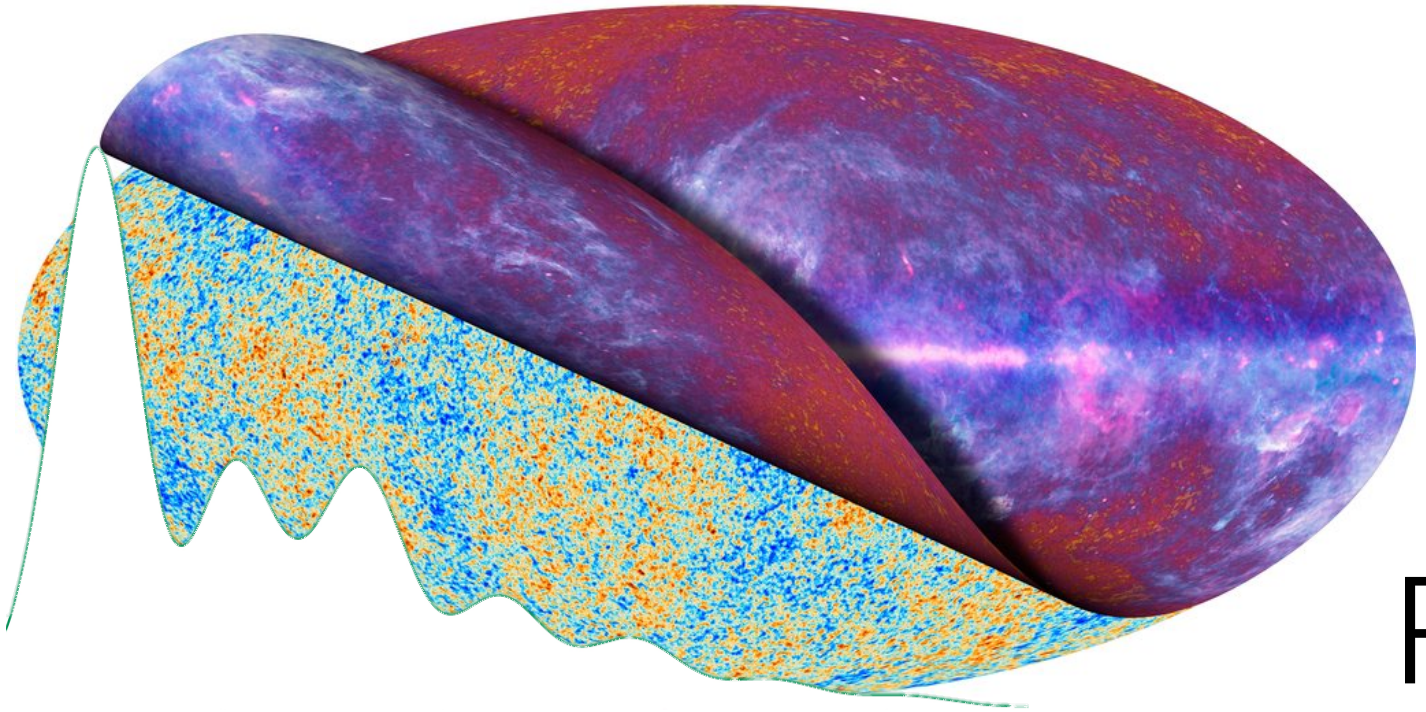


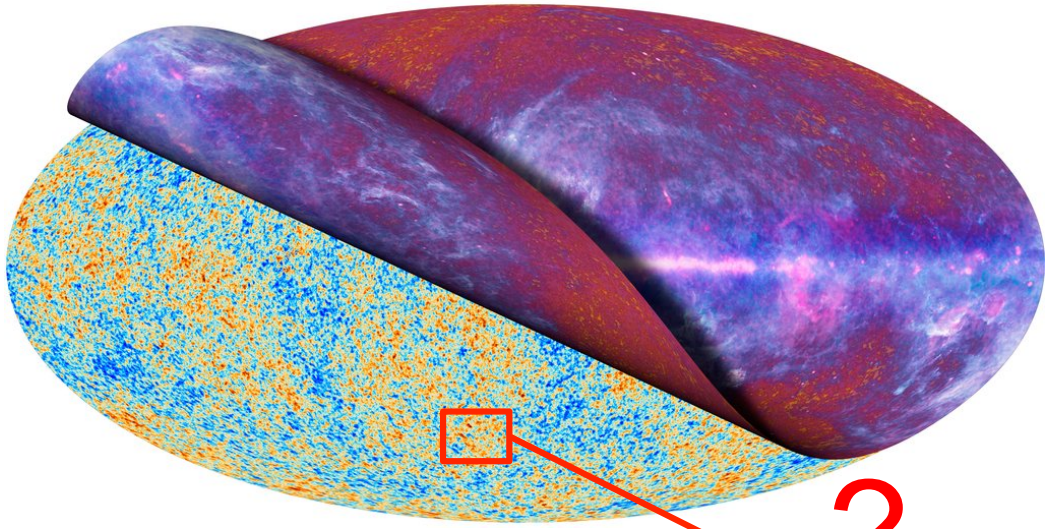
Planck & the large scale structure

Hervé Dole

on behalf of the Planck collaboration

Institut d' Astrophysique Spatiale, Orsay, France
Université Paris Sud & CNRS & univ. Paris-Saclay
Institut Universitaire de France
http://www.ias.u-psud.fr/dole/

the two outstanding questions in cosmology



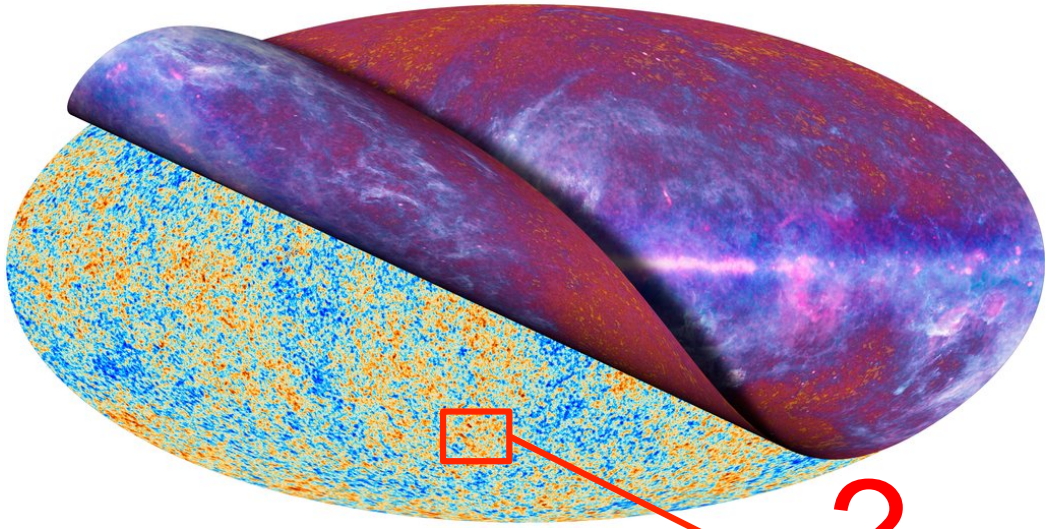
?

homogeneous universe

?

structured, inhomogeneous universe

the two outstanding questions in cosmology



?

homogeneous universe

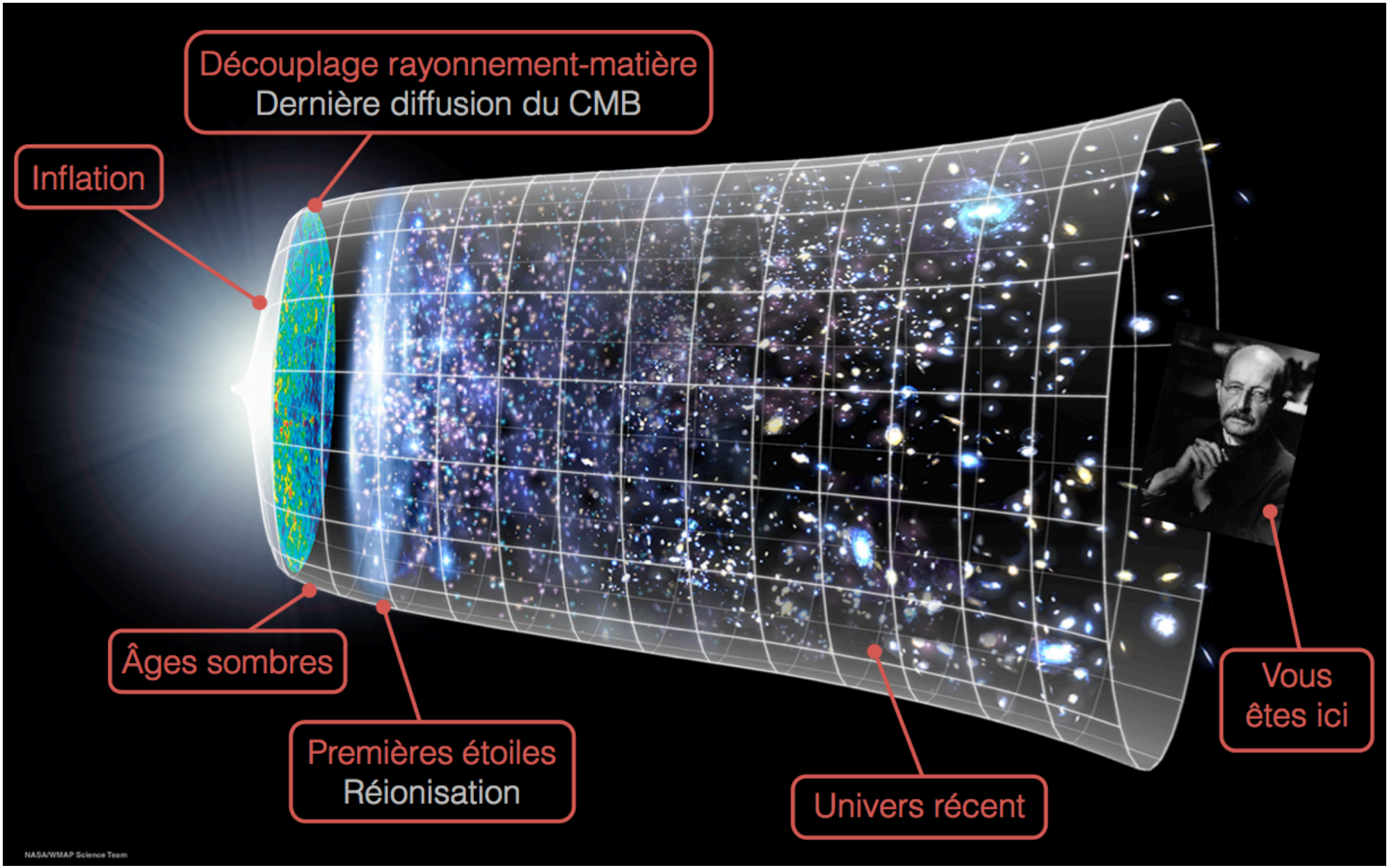
inflation models ?

?

structured, inhomogeneous universe

structure formation, ΛCDM

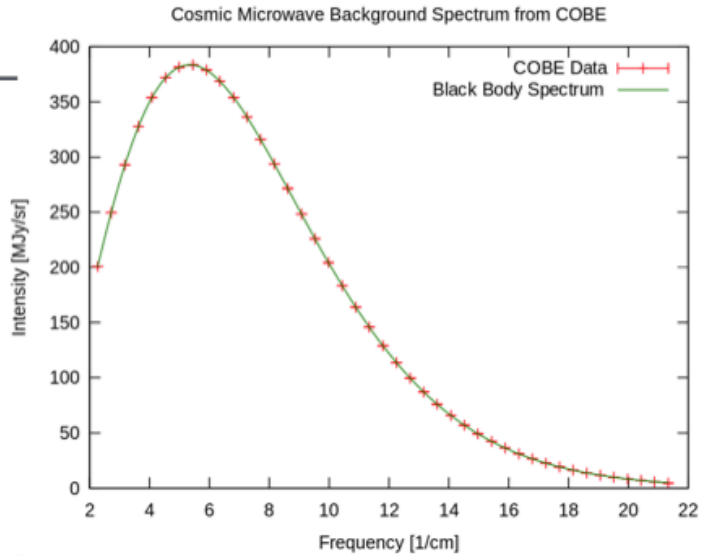
a short history of the 13.8b yr old universe

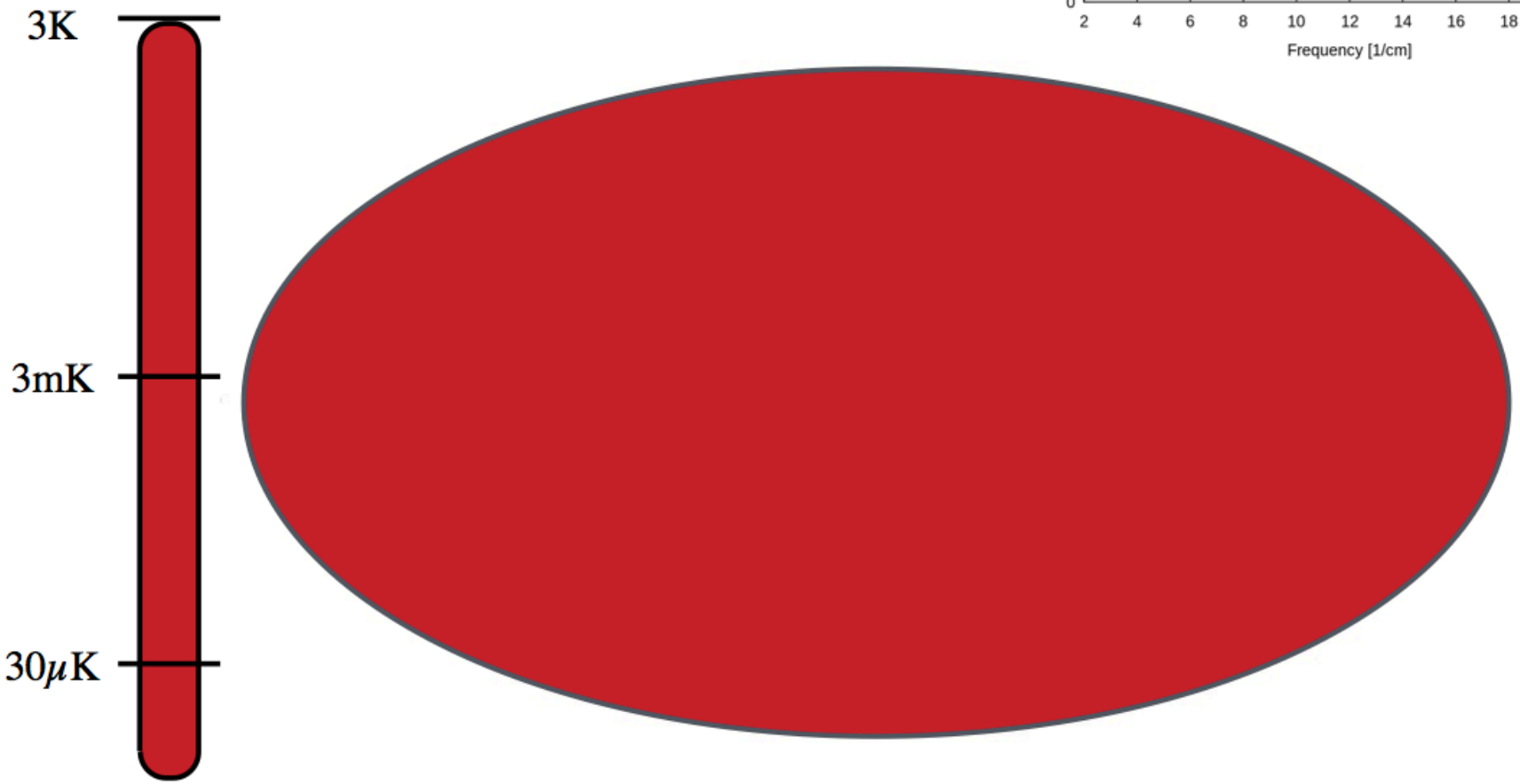


courtesy WMAP, Planck, J. Aumont

Le Fond Diffus Cosmologique (CMB)

★ Rayonnement découvert par [Penzias et Wilson 1965]
★ En première approximation homogène et isotrope,
$T = 2.725 \pm 0.001$ K

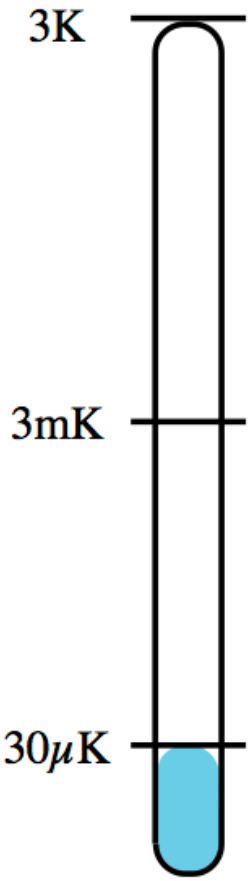


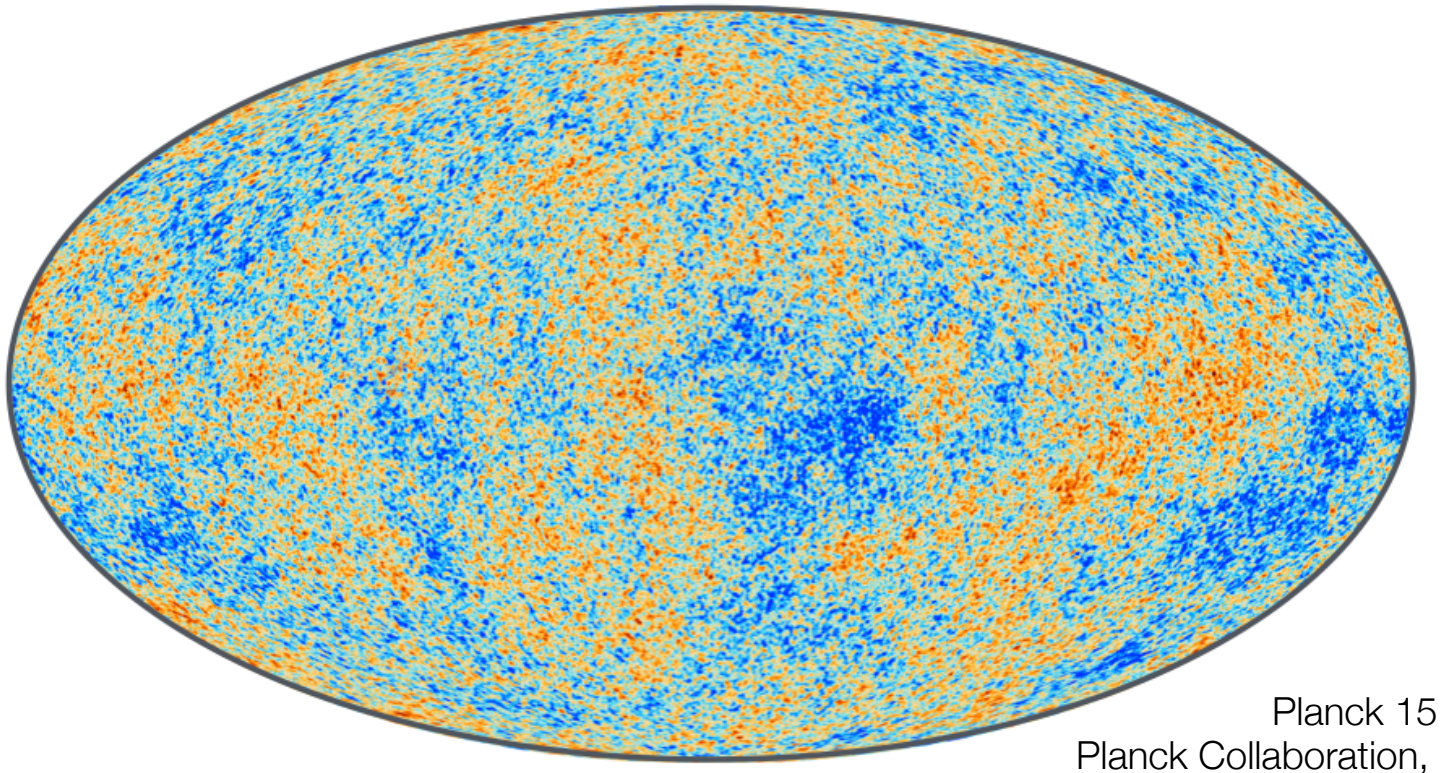


courtesy J. Aumont

Le Fond Diffus Cosmologique (CMB)

- ★ Rayonnement découvert par [Penzias et Wilson 1965]
- ★ En première approximation homogène et isotrope, $T = 2.725 \pm 0.001$ K
- ★ … mais il existe des anisotropies qui sont les empreintes des fluctuations de densité primordiales



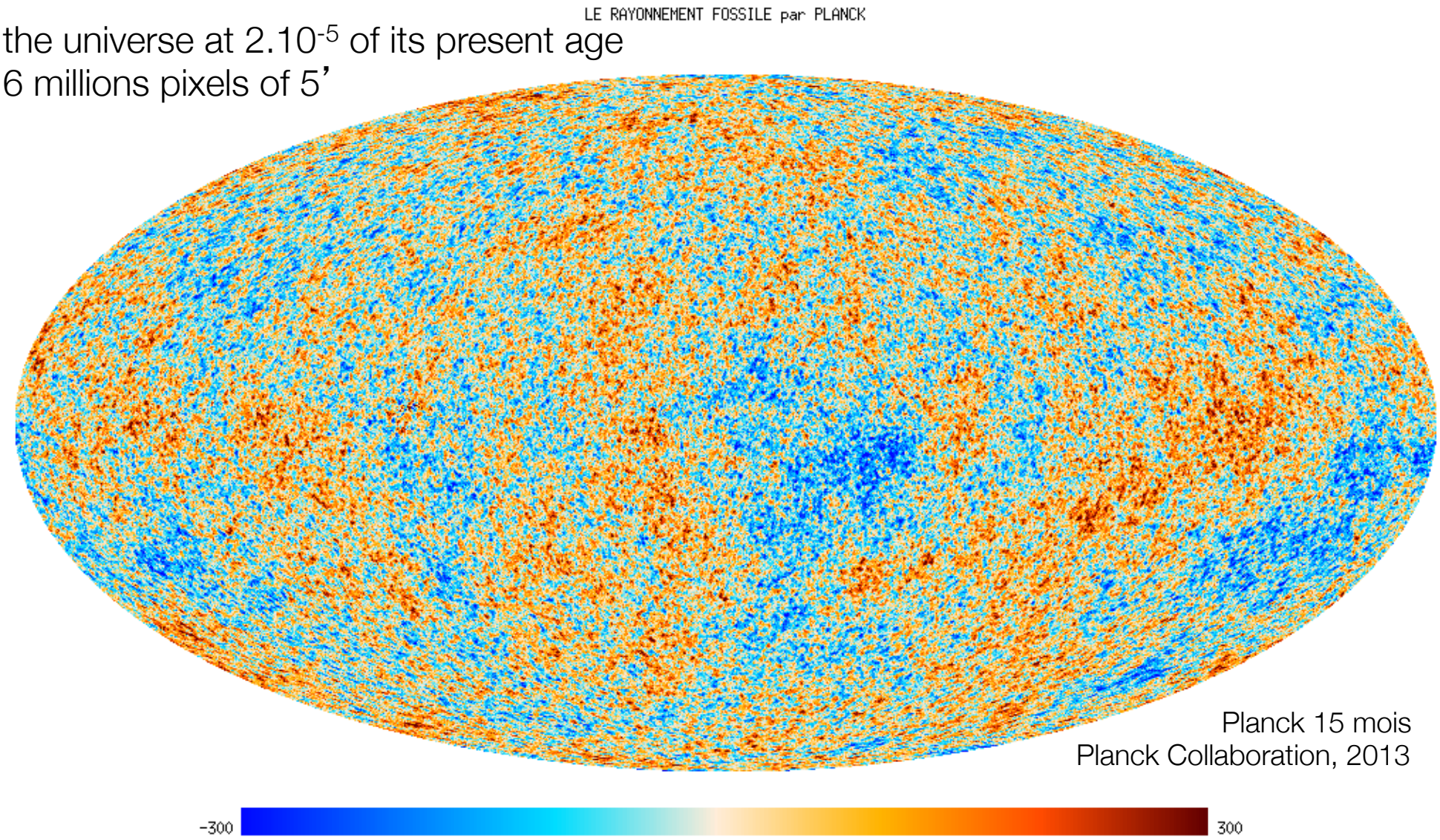


Planck 15 mois
Planck Collaboration, 2013

courtesy J. Aumont

CMB temperature anisotropies

the universe at 2.10^{-5} of its present age
6 millions pixels of 5’

