

WISPy Cold Dark Matter

-

From theory to detection

J. Jaeckel^{**}

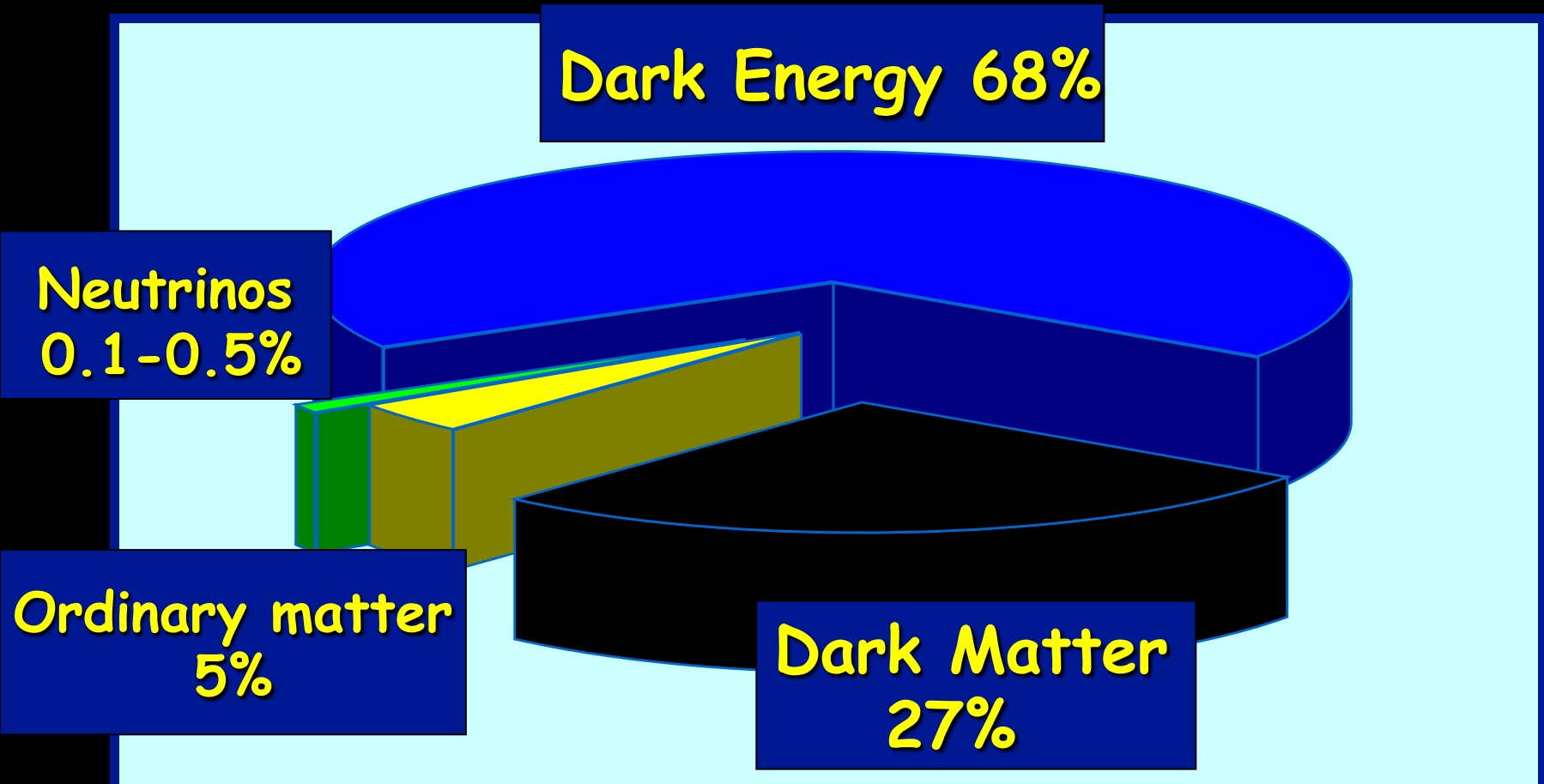
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We know...

...nothing

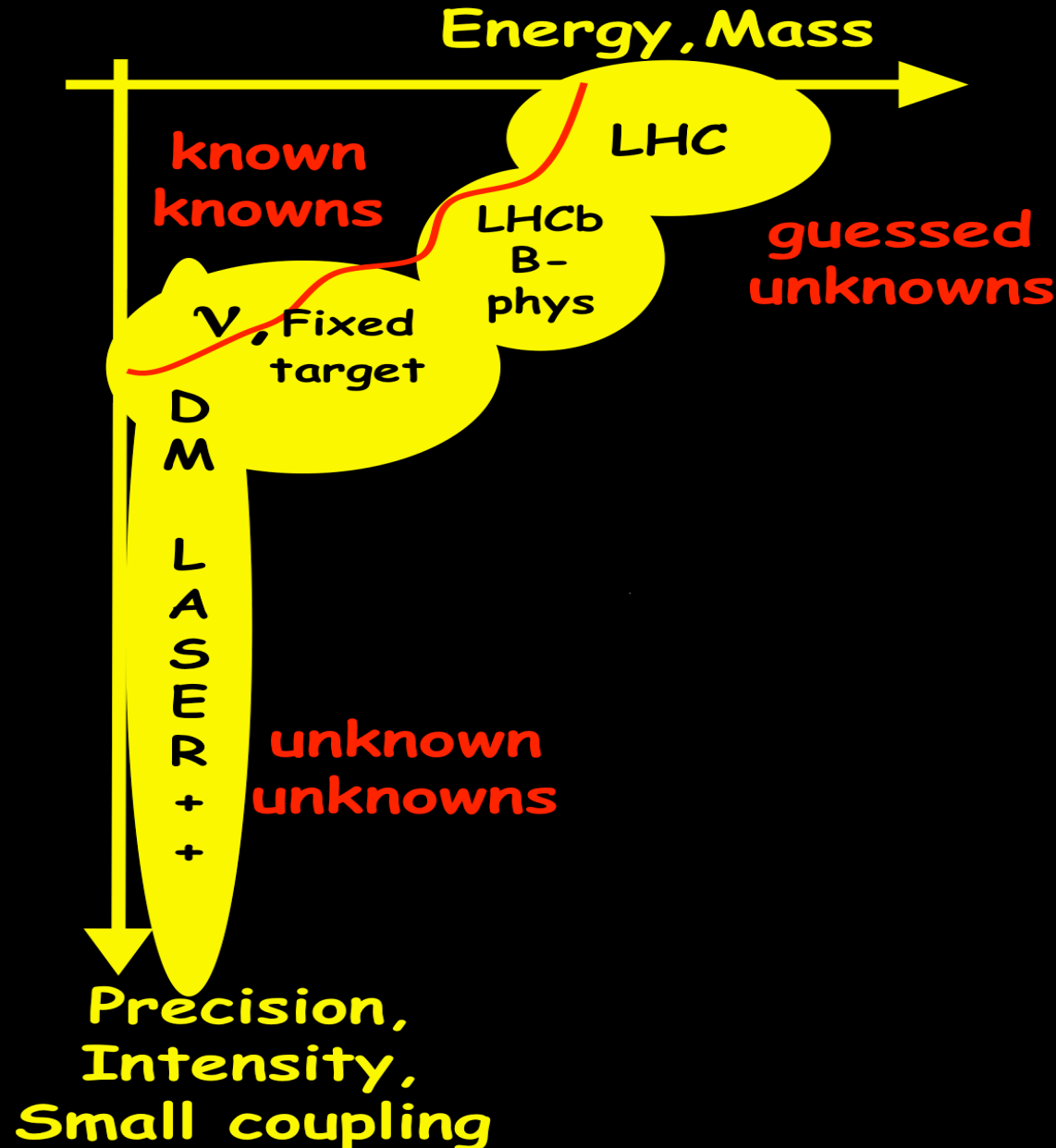
Inventory of the Universe



Where does physics
beyond the SM
hide?



Exploring is (at least) 2 dimensional



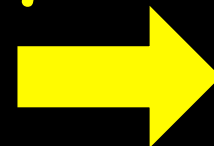
Can Dark Matter be WISPy?

(Weakly Interacting Sub-eV Particley)
Slim

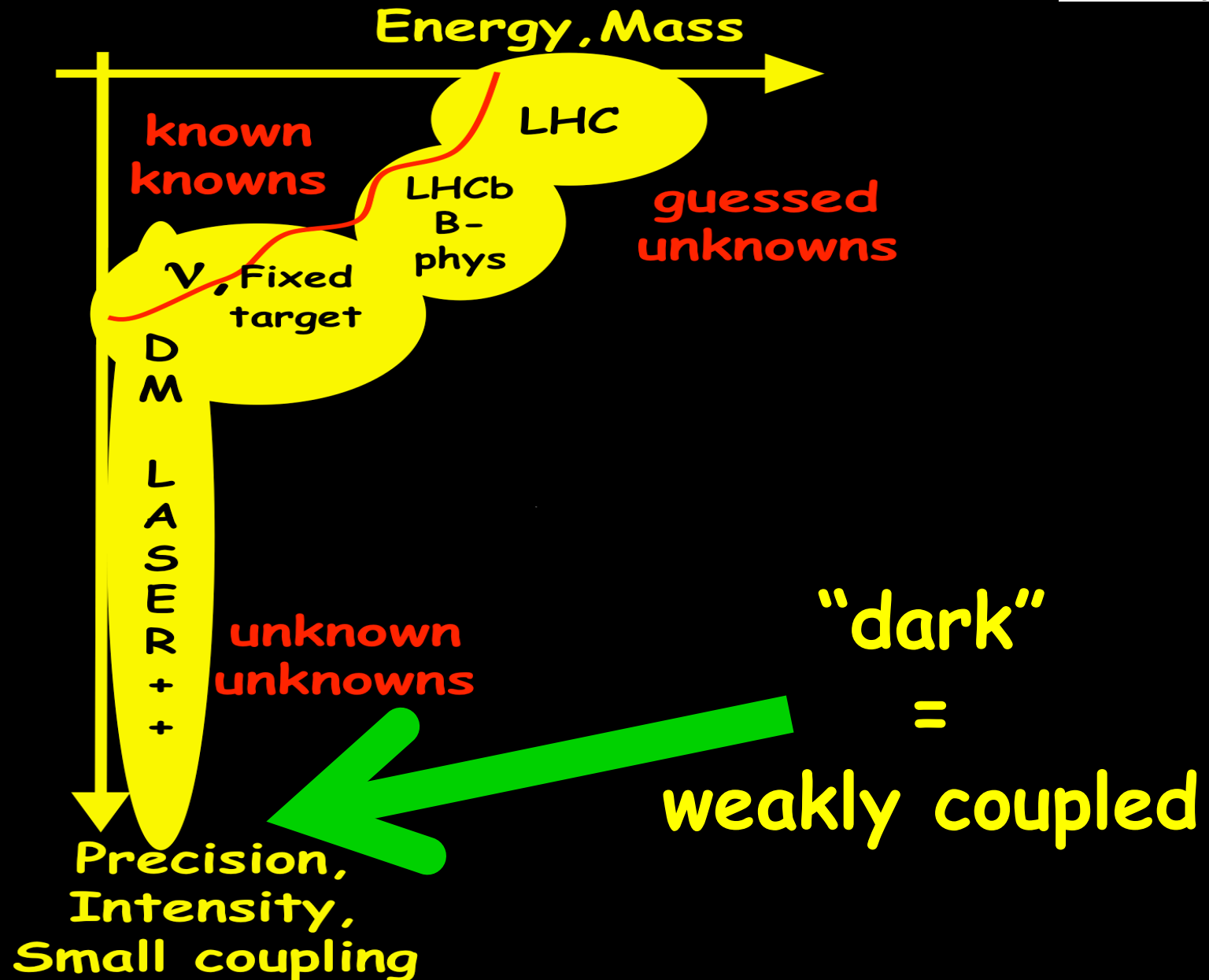


Properties of Dark Matter

- Dark matter is dark, i.e.
it doesn't radiate!
(and also doesn't absorb)
- very, very weak interactions with light
and with ordinary matter
- Exactly the property of
WISPs



Exploring is (at least) 2 dimensional



A common prejudice

- Dark Matter has to be heavy: $m_{\text{DM}} \gtrsim \text{keV}$.
- Prejudice based on thermal production!
and/or fermionic DM!

