X-ray signatures of axions

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Phenomenology 2020 Symposium

1910.02956: CD, J. Foster, B. Safdi
1910.04164: M. Buschmann, R. Co, CD, B. Safdi
Why Axions?

• The QCD axion is a highly-motivated extension of the Standard Model
• Here we focus on axion-like particles
• Both couple to electromagnetism and matter
The CAST Experiment

\[ \mathcal{L} = g_{a\gamma\gamma} a E \cdot B \]

\[ P_{a\rightarrow\gamma} \approx (g_{a\gamma\gamma} B L)^2 \]
Neutron Stars and Axions

\[ B \sim 10^{13} \text{ G} \]

\[ T_{\text{surf}} \sim 100 \text{ eV} \]

\[ T_{\text{core}} \sim 10 \text{ keV} \]

Energy

0.1 keV

2 keV

10 keV

Flux
Axion Production in Neutron Stars

\[ \mathcal{L}_{aNN} = \frac{C_N}{f_a} (\partial_\mu a) \bar{N} \gamma_\mu \gamma_5 N \]

\[ \frac{dF}{dE} \propto \frac{z^3 (z^2 + 4\pi)}{e^z - 1}, \quad z = \frac{E}{T} \]

\[ L_{\text{NS},a} \approx 0.05L_\odot \left( \frac{g_{\text{ann}}}{10^{-10}} \right)^2 \left( \frac{T_c}{10^8 \text{ K}} \right)^6 \]

Axion-photon conversion – Strong Dipole

\[ P_{a \rightarrow \gamma} \approx 10^{-4} \left( \frac{g_{a\gamma\gamma}}{10^{-11} \text{ GeV}^{-1}} \right)^2 \left( \frac{1 \text{ keV}}{\omega} \right)^{4/5} \left( \frac{B_0}{10^{13} \text{ G}} \right)^{2/5} \left( \frac{R_{NS}}{10 \text{ km}} \right)^{6/5} \]
Neutron Star Targets

The Magnificent Seven:

- 7 neutron stars 100 pc away
- $B \sim 10^{13}$ G
- $T_{\text{surf}} \sim 100$ eV
- Near-perfect blackbodies → zero background $> 1$ keV
XMM-Newton and Chandra (PN, MOS)
RX J1856.6-3754 spectrum
Data Summary

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Data Summary

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RX J1856.6-3754 Axion Predictions

![Graph showing axion model predictions compared to PN+MOS+Chandra data.]
Results: Limits and Preferred Region

CAST2017 + NS cooling

95% exclusion

$g_{\gamma\gamma} / g_{\text{ann}}$ [GeV$^{-1}$]

1σ

2σ

$m_\alpha$ [eV]
Follow-up Measurements: High Energy
Follow-up Measurements: High Energy

![Graph showing energy distribution](graph.png)
Conclusion

• Astrophysics is a powerful probe of axions.

• We found an excess of X-rays in the Magnificent Seven neutron stars that is consistent with an axion-like particle interpretation.

• Instrumental origin seems unlikely!

• Several ideas to further characterize the nature of this excess.
Questions?
Systematics: Background Point Sources

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Systematics: Pileup
Inferred Core Temperatures

1 and 2 σ predictions from NS modeling
1 and 2 σ measurement from X-ray data

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Intensity Predictions

1 and 2 $\sigma$ predictions from NS modeling
1 and 2 $\sigma$ measurement from X-ray data

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Follow-up Measurements: White Dwarf

• RE J0317-853: the hottest known magnetic white dwarf
• 40 ks Chandra data this year!

1903.05088: CD, A. Long, B. Safdi, PRL
Other Emission Mechanisms?

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