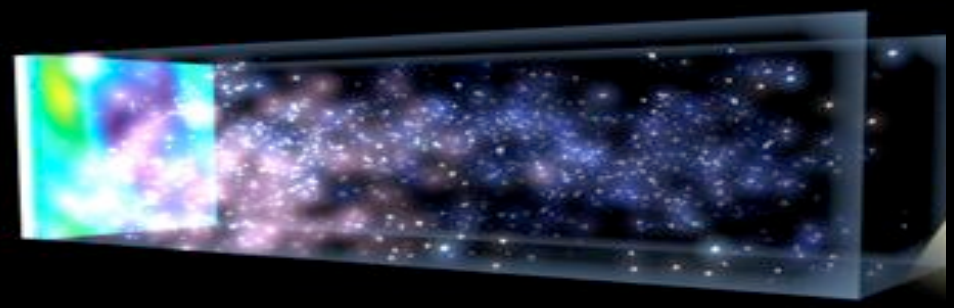
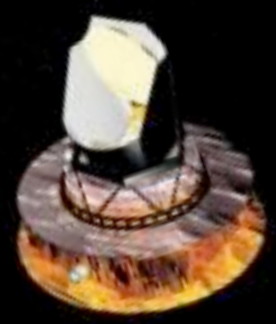
Probing neutrino masses with CMB lensing:





Forecasts for Planck and beyond

Laurence Perotto; LAL Orsay

NDM 06

In what Cosmology is concerned with neutrino masses?

Particules physicist point-of-view

➡ providing interesting bounds in complement to the terrestrial experiments.

In what Cosmology is concerned with neutrinos mass?

The present status

Tritium beta decay	$\left(\sum_i \lvert U_{ei}\rvert^2 m_i^2\right)^{1/2}$	< 2.3 eV
Neutrinoless double beta decay	$\left\lvert \sum_i U_{ei}^2 m_i \right\rvert$	< 0.3-1.2 eV
Cosmology	$\sim \sum_i m_i$	< 0.7eV

In what Cosmology is concerned with neutrino mass?

Particules physicist point-of-view

➡ providing interesting bounds in complement to the terrestrial experiments.

Cosmologist point-of-view

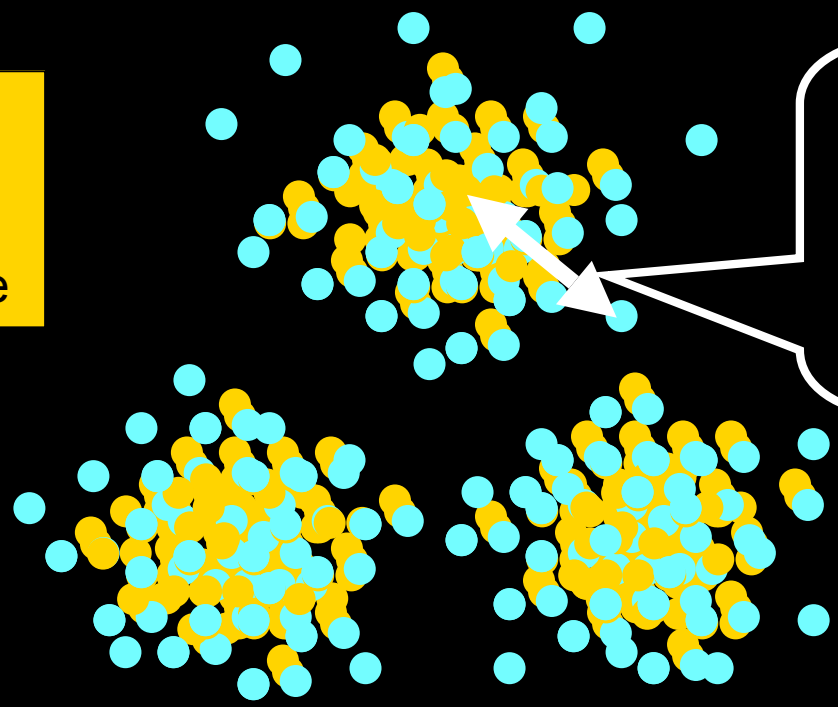
➡ the « minimal » cosmological model should soon include M_nu:

With the next generation of cosmological experiment, avoiding M_nu in the model could lead to a misestimate of the other parameters.

How to probe neutrino mass in Cosmology?

The clearer signature of massive neutrinos: the free-streaming effect

Gravitationnal collapse in an expanding Universe



Neutrinos cannot collapse below a diffusion lenght:
$\lambda = \int v\, dt$

baryons+CDM

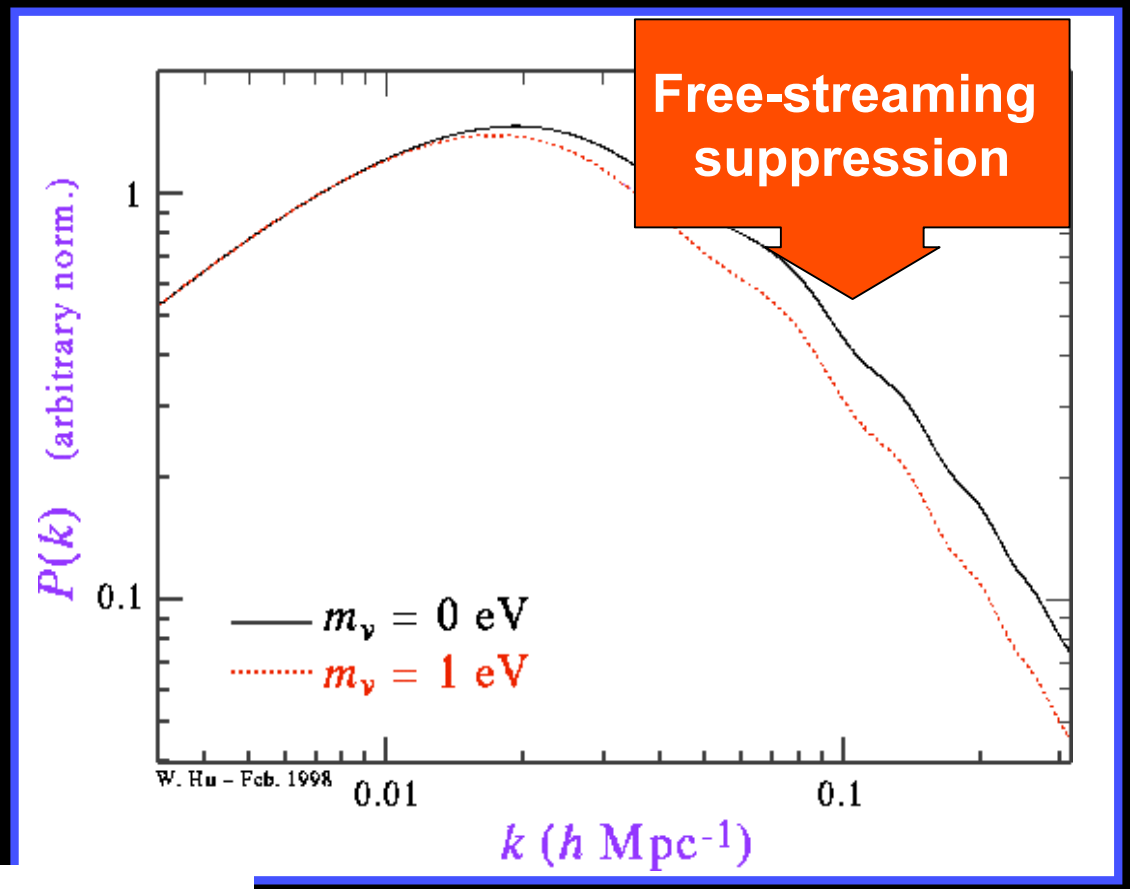
neutrinos

For $(2\pi/k) < \lambda$,
free-streaming supresses growth of structures.

