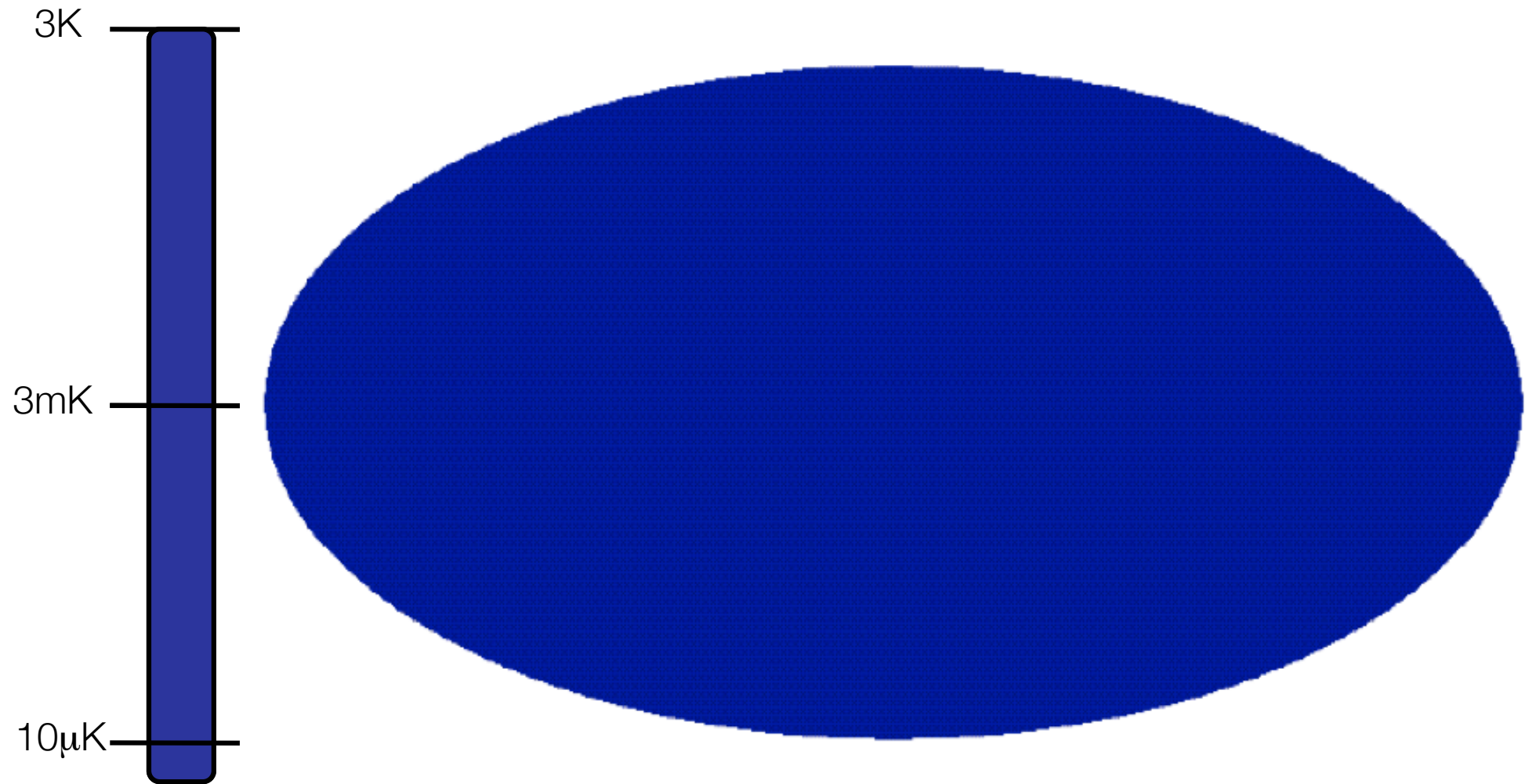
# comment se forment les structures ?



Hu & White, 2004

# fond diffus cosmologique: monopôle

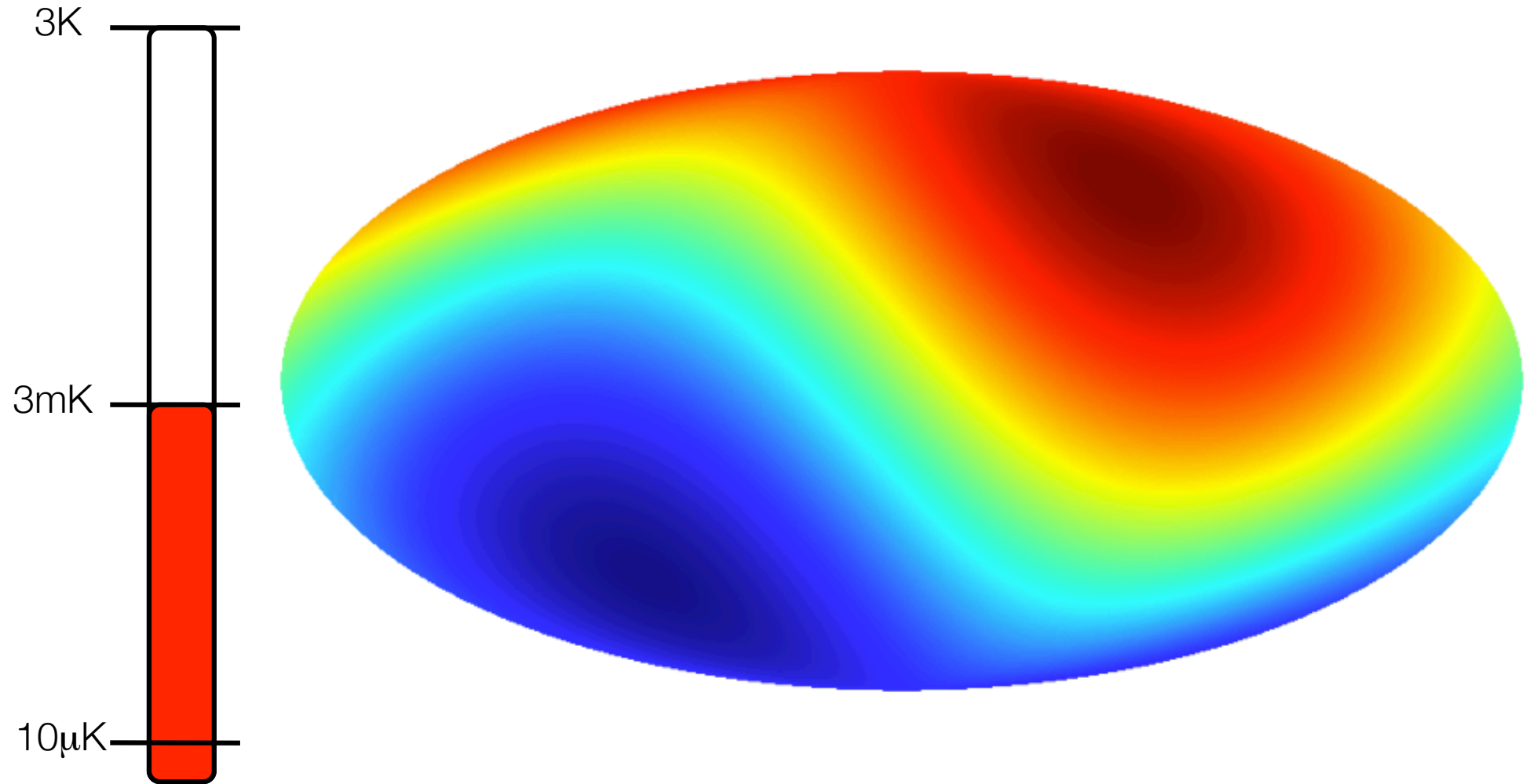
---





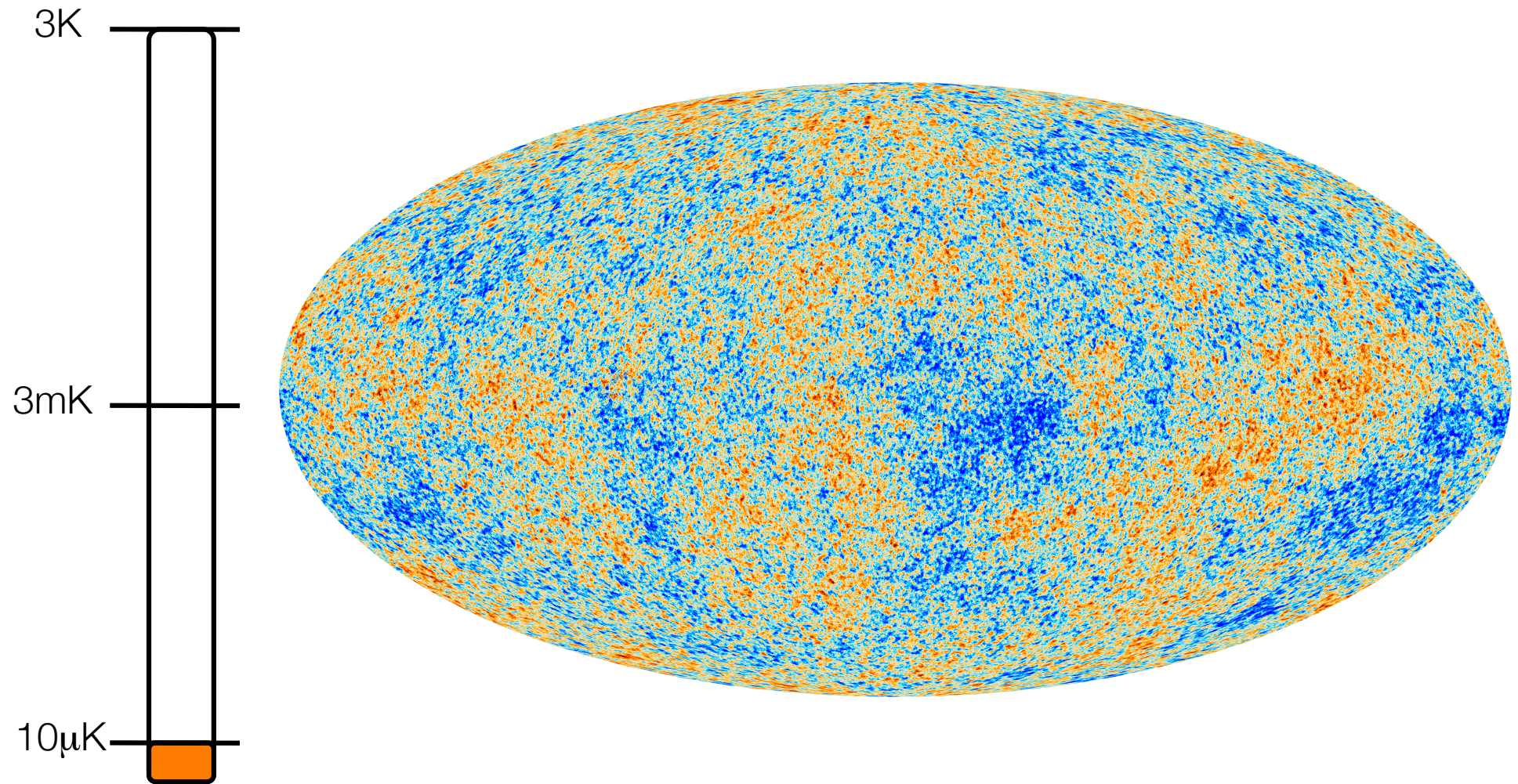
# fond diffus cosmologique: dipôle

---



# fond diffus cosmologique: fluctuations

---



# plan

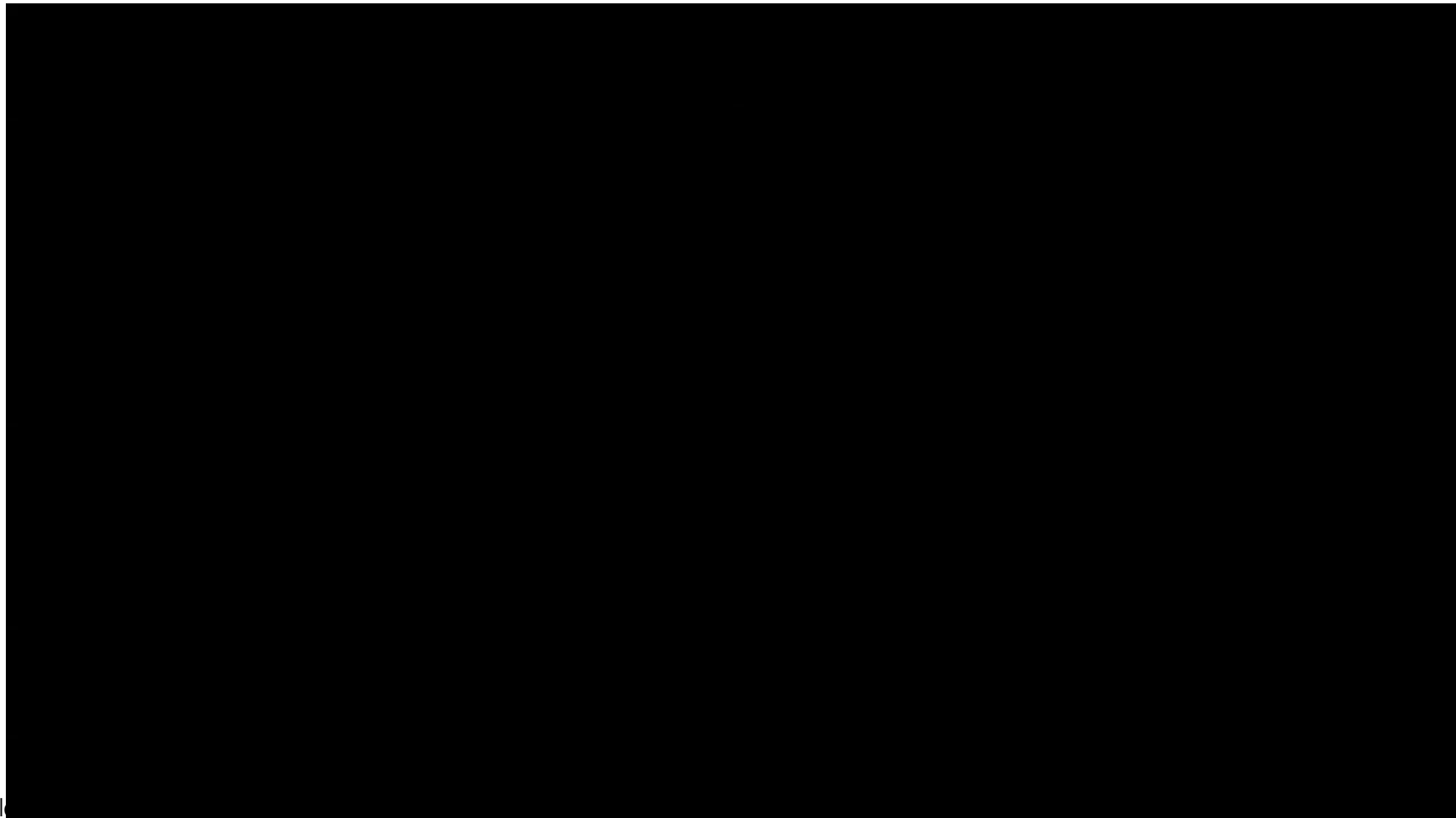
---

1. pourquoi Planck ?
2. le fond diffus cosmologique (CMB) et les composantes astrophysiques
3. analyses du CMB: spectre de puissance angulaire
4. implications cosmologiques
5. un mot d'inflation
6. un univers structuré: matière noire
7. en grattant de le rayonnement de fond infrarouge

# Planck goals and key facts

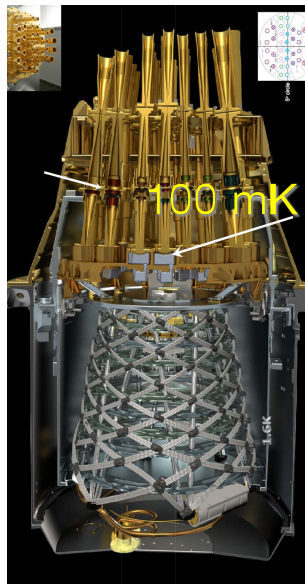
---

- selected in 1996 by ESA – launched in 2009
- HFI cooled at 100 mK -> bolometer technology
- 29 months of operation (goal was 12: nominal mission)
  - 5 all-sky surveys instead of 2 (nominal mission, this data release)

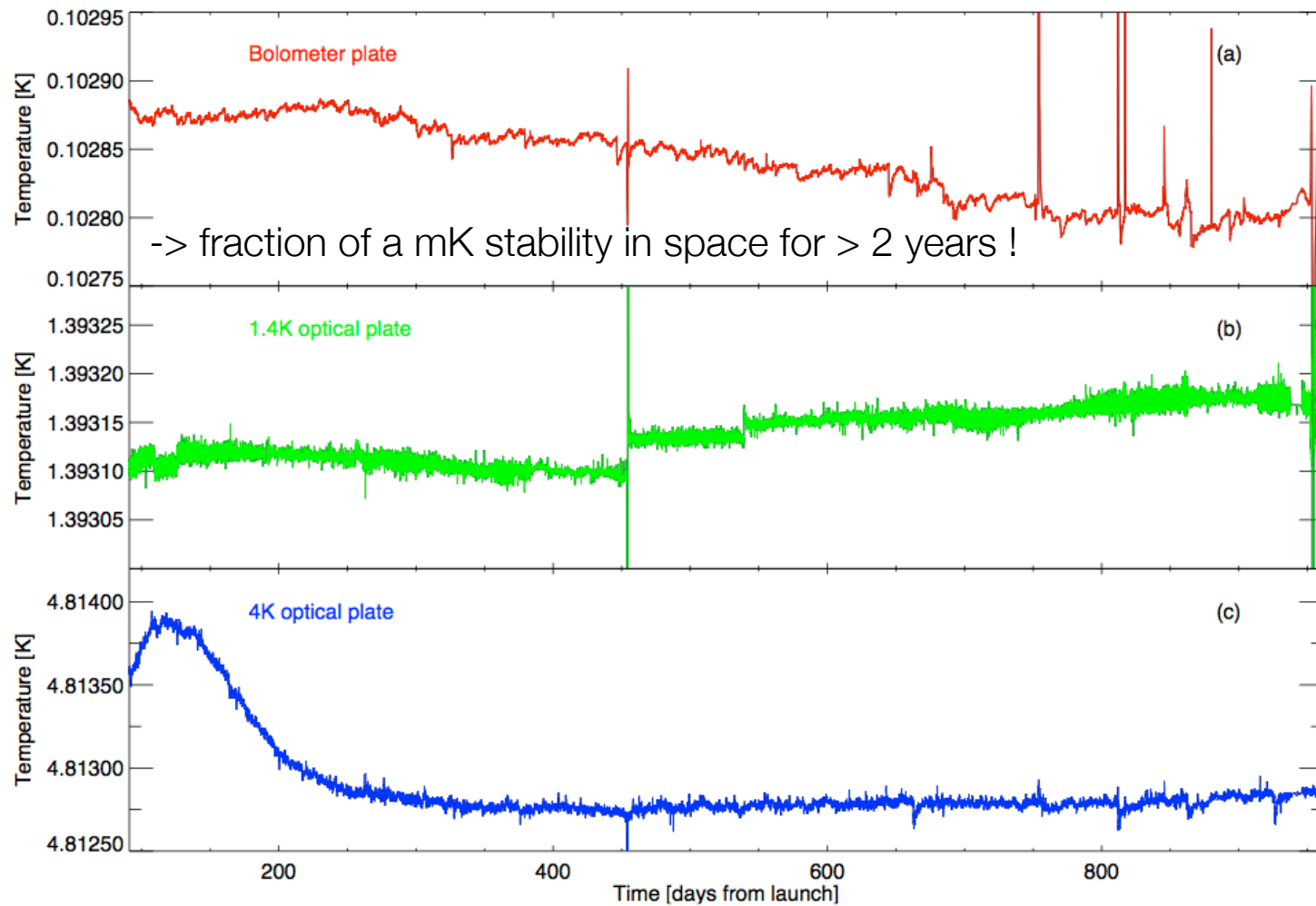


# a technological success

stability: 0.1 mK !

