EMISSION OF SPIN-2 PARTICLES FROM THE SUN

CAMILO GARCIA-CELY.

SEPTEMBER 9, 2025

COSMIC WISPers
Sofia, Bulgaria

In collaboration with Andreas Ringwald

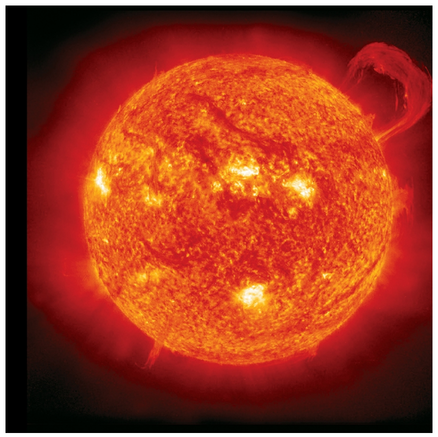
CSIC
Consejo Superior de Investigaciones Científicas

Vniversitat de València

IFIC Institut de Física Corpuscular

Excelencia Severo Ochoa

SPIN-2 PARTICLES



$$\mathcal{L} = \frac{1}{2}\partial_\rho h_{\mu\nu}\partial^\rho h^{\mu\nu} - \frac{1}{2}\partial_\rho h \partial^\rho h + \partial_\rho h \partial_\nu h^{\rho\nu} - \partial_\rho h_{\mu\nu}\partial^\nu h^{\mu\rho}$$
$$-m^2(h_{\mu\nu}h^{\mu\nu} - h^2)/2 + (8\pi G')^{\frac{1}{2}} h_{\mu\nu}T^{\mu\nu} \,,$$

Fierz-Pauli, 1939

Hoof et al, 2021

SPIN-2 PARTICLES

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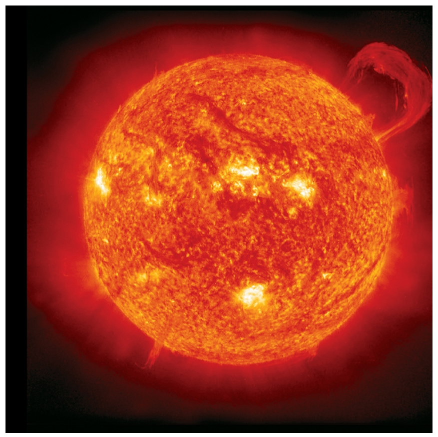

- Mediators of dark Yukawa forces

Hoof et al, 2021

SPIN-2 PARTICLES

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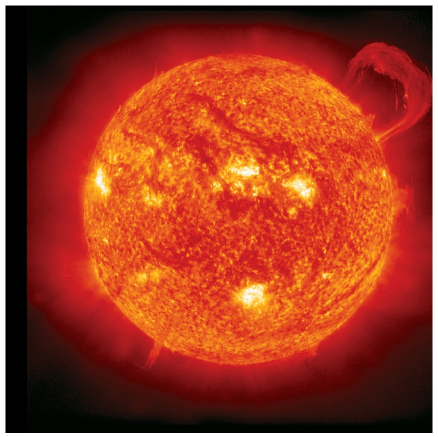

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Hoof et al, 2021

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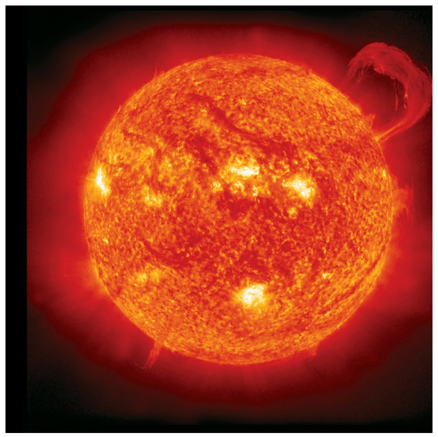
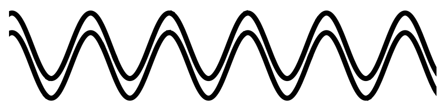


$h_{\mu\nu}$



- Mediators of dark Yukawa forces

- Spin -2 Dark Matter

- Bimetric theories

Hoof et al, 2021

SPIN-2 PARTICLES

$$\mathcal{L} = \frac{1}{2}\partial_\rho h_{\mu\nu}\partial^\rho h^{\mu\nu} - \frac{1}{2}\partial_\rho h \partial^\rho h + \partial_\rho h \partial_\nu h^{\rho\nu} - \partial_\rho h_{\mu\nu}\partial^\nu h^{\mu\rho}$$
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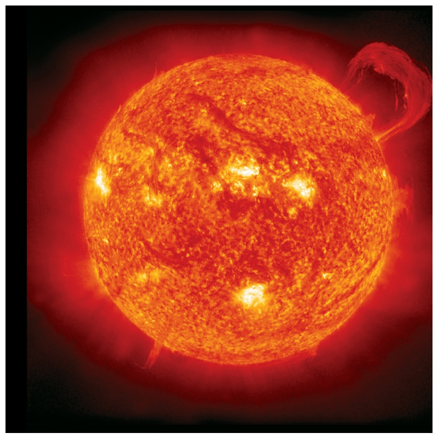


- Mediators of dark Yukawa forces

- Spin -2 Dark Matter

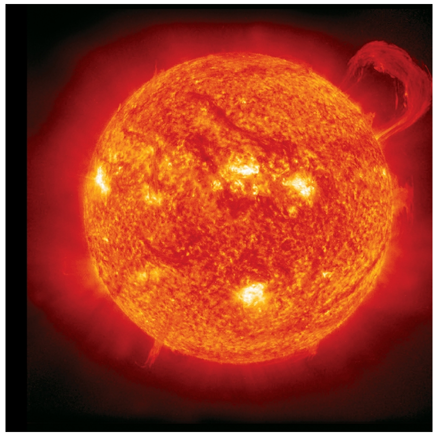
- Bimetric theories

Naturally related to solar gravitational waves!

García-Cely, Ringwald, PRL 2025

Hoof et al, 2021

SOLAR EMISSION OF AXIONS



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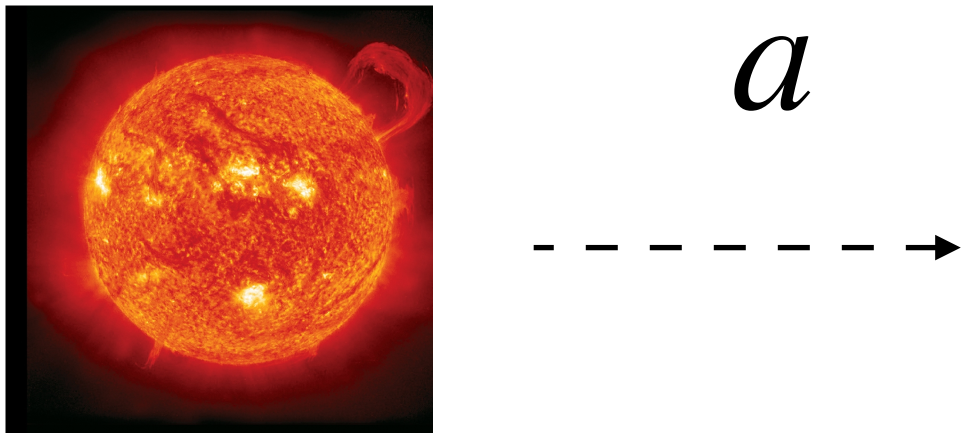
Hoof et al, 2021

SOLAR EMISSION OF AXIONS



PHYSICAL REVIEW D VOLUME 33, NUMBER 4 15 FEBRUARY 1986

Astrophysical axion bounds diminished by screening effects

Georg G. Raffelt

PHYSICAL REVIEW D VOLUME 37, NUMBER 6 15 MARCH 1988

Plasmon decay into low-mass bosons in stars

Georg G. Raffelt

PHYSICAL REVIEW D **102,** 043019 (2020)

Axion helioscopes as solar magnetometers

Ciaran A. J. O'Hare,[1,*] Andrea Caputo,[2,†] Alexander J. Millar,[3,4,‡] and Edoardo Vitagliano[5,§]

PHYSICAL REVIEW D **101,** 123004 (2020)

Revisiting longitudinal plasmon-axion conversion in external magnetic fields

Andrea Caputo,[1,*] Alexander J. Millar,[2,3,†] and Edoardo Vitagliano[4,‡]

PHYSICAL REVIEW D **102,** 123024 (2020)

Production of axionlike particles from photon conversions in large-scale solar magnetic fields

Ersilia Guarini,[1] Pierluca Carenza,[1,2] Javier Galán,[3] Maurizio Giannotti,[4] and Alessandro Mirizzi[1,2]

Axion emission by magnetic-field induced conversion of longitudinal plasmons

N. V. Mikheev
Department of Theoretical Physics, Yaroslavl State University, Sovietskaya 14, Yaroslavl 150000, Russia

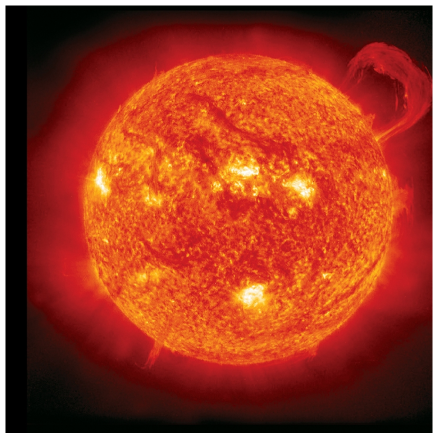
G. Raffelt
Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), Föhringer Ring 6, 80805 München, Germany

