Challenges and Opportunities for the Next-Generation of Photon Regeneration Experiments

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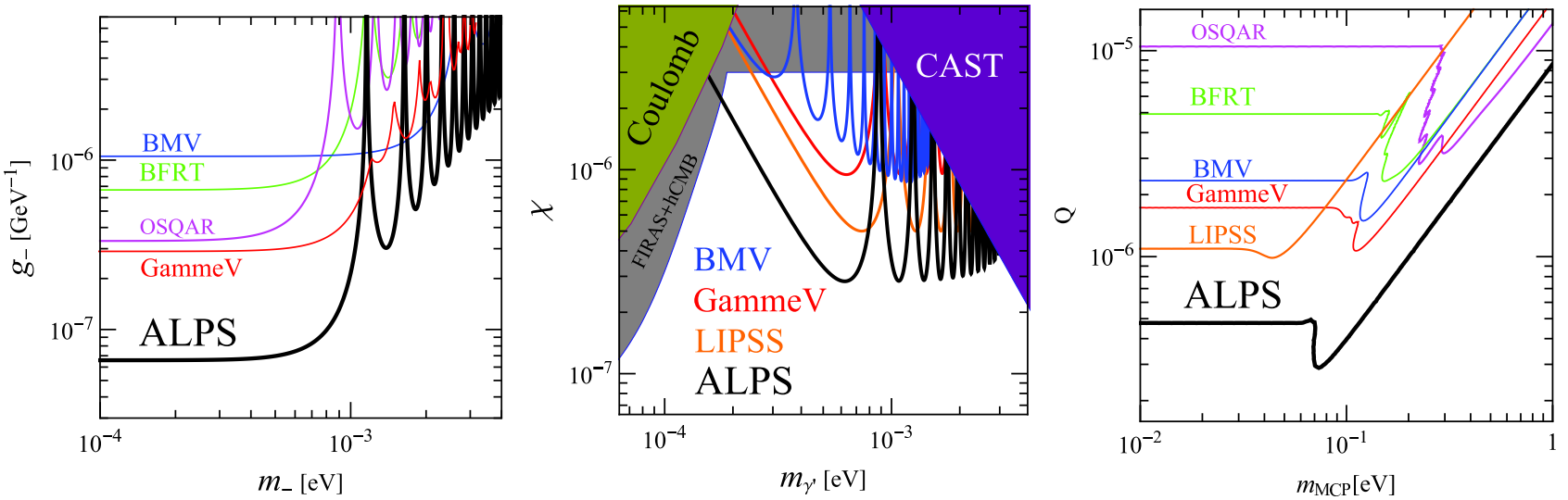
Remarkable progress in photon regeneration experiments:

- PVLAS has triggered a number of experiments for various WISPs:



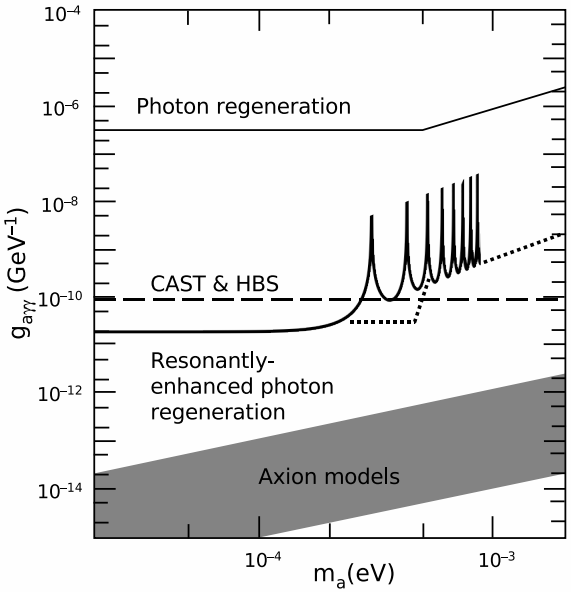
[ALPS Collaboration PRELIMINARY]

- Planning for the next-generation of experiments has started
- What should be their target?

