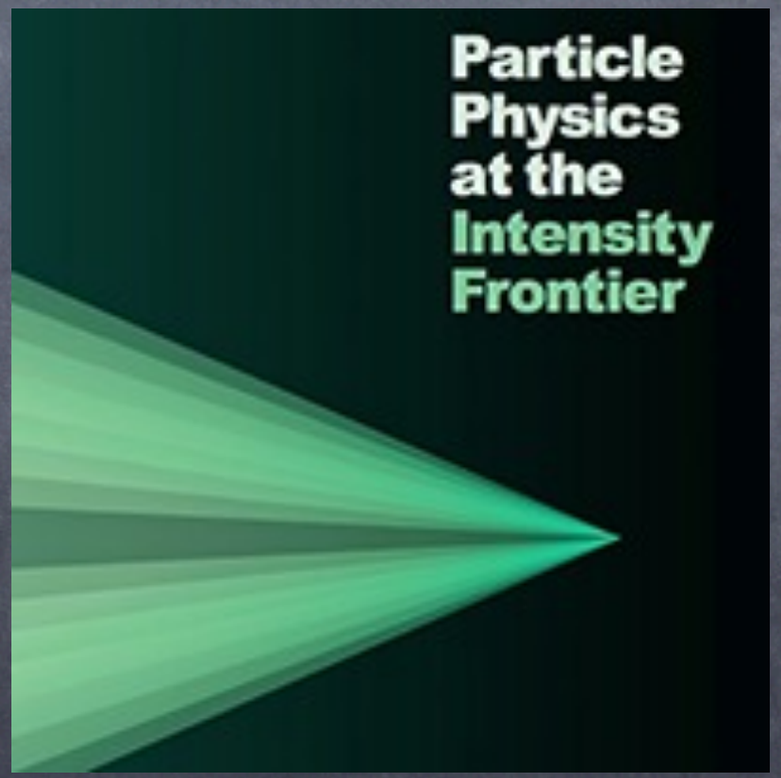
Weakly interacting slim particles (WISPs)

Theory and phenomenology update

Javier Redondo (LMU & MPP München)



Outline

- MOTIVATION for WISPs

  ALPs, HPs, ...

- GENERALITIES

- WHAT'S NEW?

Beyond Standard model

Dark Matter

Universe transparency

Flavor structure

Dark Energy

Strong CP problem

Neutrino masses

Anomalous anomalous muon g-2

EW Hierarchy Problem

Quantum Gravity

Beyond Standard model

Universe transparency

Dark Matter

Dark Energy

TOP

BOTTOM

All problems at a time
(O(?) New particles...)

One problem at a time
(O(1) New particles...)

Problem

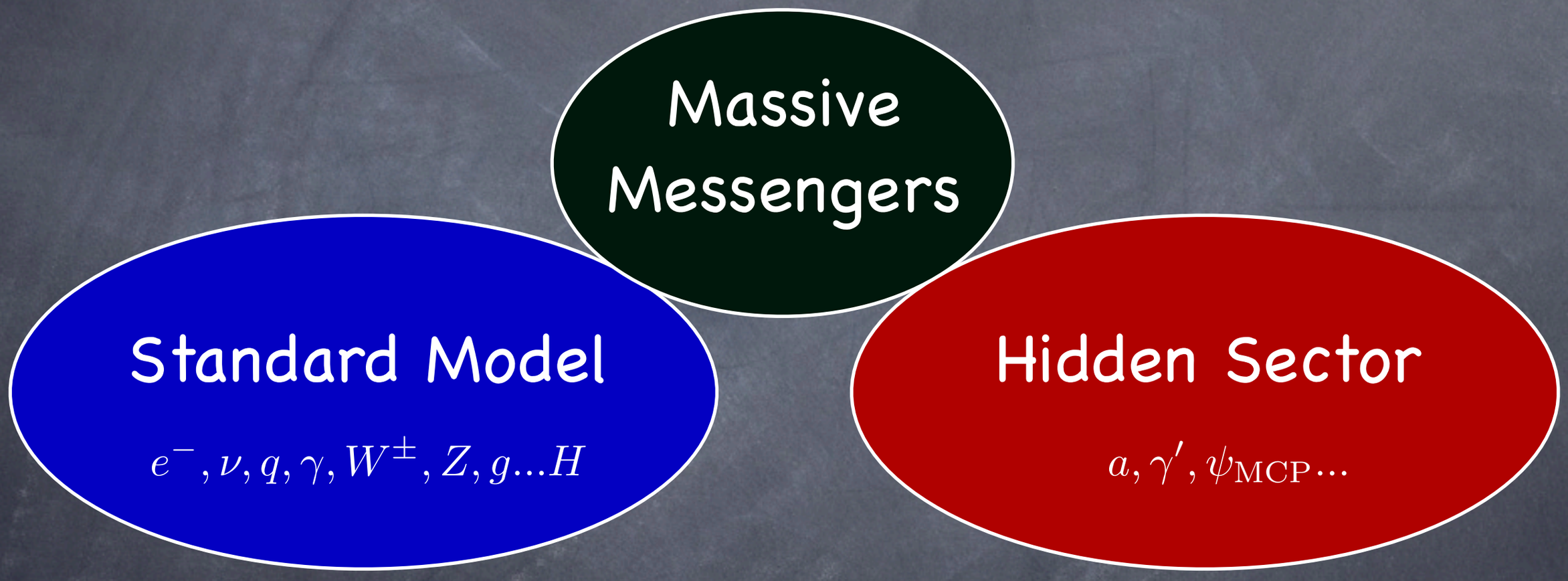
Neutrino

EW Hierarchy Problem

Quantum Gravity

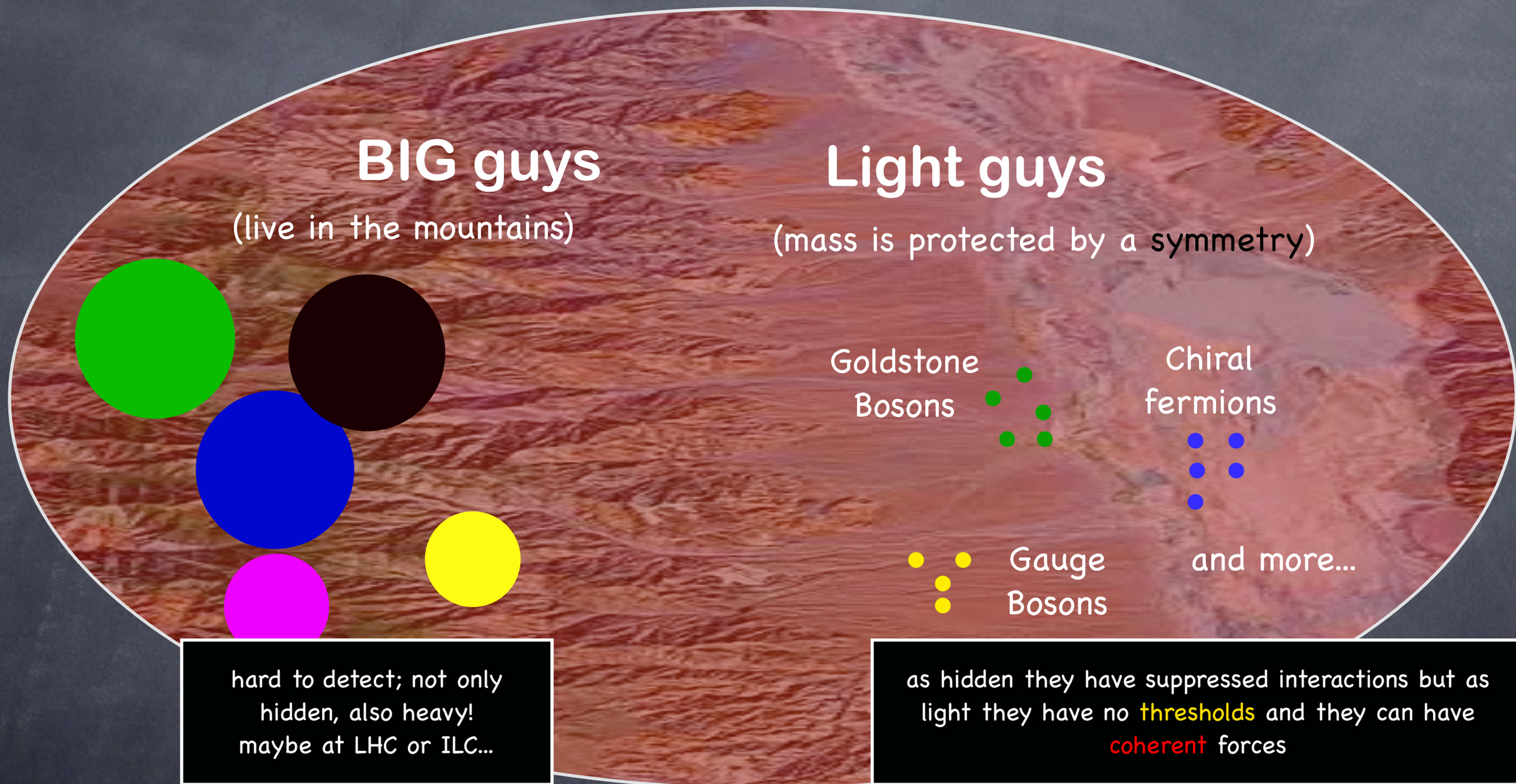
Hidden Sectors

Fields coupled through gravity or HE "messenger" fields...



String Theory, SUSY breaking, ...

Hidden Sectors can be quite complicated

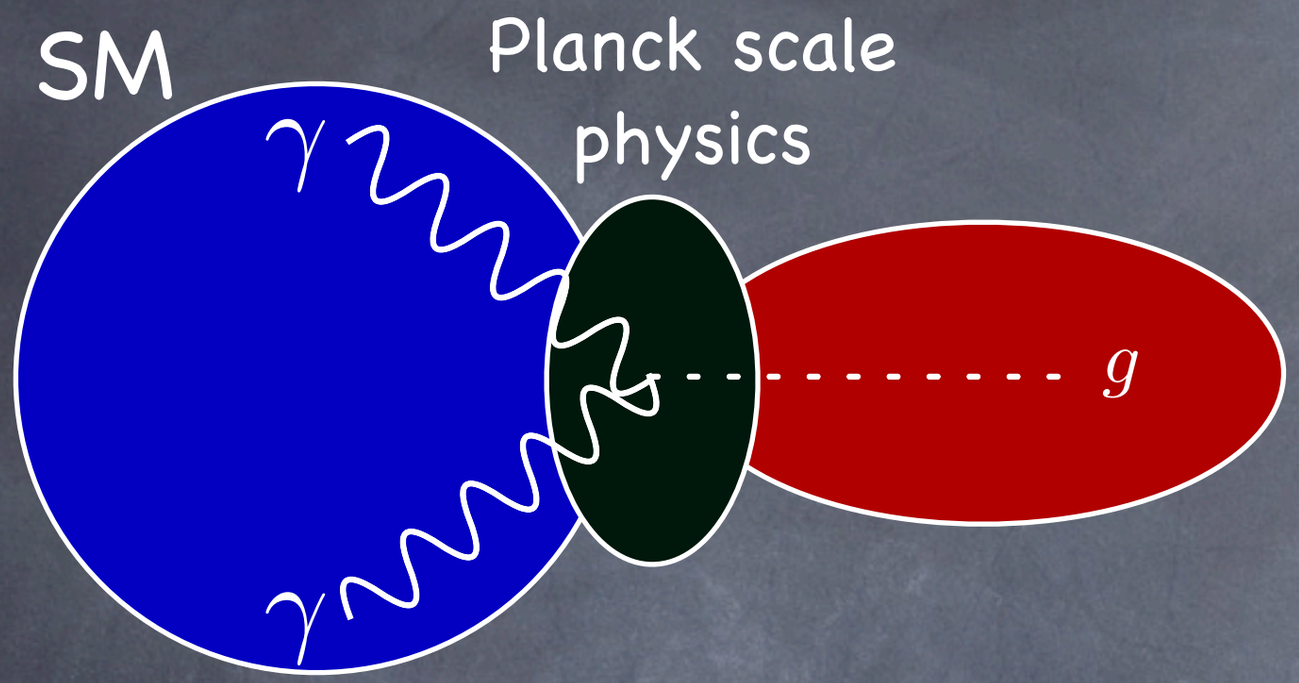


Let symmetry be our guide !

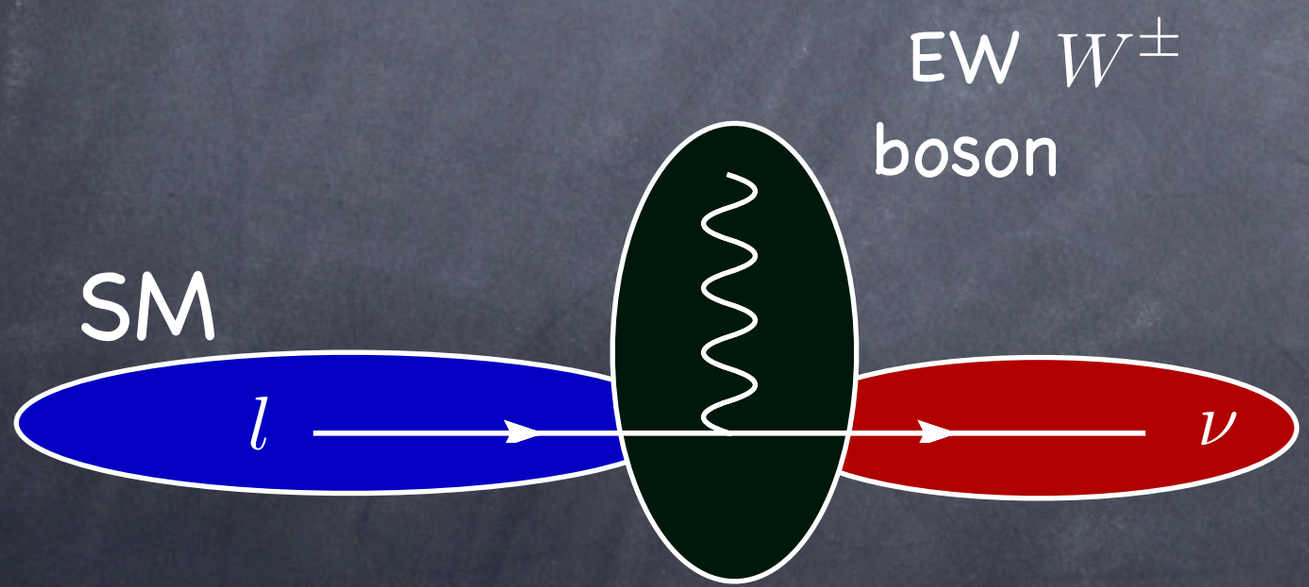
Hidden Sectors can be quite complicated

Let symmetry be our guide !

There are ``WISPs'' in the SM ... !