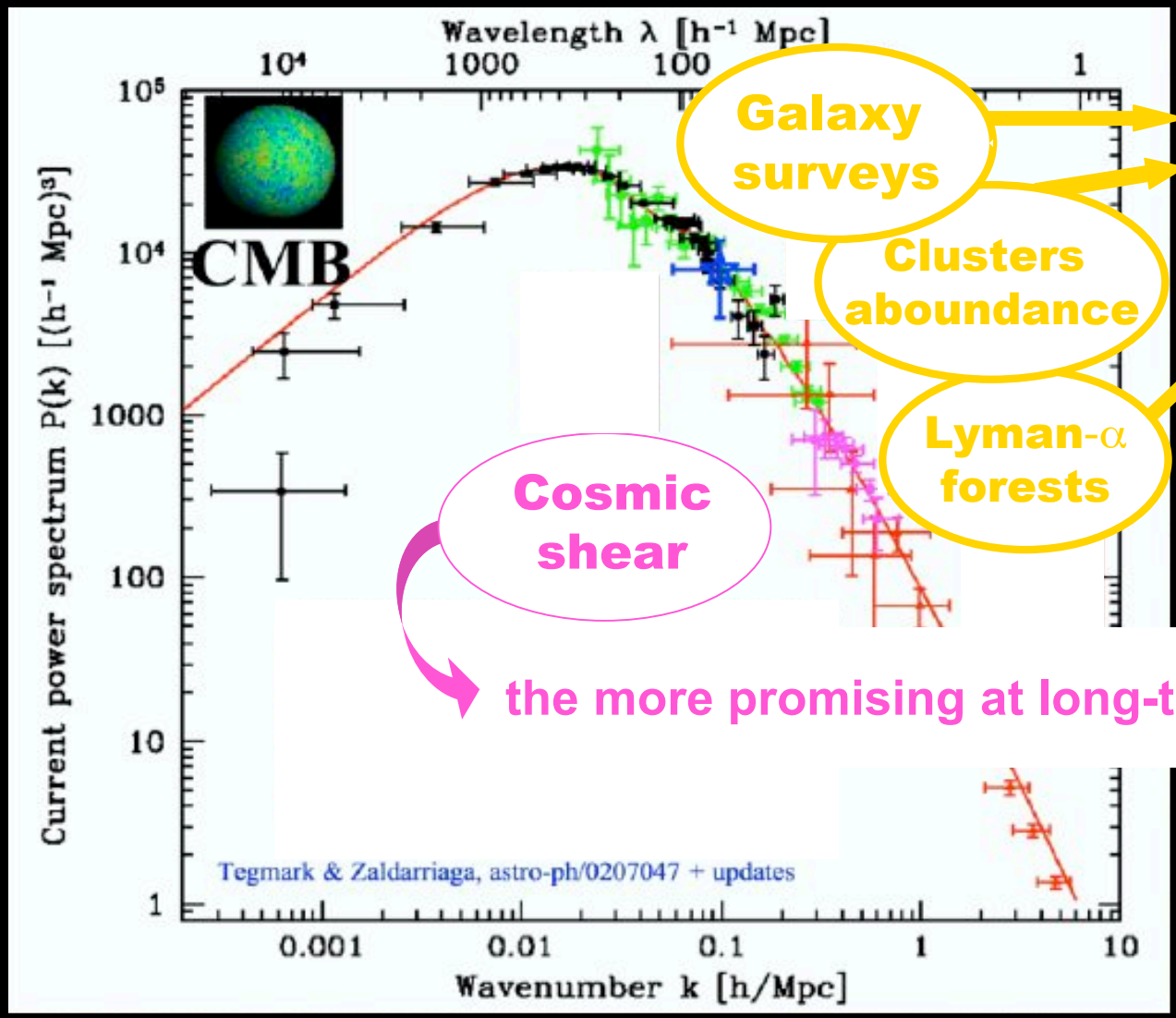
Effect on the matter power spectrum

$$\delta(x) = \frac{\delta\rho(x)}{\bar{\rho}}$$

Matter power spectrum is the Fourier transform of the two-point correlation function



Measures of the large scale structures



Galaxy surveys

Clusters aboundance

Lyman-α forests

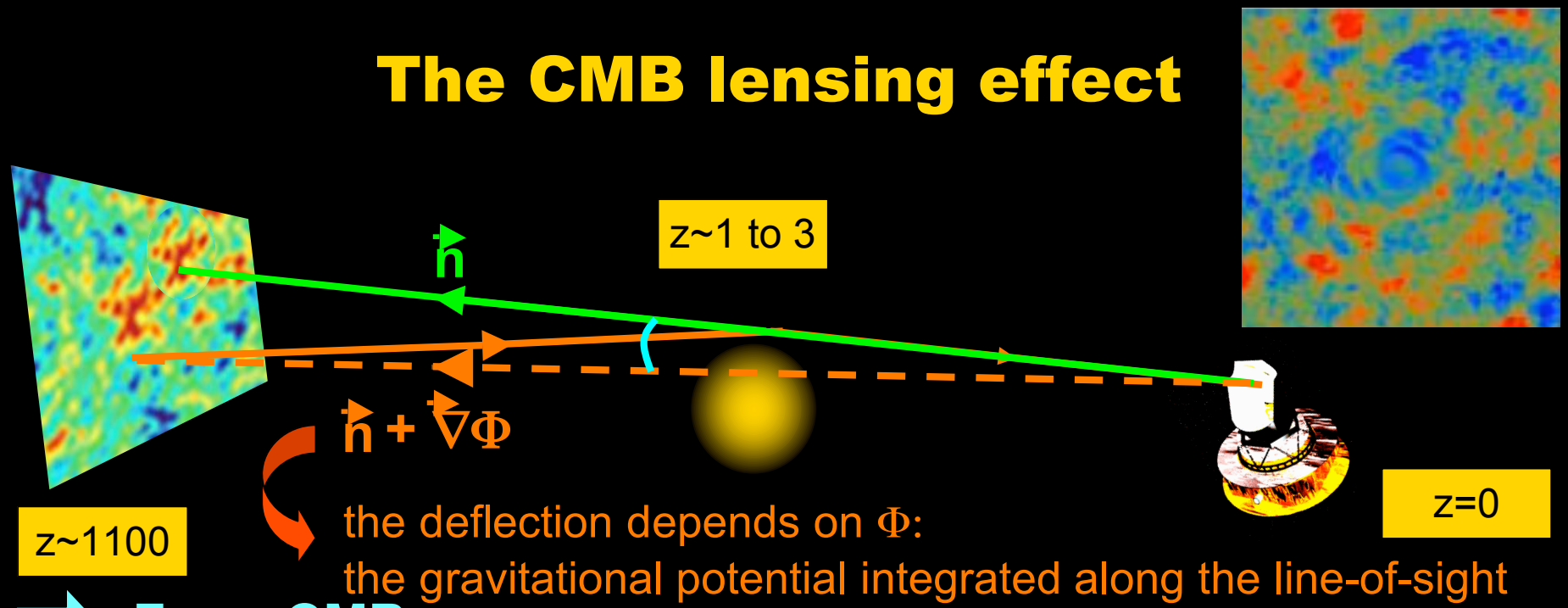
Indirect probes of the total mass of the structures

➡ may suffer from **systematics**

Cosmic shear

the more promising at long-term

The CMB lensing effect



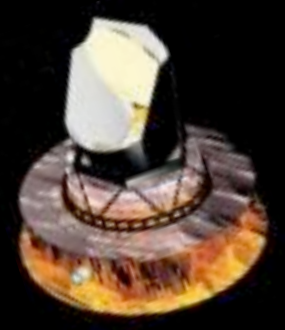
the deflection depends on Φ:
the gravitational potential integrated along the line-of-sight

From CMB maps,
gravitational potential can be statistically reconstructed

an advantageous measure of the matter density

- no bias
- probing high redshift structures: still in their linear regime
- no need to a dedicated experiment

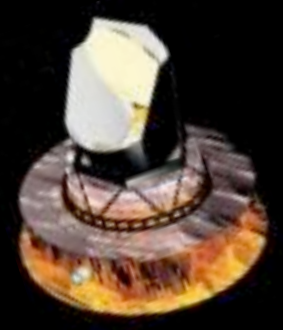
Probing the matter distribution with Planck