Both assumptions give minimal velocity
(thermal/Fermi)

→ galaxy, i.e. structure, formation inhibited!

Weakly interacting sub-eV DM

- Has to be non-thermally (cold!!!) produced

➡ See misalignment mechanism ✓

- Bosonic!

➡ Axion(-like particles)
Hidden Photons ✓

Dark matter has to be heavy...

Dark matter has to be heavy $m_{\text{DM}} \gtrsim \text{keV}?$

Dark matter has to be heavy...

Dark
MYTH BUSTED
keV?

Example WISP:

Axions in a nutshell

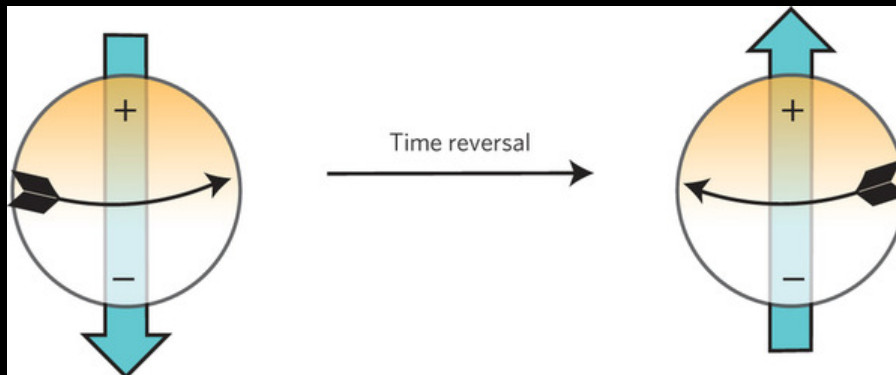
A dirty little secret...

$$S = \int d^4x \left[-\frac{1}{4} G^{\mu\nu} G_{\mu\nu} - \frac{\theta}{4} G^{\mu\nu} \tilde{G}_{\mu\nu} + \bar{\psi} D_\mu \gamma^\mu \psi + \bar{\psi} M \psi \right]$$

” $\sim \theta \vec{E} \cdot \vec{B}$ ”

- The θ -term violates time reversal (T=CP)!
- Connected to strong interactions!

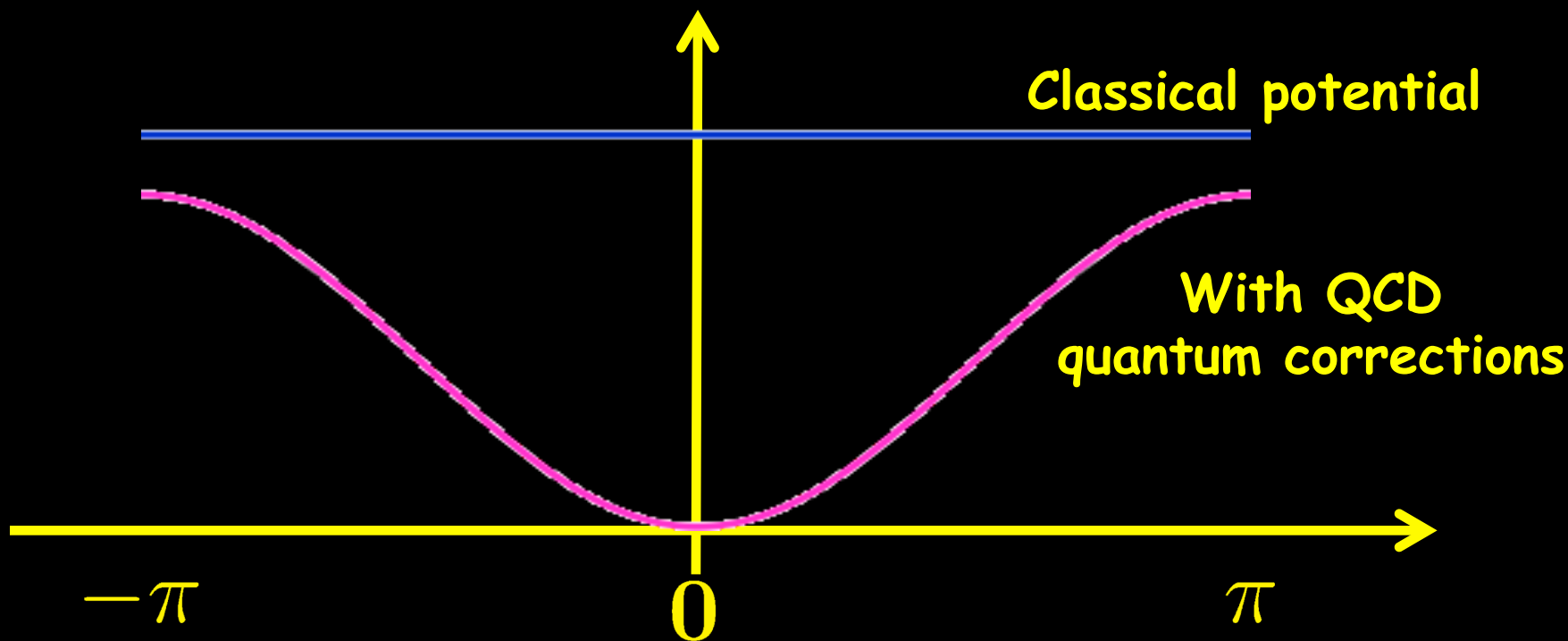
➔ Electric dipole moment
of the neutron!



Not found
➔ $\theta \sim 0!!!$

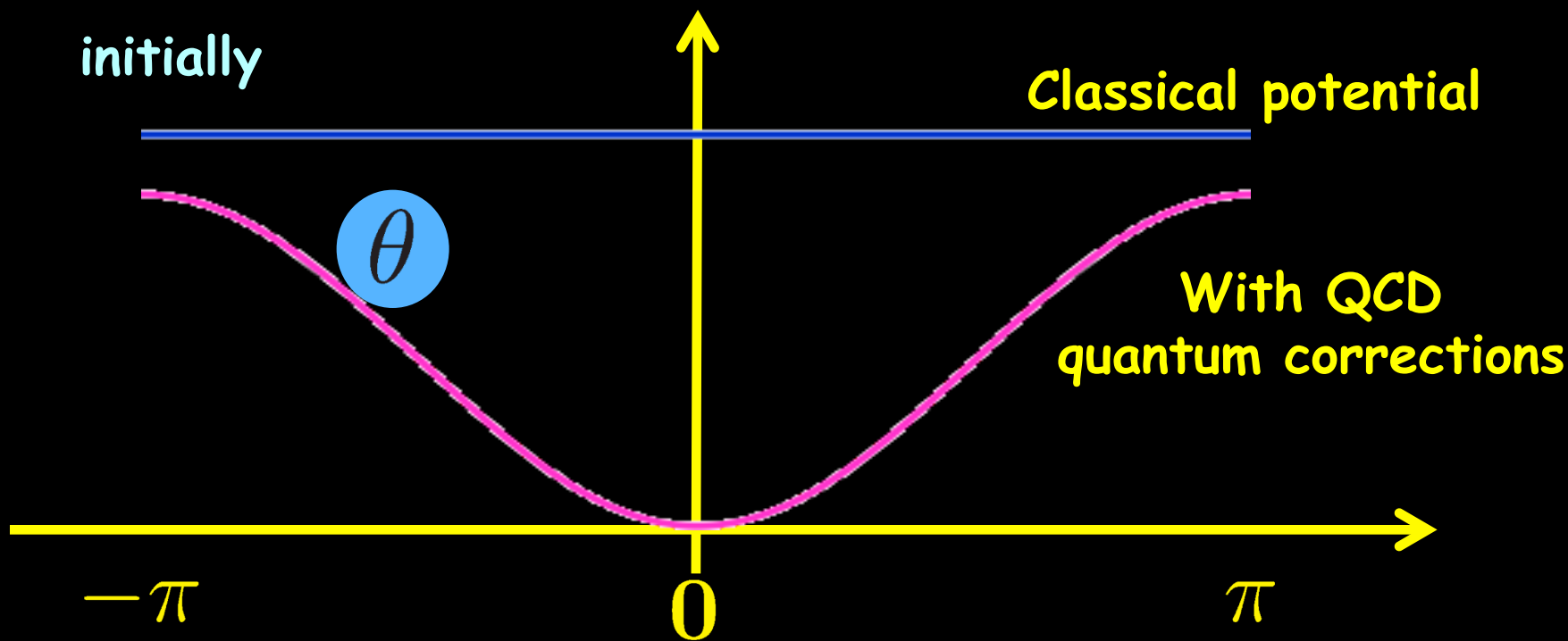
The axion solution to the strong CP problem

- Make θ dynamical $\rightarrow$ it can change its value



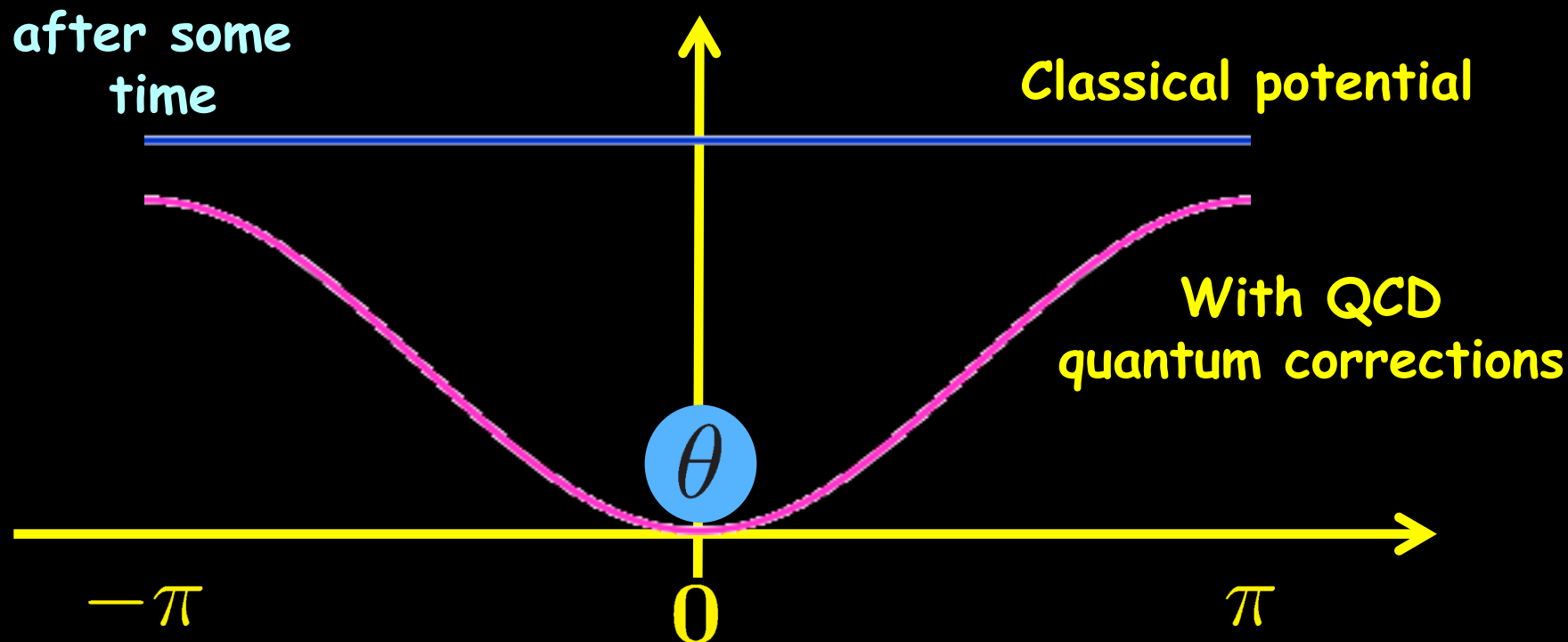
The axion solution to the strong CP problem

