The WISP Paradigm

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MPI 14/12/2009

Hidden Sectors in PBSM

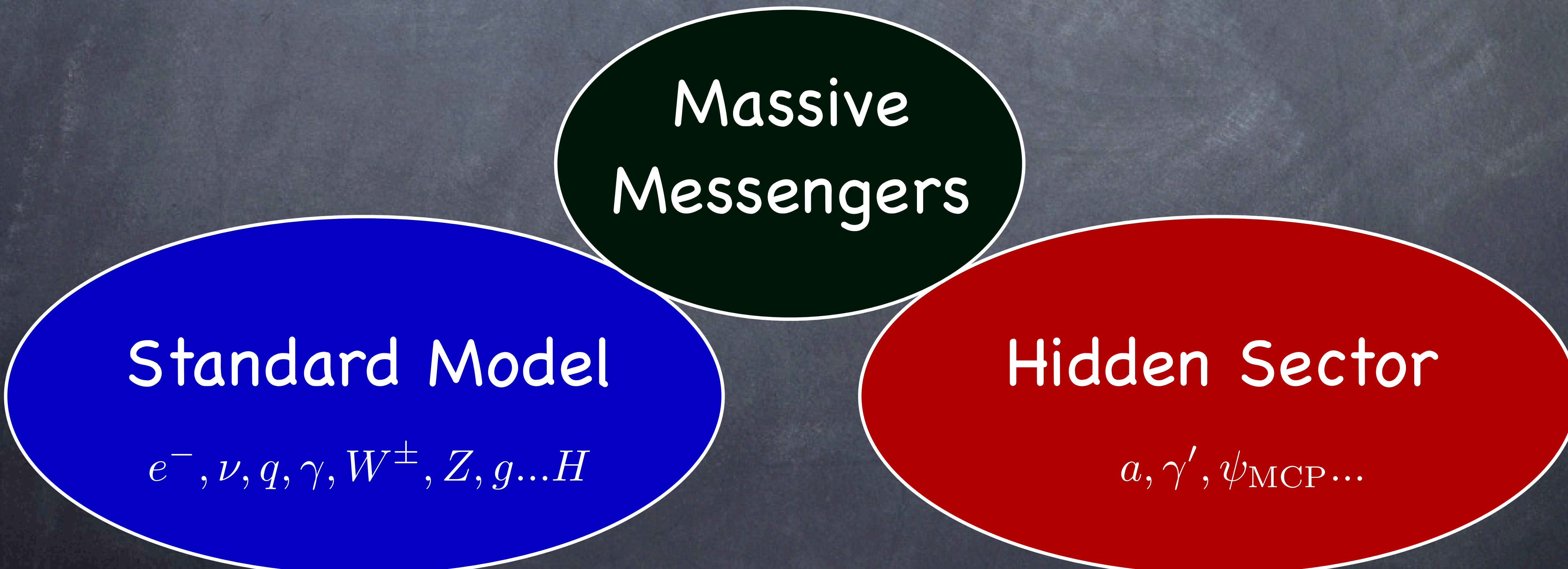
Extensions of SM often include Hidden Sectors

Fields coupled to SM only through gravity or high energy "messenger" fields...

This is the case in string theory (compactifications produce many particles, new gauge symmetries, and KKs)

Desirable for ~~SUSY~~

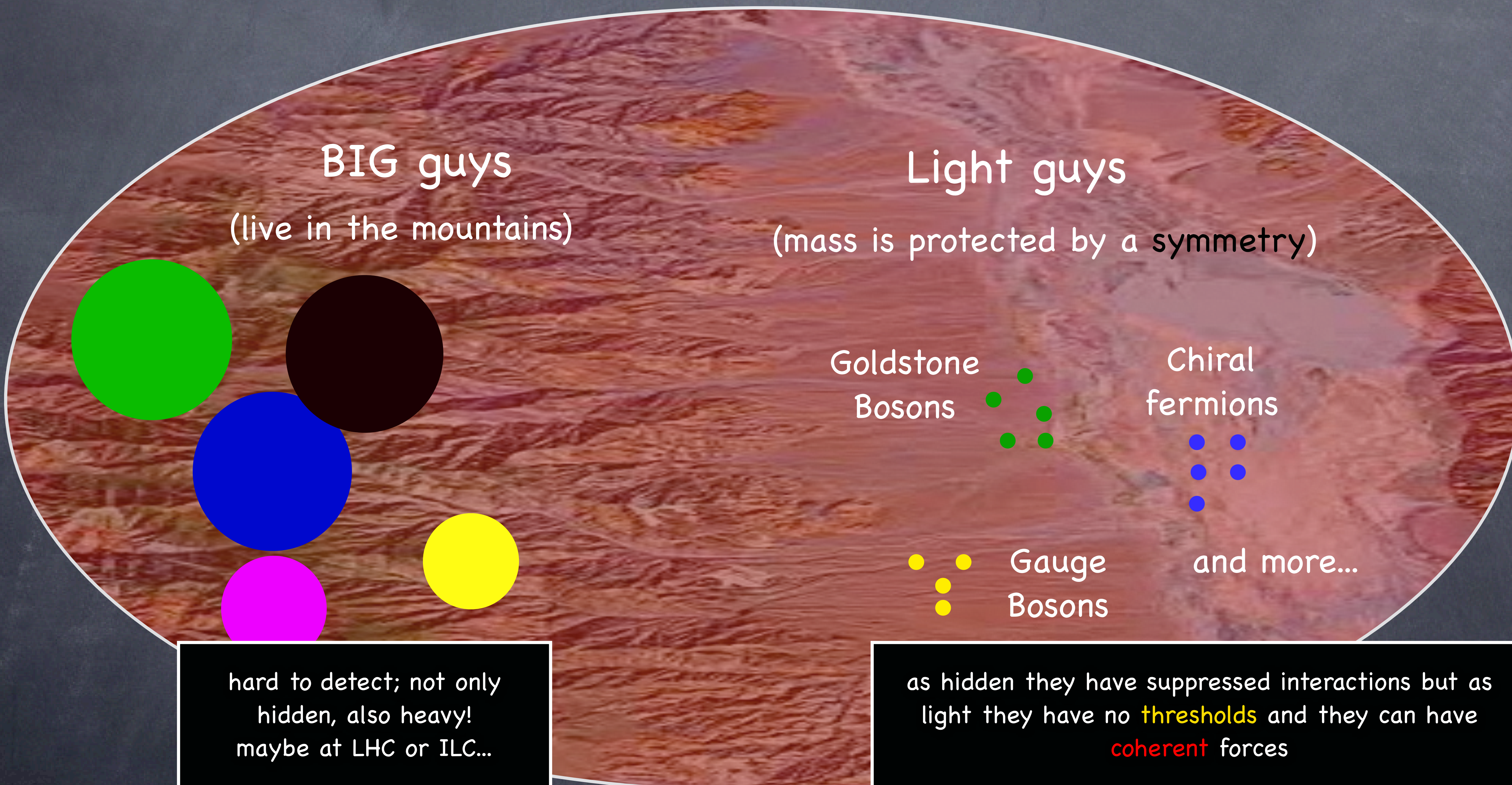
Also in GUT theories...



Hidden Sectors can be quite complicated

we certainly don't know!

Hidden Sector



Let symmetry be our guide !

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we certainly don't know!

Hidden Sector

Let symmetry be our guide !

Axion-like-Particles and Axions

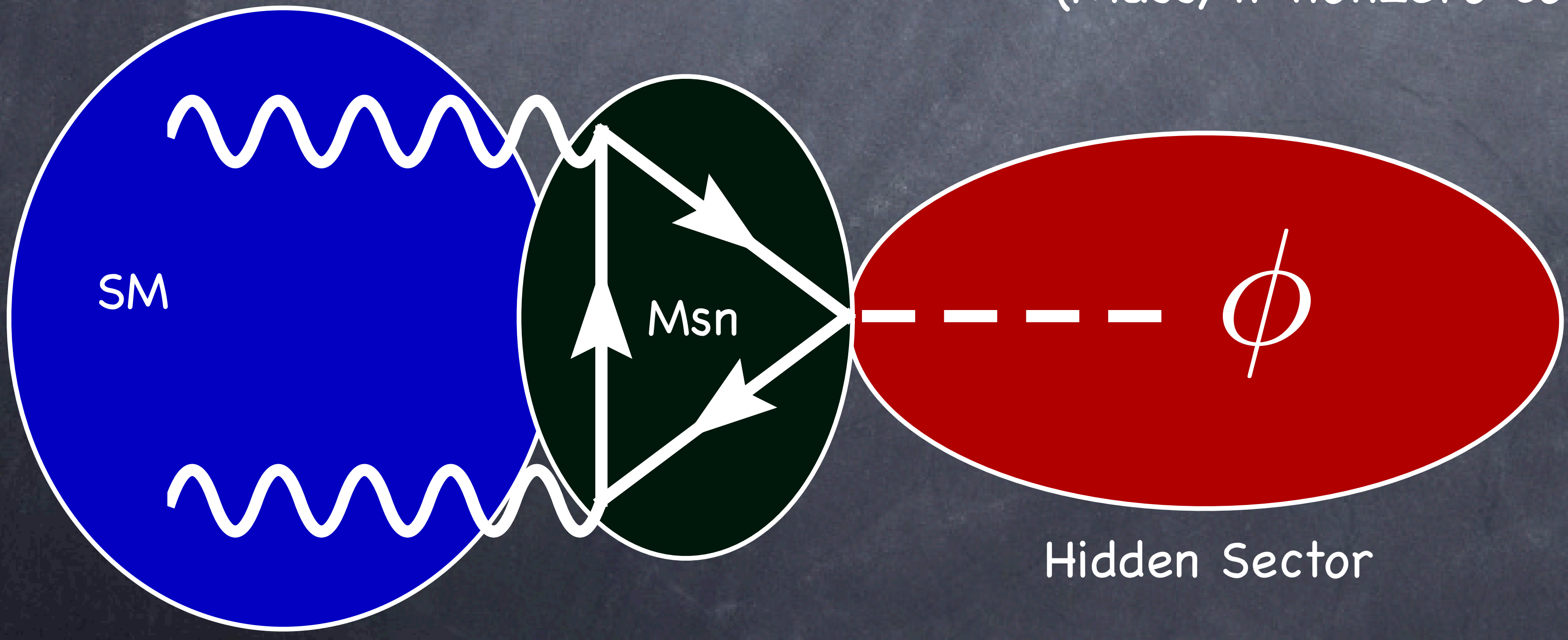
Axions are GB of a color anomalous U(1) $\longrightarrow \frac{1}{4f_a}\mathrm{Tr}\{G_{\mu\nu}\widetilde{G}^{\mu\nu}a\}$

The color anomalous term creates a potential with CP conserving minimum which gives the axion a mass $\longrightarrow$ Solution to Strong CP

$$m_a \simeq \frac{m_\pi f_\pi}{f_a} \simeq 0.6\ \mathrm{meV}\left(\frac{10^{-10}\mathrm{GeV}^{-1}}{f_a}\right)$$

Axion-like-particles have electromagnetic anomaly but no color anomaly,

(Mass, if nonzero comes from small U(1) breaking)

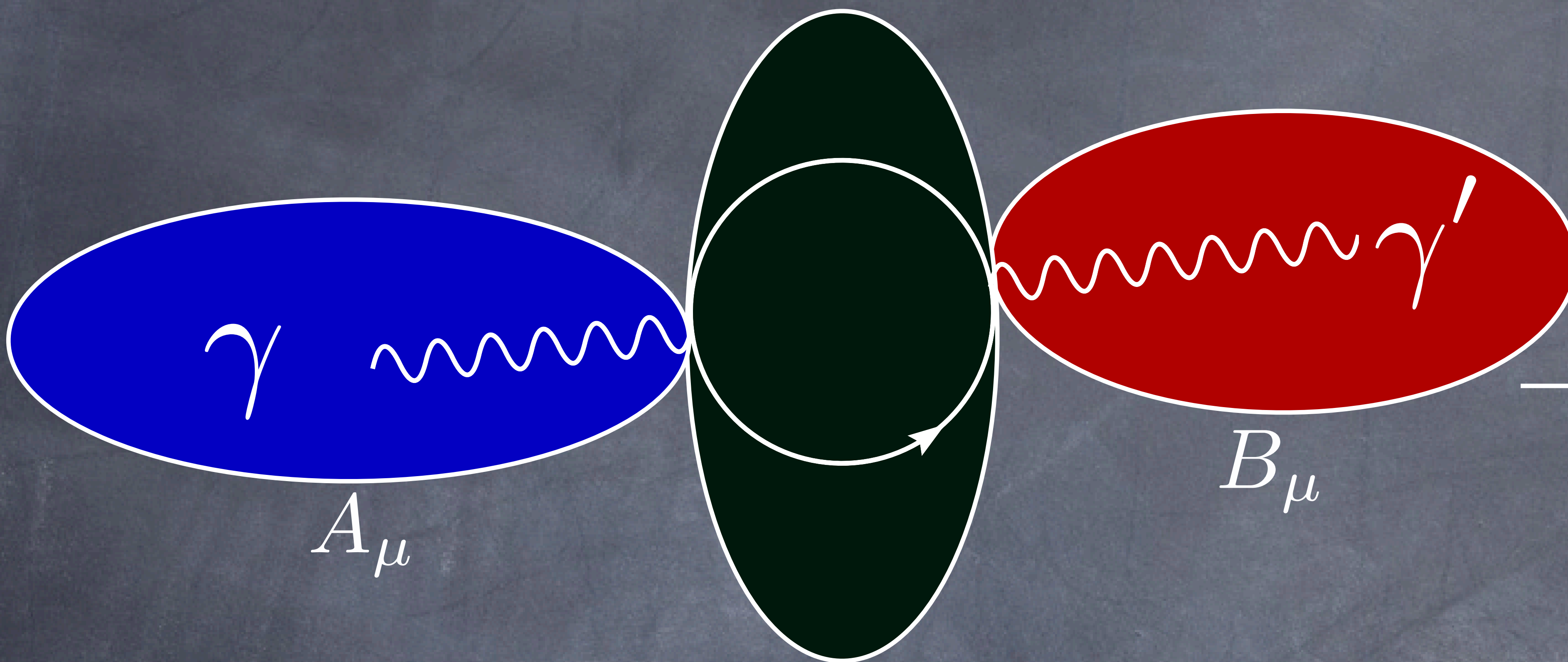


$\longrightarrow \frac{1}{4}g_{\phi\gamma}F_{\mu\nu}\widetilde{F}^{\mu\nu}\phi$

$$g_{\phi\gamma} \sim \alpha/M_{\mathrm{mess}}$$

Hidden Photons

$U(1)_{\rm EM} \times U(1)_{\rm hidden}$



$$\longrightarrow \frac{\sin\chi}{2} F_{\mu\nu} B^{\mu\nu}$$

kinetic mixing with photon

$$\sin\chi = \frac{e g_B}{6\pi^2} \sum_i Q_A Q_B \, {\rm Log} \frac{M_i}{\mu}$$

Loop suppression but NO mass suppression, just a log

small values can come from mass degeneracy of particles with opposite charges (GUT...)