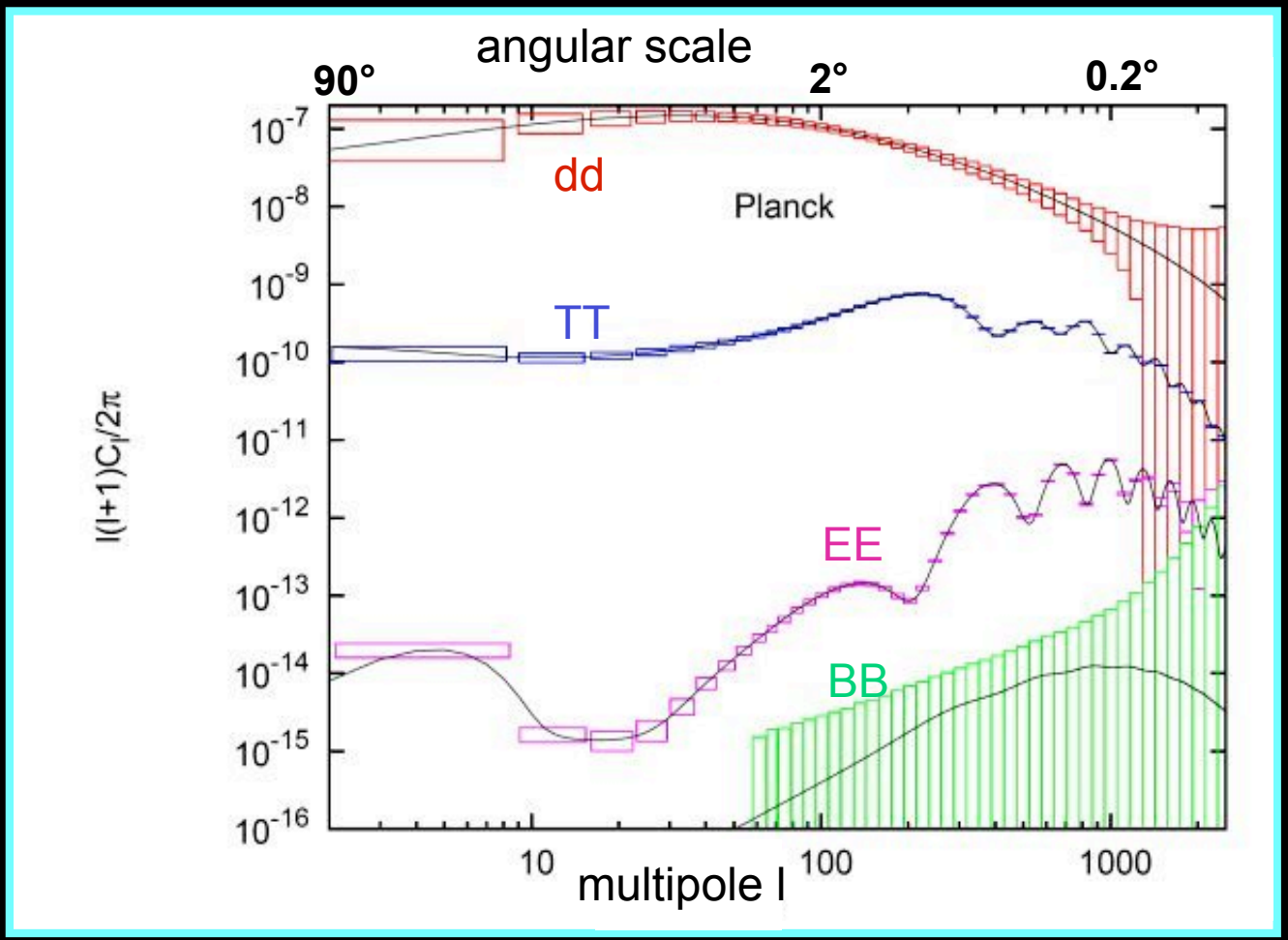
- an european satellite launched in early 2008

- designed to produce high resolution (~5') maps of **temperature** and **polarisation** of CMB anisotropies, with microkelvin sensitivity per resolution element.

Probing the matter distribution with Planck



The expected error on angular power spectra reconstruction:



deflection angles field

Temperature

E-mode (curl-free)

B-mode (gradient-free)

J. Lesgourgues, L. P., S. Pastor, M. Piat [Phys. Rev. D (2006)]

How to get a forecast on the sensitivity to neutrino mass?

Assuming a **fiducial cosmological model**
and for a future experiment with **known specifications**
parameter estimation methods (e. g. Fisher analysis, MCMC method)
can be used to **forecast the sensitivity** to cosmological parameter.

The choice of the fiducial model:

an important test: the robustess of the infered sensitivities against the add of extra-parameters.

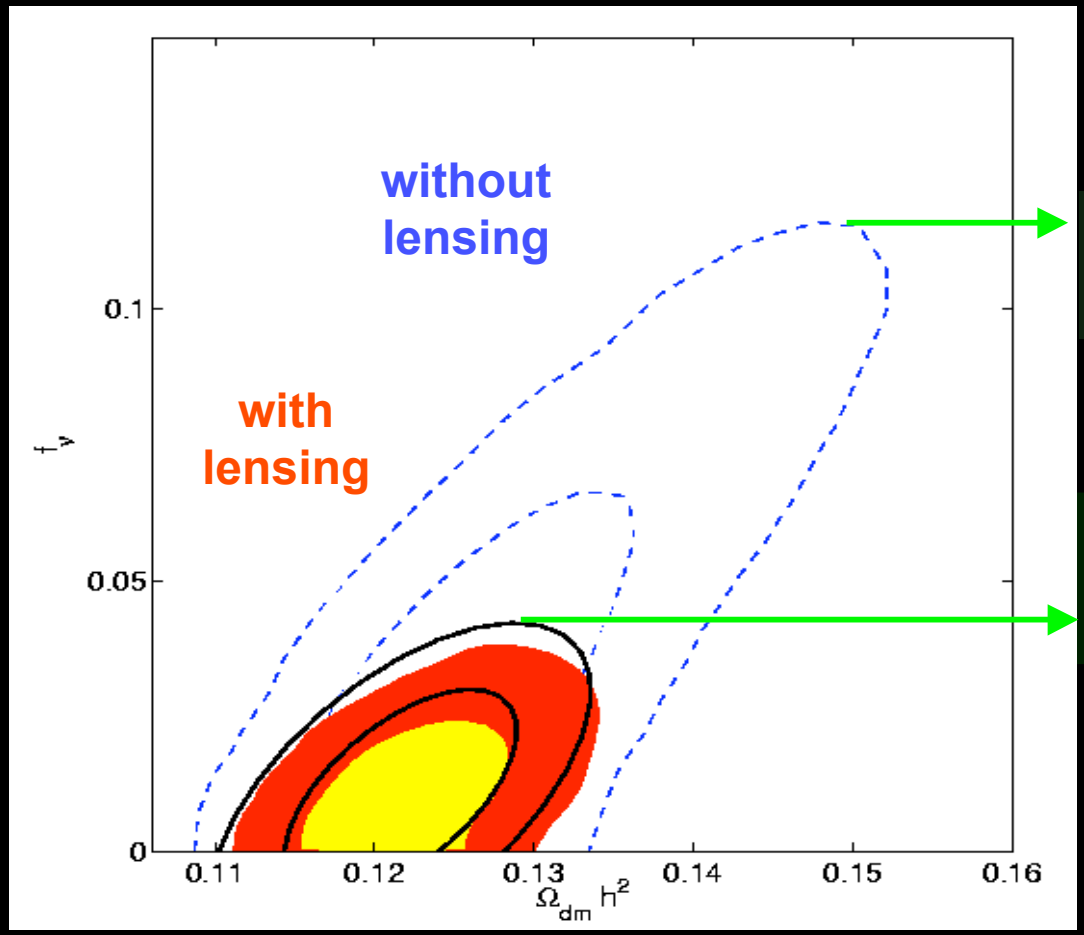
an 11-parameters fiducial model:

(minimal 7p ΛCDM + Σm_ν + 3 (well-motivated) extra-parameters)