Challenge: Increase sensitivity beyond astro, cosmo and lab bounds

- **ALP:** not shown: upper bound, $g_{\phi\gamma} \lesssim 1 \times 10^{-11}\,\mathrm{GeV}^{-1}$, for $m_\phi \lesssim 10^{-9}\,\mathrm{eV}$, from non-observation of gamma ray burst in coincidence with SN 1987A neutrino burst

[Brockway,Carlson,Raffelt '96; Grifols,Masso,Toldra '96]

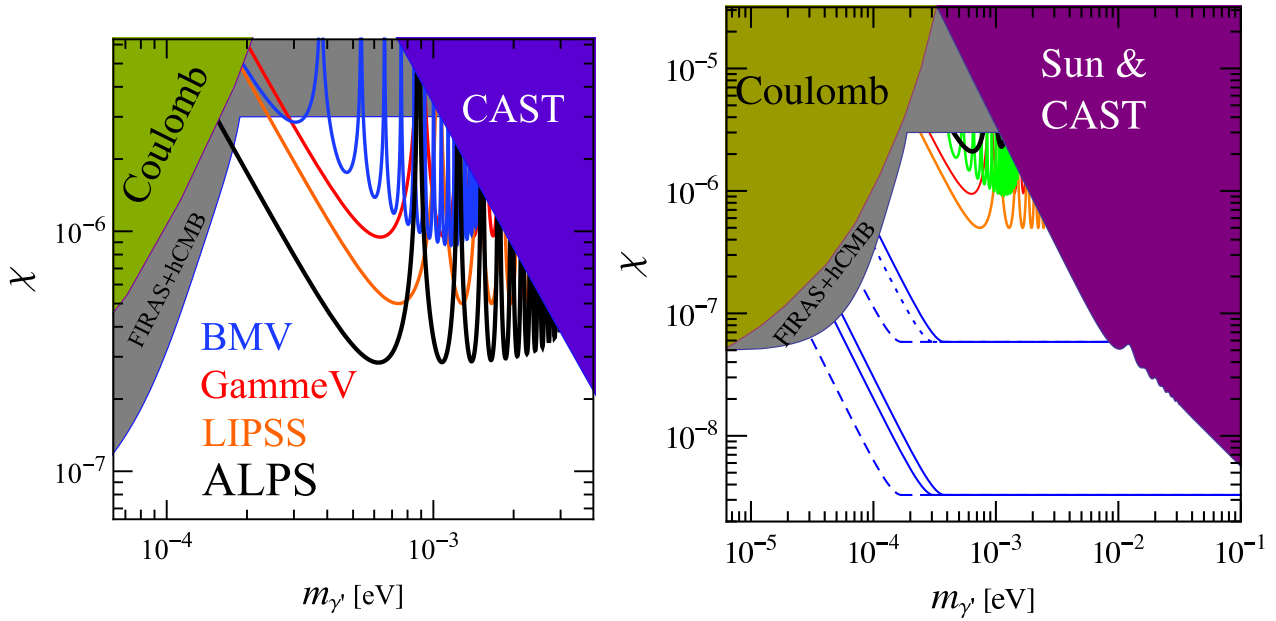


[Mueller,Sikivie,Tanner,van Bibber '09]

$\Rightarrow$ seems doable with some effort (here, e.g., 6+6 Tevatron/HERA magnets)

Challenge: Increase sensitivity beyond astro, cosmo and lab bounds

- **HP:** lots of photon regeneration possibilities: increase length of cavities and finesse; exploit resonantly enhanced photon regeneration



[Redondo '09]

