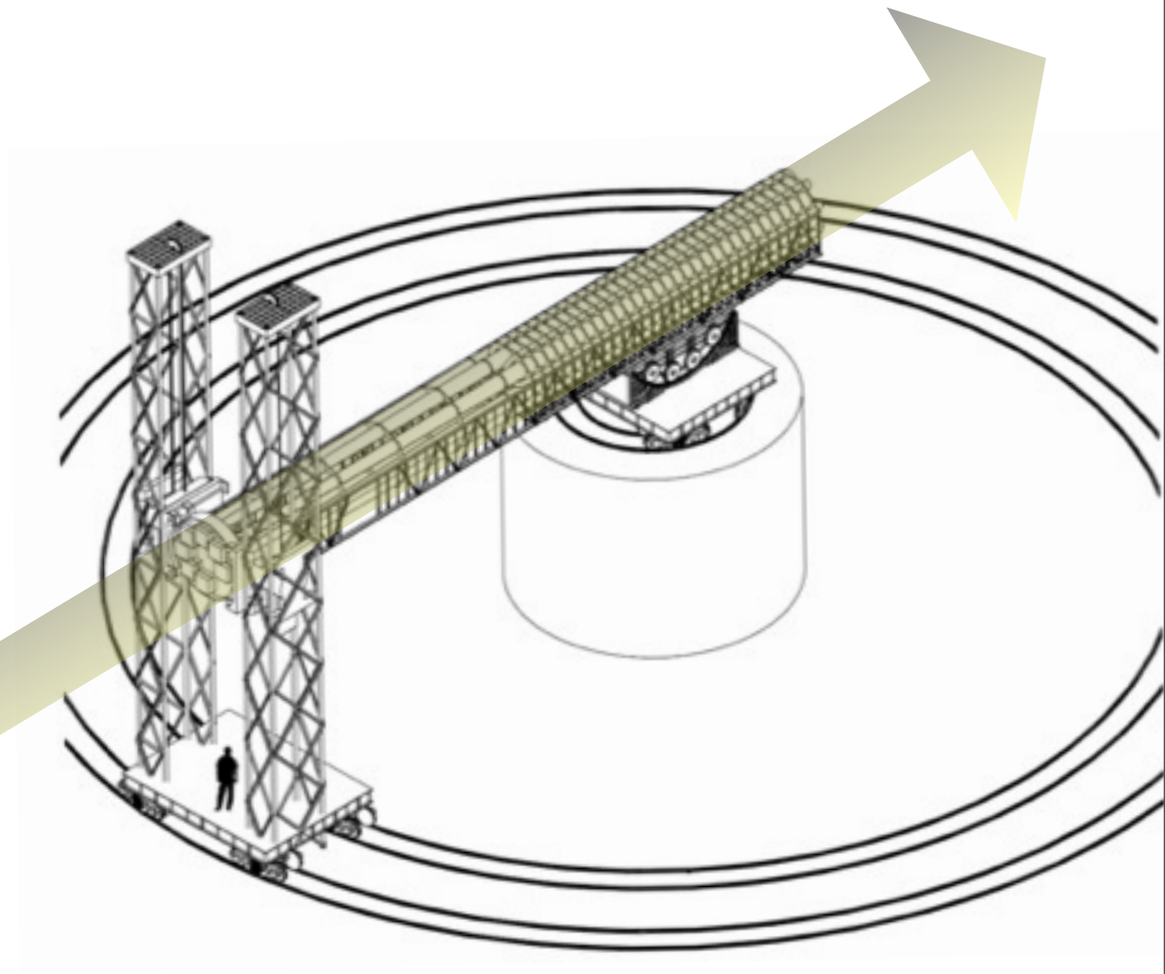
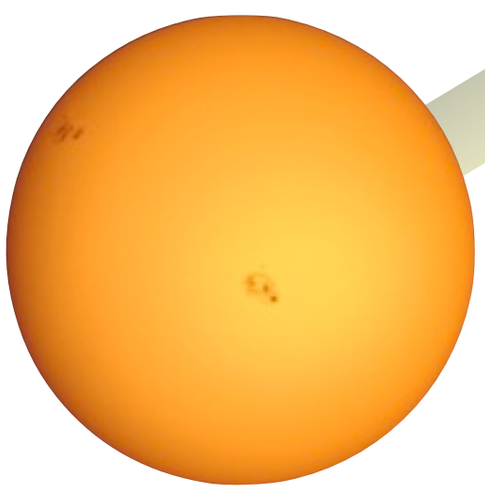
IAXO

nternational
ion
bservatory





Javier Redondo (MPP Munich)

Outline

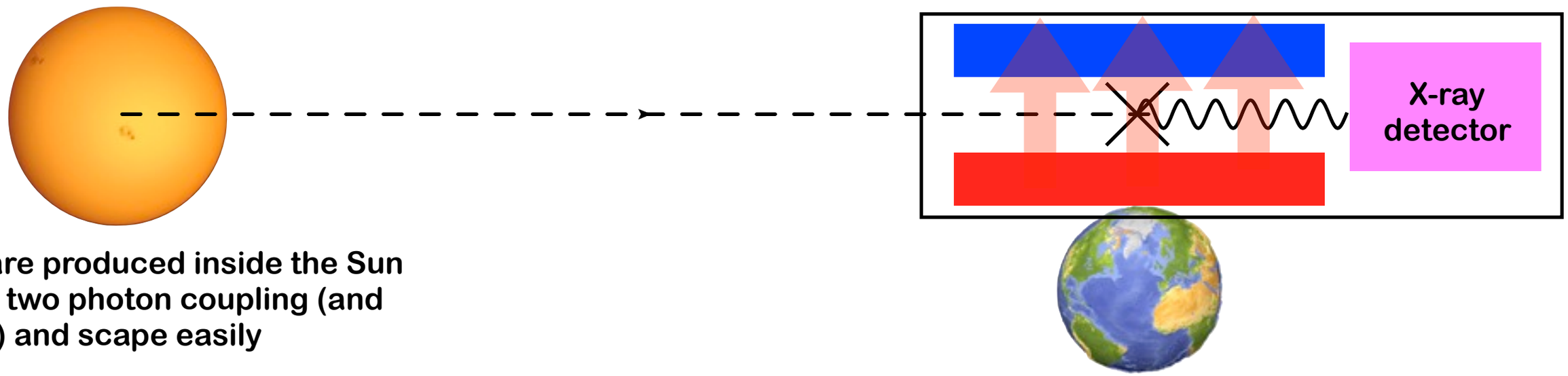
- what is IAXO?
- axion-like particles in PBSM
- hints of the existence of ALPs
    - strong CP and axions
    - Anomalous cooling of white dwarfs
    - TeV-gamma-ray transparency of the universe
    - Dark Matters

- can IAXO cast light on these hints?

IAXO is an Axion-like particle detector

Axion-like particle ϕ (small mass and small coupling to two photons)

$$\mathcal{L}_\phi \in -\frac{g_{\phi\gamma}}{4} F_{\mu\nu}\widetilde{F}^{\mu\nu}\phi$$

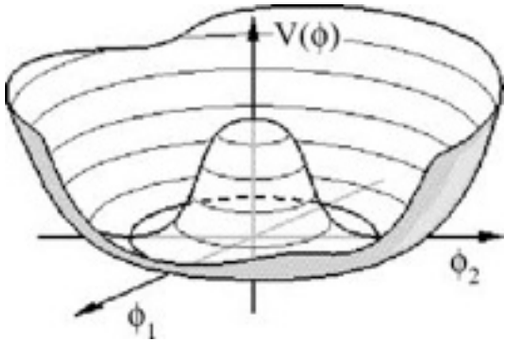


ALPs are produced inside the Sun via the two photon coupling (and others) and scape easily

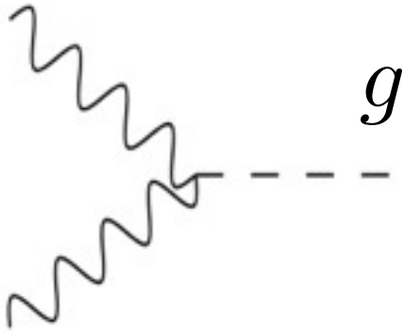
- B's of order 5 T,
- L's of order 20 m
- order Zero backgrounds

Theory provides us with ALP candidates

pseudo Nambu Goldstone bosons



Global continuous symmetry spontaneously broken at high energy scale M implies a low mass particle (Nambu-Goldstone boson) with weak couplings



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

Existing examples: $\pi^0, \eta, \eta', \ldots$

Hypothetical fancies: axion, majoron, R-axion, familons, and a loooong etc.

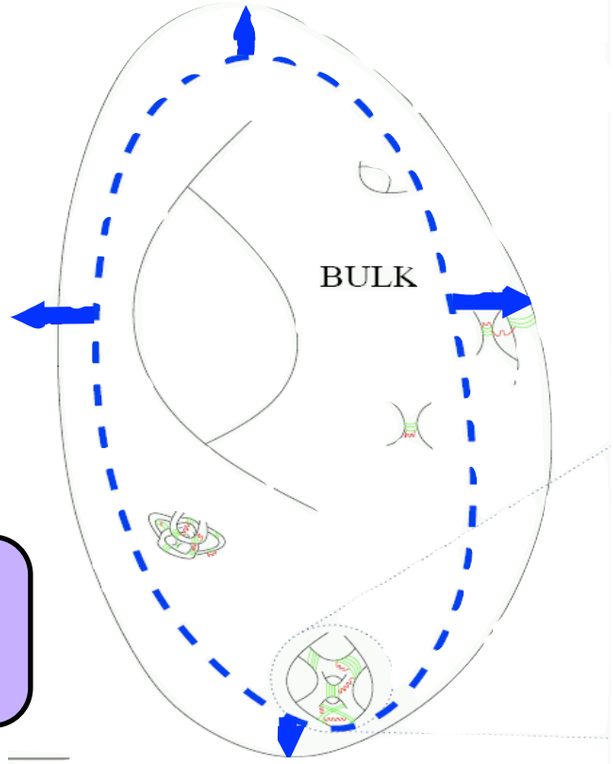
stringy 'axions' & string Axiverse

Arvanitaki, Dimopoulos Phys.Rev. D81 (2010)

Scalars and pseudoscalars that govern the sizes and deformations of extra dimensions, gauge couplings,etc...
(typically there are O(100) of these)

$$g \sim \frac{\alpha}{2\pi M_{\rm string}}$$

Moduli, Radion, Dilatons



Phenomenology offers some hints - I

Strong CP problem

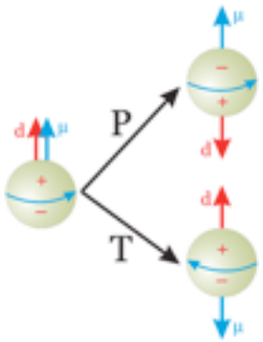
We expect P and T to be violated in a generic QCD-like theory, the size of the violation is set by :

the theta angle, θ

$$\mathcal{L}_\theta = \frac{\alpha_s}{8\pi}\mathrm{tr}\left\{G_a^{\mu\nu}\widetilde{G}_{a\mu\nu}\right\}\theta$$

However, NO neutron Electric Dipole Moment, nor any other sign of P, T or CP violation in the strong interactions has ever been measured !!

