Probing the Hidden Sector @ Low Energies

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Where we want to go…

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The Standard Model

+

Beyond the SM
(directly accessible to colliders)

The Hidden Sector

Here be Dragons

Exploring is (at least) 2 dimensional

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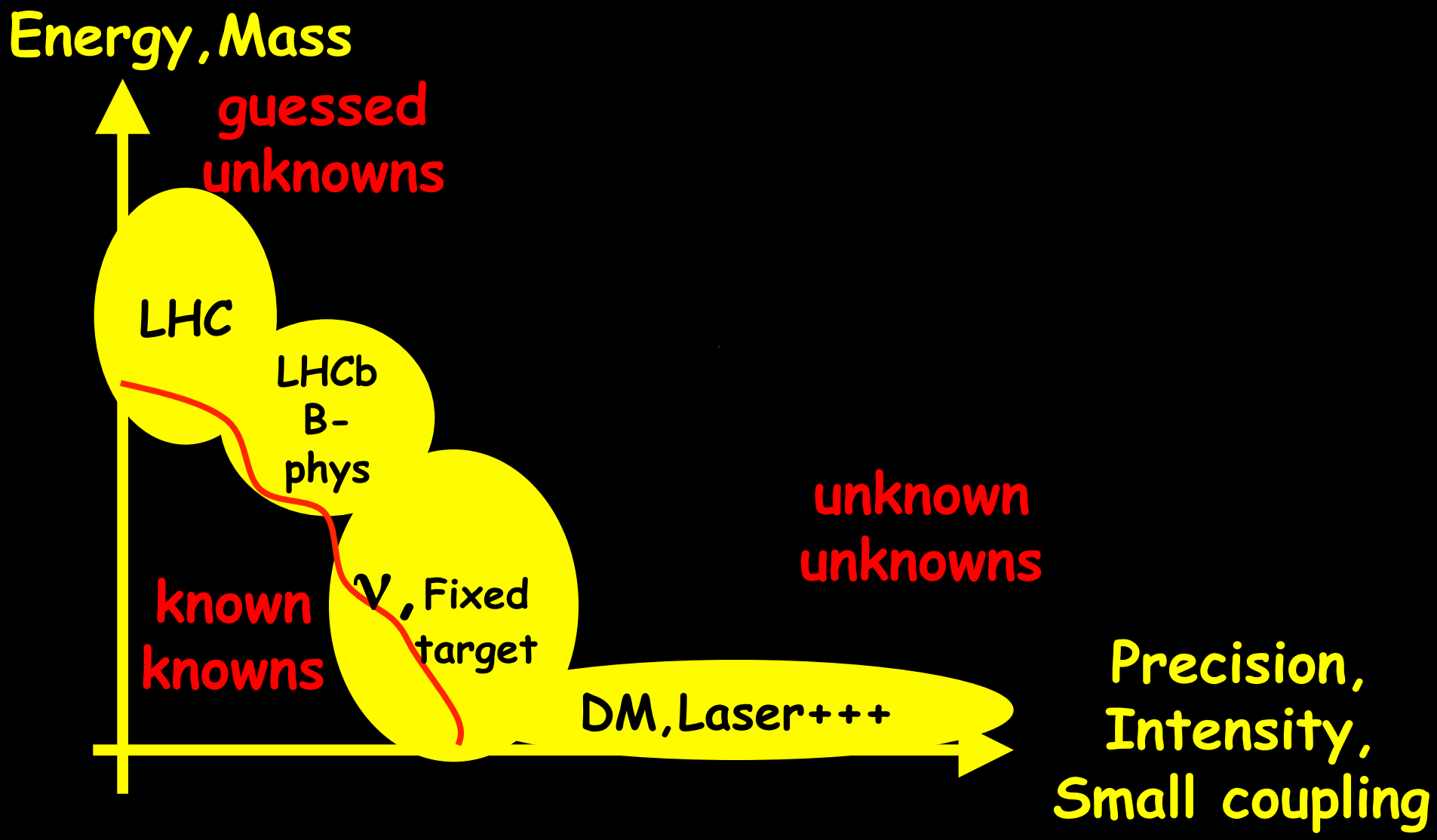

We need...

Physics beyond the Standard Model

The Standard Model

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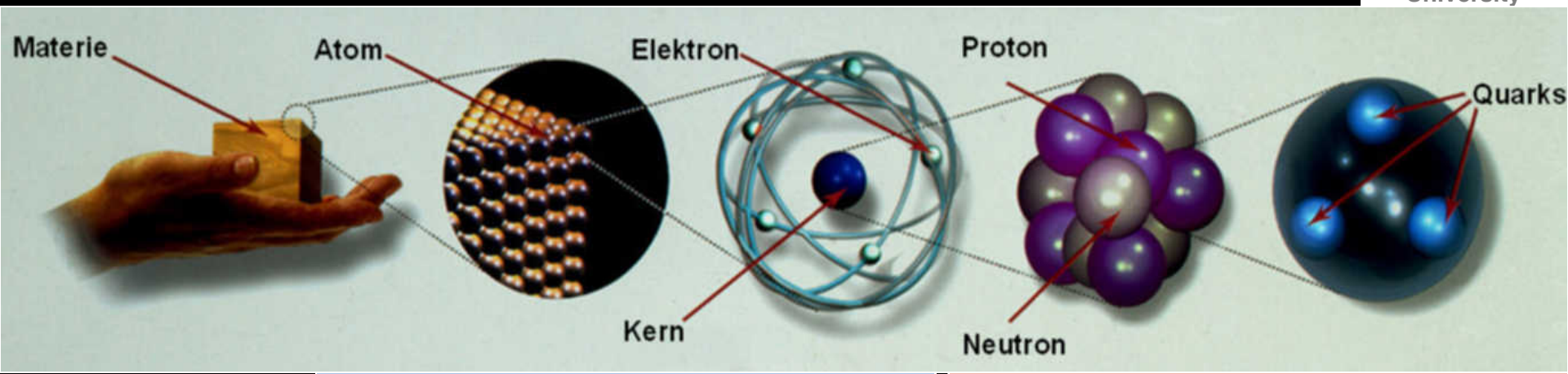

	Quarks		Leptons	
	Charge +2/3	Charge -1/3	Charge -1	Charge 0
1. Family	Up u	Down d	Electron e	e-Neutrino ν_e
2. Family	Charm c	Strange s	Myon μ	μ-Neutrino ν_μ
3. Family	Top t	Bottom b	Tau τ	τ-Neutrino ν_τ

Gravitation ➡ graviton

Weak forces ➡ W- und Z-bosons

Electromagnetism ➡ photons (γ)

Strong forces ➡ gluons

Hints for new Physics

Uglyness of old models

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- The Standard Model has many free parameters: O(30)

- Naturalness problems. Finetuning.

  Examples:
  Higgs mass, θ-angle (strong CP-problem)

A dirty little secret...

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

- The θ-term is CP violating!
- Connected to strong interactions!

➡ Measure electric dipole moment of the neutron!

Neutron electric dipole moment

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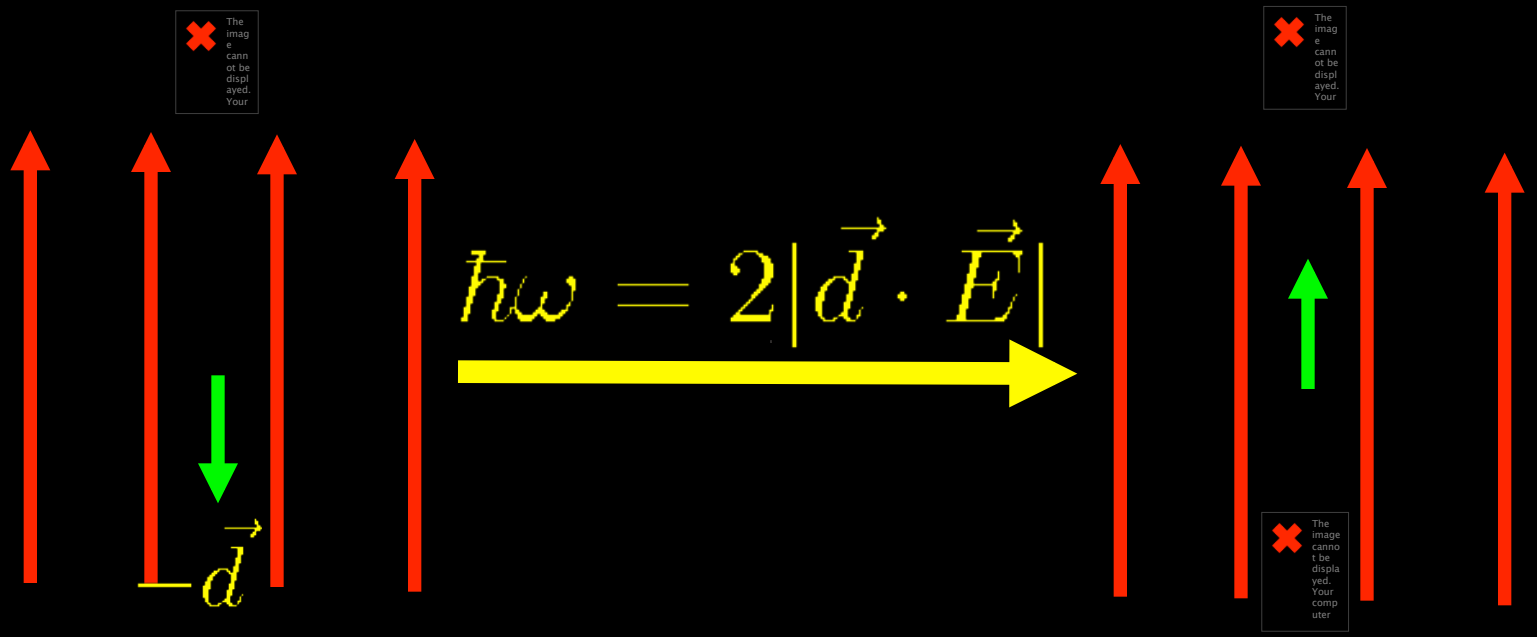
- θ would cause neutron EDM ➡ Experiment



➡ Measure transition frequency.

No neutron electric dipole moment...

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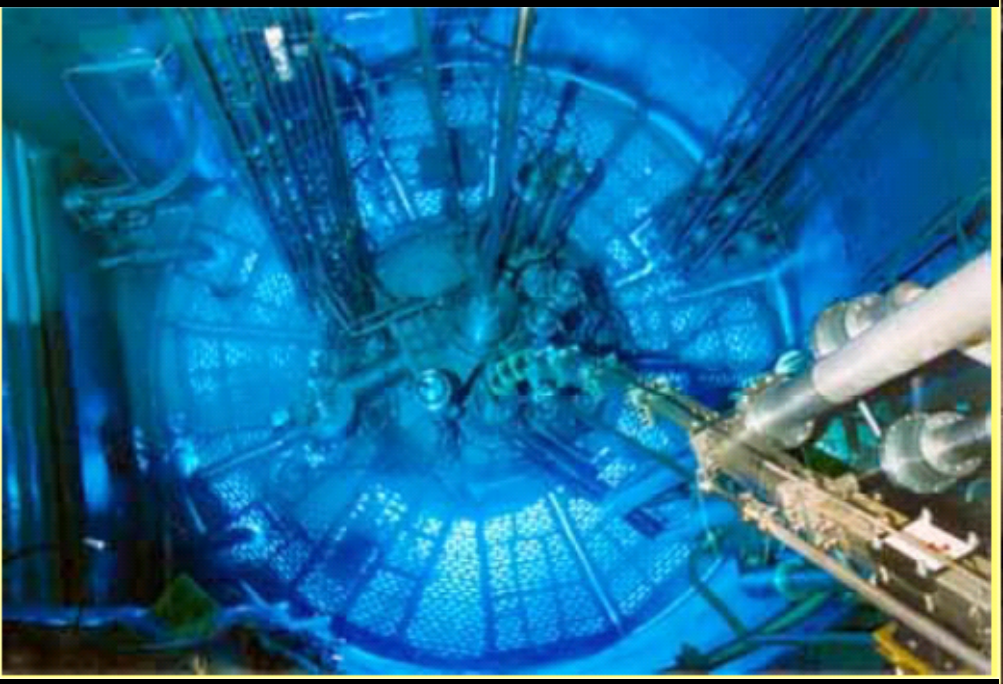

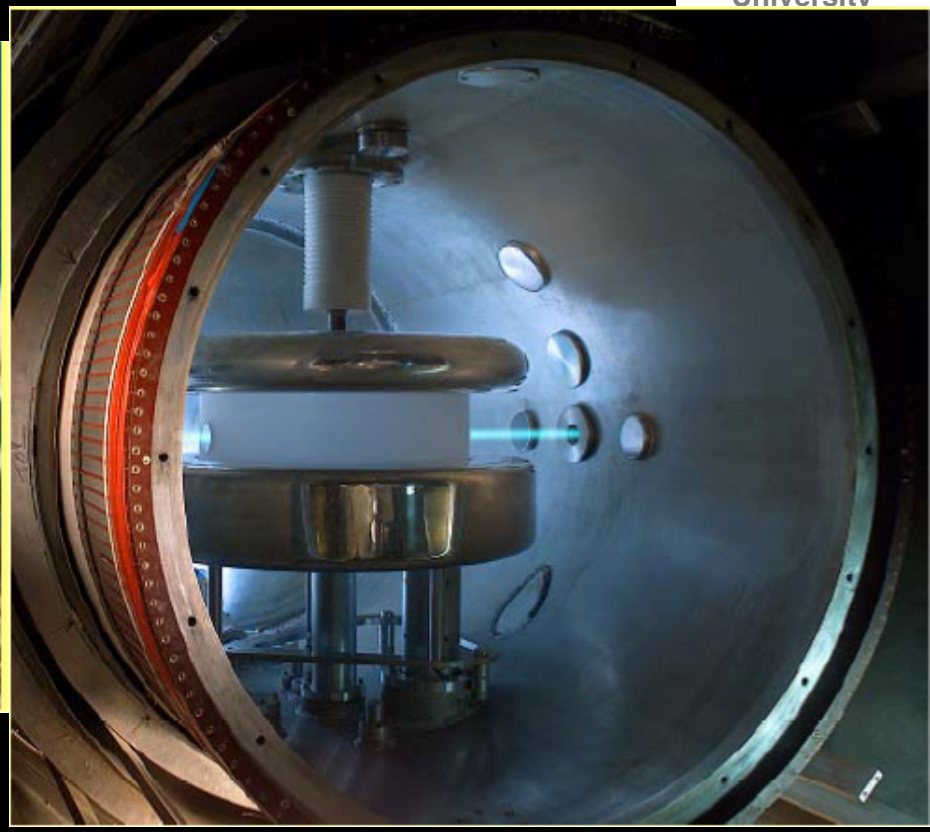

$$|\vec{d}| < 3\,10^{-26} e\,cm$$
$$= 3\,10^{-13} e\,fm$$

No neutron electric dipole moment...

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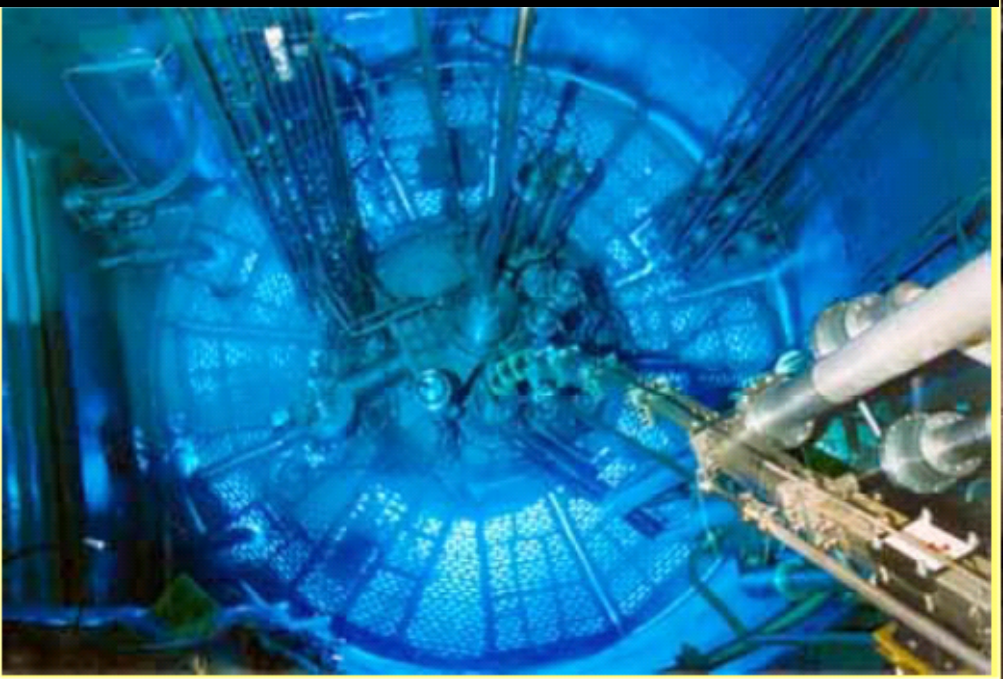

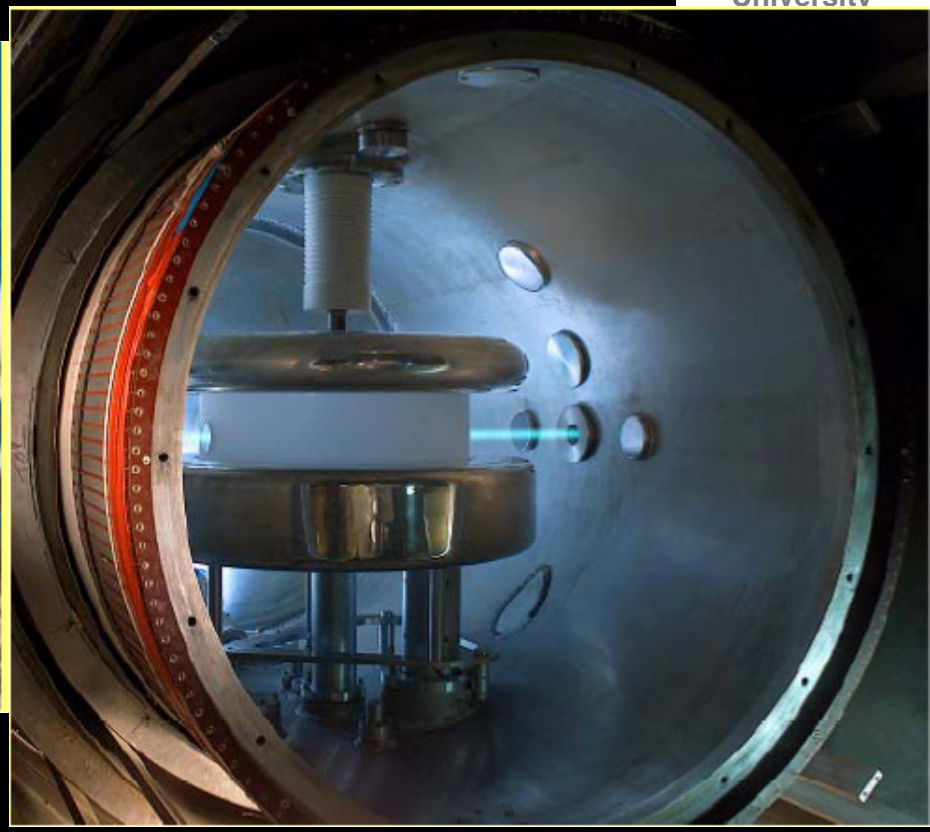

$$|\vec{d}| < 3\,10^{-26} e\,cm$$
$$= 3\,10^{-13} e\,fm \lll \frac{\theta}{16\pi^2}\, e\,fm$$

➡ **Very unnatural!**

Uglyness of old models

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- The Standard Model has many free parameters: O(30)

- Naturalness problems. Finetuning.

  Examples:
  Higgs mass, θ-angle (strong CP-problem)

- Gravity separate, i.e. not unified.

- (Probably) Breaks down at a finite energy scale

  Landau poles etc.

Unexplained Stuff

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- Dark Matter (25%)
  (astrophysical + cosmological observations)

- Dark Energy (70%)
  (astrophysical + cosmological observations)

- Mass Hierarchies
  (colliders, neutrino exp, etc)

- Small parameters (θ-angle, again)
  (neutron electric dipole measurements)

BSM physics @ Work

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- $(g-2)_\mu$ deviations from SM prediction

- DAMA anomaly
- CoGeNT etc.

