

WISPy Cold Dark Matter

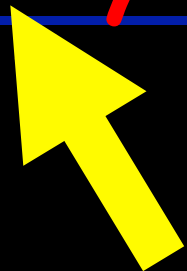


J. Jaeckel^{**}

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A. Ringwald^{*}, F. Rompineve^{**}, K. Schmidt-Hoberg^{*}, L. Witkowski^{**}
and The FUNK Collaboration

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WISPy Cold Dark Matter



Weakly interacting sub-eV particle

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Example WISP:

Axions in a nutshell

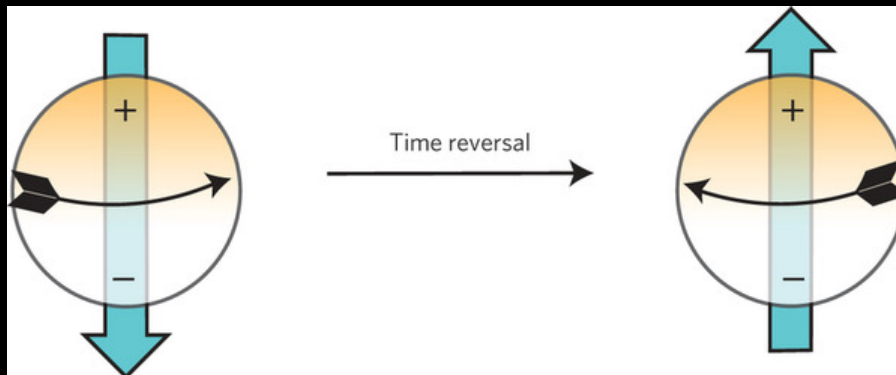
A dirty little secret...

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

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

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

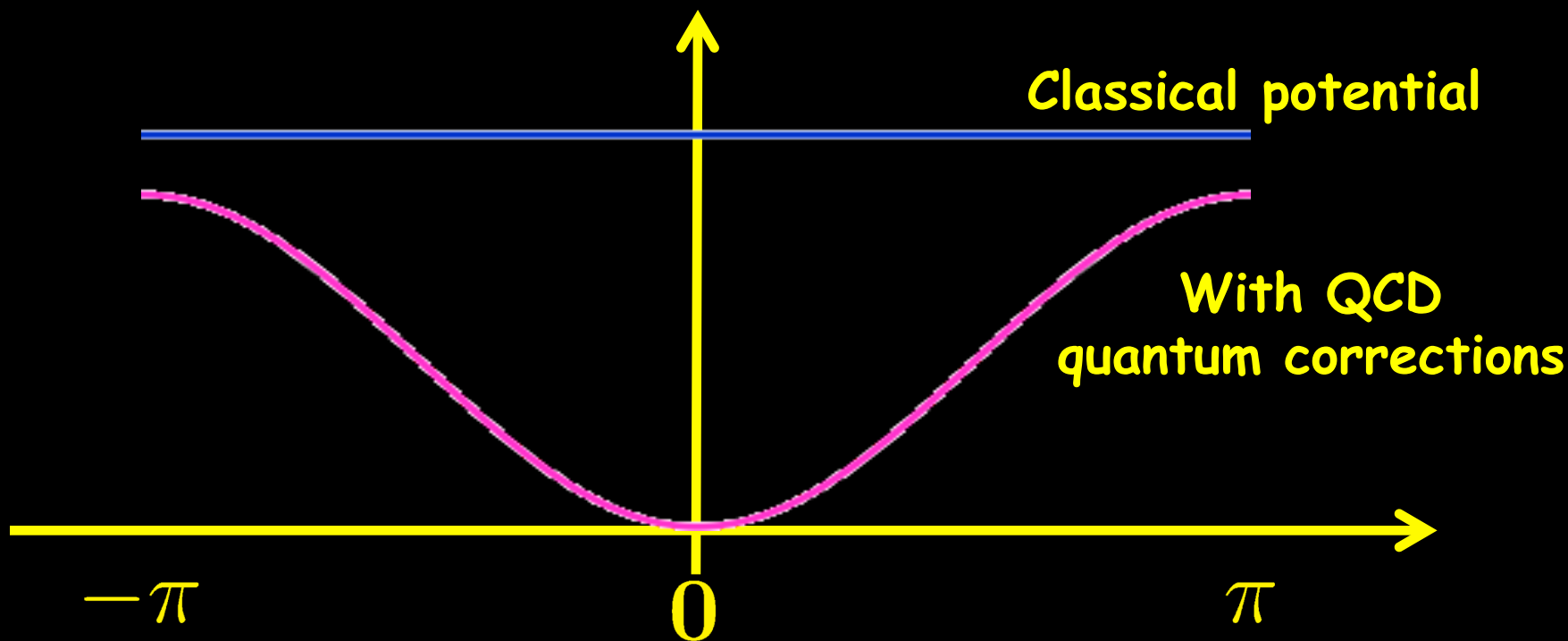
➔ Electric dipole moment
of the neutron!



Not found
➔ $\theta \sim 0!!!$

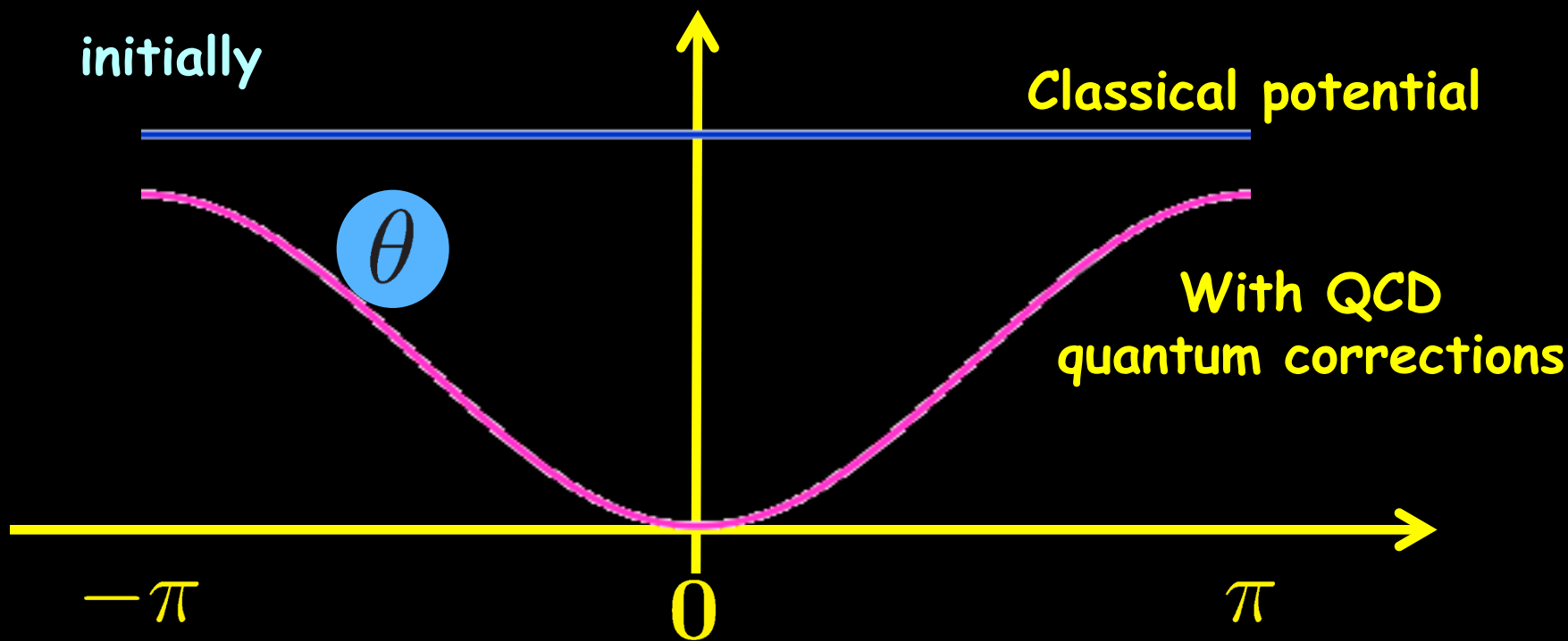
The axion solution to the strong CP problem

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



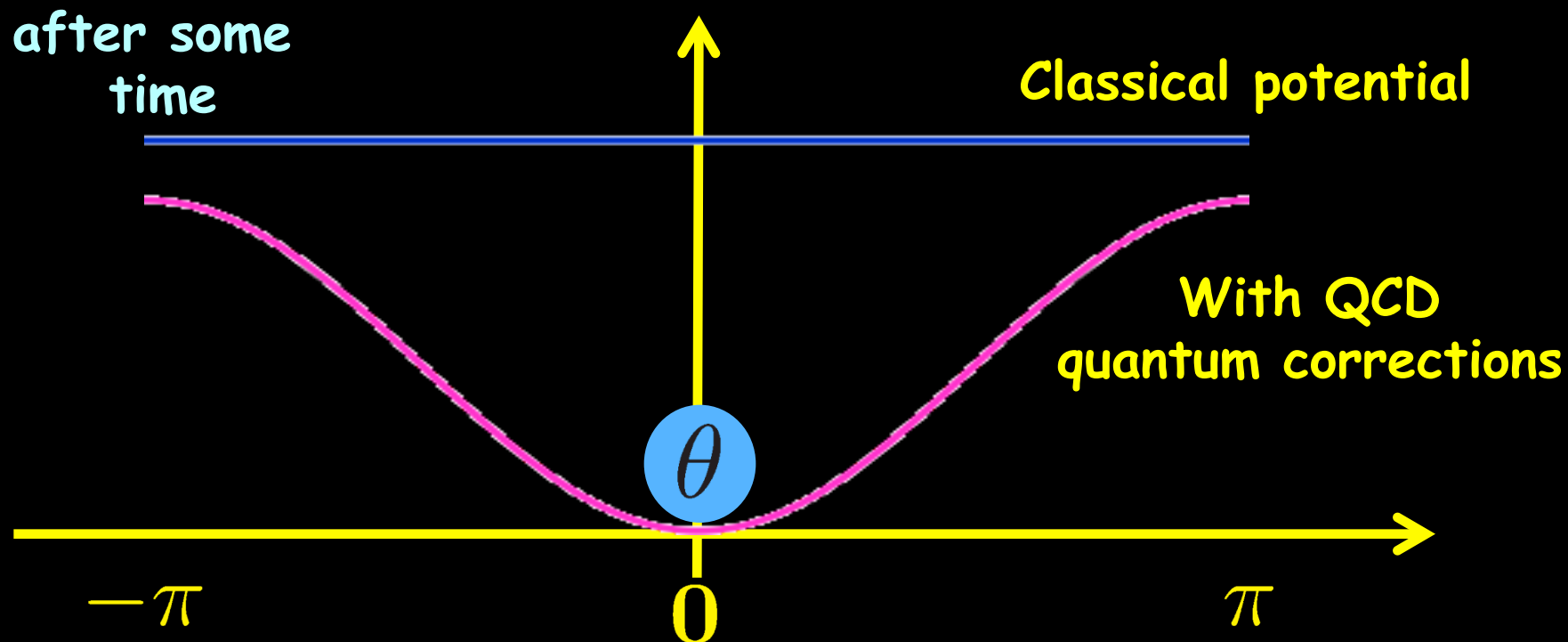
The axion solution to the strong CP problem

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



The axion solution to the strong CP problem

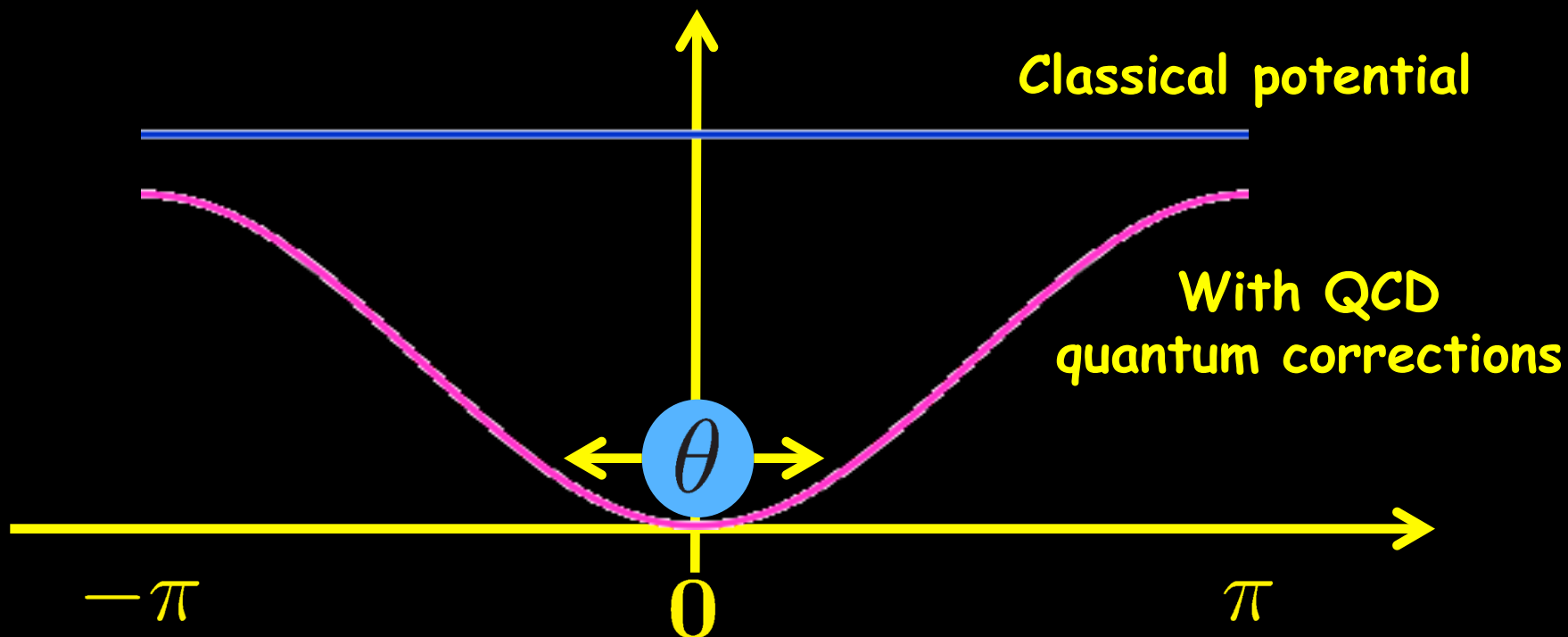
- Make θ dynamical $\rightarrow$ it can change its value



$\rightarrow$ 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

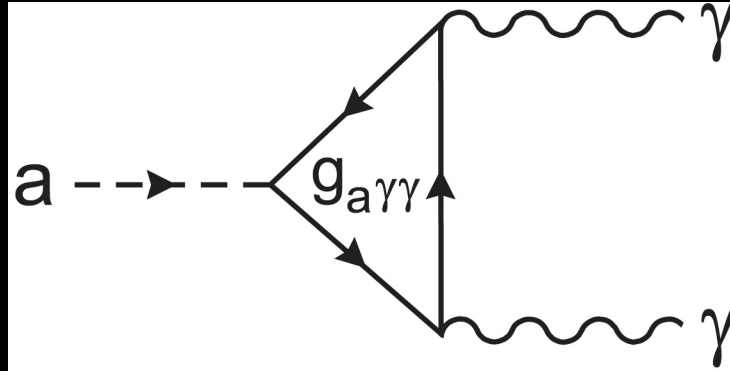


$\rightarrow$ Can still move

$\rightarrow$ 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 couples to two photons



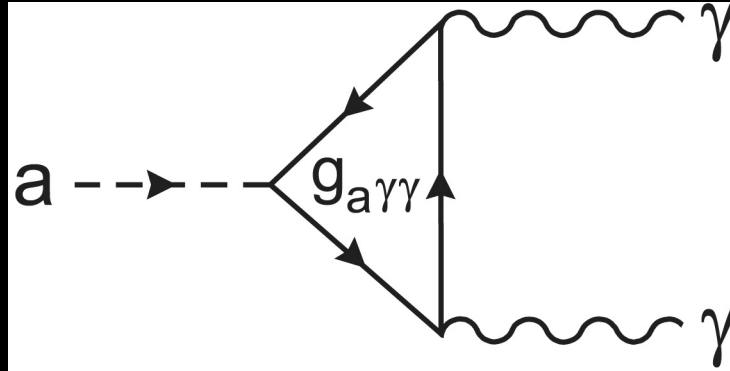
$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}\partial_\mu a\partial^\mu a - \frac{1}{2}m^2 a^2 - \frac{1}{4}g_{a\gamma\gamma}aF^{\mu\nu}\tilde{F}_{\mu\nu} + \dots$$

