Future 21cm-cosmology probe of decaying DM

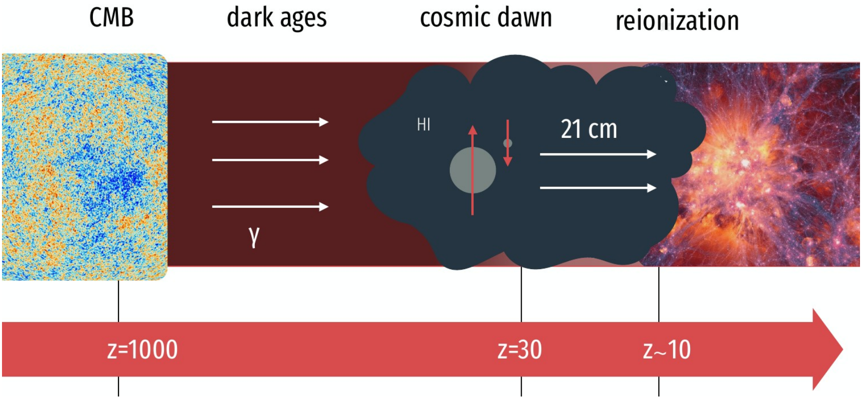
Laura Lopez Honorez

based on 2309.XXXXX with G. Facchinetti, Y. Qin and A. Mesinger

Corfou 2023 - Workshop on the Standard Model and Beyond
28/08-7/09/23

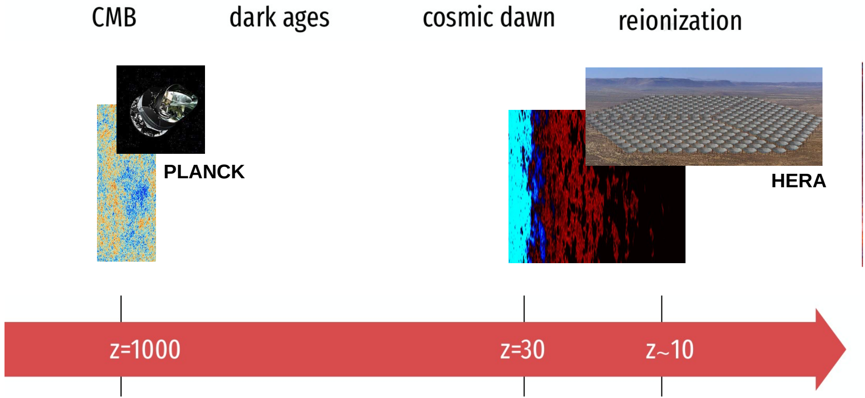
80% of the matter content is made of Dark Matter

Cosmology Probes

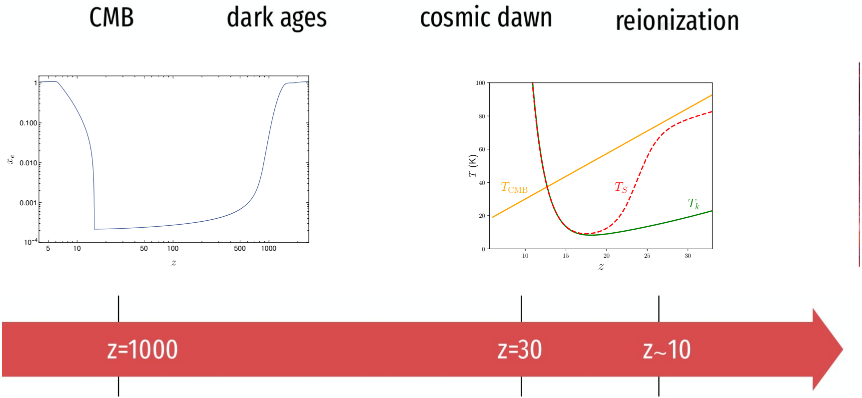


©G. Facchinetti

Cosmology Probes



Cosmology Probes



DM energy injection/deposition in early universe

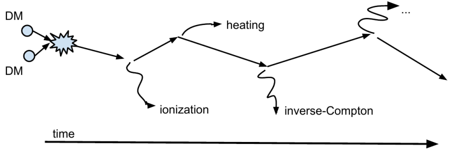
see previous work e.g. [Adams'98,Chen'03, Hansen'03, Pierpaoli'03, Padmanabhan'05, Slatyer'15, Liu'19] for CMB, [Shchekinov'06, Furlanetto'06, Valdes'07, Chuzhoy'07, Cumberbatch'08, Natarajan'09, Yuan'09, Valdes'12, Evoli'14,LLH'16] for 21cm

- DM particles can decay into:
  - f, γ, W, Z, ... injected $\rightsquigarrow e^+, e^-, \gamma$
  - neutrinos $\rightsquigarrow$ suppressed depos. but possible via EW corrections

DM energy injection/deposition in early universe

see previous work e.g. [Adams'98,Chen'03, Hansen'03, Pierpaoli'03, Padmanabhan'05, Slatyer'15, Liu'19] for CMB, [Shchekinov'06, Furlanetto'06, Valdes'07, Chuzhoy'07, Cumberbatch'08, Natarajan'09, Yuan'09, Valdes'12, Evoli'14,LLH'16] for 21cm

- DM particles can decay into:
  - $f, \gamma, W, Z, \ldots$ injected $\rightsquigarrow e^+, e^-, \gamma$
  - neutrinos $\rightsquigarrow$ suppressed depos. but possible via EW corrections
- Effectively DM deposit energy in the early Universe



[image from A. Vincent]

Rate of energy injection/deposition into c = heat, ionization, excitation

$$\left(\frac{dE_c(\mathbf{x},z)}{dtdV}\right)_{\text{deposited}} \equiv f_c(z)\left(\frac{dE(\mathbf{x},z)}{dtdV}\right)_{\text{injected}} \equiv f_c(z) \times \frac{\rho_{DM}}{\tau_{DM}} e^{-t/\tau_{DM}} .$$

$f_c(z)$ = energy deposition efficiency per channel
(can be obtained using `DarkHistory` [Liu '19, Liu'23])

Decaying DM $\equiv$ "Late" energy injection

Late energy inj. for decaying DM (w.r.t. annihilating vanilla WIMP):

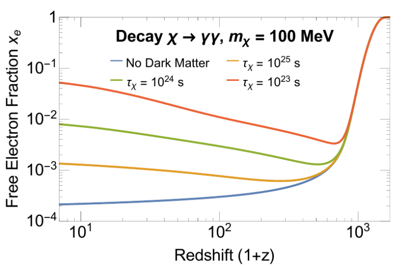
$$\frac{dE_{\rm inj/b}}{dz} \propto \frac{\rho_{\rm DM}}{n_b(1+z)H}\frac{1}{\tau_{\rm DM}}$$

focus on $\tau_{\rm DM} > t_u$

Decaying DM $\equiv$ "Late" energy injection

Late energy inj. for decaying DM (w.r.t. annihilating vanilla WIMP):

$$\frac{dE_{\rm inj/b}}{dz} \propto \frac{\rho_{\rm DM}}{n_b(1+z)H}\frac{1}{\tau_{\rm DM}}$$
$$\propto (1+z)^{-5/2}\frac{1}{\tau_{\rm DM}}$$



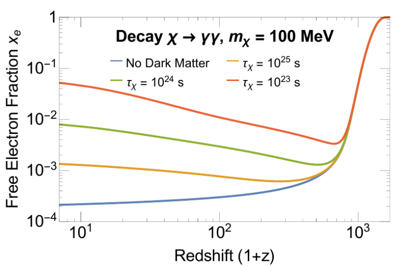
[Liu'16]

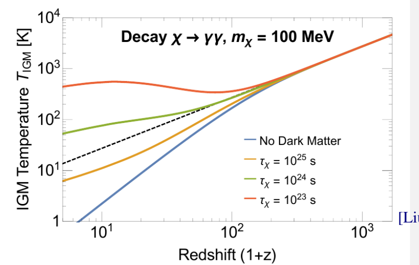
focus on $\tau_{\rm DM} > t_u$

Decaying DM ≡ "Late" energy injection

Late energy inj. for decaying DM (w.r.t. annihilating vanilla WIMP):

$$\frac{dE_{\rm inj/b}}{dz} \propto \frac{\rho_{\rm DM}}{n_b(1+z)H}\frac{1}{\tau_{\rm DM}}$$
$$\propto (1+z)^{-5/2}\frac{1}{\tau_{\rm DM}}$$

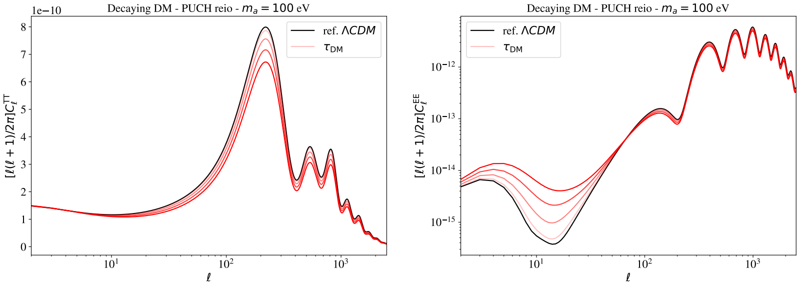




[Liu'16]

focus on $\tau_{\rm DM} > t_u$

DM Decay imprint on CMB anisotropy spectra

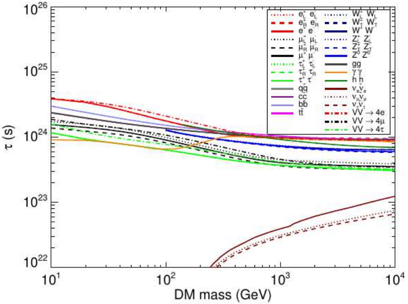


- increased residual ionization after recombination (steadily growing with time)
- increased the optical depth to reionization $\tau_{\rm reio} = \int dt\, x_e n_b \sigma_T$
- attenuates correlations at small scales (large ℓ) and enhances low-ℓ polarisation power.

The low-ℓ data are important to discriminate energy injection from other cosmo params such as n_s, A_s affecting the amplitude of the CMB peaks.

Existing CMB constraints on DM decay

see also [LLH'13, Liu'16, Slatyer'16,Capozzi'23,...]



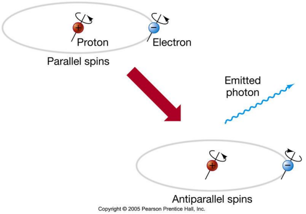
$\rightsquigarrow$ $\tau_{\rm DM} \gtrsim$ few $\times\, 10^{24-26}$ s at 95% CL [Slatyer'16,Capozzi'23]

CMB bounds are usually weaker than indirect DM searches
probing up to $\tau \sim 10^{27-30}$s
except for MeV-GeV DM decaying to e^+e^- and <MeV DM decaying to $\gamma\gamma$.

