Polarized Signatures of Axions at Magnetic White Dwarfs

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2203.04319, 24xx.xxxxx

D. Dunsky, B. Safdi, C. Scherb

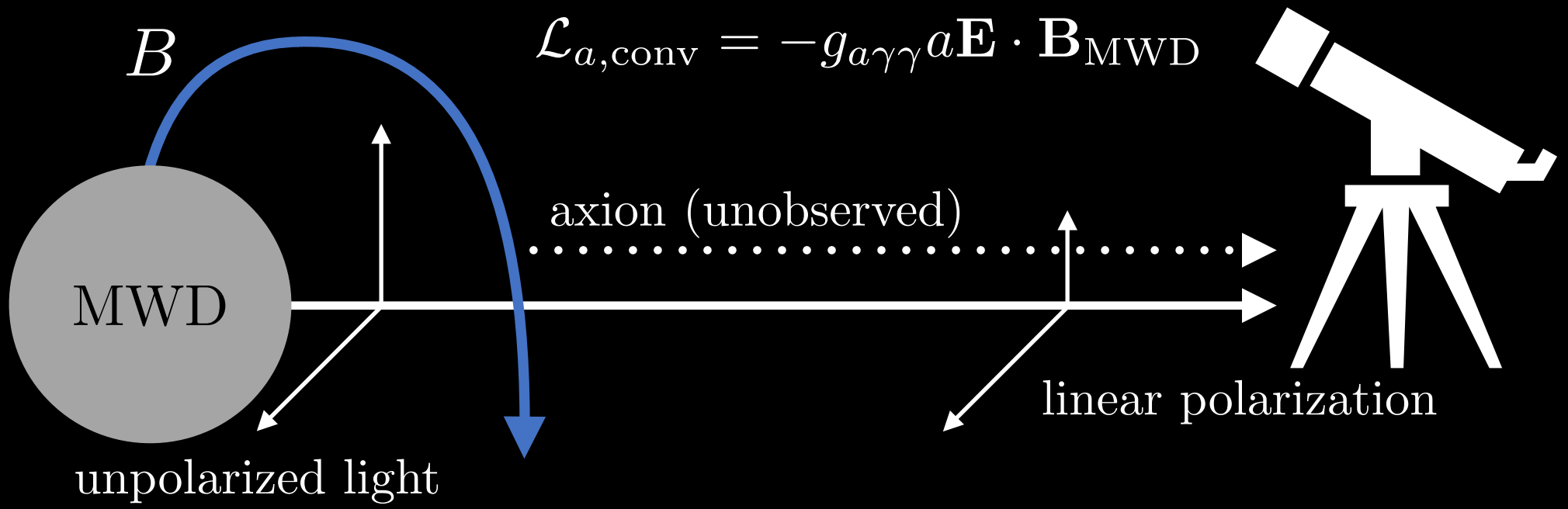
Axions++ 2023

NYU FLATIRON INSTITUTE

Carl Knox, OzGrav

R. Gill, J. Heyl
arXiv:1105.2083

Polarization of MWDs



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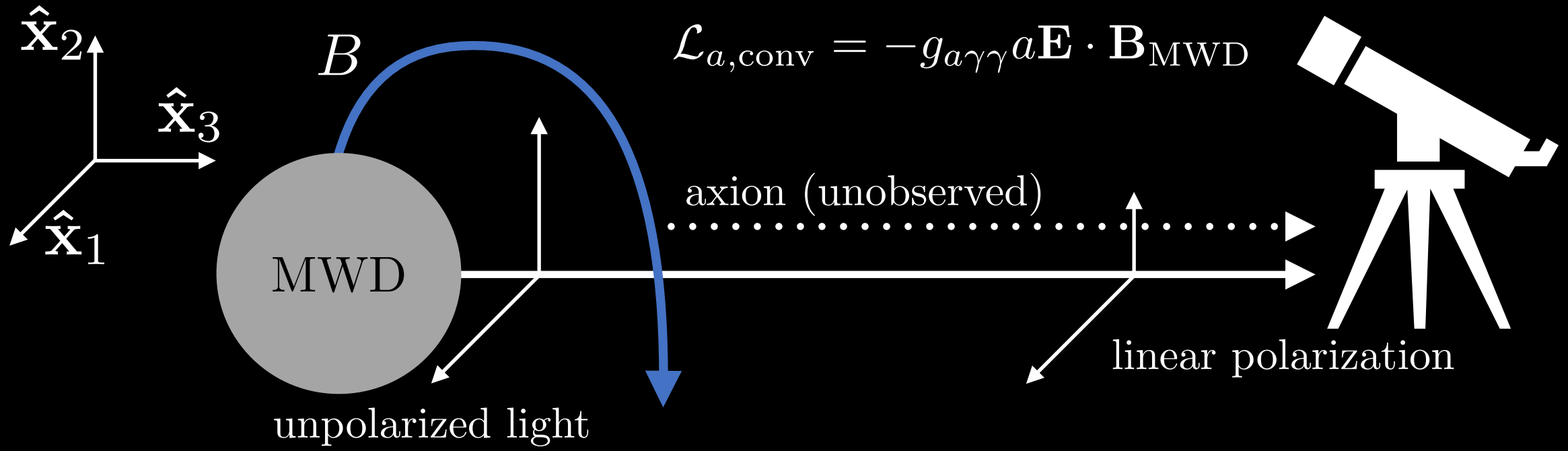

$$\mathbf{A} = \frac{A}{\sqrt{2}} \left[a_1 \hat{\mathbf{x}}_1 + a_2 \hat{\mathbf{x}}_2 \right]$$

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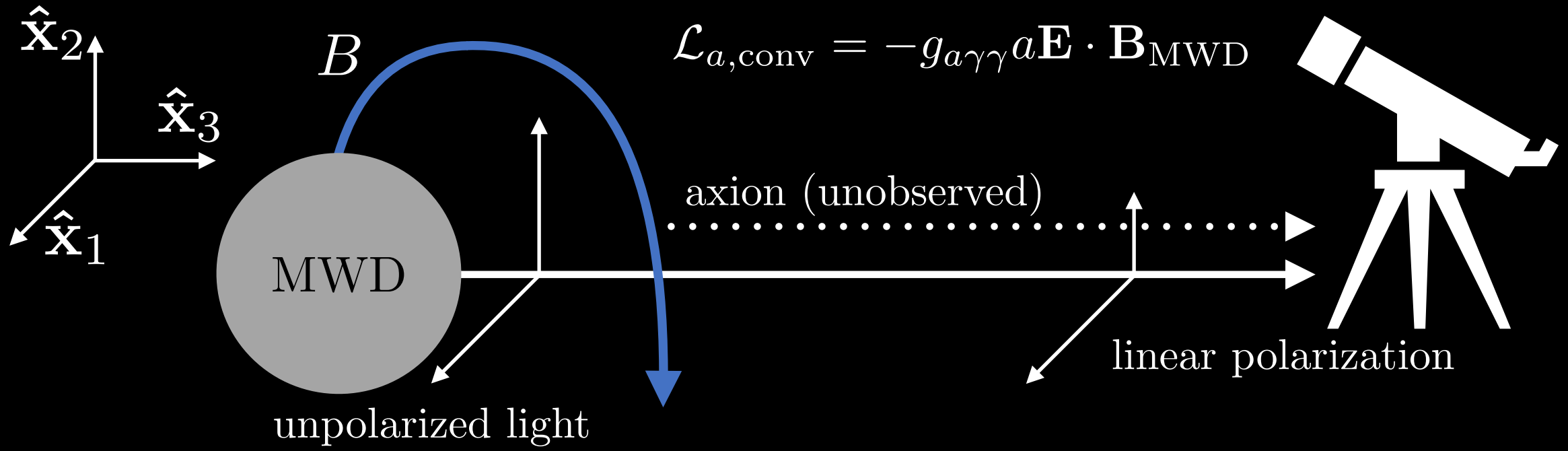


$$\mathbf{A} = \frac{A}{\sqrt{2}} \left[a_1 \hat{\mathbf{x}}_1 + a_2 \hat{\mathbf{x}}_2 \right] \rightarrow \frac{A}{\sqrt{2}} \left[a_1 \hat{\mathbf{x}}_1 + a_2 \left(1 - P_L \right) \hat{\mathbf{x}}_2 \right]$$

