NYU
Center for Cosmology and Particle Physics
CERN

21cm from Dark Photons

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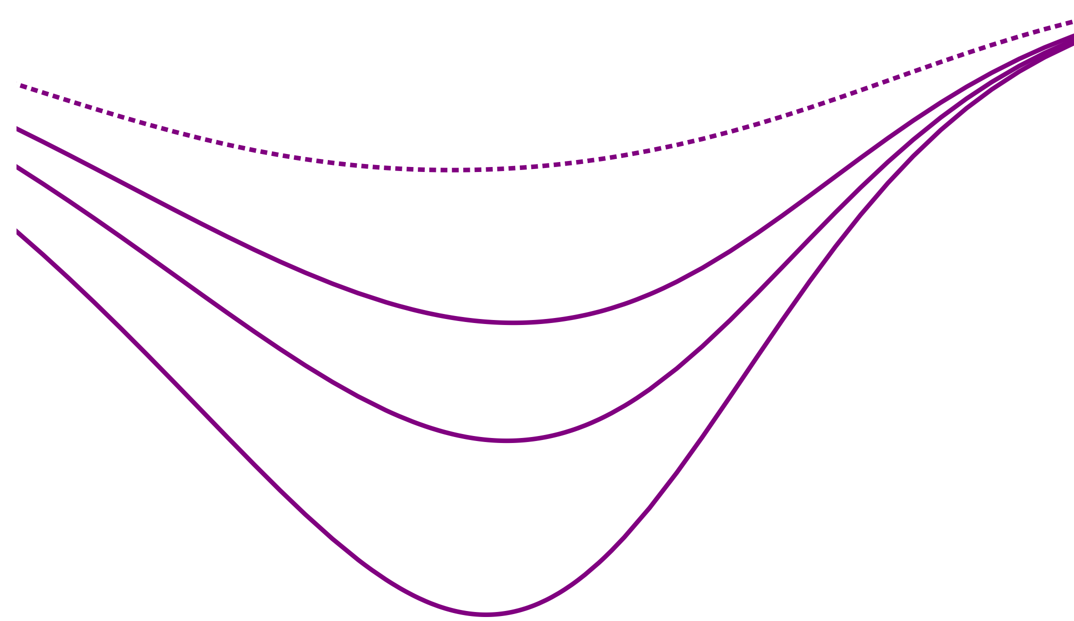
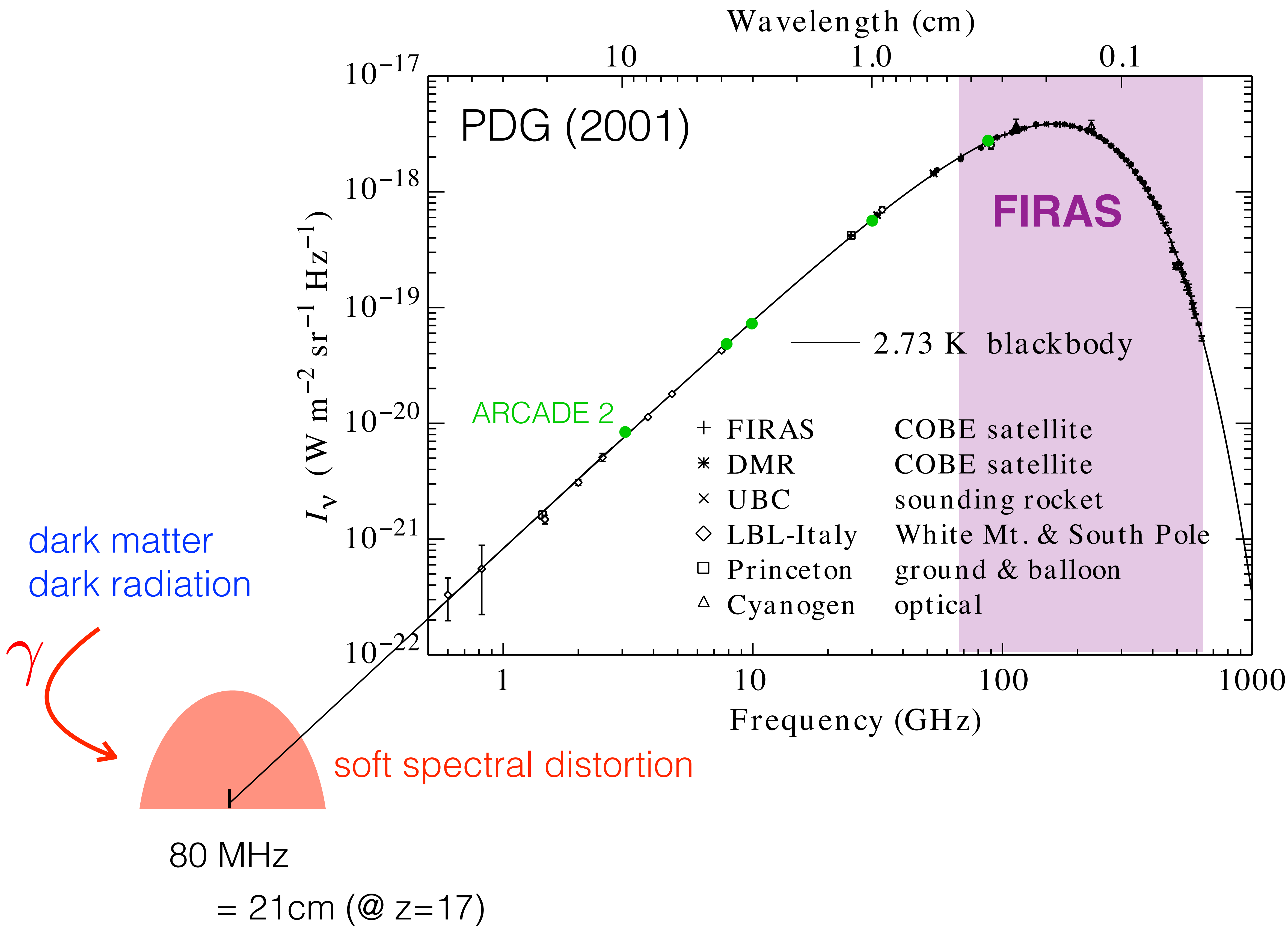
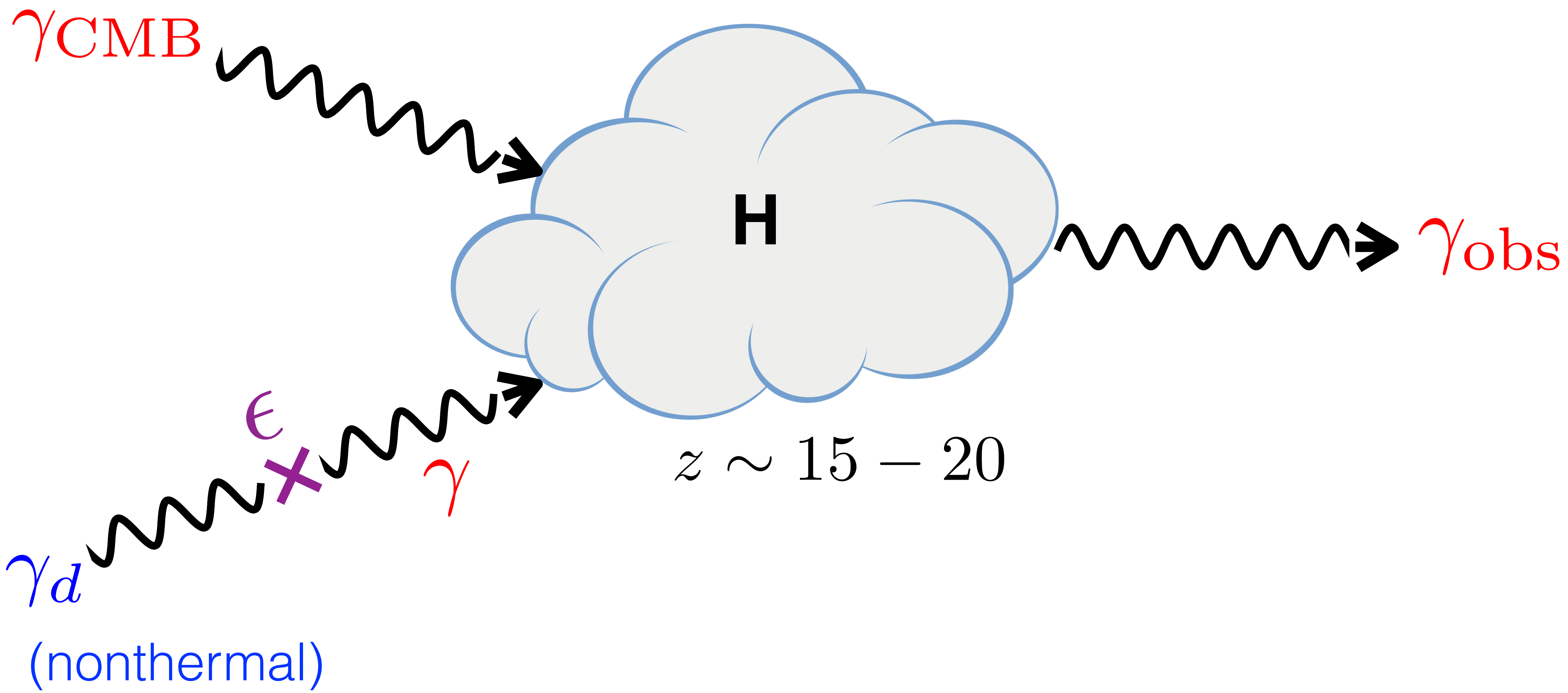