Coupling to two photons

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

Because: Very large

Axion is very light



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

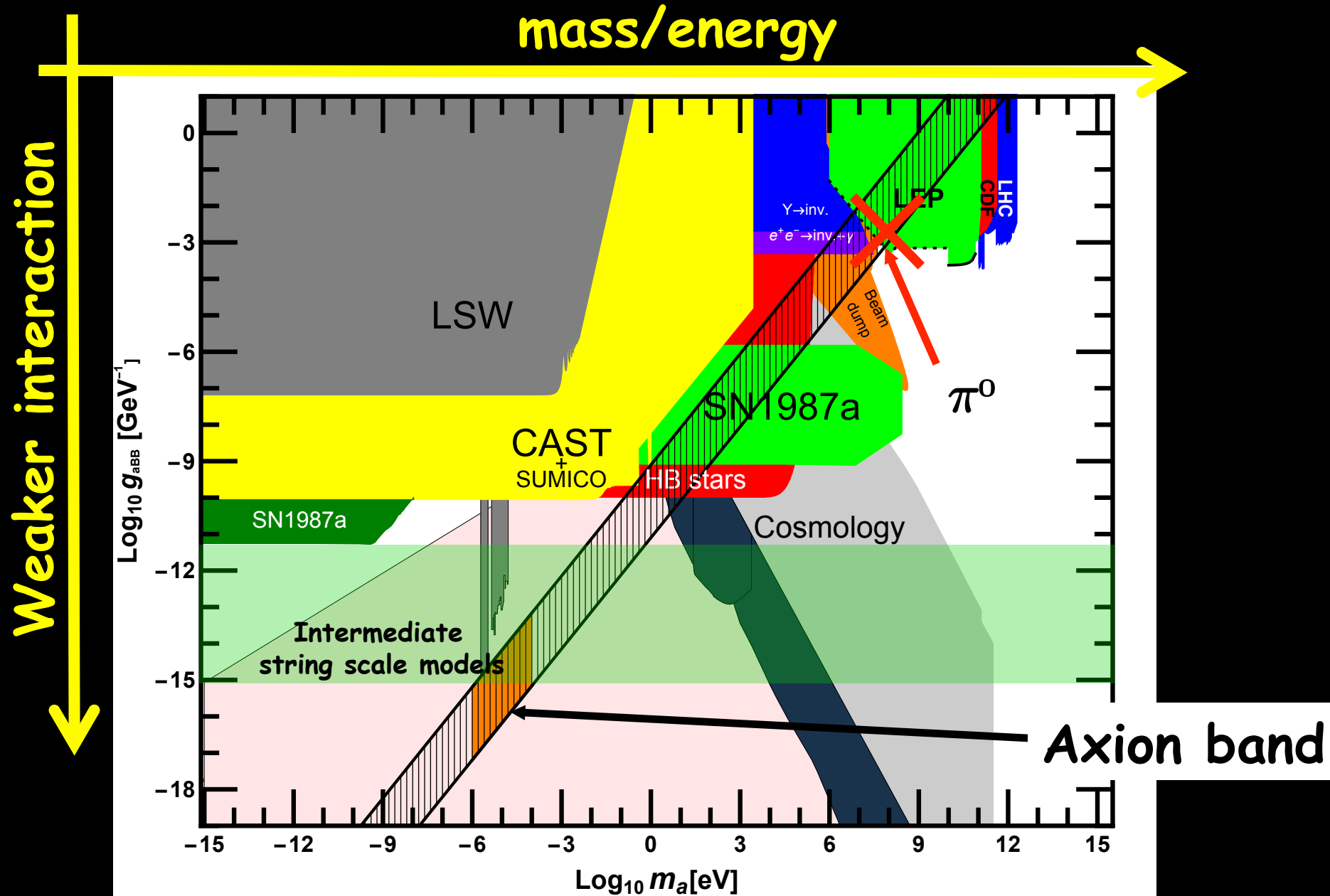
Mass

Very very small

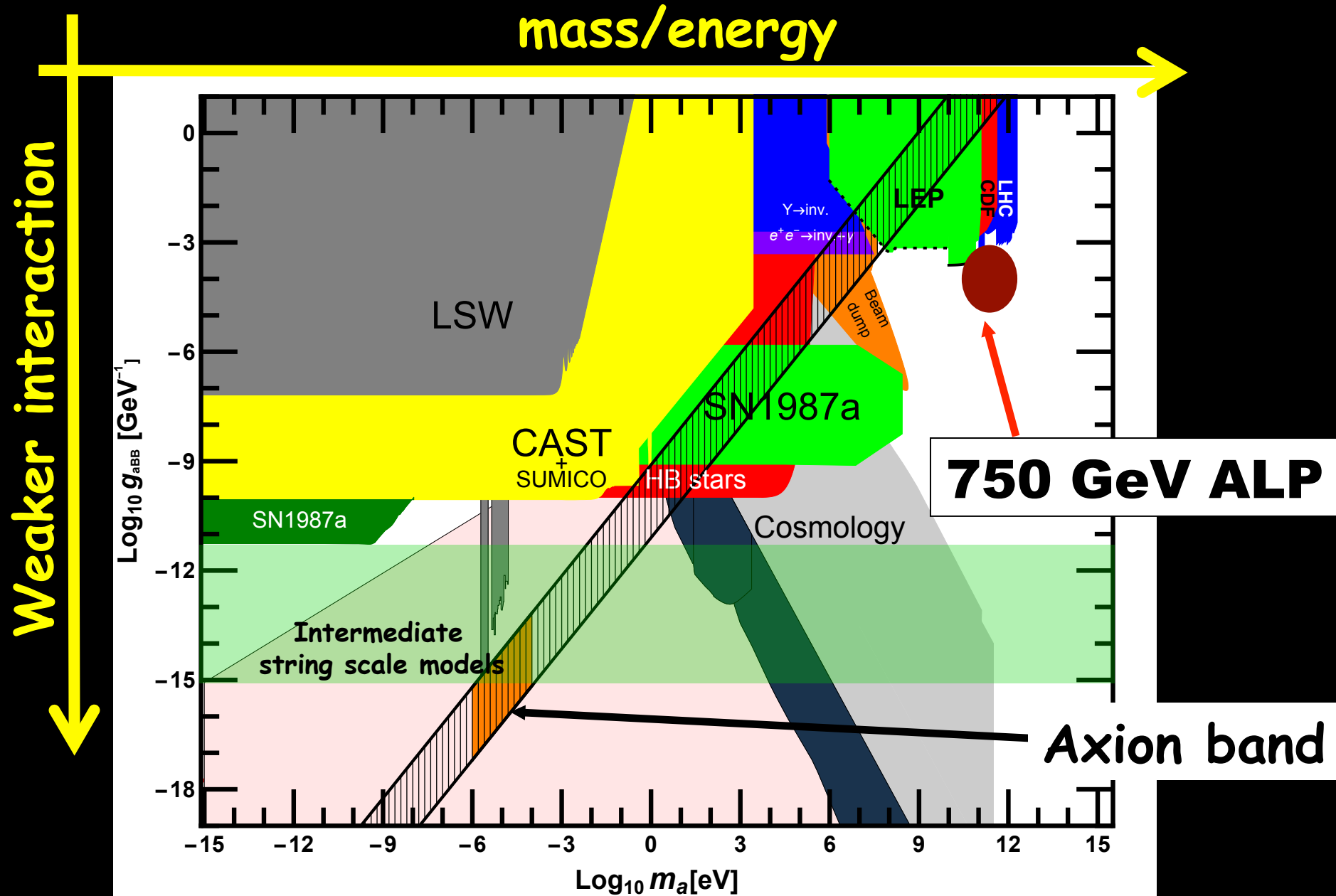
Because: Very large

$$m \sim \frac{m_\pi^2}{f_a}$$

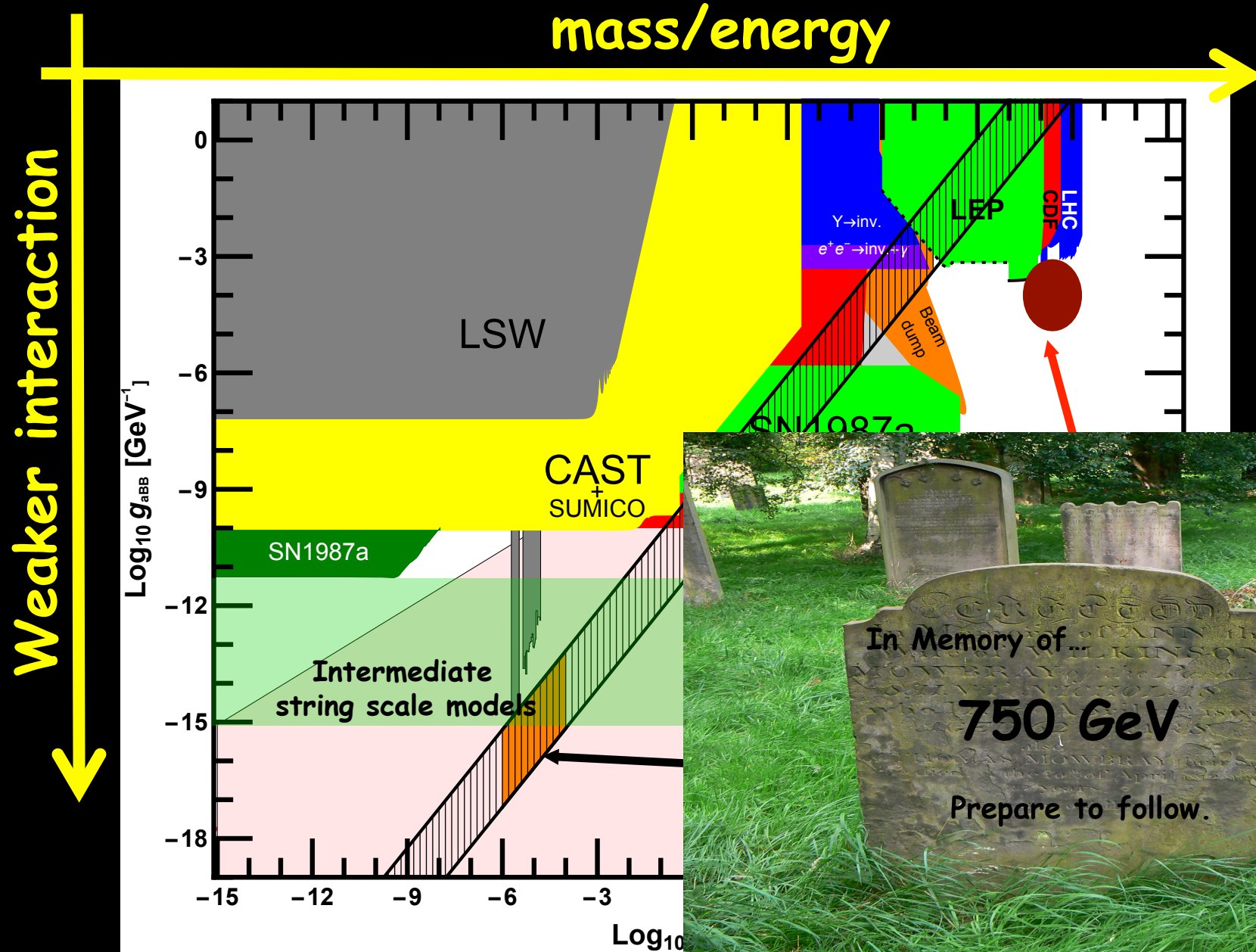
Axion-like Particles



Axion-like Particles

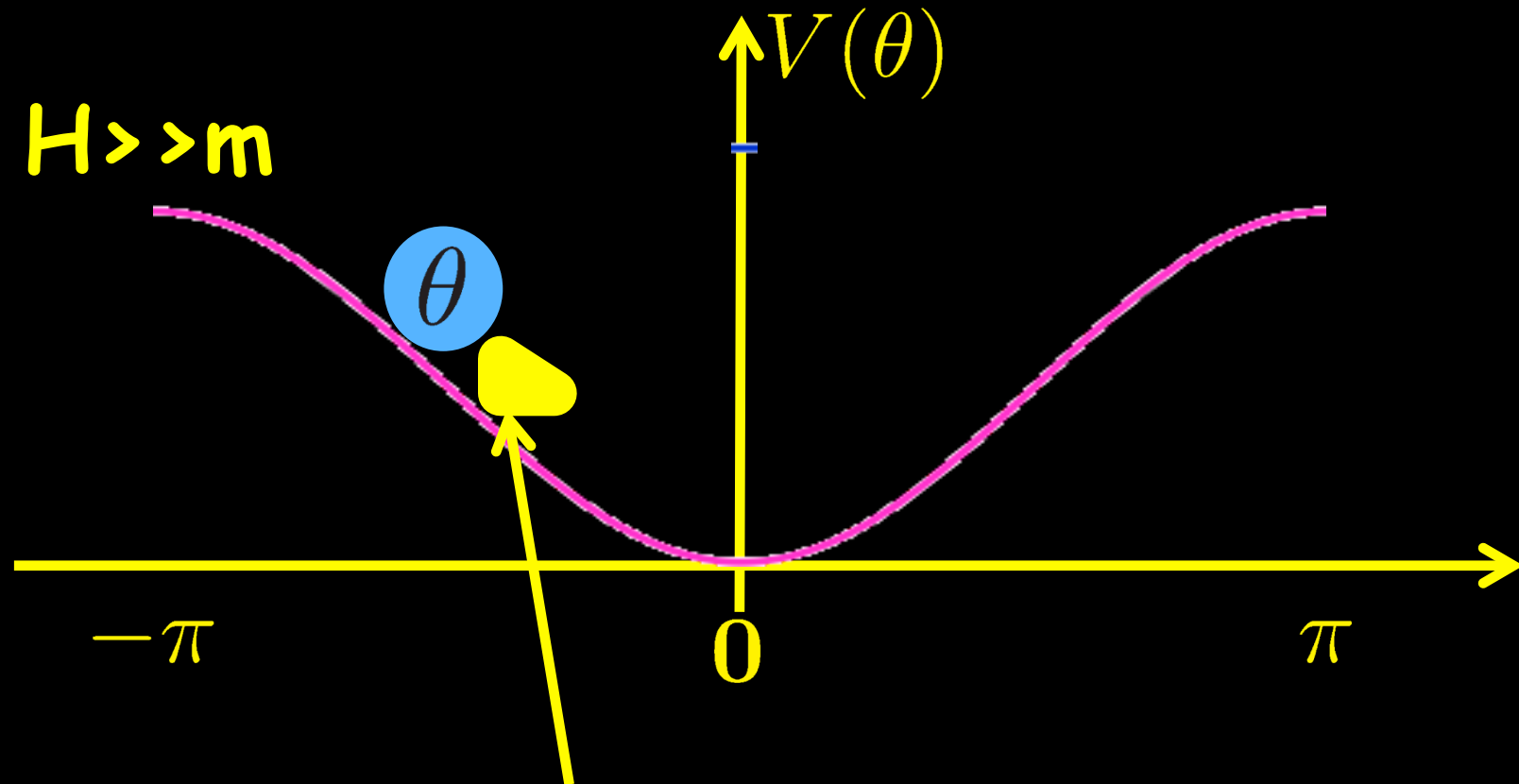


Axion-like Particles



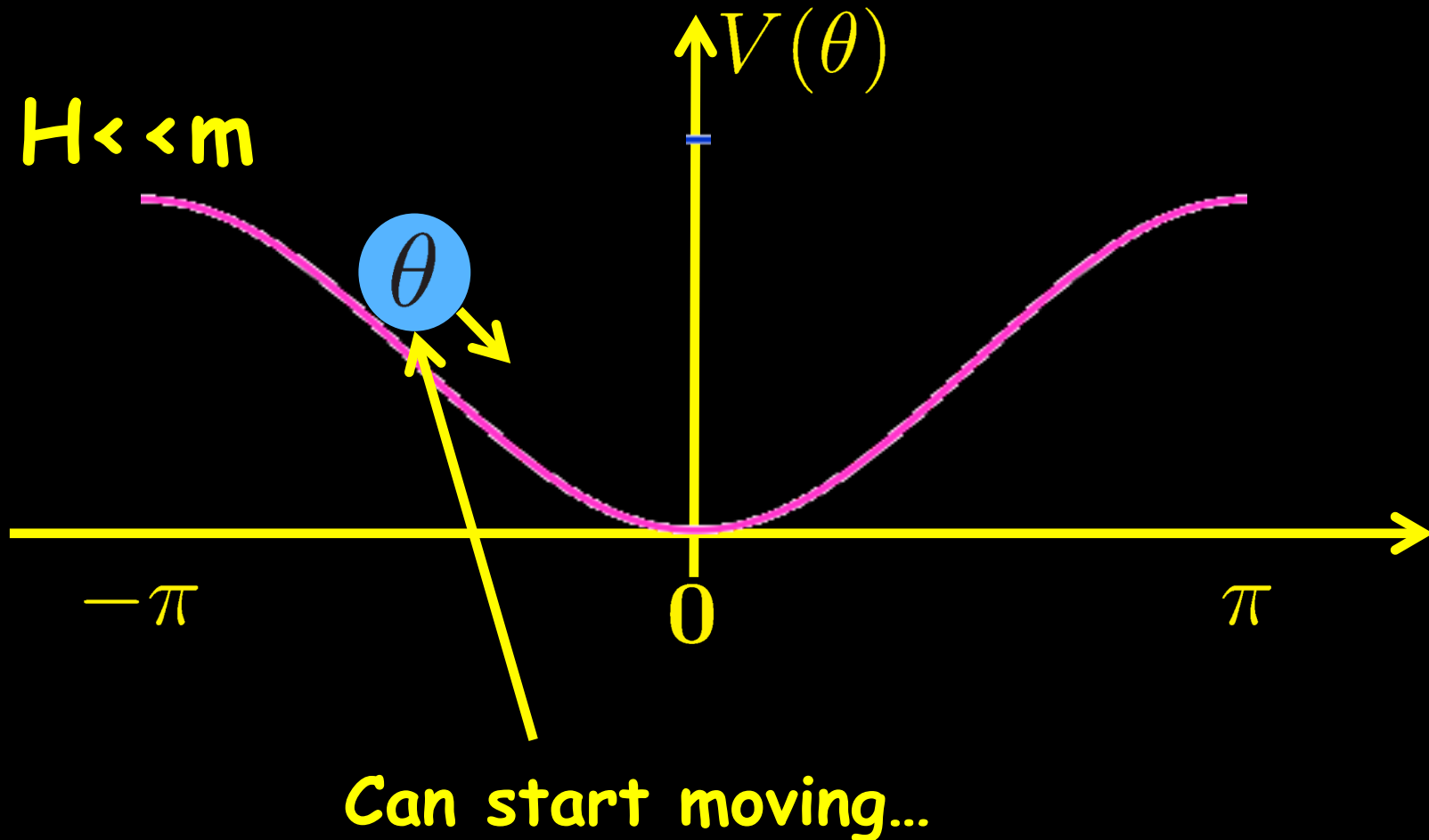
Dark Matter(s)

