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Heidelberg University

WISPy Cold Dark Matter

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[**]ITP Heidelberg, [z]CERN, [†]IPPP Durham, [*]DESY, [Y]MPIfR Bonn, [x]U. Zaragoza, [xx]Paris LPTHE, [0]ITP Jena

WISPy Cold Dark Matter

Weakly interacting sub-eV particle

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Example WISPs:
Axion-like particles

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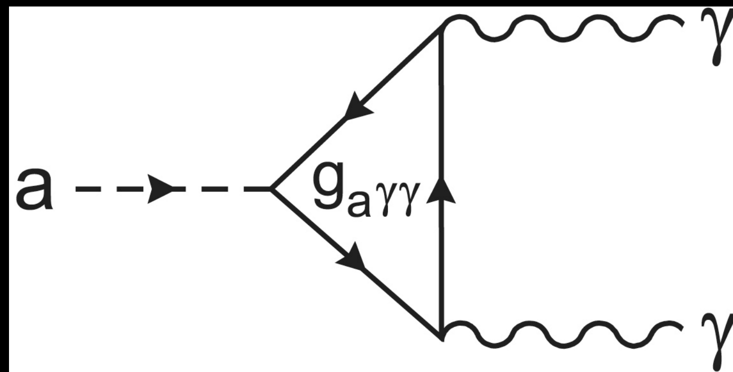
Axion couples to two photons



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

Coupling to two photons

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

Because: Very large

Axion is very light

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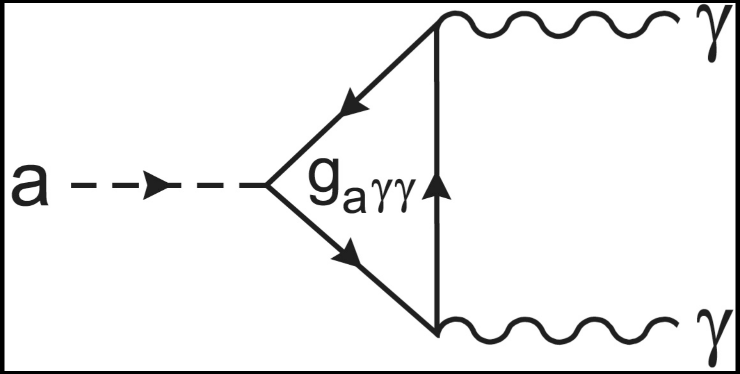


$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{1}{2}m^2 a^2 - \frac{1}{4}g_{a\gamma\gamma} a F^{\mu\nu}\tilde{F}_{\mu\nu} + \ldots$$

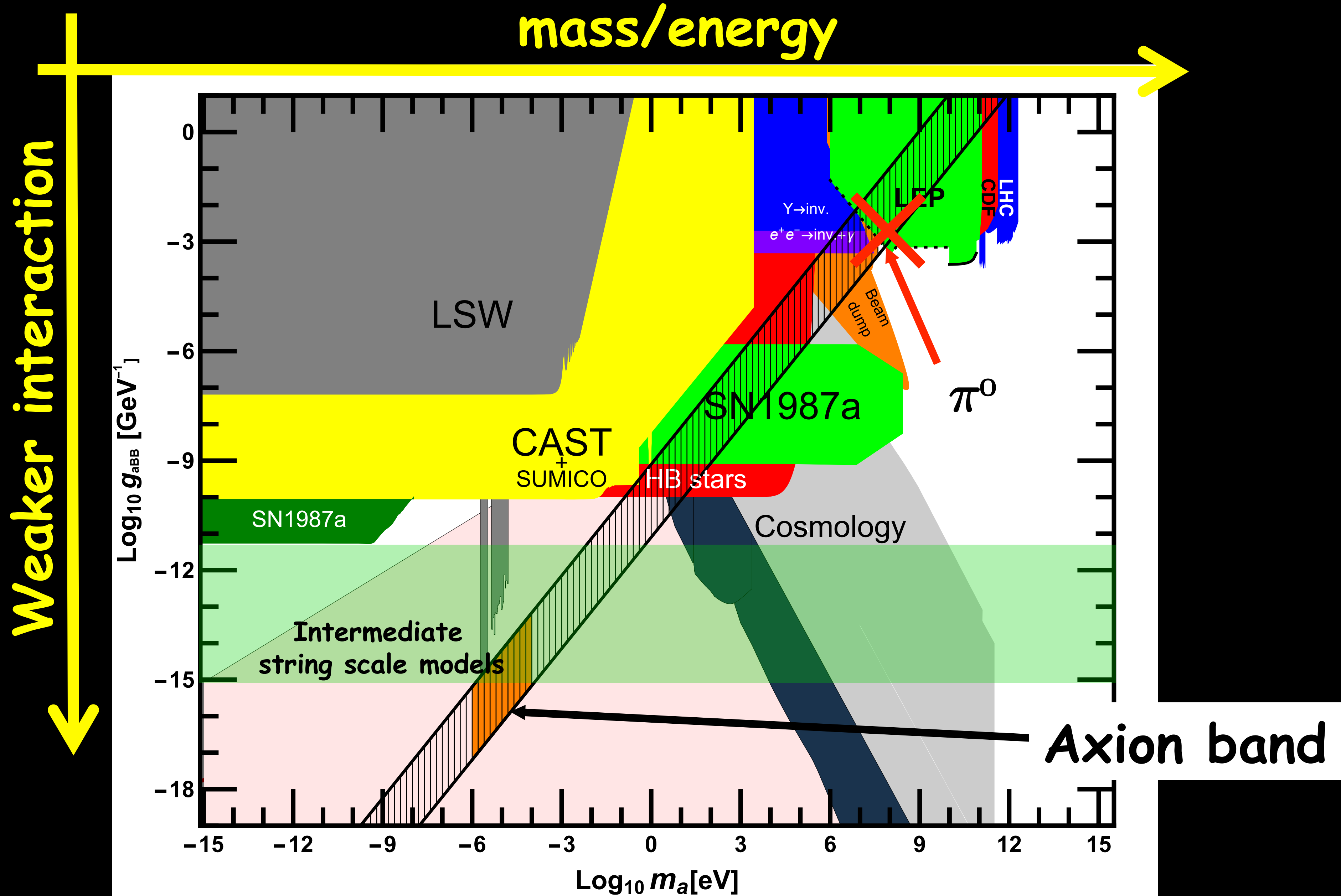
Mass

Very very small

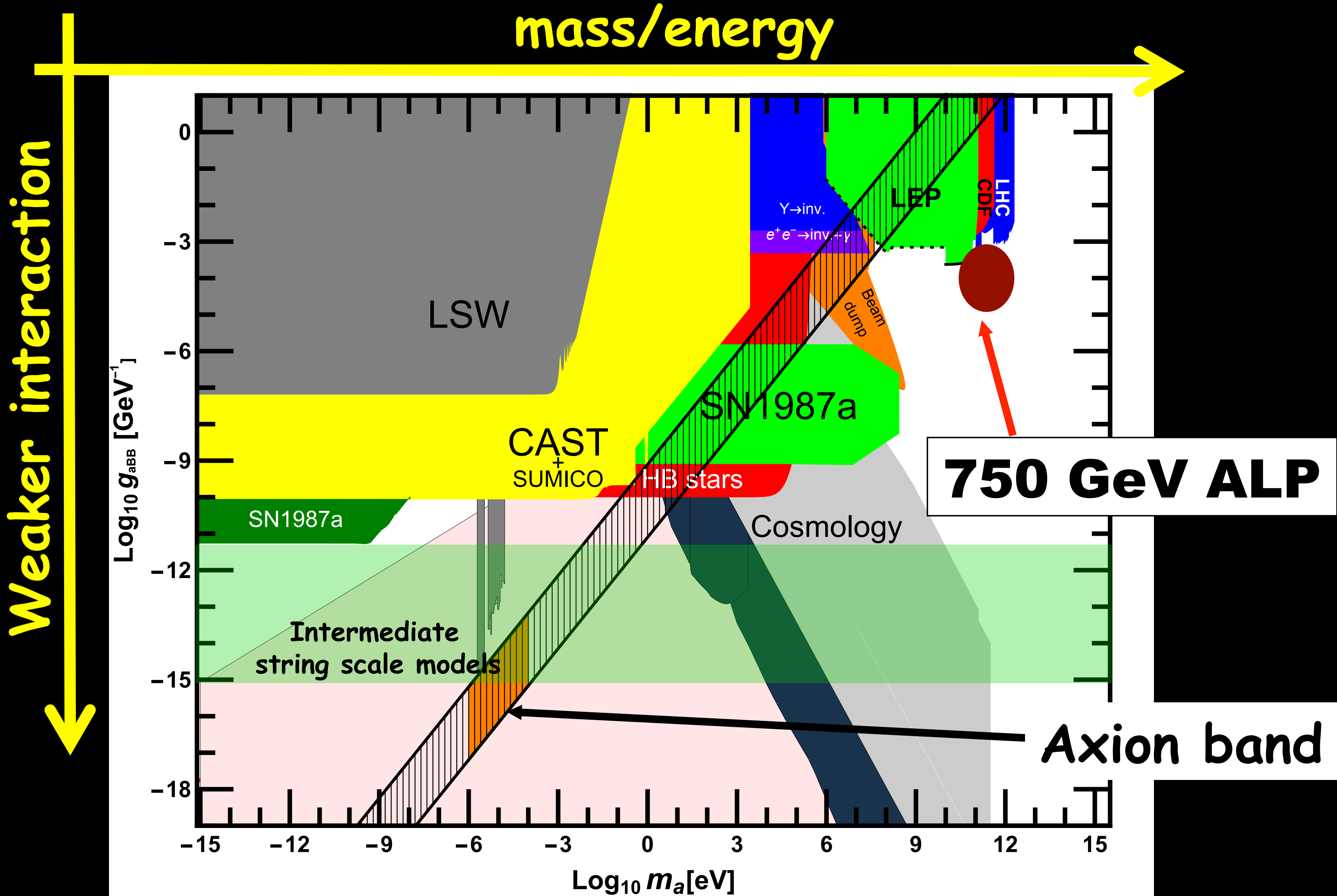
$$m \sim \frac{m_\pi^2}{f_a}$$

Because: Very large

Axion-like Particles

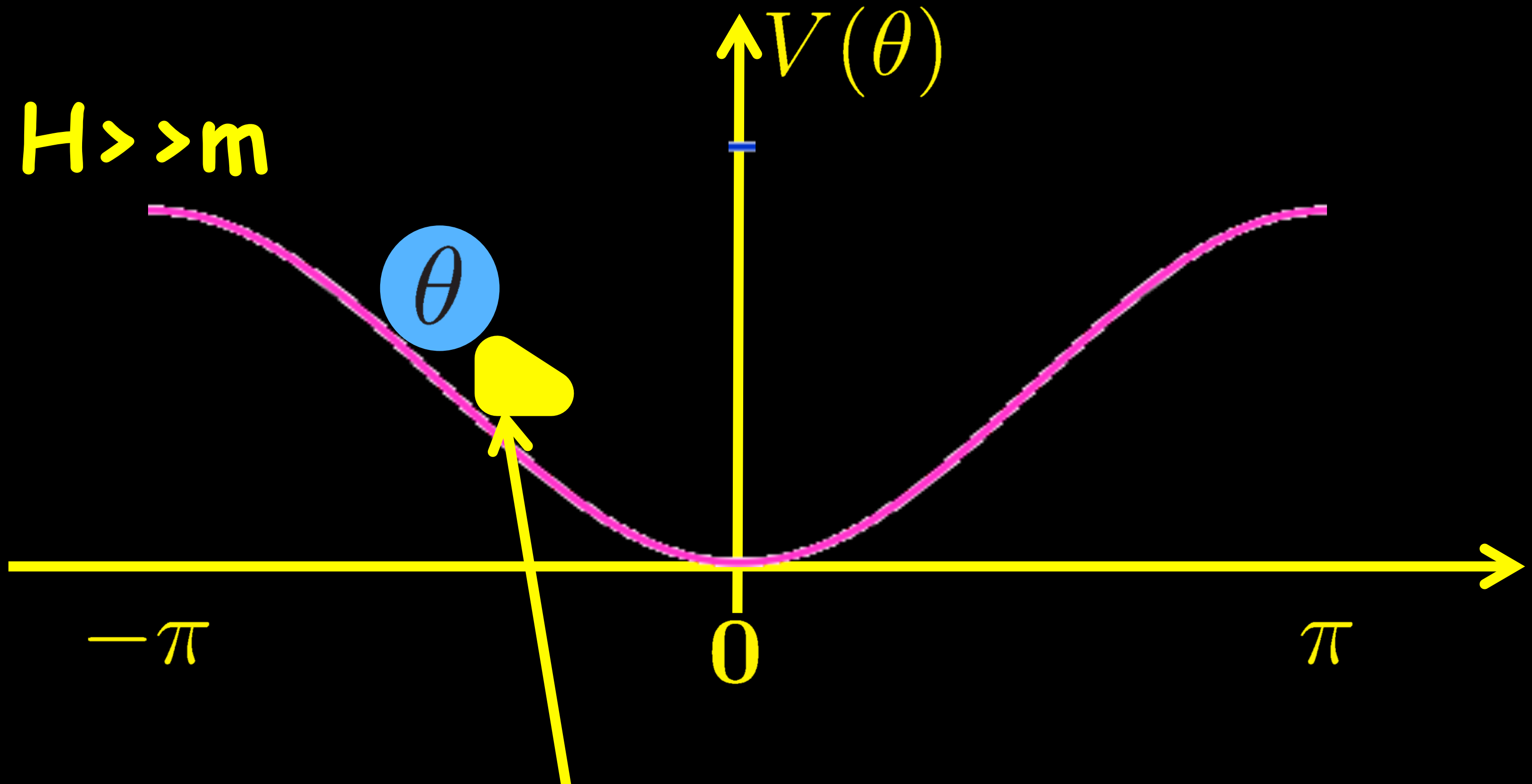


Axion-like Particles



Dark Matter(s)

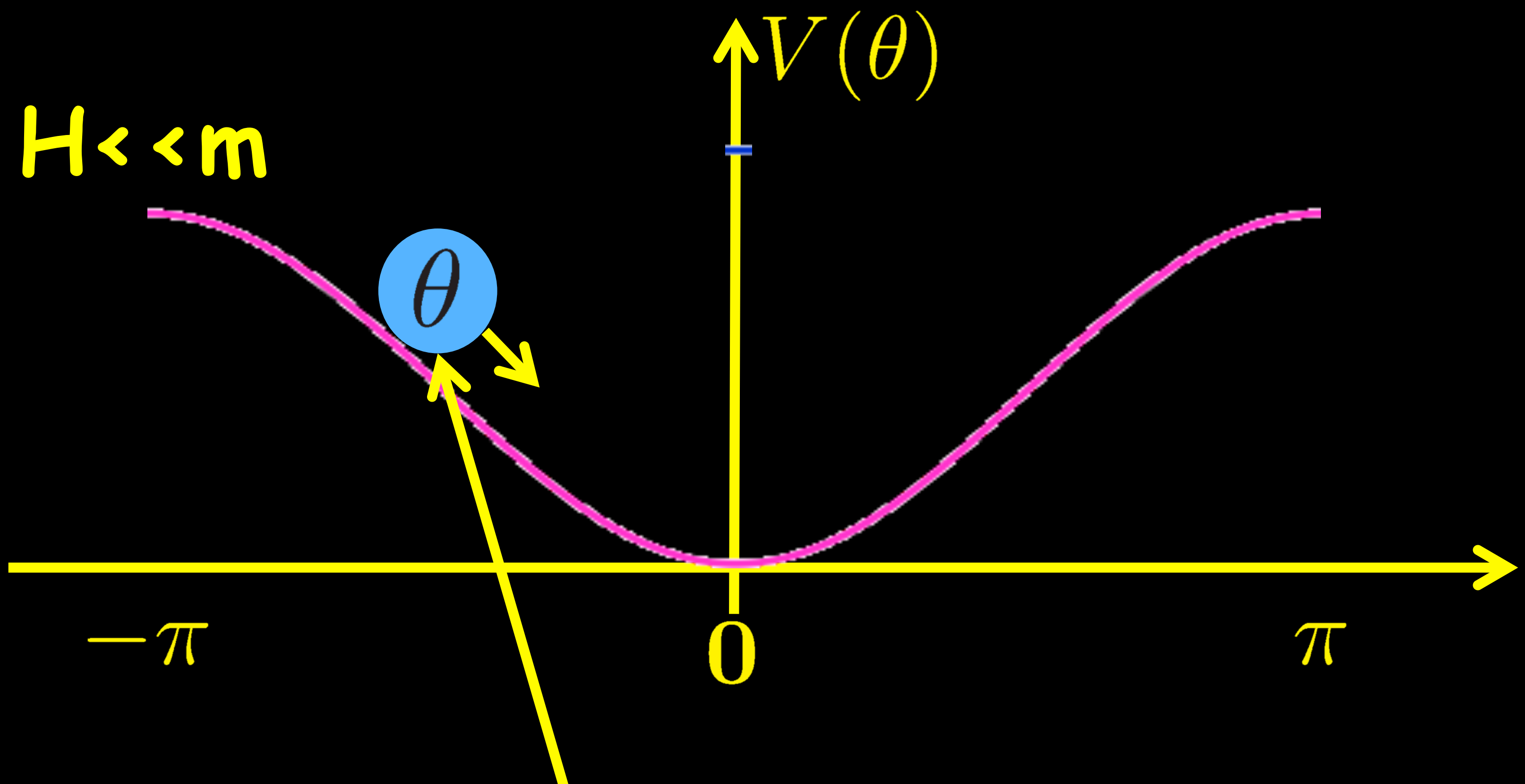
The axion has no clue where to start



Field is stuck because of Hubble "breaking"