- PAMELA observation

- WMAP observes extra "neutrinos"

Hints for new Physics

Model Building

Bottom-up (pheno)

Fix problem
`here and now'

Top-down (theory)

Go back to drawing board
`Start from scratch'

The strong CP problem: Axions

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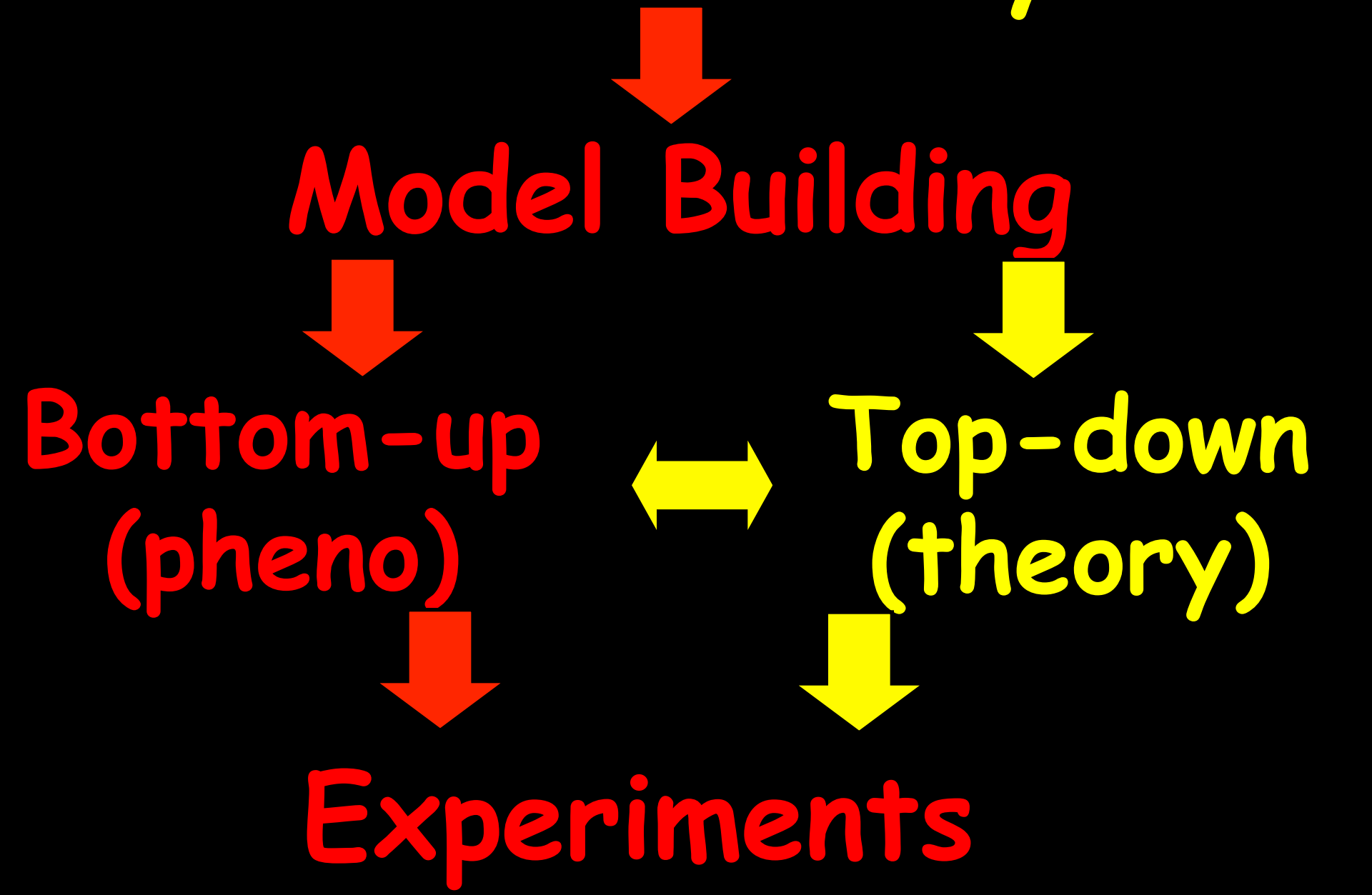
- Introduce new Peccei-Quinn symmetry to solve naturalness problem

- Predict as a consequence a new particle:
  The Axion
  (it's a Weakly Interacting Sub-eV Particle)

Dark matter candidate

Good motivation
for axion/WISP experiments

Hints for new Physics



Exploring fundamental high energy physics…

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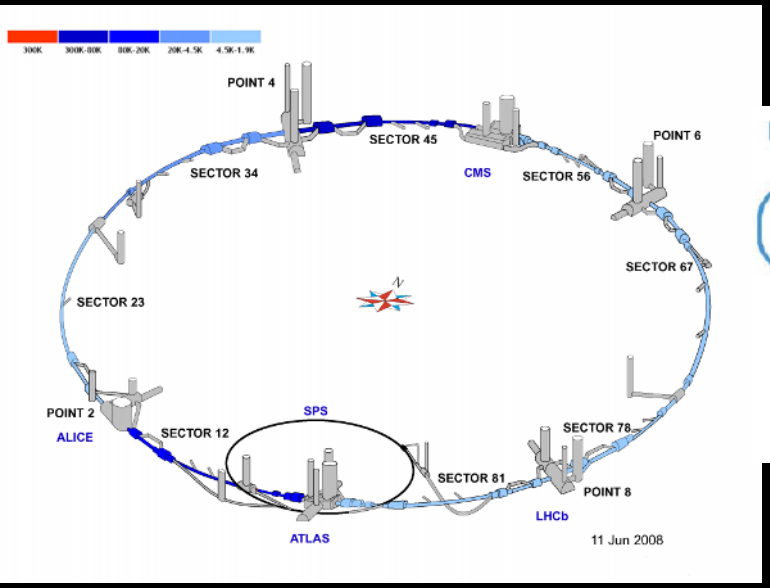
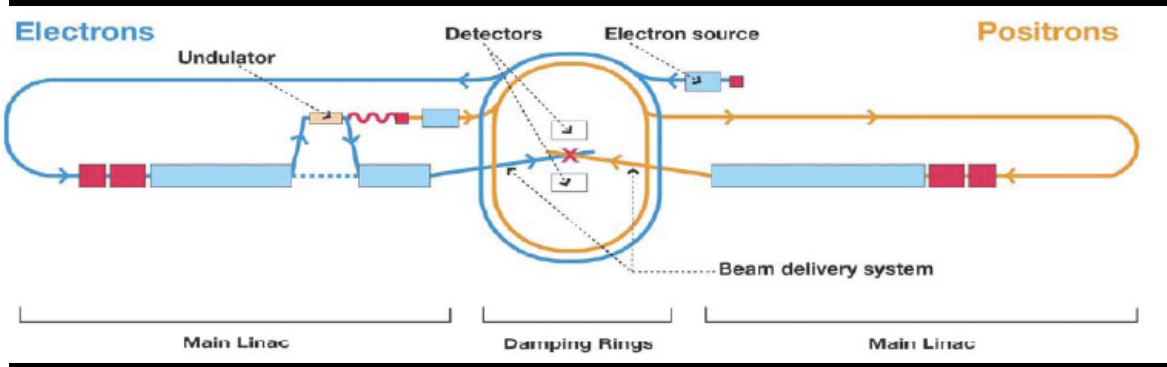
- The direct approach: MORE POWER

LHC, Tevatron + ILC,CLIC





- Detects most things within energy range
- E.g. may find SUSY particles, WIMPs etc.

But…

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- May miss very weakly interacting matter (Axions, WIMPs, WISPs…)
- Current maximal energy few TeV

- Man its DANGEROUS…

But…

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- May miss very weakly interacting matter: Hidden photons, (Axions, WIMPs, WISPs…)
- Current maximal energy few TeV

- Or much much more horrifying:

NO SIGNAL ABOVE BACKGROUND!

Recycling...

Complementary approaches

Light shining through walls

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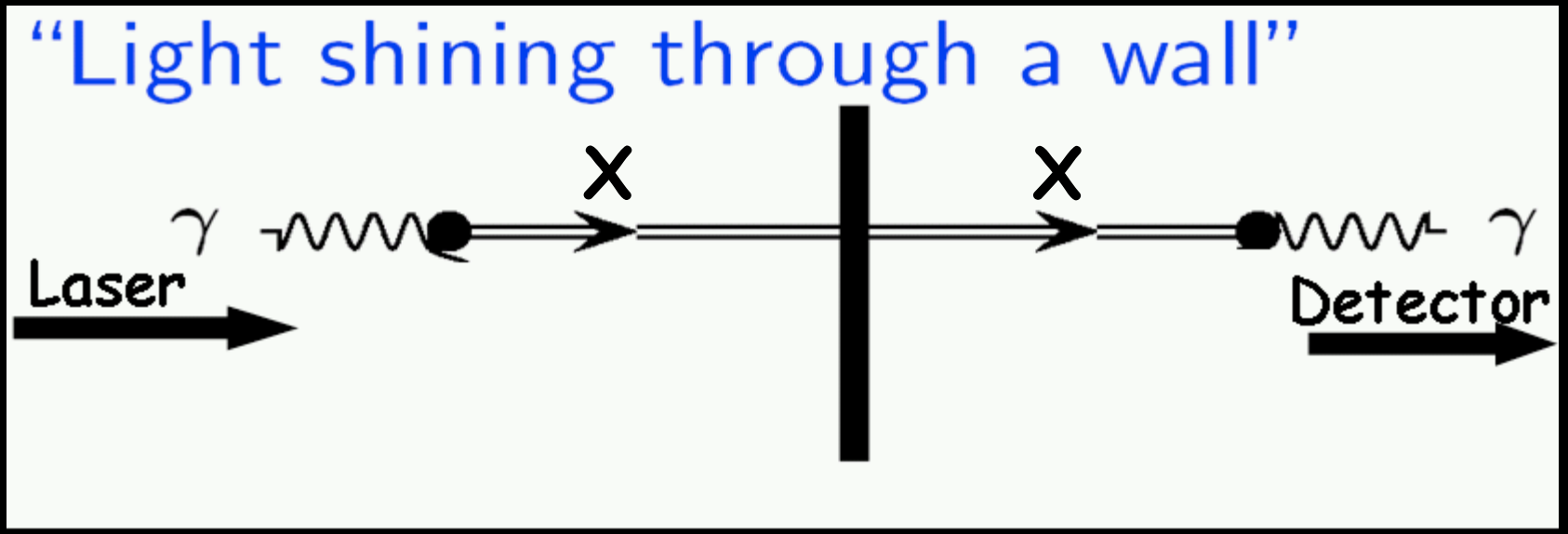

Light shining through walls

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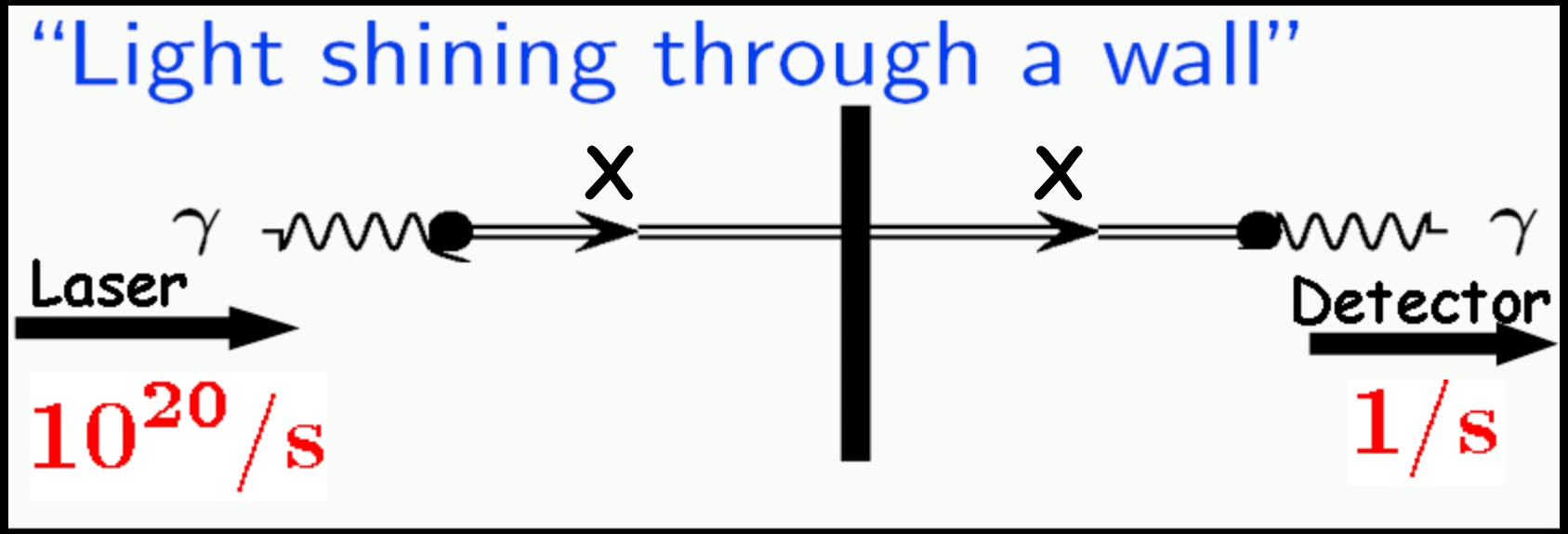

- Test $P_{\gamma \to X \to \gamma} \lesssim 10^{-20}$

- Enormous precision!
- Study extremely weak couplings!

Photons coming through the wall!

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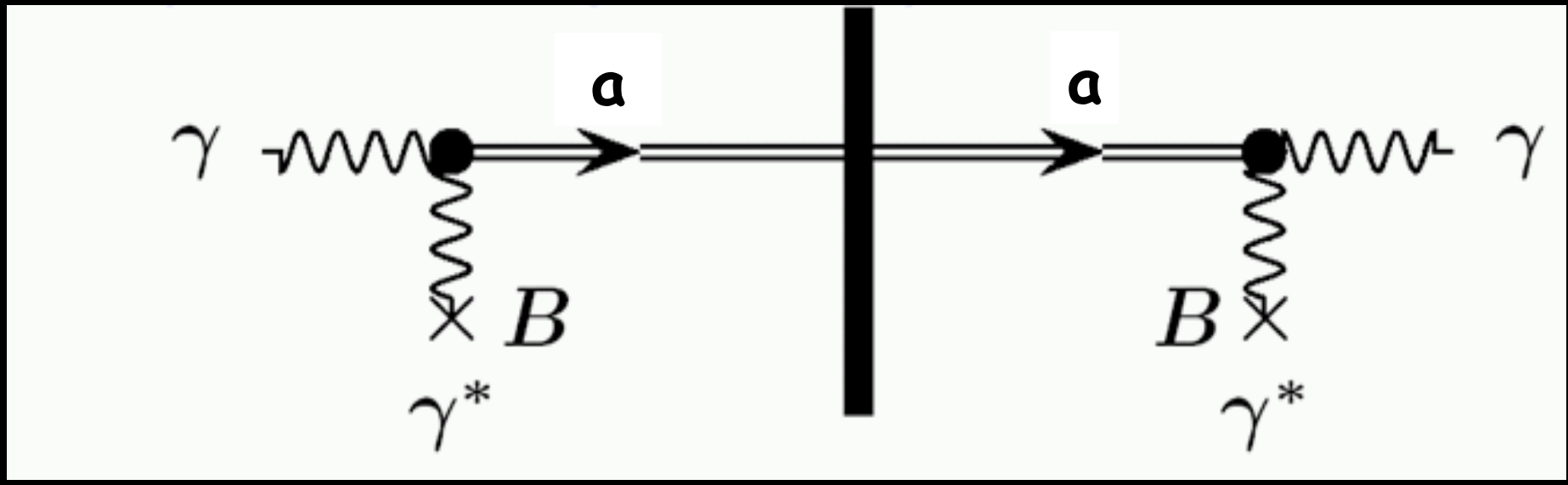
- It could be Axion(-like particle)s!
- Coupling to two photons: $\frac{1}{M} a \tilde{F} F \sim \frac{1}{M} a \vec{E} \cdot \vec{B}$



$$P_{\gamma \to a \to \gamma} \sim N_{\text{pass}} \left(\frac{BL}{M} \right)^4$$

Light Shining Through Walls

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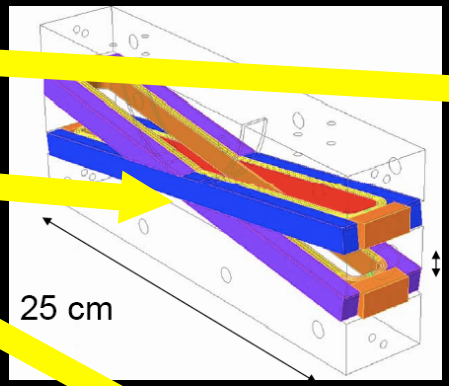
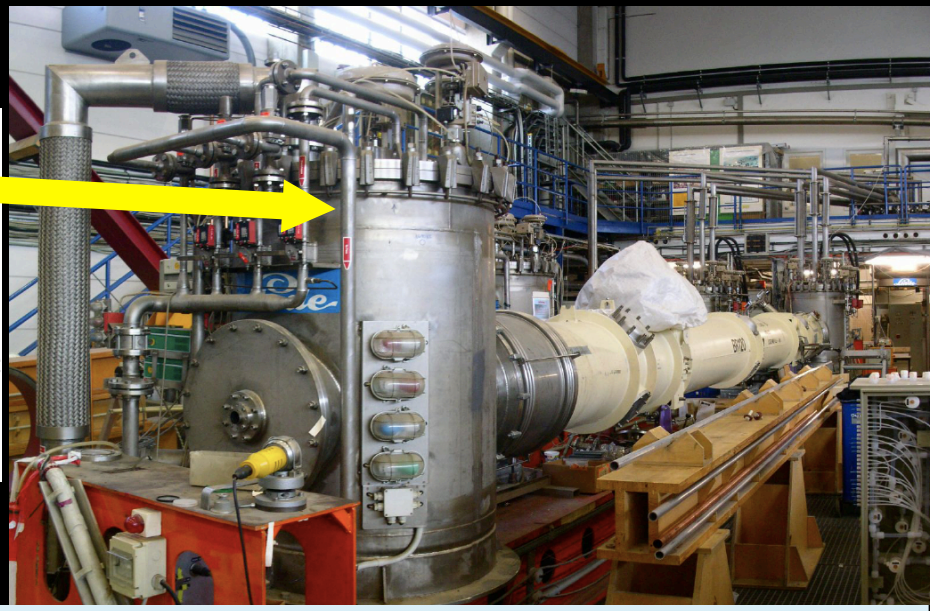
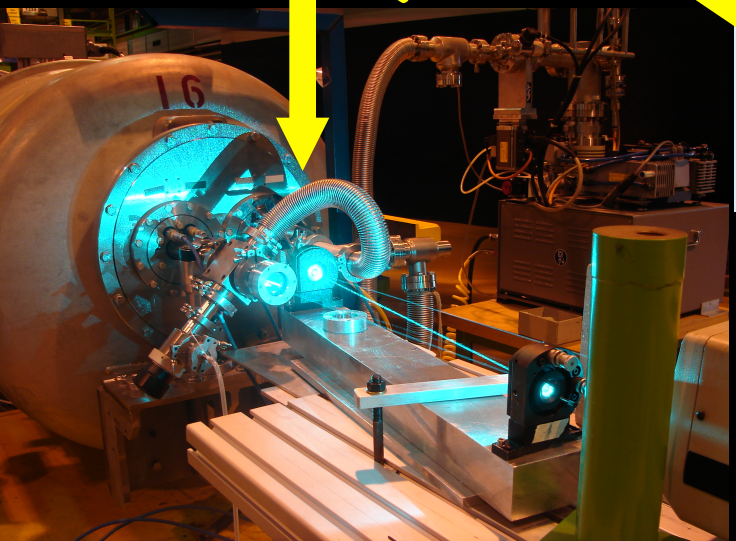
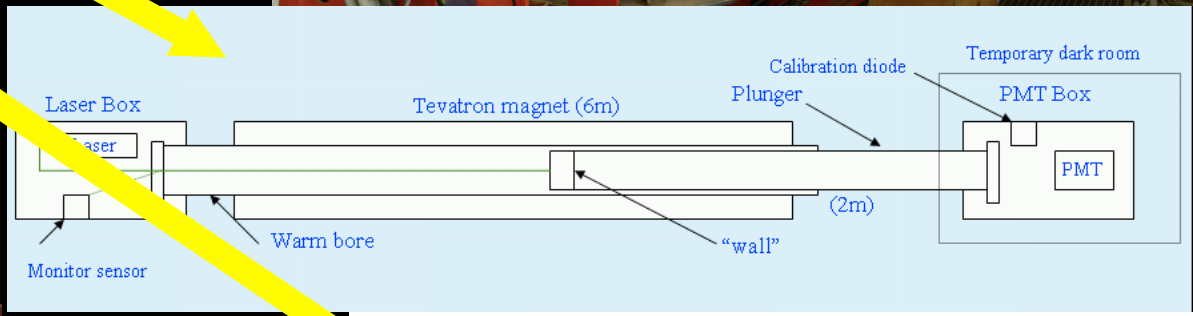
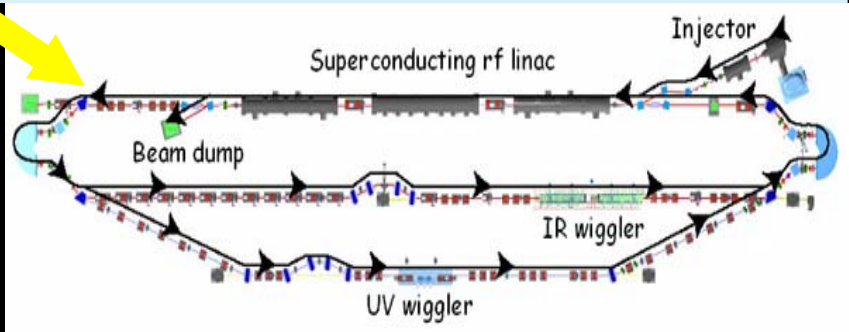
- A lot of activity
  - ALPS
  - BMV
  - GammeV
  - LIPPS
  - OSQAR