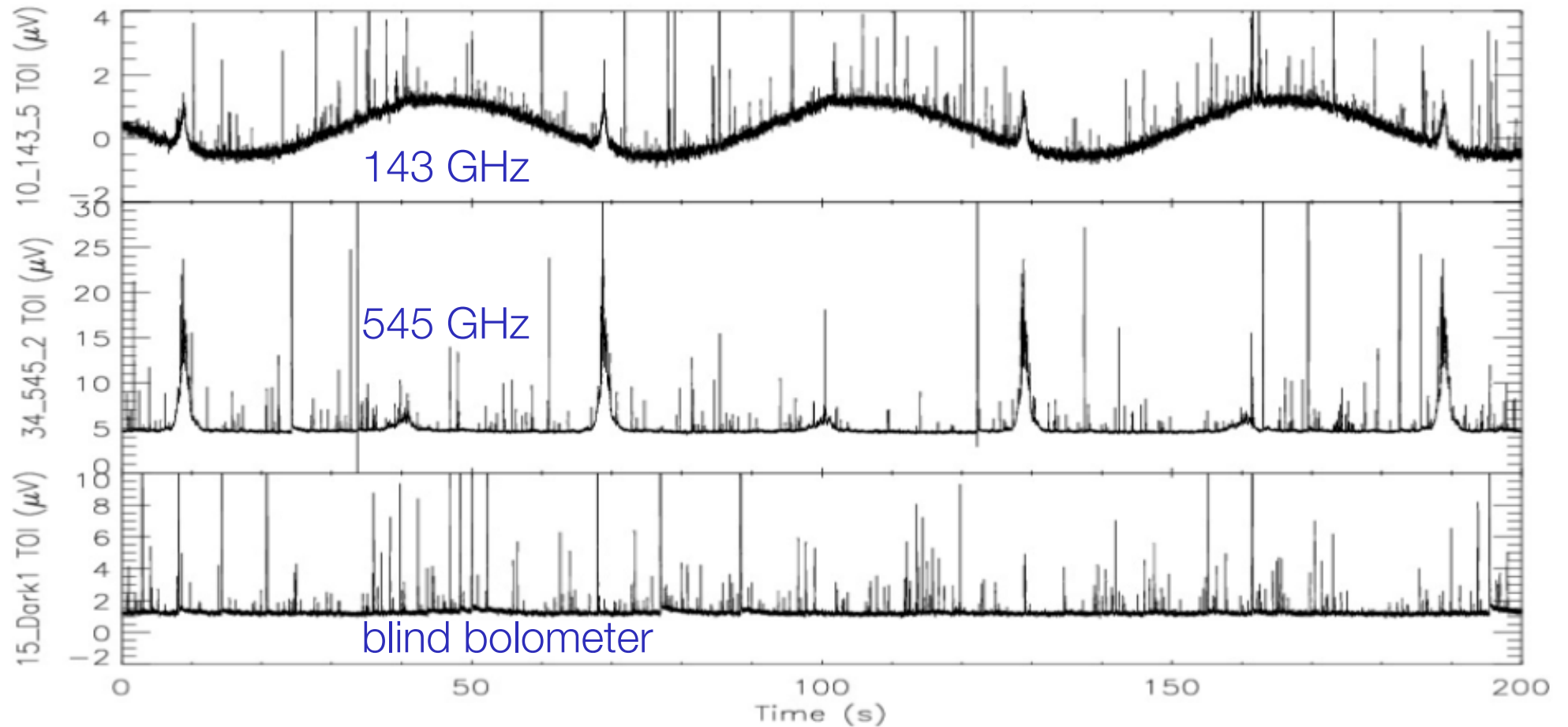


Cryostat:  
dilution He3/He4



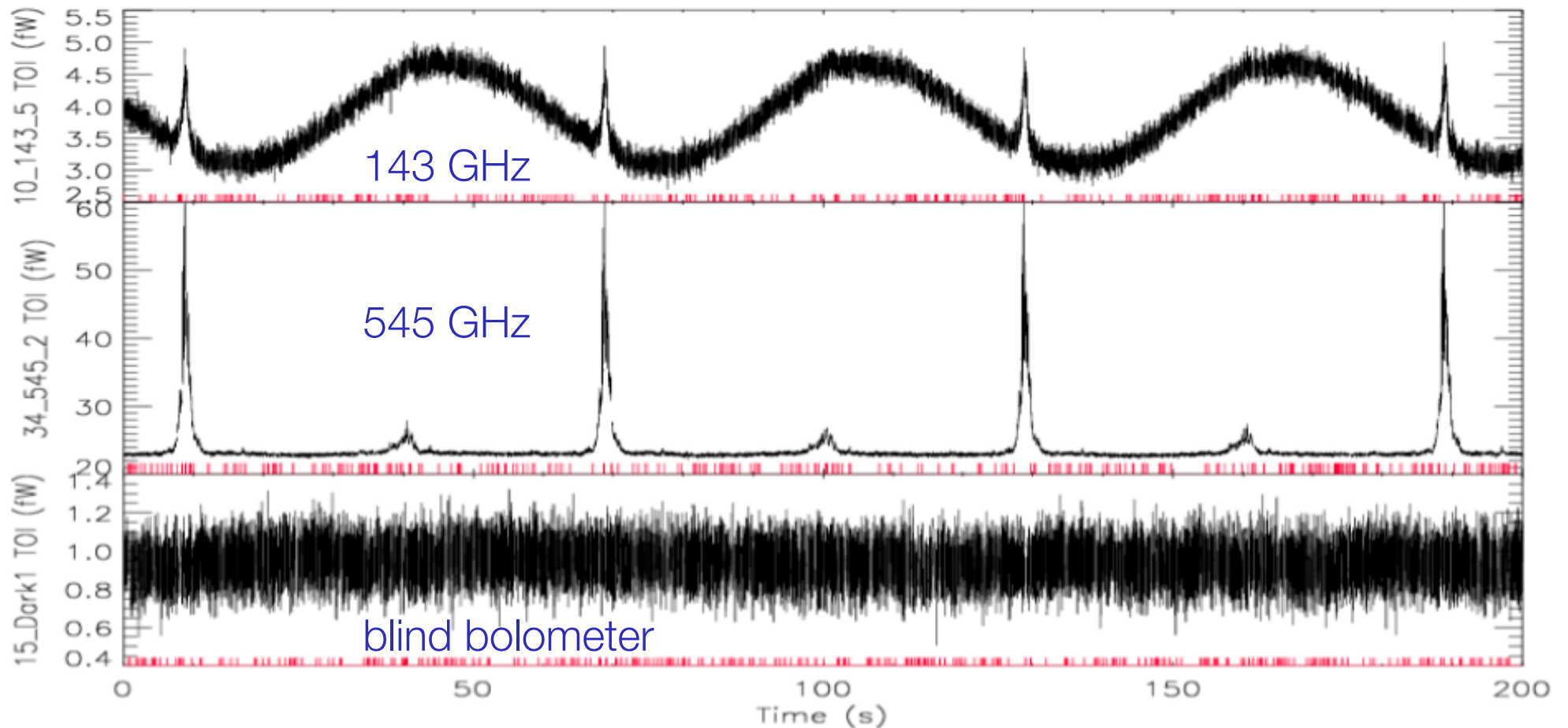
**Fig. 7.** The impressive stability of the HFI thermal stages during operations. Shown is the temperature evolution of the bolometer stage (*top*), the 1.6 K optical filter stage (*middle*) and the 4-K cooler reference load stage (*bottom*). The horizontal axis displays days since the beginning of the nominal mission.

# a challenging analysis success



Planck-HFI Core Team, 2011

# a challenging analysis success



de <20% de données perdues à cause des glitches

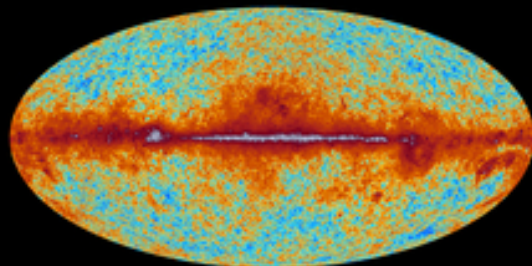
Planck-HFI Core Team, 2011

# Planck all-sky maps

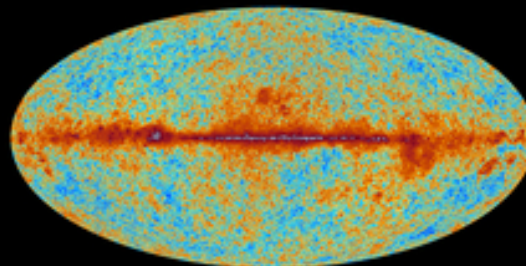


planck

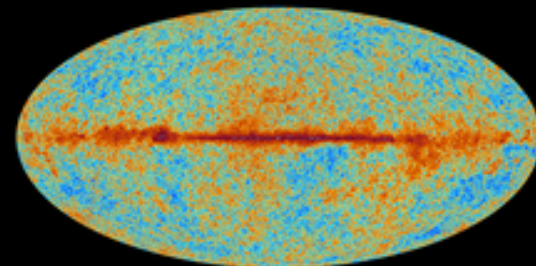
*The sky as seen by Planck*



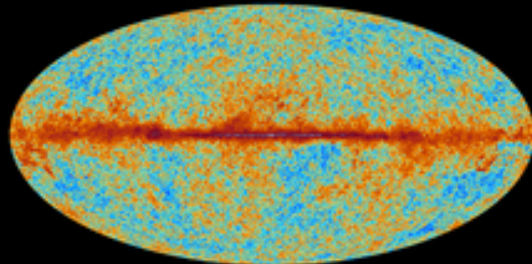
30 GHz



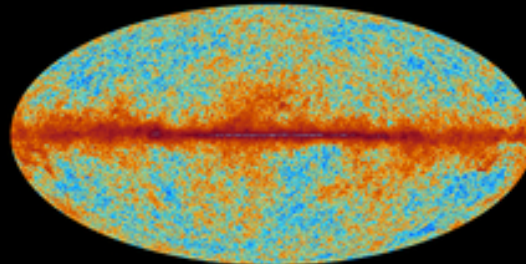
44 GHz



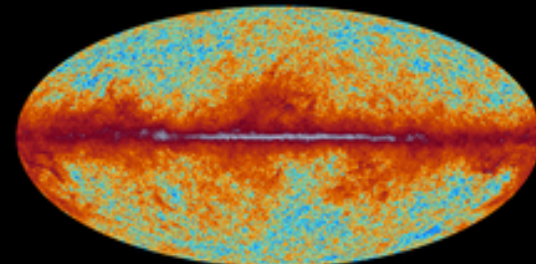
70 GHz



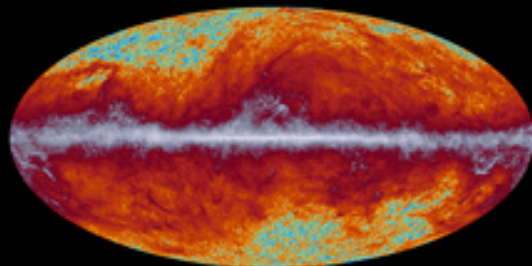
100 GHz



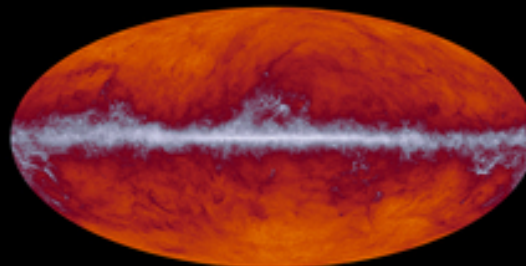
143 GHz



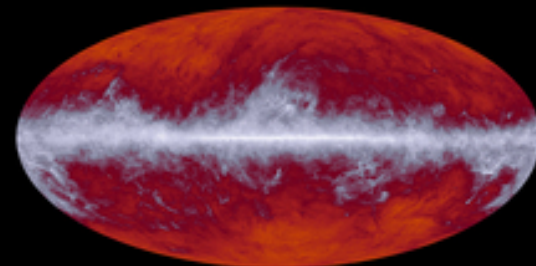
217 GHz



353 GHz



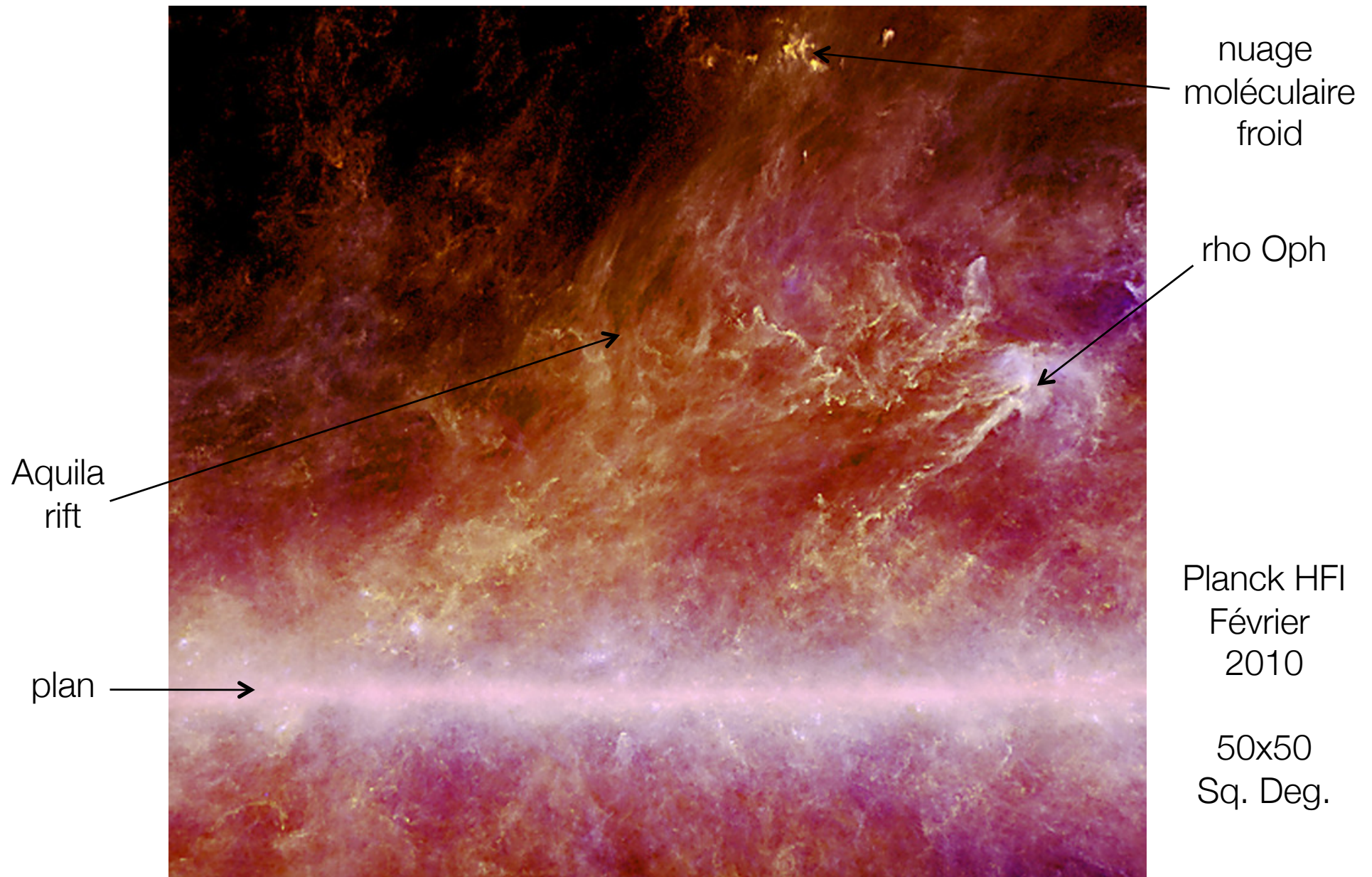
545 GHz



857 GHz



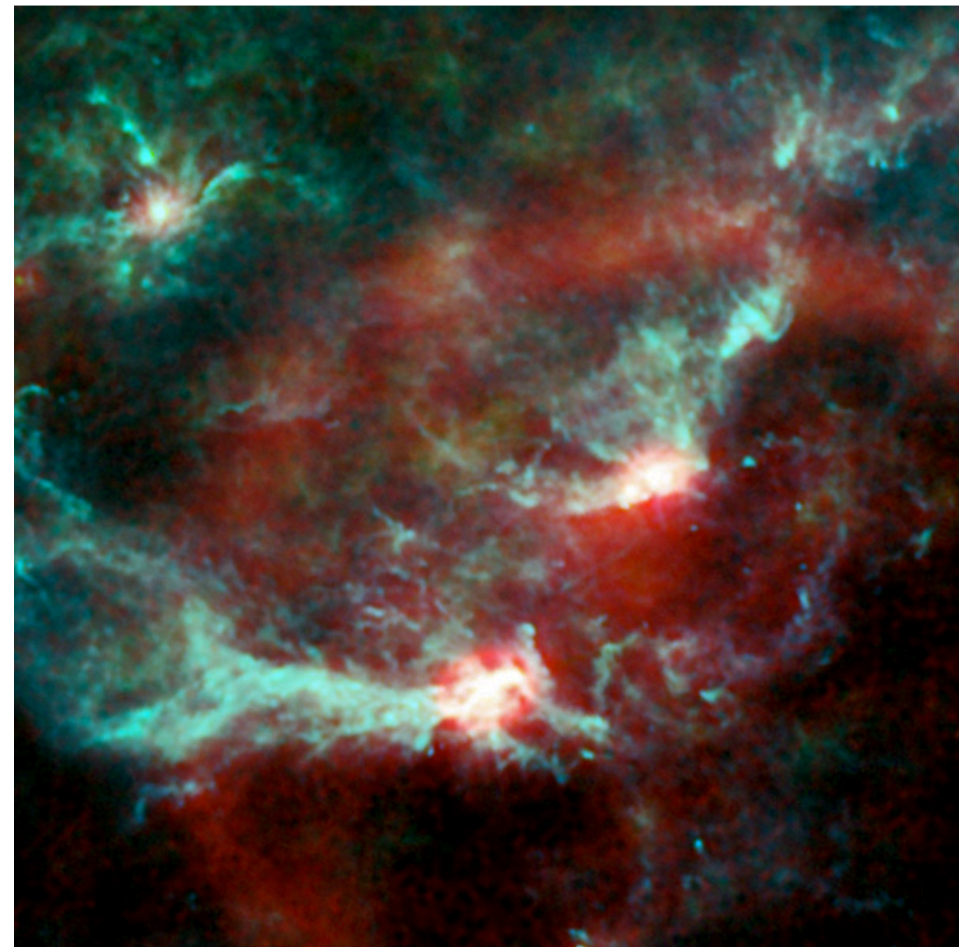
# first Planck released images



# first Planck released images

---

Planck HFI - Mars 2010 - Orion



# Planck 2013 papers

- Planck 2013 results. I. Overview of products and results
- Planck 2013 results. II. Low Frequency Instrument data processing
- Planck 2013 results. III. LFI systematic uncertainties
- Planck 2013 results. IV. LFI beams
- Planck 2013 results. V. LFI calibration
- Planck 2013 results. VI. High Frequency Instrument data processing
- Planck 2013 results. VII. HFI time response and beams
- Planck 2013 results. VIII. HFI calibration and mapmaking
- Planck 2013 results. IX. HFI spectral response
- Planck 2013 results. X. HFI energetic particle effects
- Planck 2013 results. XI. Consistency of the data

11 papers:  
instrument: calibration, processing, systematics

- Planck 2013 results. XII. Component separation
- Planck 2013 results. XIII. Galactic CO emission
- Planck 2013 results. XIV. Zodiacal emission

3 papers:  
component separation

2 papers:  
cosmological parameters, p. spectra, likelihood

- Planck 2013 results. XVII. Gravitational lensing by large-scale structure
- Planck 2013 results. XVIII. The gravitational lensing-infrared background correlation
- Planck 2013 results. XIX. The integrated Sachs-Wolfe effect

3 papers:  
line of sight effects: lensing, CIB, ISW

- Planck 2013 results. XX. Cosmology from Sunyaev-Zeldovich cluster counts
- Planck 2013 results. XXI. All-sky Compton parameter map and characterization
- Planck 2013 results. XXII. Constraints on inflation
- Planck 2013 results. XXIII. Isotropy and statistics of the CMB
- Planck 2013 results. XXIV. Constraints on primordial non-Gaussianity
- Planck 2013 results. XXV. Searches for cosmic strings and other topological defects
- Planck 2013 results. XXVI. Background geometry and topology of the Universe
- Planck 2013 results. XXVII. Special relativistic effects on the CMB dipole
- Planck 2013 results. XXVIII. The Planck Catalogue of Compact Sources
- Planck 2013 results. XXIX. The Planck catalogue of Sunyaev-Zeldovich sources
- Planck 2013 results. Explanatory supplement

