The low energy frontier: searches for ultra-light particles beyond the standard model

Axel Lindner, DESY

Séminaire SPP, CEA-Saclay, 25 June 2012

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Outline

- Introduction
- Could there be any low-mass-low-coupling particle physics?
  What theory tells and a visit to the WISP zoo …
- If it is possible: are there any hints?
  Some open questions in (astro)physics …
- A new particle habitat?
- Experimental WISP searches:
  basics, direct searches and future prospects.
- Some crazy ideas
- Advertisement
- Summary

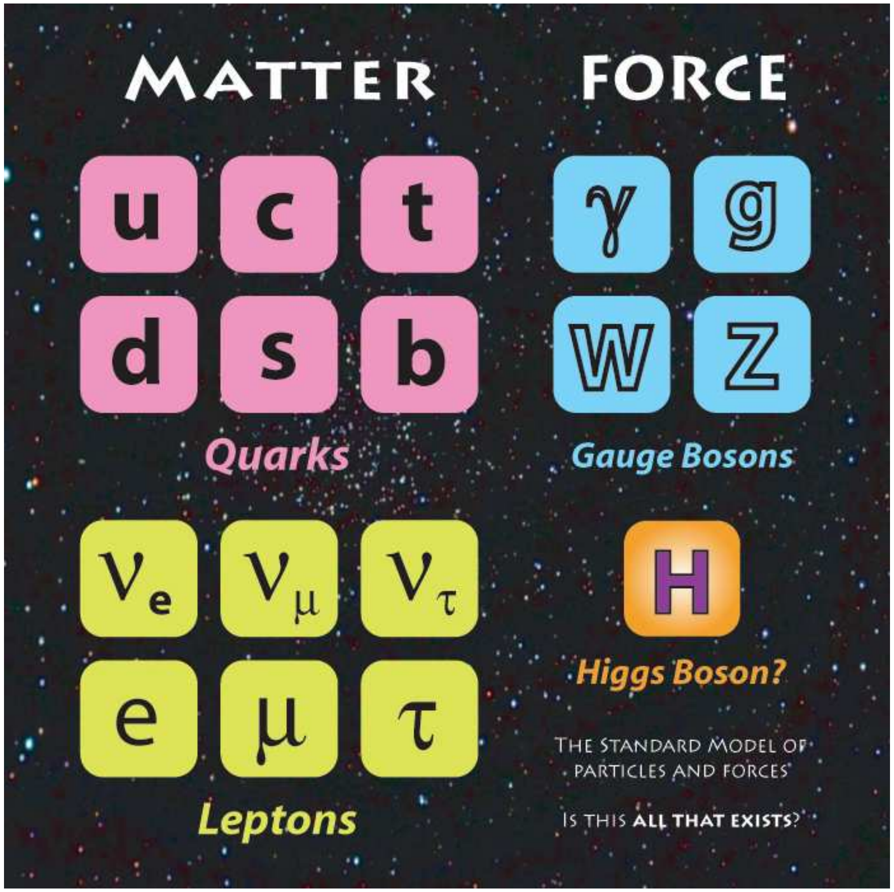
Our starting point: the standard model

<u>Constituents:</u>

- Quarks
- Leptons

<u>Forces:</u>

- electromagnetic
- strong
- weak
- gravitation



http://www.gridpp.ac.uk/cubes/

Only the Higgs boson is missing!

LHC is on the way to probe its existence.

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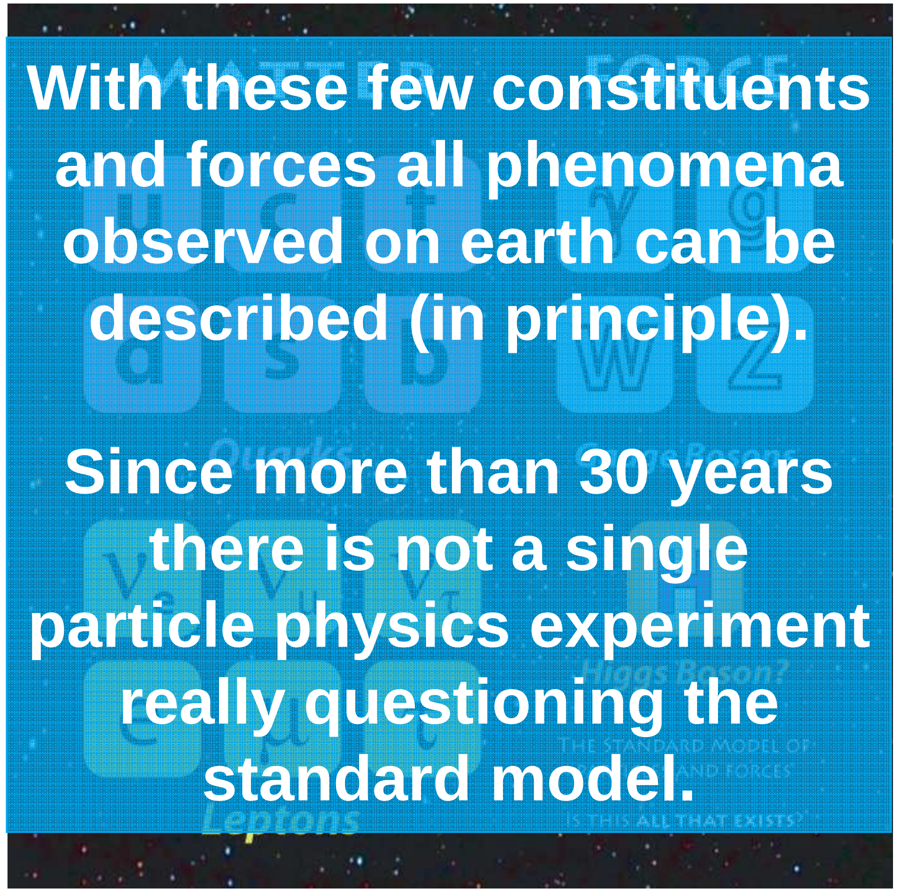