21cm Cosmology : near future late time probe

Cosmic Dawn and 21 cm signal

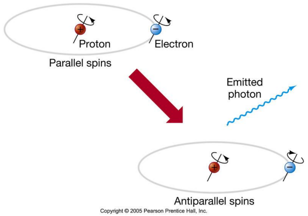
The Cosmic Dawn $\equiv$ period where first galaxies started to shine up until reionization (EoR). The most powerful probe is 21 cm spin flip line of HI :



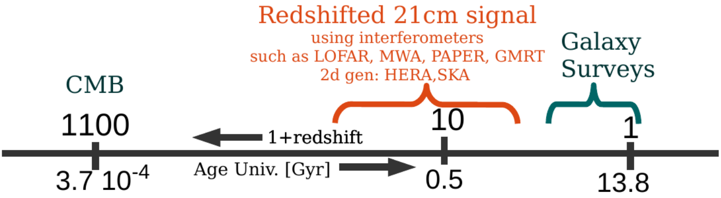
- Transitions between the two ground state energy levels of neutral hydrogen HI $\rightsquigarrow$ 21 cm photon ($\nu_0 = 1420$ MHz)

Cosmic Dawn and 21 cm signal

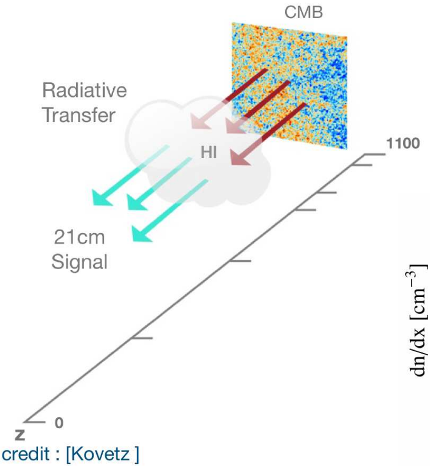
The Cosmic Dawn ≡ period where first galaxies started to shine up until reionization (EoR). The most powerful probe is 21 cm spin flip line of HI :



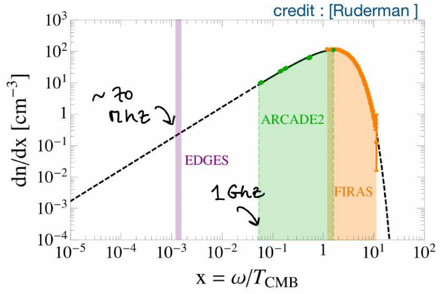
- Transitions between the two ground state energy levels of neutral hydrogen HI $\rightsquigarrow$ 21 cm photon ($\nu_0 = 1420$ MHz)
- 21 cm photon from HI clouds during Cosmic Dawn & EoR redshifted to $\nu \sim 100$ MHz $\rightsquigarrow$ new cosmology probe



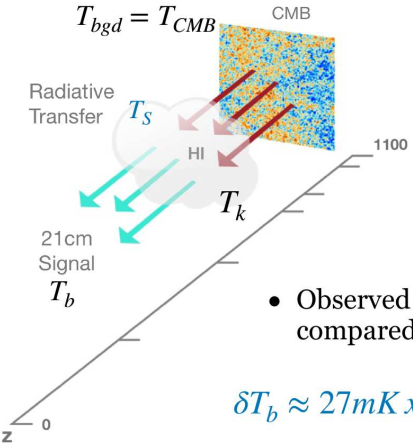
21 cm in practice



- 21cm signal observed as CMB spectral distortions



21 cm in practice



credit : [Kovetz]

- 21cm signal observed as CMB spectral distortions
- The spin temperature (= excitation T of HI) charaterises the relative occupancy of HI gnd state

$$n_1/n_0 = 3\exp(-h\nu_0/k_B T_S)$$

- Observed brightness of a patch of HI compared to CMB at $\nu = \nu_0/(1+z)$

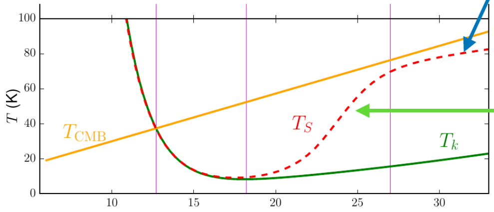
$$\delta T_b \approx 27 mK\, x_{HI}(1+\delta)\sqrt{\frac{1+z}{10}}\left(1 - \frac{T_{CMB}}{T_S}\right)$$

The spin temperature

$$T_S^{-1} = \frac{T_{CMB}^{-1} + x_c T_k^{-1} + x_\alpha T_c^{-1}}{1 + x_c + x_\alpha}$$

Emmission/ absorption of CMB photons

$T_S \rightarrow T_{CMB}$



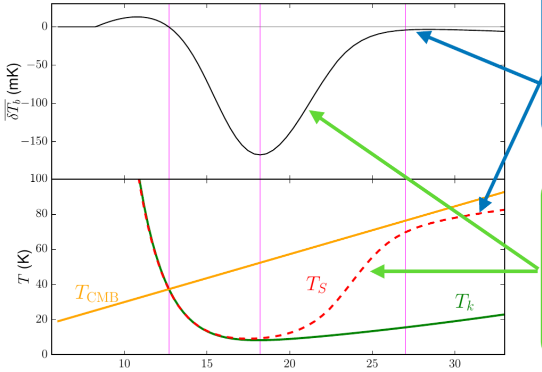
- Collisions with H, e
- Scattering of Ly-α photons (Wouthuysen-Field effect)

$T_S \rightarrow T_k$

$T(K)$ and δT_b obtained using `21cm Fast` [Mesinger'10]

The spin temperature

$$T_S^{-1} = \frac{T_{CMB}^{-1} + x_c T_k^{-1} + x_\alpha T_c^{-1}}{1 + x_c + x_\alpha}$$

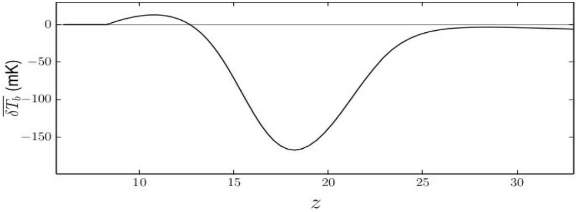


- Emmission/ absorption of CMB photons
  $T_S \rightarrow T_{CMB}$

- Collisions with H, e
- Scattering of Ly-α photons (Wouthuysen-Field effect)
  $T_S \rightarrow T_k$

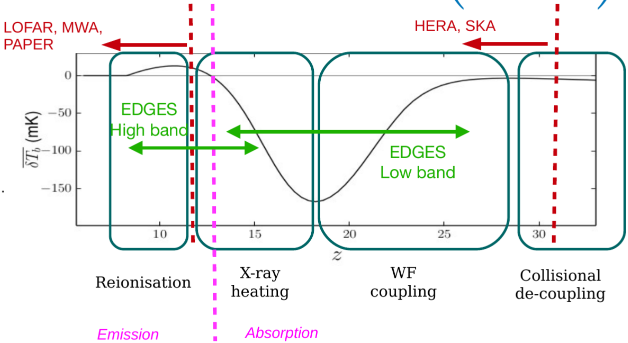
$T(K)$ and δT_b obtained using `21cm Fast` [Mesinger'10]

$$\delta T_b \approx 27mK\, x_{HI}(1+\delta)\sqrt{\frac{1+z}{10}}\left(1-\frac{T_{CMB}}{T_S}\right)$$



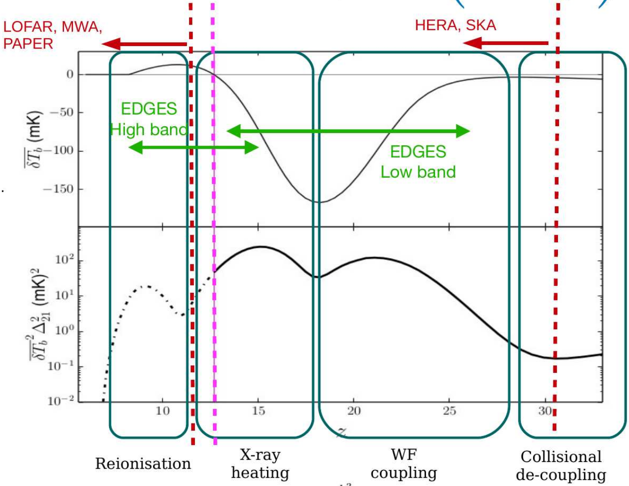
δT_b and Δ_{21} obtained using `21cm Fast` [Mesinger'10]

$$\delta T_b \approx 27mK\, x_{HI}(1+\delta)\sqrt{\frac{1+z}{10}}\left(1-\frac{T_{CMB}}{T_S}\right)$$



δT_b and Δ_{21} obtained using `21cm Fast` [Mesinger'10]

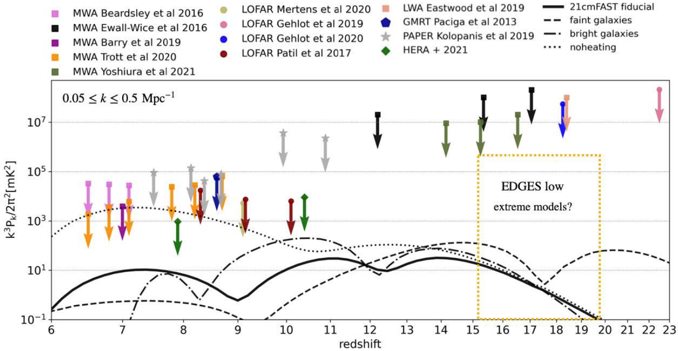
$$\delta T_b \approx 27mK\, x_{HI}(1+\delta)\sqrt{\frac{1+z}{10}}\left(1-\frac{T_{CMB}}{T_S}\right)$$



$\langle \widetilde{\delta}_{21}(\mathbf{k},z)\widetilde{\delta}^*_{21}(\mathbf{k}',z)\rangle \equiv (2\pi)^3\delta^D(\mathbf{k}-\mathbf{k}')P_{21}(k,z)$ $\qquad \Delta^2_{21}(k,z) = \frac{k^3}{2\pi^2}P_{21}(k,z)$

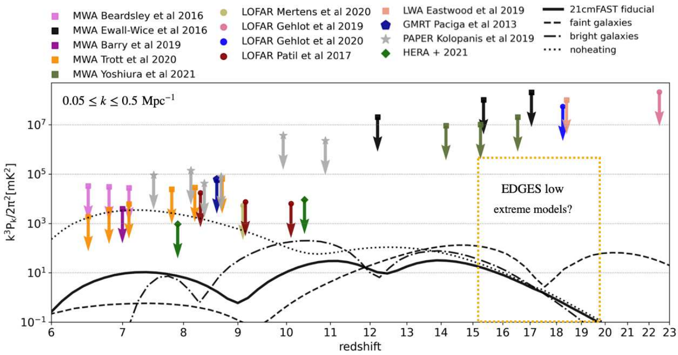
δT_b and Δ_{21} obtained using `21cm Fast` [Mesinger'10]

Constraints on 21cm Power spectrum?



[Shimabukuro'23]

Constraints on 21cm Power spectrum?