Forecast on the Planck sensitivity to M_ν: results

projected 68% and 95% C. L. within the 11-parameters model

$f_\nu = \Omega_\nu / \Omega_{dm}$

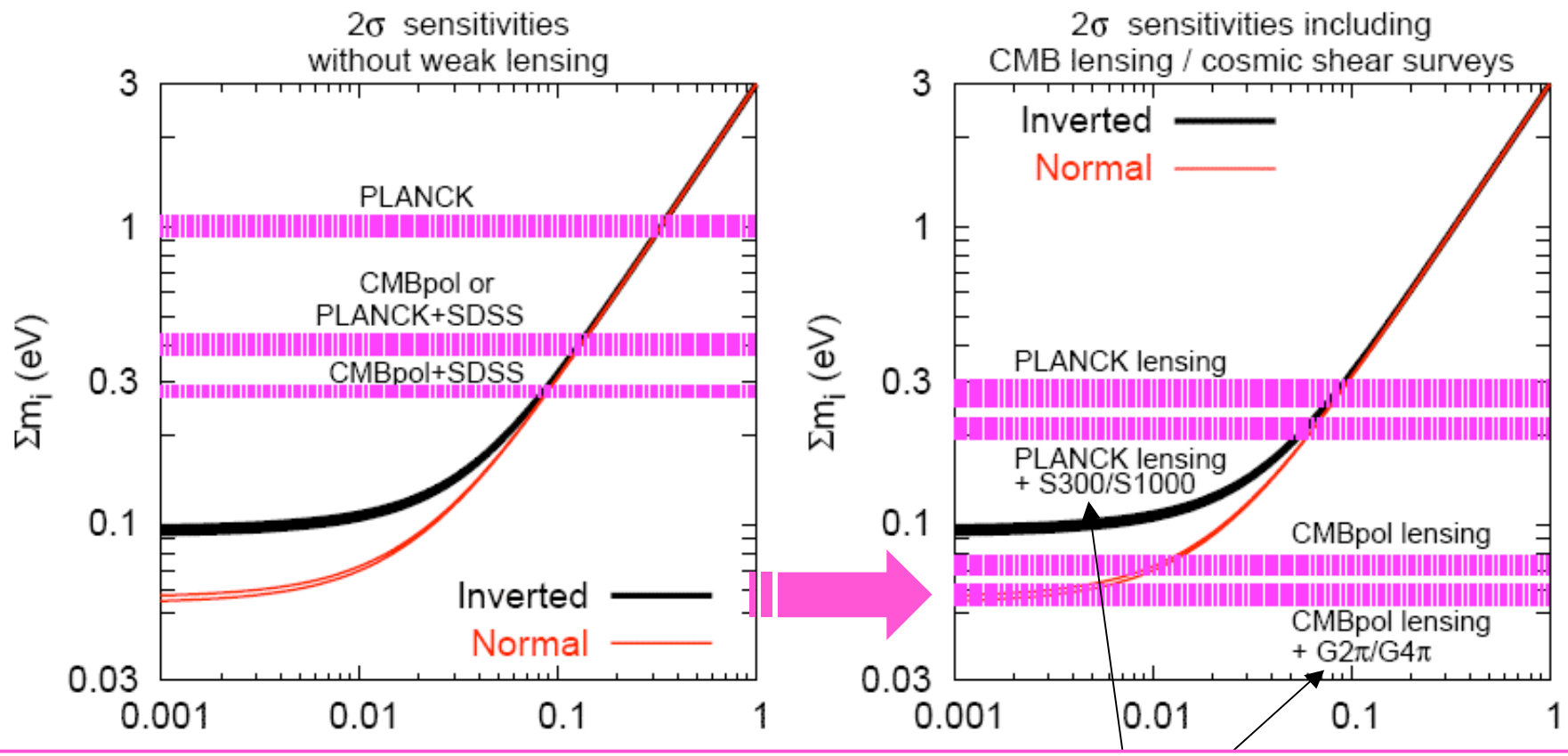


2σ sensitivity to M_ν of 1 eV

2σ sensitivity to M_ν of 0.3 eV

LP, J. Lesgourgues, S. Hannestadt, H. Tu, Y. Wong [astro-ph/06062271]

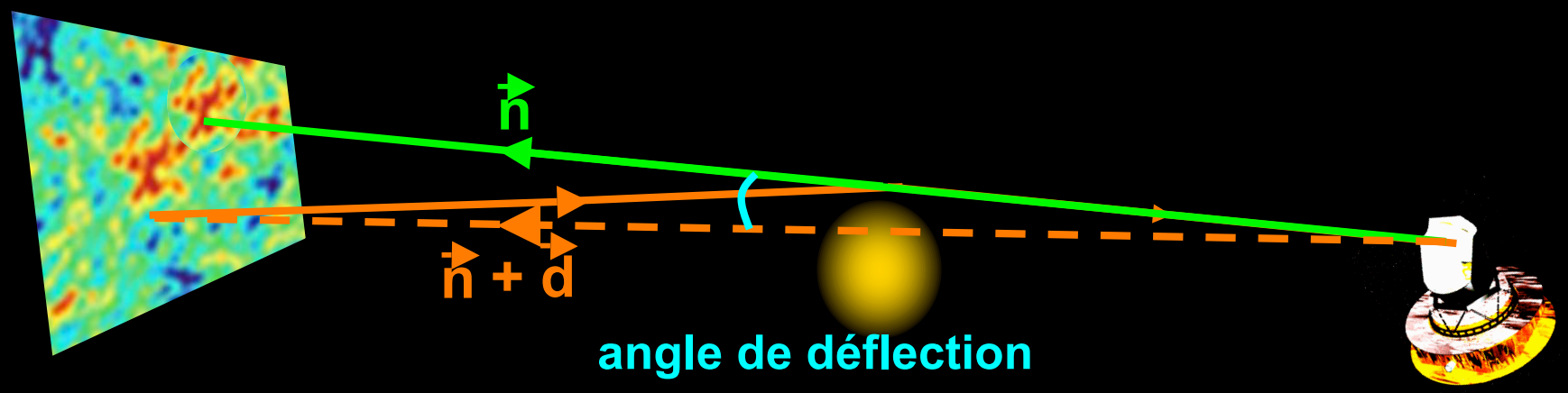
Summary of future sensitivities



At long-term, Cosmology could provide a 2σ detection of Mν regardless how small it is!

FIN

L'effet de lentille gravitationnelle



$$P(\vec{n}) = \tilde{P}(\vec{n} + \vec{d})$$

P = { I, Q, U }, les paramètres de Stokes

$$\vec{d}(\vec{n}) = \vec{\nabla}\Phi(\vec{n})$$

$\Phi(\vec{n})$ le potentiel gravitationnel projeté le long de la ligne de visée

➡ méthodes d'extraction des lentilles $C_l^{dd} = l(l+1)C_l^{\Phi\Phi}$

How to get a forecast on the sensitivity to neutrino mass?

Assuming a **fiducial cosmological model**
and for a future experiment with **known specifications**
parameter estimation methods (e. g. Fisher analysis, MCMC method)
can be used to **forecast the sensitivity** to cosmological parameter.

The choice of the fiducial model:

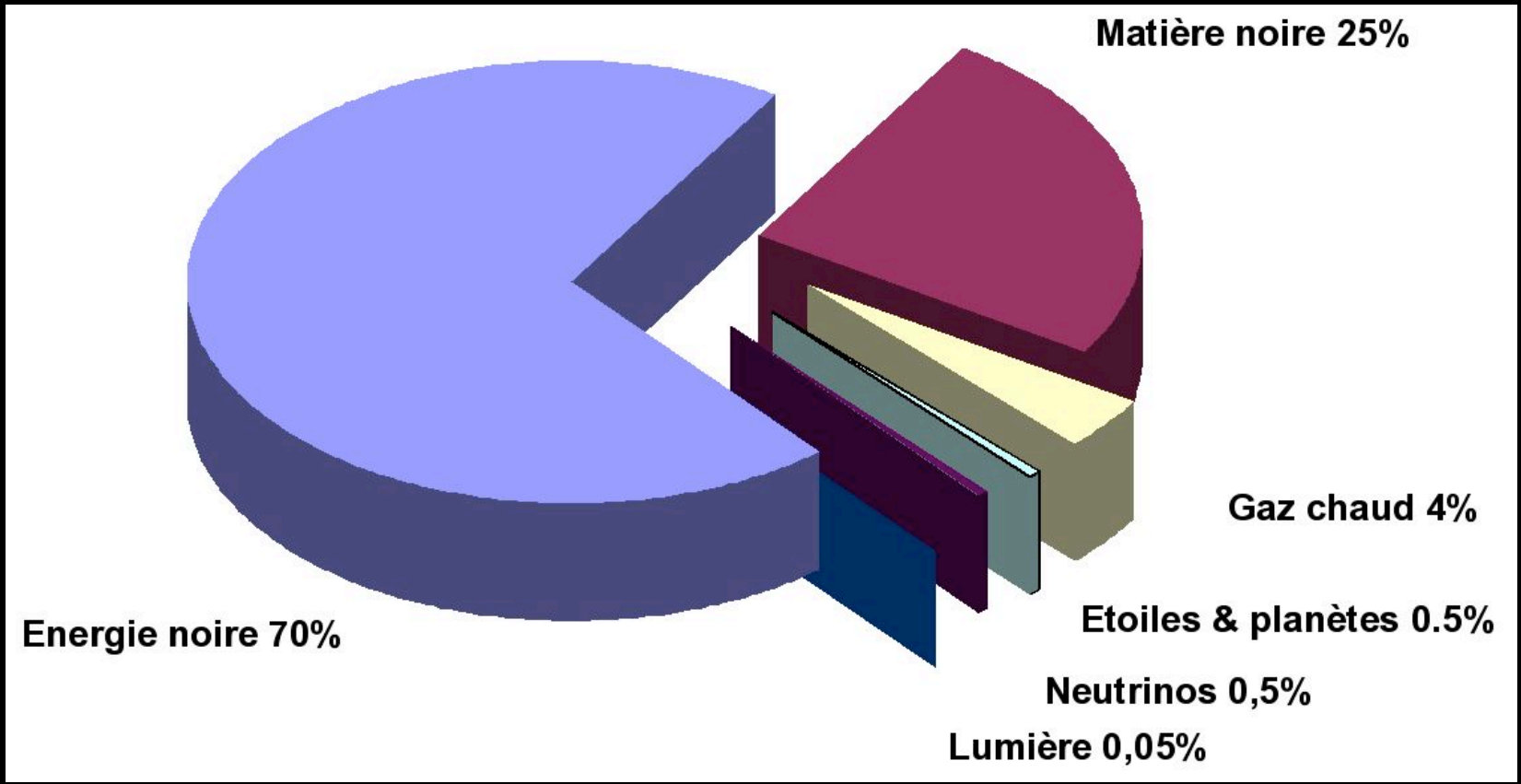
$$(\Omega_b h^2 , \Omega_m h^2 , \Omega_\Lambda , A_s , n_s , \tau , Y_{He} , \Sigma m_\nu , w, \alpha, N_{eff}) =$$
$$(0.0245 , 0.148 , 0.70 , 0.8 , 0.98 , 0.12 , 0.24 , 0.1 , -1 , 0 , 3.04)$$

all data best-fit model

well_motivated potentially detectable parameter

extra parameters

Le modèle « Standard » de la Cosmologie

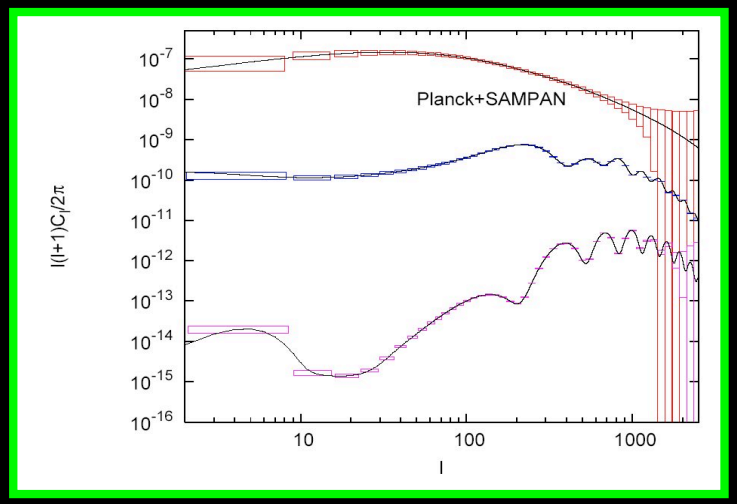


Forecast on the Planck sentivity to M_nu: method

Fidicial cosmological model

Experimental characteristics

Linear perturbation theory



Exploring parameters space

Forecast of the sensitivity to parameters

Les motivations

Expériences d'oscillations : au moins 2 neutrinos massifs

$$\Delta m^2_{\rm atm} = \Delta m^2_{32} = (2.4^{+0.5}_{-0.6}) \times 10^{-3}\ {\rm eV}^2 (2\sigma)$$
$$\Delta m^2_{\rm sun} = \Delta m^2_{21} = (8.0^{+0.7}_{-0.6}) \times 10^{-5}\ {\rm eV}^2 (2\sigma)$$

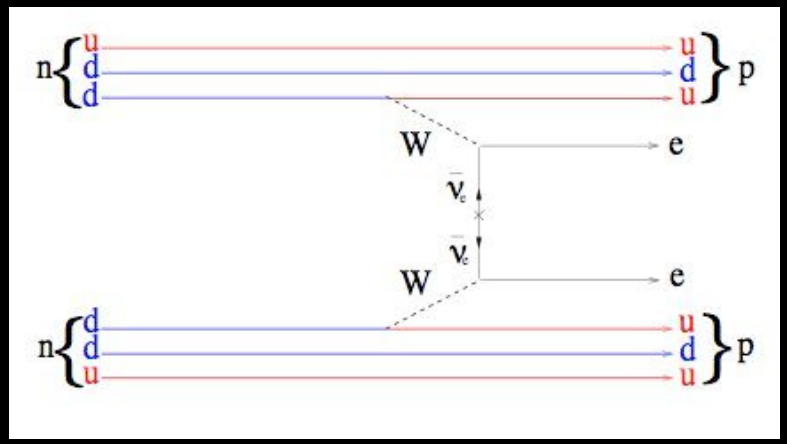
Faibles contraintes sur la masse (échelle absolue) par les exp. terrestres

Désintégration du tritium

$$m_\nu < 2.2\ {\rm eV}\ (95\%\ {\rm C.L.})$$

Mainz et Troitsk

Double β sans neutrinos



Les signatures des neutrinos massifs

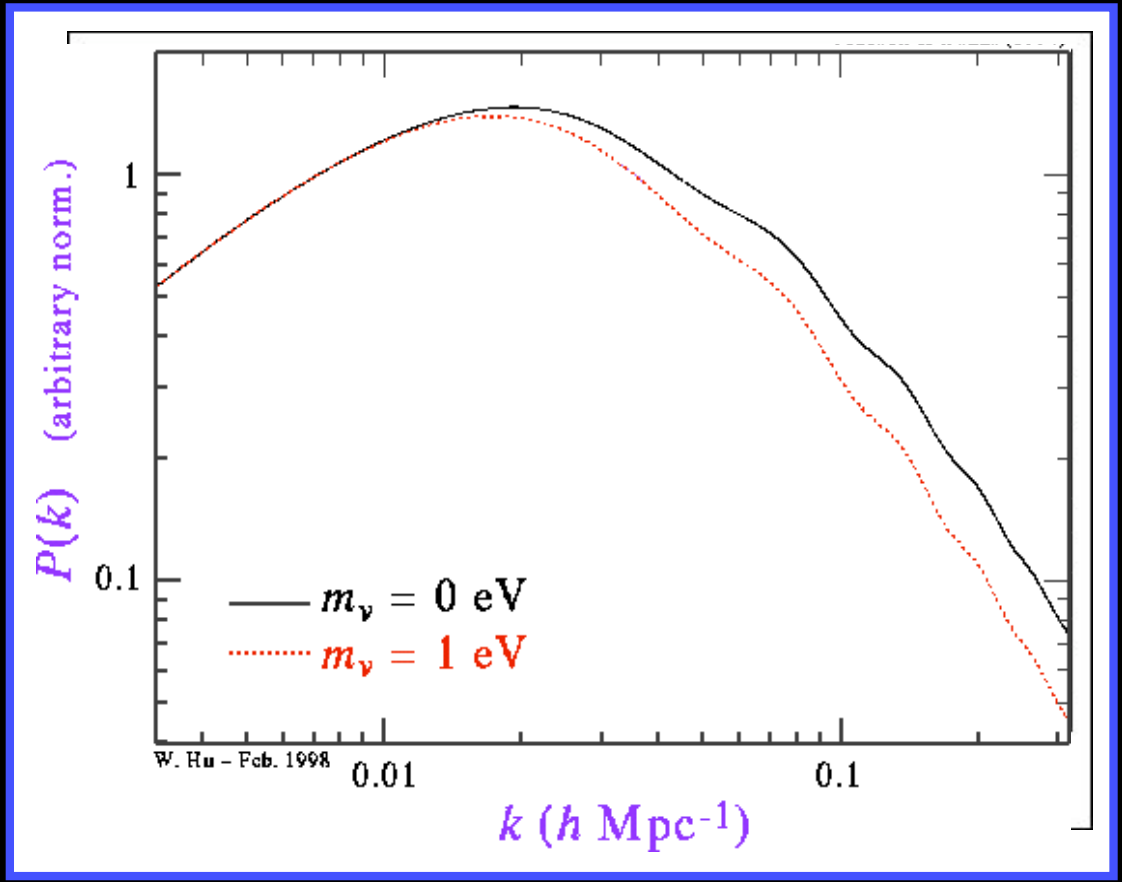
Effet du fond de neutrinos :

