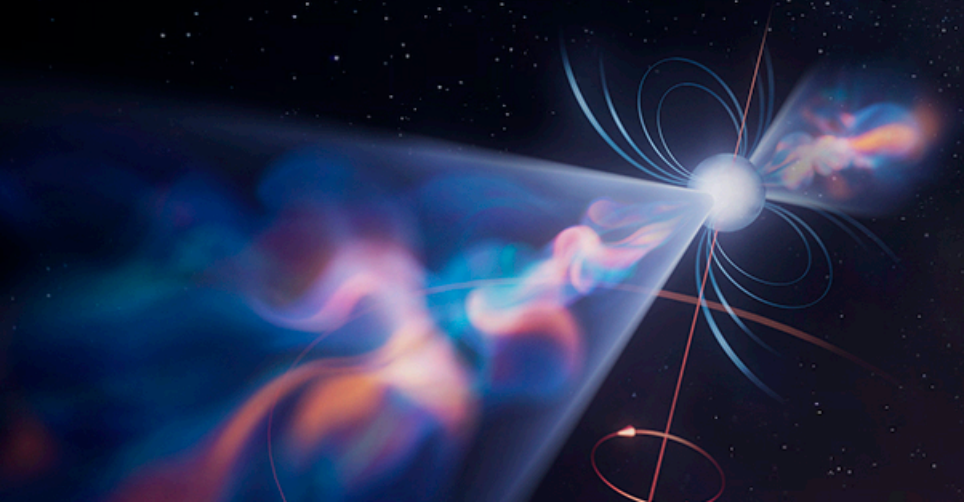
An Axion Pulsarscope

Mariia Khelashvili
SISSA & INFN



Invisibles25, CERN

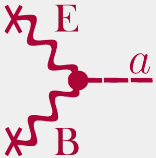
September 3, 2025

[image: NANOGrav]

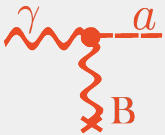
Axion coupling to EM field

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

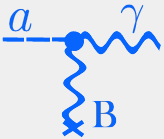
Emission



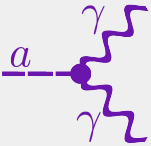
Primakoff effect



Inverse Primakoff



Decay



Axion Detection Experiments

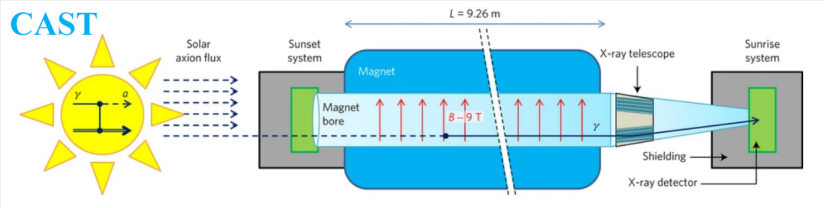
CAST
CERN Axion Solar Telescope
(helioscope)

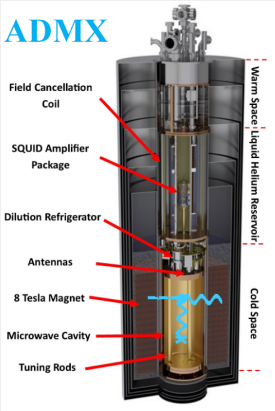
- Solar axions
- Broad ∼ keV spectrum

ADMX
Axion Dark Matter eXperiment
(haloscope)

- Dark matter halo axions
- Resonant

[images: CAST Collaboration (2017), ADMX]



