

# Spectral Distortions of Astrophysical Blackbodies as Axion Probes

Erwin Tanin

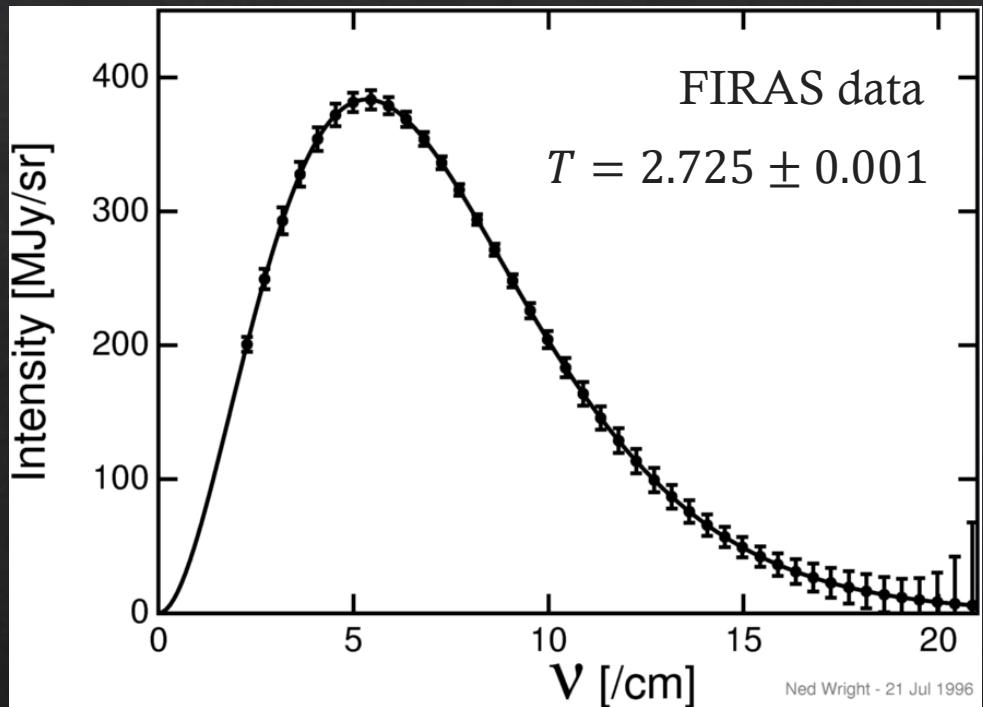
Johns Hopkins University

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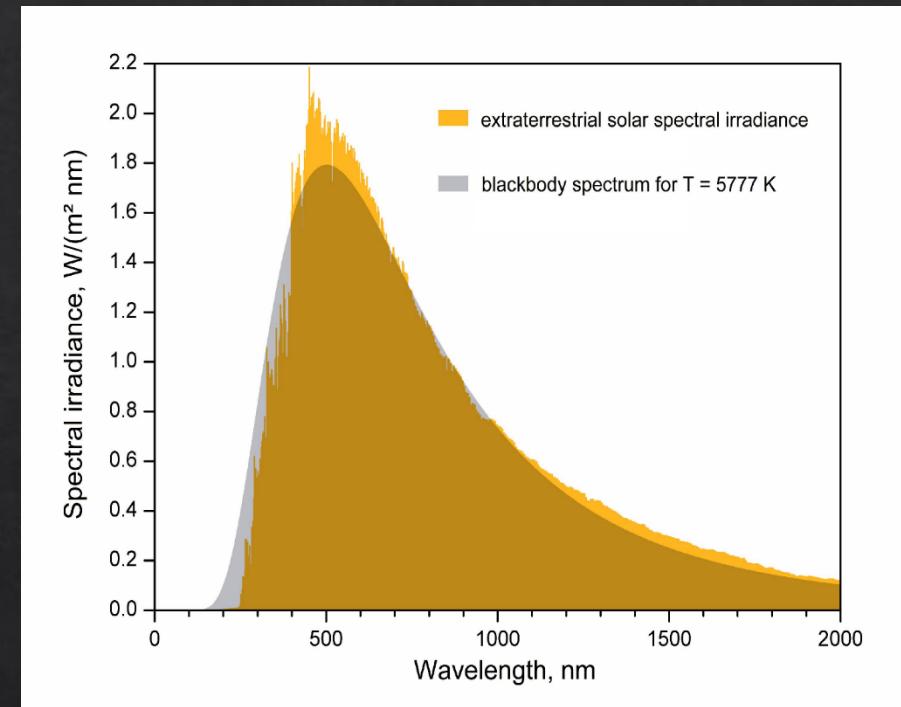
with Jae Hyeok Chang, Reza Ebadi, and Xuheng Luo

May, 2022

# CMB



# Sun



Perhaps the **best blackbody** in nature  
**Sensitive** to a wide array of BSM physics  
Is there an **astrophysical analog** of it?

