Title: Polarized Signatures of Axions at Magnetic White Dwarfs

Speakers: Christopher Dessert

Series: Particle Physics

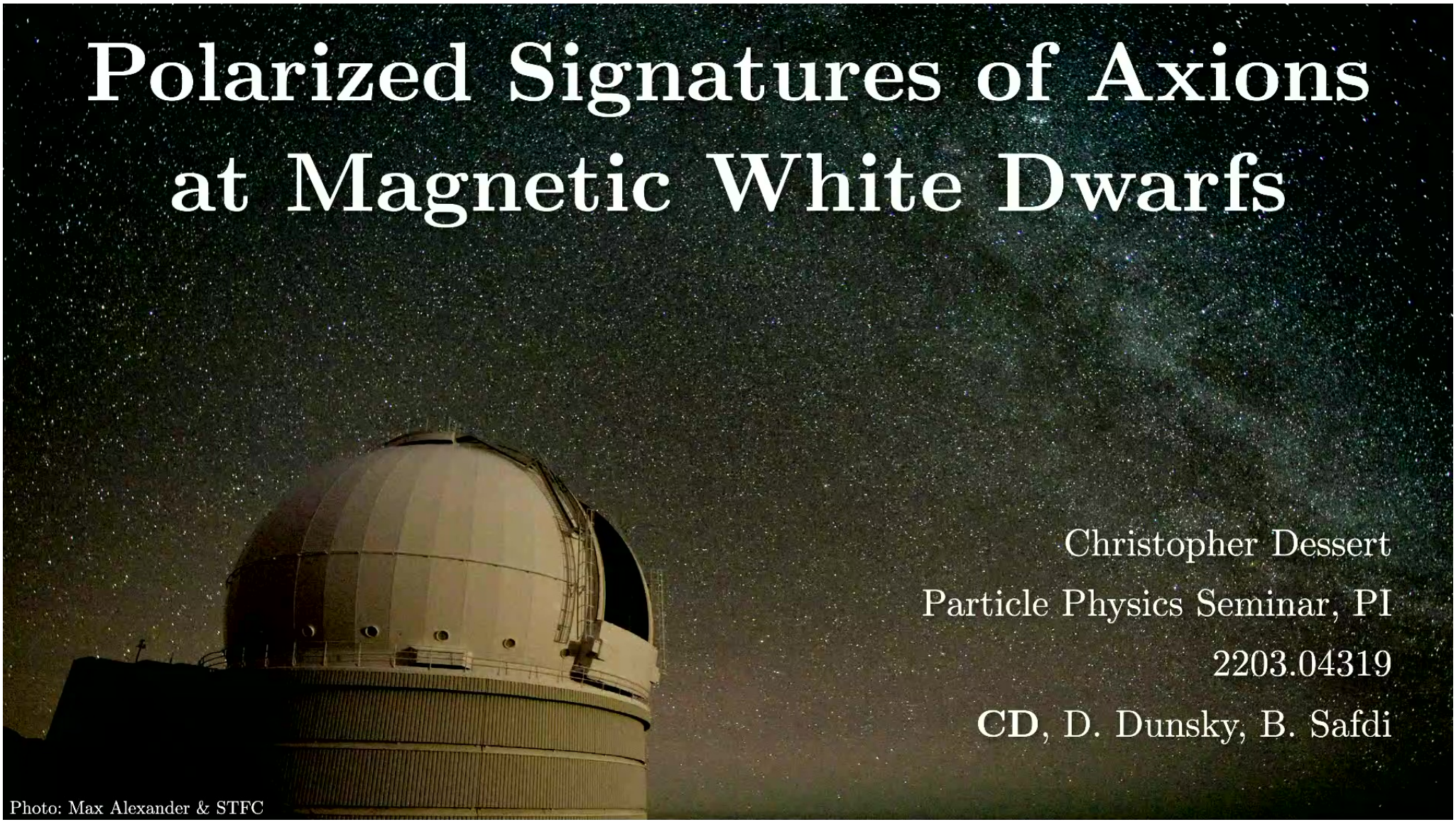
Date: April 11, 2023 - 1:00 PM

URL: https://pirsa.org/23040068

Abstract: I will discuss a novel search for axions using spectropolarimetric observations of magnetic white dwarfs (MWDs). Photons produced as thermal radiation at the MWD surface may convert into an axion as they traverse the magnetosphere, but only the component polarized parallel to the MWD magnetic field. Therefore the MWD radiation at Earth is linearly polarized perpendicular to the magnetic field direction. I detail the analysis of archival linear polarization spectra of a few nearby MWDs that excludes the axion interpretation of the TeV gamma-ray transparency anomalies. I briefly discuss the sensitivity of ongoing and future searches using dedicated data at the Lick Observatory.

Zoom Link: https://pitp.zoom.us/j/97657182582?pwd=ZlFYWWtoYXhQZUtnOUxsZFpqMUo1Zz09

Polarized Signatures of Axions at Magnetic White Dwarfs



Christopher Dessert

Particle Physics Seminar, PI

2203.04319

CD, D. Dunsky, B. Safdi

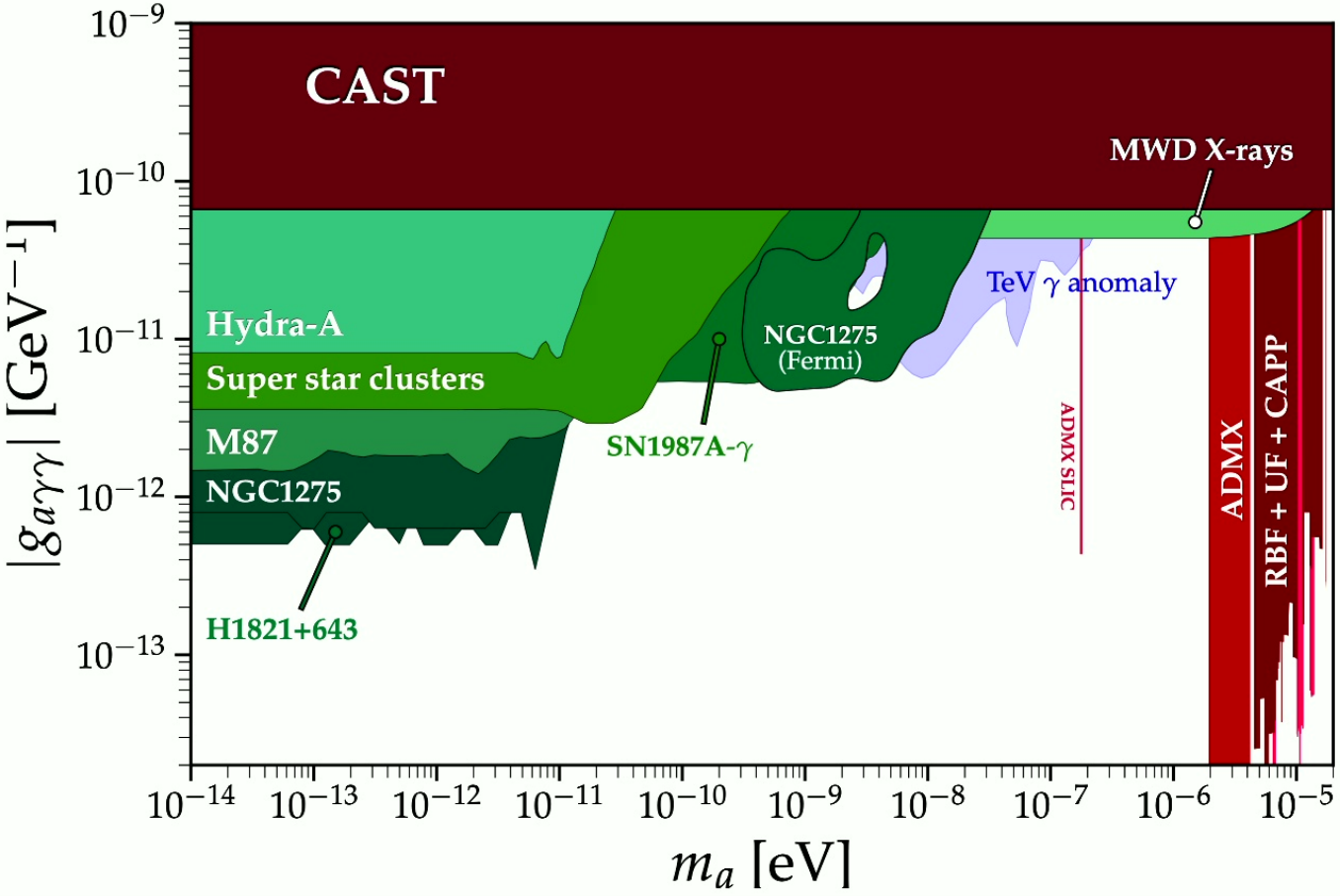
Photo: Max Alexander & STFC

Why axions?