Pospelov, Pradler, JTR, Urbano, **1803.07048**

Cosmic Microwave Background

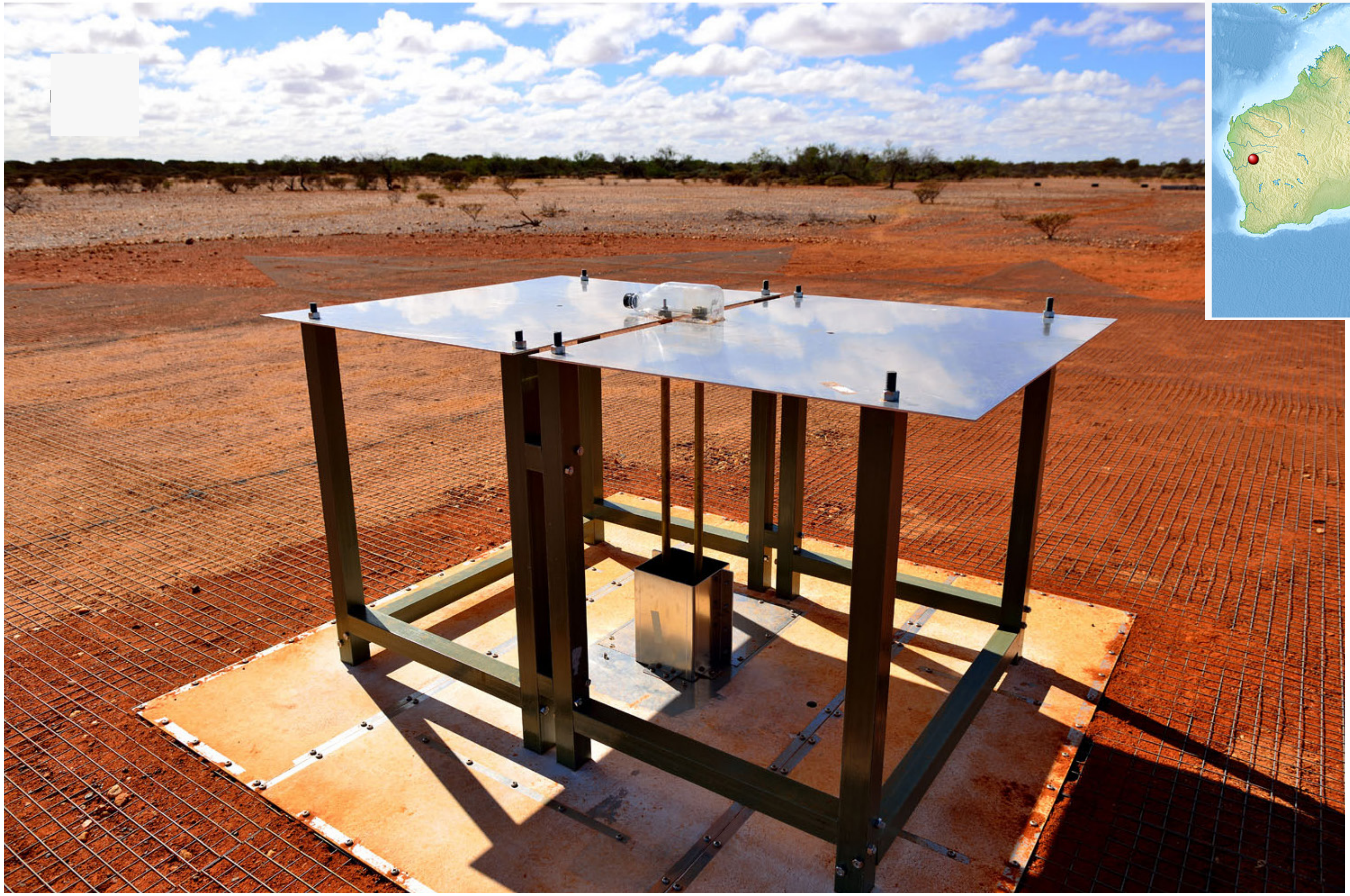


21cm Cosmology



EDGES

Experiment to **D**etect the **G**lobal **E**poch of Reionization **S**ignature

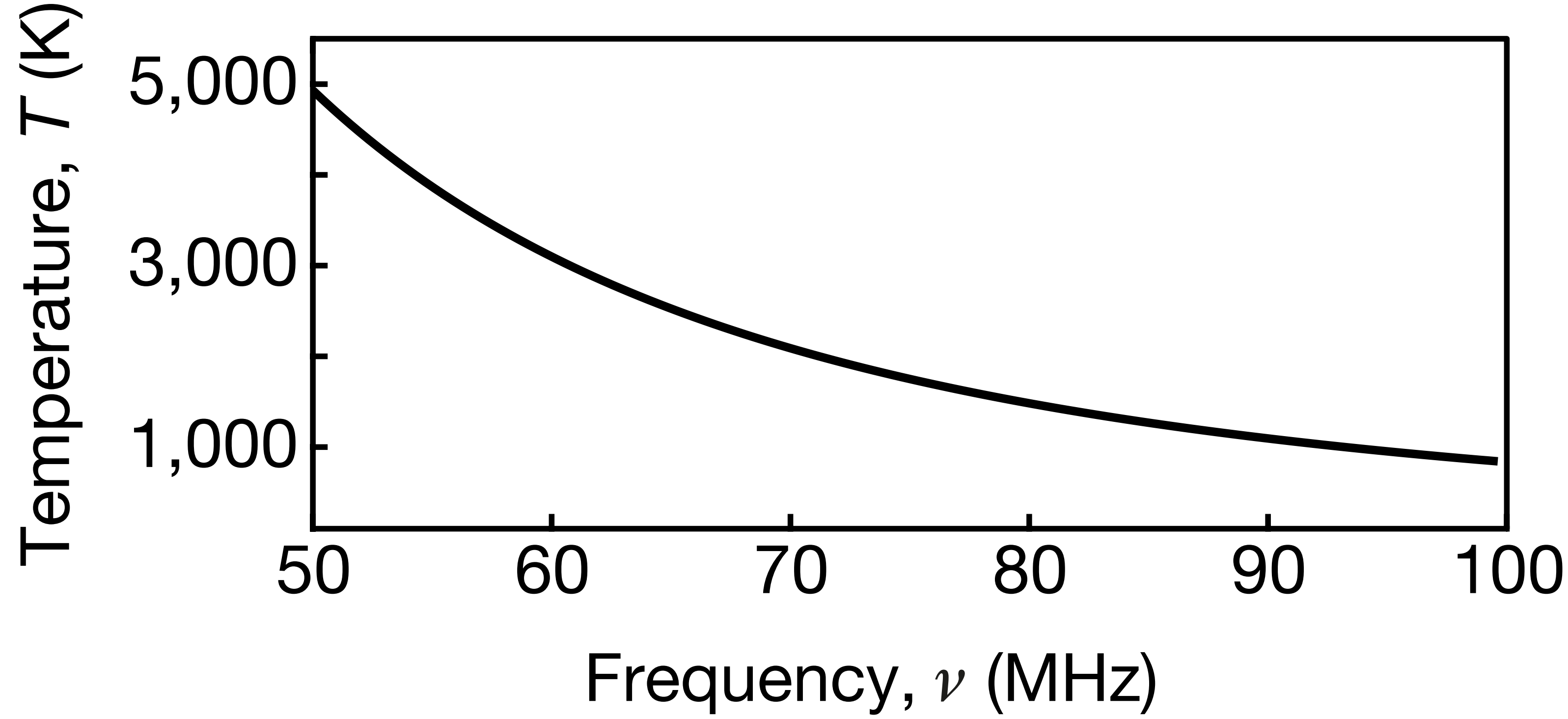


Bowman *et. al.* Nature **555**, 67 (2018)

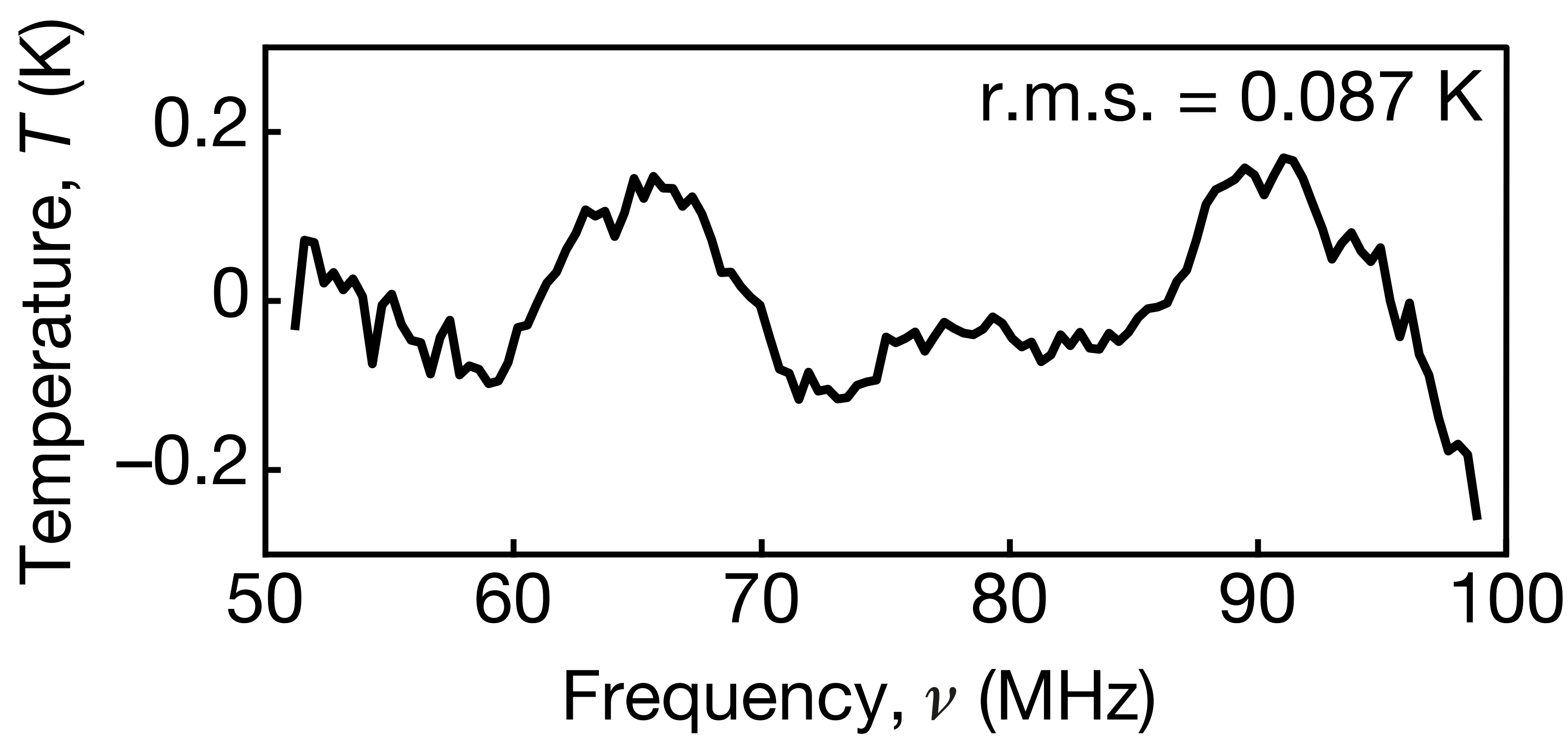
EDGES

Experiment to **D**etect the **G**lobal **E**poch of Reionization **S**ignature

measured spectrum:



residuals
(foregrounds only):

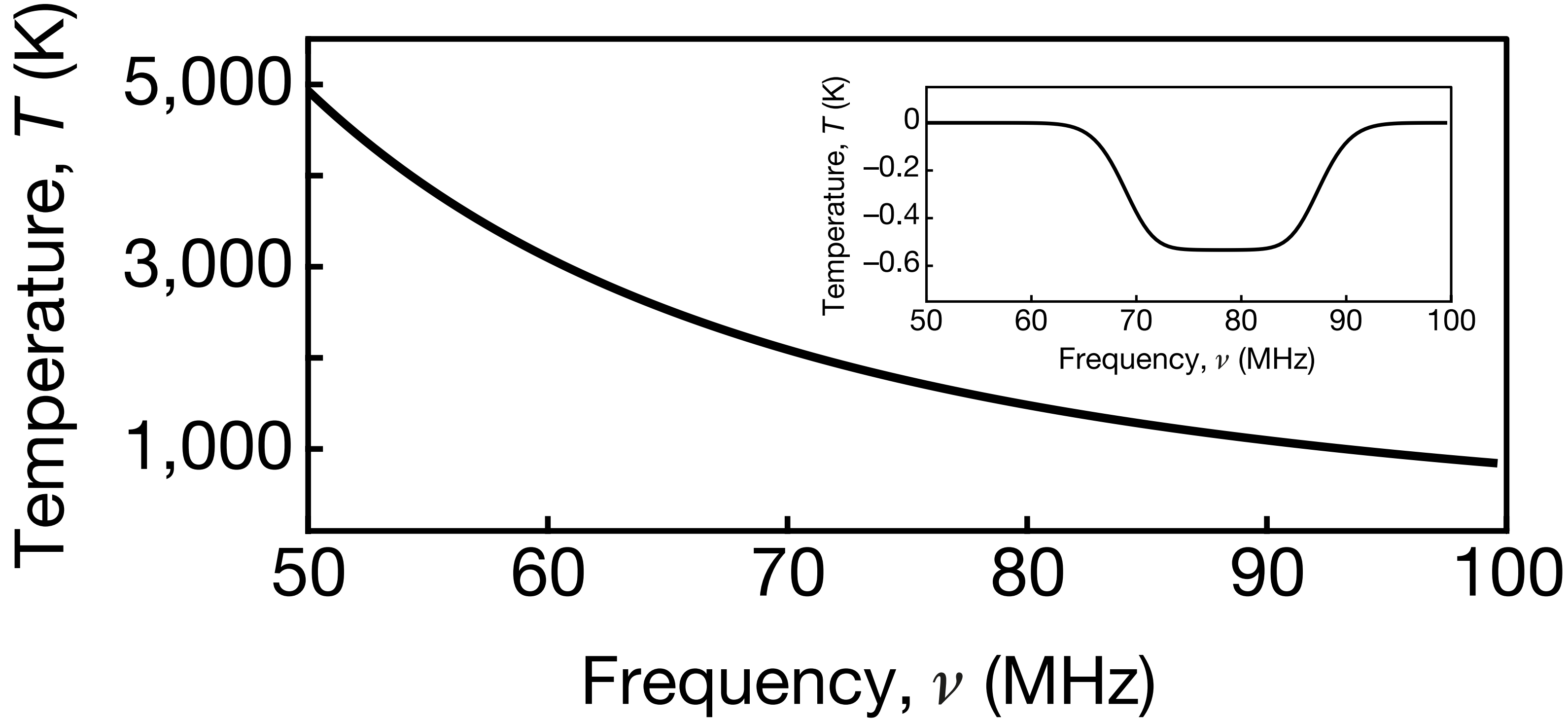


Bowman *et. al.* Nature **555**, 67 (2018)

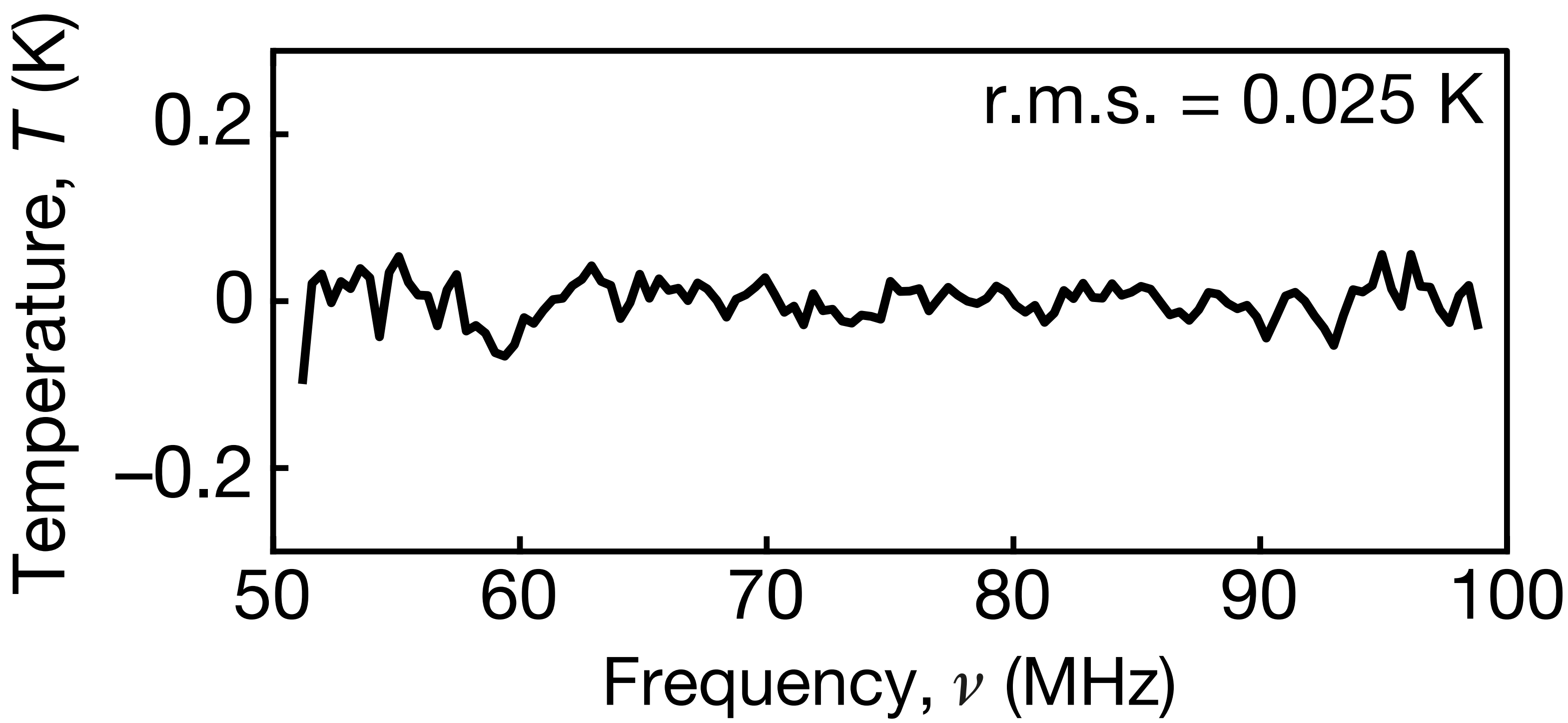
EDGES

Experiment to **D**etect the **G**lobal **E**poch of Reionization **S**ignature

measured spectrum:



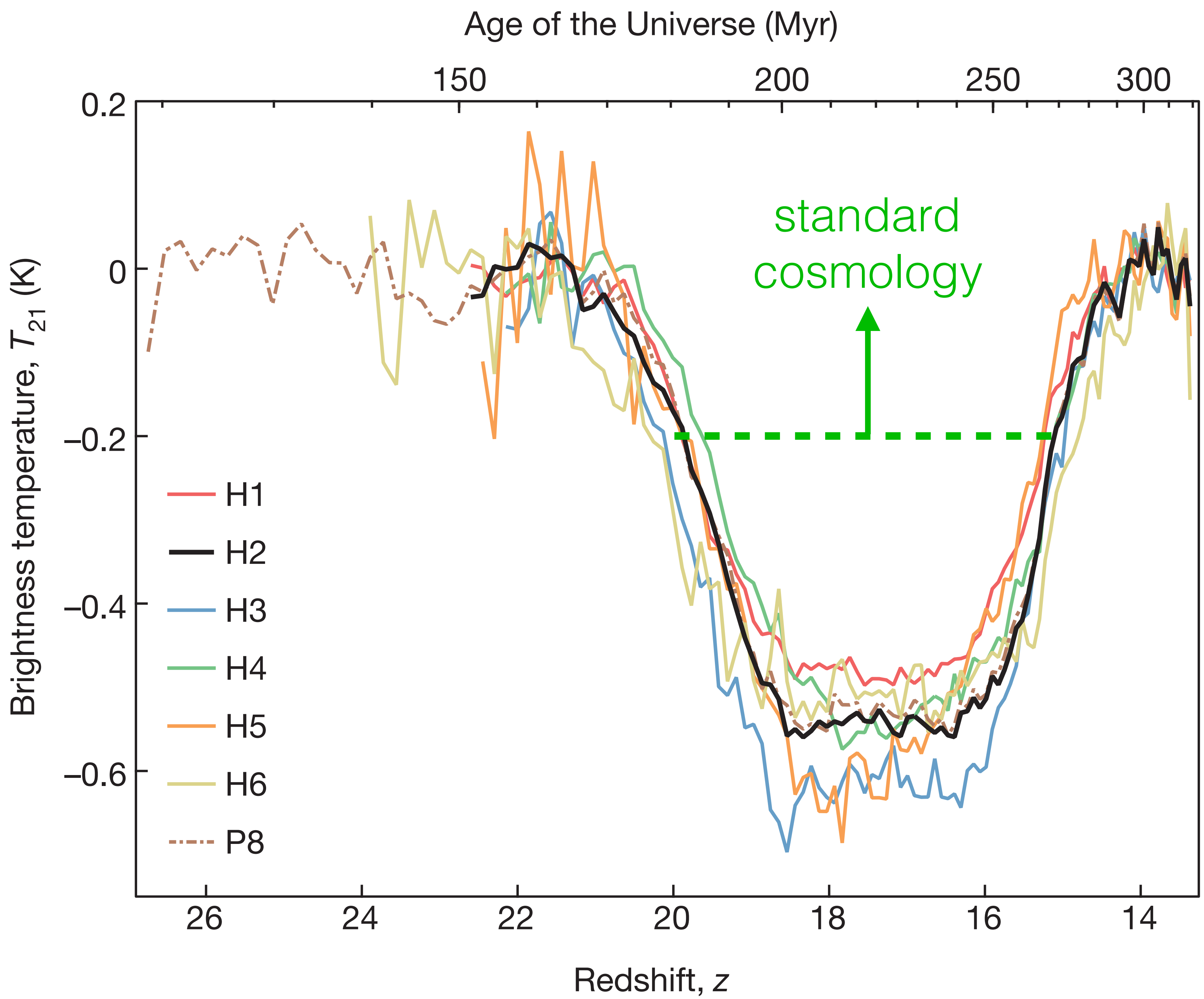
residuals
(including absorption):



Bowman *et. al.* Nature **555**, 67 (2018)

EDGES

Experiment to **D**etect the **G**lobal **E**poch of Reionization **S**ignature



EDGES:
$$T_{21} = -0.5^{+0.2}_{-0.5}\,\mathrm{K}$$

(99% C.L.)

standard cosmology:
$$T_{21} > -0.2\,\mathrm{K}$$

absorption: ~6σ

BSM: ~4σ

Bowman *et. al.* Nature **555**, 67 (2018)

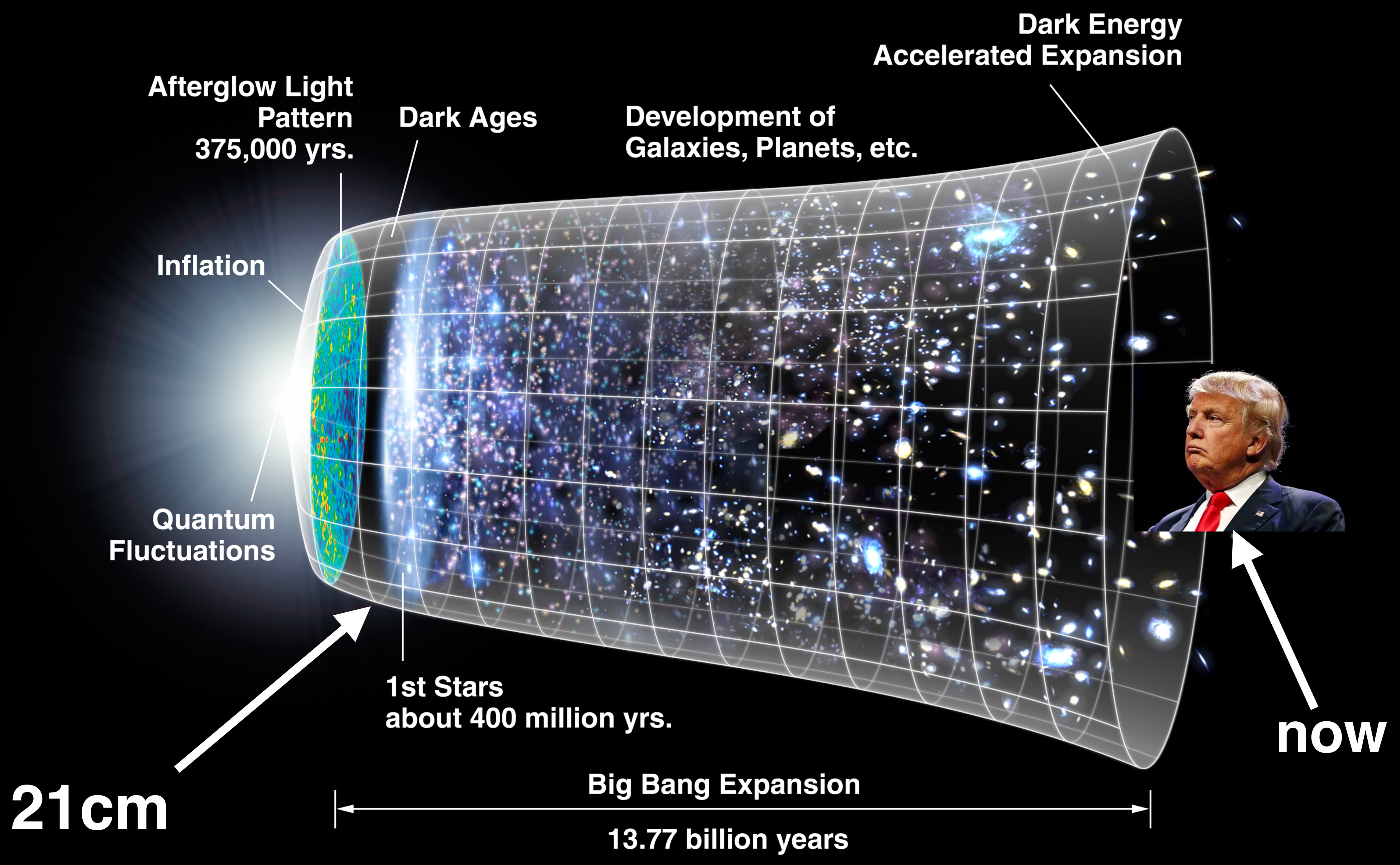
Plan

I. 21cm Primer

II. $\gamma_d \to \gamma$

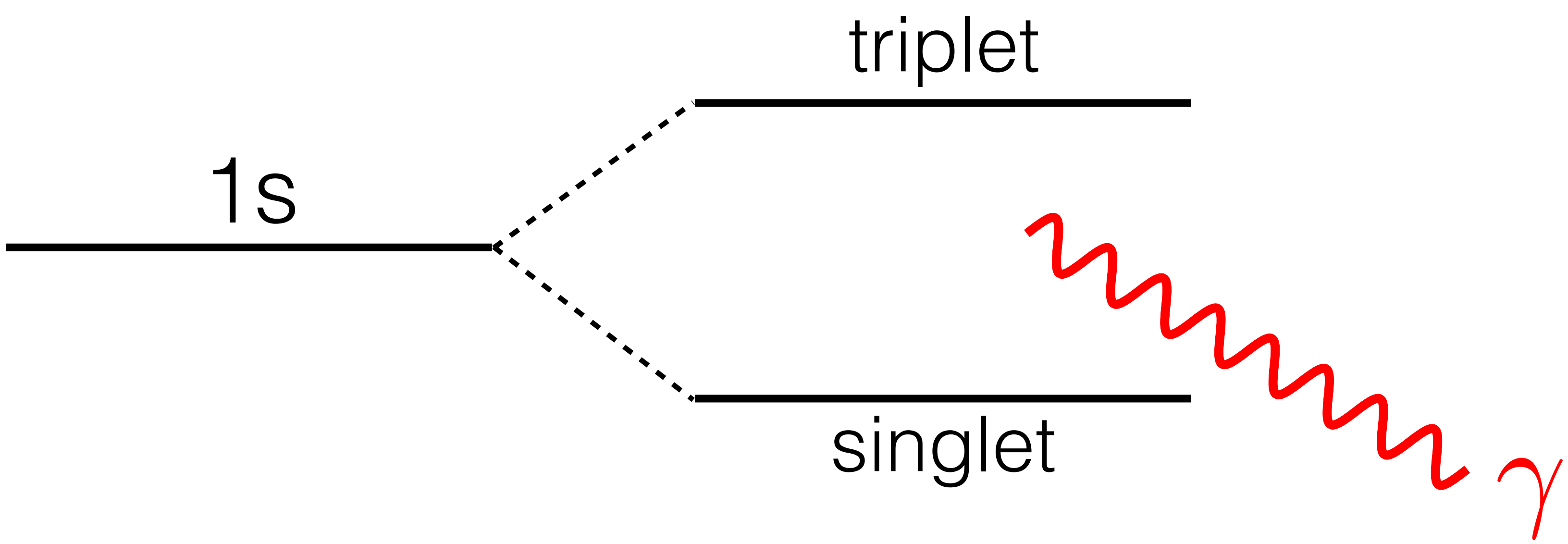
III. γ_d from Decaying Dark Matter

I. 21cm Primer



21cm Line of Hydrogen

- hyperfine splitting of hydrogen 1s:



$$\lambda = 21\,\mathrm{cm}$$

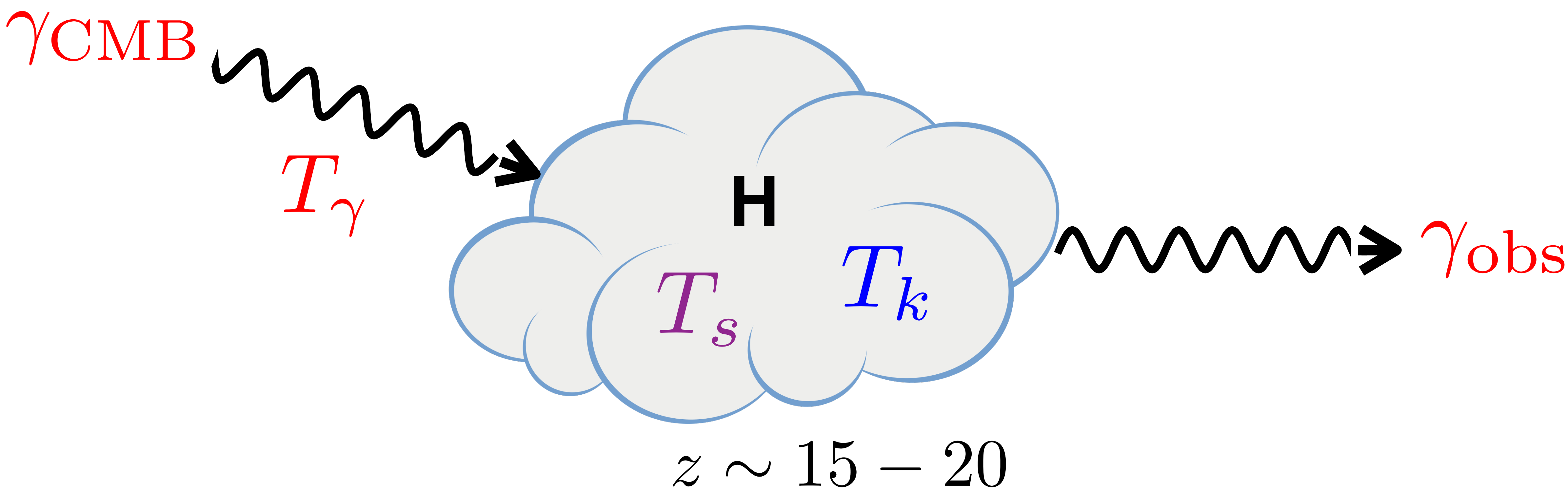
$$\omega_{21} = 5.9\,\mu\mathrm{eV}$$

- redshift: $\omega_{\rm obs} = \dfrac{\omega_{21}}{1+z}$

- hydrogen spin temperature: T_S

$$\frac{n_t}{n_s} = 3\,e^{-\omega_{21}/T_S}$$

Temperatures and Absorption



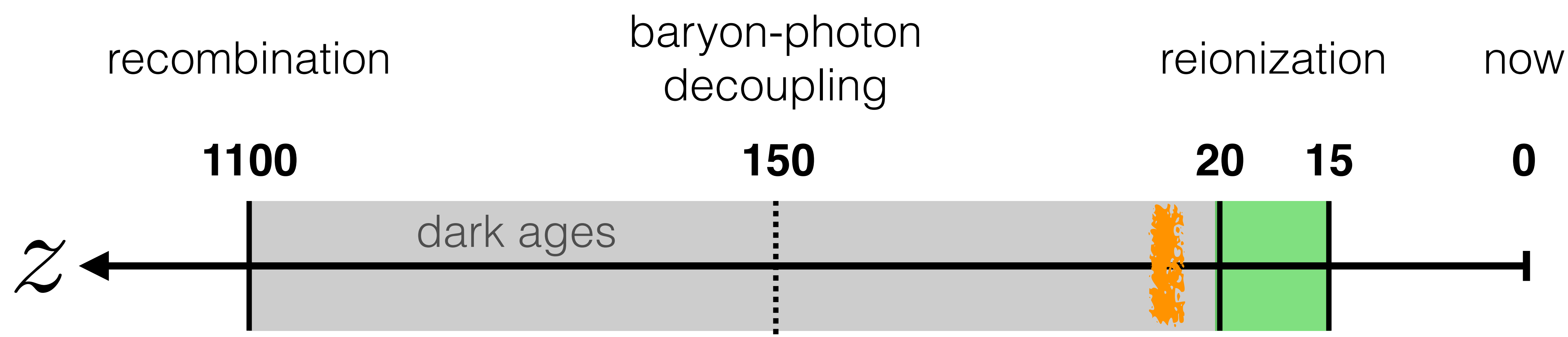
temperatures: T_γ, T_k, T_s

- photon: $T_\gamma = T_{\rm CMB}$
- hydrogen kinetic: T_k
- hydrogen spin: T_s

absorption:

$$\Delta T_{21}(z) = 32\,{\rm mK} \times \left(1 - \frac{T_\gamma(z)}{T_s(z)}\right)\sqrt{\frac{1+z}{18}}$$

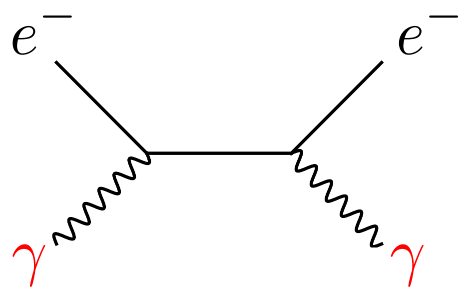
Temperature Evolution



EDGES

$T_\gamma \propto (1+z)$

$T_\gamma \propto (1+z)$
$T_k \propto (1+z)^2$



$$T_{s,k} \approx T_\gamma$$

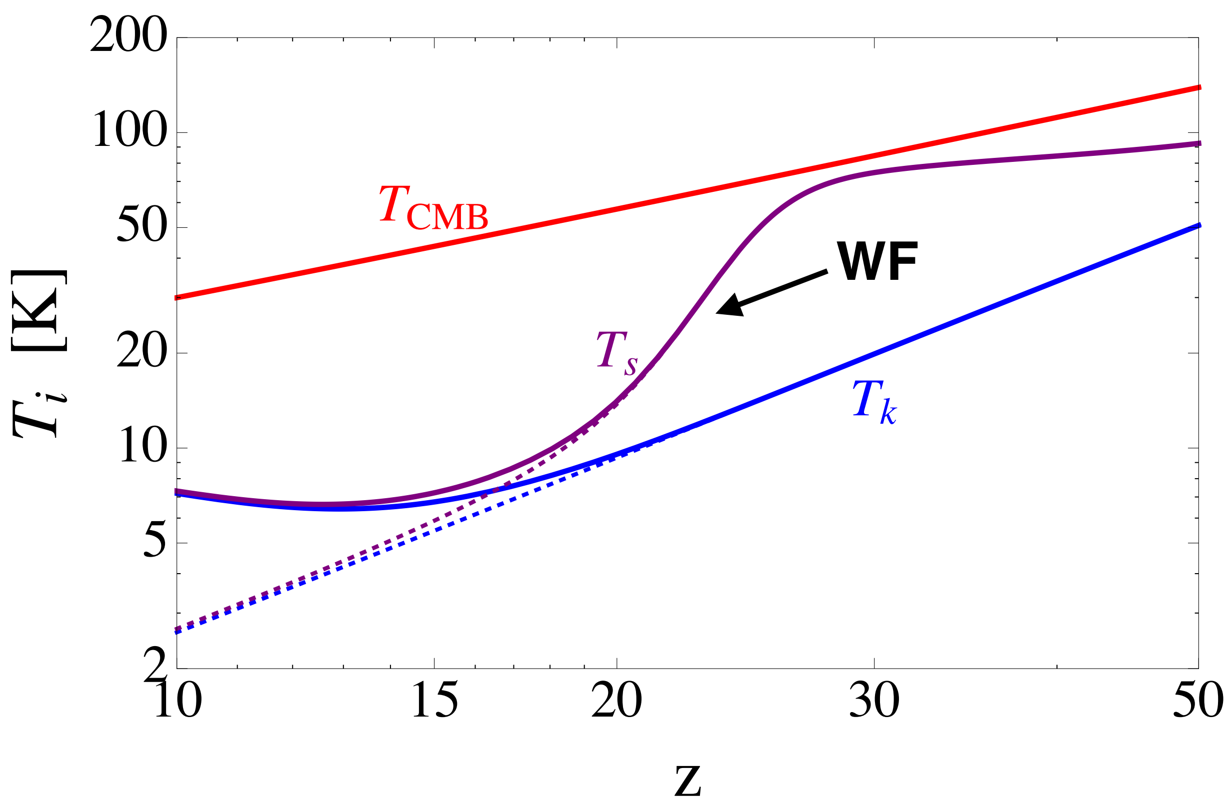
$$T_k \leq T_s \leq T_\gamma$$

Woutuysen-Field Effect:

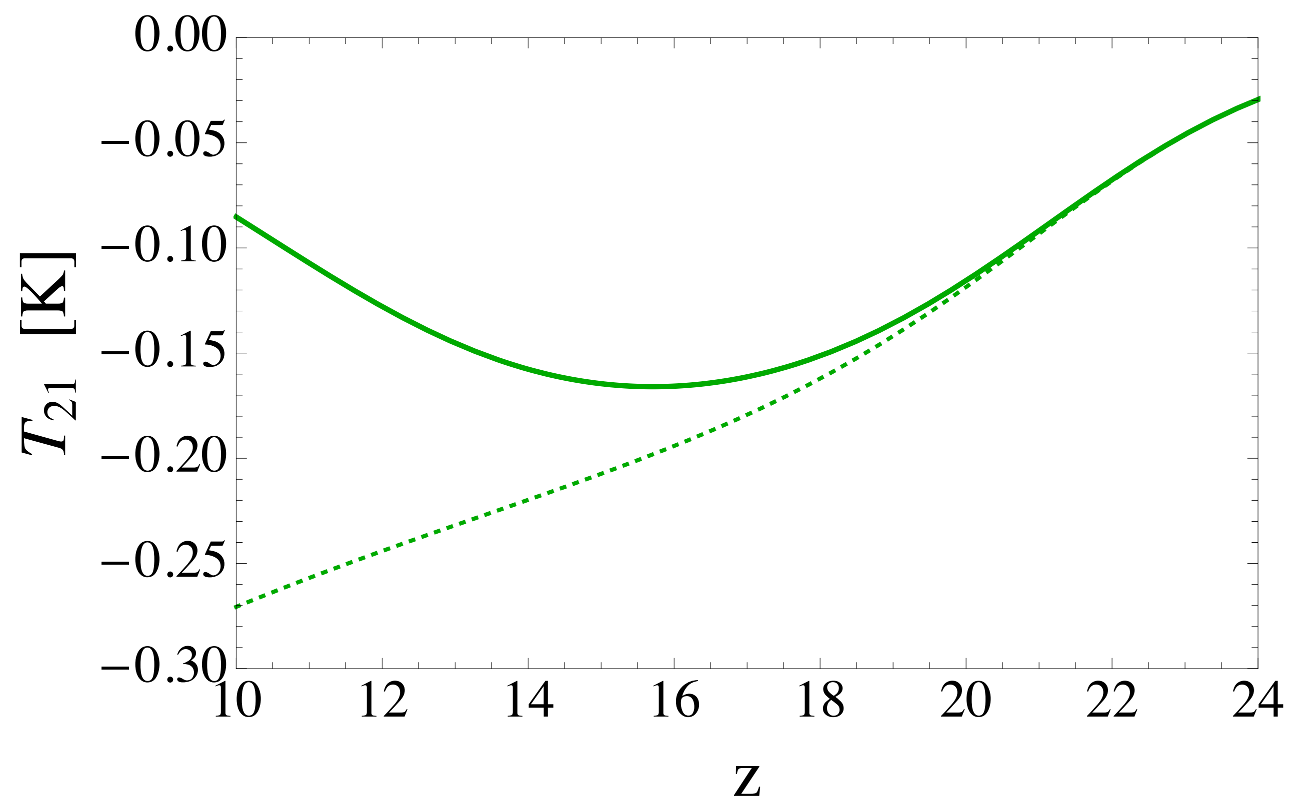
UV light from first stars couples: $T_s \to T_k$

Temperatures and Absorption

temperature evolution



21cm absorption



without gas heating (dotted)

with gas heating (solid)

WF

$$T_s^{-1} = \frac{x_{\rm CMB} T_\gamma^{-1} + \tilde{x}_\alpha T_c^{-1} + x_c T_k^{-1}}{x_{\rm CMB} + \tilde{x}_\alpha + x_c}$$

adiabatic cooling — **heating**

$$(1+z)\frac{dT_k}{dz} = 2T_k - \frac{\mathcal{E}_{\rm Comp} + \mathcal{E}_{{\rm Ly}\alpha} J/J_0 + \mathcal{E}_{\rm CMB}}{1 + f_{\rm He} + x_{\rm e}} T_k$$

evolution equations from: Venumadhav, Dai, Kaurov, Zaldarriaga, **1804.02406**

21cm Probes New Physics

increasing 21cm absorption with new physics:

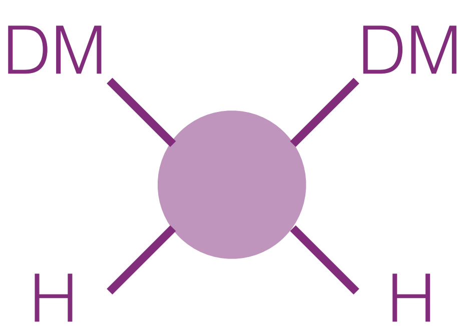
$$T_{21} \propto 1 - \frac{T_\gamma}{T_s}$$

add photons $T_\gamma > T_{\rm CMB}$

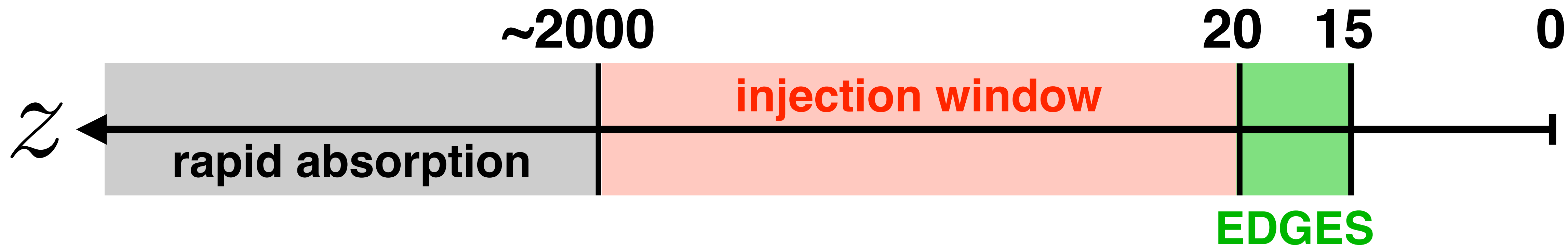
(easy!)

cool baryons*

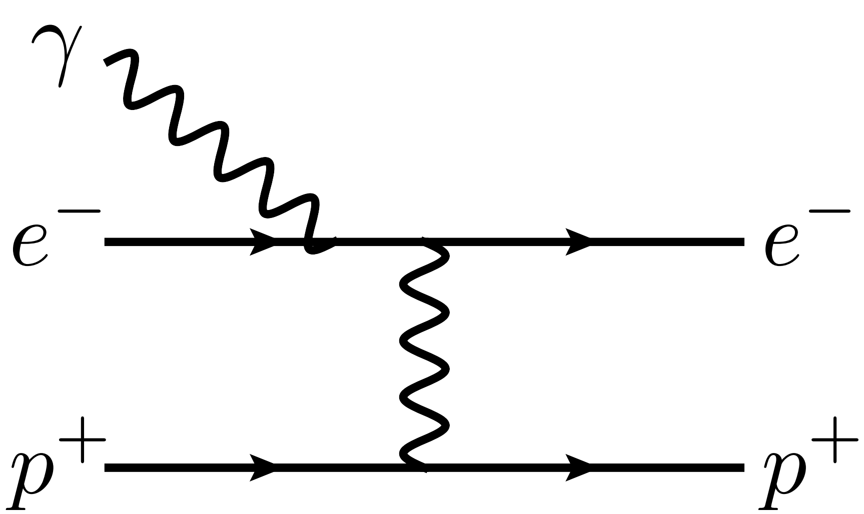
(hard)



