Bounds on Weakly Interacting Sub eV Particles (WISPs) from Cosmology and Astrophysics

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DESY 2008

First some apologies ...

The topic is vast, so many interesting arguments will be missing (some on purpose...)

In particular WIMP bounds will not be covered

....

Motivation & Outline

We have a successful picture of the evolution of the universe that we can use to test the existence and properties of new particles

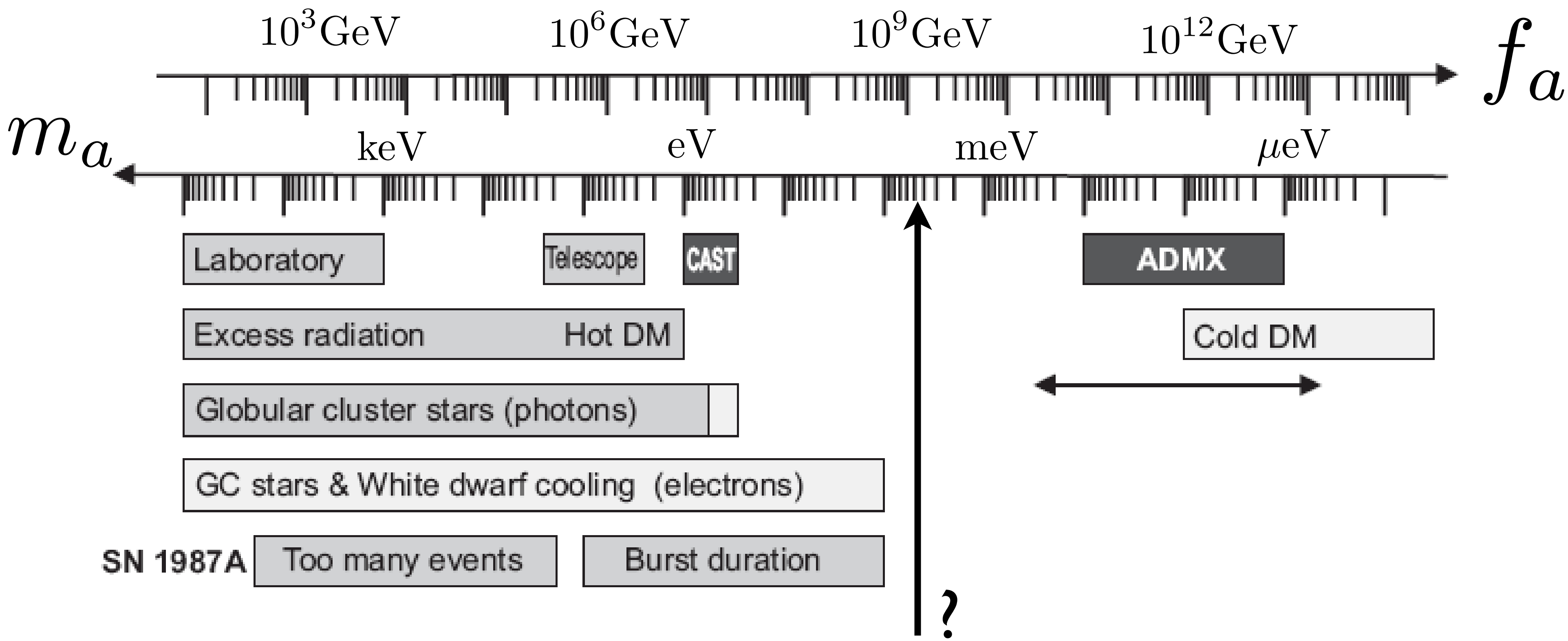
Universe starts as a dense and hot plasma of elementary particles that expands against gravity. As it cools down, the 3 known `long range' forces cluster the elementary constituents into known structures, from the smallest to the largest ...

hadrons, nuclei, atoms, ..., stars, clusters, galaxies...

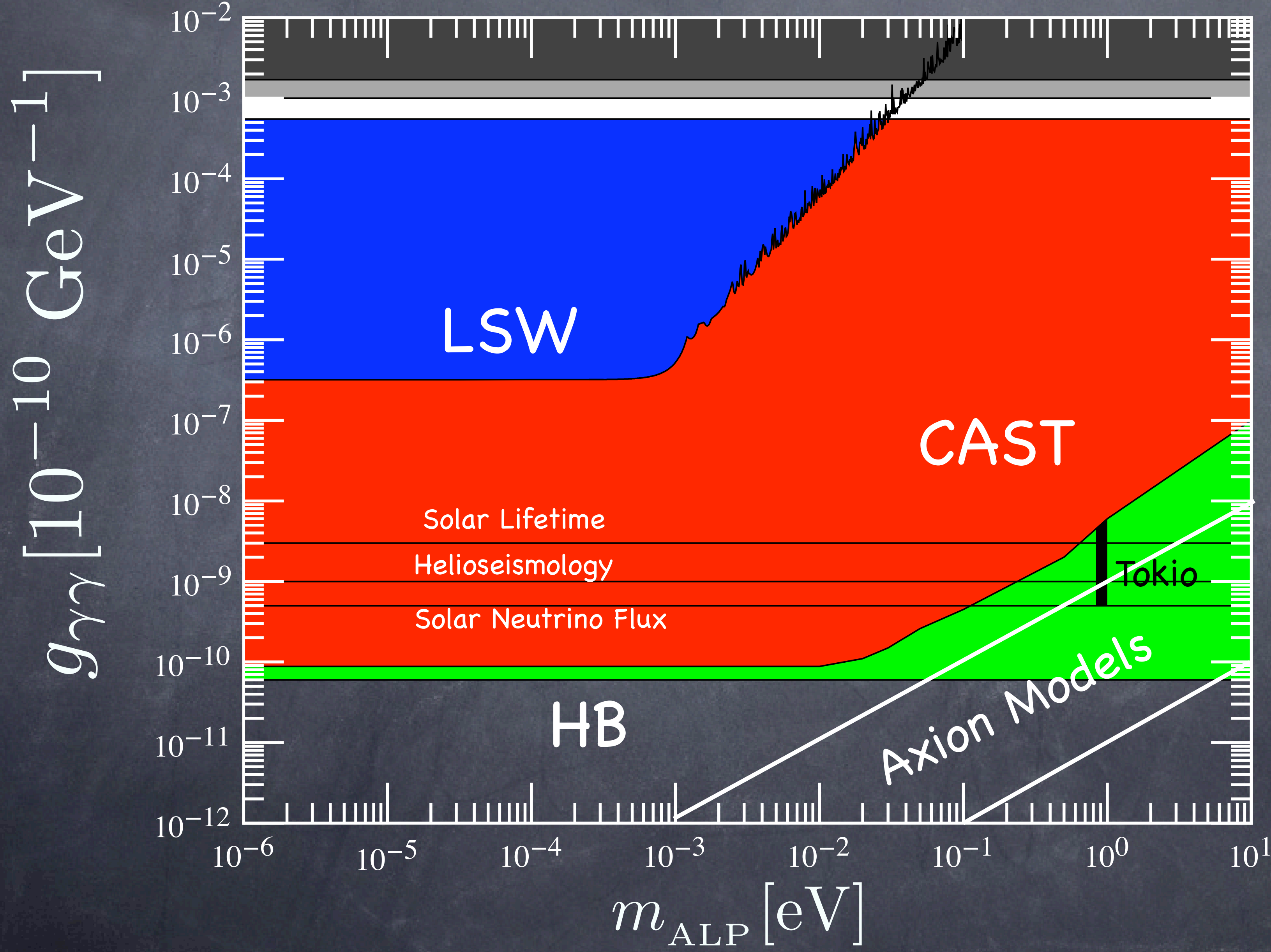
These phase transitions are predictable and contrastable with observations. The effects of additional elementary particles can usually be probed in this comparison.

Usually the Cosmological and astrophysical bounds are the most demanding and leave few parameter space for laboratory searches!

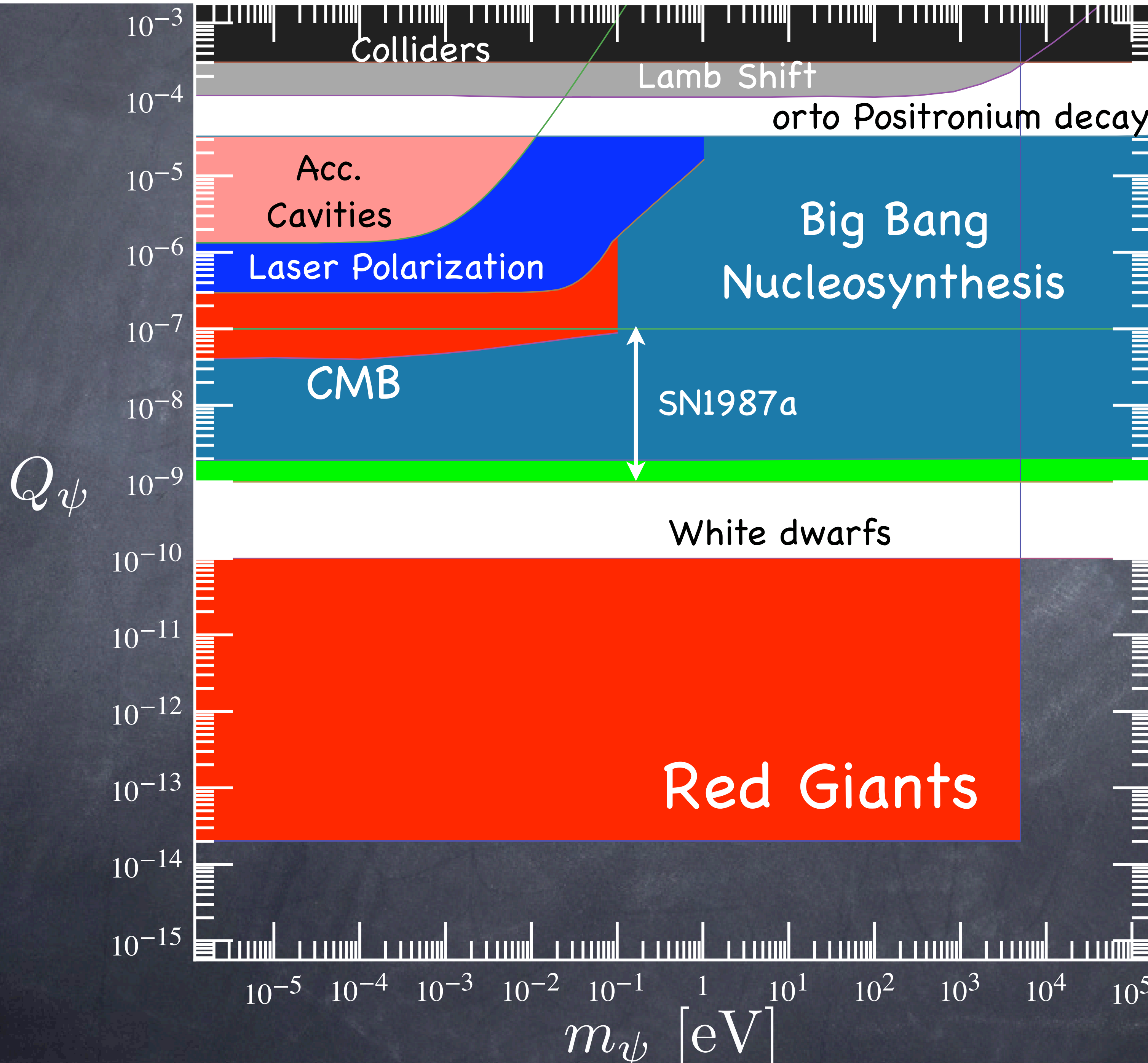
A summary : Axions



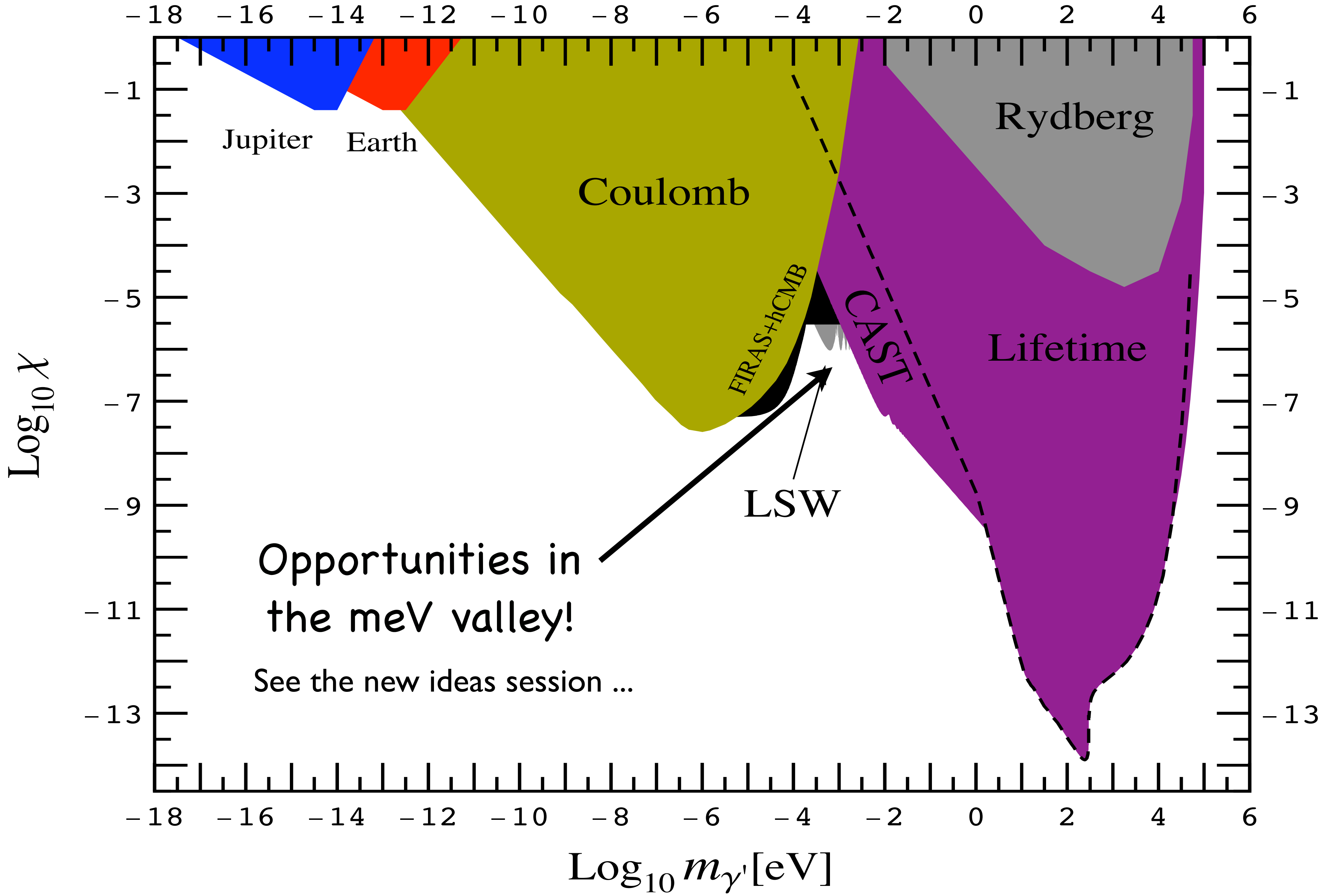
A summary: general ALPS (pseudoscalars coupled to 2 photons)



MiniCharged Particles (MCPs)



Hidden Photons : a rare exception...



Motivation & Outline

Bounds from Cosmology

BBN & CMB bounds on the Cosmic radiation density

CMB Blackbody distortions

Dark Matter axions ...

Bounds from Astrophysics

Energy Loss argument from Globular clusters and the Sun

Supernovae, white dwarfs, ...

Helioscopes

Helioseismology

Solar neutrino fluxes

Distortions of the spectra from distant sources

A beginning: Cosmology ... of sub eV particles

0. At HIGH energy, even ultra weakly interacting particles might have normal int.

Inflation period dissolves pre-primordial (unobserved) particles (?)

Still they can be produced through their ultra weak interactions with SM fields

1. CMB decoupling at T= eV. Particles with sub eV mass always behave as radiation

But we can probe the radiation density at BBN and CMB epochs $N_{\rm eff}$

2. Non relativistic Axions can be also produced: Misalignment mechanism & CDM

See the public lecture by Sikivie!

Cosmology: BBN bounds on cosmic radiation density

BBN timeline

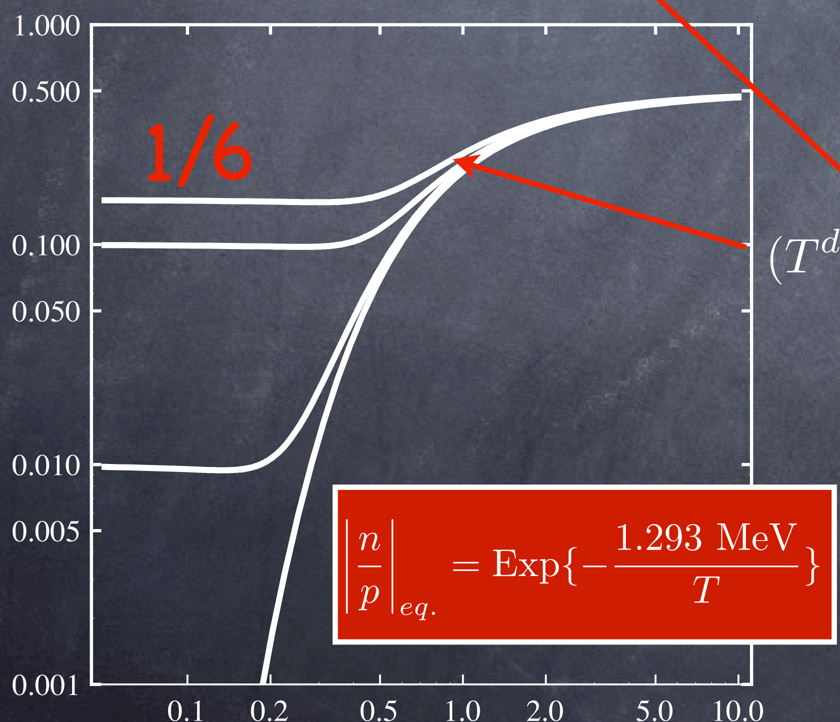
1 MeV — 60 keV — 10 keV

$n \leftrightarrow p$	$n \to D \to {}^3\mathrm{He}, {}^3\mathrm{T}$	$n's \to {}^4\mathrm{He}$	...

$$\Gamma_{\mathrm{weak}} \sim H \propto \sqrt{\rho}$$

$$\rho = \frac{\pi^2}{15} g_* T^4 \qquad g_* \equiv \frac{\rho}{\frac{\pi^2}{15} T^4}$$

$$g_* = \sum_B g_i \left(\frac{T_i}{T}\right)^4 + \frac{7}{8} \sum_F g_i \left(\frac{T_i}{T}\right)^4$$



$$(T^{dec.} \simeq 0.8\ MeV)$$

$$g_*(std) = \underset{(\gamma)}{2} + \frac{7}{8} \times (\underset{(e^\pm)}{4} + \underset{(\nu_{e,\mu,\tau})}{3 \times 2}) = 10.75$$

$$Y_p = \frac{m_{\mathrm{He}}}{m_B} \simeq 4 \frac{n/2}{p+n} \simeq \frac{4}{6 \times 2} = 0.25$$