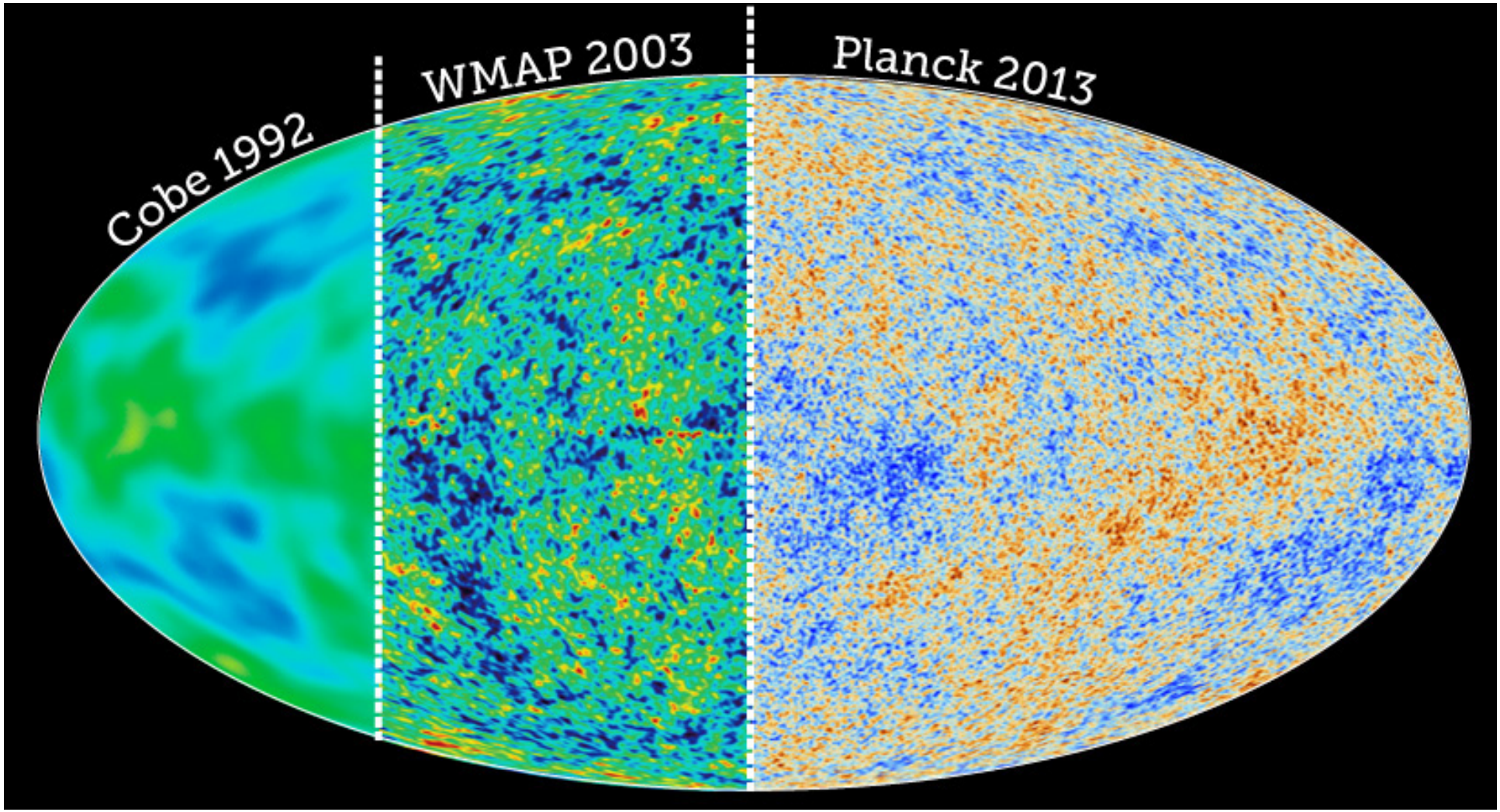


Planck 15 mois
Planck Collaboration, 2013

and a fairly wide coverage

March 21st or 22nd, 2013

improvements with time & technology

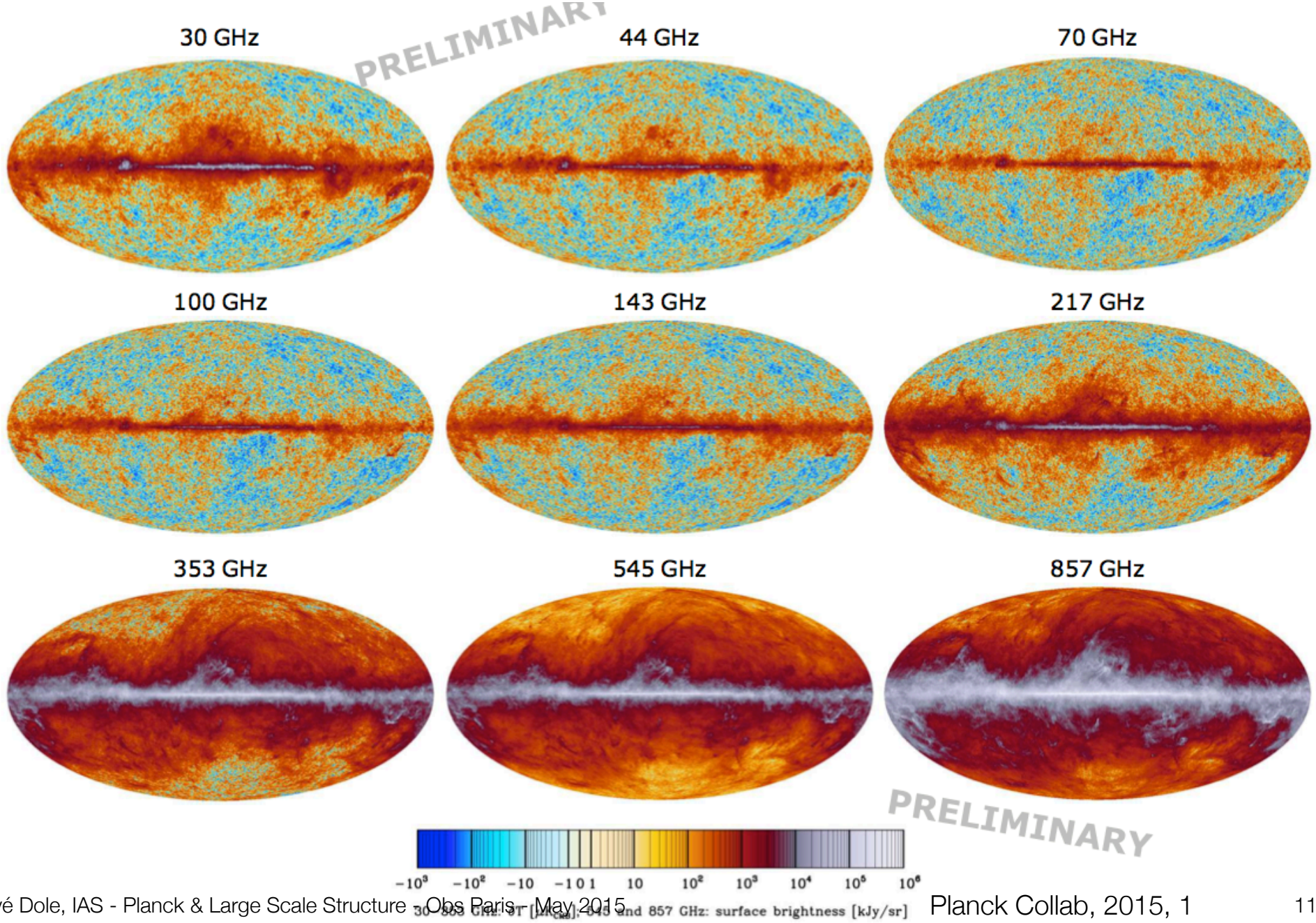


Planck sensitivity (in T) in 1yr ~ 1000 years of WMAP

outline

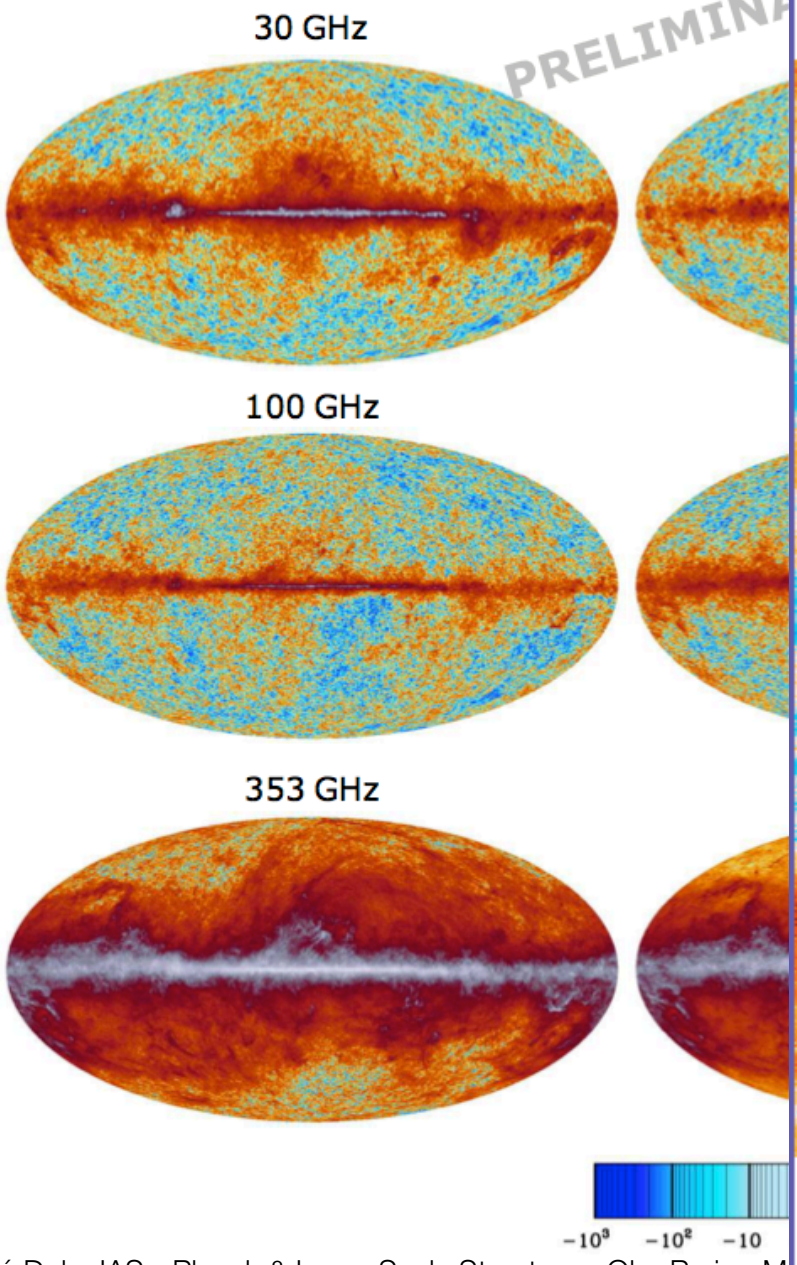
1. why Planck ? why the CMB ?
2. Planck 2015 new data
3. the Cosmic Microwave Background (CMB)
   - analysis of the CMB: angular power spectra
   - cosmological implications
   - a word about inflation
4. a clumpy Universe
   1. dark matter
   2. galaxy clusters via SZ
5. digging into the Cosmic Infrared Background
   1. overdensities: clusters of dusty galaxies ?
   2. the brightest lensed sources in the sky