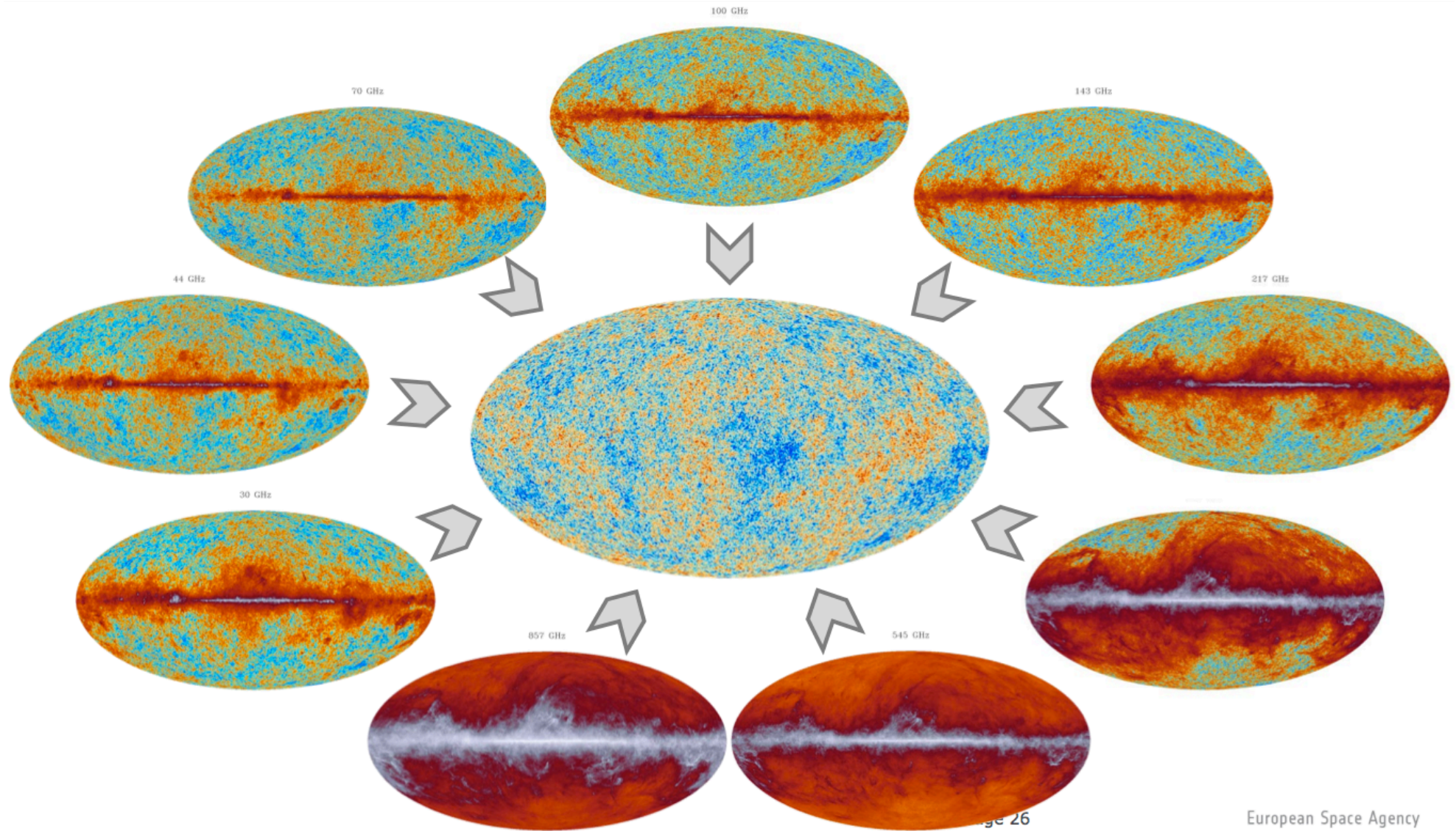
2 papers:  
SZ clusters and map

6 papers:  
cosmology, constraints

3 papers: products (catalog), XS

29 papers (+1 to come on CIB) ; 800+ pages  
1 Explanatory Supplement  
all products available online

# 2. component separation

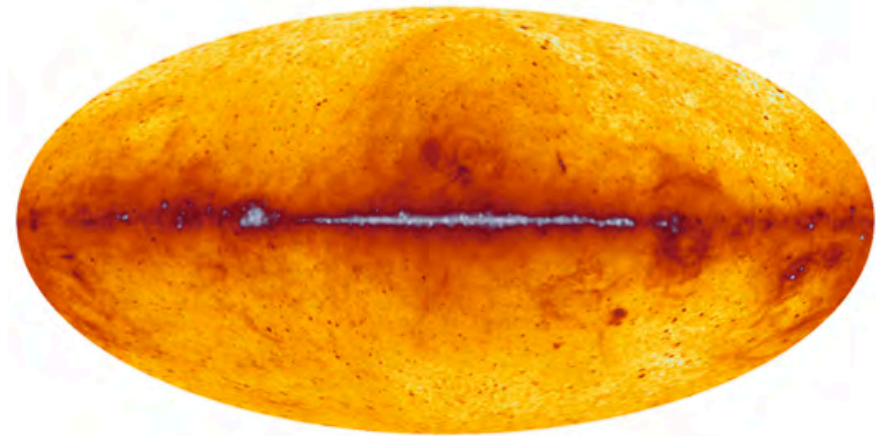


Page 26

European Space Agency

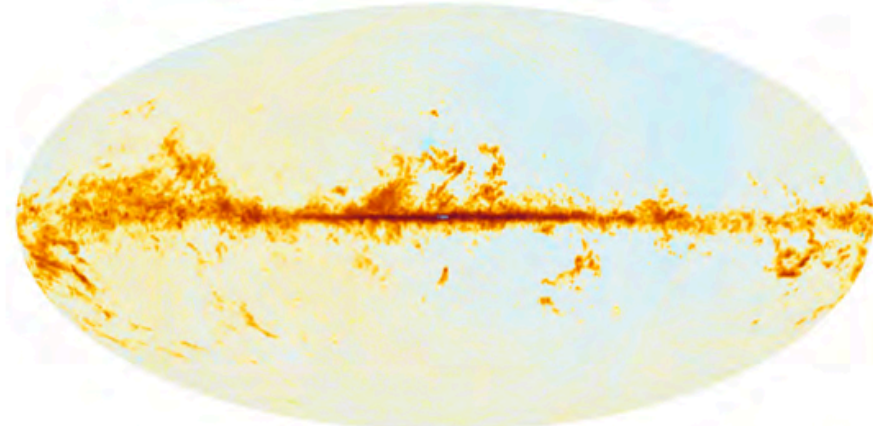
# some components

low frequency emission



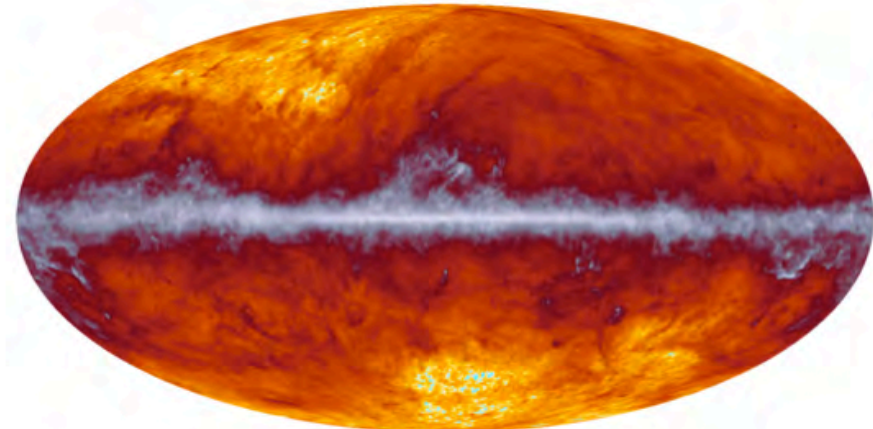
Commander: Low-Frequency Emission Amplitude @ 30 GHz

CO map

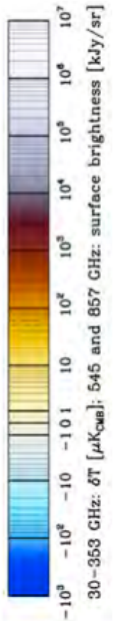


Commander: "discovery" CO map @ 100 GHz

dust at high frequency



Commander: Dust Amplitude @ 353 GHz



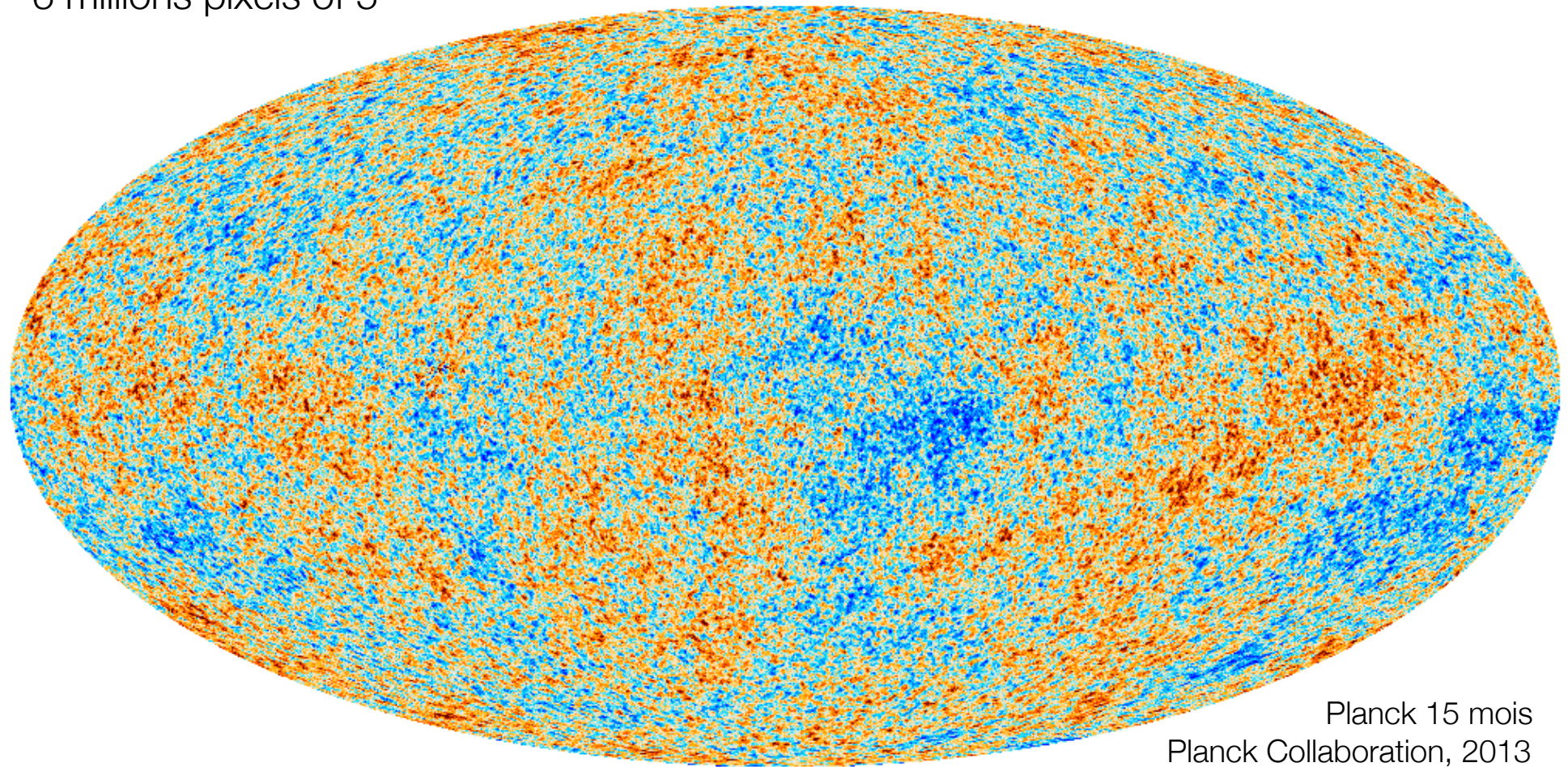
Planck Collab, 2013, 1, 12, 13, 14

# temperature anisotropies

---

LE RAYONNEMENT FOSSILE par PLANCK

6 millions pixels of 5'



# and a fairly wide coverage

**HAVANA DECO**  
SAVING A CITY'S ARCHITECTURE  
PAGE 13 | CULTURE

**PLAYERS UNITED**  
BIGGER CHECKS ON THE WAY  
PAGE 14 | SPORTS

**FLOYD NORRIS**  
THE FOLLY OF GIANT BANKS  
BACK PAGE | BUSINESS WITH REUTERS

**International Herald Tribune**  
THE GLOBAL EDITION OF THE NEW YORK TIMES  
GLOBAL.NYTIMES.COM

FRIDAY, MARCH 22, 2013

## Kurd leader issues a call for cease-fire with Turkey

DIYARBAKIR, TURKEY

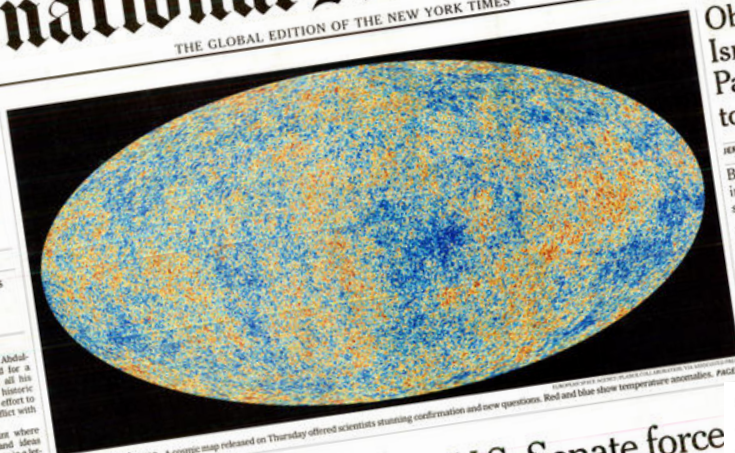
From jail, Ocalan makes bold move to hasten end of a bitter conflict

BY SEENEM ARSU

The jailed Kurdish rebel leader Abdullah Ocalan on Thursday called for a cease-fire and the removal of all his fighters from Turkish soil, in a historic moment for a newly emerged effort to end a three-decade armed conflict with the Turkish government.

"We have reached the point where weapons should go silent and ideas should speak," Mr. Ocalan wrote in a letter read out to jubilant crowds gathered in the Kurdish heartland here in southern Turkey. "A new era starts when politics, instead of guns, comes to the fore-front."

The conflict between Mr. Ocalan's Kurdistan Workers' Party or P.K.K. and the Turkish government has claimed nearly 45,000 lives and has deeply scarred society since it started in 1984. While there have been previous periods of cease-fire between Turkey and the group, never before has a broad-



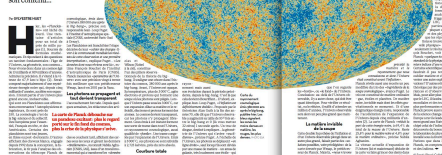
The infant universe. A cosmic map released on Thursday offered scientists stunning confirmation and new questions. Red and blue show temperature anomalies. PAGE 4

## Once rarity, women are U.S. Senate force

WASHINGTON

### SCIENCE

Un livre, une équipe de 500 astronomes a publié la carte du cosmos, du zéro à 13,8 milliards d'années. Dessiné par le physicien français, elle révèle son âge, son passé, sa vitesse d'expansion, son contenu...



**H**ier, une équipe de 500 astronomes a publié la carte du cosmos, du zéro à 13,8 milliards d'années. Dessiné par le physicien français, elle révèle son âge, son passé, sa vitesse d'expansion, son contenu...

## Obama asks Israelis and Palestinians to talk again

By not insisting on freeze in settlement activity, he softens his earlier stance

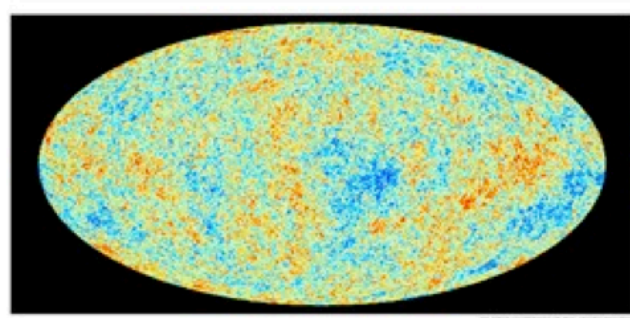
BY MARK LANDLER AND RICK GLADSTONE

President Barack Obama, speaking on Thursday first to Palestinians in the occupied West Bank and then to young Israelis in Jerusalem, called on both sides for fresh thinking, greater understanding of the others' fears and concerns, and a new willingness to reach across the bitter divide separating them.

"If we're going to have to do is get out of the freeze and habits that have out of a blocked progress," Mr. Obama said in a speech in the West Bank city of Ramat

## The New York Times

VOL. CLXXII • No. 51,040 • Friday, March 22, 2013 • \$2.50



**The Common, Back in the Day**  
An image from data collected by a European Space Agency satellite shows a faint map of the universe as it lay some 375,000 years after the Big Bang. PAGE A10.

**Bronx Inspector, Secretly Taped, Suggests Race Is a Factor in Stops**  
By ANNEFELICIA...  
The police, the debate over the new New York City Department of Public Safety...  
The Bronx, a vibrant community that recorded the highest number of police stops in the city...  
The commanding officer, Deputy Inspector Christopher M. Blackwell, urged the officer to be more active, emphasizing the need to conduct more street stops. "We go out there and we stop people..."

**Once Few, Women Hold More Power in Senate**  
By JENNIFER...  
Ms. Aquino's induction that January day in 2013 into the most powerful body of the nation's government...  
A historic moment...  
The Senate...  
The House...  
The President...  
The Vice President...  
The Chief Justice...  
The Speaker of the House...  
The Minority Leader...  
The Majority Leader...  
The Senate...  
The House...  
The President...  
The Vice President...  
The Chief Justice...  
The Speaker of the House...  
The Minority Leader...  
The Majority Leader...

