Polarized Signatures of Axions at Magnetic White Dwarfs

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2203.04319, 24xx.xxxxx

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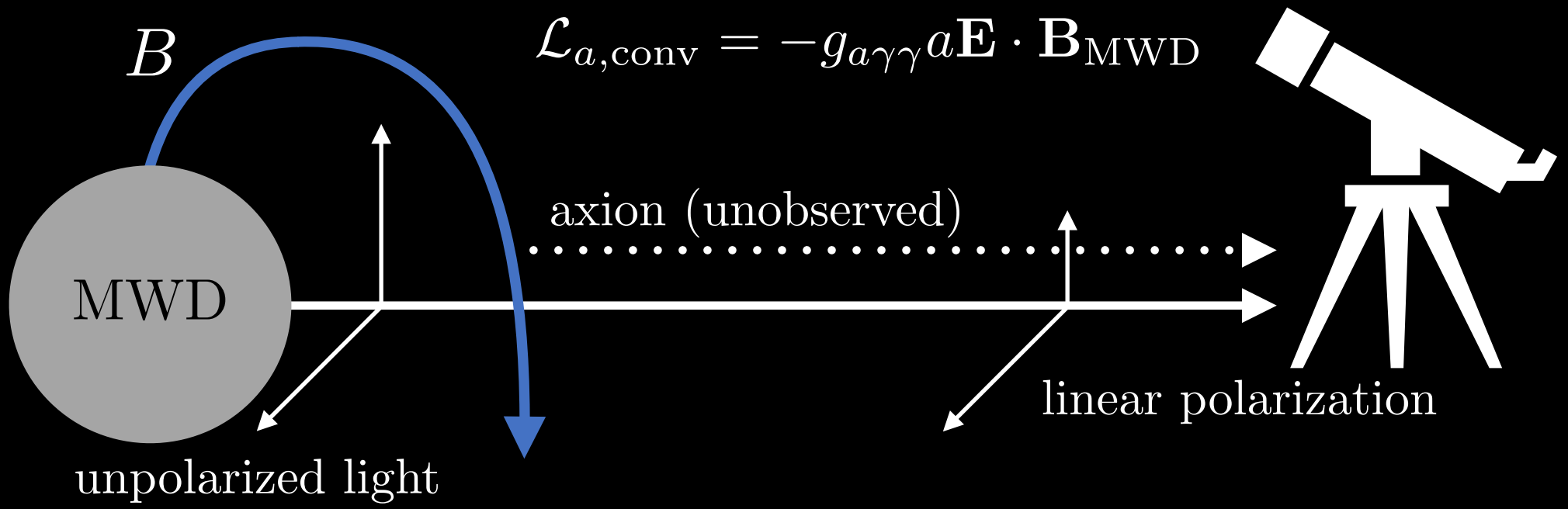
PNU-IBS Axions Workshop

FLATIRON INSTITUTE

Carl Knox, OzGrav

R. Gill, J. Heyl
arXiv:1105.2083

Polarization of MWDs



R. Gill, J. Heyl
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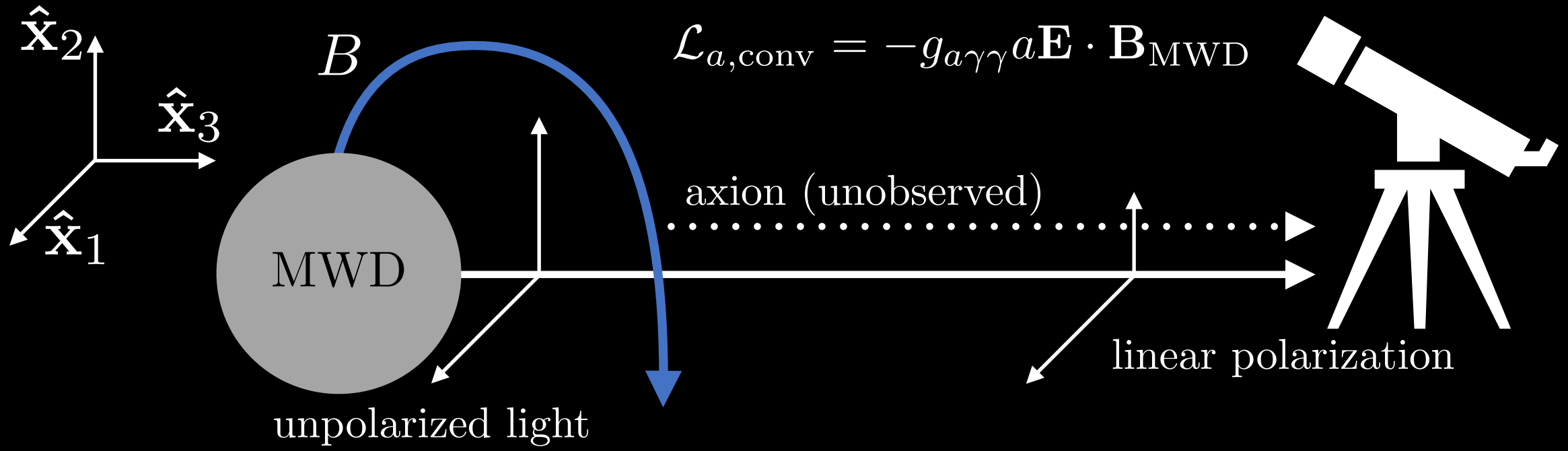
Polarization of MWDs



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

R. Gill, J. Heyl
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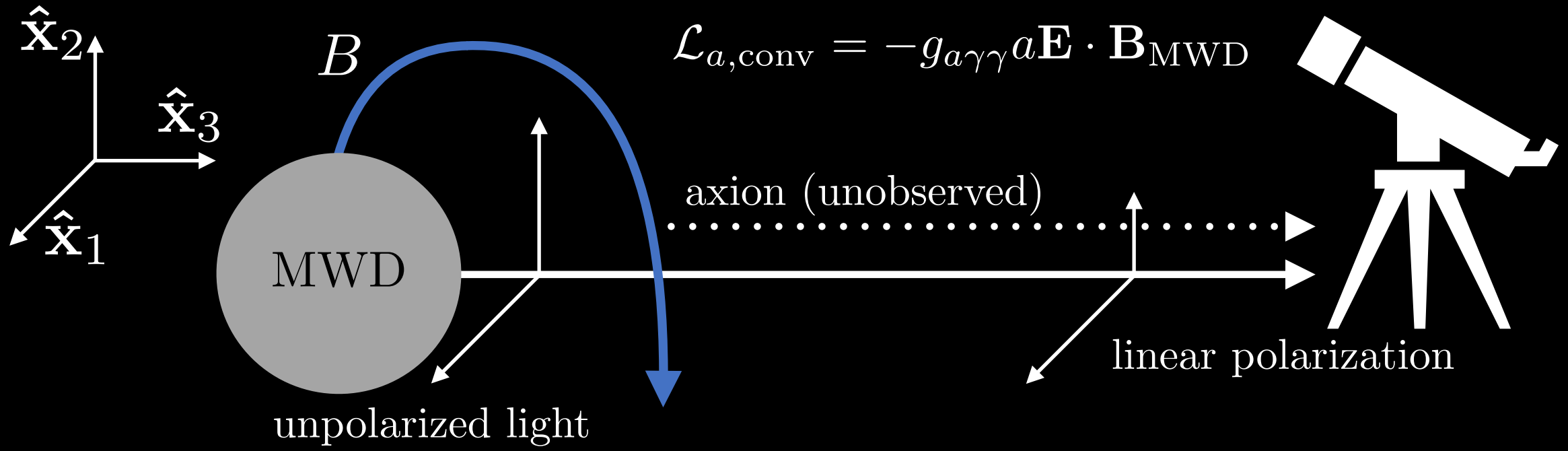
Polarization of MWDs



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

Euler-Heisenberg Mixing

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

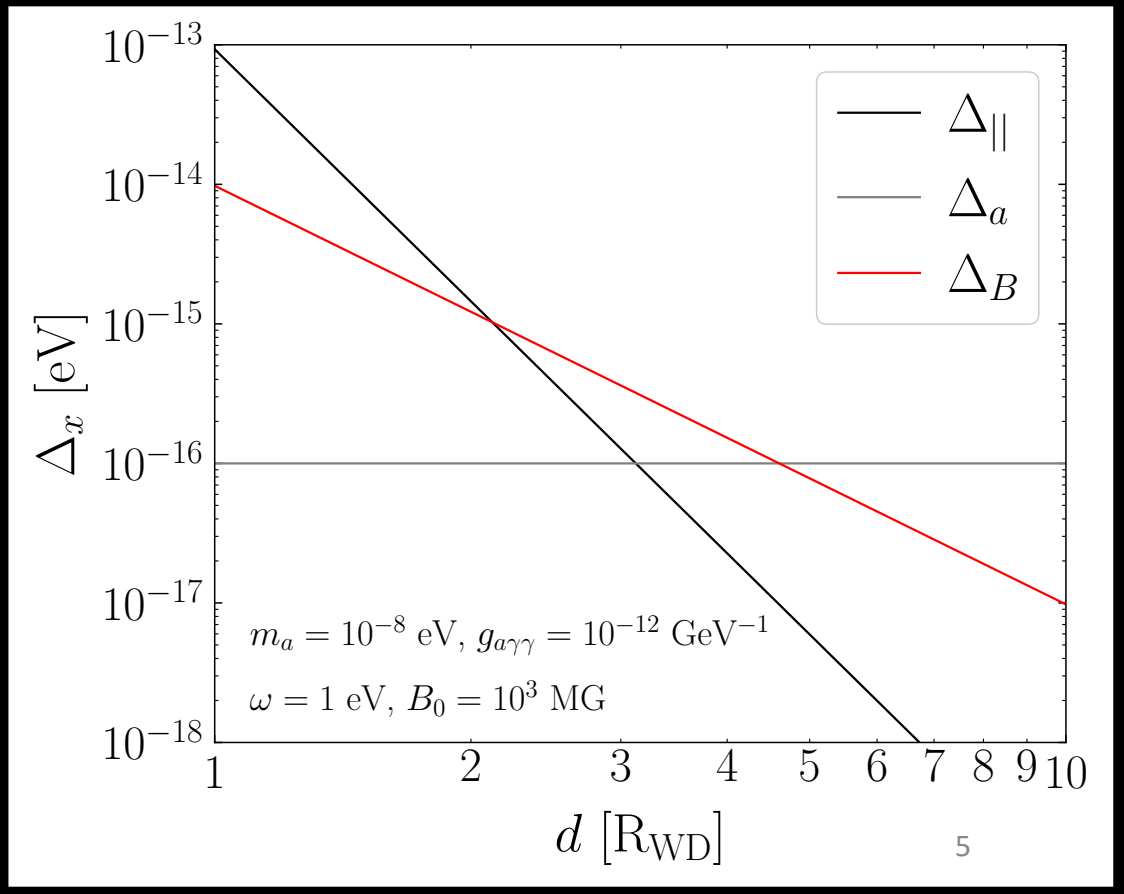
- Axion-photon EOM:

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

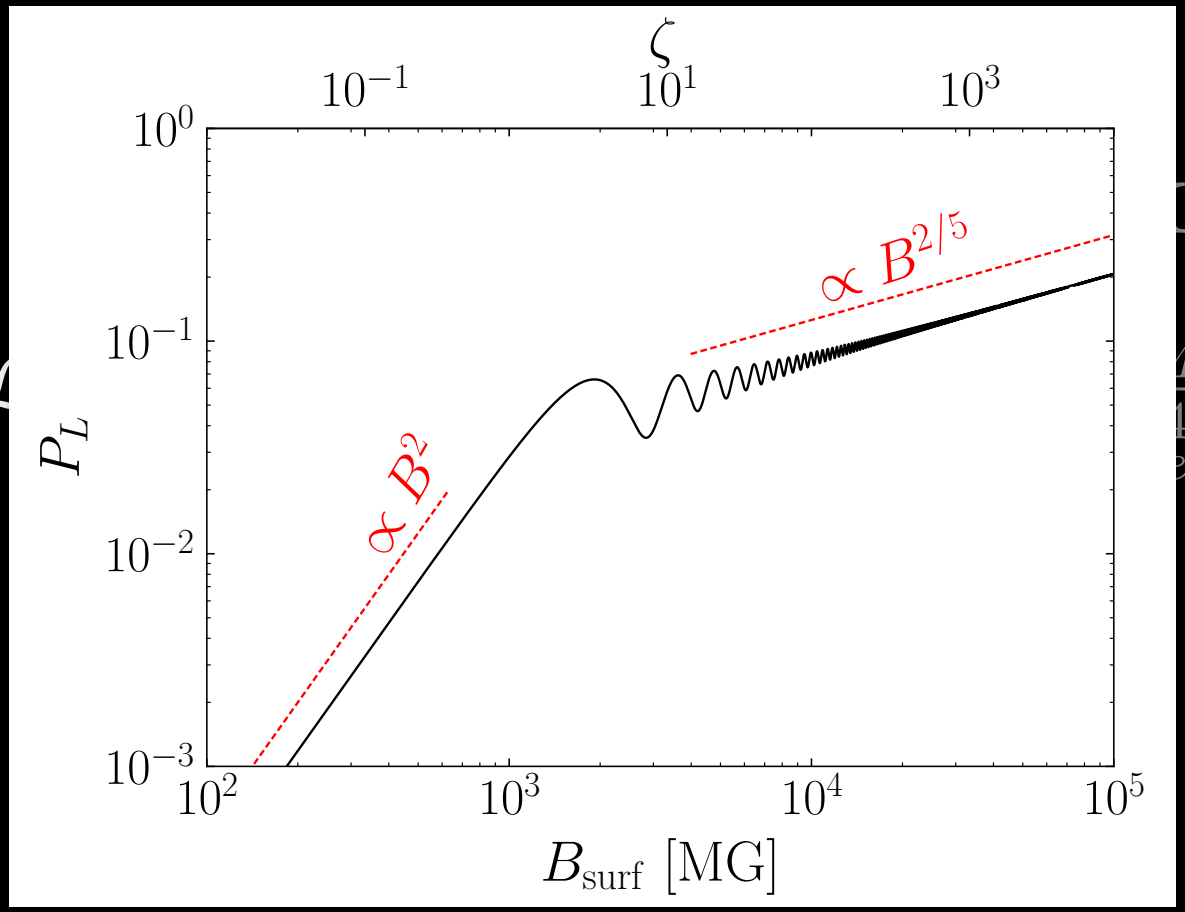
$$\Delta_\parallel \propto \omega\left(\frac{B}{B_{\mathrm{crit}}}\right)^2$$

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

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



*The low-field approximation is valid for MWDs, but not for NSs



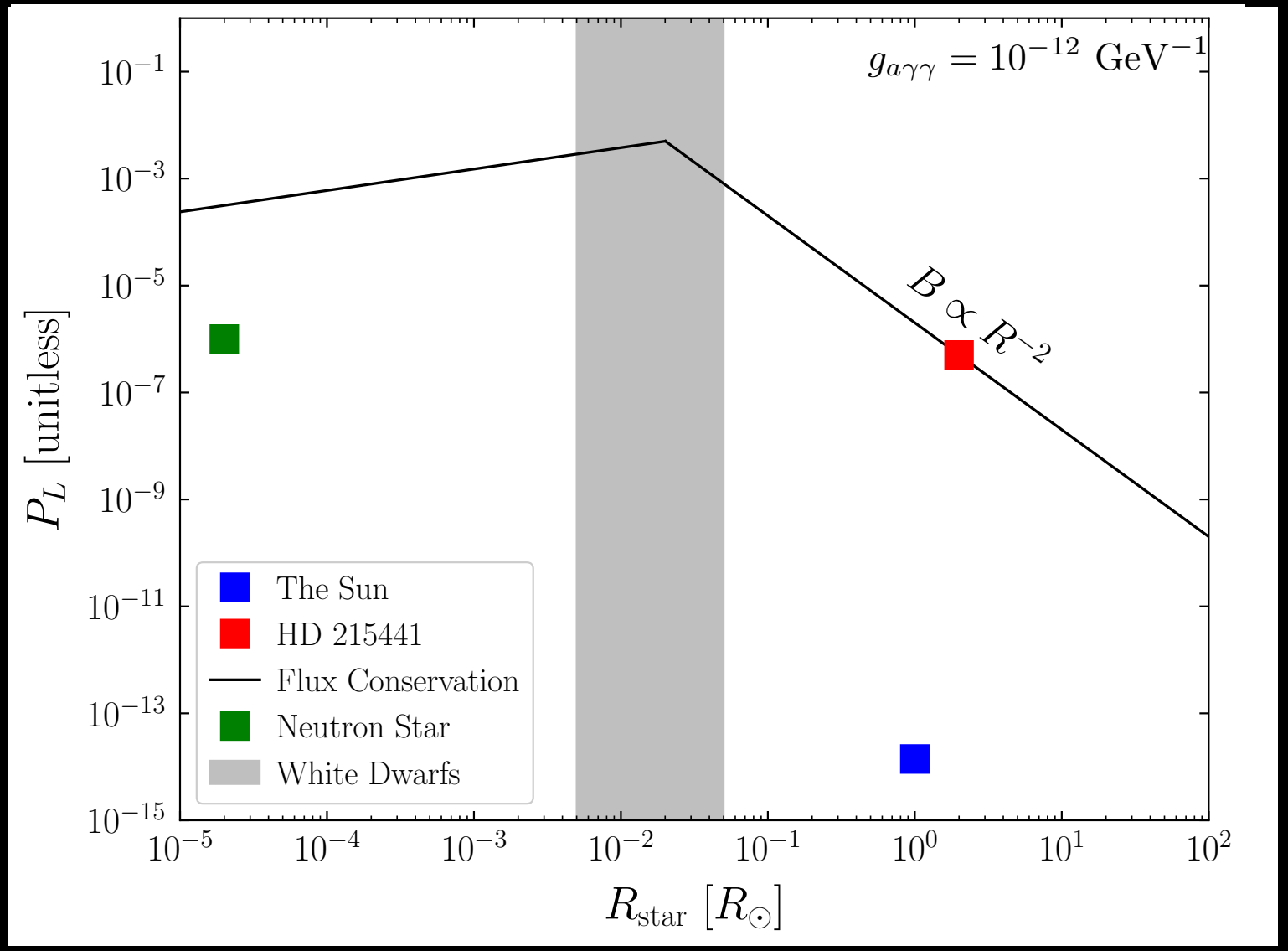
ing

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

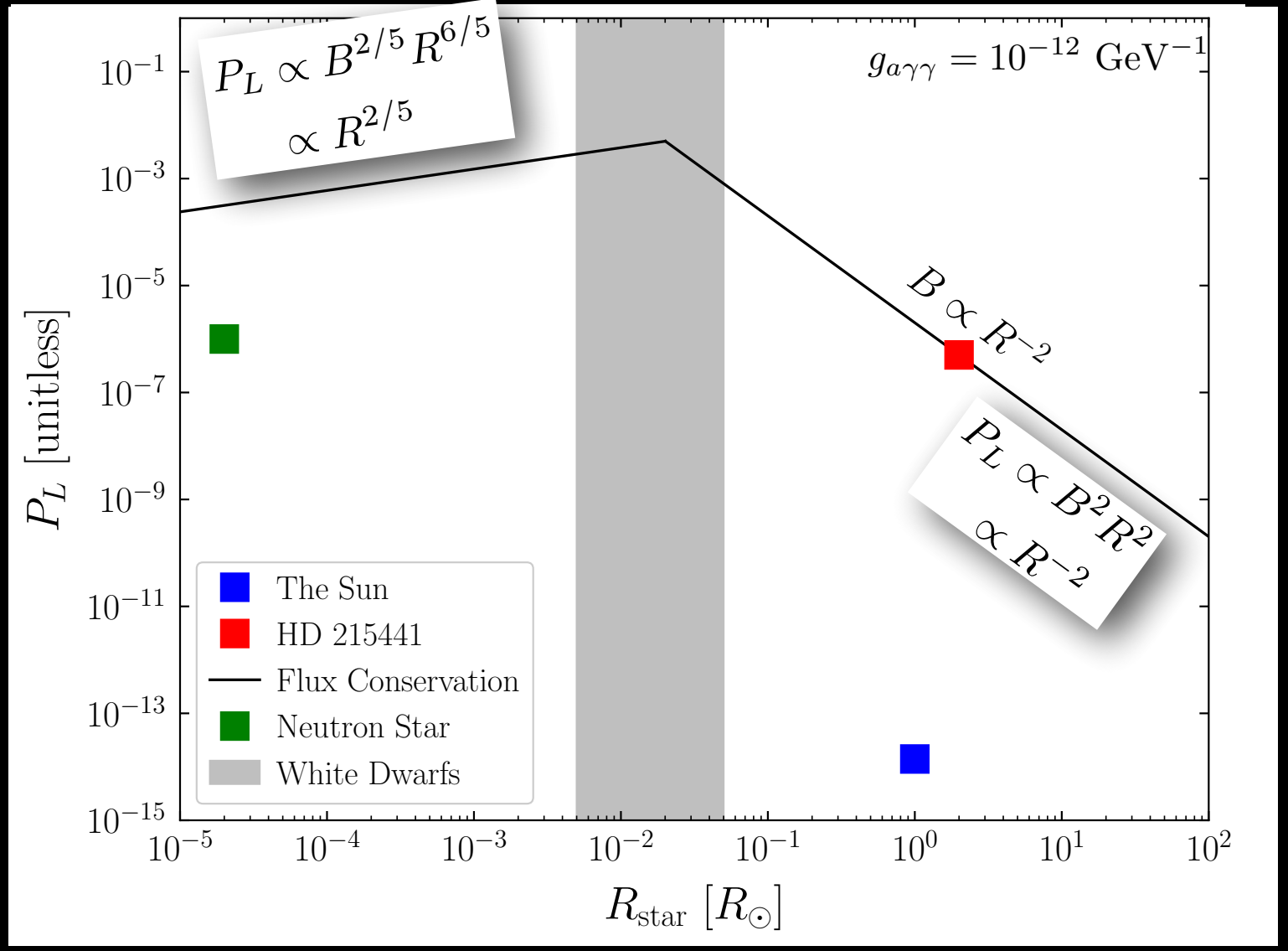
$$\zeta \approx 10^{-2} \left(\frac{R_{\rm star}}{0.01\, R_\odot} \right) \left(\frac{\omega}{1\,{\rm eV}} \right) \left(\frac{B_0}{100\,{\rm MG}} \right)^2$$

