Searching for Axions at Magnetic White Dwarfs

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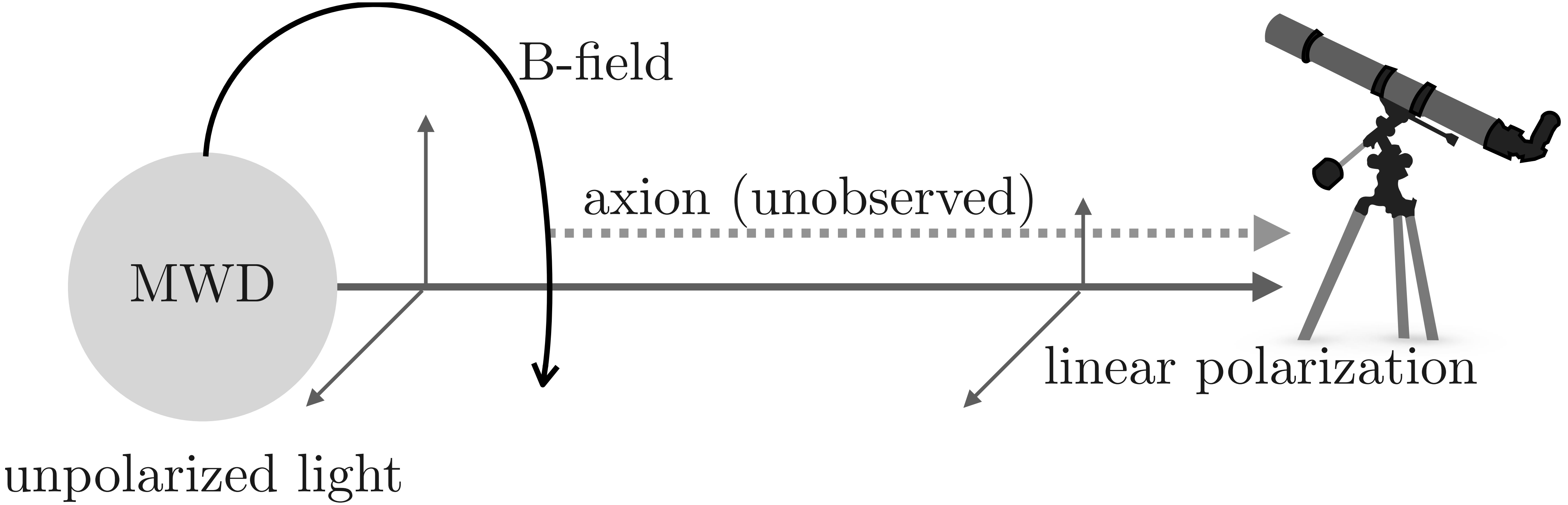
Illustration by Sandbox Studio, Chicago with Ana Kova (Symmetry Magazine)