**Le Monde**

3.99 COLLECTION LE MONDE EST MATHÉMATIQUE

**CRISE CHYPRIOTE: L'ULTIMATUM DE FRANCFORT**  
ÉCONOMIE - LIRE PAGE 12

Vendredi 22 mars 2013 - 6<sup>e</sup> année - N°2404 - 1,80 € - France métropolitaine - www.lemonde.fr

**En Tunisie, le drame des disparus de la révolution**  
ENQUÊTE - LIRE PAGE 16

**Moins d'impôts et plus d'austérité, Londres persiste**  
Le Royaume-Uni fait cavalier seul en matière fiscale. Une panne de croissance comme le reste de l'Europe, est mise toujours plus sur la Banque d'Angleterre et les politiques d'austérité en question  
LA CHRONIQUE D'ALAIN FRACHON P. 20

**LE MONDE DES LIVRES**  
Spécial Salon du livre de Paris  
► Barcelone ville invitée, Roumanie à l'honneur et au lycée? Regards d'auteurs et d'enseignants  
► Le livre numérique peine à décoller  
► VÉLÉMENT, DÉBATS P. 10-12 ET P. 14

**C'ÉTAIT L'UNIVERS IL Y A 13,8 MILLIARDS D'ANNÉES**  
Des images inédites du satellite européen Planck dévoilent l'enfance du monde. Ni étoile ni galaxie, mais des particules microscopiques, des électrons et des protons LIRE PAGES 2-3

**DES GTI POUR ROULER**  
DES MÉCANIQUES  
CULTURE & STYLES - LIRE PAGE 19

Fondateur: Hubert Beuve-Méry - Directrice: Natalie Nougayrède

LE MONDE DES LIVRES SUPPLÉMENT 22 MARS

Image du rayonnement primordial de Planck prise par le satellite européen Planck. (1)

La taxe à 75% ne passe pas au Conseil d'Etat  
La haute juridiction

Mise en vente d'une œuvre exceptionnelle de Bacon  
Painting March

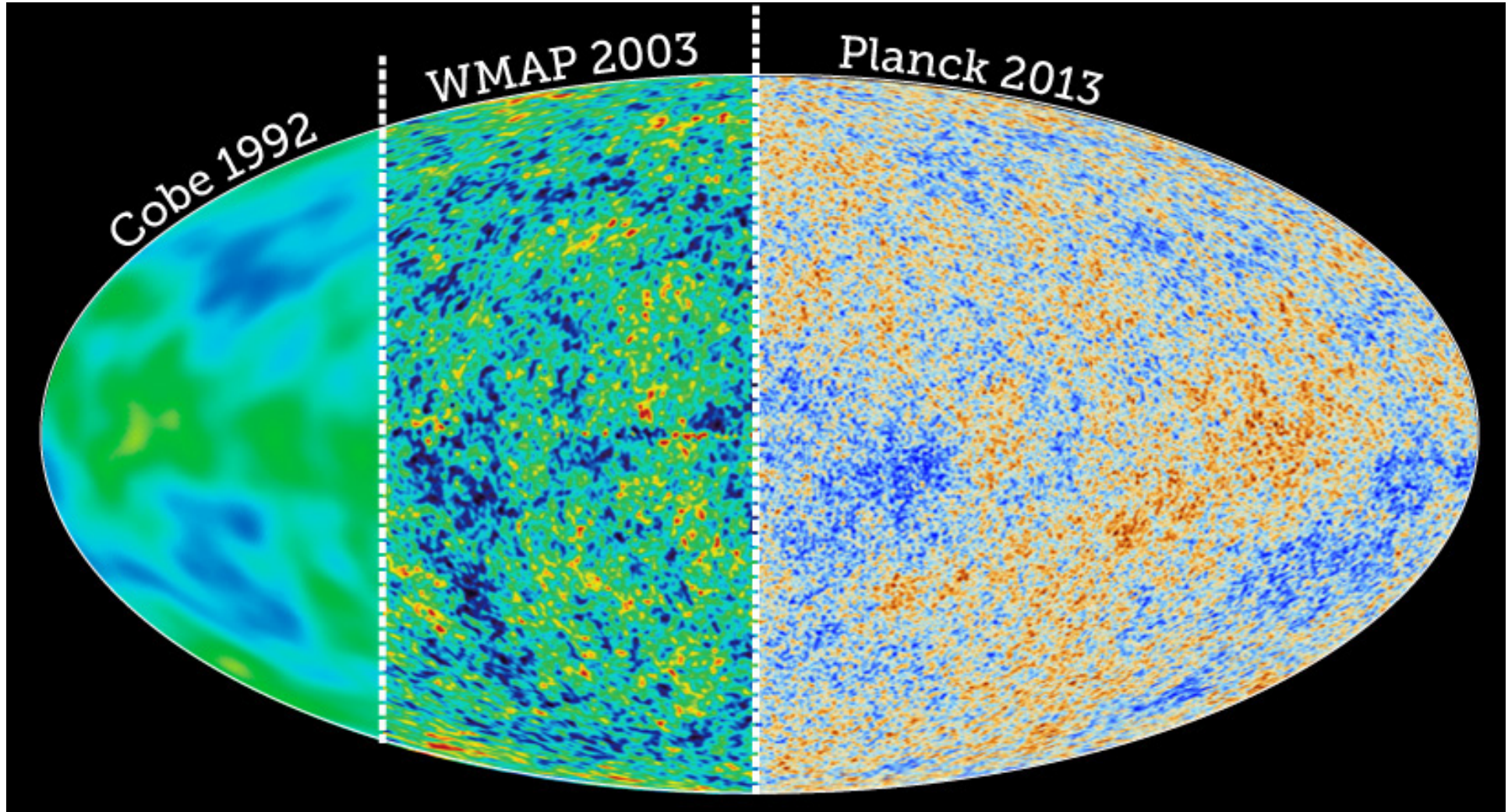
March 21st or 22nd, 2013

La mappemonde de l'Univers

Hervé Dole, IAS - Nuit noire ? Résultats Planck - 30 Nov 2013 - Plaisir

# improvements with time & technology

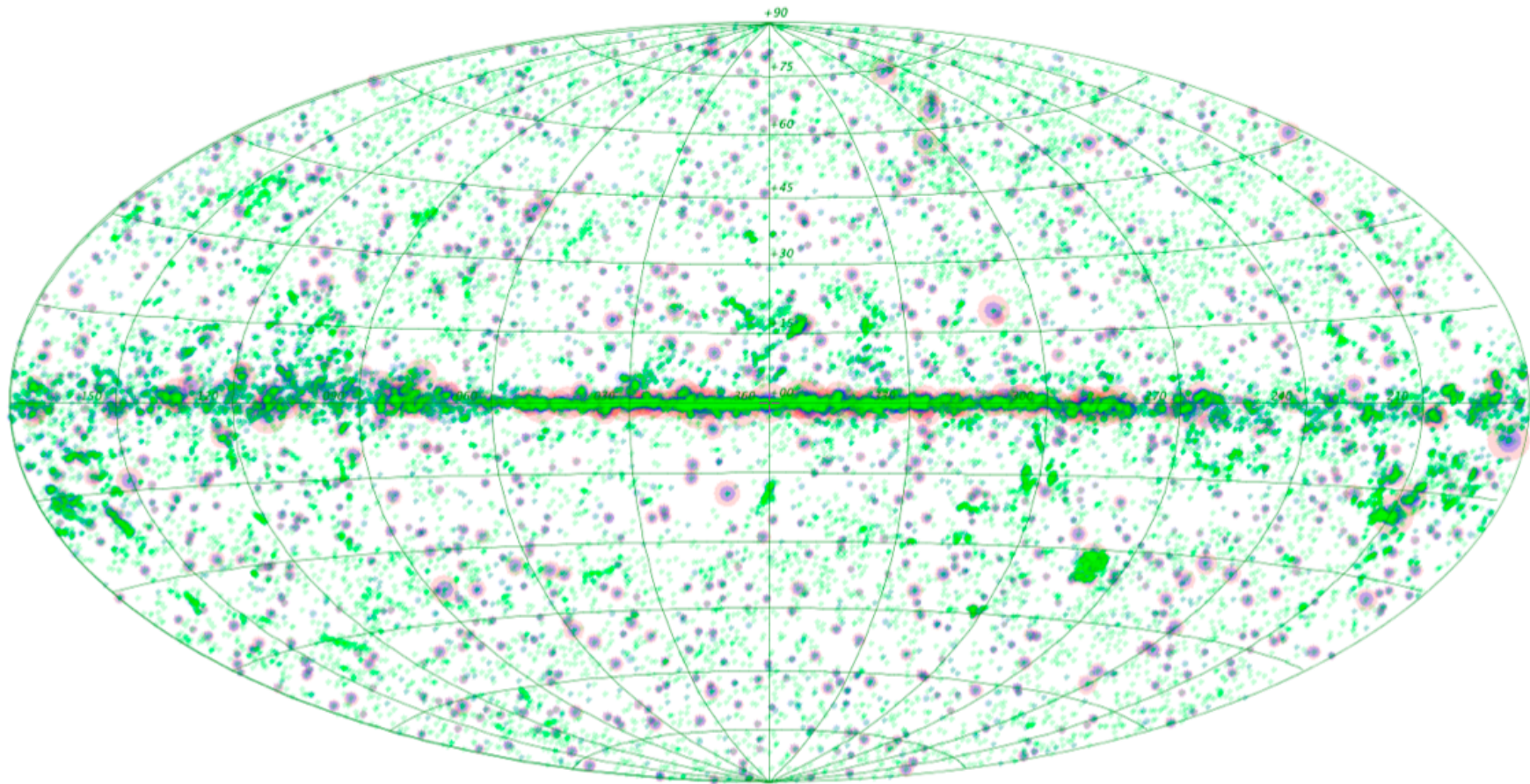
---





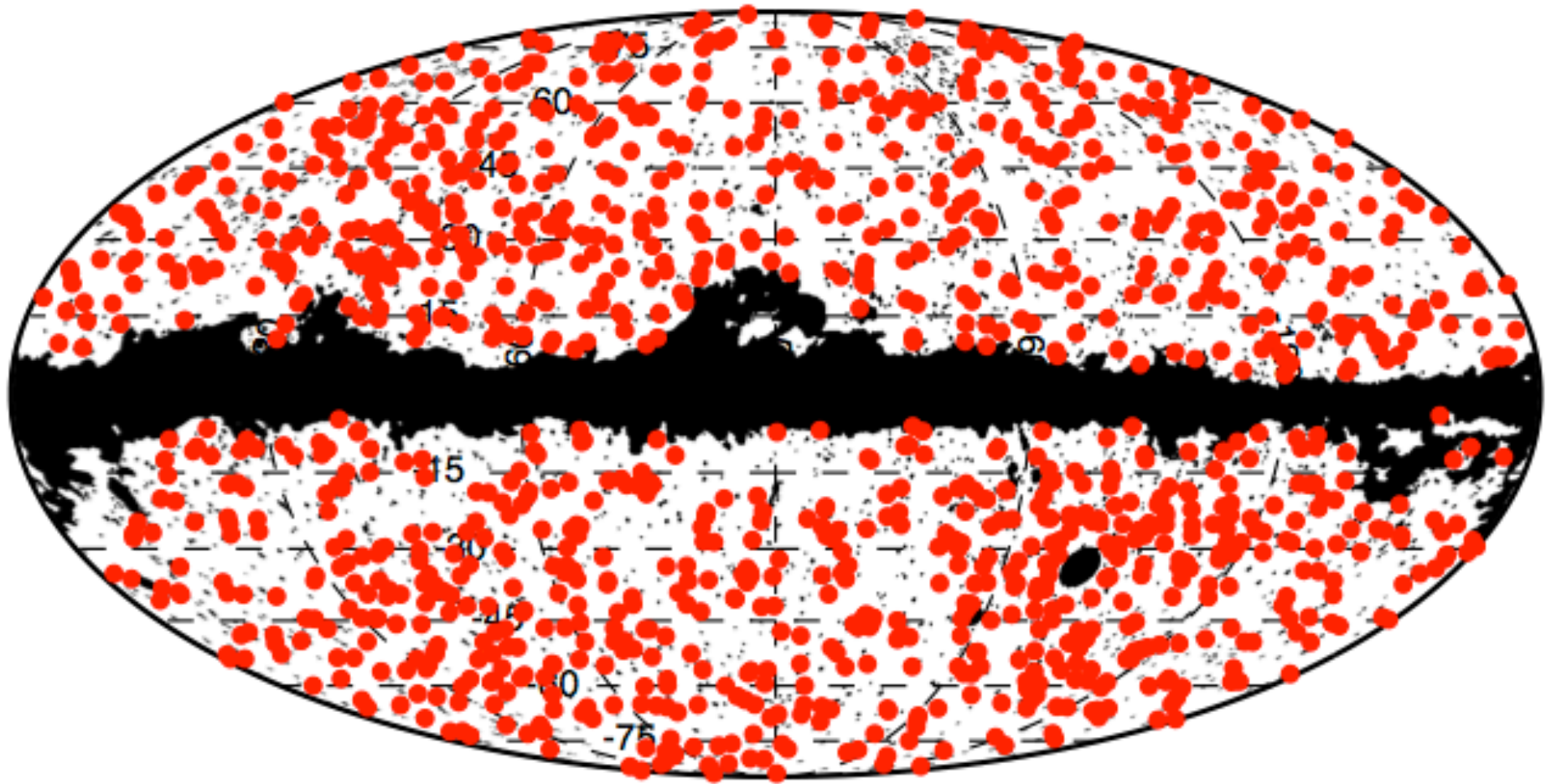
# Planck Catalogue of Compact Sources [PCCS]

---



# galaxy clusters: Sunyaev-Zeldovich effect

---

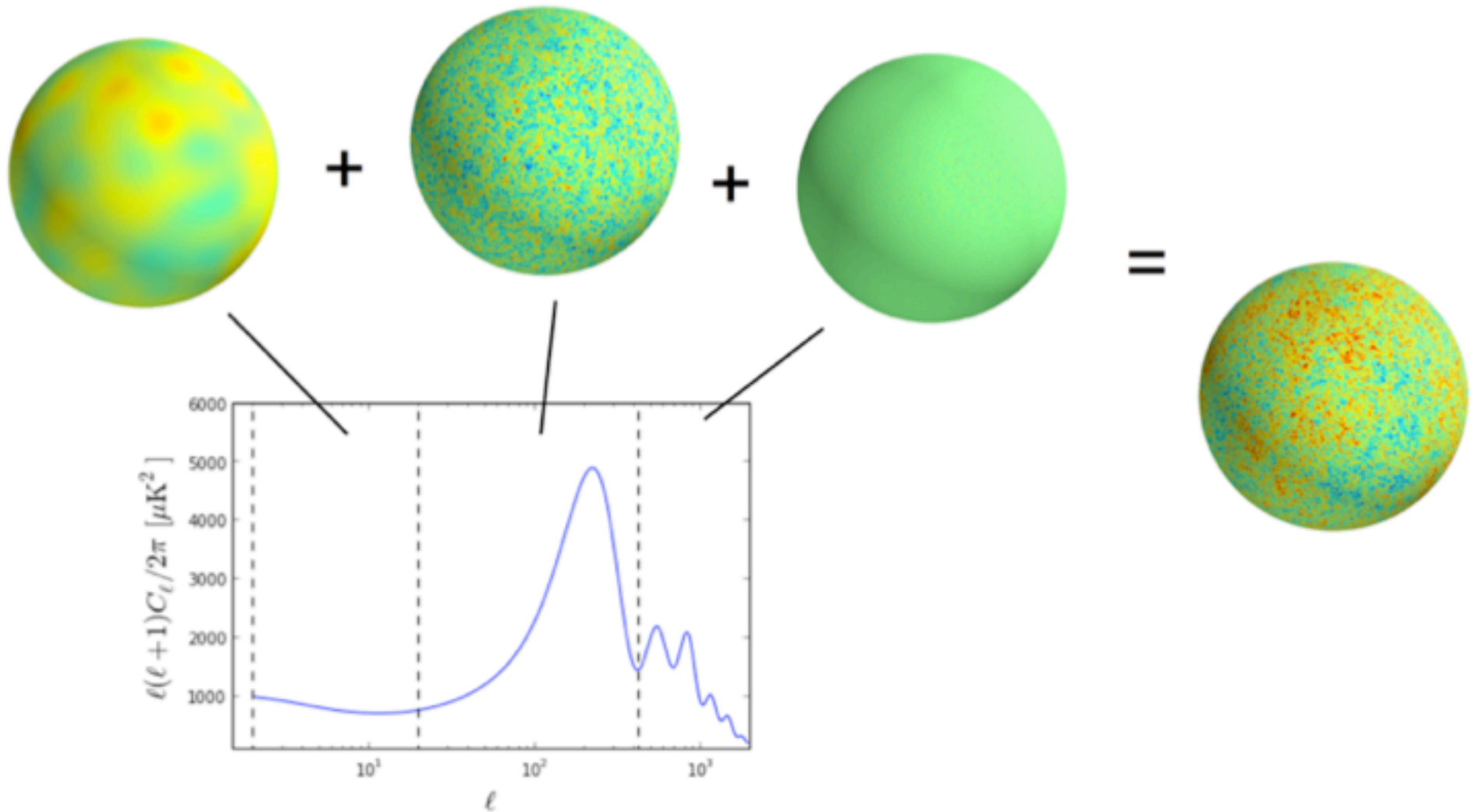


1227 SZ clusters -> including 366 brand new cluster candidates

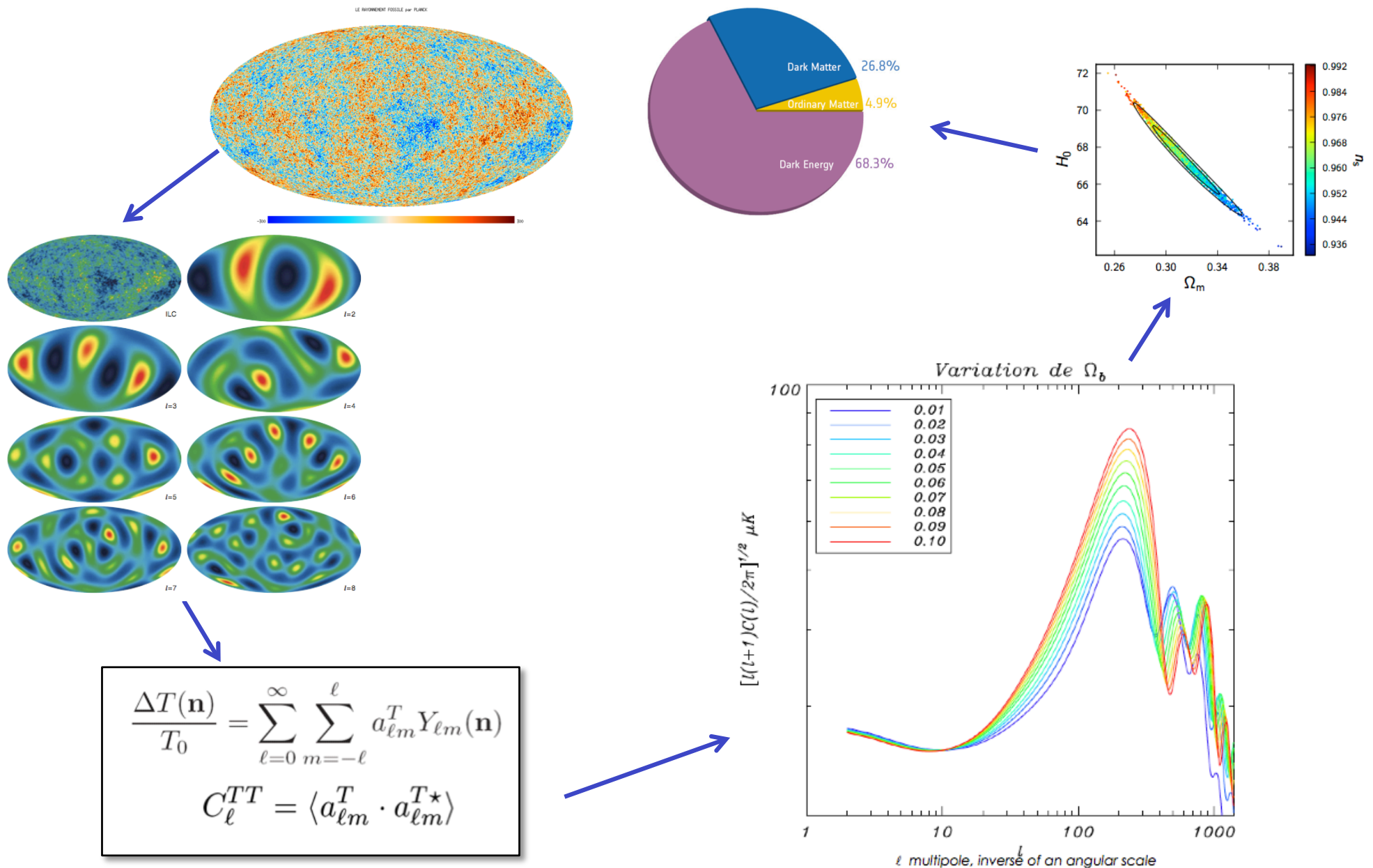
Planck Collab, 2013, 29

# 3. angular power spectra

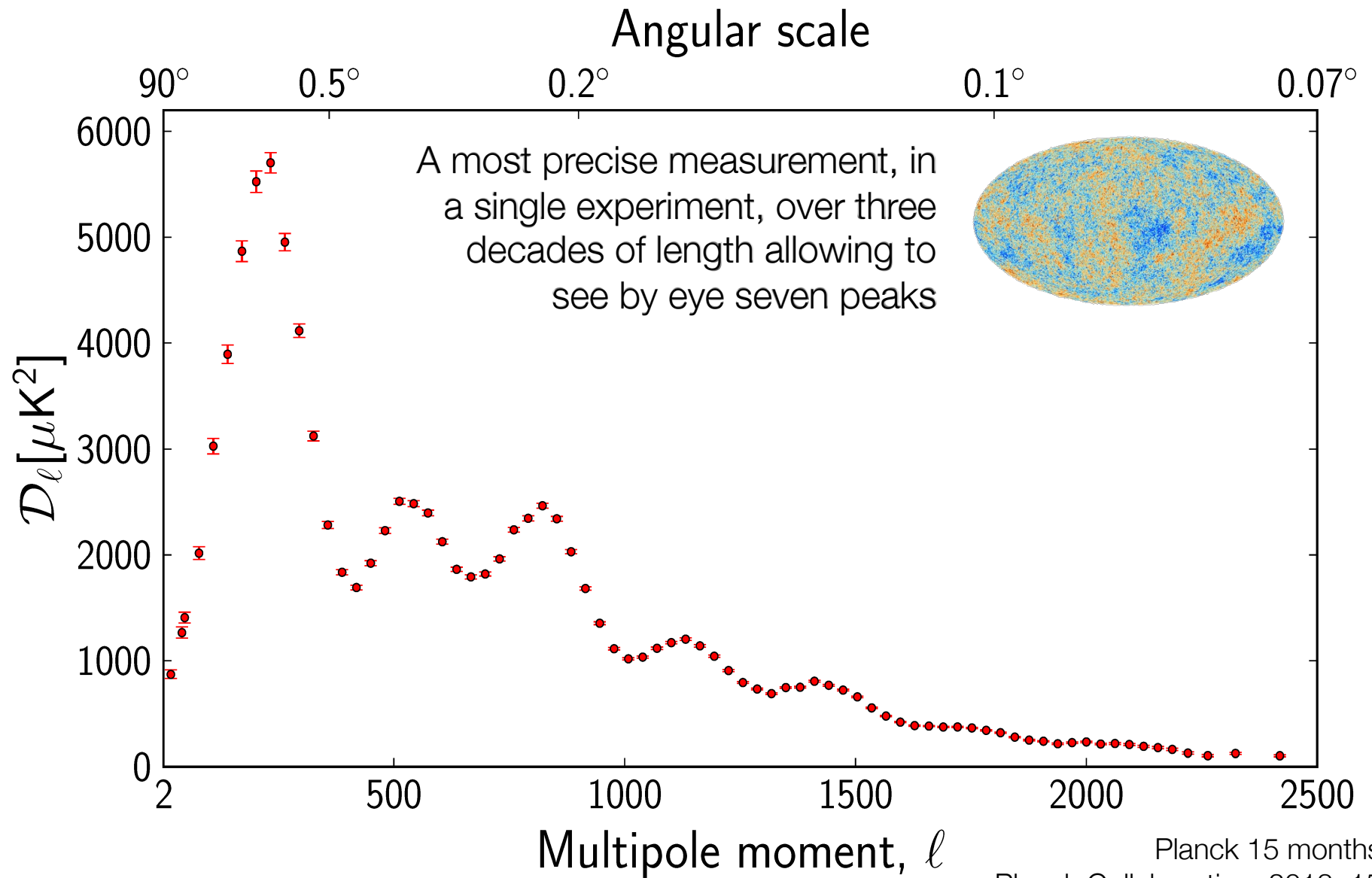
$$\langle a_{lm}^* a_{lm} \rangle = C_l$$