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

Axion-Induced Polarization



Axion-Induced Polarization



Astrophysical MWD Polarization

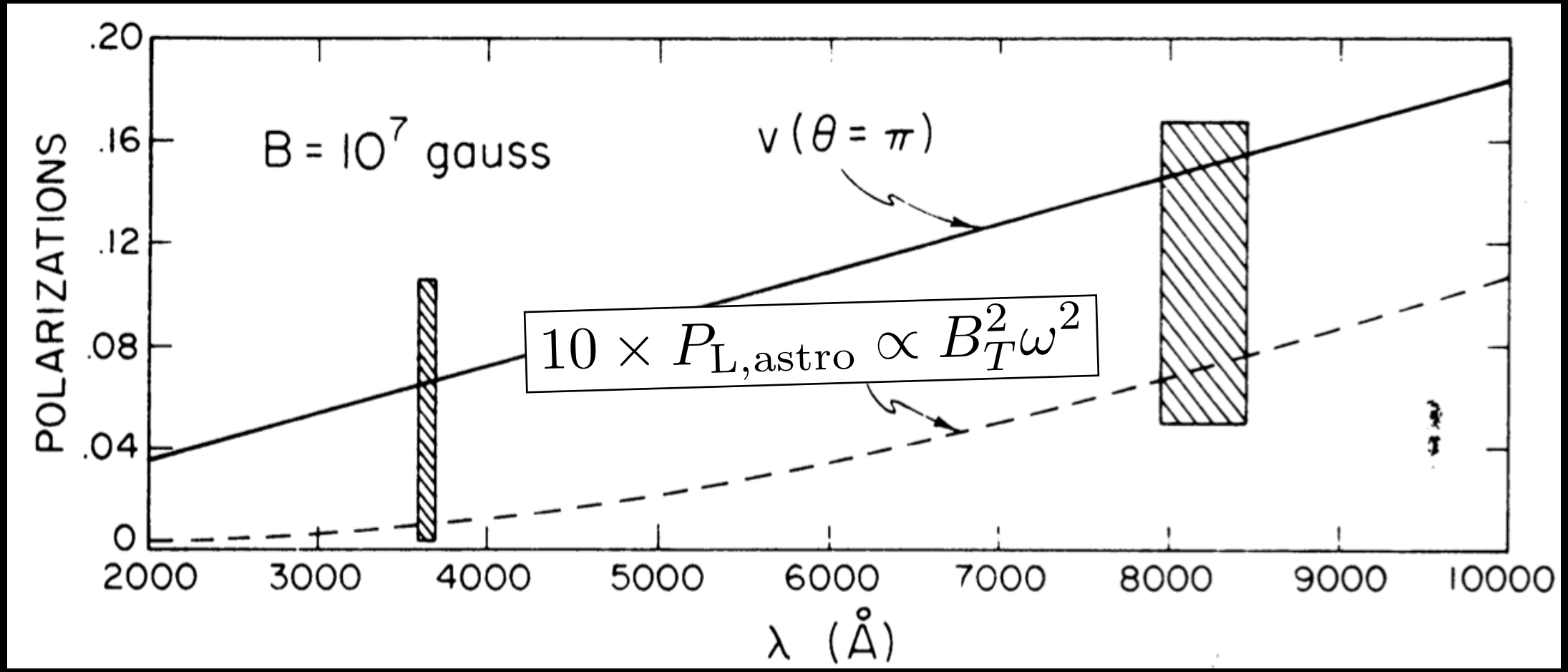
- Photons propagate unpolarized from deep in MWD atmosphere
- Astrophysical polarization created by bound-free absorption in the hydrogen atmosphere

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

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

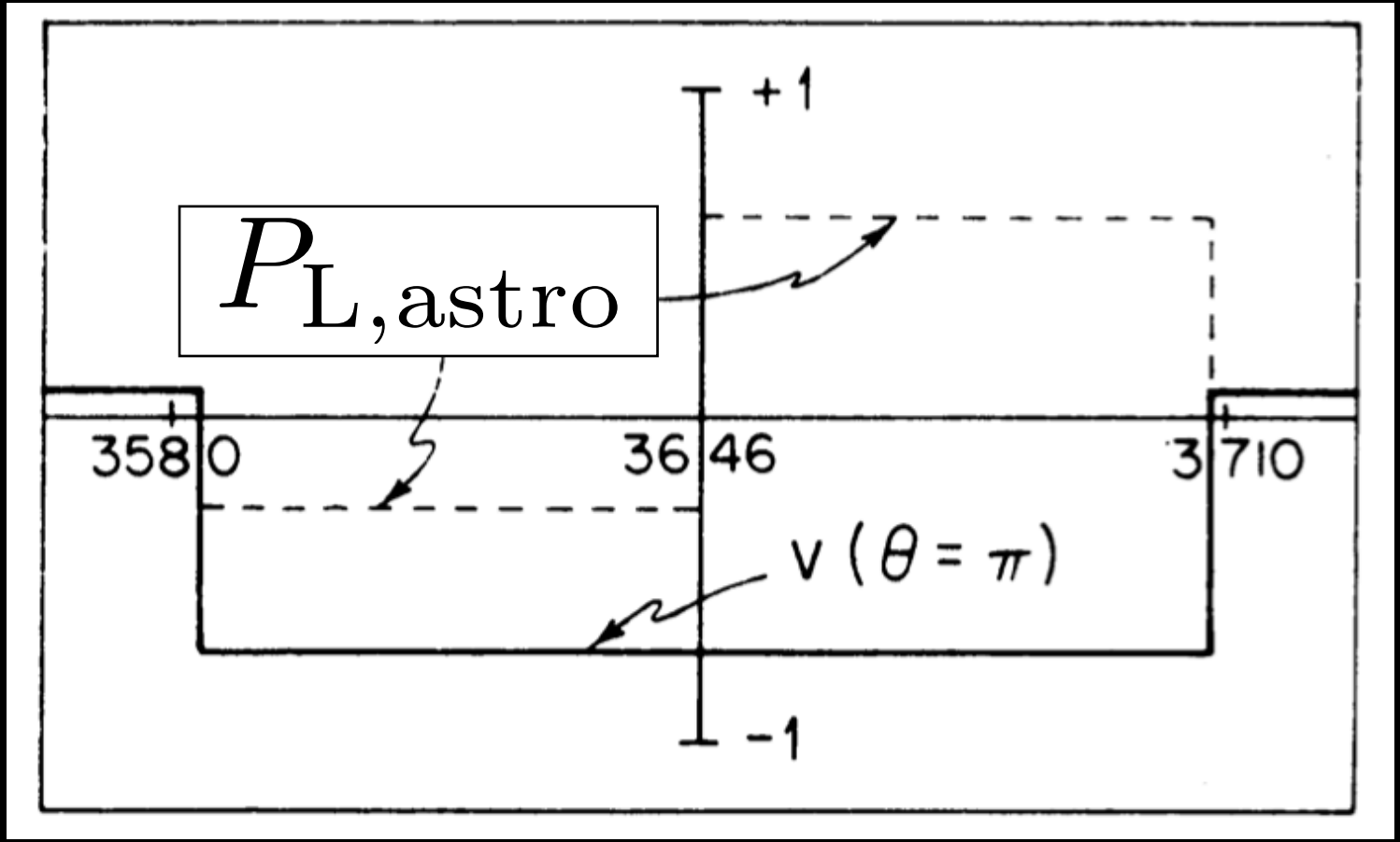
Lamb et al. 1974

Astrophysical MWD Polarization



Lamb et al. 1974

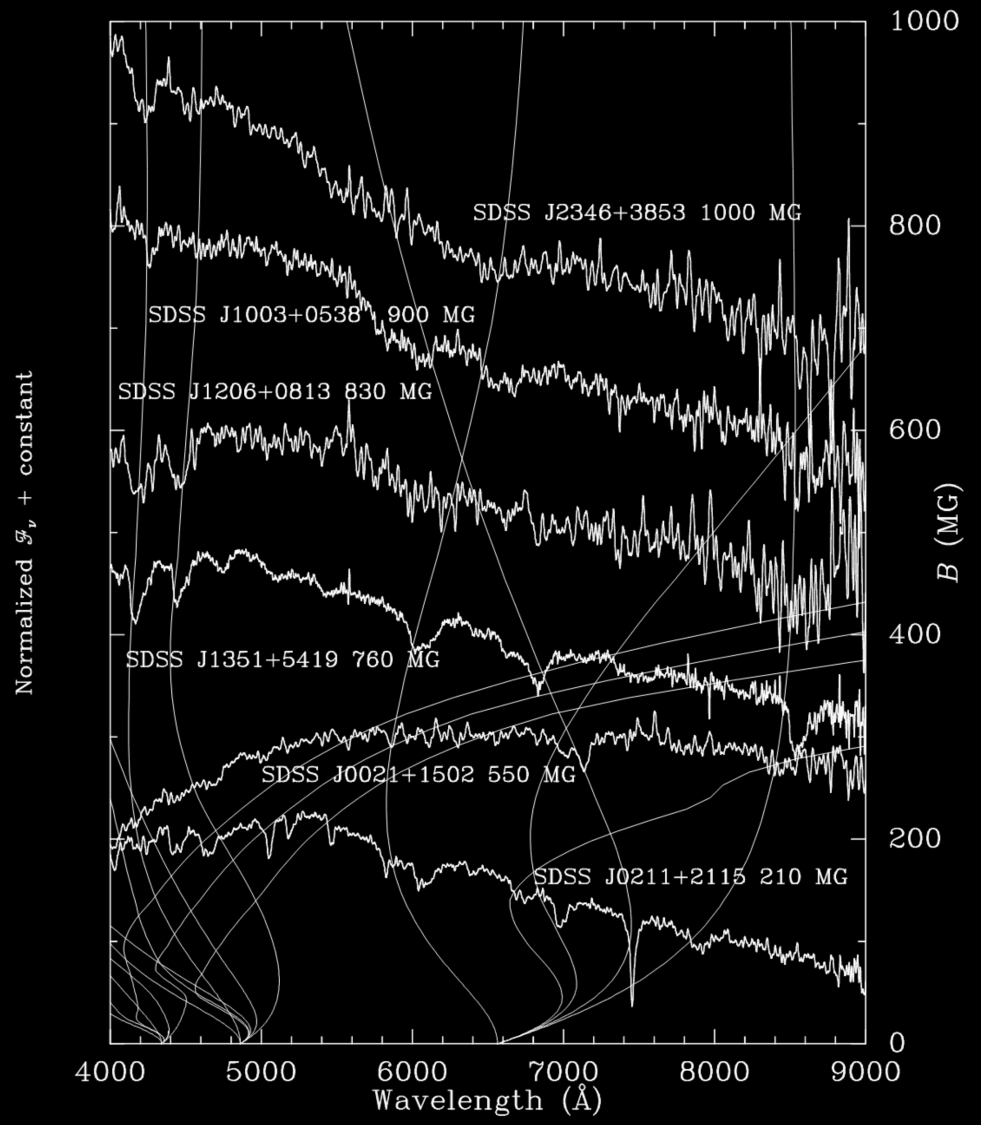
Astrophysical MWD Polarization



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

Promising MWD Targets

RE J0317 − 853 ($B = 200 - 800$ MG)