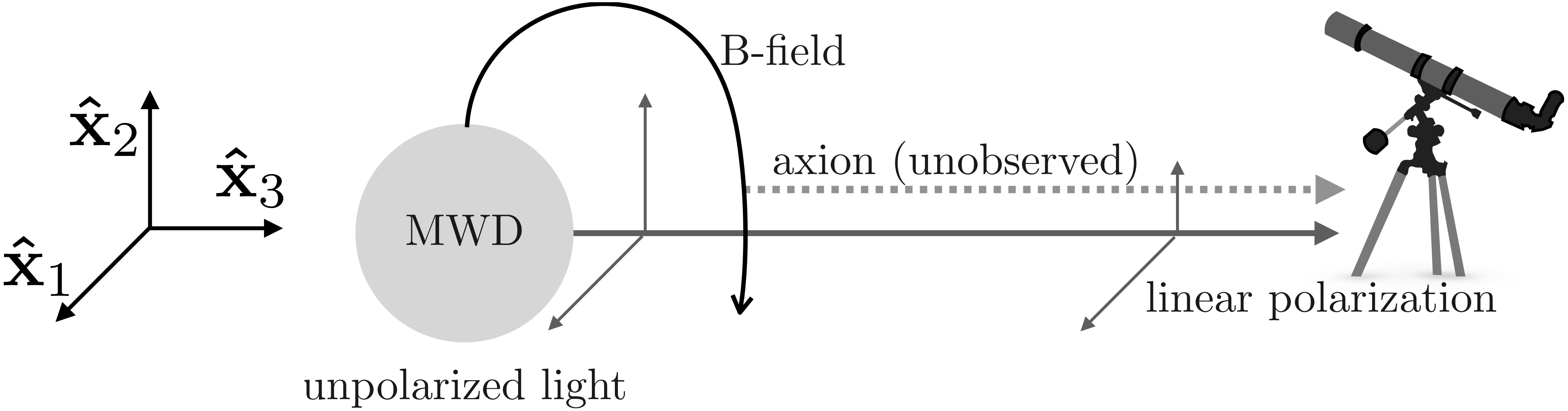
R. Gill, J. Heyl
arXiv:1105.2083

MWD Polarization Probes of Axions



Axion-Induced Polarization

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



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

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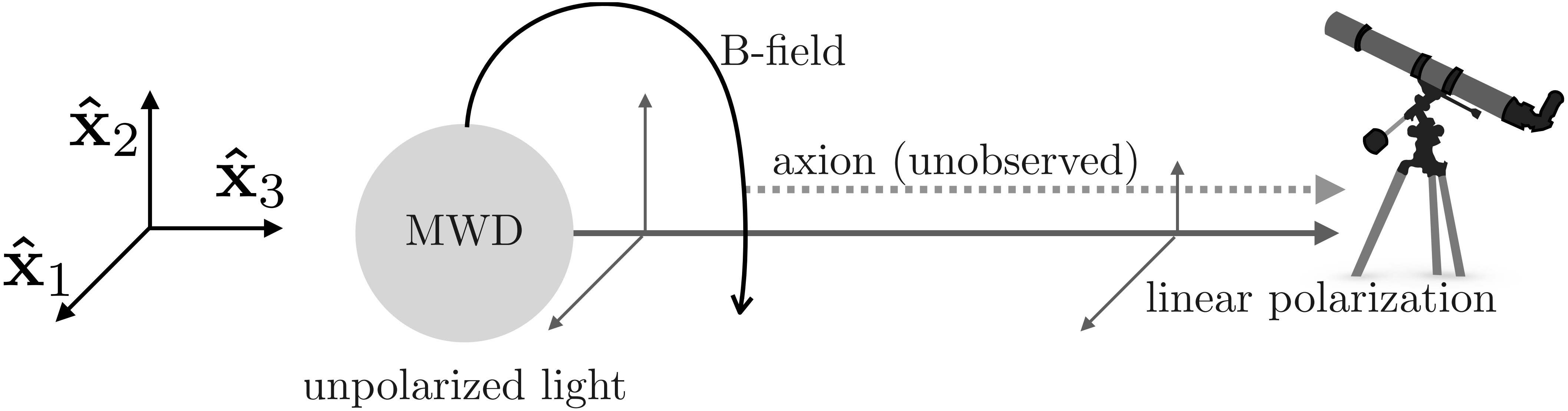


$$\mathbf{A} = \frac{A}{\sqrt{2}} \left[a_1 \hat{\mathbf{x}}_1 + a_2 \hat{\mathbf{x}}_2 \right] \qquad \mathbf{A}(r) = \frac{A}{\sqrt{2}} \left[a_1 \hat{\mathbf{x}}_1 + a_2 \left(1 - P_L\right) \hat{\mathbf{x}}_2 \right]$$

Axion-Photon Mixing

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

- Axion-photon EOM:

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

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

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

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

$$\implies \tan 2\theta = \frac{2\Delta_B}{\Delta_\parallel - \Delta_a}$$

Axion Conversion in Dipole Field

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

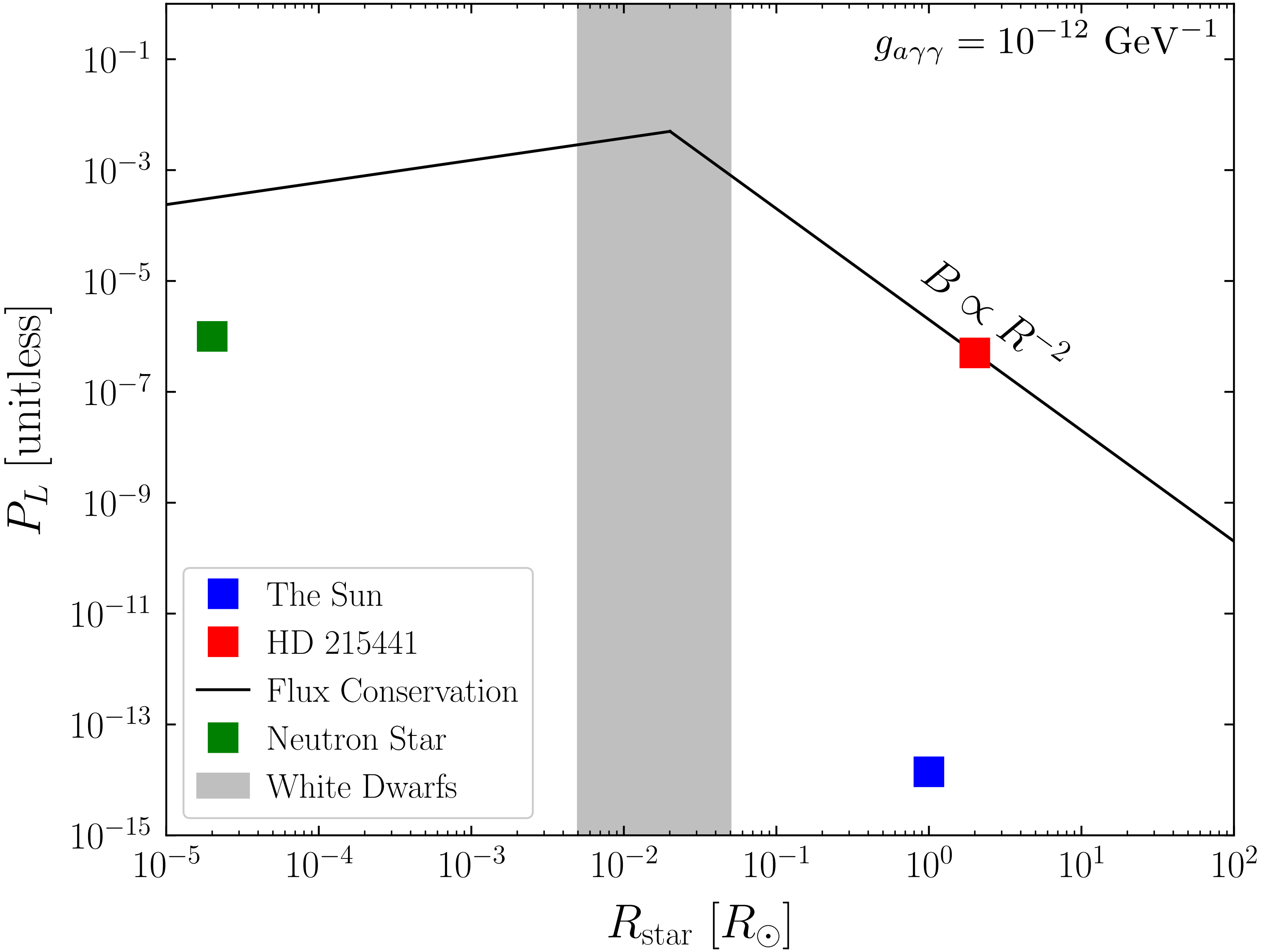
- Axion-photon EOM:

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

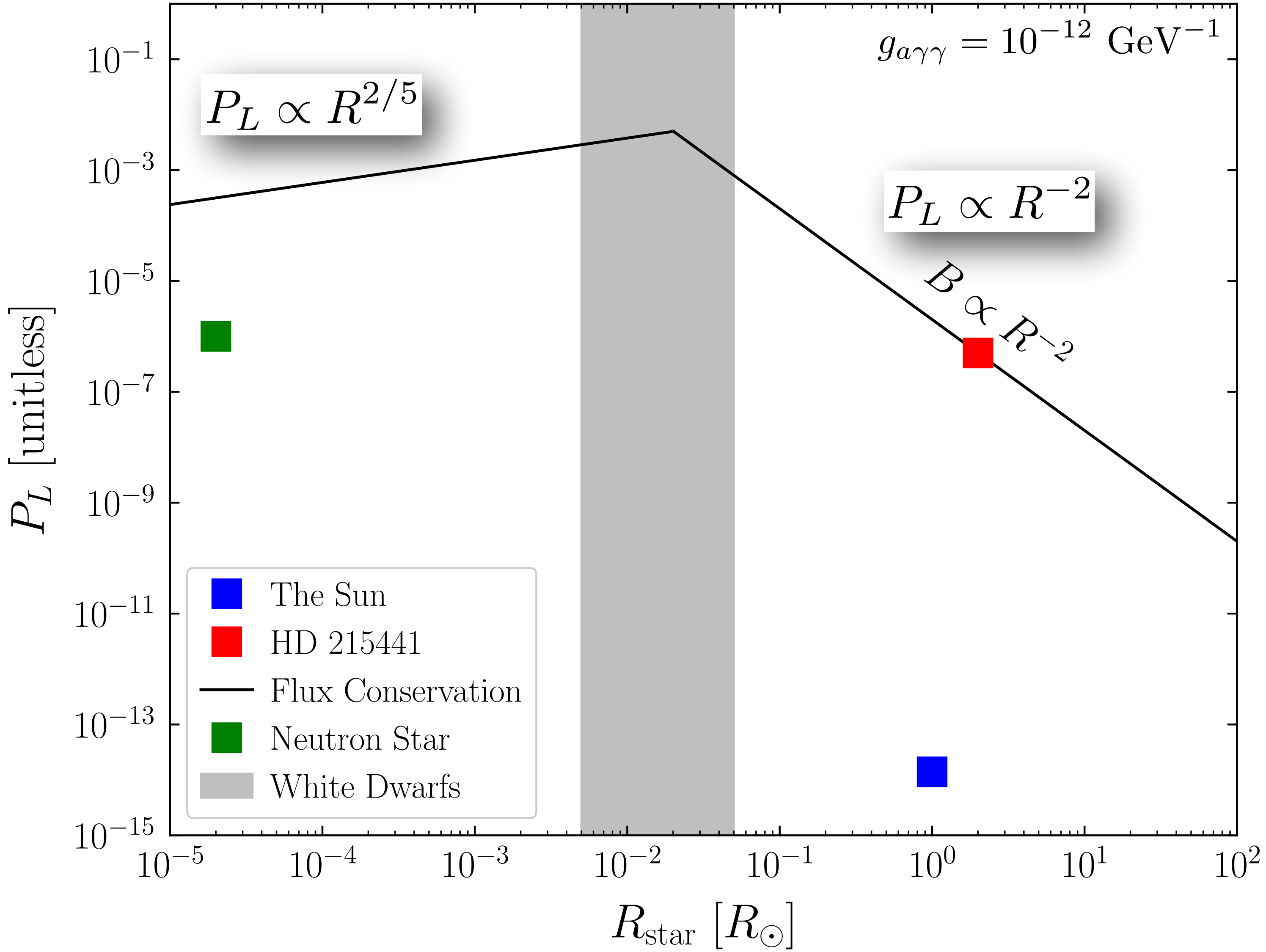
$$\zeta \approx 10^{-2}\left(\frac{R_{\rm star}}{0.01\,R_\odot}\right)\left(\frac{\omega}{1\,\mathrm{eV}}\right)\left(\frac{B_0}{100\,\mathrm{MG}}\right)^2$$

