

Astrophysique et Besoins en refroidissement des instruments submillimétriques

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Enjeux astrophysiques

- Comment s'est formé l'univers?
- Comment se forment les galaxies?
- Comment se forment les étoiles?
- Connection Diffus-Ponctuel
- Pourquoi le (sub)millimétrique?



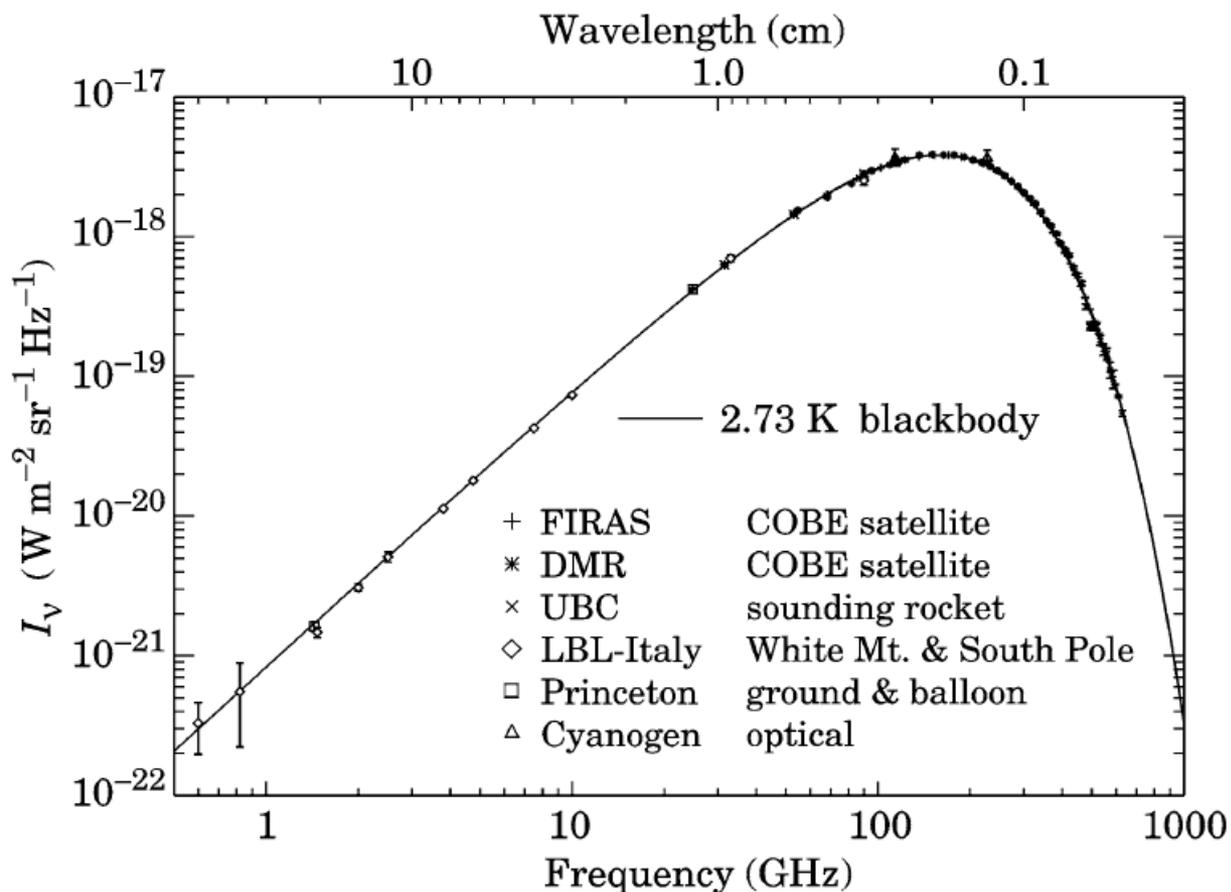
Cobe-Firas

- Histoire chaude de l'univers :
- Big Bang (3 piliers)
- $T_{\text{cmb}} = 2.725\text{K} \pm 0.001\text{K}$ (Fixsen & Mather, 2002)
- [Formule de Planck]

$$B_{\nu}(T) = \frac{2h\nu^3}{c^2} \frac{1}{\exp\left(\frac{h\nu}{kT}\right) - 1}$$

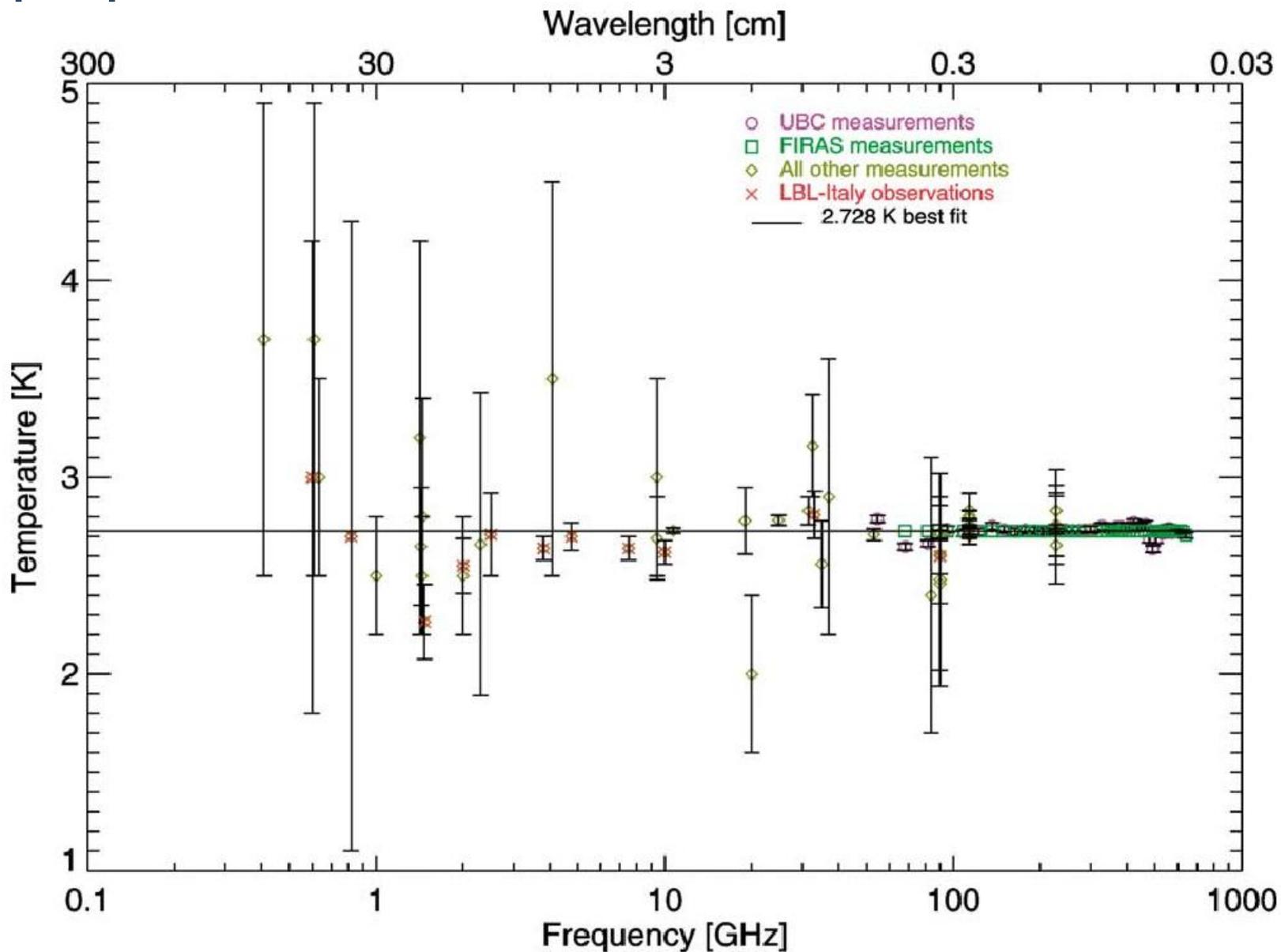


Spectre du CMB





Spectre du CMB





Anisotropies du CMB WMAP

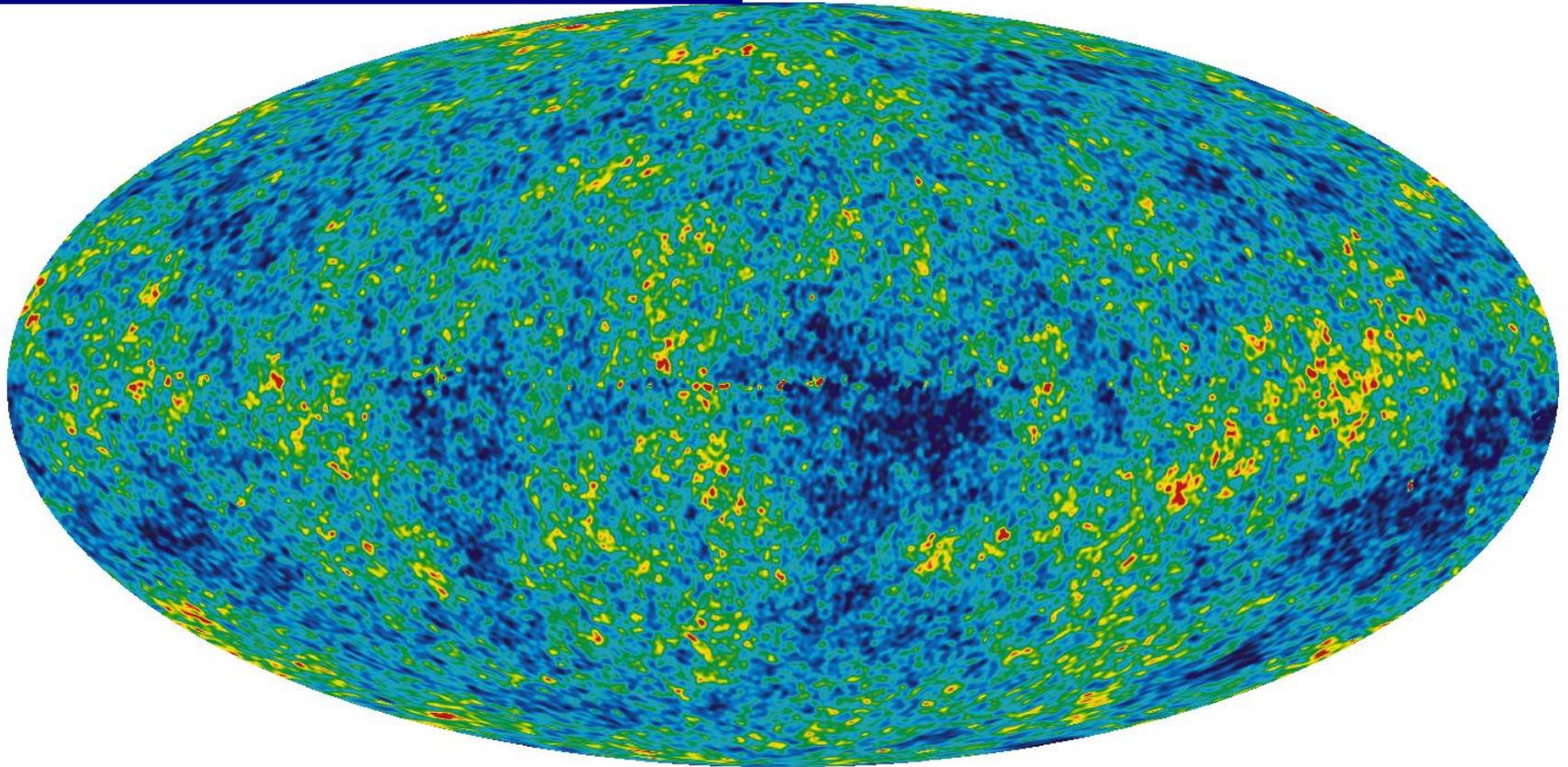
- Seul fond vraiment diffus
- [carte]
- [CI]