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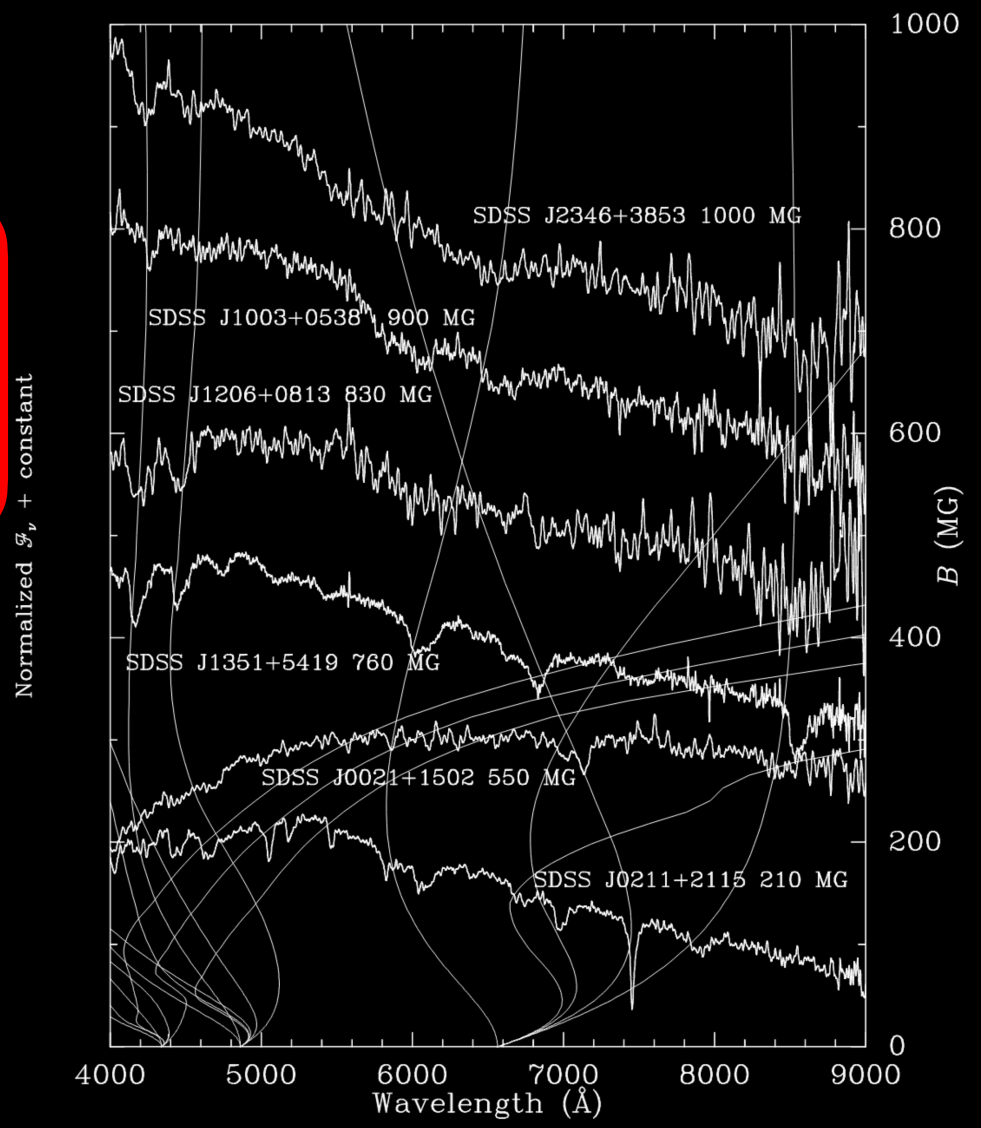

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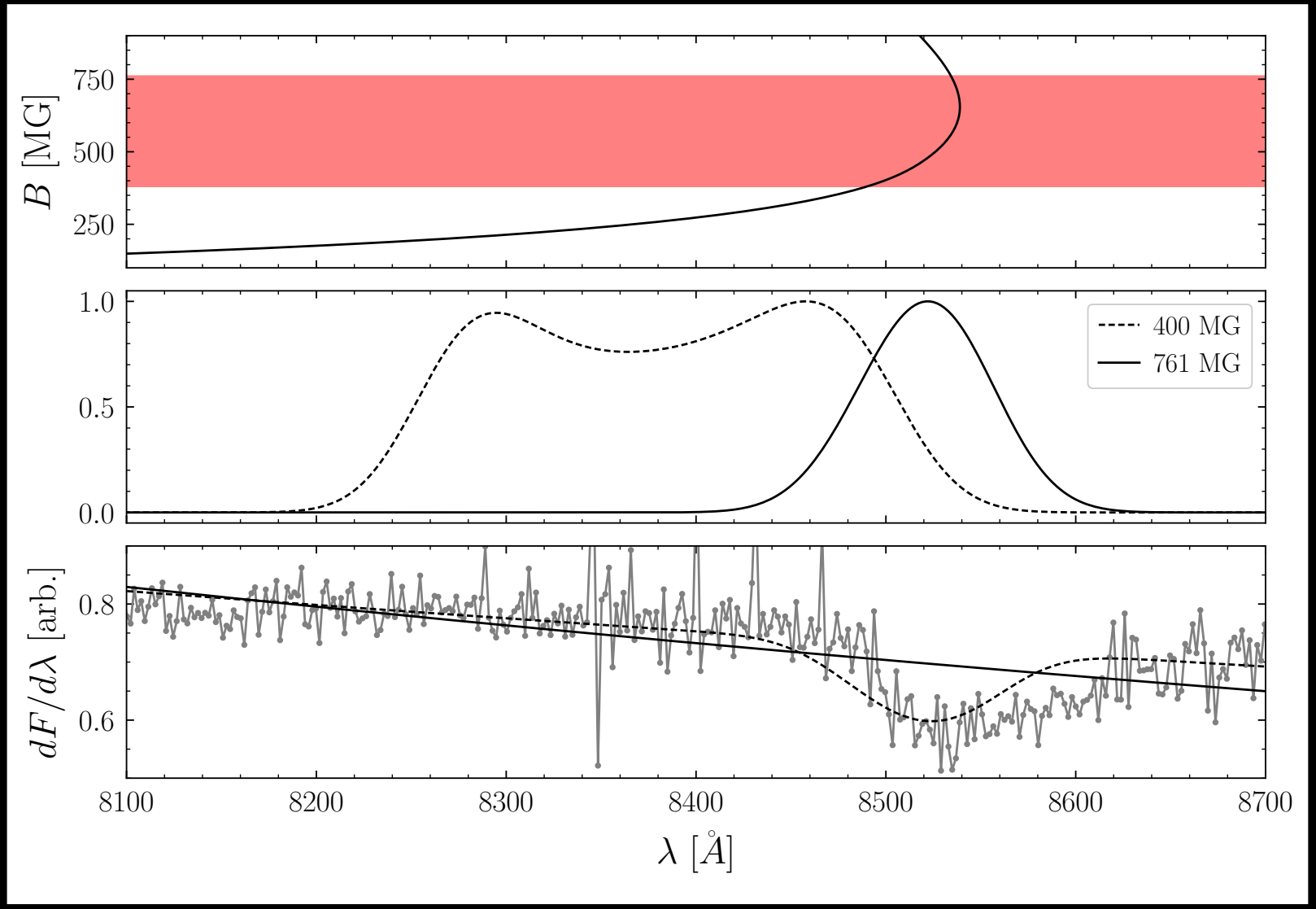
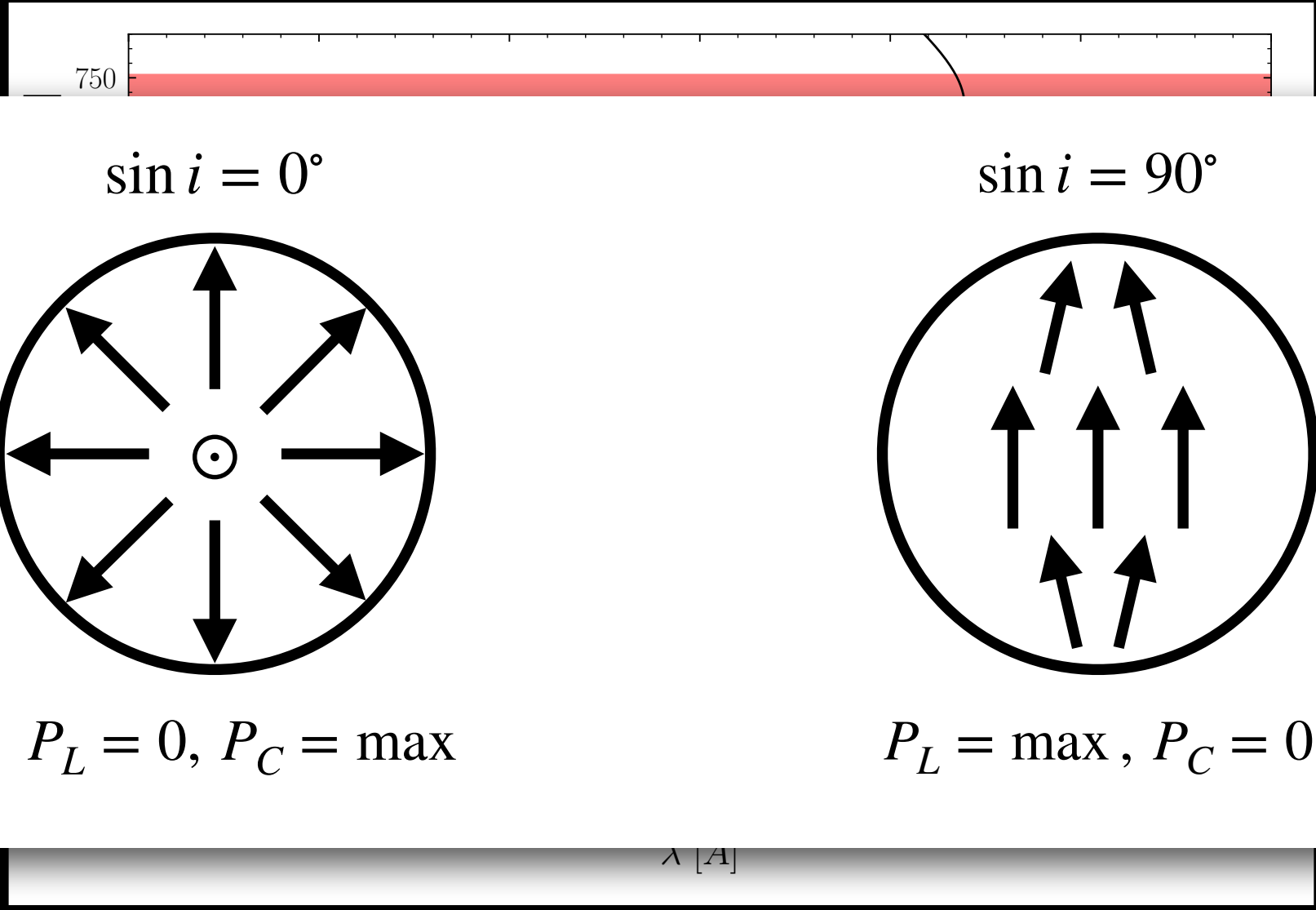
Magnetic Field Measurements



