Impacts of Z3 symmetric dark matter models on global 21-cm signal

Debarun Paul
ISI, Kolkata

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arXiv: 2308.04955

Collaborators:
A. Dey, A. D. Banik, S. Pal

PPC 2024
17th International Conference on Interconnections between Particle Physics and Cosmology
IIT Hyderabad

Primary Agenda Topics

- Relation between particle DM model and cosmology
- Analysis with EDGES observation
- Signatures at Dark Ages
- Impacts at other eras
- Conclusion

Why particle physics+cosmology...

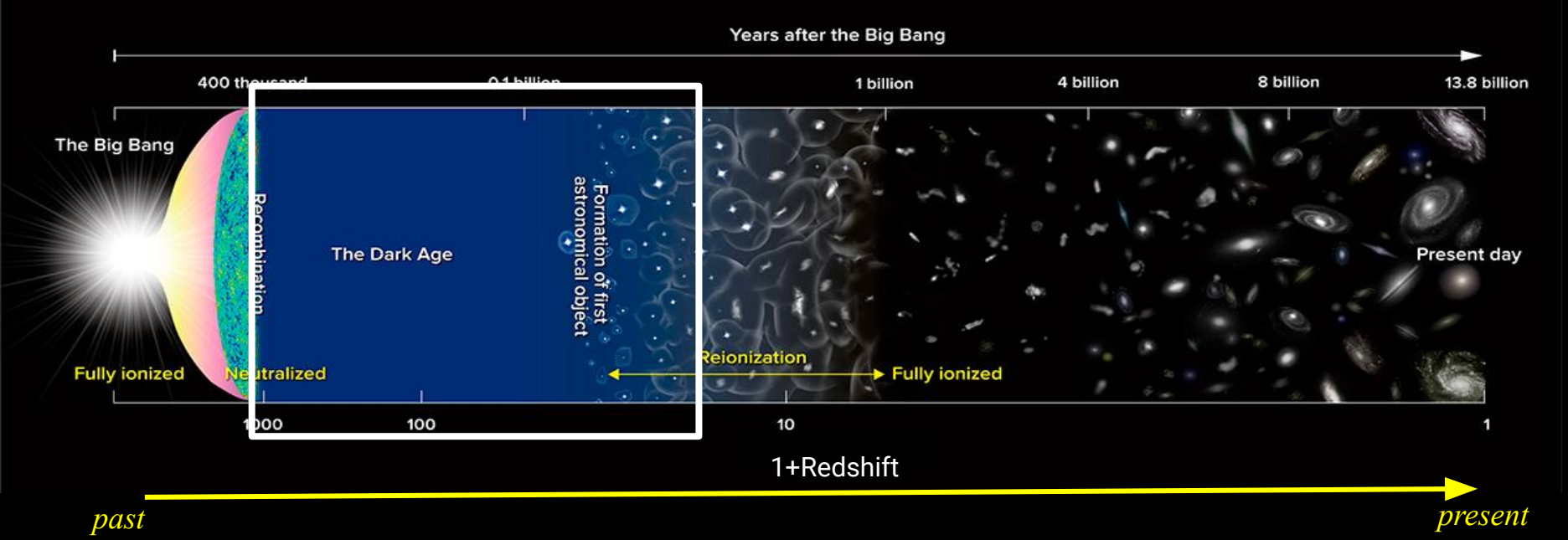
Particle physics provides behaviour of elementary particles

+

Cosmology and astrophysics help us to understand the development of the Universe

→

Both of them, togetherly, can bring more stringent constraints on the properties of the particles



Dark age *no astrophysical objects (z≳30)*

Cosmic Dawn *first stars, galaxies formed (z~30)*

Reionization everything *started to ionize again(z≈30-5)*

What the 21-cm signal is …

HI hyperfine transition;
Spin flip between proton and electron

Emitted frequency, $\nu \approx 1421$ MHz

Wavelength, $\lambda \approx 21$ cm

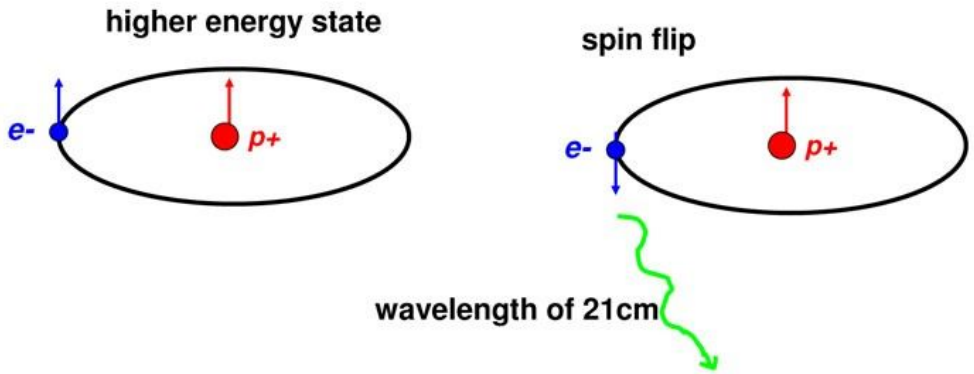
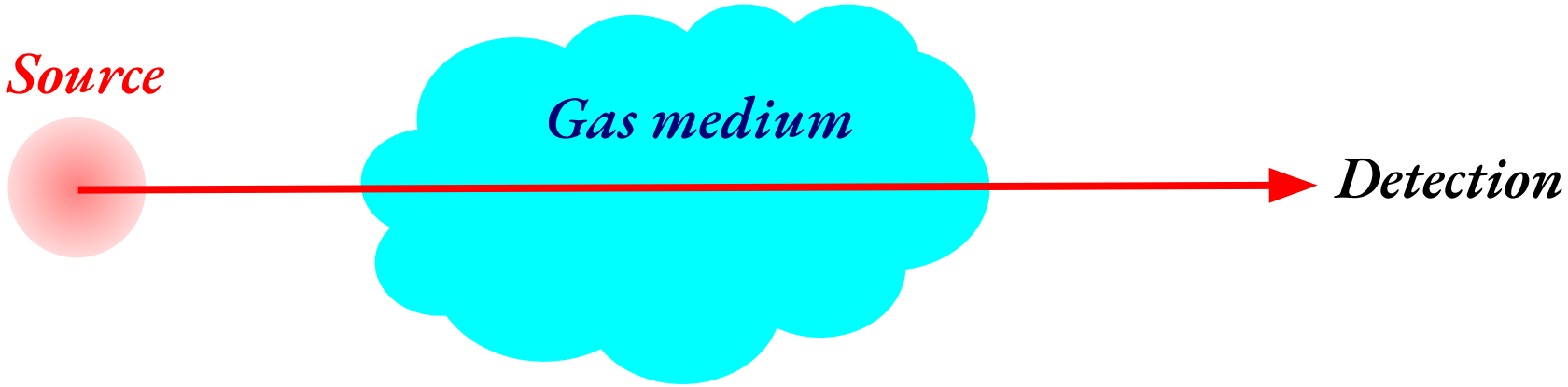


Fig. Credit: blog of Abraham Loeb

Signature of Dark Matter on 21-cm Cosmology



Carries the information of the 'medium'

An important probe for Dark Matter

Signature of Dark Matter on 21-cm Cosmology

$$T_{21} \simeq 27 x_{\rm HI} \left(\frac{\Omega_b h^2}{0.023}\right) \left(\frac{0.15}{\Omega_m h^2} \frac{1+z}{10}\right)^{\frac{1}{2}} \left(1 - \frac{T_\gamma}{T_s}\right) \ {\rm mK}$$

where, $T_s^{-1} = \dfrac{T_\gamma^{-1} + x_k T_k^{-1} + x_\alpha T_\alpha^{-1}}{1 + x_k + x_\alpha}$