The axion has no clue where to start

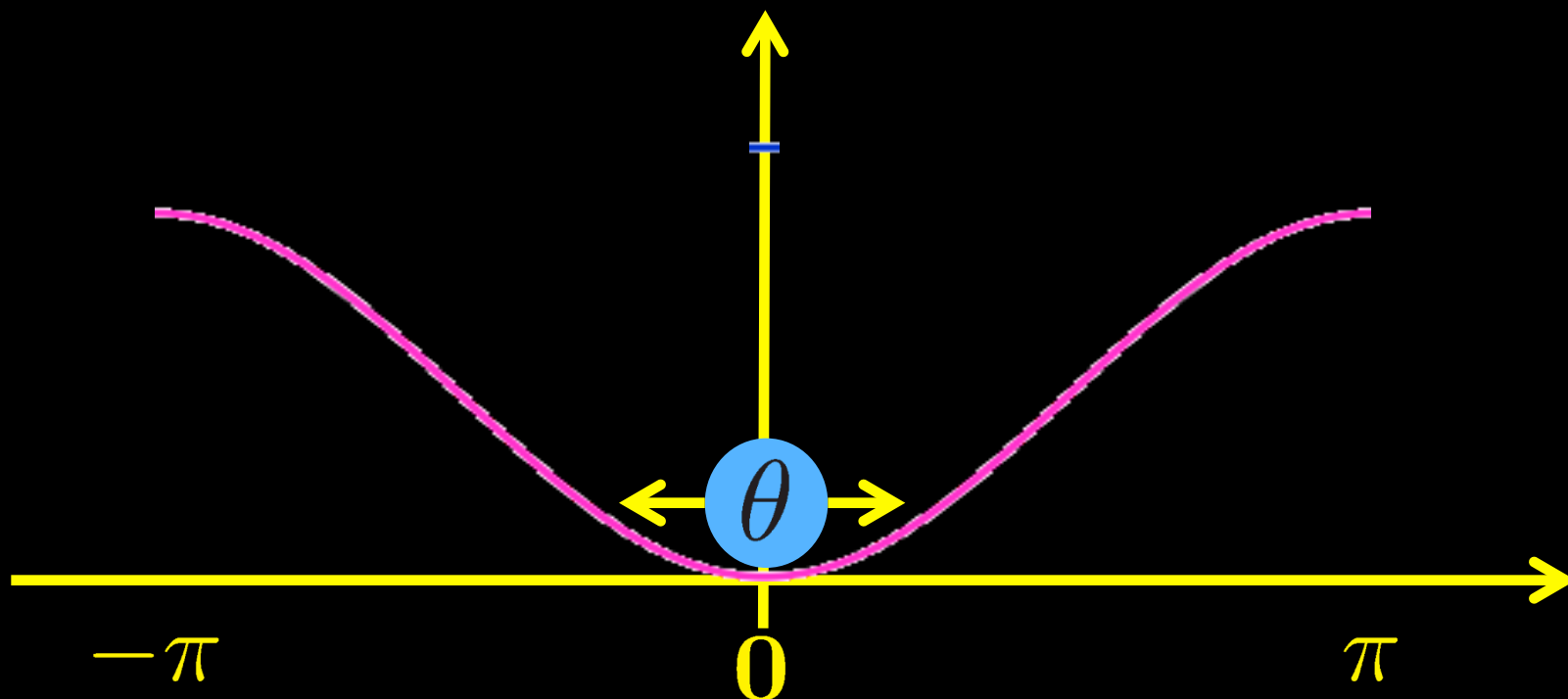


Field is stuck because of Hubble "breaking"

The axion has no clue where to start



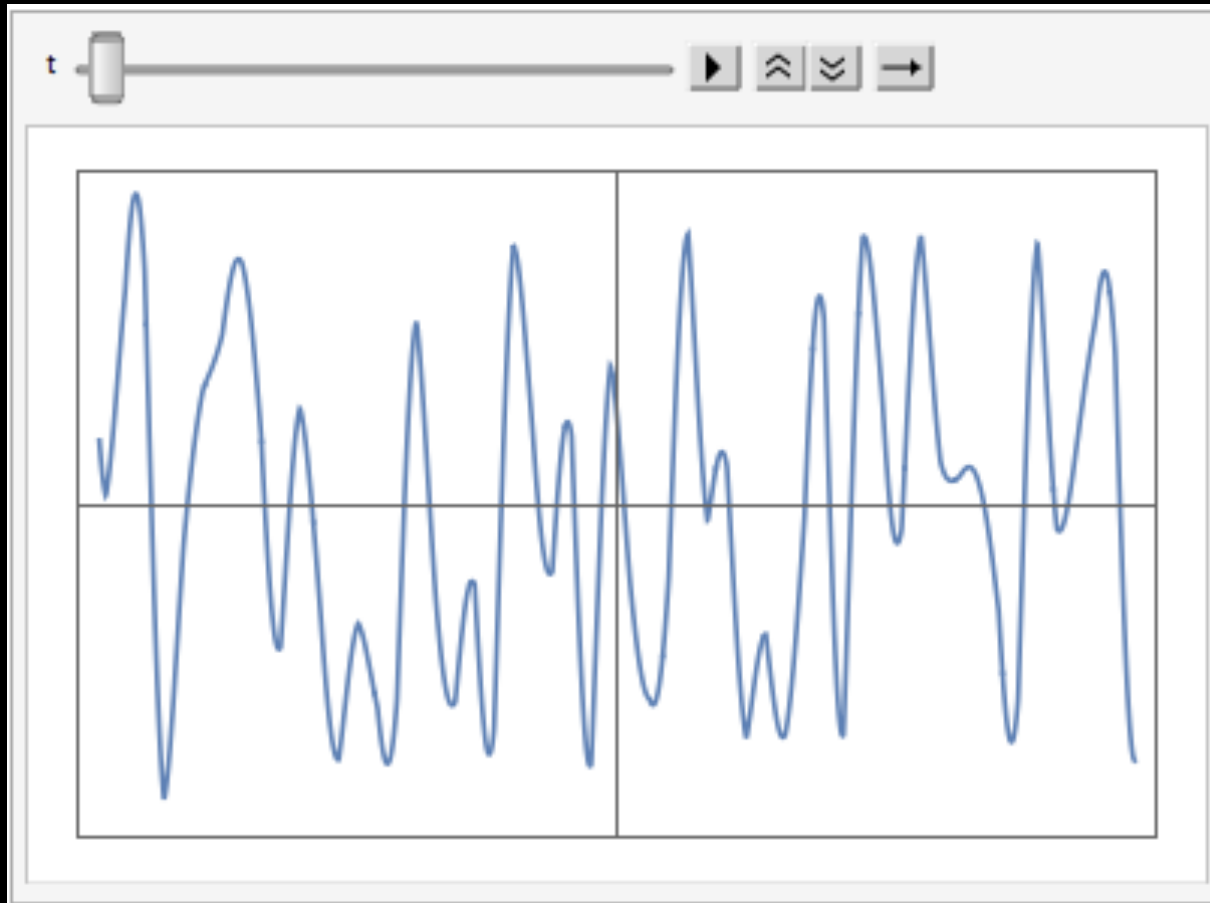
The axion solution to the strong CP problem



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

Why Cold? Inflation!

Field
value

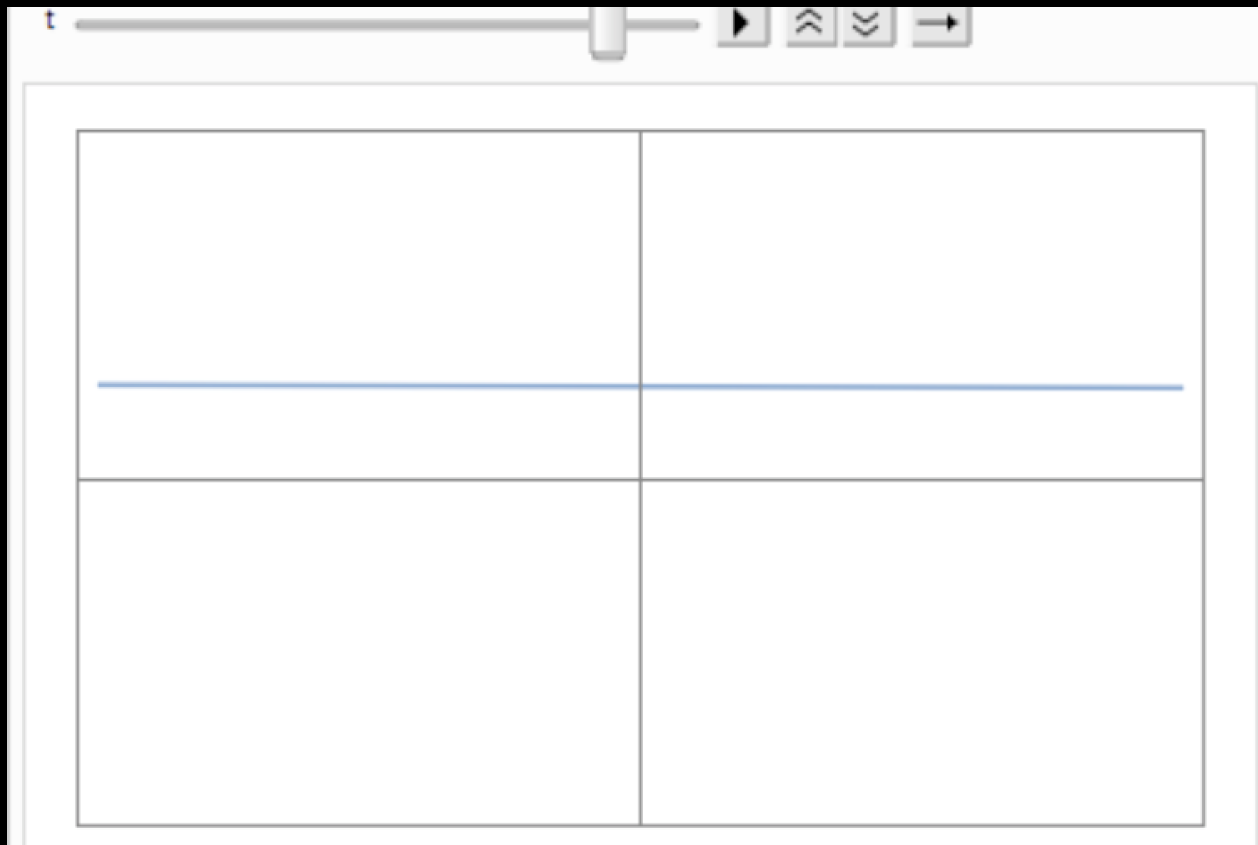


space

$$velocity \sim \frac{p}{m} \sim \frac{\hbar}{m} \frac{d}{dx} \rightarrow 0$$

Why Cold? Inflation!

