Models of reionization and dark matter decay

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Springworkshop RTG

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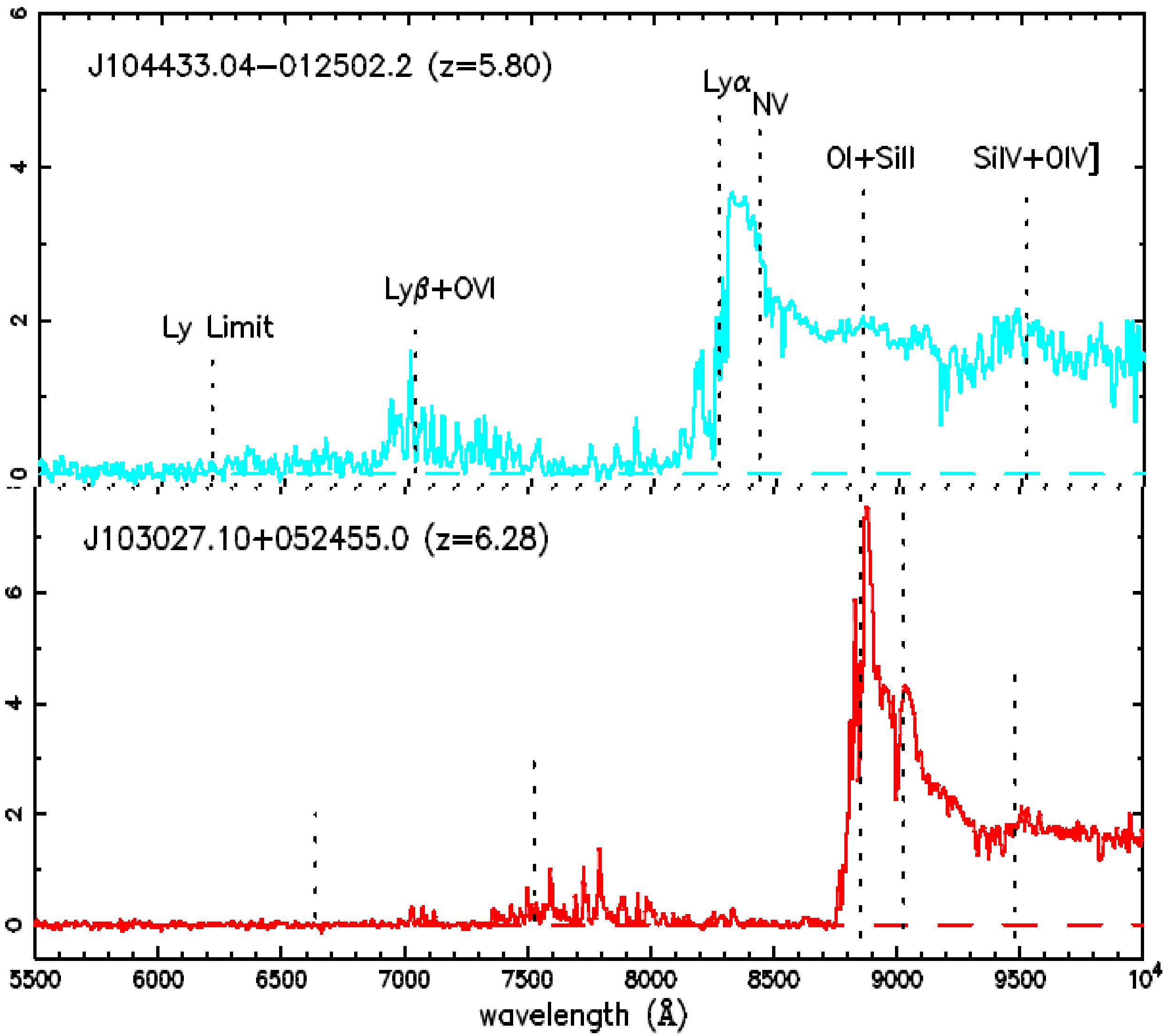
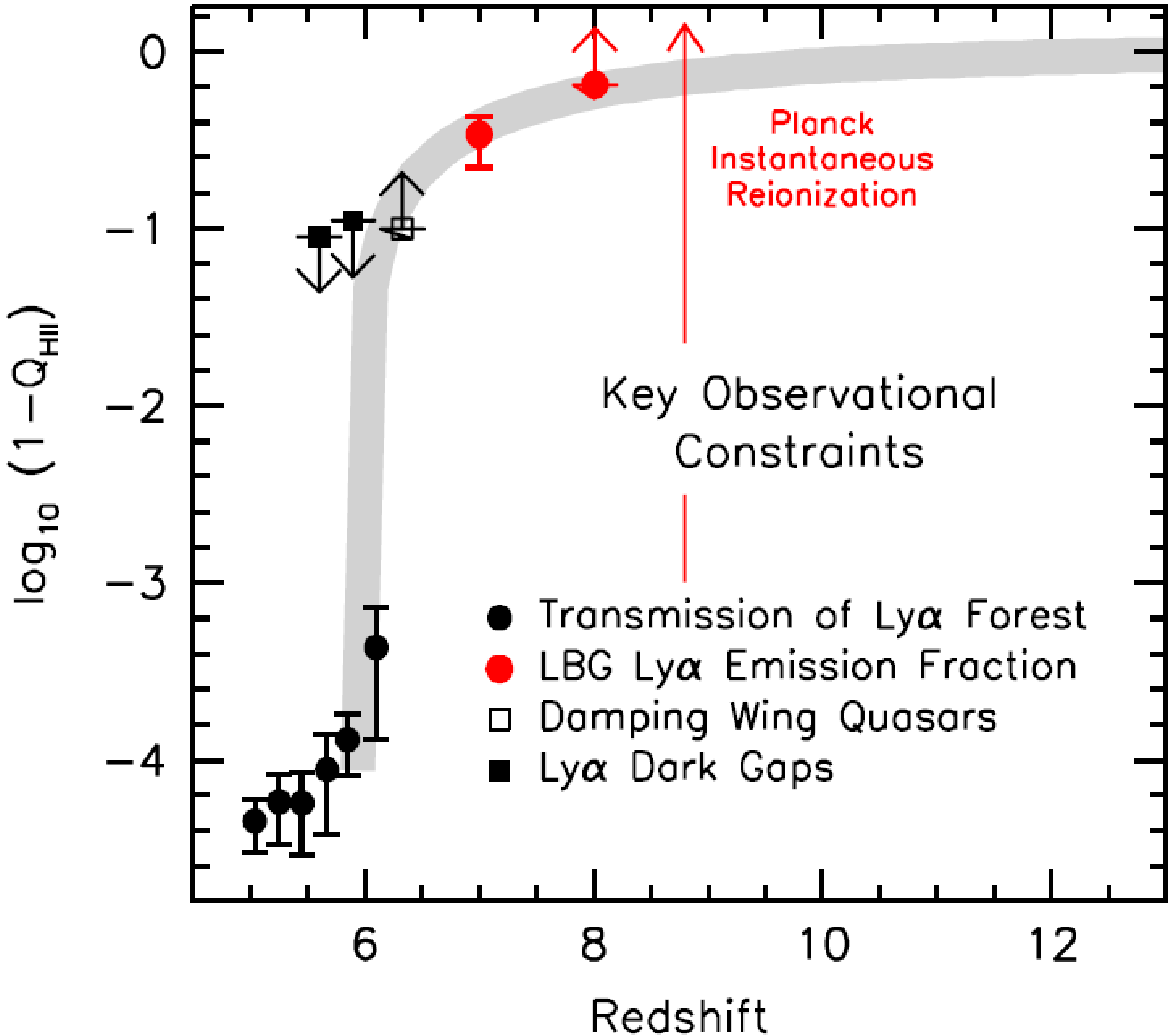
Direct observation (Lyman-α, Gunn-Peterson)