Equation Ref.: *Pritchard et. al. Rep. Prog. Phys. 75, 086901 (2012)*

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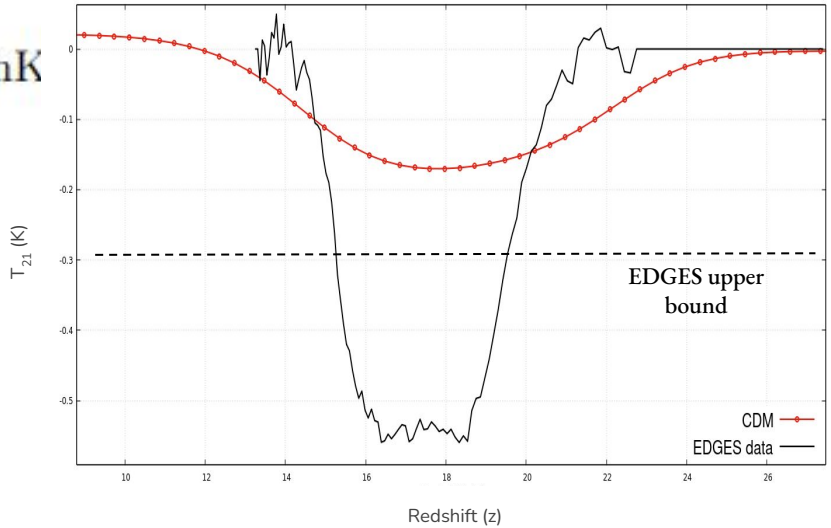

$$\delta T_b = -500^{+200}_{-500}\ mK$$

EDGES: *Experiment to Detect the Global Epoch of Reionization Signature*

Equation Ref.: *Pritchard et. al. Rep. Prog. Phys. 75, 086901 (2012)*

EDGES data: http://loco.lab.asu.edu/edges/edges-data-release/

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We can increase the radiation temperature

Excess radiation is supported by ARCADE-2 experiment

(Fixsen et. al. (2011) ApJ 734)

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We can cool the gas temperature

DM+Baryon interaction

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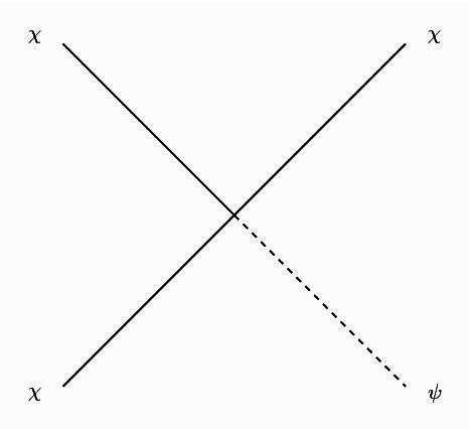
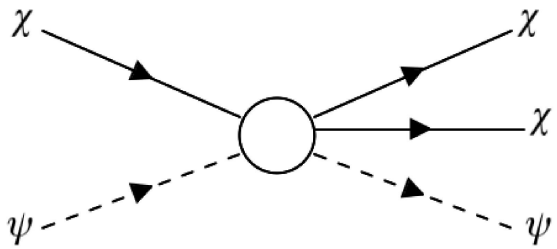
Z3 Symmetric Dark Matter

$$X \rightarrow exp(i2\pi/3)X$$

Semi-annihilating Dark Matter



Co-SIMP 2→3 interaction



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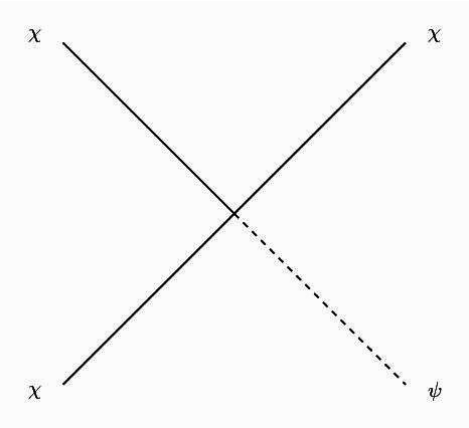
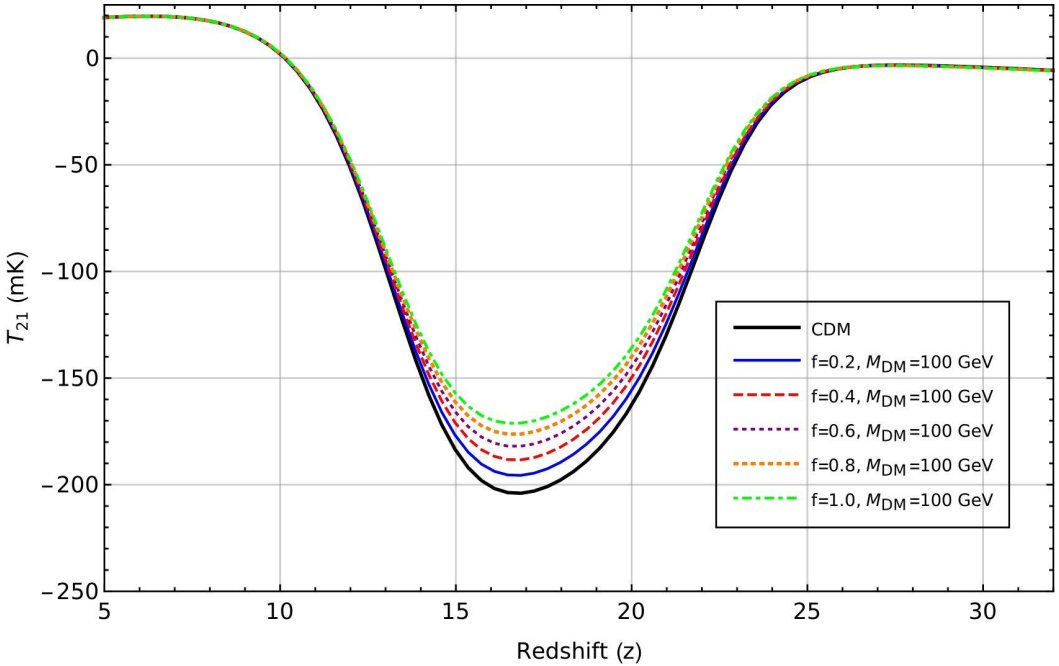


$$\left.\frac{dE}{dV\,dt}\right|_{\rm SADM} = 2 f \rho_{\rm DM}^2 \frac{\langle\sigma v\rangle_{\rm SADM}}{M_{\rm DM}}$$



