Axions and WISPs
or
Fundamental Physics @ Low Energies

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In the year 1 AH*

...we think we understand EW symmetry breaking

* After Higgs discovery
Understanding the origin of mass

We are still trying to understand most of the mass in the Universe: The Dark Matter Mass

**SUSY WIMPs**

\[ m_{WIMP} \sim M_{SUSY} - \text{const.} \]

\[ \frac{m_z^2}{M_{SUSY}} \]

0% - ε% understood
Understanding the origin of mass

We are still trying to understand most of the mass in the Universe: The Dark Matter Mass

**SUSY WIMPs**

\[ m_{\text{WIMP}} \sim M_{\text{SUSY}} - \text{const.} \]

- \( m^2_z \)  
- \( M_{\text{SUSY}} \)

0% - ε% understood

**Axions**

\[ m_{\text{axion}} \sim \sqrt{m_{\text{quark}} \Lambda_{\text{QCD}} \Lambda_{\text{QCD}}} \]

\( M_{\text{PQ}} \)

>75% understood
Where we want to go... a mythical story

The Standard Model

+ Beyond the SM
  (directly accessible to colliders)

The Hidden Sector

Here be Dragons
Exploring is (at least) 2 dimensional

Energy, Mass

LHC

LHCb

B-phys

V

Fixed target

DM, Laser+++

Precision, Intensity, Small coupling

unknown unknowns

guessed unknowns

known knowns

 guessed unknowns
Today's question:
Are the extra (gauge) Forces?
SU(3) x SU(2) x U(1) x ????
The simplest case

Hidden Photons:

$$??? = U(1)_{\text{hid}}$$
The simplest case

Hidden Photons:

\(???? = U(1)_{hid}\)

Will be light + very weakly coupled

\(\rightarrow\) Weakly Interacting Slim Particle = WISP
String theory likes extra gauge groups

Many extra U(1)s!
String theory likes extra gauge groups

Many extra $U(1)$s!
String theory likes extra gauge groups

Many extra U(1)s!
Hidden Photon interactions

• Kinetic mixing

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

\[ + \text{ Mass} \]

\[ \mathcal{L}_{\text{mass}} = \frac{1}{2} m_{\gamma'}^2 X^\mu X_\mu \]
Modified Coulomb’s Law $\rightarrow$ Extra force!

- Kinetic mixing

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

“Our” U(1)  “Hidden” U(1)  Mixing

+ Mass

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

Hidden by small coupling

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

Hidden by large mass
Hidden Photon interactions

- Kinetic mixing

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

"Our" U(1) \quad "Hidden" U(1) \quad Mixing

+ Mass

\[ \mathcal{L}_{\text{mass}} = \frac{1}{2} m_\gamma^2 X^\mu X_\mu \]

A \quad X \quad A

= analog \ \nu\text{-oscillations}
Explore fundamental properties.

\[ \chi \sim \frac{g_s}{8\pi} \frac{1}{\text{Volume}^x} \quad m_{\gamma'}^2 \sim \frac{M_s}{\text{Volume}^y} \]

- Global feature
- Fundamental high energy scale!
Hidden Photons, all over the place
Low energy Experiments
Exploring fundamental high energy physics...

- The direct approach: MORE POWER

LHC, Tevatron + ILC, CLIC

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

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

- Man its DANGEROUS... 😊
But...

- 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!
Complementary approaches
Light shining through walls

“Light shining through a wall”

Laser → ↓ × ↓ → Detector
Light shining through walls

“Light shining through a wall”

- Test \( P_{\gamma \rightarrow X \rightarrow \gamma} \lesssim 10^{-20} \)
- Enormous precision!
- Study extremely weak couplings!
Light Shining Through Walls

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

LSW already competitive + testing interesting area
Coincidences?

- Neutrino masses:
  \[ m_\nu \sim \text{meV} \]

- Scale of dark energy:
  \[ \rho_\Lambda \sim (\text{meV})^4 \]

- Energy density of the Universe:
  \[ \rho_{\text{today}} \sim (\text{meV})^4 \]
Hidden Photons

LSW already competitive + testing interesting area

Dark energy scale
Helioscopes

CAST@CERN
SUMICO@Tokyo
SHIPS@Hamburg

“Light shining through a wall”
Helioscopes sensitivity

The diagram illustrates the sensitivity of helioscopes to different dark matter models and the expected dark matter interaction strengths. The x-axis represents the logarithm of the dark matter mass in eV ($\log_{10} m_\gamma [\text{eV}]$), while the y-axis shows the logarithm of the cross-section ($\log_{10} \langle \sigma v \rangle$). Various regions on the graph correspond to different dark matter models and interactions, such as the Coulomb, Rydberg, and Solar Lifetime regions, among others. The diagram also highlights the locations of the LSW, CMB, and other relevant astrophysical features.
WISPS = Weakly interacting sub-eV particles

- **Axions**

- **Massive hidden photons (without B-field)**
  = analog $\nu$-oscillations

- **Hidden photon + minicharged particle (MCP)**
Dark Matter(s)
Hidden = Dark photon matter

\[ \dddot{X}_i + 3H \dot{X}_i + m_{\gamma'}^2 X_i = 0 \]
\[ \bar{X}_i = X_i / a(t) \]

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

- \( H \gg m_{\gamma'} \) \( \Rightarrow \) overdamped oscillator

- \( H \ll m_{\gamma'} \) \( \Rightarrow \) damped oscillator

\[ \rho_X(t) = \frac{\rho_{ini}}{a^3(t)} \] \( \Rightarrow \) Dark Matter
Hidden Photon Dark Matter

\[ \log_{10} \chi \]

\[ \log_{10} m_\gamma \text{[eV]} \]

- CMB
- Coulomb
- ALPS
- CAST
- Solar Lifetime
- Cosmology of thermal HP DM
- X-rays

- \( \tau_2 > 1 \)
- CMB Distortions
- Neff
- Haloscope Searches
- Allowed HP CDM
- HB
Use a plentiful source of HPs

- Photon Regeneration

Photon (amplified in resonator)

Hidden photon (dark matter)

➡ See ADMX talk
Electricity from Dark Matter ;-).

- Photon Regeneration

Photon (amplified in resonator)

Hidden photon (dark matter)

10^{-23} W!
An extremely sensitive probe!!!
Dark Matter Antenna

Antenna converts HP $\rightarrow$ photon

Radiation concentrated in center

Detector

Probes here; very sensitive!!
Many more tests...

Exciting things go on NOW!!!
Conclusions
Conclusions

- Good Physics Case for HPs + other light stuff
  explore `The Low Energy Frontier`

- **Ongoing**: Low energy experiments test directions not tested in accelerators

- Complementary!

- May provide information on hidden sectors and thereby on the underlying fundamental theory

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The Standard Model + Beyond the SM (accessible to colliders) Here be Dragons
Discover the Hidden Islands