Cosmology after Planck and BOSS

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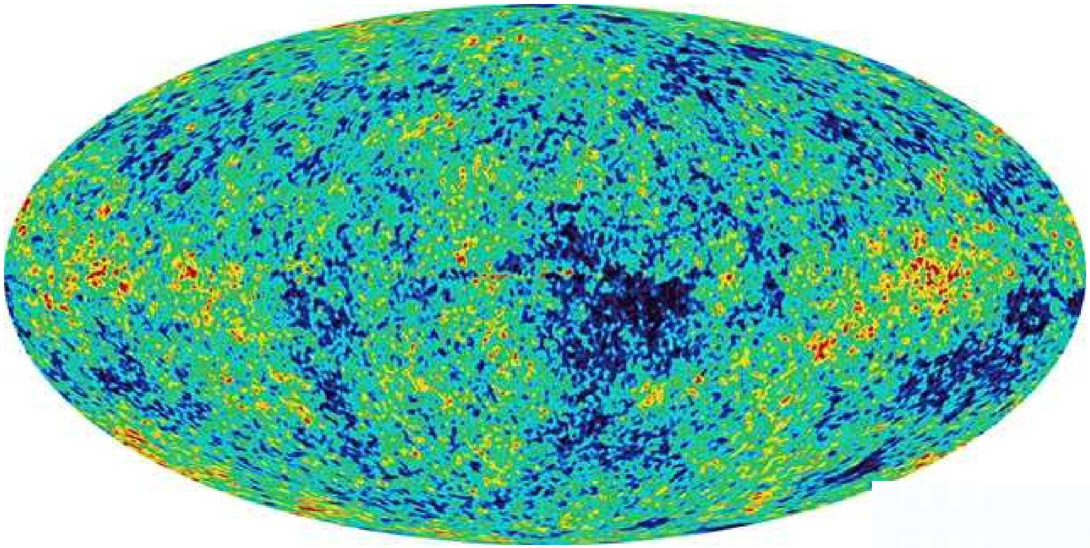
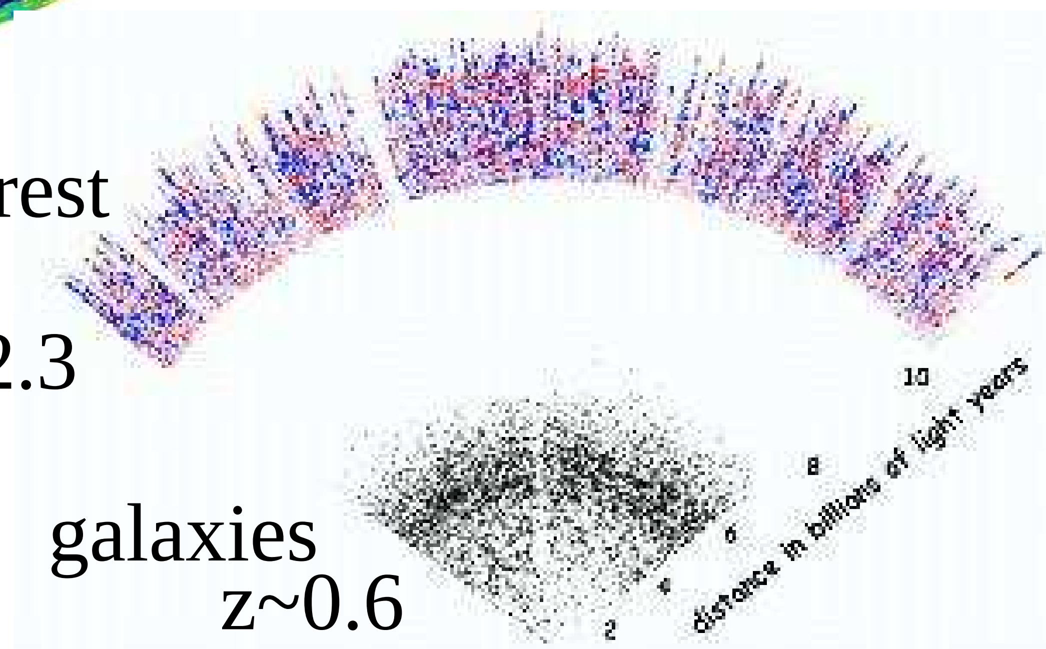