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The axion solution to the strong CP problem

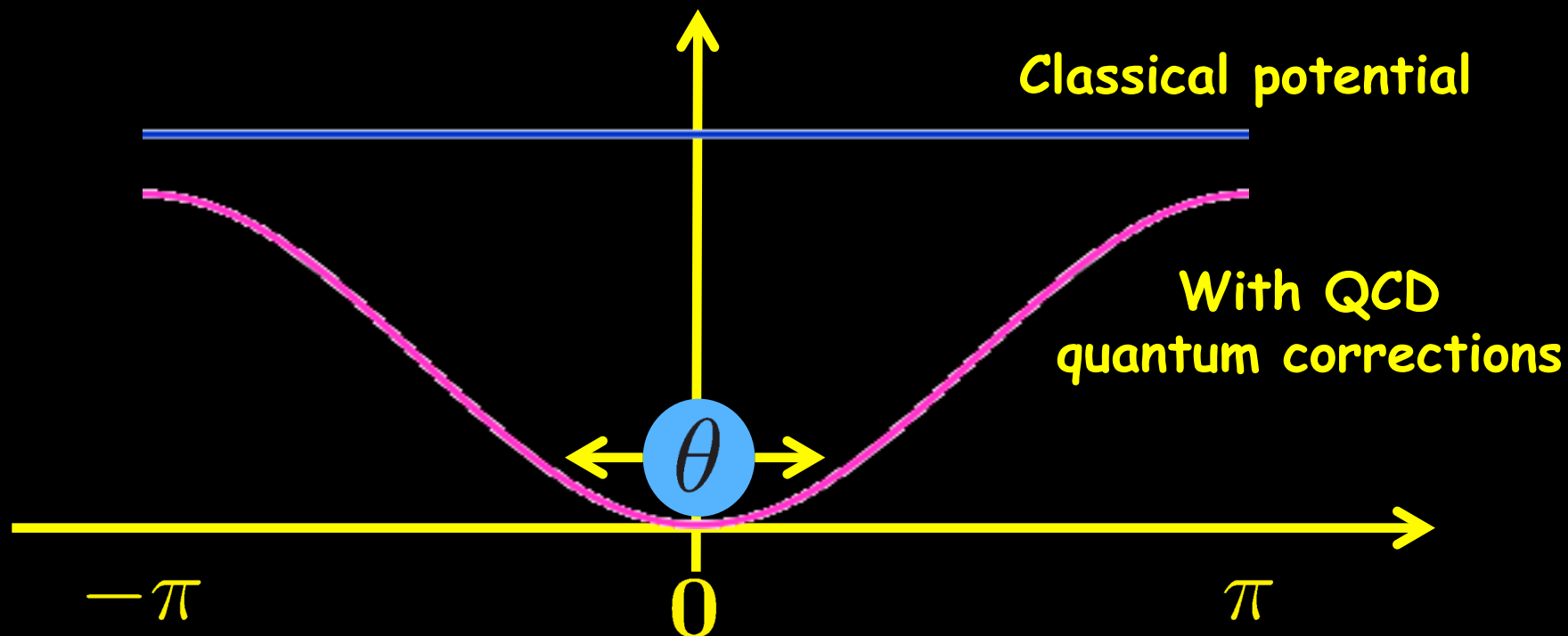
- Make θ dynamical $\rightarrow$ it can change its value



$\rightarrow$ QCD likes to be CP conserving (if we allow it)

The axion solution to the strong CP problem

- Make θ dynamical $\rightarrow$ it can change its value

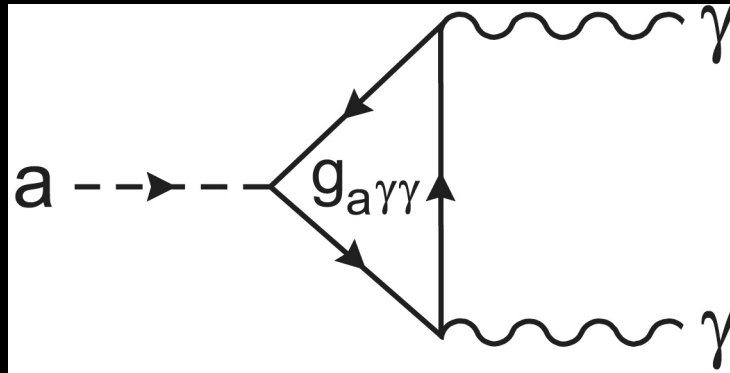


$\rightarrow$ Can still move

$\rightarrow$ new particle = axion

- Classical flatness from symmetry
 - Quantum corrections are small
 - New **light** particle: **The Axion**
(it's a **Weakly Interacting Sub-eV Particle**)
- ↓
- Dark matter candidate
- ↓
- Good motivation
for axion/WISP experiments**

Axion also couples to two photons



$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}\partial_\mu a\partial^\mu a - m^2 a^2 - \frac{1}{4}g_{a\gamma\gamma}aF^{\mu\nu}\tilde{F}_{\mu\nu} + \dots$$

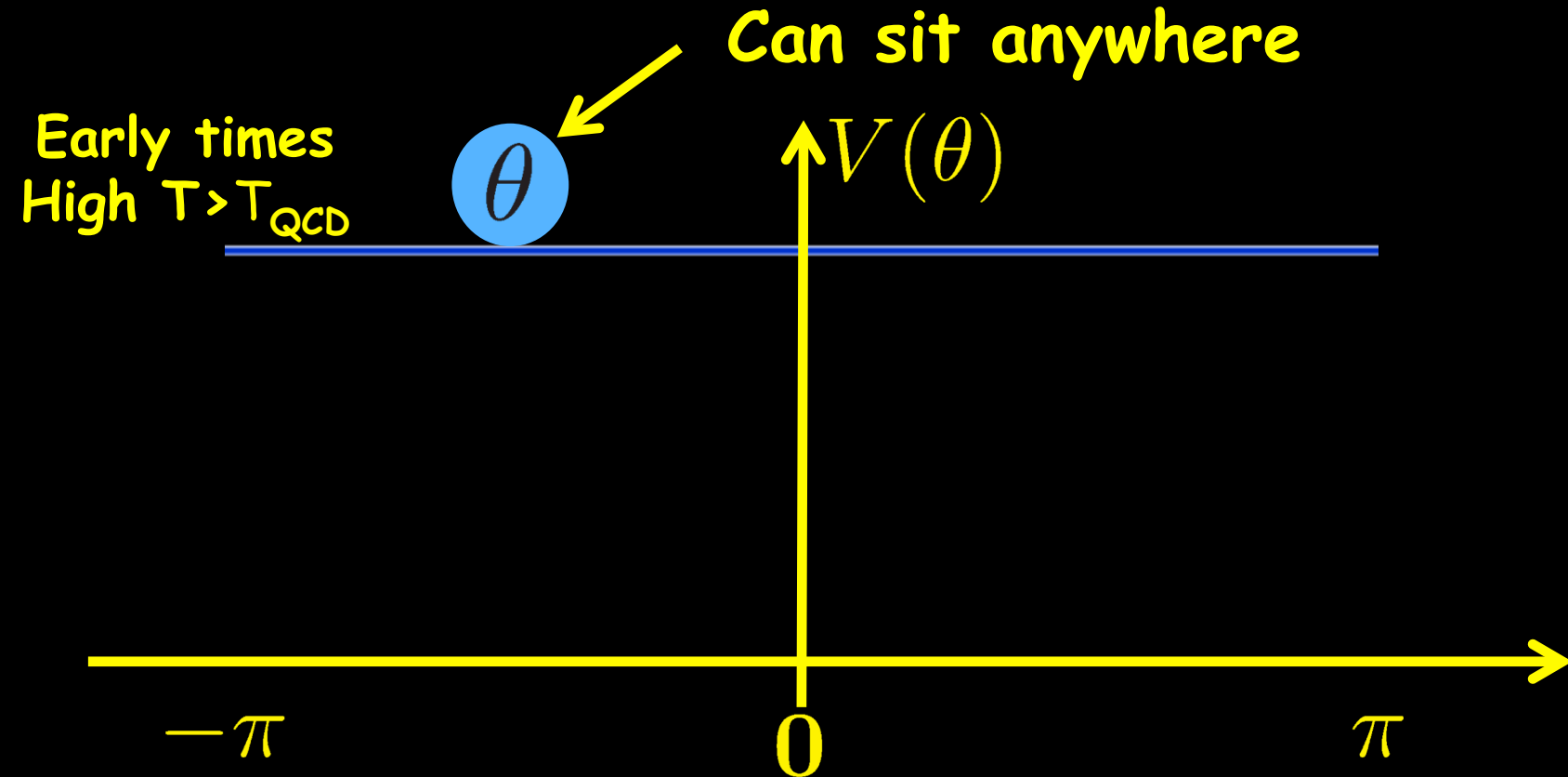
Coupling to two photons

Very very weak $g_{a\gamma\gamma} \sim \frac{\alpha}{2\pi f_a}$

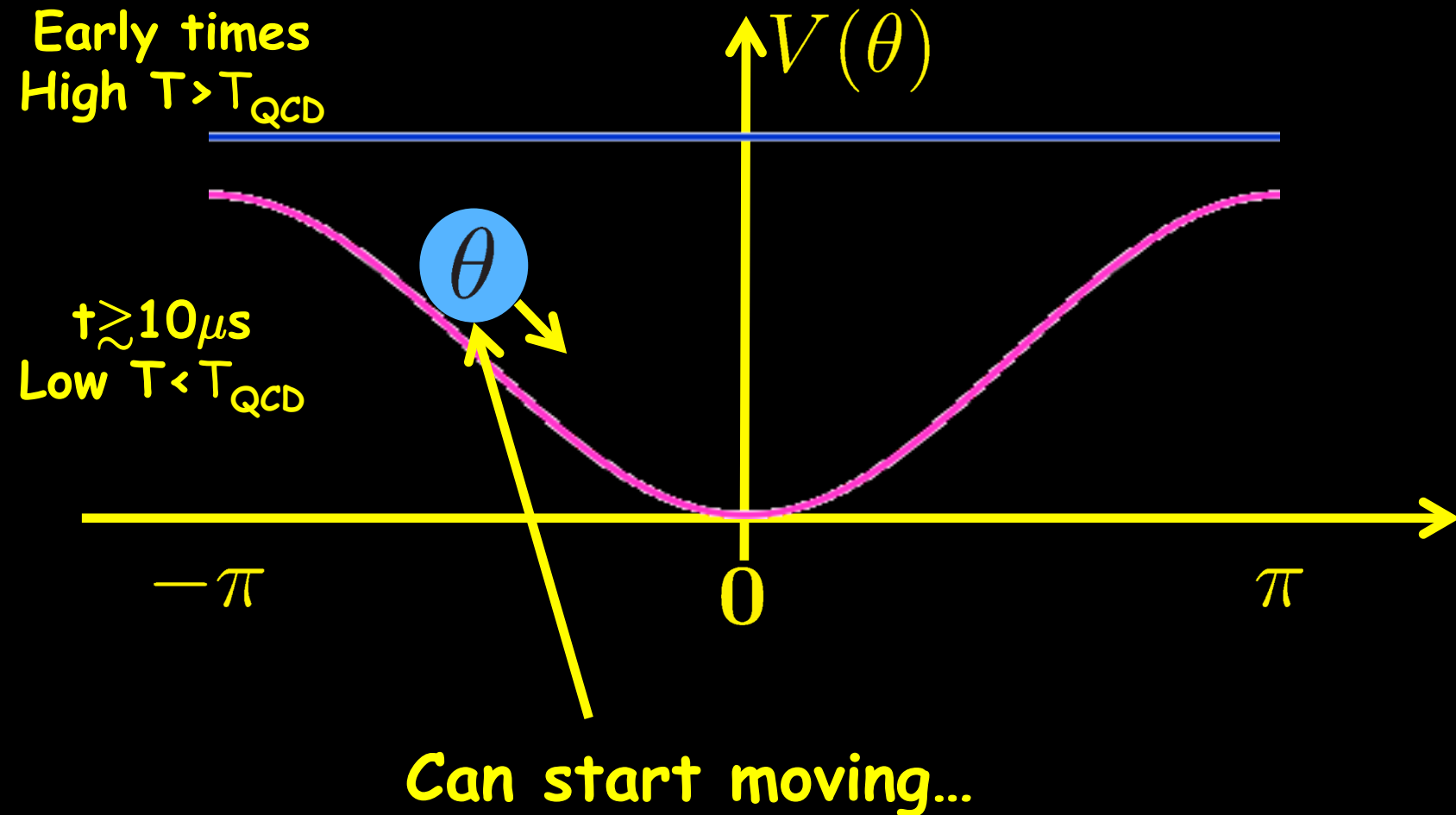
Because: Very large

Dark Matter(s)

