The Echo Method to Search for Axion Dark Matter

XXth Rencontres du Vietnam

The Axion Quest

ICISE, Quy Nhon, Vietnam

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Dark Matter Axions

Axions could solve the Dark Matter problem if they were produced in the early universe by a non-thermal mechanism

(Preskill, Wise and Wilczek; Abbott and Sikivie; Dine and Fischler 1983)

$$f_a \sim 10^{12}\text{GeV} \quad \Rightarrow \quad m_a \sim 10^{-5}\text{eV}$$

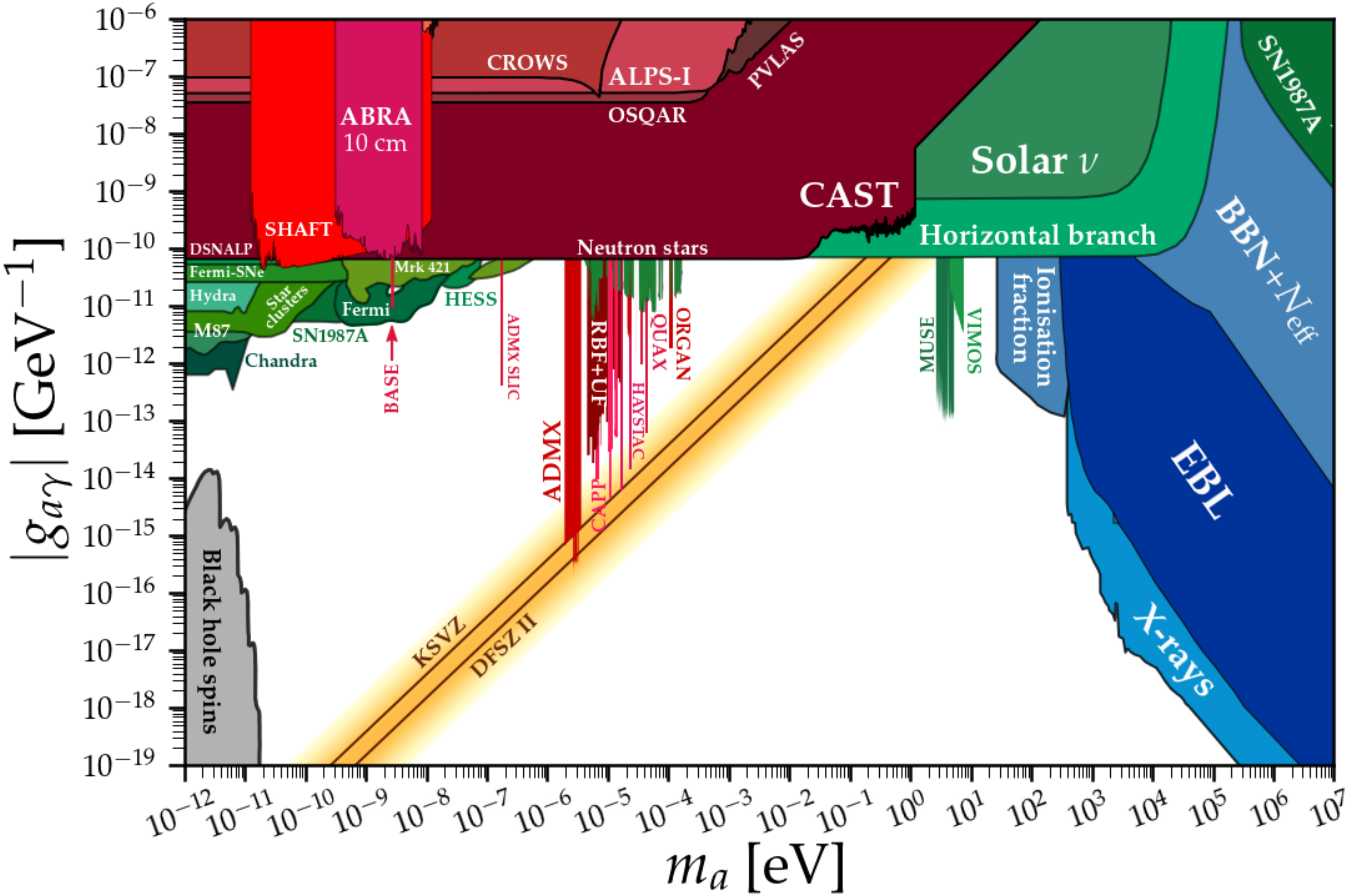
Axion Like Particles (ALPs):

(Svrcek and Witten 2006)

Motivated by extensions of the Standard Model, they also are cold dark matter candidates

(Arias et al. 2012)