$$I_\nu = \frac{dB_\nu}{dT} (2.725\text{K}) \cdot \Delta T$$

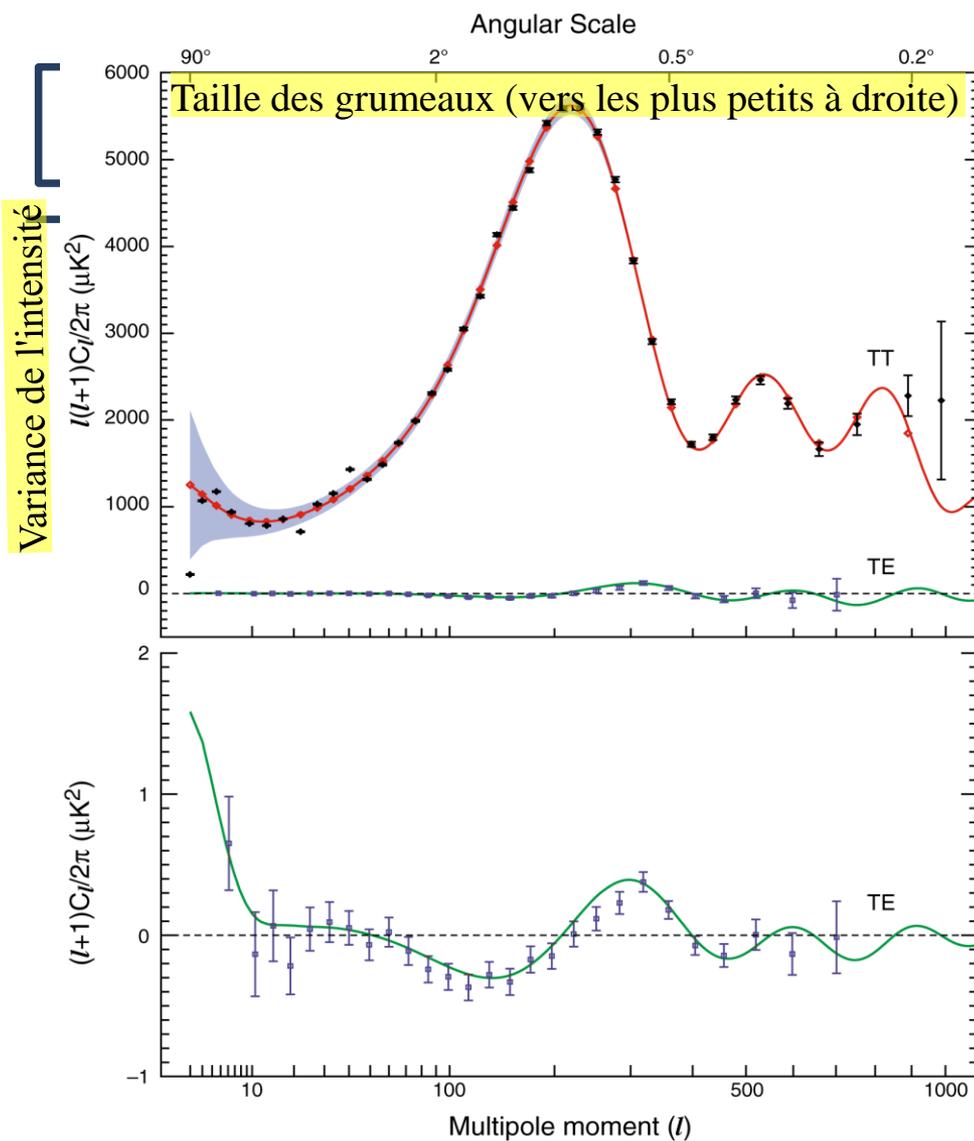
$T_0 = 2.725 \pm 0.001 \text{ K}$ (COBE)

$\Delta T \sim 100 \mu\text{K}$ (WMAP)

WMAP 5 ans



- Mesurer les paramètres cosmologiques
- La trace fossile des inhomogénéités \rightarrow formation des galaxies
- Contraintes sur l'univers primordial et la physique des particules