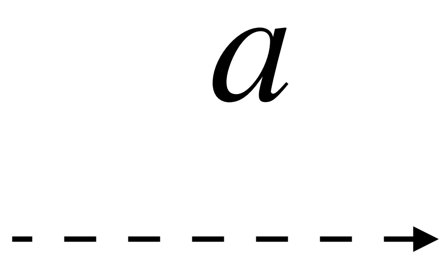
L. A. Vassilevskaya

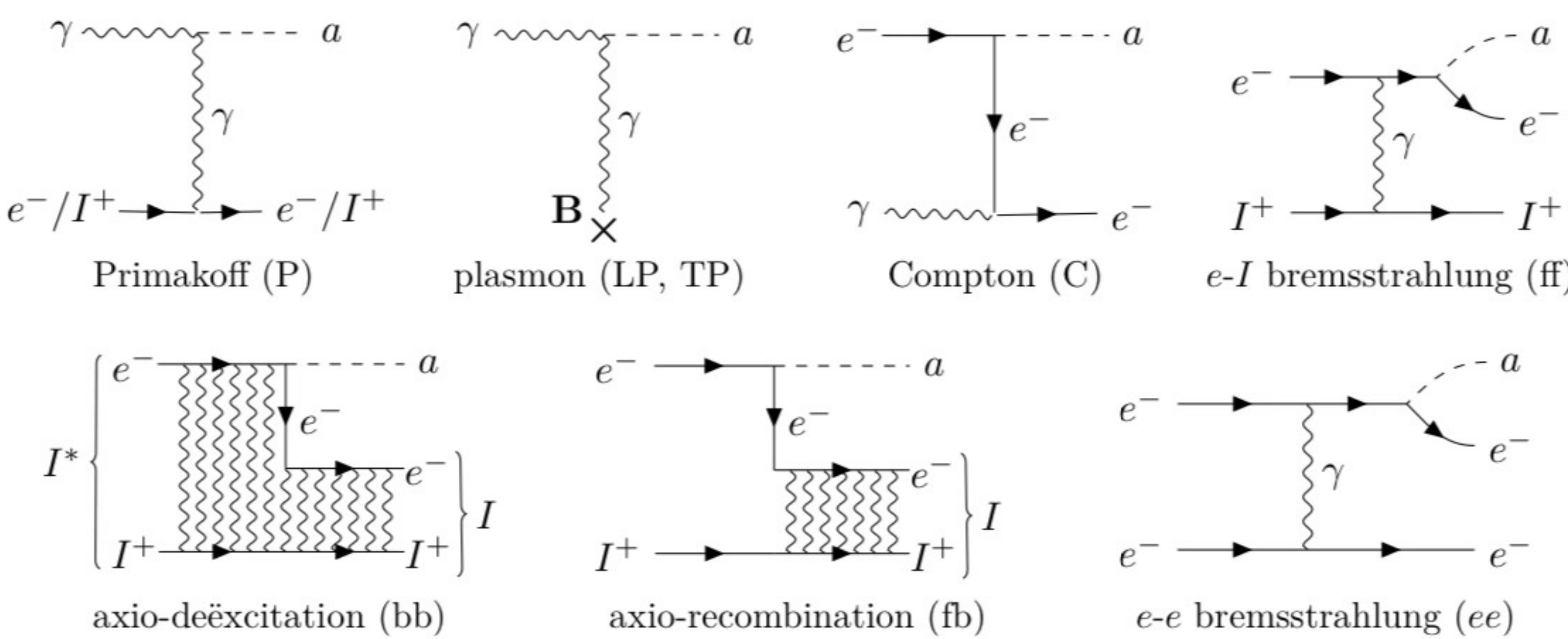
Solar axion flux from the axion-electron coupling

Javier Redondo (Munich U., ASC and Munich, Max Planck Inst.)
Oct 2, 2013

SOLAR EMISSION OF AXIONS







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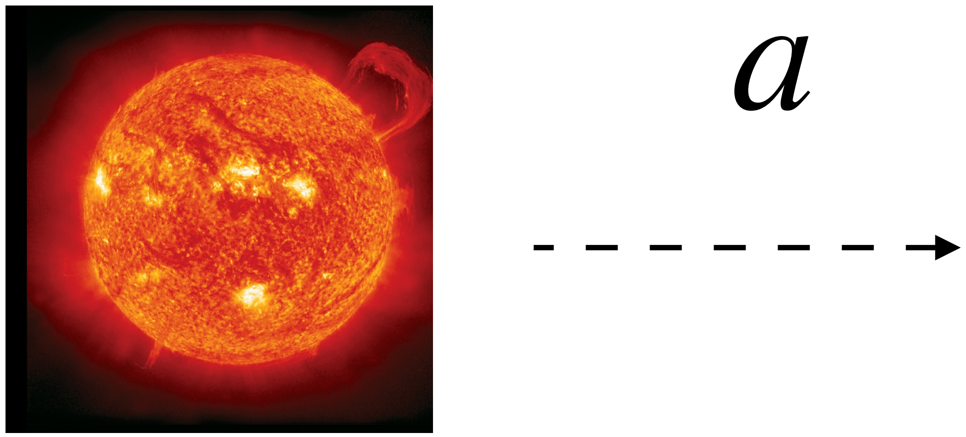
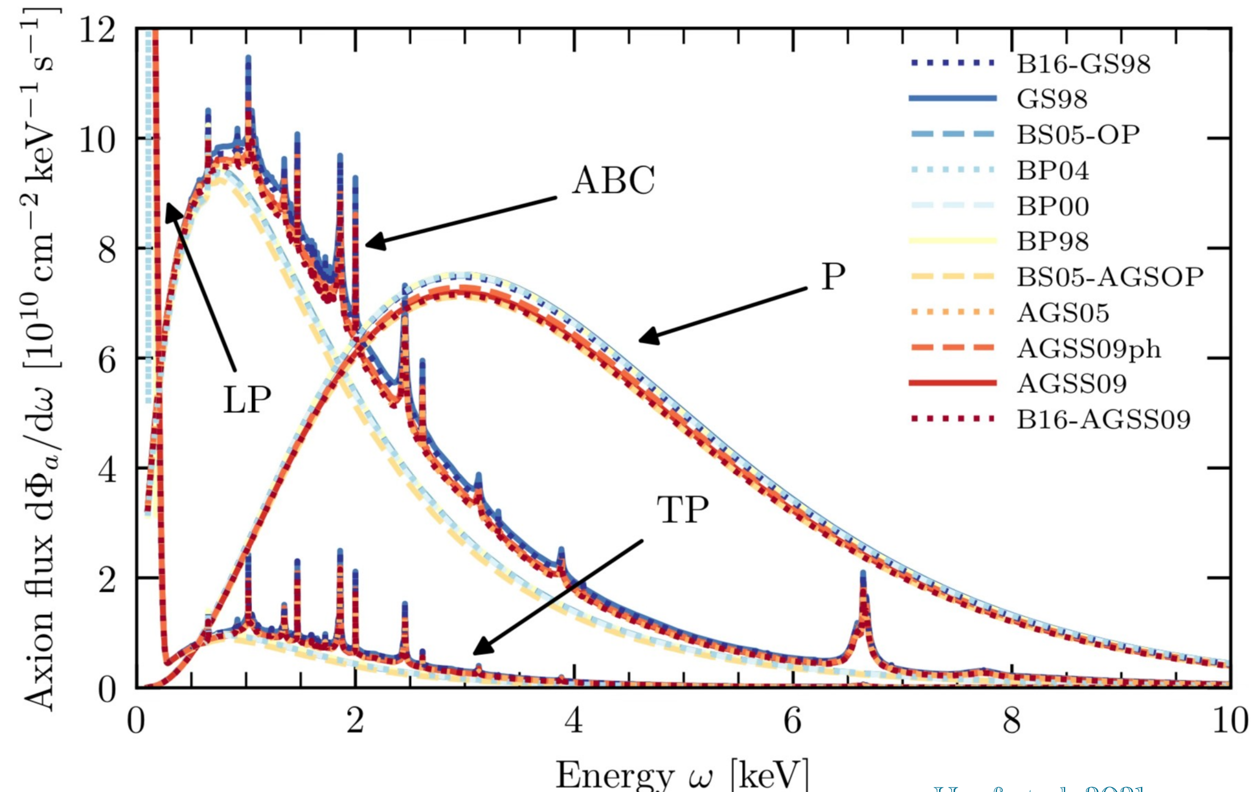
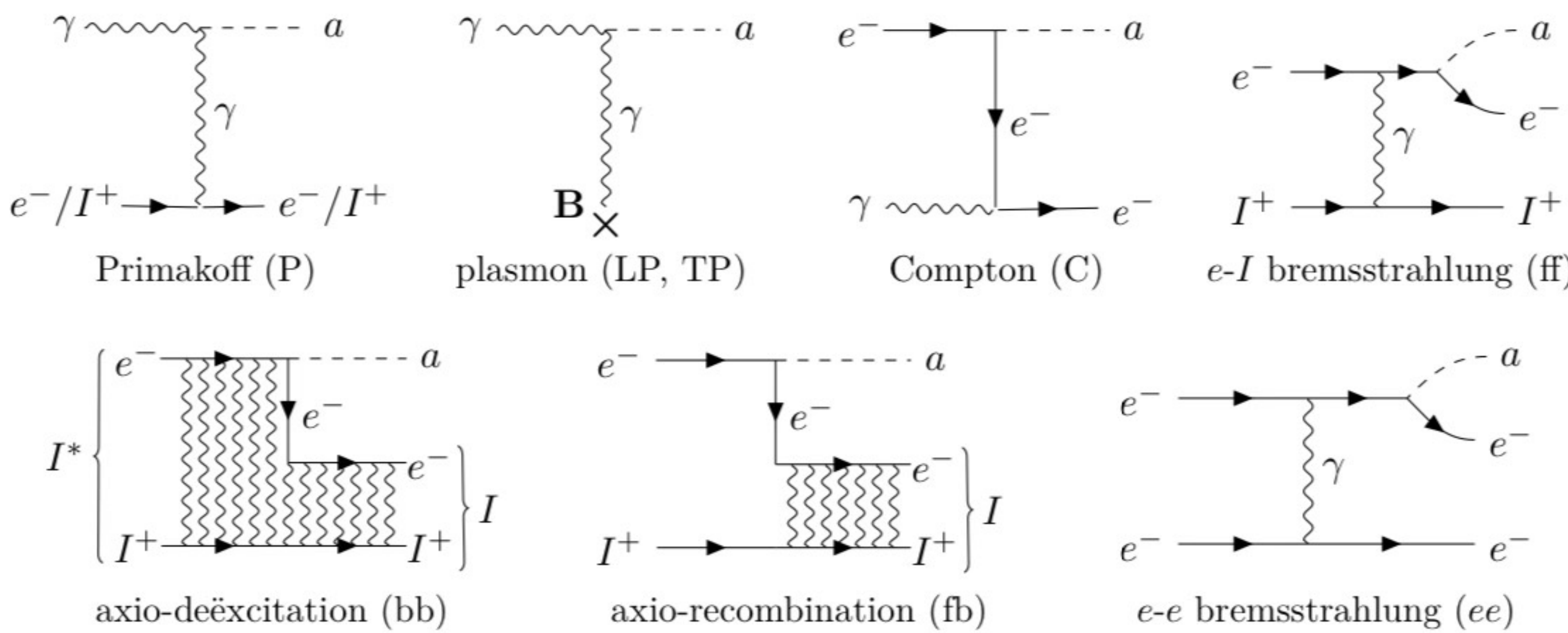
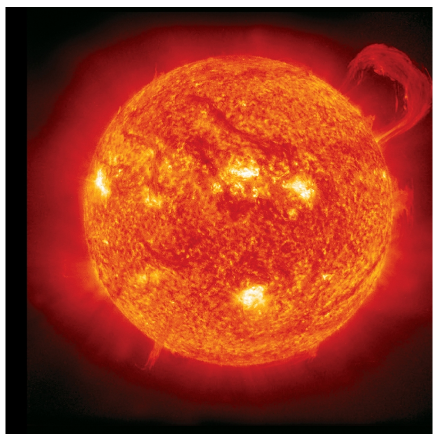