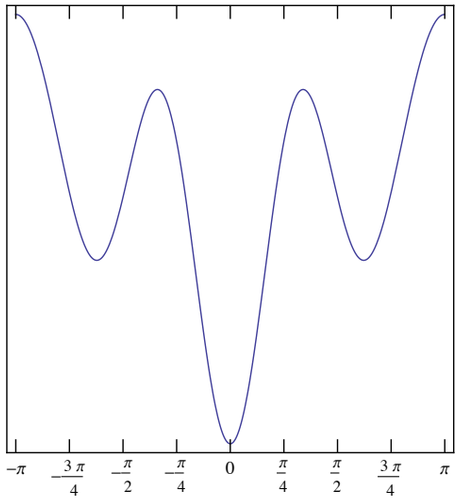
$$\theta < 10^{-11}$$



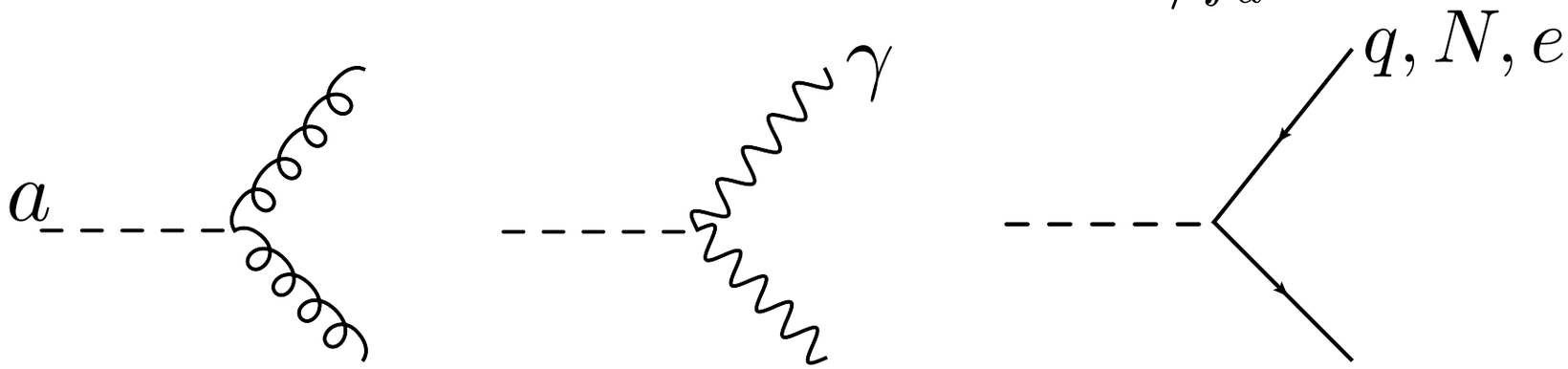
Peccei-Quinn-Weinberg-Wilczek showed that a pseudo Nambu-Goldstone boson, solves the problem

Peccei,Quinn 1977, Weinberg 1978, Wilzcek 1978

$$\mathcal{L}_\theta = \frac{\alpha_s}{8\pi}\mathrm{tr}\left\{G_a^{\mu\nu}\widetilde{G}_{a\mu\nu}\right\}\left(\theta + \frac{a}{f_a}\right)$$



- Relevant AXION couplings to SM particles, always suppressed by $1/f_a$



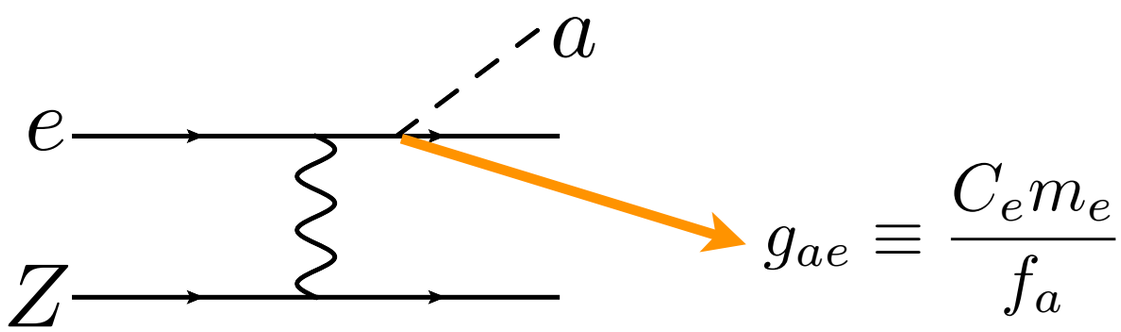
- Mixing with pseudoscalar mesons gives the AXION a mass

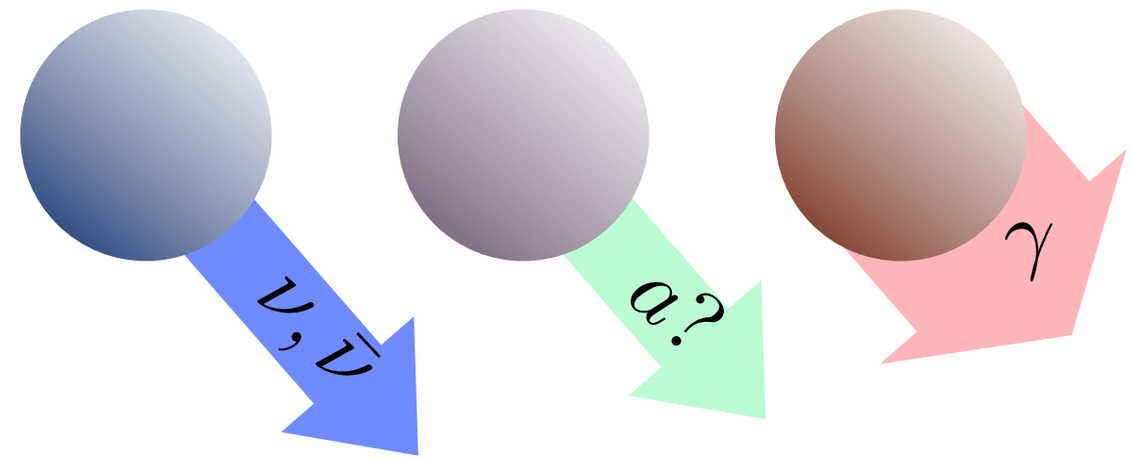
$$m_a \simeq \frac{m_\pi f_i}{f_a} \simeq 6\,\mathrm{meV}\frac{10^9\mathrm{GeV}}{f_a}$$