$$\Omega_{\text{tot}} = 0.99 \pm 0.02$$

$$\Omega_{\Lambda} = 0.75 \pm 0.04$$

+SNLS

$$w = -0.98 \pm 0.08$$

$$\Omega_{\text{m}} = 0.24 \pm 0.02$$

$$\Omega_{\text{b}} = 0.042 \pm 0.002$$

$$n_{\text{s}} = 0.95 \pm 0.02$$

$$\tau = 0.09 \pm 0.03$$

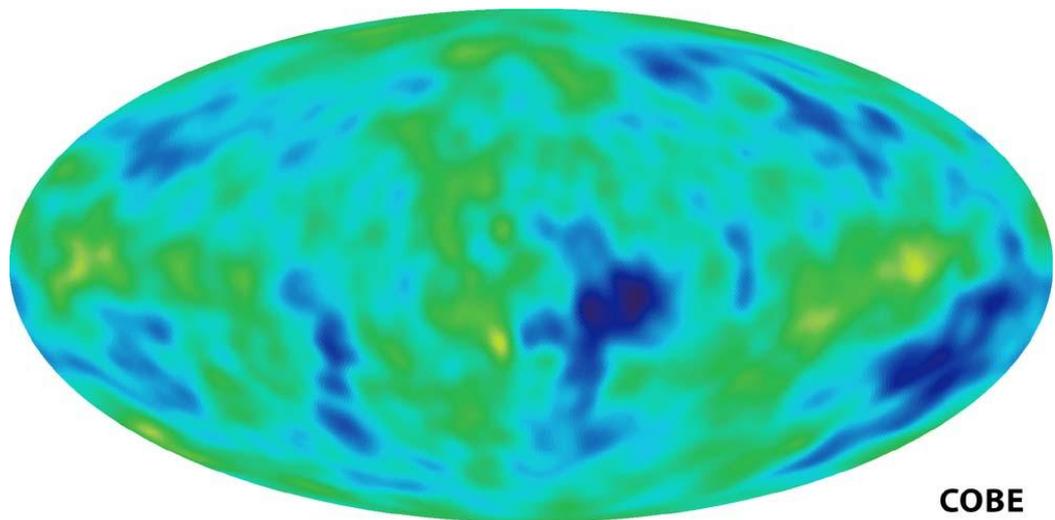
$$h = 0.73 \pm 0.03$$

$$\sigma_8 = 0.75 \pm 0.05$$

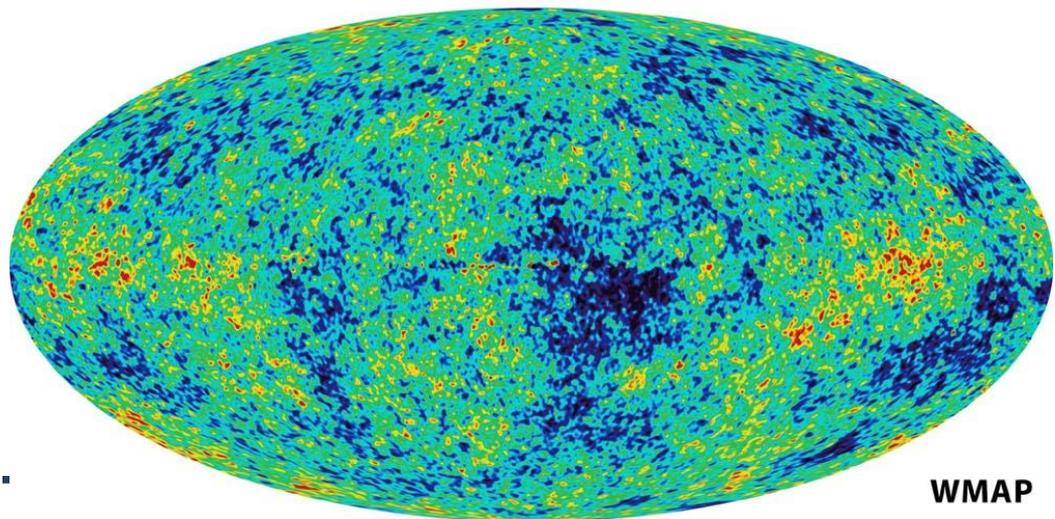
WMAP + ACBAR + CBI + 2dF + Ly α



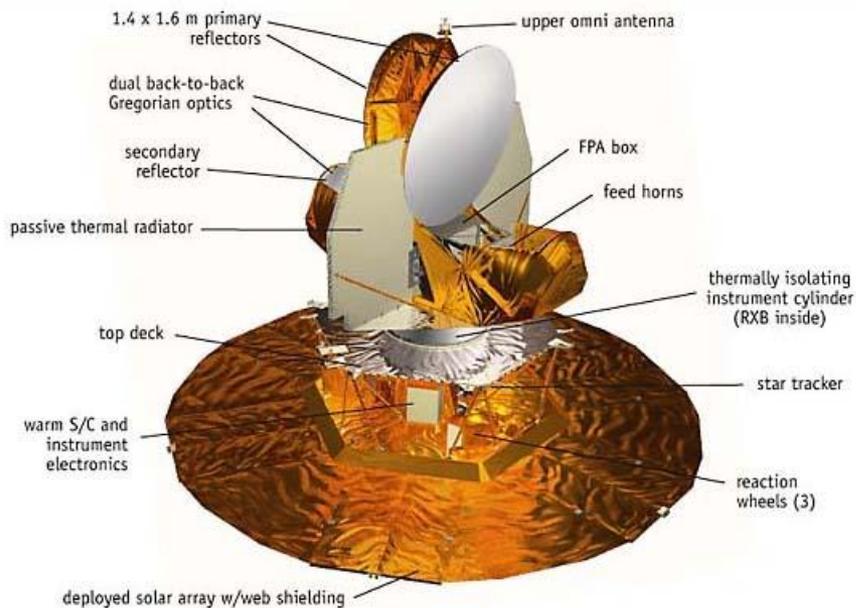
COBE & WMAP



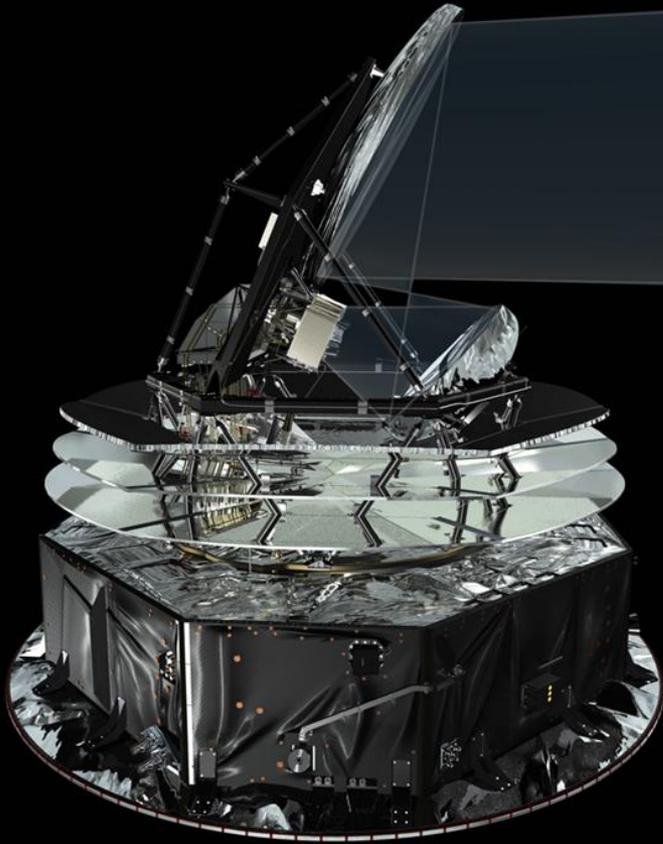
COBE



WMAP



Planck





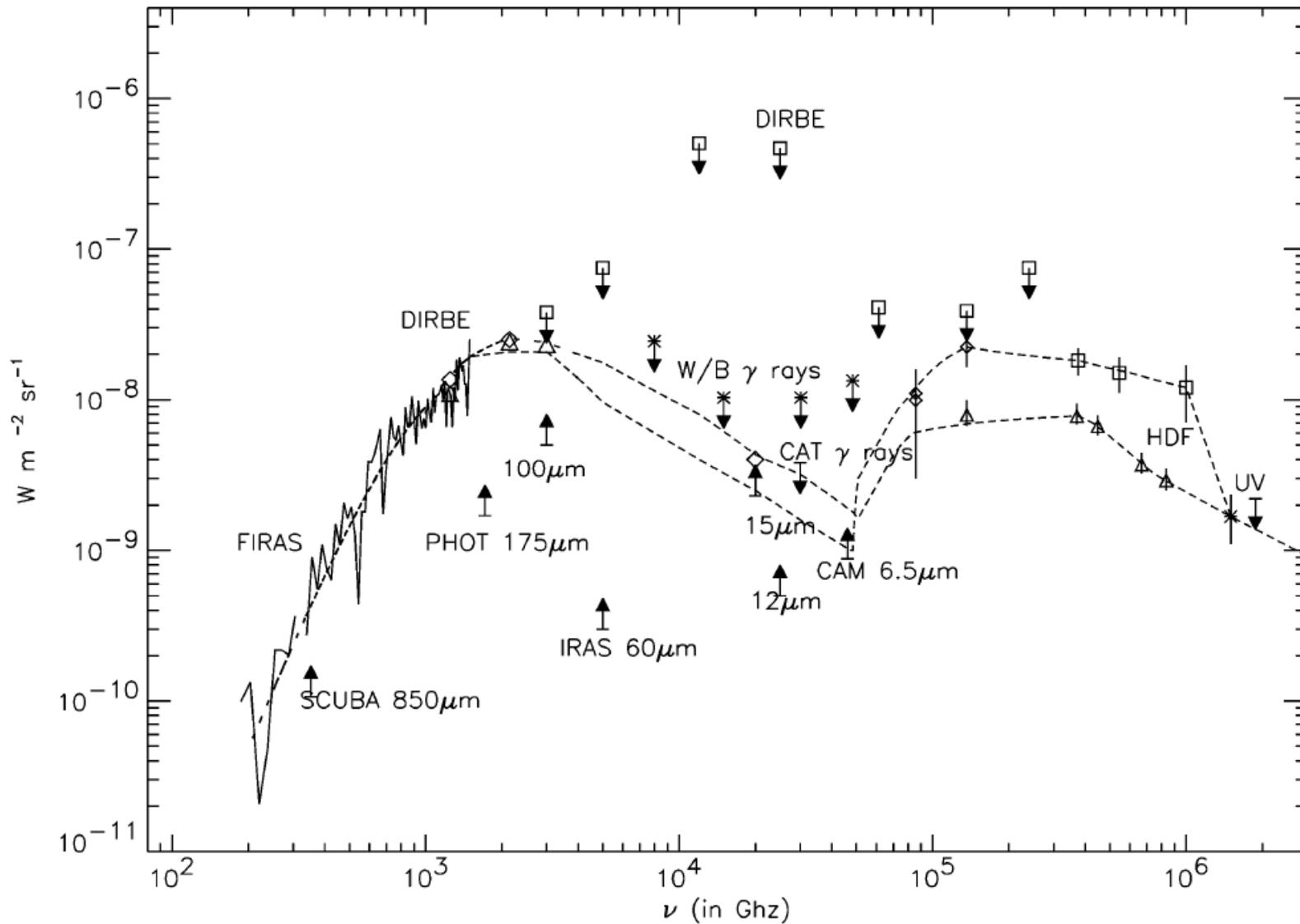
Planck en bref

- 3^{ème} Satellite pour la mesure du 3K, après COBE et WMAP
- 1900 kg au décollage (Ariane 5, 14 mai 2009), orbite autour du point de Lagrange L2
- Télescope hors-axe: primaire 1.5m, secondaire 1m, pointage à 85 degrés de l'axe de rotation.
- 2kW, Télémétrie: 100kbit/s (3 heures par jour), 2TéraOctets par an
- Lancement à chaud, refroidissement passif, chaîne cryogénique 20, 4, 1.6, 0.1K (48.000 litres d'He embarqués)
- 52 bolomètres (HFI) et 22 radiomètres (LFI)
- 4 cartes complètes du ciel à 9 fréquences 30-900 GHz (1cm-0.33mm) par balayage du ciel 1 tour/minute
- 600 scientifiques, 650 MEuros, 1991-2009, projet ESA de classe Moyenne (450 Meuros pour l'ESA)
- HFI= 150 MEuros dont 56% France : CNES+CNRS



Fond Infrarouge

vers le CMB

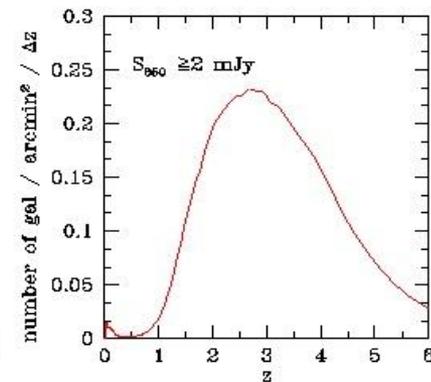
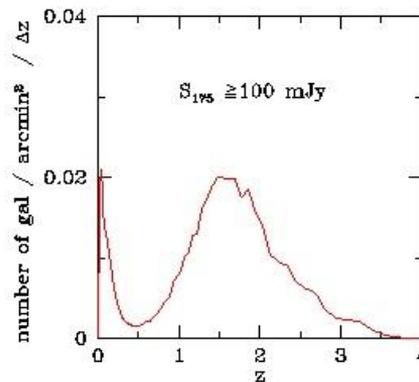
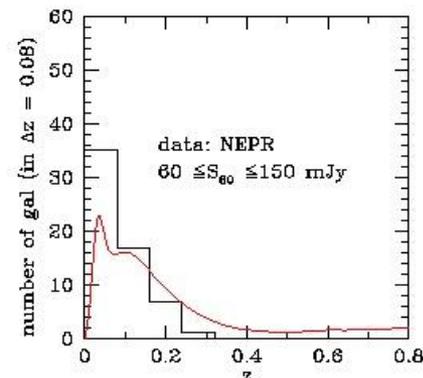
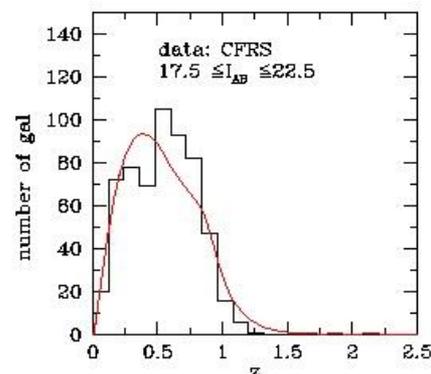
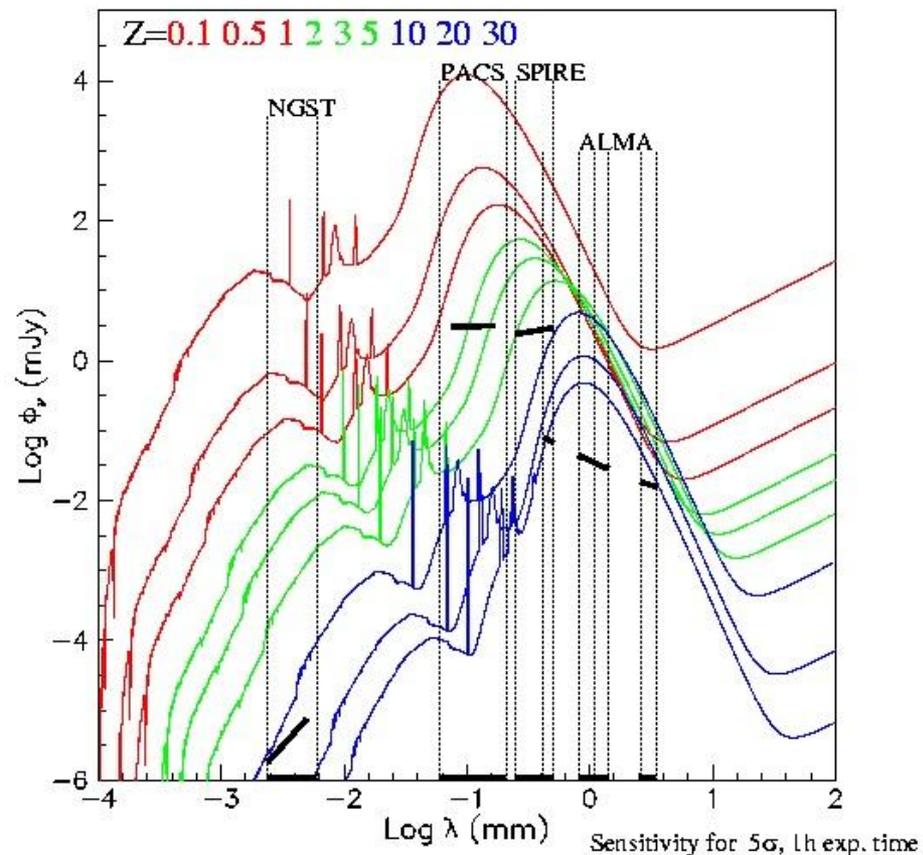




Comptage de galaxies

Strong starburst – $L_{\text{IR}}=2.2 \times 10^{12} L_{\odot}$ – $\text{SFR}=373 M_{\odot} \text{ yr}^{-1}$

Melchior et al. *astroph/0102086*



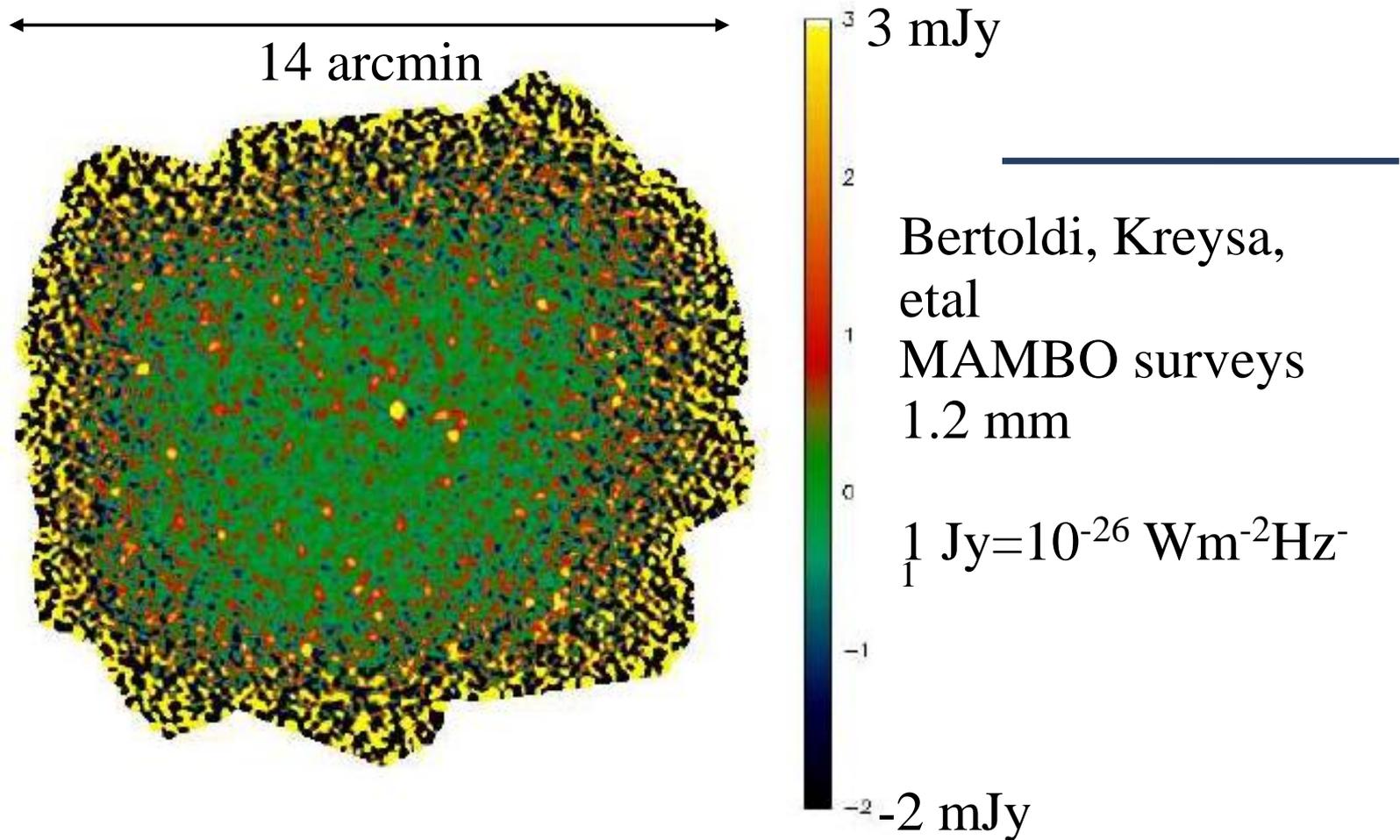
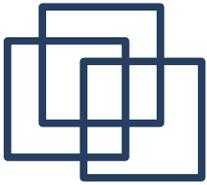


