



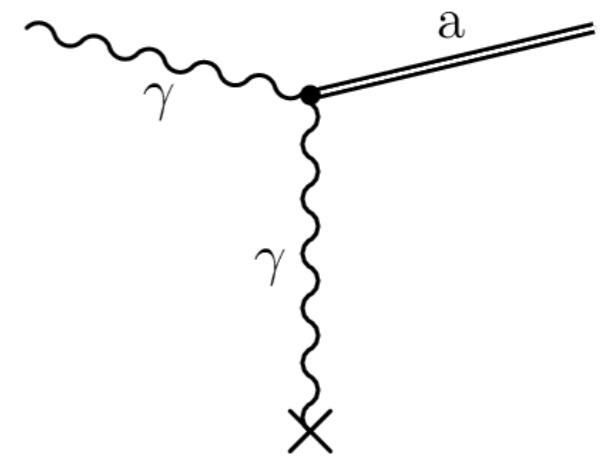
# Gegenschein signal from an inhomogeneous axion DM distribution

Takuya Okawa, Francesc Ferrer, Bhupal Dev

Particle Physics on the Plains 2022

# Axion-like Particles (ALPs)

$$\mathcal{L} = \frac{1}{2}m_a^2 a^2 + \frac{g_{a\gamma\gamma}a}{4}F_{\mu\nu}\tilde{F}^{\mu\nu} = \frac{1}{2}m_a^2 a^2 - g_{a\gamma\gamma}a\mathbf{E} \cdot \mathbf{B}$$

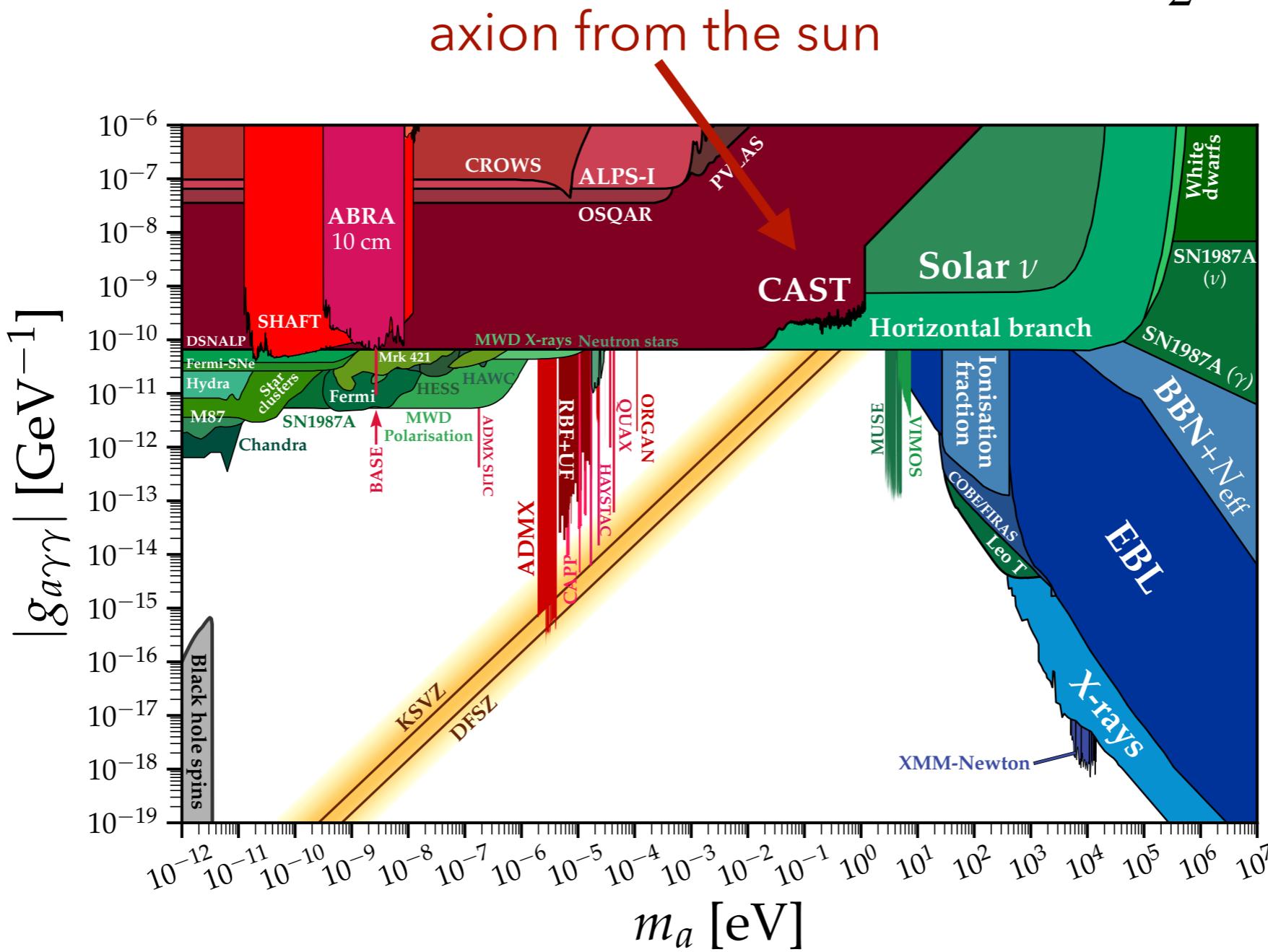


Related interaction processes:

- Primakoff process:  $\gamma + e \rightarrow e + a$
- Stimulated decay:  $a \rightarrow 2\gamma$

# Observational signatures

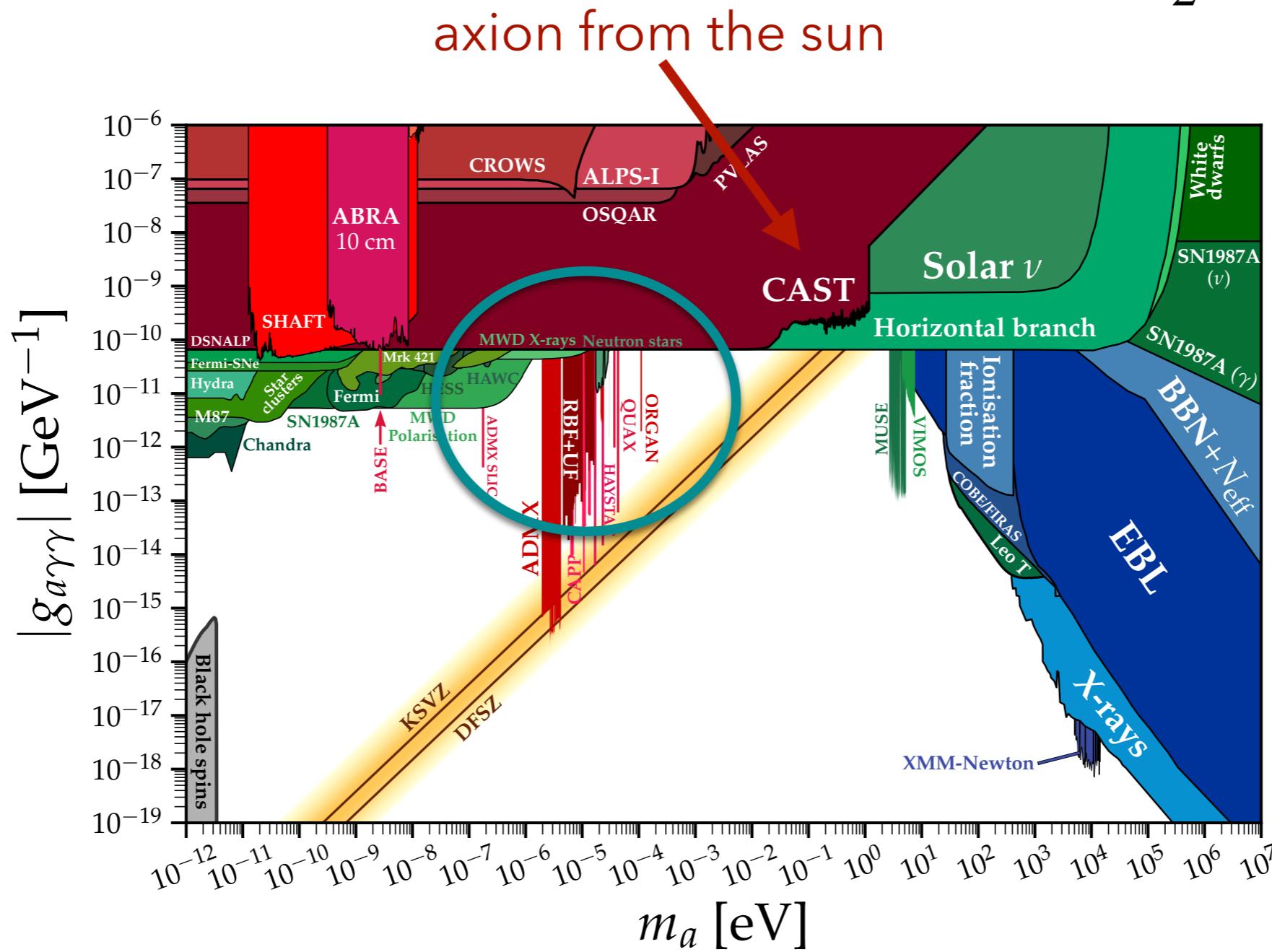
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C. O'Hare, "cajohare/axionlimits: Axionlimits,"