Gravitons

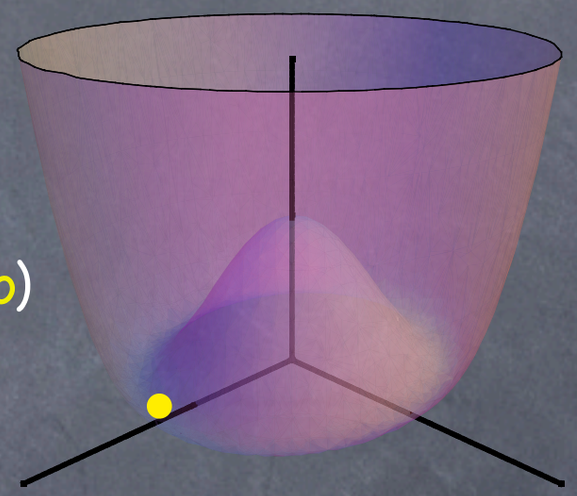


Neutrinos

Symmetries and WISPs

1- Shift symmetries and Goldstone Bosons

When a global symmetry is spontaneously broken in the vacuum
(i.e. respected by the interactions but not by the vacuum)
there appears a massless particle in the spectrum: a Goldstone boson
(if it is slightly explicitly broken... then it acquires a little mass-> pseudo)



2- Local U(1)s : Hidden Photons

Gauge invariance protects masses of gauge bosons (m=0 for non-abelian group, not for U(1))
Masses can be given by the Stückelberg mechanism
Kinetic mixing with the photon is the stronger of all mediator mechanisms (discussed here)
(Additional U(1)'s are ubiquitous in PBSM)

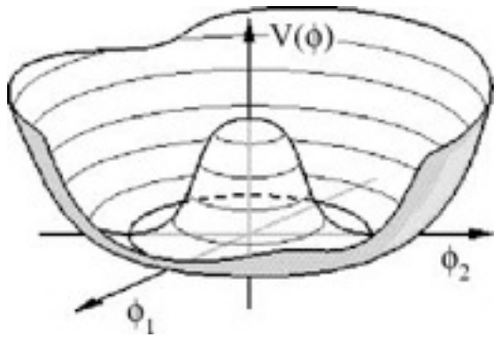
3- Chiral sym : Mini-charged Particles/sterile nu's

Chiral symmetries may forbid a mass term for fermions; or protect it.
When these particles have interactions with a hidden U(1) that mixes with Photon they appear as mini-charged particles

Axion-like particles (ALPs) 0^-

pseudo Goldstone bosons

Global continuous symmetry spontaneously broken at high energy scale M

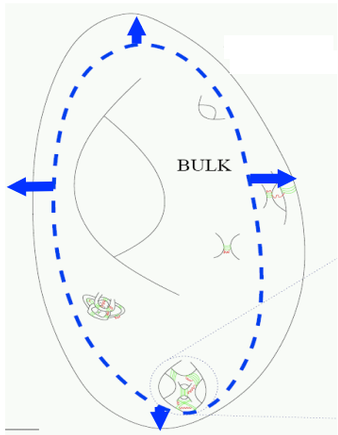


π^0 η' MAJORONS

η a R-AXION FAMILONS

String 'axions'

Sizes and deformations of extra dimensions, gauge couplings



DILATONS

RADION

MODULI

Axiverse!

Supersymmetry/supergravity

EACH GAUGE GROUP HAS ITS OWN AXION

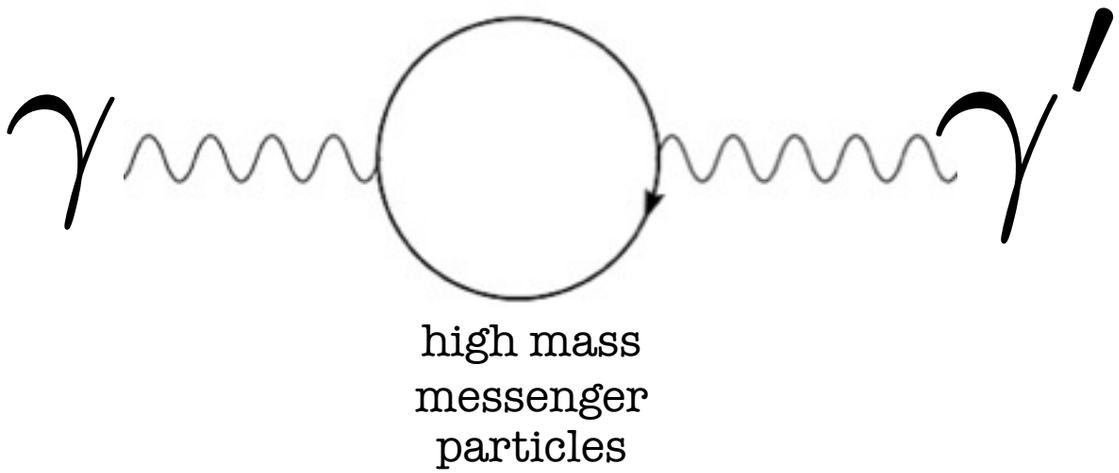
$$\mathrm{Re}(f(\Phi))\int\sqrt{g}F_{\mu\nu}F^{\mu\nu}+\frac{i}{2}\mathrm{Im}(f(\Phi))\int\epsilon^{\mu\nu\rho\sigma}F_{\mu\nu}F_{\rho\sigma}$$

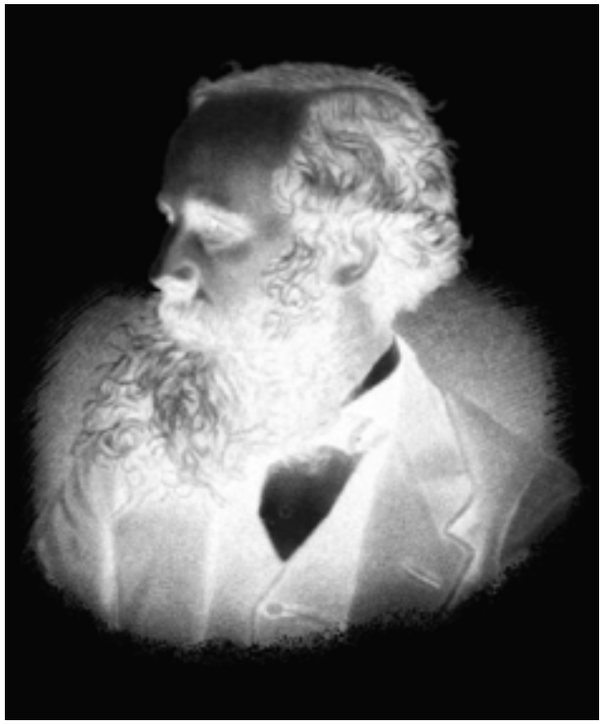
$$\frac{1}{g^2}\int\sqrt{g}F_{\mu\nu}F^{\mu\nu}+i\theta\int\epsilon^{\mu\nu\rho\sigma}F_{\mu\nu}F_{\rho\sigma}$$

Local U(1)'s: Hidden Photons & kinetic mixing

Extra U(1) symmetries are ubiquitous BSM (for instance in String Theory)

If the corresponding Hidden photon does not couple to SM particles -> HIDDEN PHOTON



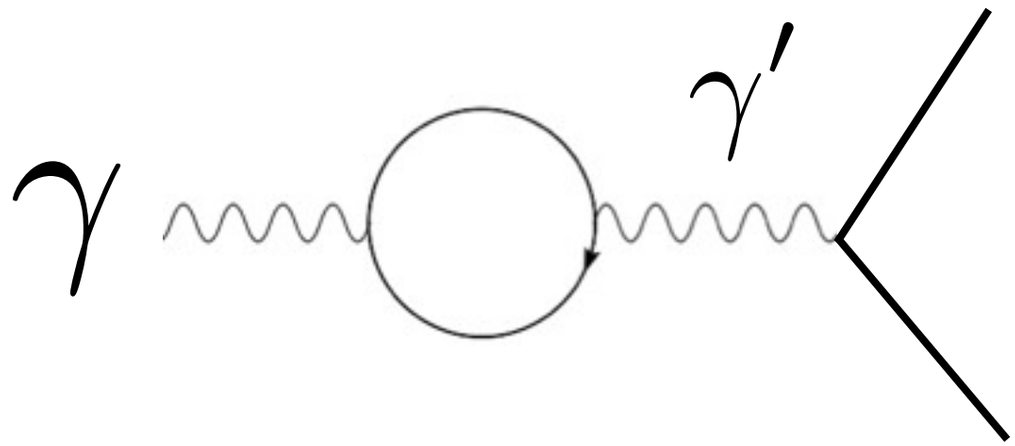


Kinetic mixing is the most relevant interaction at low energies

$$\mathcal{L}_I = -\frac{1}{2}\chi F_{\mu\nu}B^{\mu\nu}$$

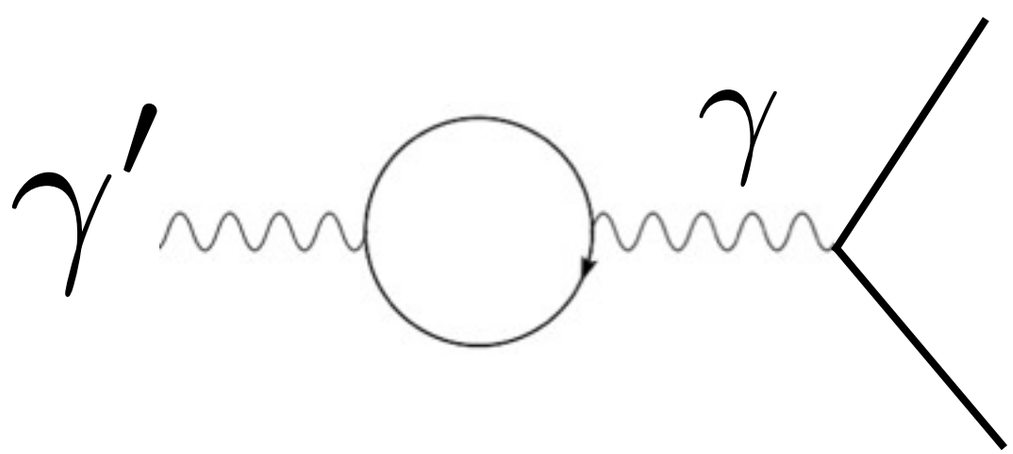
Mini-charged particles (MCPs)

Low mass particles charged under the hidden U(1) appear as MCPs



$$Q = \frac{g_h}{e}\chi Q^h$$

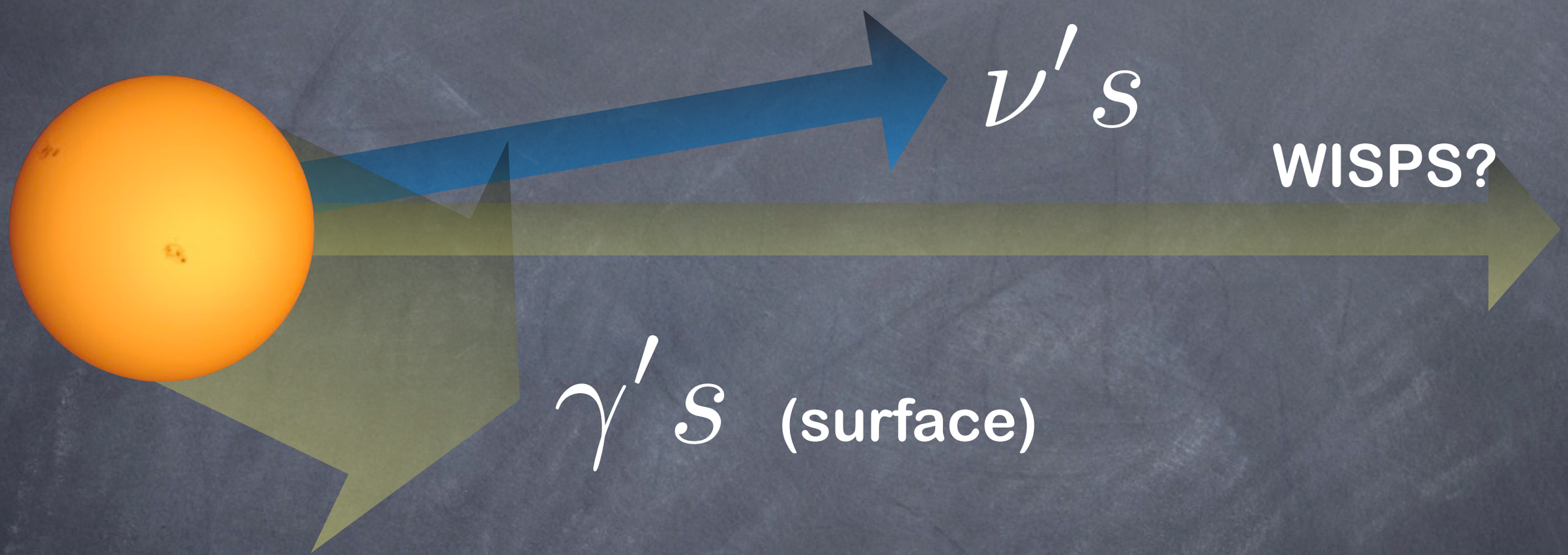
Aternatively, SM charged particles couple directly to HPs



$$Q^h = \frac{e}{g_h}\chi Q$$

Generalities

1- stellar WISP emission (VOLUME)