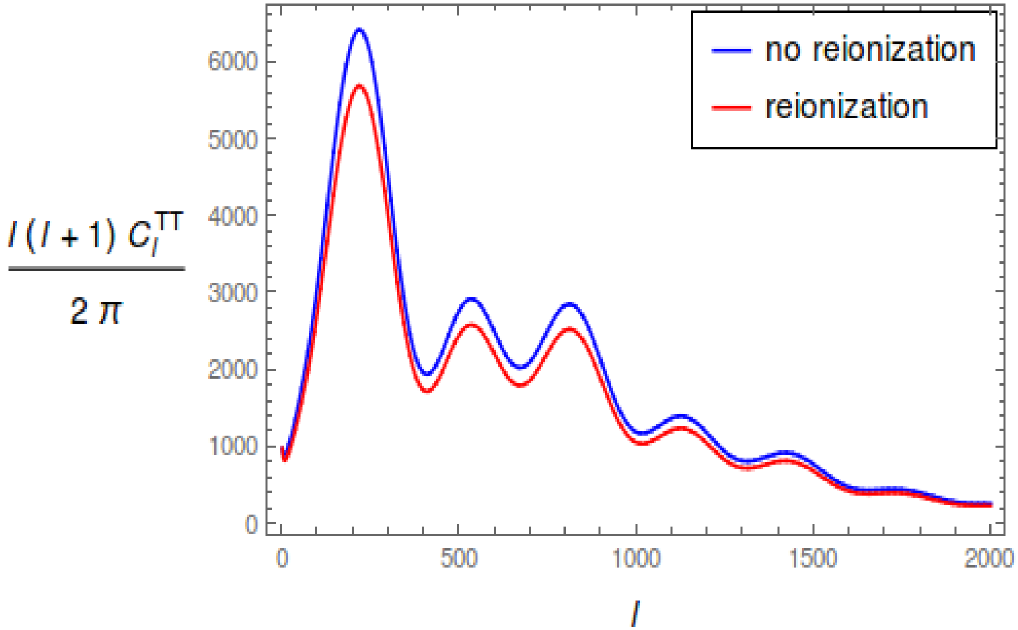
Becker et al., 2001



Bouwens et al., Mar 2015

Indirect probe: CMB

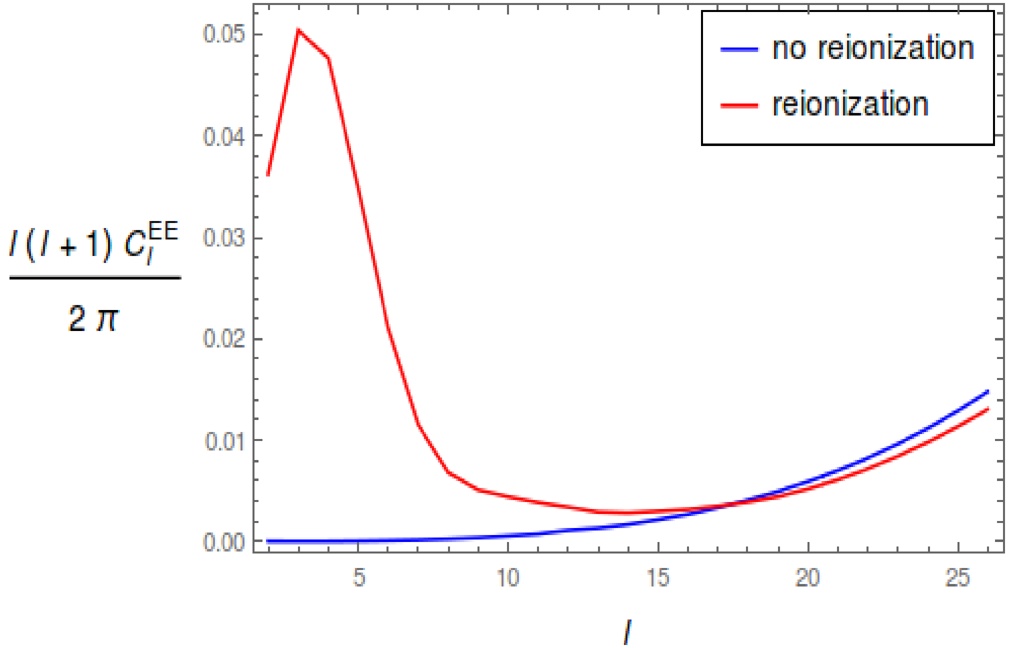
High ℓ:



→ Suppression by $e^{-2\tau}$

Optical depth: $\tau(z) \equiv \int_0^z n_e(z)\sigma_{\mathrm{T}}\frac{\mathrm{d}t}{\mathrm{d}z'}\mathrm{d}z'$

Low ℓ:



→ characteristic bumb

Evolution of free electron fraction at high z → **Recombination codes**, e.g. CosmoRec

At low z → Boltzmann codes, e.g. CAMB:

$$\boxed{x_{\mathrm{e}}(z)\big|_{\mathrm{CAMB}} = \frac{1.08}{2}\left[1 + \tanh\left(\frac{(1+z_{\mathrm{re}})^{3/2} - (1+z)^{3/2}}{\Delta}\right)\right]}$$

Note: $x_{\mathrm{e}} \equiv \frac{n_{\mathrm{e}}}{n_{\mathrm{H}}} = \frac{n_{\mathrm{e,H}}}{n_{\mathrm{H}}} + \frac{n_{\mathrm{e,HeII}}}{n_{\mathrm{H}}} + \frac{n_{\mathrm{e,HeIII}}}{n_{\mathrm{H}}} \xrightarrow{\text{compl. reion.}} 1.0 + 0.08 + 0.08$

Second helium ionization at lower z → second „step“

<u>Empirical parametrization</u> (arxiv: 1509.02785, Douspis, Aghanim, Ilic and Langer):