Euler-Heisenberg Mixing

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

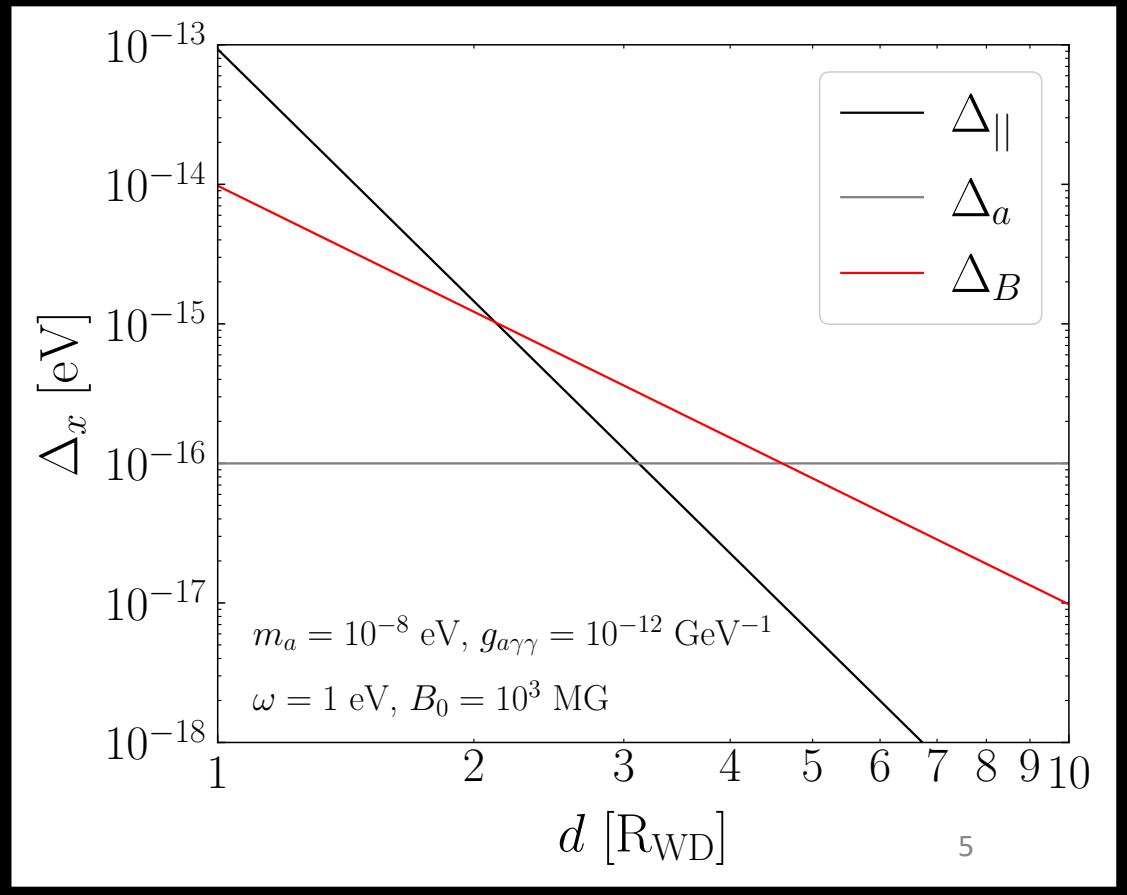
- Axion-photon EOM:

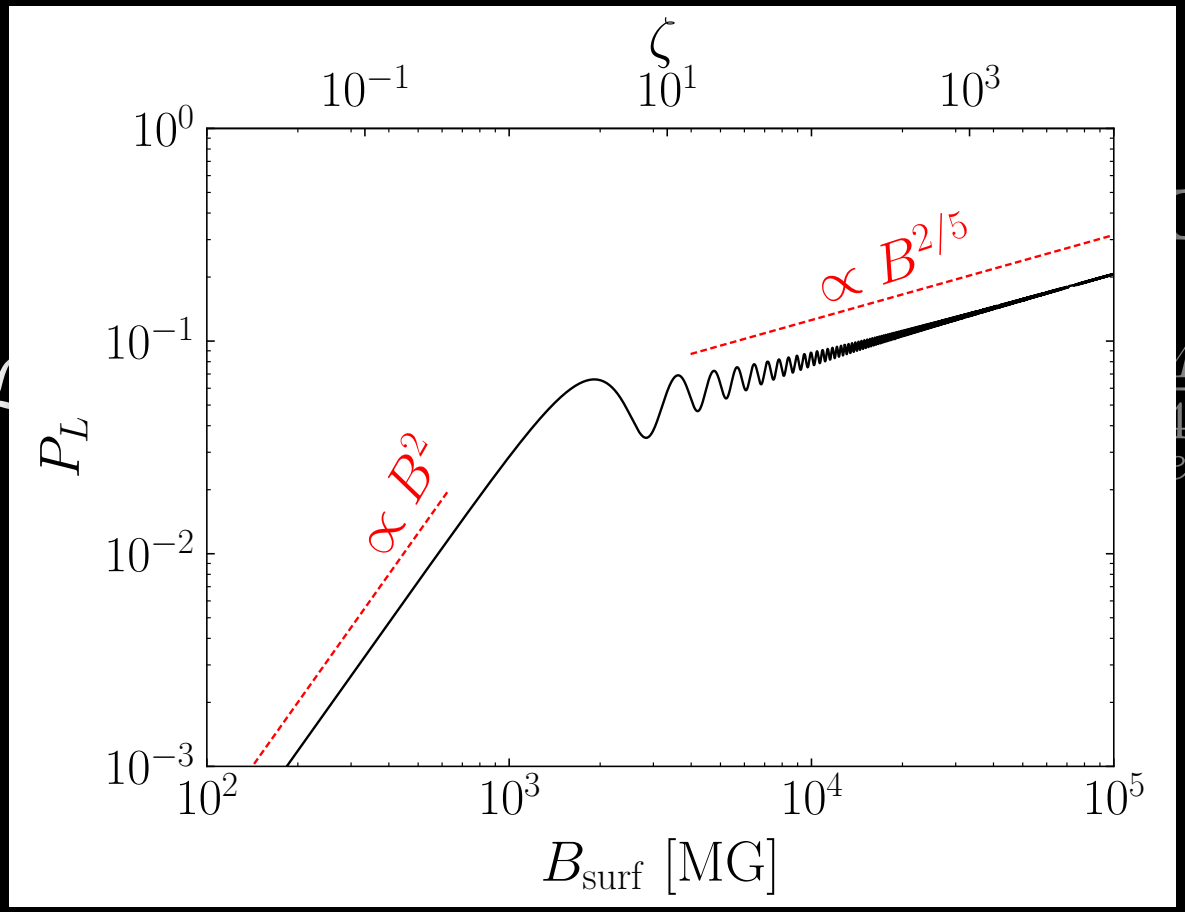
$$\left[i\partial_r + \begin{pmatrix} \Delta_\parallel & \Delta_B \\ \Delta_B & \Delta_a \end{pmatrix}\right]\begin{pmatrix} A_\parallel \\ a \end{pmatrix} = 0$$

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

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

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





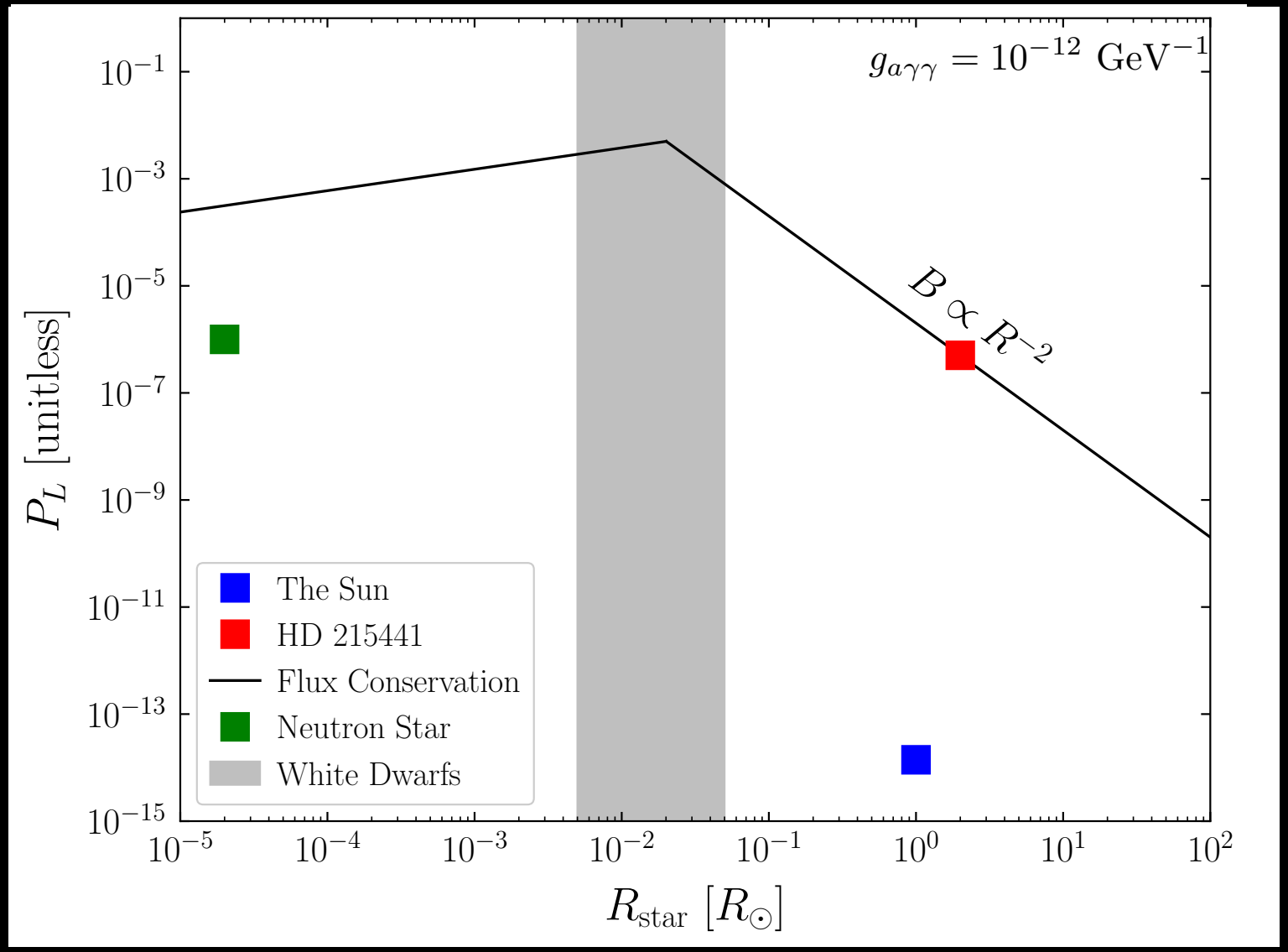
ing

$$\frac{M}{4} \left[(\mathbf{E}^2 - \mathbf{B}_{\rm MWD}^2)^2 + 7(\mathbf{E}\cdot\mathbf{B}_{\rm MWD})^2\right]$$