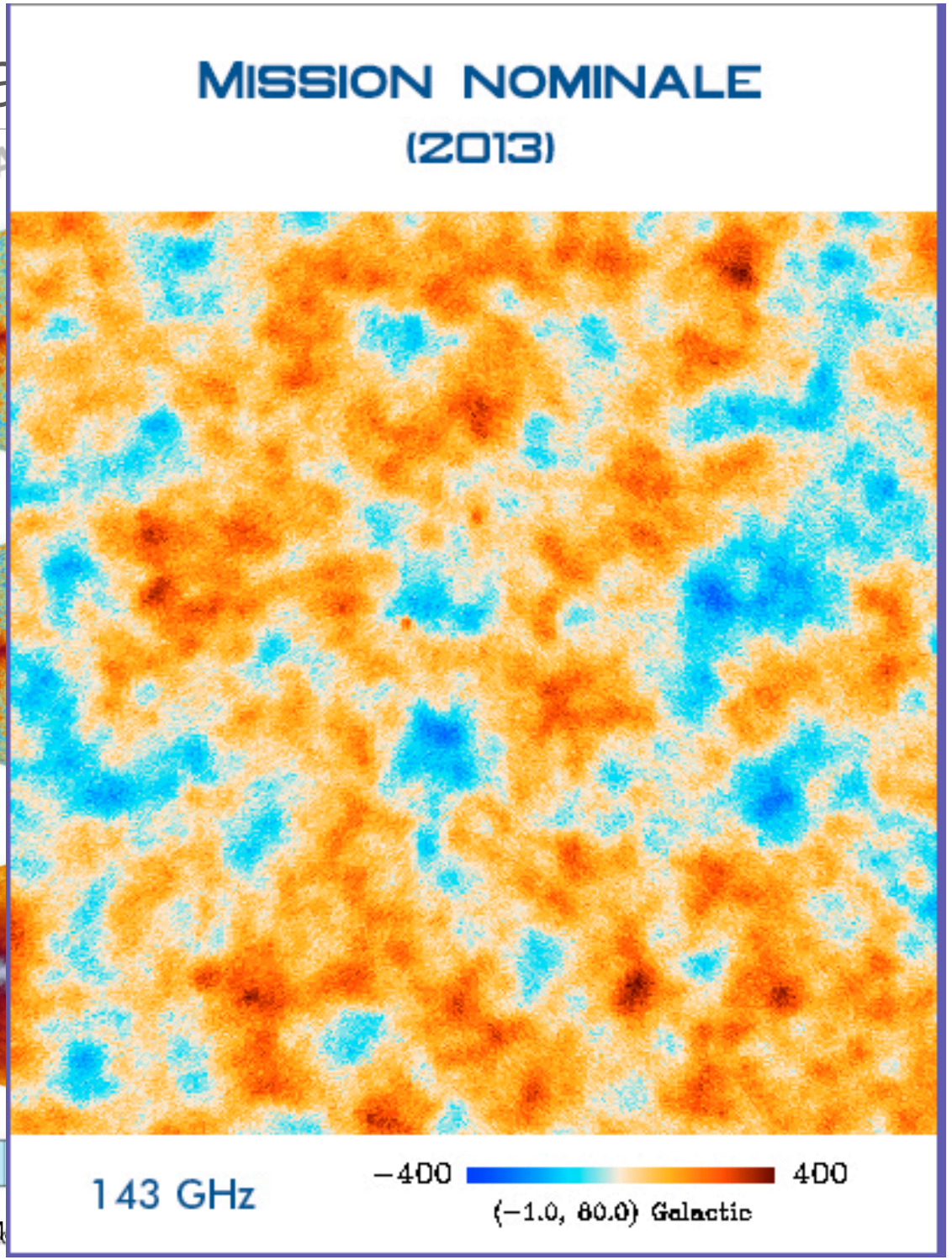
2. Planck all-sky maps 2015



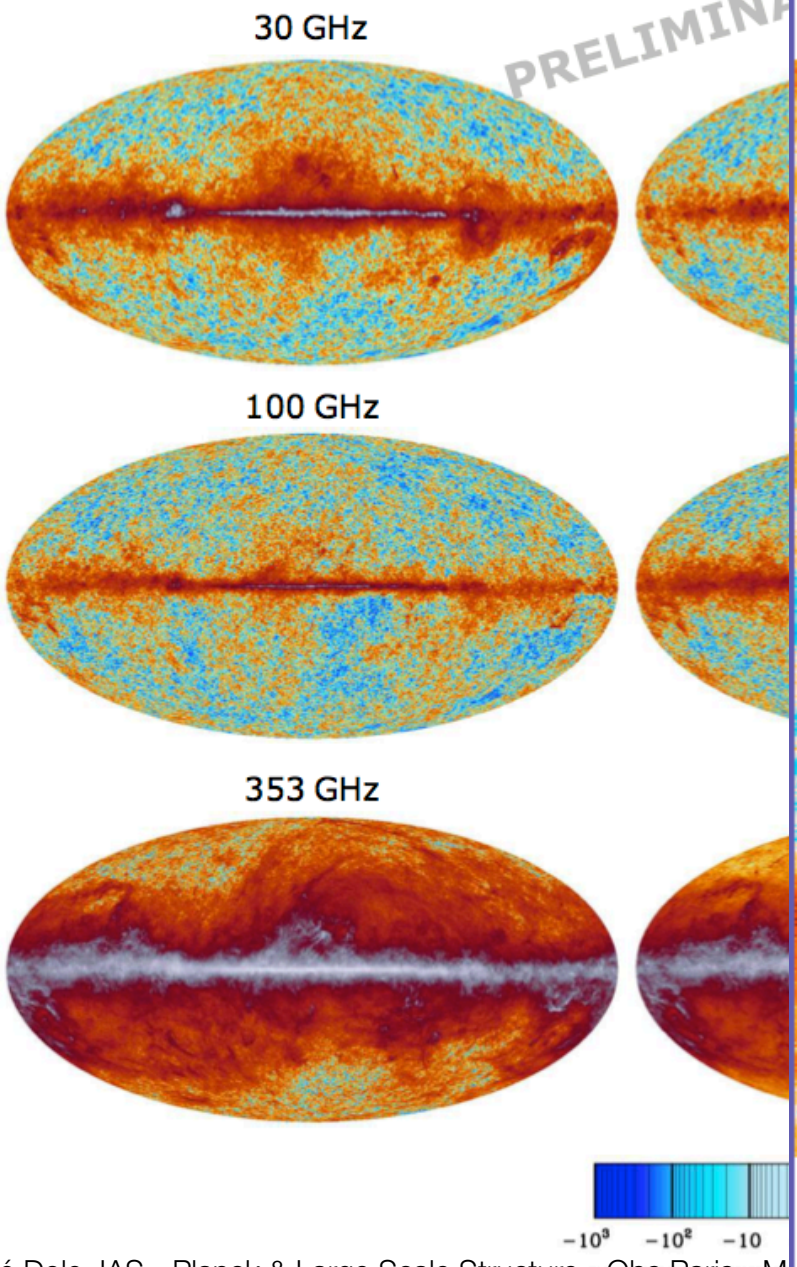
Planck Collab, 2015, 1

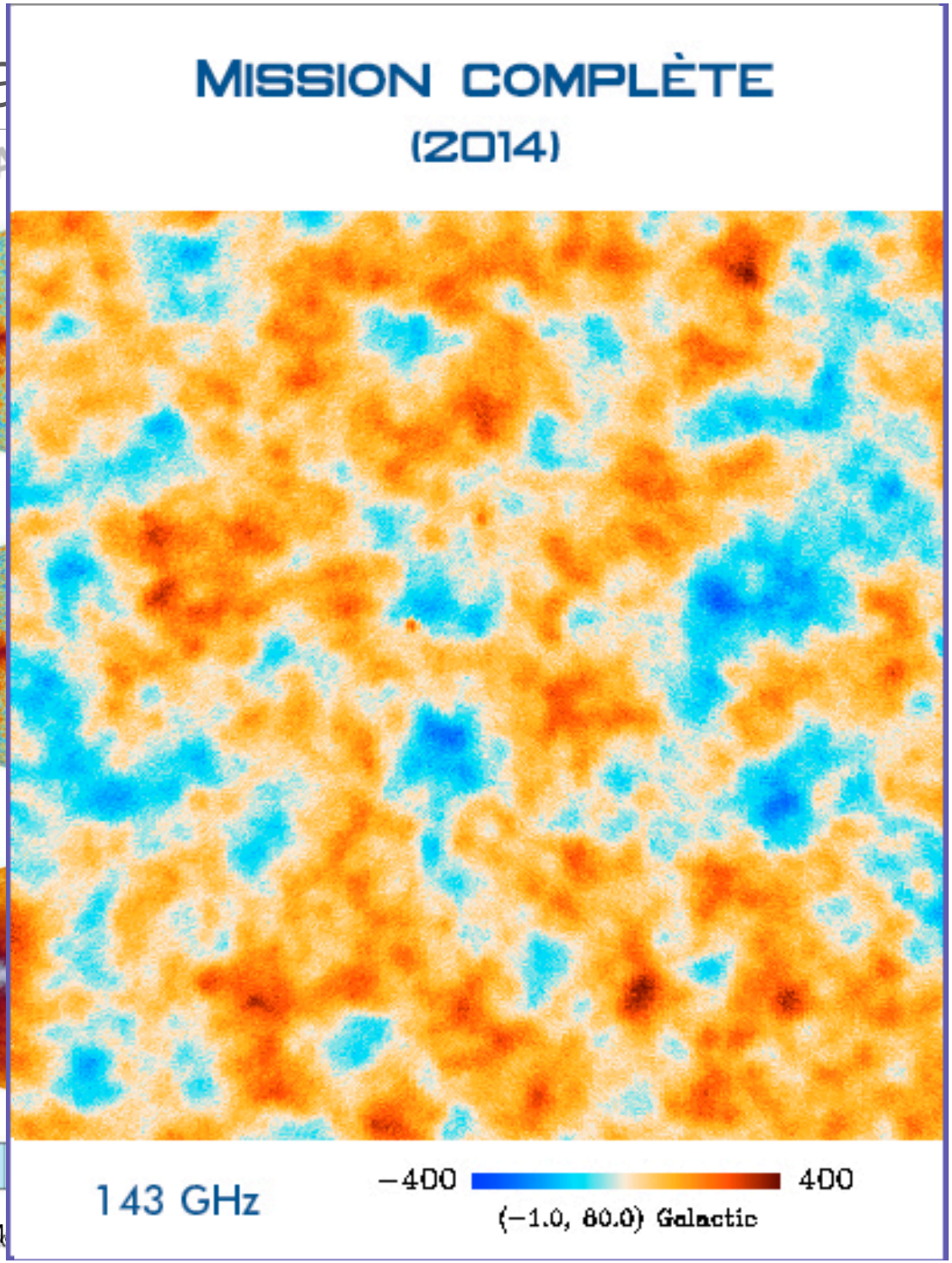
2. Planck all-sky ma



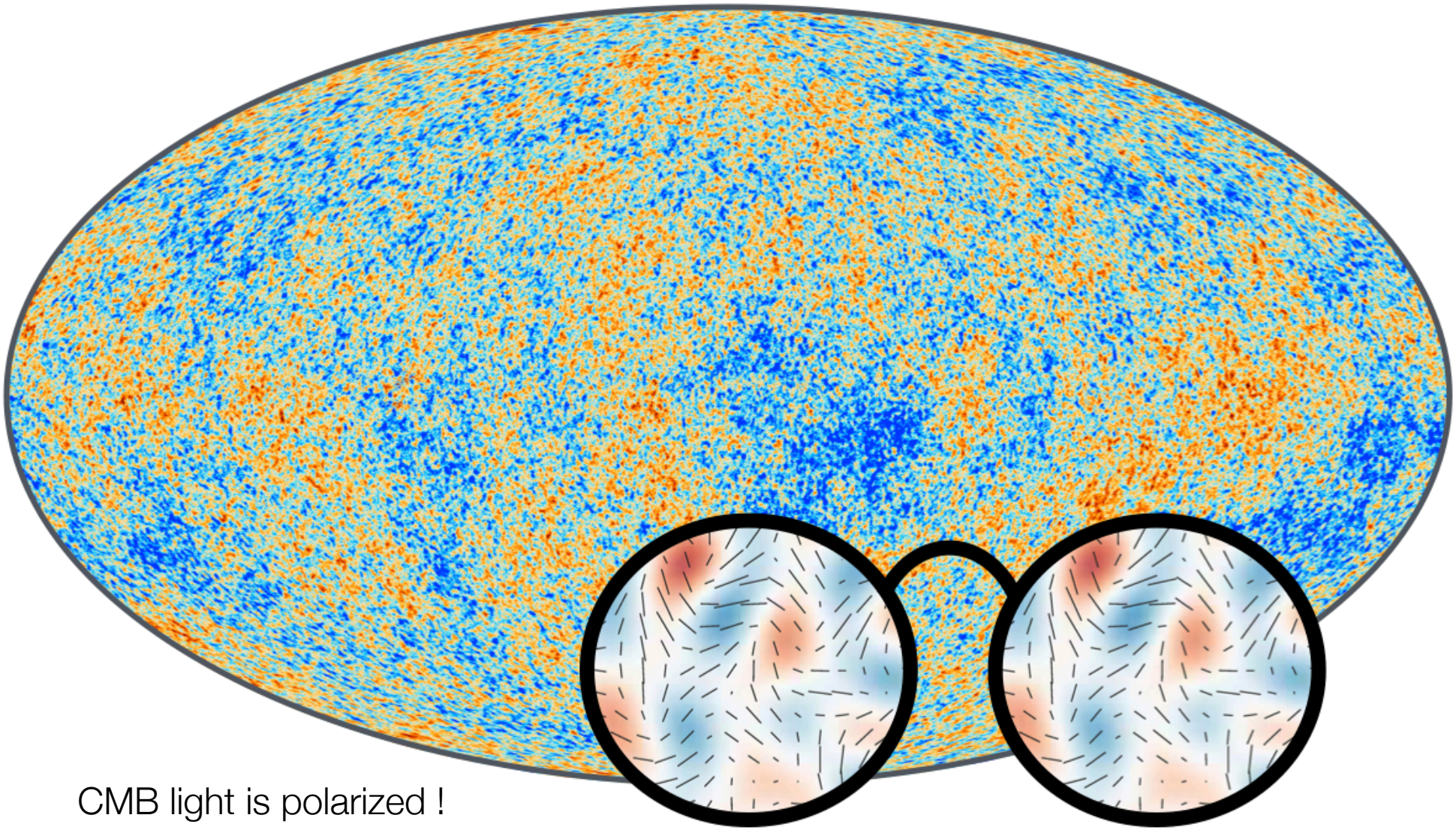


2. Planck all-sky ma





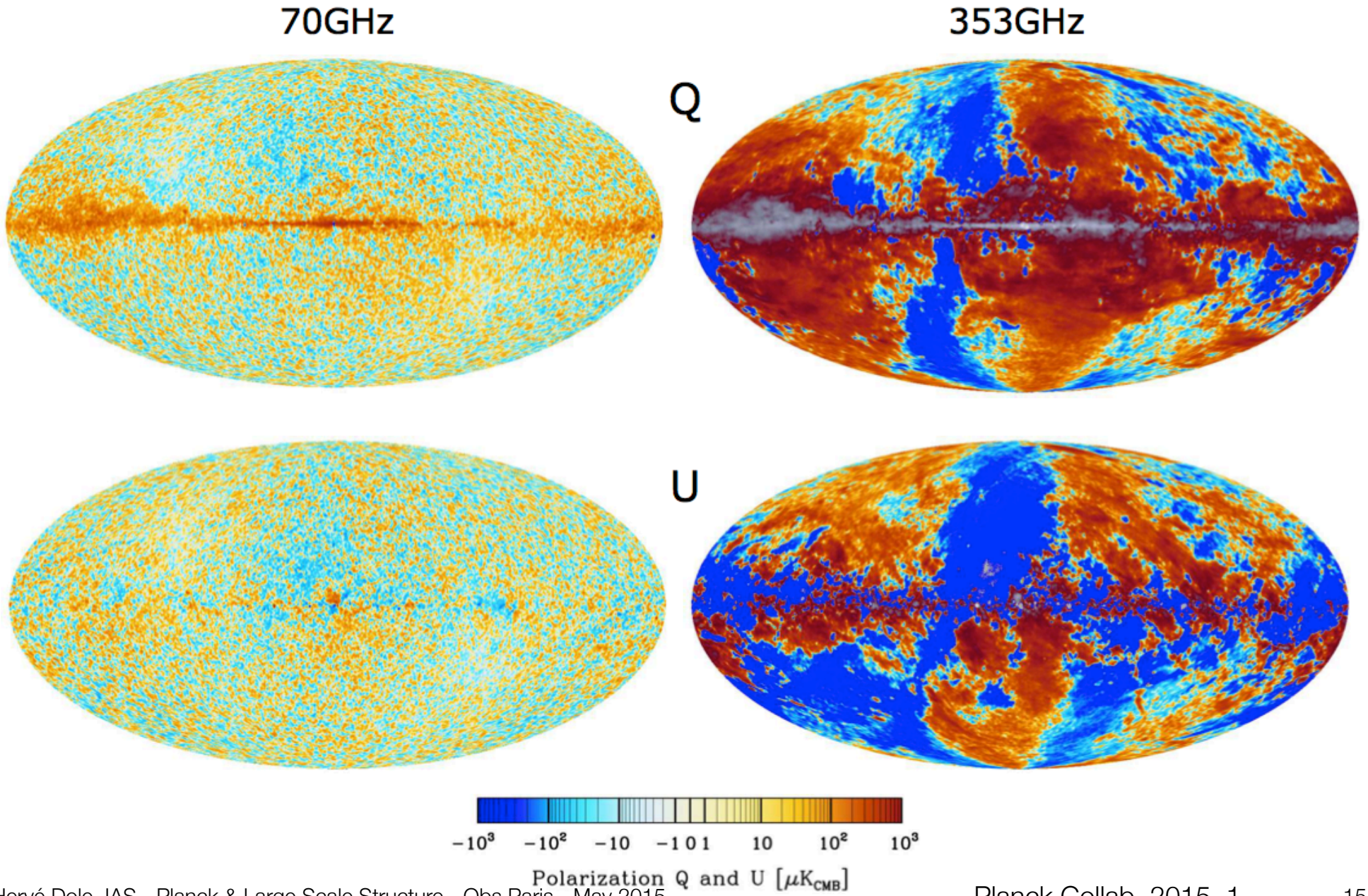
but there is more in CMB light: polarization



CMB light is polarized !

