Hidden Photons from the Sun

(don't need cream or sun glasses for these...)

Javier Redondo (MPP München)

Outline

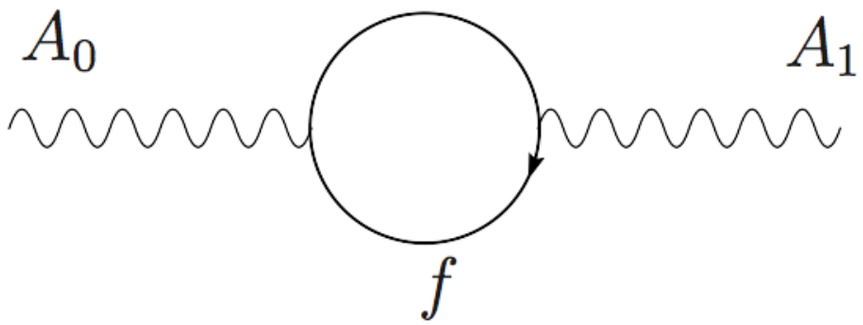
- Hidden photons: a brief motivation
- Photon oscillations
- The Sun in hidden photons
- The flux of sub eV mass HPs
- A new Helioscope: SHIPS

Hidden Photons:

what are we talking about?

Hidden Photons are gauge bosons of a local U(1) symmetry which is hidden
(SM particles are un-charged under the corresponding hidden force)(Okun 1982)

Very massive particles with both hidden and electric charge will induce kinetic mixing of HPs with standard photons. (Holdom 1986)



$$\mathcal{L}_{\rm mix} = -\frac{\sin\chi}{2} A_{\mu\nu} B^{\mu\nu}$$

$$\sin\chi = \frac{e g_B}{6\pi^2} \sum_f Q_A Q_B \,\mathrm{Log}\frac{M_f}{\mu}$$

The typical size of kinetic mixing is that of a radiative correction sim 0.001
If U(1)_em or U(1)_h are embedded in a Non abelian gauge symmetry (SU(2)...) (0.001)^2,3

These additional symmetries arise frequenctly in the most popular extensions of the SM
(such as those based on string theory)
(Dienes , Abel, Ringwald, Goodsell, Jaeckel ... even me ;-))

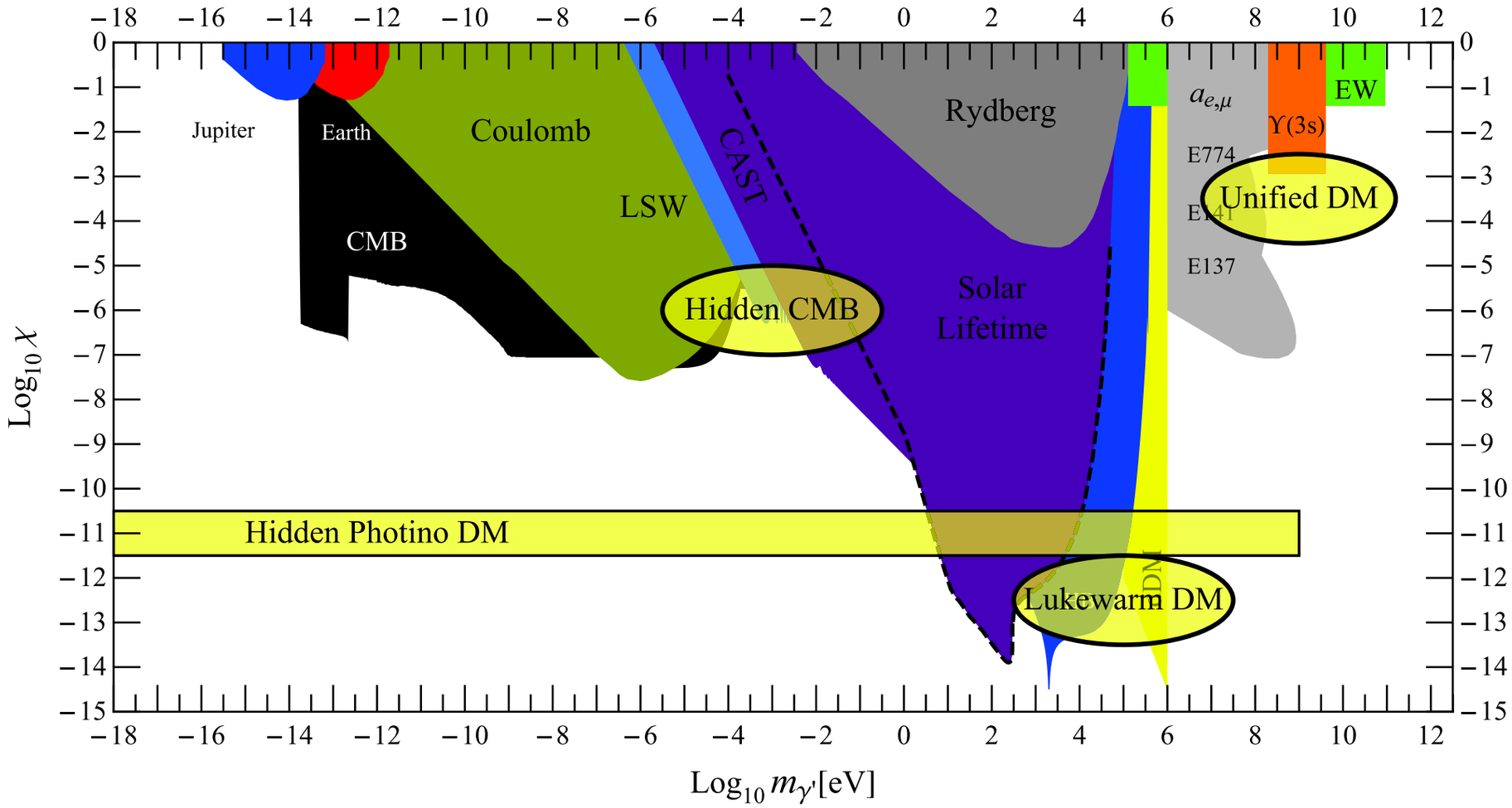
The hidden photon may acquire mass from a Stückelberg, a Higgs-like mechanism, ...
(The latter case is subject to strong constraints! see Ahlers et al. PRD78 (2008))

Hidden Photons:

what do we know?

Naturally they can interact very weakly with SM particles, they are perfect candidates for the DARK SECTOR that cosmology and astrophysics are revealing.

- Dark Matter candidates or provide Dark Forces to the DM
- Dark Radiation (extra neutrino-like particles favored by BBN and CMB probes)



Photon - HP oscillations

HPs are a very particular sort of WISP because the only way of producing them is via photon oscillations.

Due to the kinetic mixing, the INTERACTION and PROPAGATION eigenstates in (photon,HP) space, are misaligned

$$-\frac{1}{4}A_{\mu\nu}A^{\mu\nu} + ej_\mu A^\mu \quad -\frac{\sin\chi}{2}A_{\mu\nu}B^{\mu\nu} \qquad -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}m^2_{\gamma'}B_\mu B^\mu$$

$$A^\mu \equiv \tilde{A}^\mu - \sin\chi B^\mu \simeq \tilde{A}^\mu - \chi B^\mu$$

$$-\frac{1}{4}\tilde{A}_{\mu\nu}\tilde{A}^{\mu\nu} \quad ej_\mu(\tilde{A}^\mu - \chi B^\mu) \qquad -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}m^2_{\gamma'}B_\mu B^\mu$$

We can define a linear combination that is STERILE to EM interactions (and the rest...)

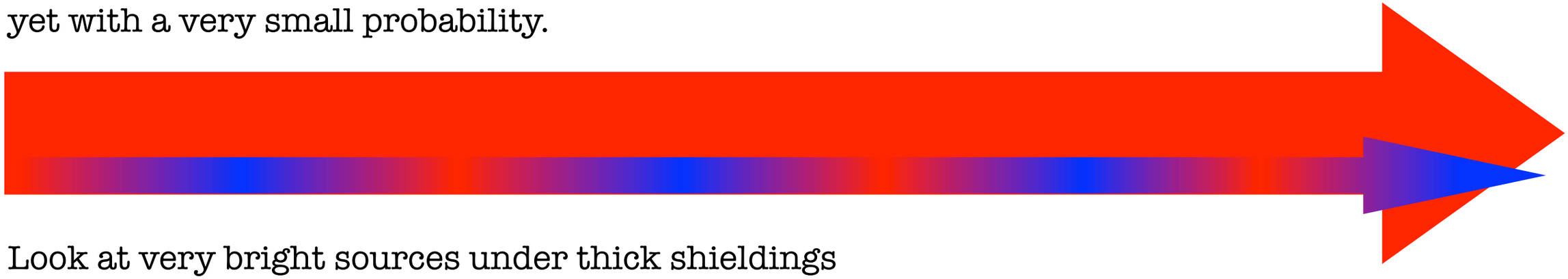
$$A' = \chi\tilde{A} + B$$

$$P(\gamma \to \gamma') = 4\chi^2 \times \sin^2 \frac{m^2_{\gamma'}L}{4\omega}$$

Hidden Photons:

where to look at...

Photons convert into an sterile form of radiation as they propagate,
yet with a very small probability.

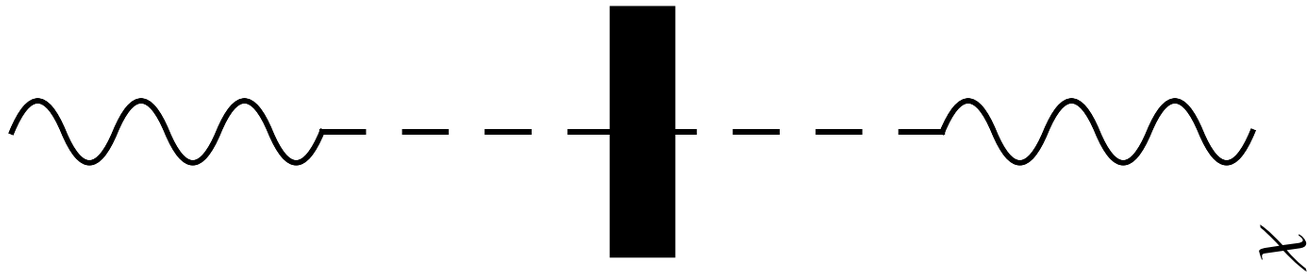


Look at very bright sources under thick shieldings

Light shining through walls (LSW) experiments (ALPS, BMV, LIPSS ...)

ALPS

Ehret et al. 2010



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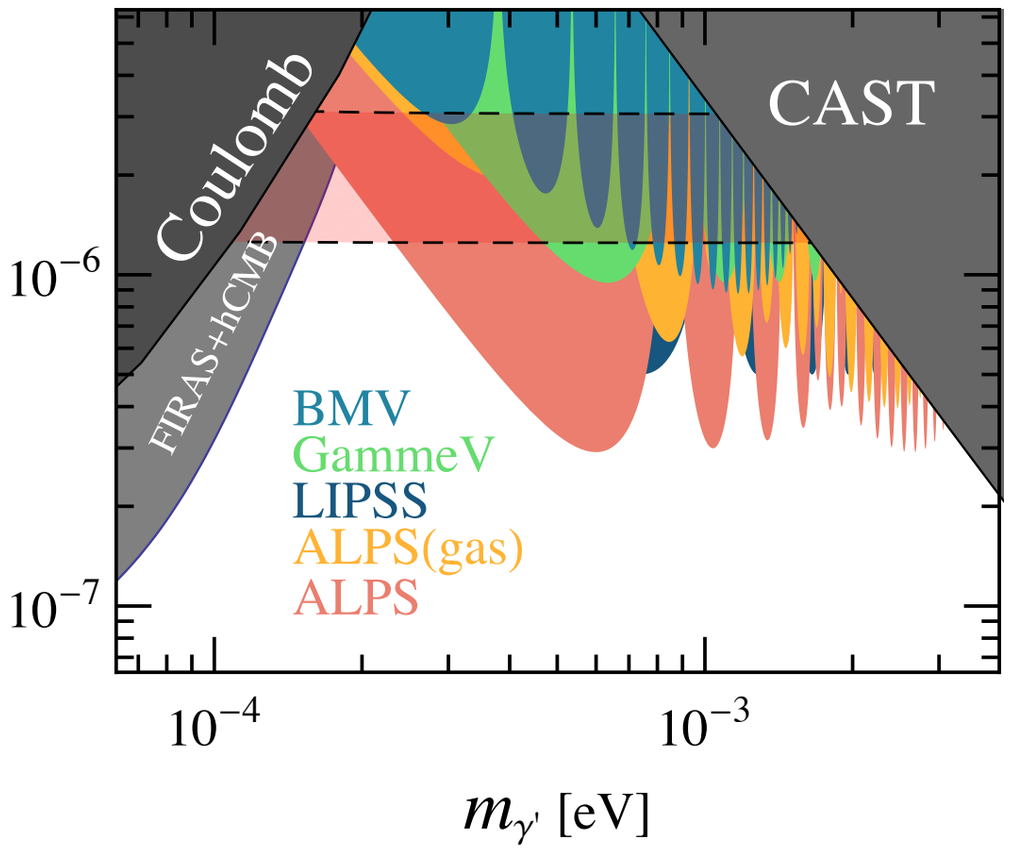
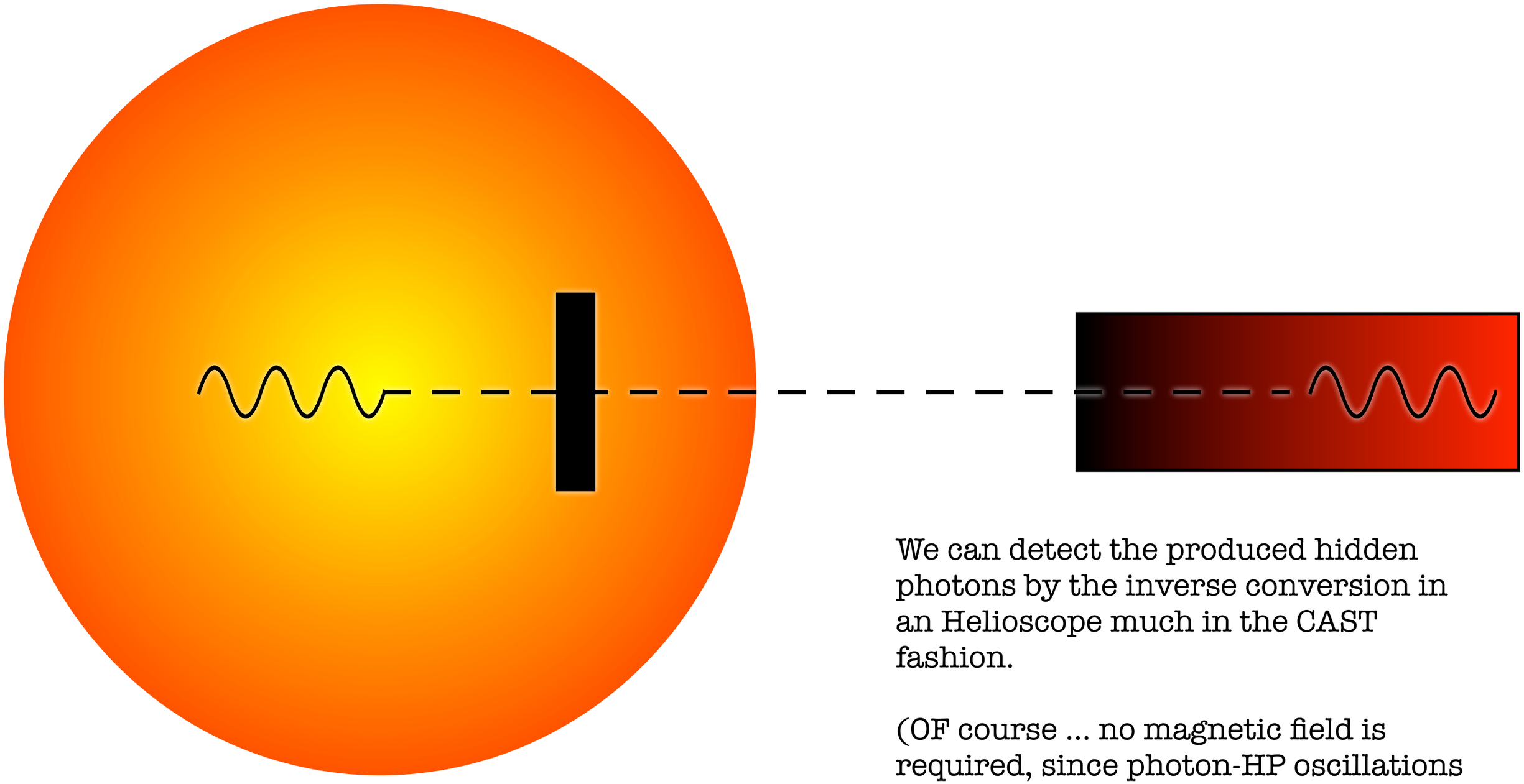