Challenge: Increase sensitivity beyond astro, cosmo and lab bounds

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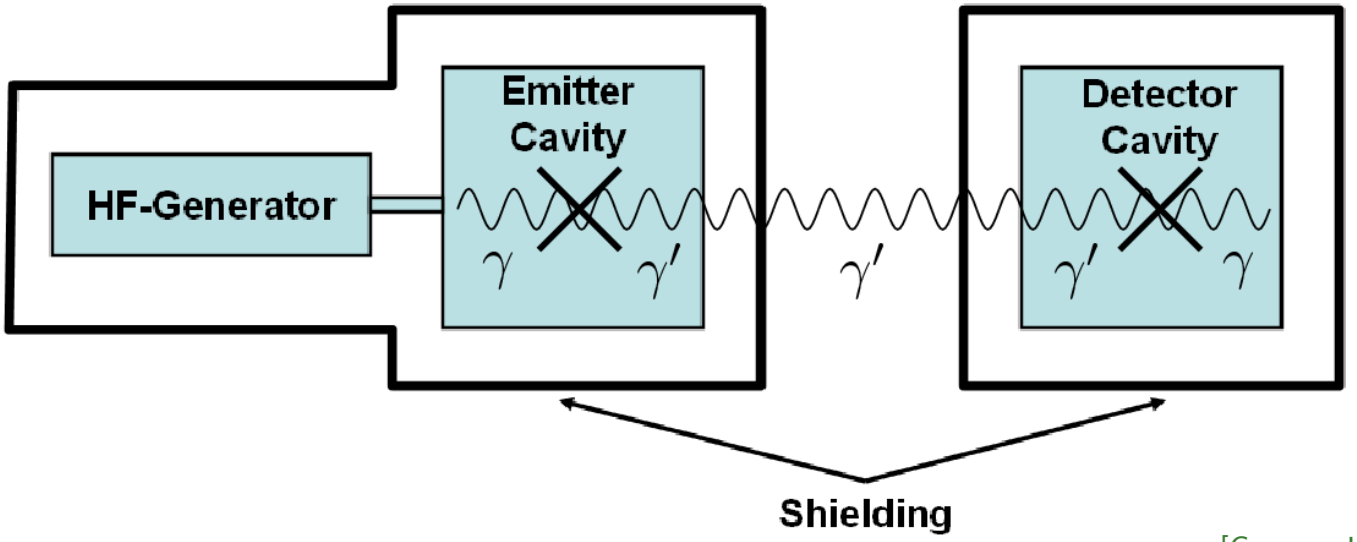

[Caspers,Jaeckel,AR '09]

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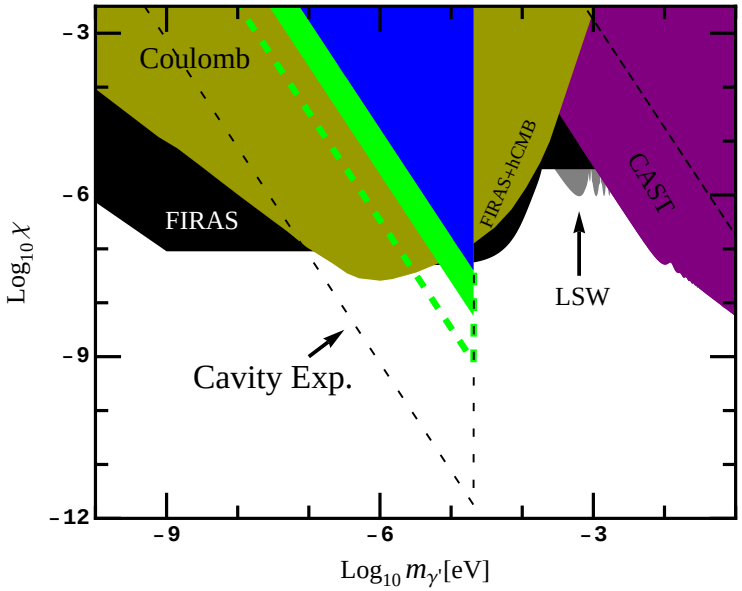
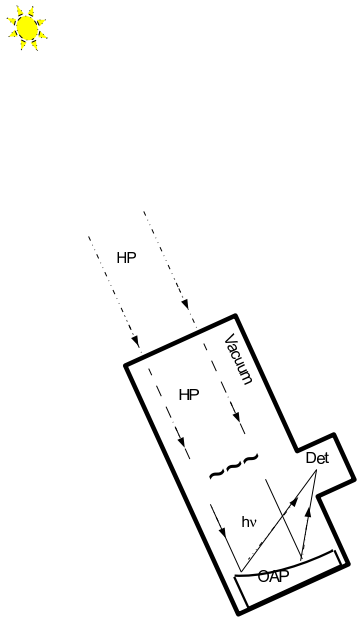
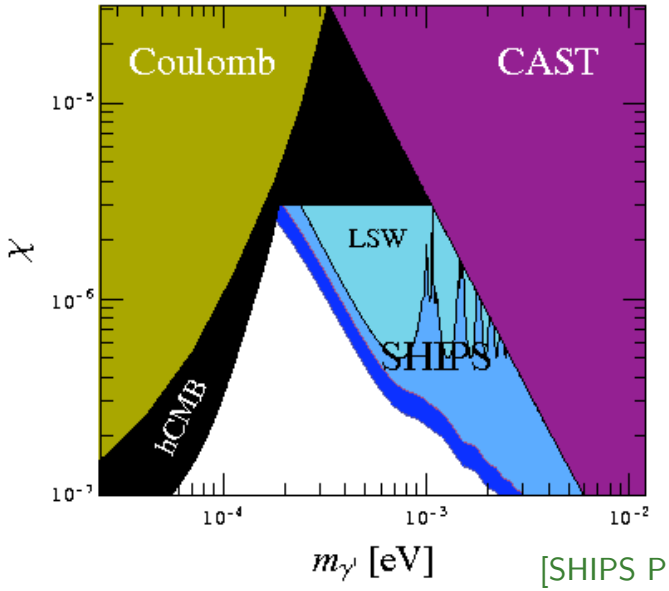


