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Implications of the Possible 21-CM Line Excess at Cosmic Dawn on Dynamics of Dark Energy

中国科学技术大学
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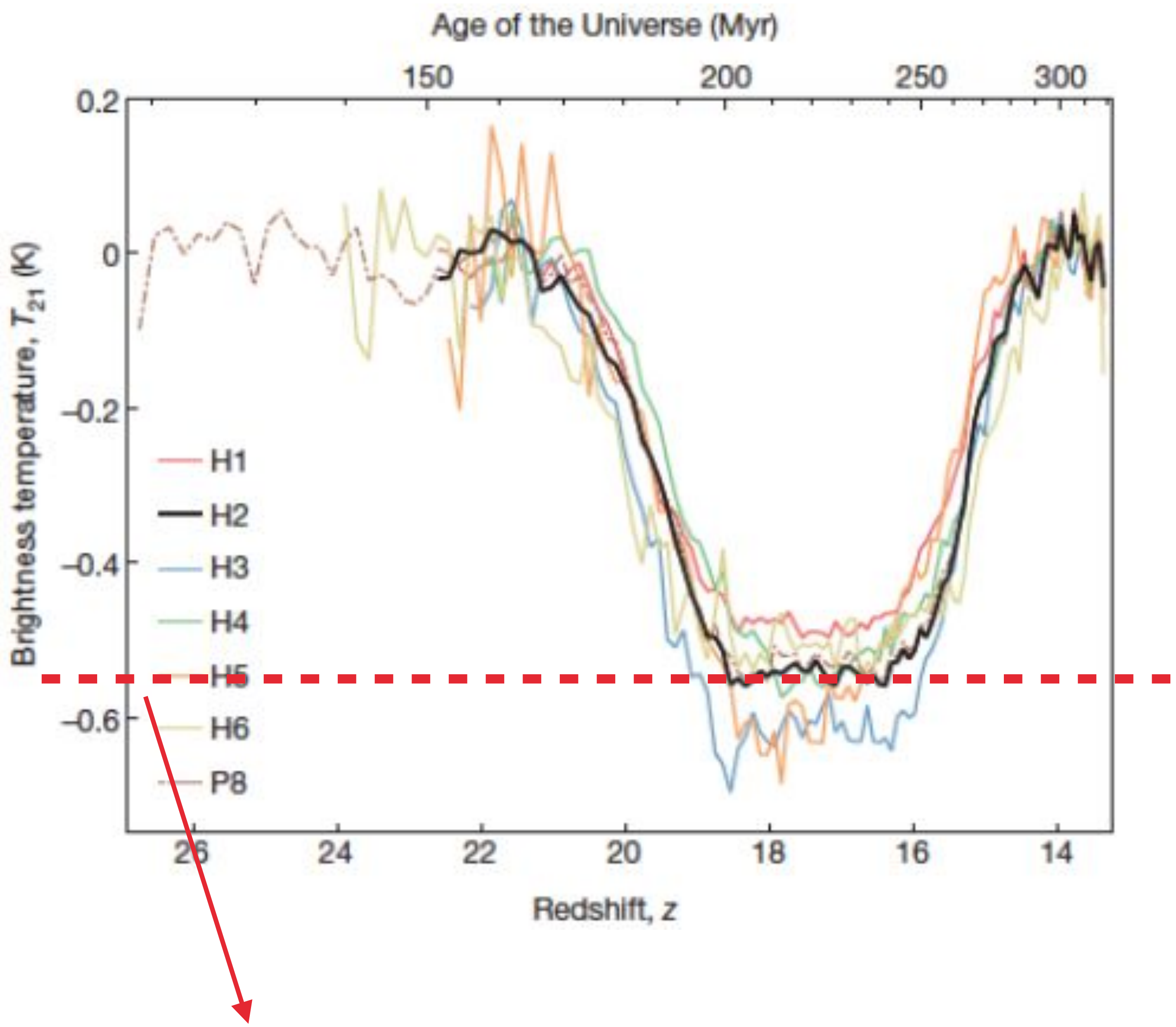
Experiment to Detect the Global Epoch of reionization Signature (EDGES)



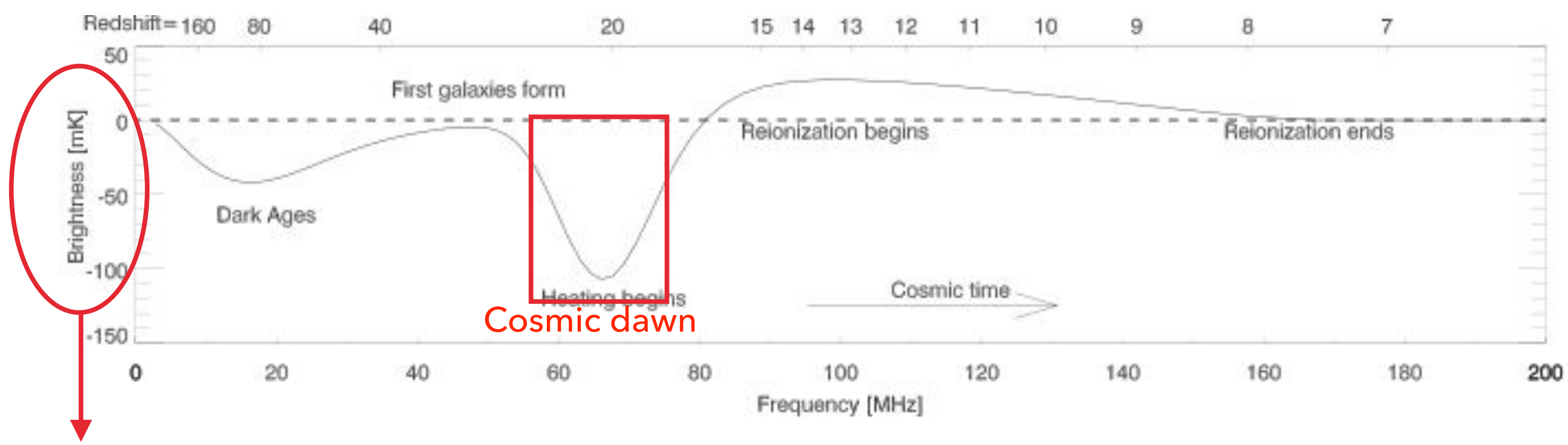
The first time to detect the 21-cm line signal from comic dawn

