



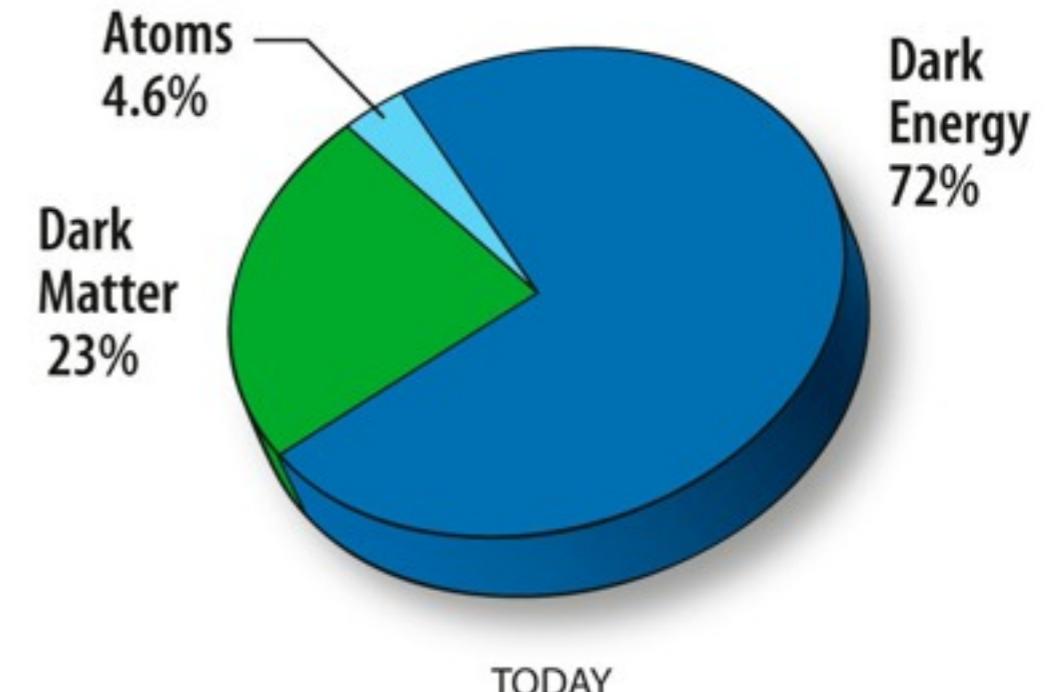
PLANCK status and performance

la cosmologie



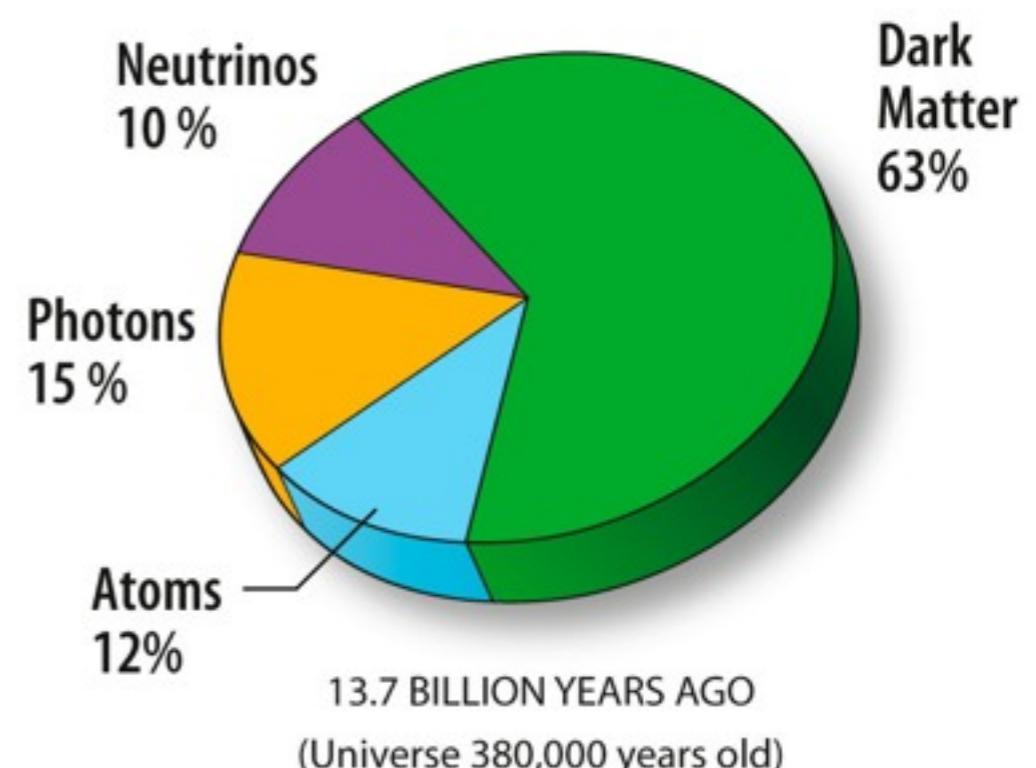
- **des questions :**

- **Quel est l'âge de l'Univers ?**
- **Quelle est sa composition ?**
- **Comment décrire son évolution ?**



- **Qui amènent d'autres questions :**

- **De quoi est fait la matière noire ?**
- **Qu'est-ce que l'énergie noire ?**
- ...



cosmologie standard

- **un principe cosmologique**

- "l'Univers est homogène et isotrope"
- défini la métrique (**Friedmann-Robertson-Walker**)

$$ds^2 = -dt^2 + a^2(t) \left[\frac{dr^2}{1 - \kappa r^2} + r^2 (d\theta^2 + \sin^2 \theta d\phi^2) \right]$$

- **un cadre général pour décrire l'évolution et la structure de l'Univers à grande échelle**

- la relativité générale pour la gravitation (eq. d'Einstein)
- thermodynamique et mécanique quantique pour décrire les composants (à travers leur équation d'état)



Equations de Friedmann-Lemaitre

$$\begin{aligned} \left(\frac{\dot{a}}{a} \right)^2 &= H^2 = \frac{8\pi G \rho}{3} - \frac{\kappa}{a^2} + \frac{\Lambda}{3}, \\ \frac{\ddot{a}}{a} &= -\frac{4\pi G}{3} (\rho + 3p) + \frac{\Lambda}{3}. \end{aligned}$$

description géométrique

- **Densités**

$$\left(\frac{\dot{a}}{a}\right)^2 = H^2 = \frac{8\pi G\rho}{3} - \frac{\kappa}{a^2} + \frac{\Lambda}{3}$$

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3} (\rho - \rho^\kappa + \rho^\Lambda)$$

$$\begin{aligned}\Omega_m &= \rho/\rho_c \\ \Omega_\kappa &= \rho^\kappa/\rho_c = \kappa/(a^2 H^2) \\ \Omega_\Lambda &= \rho^\Lambda/\rho_c = \Lambda/(3H^2)\end{aligned}$$

$$\Omega_\kappa = \Omega_m + \Omega_\Lambda - 1$$

modèle de Big-Bang

- description géométrique

+

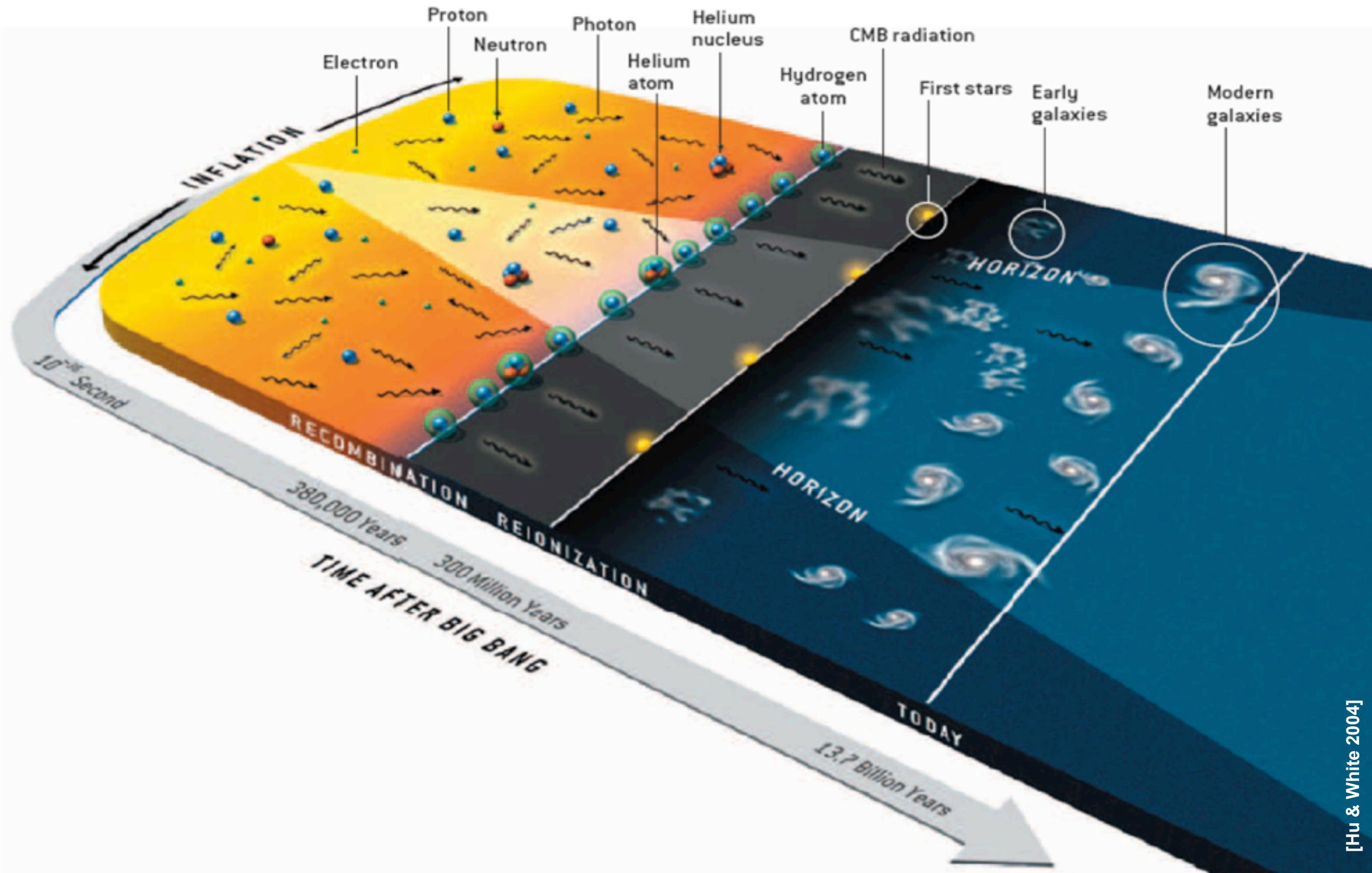
- 3 piliers

- expansion de l'Univers (Hubble 1929)
- nucléosynthèse primordiale (Gamow 1946)
- découplage des photons



- un modèle de d'évolution
 - le modèle de Big-Bang
- une extension
 - l'inflation

modèle de Big-Bang



modèle de concordance

mesurer les paramètres cosmologiques (~ 10 dont H_0 , Ω_m , Ω_k , Ω_Λ, \dots) à l'aide d'observables complémentaires :

- **mesure de luminosité apparente**

- chandelles standards (SNIa, ...) de luminosité connue
⇒ flux apparent $\Phi \propto 1/R^2$ (proportionnel au redshift)

- **mesure de la distribution de la matière à différents redshift**

- CMB
 - BAO

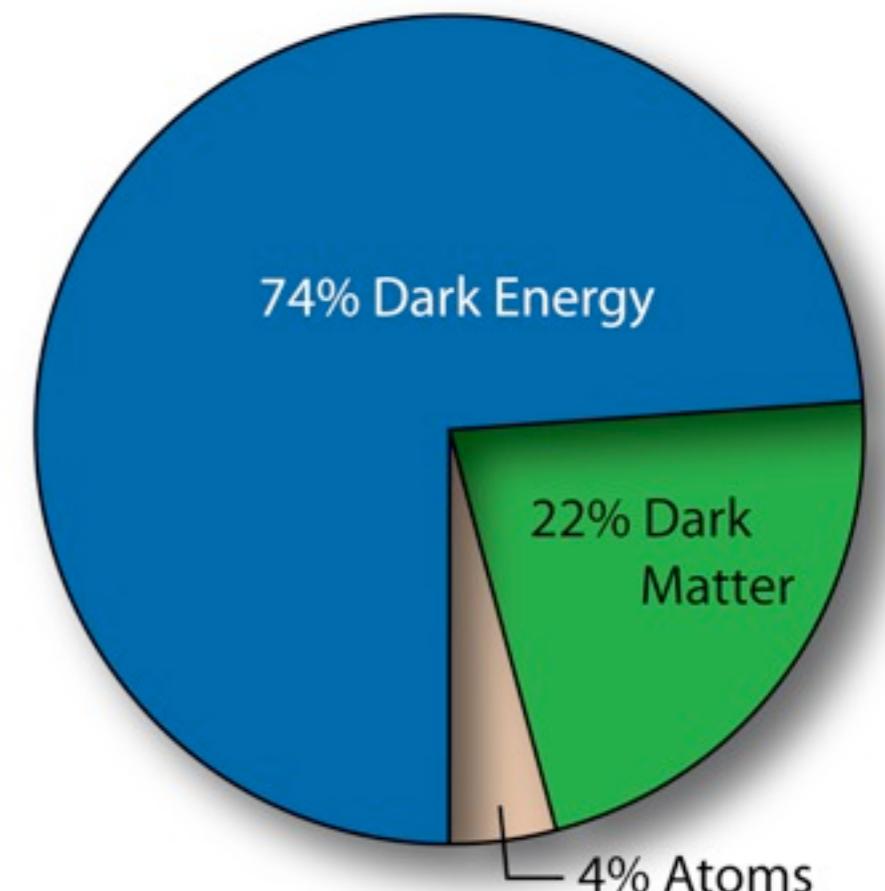
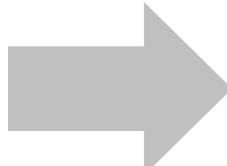
- **comptage de galaxies**

- variation de l'élément de volume

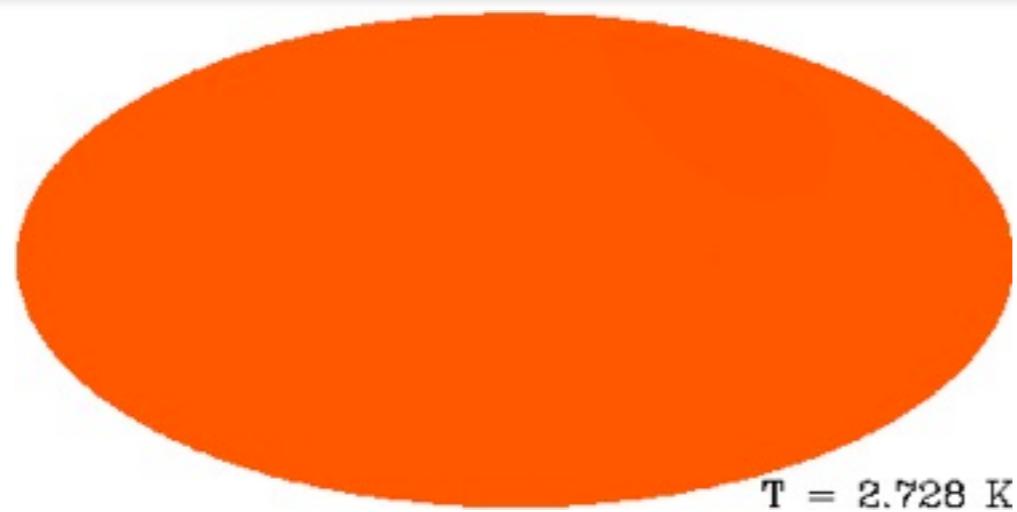
- ...

modèle de concordance

- Univers plat ($\Omega_{\text{tot}} = 1$)
- 74% d'énergie noire
- 22% de matière noire
- spectre de la matière en loi de puissance