Figure 1. A preliminary ≈ 14 arcmin diameter 1.2 mm MAMBO image of the NTT Deep Field. The rms noise is 0.5 mJy in the image center, and rises toward the edges. At least 20 significant sources can be seen, including the strong $z = 4.7$ quasar BR 1202-0725. During the last two winters we used MAMBO to obtain maps of three fields with a total area of about 300 arcmin² covered to a noise rms < 1 mJy. We found almost 100 point sources with fluxes above 1.5 mJy (Bertoldi et al. 2000; Carilli et al. 2000; Menten & Bertoldi 2000).



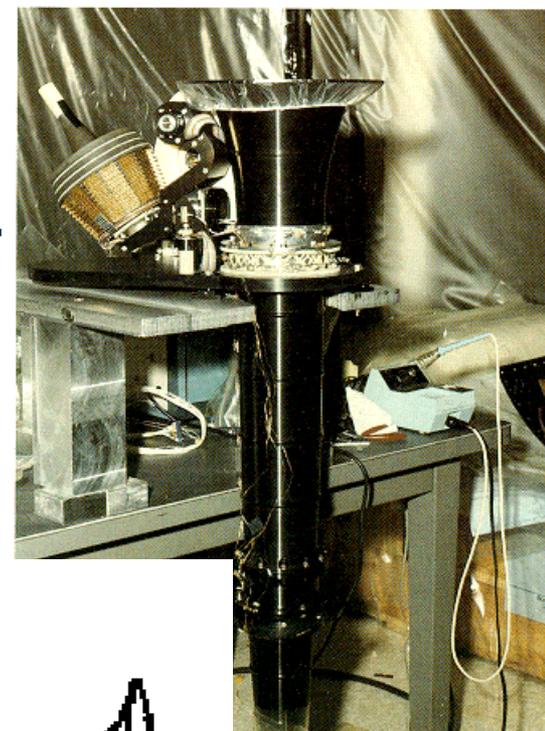
Arbre de choix

- Résolution angulaire: diffraction
- $\theta = \lambda/D = 1 \text{ mradian}$ pour $1 \text{ mm}/1 \text{ m}$ soit $57 \text{ millideg.} = 4 \text{ arcmin}$
- Choix du télescope: Télescope unique ou interféromètre
- sol-ballon-espace
- Résolution spectrale
 - Continuum: bolometre
 - Haute résolution: hétérodyne
- sensibilité
- Polarisation (to B or not to B).

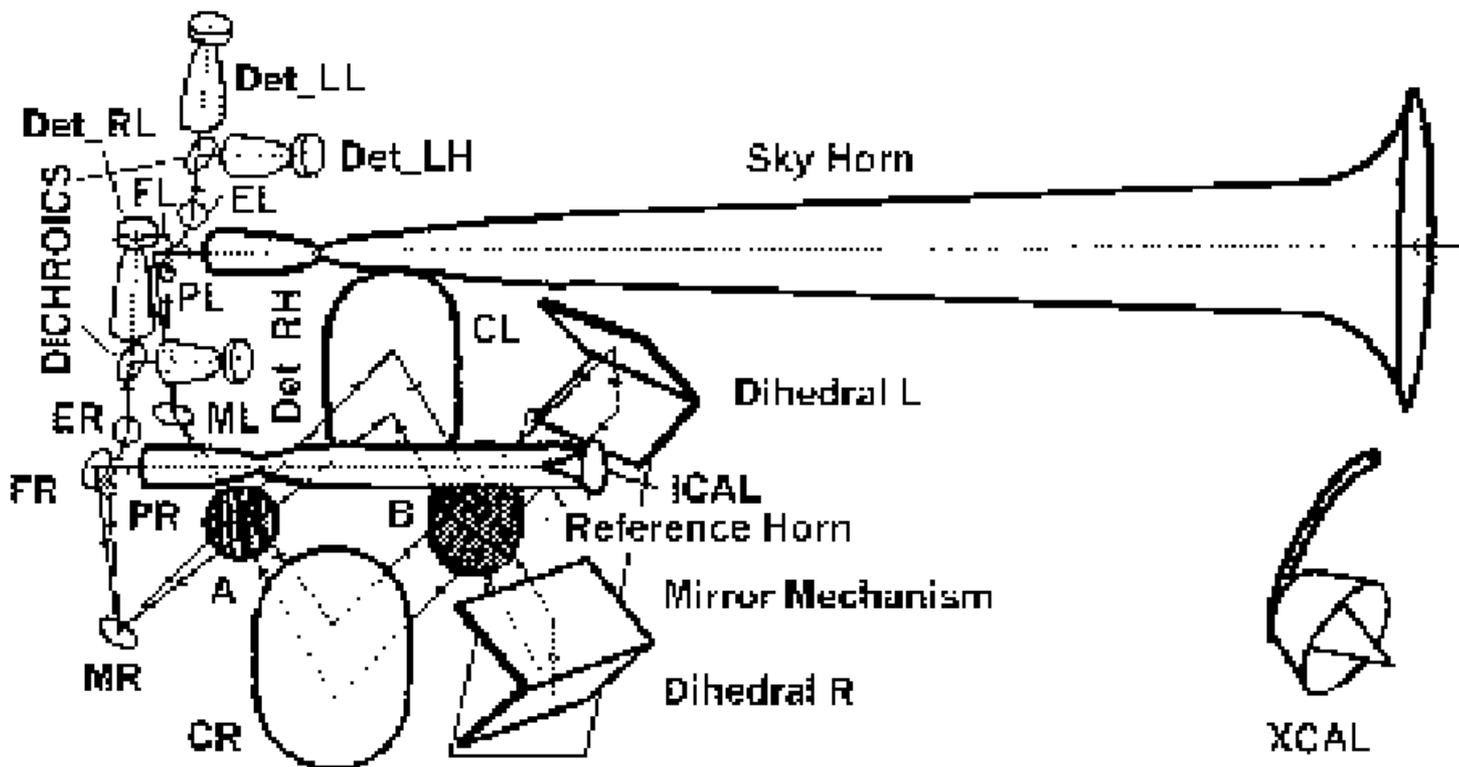


FIRAS

- Martin Puppel Spectrometer, lobe 7degrés
- 100 cm⁻¹ to 1 cm⁻¹, 0.5 cm⁻¹ res.
- Bolometers at 0.9K ! NEP ~ 3x10⁻¹⁵WHz^{-1/2}



ovable calibrator. Protective removed.



Diabolo

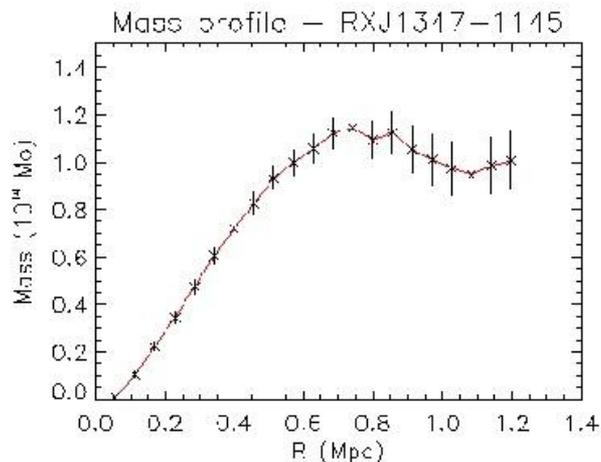
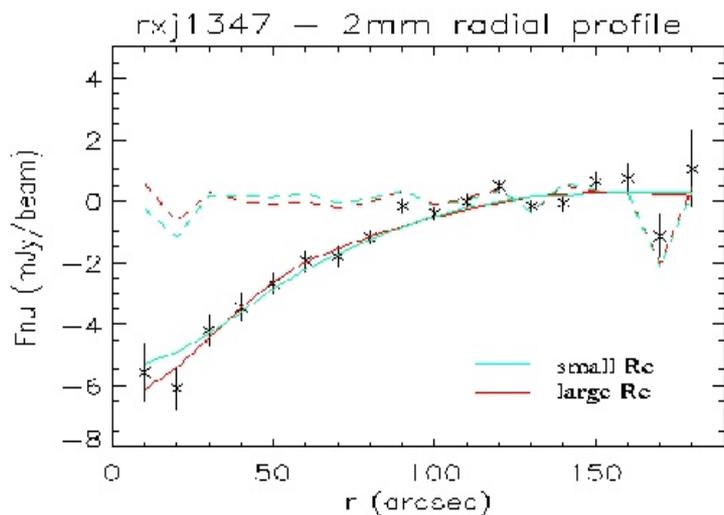
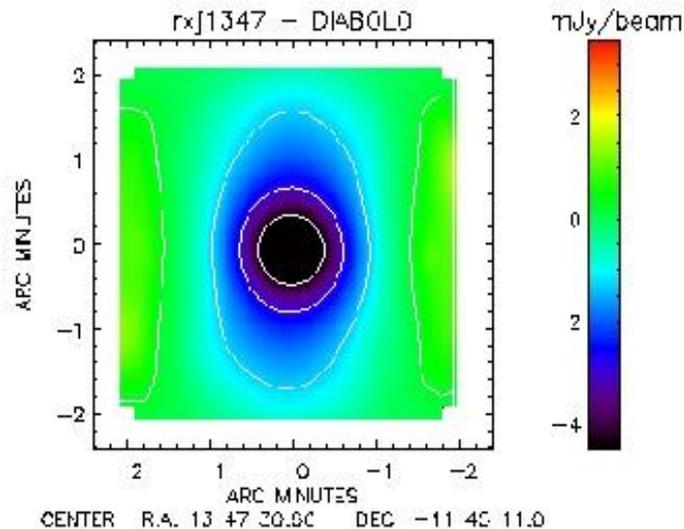
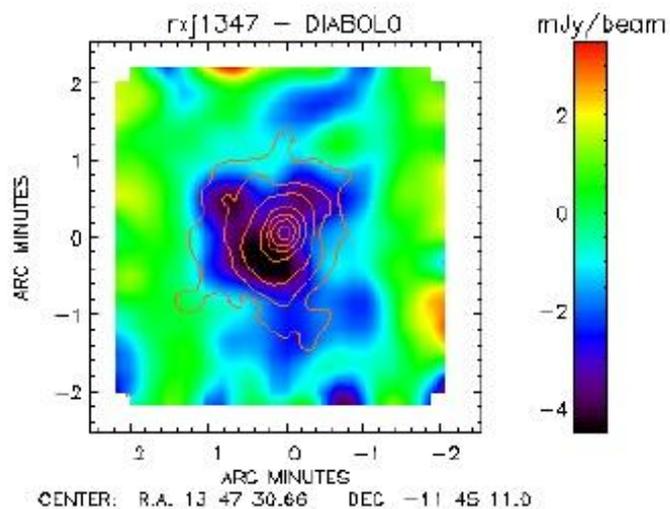


