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

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

Advanced 21-cm Cosmology School & Workshop

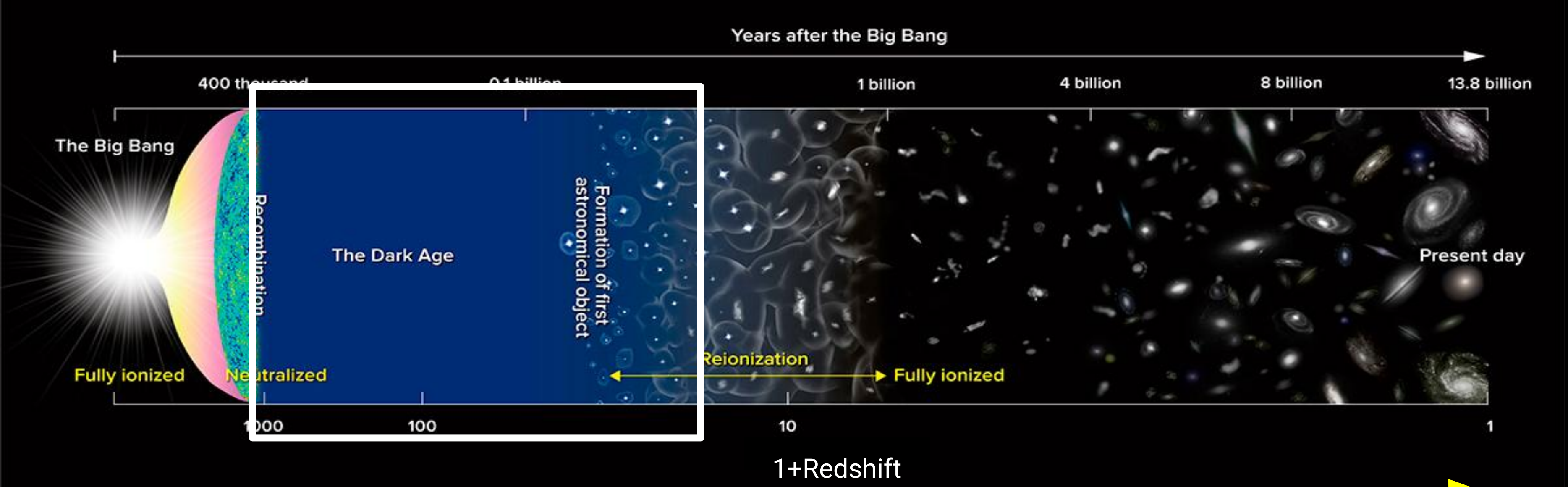
NISER Bhubaneswar

Primary Agenda Topics

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

Why astroparticle physics …

- Particle physics provides behaviour of elementary particles
- Cosmology and astrophysics help to understand the development of the universe
- … can bring more stringent constraints on the properties of the particles



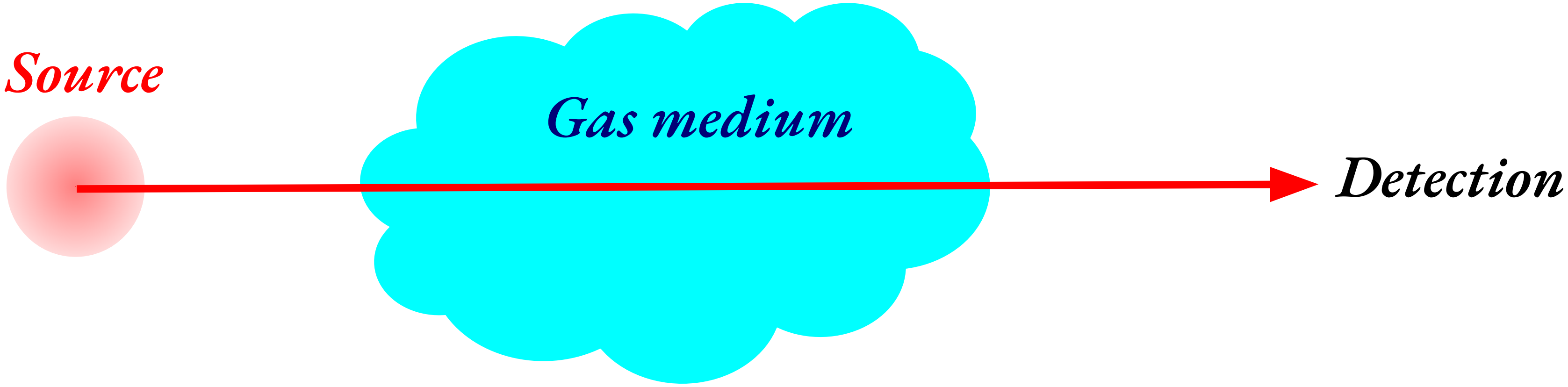
past → *present*

Dark age *no astrophysical objects (z≳50)*

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

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

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

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

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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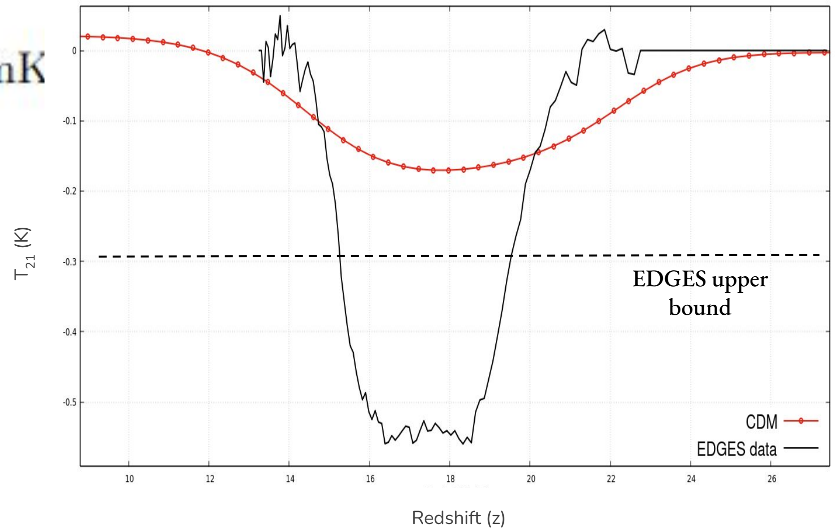

$$\delta T_b = -500^{+200}_{-500} \ mK$$

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/*](http://loco.lab.asu.edu/edges/edges-data-release/)

