An Axion Pulsarscope

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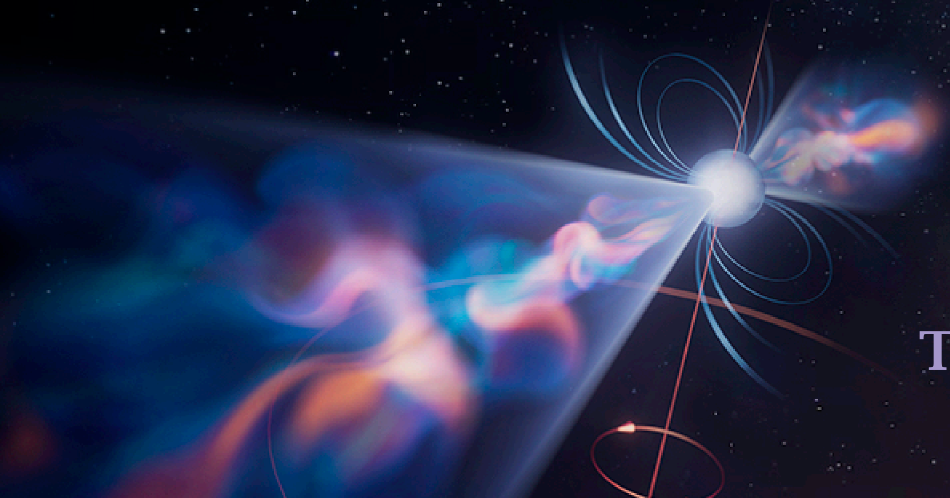
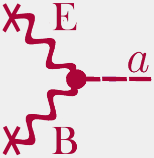


[image: NANOGrav]

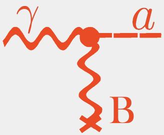
Axion coupling to EM field

$$g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

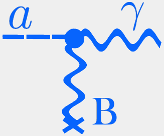
Emission



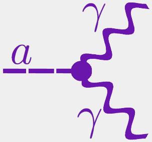
Primakoff effect

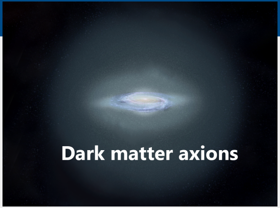


Inverse Primakoff



Decay





CAST

CERN Axion Solar Telescope
(helioscope)

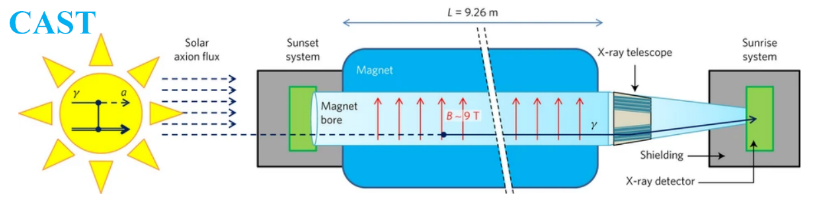
- Solar axions
- Broad $\sim$ keV spectrum

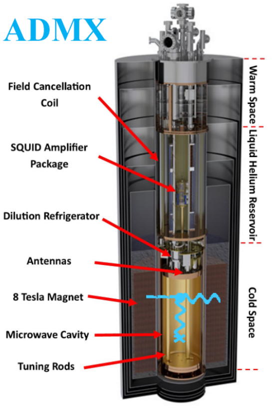
ADMX

Axion Dark Matter eXperiment
(haloscope)

- Dark matter halo axions
- Resonant

[images: CAST Collaboration (2017), ADMX]

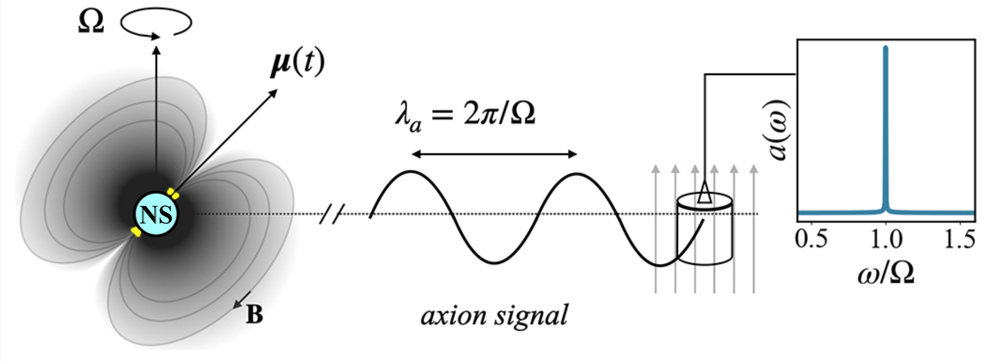




Pulsarscope!!