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

Axion-Induced Polarization

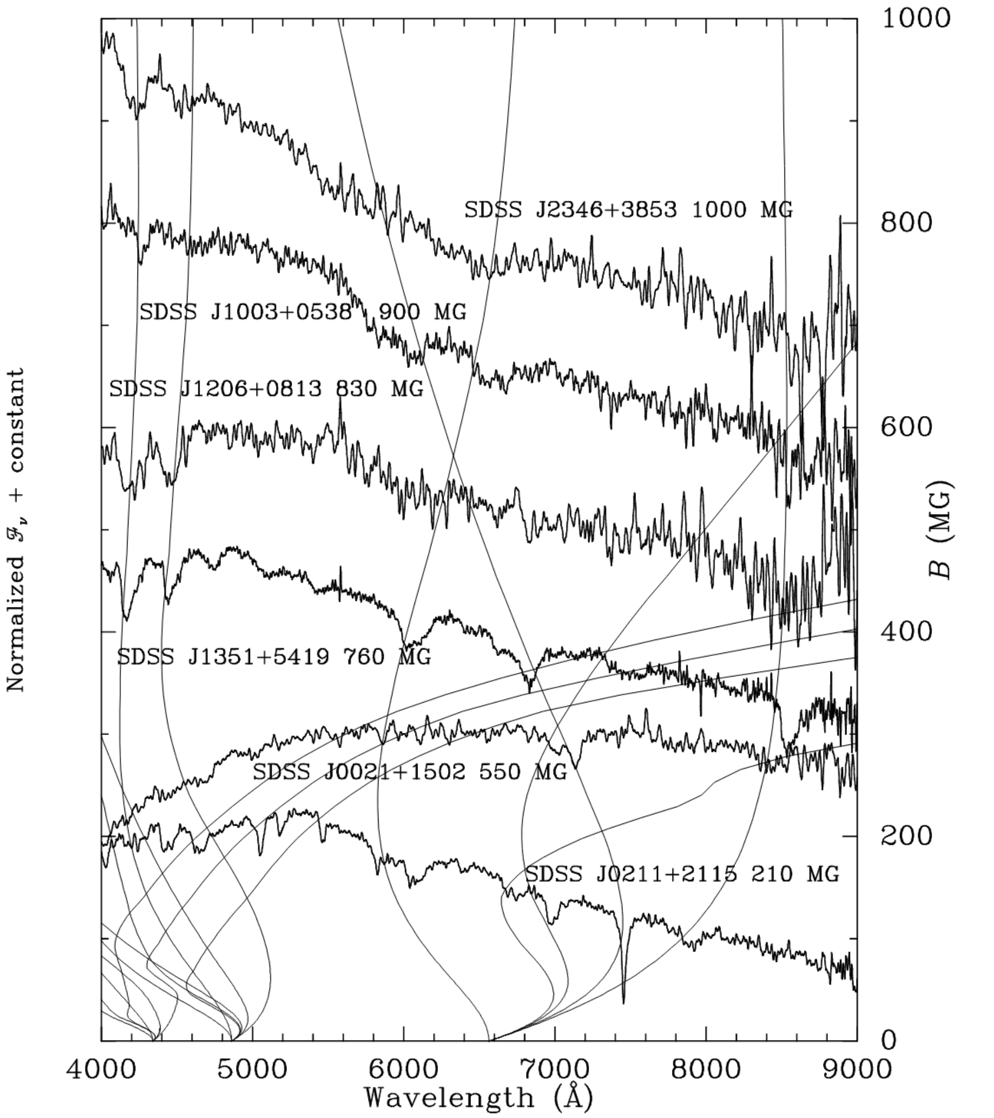


Axion-Induced Polarization



Promising MWD Targets

$$\text{RE J0317} - 853 \ (B = 200 - 800 \text{ MG})$$
$$\text{SDSS J1351} + 5419 \ (B = 761 \pm 54 \text{ MG})$$
$$\text{Grw} + 70^\circ 8247 \ (B \approx 350 \text{ MG})$$
$$\text{PG1031} + 234 \ (B \approx 400 - 1000 \text{ MG})$$
$$\text{SDSS J234605} \ (B = 798 \pm 164 \text{ MG})$$
$$\text{HE } 1043 - 0502 \ (B \approx 820 \text{ MG})$$
$$\text{SDSS J1206} + 0613 \ (B = 761 \pm 282 \text{ MG})$$
$$\text{SDSS J1003} + 0538 \ (B = 672 \pm 119 \text{ MG})$$
$$\text{SDSS J0021} + 1502 \ (B = 531 \pm 64 \text{ MG})$$