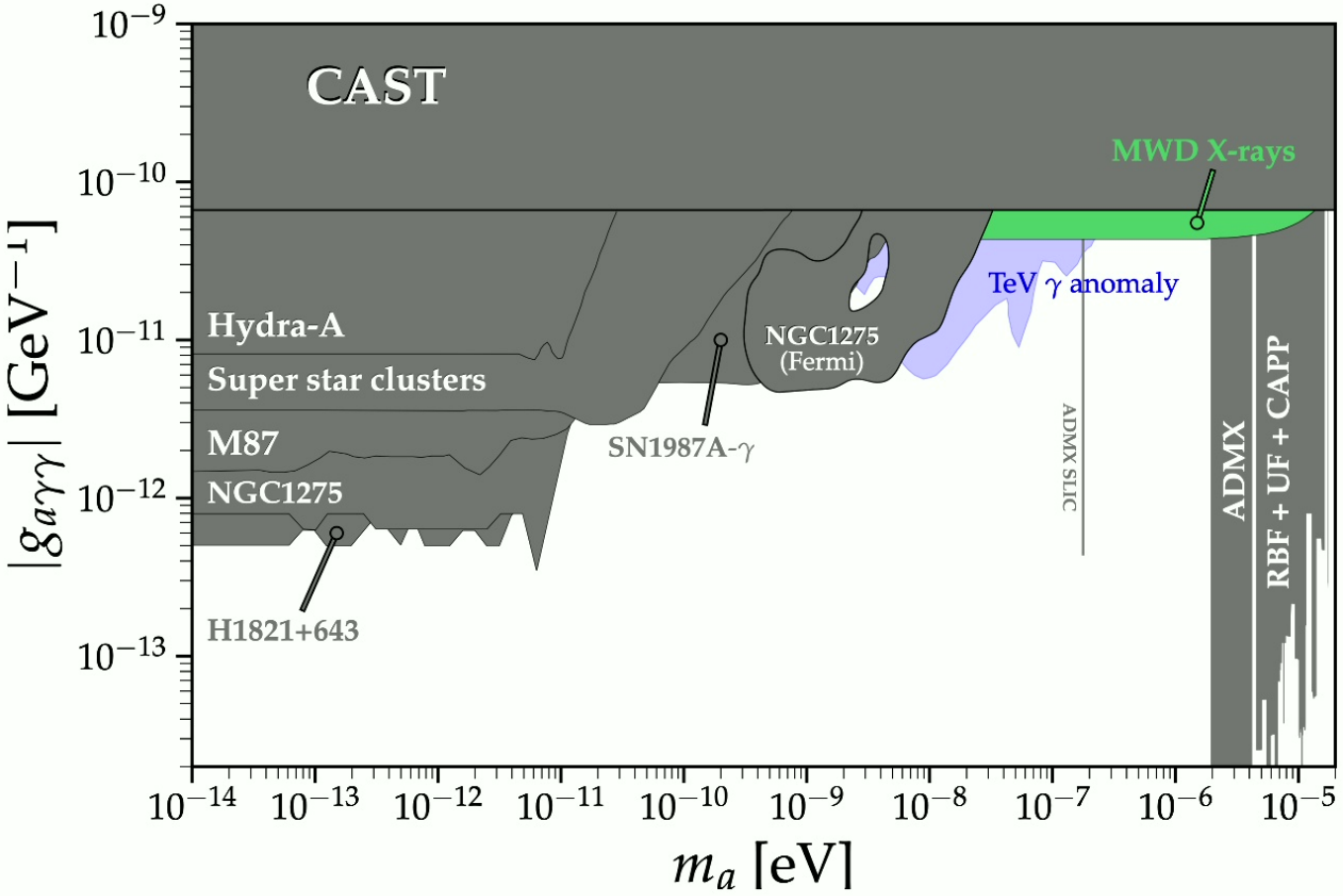
- Axion: a hypothetical fundamental pseudoscalar particle
- Can solve the Strong CP problem and make up dark matter
- Strongly coupled, low-mass axions appear in string theory constructions — the "Axiverse"

$$\mathcal{L}_a \supset -\frac{g_{a\gamma\gamma}}{4} a F \tilde{F} = -g_{a\gamma\gamma} a \mathbf{E} \cdot \mathbf{B}$$

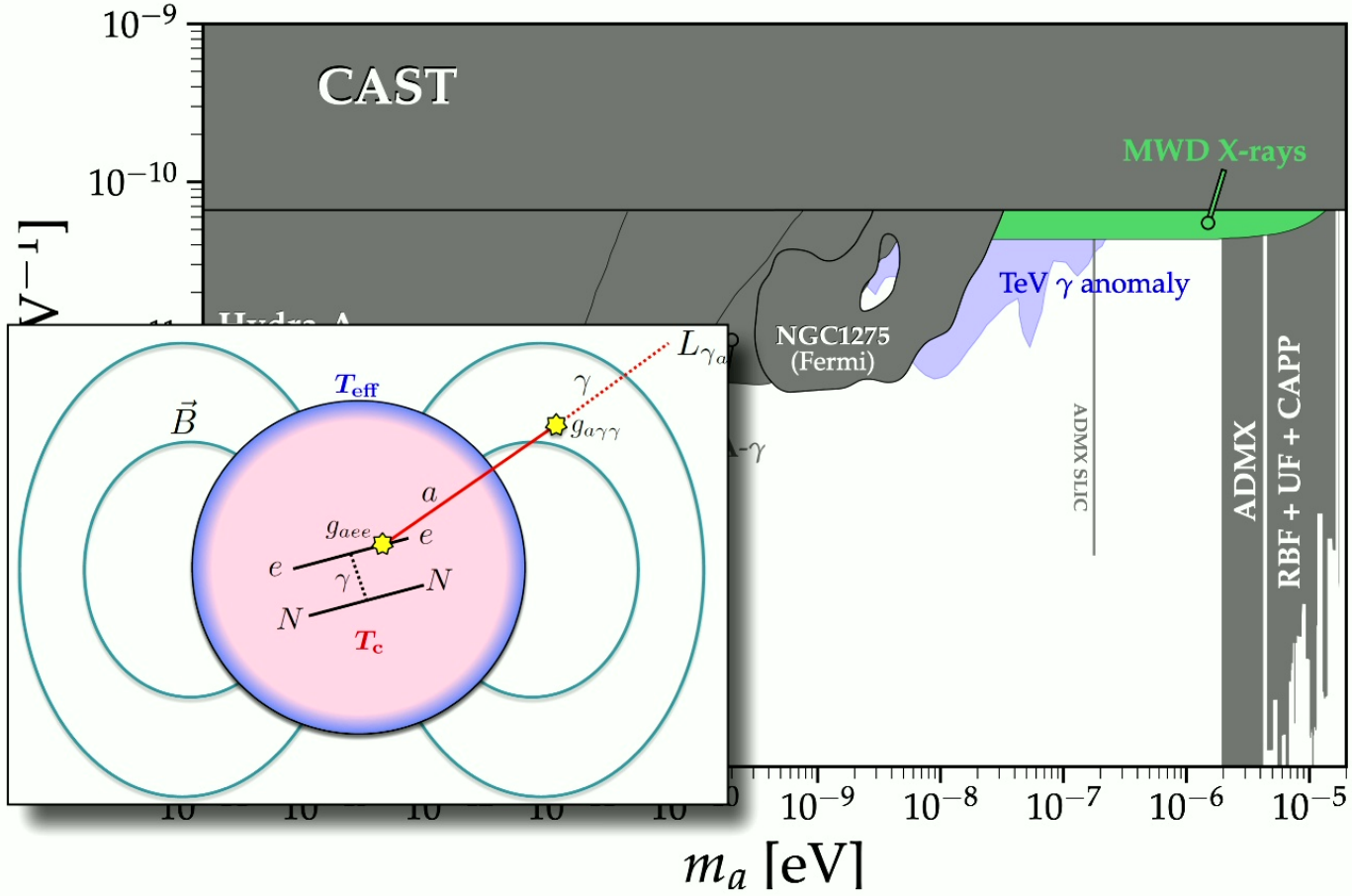
Why axions?


CAST
MWD X-rays
Hydra-A
Super star clusters
M87
NGC1275
H1821+643
NGC1275
(Fermi)
SN1987A-γ
TeV γ anomaly
ADMX SLIC
ADMX
RBF + UF + CAPP
$|g_{a\gamma\gamma}|$ [GeV^{-1}]
m_a [eV]
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14} 10^{-13} 10^{-12} 10^{-11} 10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5}