Current status of the axion search



Ciaran O'Hare data basis https://cajohare.github.io/AxionLimits/docs/ap.html

Stimulated axion decay into two photons

$$\tau_a^0 = \frac{64\pi}{m^3 g^2}$$ **axion life-time for spontaneous decay**

$$m = 10^{-5}\text{eV}$$
$$g = 10^{-15}\text{GeV}^{-1}$$

→ $$\tau_a^0 \sim 10^{42}\text{yr}$$

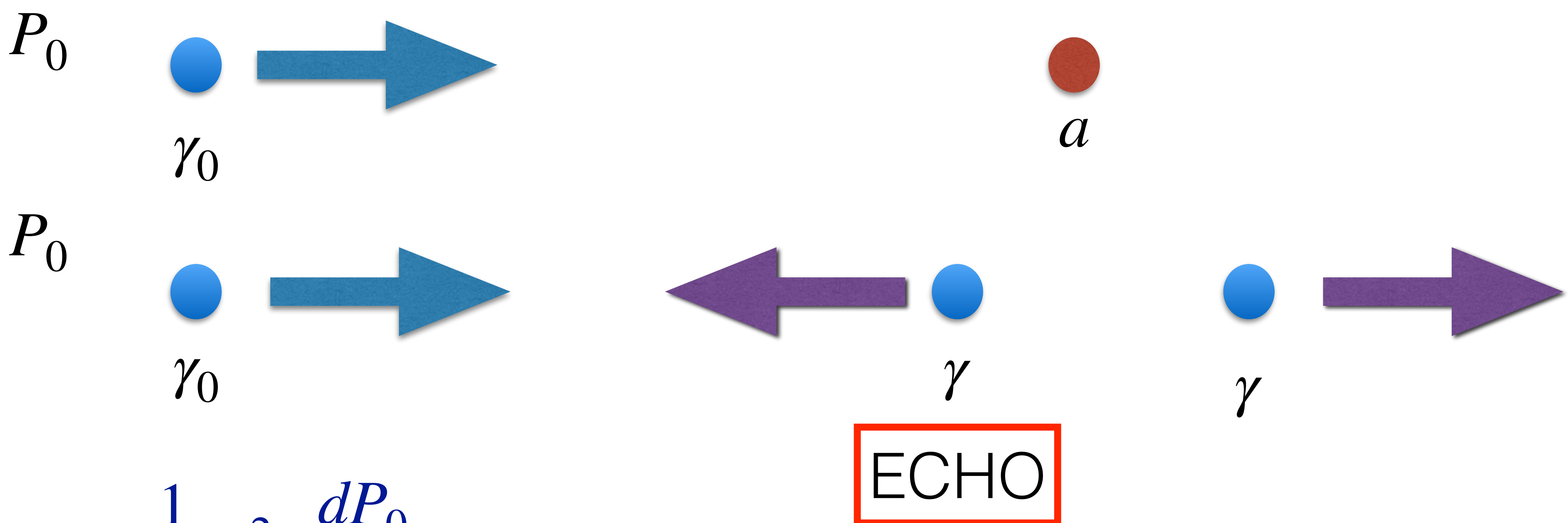
$$\tau_a = \frac{\tau_a^0}{1 + f_\gamma}$$ **Actual Axion Life-Time**

$$f_\gamma = \frac{16\pi^2 \rho_\gamma}{m^3 \Delta\omega}$$ **stimulated axion decay** $$\omega_\gamma = m/2$$

Let's suppose a power of 1kWatt with a bandwidth of 1MHz during a time of 1 second in a volume of 1 meter cube

→ $$f_\gamma \sim 10^{25}$$

Stimulated axion decay into two photons (The Echo)



$$P_- = \frac{1}{16} g^2 \rho \frac{dP_0}{d\nu} t$$

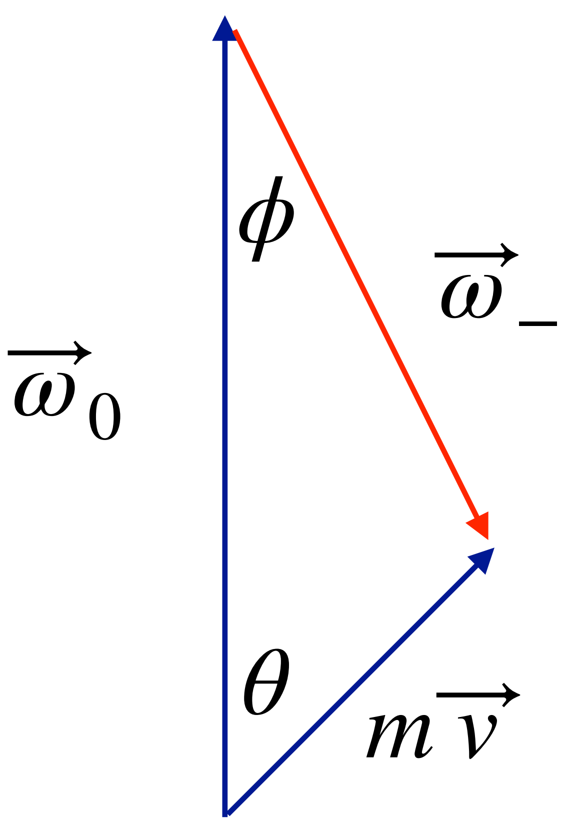
$$\omega_0 = \omega_- = \frac{m}{2}$$

$P_0 = 1\text{kW}$ $t = 1000\text{s}$ $\Delta\nu = 100\,\text{Hz}$

Isothermal dark matter model → $P_- \sim 10^{-21}\text{W}$

(Arza and Sikivie [1902.00114])

The Echo in a cold flow



$$\omega_0 = \frac{m}{2}(1 + v_{\parallel}) + \mathcal{O}(v^2)$$

$$\omega_- = \frac{m}{2}(1 - v_{\parallel}) + \mathcal{O}(v^2)$$

$$\phi \simeq 2\,|\,v_{\perp}\,|$$

The detector collects echo coming from distances no larger than

$$d_{max} = C\frac{R}{|\,v_{\perp}\,|}$$

The echo in a cold flow

$$\rho = \int d^3 v \frac{d^3 \rho}{d v^3}(\overrightarrow{v})$$

The echo spreads also in frequency

$$\delta\nu_{-} = \min\left(\frac{m}{4\pi}\delta v_{\parallel}, \delta\nu_0\right) \qquad P_c = \frac{1}{16}\frac{g^2 \rho P_0}{\Delta} C \frac{R}{|v_{\perp}|}$$