Diabolo (1994 - 2001) :
photomètre (2x3 bolo 100mK)
qui a utilisé pour la
première fois en astrophysique
un système à dilution ouvert,
précurseur de Planck



RXJ1347-1145 Most massive object Pointecouteau *et al.* 2001, *ApJ*

Colours = Diabolo 2.1mm (map obtained by scanning the 3 pixels across the field, @30m in 15 hours)
Contours = X-ray (Rosat) (southern extension has since been confirmed by Chandra)

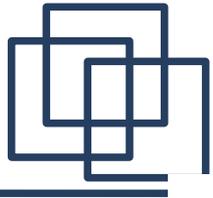




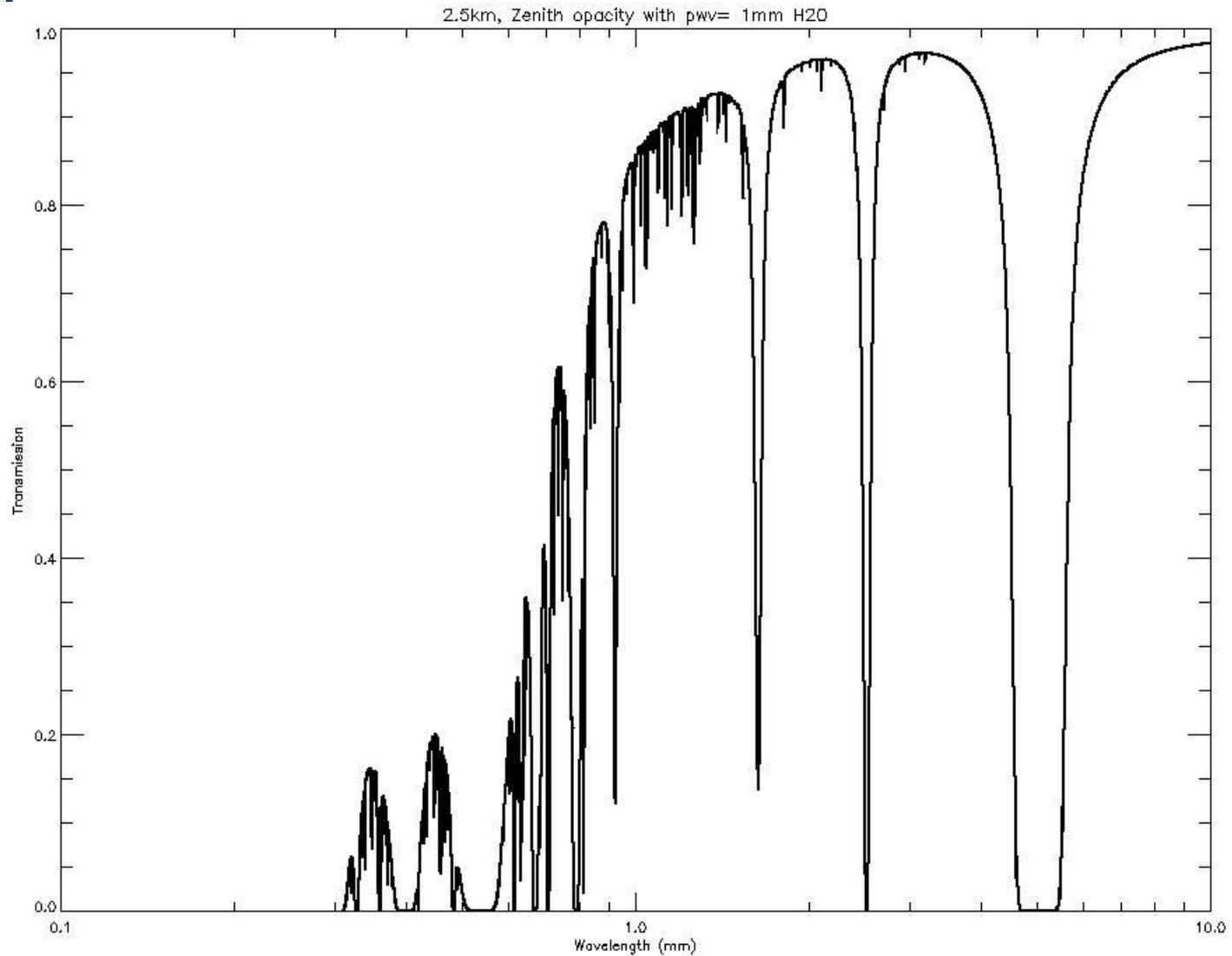
IRAM

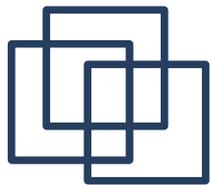
Pico Veleta Espagne IRAM 30m (<10 arcsecondes @1.2mm)



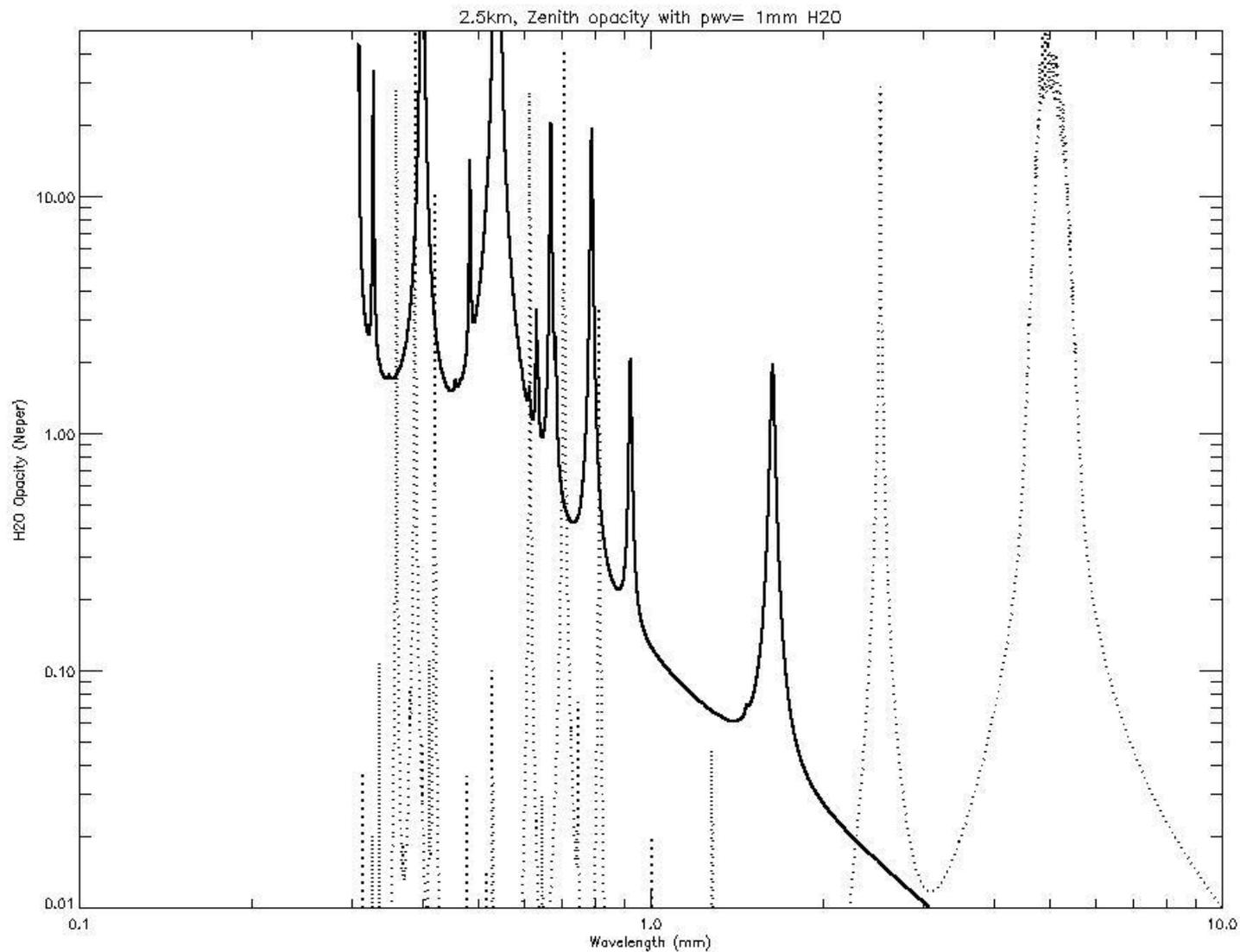


Transmission du ciel





Emissivité du ciel et bruit de ciel





Le rayonnement électromagnétique

- 4 variables:
 - Variation angulaire
 - résolution vs. Champ de vue
 - Spectre
 - continuum (bolo) raies (hétérodyne)
 - Polarisation: I, Q, U (, V)
 - Variation temporelle



Besoin en refroidissements

- Gain en sensibilité
- Bolomètres classiques
- TES
- KIDs
- Sensibilité liée au background/ λ

4.3. *The need for 0.1 K temperature in ground-based experiments*

Benoit et al 2000
Astr. Ap. Sup. Ser.

The background is relatively large in the case of ground-based experiments. There is a general prejudice that very low temperatures are thus not needed. Actually, the temperature required for optimised bolometers depends only on the wavelength, because the photon and bolometer noises both increase as the square root of the incoming background. The general formula is (Mather 1984; Griffin 1995; Benoit 1996):

$$T_{\max} = \frac{hc}{k} \frac{p}{\lambda}, \quad (7)$$

where $hc/k = 14.4 \text{ K mm}$ and p is a dimensionless constant. It turns out that for classical bolometers with a resistive thermometer, one has typically $p \simeq 0.025$, so that the maximum temperature for millimetre continuum astronomy is 0.4 K. Allowing for non ideal effects and bolometers which would be 0.7 less noisy than the background noise, a temperature of 0.1 K is required in the 2 mm cosmological atmospheric window. The ultimate noise equiv-



BLIP

$$NEP \sim 1 \times 10^{-17} \text{W} \cdot \text{Hz}^{-1/2} \sqrt{\frac{T}{0.1 \text{ K}} \frac{P}{1 \text{ pW}}}$$



Le sol

- Permet de grands télescopes
- Interféromètres
- Temps de développement plus court
- Voir autour d'objets
- Fort fond de ciel
- Bruit de ciel et émission diffuse
- soustraction spatiale, spectrale
- Matrices à cornets ou plein échantillonnage