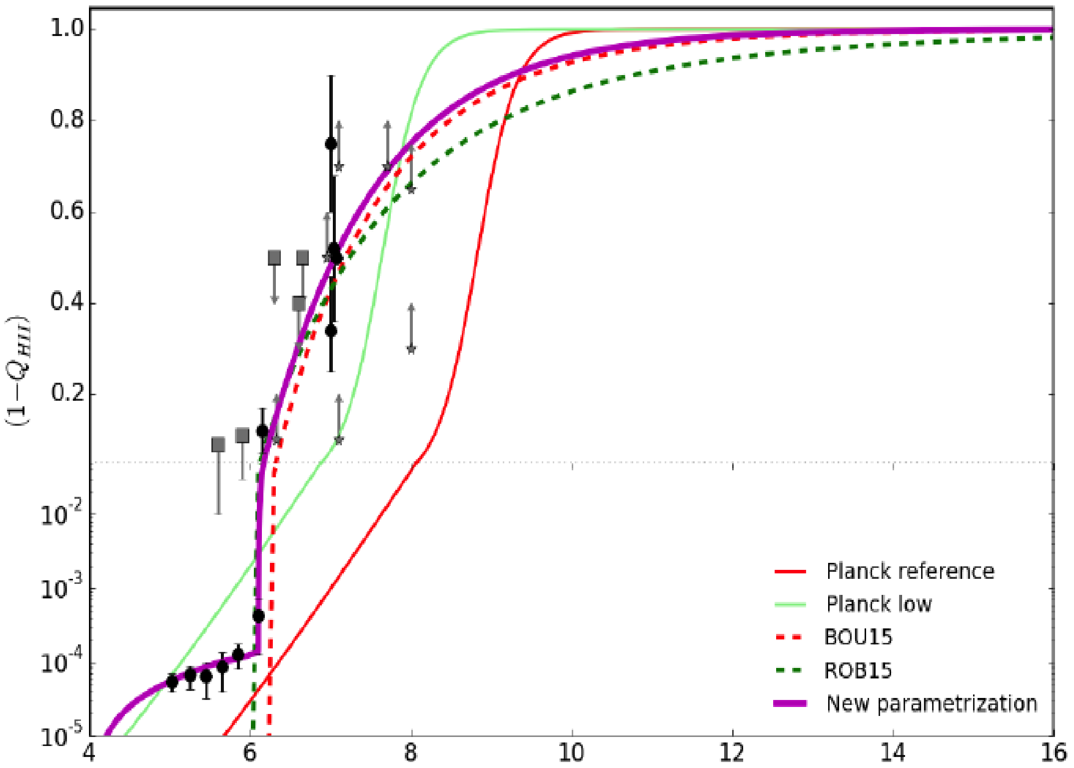
$$Q_{\mathrm{HII}}(z) = \begin{cases} \frac{1-Q_{\mathrm{q}}}{(1+z_{\mathrm{q}})^3-1}\left((1+z_{\mathrm{q}})^3-(1+z)^3\right)+Q_{\mathrm{q}} & \text{for } z < z_{\mathrm{q}} \\ Q_{\mathrm{q}} e^{-\lambda(z-z_{\mathrm{q}})} & \text{for } z \geq z_{\mathrm{q}}. \end{cases}$$

Keep $\underbrace{z_{\mathrm{q}} \text{ and } Q_{\mathrm{q}}}$ fixed:

$$z_{\mathrm{q}} = 6.1 \quad Q_{\mathrm{q}} = 0.99986$$

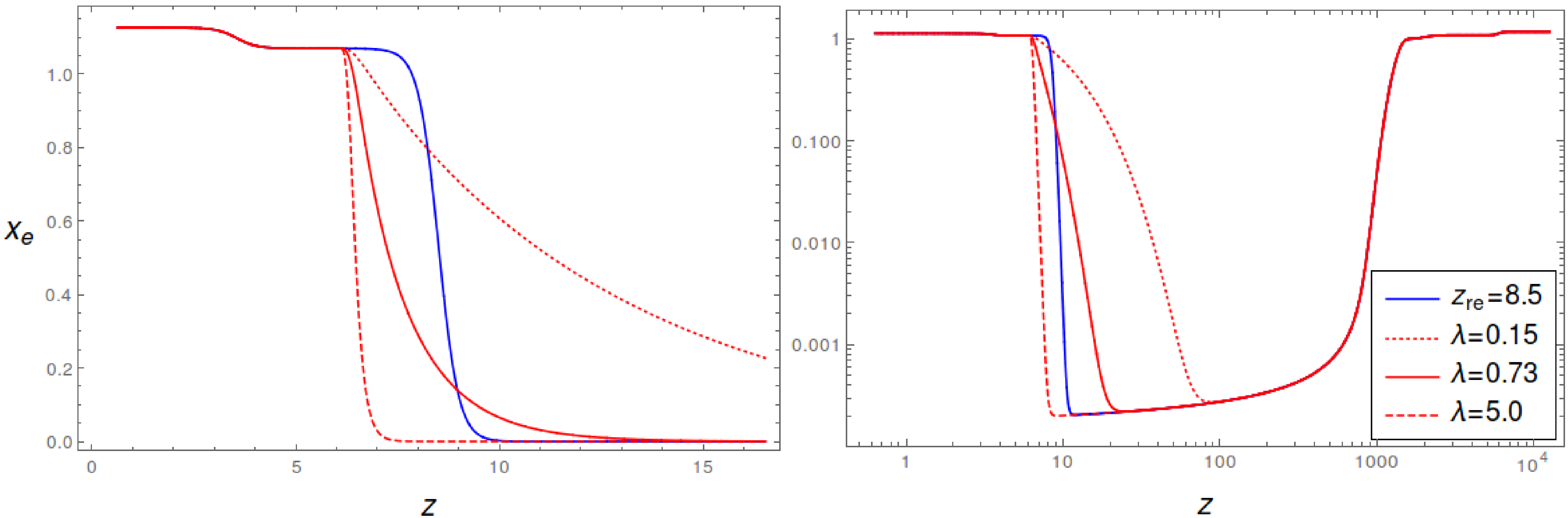
→ **only free parameter:**

evolution parameter λ



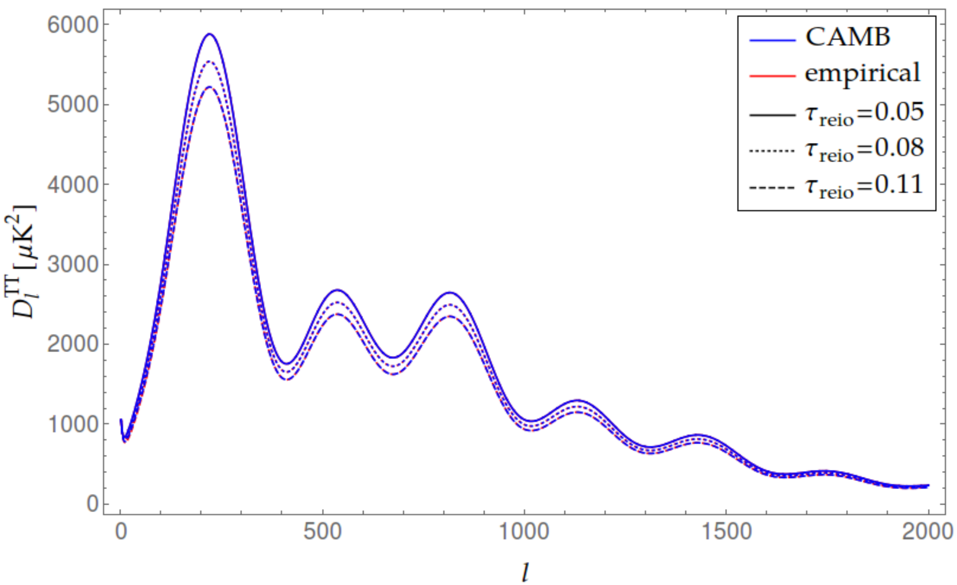
- **First** helium ionization: → $x_e(z)\big|_{\text{emp.}} = 1.08 \times Q_{\text{HII}}(z)$
- **Second** helium ionization: second step at lower z

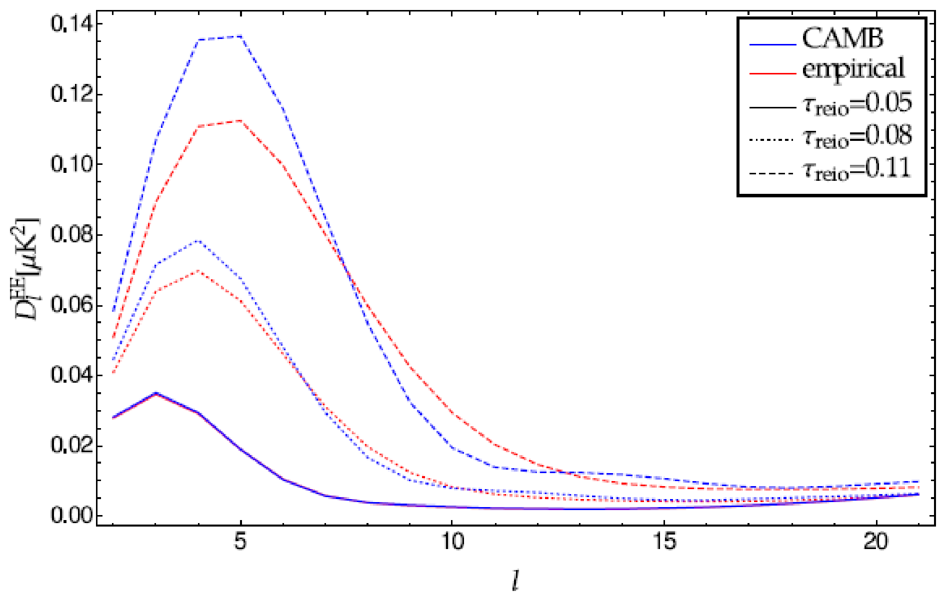
Analogous to CAMB



Can we really distinguish the two parametrizations by CMB data?

Fixed optical depth





No?

YES!