$$T_{21} = -500^{+200}_{-500}\ mK\ (99\%)\ at\ z = 17.2$$

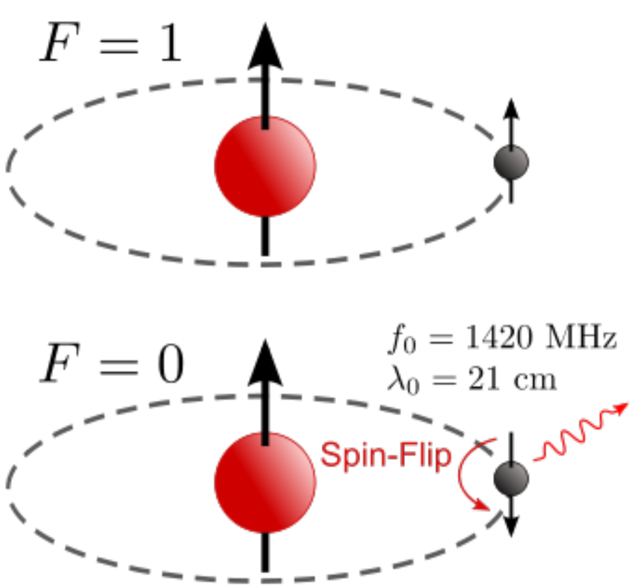
Standard expectations: -209mK

3.8σ below the strongest possible absorption under standard expectations

The sky-averaged global 21-cm line signal at cosmic dawn:



$T_{21} \sim T_{spin} - T_{CMB}$



a . Spin temperature T_{spin}

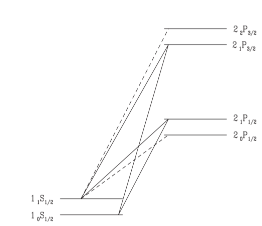
b . Background radiation temperature T_{CMB}

c . Gas temperature T_{gas}

At cosmic dawn:

$T_{spin} = T_{gas} < T_{CMB}$ *absorption signal*

lyman-alpha coupling



Explanations to the excess signal:

$$|T_{21}| \sim T_{CMB}\uparrow - T_{spin}\downarrow$$

$T_{spin} = T_{gas}$ *at cosmic dawn*

$$T_{gas}\downarrow$$

$$\frac{dT_{gas}}{dz}(1+z) = 2T_{gas} + \frac{T_{gas} - T_{\gamma}}{t_C H(z)}$$

Adiabatic cooling

Compton scattering term

$z_c\uparrow \quad T_{gas}\downarrow$

$$At\ redshift\ z_c,\ \ H \sim \frac{1}{t_C},\ Compton - heating\ decouples$$

$$T_{21} \equiv \frac{T_{emission} - T_{CMB}}{1+z} = \frac{(T_{spin} - T_{CMB})\tau}{1+z}$$

Optical depth:

$$\tau = \frac{3}{32\pi}\frac{T_*}{T_{spin}} n_{HI} \lambda_{21}^3 \frac{A_{10}}{H(z)}$$

The dynamics of cosmological background have influence on the 21-cm line at cosmic dawn.

At the redshift related to the 21-cm line:

Our Universe is **matter-dominated**.

① $H^2 = \frac{8\pi G}{3}\rho_m'$

Change the amount of matter

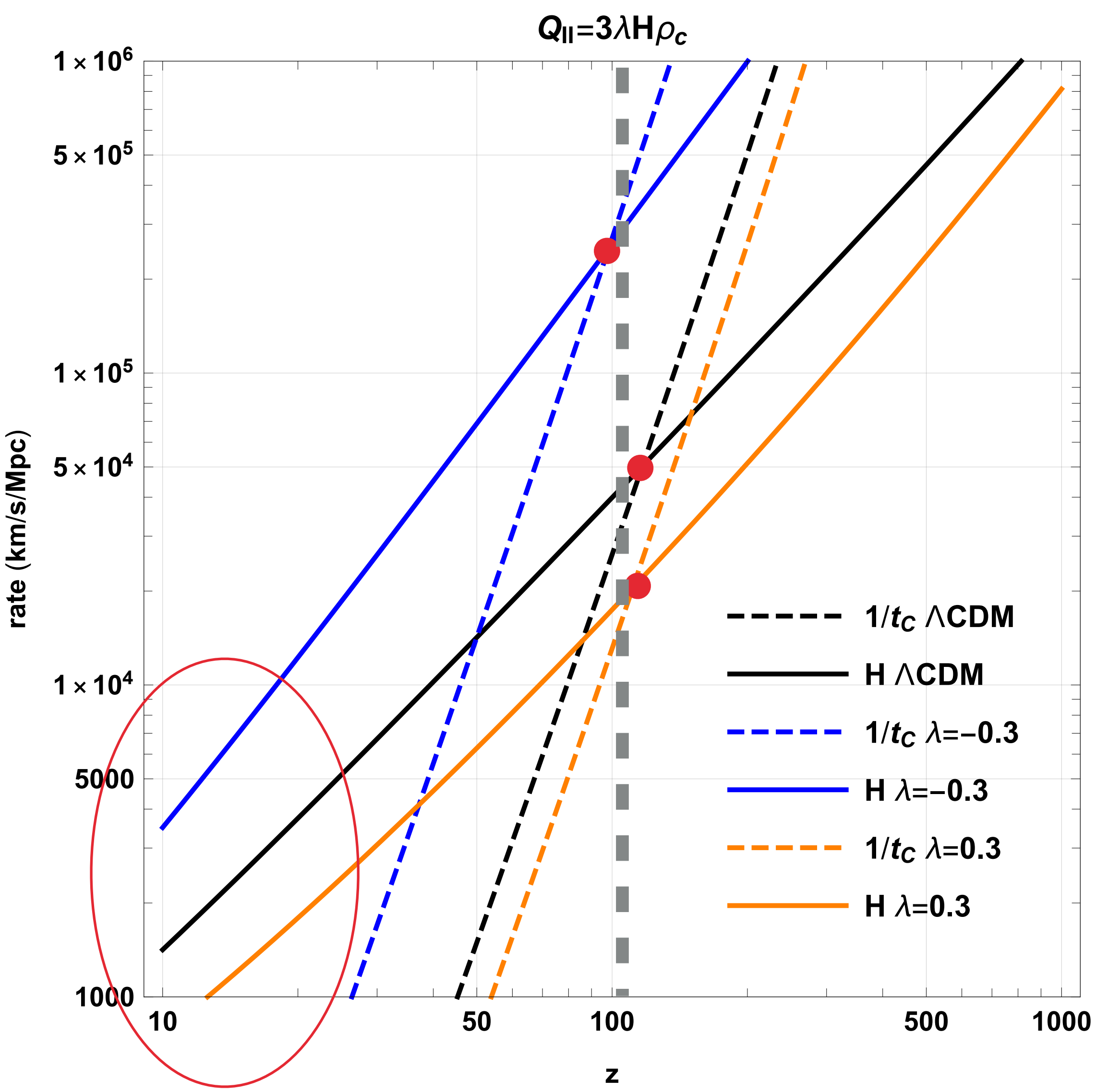
② $H^2 = \frac{8\pi G}{3}(\rho_m + \rho_x)$