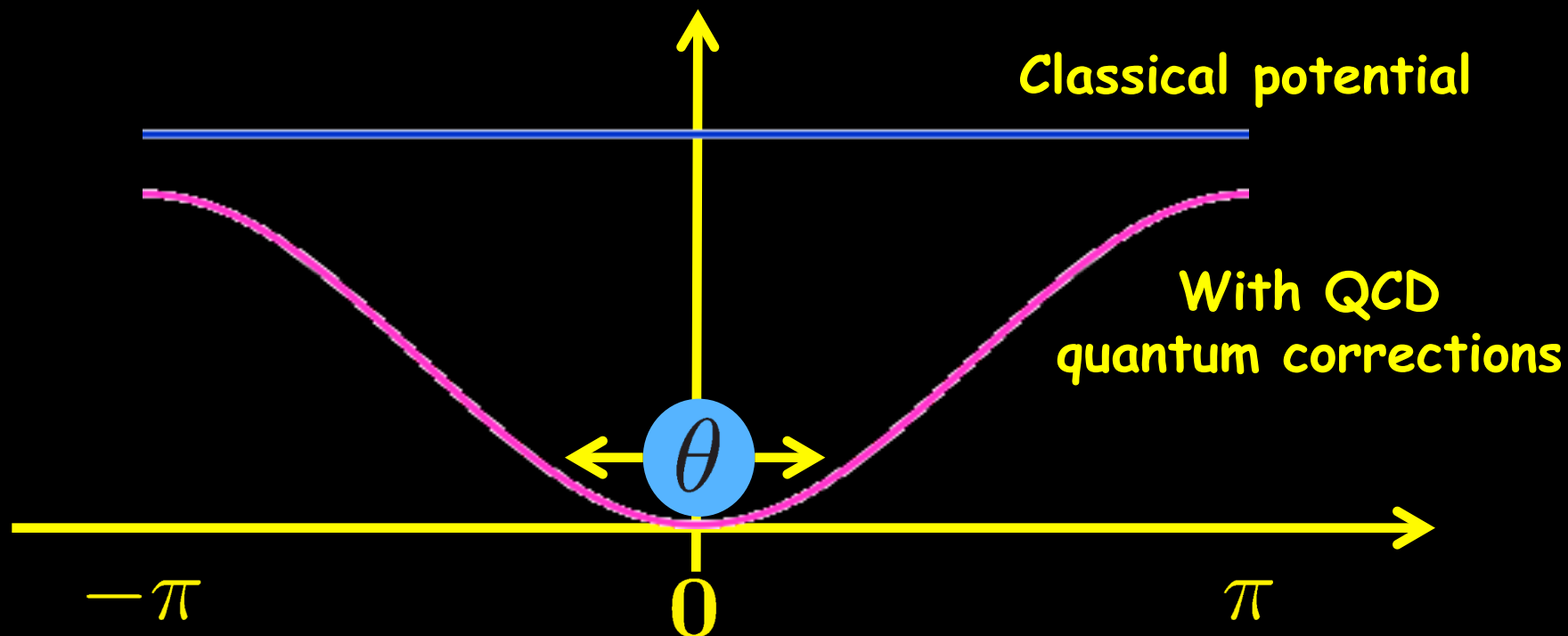
The axion has no clue where to start



The axion has no clue where to start



The axion solution to the strong CP problem

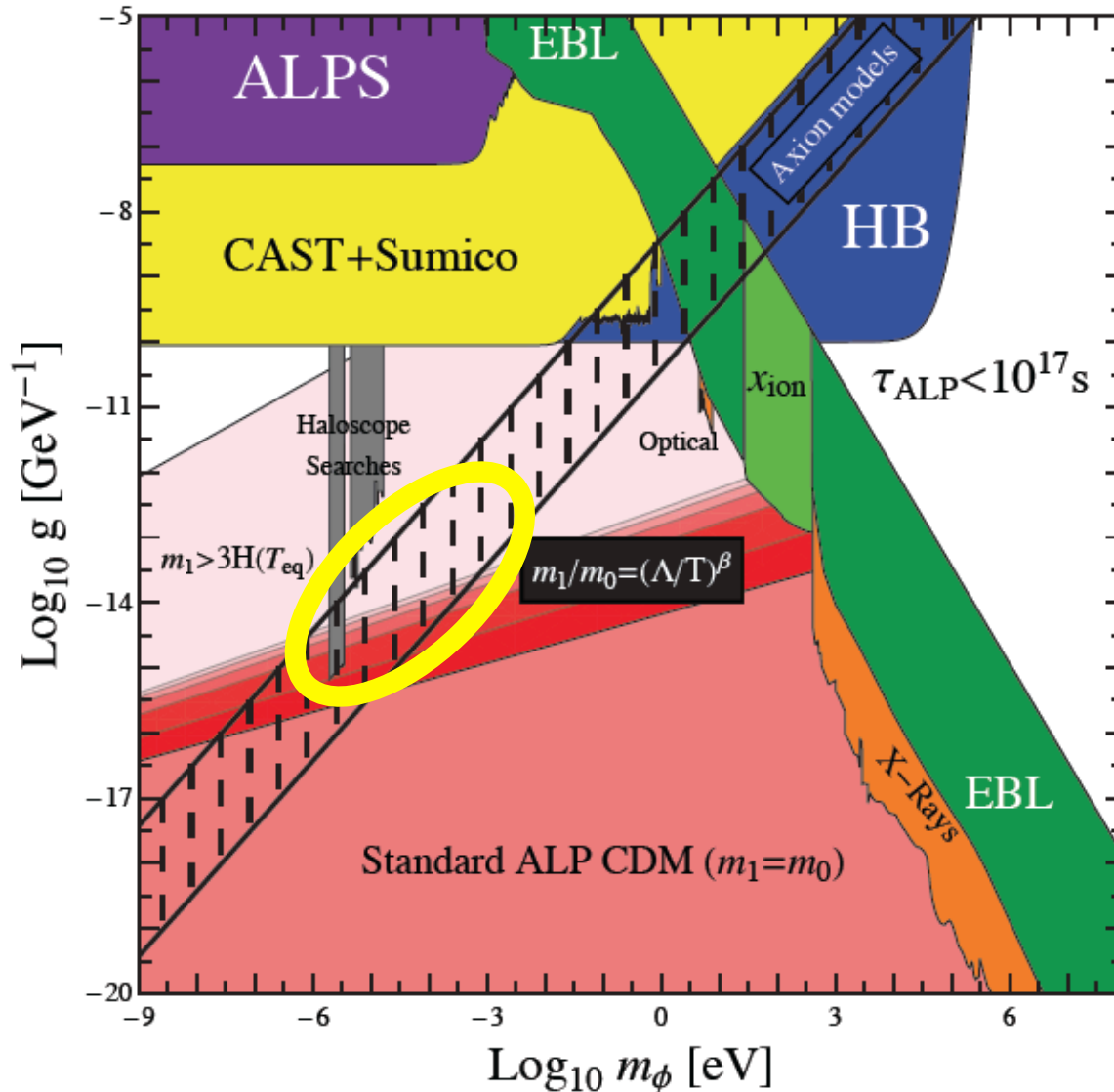


- Oscillations contain energy
- behave like non-relativistic particles ($T=0$)

Axion(-like particle) Dark Matter

$\sim 10^8 \text{ GeV}$

$\sim 10^{12} \text{ GeV}$



Have we already
seen it?

Observation:
The 3.55 keV line

Current experimental situation...