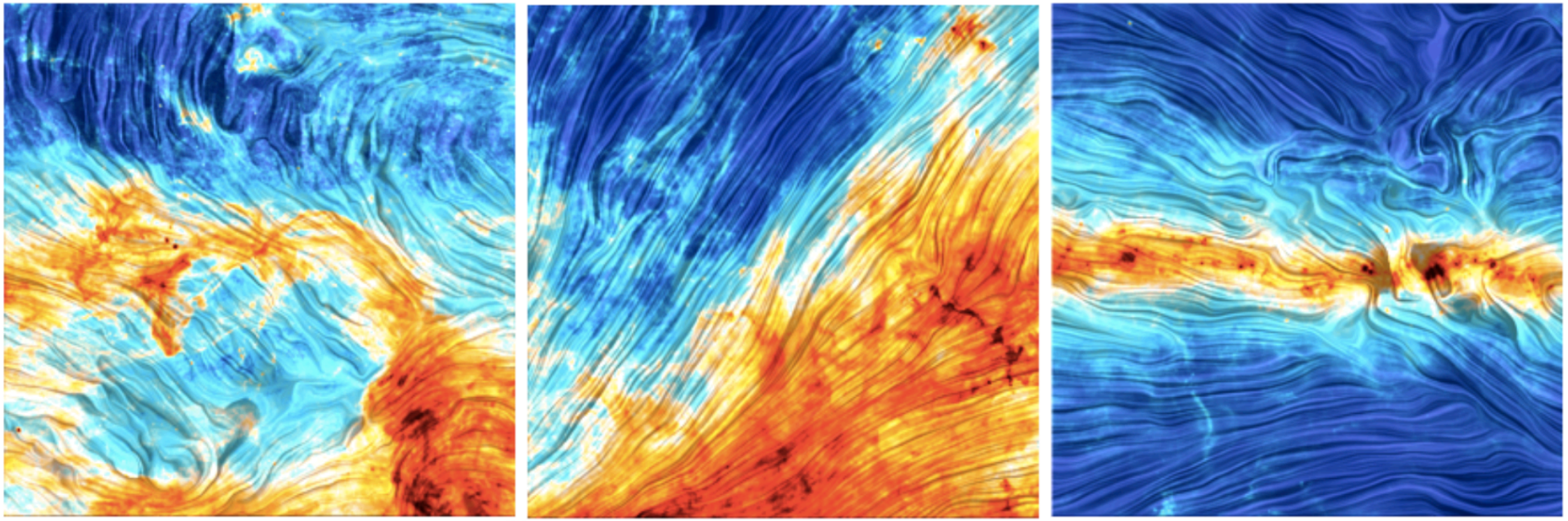
courtesy J. Aumont

new results 2015: polarization

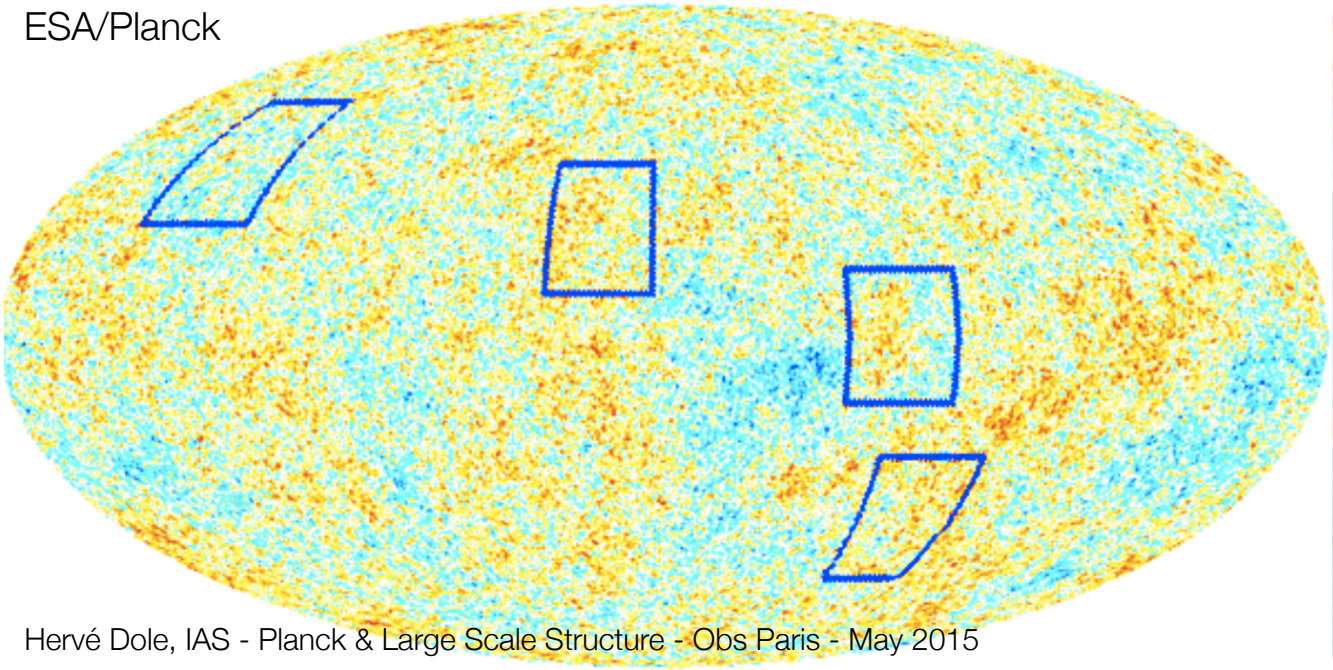


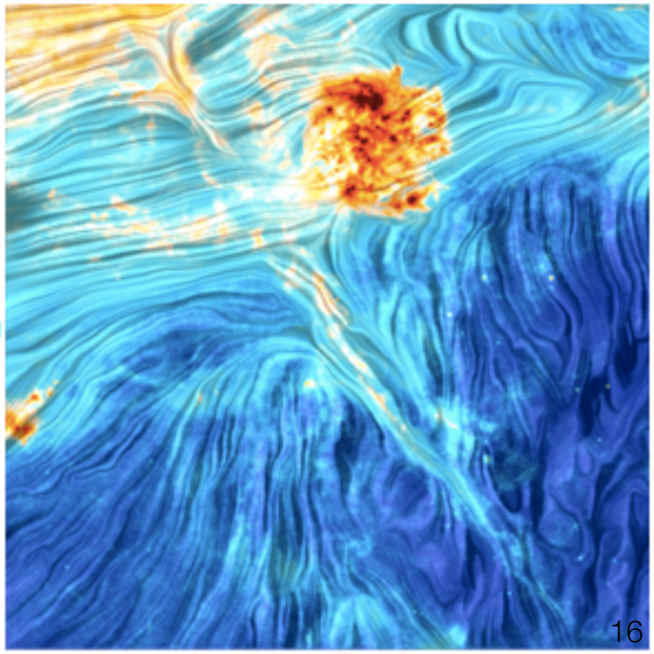
Planck Collab, 2015, 1

new results 2015: polarization and mag. field

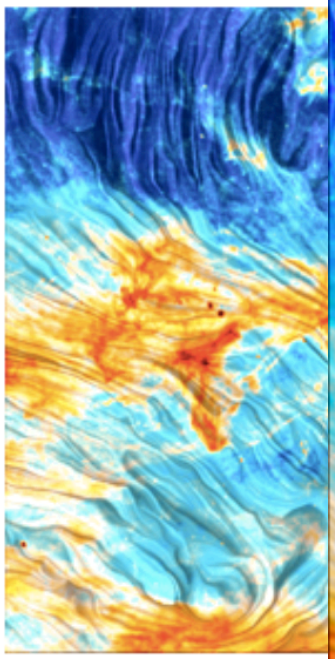


ESA/Planck

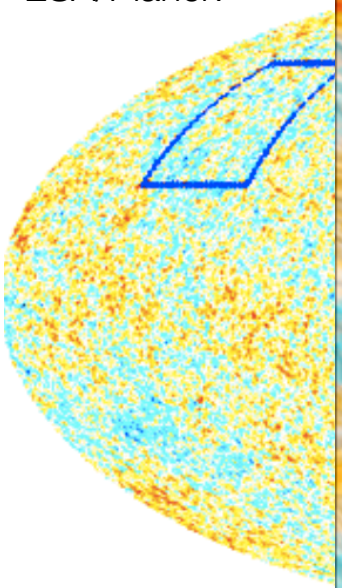


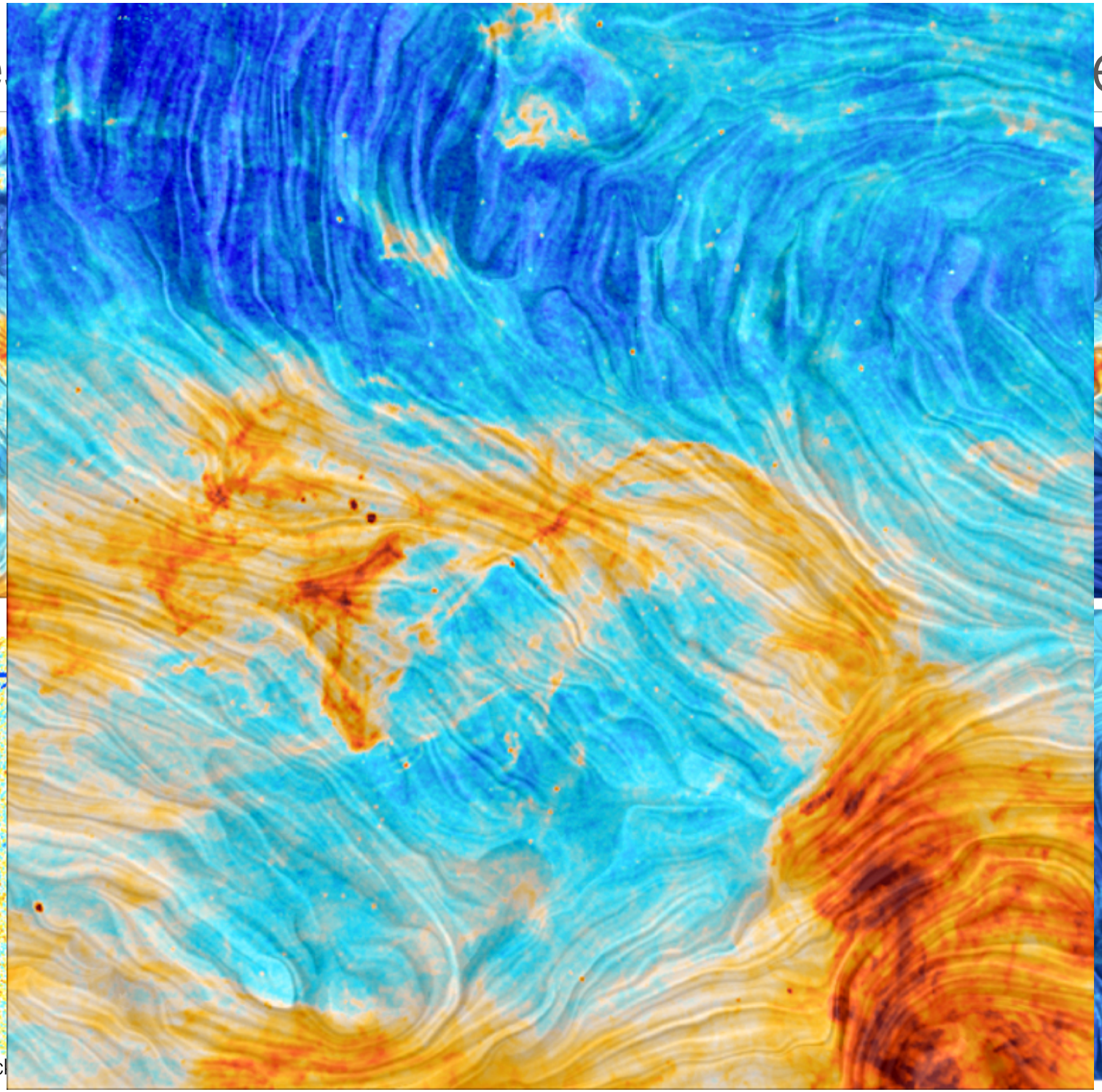


new re eld



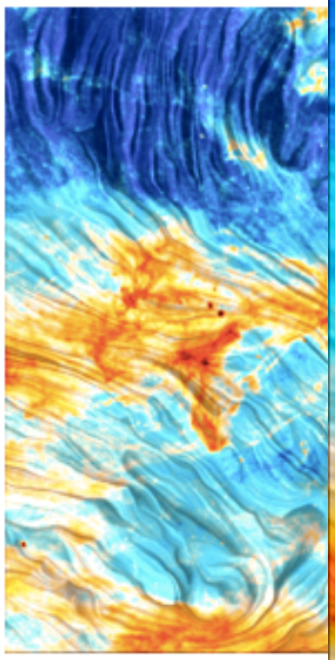
ESA/Planck



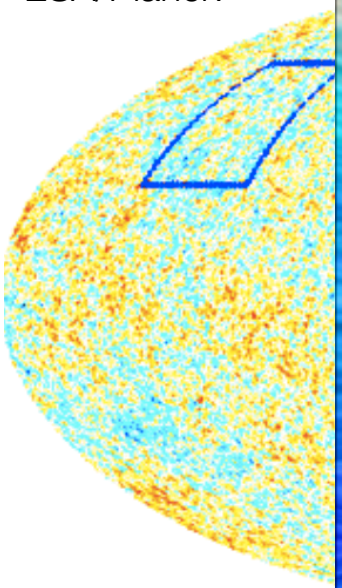


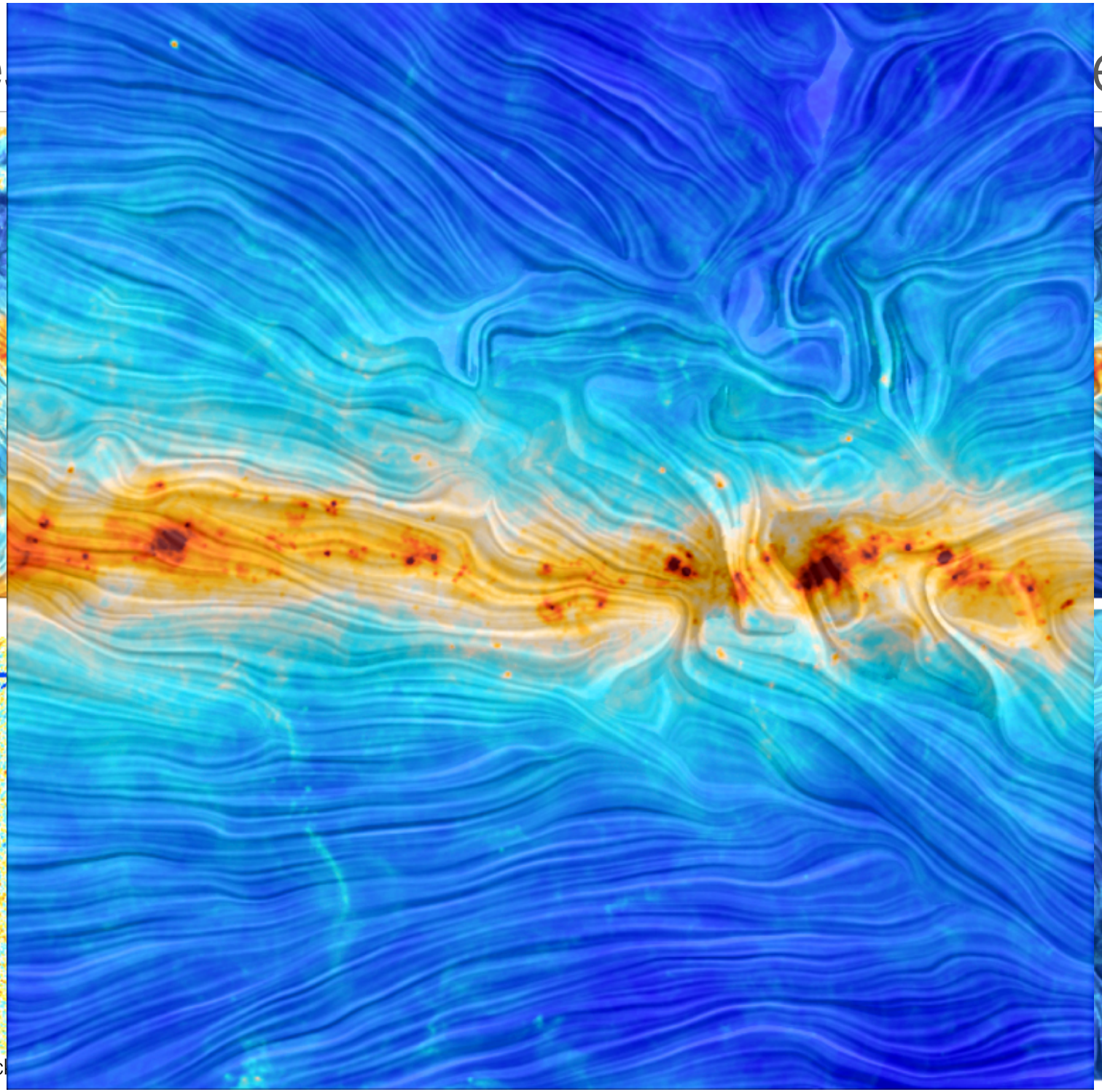
ESA/Planck and M-A Miville-Deschênes

new re eld



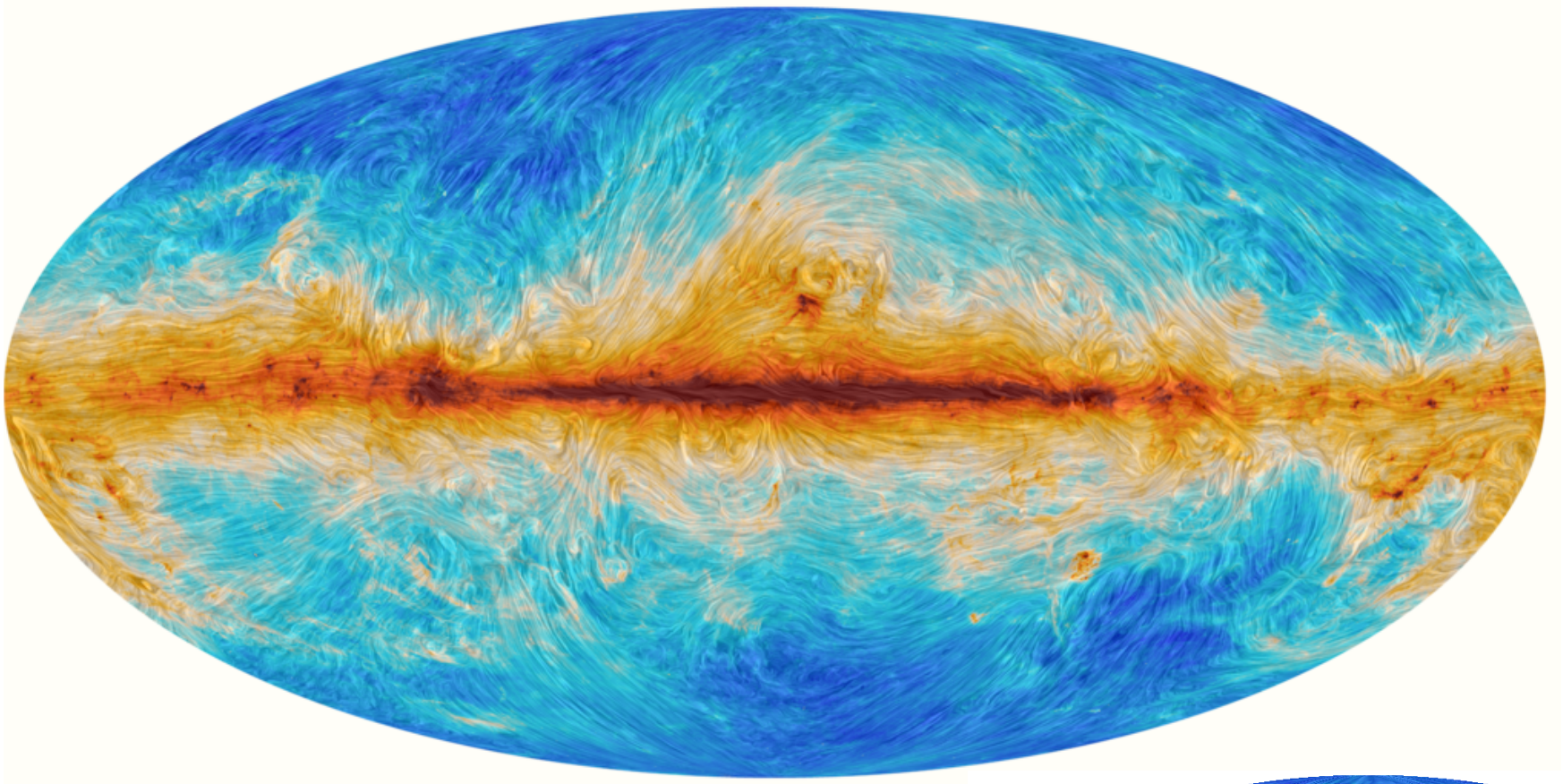
ESA/Planck

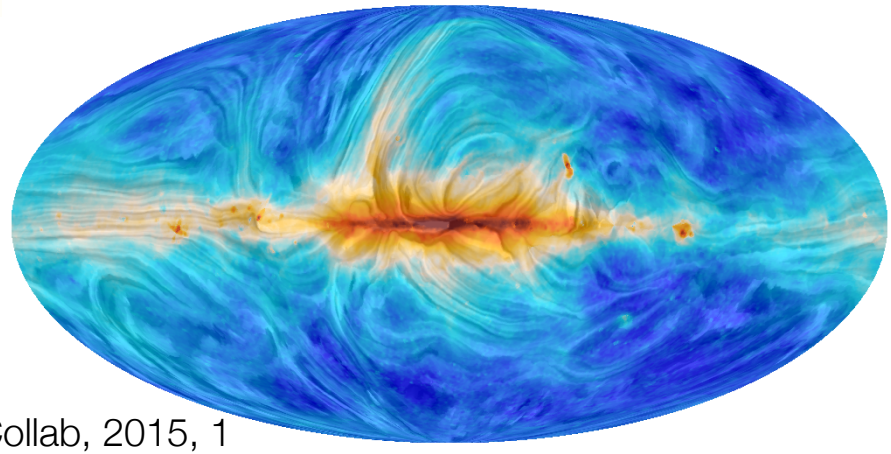




ESA/Planck and M-A Miville-Deschênes

key foreground polarization maps



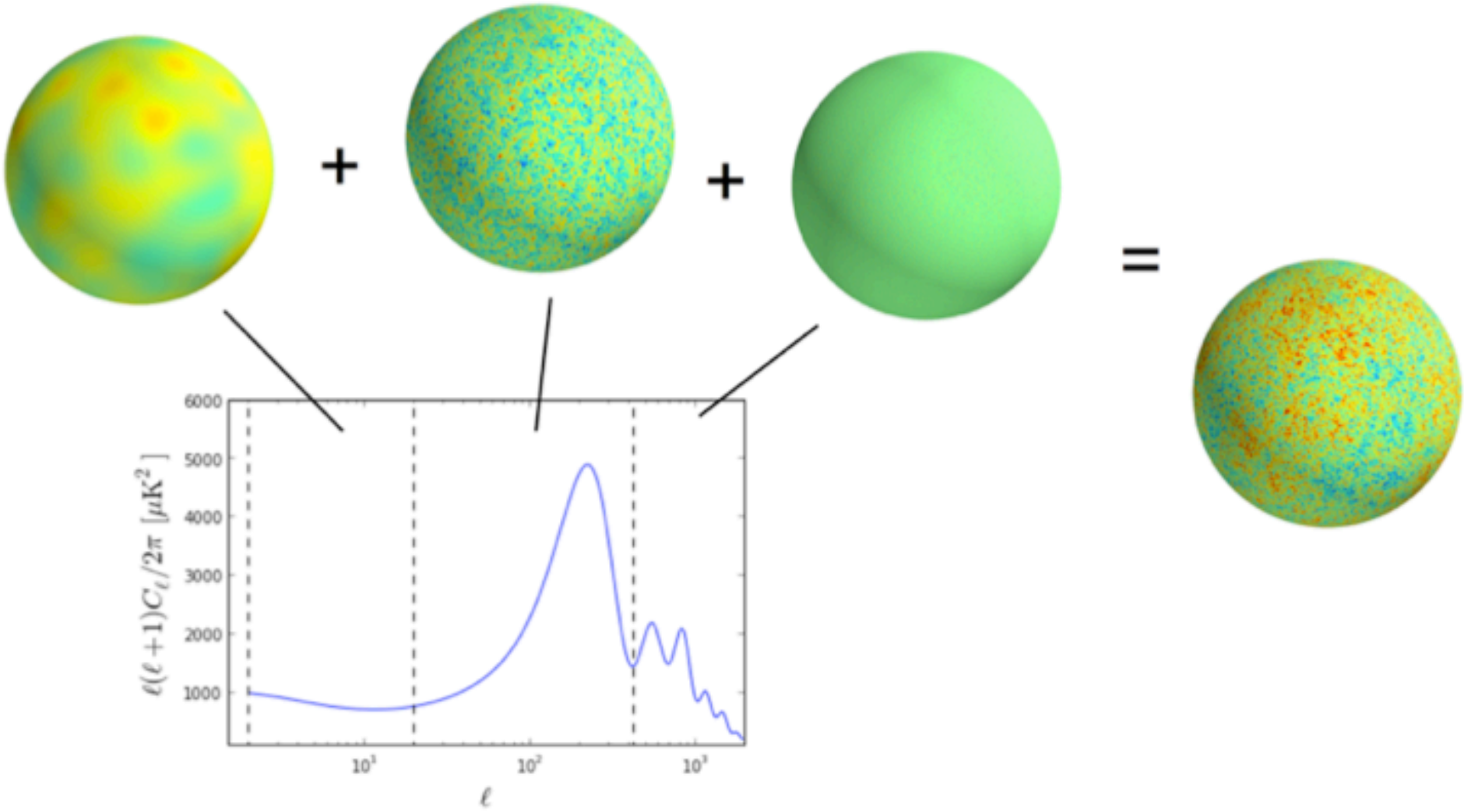


B field.
top: dust @ 353 GHz
right: synchrotron @ 30 GHz

Planck Collab, 2015, 1

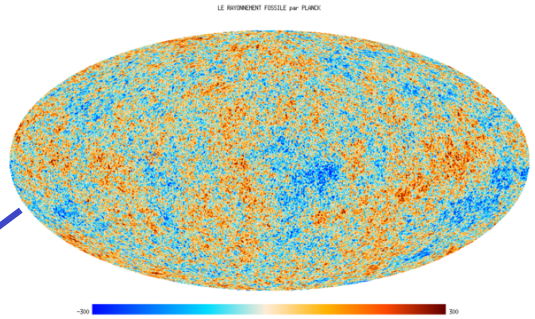
3. CMB and angular power spectra

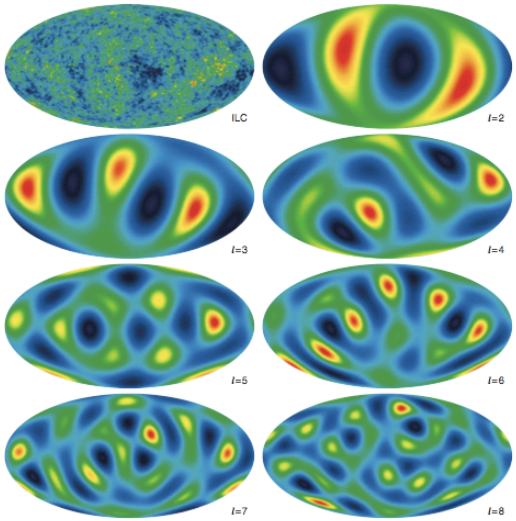
$$\langle a^*_{lm} a_{lm} \rangle = C_l$$



courtesy Olivier Doré

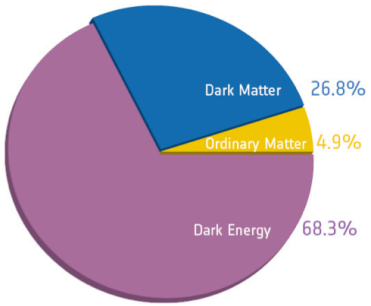
from maps to 6 cosmological parameters

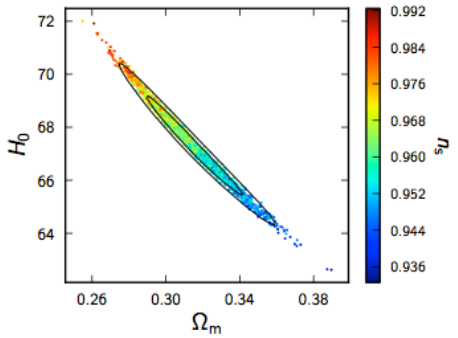


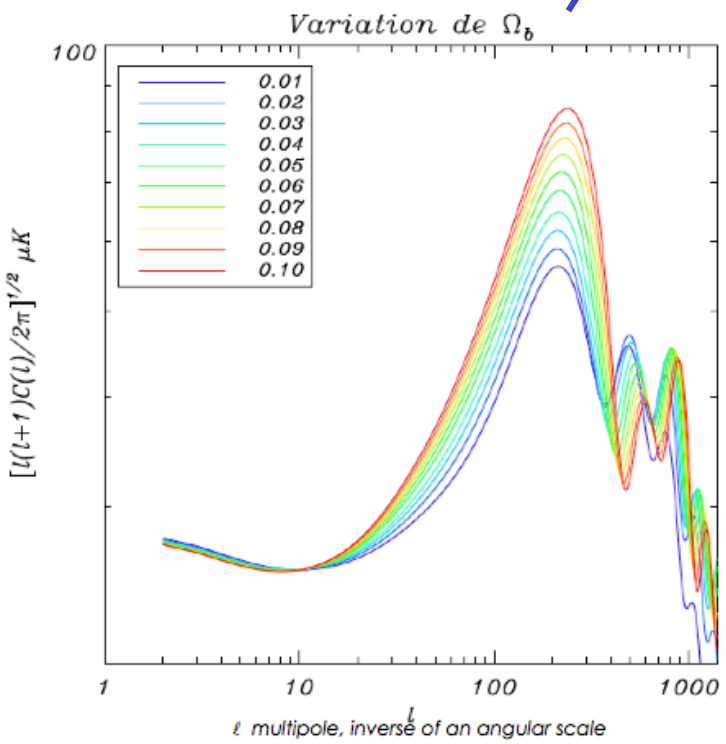


$$\frac{\Delta T(\mathbf{n})}{T_0} = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell m}^T Y_{\ell m}(\mathbf{n})$$

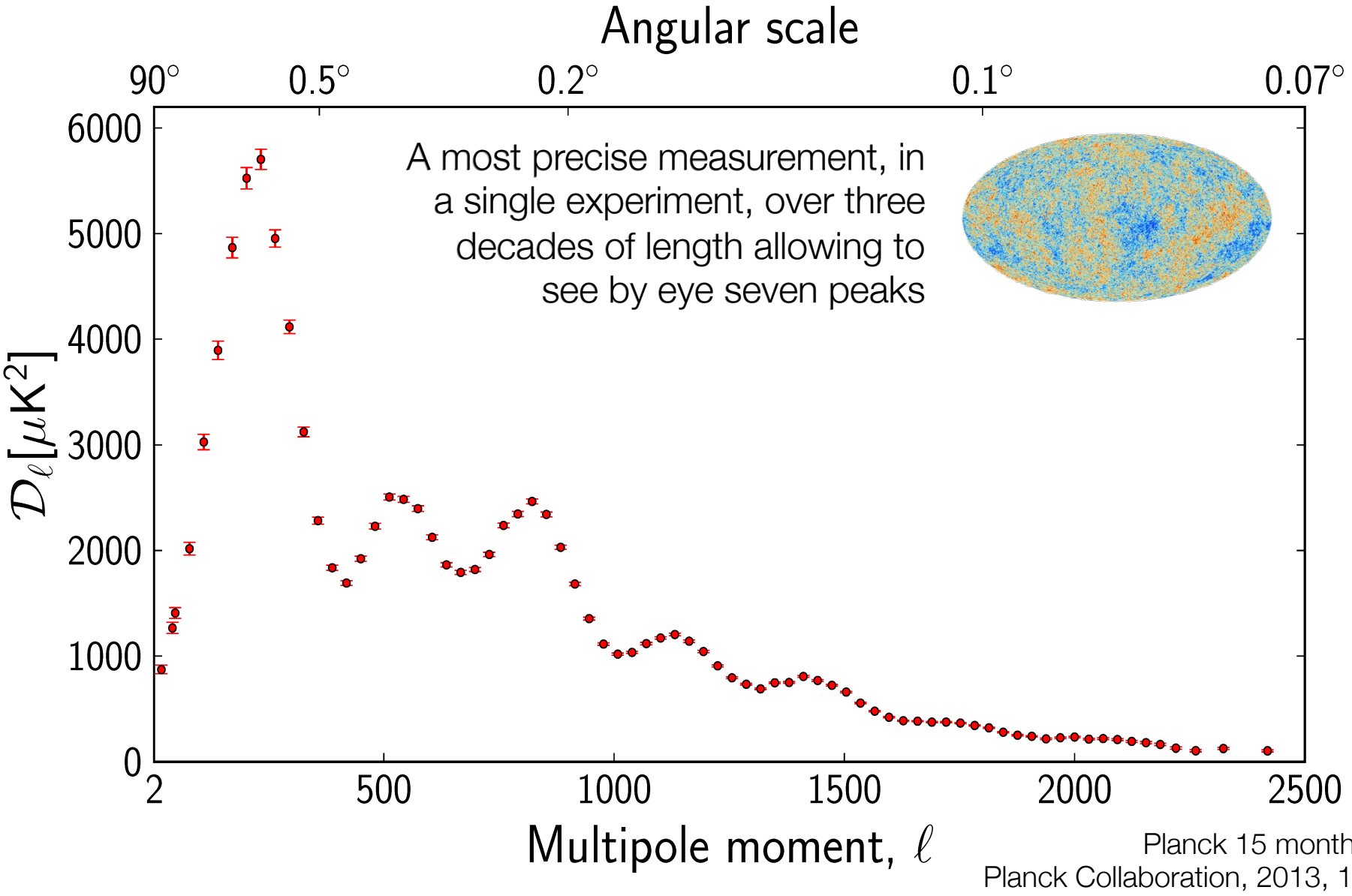
$$C_\ell^{TT} = \langle a_{\ell m}^T \cdot a_{\ell m}^{T\star} \rangle$$







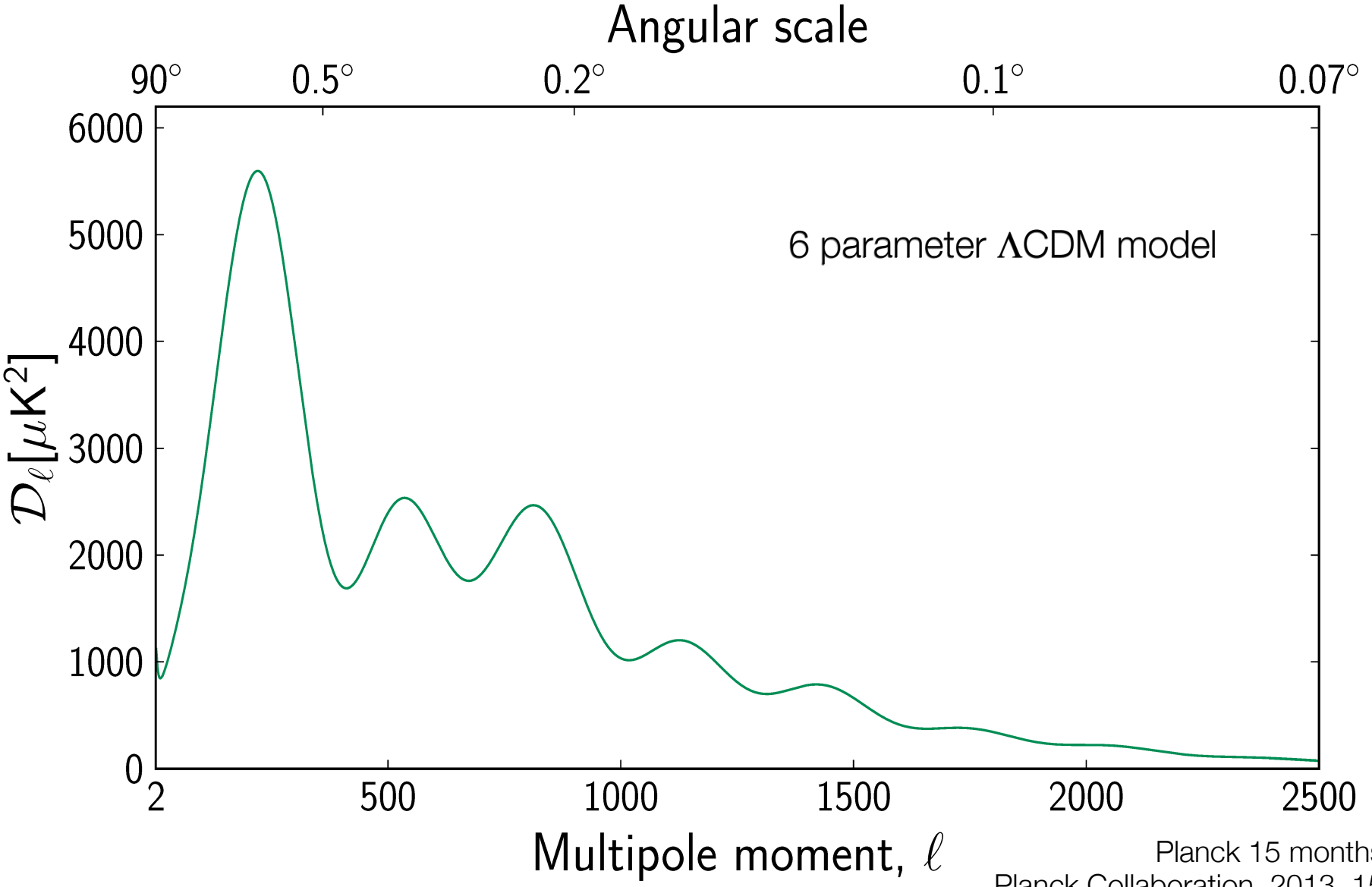
the Planck spectrum of temperature anisotropies