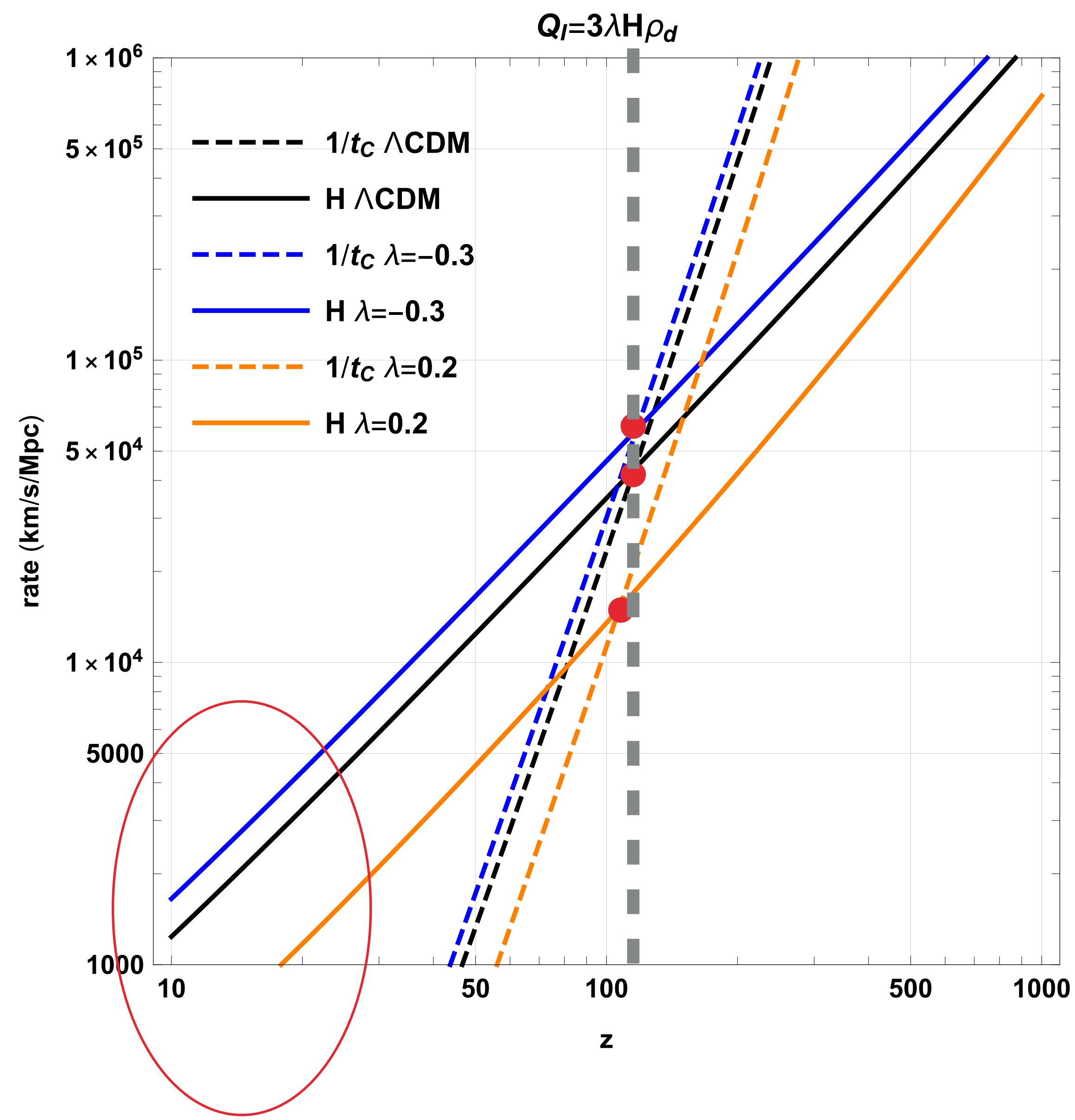
Add new component to the Universe

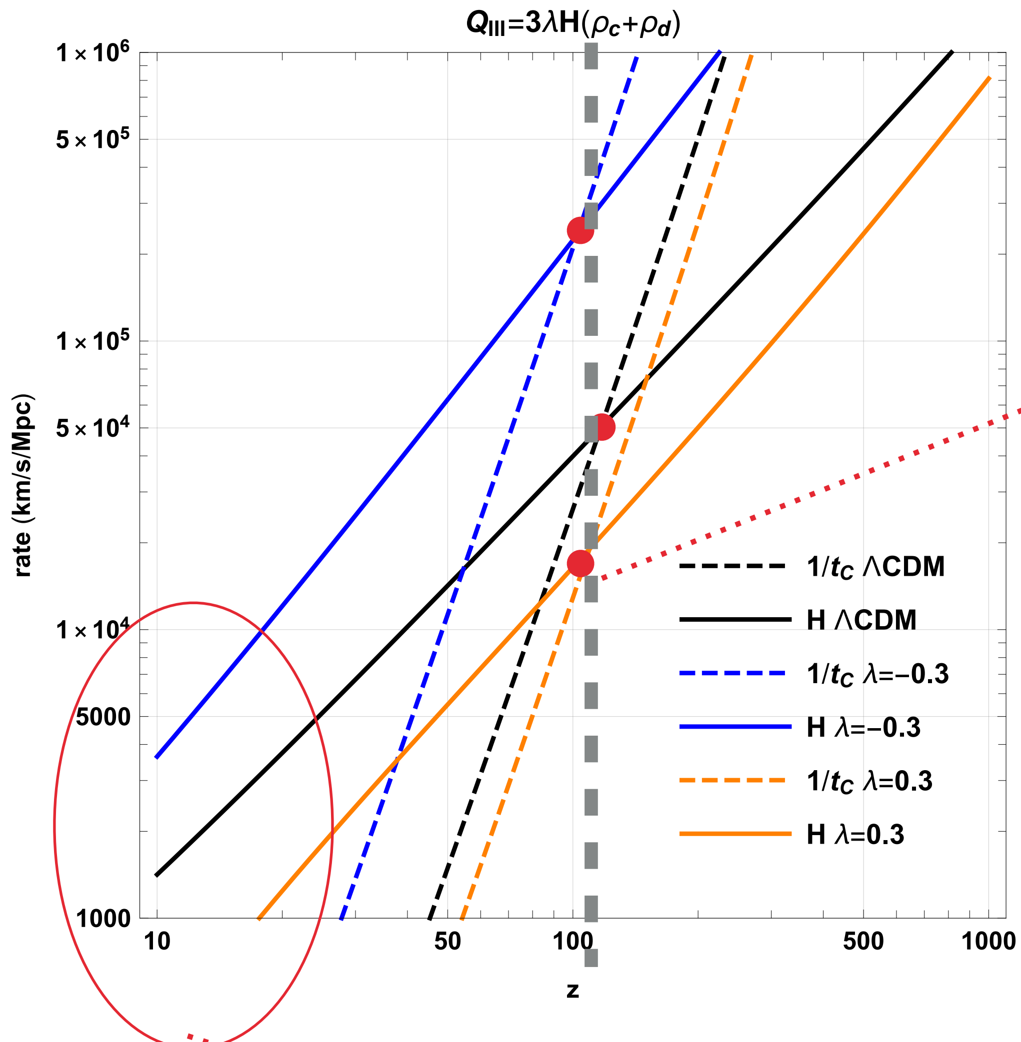
① Change the amount of matter——interacting dark energy model

Cold dark matter $$(1+z)H\frac{d\rho_c}{dz} - 3H\rho_c + Q = 0$$

Dark energy $$(1+z)H\frac{d\rho_d}{dz} - 3H(1+\omega)\rho_d - Q = 0$$







$$\frac{dT_{gas}}{dz}(1+z) = 2T_{gas} + \frac{T_{gas} - T_\gamma}{t_C H(z)}$$