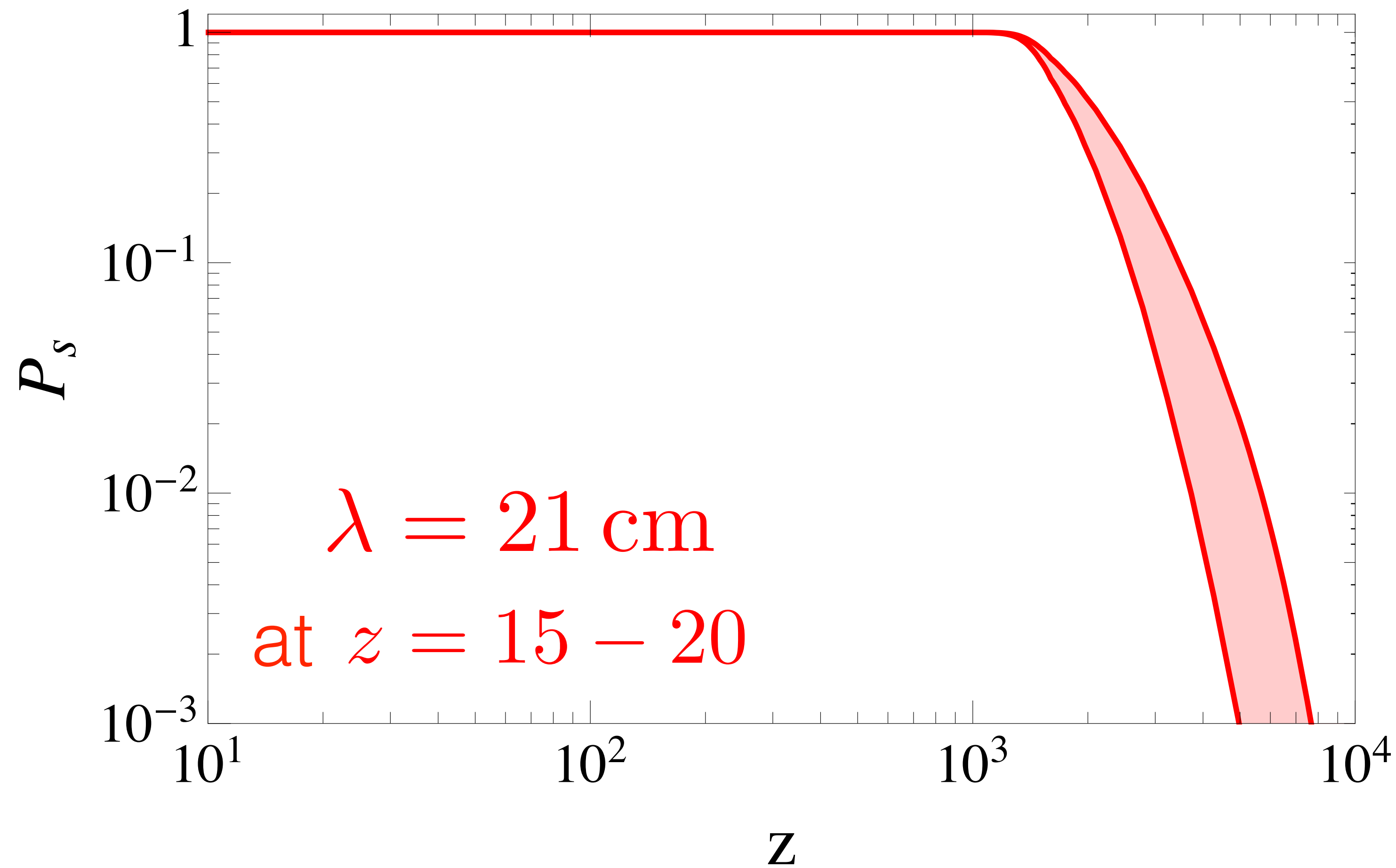
When to Add 21cm Photons



free-free absorption:



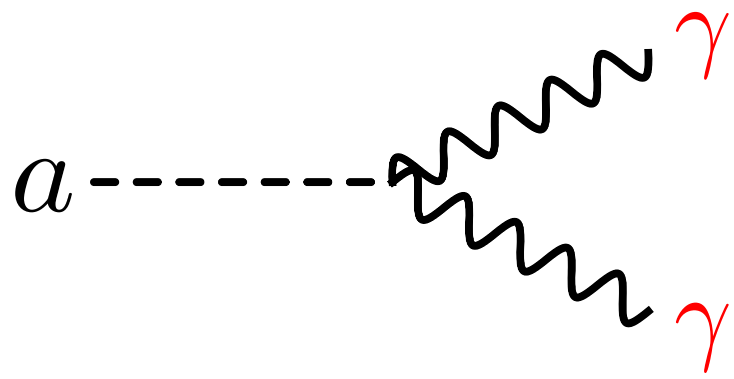
survival probability



Chluba, **1506.06582**

What if dark matter decays to photons?

ex) $\frac{1}{f}\, a\, F\tilde{F}$



$$10^{-5}\,\mathrm{eV} < m_a < 10^{-3}\,\mathrm{eV}$$

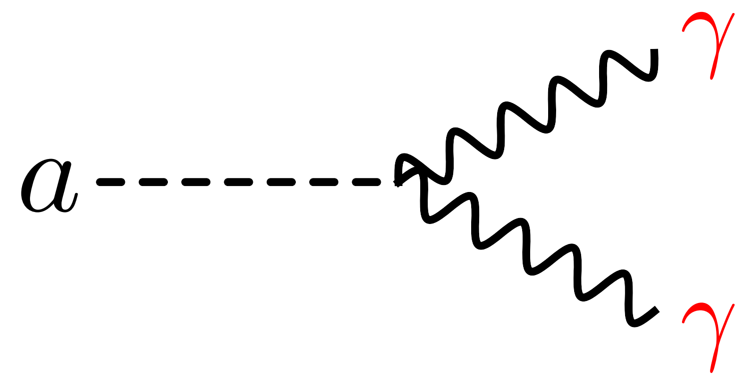
$\lambda > 21\,\mathrm{cm}$

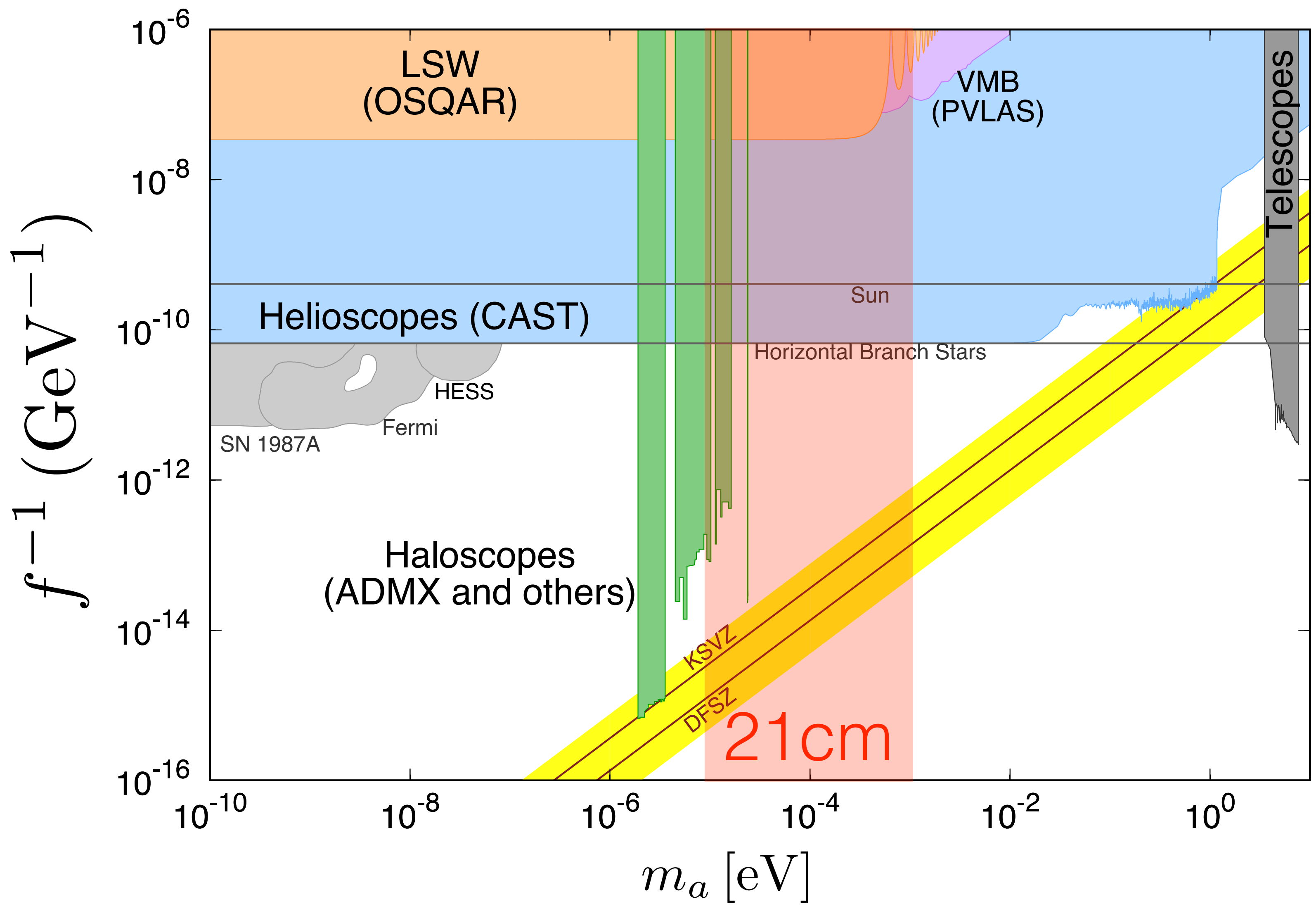
21cm photons absorbed

Fraser *et. al.*, **1803.03245**

What if dark matter decays to photons?

ex) $\frac{1}{f}\, a\, F\tilde{F}$





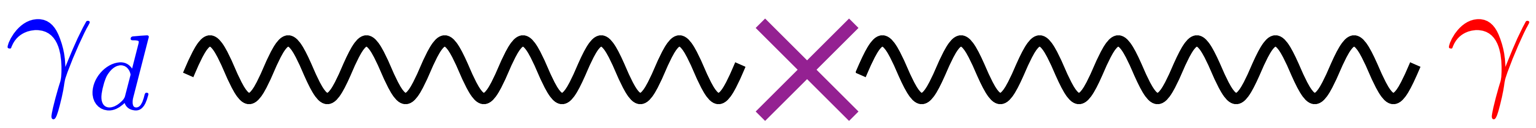
$$f > 10^{10}\ \mathrm{GeV}$$

$$\downarrow$$

$$\left.\frac{n_{a\to\gamma\gamma}}{n_\gamma^{\mathrm{CMB}}}\right|_{21\ \mathrm{cm}} \lesssim 10^{-12}$$