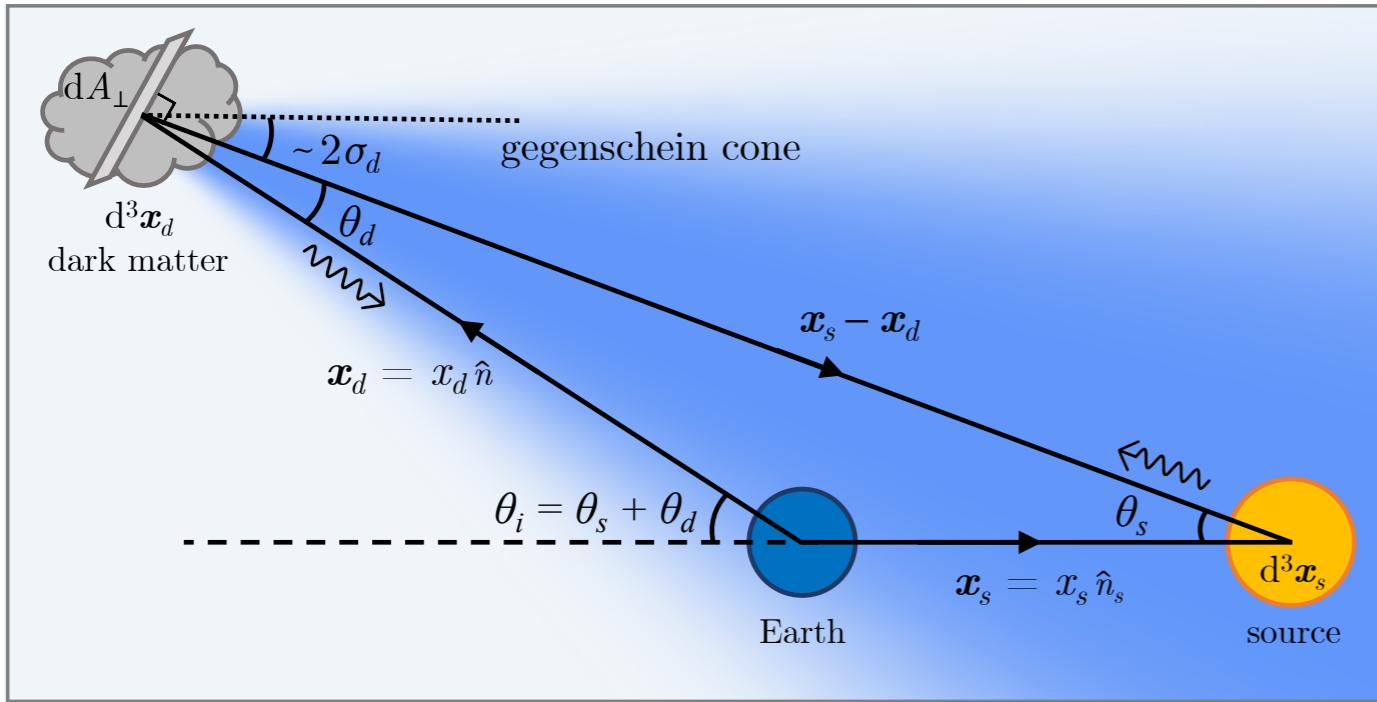
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# Gegenschein



Oindrila Ghosh, Jordi Salvado, and Jordi Miralda-Escude (2020)  
Yitian Sun, Katelin Schutz, Anjali Nambrath, and Kiyoshi Masui (2021)

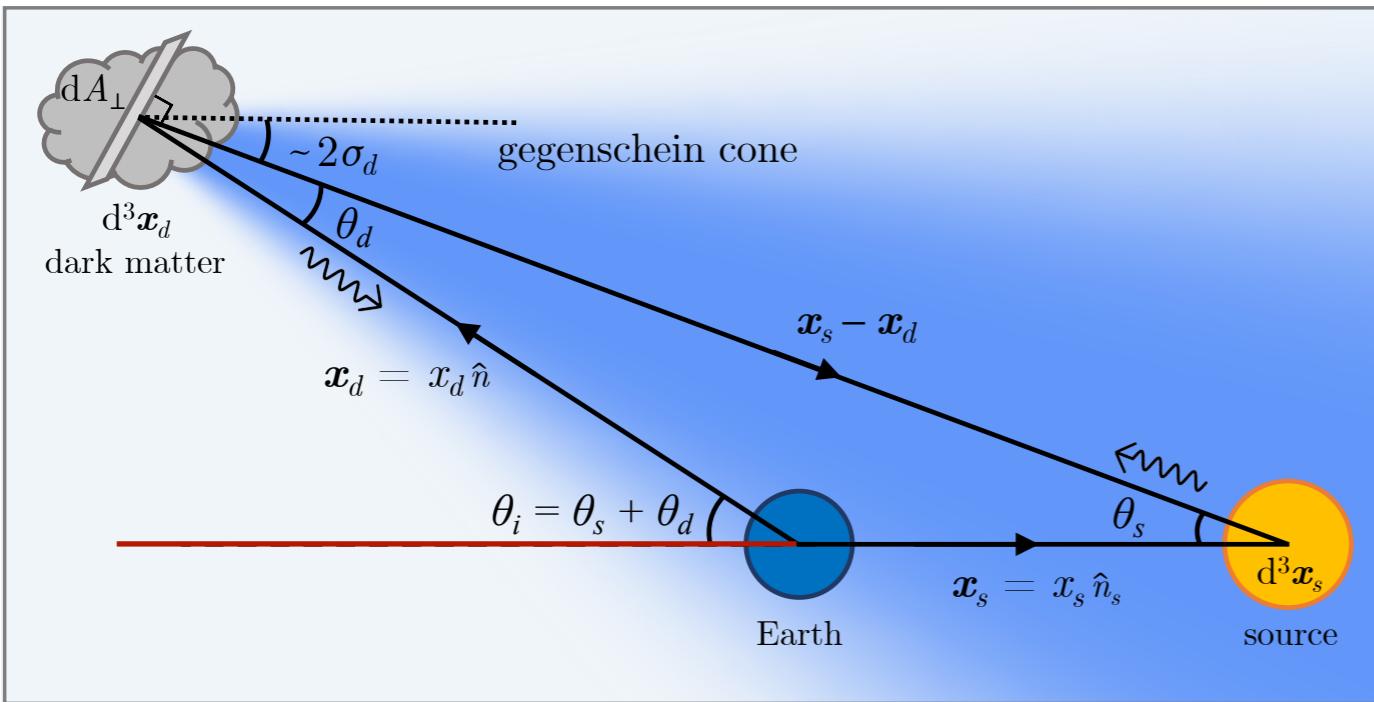
The intensity of gegenschein signal from a volume element  $d^3x$ :