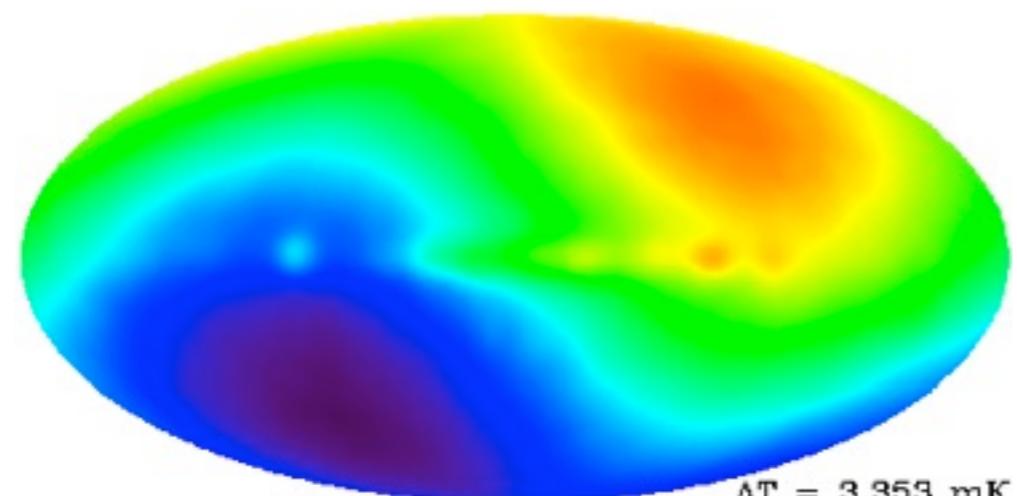


le CMB



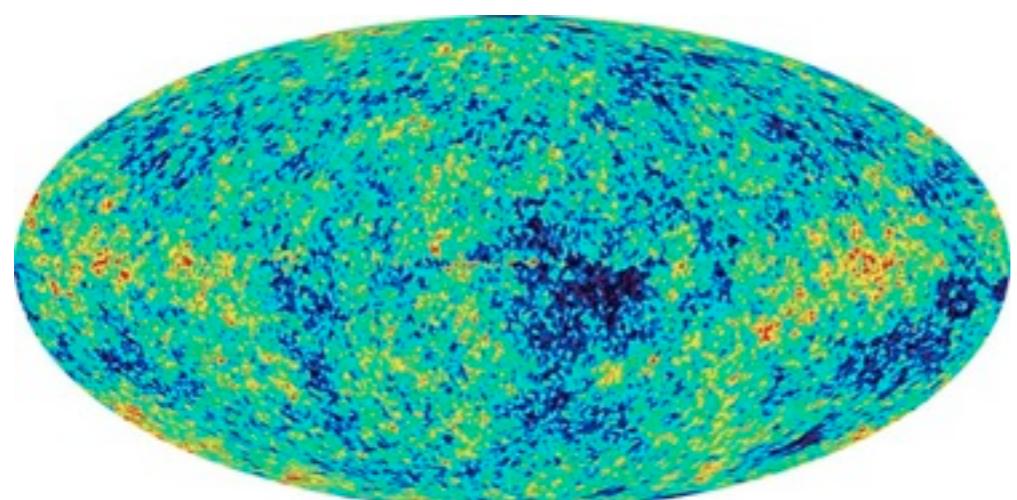
CMB
rayonnement isotrope, corps noir à T_{CMB}

$$\rightarrow T_{\text{CMB}} = 2.73$$



dipôle galactique
lié au mouvement du système solaire par rapport à la surface de dernière diffusion

$$\rightarrow \Delta T/T = 10^{-3}$$



anisotropies
liées aux fluctuations de densité de l'Univers primordial

$$\rightarrow \Delta T/T = 10^{-5}$$

PLANCK : objectifs de physique

• anisotropies primaires

- cosmologie, inflation, Univers primordial
- température
- polarisation (modes E et B ?)
- contraintes sur les paramètres cosmologiques limitées par le bruit de photon (+ avant-plans)

• anisotropies secondaires

- amas de galaxies
(effet SZ thermal et cinétique)
- CMB gravitational lensing
(mesure le spectre de la matière et sensible à la masse des neutrinos)
- Integrated Sachs-Wolfe effect
(test de la physique à bas redshift, sensible aux fluctuations de l'équation d'état de l'énergie noire)

• non-CMB

- Galactique (1ère cartes complètes dans le millimétrique)
- extragalactique
- système solaire

non-CMB science



- **Extragalactic**

- **survey of extreme radio sources**
- **astrophysics of quasars**
- **nearby galaxies**
- **High-z dusty galaxies**
- **statistical properties of radio and submillimetre sources**
- **power spectrum of the CIB, high-z infrared galaxies spatial distribution**

- **Galactic**

- **HI survey**
- **CO survey**
- **3D galactic model of H₂, HI, H⁺**
- **relation between phases of the ISM**
- **diffuse synchrotron**
- **anomalous emission**
- **dust in nearby molecular clouds**
- **dust at high galactic latitude**
- **interstellar clouds polarisation**
- **dust properties from polarisation**
- **large scale galactic magnetic field**
- **cold cores (joint with Herschel)**
- **solar system objects**
- **zodiacal light**

Planck goals

3ième génération d'expérience satellite CMB

- ◆ Gain d'un facteur 2.5 sur la résolution angulaire et 1 ordre de grandeur en sensibilité par rapport à WMAP
- ◆ bruit limité par le bruit de photon pour les canaux CMB (100–217 GHz)
- ◆ Reconstruction du spectre de puissance en température limitée uniquement par la capacité de séparation des avant-plans
 - ◆ couverture en fréquence très large de 30 GHz à 1 THz
- ◆ détecteurs HFI : bolomètres
 - ◆ refroidit à 100 mK
 - ◆ 52 bolomètres répartis en 6 bandes de 100 à 857 GHz
- ◆ détecteurs cohérents LFI
 - ◆ HEMTS based amplifiers
 - ◆ 3 bandes de 30 à 70 GHz
 - ◆ référence à 4K sur HFI FPU

couverture en fréquence et avant-plans

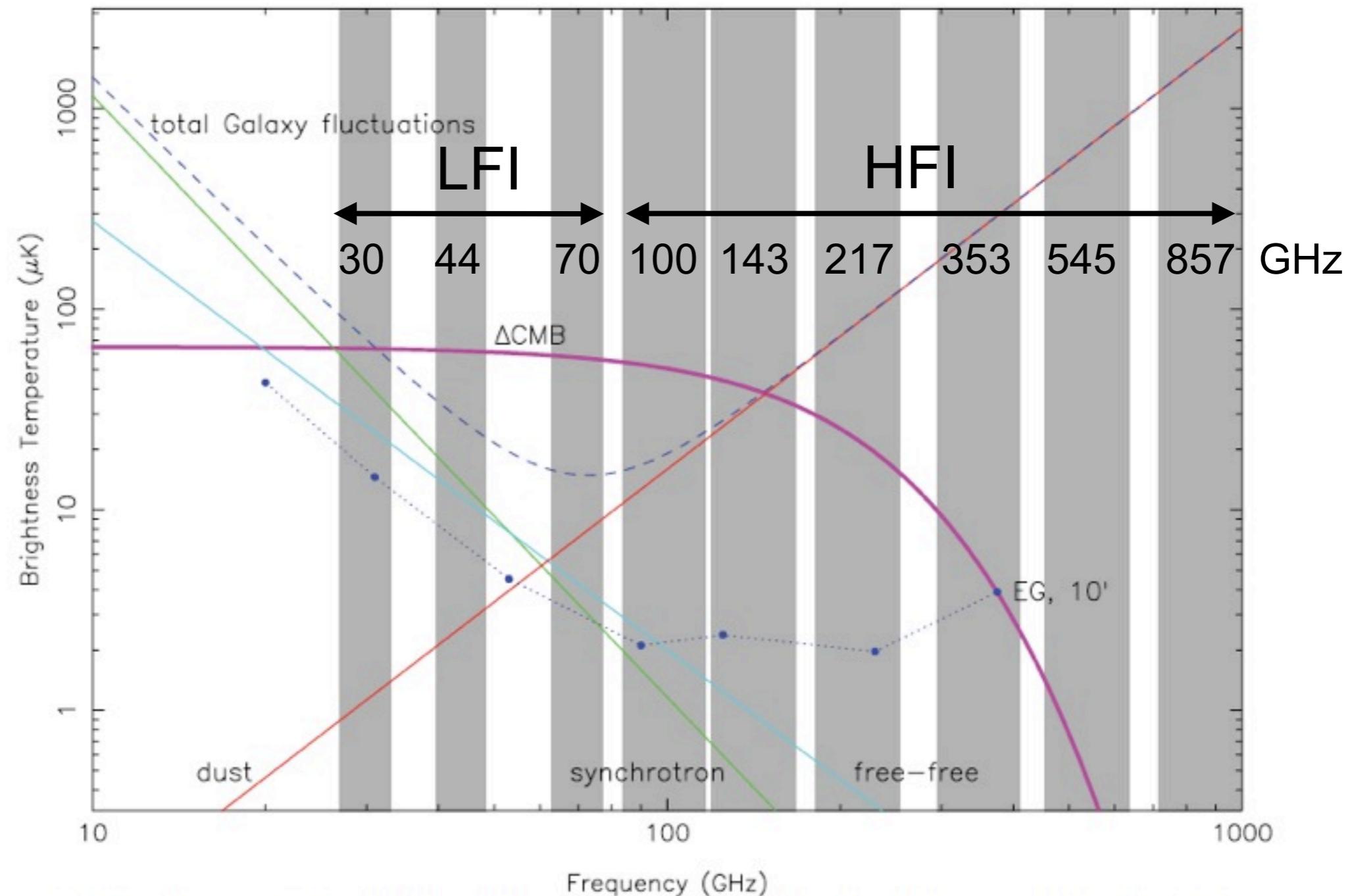
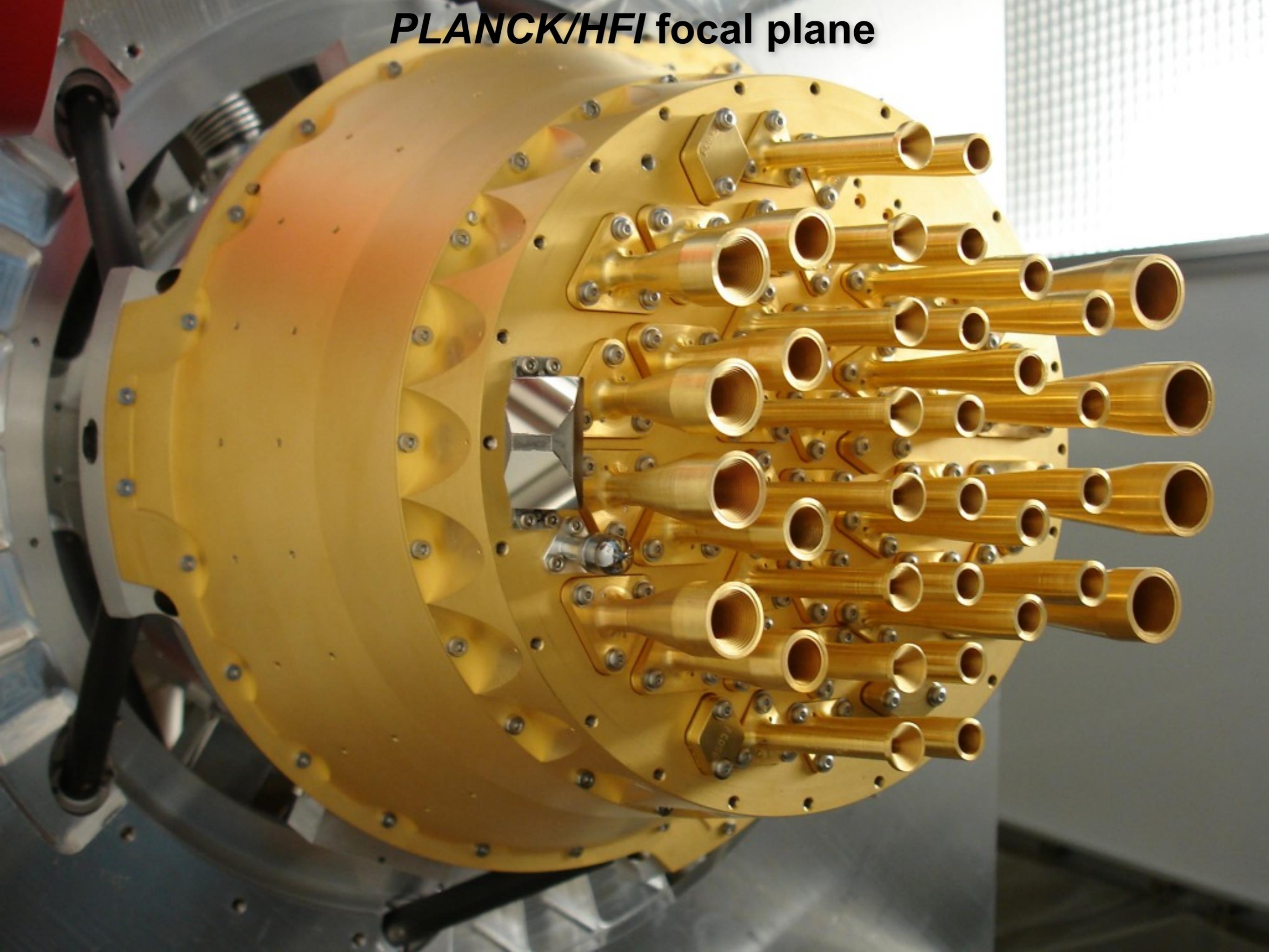
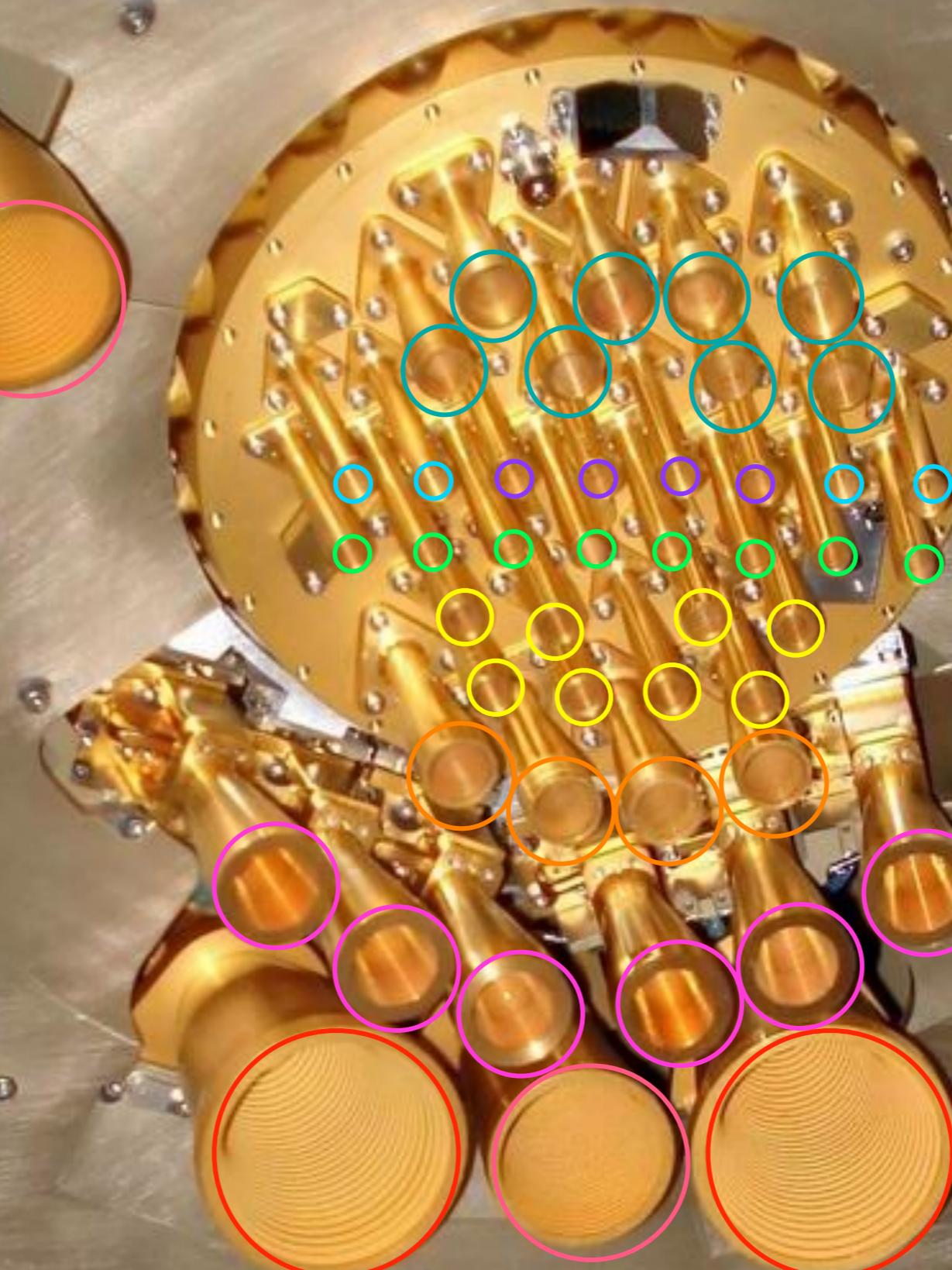


FIG 1.3.— Spectrum of the CMB, and the frequency coverage of the *Planck* channels. Also indicated are the spectra of other sources of fluctuations in the microwave sky. Dust, synchrotron, and free-free temperature fluctuation (i.e., unpolarized) levels correspond to the WMAP Kp2 levels (85% of the sky; Bennett et al. 2003). The CMB and Galactic fluctuation levels depend on angular scale, and are shown for $\sim 1^\circ$. On small angular scales, extragalactic sources dominate. The minimum in diffuse foregrounds and the clearest window on CMB fluctuations occurs near 70 GHz. The highest HFI frequencies are primarily sensitive to dust.

