# Reionisation à petite et grande échelle mesurée par le CMB

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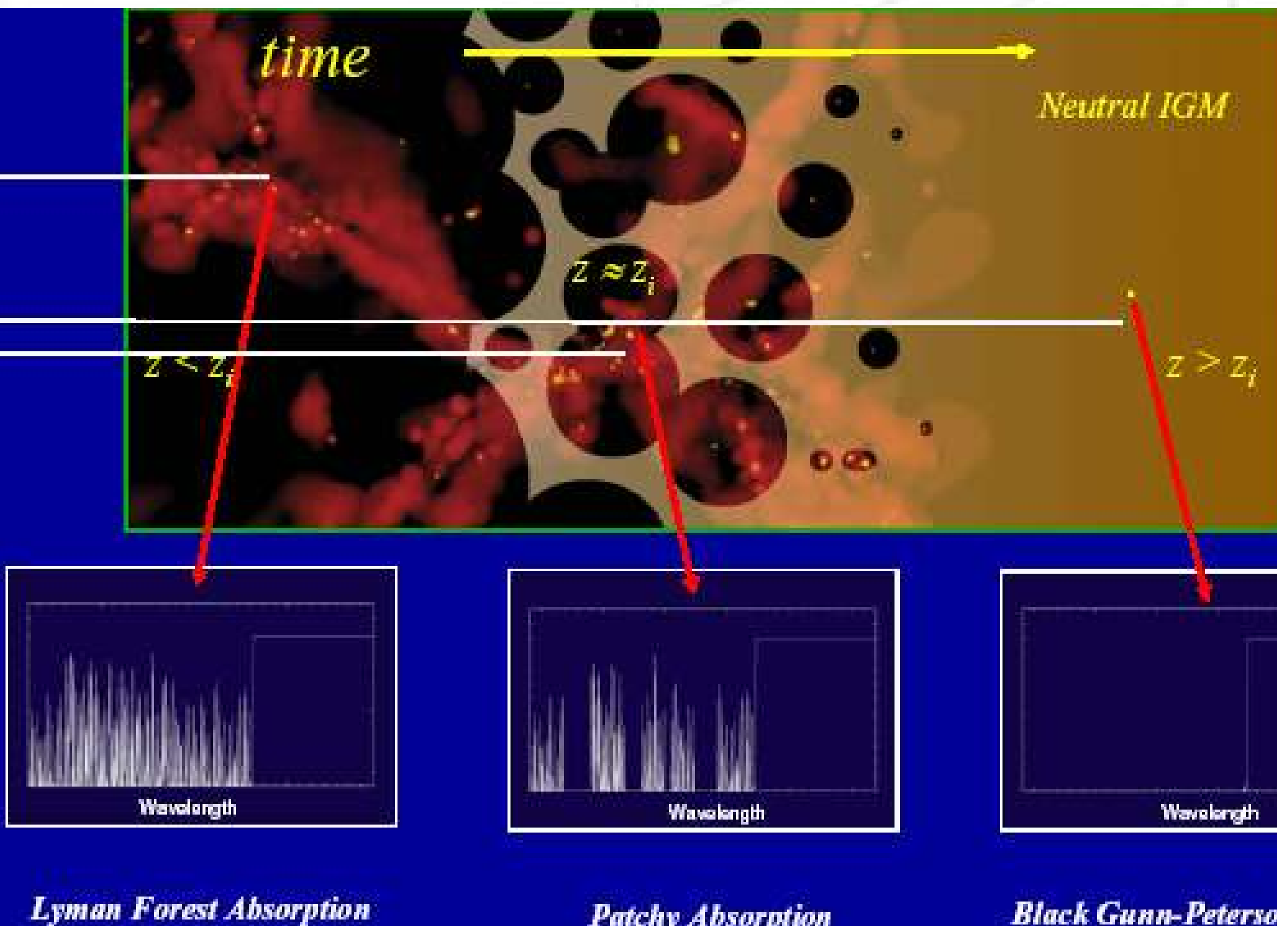
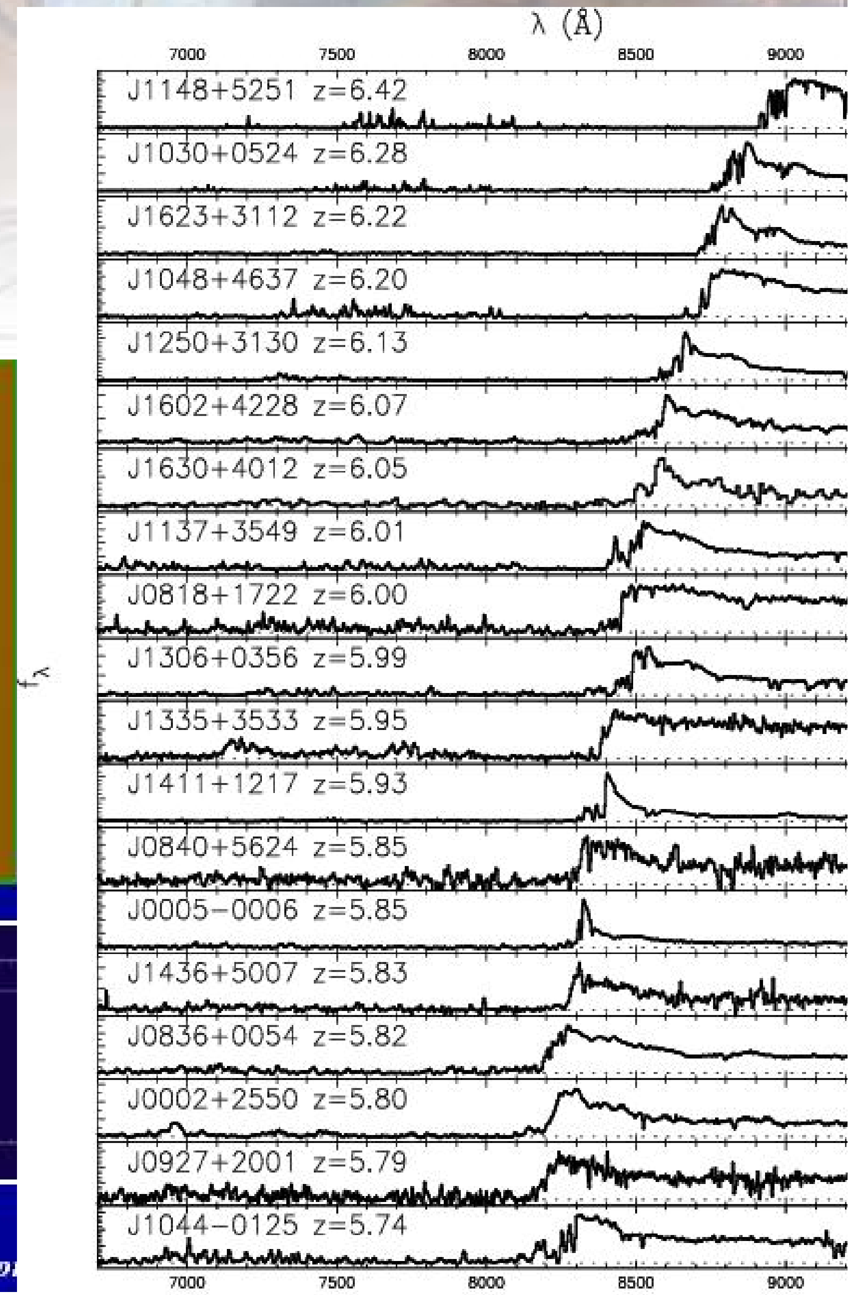
Reionisation = transition from neutral to ionised between z~1000 and z~20 to 6