$$dI_g = \frac{\hbar c^4}{16} g_{a\gamma}^2 I_{s\nu}(\nu_d, \mathbf{x}) \rho_a(\mathbf{x}) d^3x$$

$I_{s\nu}$ : the intensity of source

$\rho_a$ : mass density of ALP

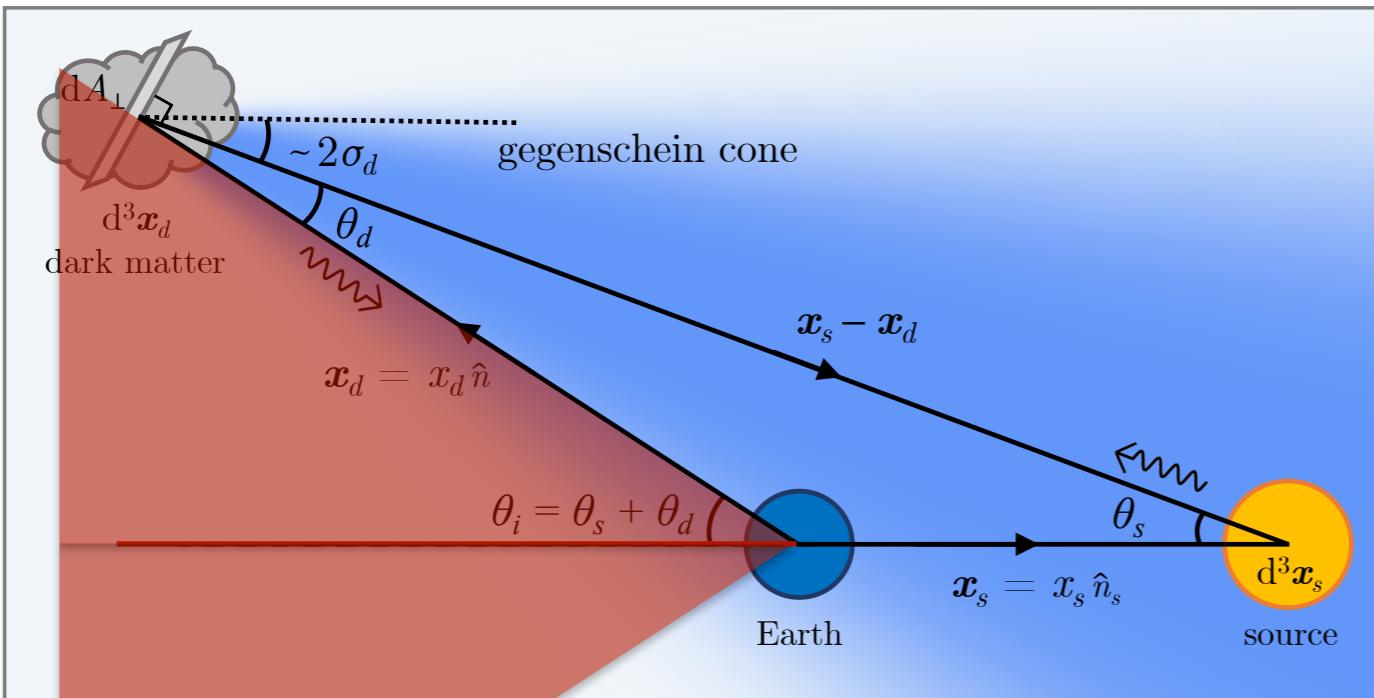
# Gegenschein



Oindrila Ghosh, Jordi Salvado, and Jordi Miralda-Escude (2020)