3.55 keV = X-ray

- Atmosphere opaque to X-rays
→ Need satellites



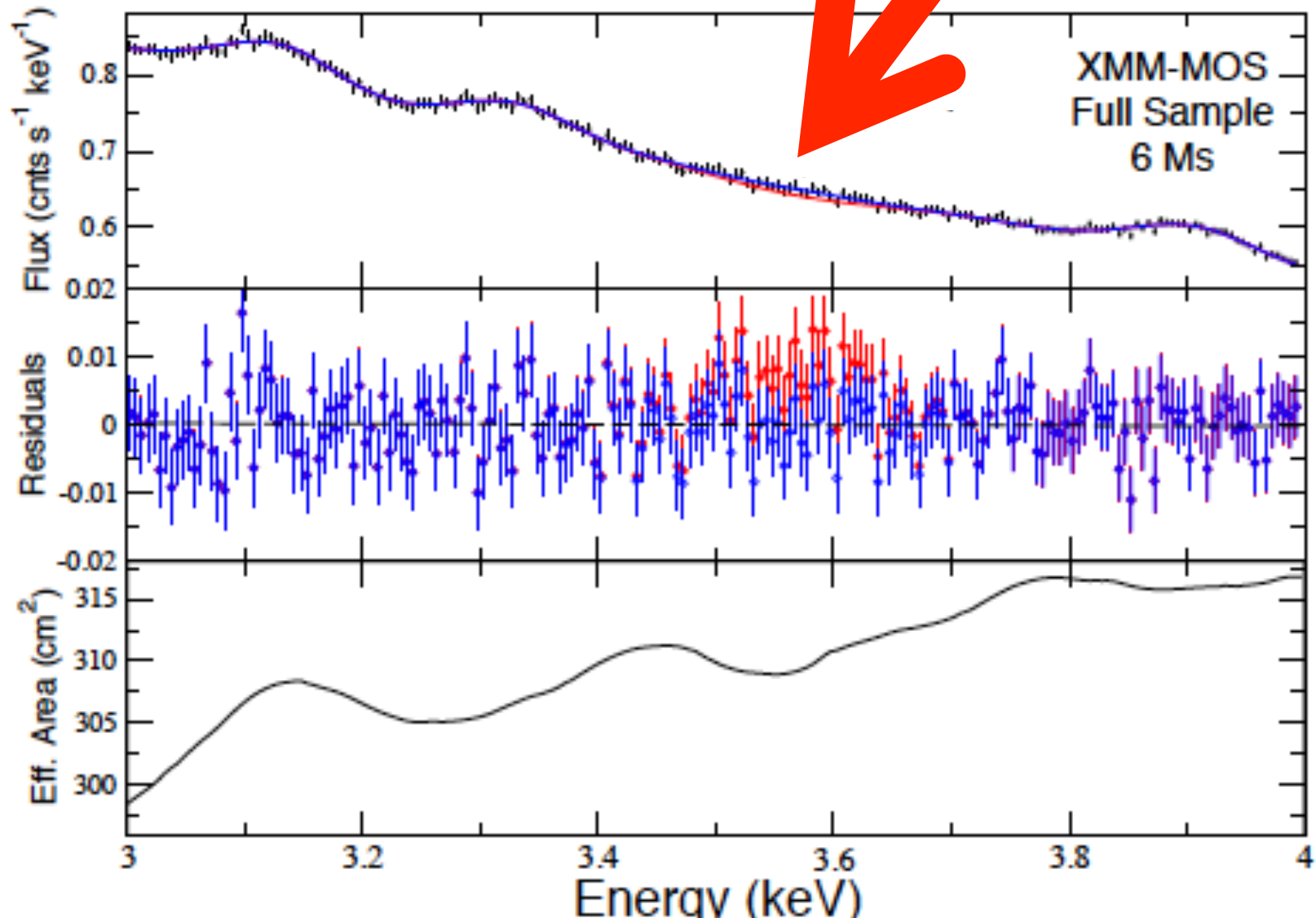
XMM-Newton



Chandra

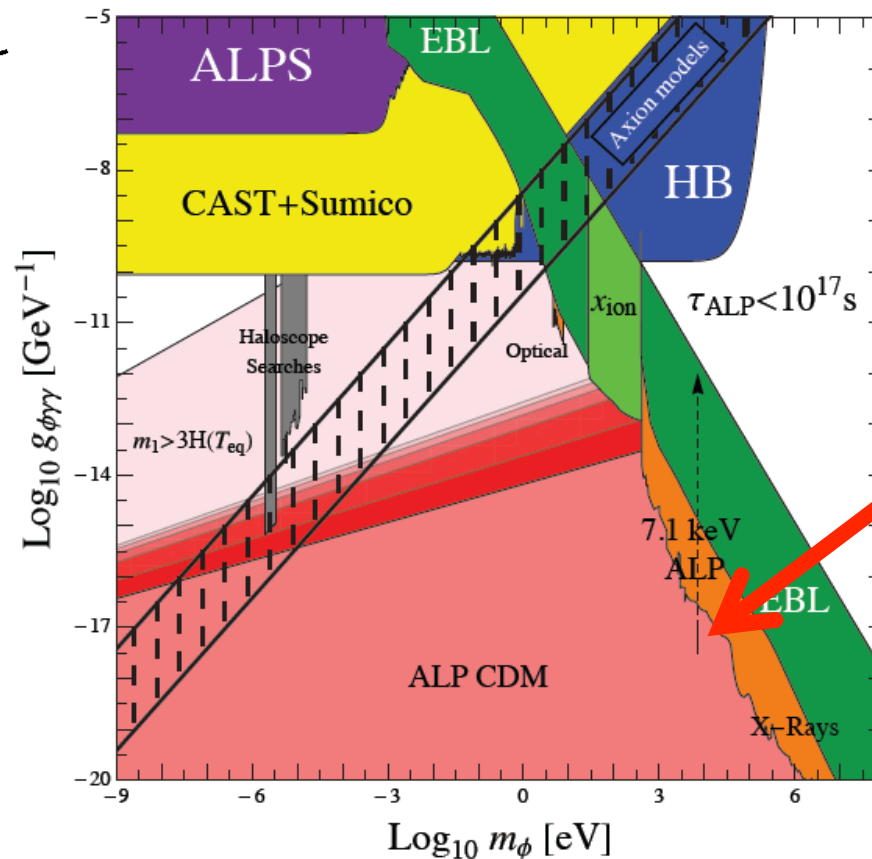
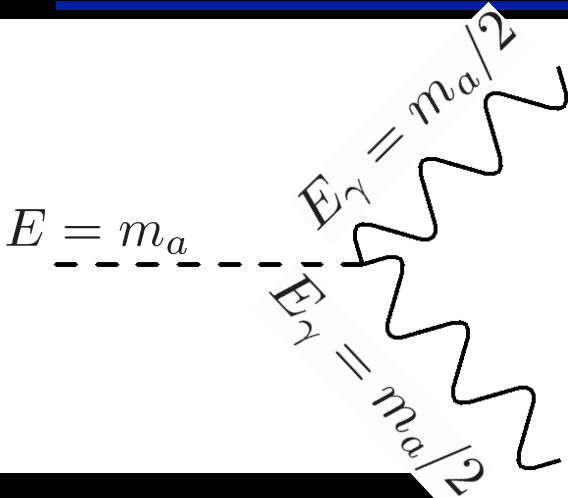
Find the line...

Clear Peak!!!!

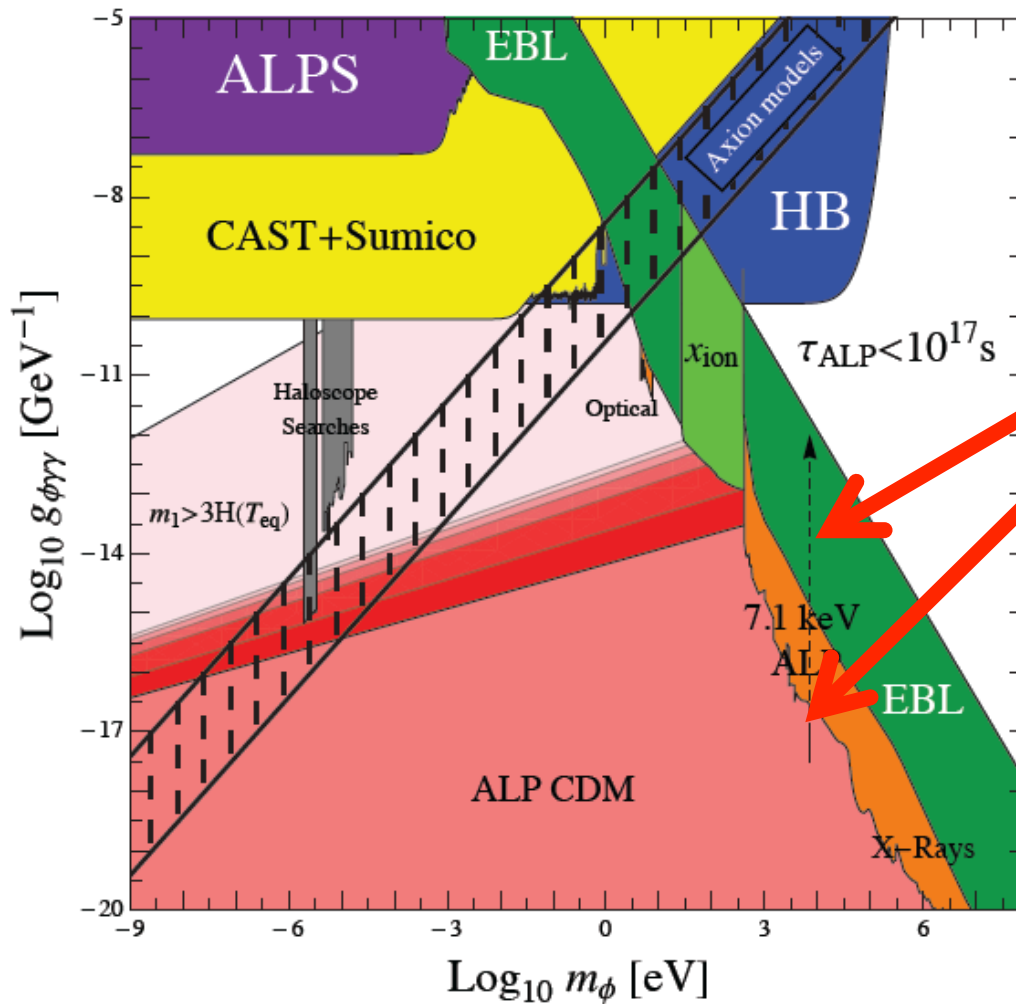


And the winner is...

ALP decay to two photons!



Subdominant ALP DM



All equal
From FT
perspective

Subdominant
better
If BICEP 2
(isocurvature)

Flexing BICEP 2



Axion/ALP DM: Two Scenarios

1) Phase Transition before inflation

Inflation ensures:

same initial field value everywhere

→ Can choose this value

→ Tune to right DM density (always poss.)

But quantum fluctuations from inflation

→ Isocurvature fluctuations $\sim H_I$

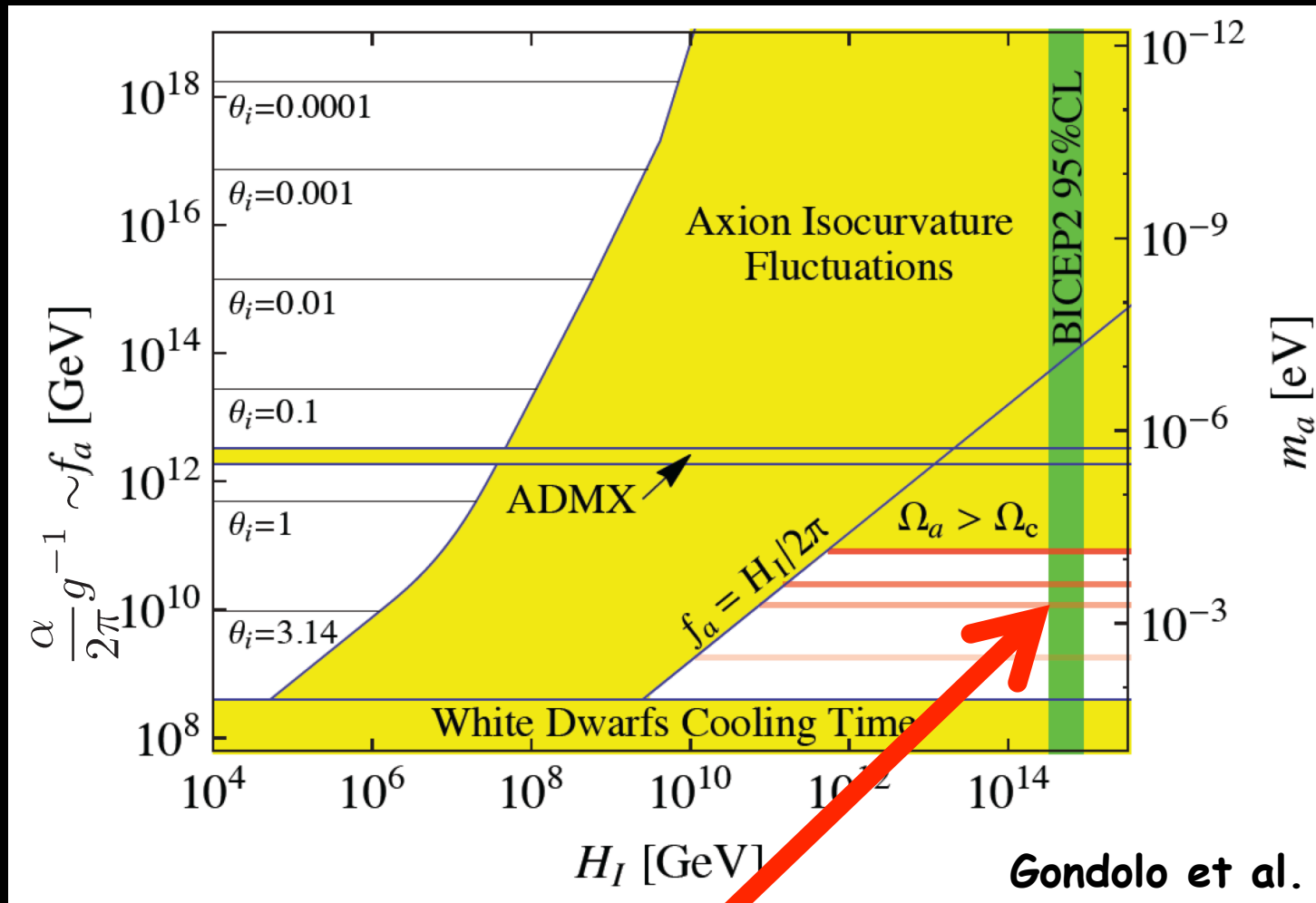
2) Phase Transition after inflation

average over initial field values

→ Predict DM density (correct only for specific mass/coup.)

→ No isocurvature fluctuations

What is allowed?



Preferred range!

Two.5 comments

1) Similar behavior for other ALPs/WISPs

2) Can be circumvented by non-trivial couplings to gravity.