Hoof et al, 2021

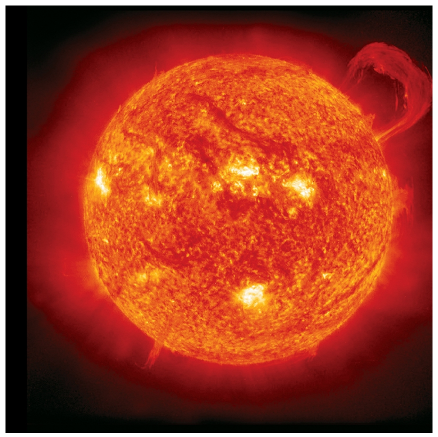


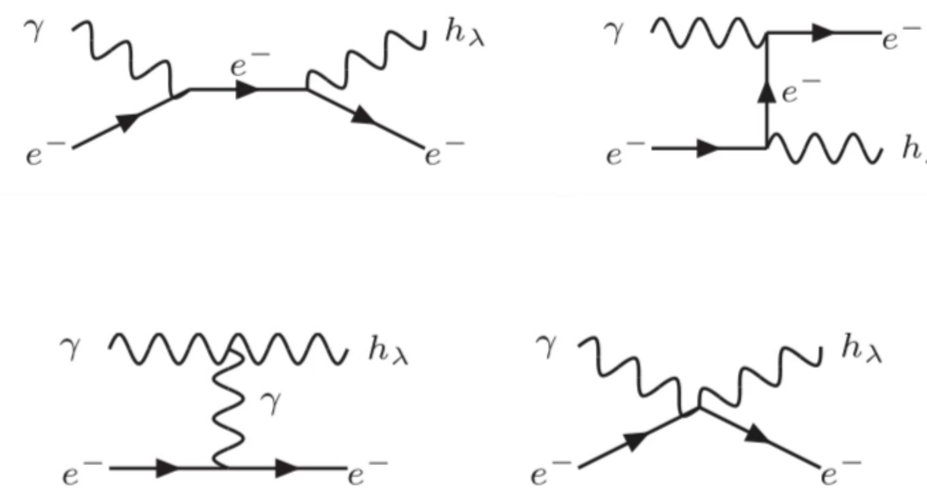
SOLAR EMISSION OF SPIN-2 PARTICLES



SOLAR EMISSION OF SPIN-2 PARTICLES

Photoproduction





CGC, Ringwald, 2025 **PRELIMINARY**

SOLAR EMISSION OF SPIN-2 PARTICLES

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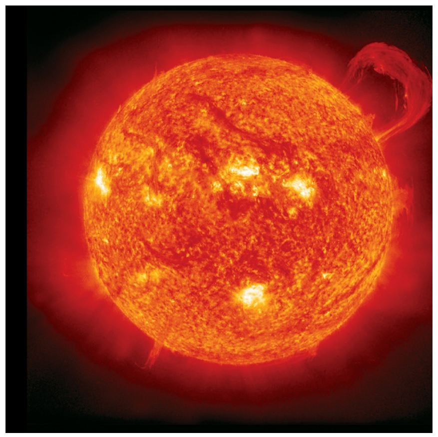
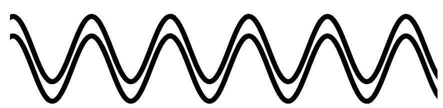
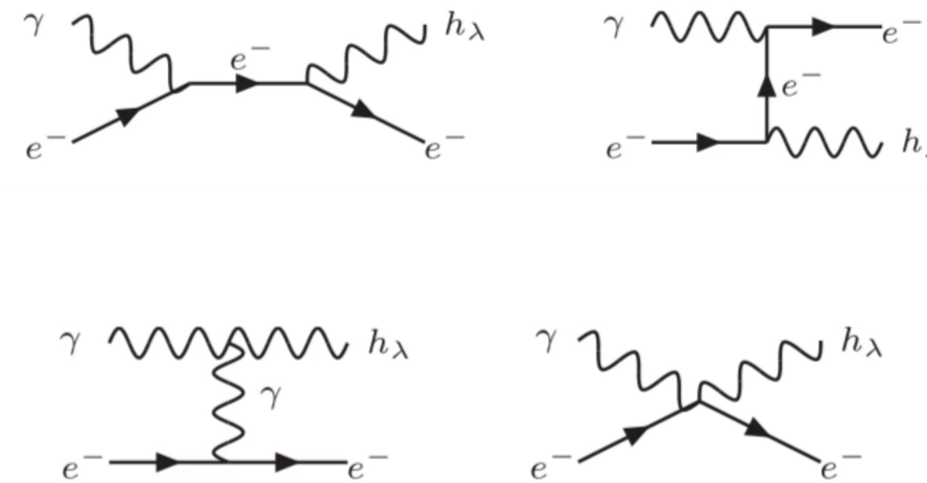


$h_{\mu\nu}$

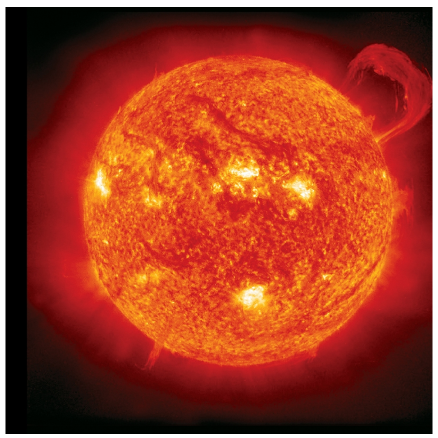




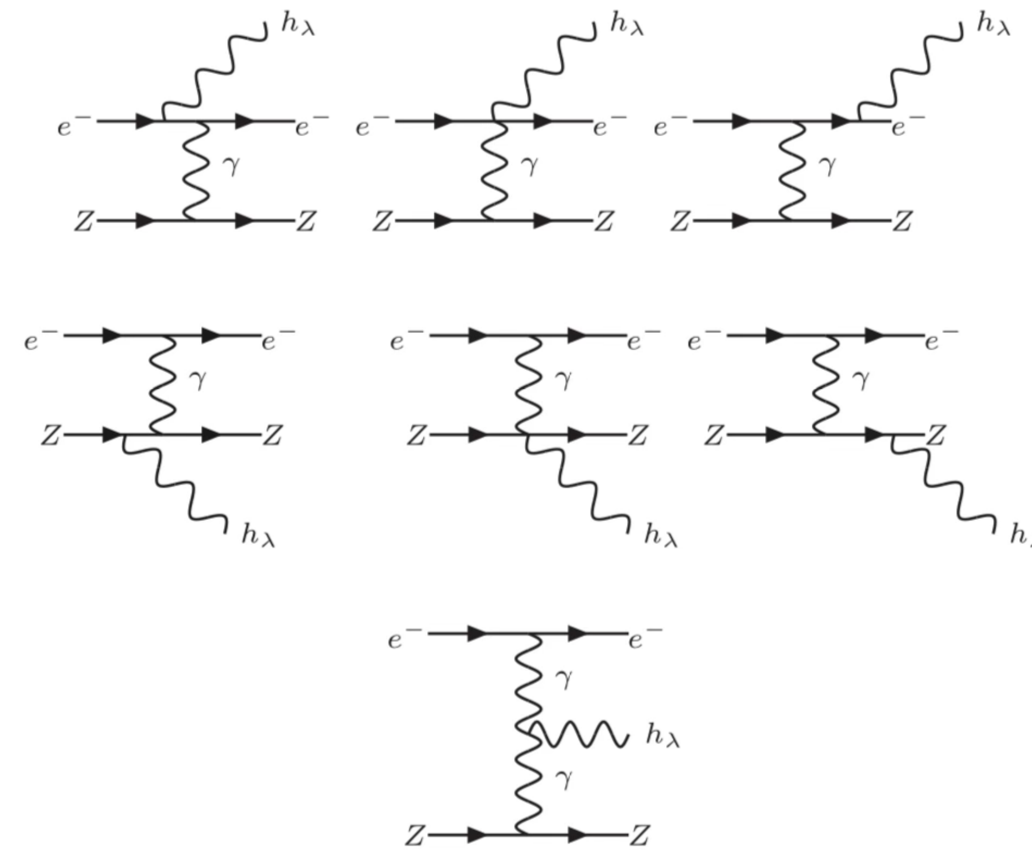
Collision	λ	$\frac{\mathrm{d}\Gamma}{\mathrm{d}\omega\mathrm{d}V}$	
Photo-production $\gamma Z \to Z\, h_\lambda$	± 2	$n_\gamma n_Z G' Z^2 \alpha\pi\, \delta(\omega - p_i) \int \mathrm{d}\cos\theta \cot^2\frac{\theta}{2}[1+\cos^2\theta] F(\theta)$	$F(\theta) = \frac{\left(2\omega \sin\frac{\theta}{2}\right)^2}{\kappa^2 + \left(2\omega\sin\frac{\theta}{2}\right)^2}$
	± 1	0	
	0	$\frac{4}{3} n_\gamma n_Z G' Z^2 \alpha\pi\, \delta(\omega - p_i) \int \mathrm{d}\cos\theta \cot^2\frac{\theta}{2} \sin^4\frac{\theta}{2} F(\theta)$	

CGC, Ringwald, 2025 **PRELIMINARY**

SOLAR EMISSION OF SPIN-2 PARTICLES



Bremsstrahlung



CGC, Ringwald, 2025 **PRELIMINARY**

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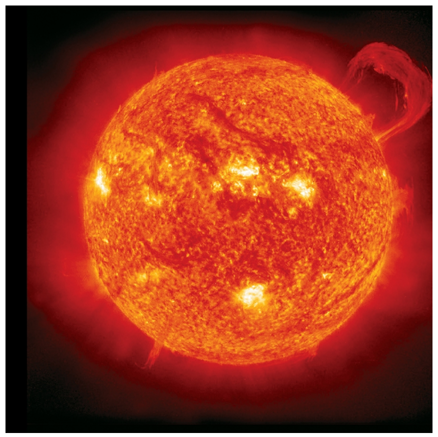

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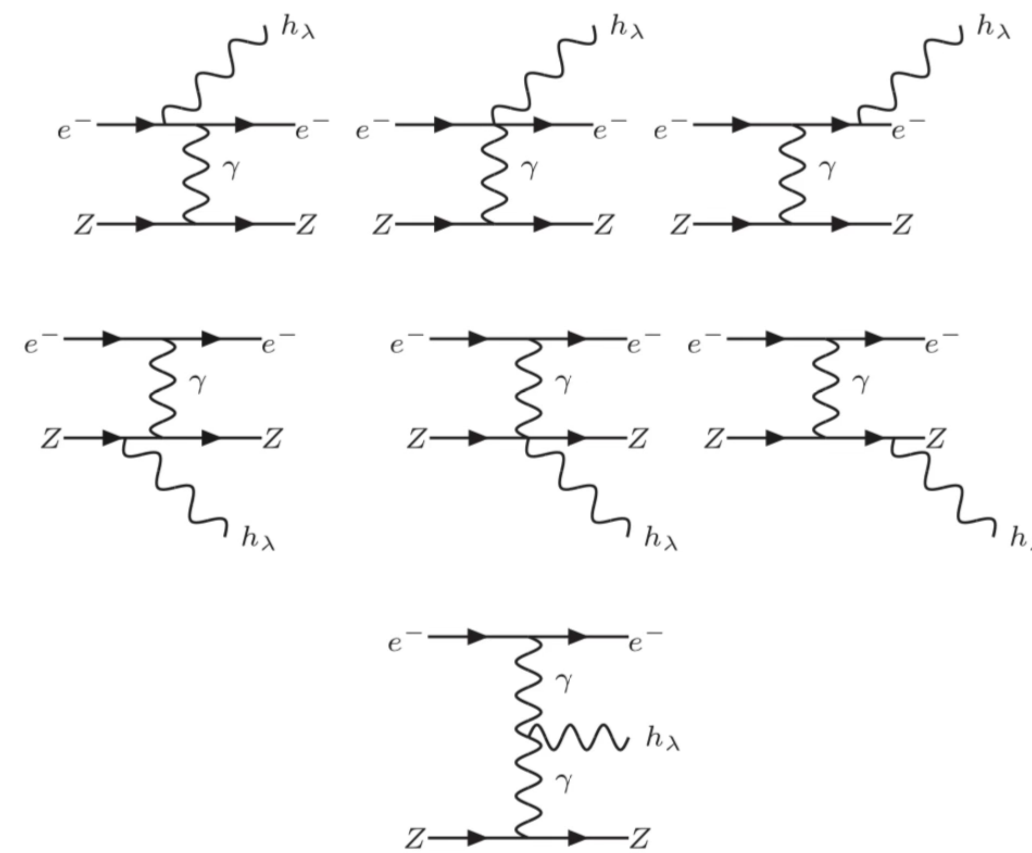

