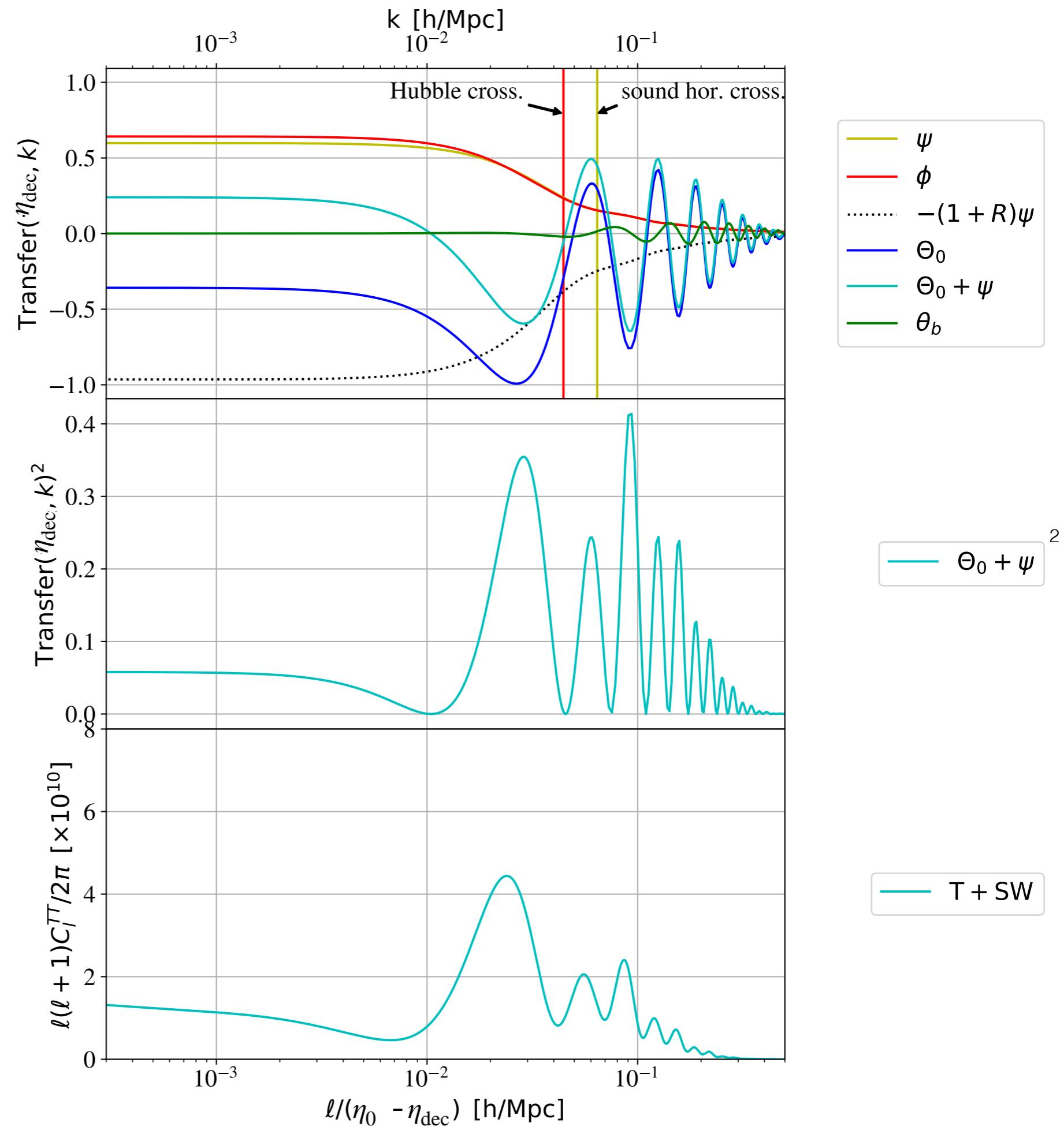
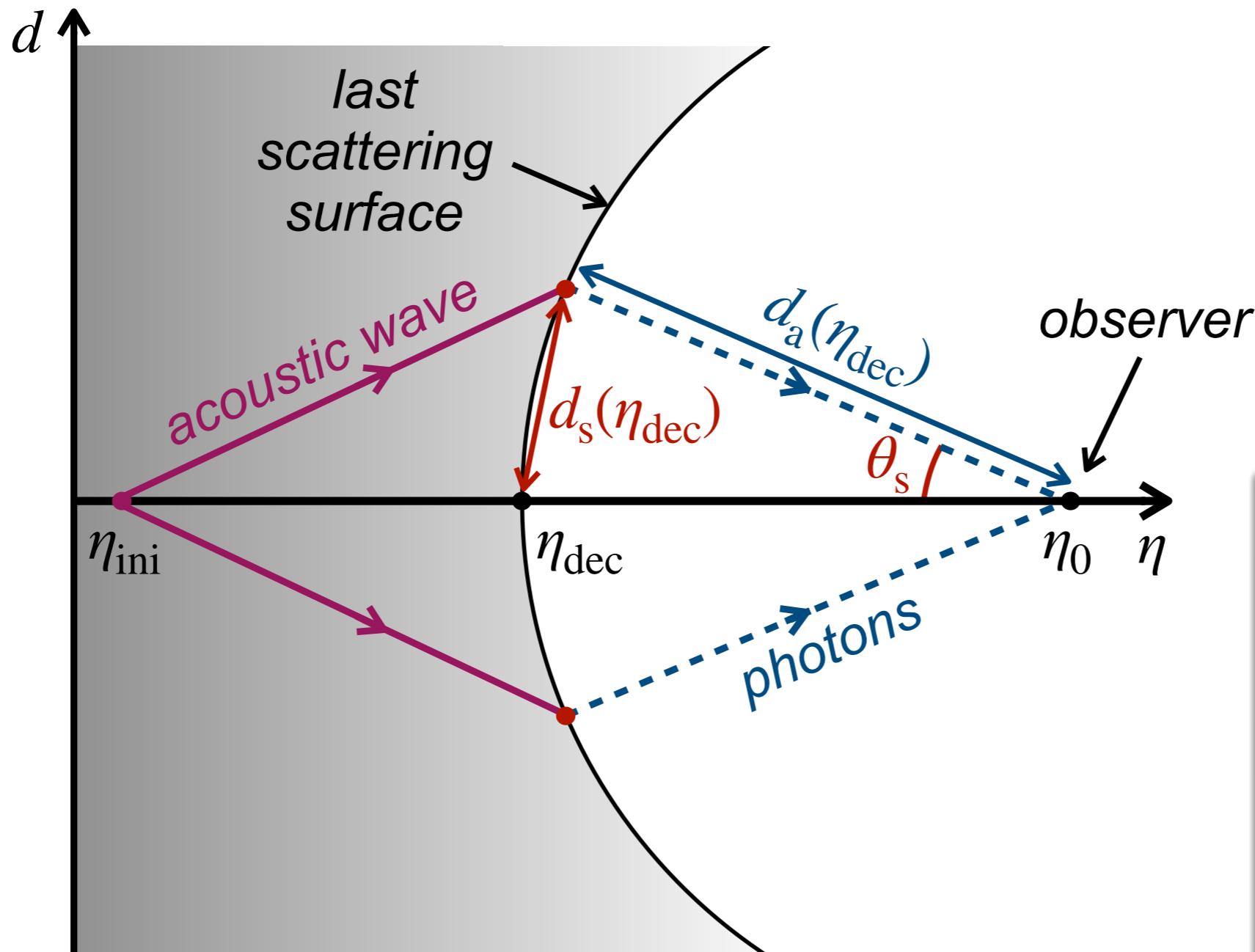


from transfer  
to  $C_\ell$ :

$\Theta_0(\eta_{\text{dec}}, k) + \psi(\eta_{\text{dec}}, k)$   
independent of  $k$  would  
give  $l(l+1)C_l = \text{constant}$



# The real space view

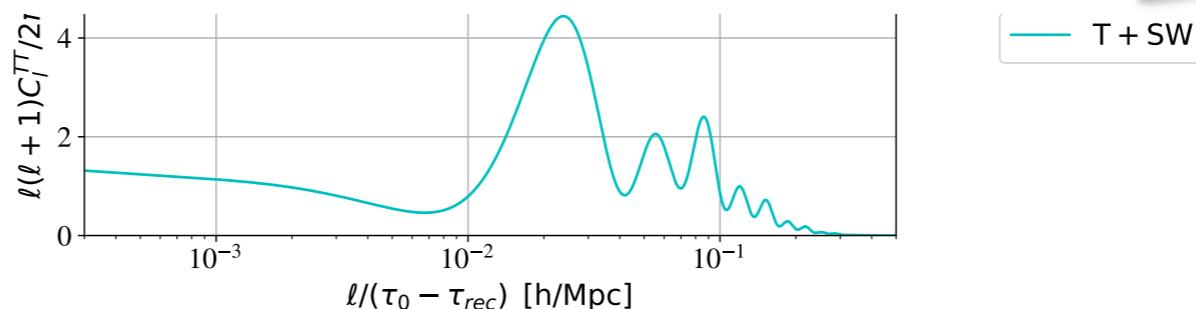


sound horizon

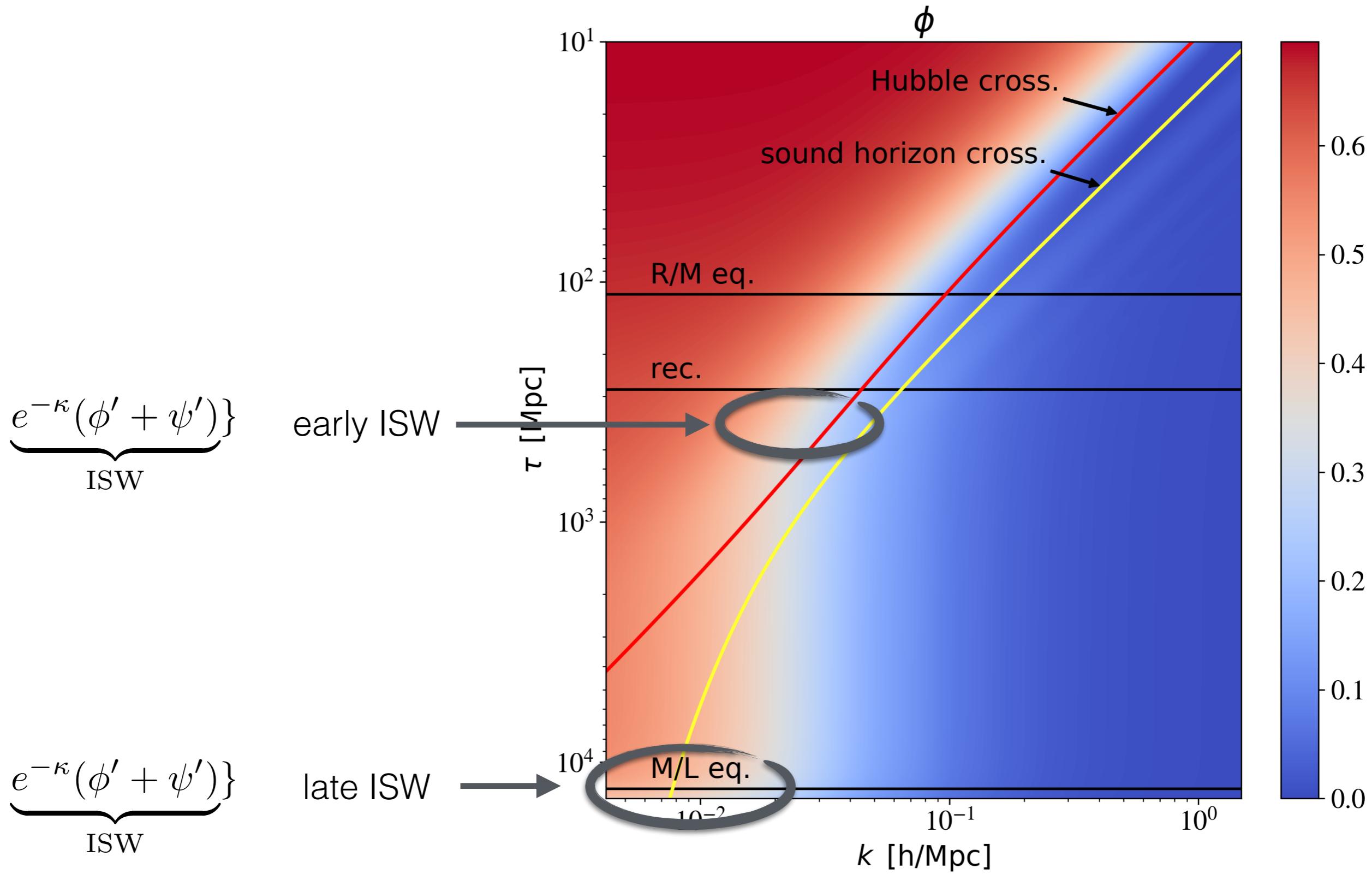
$$d_s(\eta) = a(\eta) \int_0^\eta c_s d\tilde{\eta}$$

seen under

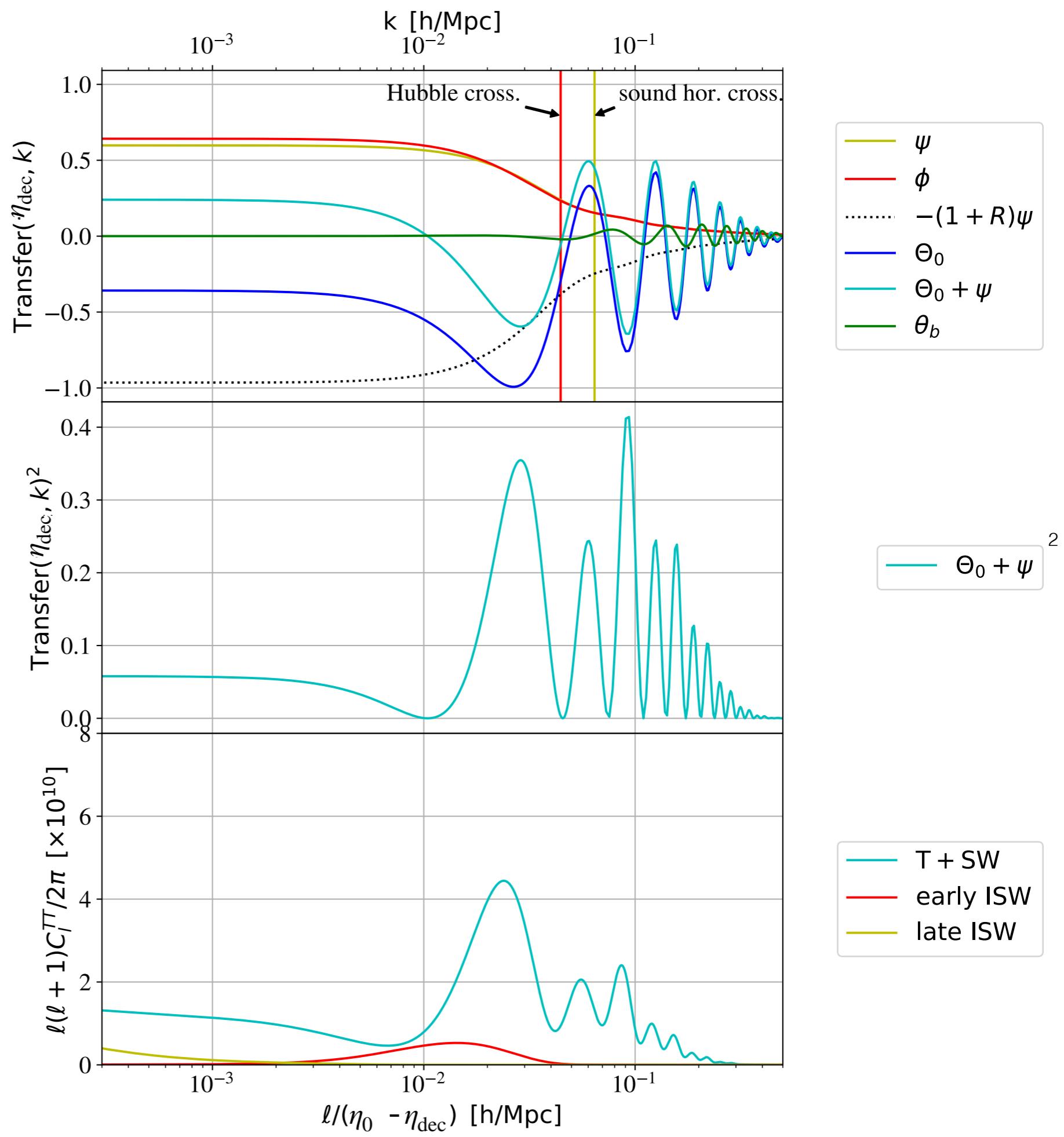
$$\frac{\pi}{l} = \theta_s = \frac{d_s(\eta_{dec})}{d_a(\eta_{dec})}$$