WMAP CMB map



Lya forest

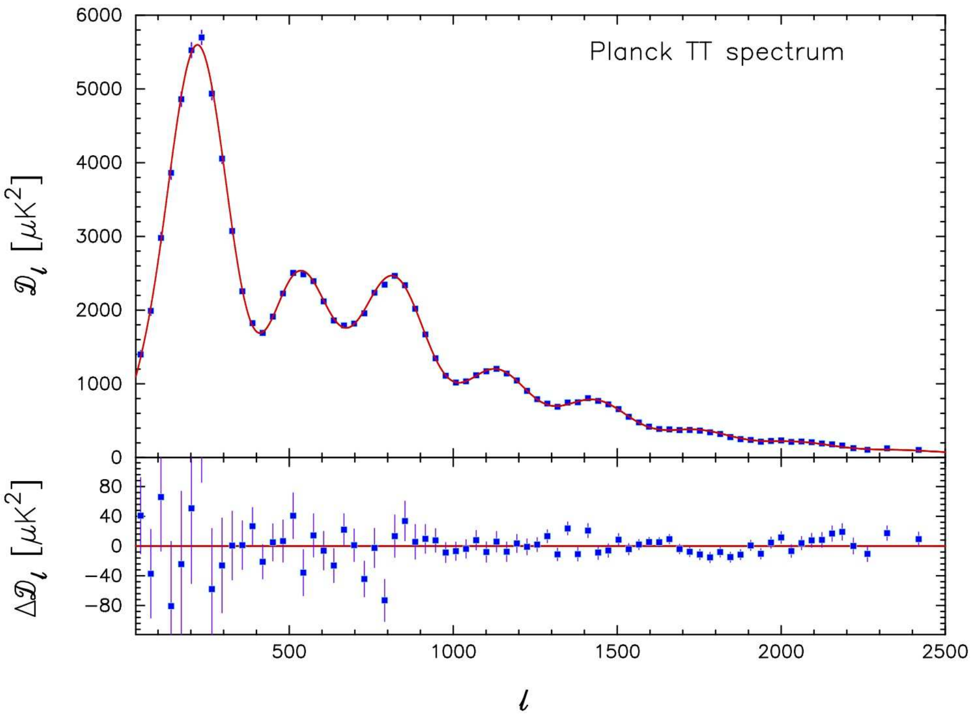
z~2.3

galaxies

z~0.6

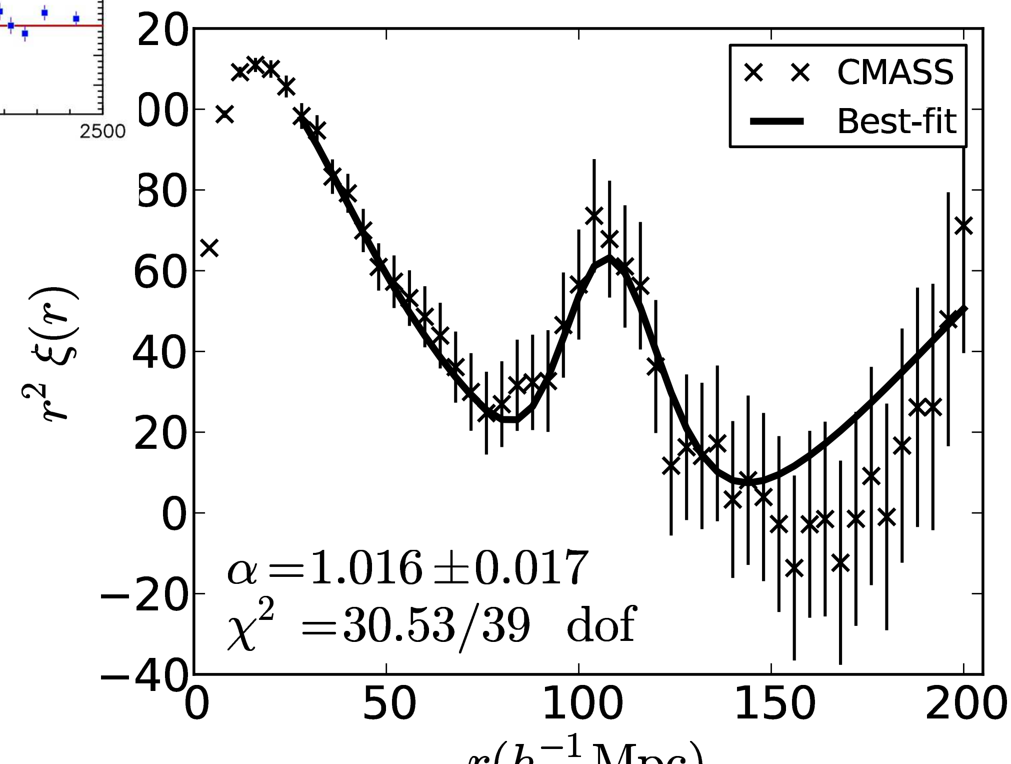
SDSS-BOSS
matter map

Baryon Acoustic Oscillations : BAO

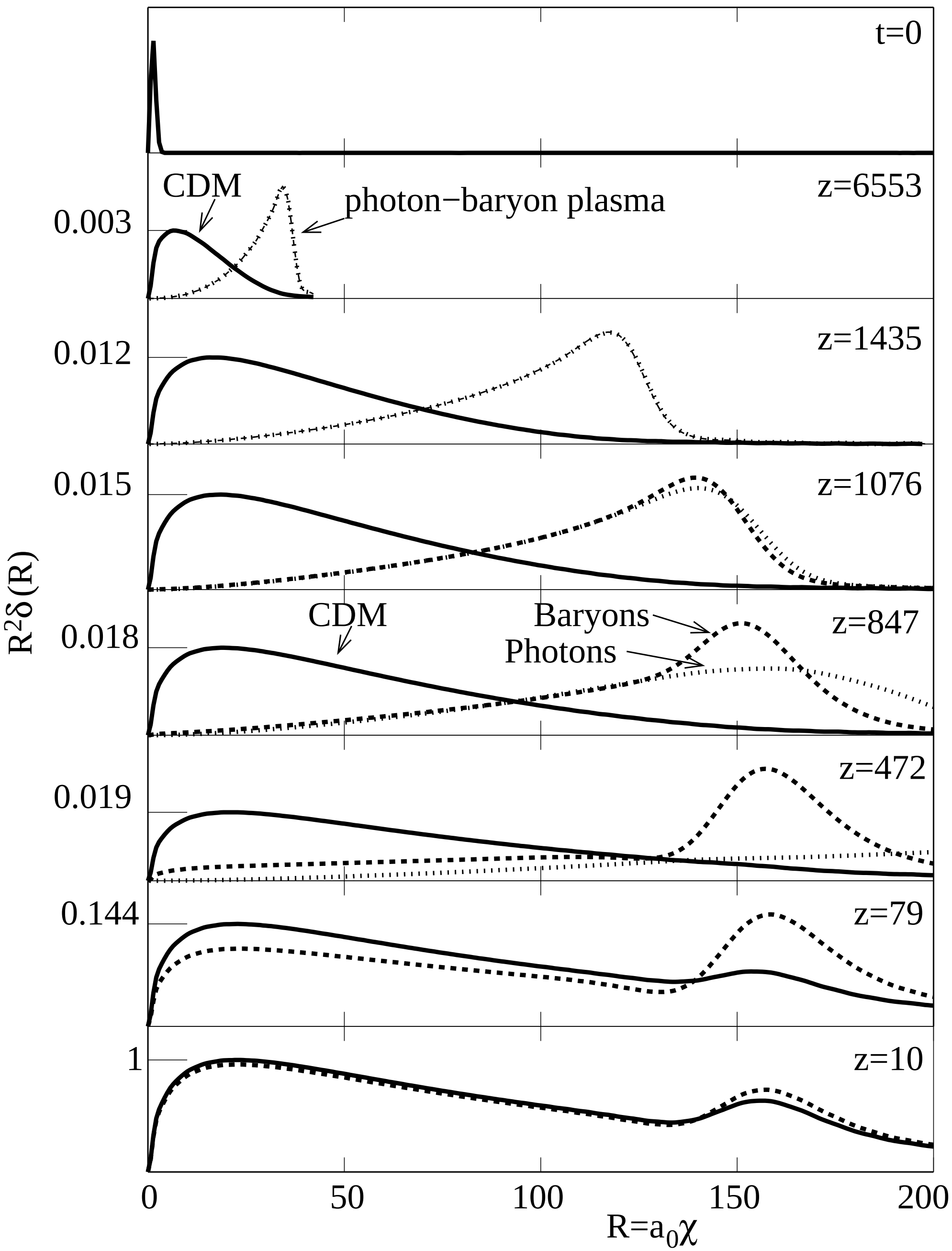


Boomerang/Maxima
WMAP/Planck :
CMB correlations peaked at 1deg

SDSS/WiggleZ/BOSS :
Galaxies like to be separated by 150Mpc



A Universe with one perturbation



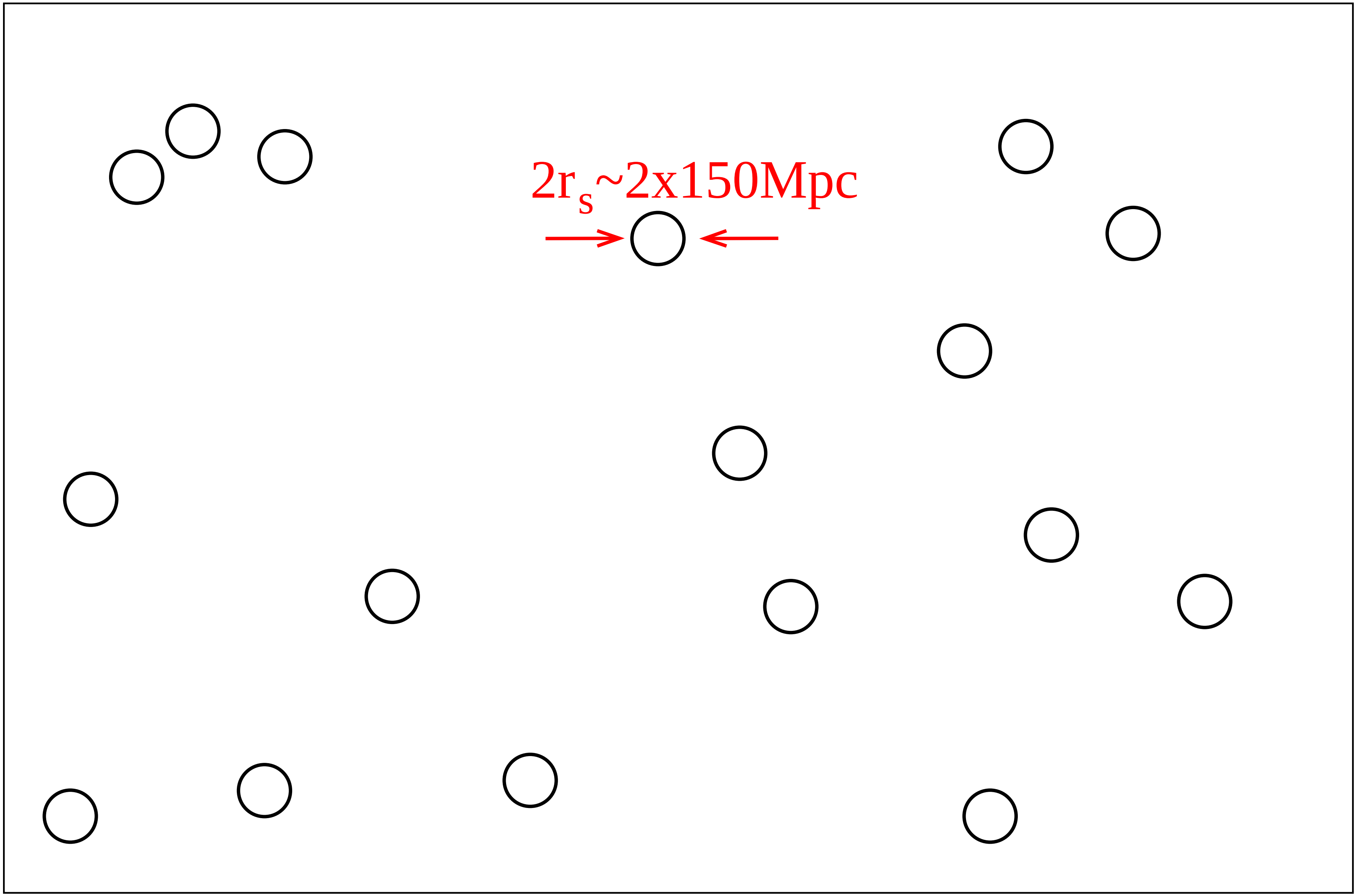
$t = 0$

$c_s \sim c/\sqrt(3)$
(γ,p,e plasma)

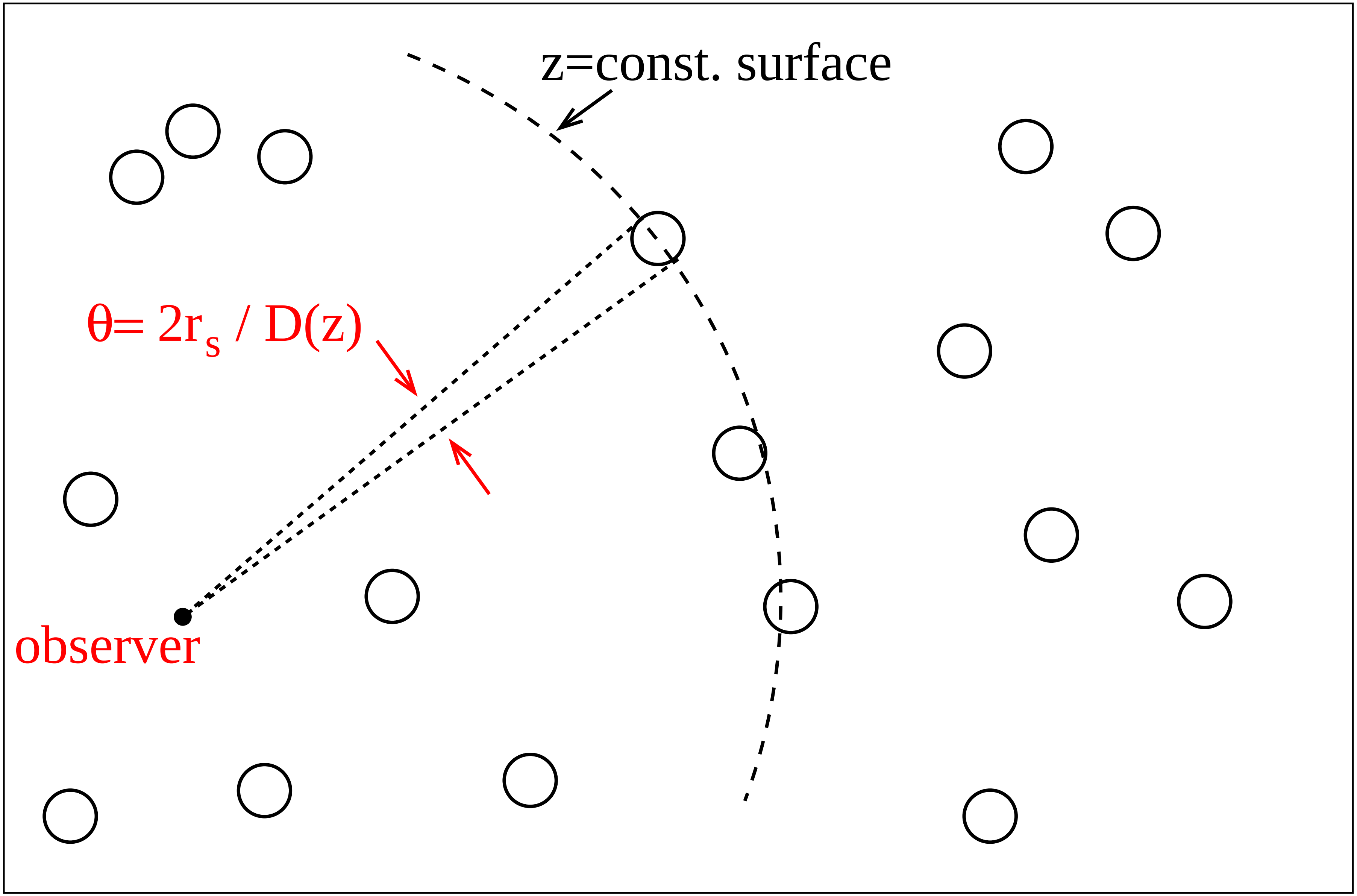
Wave stops at recombination
($r \sim 150\text{kpc}$)