Bremsstrahlung	± 2	$\frac{32 n_e n_Z G' Z^2 \alpha^2 p_i}{15\omega}\left(\frac{1}{m_e}+\frac{1}{m_Z}\right)\left(3(1+\xi^2)L+10\xi+\mathcal{O}(\xi_s^2)\right)$	$\xi=\frac{p_f}{p_i}, \quad \xi_s=\frac{\kappa}{p_i}$
$eZ \to eZ\, h_\lambda$	± 1	0	
	0	$\frac{16 n_e n_Z G' Z^2 \alpha^2 p_i}{45\omega}\left(\frac{1}{m_e}+\frac{1}{m_Z}\right)\left((1+\xi^2)L+30\xi+\mathcal{O}(\xi_s^2)\right)$	$\omega=E_i(1-\xi^2)$
Bremsstrahlung	± 2	$\frac{16 n_e^2 G' \alpha^2 p_i}{15\omega m_e}\left(\left(6(1+\xi^2)-\frac{3(1-\xi^2)^4+7(1-\xi^4)^2}{2(1+\xi^2)^3}\right)L+20\xi-\frac{6\xi(1+\xi^4)}{(1+\xi^2)^2}+\mathcal{O}(\xi_s^2)\right)$	$L=\log\sqrt{\frac{(1+\xi)^2+\xi_s^2}{(1-\xi)^2+\xi_s^2}}$
$ee \to ee\, h_\lambda$	± 1	0	
	0	$\frac{16 n_e^2 G' \alpha^2 p_i}{15\omega m_e}\left(\left(\frac{1}{3}(1+\xi^2)-\frac{(1-\xi^2)^4+29(1-\xi^4)^2}{12(1+\xi^2)^3}\right)L+\frac{29\xi}{3}+\frac{2\xi^3}{3(1+\xi^2)^2}+\mathcal{O}(\xi_s^2)\right) <$	

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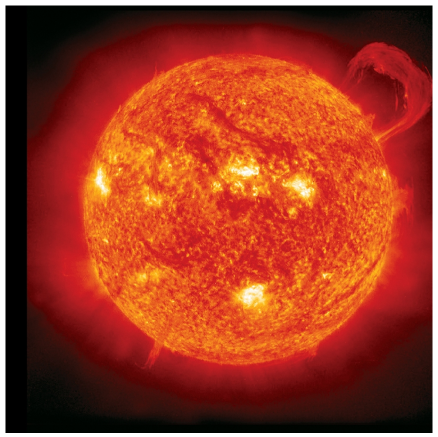
SOLAR EMISSION OF SPIN-2 PARTICLES



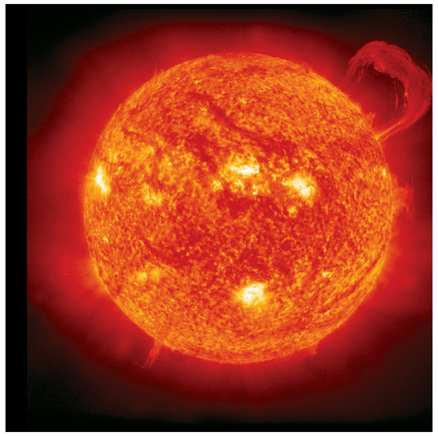
We thus verify the vDVZ discontinuity

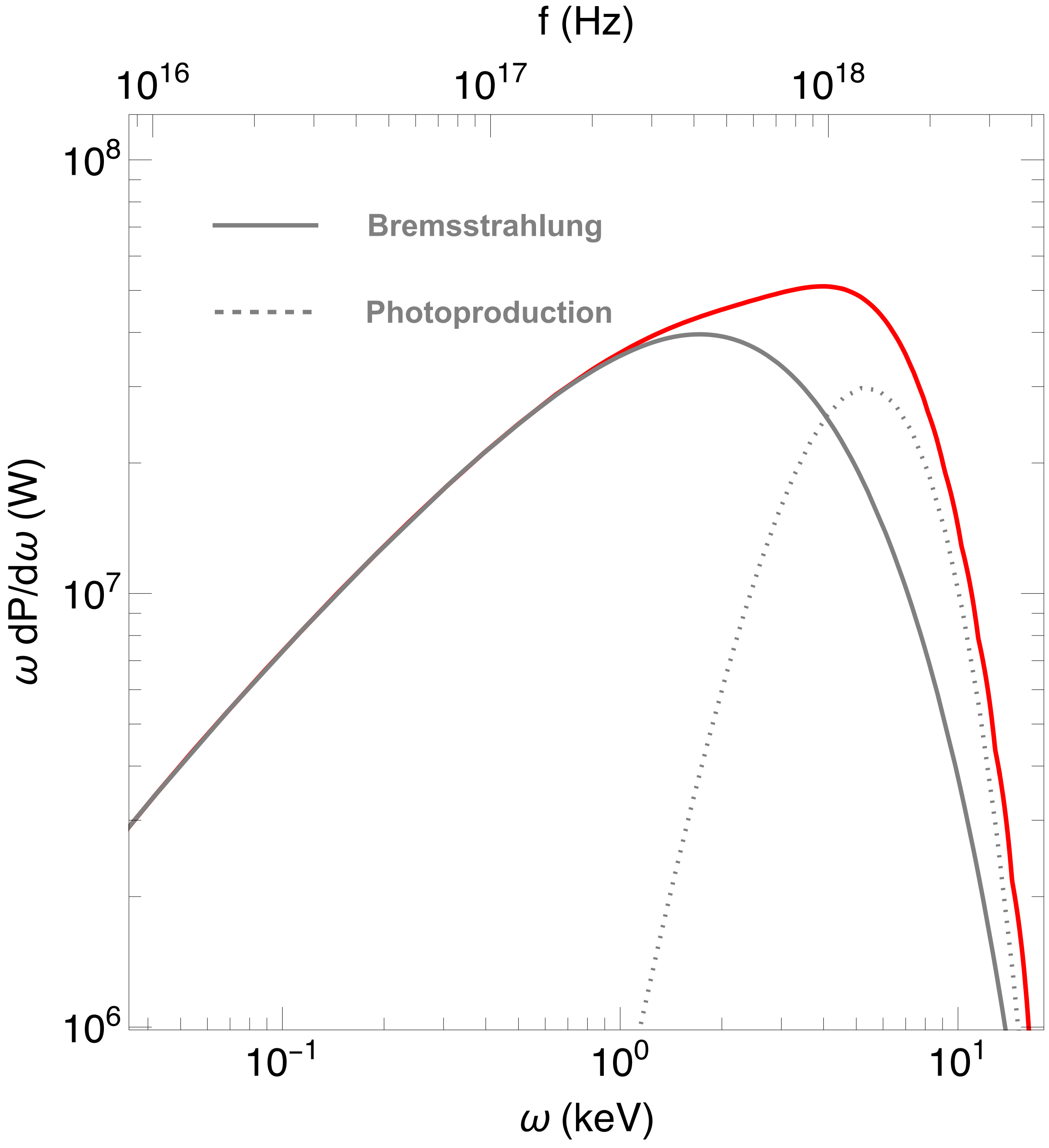
van Dam, Veltman, 1970; Zahkarov, 1970

Collision	λ	$\frac{\mathrm{d}\Gamma}{\mathrm{d}\omega \mathrm{d}V}$	
Photo-production	± 2	$n_\gamma n_Z G' Z^2 \alpha\pi\, \delta(\omega - p_i) \int \mathrm{d}\cos\theta \cot^2\frac{\theta}{2}[1+\cos^2\theta]F(\theta)$	$F(\theta) = \frac{\left(2\omega \sin\frac{\theta}{2}\right)^2}{\kappa^2 + \left(2\omega\sin\frac{\theta}{2}\right)^2}$
$\gamma Z \to Z\, h_\lambda$	± 1	0	
	0	$\frac{4}{3} n_\gamma n_Z G' Z^2 \alpha\pi\, \delta(\omega - p_i) \int \mathrm{d}\cos\theta \cot^2\frac{\theta}{2} \sin^4\frac{\theta}{2} F(\theta)$	
Bremsstrahlung	± 2	$\frac{32 n_e n_Z G' Z^2 \alpha^2 p_i}{15\omega}\left(\frac{1}{m_e} + \frac{1}{m_Z}\right)\left(3(1+\xi^2)L + 10\xi + \mathcal{O}(\xi_s^2)\right)$	$\xi = \frac{p_f}{p_i}, \quad \xi_s = \frac{\kappa}{p_i}$
$eZ \to eZ\, h_\lambda$	± 1	0	
	0	$\frac{16 n_e n_Z G' Z^2 \alpha^2 p_i}{45\omega}\left(\frac{1}{m_e} + \frac{1}{m_Z}\right)\left((1+\xi^2)L + 30\xi + \mathcal{O}(\xi_s^2)\right)$	$\omega = E_i(1-\xi^2)$
Bremsstrahlung	± 2	$\frac{16 n_e^2 G' \alpha^2 p_i}{15\omega m_e}\left(\left(6(1+\xi^2) - \frac{3(1-\xi^2)^4 + 7(1-\xi^4)^2}{2(1+\xi^2)^3}\right)L + 20\xi - \frac{6\xi(1+\xi^4)}{(1+\xi^2)^2} + \mathcal{O}(\xi_s^2)\right)$	$L = \log\sqrt{\frac{(1+\xi)^2+\xi_s^2}{(1-\xi)^2+\xi_s^2}}$
$ee \to ee\, h_\lambda$	± 1	0	
	0	$\frac{16 n_e^2 G' \alpha^2 p_i}{15\omega m_e}\left(\left(\frac{1}{3}(1+\xi^2) - \frac{(1-\xi^2)^4 + 29(1-\xi^4)^2}{12(1+\xi^2)^3}\right)L + \frac{29\xi}{3} + \frac{2\xi^3}{3(1+\xi^2)^2} + \mathcal{O}(\xi_s^2)\right) <$	

CGC, Ringwald, 2025 **PRELIMINARY**

CASE G=G'