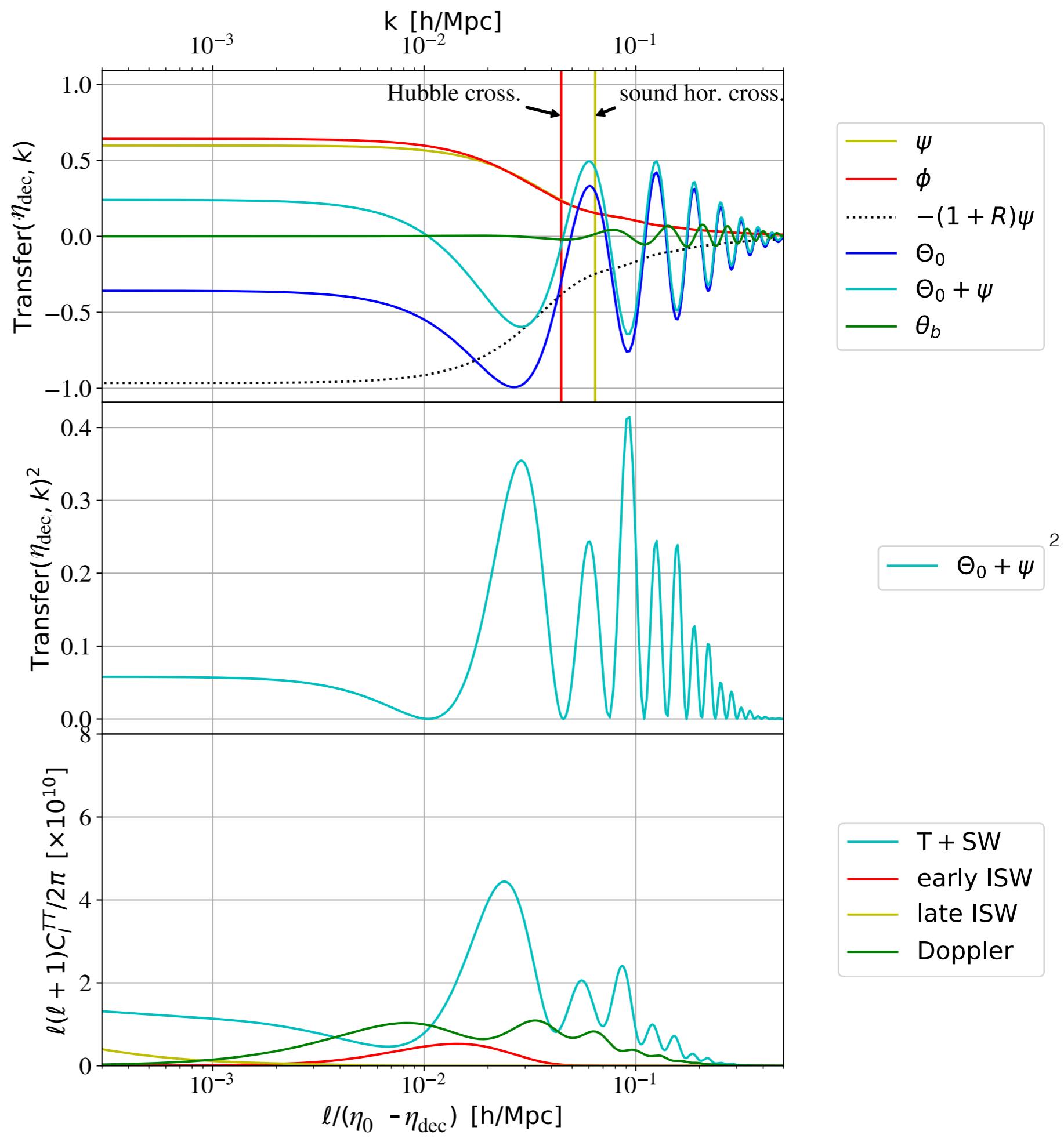
# ISW contribution



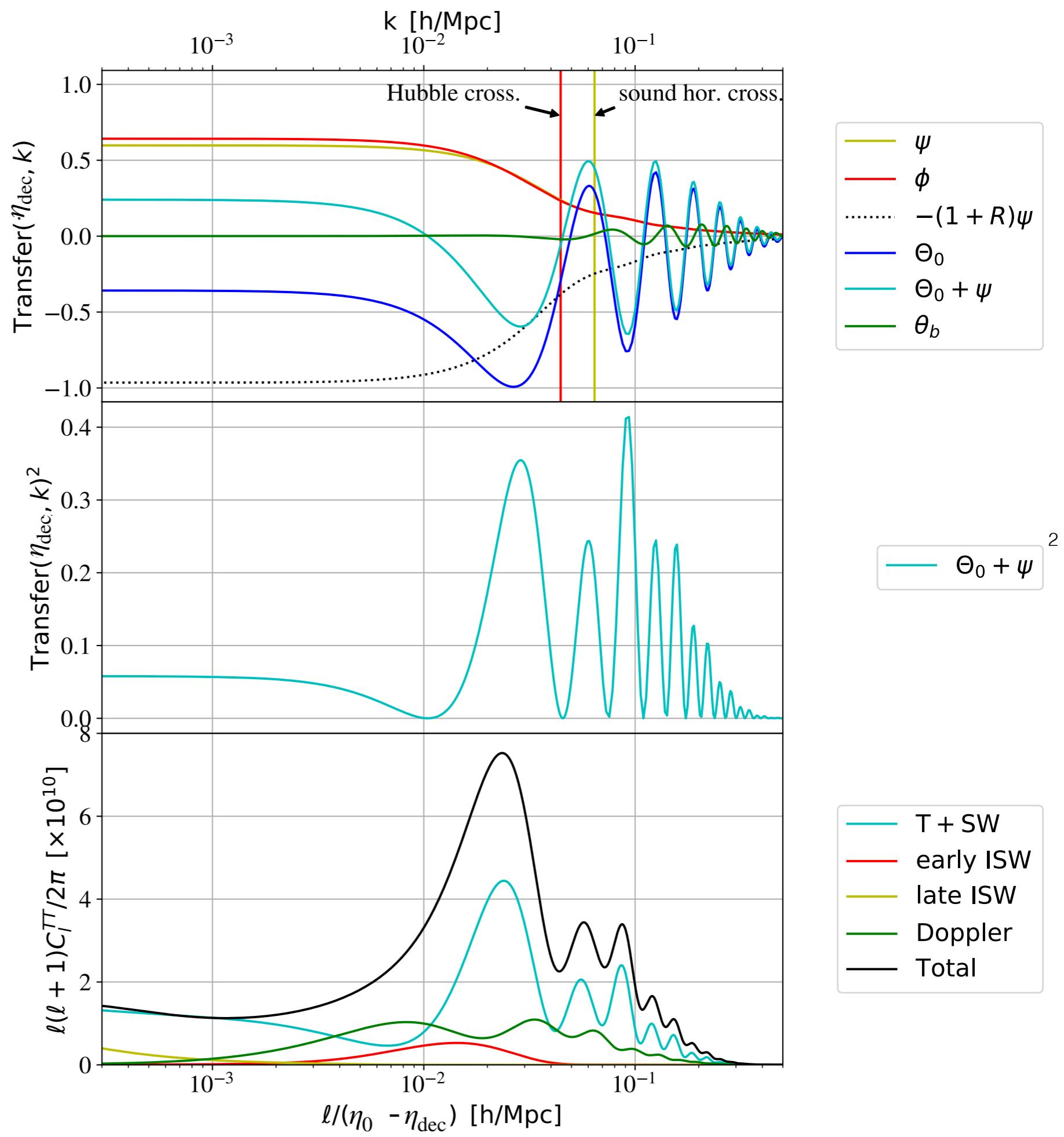
from transfer  
to  $C_\ell$ :



from transfer  
to  $C_\ell$ :



from transfer  
to  $C_\ell$ :



# $\Lambda$ CDM parameter effects on temperature spectrum

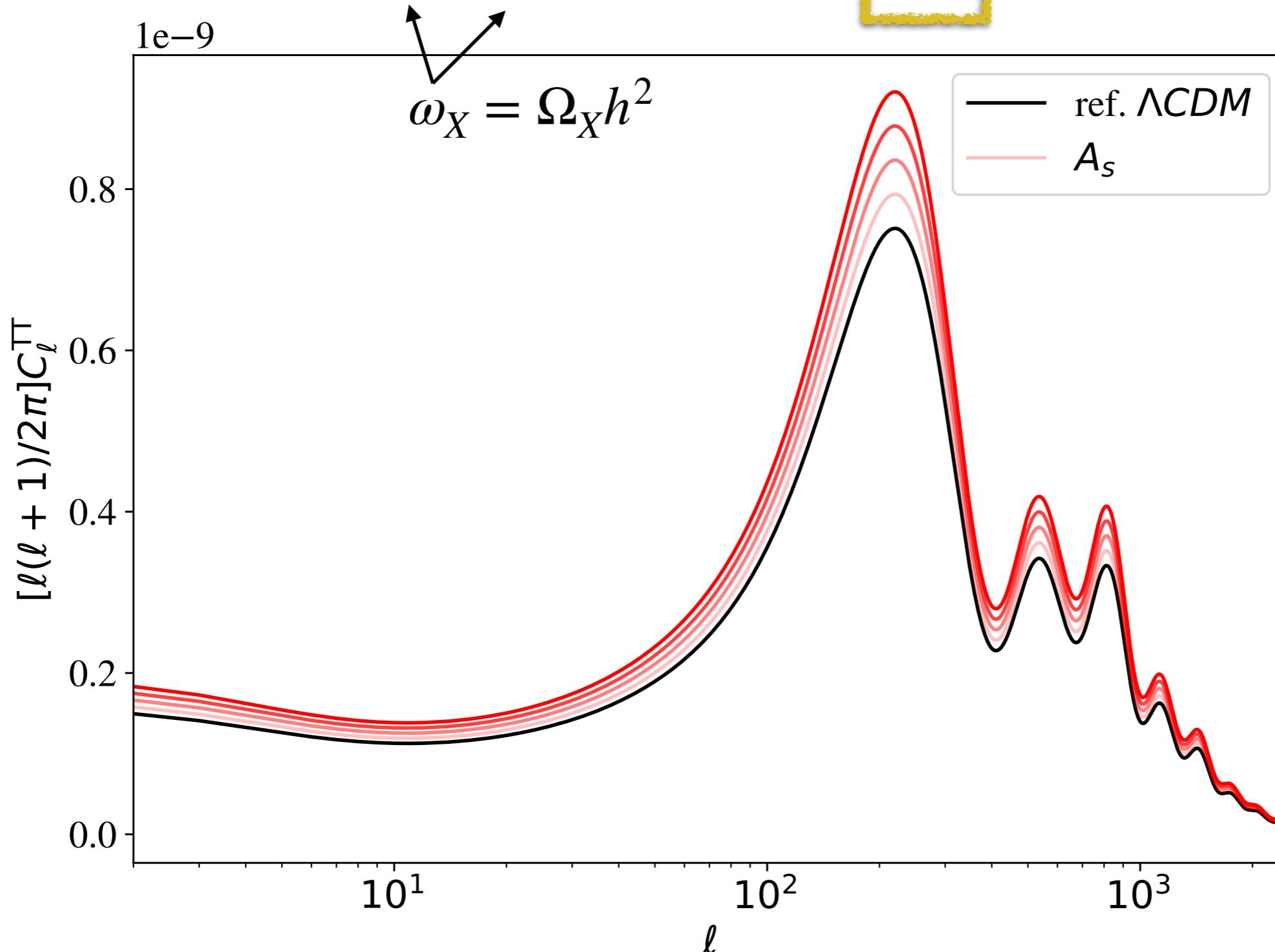
# Why can we measure 6 $\Lambda$ CDM parameters independently with CMB?

- Flat FLRW ( $\Omega_k = 0$ ),
- Cosmological constant ( $w = -1$ ),
- Plain decoupled / stable / cold dark matter,
- Neutrino mass neglected or fixed to minimal value,
- $N_{\text{eff}} = 3.043$ ,
- Power-law primordial spectrum...

Possible basis:  $\{\omega_b, \omega_m, \Omega_\Lambda, \tau_{\text{reio}}, A_s, n_s\}$