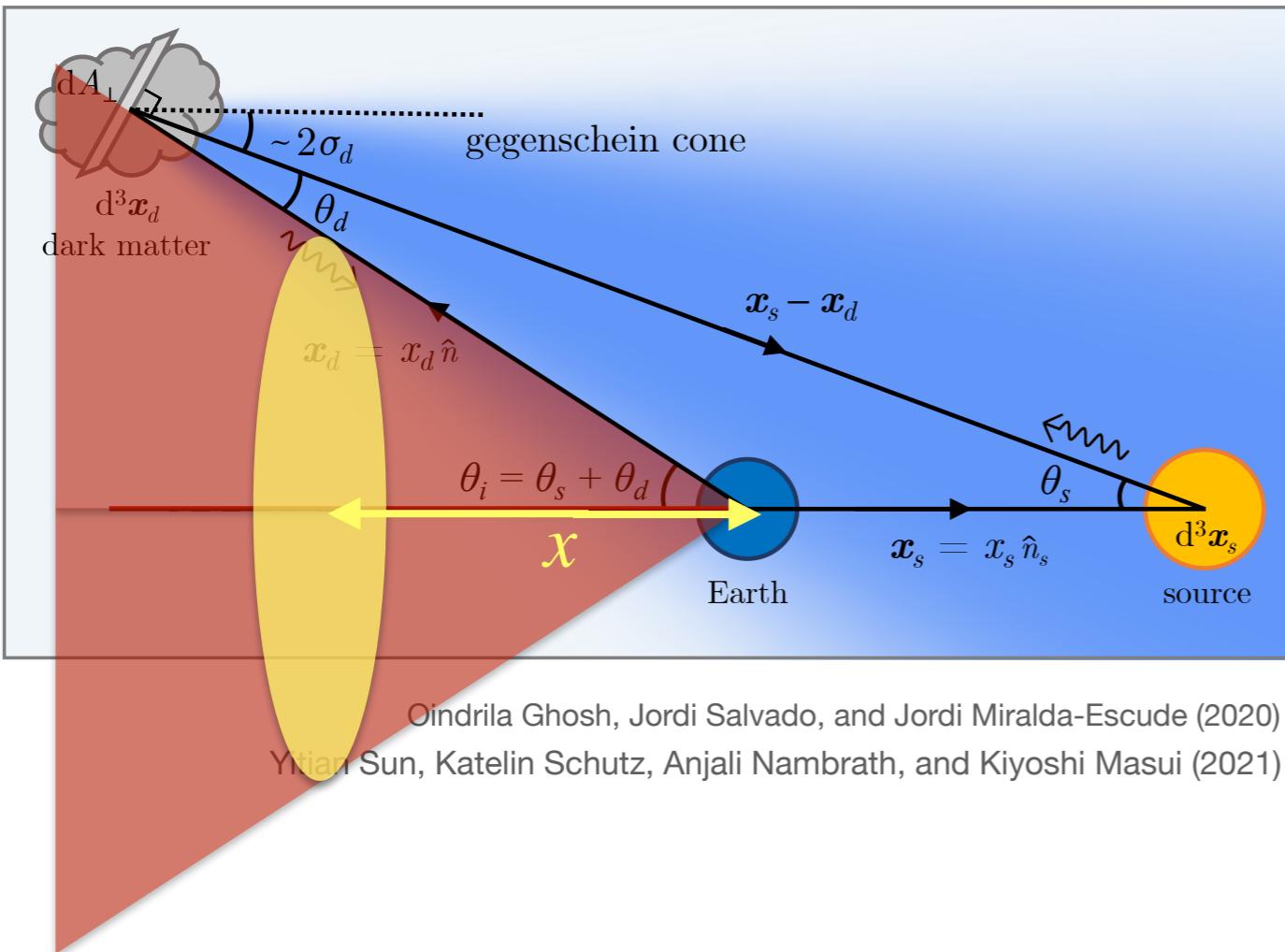
Yitian Sun, Katelin Schutz, Anjali Nambrath, and Kiyoshi Masui (2021)

# Gegenschein



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# Gegenschein



$$x_s \gg x_d$$

$$dI_g = \frac{\hbar c^4}{16} g_{a\gamma}^2 I_{s\nu} (\nu_d, \mathbf{x}) \rho_a(\mathbf{x}) d^3x$$