$$\Omega_\nu = \frac{\rho_\nu}{\rho_c} = \frac{M_\nu}{93.14\, h^2 \text{ eV}}$$

$M_\nu = m_1 + m_2 + m_3$

h : paramètre de Hubble

unité : $100 \text{ km s}^{-1} \text{ Mpc}^{-1}$



Effet de « free-streaming » :

Statut de l'analyse

Les meilleures contraintes actuelles

WMAP + SDSS $M_\nu < 1\,\mathrm{eV}\ (95\ \mathrm{C.L.})$

Prédictions des contraintes futures

CMB + relevé de redshifts de galaxies

J. Lesgourgues (LAPTH), S. Pastor (Univ. Valencia), L. Perotto (APC)
Phys. Rev. D (2004)

CMB seul

J. Lesgourgues (LAPTH), L. Perotto (APC),
S. Pastor (Univ. Valencia), M. Piat (APC)
Phys. Rev. D (2006)

Introduction de l'effet de lentille

T, E, B → $\tilde{T}, \tilde{E}$ + $\vec{d}$

non gaussiennes — gaussiennes

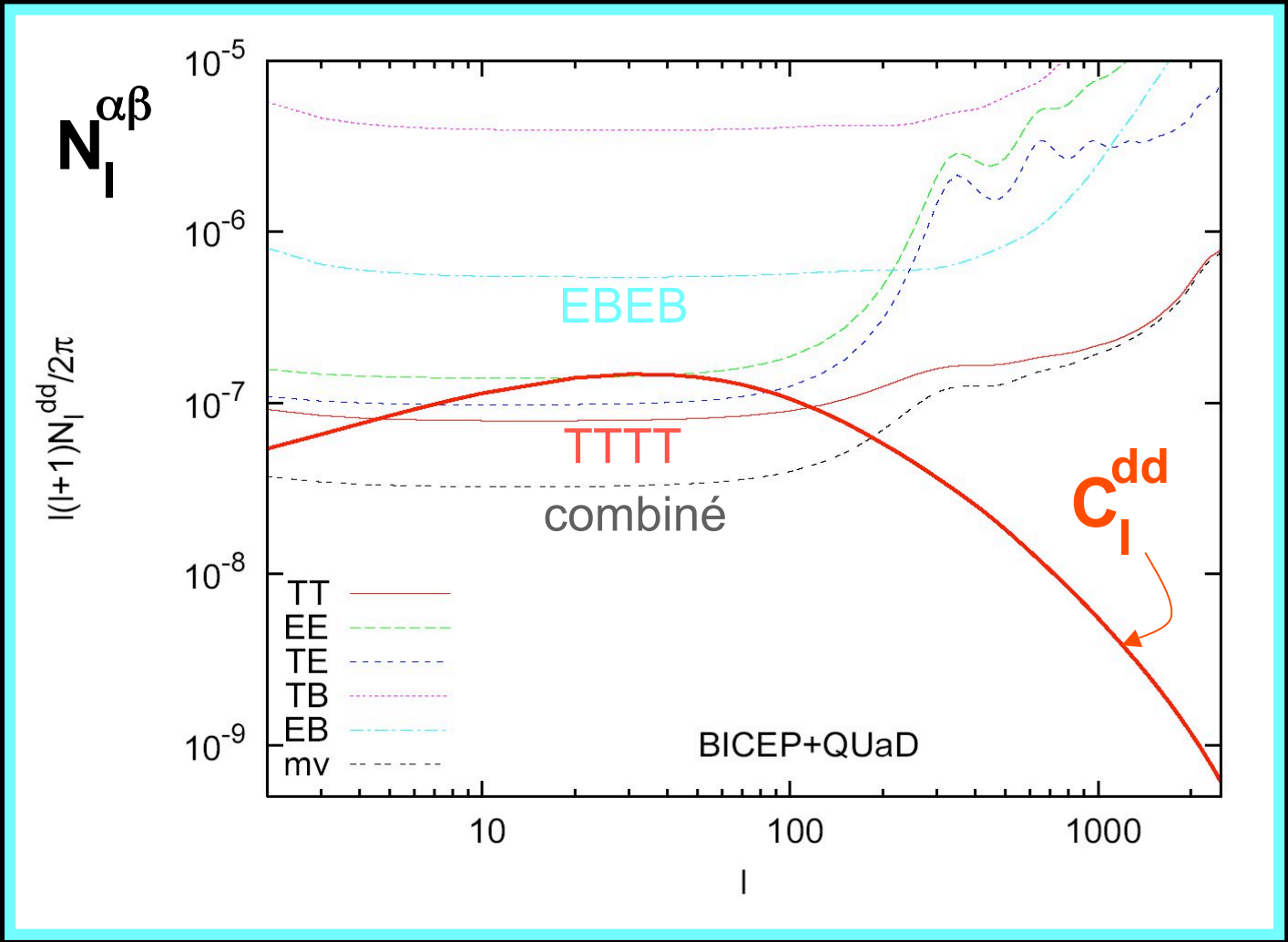
$\hat{d}^{\alpha}_{LM}$ Somme pondérée de produits d'observables lentillées