[Caspers,Jaeckel,AR '09]

Challenge: Increase sensitivity beyond astro, cosmo and lab bounds

- **HP:** lots of photon regeneration possibilities: increase length of cavities and finesse; exploit resonantly enhanced photon regeneration; build a microwave cavity experiment and a new helioscope



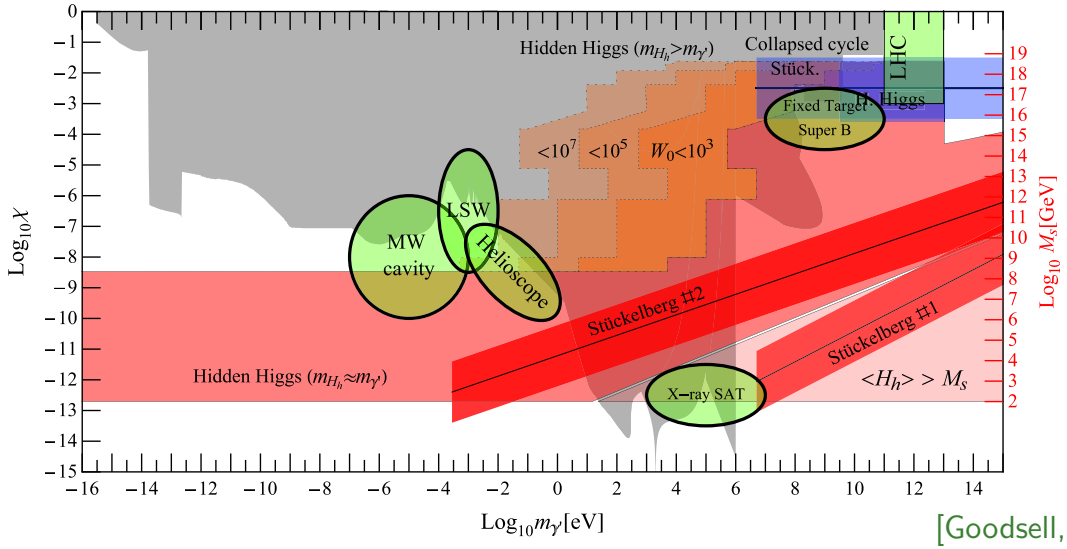


[SHIPS Proposal]

Challenge: Increase sensitivity beyond astro, cosmo and lab bounds

- **HP:** lots of photon regeneration possibilities: increase length of cavities and finesse; exploit resonantly enhanced photon regeneration; build a microwave cavity experiment and a new helioscope

  Probe intermediate string scales! If mass arises via hidden Higgs mechanism, stronger astro bounds apply, since hidden Higgs acts like MCP: $Q_{\rm hH} = \chi e_{\rm h}/e \lesssim 10^{-14}$ [Ahlers,Jaeckel,Redondo,AR '08]



[Goodsell,Jaeckel,Redondo,AR '09]

