Beyond Standard Model: From Theory to Experiment (BSM-2021)
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Probing Interacting Dark Energy and Scattering of Baryons with Dark Matter in Light of EDGES 21cm Signal

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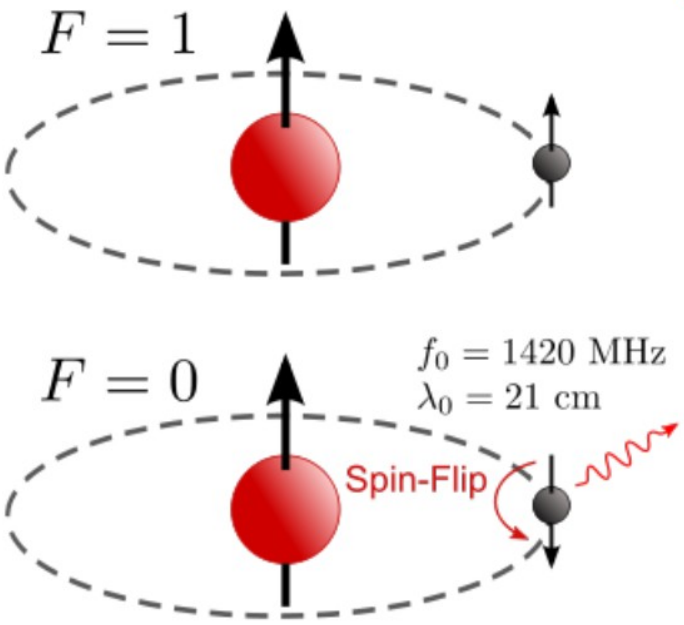
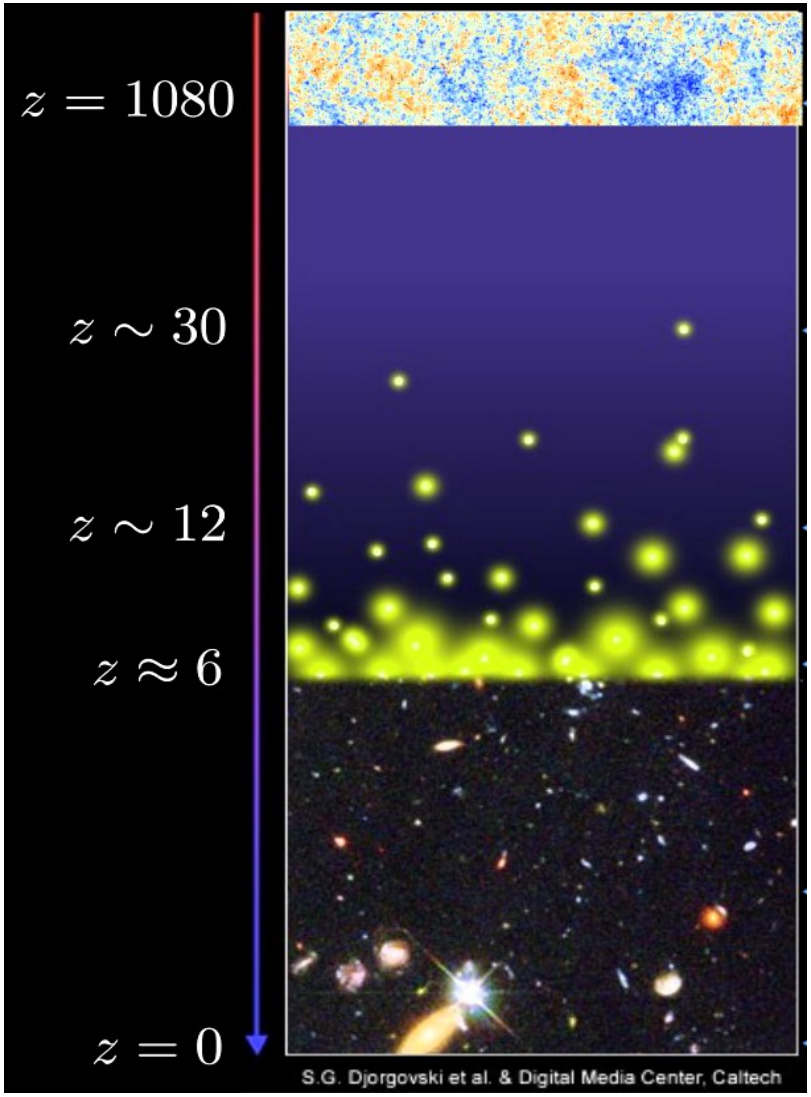
Plan of Talk