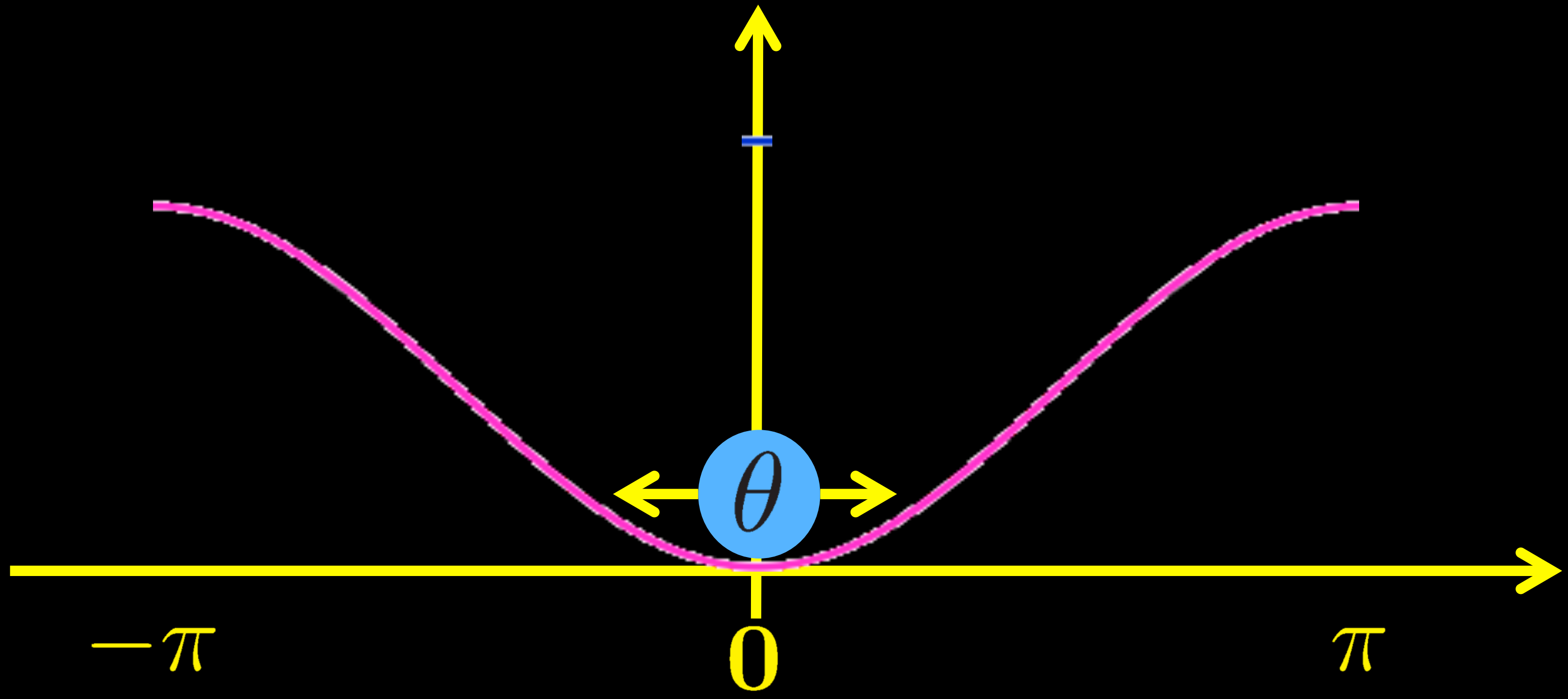
The axion has no clue where to start

H<<m



Can start moving...

The axion solution to the strong CP problem



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

Why Cold? Inflation!

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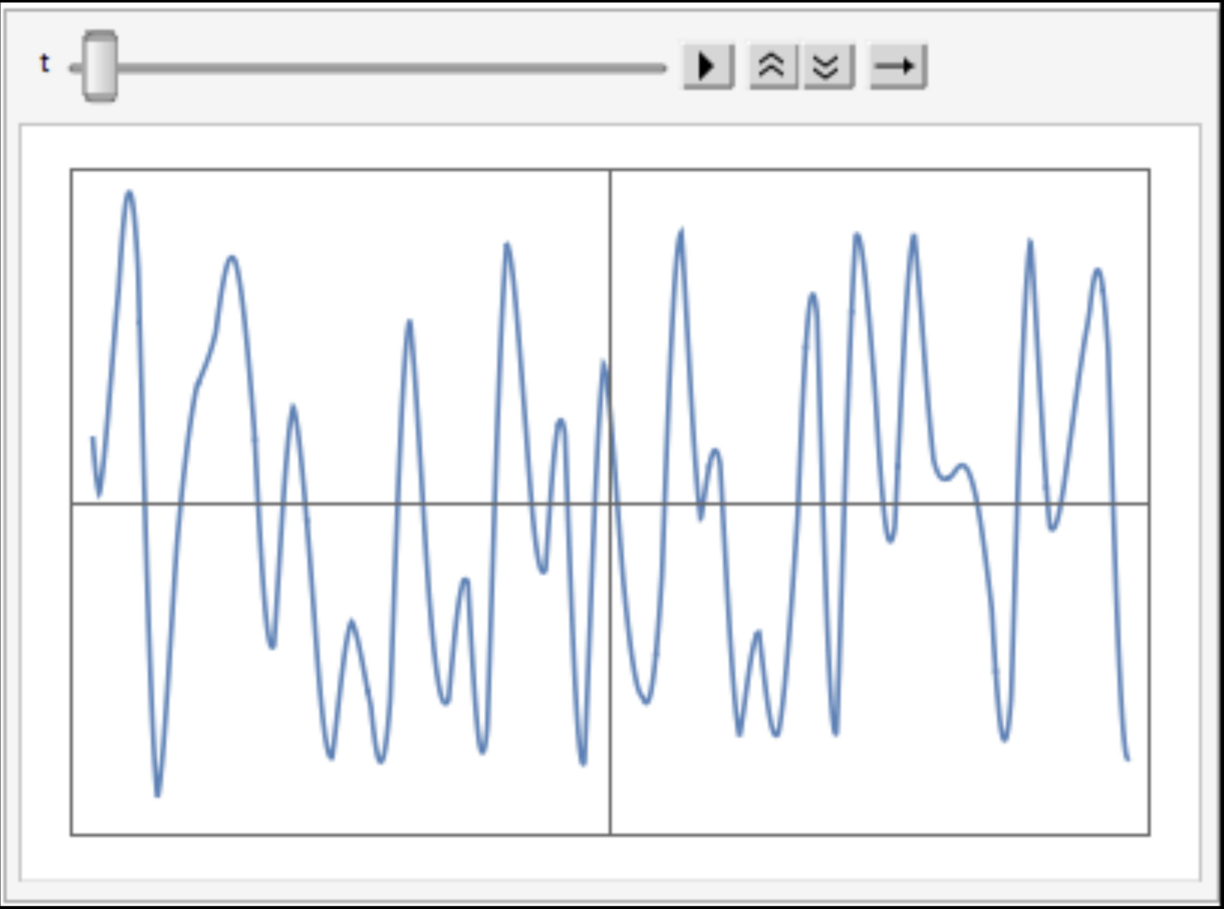
Field value

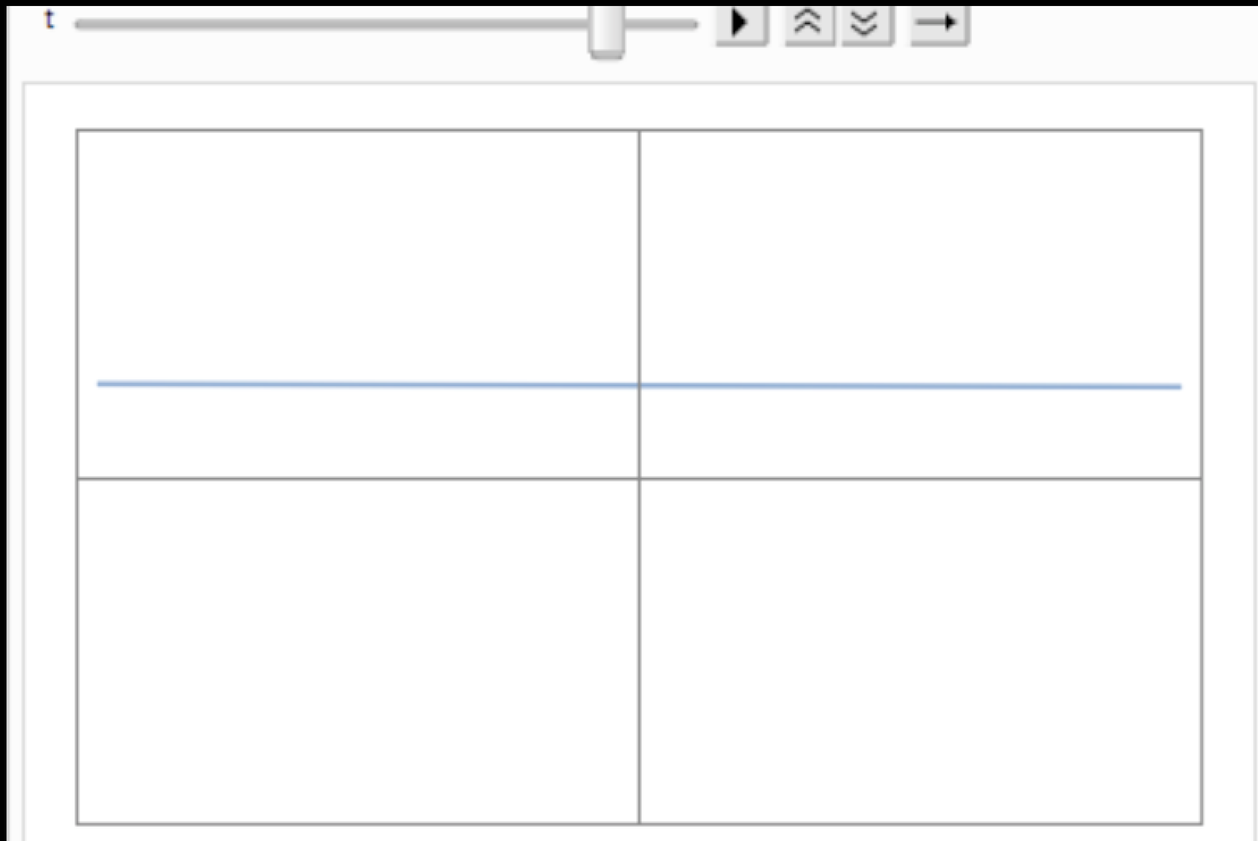


space

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

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

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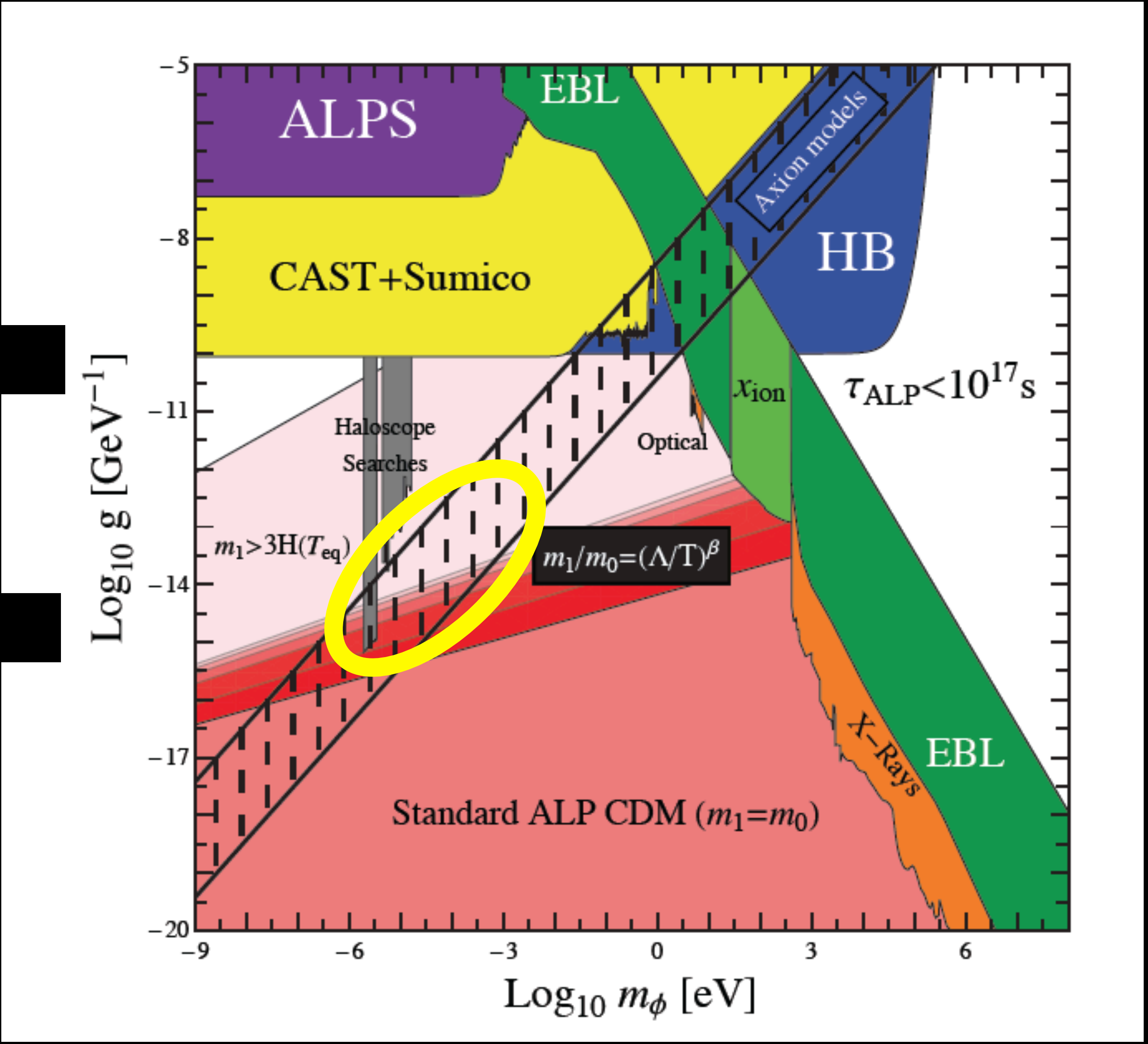
~10^7 GeV