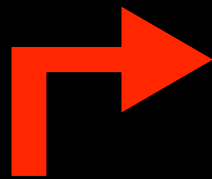
2.5) Needs to be confirmed -> probably not

Detecting WISPy
DM

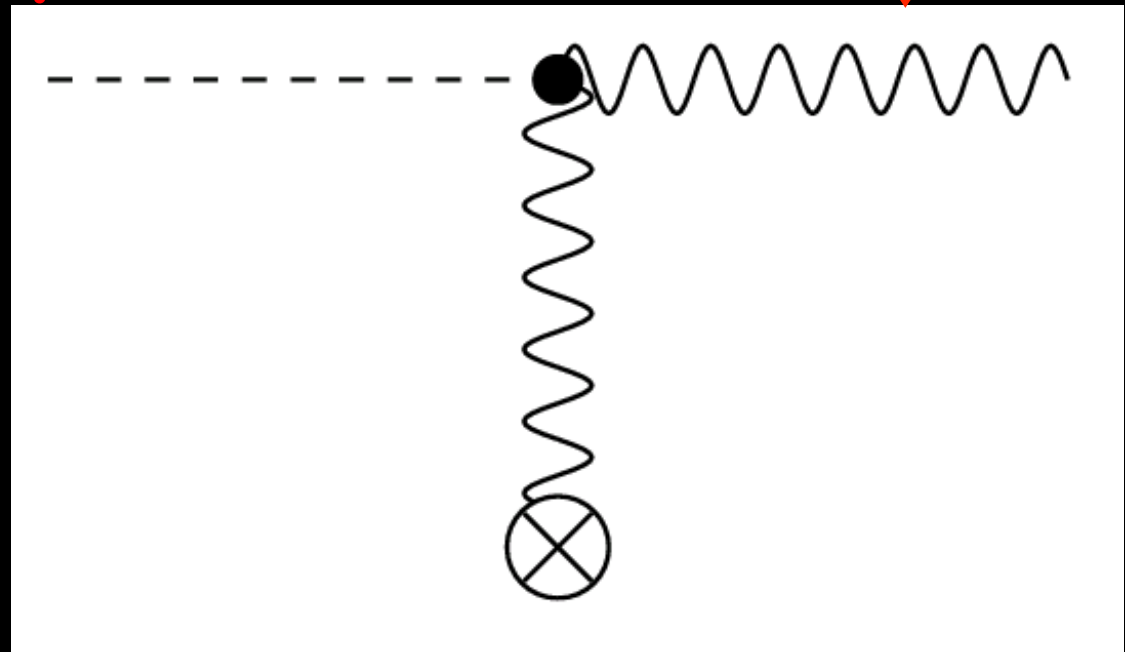
Use a plentiful source of axions

- Photon Regeneration

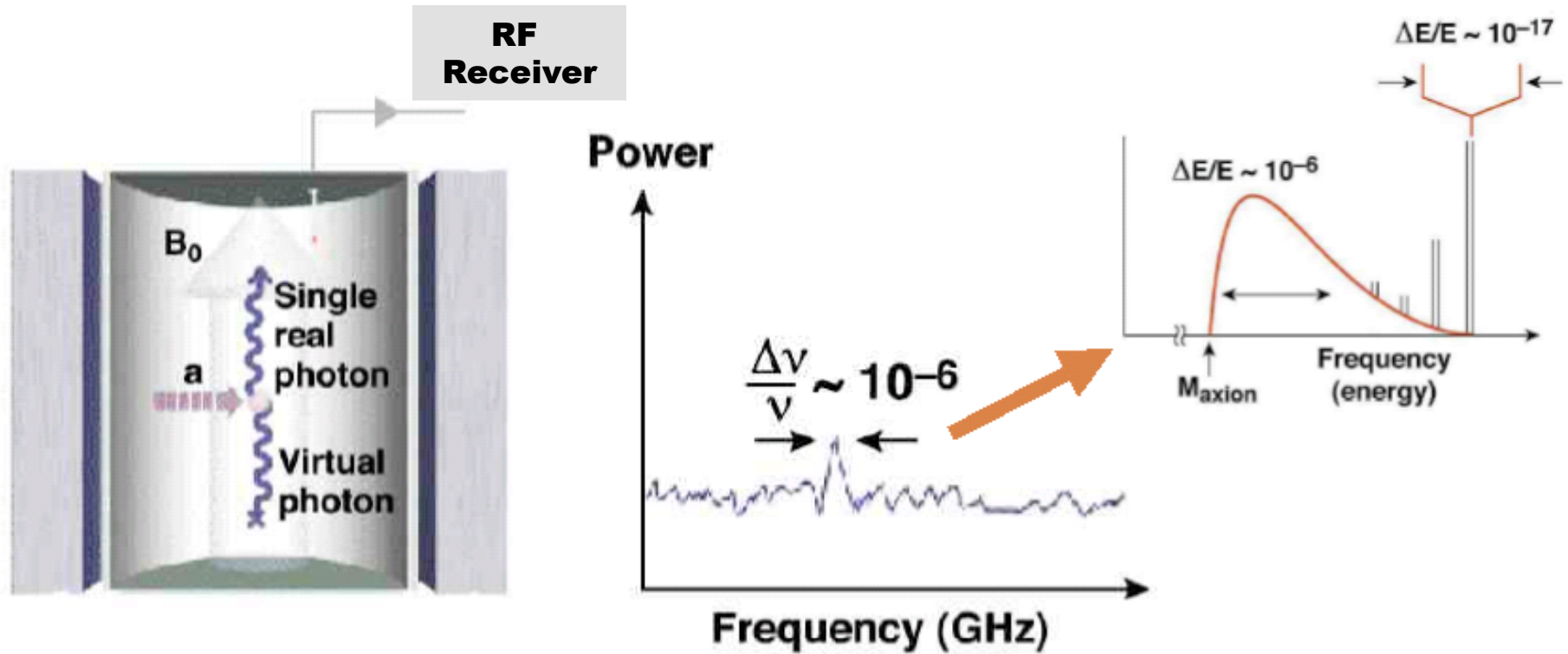
Photon
(amplified in resonator)



axion
(dark matter)



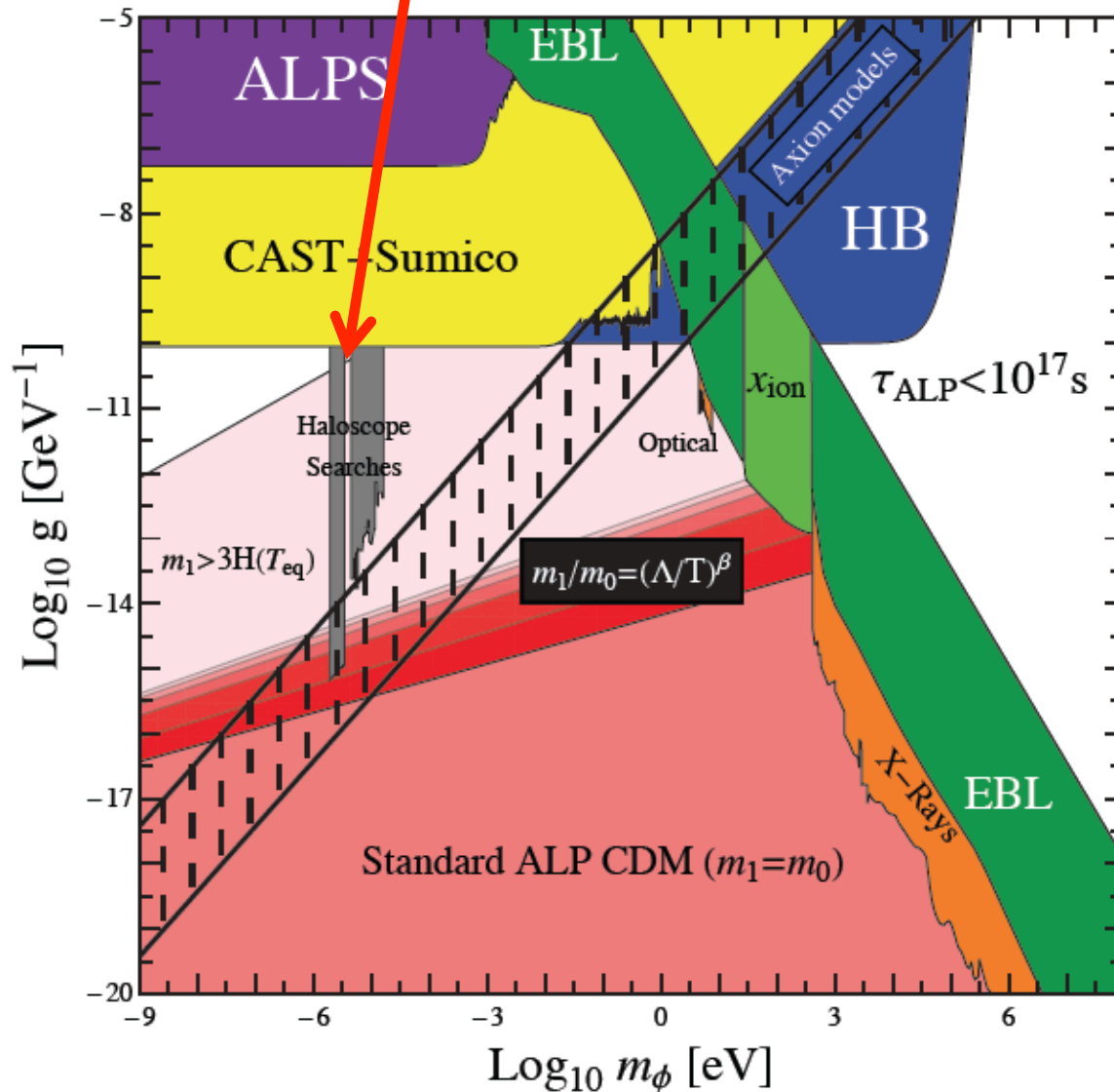
Signal: Total energy of axion



$$h\nu = m_a c^2 [1 + \mathcal{O}(\beta^2 \sim 10^{-6})]$$

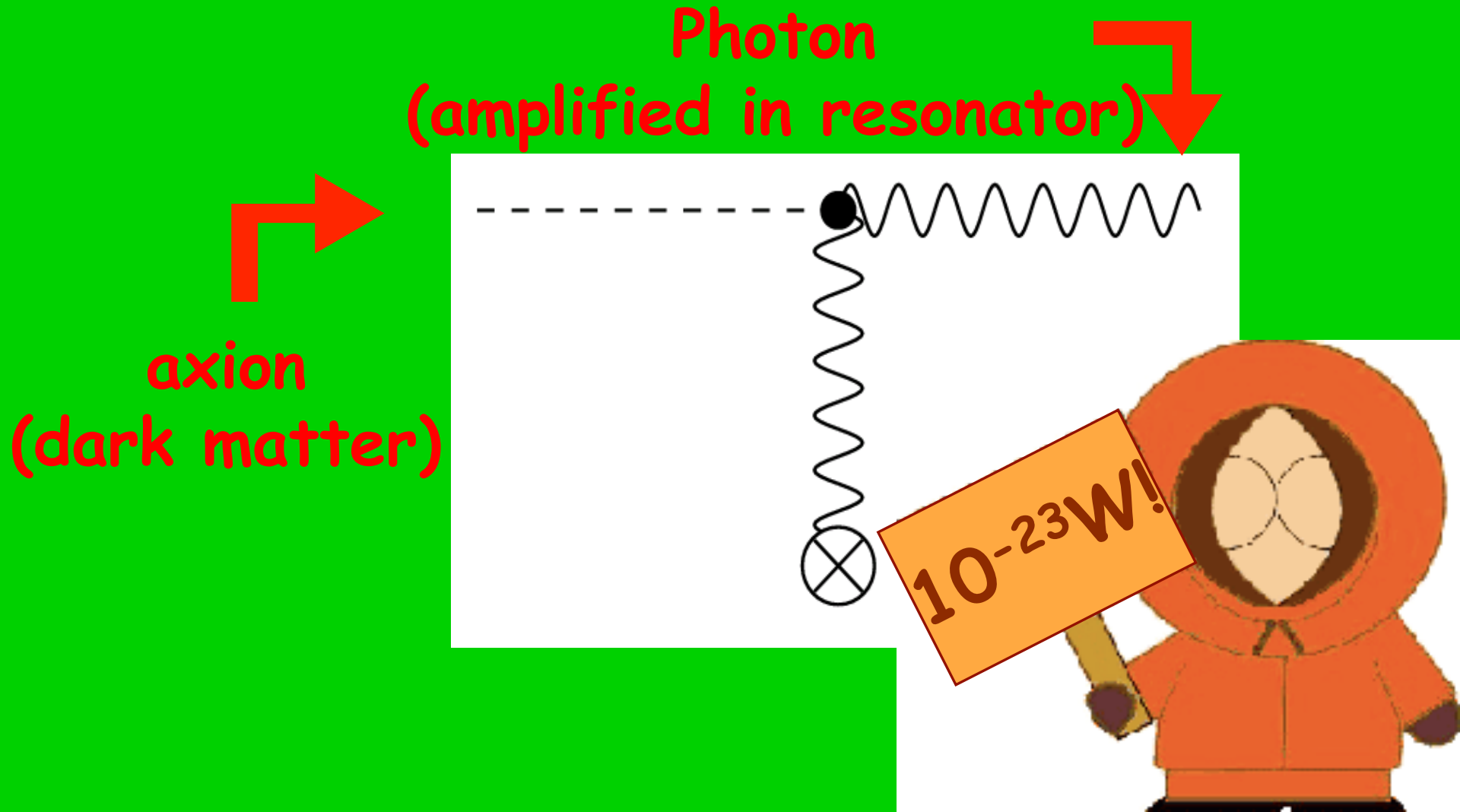
Virial velocity
in galaxy halo!