Phenomenology offers some hints - II

White dwarf cooling

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

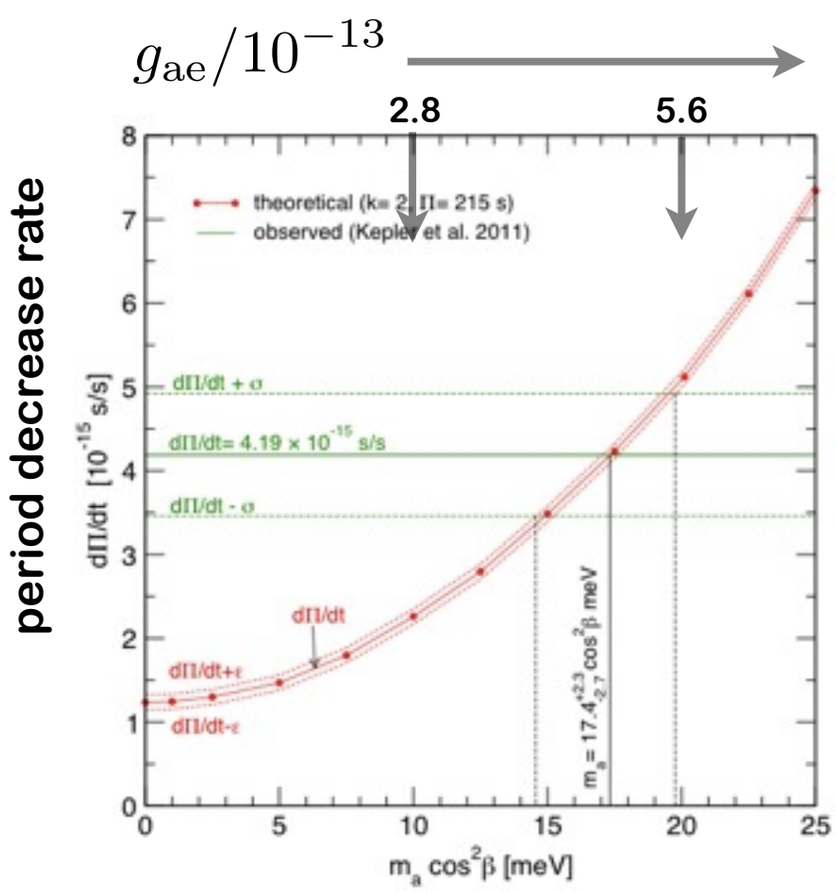




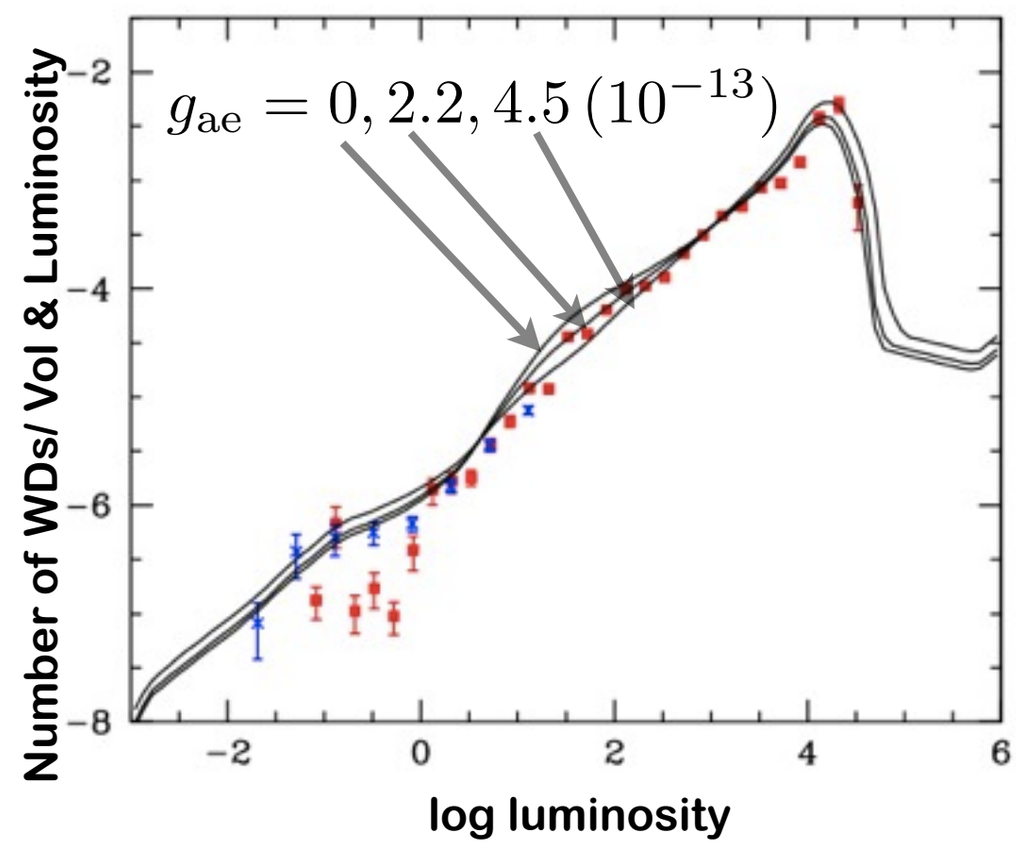
Period decrease of G117−B15A

WD luminosity function

Corsico et al. arXiv:1205.6180



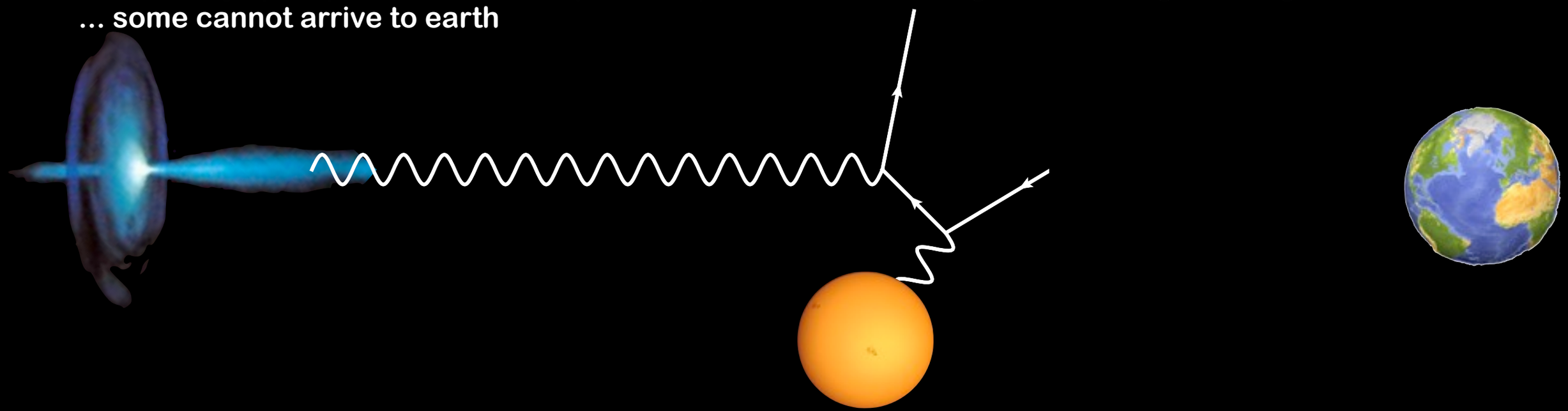
Isern et al. arXiv:1204.3565



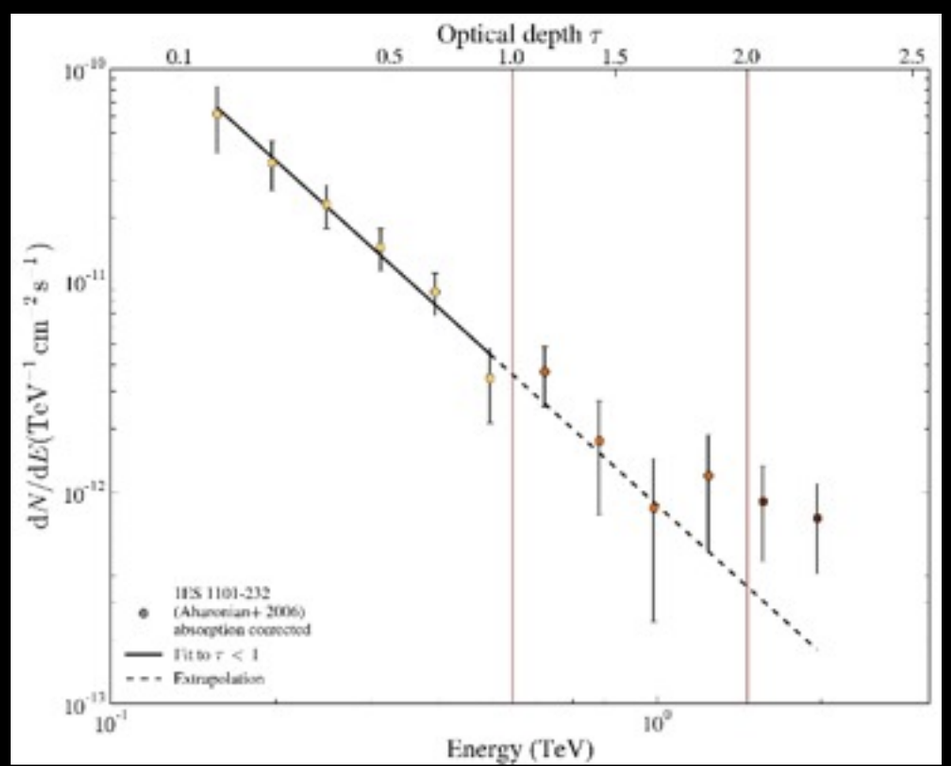
Phenomenology offers some hints - III

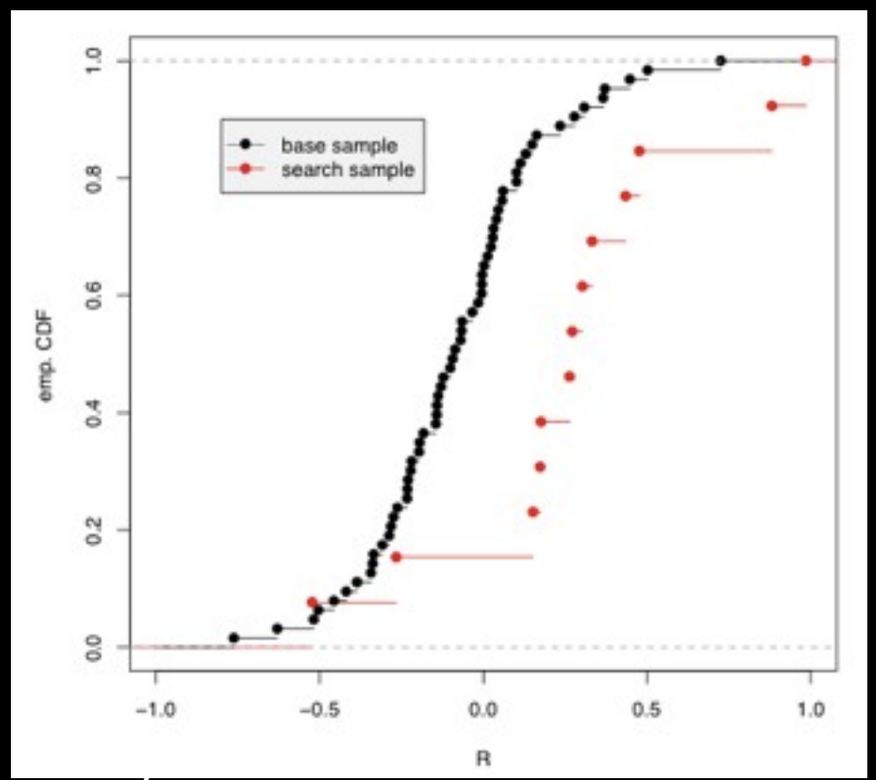
Transparency of the universe to gamma rays