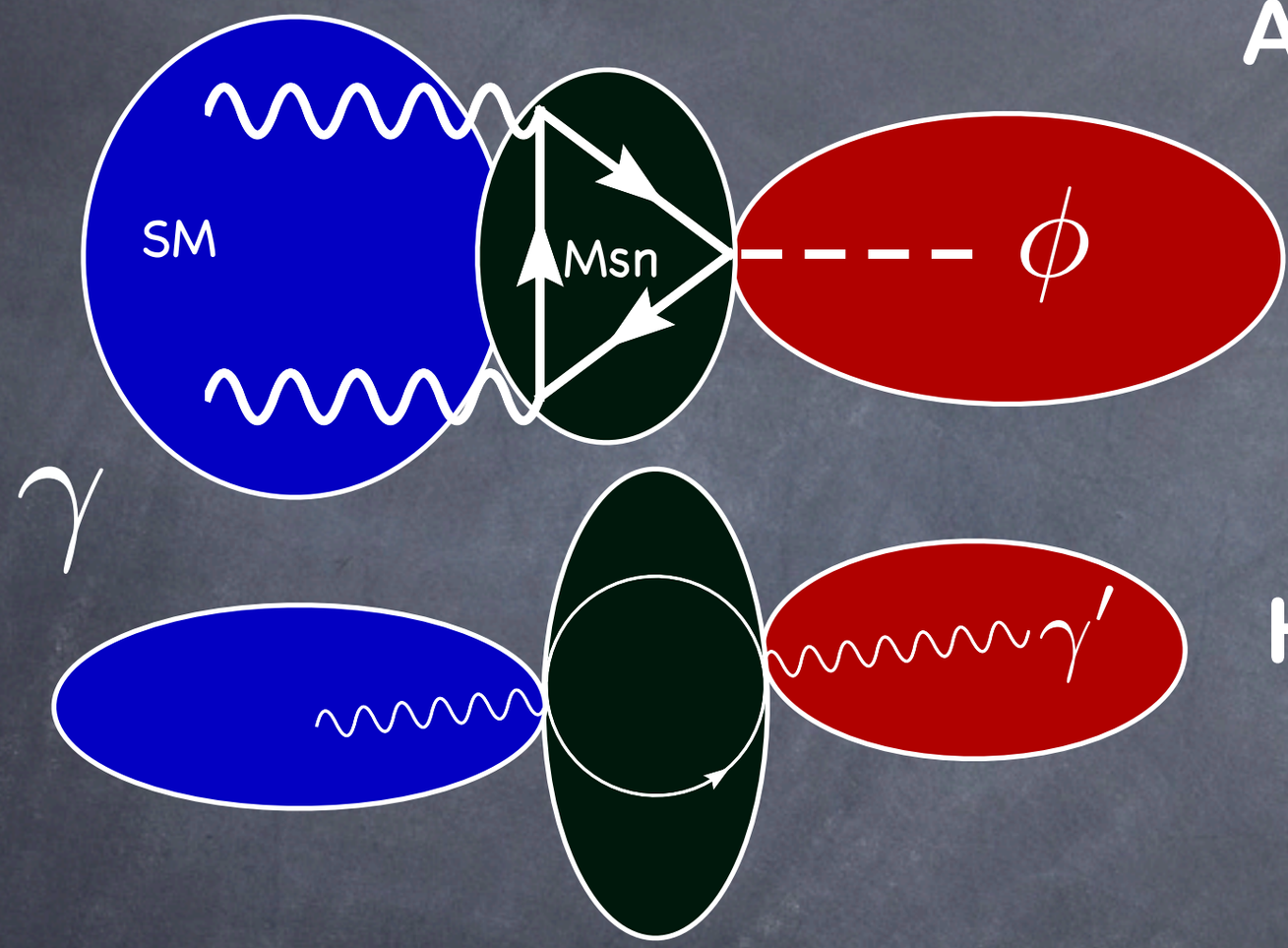


- Stellar constraints are very strong -> very WISP
- WISPs can help fitting theory and observations

(WDs)

Generalities

2- coupling to photons



Axion-like Particle

$$\frac{\alpha}{8\pi M} F_{\mu\nu}\widetilde{F}^{\mu\nu}\phi$$

$$g = \frac{\alpha}{2\pi M}$$

Hidden Photon

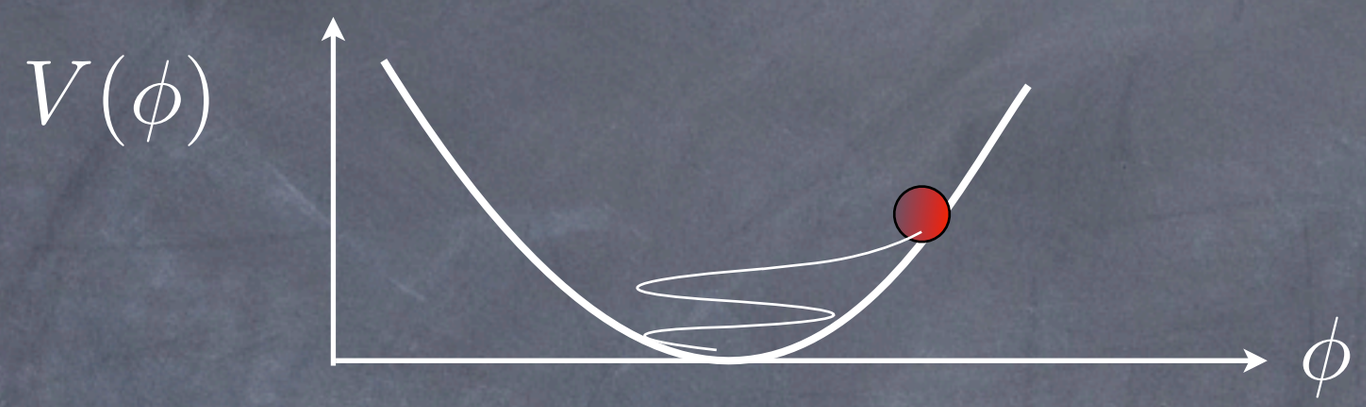
$$-\frac{1}{2}\chi F_{\mu\nu}B^{\mu\nu}$$

$$\chi \ldots$$

- Very generic
- Advantageous for experimental detection

Generalities

3- WISPy cold dark matter (any boson)



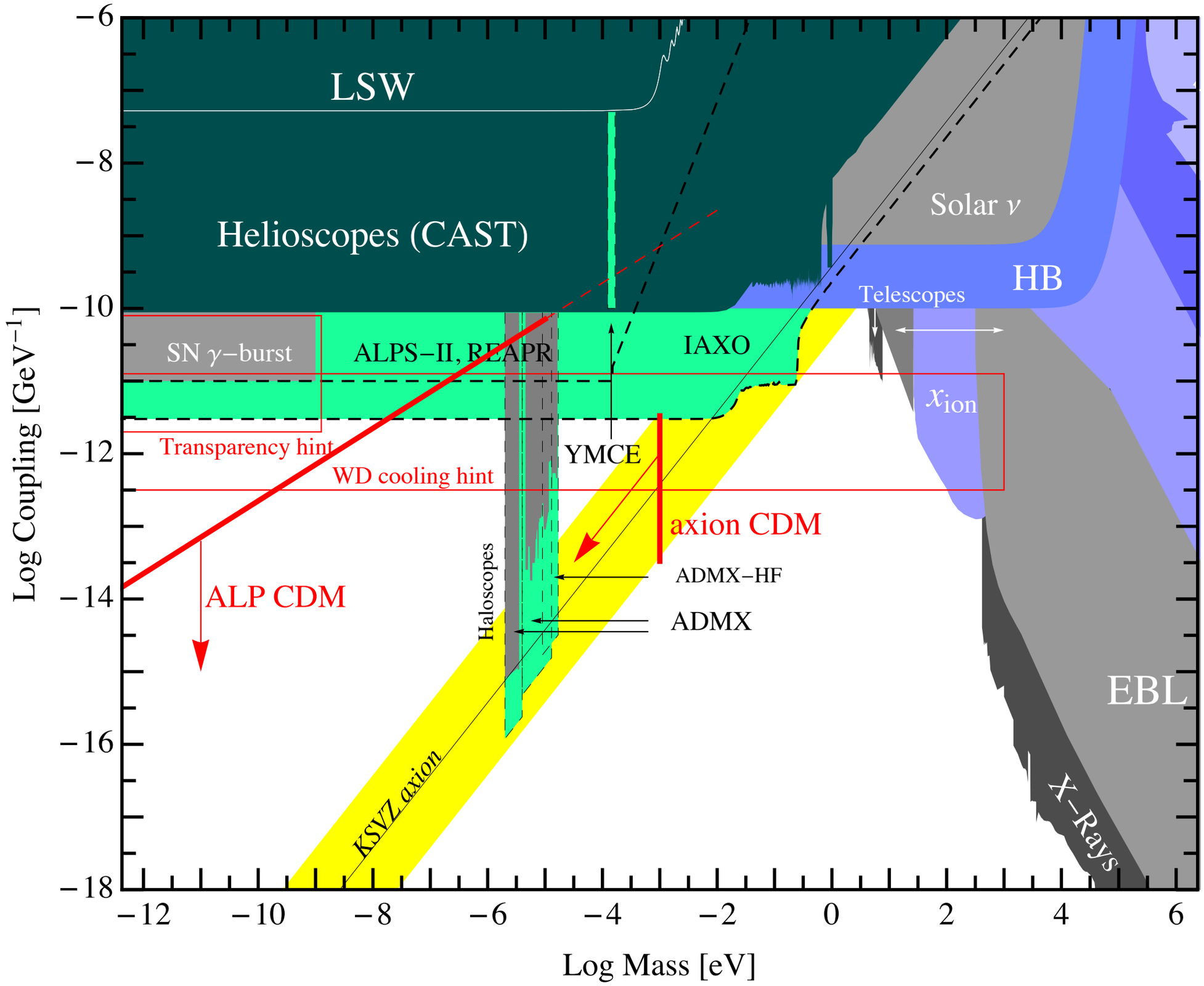
- WISPs don't thermalize!!!
- DM set by initial conditions (after Inflation)

$$\rho_{\rm CDM} \simeq \rho_{\rm measured} \times \sqrt{\frac{m_\phi}{\rm eV}} \left(\frac{\phi_0}{4.8 \times 10^{11}\,{\rm GeV}} \right)^2 \mathcal{F},$$

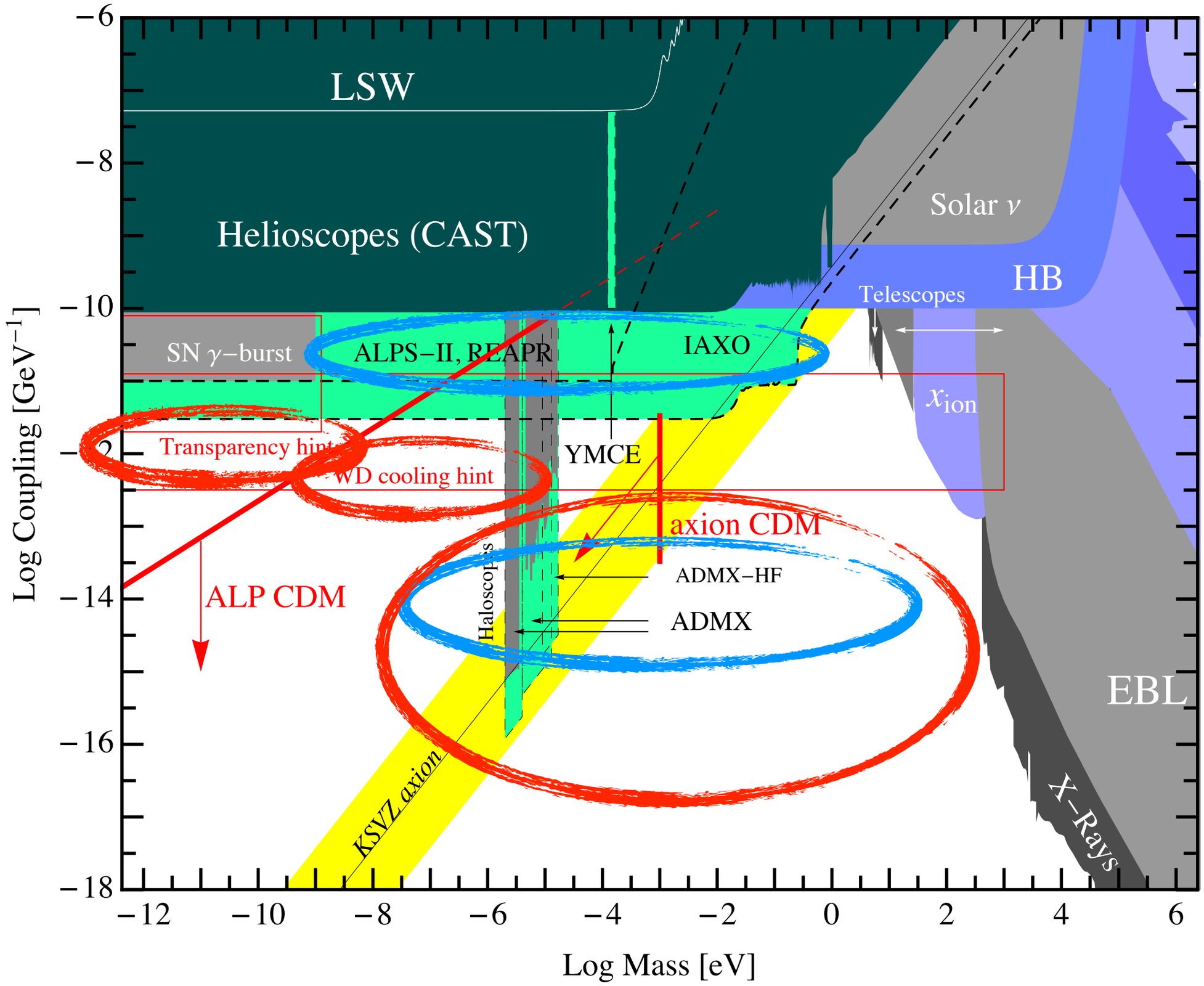
- ALPs $\phi_0 \lesssim \pi f_\phi(M_s)$; HPs ... ??

- Isocurvature constraints

Status on ALP searches (as of Jan 2013)

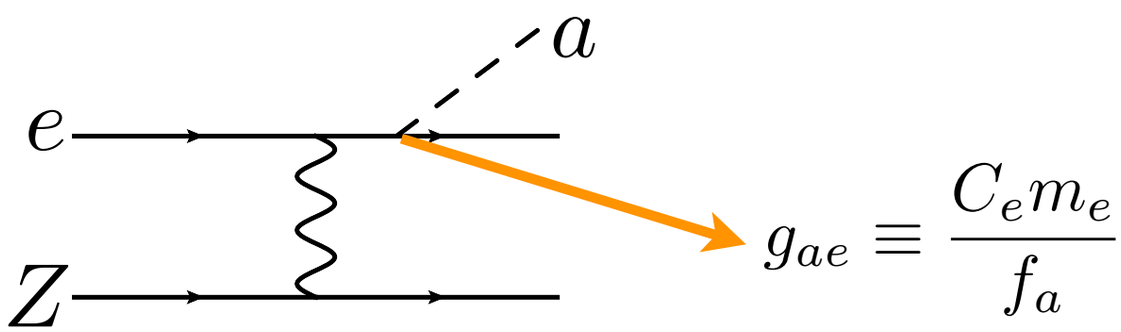


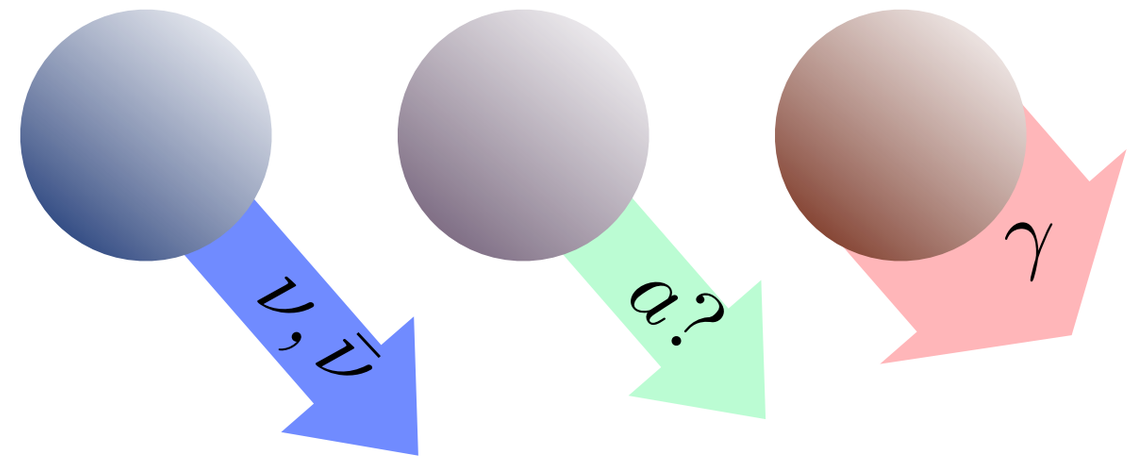
Updates on ALP parameter space



Accumulated hints from White dwarfs (...)