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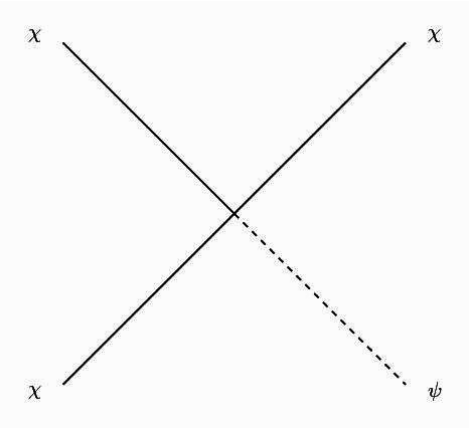
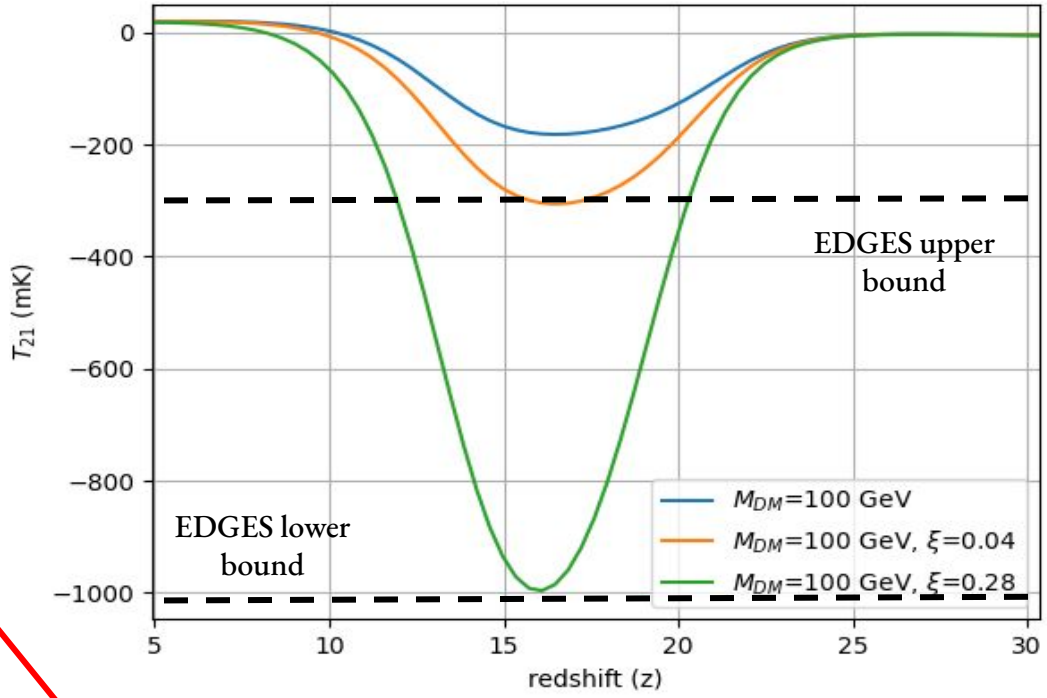


$$T(\nu) = T_{CMB} + \xi T_R \left(\frac{\nu}{\nu_0}\right)^{\beta}$$



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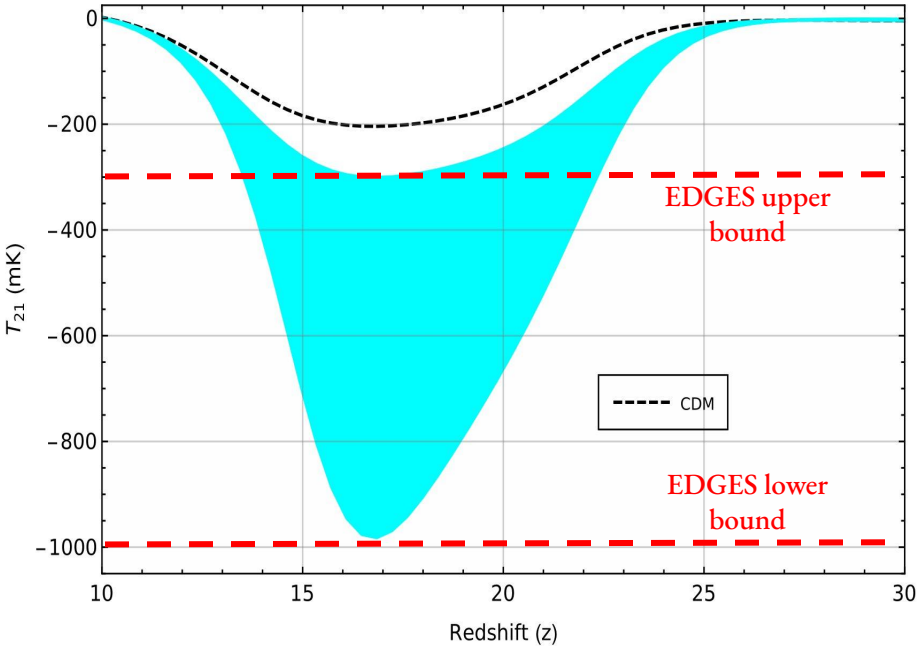

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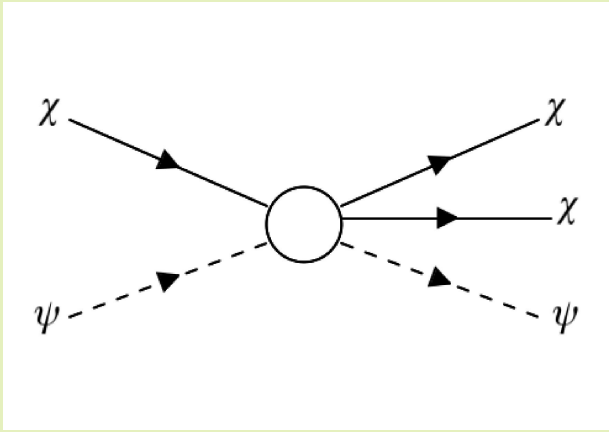

$$\left.\frac{dE}{dV\,dt}\right|_{2\to3} = -\tilde{f}\sqrt{\frac{M_{\rm DM}c^2}{(M_{\rm SM}c^2)^3}}\sqrt{\rho_{\rm SM}^3\rho_{\rm DM}}\,\langle\sigma v\rangle_{2\to3}$$

$\tilde{f} \in [0.56,1.51]$

$\langle\sigma v\rangle_{2\to3}$ = 1.5x 10^{-22} cm^3/s

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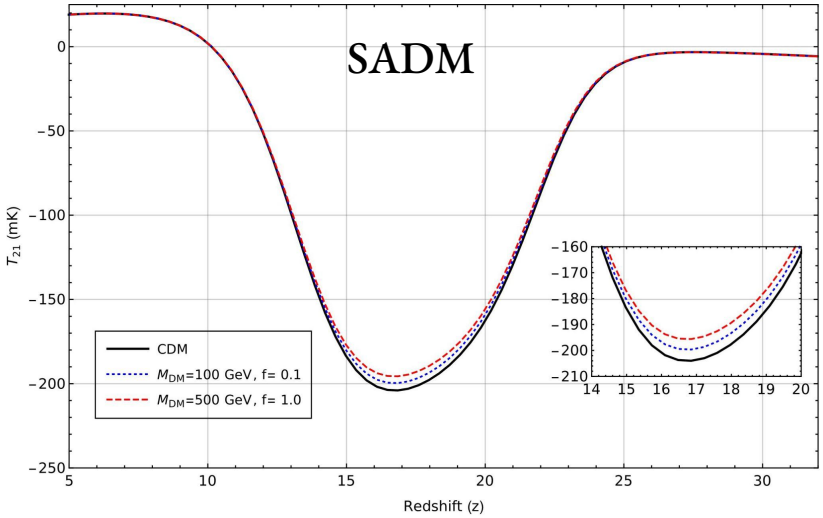
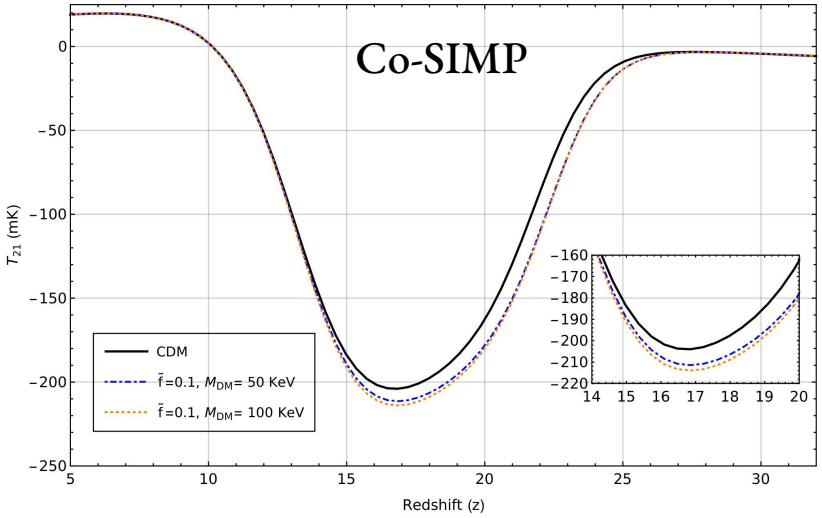
Wait!!... there is a debate