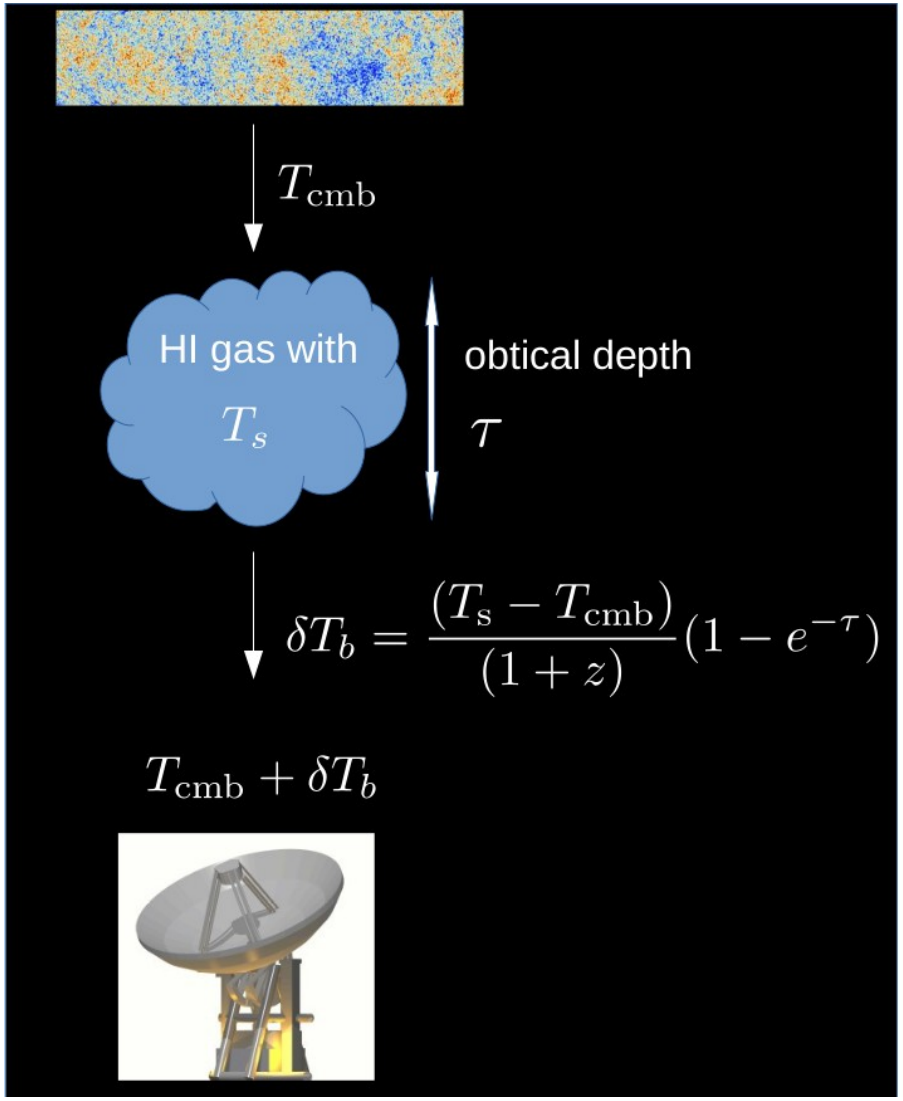
- **Objective or Motivation**
- **Formalism**
- **Results**
- **Conclusion and take home messages**

21cm Line and Cosmic Dawn



21cm line photons are emitted from the hyperfine structure transition of the hydrogen