Small coupling, small mass

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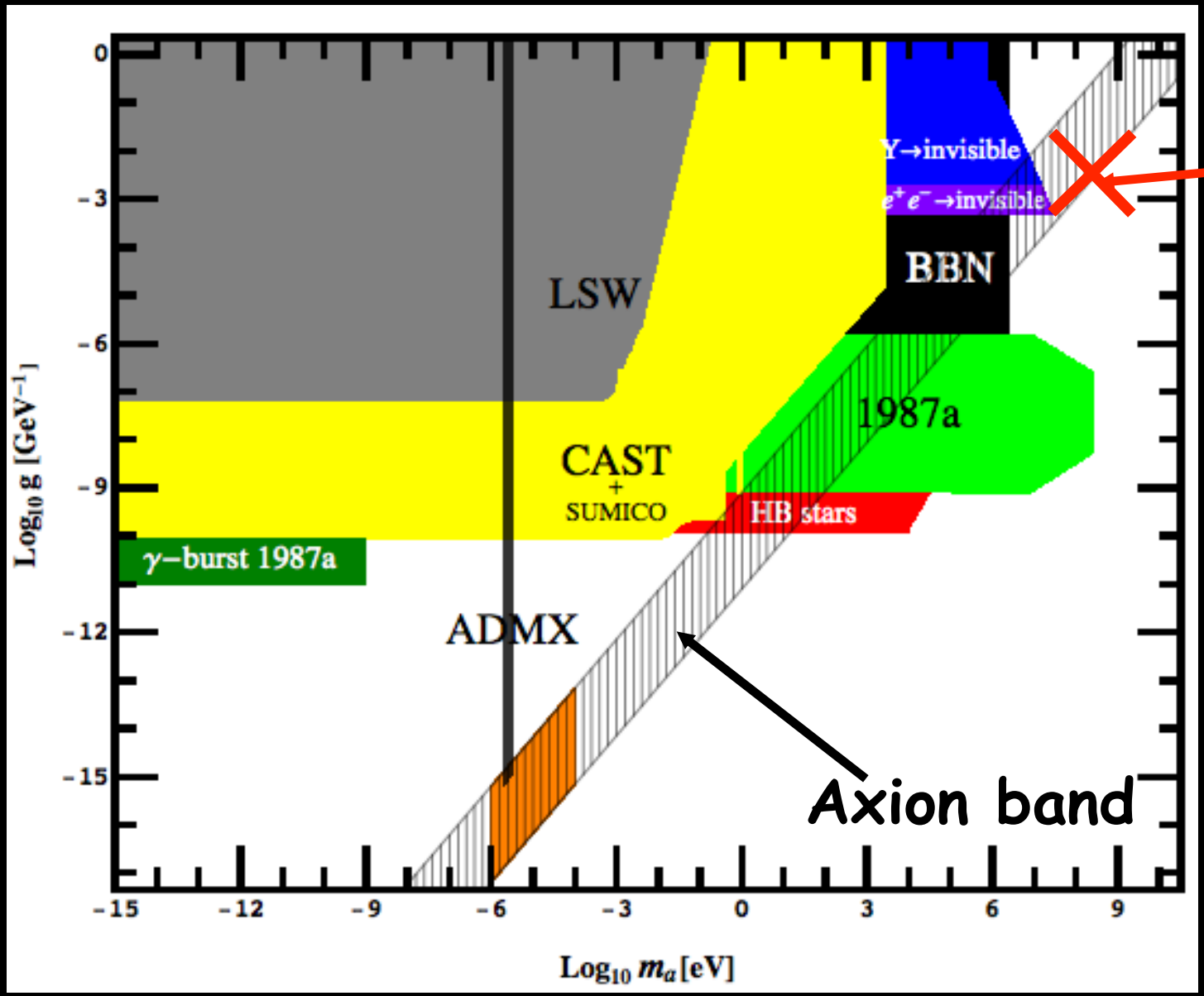

Helioscopes

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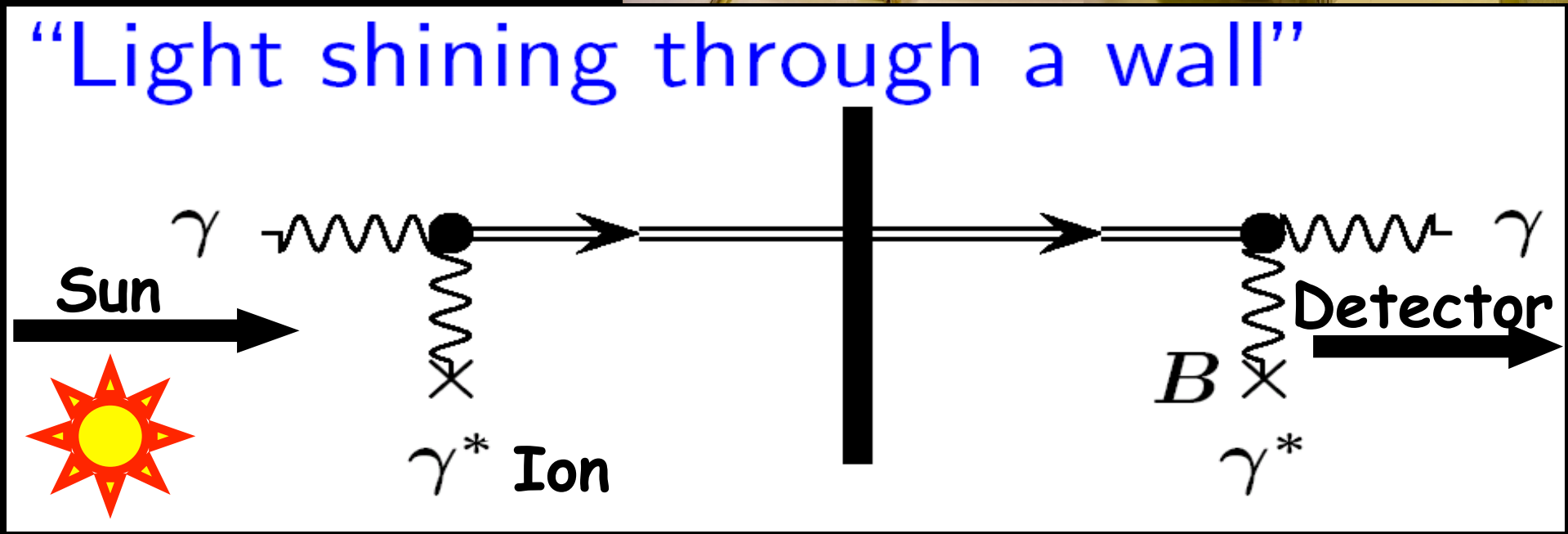
CAST@CERN
SUMICO@Tokyo

SHIPS@Hamburg



Perfect for astronomy in bad weather

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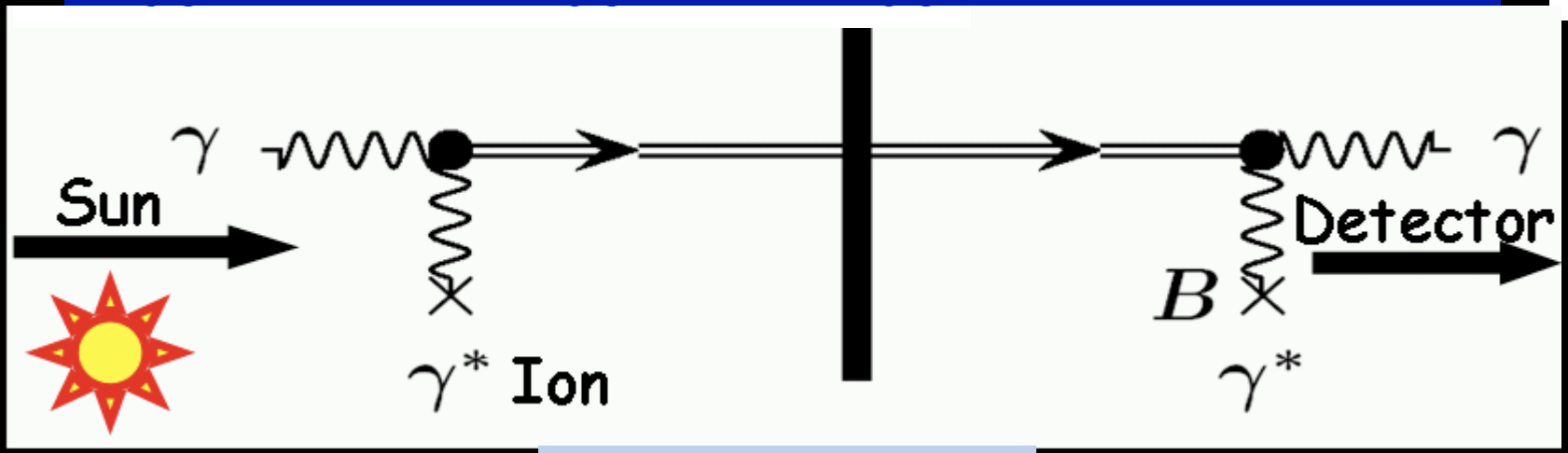

This isn't Dark matter,

I just forgot to take off the lens cap

Sensitivity

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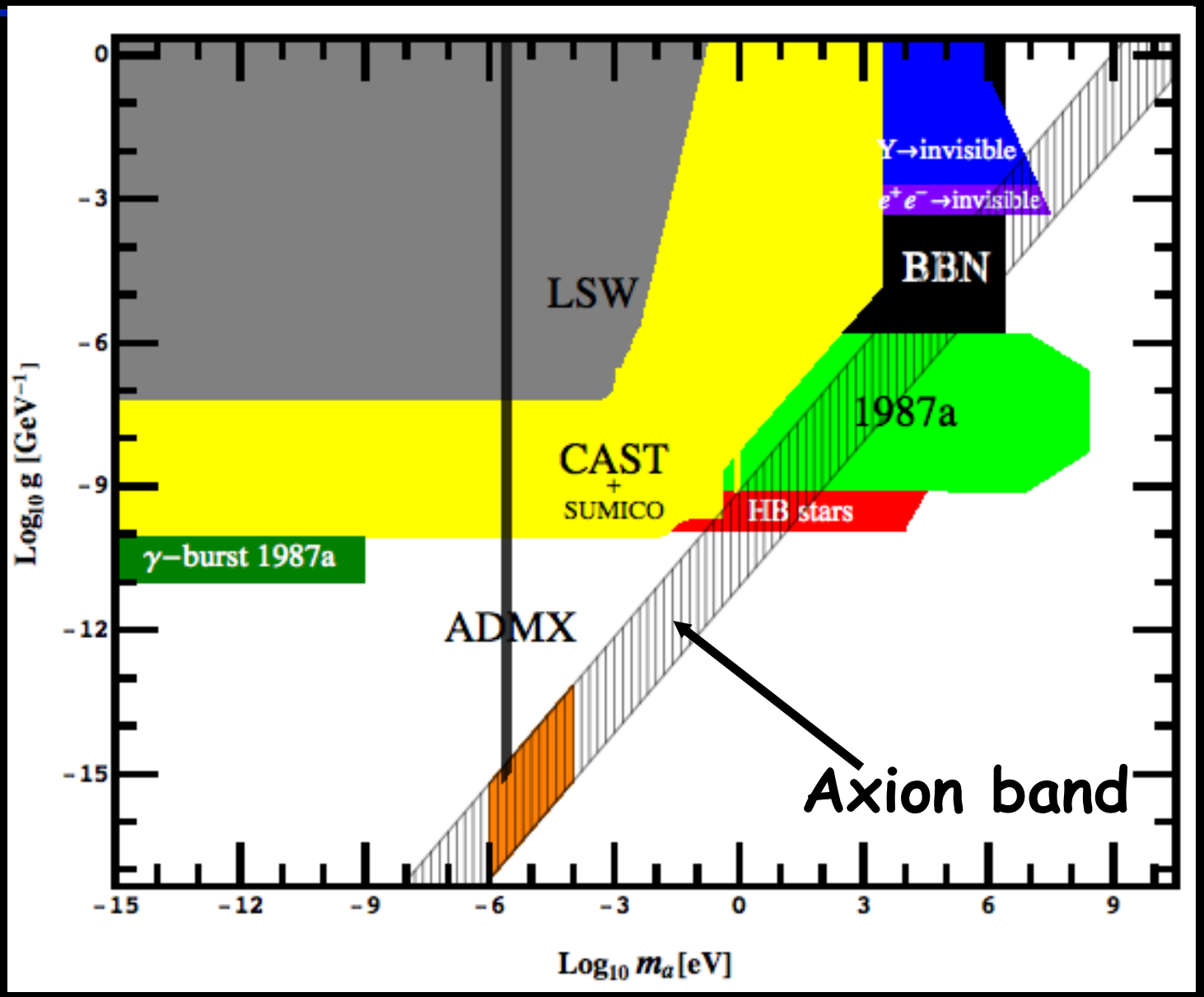

WISPS=Weakly interacting sub-eV particles

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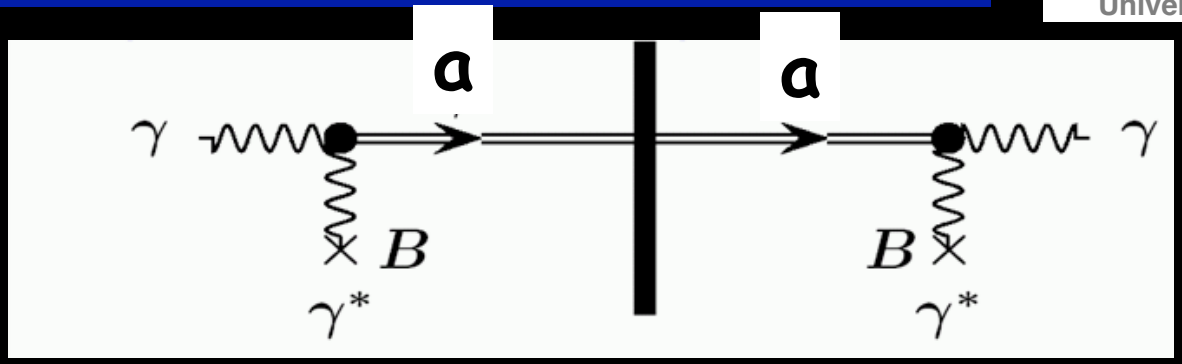
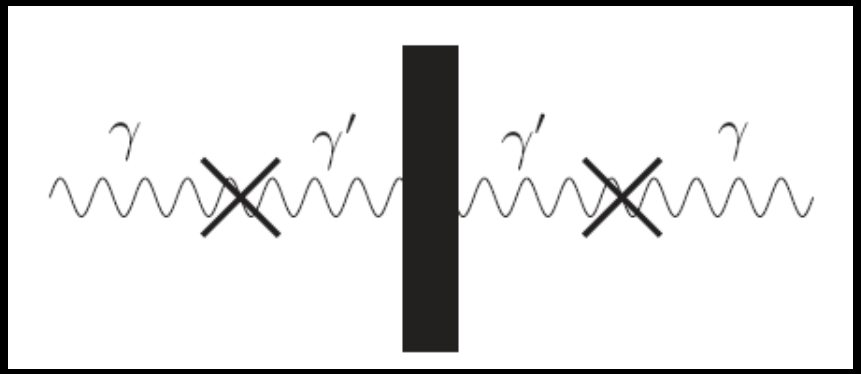
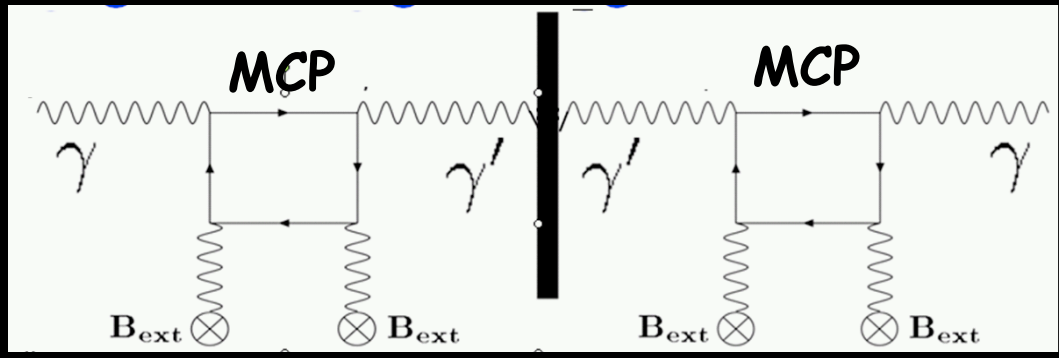
- Axions



- Massive hidden photons (without B-field) =analog ν-oscillations



- Hidden photon + minicharged particle (MCP)



Hidden Photons

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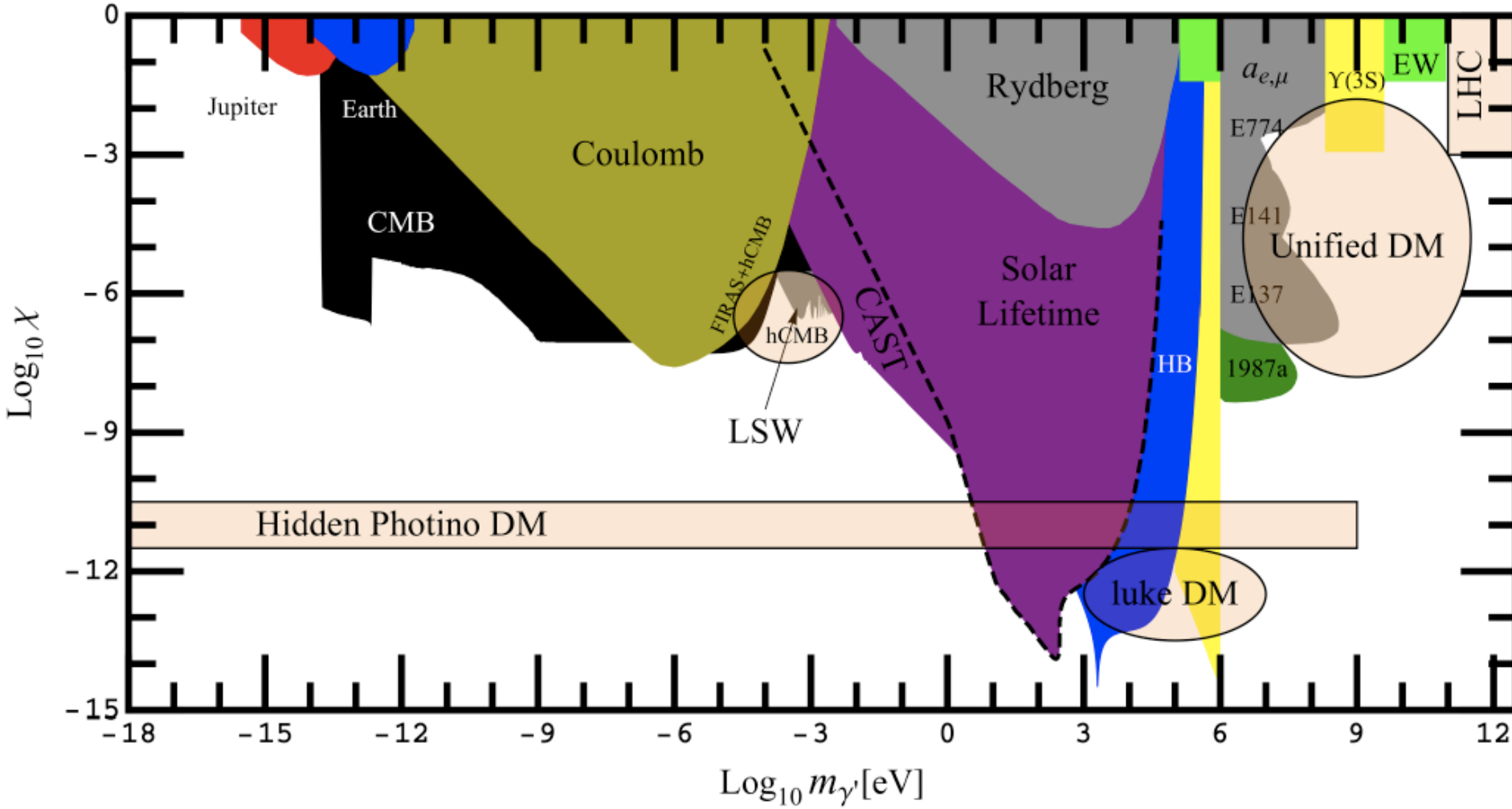
LSW already competitive + testing interesting area



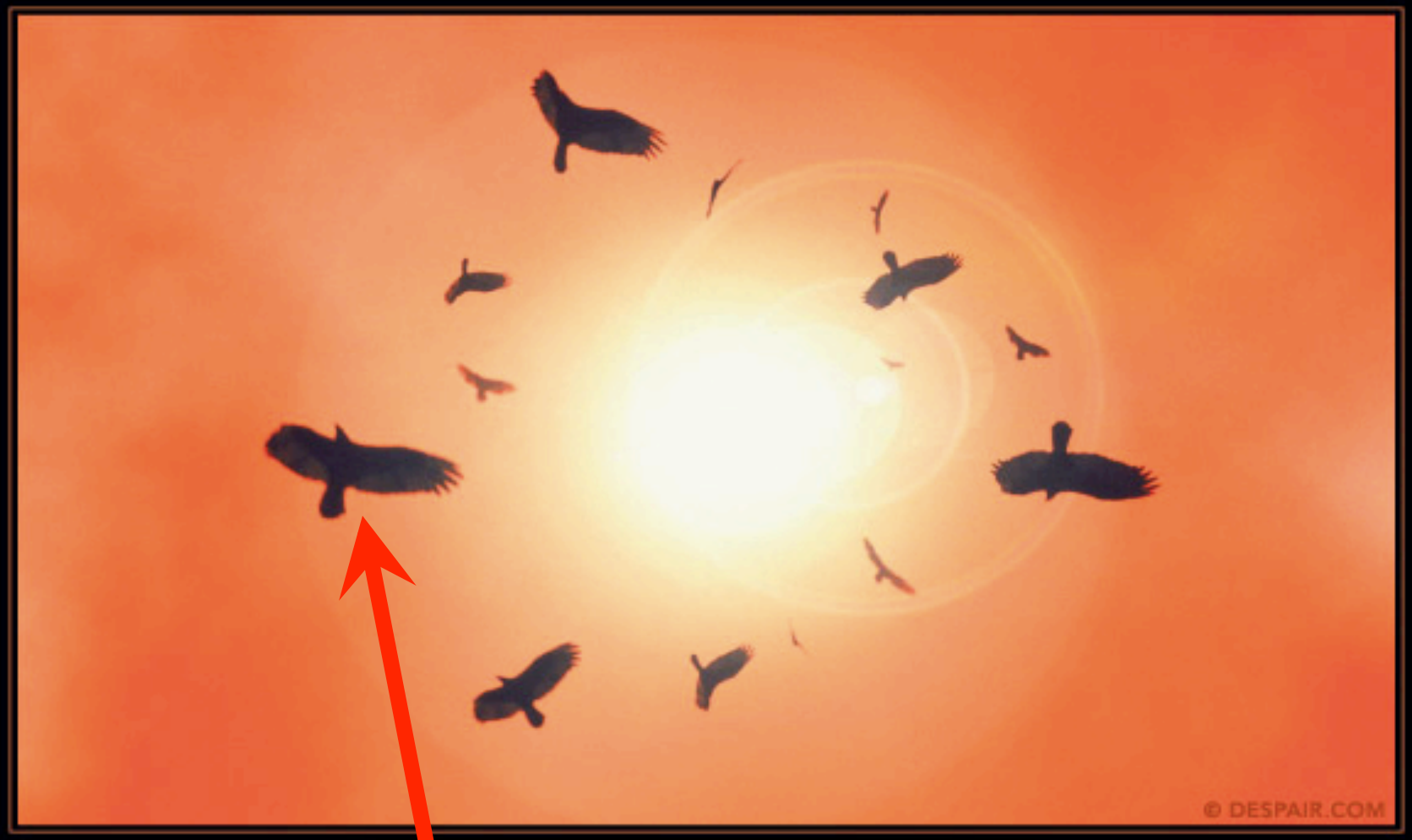
Hints for new Physics

Model Building

HOPE

MAY NOT BE WARRANTED AT THIS POINT.

for light particles?