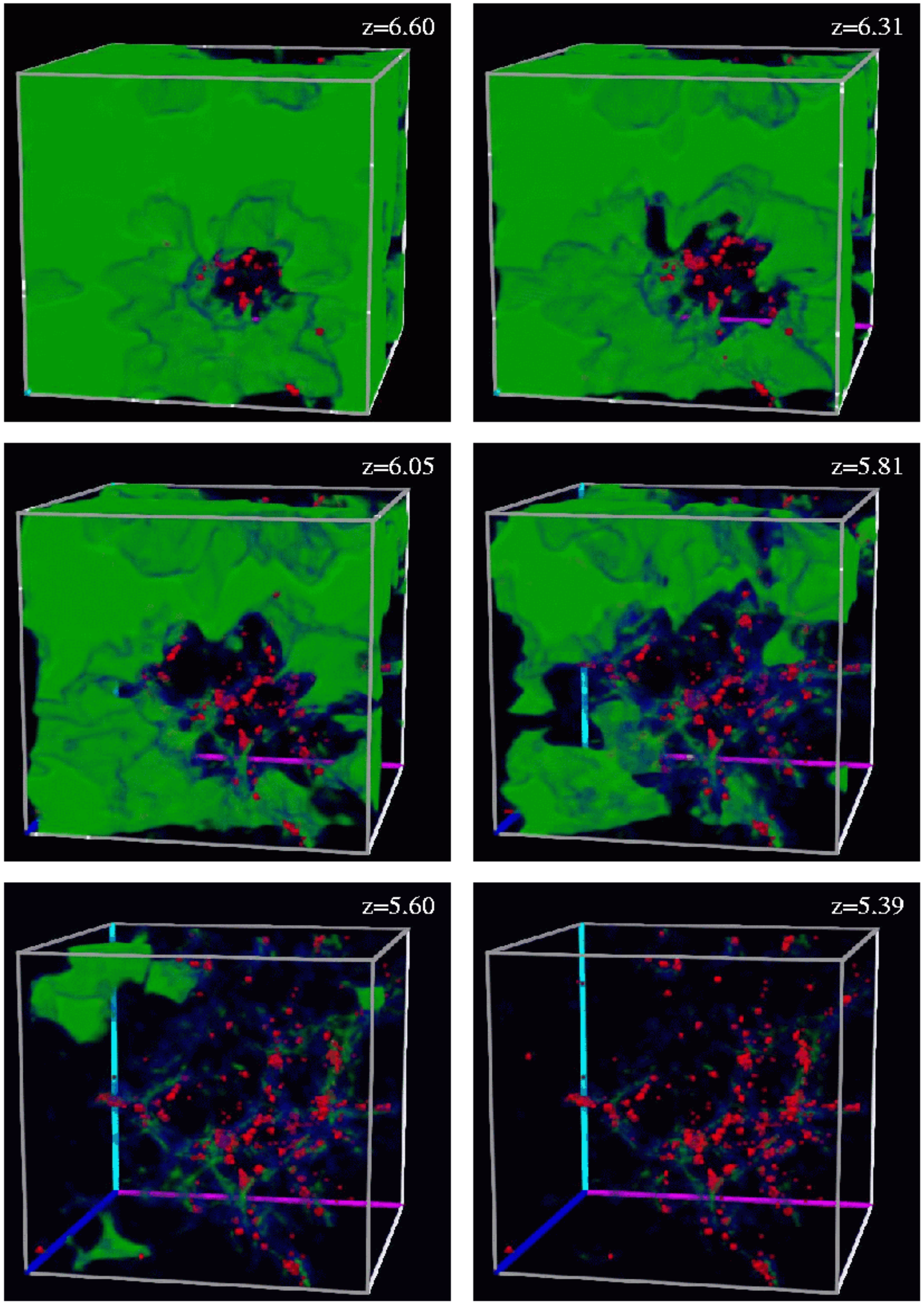
One observational evidence for reionisation:

**Gun-Peterson test**

Back in time, universe is more and more neutral





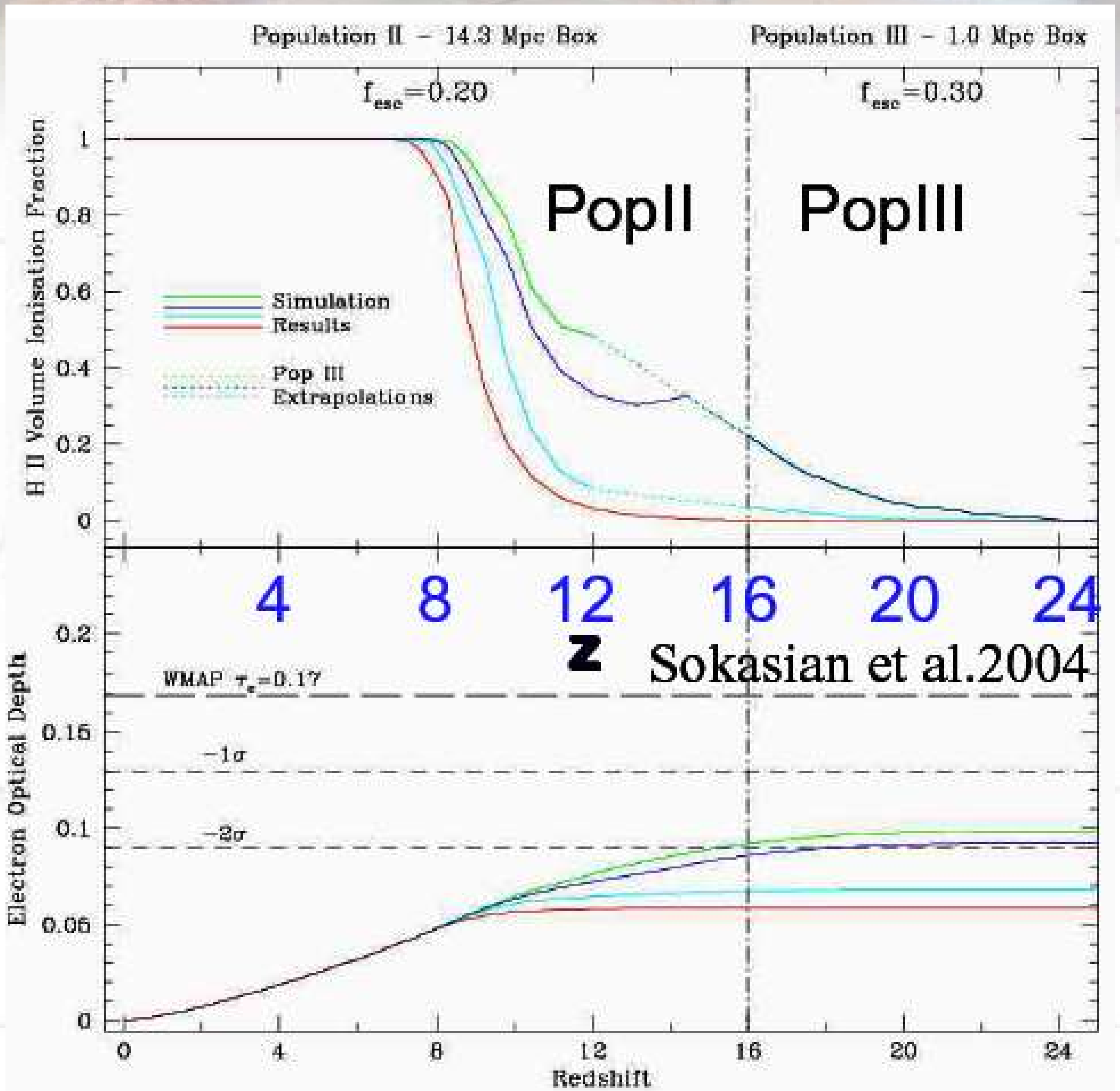

* When and how long did reionisation take place? Can we test for reionisation models?

* What are the source of ionising photons: objects? particles?

* What are the first emitting objects formed: mini-BH? metal free massive stars (pop III)? star-burts galaxies?

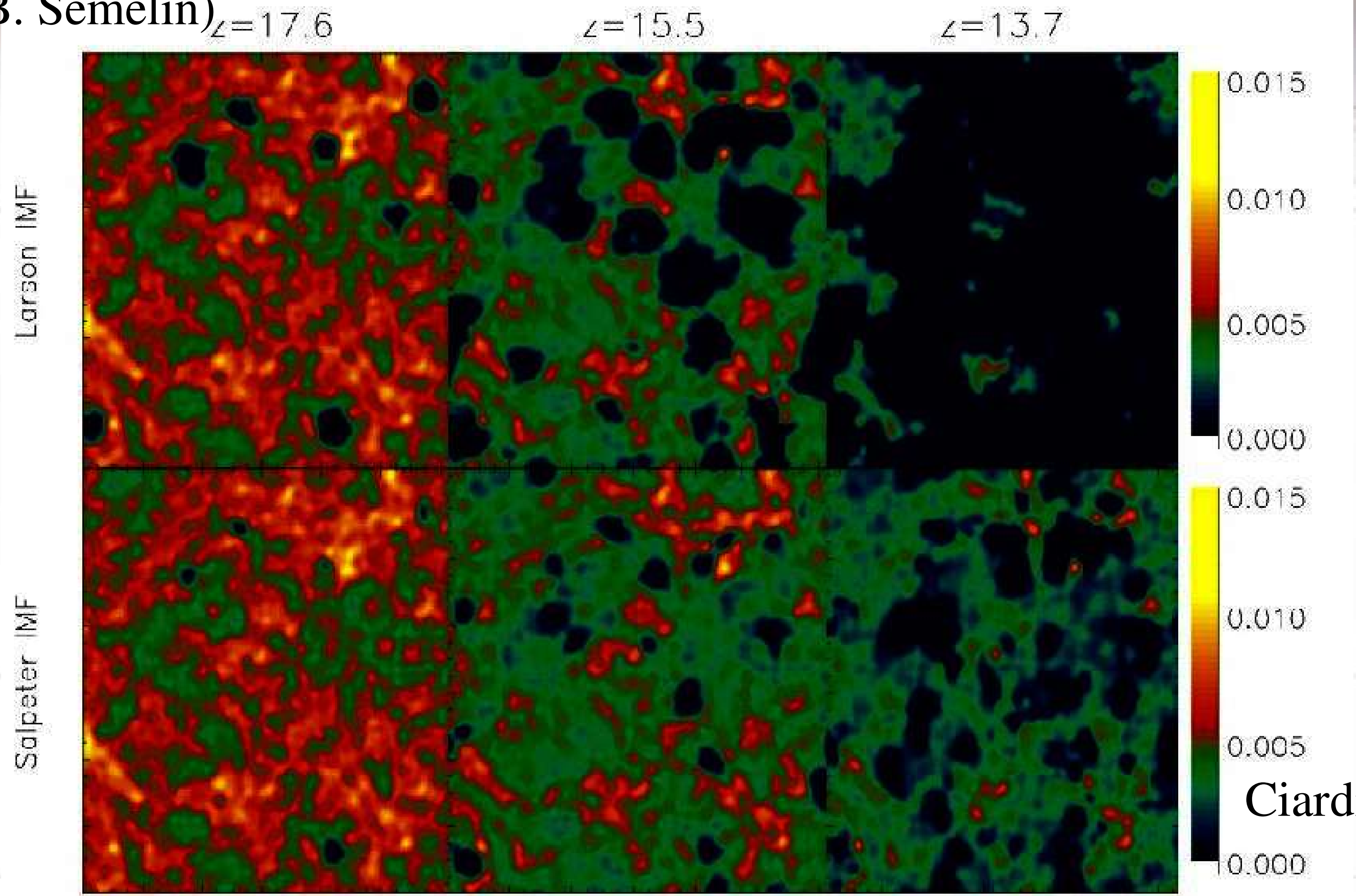
* What are the different signatures?