we observe 21cm line with CMB as background light

if $T_s > T_{\rm cmb}$ **emission**

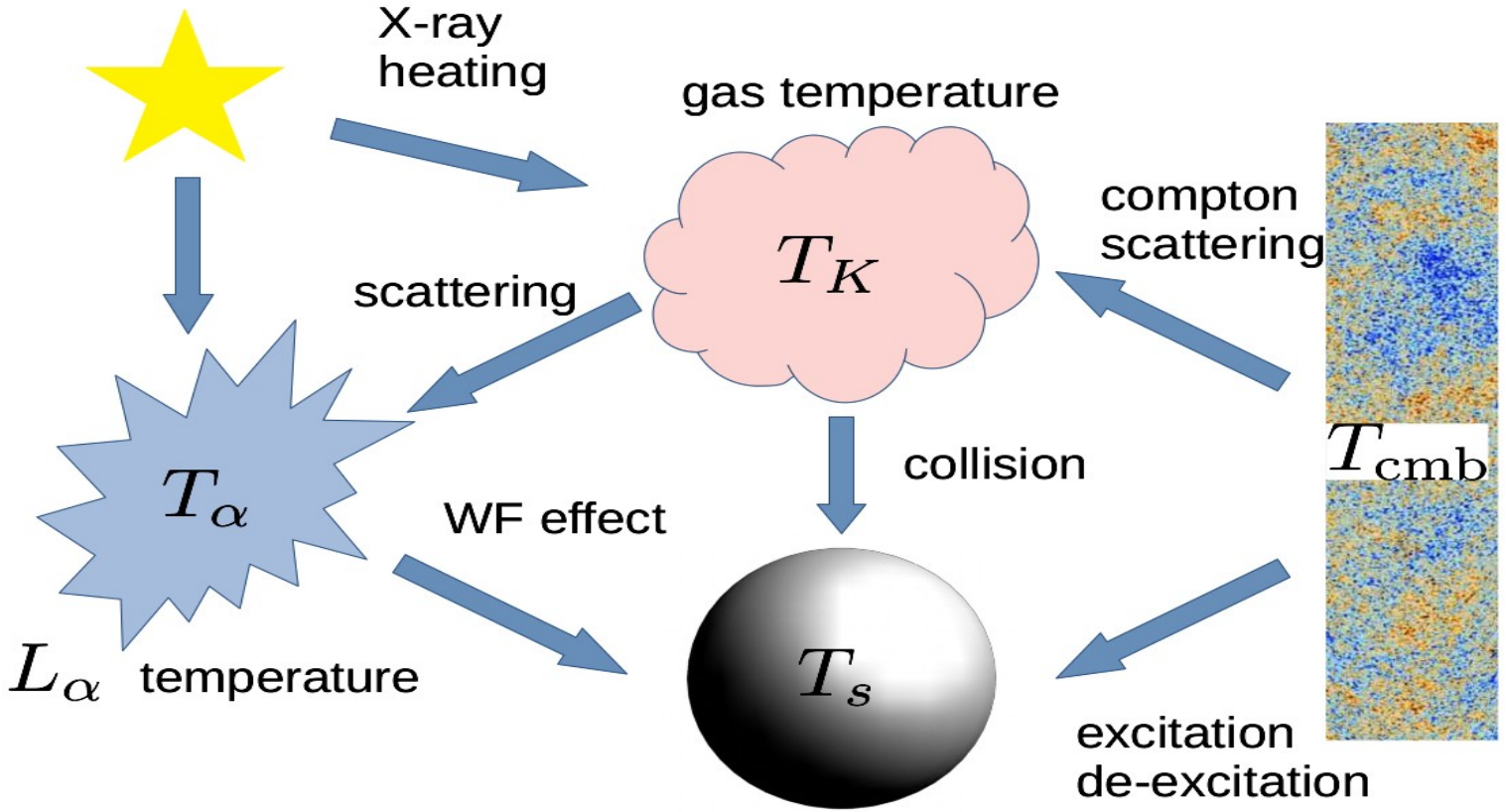
if $T_s < T_{\rm cmb}$ **absorption**

Because it is a line, we can observe the universe at each redshift

redshift	λ	ν
0	21cm	1420MHz
9	2.1 m	142MHz
19	4.2 m	71MHz

Spin Temperature

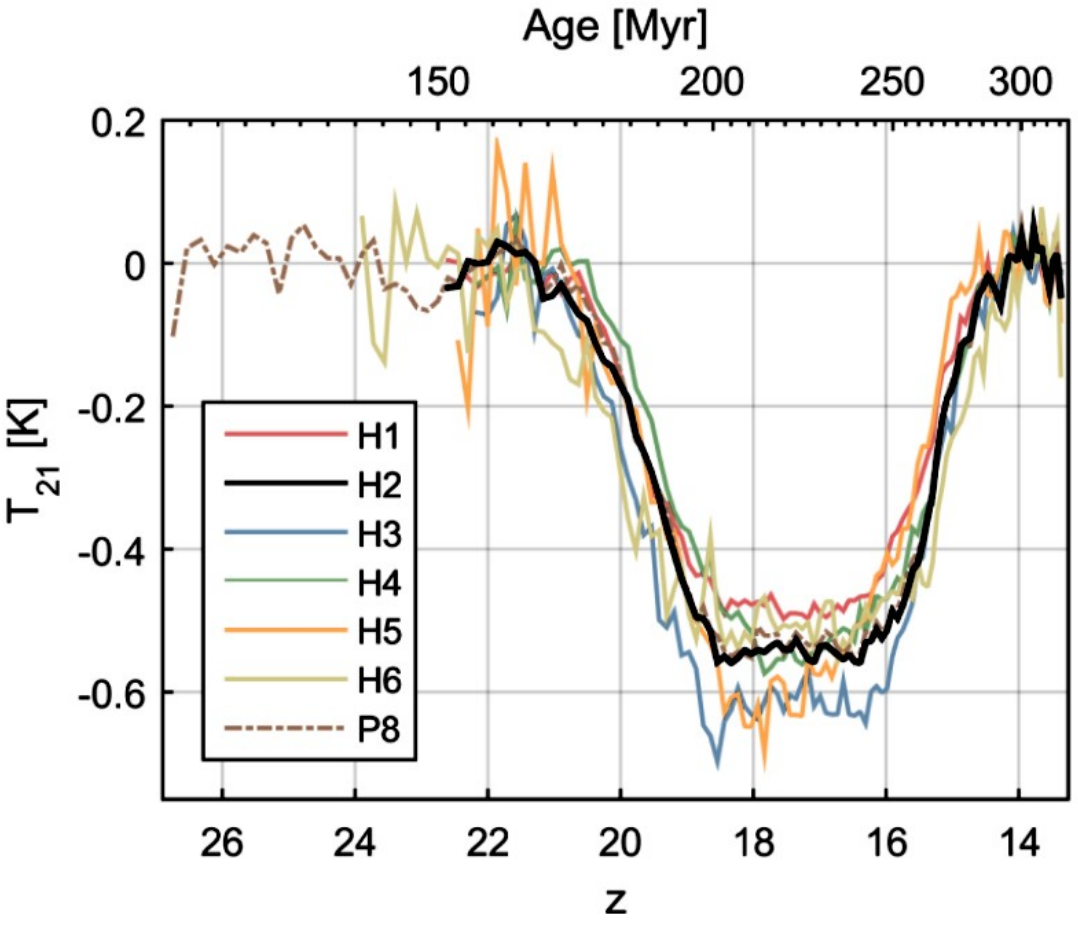
- The excitation temperature of 21 cm line is known as the spin temperature, $n_1/n_0 = g_1/g_0 \exp(-T_*/Ts)$
- Depends on i) CMB ii) gas temperature iii) Lyα photons