Opportunity: Laboratory test of hints for cosmic photon regeneration

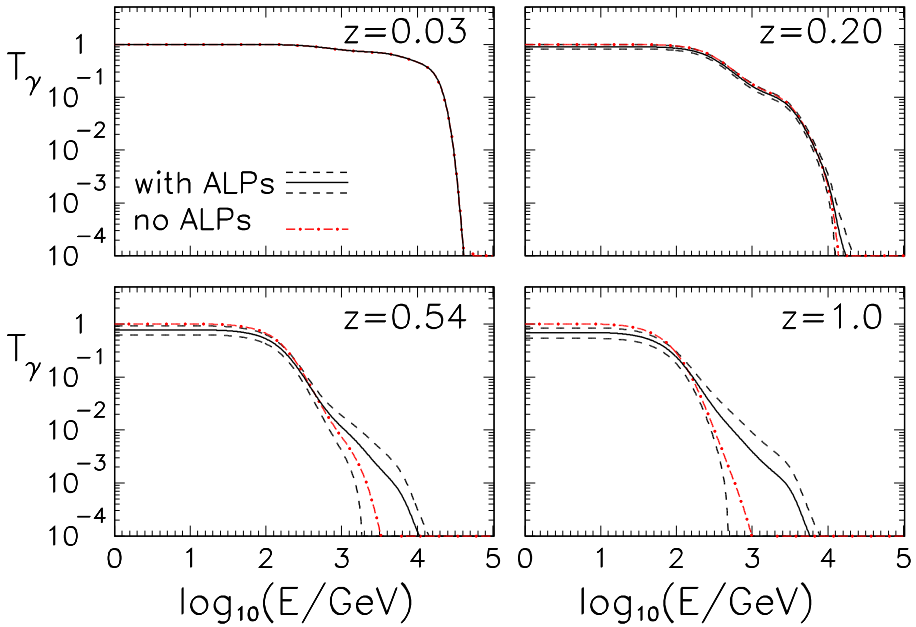
- Recent observations of cosmologically distant γ-ray sources have revealed surprising degree of transparency of the universe to VHE ($E > 100$ GeV) photons [H.E.S.S. Collaboration '06;...; MAGIC Collaboration '08;...]
- Possible explanations:
  - Extragalactic Background Light (EBL) less dense than expected $\Rightarrow$ less absorption of VHE photons due to e^+e^- production on EBL?
  - harder injection spectra than initially thought?
  - VHE $\gamma \leftrightarrow$ ALP conversions, i.e. cosmic photon regeneration, with

$$10^{-12}\,\mathrm{GeV}^{-1} \lesssim g_{\phi\gamma} \lesssim 10^{-11}\,\mathrm{GeV}^{-1}, \qquad m_\phi \lesssim 10^{-10}\,\mathrm{eV}\,?$$

    * $\gamma \longrightarrow$ ALP conversion in magnetic field around source and ALP $\longrightarrow \gamma$ in magnetic field of Milky Way [Hooper,Serpico '07; Hochmuth,Sigl '07; ...]
    * $\gamma \leftrightarrow$ ALP in random extragalactic magnetic fields [De Angelis,Mansutti,Roncadelli '07; ...]

Opportunity: Laboratory test of hints for cosmic photon regeneration

- **Photon transfer function,** taking into account γ-ALP conversions, with $g = 10^{-11}\,\mathrm{GeV}^{-1}, m_\phi \lesssim 10^{-10}\,\mathrm{eV}$, has relevant dispersion due to randomness of EG magnetic fields:



[Mirizzi,Montanino '09]

Opportunity: Laboratory test of hints for cosmic photon regeneration

⇒ **Signature:** reconstructed EBL density from TeV photon observations which appears to vary over different directions of sky

- **Similarly,** scatter in observed HE luminosities of compact sources in clusters of galaxies may be a signal of ALPs in same parameter range!

[Burrage,Davis,Shaw '09]

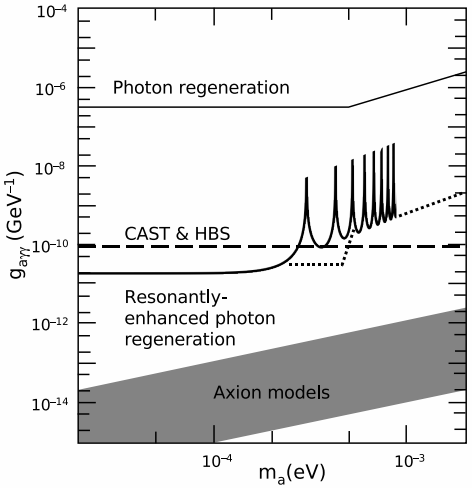
- Observed alignment of polarization vectors of very distant quasars may also be explained by selective photon disappearance from photon-ALP oscillations in same parameter range! [Payez,Cudell,Hutsemekers '08]
- Photon-ALP oscillations from this parameter range have also been invoked to explained the origin of the debated correlation of arrival direction of UHE cosmic rays and BL-Lacs [Fairbairn,Rashba,Troitsky '09]
- ALPs of similar nature may solve problematic aspects of solar physics: X-ray activity, corona problem, triggering of solar flares. [Zioutas *et al.* '08,'09]