An extremely sensitive probe!!!

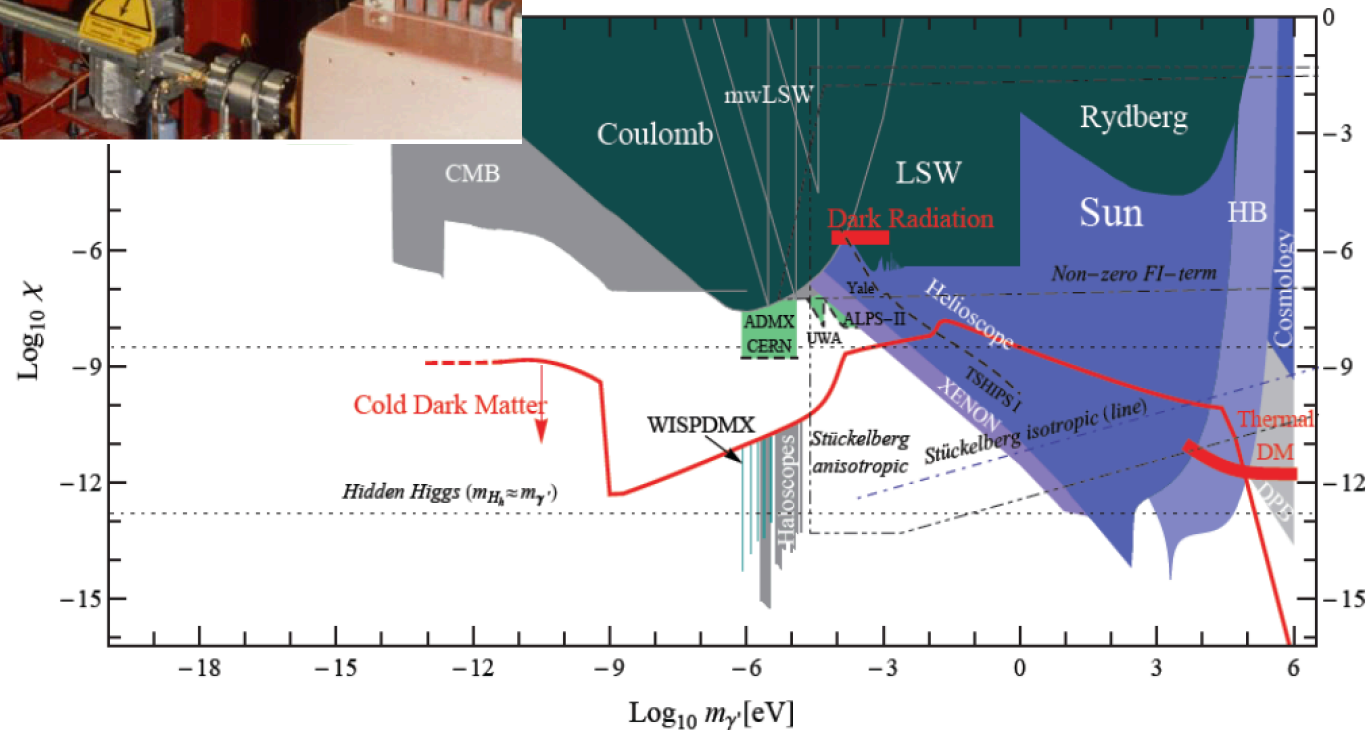
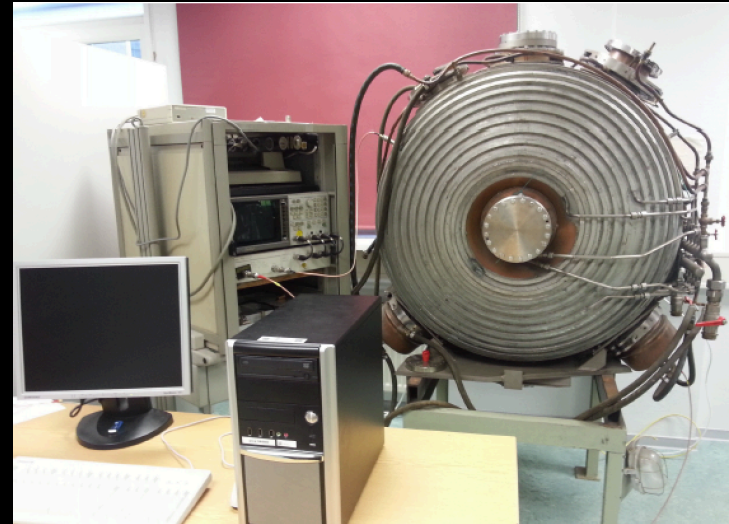
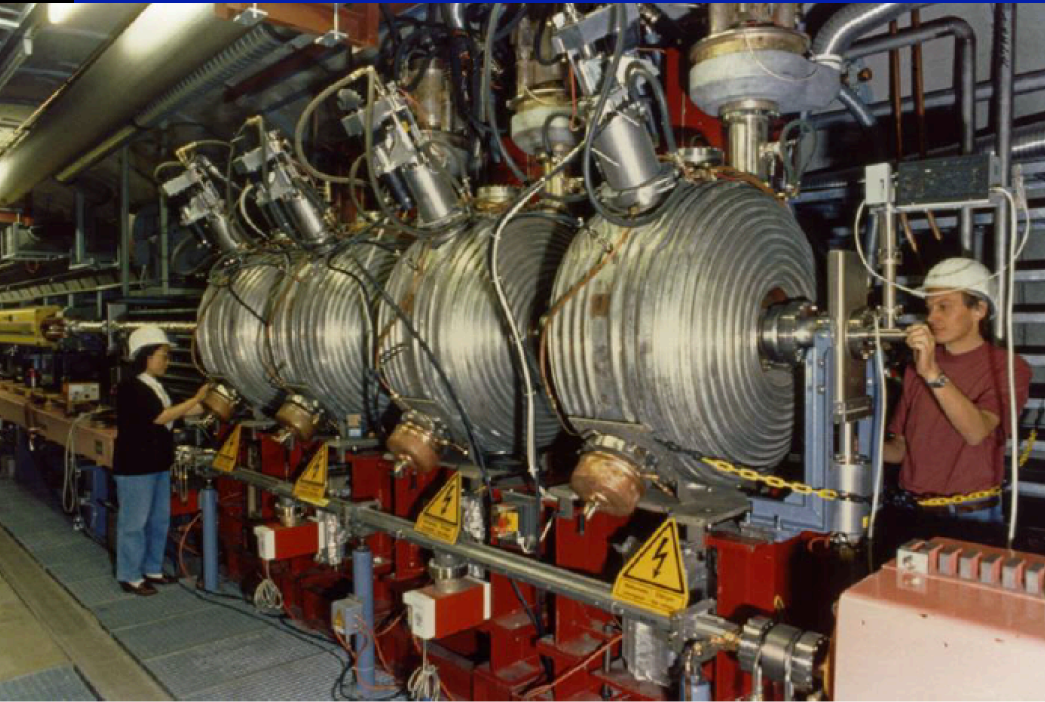


Electricity from Dark Matter :-).

- Photon Regeneration

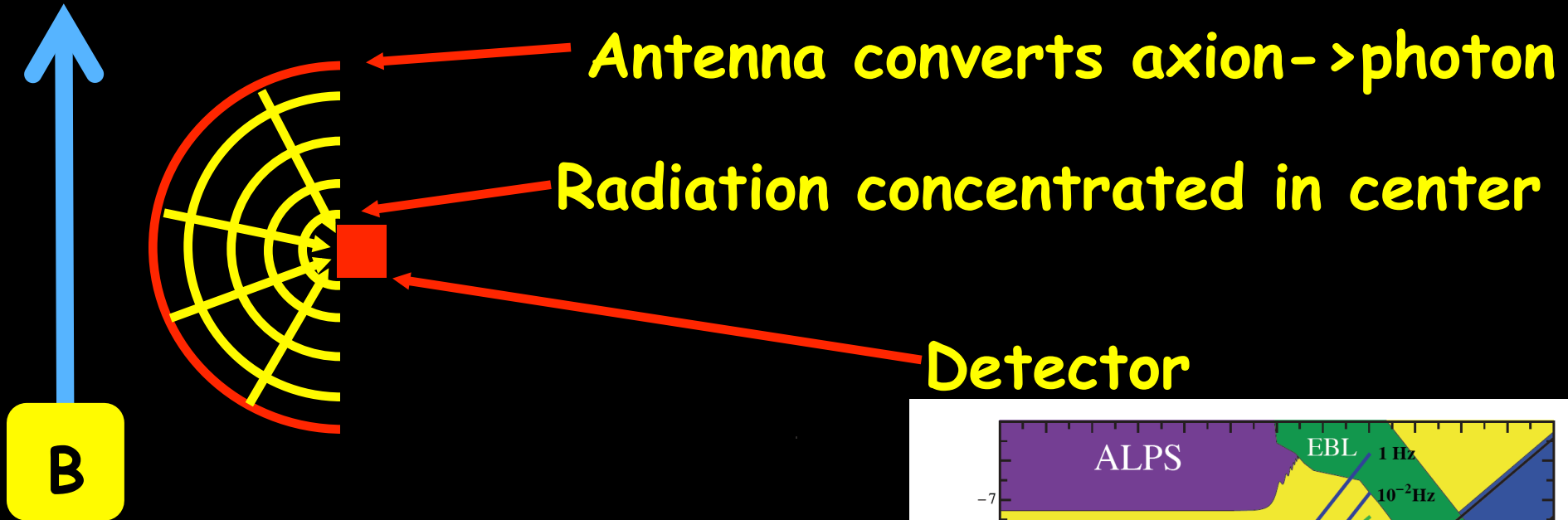


@ DESY + Bonn: WISPDMMX

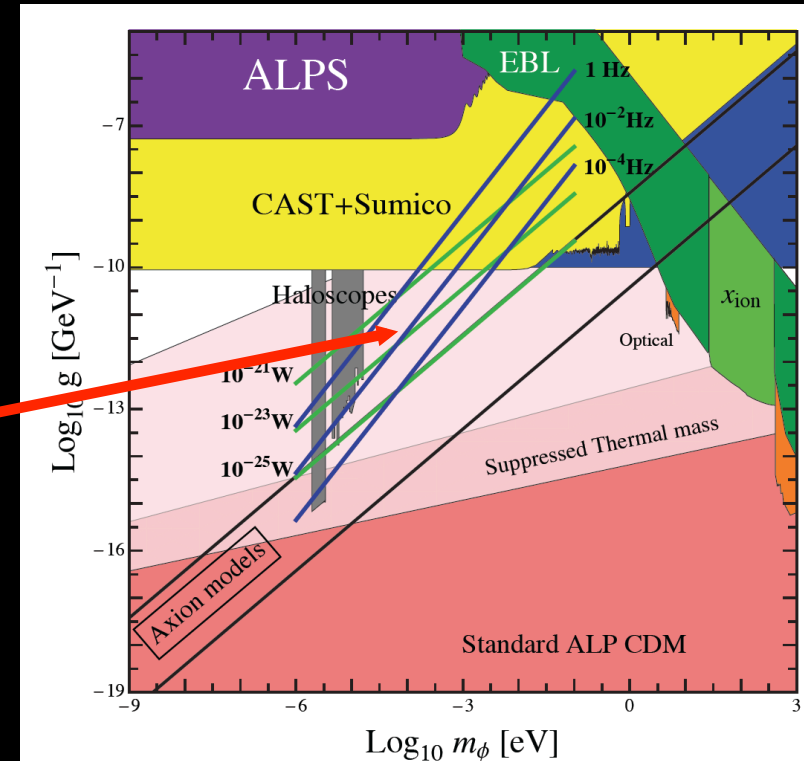


Broadband Search Strategy

Dark Matter Antenna



Probes here;
very sensitive!!