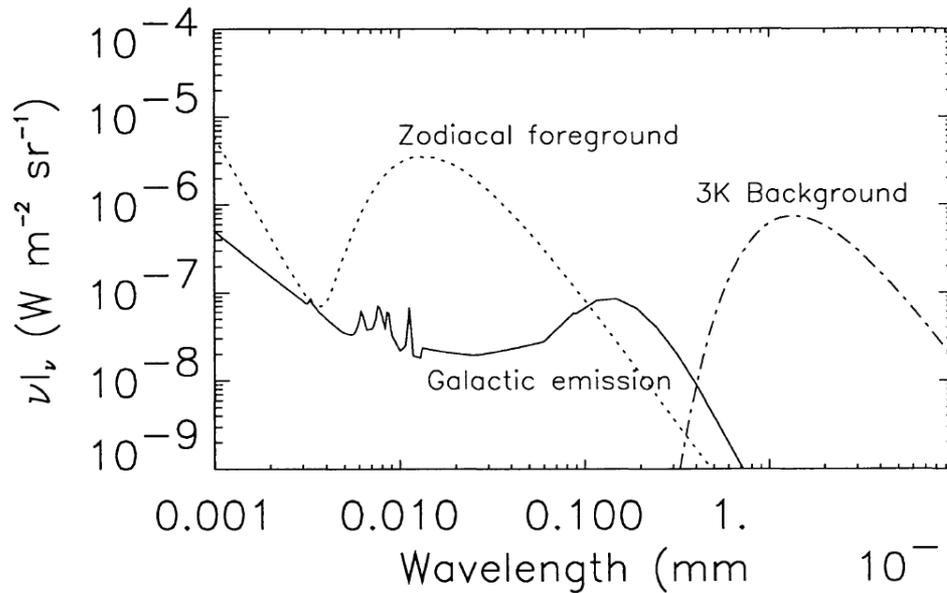


L'espace

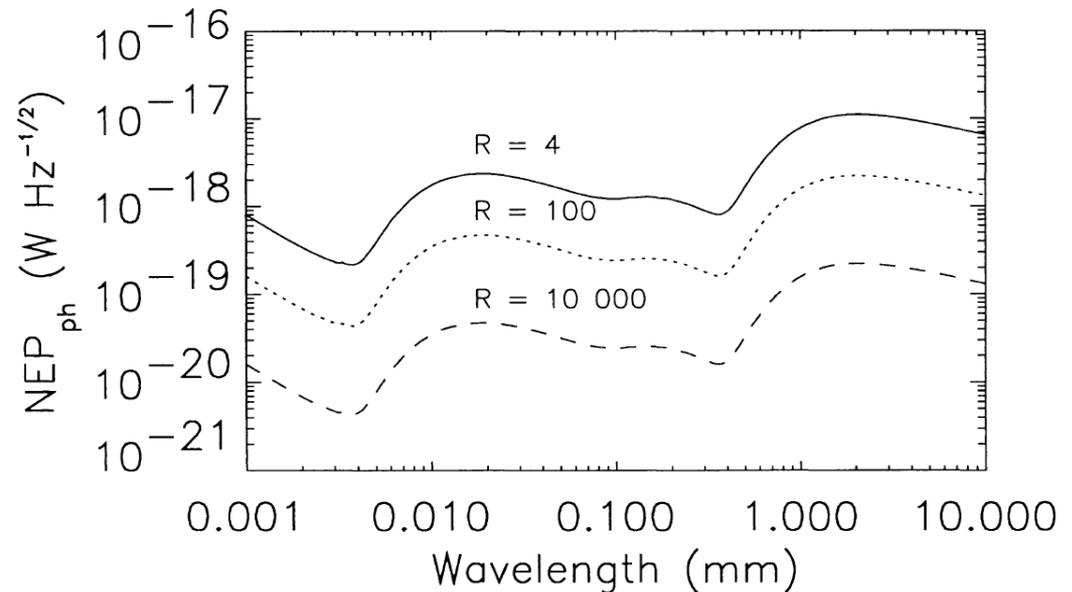
- Faible puissance électrique: qqs kW
- Vibrations
- Pas de ravitaillement en vol
- Stabilité
- Temps d'intégration
- Emission diffuse
- Meilleur contrôle des effets systématiques
- Montrer avantage par un facteur 10 dans au moins une dimension par rapport au sol
- Temps de développement long, complexité forte



Refroidissement des télescopes spatiaux



- Lamarre et al (Space Science Reviews 74, 27 1995)



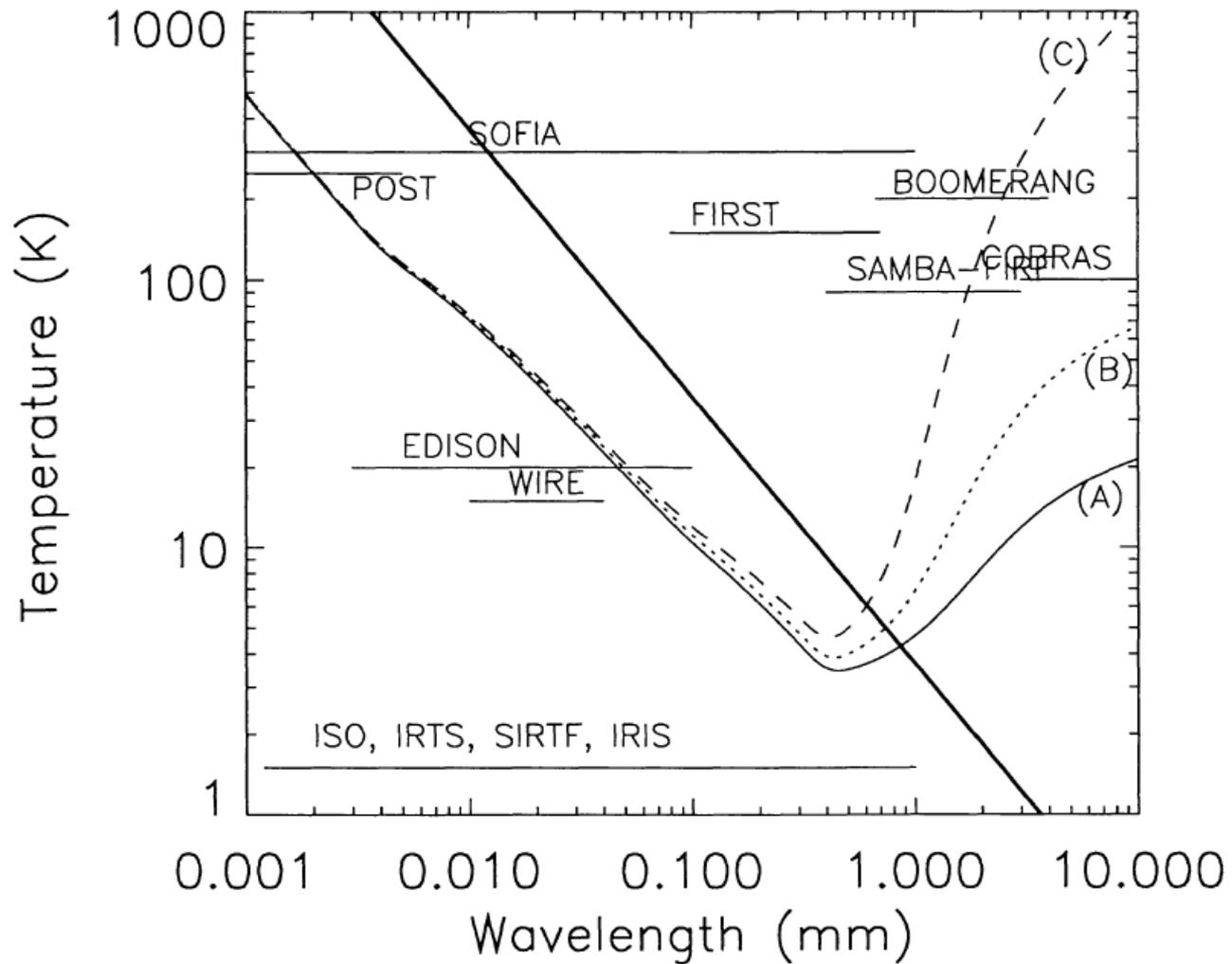
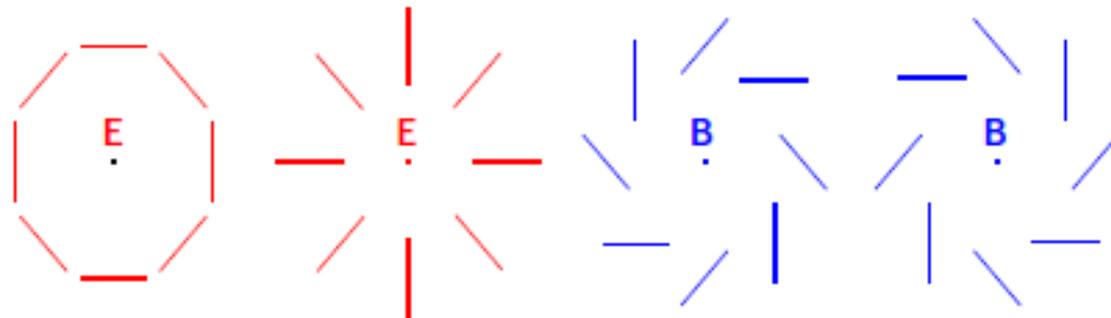
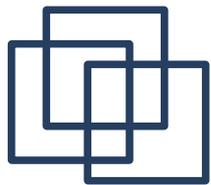
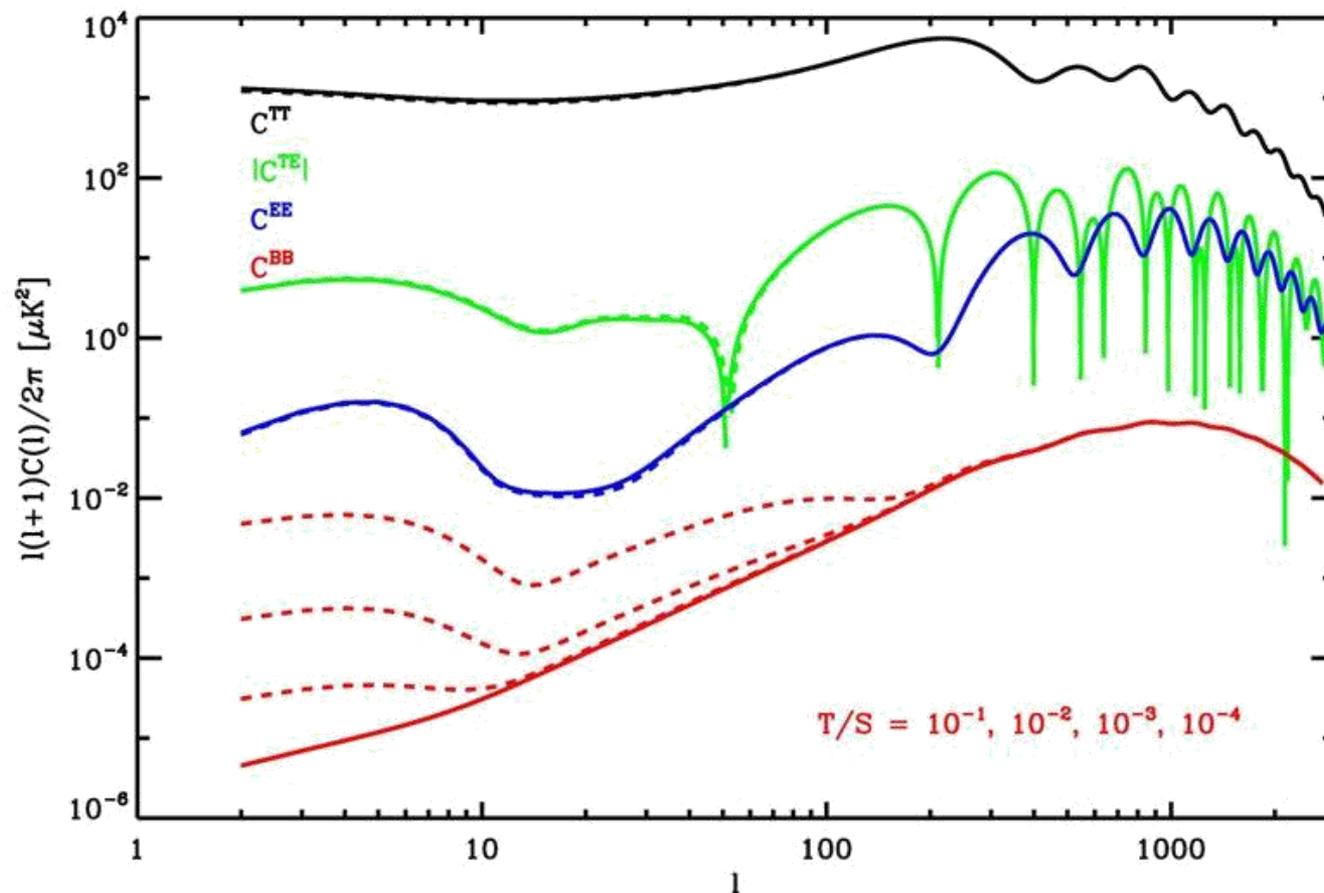
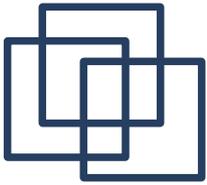


Fig. 2. Maximum allowed instrument temperature for the experiment to be background limited. A rough working range of wavelengths and temperature for a series of planned experiments are also indicated, see this conference proceedings for more details. Lines A, B, and C refer to Section 4.1 concerning the telescope configuration (equations 5, 6, and 7 resp.). The thick line represents Wien's displacement law for the maximum of νI_ν of a blackbody