SUSY, String theory ...

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

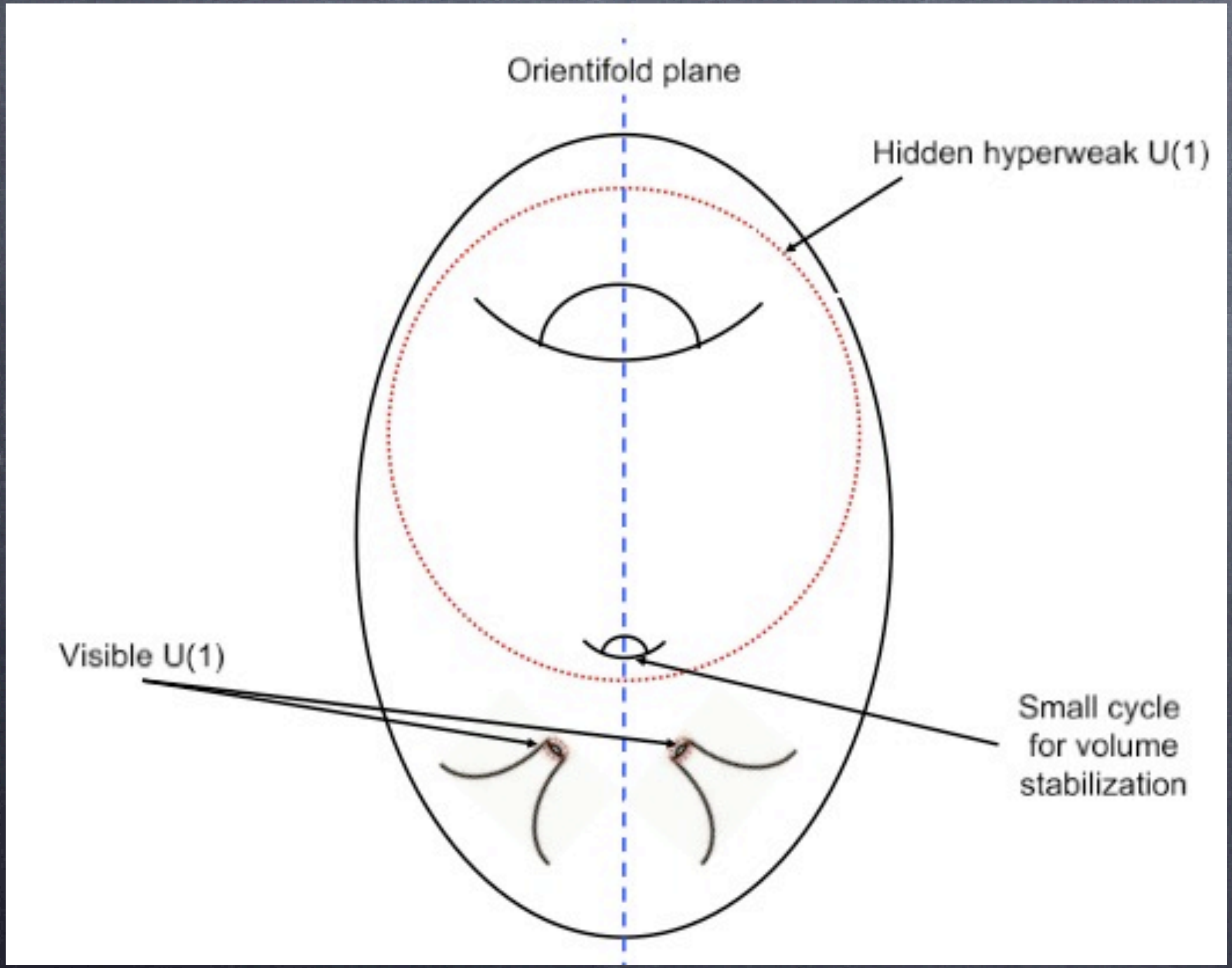
K. R. Dienes, C. F. Kolda, and J. March-Russell. Nucl. Phys., B492:104–118, 1997.

Hidden Photons in LARGE volume scenarios

Goodsell, Jaeckel, Redondo, Ringwald JHEP11, (2009) 027

tiny kinetic mixings can arise from small coupling constants (Hidden U(1)´s from cycles with LARGE volume $\mathcal{V}_q$)

$$\sin\chi \sim \frac{e g_{\rm h}}{16\pi^2} \qquad g_{\rm h}^2 \simeq \frac{2\pi g_s}{\mathcal{V}_q} \propto \left(\frac{M_s}{M_{\rm Pl}}\right)^{q/3}$$



Small masses also likely

Stueckelberg #1

$$m_{\gamma'}^2 \propto \mathcal{V}^{-1} M_s^2$$

Stueckelberg #2

$$m_{\gamma'}^2 \propto \mathcal{V}^{-1/3} M_s^2$$

Hidden Higgs

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Goodsell, Jaeckel, Redondo, Ringwald JHEP11, (2009) 027

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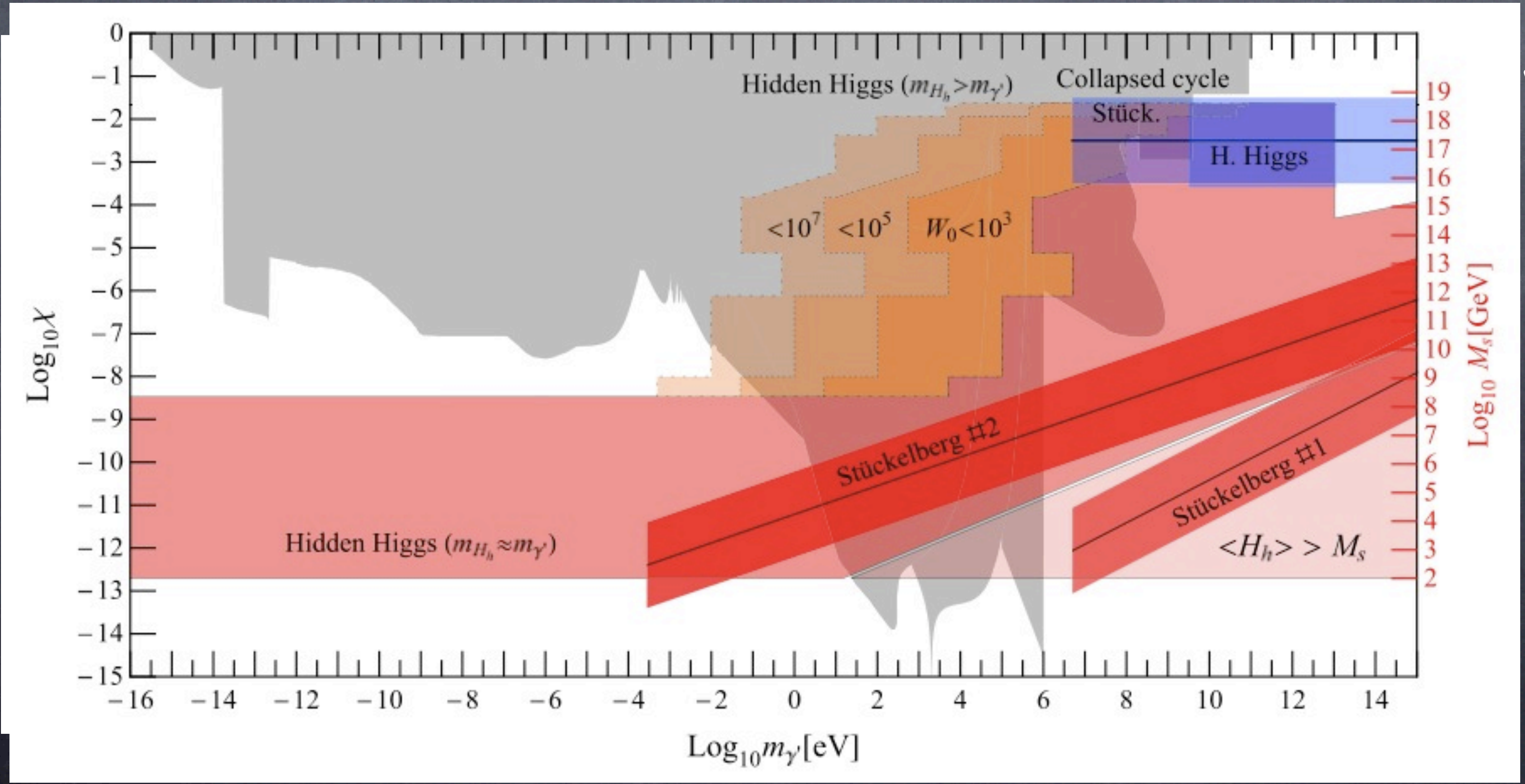


Impact of WISPs

- Despite the feebleness of their interactions with SM particles, WISPs can have an enormous impact ... in :

- Astrophysics:

    * Stellar evolution (they provide additional mechanisms for stellar cooling)

    * Gamma ray propagation (Photon oscillations into WISPs)

- Cosmology

    * Big Bang Nucleosynthesis

    * CMB physics

    * Dark Matter Issues (even give `cold' Dark Matter candidates)

Impact of WISPs

- Despite the feebleness of their interactions with SM particles, WISPs can have an enormous impact ... in :

- Astrophysics:

The impact can be usually used to put very stringent bounds

BUT sometimes can explain some anomalies (and there are some ...)

It might be very difficult to confirm a WISP this way
(For that we need laboratory experiments!)

- Cosmology

  * Big Bang Nucleosynthesis

  * CMB physics

  * Dark Matter Issues (even give `cold' Dark Matter candidates)

WISPS and Stars

Stars have a finite amount of nuclear fuel

The speed at which it is burned (and thus, the stellar evolution) is limited by the effectiveness of the energy drain from the interior

Main energy losses are:
- Photons from the surface
- Neutrinos from the core

... WISPs ??