Hidden Photons:

where to look at...

The Sun is filled with photons willing to scape from such an ungodly environment

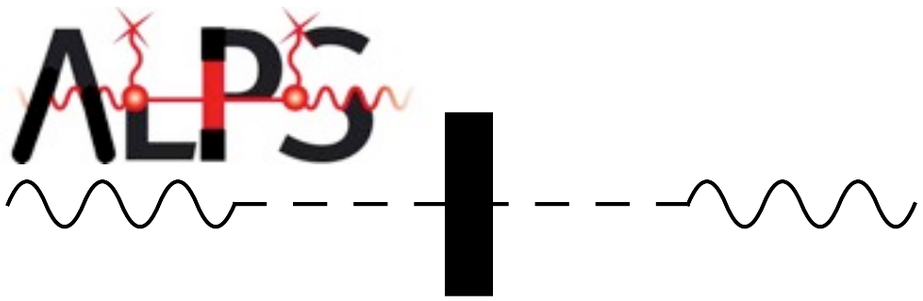


We can detect the produced hidden photons by the inverse conversion in an Helioscope much in the CAST fashion.

(OF course ... no magnetic field is required, since photon-HP oscillations happen in vacuum)

Hidden Photons:

LSW vs. Sun



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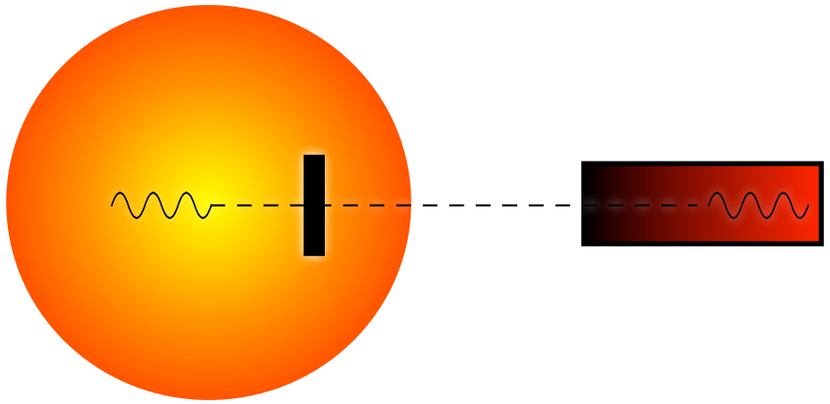

Lets compare with a LSW experiment: ALPS

ALPS: 1200 Watt of visible light

Sun: cannot afford loosing more than 10% of his photon luminosity (3.84 10^26 Watt)
in a new kind of exotic radiation (Gondolo&Raffelt 2009)
(otherwise the neutrino flux would exceed the measured values)

3.84 10^25 Watt but the solid angle is only (1/150 10^9)^2/4 pi for 1 m^2 telescope

Hidden Photons:

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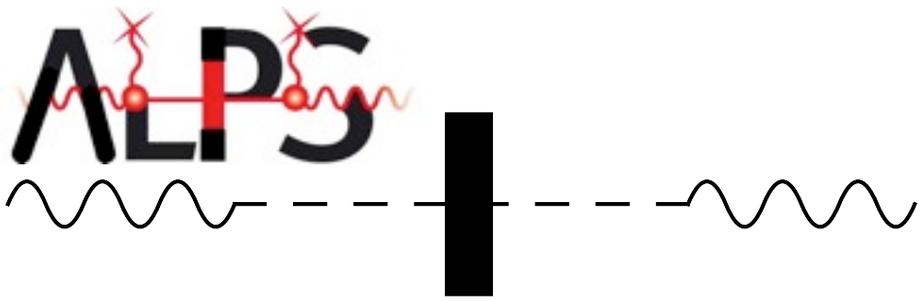

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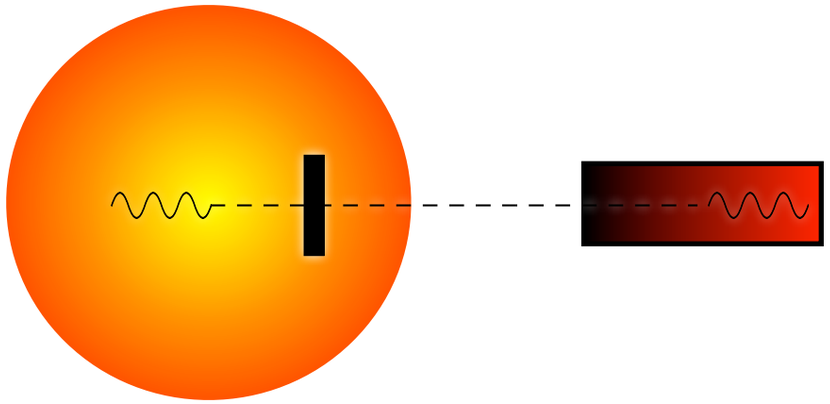

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Effectively, the Sun can provide
up to 140 W of HIDDEN PHOTON power
without contradicting solar dynamics.

Oscillations in a dense medium ... (Matter effects matter)

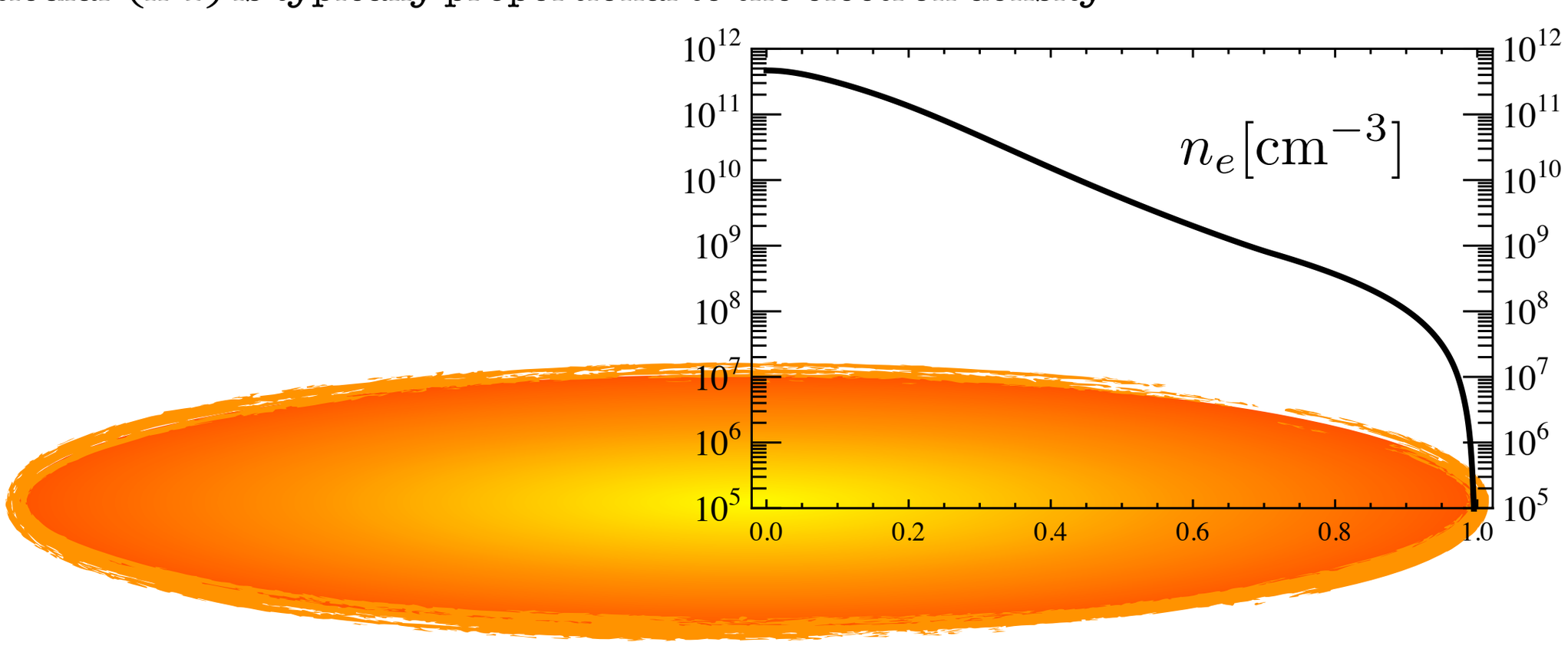
In a dense medum, refraction and absorption properties of photons

$$m_\gamma^2 + i\omega\Gamma \equiv -2\omega^2(n-1)$$

affect the conversion probability (no more an oscillation)

$$P(\gamma \to \gamma') = \frac{m_{\gamma'}^4}{(m_{\gamma'}^2 - m_\gamma^2)^2 + (\omega\Gamma)^2}$$

In particular (n-1) is typically proportional to the electron density



Oscillations in a dense medium ... (Matter effects matter)

Whenever ionization is not important (solar interior)

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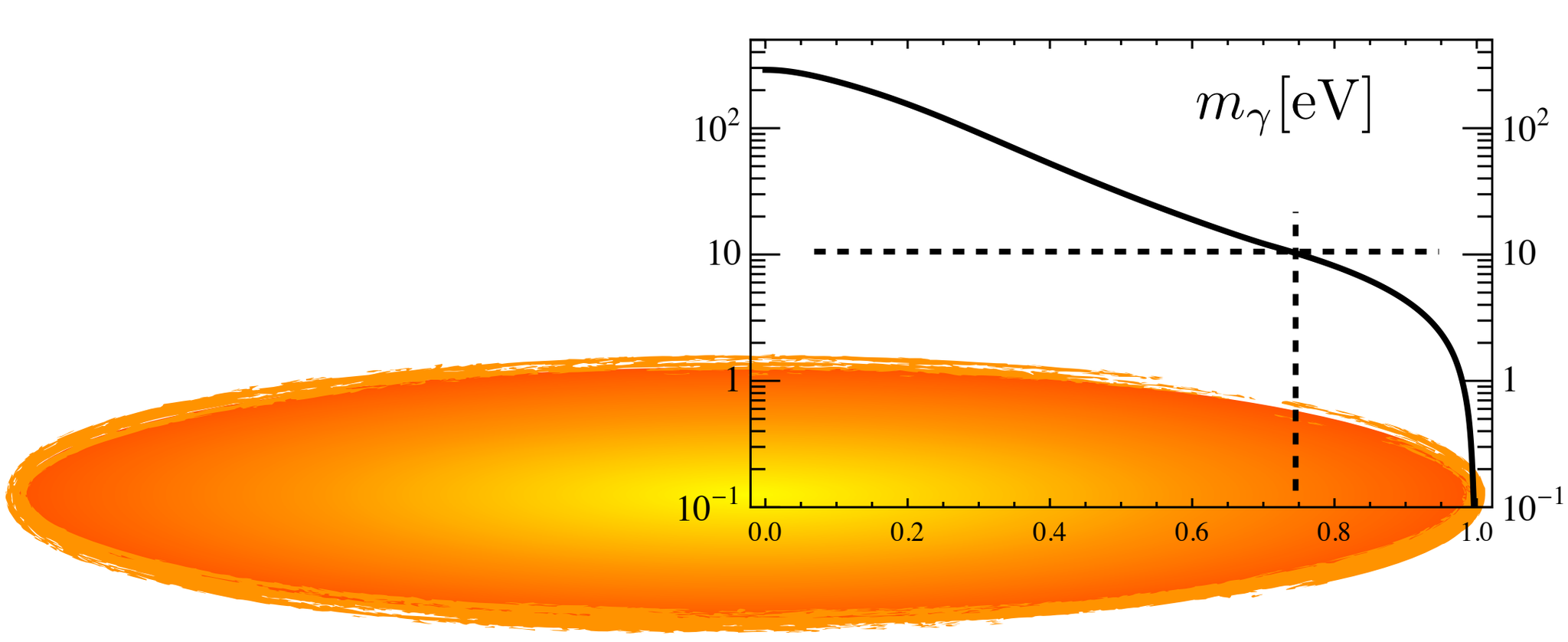