Gamma rays pair-produce electron/positron pairs from the extragalactic background light
... some cannot arrive to earth



However, they do ...(Roncadelli et al PRD 84, Sanchez-Conde et al JCAP 1111, Horns and Meyer JCAP 1202)





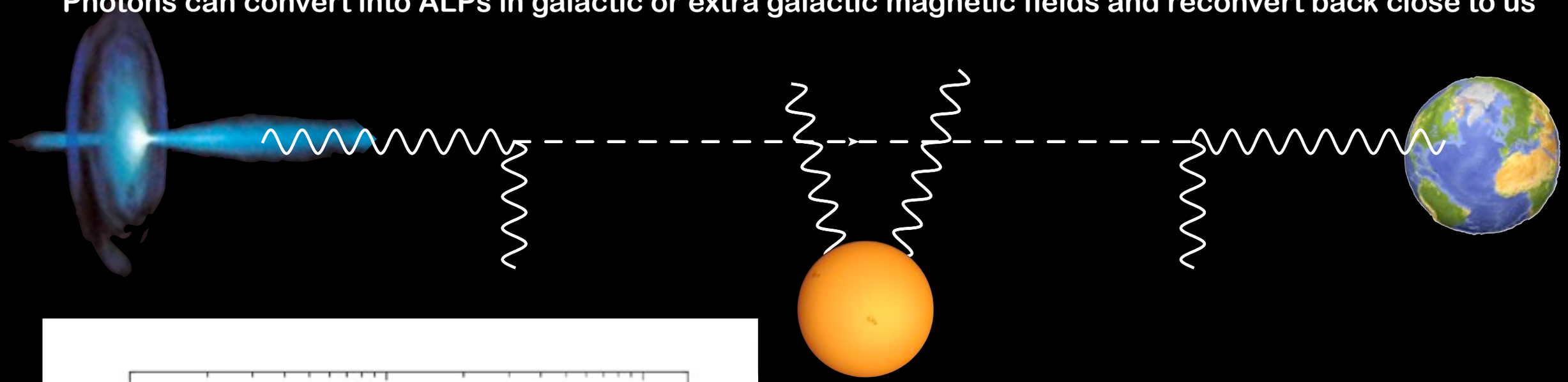
Excess persists at

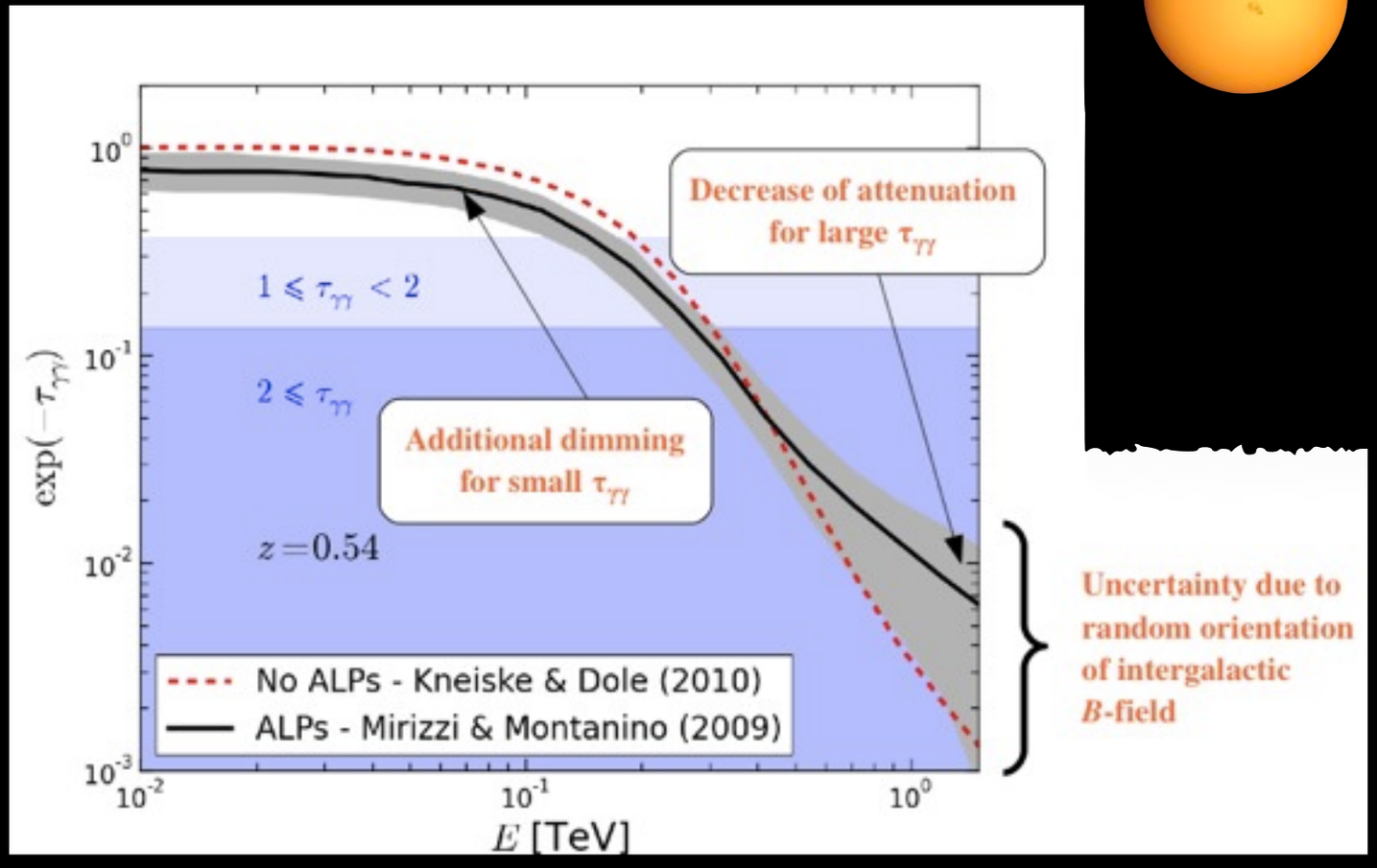
4.2σ

Phenomenology offers some hints - III

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

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

Phenomenology offers some hints - III

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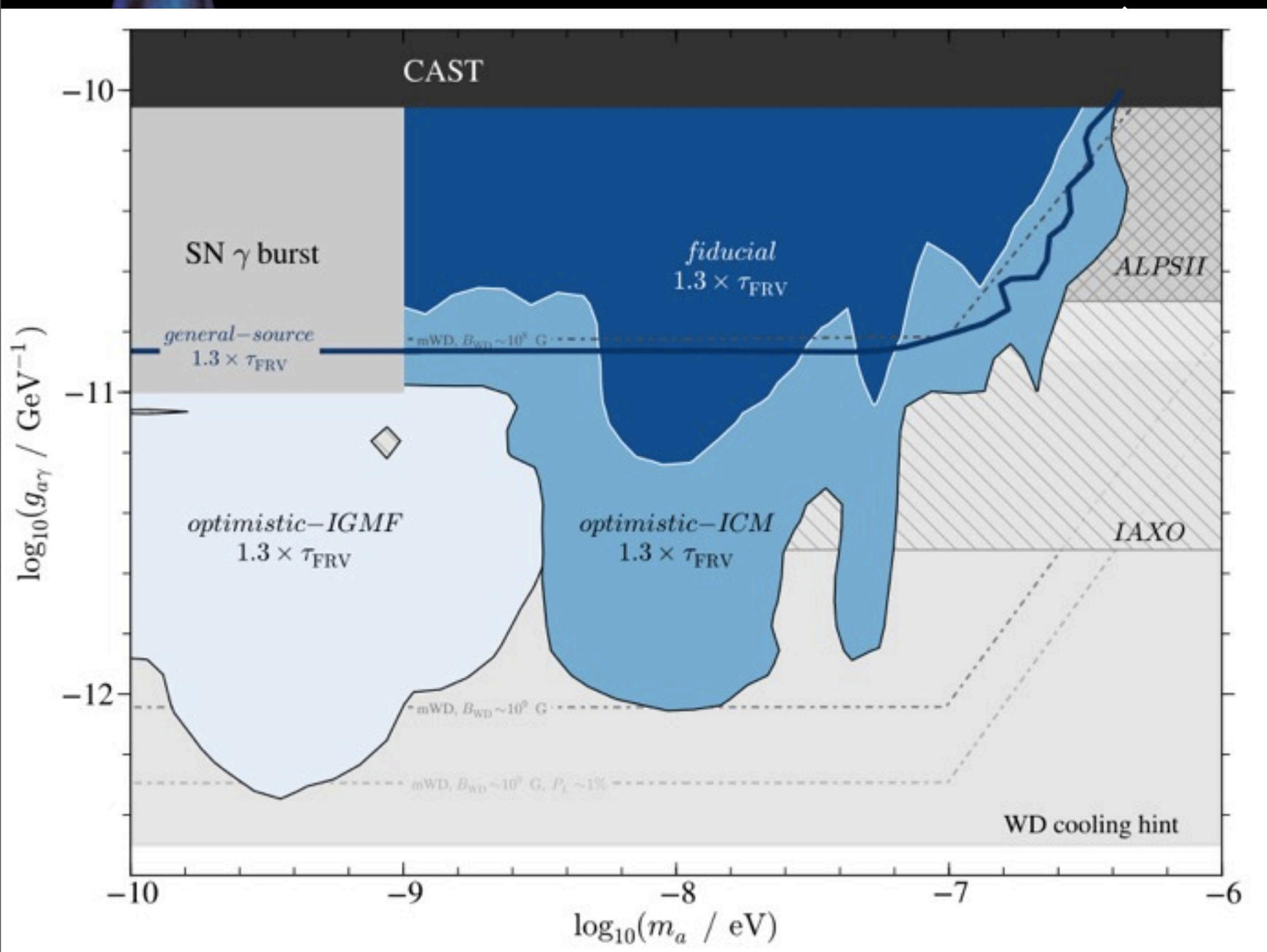