1504.08072

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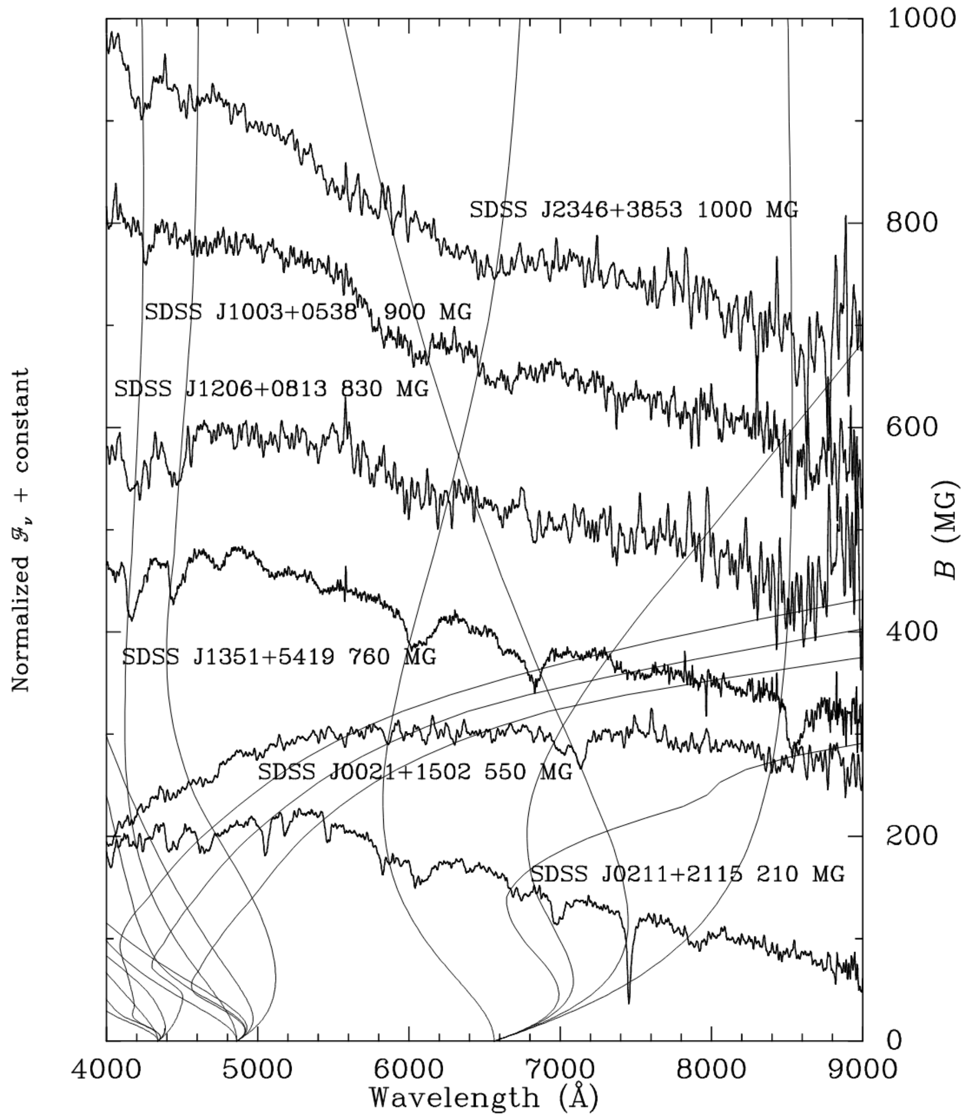