$$\Delta = \max\left(\frac{m}{4\pi}\delta v_{\parallel}, \delta\nu_0\right)$$

The caustic ring halo model and fine grained streams

The local dark matter distribution is dominated by a single flow

$v = 300\text{km/s}$ $\delta v = 70\text{m/s}$ $\rho = 1\text{GeV/cm}^3$

$B = 4 \times 10^{-8} m$ $\theta = 0.017$ $v_\perp = 5\text{km/s}$

Observations consistent with the CRM

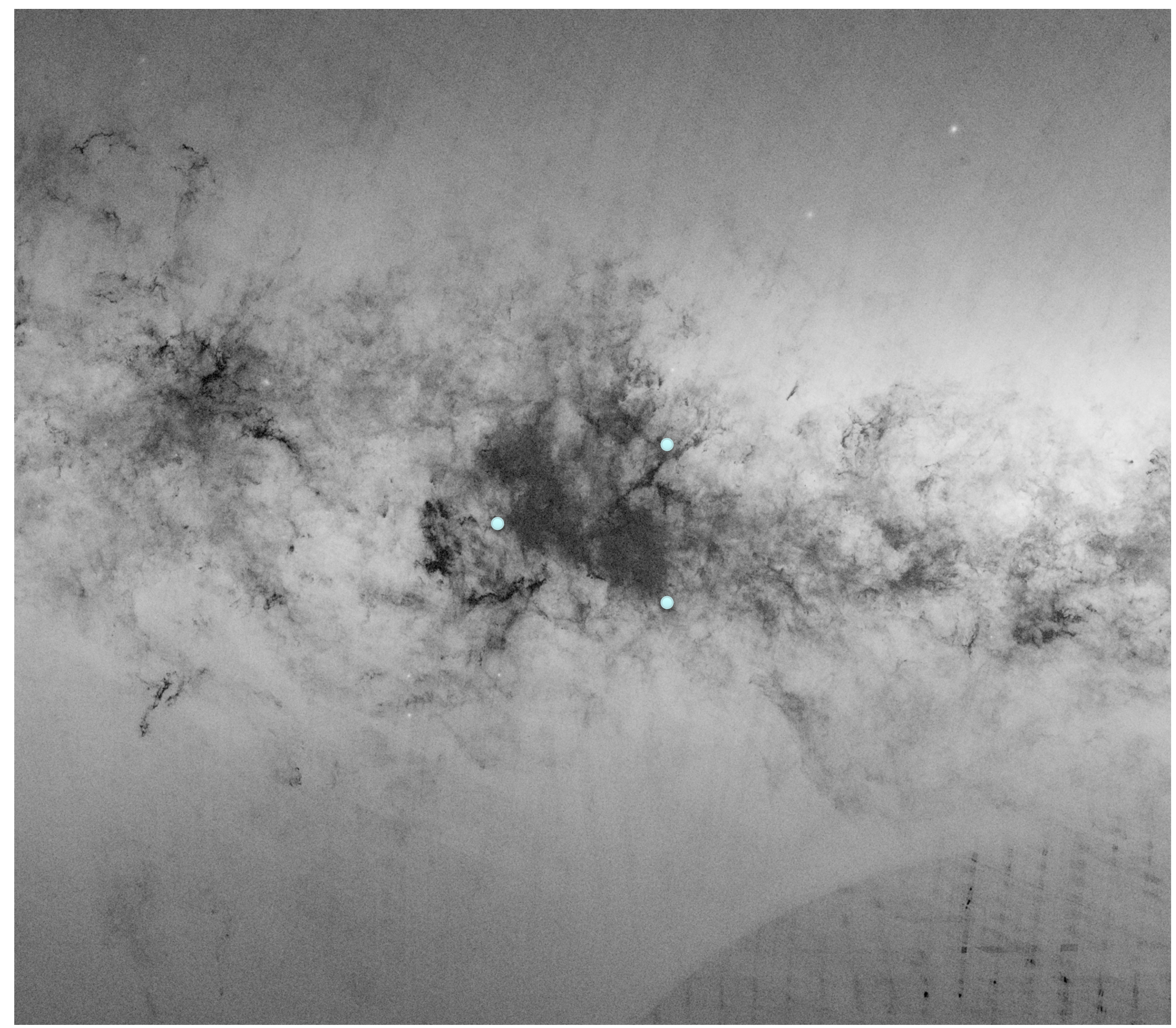
Chakrabarty et. al. arXiv:2007.10509

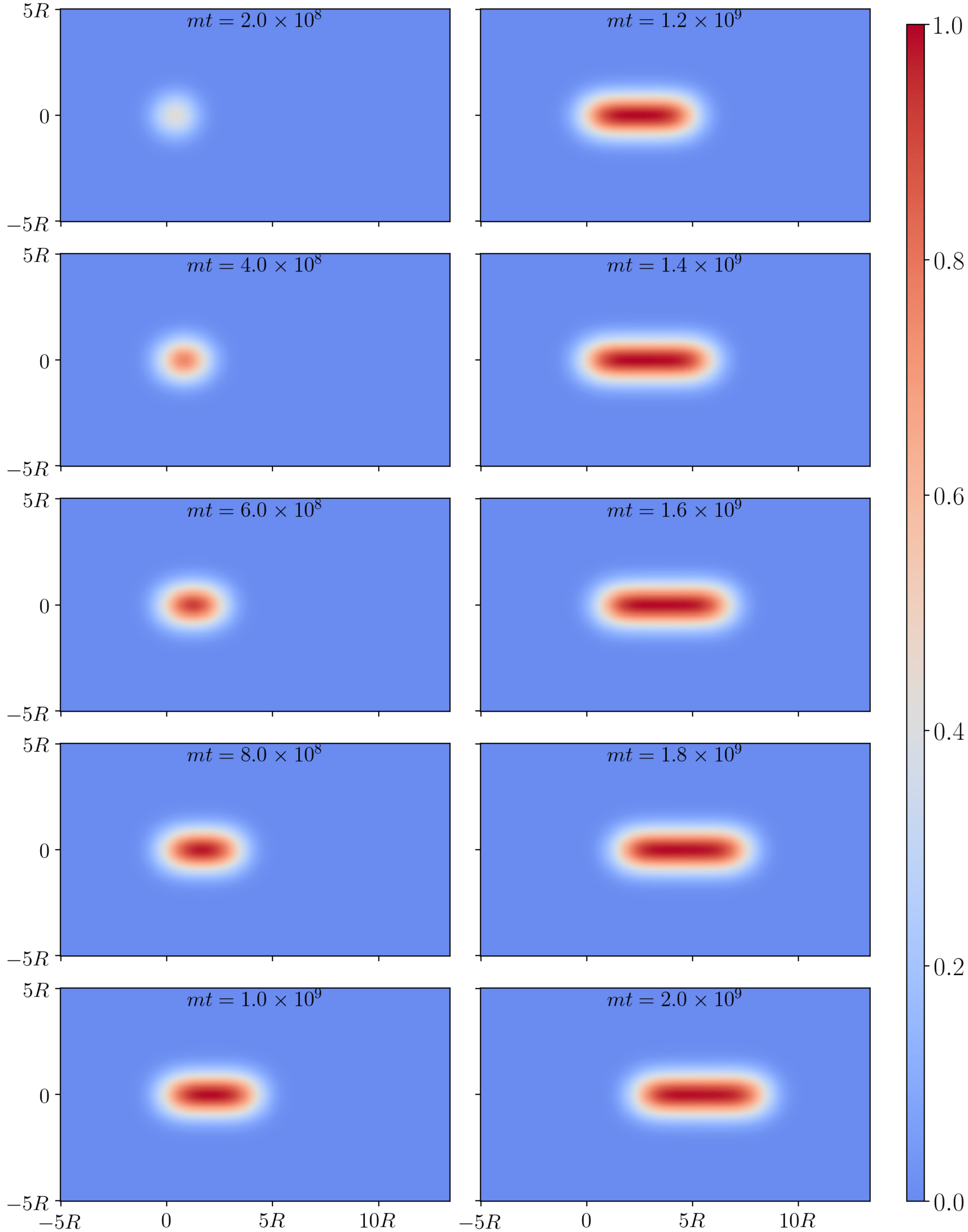
Dumas et. al. arXiv:1508.04494