Only **decoupled** photons escape  
**Cluttered** with various absorption features

Image from: Wright 1996, Smerlak 2011



best astrophysical blackbodies



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About 256,000 results (0.32 seconds)



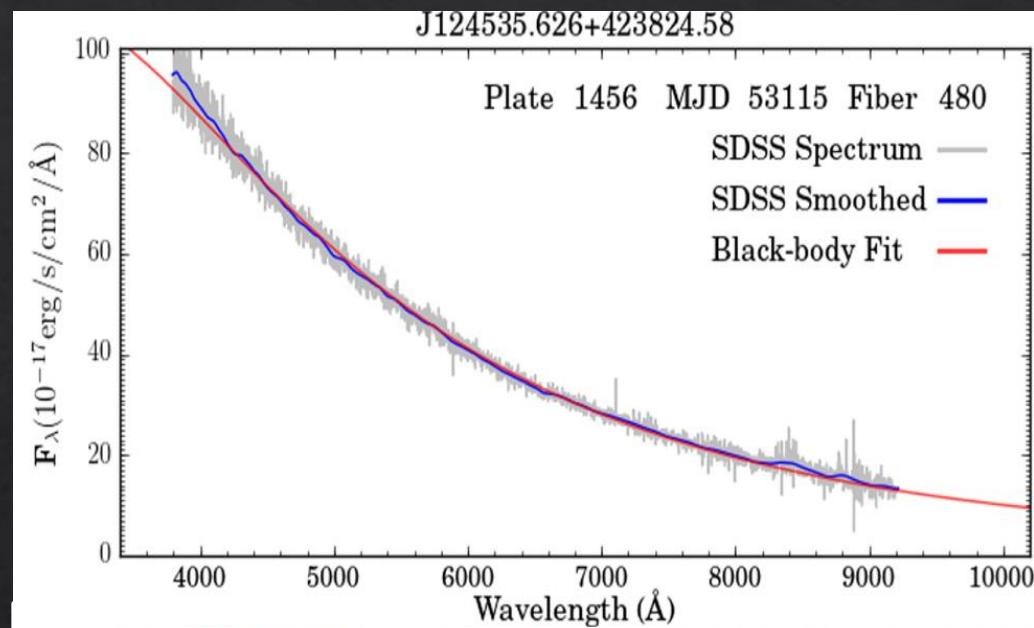
AAS Nova

<https://aasnova.org> › 2018/10/31 › perfect-blackbodie... ::

## Perfect Blackbodies in the Sky

Oct 31, 2018 – The 17 **blackbody** stars pose an intriguing puzzle: what are these oddly ideal bodies? Suzuki and Fukugita argue that the stars' properties are ...

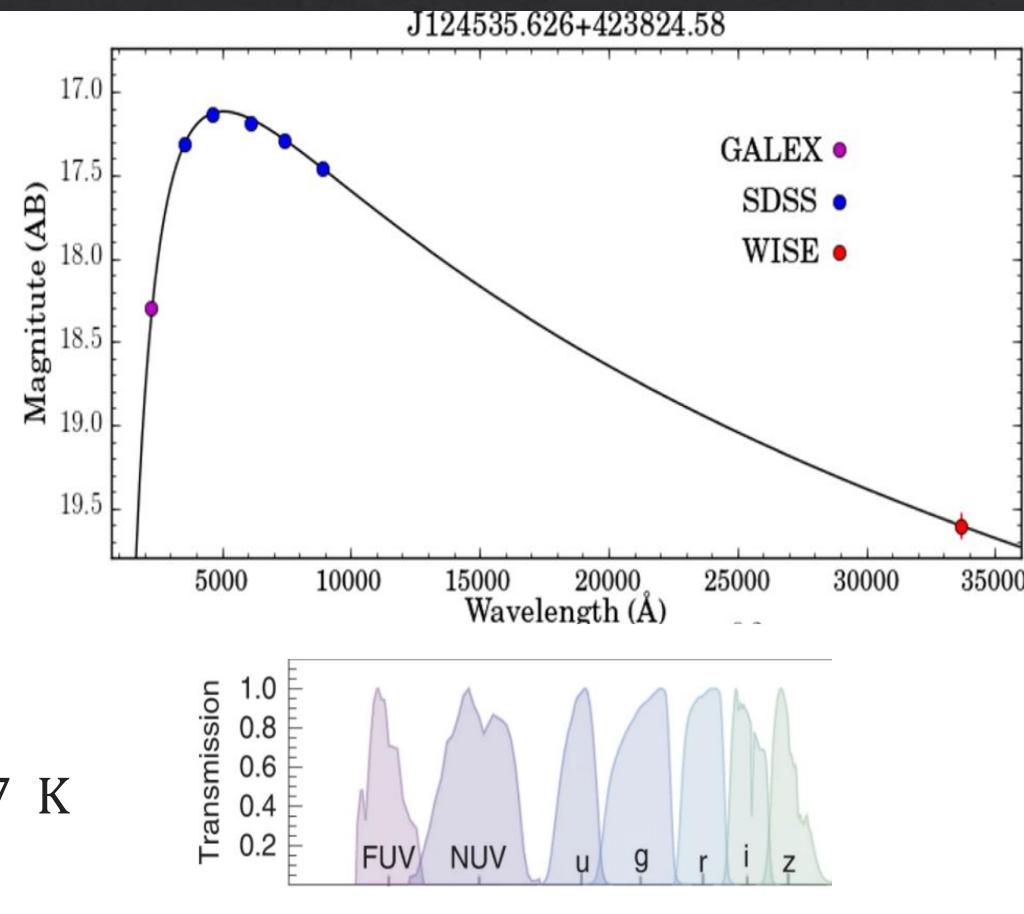
## Spectrometry



Flux per unit wavelength

$$F_\lambda = a \frac{4\pi}{\lambda^5} \frac{1}{e^{2\pi/\lambda T} - 1} \quad T = 10086 \pm 67 \text{ K}$$