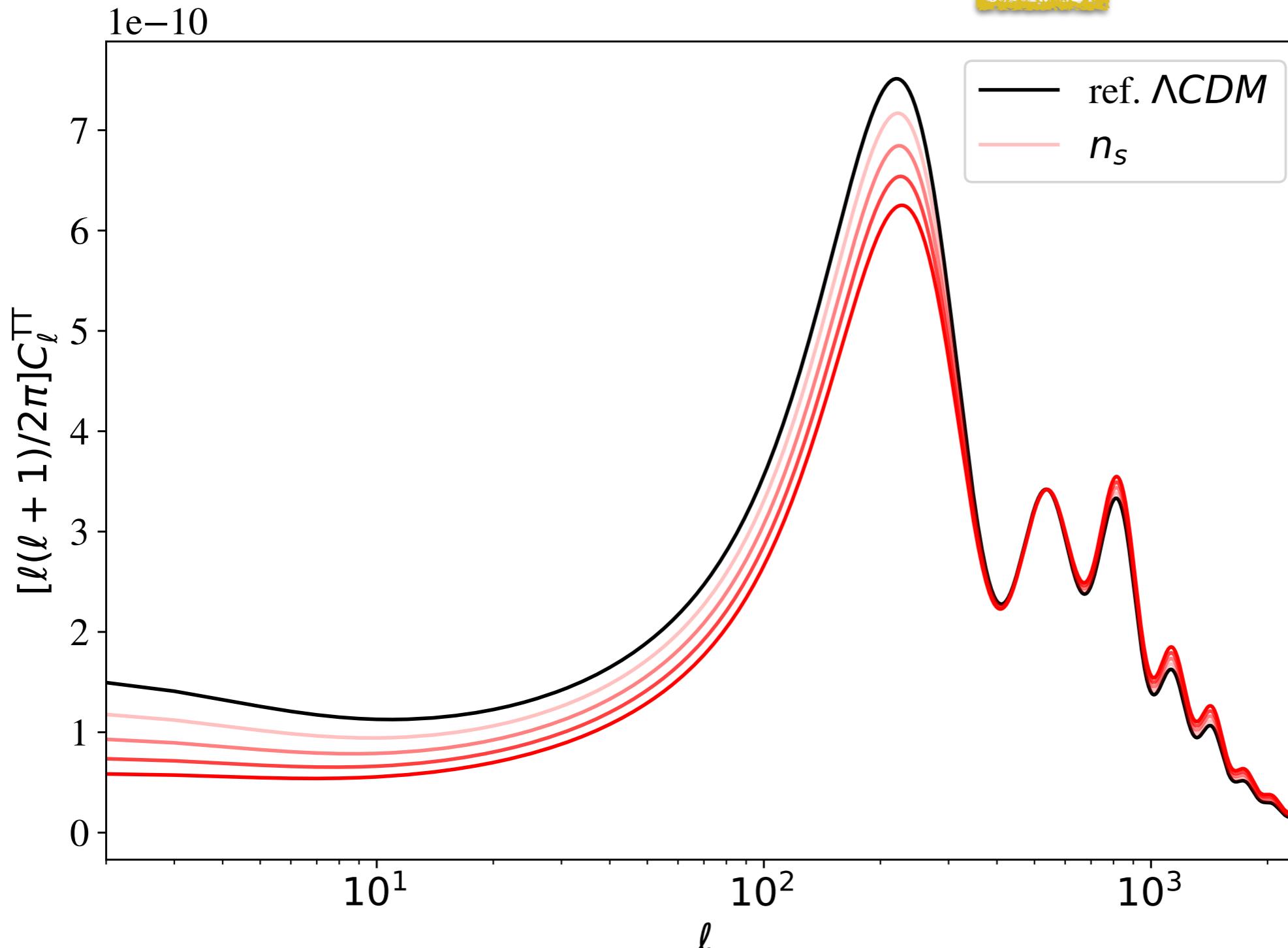
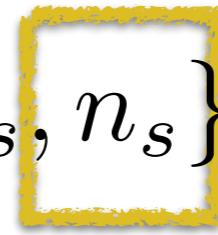
$$\omega_X = \Omega_X h^2$$

parameter of CMB, not of LSS

$\{\omega_b, \omega_m, \Omega_\Lambda, \tau_{\text{reio}}, A_s, n_s\}$ 


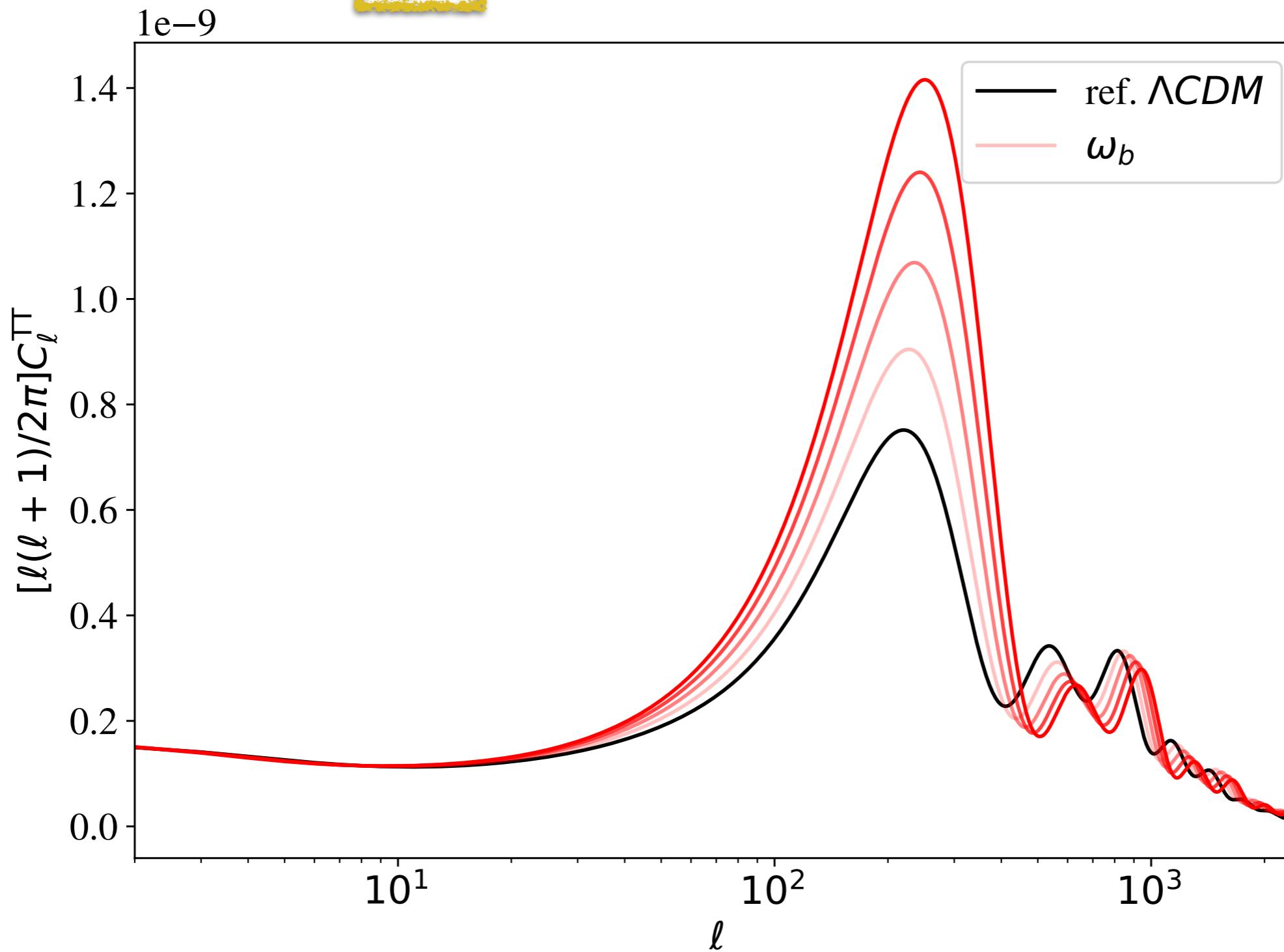
$$C_l^{XY} = 4\pi \int dk \ k^2 \Delta_l^X(k) \Delta_l^Y(k) \mathcal{P}_{\mathcal{R}}(k) \quad \mathcal{P}_{\mathcal{R}}(k) = A_s(k_*) \left(\frac{k}{k_*}\right)^{n_s-1}$$

$$\{\omega_b, \omega_m, \Omega_\Lambda, \tau_{\text{reio}}, A_s, n_s\}$$

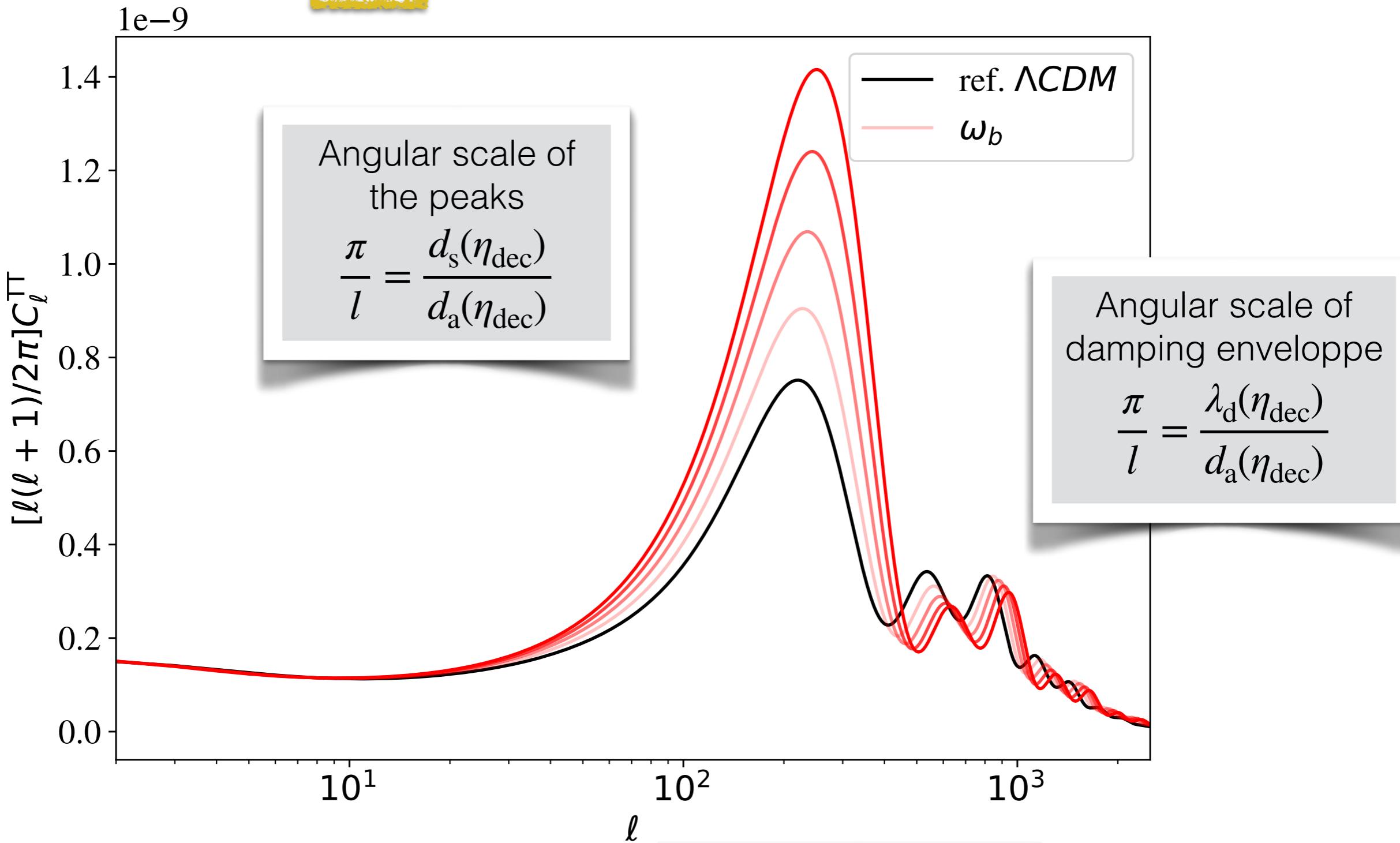


$$C_l^{XY} = 4\pi \int dk \ k^2 \Delta_l^X(k) \Delta_l^Y(k) \mathcal{P}_{\mathcal{R}}(k) \quad \quad \mathcal{P}_{\mathcal{R}}(k) = A_s(k_*) \left( \frac{k}{k_*} \right)^{n_s - 1}$$

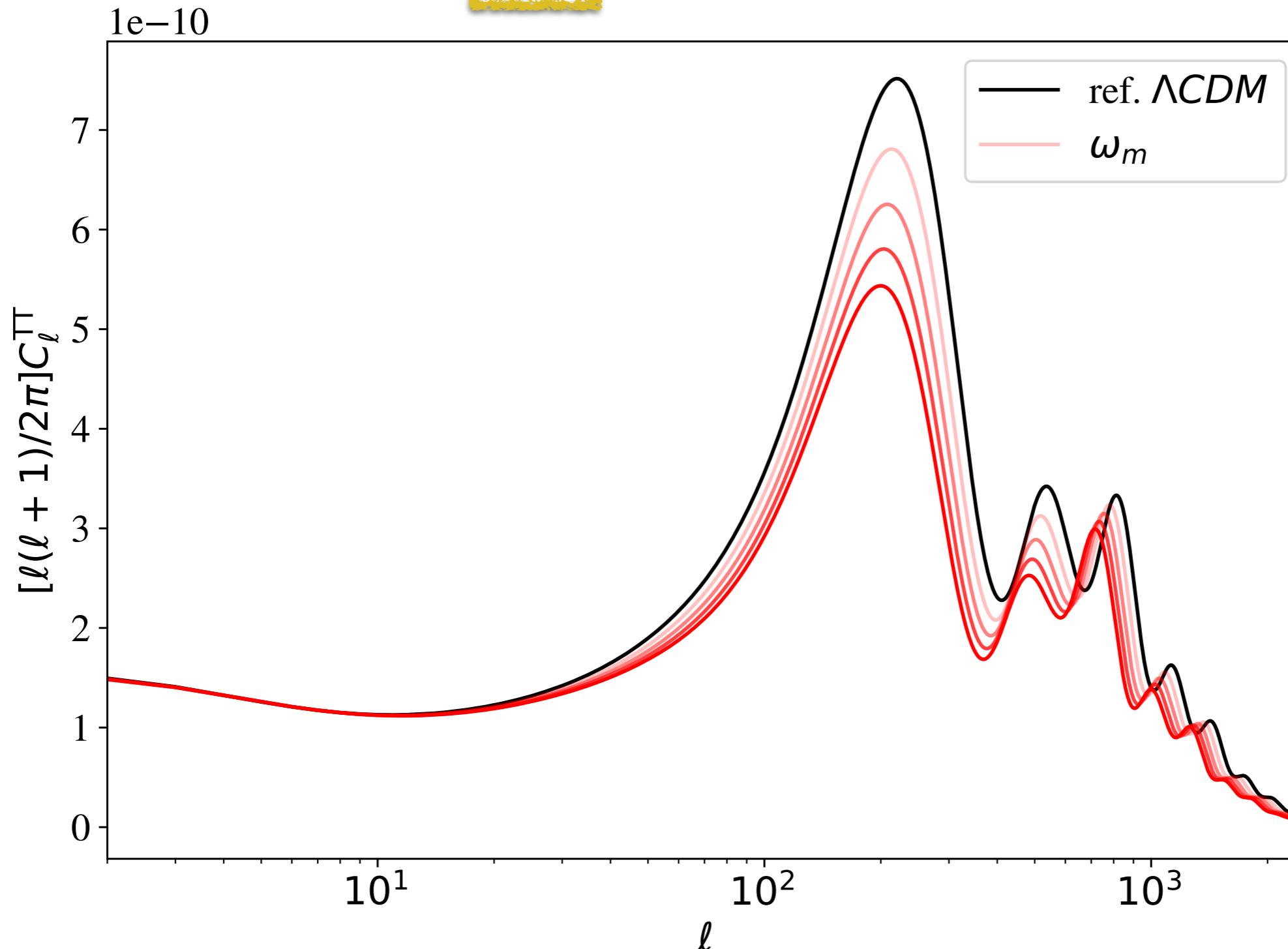
$$\{\omega_b, \omega_m, \Omega_\Lambda, \tau_{\text{reio}}, A_s, n_s\}$$