Axion emission can accelerate the WD cooling between neutrino and surface dominated cooling periods.

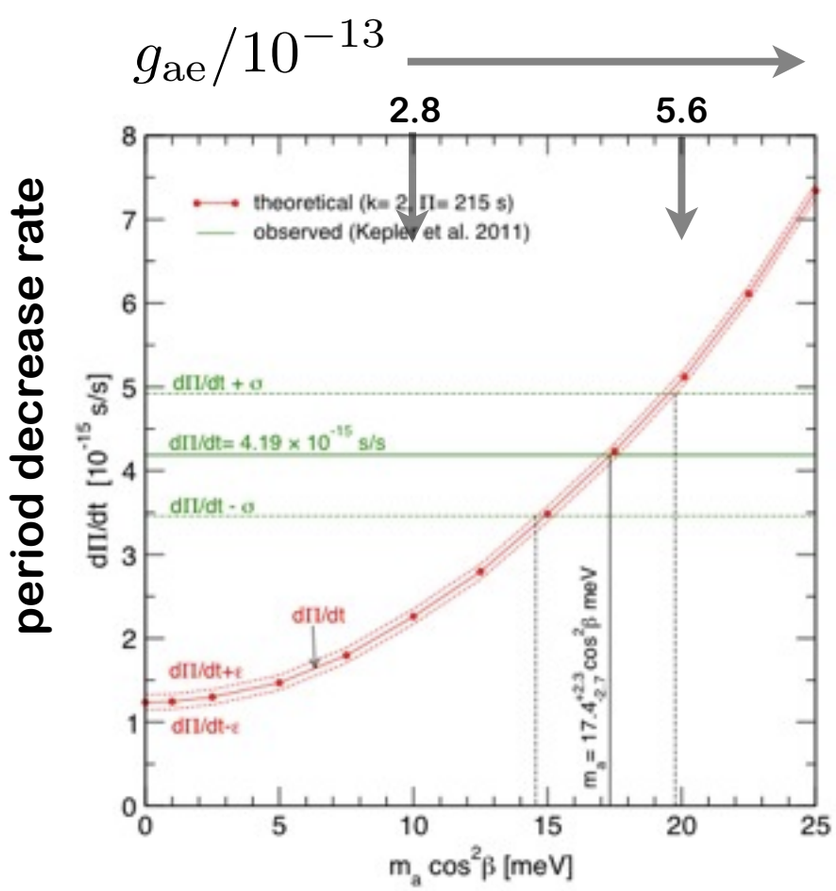




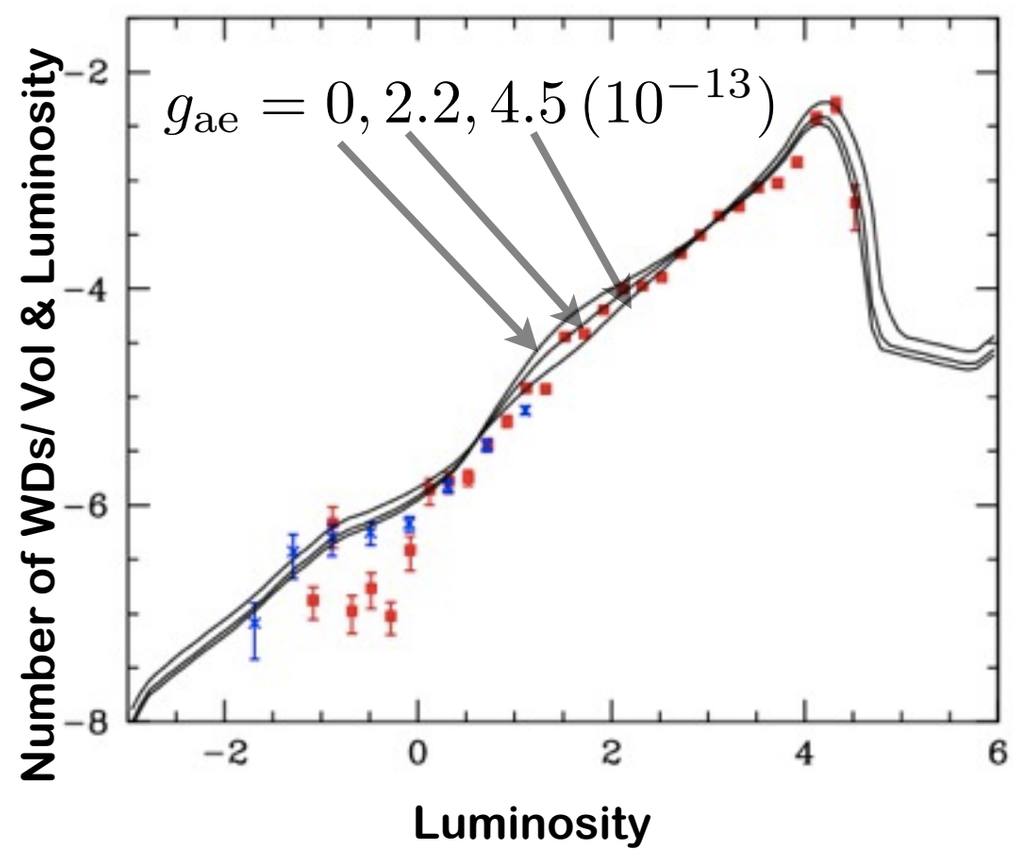
Period decrease of G117−B15A

WD luminosity function

Corsico et al. arXiv:1205.6180



Isern et al. arXiv:1204.3565

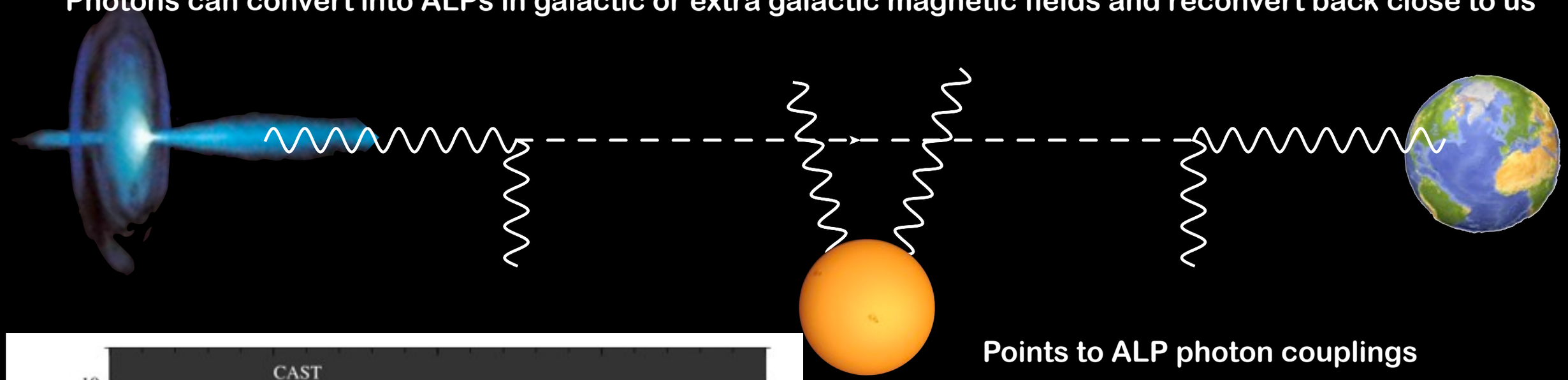


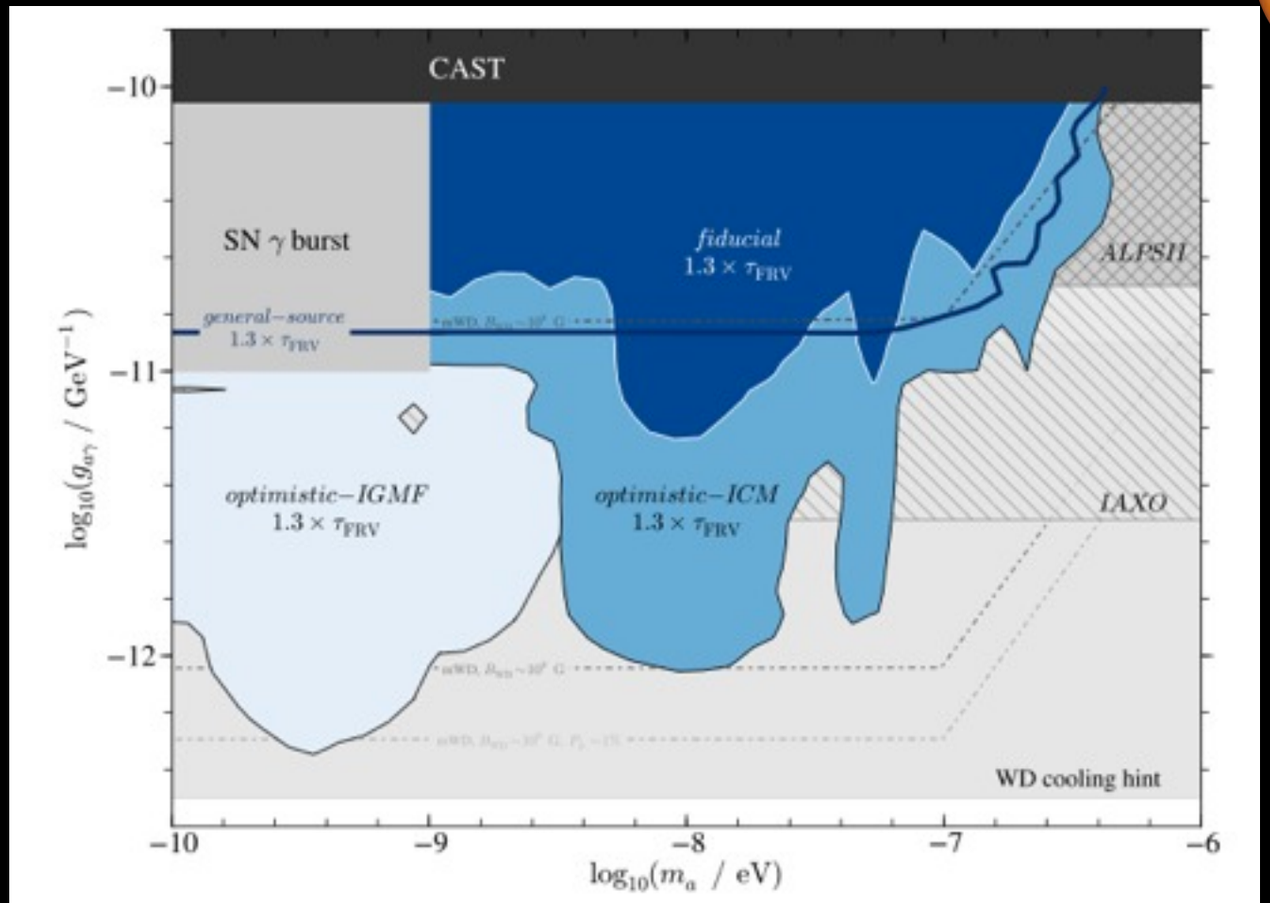
Transparency of the universe: lower limits of g!

Meyer et al, PRD87 (2013)

Transparency of the universe to gamma rays and ALPs

Photons can convert into ALPs in galactic or extra galactic magnetic fields and reconvert back close to us