PLANCK/HFI focal plane



PLANCK focal plane



HFI 143 GHz

HFI 545 857 GHz

HFI 353 GHz

HFI 217 GHz

HFI 100 GHz

LFI 70 GHz

LFI 30 GHz

LFI 44 GHz

PLANCK ready to launch at Kourou



Last time the human eye saw *PLANCK*

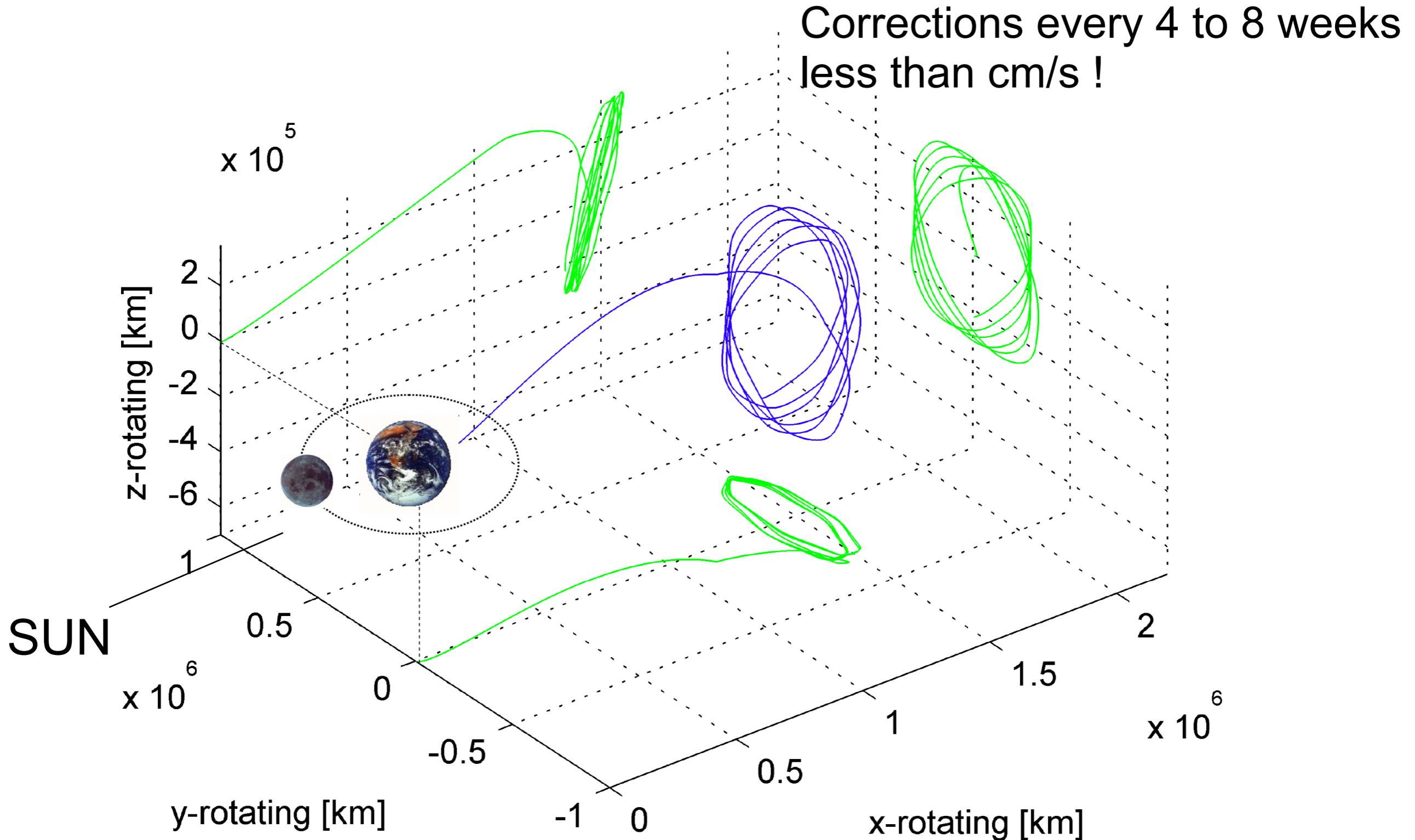


May 14th 2009 13:12z

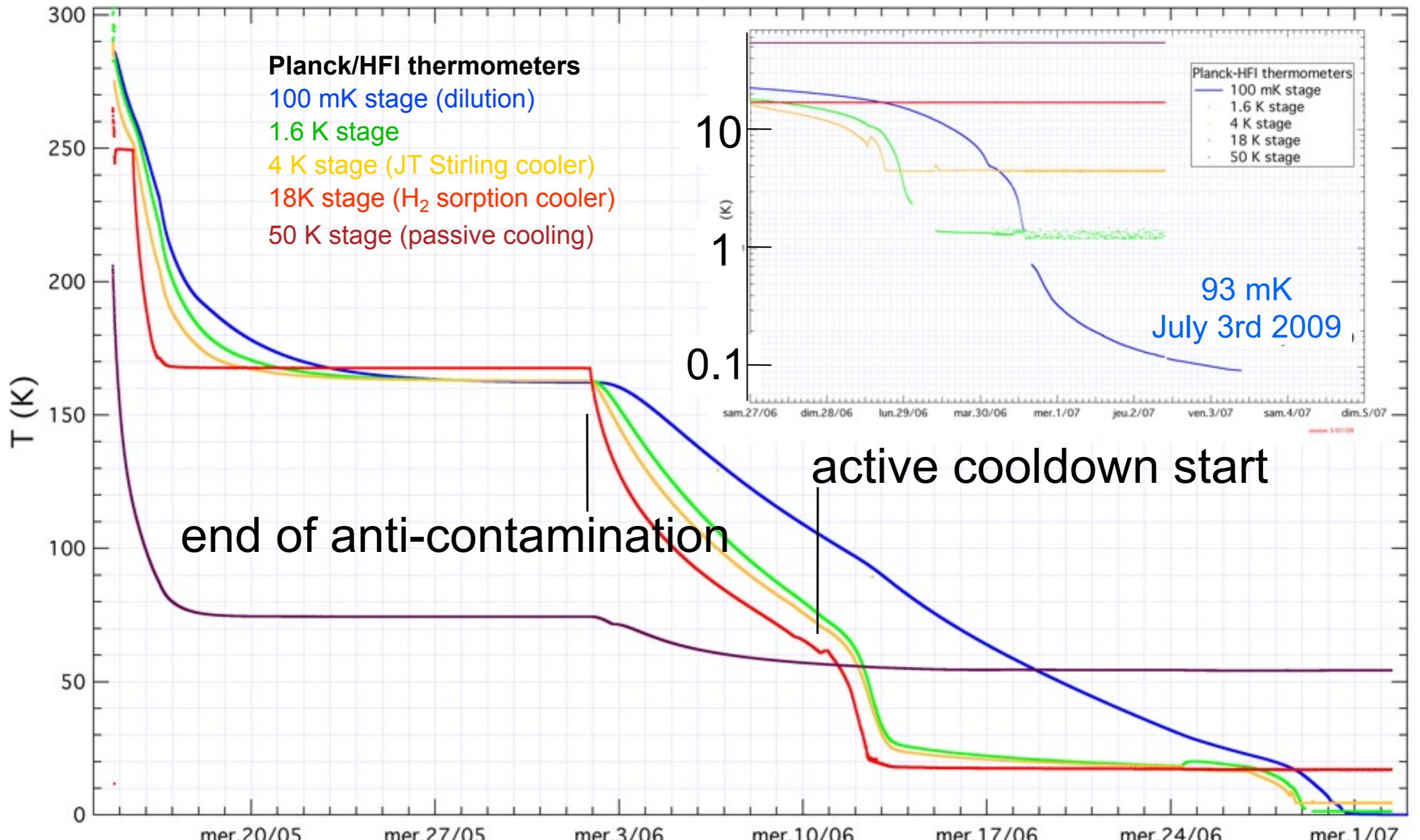
Planck and Herschel launch



Injection and L2 orbit maintenance



Planck cooldown



Planck operations

- ◆ 2 Juillet 2009 : Injection sur l'orbite L2
- ◆ Juillet-Aout 2009 : Calibration and Performance Verification
- ◆ 6 aout 2009 : problème de l'étage 4K
 - ◆ perte de la chaîne cryogénique
 - ◆ re-descente en froid en 6 jours
- ◆ Opérations sur le satellite
 - ◆ modification mineure du pointage, du contrôle thermique
 - ◆ envoi de la stratégie de balayage complète
- ◆ 13 aout - 27 aout 2009 : First light survey
- ◆ 13 aout 2009 - 13 février 2010 : First all-sky survey
- ◆ 13 février - 13 aout 2010 : Second all-sky survey
- ◆ 13 aout 2010 - aujourd'hui : Third all-sky survey

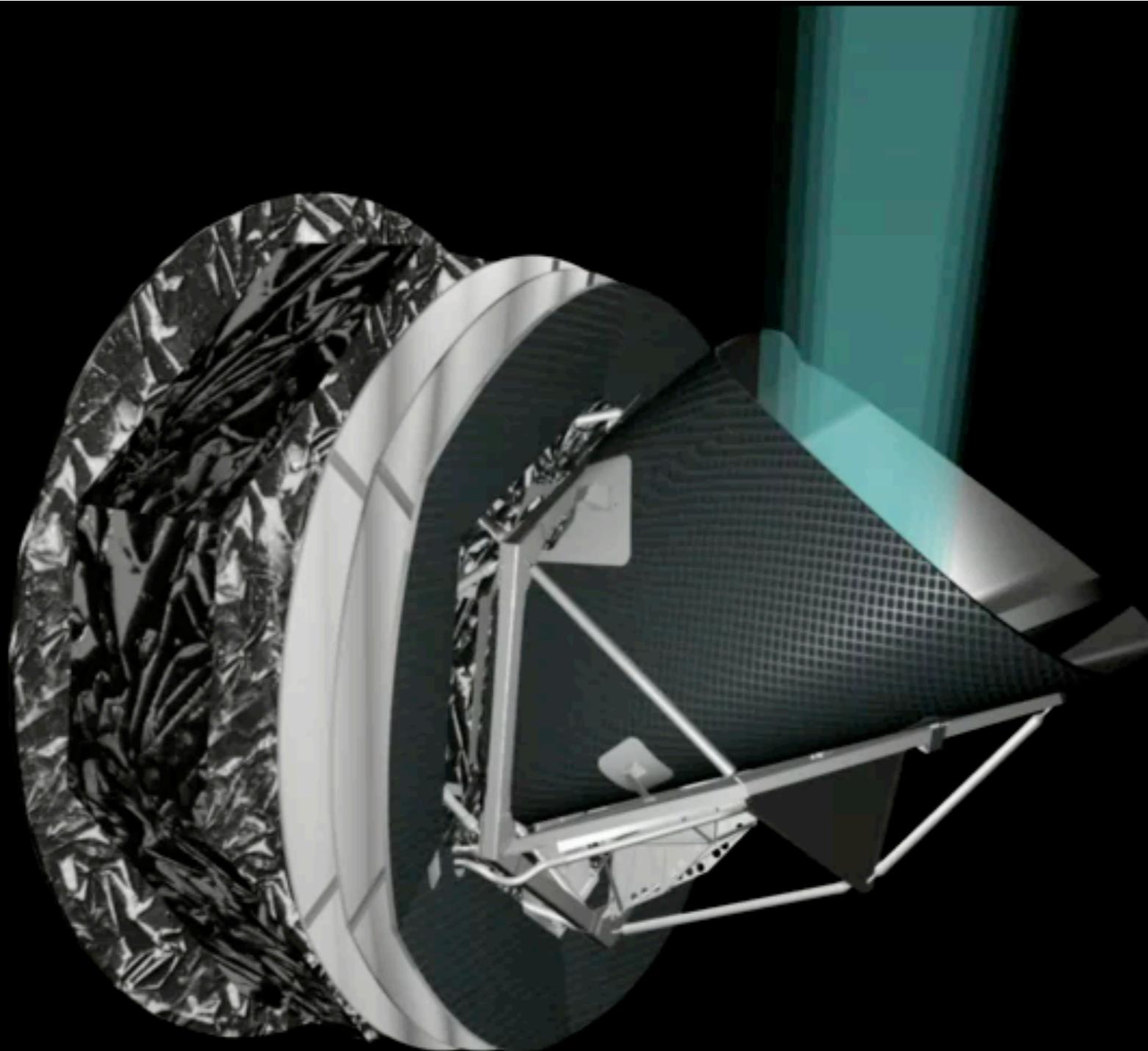
Planck/HFI status



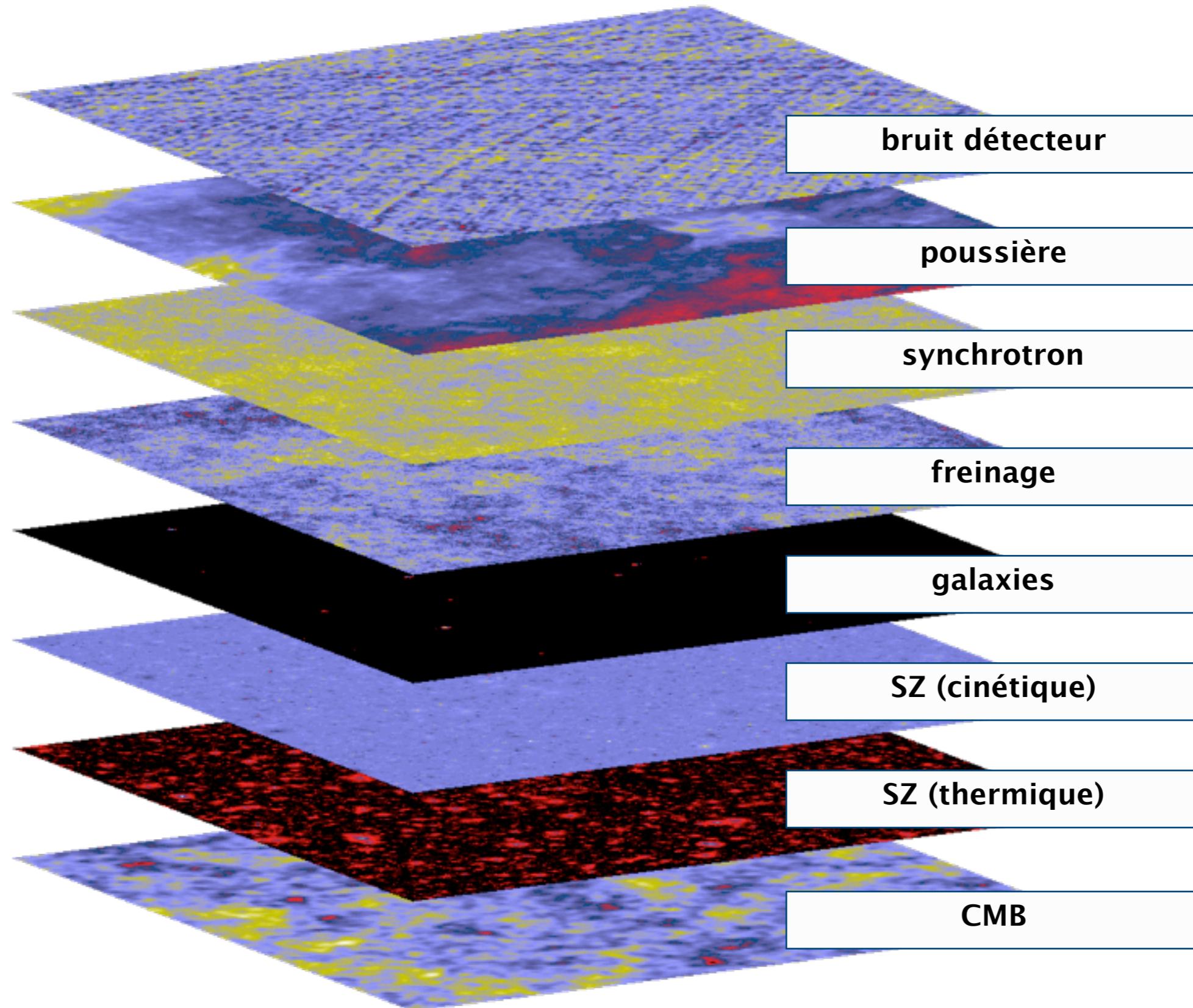
- ◆ 4 étages de refroidissement régulés aux températures nominale :
 - ◆ étage 18 K à 17.5 K
 - ◆ étage 4 K à 4.72 K
 - ◆ étage 1.6 K à 1.38 K
 - ◆ dilution à 101 mK, obtenu à partir du plus bas débit He3/He4 possible
⇒ **30 mois d'observations**
- ◆ DéTECTEURS à 103 mK
 - ◆ comportement identique à celui observé durant les tests au sol
- ◆ Pointage
 - ◆ erreur moyenne : 6"
 - ◆ residual nutation : 3"
- ◆ Niveau de Bruit
 - ◆ conforme aux mesures au sol