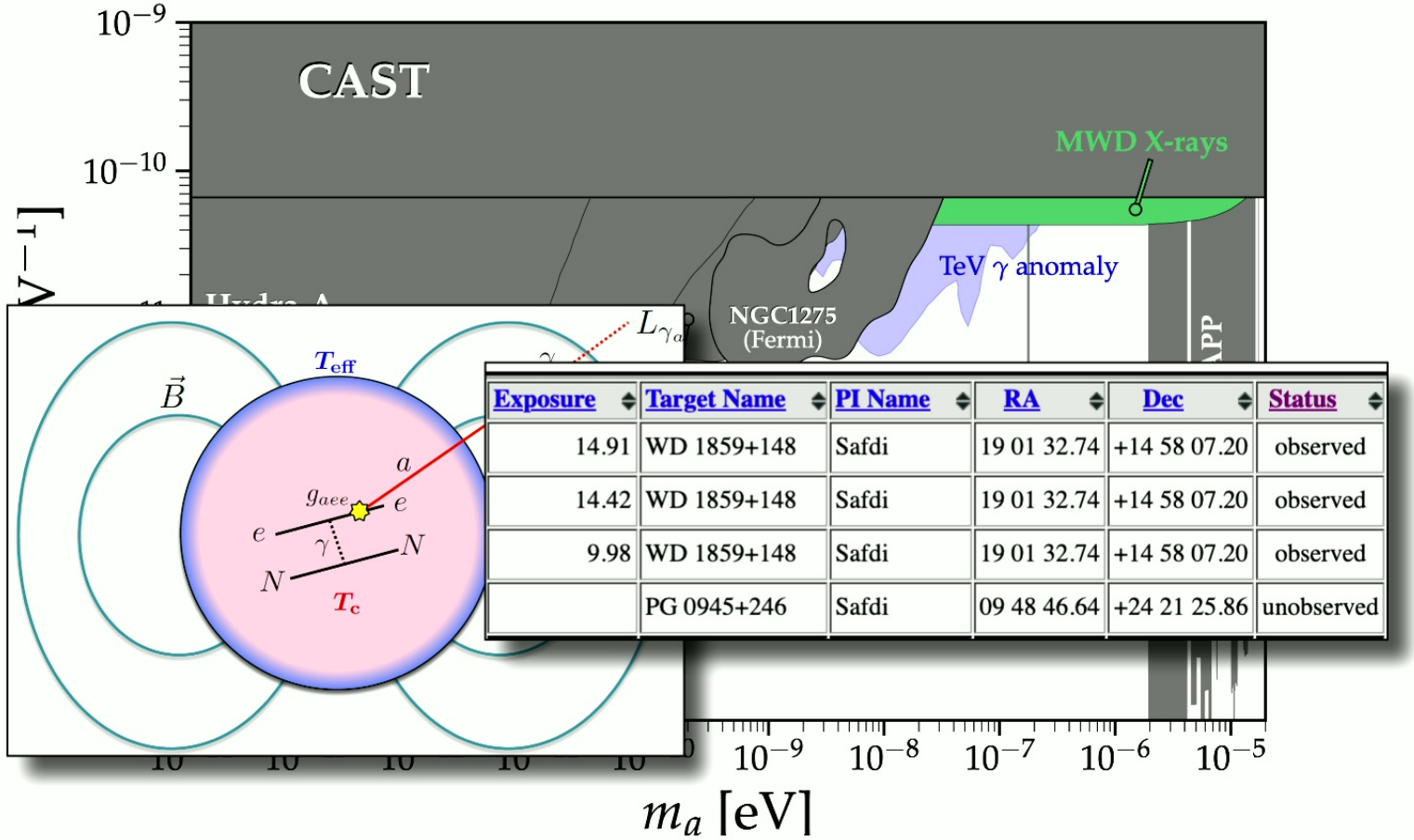
Compact objects and axions



Compact objects and axions



Compact objects and axions

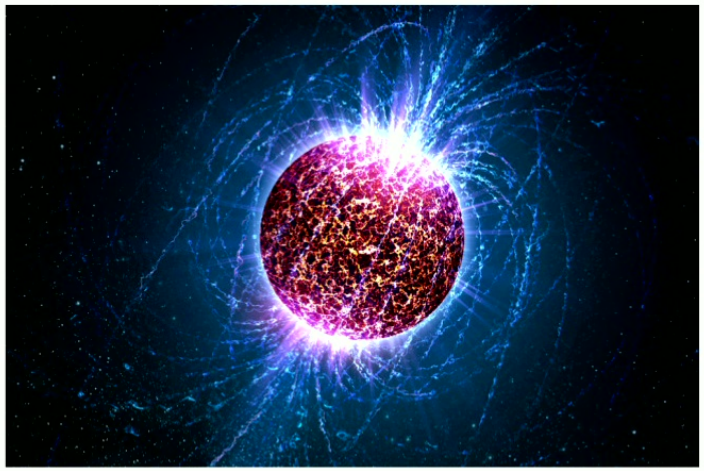


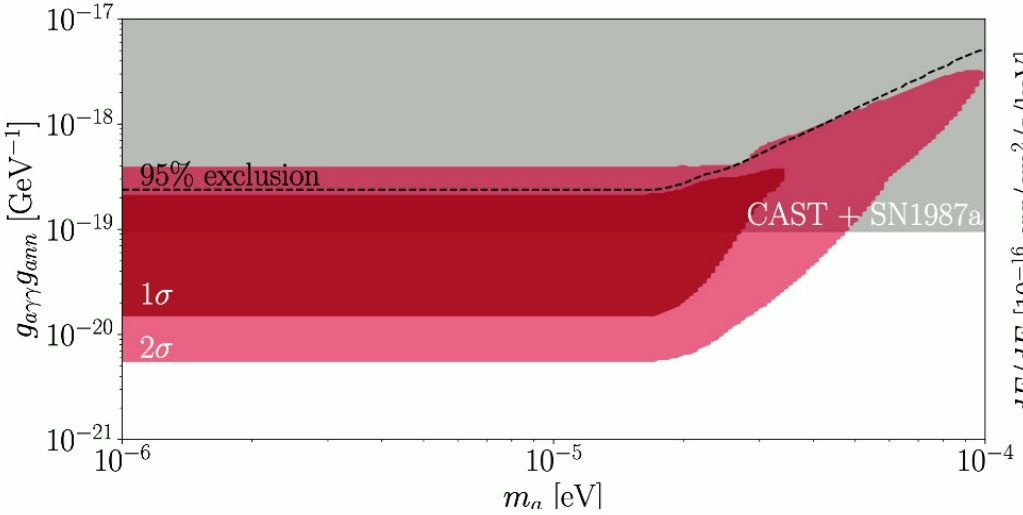
Exposure	Target Name	PI Name	RA	Dec	Status
14.91	WD 1859+148	Safdi	19 01 32.74	+14 58 07.20	observed
14.42	WD 1859+148	Safdi	19 01 32.74	+14 58 07.20	observed
9.98	WD 1859+148	Safdi	19 01 32.74	+14 58 07.20	observed
	PG 0945+246	Safdi	09 48 46.64	+24 21 25.86	unobserved