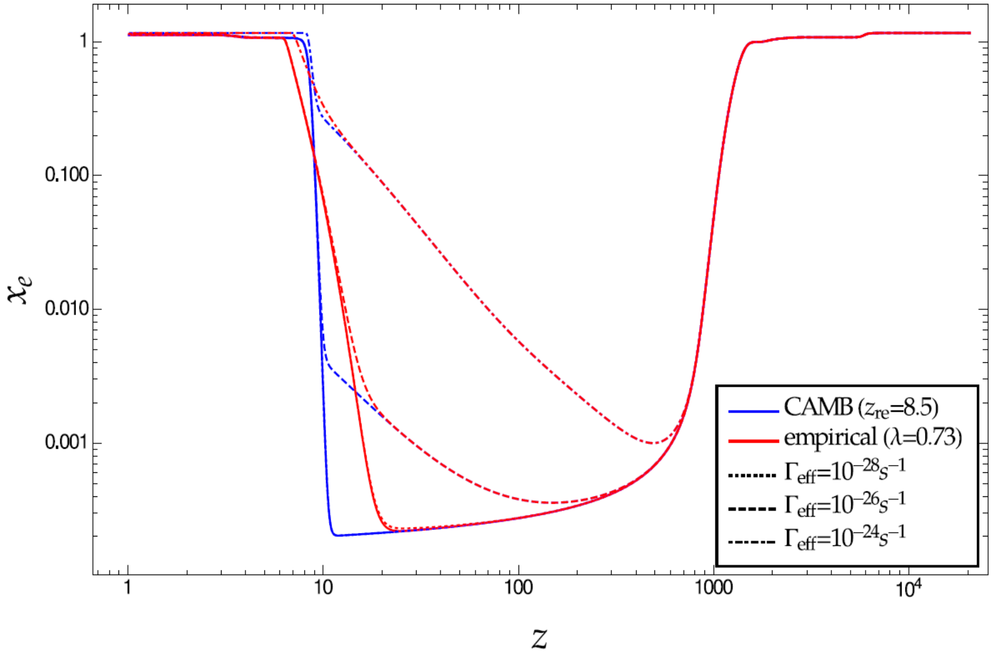
Alternative source of reionization: **Dark matter decay**

Injected energy: $$\left(\frac{dE}{dt\,dV}\right)_{inj} = m_{\rm d}\Gamma_{\rm em,s}n_{\rm d}(t)$$

Deposited energy: $$\left(\frac{dE}{dt\,dV}\right)_{dep} = f(z, m_{\rm d})\left(\frac{E_{\rm d}}{m_{\rm d}}\right)\left(\frac{dE}{dt\,dV}\right)_{inj}$$

$$= 1.23 \times 10^9\, n_{\rm H}\, f(z, m_{\rm d}) \underbrace{\left(\frac{E_{\rm d}}{m_{\rm d}}\right)\left(\frac{\rho_{\rm d}}{\rho_{\rm b}}\right)\Gamma_{\rm em,s}}_{\Gamma_{\rm eff}}\ \mathrm{eV}$$

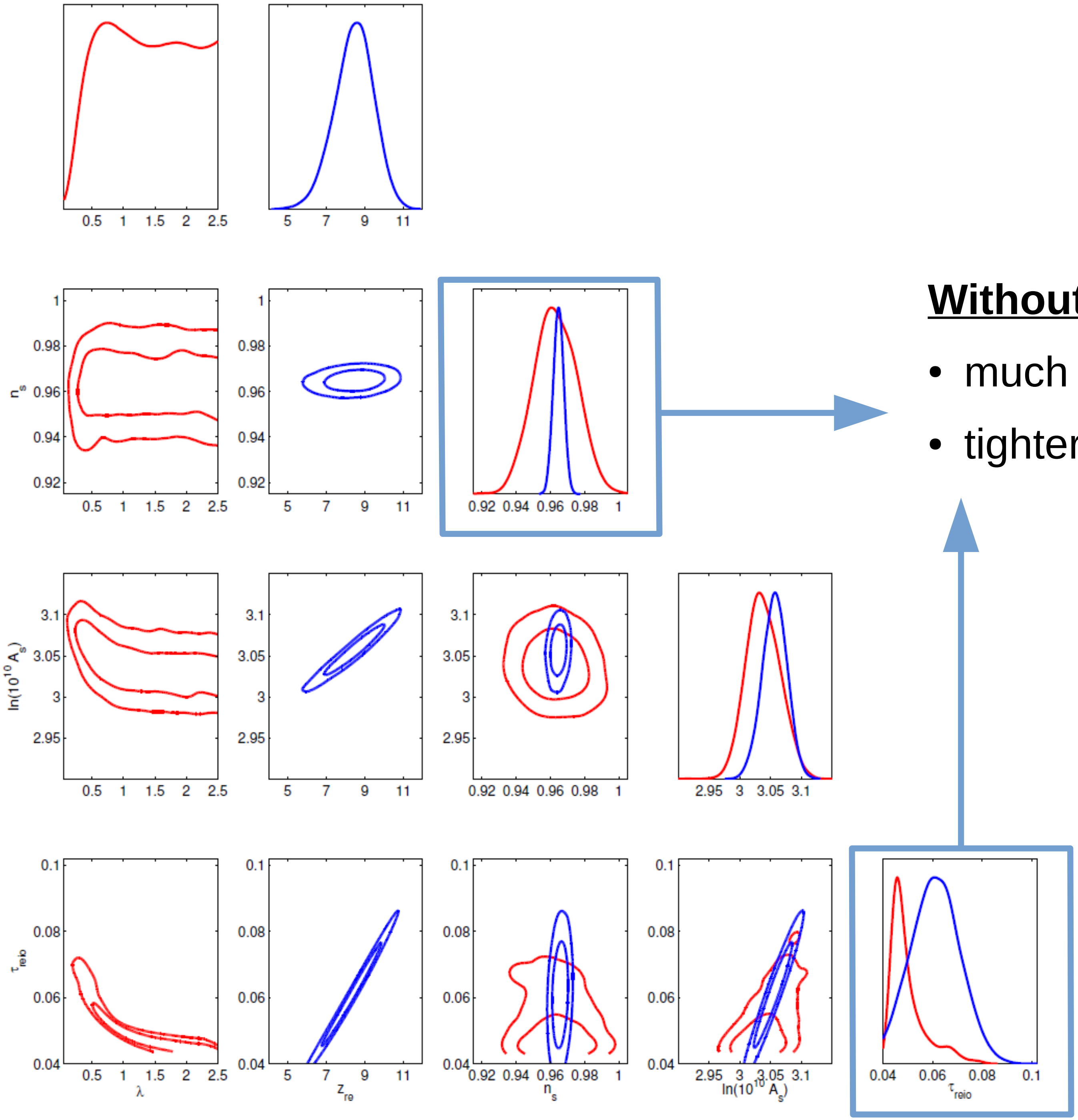
complicated!