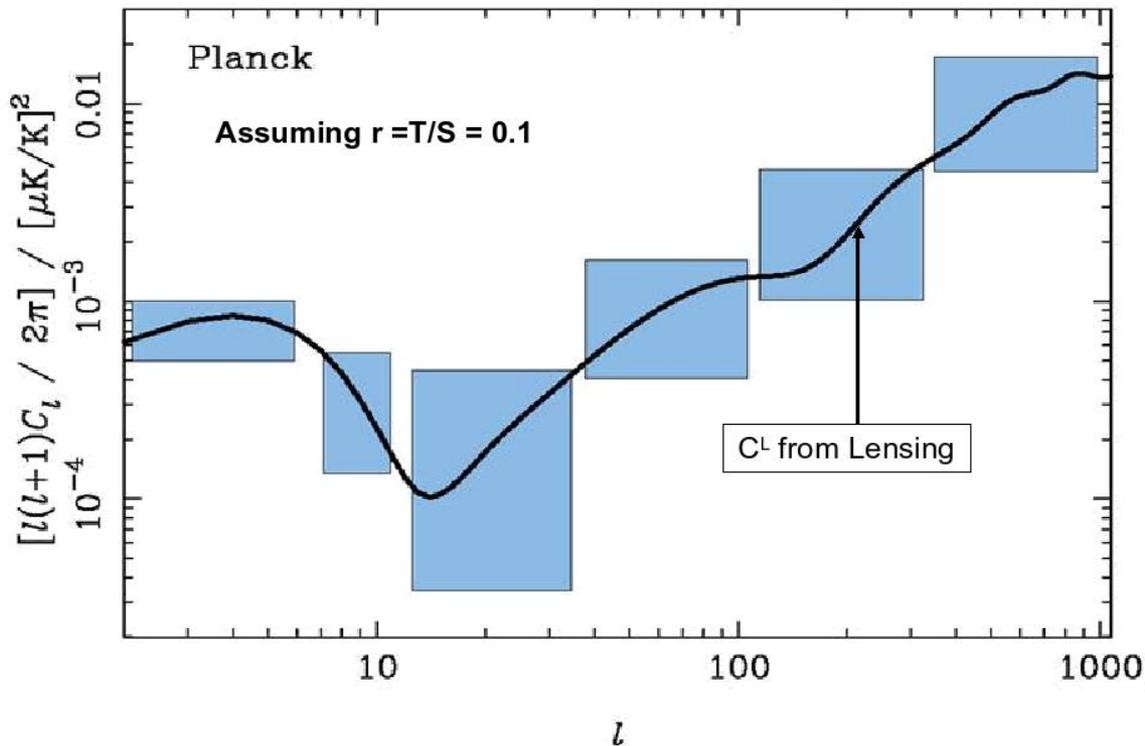


Polarisation





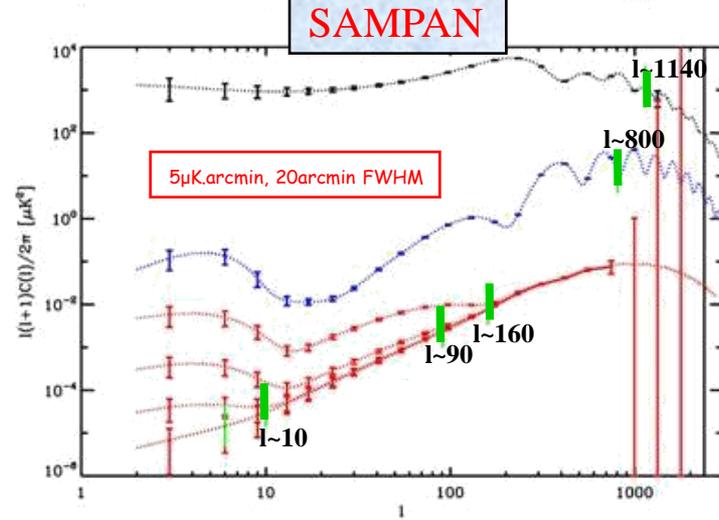
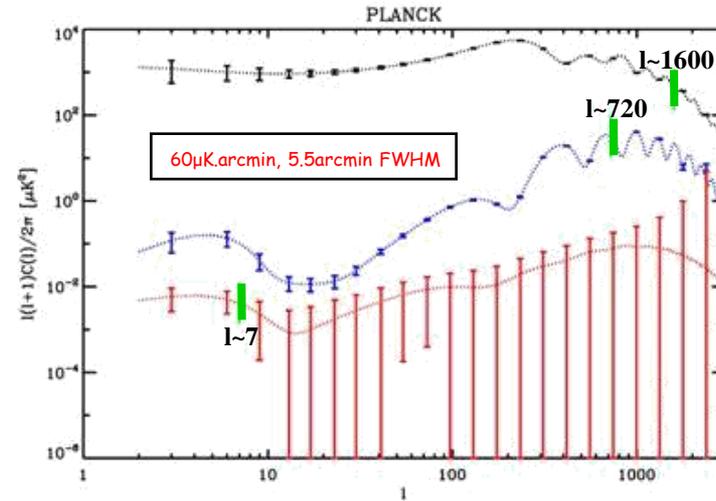
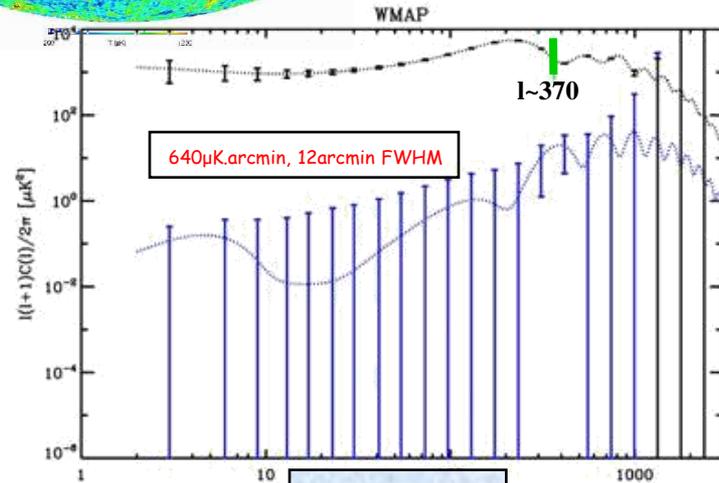
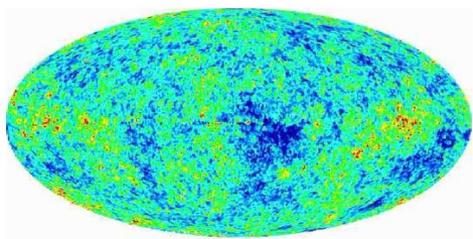
Planck & the B modes



Planck will be limited by its (polarisation) sensitivity ($\sim 60 \mu\text{K}\cdot\text{arcmin}$ at very best)

Indeed, it was conceived to be limited by unpolarised foregrounds confusion

Measurements in perspective



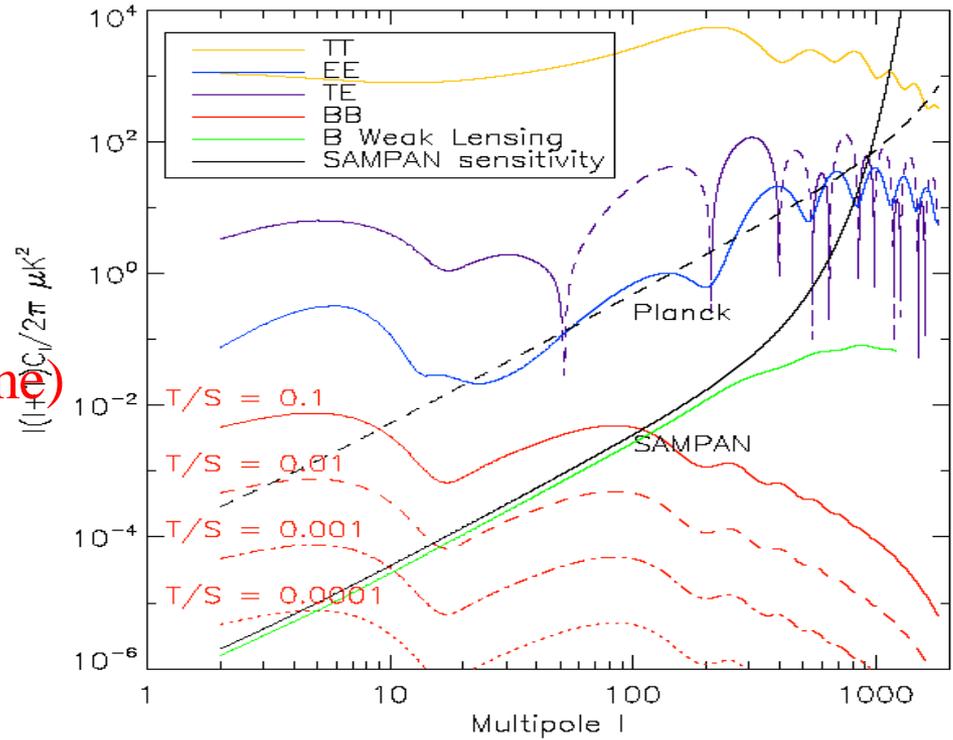
	Fiducial model	SAMPAN 20' fwhm, (5μK · arcmin) ² (No reionization)					
		TT	TE	EE	BB	BB+EE	All
r	0.0	1.57×10^{-1}	7.19×10^{-2}	1.32×10^{-2}	1.58×10^{-3}	6.71×10^{-4}	6.60×10^{-4}
$\delta A_S / A_S$	1.00×10^0	3.14×10^{-1}	6.15×10^{-3}	3.81×10^{-3}	2.70×10^0	3.57×10^{-3}	1.27×10^{-3}
H	7.20×10^1	9.96×10^{-2}	6.62×10^{-2}	9.91×10^{-2}	5.94×10^0	8.06×10^{-2}	3.93×10^{-2}
Ω_b	5.00×10^{-2}	3.43×10^{-4}	2.68×10^{-4}	6.01×10^{-4}	3.91×10^{-2}	4.88×10^{-4}	1.39×10^{-4}
Ω_c	2.50×10^{-1}	3.73×10^{-5}	5.03×10^{-5}	1.34×10^{-4}	3.45×10^{-2}	1.28×10^{-4}	2.68×10^{-5}
n_s	1.00×10^0	3.47×10^{-3}	6.69×10^{-3}	3.98×10^{-3}	1.49×10^{-1}	3.74×10^{-3}	1.84×10^{-3}
Ω_k	0.0	5.53×10^{-4}	4.37×10^{-4}	3.08×10^{-4}	3.04×10^{-2}	3.01×10^{-4}	1.87×10^{-4}
τ	0.0	1.73×10^{-1}	8.00×10^{-4}	1.19×10^{-5}	1.60×10^0	5.96×10^{-6}	5.96×10^{-6}

Table 2: 1σ errors resulting from the fit of an eight parameter family of cosmological models for a detector white noise level of $5\mu\text{K} \cdot \text{arcmin}$ and a resolution of 20 arc minute. (Note that $\delta A_S / A_S$ denotes the variation on the normalisation of the scalar power spectrum as compared to that inferred from COBE data.) This table confirms that a tensor to scalar ratio r greater than 2×10^{-3} could be detected at the 3σ level even without relying on the low- ℓ reionisation bump.

l bounds region (at left) with modes measured @ S/N > 1

Comment obtenir la sensibilité brute de Sampan?