[*Planck pre-launch status of the Planck mission, 2010, special issue A&A 520*]

Planck scanning strategy

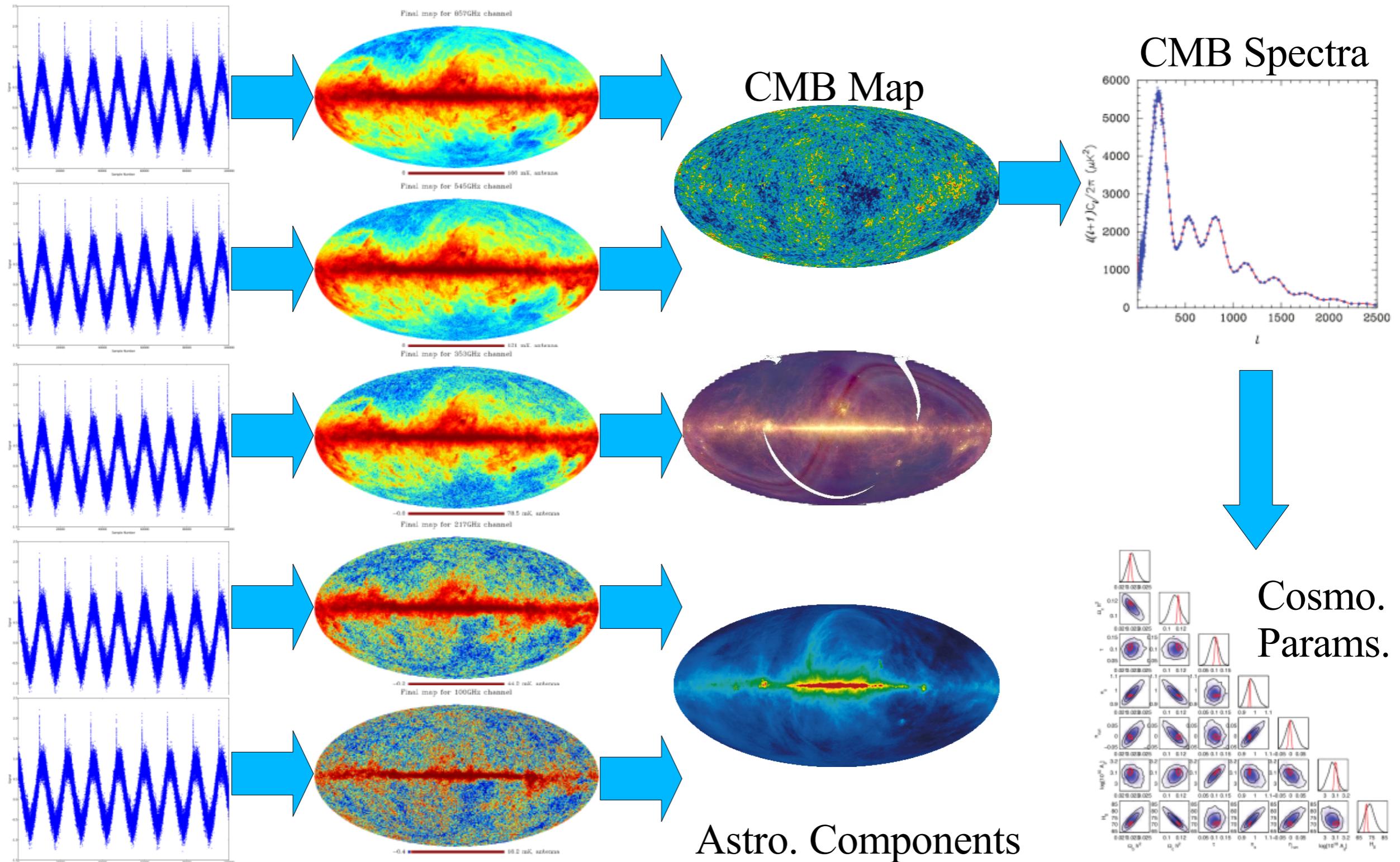


observations du CMB

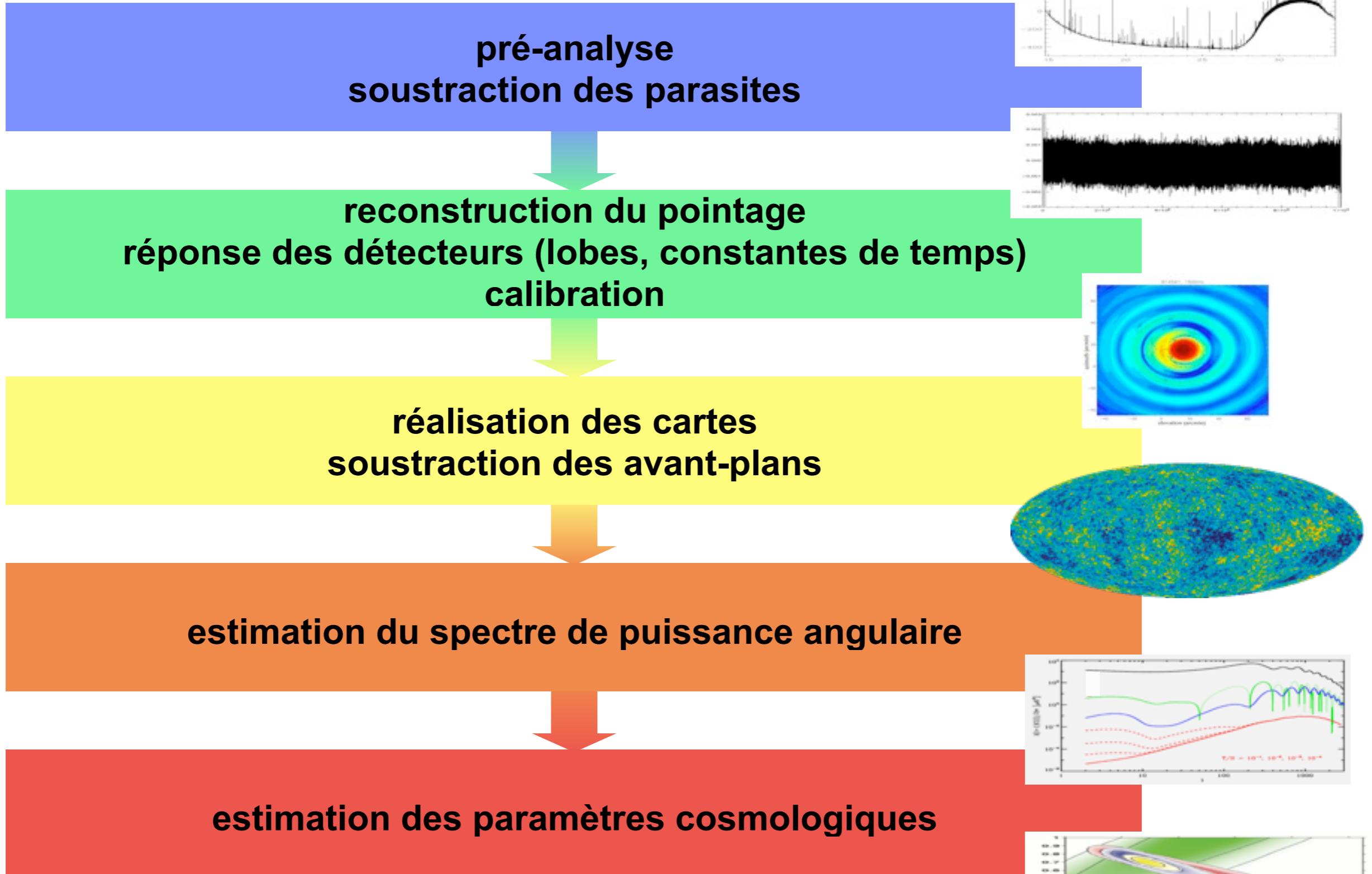


F.R. BOUCHET & R. GISPERT 1996

traitement de données CMB



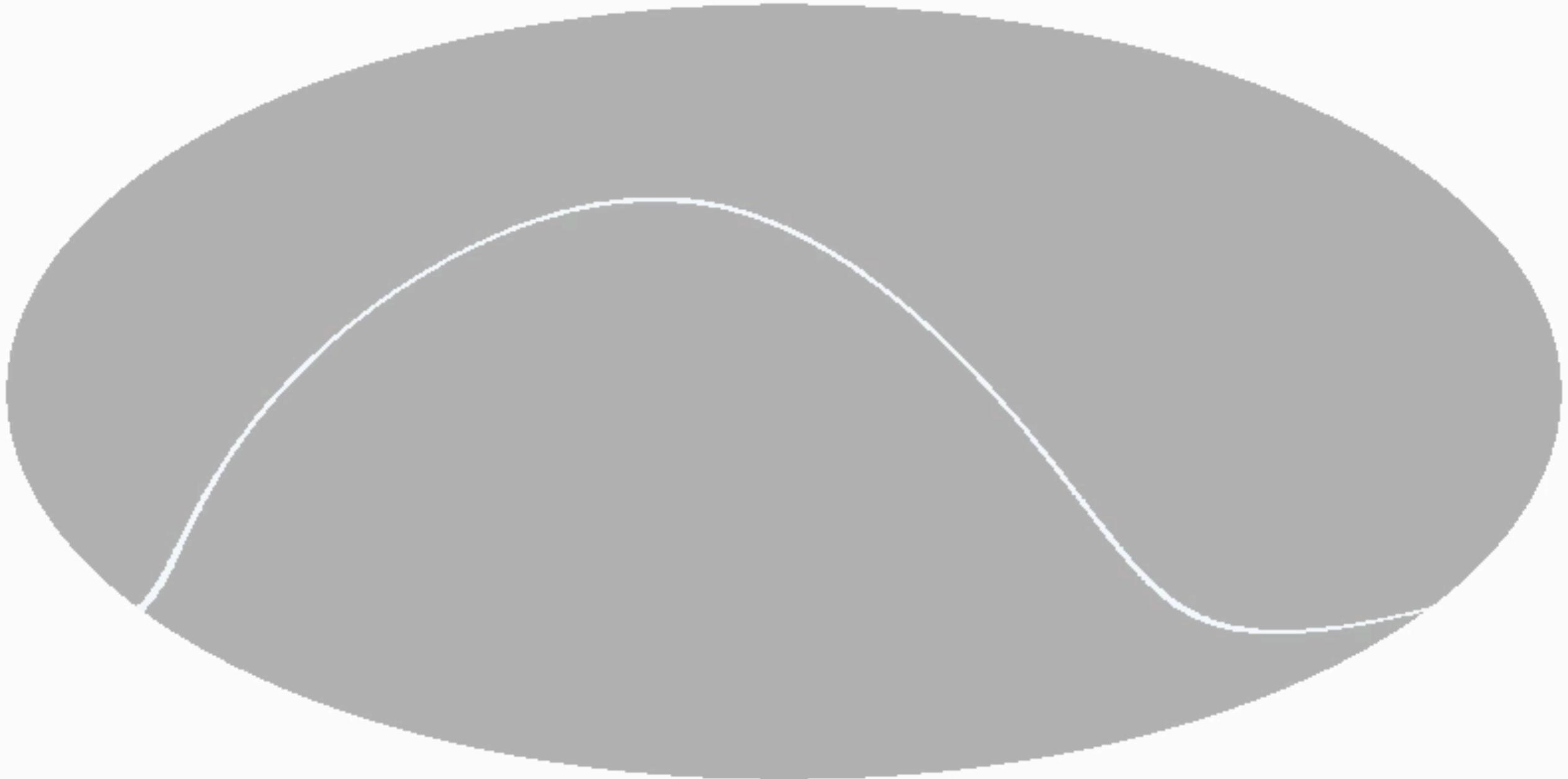
Analyse des données



Sky coverage

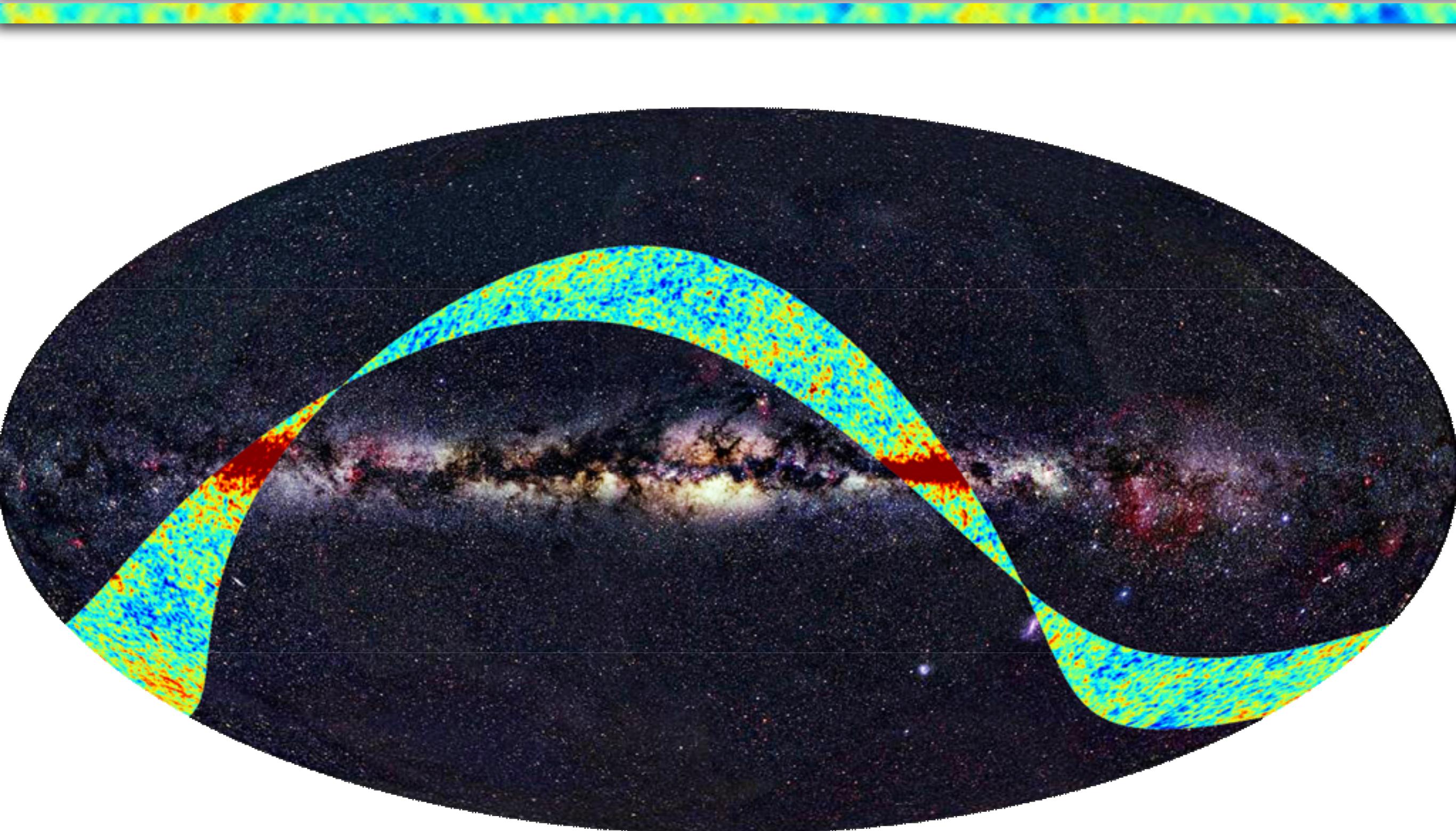
Planck scanning (Survey 1)