Key advantages:

- known frequency
- monochromatic signal
- higher signal quality



Pulsars are highly magnetized rotating **neutron stars**

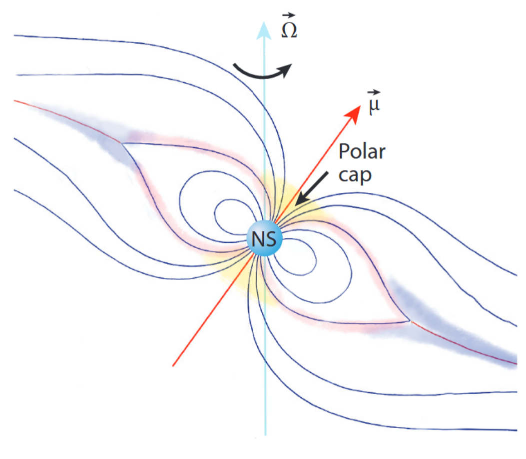
Emit pulses of radiation at regular intervals

Rotation period:

$$P = \frac{2\pi}{\Omega} = 1.4\text{ms} - 76\text{s}$$

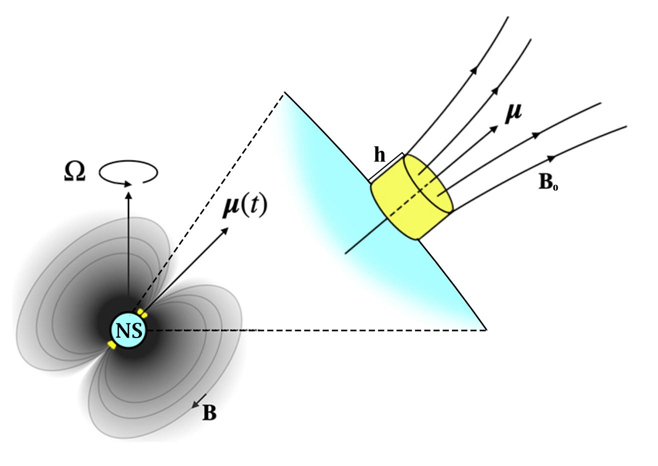
Magnetic field: $B_0 \sim 10^8 - 10^{15}\text{G}$

Radius: $R_{\text{NS}} \sim 12\text{km}$



[Philipov & Kramer 2022]

Axions are emitted only from the small polar cap regions above the magnetic poles of a pulsar.



The equation of motion:

$$(\Box + m^2)a = g_{a\gamma\gamma}\mathbf{E}\cdot\mathbf{B}$$

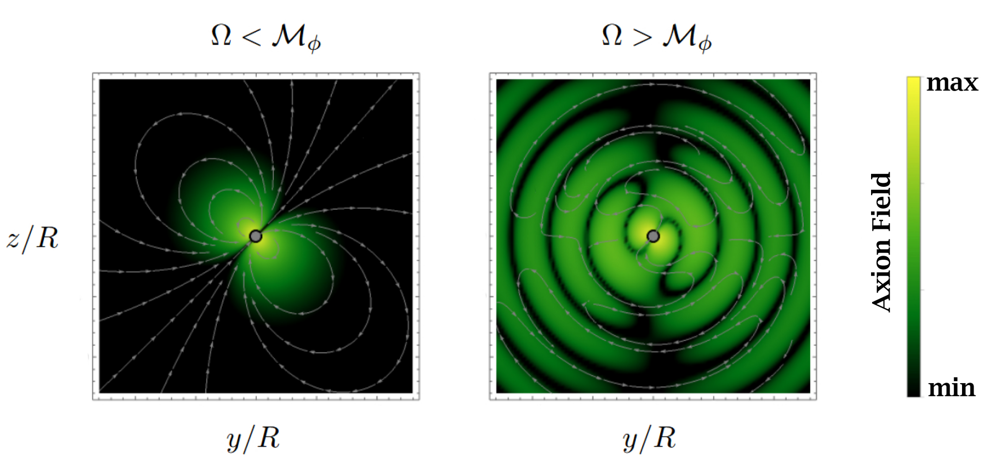
- **Monochromatic axion signal** on pulsar rotation frequency Ω
- Axion emission power:

$$P_a \propto g_{a\gamma\gamma}^2 B_0{}^4\,\Omega^8 R_{\rm NS}^8 h^4$$

[MK, M. Lisanti, A. Prabhu, B. Safdi (2024) arXiv:2402.17820]

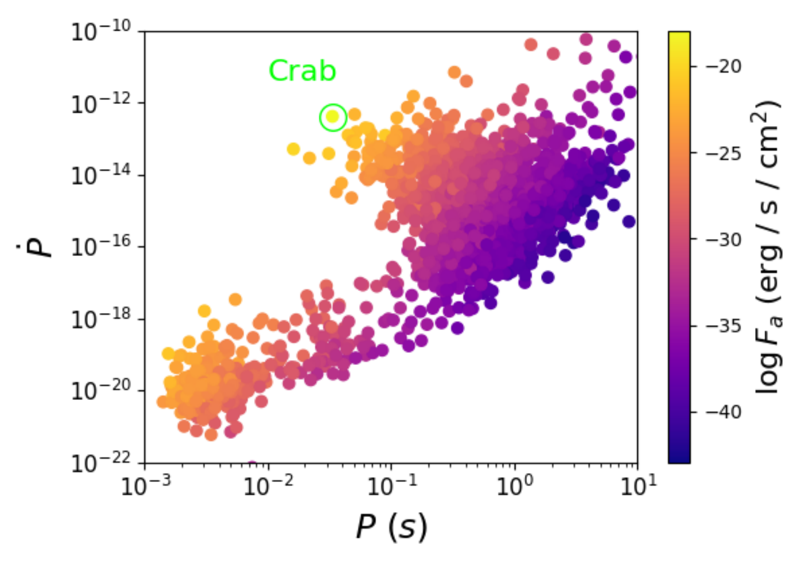
The Vacuum Dipole Model (VDM)

Axions are emitted from the entire volume of a pulsar's magnetosphere.



[Garbrecht, McDonald (2018)]

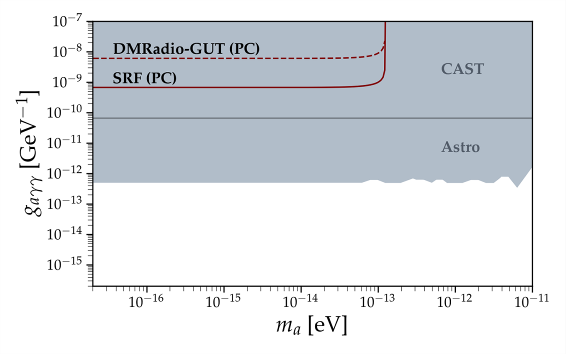
The axion emission power: $P_a \propto g_{a\gamma\gamma}^2 {B_0}^4 \Omega^6 R_{NS}^{10}$



P - pulsar's rotation period

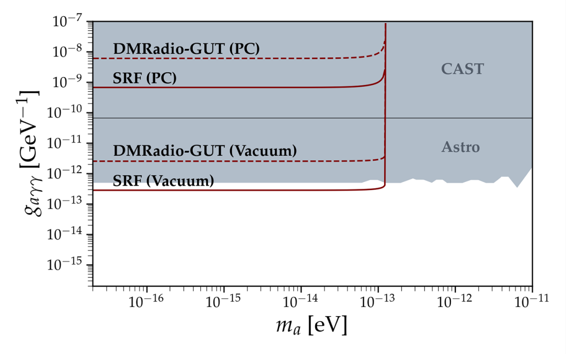
$\dot{P}$ - pulsar's spin-down rate

[MK, M. Lisanti, A. Prabhu, B. Safdi (2024) arXiv:2402.17820]



Projected sensitivity for SRF, DMRadio-GUT and CASPEr experiments to axions emitted by Crab pulsar (polar gap and vacuum dipole magnetosphere model).