Today : Enhanced correlation
at $r = 147.5$Mpc

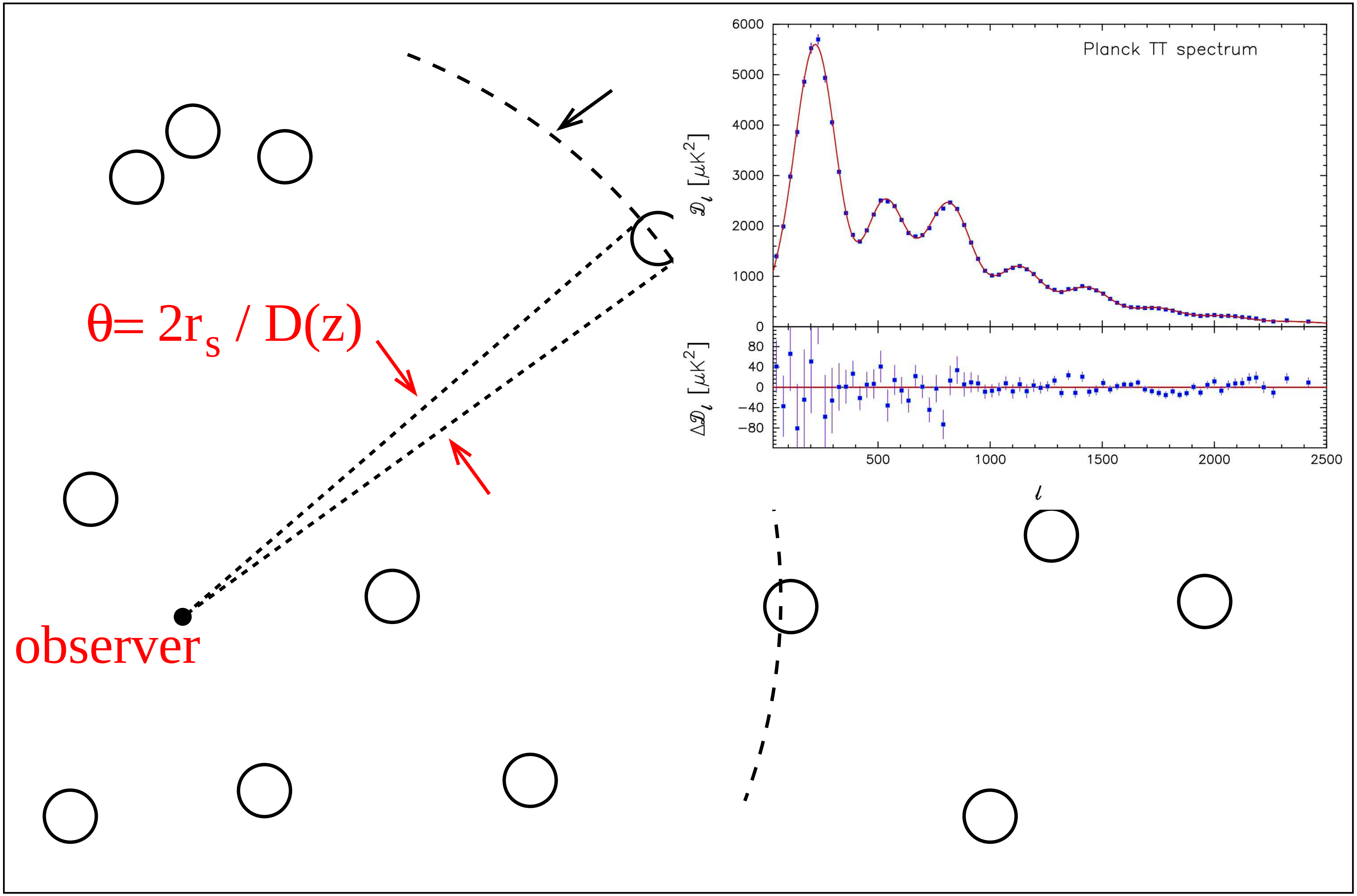
A universe with spherical structures :



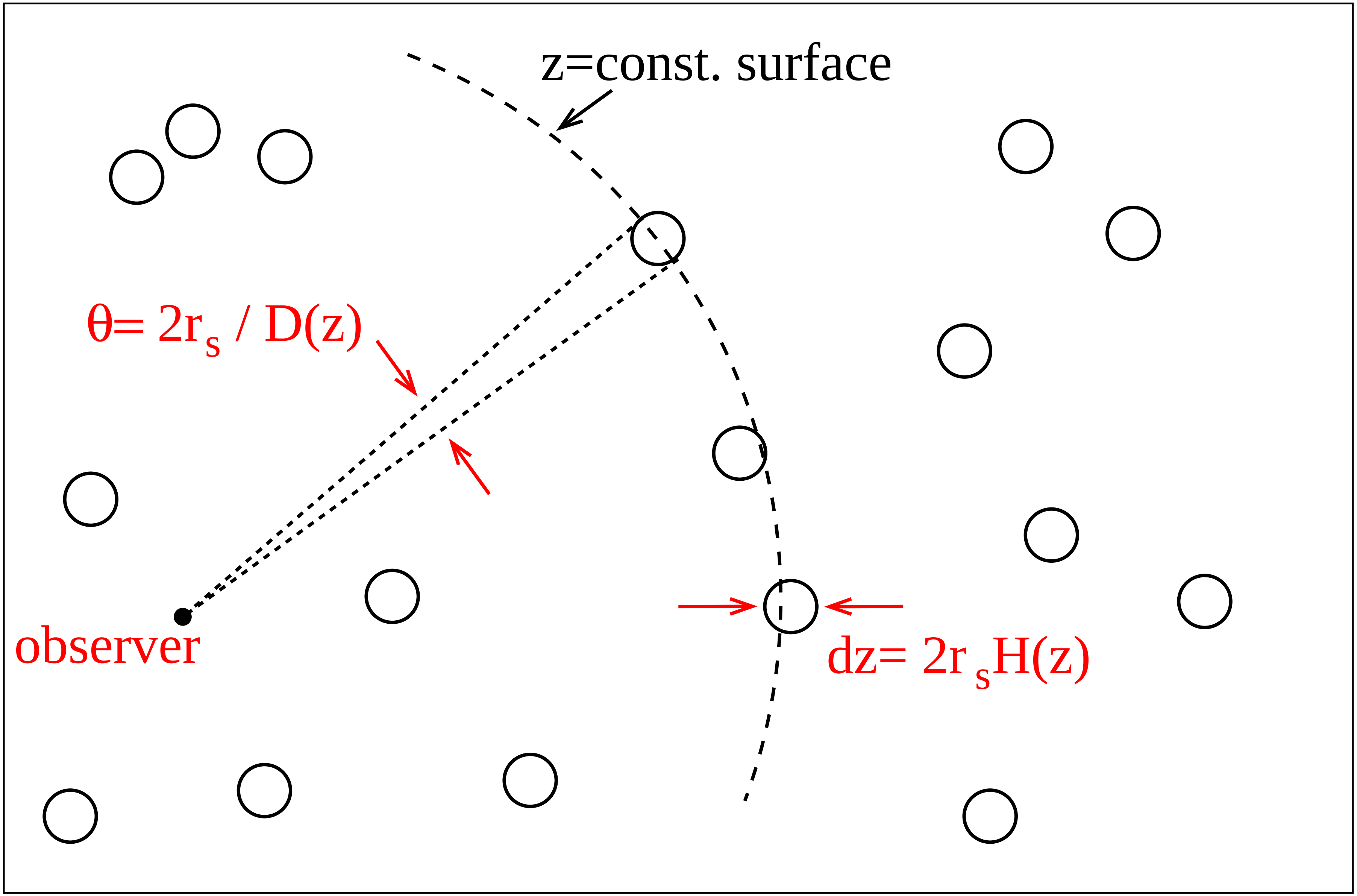
An Observer looking at redshift$= z$



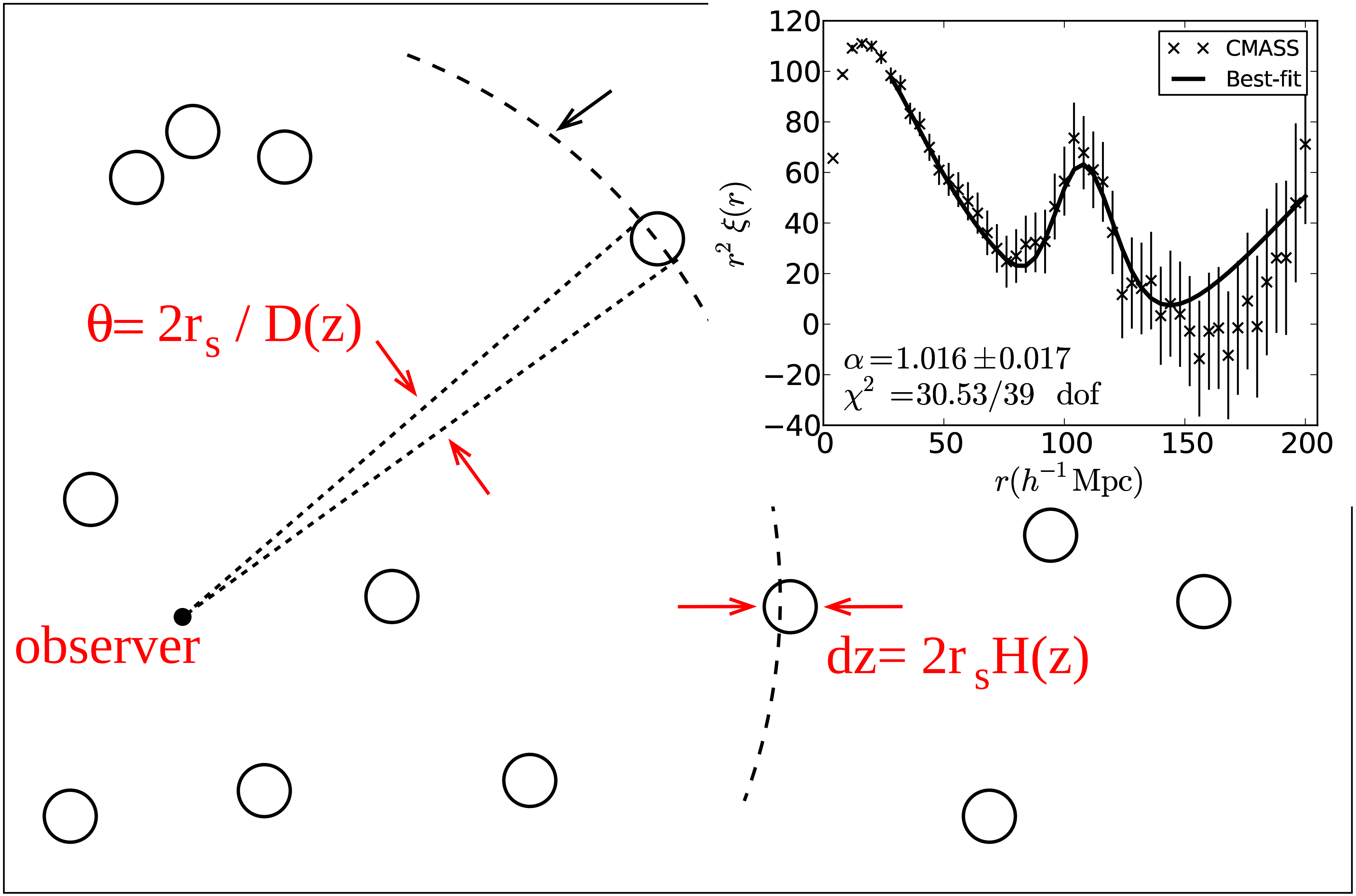
$z = 1090 \Rightarrow$ **CMB correlated** $\theta < 2r_s/D$