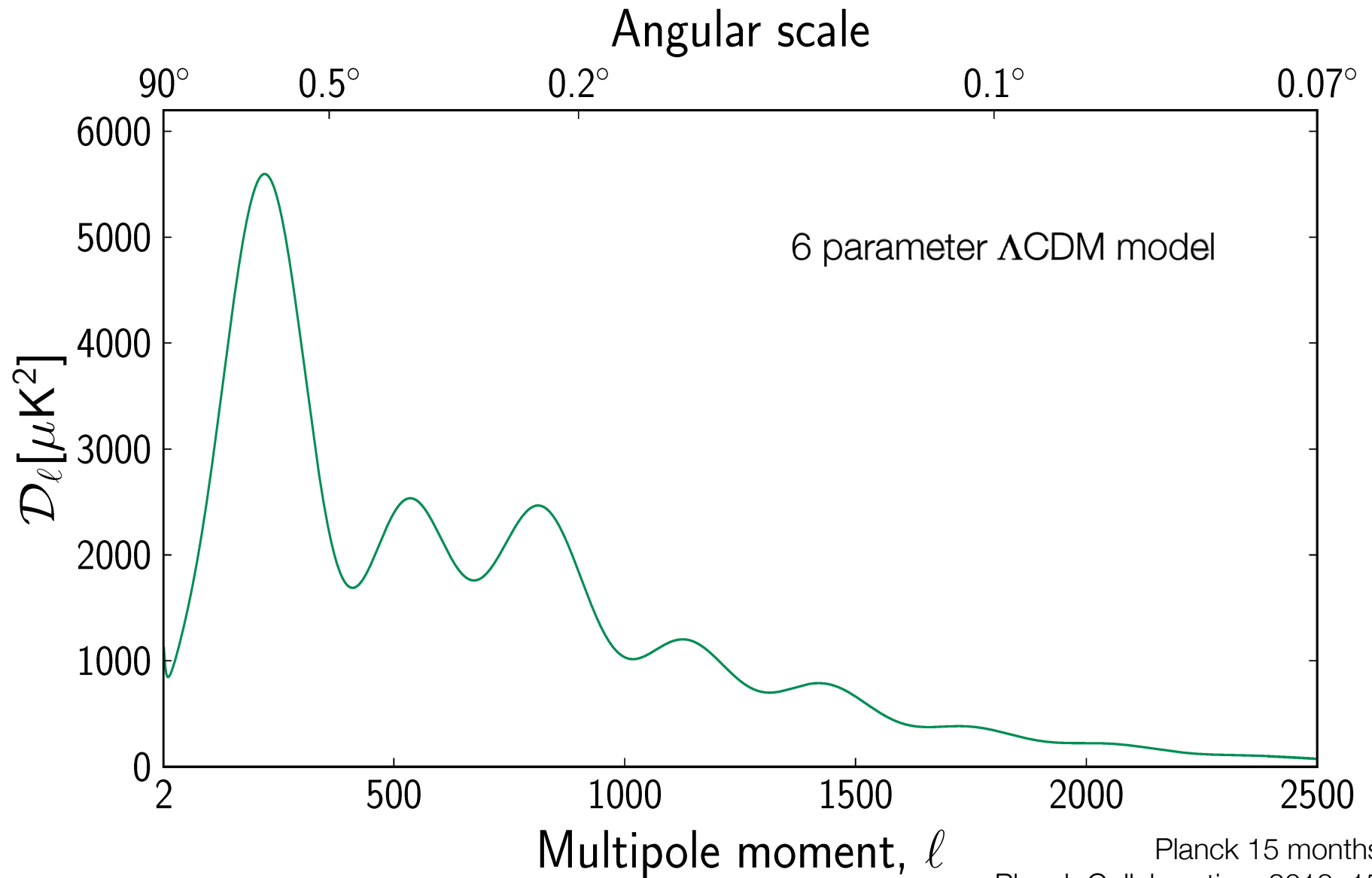
# from maps to 6 cosmological parameters



# the Planck spectrum of temperature anisotropies

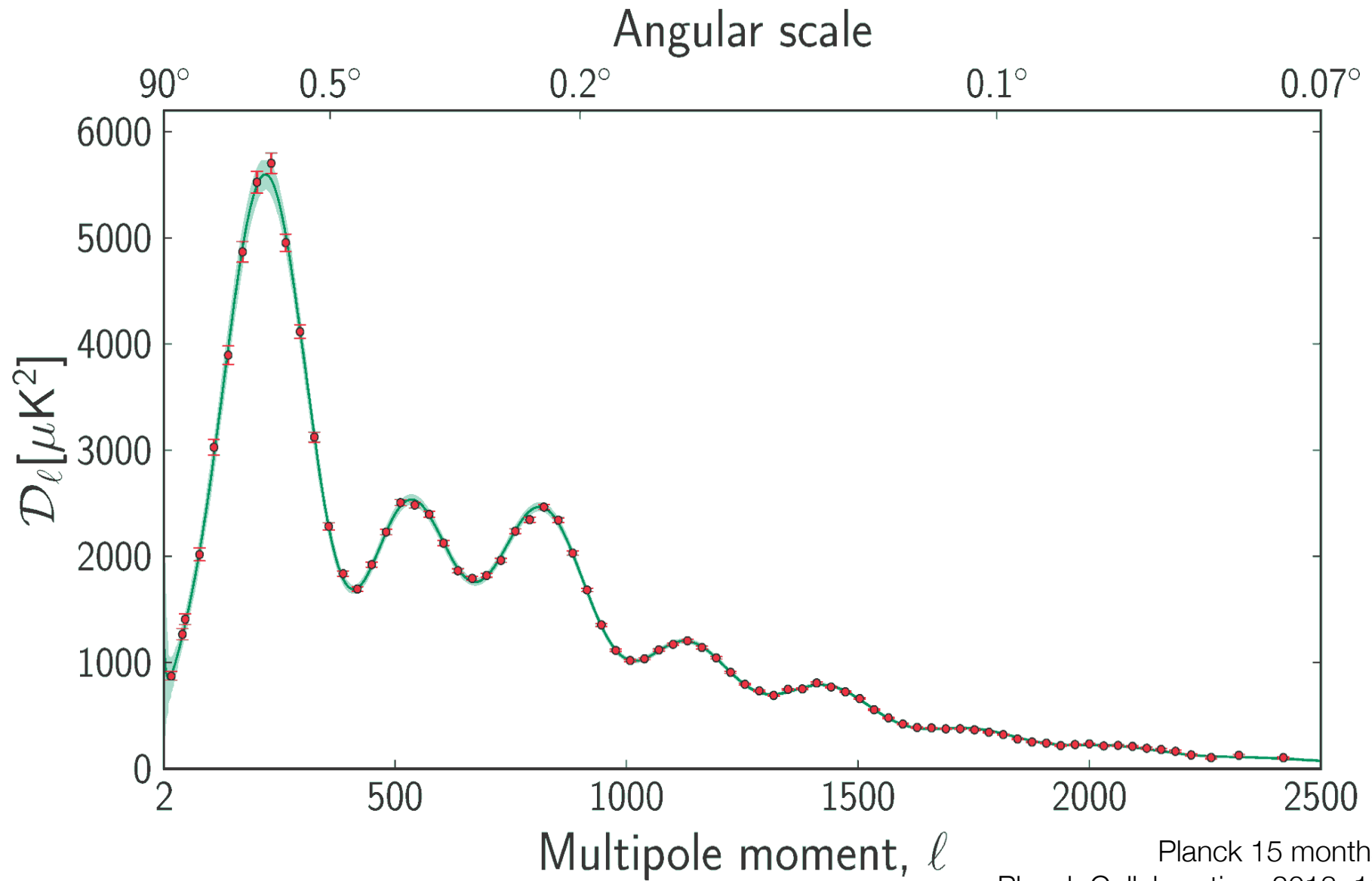


# Planck best fitting theoretical model

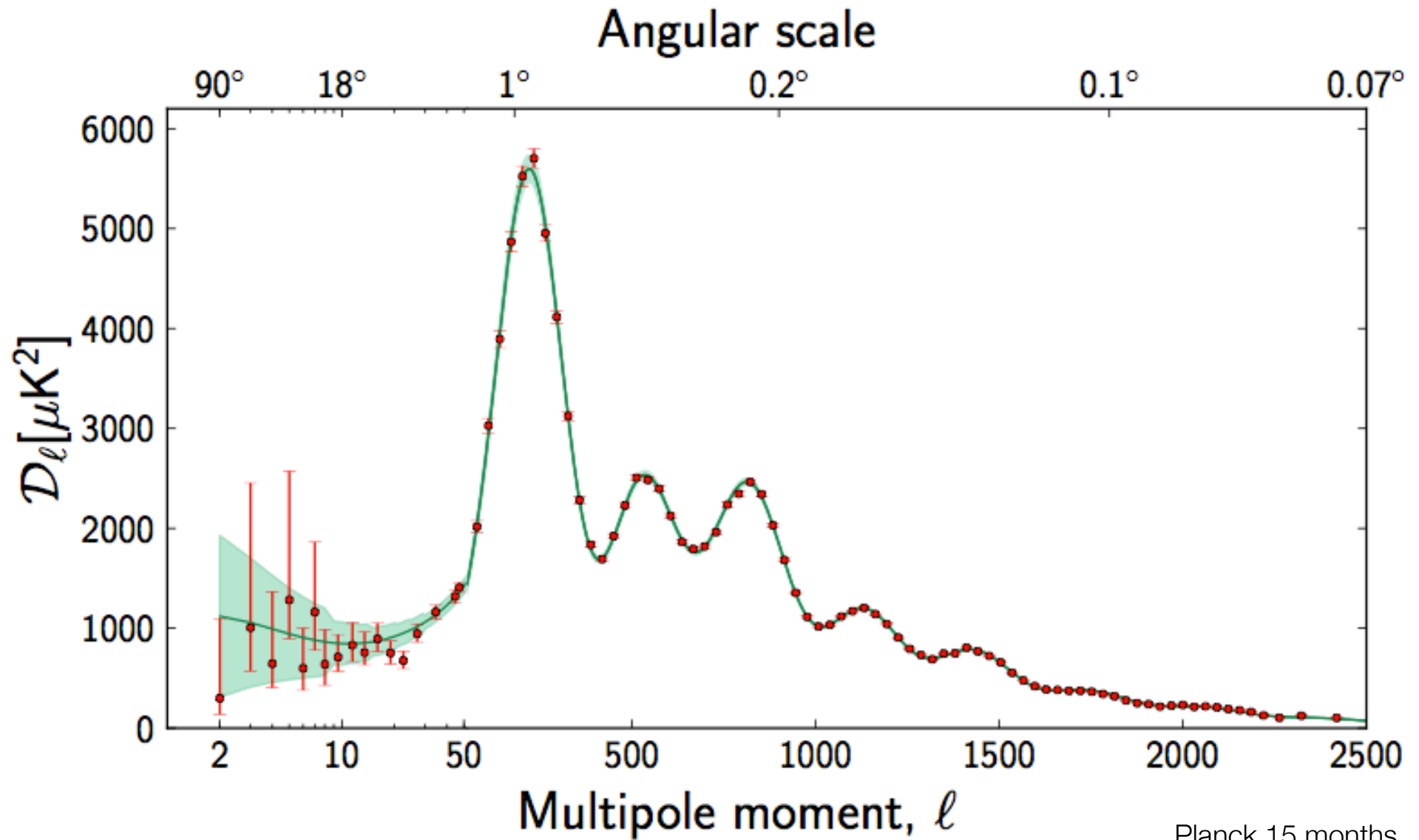


Planck 15 months  
Planck Collaboration, 2013, 15

# theory confronts data – 1



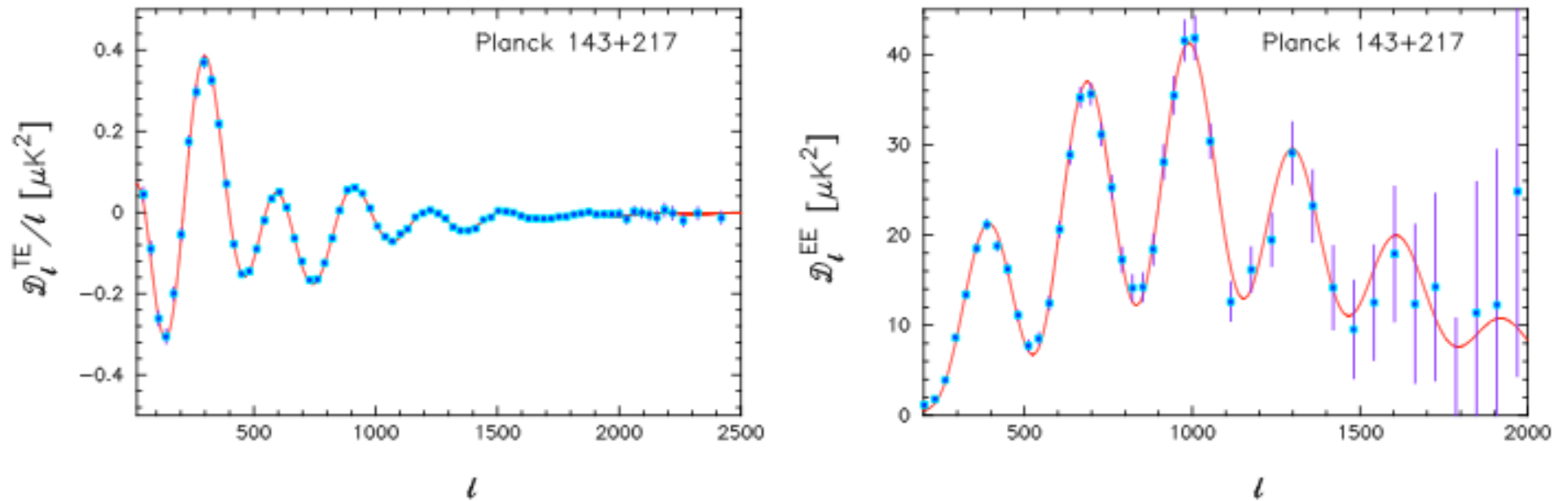
# theory confronts data – 2



Planck 15 months  
Planck Collaboration, 2013, 15



# theory confronts data – 3 – polarization

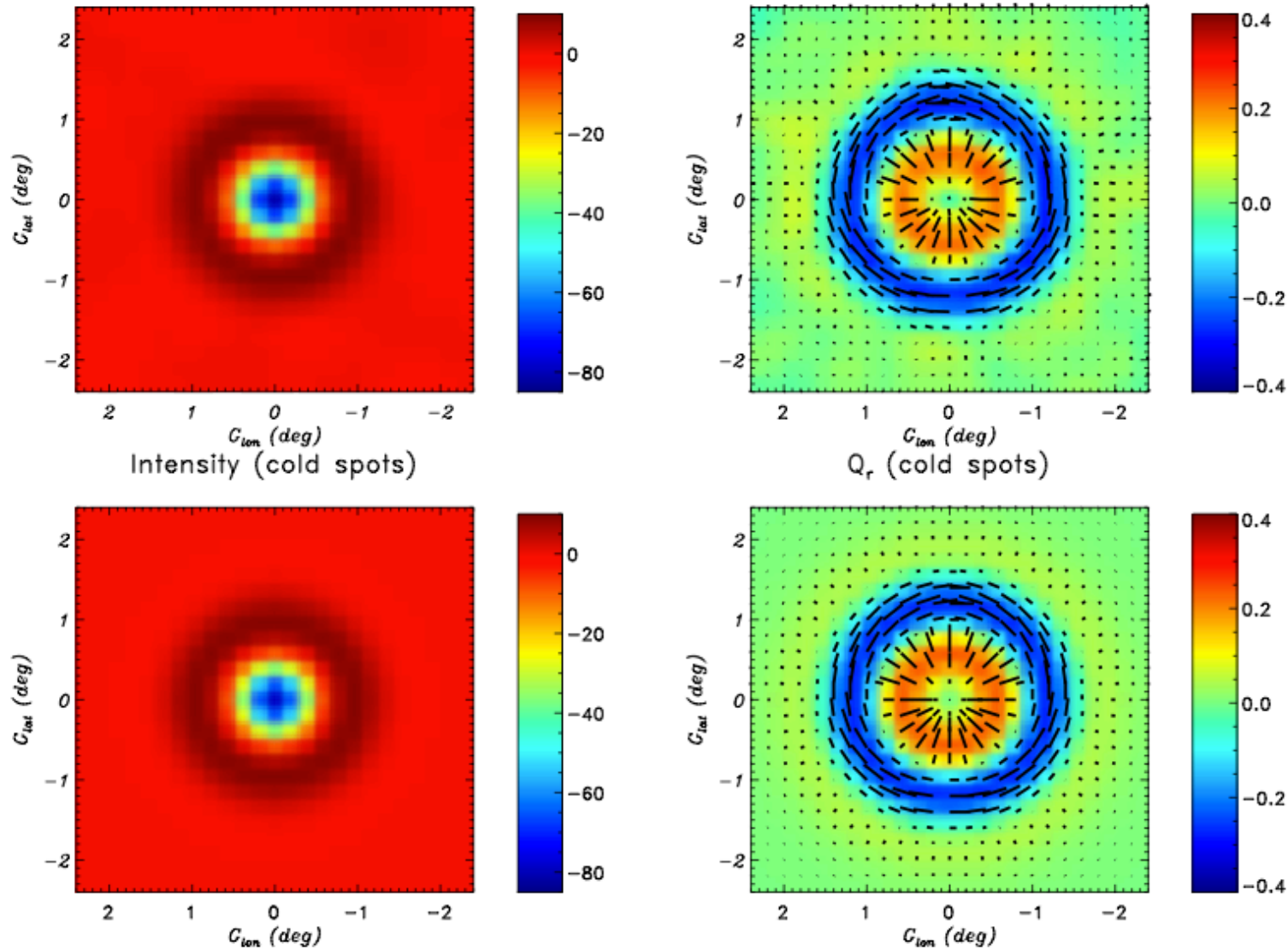


**Fig. 11.** *Planck TE* (left) and *EE* spectra (right) computed as described in the text. The red lines show the polarization spectra from the base  $\Lambda$ CDM *Planck*+WP+highL model, which is fitted to the *TT* data only.

-> NOT a fit to TE and EE, just an overplot at high-ell

Planck 15 months  
Planck Collaboration, 2013, 15

# matter density and velocity at recombination



Data (top) versus expectation (bottom) of stacked cold spots

→ Planck “sees” precisely the dynamics of fluctuations, at  $\sim 380\,000$  years

Planck 15 months  
Planck Collaboration, 2013, 1

# 4. le modèle standard $\Lambda$ -CDM

Univers plat, avec constante cosmologique et matière noire froide

Seulement 6 paramètres.....