Field
value



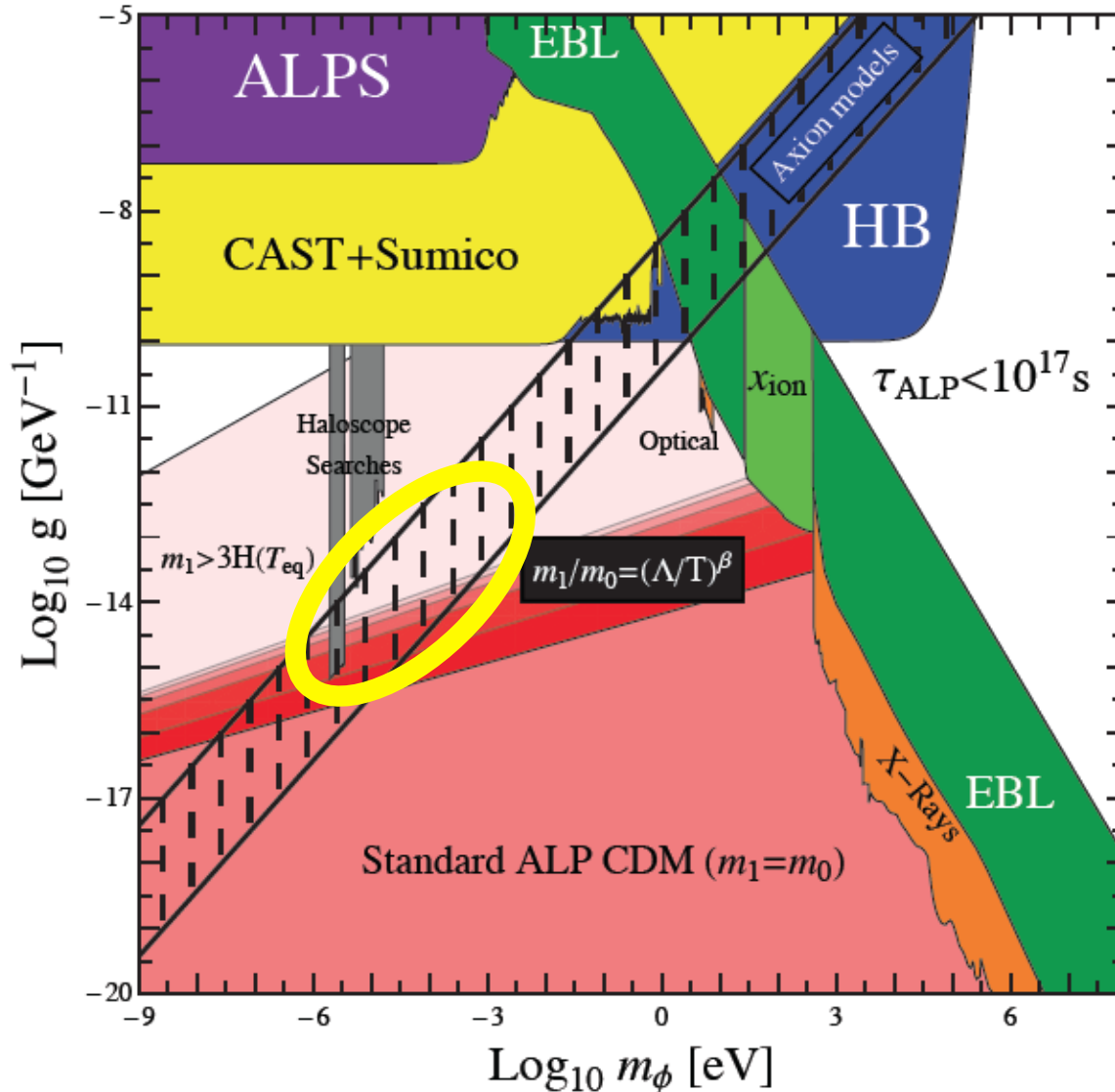
space

$$velocity \sim \frac{p}{m} \sim \frac{\hbar}{m} \frac{d}{dx} \rightarrow 0$$

Axion(-like particle) Dark Matter

$\sim 10^7 \text{ GeV}$

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

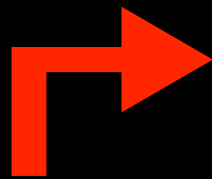


Detecting WISPy
DM

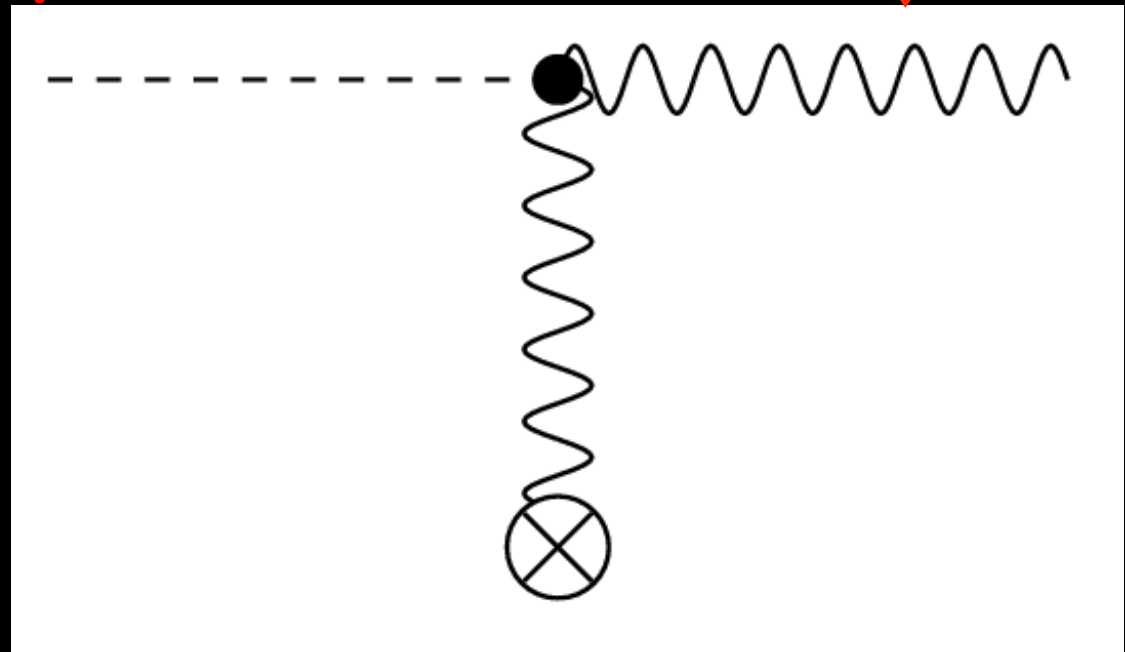
Use a plentiful source of axions

- Photon Regeneration

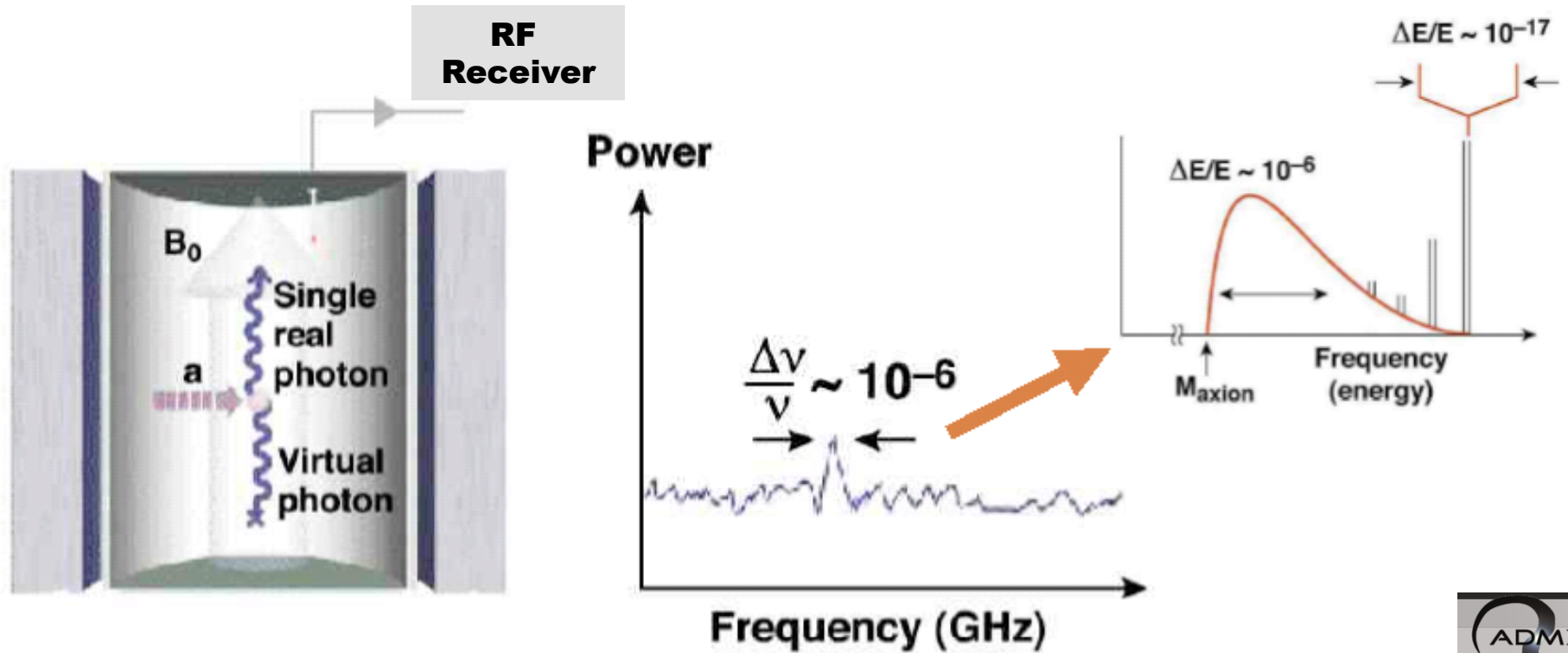
Photon
(amplified in resonator)



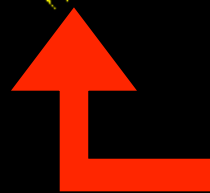
axion
(dark matter)



Signal: Total energy of axion

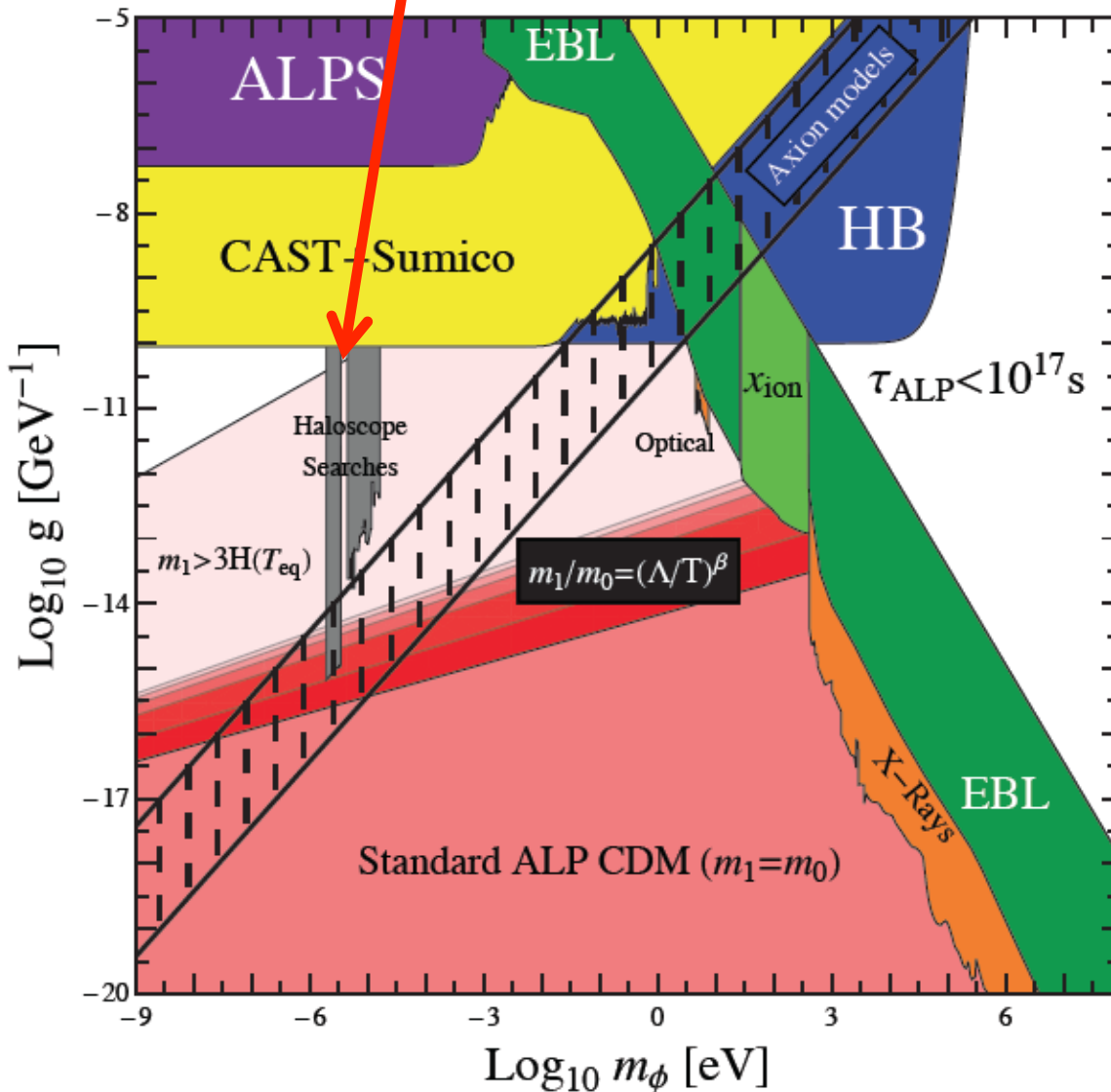


$$h\nu = m_a c^2 [1 + \mathcal{O}(\beta^2 \sim 10^{-6})]$$

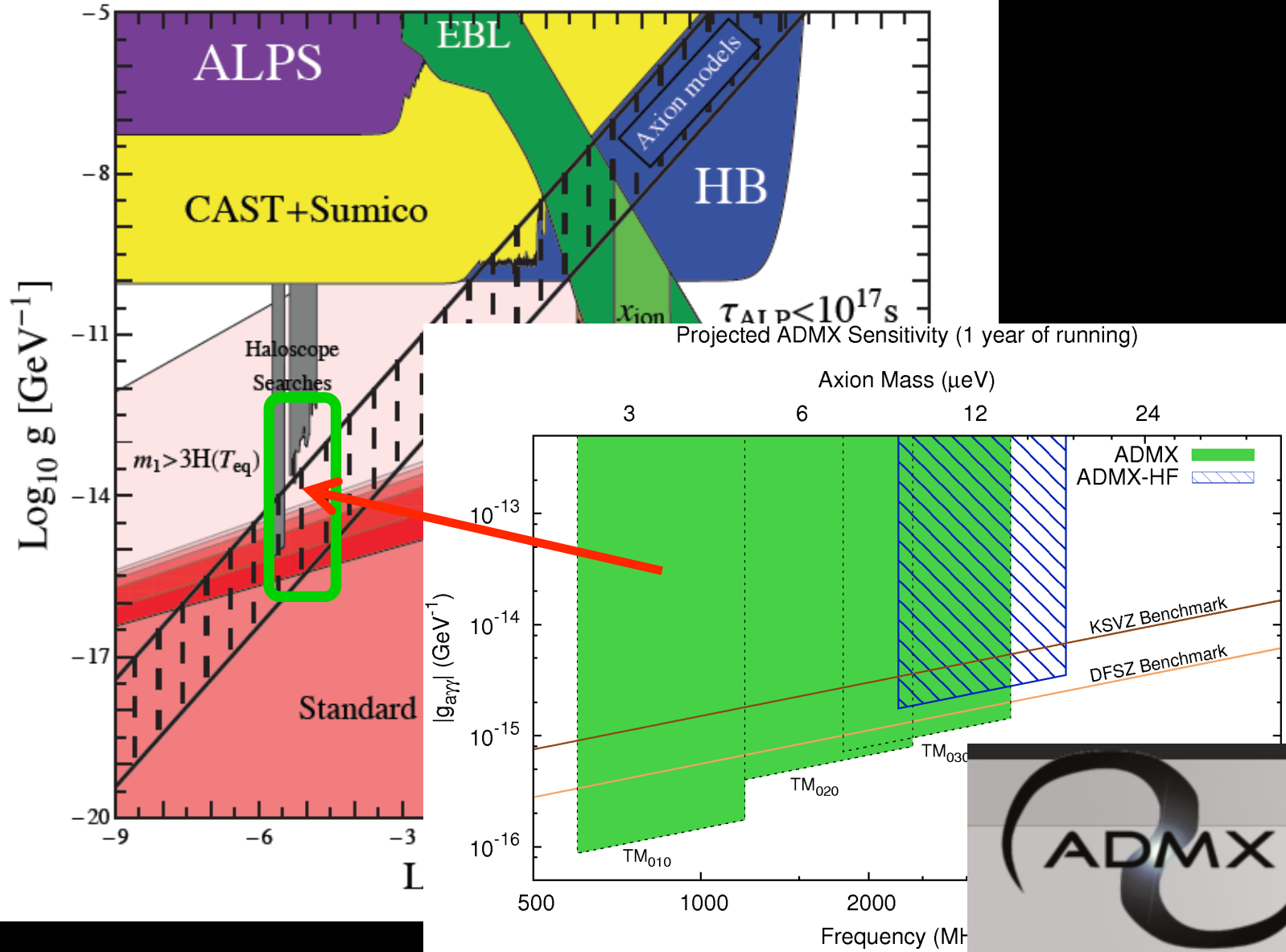


Virial velocity
in galaxy halo!

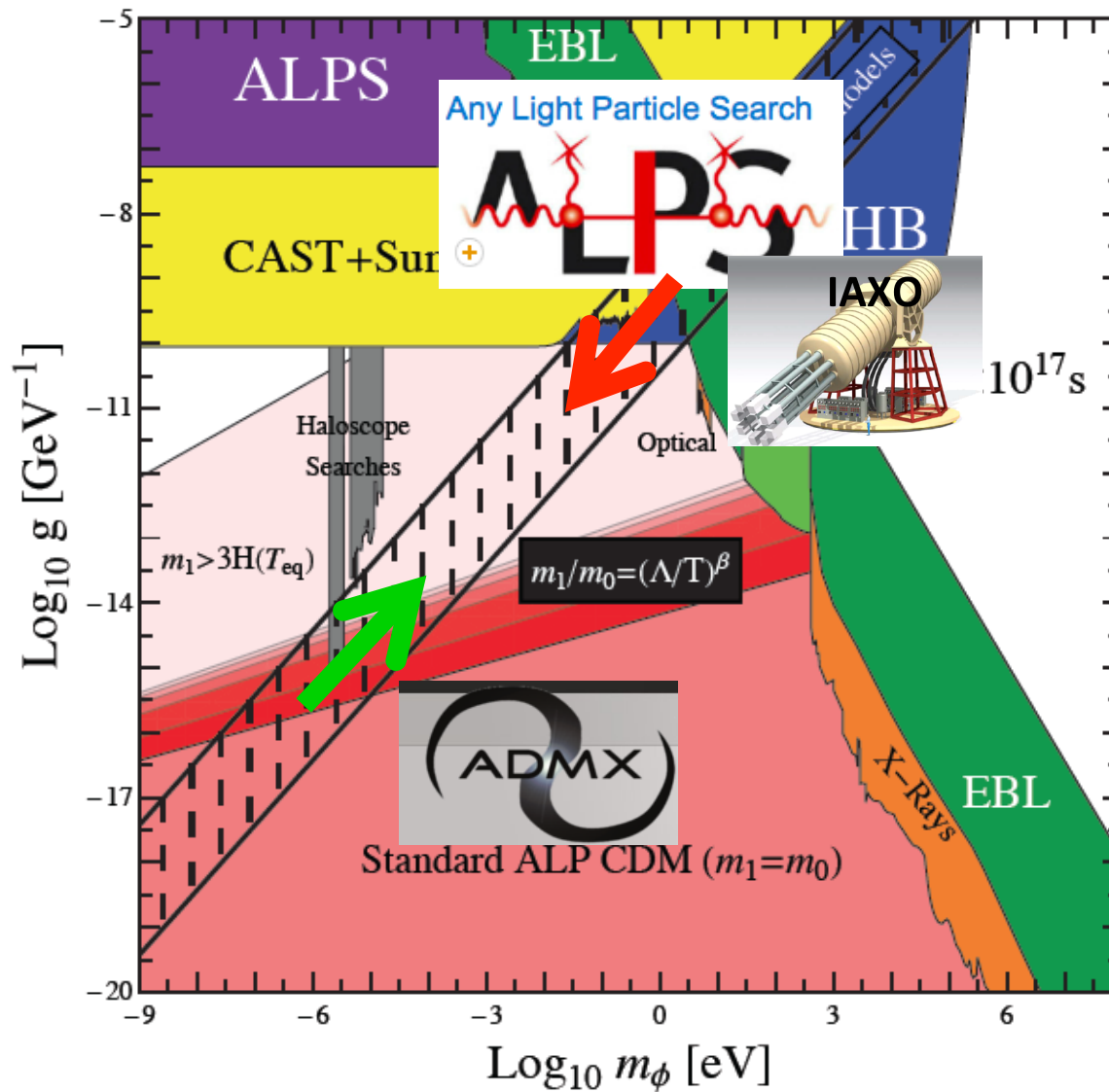
An extremely sensitive probe!!!