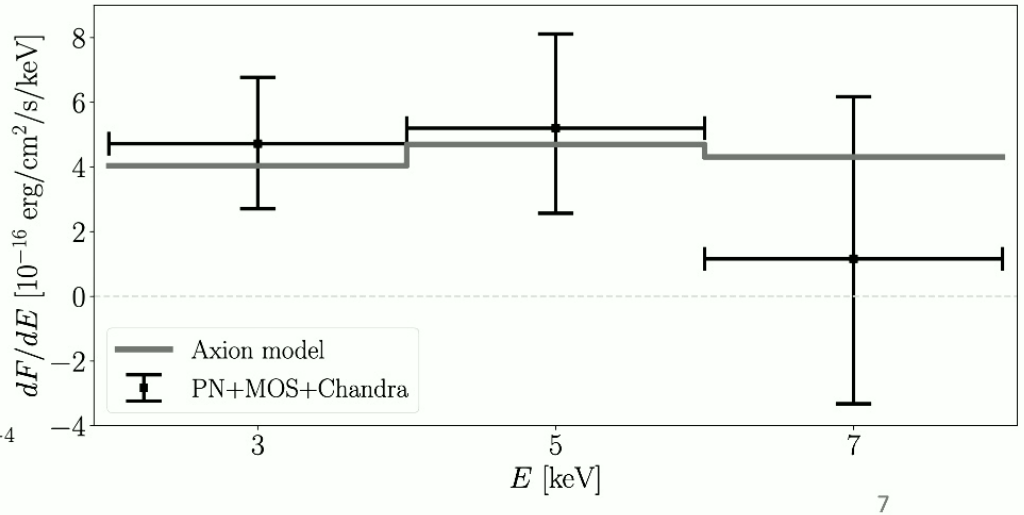
1910.02956, 1910.04164

Compact objects and axions

- Hard X-ray excess consistent with an axion at seven nearby neutron stars

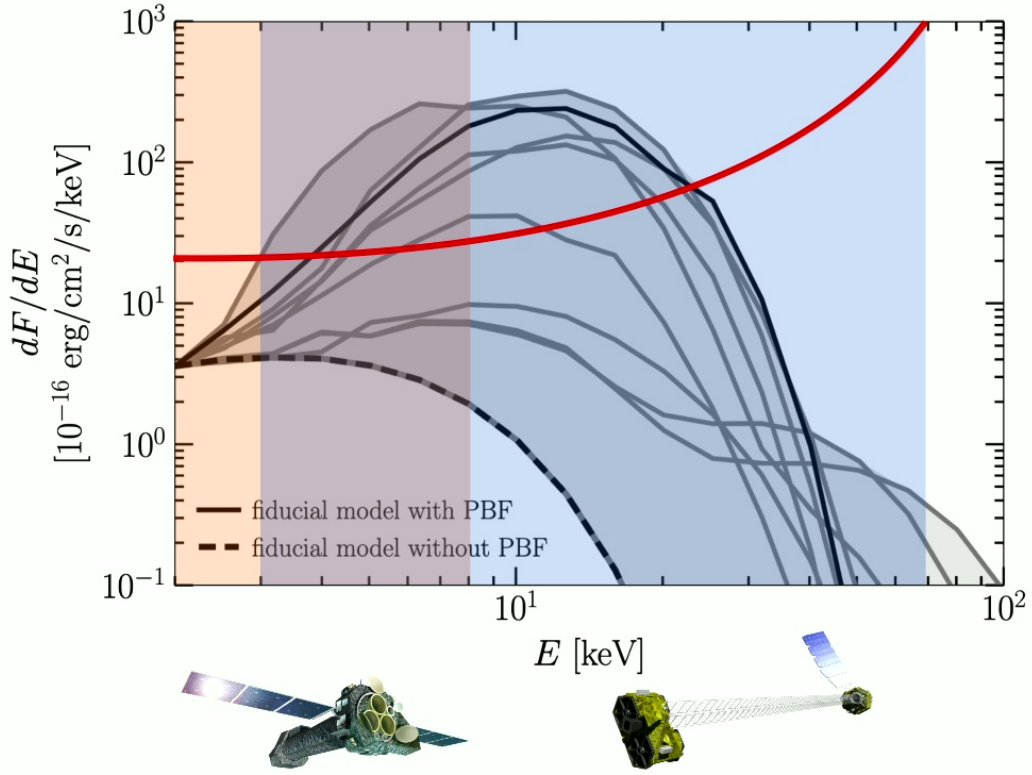


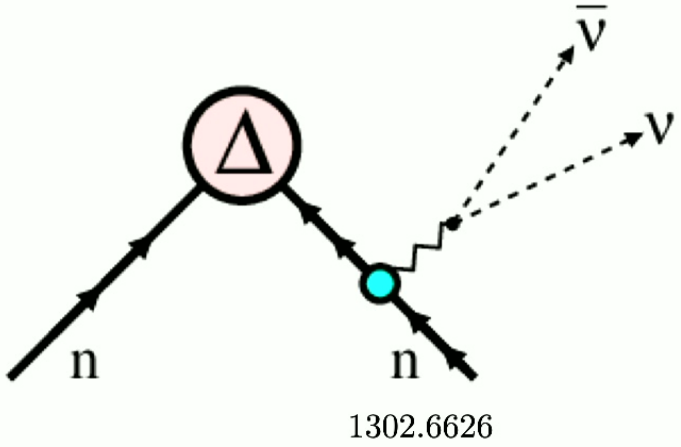




1910.02956, 1910.04164

Compact objects and axions

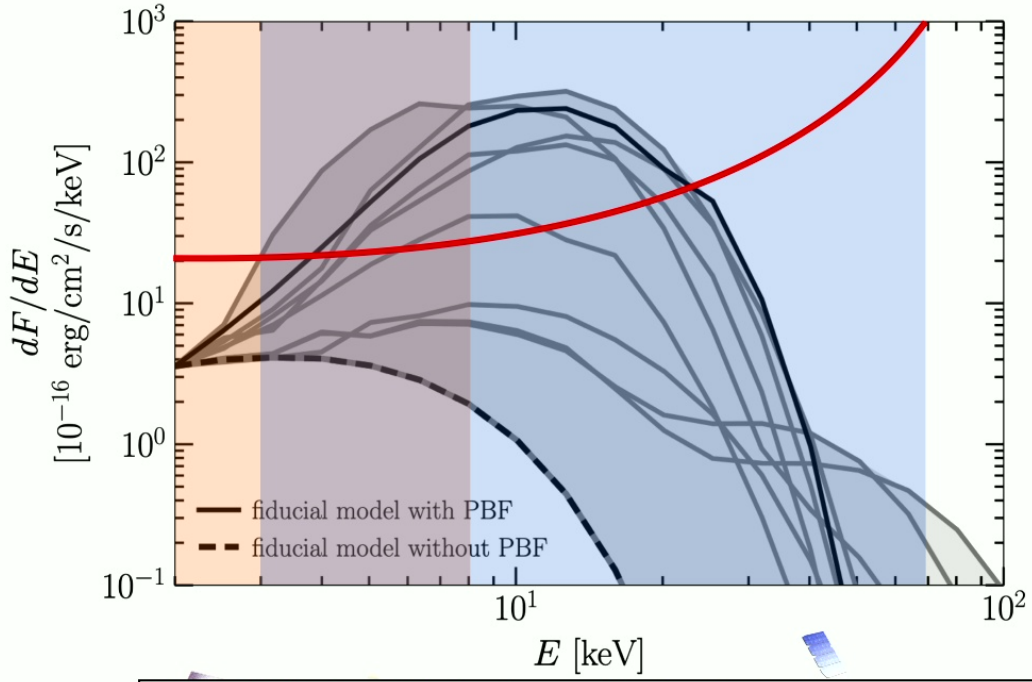


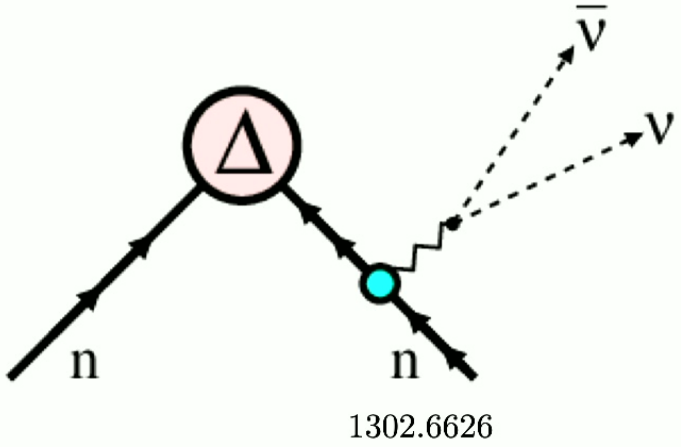


1302.6626

1910.02956, 1910.04164

Compact objects and axions





1302.6626

NuSTAR Master Catalog (numaster) Bulletin

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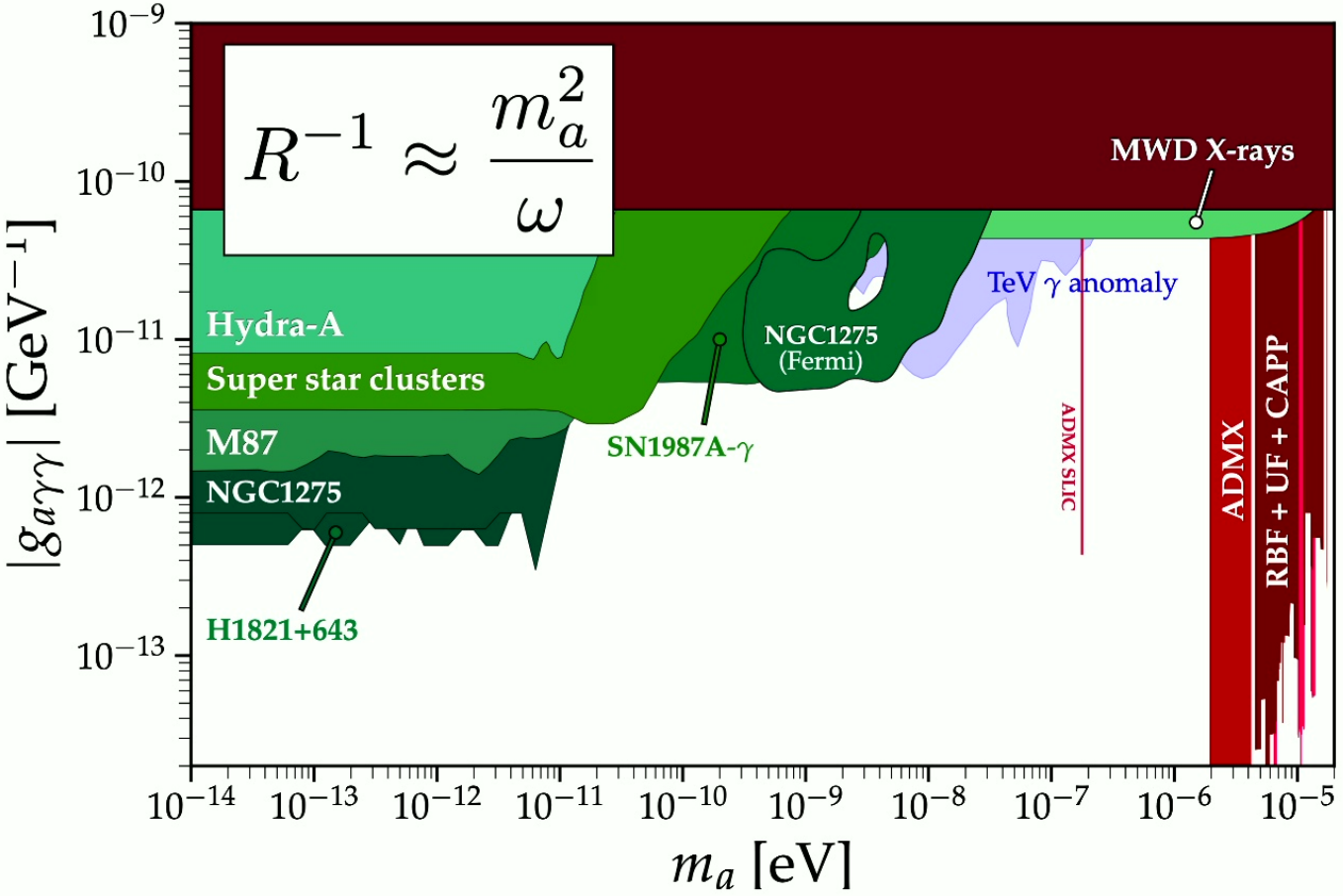
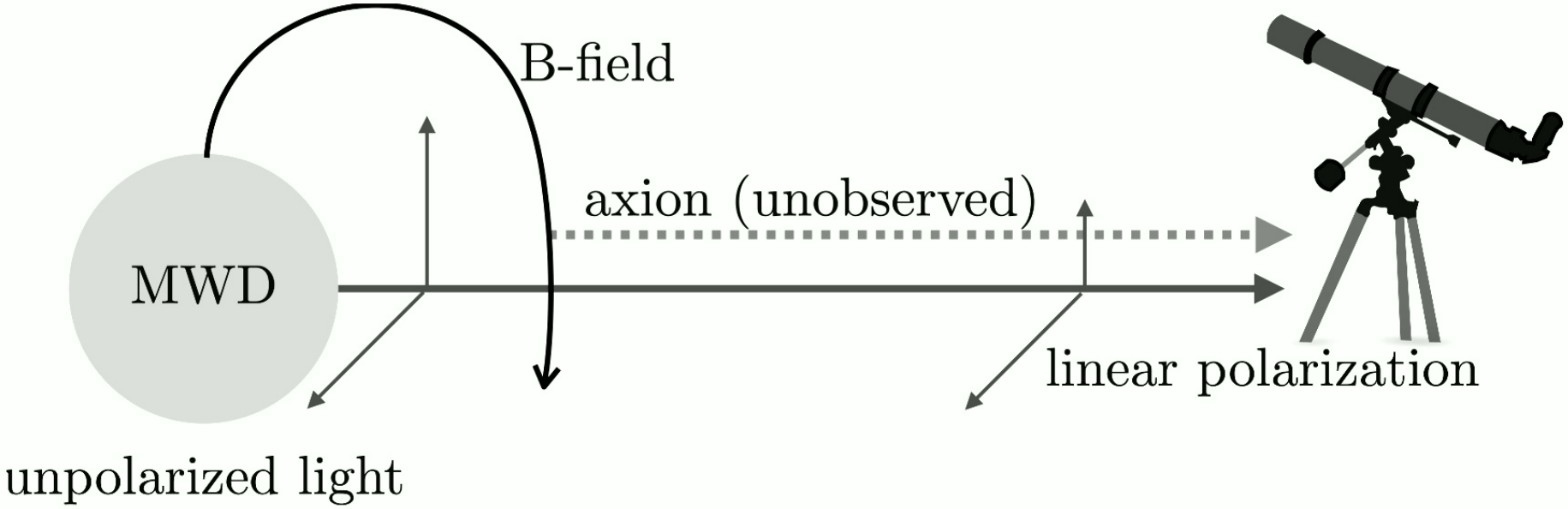
How to find axions



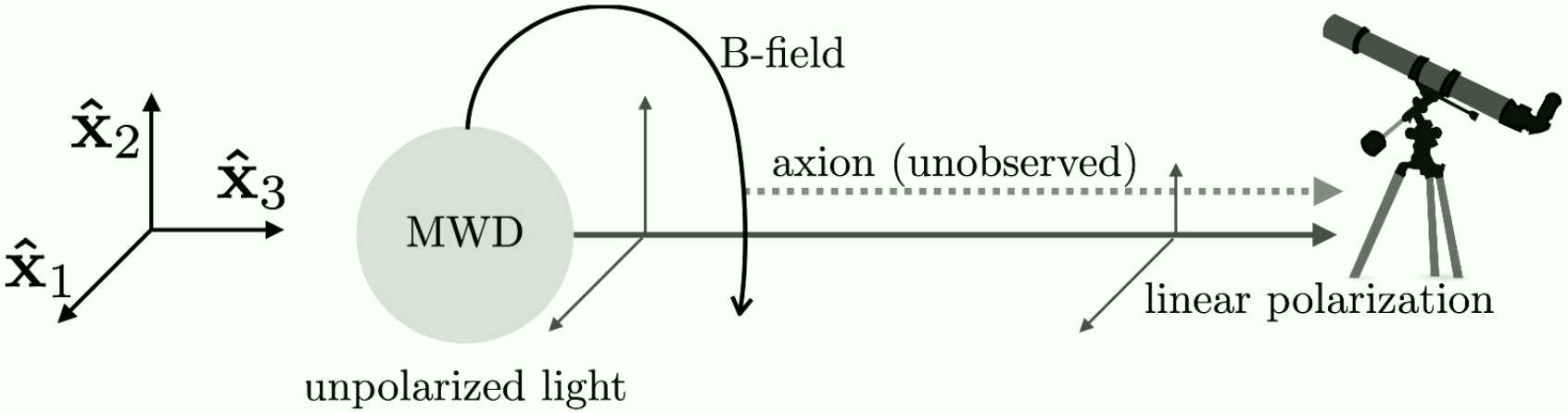
R. Gill, J. Heyl
arXiv:1105.2083

MWD Polarization Probes of Axions



Axion-Induced Polarization

$$\mathcal{L}_{a\gamma B} = -g_{a\gamma\gamma} a \mathbf{E} \cdot \mathbf{B}_{\mathrm{MWD}}$$



$$\mathbf{A} = \frac{A}{\sqrt{2}} \left[a_1 \hat{\mathbf{x}}_1 + a_2 \hat{\mathbf{x}}_2 \right]$$

Axion Conversion in Dipole Field

$$\mathcal{L}_{a,\mathrm{conv}} = -g_{a\gamma\gamma} a \mathbf{E}\cdot\mathbf{B} + \frac{2\alpha_{EM}^2}{45 m_e^4}\left[(\mathbf{E}^2-\mathbf{B}^2)^2 + 7(\mathbf{E}\cdot\mathbf{B})^2\right]$$