Magnetic Field Measurements



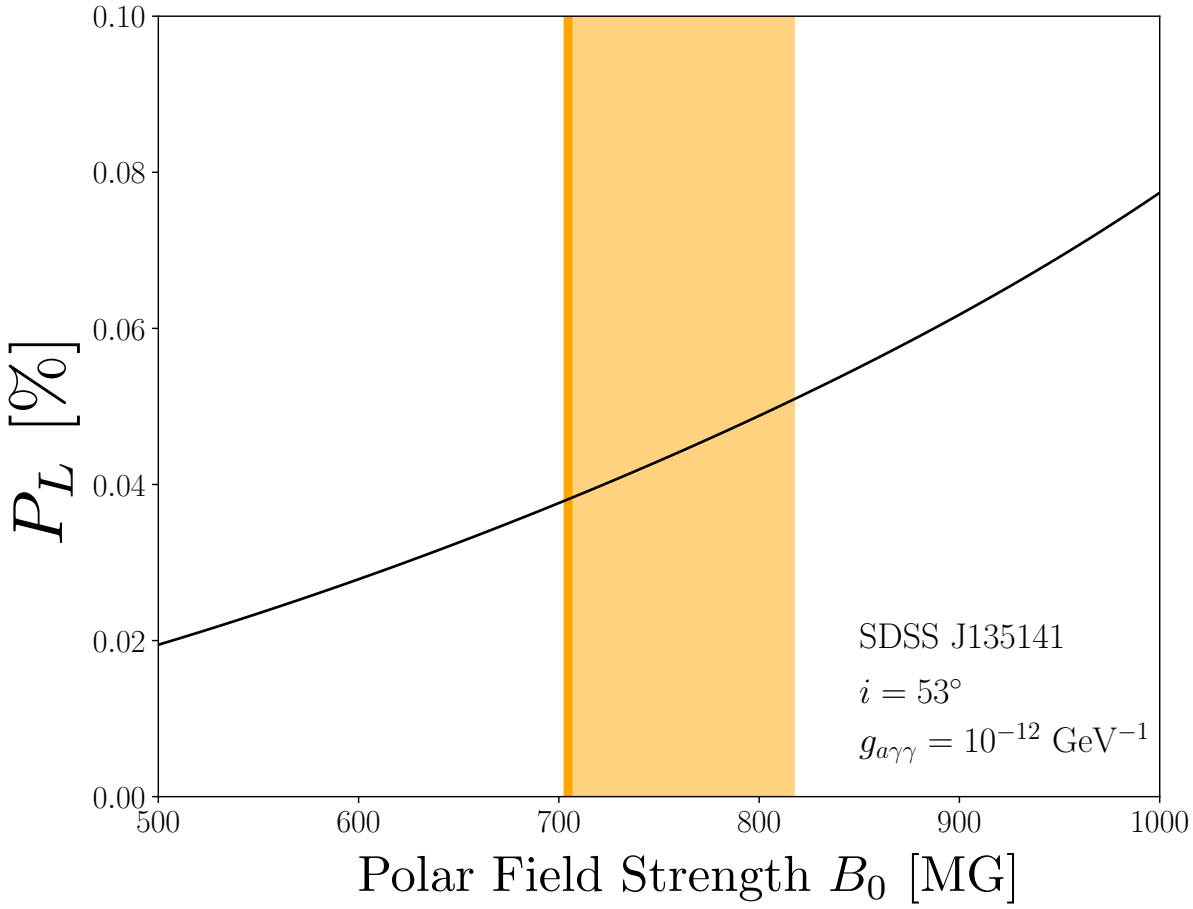
$\sin i = 0°$

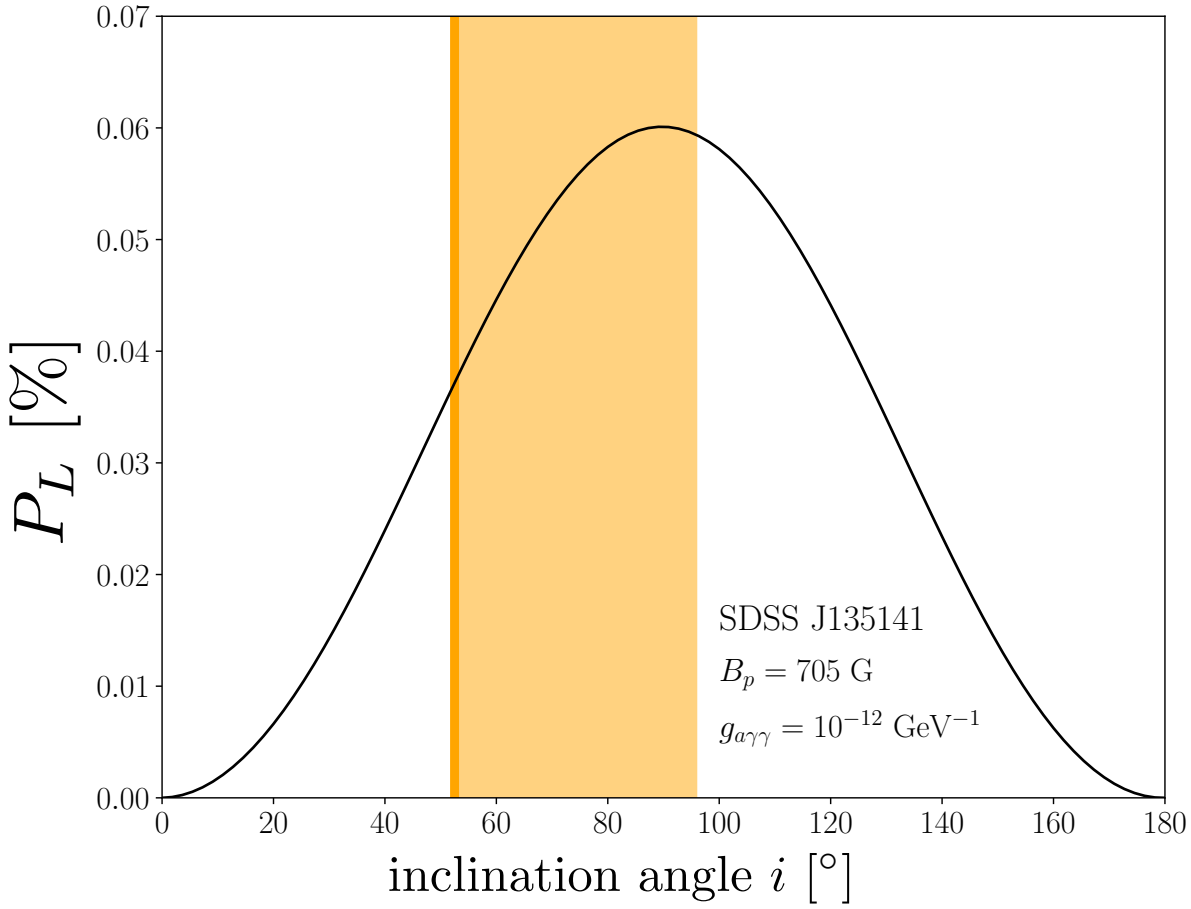
$P_L = 0,\ P_C = \max$

$\sin i = 90°$

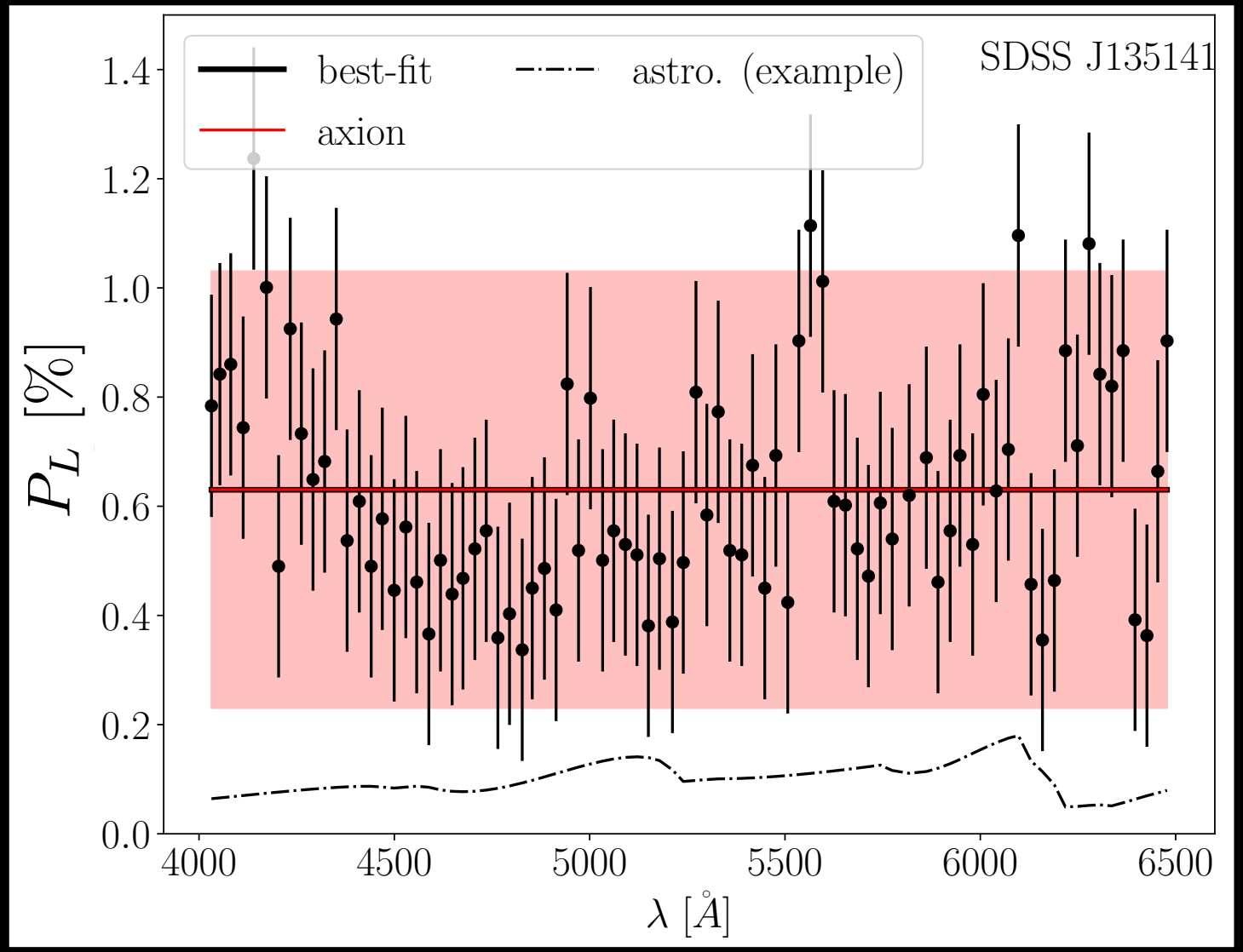
$P_L = \max,\ P_C = 0$

SDSS J1351+5419

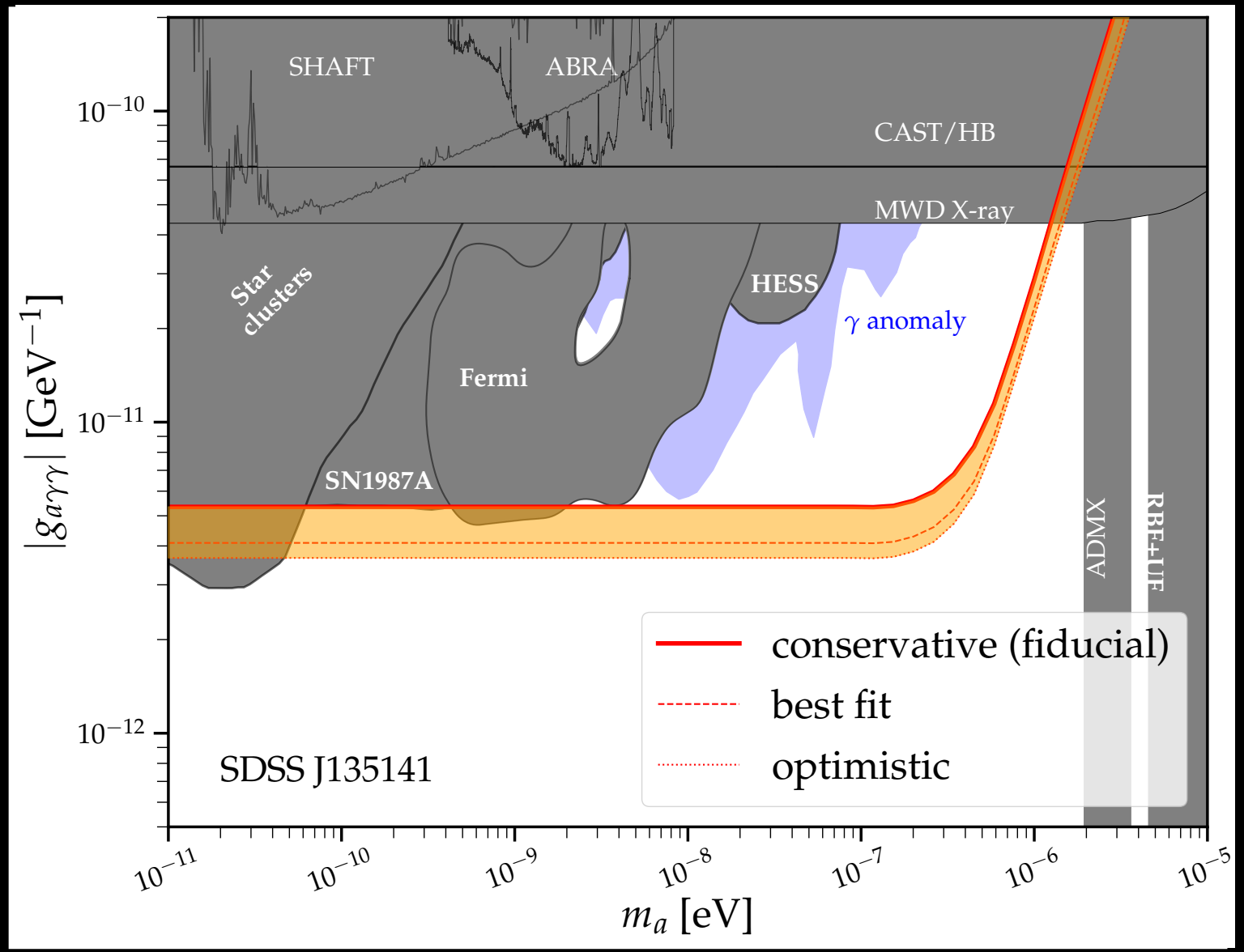




SDSS J1351


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

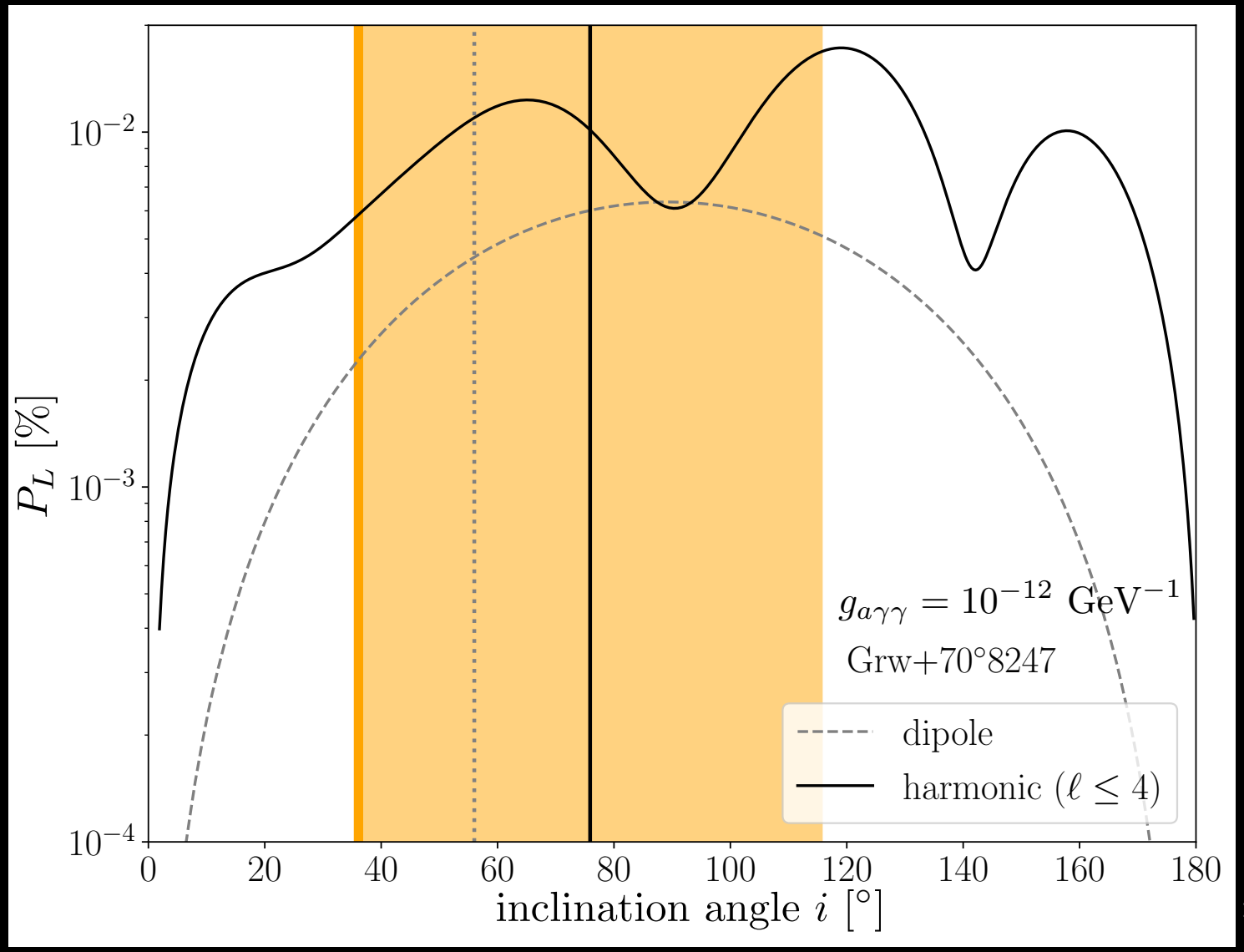
SDSS J1351


SHAFT
ABRA
CAST/HB
MWD X-ray
Star clusters
HESS
γ anomaly
Fermi
SN1987A
ADMX
RBF+UF
conservative (fiducial)
best fit
optimistic
SDSS J135141
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]