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

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

Axion-Induced Polarization



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)

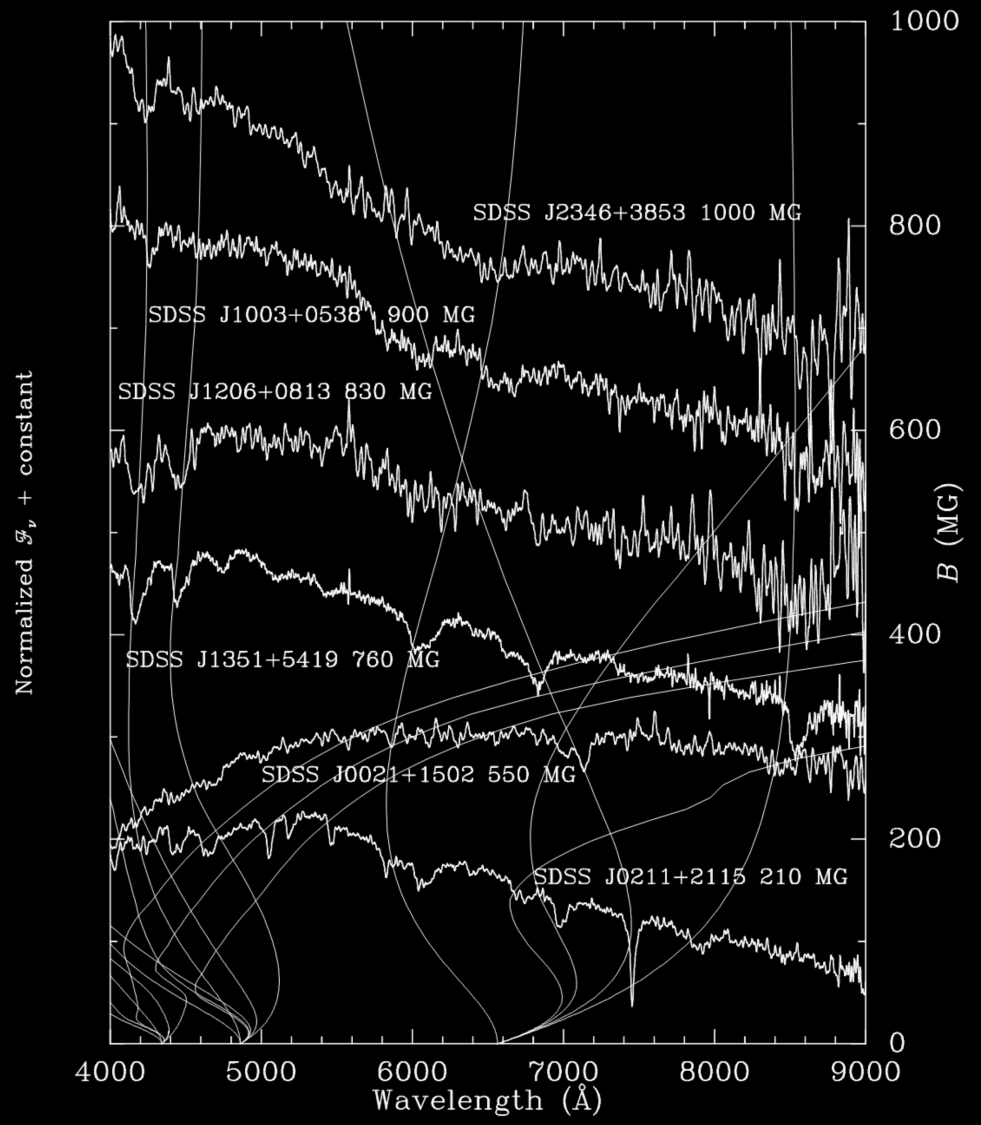
HE 1043 − 0502 ($B \approx 820$ MG)

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

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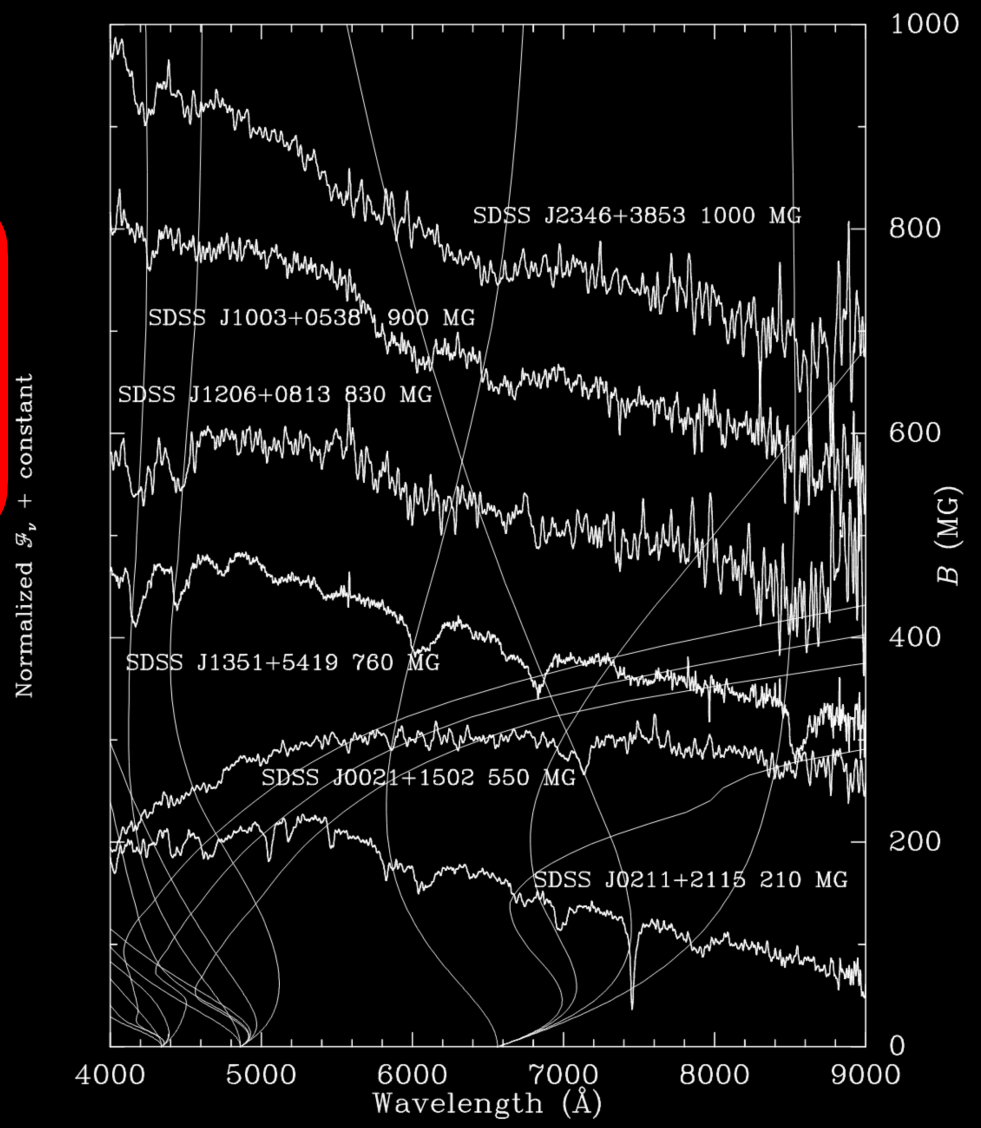
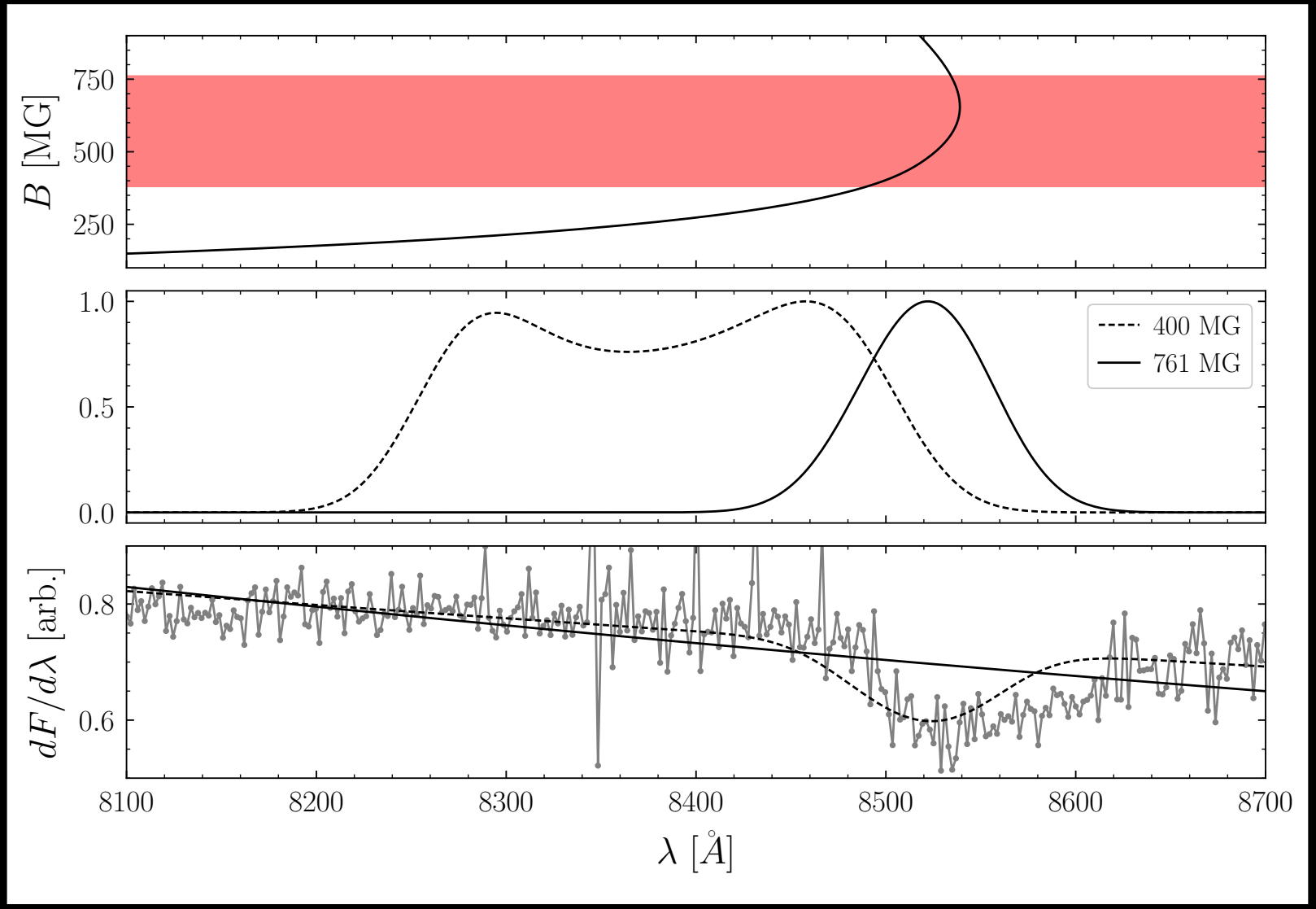
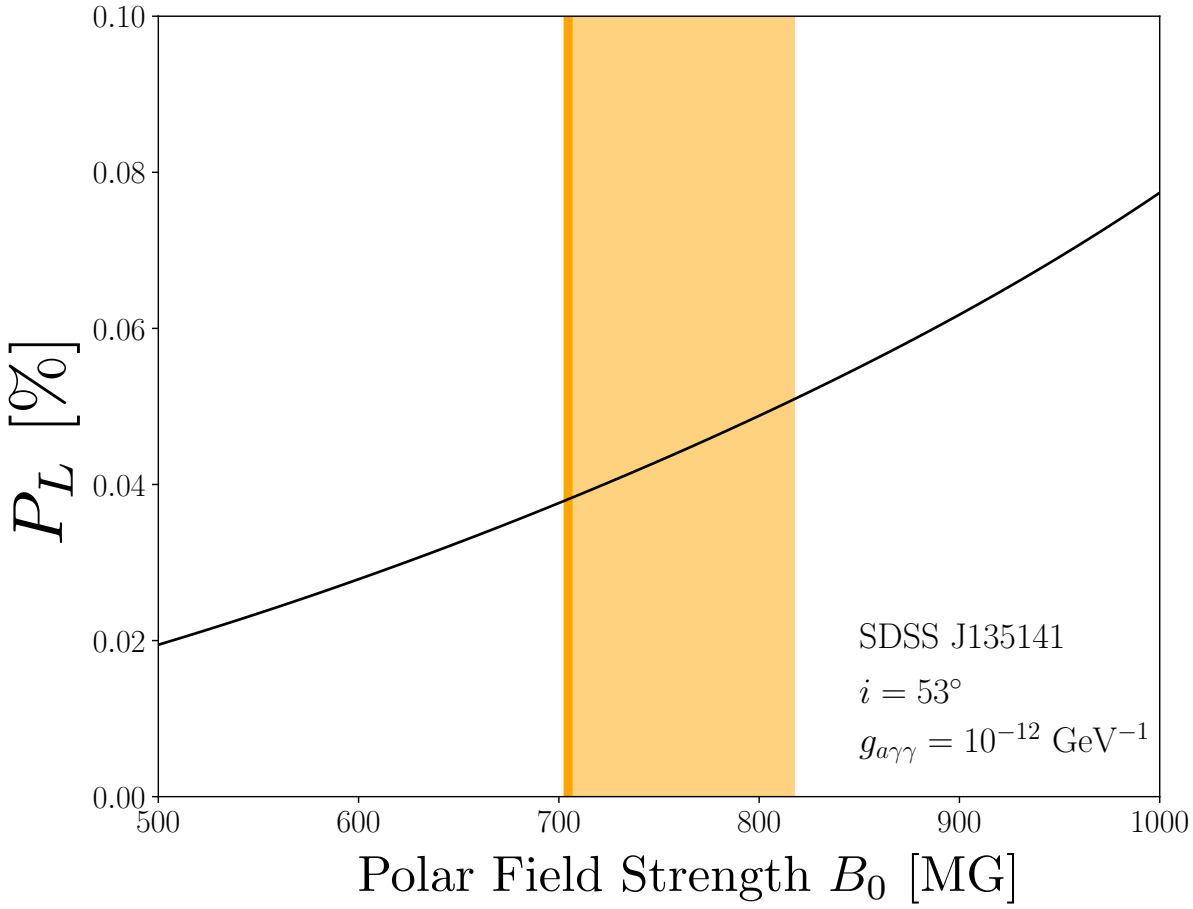