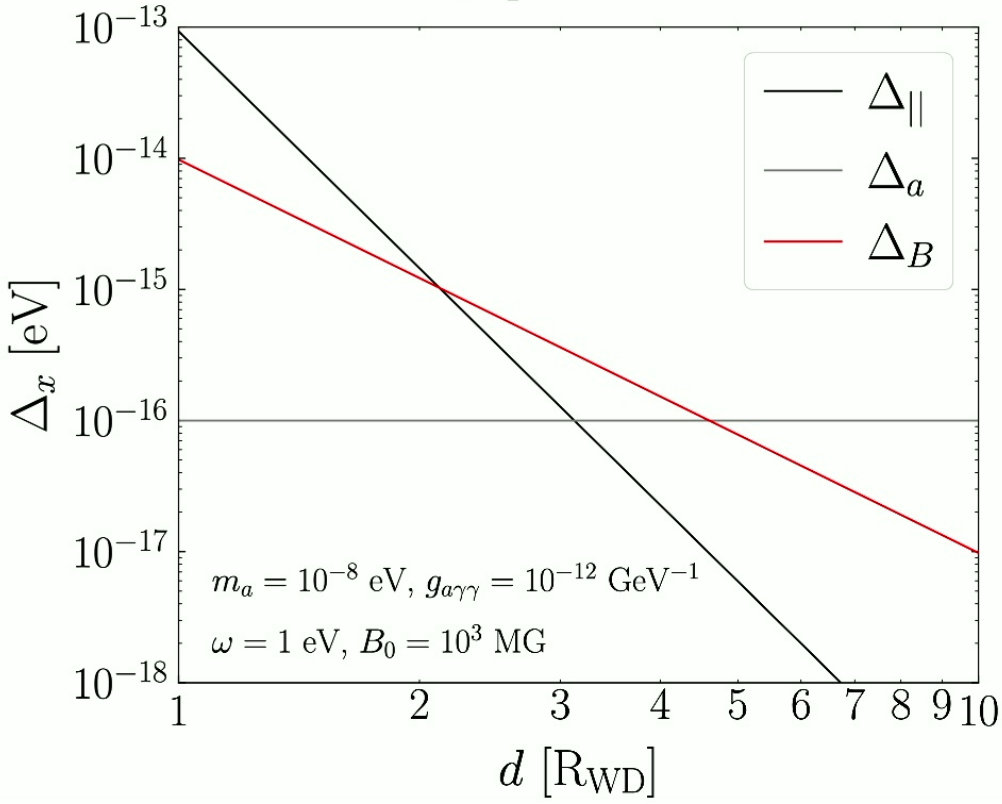
- Axion-photon EOM:

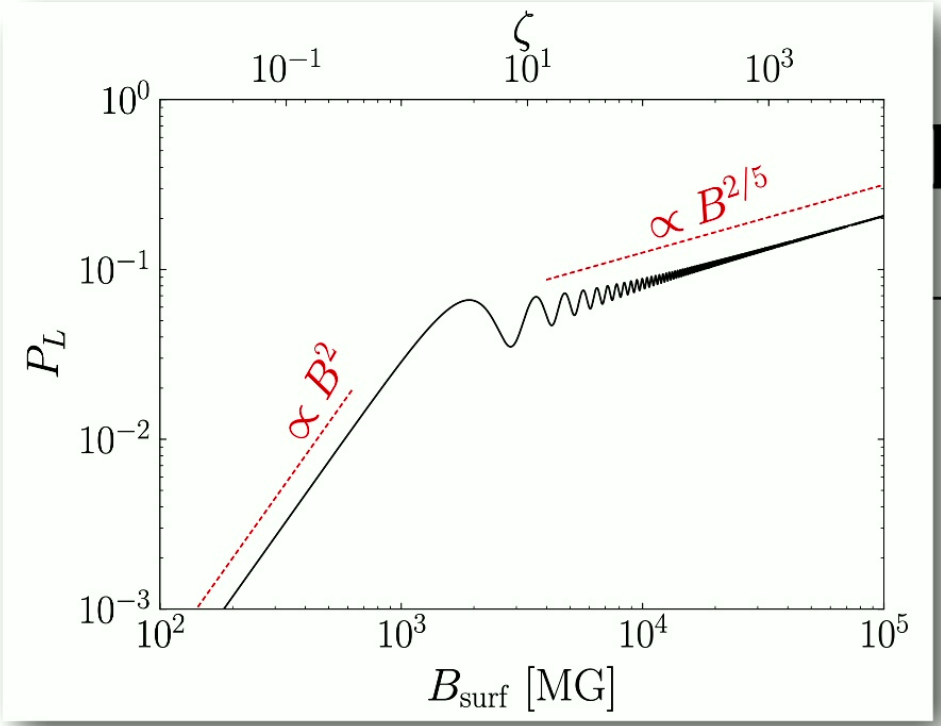
$$\left[i\partial_r + \begin{pmatrix} \Delta_\parallel & \Delta_B \\ \Delta_B & \Delta_a \end{pmatrix}\right]\begin{pmatrix} A_\parallel \\ a \end{pmatrix} = 0$$

$$\Delta_\parallel \propto \omega\left(\frac{B}{B_{\mathrm{crit}}}\right)^2$$

$$\Delta_a \propto -\frac{m_a^2}{\omega}$$

$$\Delta_B \propto g_{a\gamma\gamma} B$$





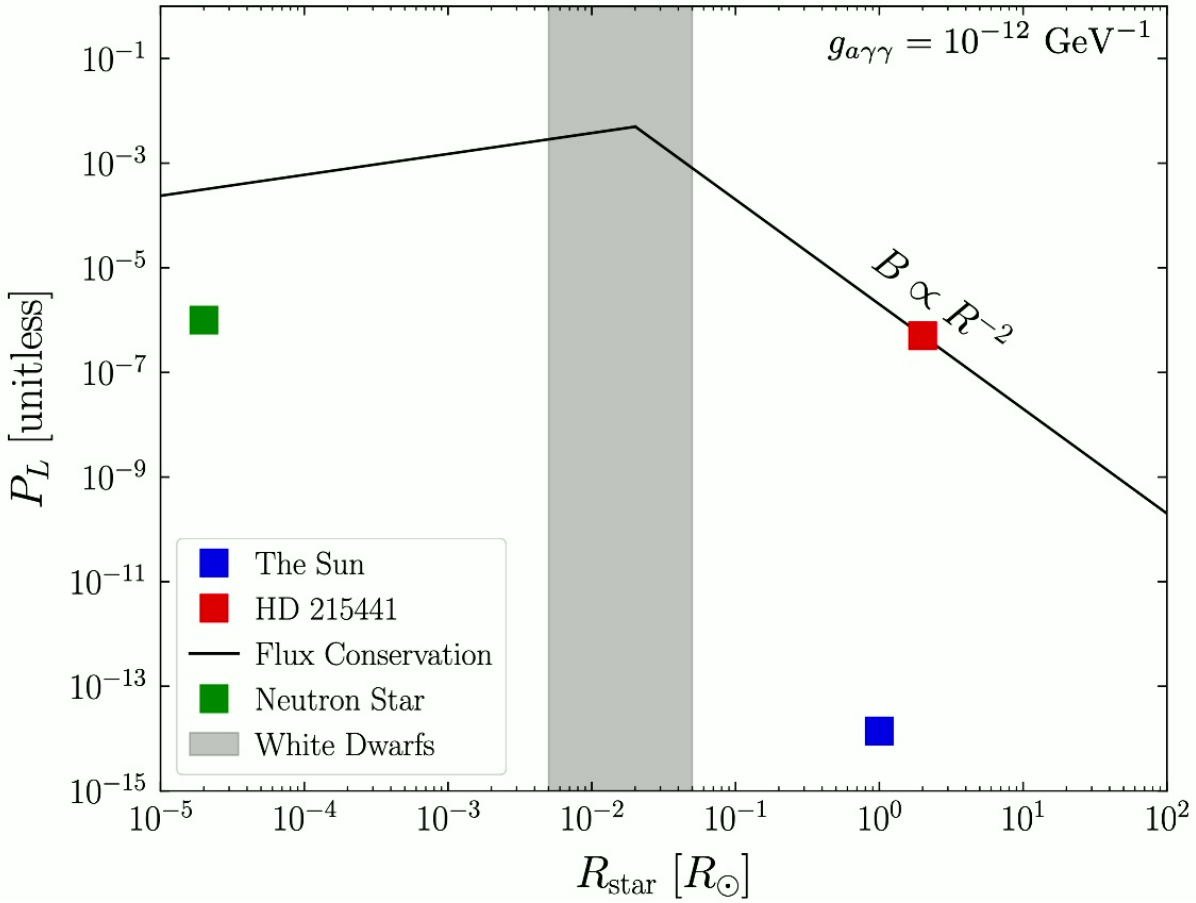
Dipole Field

$$- \mathbf{B}^2)^2 + 7(\mathbf{E}\cdot\mathbf{B})^2]$$

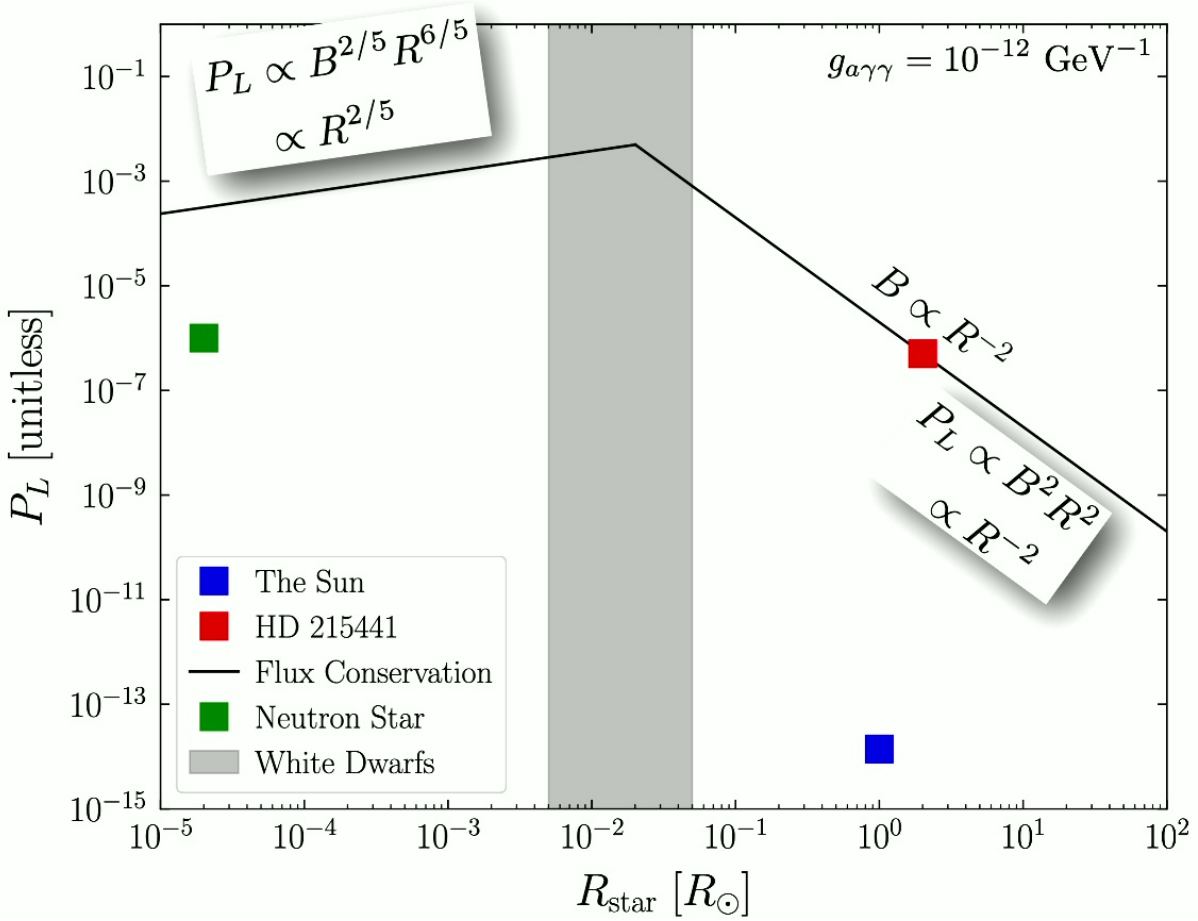
$$\zeta \approx 10^{-2} \left(\frac{R_{\rm star}}{0.01\,R_\odot}\right) \left(\frac{\omega}{1\,{\rm eV}}\right) \left(\frac{B_0}{100\,{\rm MG}}\right)^2$$