~10^{12} GeV



Detecting WISPy DM

Use a plentiful source of axions

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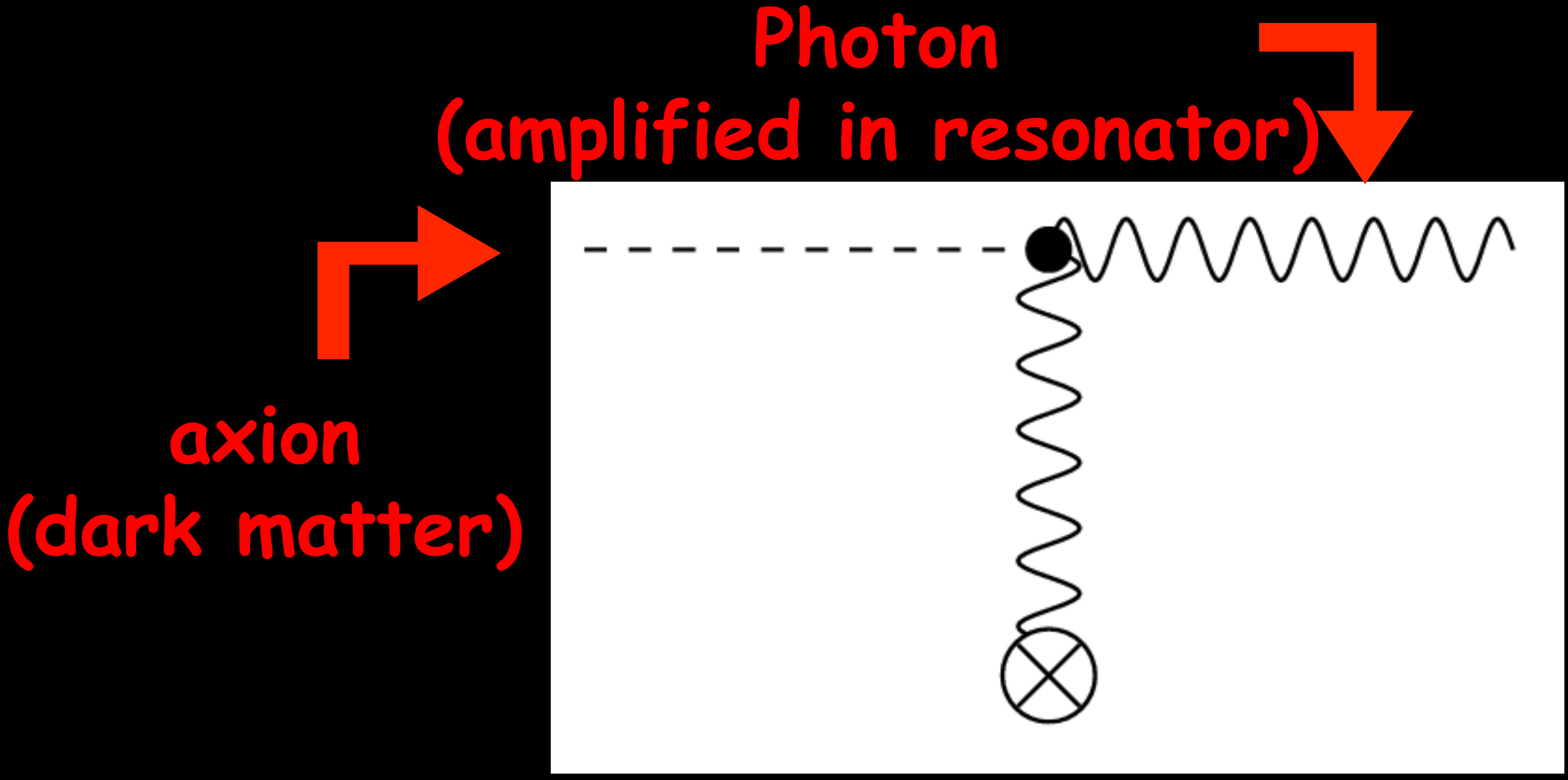
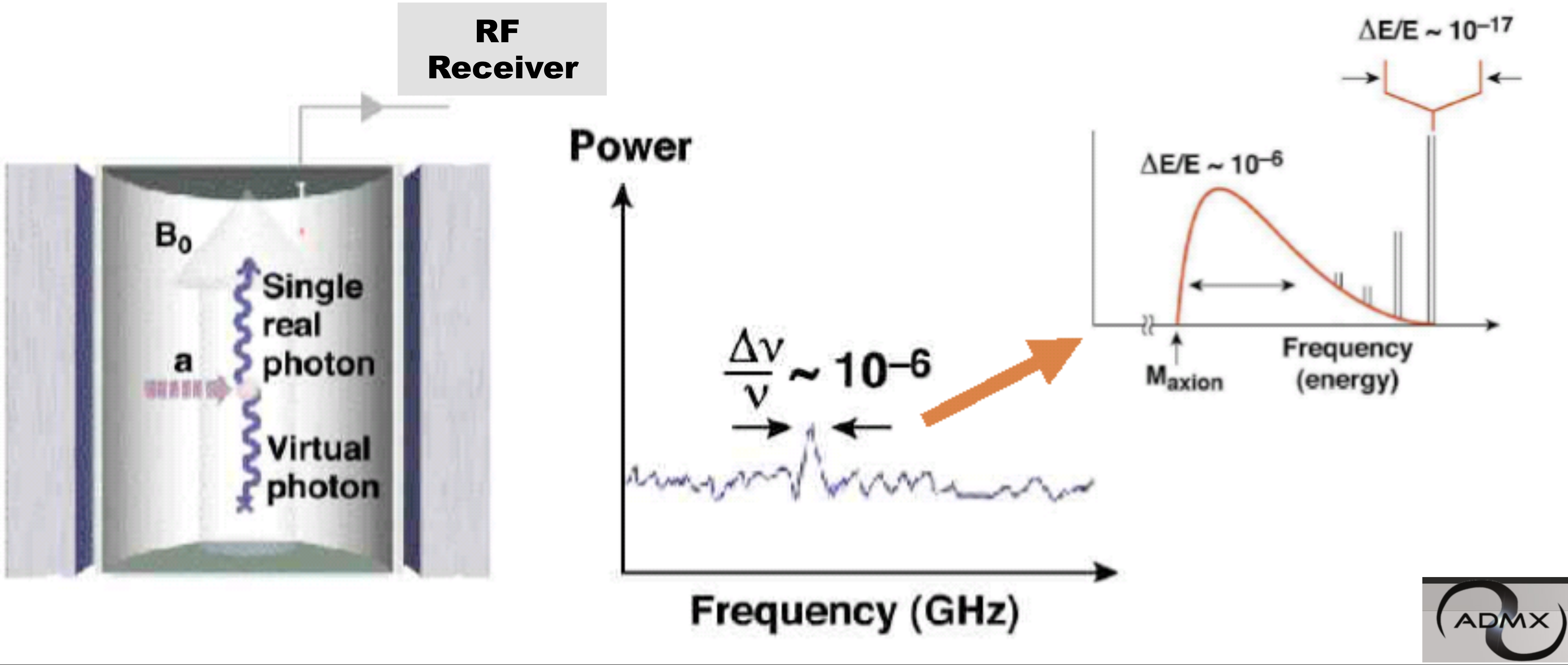
- Photon Regeneration



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!!!

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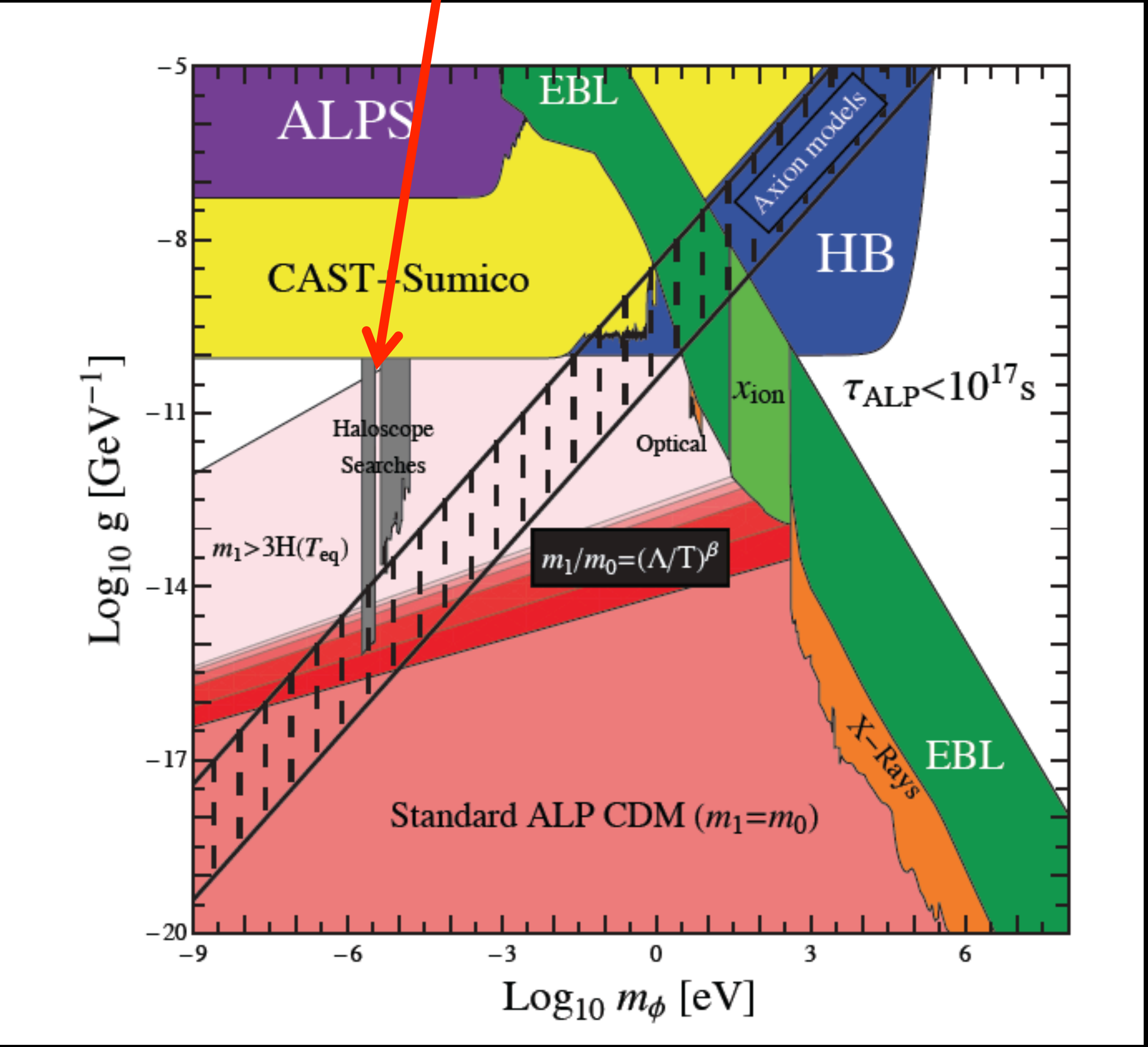
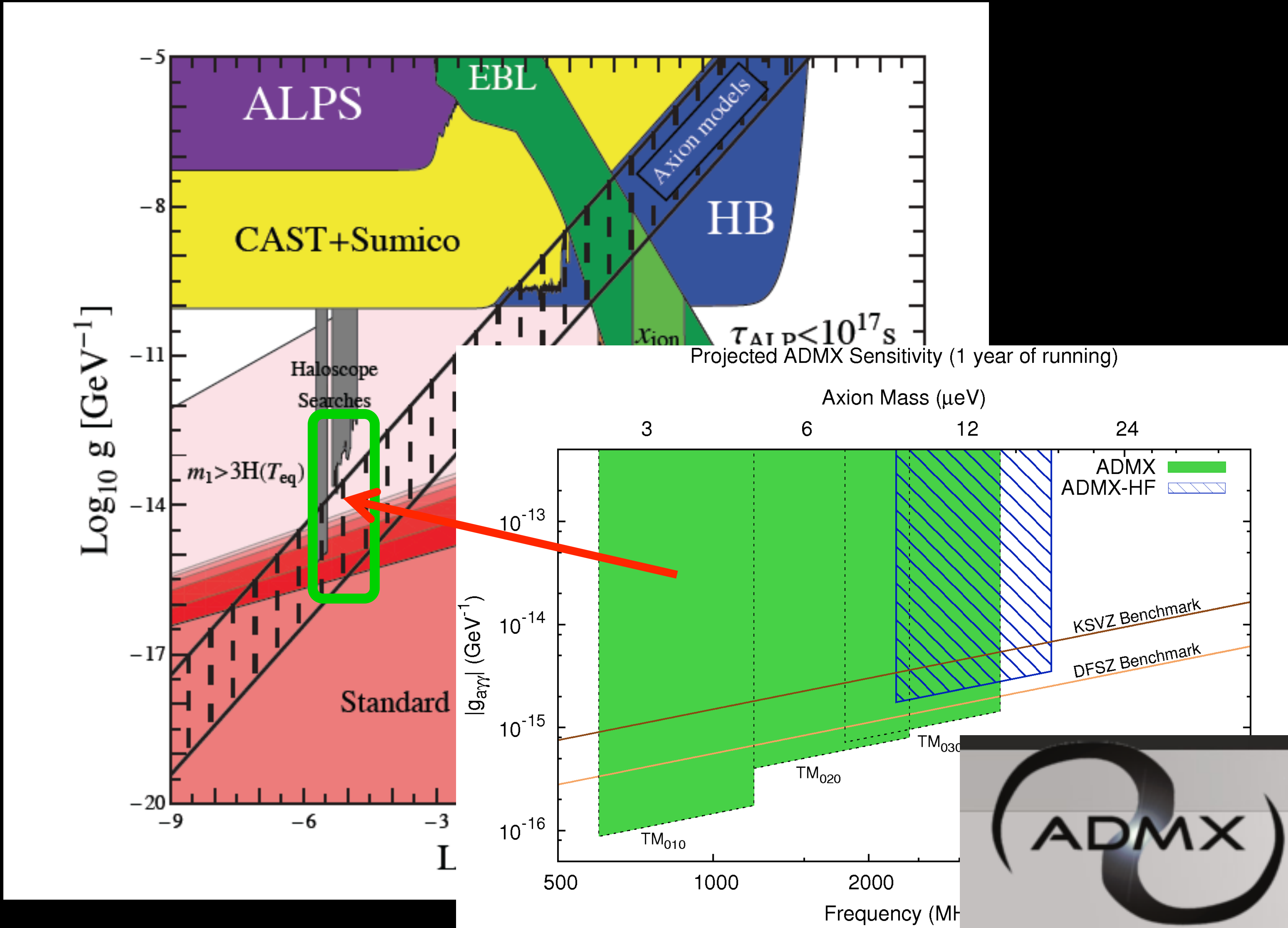


A discovery possible any minute!