2009-08-21

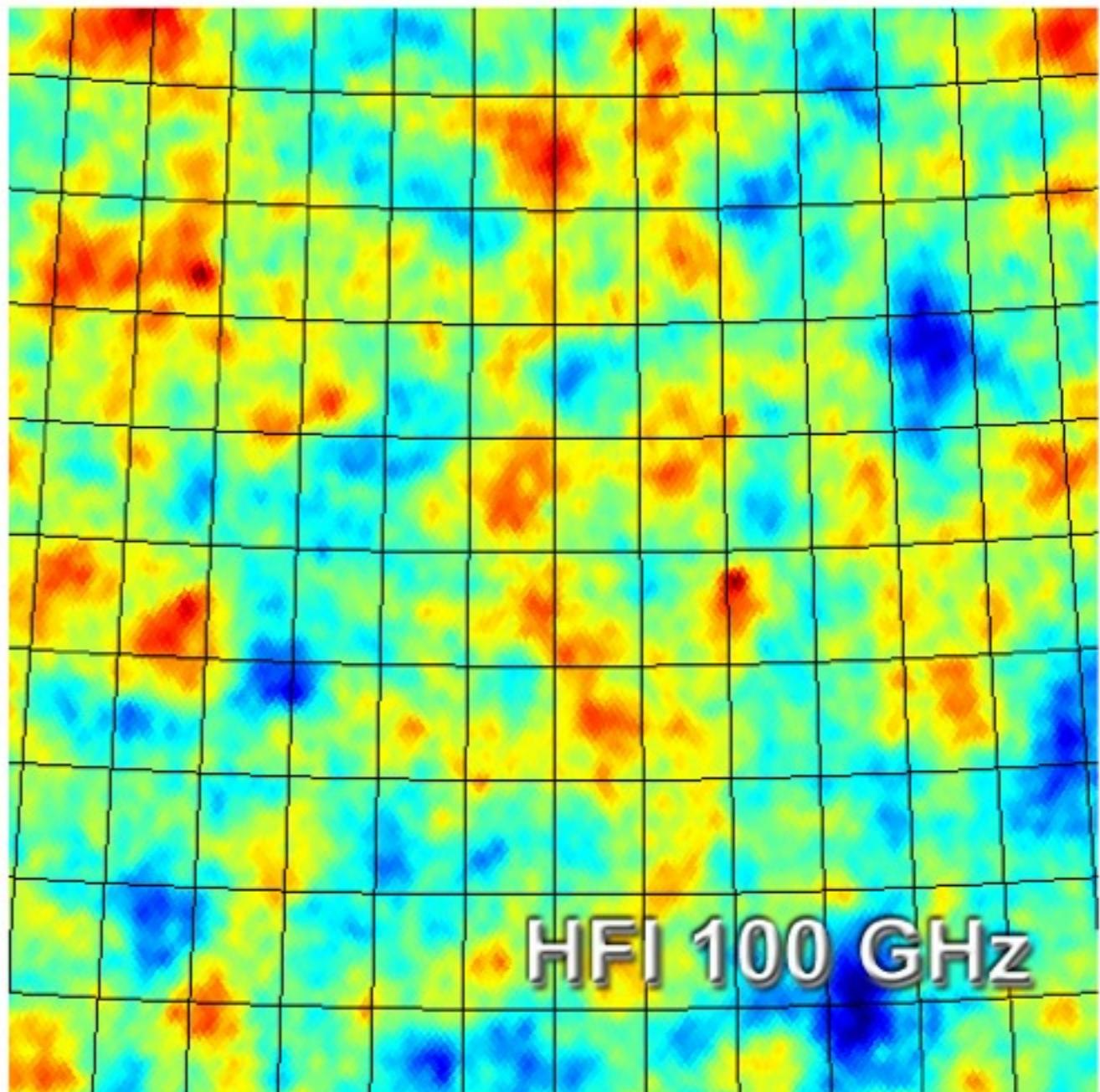
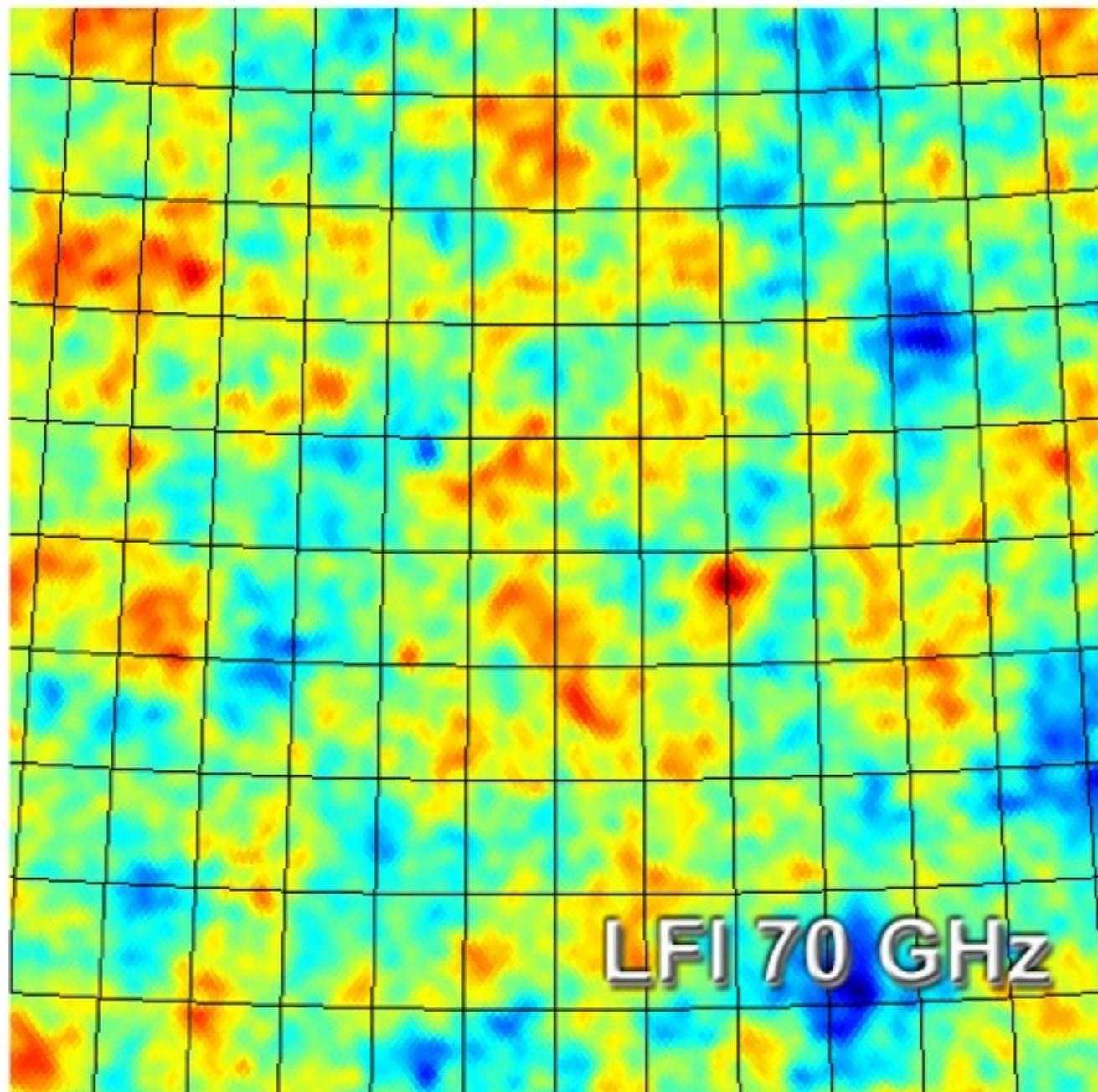


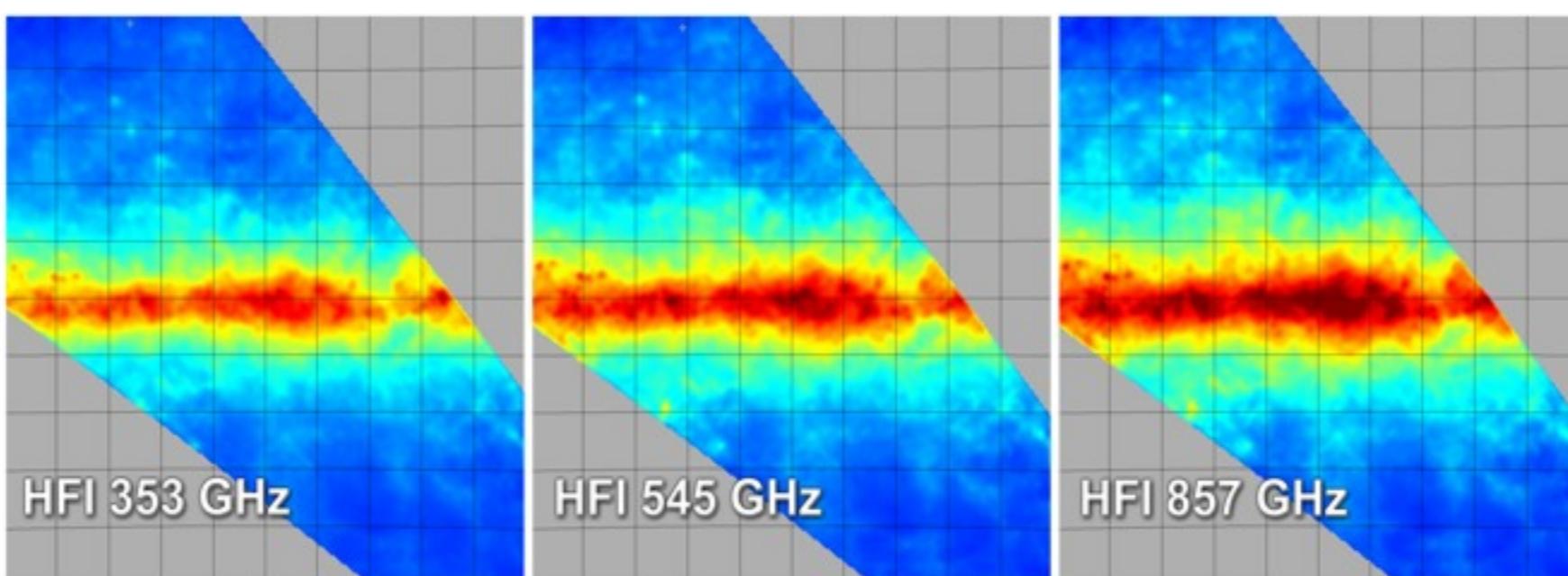
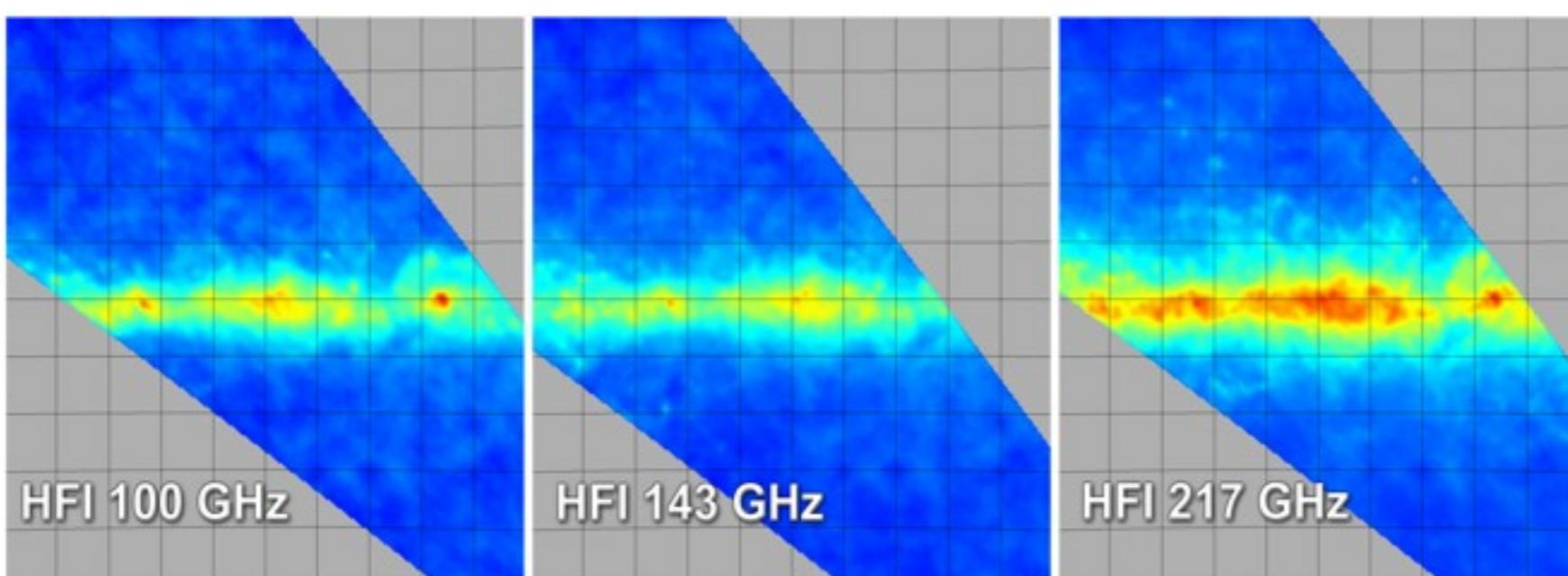
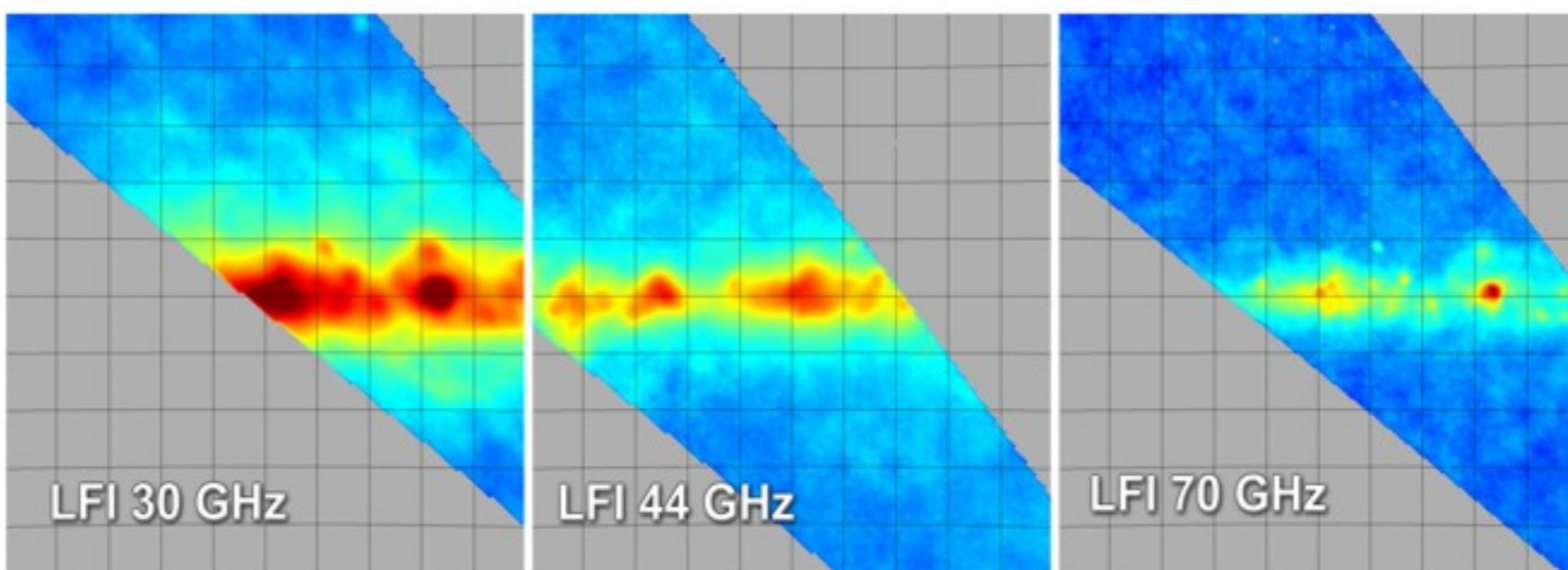
Background Image credit: NASA/WMAP; Animation credit: Chris North