Compton scattering term

At redshift z_c, $H \sim \frac{1}{t_C}$, *Compton − heating decouples*

has little change.

$$T_{21} \equiv \frac{T_{emission} - T_{CMB}}{1+z} = \frac{(T_{spin} - T_{CMB})\tau}{1+z}$$

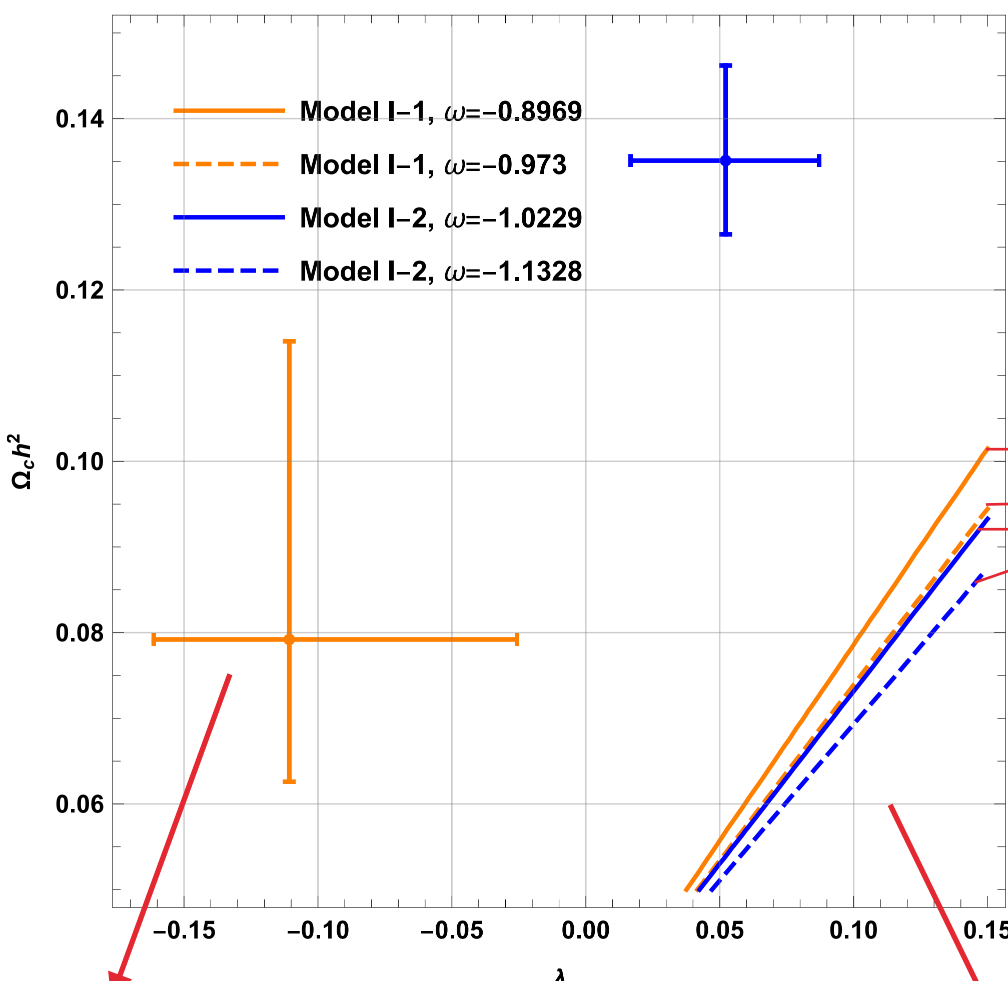
$$\tau = \frac{3}{32\pi}\frac{T_*}{T_{spin}} n_{HI} \lambda_{21}^3 \frac{A_{10}}{H(z)}$$

The main effects are caused by the change of the optical depth.