α = TT, TE, TB, EE, EB

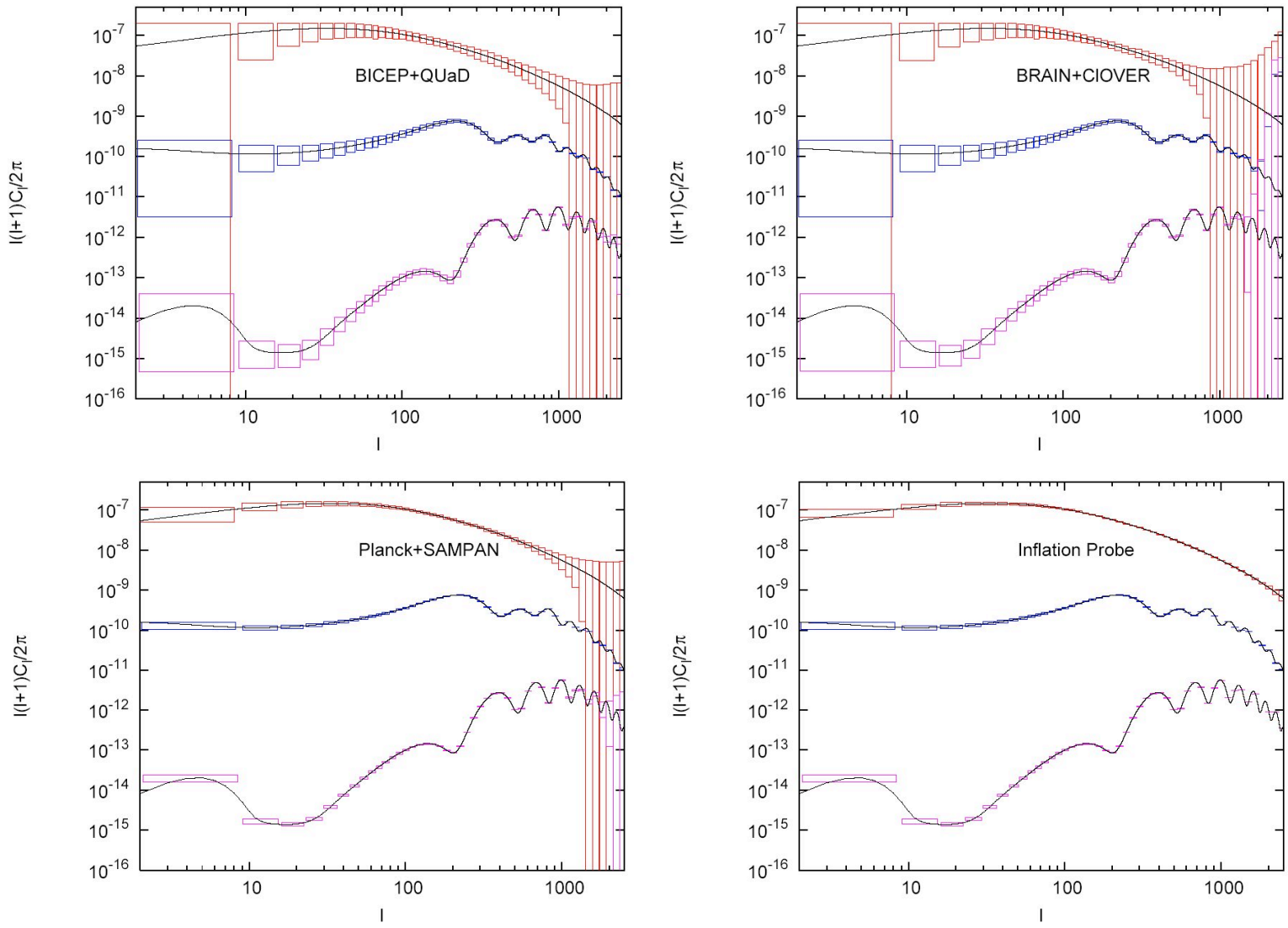
$$< \hat{d}^{\alpha}_{LM} \hat{d}^{\beta *}_{L'M'} > \equiv \delta_{L,L'} \delta_{M,M'} \left[C^{dd}_{L} + N^{\alpha\beta}_{L} \right]$$

bruit de la méthode
bruit instrumental

Le bruit de l'estimation des lentilles



Sensibilité des expériences futures

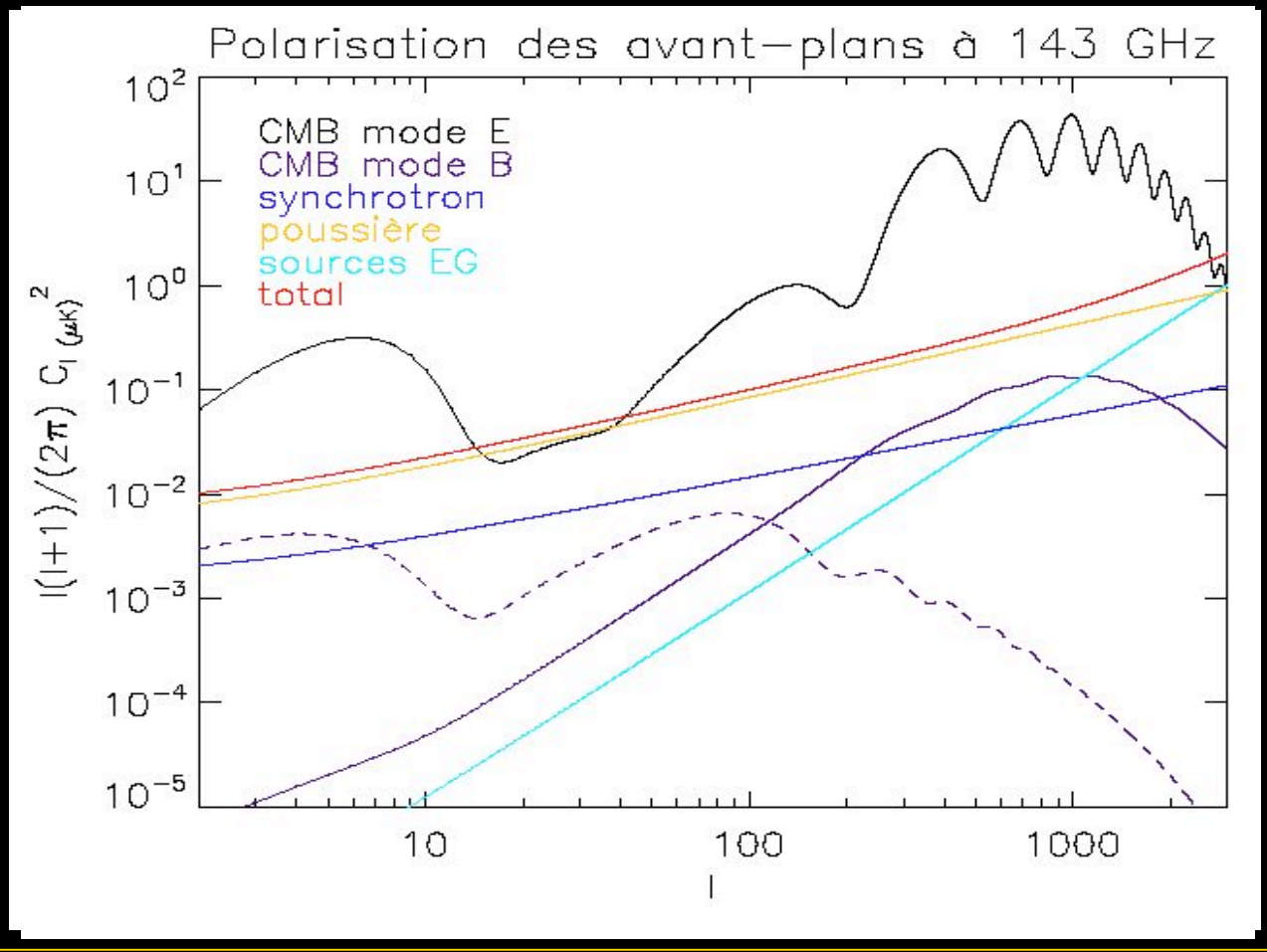


Introduction des avant-plans

Hyp : non-corrélés au signal ni au bruit instrumental

Composante de bruit supplémentaire

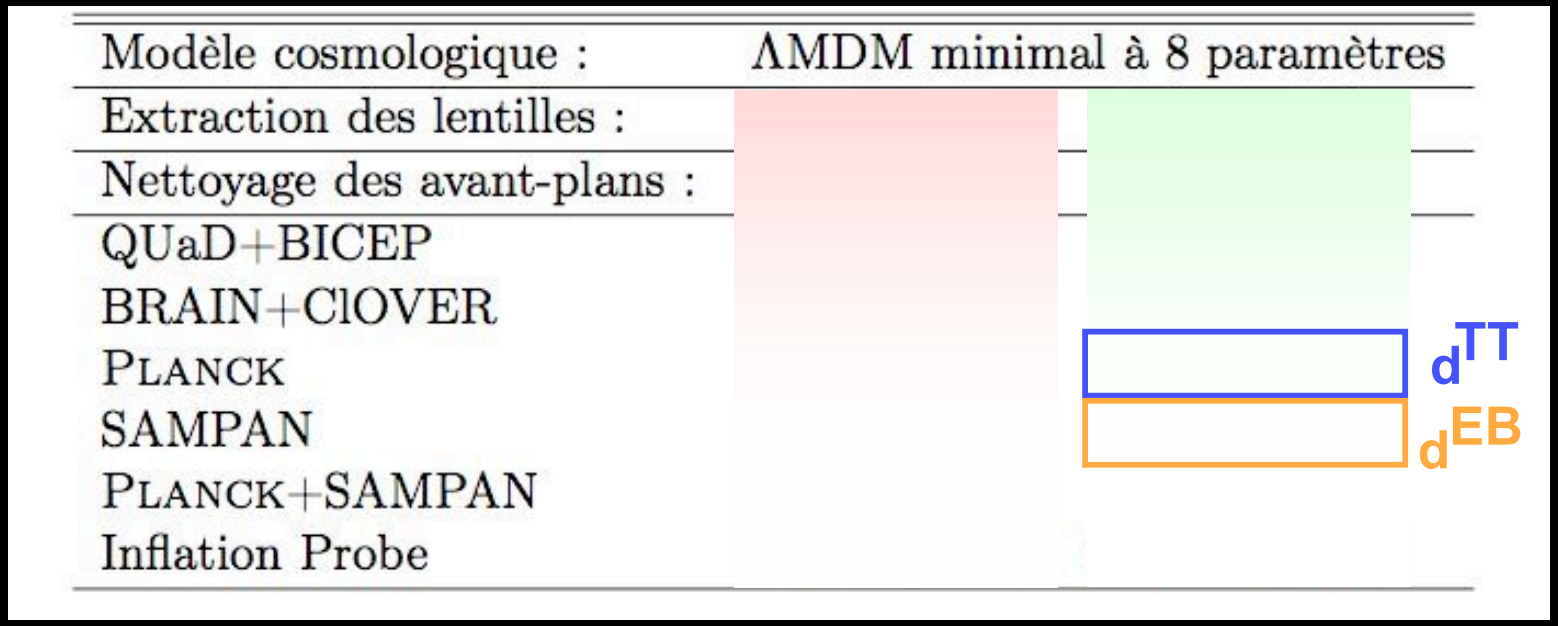
M. Tegmark et al.
(astro-ph/9905257)