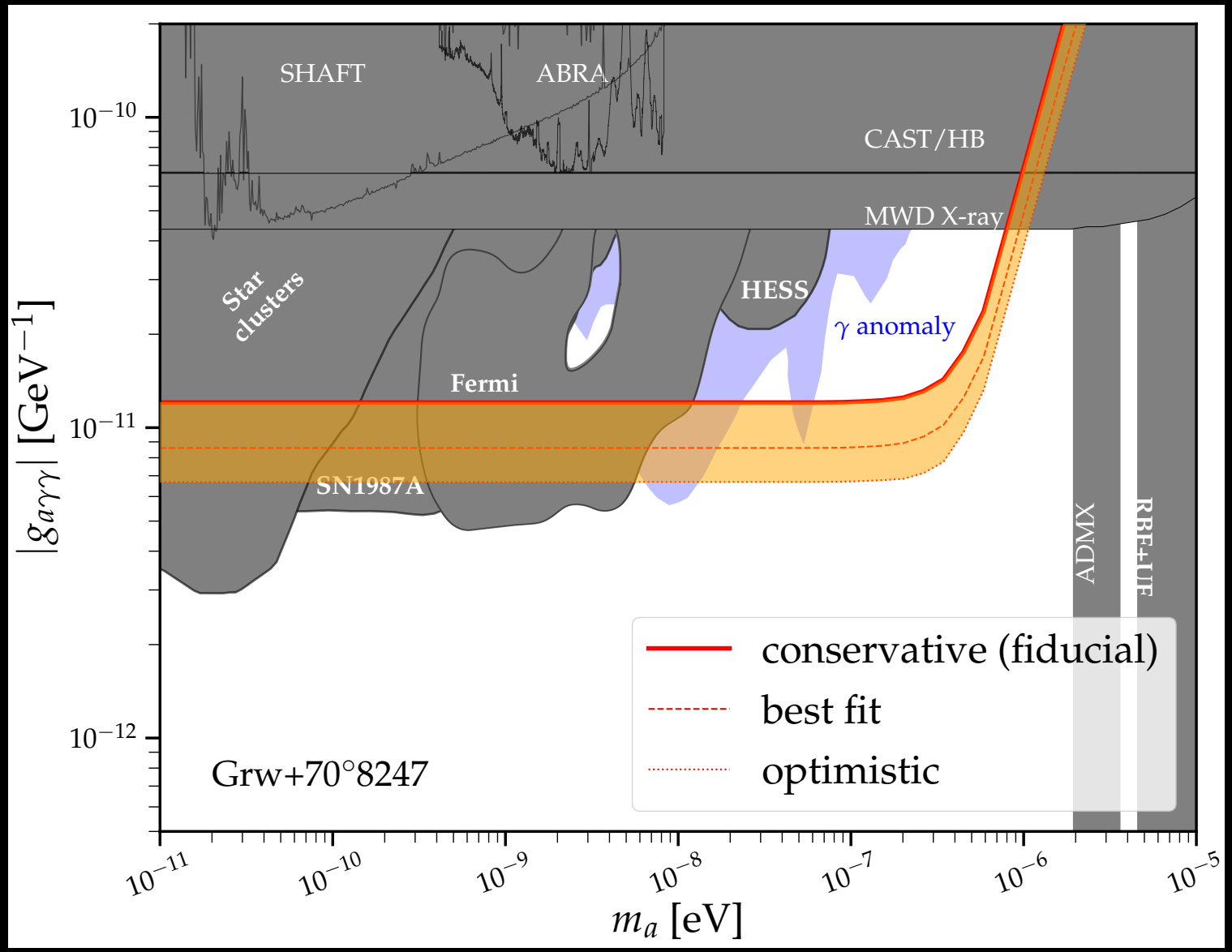
GRW+70°8247 Modeling

1904.08327:

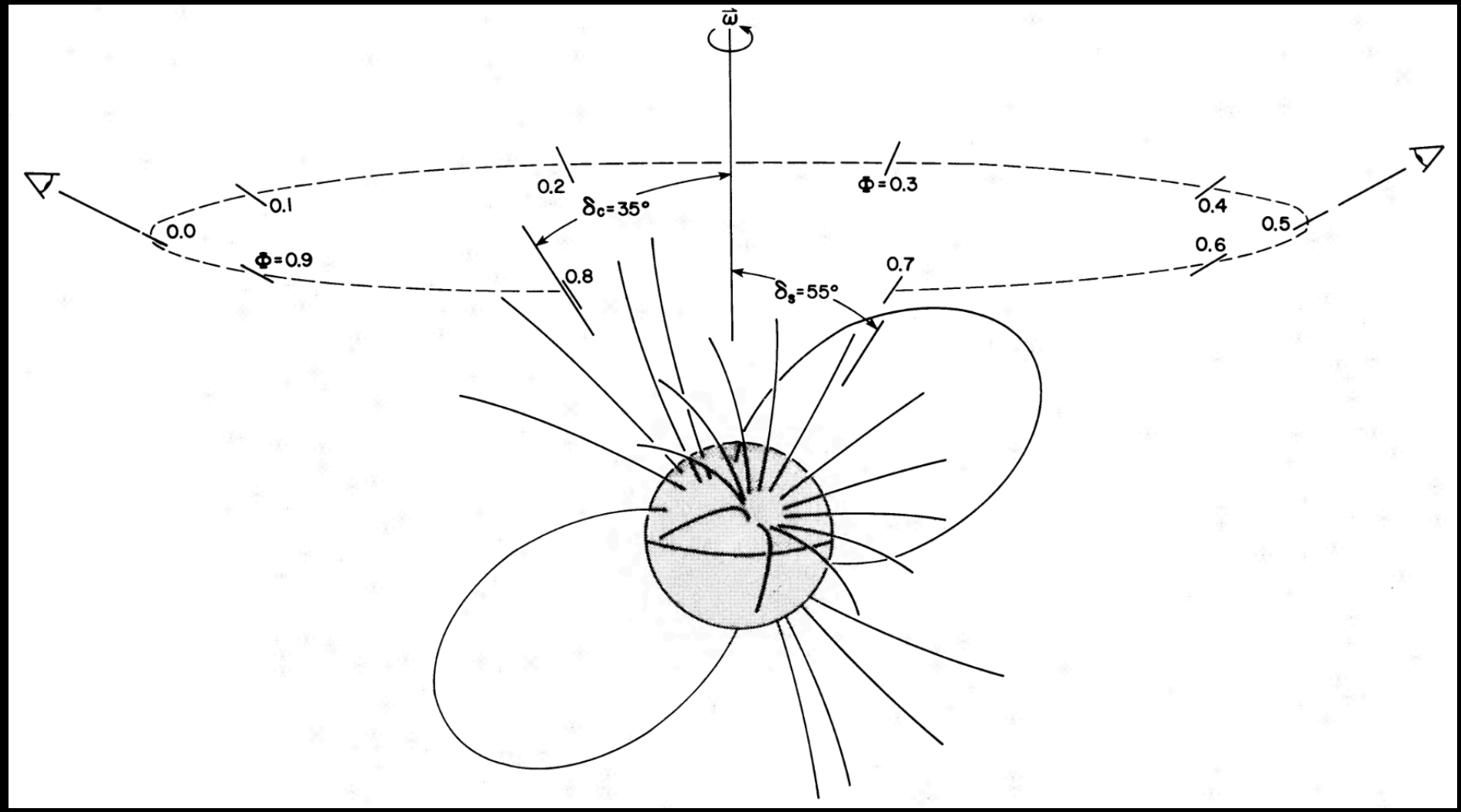
$$P_L^{95\%} = 0.73\%$$



GRW+70°8247 Constraints

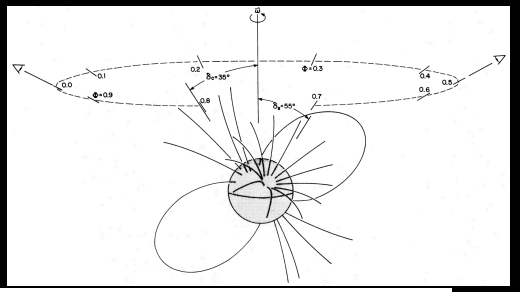


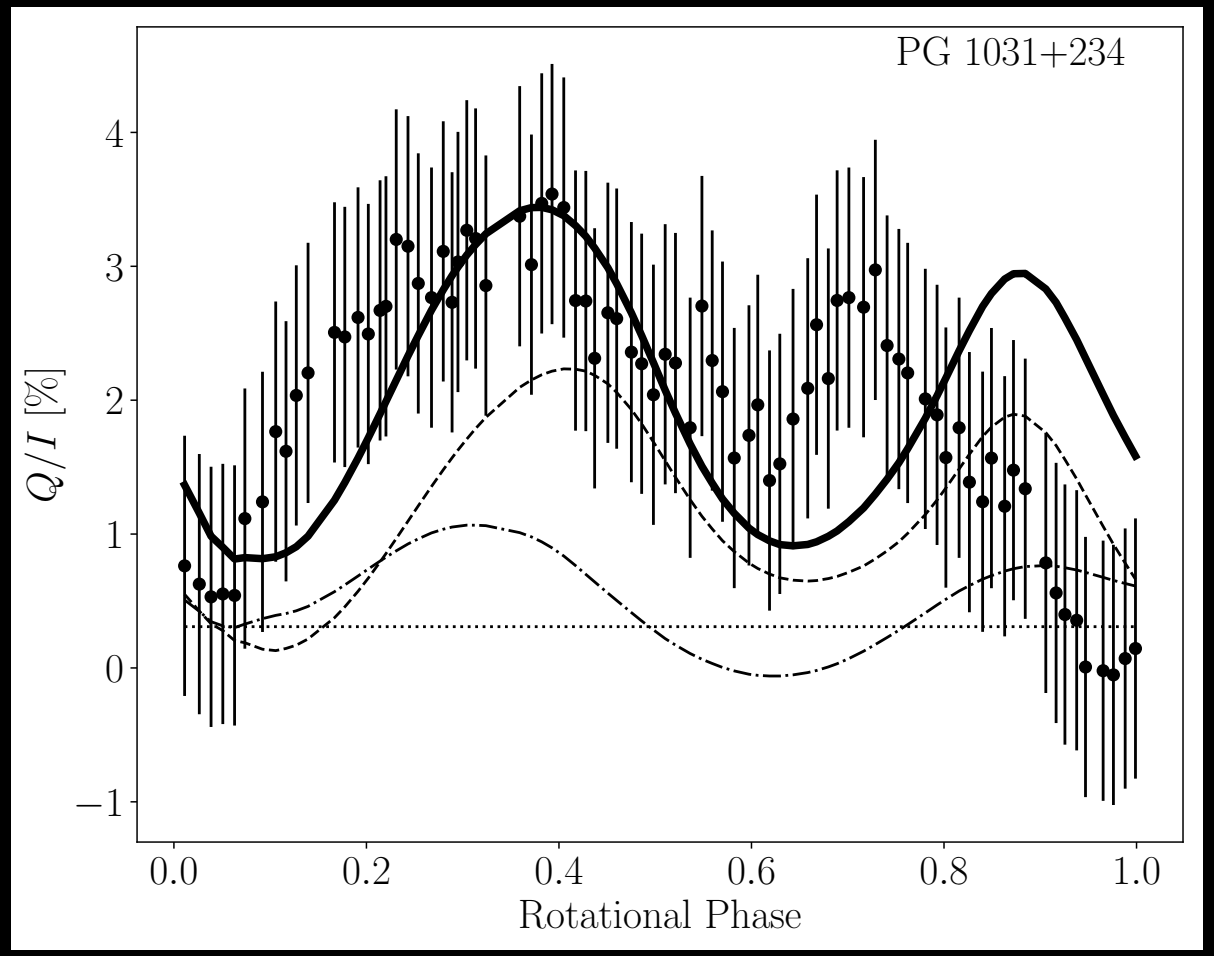
PG 1031+234 Field Geometry

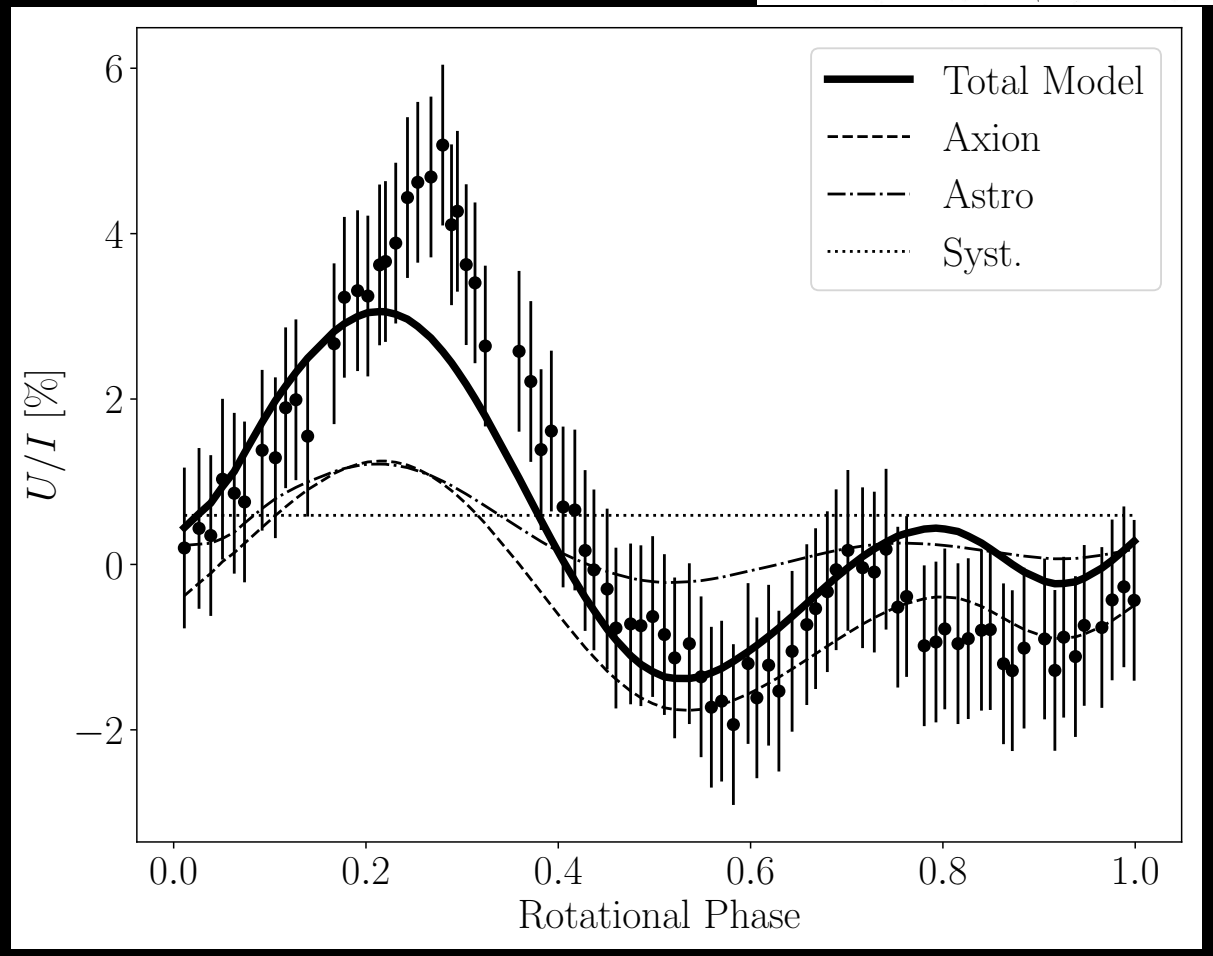


Schmidt et al. ApJ, 309:218-229,1986

PG 1031+234 Analysis







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

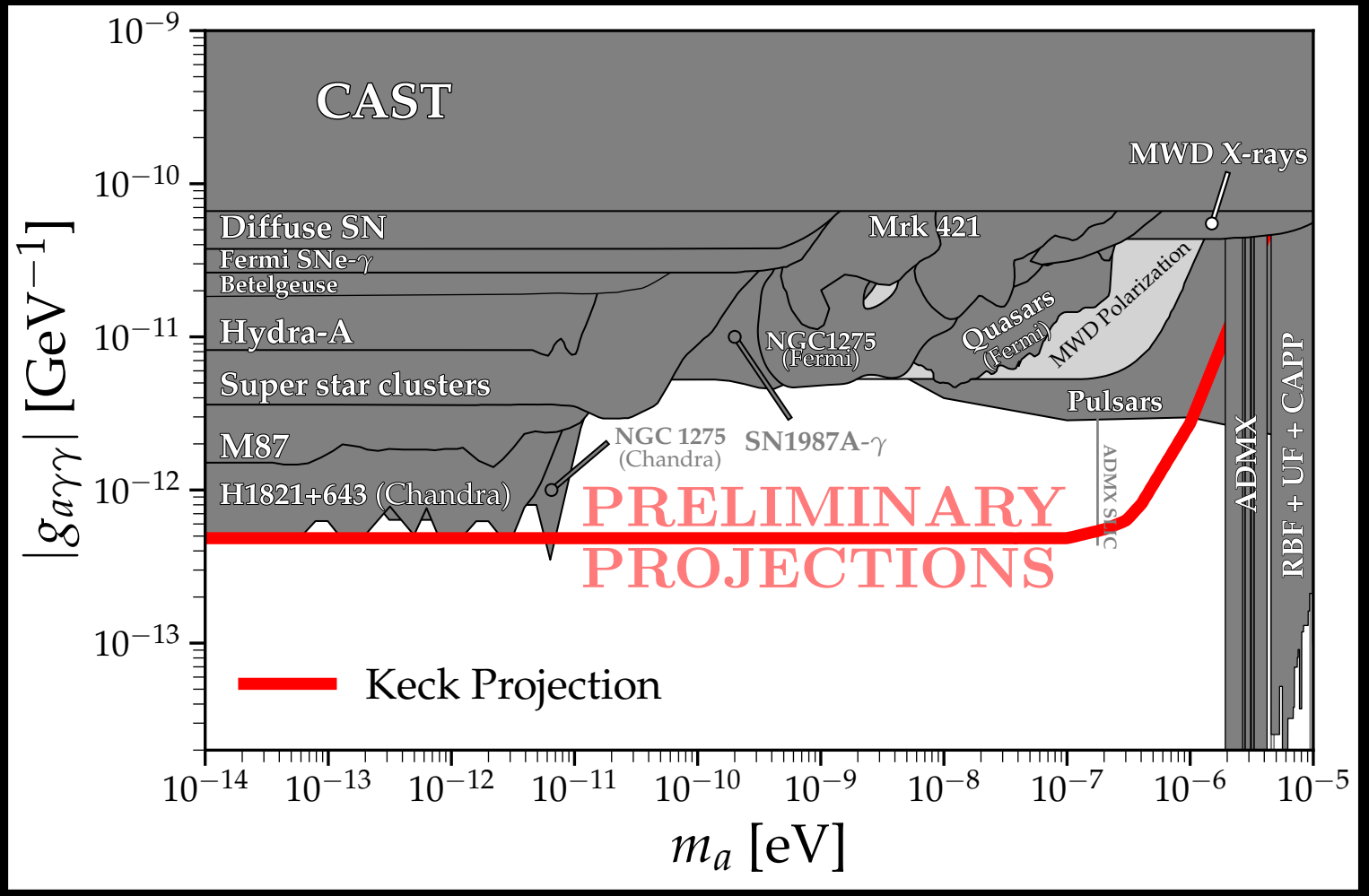
Schmidt et al. ApJ, 309:218-229,1986