[MK, M. Lisanti, A. Prabhu, B. Safdi (2024) arXiv:2402.17820]



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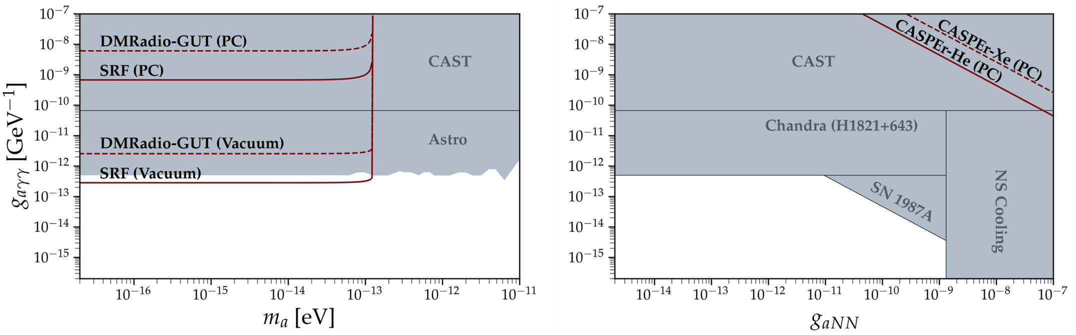

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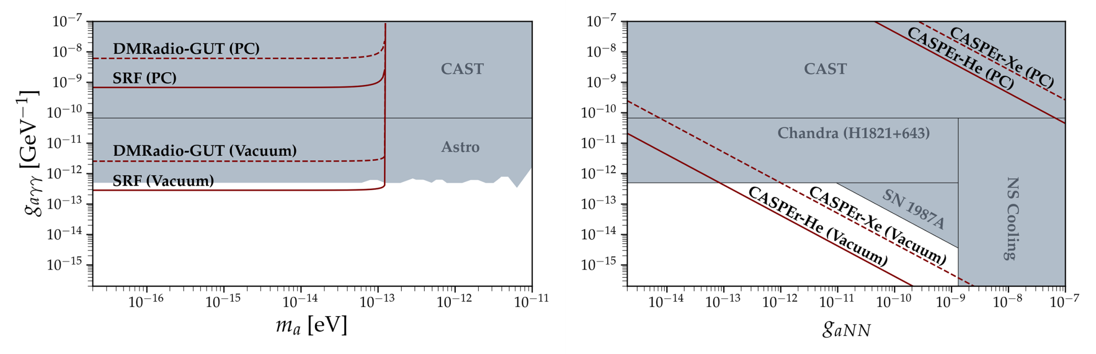

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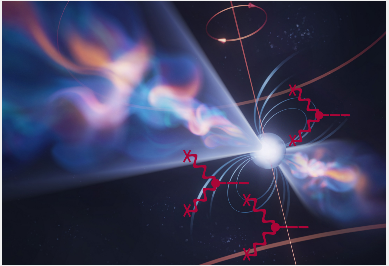


Conclusions:

- A new target for axion detection is proposed – axions emitted by pulsars.
- Can potentially improve current laboratory constraints in mass range $m_a \lesssim 10^{-13}$ eV, depending on magnetosphere model.

Future work:

- Detailed PIC simulations of the pulsar's magnetosphere will provide a more precise estimation of axion emission power, refining targets for experiments.

[MK, M. Lisanti, A. Prabhu, B. Safdi (2024) arXiv:2402.17820]

Thank You!