## Photometry (broadband)



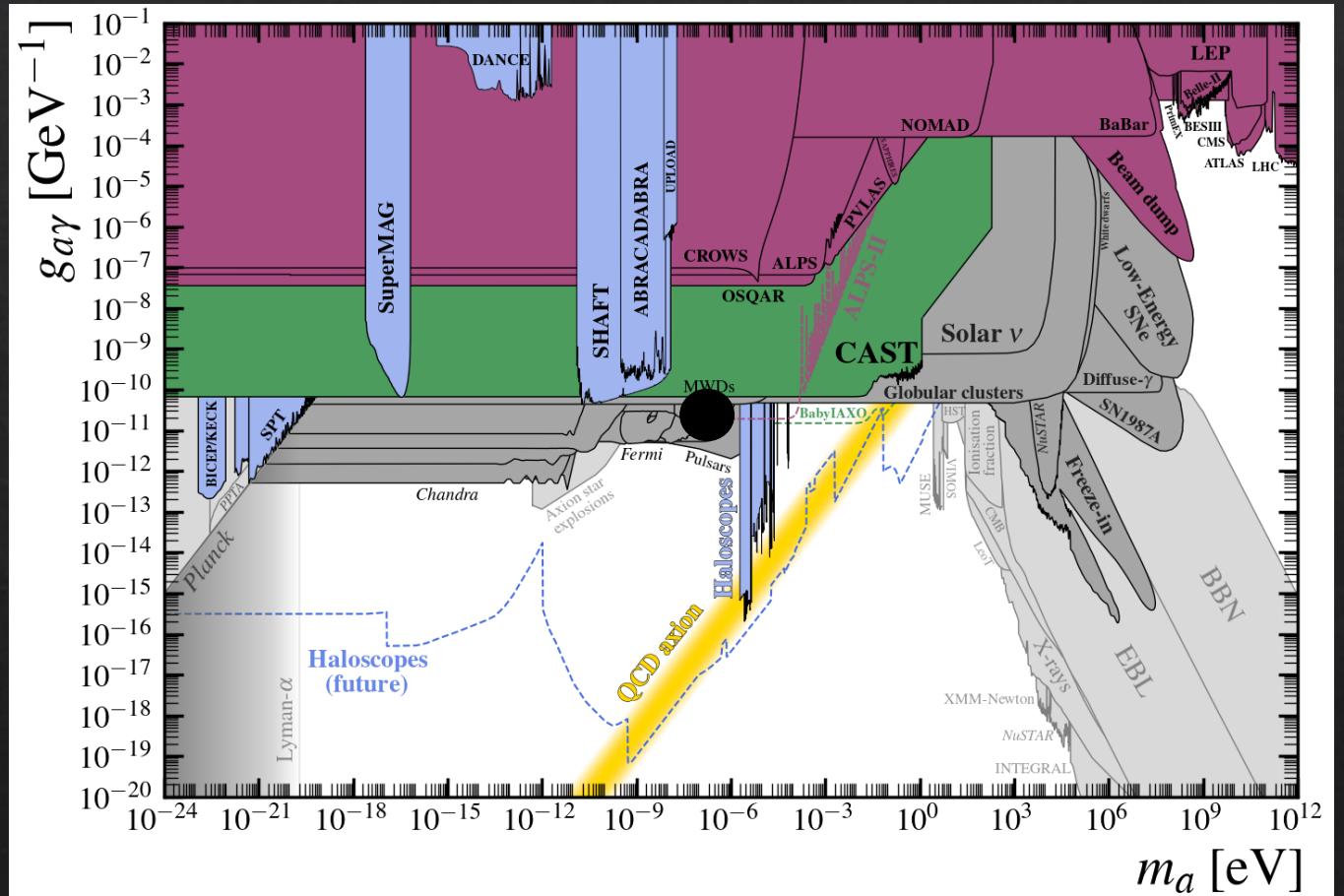
# Blackbody Stars

- ❖ 17 stars in the Sloan Digital Sky Survey (**SDSS**) catalog
- ❖ Located **70-200 pc** away (from Gaia parallaxes)
- ❖ **White dwarfs** of DC type (no visible spectral lines)
  - ❖ Earth size, solar mass, high surface gravity ( $\sim 10^6 \text{ m/s}^2$ )
  - ❖ Atmosphere: 8000-11000 K, helium-rich

# Axionlike particles

$$\mathcal{L}_a \supset \frac{1}{2}(\partial a)^2 - \frac{1}{2}m_a^2 a^2 - \frac{g_{a\gamma\gamma}}{4} a F\tilde{F}$$