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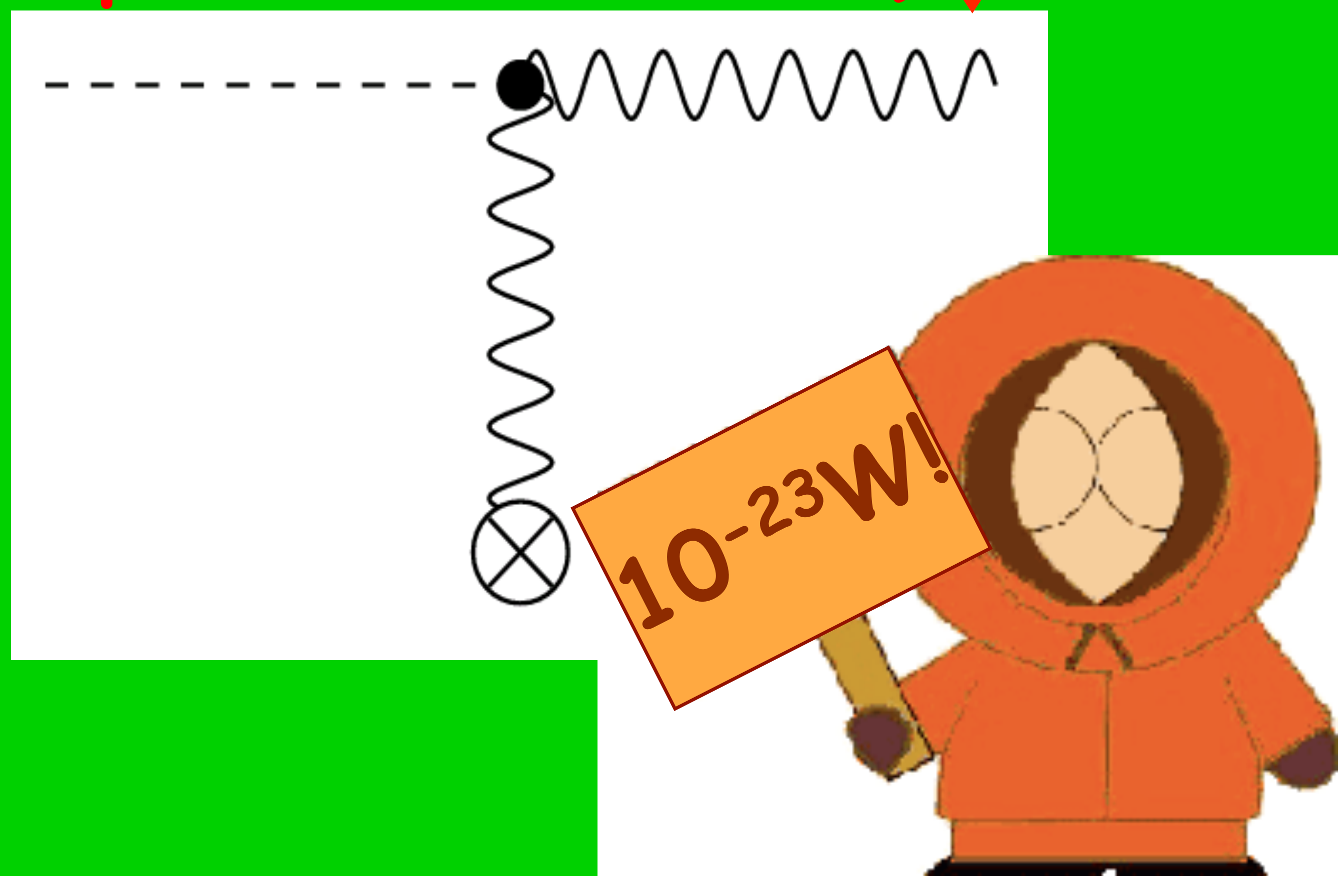
Electricity from Dark Matter ;-).

- Photon Regeneration

Photon
(amplified in resonator)

axion
(dark matter)



Encircling the axion…

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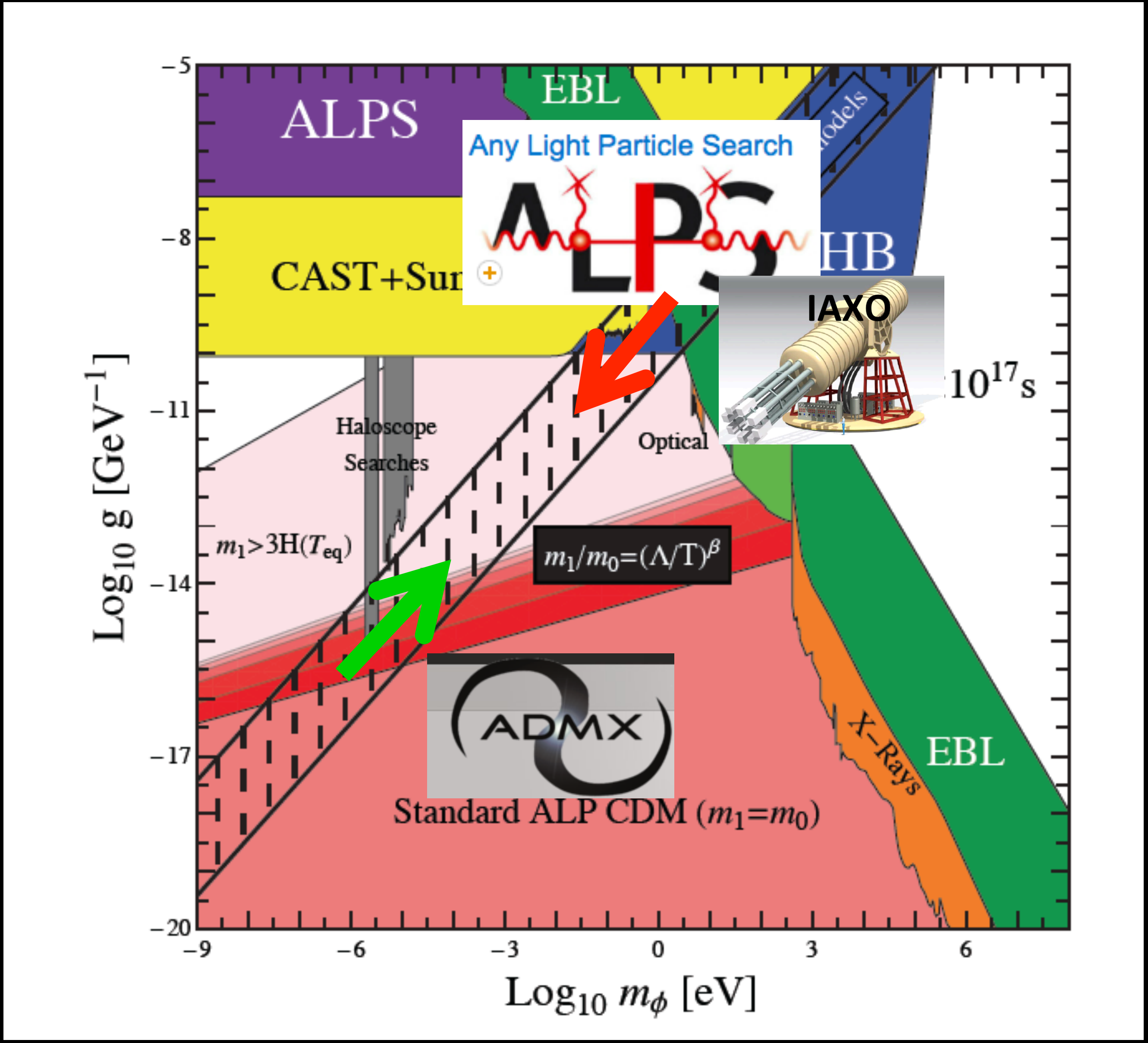

Beyond ALPs

Hidden photons

- Photon Regeneration

Photon
(amplified in resonator)

Hidden photon

$$\mathcal{L}_{\text{gauge}} = -\frac{1}{4} F^{\mu\nu}_{(\text{A})} F_{(\text{A})\mu\nu} - \frac{1}{4} F^{\mu\nu}_{(\text{B})} F_{(\text{B})\mu\nu} + \frac{\chi}{2} F^{\mu\nu}_{(\text{A})} F_{(\text{B})\mu\nu},$$

„Our“ U(1)

„Hidden“ U(1)

Mixing

+ Mass $$\mathcal{L}_{\text{mass}} = \frac{1}{2} m^2_{\gamma'} X^\mu X_\mu$$

Also for hidden photons!!!

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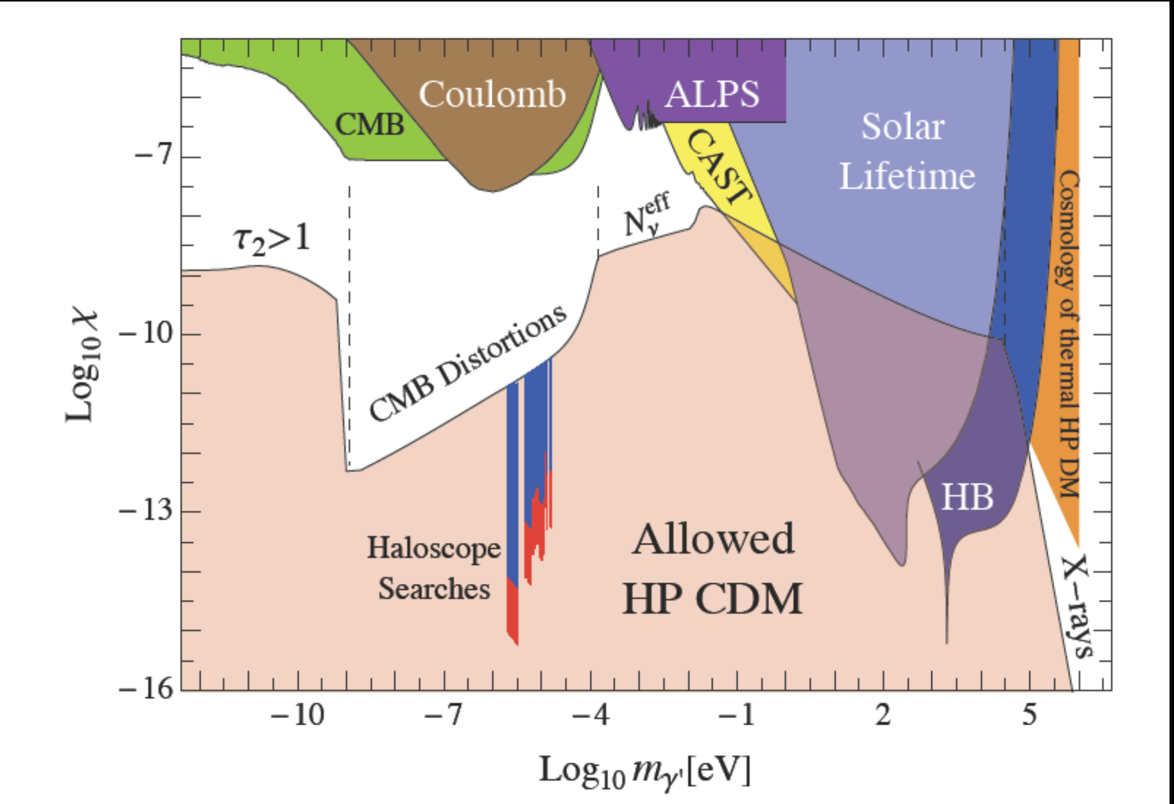
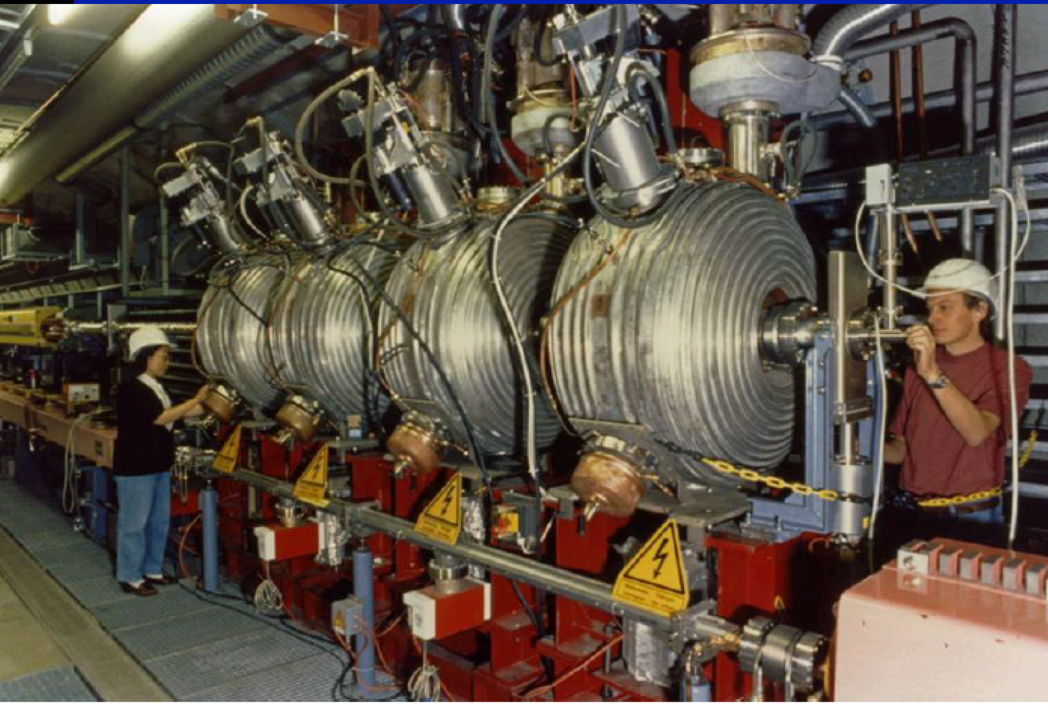
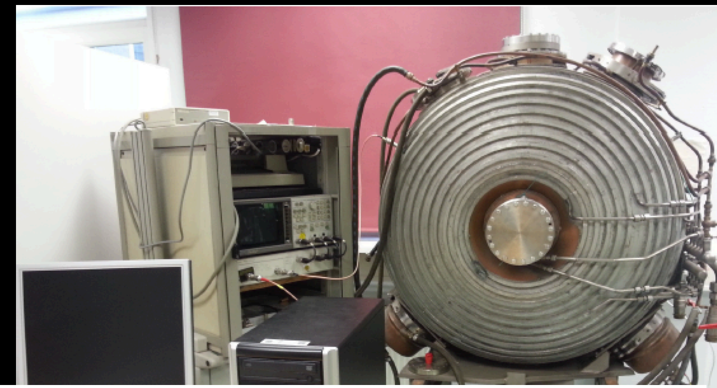
- There are other very light DM candidates
- E.g

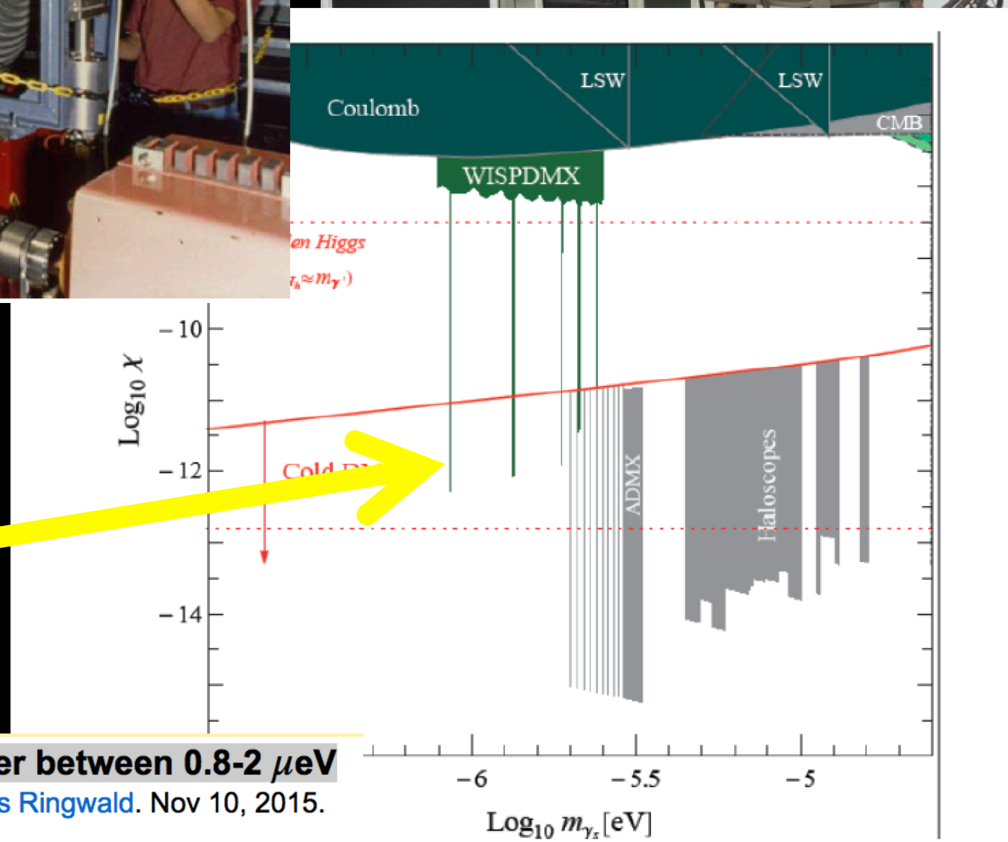
  extra (hidden) U(1) bosons=hidden photons!!!