Problems in EDGES Results

Large absorption feature than expected

Smaller spin temperature,
Larger background temperature,
Larger optical depth



Doi:10.1038/nature25792

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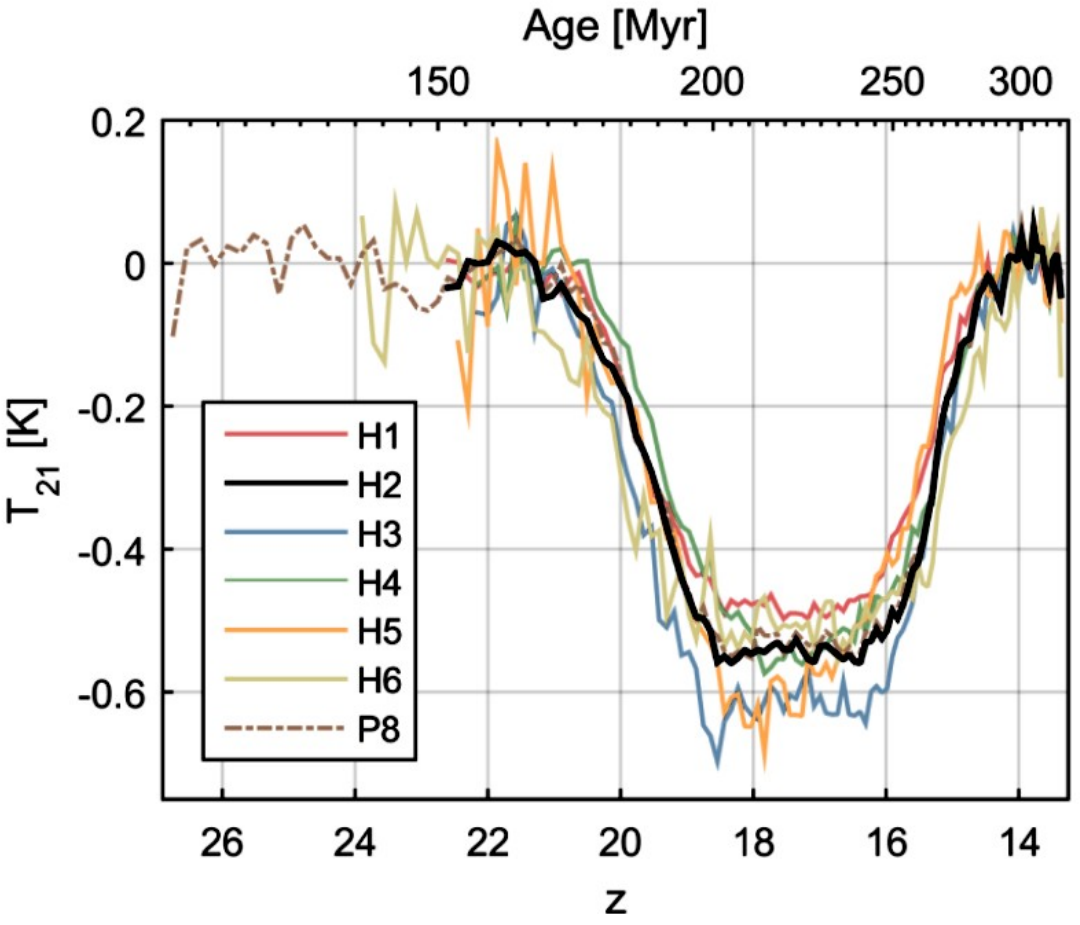


Doi:10.1038/nature25792

- Dark Matter – Baryon Interaction
- Interacting Dark Energy scenario

Constraints on model parameters

Effects of the Interactions Between DM and Baryon Fluid

- There is a temperature difference as well as velocity difference between the DM and baryon fluid.
- The interactions between two fluids of different temperature will heat up the colder fluid and cool down the warmer one. Also for the different velocities, a heating term can arise.

$$\frac{dQ_b}{dt} = \frac{2m_b\rho_\chi\sigma_0 e^{-r^2/2}(T_\chi - T_b)}{(m_\chi + m_b)^2\sqrt{2\pi}u_{\rm th}^3} + \frac{\rho_\chi}{\rho_m}\frac{m_\chi m_b}{m_\chi + m_b}V_{\chi b}D(V_{\chi b})$$

- The dragging term to damp the relative velocity

$$D(V_{\chi b}) \equiv -\frac{dV_{\chi b}}{dt} = \frac{\rho_m\sigma_0}{m_b + m_\chi}\frac{1}{V_{\chi b}^2}F(r)$$

$$F(r) \equiv \mathrm{erf}(\frac{r}{\sqrt{2}}) - \sqrt{\frac{2}{\pi}}e^{-r^2/2}r$$

$$r \propto V_{\chi b}$$

J. B. Munoz, et.al, Phys. Rev. D 92, 083528 (2015).

Effects of Interactions Between DM and DE on 21cm Absorption Line

- Considering the interactions between DM and DE, the continuity equations are given as

$$(1+z)H(z)\frac{d\rho_\chi}{dz} - 3H(z)\rho_\chi = -Q \ ,$$

$$(1+z)H(z)\frac{d\rho_{\rm de}}{dz} - 3H(z)(1+\omega)\rho_{de} = Q$$

- Modification of the evolution of the Universe due to this interaction

$$H(z) \neq H_0\sqrt{\Omega_{m0}(1+z)^3 + \Omega_{\rm de0}(1+z)^{3(1+\omega)}}$$

- It will modify the optical depth

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

DM-DE interaction (contd.)

- Three phenomenological models of this interaction are

$$M-I \quad \mathrm{Q}{=}3\ \lambda H(z)\rho_{\mathrm{de}}\ ,$$

$$M-II \quad \mathrm{Q}{=}3\ \lambda H(z)\rho_{\chi}\ ,$$

$$M-III \quad \mathrm{Q}{=}3\ \lambda H(z)(\rho_{\mathrm{de}}+\rho_{\chi})$$

- Experimental constraints on these models

Model	ω	λ	H_0
$3\lambda H\rho_{\mathrm{de}}$	$-0.9191^{+0.0222}_{-0.0839}$	$-0.1107^{+0.085}_{-0.0506}$	$68.18^{+1.43}_{-1.44}$
$3\lambda H\rho_{\mathrm{de}}$	$-1.088^{+0.0651}_{-0.0448}$	$0.05219^{+0.0349}_{-0.0355}$	$68.35^{+1.47}_{-1.46}$
$3\lambda H\rho_{\chi}$	$-1.1041^{+0.0467}_{-0.0292}$	$0.0007127^{+0.000256}_{-0.000633}$	$68.91^{+0.875}_{-0.997}$
$3\lambda H(\rho_{\mathrm{de}}+\rho_{\chi})$	$-1.105^{+0.0468}_{-0.0288}$	$0.000735^{+0.000254}_{-0.000679}$	$68.88^{+0.854}_{-0.97}$

C. Li, et.al, Phys. Lett. B801 (2020) 135141.

- We will investigate that whether a IDE model, which is well in agreement with the constraints given from other experiments, could also be consistent in explaining the EDGES results.