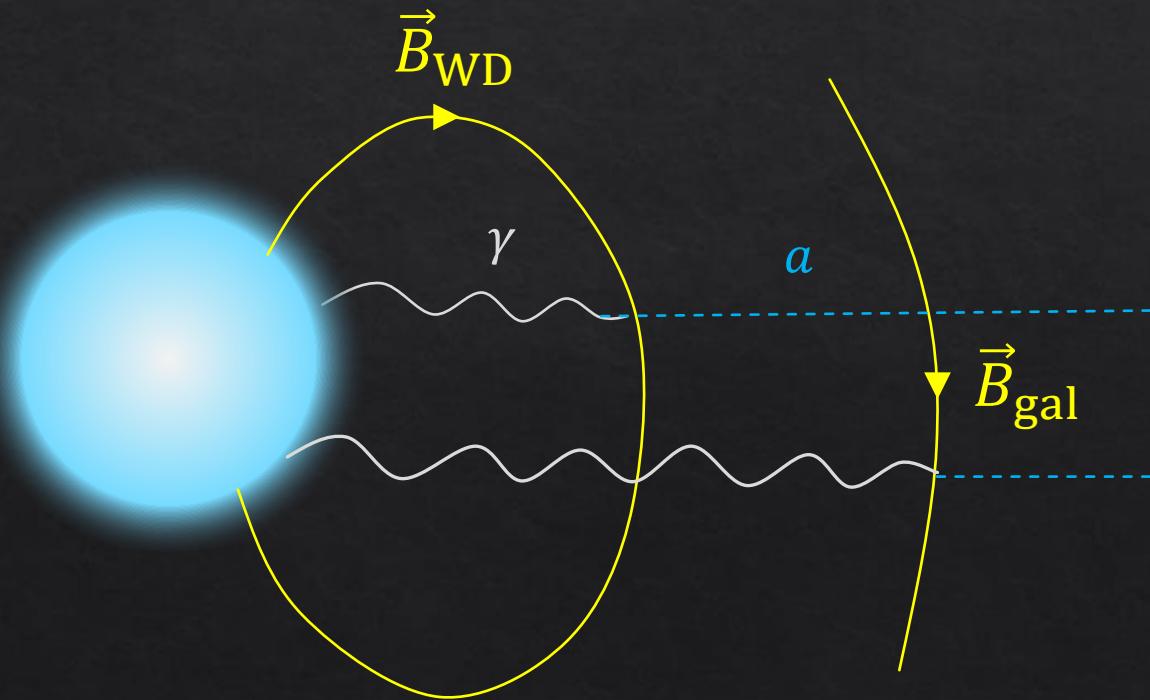
- ❖ Solve problems
  - DM, inflation, relaxion,...
- ❖ Popular
  - Convenient benchmark



# Axion signals: disappearing photons

$$\mathcal{L}_a \supset -\frac{g_{a\gamma\gamma}}{4} a F\tilde{F} = g_{a\gamma\gamma} \vec{E} \cdot \vec{B} \sim \left( \frac{g_{a\gamma\gamma} B_{\text{ext}}}{\lambda} \right) a A_{\parallel}$$

Propagation eigenstates rotated wrt  $(\gamma, a)$



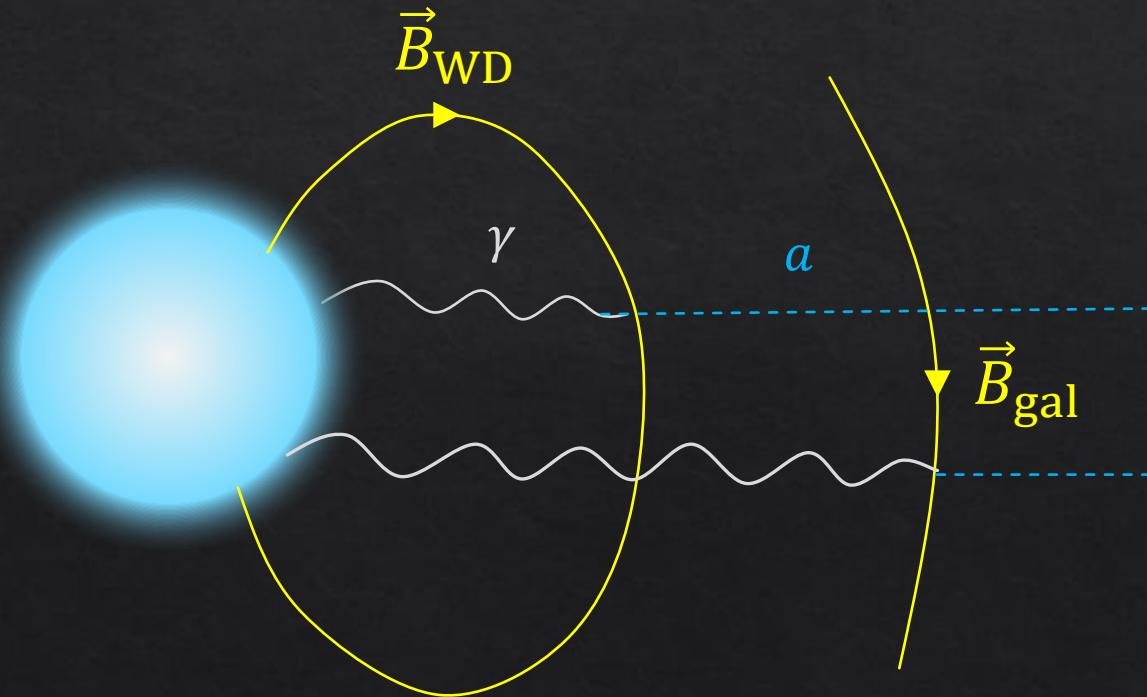
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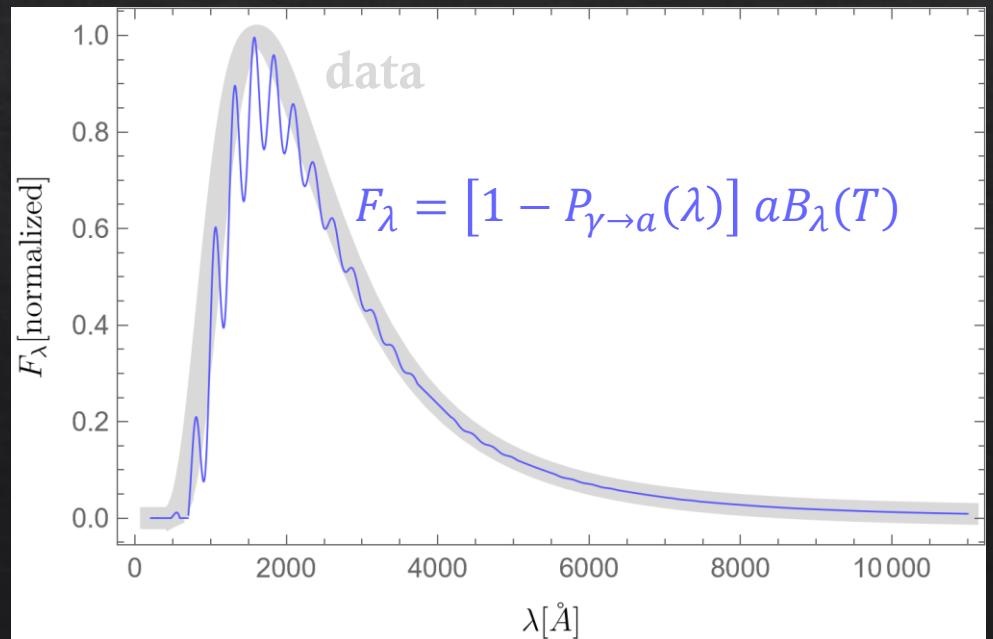
$$P_{\gamma \rightarrow a} \ll 1$$