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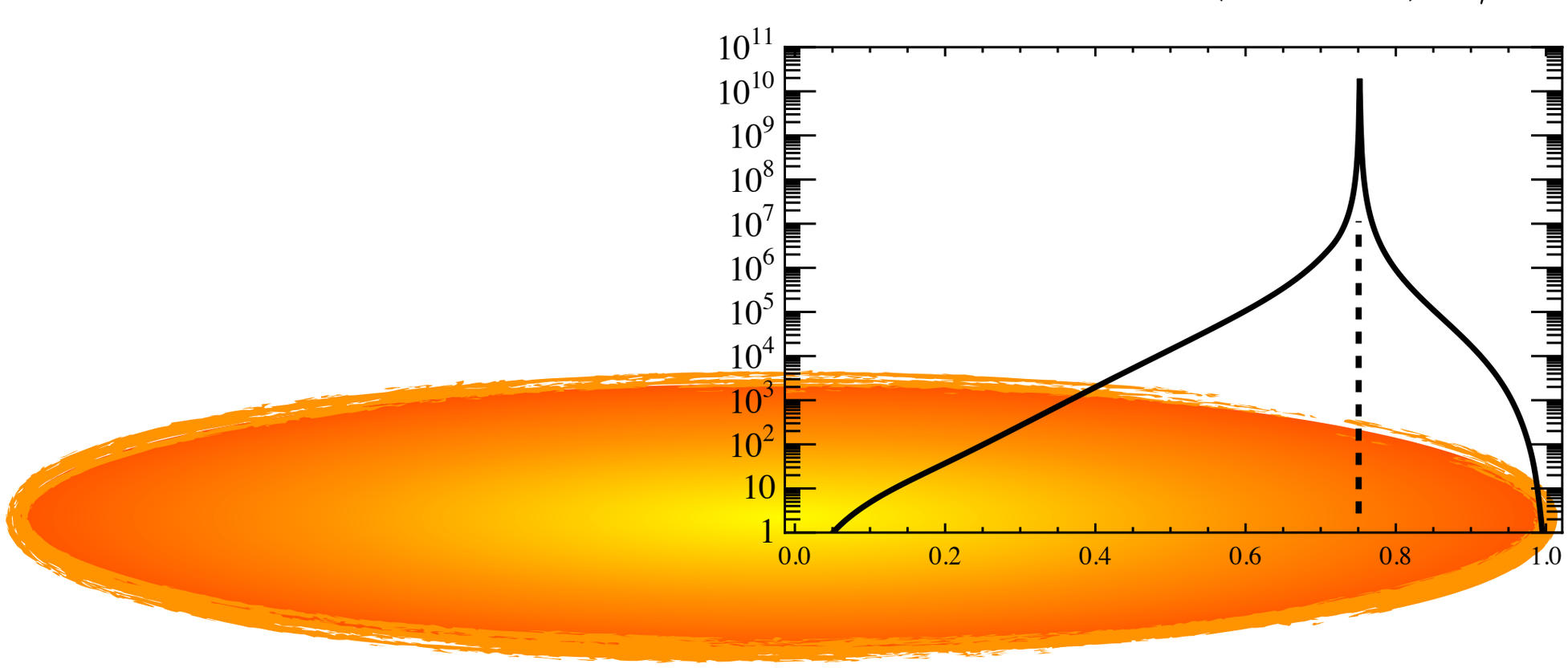

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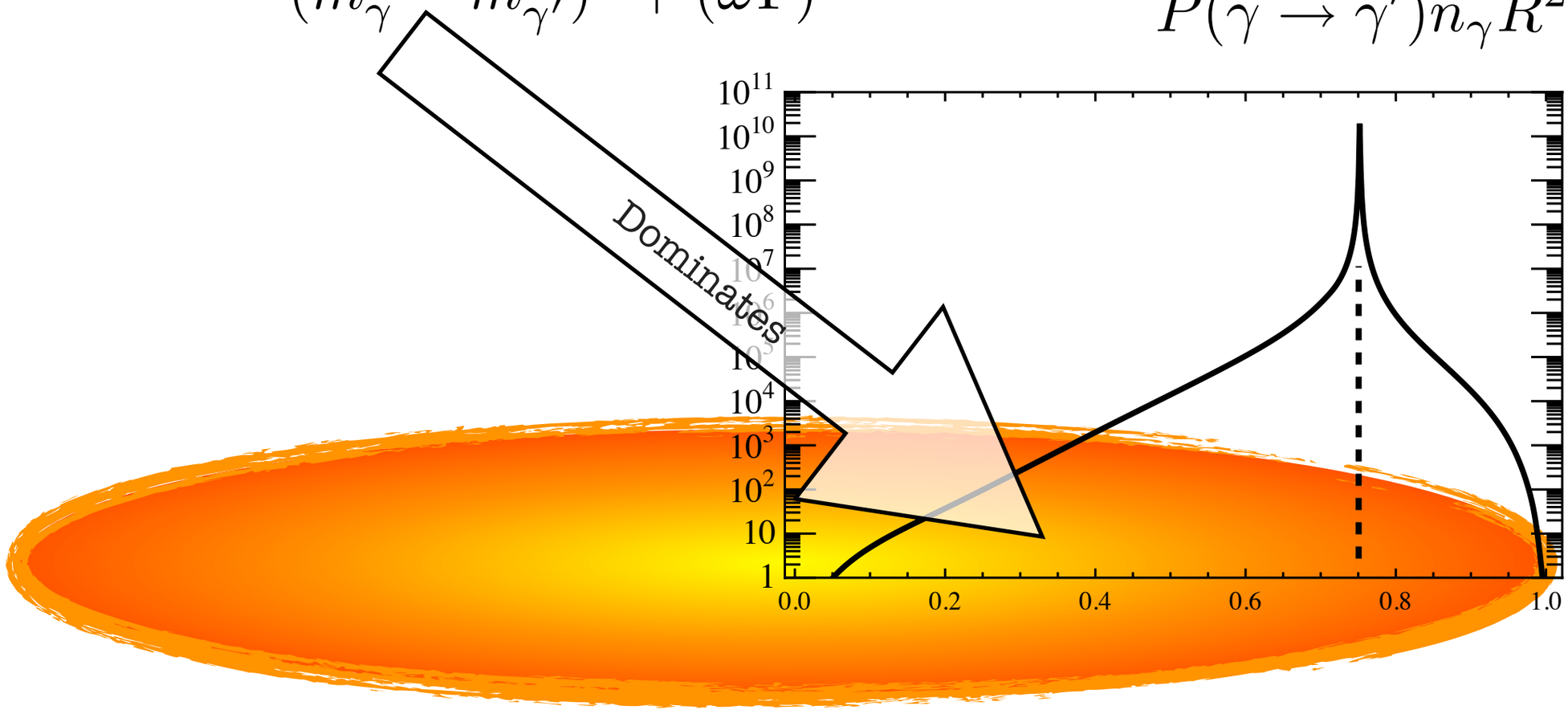

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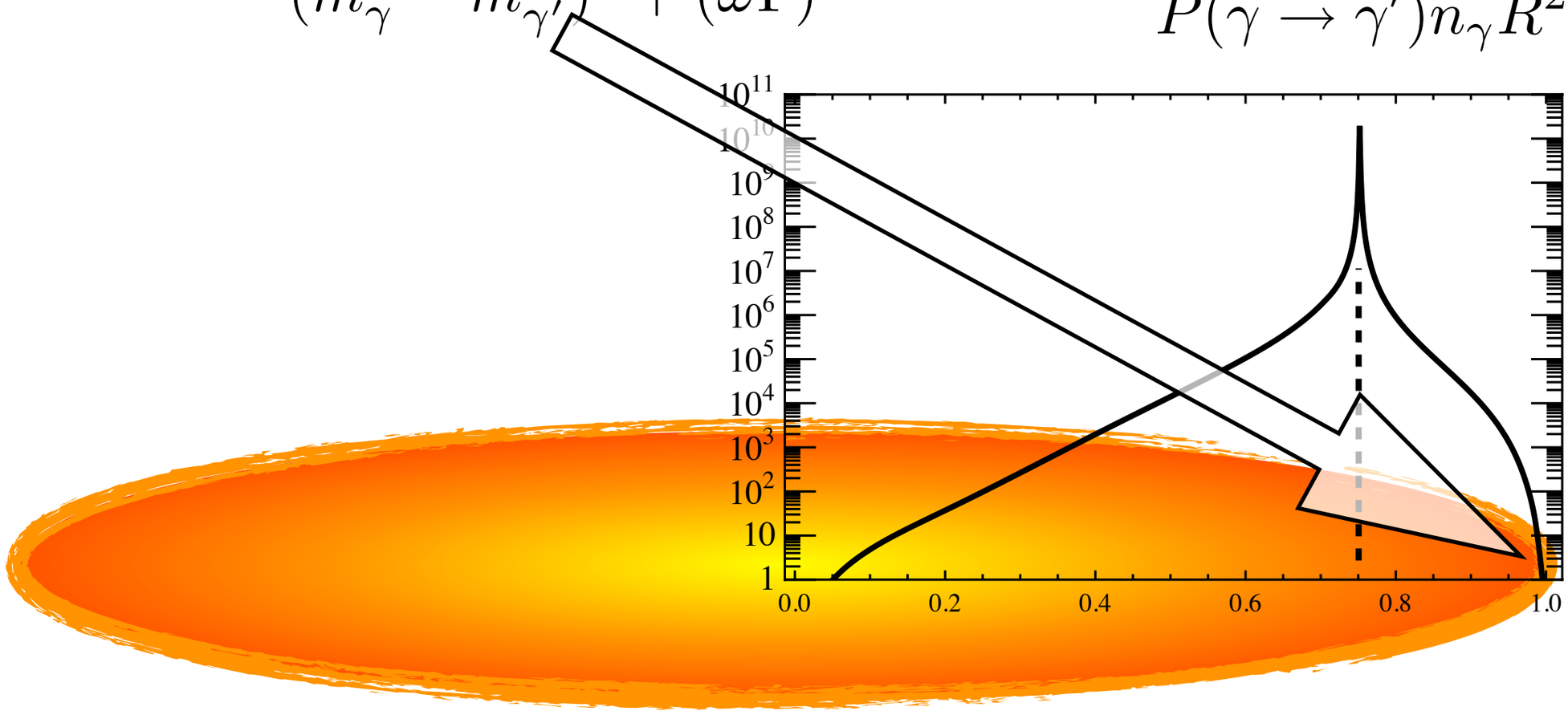

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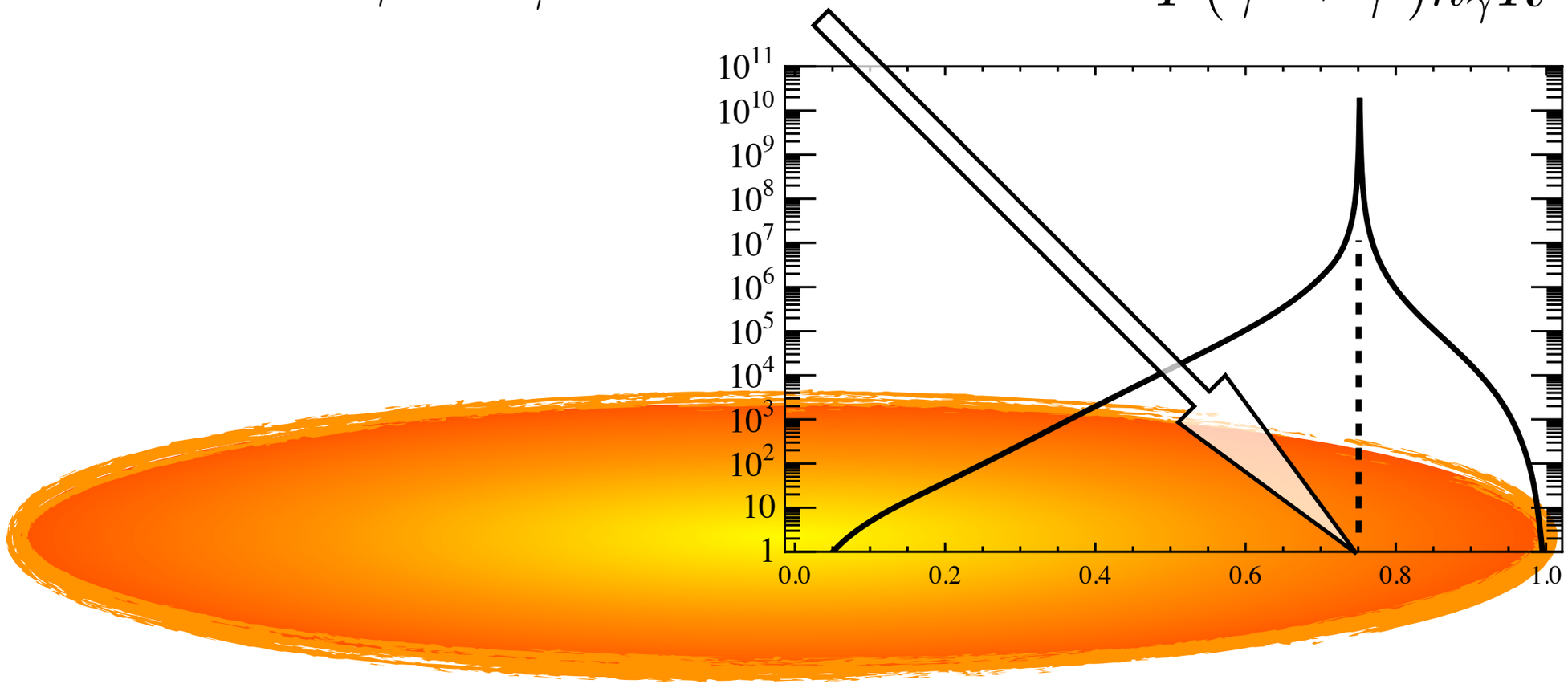