Planck 15 months
Planck Collaboration, 2013, 15

courtesy François Bouchet

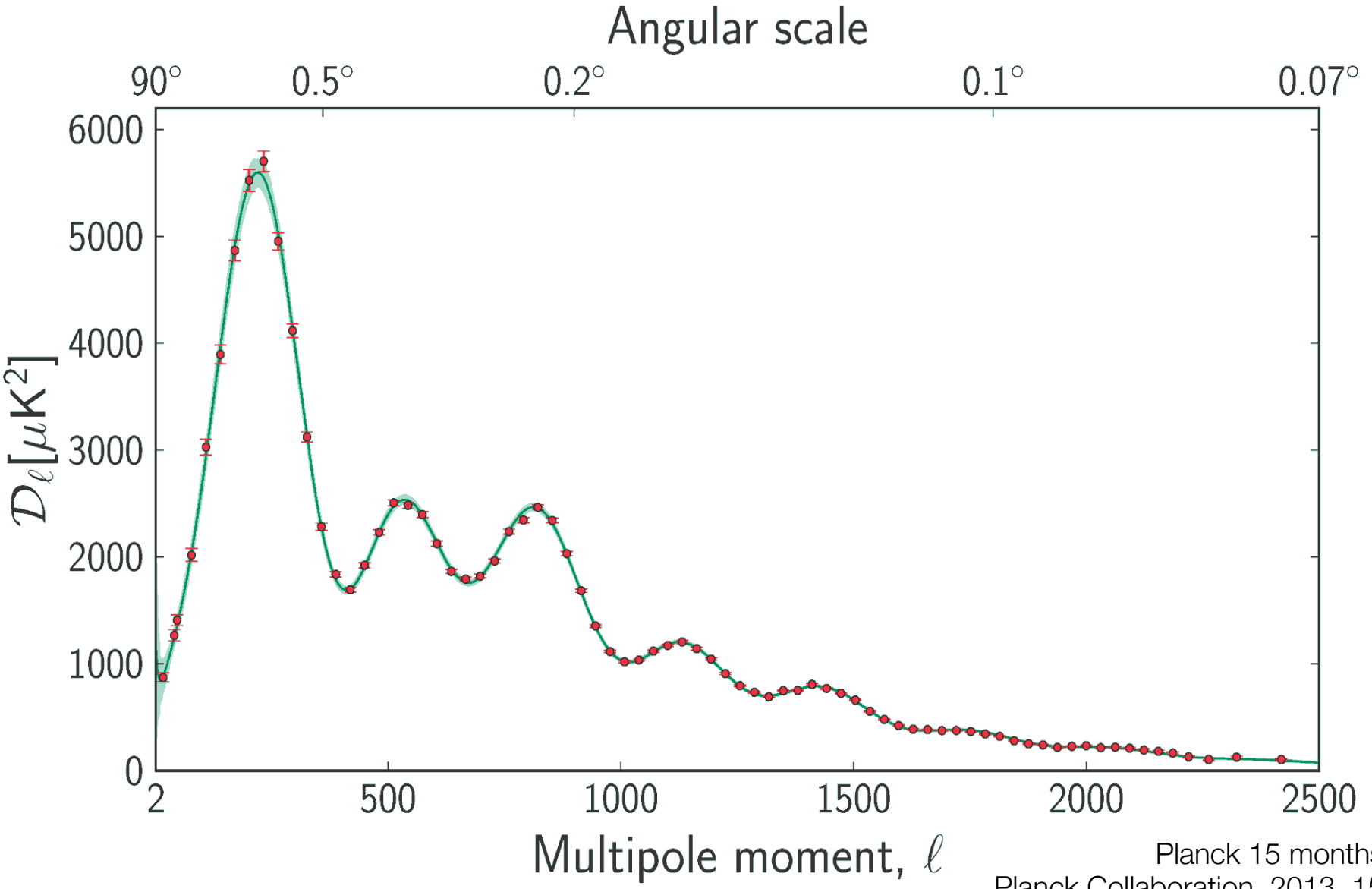
Planck best fitting theoretical model



Planck 15 months
Planck Collaboration, 2013, 15

courtesy François Bouchet

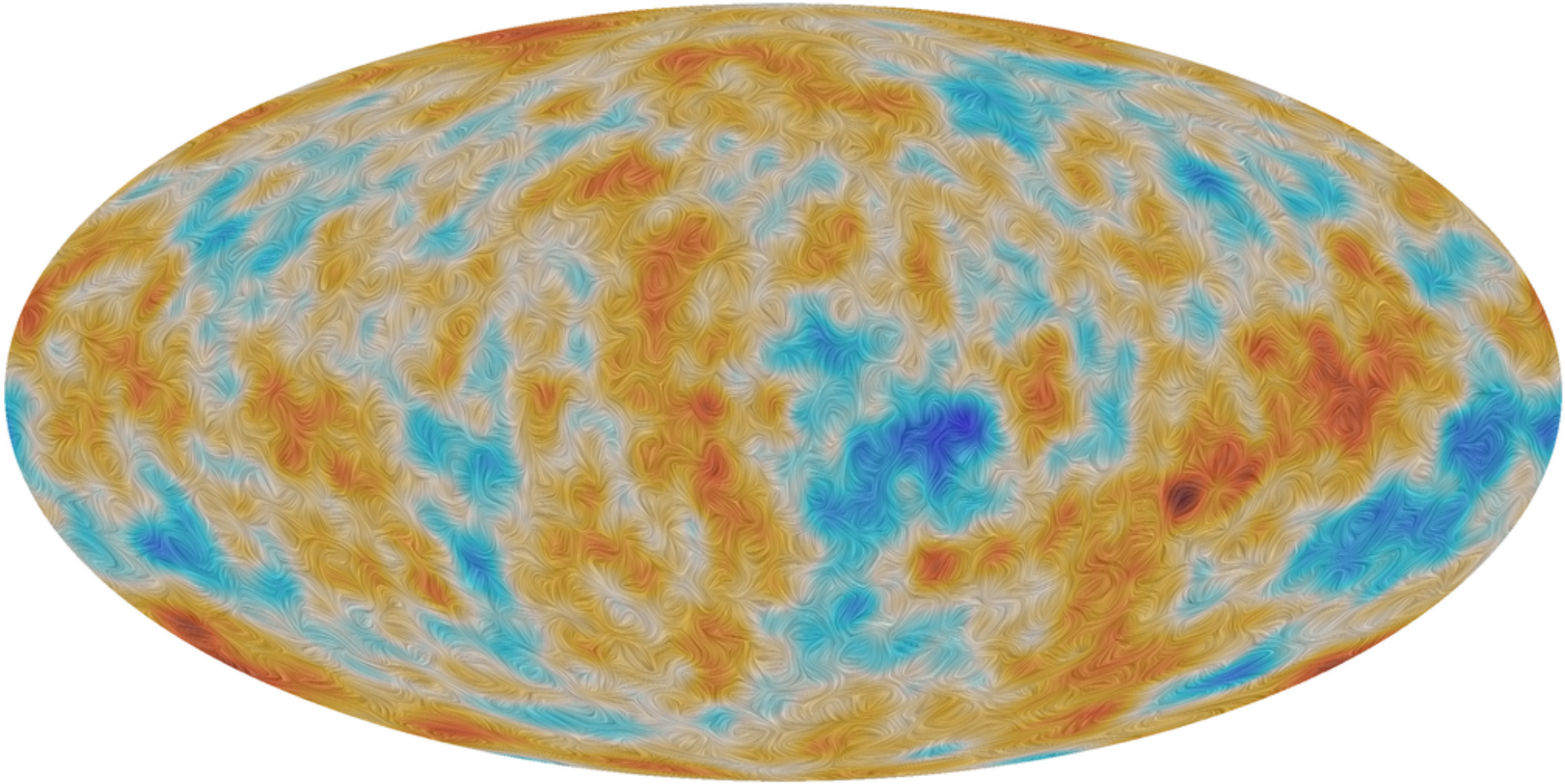
theory confronts data



Planck 15 months
Planck Collaboration, 2013, 15

courtesy François Bouchet

Planck 2015 all sky CMB polarization

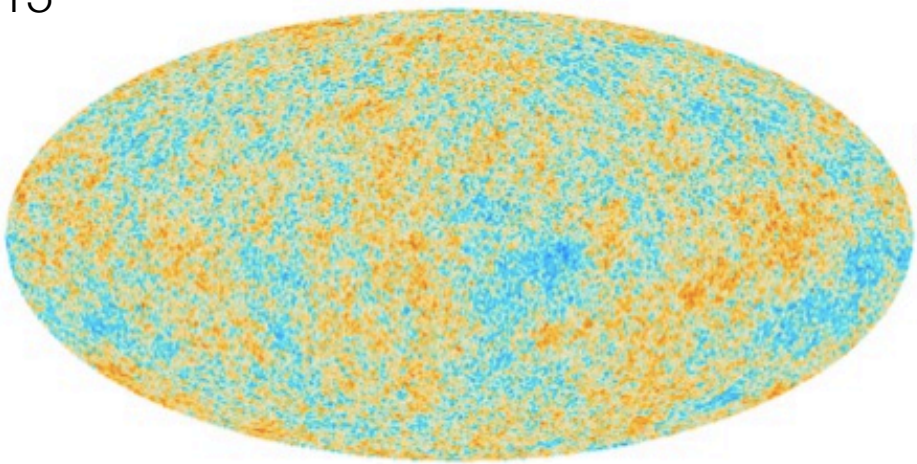


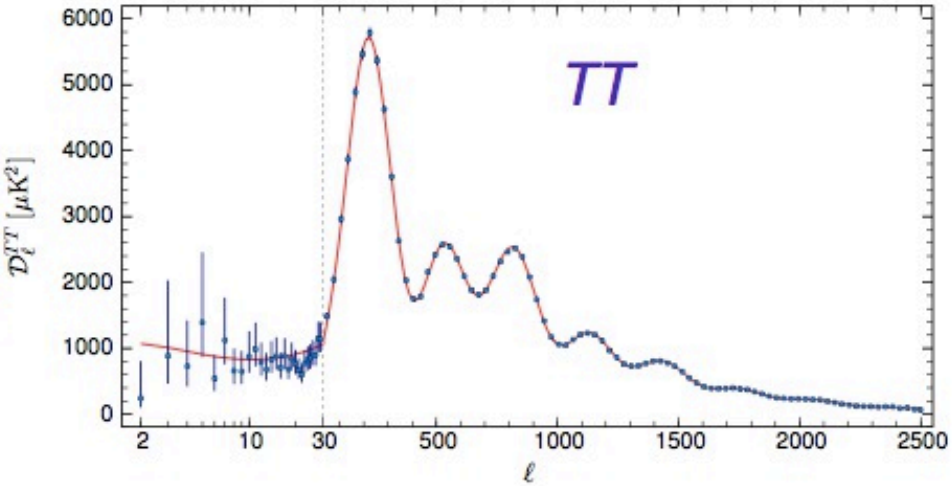
Planck Collab, 2015, 1

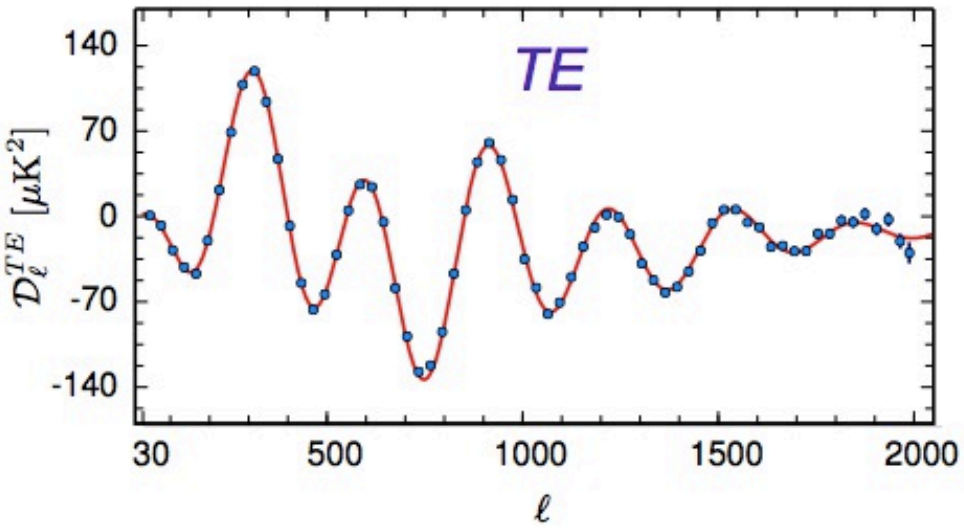
theory confronts data – from 7 to 19 peaks

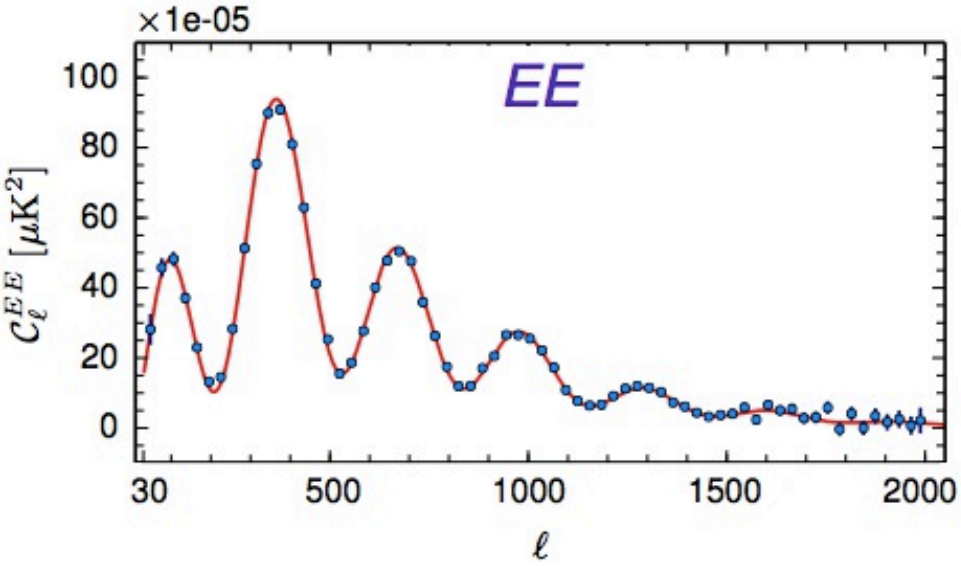
Le rayonnement fossile mesuré par Planck

2015









Planck 2015

2015 cosmological parameters

Table 9. Parameter 68 % confidence levels for the base ΛCDM cosmology computed from the *Planck* CMB power spectra, in combination with the CMB lensing likelihood ("lensing").

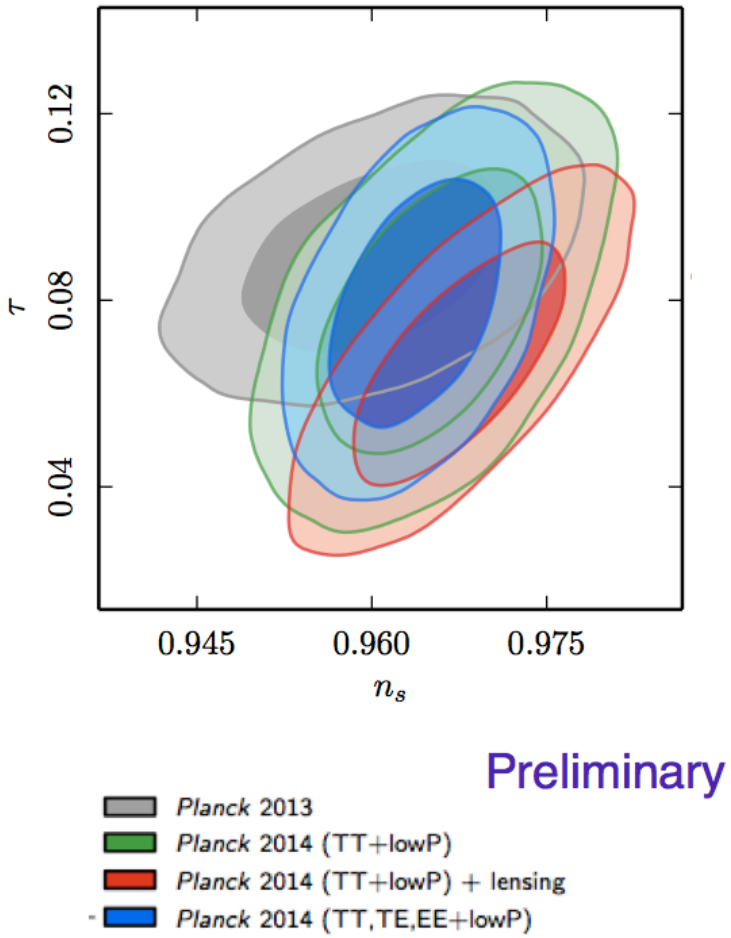
Parameter	*Planck* TT+lowP+lensing
$\Omega_b h^2$	0.02226 ± 0.00023
$\Omega_c h^2$	0.1186 ± 0.0020
$100\theta_{MC}$	1.04103 ± 0.00046
τ	0.066 ± 0.016
$\ln(10^{10} A_s)$	3.062 ± 0.029
n_s	0.9677 ± 0.0060
H_0	67.8 ± 0.9
Ω_m	0.308 ± 0.012
$\Omega_m h^2$	0.1415 ± 0.0019
$\Omega_m h^3$	0.09591 ± 0.00045
σ_8	0.815 ± 0.009
$\sigma_8 \Omega_m^{0.5}$	0.4521 ± 0.0088
Age/Gyr	13.799 ± 0.038
r_{drag}	147.60 ± 0.43
k_{eq}	0.01027 ± 0.00014

6 cosmological parameters

0.3% uncertainty !

inflation 2015

Planck 2014 n_s



$$\mathcal{P}_{\mathcal{R}}(k) = A_{\rm s}\left(\frac{k}{k_*}\right)^{n_{\rm s}-1}$$

$$n_{\rm s} = 0.9652 \pm 0.0062 \quad (68\,\%{\rm CL}\,, \textit{Planck}\,{\rm TT}+{\rm lowP})$$

$$\tau = 0.078 \pm 0.019 \quad (68\,\%{\rm CL}\,, \textit{Planck}\,{\rm TT}+{\rm lowP})$$

Compare with Planck 2013 results:

$$n_{\rm s} = 0.9603 \pm 0.0073 \quad (68\,\%{\rm CL}\,, \textit{Planck}\,2013)$$

The polarization results reported here and in the folllowing slides are preliminary, because we do not yet have confidence that all systematic and foreground uncertainties have been properly characterized, and the results may therefore be subject to revision.

courtesy Finelly

inflation 2015

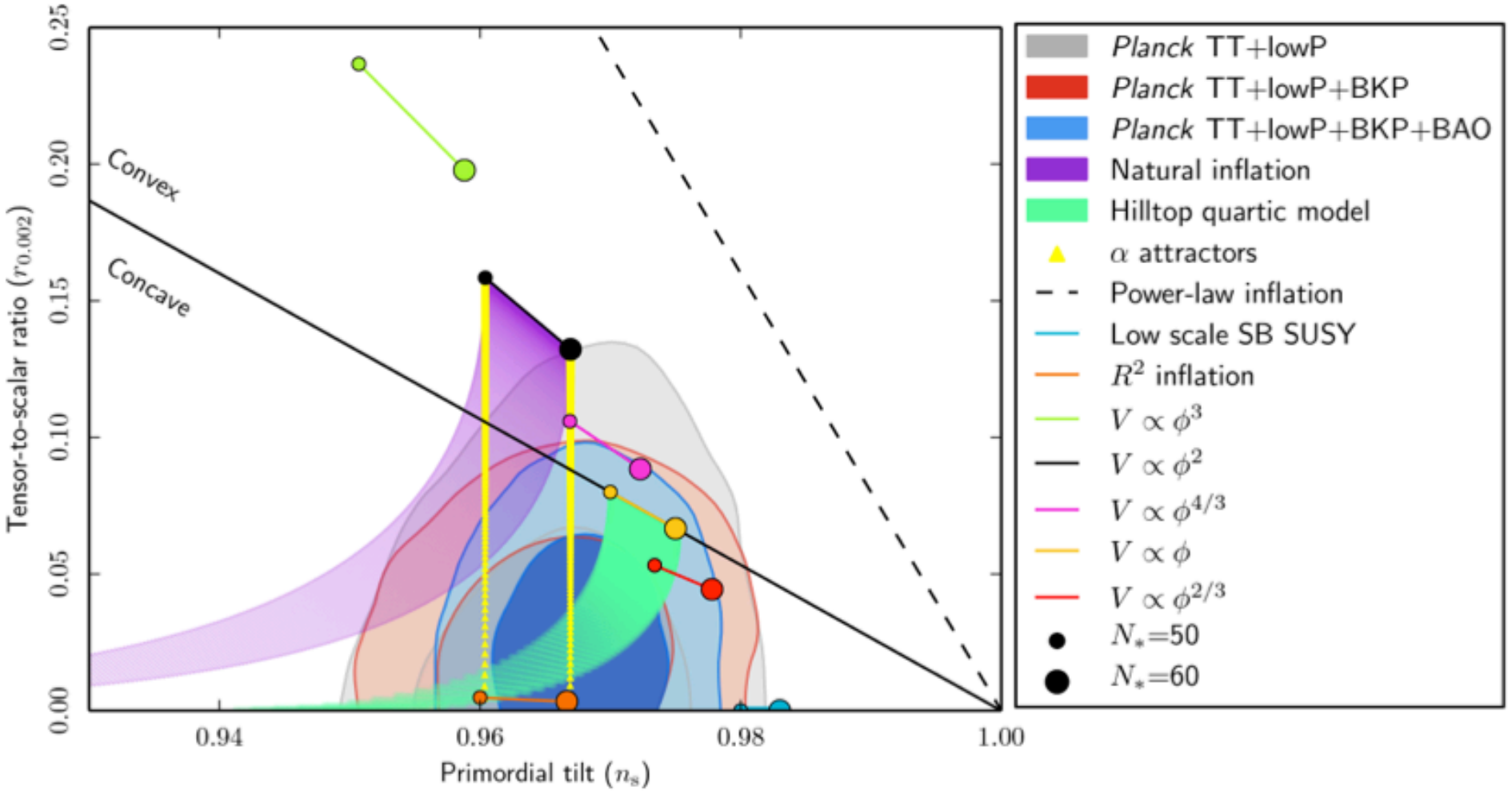
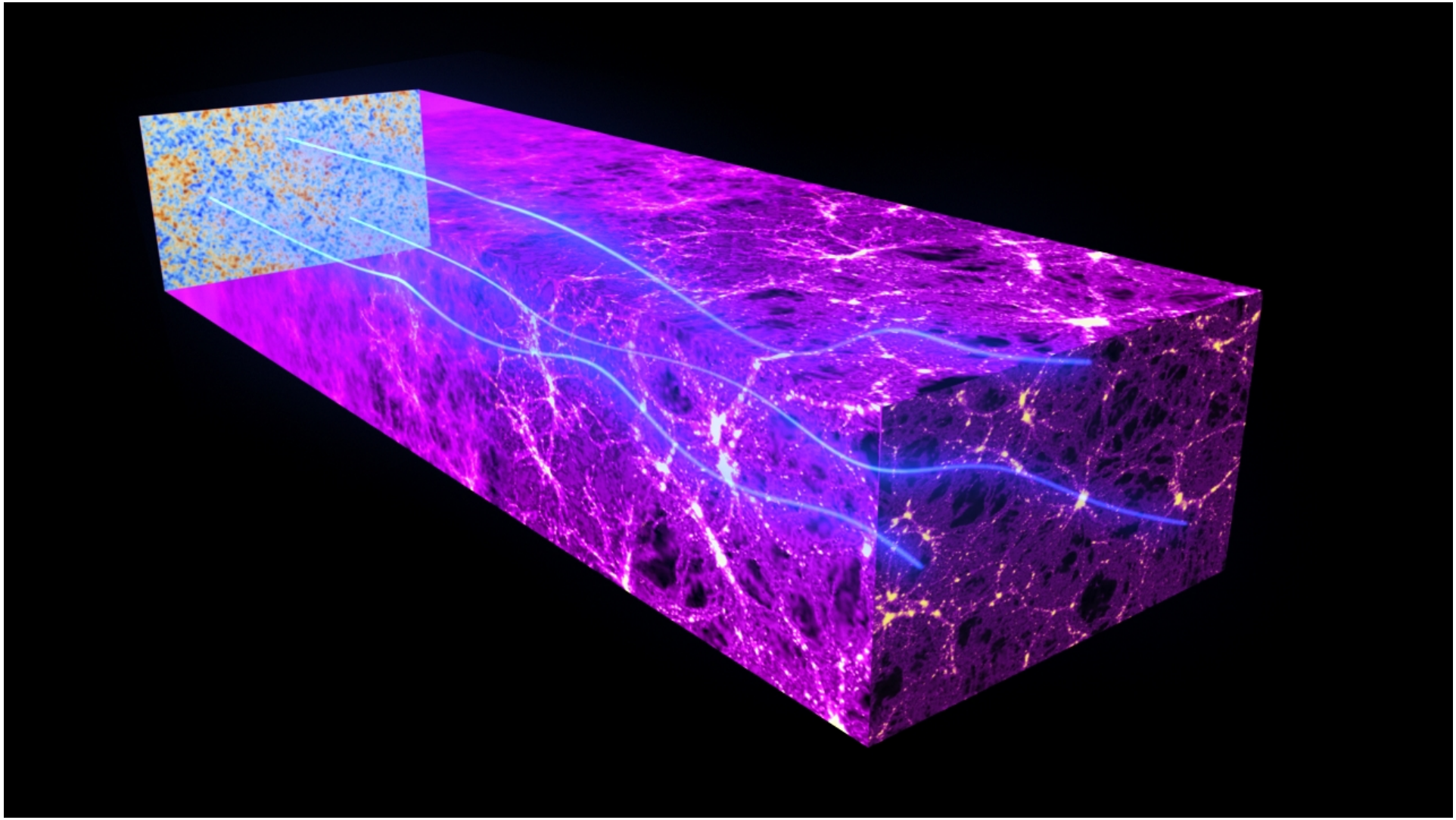


Fig. 54. Marginalized joint 68 % and 95 % CL regions for n_s and $r_{0.002}$ from *Planck* alone and in combination with its cross-correlation with BICEP2/Keck Array and/or BAO data compared with the theoretical predictions of selected inflationary models.