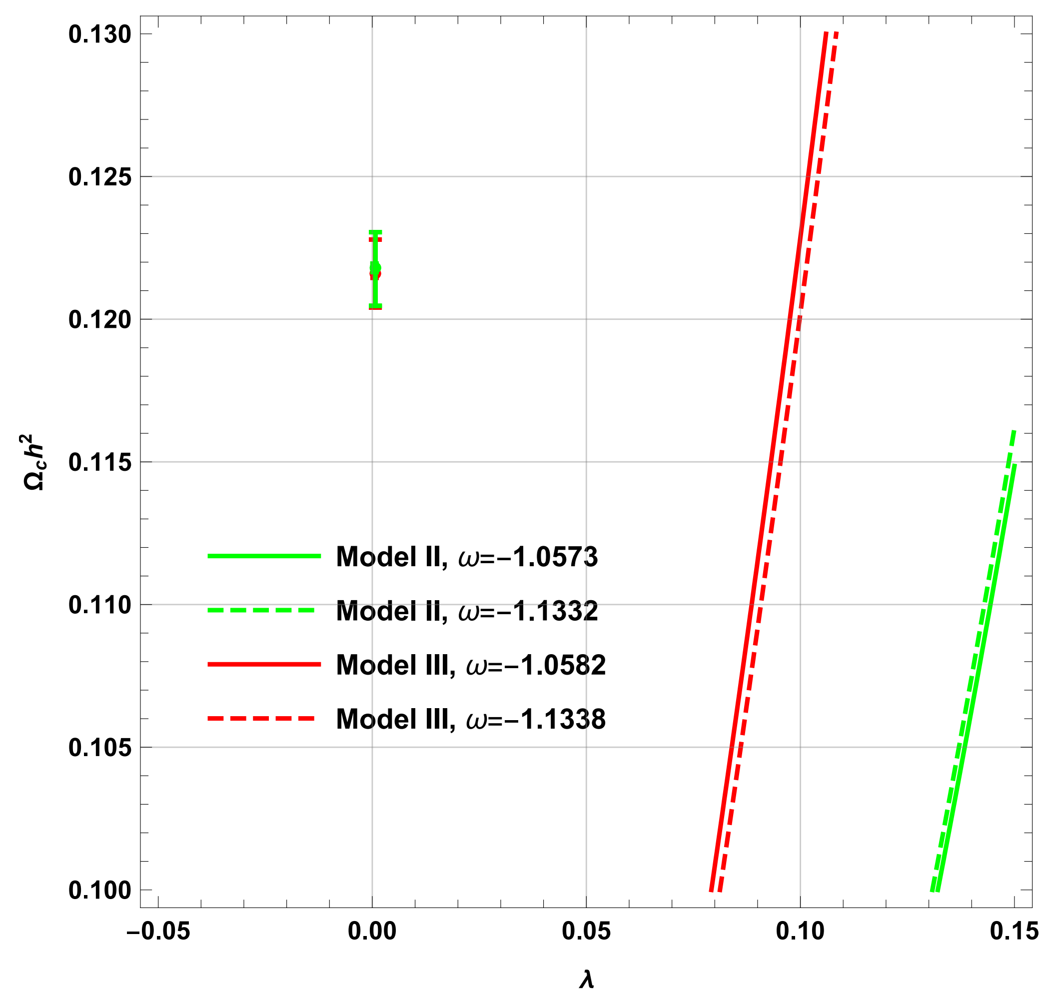
② Constraints from Planck 2015, BAO, SNIa

Model	ω	λ	$\Omega_c h^2$
I-1: $Q_{I-1} = 3\lambda H\rho_d$	$-0.9191^{+0.0222}_{-0.0839}$	$-0.1107^{+0.085}_{-0.0506}$	$0.072^{+0.0348}_{-0.0166}$
I-2: $Q_{I-2} = 3\lambda H\rho_d$	$-1.088^{+0.0651}_{-0.0448}$	$0.05219^{+0.0349}_{-0.0355}$	$0.1351^{+0.0111}_{-0.00861}$
II: $Q_{II} = 3\lambda H\rho_c$	$-1.104^{+0.0467}_{-0.0292}$	$0.0007127^{+0.000256}_{-0.000633}$	$0.1216^{+0.00119}_{-0.00119}$
III: $Q_{III} = 3\lambda H(\rho_d + \rho_c)$	$-1.105^{+0.0468}_{-0.0288}$	$0.000735^{+0.000254}_{-0.000679}$	$0.1218^{+0.00125}_{-0.00133}$

A. A. Costa, X. D. Xu, B. Wang and E. Abdalla, JCAP 1701, no. 01, 028 (2017) doi:10.1088/1475-7516/2017/01/028



The upper limit of EDGES's results $T_{21} = -0.3K$



Constraints from other experiments.

are supported by EDGES.