Cosmology: BBN bounds on cosmic radiation density

BBN timeline

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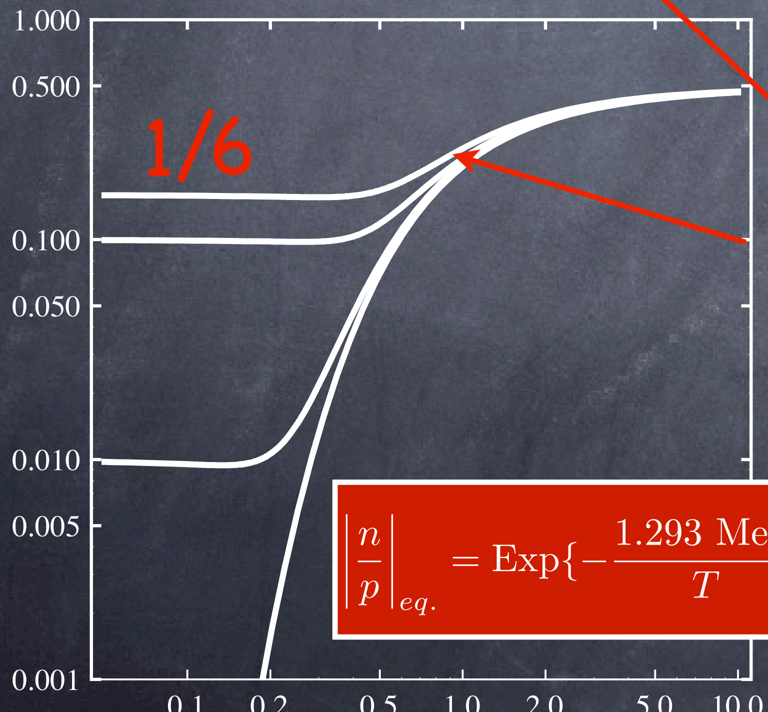


$$\left|\frac{n}{p}\right|_{eq.} = \mathrm{Exp}\{-\frac{1.293\ \mathrm{MeV}}{T}\}$$

$$(T^{dec.} \simeq 0.8\ MeV)$$

$$g_* = 10.75 + \frac{7}{8} \times (N_\nu - 3) \times 2$$

$$Y_p \simeq 0.25 + 0.012(N_\nu - 3)$$

Measuring D we get Y_p and

$$N_\nu = 2.4^{+0.9}_{-0.8} \quad (95\%)$$

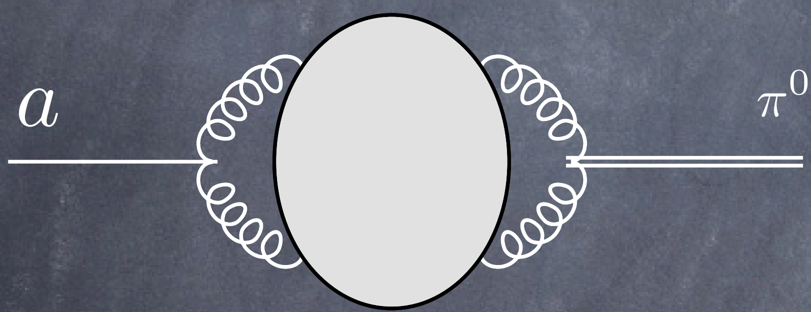
(G. Steigman 2008)

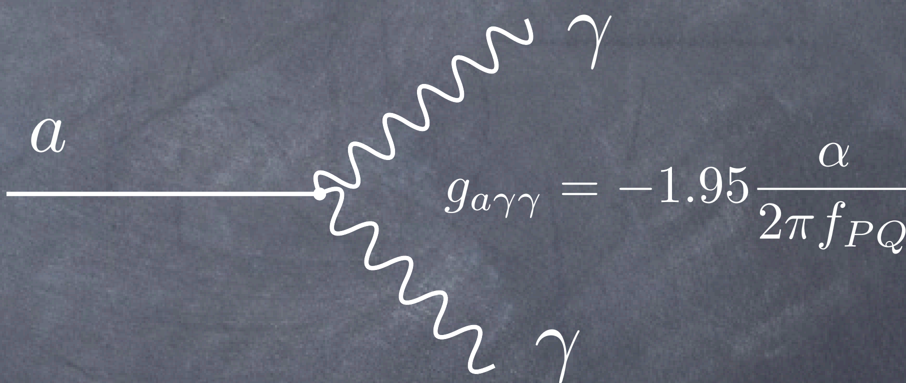
Cosmology: BBN bounds on cosmic radiation density $N_\nu = 2.4^{+0.9}_{-0.8}$ (95%)

Computing thermal relics: Interactions with SM particles

Axions...

Couplings depend on PQ charge of SM particles but...





model independent coupling!

$$g_{aX} \propto g_{\pi^0 X}$$

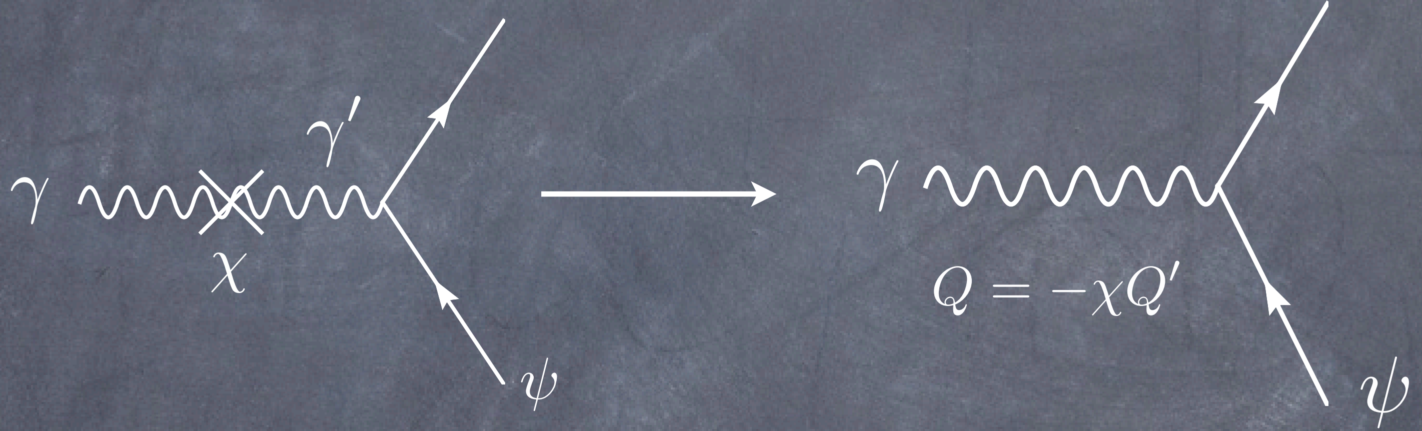
A Thermal axion (or axion-like-particle) contributes 4/7 of a neutrino, and cannot be excluded...

$$N_\nu = 4/7...$$

Cosmology: BBN bounds on cosmic radiation density $N_\nu = 2.4^{+0.9}_{-0.8}$ (95%)

Computing thermal relics: Interactions with SM particles

Minicharged particles...

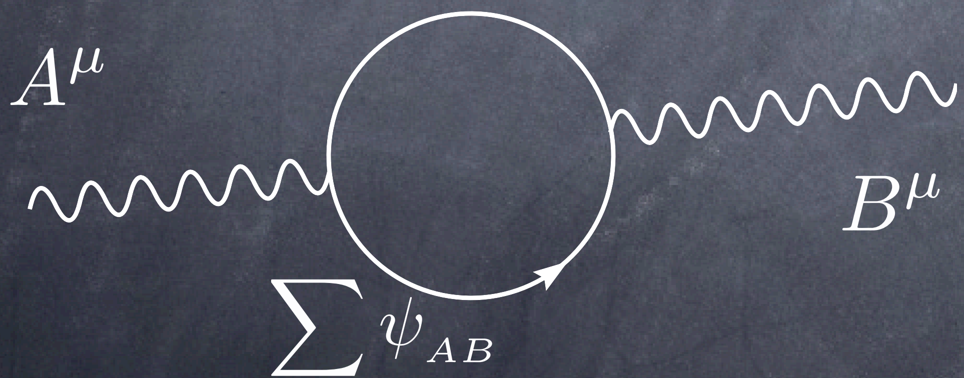


kinetic mixing

$$\mathcal{L}_H = -\underbrace{\frac{\sin\chi}{2} A_{\mu\nu} B^{\mu\nu}}_{} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$$

kinetic mixing with photon (or hypercharge)

- In principle can have any value between 0 and 1...
- If B belongs to a broken non abelian group, $\sin\chi = 0$ at high E, but it can develop a nonzero value below the SSB scale



$$= \frac{e g_B}{6\pi^2} \sum_{\psi_{AB}} Q_A Q_B \,\mathrm{Log}\, \frac{m_{\psi_{AB}}}{\mu}$$

SUSY, String theory ...

$$\sin\chi = 10^{-4,-16}$$

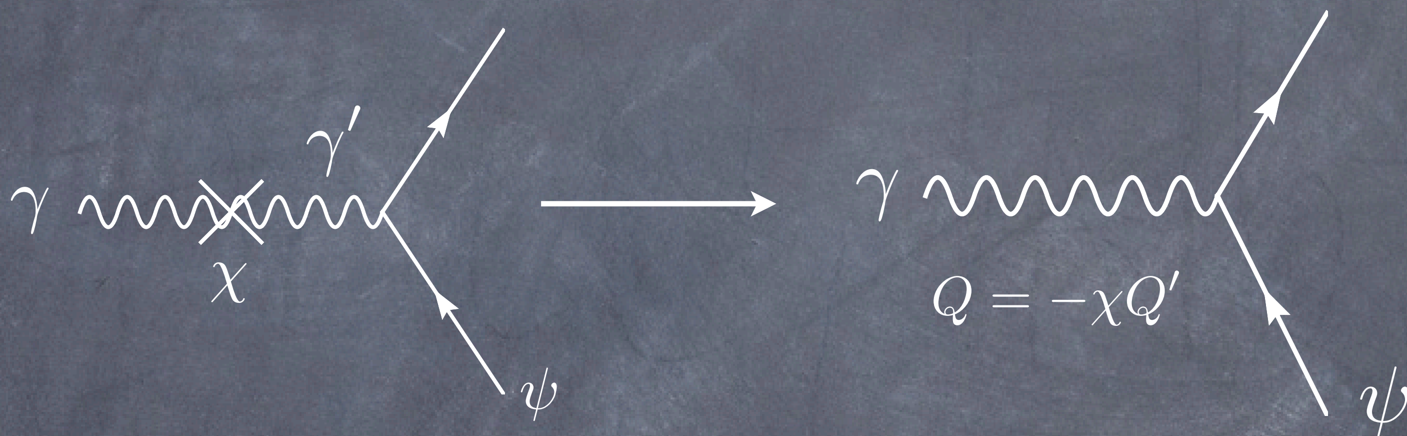
mass degeneracy

K. R. Dienes, C. F. Kolda, and J. March-Russell. Nucl. Phys., B492:104–118, 1997.

Cosmology: BBN bounds on cosmic radiation density $N_\nu = 2.4^{+0.9}_{-0.8}$ (95%)

Computing thermal relics: Interactions with SM particles

Minicharged particles...



$$e^+e^- \to \overline{\psi}\psi$$

$$\gamma\psi \to \gamma'\psi$$

$$N_\nu = 2 + 1!$$

$$\Gamma_{rel} = \frac{\alpha^2 Q^2}{2} T$$

$$\Gamma_{non-rel} \sim \frac{\alpha^2 Q^2}{m_e^2} T^3$$

$$\frac{\Gamma}{H} \ll 1 \to Q < 10^{-9}$$

$$T \sim 5\ MeV$$

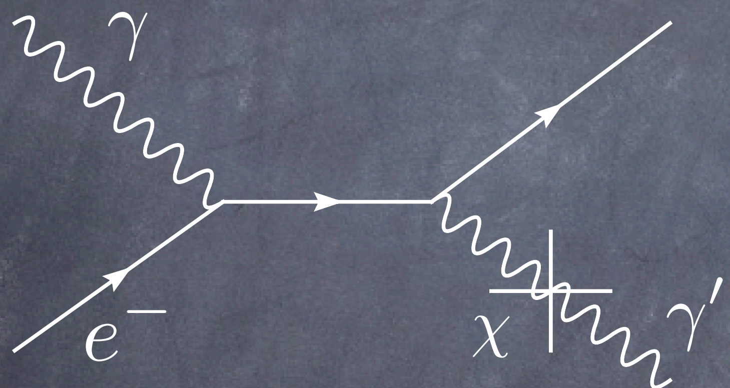
Davidson et al (2000) find a robust 2×10^{-9}

Cosmology: BBN bounds on cosmic radiation density $N_\nu = 2.4^{+0.9}_{-0.8}$ (95%)

Computing thermal relics:

Interactions with SM particles

hidden photons



photon "Flavor" oscillations & kinetic mixing

L. B. Okun. Sov. Phys. JETP, 56:502, 1982.

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

$$A^\mu \longrightarrow \tilde{A}^\mu - \sin\chi B^\mu \sim \tilde{A}^\mu - \chi B^\mu$$

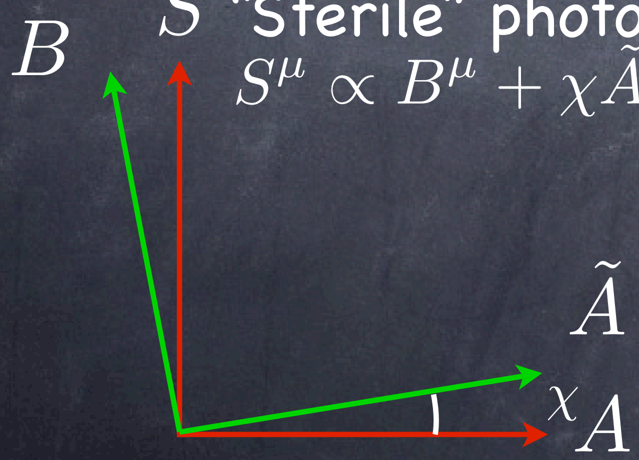
$$-\frac{1}{4}\tilde{A}_{\mu\nu}\tilde{A}^{\mu\nu} \quad ej_\mu(\tilde{A}^\mu - \chi B^\mu) \quad -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}m_{\gamma'}^2 B_\mu B^\mu$$

"Flavor" eigenstate

"mass" eigenstates

S "Sterile" photon

$S^\mu \propto B^\mu + \chi\tilde{A}^\mu$



photon-sterile oscillation prob.

$$P_{A-S} = \sin^2 2\chi \times \sin^2 \frac{m_{\gamma'}^2 L}{4\omega}$$

photon oscillations ... in a plasma

$$-\frac{1}{4}A_{\mu\nu}A^{\mu\nu} + j_\mu A^\mu$$

$$-\frac{\chi}{2}A_{\mu\nu}B^{\mu\nu}$$

$$-\frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}m^2_{\gamma'}B_\mu B^\mu$$

$A^\mu \longrightarrow \tilde{A}^\mu - \overline{\chi}\tilde{S}^\mu$ (if small mixing)

$$-\frac{1}{4}\tilde{A}_{\mu\nu}\tilde{A}^{\mu\nu} + \frac{1}{2}m^2_\gamma \tilde{A}_\mu \tilde{A}^\mu$$

$$j_\mu(\tilde{A}^\mu - \chi_{eff}\tilde{S}^\mu)$$

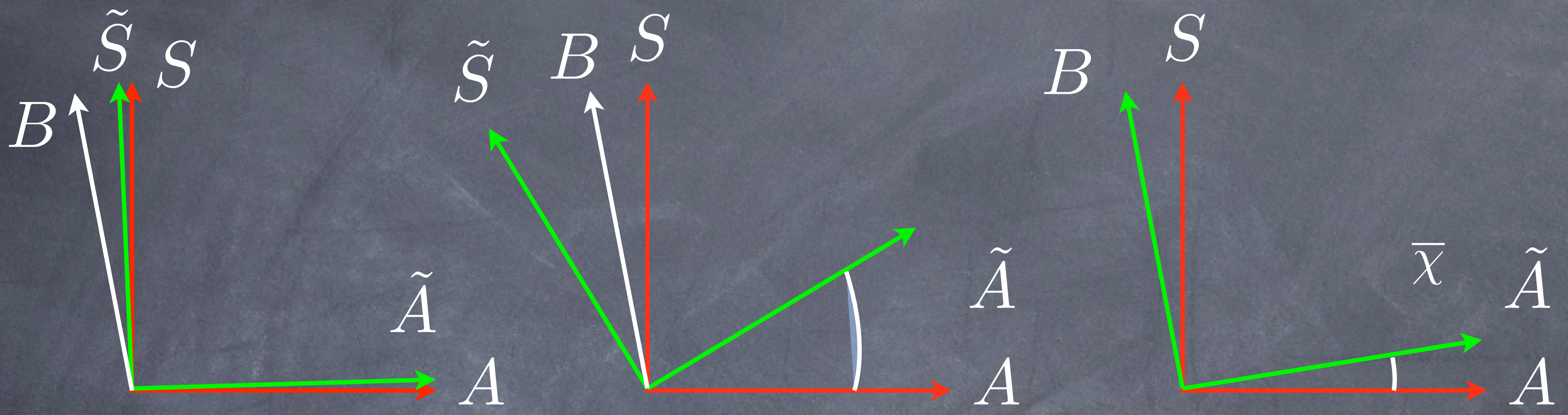
$$-\frac{1}{4}\tilde{S}_{\mu\nu}\tilde{S}^{\mu\nu} + \frac{1}{2}m^2_{\gamma'}\tilde{S}_\mu \tilde{S}^\mu$$

Plasma induces a photon anomalous dispersion relation -> mass

$$\chi_{eff} = \chi \frac{m^2_{\gamma'}}{\omega_P^2 - m^2_{\gamma'}}$$

$$m^2_\gamma = \omega^2_P \qquad \omega^2_P = \frac{4\pi\alpha n_e}{m_e}$$

photon oscillations ... in a plasma



$\chi_{eff}(m_{\gamma'} \simeq \omega_P) > \chi$ $\chi_{eff}(m_{\gamma'} \ll \omega_P) \ll \chi$ $\chi_{eff}(m_{\gamma'} \gg \omega_P) \simeq \chi$

