First Constraint on Axion–Photon Coupling g_γ from Neutron Star Observations

Jun-Chen Wang

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In collaboration with Qing-Hong Cao, Yandong Liu, Lijing Shao, Shunshun Cao and Jinchen Jiang

School of Physics, Peking University

Motivation

We aim to detect axions through directly measuring axion-photon coupling g_γ

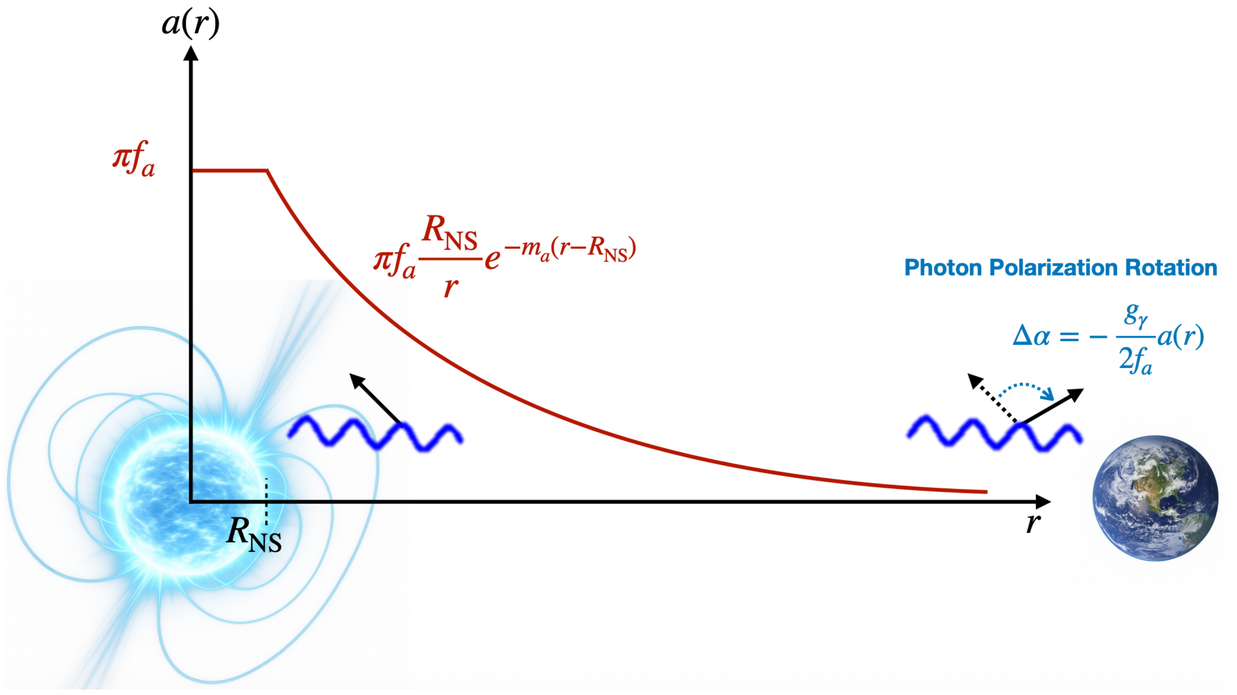
$$\mathscr{L} = \frac{\alpha_s}{8\pi}\frac{a}{f_a}G^b_{\mu\nu}\tilde{G}^{b\mu\nu} + \frac{g_\gamma}{4f_a}aF^{\mu\nu}\tilde{F}_{\mu\nu}$$

Axion profile change in the neutron star

- General axion potential
- QCD chiral symmetry restoration
- Axion equation of motion

Huang et al. 2019

$$a(r) = \begin{cases} \pi f_a\ , & r < R_{\rm NS} \\ \pi f_a \dfrac{R_{\rm NS}}{r} e^{-m_a(r-R_{\rm NS})}, & r > R_{\rm NS} \end{cases}$$



Photon polarization rotation

- Axion-induced birefringence Sikivie et al. 2021

$$\Delta\alpha = -\,g_\gamma a(r)/(2f_a)$$

- Radius-Frequency Mapping Qiu et al. 2023

$$\omega_c = (9/8)\sqrt{(2\pi)}\gamma^3/\sqrt{P_{\rm NS} r}$$

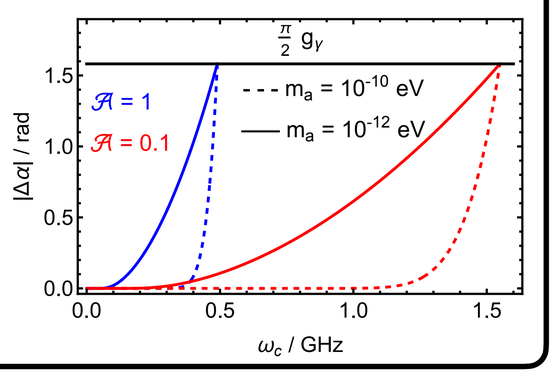
Theoretical prediction

- Relation between the pulsar emission polarization rotation and the frequency

$$\Delta\alpha(\omega_c) = -\frac{\pi g_\gamma}{2}\frac{R_{\rm NS}P_{\rm NS}\omega_c^2}{7.95\gamma^6}e^{-m_a\left(\frac{7.95\gamma^6}{P_{\rm NS}\omega_c^2} - R_{\rm NS}\right)}$$

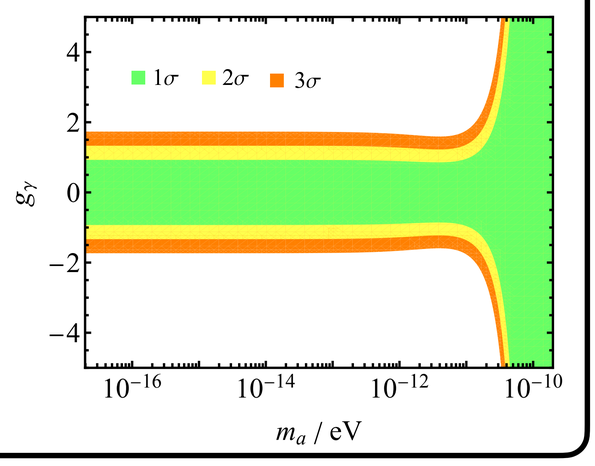
$$\omega_{\rm max} = \sqrt{0.24/\mathscr{A}}\ \text{GHz}$$

$$|\Delta\alpha|_{\rm max} = \pi g_\gamma/2$$



Analysis of astronomical observation data

- Observation data from FAST
- Focus on the pulsar PSR B1919+21
- Eliminate Faraday rotation effects
- Use the χ^2 fitting method
- Fit two pulsar parameters and two axion parameters



Significance of detecting g_γ

$$g_\gamma = \frac{\alpha_{\rm EM}}{2\pi}\left(\frac{E}{N} - 1.92\right)$$

- Obvious Experimental Signal
- Theoretical Significance
  - Determine UV axion models
  - Exclude some typical models
  - Explore SM Global Structure
  - Find generalized symmetries

Choi et al. 2024

Final Constraints on Axion Parameters

$|g_\gamma| < 0.93$ at 1σ level for $m_a < 10^{-11}$ eV

Conclusion

We propose novel methods for detecting axions that uniquely depend on the dimensionless axion-photon coupling through neutron stars. Based on the axion profile change in neutron stars and the axion-induced photon polarization rotation, we constrain the axion parameters by processing the observational data from FAST.