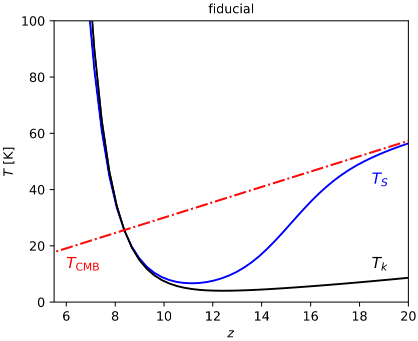
[Shimabukuro'23]

- We will consider HERA interferometer in South Africa with 331 antenas (14m dishes) under deployment (=SKA precursor).
- First data from HERA phase I probed $z \sim 8 - 10$ with only ~ 70 ant. already set a lower bound on X-ray heating [HERA'21& 22]. Actually the full set of 331 antennas is already build and soon taking data.

Decaying DM and 21cm power spectrum

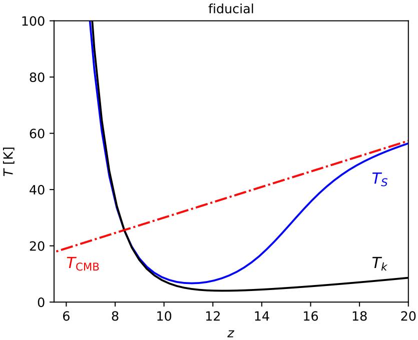
2309.XXXXX with G. Facchinetti, Y. Qin and A. Mesinger

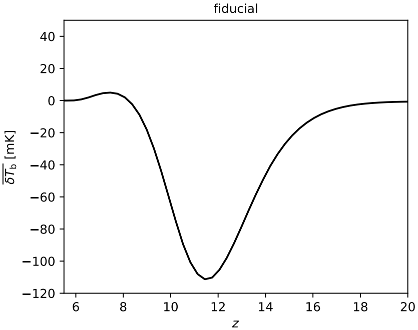
Impact of decaying DM on T_k and δT_b



plots made using exo21cmFast developped by G. Facchinetti merging 21cmFast and DarkHistory

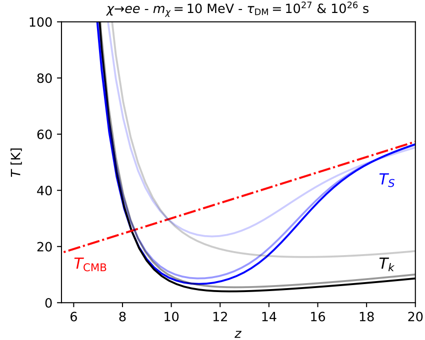
Impact of decaying DM on T_k and δT_b

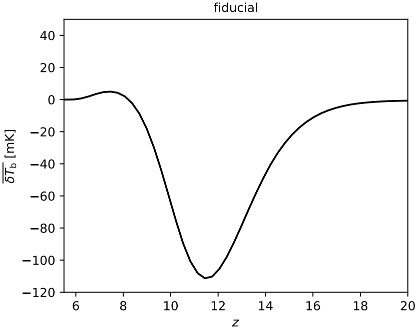




plots made using exo21cmFast developped by G. Facchinetti merging 21cmFast and DarkHistory

Impact of decaying DM on T_k and δT_b



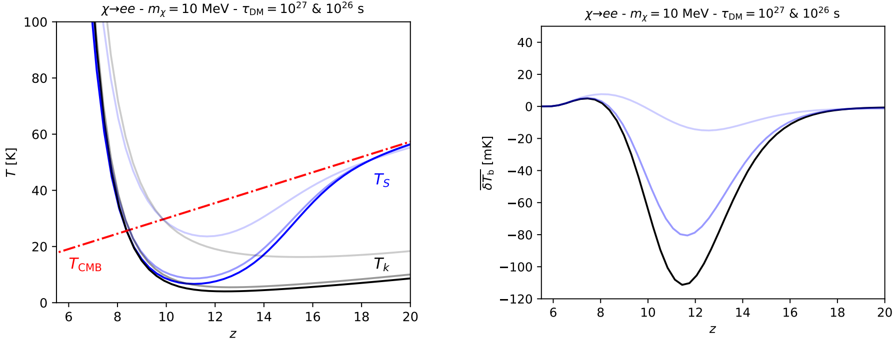


DM energy injection implies

- new source of heating, earlier than X-rays from stars

plots made using exo21cmFast developped by G. Facchinetti merging 21cmFast and DarkHistory

Impact of decaying DM on T_k and δT_b

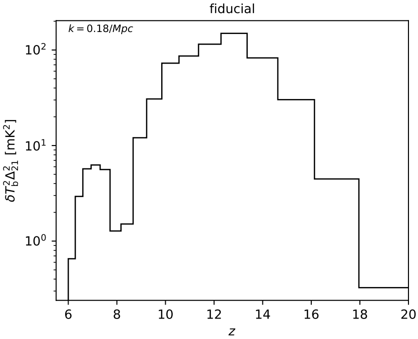


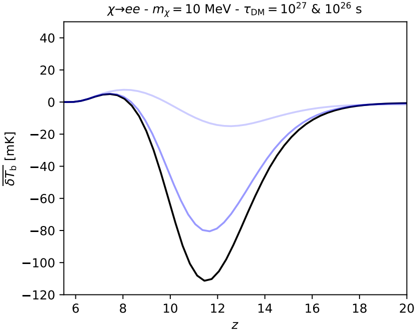
DM energy injection implies

- new source of heating, earlier than X-rays from stars
- suppressed absorption in $\delta T_{\rm b}$

plots made using exo21cmFast developped by G. Facchinetti merging 21cmFast and DarkHistory

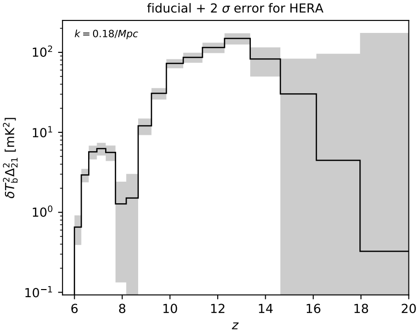
Impact of decaying DM on δT_b and Δ_{21}

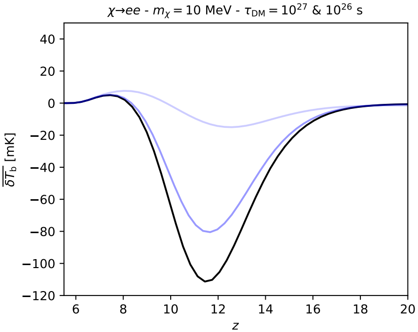




plots made using exo21cmFast developped by G. Facchinetti merging 21cmFast and DarkHistory.
$k = 0.18$/Mpc is relatively free from foregrounds.

Impact of decaying DM on δT_b and Δ_{21}

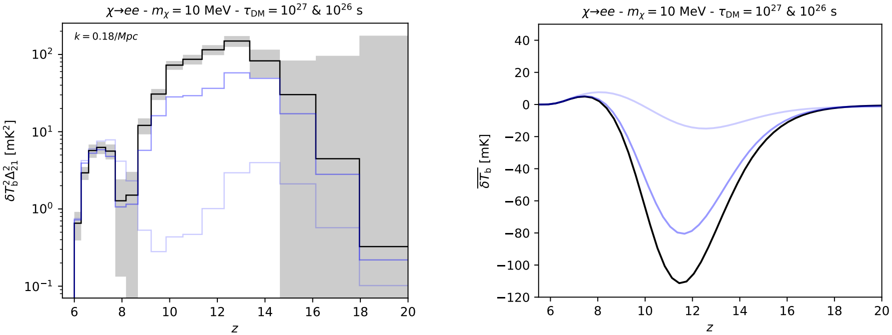




- 2 σ error bands from 21cmSense for HERA.

plots made using exo21cmFast developped by G. Facchinetti merging 21cmFast and DarkHistory.
$k = 0.18$/Mpc is relatively free from foregrounds.

Impact of decaying DM on δT_b and Δ_{21}

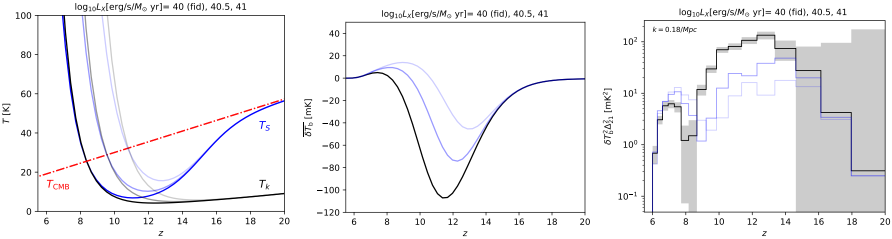


- 2 σ error bands from 21cmSense for HERA.
- DM decays give suppressed power around X-ray heating - Lyman-α coupling time
- Lifetimes as large as $\tau_{DM} = 10^{27}$ s shall leave a measurable imprint

plots made using exo21cmFast developped by G. Facchinetti merging 21cmFast and DarkHistory.
$k = 0.18$/Mpc is relatively free from foregrounds.

Degeneracies with astro parameters

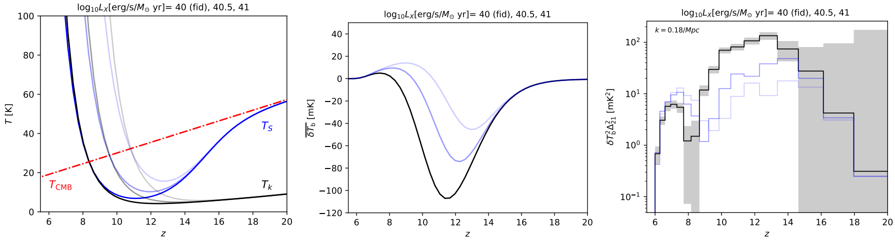
For example, X-ray heating from stars parametrized with a normalisation of soft-band X-ray luminosity per unit SFR: $L_X \sim 10^{40}$ [erg/s/$M_\odot$ yr].



plots with exo21cmFast developped by G. Facchinetti merging 21cmFast and DarkHistory

Degeneracies with astro parameters

For example, X-ray heating from stars parametrized with a normalisation of soft-band X-ray luminosity per unit SFR: $L_X \sim 10^{40}$ [erg/s/$M_\odot$ yr].

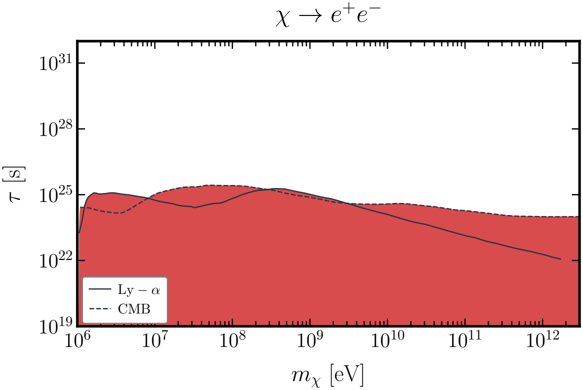


- Increasing L_X also gives rise to a suppression of the PS at large z
- X-rays from stars drive a 21cm signal saturated earlier $\rightsquigarrow$ stronger contrast at low z.