$$P_L \approx \begin{cases} 10^{-4} \left(\frac{g_{a\gamma\gamma}}{10^{-12}\ {\rm GeV}^{-1}}\right)^2 \left(\frac{B_0}{100\ {\rm MG}}\right)^2 \left(\frac{R_{\rm star}}{0.01\ R_\odot}\right)^2 , & \zeta \ll 1 \\ 10^{-4} \left(\frac{g_{a\gamma\gamma}}{10^{-12}\ {\rm GeV}^{-1}}\right)^2 \left(\frac{B_0}{100\ {\rm MG}}\right)^{2/5} \left(\frac{1\ {\rm eV}}{\omega}\right)^{4/5} \left(\frac{R_{\rm star}}{0.01\ R_\odot}\right)^{6/5} , & \zeta \gg 1 \end{cases}$$

Axion-Induced Polarization



Axion-Induced Polarization



Astrophysical MWD Polarization

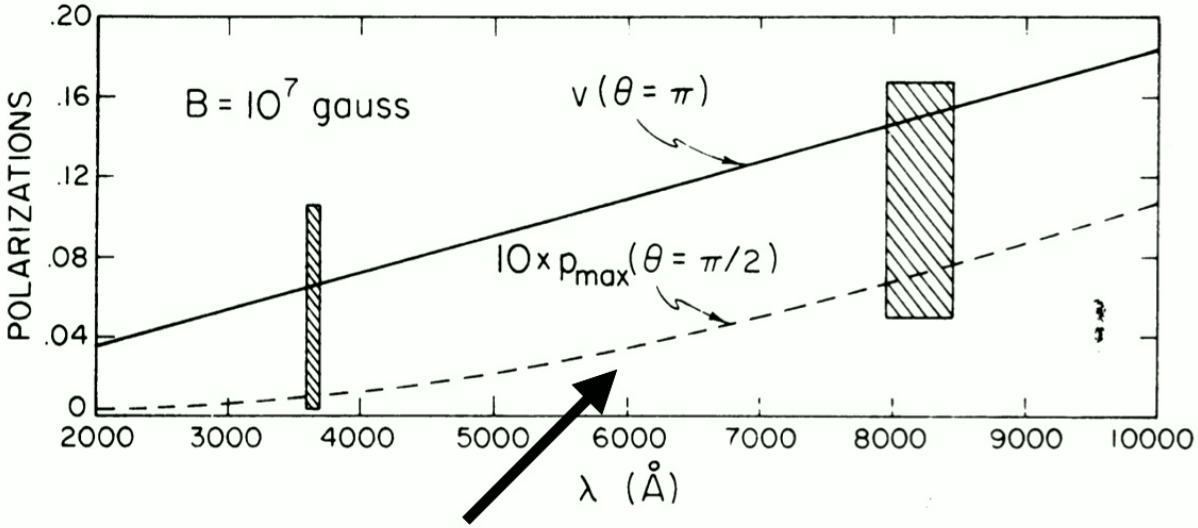
- Photons propagate unpolarized from deep in MWD atmosphere
- Astrophysical polarization created by bound-free absorption in the hydrogen atmosphere

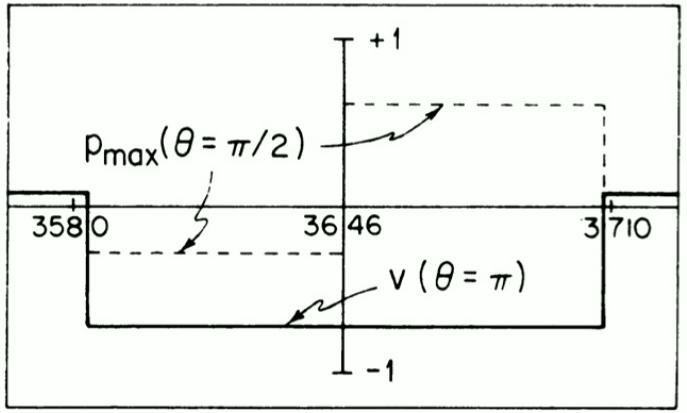
$$e^-(-E_n) + \gamma(\omega) \rightarrow e^-(\omega - E_n)$$

- At zero field, $\sigma^{\rm bf} \propto \sum_n^\infty \begin{cases} n^{-5}\omega^{-3}, & -E_n < \omega \\ 0, & \text{else} \end{cases}$
- In magnetic field, use Zeeman effect: $\sigma^{\rm bf}(\omega) \rightarrow \sigma^{\rm bf}(\omega - q\Omega_C)$

Lamb et al. 1974

Astrophysical MWD Polarization





$$P_{\mathrm{L,astro}} \propto B_T^2 \omega^2$$

$$\frac{Q}{I} = \frac{\delta s}{4}(2\mathcal{K}_0 - \mathcal{K}_+ - \mathcal{K}_-)\sin^2\theta$$

$$P_{L,\mathrm{astro}} = \frac{|Q|}{I}$$

Lamb et al. 1974

Promising MWD Targets

RE J0317 − 853 ($B = 200 - 800$ MG)

SDSS J1351 + 5419 ($B = 761 \pm 54$ MG)

Grw + 70°8247 ($B \approx 350$ MG)

PG1031 + 234 ($B \approx 400 - 1000$ MG)

SDSS J234605 ($B = 798 \pm 164$ MG)

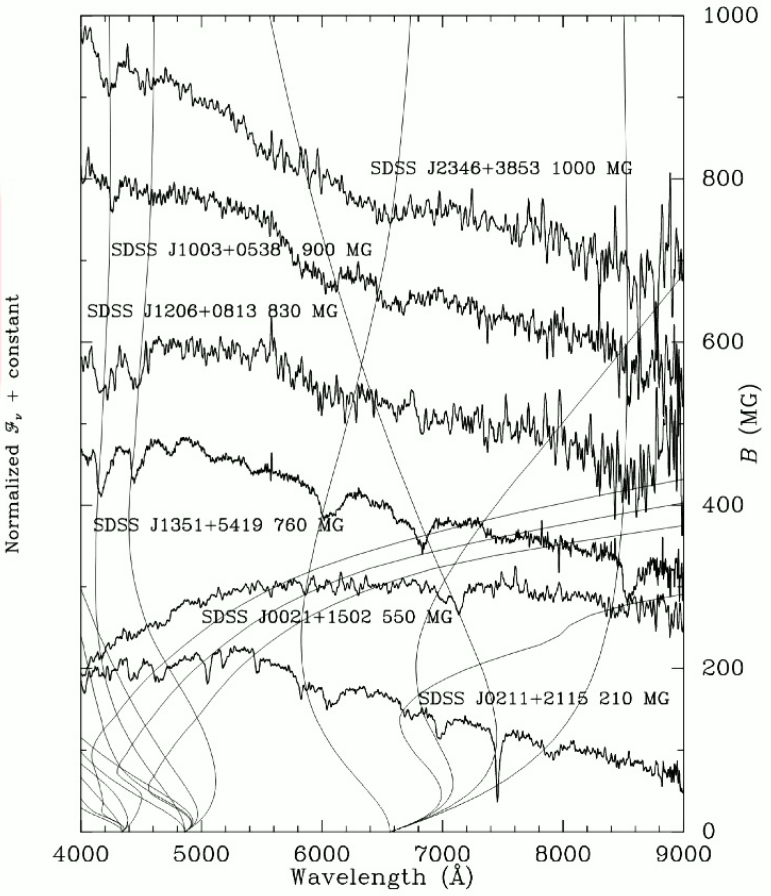
HE 1043 − 0502 ($B \approx 820$ MG)

SDSS J1206 + 0613 ($B = 761 \pm 282$ MG)

SDSS J1003 + 0538 ($B = 672 \pm 119$ MG)