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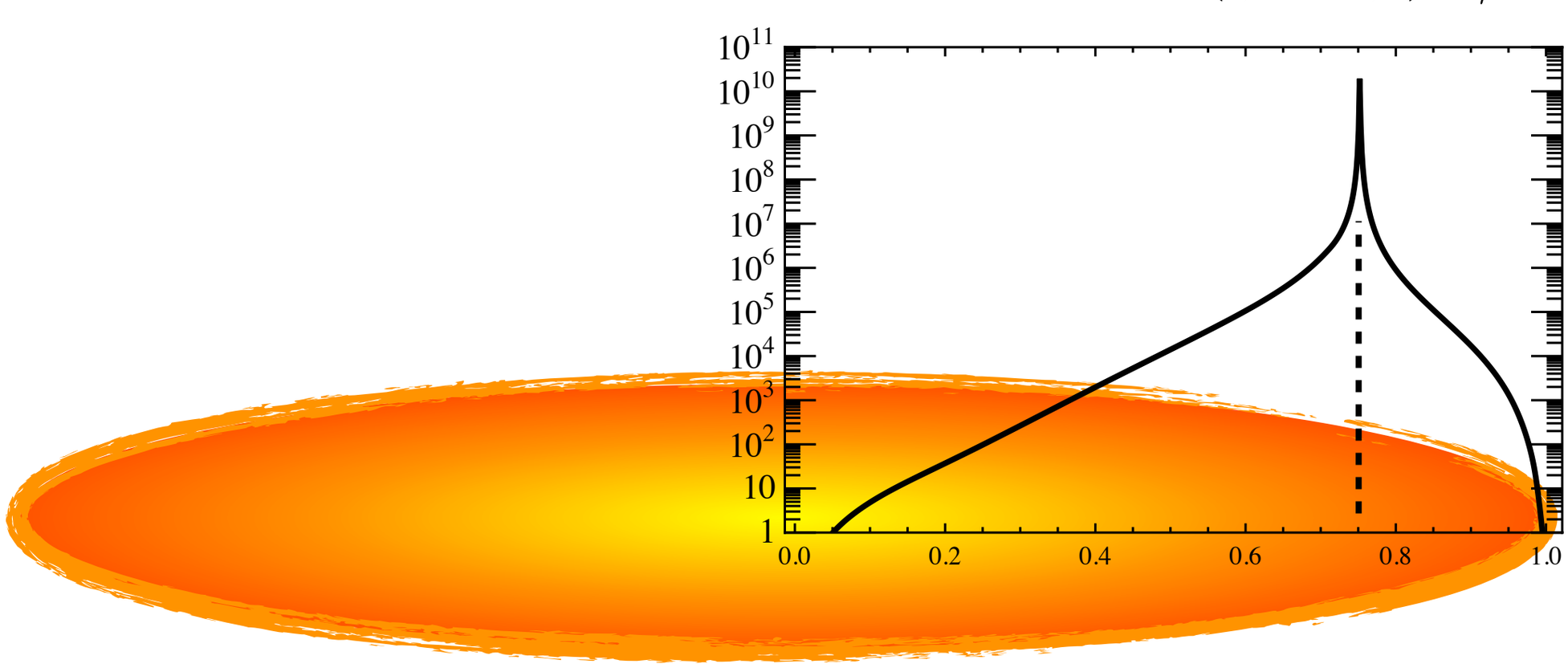


Resonant production

... (resonance matters)

Linearizing the Sun density profile (sharp resonance) the HP flux is analytical

$$\frac{d\Phi_{\gamma'}}{d\omega} = \frac{1}{4\pi R^2_{\rm earth}} \int_0^{R_\odot} 4\pi R^2 dR \frac{1}{\pi^2} \frac{\omega\sqrt{\omega^2 - m^2_{\gamma'}}}{e^{\frac{\omega}{T}} - 1} \frac{\chi^2 m^4_{\gamma'}}{(m^2_\gamma - m^2_{\gamma'})^2 + (\omega\Gamma)^2}\Gamma$$

$$\simeq 2\frac{R^2_*}{R^2_{\rm earth}} \frac{\chi^2 m^4_{\gamma'}}{\omega\frac{dm^2_\gamma}{dR}} \frac{\omega\sqrt{\omega^2 - m^2_{\gamma'}}}{\pi^2(e^{\frac{\omega}{T}} - 1)}$$

and it does NOT DEPEND on the absorption coeficient!!

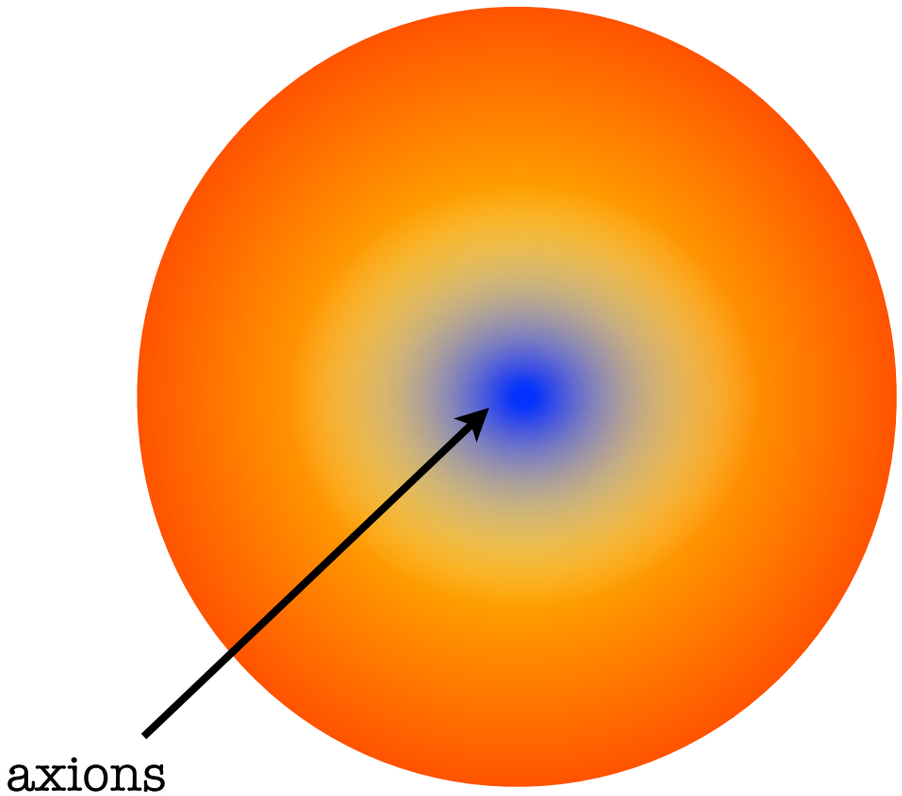
$$\frac{\chi^2 m^4_{\gamma'}}{\omega\frac{dm^2_\gamma}{dR}} \simeq \frac{\chi^2 m^2_{\gamma'} R_\odot}{(100 - 1000)\omega}$$

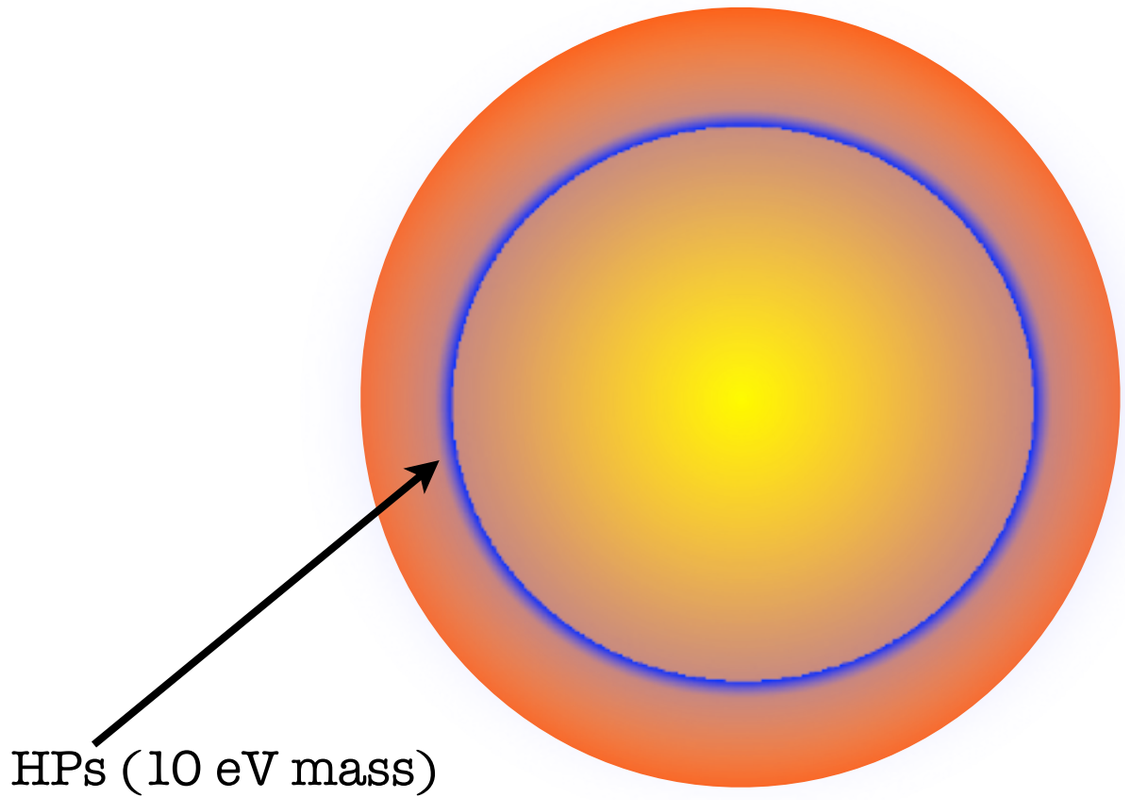
Photon distribution
(with HP threshold)

The Sun in hidden photons

... (resonance matters)

- The resonance typically dominates
- The predictions are extremely different to solar axions





Possibility from determining their mass directly from the region of emission

The Sun in hidden photons

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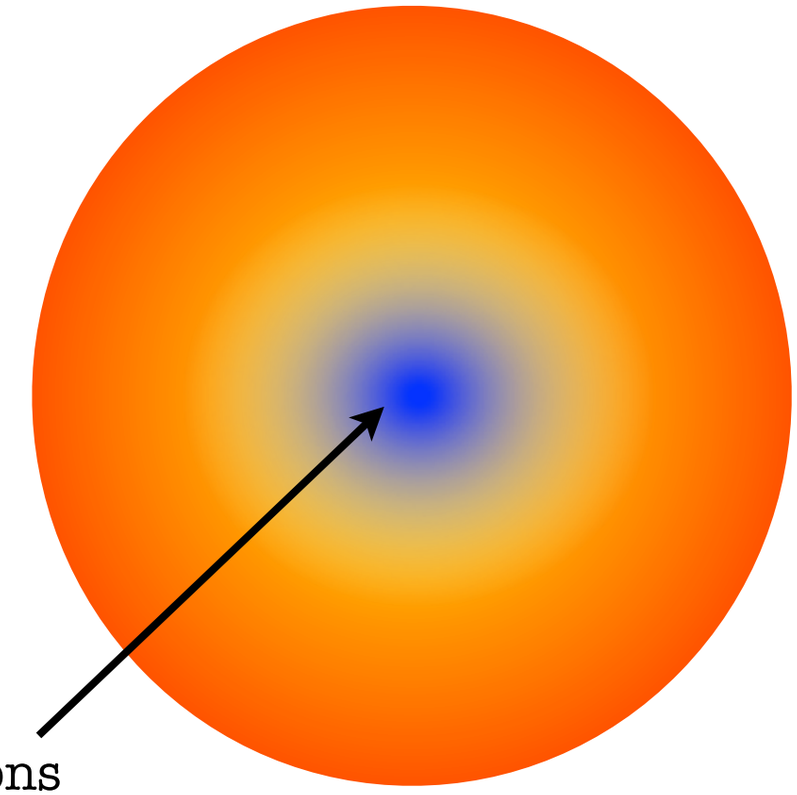