Points to ALP photon couplings

$$g_{\phi\gamma} \sim 10^{-11}\mathrm{GeV}^{-1}$$

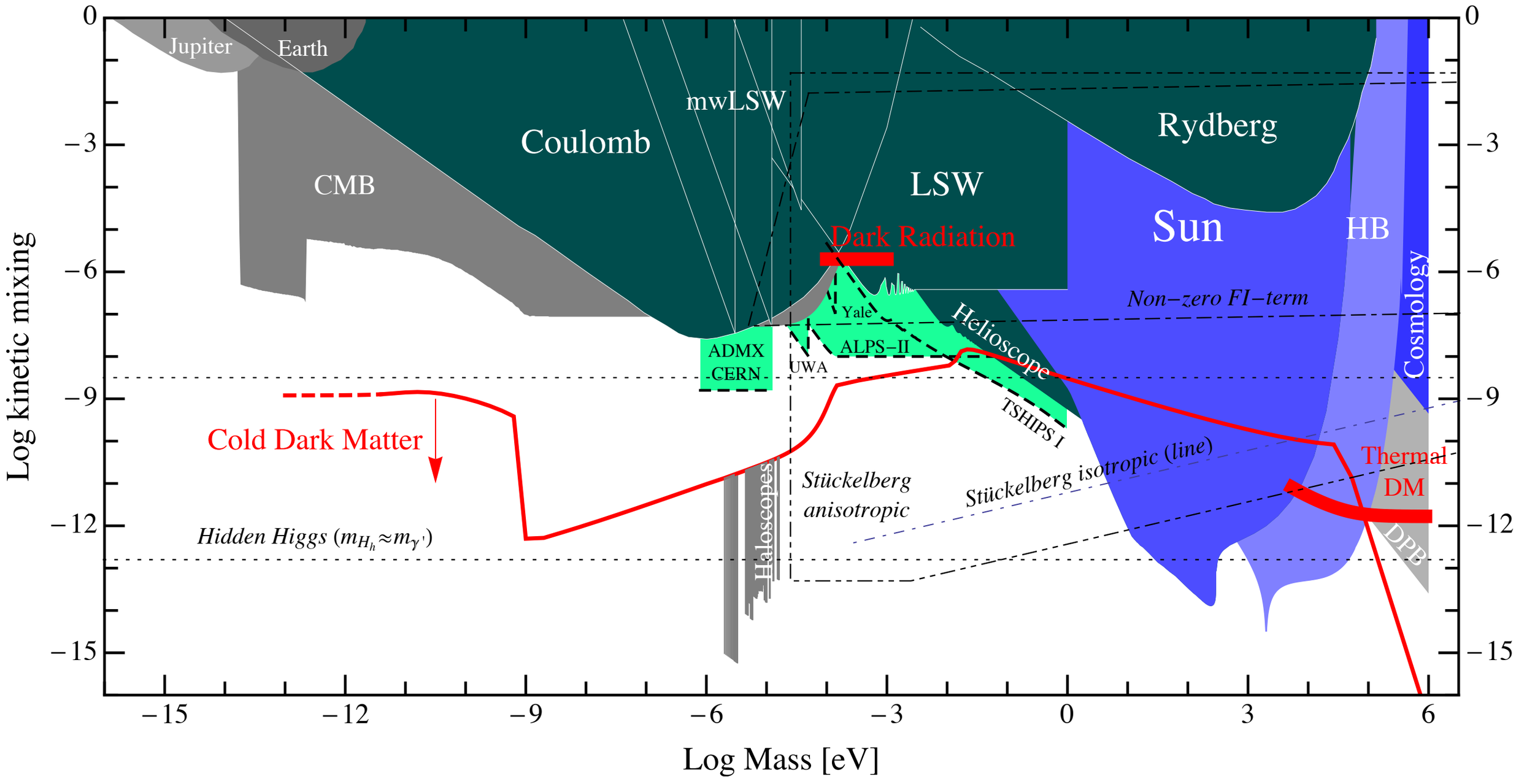
$$B \sim \mathrm{nG}$$

Requires very small ALP masses

$$m_\phi < \mathrm{neV}$$

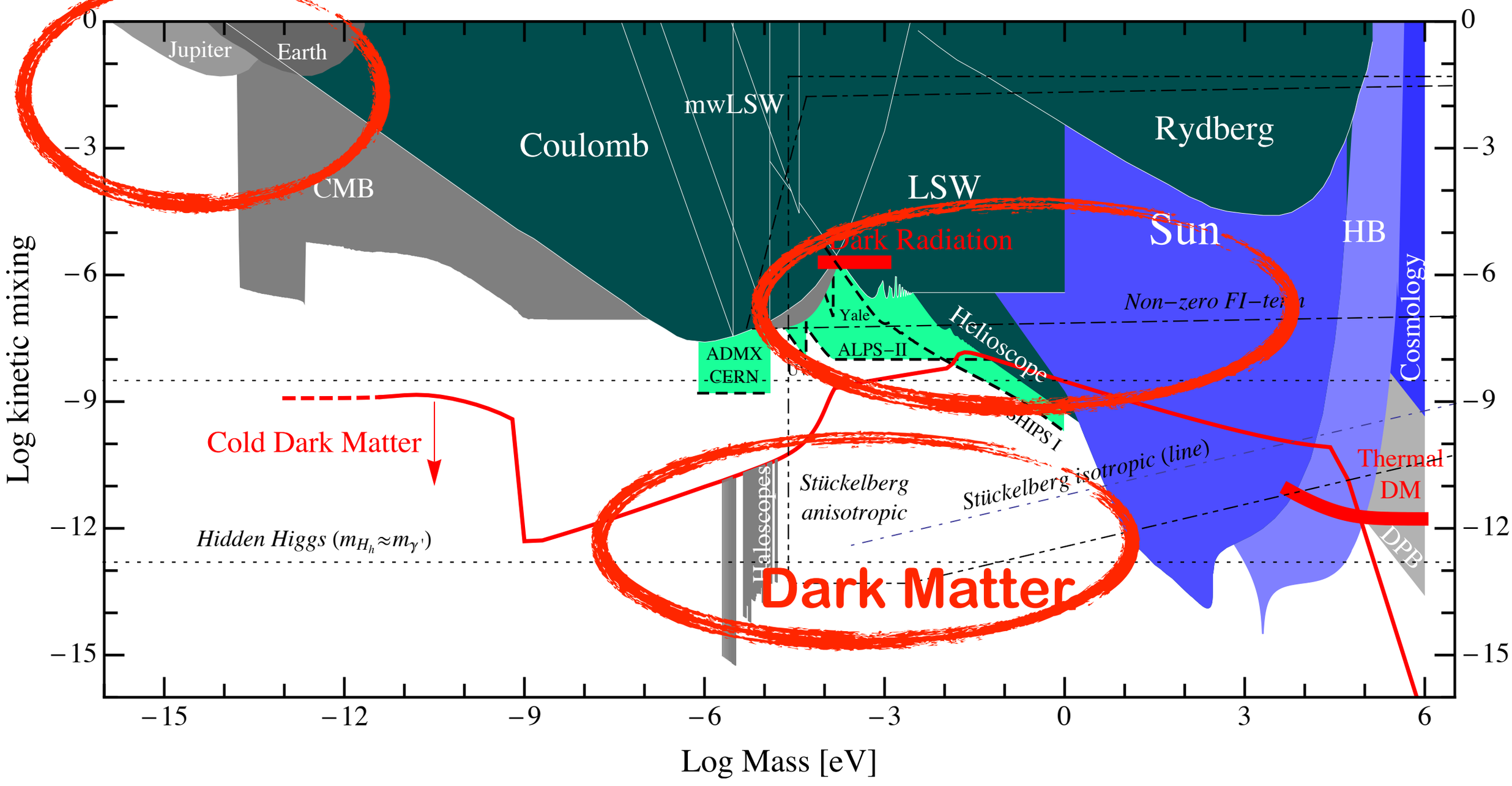
Challenged by Magnetic-WD constraints!
Gill et al. PRD84 (2011)

Status on HP searches (as of Jan 2013)



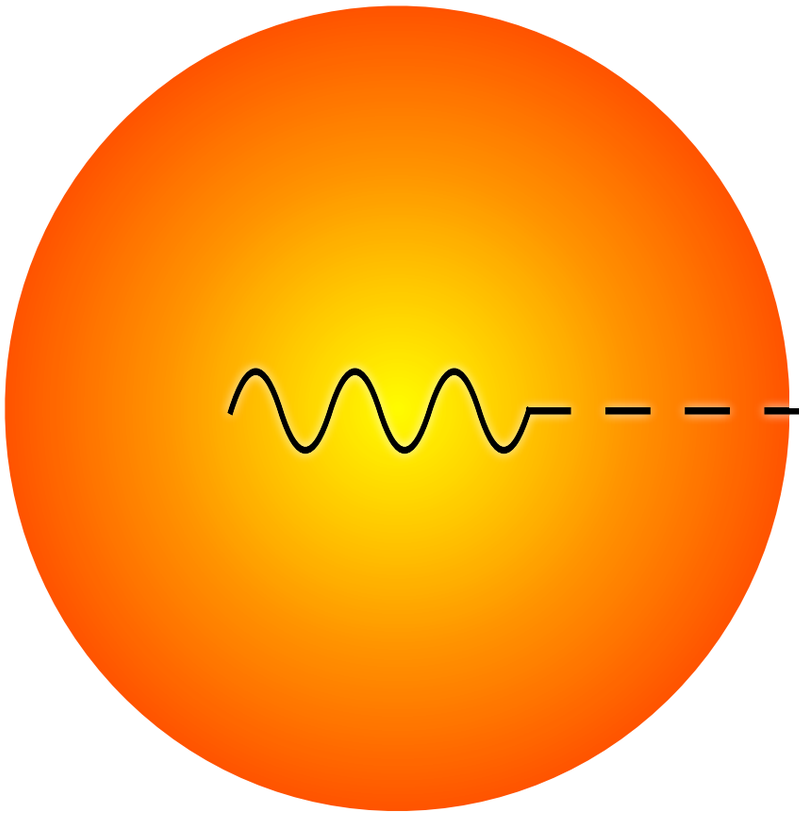
Major updates on HP parameter space

Lobanov et al. arXiv:1211.6268



Solar HPs

Ann et al. 1302.3884, Redondo & Raffelt (in prep)



Production is proportional to photon's

$$\Gamma(\gamma') = \mathrm{Im}\frac{1}{K^2 - \Pi}\chi^2 m^4$$

$$\mathrm{Re}\Pi_L = \omega_P^2 \quad ; \quad \mathrm{Re}\Pi_L = \omega_P^2/Z_L$$

Ann et al. 1302.3884

$$\Gamma_L(\gamma') = Z_L \mathrm{Im}\Pi_L(\gamma)\frac{Z_L}{(\omega^2 - \omega_P^2)^2 + (Z_L \mathrm{Im}\Pi_K)^2}\chi^2 m^4$$

Forgotten renormalization factor is huge for small masses!!

$$Z_L = \omega^2/K^2 = \omega^2/m^2$$

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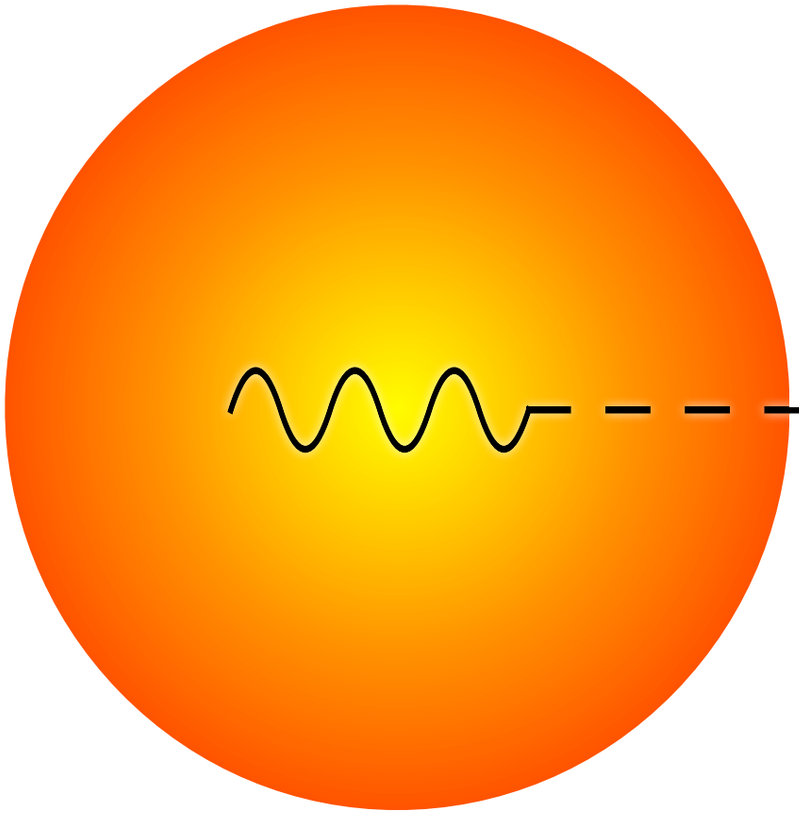
Ann et al. 1302.3884, Redondo & Raffelt (in prep)



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Ann et al. 1302.3884

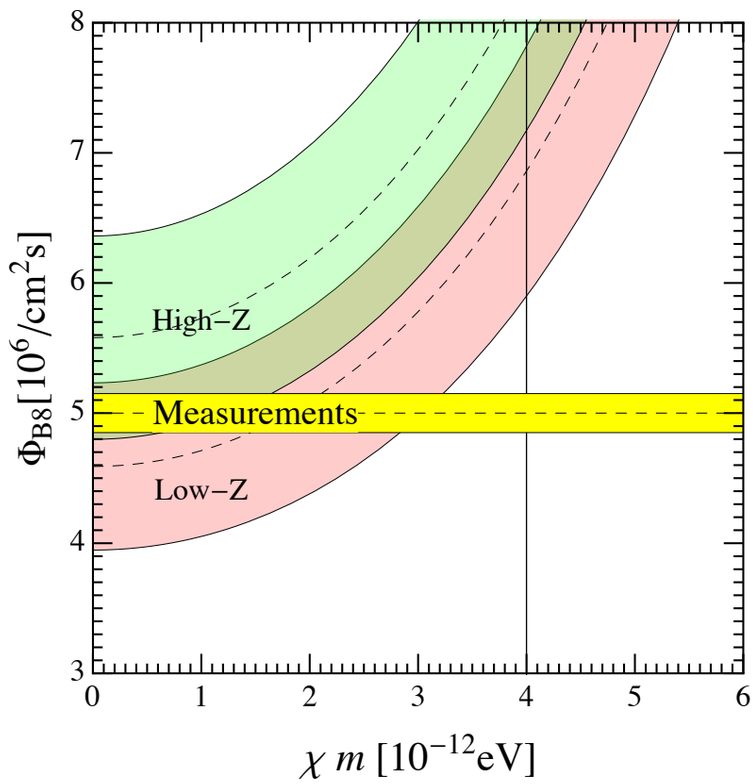
$$\Gamma_L(\gamma') = \Gamma_L(\gamma)\frac{Z_L}{(\omega^2 - \omega_P^2)^2 + (\omega\Gamma_L(\gamma))^2}\chi^2 m^4$$

Forgotten renormalization factor is huge for small masses!!