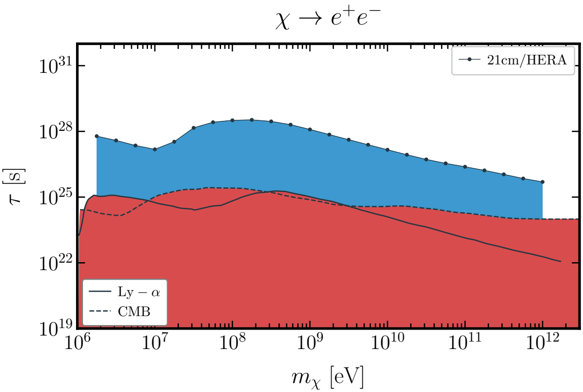
It is possible to disentangle L_X effect from τ_{DM}

plots with exo21cmFast developped by G. Facchinetti merging 21cmFast and DarkHistory

Forecasts of 21cm bounds on $\chi \to ee, \gamma\gamma$



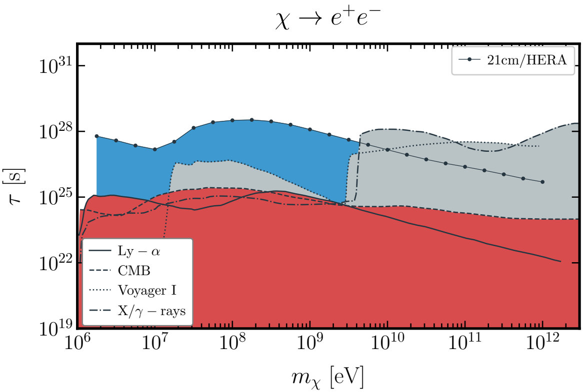
Forecasts of 21cm bounds on $\chi \to ee, \gamma\gamma$



- (optimistic) Fisher Matrix forecasts for HERA 331 antennas and $t_{obs} = 1000$ h
- $\tau_{\rm DM} \gtrsim 10^{27-28}$s

- Future redhifted 21cm signal power-spectrum measurements can surpass current CMB and/or Lyman-α sensitivity by 2-3 orders of magnitude.

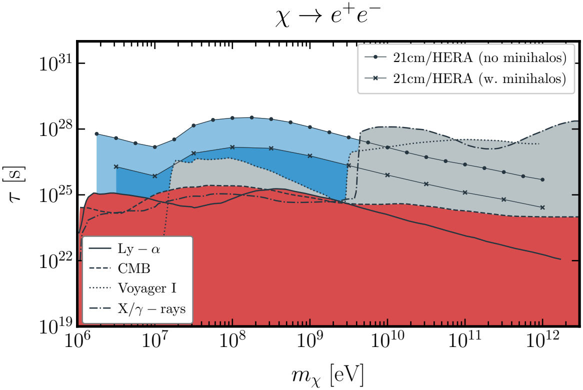
Forecasts of 21cm bounds on $\chi \to ee, \gamma\gamma$



- (optimistic) Fisher Matrix forecasts for HERA 331 antennas and $t_{obs} = 1000$ h
- $\tau_{\rm DM} \gtrsim 10^{27-28}$s

- Future redhifted 21cm signal power-spectrum measurements can surpass current CMB and/or Lyman-α sensitivity by 2-3 orders of magnitude.
- Can put more stringent bounds than indirect DM searches bounds...

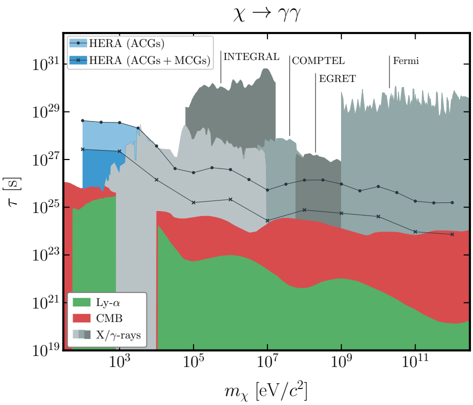
Forecasts of 21cm bounds on $\chi \to ee, \gamma\gamma$



- (optimistic) Fisher Matrix forecasts for HERA 331 antennas and $t_{obs} = 1000$ h
- $\tau_{\rm DM} \gtrsim 10^{27-28}$s

- Future redhifted 21cm signal power-spectrum measurements can surpass current CMB and/or Lyman-α sensitivity by 2-3 orders of magnitude.
- Can put more stringent bounds than indirect DM searches bounds...
- ...even when considering an early second population of stars (POPIII)

Forecasts of 21cm bounds on $\chi \to ee, \gamma\gamma$



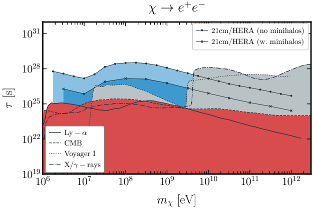
- (optimistic) Fisher Matrix forecasts for HERA 331 antennas and $t_{obs} = 1000$ h
- $\tau_{\rm DM} \gtrsim 10^{27-28}$s

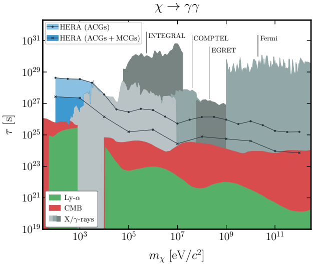
- Future redhifted 21cm signal power-spectrum measurements can surpass current CMB and/or Lyman-α sensitivity by 2-3 orders of magnitude.
- Can put more stringent bounds than indirect DM searches bounds...
- ...even when considering an early second population of stars (POPIII)

Conclusions

Dark matter energy injection through decays imply rather late time (later than WIMP) enhancement of ionization and IGM temperature.
Low z data such as 21cm power spectrum measurements might become a key probe for decaying DM

- We forecast HERA sensitivity with 331 antennas under deployment in South Africa and taking data.
- Expected to surpass CMB/ Lyman-α sensitivity and reach $\tau_{DM} > 10^{27-28}$ s.
- DM annihilation is the next step, checking the impact of the $B(z)$.





Thank you for your attention!!

Backup

DM energy injection/deposition in early universe

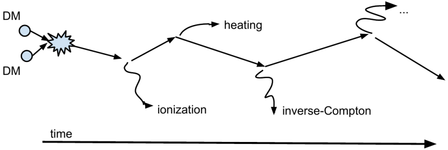
see previous work e.g. [Adams'98,Chen'03, Hansen'03, Pierpaoli'03, Padmanabhan'05, Slatyer'15, Liu'19] for CMB, [Shchekinov'06, Furlanetto'06, Valdes'07, Chuzhoy'07, Cumberbatch'08, Natarajan'09, Yuan'09, Valdes'12, Evoli'14,LLH'16] for 21cm

- DM particles can annihilate/decay into:
  - f, γ, W, Z, ... injected $\rightsquigarrow e^+, e^-, \gamma$
  - neutrinos $\rightsquigarrow$ suppressed depos. but possible via EW corrections

DM energy injection/deposition in early universe

see previous work e.g. [Adams'98,Chen'03, Hansen'03, Pierpaoli'03, Padmanabhan'05, Slatyer'15, Liu'19] for CMB, [Shchekinov'06, Furlanetto'06, Valdes'07, Chuzhoy'07, Cumberbatch'08, Natarajan'09, Yuan'09, Valdes'12, Evoli'14,LLH'16] for 21cm

- DM particles can annihilate/decay into:
  - f, γ, W, Z, ... injected $\rightsquigarrow e^+, e^-, \gamma$
  - neutrinos $\rightsquigarrow$ suppressed depos. but possible via EW corrections
- Effectively DM deposit energy in the early Universe



[image from A. Vincent]

Rate of energy injection/deposition into c = heat, ionization, excitation

$$\left(\frac{dE_c(\mathbf{x},z)}{dtdV}\right)_{\text{deposited}} \equiv f_c(z) \left(\frac{dE(\mathbf{x},z)}{dtdV}\right)_{\text{injected}} \equiv f_c(z) \times \begin{cases} \rho_{DM}^2 \langle\sigma v\rangle / m_{\text{DM}} & \text{annihil} \\ \rho_{DM}/\tau_{DM} e^{-t/\tau_{DM}} & \text{decay} \end{cases}$$

$f_c(z)$ = energy deposition efficiency per channel
(can be obtained using `DarkHistory` [Liu '19, Liu'23])

Decaying DM = Later energy injection

Early energy inj. for s-wave ann. DM:

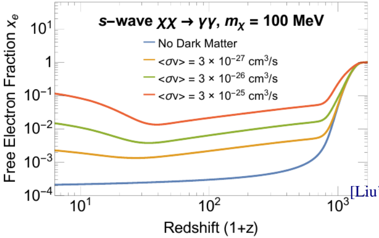
$$\frac{dE_{\rm inj/b}}{dz} \propto \frac{\rho_{\rm DM}^2}{n_b(1+z)H}\frac{\sigma v_0}{m_{\rm DM}}$$

$$\propto (1+z)^{1/2}\frac{\sigma v_0}{m_{\rm DM}}$$

Decaying DM = Later energy injection

Early energy inj. for s-wave ann. DM:

$$\frac{dE_{\rm inj/b}}{dz} \propto \frac{\rho_{\rm DM}^2}{n_b(1+z)H}\frac{\sigma v_0}{m_{\rm DM}}$$
$$\propto (1+B(z))(1+z)^{1/2}\frac{\sigma v_0}{m_{\rm DM}}$$



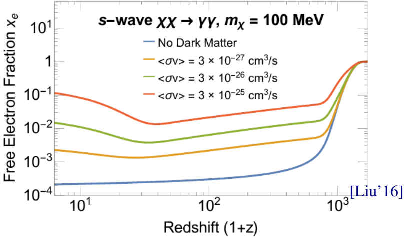
[Liu'16]

+ later Boost $\sim B(z)$ of $\bar{\rho}_\chi^2$ from structure formation see e.g. [LLH'13, Liu'16, etc]

Decaying DM = Later energy injection

Early energy inj. for s-wave ann. DM:

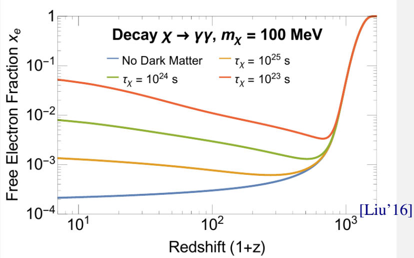
$$\frac{dE_{\rm inj/b}}{dz} \propto \frac{\rho_{\rm DM}^2}{n_b(1+z)H}\frac{\sigma v_0}{m_{\rm DM}}$$
$$\propto (1+B(z))(1+z)^{1/2}\frac{\sigma v_0}{m_{\rm DM}}$$



+ later Boost $\sim B(z)$ of $\bar{\rho}_\chi^2$ from structure formation see e.g. [LLH'13, Liu'16, etc]

Late energy inj. for decaying DM:

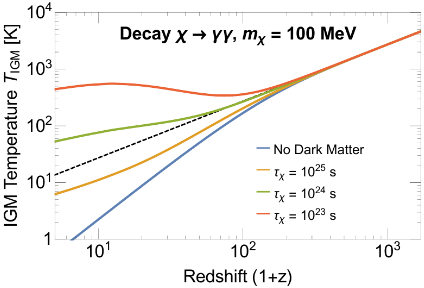
$$\frac{dE_{\rm inj/b}}{dz} \propto \frac{\rho_{\rm DM}}{n_b(1+z)H}\frac{1}{\tau_{\rm DM}}$$
$$\propto (1+z)^{-5/2}\frac{1}{\tau_{\rm DM}}$$



focus on $\tau_{\rm DM} > t_u$

DM energy injection implies earlier heating

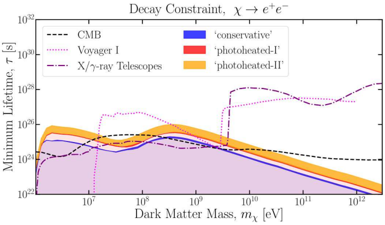
DM decays heats the IGM before astro sources light-on.