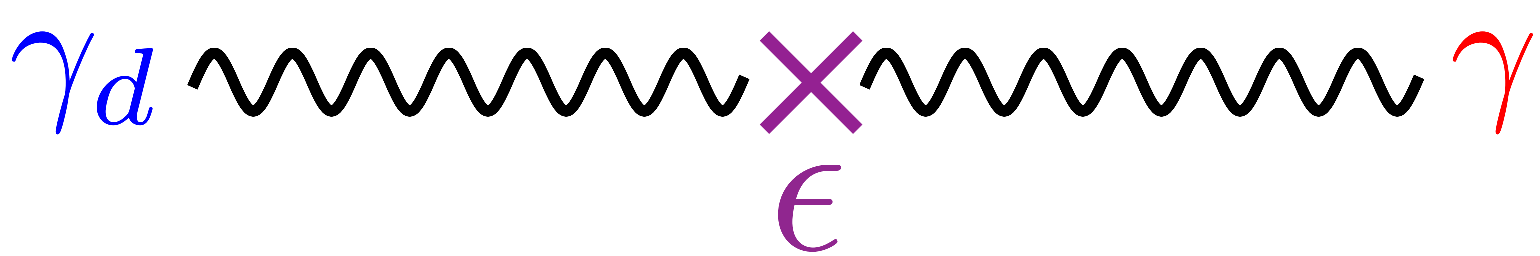
Fraser *et. al.*, **1803.03245**

II. $\gamma_d \to \gamma$



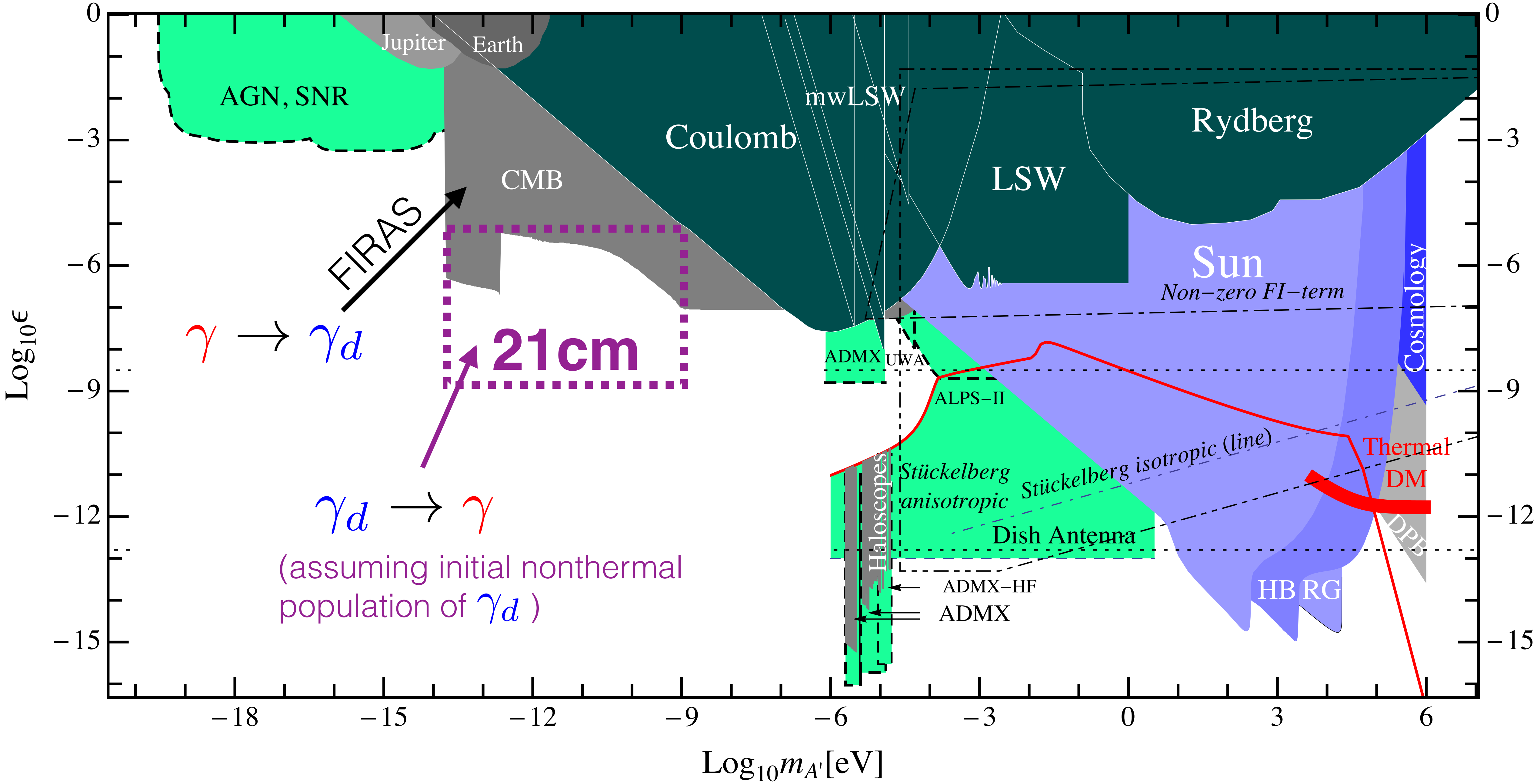
Kinetic Mixing Portal

$$-\frac{\epsilon}{2} F^{d}_{\mu\nu} F^{\mu\nu} + \frac{m^2_{\gamma_d}}{2} \gamma_d^2$$



Holdom, Phys. Lett. **166B**, 196 (1986)

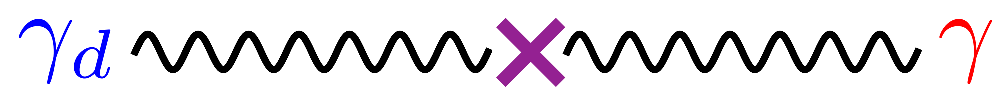
$$(\epsilon, m_{\gamma_d})$$



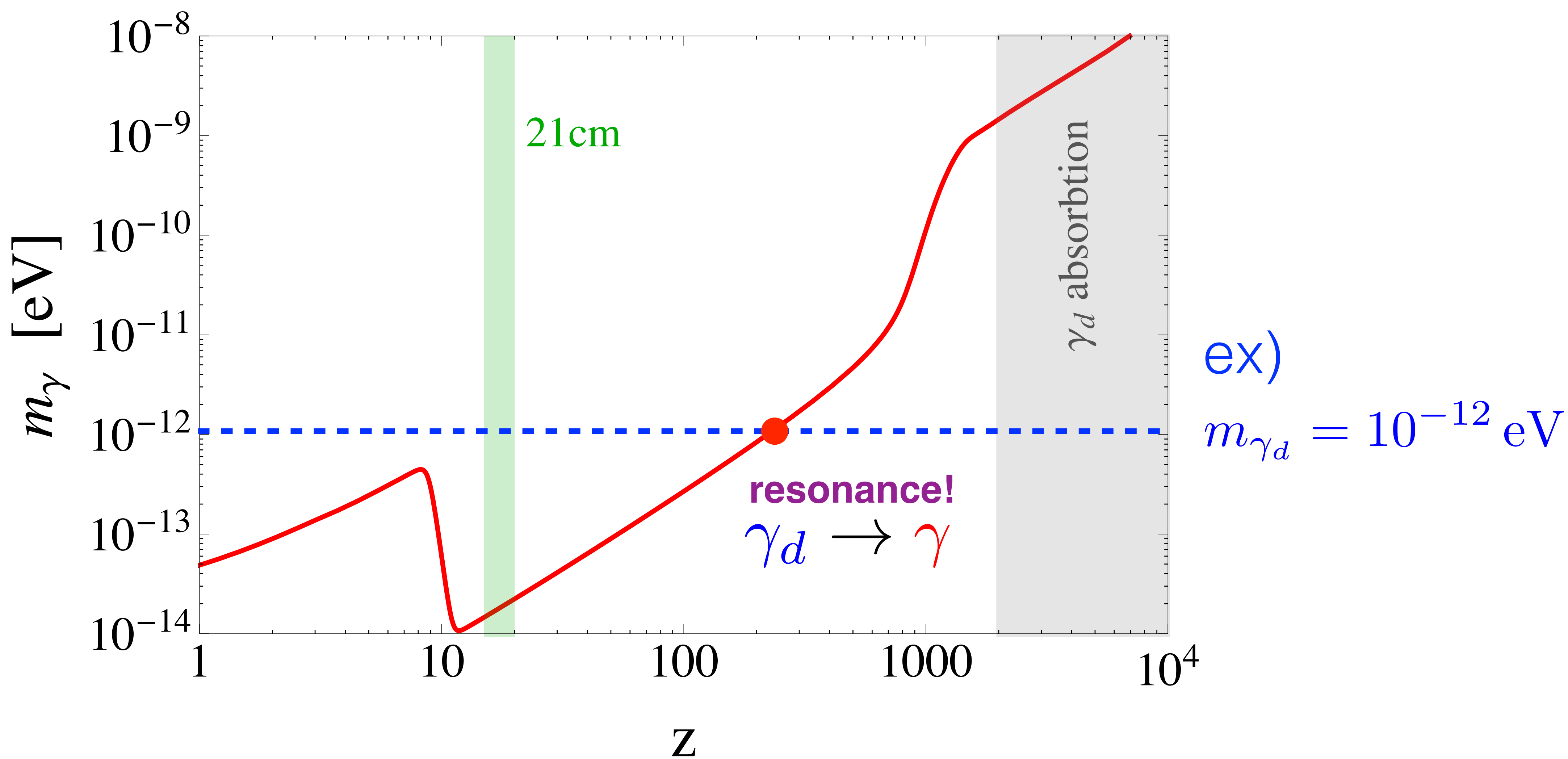
Essig *et. al.*, Snowmass, **1311.0029**

Resonant $\gamma_d \to \gamma$ Oscillations

$$m_\gamma(z) \approx m_{\gamma_d}$$



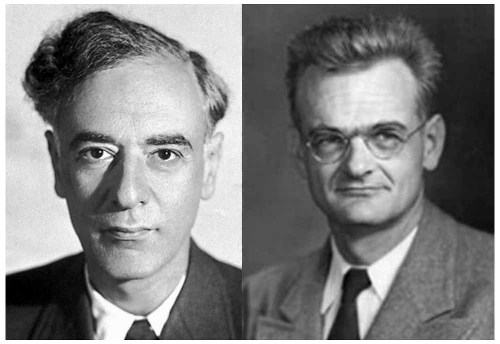
$$m_\gamma(z) = \sqrt{\frac{4\pi\alpha\, n_e(z)}{m_e}} = 1.6 \times 10^{-14}\,\mathrm{eV} \times (1+z)^{3/2} \sqrt{x_e(z)}$$



Mirizzi, Redondo, Sigl, **0901.0014**

Oscillation Probability

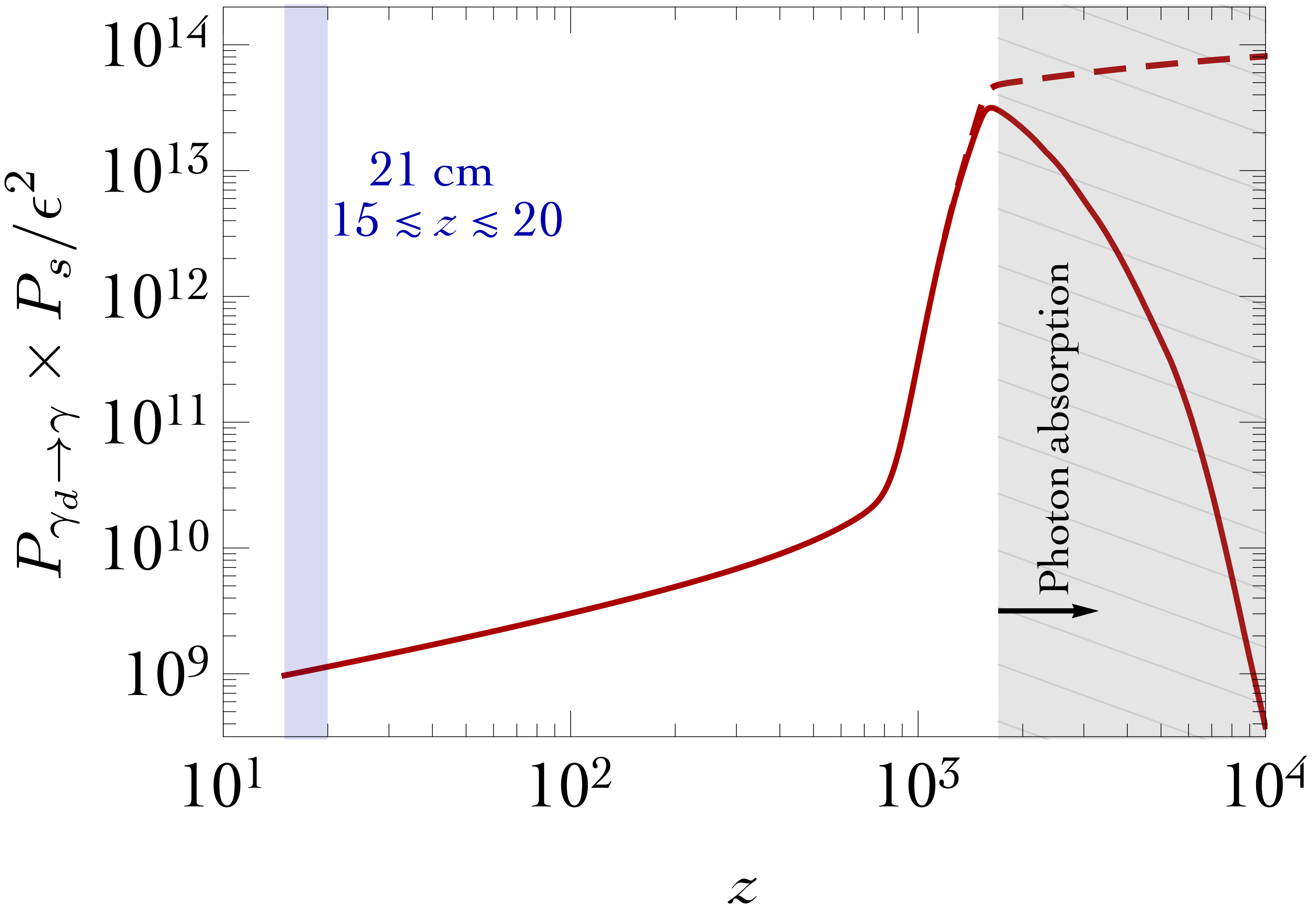
Landau-Zener formula for non-adiabatic level crossing



$$P_{\gamma_d \to \gamma} = \frac{\pi \epsilon^2 m_{\gamma_d}^2}{\omega} \left| \frac{d \log m_\gamma^2}{dt} \right|^{-1}$$

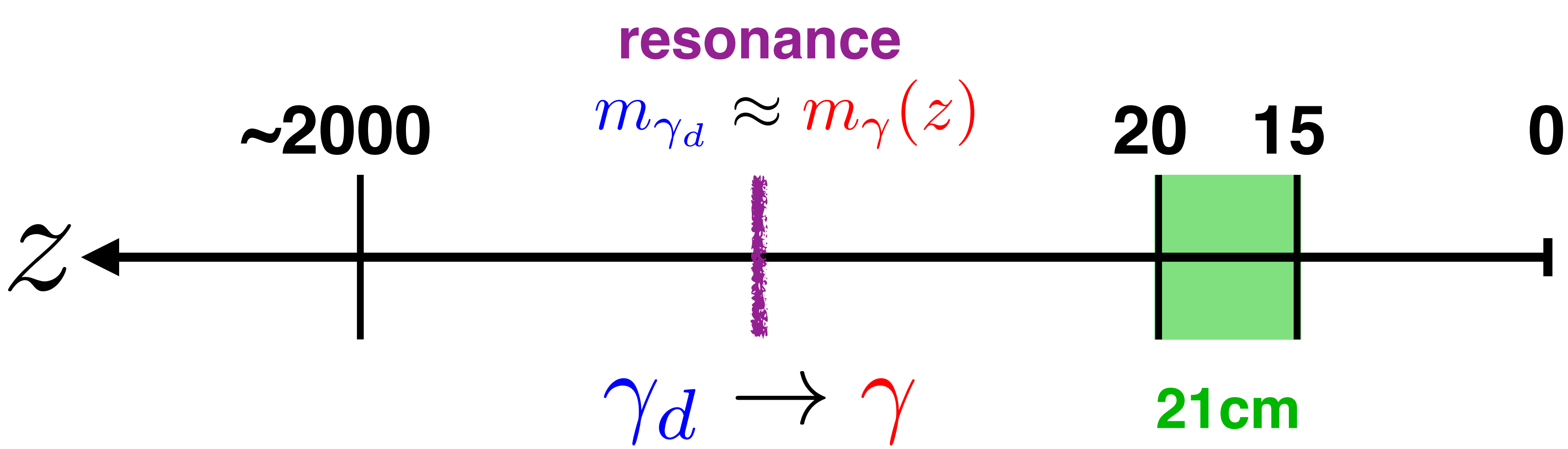
$$\propto \frac{m_{\gamma_d}^2}{\omega H_0} z^{-5/2} \epsilon^2$$