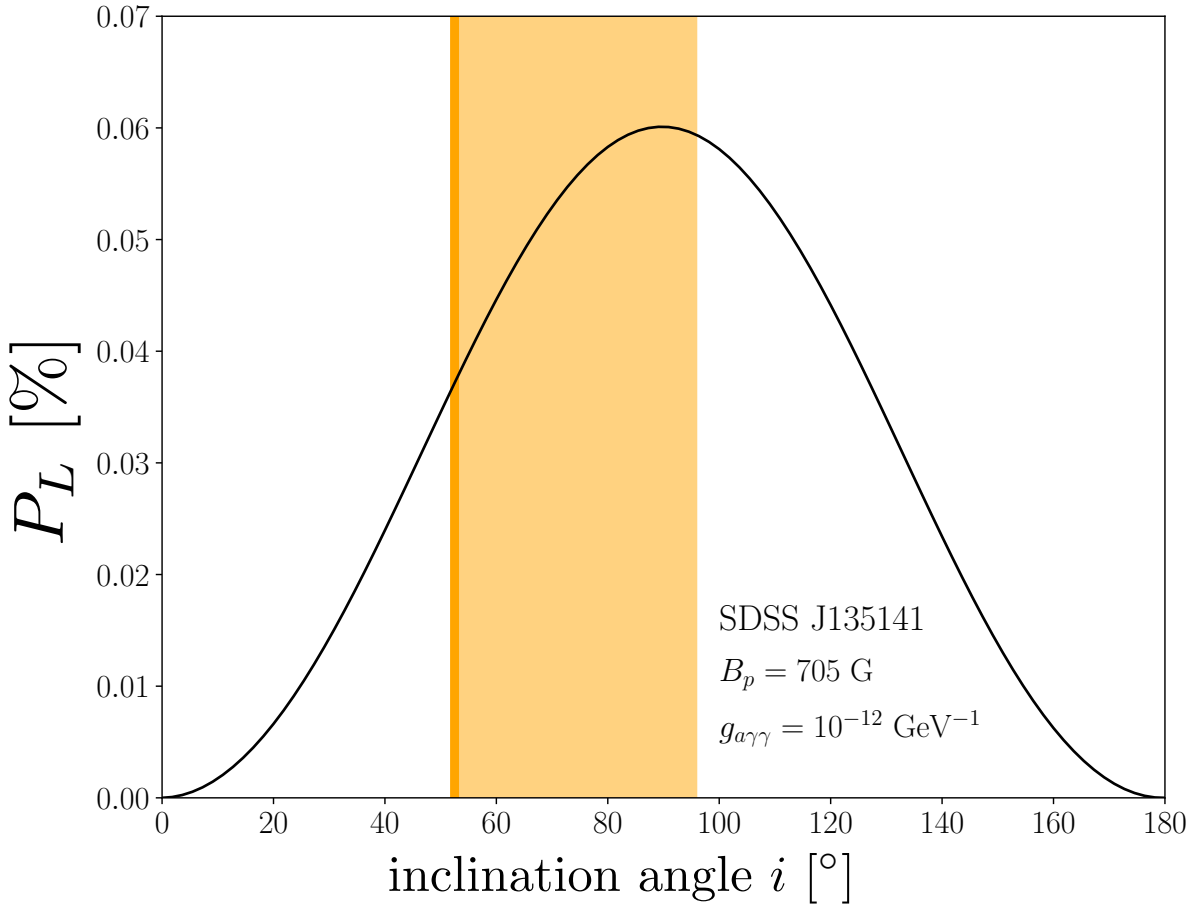
1504.08072

Magnetic Field Measurements

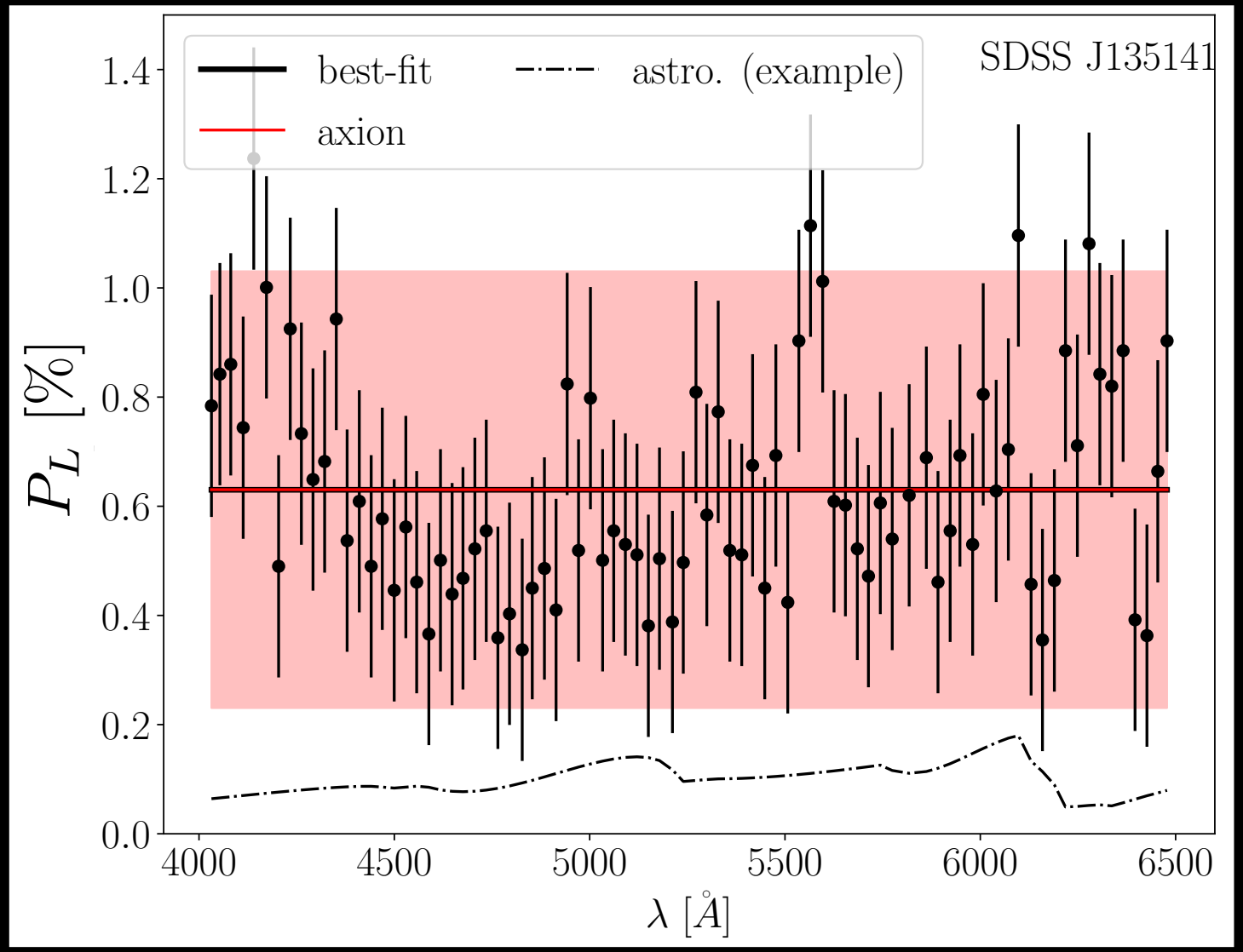


SDSS J1351+5419

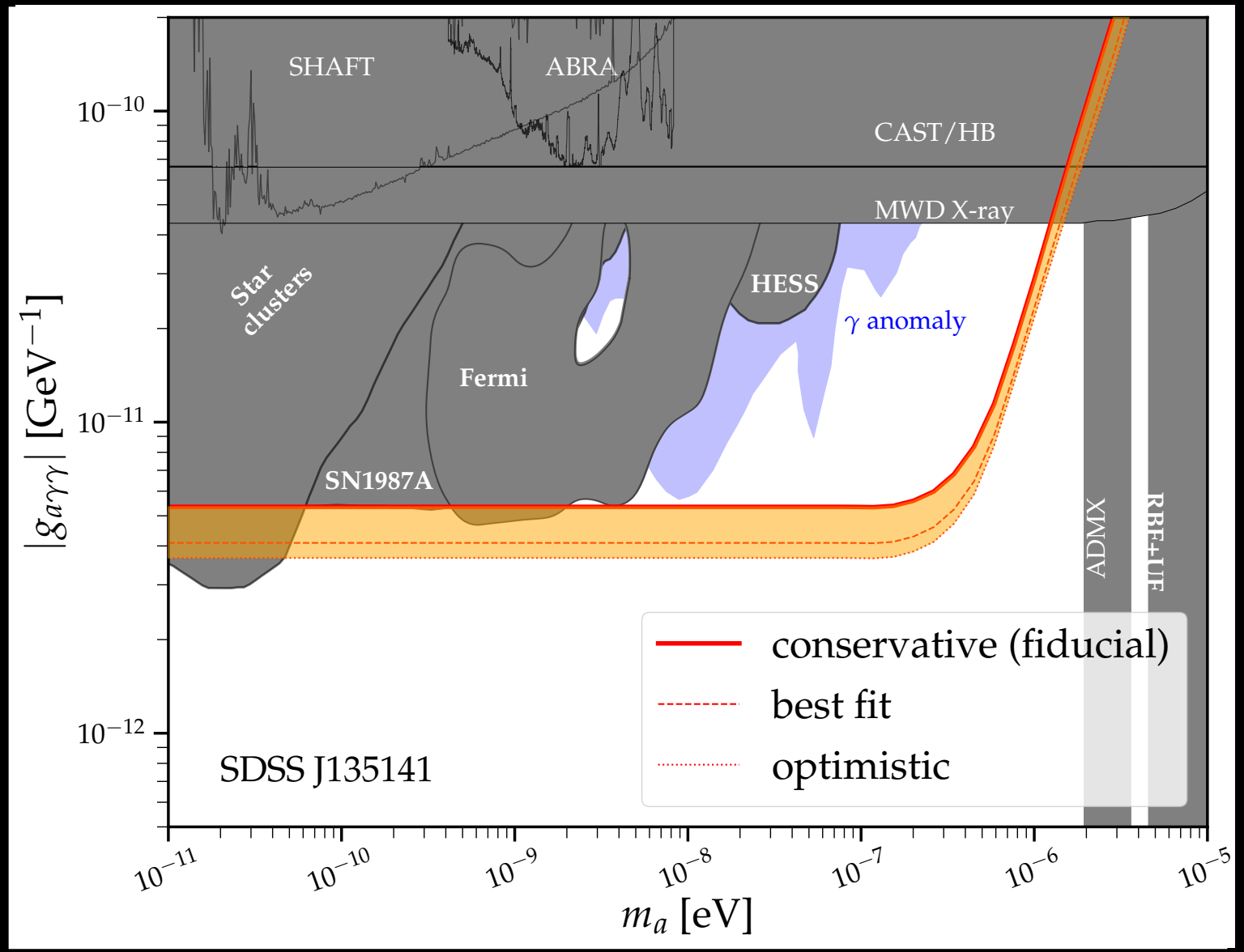




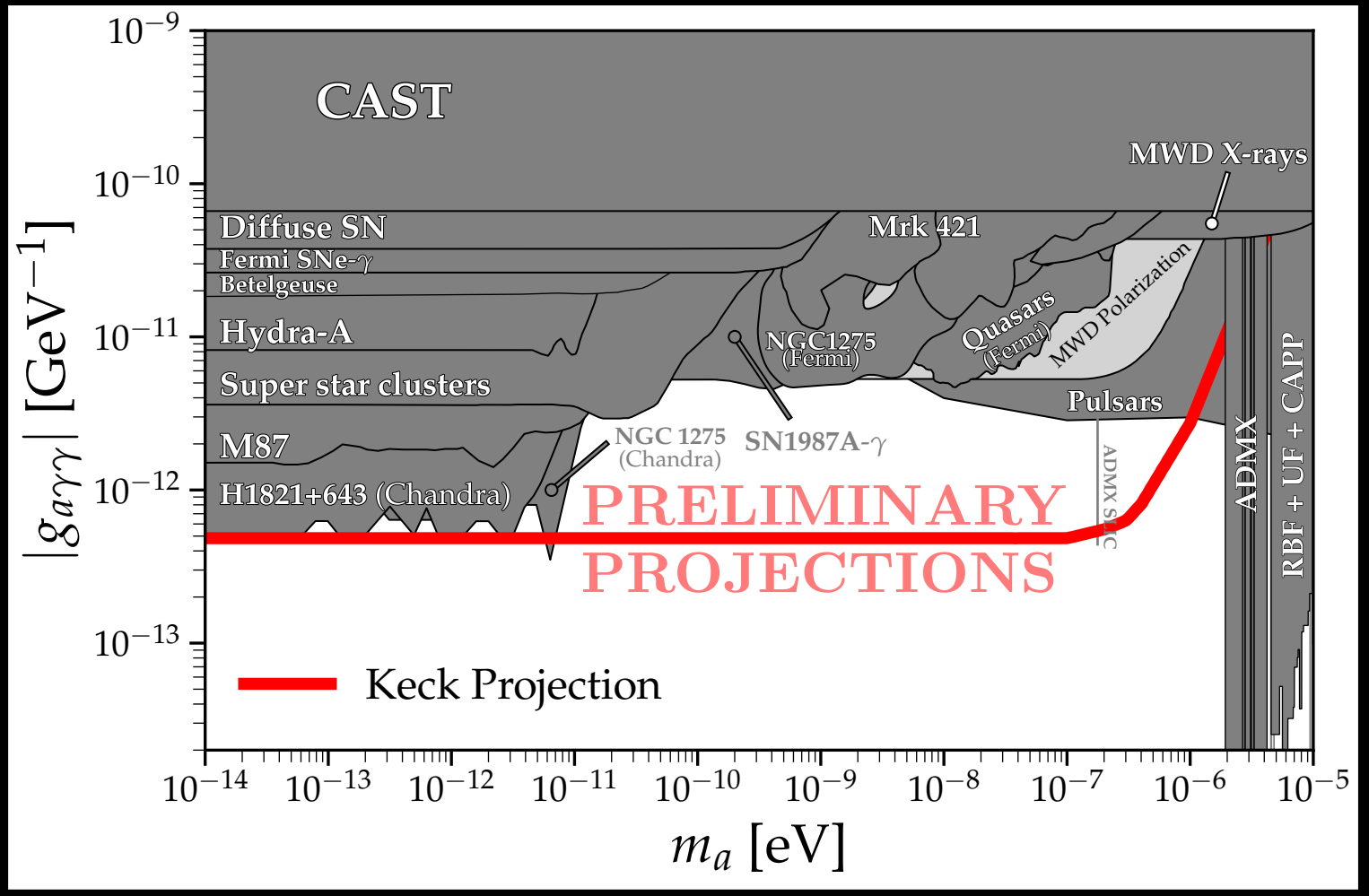
SDSS J1351


best-fit
astro. (example)
axion
SDSS J135141
P_L [%]
λ [Å]
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
4000
4500
5000
5500
6000
6500

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}

Ongoing and Proposed Observations



Keck Observatory

Conclusion

- Polarization probes of MWDs poised to be one of the strongest constraints on light axions
- Ongoing dedicated *Lick* and *Keck Observatory* observations of MWDs with Alex Filippenko at UC Berkeley


Thank you!