EDGES

SARAS 3





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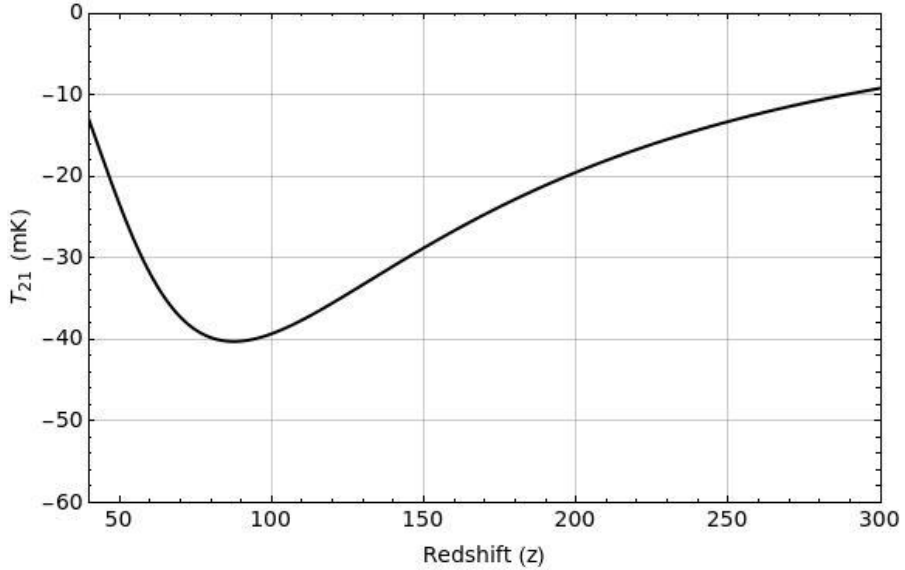
Impacts at dark ages



- *Lunar Surface Electromagnetics Explorer (LuSEE Night)*
- *Dark Ages Polarimeter PathfindER (DAPPER)*
- *Probing ReionizATion of the Universe using Signal from Hydrogen (PRATUSH)*
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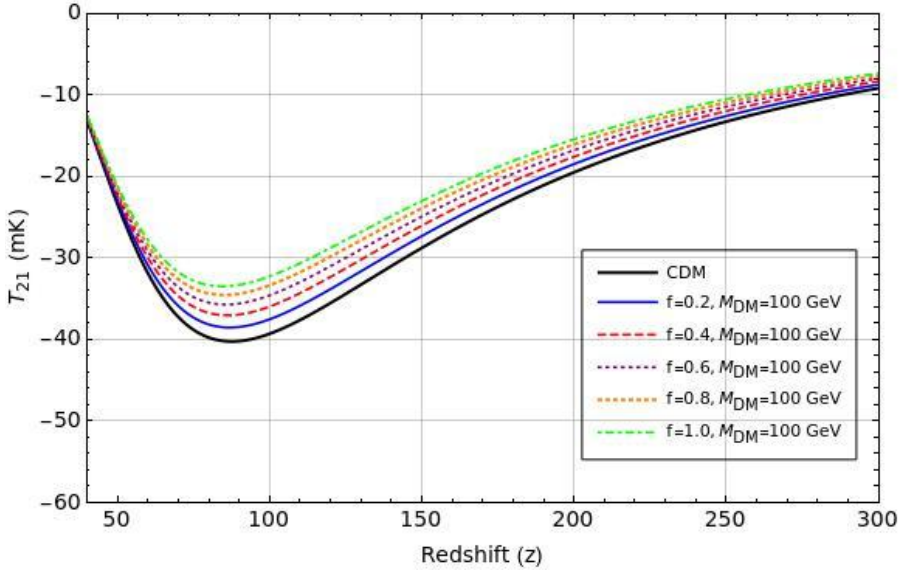

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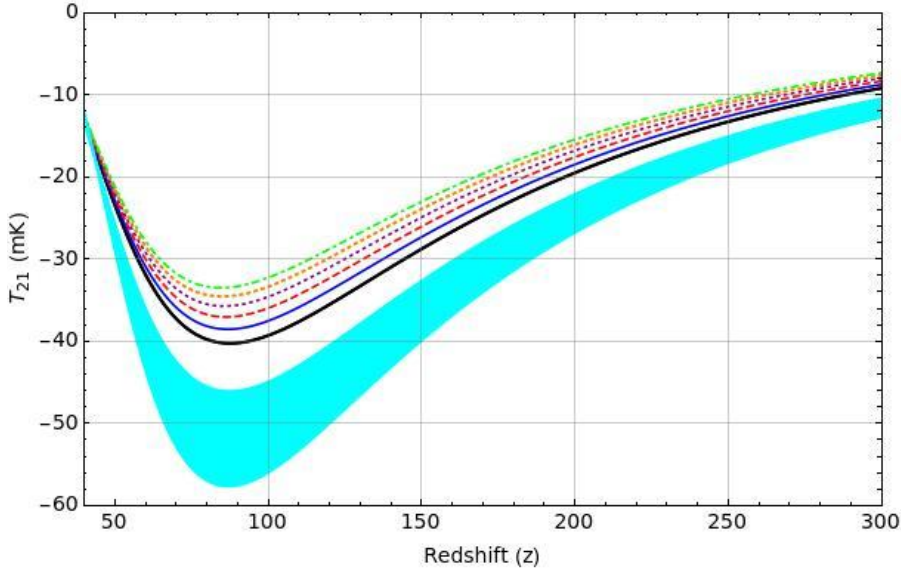