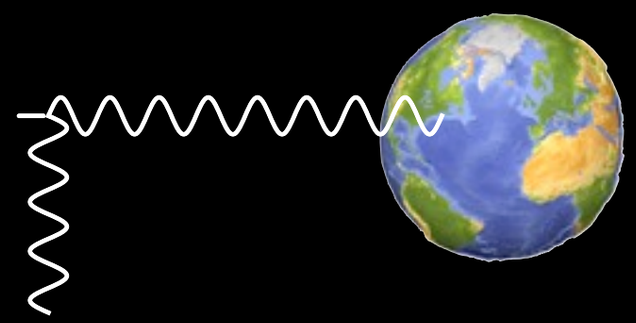

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arXiv:1302.1208

Phenomenology offers some hints - IV

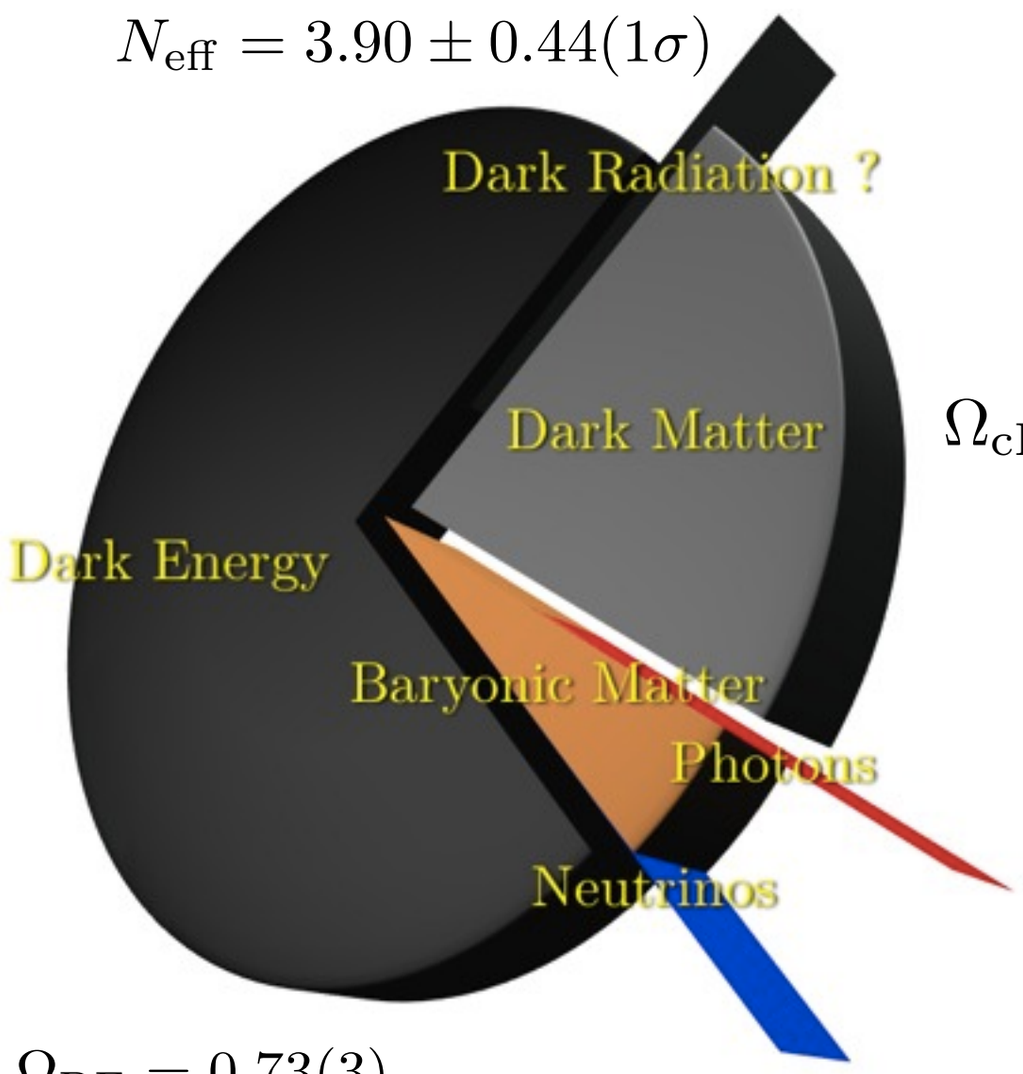
Dark stuff

Cosmology demands 3 new substances:
(the 3 of them can be ALPs)

- **Dark Energy (very weakly coupled or chameleons)**
- **Dark Radiation (only hints so far)**
- **Dark Matter (cold or mildly warm; non-thermal)**

PDG 2012; Nollet and Holler arXiv:1112.2683

$N_{\rm eff} = 3.90 \pm 0.44 (1\sigma)$



$\Omega_{\rm cDM} = 0.22(3)$

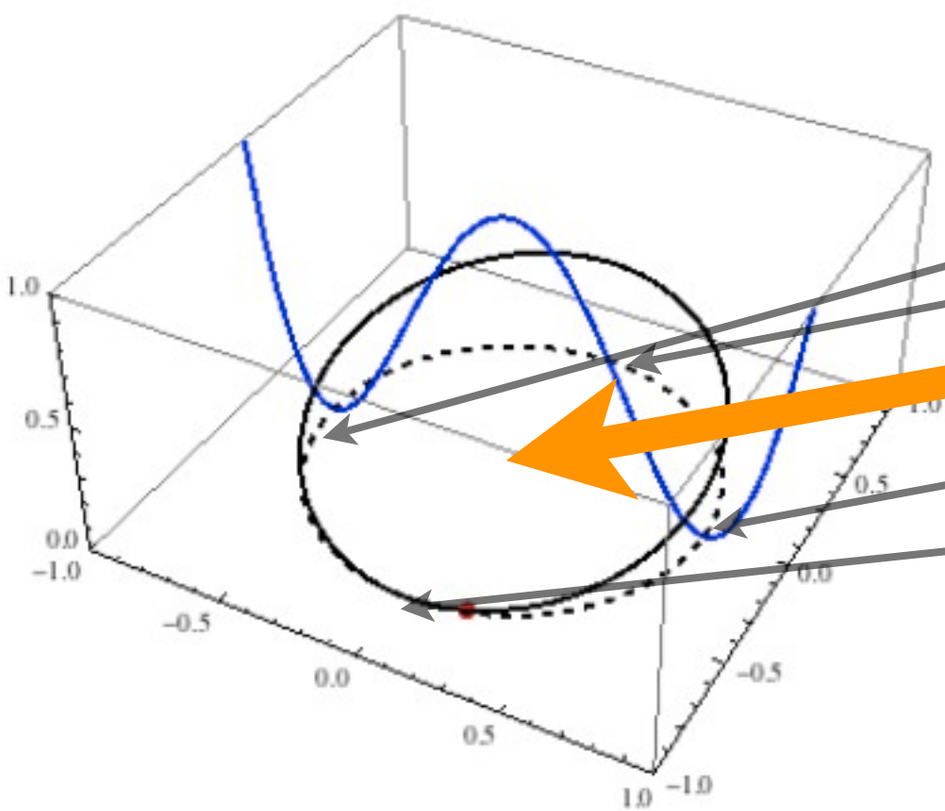
$\Omega_{\rm DE} = 0.73(3)$

Axion cold Dark Matter

Axions (and ALPs) are produced non-thermally by three mechanisms

Realignment mechanism

(Field space)



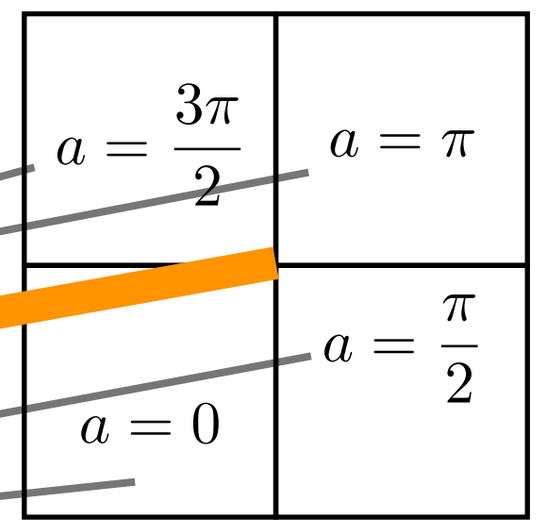
$$\Phi(x) = \rho(x) e^{i \frac{a(x)}{f_a}}$$

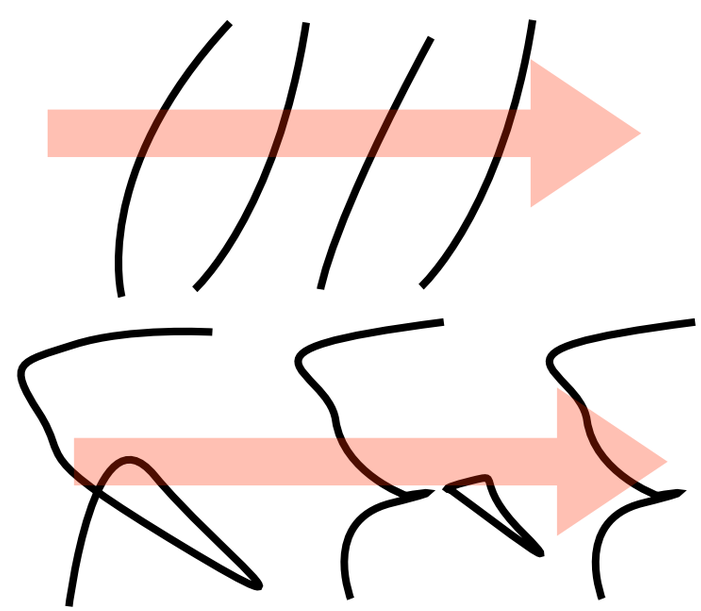
$$\frac{\Omega_{a,VR}}{\Omega_{\rm obs}} \sim \left(\frac{40\mu{\rm eV}}{m_a}\right)^{1.184}$$