# Global properties of reionisation: ionisation fraction & optical depth



# Topological properties of reionisation

Different evolution and distribution of sources -> different reionisation histories. Here, simulations with 2 different IMF (talk by J. Devriendt, B. Semelin)

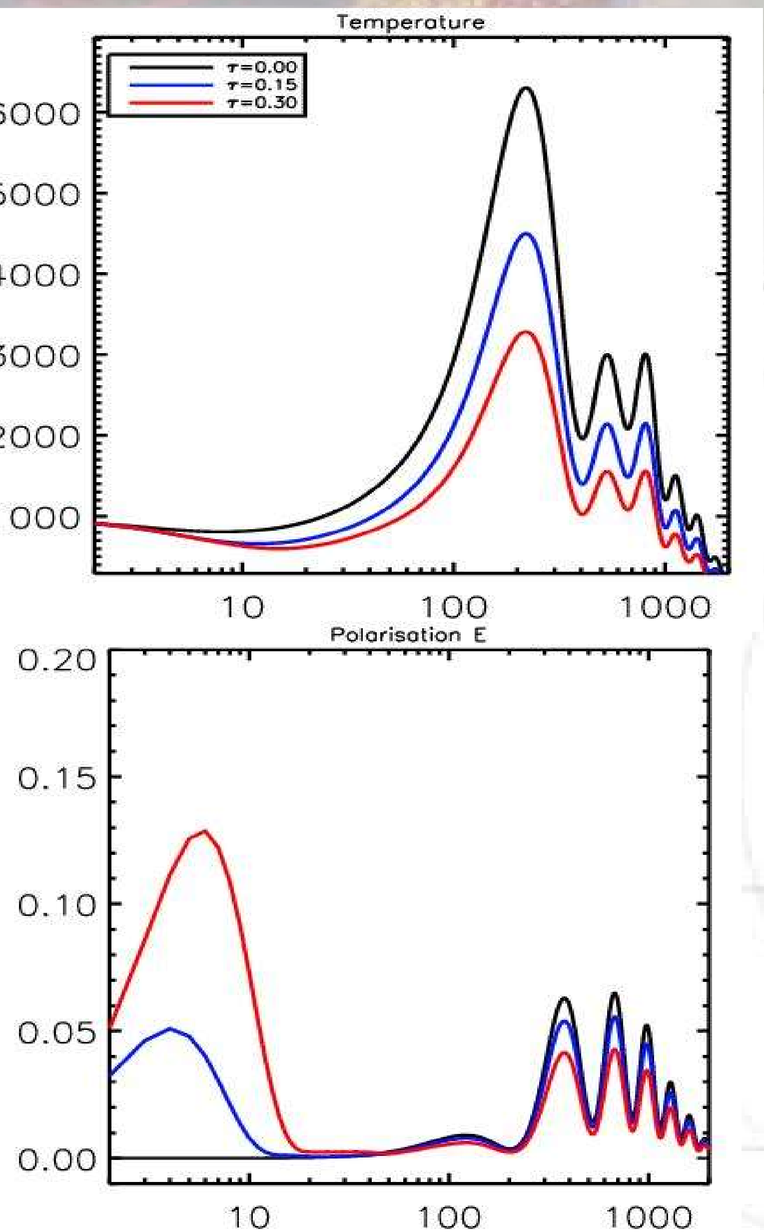



Ciardi et al. 03

# CMB polarisation and temperature

E modes (scattering) probe ionised phases: decoupling and reionisation

Reionisation -> large scales & peaks -> Optical depth, reion. epoch



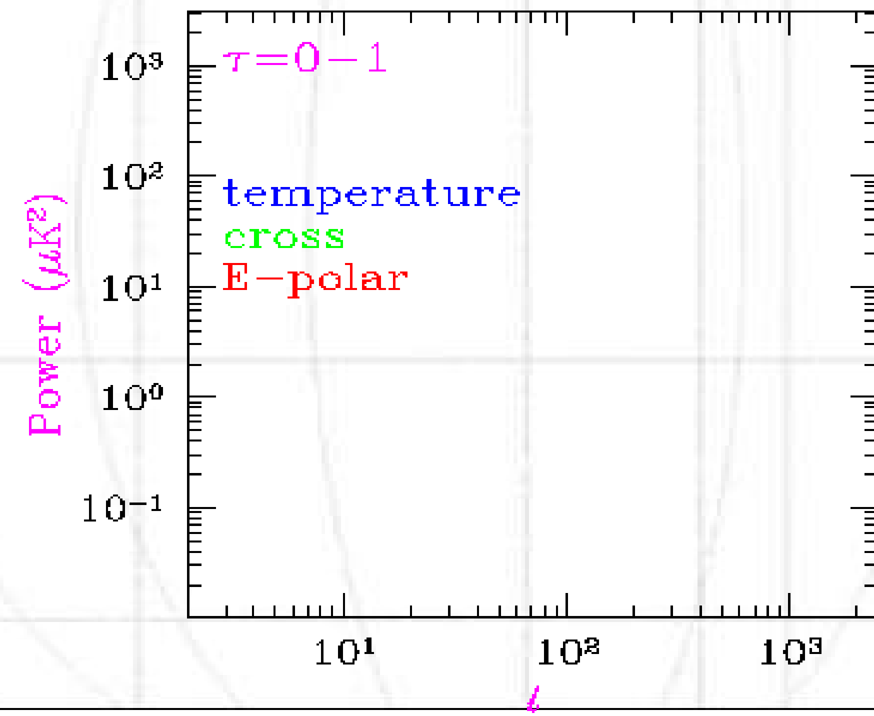

Damping of temp. anisotropies

Bump in EE spectrum at large scales :

    <u>position</u> = horizon at reionisation -> reionisation redshift

    <u>width</u> -> duration of reionisation

    <u>amplitude</u> proportional (optical depth)^2



# Reionisation effects at small angular scales

$$\frac{\Delta T}{T}(\theta) = \int \mathrm{d}\eta\, a(\eta) g(\eta) v_{\mathrm{r}}(\theta, \eta) = - \int \mathrm{d}t\, \sigma_T \mathrm{e}^{-\tau(\theta,t)} n_e(\theta,t) v_r(\theta,t)$$

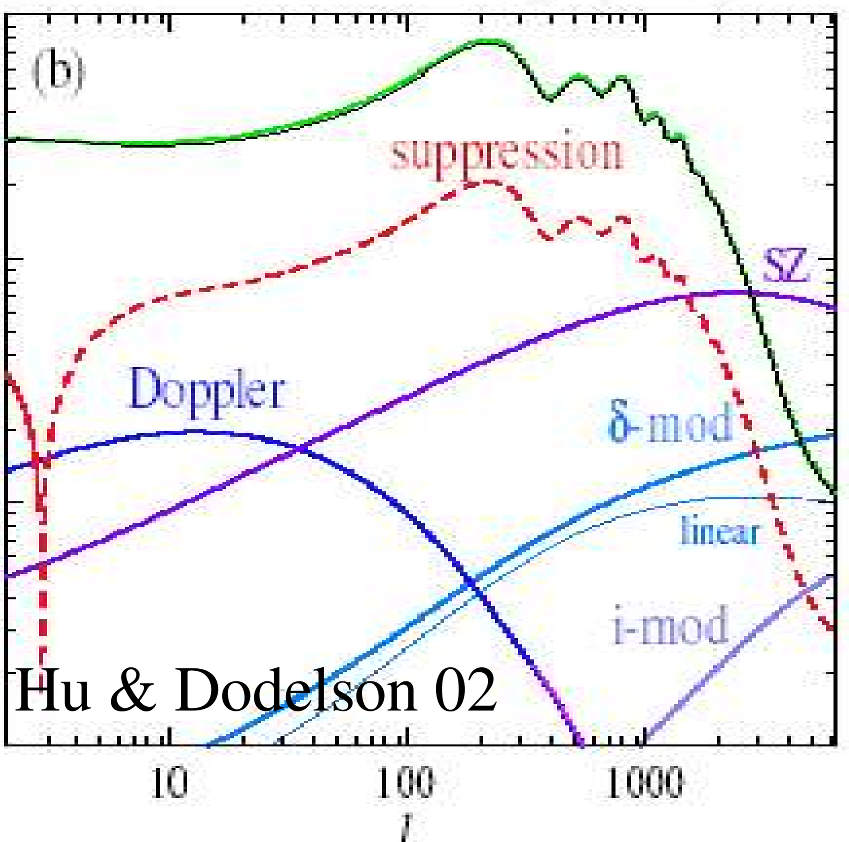
$$n_e(\theta,t) = \bar{n}_e(\theta,t)[1+\delta+\delta_{\chi_e}]$$

