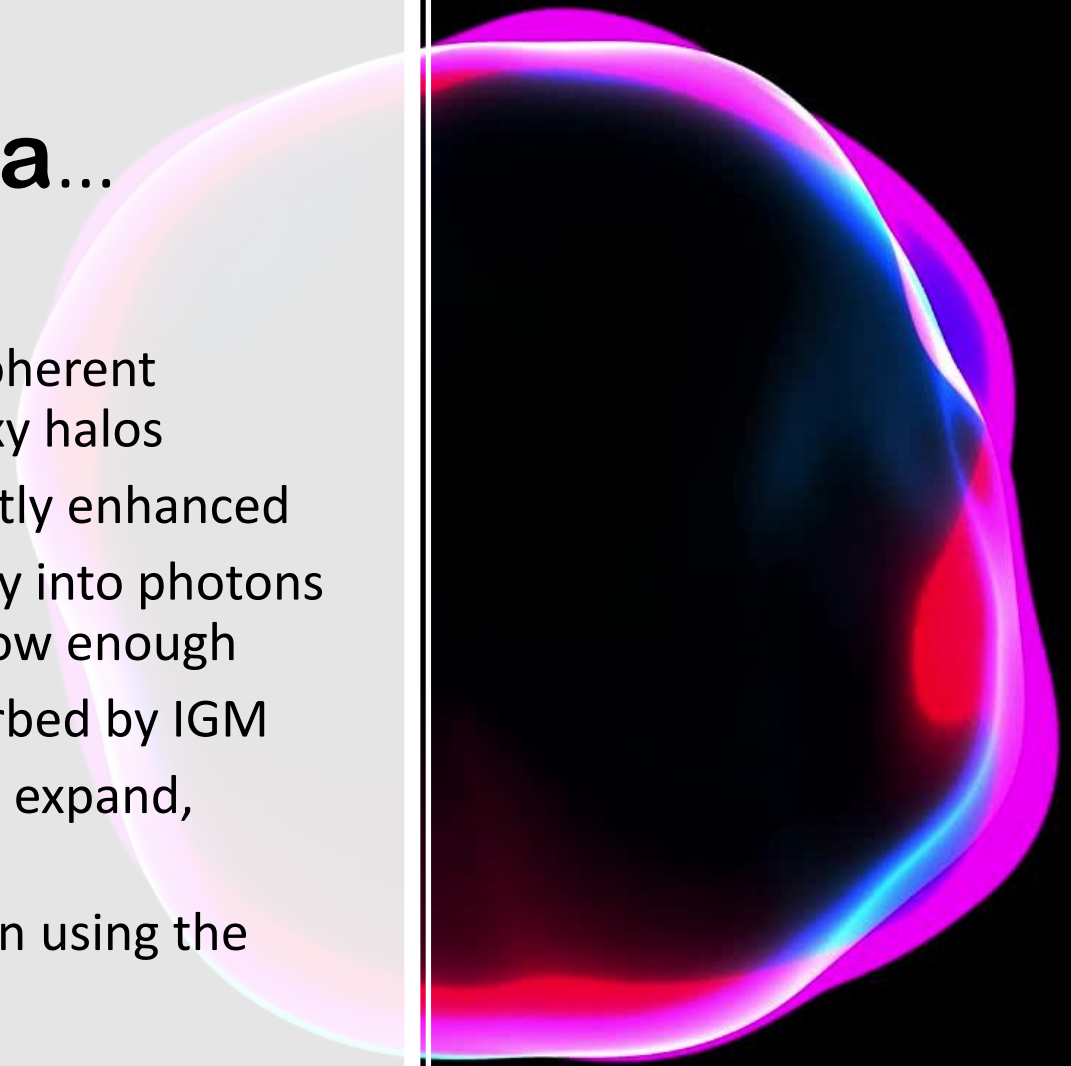
Axion Star Explosions: A New Source for Axion Indirect Detection

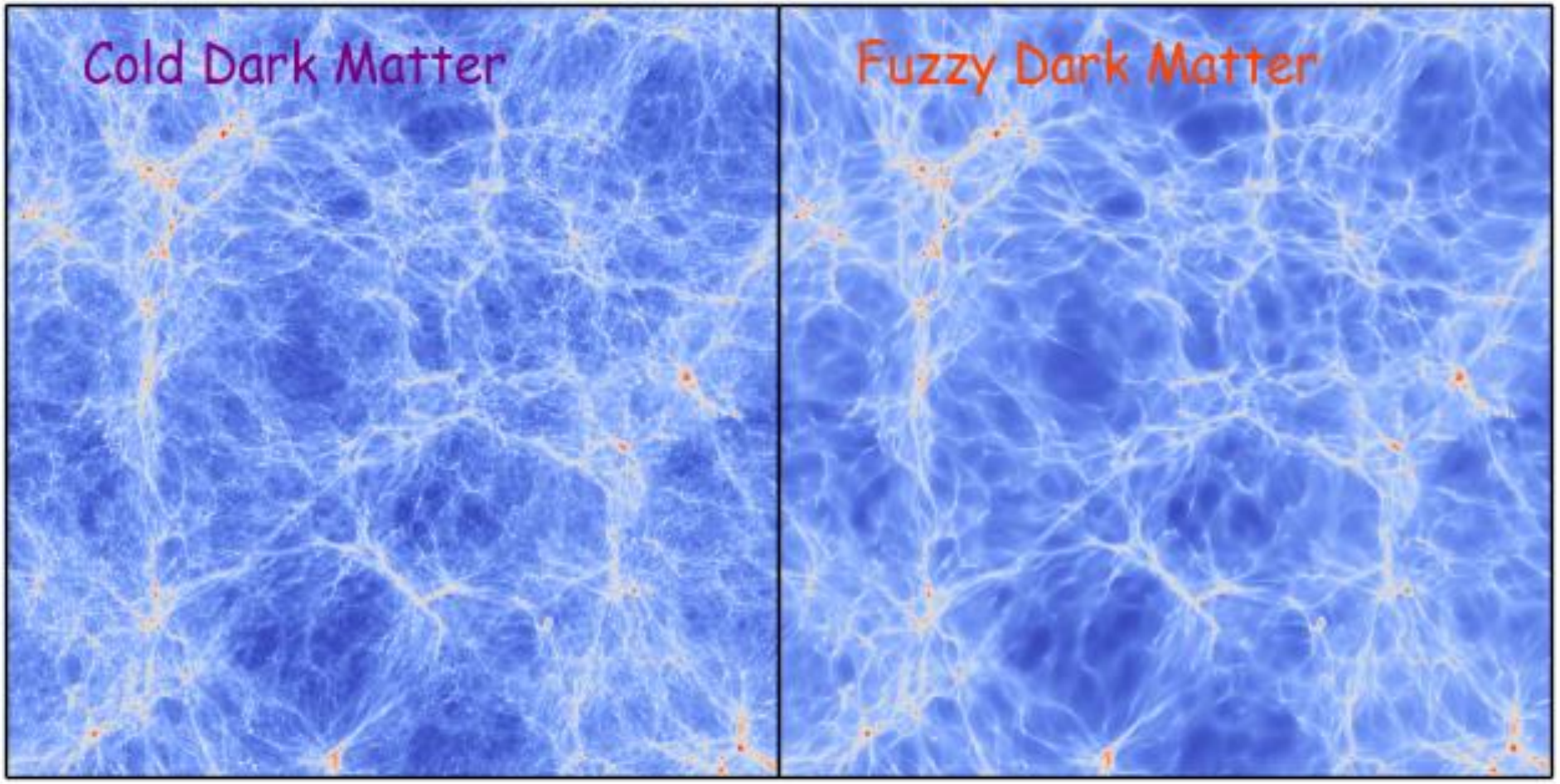
Malcolm Fairbairn

With Xiaolong Du, Charis Pooni, Miguel Escudero, Doddy Marsh & Diego Blas

Here is the Idea…

- Light dark matter forms coherent solitonic cores inside galaxy halos
- Decay to photons resonantly enhanced
- Dense cores partially decay into photons when electron density is low enough
- Low energy photons absorbed by IGM
- Shock bubbles form which expand, ionising the Universe
- We constrain the ionisation using the CMB