Cosmic Strings

(Position space)

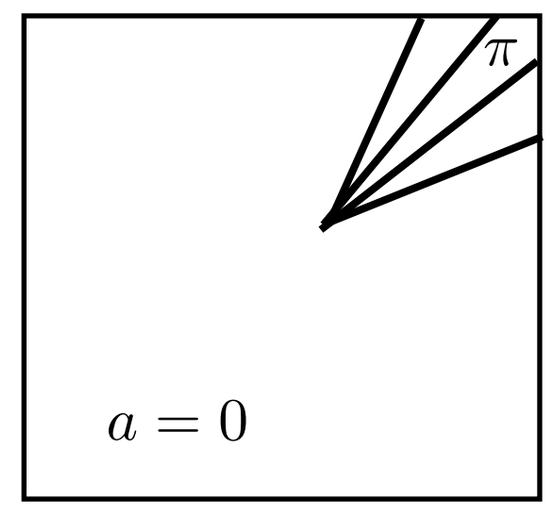
(T>QCD)

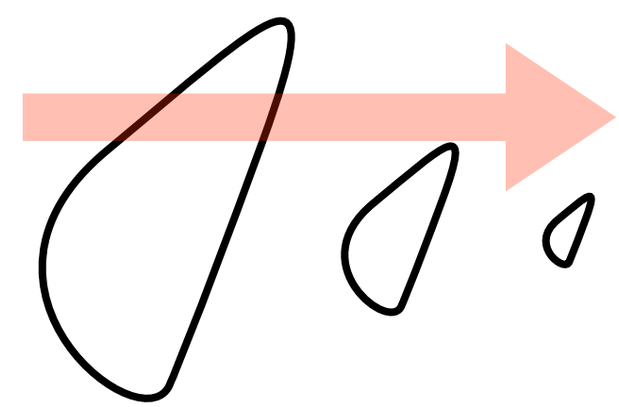




Domain Walls

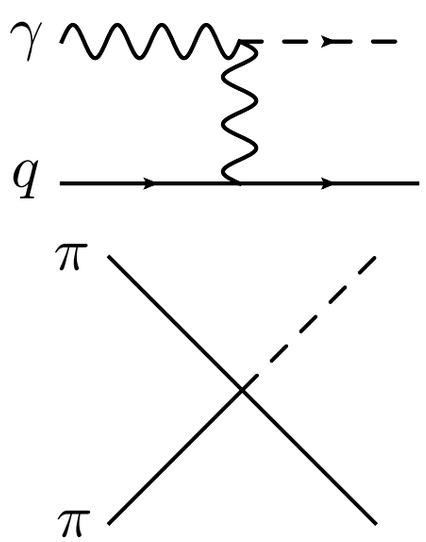
(T<QCD)





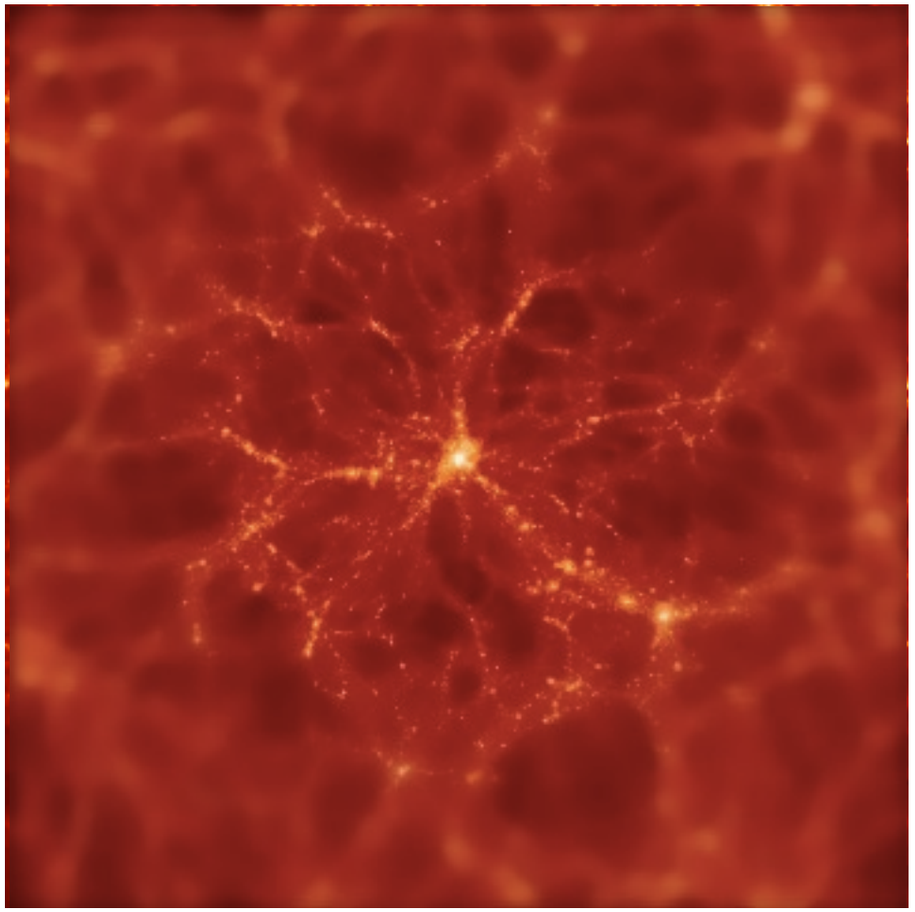
Axion or ALP hot Dark Matter (or Dark Radiation)

Axions are thermally produced in the early universe by a number of processes



Such small mass ALPs behave as hot DM, which is not favored by observations.

$$\frac{\Omega_{a,\mathrm{hDM}}}{\Omega_{\mathrm{obs}}} \sim \frac{m_a}{154\,\mathrm{eV}}\mathcal{C}(g's)$$



They should be a subdominant component of DM

Hannestad et al. JCAP 1008

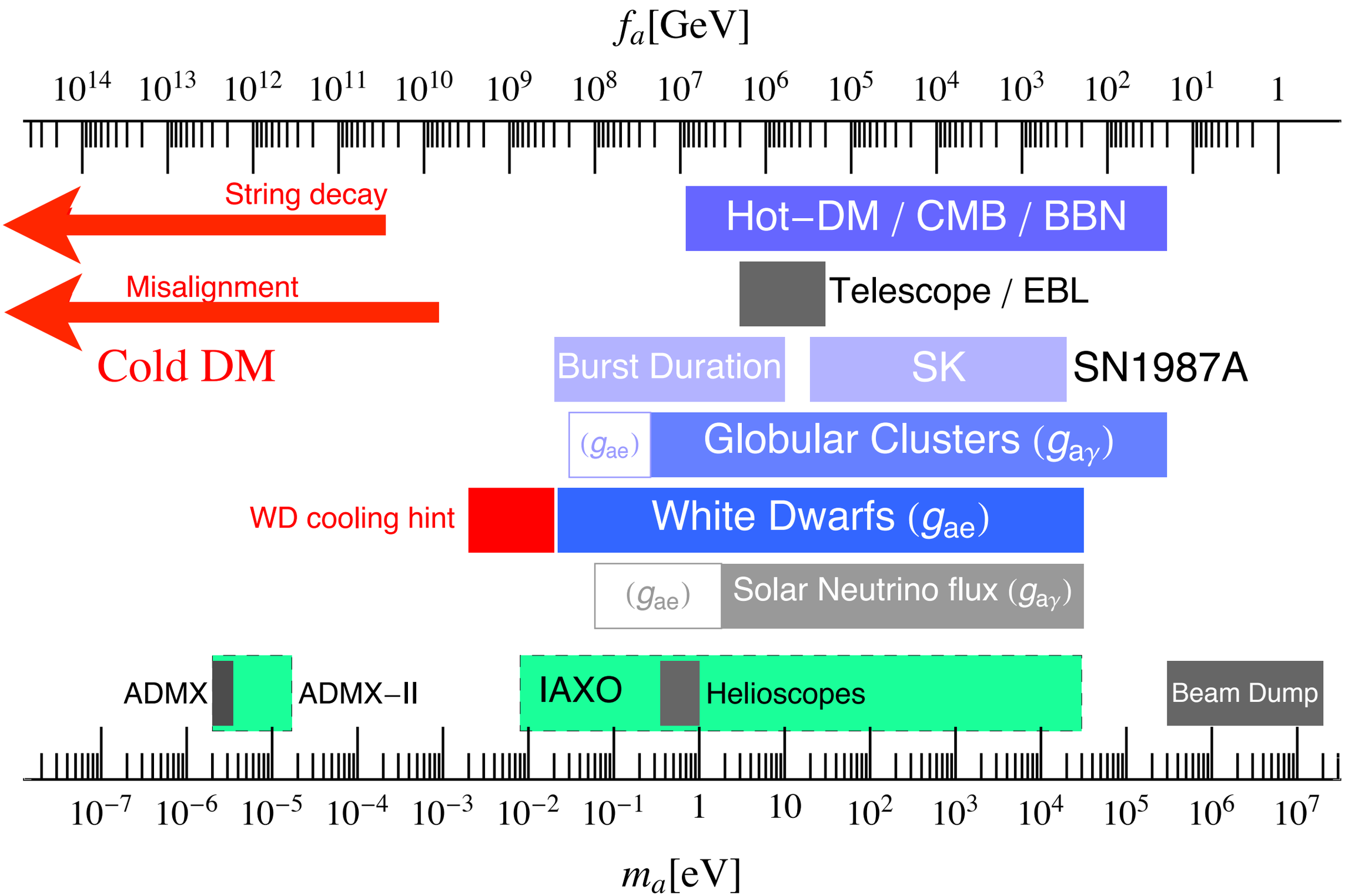
$$\frac{\Omega_{\mathrm{hDM},a}}{\Omega_{\mathrm{DM,obs}}} < 0.03 \quad (m_a < 0.72\,\mathrm{eV})$$

