Recent Progress in Radio Searches for Axion DM

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Based on **Phys.Rev.D 102 (2020) 2, 023504** and **JHEP 09 (2021) 105** and **Phys.Rev.D 105 (2022) 2, L021305**

Collaborators: R. A. Battye, S. Srinivasan, F. Pace and B. Stappers, P. Weltevrede, M. Keith (U. Manchester) B. Garbrecht,(TU Munich), J. Darling (Colorado), S. Witte (GRAPPA)

Axions

Generic class of particle: light (psuedo) scalar: a

$$\mathcal{L}_a = \frac{1}{2}\partial_\mu a \partial^\mu a + V(a)$$

Can couple to photons:

$$\mathcal{L}_{SM} = \frac{g_{a\gamma\gamma}}{2} a \underbrace{F_{\mu\nu}\tilde{F}^{\mu\nu}}_{\text{electromagnetism}}$$

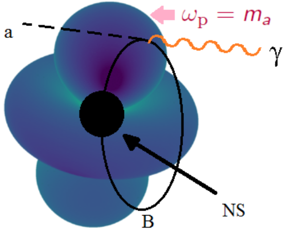
Main motivations:

- **Occurs in many extensions of the SM** (e.g. "string axiverse")
- **Strong CP Problem** Peccei, Quinn (1977)

$$\mathcal{L}_\theta = \frac{\theta_{QCD}}{32\pi} \mathrm{Tr}\, G_{\mu\nu}\tilde{G}^{\mu\nu} \qquad \theta \lesssim 10^{-10}$$

- **DM Candidate**

Resonant Axion DM Conversion Around Neutron Stars



$$P_{a\to\gamma} \sim \frac{g_{a\gamma\gamma}^2 B^2}{\frac{d}{dz}(\omega_p(x_{res}))}$$

Goldreich-Julien (1960s) of plasma around NSs

$$n_{GJ}(\mathbf{r}) = \frac{2\,\mathbf{\Omega}\cdot\mathbf{B}}{e}\frac{1}{1-\Omega^2\,r^2\,\sin^2\theta}\,, \qquad \omega_p = \sqrt{\frac{4\pi\,\alpha_{EM}\,|n_{GJ}|}{m_e}},$$

A. Hook, Y. Kahn B. Safdi, Z. Sun Phys. Rev. Lett. 121 (2018) 24, 241102

F. P. Huang, K. Kadota, T. Sekiguchi, H. Tashiro Phys.Rev.D 97 (2018) 12, 123001

M.S. Pshirkov, S.B. Popov J. Exp. Theor. Phys. 108 (2009) 384-388 (Original Proposal!)

Observations

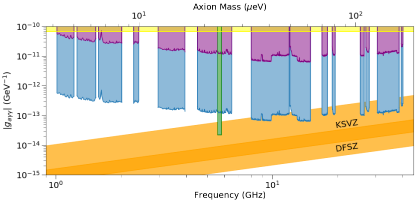
Green Bank (US)

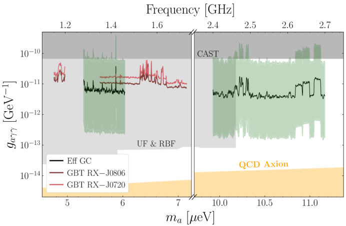
Foster et al.
Phys.Rev.Lett. 125 (2020) 17, 171301

J. Darling
Phys.Rev.Lett. 125 (2020) 12, 121103
& Astrophys.J.Lett. 900 (2020) 2, L28

Karl J Jansky VLA

Effelsberg (Ger)



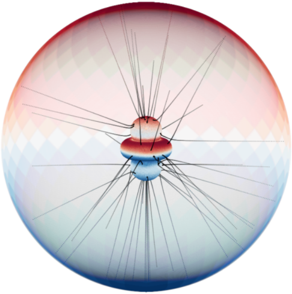


Theory: Signal Modelling

M. Leroy, M. Chianese, T. Edwards, C. Weniger Phys. Rev. D 101, 123003 (2020)

S. Witte , D. Noordhuis, T. Edwards, and C. Weniger Phys. Rev. D 104, 103030 (2022)

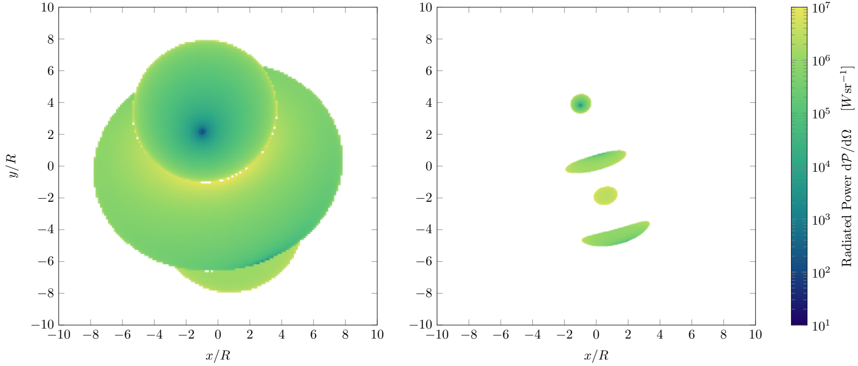
R. Battye, B. Garbrecht, **J. I. McDonald**, S. Srinivasan JHEP 09 (2021) 105