Redshift surveys ⇒ radial correlations



Redshift surveys ⇒ radial correlations



Simple physics of $D(z)/r_s$

r_s : matter and radiation before recombinations

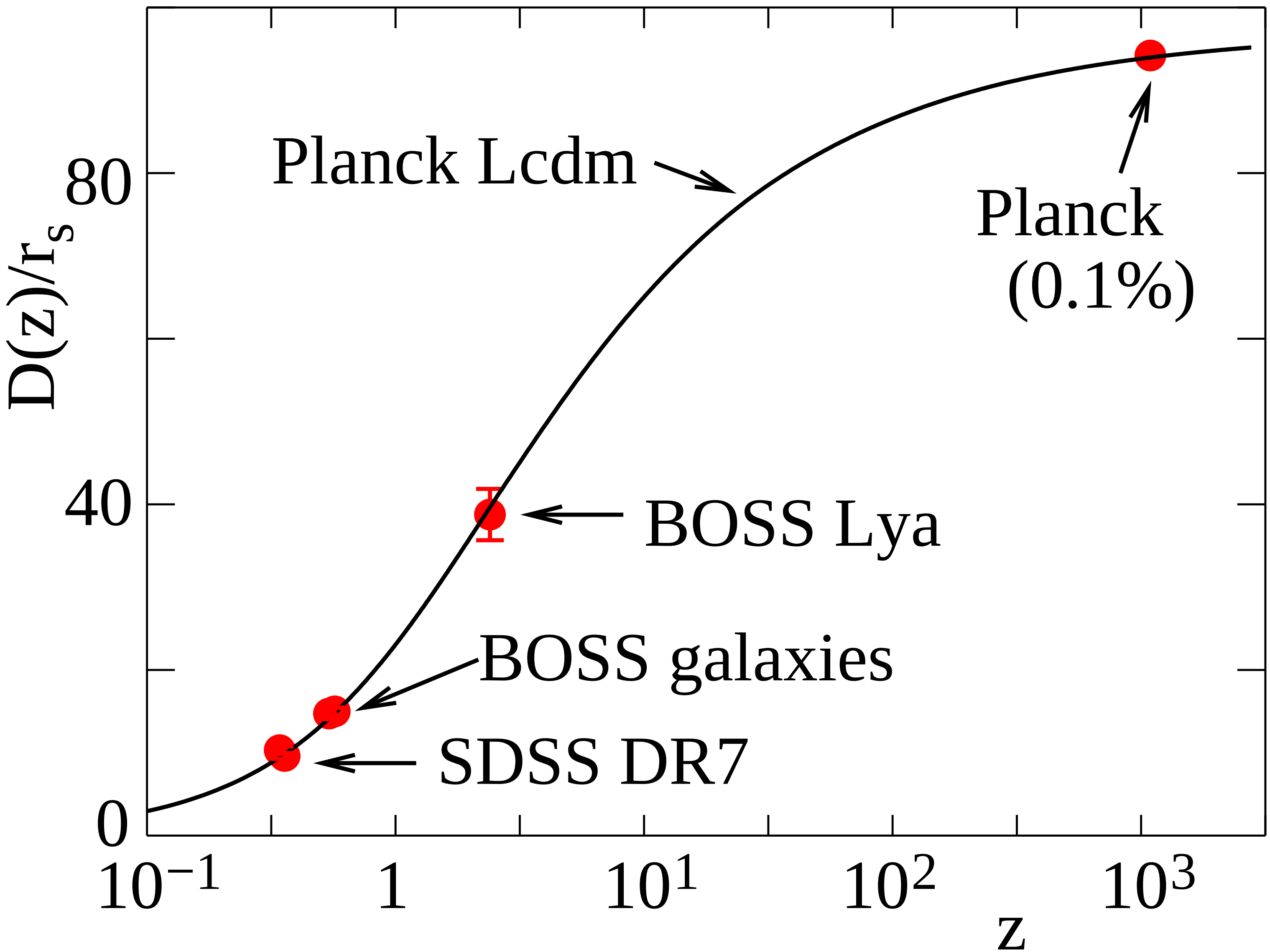
$$r_s = \int_{z_{rec}}^{\infty} \frac{c_s(z)dz}{\frac{8\pi G}{3}\left[\rho_{matter} + \rho_\gamma + \rho_\nu\right]}$$

$D(z)$: all things after redshift z

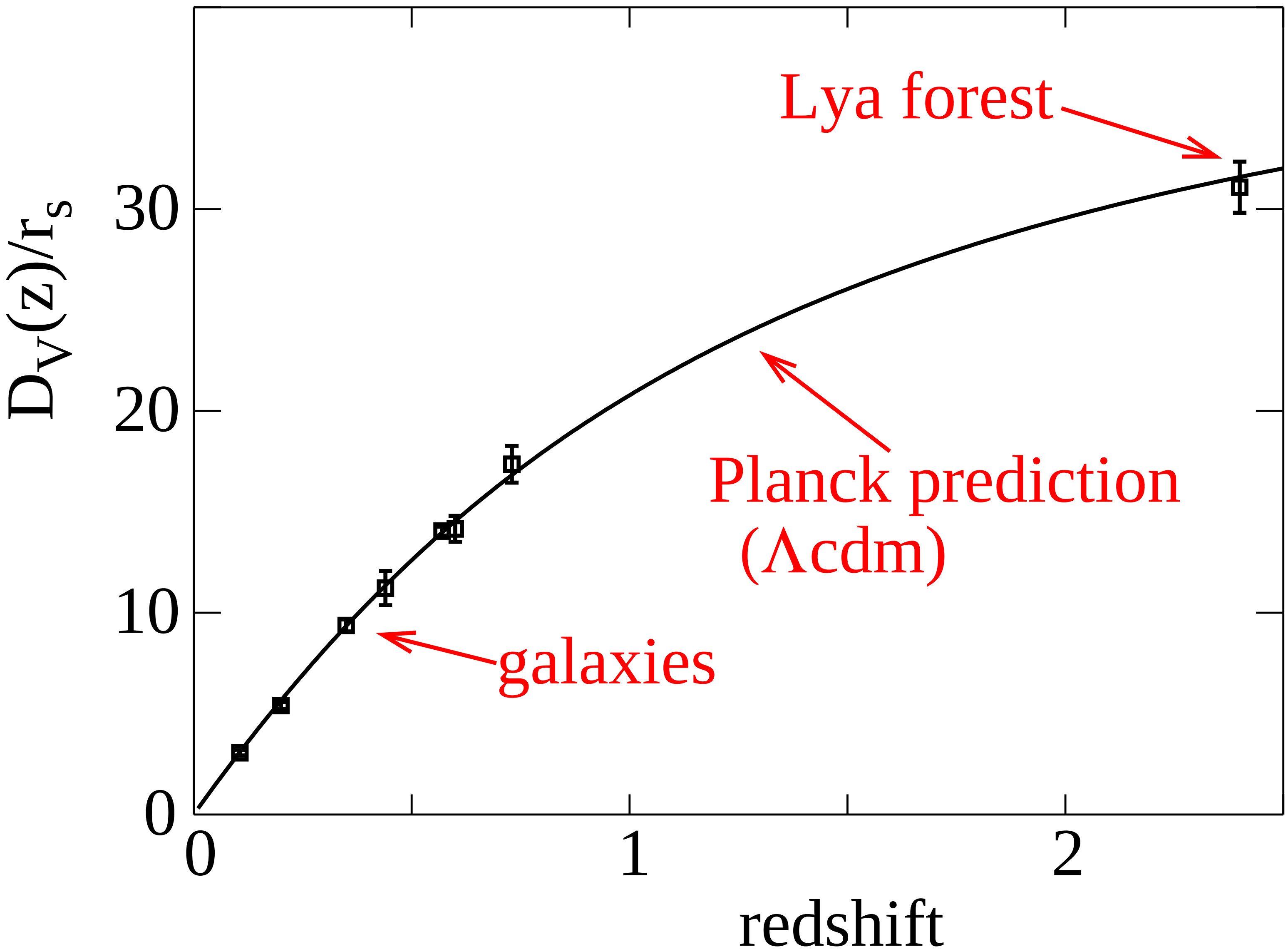
$$D(z) = \int_0^z \frac{dz}{\frac{8\pi G}{3}\left[\rho_{de} + \rho_{matter} + \rho_\gamma + \rho_\nu + \rho_{curvature}\right]}$$

$\Rightarrow$ $D(z)/r_s$ depends on matter, radiation, and vacuum contents and on (m_ν, N_ν).