Sub eV axions or ALPs behave as Dark Radiation but $N_{\mathrm{eff}} < 3.9$
(There are however other DR production mechanisms)

Sikivie PRL 108, Takahashi arXiv:1201.4816

Summary of axion searches and perspectives

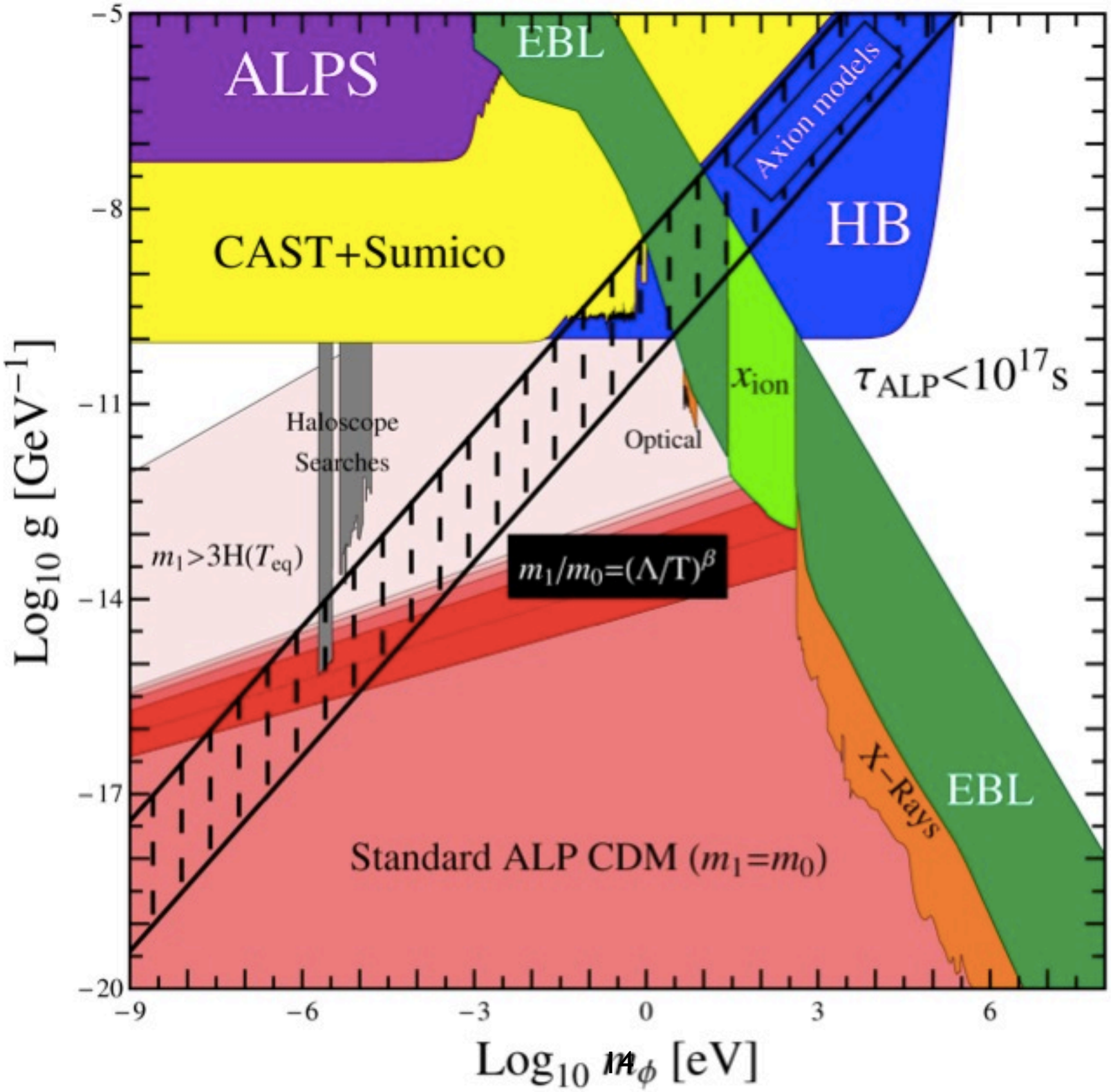
Intensity Frontier Report for DOE 2012



ALP cold Dark Matter

Arias et al. JCAP 0612

Essentially all the DM producing mechanisms outlined above apply for ALPs



ALP cold Dark Matter

Arias et al. JCAP 0612

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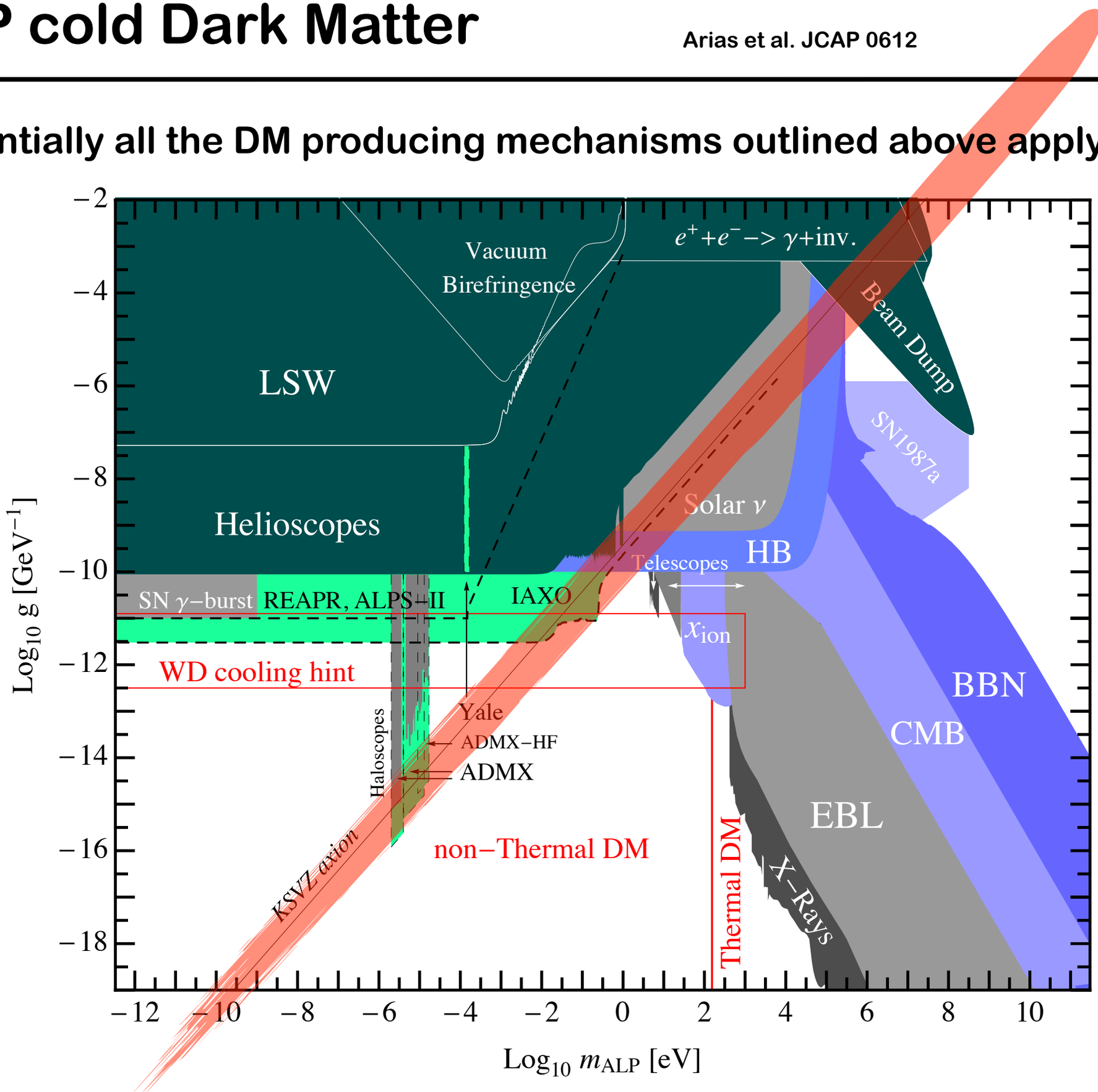


Can IAXO clarify these hints? ... yes!

Strong CP problem

IAXO can find the axion up to $m_a \gtrsim 1 \sim 10\mathrm{meV}$
- Through the photon or electron couplings
- In this range, IAXO can measure, coupling and mass

WD cooling

If the axion is responsible, IAXO can find it $m_a \gtrsim 1 \sim 10\mathrm{meV}$
If it is an ALP, it can strongly depend (photon coupling might be very small)

Transparency of the universe due to ALPs

IAXO will settle this issue (recall $g_{\phi\gamma} \sim 10^{-11}\mathrm{GeV}^{-1}, m_\phi \lesssim n\mathrm{eV}$)

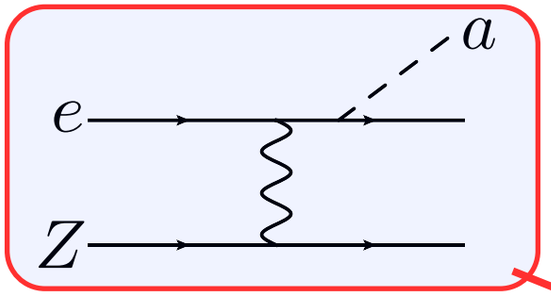
Dark matter

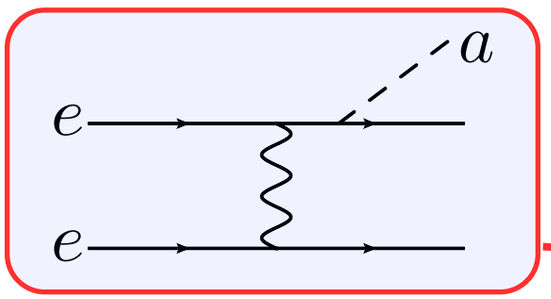
- In the strong CS&DW-contribution scenario, $m_a \sim \mathrm{meV}$, IAXO is the only experiment proposed up-to-date that can find these axions.
- Also if they are s sub-dominant contribution of DM
- In the event of discovery, IAXO can measure the axion mass, and help designing a dedicated experiment to detect directly DM axions.