HOPE for light particles?

Needs the high (scale) point of view

Coincidences?

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- Neutrino masses:

$$m_\nu \sim \mathrm{meV}$$

- Scale of dark energy:

$$\rho_\Lambda \sim (\mathrm{meV})^4$$

- Energy density of the Universe:

$$\rho_{\mathrm{today}} \sim (\mathrm{meV})^4$$

Hidden Photons

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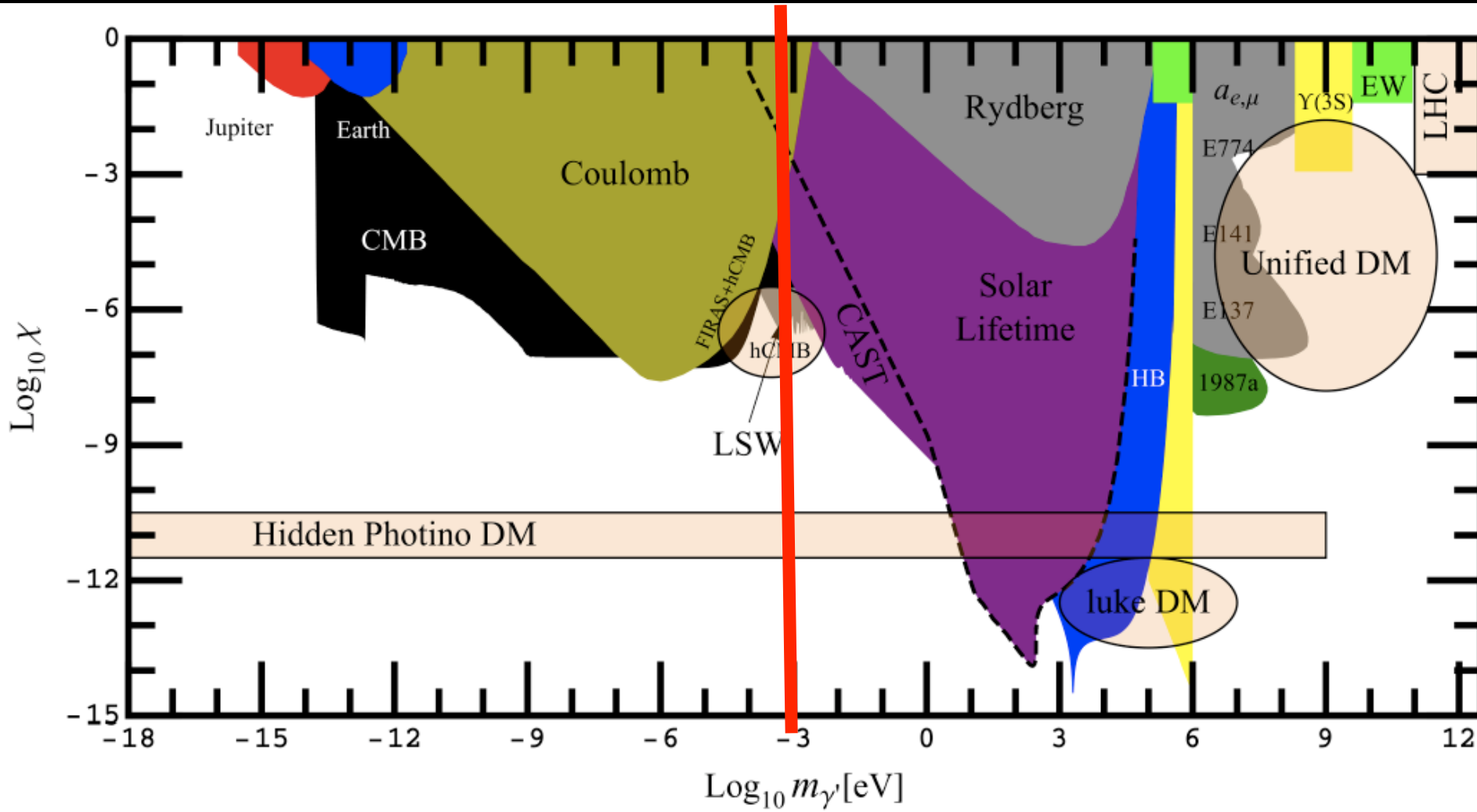
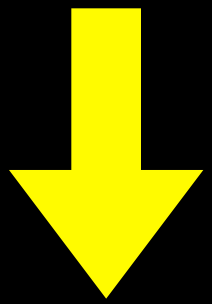
LSW already competitive + testing interesting area

Dark energy scale



High Scale



Small Coupling

Example: Axion coupling

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- Effective higher dimensional coupling

$$\mathcal{L}_{Int} = -\frac{1}{4} g a F^{\mu\nu} \tilde{F}_{\mu\nu} = -g a \mathbf{E} \cdot \mathbf{B}$$

- Small coupling for large axion scale:

small → $g \sim \frac{\alpha}{2\pi f_a}$ ← large

Huge Scale>> LHC Energy!

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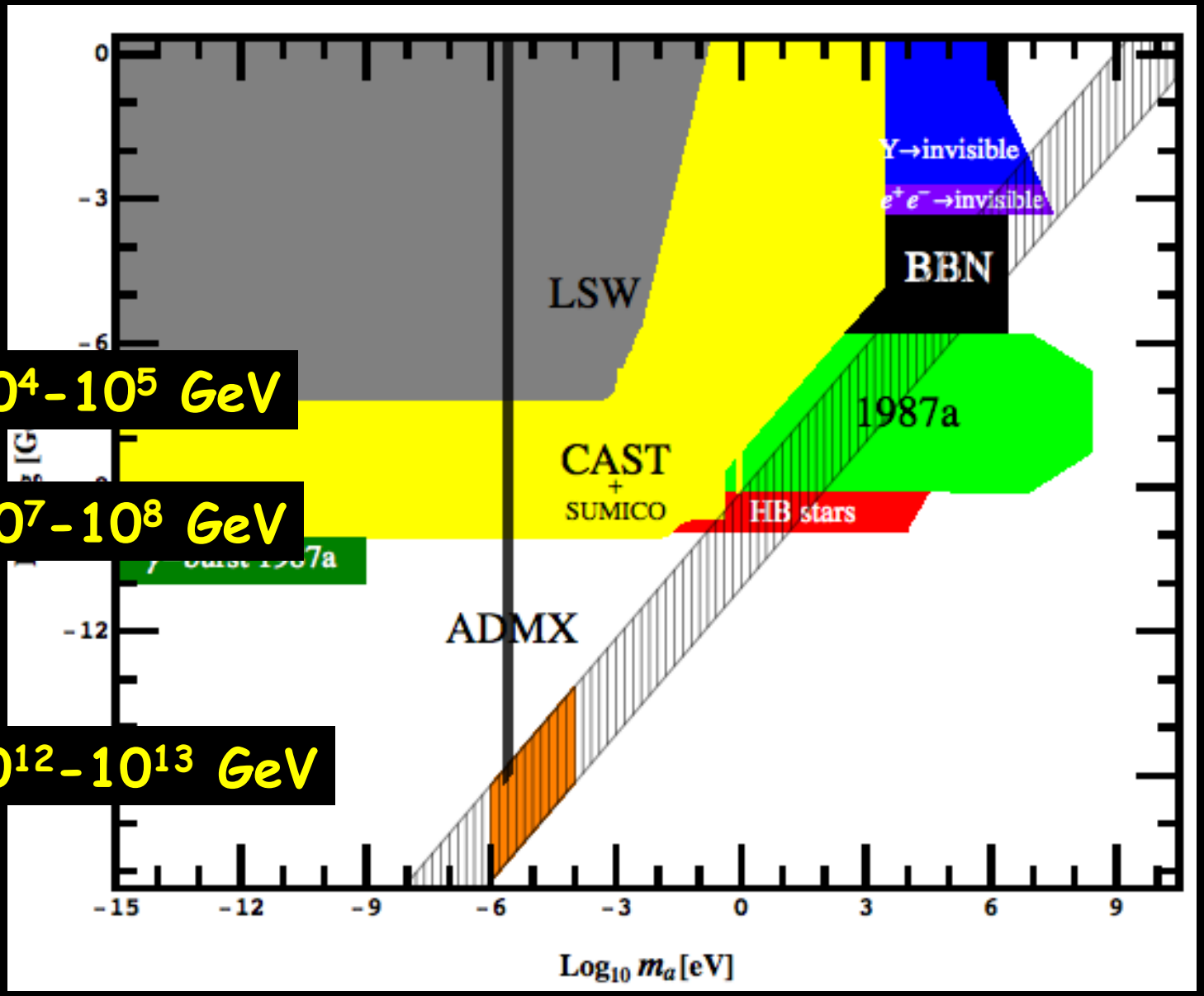
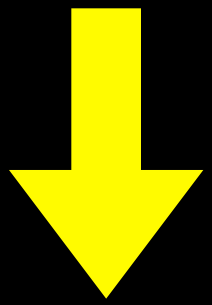


ca 10^4-10^5 GeV

ca 10^7-10^8 GeV

ca 10^{12}-10^{13} GeV

High Scale



Small Mass

Example: Axion See-Saw

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- The axion mass is small, too!

Small → $m_a \sim \frac{m_\pi f_\pi}{f_a}$ ← Large

Example: Axion See-Saw

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- The axion mass is small, too!

Small → $m_a \sim \frac{m_\pi f_\pi}{f_a}$ ← Large

Pseudo-Goldstone Boson!

Example: Axion See-Saw

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- The axion mass is small, too!

$$m_a \sim \frac{m_\pi f_\pi}{f_a}$$

$$\sim 0.6\,\mathrm{meV}\left(\frac{10^{10}\,\mathrm{GeV}}{f_a}\right)$$

Sub-eV mass

Large scale

Large Scale but light!

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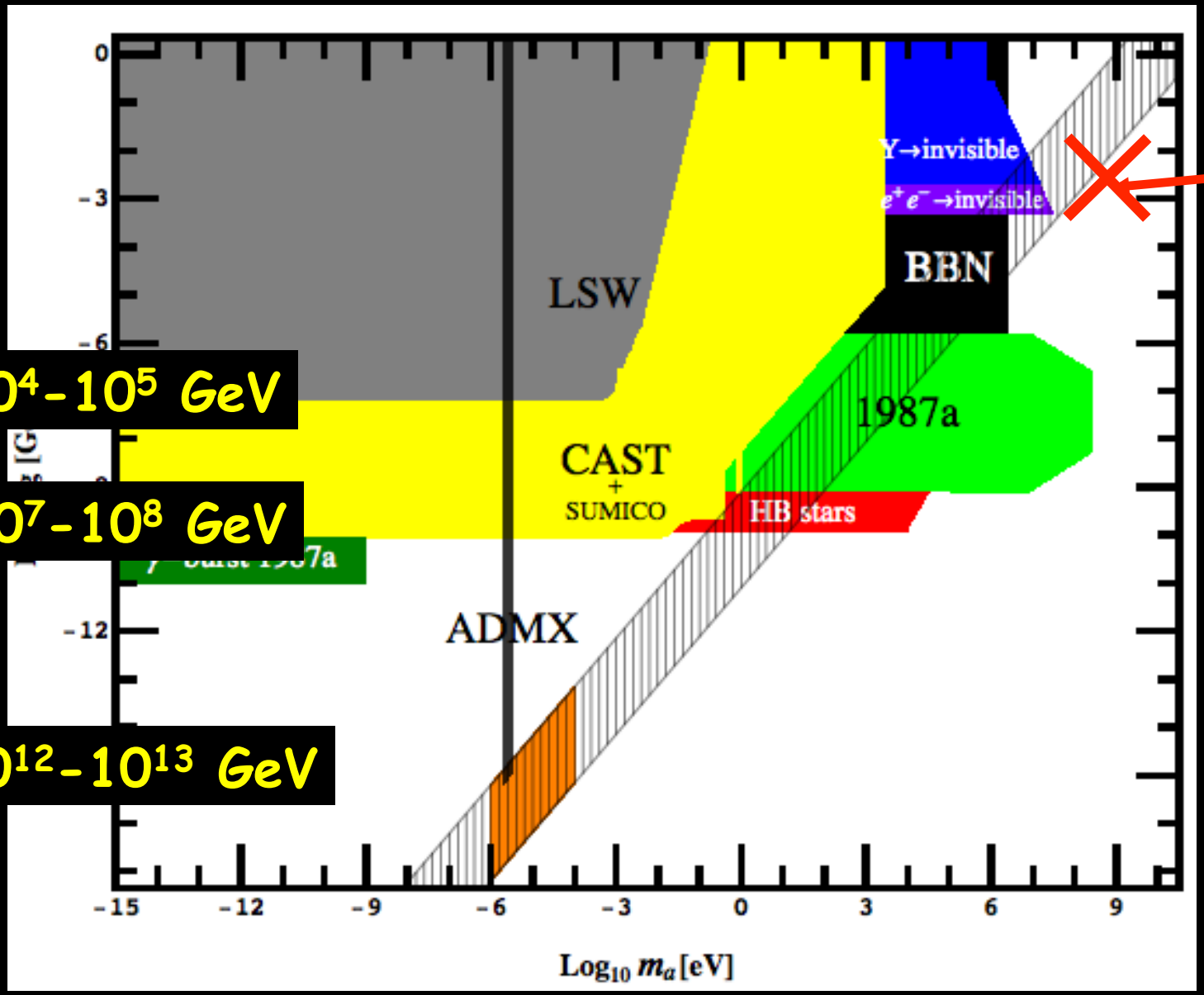


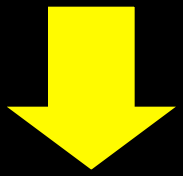
ca 10^4-10^5 GeV

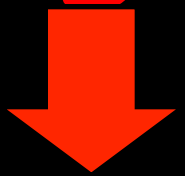
ca 10^7-10^8 GeV

ca 10^{12}-10^{13} GeV

Hints for new Physics

Model Building





Bottom-up (pheno)

Top-down (theory)

Go back to drawing board
`Start from scratch'

WISPs
from
String Theory

String theory

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- Attempt to unify SM with gravity
- New concept: strings instead of point particles

Axion(-like particles)

String theory: Moduli and Axions

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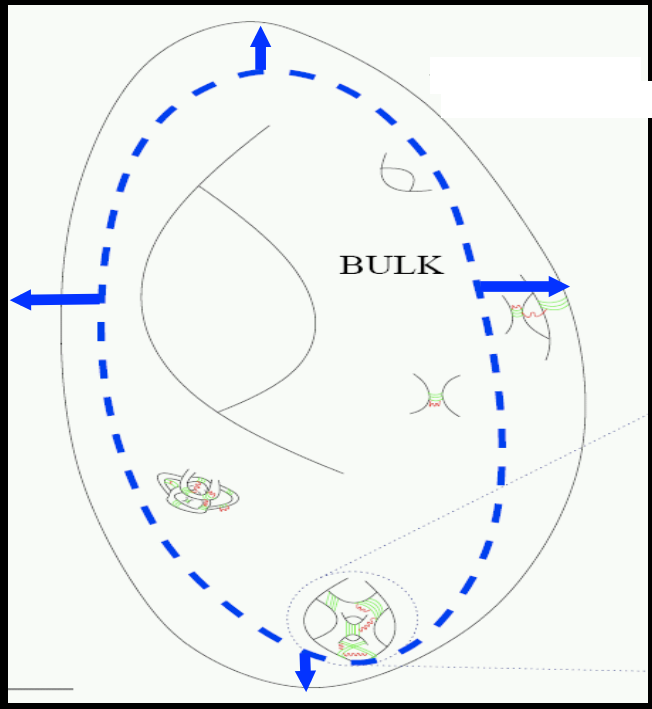
- String theory needs Extra Dimensions

↓

Must compactify

- Shape and size deformations correspond to fields:
  Moduli (WISPs) and Axions
  Connected to the fundamental scale, here string scale



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WISP candidates

Axion (like particles): Where are we?

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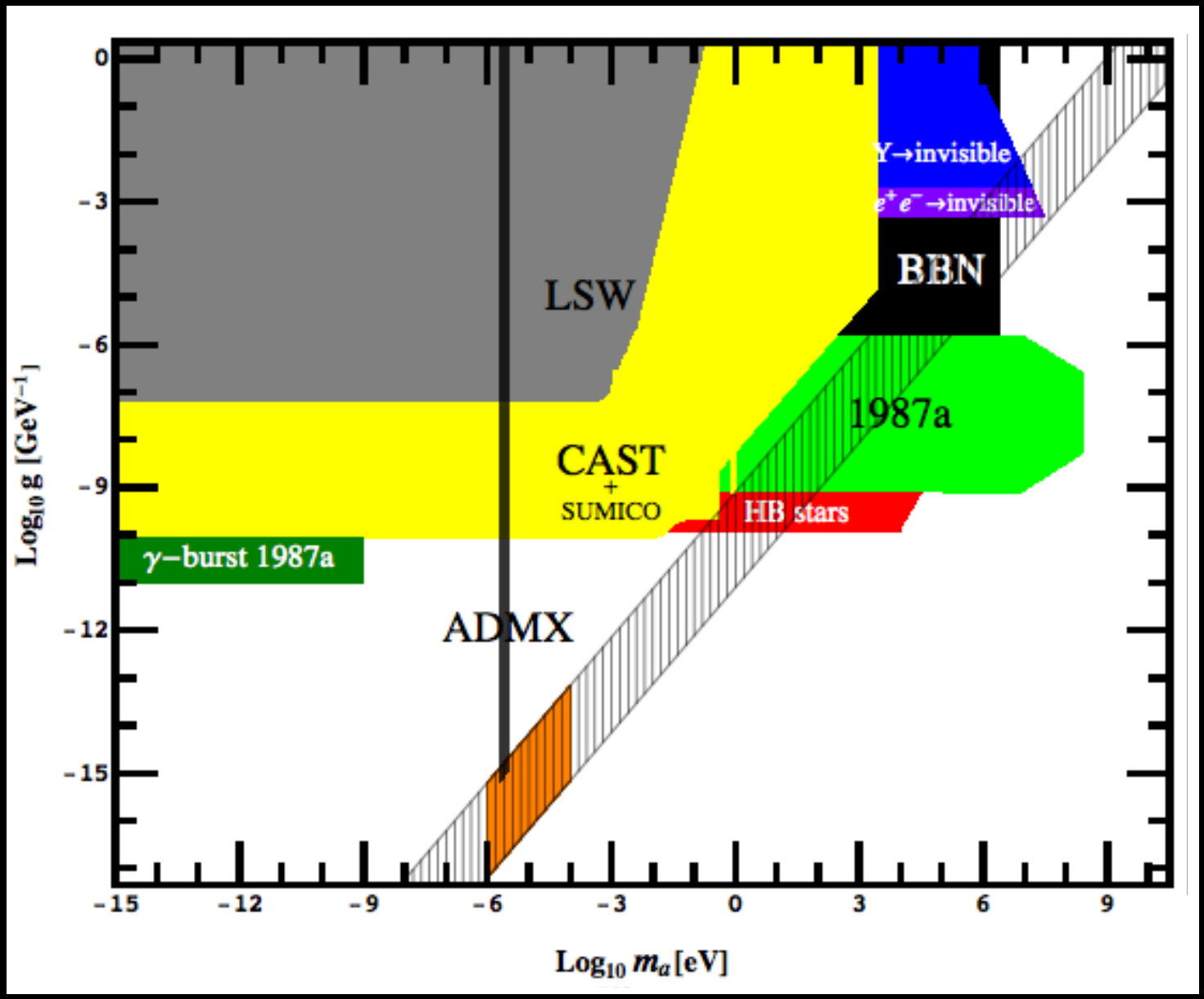

Axion (like particles): Where are we?