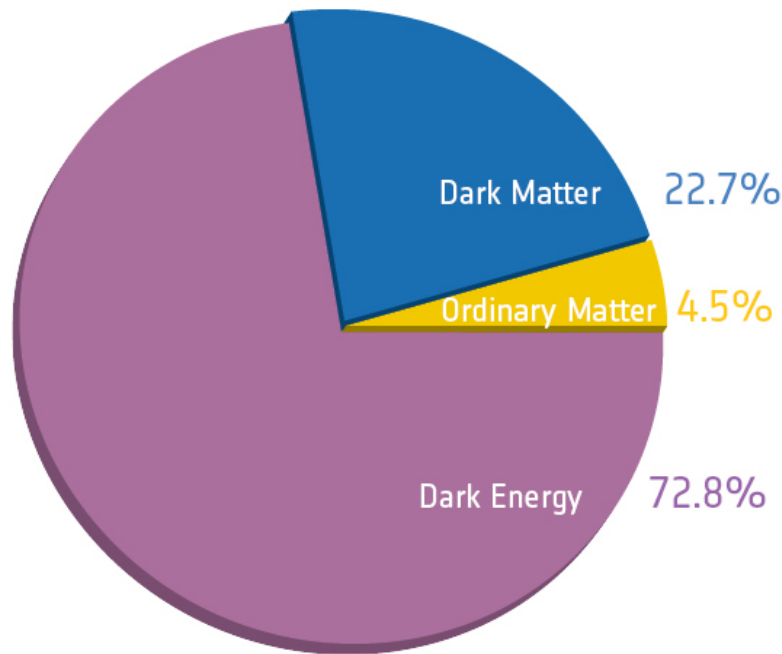
	Parameter	Best fit	68% limits
Quantité d'atomes	$\Omega_b h^2$ . . . . .	0.022068	$0.02207 \pm 0.00033$
Quantité de matière noire	$\Omega_c h^2$ . . . . .	0.12029	$0.1196 \pm 0.0031$
Lié à la distance que parcourt le son	$100\theta_{MC}$ . . . . .	1.04122	$1.04132 \pm 0.00068$
Fraction de diffusion récente	$\tau$ . . . . .	0.0925	$0.097 \pm 0.038$
Variation d'échelles de la granulosité	$n_s$ . . . . .	0.9624	$0.9616 \pm 0.0094$
Force de la granulosité	$\ln(10^{10} A_s)$ . . . . .	3.098	$3.103 \pm 0.072$

Et quelques paramètres dérivés

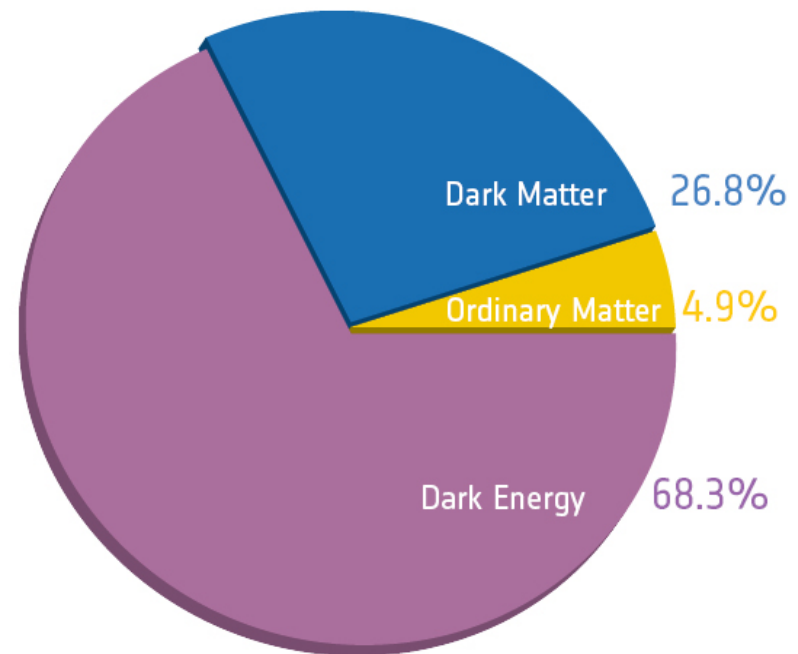
$H_0$ . . . . .	67.11	$67.4 \pm 1.4$
$\Omega_\Lambda$ . . . . .	0.6825	$0.686 \pm 0.020$
$\Omega_m$ . . . . .	0.3175	$0.314 \pm 0.020$

# the Universe gets heavier...

---



Before Planck



After Planck

La quantité de matière ordinaire et de matière noire doit être augmentée de 10% par rapport aux estimations précédentes.

Planck 15 months

# ... and older

Parameter	Planck+WP		Planck+WP+highL		Planck+lensing+WP+highL		Planck+WP+highL+BAO	
	Best fit	68% limits	Best fit	68% limits	Best fit	68% limits	Best fit	68% limits
$\Omega_b h^2$	0.022032	$0.02205 \pm 0.00028$	0.022069	$0.02207 \pm 0.00027$	0.022199	$0.02218 \pm 0.00026$	0.022161	$0.02214 \pm 0.00024$
$\Omega_c h^2$	0.12038	$0.1199 \pm 0.0027$	0.12025	$0.1198 \pm 0.0026$	0.11847	$0.1186 \pm 0.0022$	0.11889	$0.1187 \pm 0.0017$
$100\theta_{MC}$	1.04119	$1.04131 \pm 0.00063$	1.04130	$1.04132 \pm 0.00063$	1.04146	$1.04144 \pm 0.00061$	1.04148	$1.04147 \pm 0.00056$
$\tau$	0.0925	$0.089^{+0.012}_{-0.014}$	0.0927	$0.091^{+0.013}_{-0.014}$	0.0943	$0.090^{+0.013}_{-0.014}$	0.0952	$0.092 \pm 0.013$
$n_s$	0.9619	$0.9603 \pm 0.0073$	0.9582	$0.9585 \pm 0.0070$	0.9624	$0.9614 \pm 0.0063$	0.9611	$0.9608 \pm 0.0054$
$\ln(10^{10} A_s)$	3.0980	$3.089^{+0.024}_{-0.027}$	3.0959	$3.090 \pm 0.025$	3.0947	$3.087 \pm 0.024$	3.0973	$3.091 \pm 0.025$
$A_{100}^{PS}$	152	$171 \pm 60$	209	$212 \pm 50$	204	$213 \pm 50$	204	$212 \pm 50$
$A_{143}^{PS}$	63.3	$54 \pm 10$	72.6	$73 \pm 8$	72.2	$72 \pm 8$	72.2	$72 \pm 8$
$A_{217}^{PS}$	117.0	$107^{+20}_{-10}$	59.5	$59 \pm 10$	60.2	$58 \pm 10$	60.2	$58 \pm 10$
$A_{143}^{CIB}$	0.0	$< 10.7$	3.57	$3.24 \pm 0.83$	3.25	$3.24 \pm 0.83$	3.25	$3.24 \pm 0.83$
$A_{217}^{CIB}$	27.2	$29^{+6}_{-9}$	53.9	$49.6 \pm 5.0$	52.3	$50.0 \pm 5.0$	52.3	$50.0 \pm 5.0$
$A_{143}^{tSZ}$	6.80	...	5.17	$2.54^{+1.1}_{-1.9}$	4.64	$2.51^{+1.1}_{-1.9}$	4.64	$2.51^{+1.1}_{-1.9}$
$r_{143 \times 217}^{PS}$	0.916	$> 0.850$	0.825	$0.823^{+0.069}_{-0.077}$	0.814	$0.825 \pm 0.069$	0.814	$0.825 \pm 0.069$
$r_{143 \times 217}^{CIB}$	0.406	$0.42 \pm 0.22$	1.0000	$> 0.930$	1.0000	$> 0.930$	1.0000	$> 0.930$
$\gamma^{CIB}$	0.601	$0.53^{+0.13}_{-0.12}$	0.674	$0.638 \pm 0.081$	0.656	$0.643 \pm 0.081$	0.656	$0.643 \pm 0.081$
$\xi^{tSZ \times CIB}$	0.03	...	0.000	$< 0.409$	0.000	$< 0.389$	0.000	$< 0.410$
$A^{kSZ}$	0.9	...	0.89	$5.34^{+2.8}_{-1.9}$	1.14	$4.74^{+2.6}_{-2.1}$	1.58	$5.34^{+2.8}_{-2.0}$
$\Omega_\Lambda$	0.6817	$0.685^{+0.018}_{-0.016}$	0.6830	$0.685^{+0.017}_{-0.016}$	0.6939	$0.693 \pm 0.013$	0.6914	$0.692 \pm 0.010$
$\sigma_8$	0.8347	$0.829 \pm 0.012$	0.8322	$0.828 \pm 0.012$	0.8271	$0.8233 \pm 0.0097$	0.8288	$0.826 \pm 0.012$
$z_m$	11.37	$11.1 \pm 1.1$	11.38	$11.1 \pm 1.1$	11.42	$11.1 \pm 1.1$	11.52	$11.3 \pm 1.1$
$H_0$	67.04	$67.3 \pm 1.2$	67.15	$67.3 \pm 1.2$	67.94	$67.9 \pm 1.0$	67.77	$67.80 \pm 0.77$
Age/Gyr	13.8242	$13.817 \pm 0.048$	13.8170	$13.813 \pm 0.047$	13.7914	$13.794 \pm 0.044$	13.7965	$13.798 \pm 0.037$
$100\theta_s$	1.04136	$1.04147 \pm 0.00062$	1.04146	$1.04148 \pm 0.00062$	1.04161	$1.04159 \pm 0.00060$	1.04163	$1.04162 \pm 0.00056$
$r_{dmg}$	147.36	$147.49 \pm 0.59$	147.35	$147.47 \pm 0.59$	147.68	$147.67 \pm 0.50$	147.611	$147.68 \pm 0.45$

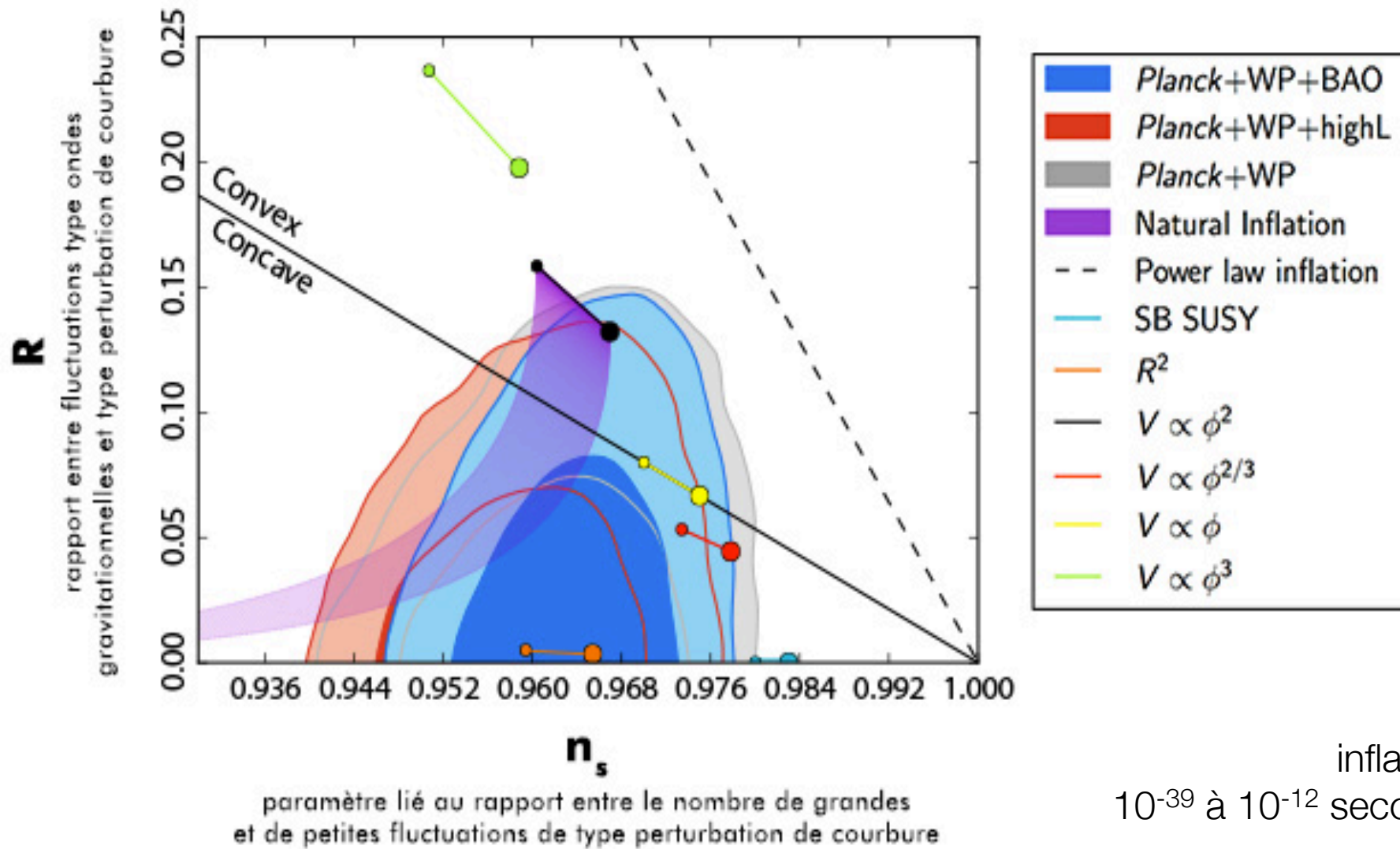
km/s/Mpc

$67.80 \pm 0.77$

Gyr

$13.798 \pm 0.037$

# 5. some inflation models excluded



inflation:  
 $10^{-39}$  à  $10^{-12}$  seconde

# more implications

---

- $\theta$ : sound horizon is determined by the position of the 7 peaks, and now measured at 0.05% precision
- $n_s$ : exact scale invariance of the primordial fluctuations is ruled out, at more than  $7\sigma$  (as predicted by base inflation models)
- upper limit on neutrino masses
- 3 neutrinos species favored by Planck
- no evidence for dynamical dark energy