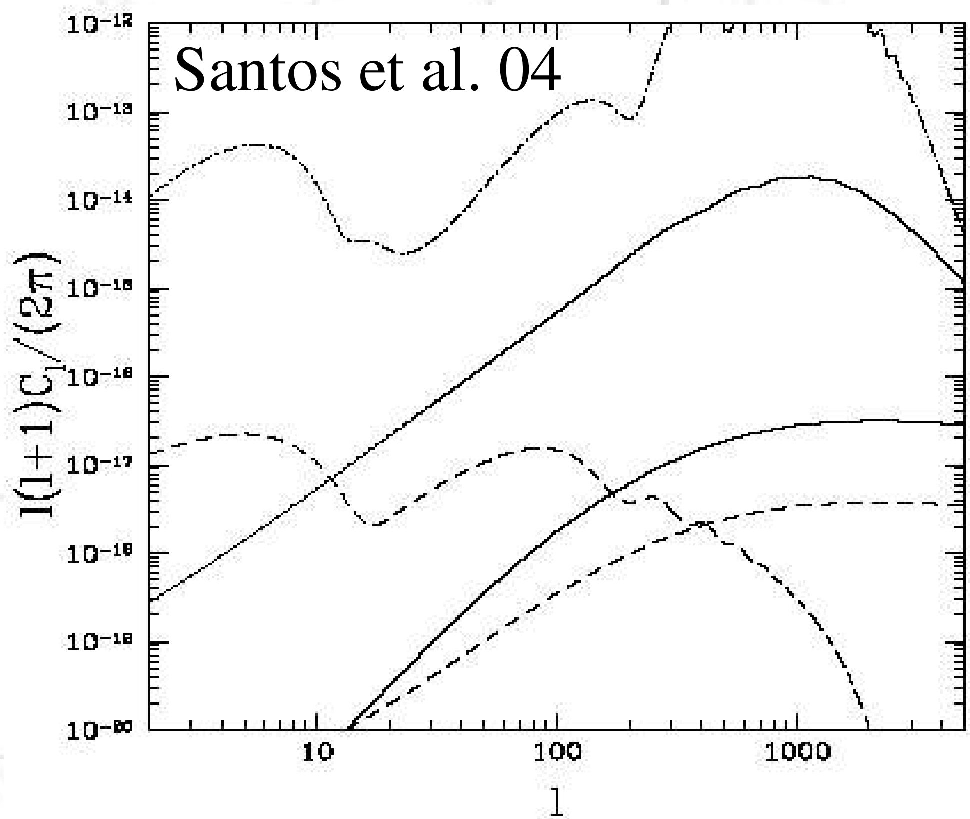
Density modulation: OV (linear) + non-linear

Ionisation modulation: Inhomogeneous reionisation

Polarisation second. anisotropies

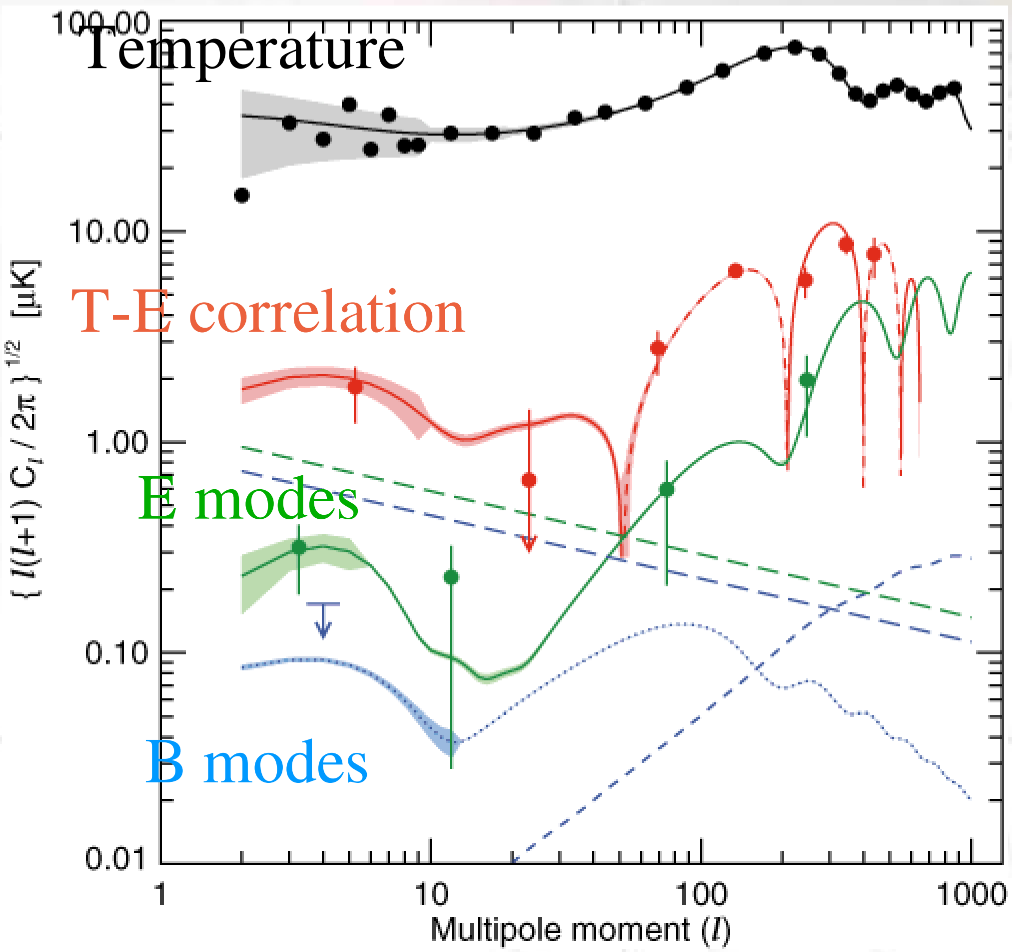
$$\Delta_{Q\pm iU} \propto \int d\tau\, g(\tau) Q_{\mathrm{rms}} \delta_e \propto \kappa Q_{\mathrm{rms}} \delta_e.$$