$$P_{\gamma \rightarrow a}(\lambda) = \frac{1}{2} \left| \frac{g_{a\gamma\gamma}}{2} \int_0^d dz' B(z') e^{i \int_0^{z'} dz'' \frac{\omega_p^2(z'') - m_a^2}{4\pi} \lambda} \right|^2$$

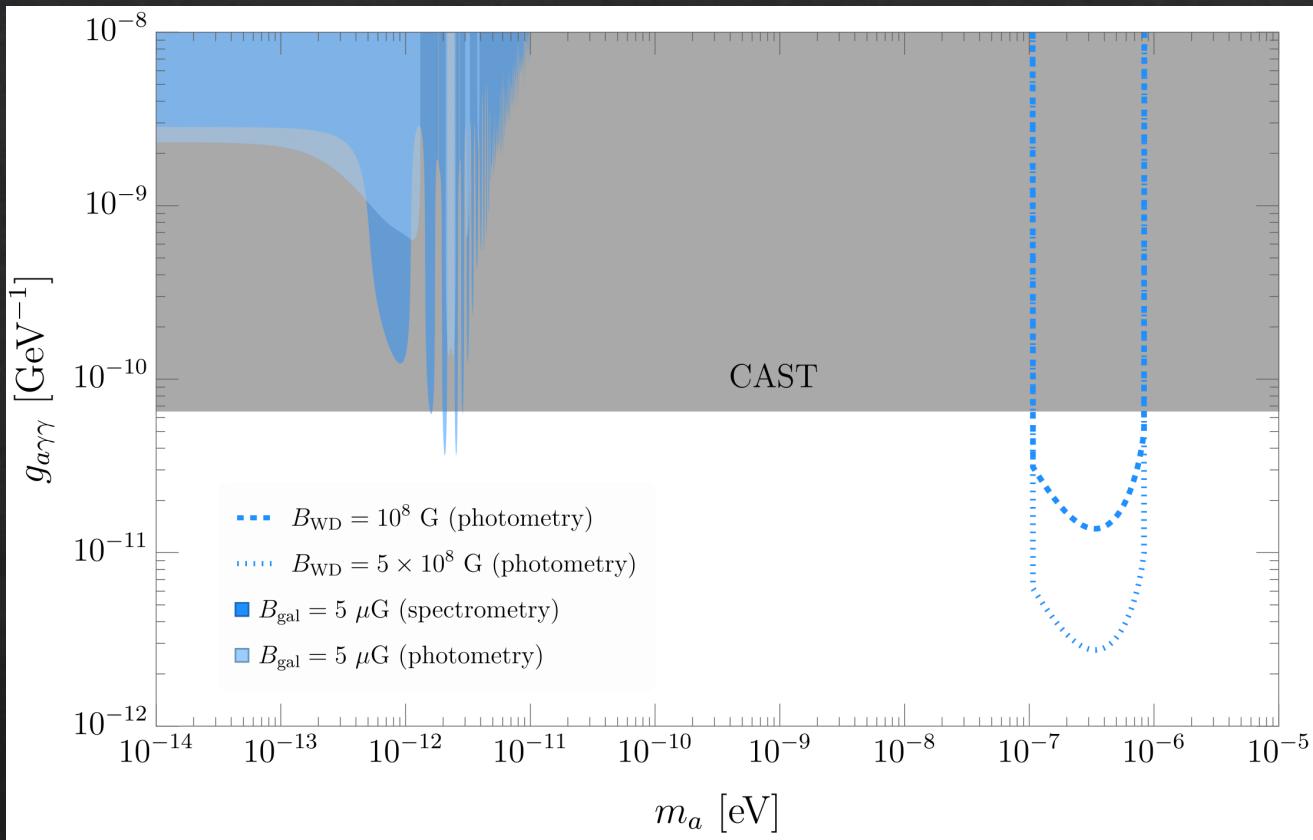
Propagation eigenstates rotated wrt  $(\gamma, a)$