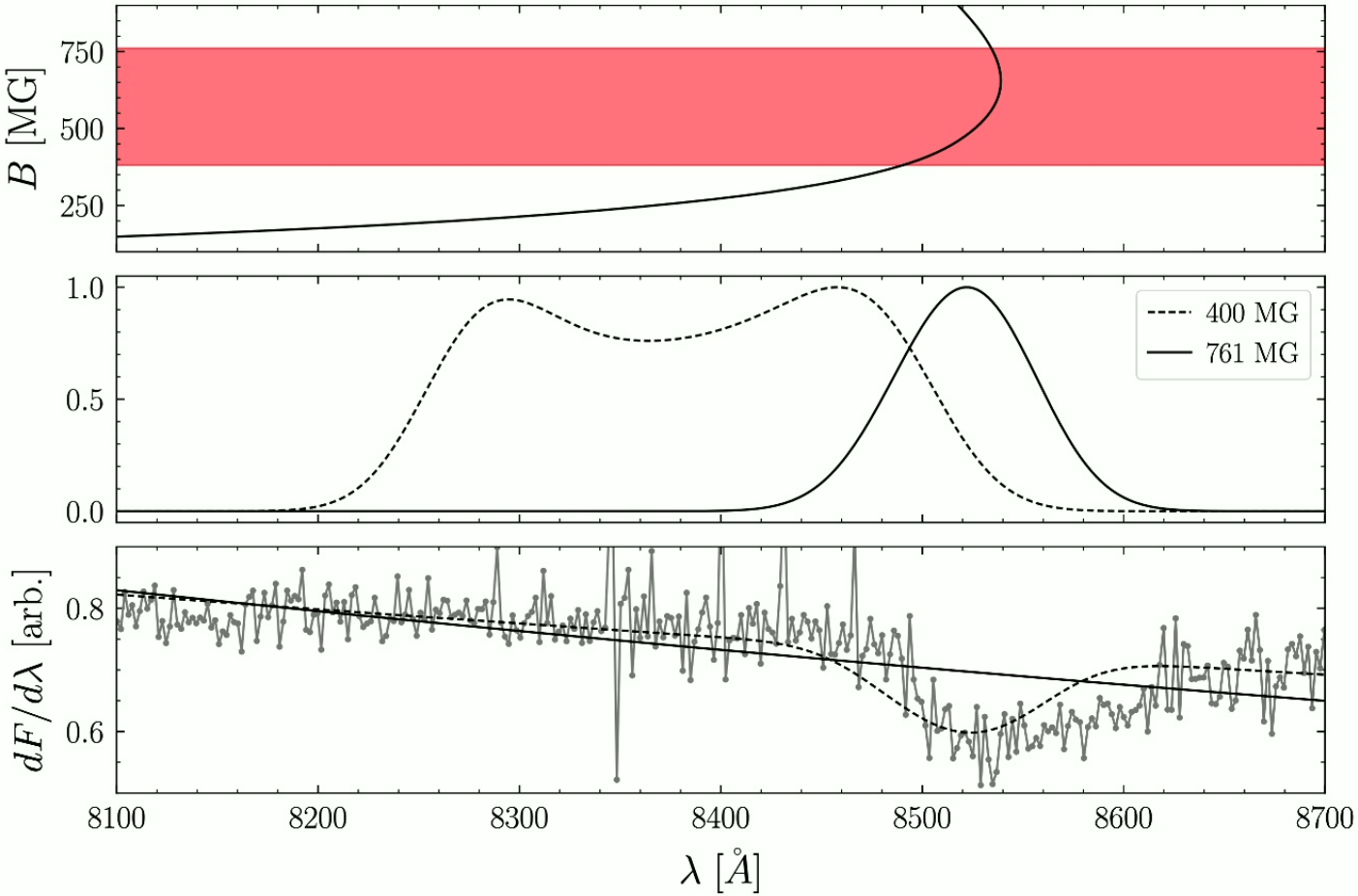
SDSS J0021 + 1502 ($B = 531 \pm 64$ MG)

SDSS J0333 + 0720 ($B = 850 \pm 52$ MG)

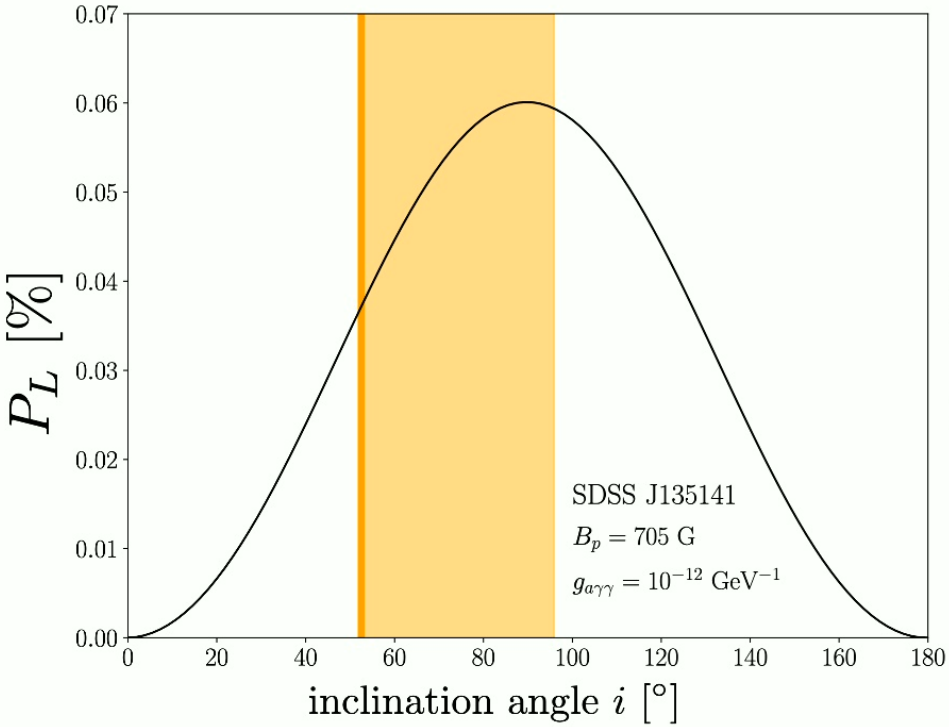


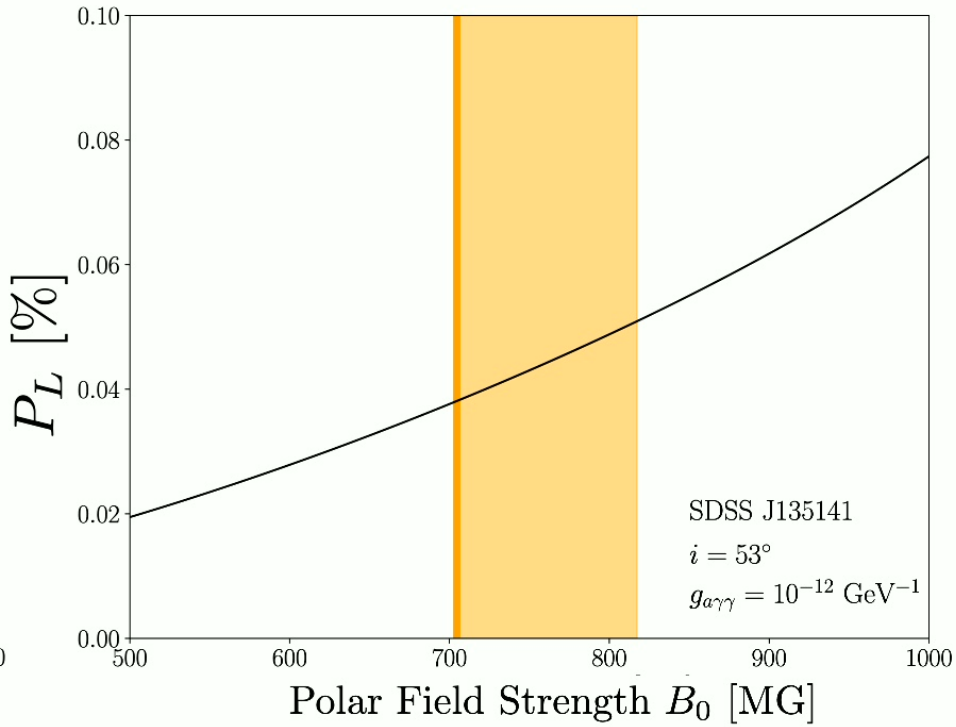
1504.08072

SDSS J1351

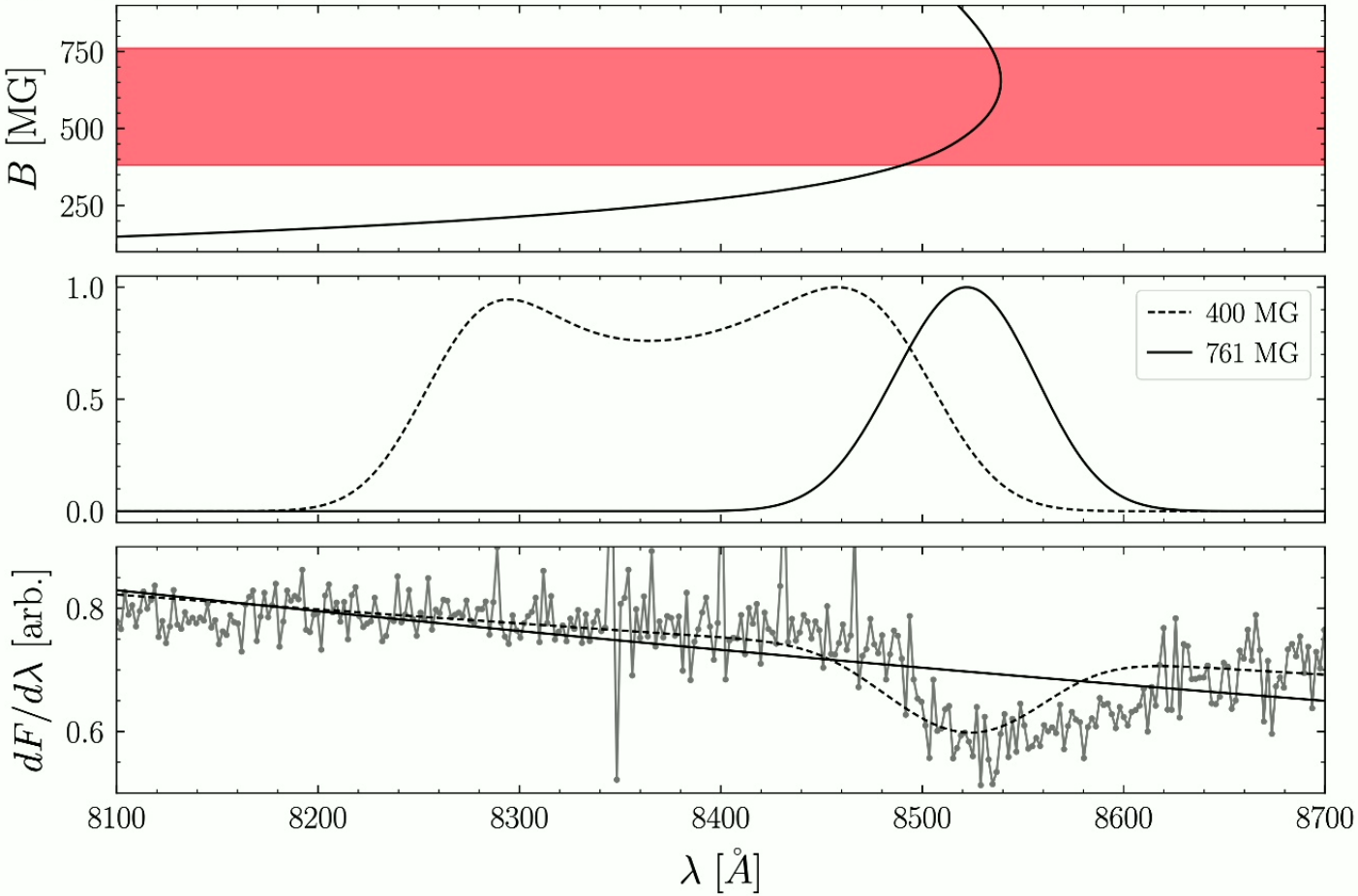

B [MG]
750
500
250
1.0
0.5
0.0
400 MG
761 MG
dF/dλ [arb.]
0.8
0.6
8100
8200
8300
8400
8500
8600
8700
λ [Å]