A discovery possible any minute!

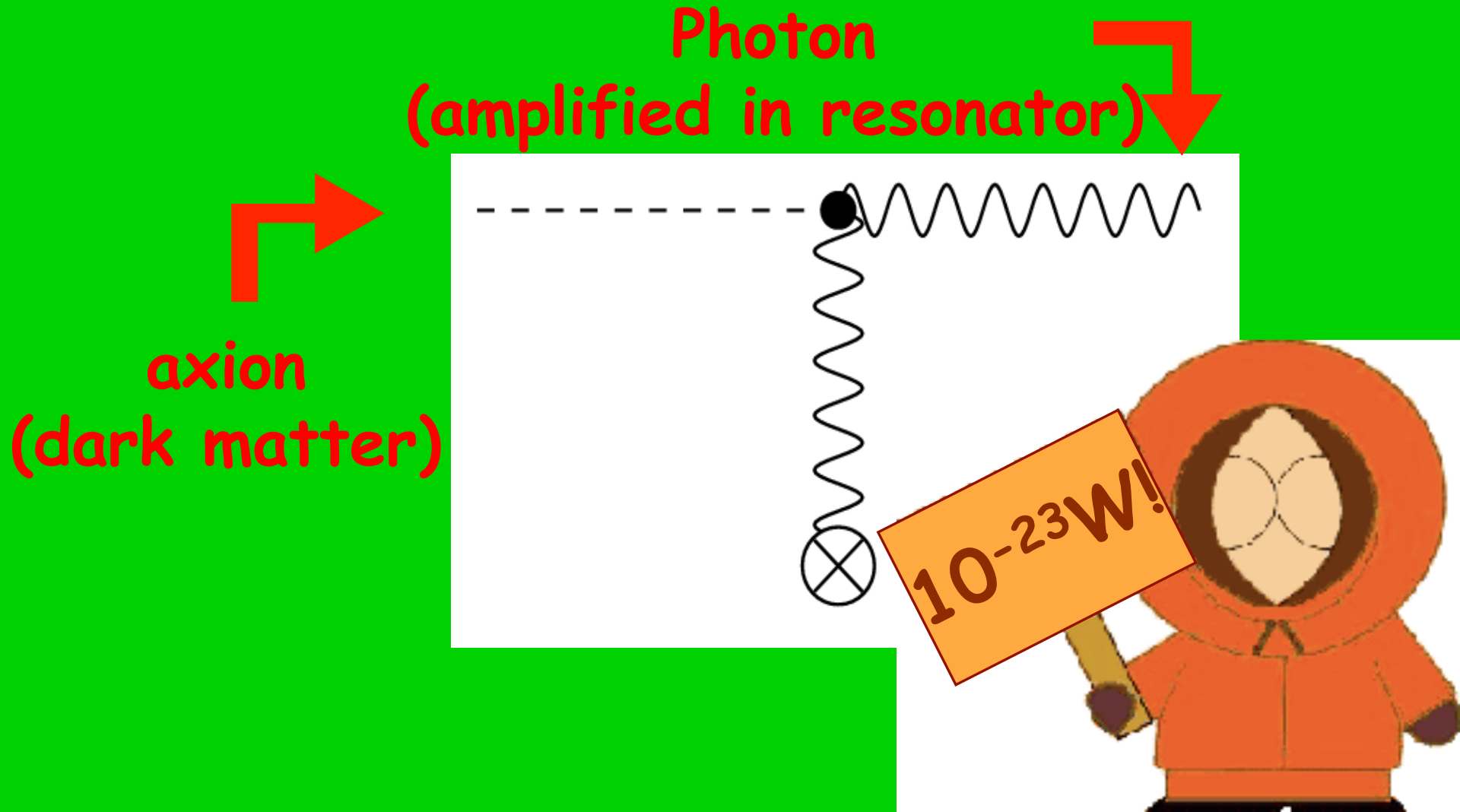


Encircling the axion...



Electricity from Dark Matter :-).

- Photon Regeneration



Really sustainable Energy

- Galaxy contains $(6-30) \times 10^{11}$ solar masses of DM

→ $(3-15) \times 10^{43}$ TWh

@100000 TWh per year (total world today)

→ 10^{38} years ☺

DM power

$$\rho * v \sim 300 \text{ MeV/cm}^3 * 300 \text{ km/s} \sim 10 \text{ W/m}^2$$

compared to 2 W/m^2 for wind

**Dark
Matter**

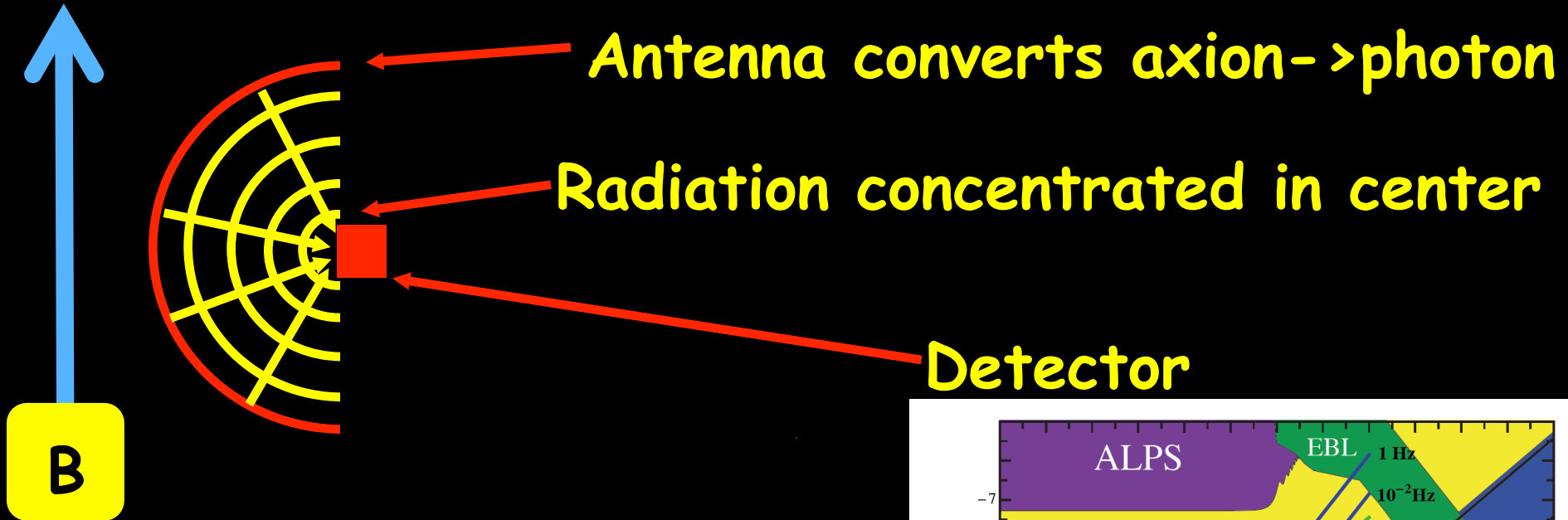


**Dark
Matter**

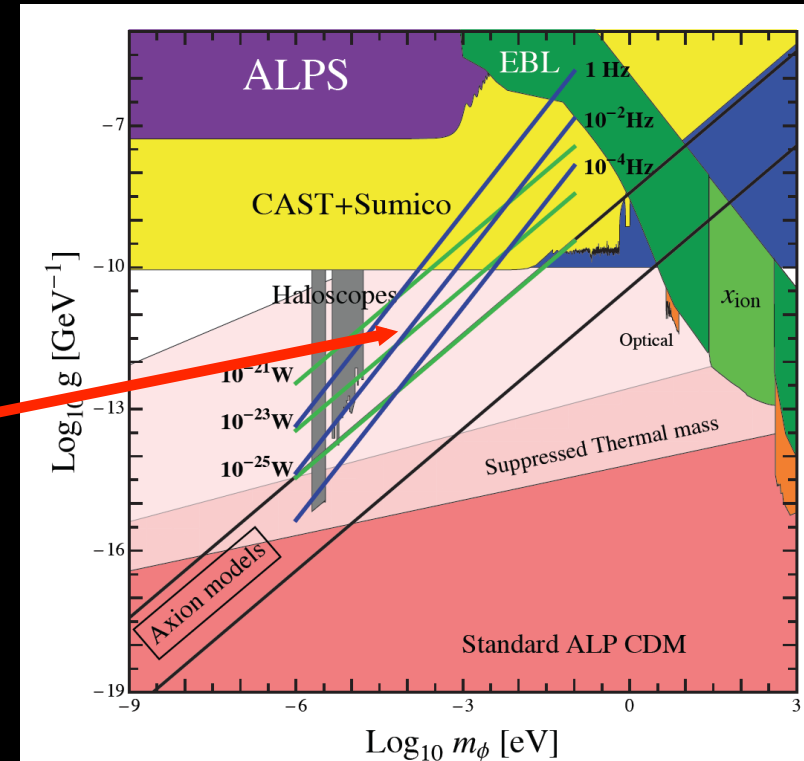


Broadband Search Strategy

Dark Matter Antenna



Probes here;
very sensitive!!