Effects are distinguishable

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$$\omega_b, \omega_{\rm dm}, \theta_s, n_s, A_s, \tau_{\rm reio}, \Gamma_{\rm int}, \tilde{f}$$

cosmological params

model params

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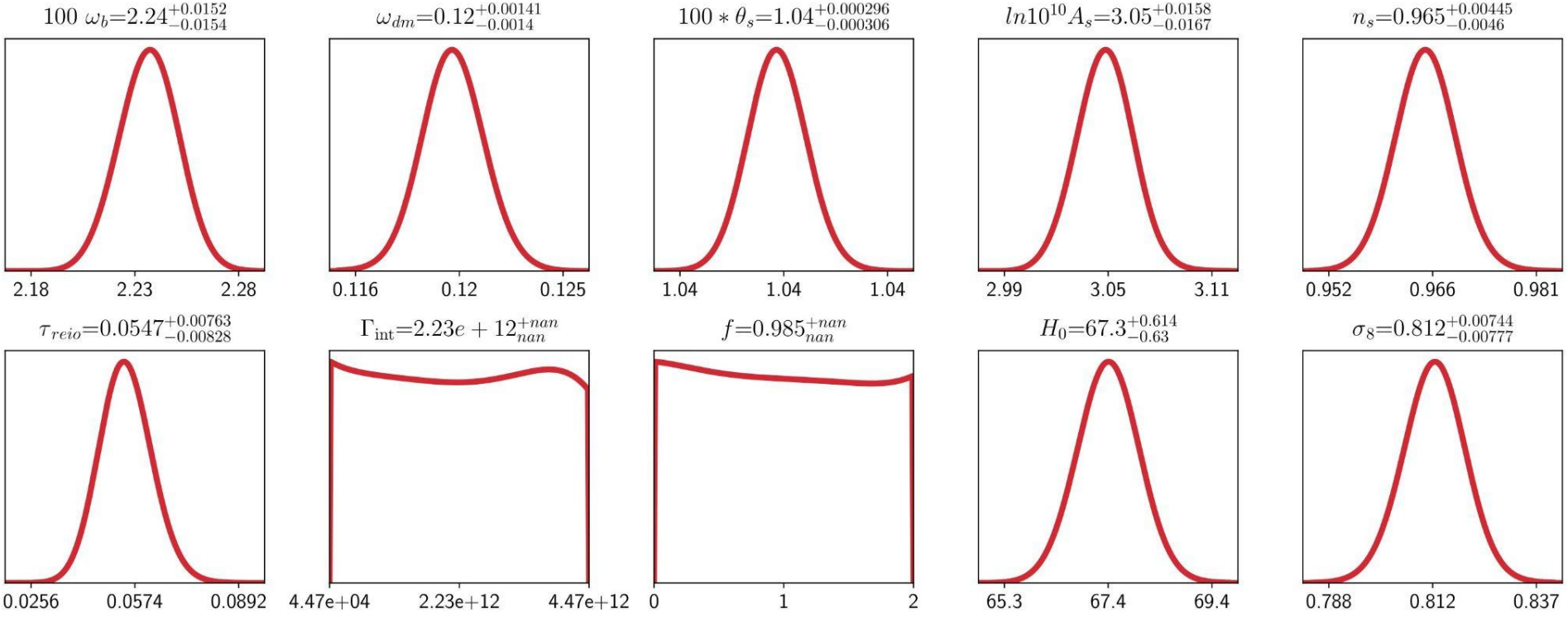
$$\sqrt{\frac{M_{\rm DM}/M_{\rm DM}^{(r)}}{M_{\rm SM}^3/M_{\rm SM}^{3(r)}}\,\frac{\langle\sigma v\rangle}{\langle\sigma v\rangle^{(r)}}}$$

Planck 2018 (high-l TT+TE+EE, low-l TT+EE)



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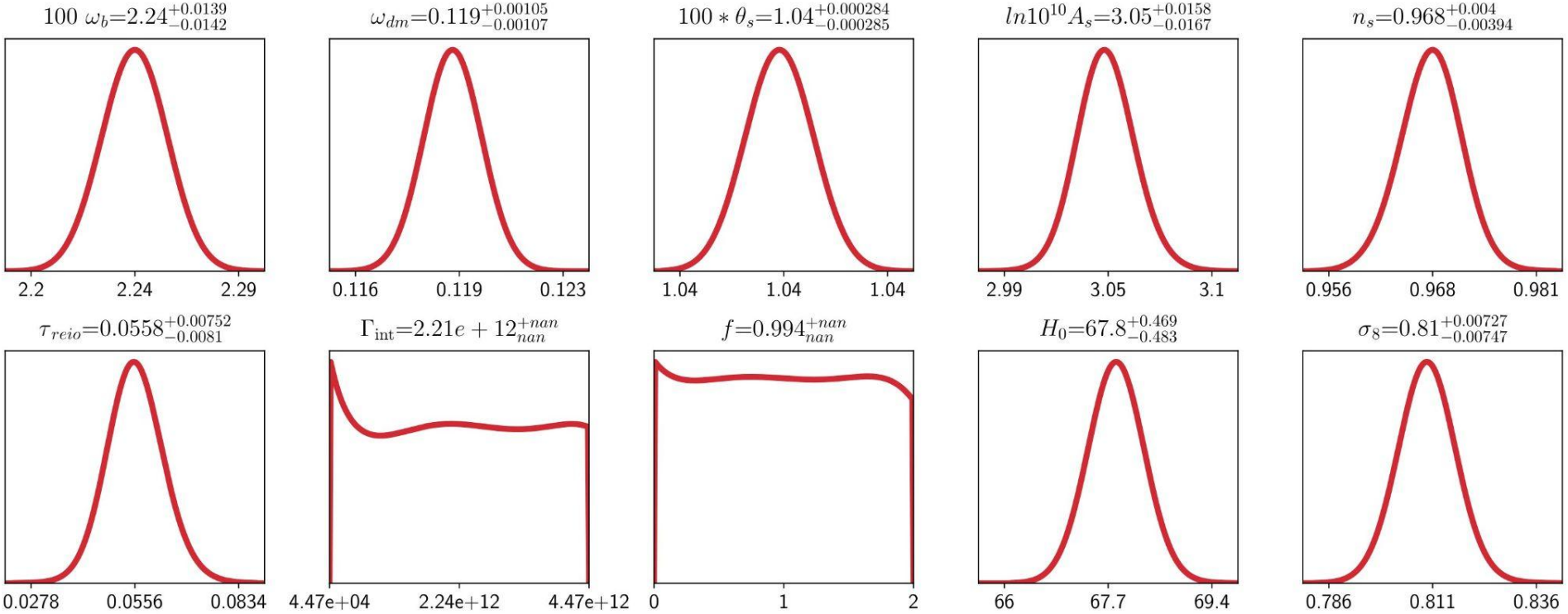
Planck 2018 + BAO



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Co-SIMP model is consistent

Parameter	Planck 2018		Planck 2018+BAO	
	Co-SIMP	ΛCDM	Co-SIMP	ΛCDM
	mean $\pm\sigma$	mean $\pm\sigma$	mean $\pm\ \sigma$	mean$\pm\sigma$
$100\ \omega_b$	2.237 ± 0.015	2.236 ± 0.015	2.245 ± 0.014	2.242 ± 0.014
$\omega_{\rm dm}$	0.1201 ± 0.0014	0.1202 ± 0.0014	0.1191 ± 0.0011	0.11933 ± 0.00091
$100\ \theta_s$	$1.042^{+0.0003}_{-0.00031}$	1.04090 ± 0.00031	1.042 ± 0.00028	1.04101 ± 0.00029
$\ln(10^{10} A_s)$	$3.046^{+0.016}_{-0.017}$	3.045 ± 0.016	$3.046^{+0.016}_{-0.017}$	3.047 ± 0.014
n_s	$0.9654^{+0.0044}_{-0.0046}$	0.9649 ± 0.0044	$0.9681^{+0.004}_{-0.0039}$	0.9665 ± 0.0038
τ_{reio}	$0.0547^{+0.0076}_{-0.0083}$	$0.05578^{+0.0070}_{-0.0081}$	$0.05578^{+0.0075}_{-0.0081}$	0.0561 ± 0.0071
$\Gamma_{\rm int}$	–	–	–	–
$\tilde{f}$	–	–	–	–
H_0	$67.35^{+0.61}_{-0.63}$	67.27 ± 0.60	$67.81^{+0.47}_{-0.48}$	67.66 ± 0.42
σ_8	$0.8122^{+0.0074}_{-0.0078}$	0.8120 ± 0.0073	$0.8096^{+0.0073}_{-0.0075}$	0.8111 ± 0.0060