$D(z)/r_s$ vs. z (SDSS and Planck)

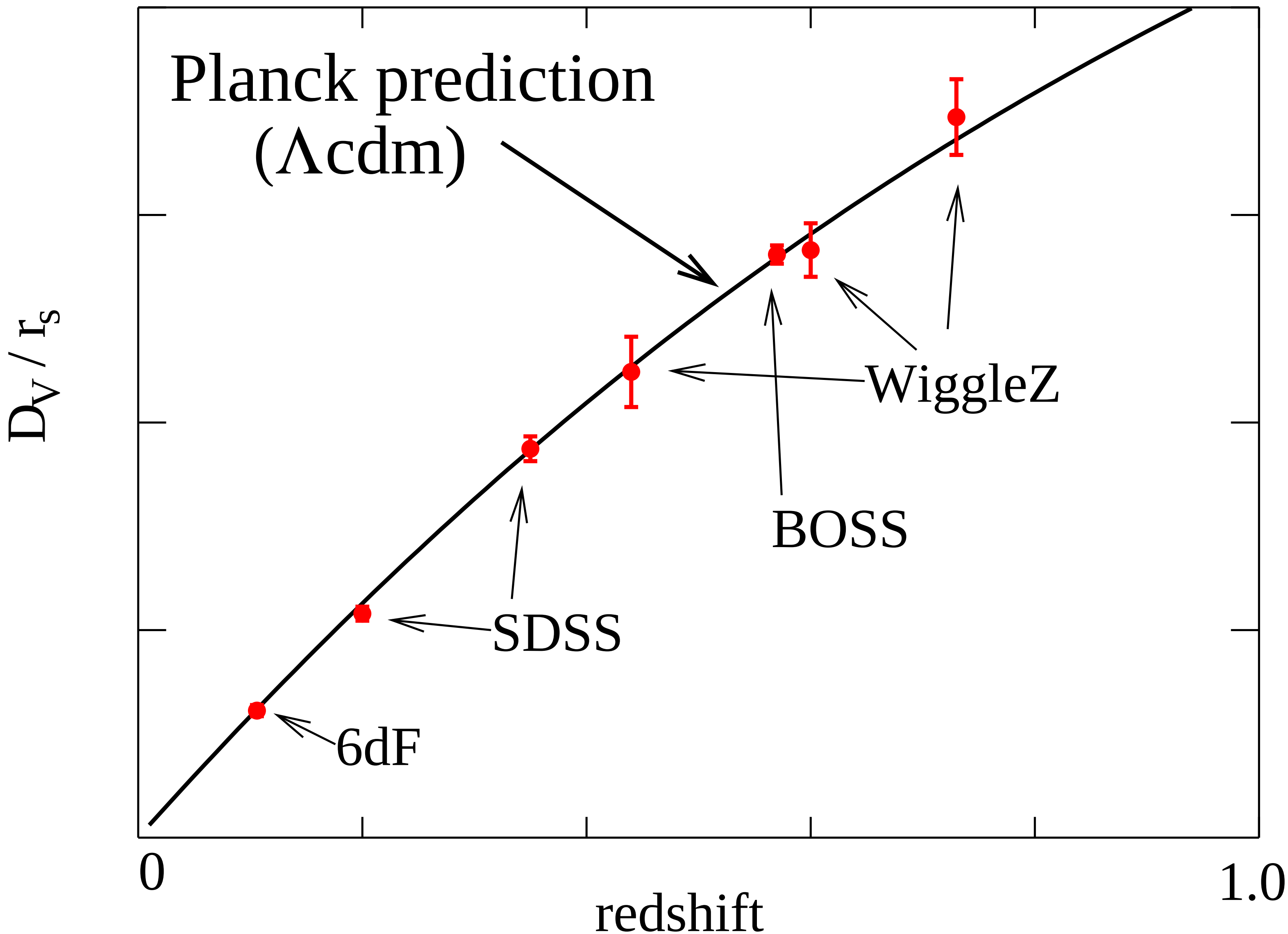


$D_V(z)/r_s$ (BAO)

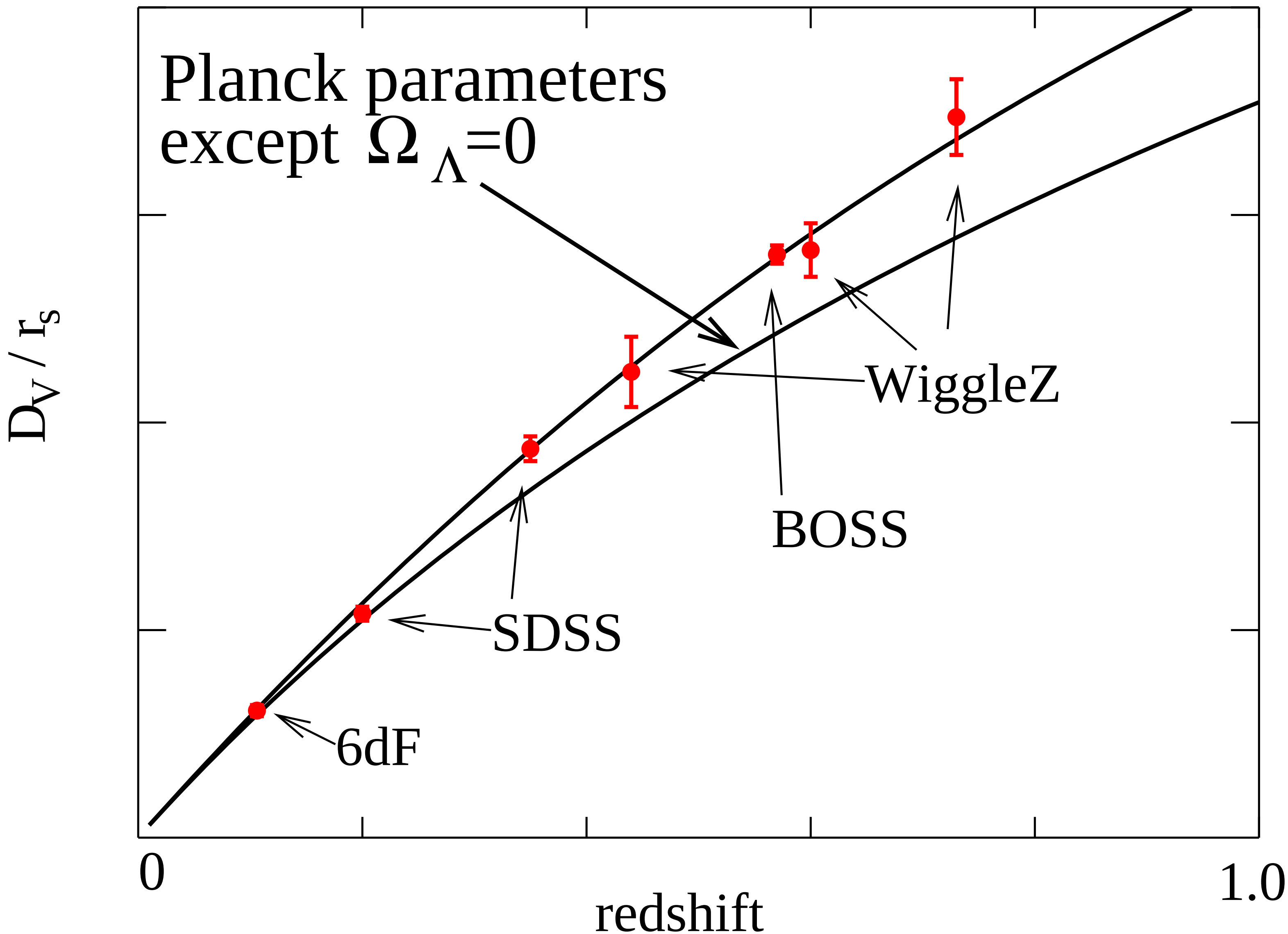


Lya forest
Planck prediction
(Λcdm)
galaxies
$D_V(z)/r_s$
30
20
10
0
0
1
2
redshift

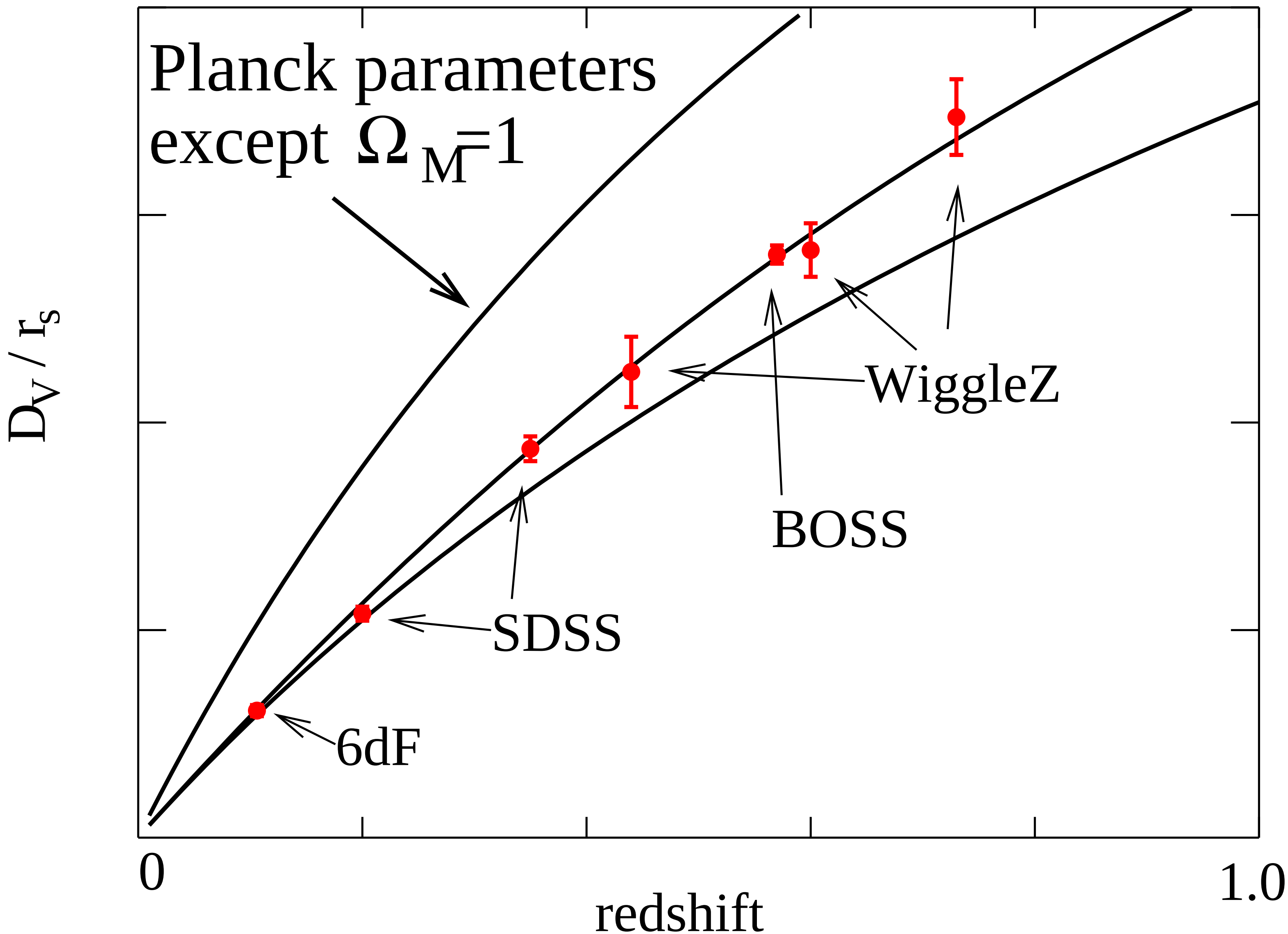
$D_V(z)/r_s$ (BAO galaxies)