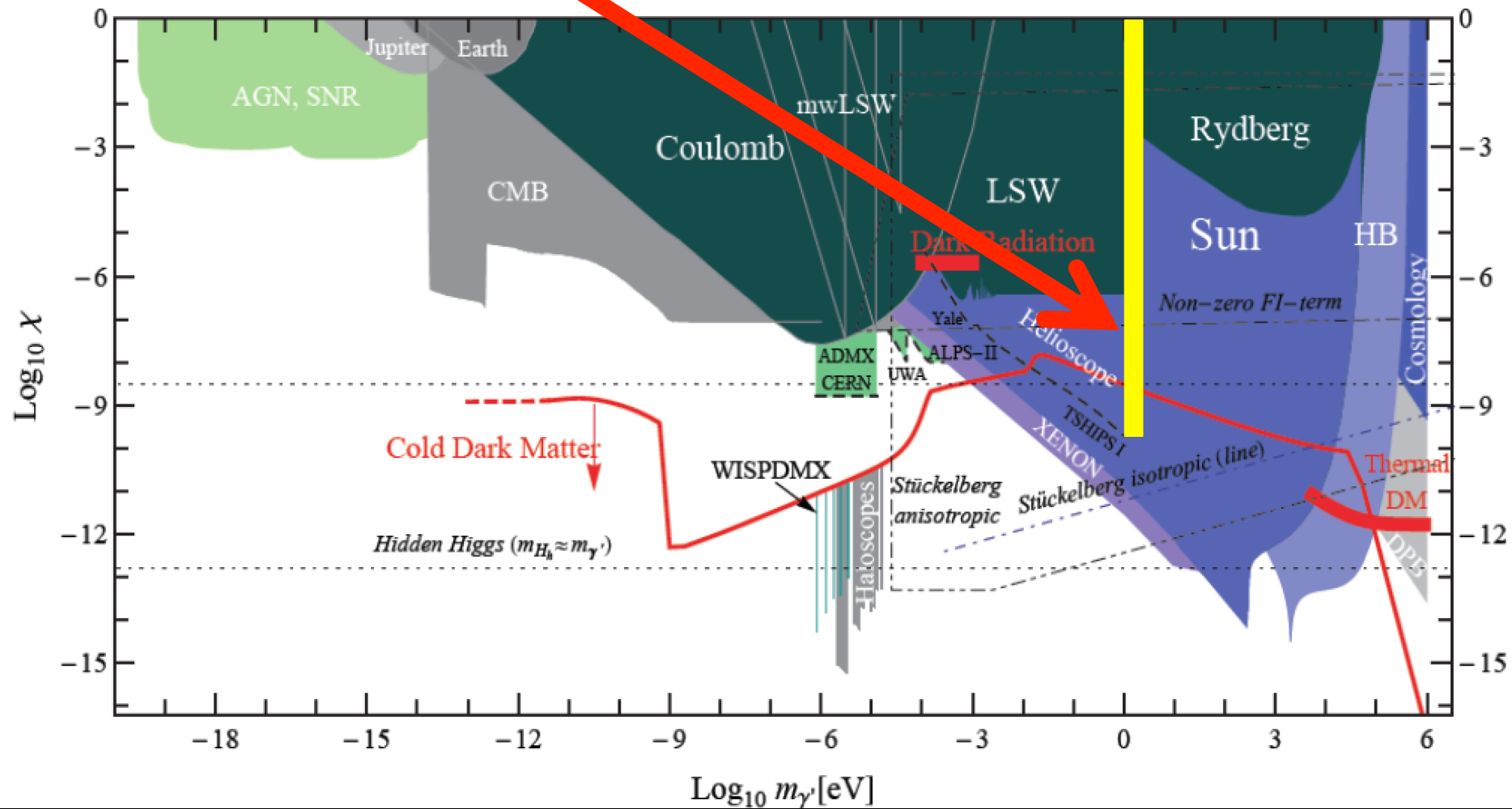
The FUNK Experiment

Recycle Auger mirror

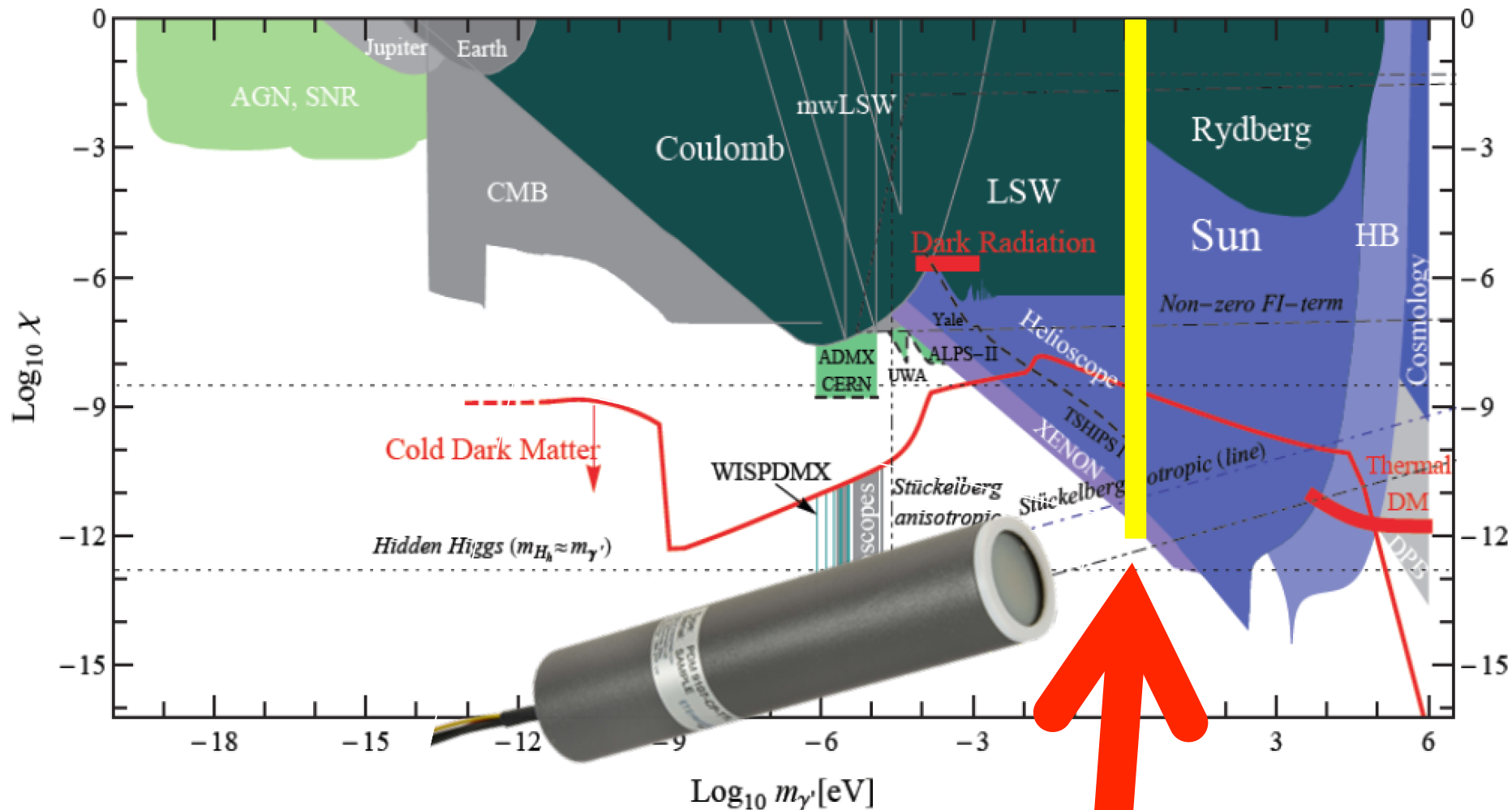
Detector



First Results



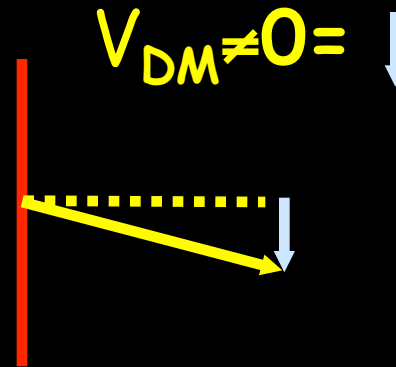
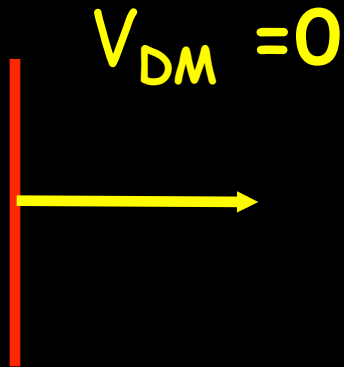
Upgrade: The PMT 9000(+107)



Discovery Potential ☺!!!

A Dream for Astrology ehbm Astronomy

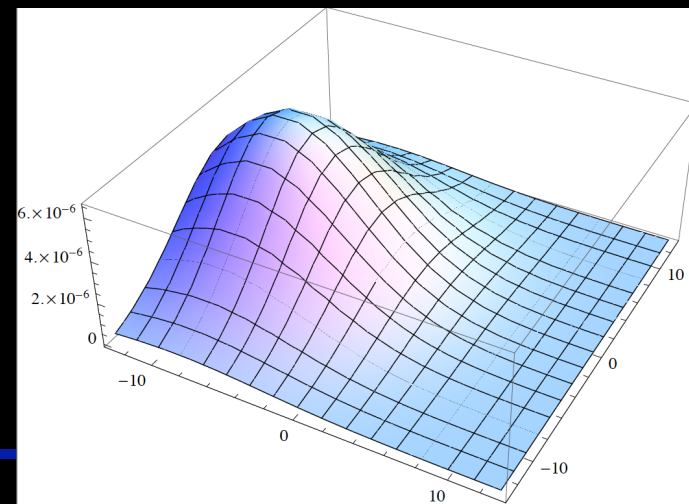
- Emission from moving dark matter



- A picture of the DM-velocity distribution



Screen

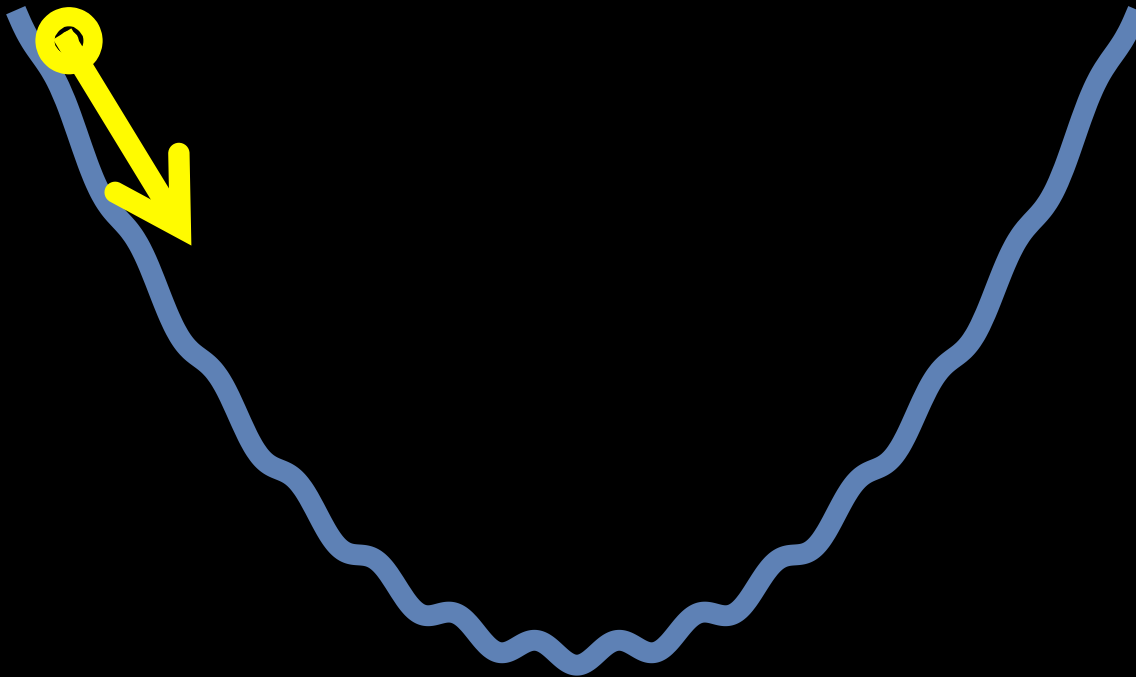


Going
Monodromic

Axion Monodromy

- Allows for extended field range

$$V(\phi) = \frac{1}{2}m^2\phi^2 + \Lambda^4 \left(1 - \cos \left(\frac{\phi}{2\pi f} \right) \right)$$

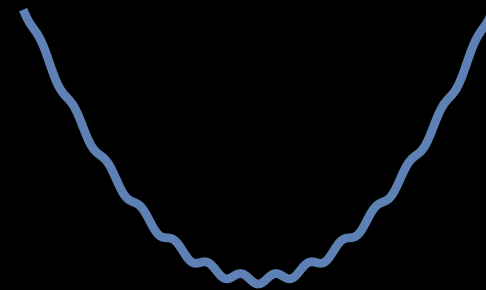


Advantages

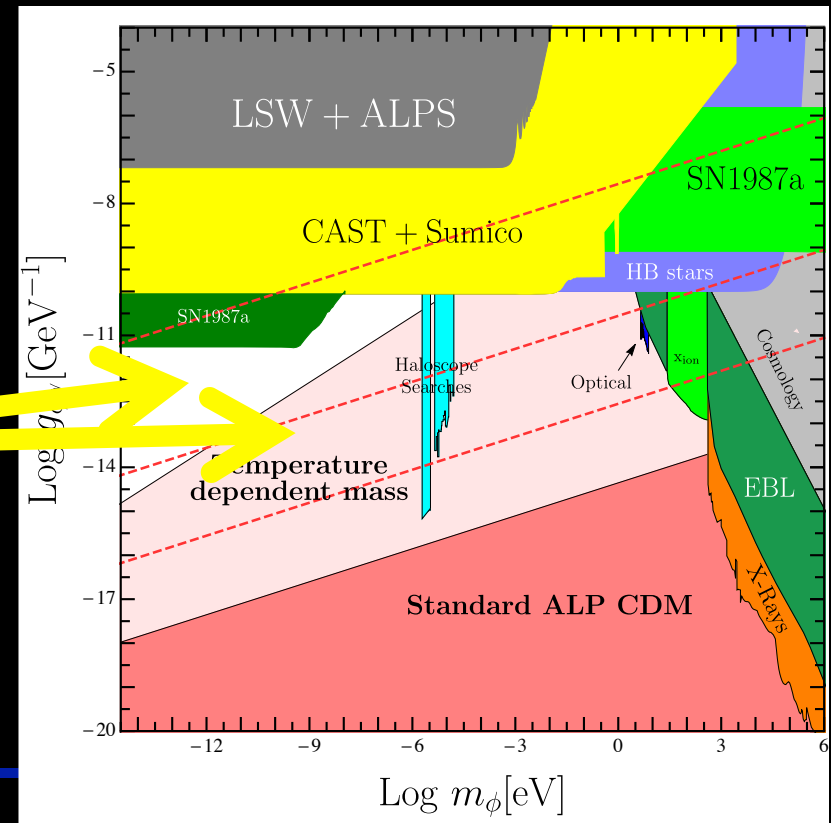
- Allows to start with higher energy density
→ More DM



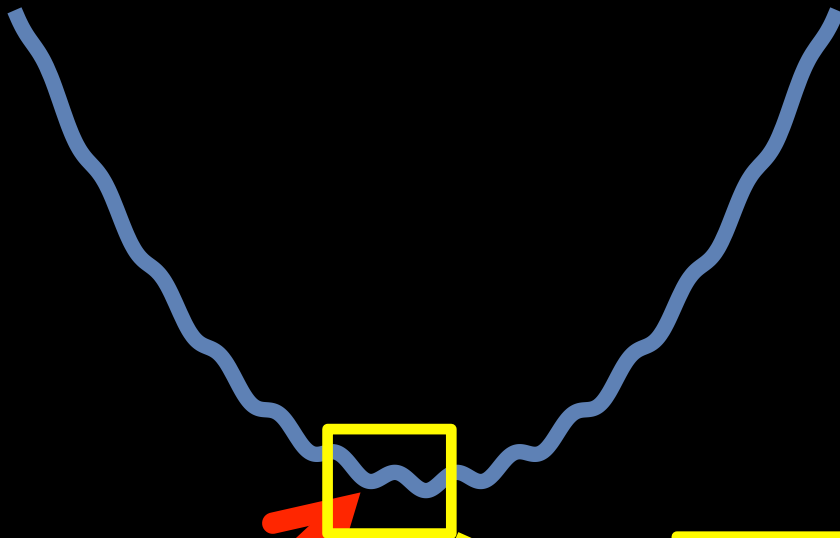
vs



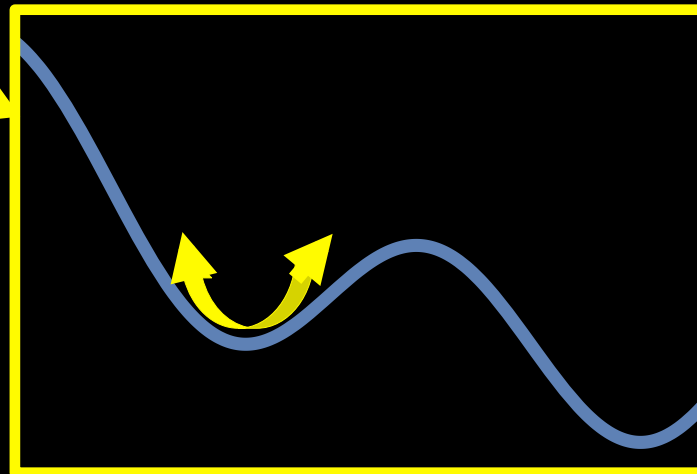
Models
in this region!



Interesting Phenomena??

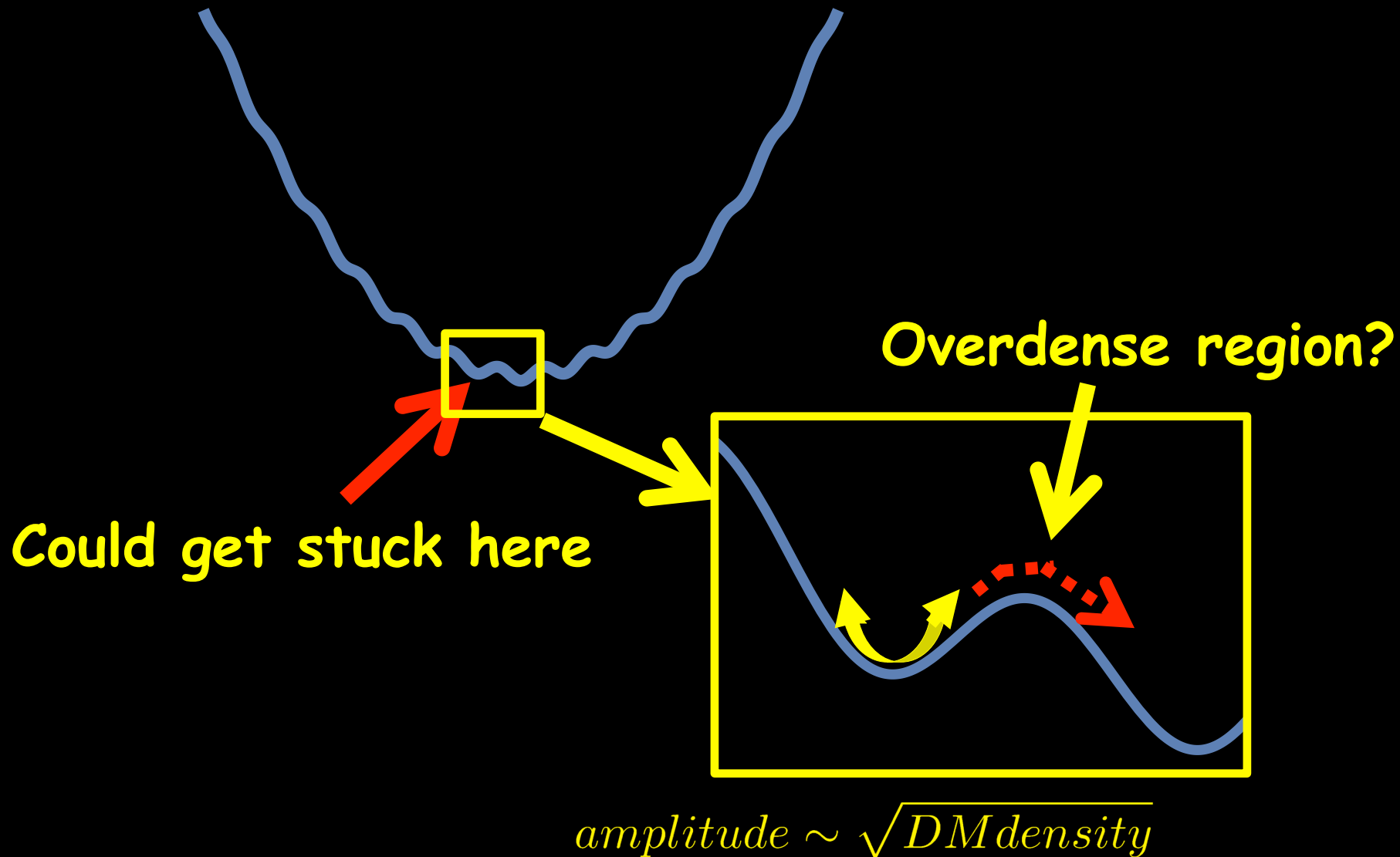


Could get stuck here

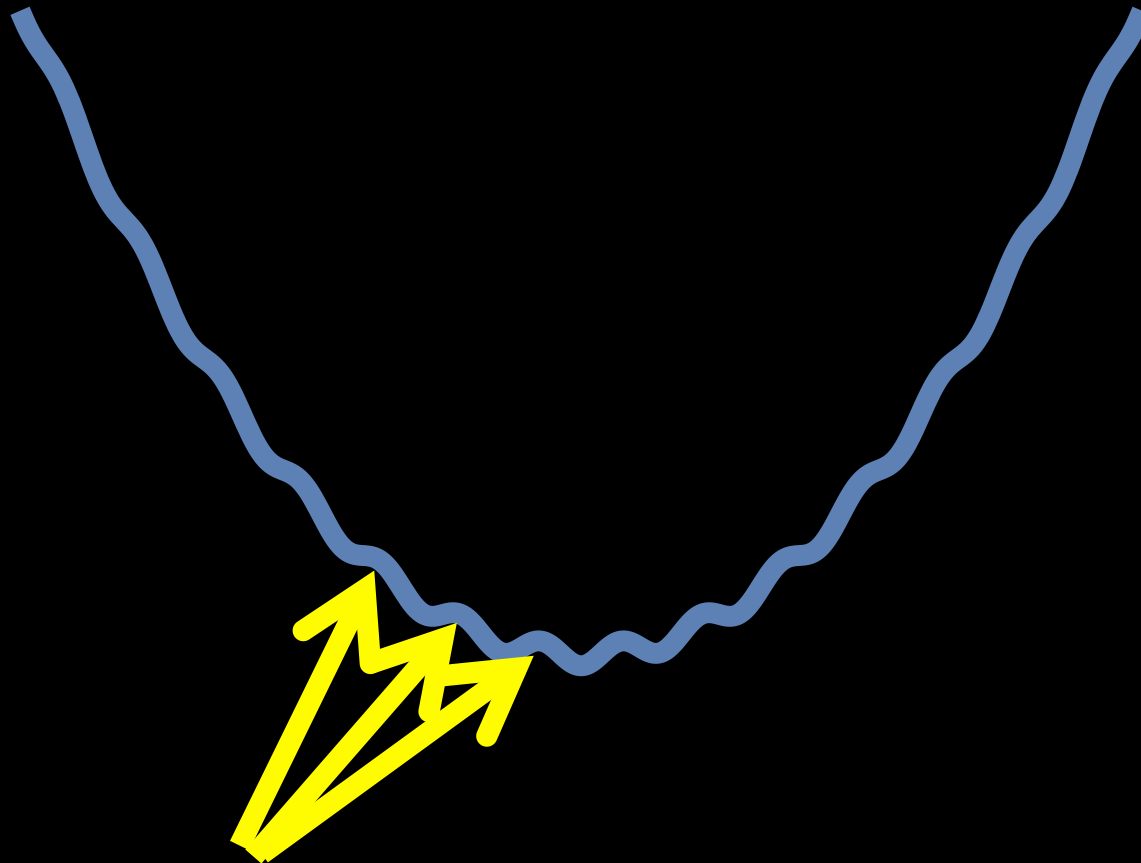


Oscillations like DM!