@ DESY + Bonn: WISPDMX





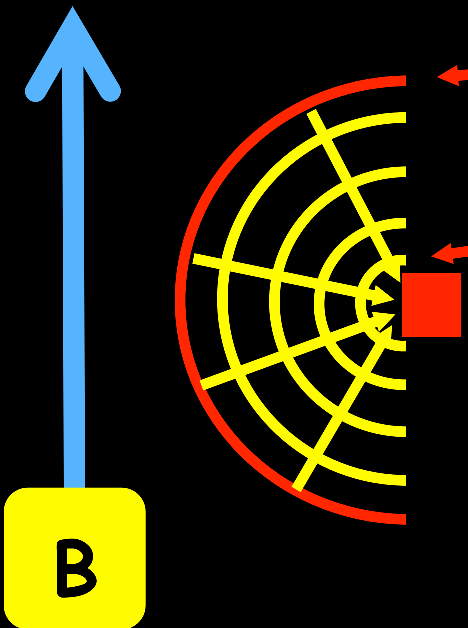


New Results!

1. **WISPDMX: A haloscope for WISP Dark Matter between 0.8-2 μeV**
Le Hoang Nguyen, Dieter Horns, Andrei Lobanov, Andreas Ringwald. Nov 10, 2015.
DESY-15-185
e-Print: arXiv:1511.03161 [physics.ins-det] | PDF

Broadband Search Strategy

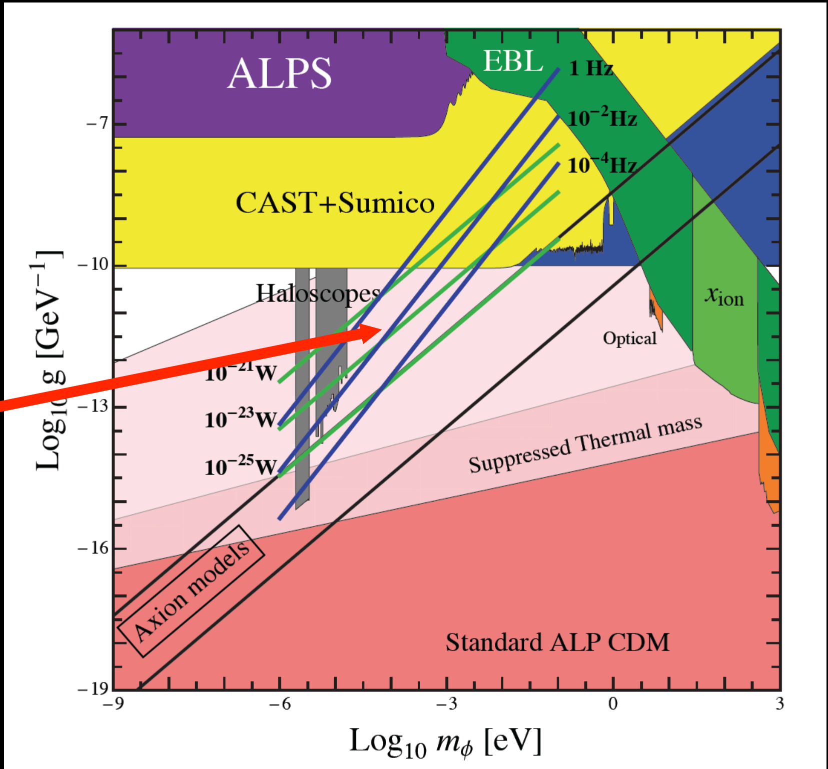
Dark Matter Antenna



Antenna converts axion->photon

Radiation concentrated in center

Detector



Probes here;
very sensitive!!

The FUNK Experiment

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Recycle Auger mirror

Detector

First Results

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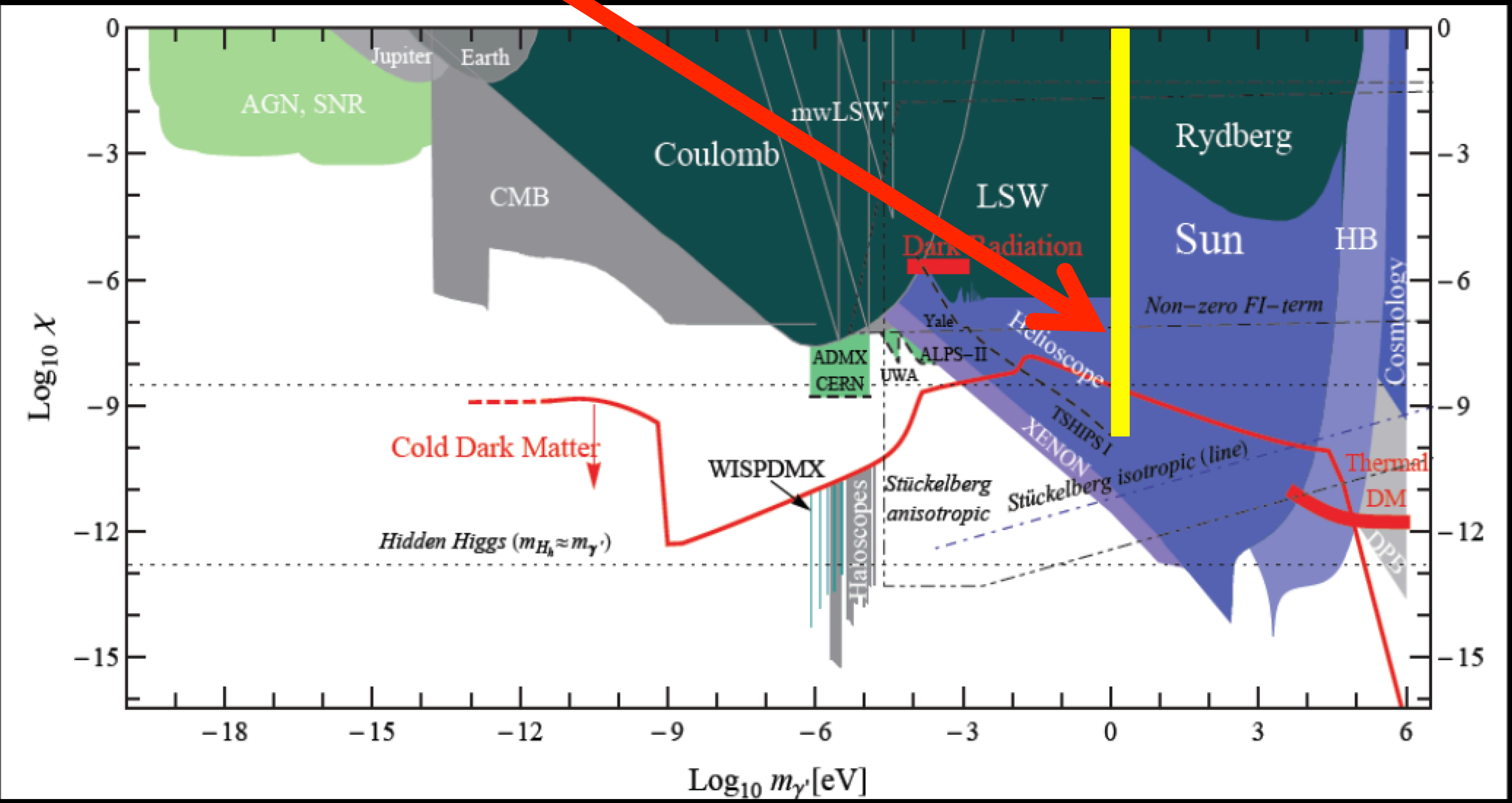

Upgrade: The PMT 9000(+107)

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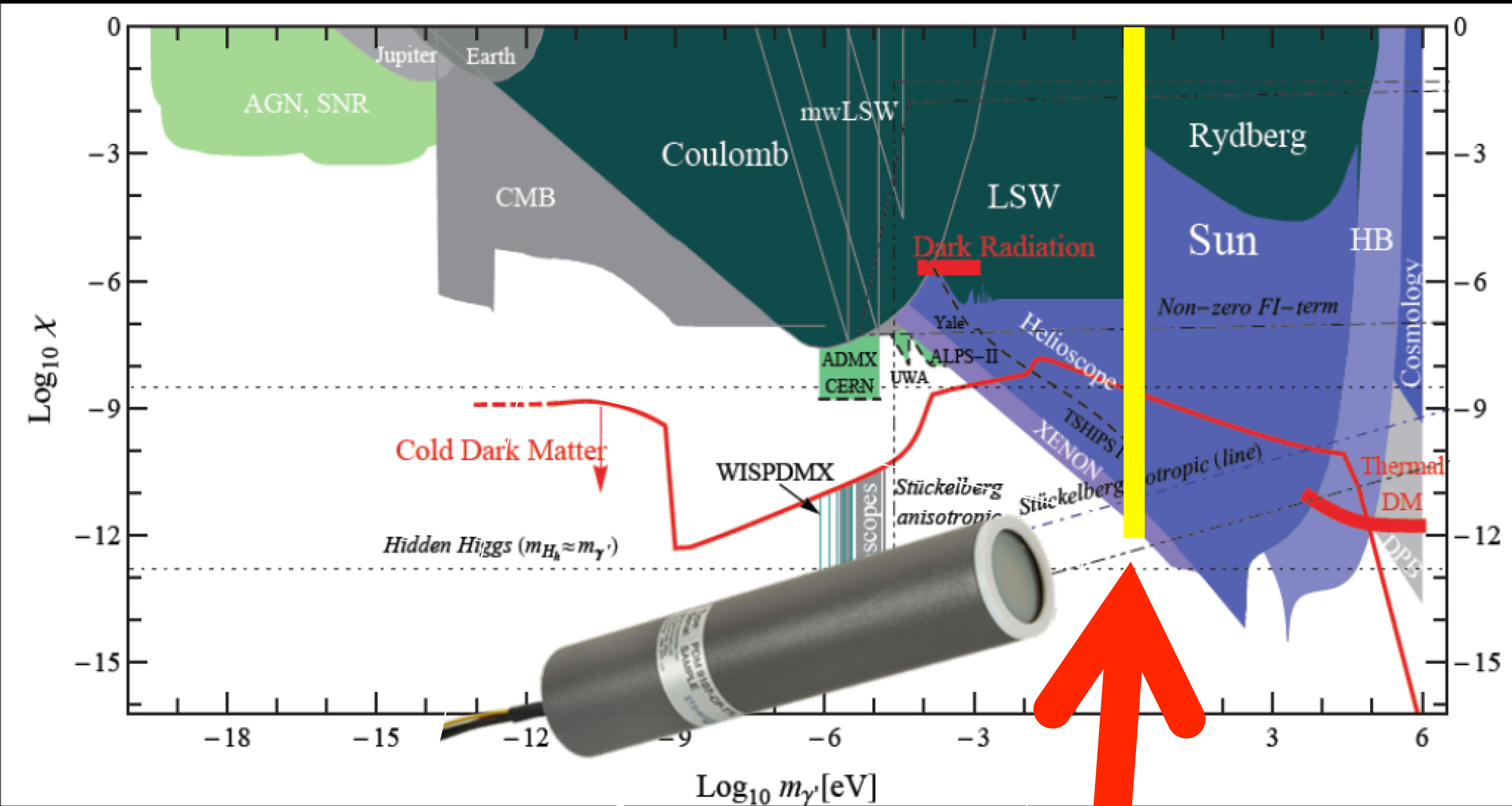

Discovery Potential ☺!!!

A Dream for ~~Astrology~~ ehhm Astronomy

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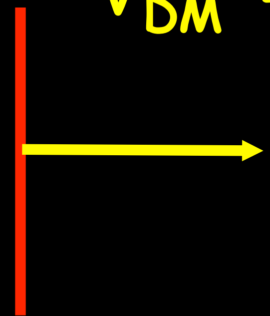
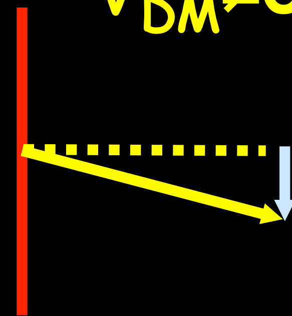
- Emission from moving dark matter

$V_{DM} = 0$

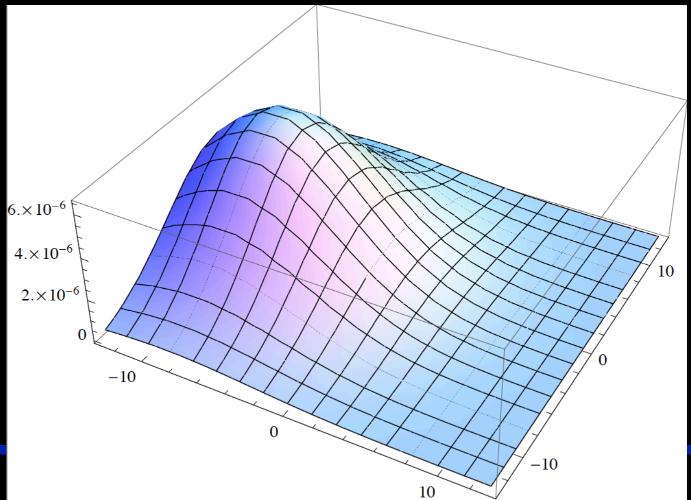


$V_{DM} \neq 0 =$



- A picture of the DM-velocity distribution

Screen



Going Monodromic

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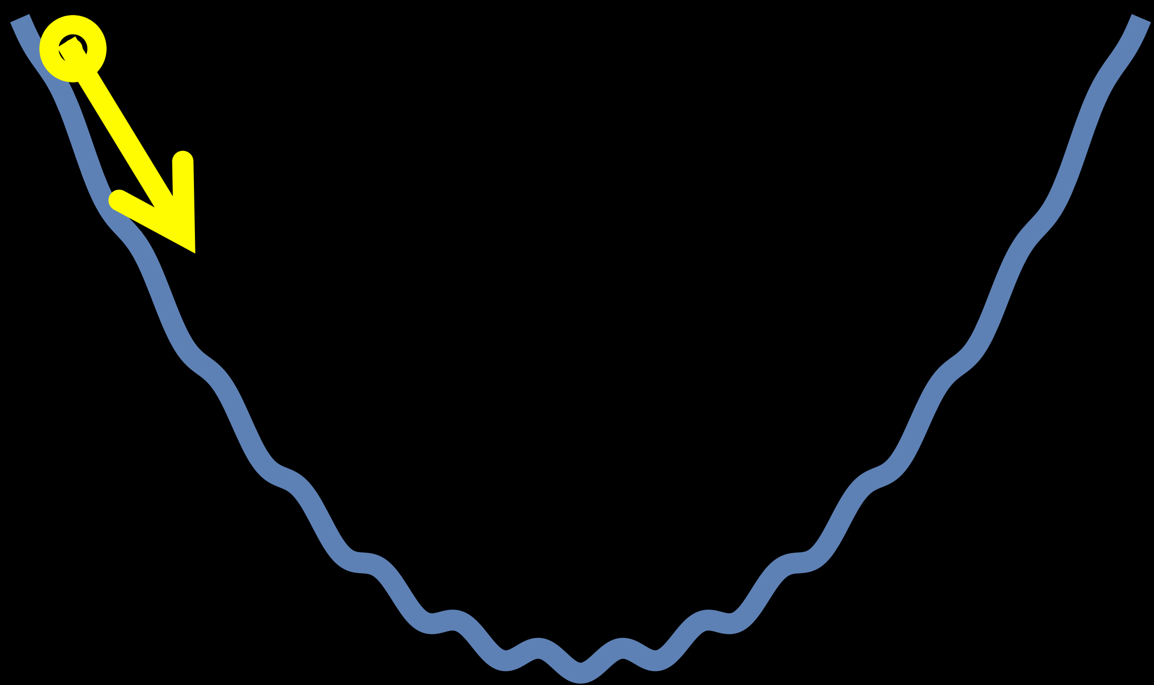
Axion Monodromy