cosmic inflation < 10^{-35} second

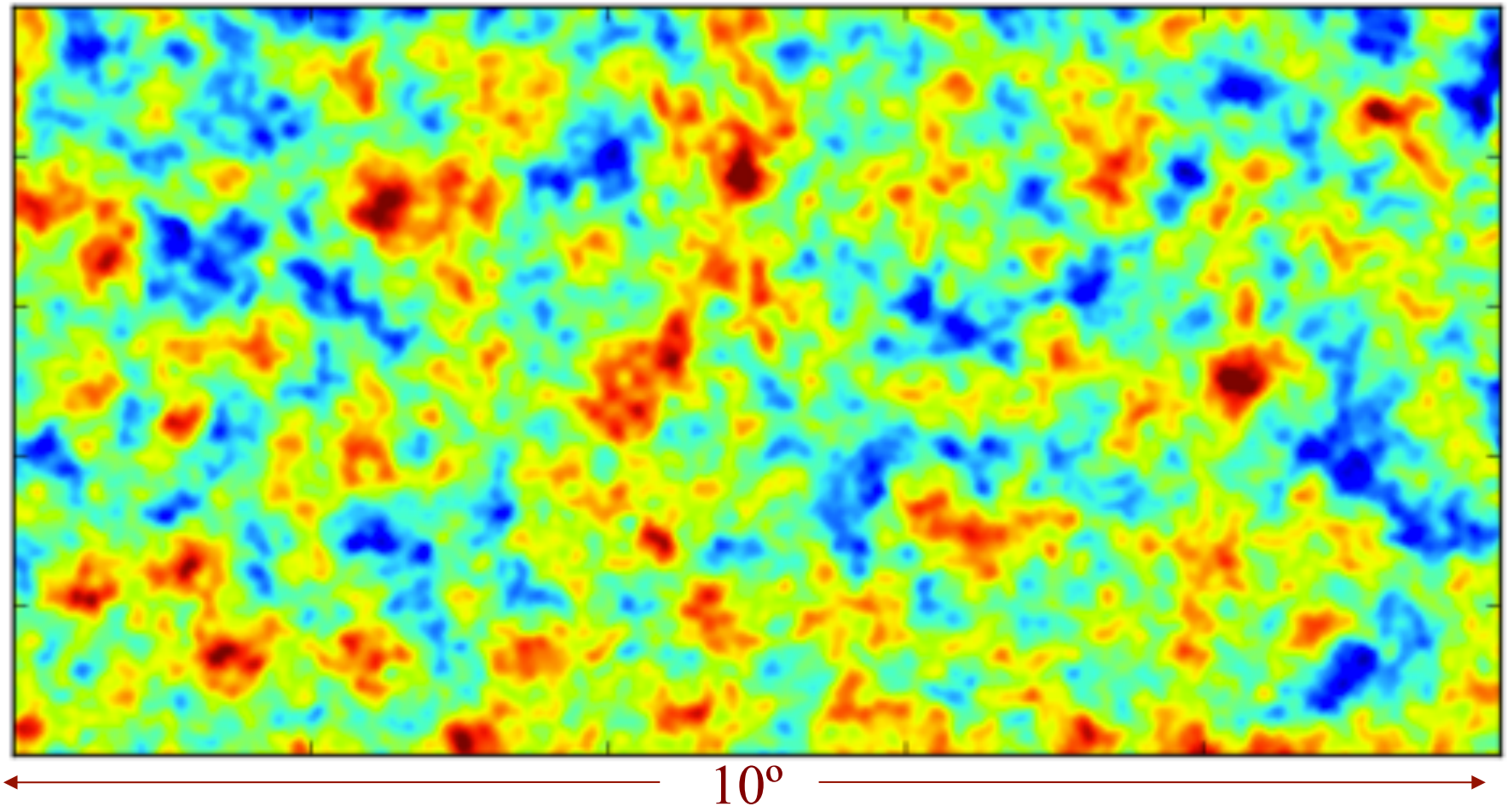
Planck 2015, 20

4. between CMB and us: structures



gravitational lensing of the CMB

A simulated patch of CMB sky – before lensing

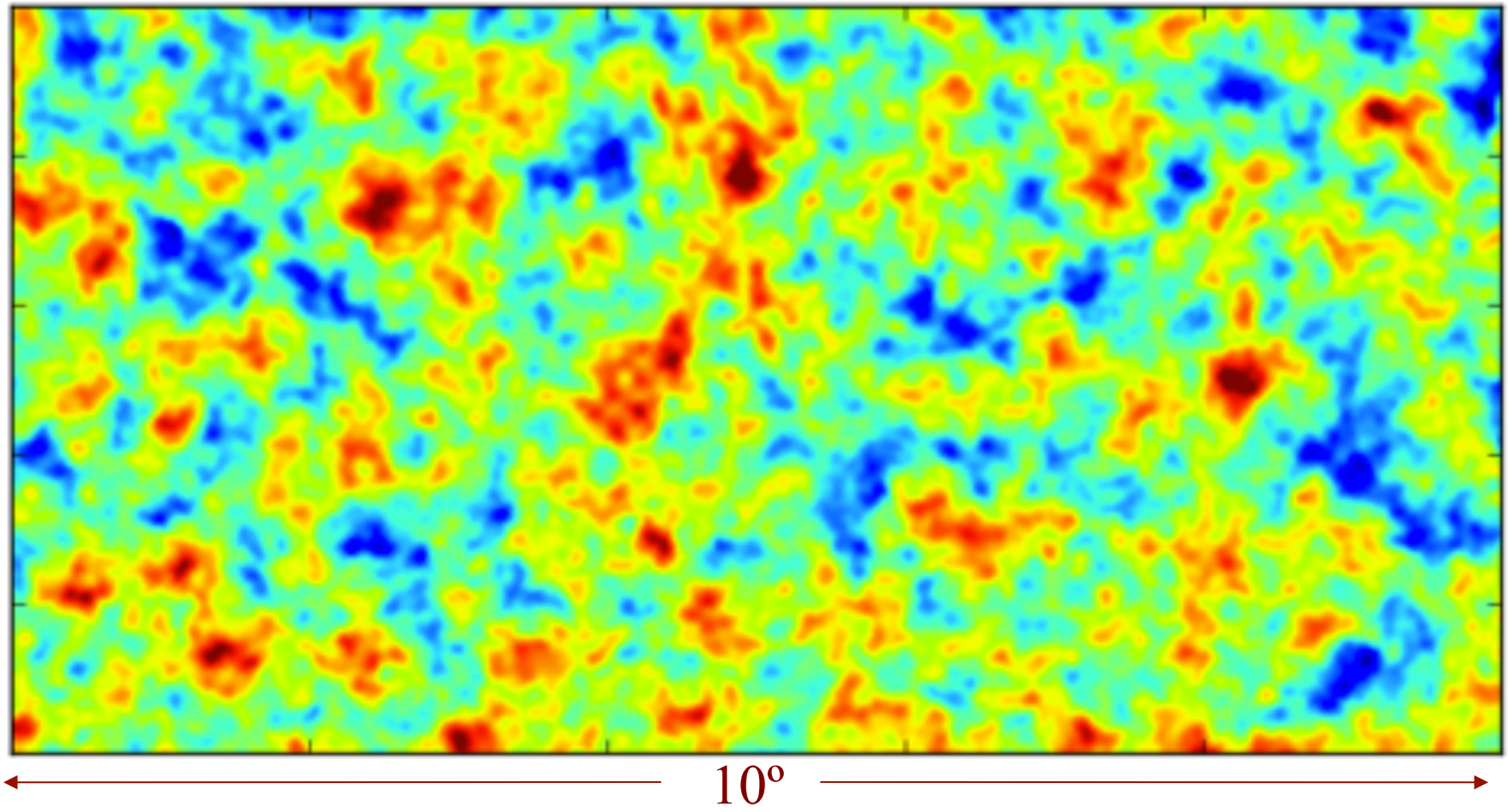


typical deflection: 2.4 arcmin

Planck 15 months
Planck Collaboration, 2013, 17

gravitational lensing of the CMB

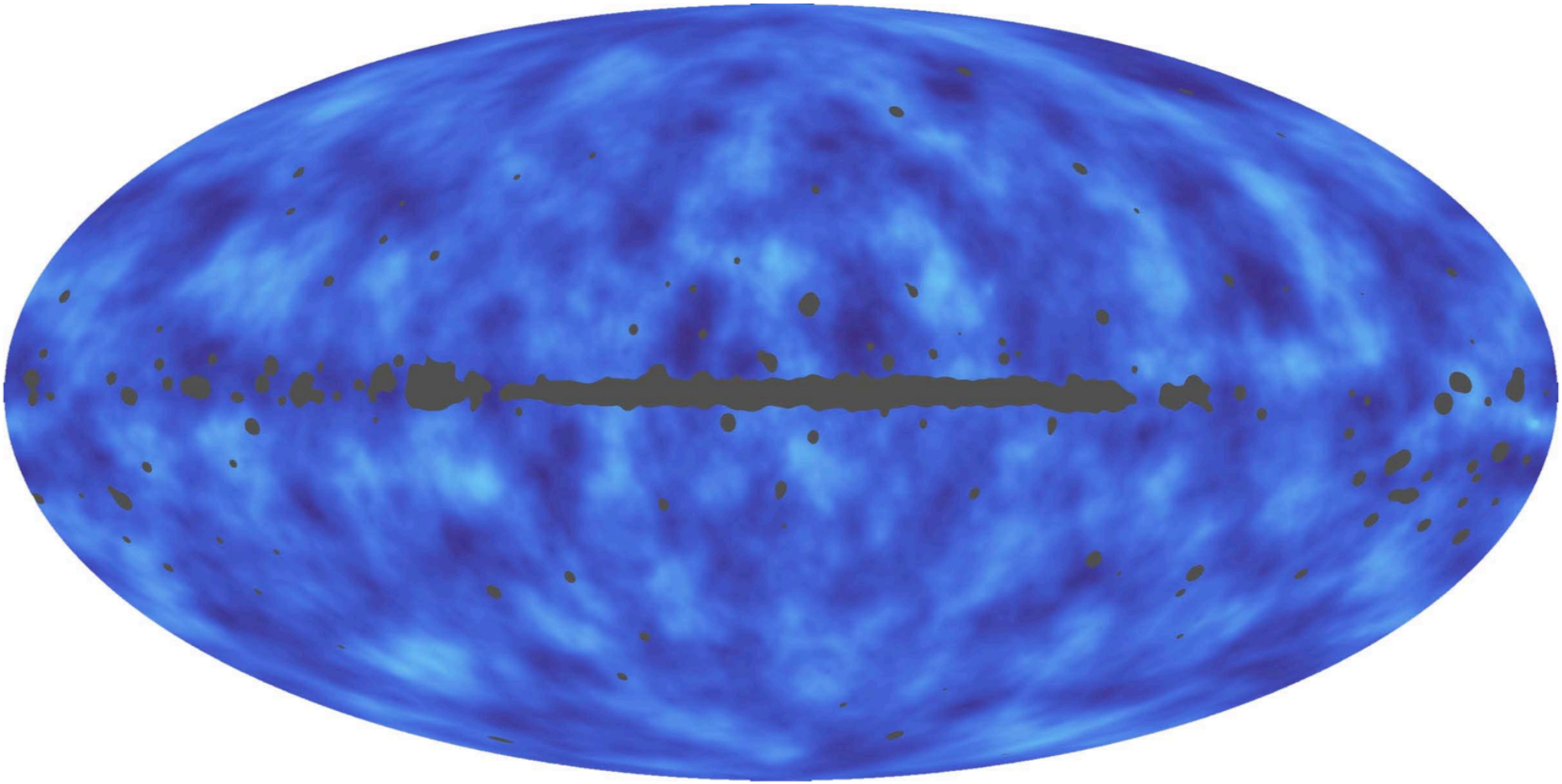
A simulated patch of CMB sky – after lensing



typical deflection: 2.4 arcmin

Planck 15 months
Planck Collaboration, 2013, 17

Planck all-sky map of the dark matter

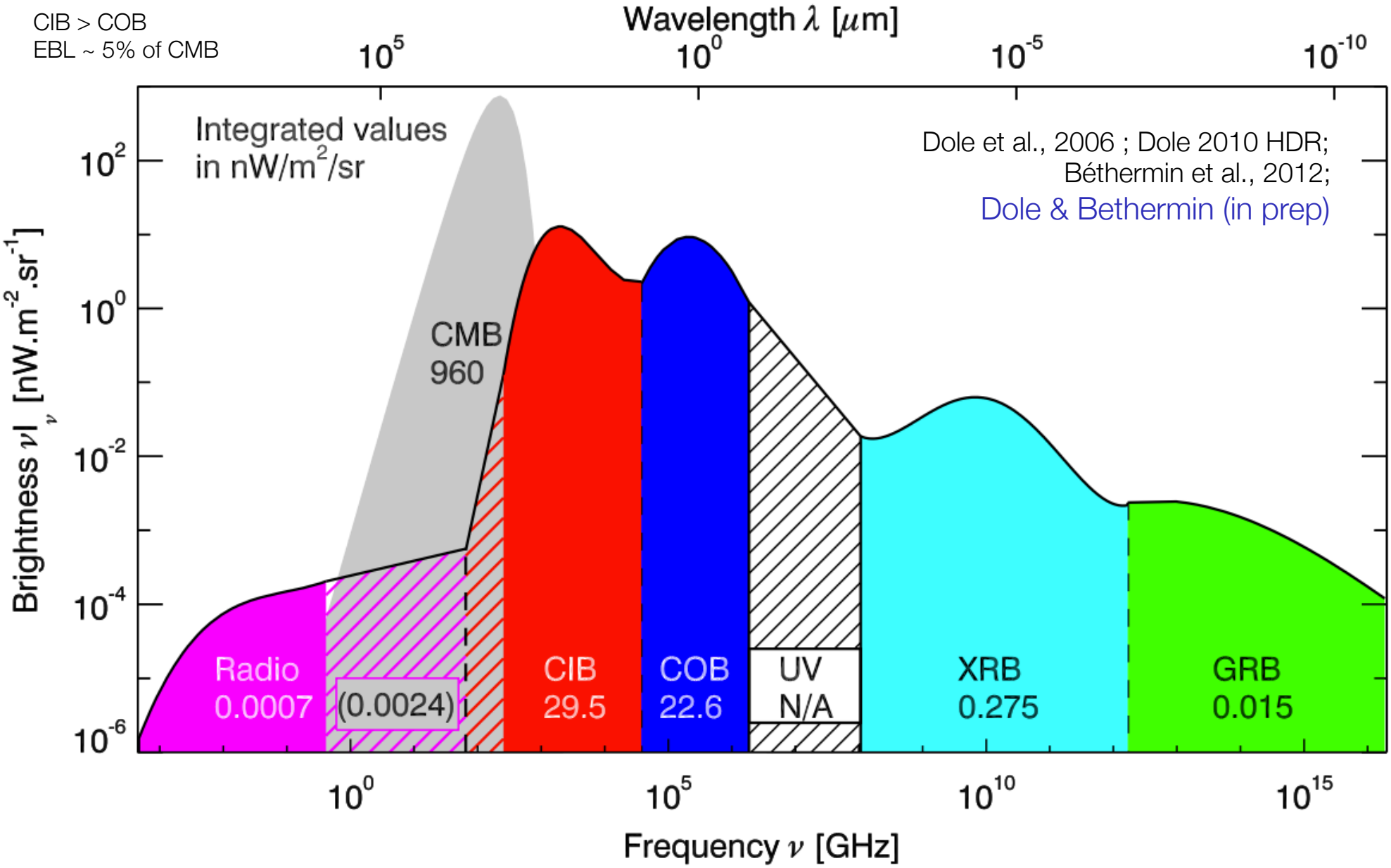


= Carte de la masse projetée sur la ligne de visée

Planck 2015

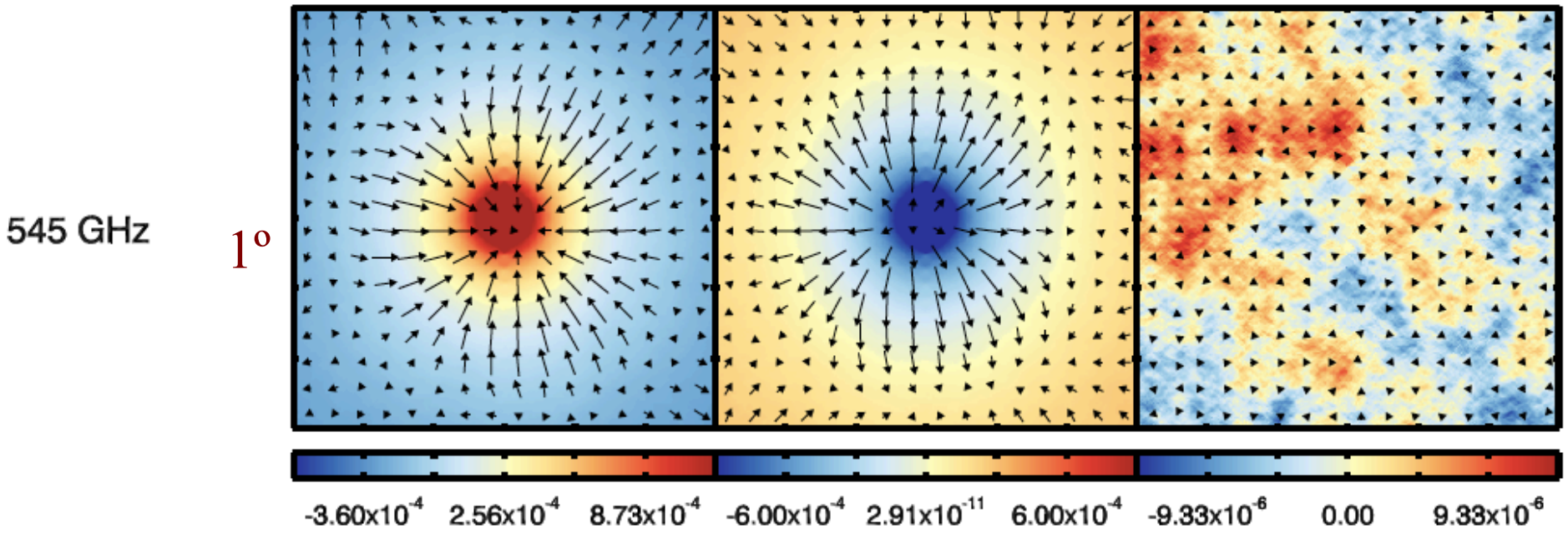
5. Extragalactic Bkg. Light Spectral En. Distrib.

CIB > COB
EBL ~ 5% of CMB



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.



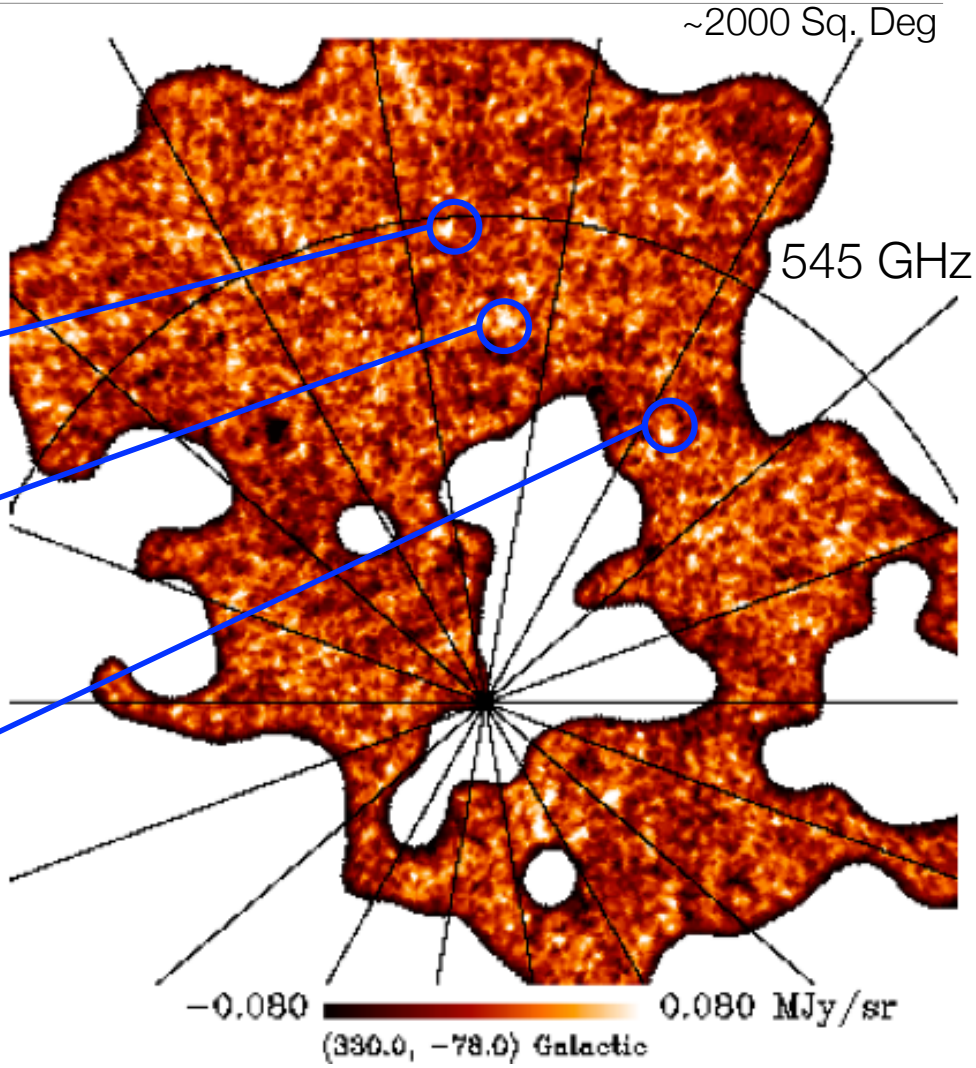
see also Hanson et al., 2013 about lensing induced B-modes (NOT primordial B-modes !)

Planck 15 months
Planck Collaboration, 2013, 18

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 ?

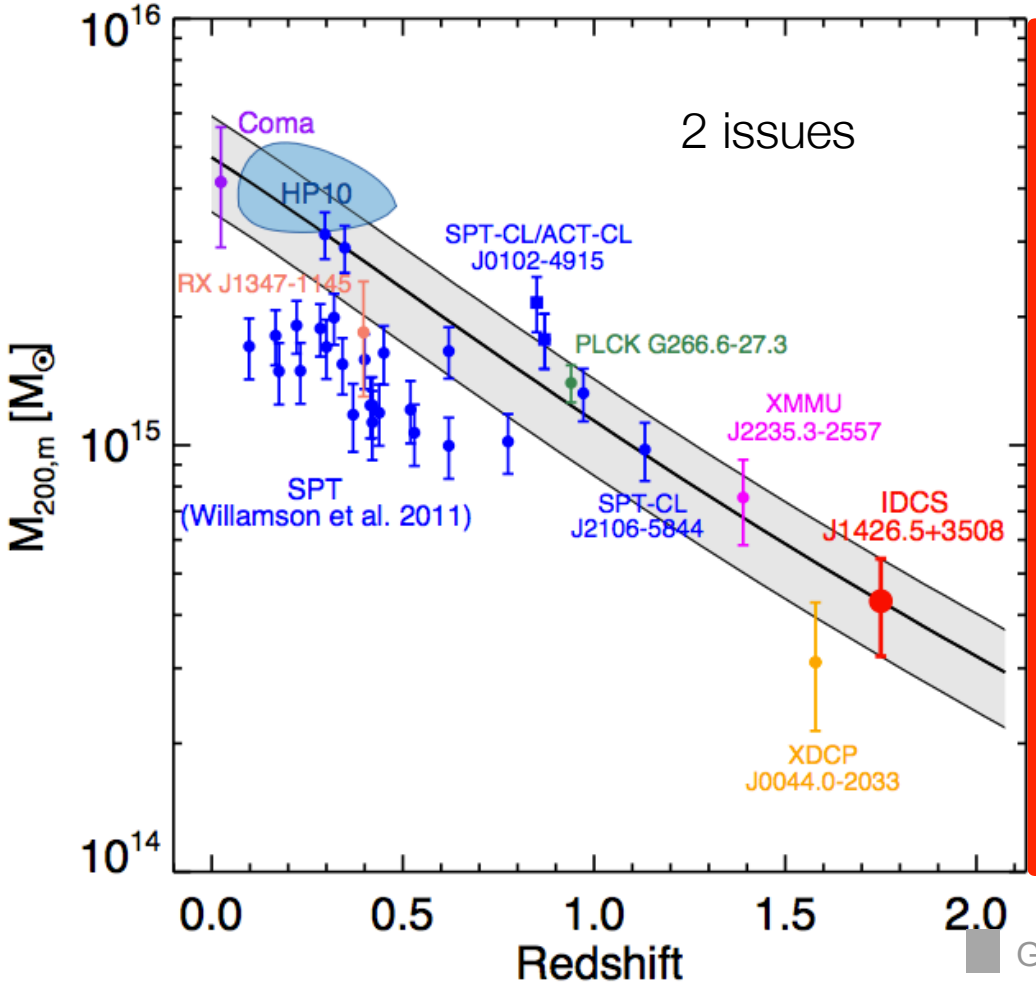


Planck Collab., 2013, 30

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

searching for high-z massive structures: probe of DE ?

Predictions / mesurements: massive clusters vs redshift



Q: processes of cluster
- stellar mass assembly
- star formation ?
--> can we find a new way to select **highly star-forming clusters** ?

z > 2
Planck
Herschel, ALMA
then Euclid,
WFIRST, JWST

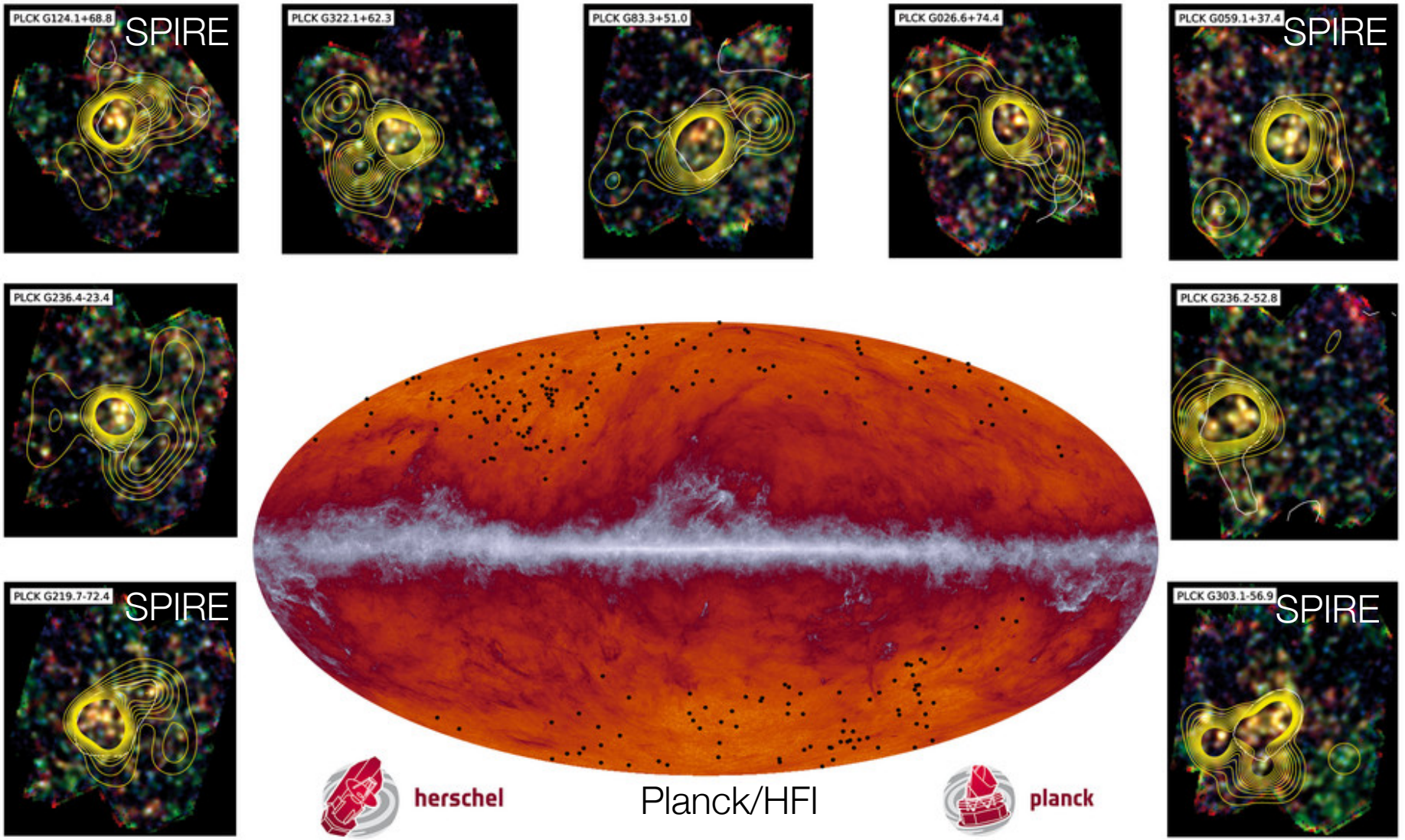
Brodwin et al, 2012 – Mortonson et al., 2011

Gobat Cl.

how to find z>2 clusters ?
(observationnally) rare objects can be unveiled using all-sky surveys: Planck, Euclid, and further studied with JWST, WFIRST

Galaxy clusters are proxies for massive DM halos

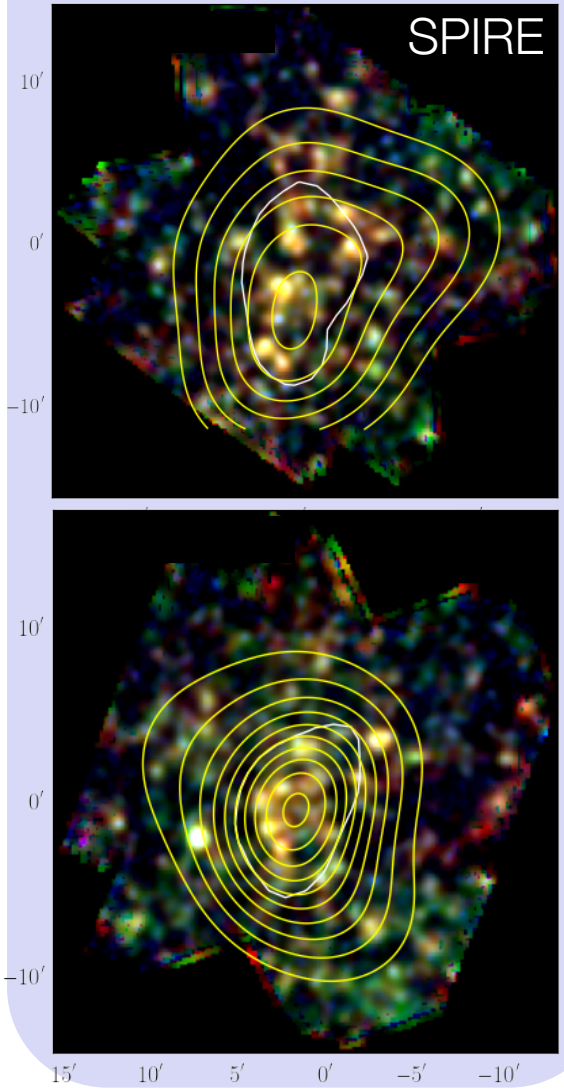
→ Herschel and Planck proto-cluster candidates