Co-SIMP model is consistent

Parameter	Planck 2018		Planck 2018+BAO	
	Co-SIMP	ΛCDM	Co-SIMP	ΛCDM
	mean $\pm\sigma$			mean$\pm\sigma$
$100\ \omega_b$				
τ_{reio}				0.0071
$\Gamma_{\rm int}$	–	–	–	–
$\tilde{f}$	–	–	–	–
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Co-SIMP model is consistent with CMB and BAO data

It retains the success of ΛCDM at large scale

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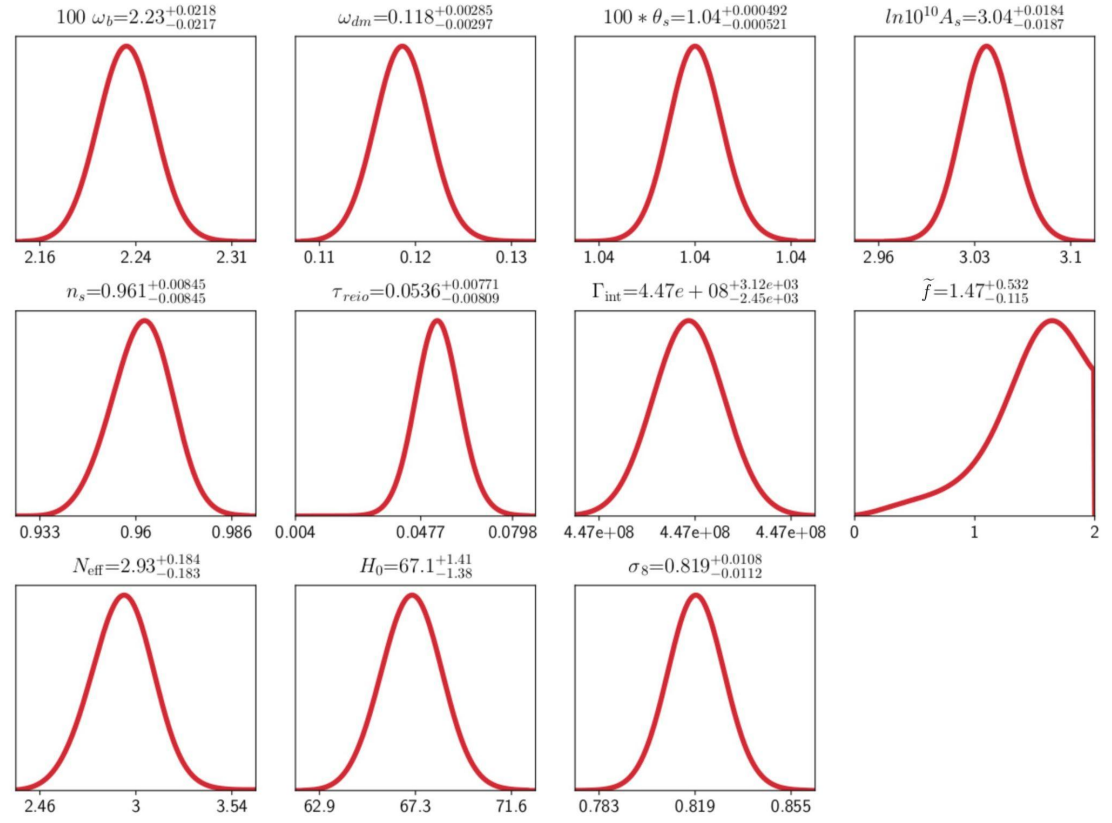
$$\omega_b, \omega_{\rm dm}, \theta_s, n_s, A_s, \tau_{\rm reio}, \Gamma_{\rm int}, \tilde{f} \; + \; N_{\rm eff}$$

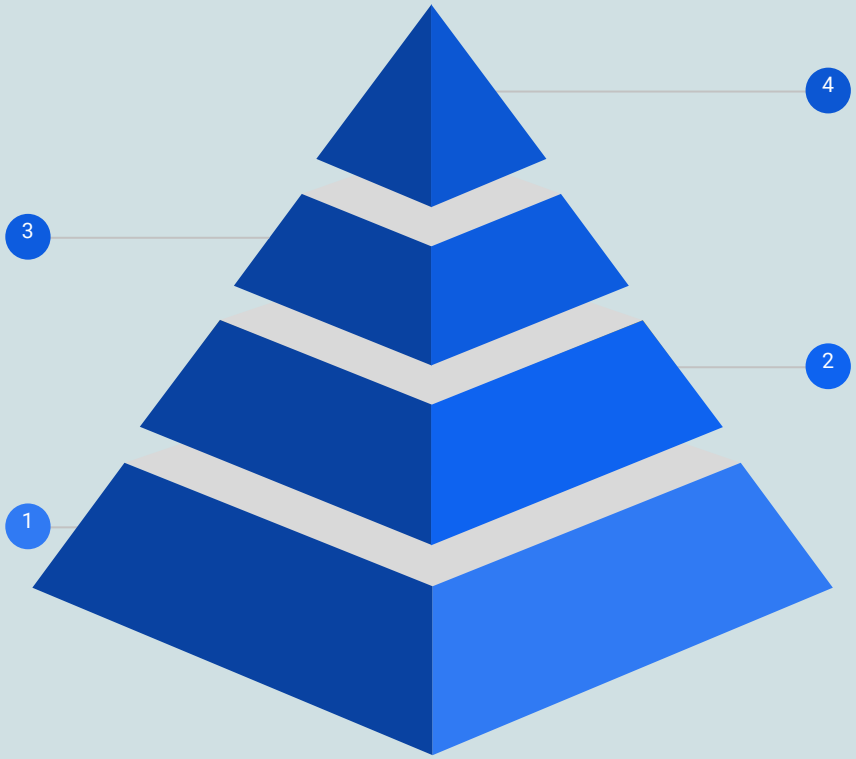


Addressing the EDGES signal

Z3 symmetric DM model has a potential to address the depth of EDGES absorption feature

Impact at dark age

At the dark age, both the models have distinctive impacts



Stands out around the controversy between EDGES and SARAS 3

We are able to show that both the models can sustain for a particular set of model parameters if EDGES needs further reassessment.

Retain the success of LCDM at large scale

Our chosen models are consistent with other cosmological obs. e.g. CMB, BAO.