Sikivie arXiv:astro-ph/0109296

For axion fine grained streams, see

Arza et. al. arXiv:2212.10905




$mt = 2.0 \times 10^8$
$mt = 4.0 \times 10^8$
$mt = 6.0 \times 10^8$
$mt = 8.0 \times 10^8$
$mt = 1.0 \times 10^9$
$mt = 1.2 \times 10^9$
$mt = 1.4 \times 10^9$
$mt = 1.6 \times 10^9$
$mt = 1.8 \times 10^9$
$mt = 2.0 \times 10^9$
$5R$
0
$-5R$
$10R$
1.0
0.8
0.6
0.4
0.2
0.0

The isothermal halo model

The velocity distribution is Gaussian

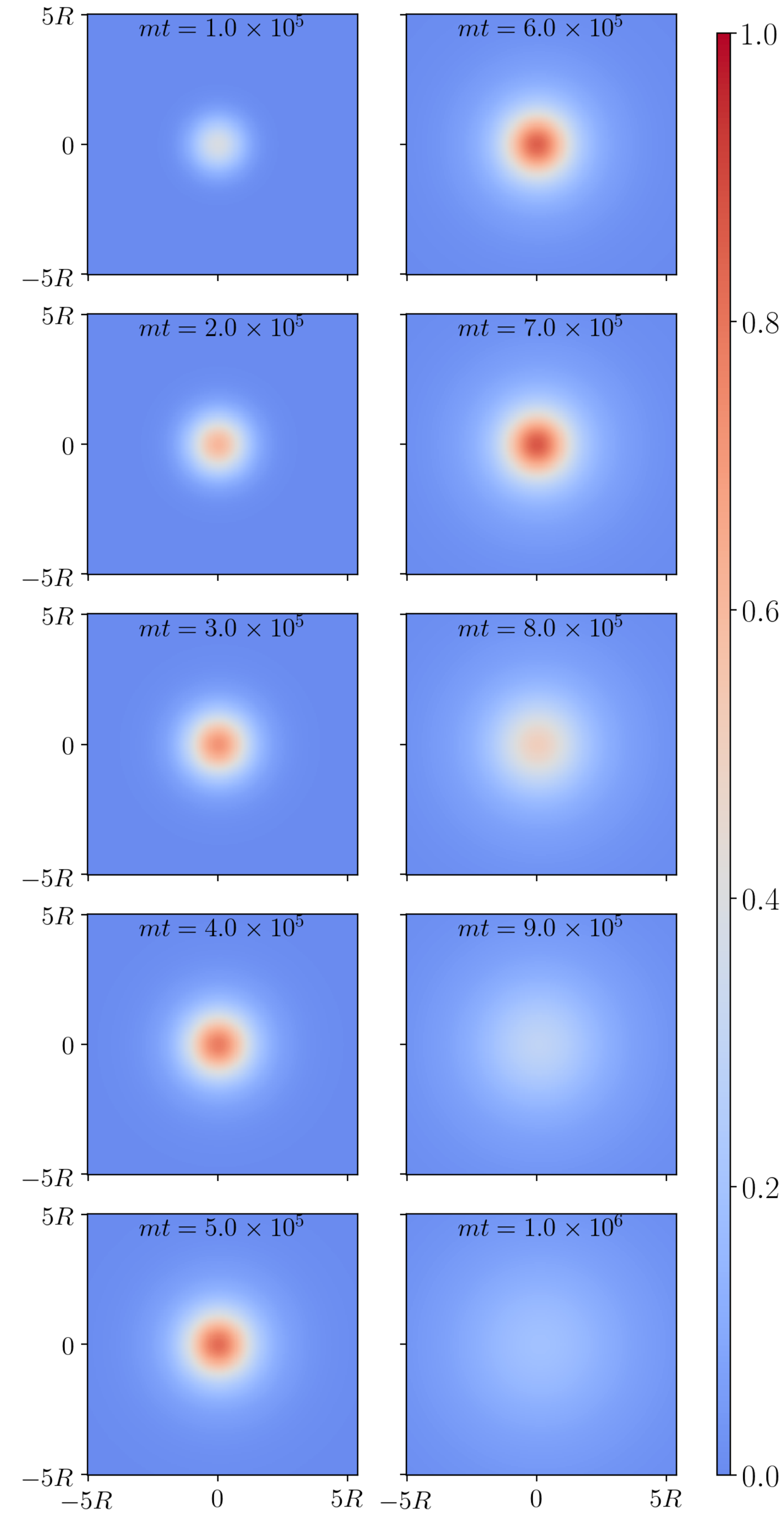
$$v = 220\text{km/s} \qquad \delta v = 270\text{km/s}$$