② Early dark energy model

ρ_{ee} Early dark energy density

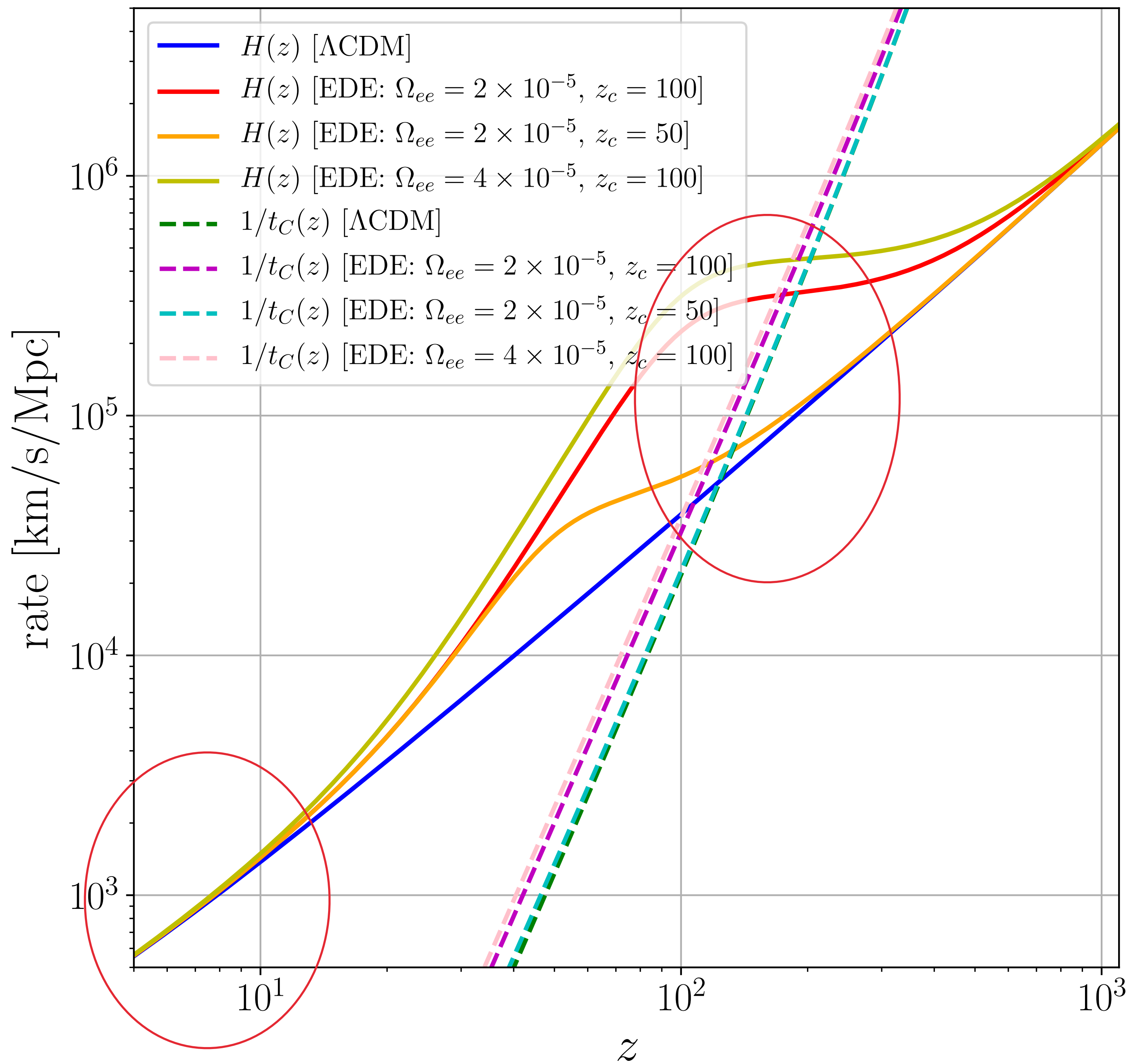
$$H^2 = \frac{8\pi G}{3}(\rho_m + \rho_{ee})$$

$$\rho_{ee}(a) = \rho_c \Omega_{ee} \left(\frac{1 + a_c^6}{a^6 + a_c^6} \right)$$

$$\omega_{ee} = \frac{a^6 - a_c^6}{a^6 + a_c^6}$$

$a << a_c \quad \omega_{ee} \longrightarrow -1$

$a >> a_c \quad \omega_{ee} \longrightarrow 1$



arXiv:1803.07555v2

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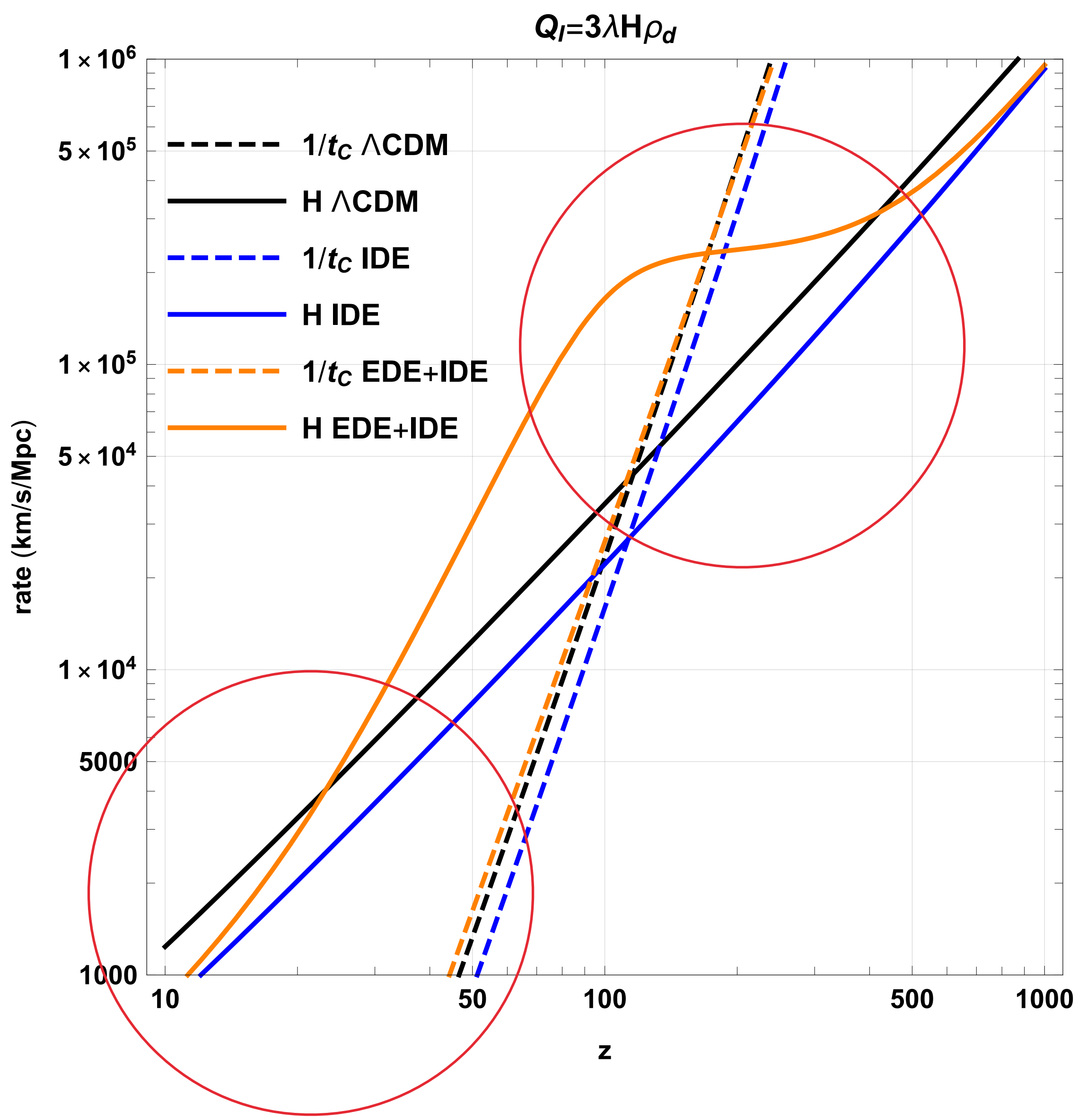
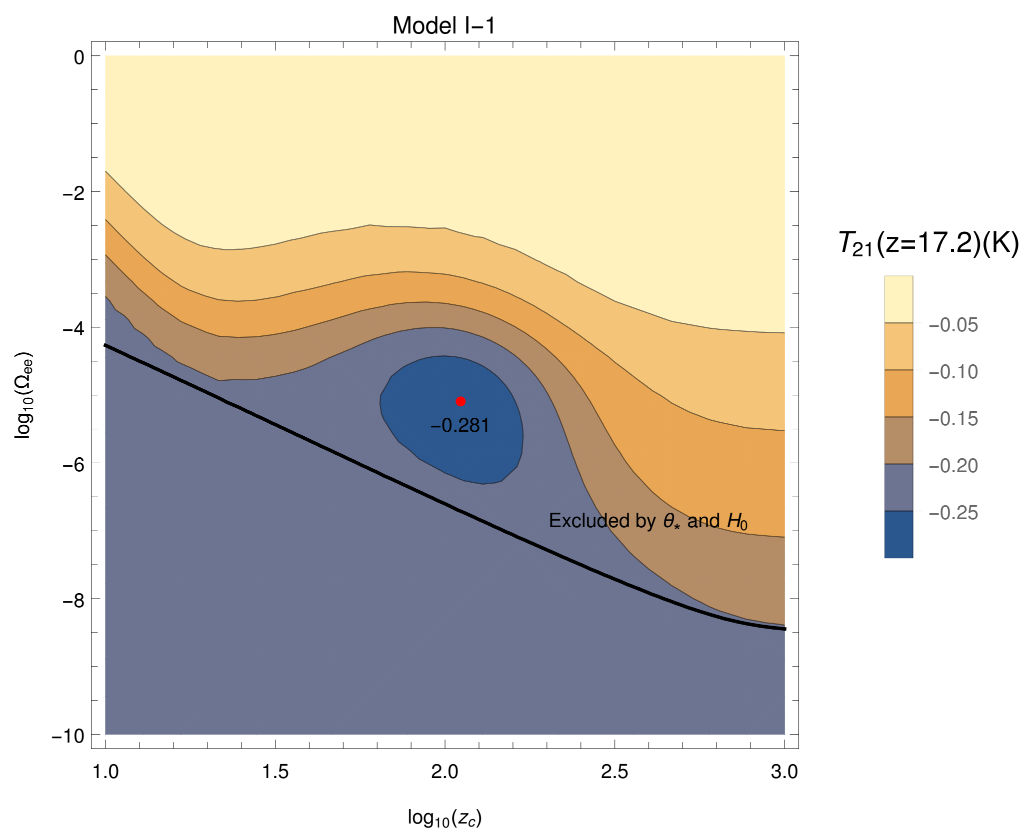