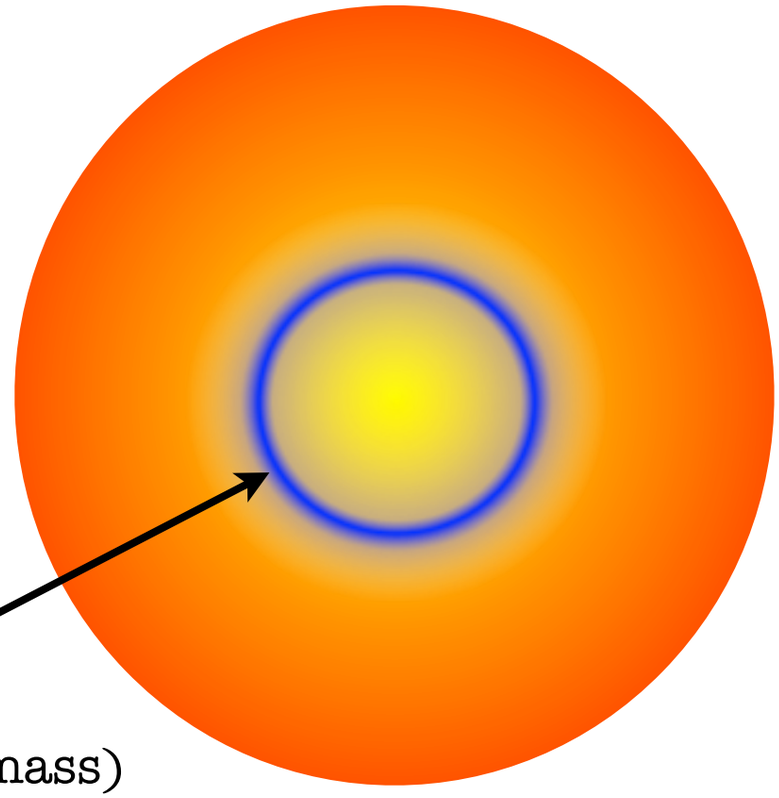

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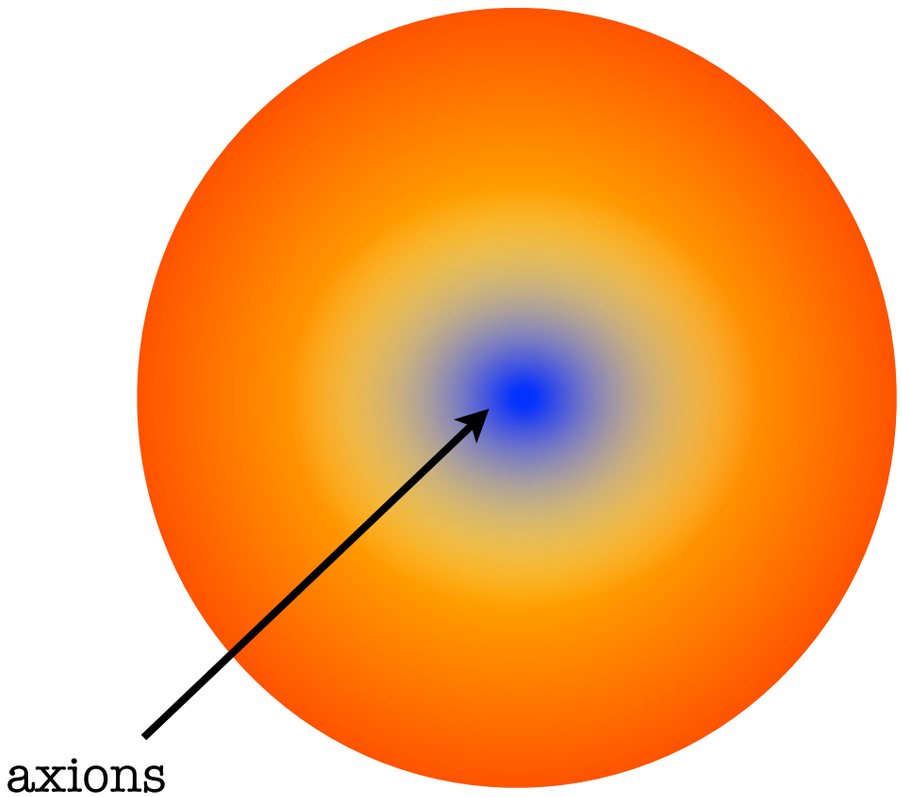
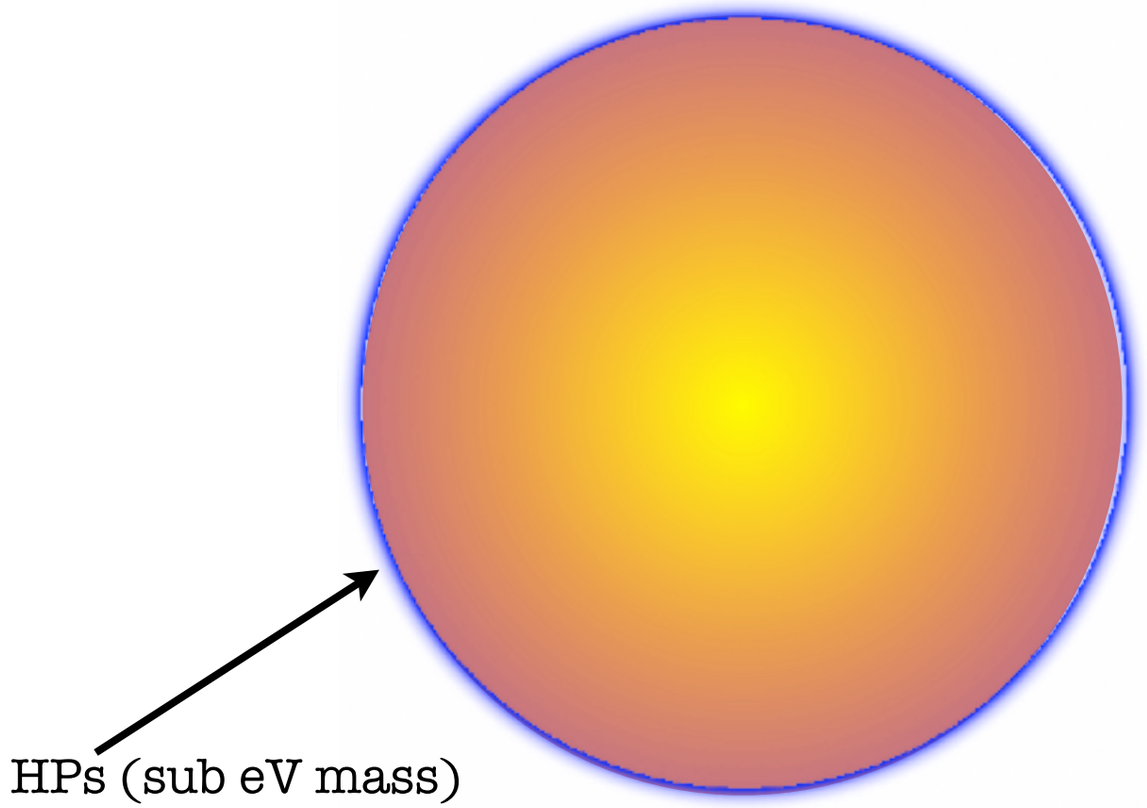
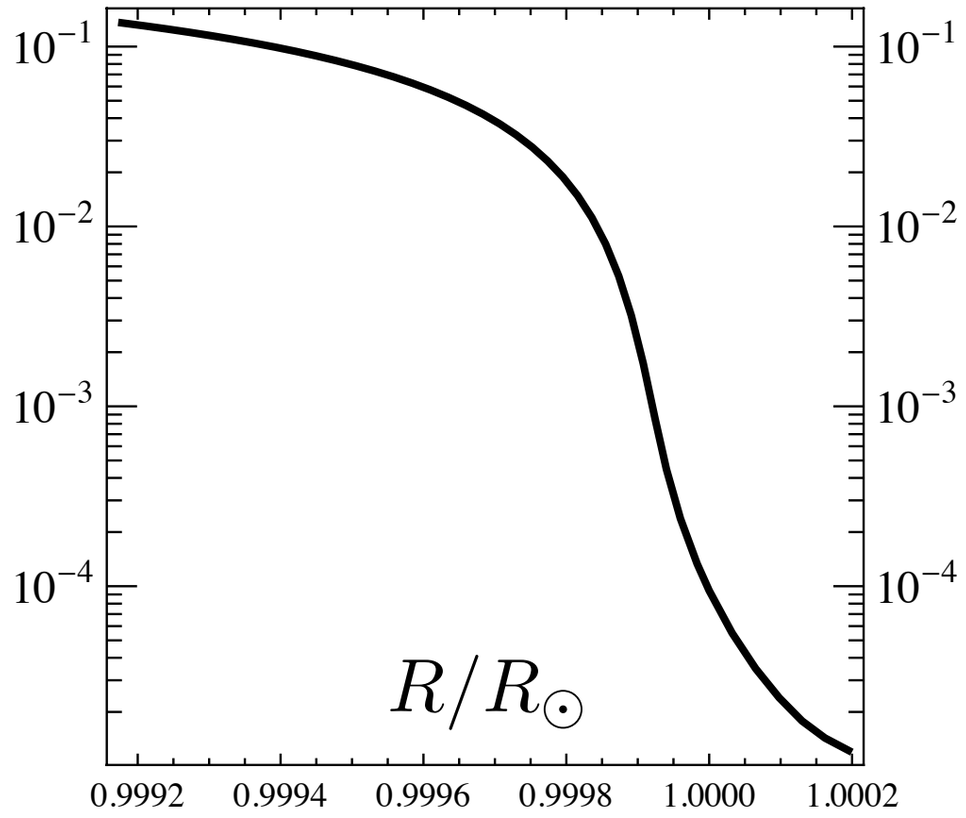




Sub eV Hidden Photons ... (photospheric nightmare)

Sub eV HPs will be produced resonantly in the outer layers of the Sun when ionization is not complete.

$$\frac{p^+}{H^0 + p^+}$$



Photon propagation is affected by FREE and BOUNDED electrons

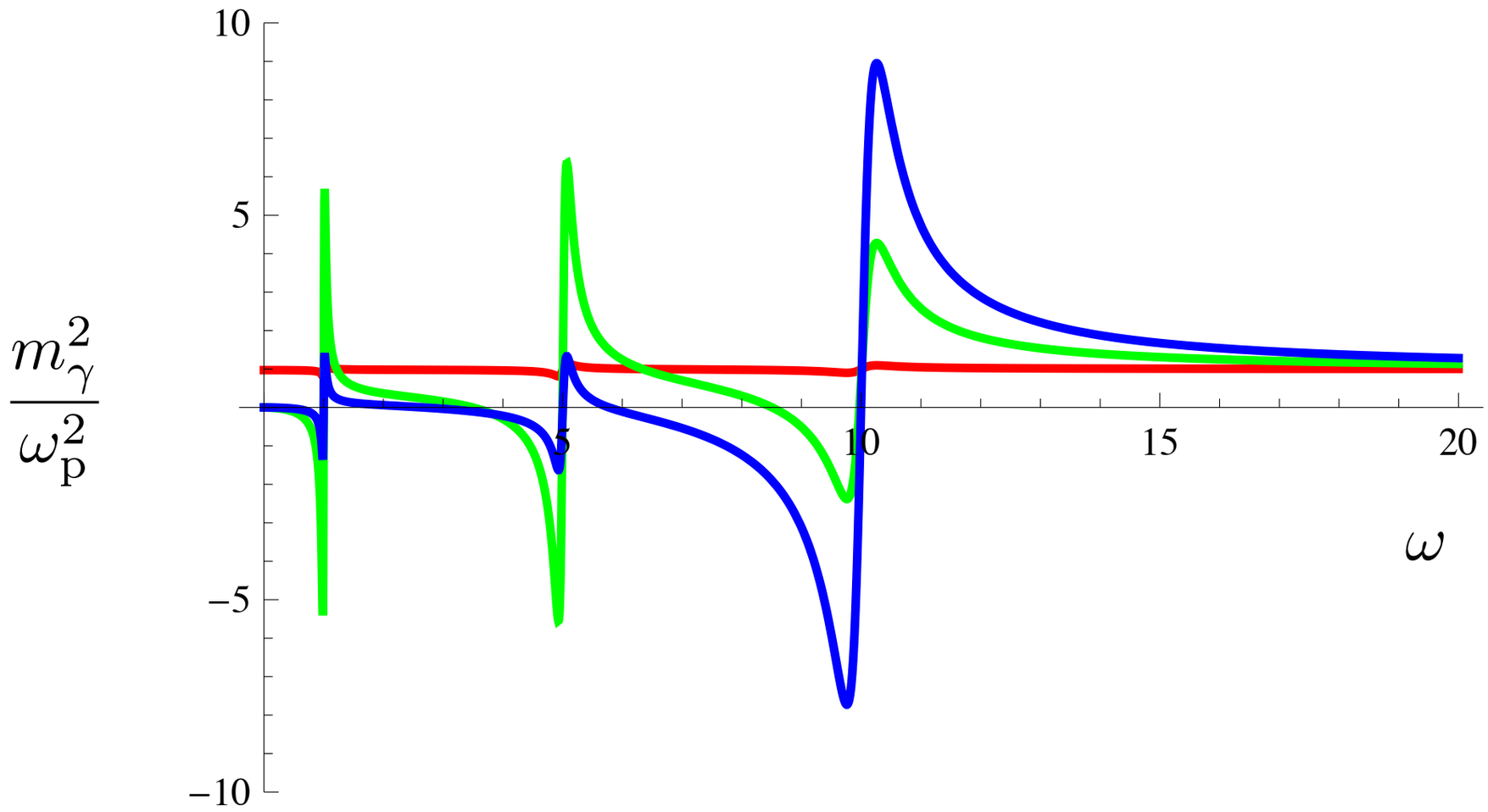
Bounded electrons produce a NEGATIVE contribution to m_γ^2 at low frequencies

$$m_\gamma^2 + i\omega\Gamma = \omega_{\rm p}^2 \frac{\omega^2}{\omega^2 - \omega_k^2 + 1\omega\gamma_k}$$