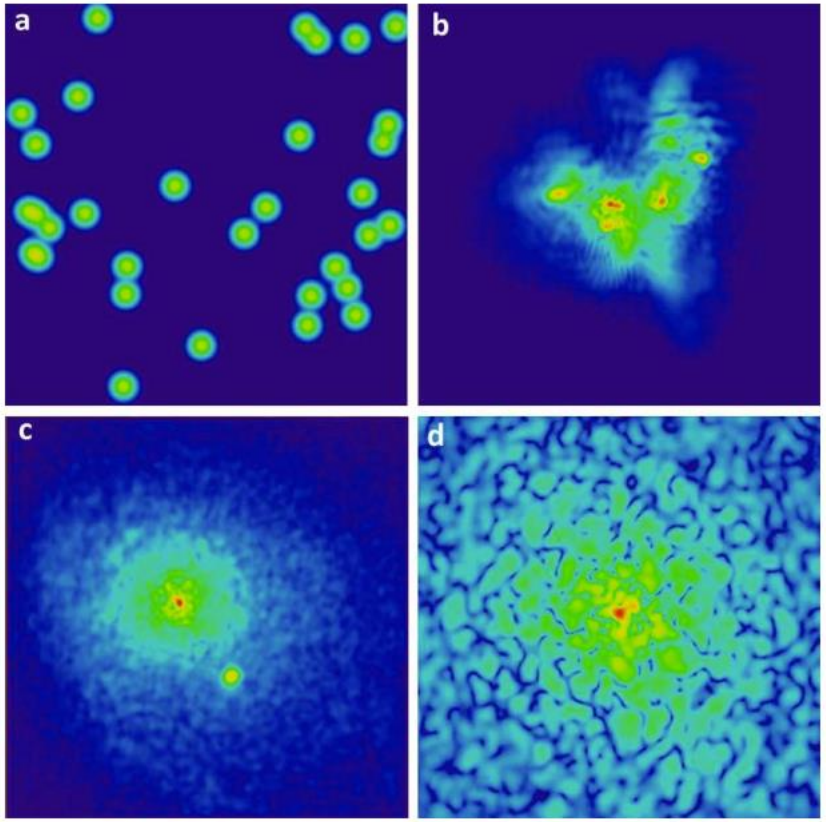


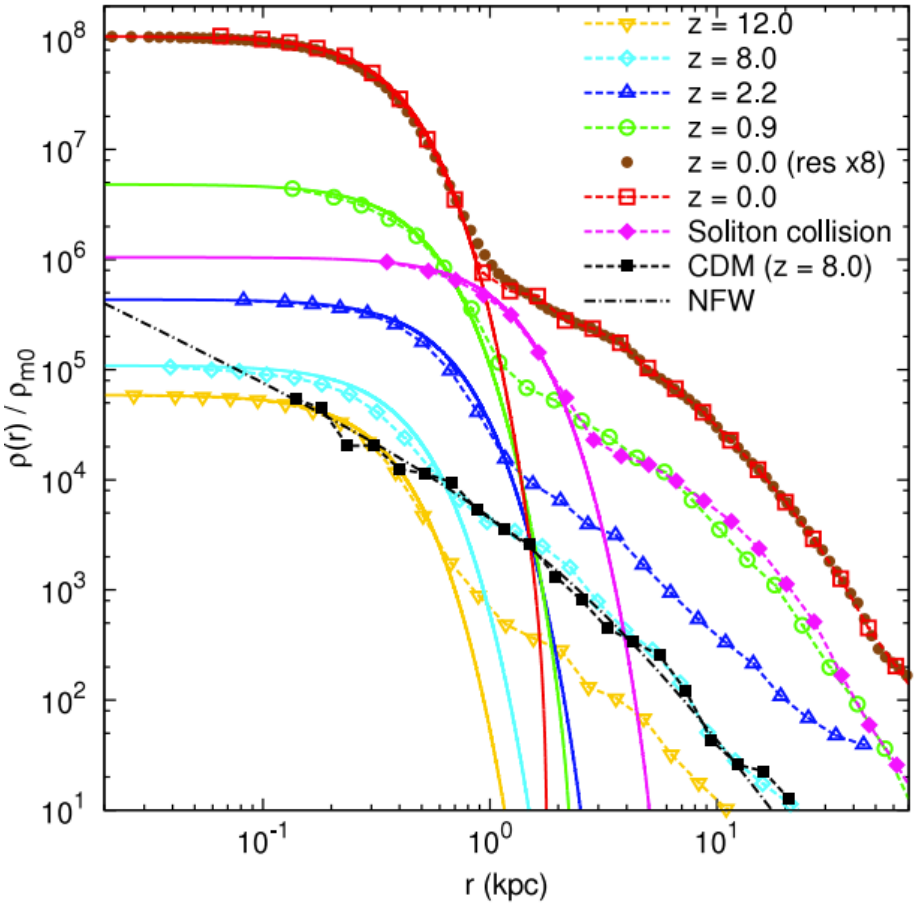


$$i\hbar\frac{\partial\psi}{\partial t} = -\frac{\hbar^2}{2ma^2}\nabla^2\psi + \frac{m\Phi}{a}\psi$$

$$\nabla^2\Phi = 4\pi G m(|\psi|^2 - \langle|\psi|^2\rangle)$$

Fuzzy Halos form Solitonic Cores





$$M_c = \frac{1}{4} a^{-1/2} \left(\frac{\zeta(z)}{\zeta(0)}\right)^{1/6} \left(\frac{M_h}{M_{min,0}}\right)^{1/3} M_{min,0}$$

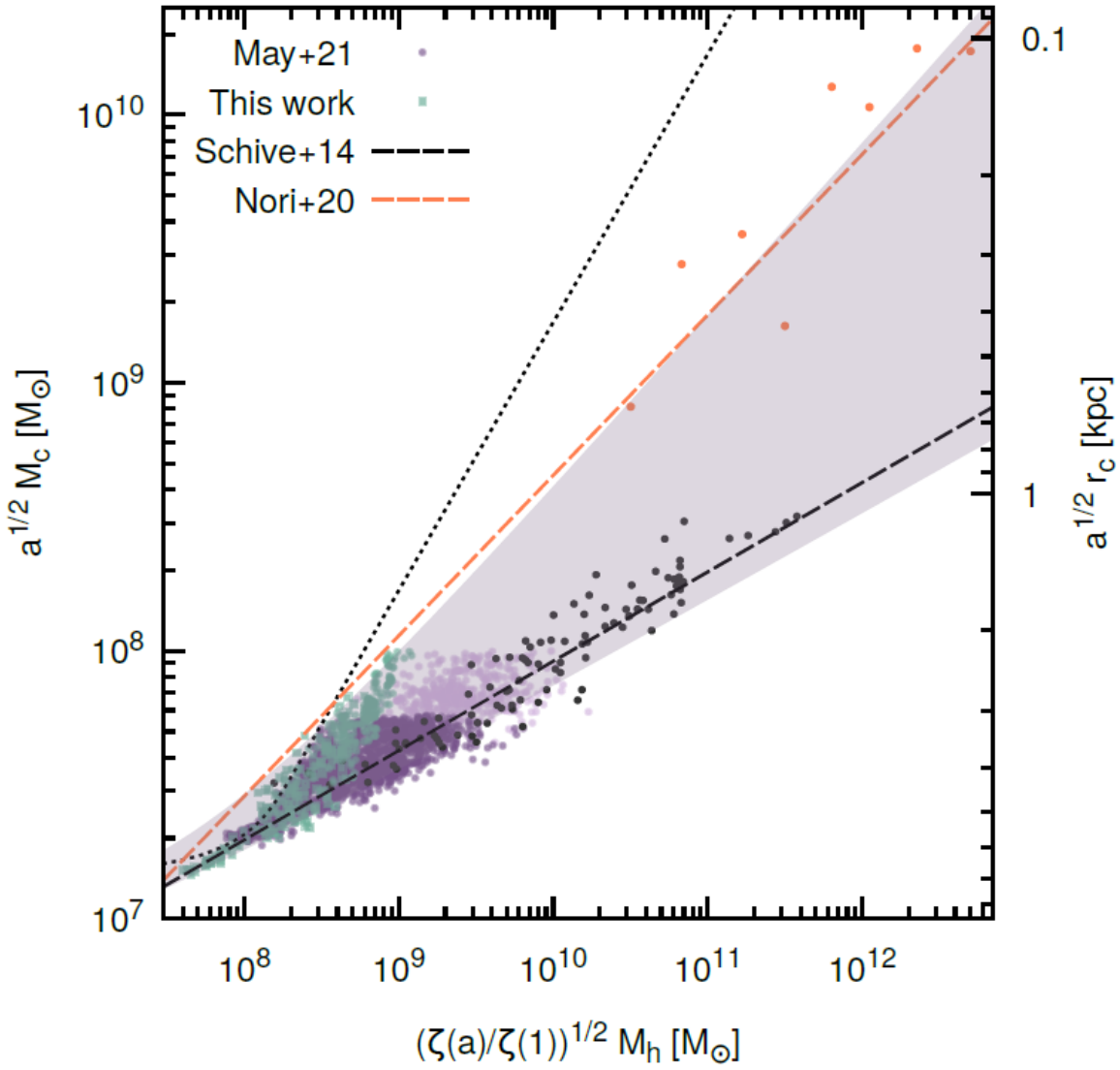
$$M_{\rm min,0} \sim 4.4 \times 10^7 (mc^2/(10^{-22}\,{\rm eV}))^{-3/2} {\rm M}_\odot$$