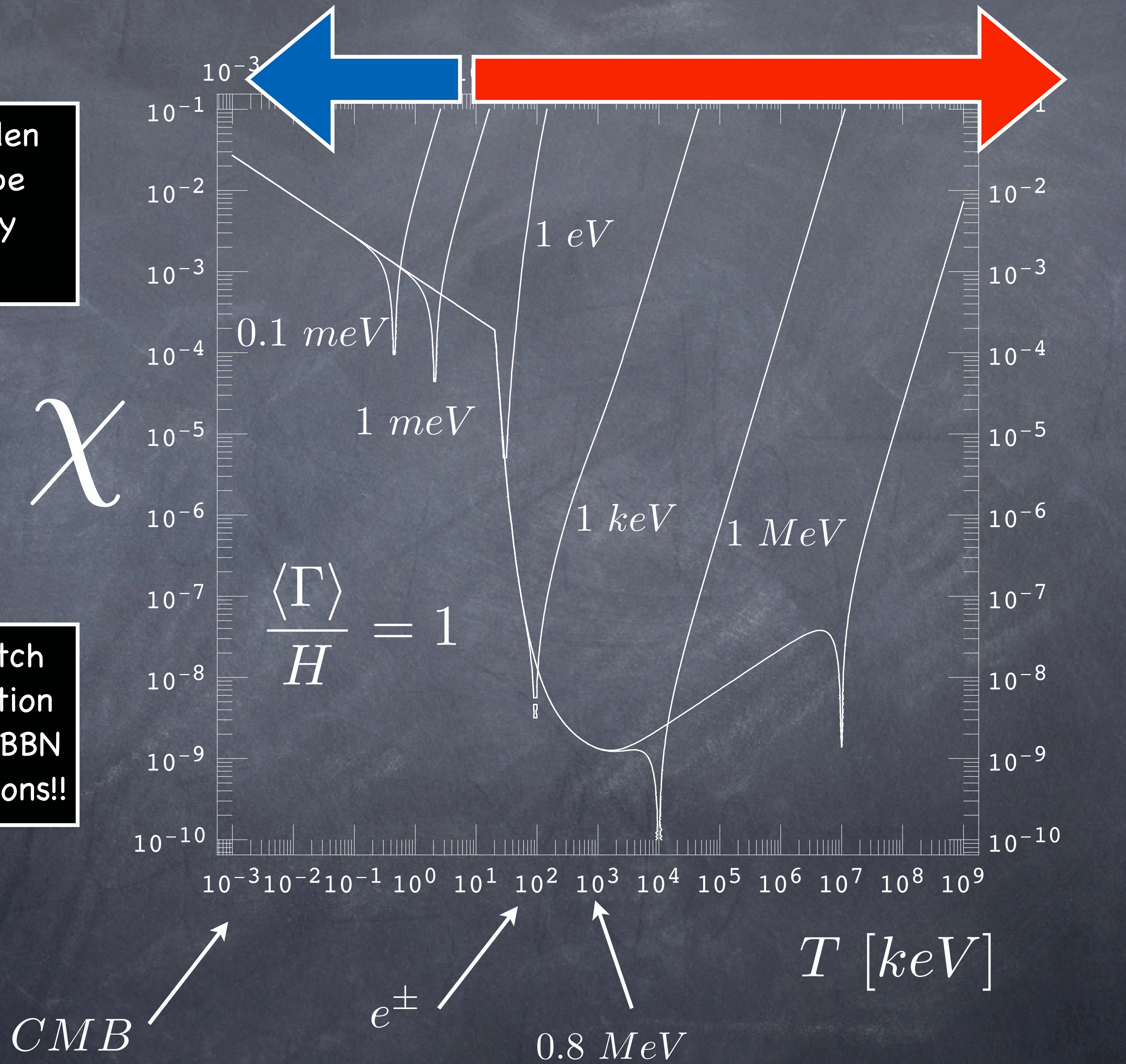
Suppression Resonance Vacuum

Interaction Eigenstates

Propagation Eigenstates

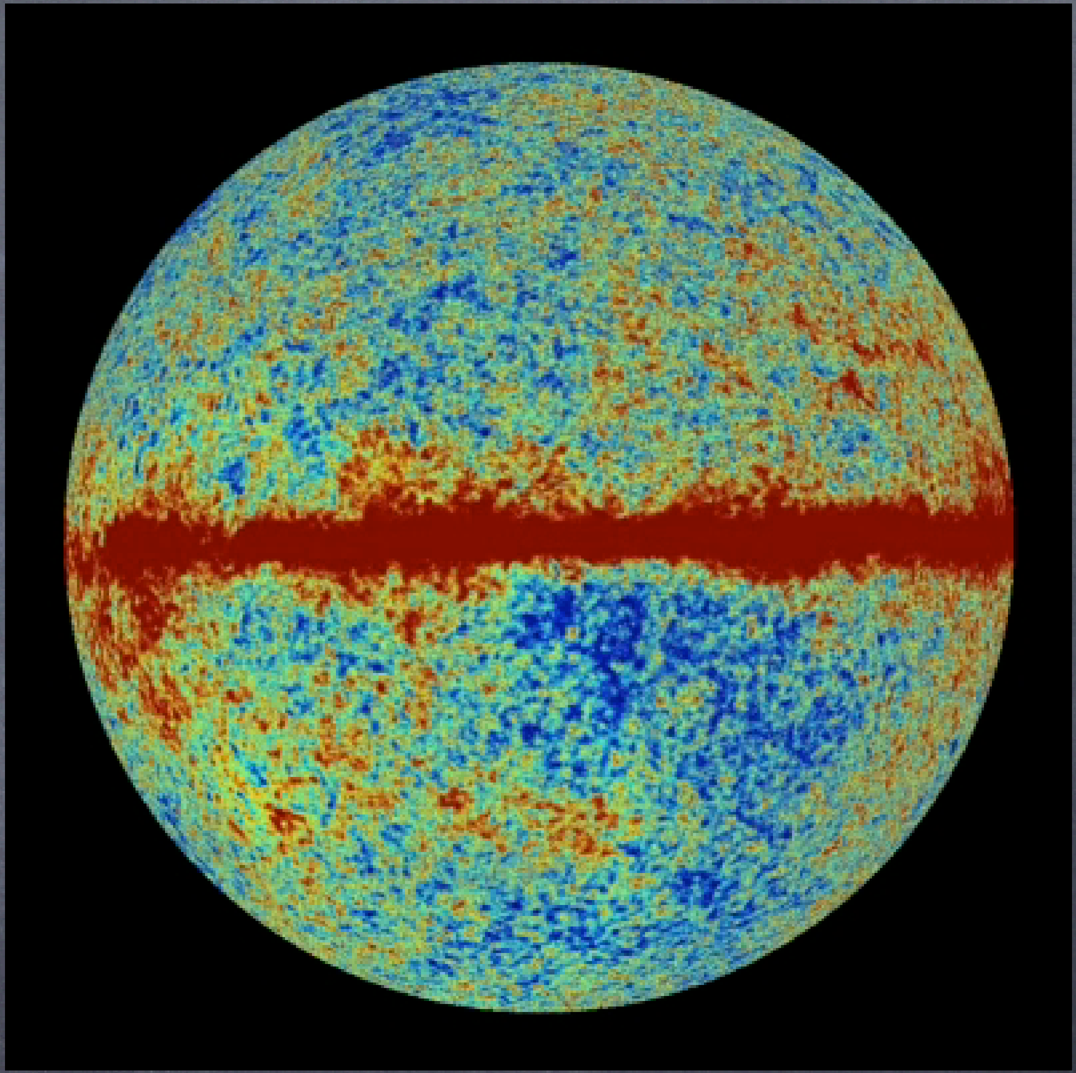
$$\chi_{eff} = \chi \frac{m_{\gamma'}^2}{\omega_P^2 - m_{\gamma'}^2}$$

Low mass hidden photons can be produced only after BBN!



They can mismatch the cosmic radiation density between BBN and CMB estimations!!

CMB bounds on hidden photons and MCPs



For the corresponding bounds on Axions, see the talk of Raffelt

Cosmology: CMB bounds on cosmic radiation density

N_ν^{eff} changes shifts positions of peaks and makes the first higher

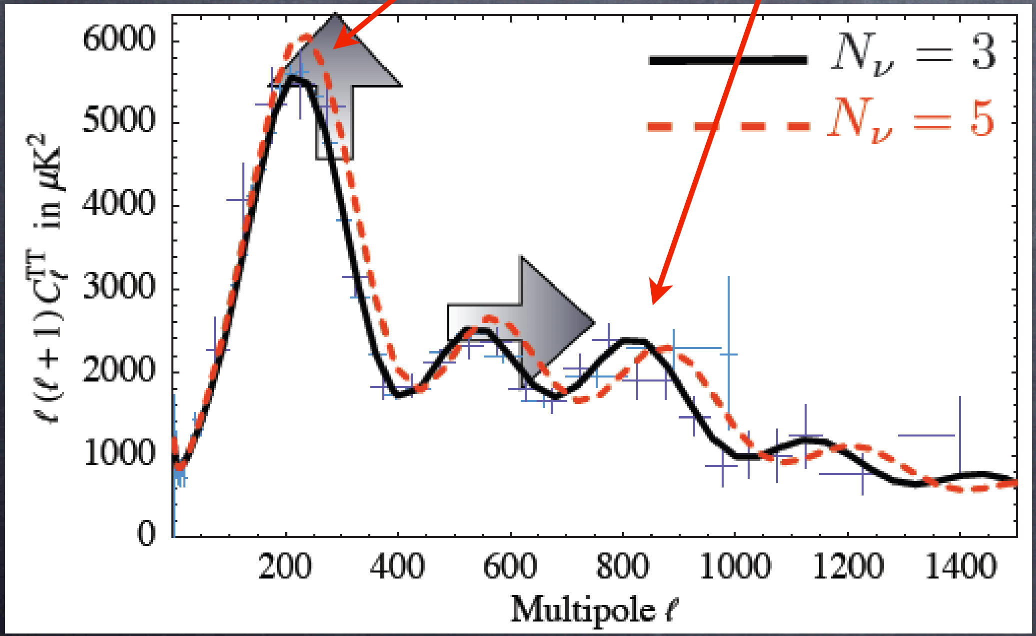
several causes :

Changes time of matter-radiation equality

$\Omega_m(z_{eq}) = \Omega_{rad}(z_{eq})$ degeneracy with Ω_m

Early Integrated Sachs-Wolfe effect

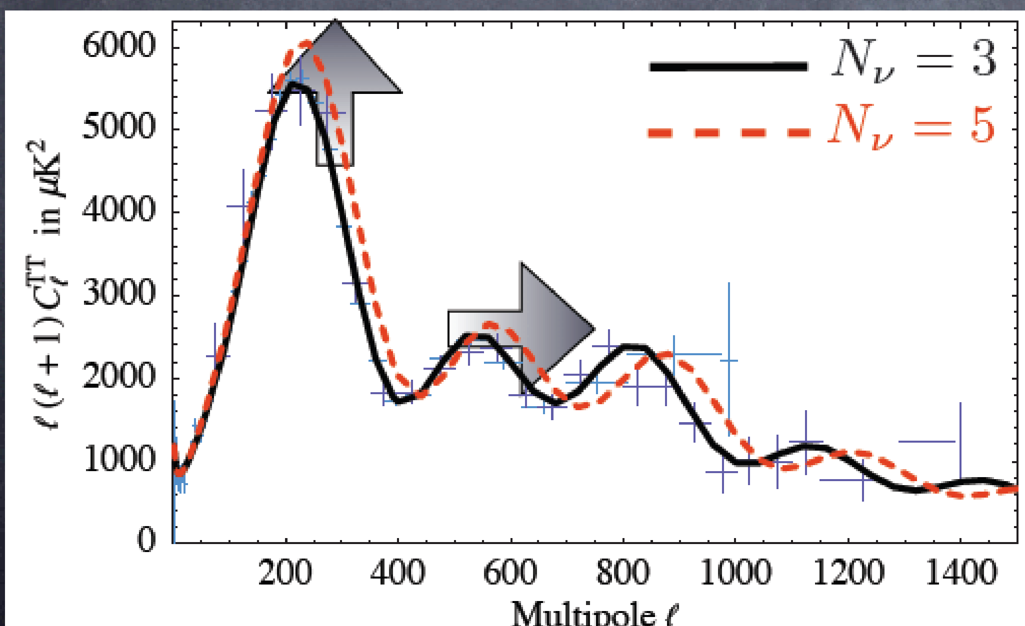
Free streaming of neutrinos

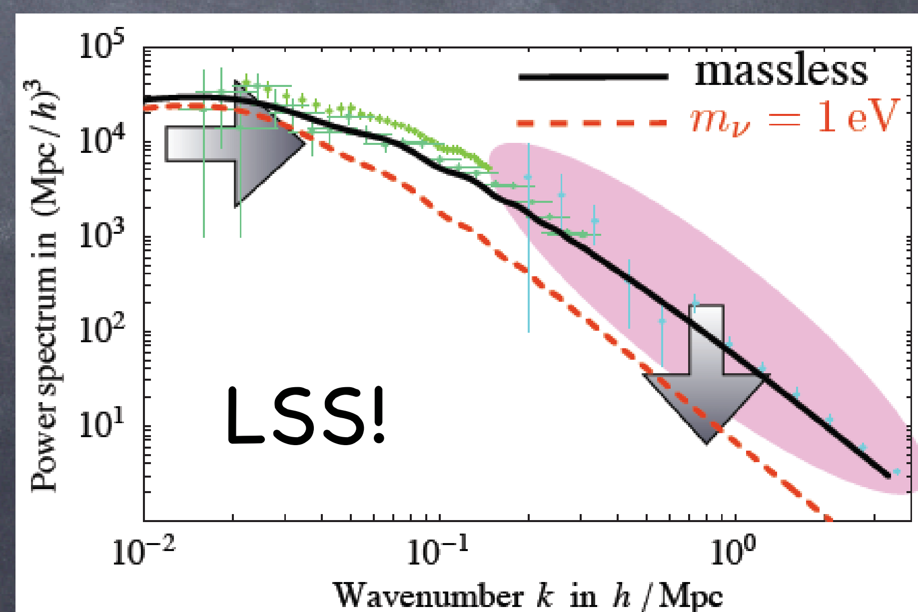


Cosmology: CMB bounds on cosmic radiation density

N_ν^{eff} changes shifts positions of peaks and makes the first higher

degeneracies can be broken by using further experiments
in particular large scale structure,
Hubble space telescope and
Supernovae data





Cosmology: CMB bounds on cosmic radiation density

N_ν^{eff} changes shifts positions of peaks and makes the first higher

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Inclusion of Ly-alpha data systematically favors $N_\nu^{eff} > 3$

possibly due to systematics (σ_8)

Latest fit (Steigman 2008)
WMAP5+SDSS+2dFGRS+(ACBAR+BOOM...)+HST+SN

$$N_\nu^{eff} = 2.9^{+2.0}_{-1.4} \quad 95\%$$

Careful inclusion of Ly-alpha (Hamann 2007)
WMAP3+Ly-alpha+others...

$$N_\nu^{eff} = 3.8^{+2.0}_{-1.6} \quad 95\%$$

Cosmology: Other CMB bounds on cosmic radiation density

	95% limit	Data set
Seljak, Slosar, McDonald [4]	$N_\nu = 5.3^{+2.1}_{-1.7}$	All
	$N_\nu = 4.8^{+1.6}_{-1.4}$	All + HST
	$N_\nu = 6.0^{+2.9}_{-2.4}$	All − BAO
	$N_\nu = 3.9^{+2.1}_{-1.7}$	All − Lyα
	$N_\nu = 7.8^{+2.3}_{-3.2}$	WMAP3+SN+SDSS(main)
	$N_\nu = 3.2^{+3.6}_{-2.3}$	WMAP3+SN+2dF
	$N_\nu = 5.2^{+2.1}_{-1.8}$	All-2dF-SDSS(main)
Ichikawa, Kawasaki, Takahashi [11]	$N_\nu = 3.1^{+5.1}_{-2.2}$	WMAP3+SDSS(LRG)

Table 1: Comparison of N_ν constraints using various data set combinations. "All" refers to WMAP3 + other CMB + Lyα + galaxy power spectrum (SDSS main sample + 2dF) + SDSS baryon acoustic oscillation (BAO) + Supernovae Ia (SN). See Ref. [4] for details. SDSS (main) and Lyα favor $N_\nu > 3$.

taken from *K. Ichikawa arXiv:0706.3465v1 [astro-ph]*

Late cosmology the meV Valley: Hidden CMB !

For low χ only resonance is relevant

Oscillations transfer energy from photons to hidden photons

$$x \equiv \frac{\rho_{\gamma'}}{\rho_\gamma}$$

Photon temperature readjusted after

$$T^{after} = (1-x)^{1/4} T^{before}$$

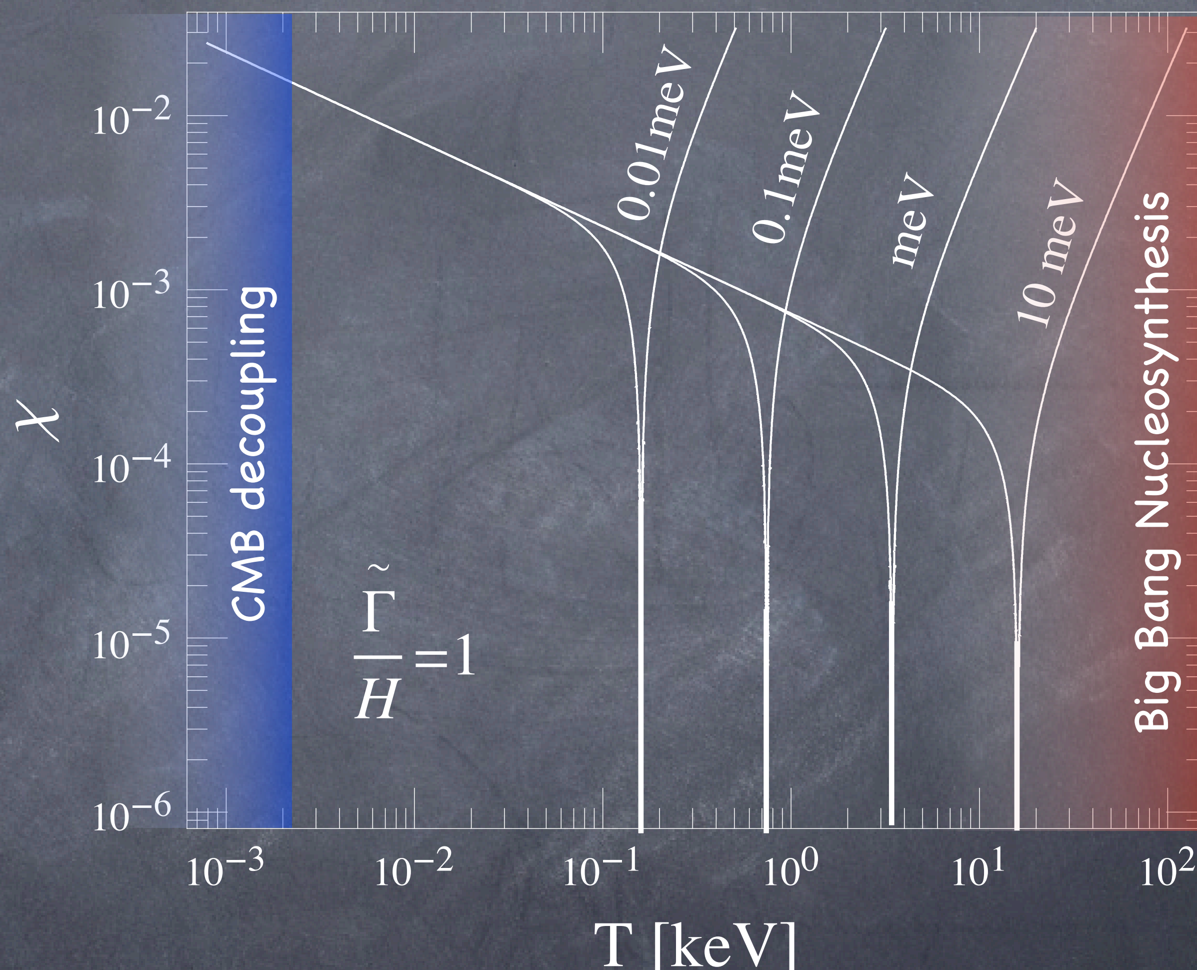
but standard neutrinos untouched so its temperature relative to photons is increased!