# Gegenschein

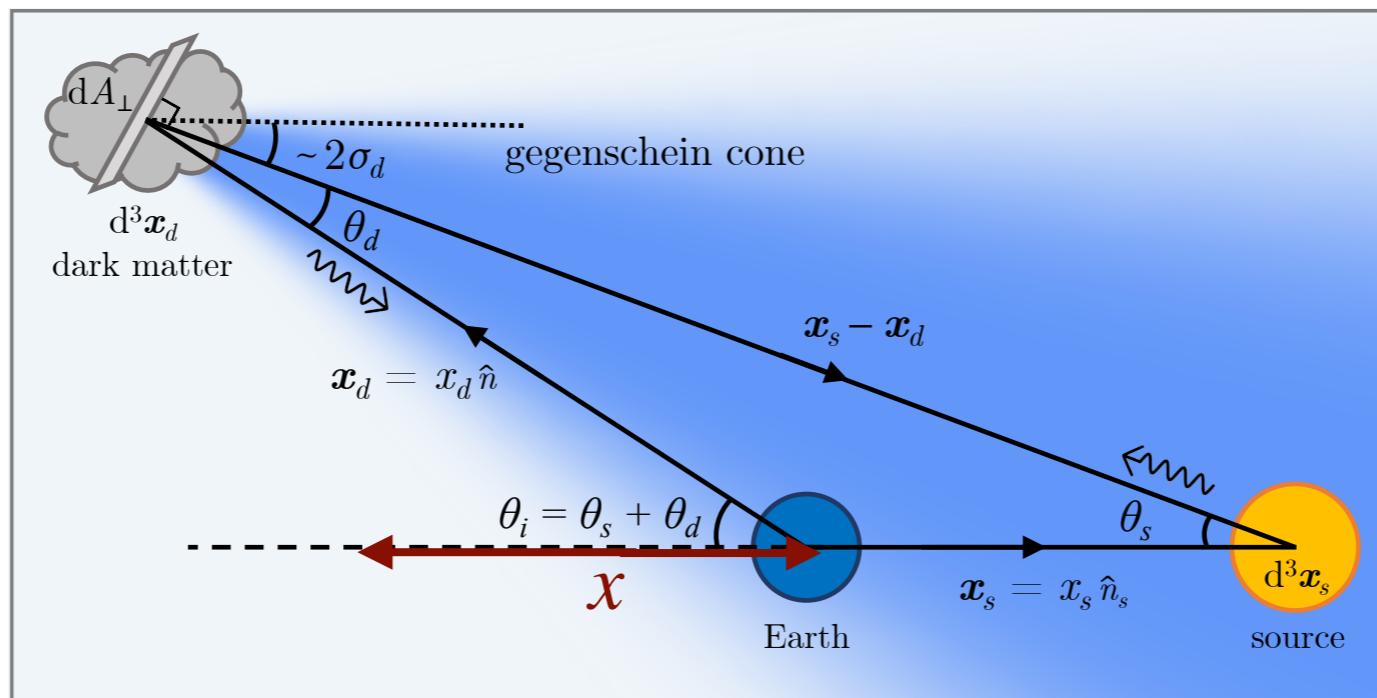
The flux of gegenschein signal:

$$S_{Ag} = \frac{\hbar c^4}{16} g_{a\gamma\gamma}^2 S_{A\nu} (\nu_d) \int_0^{R_{vir}} dx \rho_a[r(x)]$$

$S_{A\nu}$ : the flux of SNR seen by the earth

$R_{vir}$ : virial radius of the Galaxy

$r(x)$ : distance from the Galactic center



# Radio source

## Cygnus A

- The brightest extragalactic radio source
- $\simeq 232$  Mpc ( $\gg R_{vir}$ ) away from the Earth
- spectrum

$$\log S_{A\nu_d}(\nu_d) = a + b \log \nu_d + c \log^2 \nu_d$$
$$(a = 4.695, b = 0.085, c = -0.178)$$