$$r_c = 1.6\ m_{22}^{-1} a^{1/2} \left(\frac{\zeta(z)}{\zeta(0)}\right)^{-1/6} \left(\frac{M_h}{10^9\ M_\odot}\right)^{-1/3} \ {\rm kpc}$$

Schive et al 2014

$$M_c = \frac{\sqrt{1+z}}{4}\left[\frac{\zeta(z)^{1/2}}{\zeta(z=0)^{1/2}}\frac{M_h}{M_h^{\min}}\right]^{\alpha} M_h^{\min}$$

IMPORTANT PARAMETER RELATES CORE MASS TO HALO MASS



Schive et al found α=1/3

This more recent work (Chan, Ferreira, May, Hayashi & Chiba) finds that α=3/5

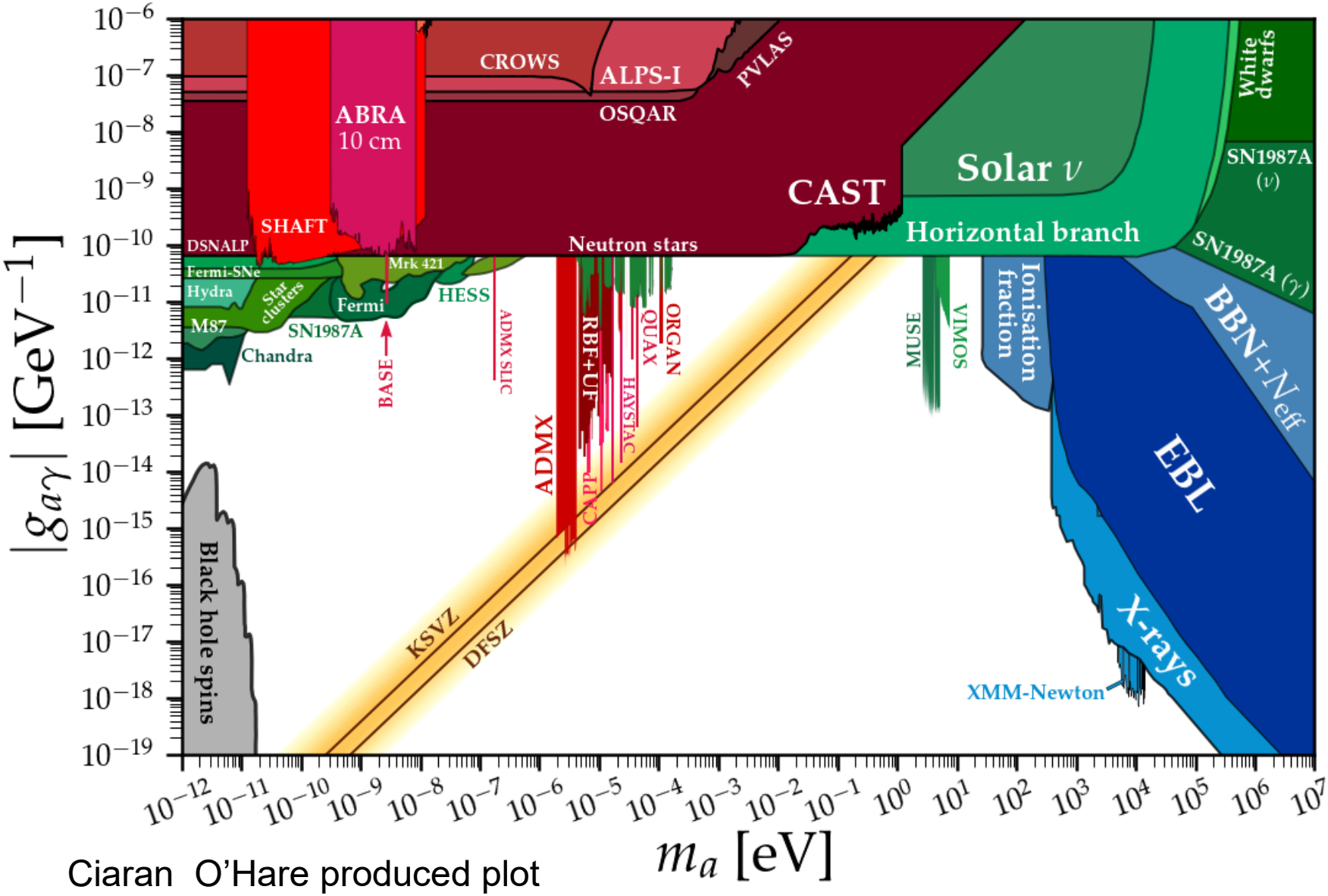
Coupling to Photons

If the fuzzy dark matter is an axion then there can also an induced coupling to photons.

$$\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) - \frac{g_{a\gamma\gamma}}{4}\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$$

Bounds on axion-photon coupling

$$g_{a\gamma\gamma} < 0.66 \times 10^{-10}\,\mathrm{GeV}^{-1} \text{ for } m_a < 0.02\,\mathrm{eV}$$



Ciaran O'Hare produced plot

Concentrate on parametric resonance

Stimulated emission exponentially enhances decay

$$\Gamma_{\rm exp}\, L \gtrsim 1\,, \qquad \text{where} \qquad \Gamma_{\rm exp} \equiv g_{a\gamma\gamma}\sqrt{\frac{\rho_a}{2}}$$

Translates into halos with a certain minimum mass

$$M_S^{\rm decay} \simeq 8.4\times 10^{-5}\, M_\odot \left(\frac{10^{-11}\,{\rm GeV}^{-1}}{g_{a\gamma\gamma}}\right)\left(\frac{10^{-13}\,{\rm eV}}{m_a}\right)$$