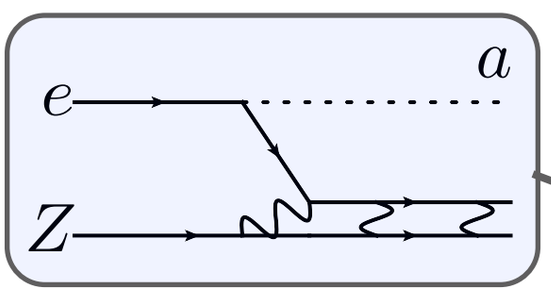
Dark radiation

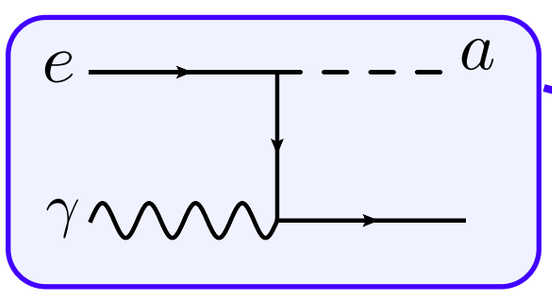
- Discovering the axion or an ALP immediately implies a DM and DR candidate

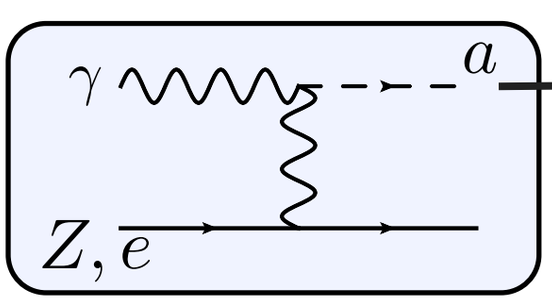
The solar axion (ALP) flux is well understood











With e-coupling Redondo, in preparation; (See also 1302.6283)

Brem. Z

Brem. e

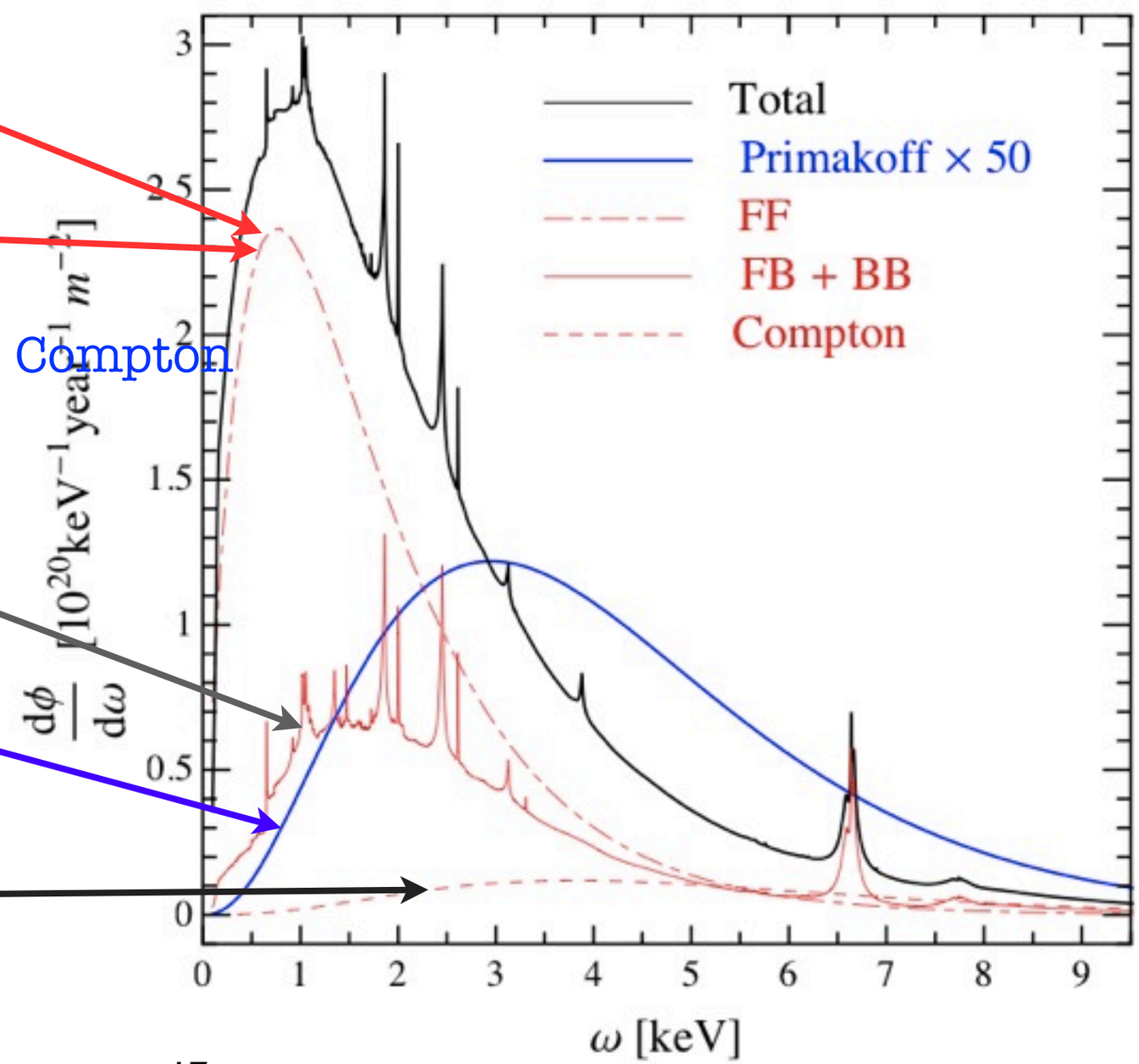
Axiorec.

Axiorec.

Compton

Compton

Primakoff



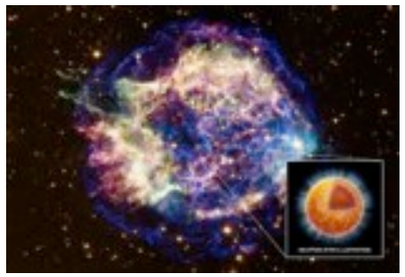
stuff I didn't talk about

- The IAXO magnet can be used for a direct DM search

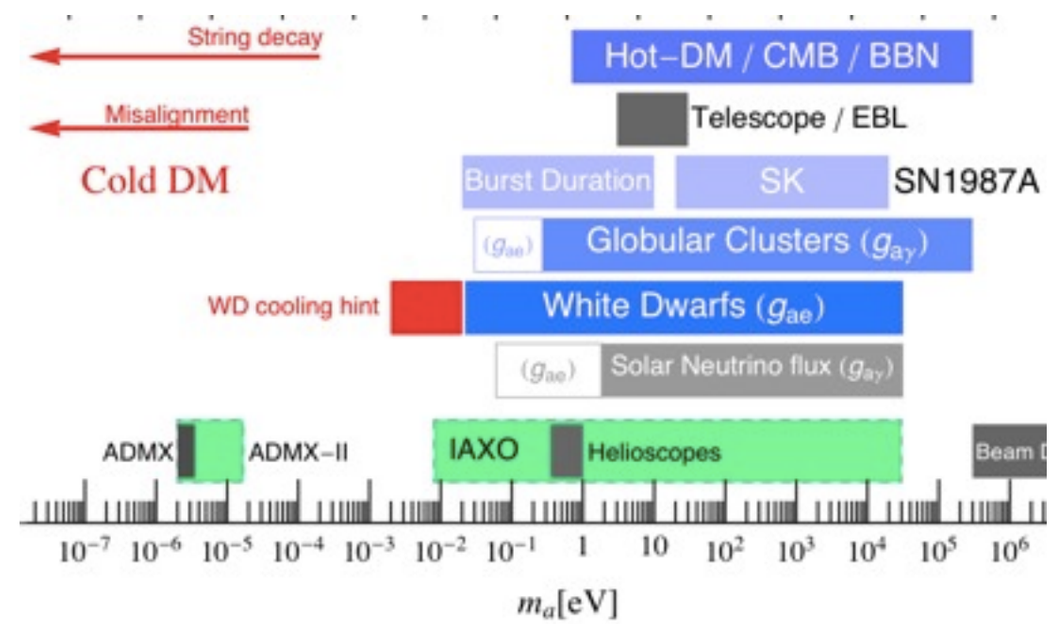
- Axions at the meV mass frontier will have subtle implications in other astrophysical systems

Neutron stars

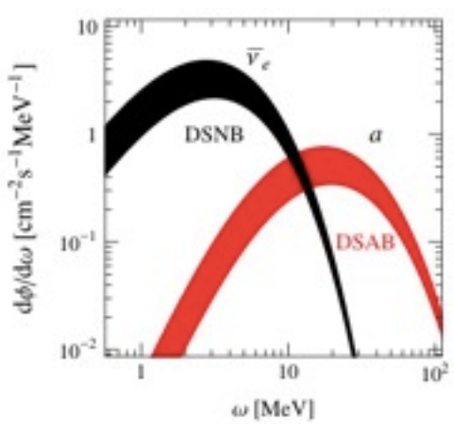
Keller, Sedrakian, arXiv:1205.6940



Casiopea A super-fast cooling
Page et al. PRL 106



Supernovae



- **DSAB**, Raffelt et al. PRD 84
- Axions from Betelgueuse with IAXO & Supernova warning
- More on uncertainties
  Stoica et al. arXiv:1205.7048

Red giants in globular clusters

- Existing limits based on 80's data and simulations
- New analysis in underway