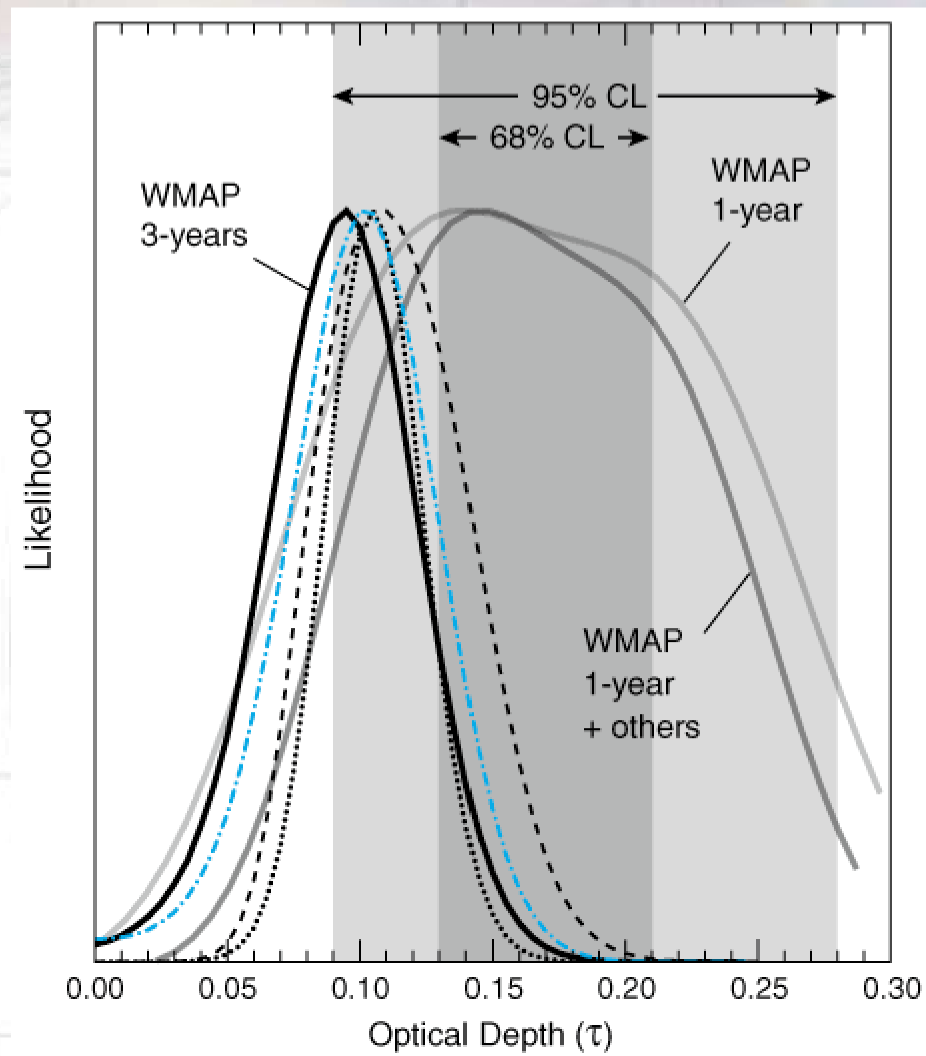


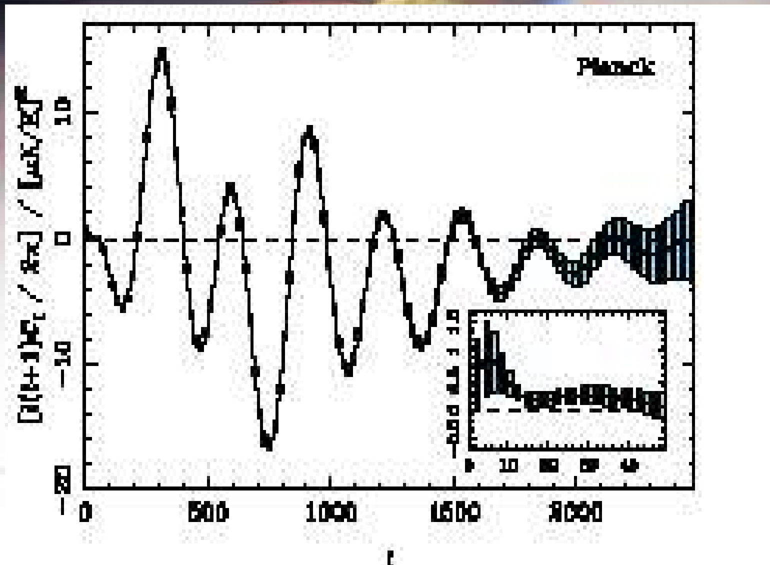
# Present situation: WMAP-3yrs results

Optical depth ~0.09
Reionisation redshift ~ 10

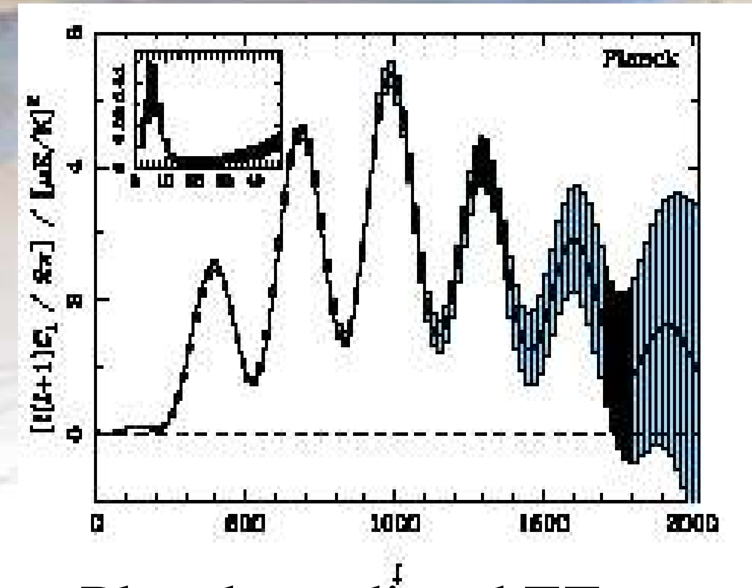



Courtesy WMAP team



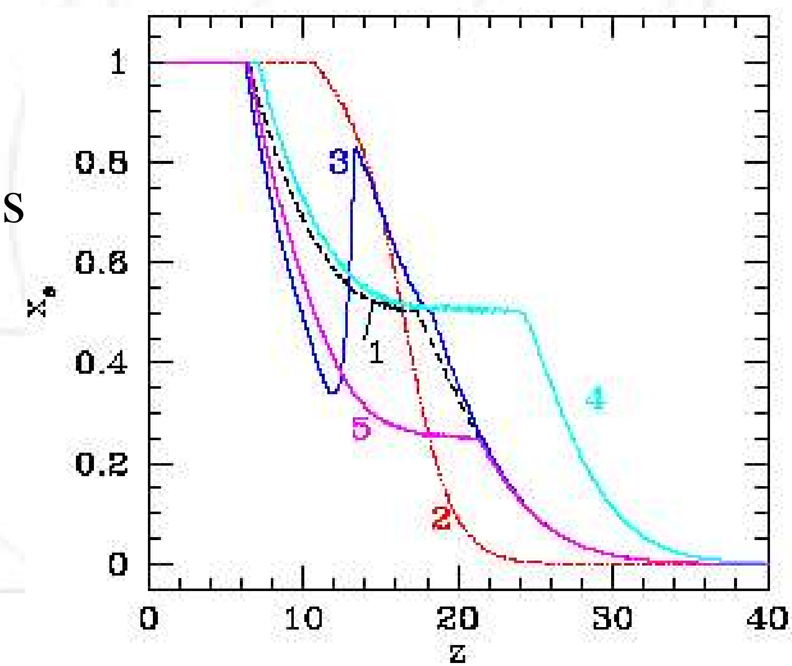

Planck predicted TE

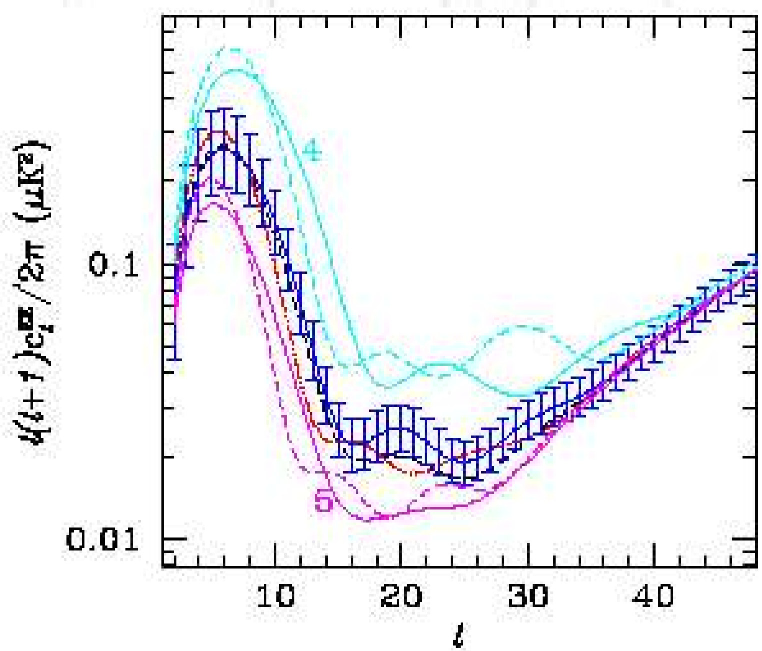


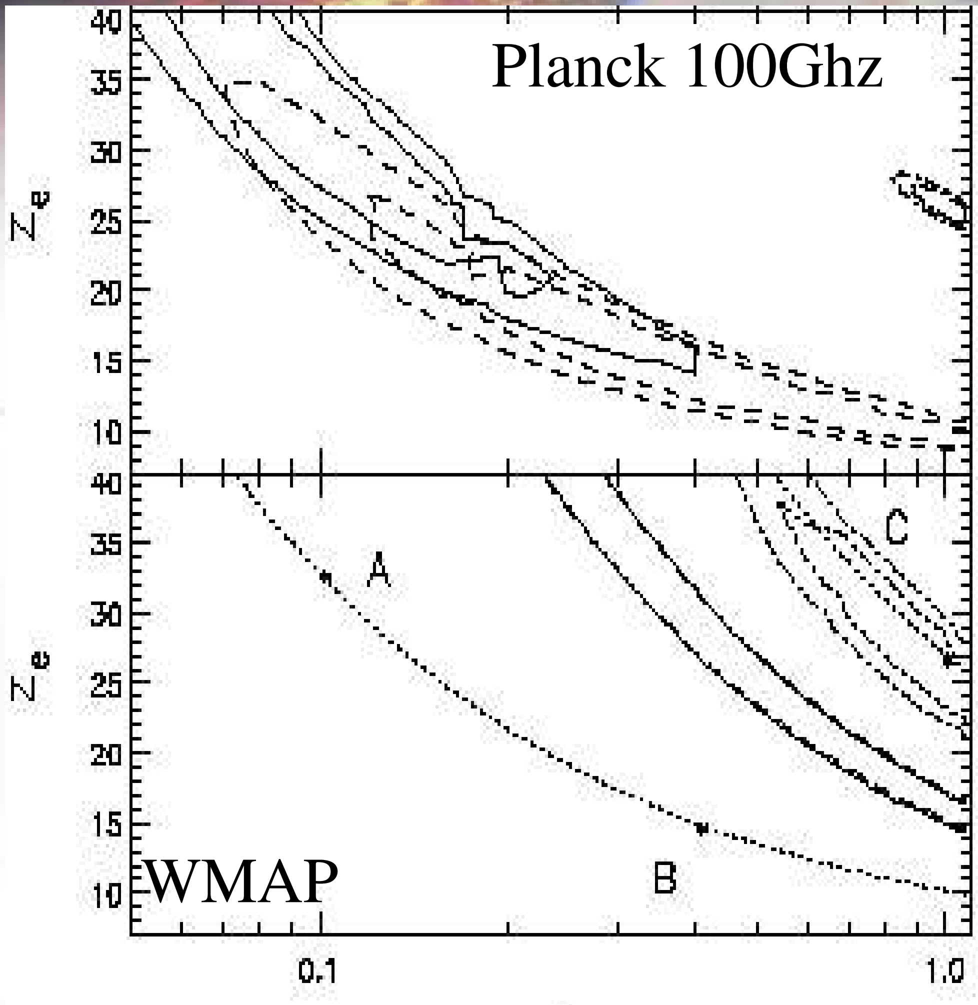

Planck predicted EE

Holder et al. '03

Different reionisation histories -> different signatures in CMB TE and EE spectra