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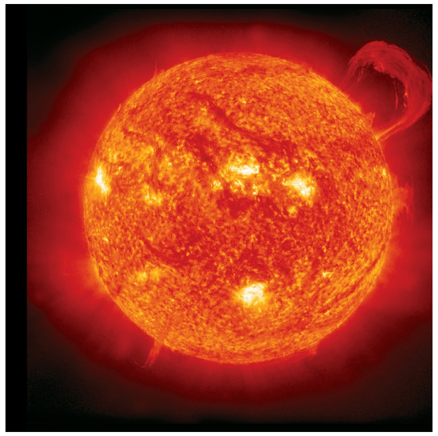
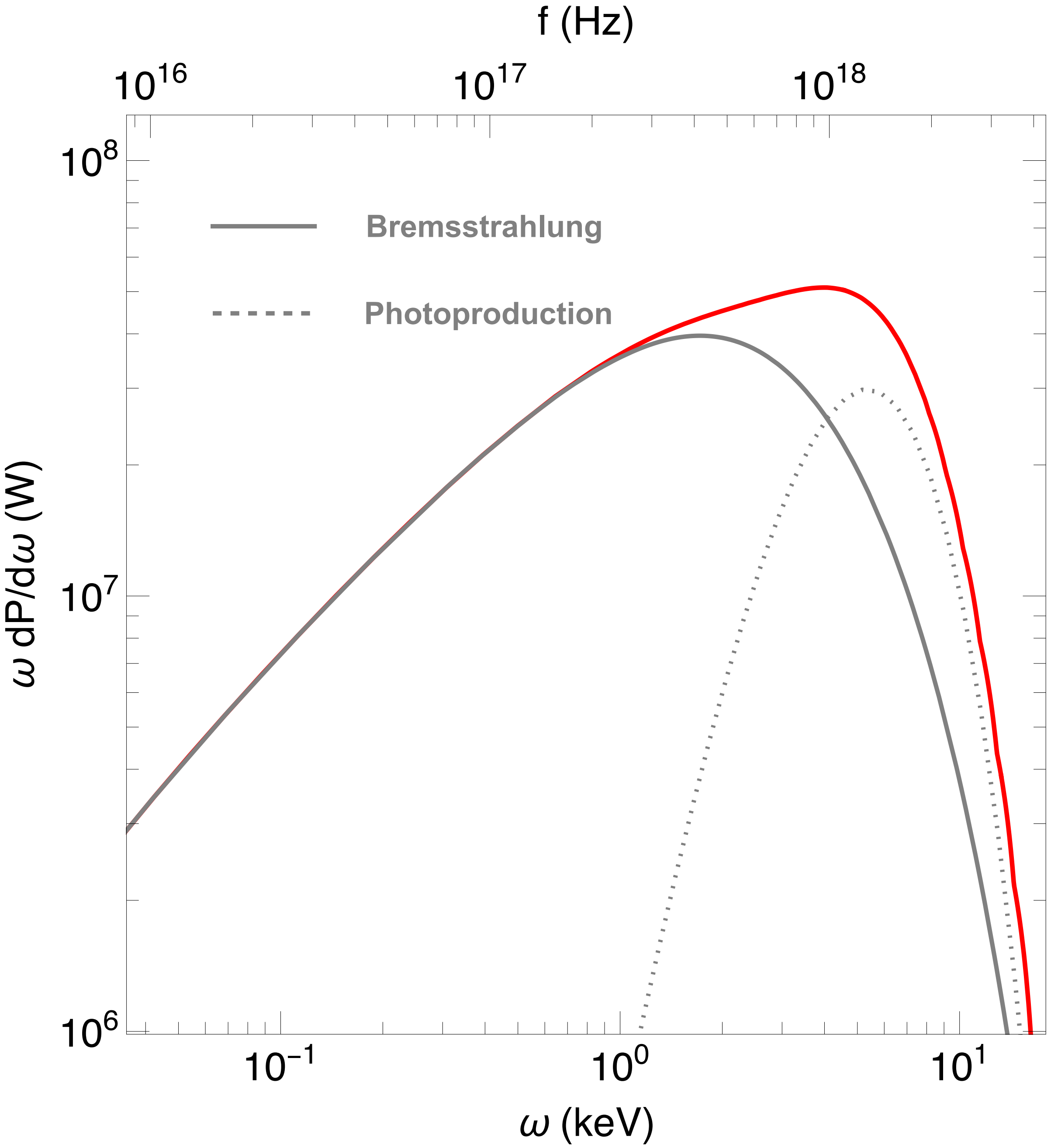


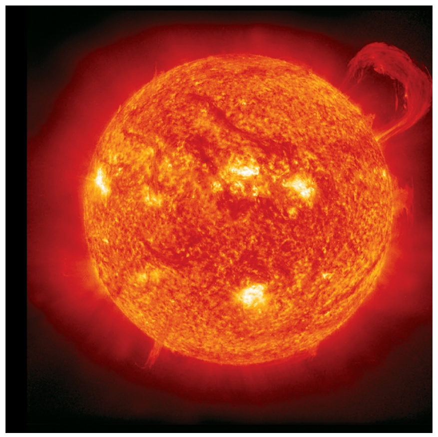
$$P_\odot = \left(1.5\times 10^{15}\,\mathrm{erg/s}\right)\frac{G'}{G}$$

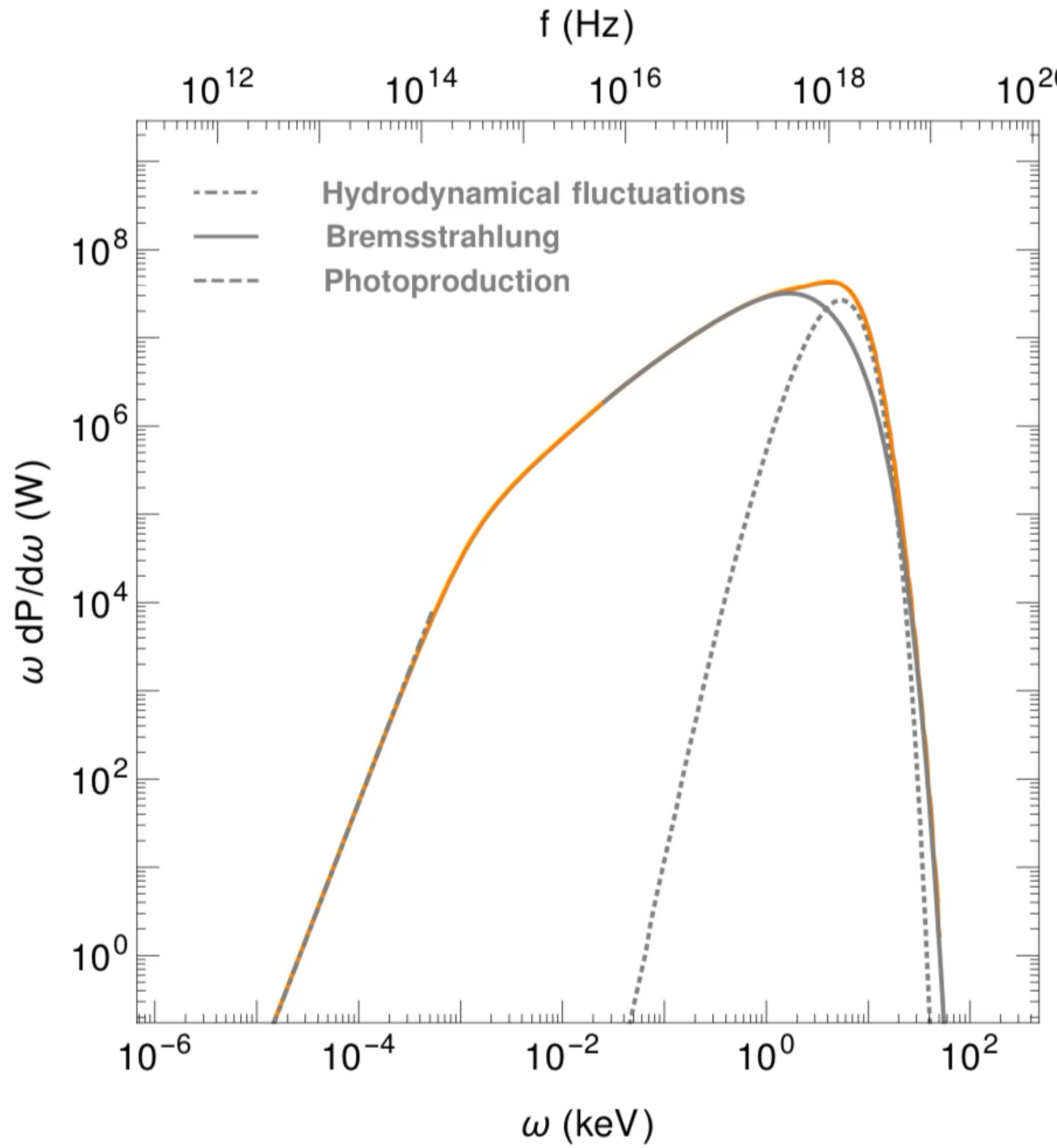
CGC, Ringwald, 2025 **PRELIMINARY**



CASE G=G'

Naturally related to solar gravitational waves!





$$P_\odot = \left(1.5 \times 10^{15}\,\mathrm{erg/s}\right)\frac{G'}{G}$$

CGC, Ringwald, 2025 **PRELIMINARY**

Infrared Photons and Gravitons*

STEVEN WEINBERG†

Department of Physics, University of California, Berkeley, California

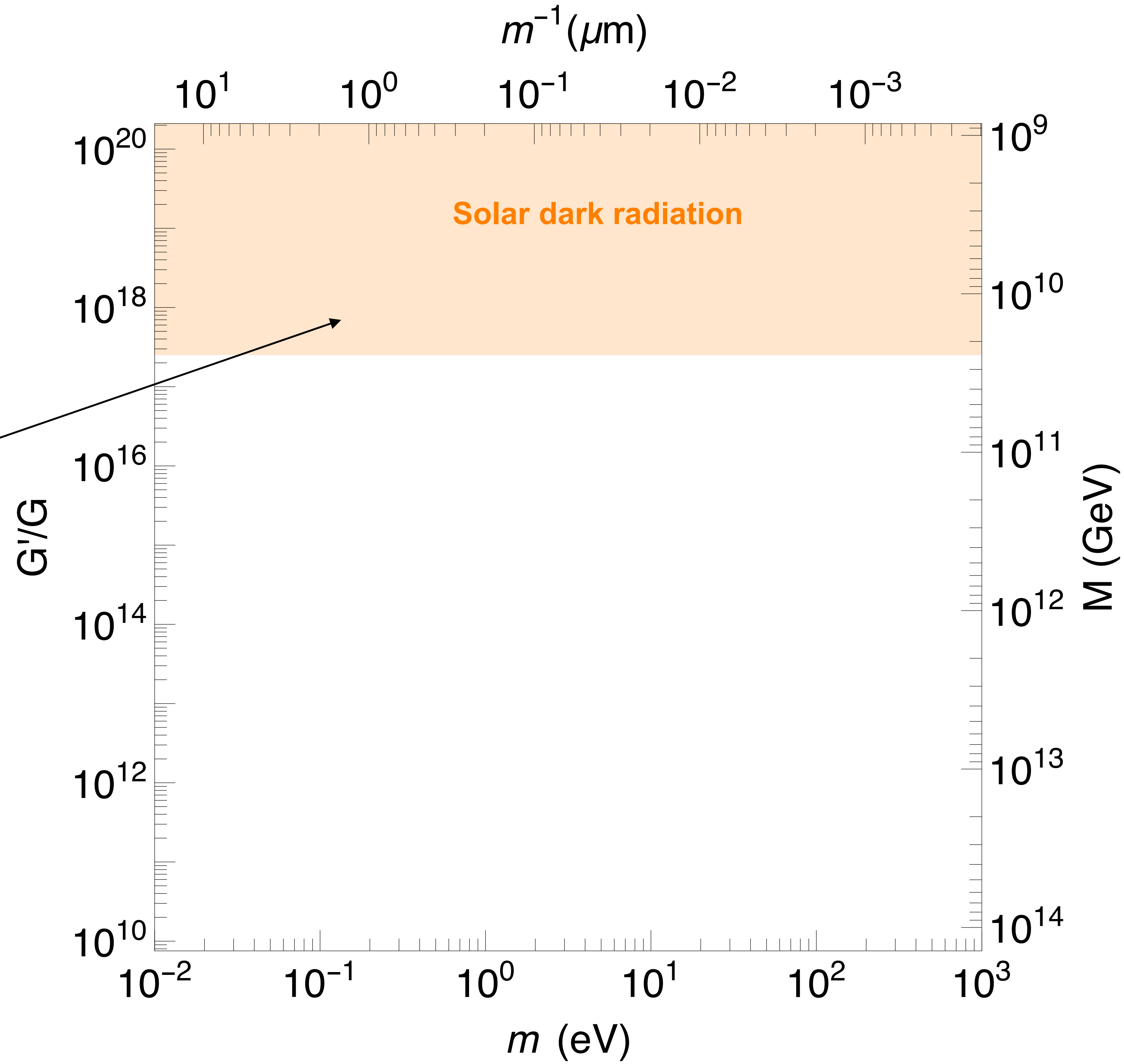
(Received 1 June 1965)