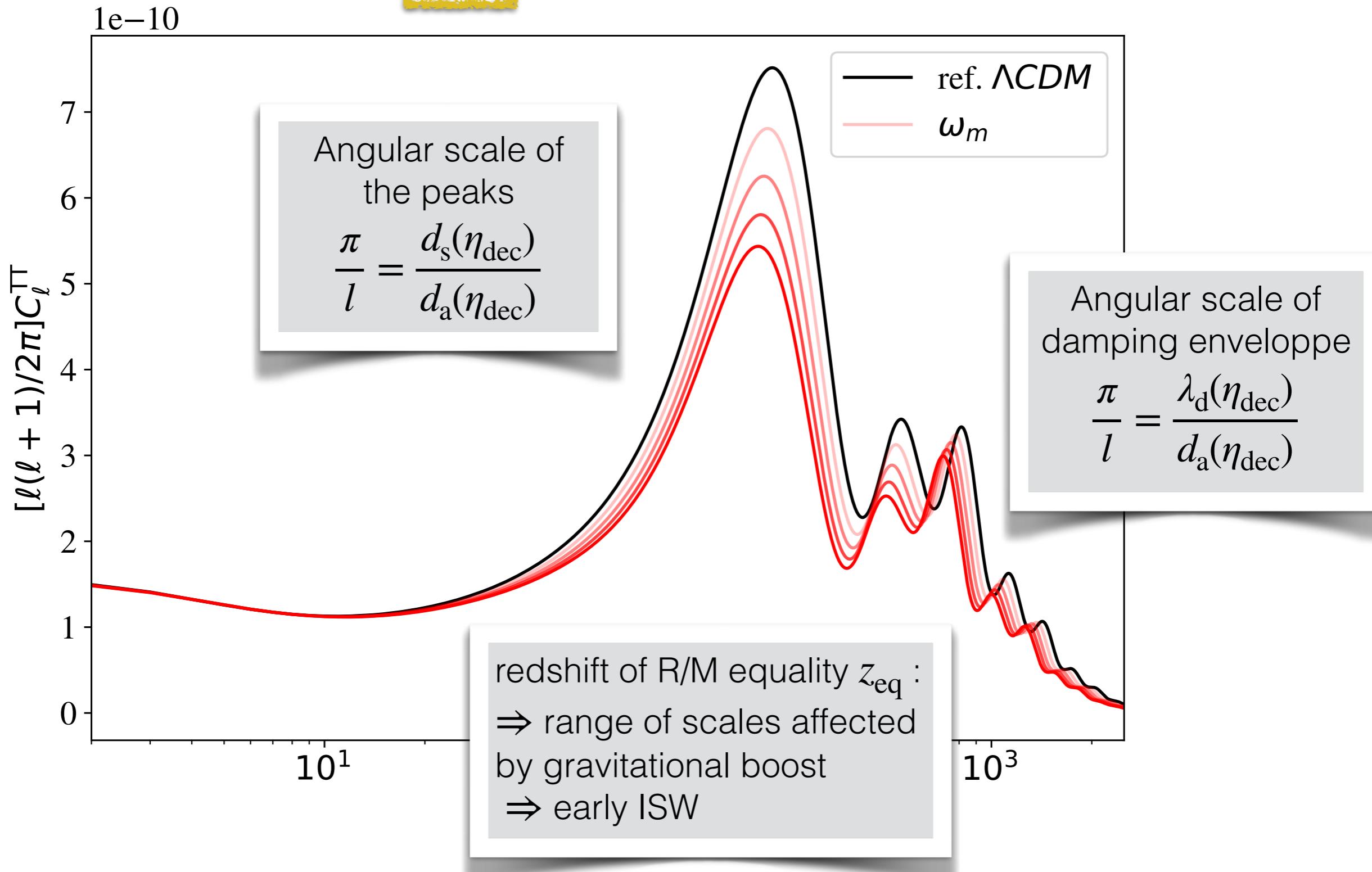
$$\{\omega_b, \omega_m, \Omega_\Lambda, \tau_{\text{reio}}, A_s, n_s\}$$



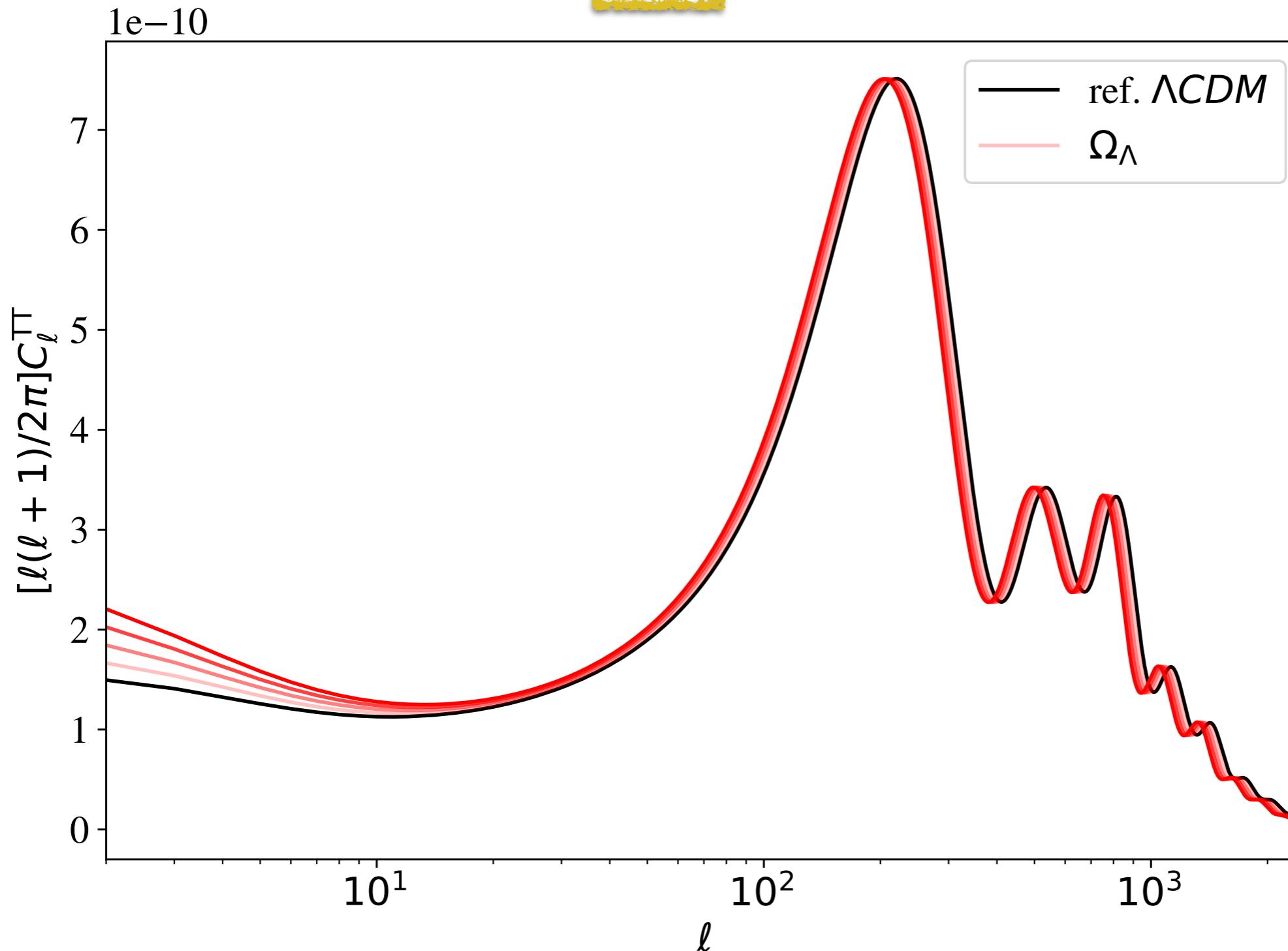
$$\{\omega_b, \boxed{\omega_m}, \Omega_\Lambda, \tau_{\text{reio}}, A_s, n_s\}$$



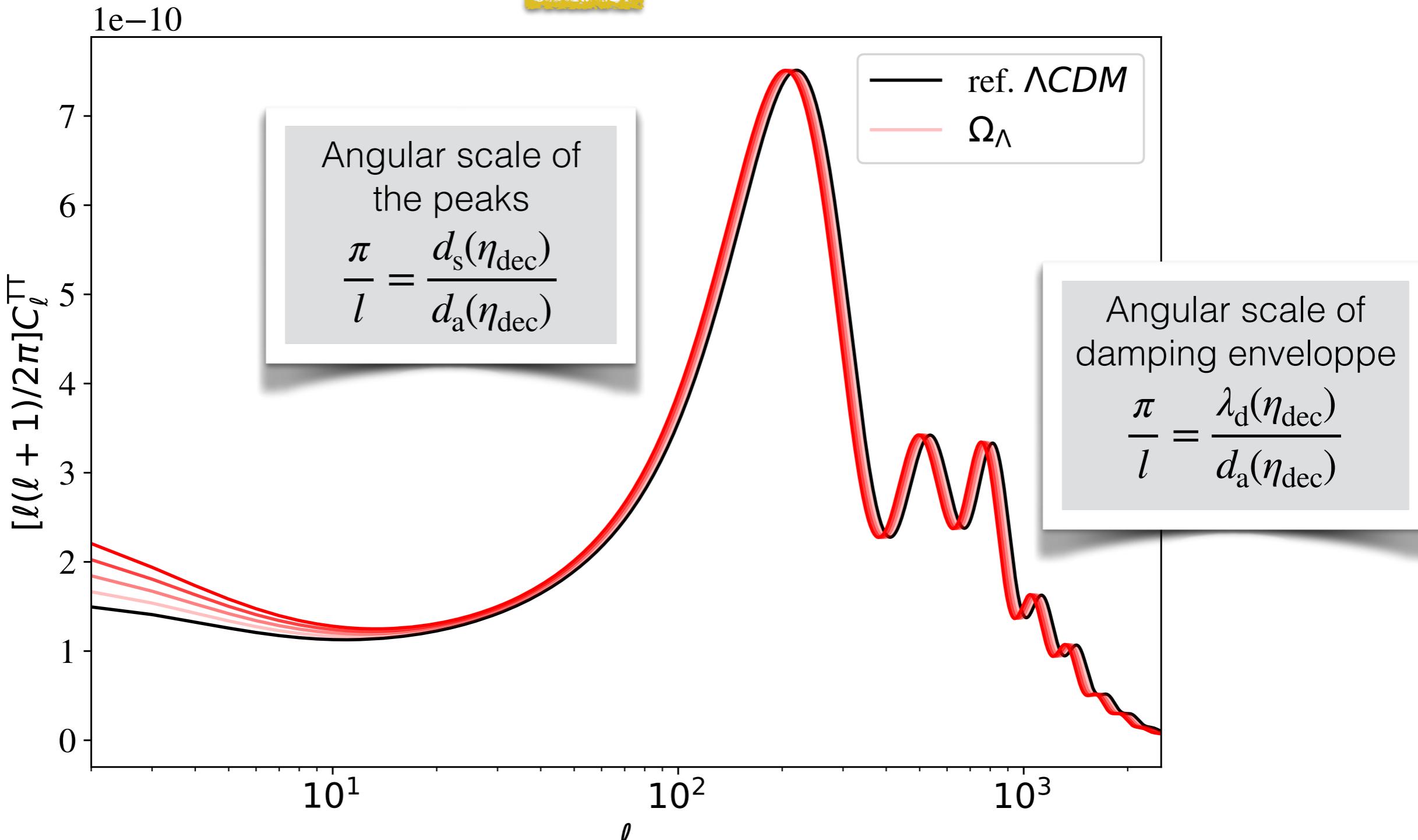
$$\{\omega_b, \boxed{\omega_m}, \Omega_\Lambda, \tau_{\text{reio}}, A_s, n_s\}$$