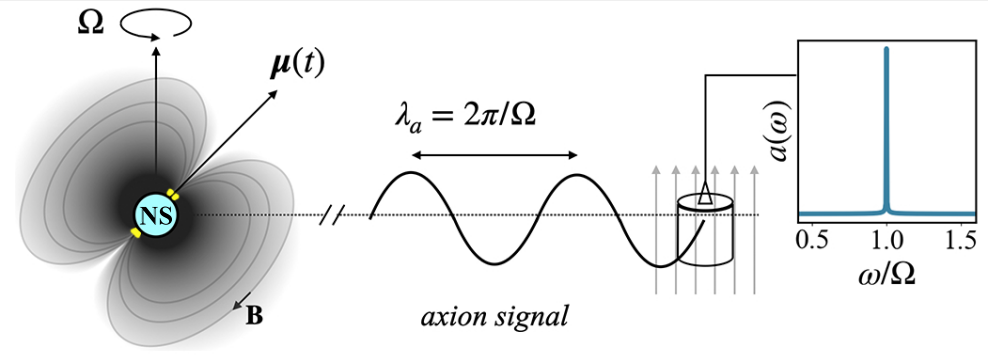


New Axion Detection Target

Pulsarscope!!

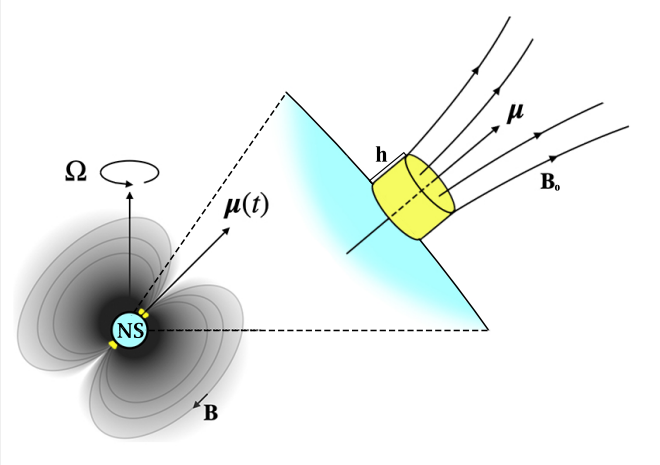
Key advantages:

- known frequency
- monochromatic signal
- higher signal quality



The Polar Cap (PC) Model

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



The equation of motion:

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

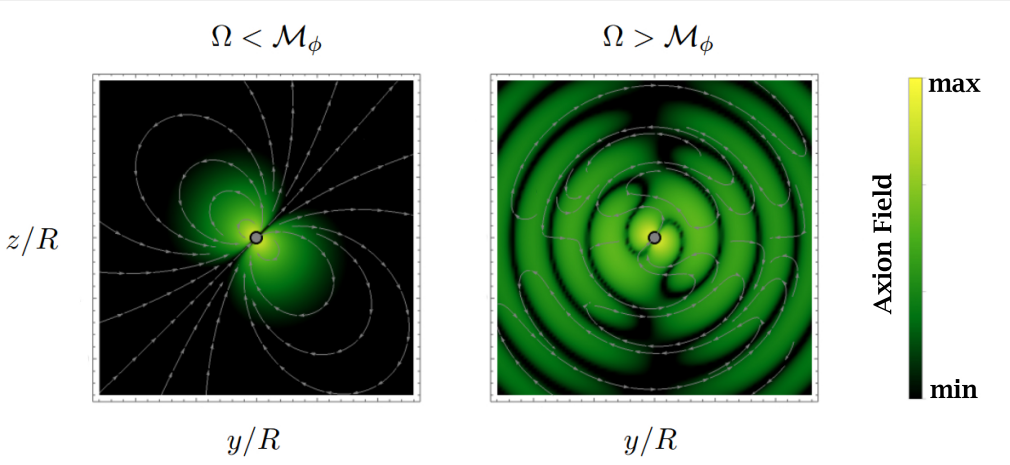
- **Monochromatic axion signal** on pulsar rotation frequency Ω
- Axion emission power:

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

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

The Vacuum Dipole Model (VDM)