Signature of Dark Matter on 21-cm Cosmology

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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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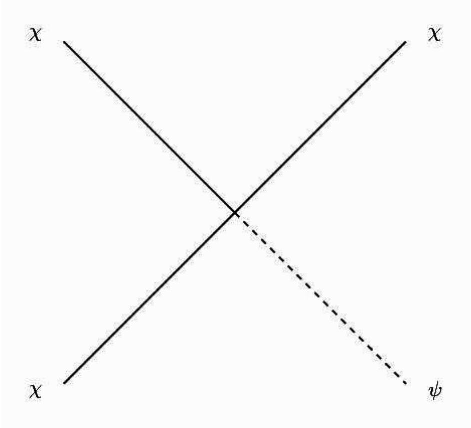
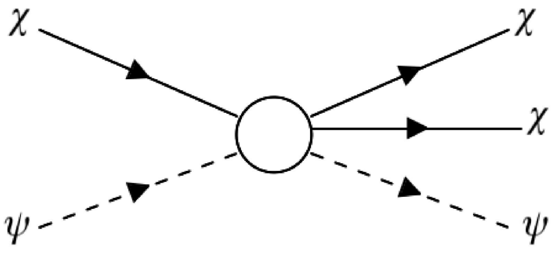
Z3 Symmetric Dark Matter

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

Semi-annihilating Dark Matter



Co-SIMP 2→3 interaction



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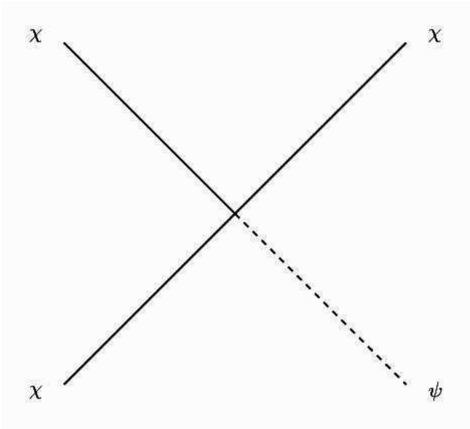

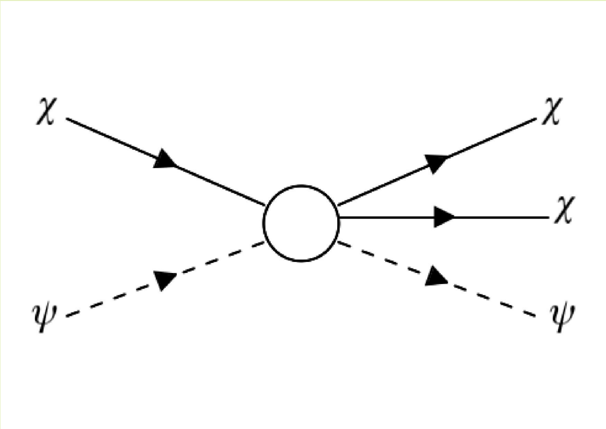

$$\left.\frac{dE}{dV\,dt}\right|_{\rm SADM} = 2f\rho_{\rm DM}^2\frac{\langle\sigma v\rangle_{\rm SADM}}{M_{\rm DM}}$$

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

Always heats the gas

A possibility to cool down the gas

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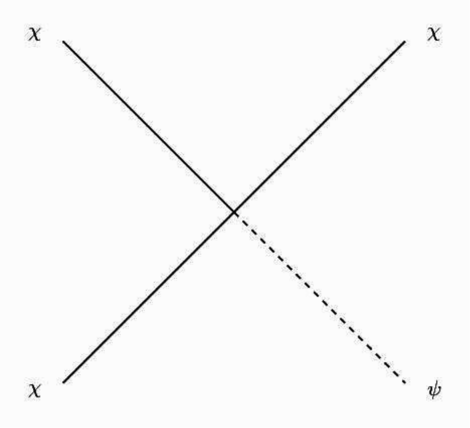
Semi-annihilating Dark Matter



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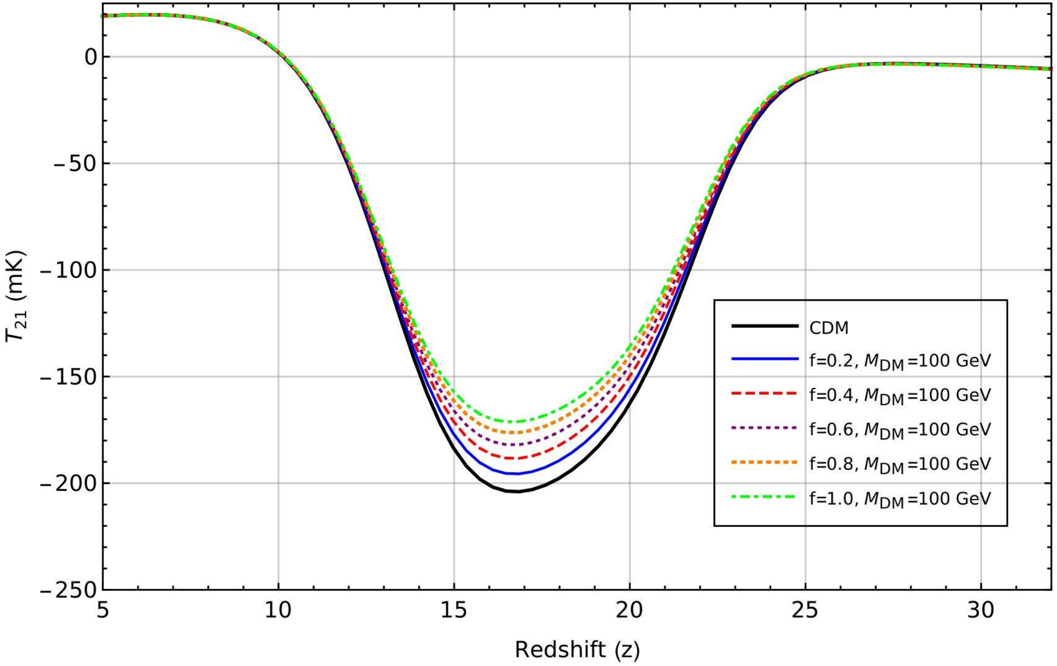