$10^{-33}\,\mathrm{eV}$



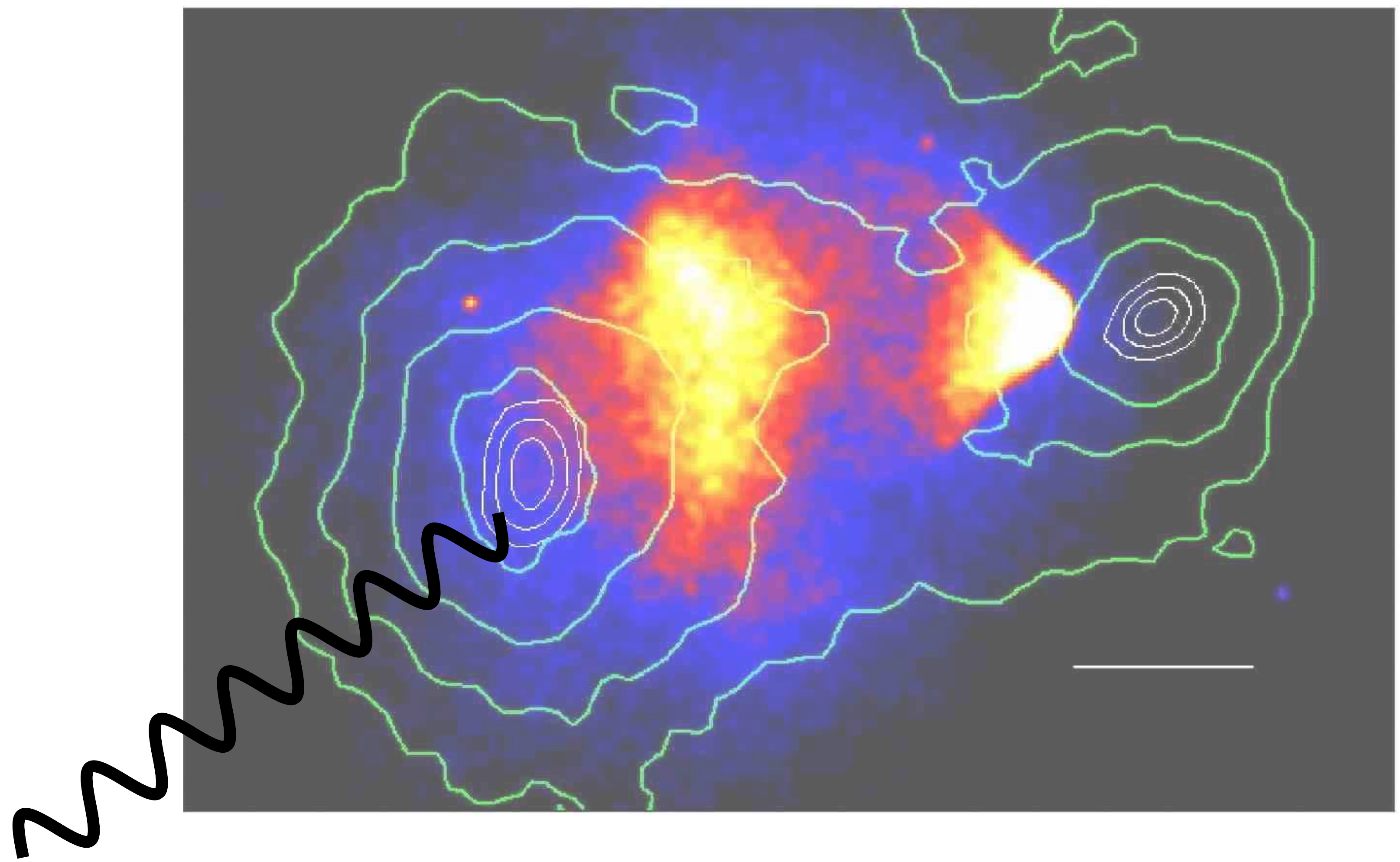
Mirizzi, Redondo, Sigl, **0901.0014**

Summary so Far

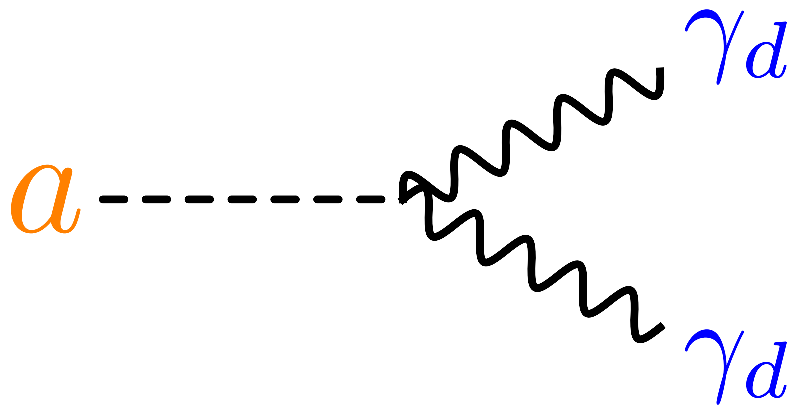


need: nonthermal population of γ_d during the dark ages

III. γ_d from Decaying Dark Matter



Dark Matter Decays to Dark Photons



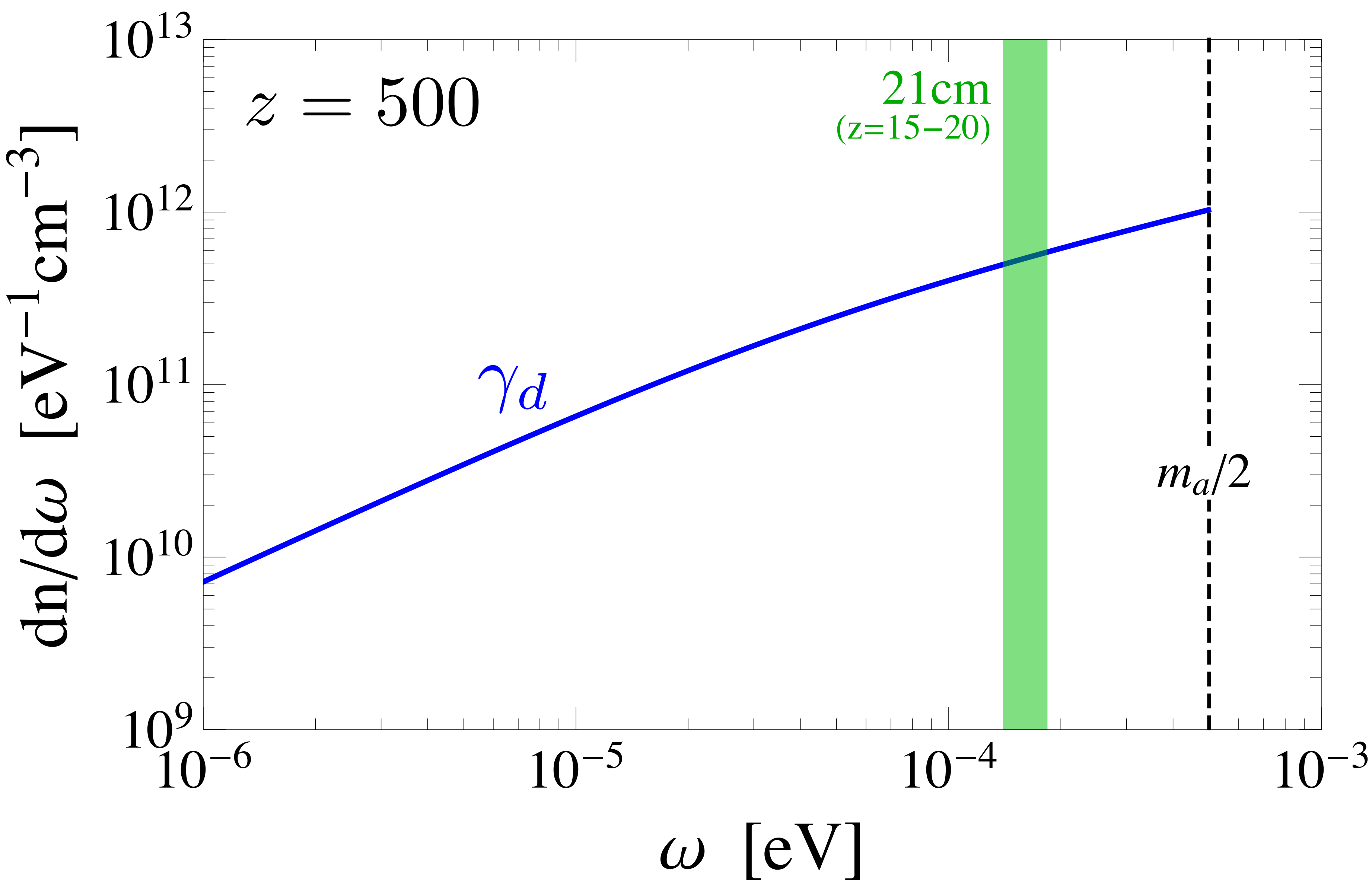
$$\frac{1}{f} a F_d \tilde{F}_d$$

ex)

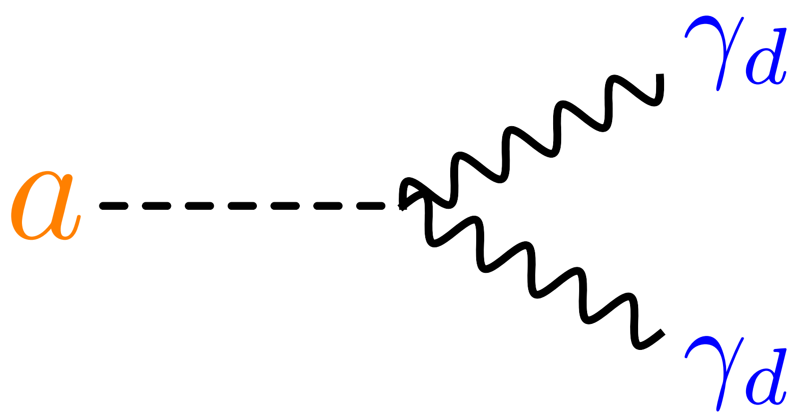
$m_a = 10^{-3}\,\mathrm{eV}$

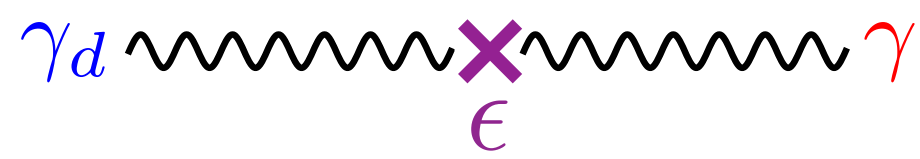
$f = 600\,\mathrm{GeV}$

$\tau_a = 1.4 \times 10^{12}\,\mathrm{y}$



Dark Matter Decays to Dark Photons





ex)

$m_a = 10^{-3}\,\mathrm{eV}$

$f = 600\,\mathrm{GeV}$

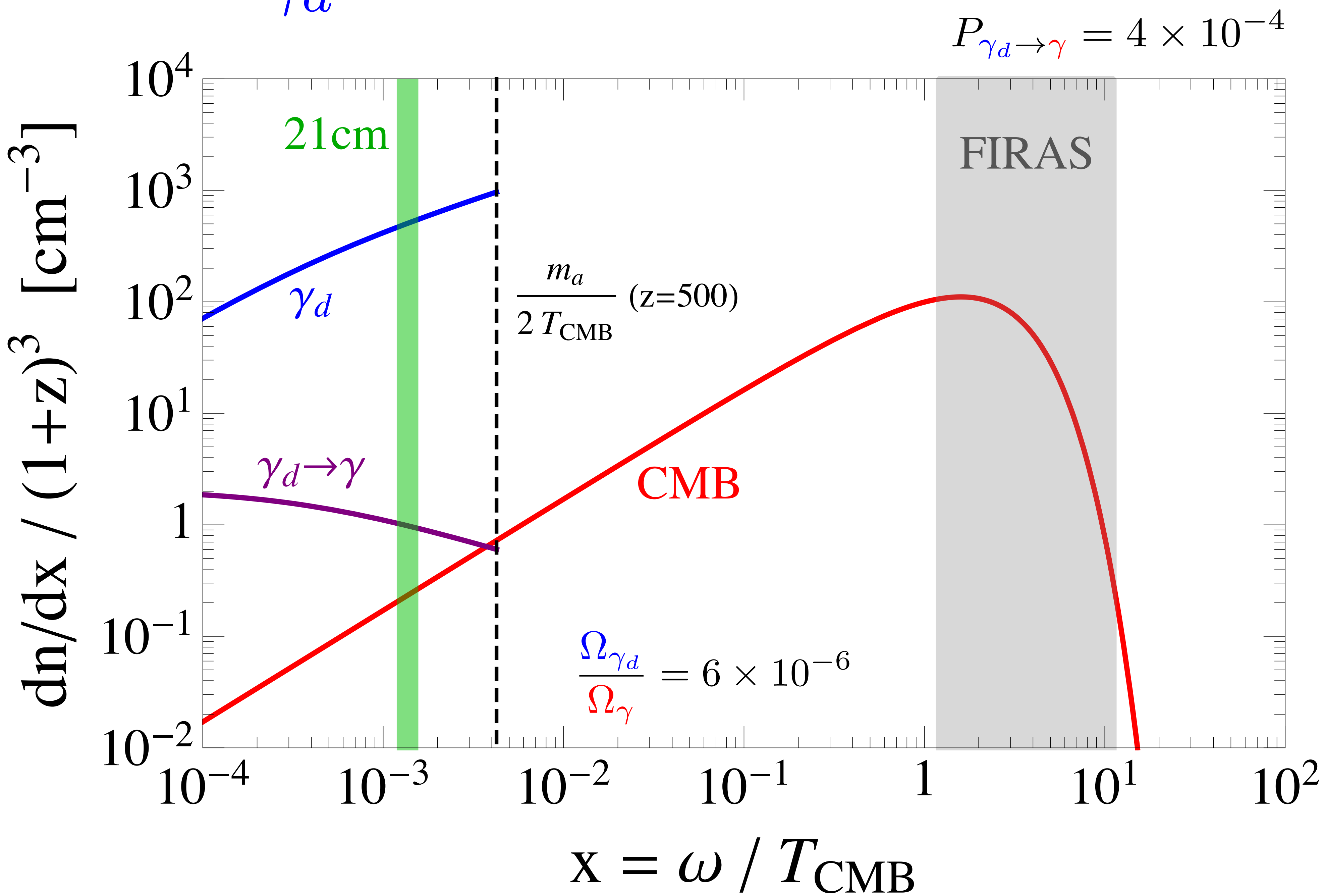
$m_{\gamma_d} = 5 \times 10^{-12}\,\mathrm{eV}$