Ongoing/Future Work

- Simple analyses on archival datasets motivate dedicated observations
- 3 MWDs with Lick Observatory, 3 with Keck Observatory
- 5x smaller polarization uncertainty

Top photo: Max Alexander & STFC, Lick Observatory
Bottom photo: Getty Images / Julie Thurston Photography, Keck Observatory

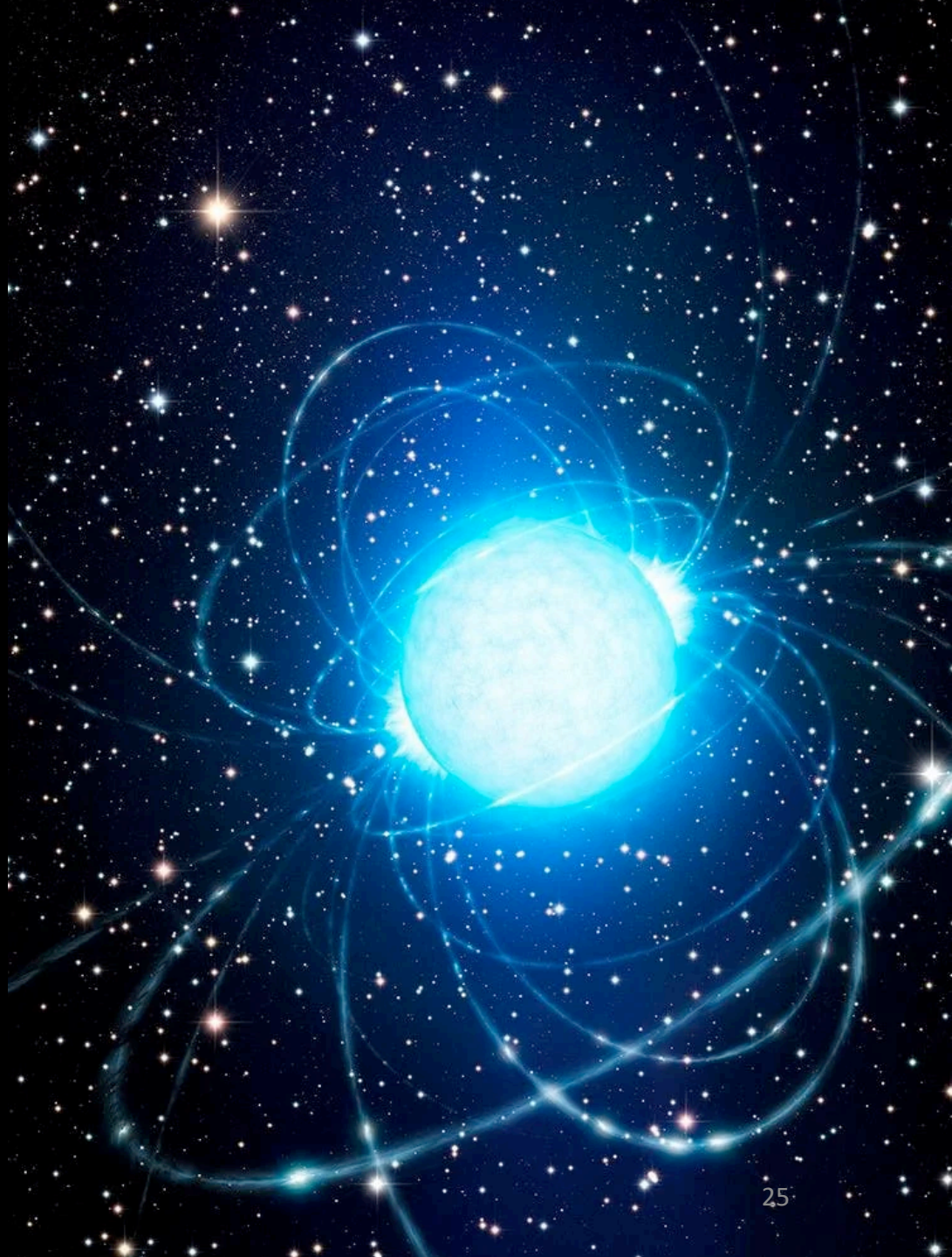
Ongoing Observations



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!