$\Rightarrow$ **A new (pseudo-?)Nambu-Goldstone boson ϕ,** with decay constant

$$f_\phi \sim \alpha / g_{\phi\gamma} \sim 10^9 \div 10^{10}\ \mathrm{GeV?}$$

$\Rightarrow$ **Opportunity for a next-generation lab LSW experiment probing:**

$$10^{-12}\,\mathrm{GeV}^{-1} \lesssim g_{\phi\gamma} \lesssim 10^{-11}\,\mathrm{GeV}^{-1}, \qquad m_\phi \lesssim 10^{-12} \div 10^{-10}\,\mathrm{eV}$$



[Mueller,Sikivie,Tanner,van Bibber '09]

$\Rightarrow$ **Need to be a bit more ambitious: increase $B \cdot L$ by factor 10!**

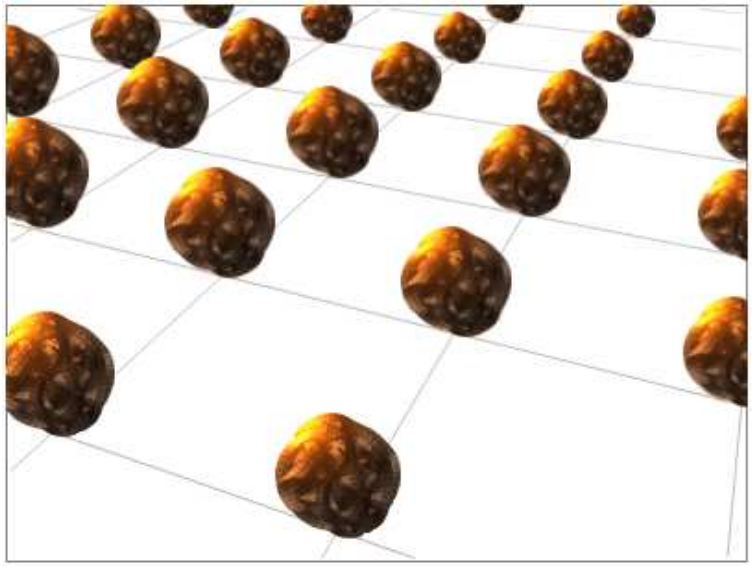
Opportunity: Laboratory test of intermediate scale string scale axion

- **Axions in string theory:**
  Axions and ALPs generic in string compactifications: KK zero modes of form fields [Witten '87; ...; Conlon '06, Svrcek,Witten '06; Arvanitaki *et al.* '09;...]
  Very promising possibility: axions with [Cicoli,Goodsell,Redondo,AR in prep.]

$$10^9\,\mathrm{GeV} \lesssim \quad f_a \sim M_s \quad \lesssim 10^{16}\,\mathrm{GeV}$$
$$10^{-2}\,\mathrm{eV} \gtrsim \quad m_a \sim \tfrac{m_\pi f_\pi}{M_s} \quad \gtrsim 10^{-9}\,\mathrm{eV}$$