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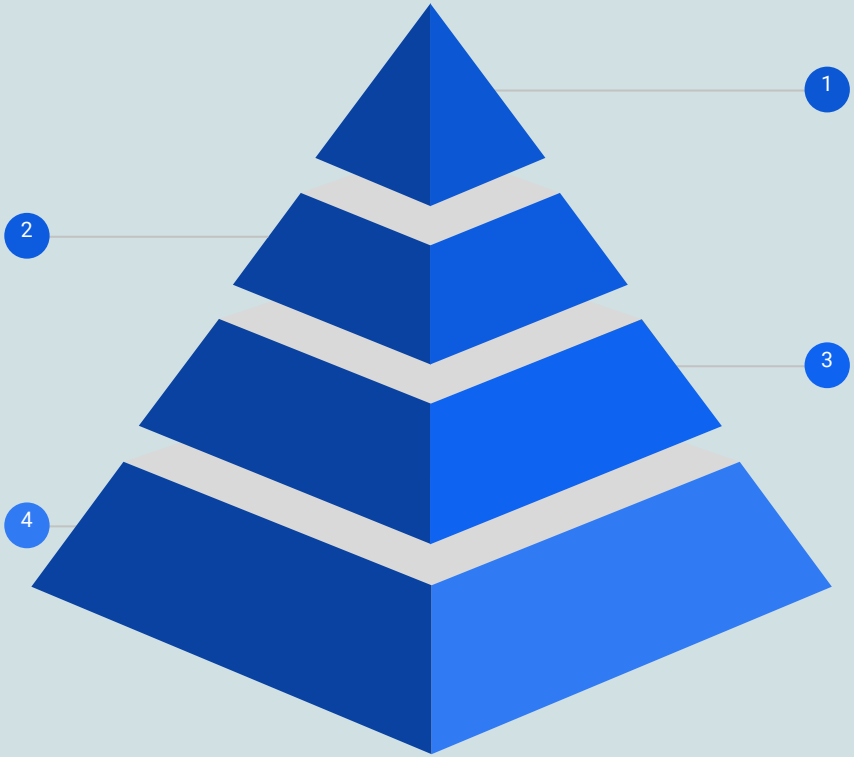

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Reserved Slides...

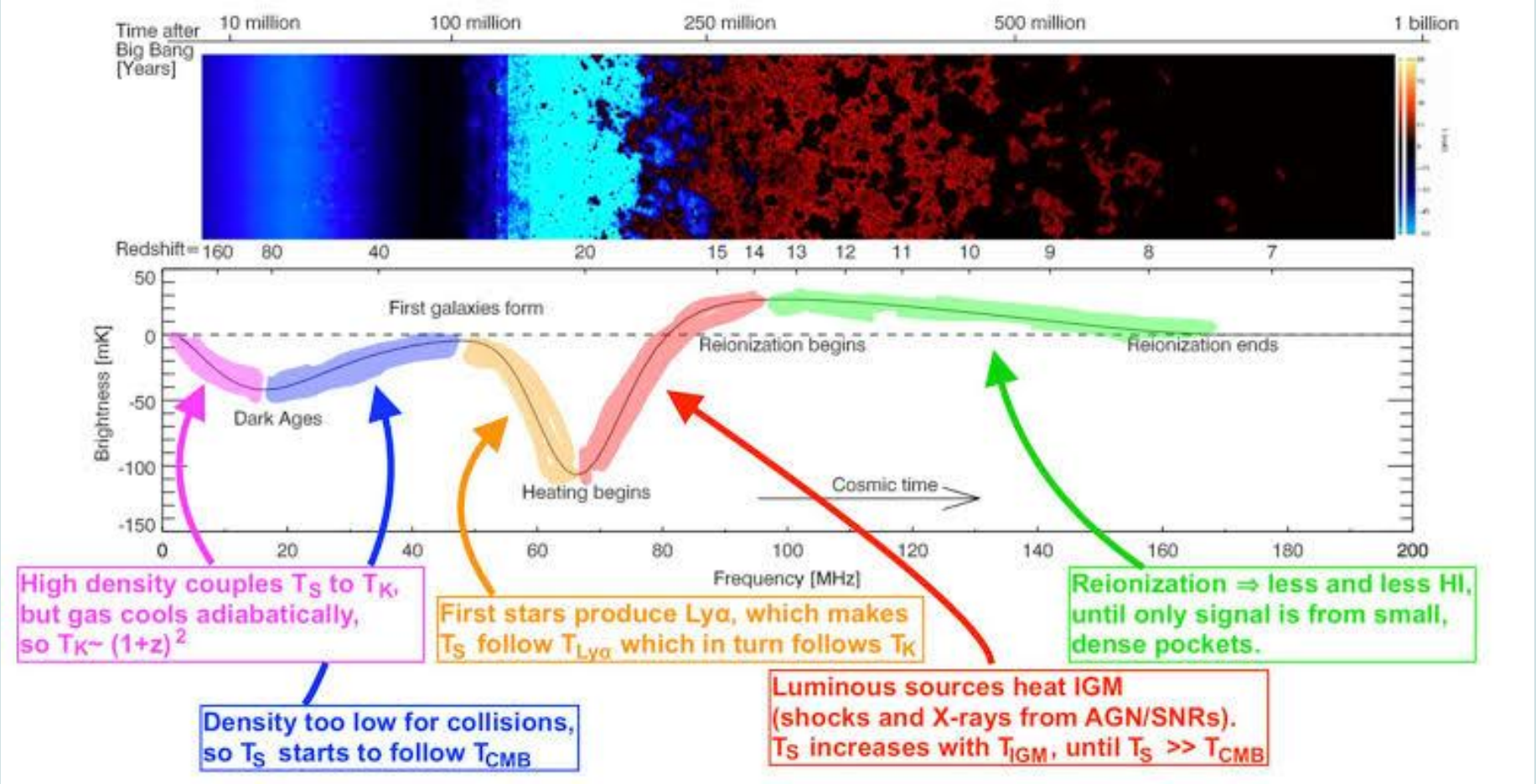
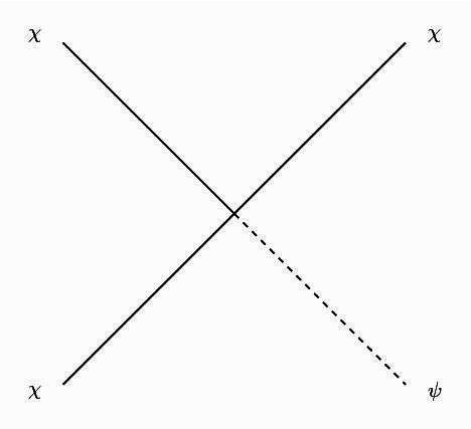


Fig. Credit: https://astronomy.stackexchange.com

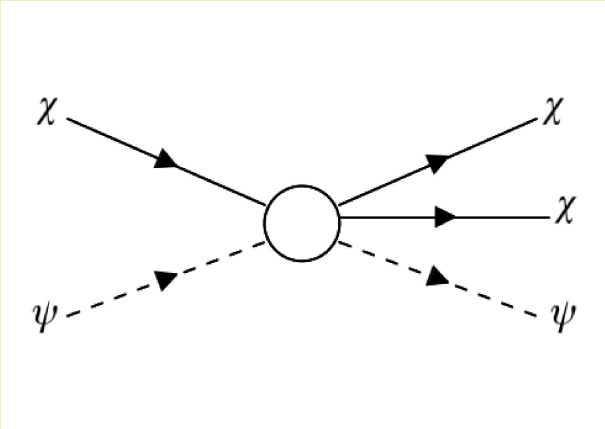
Semi-annihilating Dark Matter



$$\left.\frac{dE}{dV\,dt}\right|_{\rm SADM} = 2 f \rho_{\rm DM}^2 \frac{\langle \sigma v \rangle_{\rm SADM}}{M_{\rm DM}}$$

Always heats the gas

Co-SIMP 2→3 interaction



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A possibility to cool down the gas