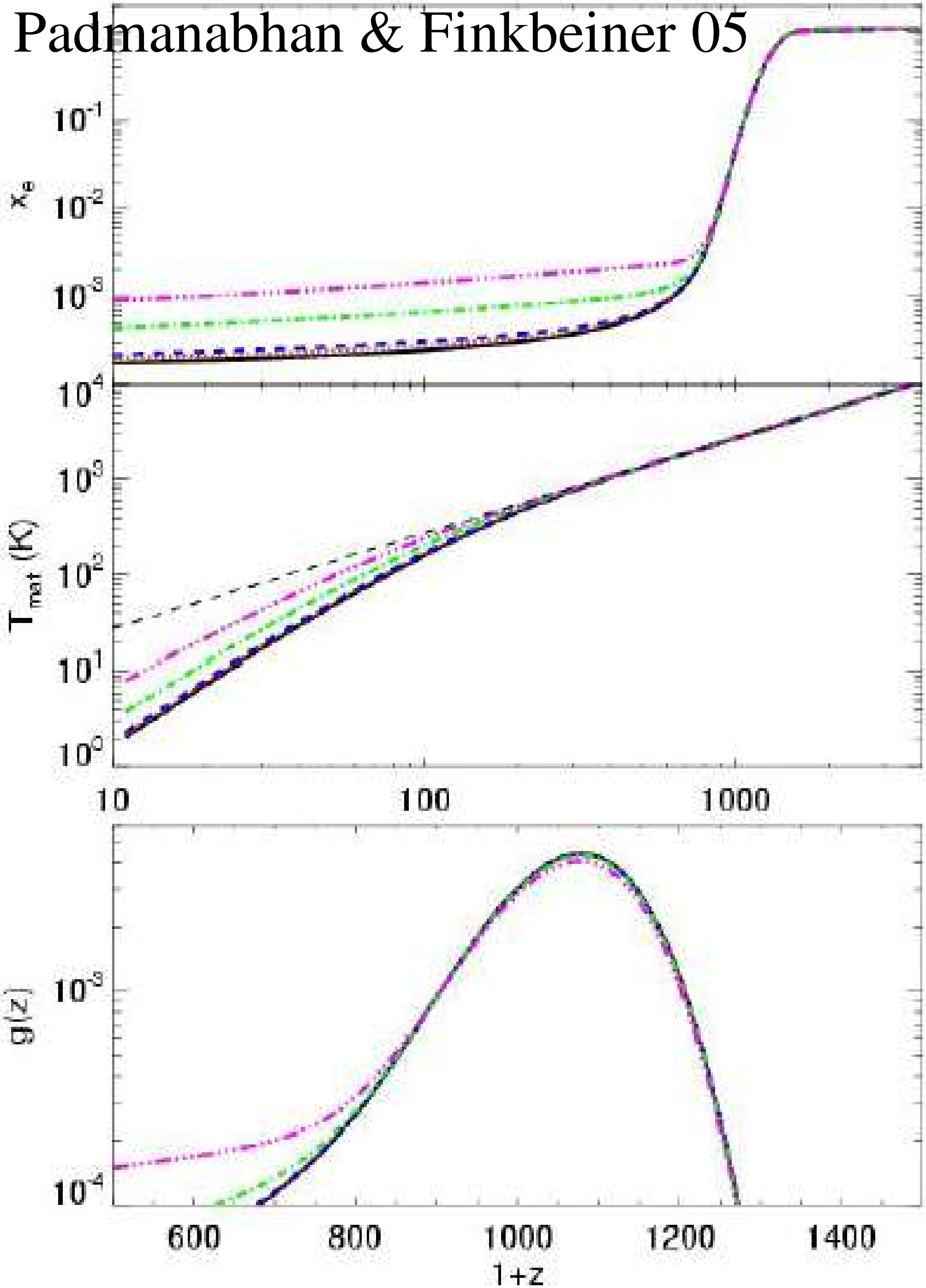

Kaplinghat et al. 03

Reionisation models:
A and B -> tau=0.065, C -> tau=0.25

Planck will be able to rule out simple one step reionisation models

# CMB probes Dark Matter

Padmanabhan & Finkbeiner 05



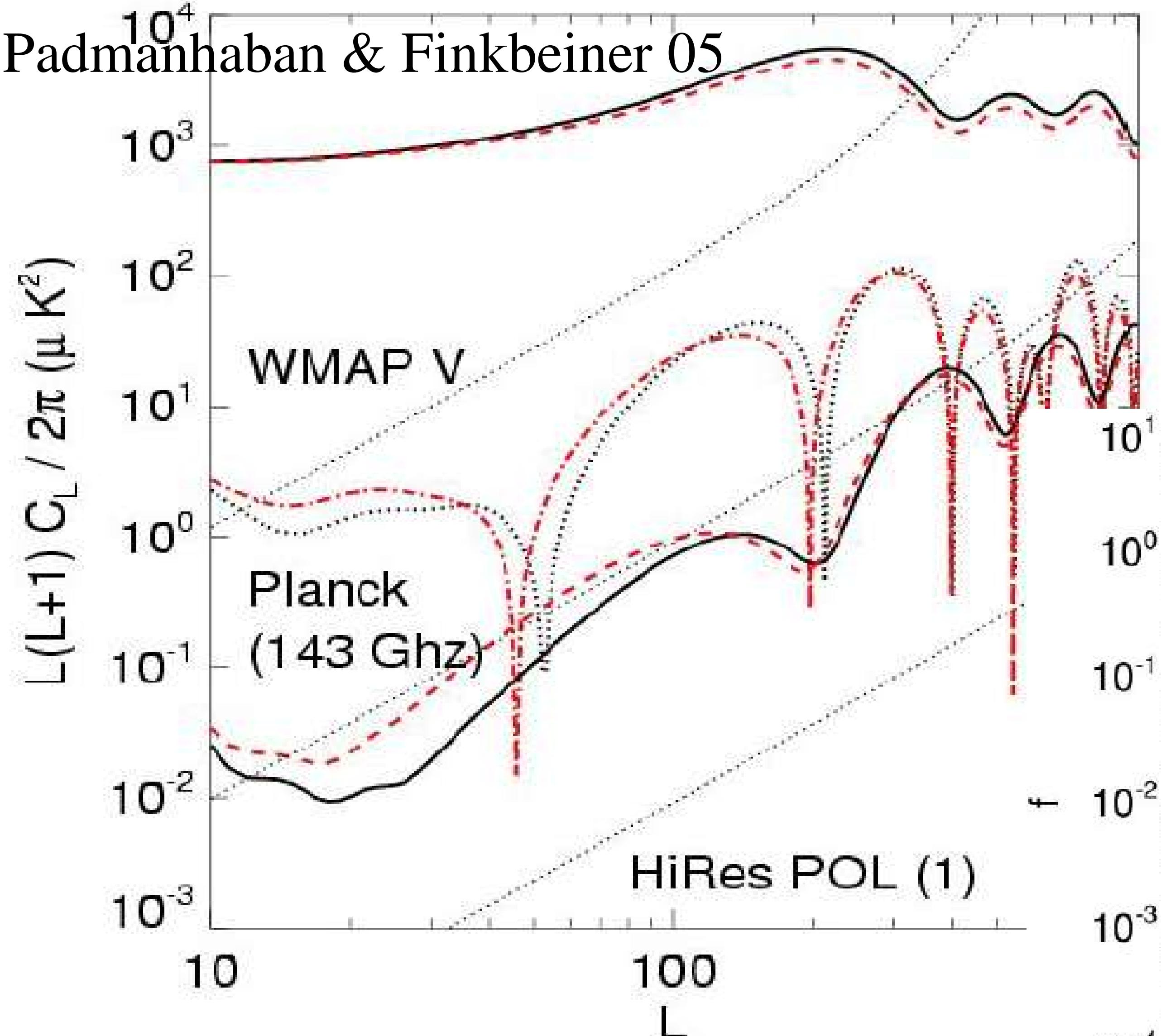

DM particles (Boehm et al. 04) annihilation -> energy injection through ionisation and collisional processes

Effects of DM annihilation (ionis. fraction, temperature, visibility function)

Energy injection at rate:

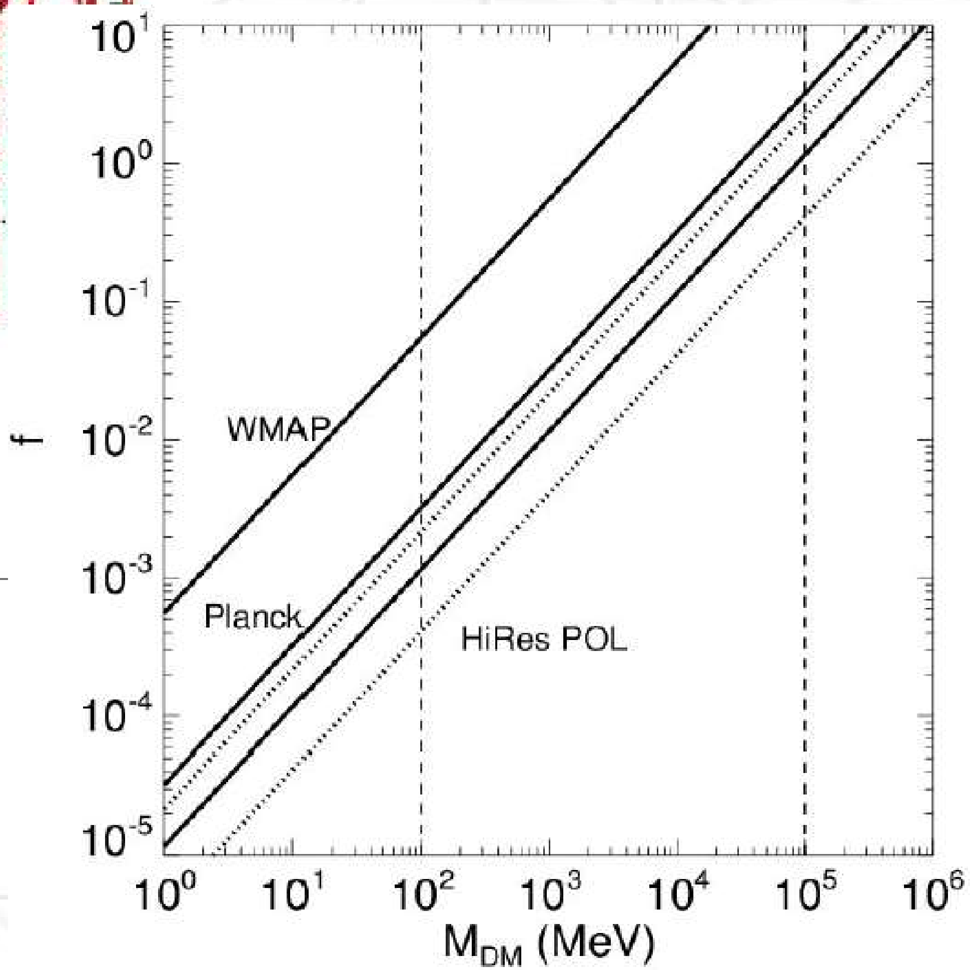
5, 10, 100, 500 10^-25 eV/s

Padmanhaban & Finkbeiner 05




Predicted CMB signals for injection rate 10^-22 eV/s

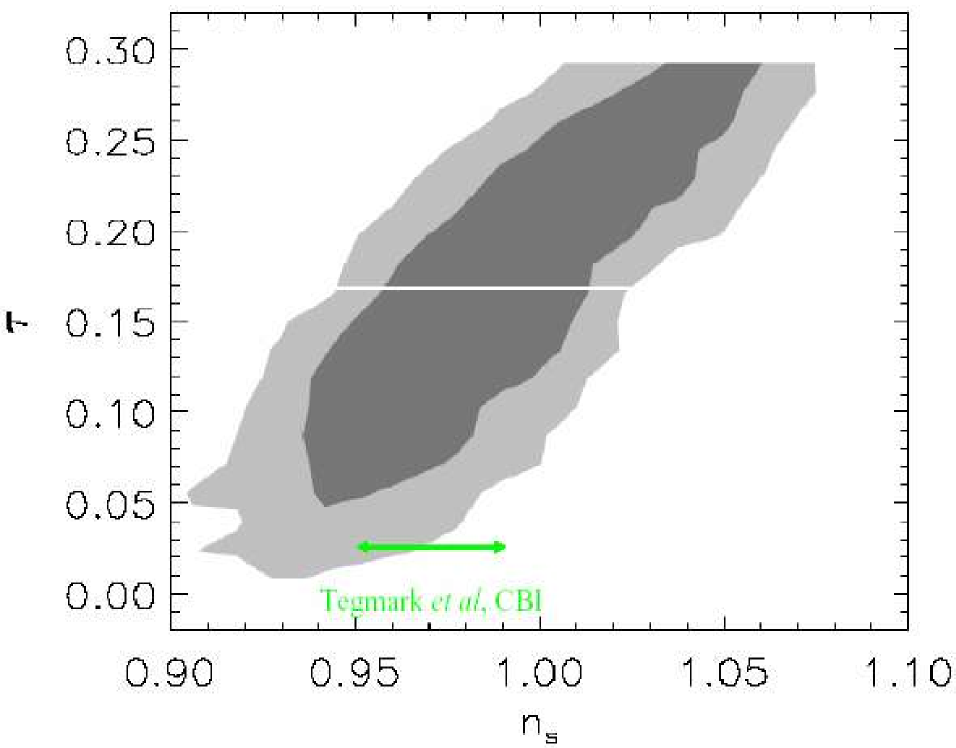
Exclusion region:
DM mass-frac energy used for reionisation

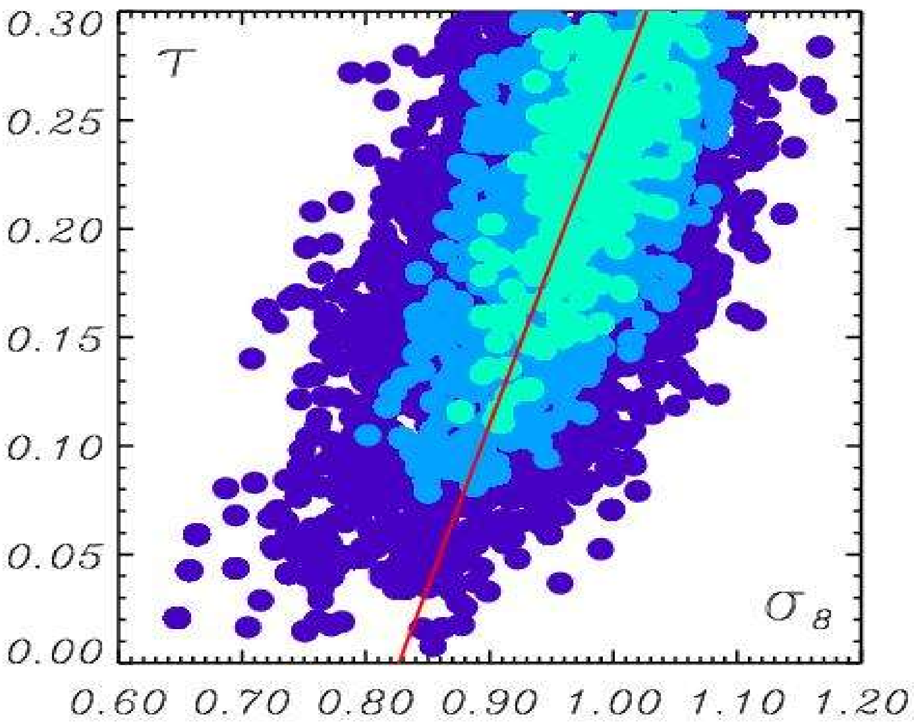


# Reionisation and primordial universe

Precise measurements of reionisation (optical depth, epoch, duration) are needed to probe inflation through:

* Power spectrum (spectral index, running index, normalisation)
* Energy scale -> enhanced BB spectrum from gravitational waves




Degeneracies spectral index, optical depth, normalisation

# 21cm direct reionisation probe: Neutral H absorption

Optical depth to 21cm line

$$\tau = \frac{3c^3 h A_{10} n_{HI}}{16 k_B \nu_{21}^2 T_S H(z)} \sim 0.0074 \frac{x_{HI}}{T_S}(1+\delta)(1+z)^{3/2}[H(z)/(\frac{dv}{dr})]$$

RJ Temperature anisotropy:

$$T_B \approx \frac{T_S - T_{\rm CMB}}{1+z}\tau \approx 7(1+\delta)x_{HI}(1-\frac{T_{CMB}}{T_S})(1+z)^{1/2}\ \mathrm{mK}$$

Ts ~ Tcmb -> no signal, Ts >> Tcmb -> Tb independent of Ts

Ts << Tcmb -> absorption against CMB

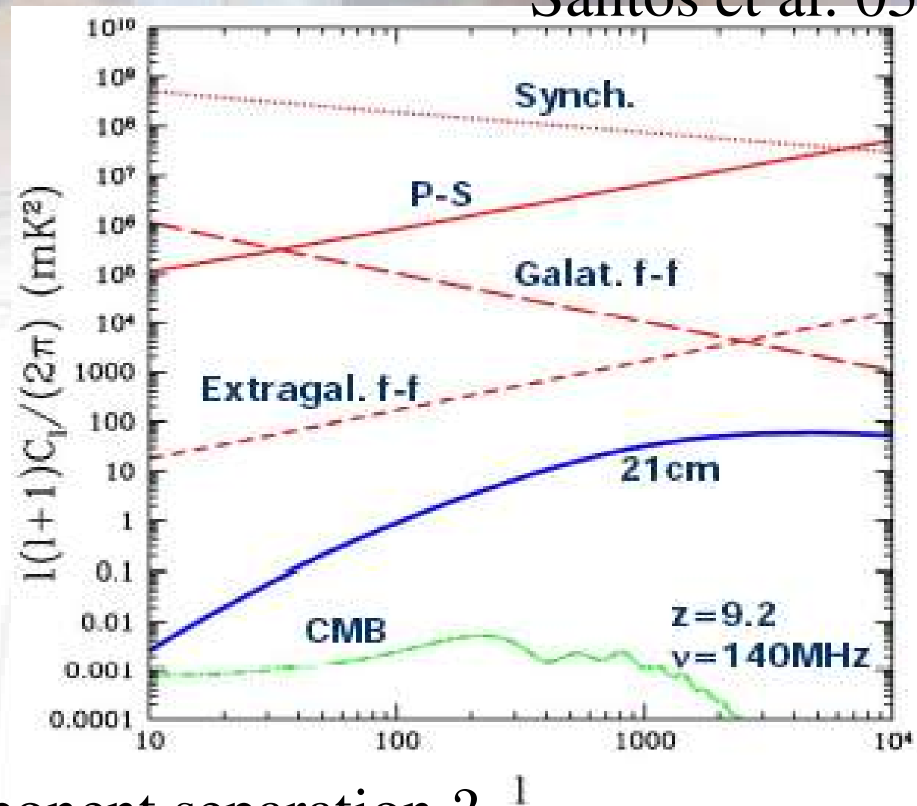
z>200 -> Ts, Tk, Tcmb in equil. -> no 21cm signal
z~ 200-30 -> gas cools Ts, Tk coupled -> 21cm absorption
z~30-20 -> mixture of absorption, emission and no signal
z~20-6 -> IGM heated, Ts > Tcmb 21cm signal