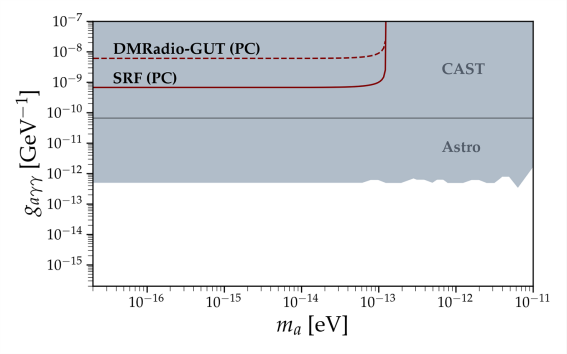
Axions are emitted from the entire volume of a pulsar's magnetosphere.



[Garbrecht, McDonald (2018)]

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

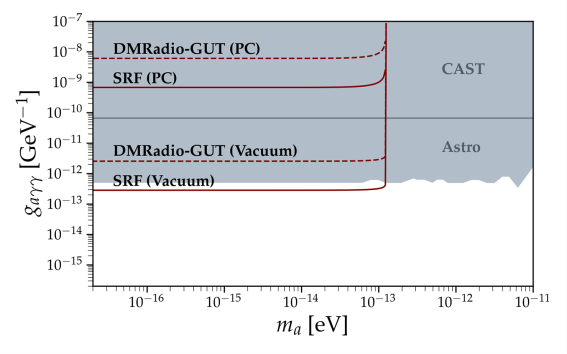
The Projected Sensitivity



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]

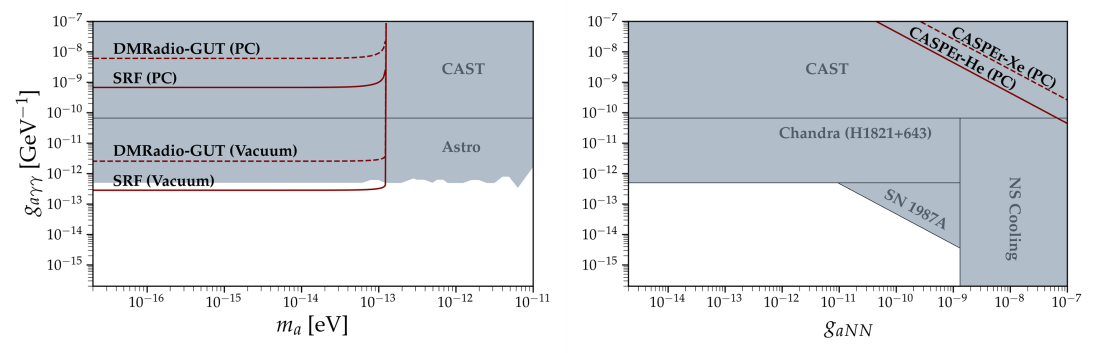
The Projected Sensitivity



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]

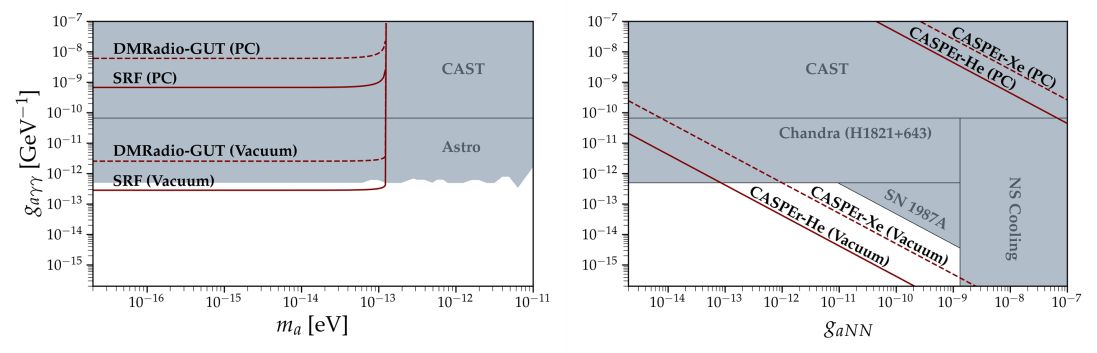
The Projected Sensitivity



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]