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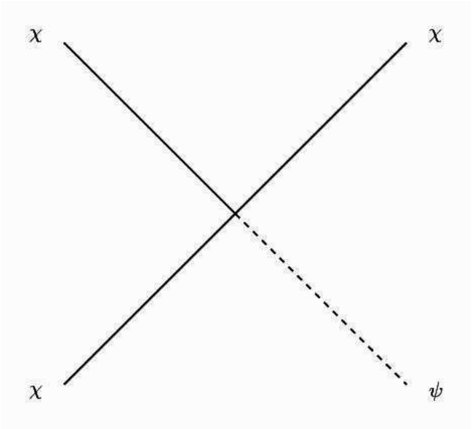
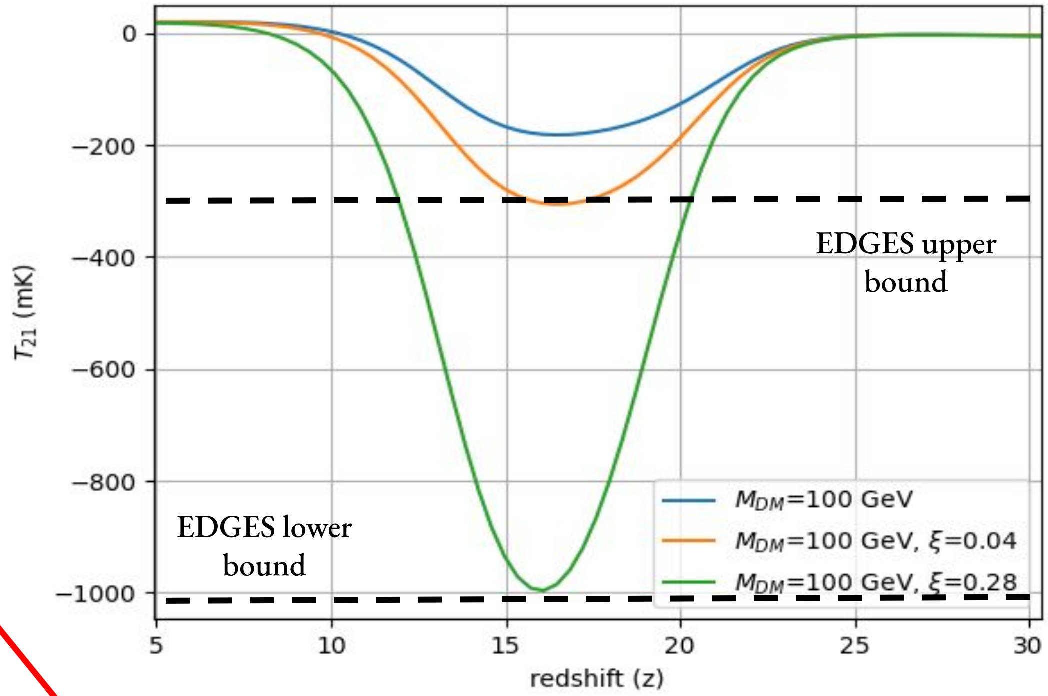


$$T(\nu) = T_{CMB} + \xi T_R \left(\frac{\nu}{\nu_0}\right)^{\beta}$$



Modelling of excess radiation over CMB measured by ARCADE

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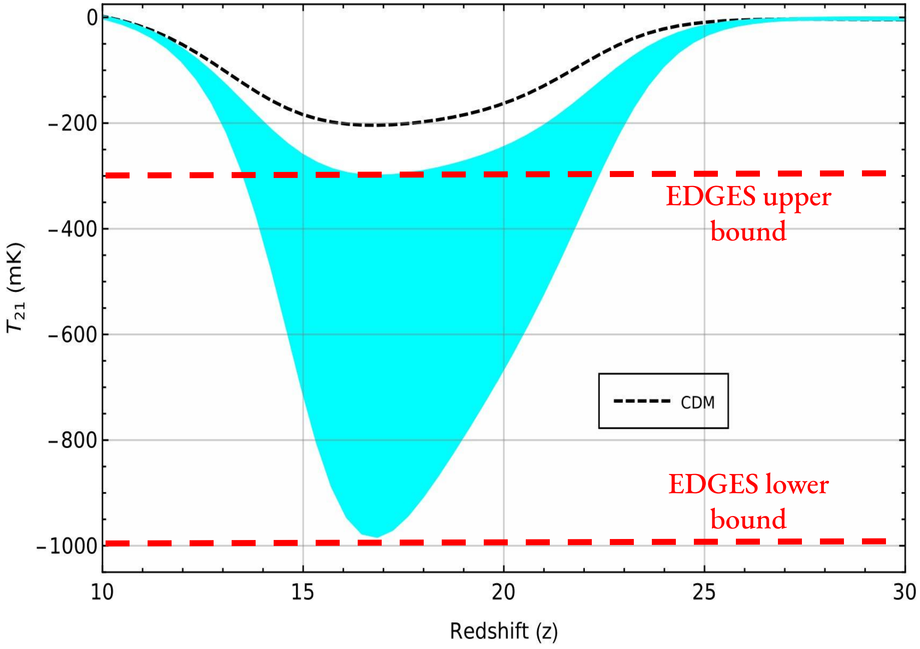
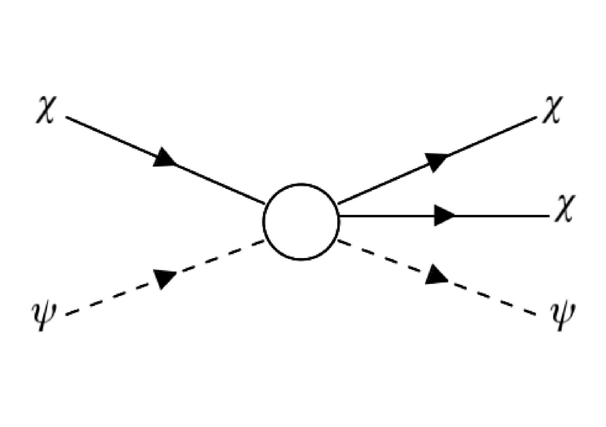
Co-SIMP 2→3 interaction