The solar gravitational radiation power is then

$$P_\odot \simeq 6\times 10^{14}\,\mathrm{erg/sec}. \quad (4.24)$$

PARAMETER SPACE OF SPIN-2 PARTICLES

Sun must not radiate more than 10% of its luminosity in non-SM particles

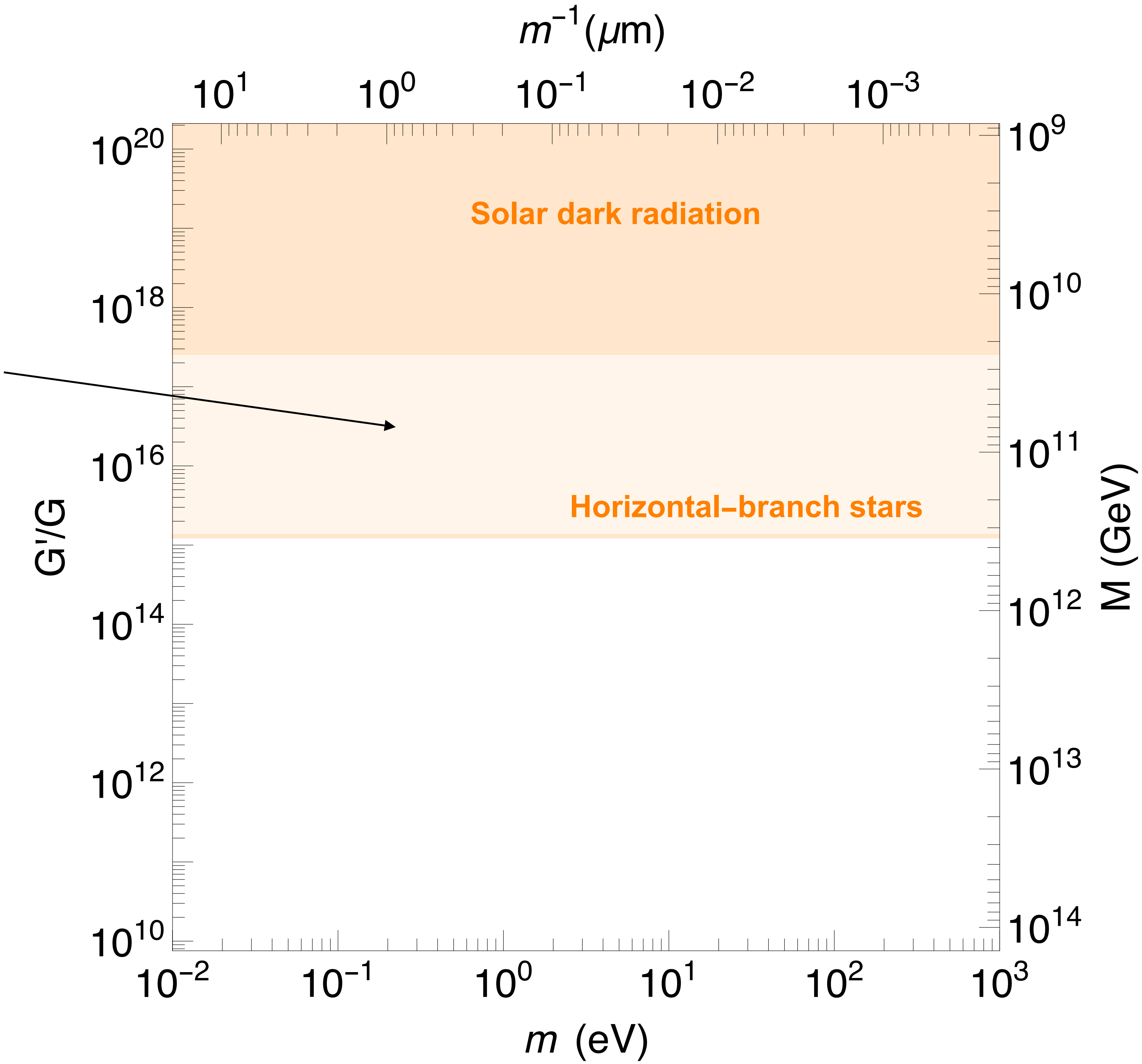


CGC, Ringwald, 2025 **PRELIMINARY**

PARAMETER SPACE OF SPIN-2 PARTICLES

In horizontal branch stars, an extra energy loss will make the star burn Helium faster. To keep the helium-burning lifetime from shrinking by more than about ten percent.

Raffelt, 1995



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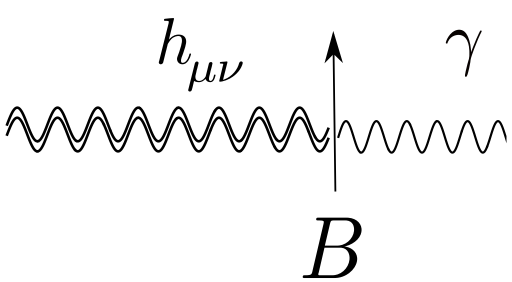

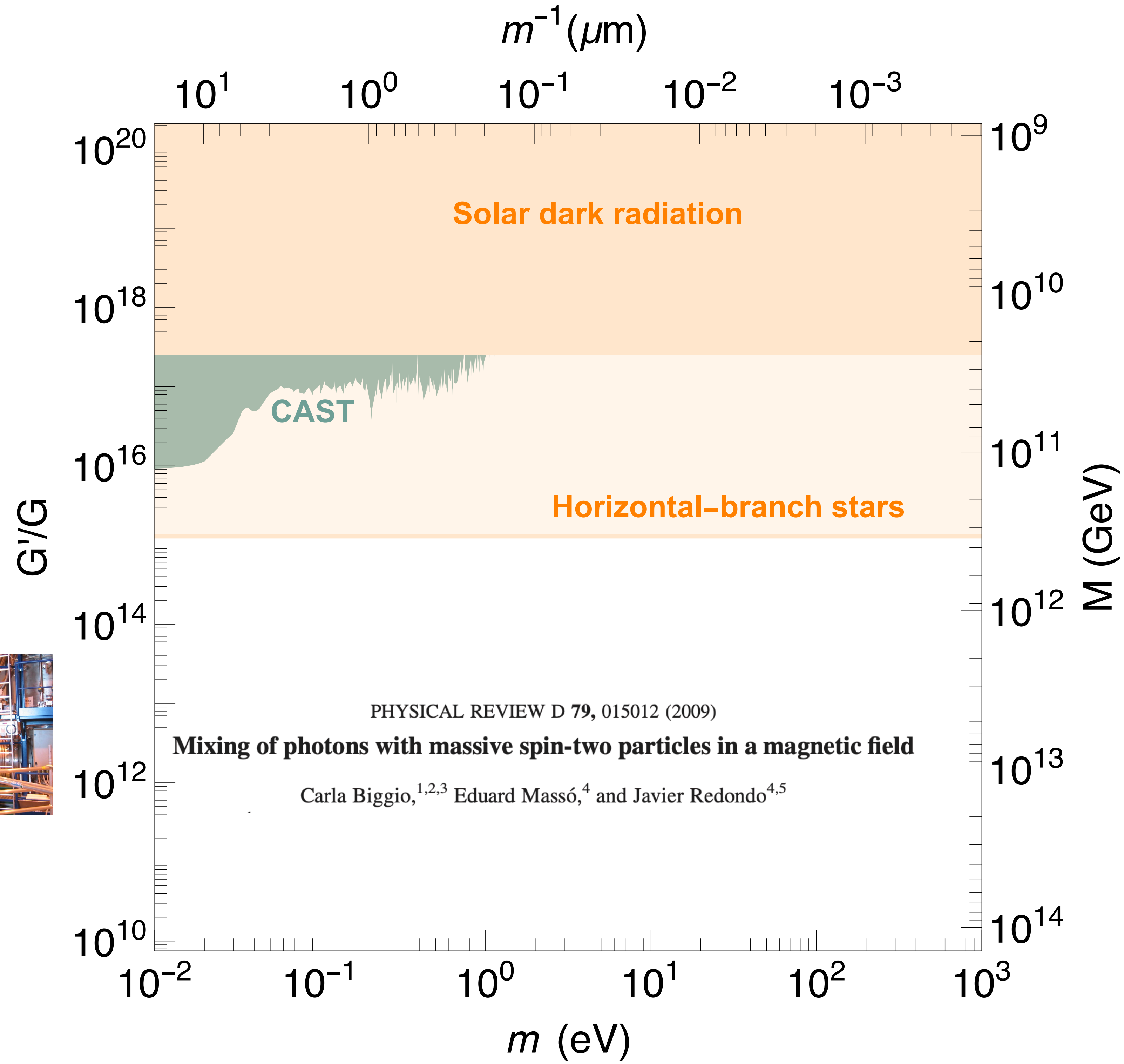

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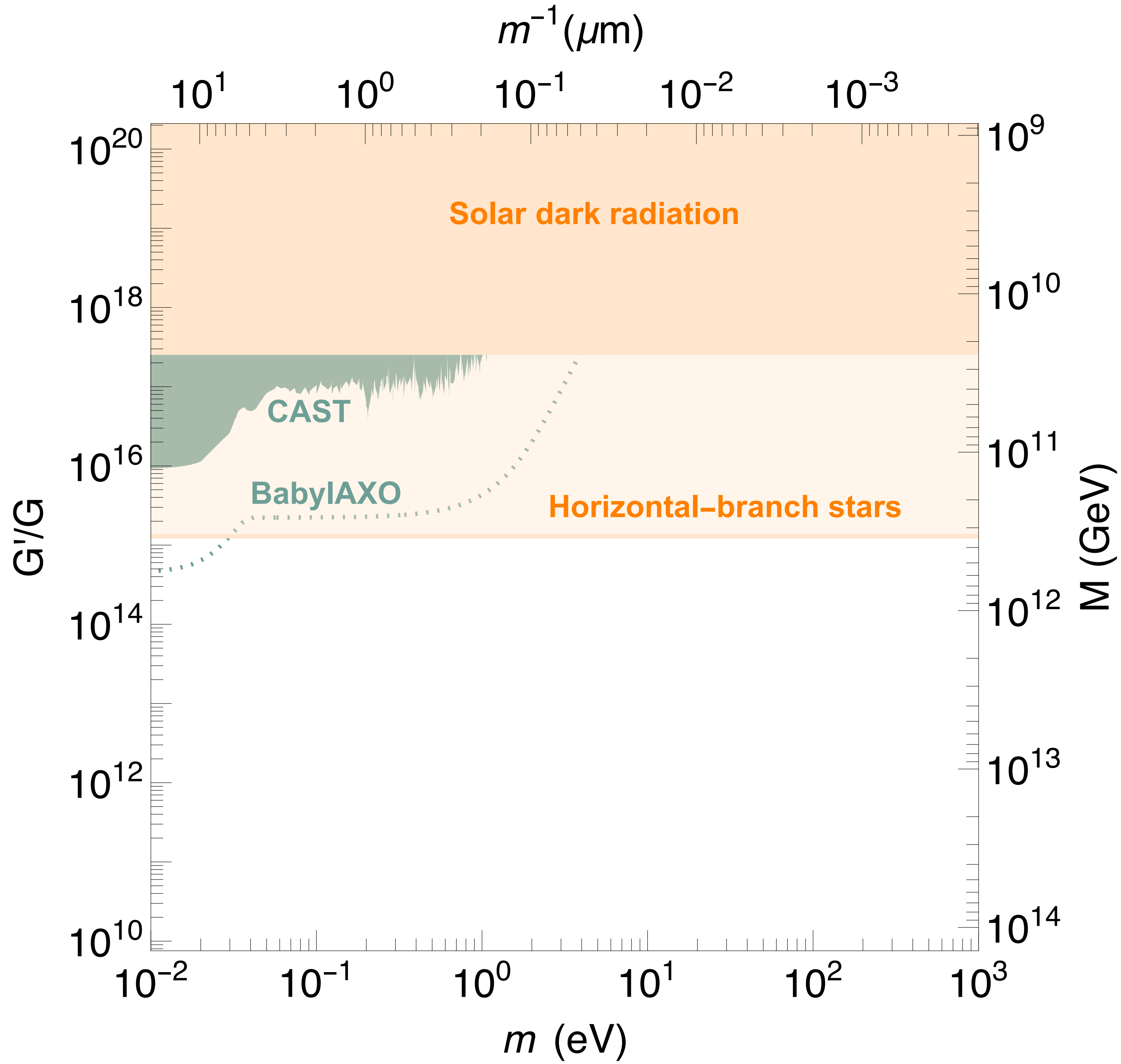