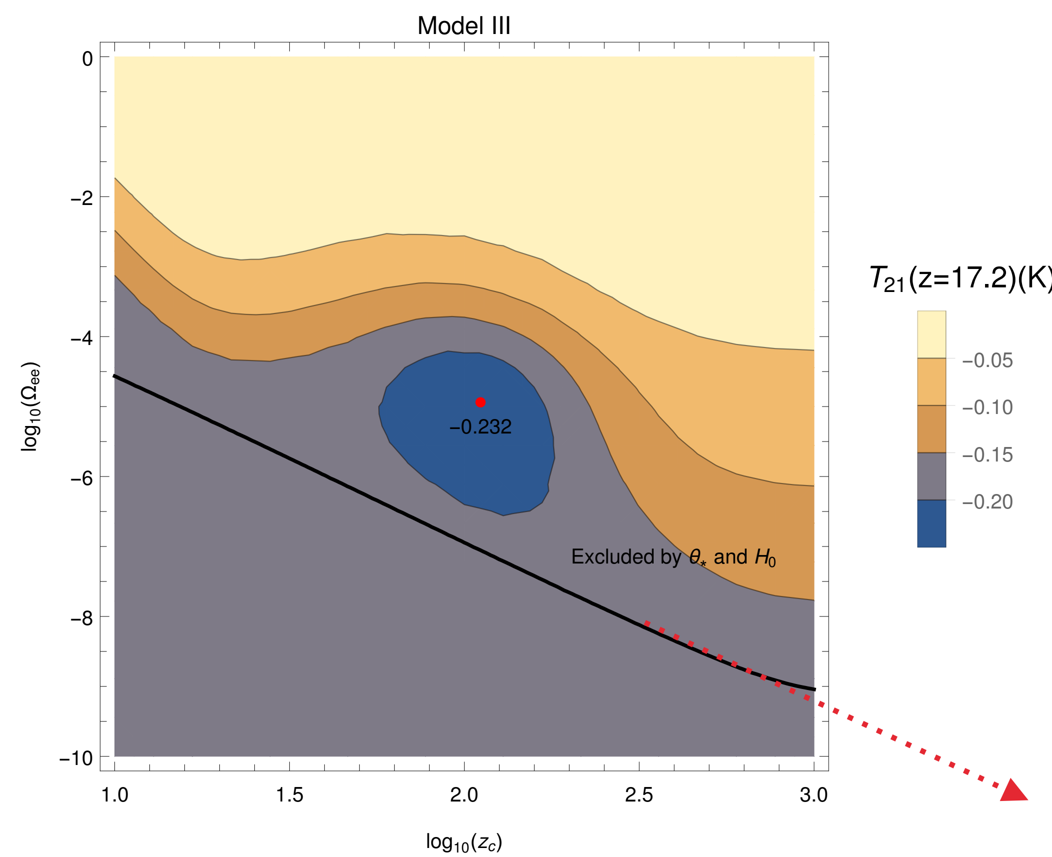
An excess 21-cm signal implies two points about the dynamics of the cosmological background in the early Universe:

- An early smooth evolution stage around z ~ 100.
- A smaller value of H at z ~ 17 than that of the standard cosmology.