and, at same time, ALPs with

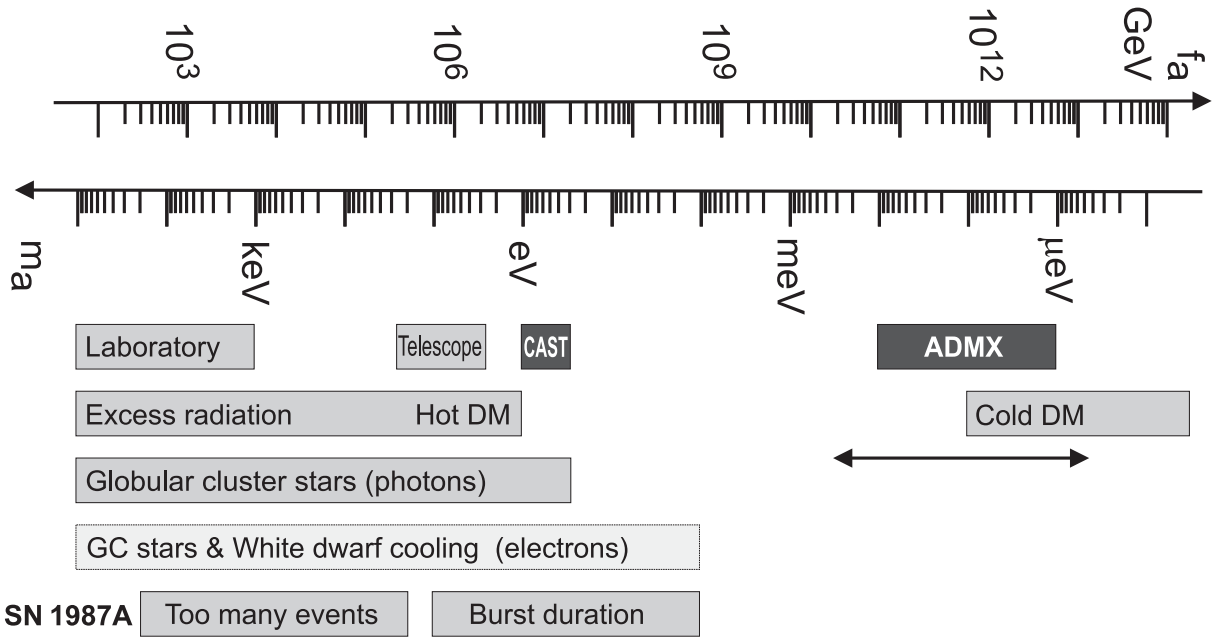
$$f_\phi \sim f_a \sim M_s, \qquad 0 \leq m_\phi \sim \frac{\Lambda^2}{M_s} \lesssim m_a$$



⇒ **Cosmic PR may point to**

$$\boldsymbol{M_s \sim f_a \sim 10^9 \div 10^{10}\,\mathrm{GeV}}$$

Opportunity: Laboratory test of intermediate scale string scale axion



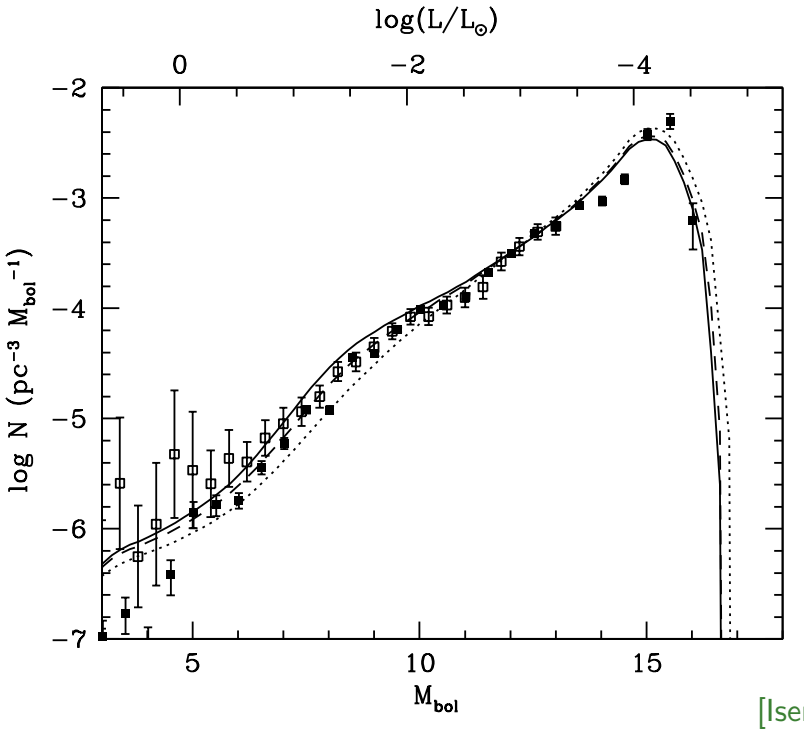
[PDG]

- **Non-standard energy loss in white dwarfs,** compatible with existence of axions with an axion-electron coupling, $g_{ae} \sim 10^{-13}$

[Isern *et al.* '08]