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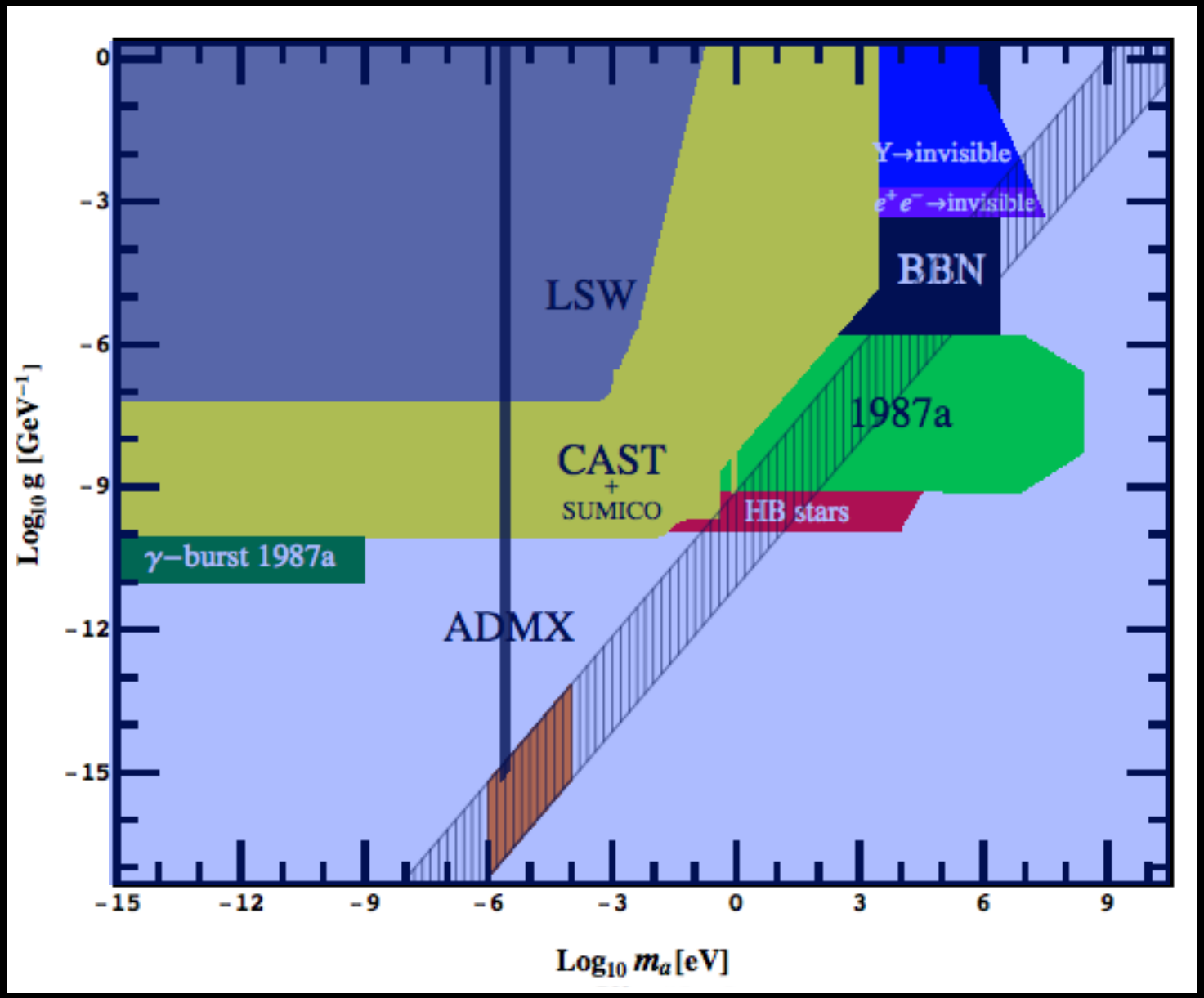

Hidden Photons

String theory likes extra gauge groups

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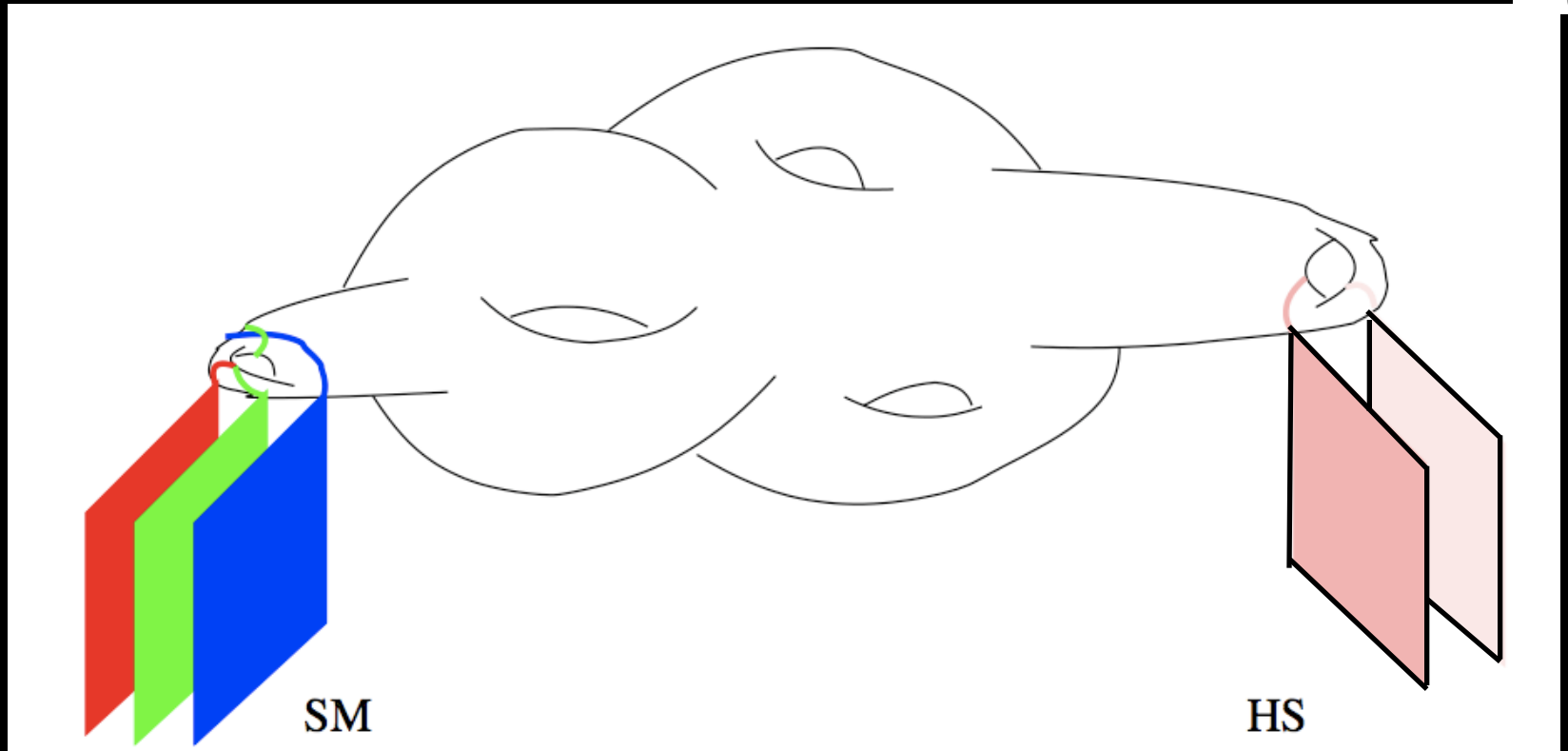

$U(A) \times U(B) \times U(C)$

$U(A) \times U(B)$

➡ Many extra U(1)s!

➡ Candidates for WISPs

Hidden by distance

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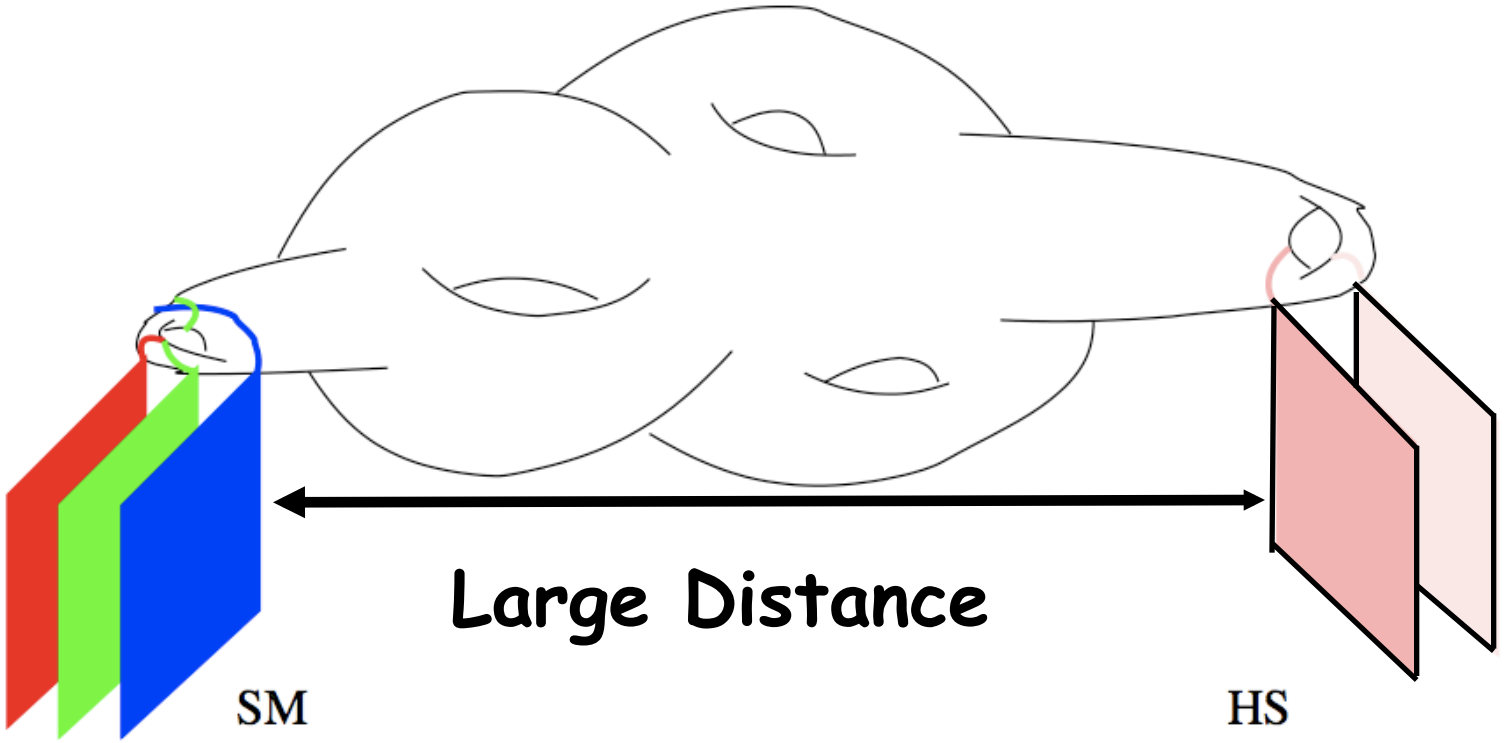

$U(A) \times U(B) \times U(C)$

$U(A) \times U(B)$

$$\chi \sim \frac{g_s}{8\pi} \frac{1}{Volume^x}$$

$$g_{\rm hid} \sim 1$$

Hidden by weakness

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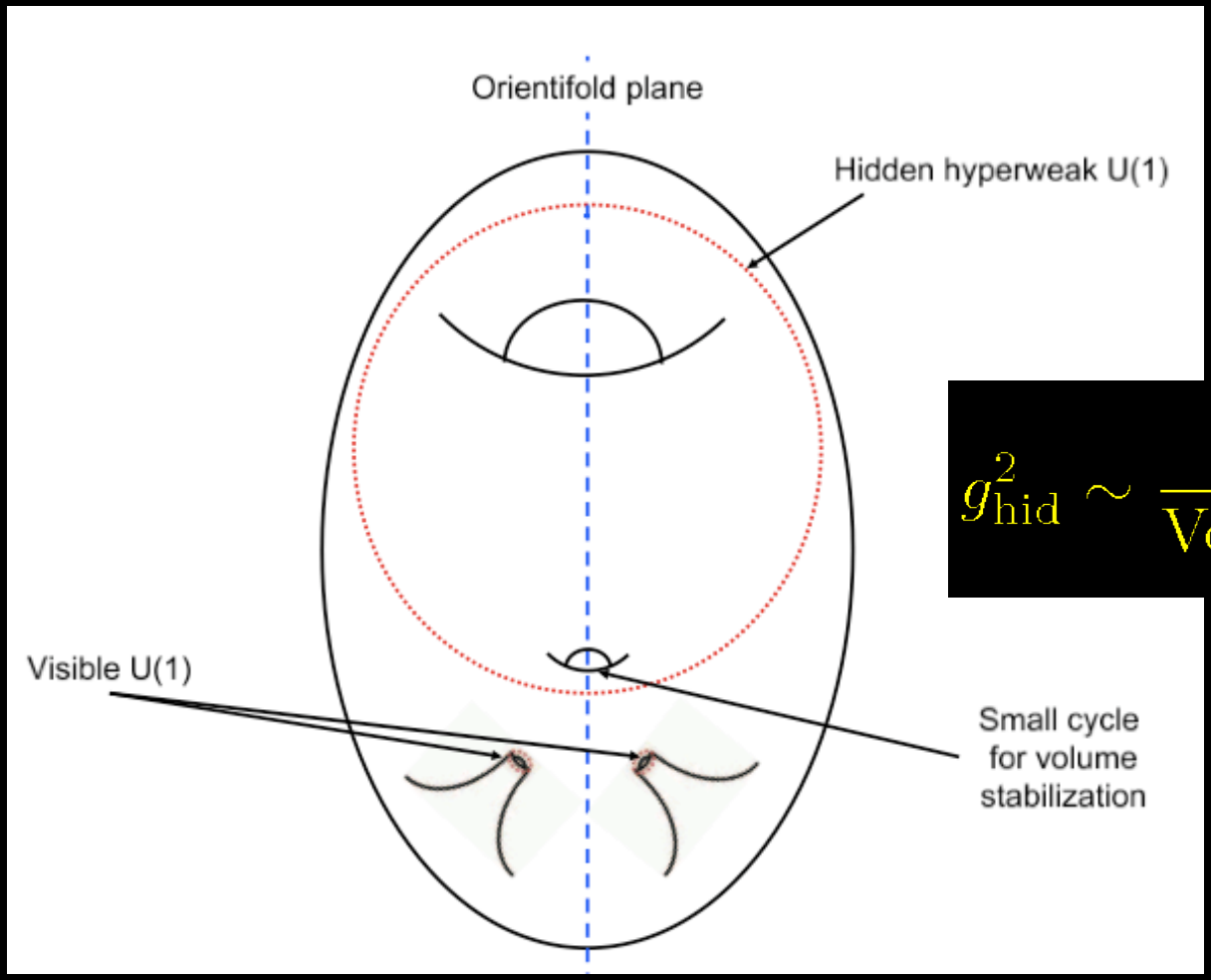

$$g^2_{\rm hid} \sim \frac{2\pi g_s}{\rm Volume^x} \sim \left(\frac{M_s^2}{M_P^2}\right)^x \ll 1$$

$$\chi \sim \frac{g_{\rm vis} g_{\rm hid}}{16\pi^2} \sim \frac{2\pi g_s}{\rm Volume^{x/2}} \sim \left(\frac{M_s^2}{M_P^2}\right)^{x/2} \ll 1$$

Hidden Photons, all over the place

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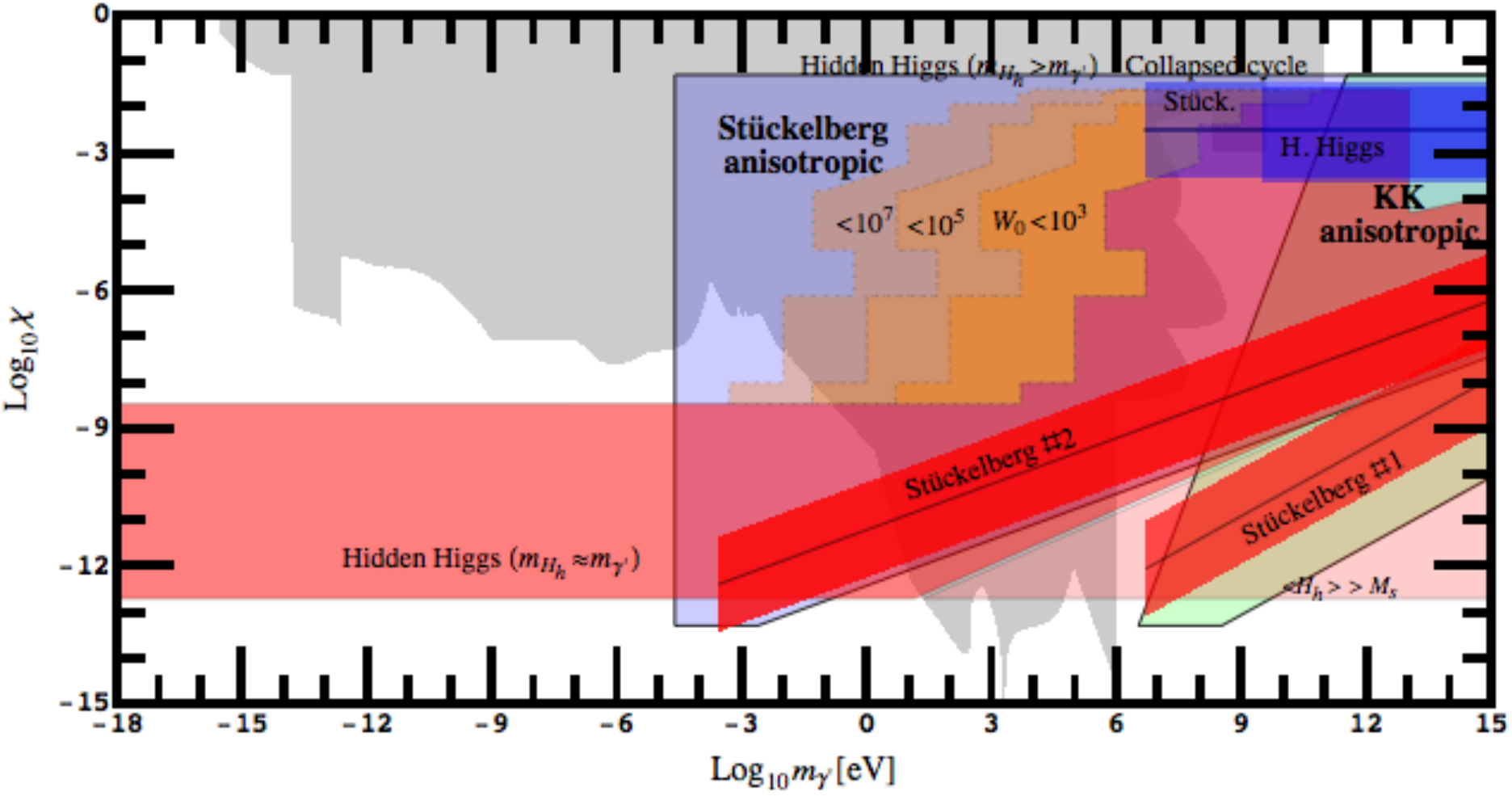

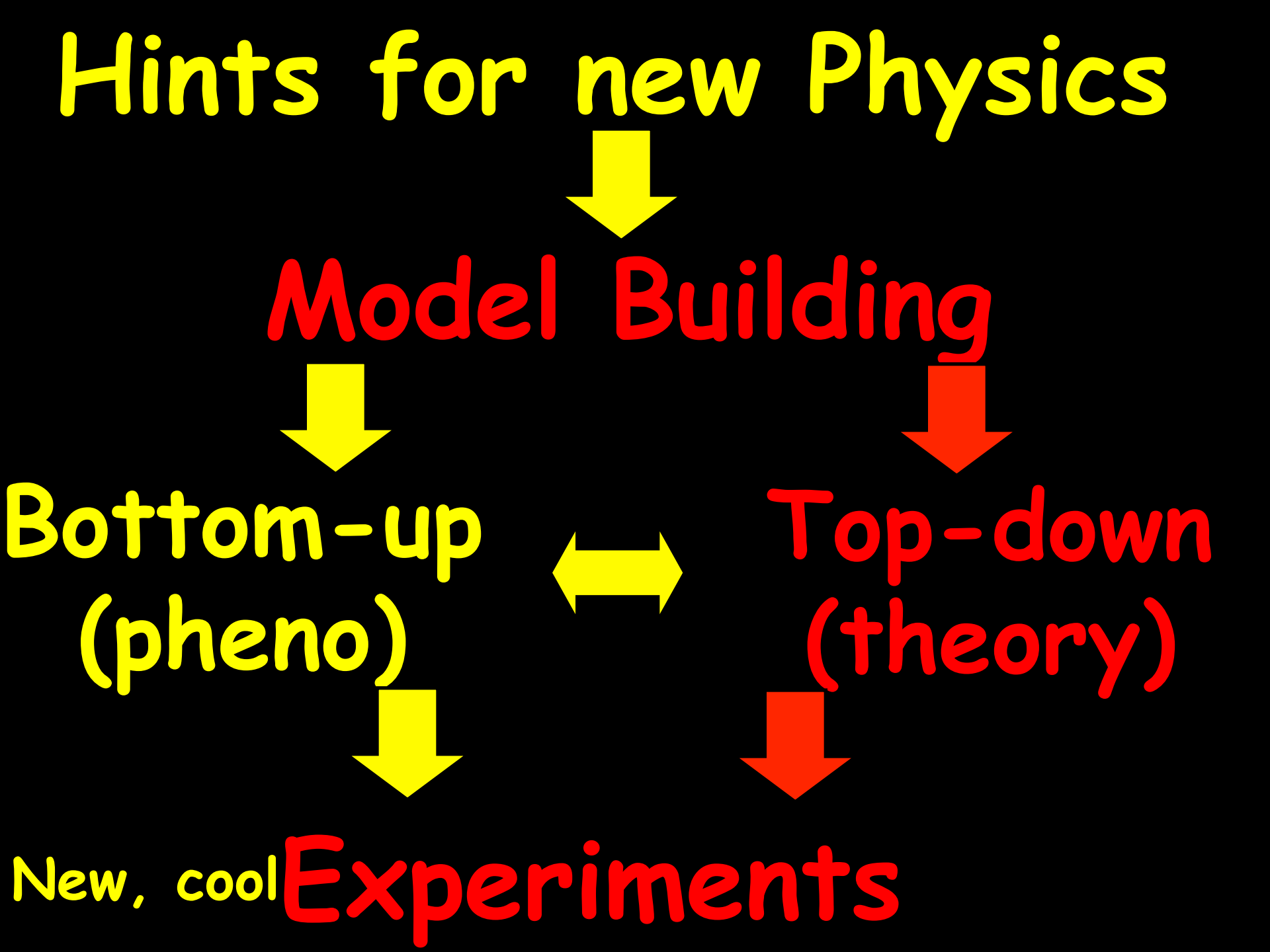
Hints for new Physics
Model Building
Bottom-up
(pheno)
Top-down
(theory)
New, cool Experiments