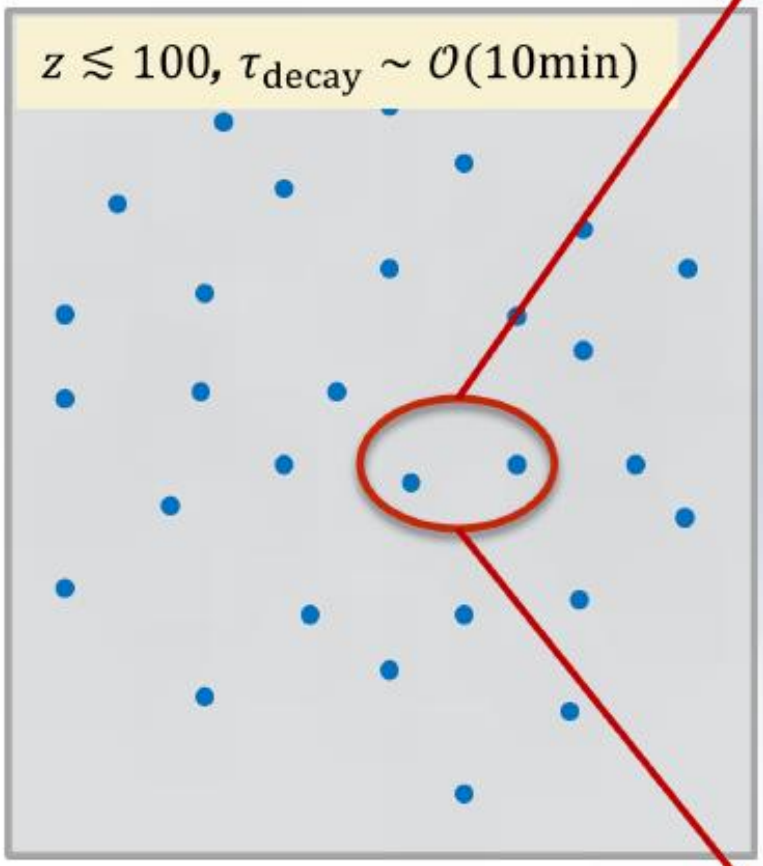
And it doesn't take long to happen…

$$\tau_S^{\rm decay} \simeq r_c \simeq {\rm day}\left(\frac{8.4\times 10^{-5} M_\odot}{M_S}\right)\left(\frac{10^{-13}\,{\rm eV}}{m_a}\right)^2$$

Levkov, Tkachev et al.

Energy Density of Critical Solitons

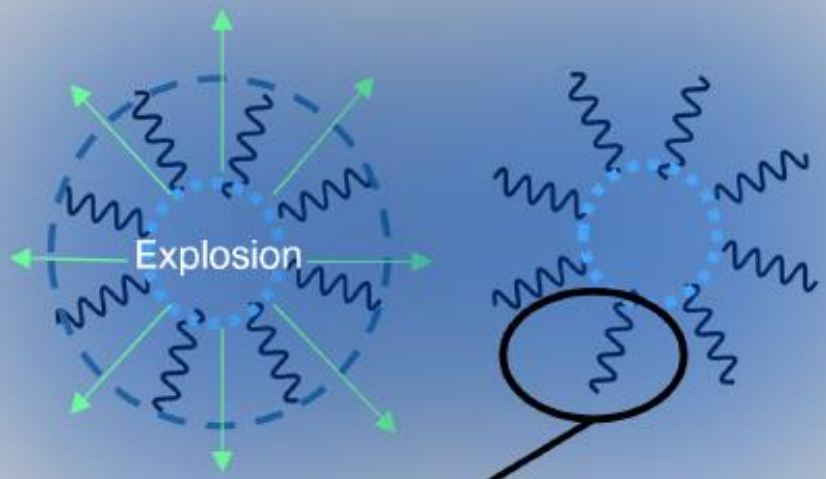
(Du et., al 2023)