---

*Planck+WP+highL+BAO*

---

$$1.04147 \pm 0.00056$$

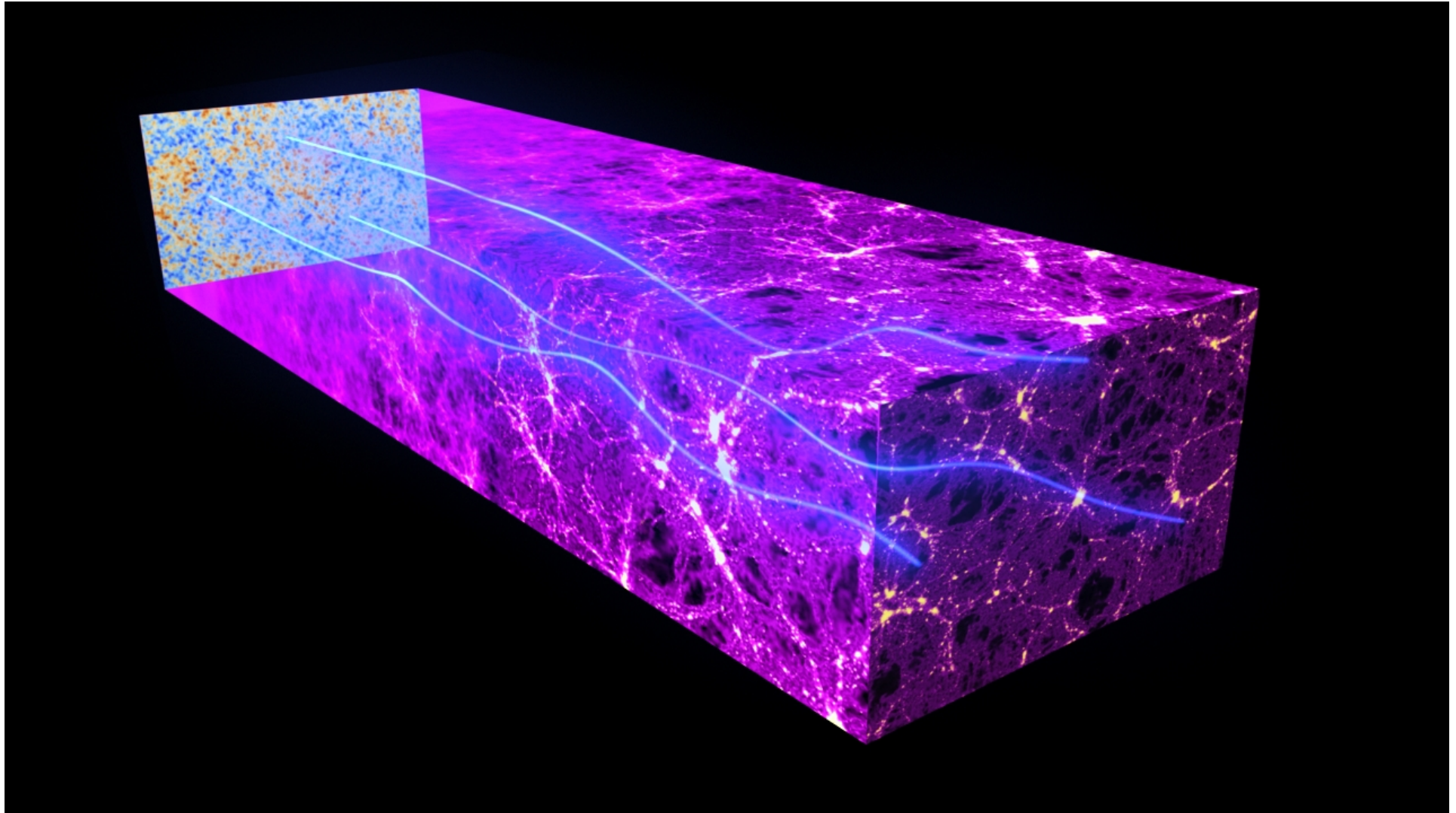
$$0.9608 \pm 0.0054$$

$$\sum m_\nu < 0.23 \text{ eV} \quad (95\%; \text{Planck+})$$

$$N_{\text{eff}} = 3.30^{+0.54}_{-0.51} \quad (95\%; \text{Pla})$$

## 6. between CMB and us: structures

---

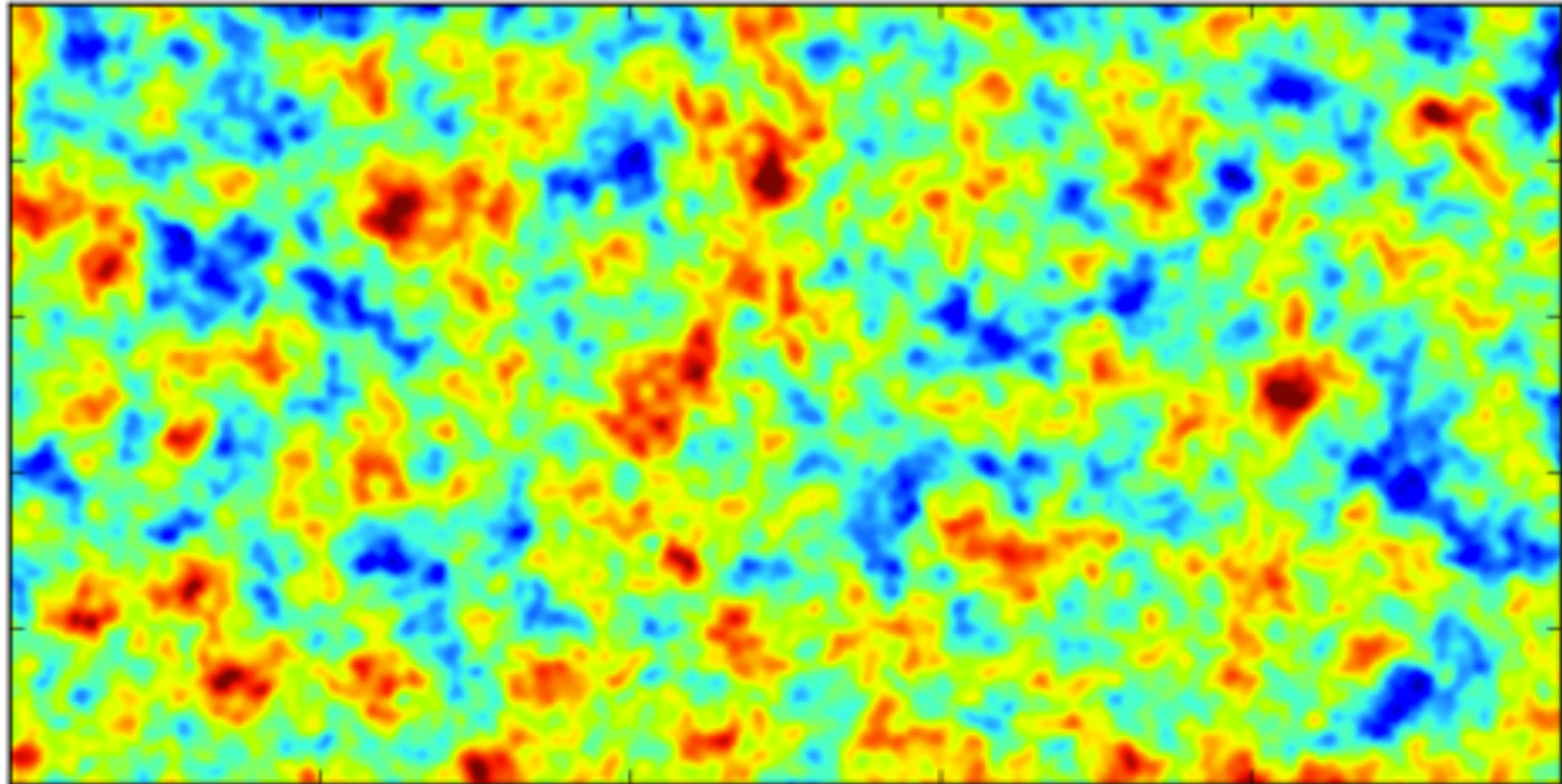




# gravitational lensing of the CMB

---

A simulated patch of CMB sky – before lensing



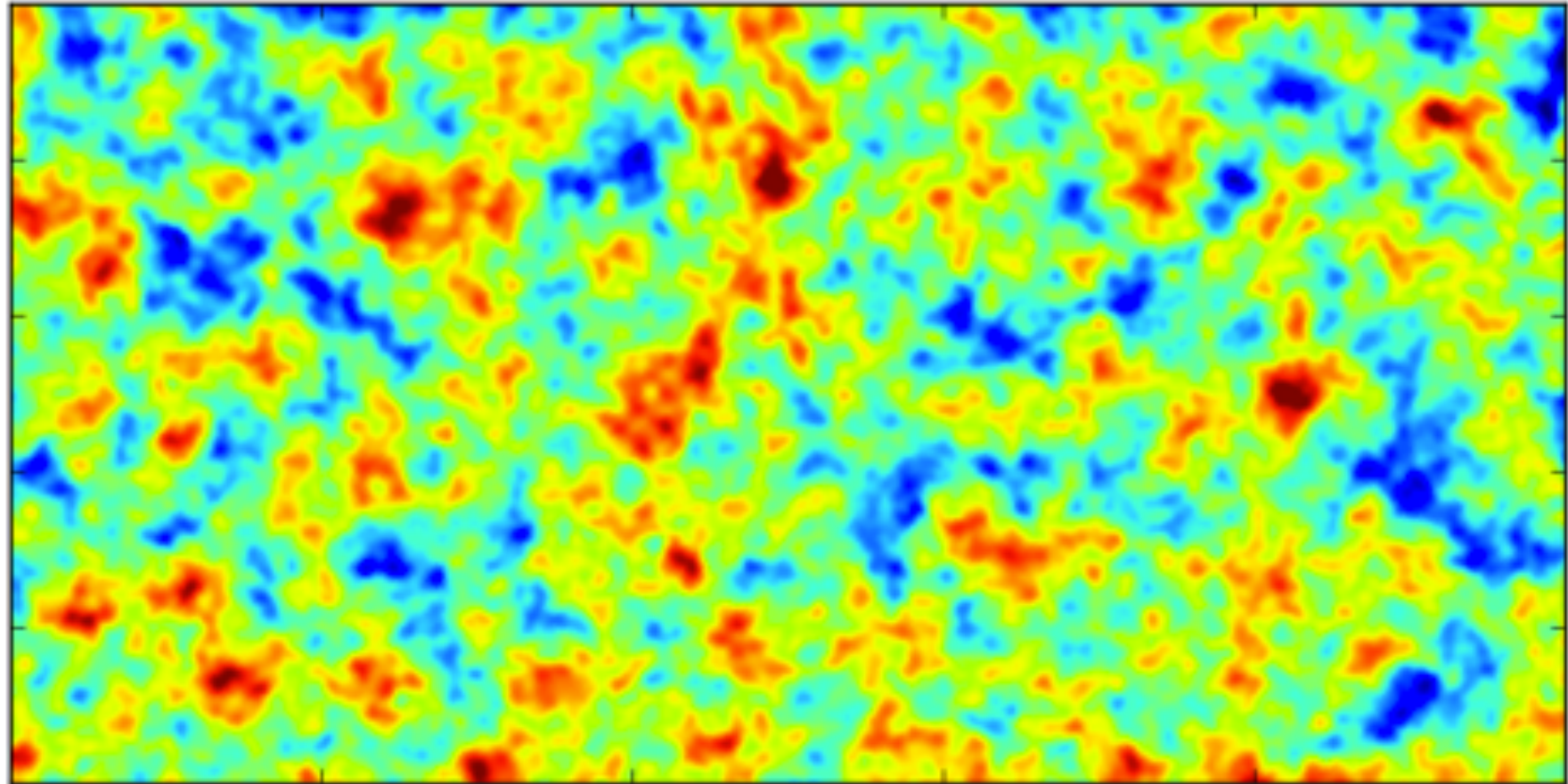
←—————  $10^\circ$  —————→

typical deflection: 2.4 arcmin

# gravitational lensing of the CMB

---

A simulated patch of CMB sky – *after lensing*

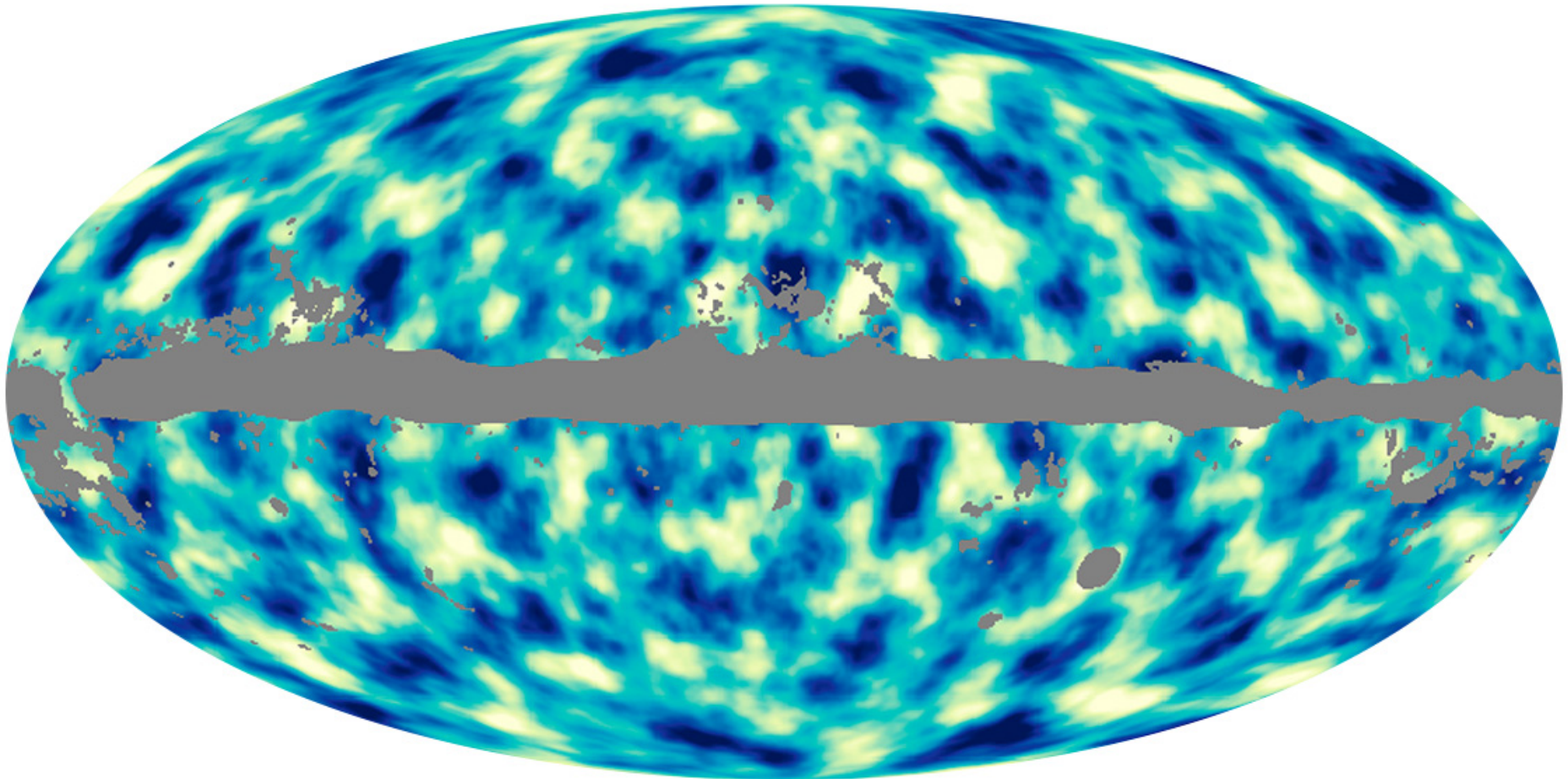


←—————  $10^\circ$  —————→

typical deflection: 2.4 arcmin

# Planck all-sky map of the dark matter

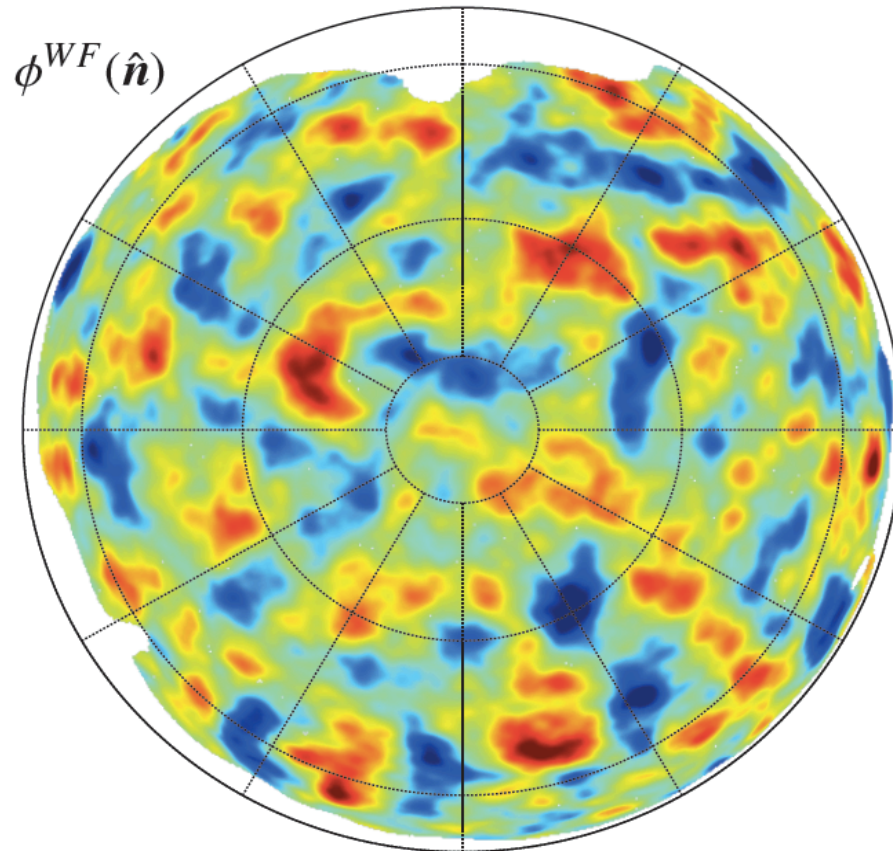
---



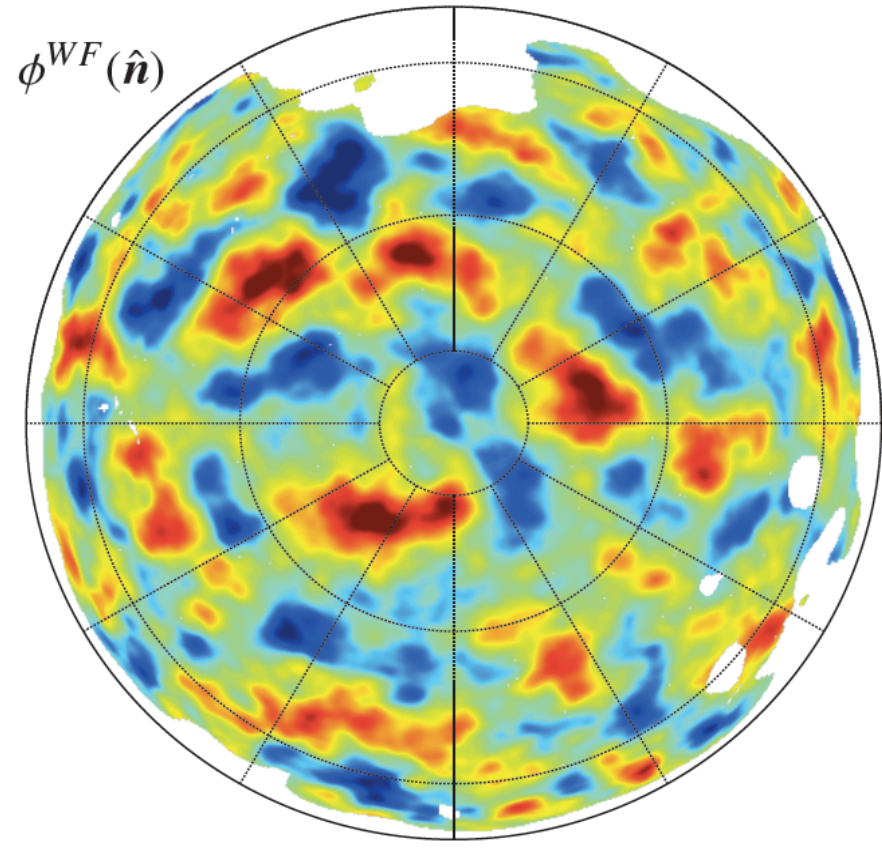
= Carte de la masse projetée sur la ligne de visée

Planck 15 months  
Planck Collaboration, 2013, 17

# Planck all-sky map of the dark matter



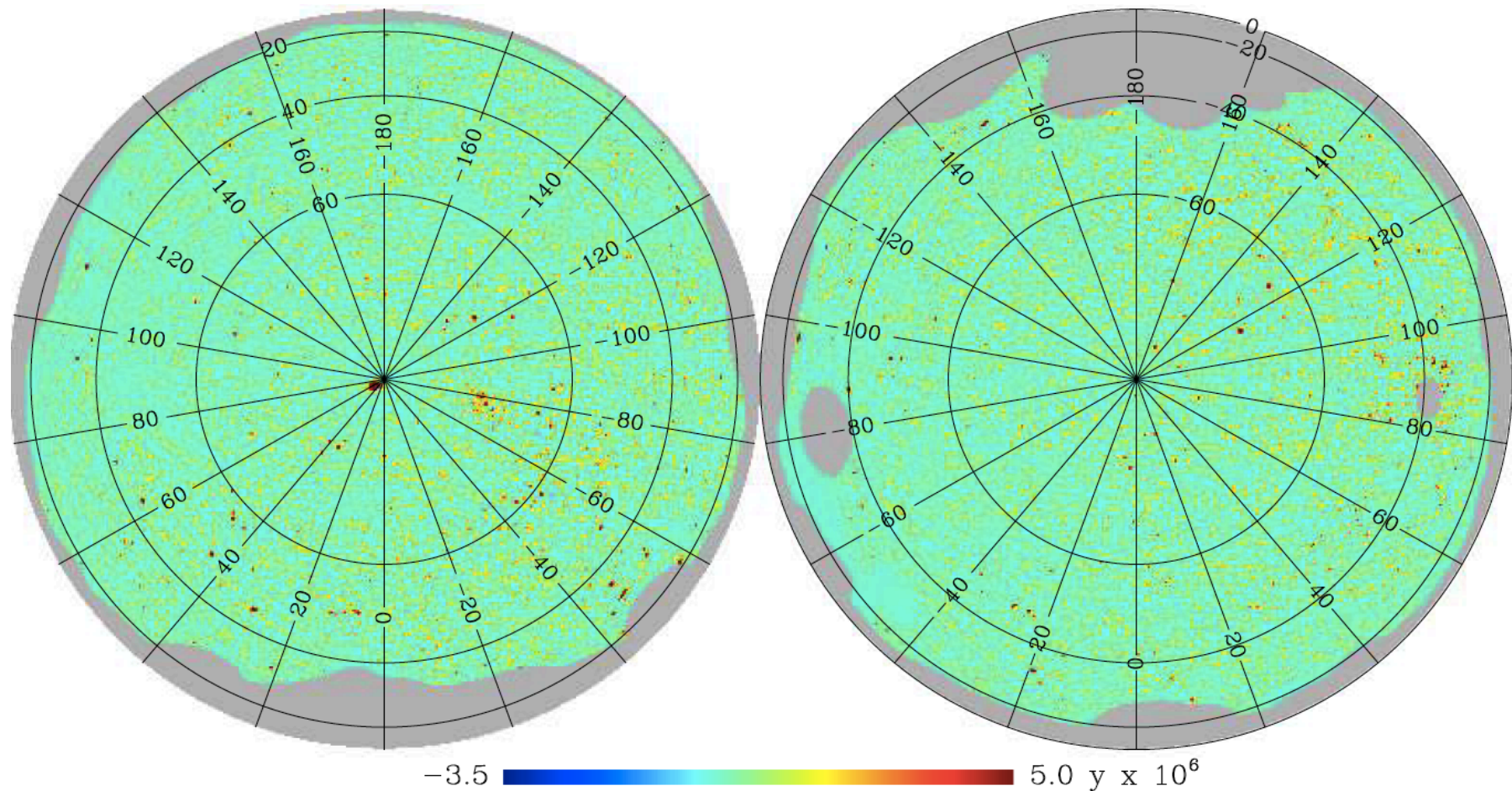
Galactic North



Galactic South

# Planck map of the baryon distribution

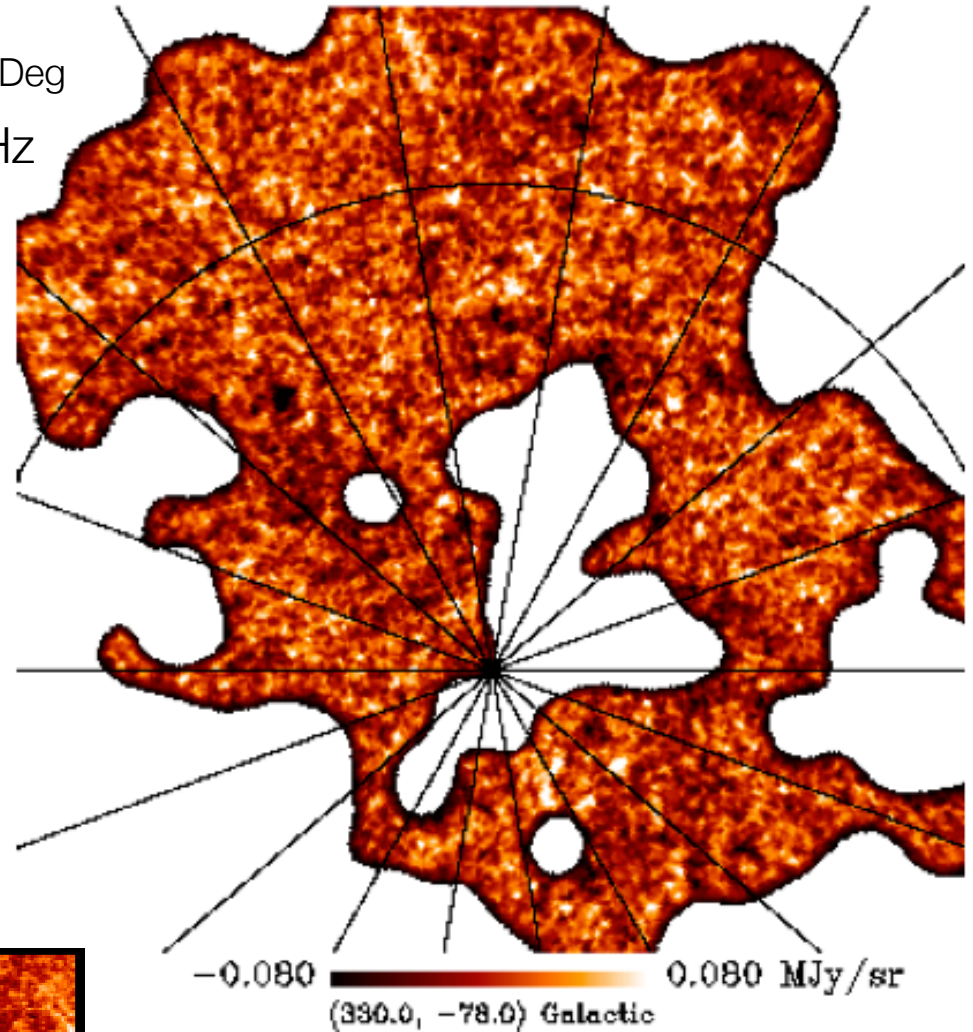
Planck can also image the gas (baryon) distribution in the low-redshift Universe using scattering of CMB photons off the electrons. This SZ (Sunyaev-Zeldovich) effect causes a change in the shape of the CMB spectrum