Hidden Photons: Back to Experiment

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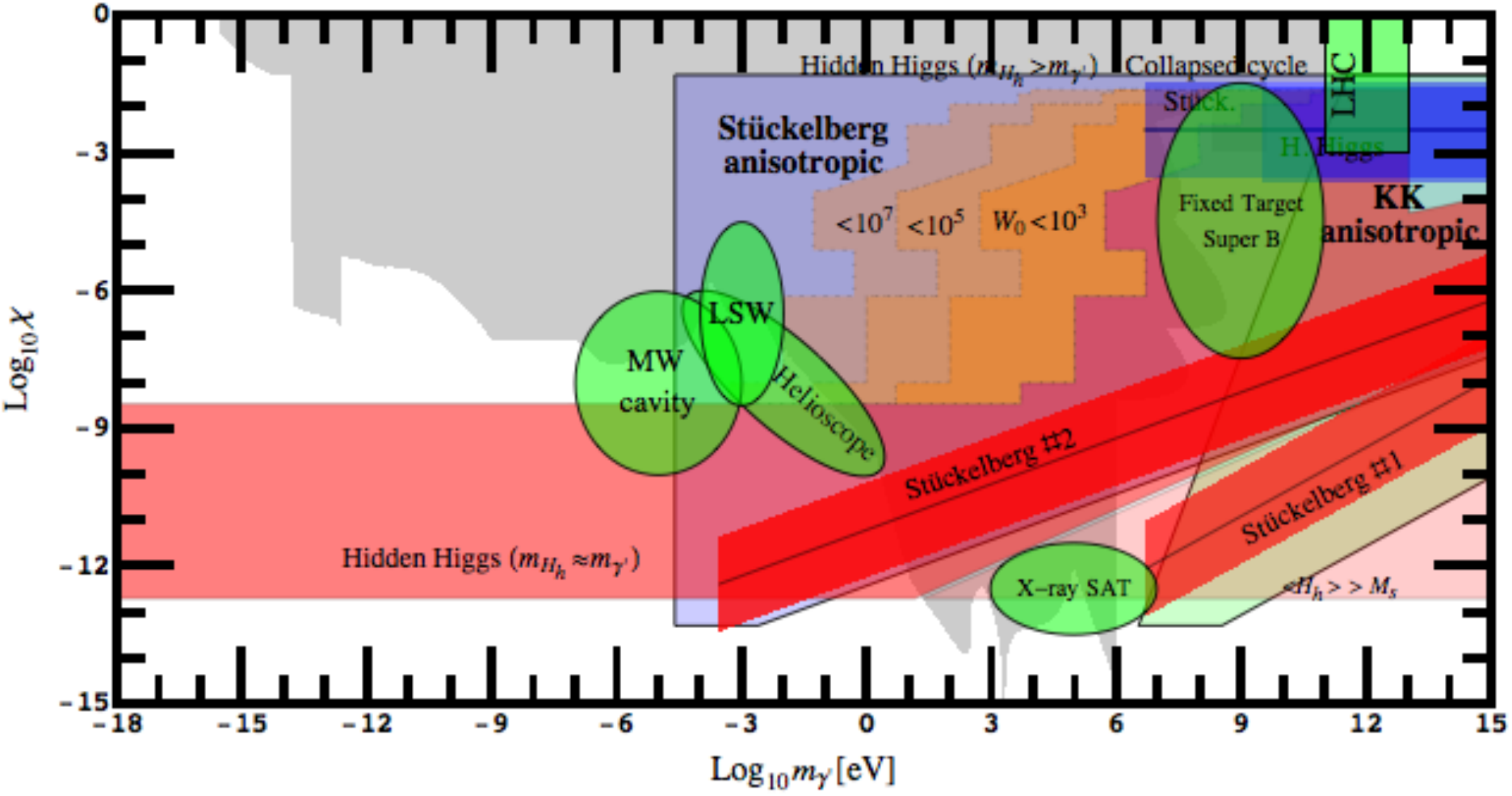

Secret door

Dark Matter(s)

Hidden = Dark photon matter (or axions)

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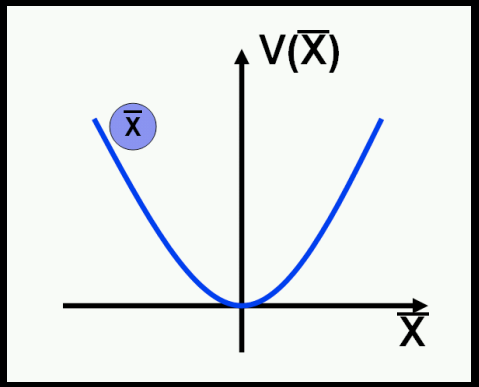
$$\ddot{\bar{X}}_i + 3H\dot{\bar{X}}_i + m^2_{\gamma'}\bar{X}_i = 0$$

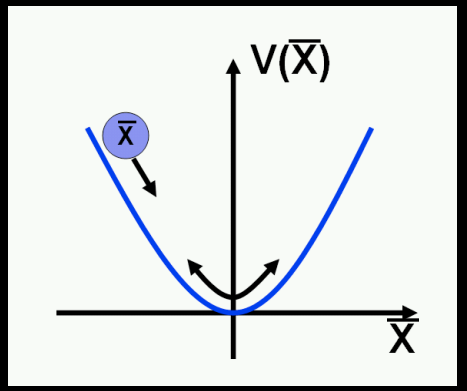
$$\bar{X}_i = X_i/a(t)$$

(includes non-minimal coupling to gravity $(R/12)X^\mu X_\mu$)

- $H \gg m_{\gamma'}$ ➔ overdamped oscillator



- $H \ll m_{\gamma'}$ ➔ damped oscillator



$$\rho_X(t) = \frac{\rho_{ini}}{a^3(t)}$$ ➔ Dark Matter

Hidden Photon Dark Matter

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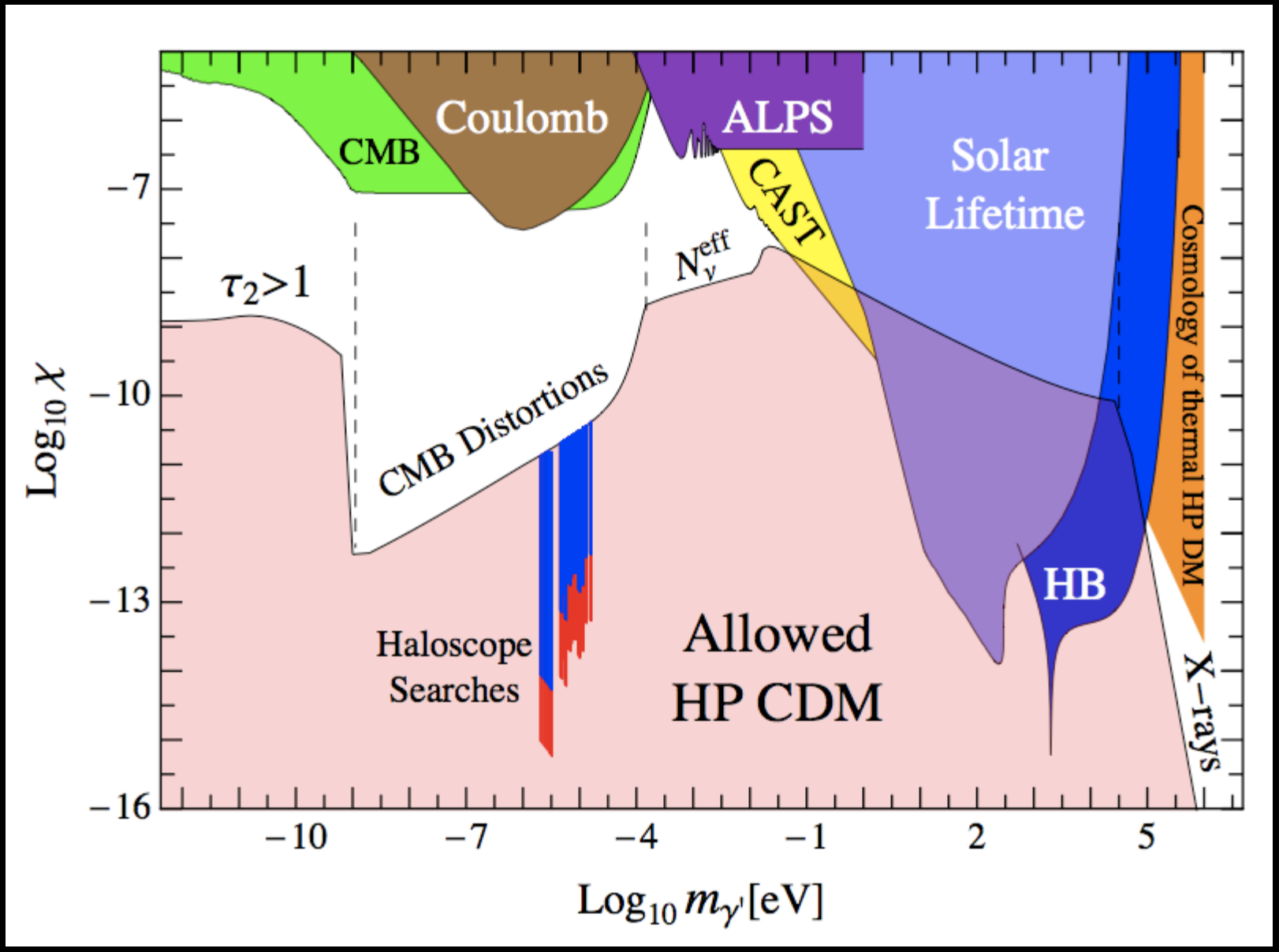

Use a plentiful source of HPs

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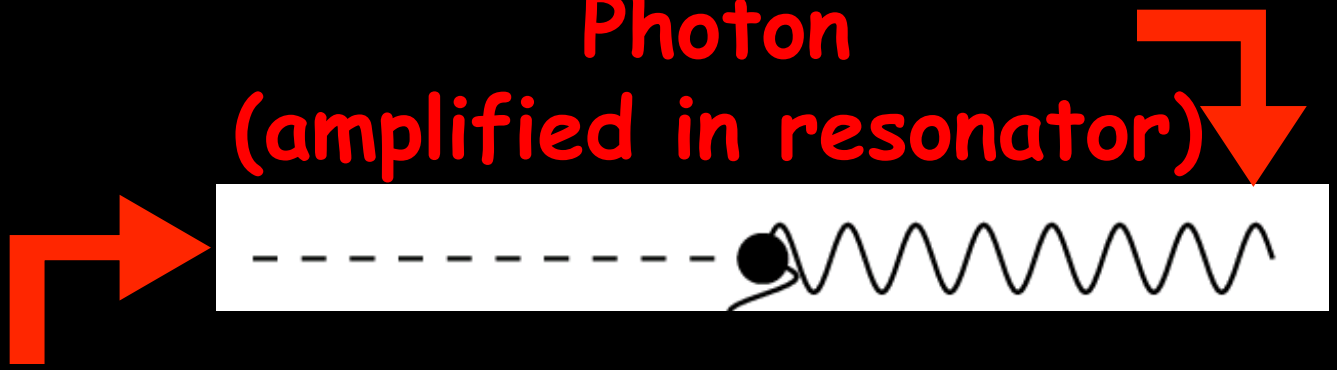
- Photon Regeneration



Signal: Total energy of hidden photon

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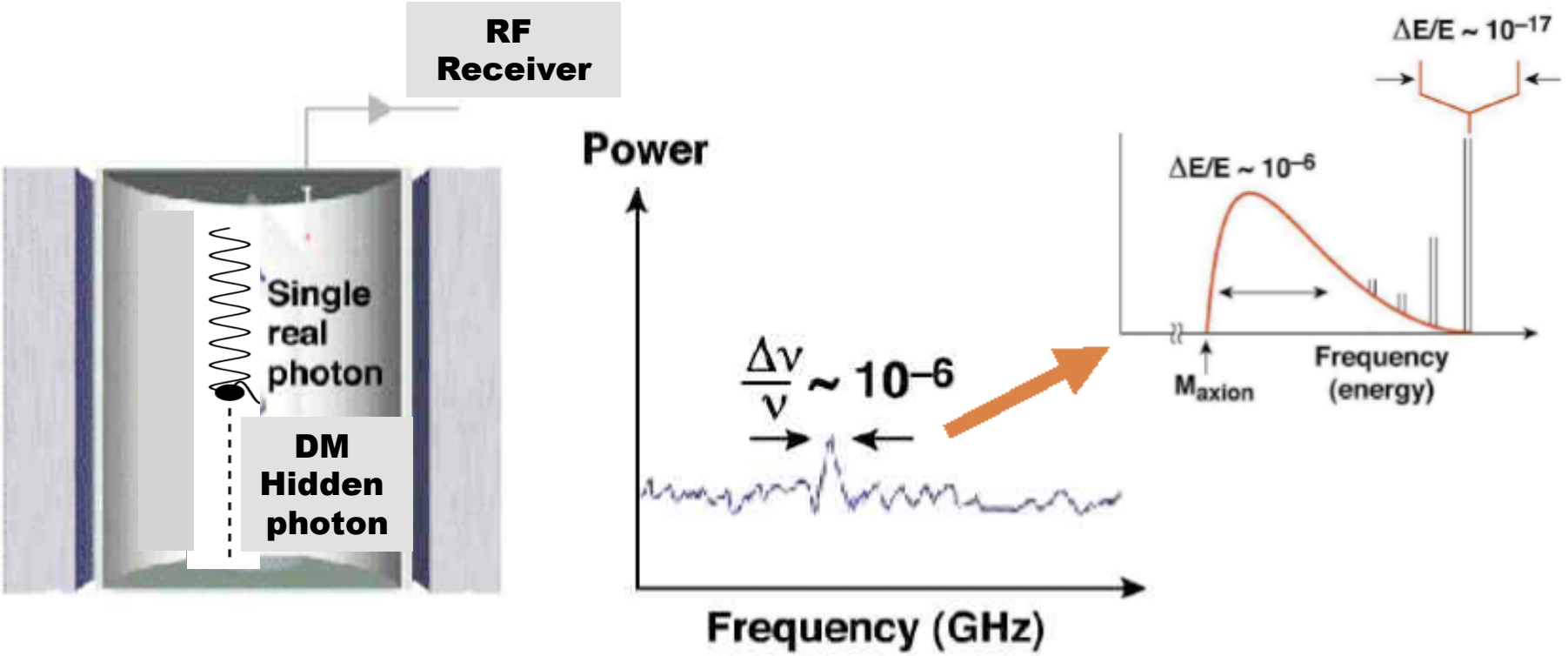

$$h\nu = m_a c^2 [1 + \mathcal{O}(\beta^2 \sim 10^{-6})]$$

Virial velocity in galaxy halo!

Electricity from Dark Matter ;-).

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Photon
(amplified in resonator)

Hidden photon
(dark matter)

An extremely sensitive probe!!!

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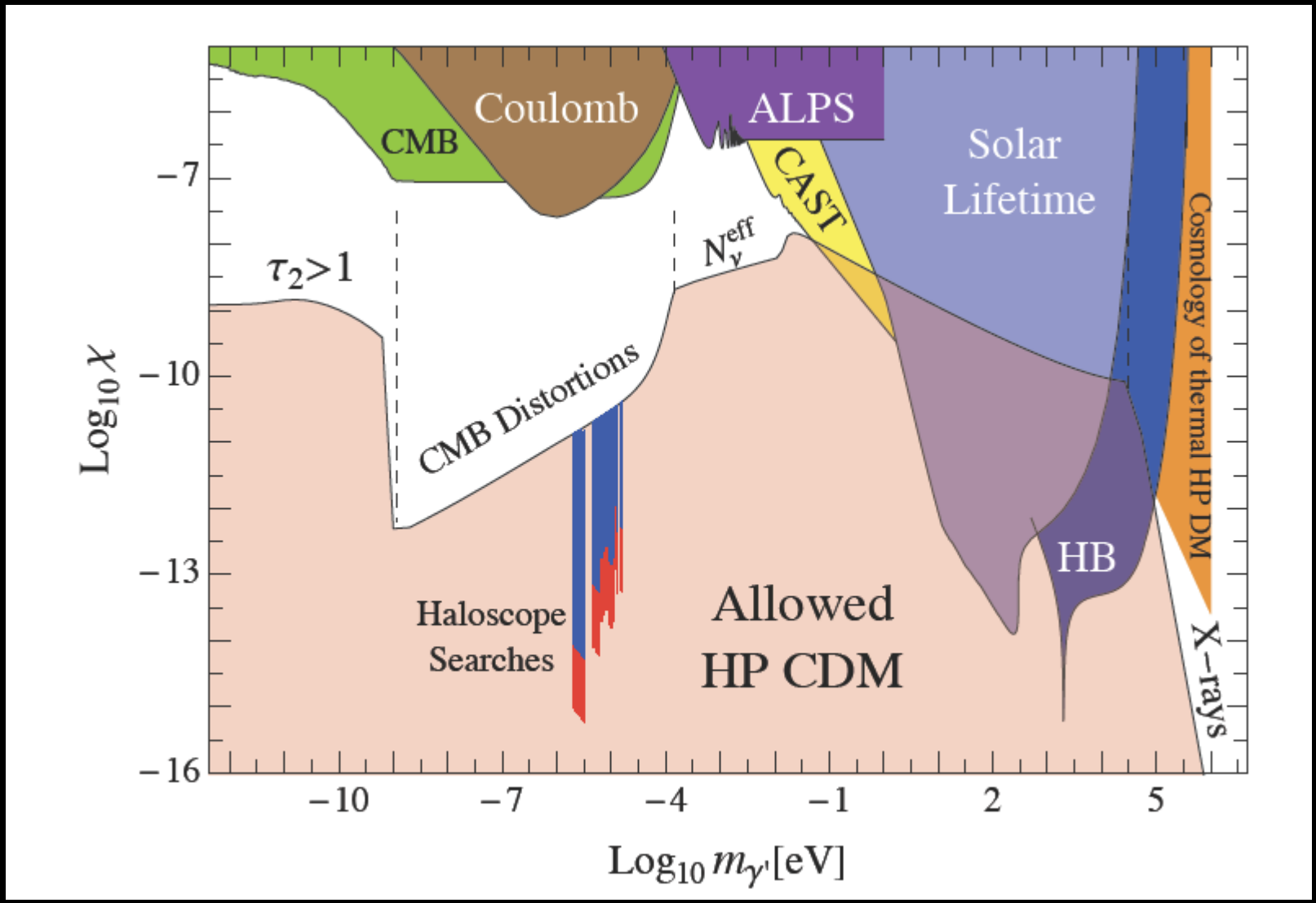

Broadband Search Strategy

Dark Matter Antenna

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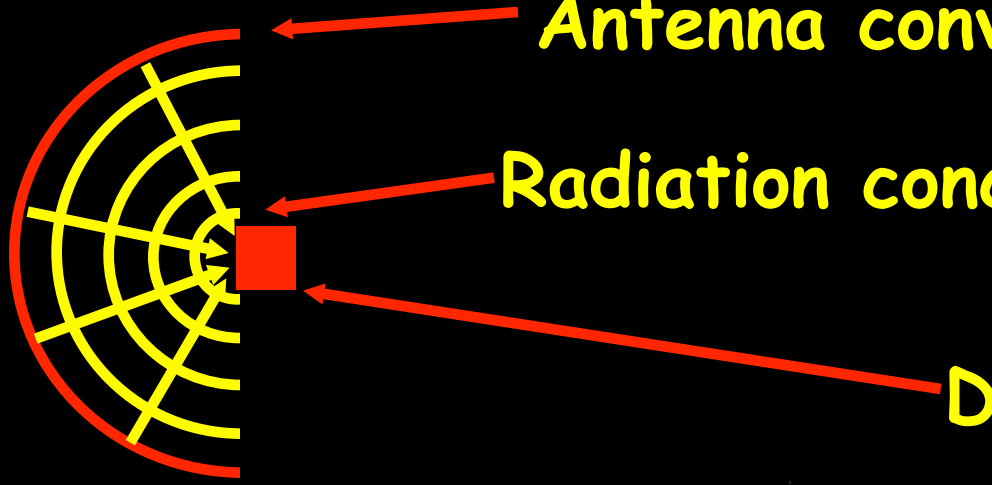
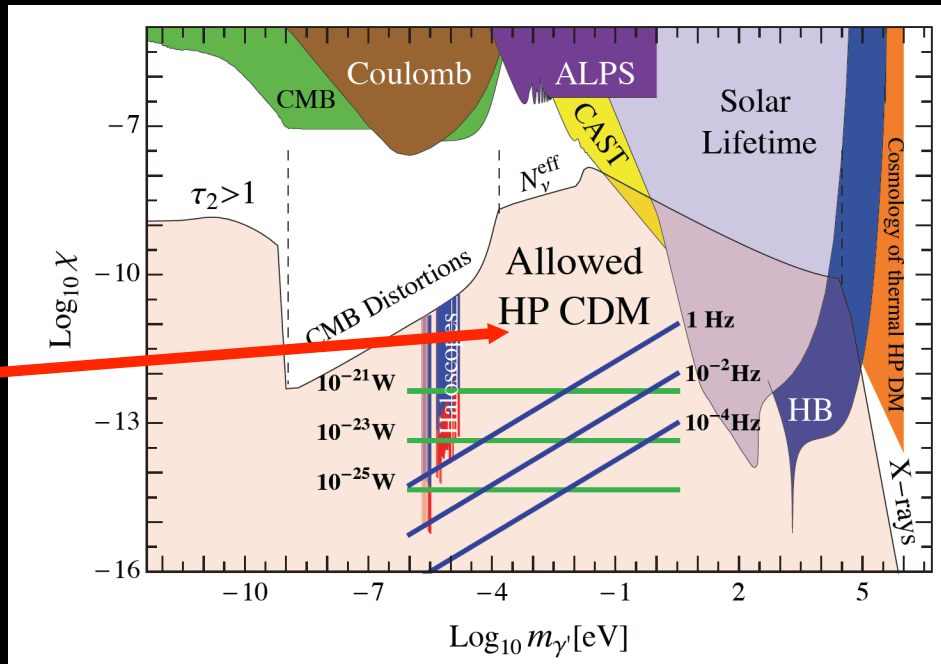


Probes here; very sensitive!!