Astrophysical MWD Polarization

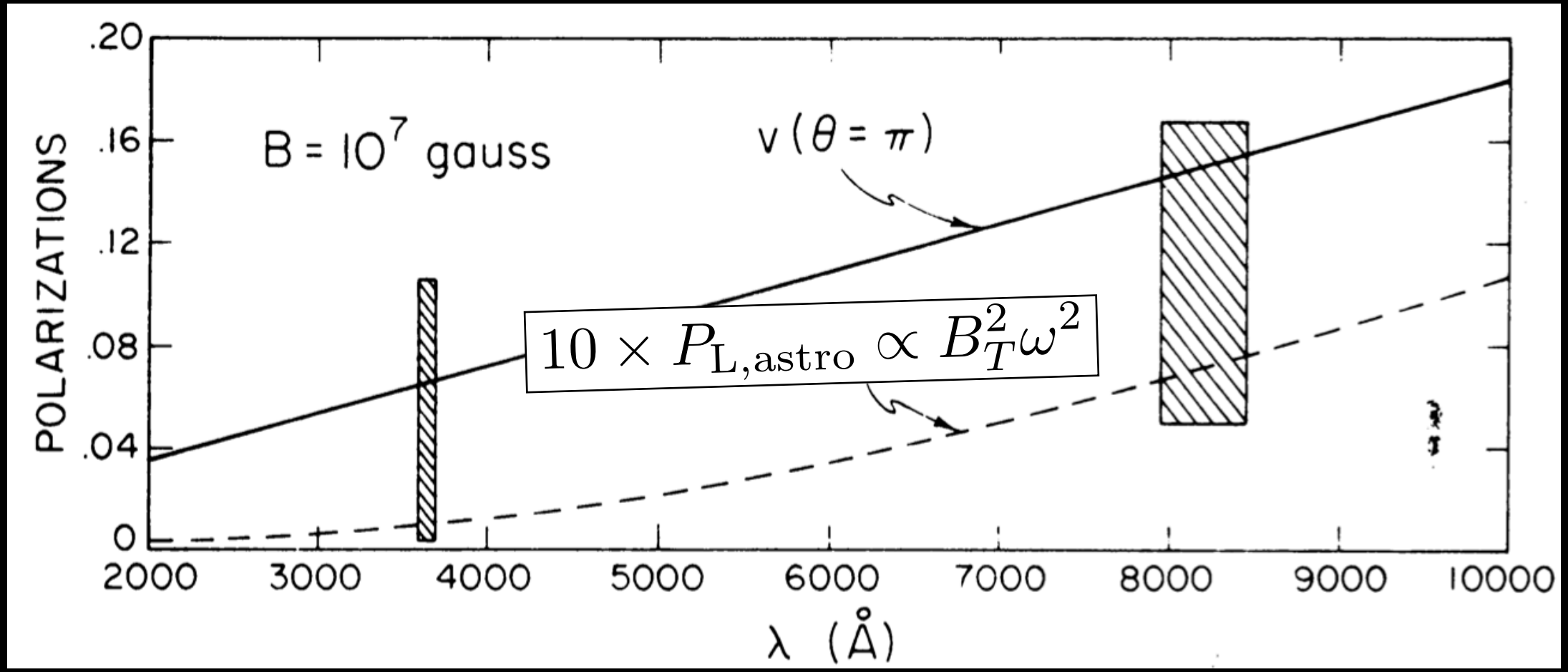
- Photons propagate unpolarized from deep in MWD atmosphere
- Astrophysical polarization created by bound-free absorption in the hydrogen atmosphere

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

- 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: $\sigma^{\rm bf}(\omega) \rightarrow \sigma^{\rm bf}(\omega - q\Omega_C)$