21cm for reionisation -> talk by P. Petitjean

# 21cm power spectrum

Santos et al. 05

$$P_{21}(k,z) = c^2 \left[(1-\bar{x}_e)^2 P_{\delta\delta}(k,z) + \bar{x}_e^2 P_{\delta_x\delta_x}(k,z) - 2P_{\delta\delta_x}(k,z)\bar{x}_e(1-\bar{x}_e)\right]$$




Study as a function of z -> reionisation history

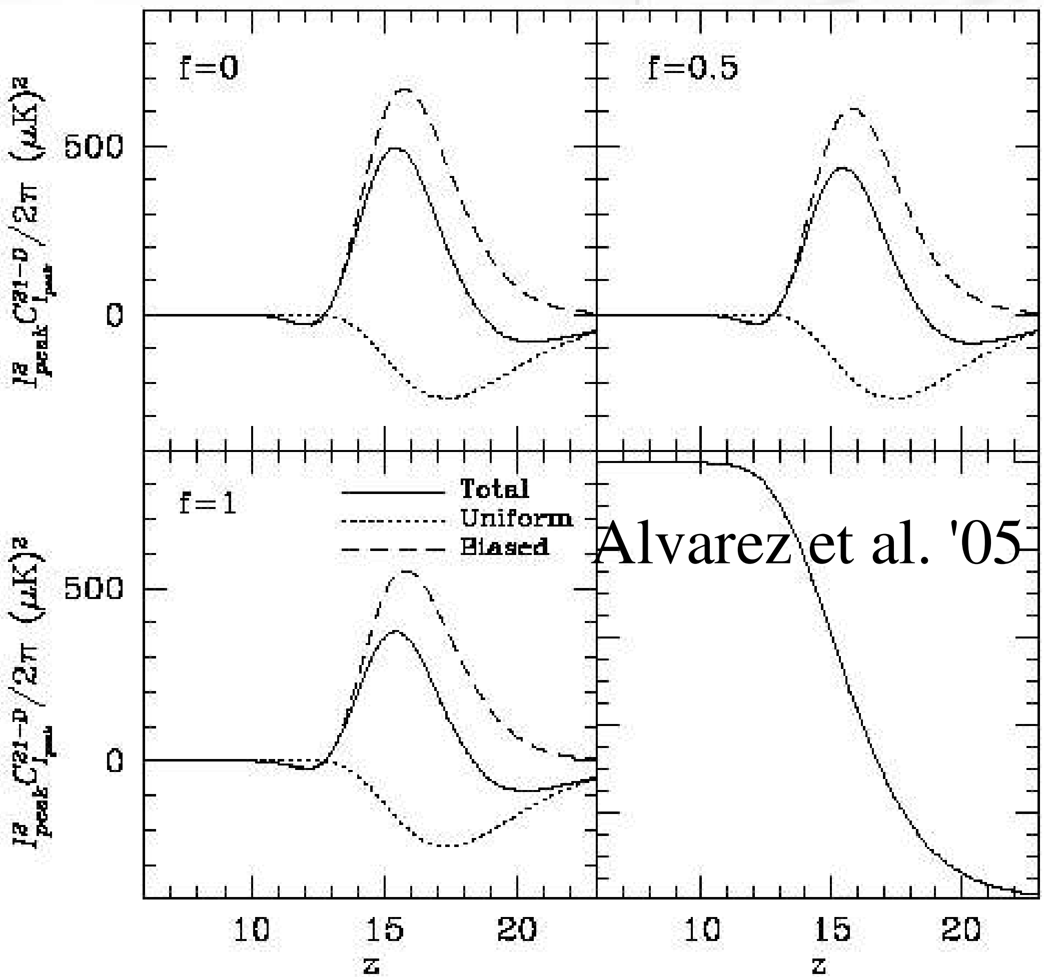
Challenge : foreground emissions and component separation ?

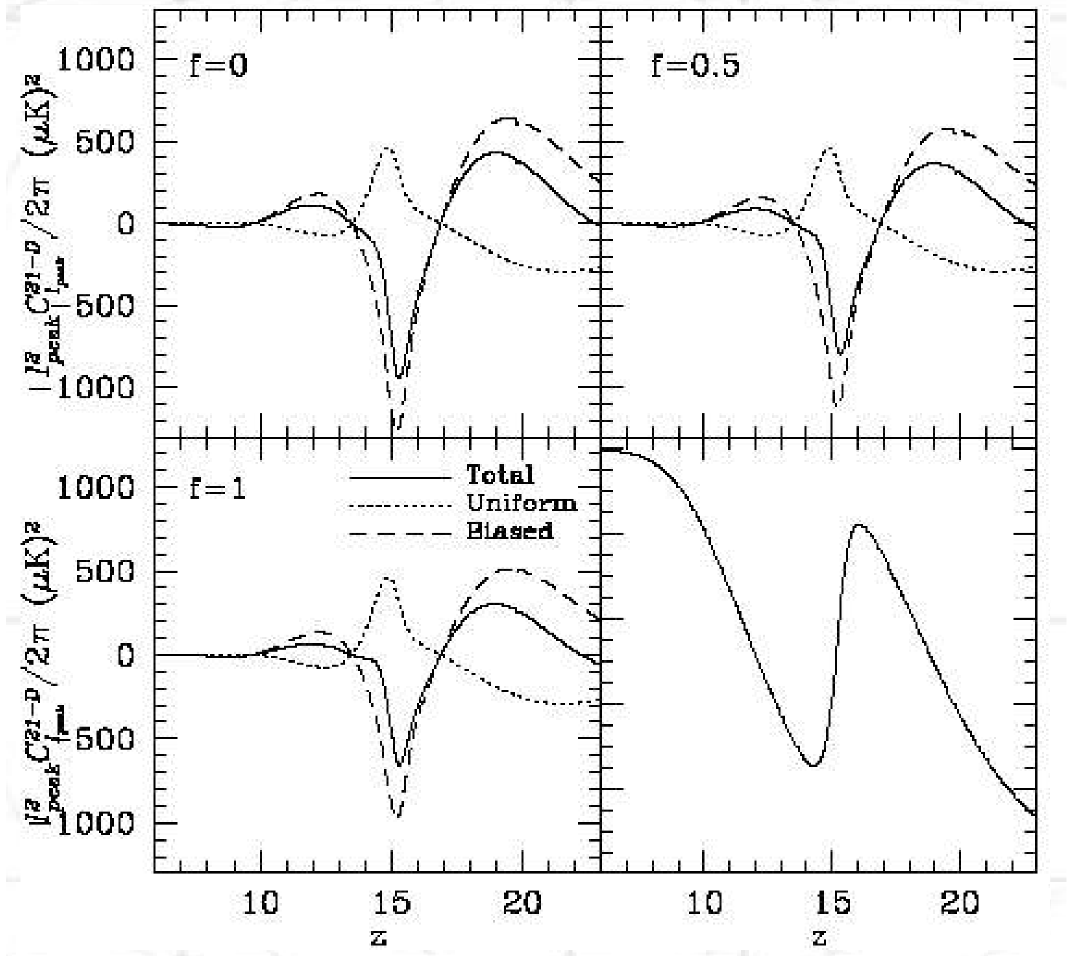
Spectral behaviour of the galactic foregrounds different from that of reionisation (talk by M.A. Miville-Deschenes)

# CMB-21cm correlation

Combining Doppler effect from CMB (ionised regions) and 21cm line (neutral regions).
Signal @l~100 when ionisation fraction ~1/2 depends on structure growth and reionisation proceeds

Correlation sign -> hint of recombination period -> two step ionisation history




Alvarez et al. '05

# Conclusions

* Formation and evolution of structures: Reionisation corresponds to the onset of first emitting object (what are they? How many?...)

* Effects of reionisation: metal enrichement, generation of extra-galactic magnetic field, degeneracy with inflation parameters, ...

Different observational probes: temperature + polarisation of CMB (ionised gas), 21cm (neutral), GRB, high-z galaxies, Lyman alpha forest, IR background -> Correlations

How to reconstruct reionisation history?

Study the sources (simulations, observations)

Study the detailed structure of ionised and neutral gas