$$\{\omega_b, \omega_m, \Omega_\Lambda, \tau_{\text{reio}}, A_s, n_s\}$$

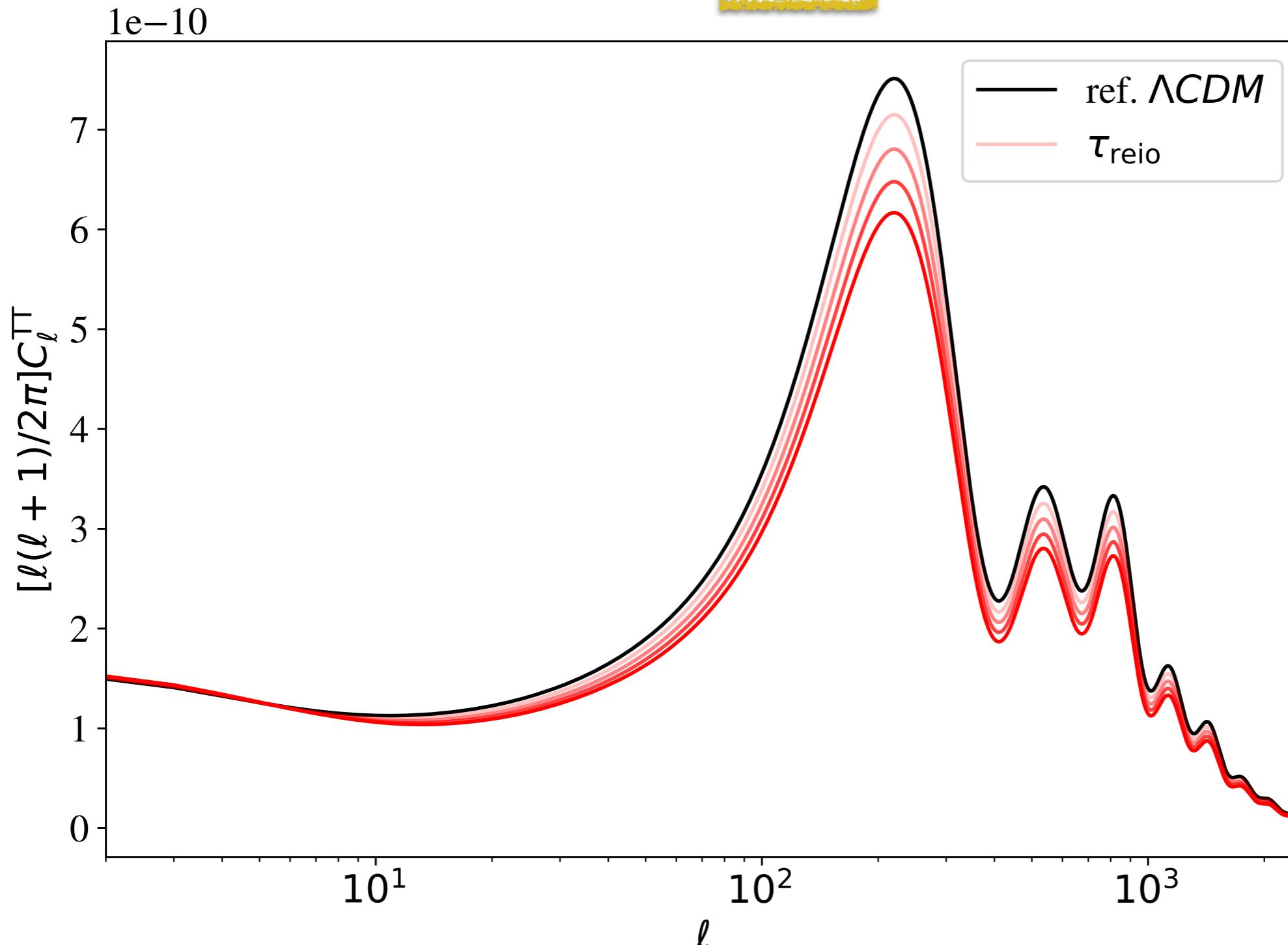


$$\{\omega_b, \omega_m, \Omega_\Lambda, \tau_{\text{reio}}, A_s, n_s\}$$

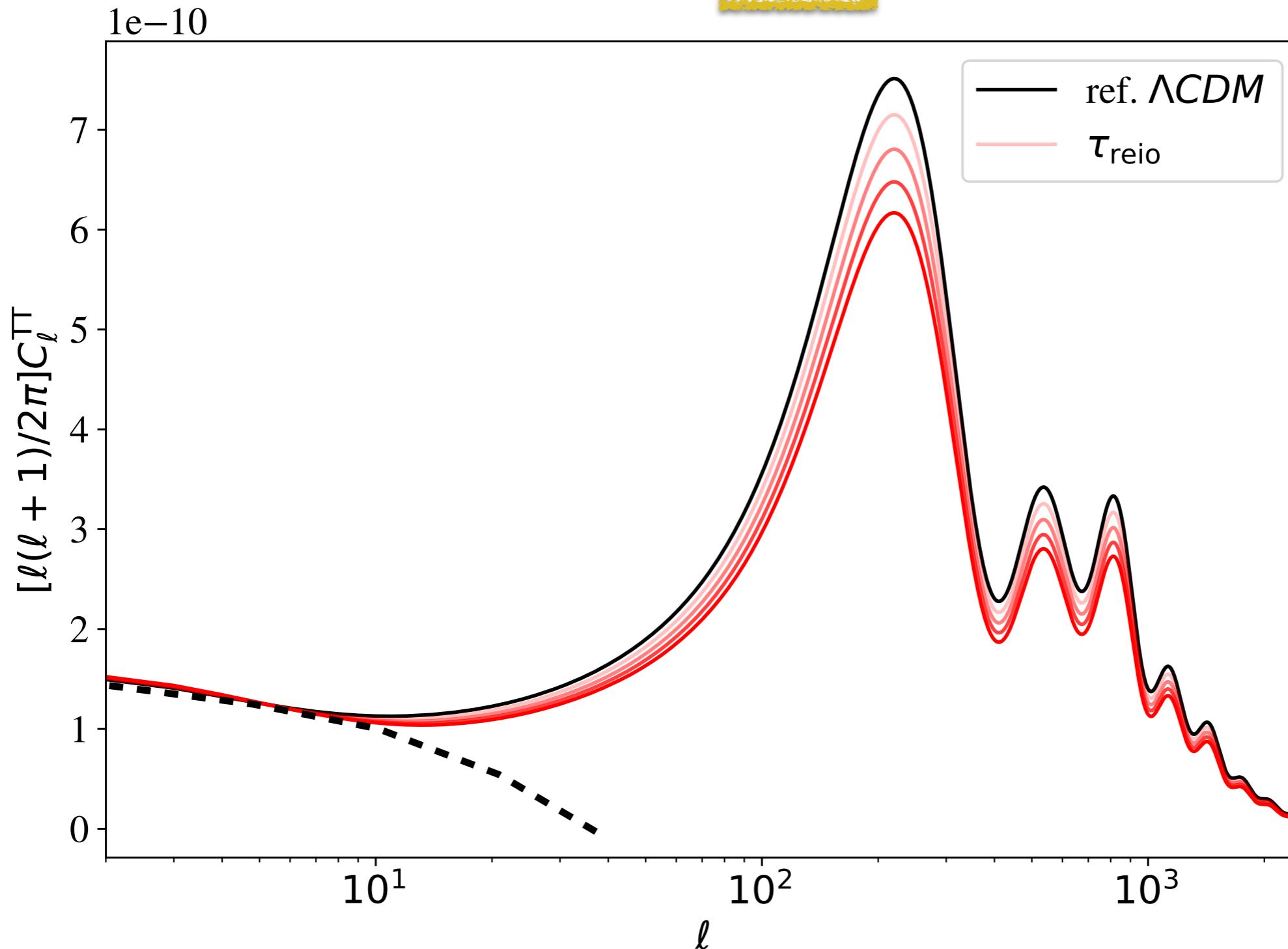


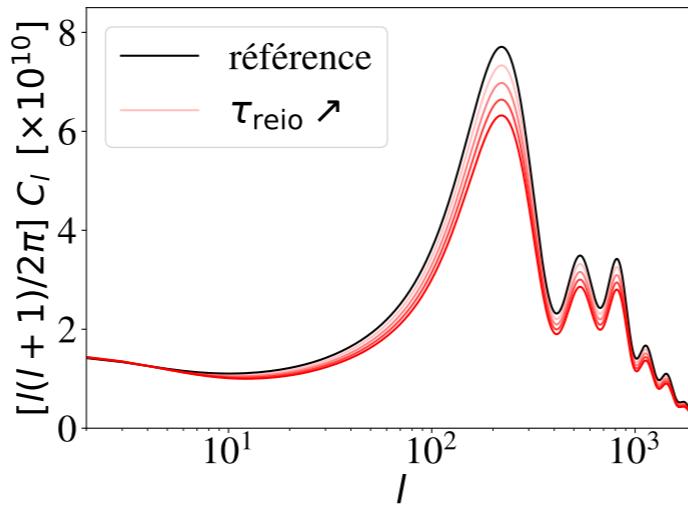
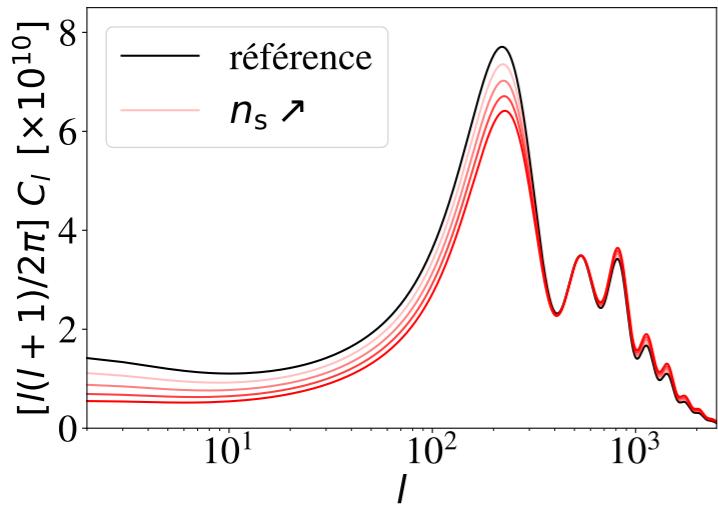
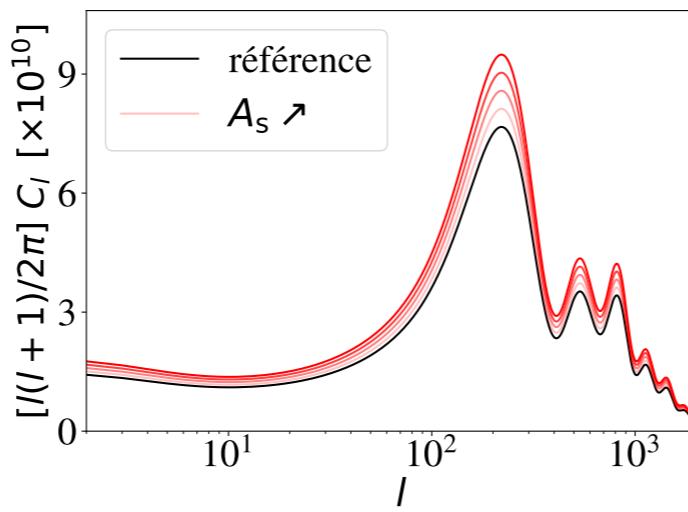
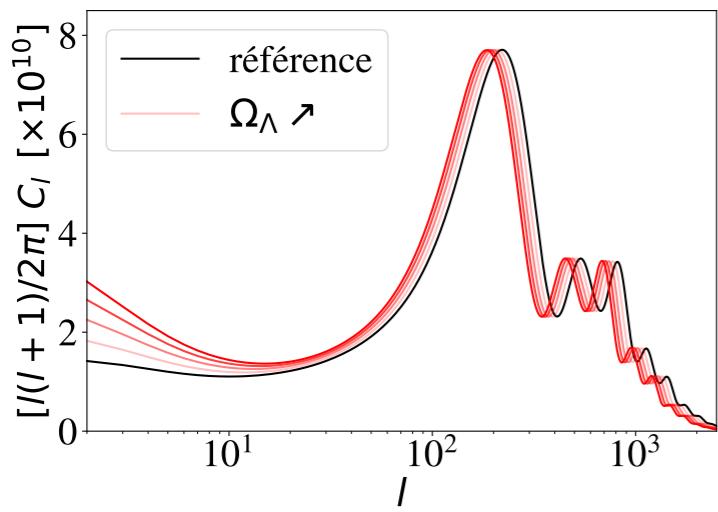
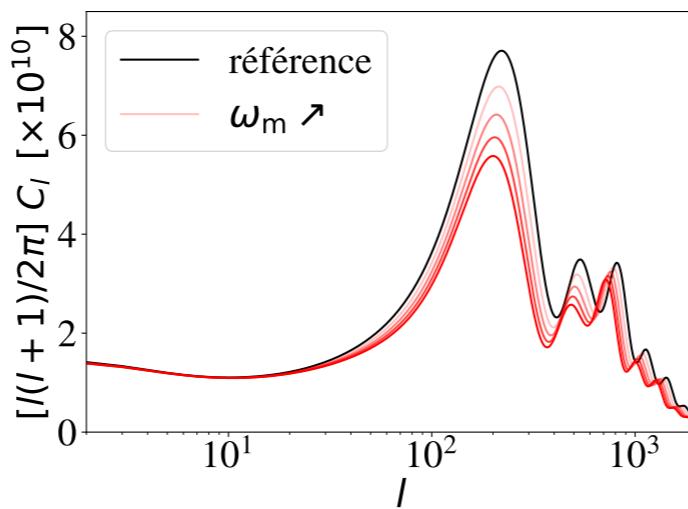
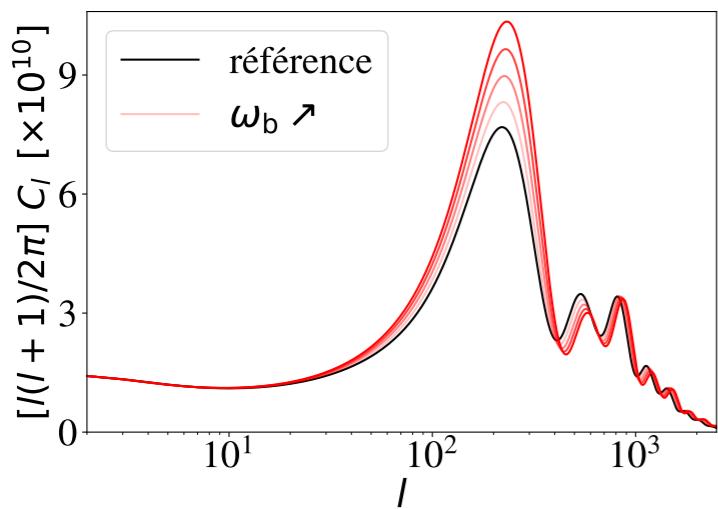
redshift of M/Λ equality  $z_{\text{eq}}$  :  
 $\Rightarrow$  late ISW

$$\{\omega_b, \omega_m, \Omega_\Lambda, \tau_{\text{reio}}, A_s, n_s\}$$



$$\{\omega_b, \omega_m, \Omega_\Lambda, \tau_{\text{reio}}, A_s, n_s\}$$





8 physical governing  $C_l$ 's shape

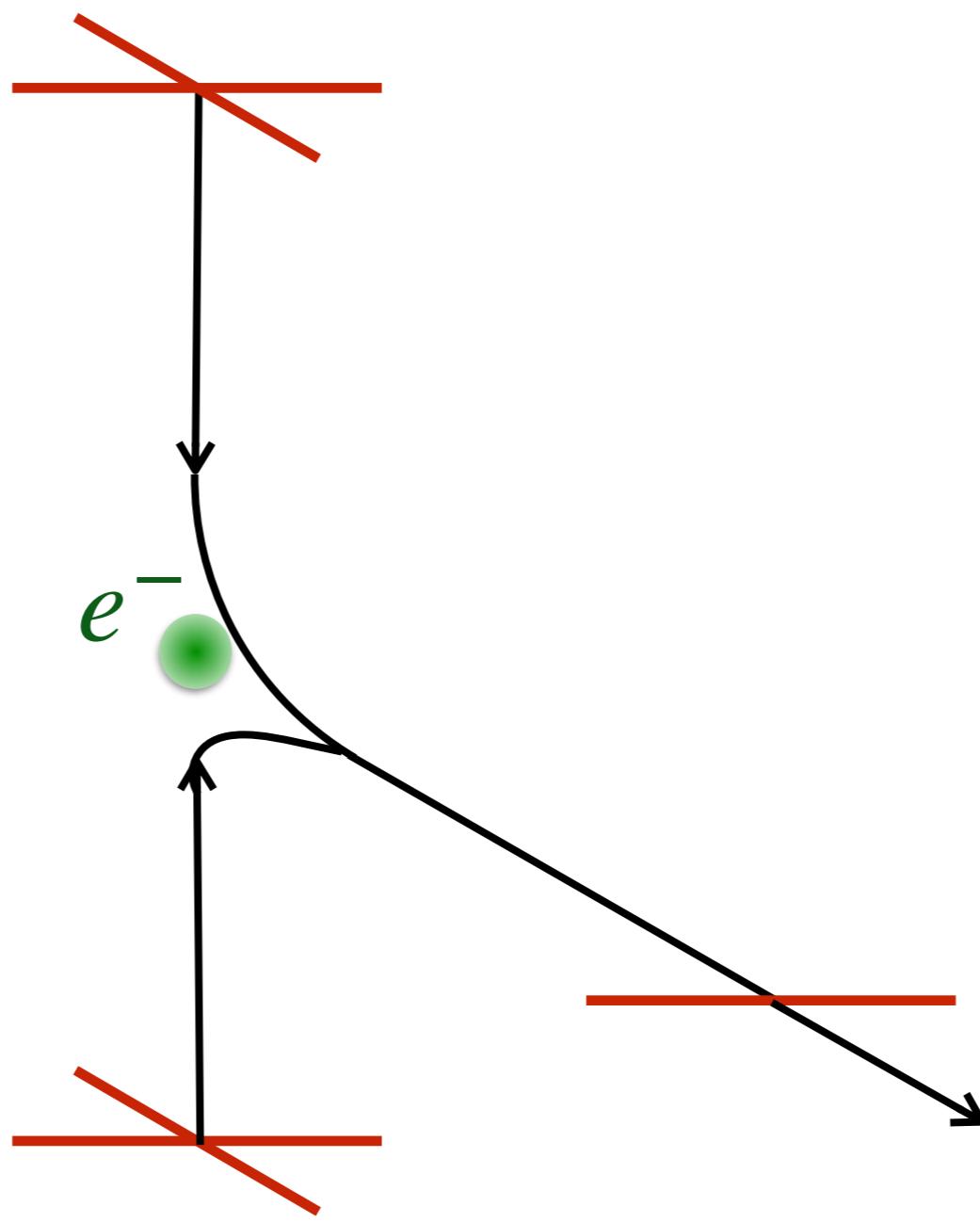
- C1: angular scale of the peaks,  $\theta_s$
- C2: pressure at recombination,  $R_{rec}$
- C3: metric (value and derivative) at  $z_{eq}$
- C4: angular scale of damping enveloppe,  $\theta_d$
- C5: global amplitude
- C6: global tilt
- C7: plateau tilting by late ISW
- C8: reionisation steplike suppression