SDSS J1351

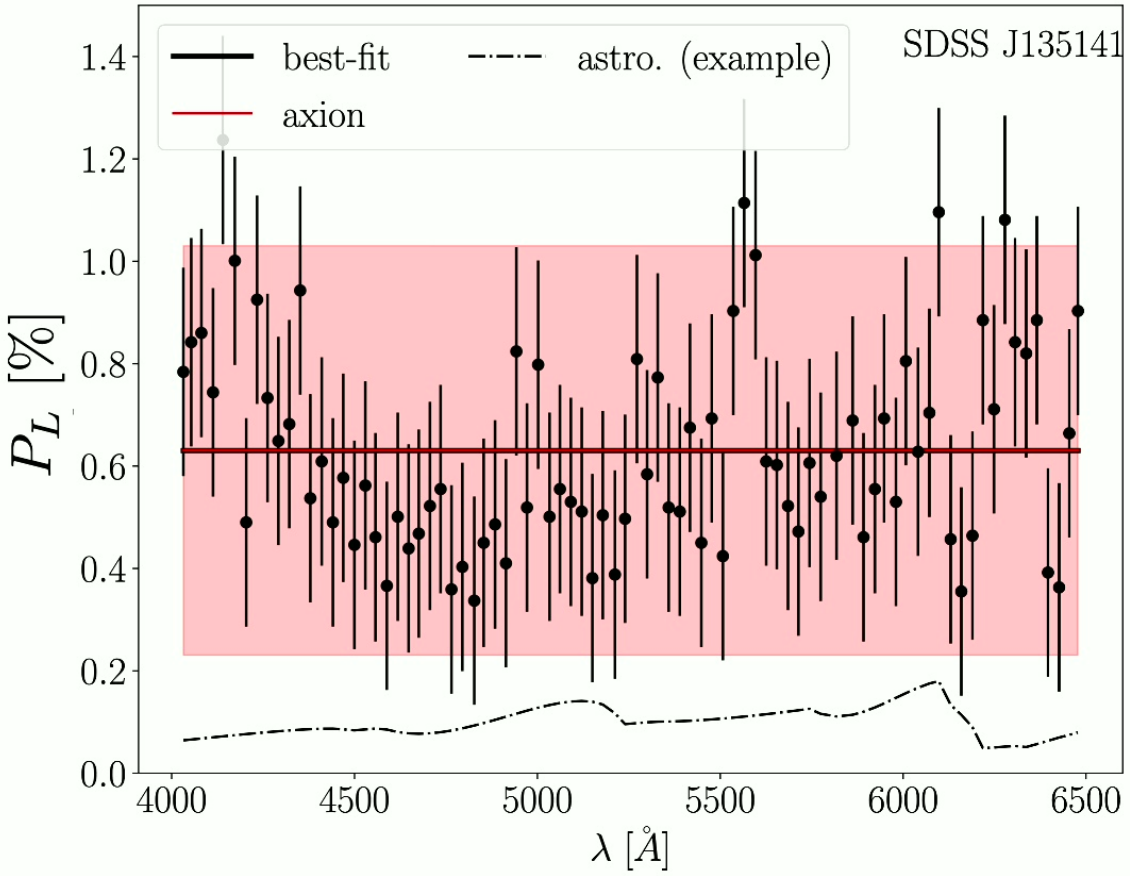

0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
P_L [%]
0
20
40
60
80
100
120
140
160
180
inclination angle i [°]
SDSS J135141
$B_p = 705$ G
$g_{a\gamma\gamma} = 10^{-12}$ GeV^{-1}


0.10
0.08
0.06
0.04
0.02
0.00
P_L [%]
500
600
700
800
900
1000
Polar Field Strength B_0 [MG]
SDSS J135141
$i = 53°$
$g_{a\gamma\gamma} = 10^{-12}$ GeV^{-1}

SDSS J1351

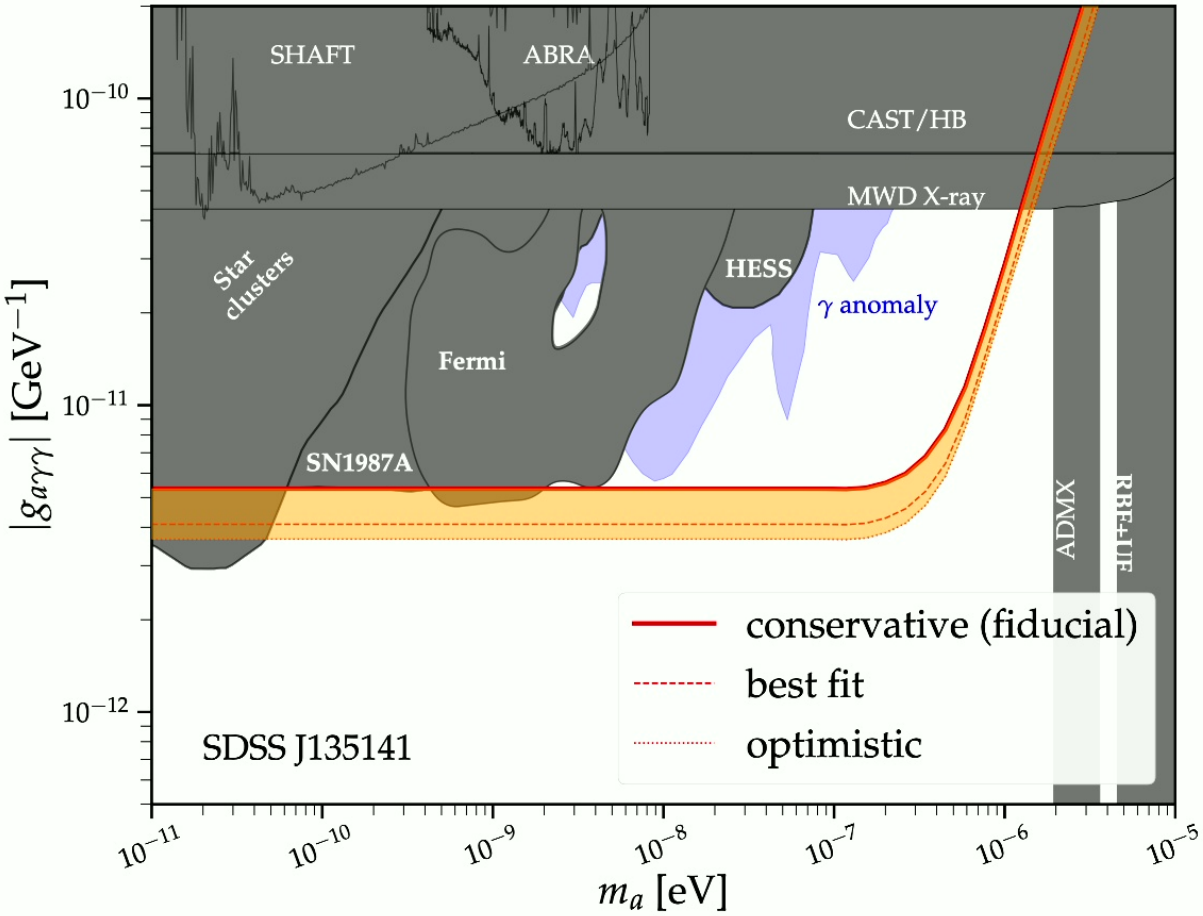

B [MG]
750
500
250
1.0
0.5
0.0
400 MG
761 MG
dF/dλ [arb.]
0.8
0.6
8100
8200
8300
8400
8500
8600
8700
λ [Å]

SDSS J1351



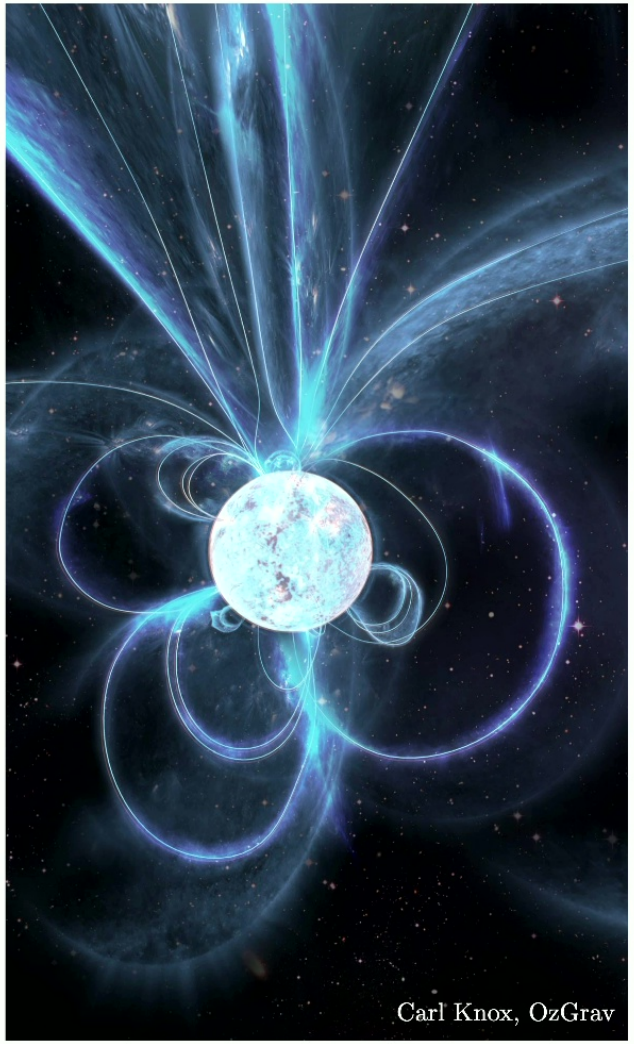
Physics of Magnetic Stars, Piotrovich et al. (2019)

SDSS J1351


SHAFT
ABRA
CAST/HB
MWD X-ray
Star clusters
HESS
γ anomaly
Fermi
SN1987A
ADMX
RBF+UF
conservative (fiducial)
best fit
optimistic
SDSS J135141
$|g_{a\gamma\gamma}|$ [GeV^{-1}]
m_a [eV]
10^{-10}
10^{-11}
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}

Conclusion

- Magnetic white dwarfs are very powerful probes of axions
- Simple analyses motivate future work
  - Ongoing dedicated *Lick Observatory* observations of MWDs with Alex Filippenko at UC Berkeley
  - Contributions from tangled fields




Thank you!