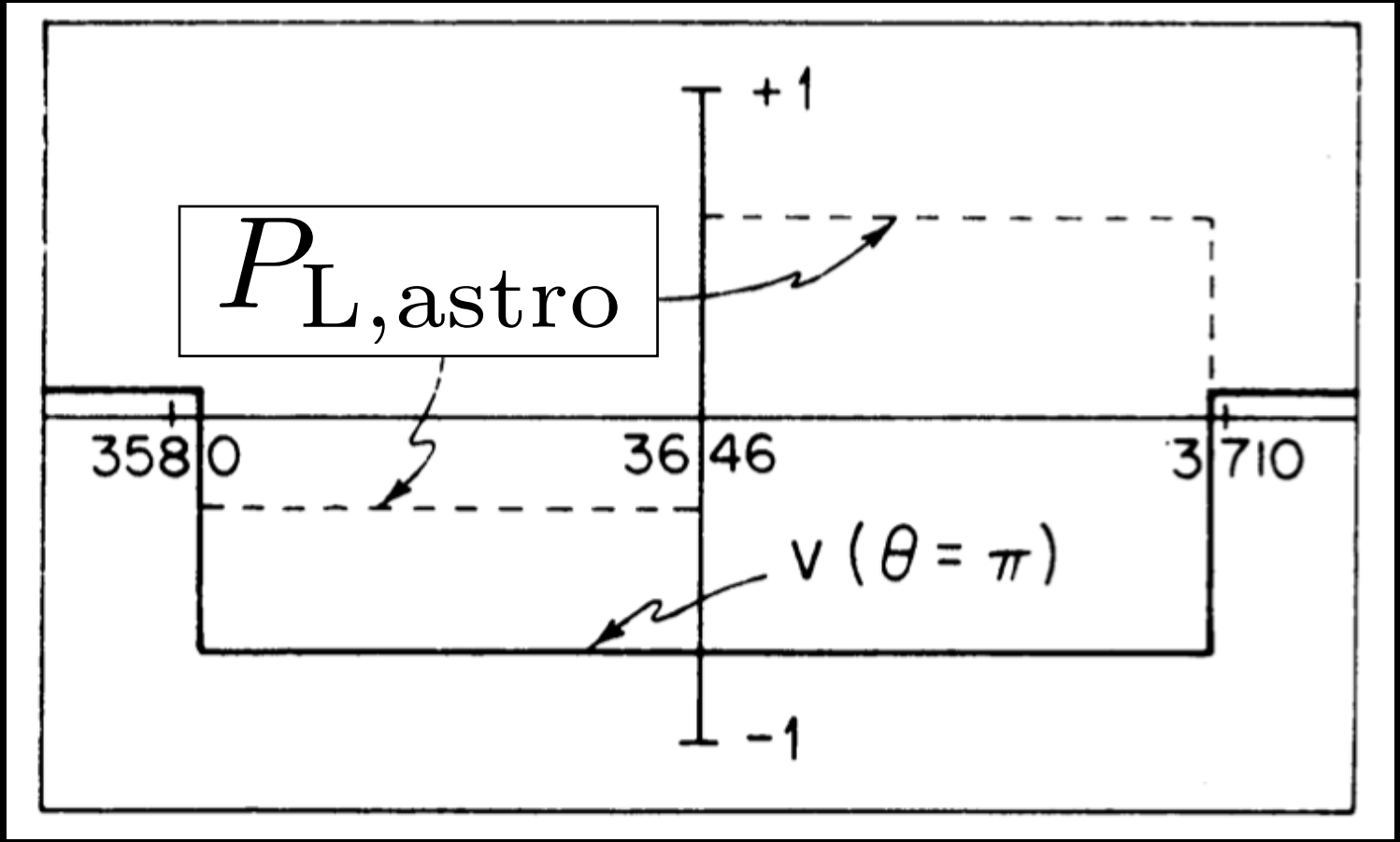
Lamb et al. 1974

Astrophysical MWD Polarization



Lamb et al. 1974

Astrophysical MWD Polarization

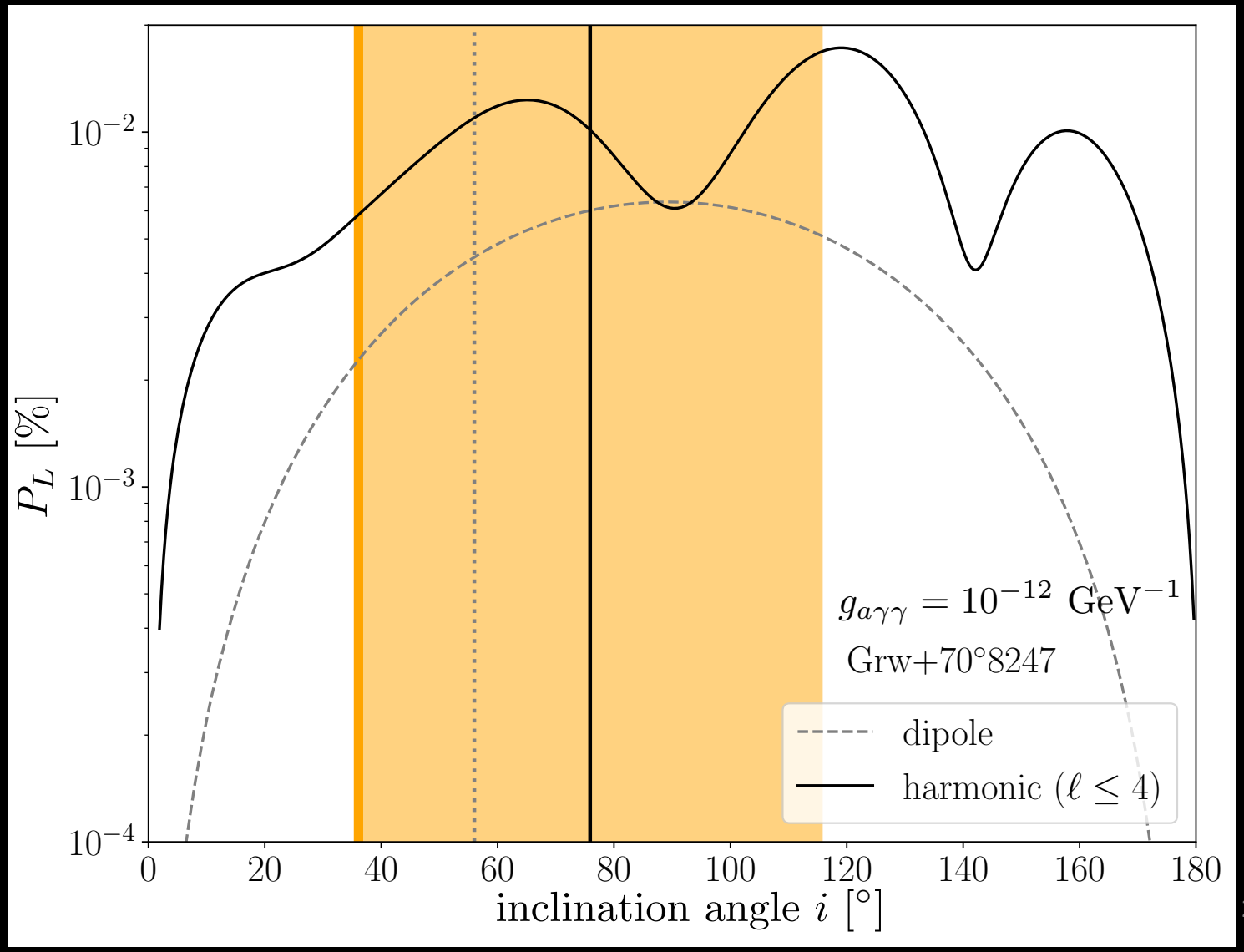


Lamb et al. 1974

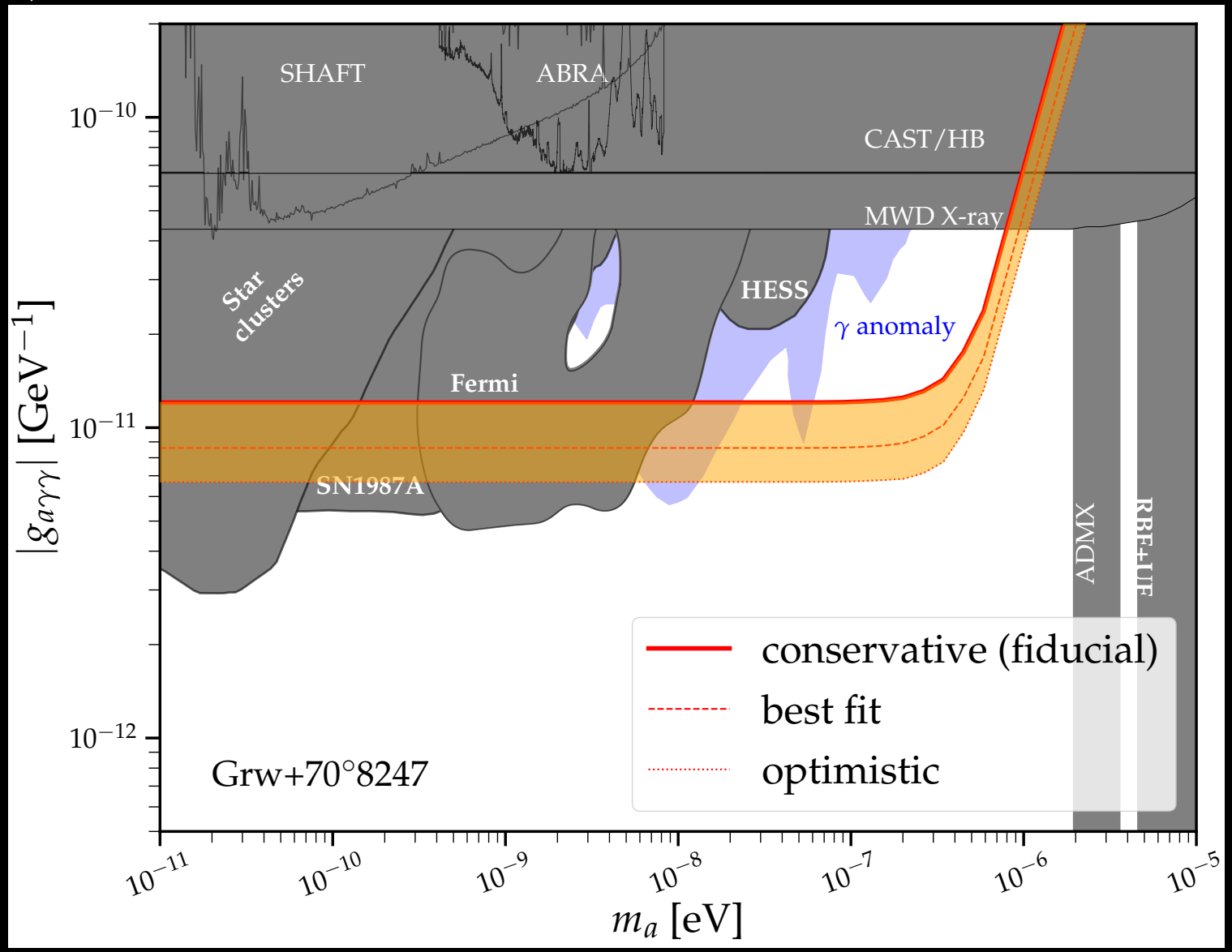
GRW+70º8247 Modeling

1904.08327:

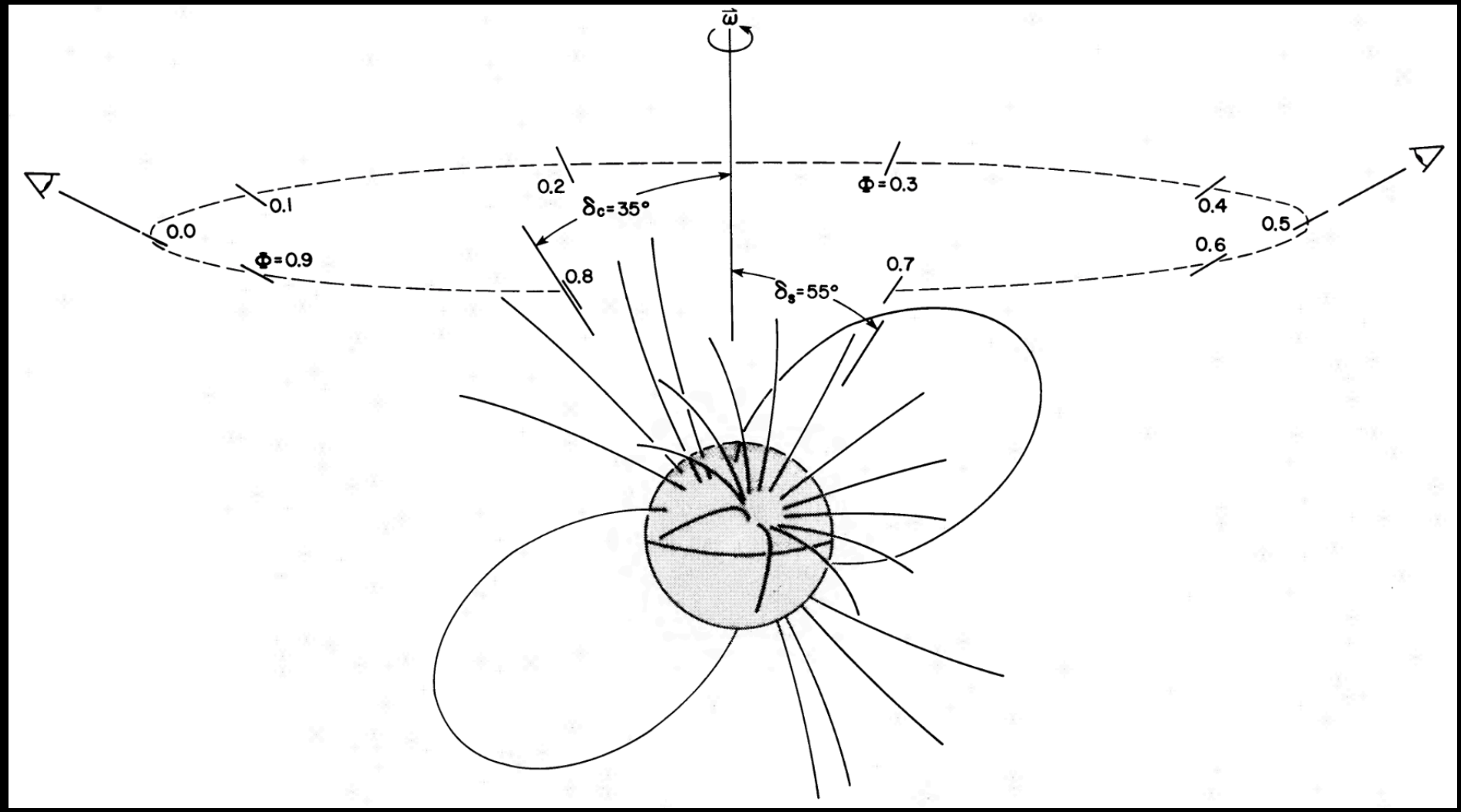
$$P_L^{95\%} = 0.73\%$$



GRW+70º8247 Constraints

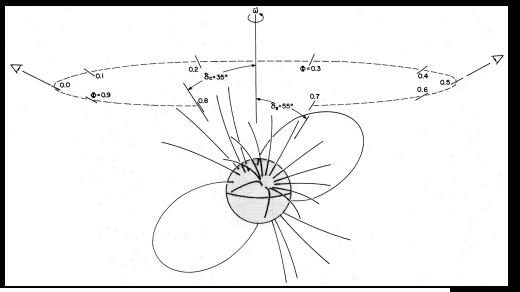


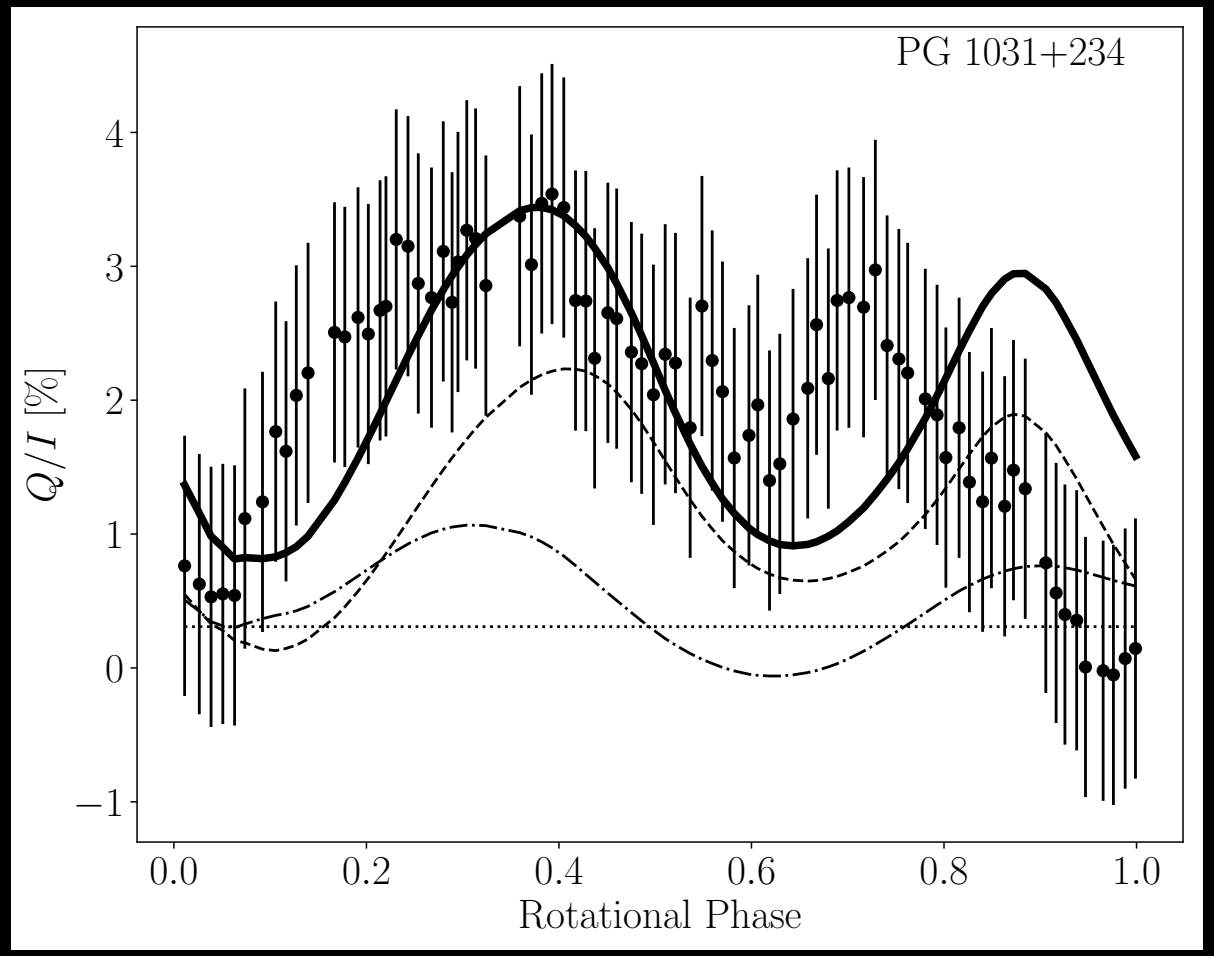
PG 1031+234 Field Geometry

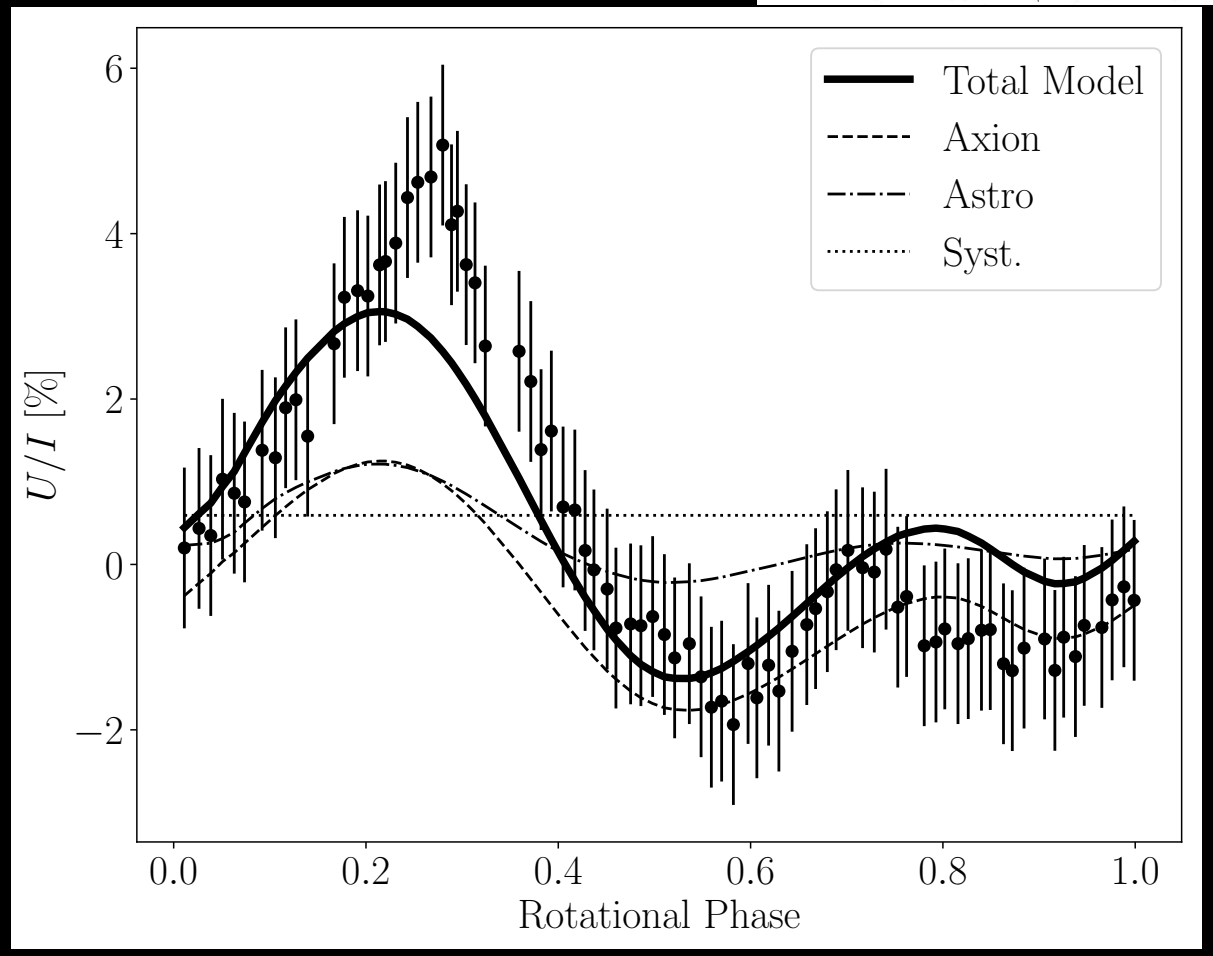


Schmidt et al. ApJ, 309:218-229,1986

PG 1031+234 Analysis







$$g_{a\gamma\gamma}^{95\%} = 8.8 \times 10^{-12}\ \mathrm{GeV}^{-1} \text{ for } m_a \ll 10^{-7}\ \mathrm{eV}$$

Schmidt et al. ApJ, 309:218-229,1986