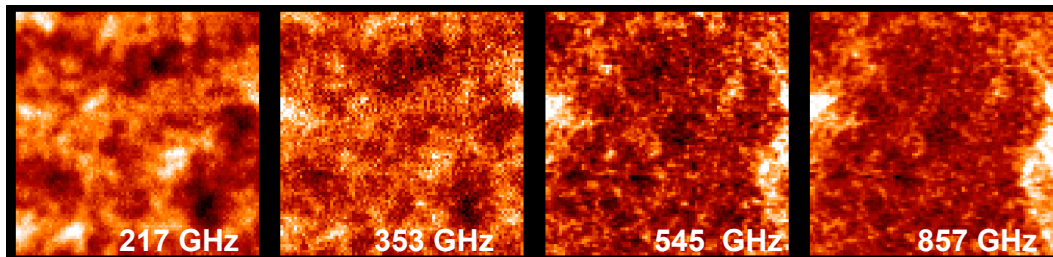
Planck 15 months  
Planck Collaboration, 2013, 21

# Cosmic IR Background maps probe high-z SFR

~2000 Sq. Deg  
545 GHz



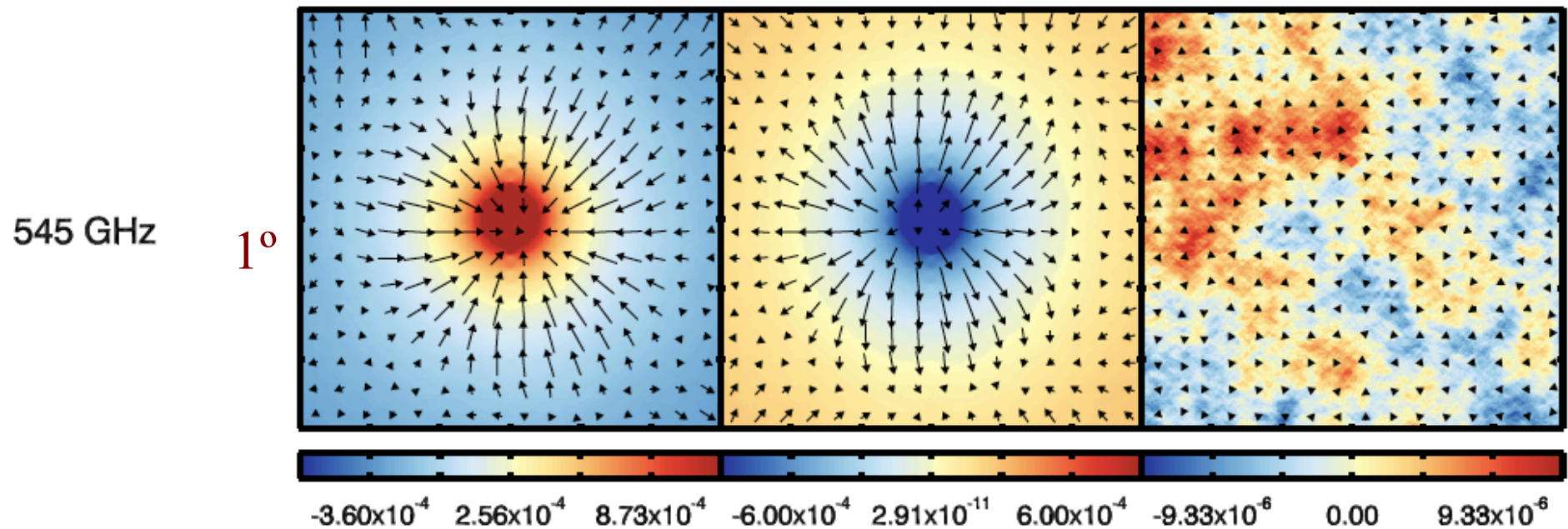
Planck Collab., 2013, 30



few 10 Sq Deg fields in 2011

# CIB peaks correspond to mass peaks

Stacking the Planck mass maps at the positions of peaks and troughs of Cosmic Infrared Background leads to a strong detection of the mass associated with these distant star forming galaxies. This is mostly Dark Matter.



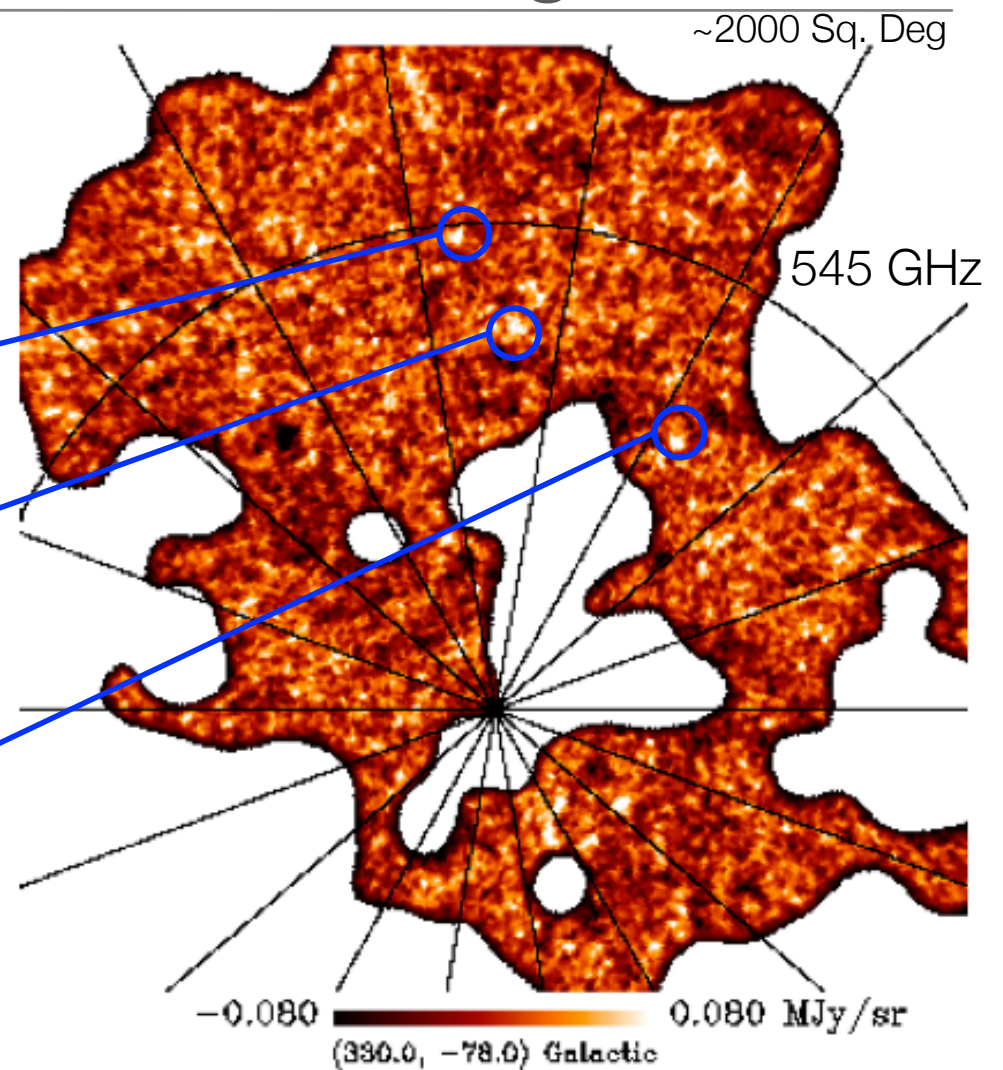
see also Hanson et al., 2013 about  
lensing induced B-modes  
(NOT primordial B-modes !)

Planck 15 months  
Planck Collaboration, 2013, 18

# 7. digging into the Cosmic IR Background

« cold sources » of the CIB  
in Planck data (4.5' beam)

- $z > 1.5$  overdensities of intensely star forming galaxies ?
- $z > 1.5$  extremely bright lensed sources ?
- large scale structure alignments ?
- residual cirrus ?



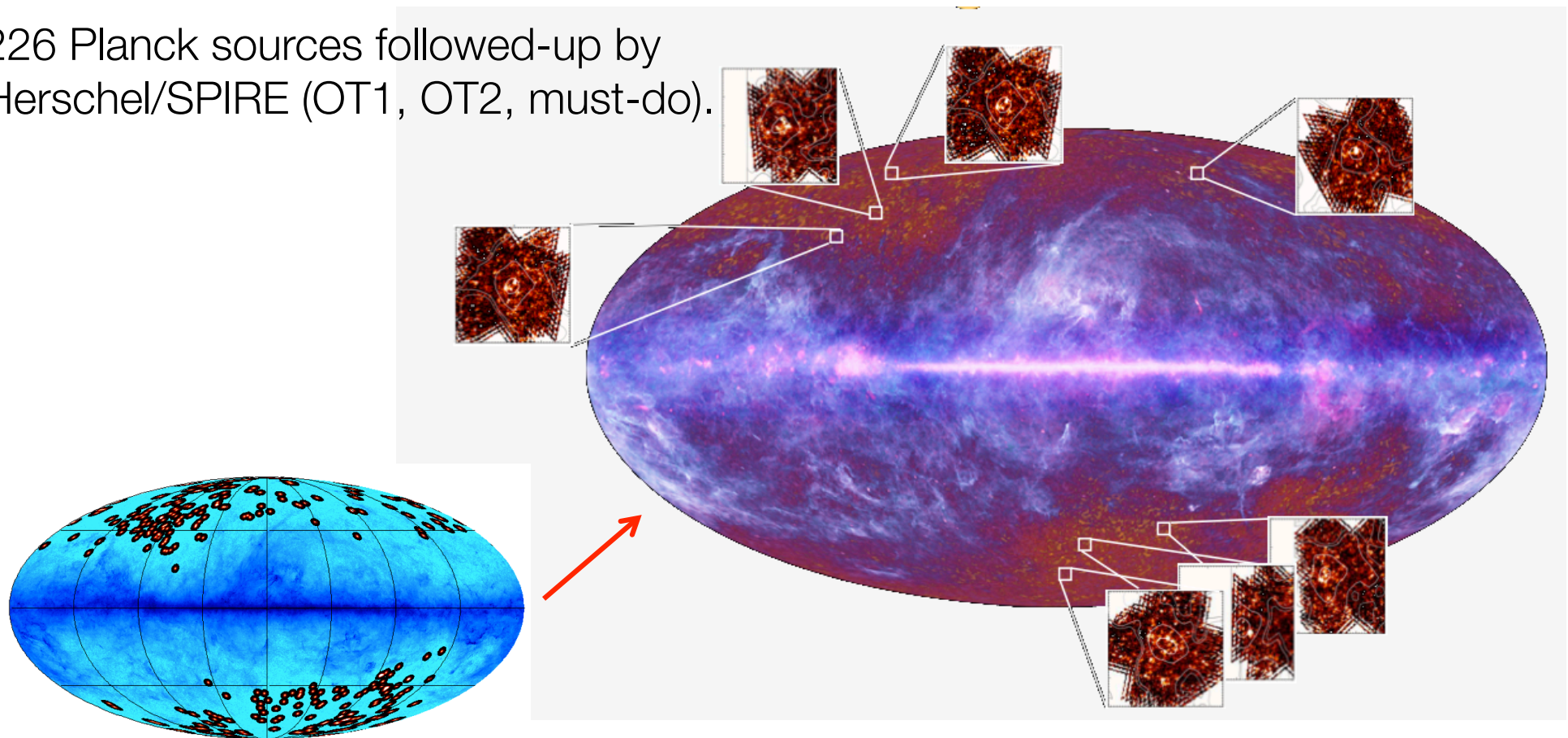
Planck Collab., 2013, 30

predicted number of extragalactic objects :  
100 – 1000 (Negrello+2005)



# several hundred Planck high-z candidates

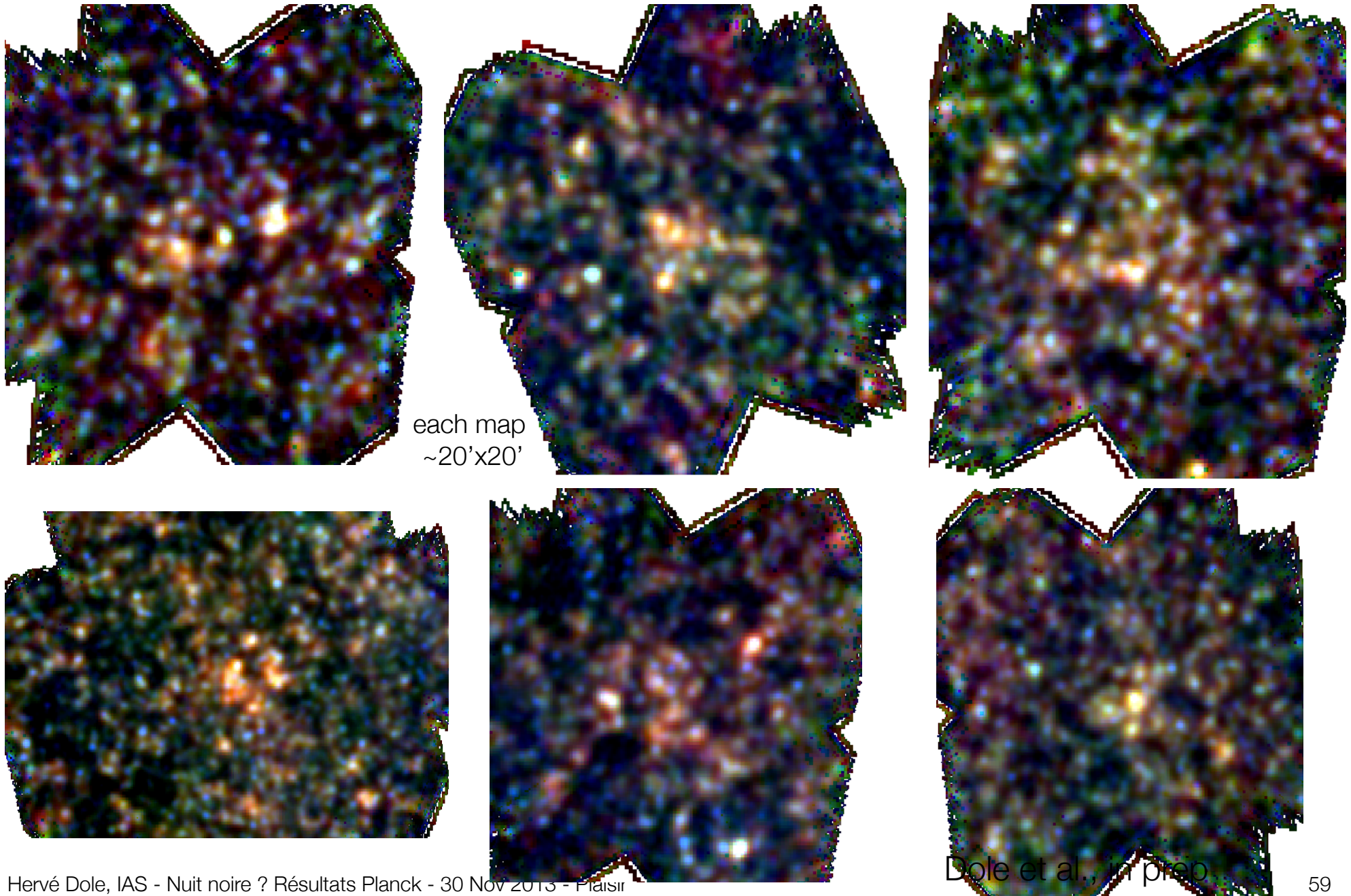
226 Planck sources followed-up by  
Herschel/SPIRE (OT1, OT2, must-do).



98% success

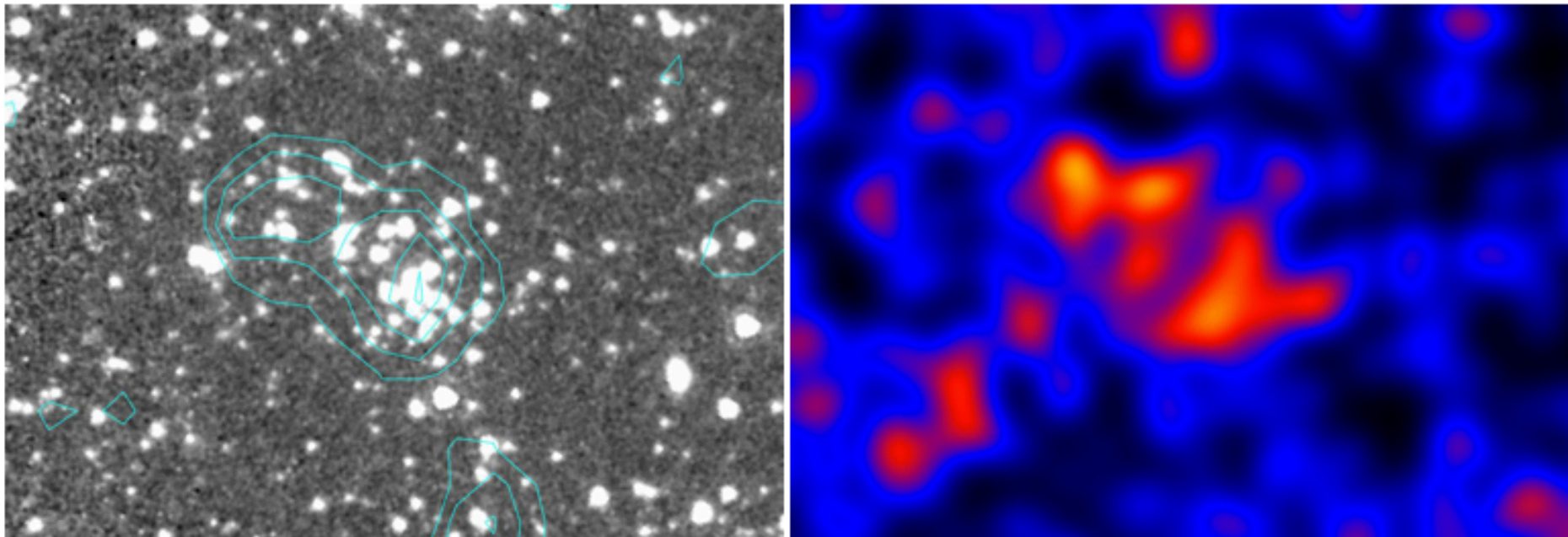
- either bright lensed candidates
- or overdensities of red galaxies
- 1.4% of the fields were cirrus

# a remarkable dataset



# more identifications to go

---



**Figure 10.** A high- $z$  cluster candidate observed by *Planck*, *Herschel*, and here *Spitzer-IRAC* ( $3.5' \times 2.3'$ ). Left: *IRAC* channel 2 ( $4.5 \mu\text{m}$ ) with *SPIRE*  $350 \mu\text{m}$  contour. Right: color image of the  $4.5/3.6$  color ratio, showing the red color of the sources within the cluster candidate.

# au final

---

- un tour sur le ciel par minute (répété 50 fois au même endroit)
- 200 mesures du ciel par seconde et par détecteur, en continu pendant 30 mois à 0.1K
- ~1000 milliards d'échantillons (72 voies, 30 mois) et quelques milliards de paquets de télémétrie à « descendre »
- données brutes d'un détecteur (TOI)
  - 50 Go (et on a 52 détecteurs, et plusieurs versions)
- 1 release: 1 mois de processing, 2200 cartes
- cartes du ciel: 50 millions de pixels (6 fréquences HFI + 3 LFI)
- spectres de puissance du fond diffus cosmologique: 1000 valeurs
- **seulement 6 paramètres cosmologiques** ajustant parfaitement les données
- année prochaine: données de POLARISATION !

# au final

LE RAYONNEMENT FOSSILE par PLANCK

- un tour sur l'
  - 200
- pour obtenir la meilleure image de l'univers jeune  
(~380 000 ans ou  $z=1090$ )

... et tout cela pour  
7 centimes/européen/an sur 20 ans

stant parfaitement