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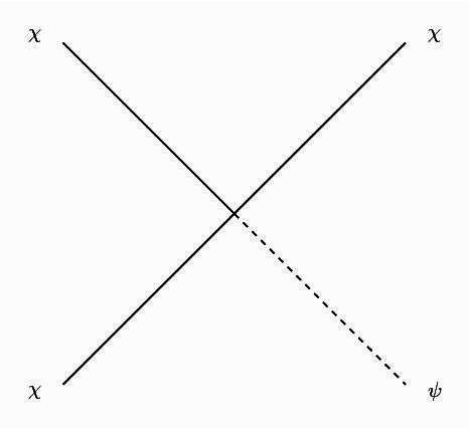

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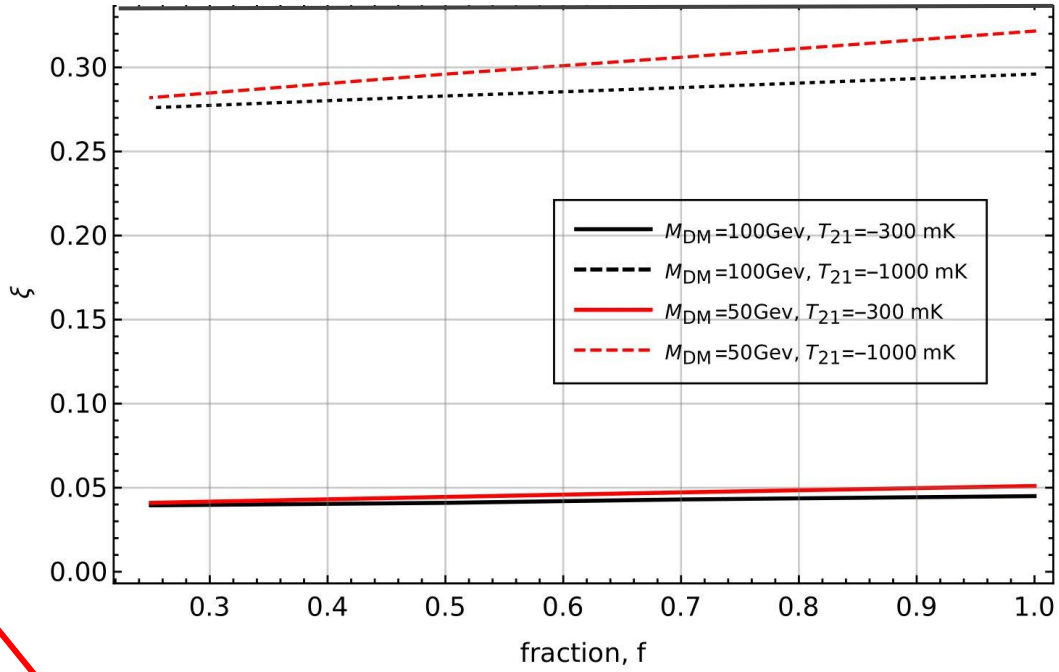

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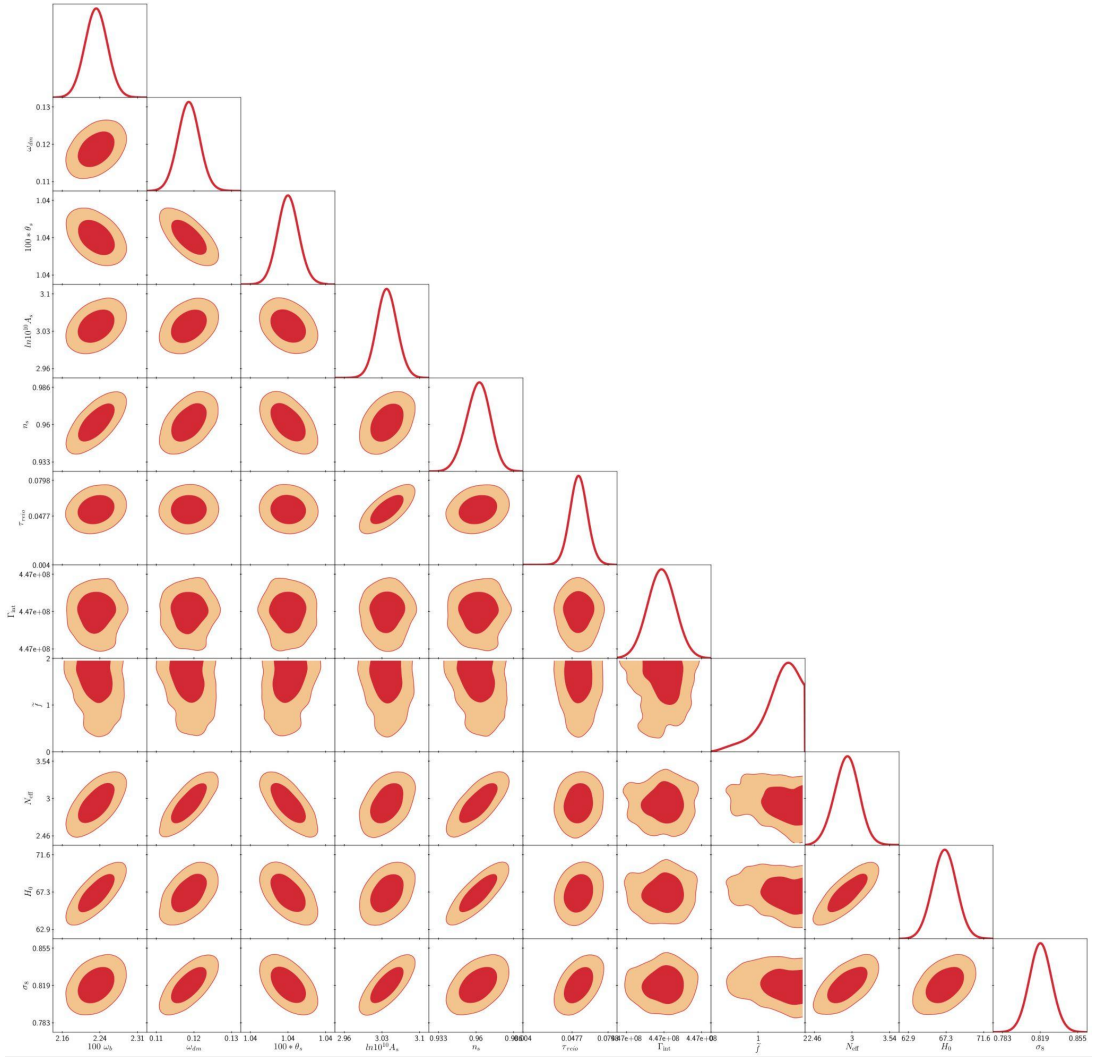
cosmological params

model params

Parameter	Prior
$100\ \omega_b$	Flat, unbounded
$\omega_{\rm dm}$	Flat, unbounded
$100\ \theta_s$	Flat, unbounded
$\ln(10^{10} A_s)$	Flat, unbounded
n_s	Flat, unbounded
τ_{reio}	Flat, unbounded
$\Gamma_{\rm int}$	Flat, $4.47 \times 10^4 \rightarrow 4.47 \times 10^{12}$
$\tilde{f}$	Flat, $0 \rightarrow 2$

$$\sqrt{\frac{M_{\rm DM}/M_{\rm DM}^{(r)}}{M_{\rm SM}^3/M_{\rm SM}^{3(r)}}\ \frac{\langle\sigma v\rangle}{\langle\sigma v\rangle^{(r)}}}$$


$100\,\omega_b$
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$ln(10^{10}A_s)$
n_s
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Γ_{dd}
$\tilde{f}$
N_{eff}
H_0
σ_8