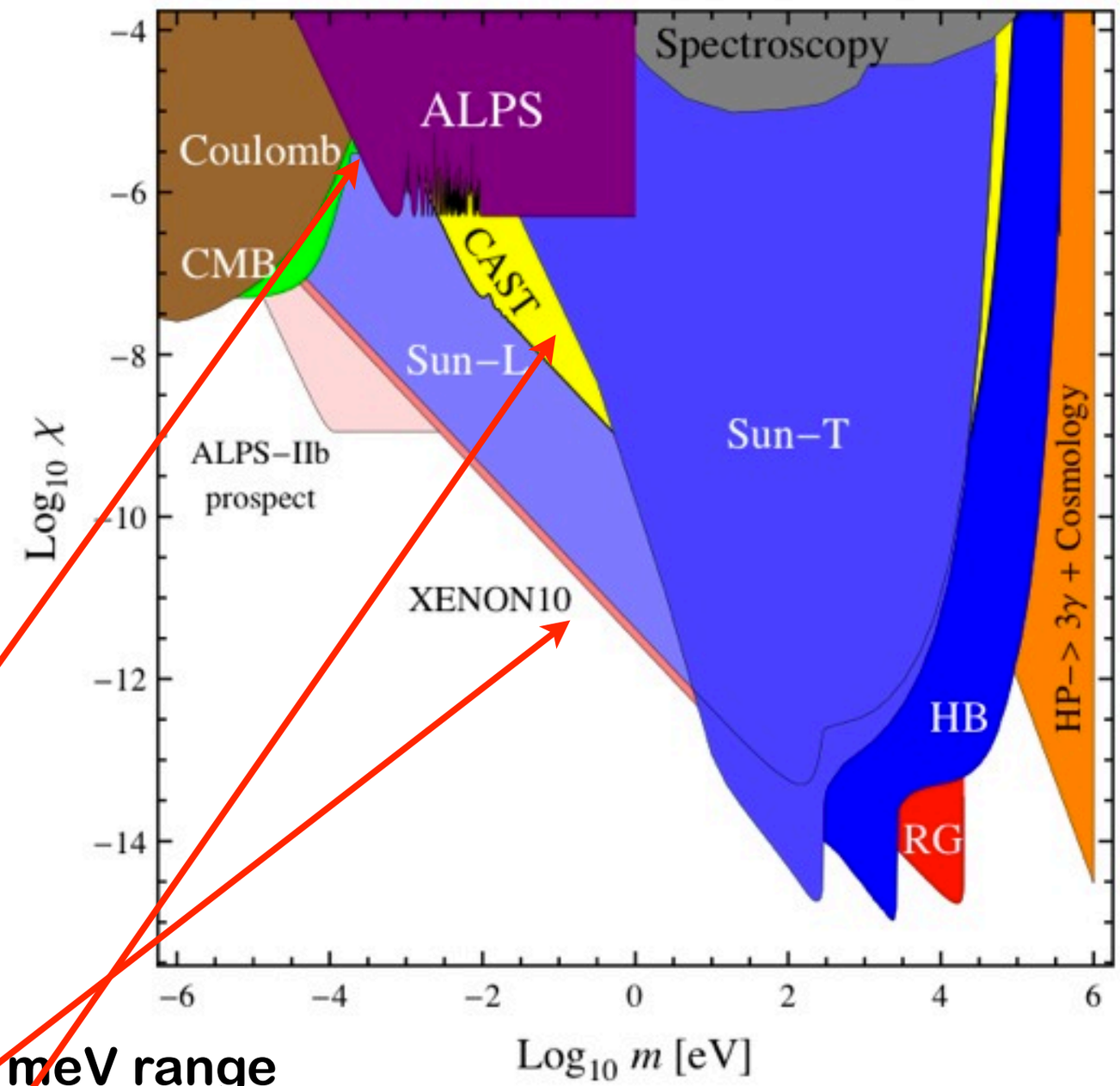
$$Z_L = \omega^2/K^2 = \omega^2/m^2$$

Solar HPs $\Phi(\gamma' L) \gg \Phi(\gamma' T)$

Boron Neutrino Flux



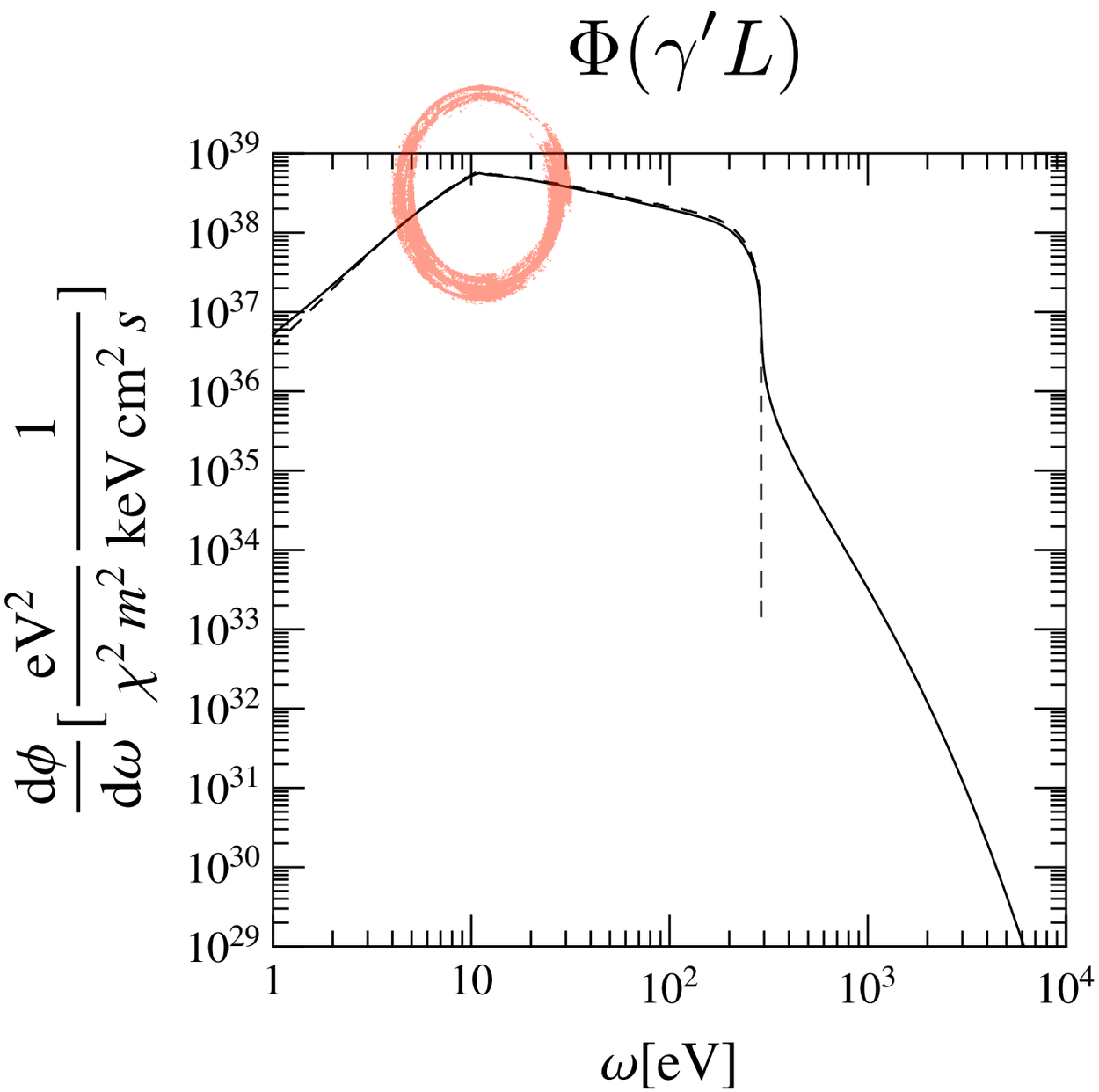
Redondo & Raffelt (in prep)



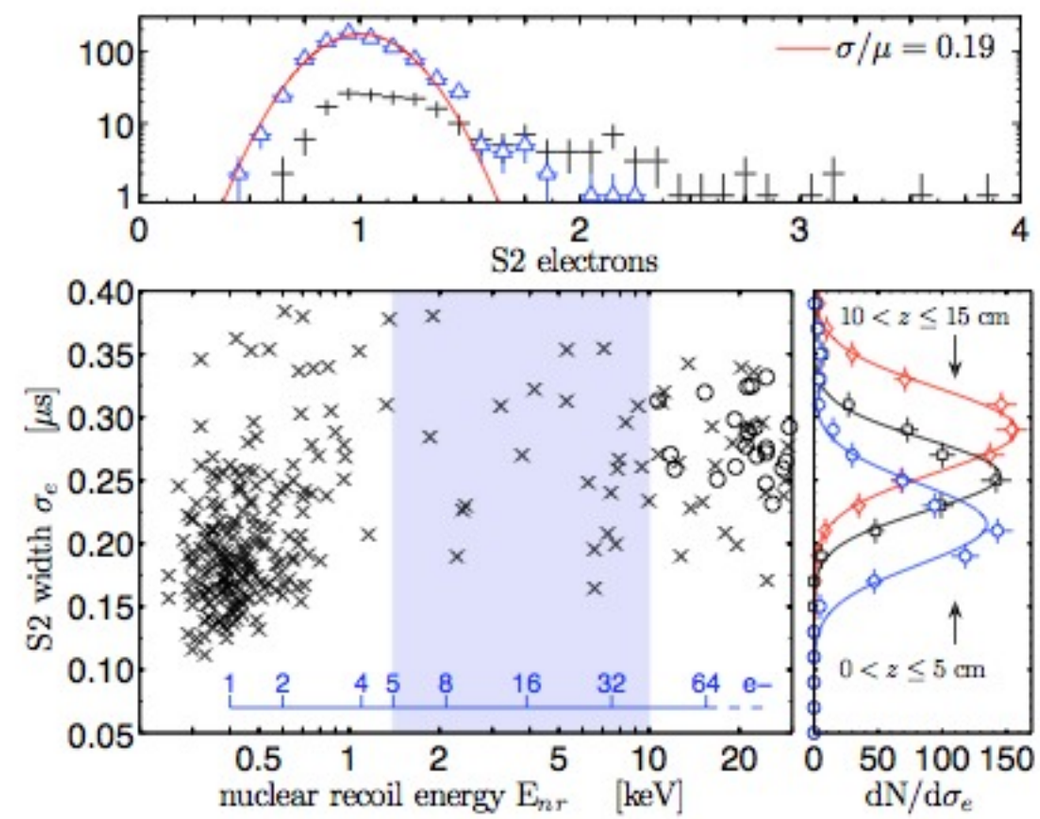
This changes many things in the meV range

- ~~Helioscopes looking for T-HPs~~
- ~~Dark Radiation~~
- XENON10 Ionization

Solar HPs: XENON10 constraints Ann et all [1304.3461]



XENON10 Ionization 1104.3088



Update: New Dark matter experiment proposed

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

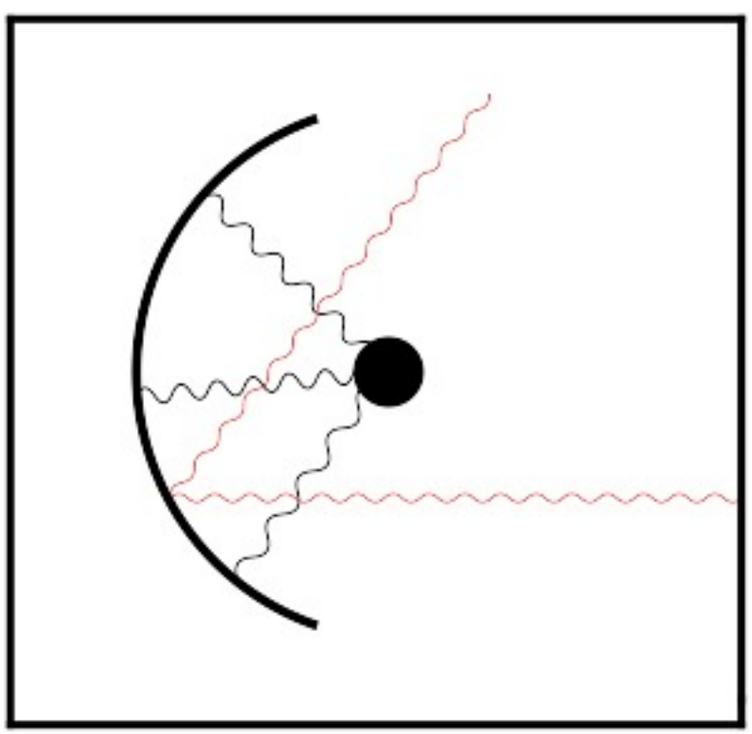
Searching for WISPy cold dark matter with a dish antenna

Dieter Horns,[a] Joerg Jaeckel,[b,c] Axel Lindner,[d] Andrei Lobanov,[e,1] Javier Redondo[f,g] and Andreas Ringwald[d]

Abstract. The cold dark matter of the Universe may be comprised of very light and very weakly interacting particles, so-called WISPs. Two prominent examples are hidden photons and axion-like particles. In this note we propose a new technique to sensitively search for this type of dark matter with dish antennas. The technique is broadband and allows to explore a whole range of masses in a single measurement.

Keywords: axions, dark matter detectors, dark matter experiments, string theory and cosmology

JCAP04(2013)016



Axion - photon mixing in a magnetic field

Raffelt, PRD'88

- In a magnetic field one photon polarization Q-mixes with the axion

$$\mathcal{L}_I = \frac{g_{a\gamma}}{4} F_{\mu\nu}\widetilde{F}^{\mu\nu} a = -g_{a\gamma}\mathbf{B}\cdot\mathbf{E}\, a$$

Not axions, nor photons are propagation eigenstates!

- Equations of motion can be easily diagonalised

$$\left[(\omega^2 - k^2)\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} + \begin{pmatrix} 0 & -g_{a\gamma}|\mathbf{B}|\omega \\ -g_{a\gamma}|\mathbf{B}|\omega & m_a^2 \end{pmatrix}\right]\begin{pmatrix} \mathbf{A}_{||} \\ a \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}.$$

- Dark matter solution $\quad v = \dfrac{k}{\omega} \quad ; \quad \omega \simeq m_a(1 + v^2/2 + ...)$

$$\begin{pmatrix} \mathbf{A}_{||} \\ a \end{pmatrix}\Bigg|_{\mathrm{DM}} \propto \begin{pmatrix} -\chi \\ 1 \end{pmatrix} \exp(-i(\omega t - kz)).$$

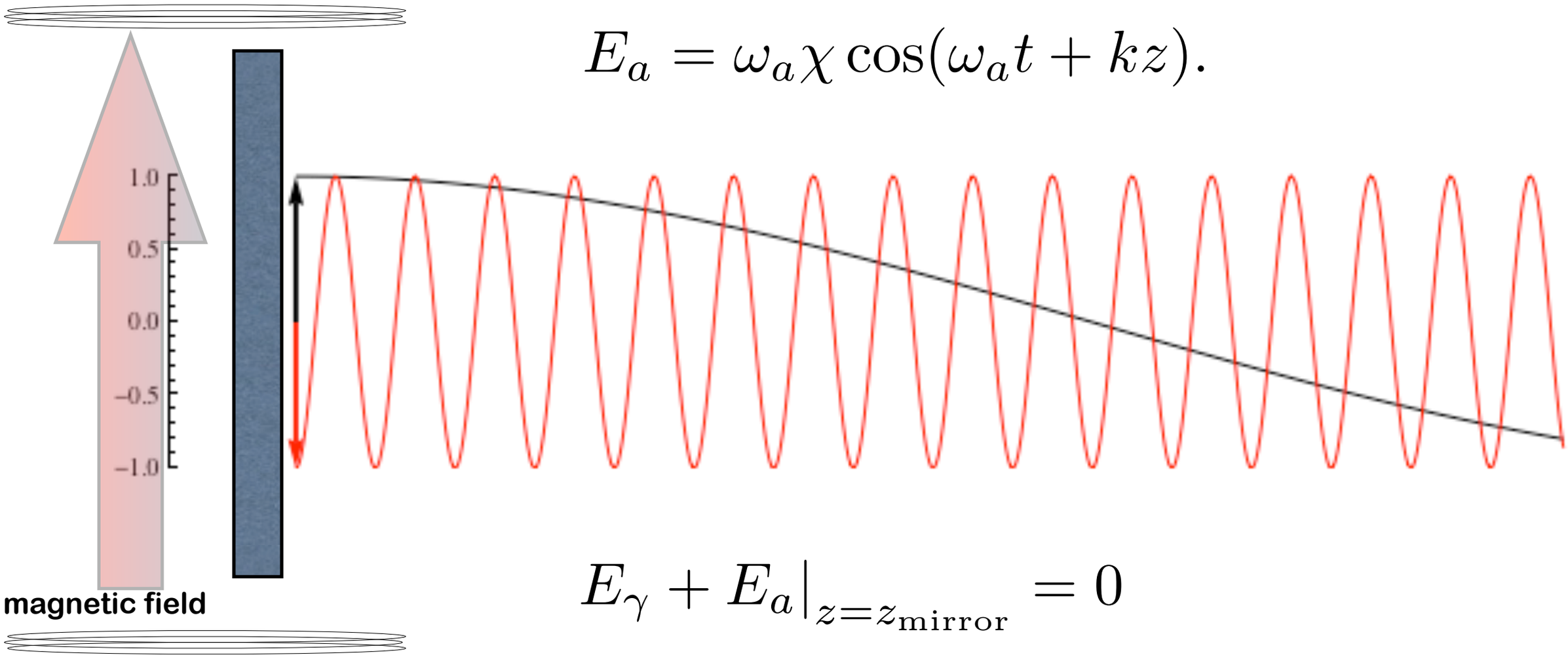
It has a small E field!