Finally:

$$N_\nu^{eff}(x) = \frac{N_\nu}{1-x} + \frac{8}{7}\frac{x}{1-x}\left(\frac{11}{4}\right)^{4/3}$$

and the bound reads

$$N_\nu^{eff} = 2.9^{+2.0}_{-1.4} \quad 95\%$$
$$x < 0.2$$



Our computation $x = 3.9 \times 10^{10} \chi^2$

$$\chi < 2 \times 10^{-6}$$

BBN results (PDG)

Assume $N_\nu = 3.046$

$$\eta^{\rm BBN} = 5.7^{+0.8}_{-0.9} \times 10^{-10}$$

CMB results (Steigman)

(WMAP5+otherCMB+LSS+SN+HST)

$$\eta^{\rm CMB} = 6.14^{+0.3}_{-0.25} \times 10^{-10}$$

$$N_\nu^{\rm eff} = 2.9^{+2.0}_{-1.4}6$$

CMB results (Hamann)

(WMAP3+...+SDSS+Ly-alpha)

$$N_\nu^{\rm eff} = 3.8^{+2.0}_{-1.6}$$

$$N_\nu^{\rm eff} < 4.8$$

$$\frac{\eta^{\rm BBN}}{\eta^{\rm CMB}} > 0.75$$

$$x < 0.2$$

$$x < 0.32$$

BBN results (PDG)

Assume $N_\nu = 3.046$

$$\eta^{\rm BBN} = 5.7^{+0.8}_{-0.9} \times 10^{-10}$$

~~CMB results (Steigman)~~

~~(WMAP5+...LSS+SN+HST)~~

~~$\eta^{\rm CMB} = 6.14^{+0.3}_{-0.25} \times 10^{-10}$~~

~~$N_\nu^{\rm eff} = 2.9^{+2.0}_{-1.4}6$~~

CMB results (Hamann)

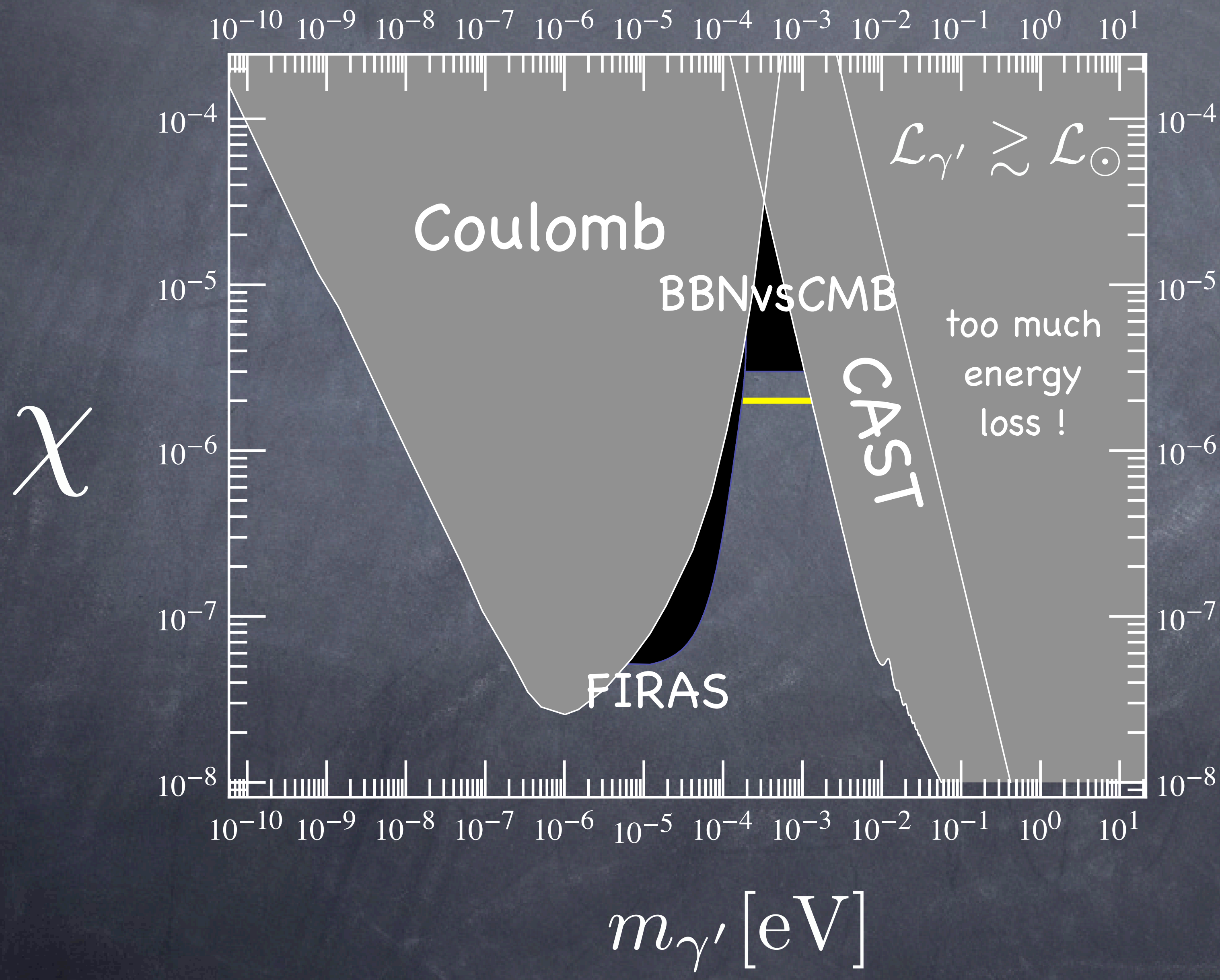
(WMAP3+...+SDSS+Ly-alpha)

$$N_\nu^{\rm eff} = 3.8^{+2.0}_{-1.6}$$

Both suggest

$$x \simeq 0.1$$

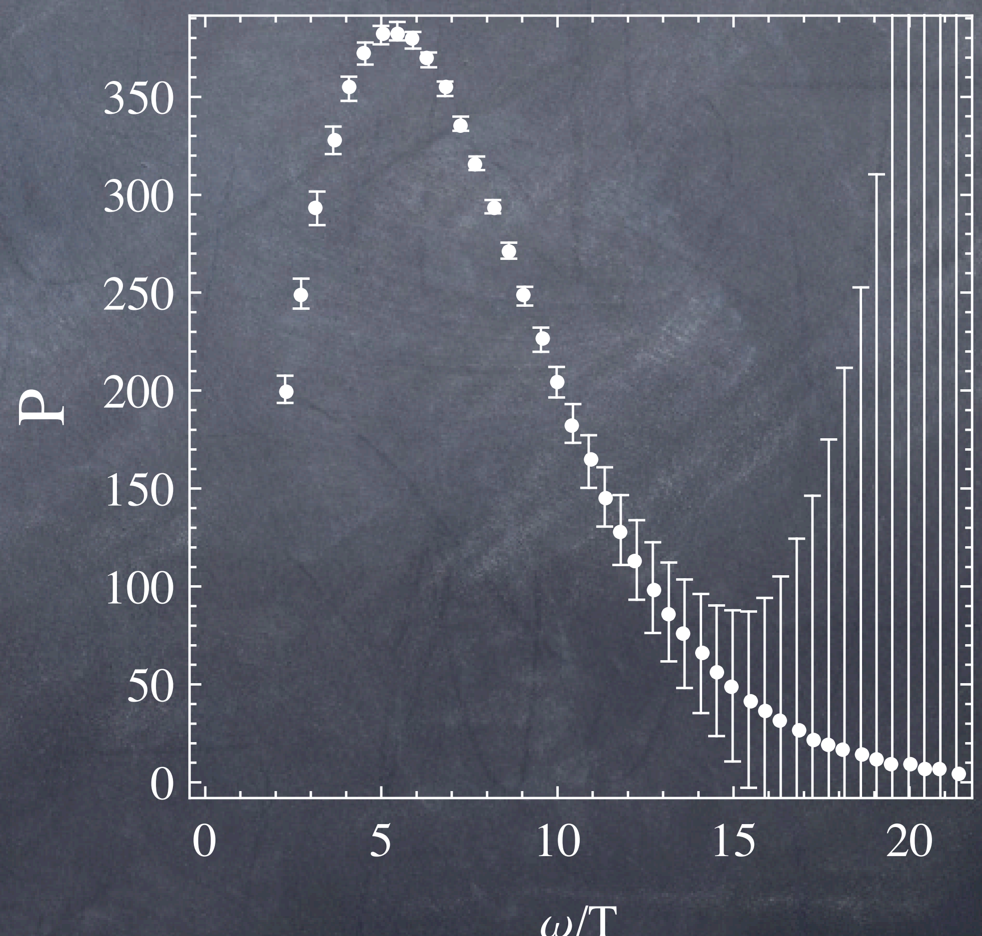
massive Hidden photons and the meV Valley



CMB Blackbody distortions

The Blackbody spectrum of CMB forms very early and becomes `unprotected' against possible distortions after $T \simeq \mathrm{keV}$.

FIRAS measurements (error magnification $\times 10^5$)

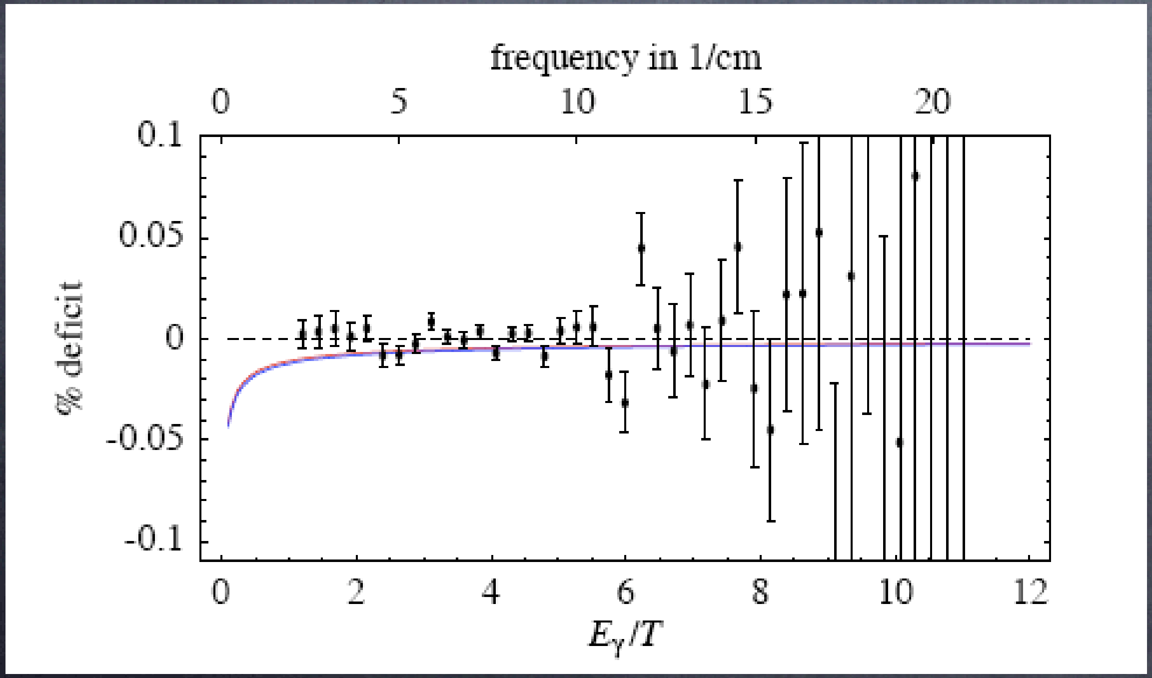


CMB Blackbody distortions : MCPs

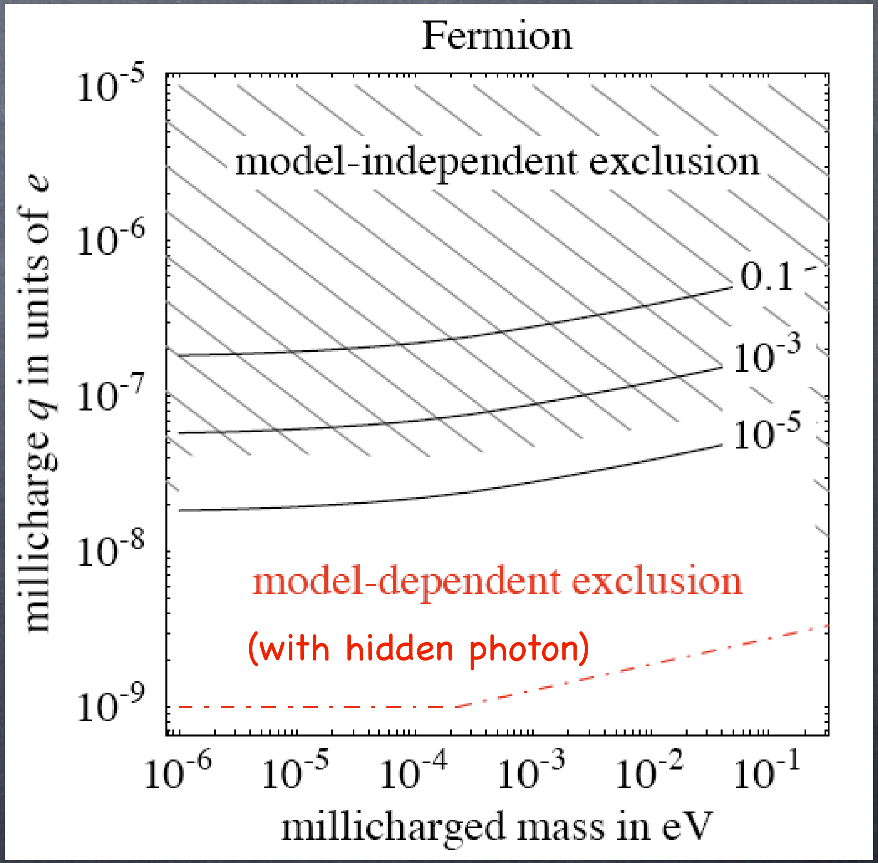
The Blackbody spectrum of CMB forms very early and becomes \`unprotected' against possible distortions after $T \simeq \mathrm{keV}$.

Small mass minicharged particles can be produced through $\gamma\gamma \to \psi\bar{\psi}$

The depletion of photons is energy-dependent!



Melchiorri et al (2007)



CMB Blackbody distortions : ALPs

The Blackbody spectrum of CMB forms very early and becomes \`unprotected' against possible distortions after $T \simeq \mathrm{keV}$.

Small mass minicharged particles can be produced through $\gamma\gamma \to \psi\overline{\psi}$

Axions and other ALPs will be produced by Primakoff process

$g \lesssim 10^{-6}\mathrm{GeV}^{-1}$ would be allowed Melchiorri et al (2007)

CMB Blackbody distortions : Hidden Photons

The Blackbody spectrum of CMB forms very early and becomes 'unprotected' against possible distortions after $T \simeq \mathrm{keV}$.

Photon hidden-photon oscillations also deplete photons $\gamma \leftrightarrow \gamma'$

Again the depletion of photons is energy-dependent! $P_{A-S} = \sin^2 2\chi \times \sin^2 \frac{m_{\gamma'}^2 L}{4\omega}$

Oscillations after decoupling (cosmological distances probe tiny masses)

$m_{\gamma'} \lesssim 10^{-17}\mathrm{eV}$ (unfortunately, only for $\chi = \mathcal{O}(1)$)

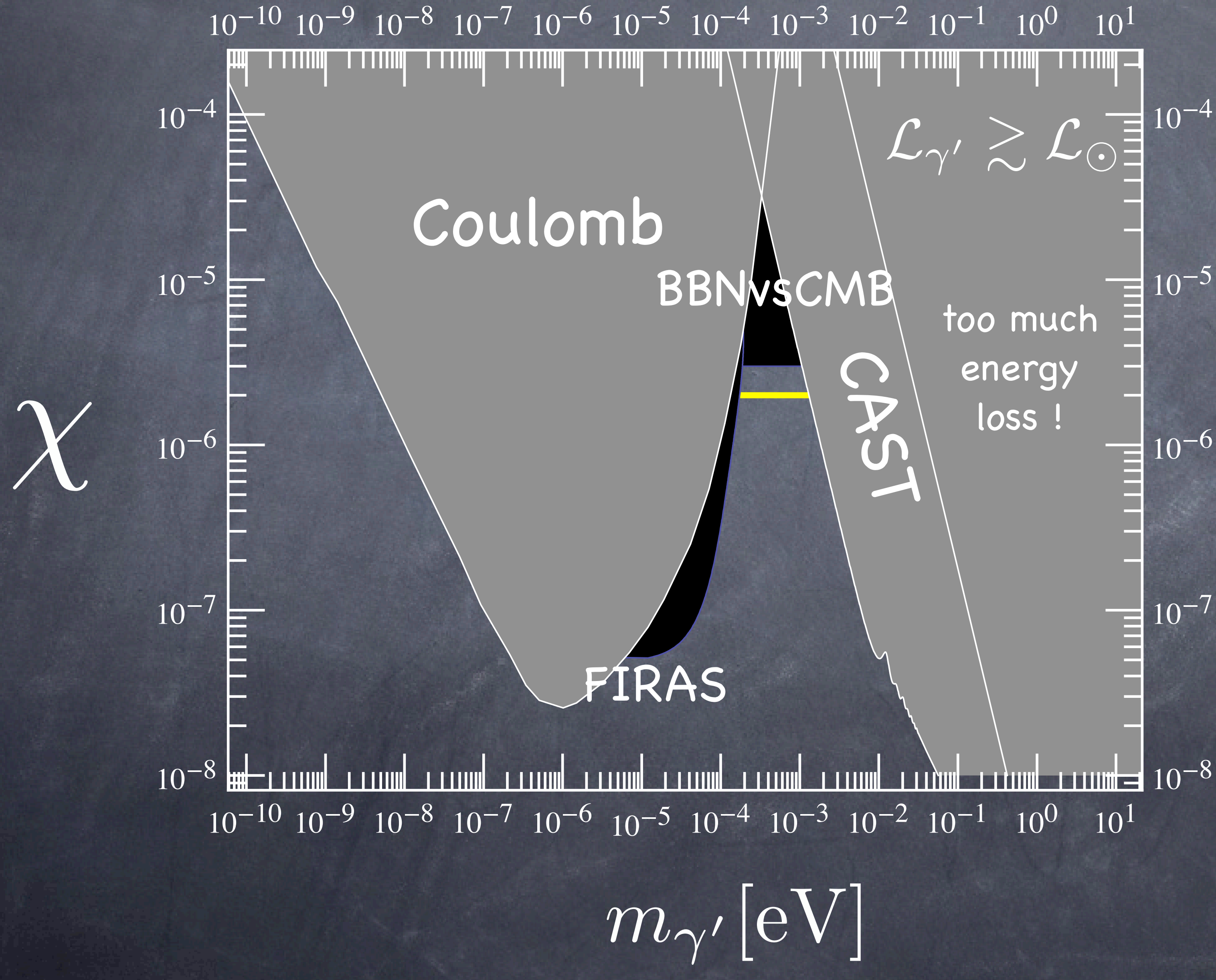
Resonant oscillations for $m_{\gamma'} \sim \mathrm{meV}\,(T \sim \mathrm{keV})$ produce distortions in a sharp time interval.

$T^{res.} > 1.2\ \mathrm{keV}(m_\gamma \sim 0.2\mathrm{meV})$ ⟶ Photon creating interactions restore BB!