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

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

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

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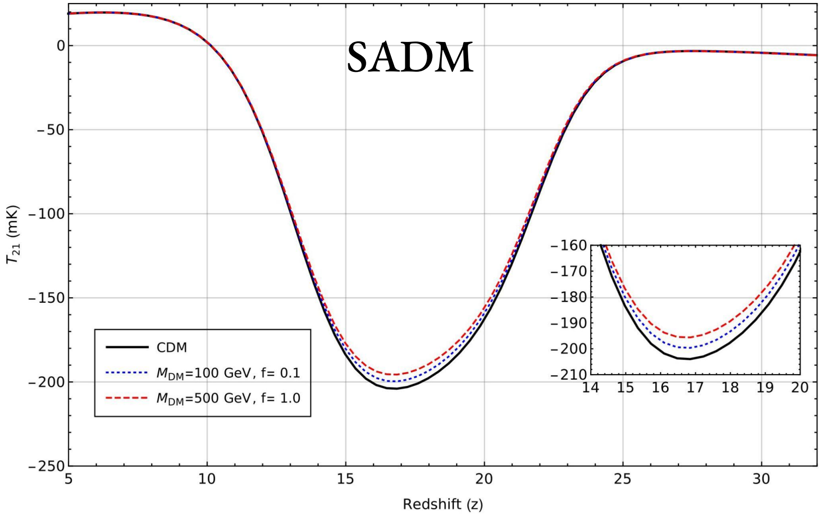
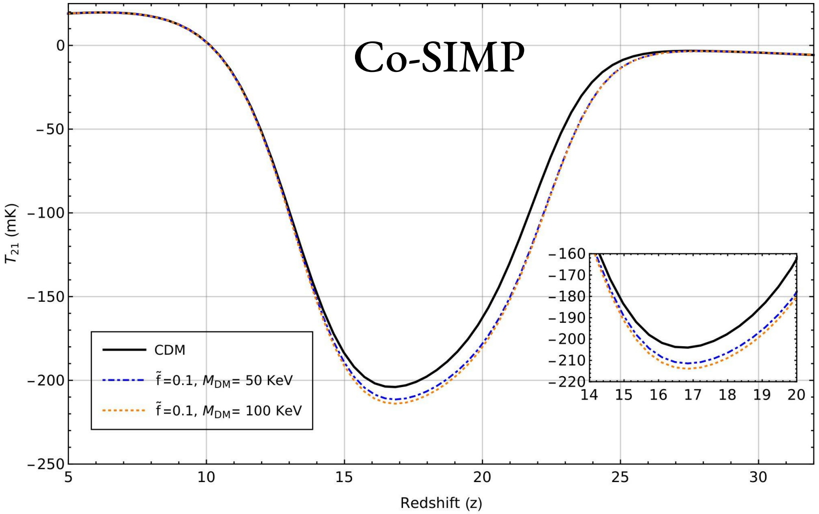
Wait!!... there is a debate

EDGES

SARAS 3





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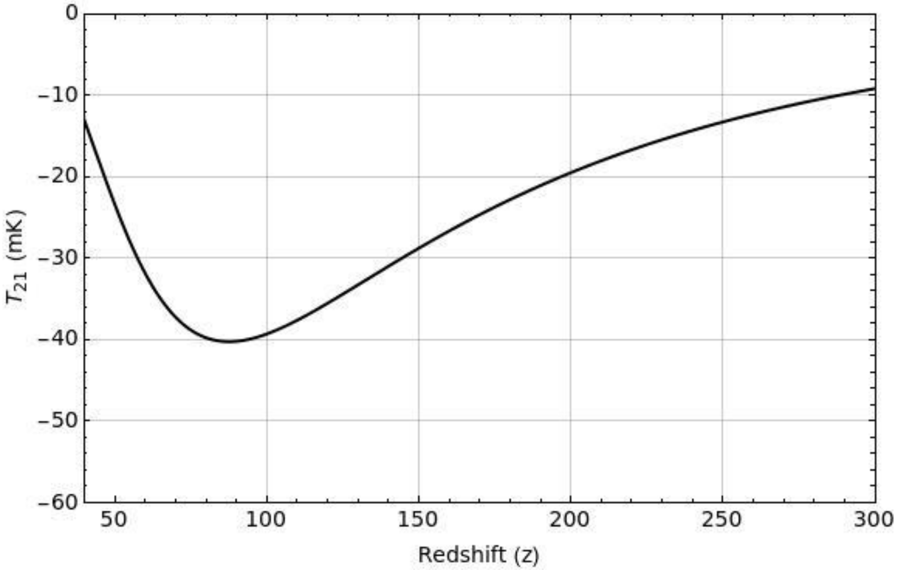
Impacts at dark ages