Equations to Solve

- Temperature evolution of DM

$$\frac{dT_\chi}{dz} = \frac{2T_\chi}{1+z} - \frac{2\dot{Q}_\chi}{3H(1+z)} - \frac{1}{n_\chi}\frac{2Q}{3H(1+z)}$$

- Temperature evolution of baryon

$$\frac{dT_b}{dz} = \frac{2T_b}{1+z} + \frac{\Gamma_c}{H(1+z)}(T_b - T_\gamma) - \frac{2\dot{Q}_b}{3H(1+z)}$$

- Evolution of free electron fraction

$$\frac{dx_e}{dz} = \frac{C_P}{H(1+z)}\left(n_H A_B x_e^2 - 4(1-x_e)B_B e^{\frac{-3E_0}{4T_\gamma}}\right)$$

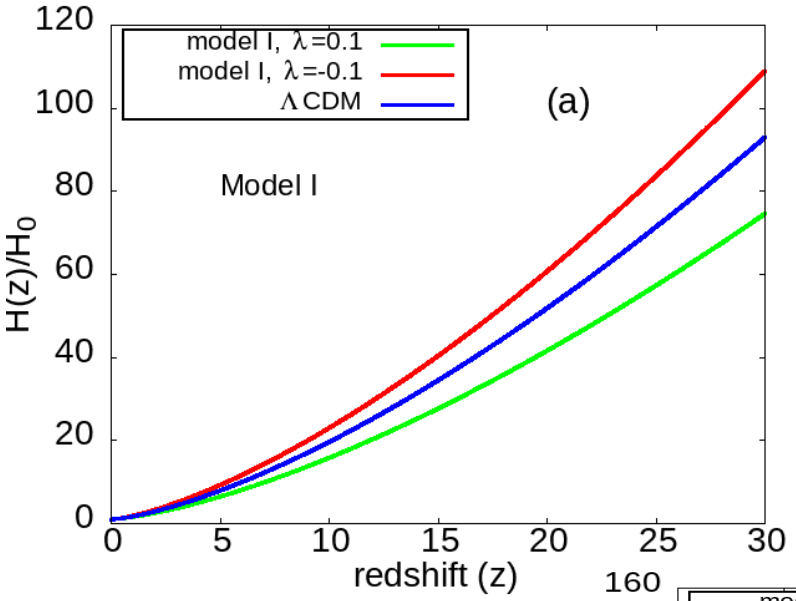
- Variation of relative velocity

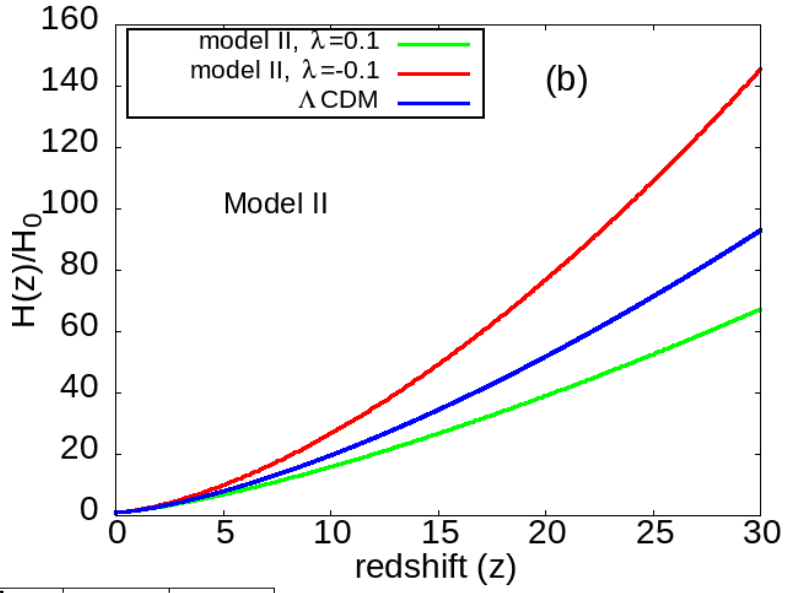
$$\frac{dV_{\chi b}}{dz} = \frac{V_{\chi b}}{1+z} + \frac{D(V_{\chi b})}{H(1+z)}$$

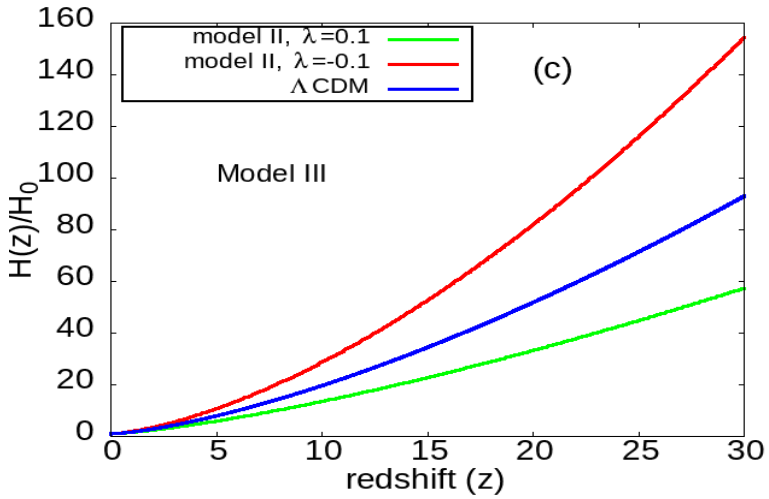
- Brightness temperature of 21 cm line

$$T_{21} = \frac{T_s - T_\gamma}{1+z}(1-\exp^{-\tau}) \approx \frac{T_s - T_\gamma}{1+z}\tau \quad \Big| \quad T_b = T_s$$