- **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

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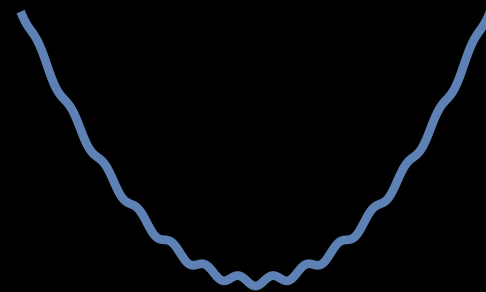
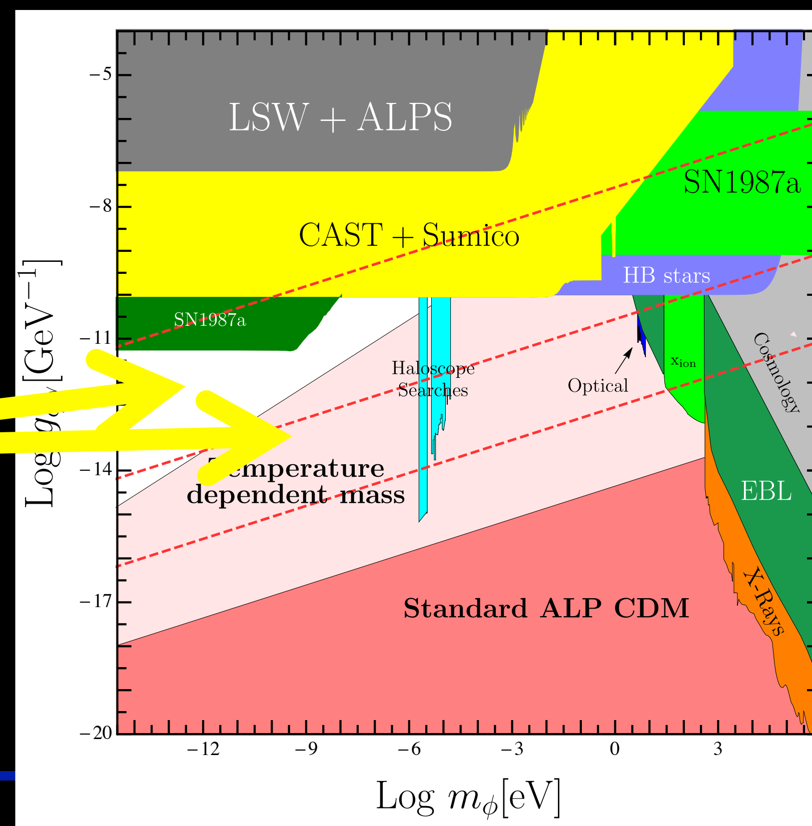
- Allows to start with higher energy density
  → More DM

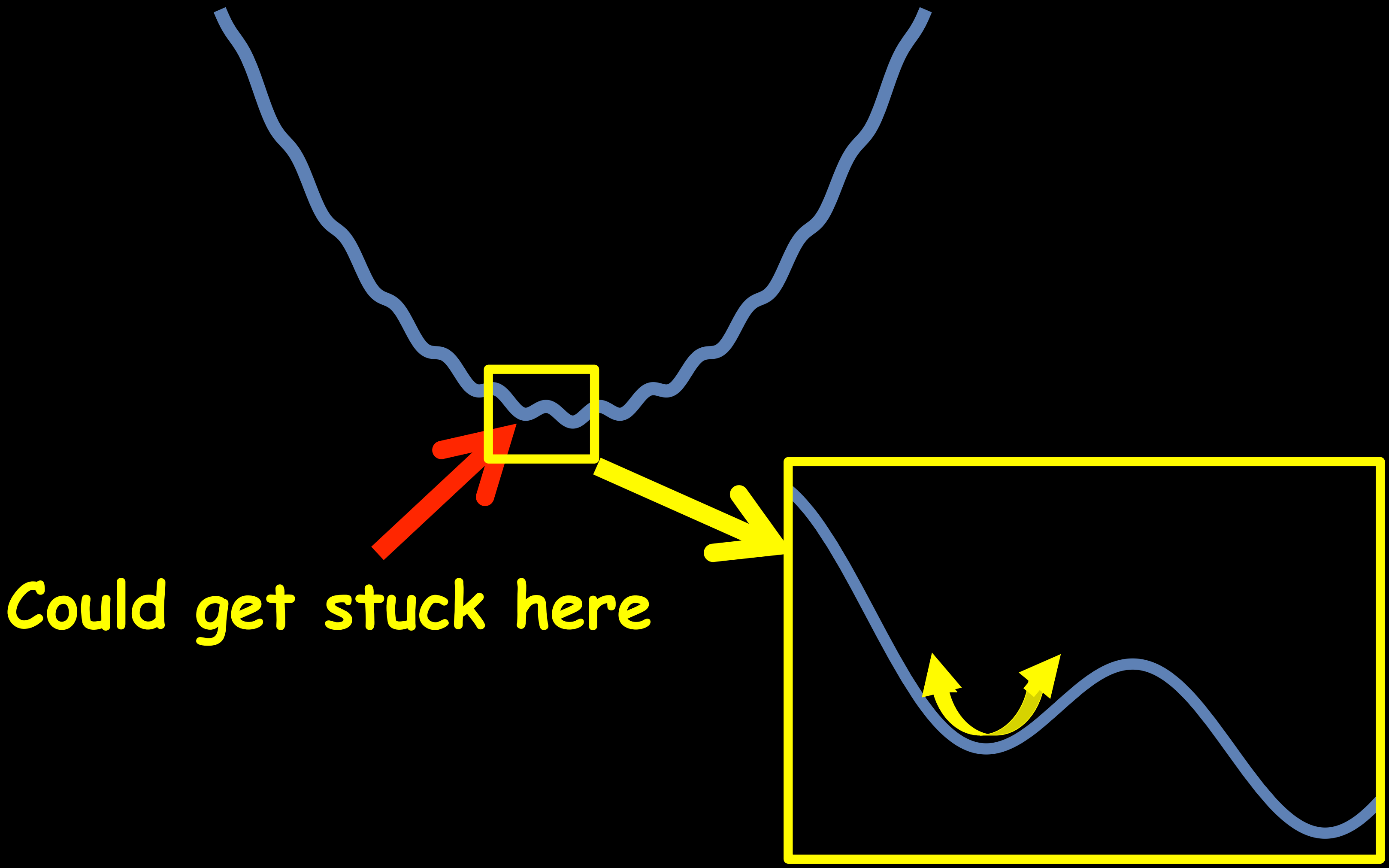
vs



Models in this region!

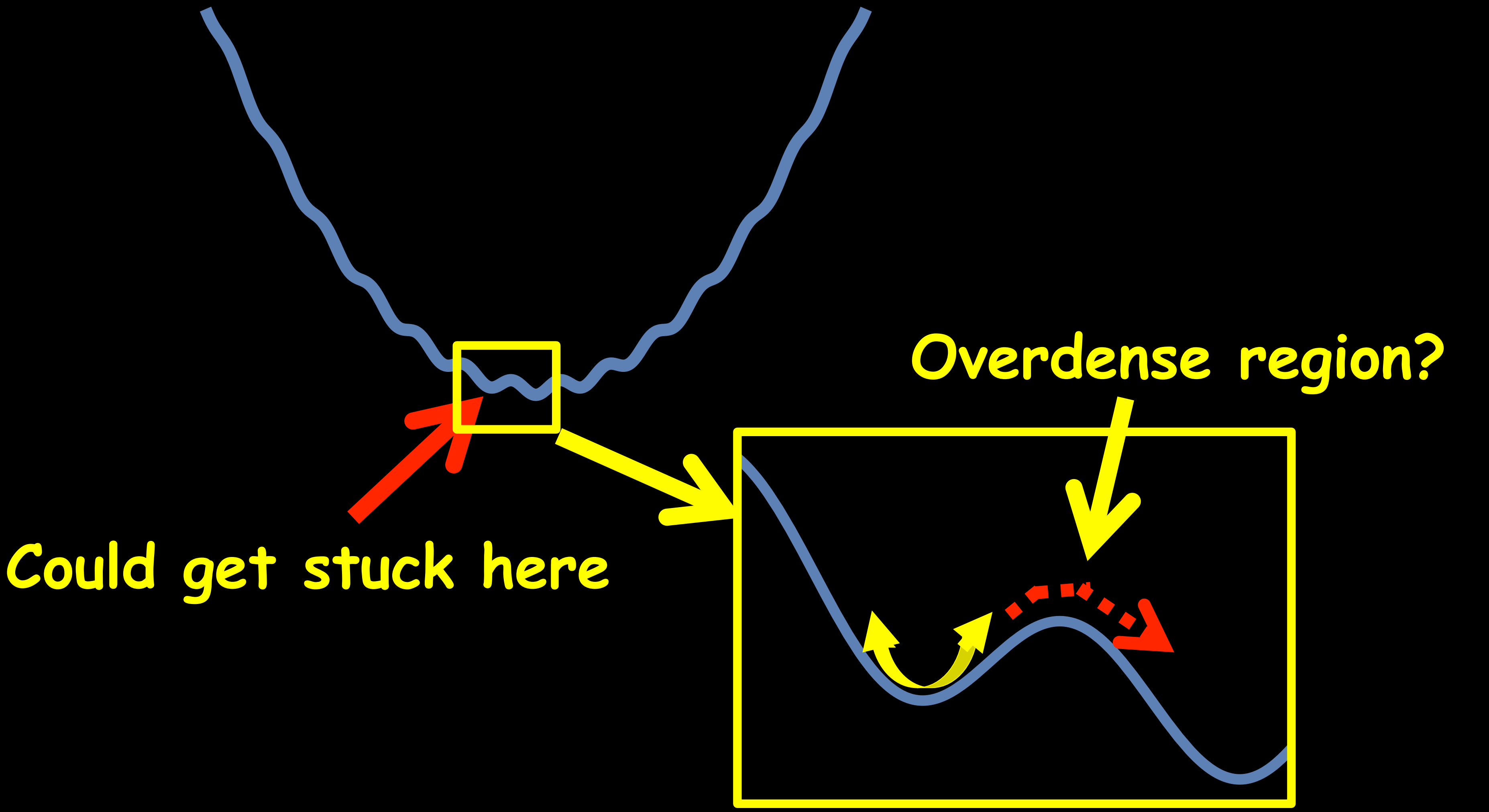


Interesting Phenomena??



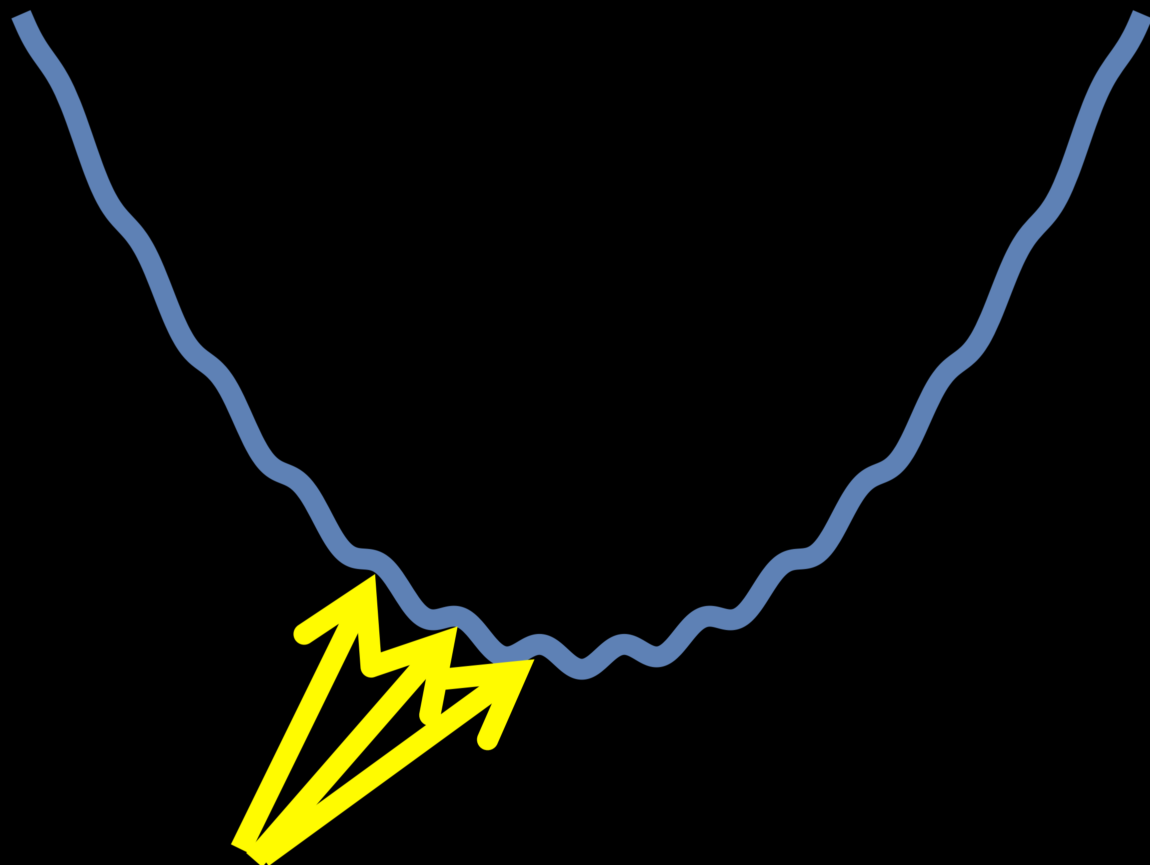
Oscillations like DM!

Interesting Phenomena??



$$amplitude \sim \sqrt{DM density}$$

Interesting Phenomena??



Regions with "negative mass"

Instability → Particle Production with p≠0?!?