Works also for axion-like particles

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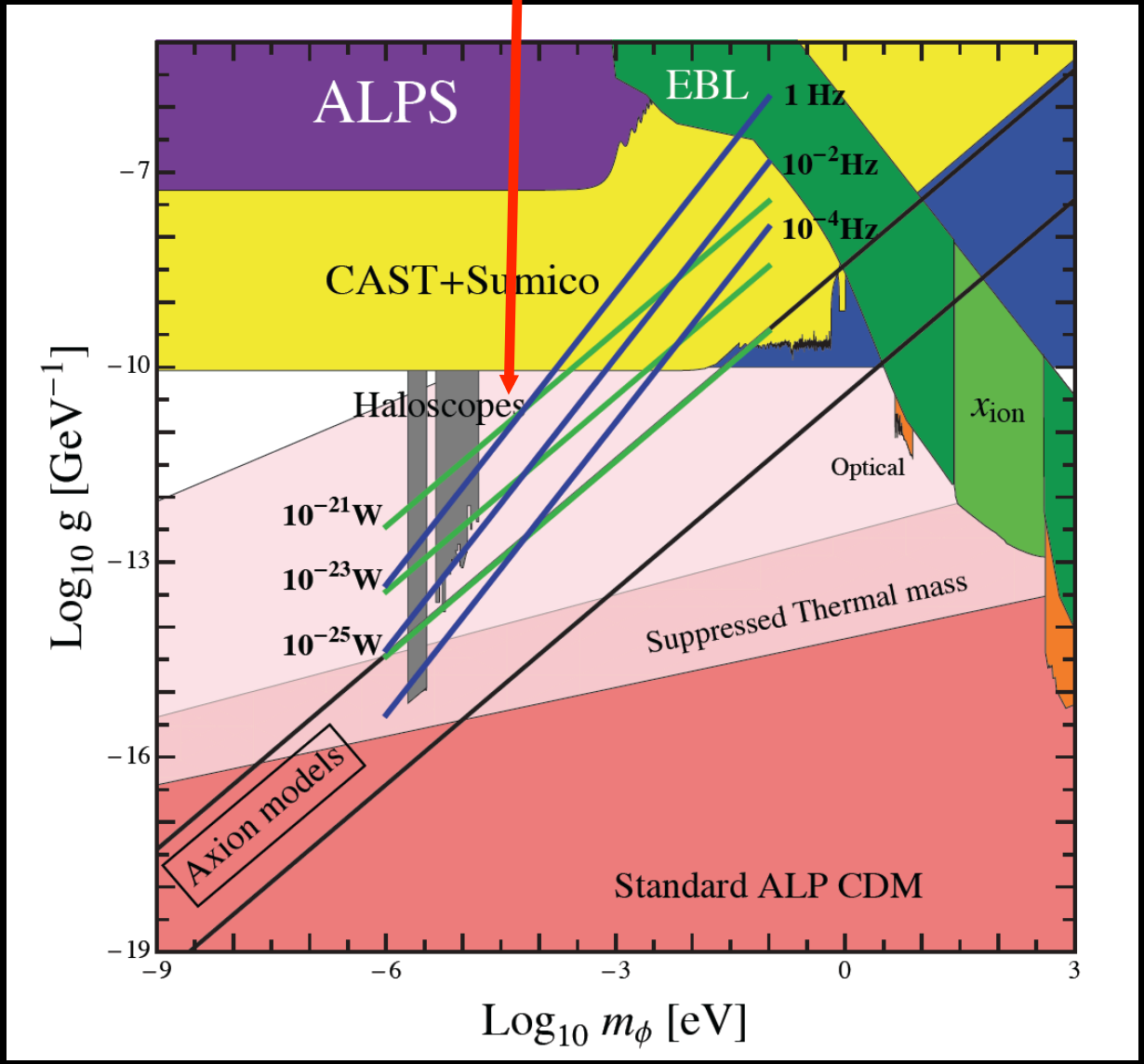

Tests new area

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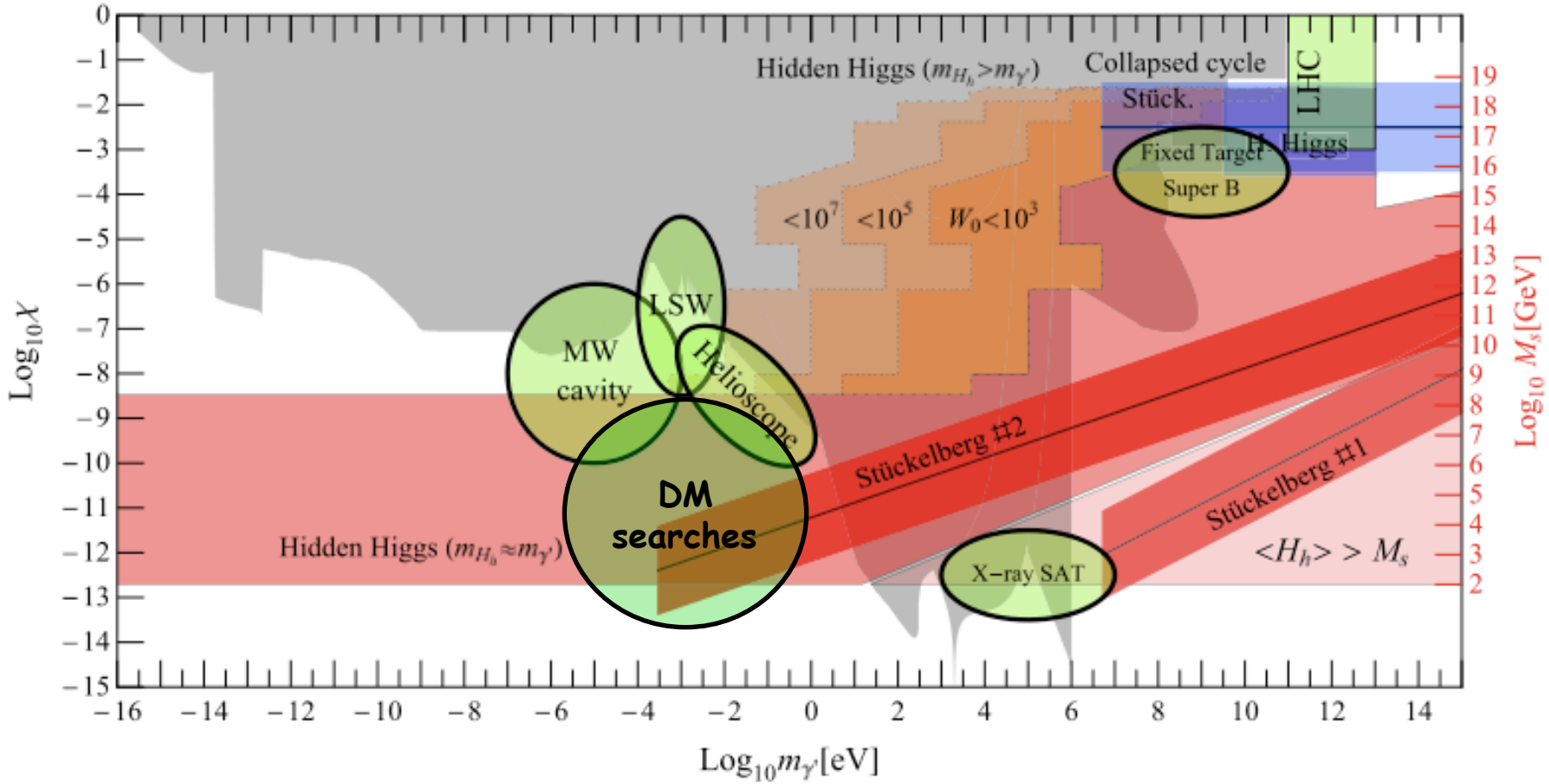

Exciting things go on NOW!!!

Conclusions

Conclusions

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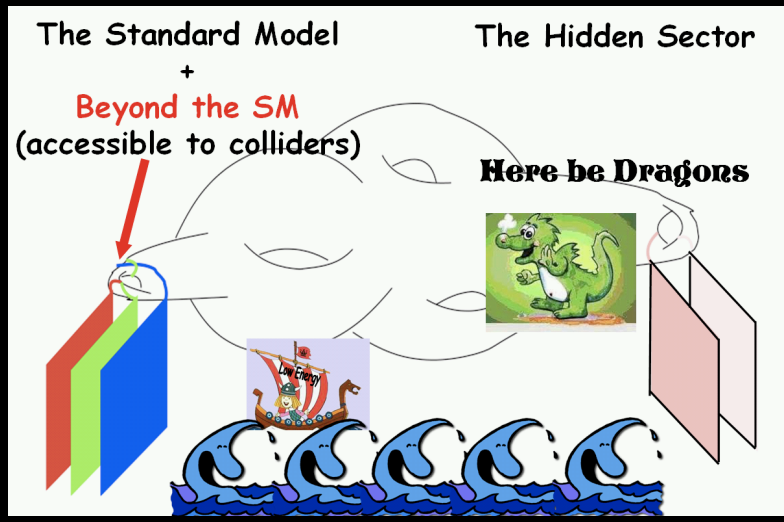
- Good Physics Case for Axions and WISPs
  ➡ explore `The Low Energy Frontier'
- Low energy experiments test energy scales much higher than accelerators
  ➡ Complementary!
- May provide information on hidden sectors and thereby into the underlying fundamental theory



- Dark Matter may be WISPy ☺


Discover the Hidden Islands

Something to Revive?!?

Tests of Coulomb's law

Test for hidden photons and MCPs

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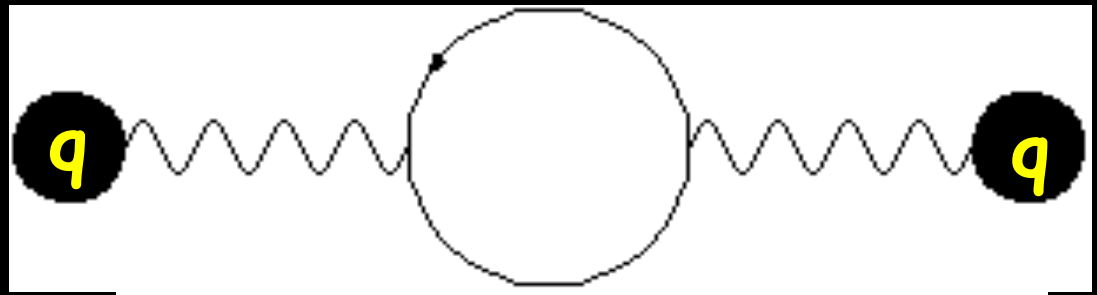
- WISPs modify Coulomb's law
- Hidden photons:

$$\delta V \sim \alpha q^2 \chi^2 \frac{\exp(-m_{\gamma'} r)}{r}$$

- Minicharged particles



$$\delta V(r) \approx \frac{Q\alpha}{r}\left[\frac{\alpha\epsilon^2}{4\sqrt{\pi}}\frac{\exp(-2mr)}{(mr)^{\frac{3}{2}}}\right.$$

Cavendish Experiments

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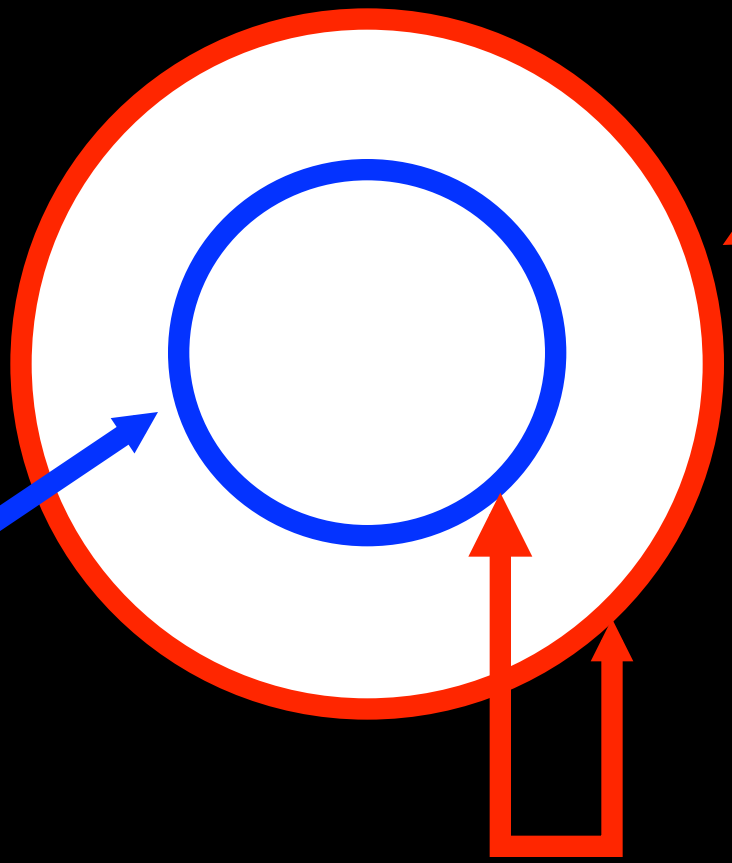

Charged with Q

uncharged

Measure Voltage
=0 for exact Coulomb

Quite sensitive

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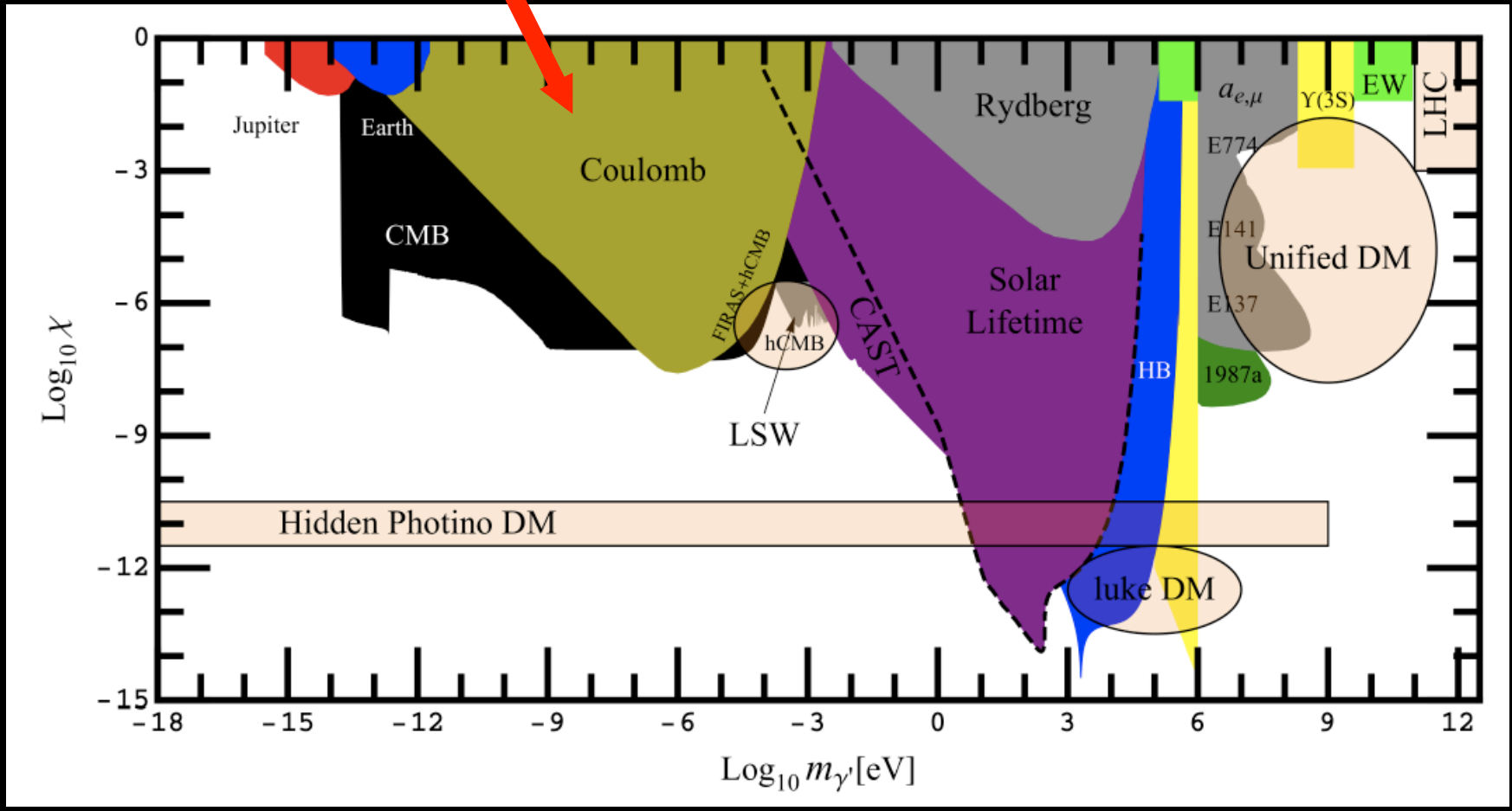

- Best experiment 40 years old!!!!

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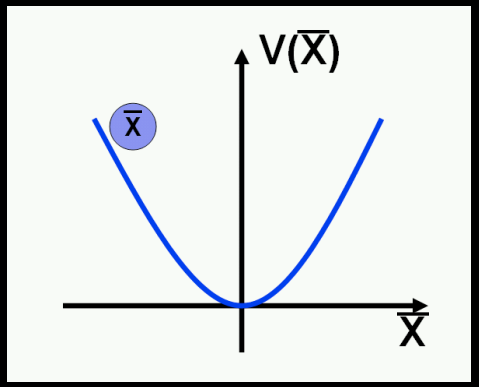

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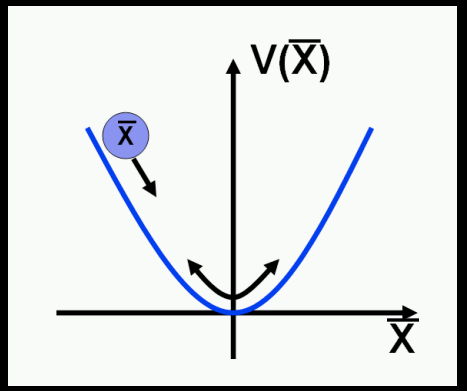

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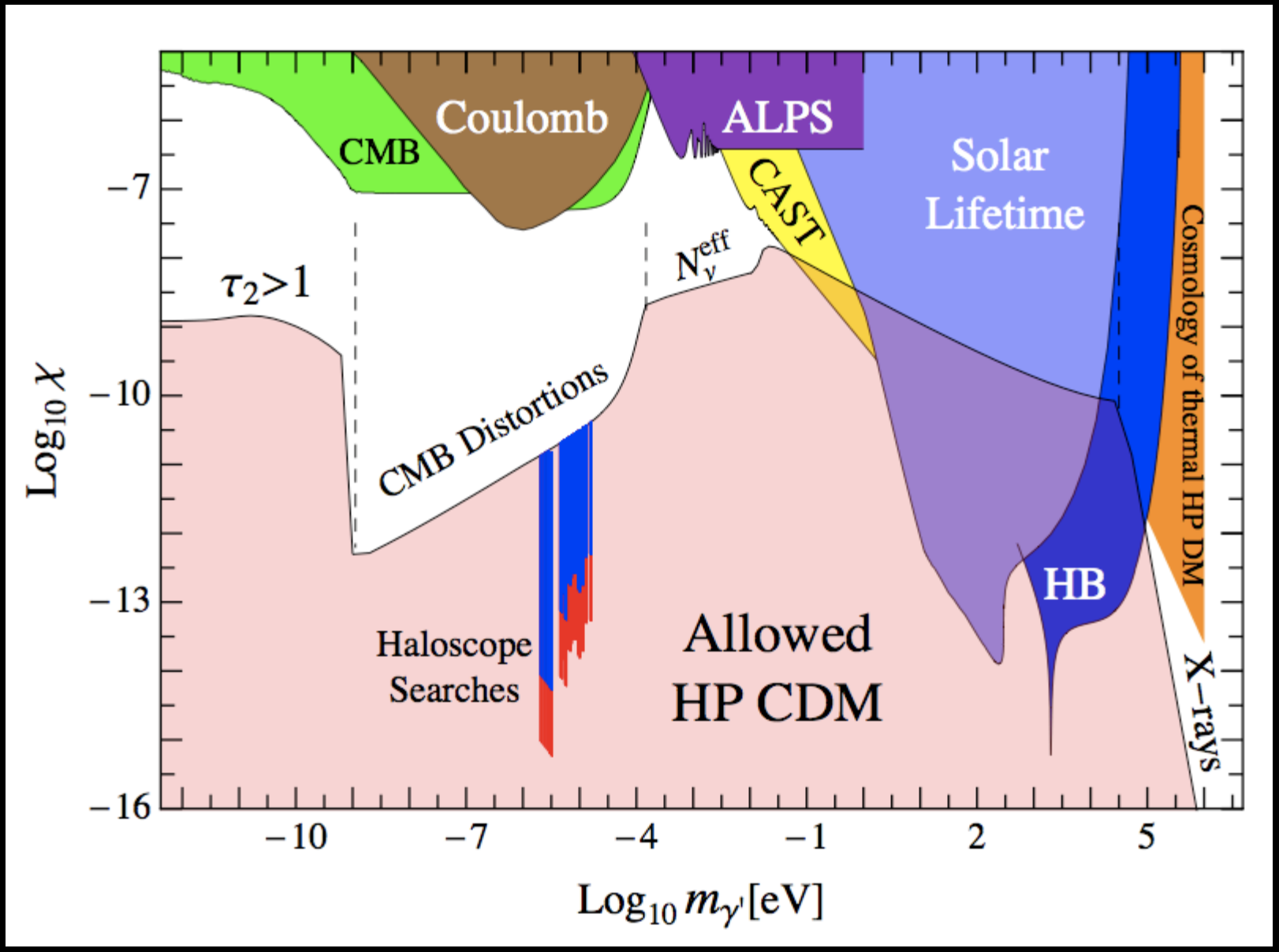