Hubble Parameter

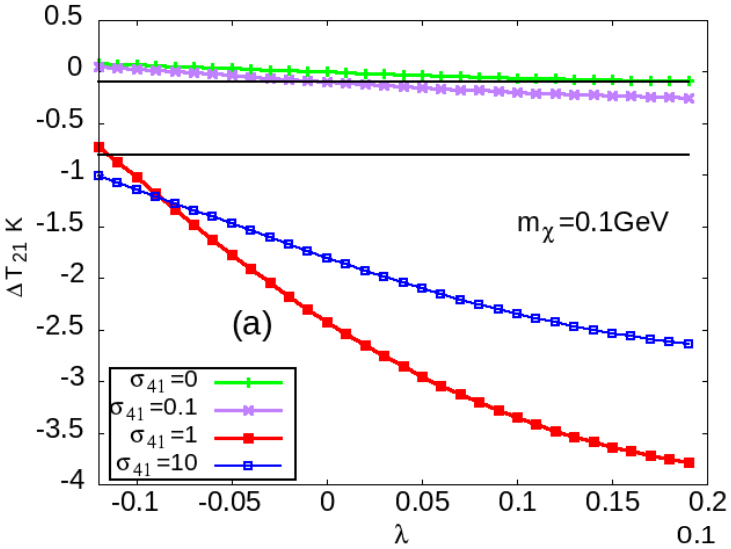


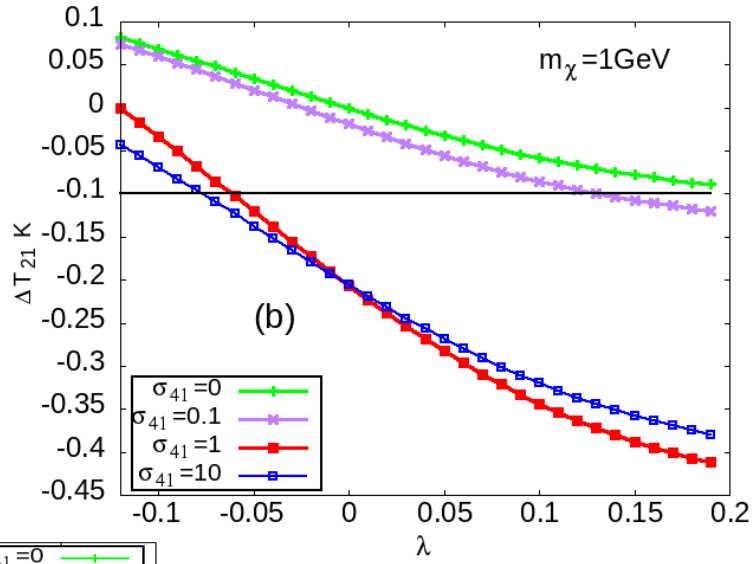


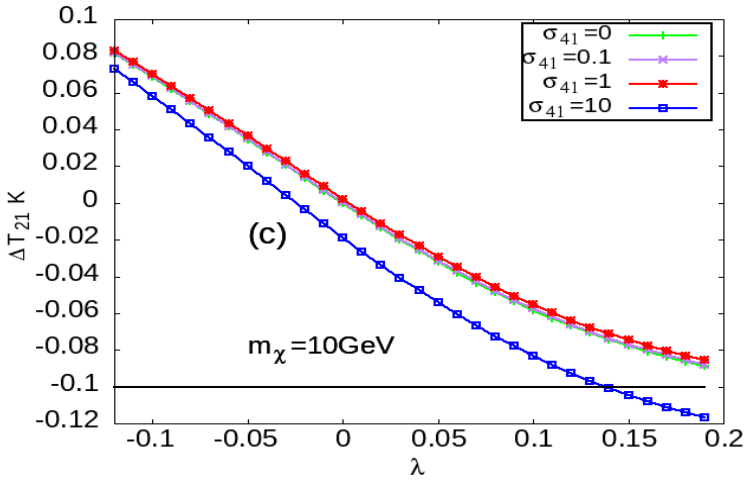


21 cm Brightness Temperature for Model-I for Different Cases

- EDGES limit $-0.1\mathrm{K} \geq \Delta T_{21} \geq -0.8\mathrm{K}$, where $\Delta T_{21} = (T_{21} - T_{21}^{0})$.