WISPS and Stars

Stars have a finite amount of nuclear fuel

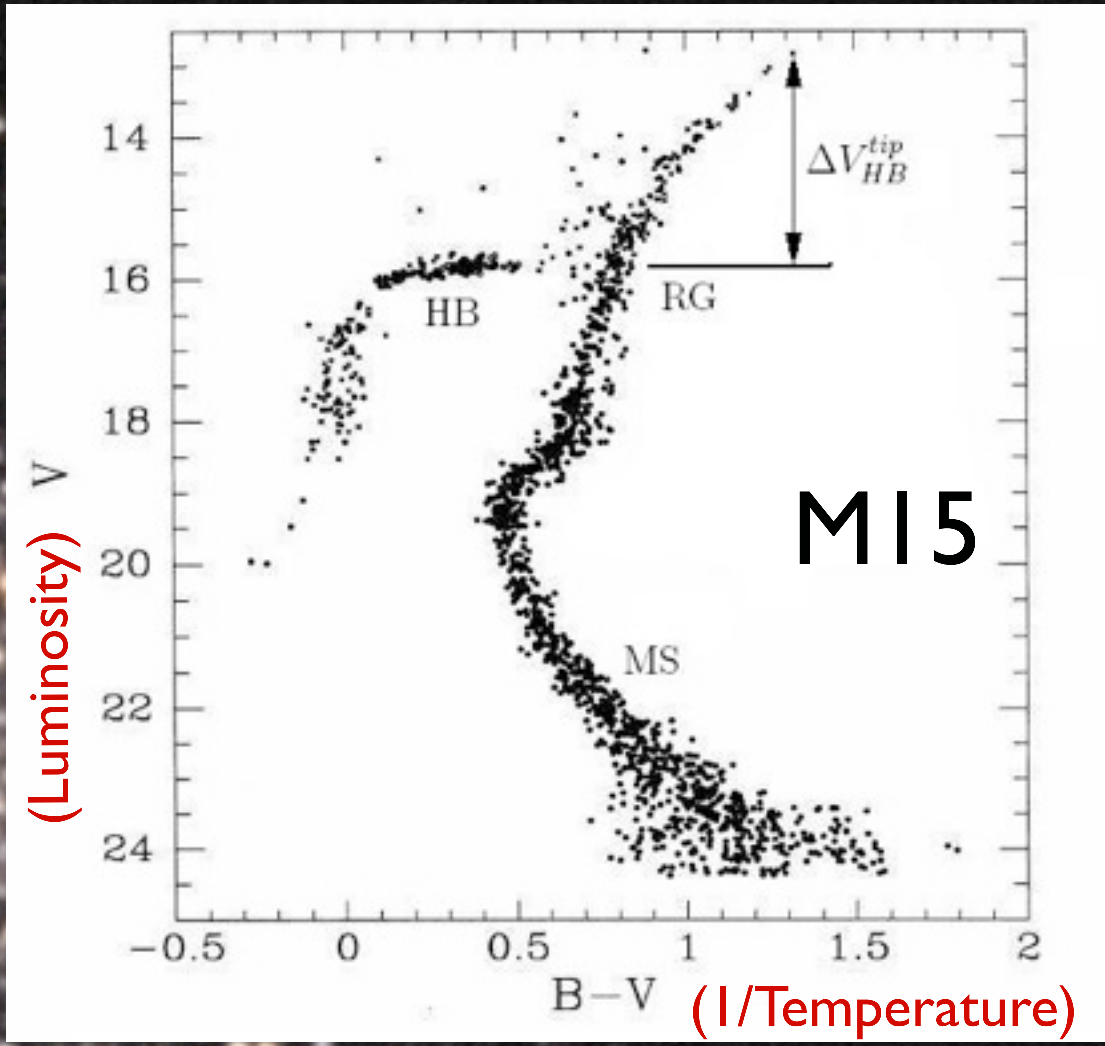
The speed at which it is burned (and thus, the stellar evolution) is limited by the effectiveness of the energy drain from the interior

Standard Physics (+ WISPs) (with many details...) that can be numerically simulated

And compared with observations ...

Globular Clusters (RG & HB)

- WISP cooling affects differently the different star types:
DISTORTS the color-magnitude diagram and CHANGES number counts of RGs, HBs...
- Numerical simulations agree with observations at the 10% level, that allows to set strong constraints (1986)



$$g_{a\gamma\gamma} \lesssim 10^{-10}\ \mathrm{GeV}^{-1}$$

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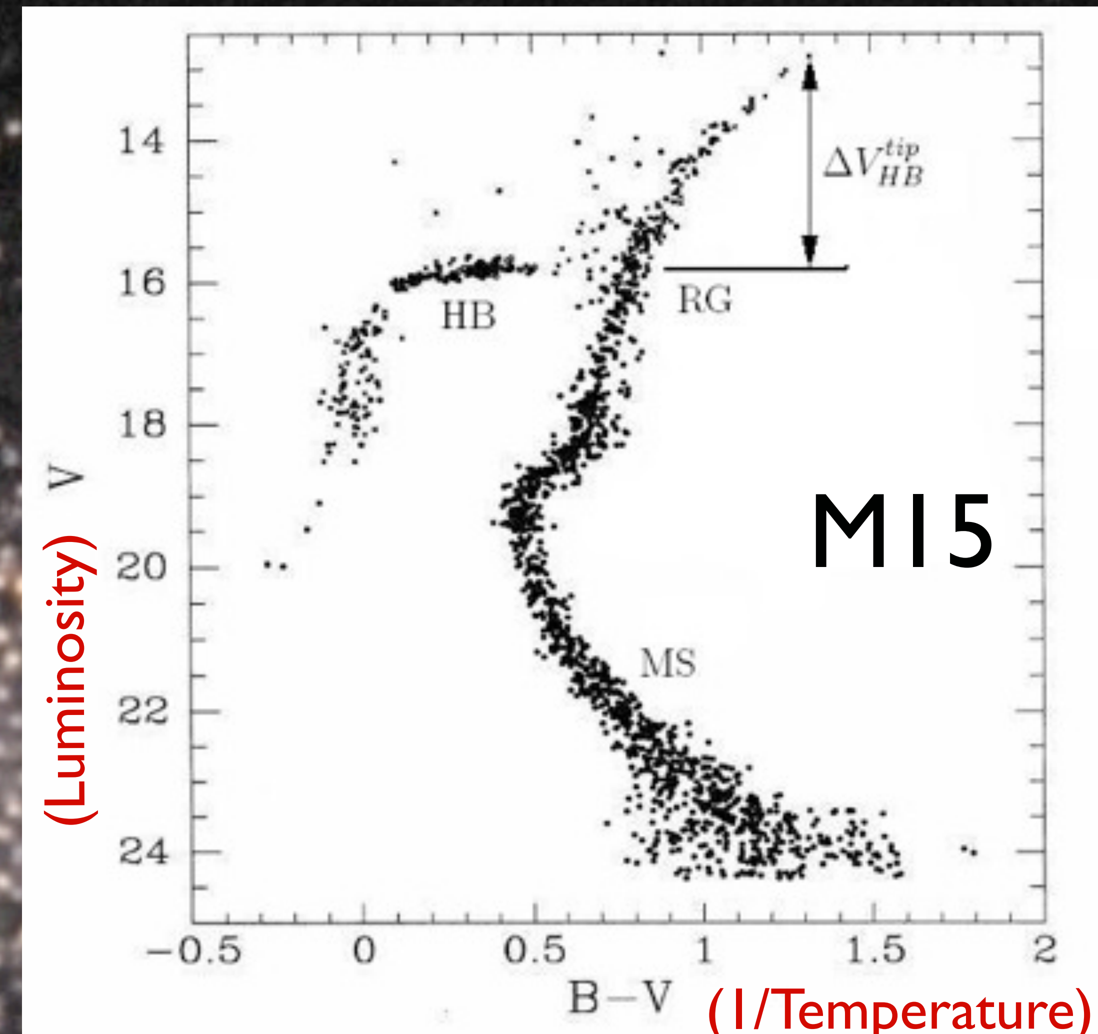


More observations are now available and much better numerical simulations are possible
(Project in collaboration with A. Weiss in MPA)

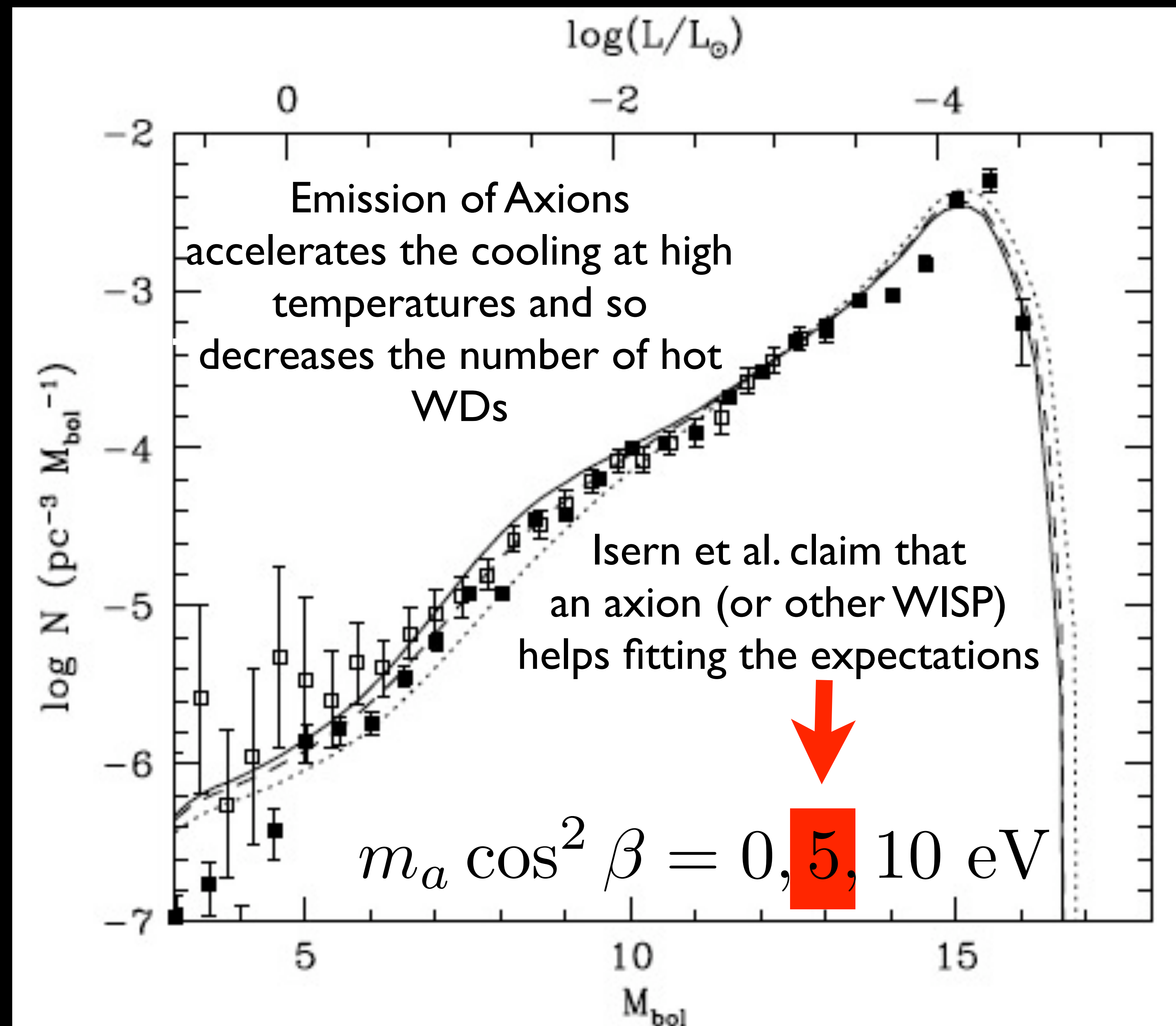
$$g_{a\gamma\gamma} \lesssim 10^{-10}\ \mathrm{GeV}^{-1}$$

White Dwarf Luminosity Function

Raffelt (1986), Isern (2008)

Probes the axion electron coupling

$$\frac{g_{aee}^2}{4\pi} = 2.8 \times 10^{-11} m_a[\text{eV}] \cos^2\beta$$



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 ...

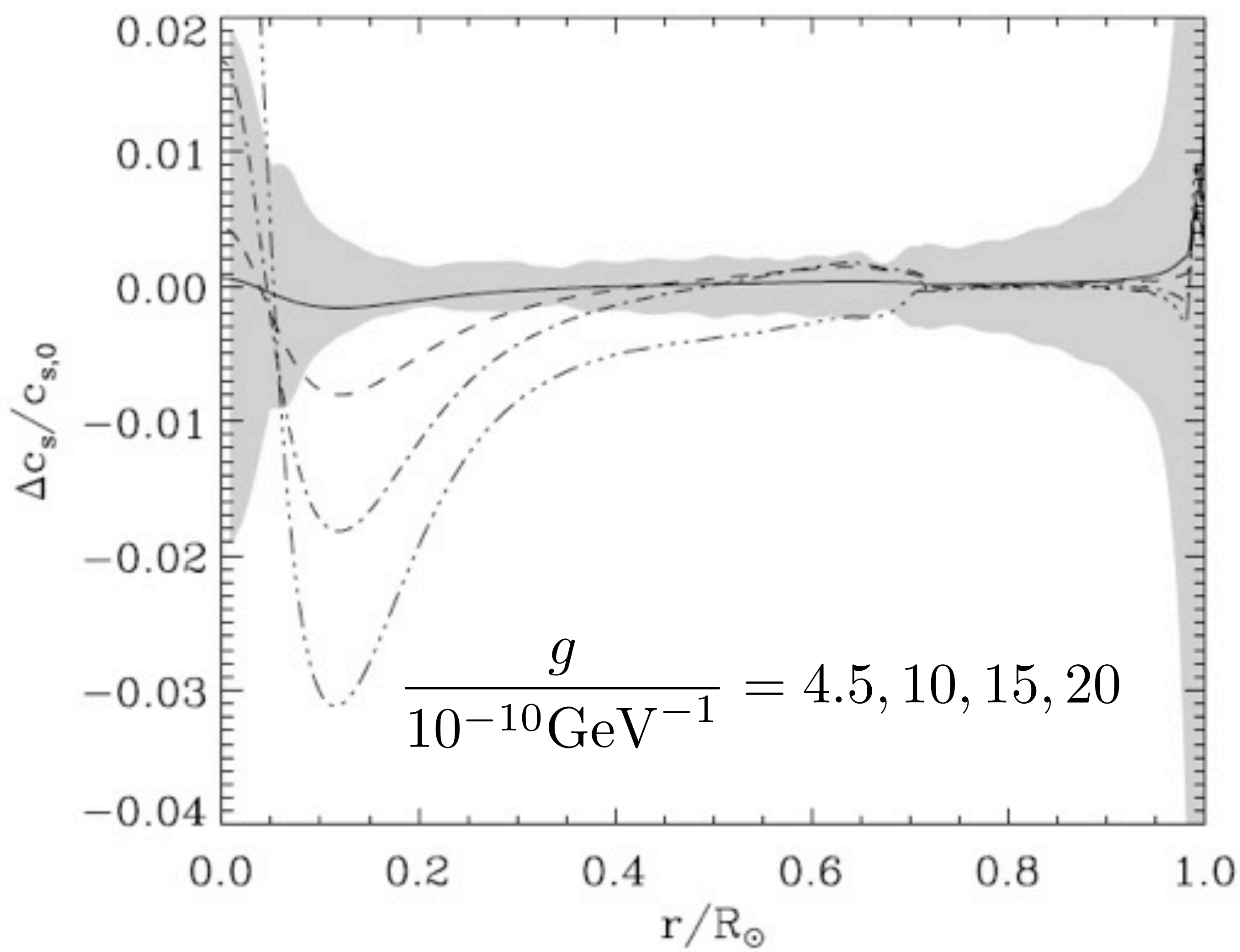
No solar model can be built with

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

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

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!