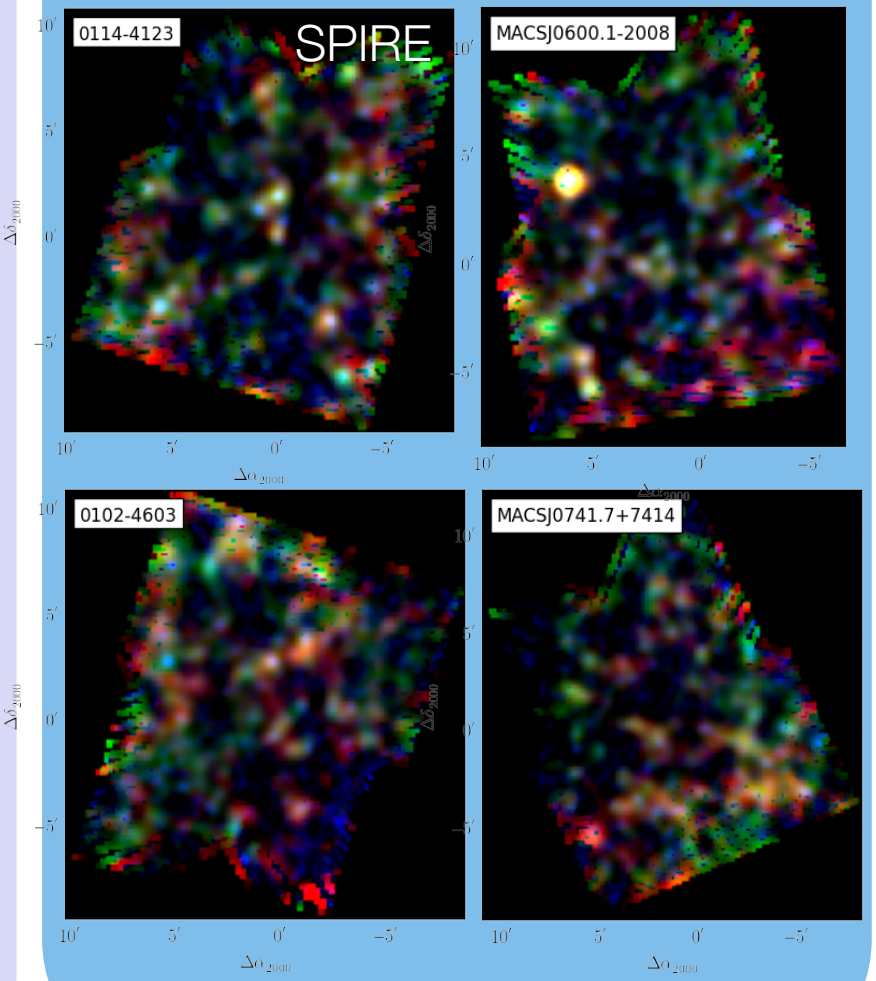
Planck Collab. Int XXVII, 2015

a remarkable Planck+Herschel dataset among others

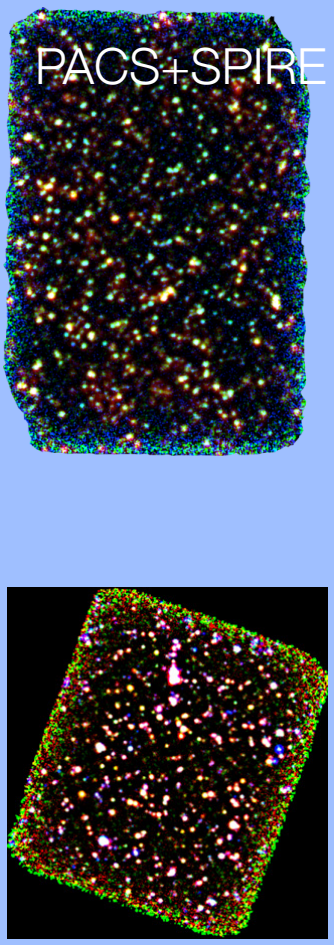
Planck/Herschel HPASSS
30’ x 30’ (Planck subm)



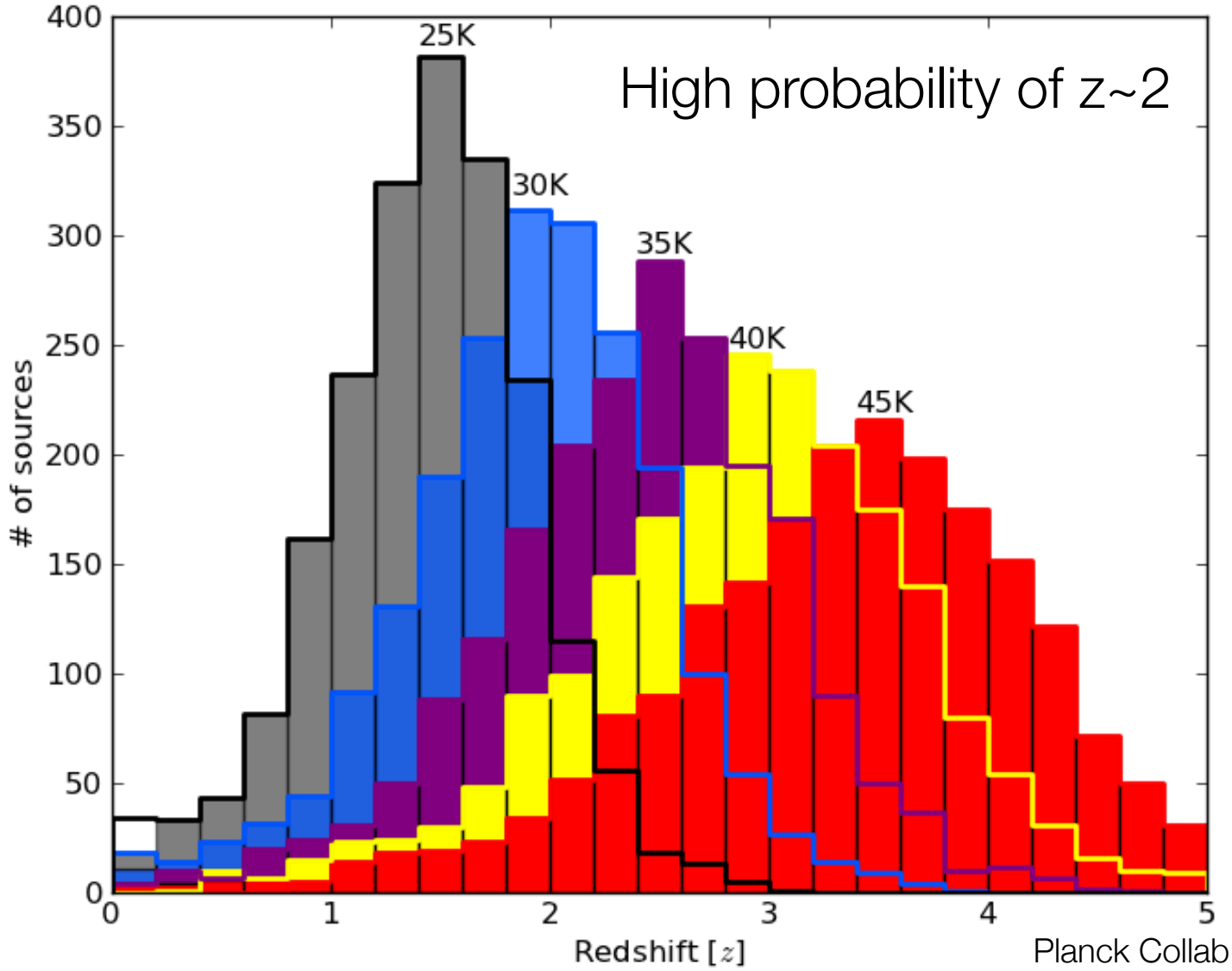
HLS 20’ x 20’
(Egami+2010)



GOODS 16’ x 10’
(Elbaz+2011)