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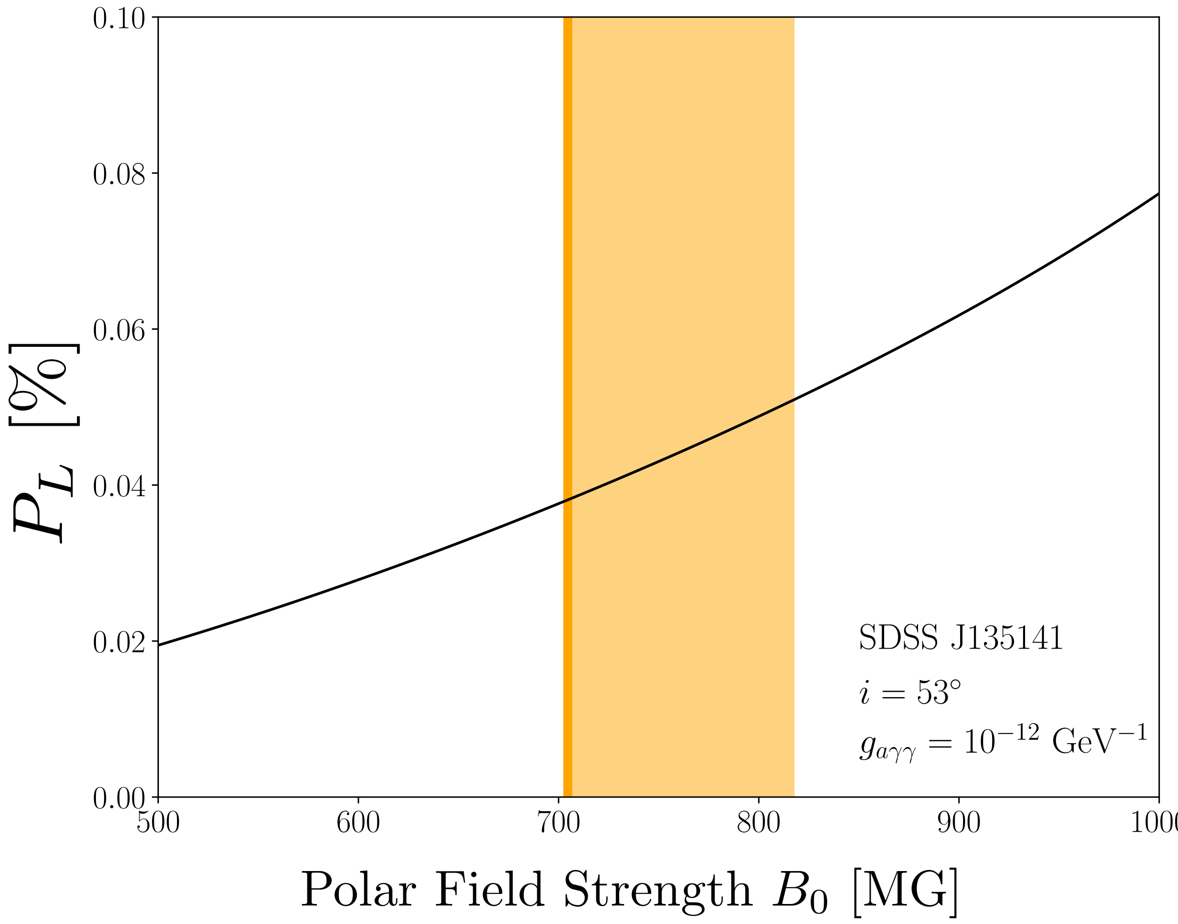