'Naive' Plasma frequency

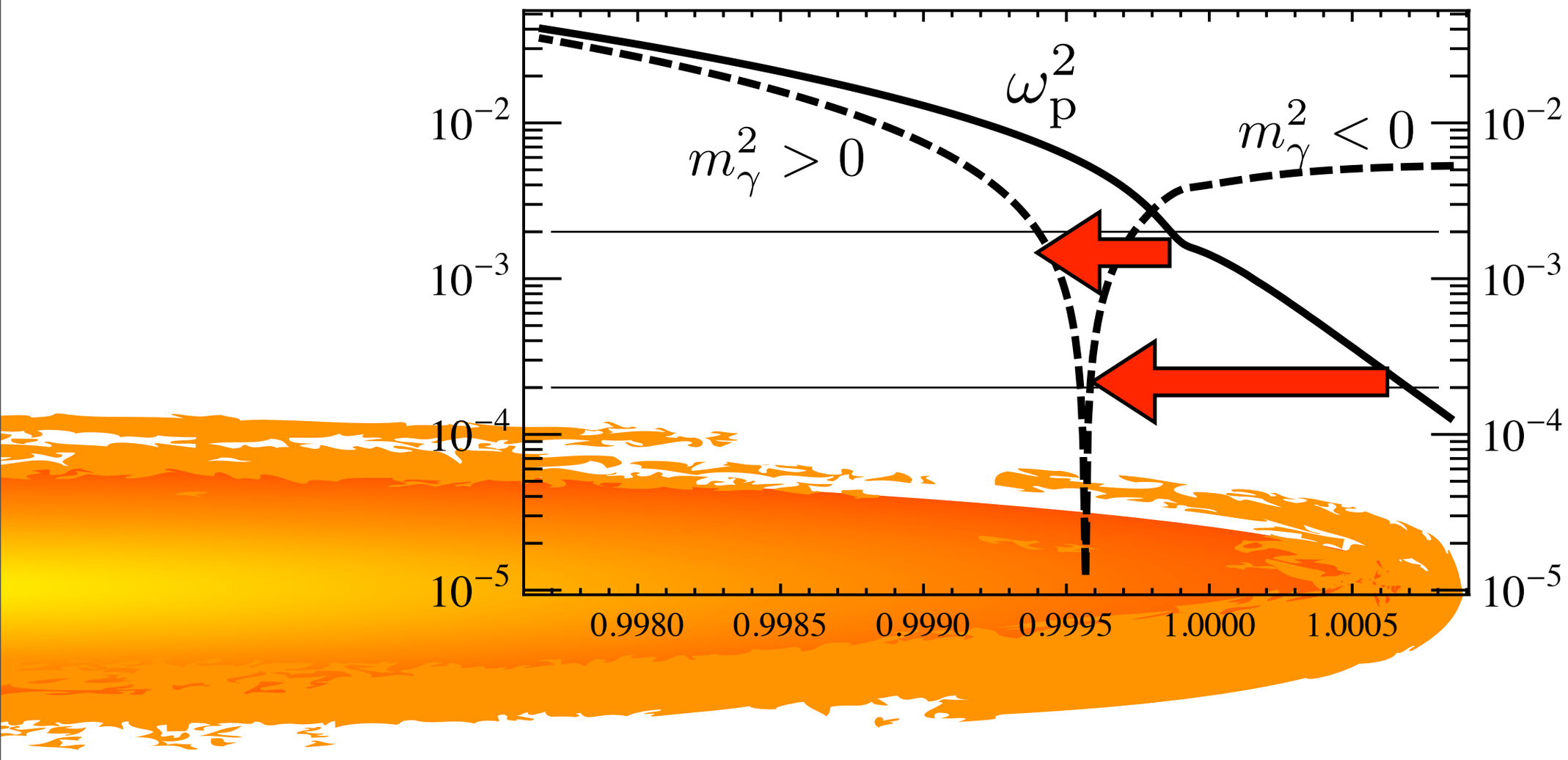
Sub eV Hidden Photons ... (photospheric nightmare)

$$m_\gamma^2 + i\omega\Gamma = \omega_{\rm p}^2 \left(\sum_j f_j \frac{\omega^2}{\omega^2 - \omega_k^2 + 1\omega\gamma_k} \right) \simeq \omega_{\rm p}^2 \left(\sum_{ir} f_k - \sum_{uv} f_k \left(\frac{\omega}{\omega_k} \right)^2 \right)$$



Sub eV Hidden Photons ... (photospheric nightmare)

In general resonances move to the interior of the Sun (far from resonances...)



Solar model from Turck-Chieze et al., ApJ, 555:L69-L73, 2001

Sub eV Hidden Photons ... (photospheric nightmare)

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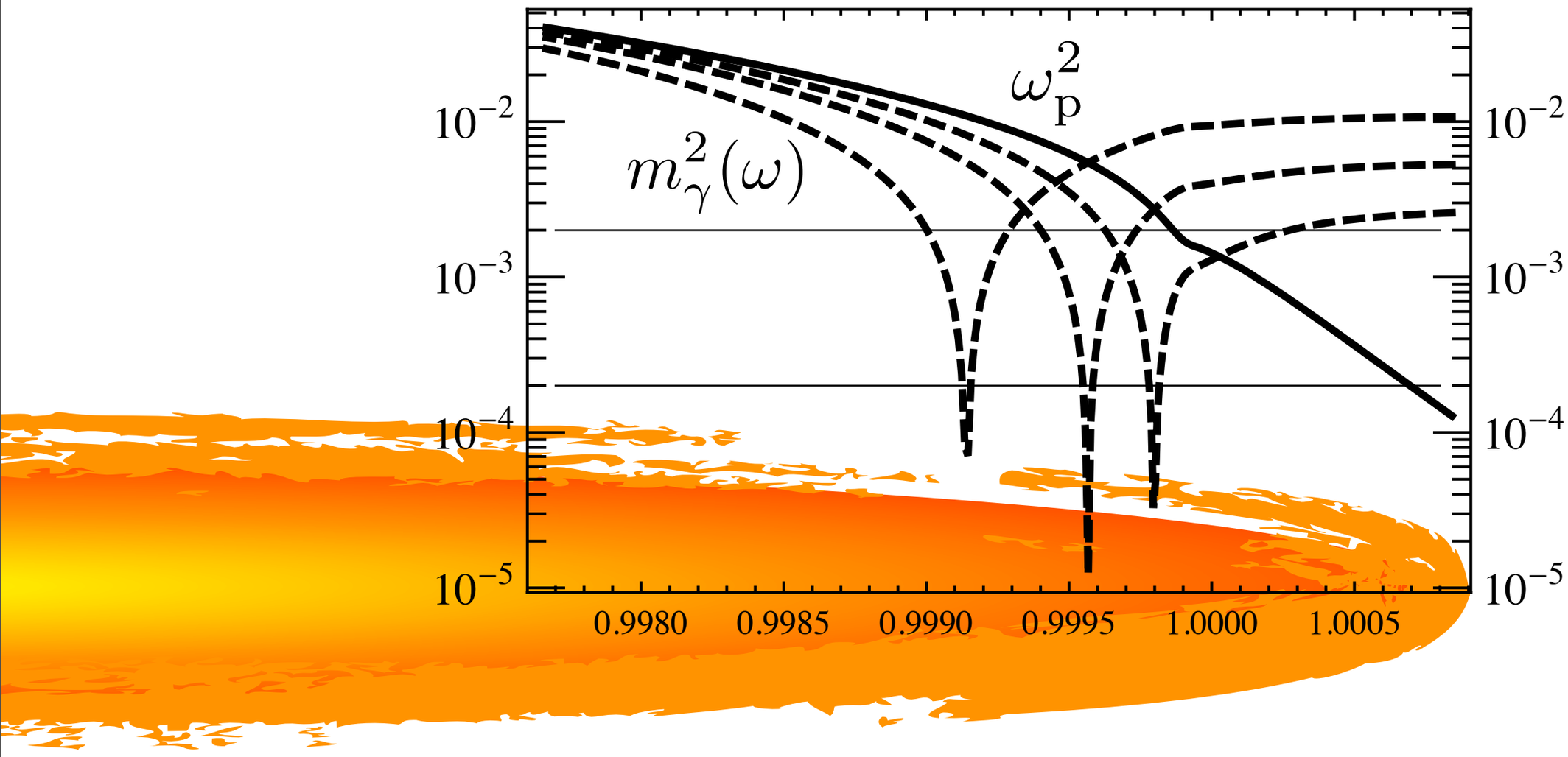
and this effect is frequency dependent...



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Sub eV Hidden Photons ... (photospheric nightmare)

Little Problems

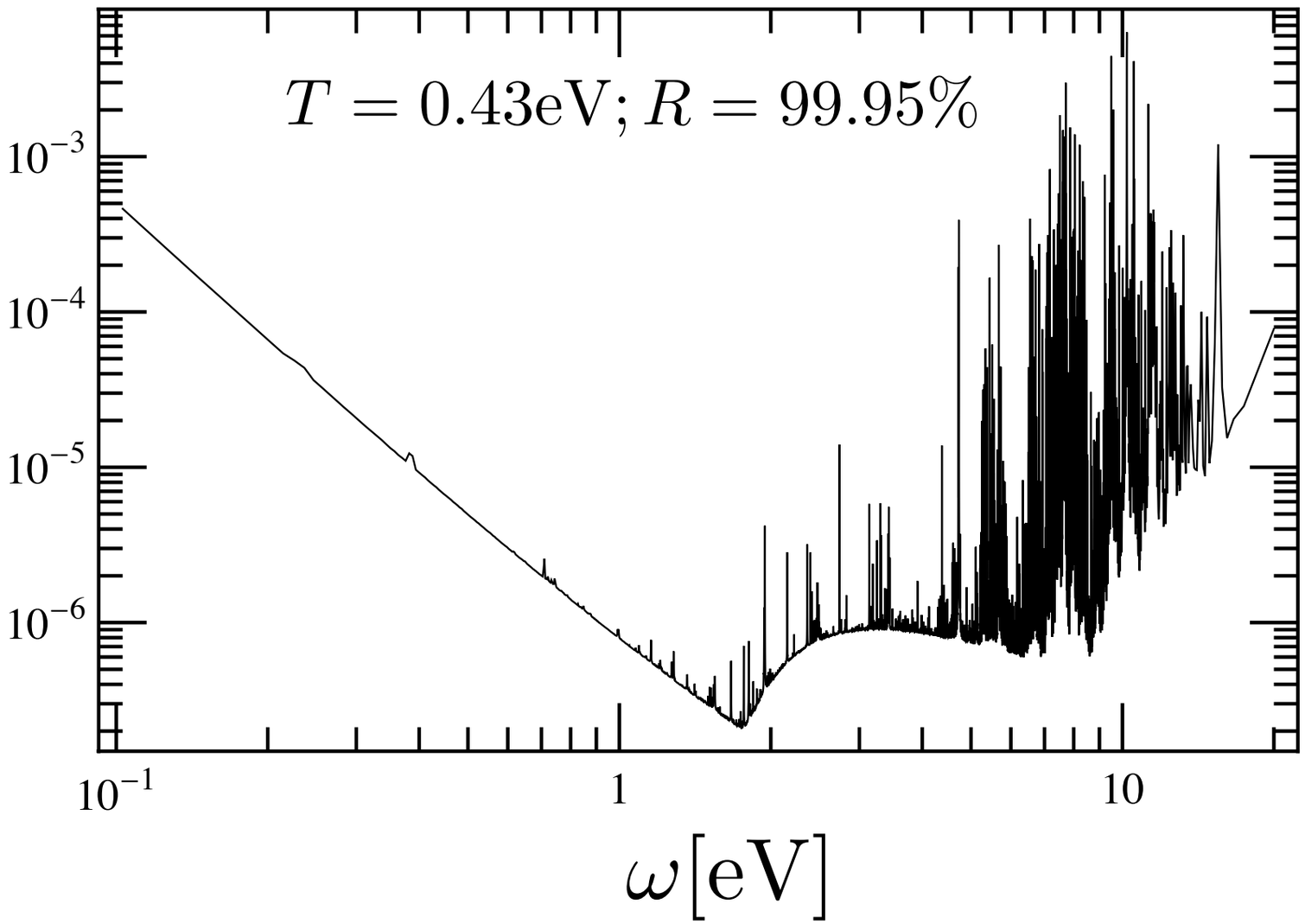
- No code for calculating m_γ^2, (KK relations?)
- All resonances in the optically thick Sun?
- Resonances do not always dominate (low mass HP)
- non isotropic emission
- ... I'm surely forgetting something

Sub eV Hidden Photons ... (photospheric nightmare)

And now, the real picture...