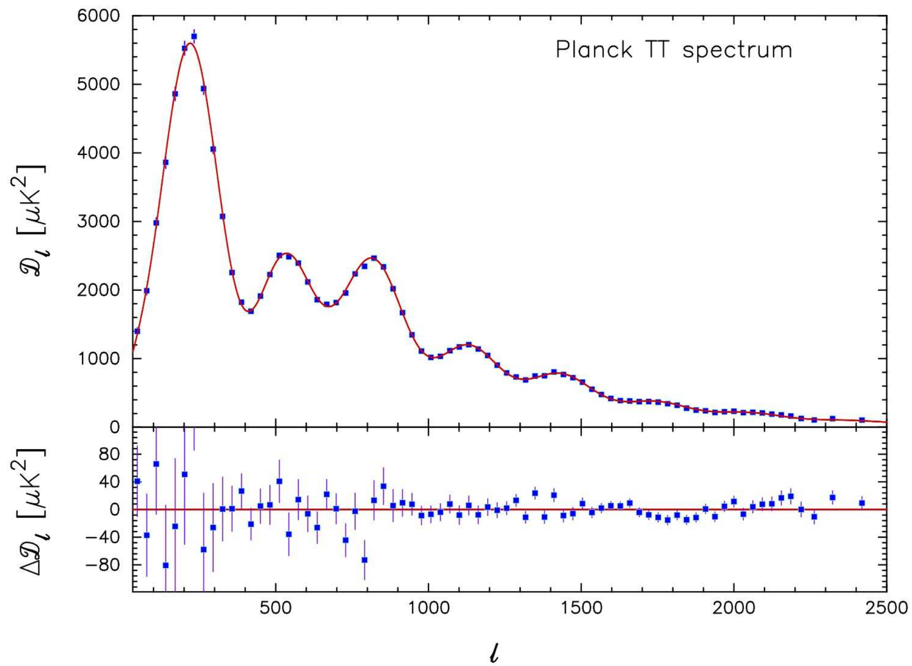
$D_V(z)/r_s$ (BAO galaxies)



$D_V(z)/r_s$ (BAO galaxies)



CMB is more than just D/r_s



- peak positions $\Rightarrow D/r_s$
- peak amplitudes
- damping at high ℓ
- Sachs-Wolfe plateau $\ell < 30$
- peak widths (lensing)

CMB determines 6 parameters of Λcdm :

$\Omega_{cdm}h^2$ (CDM)

$\Omega_b h^2$ (baryons)

$r_s/D(z = 1090)$ (or Ω_Λ)

τ optical depth to recomb.

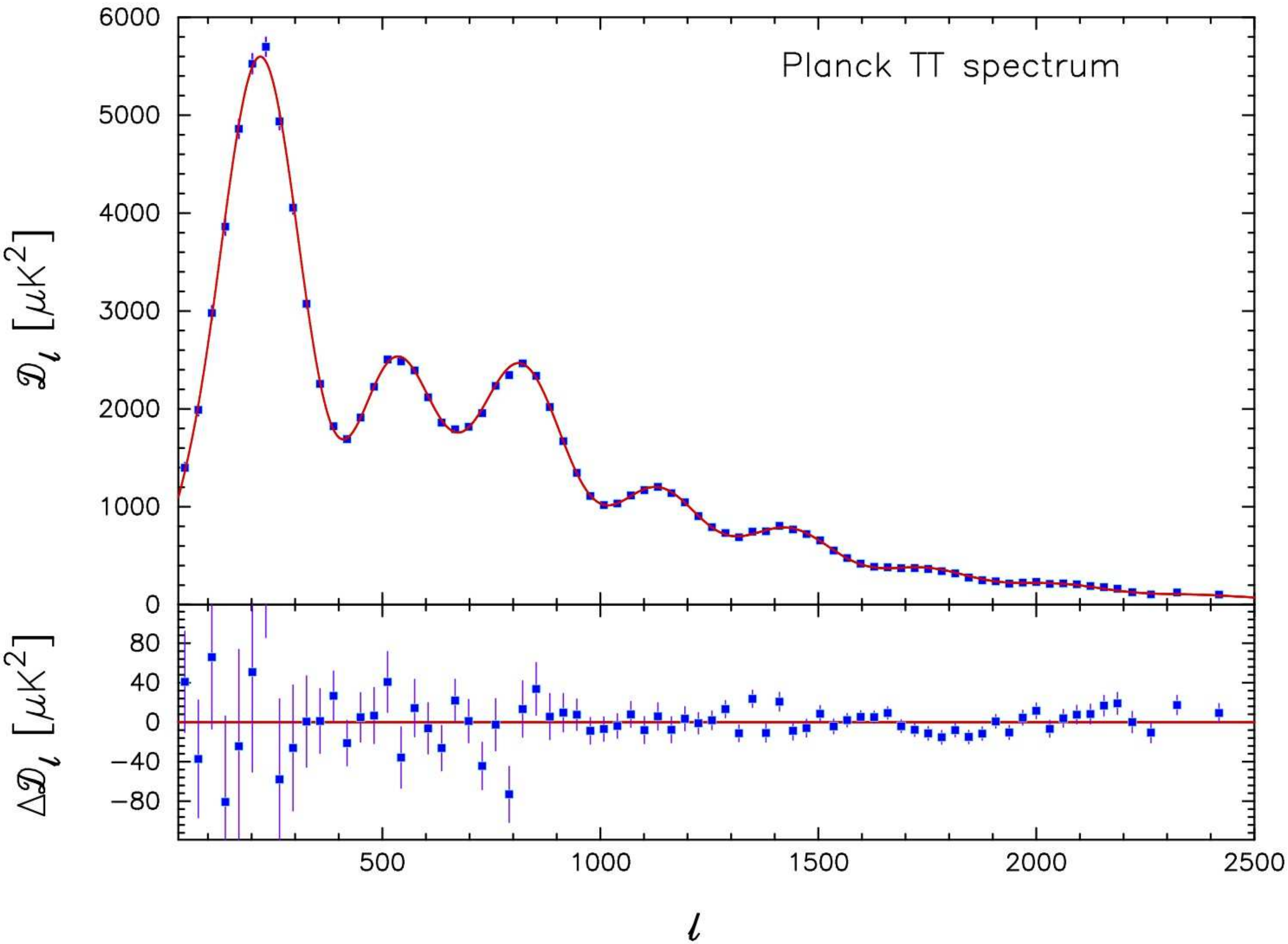
(n_s, A_s) primoridal spectrum

Λcdm assumes :

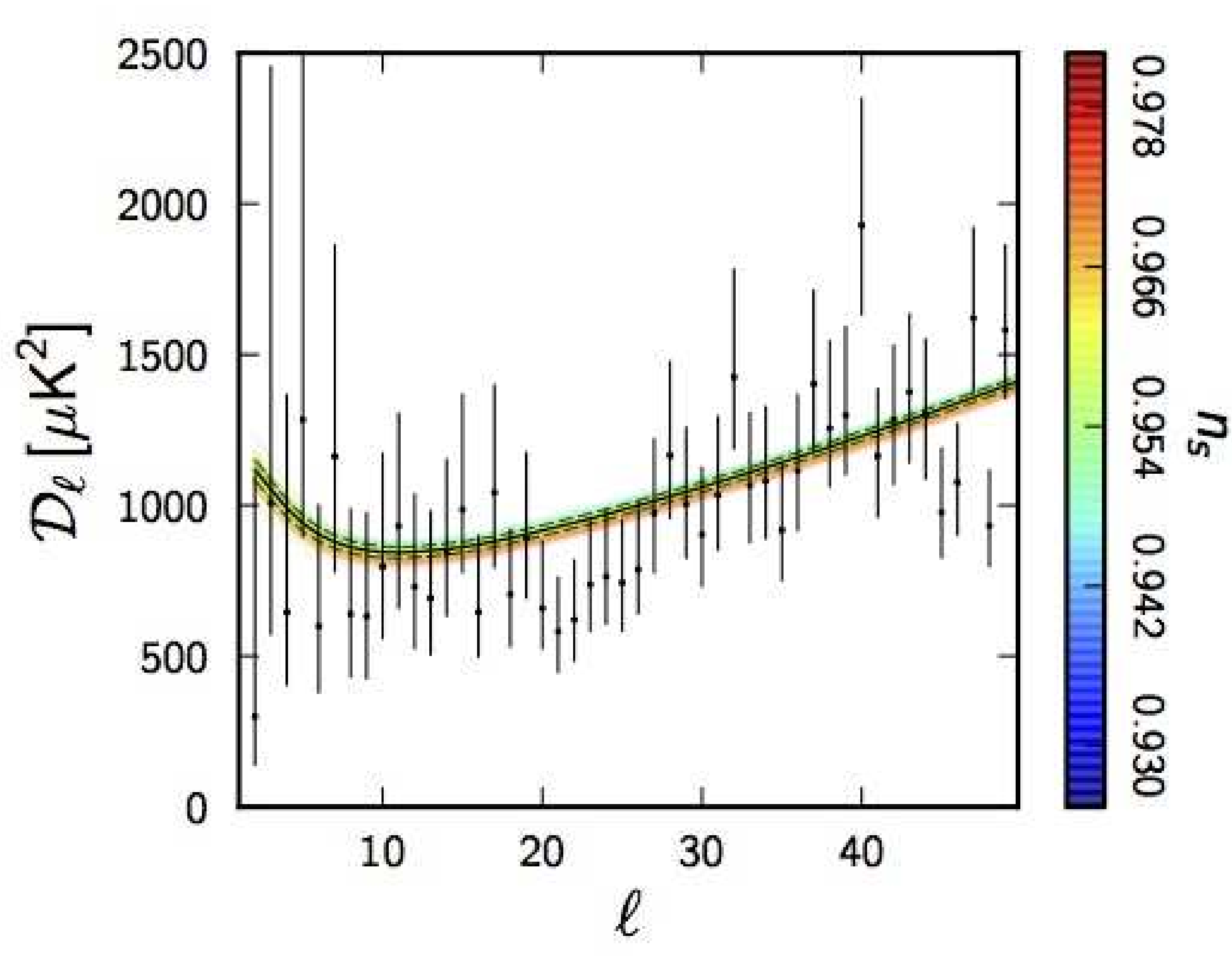
$\Omega_{cdm} + \Omega_b + \Omega_\Lambda + \Omega_\nu + \Omega_\gamma$
$= 1$ (flatness)