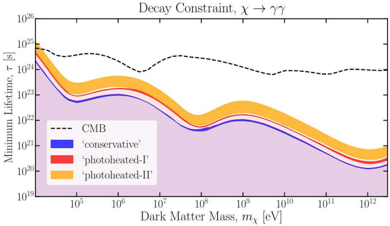


[Liu'16]

DM energy injection implies earlier heating

DM decays heats the IGM before astro sources light-on.





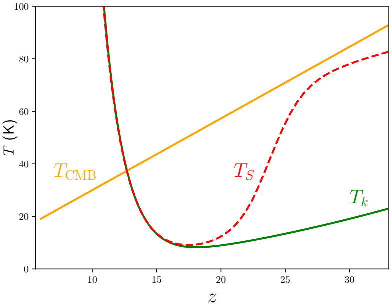
[Liu'20]

The IGM temperature T_k can be probed at low z by using:

- Lyman-α forest data at $2 \lesssim z \lesssim 6$ with $T_k \sim 10^4$ K [Liu'20,Capozzi'23]

DM energy injection implies earlier heating

DM decays heats the IGM before astro sources light-on.

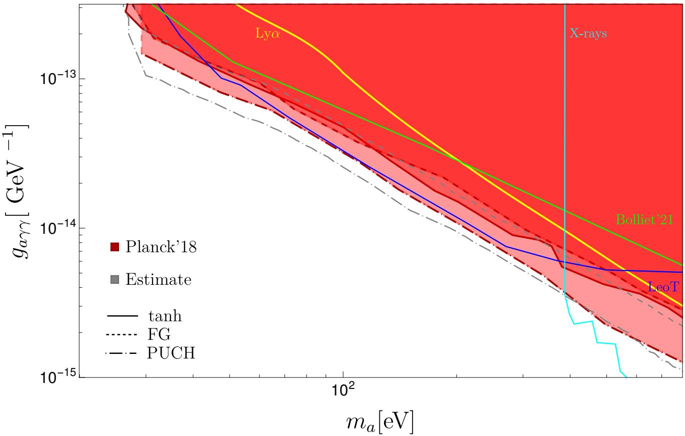


The IGM temperature T_k can be probed at low z by using:

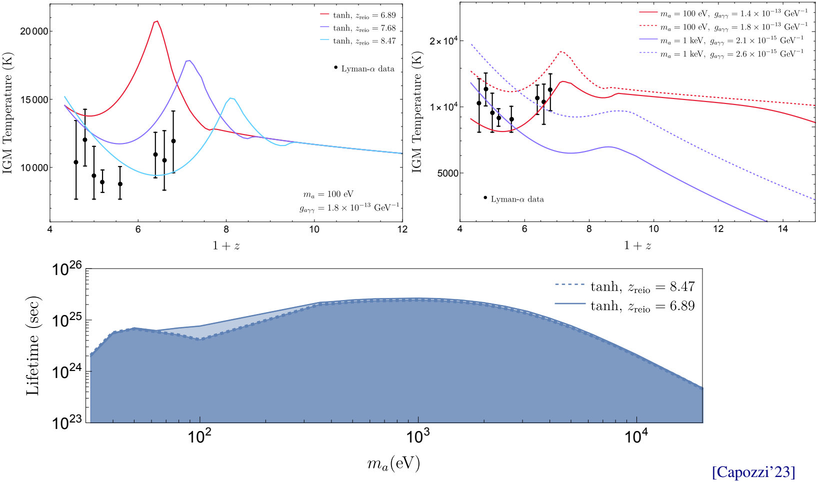
- Lyman-α forest data at $2 \lesssim z \lesssim 6$ with $T_k \sim 10^4$ K [Liu'20,Capozzi'23]
- Redshifted 21cm signal detected by radio telescope arrays that will measure $|\Delta_{21}(k,z)|^2$ at $z \subset [6,25]$ with $T_k \sim 10$ K [Furlaneto'06, Evoli'14, Liu'18]

$a \to \gamma\gamma$

Current constraints for different reionization models

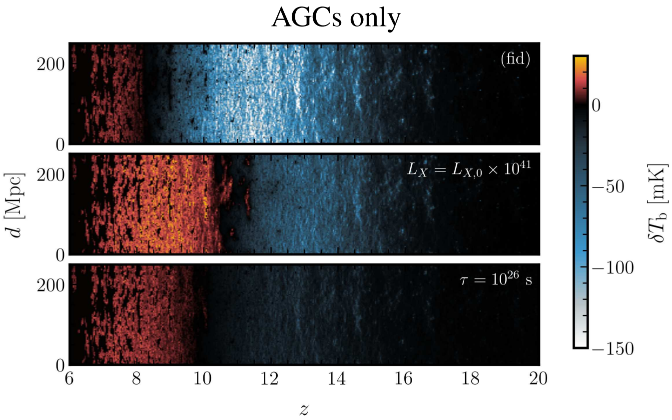


T_k for $a \to \gamma\gamma$

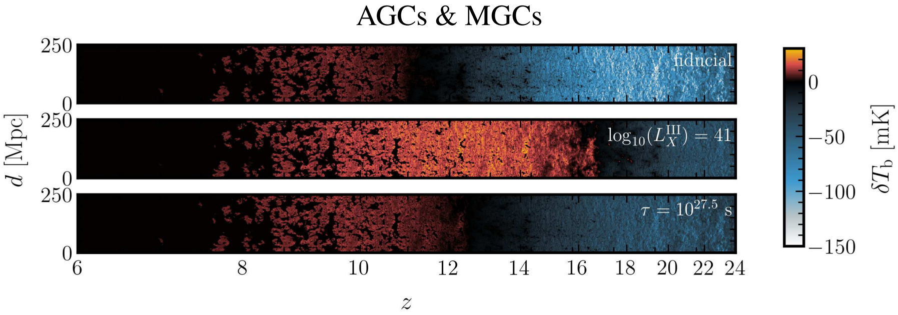


[Capozzi'23]

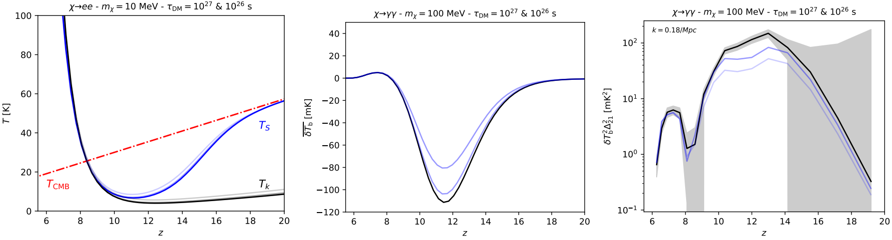
DM decay and earlier heating



DM decay and earlier heating



Impact of DM$\rightarrow \gamma\gamma$ on T_k, δT_b and Δ_{21}



DM energy injection implies

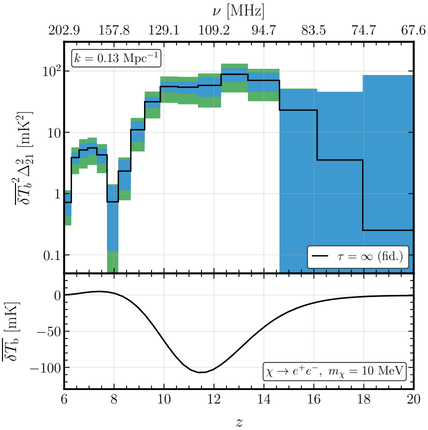
- new source of heating, earlier than X-rays from stars
- suppressed absorption in δT_b
- suppressed power at large z

plots made using exo21cmFast developped by G. Facchinetti merging 21cmFast and DarkHistory

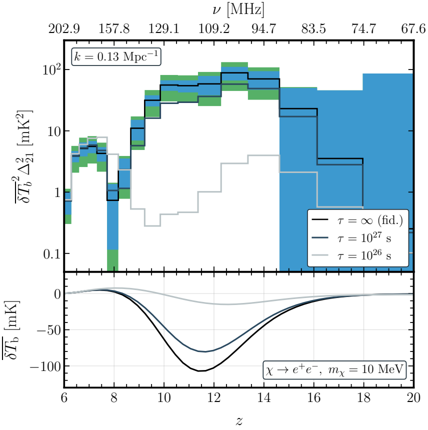
Fisher matrix analysis

- Fisher matrix can be used to estimate the minimum uncertainties of parameters given observations $\sigma_{Fish} \lesssim \sigma_{true}$ [Albrecht et al. 2009] (= optimistic estimate of the errors) (e.g. using 21cmFish by C. Mason'22, they show that $\sigma_{Fish,i}$ are within 40% of the those obstained with MCMC for ΛCDM)
- The Fisher formalism assumes that the likelihood is Gaus- sian within the parameter range under consideration and $F_{ij} = \sum_{k,z} \frac{\partial \Delta_{21}}{\partial \theta_i} \frac{\partial \Delta_{21}}{\partial \theta_j} (\sigma^2_\Delta(k,z))^{-1}$ where σ^2_Δ measurement error in Δ_{21} at a given k, z bin. Forecasted uncertainty in the i-th parameter is $\sigma(\theta_i) = \sqrt{\mathcal{C}_{ii}}$ where the covariance matrix $\mathcal{C} = F^{-1}$.
- $\sigma^2_\Delta(k,z)$ is obtained w/ 21cmSense considering HERA thermal noise plus the cosmic variance plus 20% 'modelling uncertainty'. The noise assumes 1000 hours of obs. ($\sim$ 167 days for 6h/day with max 180 effective days of obs/year) using 331 antennae.
- foregrounds are taken into account by putting a cut neglecting $k_\parallel < 0.1/Mpc$
- boxes have a comoving volume of $(250Mpc)^3$ on a grid of $z = 6 - 30$ ($\sim \nu = 50 - 250$ Mhz). We use $BW = \Delta\nu_{\max} = 8$ Mhz which sets $k_{\parallel,min}$ at a given z. Notice that given HERA config, the available $k_\parallel > k_\perp$.