Planck First Light Survey

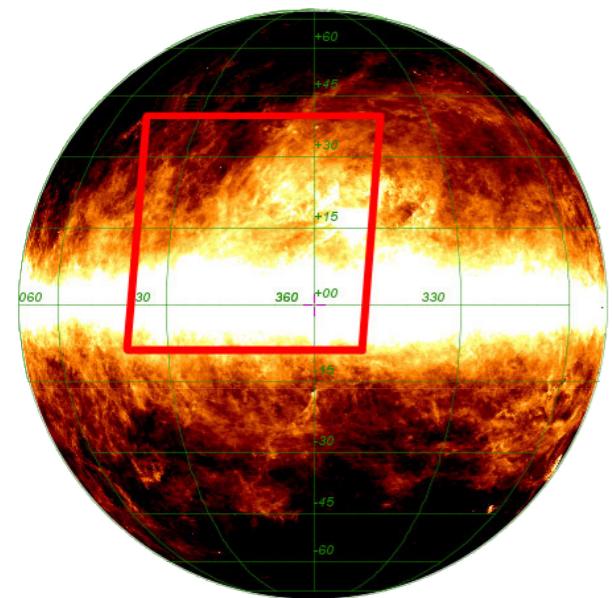
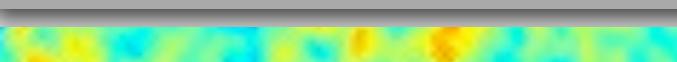


The "first light survey"