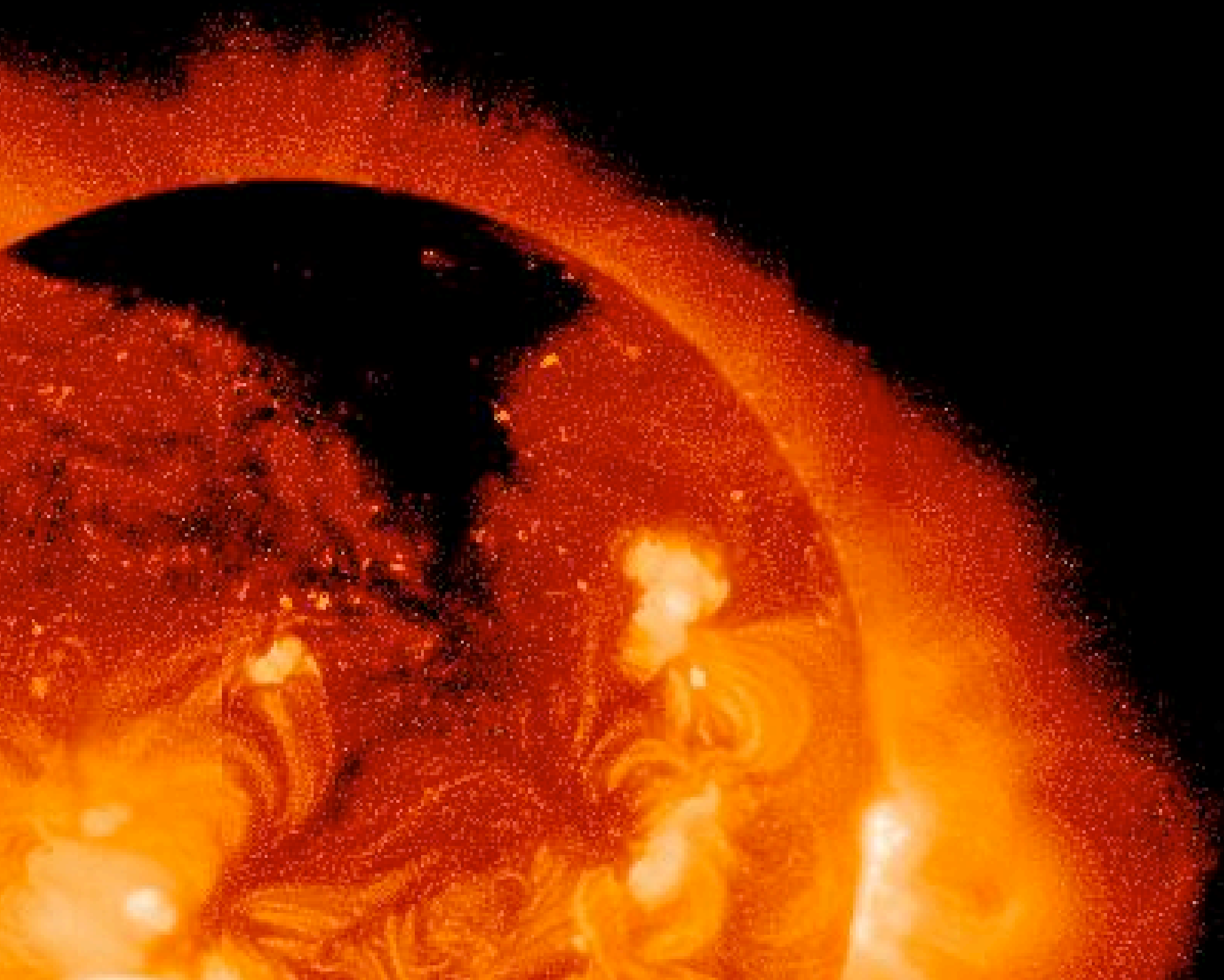
$0.1\ \mathrm{keV} > T^{res.} > 1.2\ \mathrm{keV}$ $(0.02\ \mathrm{meV} < m_\gamma < 0.2\ \mathrm{meV})$ ⟶ Thomson scattering thermalizes remaining photons but ... with a non-zero chemical potential

$\mu_{\mathrm{FIRAS}} < 9 \times 10^{-5}$ ⟶ **Bounds**

massive Hidden photons and the meV Valley

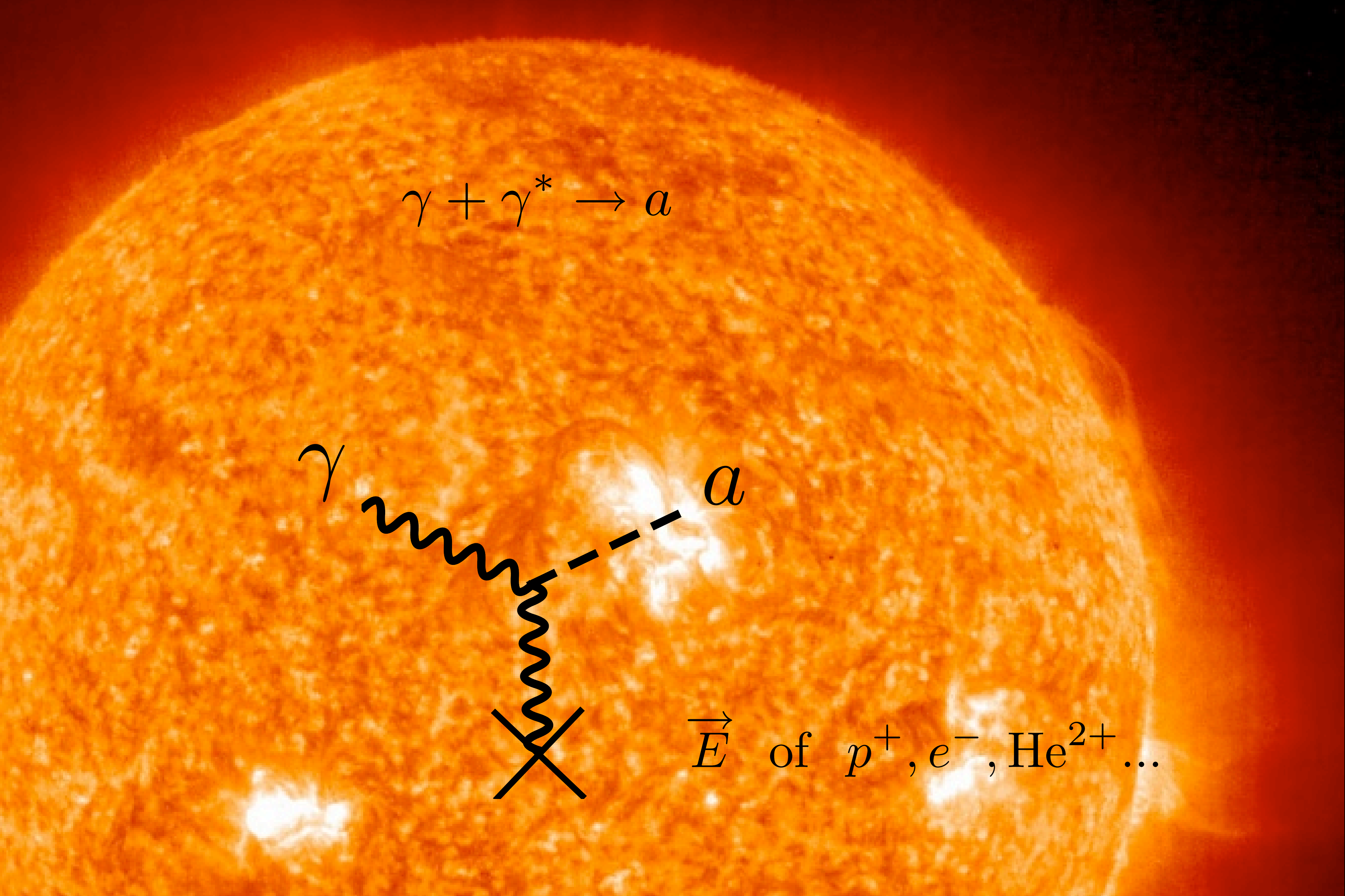


WISPS and Stars



WISPS and Stars: Primakoff Axion production

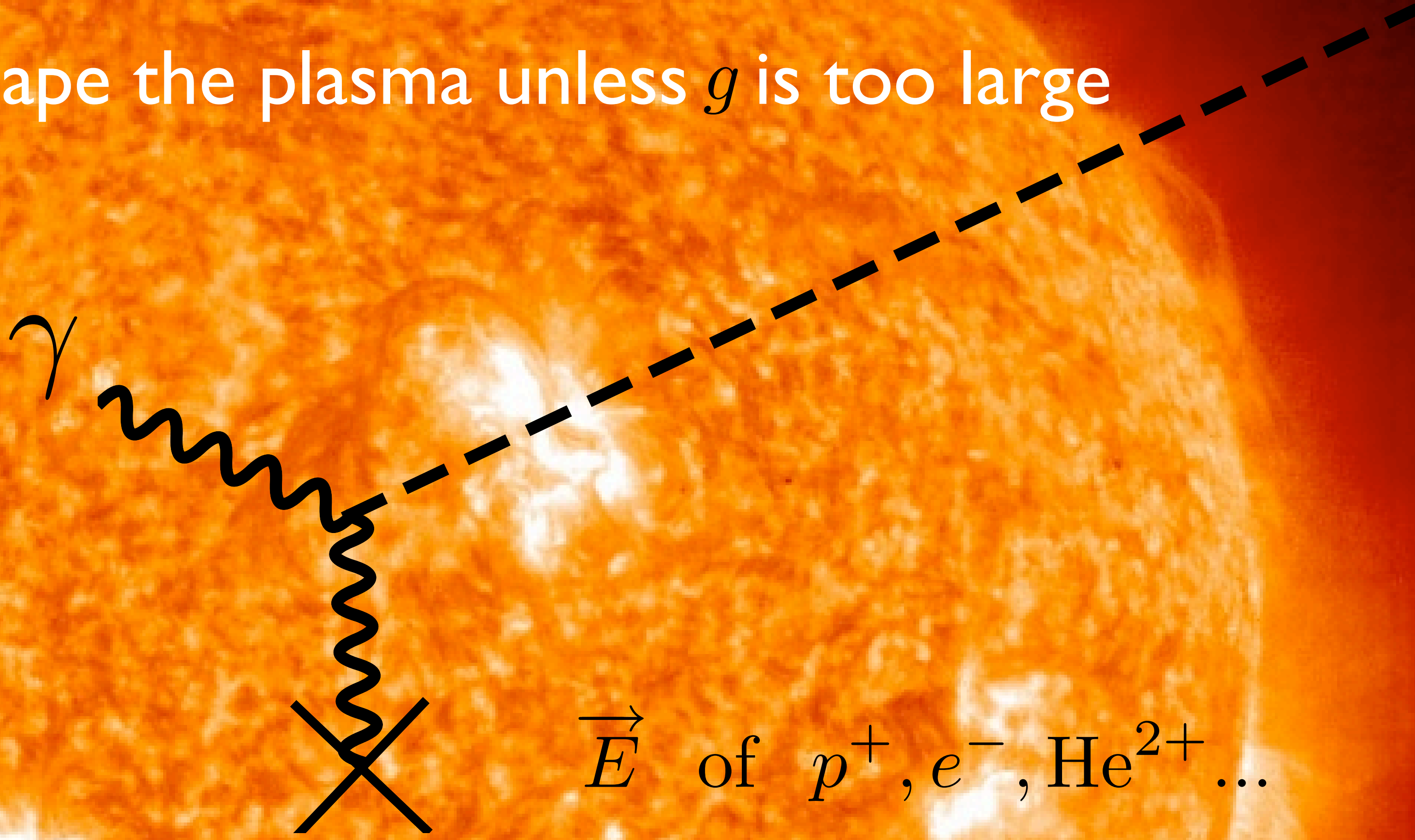
$$\gamma + \gamma^* \rightarrow a$$



WISPS and Stars: Primakoff Axion production

$$\gamma + \gamma^* \rightarrow a$$

a will escape the plasma unless g is too large

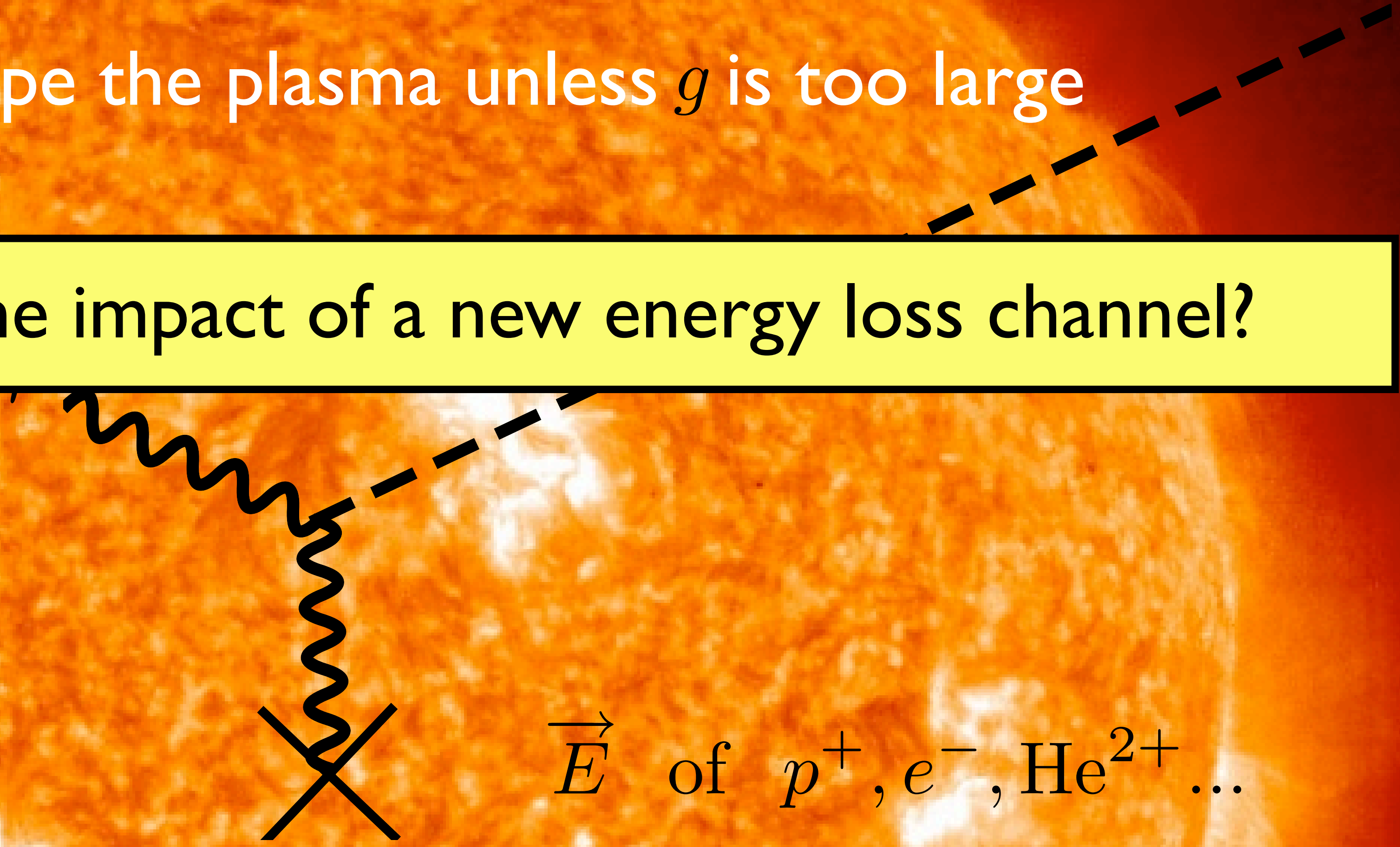


WISPS and Stars: Primakoff Axion production

$$\gamma + \gamma^* \rightarrow a$$

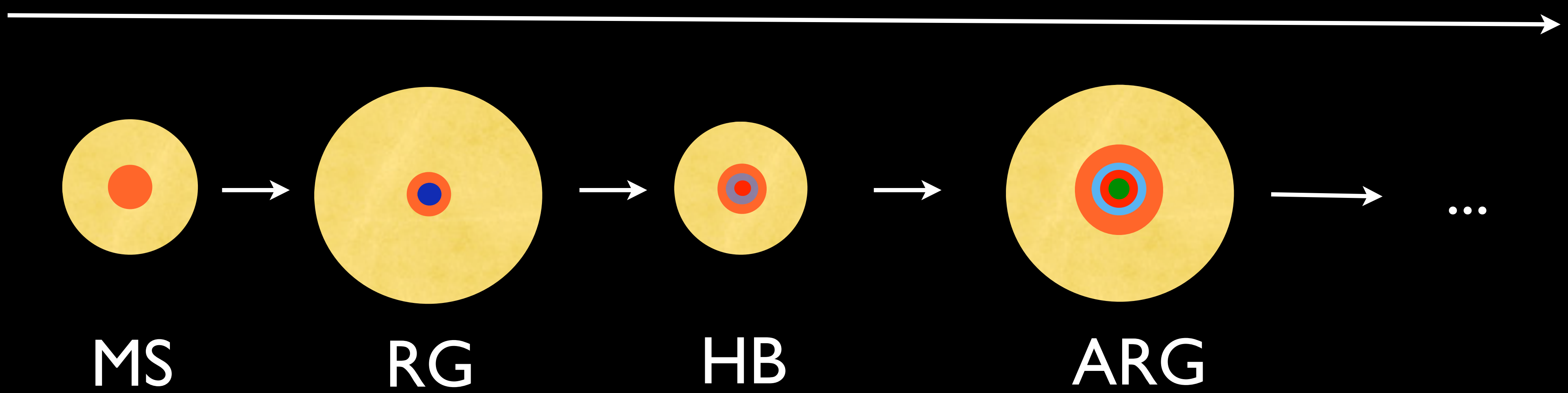
a will escape the plasma unless g is too large

what's the impact of a new energy loss channel?



$\overrightarrow{E}$ of $p^+, e^-, \mathrm{He}^{2+}$...

Low mass Stellar Evolution



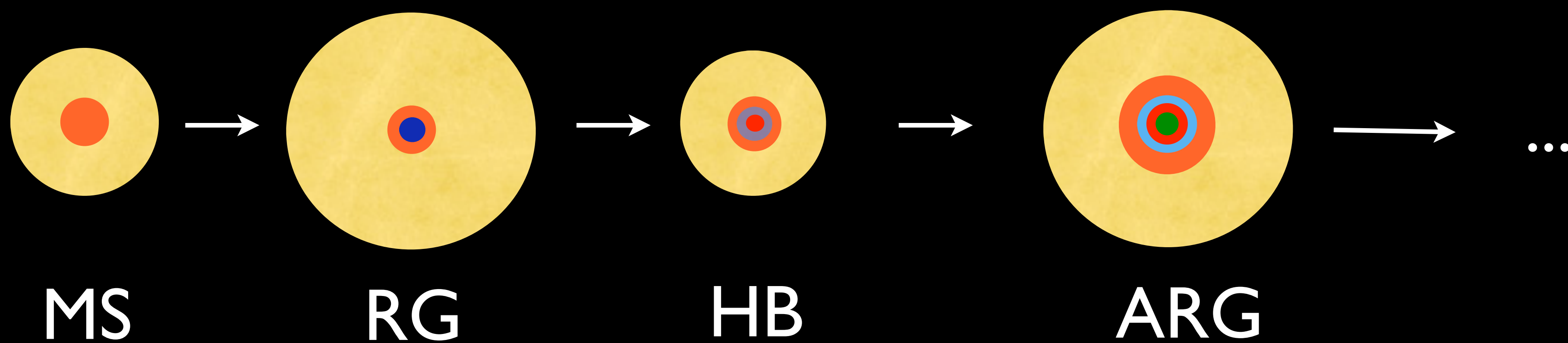
Two types of evolutionary stages: Self adjusted burning & Degenerate Core domination

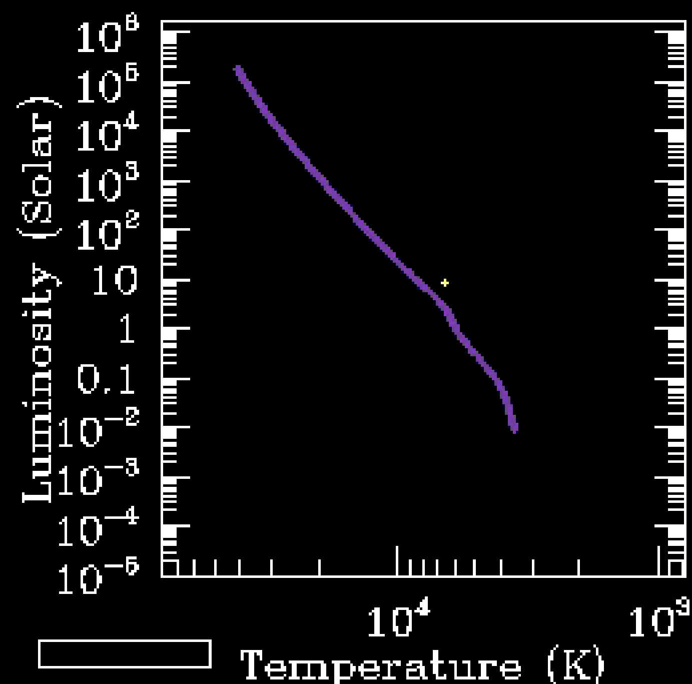
Two different ends : Formation of a degenerated core & Next element Fusion

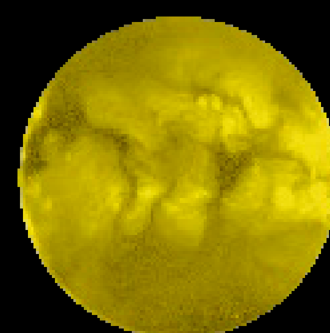
Two responses to a novel energy loss channel:

Low mass Stellar Evolution

time



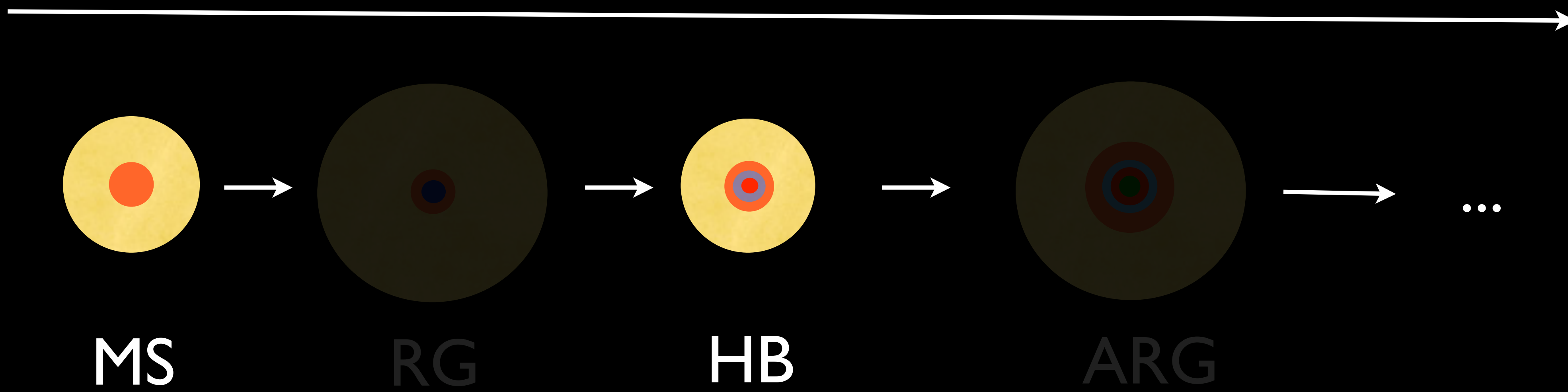




Animation courtesy of Jake Simon and Charles Hansen. See http://rainman.astro.uiuc.edu/ddr/stellar/index.html