inferred submm photometric redshifts

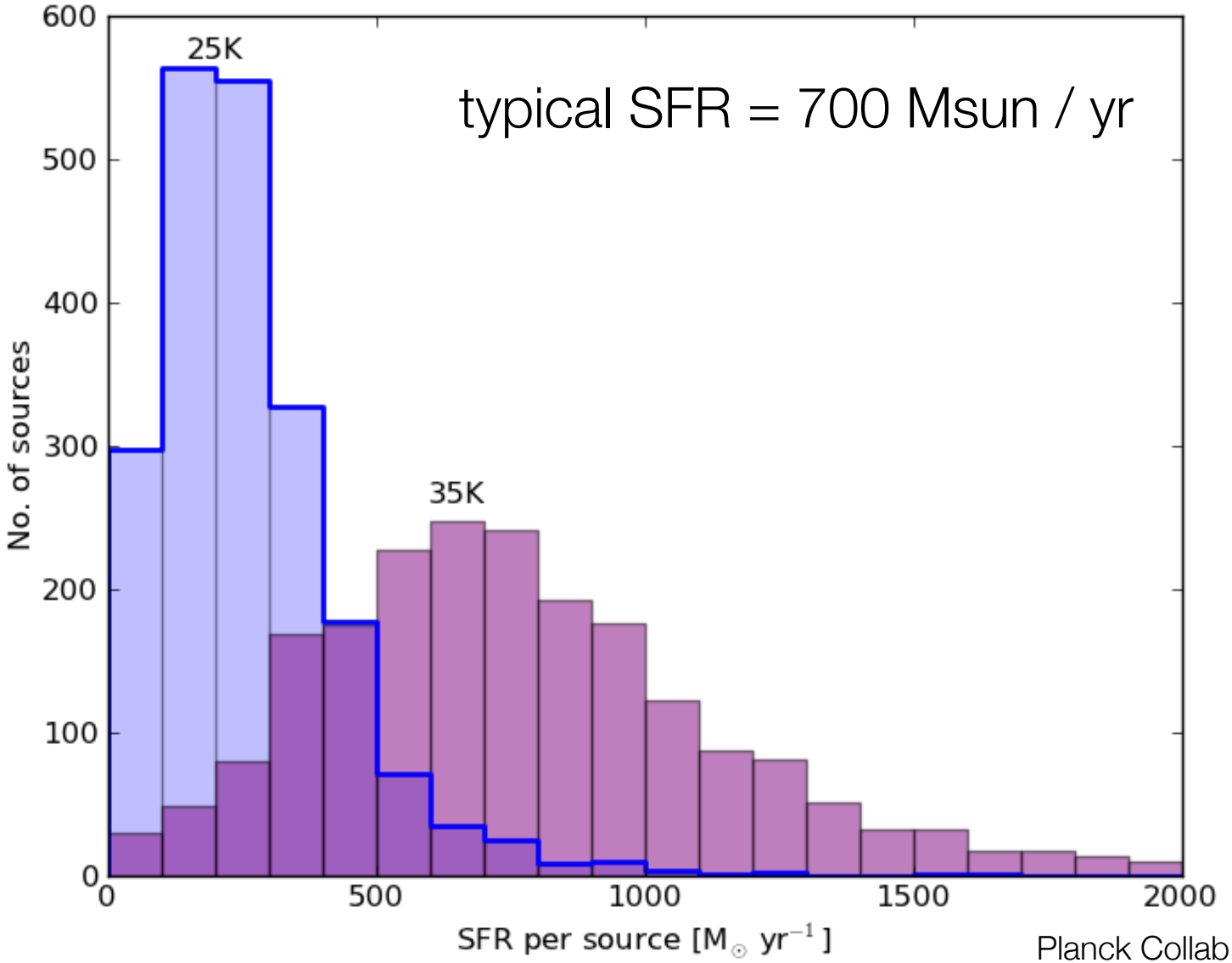


Planck Collab. Int XXVII, 2015

Thèse de David Guéry – DIM ACAV

inferred star formation rate

For: about 2000 SPIRE sources within the Planck beam

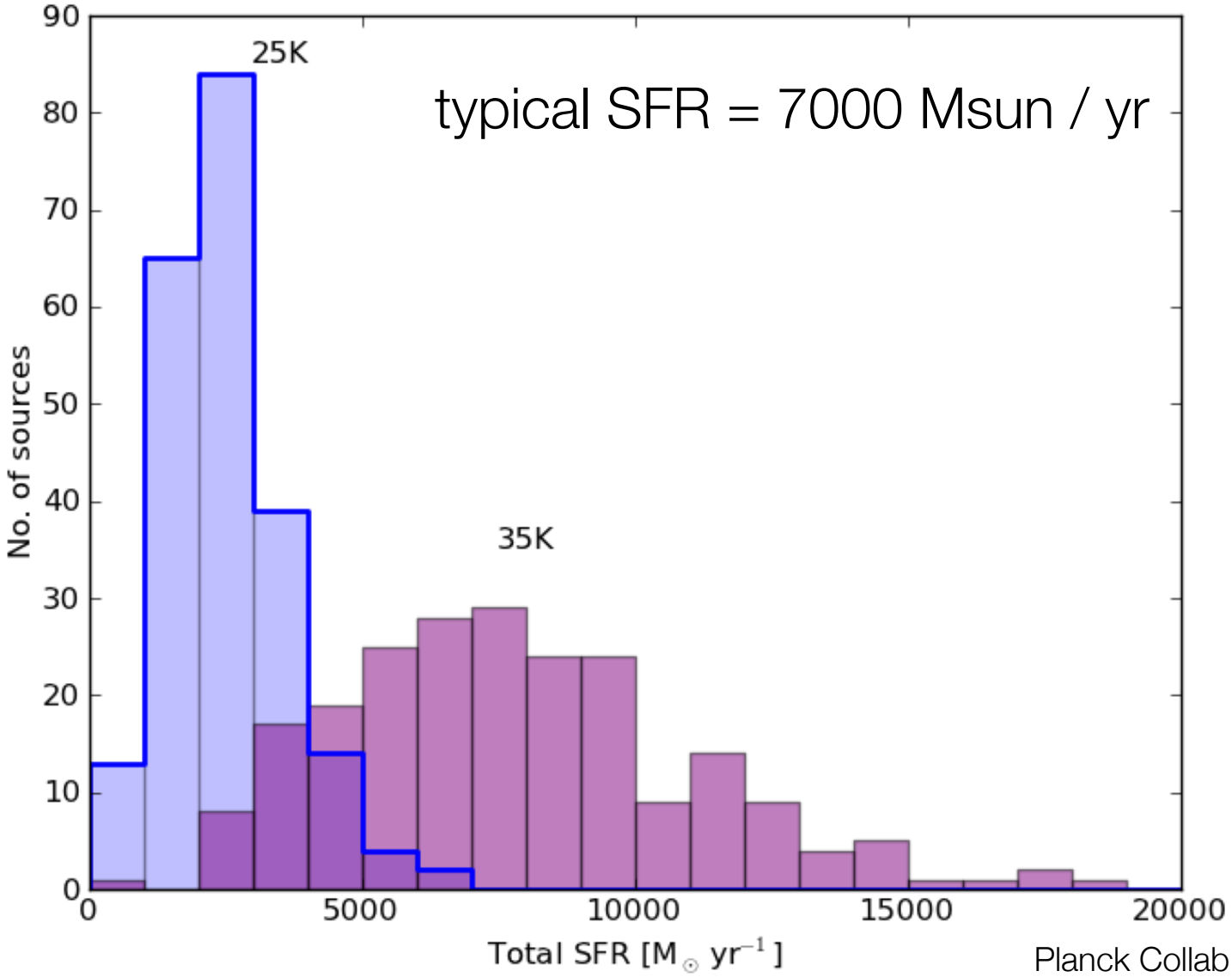


Planck Collab. Int XXVII, 2015

Thèse de David Guéry – DIM ACAV

inferred star formation rate

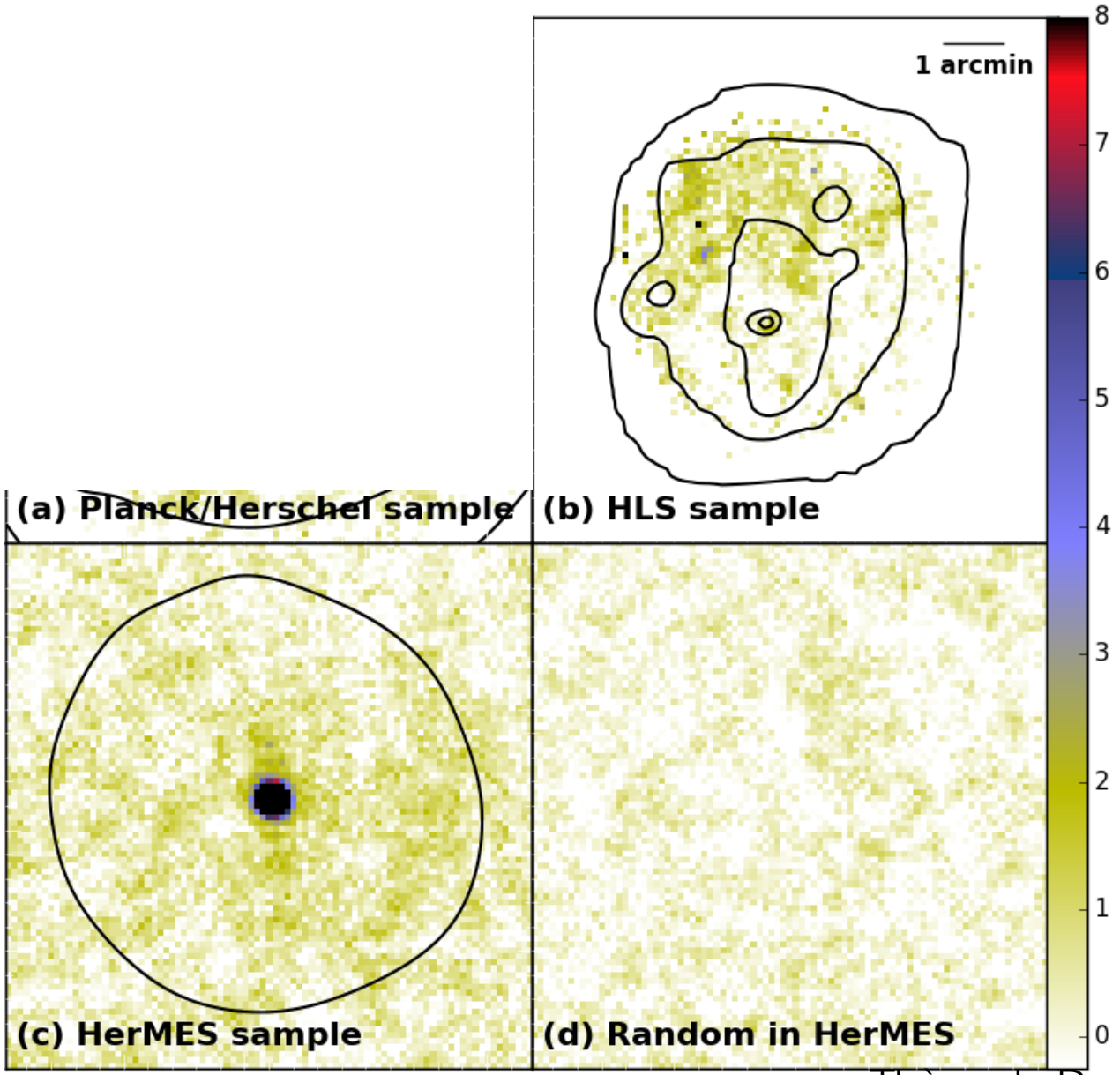
For: about 200 Planck beam fields



Planck Collab. Int XXVII, 2015

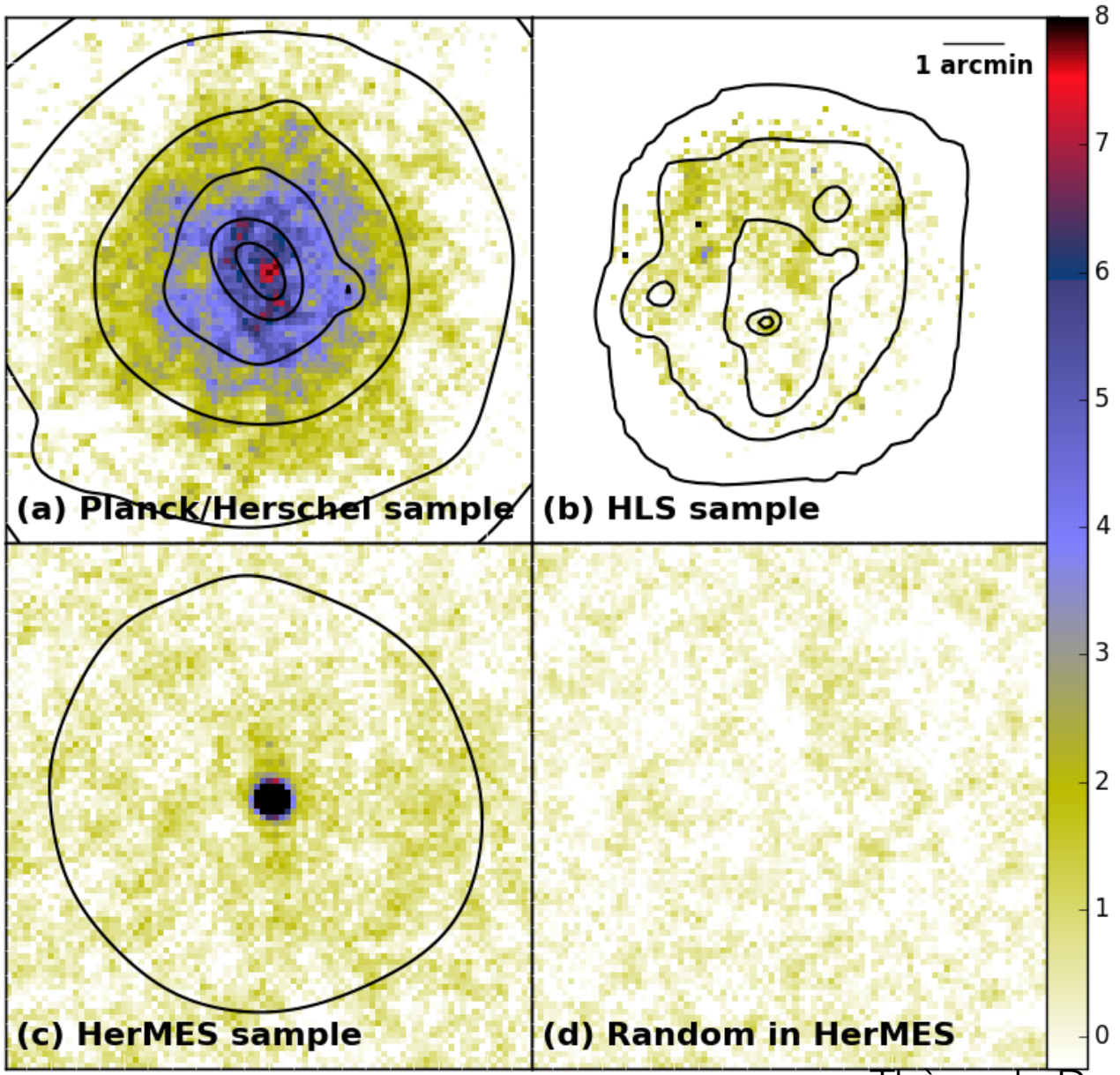
Thèse de David Guéry – DIM ACAV

extended submm signal



Planck Collab. Int XXVII, 2015

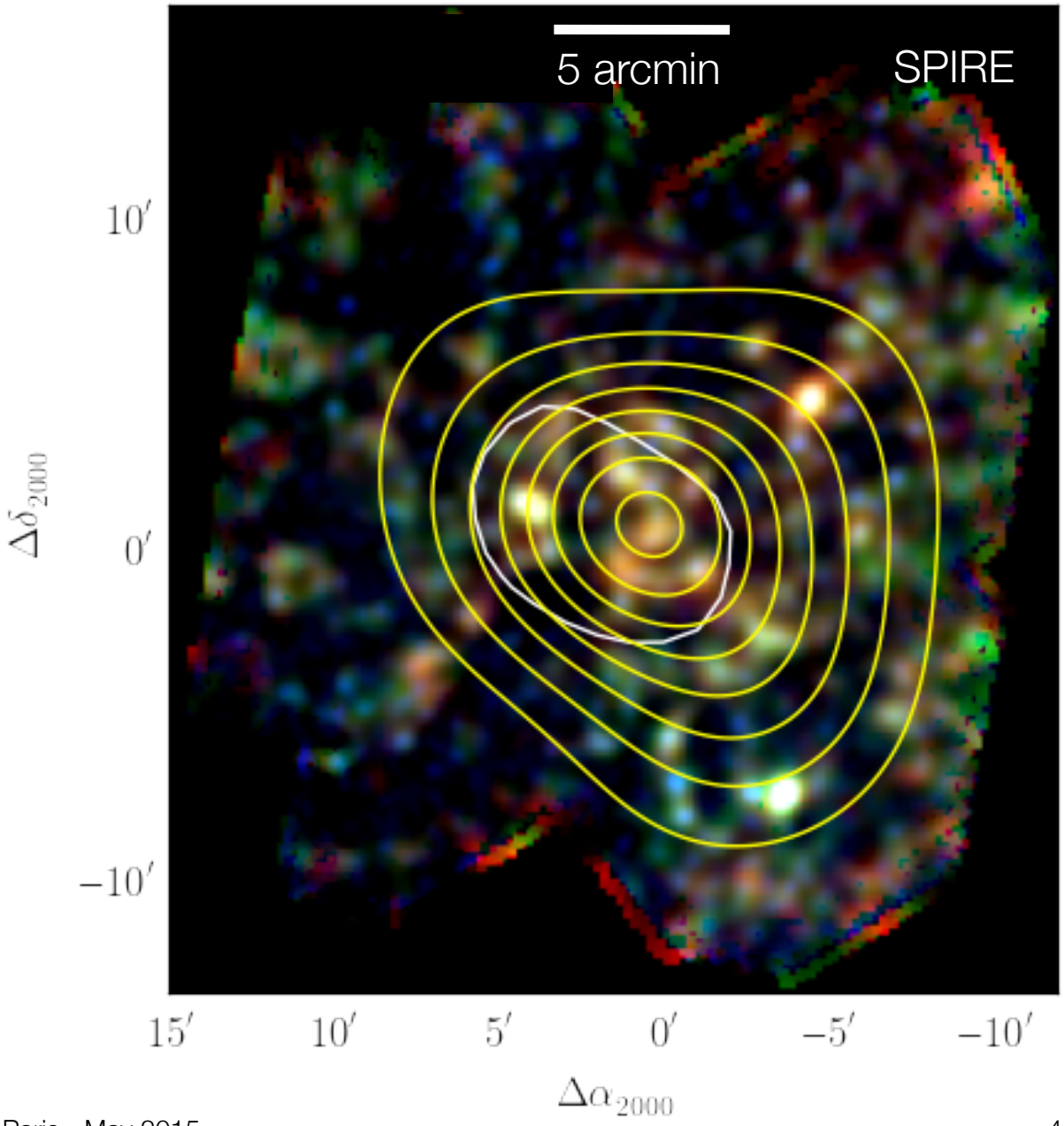
extended submm signal



Planck Collab. Int XXVII, 2015

the case of one field: Spitzer and VLT

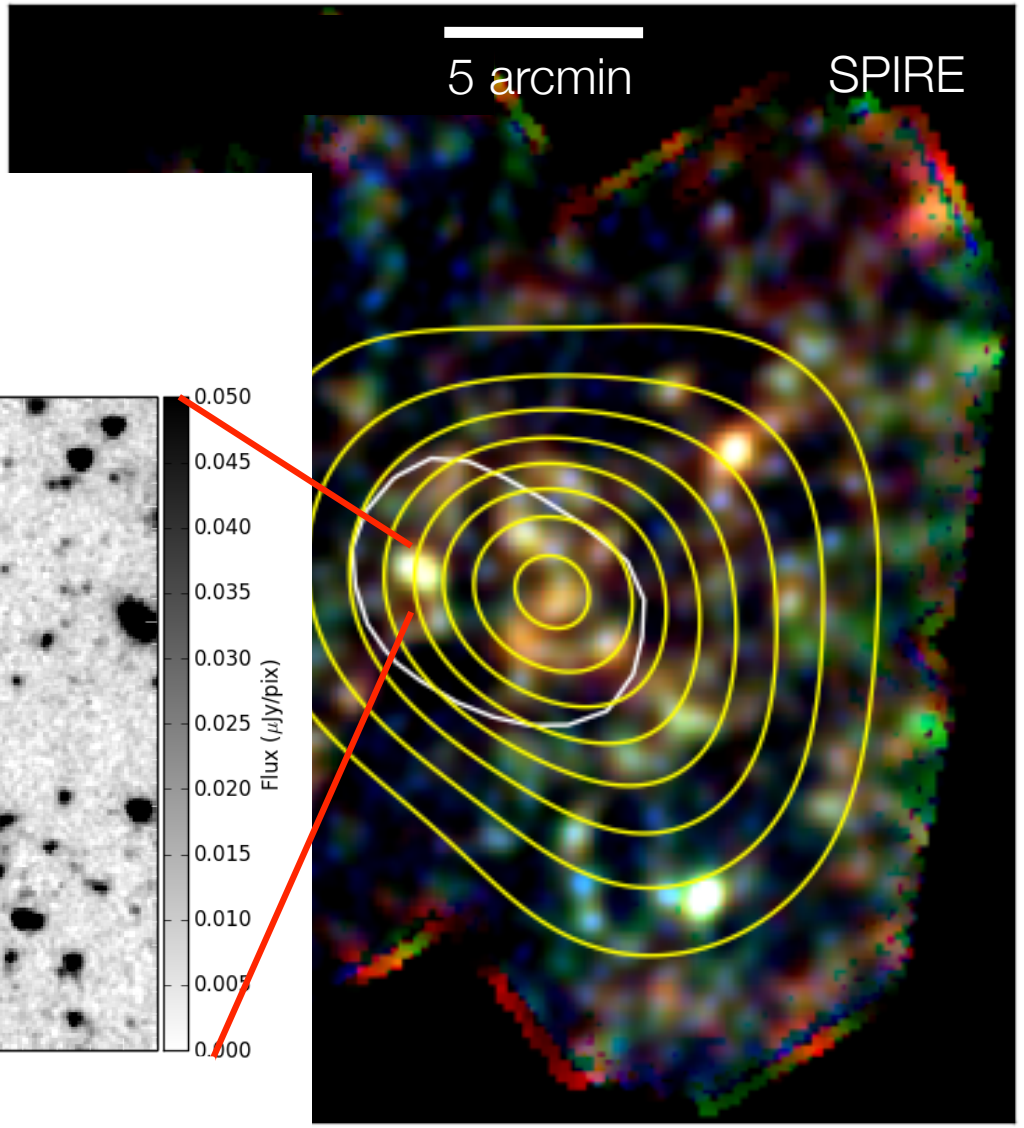
Herschel-SPIRE
3-color image:
blue = 250um
green = 350um
red = 500um

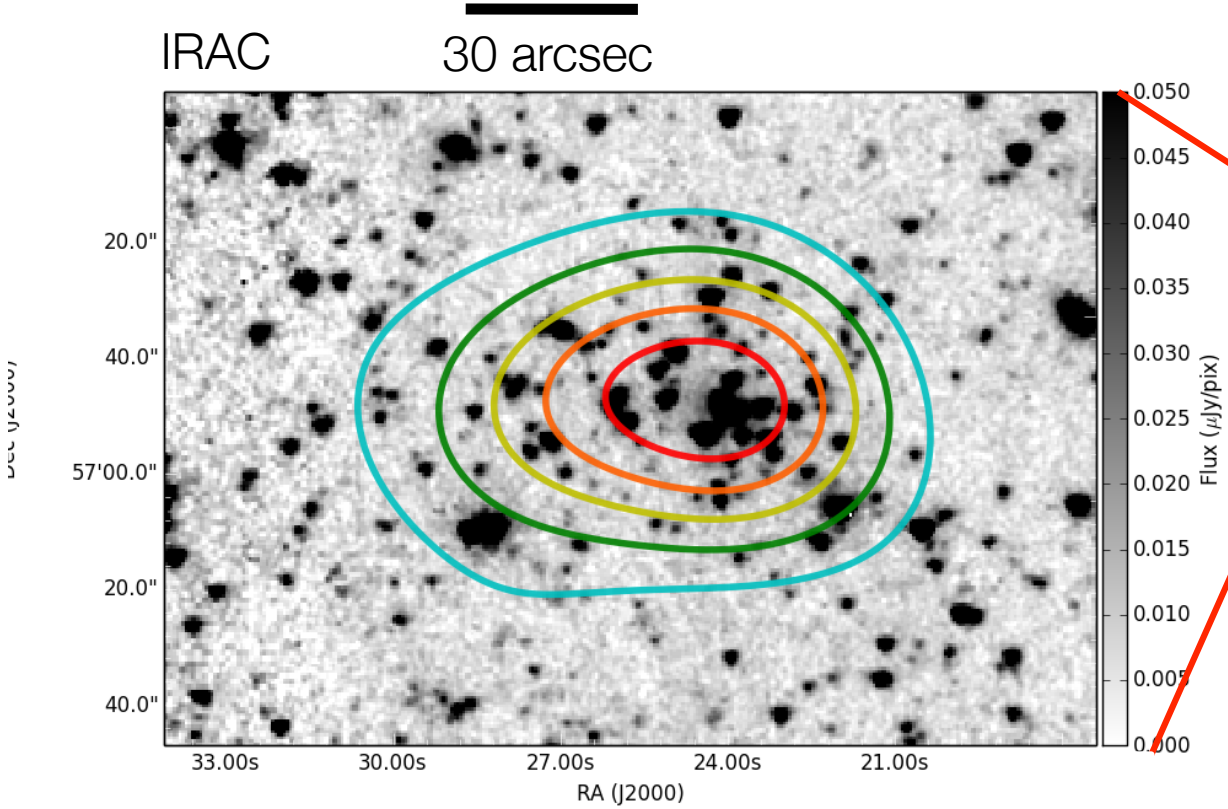


the case of one field: Spitzer and VLT

Herschel-SPIRE
3-color image:
blue = 250um
green = 350um
red = 500um

Euclid will provide this kind of sensitivity over the whole sky !
JWST and WFIRST much better, on smaller sky areas !





IRAC image at 3.6um

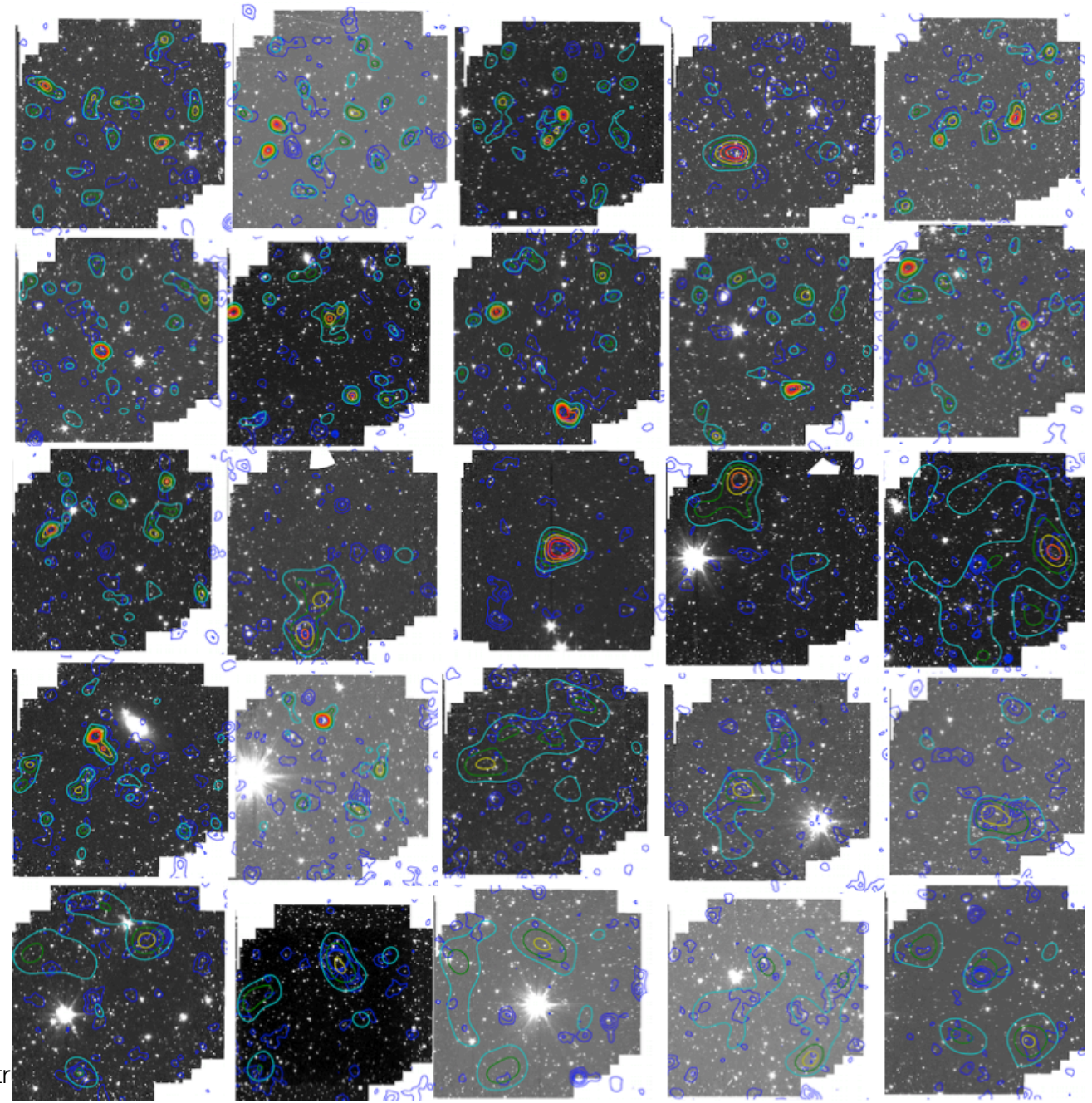
Martinache et al., in prep

25 Spitzer fields having >5σ overdensities

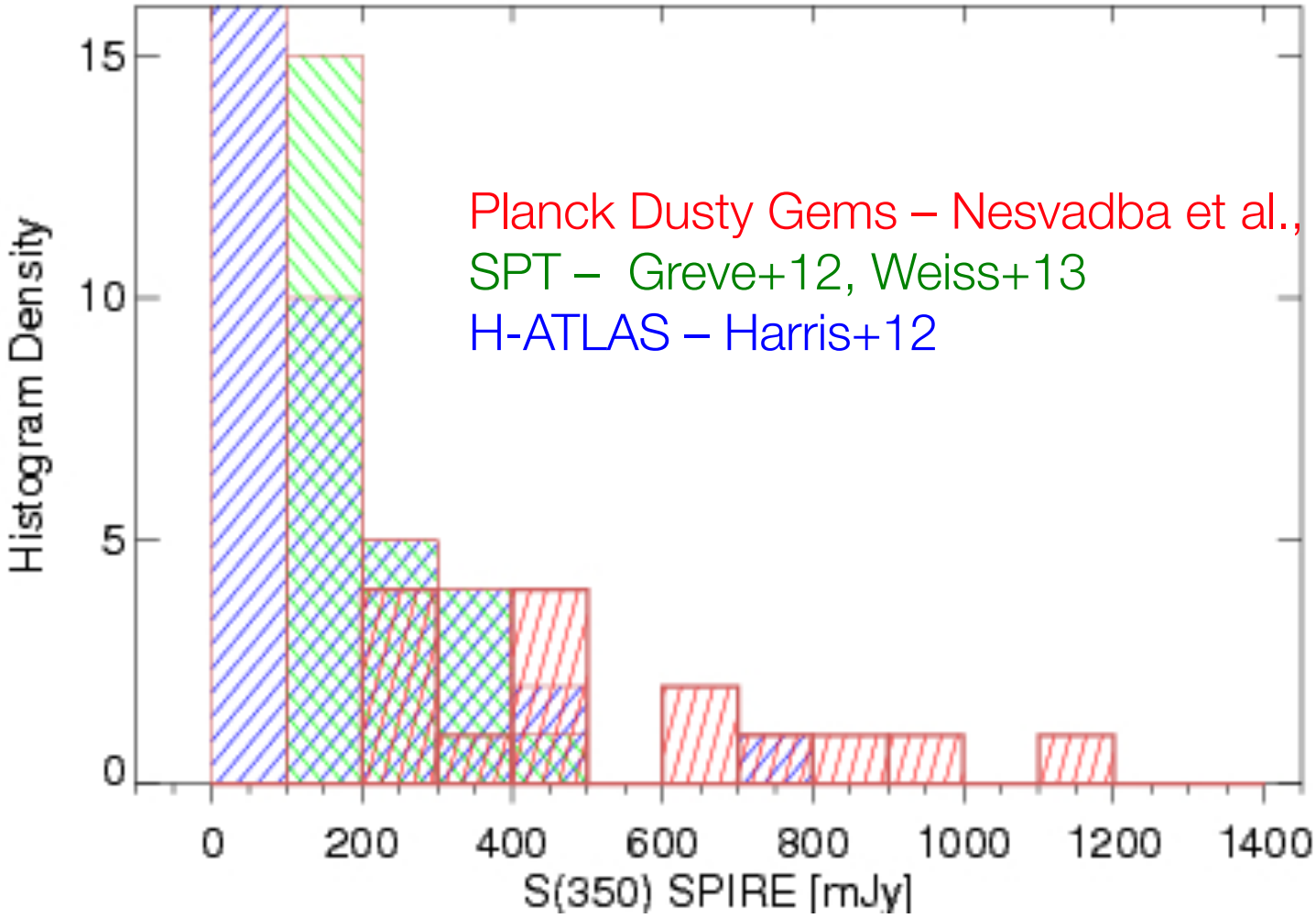
IRAC fields,
about 5’ x 5’ each
observed at
3.6 and 4.5um

color contours:
significance of red
IRAC source
overdensity

deep blue contours:
SPIRE 350um



many bright z>2.2 lensed sources



all measured redshifts at IRAM:
z: 2.2 – 3.6

major contribution from ground-based mm img/spec

Canameras, Nesvadba et al., subm

some coverage

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urprise dans les tréfonds de univers

Des observations des télescopes européens Planck et Herschel ont permis de découvrir ce qui semble être les plus anciens amas de galaxies, qui seraient à l'origine des plus grandes structures de l'univers.

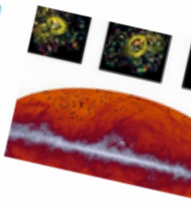
ESA Planck @Planck · 4m

RT @esascience: Astronomers mine data from @ESAHerschel and @Planck find treasure chest of galaxy clusters ow.ly/3xFptx

Herschel and Planck find missing clue to galaxy cluster formation

By combining observations of the distant Universe made with ESA's Herschel and Planck space observatories, cosmologists have discovered what could be the precursors of the vast clusters of galaxies...

View on web



Les proto-amas, chaînons manquants du cosmos

La découverte de 2 000 sources de lumière pourrait aider à comprendre la formation de l'Univers

« *Nous avons été scotchés par cette découverte !* », lance Hervé Dole, de l'Institut d'astrophysique spatiale à l'université Paris-Sud, encore tout excité par la trouvaille. Elle est d'autant plus belle qu'elle n'était pas anticipée. Cet astrophysicien est le porte-parole d'une collaboration internationale qui vient de découvrir dans le ciel sombre du cosmos près de 2 000 sources de lumière jusqu'alors inconnues, très brillantes et présentes 3 à 4 milliards d'années environ après le Big Bang.

Ce pourrait être des proto-amas de galaxies, des ensembles de galaxies très jeunes en train de se rapprocher sous l'effet de la gravitation. Une phase que notre propre galaxie, la Voie lactée, ou l'amas dans lequel elle se trouve aurait pu connaître à sa naissance, mais que personne n'avait jamais repérée.

Jusqu'à présent, les seuls rares candidats proto-amas identifiés sont bien moins étendus en taille. Leurs étoiles sont en outre « vieilles » et produites à des taux fort réduits. Au contraire, ces nouveaux venus créent quelque 100 à 1 500 soleils par an, soit 500 fois plus environ que notre galaxie aujourd'hui. D'où leur qualificatif de « *chaînon manquant* » de la cosmologie dans le communiqué de l'Agence spatiale européenne (ESA), après la parution de l'article dans *Astronomy & Astrophysics* du 31 mars.

L'autre surprise est que l'instrument utilisé n'était pas fait pour traquer ces géants. Il s'agit de Planck, un satellite de l'ESA, destiné à sonder les tréfonds du cosmos, 400 000 ans après le Big Bang qui remonte à

Mais, de façon surprenante, près de 2 000 petites taches lumineuses ont éclairé les endroits les plus dégagés du ciel, chacune ayant une surface six fois plus petite que celle de la Lune.

« Une direction inattendue »

« *Nous avons alors utilisé un deuxième instrument, Herschel, de l'ESA et de la NASA, pour mieux voir ces objets* », indique Hervé Dole. Ce télescope spatial a été la « loupe » qui a montré, grâce au rayonnement infrarouge, que ce qui n'était qu'un point pour Planck se décomposait en près d'une dizaine d'autres, toujours extrêmement brillants. Un troisième télescope spatial, Spitzer (de la NASA), a, lui, prouvé que chacun de ces points est en fait

« *Ils ont poussé Planck dans une direction inattendue. Leur hypothèse est plausible* », salue Emanuele Daddi du CEA-Saclay.

Sur 2 000 sources, seules 234 ont pu être pointées par Herschel et 219 attribuées à ces proto-amas. Les 15 autres sont des galaxies uniques dont la lumière est exaltée par un « effet de lentille ».

« *C'est une découverte, mais nous n'avons pas la preuve formelle de ce qu'elle est vraiment* », prévient Hervé Dole. Le ciel est si peuplé qu'il se pourrait bien qu'au lieu de galaxies situées à la même distance certaines taches soient le résultat de la superposition de galaxies alignées sur la même ligne de visée mais

formation de l'Univers : comment de telles structures, de plusieurs millions d'années-lumière de diamètre, se forment-elles ? S'il n'y avait que de la matière ordinaire, les gaz et poussières se condenseraient si lentement qu'à l'âge actuel de l'Univers aucune galaxie ne se serait formée... Les astrophysiciens ont donc recours (et pour d'autres raisons également) à une autre forme de matière, dite noire, cinq fois plus abondante que la matière ordinaire, et qui permet d'accélérer le processus. Quitte à aller trop vite et, dans certaines simulations, tout transformer en étoiles

large scale structures

- Significative overdensities of red and relatively bright submm sources
  - very rare otherwise

- For a reasonnable range of dust temperatures:
  - Inferred submm photometric redshift should be round 2
  - SFR peak arount 700 Msun/yr
  - If all Planck sources are gravitationnaly-bound structures (certainly not true for all ; not yet proven) then: about 10 SPIRE sources on average, with SFRs peaking at 7000 Msun/yr

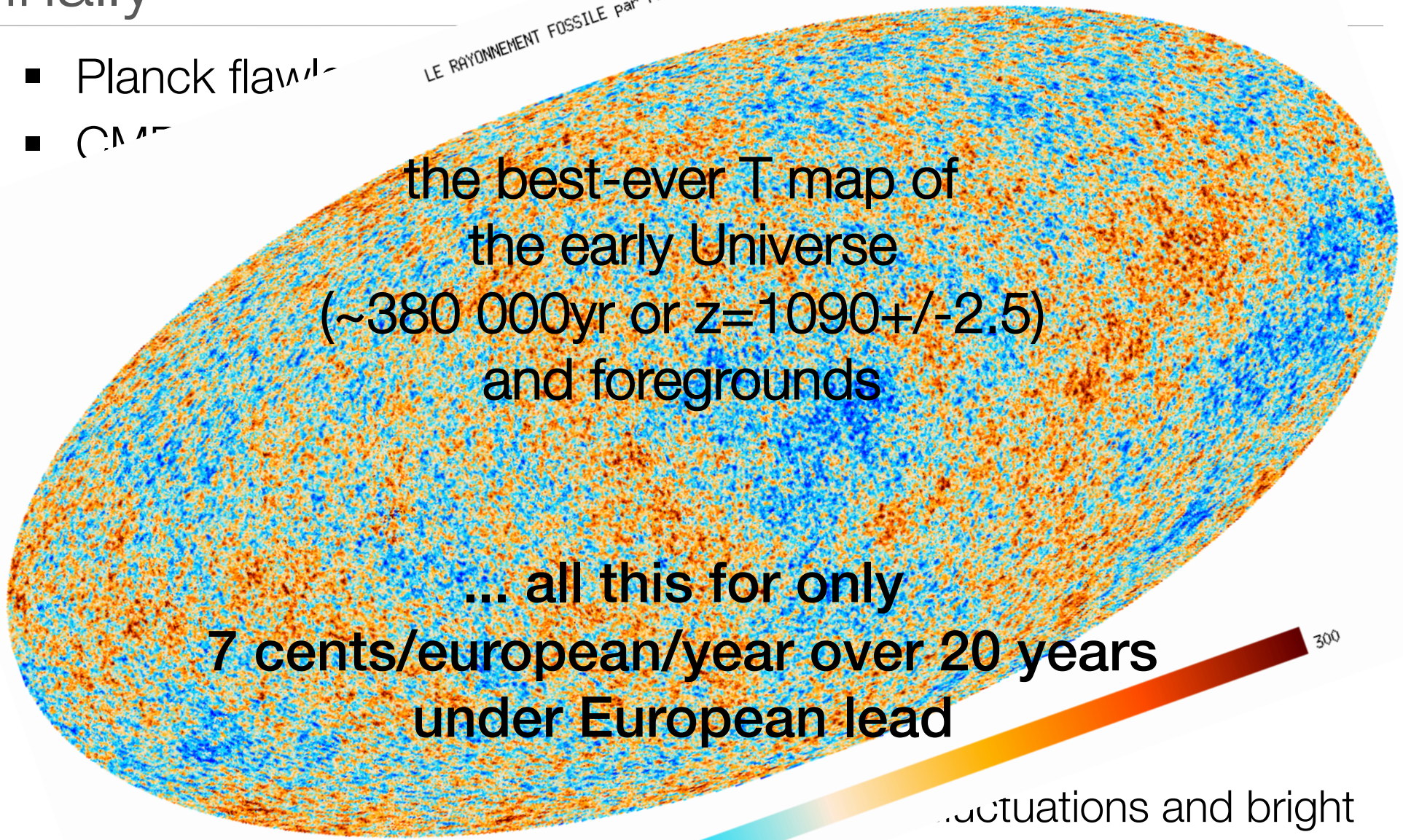
- Large scale (few arcmin) submm emission

finally

- Planck flawlessly worked at 0.1K for ~2 yrs: 5 surveys
- CMB TT ultimate measurement, TE
- Polarization: BB ongoing
- Many results
  - CMB, params, inflation, NG, neutrinos, dark matter, lensing
  - foregrounds, point sources, SZ clusters
  - polarized foregrounds: magnetic field
- Only 6 cosmological parameters perfecly fitting the data
- Some novelties
  - all-sky polarization
  - LSS with all-sky dark matter map
  - search of high-z high-SFR clusters in CIB fluctuations and bright lensed sources

finally

- Planck flawl
- CM



ctuations and bright