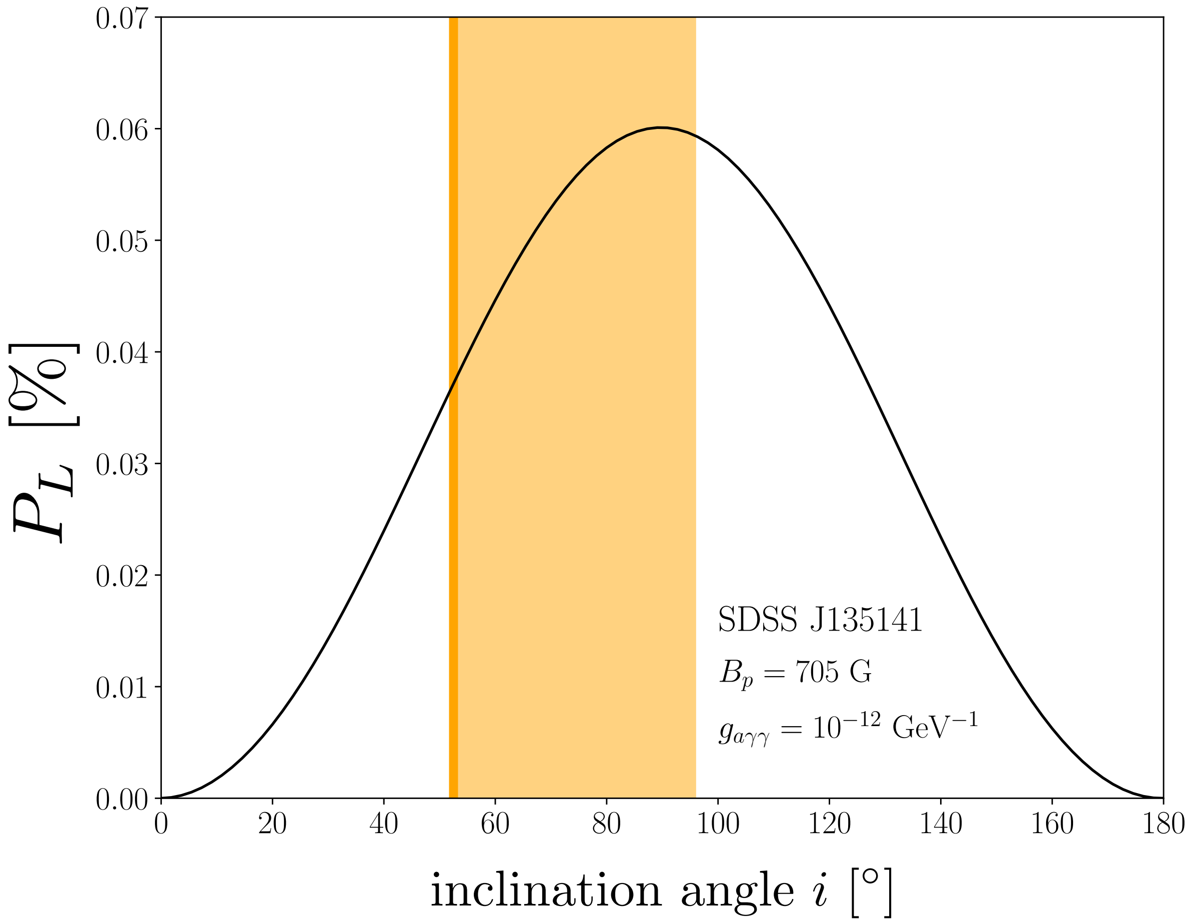
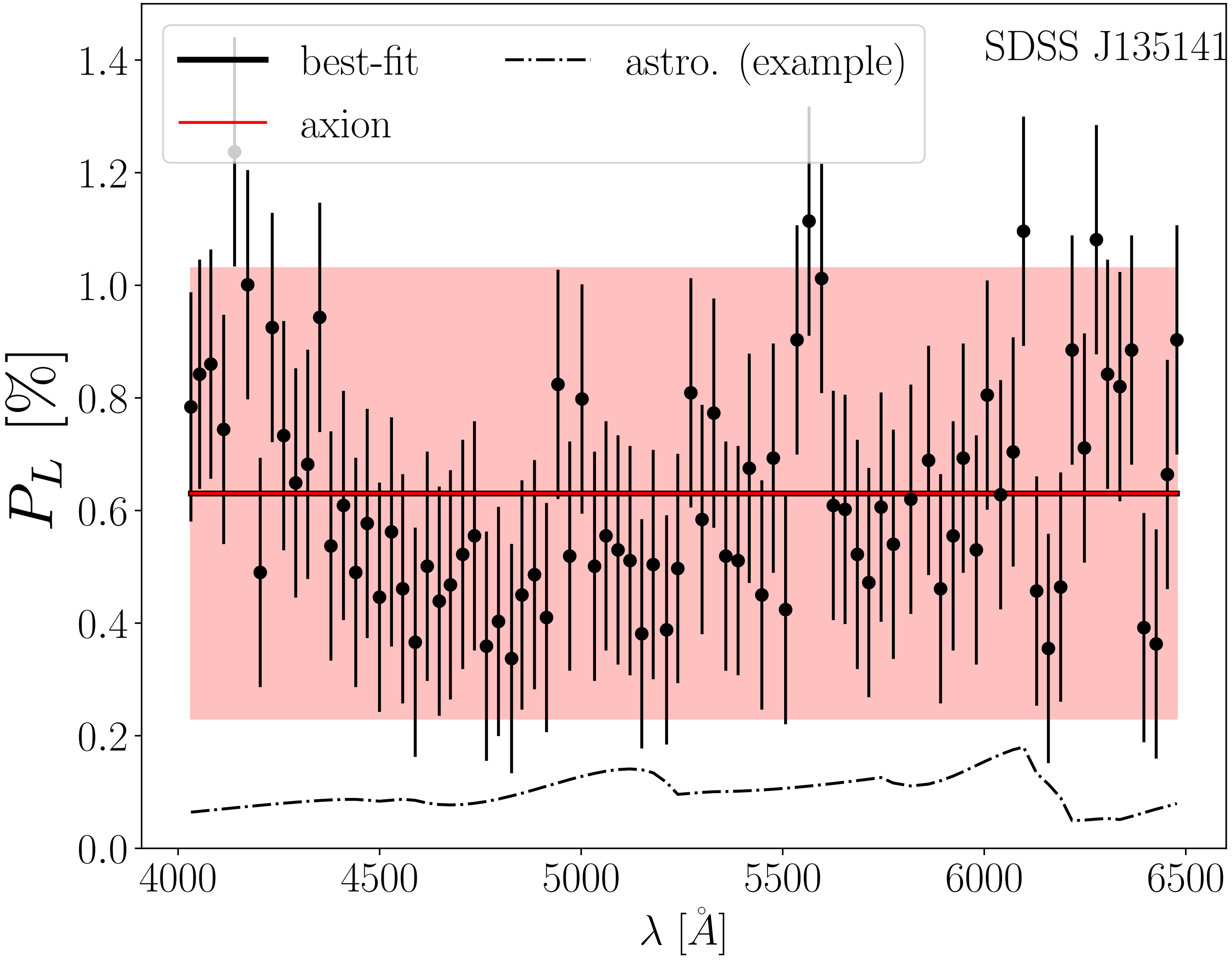
SDSS J1351 Modeling