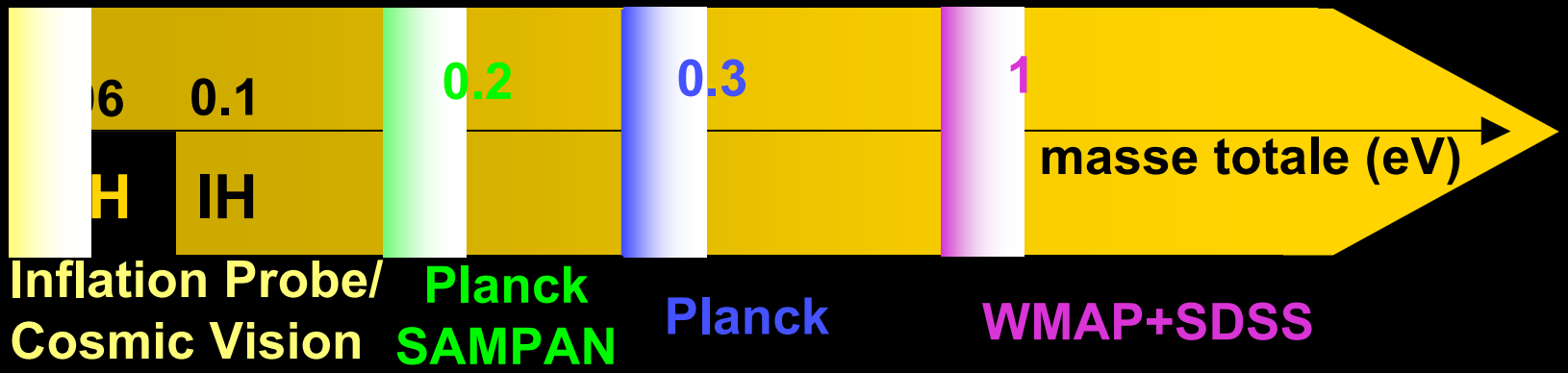


Hyp :
isotropes,
gaussiens,
corrélations EB
et TB nulles

Résultats

sensibilités à la somme des masses des neutrinos en eV

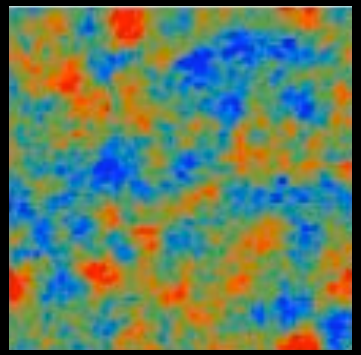


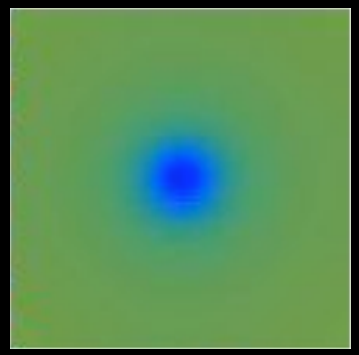


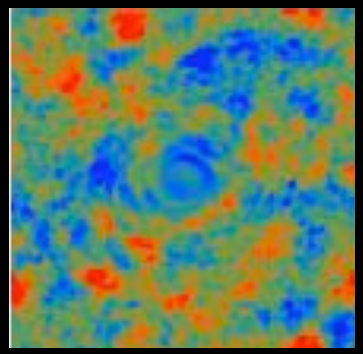
Effet de lentille sur les cartes planes

$$\mathbf{P}(\hat{\vec{n}}) = \tilde{\mathbf{P}}(\hat{\vec{n}} + \vec{\nabla}\Phi(\hat{\vec{n}}))$$

$$\mathbf{P} = \{I, Q, U\}$$



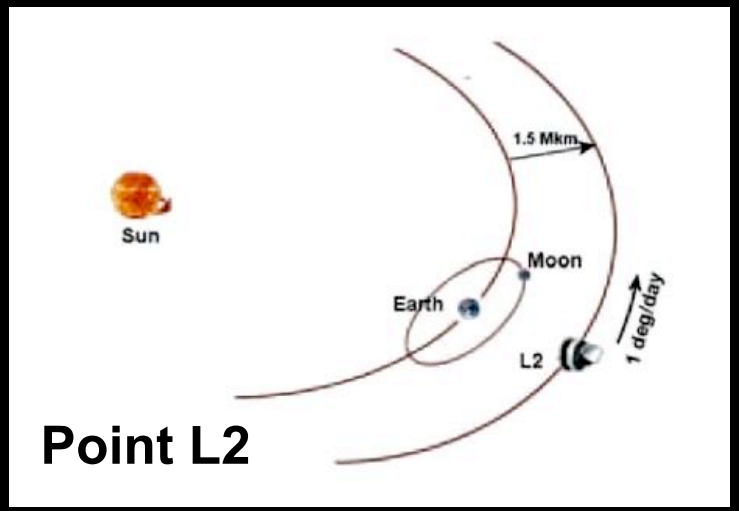




Corrélations supplémentaires entre :

- **observables T, E, B du CMB**
- **modes de Fourier différents d'une même observable**

La mission Planck



Point L2

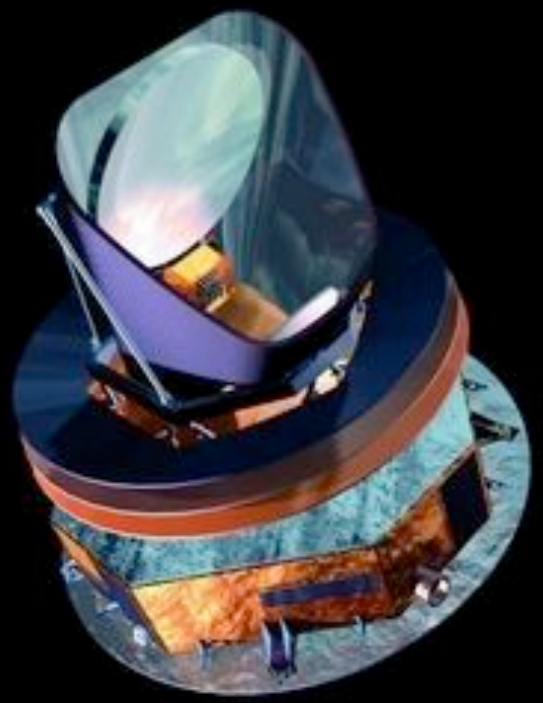
~6 mois :
un ciel complet

Télescope :

Refroidissement passif

Plan focal :

2 instruments LFI et HFI
9 canaux couvrant de 20 GHz à 1 THz
Cryogénie



Les traceurs des neutrinos

Lumière

Sondage de redshifts de galaxies

Forêts Lyman alpha

} Biais possibles

Effet gravitationnel

Cisaillement moyen des galaxies

➡ Actuellement peu de données, le plus prometteur à long terme

Effet de lentille du CMB

➡ Méthodes d'extraction du spectre du potentiel gravitationnel dans les données CMB