CGC, Ringwald, 2025 **PRELIMINARY**

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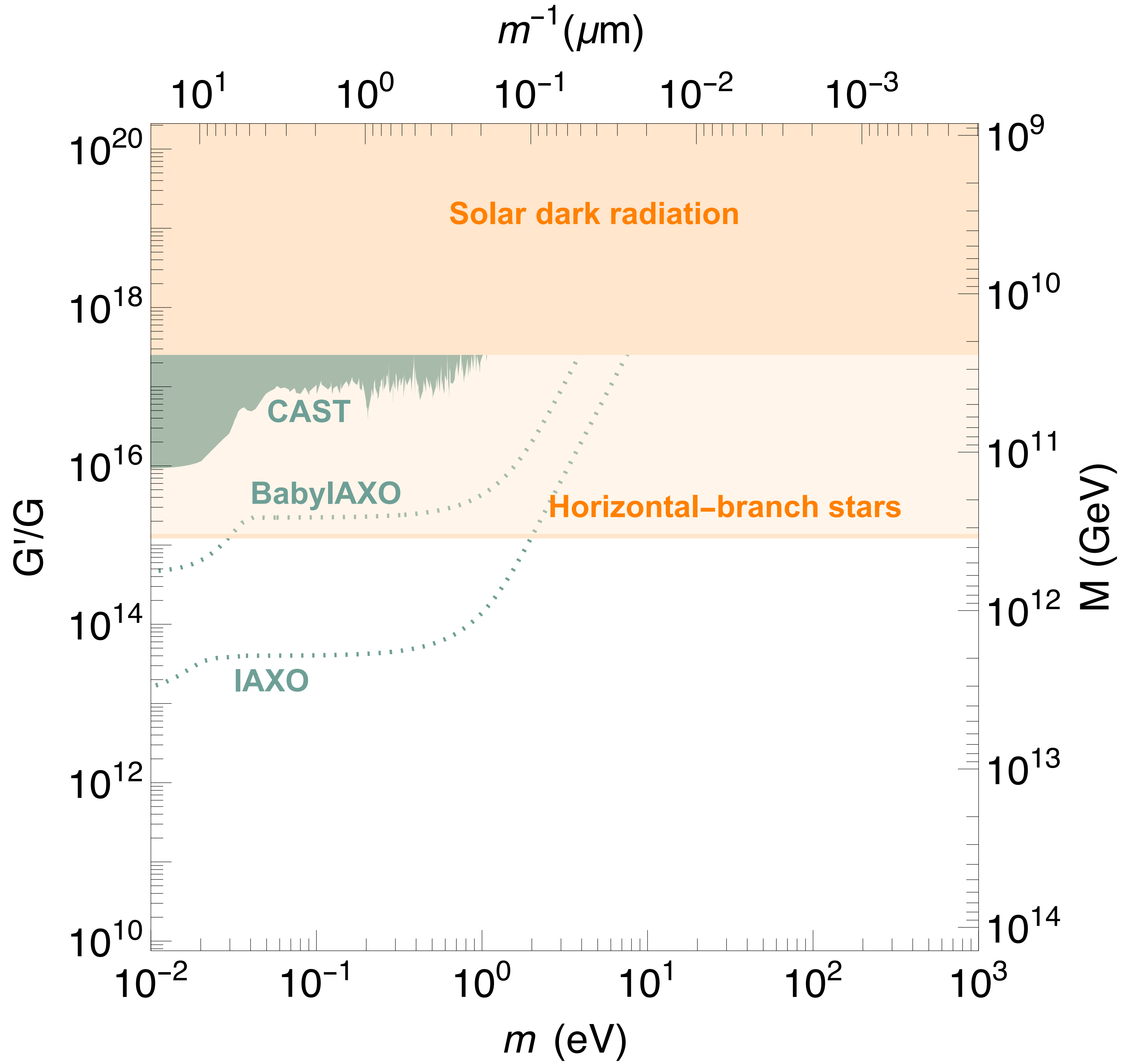

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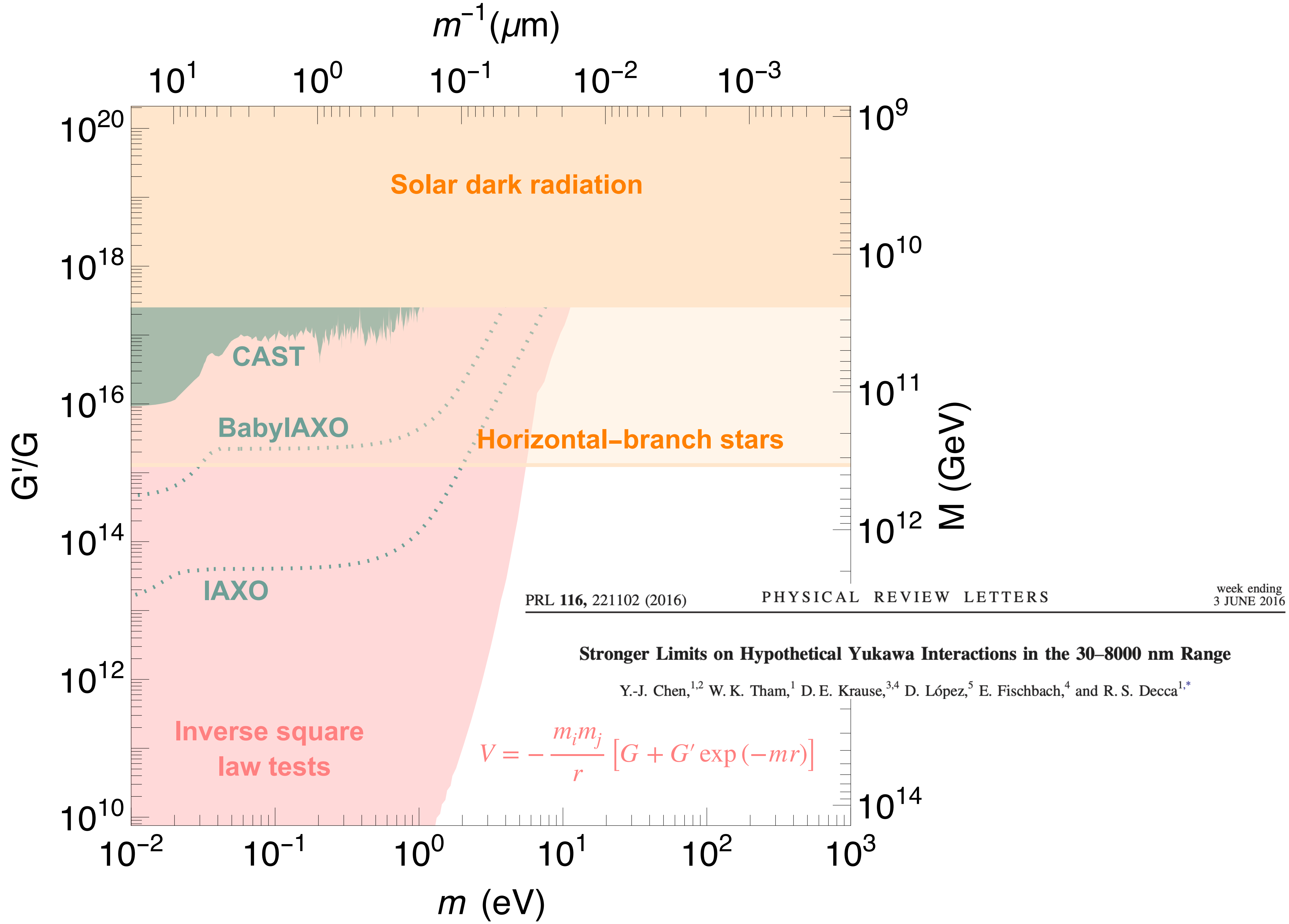

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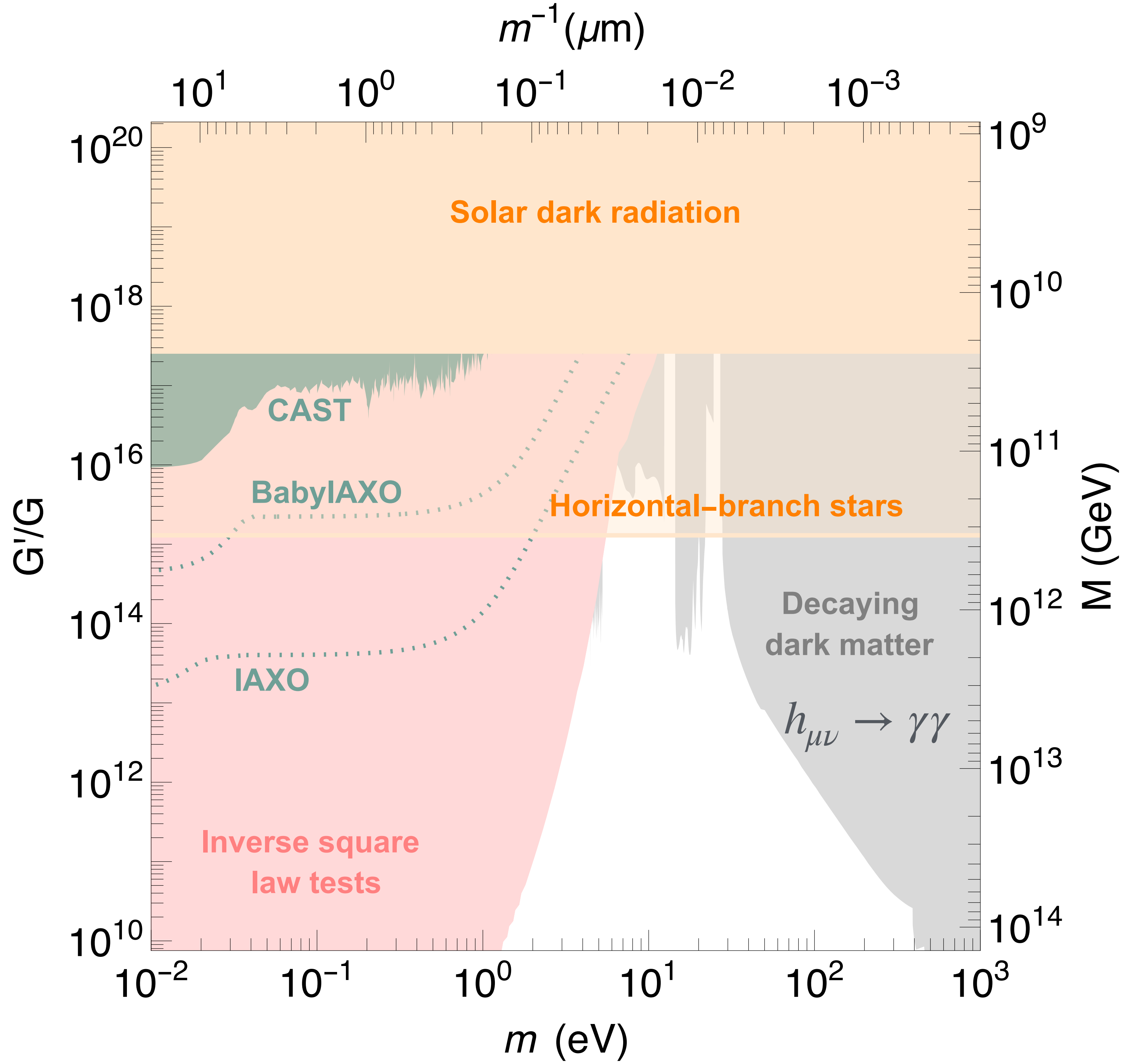