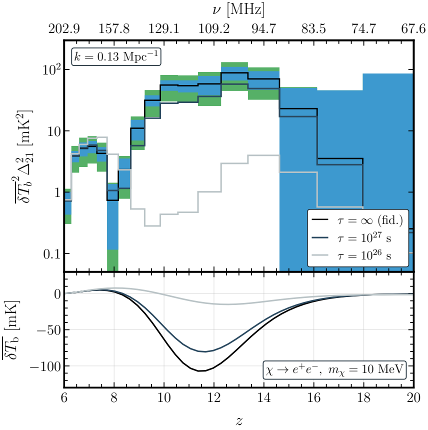
DM vs X rays with POPII stars only

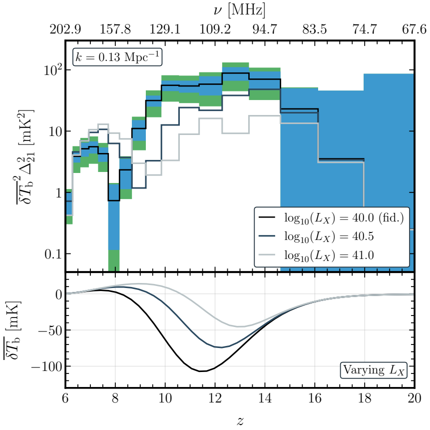


DM vs X rays with POPII stars only

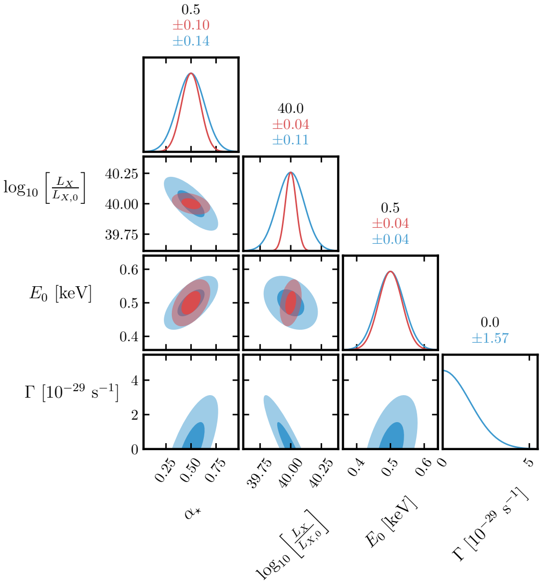


DM vs X rays with POPII stars only



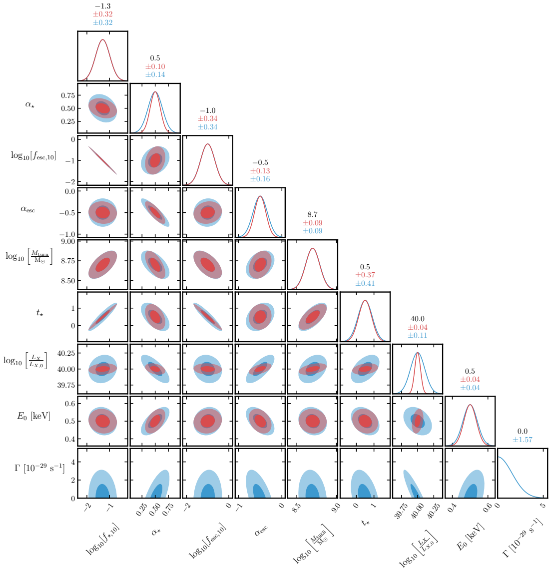


21cm Fisher results for $\chi \to ee$ $m_\chi = 100$ MeV



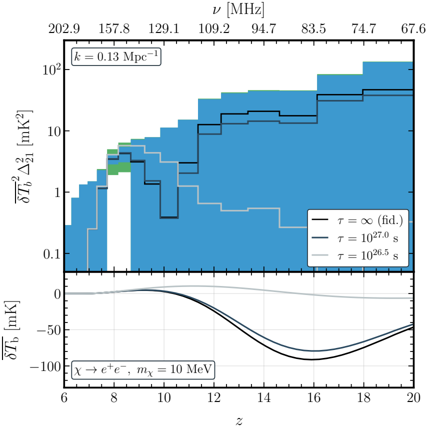
- L_X normalisation of soft-band X- ray (< 2 keV which efficiently heat IGM) luminosity per unit SFR. E_0 minimum in X-ray energies which can escape galaxies.
- stellar mass (M_*) to halo mass ratio is described by a power law: $\alpha_*, f_{*,10}$ = low mass slope, normalisation for galaxies forming pop II stars

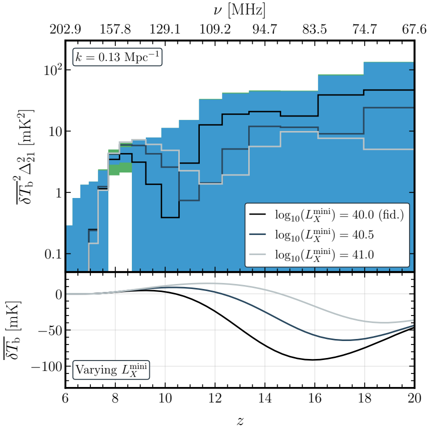
21cm Fisher results for $\chi \to ee$ $m_\chi = 100$ MeV



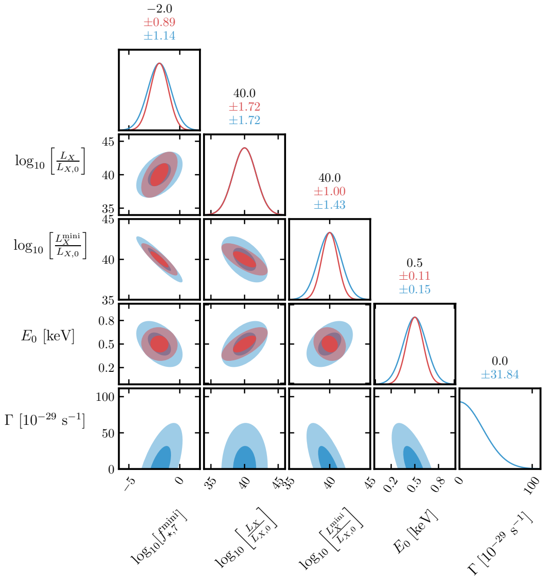
- L_X normalisation of soft-band X- ray (< 2 keV which efficiently heat IGM) luminosity per unit SFR. E_0 minimum in X-ray energies which can escape galaxies.
- stellar mass (M_*) to halo mass ratio is described by a power law: $\alpha_*, f_{*,10}$ = low mass slope, normalisation for galaxies forming pop II stars

DM vs X rays with POPII&III stars only



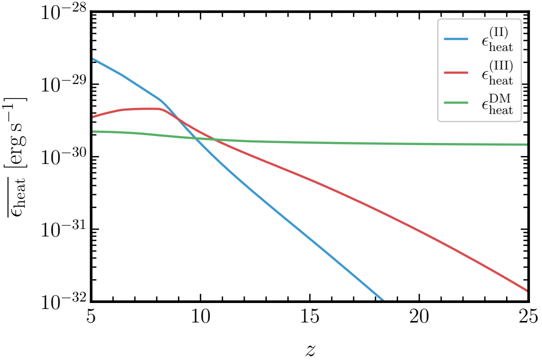


21cm Fisher for $\chi \rightarrow ee$, $m_\chi = 100$ MeV+ POPIII stars



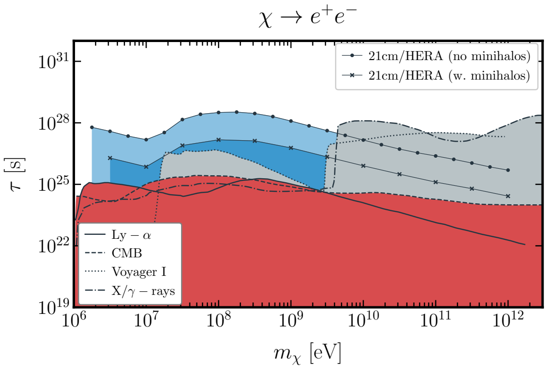
- $L_X^{\rm mini}$ normalisation of soft-band X- ray (< 2 keV which efficiently heat IGM) luminosity per unit SFR from minihalos,
- E_0 minimum in X-ray energies which can escape galaxies,
- $f_{*,7} =$ is the normalisation of the stellar mass to halo mass for galaxies forming pop III stars

Rates of energy injection into heat



- DM heats the IGM well before POPII stars but is less efficient at low z
- POPIII stars give rise to heating rate “more similar” to DM than POPII.

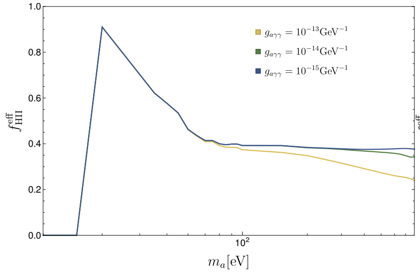
Rates of energy injection into heat



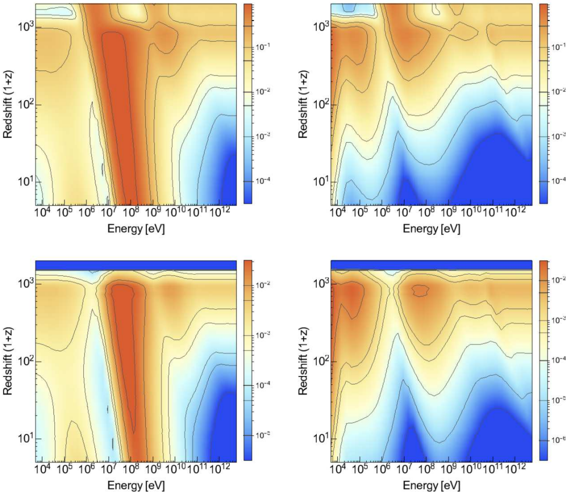
- DM heats the IGM well before POPII stars but is less efficient at low z
- POPIII stars give rise to heating rate "more similar" to DM than POPII.

Stronger degeneracy with POPIII star heating parameters
$\rightsquigarrow$ less stringent constraints on DM decay width
when POPIII stars are taken into account.

$f_{ionH,eff}$ & $f_{heat,eff}$ for $a \to \gamma\gamma$

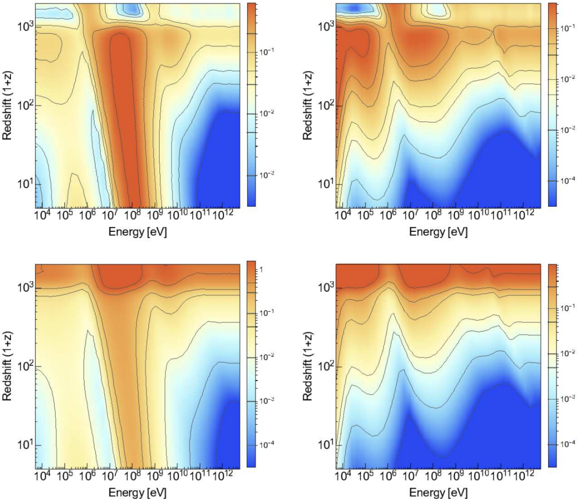


f_{ionH} & f_{ionHe} for $\chi \to ee, \gamma\gamma$



[Liu'16]

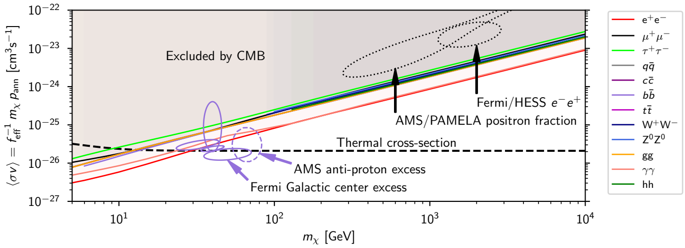
f_{exc}& f_{heat} for $\chi \to ee,\ \gamma\gamma$



[Liu'16]

CMB constraints on DM annihilation

see e.g. [Chen'03, Padmanabhan'05, Cirelli'09, Slatyer'09, Galli'11, Giesen'12, LLH'13, Galli'13, Madhavacheril'13, Poulin'15,...]