- *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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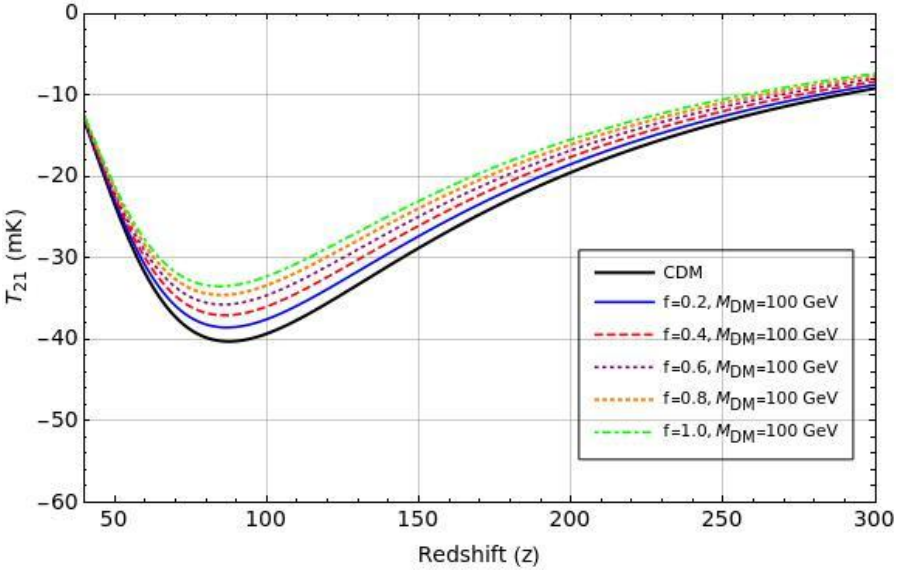
Impacts at dark ages



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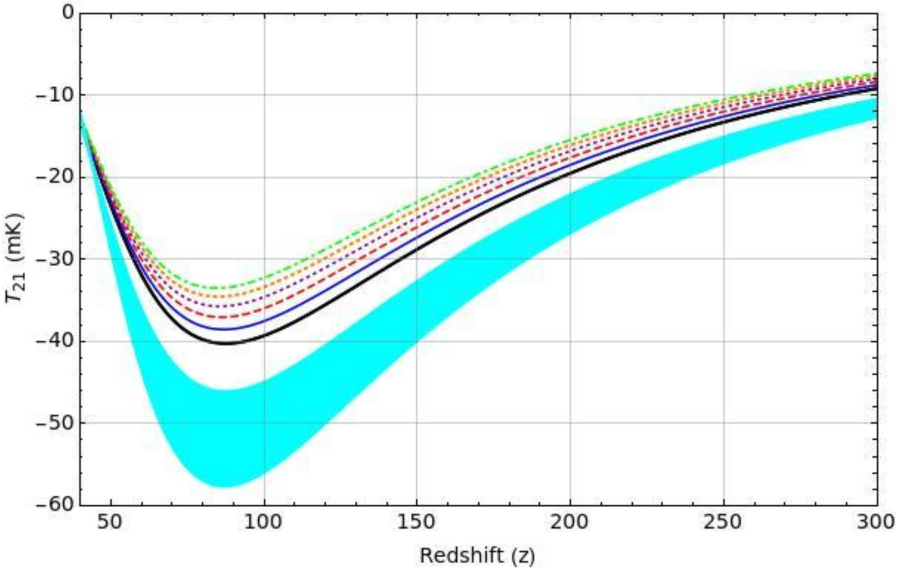

Effects are distinguishable

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$$\underbrace{\omega_b, \omega_{\rm dm}, \theta_s, n_s, A_s, \tau_{\rm reio}}_{\text{cosmological params}}, \underbrace{\Gamma_{\rm int}, \tilde{f}}_{\text{model params}}$$

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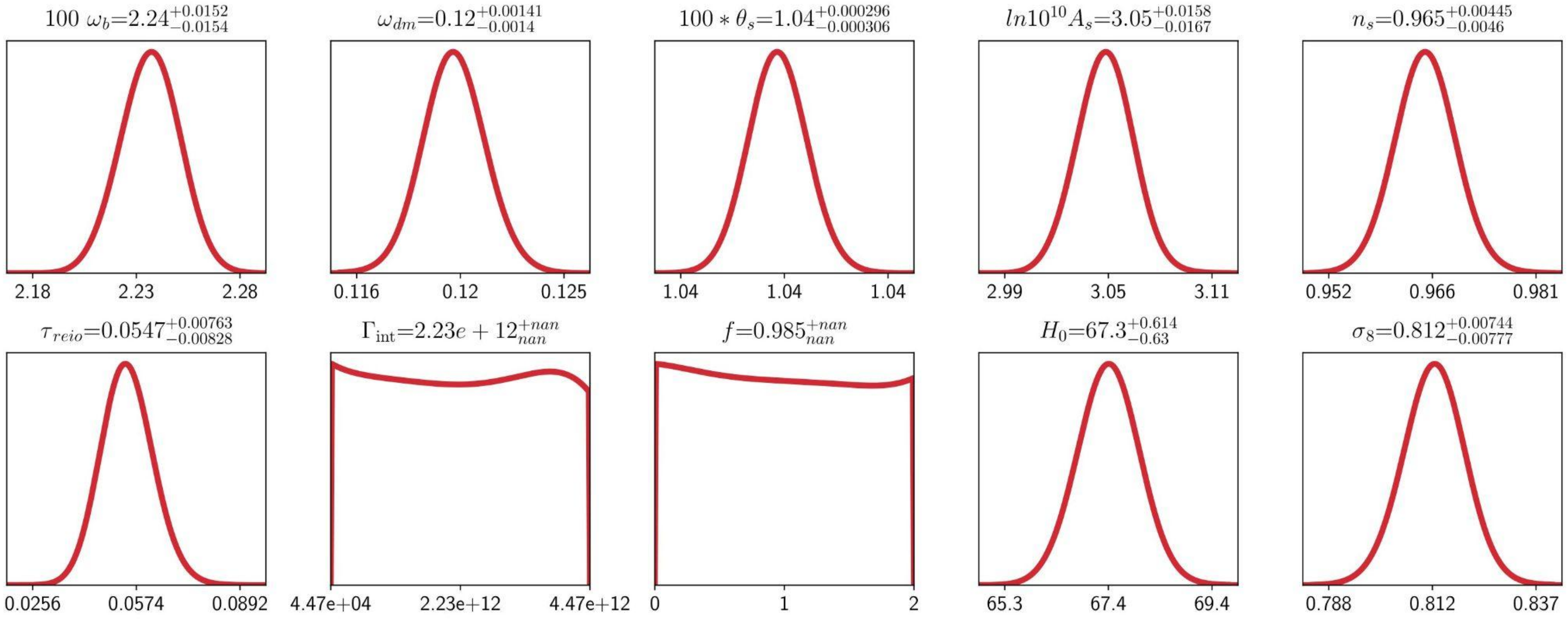
$$\omega_b, \omega_{\rm dm}, \theta_s, n_s, A_s, \tau_{\rm reio}, \Gamma_{\rm int}, \tilde{f}$$

cosmological params ($\omega_b, \omega_{\rm dm}, \theta_s, n_s, A_s, \tau_{\rm reio}$)

model params ($\Gamma_{\rm int}, \tilde{f}$)