Much progress made in plasma ray tracing

image courtesy S. Witte

straight Lines (2020) **plasma refraction (2021)**

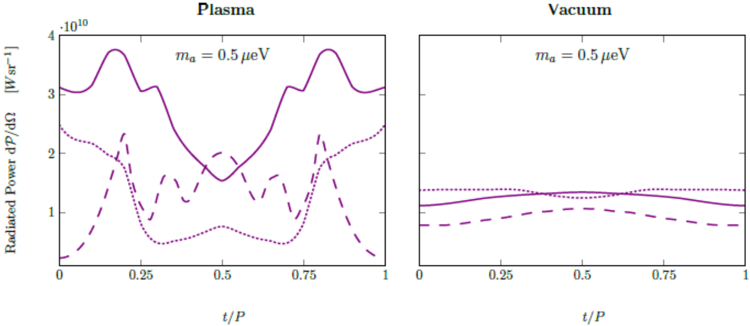


(Battye, Garbrecht, JIM, Srinivasan (2021))

Dark matter radio emission from the star strongly refracted!

Time dependence of signal can now be characterised

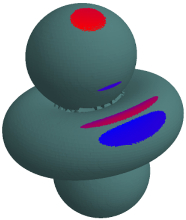
Pulse Profiles

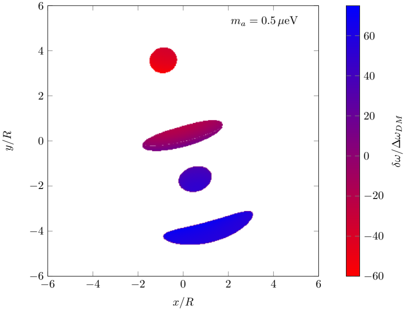


Line Shape Can Now be Characterised

Plasma Broadening - time-dependent effects

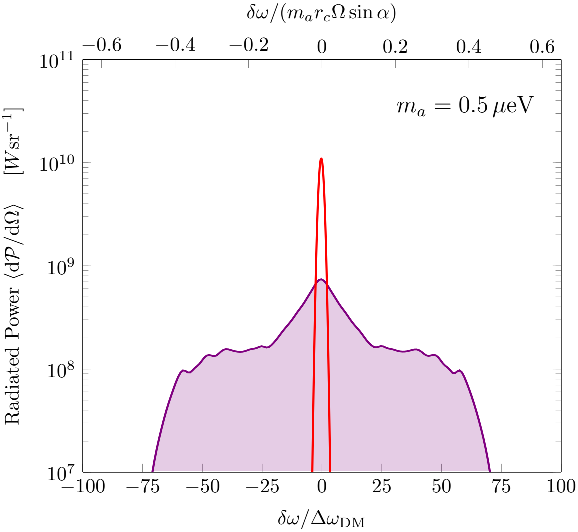
$$\frac{d\omega(x(t),t)}{dt} = \frac{1}{2\omega}\underbrace{\partial_t\omega_{\mathrm{p}}^2(t,\mathbf{x}(t))}_{\mathrm{t-dep\,plasma}}$$





$$\delta\omega \simeq \frac{1}{2\omega}\int dt'\partial_t\omega_{\mathrm{p}}^2(t',\mathbf{x}(t'))$$

Line Shape Can Now be Characterised

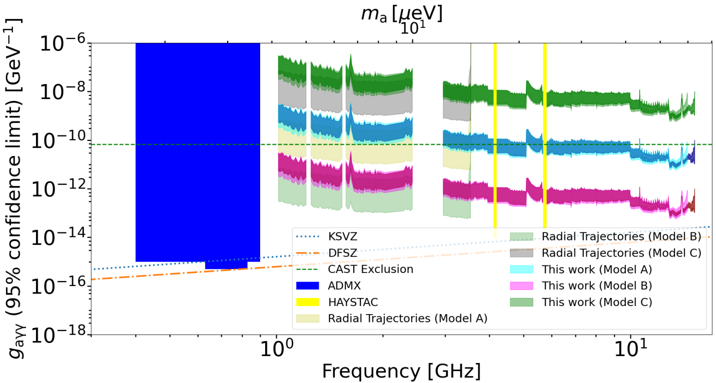


← frequency →

Theory + Observation

Ray-Tracing applied to galactic centre magnetar PSR J1745-2900

Battye, Darling, **McDonald**, Srinivasan (2021) Phys.Rev.D 105 (2022) 2, L021305



main uncertainties:

- DM density near galactic centre
- possibly magnetosphere structure?
- observing angle of neutron star

Challenges and Opportunities

- NSs offer the possibility to probe wide ranges of masses $10^{-7}\mu\text{eV} \lesssim m_a \lesssim 10^{-4}\mu\text{eV}$ complementary to experiments.
- Sensitivity of $g_{a\gamma\gamma}$ constraints to magnetosphere structure ? **Vital** question, but not yet studied
- More radio data always good (either archival or new)
- Accurate measurement of DM density near NSs of interest.

Thanks for listening!