- Is the parametrization important?
- What are the constraints from CMB data on $\Gamma_{\rm eff}$?
- How much do the constraints on $\Gamma_{\rm eff}$ depend on the parametrization of astrophysical reionization?

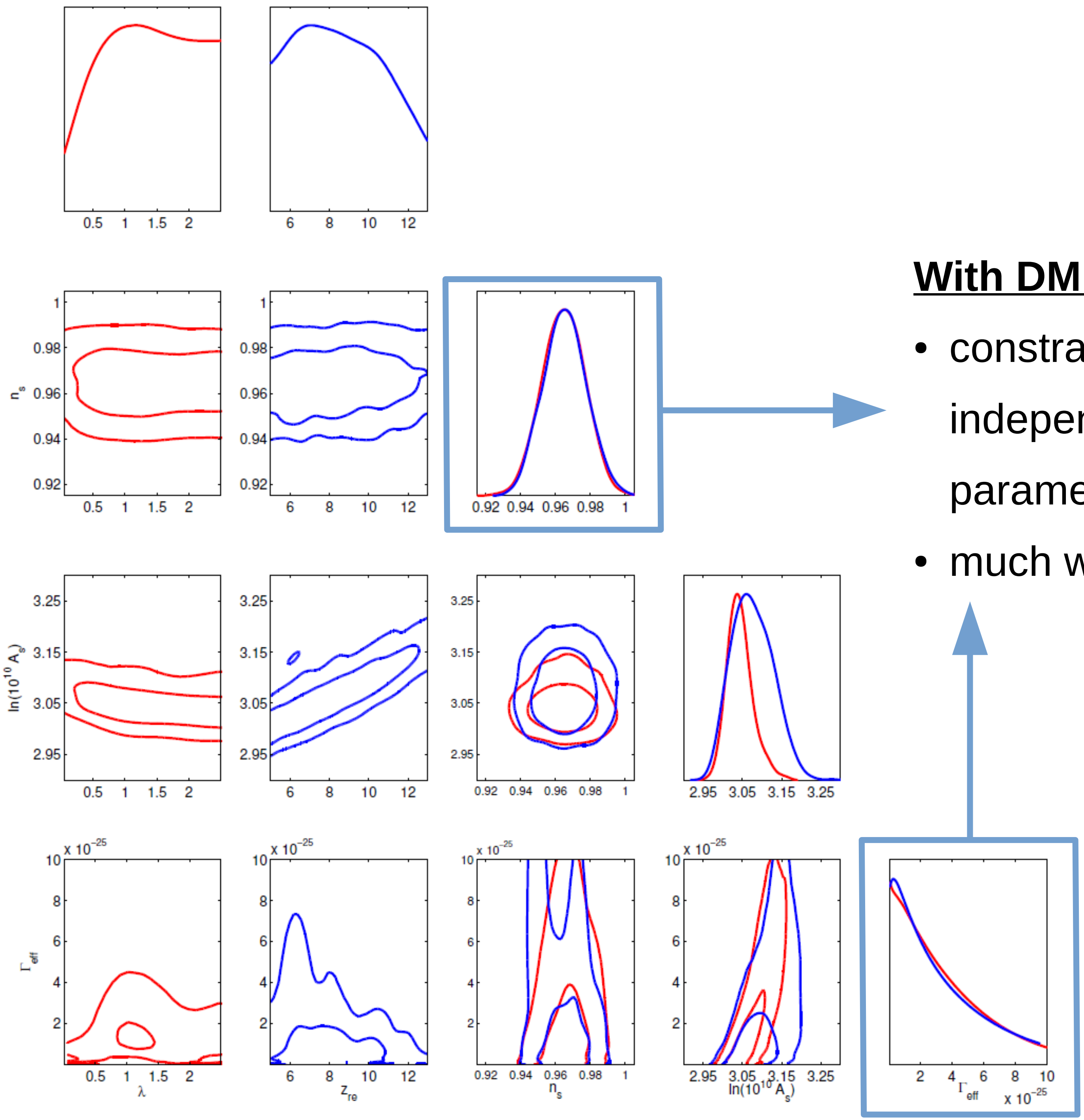
On-the-spot approximation:

$$f(z, m_{\rm d}) \approx 1$$



Without DM decay:

- much weaker constraints on $n_{\rm s}$
- tighter constraints on $\tau_{\rm reion}$



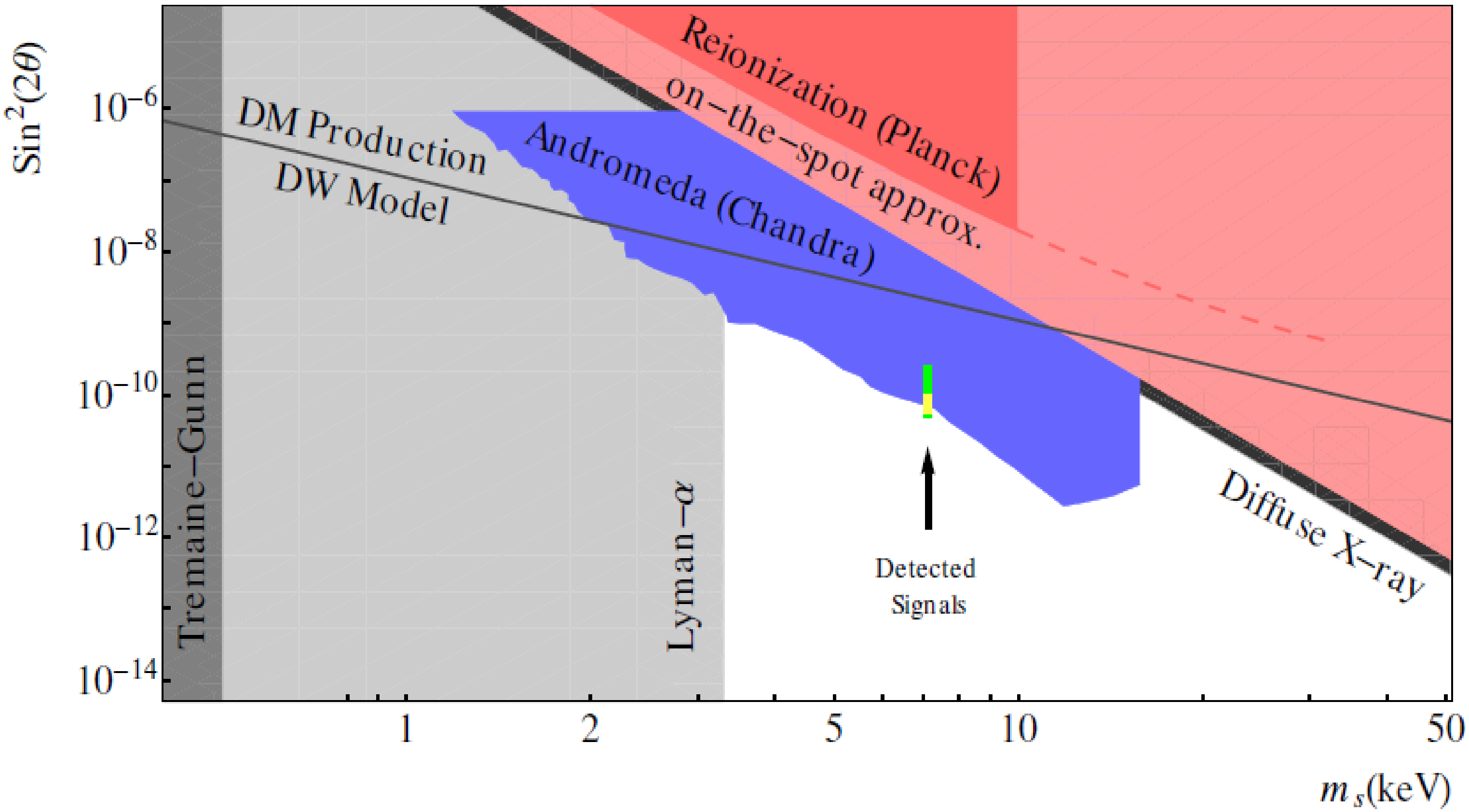
With DM decay:

- constraints on $\Gamma_{\rm eff}$ independent of chosen parametrization
- much weaker constraints on $n_{\rm S}$

Application of our constraints on Γ_{eff} :

sterile keV-mass neutrinos (warm dark matter candidates)

$$\Gamma_{\nu_s \to \gamma \nu_\alpha} = \frac{9\alpha G_F^2}{256 \times 4\pi^4} \sin(2\theta)^2 m_s^5$$



- **two parametrizations** of astrophysical reionization:

  new *empirical* parametrization → much weaker constraints on $n_{\rm s}$

  → tigther constraints on $\tau_{\rm reion}$

  → implications for inflation???

- additional source of reionization:

  dark matter decay → constraints on $\Gamma_{\rm eff}$ independent of parametrization

  → application: sterile keV-mass neutrino

  → much weaker constraints on $n_{\rm s}$