$\vec{m}_\nu = (0, 0, 0.06)eV$

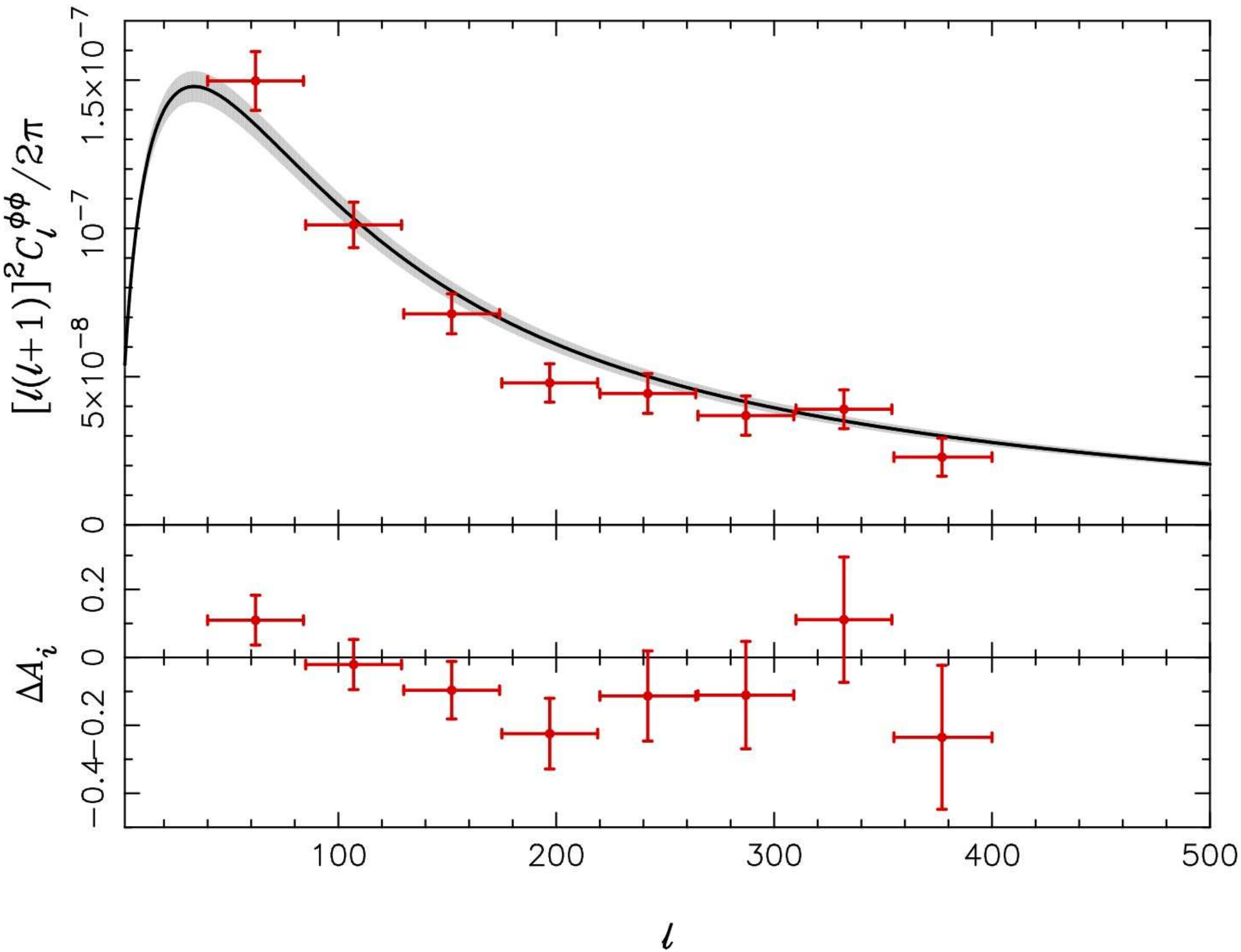
Λcdm gives a good fit to Planck data



Problems at large angular scale ?

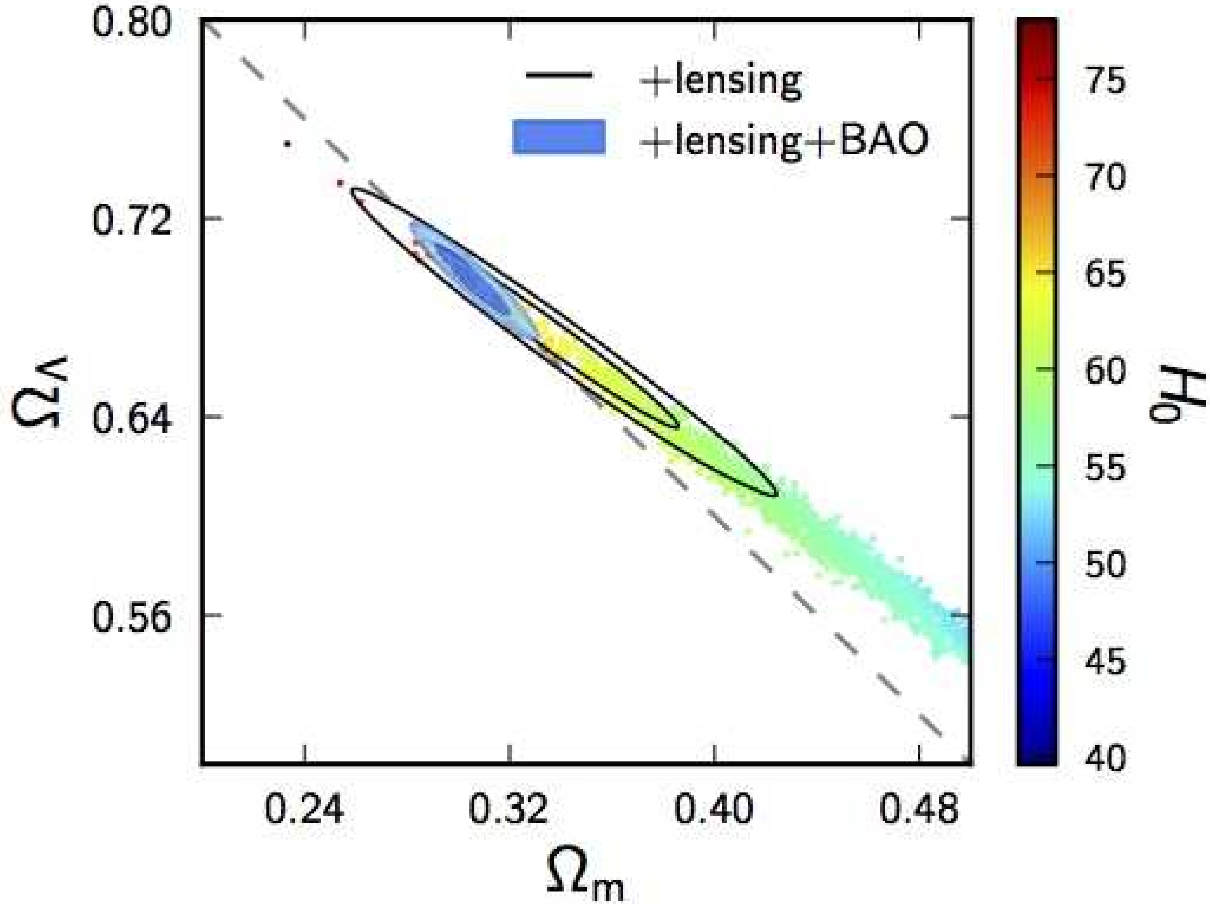


Lensing of CMB on foreground



Extended Λcdm : Curvature

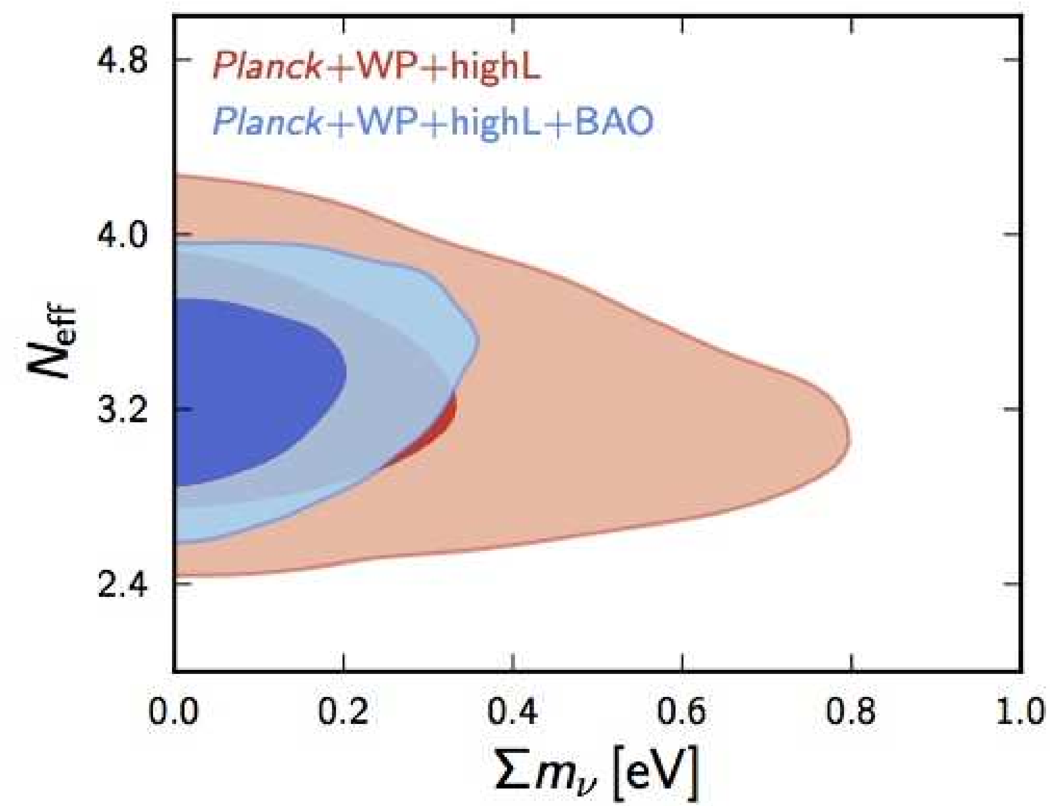
- $\sum \Omega_i \neq 1$ modifies $(D(z = 0.56)/r_s)/(D(z = 1090)/r_s)$