J. Baars, R. Genzel, I. Pauliny-Toth, and A. Witzel (1977)

# Observed gegenschein intensity

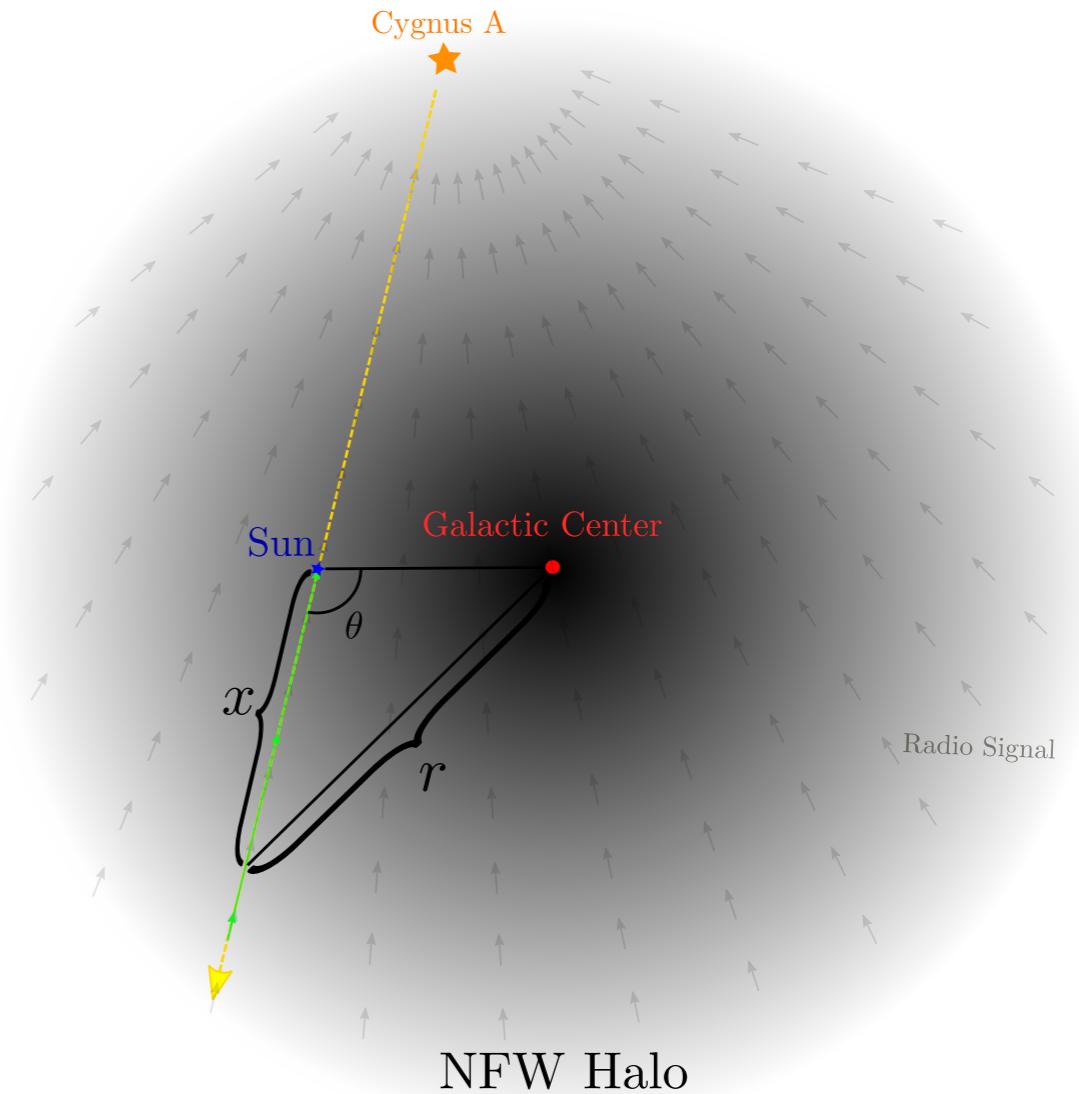
The flux of gegenschein signal:

$$S_{Ag} = \frac{\hbar c^4}{16} g_{a\gamma\gamma}^2 S_{A\nu}(\nu_d) \int_0^{R_{vir}} dx \rho_a[r(x)]$$

$$r(x) = \sqrt{x^2 + r_s^2 - 2xr_s \cos \theta}$$

$r_s$ : distance of the sun from  
the Galactic center

$$(\theta = 103.74^\circ)$$



# Distribution of ALP

Distribution of axions follows the NFW profile:

$$\rho_a(r) = \frac{\delta_c \rho_c}{(r/r_s) (1 + r/r_s)^2} \quad \delta_c = \frac{\Delta_{\text{vir}}}{3} \frac{r_c^3}{\ln(1 + r_c) - r_c/(1 + r_c)}$$

$\delta_c$  : overdensity parameter

$r_s \simeq 20$  kpc : the scale radius

$\rho_c$  : the critical density of the universe

$$\Delta_{\text{vir}} = 200$$

$R_{\text{vir}} \simeq 221$  kpc : the virial radius

$r_c \equiv R_{\text{vir}}/r_s$  : concentration

# Constraints on $g_{a\gamma\gamma}$

Obtained radio signal power:

$$P_{\text{signal}} = \eta A f_{\Delta} S_{A g} = \eta A f_{\Delta} \frac{\hbar c^4}{16} g_{a\gamma\gamma}^2 S_{A\nu}(\nu_d) \int_0^\infty dx \rho_a[r(x)]$$