**Wavelength-dependent  $\gamma \rightarrow a$  conversion**



# Limits on Axion



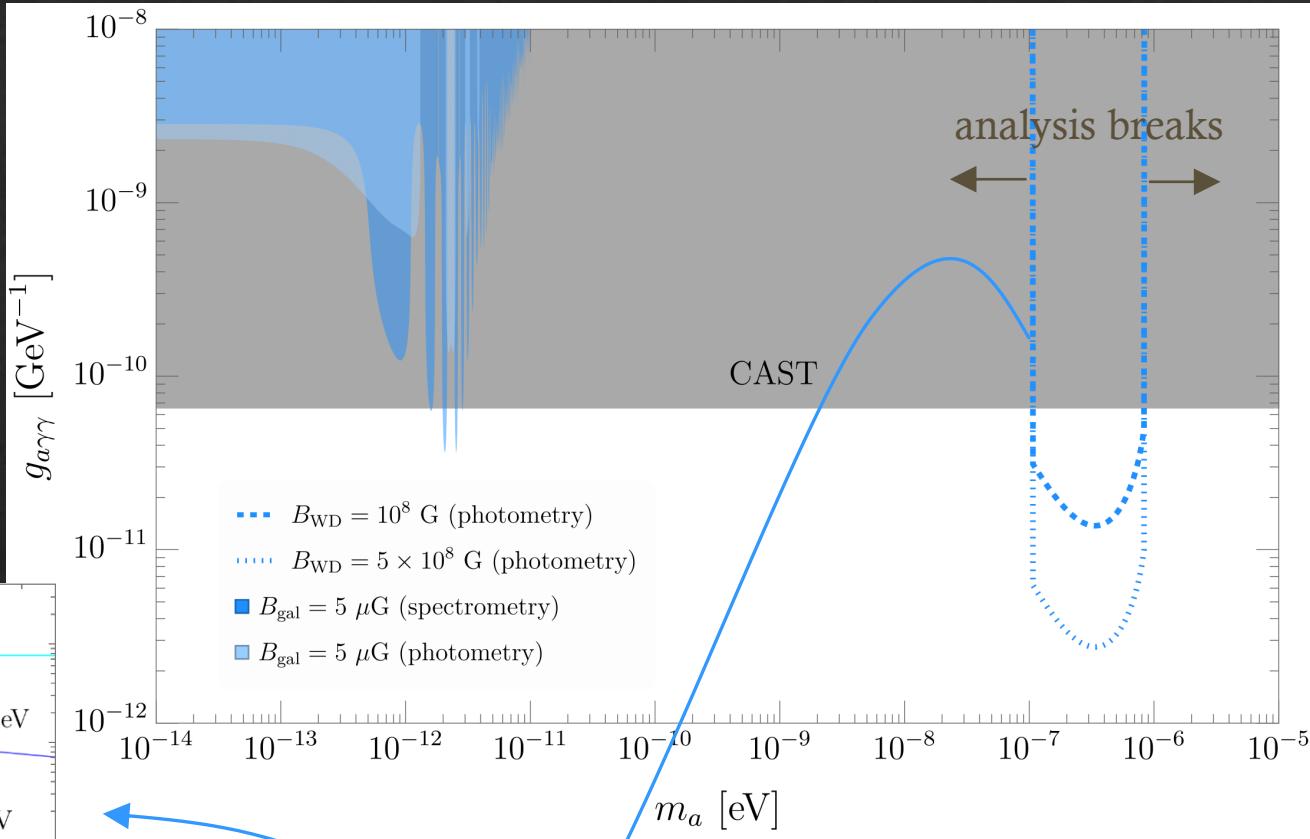
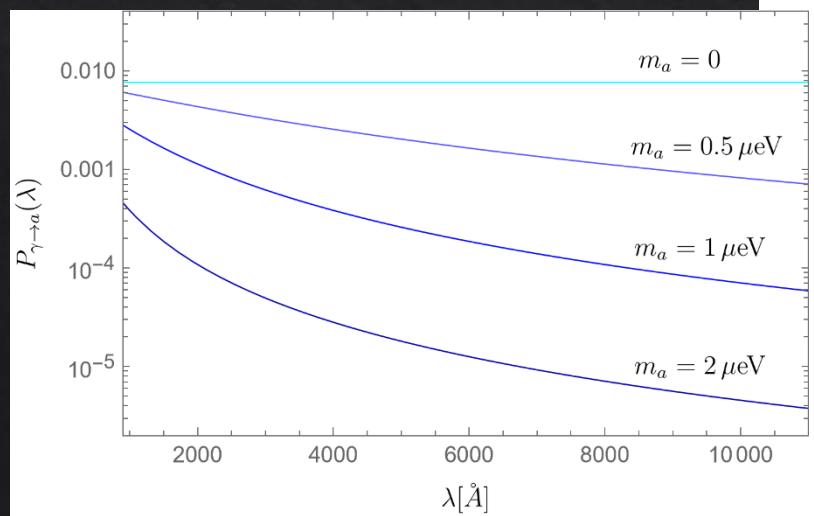
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# Summary