Monochromatic opacities: Opacity Project (Seaton et al.)
Solar Abundances: Asplund et al. 2009

$\propto \Gamma$



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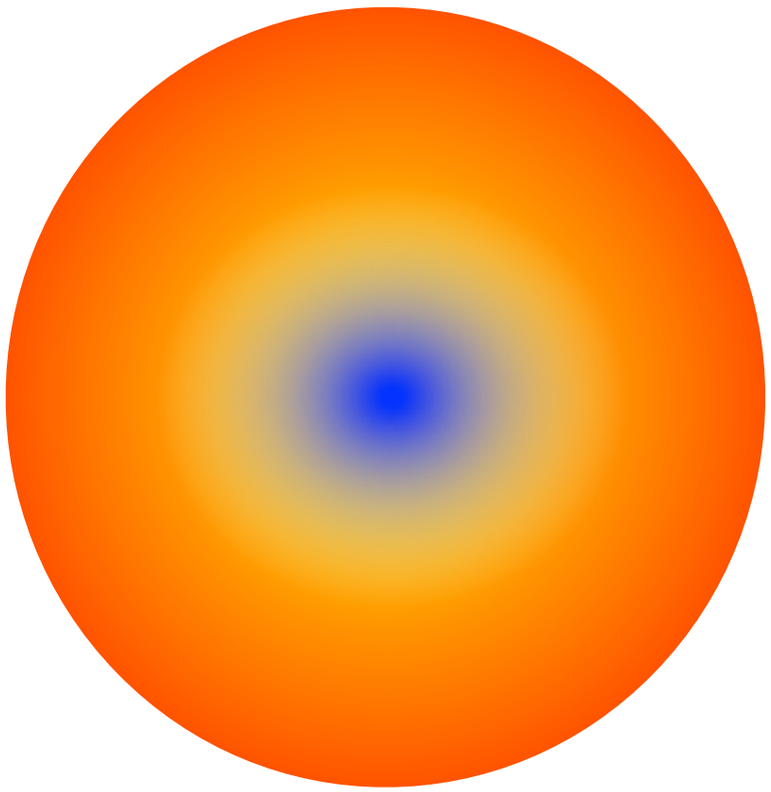
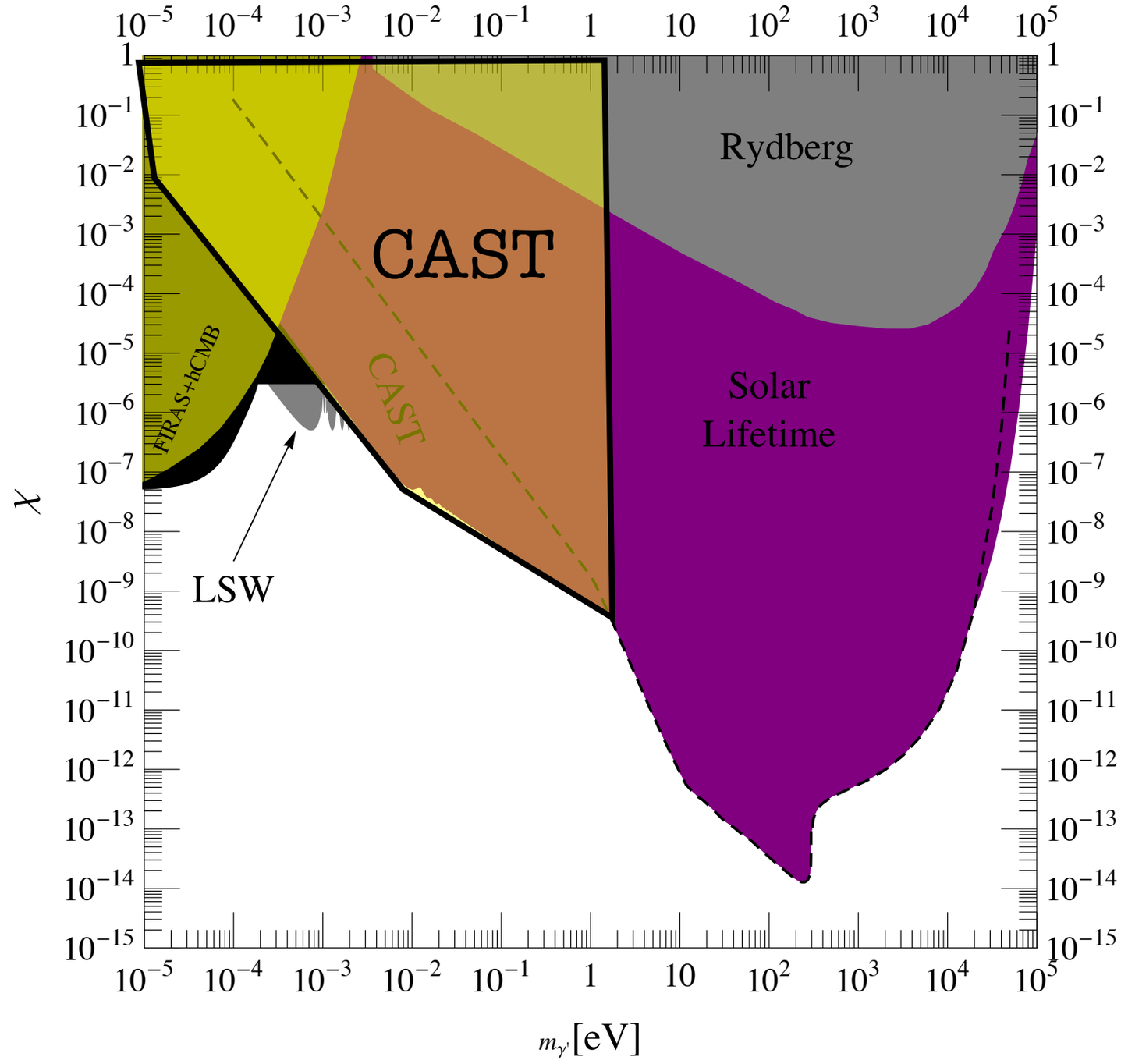
Some Results

(CAST bounds on keV energies)



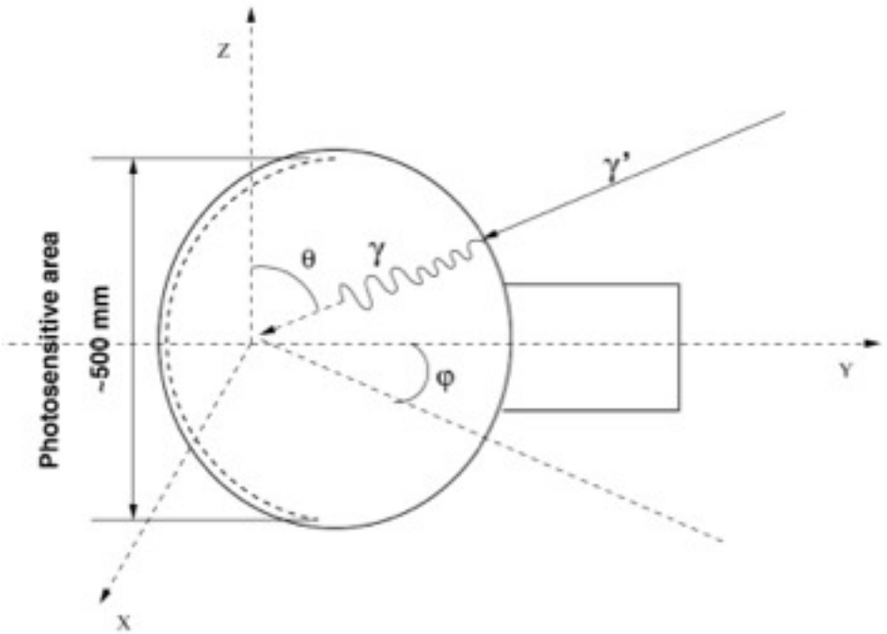
keV photons can only come from the solar core so the resonance is subdominant

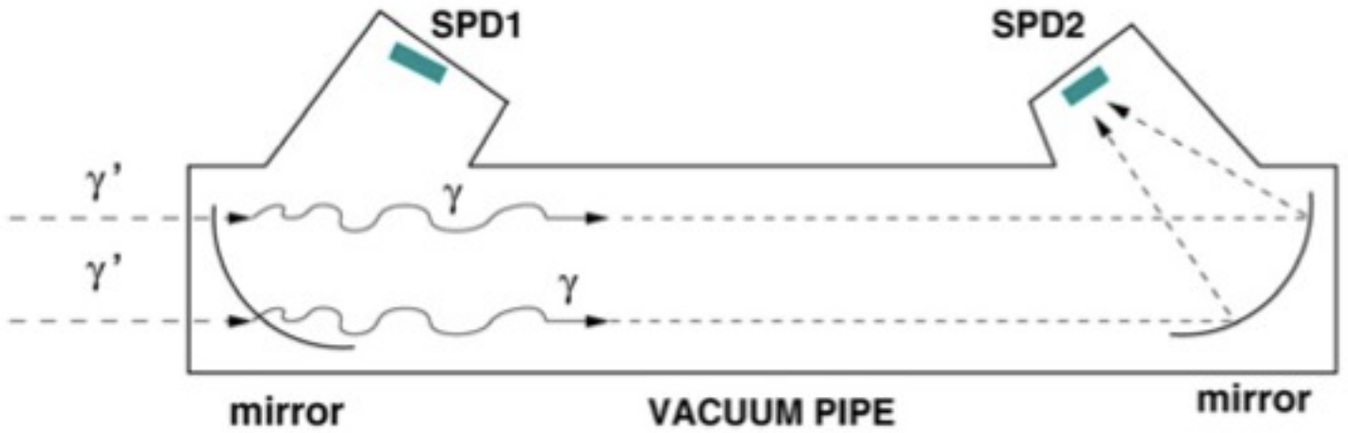
Helioscope Bounds on Hidden Sector Photons (J.R.) JCAP07(2008)008



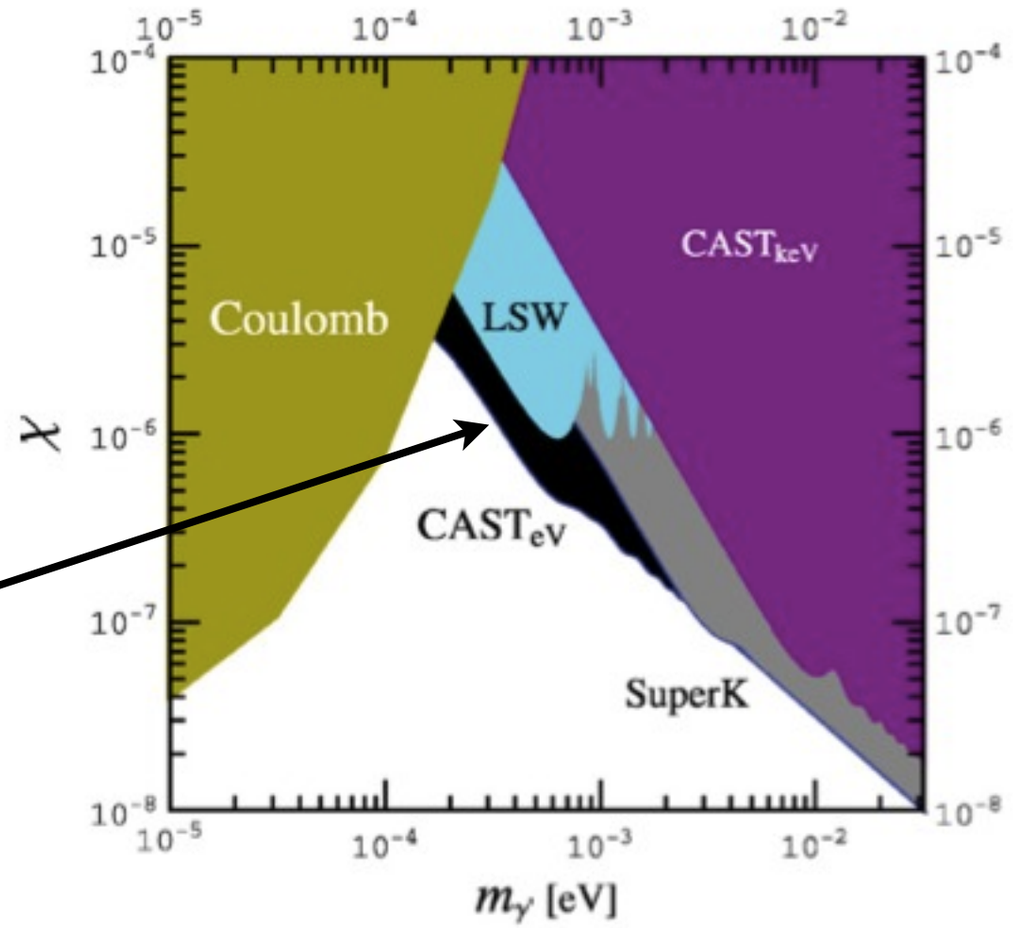
Sub eV Hidden Photons … (photospheric nightmare evaded)

On search for eV Hidden photons with Super Kamiokande and CAST experiments
(S. Gninenko, J.R.)





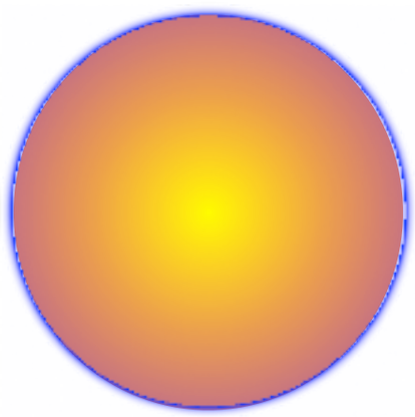
Lowest possible sensibility
(we didn't resolve the resonances)