Low mass Stellar Evolution

time



Two types of evolutionary stages: Self adjusted burning & Core dominated burning

Two different ends : Formation of a degenerated core & Next element Fusion

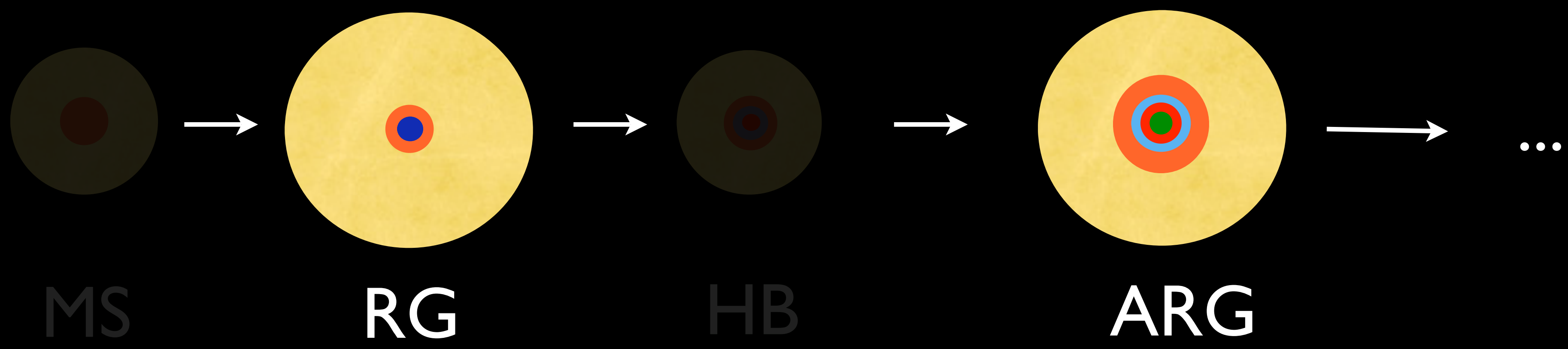
Two responses to a novel energy loss channel:

Same amount of nuclear fuel + higher luminosity = shorter life

$$t_{\gamma+\phi} = \frac{\mathcal{L}_\gamma}{\mathcal{L}_\gamma + \mathcal{L}_\phi} t_\gamma$$

Low mass Stellar Evolution

time



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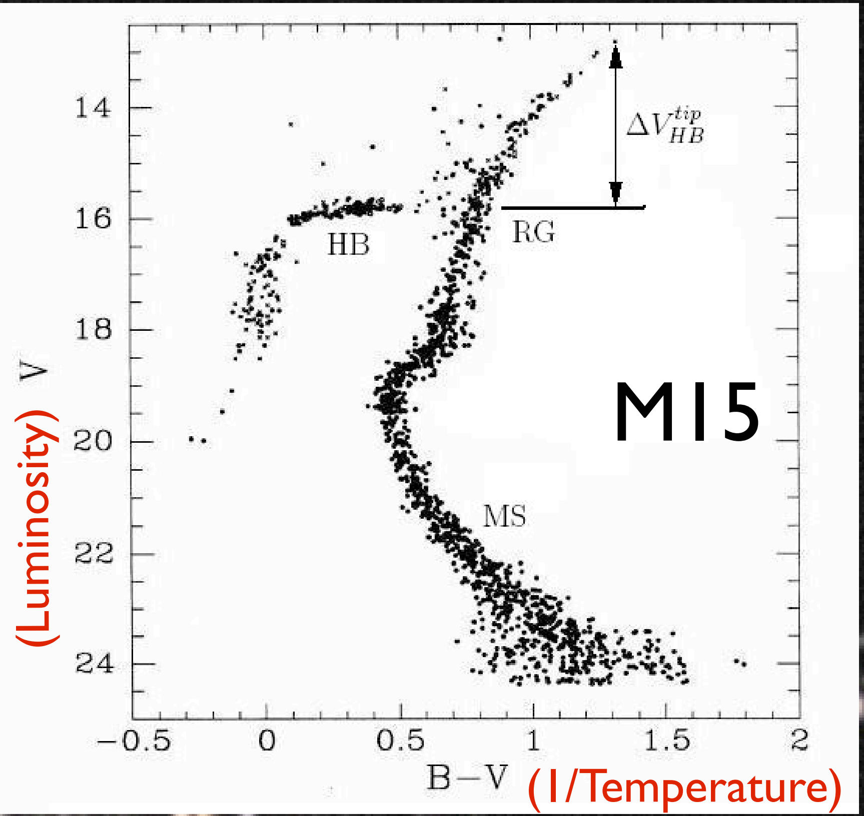
$$t_{\gamma+\phi} = \frac{\mathcal{L}_\gamma}{\mathcal{L}_\gamma + \mathcal{L}_\phi} t_\gamma$$

RG phase lasts until the degenerated Helium core is hot enough to burn

WISP losses delay the heating of the RG cores!

Globular Clusters (RG & HB)

- Clusters of around 1 million stars
- Same age, low metallicity, different mass
- Around 150 GBs in the galaxy Halo
- Color-Magnitude Diagrams



- $\frac{N_{\rm HB}}{N_{\rm RG}}$ ↓
- $\Delta V^{tip}_{\rm HB}$ ↑

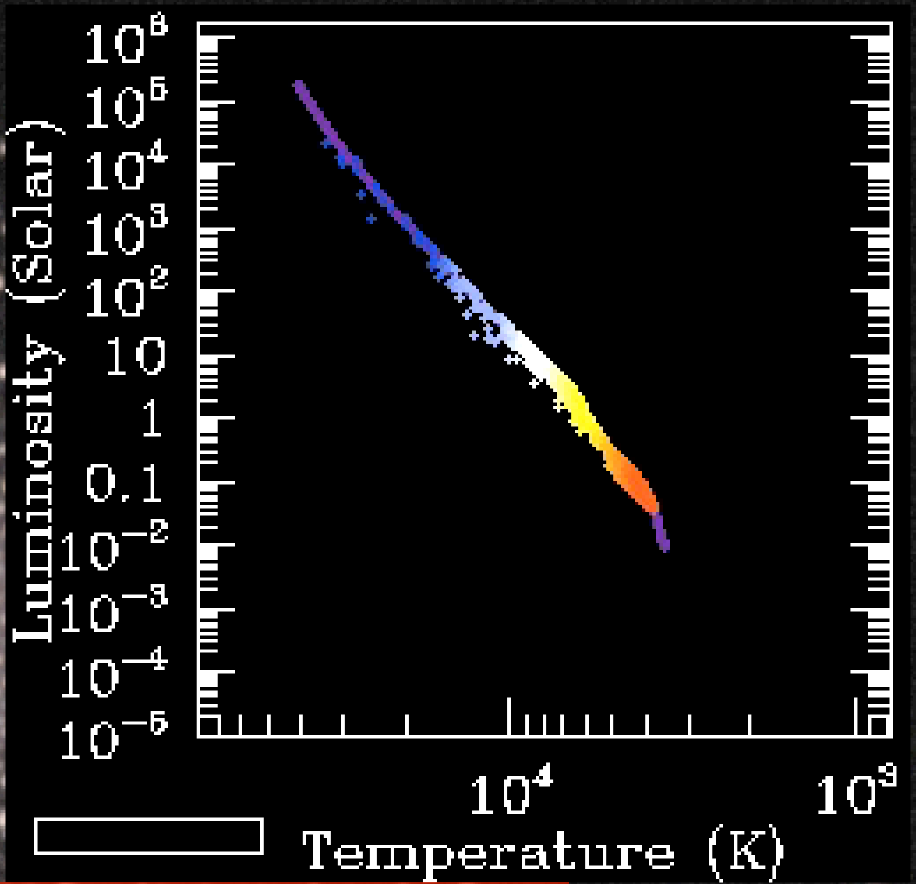
energy loss per unit mass

$$\epsilon < 10 \ {\rm erg\ gr^{-1} s^{-1}}$$

for either HB or RG cores

- Numerical simulations agree with observations at the 10% level (old data), that allows to set strong constraints

Globular Clusters (RG & HB)



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Globular Clusters (RG & HB)

$\epsilon < 10 \text{ erg gr}^{-1}\text{s}^{-1}$

HB core

$\rho \sim 10^{-4} \text{ grcm}^{-3}$

$T \sim 10^{8} \text{ K}$

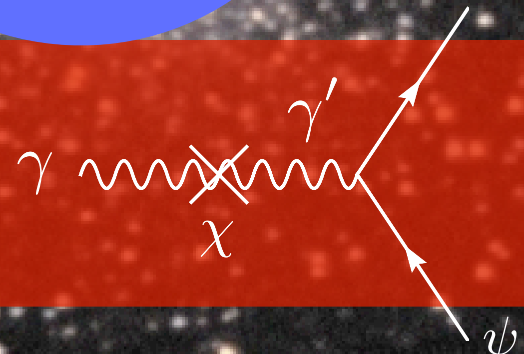
Axion photon coupling

$$\epsilon_{a\gamma\gamma} \simeq \frac{g_{a\gamma\gamma}^2}{4Pi}\frac{T^7}{\rho}$$

$$g_{a\gamma\gamma} < 0.6 \; 10^{-10} \text{ GeV}^{-1}$$

Minicharged particles; Plasmon decay

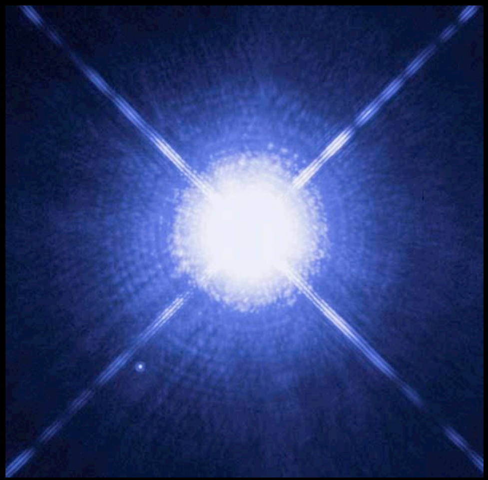
$$\epsilon_{MCP} \simeq 5 \; Q^2 \; 10^{28} \text{gr cm}^{-3}$$



$$Q < 2 \; 10^{-14}$$

Hidden Photons...

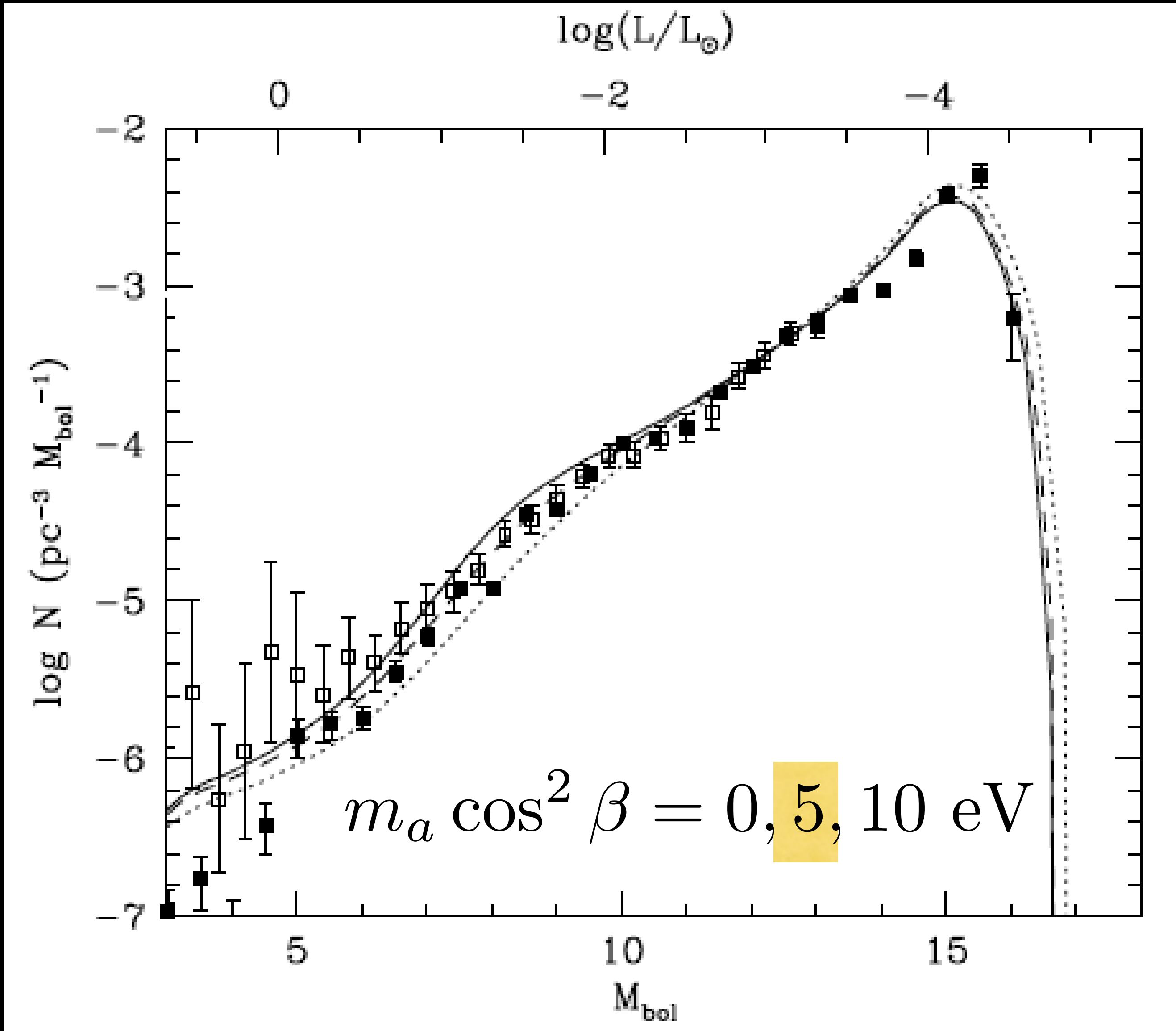
Bounds from other stars...



White dwarf cooling

Raffelt (1986), Isern (2008,today)

Luminosity function (WD's per unit mass) altered by WISP cooling



Probes the axion electron coupling

$$\frac{g_{aee}^2}{4\pi} = 2.8\times10^{-11} m_a[\mathrm{eV}]\cos^2\beta$$

Isern (2008,today)

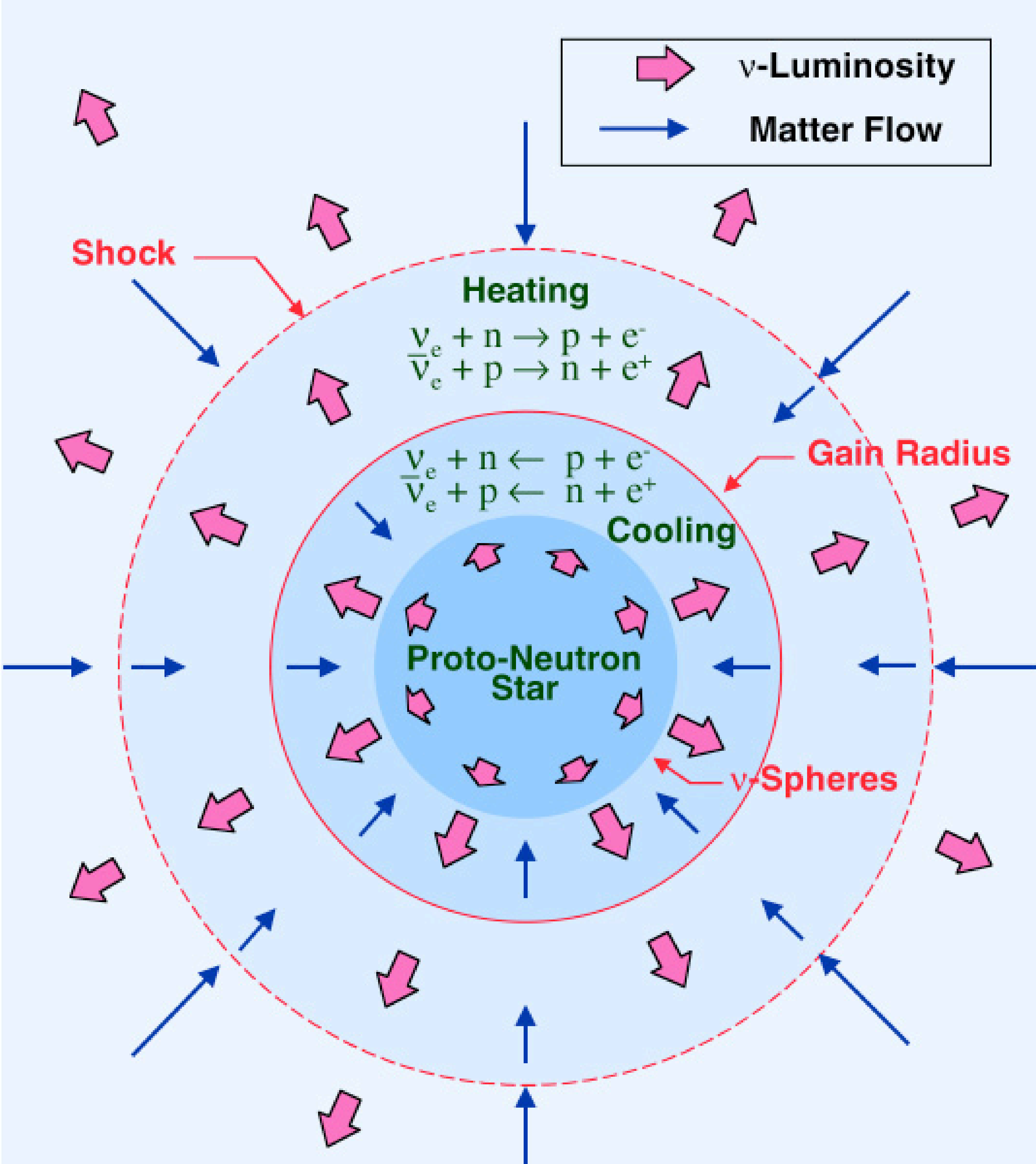
Supernova 1987a

Even neutrinos are trapped in the proto neutron star, that takes around 10 s to cool down ...

Axions with

$$f_a \lesssim 5 \times 10^8 \text{GeV}$$

Cool the PNS eficiently and reduce the neutrino burst!



Lifetime of the Sun (MS)

Radiological dating of short lived isotopes implies

$$t_{\odot} \sim 5\ 10^{9}\text{years}$$

Solar Models are designed to reproduce the currently observed properties (radius and luminosity) at this age but ...