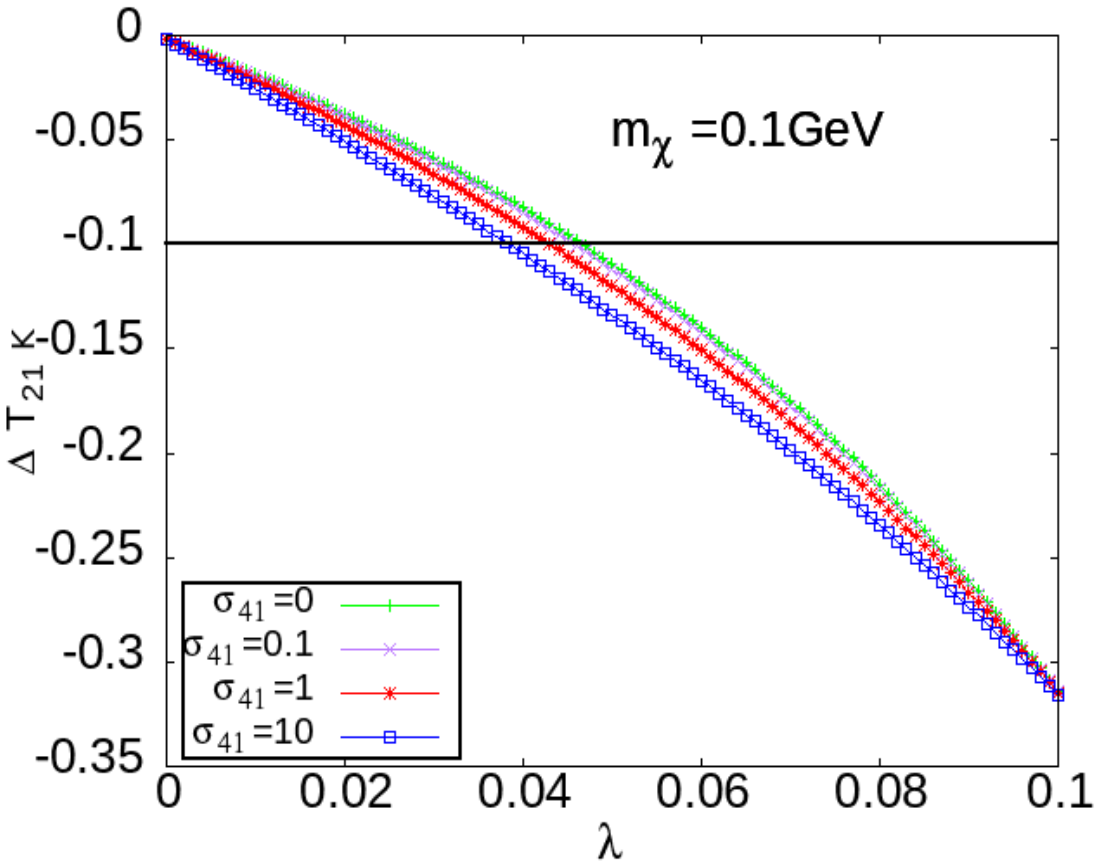






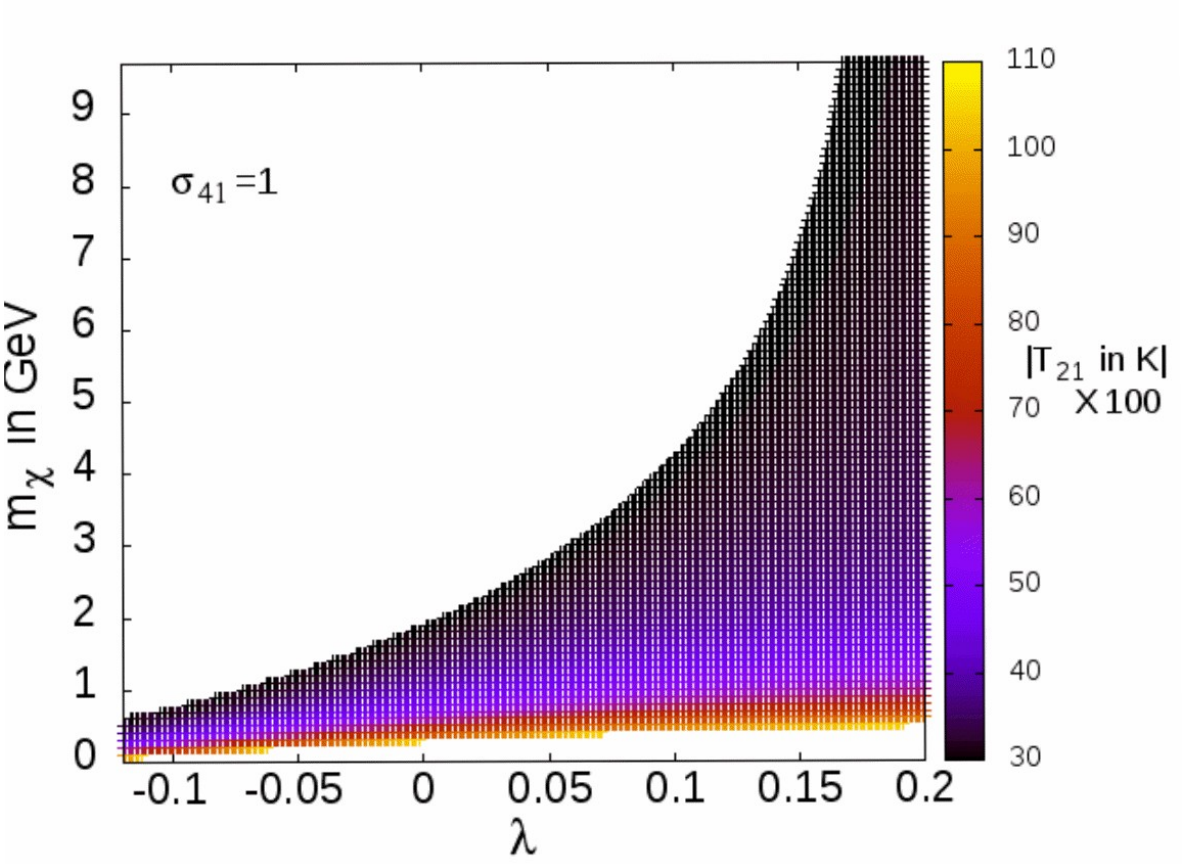
21 cm Brightness Temperature for Model-III for Different Cases

- EDGES observations are satisfied for interaction strength greater or equal to 0.04.
- It is shown from other experiments that λ should not be greater than 0.000989.
- Same conclusions can be obtained for Model-II.