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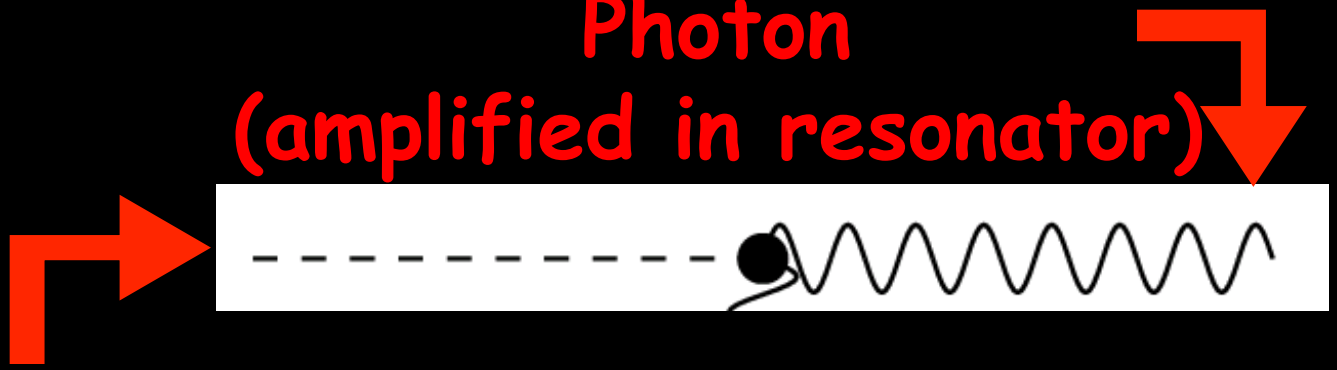

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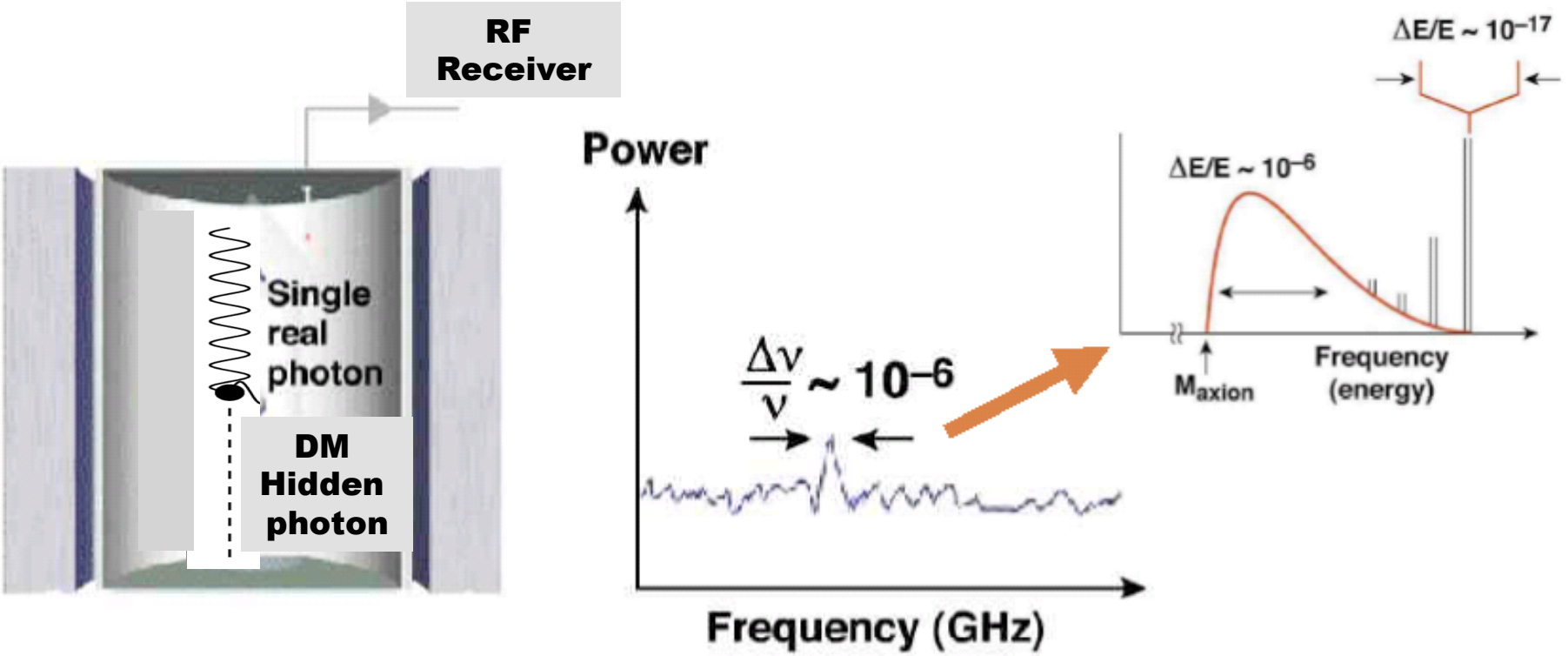

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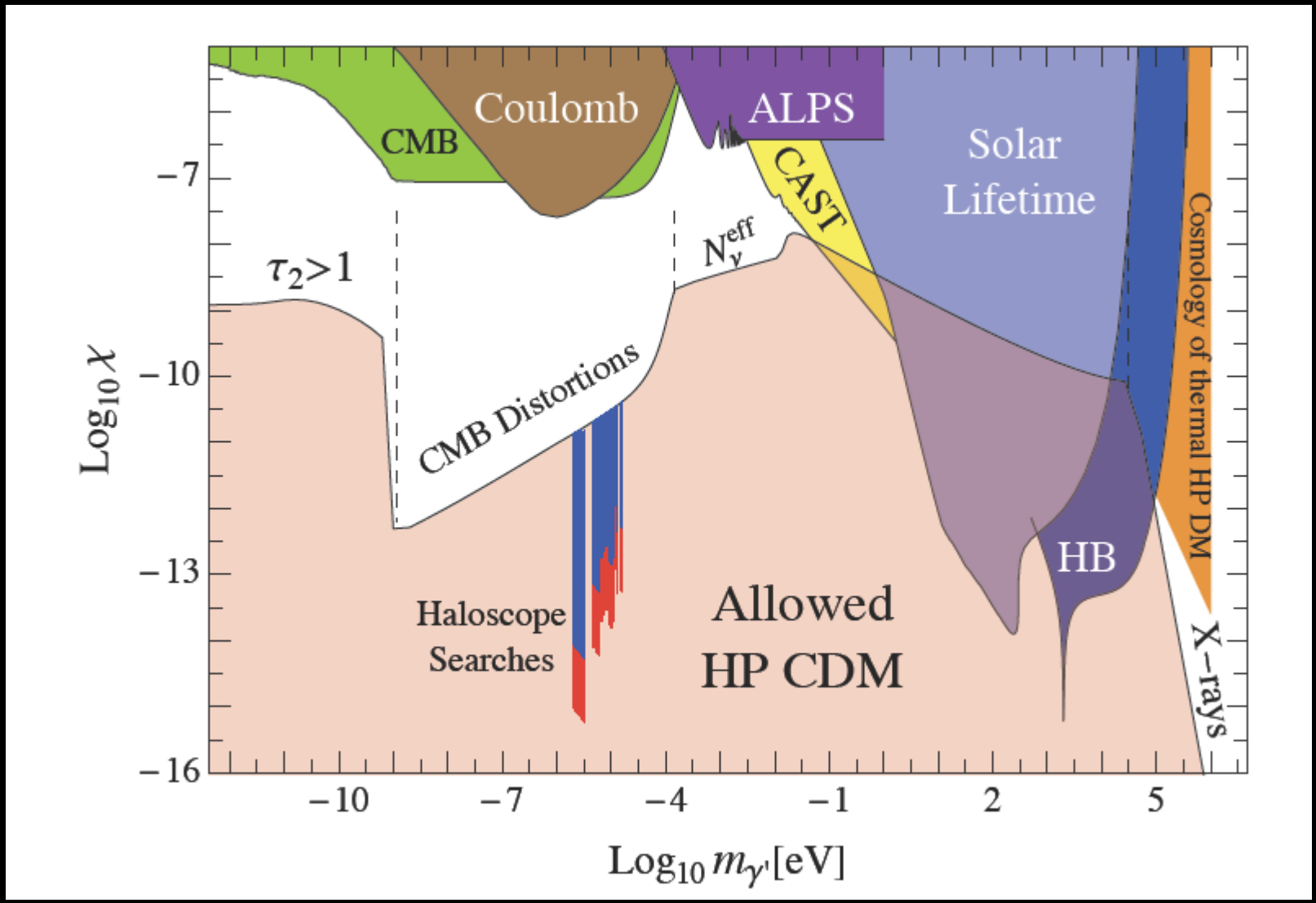

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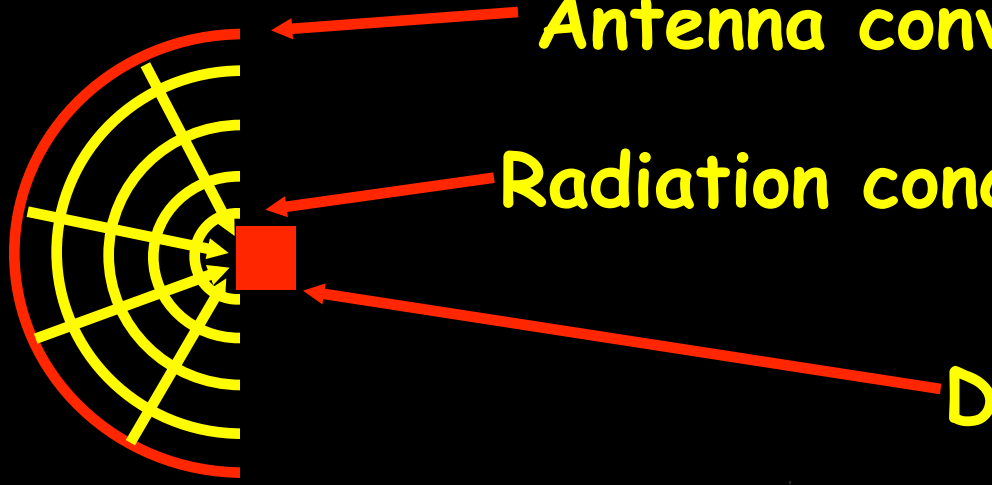

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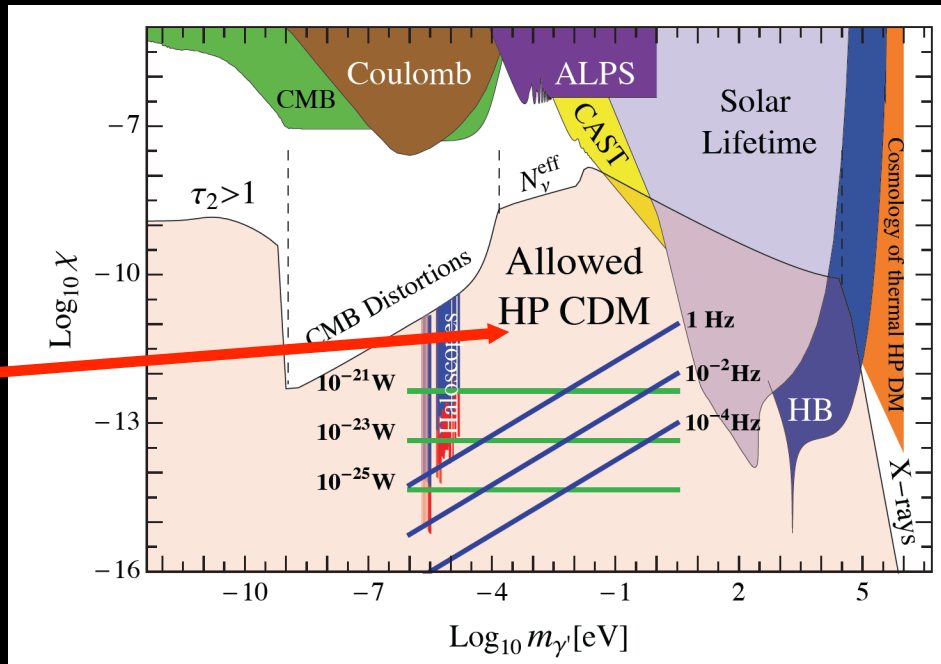

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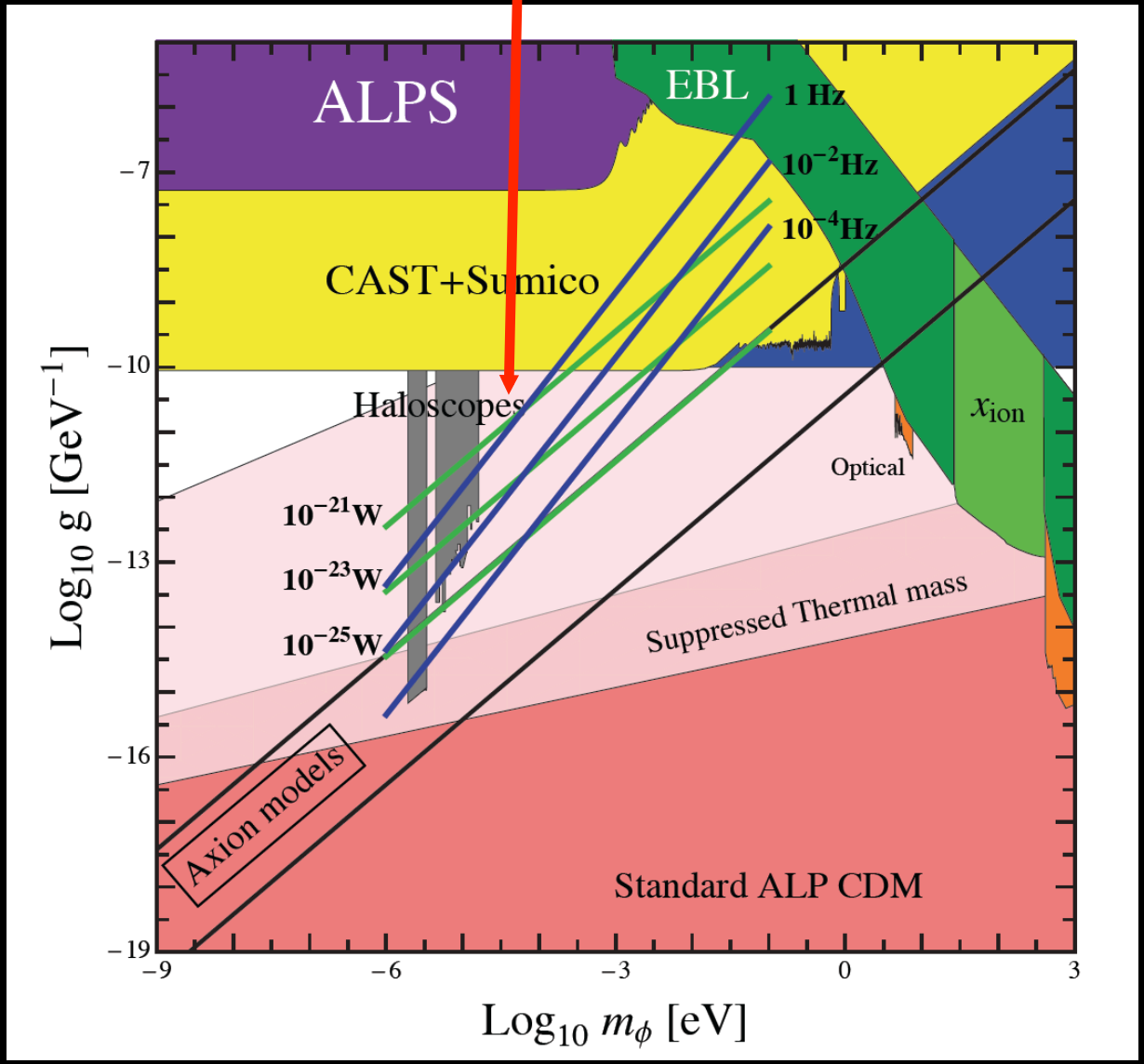

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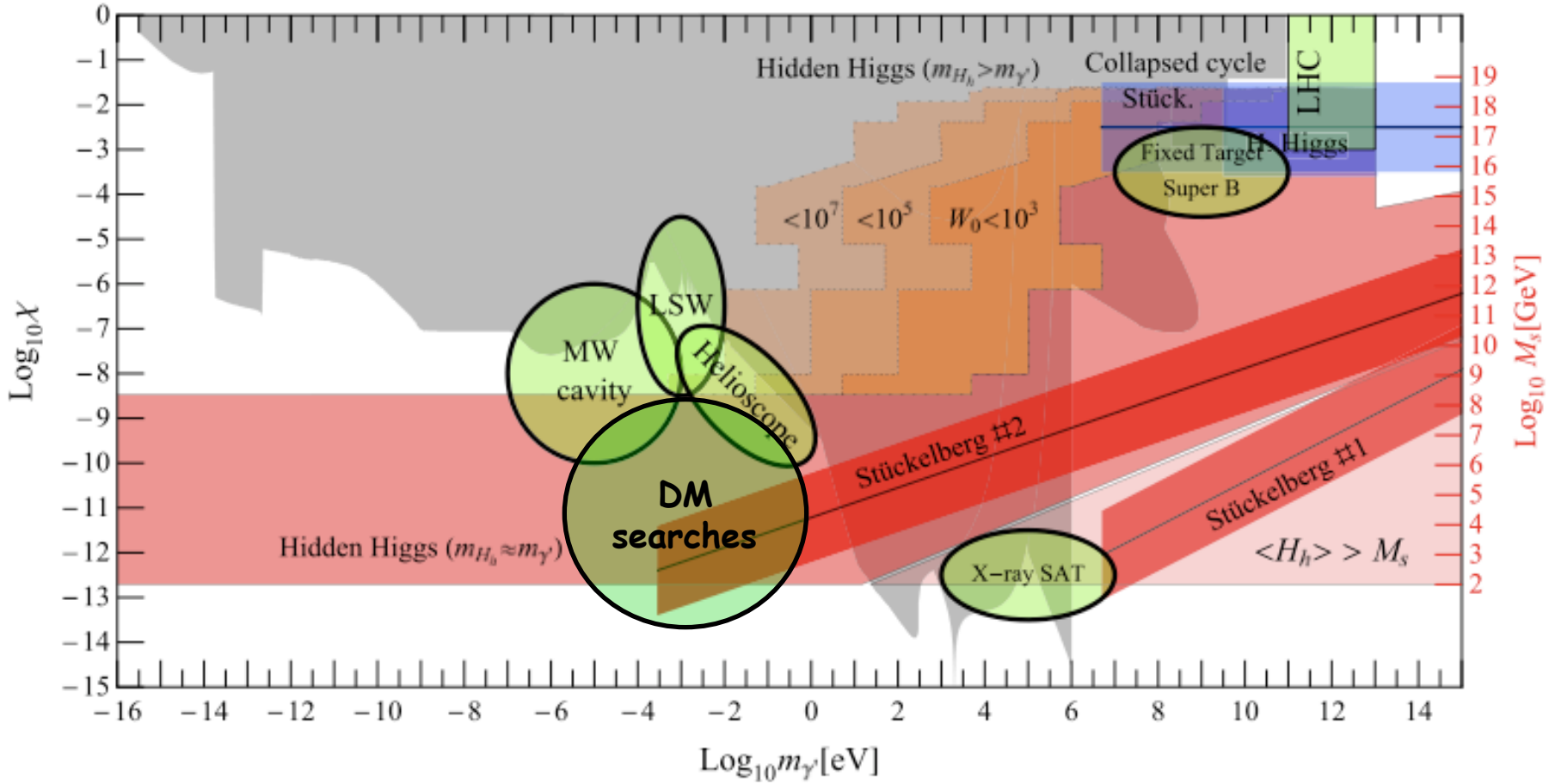

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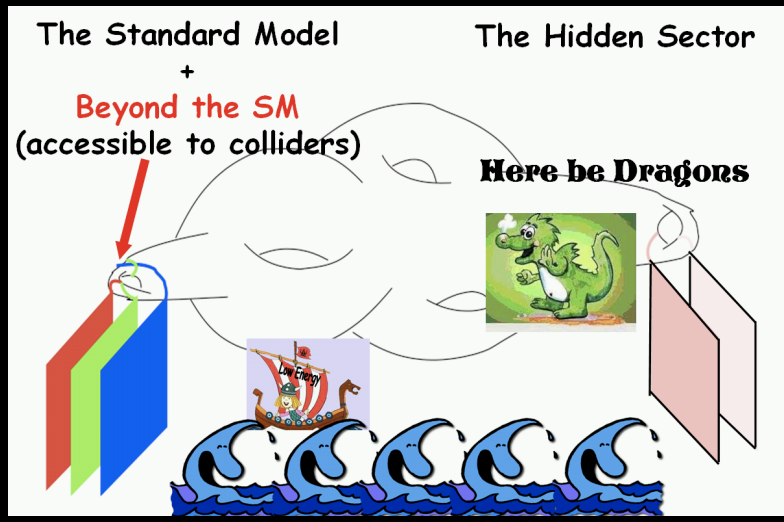

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