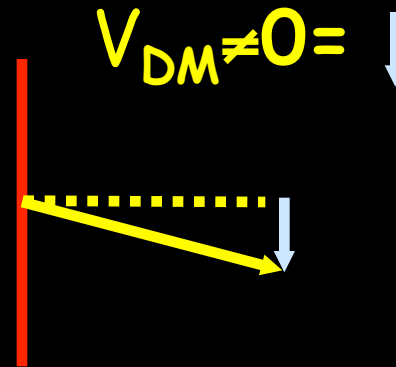
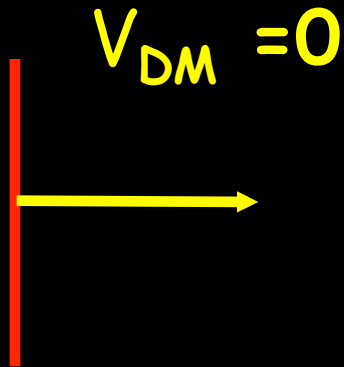


Recycle Auger mirror



A Dream for Astrology ehnm Astronomy

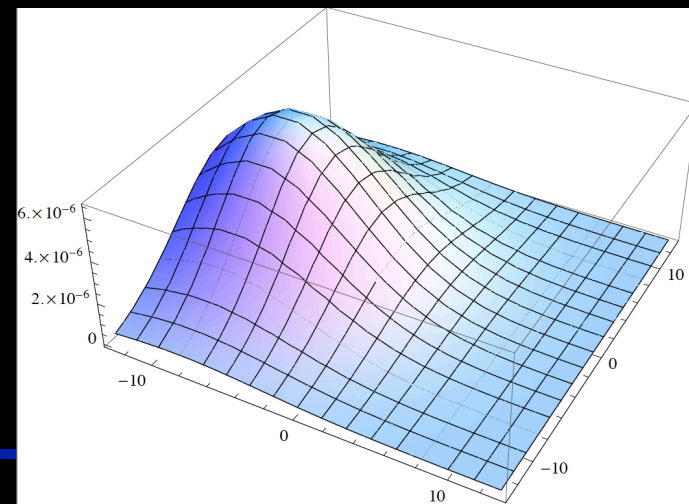
- Emission from moving dark matter



- A picture of the DM-velocity distribution



Screen



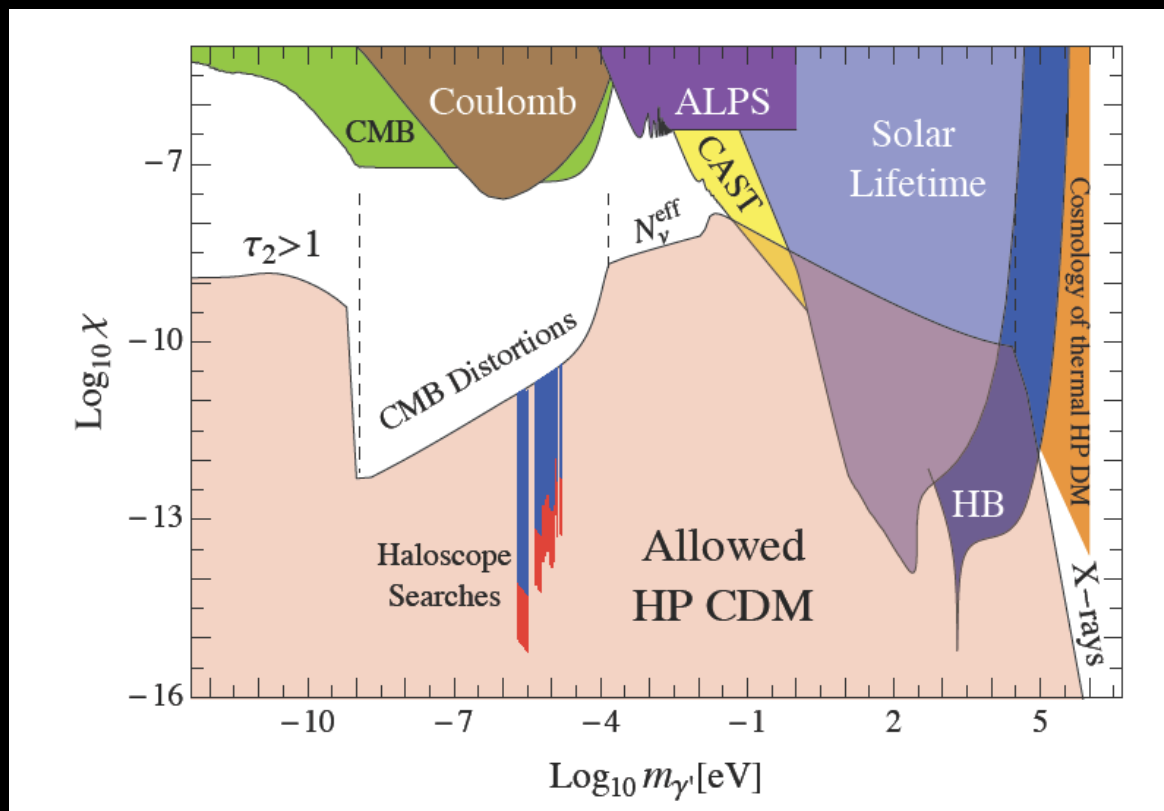
Pre-Final words

Also for hidden photons!!!

- Most things also work for other well motivated light particles.

- E.g

extra (hidden) U(1) bosons=hidden photons!!!



Beyond Photon Couplings

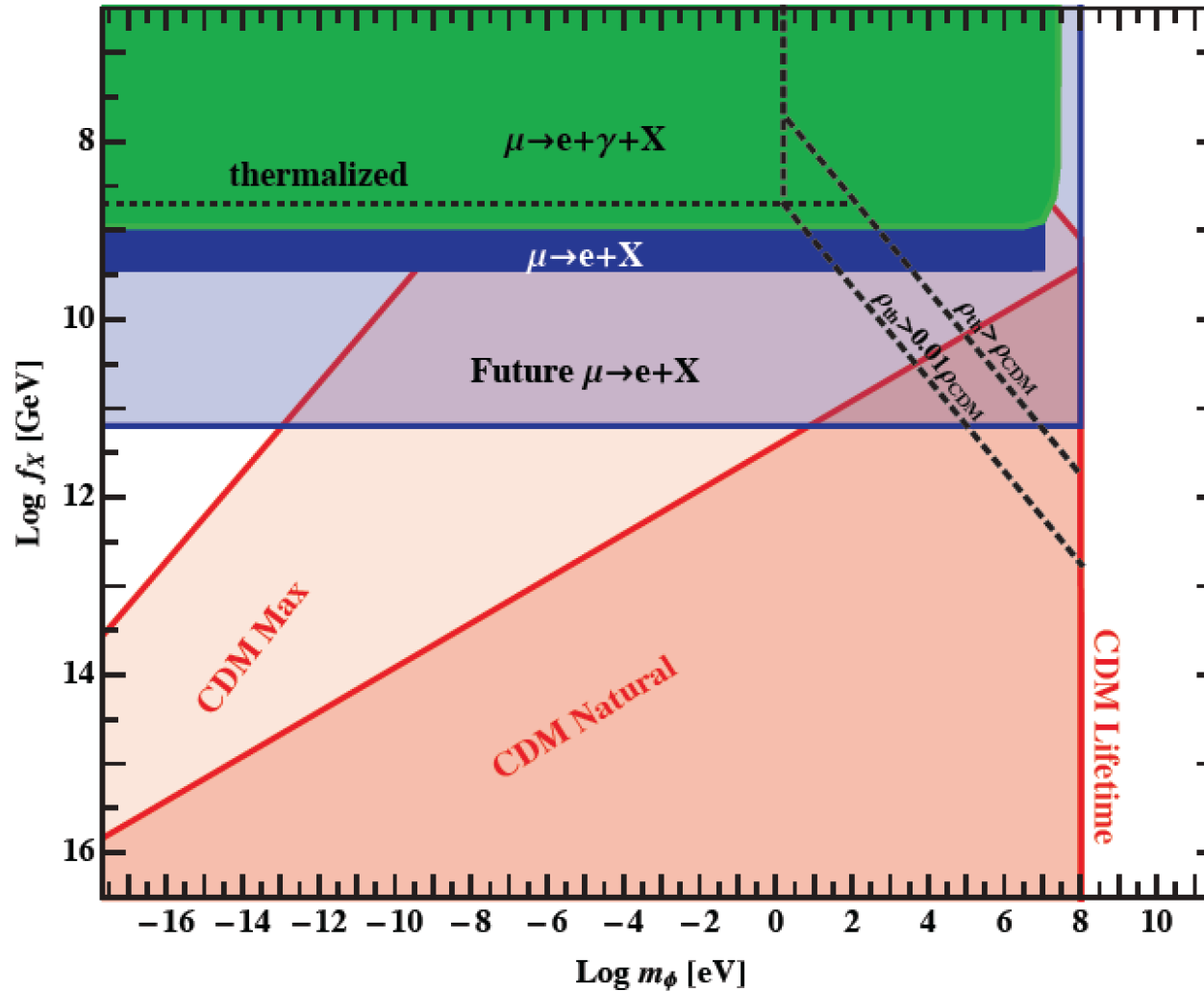
Light bosons can couple to fermions

- Goldstone bosons naturally couple to fermions (charged under the symmetry)
- E.g. Family symmetry changing e into μ

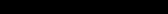
$$(\partial_\mu \phi) \bar{\mu} \gamma^\mu e + h.c.$$

Interestingly these couplings are not very constrained from astrophysics!
(not enough energy to make μ s

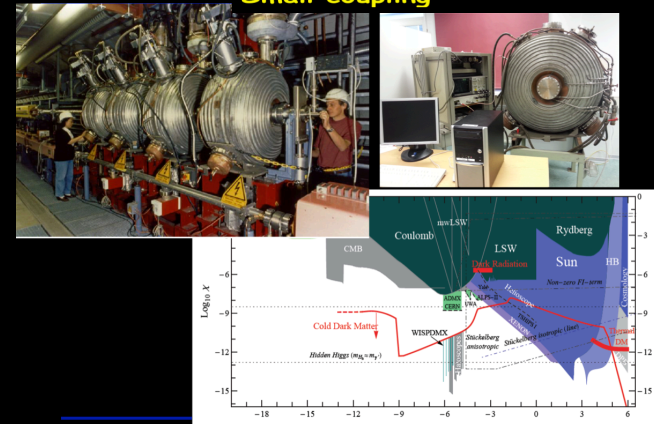
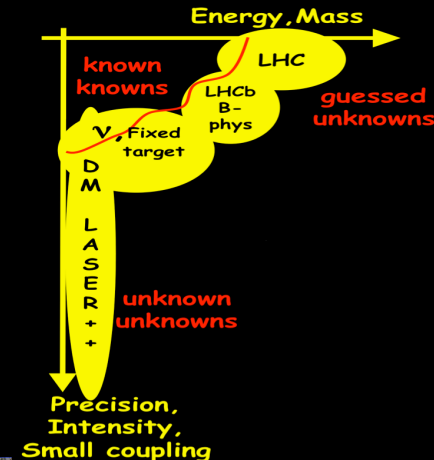
Plenty of room for dark matter



Conclusions

-  explore 'The Low Energy Frontier'

- Dark Matter may be WISPy 😊
 - ➔ New Search opportunities!
 - ➔ Searches ongoing!



Hidden sector