$$\rho = 0.45\text{GeV/cm}^3$$

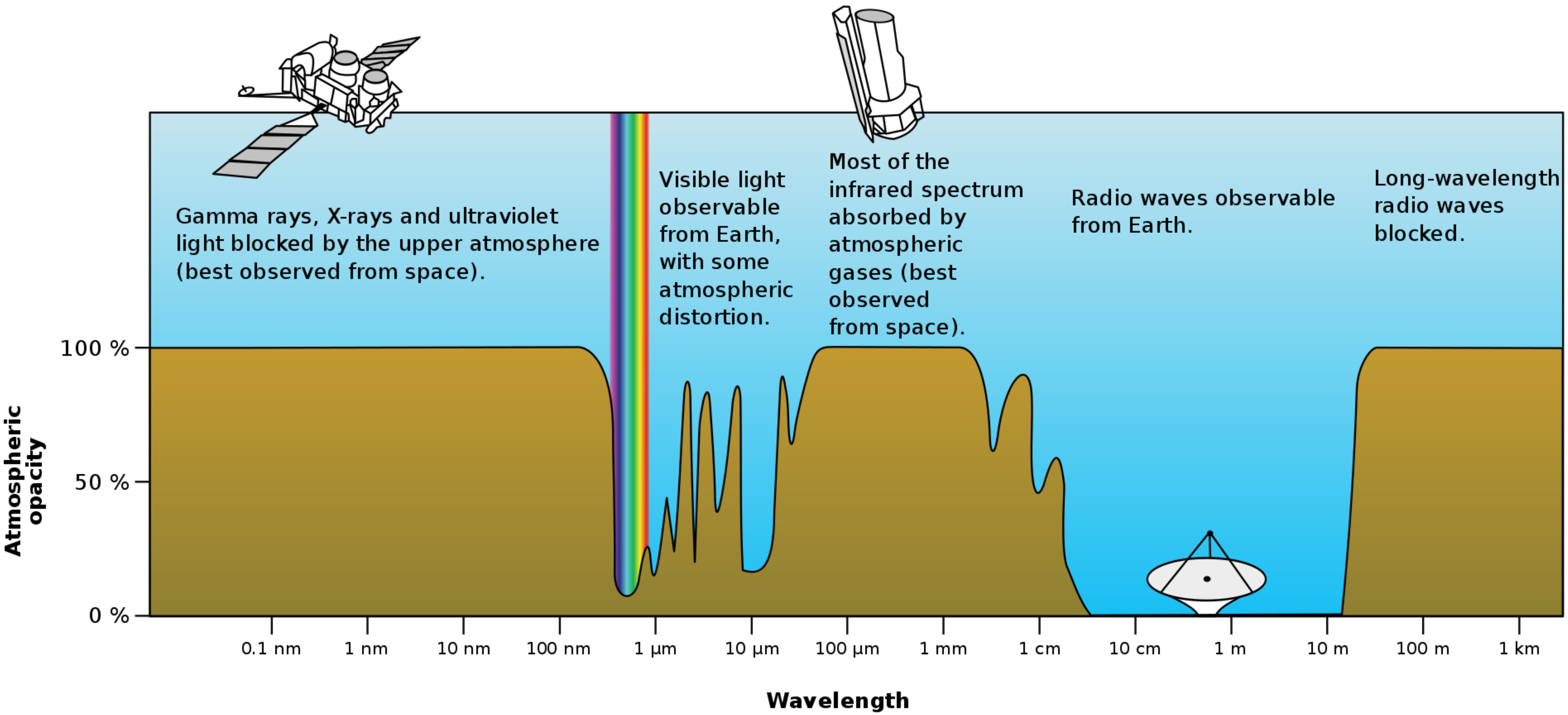
The echo spreads in all directions

$$\left\langle \frac{1}{|v_\perp|} \right\rangle = \frac{1}{124\text{km/s}}$$

$$B = 1.7 \times 10^{-4} m$$



Sensitivity



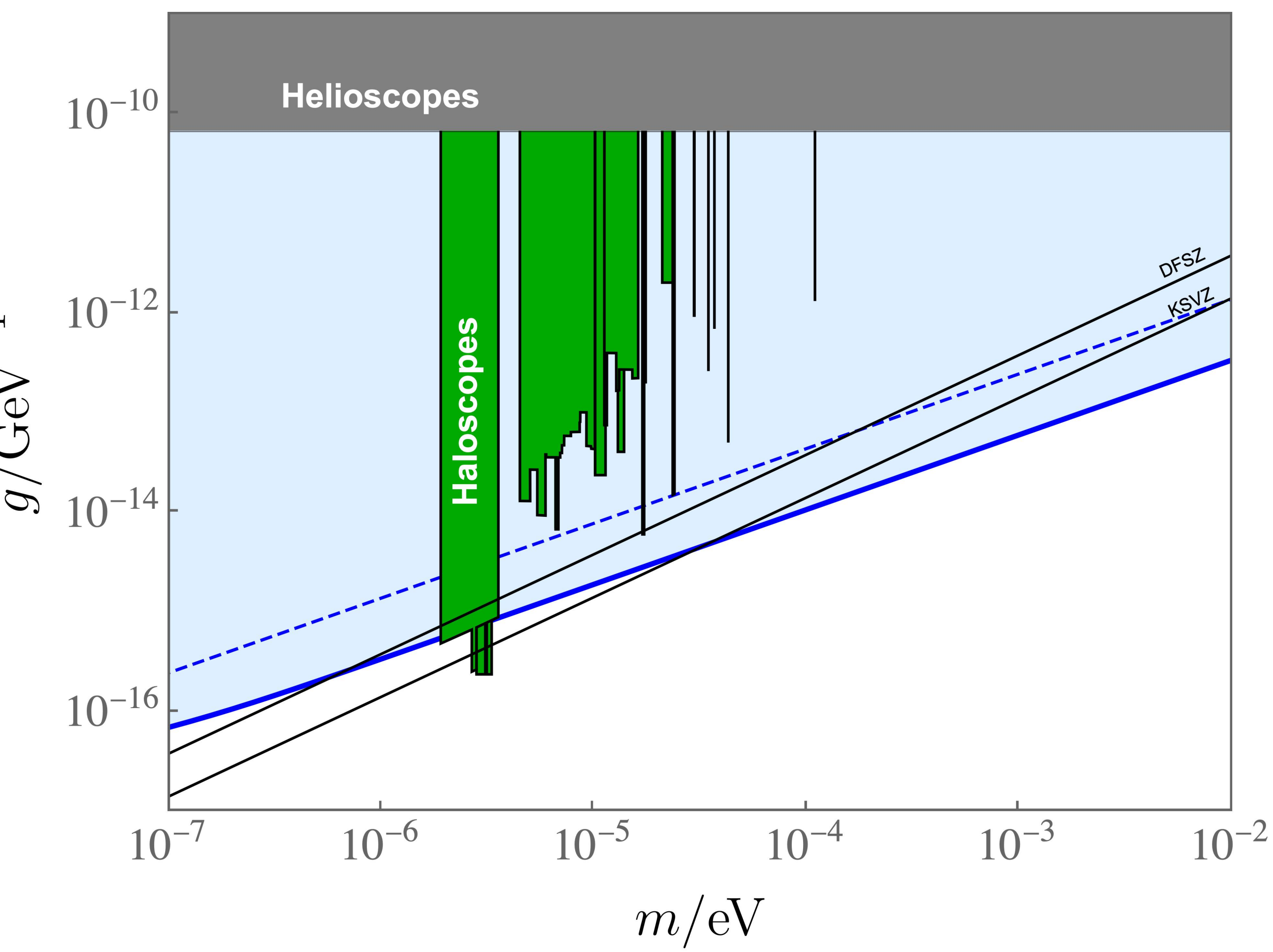
$$s/n = \frac{P_c}{T_n}\sqrt{\frac{t_m}{B}}$$