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

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



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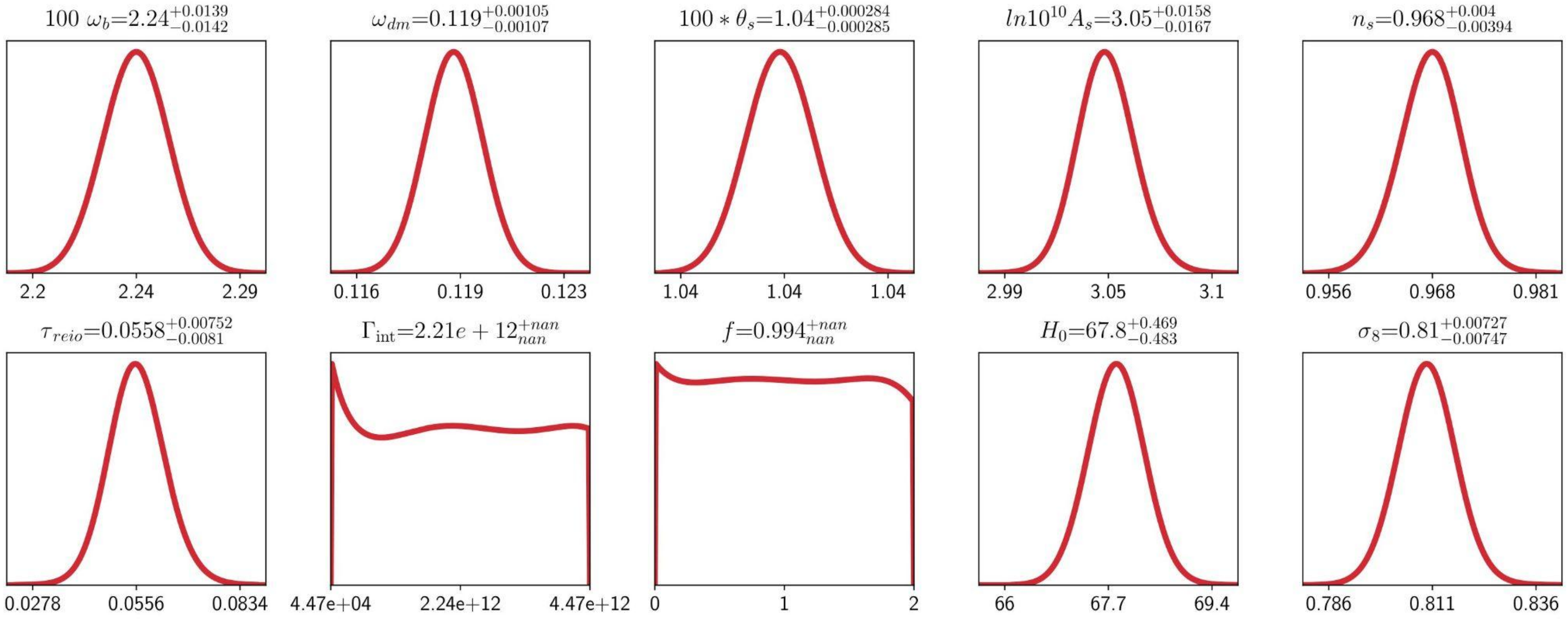
Planck 2018 + BAO



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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 $\pm$ σ	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 $\pm\sigma$	mean $\pm\sigma$	mean$\pm\sigma$
$100\,\omega_b$	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
τ_{reio}	[illegible]	[illegible]	[illegible]	[illegible]
$\Gamma_{\rm int}$	–	–	–	–
$\hat{f}$	–	–	–	–
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 with CMB and BAO data