Interesting Phenomena??



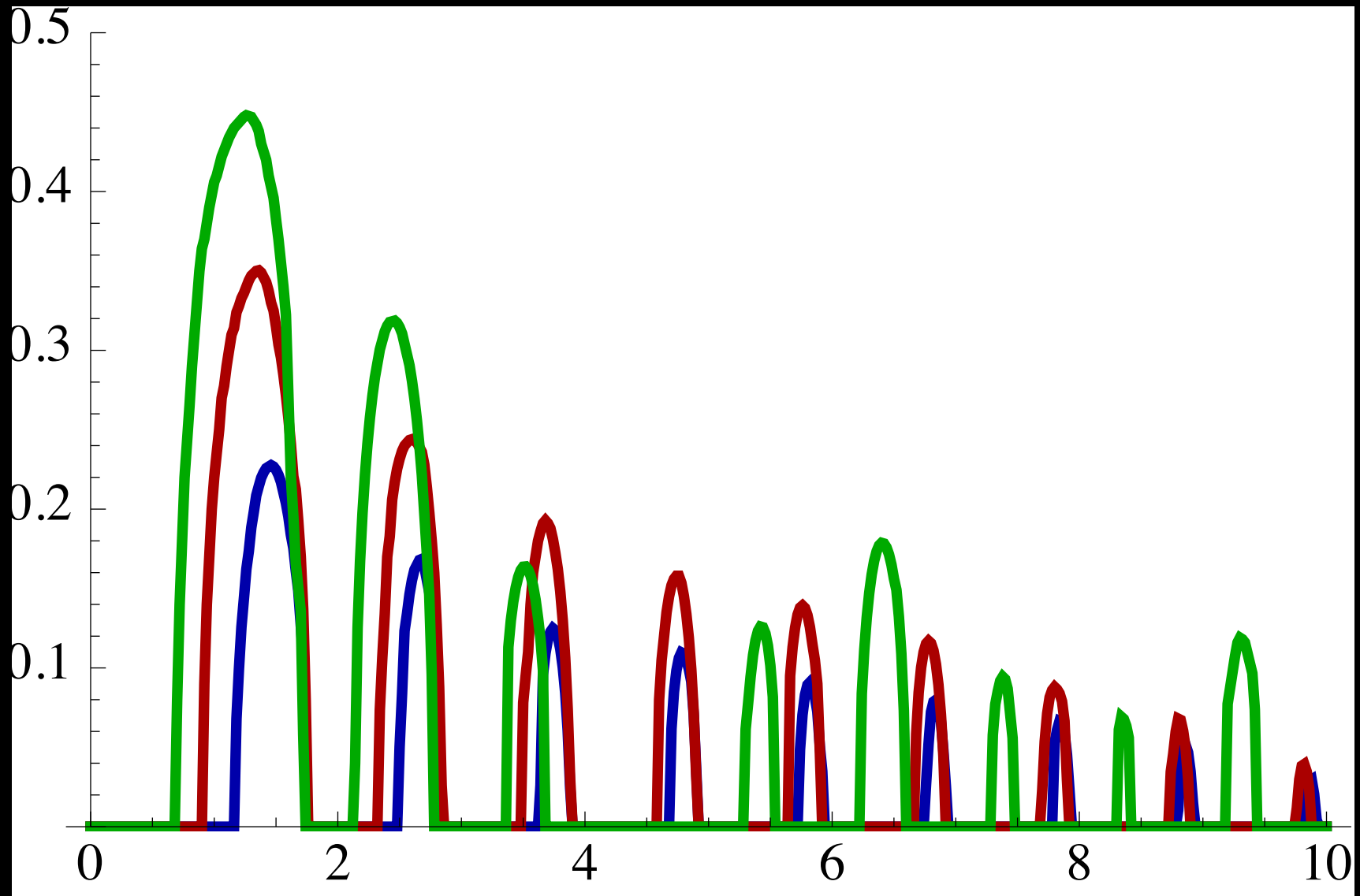
Interesting Phenomena??



Regions with “negative mass”

Instability $\rightarrow$ Particle Production with $p \neq 0$?!?

Very rapid particle production...



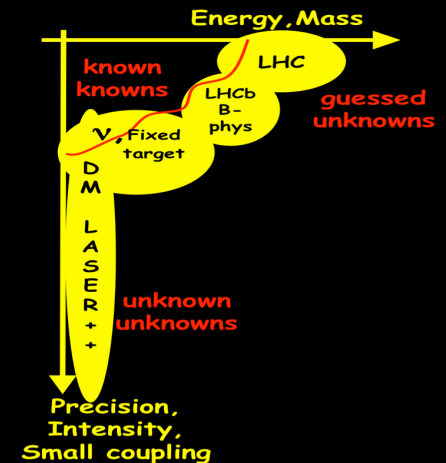
Conclusions

Conclusions

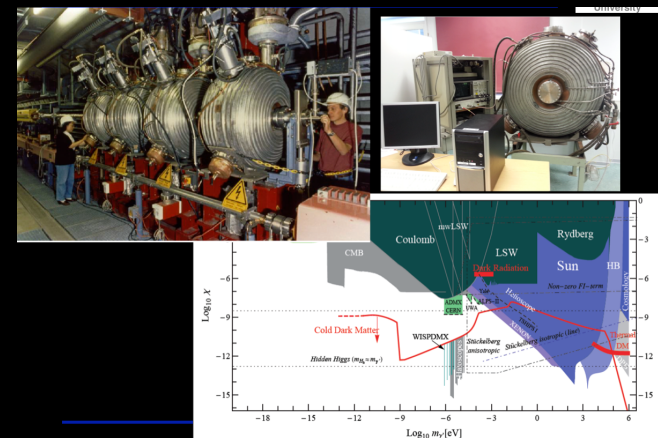
- Good Physics Case for Axions and WISPs

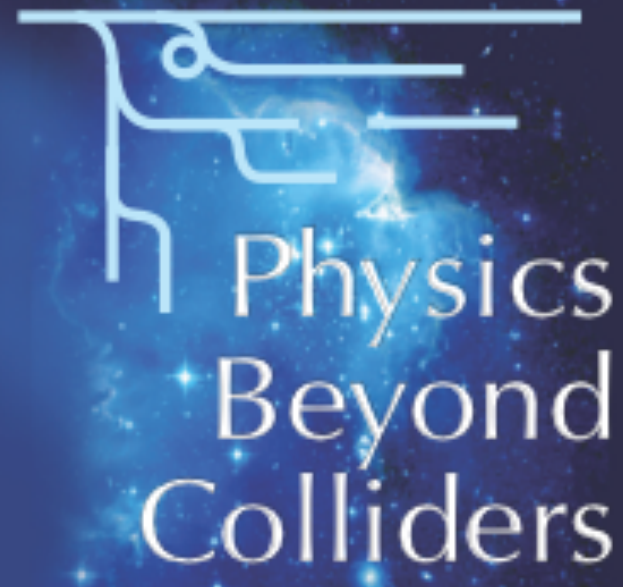
➔ explore 'The Low Energy Frontier'

- Low energy experiments complementary to accelerators!



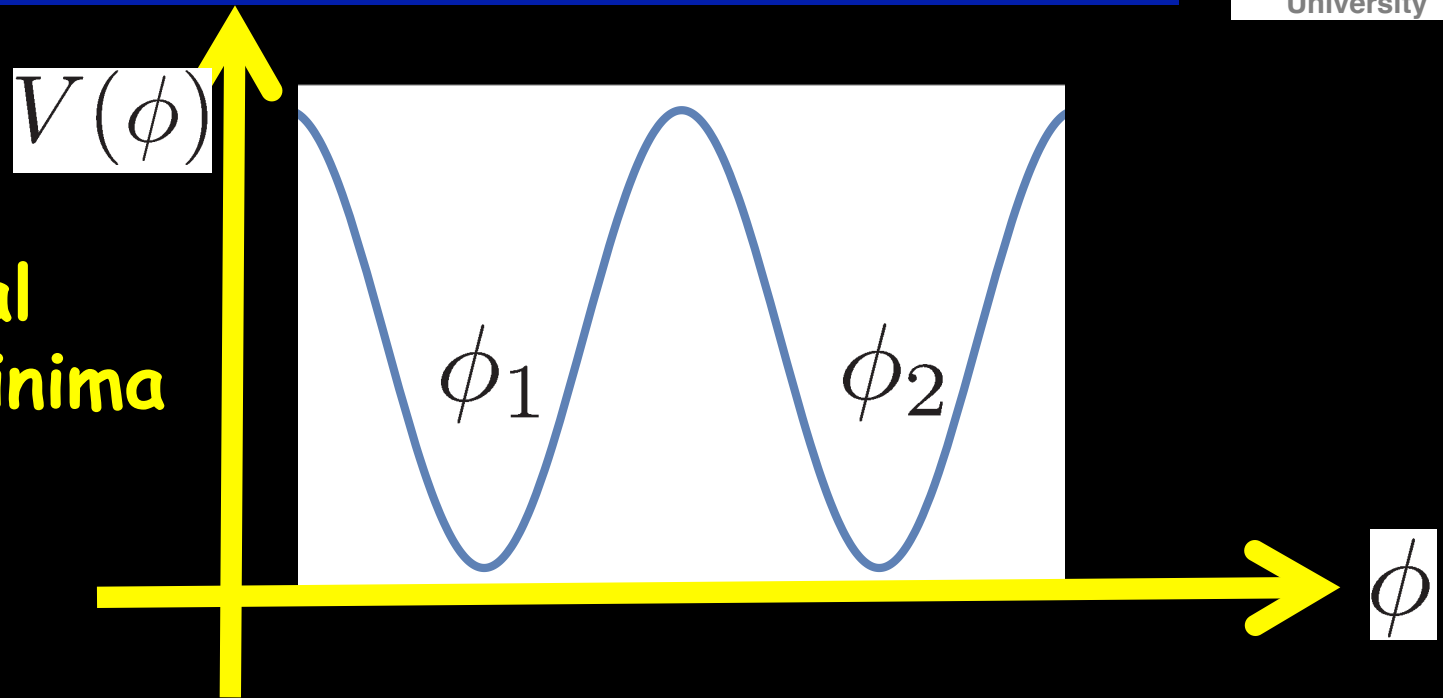
- Dark Matter may be WISPy 😊
 - ➔ New Search opportunities!
 - ➔ Searches ongoing!
 - ➔ Crazy things to explore!