Dicke's radiometer equation

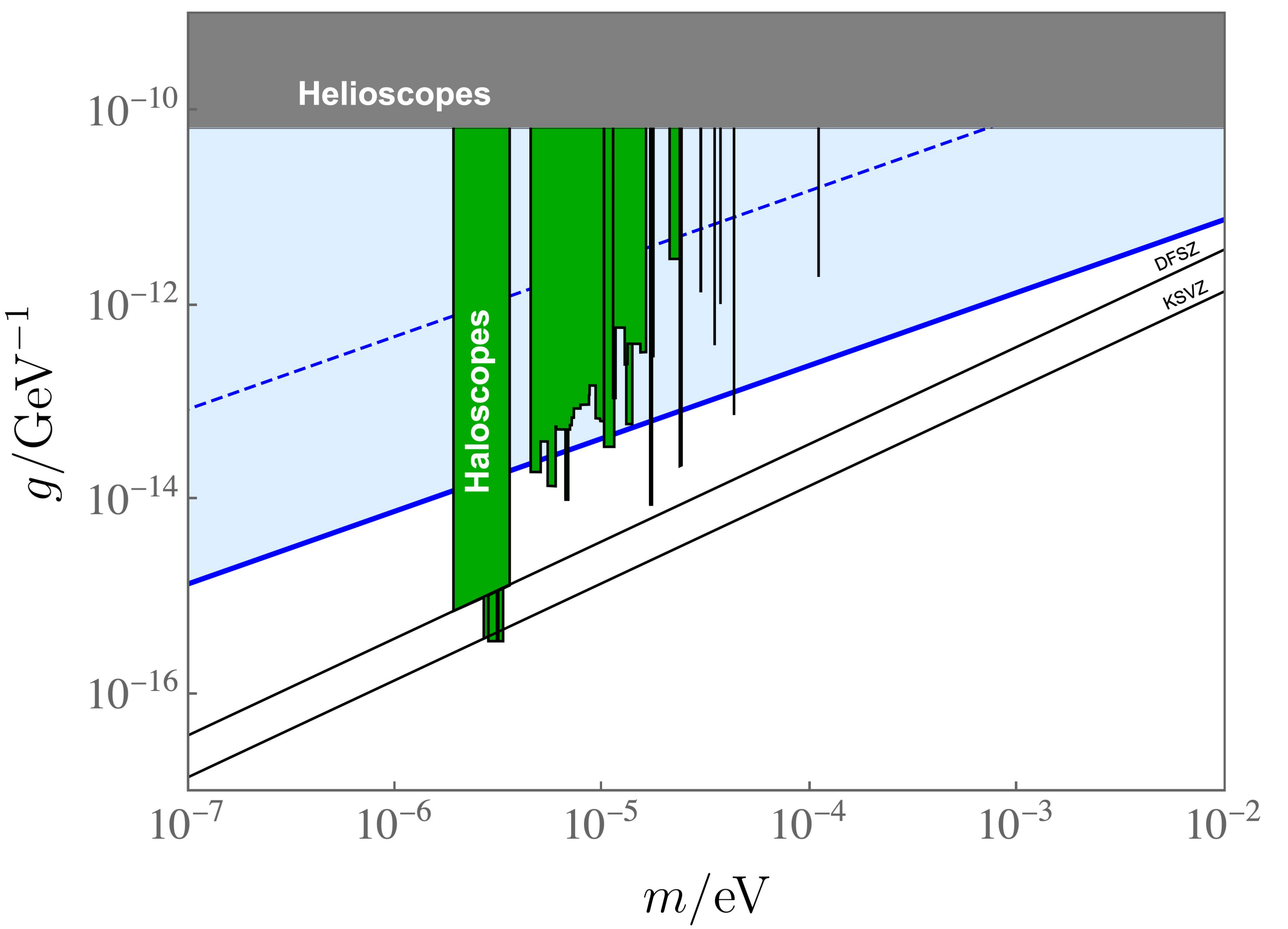
Sensitivity

We assume a receiving dish of 100 meters radius and a noise temperature of 20K

Caustic ring model

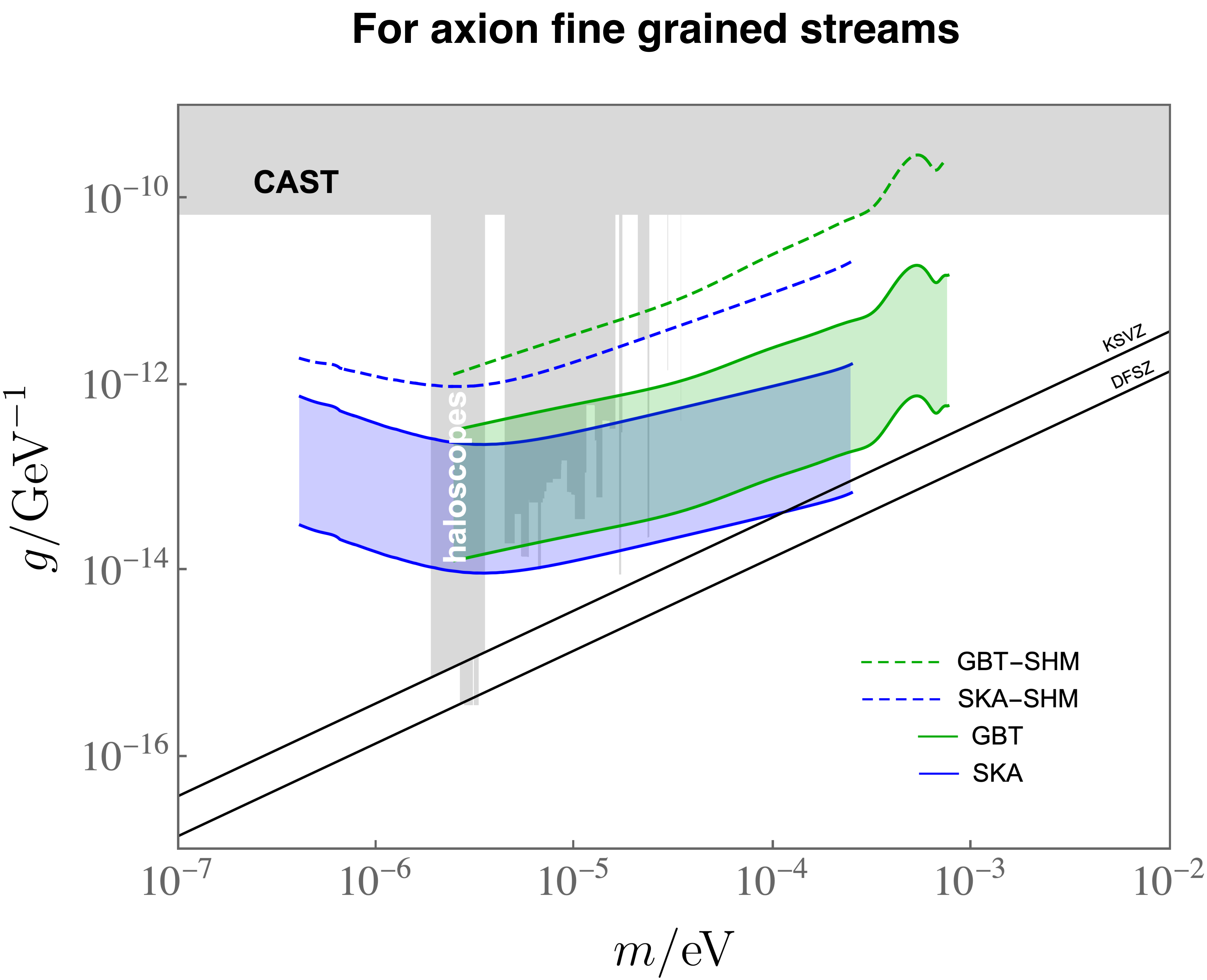


Isothermal sphere