Presentation Outline

Axion couplings to Standard Model

EM field

$g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$

Fermions

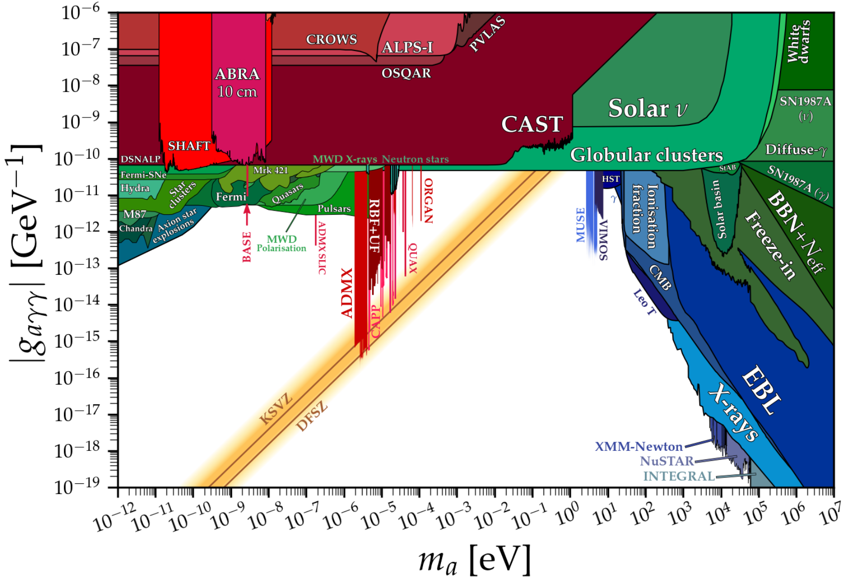
$g_{a\psi\psi} (\partial_\mu a) \bar{\Psi} \gamma^\mu \gamma^5 \Psi$

Gluons

$g_{agg} a \mathrm{Tr}[G_{\mu\nu} \tilde{G}^{\mu\nu}]$

Gravity

Current Bounds on the Axion-Photon Coupling Constant



[Axion Limits maintained by **cajohare**]

Upcoming Axion Experiments Projections

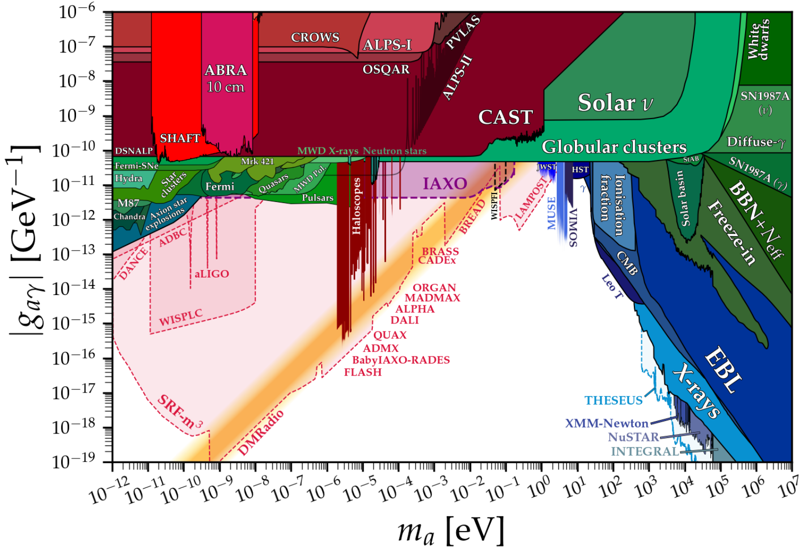
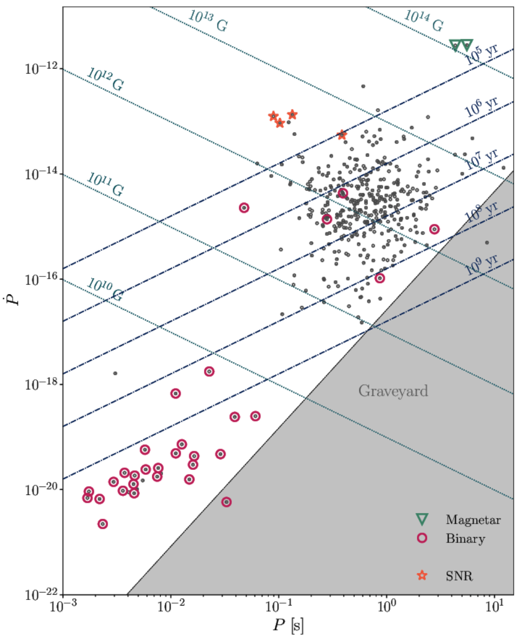
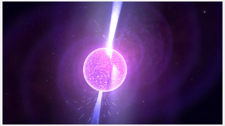


Figure 1: Axion-photon coupling bounds with projections [cajohare]