Allowed Parameter Space

$$-300\text{mK} \geq T_{21} \geq -1000\text{mK}$$



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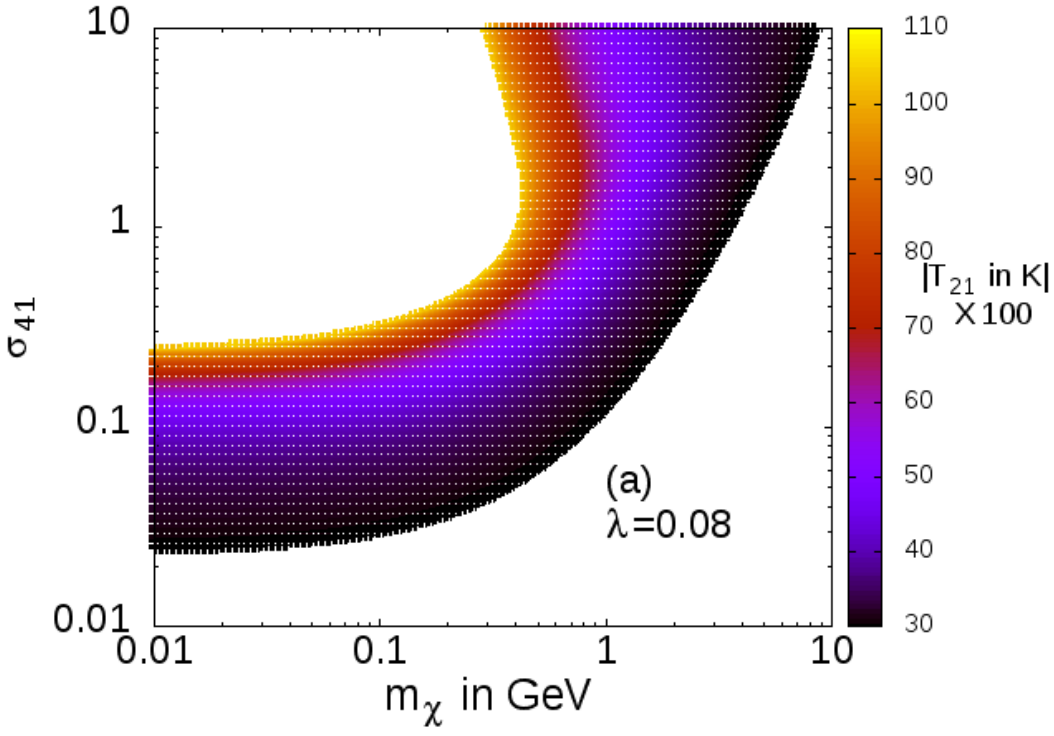

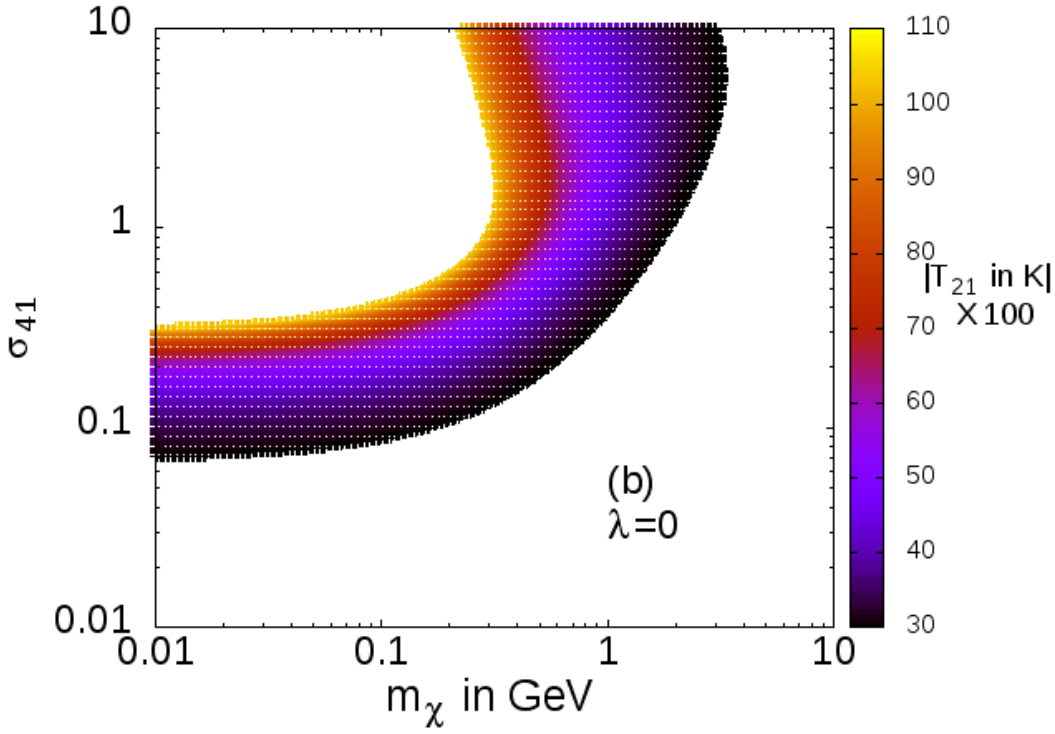

Comments, We Can make

- The EDGES experiment has observed an excess trough in the brightness temperature of the 21cm absorption line

Baryons-DM interaction DM-DE interaction

- Larger DM-baryon interaction cross section, larger DM-DE interaction parameter and smaller DM mass are more favourable to achieve the excess absorption feature.
- When Model-I is considered for DM-DE interaction, EDGES results and other experiment results are well respected but it is not so for other two IDE models.
- DM-DE interaction raises the possibility of probing larger mass ranges of DM that could have influenced the cooling effects.

THANK YOU