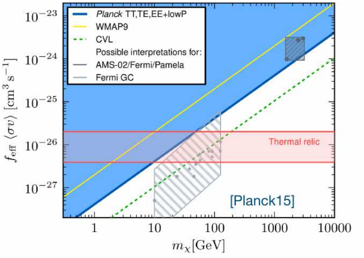


$\rightsquigarrow$ $p_{ann} = f_{eff}\langle\sigma v\rangle/m_{DM} < 3.2\,10^{-28}$ cm^3/s/GeV at 95% CL [Planck'18]

- CMB data most sensitive to annihilating DM energy injections at $z \simeq 600$ [Finkbeiner'12]. For annihilating DM, one can take $f_c(z) = f_{eff} = f_c(z = 600)$.
- Advantage of CMB compared to other DM annihilation probes: do not suffer astrophysics uncertainties (such as ρ_{DM}) and no contributions from halos for σv independent of v (s-wave annihilation) [LLH'13, Poulin'15, Hongwan'16].

DM annihilation and earlier heating

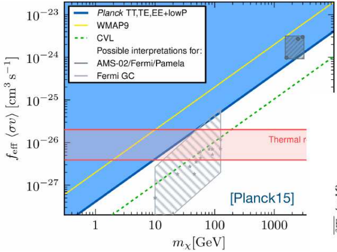
see also [Hansen'04, Pierpaoli'04, Bierman'06, Mapelli'06, Valdes'07, Natarajan'08, Evoli'14, etc]

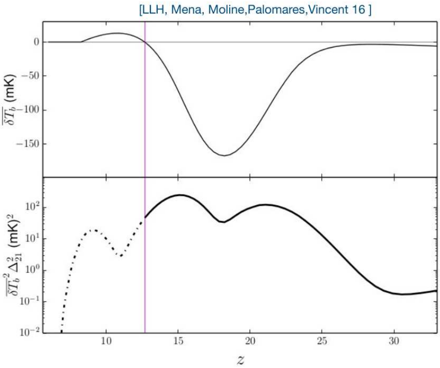


see also [Valdes13, Evoli14, D'Amico18,Liu18]

DM annihilation and earlier heating

see also [Hansen'04, Pierpaoli'04, Bierman'06, Mapelli'06, Valdes'07, Natarajan'08, Evoli'14, etc]

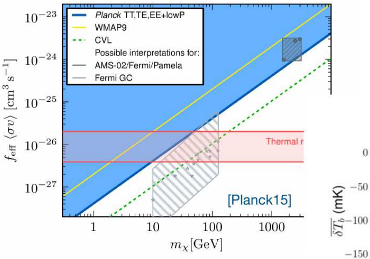




see also [Valdes13, Evoli14, D'Amico18,Liu18]

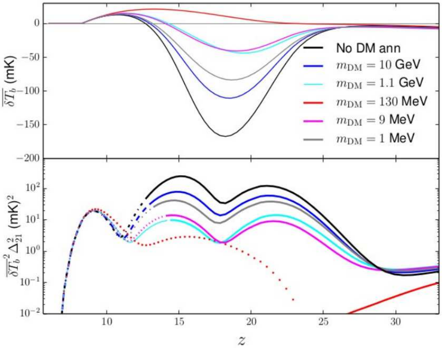
DM annihilation and earlier heating

see also [Hansen'04, Pierpaoli'04, Bierman'06, Mapelli'06, Valdes'07, Natarajan'08, Evoli'14, etc]



- Suppressed absorption
- Imposing some maximal δTb could constrain DM annihilation

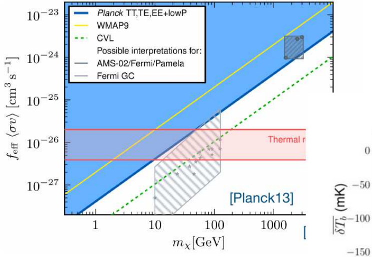
[LLH, Mena, Moline,Palomares,Vincent 16]



see also [Valdes13, Evoli14, D'Amico18,Liu18]

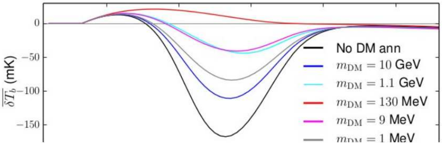
DM annihilation and earlier heating

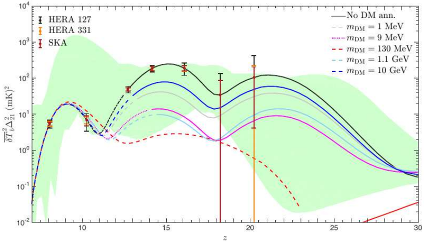
see also [Hansen'04, Pierpaoli'04, Bierman'06, Mapelli'06, Valdes'07, Natarajan'08, Evoli'14, etc]



Beware!
large astrophysics
uncertainties

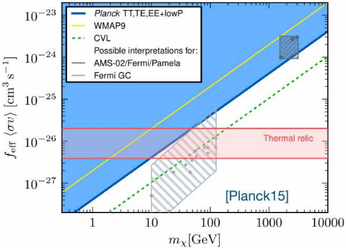
[LLH, Mena, Moline,Palomares,Vincent 13]

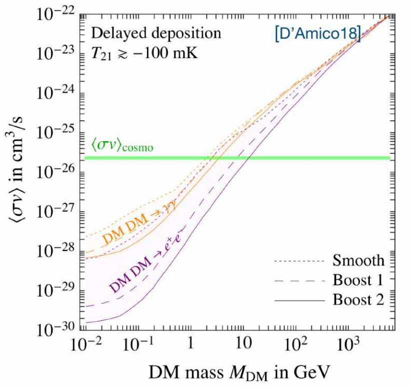




DM annihilation and earlier heating

see also [Hansen'04, Pierpaoli'04, Bierman'06, Mapelli'06, Valdes'07, Natarajan'08, Evoli'14, etc]

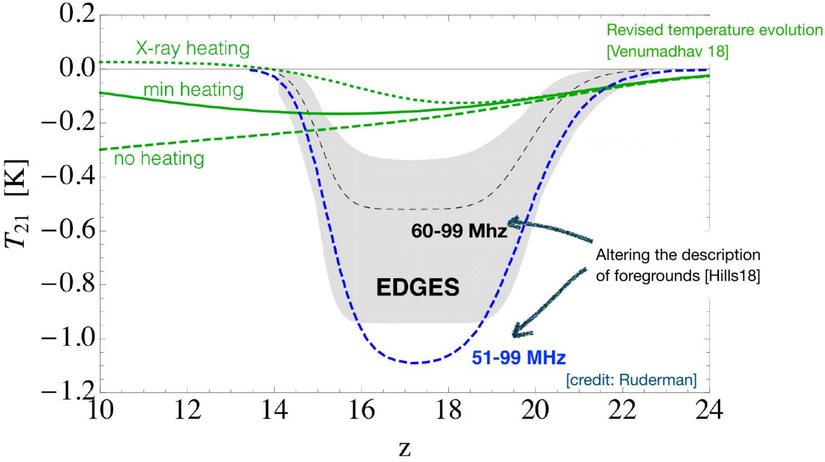




- Suppressed absorption
- Imposing some maximal δTb could constrain DM annihilation

see also [Valdes13, Evoli14,LLH16, Liu18]

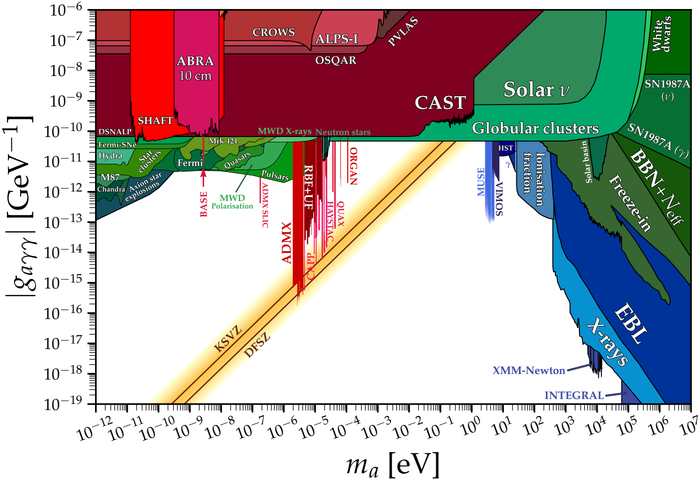
Constraints on 21cm Global signal?



Why bothering more??

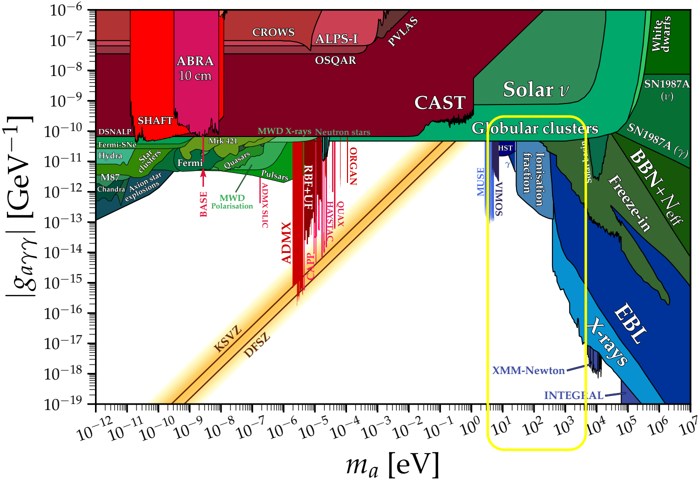
ALP decays into 2 photons

$$\Gamma_{DM} = \frac{g_{a\gamma\gamma}^2}{64\pi} m_a^3$$



ALP decays into 2 photons

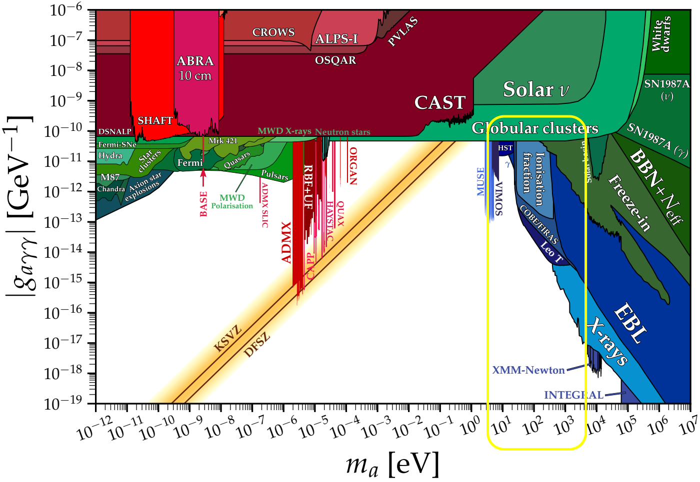
$$\Gamma_{DM} = \frac{g_{a\gamma\gamma}^2}{64\pi} m_a^3$$