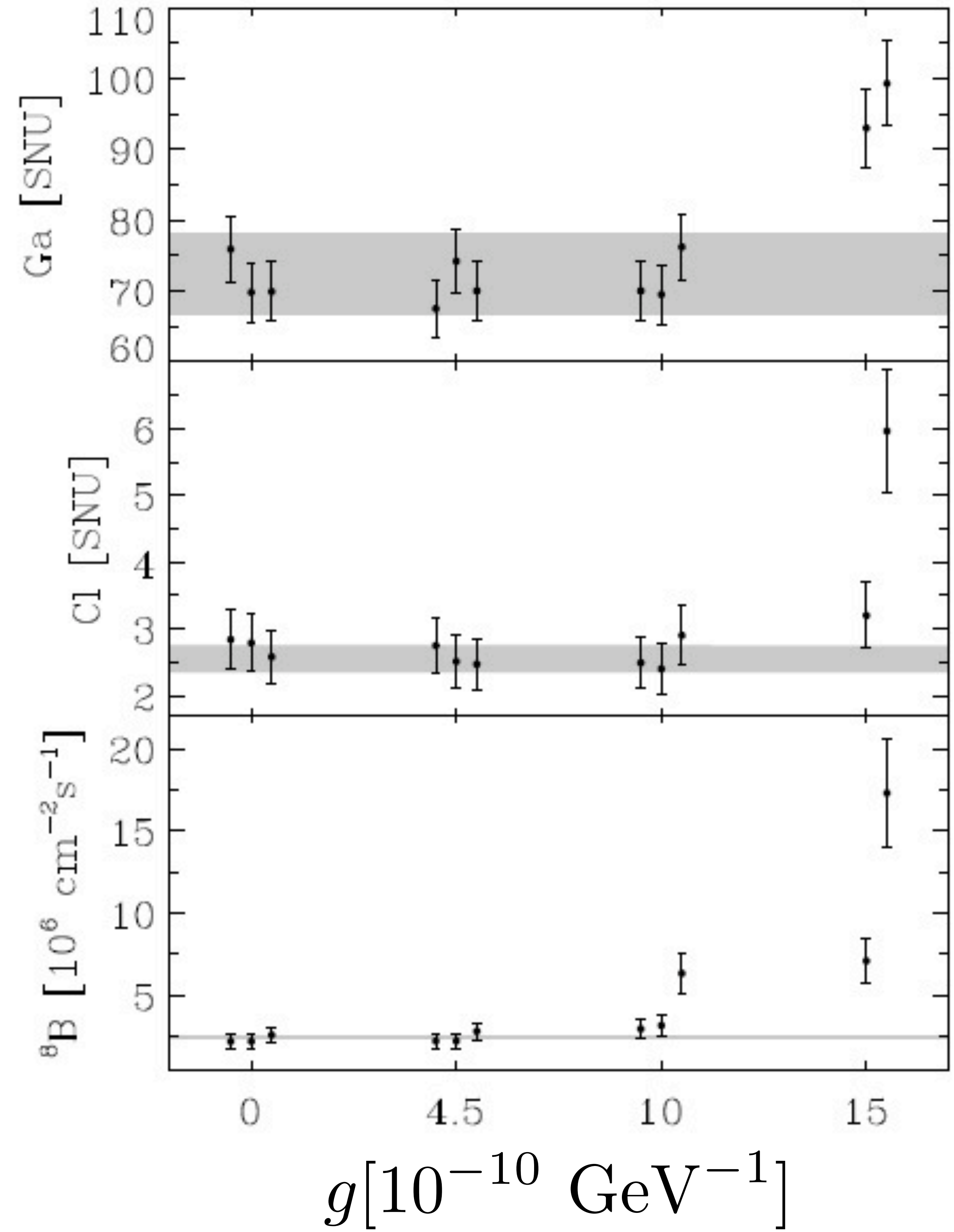
B flux (most recent data)

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

SM expectations

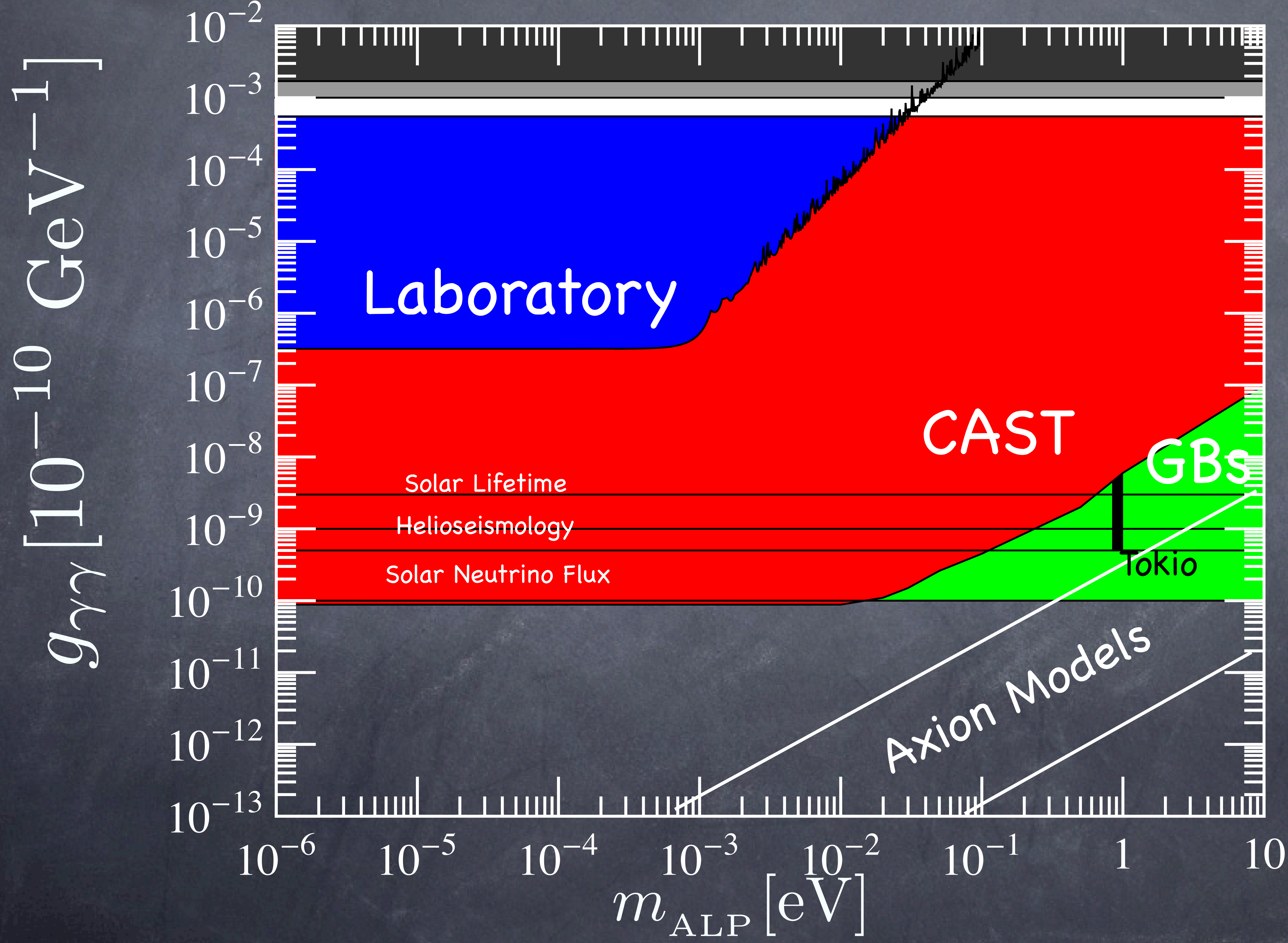
$$4.5 \sim 4.6 \times 10^6 \ \mathrm{cm}^{-1}\mathrm{s}^{-1} \pm 16\%$$

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

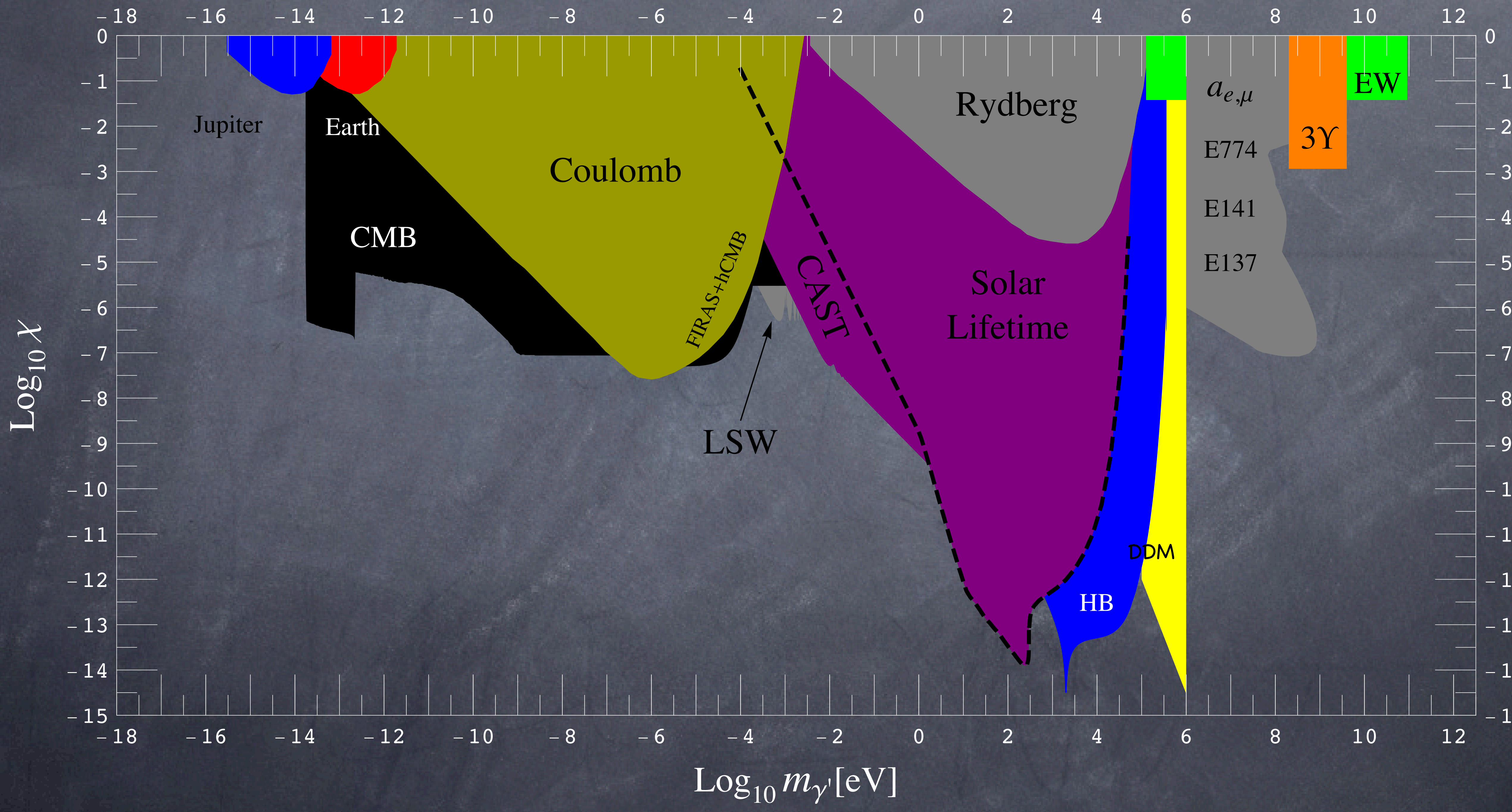


Raffelt (1999,2007)