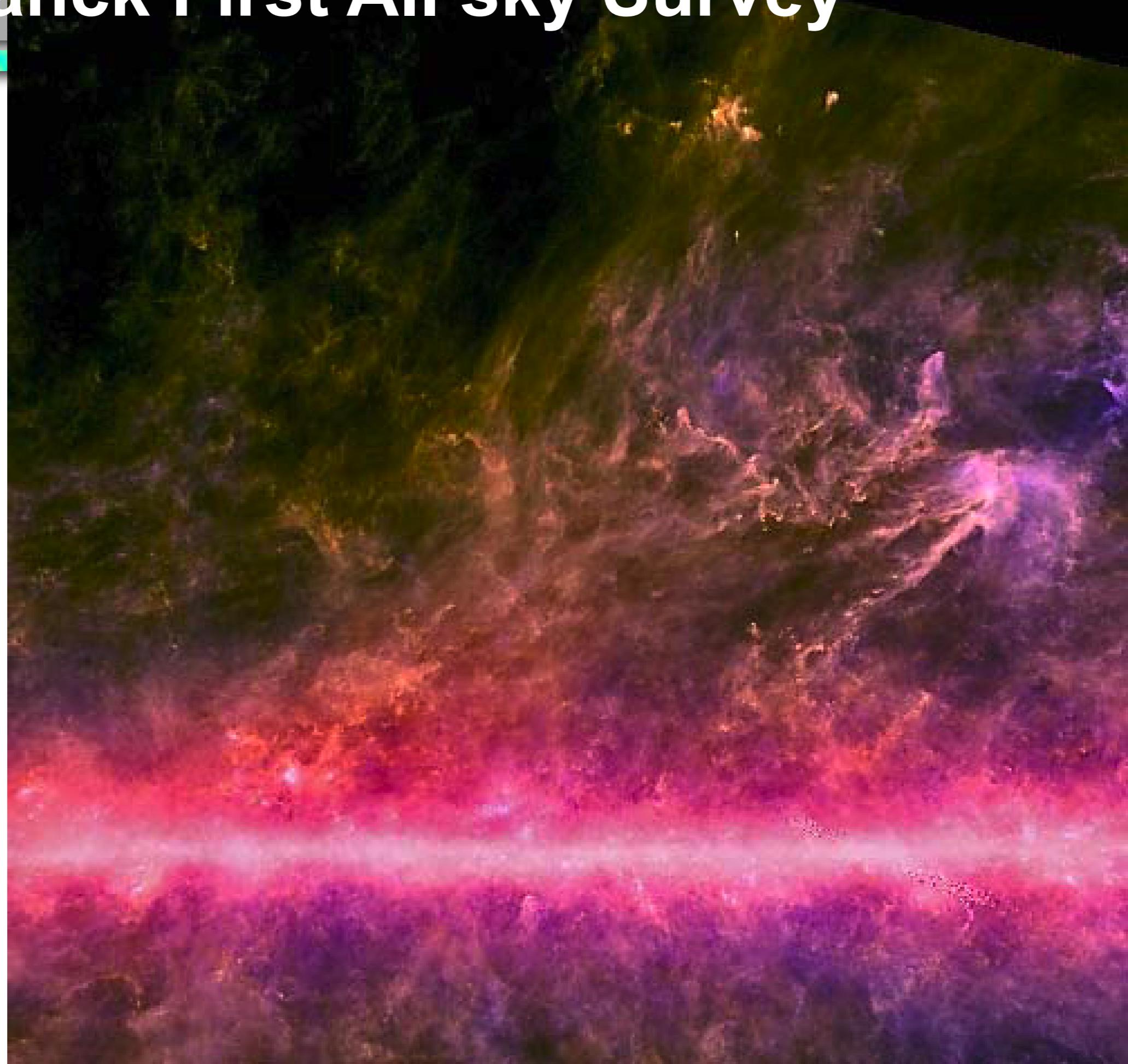


Planck First All sky Survey



HFI 545 GHz
HFI 857 GHz

IRAS 100 μ m

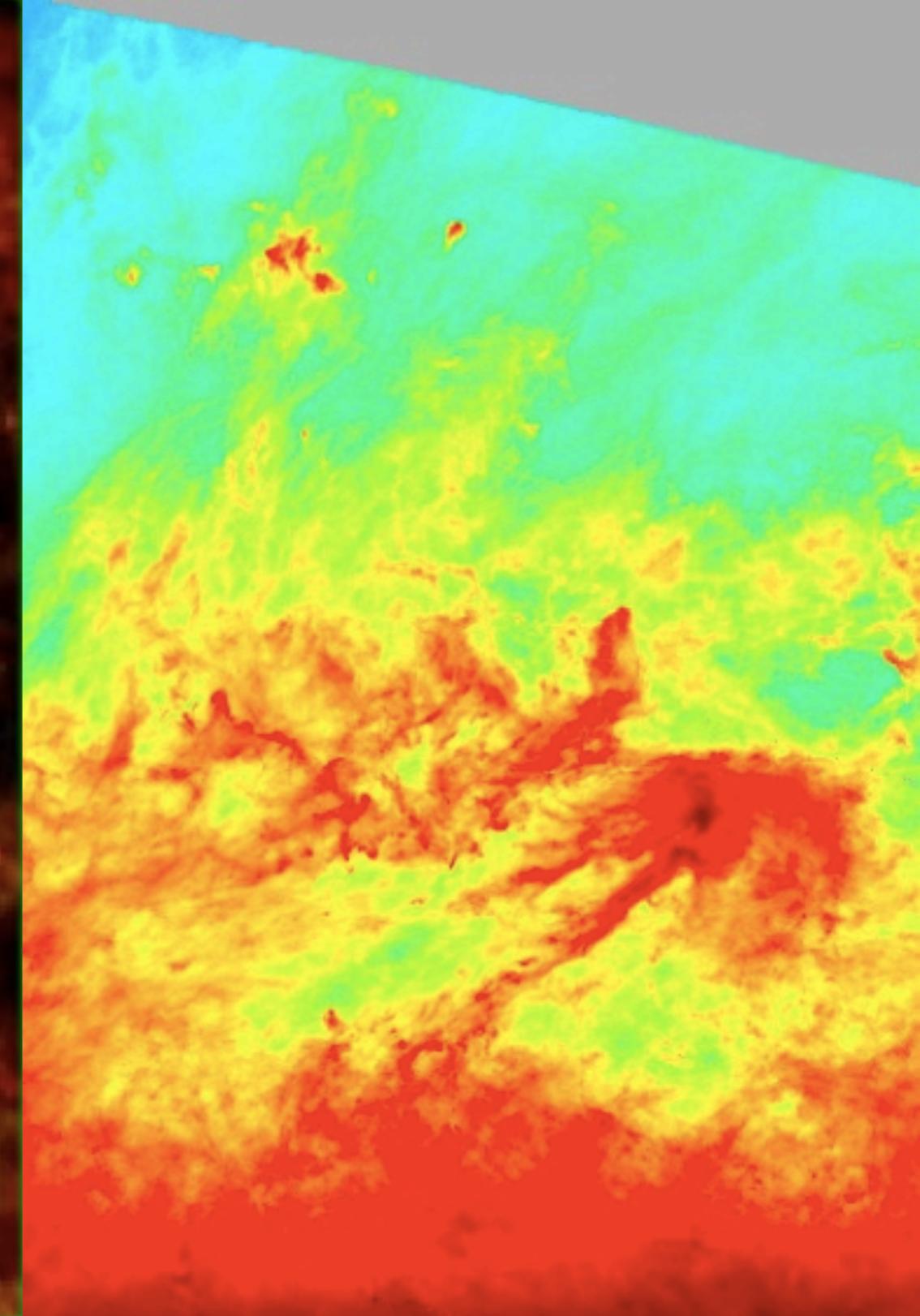




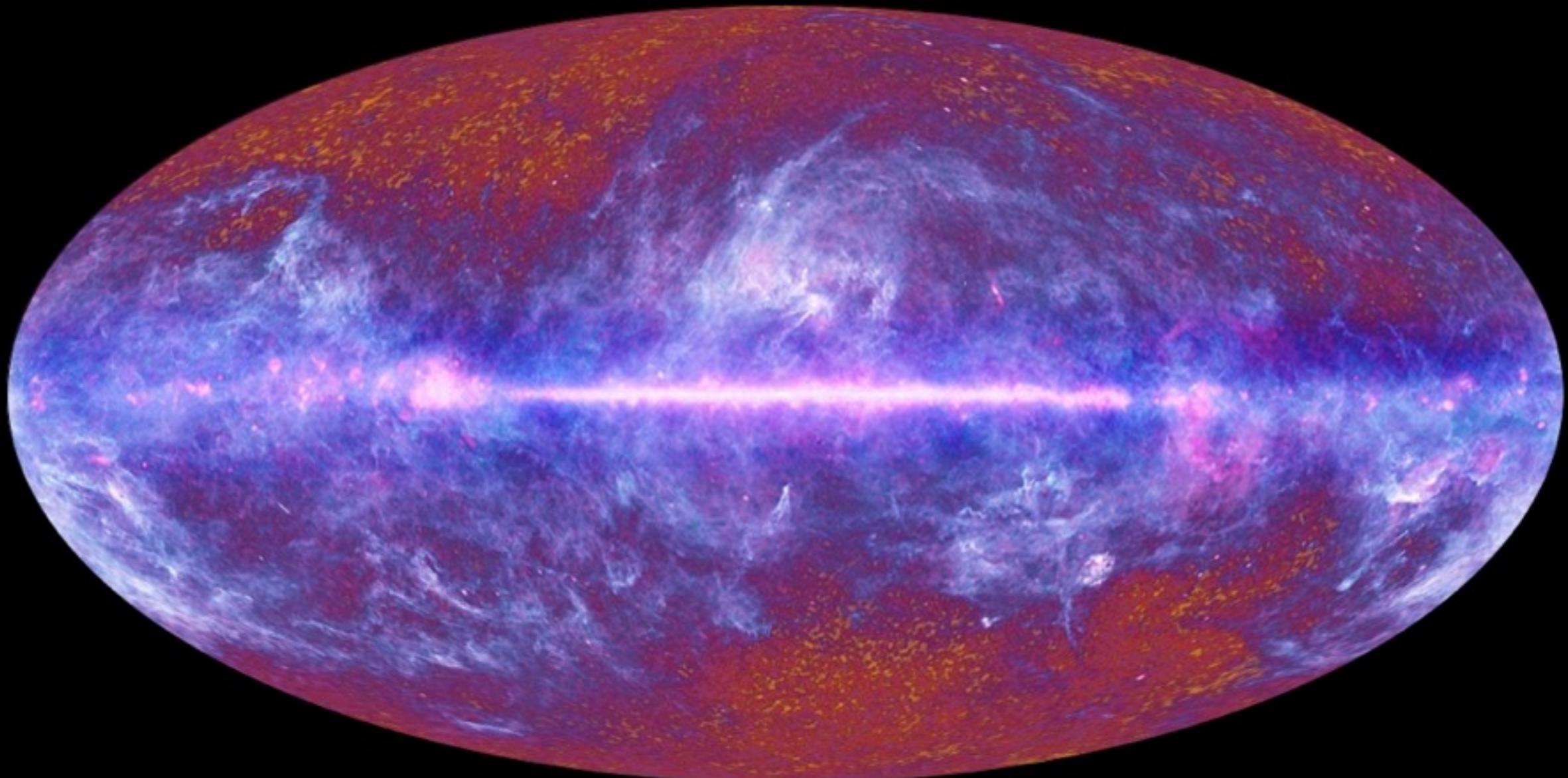
Herschel

Planck
HFI 857 GHz

M. Tristram



Planck First All sky Survey

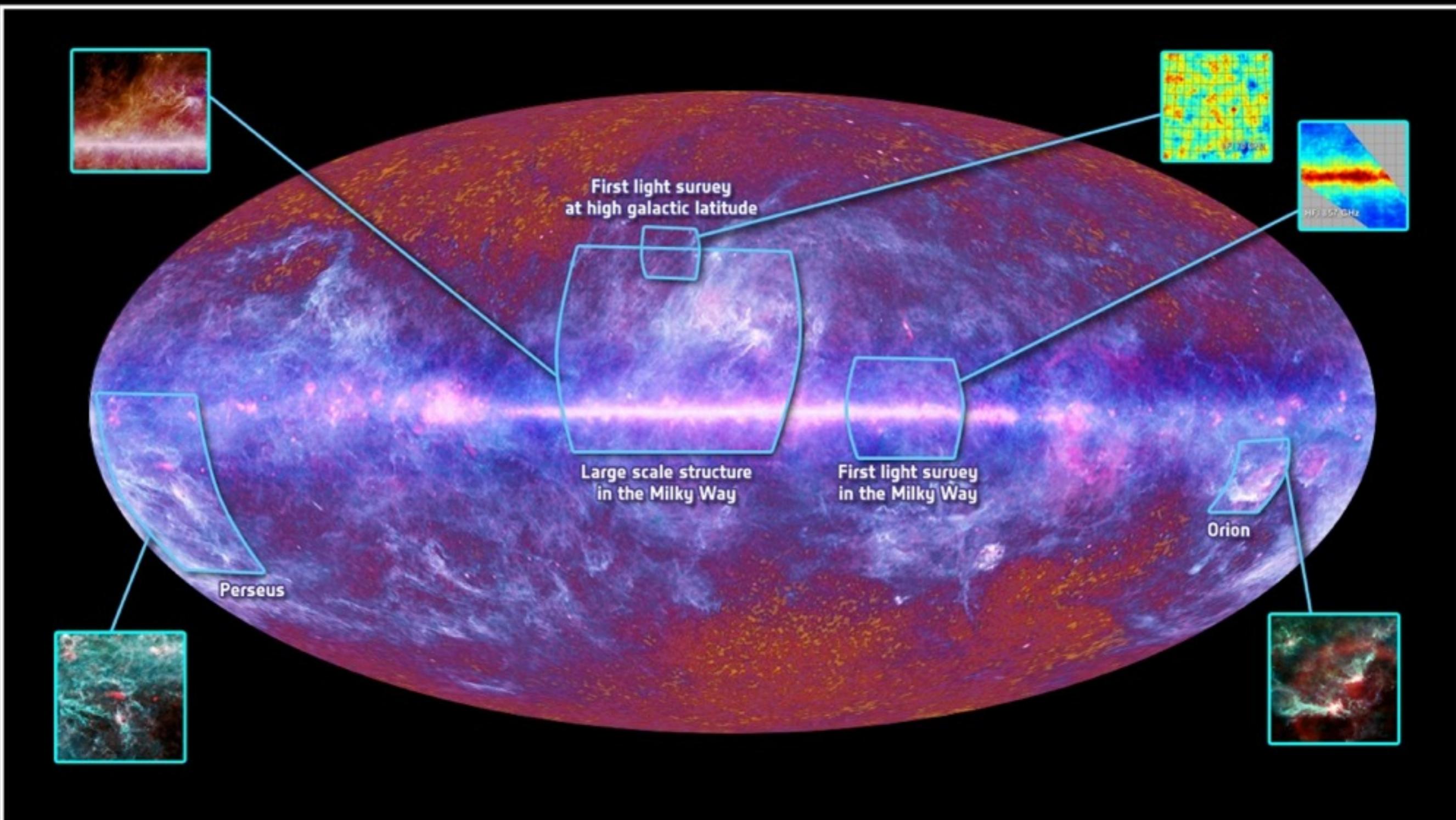


The Planck one-year all-sky survey



(c) ESA, HFI and LFI consortia, July 2010

Planck First All sky Survey

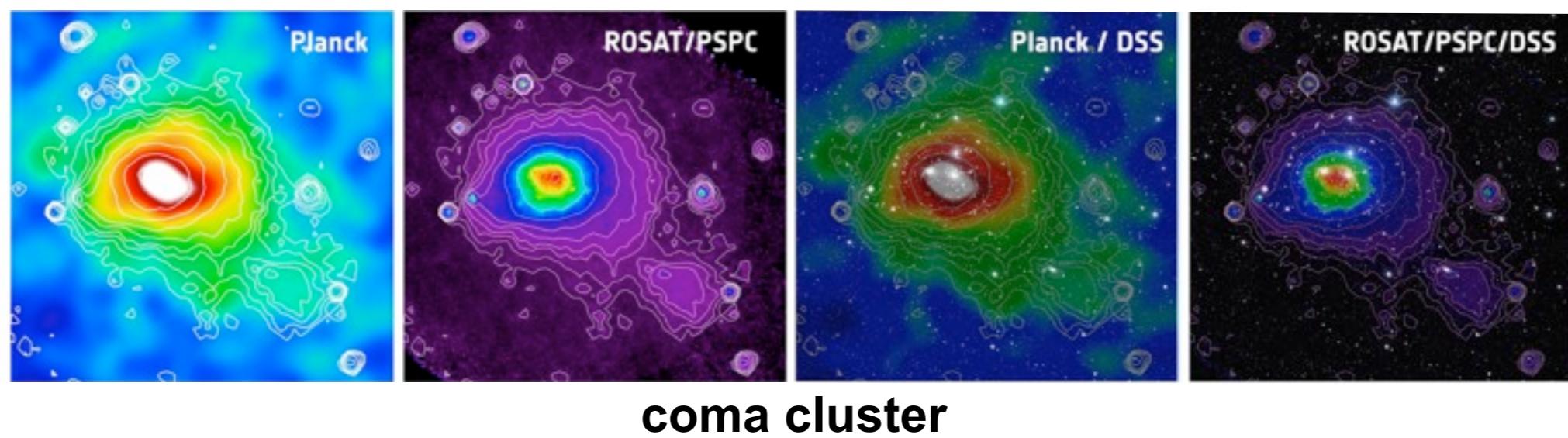
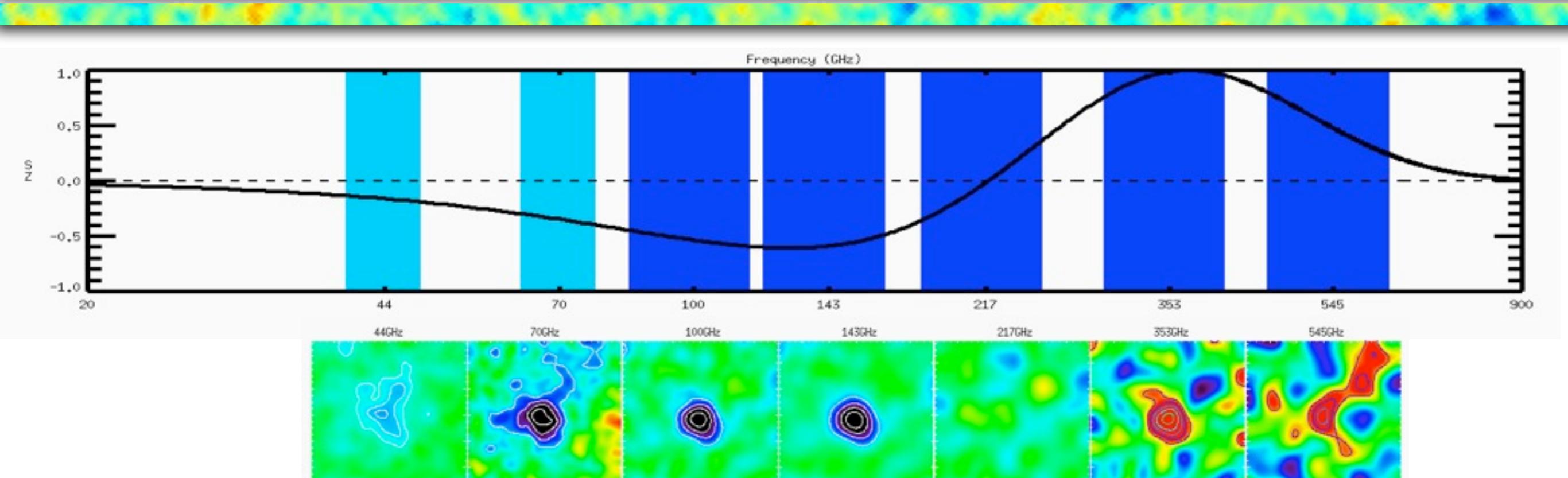


The Planck one-year all-sky survey



(c) ESA, HFI and LFI consortia, July 2010

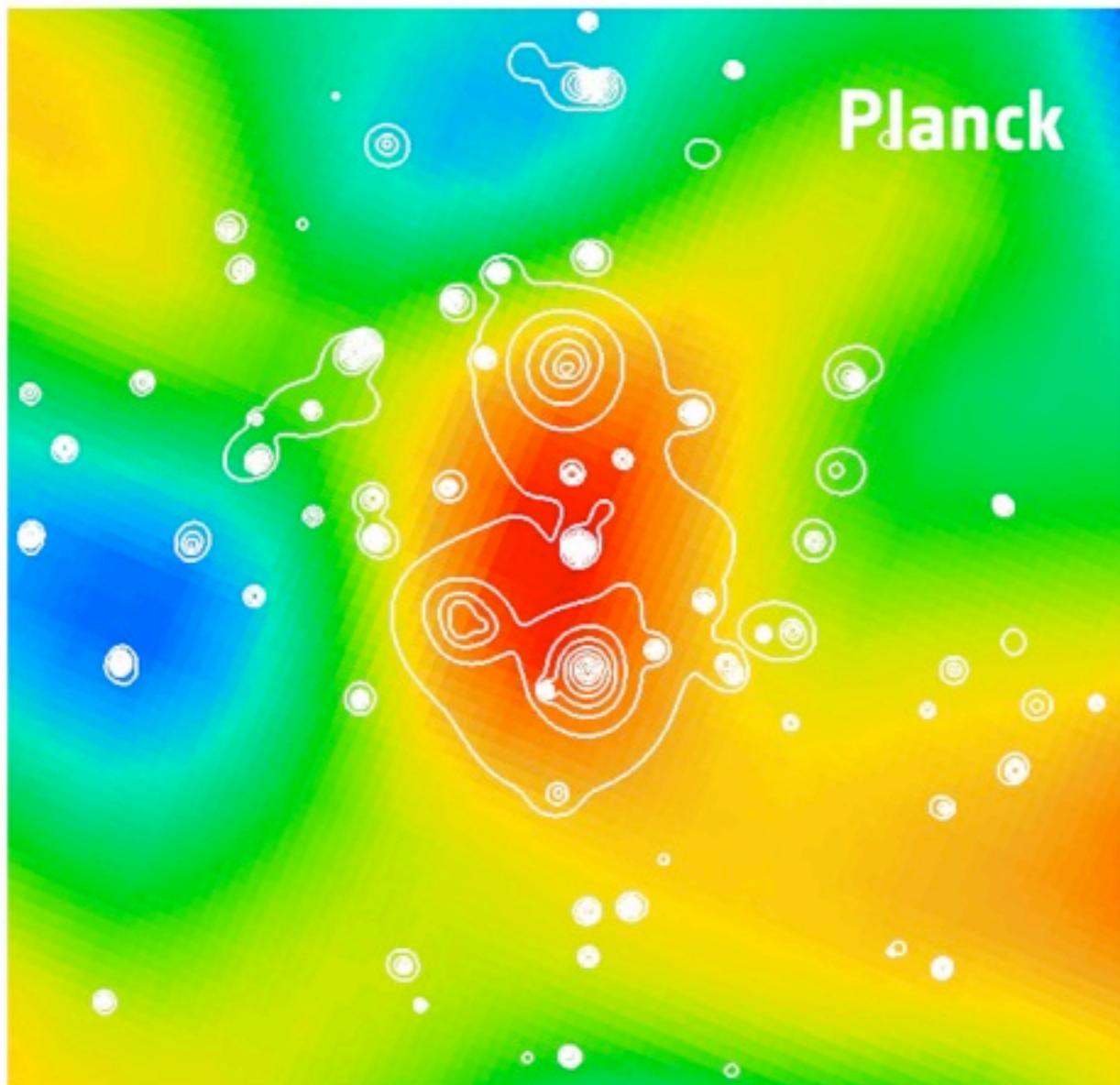
Effet Sunyaev-Zel'dovich



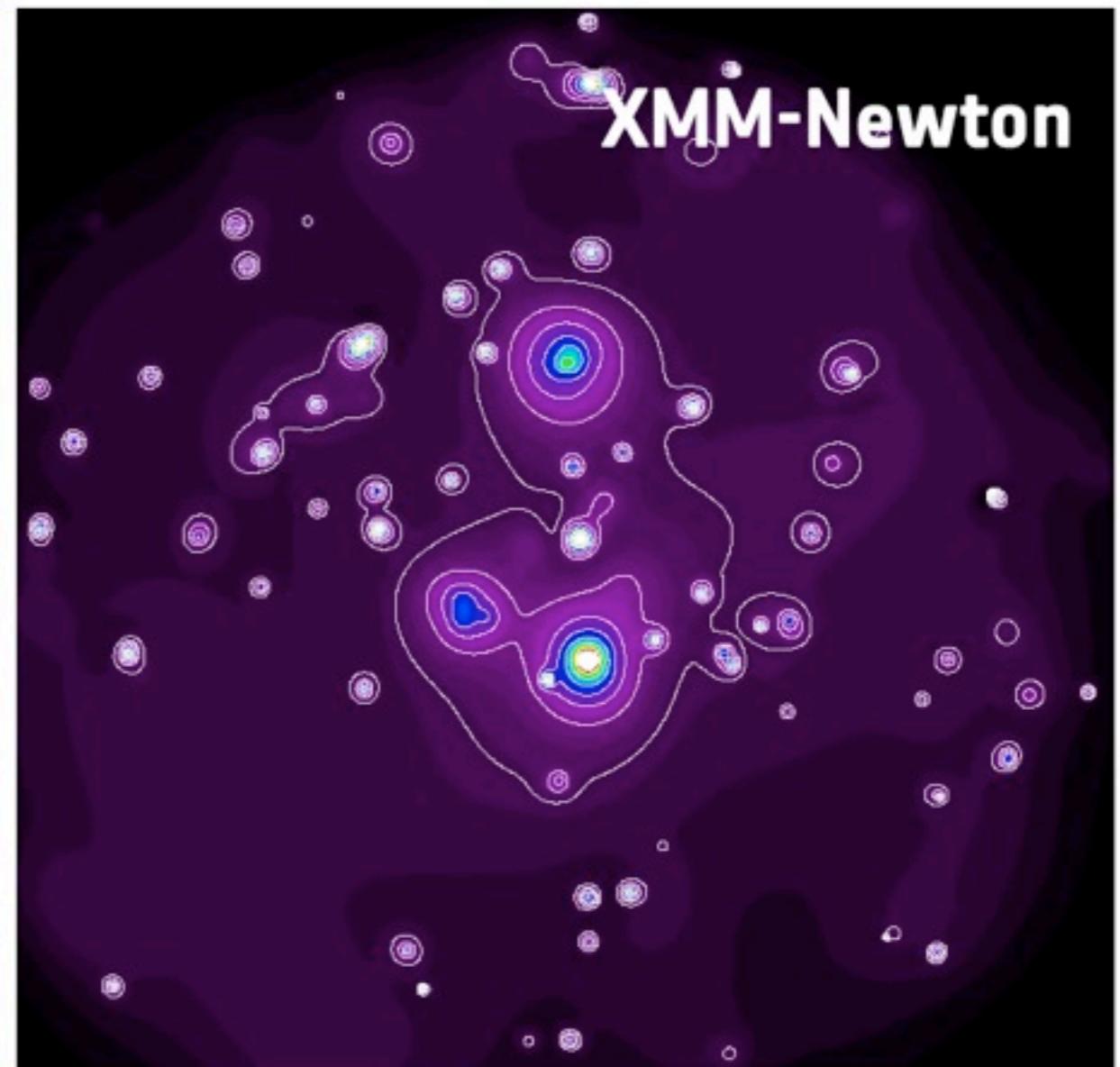
première détection d'amas !

*Un superamas de galaxies découvert par Planck :
le premier révélé par son empreinte sur le rayonnement fossile*

www.planck.fr



détection PLANCK

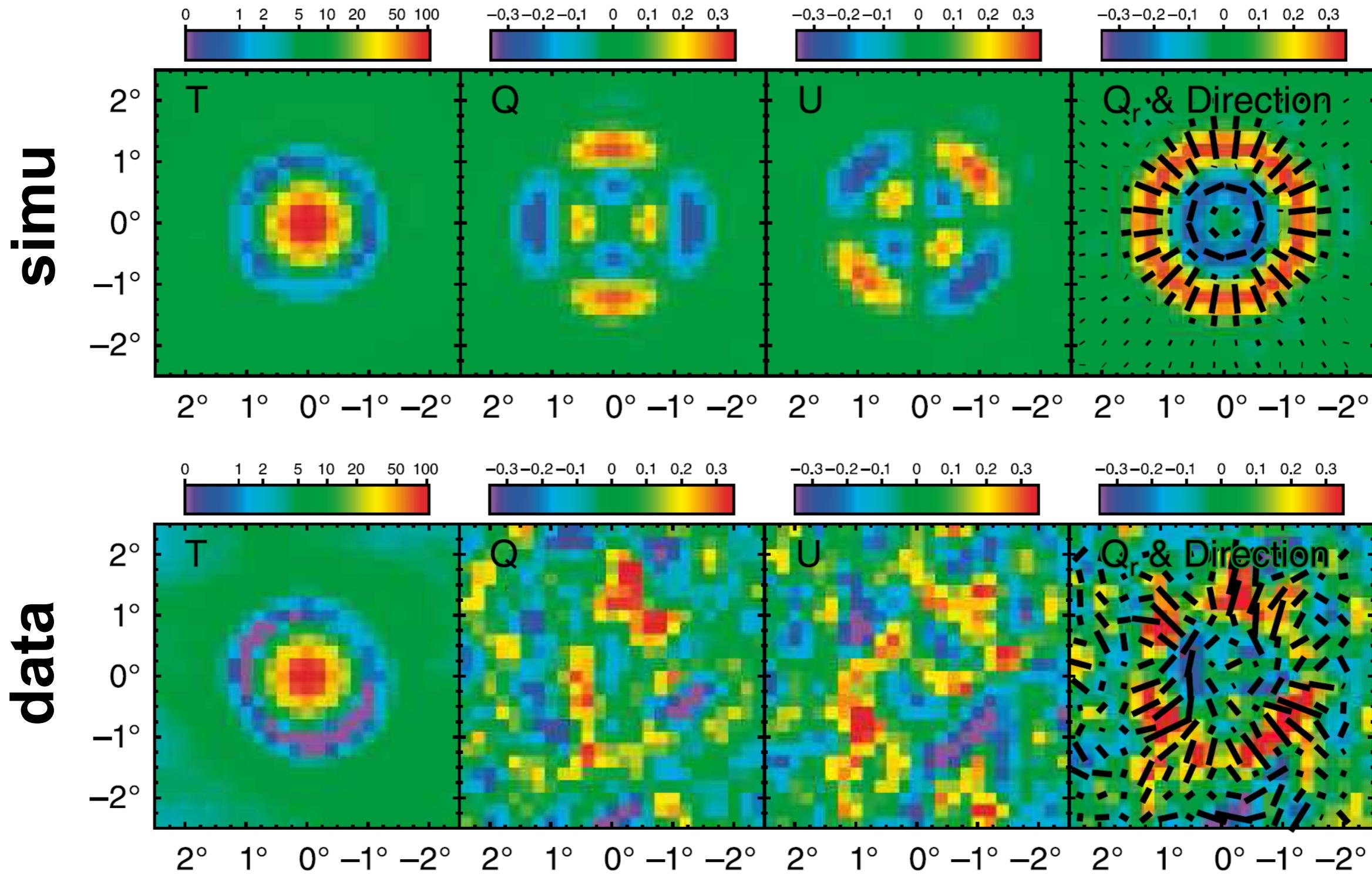


confirmation en X

anisotropies du CMB

WMAP

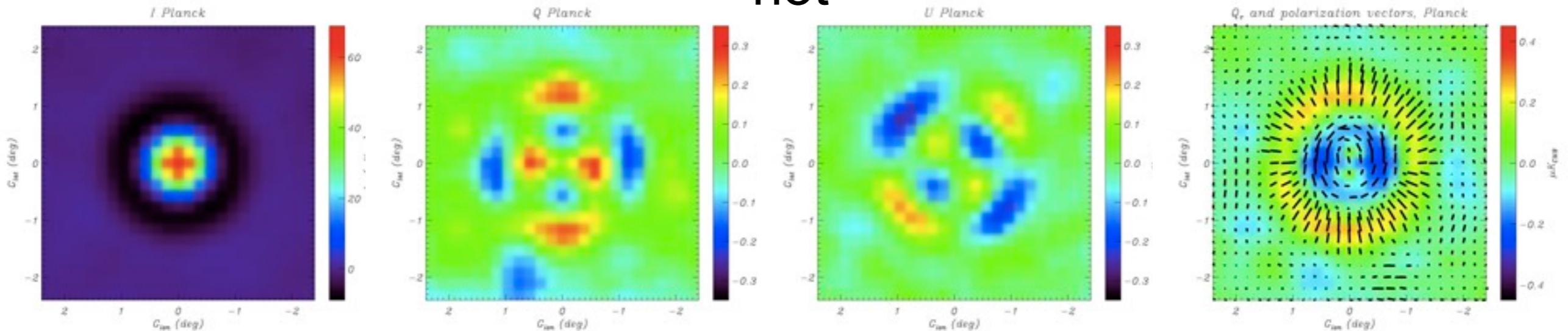
[Komatsu et al. 2010]