Very rapid particle production…

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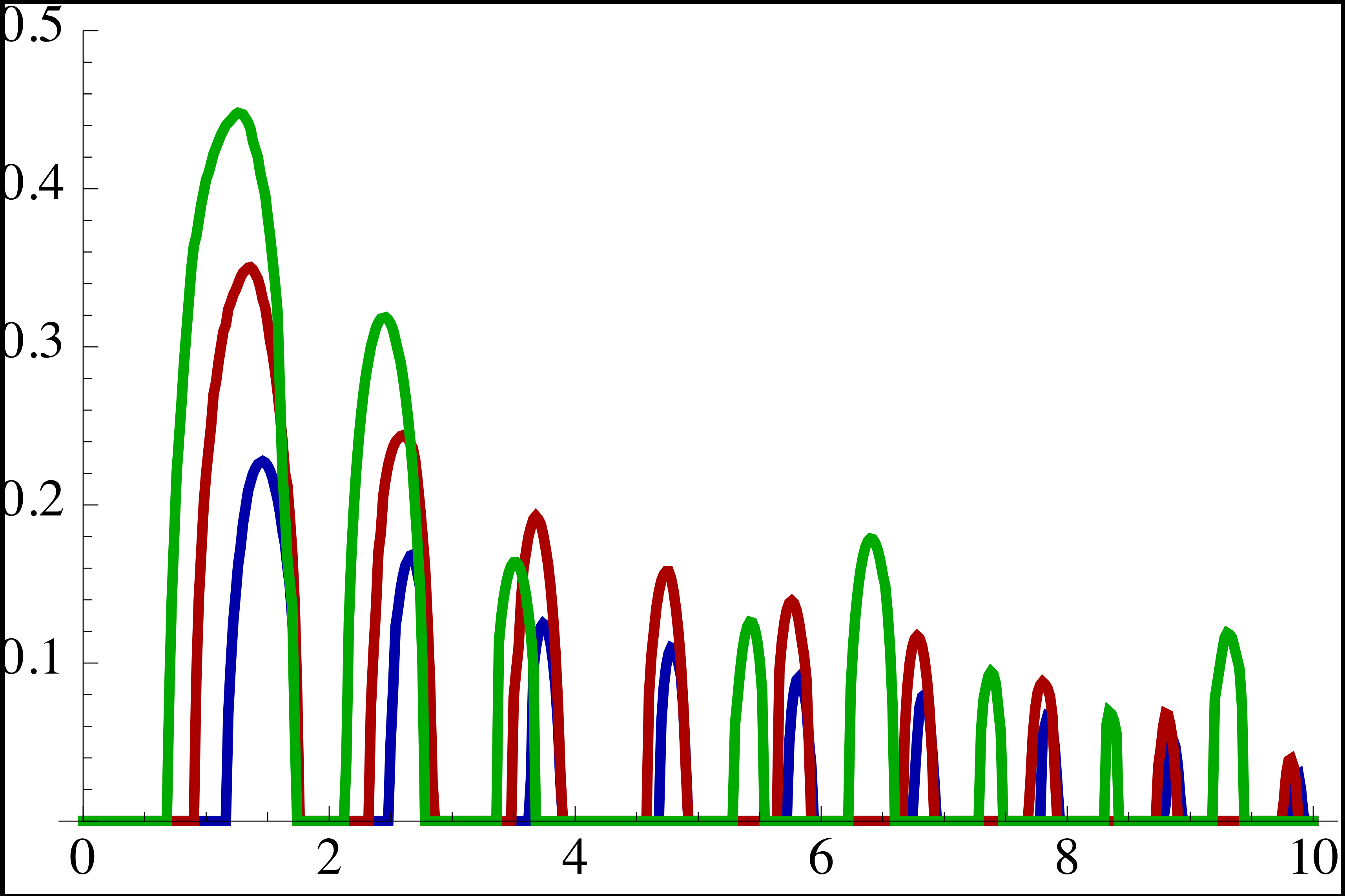

Running through walls

A WISPy Domain Wall

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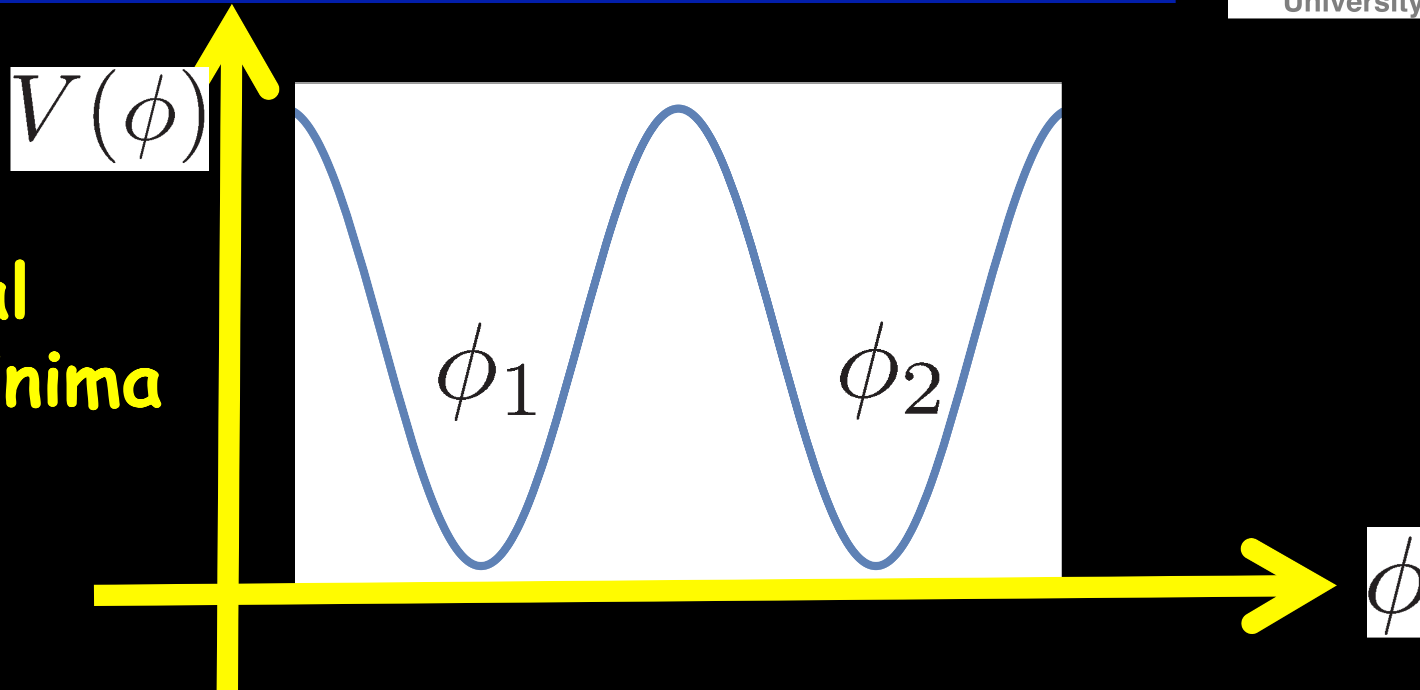
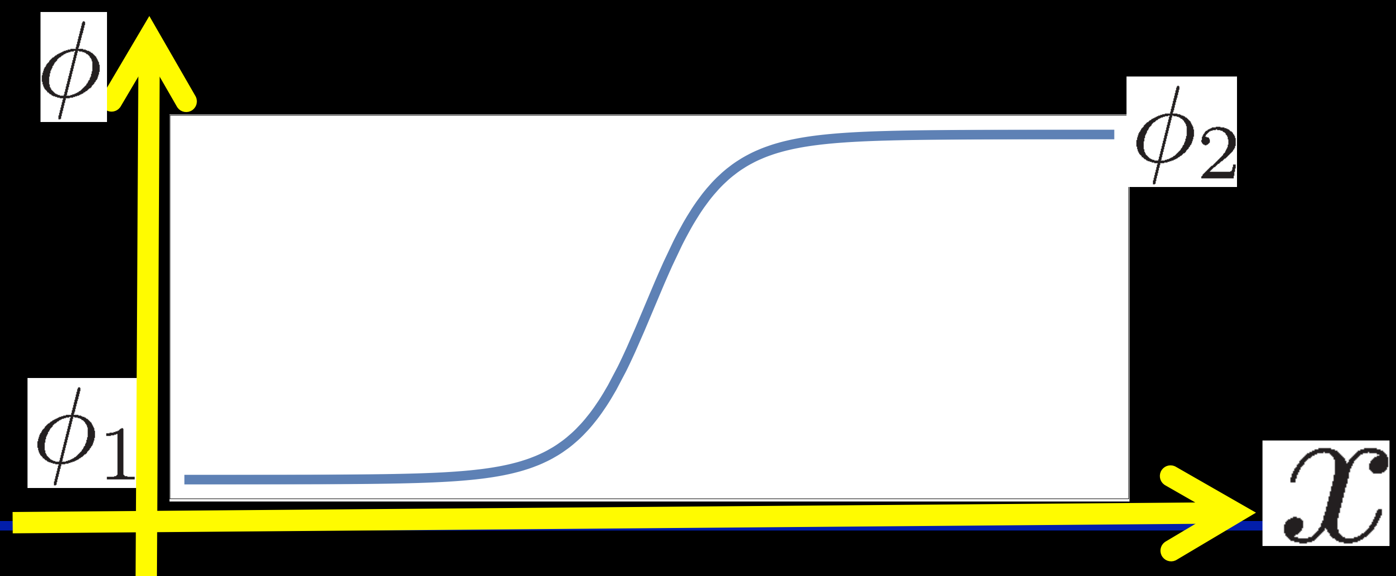
Potential with two minima



Domain wall from side 1 To side 2



A WISPy Domain Wall

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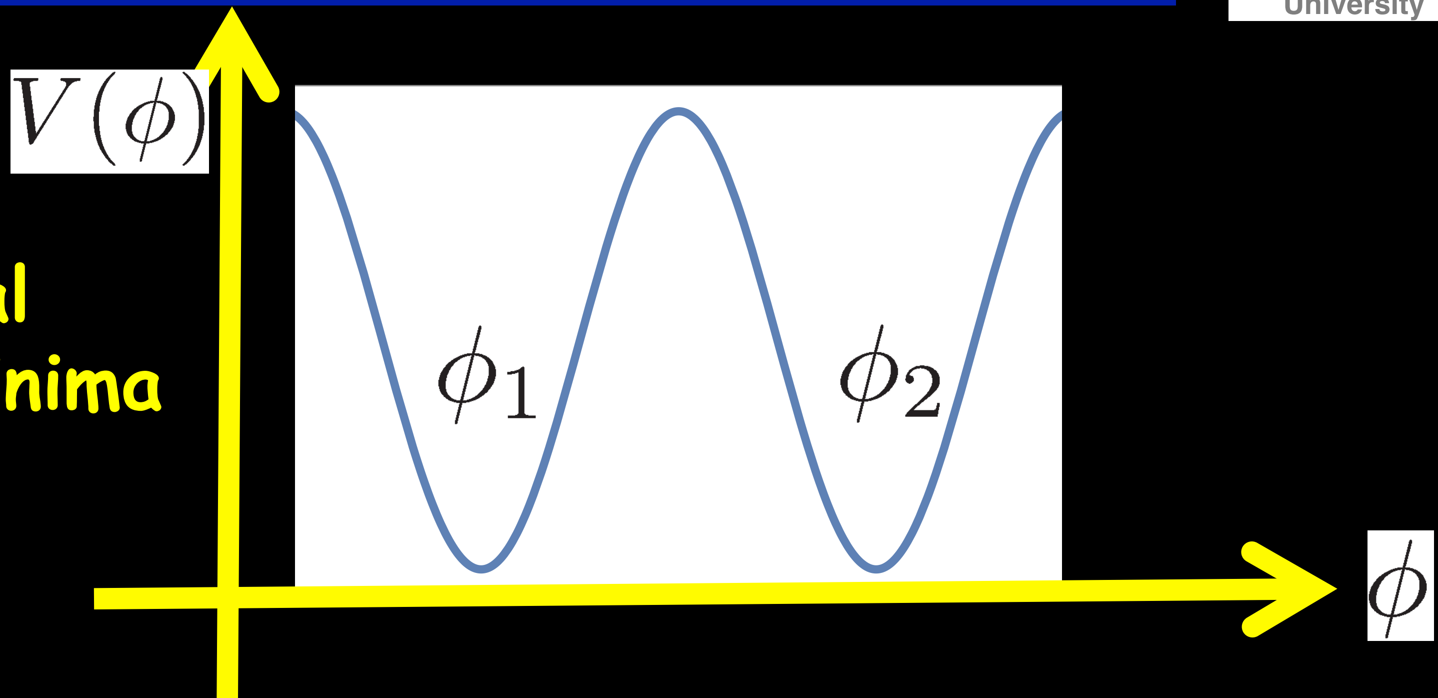
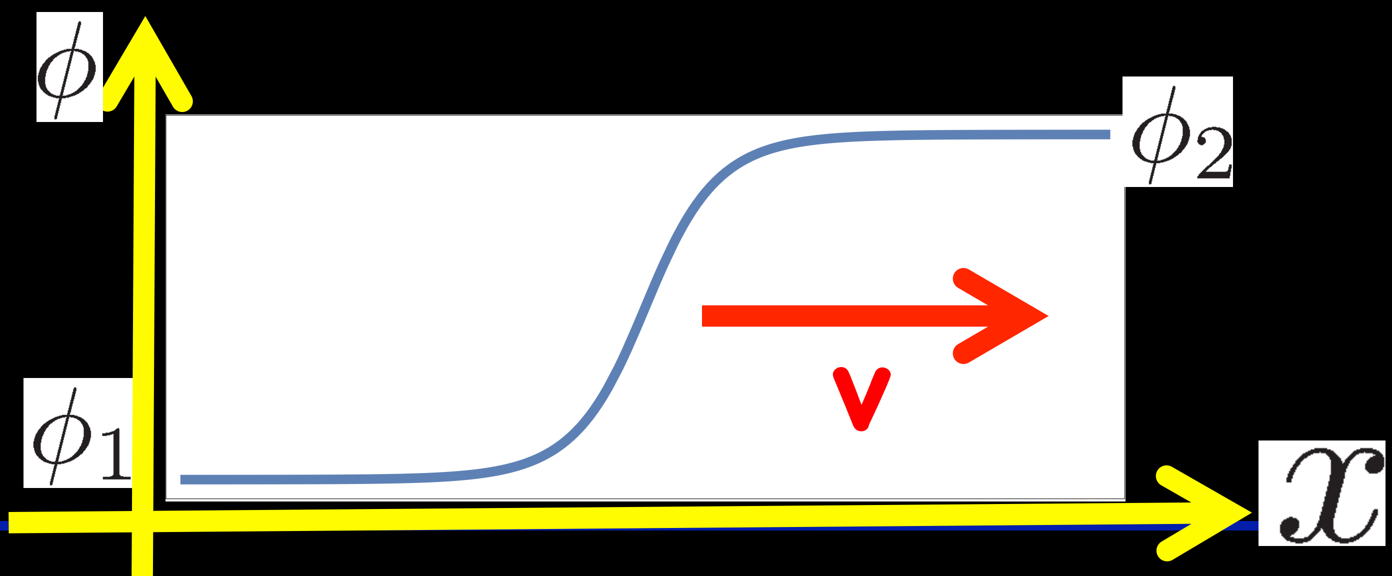
Potential with two minima

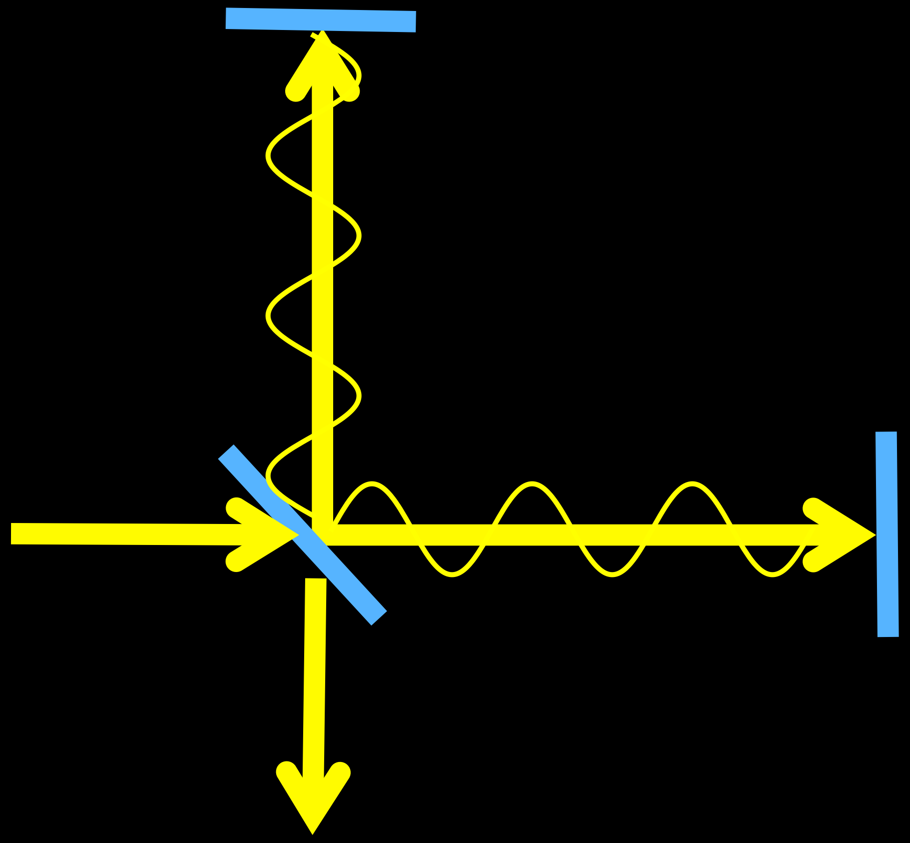


Domain wall from side 1 To side 2



aLIGO

- Has detected gravitational waves!!
- Is an Interferometer



Causing a phase shift

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- Interaction inside wall creates photon mass