It retains the success of ΛCDM at large scale

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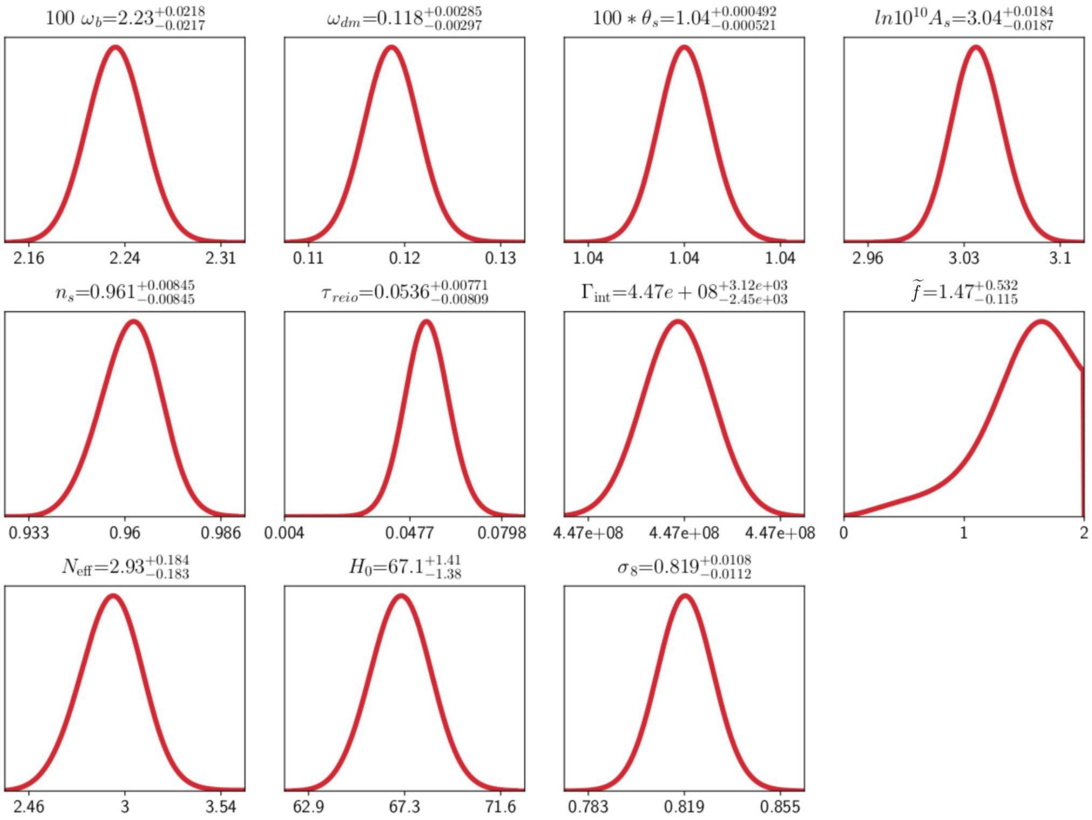
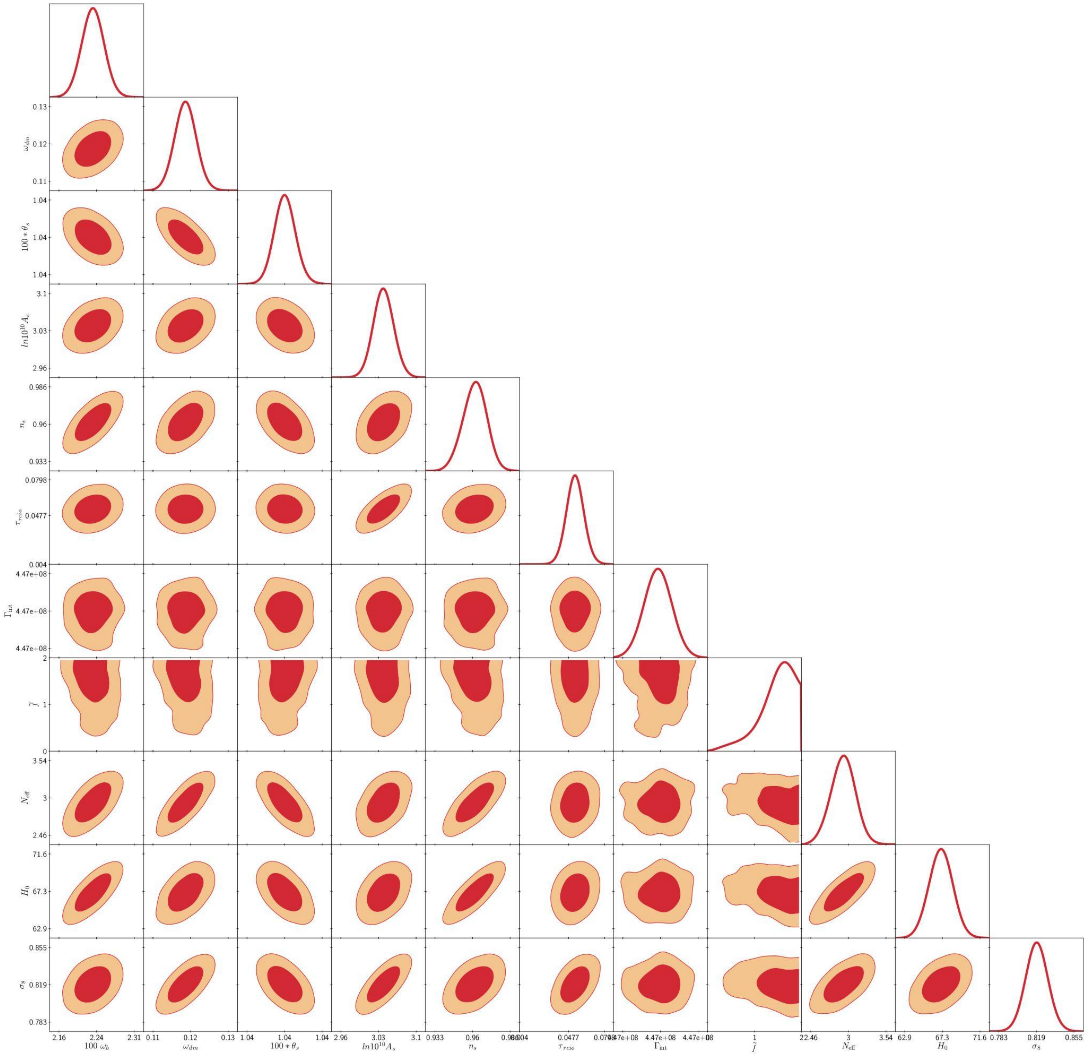
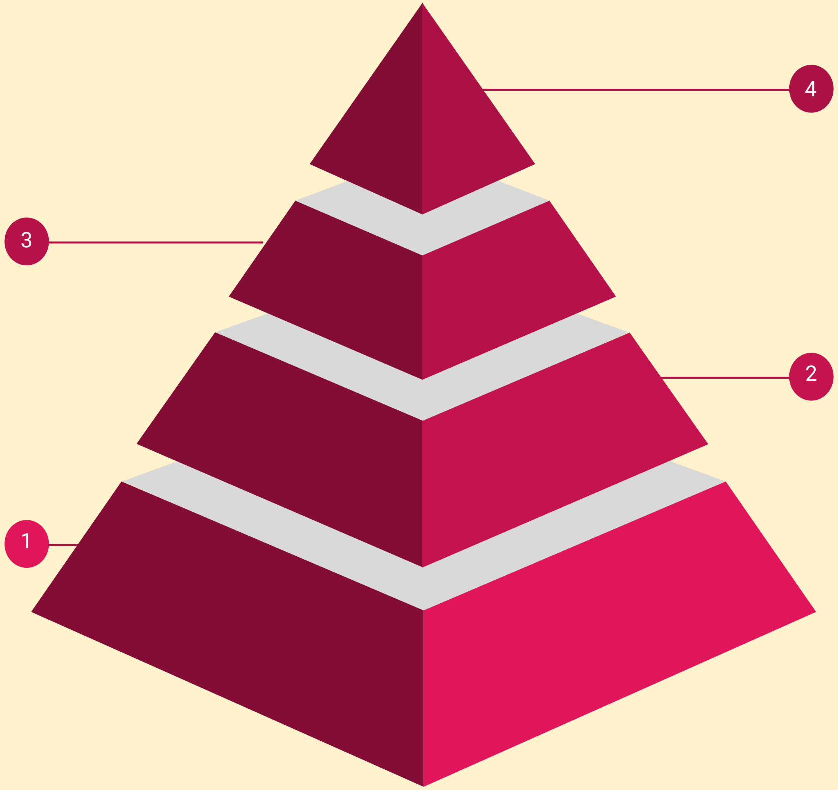
$$\omega_b, \omega_{\rm dm}, \theta_s, n_s, A_s, \tau_{\rm reio}, \Gamma_{\rm int}, \tilde{f} \;+\; N_{\rm eff}$$