$$\chi \sim \frac{g_{a\gamma}|\mathbf{B}|}{m_a}$$

Radiation from a magnetised mirror

Horns et al , JCAP04(2013)016

$$E_a = \omega_a \chi \cos(\omega_a t + kz).$$



$$E_\gamma + E_a\big|_{z=z_{\rm mirror}} = 0$$

$$E_\gamma = -\omega_a \chi \cos(\omega_\gamma (t - z)).$$

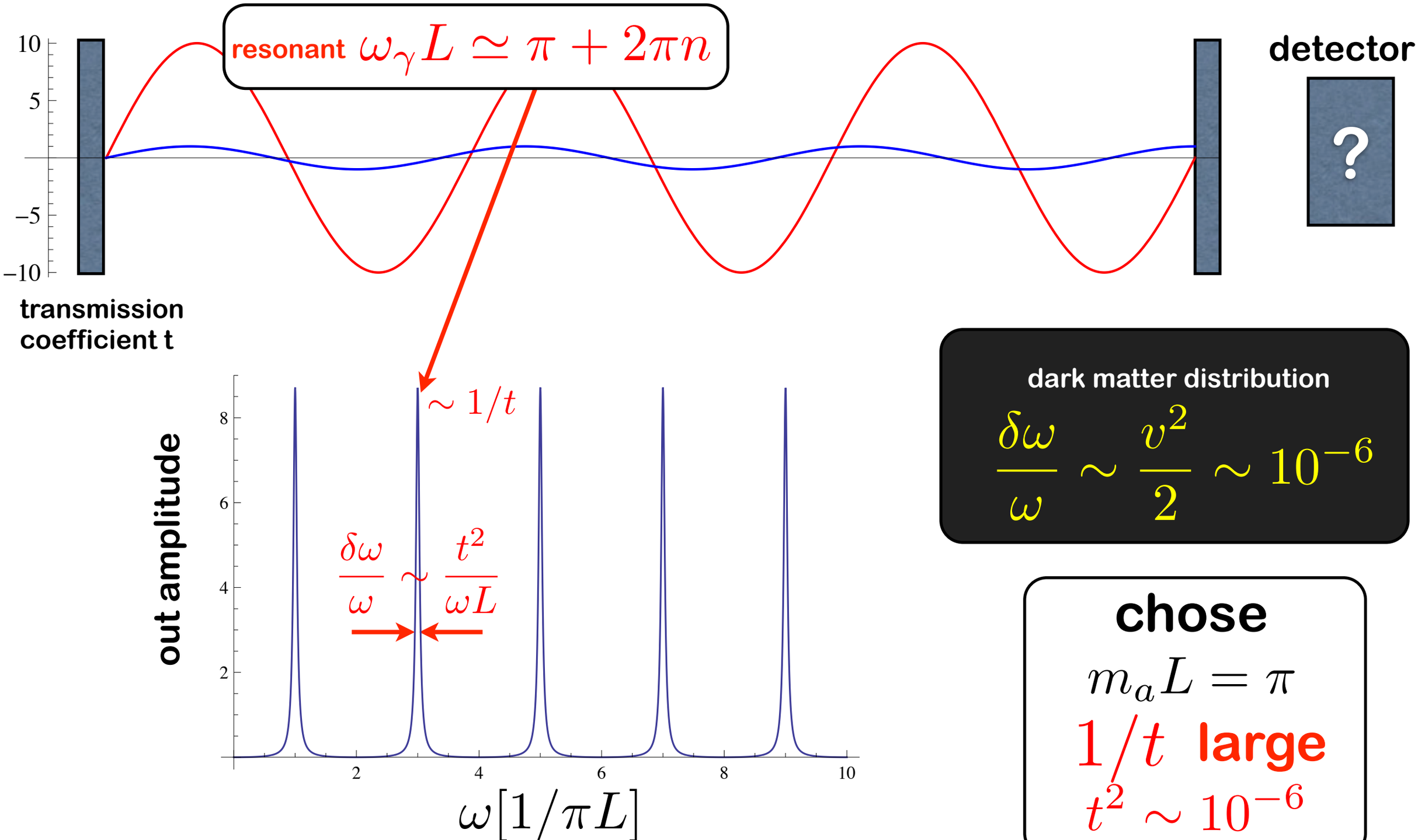
Photons radiated from the mirror with $\omega_\gamma = \omega_a = m_a(1 + v^2/2)$

Note: measuring these photons,
we measure the TOTAL DM energy,
DM mass and the velocity distribution!
also with directional sensitivity!

Cavity searches (haloscopes)

Sikivie PRL '83

- Use two facing mirrors (simplistic resonant cavity in 1D)



dark matter distribution

$$\frac{\delta\omega}{\omega} \sim \frac{v^2}{2} \sim 10^{-6}$$

chose

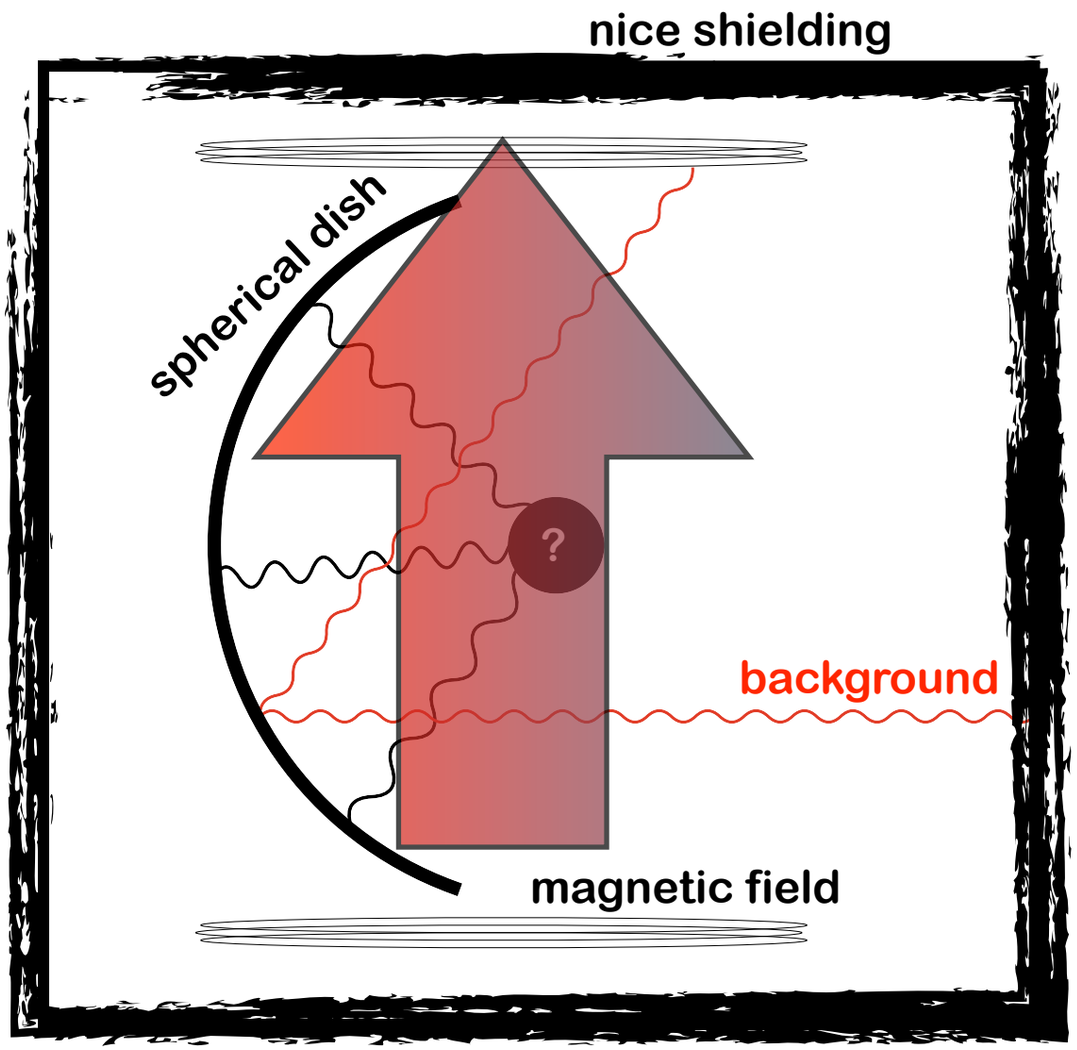
$m_a L = \pi$

$1/t$ **large**

$t^2 \sim 10^{-6}$

Dish antenna searches (broadband!)

Horns et al , JCAP04(2013)016



- Mirror radiation is perpendicular to the mirror's surface (emitted coherently from the surface!)

- concentrate emission using a spherical dish antenna!

Comparing both methods...

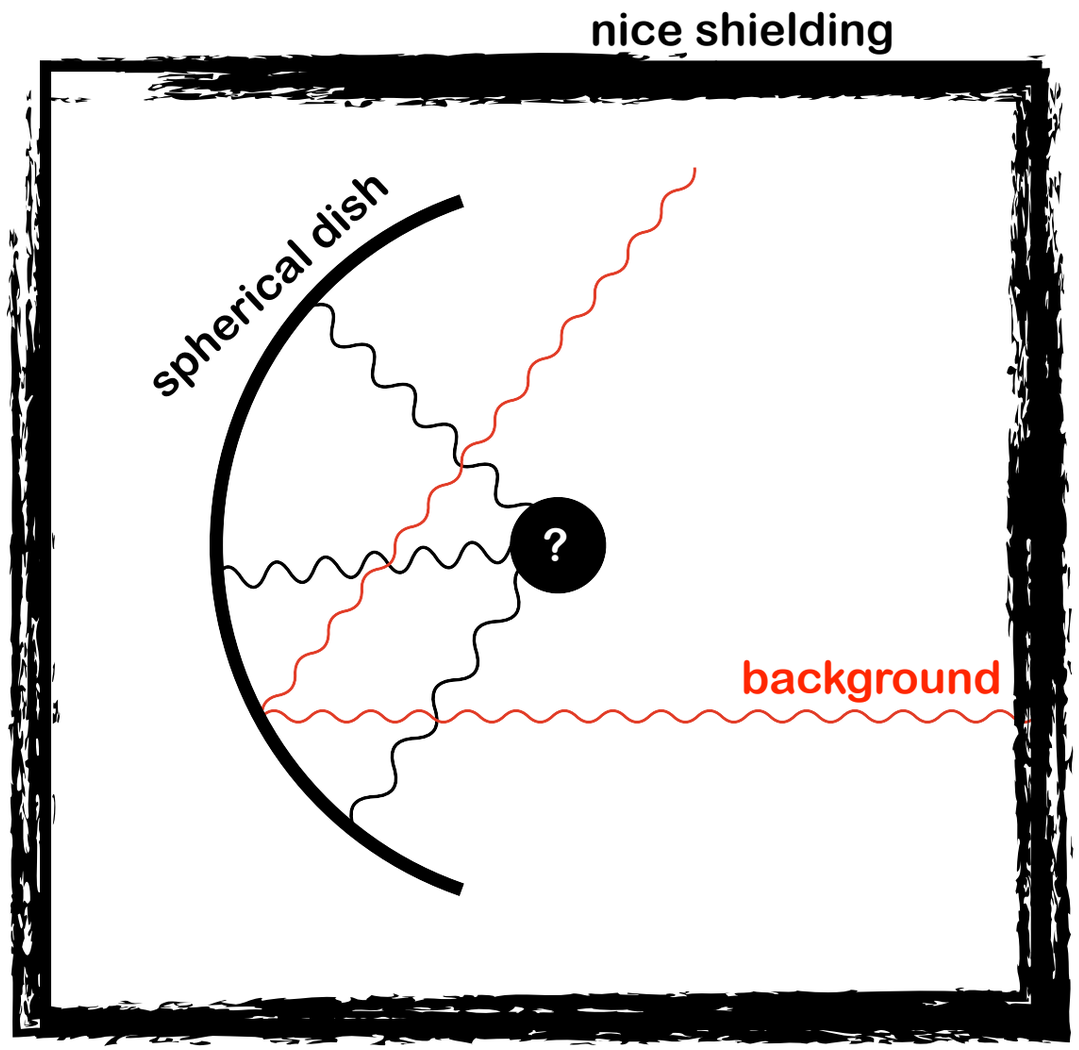
$$P_{\text{center}} \approx A_{\text{dish}} \langle |\mathbf{E}_{\text{DM},||}|^2 \rangle \sim \chi^2 \rho_{\text{CDM}} A_{\text{dish}}$$

$$P_{\text{resonant cavity}} = \kappa \chi^2 m_a \rho_{\text{CDM}} Q V_{\text{cavity}} \mathcal{G}_0(\alpha')^2.$$

$$\frac{P_{\text{center}}}{P_{\text{cavity}}} \sim \frac{A_{\text{dish}} m_a^2}{10^6}$$

Dish antenna searches (broadband!)

Horns et al , JCAP04(2013)016



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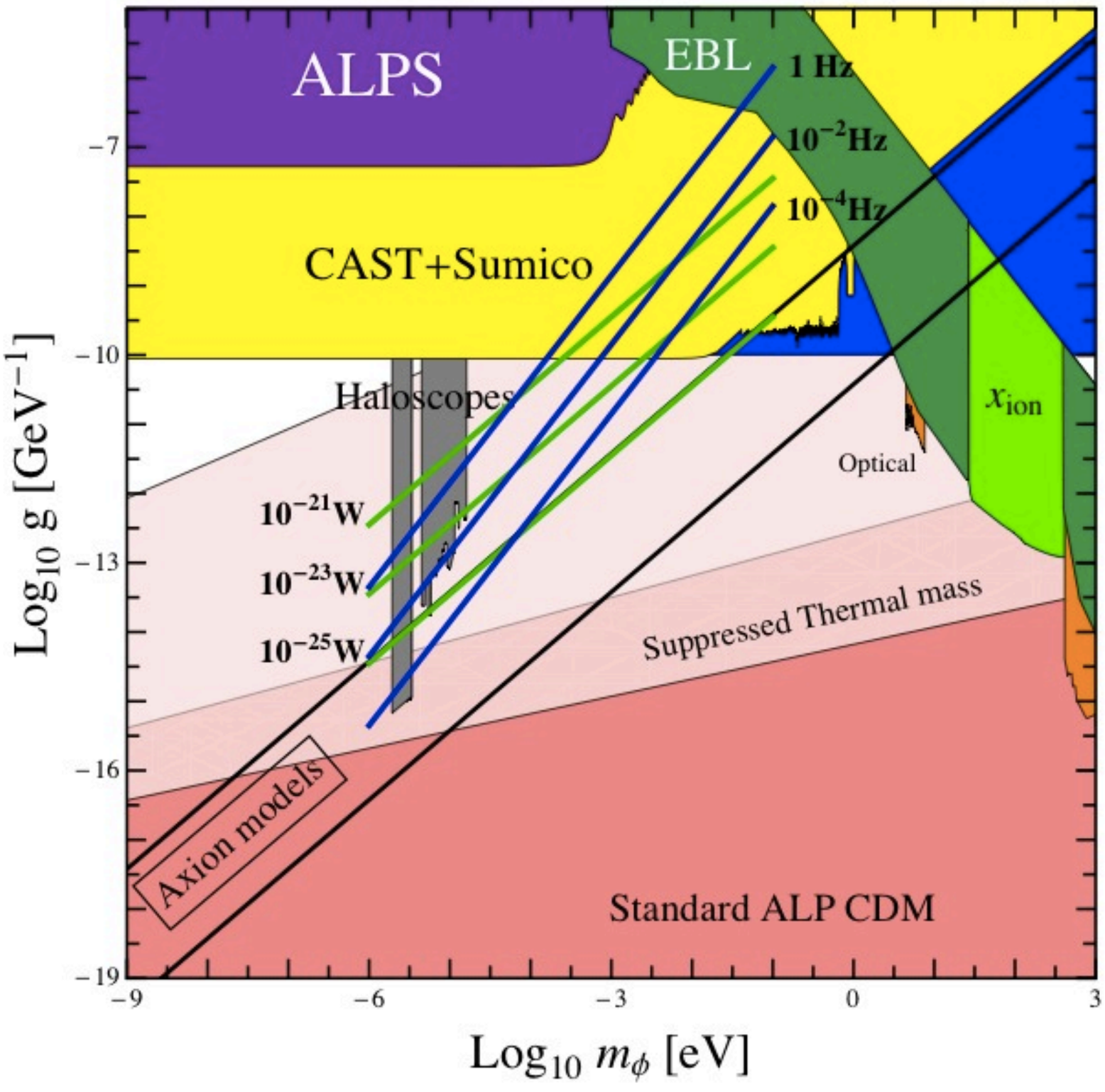
dish antenna searches (broadband!)