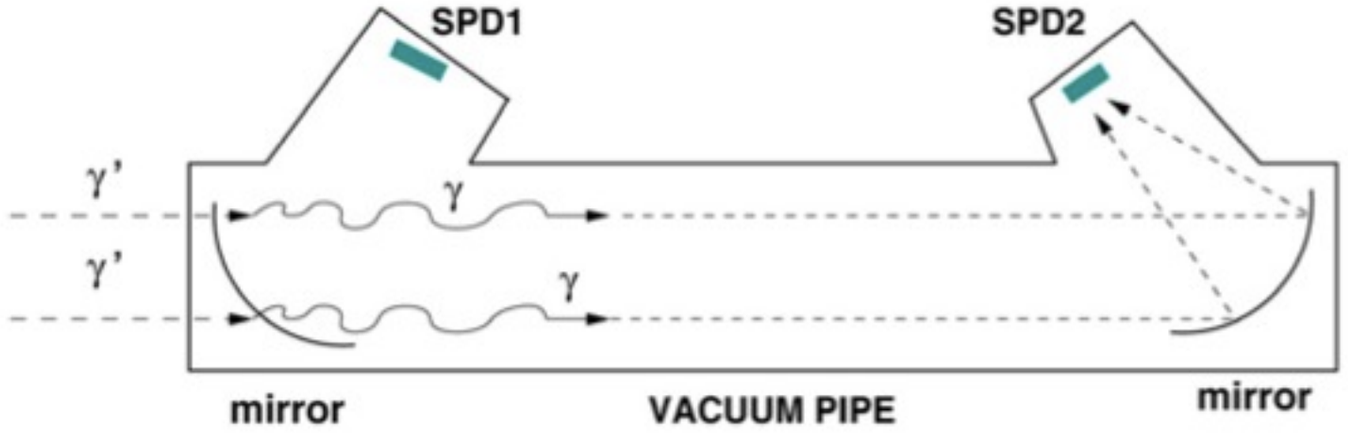


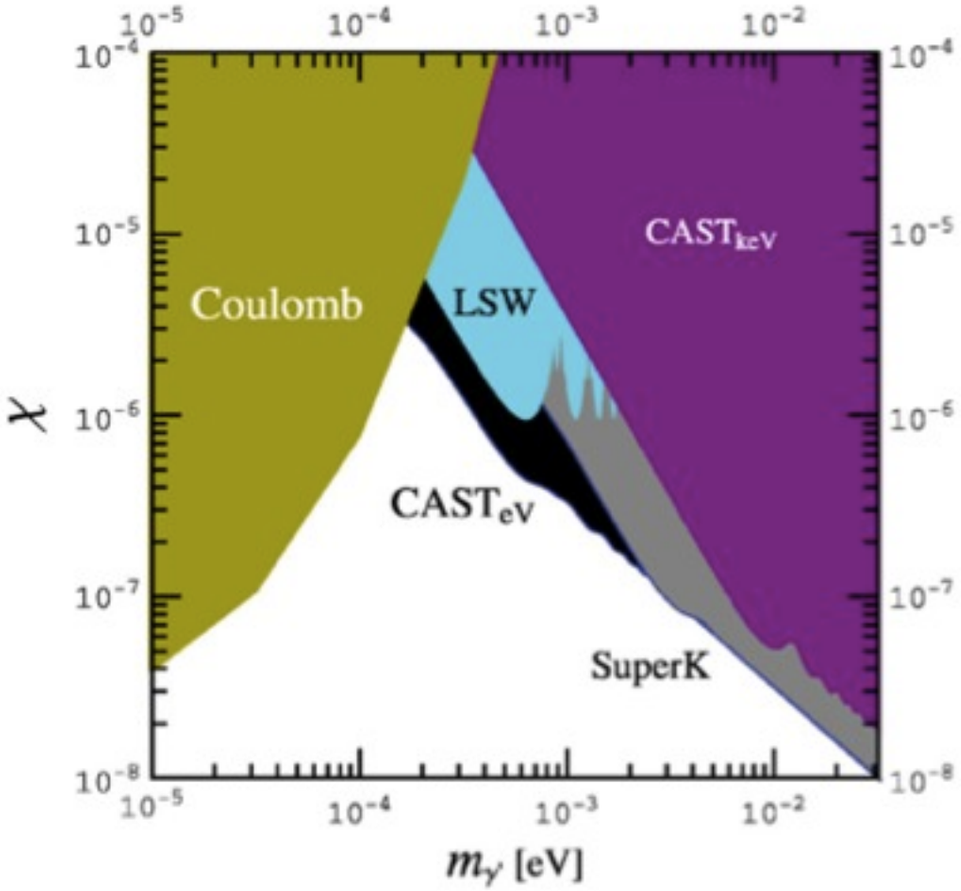
SHIPS (Solar Hidden Photon Search)

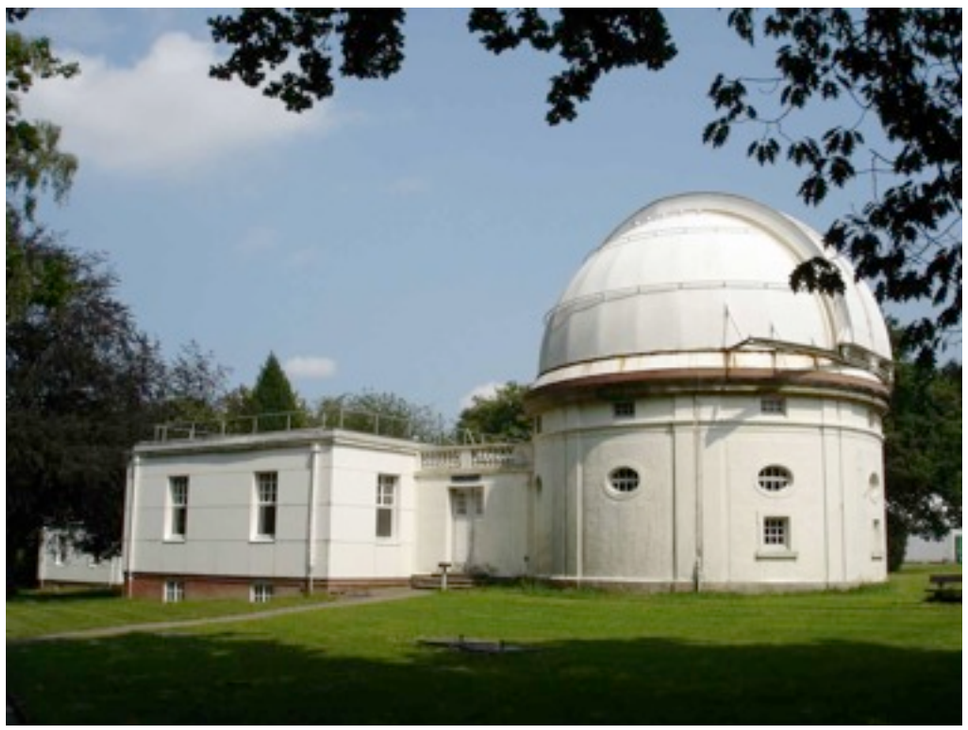
FUNDED & UNDER CONSTRUCTION!!

A dedicated search for hidden photons in the Hamburg Observatory (Wiedemann, Ringwald)





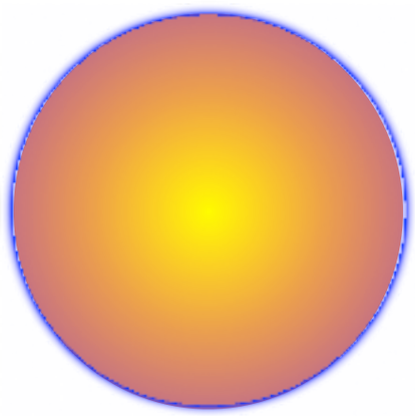


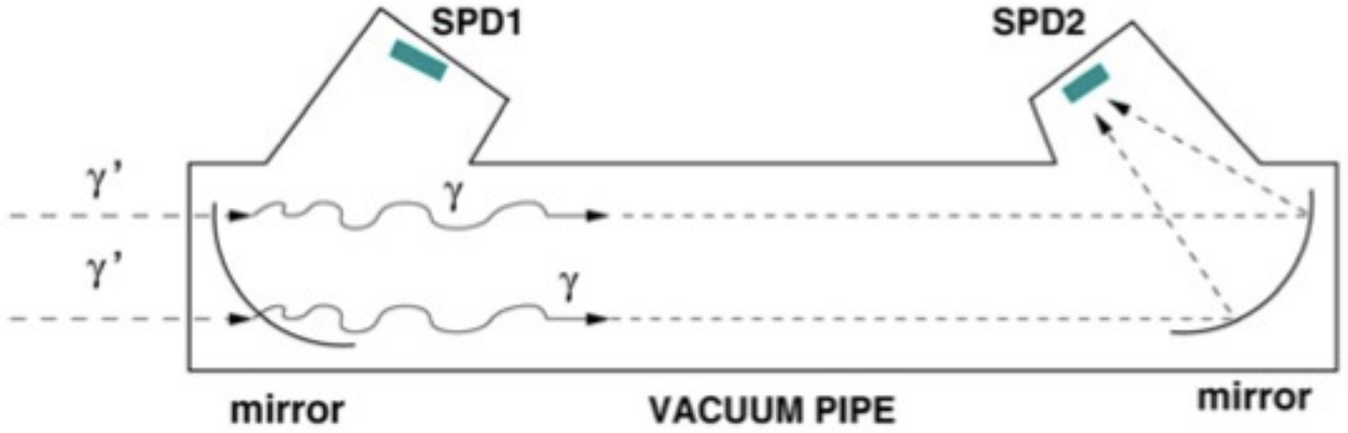


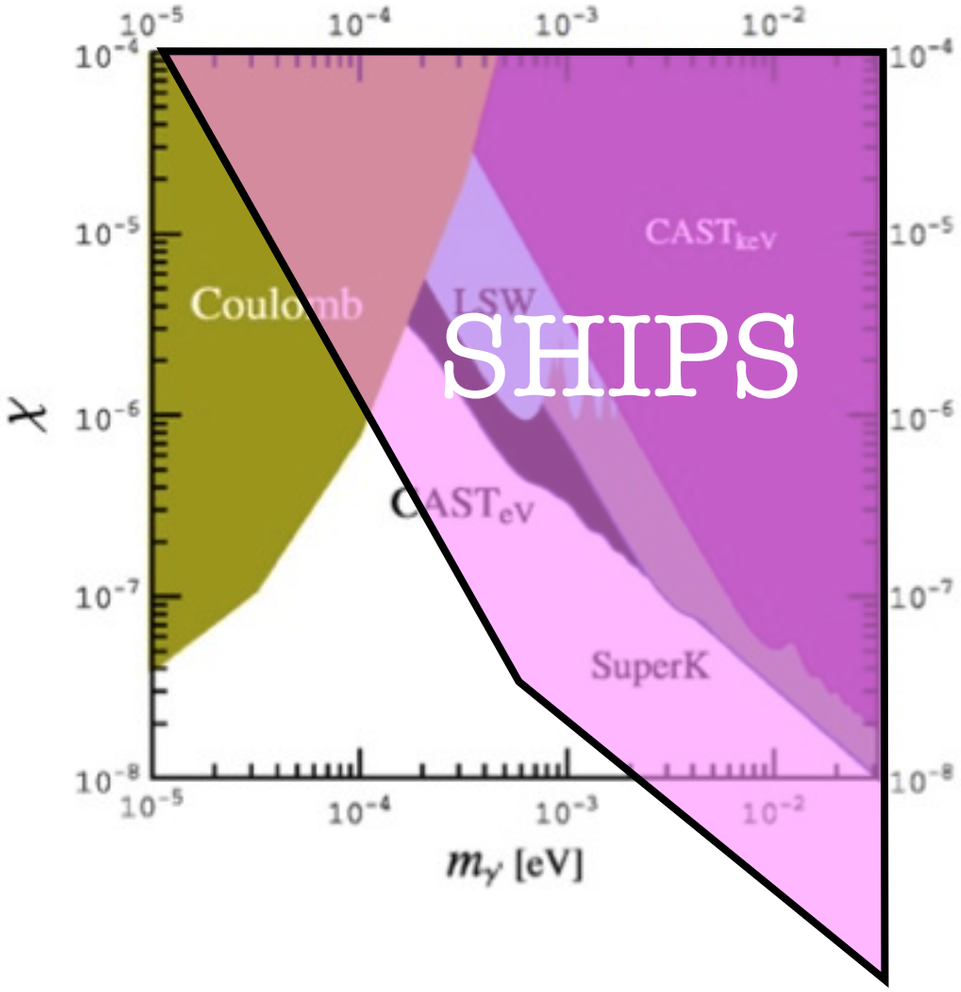
SHIPS (Solar Hidden Photon Search)

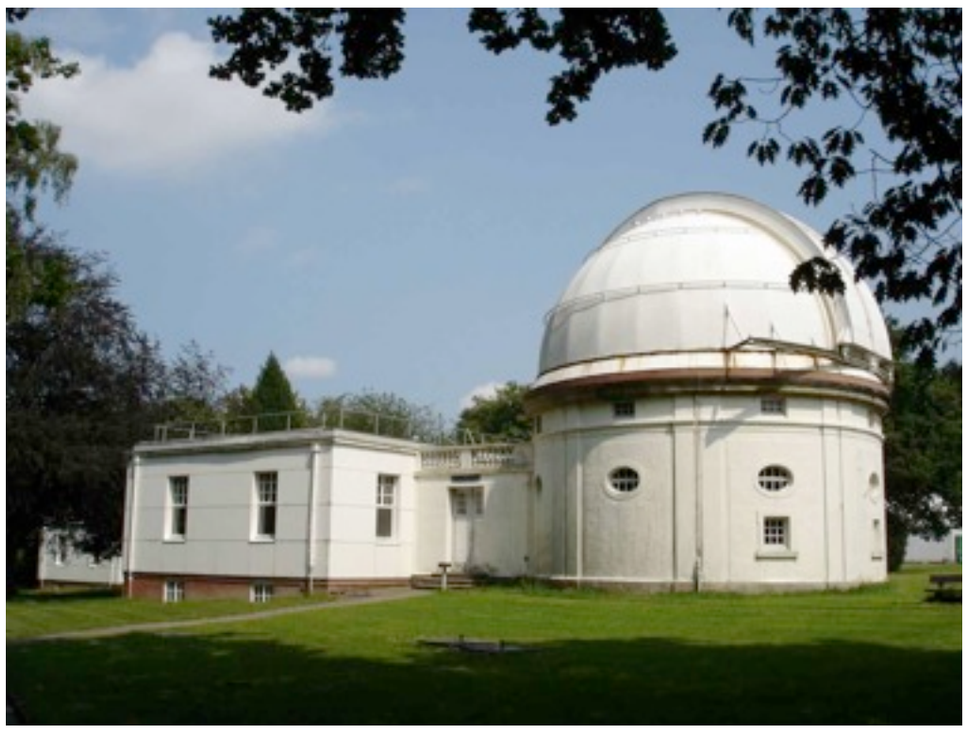
FUNDED & UNDER CONSTRUCTION!!

A dedicated search for hidden photons in the Hamburg Observatory (Wiedemann, Ringwald)









Conclusions

- Hidden photons
- Photon oscillations
- The Sun in hidden photons
- The flux of sub eV mass HPs
- A new Helioscope: SHIPS

- much to learn about HEP
- technological applications?
- Op. to Look into the Sun
- Most relevant for sub eV HPs
- We are going to make it!