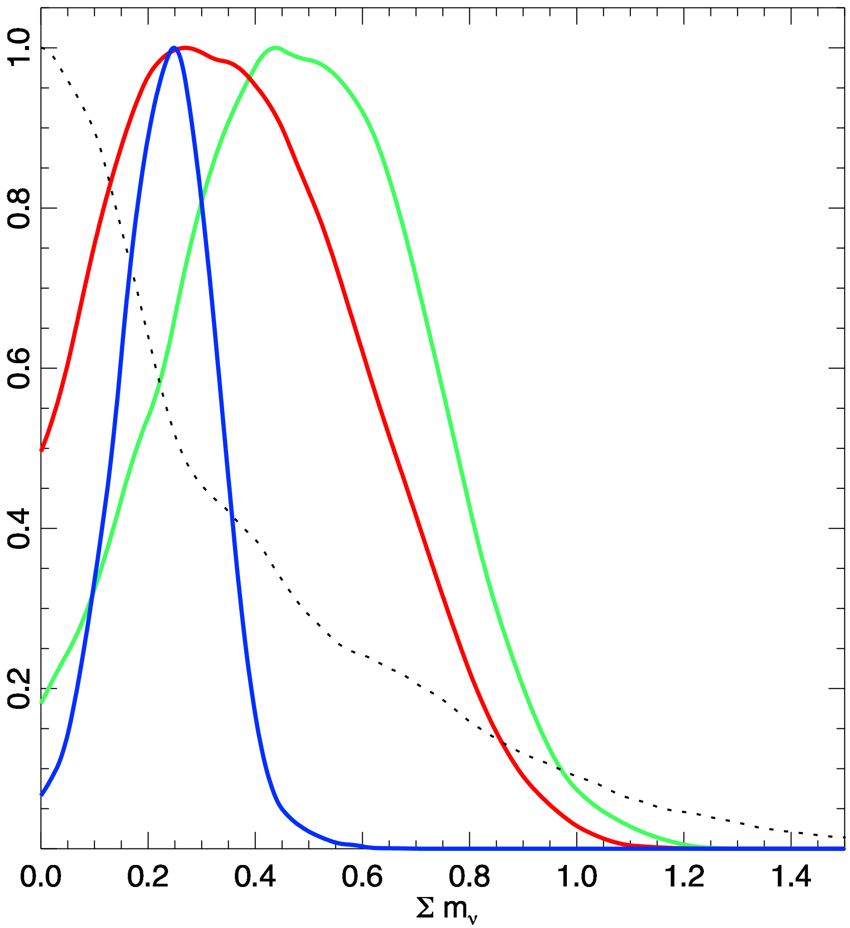
$$\Omega_k = 1 - \sum \Omega_i = 0.0005 \pm 0.0065$$

Extended Λcdm : $N_\nu > 3$, $m_\nu > 0.06eV$

- $N_\nu > 3$ decreases r_s, increases early-time ISW effect
- $m_\nu > 0.06eV$
  modifies $(D(z = 0.56)/r_s)/(D(z = 1090)/r_s)$,
  suppresses gravitational lensing



Galaxy clusters are m_ν-friendly



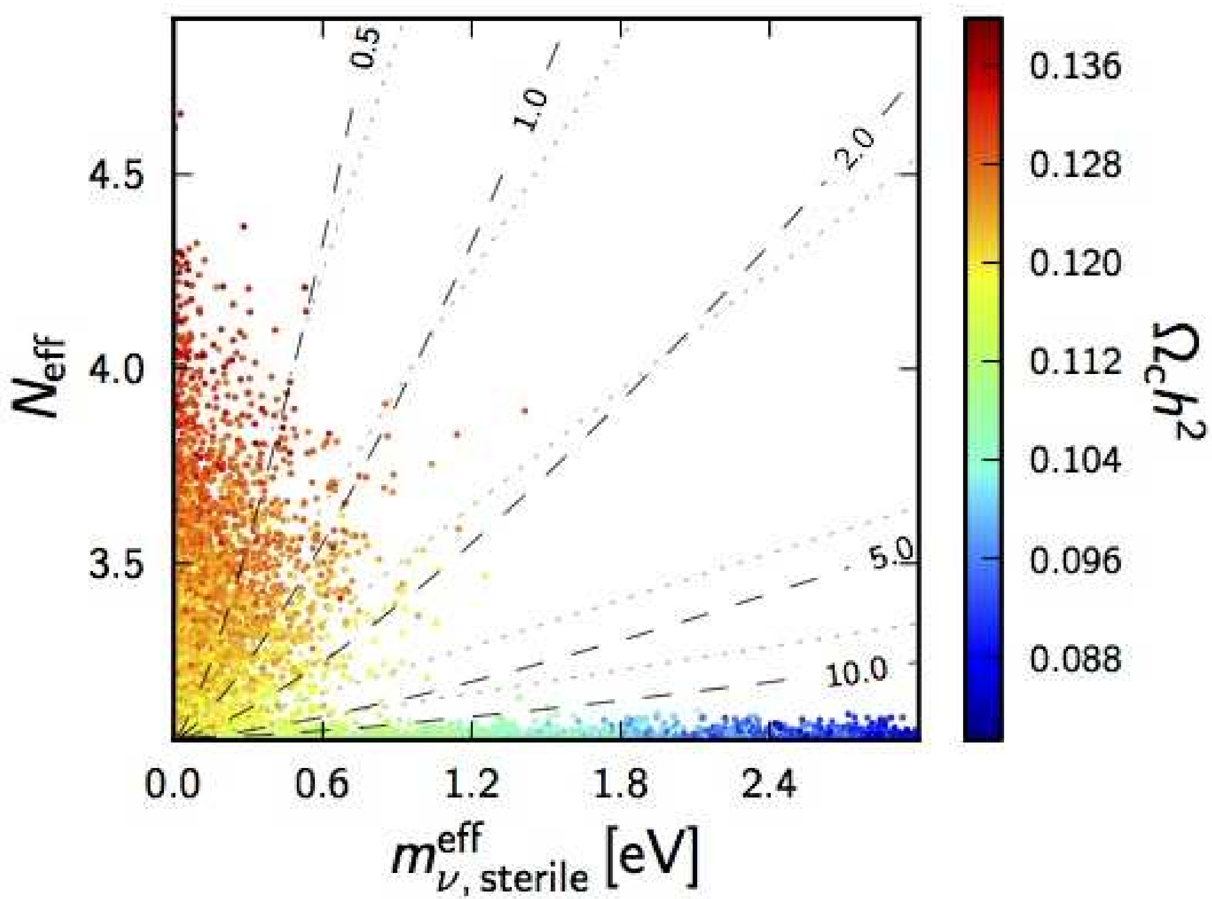
Planck CMB

Planck CMB+SZ, $M_{cluster}$ fixed

Planck CMB+SZ, $M_{cluster}$ free

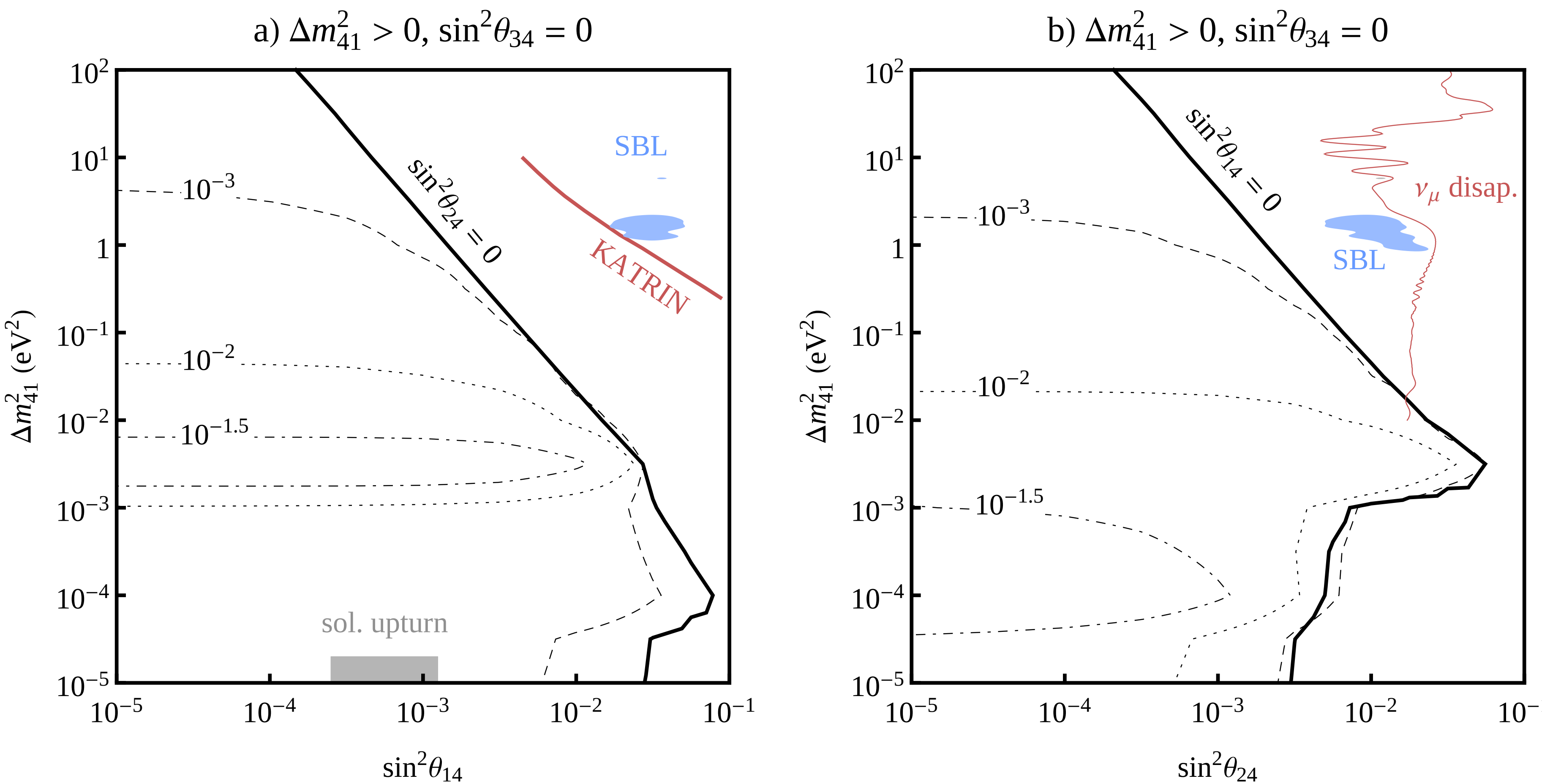
Planck CMB+SZ+BAO, $M_{cluster}$ free

Extended Λcdm : $N_\nu = 4$, (1 sterile ν)



Limits in sterile neutrino mixing

Mirizzi et al, arXiv :1303.5368, (same day as Planck !)



Short-baseline-oscillation anomolies excluded unless

$(n_\nu - n_{\bar{\nu}})/n_\nu > 10^{-2}$

Future for Neutrinos

- Σm_ν
  Planck+WP+highL+BAO : $< 0.23 eV$ (95%CL)
  Planck+BigBOSS-BAO : 0.094 (1σ ?)
  Planck+BigBOSS-BAO + broadband : 0.024
  Planck+Euclid : 0.019

- N_ν
  Planck+WP+highL+BAO : 3.30 ± 0.52(95% CL)
  Planck+BigBOSS-BAO : 0.18 (1σ ?)
  Planck+BigBOSS-BAO + broadband : 0.056

Progress requires understanding broadband correlations

Summary

- minimal Λcdm supported by
  Planck + WMAP
  BAO
  SNIa SNLS (tension no more)
  Weak shear ?
  Galaxy clusters ?
  H_0 ?
- Cosmology gives constraints on models with massive neutrinos