but all tight to 6 parameters in  $\Lambda$ CDM

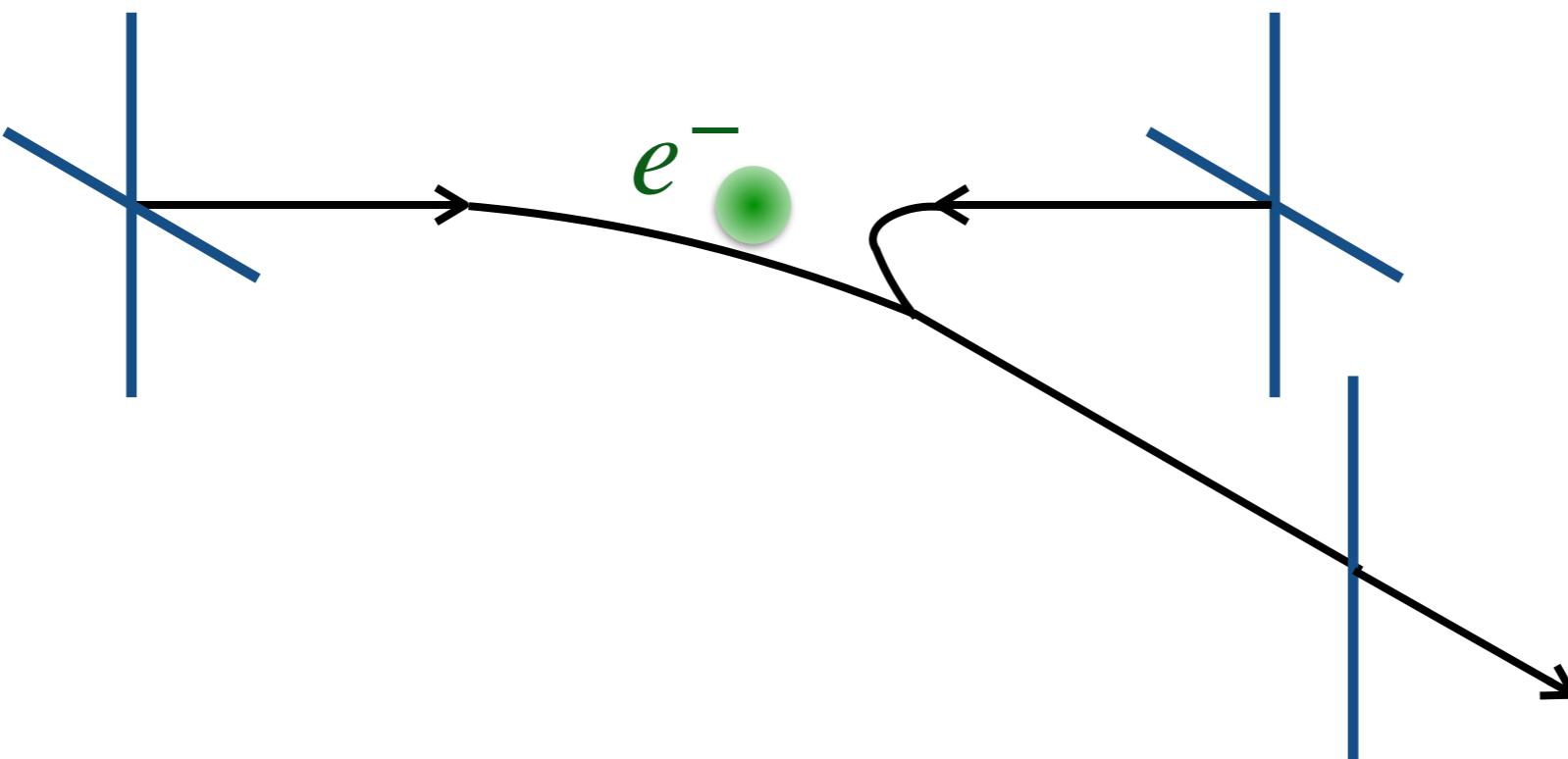
Extended cosmologies? ... more parameters ... but also more effects ...