Between 10 and 100 eV relatively poorly constrained with old CMB data

ALP decays into 2 photons

$$\Gamma_{DM} = \frac{g_{a\gamma\gamma}^2}{64\pi} m_a^3$$



Between 10 and 100 eV relatively poorly constrained with old CMB data

CMB analysis for $a \to \gamma\gamma$

Goals of our analyis:

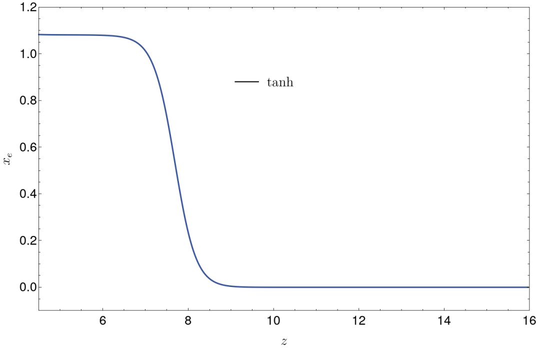
- Up to date MCMC analysis using Planck'18 data with $f_{\rm eff} = f_c(z = 300)$. The few $\times$ 10 eV energy photons are very good at ionizing the medium!
  We modified CLASS to account for $f_{\rm eff} = f_c(z = 300, m_a, g_a)$ from DarkHistory.
- Check the impact of reionization history

CMB analysis for $a \to \gamma\gamma$

Goals of our analyis:

- Up to date MCMC analysis using Planck'18 data with $f_{\rm eff} = f_c(z = 300)$.
  The few $\times$ 10 eV energy photons are very good at ionizing the medium!
  We modified CLASS to account for $f_{\rm eff} = f_c(z = 300, m_a, g_a)$ from DarkHistory.

- Check the impact of reionization history
  - parametric $x_e^{\rm tanh}$



all shown reio agree with Planck'18:
$\tau_{\rm reio} = 0.054 \pm 0.007$

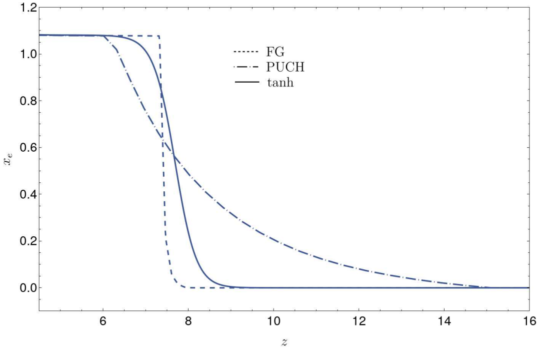
CMB analysis for $a \to \gamma\gamma$

Goals of our analyis:

- Up to date MCMC analysis using Planck'18 data with $f_{\rm eff} = f_c(z = 300)$.
  The few $\times$ 10 eV energy photons are very good at ionizing the medium!
  We modified `CLASS` to account for $f_{\rm eff} = f_c(z = 300, m_a, g_a)$ from `DarkHistory`.

- Check the impact of reionization history
  - parametric $x_e^{\rm tanh}$
  - x_e from stars
    [Puchwein'18, Fauchère-Giguère'19]

  all shown reio agree with Planck'18: $\tau_{\rm reio} = 0.054 \pm 0.007$



Without DM, PUCH reio model gives larger $\tau_{\rm reio} = \int dt\, x_e n_b \sigma_T$
$\rightsquigarrow$ Stronger CMB bounds for PUCH-like model expected

CMB analysis for $a \to \gamma\gamma$

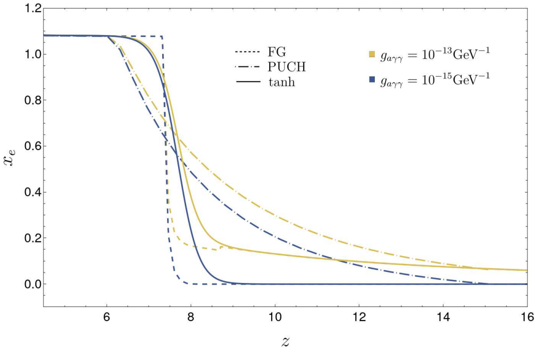
Goals of our analyis:

- Up to date MCMC analysis using Planck'18 data with $f_{\rm eff} = f_c(z = 300)$.
  The few $\times$ 10 eV energy photons are very good at ionizing the medium!
  We modified CLASS to account for $f_{\rm eff} = f_c(z = 300, m_a, g_a)$ from DarkHistory.

- Check the impact of reionization history
  - parametric $x_e^{\rm tanh}$
  - x_e from stars

    [Puchwein'18,

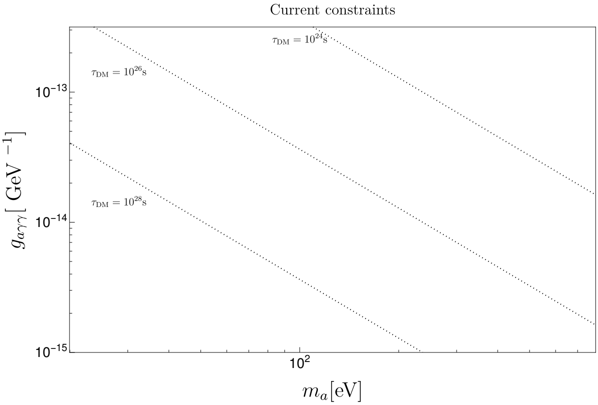
    Fauchère-Giguère'19]



Without DM, PUCH reio model gives larger $\tau_{\rm reio} = \int dt\, x_e n_b \sigma_T$

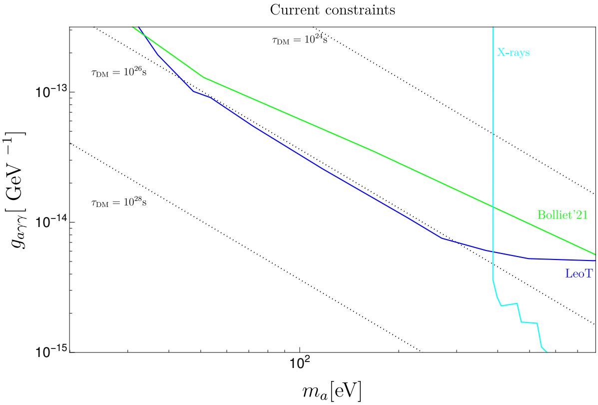
$\rightsquigarrow$ Stronger CMB bounds for PUCH-like model expected

CMB bounds $a \to \gamma\gamma$



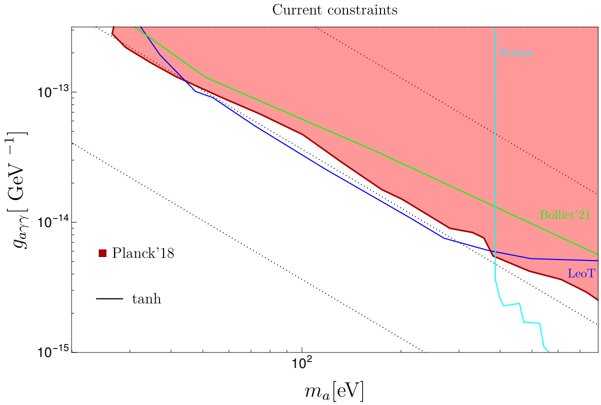
$$\tau_{DM}^{-1} = \frac{g_{a\gamma\gamma}^2}{64\pi} m_a^3$$

CMB bounds $a \to \gamma\gamma$



$$\tau_{DM}^{-1} = \frac{g_{a\gamma\gamma}^2}{64\pi} m_a^3$$

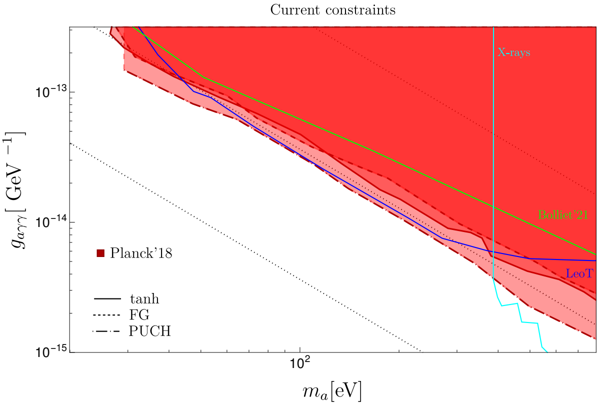
CMB bounds $a \to \gamma\gamma$



$$\tau_{DM}^{-1} = \frac{g_{a\gamma\gamma}^2}{64\pi} m_a^3$$

- For $x_e^{\rm tanh}$, $z_{\rm reio}$ is marginalized over $z_{\rm reio} = [5, 13]$.
- $\tau_{\rm DM} \gtrsim 10^{26}$s

CMB bounds $a \to \gamma\gamma$

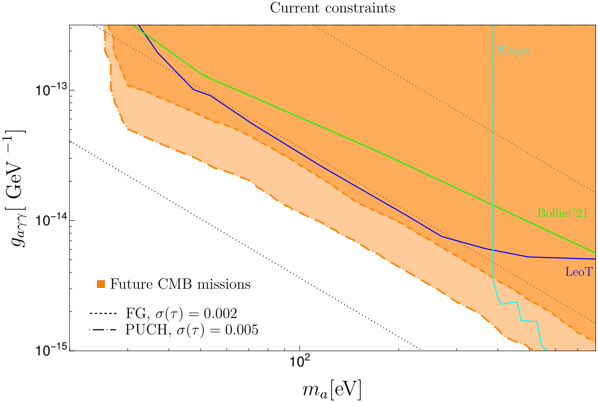


$$\tau_{DM}^{-1} = \frac{g_{a\gamma\gamma}^2}{64\pi} m_a^3$$

- For $x_e^{\tanh}$, $z_{\rm reio}$ is marginalized over $z_{\rm reio} = [5, 13]$.
- $\tau_{\rm DM} \gtrsim 10^{26}$s
- CMB bounds are of the same order as astro bound from Leo-T

- Currently, fixing $x_e(z)$ to a reionization history in agreement with Planck does not significantly change the bounds

CMB bounds $a \to \gamma\gamma$



$$\tau_{DM}^{-1} = \frac{g_{a\gamma\gamma}^2}{64\pi} m_a^3$$

- For $x_e^{\tanh}$, $z_{\rm reio}$ is marginalized over $z_{\rm reio} = [5, 13]$.
- $\tau_{\rm DM} \gtrsim 10^{26}$s
- CMB bounds are of the same order as astro bound from Leo-T

- Currently, fixing $x_e(z)$ to a reionization history in agreement with Planck does not significantly change the bounds
- Future CMB variance limited Experiments will definitively give more stringent bounds. In the latter case, the reionization history from stars will matter.

bla

This is really the end