Pulsar Population

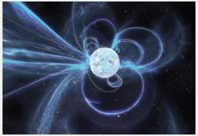


- Active



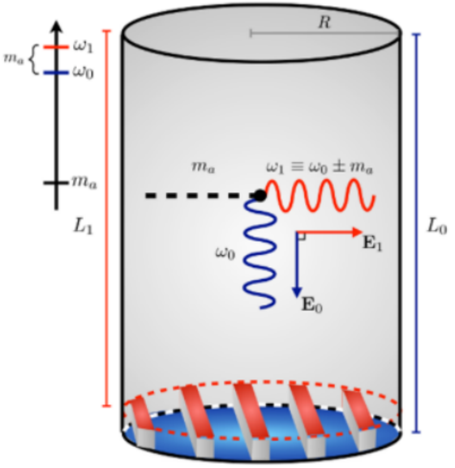
- Millisecond

- Magnetar



[Images: M. Lower et al. (2020), Kevin Gill, ESA, Francesco Ferraro, Carl Knox]

SRF



Cartoon of cavity setup.

SRF – Superconducting Radio Frequency cavity detector

- dark matter axions
- resonant

$\omega_1 \approx \omega_0 + \omega_a$

quality factor $Q_0 \sim Q_1 \sim 10^{12}$

Pulsarscope:

- quality factor $Q \sim 10^{12}$
- coherence time $\tau_{\text{coh}} \gg T_{\text{obs}}$

[Image: A. Berlin et al. (2020)]

Experiment Sensitivity Scalings

The experimental target can be modeled as resonator:

$$\ddot{x}(t) + \frac{\omega_0}{Q_0}\dot{x}(t) + \omega_0^2 x(t) = \frac{A}{\omega}\cos(\omega t + \varphi(t)) \tag{1}$$

Power extracted by oscillator from axion field:

$$\langle P \rangle = \frac{A^2 \omega_0 / Q}{2\left[(\omega^2 - \omega_0^2)^2 + (\omega_0 \omega / Q)^2\right]} \tag{2}$$

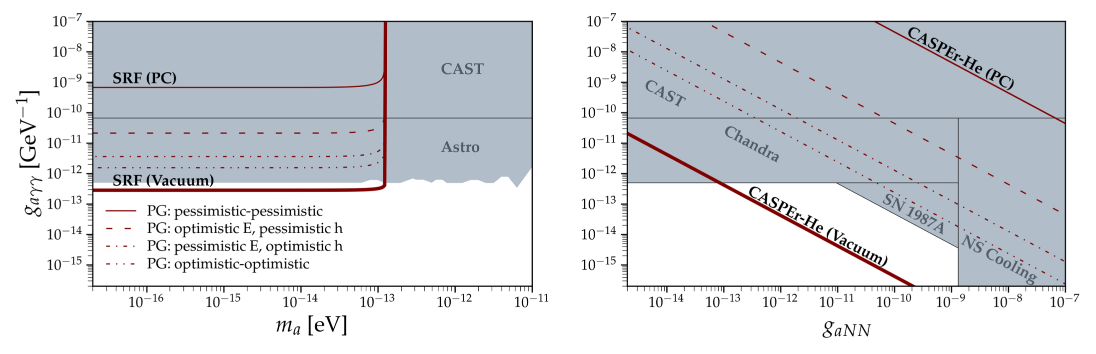
The signal-to-noise ratio for pulsar axions:

$$\mathrm{SNR} \propto g_i^2 \rho_{\mathrm{PS}} \left(\frac{\partial a}{\omega a}\right)^2 (TQ)^{1/2} \tag{3}$$

Polar Cap Models

		Polar gap height, **h**	
		positive	negative
Polar Gap electric field, **E**	positive	$h = r_{pc}$ $E = E_{\text{vac}} = \Omega R_{\text{NS}} B$	$h = h_{\text{Rud}}$ $E = E_{\text{vac}} = \Omega R_{\text{NS}} B$
	negative	$h = r_{pc}$ $E = E_{\text{Rud}} = 2\Omega h B = 2\Omega r_{pc} B$	$h = h_{\text{Rud}}$ $E = E_{\text{Rud}} = 2\Omega h B = 2\Omega h_{\text{Rud}} B$

Projections



Projected sensitivity for SRF and CASPEr experiments to axions emitted by Crab pulsar (vacuum dipole magnetosphere and several different polar gap models).