Solid line: Optimal sensitivity consuming an energy of 100 MW Yr per octave in Axion mass range

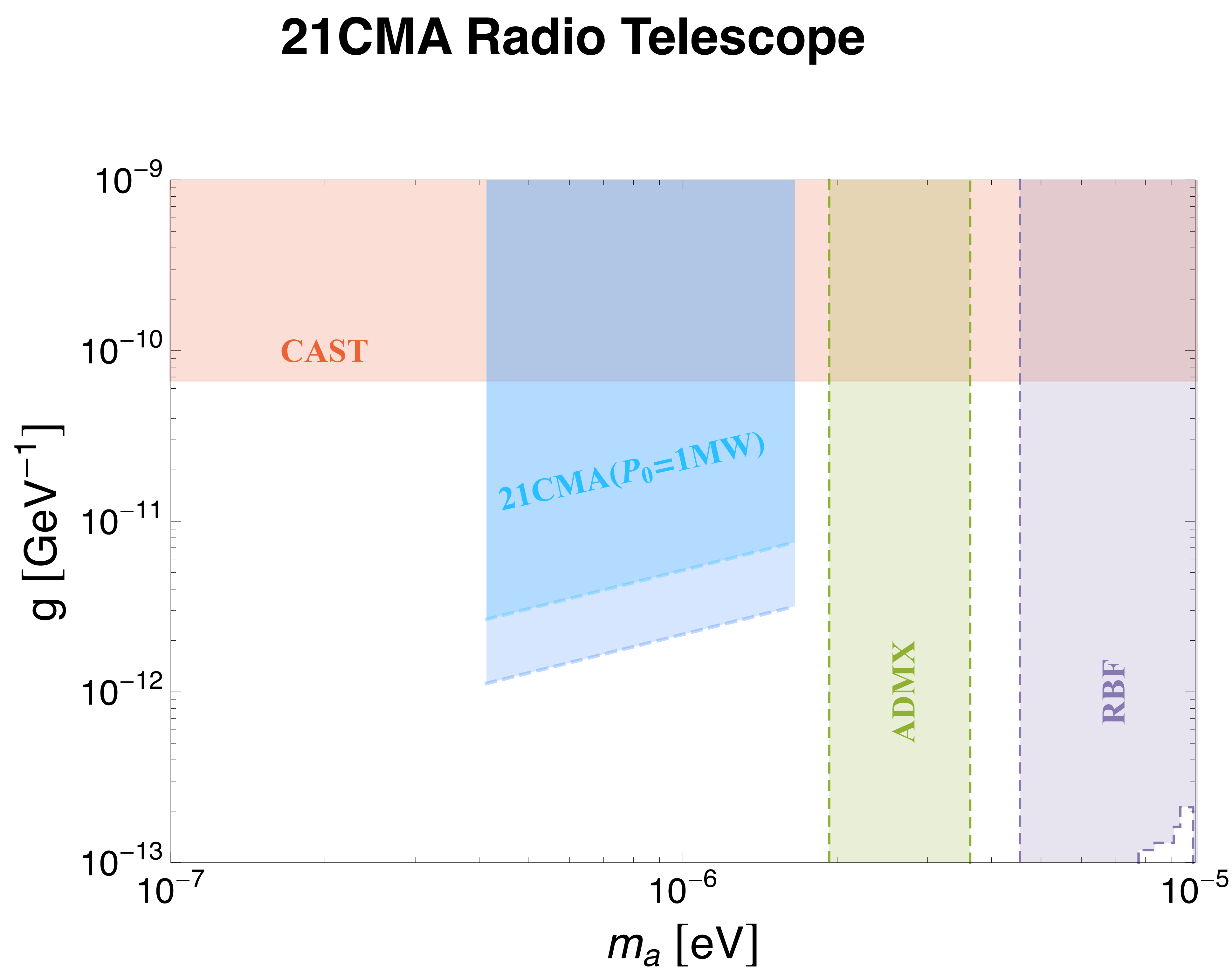
Dashed line: Sensitivity consuming a fixed output power of 10 MW during one year To cover an octave in axion mass range