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



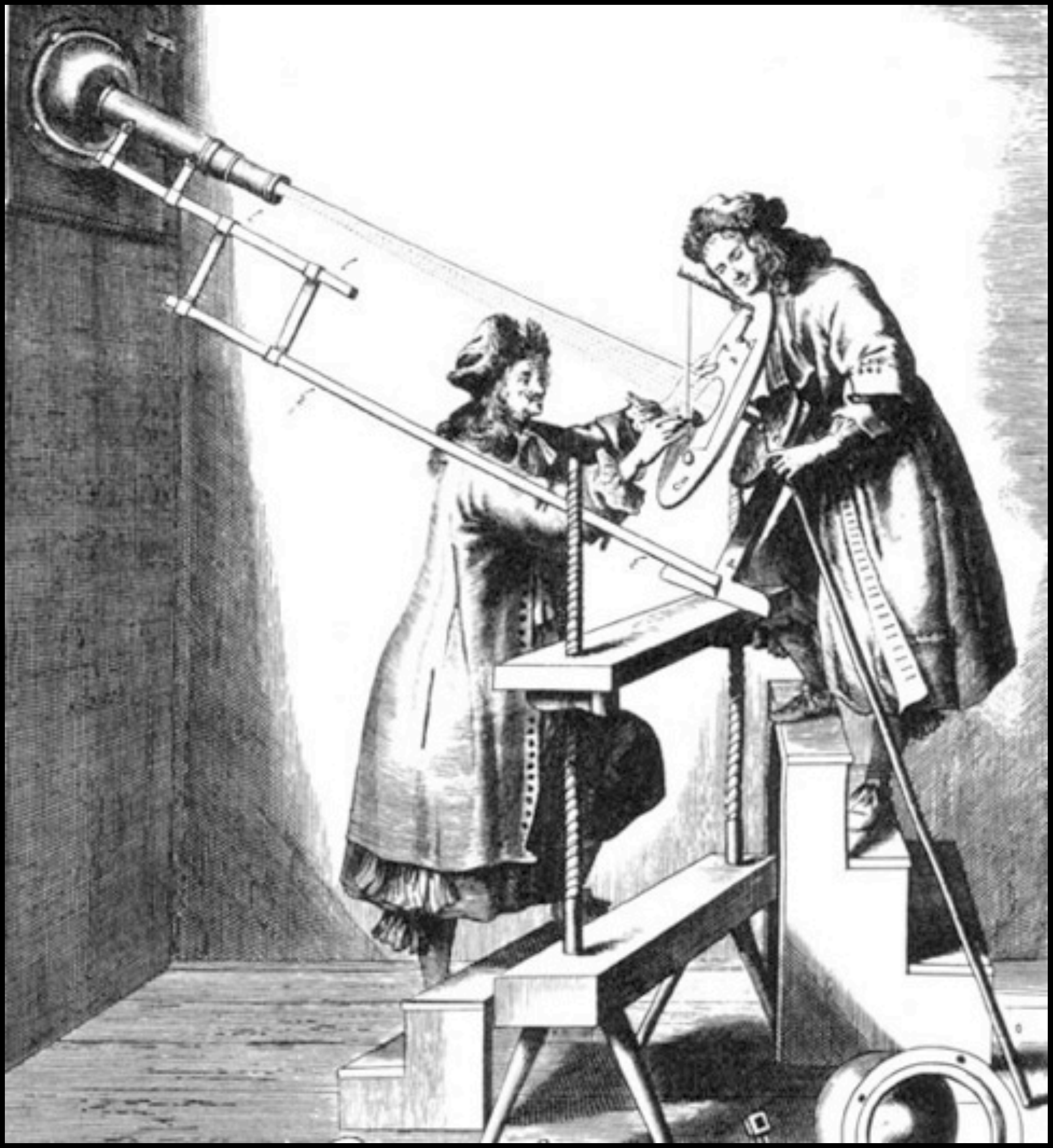
Hidden Photons



Helioscopes

Typical bounds from the Sun energy loss cannot compete with Globular Cluster limits.

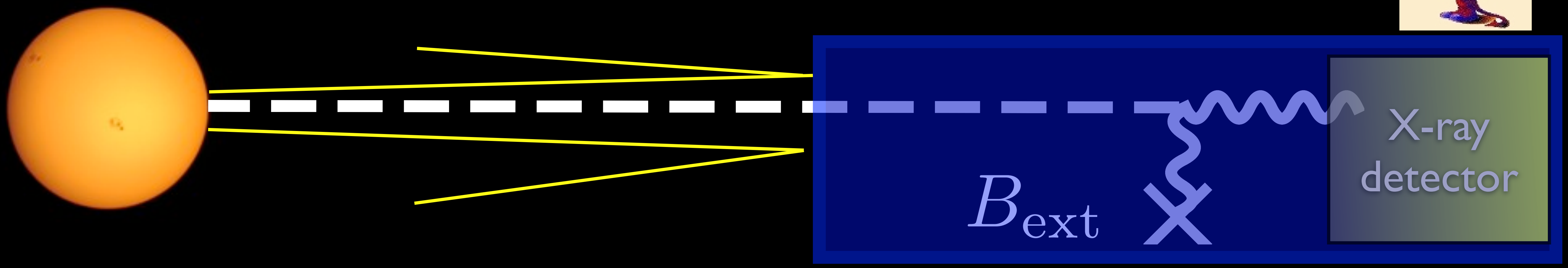
But we can try to observe WISPs from the Sun!

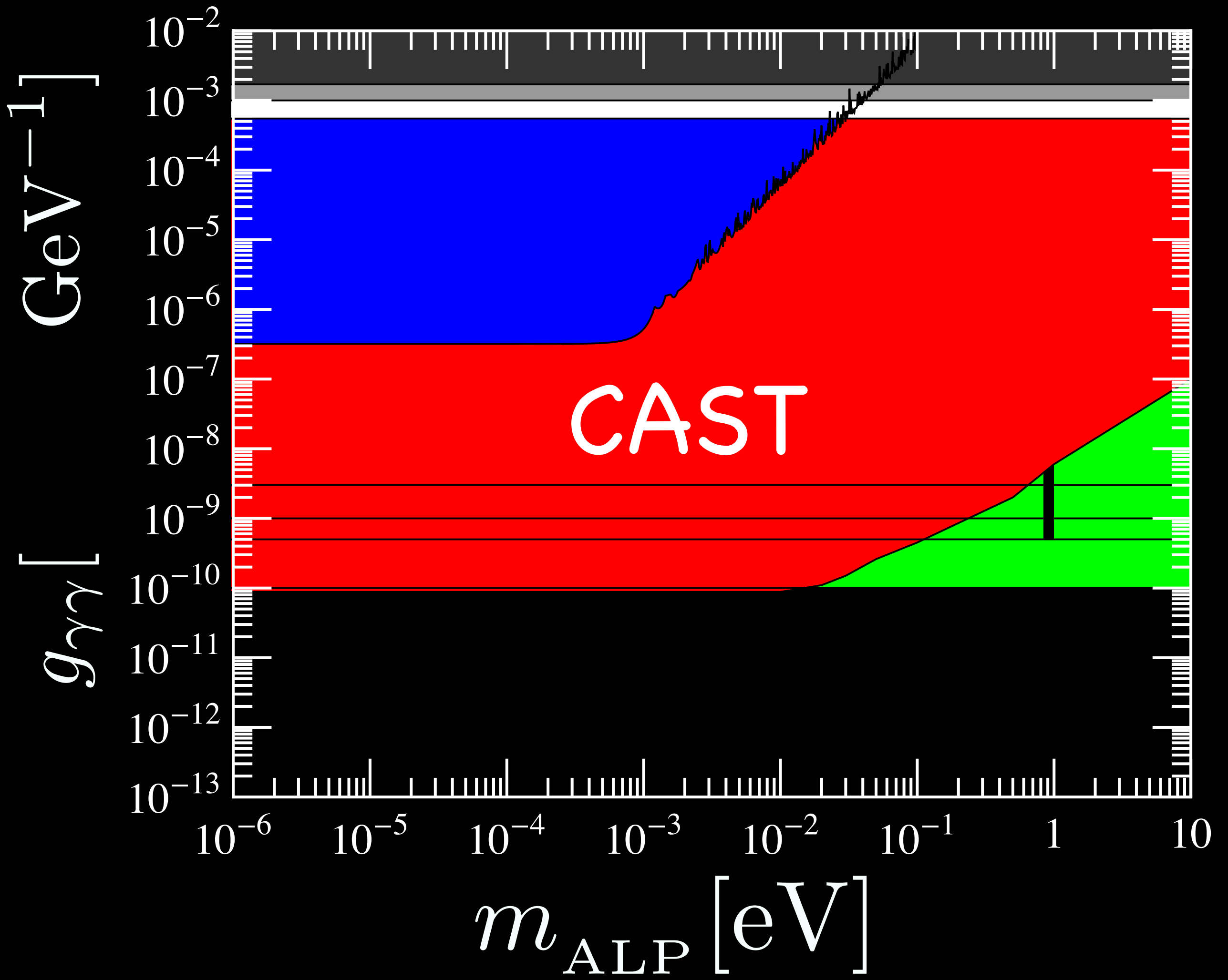


Searching for Axion-like-Particles at CERN: CAST

CAST, K. Zioutas et al., Phys. Rev. Lett. 94, 121301 (2005), hep-ex/0411033.

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



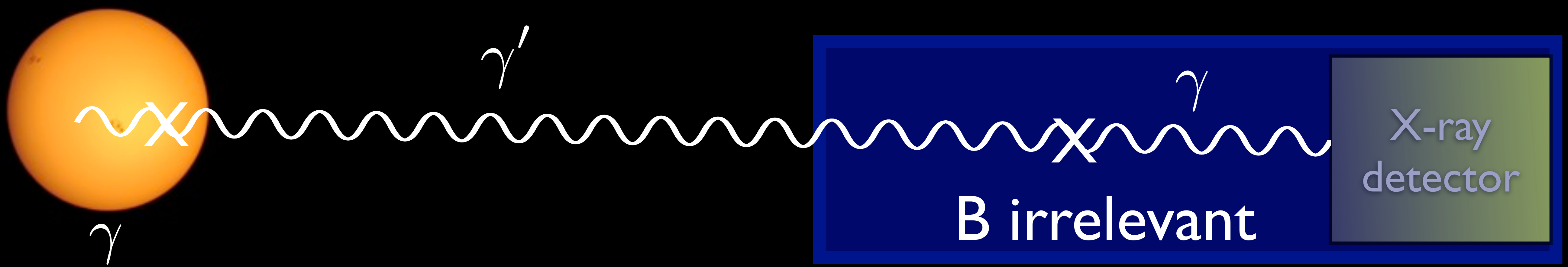


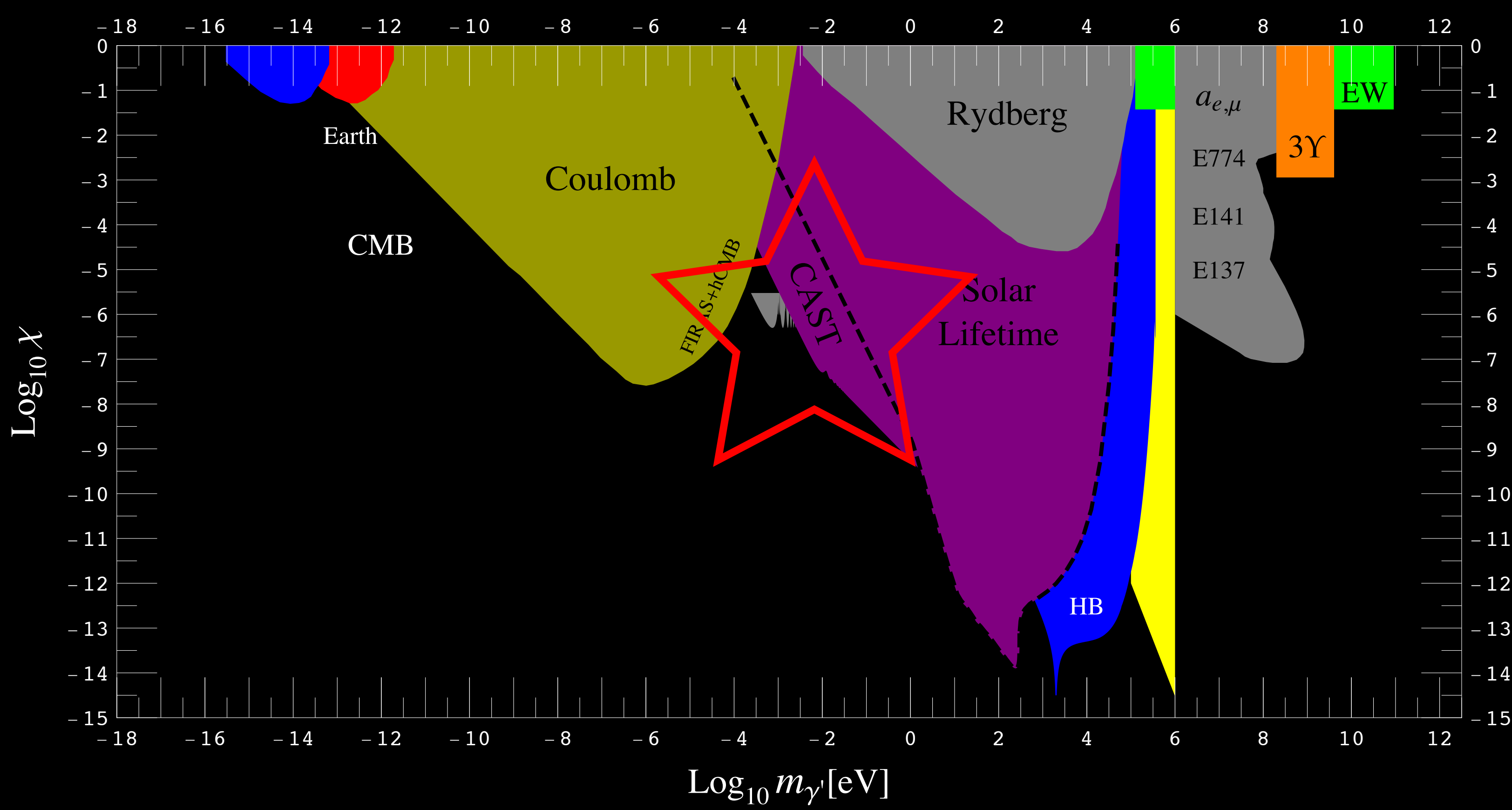
CAST Helioscope, LHC decommissioned magnet