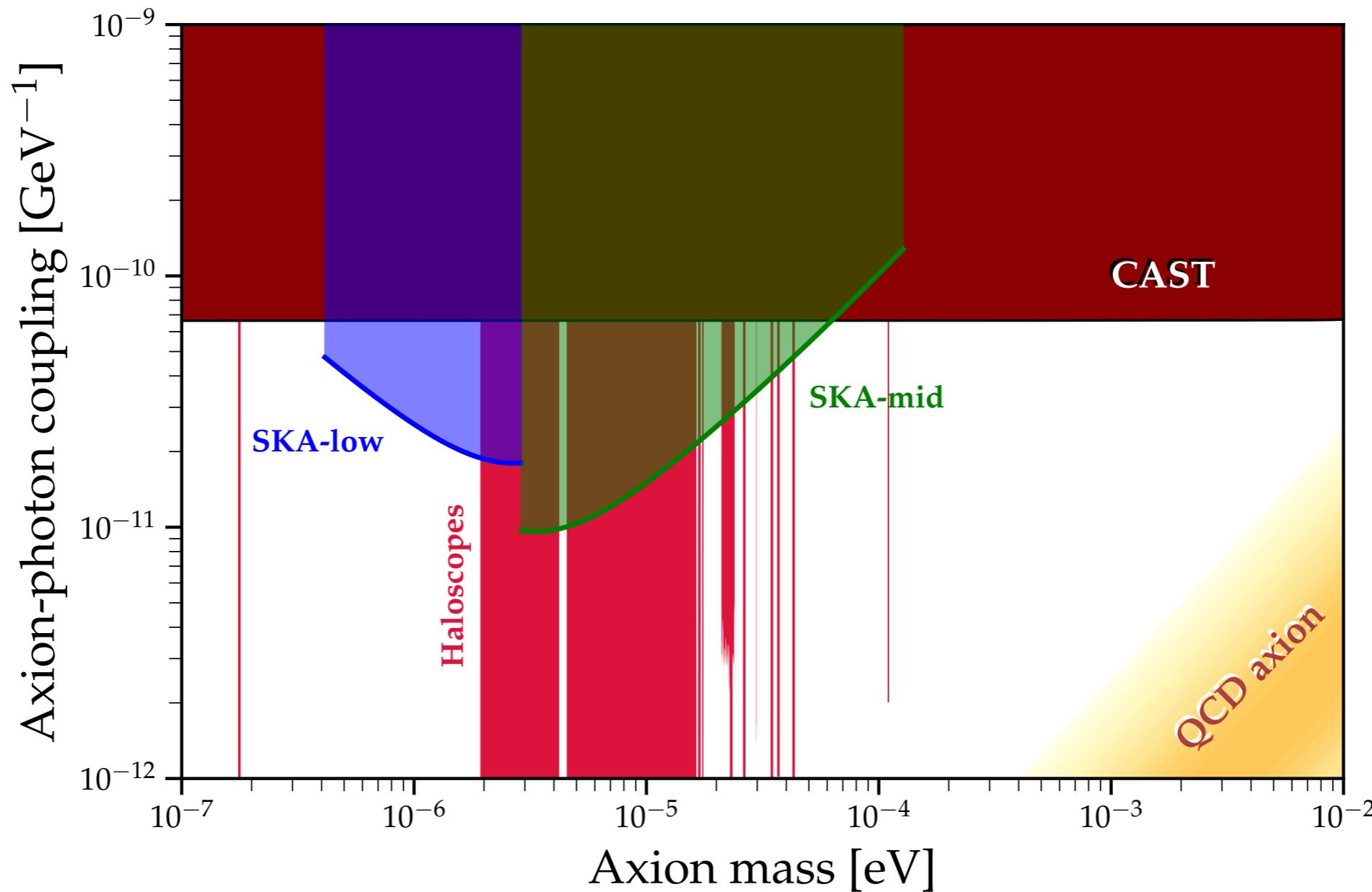
Noise measured in telescope:

$$P_{\text{noise}} = 2k_B T \sqrt{\frac{\Delta\nu}{t_{\text{obs}}}}$$

Assume we measure a gegenschein signal if  $P_{\text{signal}} / P_{\text{noise}} = n$

$$\rightarrow g_{a\gamma\gamma}^{-2} = \frac{\hbar c^4 A \eta}{32 k_B T} \sqrt{\frac{t_{\text{obs}}}{\Delta\nu}} \frac{S_{A\nu}(\nu_d) f_{\Delta}}{n} \int_0^\infty dx \rho_a[r(x)]$$

# Constraints on $g_{a\gamma\gamma}$



Oindrila Ghosh, Jordi Salvado, and Jordi Miralda-Escude (2020)

# Dilute Axion Stars

- Non-relativistic solutions of the Einstein Klein-Gordon equation:

$$g^{\mu\nu} D_\mu \partial_\nu \phi + V'(\phi) = 0$$

$$T^{\mu\nu} = \frac{1}{8\pi G} \left( R^{\mu\nu} - \frac{1}{2} R g^{\mu\nu} \right)$$

- Self-gravitating objects with the quantum pressure balancing gravity

$$R_a^{\text{dilute}} \sim (270 \text{ km}) \left( \frac{10 \mu\text{eV}}{m_a} \right)^2 \left( \frac{10^{-12} M_\odot}{M_a} \right)$$

# Results

Assume: 10% of mass within the virial radius forms dilute axion stars

Distribution of AS	flux (NFW is set to 1)
NFW	1
$\propto r^{-2}$	1.007
constant	0.923

→ As long as axion stars follow the same distribution to axions, the gegenschein flux doesn't change

Dynamical friction might change the flux?

(S. M. Koushiappas and A. Loeb (2017))

# Summary

- Gegenschein signal is expected due to the axion-photon coupling  $g_{a\gamma\gamma}$
- Non-observation of gegenschein signal place an upper bound on  $g_{a\gamma\gamma}$
- As long as axion stars follows the same distribution to axions, the gegenschein flux doesn't change
- Dynamical friction affects the flux?