Emission of photons into IGM

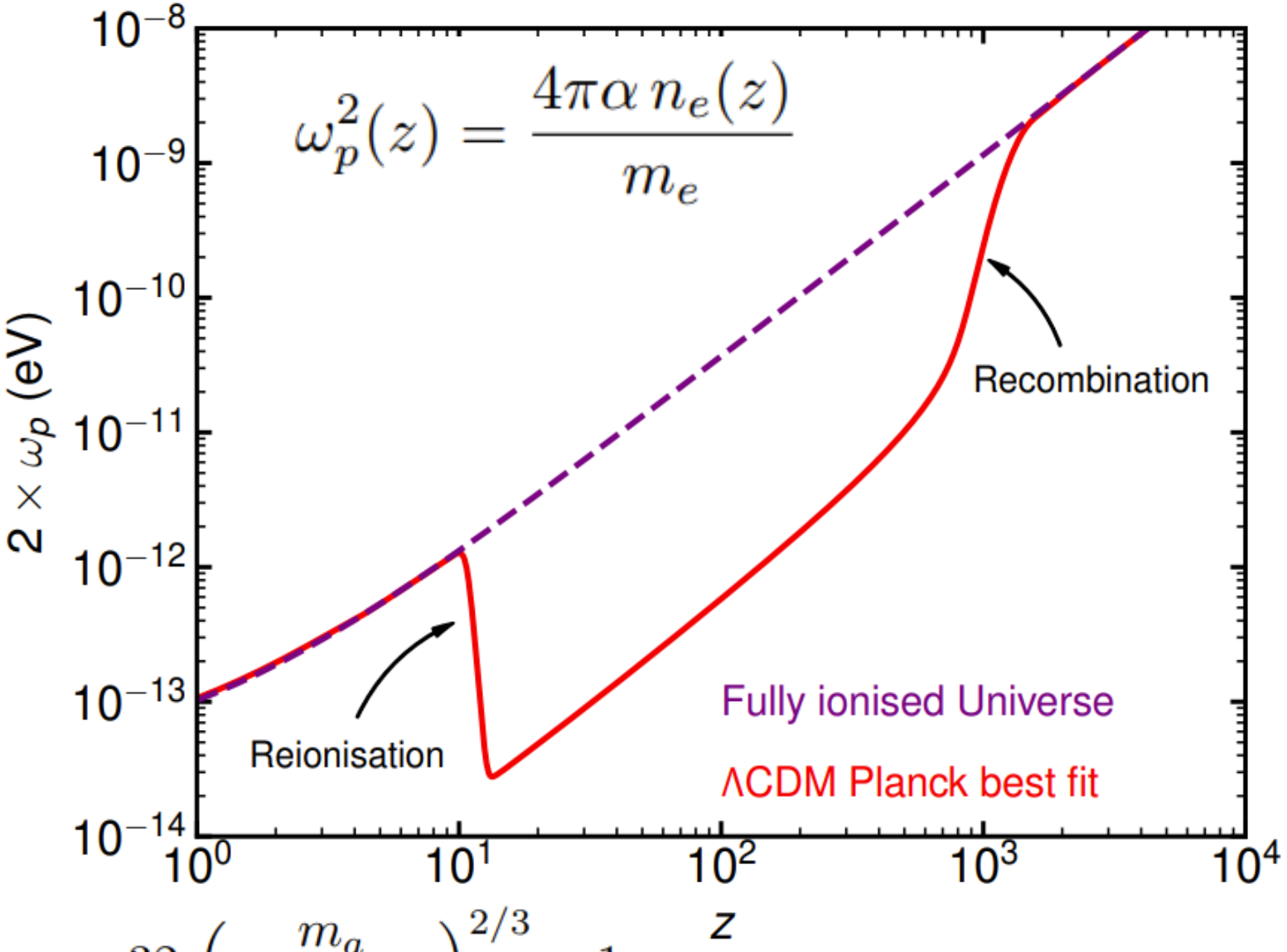
$[E \gtrsim 10^{-4} M_\odot]$

Axion stars decay into photons with energy $E_\gamma = m_a/2$



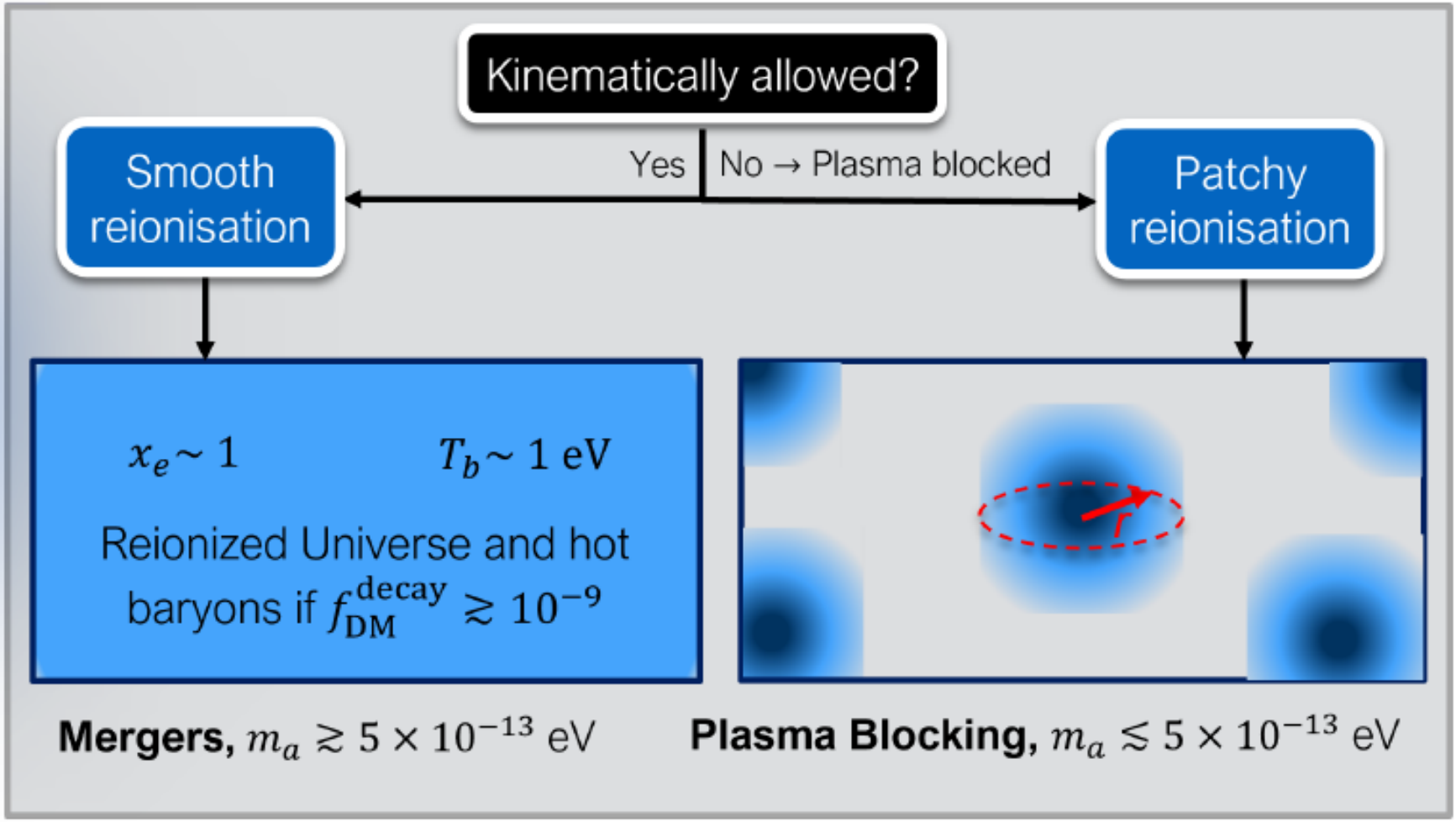
Photons undergo inverse Bremsstrahlung absorption

Photon Effective Mass can prevent Decay!

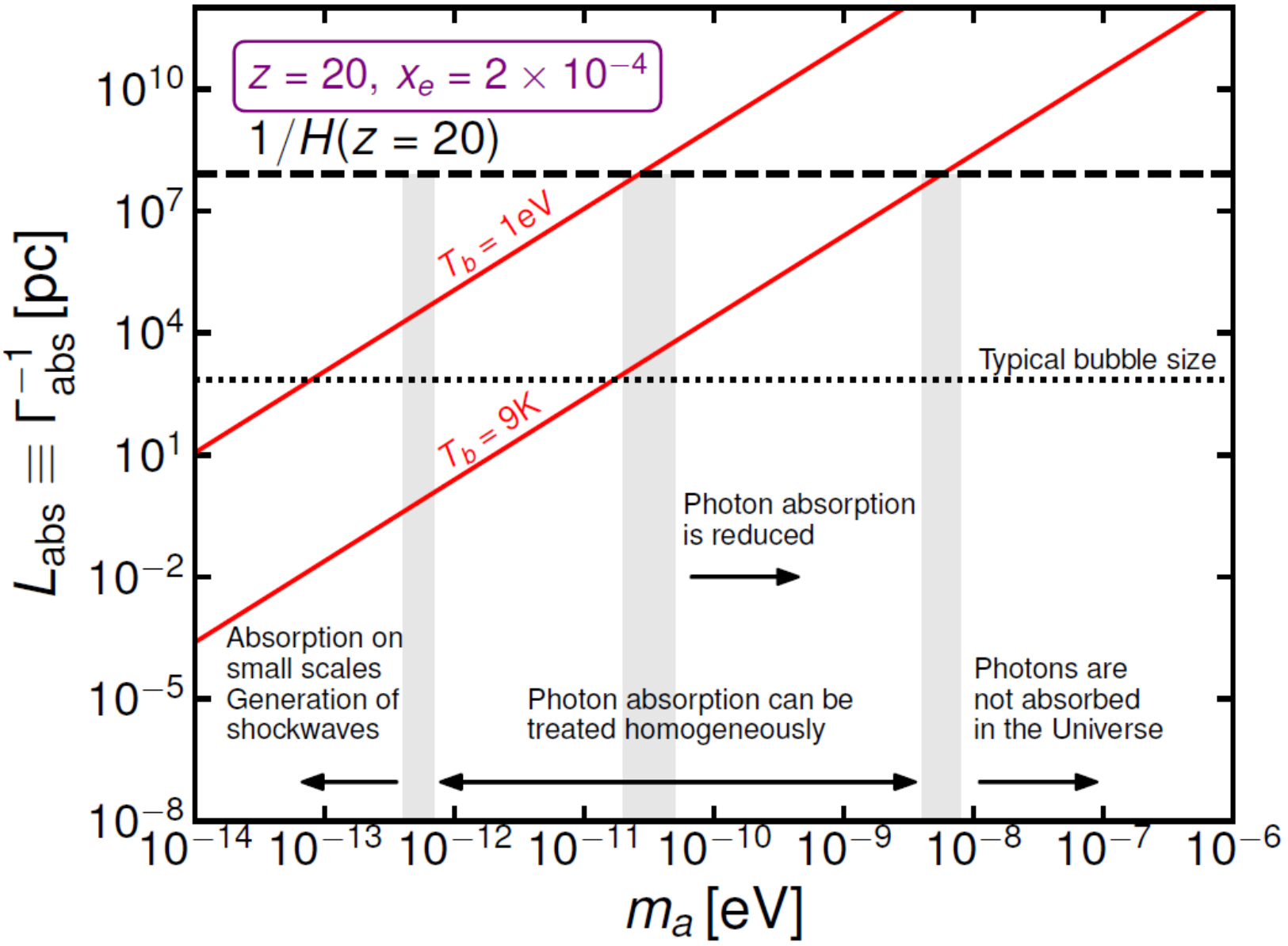


$$z_{\rm decay} \simeq 32 \left(\frac{m_a}{10^{-13}\,{\rm eV}}\right)^{2/3} - 1$$