- ❖ 17 blackbody white dwarfs
- ❖ Probe new physics that predicts spectral distortions
- ❖ Future:
  - ❖ Follow-up observations
  - ❖ More blackbody stars
  - ❖ Probing below the photosphere

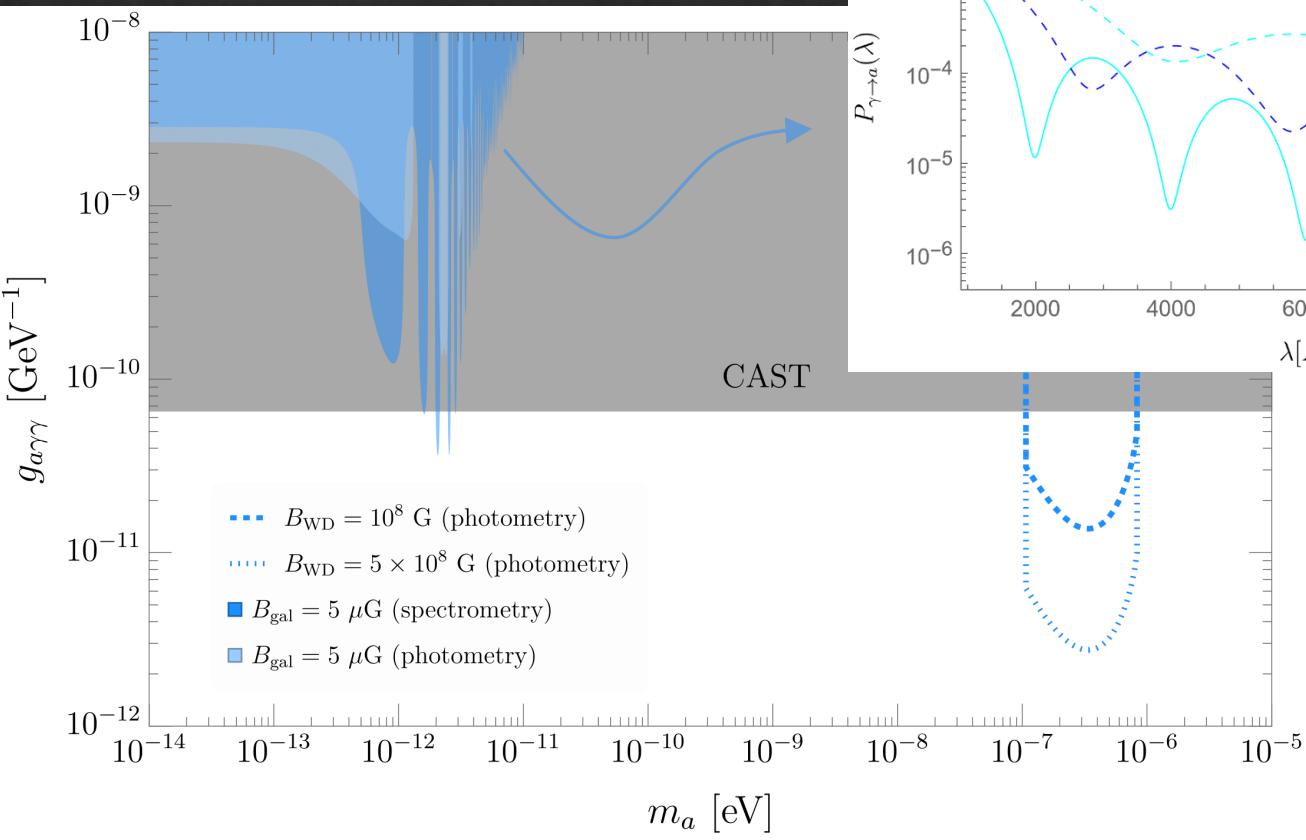
# Backup Slides

# Limits on Axion



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# Photon-Axion Oscillations

Relativistic  $(\gamma, a) \rightarrow i\partial_z \begin{pmatrix} A_{||} \\ a \end{pmatrix} = \begin{pmatrix} \omega - \frac{\omega_p^2}{2\omega} & \frac{g_{a\gamma\gamma}B_{\text{ext}}}{2} \\ \frac{g_{a\gamma\gamma}B_{\text{ext}}}{2} & \omega - \frac{m_a^2}{2\omega} \end{pmatrix} \begin{pmatrix} A_{||} \\ a \end{pmatrix}$

Uniform-medium case  $\rightarrow P_{\gamma_{||} \rightarrow a} = \left( \frac{g_{a\gamma\gamma}BL}{2} \right)^2 \left( \frac{\sin(\Delta_{\text{osc}}L/2)}{\Delta_{\text{osc}}L/2} \right)^2$

$$\Delta_{\text{osc}} = \sqrt{\left( \frac{m_a^2 - \omega_p^2}{2\omega} \right)^2 + (g_{a\gamma\gamma}B_{\text{ext}})^2}$$