$\epsilon = 4 \times 10^{-7}$

↓

$\tau_a = 1.4 \times 10^{12}\,\mathrm{y}$

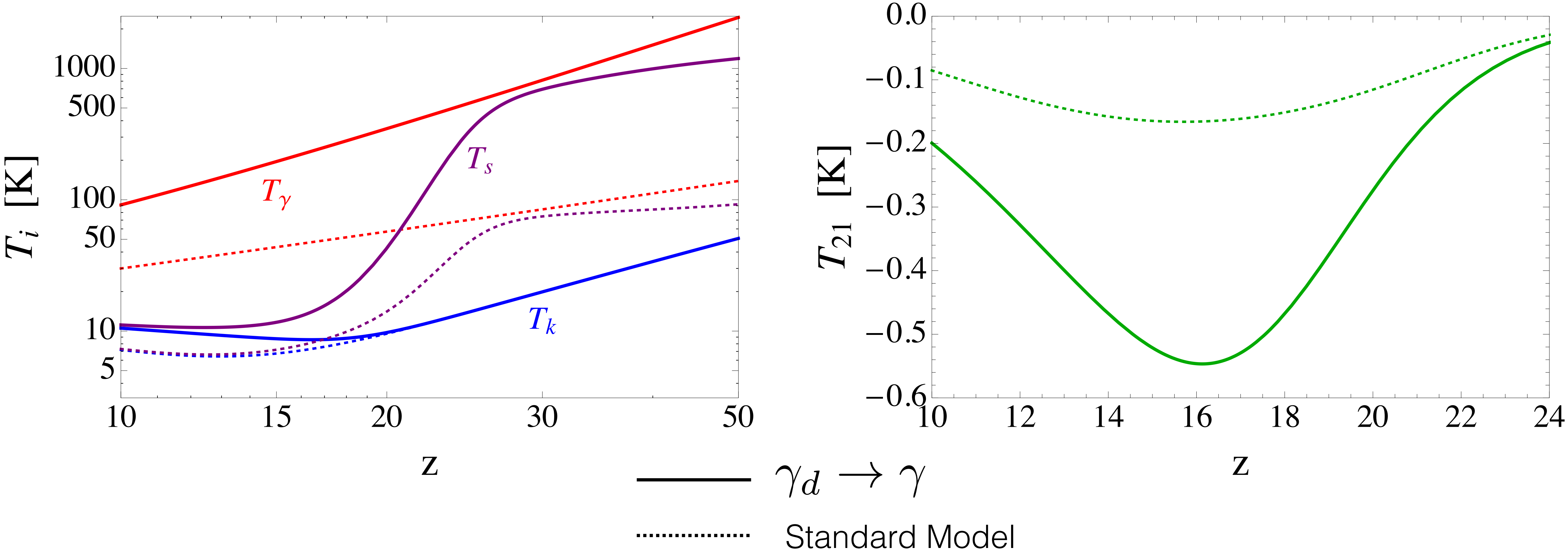
$z_{\rm res} = 500$



Temperatures and Absorption

temperature evolution

21cm absorption



WF

$$T_s^{-1} = \frac{x_{\rm CMB} T_\gamma^{-1} + \tilde{x}_\alpha T_c^{-1} + x_c T_k^{-1}}{x_{\rm CMB} + \tilde{x}_\alpha + x_c}$$

adiabatic cooling **heating**

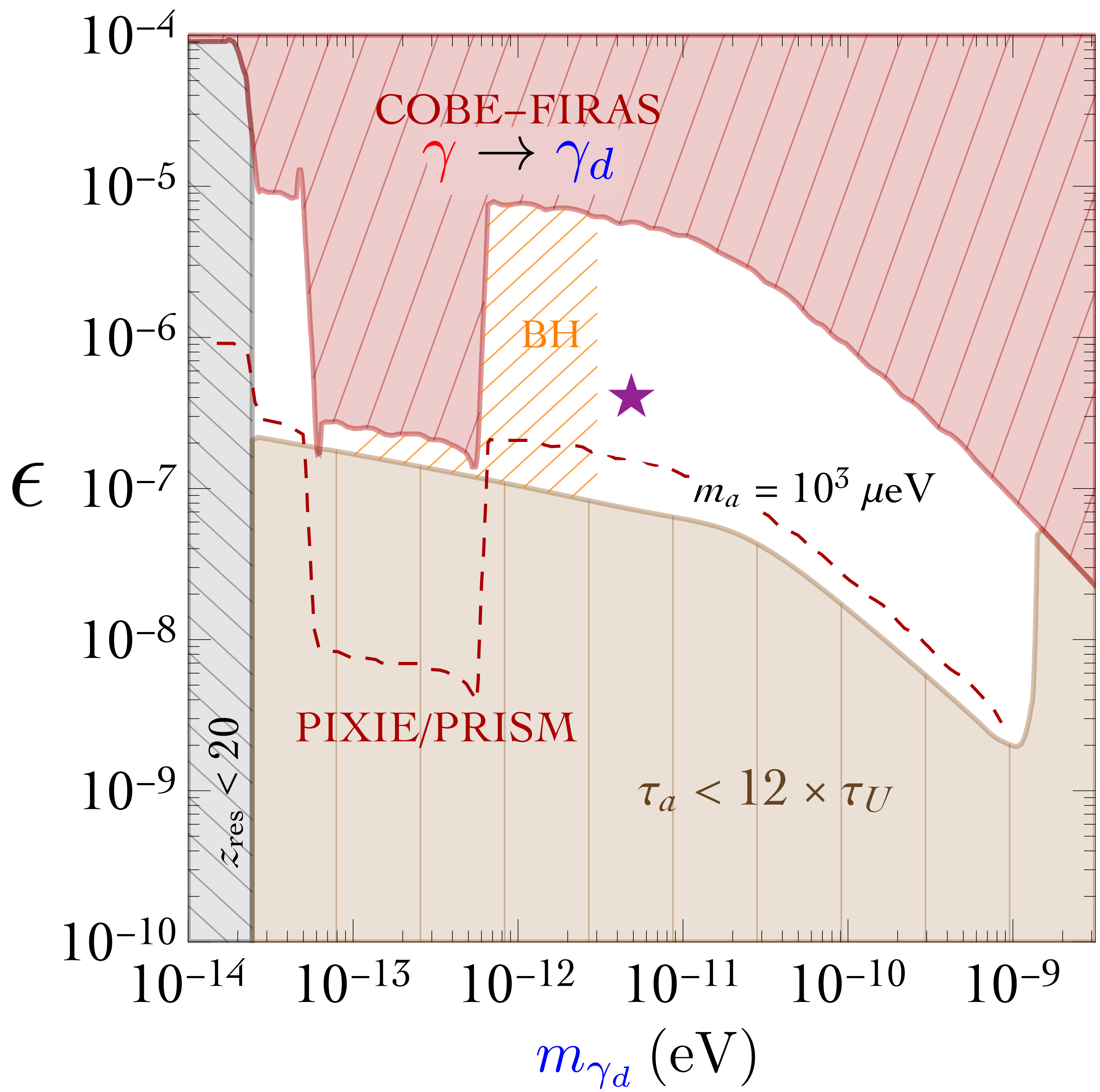
$$(1+z)\frac{dT_k}{dz} = 2T_k - \frac{\mathcal{E}_{\rm Comp} + \mathcal{E}_{\rm Ly\alpha} J/J_0 + \mathcal{E}_{\rm CMB}}{1 + f_{\rm He} + x_{\rm e}} T_k$$

evolution equations from: Venumadhav, Dai, Kaurov, Zaldarriaga, **1804.02406**

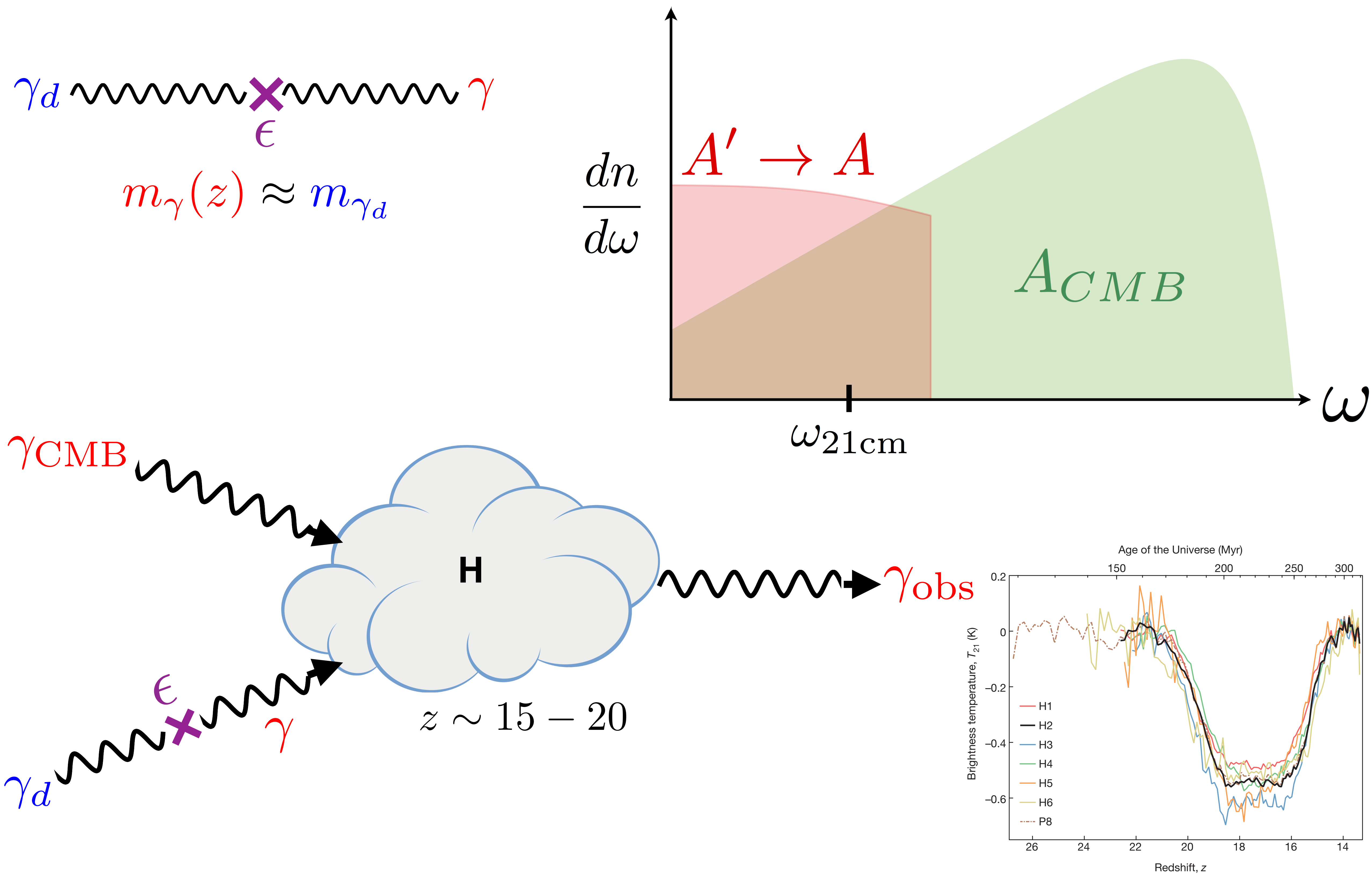
21cm from Dark Photon: Parameter Space

$m_a = 10^{-3}\,\mathrm{eV}$

choose τ_a
such that $n_{\gamma_d \to \gamma} = n_{\mathrm{CMB}}$
at 21cm



Take Away



γ_d
ϵ
γ
$m_\gamma(z) \approx m_{\gamma_d}$
$\frac{dn}{d\omega}$
$A' \to A$
A_{CMB}
ω
$\omega_{21\mathrm{cm}}$
γ_{CMB}
H
γ_{obs}
$z \sim 15 - 20$
ϵ
γ
γ_d
Age of the Universe (Myr)
150
200
250
300
0.2
0
−0.2
−0.4
−0.6
Brightness temperature, T_{21} (K)
H1
H2
H3
H4
H5
H6
P8
26
24
22
20
18
16
14
Redshift, z