# CMB polarisation

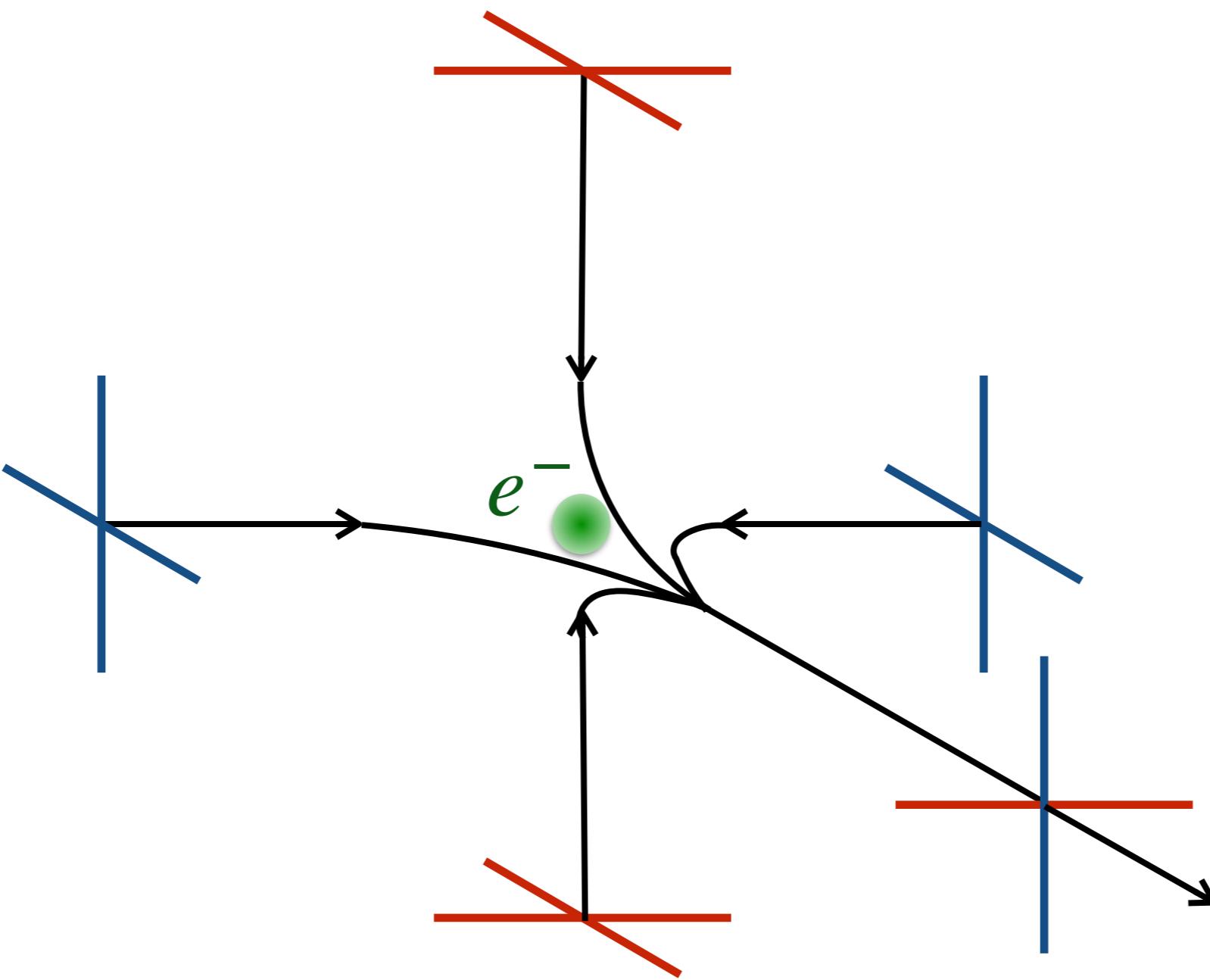
# CMB polarisation



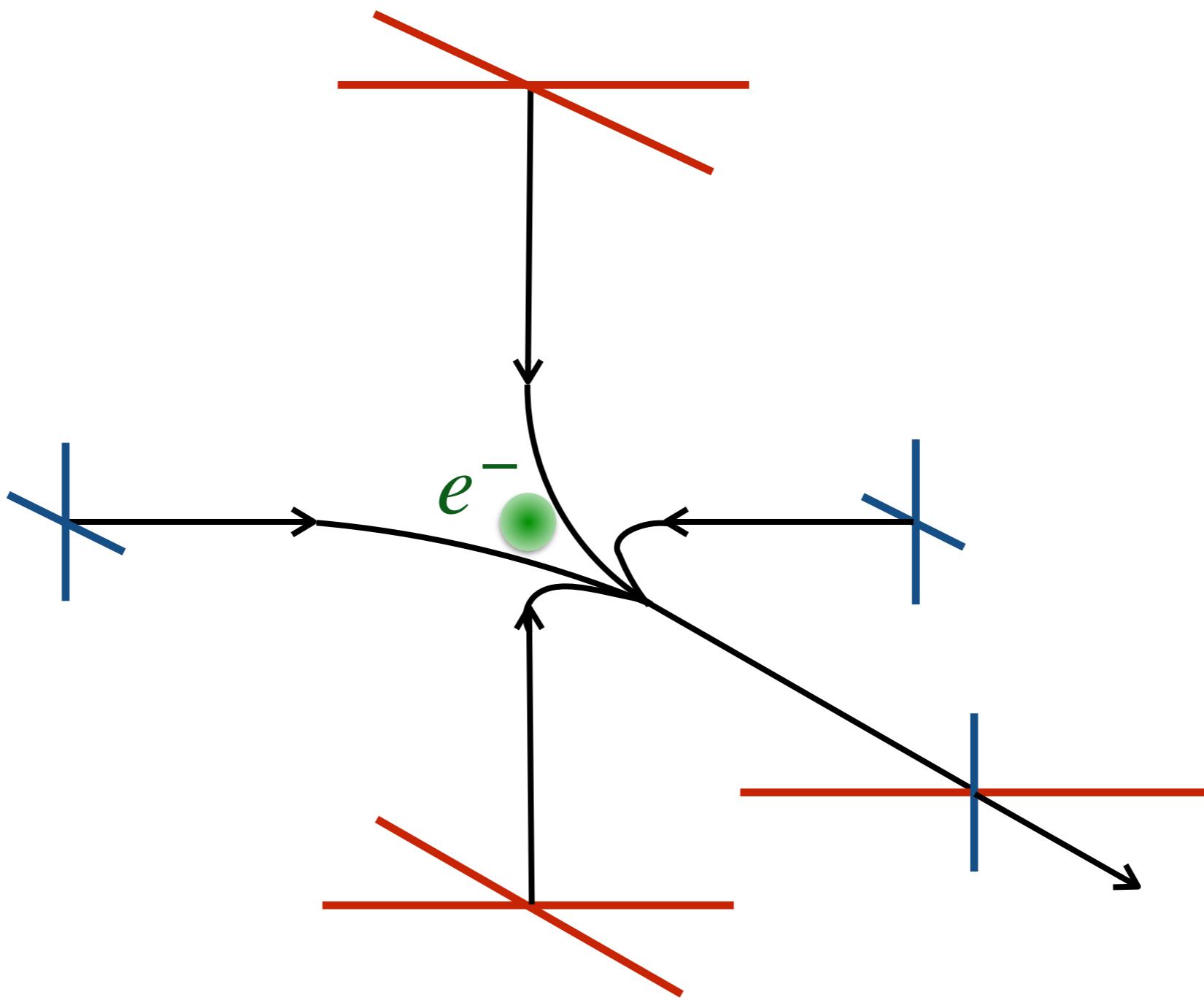
# CMB polarisation



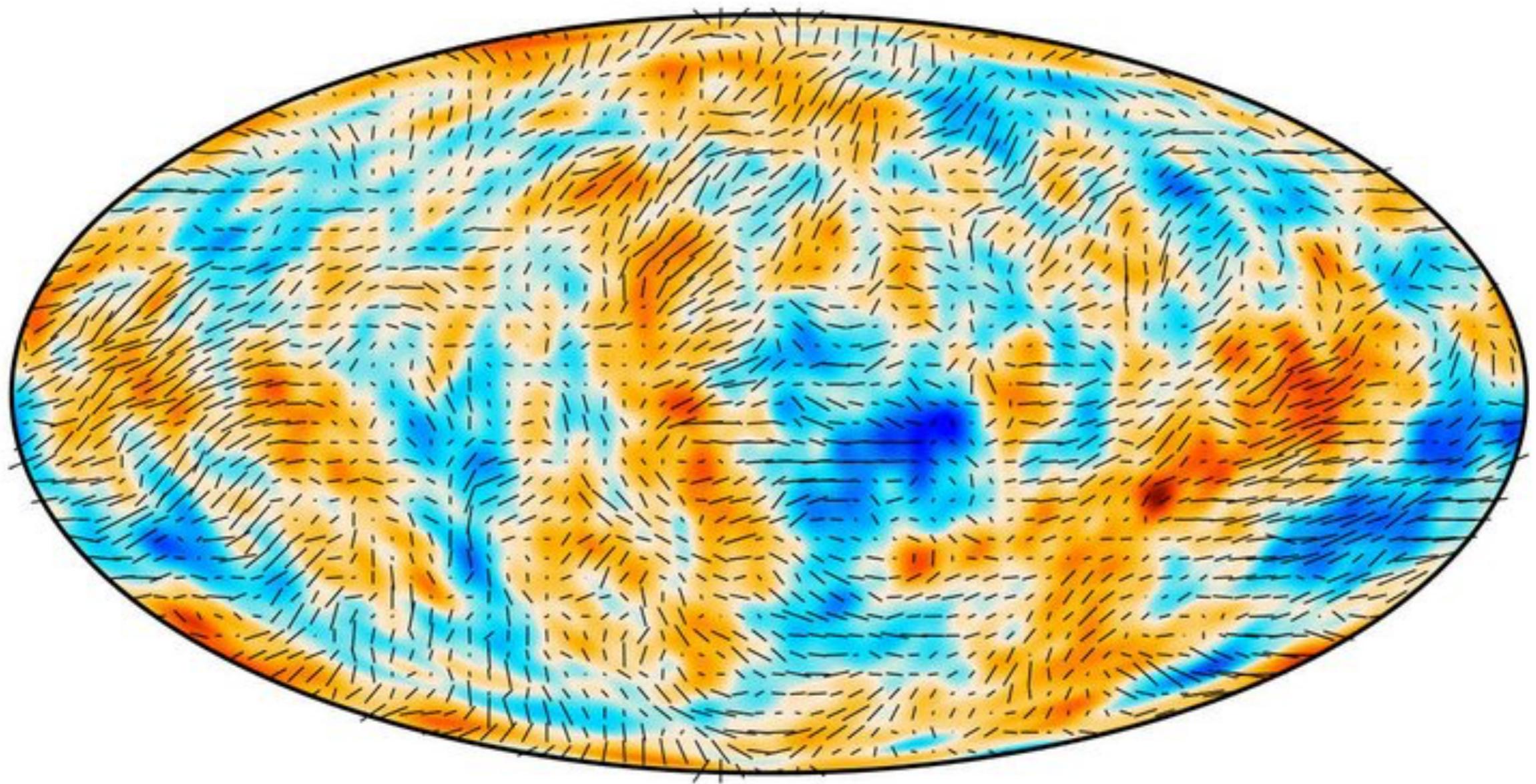
# CMB polarisation



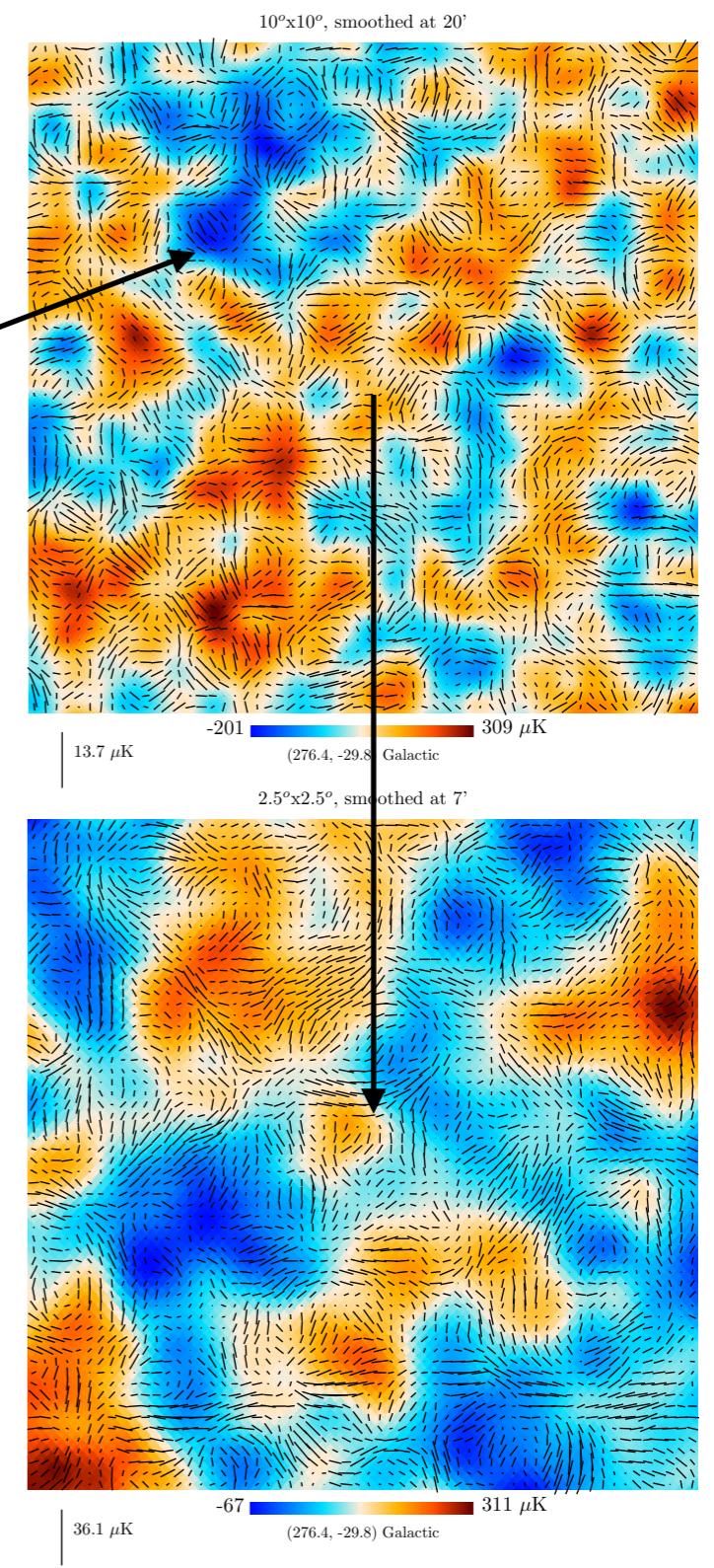
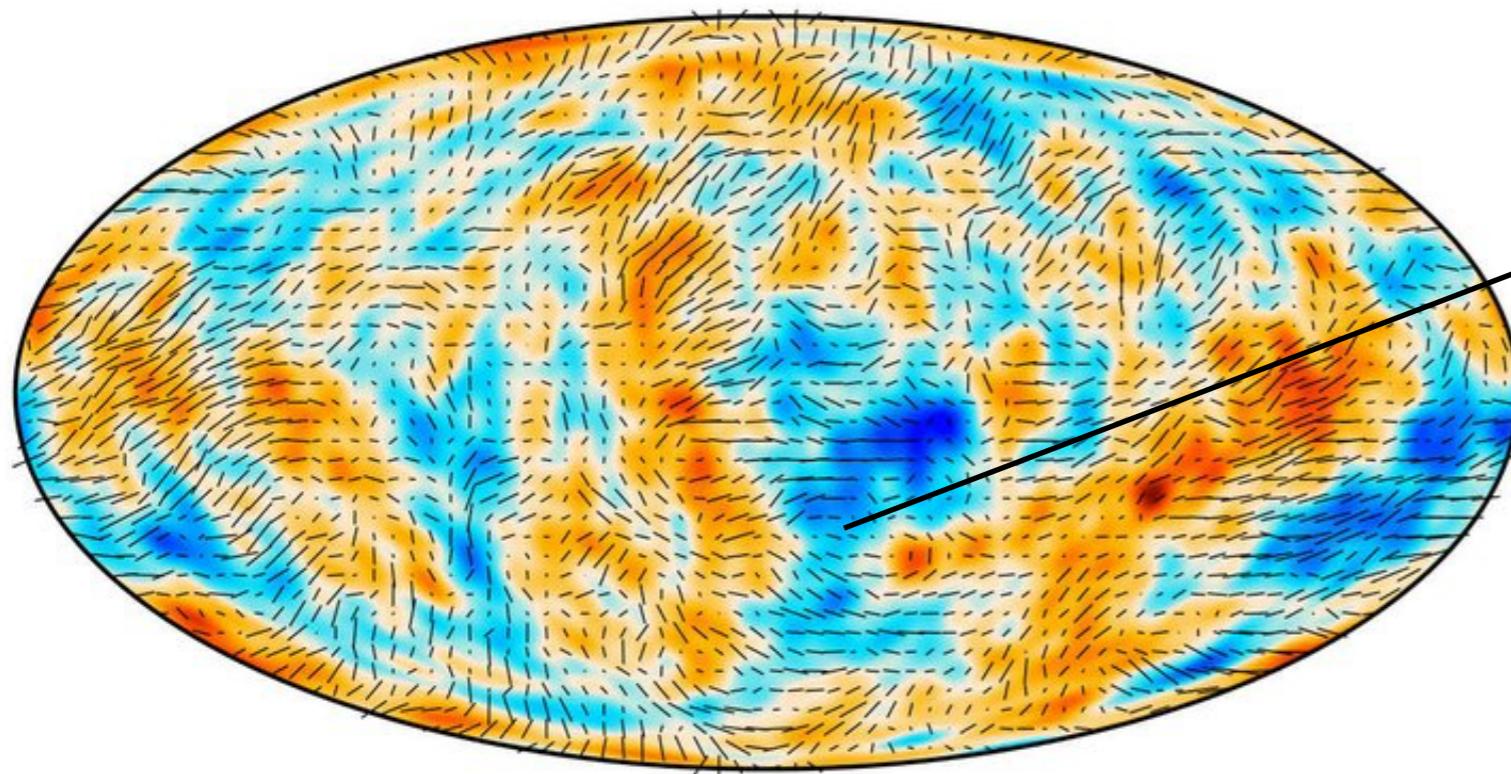
# CMB polarisation