# Photon-Axion Conversion Probabilities

relativistic ( $a, \gamma$ ) and  $P_{\gamma \rightarrow a} \ll 1 \rightarrow P_{\gamma \rightarrow a}(\omega) = \frac{1}{2} \left| \frac{g_{a\gamma\gamma}}{2} \int_0^d dz' B(z') e^{i \int_0^{z'} dz'' \frac{\omega_p^2(z'') - m_a^2}{2\omega}} \right|^2$

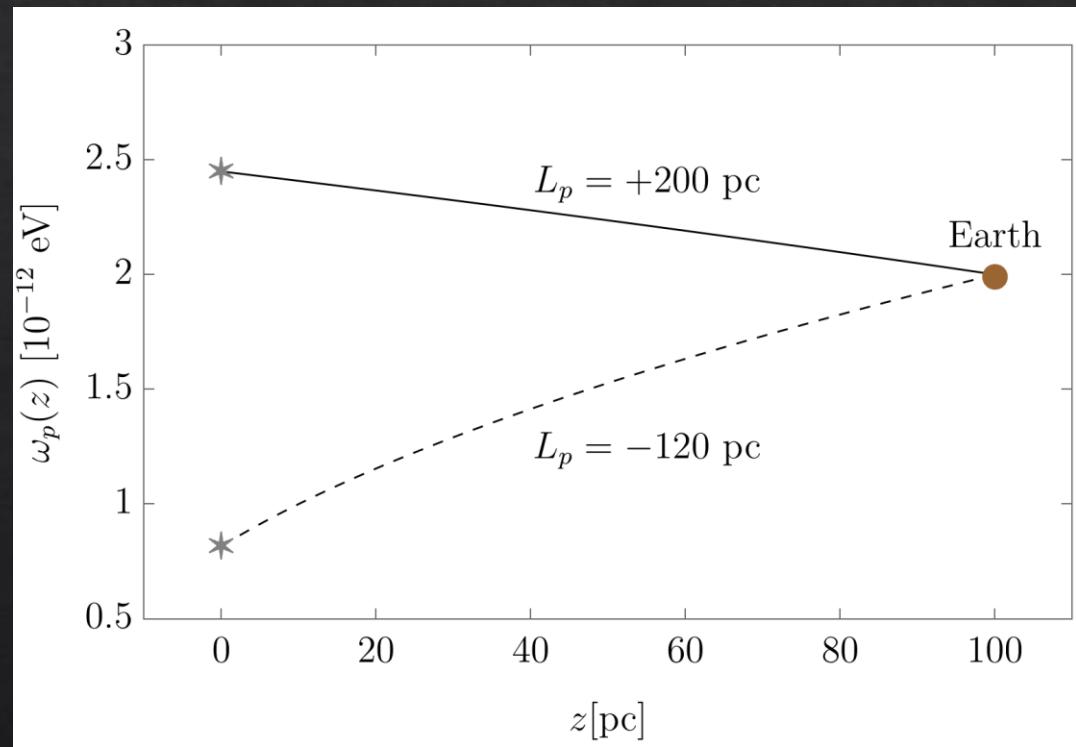
$$\vec{B}_{\text{gal}} \rightarrow P_{\gamma \rightarrow a}(\omega) = \frac{1}{2} \frac{\pi^2 g_{a\gamma\gamma}^2 B_{\text{gal}}^2 L_p}{2\omega_{p,0}^2 \lambda} |\text{Erf}[\Phi(d)] - \text{Erf}[\Phi(0)]|^2 \quad \Phi(z) = \sqrt{\frac{iL_p}{\omega}} \frac{m_a^2 - \omega_p^2(z)}{2\omega_{p,0}}$$

$$\vec{B}_{\text{WD}} \rightarrow P_{\gamma \rightarrow a}(\omega) = \frac{1}{2} F(\theta) \frac{(g_{a\gamma\gamma} B_{\text{WD}} R_{\text{WD}})^2}{16} \left| \int_1^\infty d\tilde{r} \frac{e^{i\delta_a \tilde{r}}}{\tilde{r}^3} \right|^2 \quad \delta_a = -\frac{m_a^2 R_{\text{WD}}}{2\omega}$$

# Local Interstellar Medium

$$B_{\text{gal}} = 5 \mu\text{G}$$

$$\omega_p^2(z) = \omega_{p,0}^2 \left( 1 + \frac{d-z}{L_p} \right)$$



# Chi-Squared Analysis

Flux model

$$F_\lambda = [1 - P_{\gamma \rightarrow a}(m_a, g_{a\gamma\gamma}, \lambda)] aB_\lambda(T) \quad aB_\lambda(T) = a \frac{4\pi}{\lambda^5} \frac{1}{e^{2\pi/\lambda T} - 1}$$

95% CL exclusion criterion for a given  $m_a$  (Wilk's theorem)

$$[\chi^2(g_{a\gamma\gamma})]_{\text{best}(a,T)} - [\chi^2]_{\text{best}(g_{a\gamma\gamma}, a, T)} > 2.71$$

$$\chi^2 = \sum_{i=1}^{N_{\text{bin}}} \left[ \frac{F_i - F_{\lambda_i}(m_a, g_{a\gamma\gamma}, a, T)}{\sigma_{F_i}} \right]^2$$

# Gray Atmosphere Model

Assume wavelength-independent opacity → radiative transfer equations solvable