No solar model can be built with

$$\mathcal{L}_x > \mathcal{L}_{std} \qquad g_{a\gamma\gamma} > 3\ 10^{-9}\text{GeV}^{-1}$$

G. G. Raffelt and D. S. P. Dearborn, Phys. Rev. D36, 2211 (1987).

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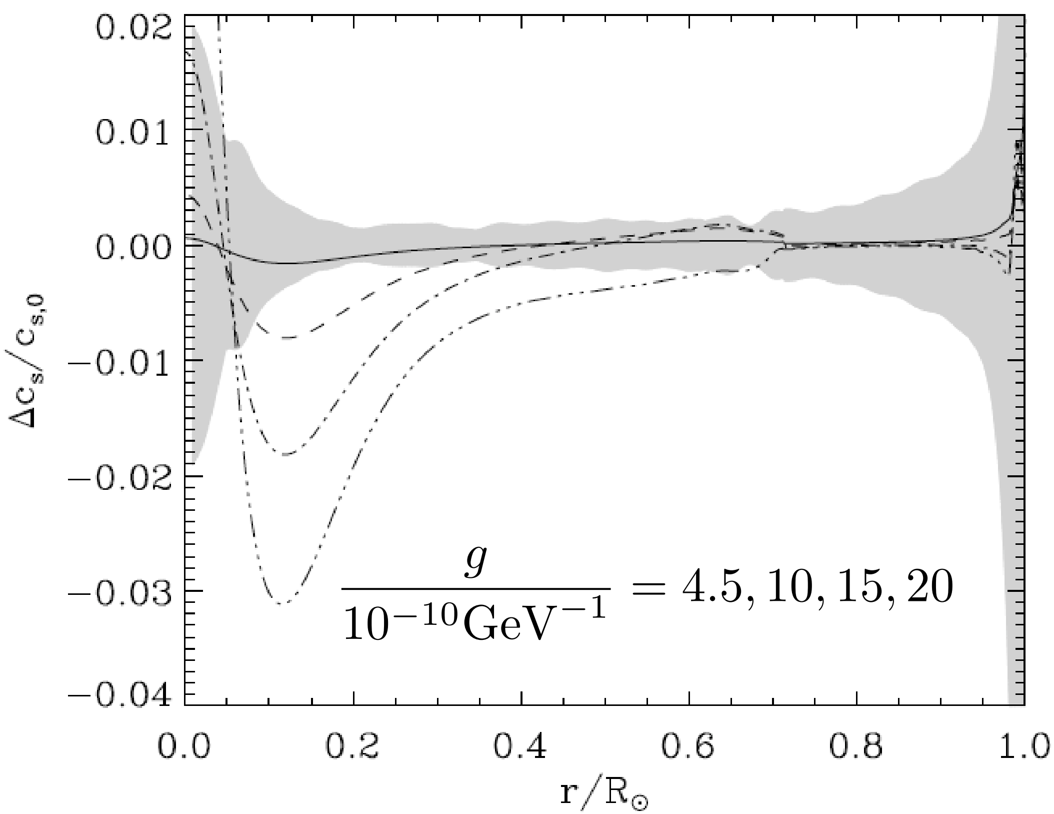
Solar Helioseismology Probes axions



Solar models with axion losses are consistent with sound profiles for $g < 0.5 \sim 1 \times 10^{-9}\ \mathrm{GeV}^{-1}$

This corresponds to $\mathcal{L}_a \simeq 0.05 \sim 0.2 \mathcal{L}_\odot$

Raffelt (1999)

Solar Neutrino Flux

Solar models with axion losses predict higher core temperatures and densities, as a result the neutrino flux is enhanced!

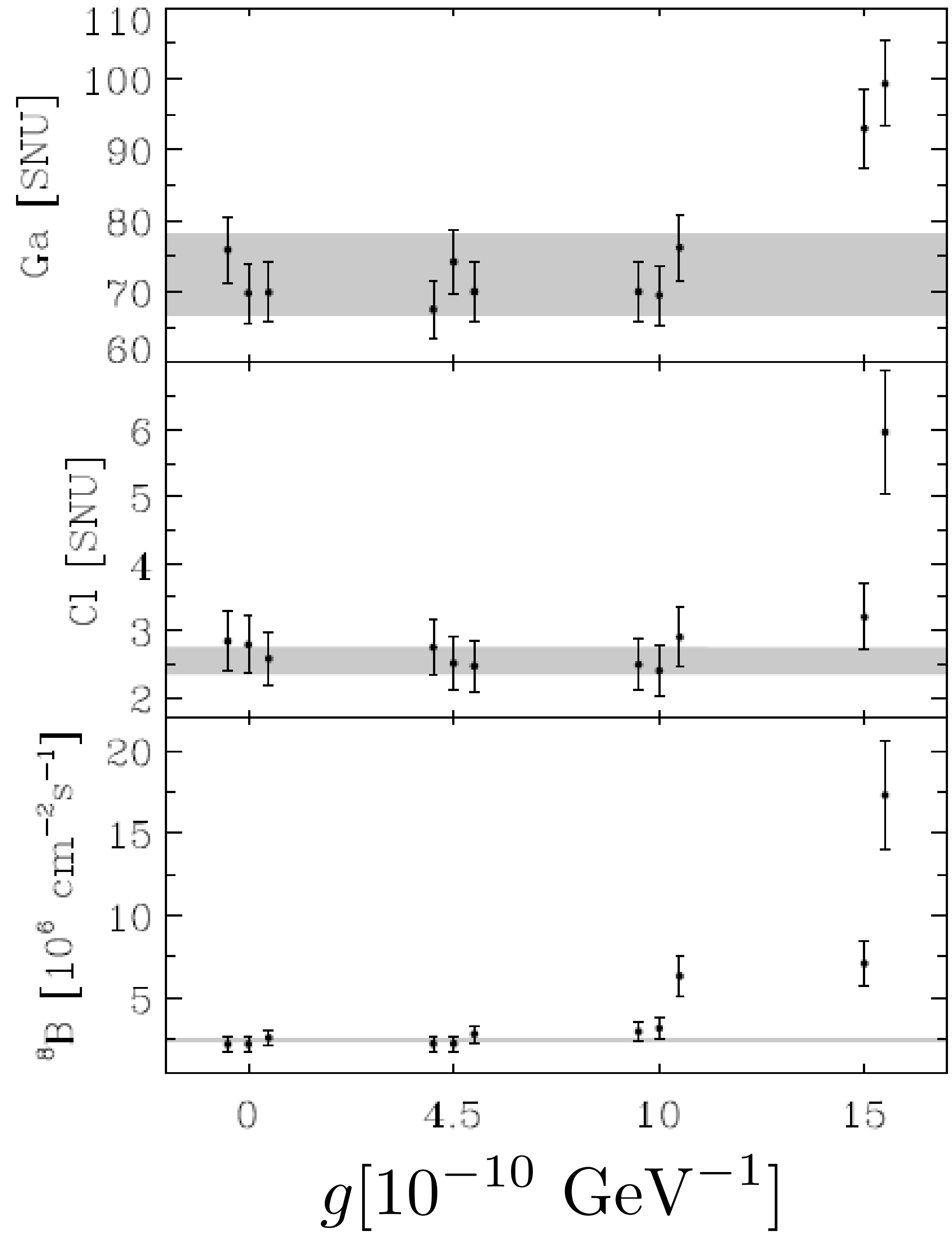
B flux (most recent data)

$$4.94 \times 10^6\ \mathrm{cm}^{-1}\mathrm{s}^{-1} \pm 8.8\%$$

SM expectations

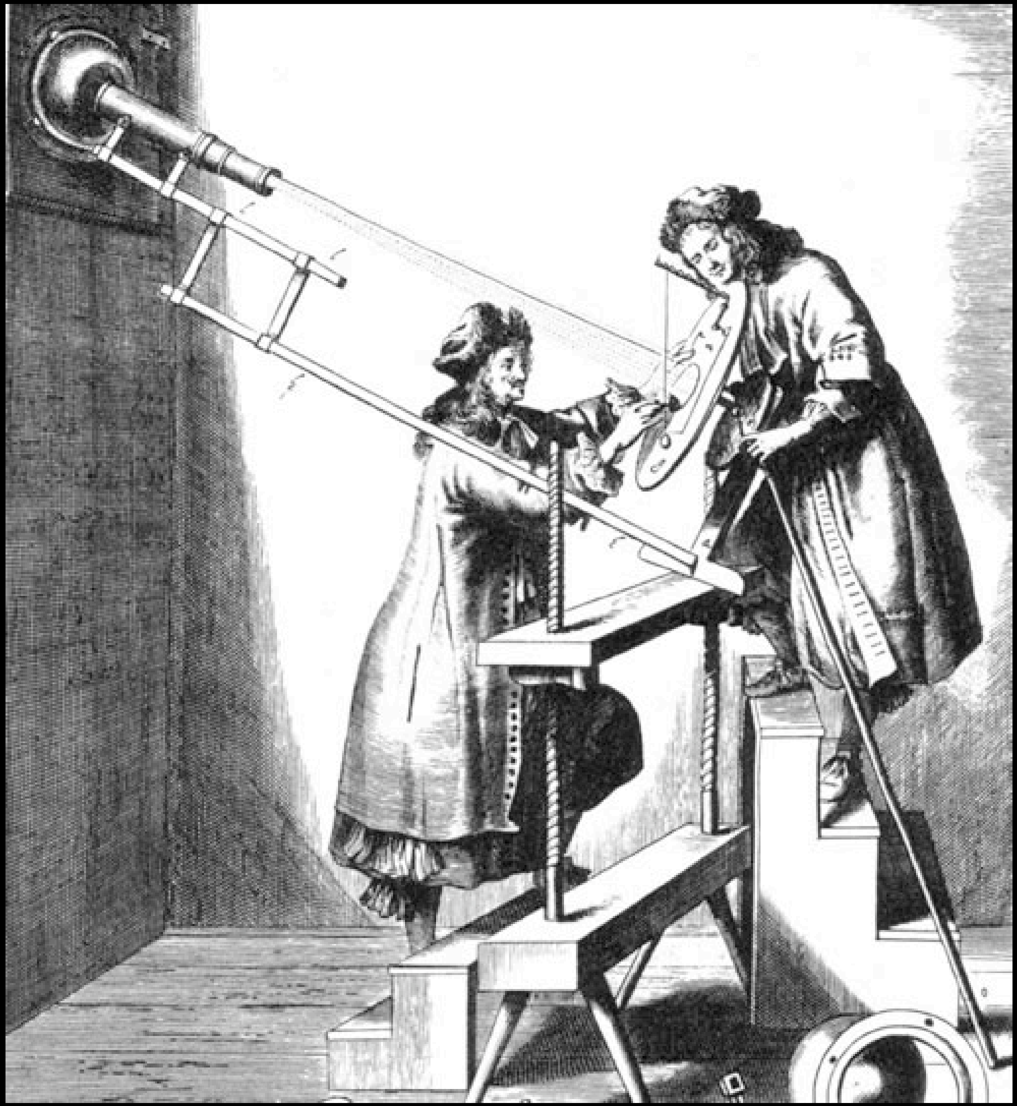
$$4.5 \sim 4.6 \times 10^6\ \mathrm{cm}^{-1}\mathrm{s}^{-1} \pm 16\%$$

$$g \lesssim 5 \times 10^{-10}\ \mathrm{GeV}^{-1}$$



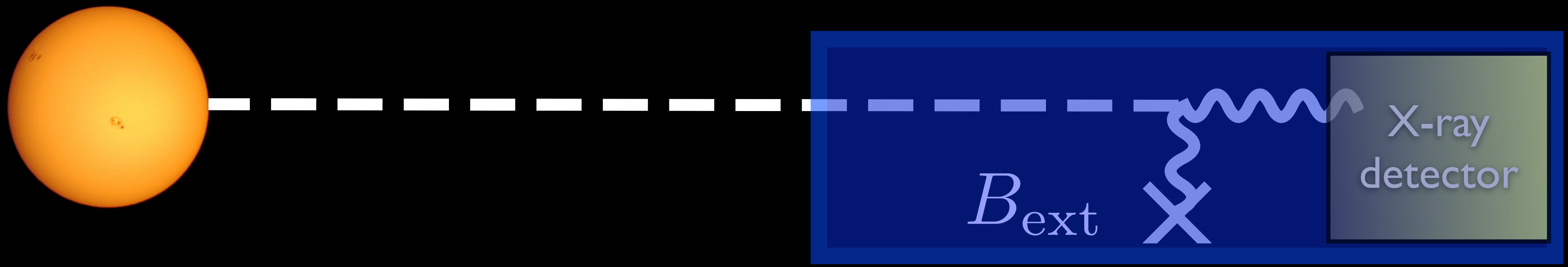
Raffelt (1999,2007)

Helioscopes



Helioscopes: Axion photon coupling

Detect Solar ALPs at earth by means of inverse Primakoff conversion in a strong magnetic field



Three Helioscopes built (with no trace of ALPs)

Brookhaven (S. Moriyama et al., Phys. Lett. B434, 147 (1998), hep-ex/9805026)
Tokio See the talk of Minowa!
CERN See the talk of Ruz !

Helioscopes: Axion photon coupling

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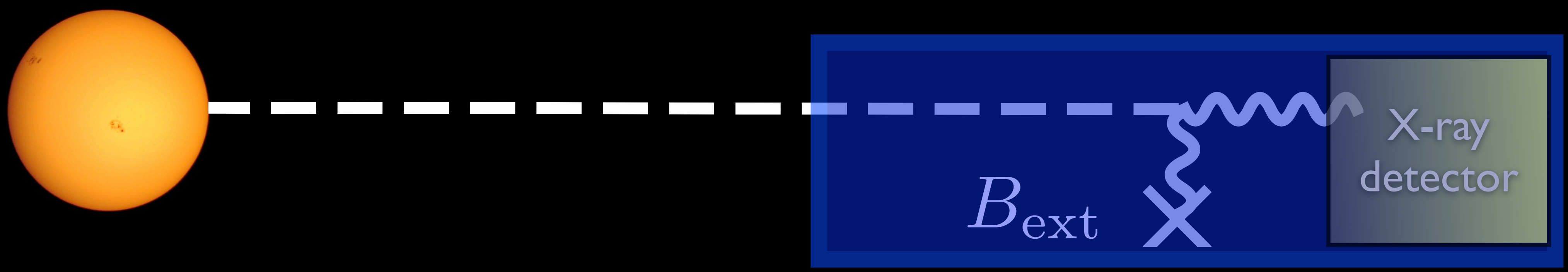


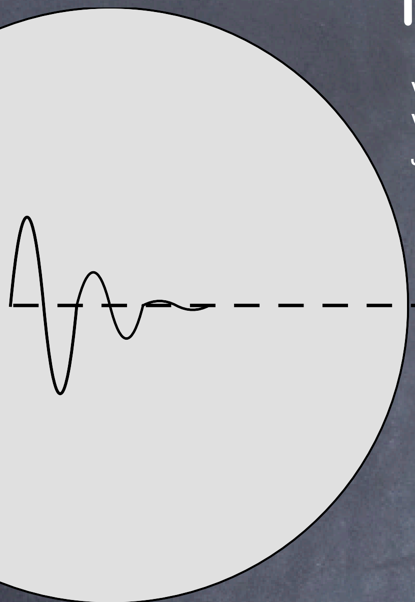
CAST Helioscope

LHC decommissioned magnet

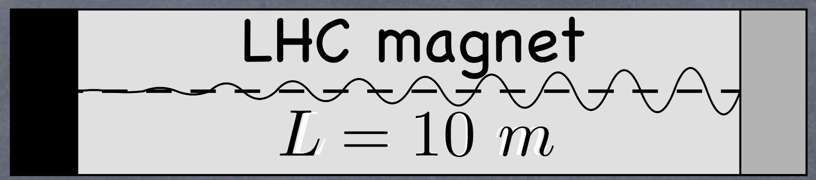
$L \sim 9.3$ m $\quad B_{ext} \sim 9$ T

The Sun as a hidden photon source

V. Popov. Turkish Journal of Physics, 23(5):943–950, 05. 1999.
V. Popov and O. V. Vasil'ev. Europhys. Lett., 15(1):7–10, 1991.
J. Redondo. arXiv:0801.1527 [hep-ph] Submitted to JCAP



$$P_{S-A} = 4\chi^2 \times \sin^2 \frac{m_{\gamma'}^2 L}{4\omega}$$



(Cern Axion Solar Telescope) CAST $\omega \sim \mathrm{keV}$

- photons behave as massive particles in a plasma with $m \simeq \omega_{\mathrm{P}}$ (plasma freq.) $\omega_P^2 \sim 1 - 300\mathrm{eV}$

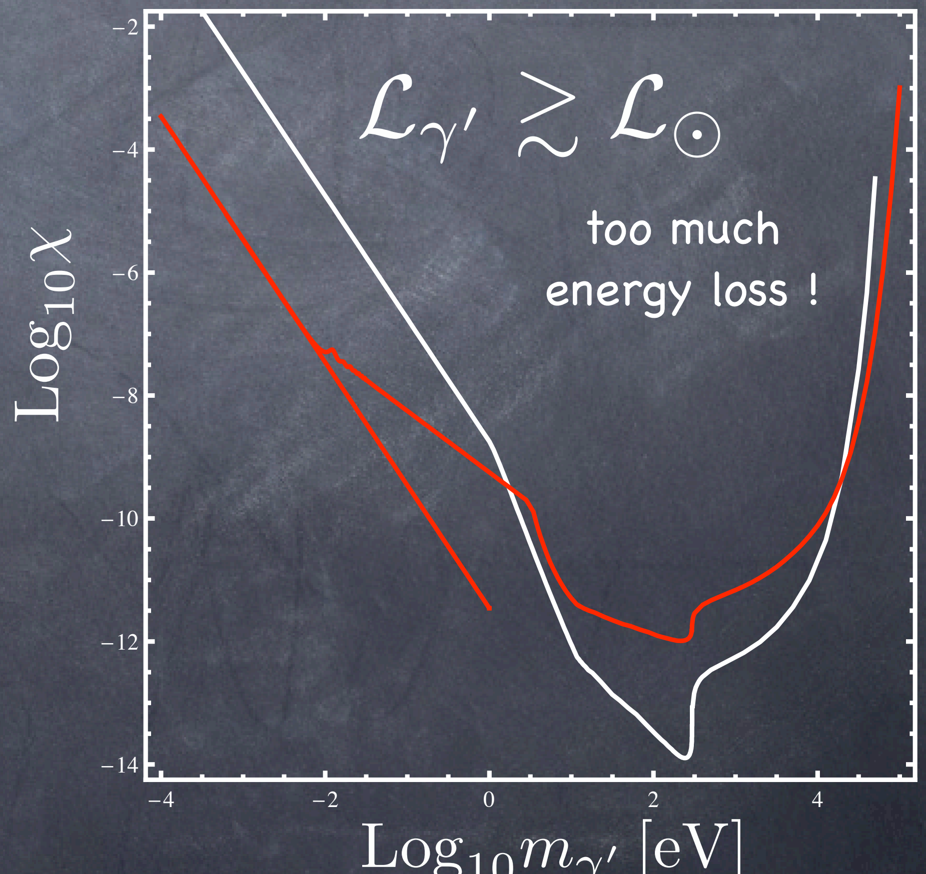
$$\chi_{eff} = \chi \frac{m_{\gamma'}^2}{\omega_P^2 - m_{\gamma'}^2 - i\omega\Gamma}$$

- Three cases:

1 - Suppressed production $m_{\gamma'} \ll \omega_P$

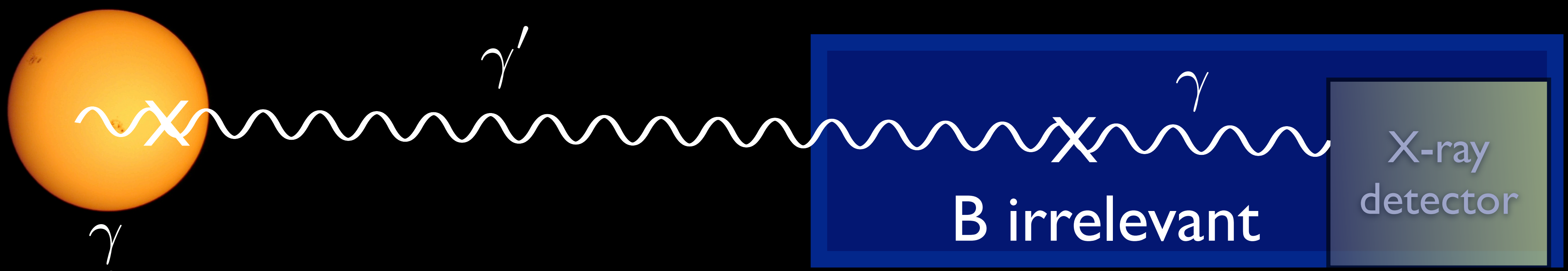
2 - Resonance $m_{\gamma'} = \omega_P \ (\omega\Gamma \ll \omega_P)$