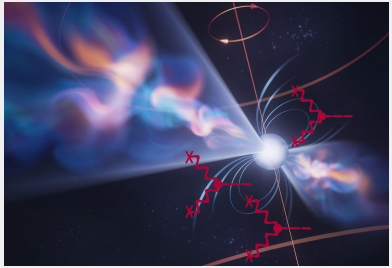
The Projected Sensitivity



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]

Conclusions



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!

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

Pulsars

Pulsars are highly magnetized rotating **neutron stars**

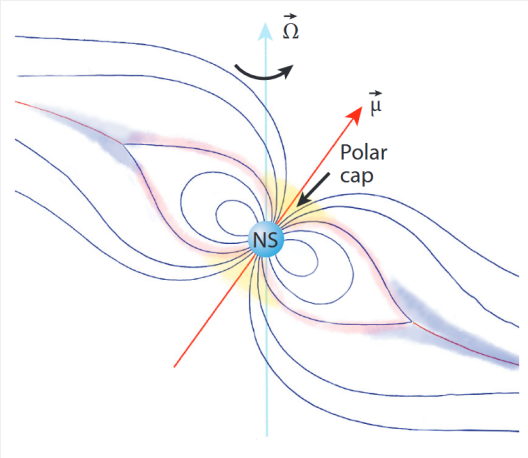
Emit pulses of radiation at regular intervals

Rotation period:

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

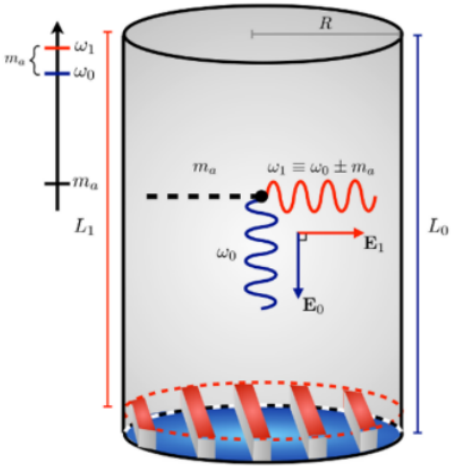
Magnetic field: $B_0 \sim 10^8 - 10^{15}$G

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



[Philipov & Kramer 2022]

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:

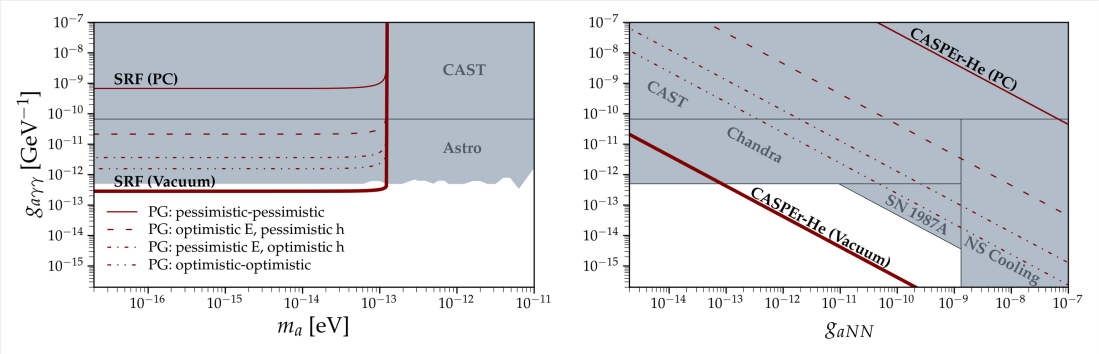
- quality factor $Q \sim 10^{12}$
- coherence time $\tau_{\text{coh}} \gg T_{\text{obs}}$

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

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).