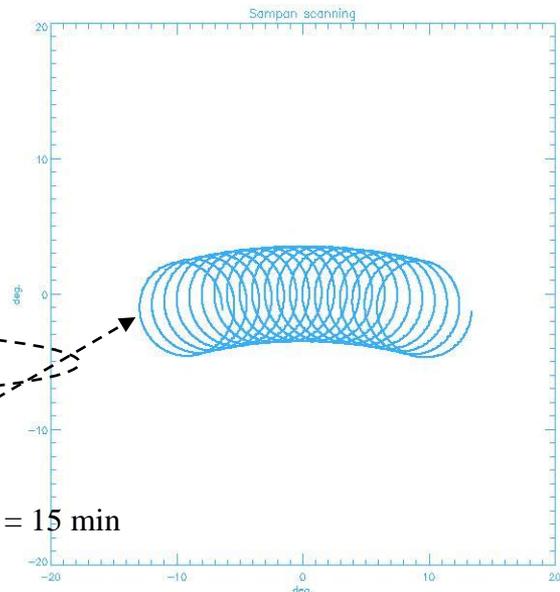
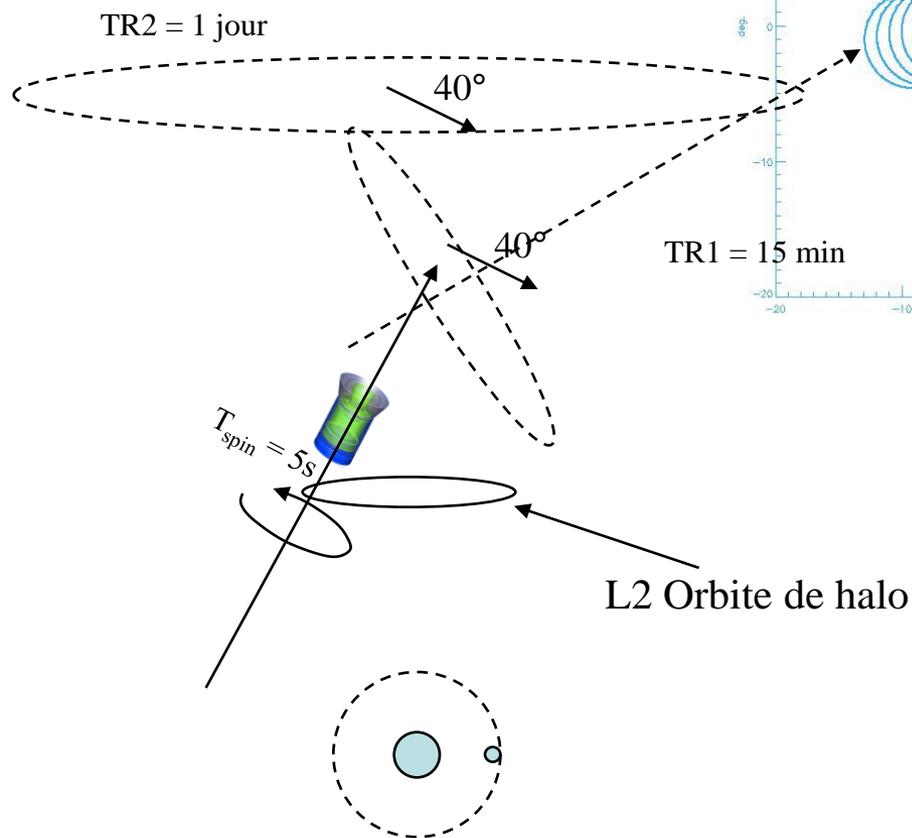
- Augmenter la sensibilité
- Quasi – impossible
- Planck est à la limite du bruit de photon (ceux du CMB lui-même)
- Accroître la durée de vie > 2 ans ?
- Accroître le nombre de détecteurs - 20 000 pixels



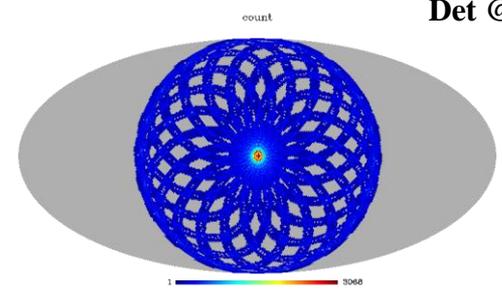
$$C_l = [2/(2l+1)/f_{sky}]^{1/2} * C_{noise} \exp(l/2 (FWHM/2.35)^2)$$

$$\text{with } C_{noise} = 2 * 4 \pi * f_{sky} * s_{det}^2 / N_{det} / T_{mission}$$

$$C_{noise} = (5 \mu K \cdot \text{arcmin})^2 (2 \text{ years}/T_{mission}) (5000/N_{det}) (s_{det}/140 \mu K \cdot s^{1/2})^2$$

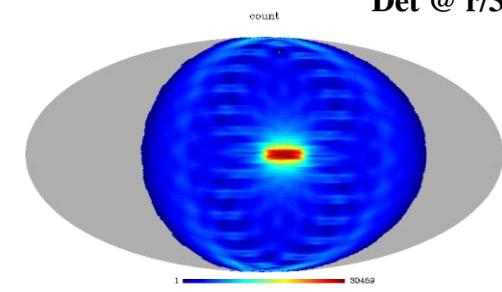


Det @ r/3, 1d



Mhit maps

Det @ r/3, 30day



Stratégie de balayage



Caméra @ 30m

λ	mm	1.2	2.1
FOV	Arcmin ²	5x5	5x5
Npix		64x64	32x32
Pixel size	arcsecond	5	10
Diffraction	arcsecond	11	18
Detectivity	mJy/s ^{1/2} par psf	50	30
YSZ	1 heure par psf		5E-5

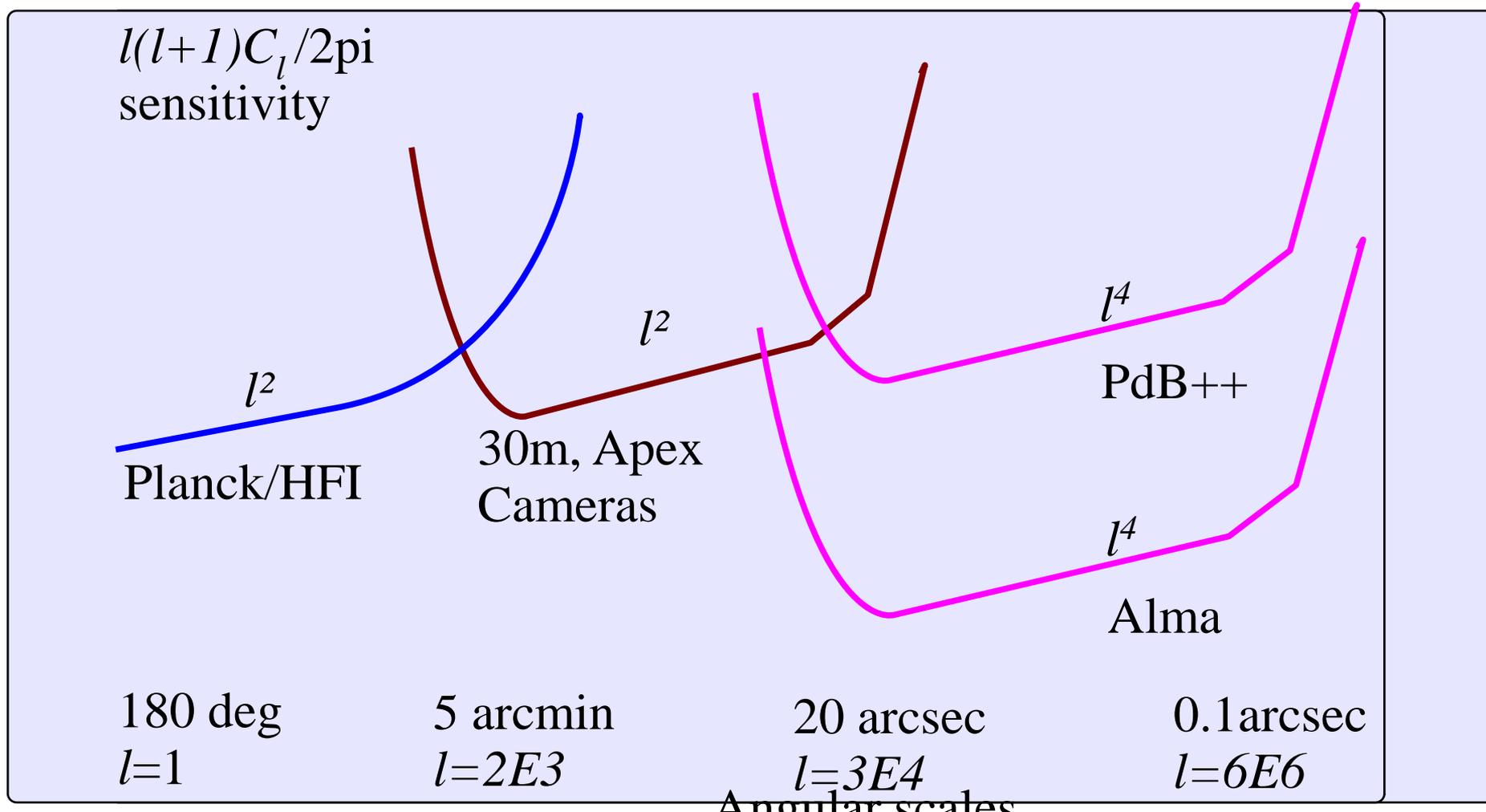
Détecter une galaxie à haut redshift à chaque heure de relevé profond (1 mJy 5 sigma 1.2 mm)
Cartographie l'effet SZ sur un amas Planck en quelques heures.





Complémentarité

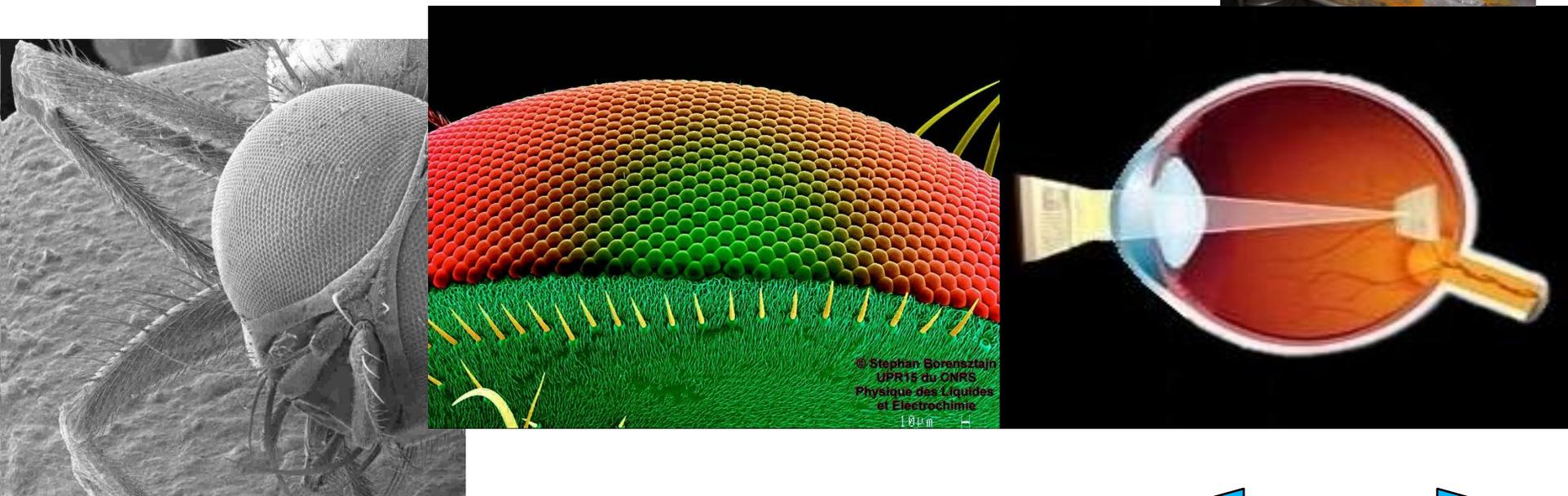
- Exemple Planck, Matrice Bolo, Alma





La biomimétique et les senseurs millimétriques

- Bulletin ESA 2006



Oeil de mouche : 1000 pixels



Oeil humain :
150 million pixels