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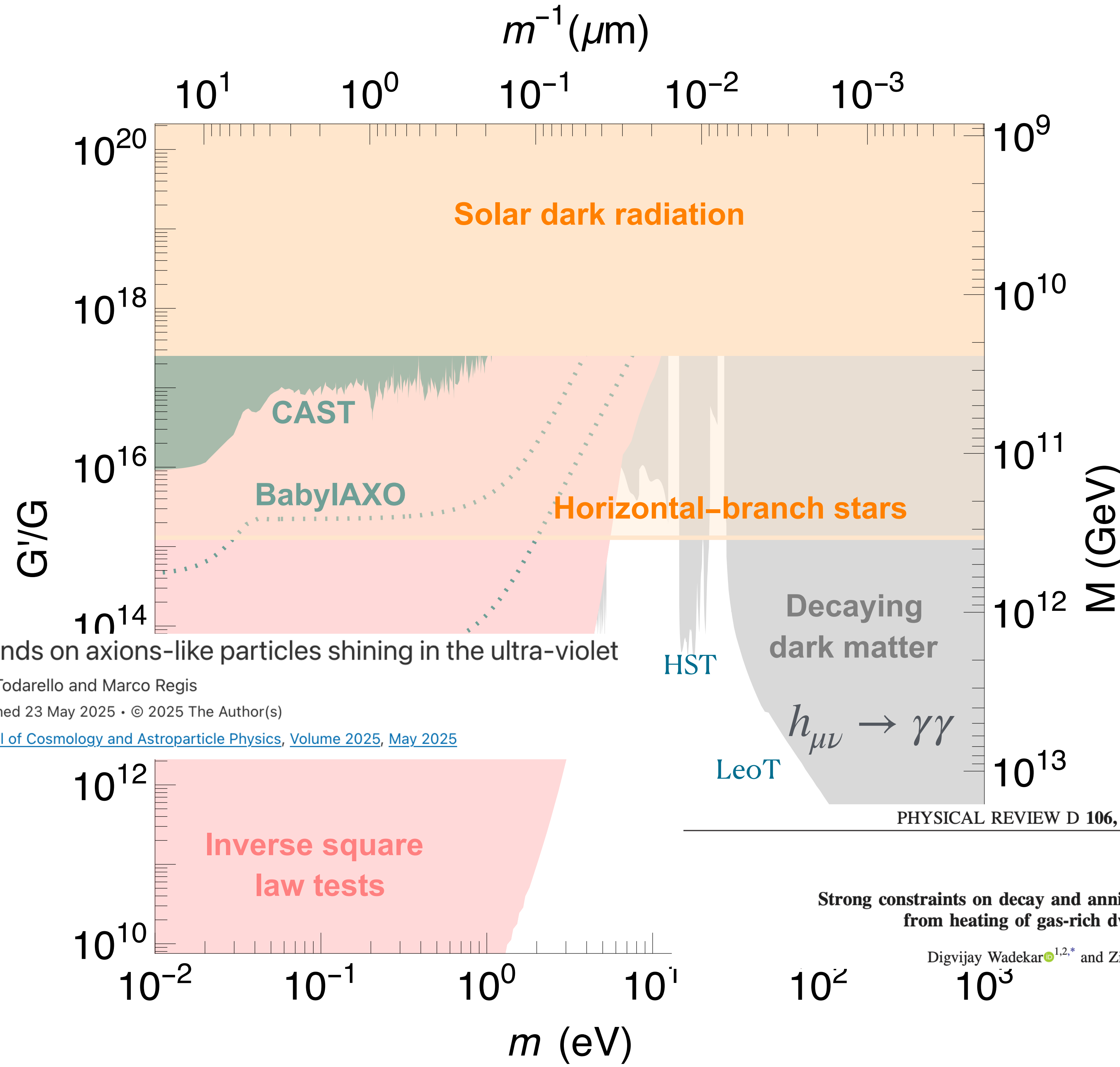

Bounds on axions-like particles shining in the ultra-violet

Elisa Todarello and Marco Regis

Published 23 May 2025 • © 2025 The Author(s)

Journal of Cosmology and Astroparticle Physics, Volume 2025, May 2025

PHYSICAL REVIEW D **106,** 075007 (2022)

Strong constraints on decay and annihilation of dark matter from heating of gas-rich dwarf galaxies

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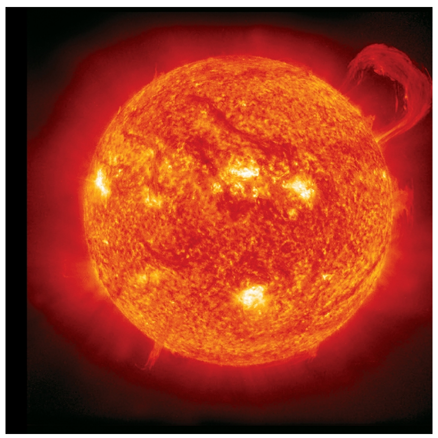
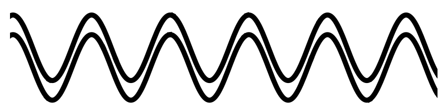
CGC, Ringwald, 2025 **PRELIMINARY**

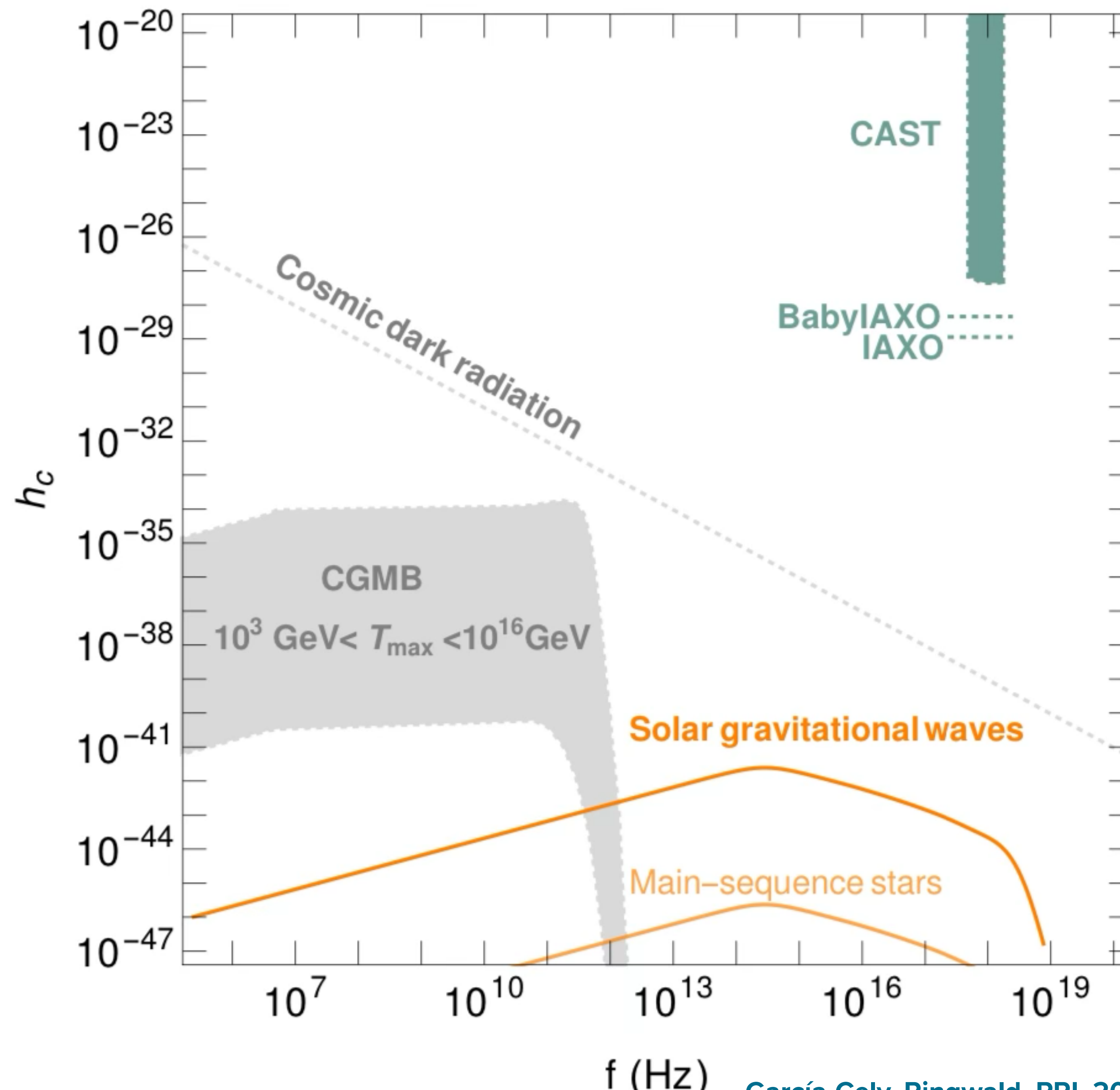
Camilo García-Cely

SOLAR GRAVITATIONAL WAVES



$$h_{\mu\nu}$$





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CONCLUSIONS

- Spin-2 particles can be emitted efficiently from the Sun through bremsstrahlung and photoproduction, providing a novel channel of “dark radiation.”

- Stellar evolution, especially the helium-burning phase of horizontal branch stars, sets strong limits on exotic energy losses, constraining the allowed parameter space of spin-2 particles.

- Solar luminosity arguments, combined with astrophysical and laboratory bounds, already probe large regions of parameter space of spin-2 particles.

- These results link solar physics, stellar evolution, and laboratory searches, showing that the Sun can serve as a laboratory for testing theories with new spin-2 states.

- There is a natural synergy with gravitational-wave physics.