CAST Helioscope: Hidden Photons

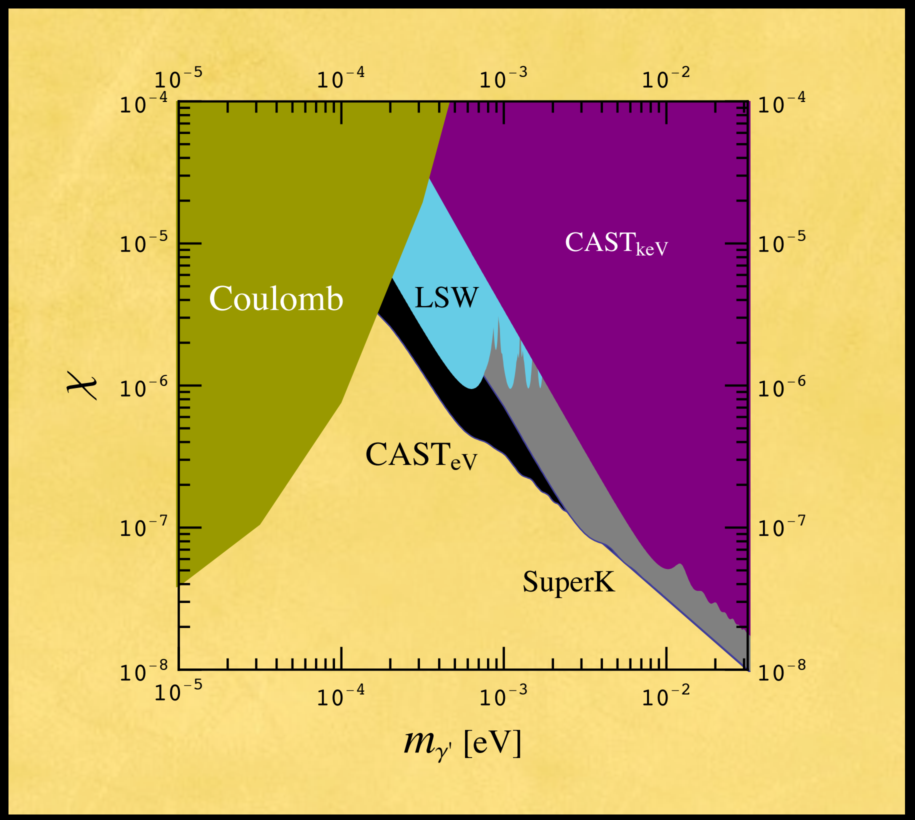
JR, JCAP 07(2008)008, Gninenko and JR Phys. Lett. B 664

Detect Solar hidden photons at earth by oscillations inside a closed cavity

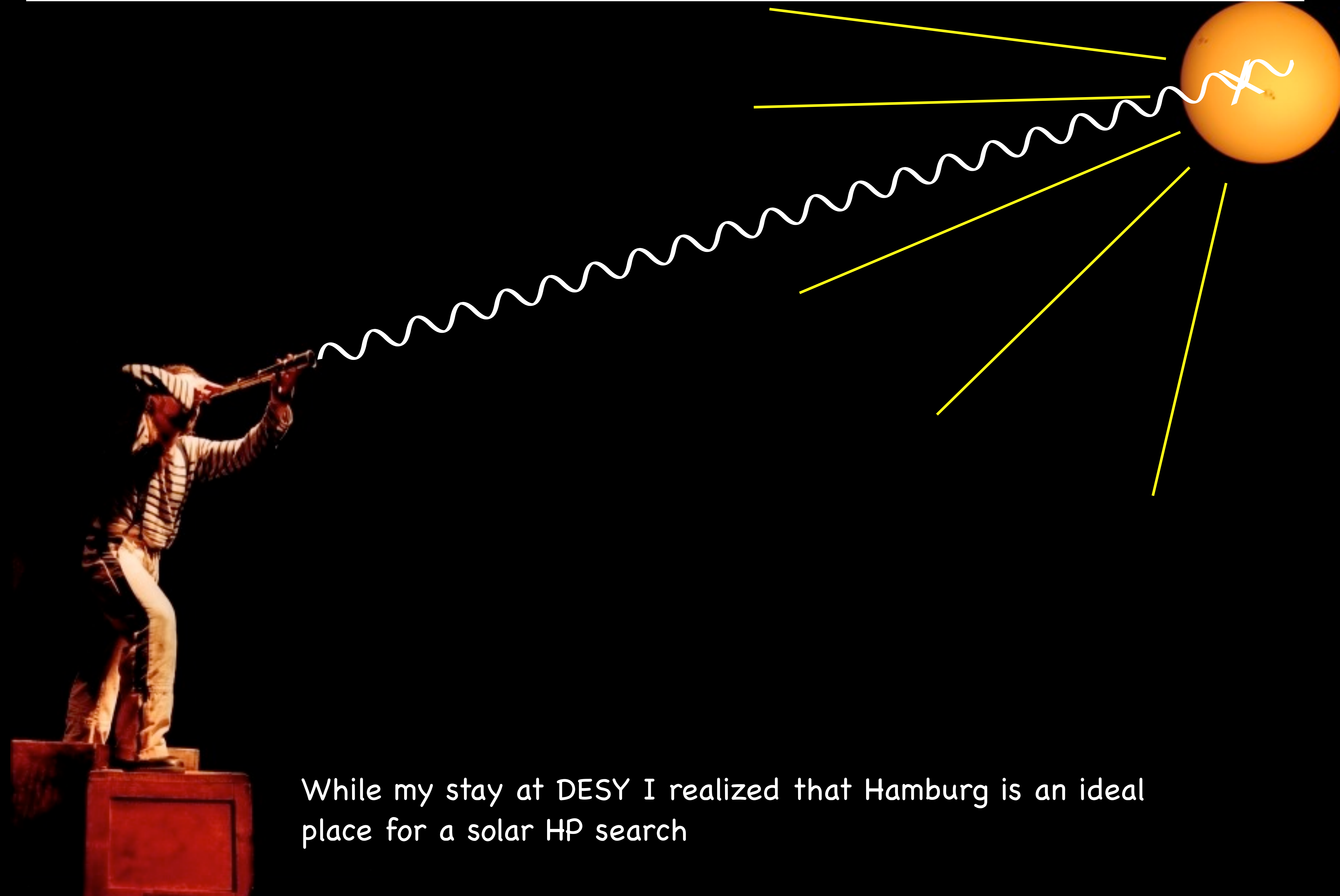




Sensitivities for a low energy (eV) HP search with CAST and SuperKamiokande



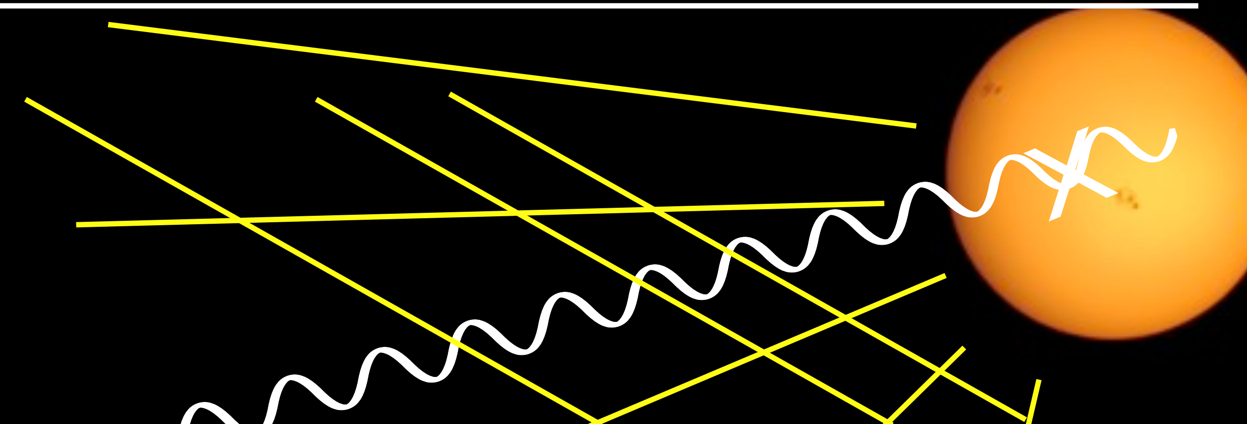
Solar Hidden Photons



While my stay at DESY I realized that Hamburg is an ideal place for a solar HP search

Solar Hidden Photons at Hamburg: SHIPS (Solar Hidden Photon Search)

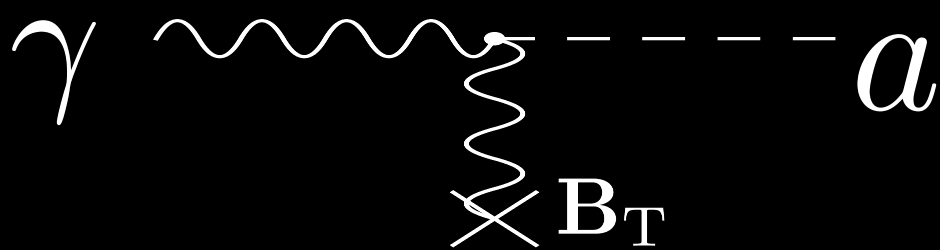
A collaboration of the Hamburger Sternwarte and DESY
G. Wiedemann, A. Ringwald, JR, et al.



While my stay at DESY I realized that Hamburg is an ideal place for a solar HP search (unfortunately...)

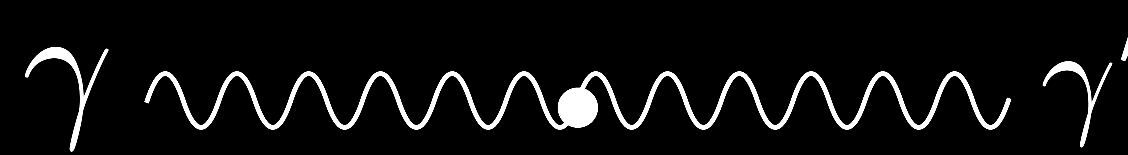
Photon-WISP oscillations of astronomical or cosmological radiation

Axion-like Particles



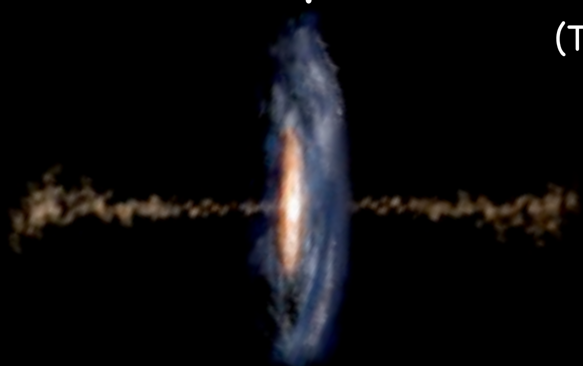
Primordial or galactic magnetic fields

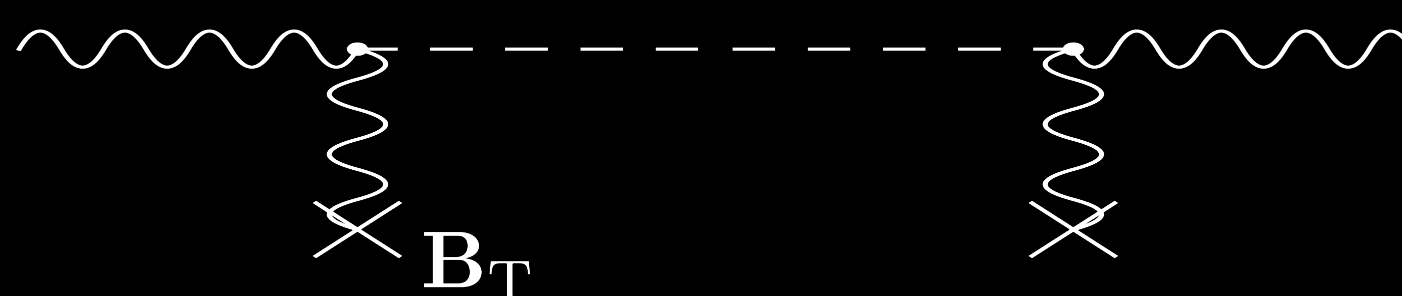
Hidden Photons



Photons can convert into WISPs while propagating through the universe
this produces distortions in the expected spectra and unusual transparency