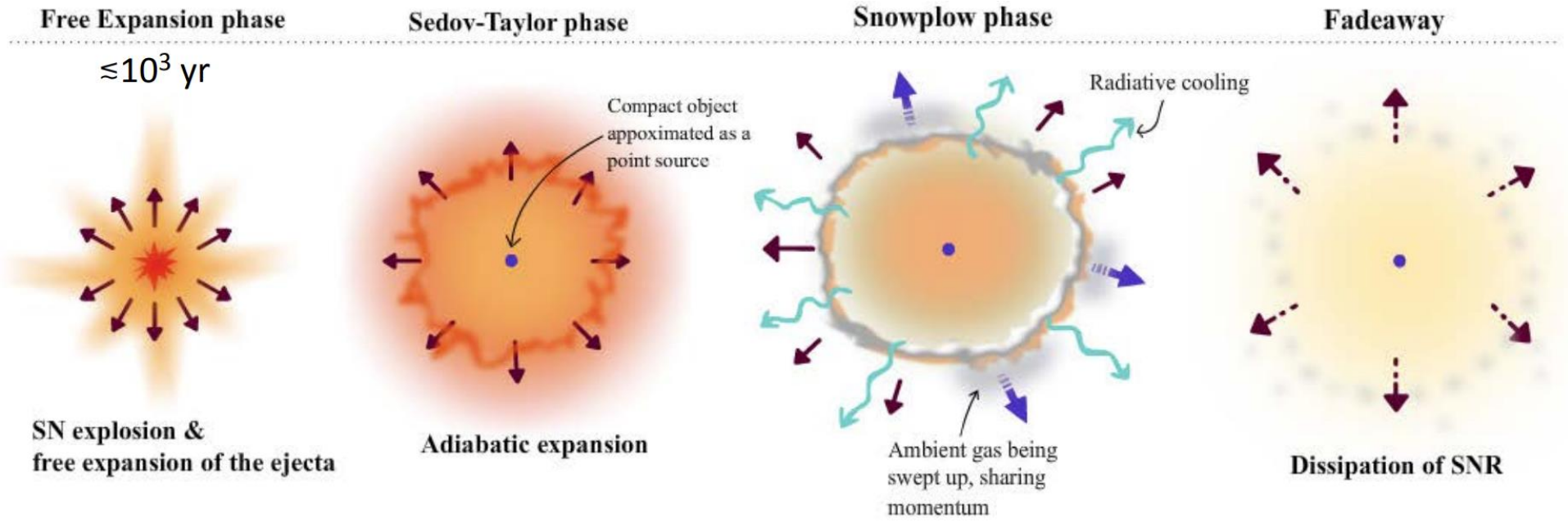
Different Signatures → Consequence of Plasma Blocking



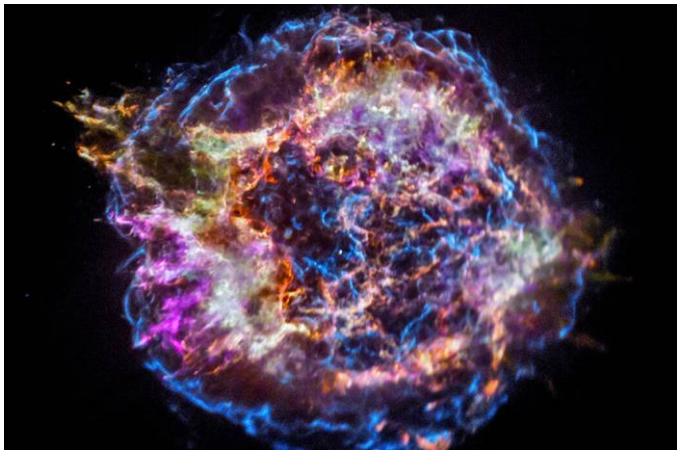
Absorption of the photons in IGM through inverse Bremsstrahlung



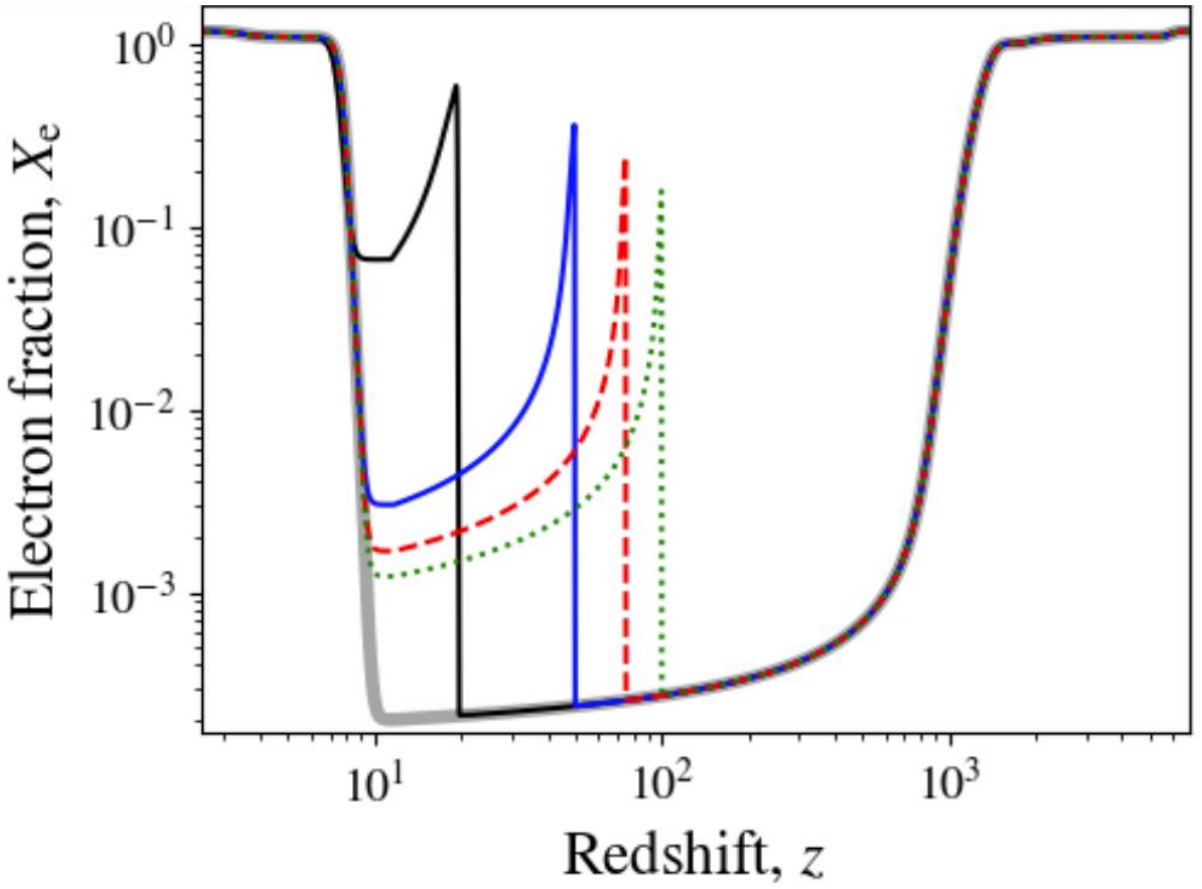
Use technology from Supernova Remnant evolution