Horns et al , JCAP04(2013)016

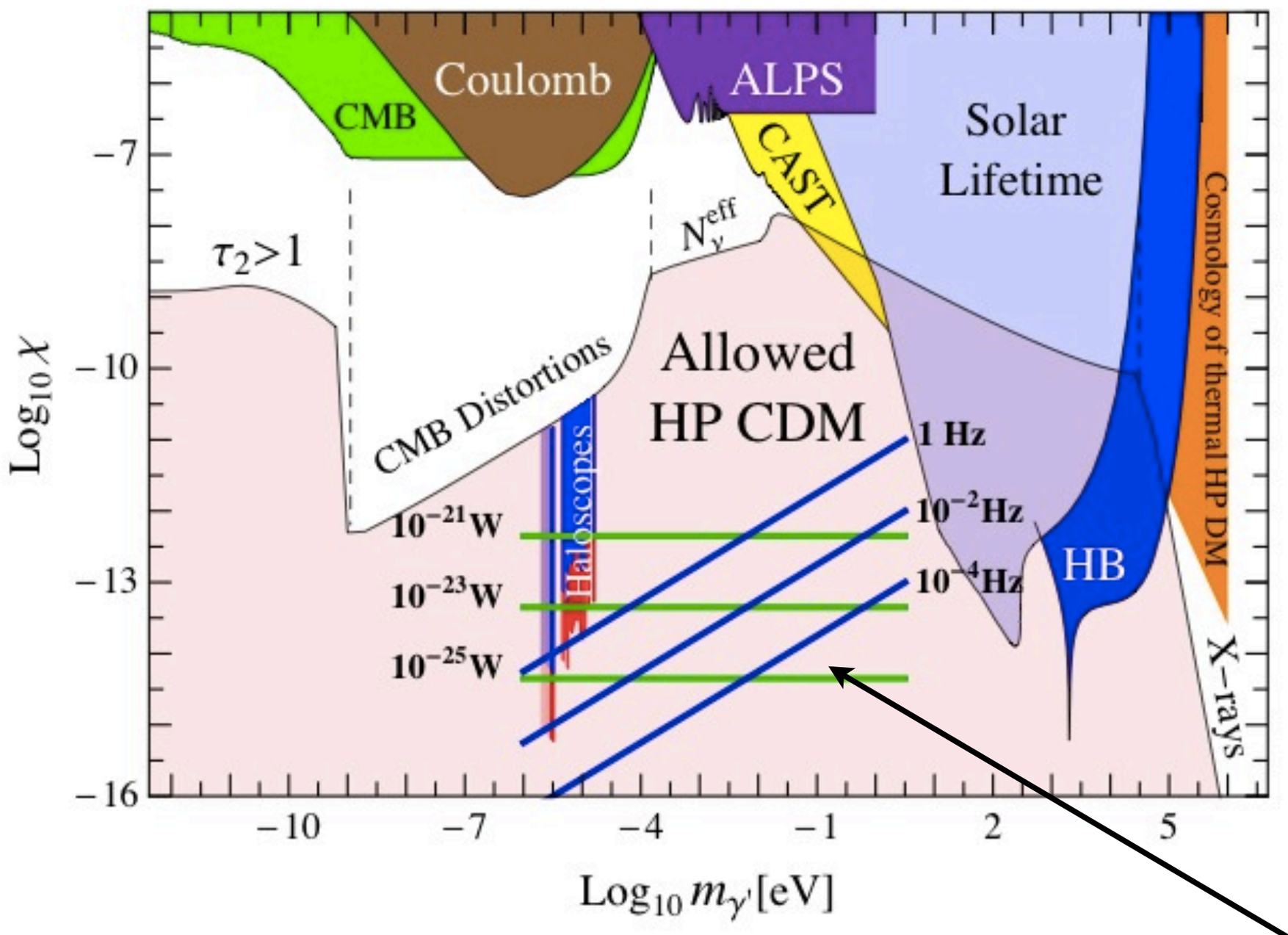


1 m^2 dish
5T magnet

dish antenna searches (broadband!)

Horns et al , JCAP04(2013)016

kinetic mixing



HP mass

1 m^2 dish
5T magnet

Conclusions

BSM physics accommodate WISPs very naturally

ALPs, HPs, MCPs, and others...

WISPs can be responsible for DM and explain astrophysics anomalies

We can look for them in laboratory experiments (couplings to photons)

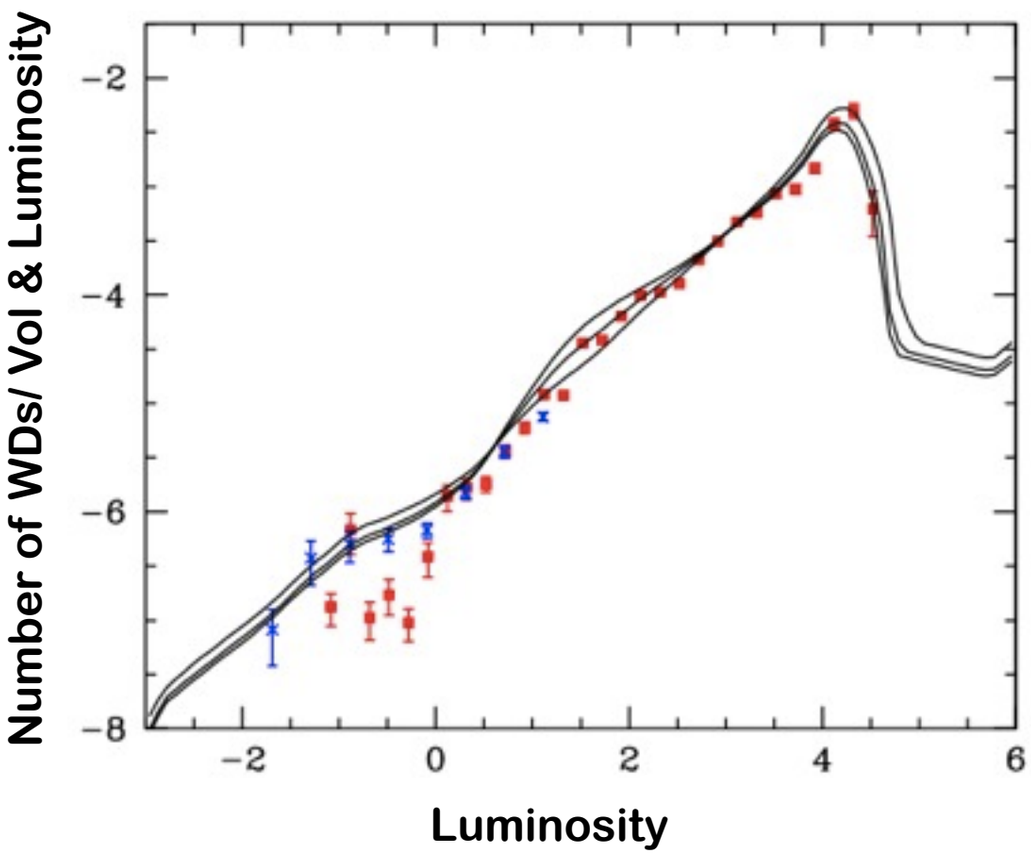
Solar HP flux revisited -> DM detectors (XENON10)

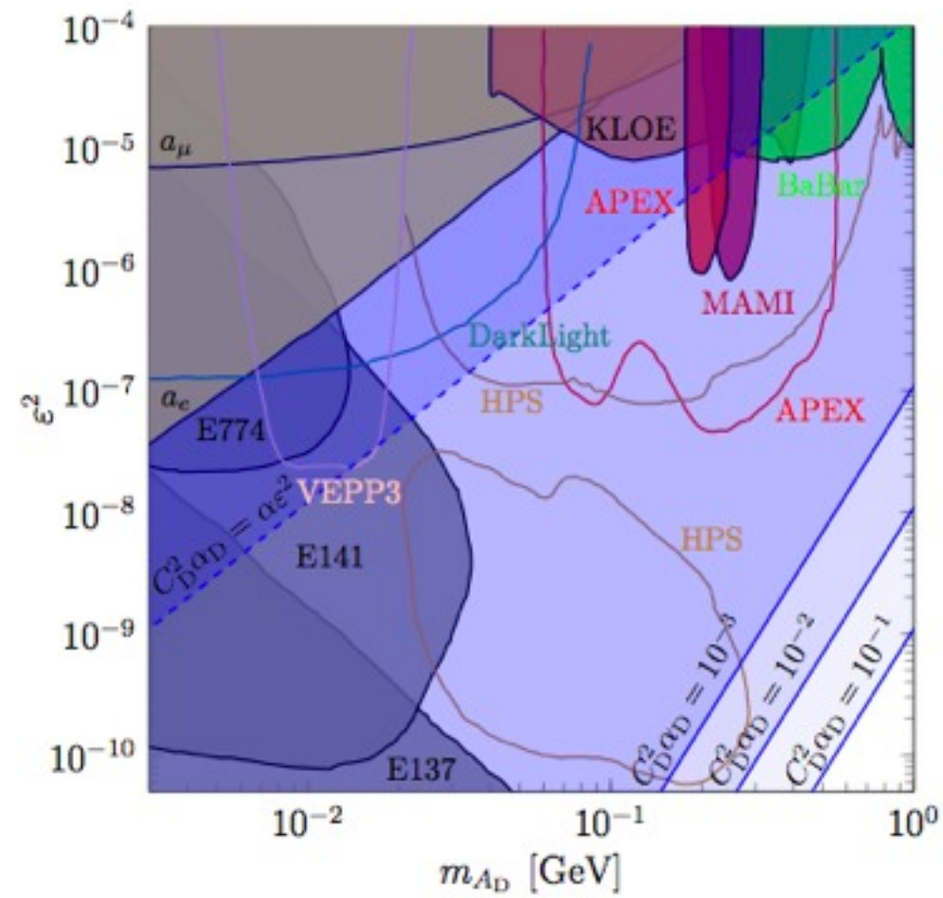
New DM detection concept (DIsh antenna)

For the Dark Forces' lovers

WD luminosity function also constrains DARK PHOTONS

Dreiner et al. 1303.7232

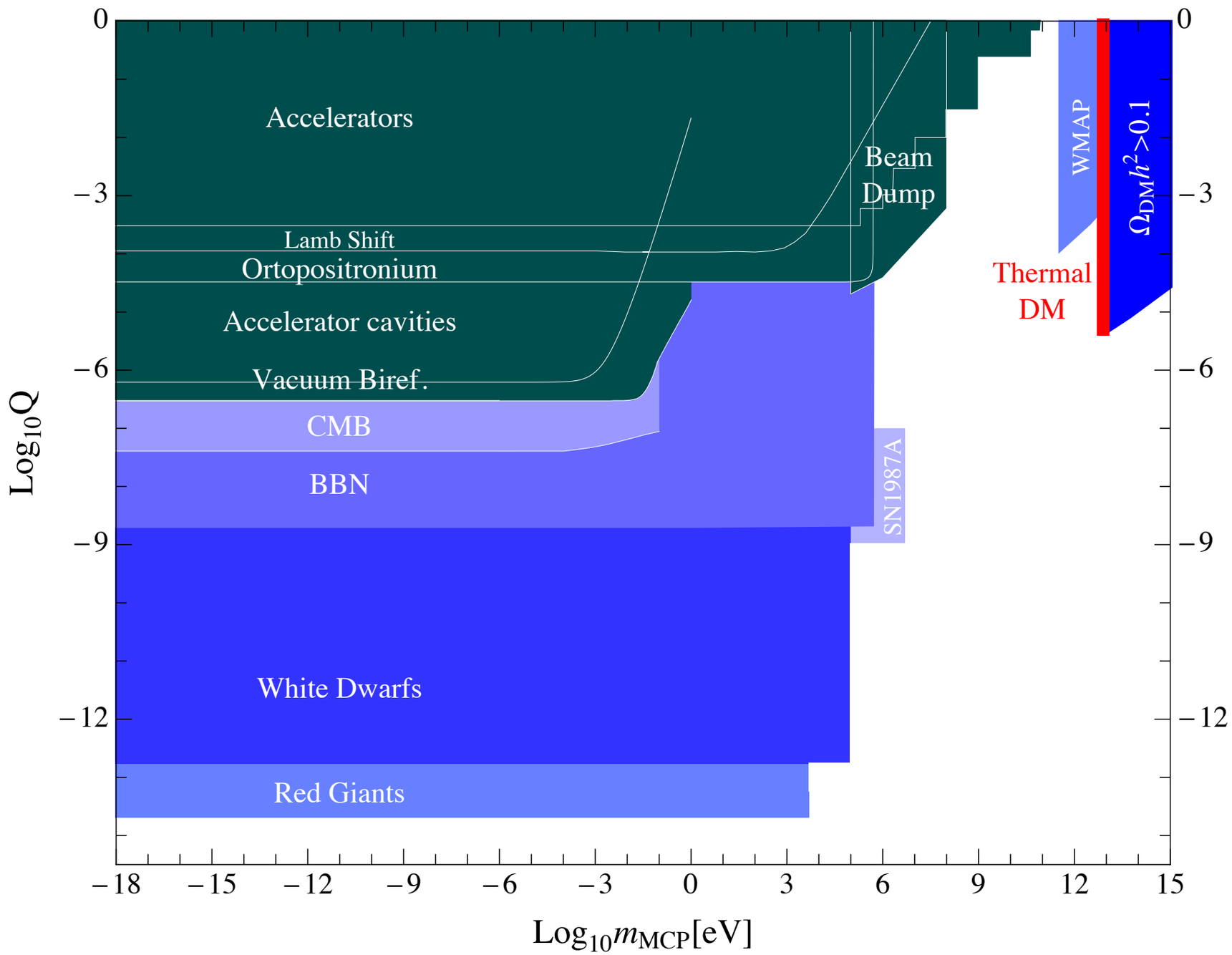




ONLY IF THERE ARE NEW light MCPS !!!!!!!

$$m_{\rm MCP} \lesssim 10{\rm keV}$$

but that was well known ...



well... this plot was done thinking about massless HPs ...