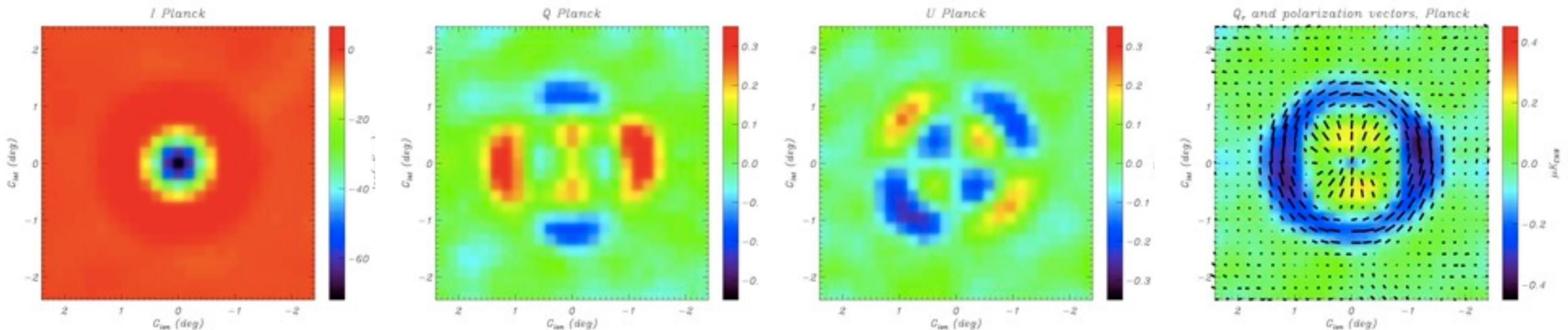
anisotropies du CMB

PLANCK

hot



cold



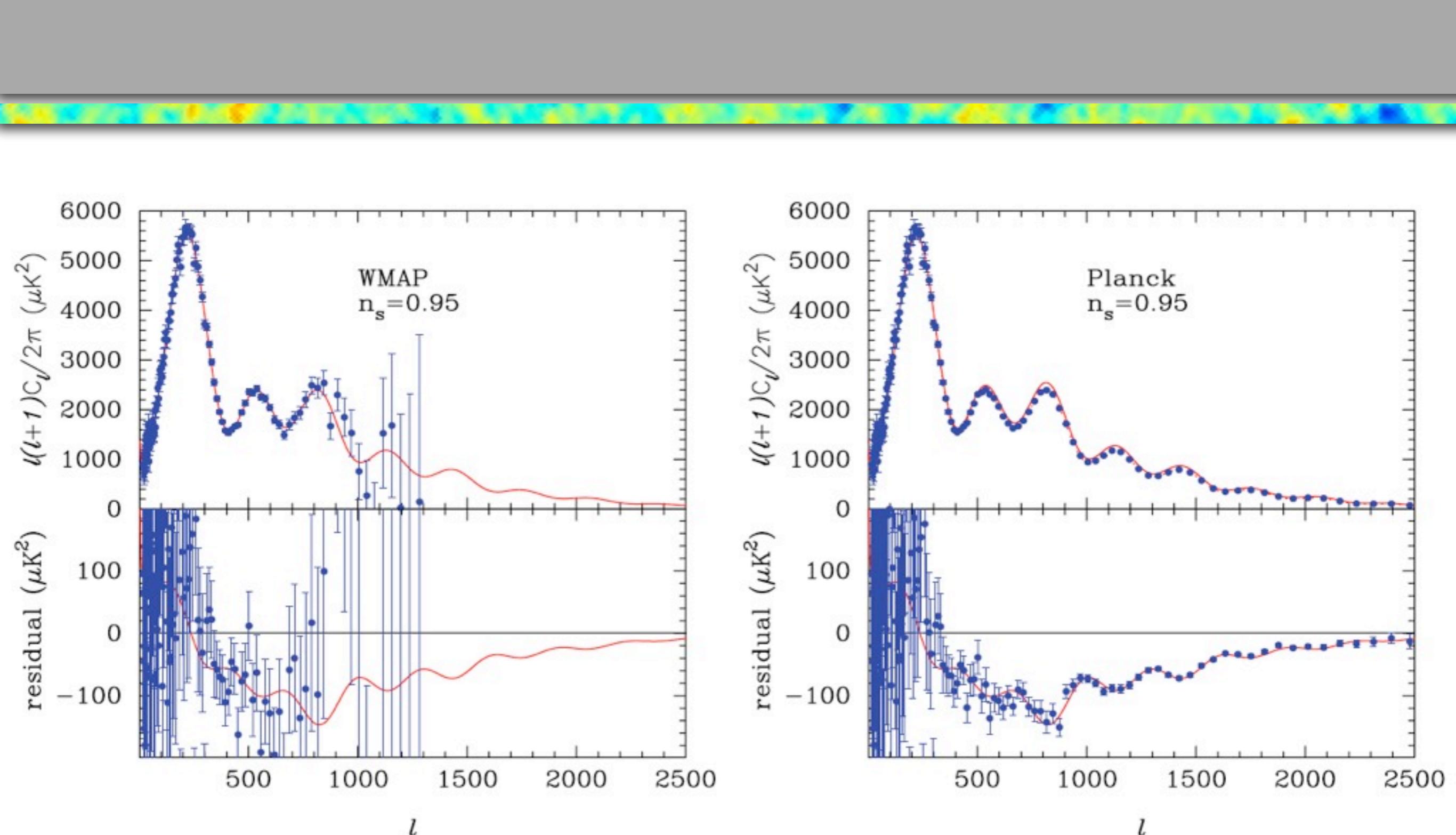


FIG 2.11.—The solid lines in the upper panels of these figures show the power spectrum of the concordance Λ CDM model with an exactly scale invariant power spectrum, $n_S = 1$. The points, on the other hand, have been generated from a model with $n_S = 0.95$ but otherwise identical parameters. The lower panels show the residuals between the points and the $n_S = 1$ model, and the solid lines show the theoretical expectation for these residuals. The left and right plots show simulations for WMAP and Planck, respectively.

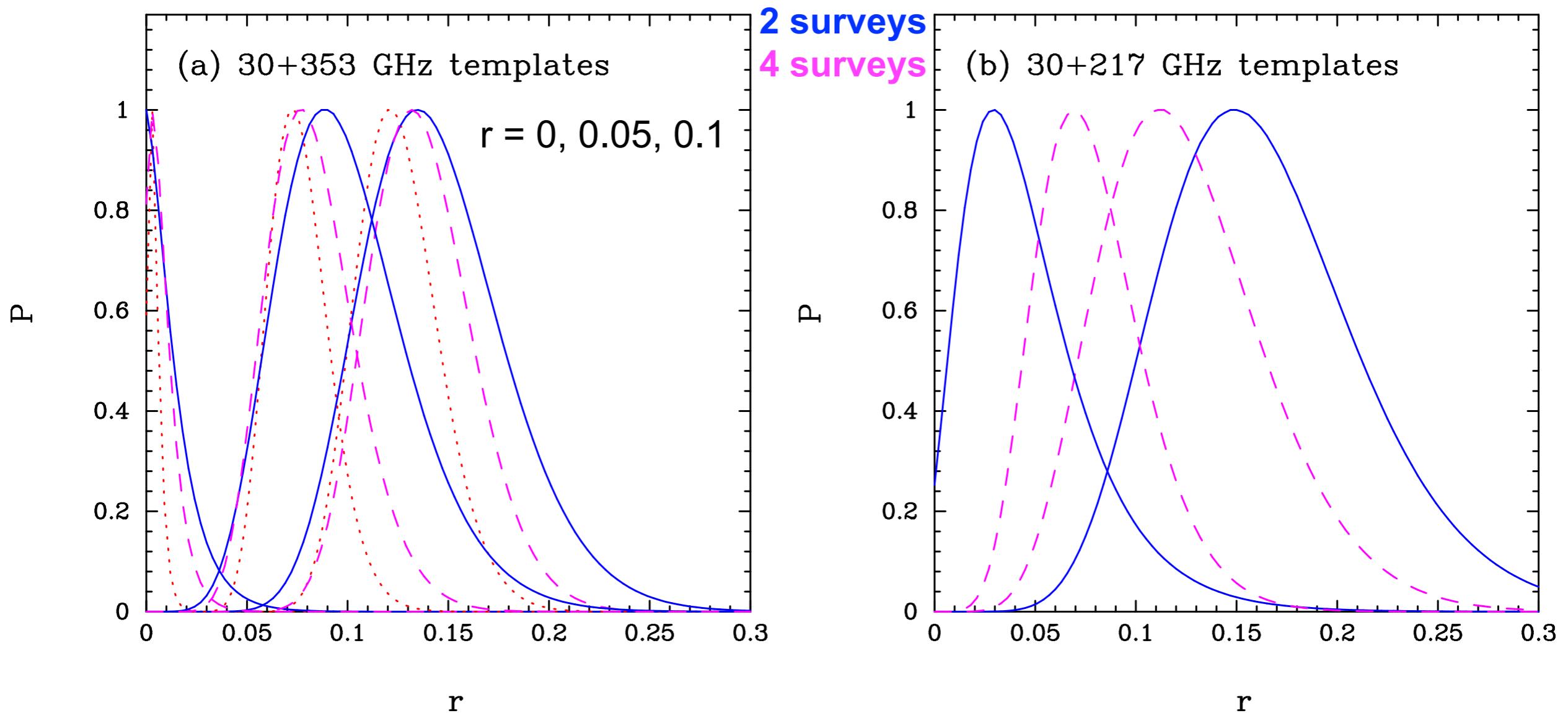
Primordial B-mode detection



- ◆ Efstathiou, Gratton (JCAP 2009)
 - ◆ using Planck Sky Model (full sky simulation)
 - ◆ nominal sensitivity and extended mission (**4 sky surveys vs 2**)
 - ◆ takes simple inflation model predictions
 $r = 0, 0.05, 0.1$ (energy scale $1.4 \cdot 10^{16}$ GeV for $r = 0.05$ with $ns=0.96$)
- ◆ can we detect the predicted B modes ?
after simple component separation assuming no systematic effects

Primordial B-mode detection

- ◆ Planck can detect tensor to scalar ratio down to 0.05
(present best direct upper limit is 0.3 one sigma, Bicep Chiang et al 2009)



[Efstathiou & Gratton 2009 JCAP]

Planck observations relevant for dark energy



- ◆ Determination of Ω_Λ with CMB alone is degenerate with Ω_K (geometrical degeneracy)
- ◆ Degeneracy removed by combination with other data like Hubble constant, LSS,...
- ◆ Equation of state constraints depends on effects at low redshifts (secondary CMB anisotropies)
 - ◆ Correlation with LSS measurements for ISW and lensing
 - ◆ Combination with BAO
 - ◆ SZ in clusters

Planck in combination with other data sets

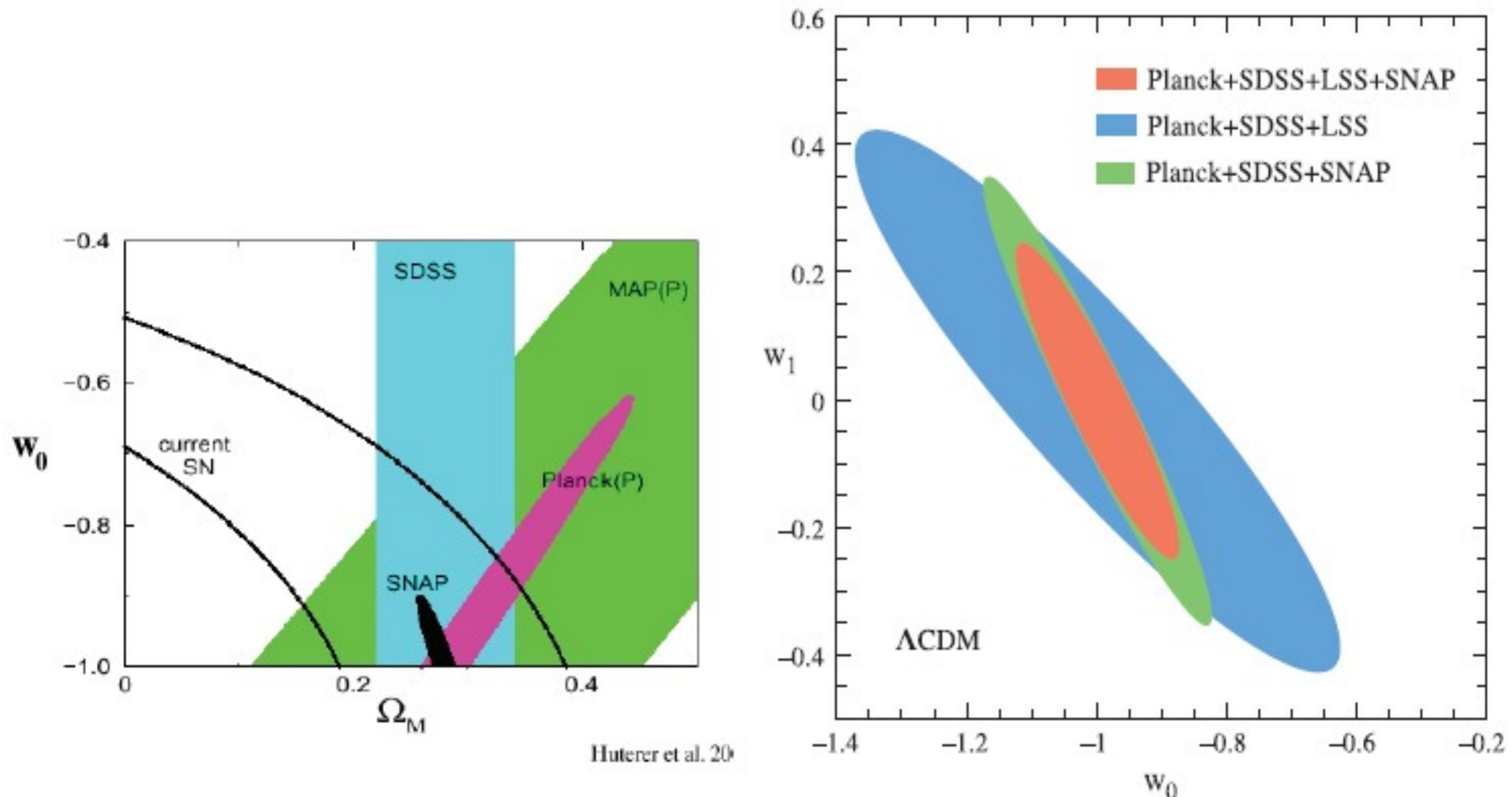


FIG 2.22.—The left panel (from Huterer & Turner 2001) shows forecasts of constraints on the dark energy equation of state parameter w and Ω_m for various experiments including *Planck*. The right panel (from Seo & Eisenstein 2003) shows forecasts of constraints on the time evolution of w , parameterised through $w \equiv w_0 + w_1 z$, for *Planck* combined with various redshift surveys and SNe observations from SNAP (see text for details).

What is coming next ?



- **Start observations** 13 aug 2009
- **Planck Early Papers on foregrounds** start 2010
2 surveys
- **public release** January 2011
Early Release Compact Sources Catalogue (ERCSC)
Publication of Planck early papers
- **Nominal mission (2 surveys) internal release** January 2011
- **Planck 2011 conference (Paris)** January 2011
"The millimeter and submillimeter sky in the Planck mission era"
- **End of PLANCK (at least HFI)** february 2012
- **Nominal mission public release** end-2012
- **Operations extention to december 2011 approved by ESA**
4 all sky surveys



FIN