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

aLIGO

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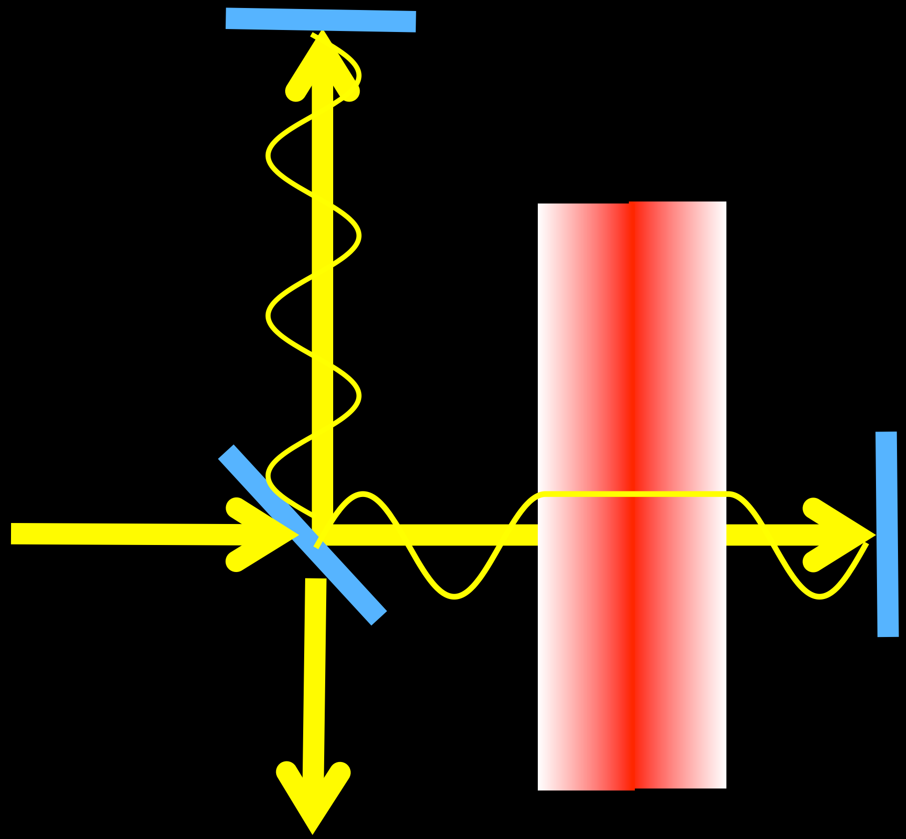
- Has detected gravitational waves!!
- Is an Interferometer



Interference pattern changed

Signal shapes

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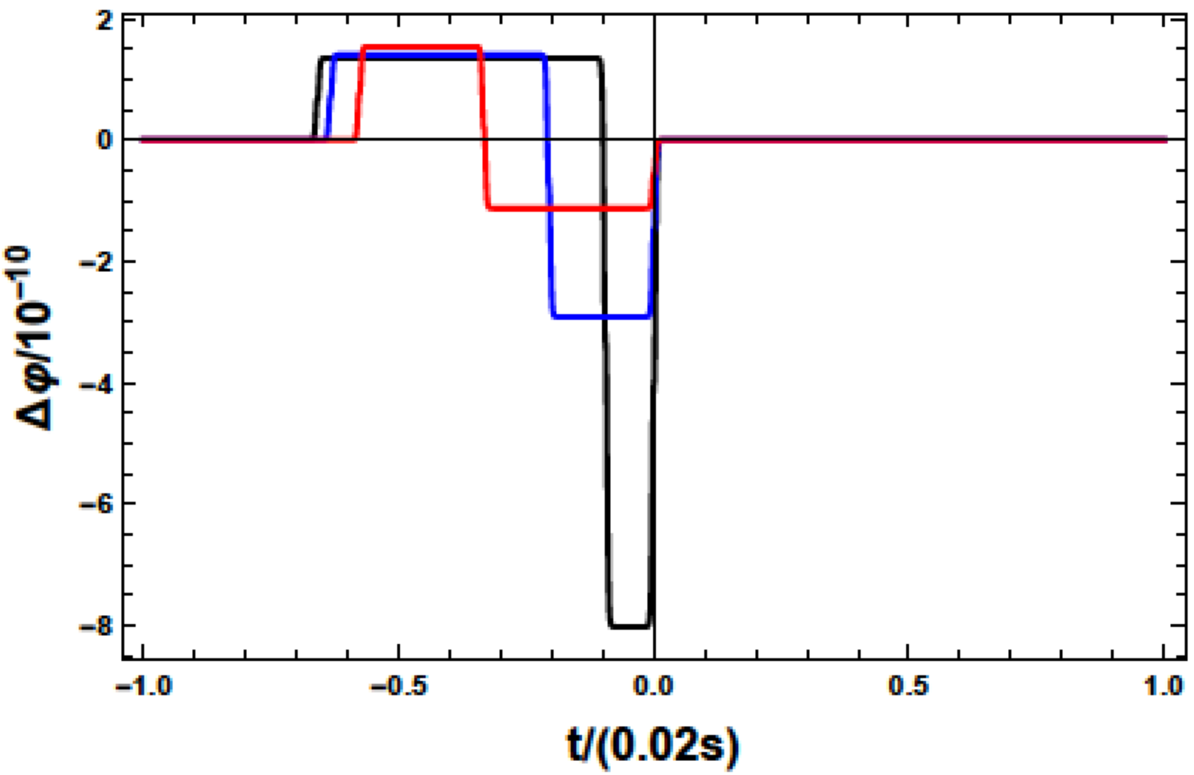

FIG. 6: $L = 4000\,\mathrm{m}$, $\omega \approx 1\,\mathrm{eV}$, $m = 10\,\mathrm{neV}$, $m_{\gamma,0} = 1\,\mathrm{neV}$, $N_A/N_\phi = 1$, $\alpha = \pi/2.2, \pi/2.5, \pi/3$ (black, blue, red), v chosen such that signal has roughly a length of $0.02\mathrm{s} \sim 1/(50\,\mathrm{Hz})$ this corresponds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

Signal shapes

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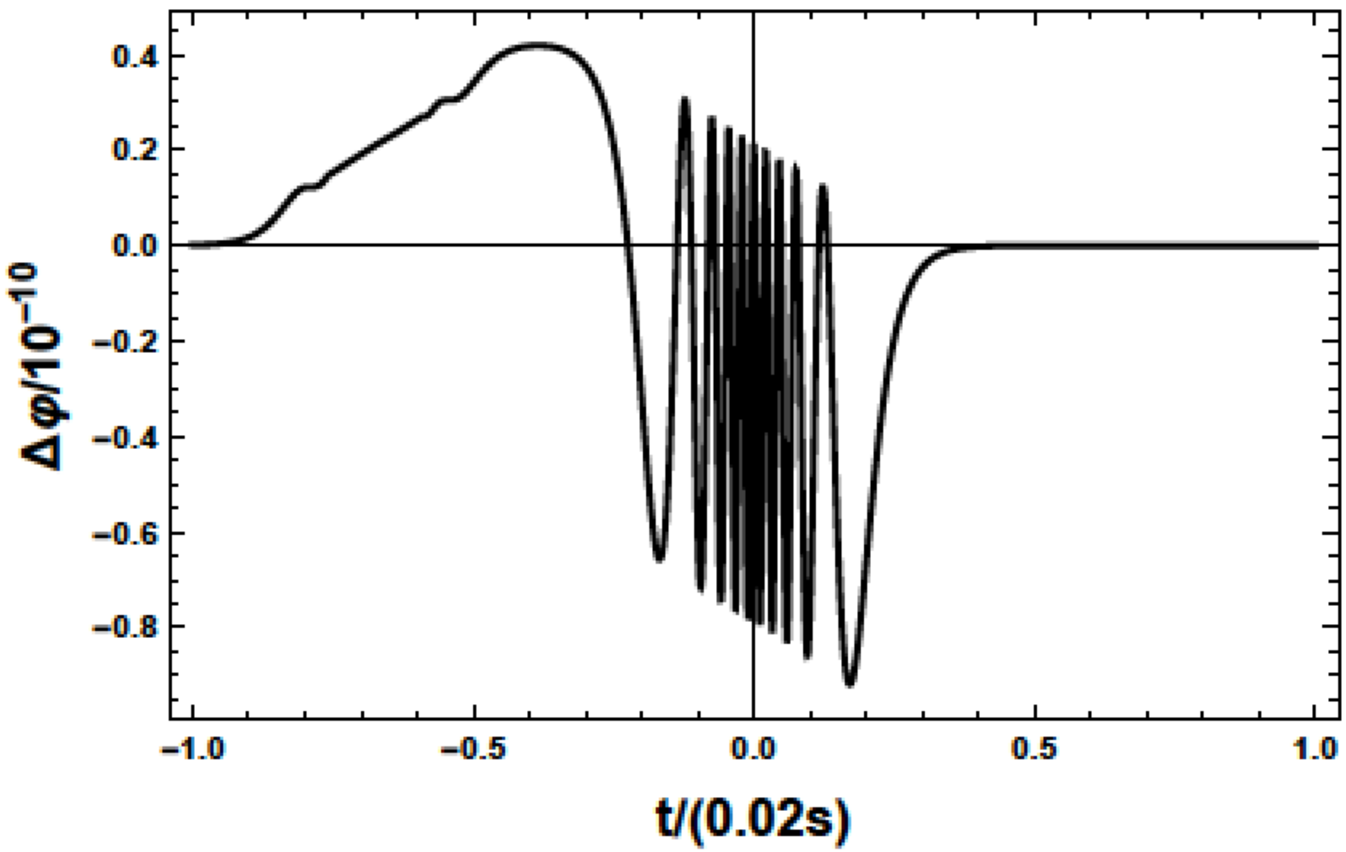

FIG. 8: As in Fig. ?? but $m_{\gamma,0} = 0.1\,\mathrm{neV}$, $N_A/N_\phi = 5$, $m = 0.5\,\mathrm{neV}$, $\alpha = \pi/2$ and $v = 1 \times 10^{-3}$.

How to distiguish from grav waves?

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

➔ Time difference between two sites ~few seconds

➔ Need careful analysis strategies

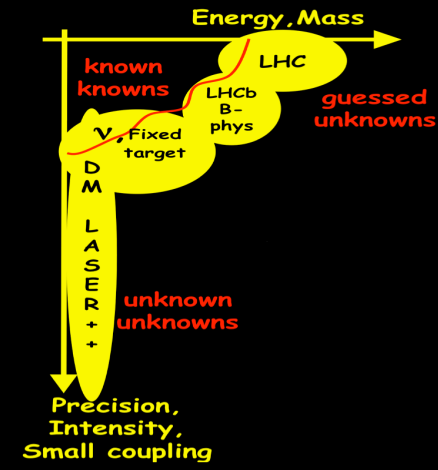
Conclusions

Conclusions

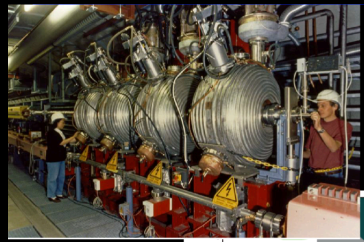
- Good Physics Case for Axions and WISPs

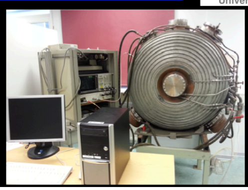
  ➡ explore `The Low Energy Frontier'

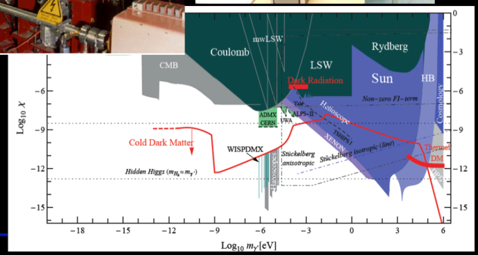
- Low energy experiments complementary to accelerators!

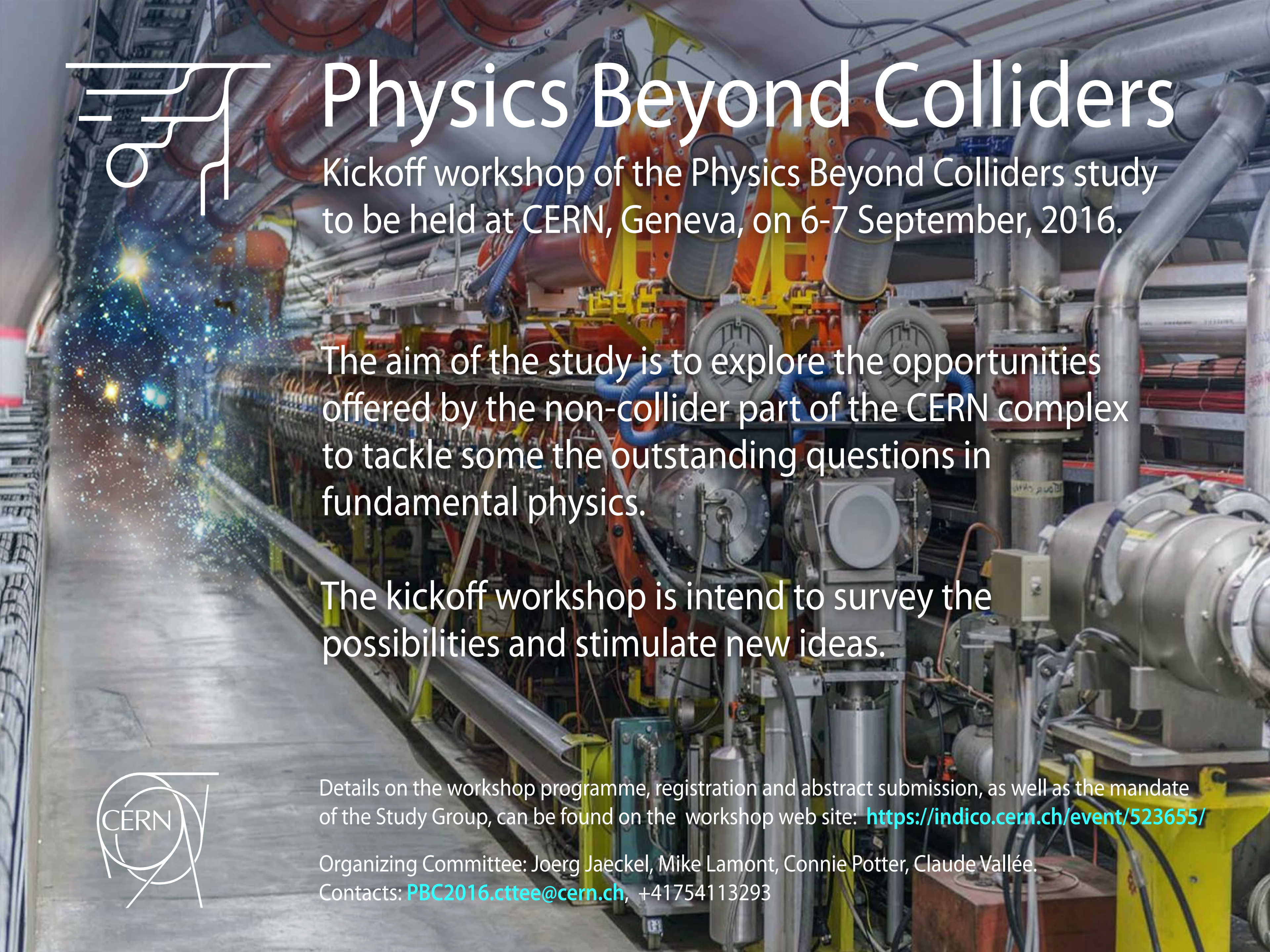


- Dark Matter may be WISPy ☺
  - ➔ New Search opportunities!
  - ➔ Searches ongoing!
  - ➔ Crazy things to explore!









Physics Beyond Colliders
Kickoff workshop of the Physics Beyond Colliders study to be held at CERN, Geneva, on 6-7 September, 2016.
The aim of the study is to explore the opportunities offered by the non-collider part of the CERN complex to tackle some the outstanding questions in fundamental physics.
The kickoff workshop is intend to survey the possibilities and stimulate new ideas.
Details on the workshop programme, registration and abstract submission, as well as the mandate of the Study Group, can be found on the workshop web site: https://indico.cern.ch/event/523655/
Organizing Committee: Joerg Jaeckel, Mike Lamont, Connie Potter, Claude Vallée.
Contacts: PBC2016.cttee@cern.ch, +41754113293
CERN


Hidden sector