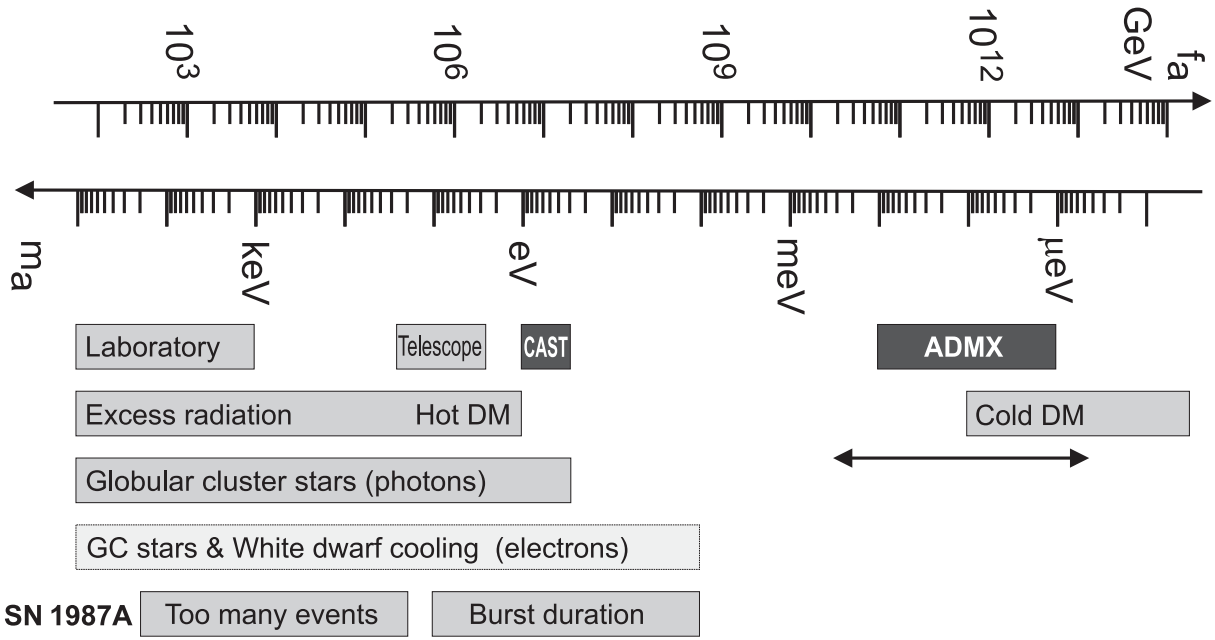
Opportunity: Laboratory test of intermediate scale string scale axion

- White dwarf luminosity function compared to predictions:
  solid: $g_{ae} = 0$ (no axion); dashed: $g_{ae} = 1.4 \times 10^{-13}$; dotted: $g_{ae} = 2.8 \times 10^{-12}$



[Isern,Catalan,Garcia-Berro,Torres '09]

Opportunity: Laboratory test of intermediate scale string scale axion

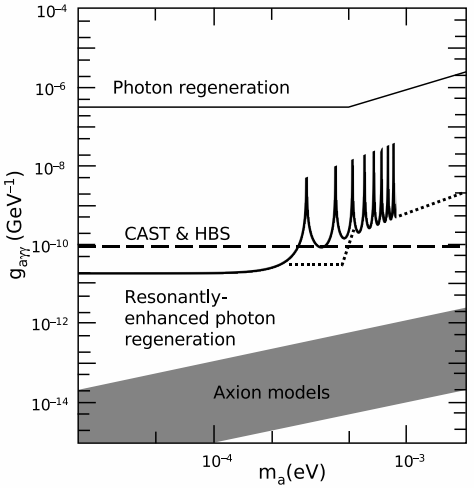


[PDG]

- **Non-standard energy loss in white dwarfs,** compatible with existence of axions with an axion-electron coupling, $g_{ae} \sim 10^{-13}$, suggesting an axion decay constant, $f_a \sim g_{ae} m_e = 4 \times 10^9 \text{ GeV} \Rightarrow g_{a\gamma} \sim 3 \times 10^{-12} \text{ GeV}^{-1}$ [Isern *et al.* '08]
  But also consistent with ALP of mass $m_\phi \ll m_a$!

⇒ **Opportunity for a next-generation lab LSW experiment probing:**

$$10^{-12}\,\mathrm{GeV}^{-1} \lesssim g_{\phi\gamma} \lesssim 10^{-11}\,\mathrm{GeV}^{-1}, \qquad m_\phi \lesssim 0.6 \div 6\,\mathrm{meV}$$



[Mueller,Sikivie,Tanner,van Bibber '09]

⇒ Need to be even more ambitious: extend sensitivity to axion band by increasing $B \cdot \sum L_i$ by factor 10, while keeping L_i small!

- May discover up to two particles in one strike:

  An ALP with $m_\phi \lesssim 10^{-10}$ eV and the axion with $m_a \sim 1$ meV!