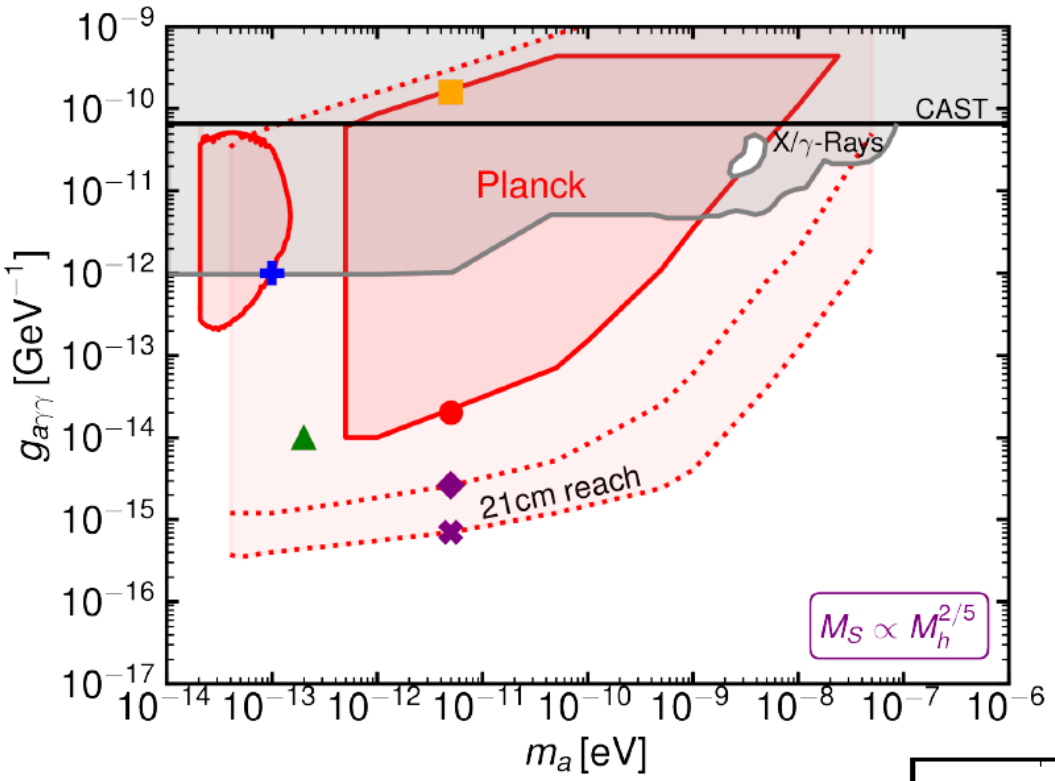
Picture from Ken Nagamine

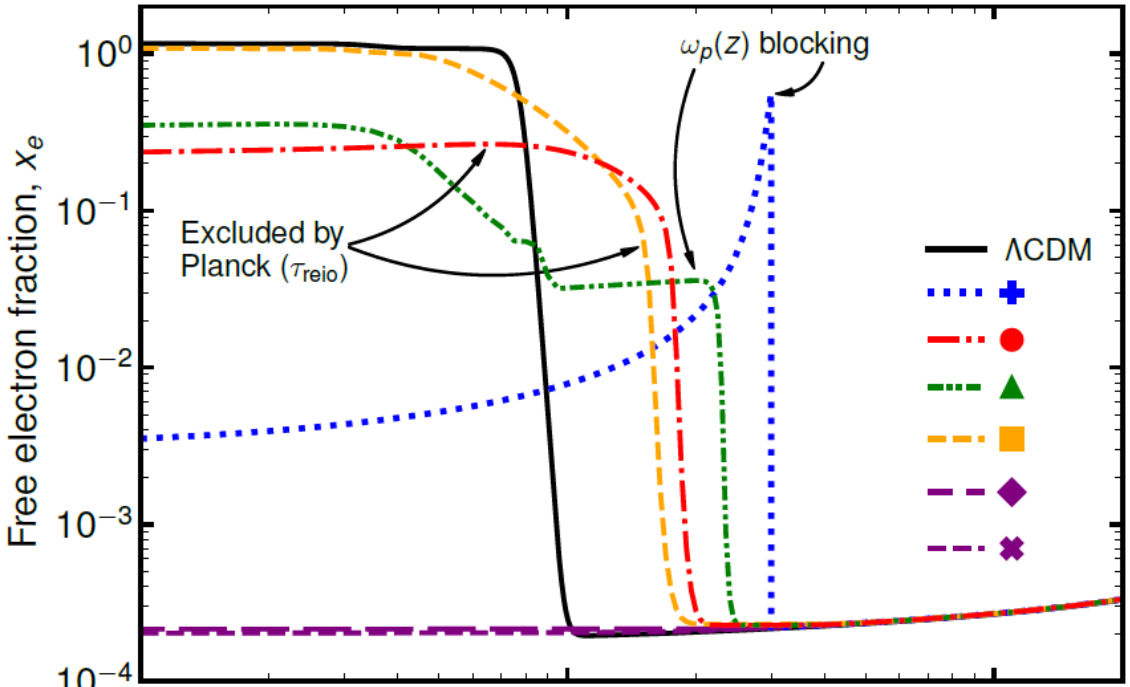


The burst of radiation changes the ionisation of the Universe

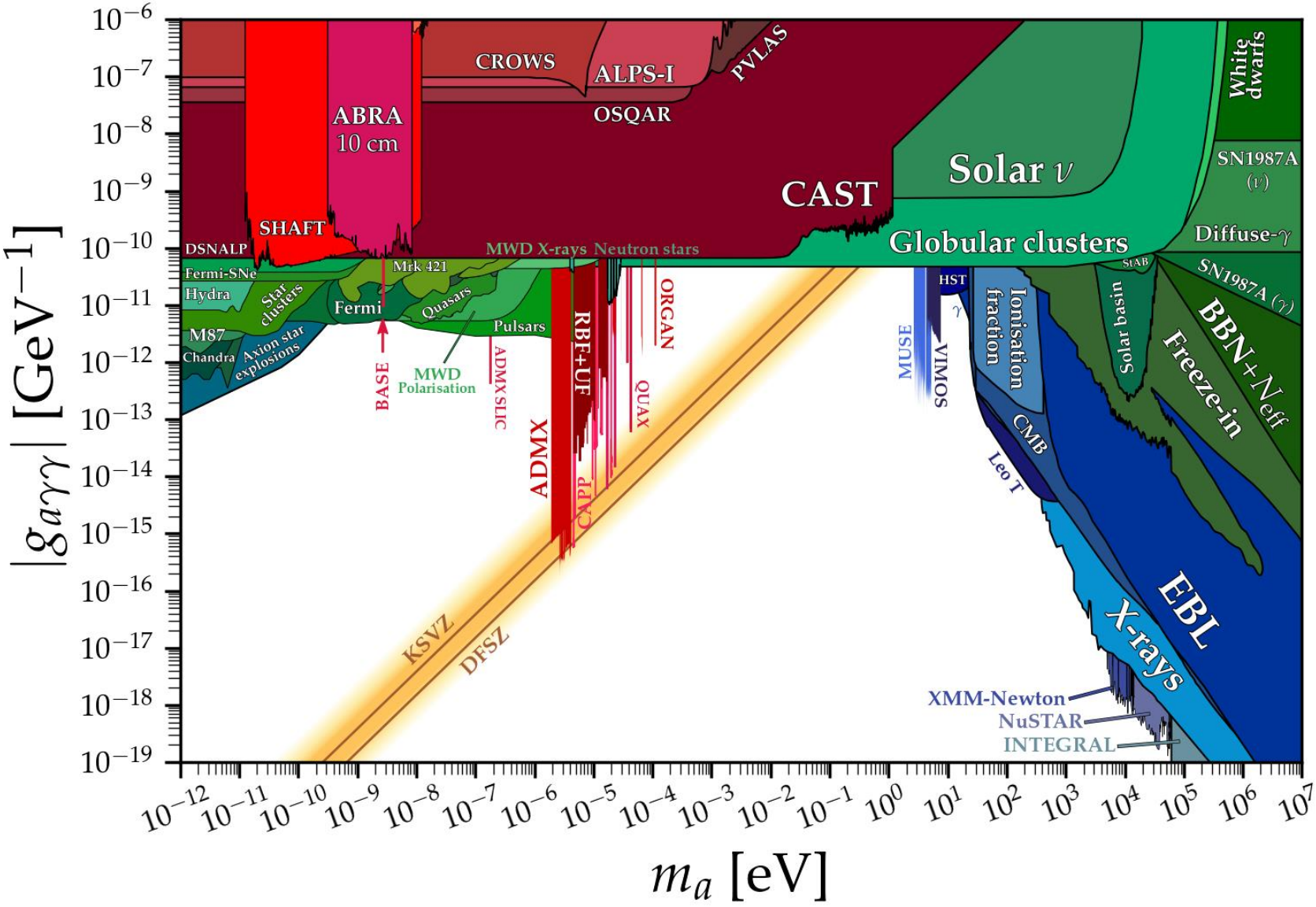


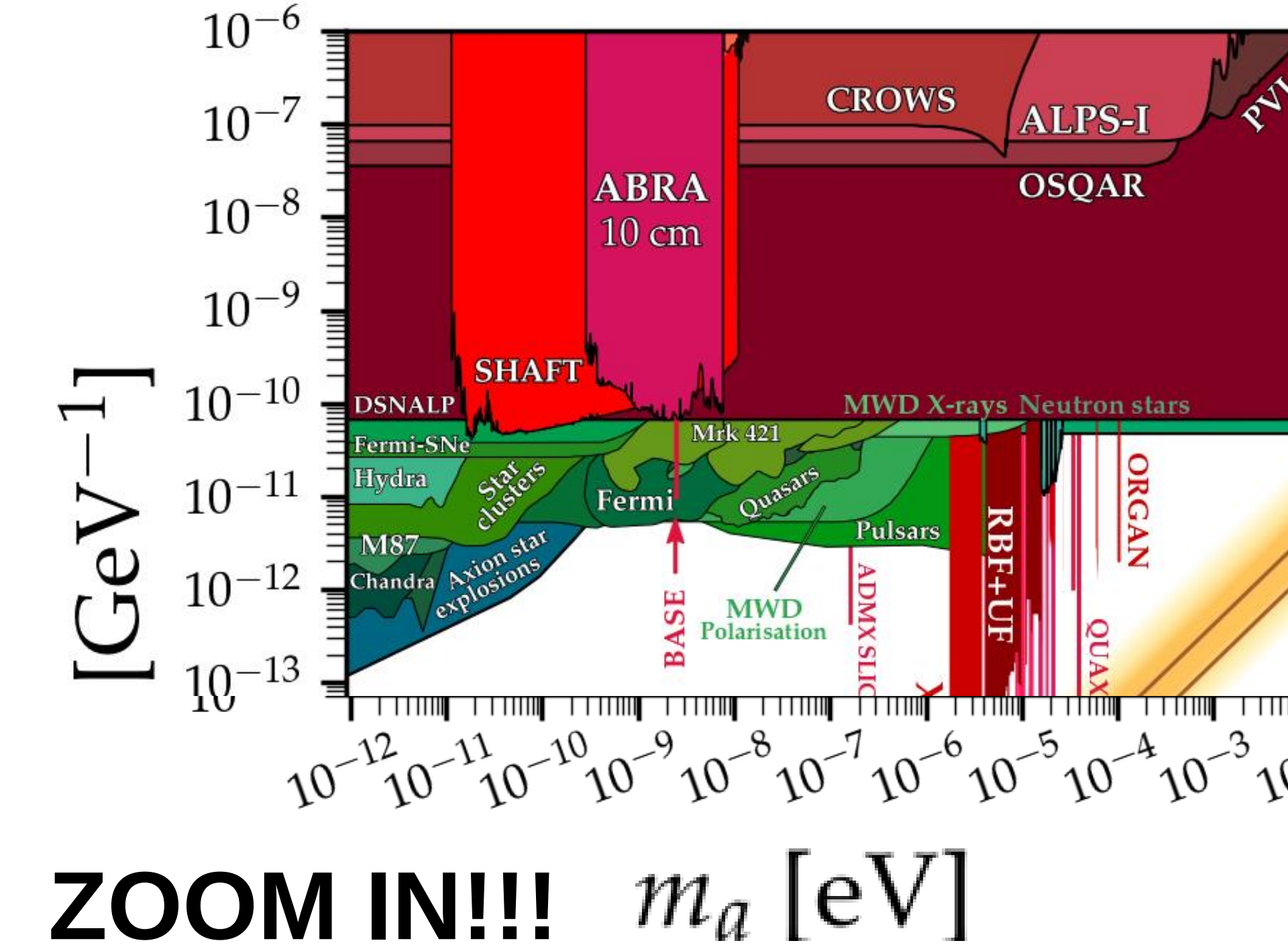
Constraints from the Opacity of the CMB



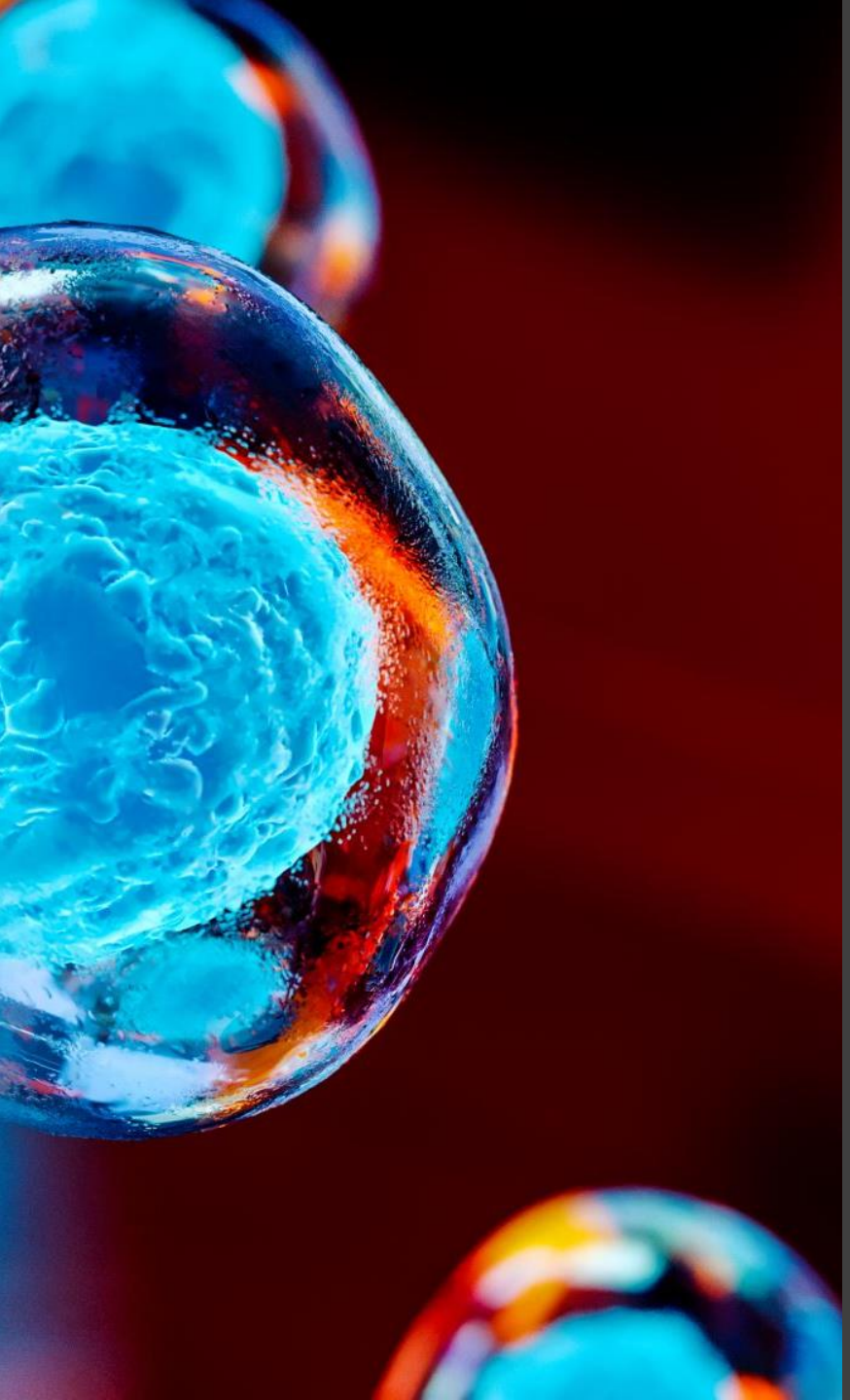


Sets new constraints, which will get stronger with 21cm observations




10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
$[\mathrm{GeV}^{-1}]$
CROWS
ALPS-I
PVL
OSQAR
ABRA
10 cm
SHAFT
DSNALP
MWD X-rays
Neutron stars
Fermi-SNe
Hydra
Star clusters
Mrk 421
Fermi
Quasars
Pulsars
M87
Chandra
Axion star explosions
BASE
MWD
Polarisation
ADMX SLIC
RBF+UF
ORGAN
QUAX
10^{-12} 10^{-11} 10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3}

ZOOM IN!!! m_a [eV]



Conclusions

- Fuzzy Dark Matter leads to solitonic cores in dark matter halos
- Axion decay into photons is enhanced in dense regions
- Solitons decay and ionise the Universe
- CMB puts constraints on this region of parameter space which may be competitive with other constraints