(The conversion Probabilities depend on the photon frequency)



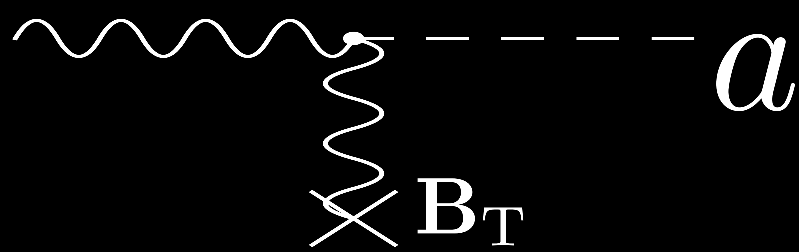


Axion-like-particles with very small mass (<< 10^-10 eV) could be responsible of different observed anomalies :

- Anomalous transparency of Gamma Rays (A. De Angelis, O. Mansutti, and M. Roncadelli, Phys. Rev. D76 (2007) 121301)
- Scatter in the Luminosity relations of AGNs (C. Burrage, A.-C. Davis, and D. J. Shaw, Phys. Rev. Lett. 102 (2009) 201101)
- Correlation of arrival directions between BL-Lacs and HECR in HiRes and AGASA (M. Fairbairn, T. Rashba, and S. Troitsky, arXiv:0901.4085 [astro-ph.HE].)
- Polarization of Quasars (A. Payez, J. R. Cudell, and D. Hutsemekers, AIP Conf. Proc. 1038 (2008) 211–219)

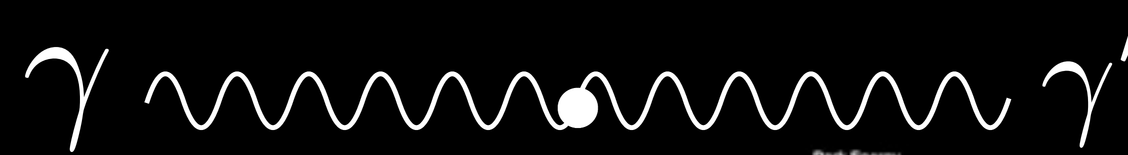
Photon-WISP oscillations: creation of a Hidden CMB

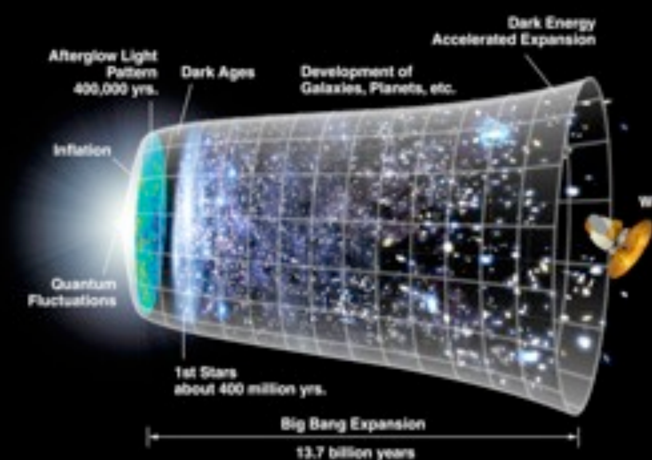
Axion-like Particles



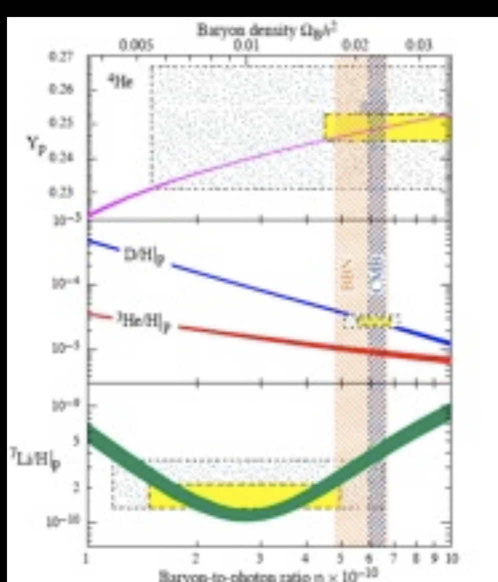
Primordial magnetic fields

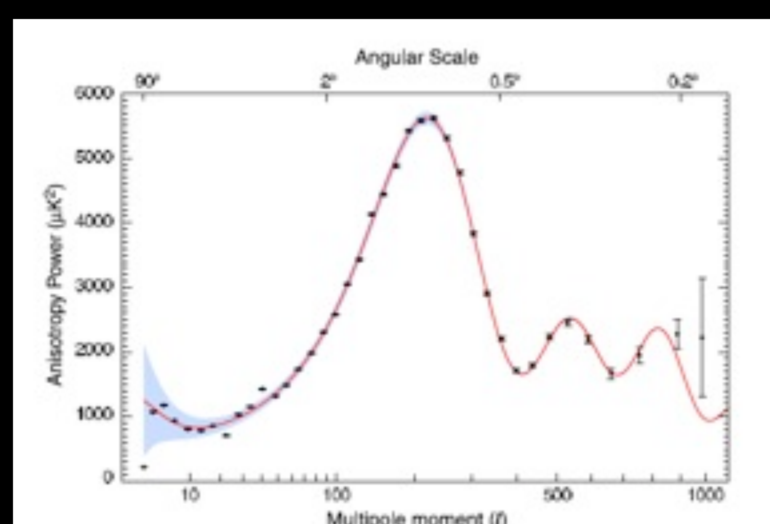
Hidden Photons



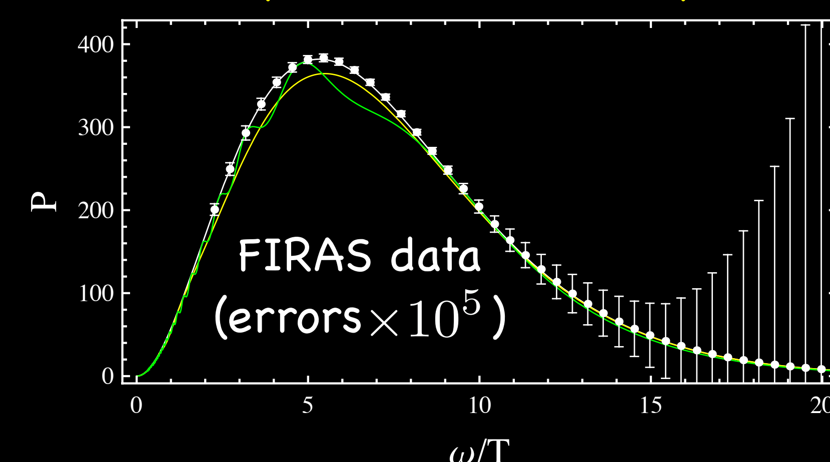


The Hidden WISP background behaves as relativistic degrees of freedom (as standard neutrinos) contributing to the universe expansion





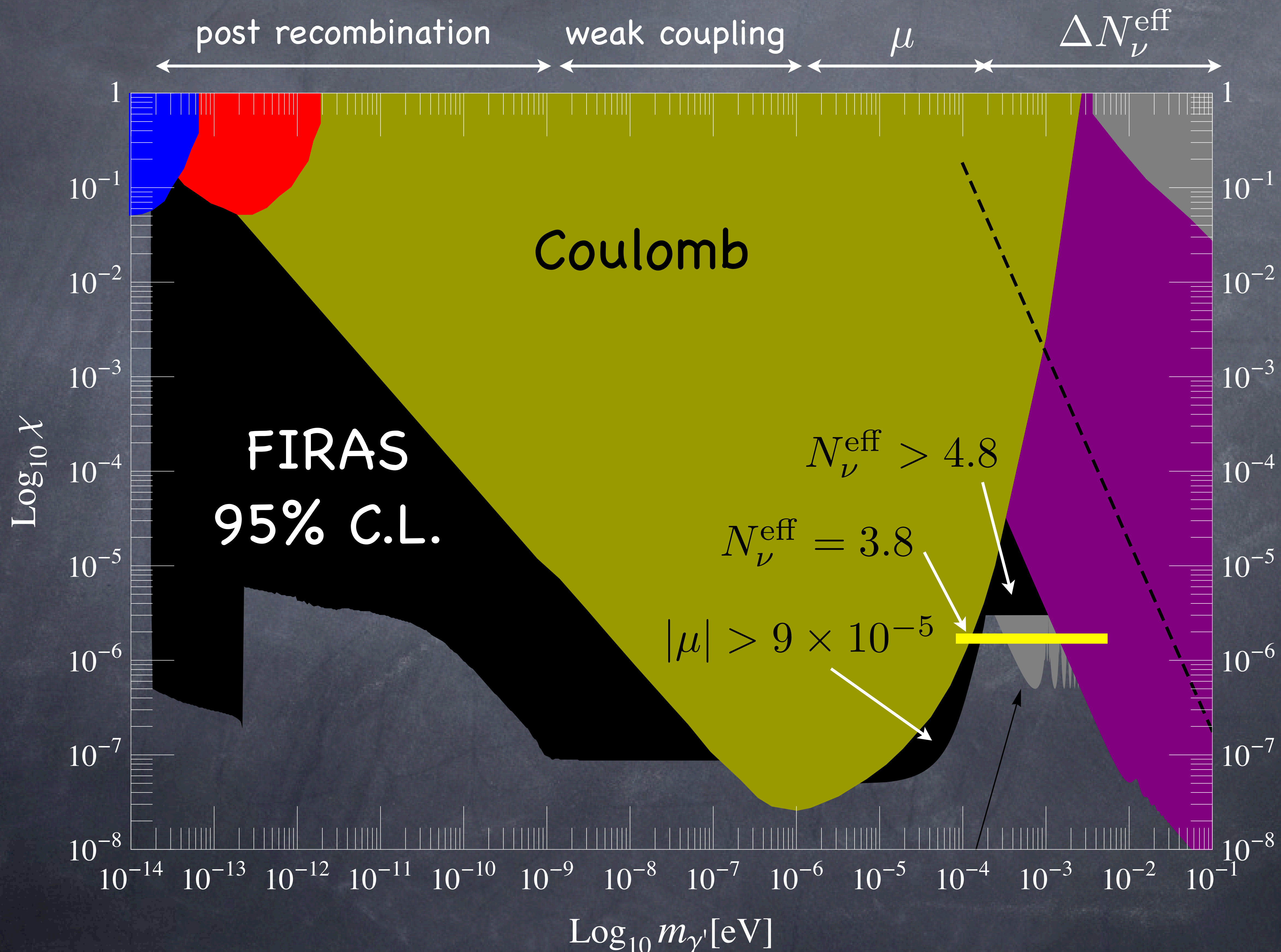
Photon oscillations into WISPs are frequency dependent and they leave their imprint on the CMB spectrum



Both BBN and CMB anisotropies (+LSS data)are sensitive to the number of effective neutrinos -> Bound

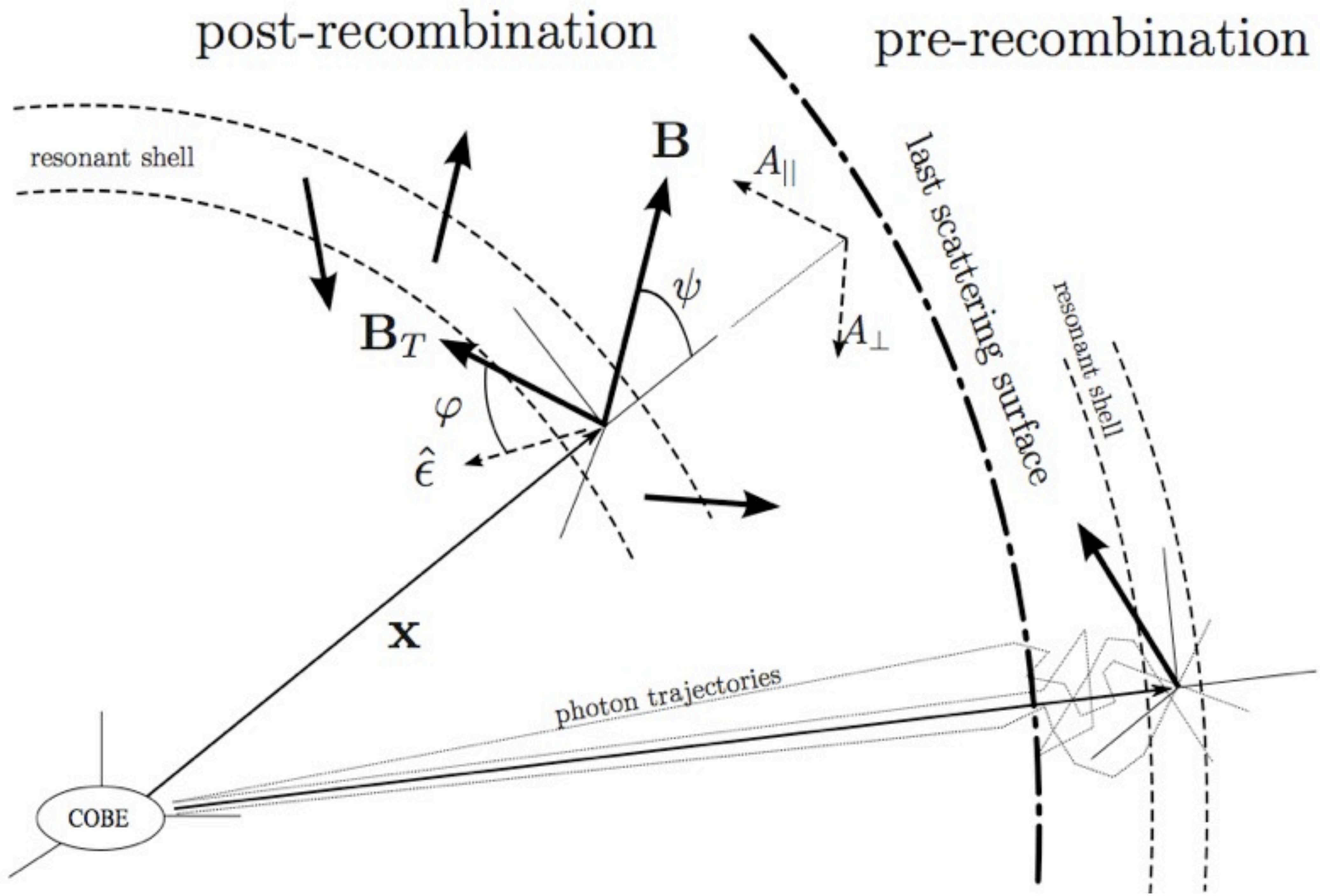
FIRAS on COBE measured the CMB spectrum with 10^4 accuracy!