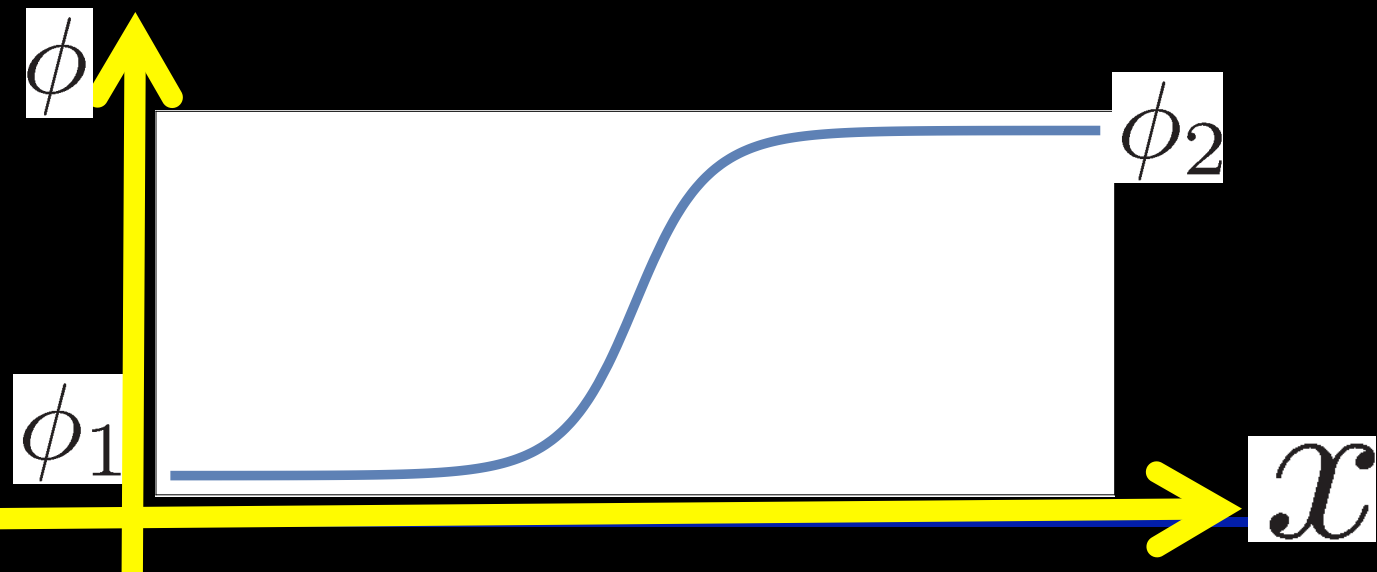


Running through walls

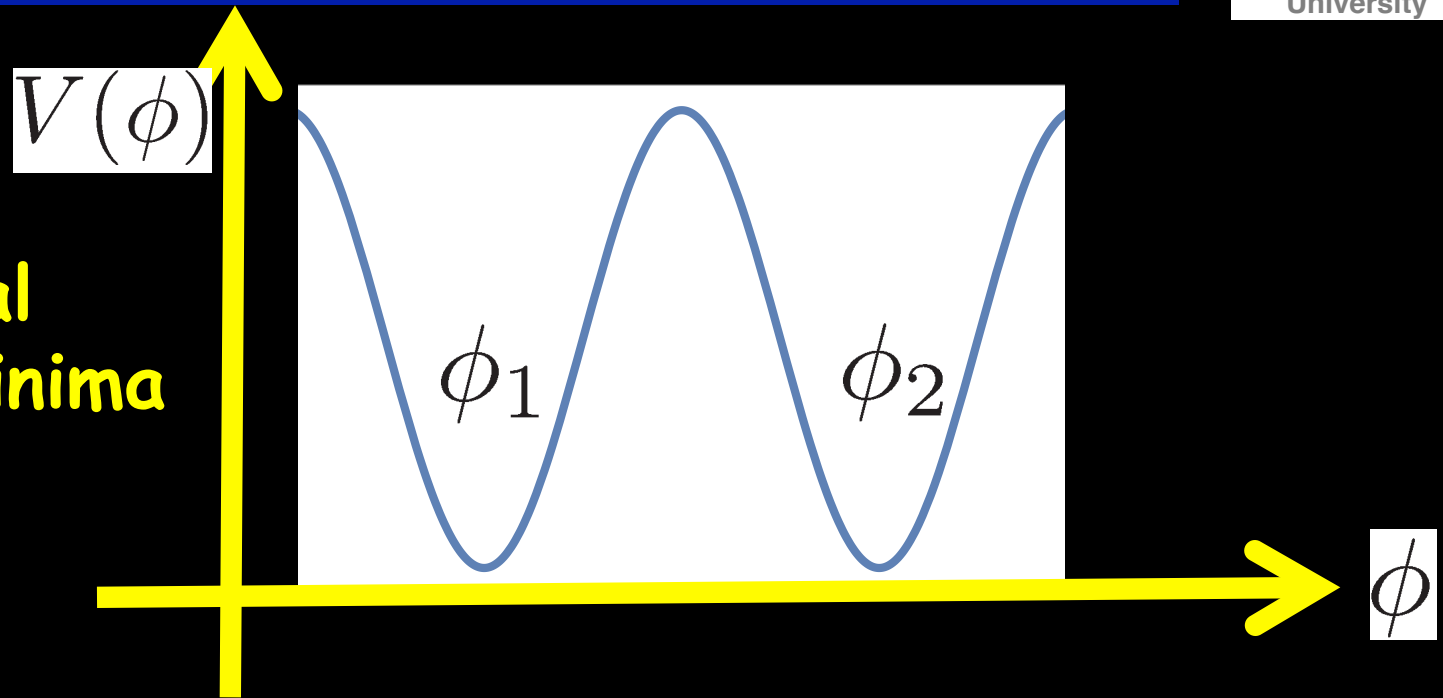
A WISPy Domain Wall



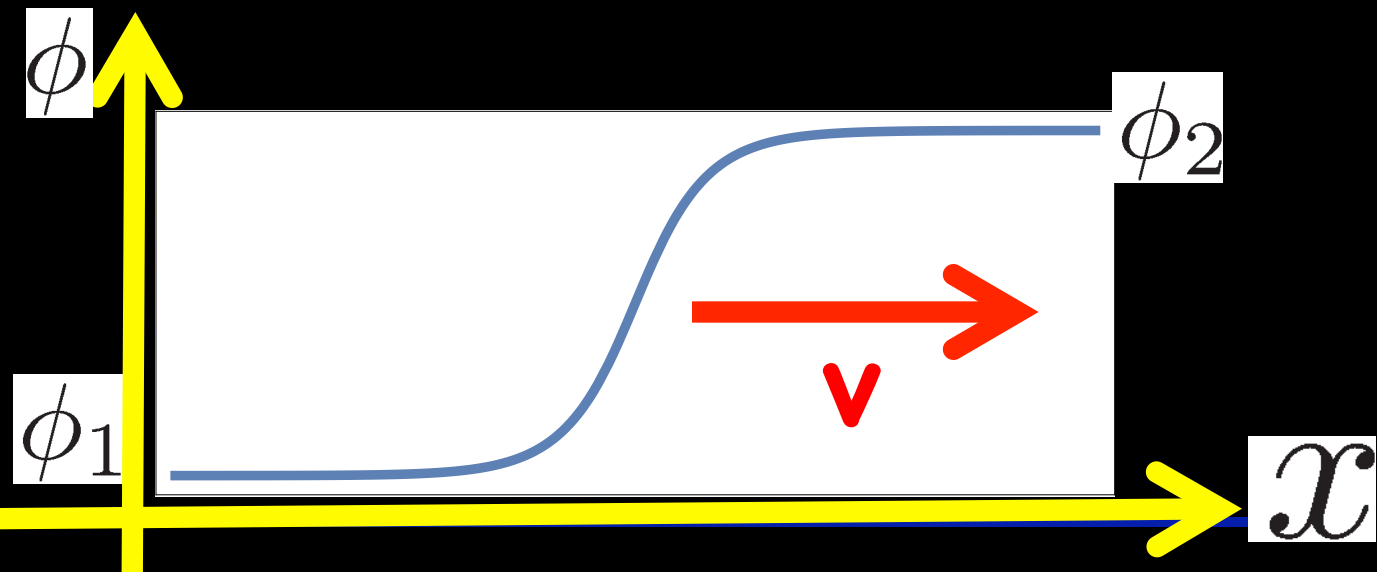
Domain wall
from side 1
To side 2



A WISPy Domain Wall

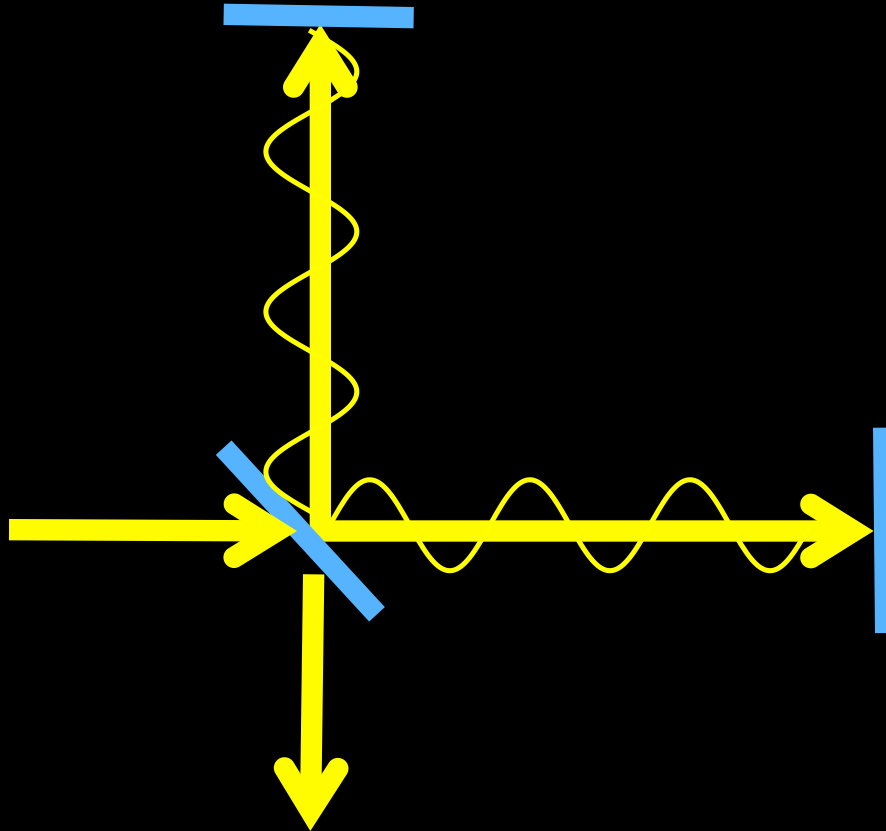


Domain wall
from side 1
To side 2



aLIGO

- Has detected gravitational waves!!
- Is an Interferometer



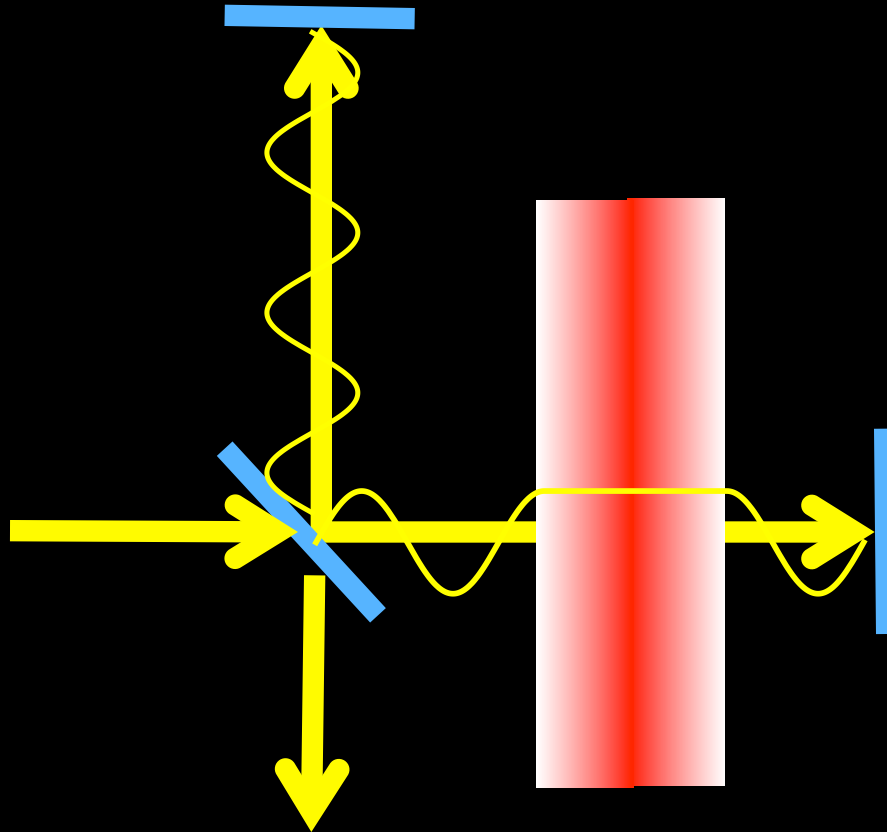
Interference pattern

Causing a phase shift

- Interaction inside wall creates photon mass

$$\mathcal{L}_A = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{2}m_{0,\gamma}^2 \sin^2 \left(\frac{N_A \phi}{f} \right) A^\mu A_\mu$$

- Has detected gravitational waves!!
- Is an Interferometer



— Interference pattern **changed** —

Signal shapes

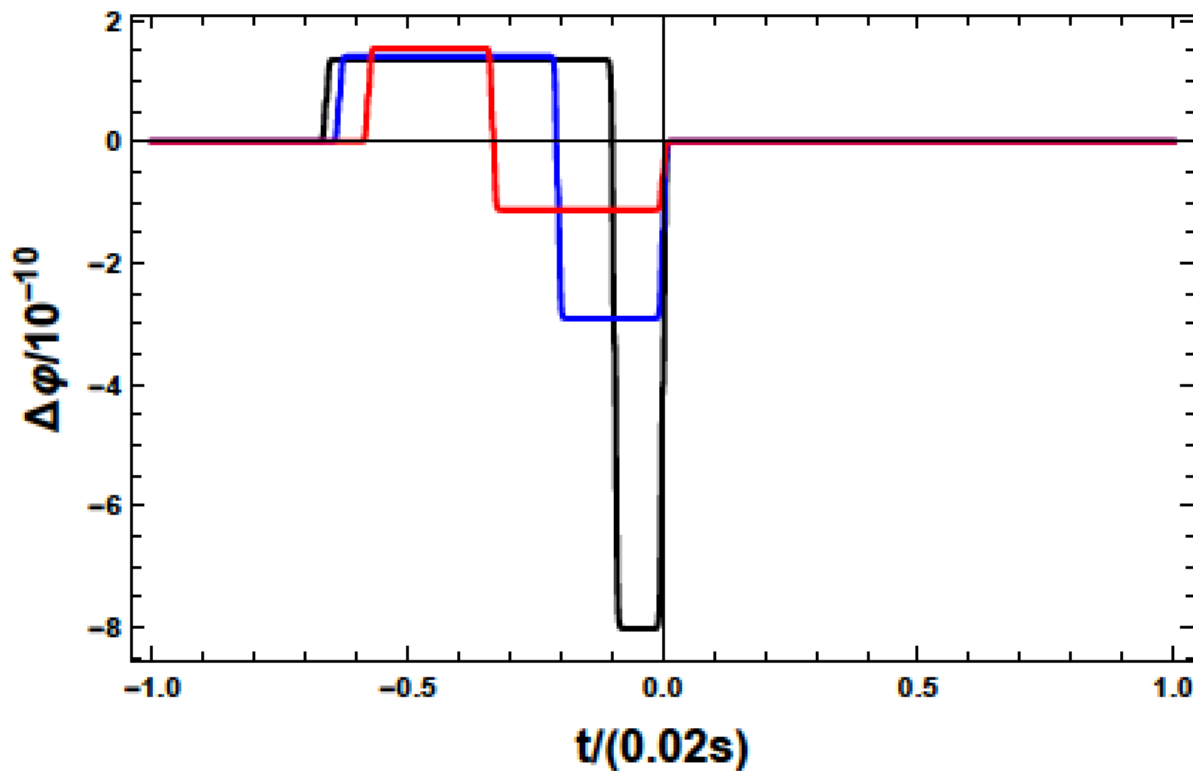


FIG. 6: $L = 4000$ m, $\omega \approx 1$ eV, $m = 10$ neV, $m_{\gamma,0} = 1$ neV, $N_A/N_\phi = 1$, $\alpha = \pi/2.2, \pi/2.5, \pi/3$ (black, blue, red), v chosen such that signal has roughly a length of $0.02s \sim 1/(50 \text{ Hz})$ this corresponds to $v = 1 \times 10^{-3}$.

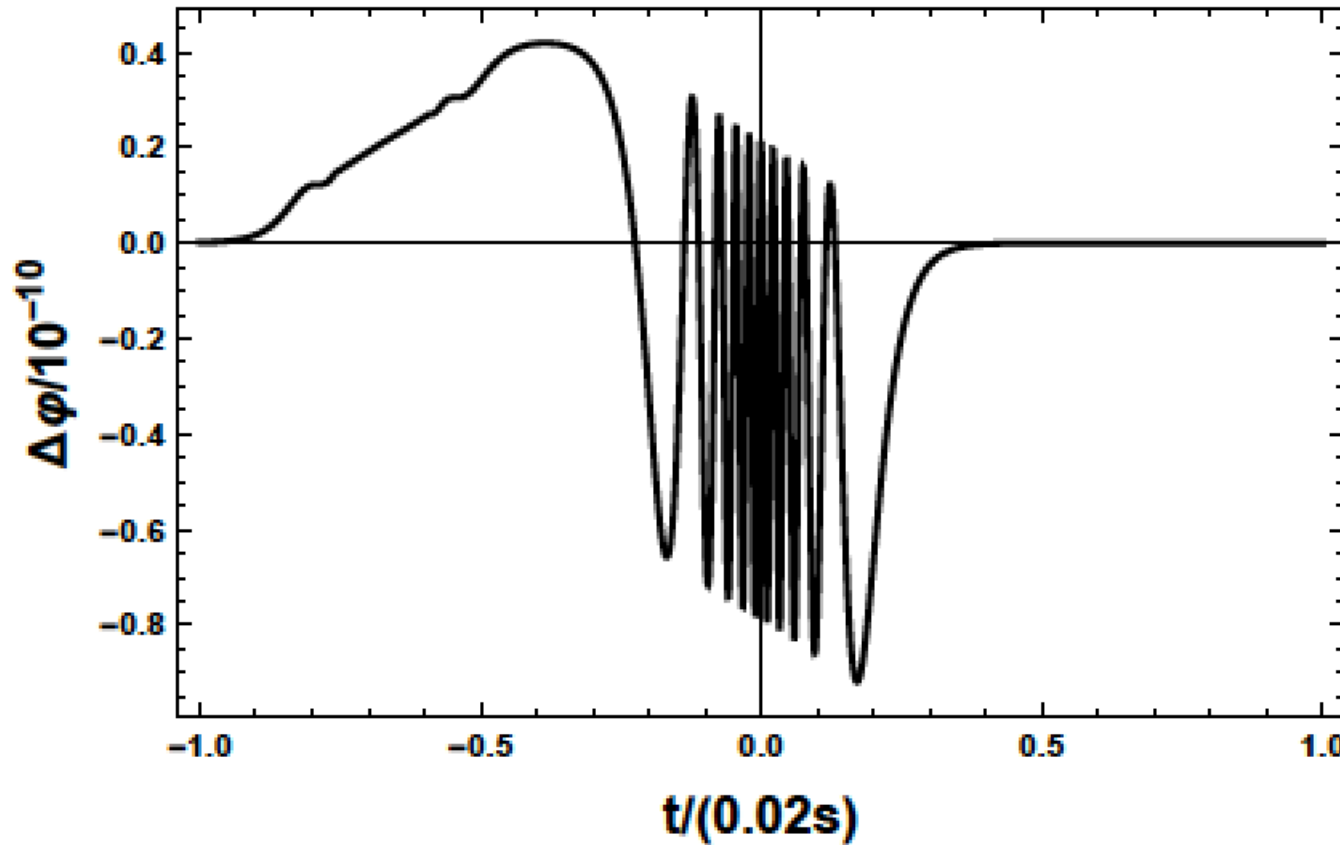


FIG. 8: As in Fig. ?? but $m_{\gamma,0} = 0.1 \text{ neV}$, $N_A/N_\phi = 5$, $m = 0.5 \text{ neV}$, $\alpha = \pi/2$ and $v = 1 \times 10^{-3}$.

How to distinguish from grav waves?

- velocity $\ll c$
- $v \sim 10^{-3}$

- Time difference between two sites
~few seconds
- Need careful analysis strategies