To realize this kind of evolution:

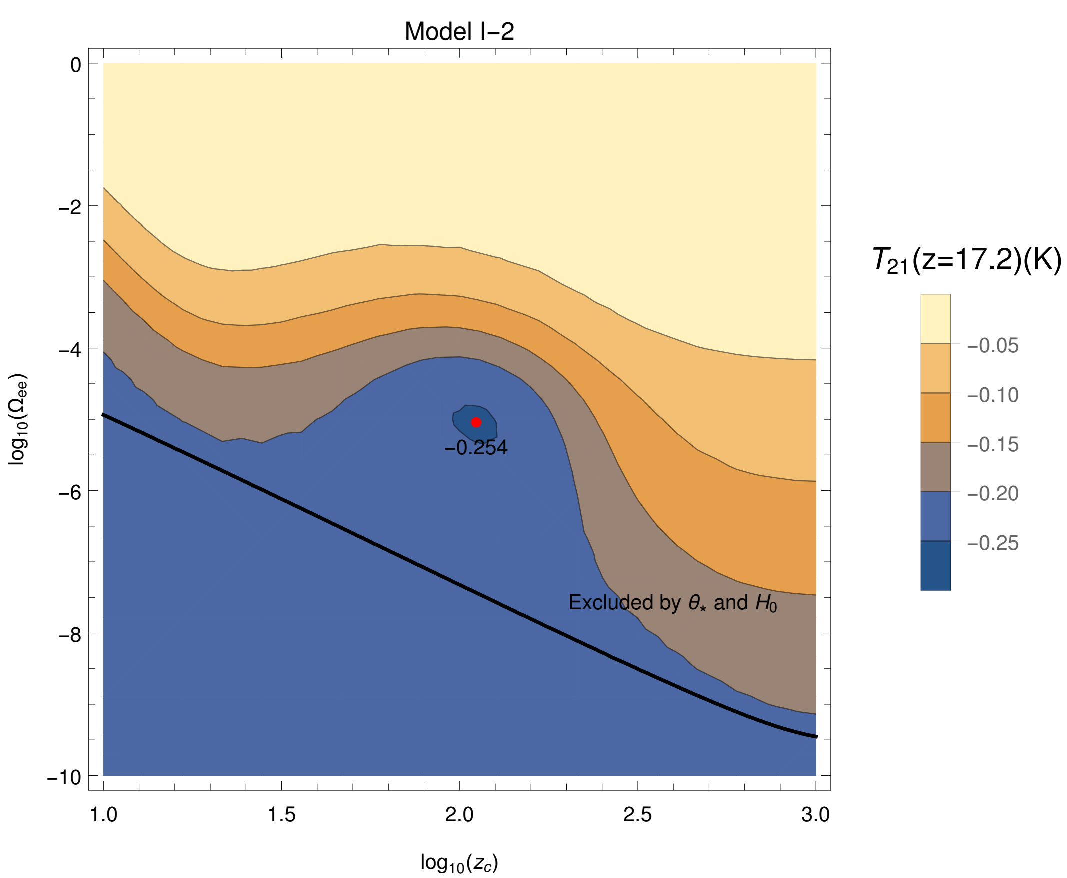
Interacting dark energy + Early dark energy

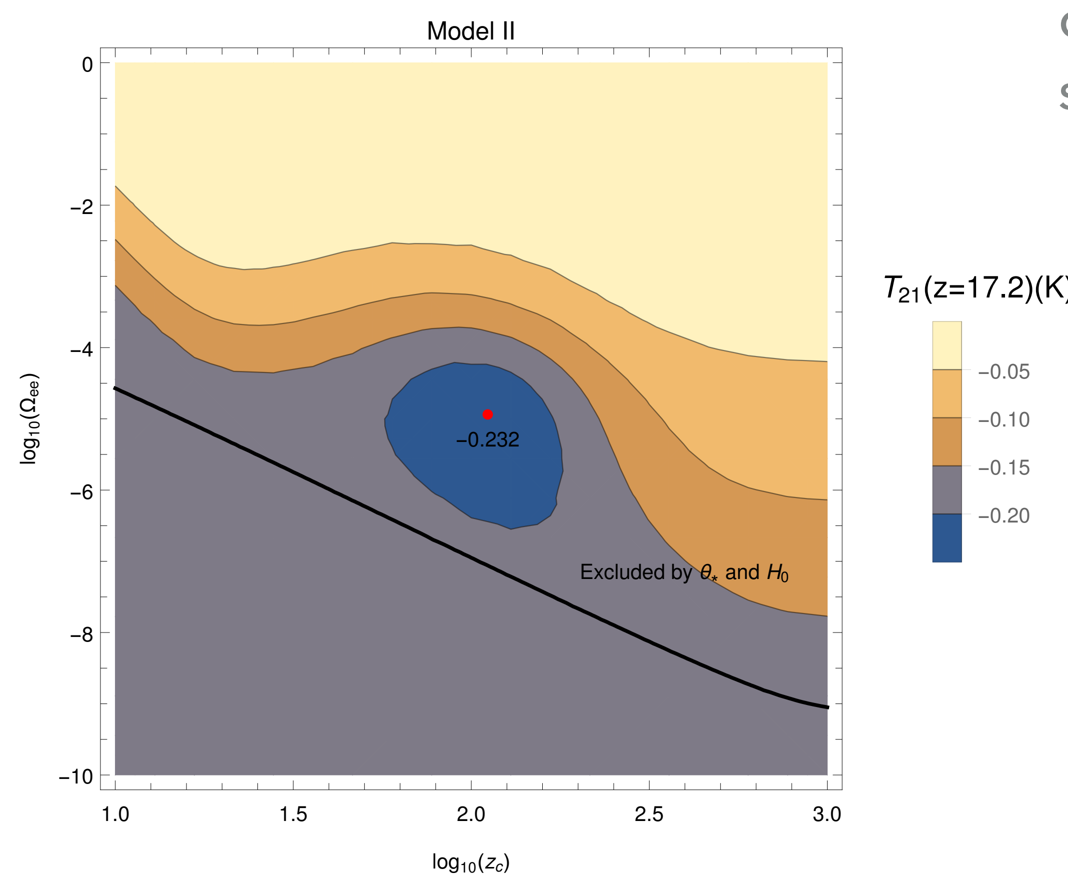




From the acoustic oscillation scale of CMB

$100\theta_*$





SUMMARY

arXiv:1904.02458

- An excess 21-cm signal might imply:
  - An early smooth evolution stage of H(z) around z ~ 100.
  - A smaller value of H(z) at z ~ 17 than that of the standard cosmology.
- There is a tension between EDGES and other experiments for the model combining this two features.
- Much more precise observations on global 21-cm signal at cosmic dawn are necessary.