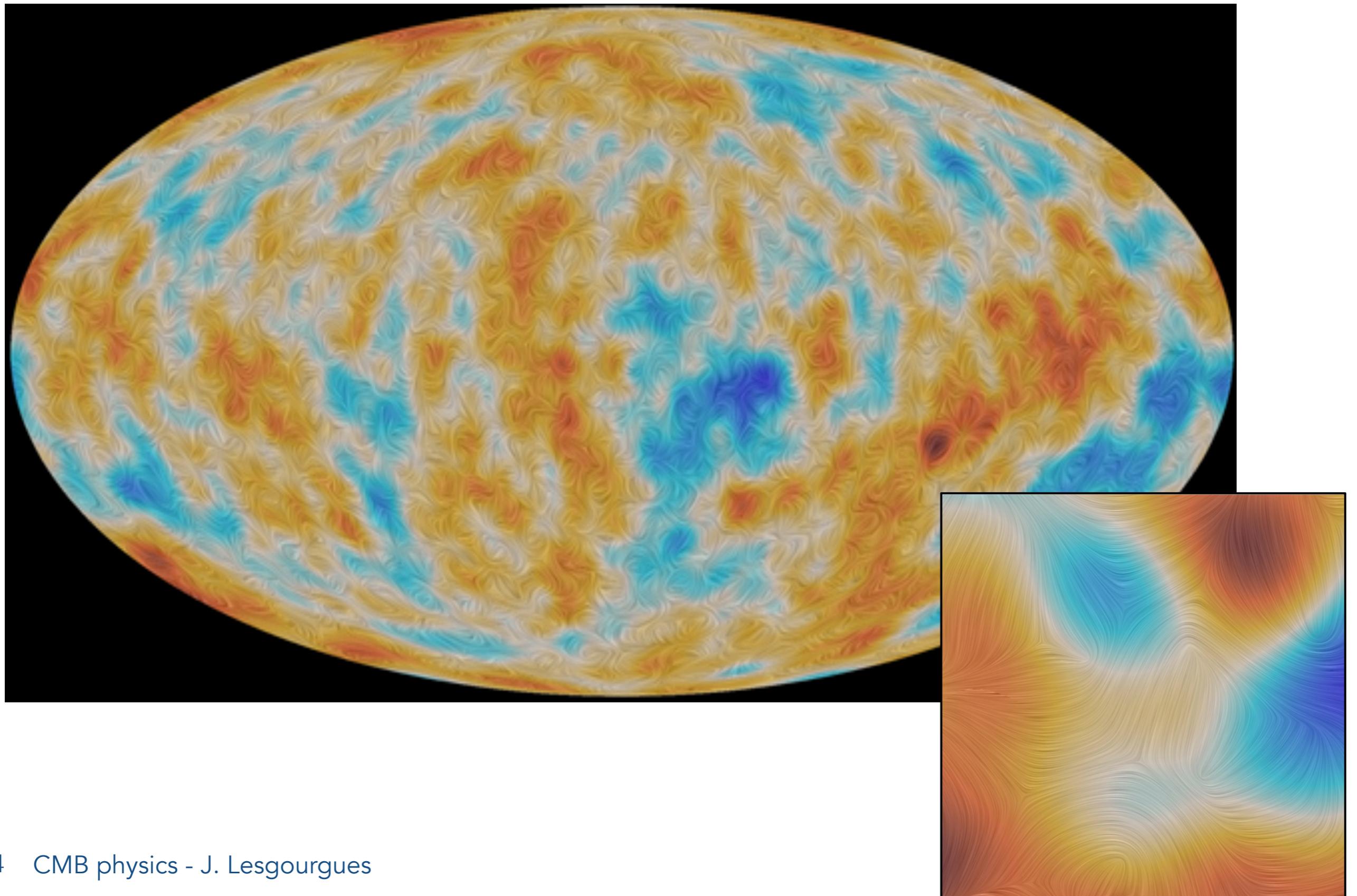
# CMB polarisation



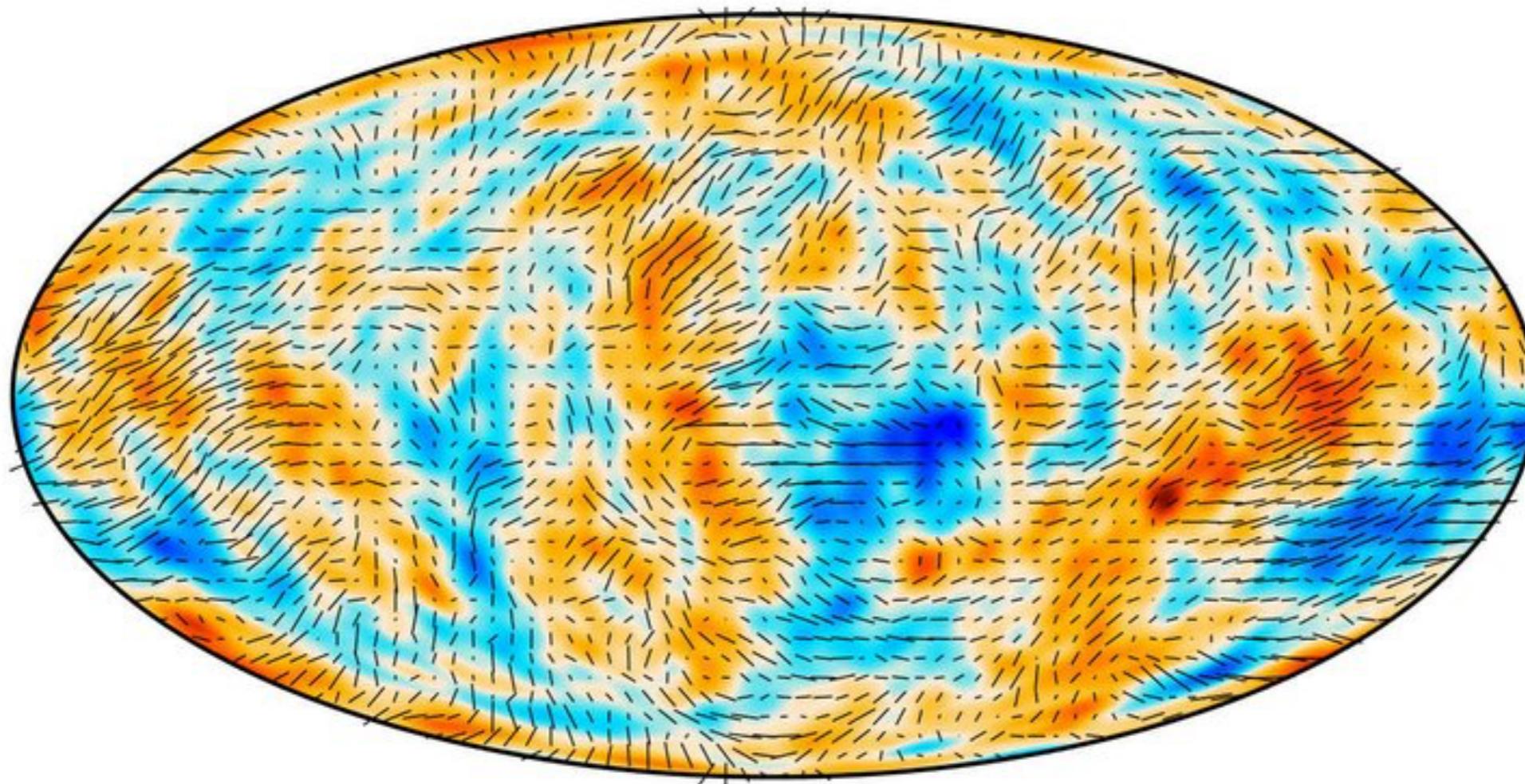
# CMB polarisation



# CMB polarisation

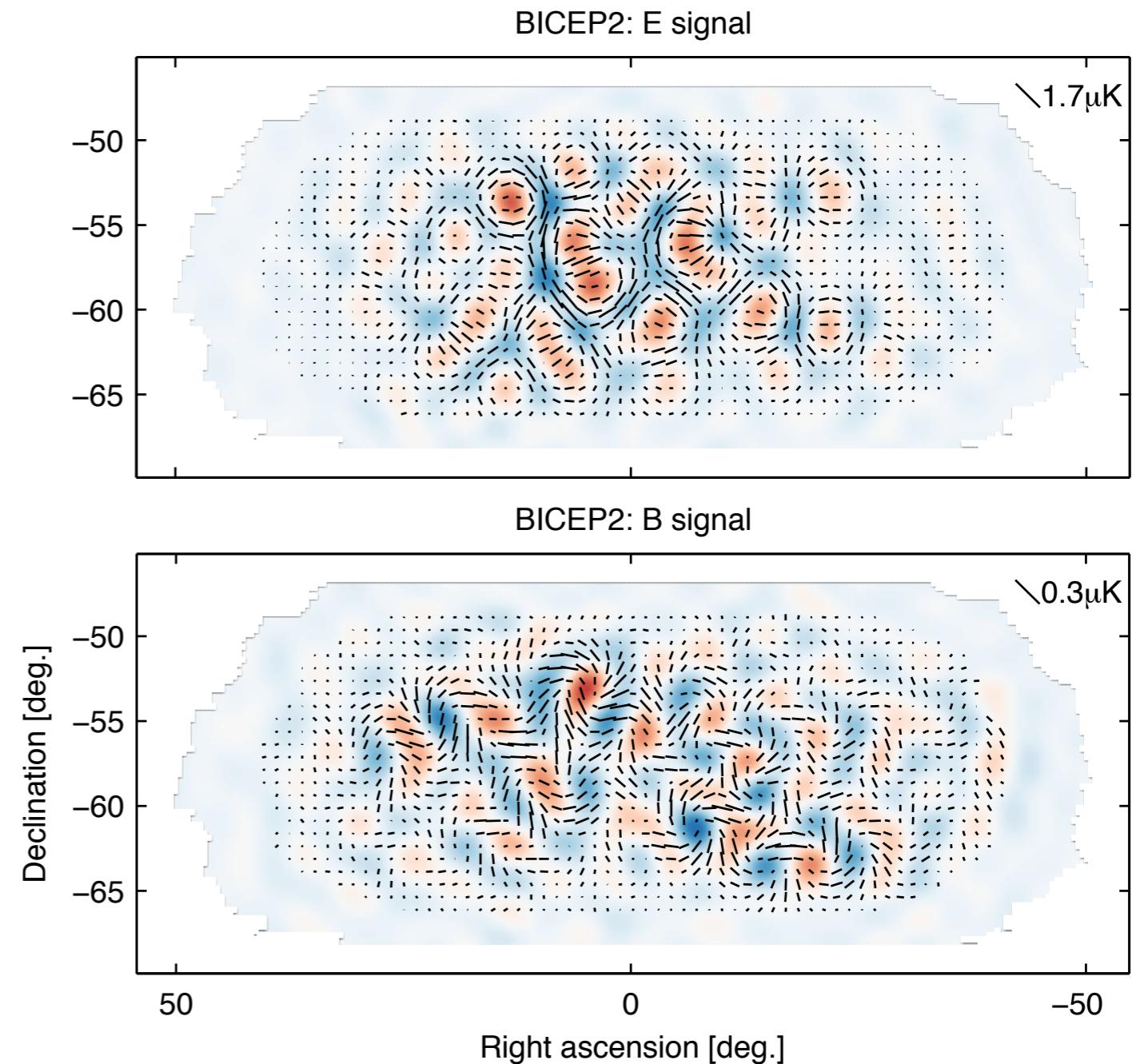
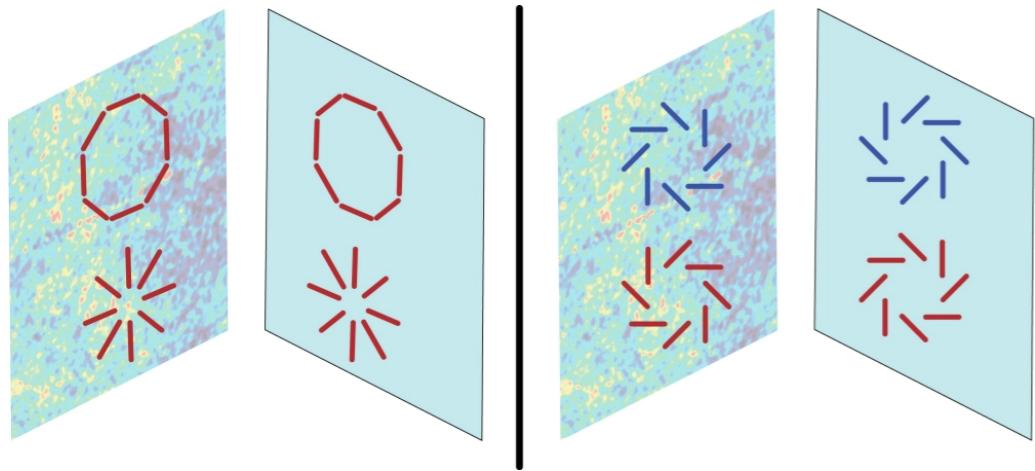


# CMB polarisation



1 spin-two map  $\Leftrightarrow$  2 scalar maps ( $E$  = gradient field,  $B$  = rotation field), but:  
scalar modes  $\rightarrow$  gradients  $\rightarrow$  B-mode vanish

# CMB polarisation



# CMB polarisation

Temperature spectrum:  $C_\ell^{TT} = \langle a_{lm}^T a_{lm}^{T*} \rangle = \frac{2}{\pi} \int dk k^2 [\Theta_\ell^T(\eta_0, k)]^2 P_{\mathcal{R}}(k)$

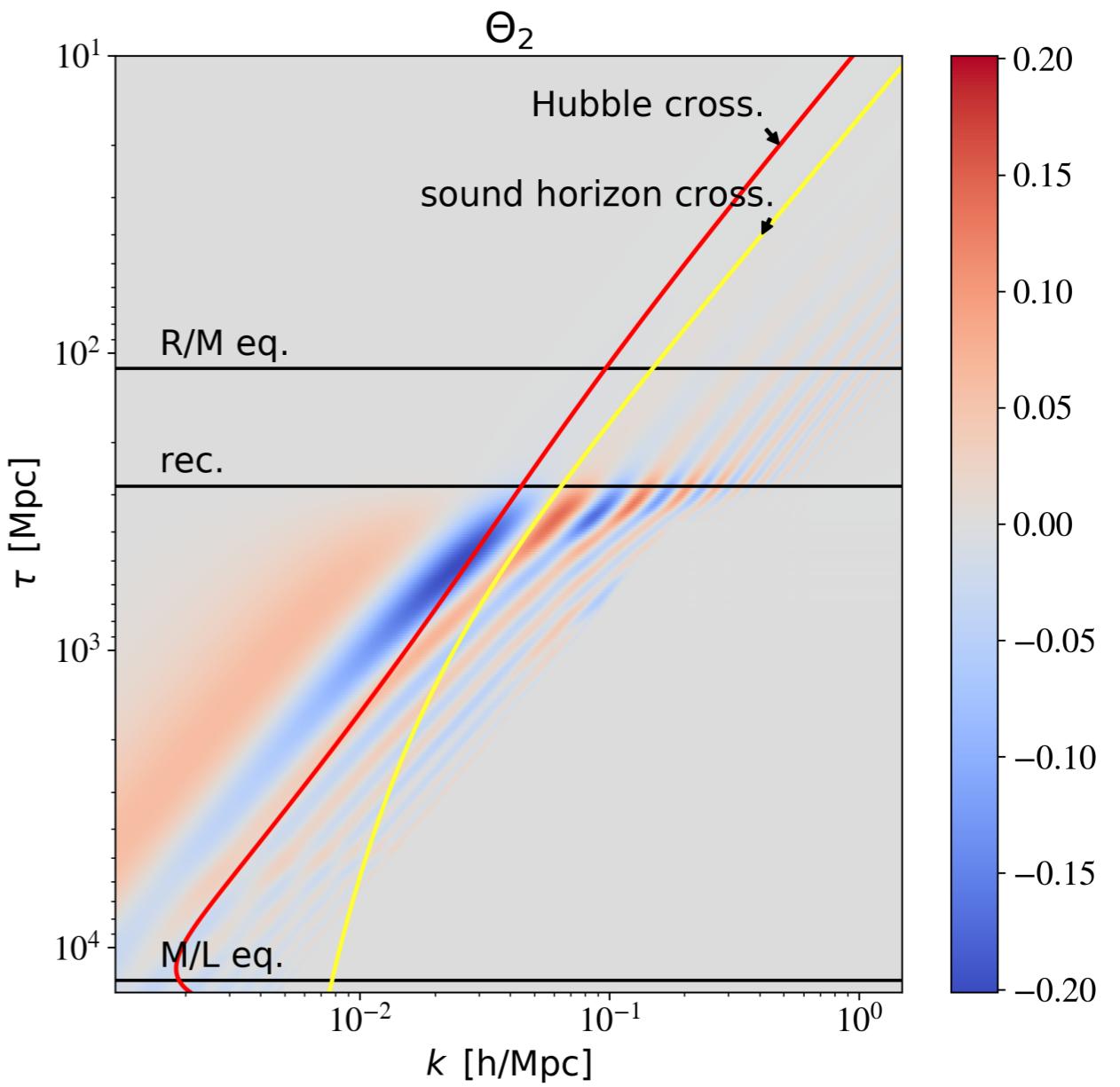
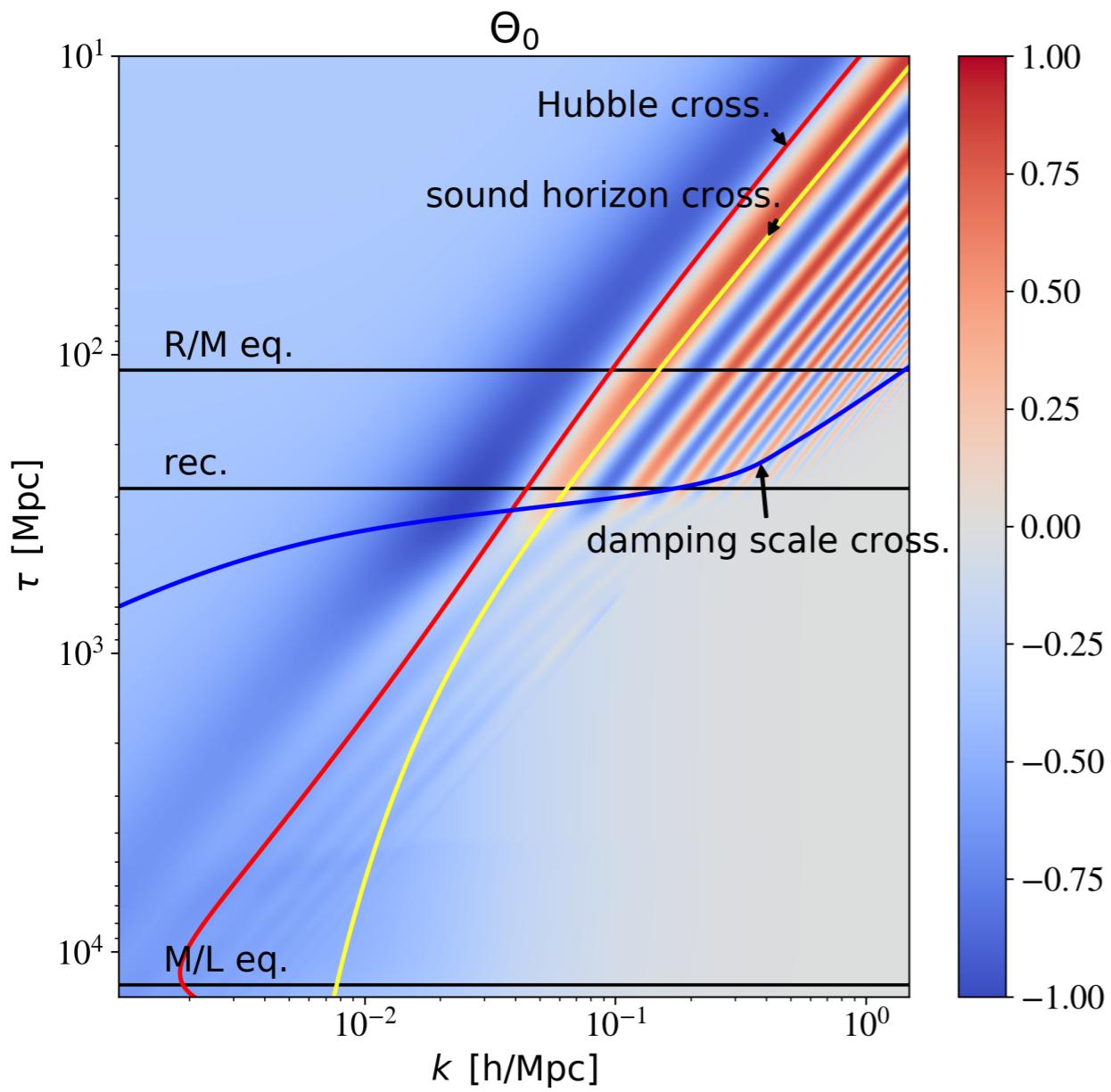
with transfer function  $\Theta_l^T(\eta_0, k) = \int_{\eta_{\text{ini}}}^{\eta_0} d\eta \left\{ g (\Theta_0 + \psi) j_l(k(\eta_0 - \eta)) \right.$   
 $+ g k^{-1} \theta_b j'_l(k(\eta_0 - \eta))$   
 $\left. + e^{-\tau} (\phi' + \psi') j_l(k(\eta_0 - \eta)) \right\}$

E-mode polarisation spectrum:  $C_\ell^{EE} = \langle a_{lm}^E a_{lm}^{E*} \rangle = \frac{2}{\pi} \int dk k^2 [\Theta_\ell^E(\eta_0, k)]^2 P_{\mathcal{R}}(k)$

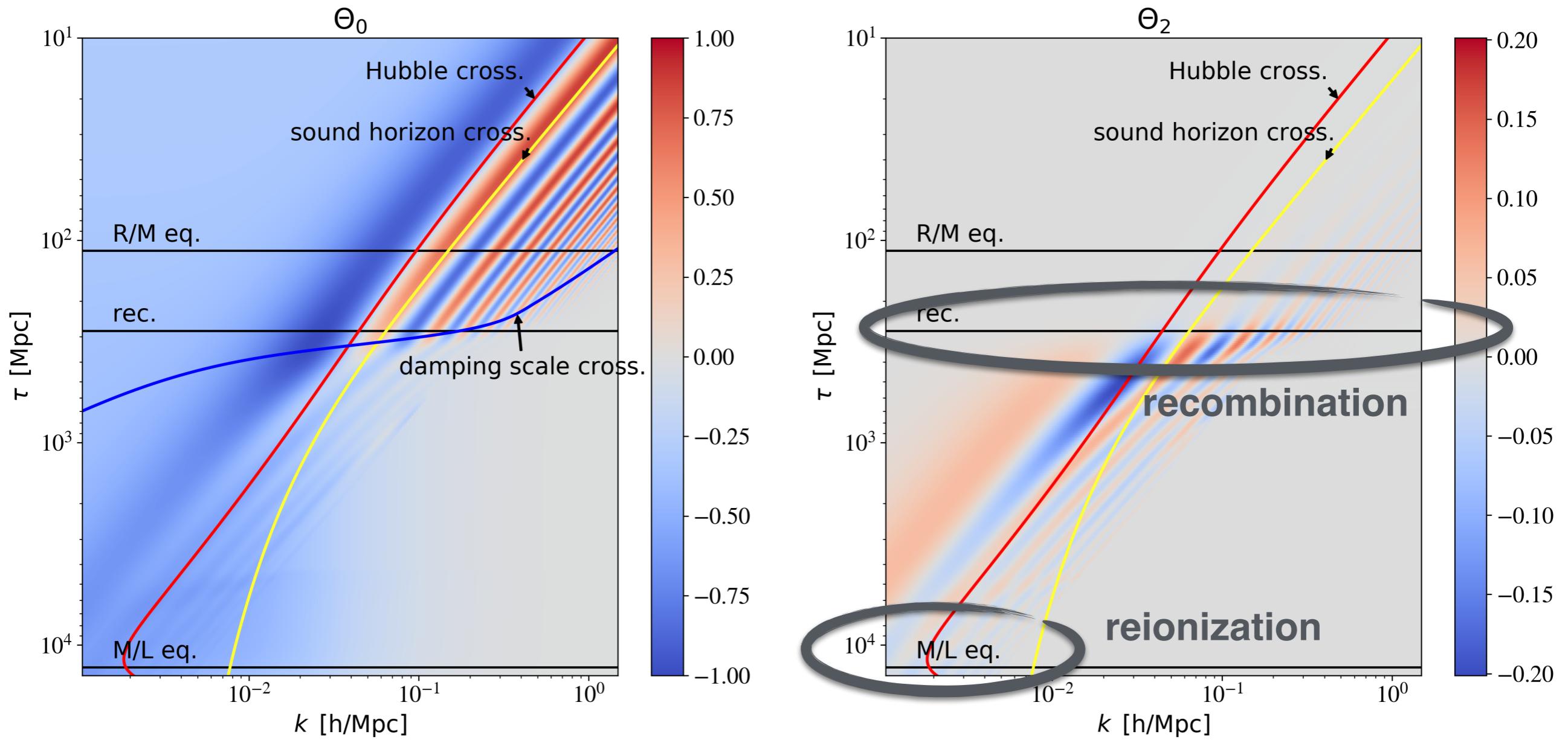
with transfer function  $\Theta_l^E(\eta_0, k) = \int_{\eta_{\text{ini}}}^{\eta_0} d\eta \ g \ \{\Theta_2 + \dots\} (\dots) j_l(k(\eta_0 - \eta))$

Seljak & Zaldarriaga astro-ph/9609170; Hu & White astro-ph/9702170

# CMB polarisation



# CMB polarisation



# CMB polarisation