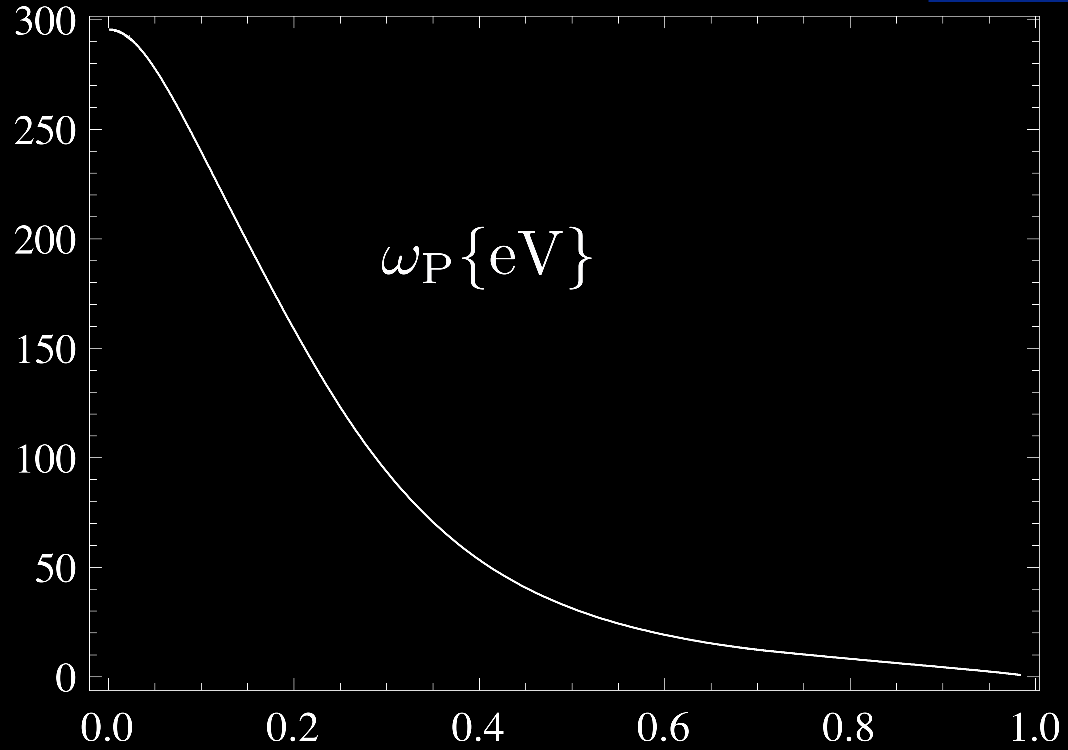
3 - Normal regime $m_{\gamma'} \gg \omega_P \ (\chi_{eff} = \chi)$



CAST Helioscope: Hidden Photons

Detect Solar Paraphotons at earth by oscillations inside a closed cavity

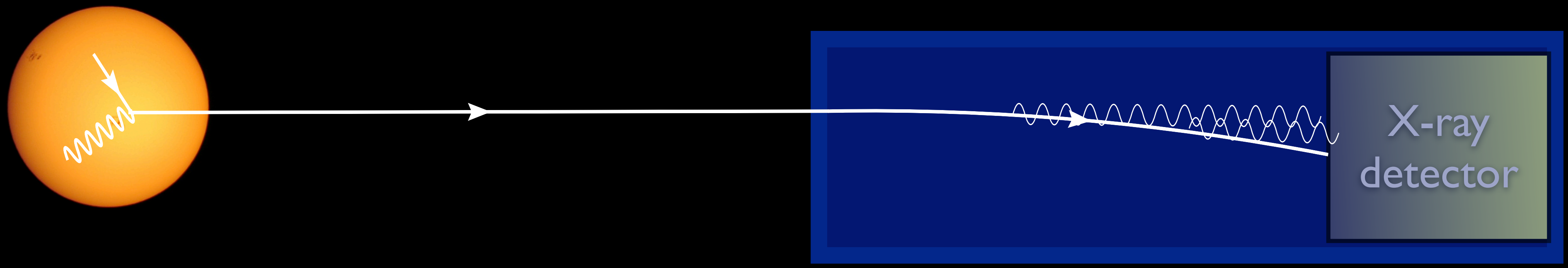




Plasma frequency typically much larger than eV (Suppressed mixing)

Helioscopes & MCPs

Detect Solar MCPs at earth by their radiation inside the magnetic field



CAST Helioscope

LHC decommissioned magnet

$$L \sim 9.3\ \mathrm{m} \quad B_{\rm ext} \sim 9\ \mathrm{T}$$

Evading the cosmological & astrophysical Bounds

it is possible in some more refined (-tuned) models

Suppressed couplings at high temperatures and/or densities

- Motivated by PVLAS signal (not confirmed)
- MR model
  E. Massó and J. Redondo, Phys. Rev. Lett. **97**, 151802 (2006)
- chameleon models
  P. Brax, C. van de Bruck, A-C Davis. Phys.Rev.Lett. **99:**121103, (2007).
- phase transition of the coupling
  R.N. Mohapatra , S. Nasri. Phys.Rev.Lett.98:050402, (2007).

and more exotic ones ...

Generally, the models involve more particles at low masses !!

Evading the cosmological & astrophysical Bounds

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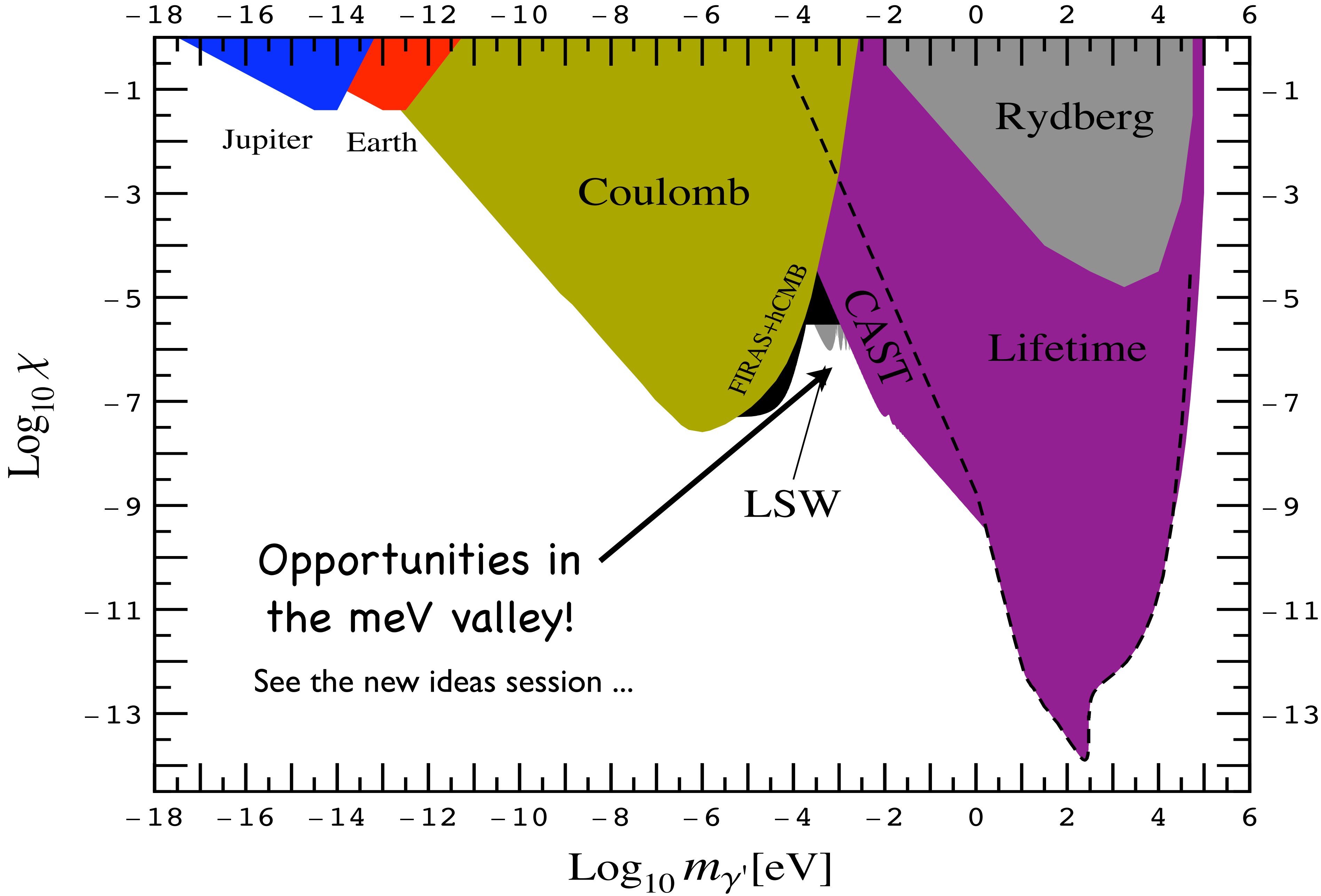
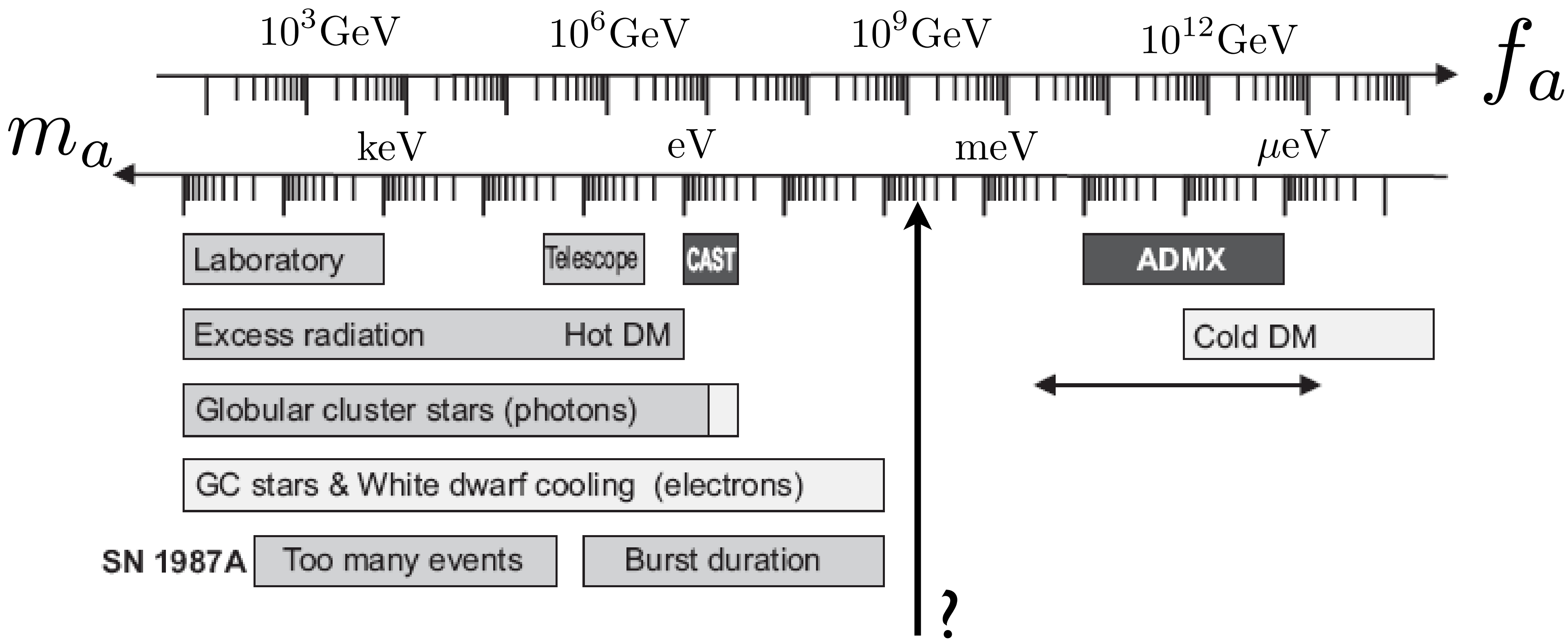
and more exotic ones ...

But recall Hidden photons in the meV valley !!!

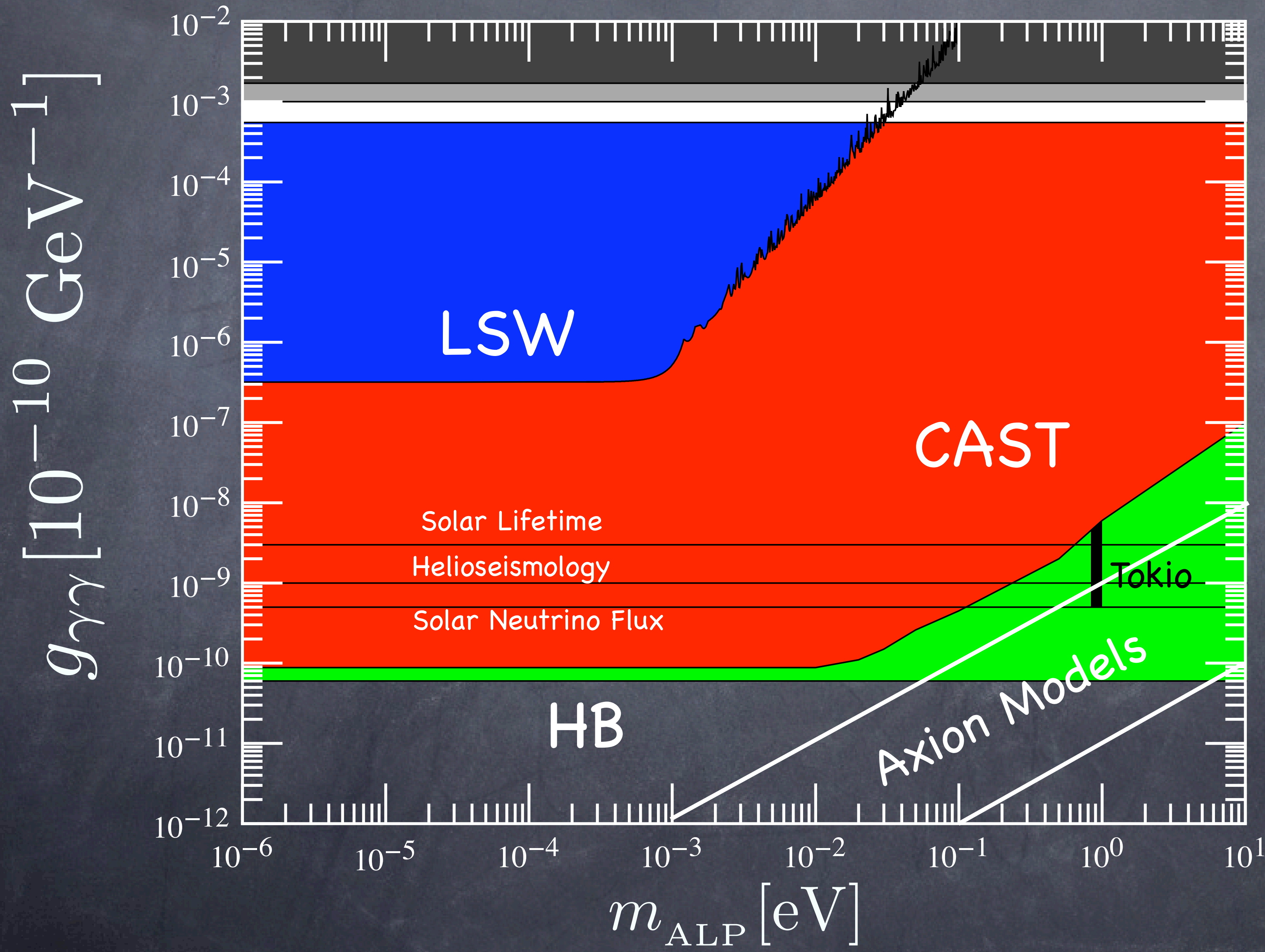
Hidden Photons in the meV valley ...



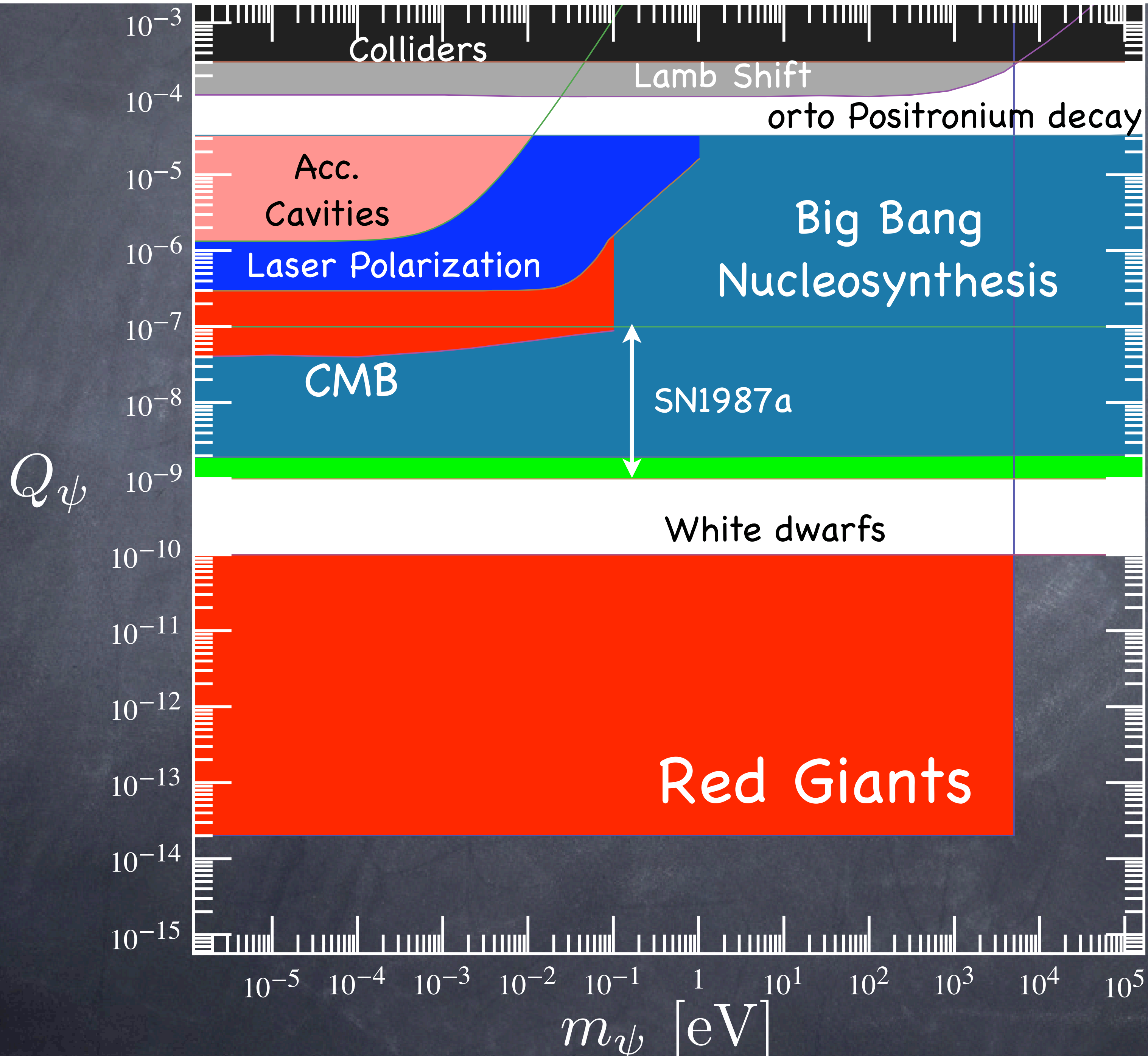
A summary : Axions



A summary: general ALPS (pseudoscalars coupled to 2 photons)



MiniCharged Particles (MCPs)



The End ??