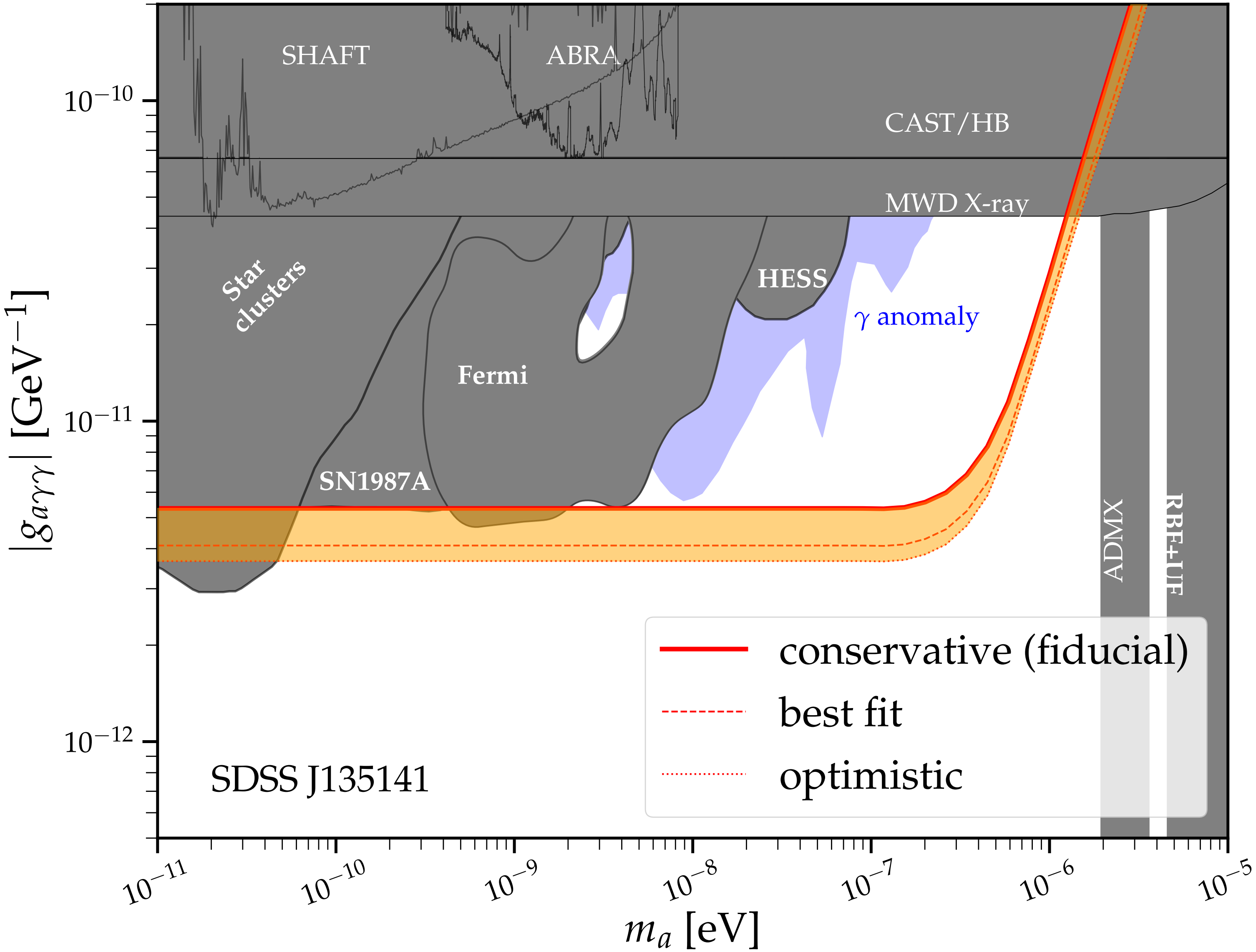




SDSS J1351 Analysis



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
10^{-10}
10^{-11}
10^{-12}
$|g_{a\gamma\gamma}|$ [GeV^{-1}]
10^{-11} 10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5}
m_a [eV]

Conclusion

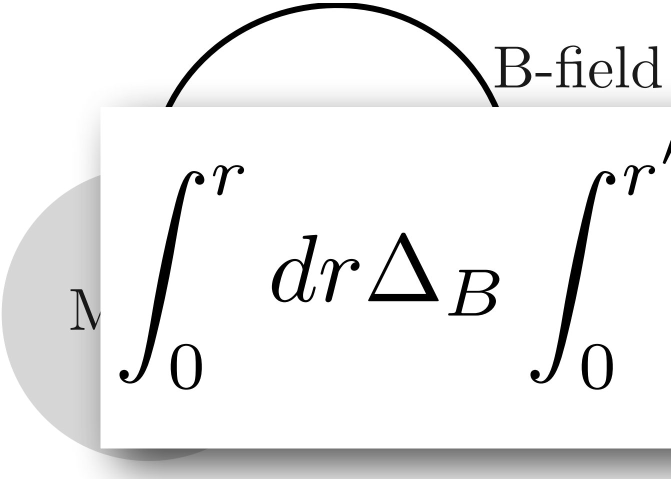
- Magnetic white dwarfs are very powerful probes of axions
- Studies still in their infancy, lots of room to improve
- Future dedicated polarization observations of MWDs

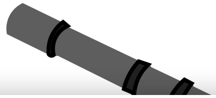
Thank you!

Illustration by Sandbox Studio, Chicago with Ana Kova (Symmetry Magazine)

Axion-Induced Polarization

$$\left[i\partial_r + \omega + \begin{pmatrix} \Delta_\parallel & \Delta_B \\ \Delta_B & \Delta_a \end{pmatrix}\right]\begin{pmatrix} A_2 \\ a \end{pmatrix} = 0$$





$$\int_0^r dr\Delta_B \int_0^{r'} dr''\Delta_B e^{-i\int_0^{r''} dr'''(\Delta_{||}-\Delta_a)}\Bigg)$$

$$\mathbf{A} = \frac{A}{\sqrt{2}}\left[a_1\hat{\mathbf{x}}_1 + a_2\hat{\mathbf{x}}_2\right] \qquad \mathbf{A}(r) = \frac{A}{\sqrt{2}}\left[a_1\hat{\mathbf{x}}_1 + a_2\hat{\mathbf{x}}_2\left(1 - P_L\right)\right]$$

Axion-Induced Polarization

$$P_L \approx 10^{-4}\left(\frac{g_{a\gamma\gamma}}{10^{-12}\ \mathrm{GeV}^{-1}}\right)^2\left(\frac{B_0}{100\ \mathrm{MG}}\right)^{2/5}\left(\frac{1\ \mathrm{eV}}{\omega}\right)^{4/5}\left(\frac{R_{\rm star}}{0.01\ R_\odot}\right)^{6/5}\times$$

$$\frac{\mathrm{Abs}\left\{\mathrm{Re}\left[(-1)^{2/5}e^{-i\frac{7}{10}\zeta}\left(\Gamma\left(\frac{4}{5}\right)-\Gamma\left(\frac{4}{5},-\frac{7}{10}i\zeta\right)\right)\right]\right\}}{0.022},$$

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

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