HIDDEN PHOTONS



AXION-LIKE PARTICLES

The case of Axions and ALPS is more delicate :
Photon-ALP oscillations require a primordial (unmeasured but somehow expected) magnetic field



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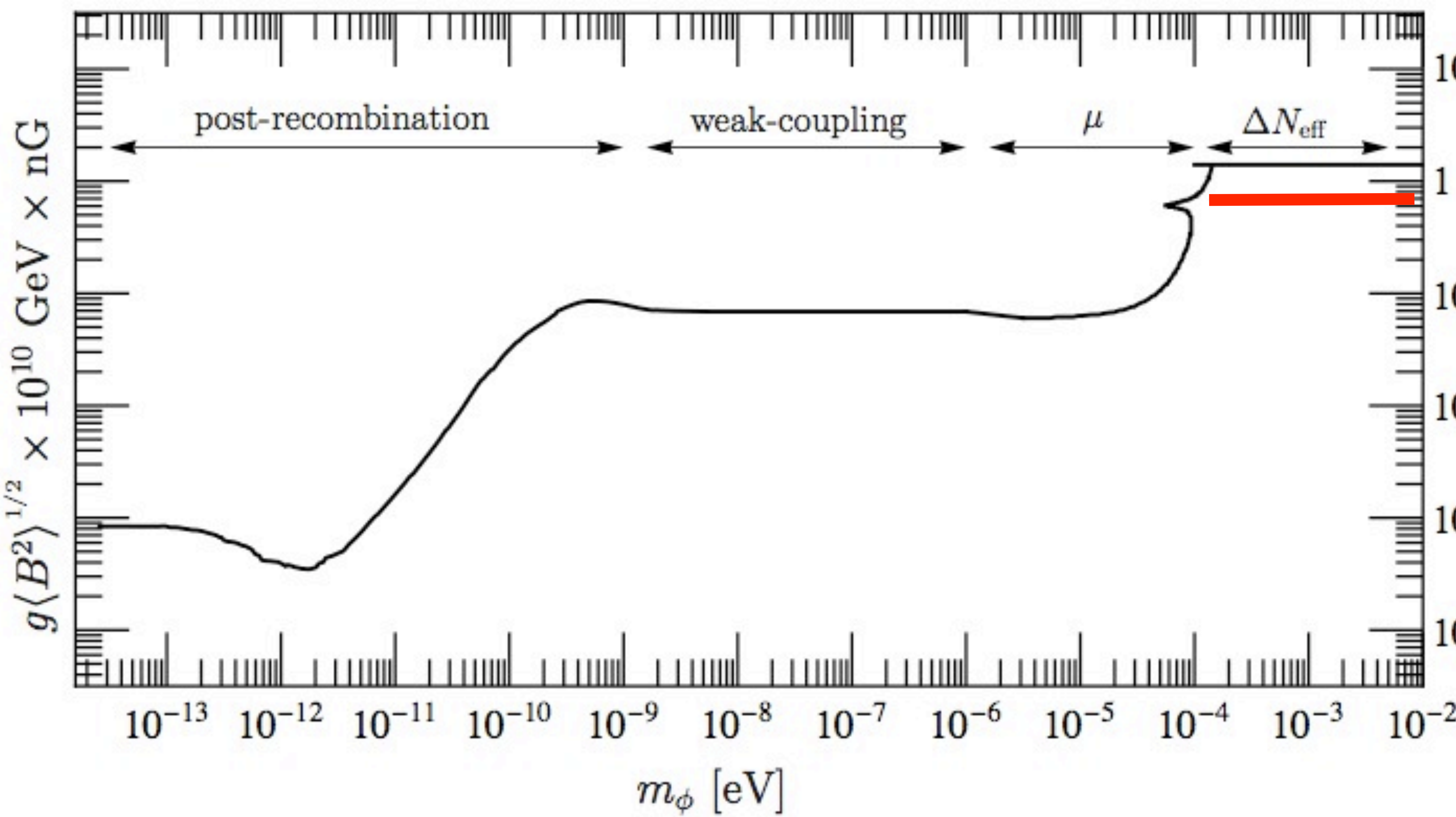
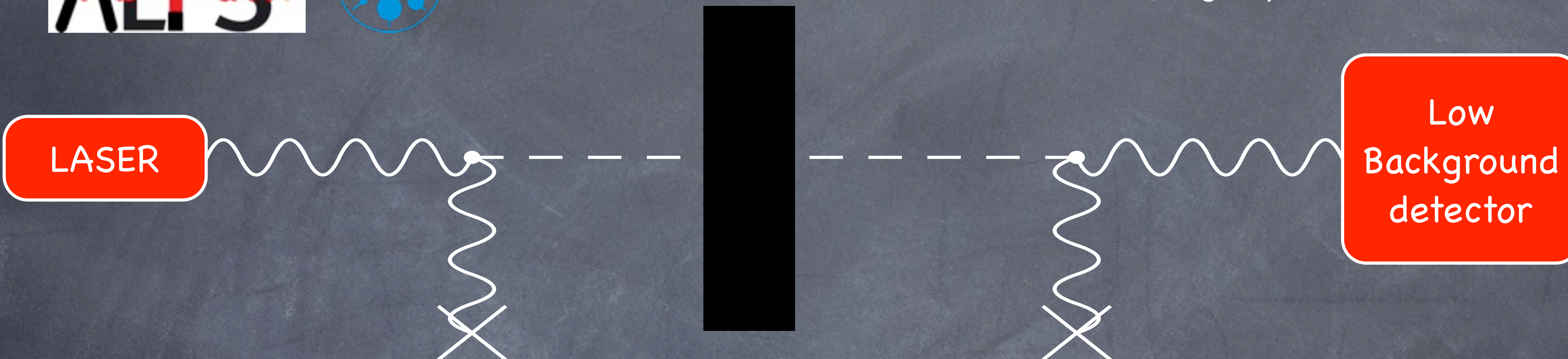


Photon Oscillations in the Lab: Light-Shining through Walls

Ehret te al. NIM A 612, and in preparation

"Axion Like Particle Search" or better ``Any-light-particle-search´´



Laser as intense/controlled source: A pioneer experiment BFRT (BNL) in early 90's and 2005 boom: ALPS (DESY), BMV (LNCMP), GammeV (FL), LIPPS (jLab), OSQAR (CERN)

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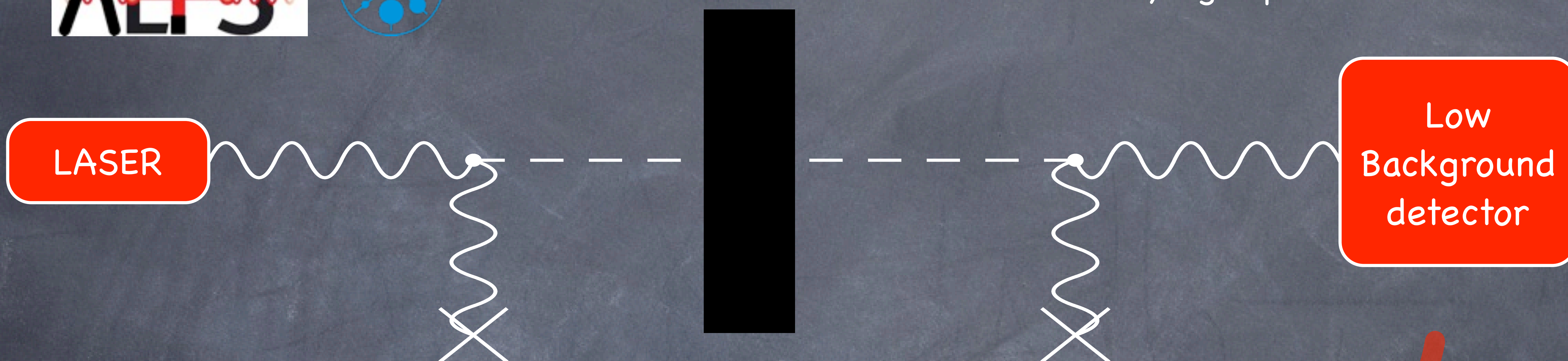

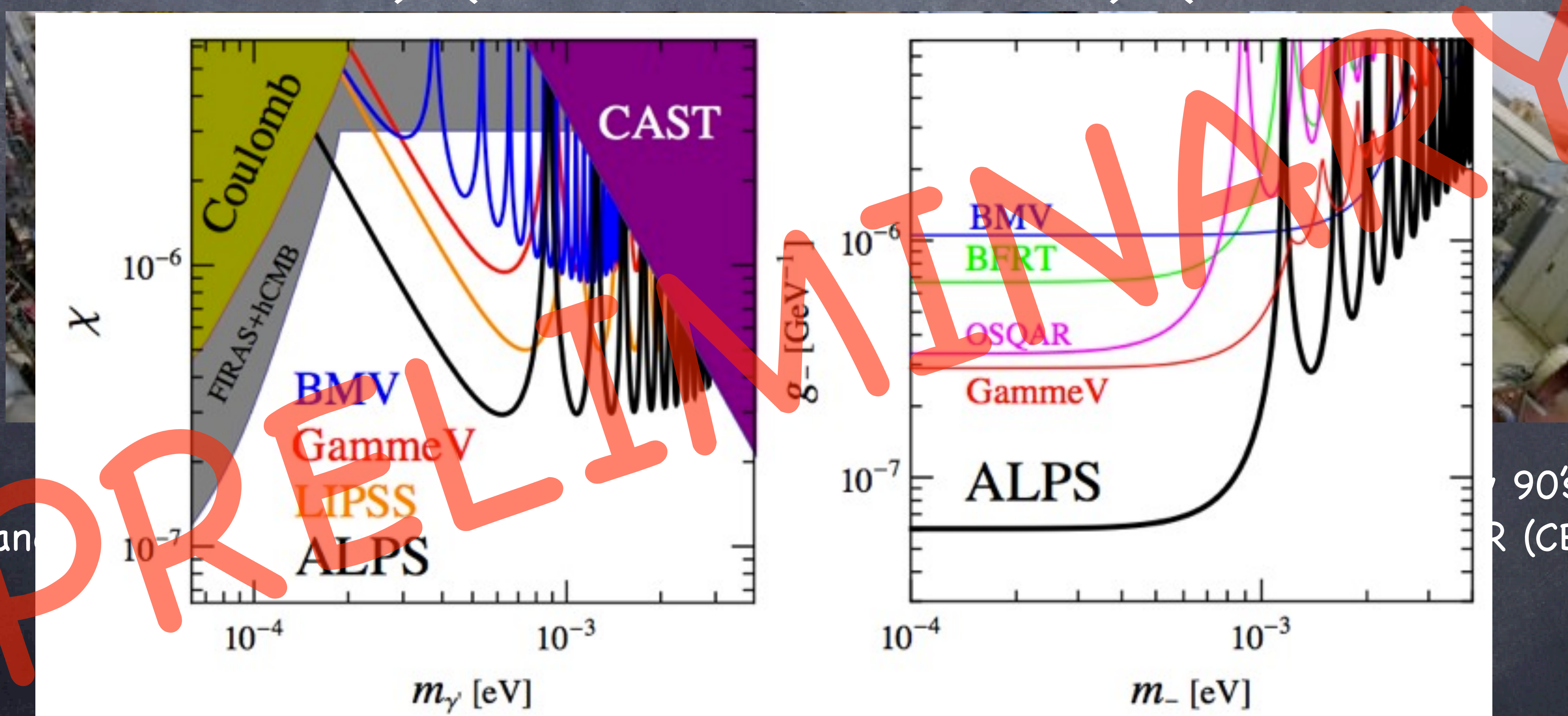

an

90's

R (CERN)

Conclusions

- WISPs and Hidden Sectors
- Strong Bounds from Astrophysics and Cosmology
- (Also some possible Hints !)
- Laboratory searches are underway (Helioscopes, Light through Walls)
- Many more things to say!

THANK YOU!