ω_{dm}
$100 * \theta_s$
$ln10^{10}A_s$
n_s
τ_{reio}
$\Gamma_{\rm int}$
$\tilde{f}$
$N_{\rm eff}$
H_0
σ_8
$100\ \omega_b$

Summary:



Addressing the EDGES signal

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

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.

Impact at dark age

At the dark age, both the models have distinctive impacts

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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Thank You

Reserved Slides...

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

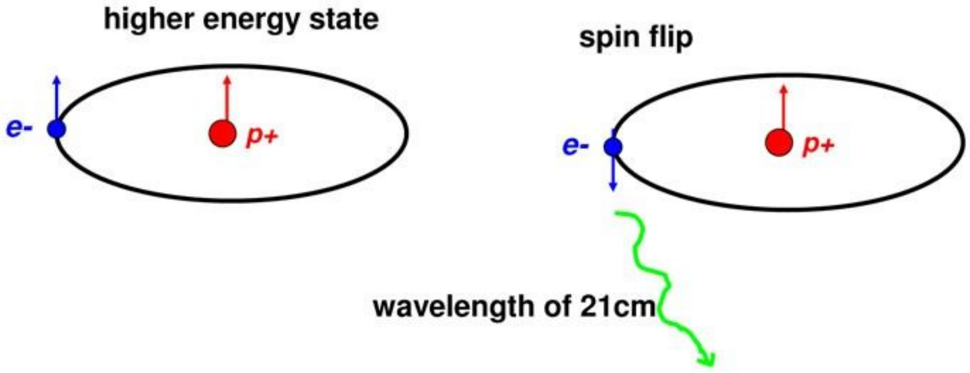

Fig. Credit: blog of Abraham Loeb

Semi-annihilating Dark Matter

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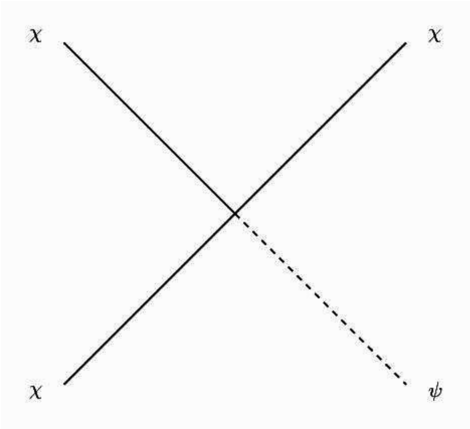

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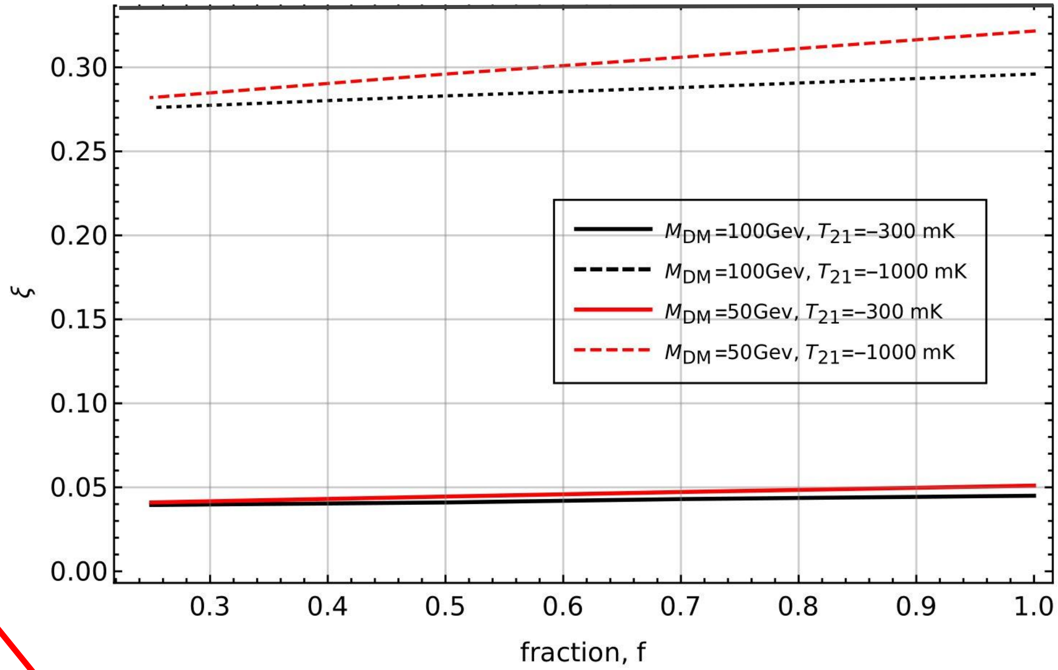

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cosmological params — model params

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, $4.47 \times 10^4 \to 4.47 \times 10^{12}$
$\tilde{f}$	Flat, $0 \to 2$

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