For axion fine grained streams
CAST
haloscopes
KSVZ
DFSZ
GBT−SHM
SKA−SHM
GBT
SKA
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
g/GeV^{-1}
m/eV

21CMA Radio Telescope

A. Arza, Quan Guo, Lei Wu, Qiaoli Yang, Xiaolong Yang, Quang Yuan and Bin Zhu arXiv:2309.06857

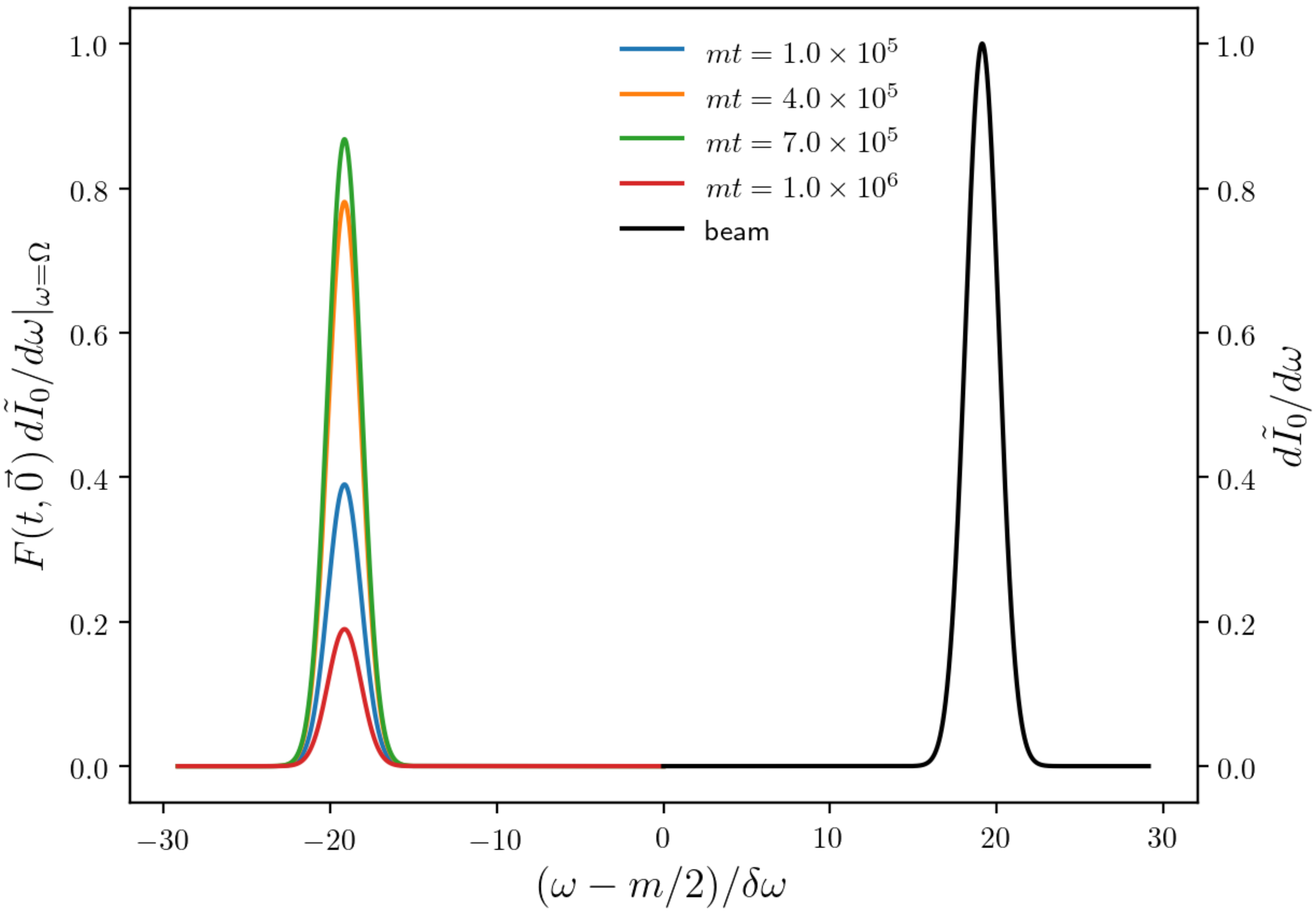


21CMA Radio Telescope
CAST
21CMA(P_0=1MW)
ADMX
RBF
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
g [GeV^{-1}]
10^{-7}
10^{-6}
10^{-5}
m_a [eV]

Issues

- Beam leakages
- Ionosphere reflections

The frequency shift of the echo signal could be useful



Next Target: Sanya Incoherent Scatter Radar (SISR)

Next Steps

- Characterization of the beam shape
- Figure it out how to solve the ionosphere issue
- Search for axion dark matter from current data
- Make our own dedicated axion echo experiment

Thanks for your attention!