With these few constituents and forces all phenomena observed on earth can be described (in principle).

Since more than 30 years there is not a single particle physics experiment really questioning the standard model.

http://www.gridpp.ac.uk/cubes/

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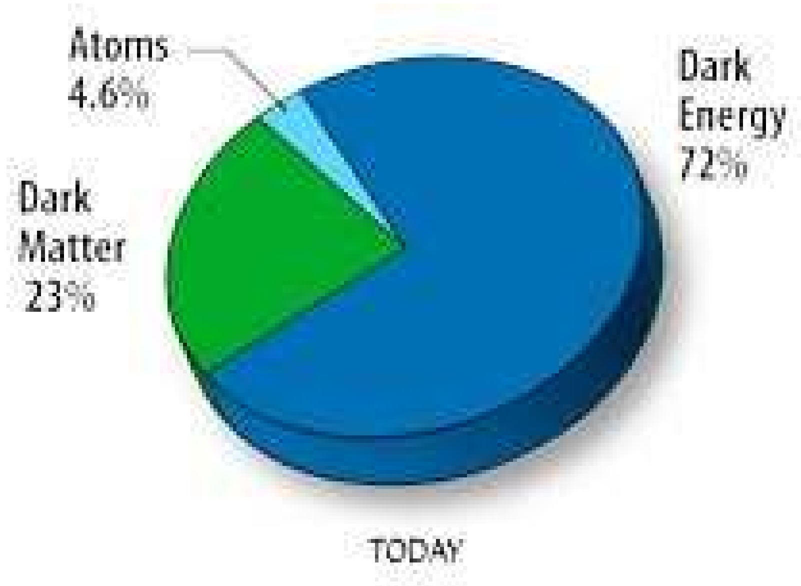
LHC is on the way to probe its existence.

A universal view of the standard model

- There remains much to be discovered in the present universe:



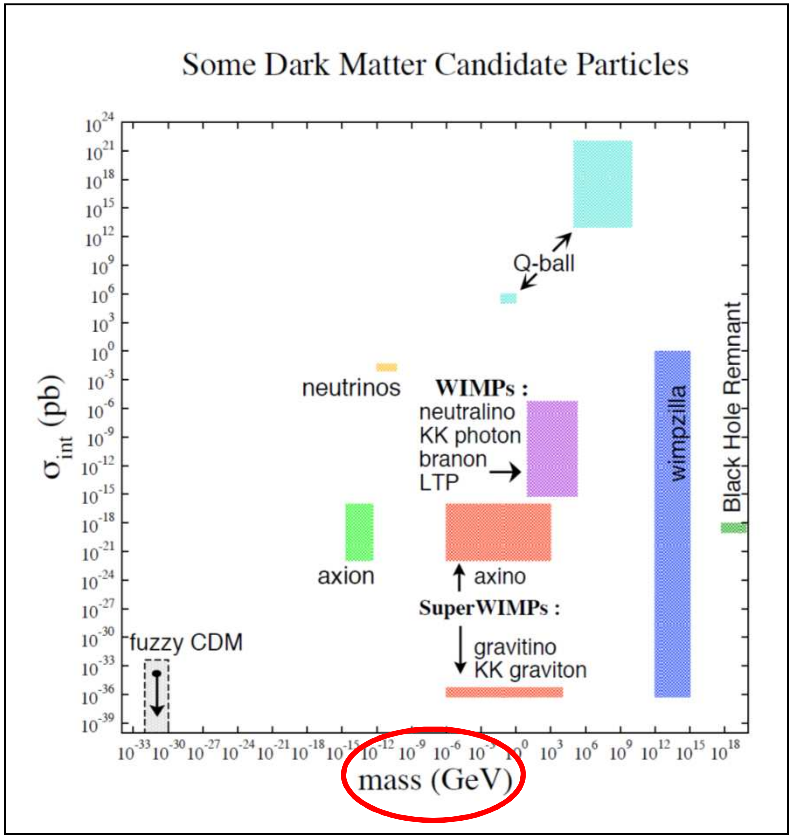
- The baryon dominance in the universe is unexplained.
- Is there a unification of forces?
- …..

What does theory tell?

Where to expect physics beyond the standard model?

- Example: dark matter:

  Candidate dark matter constituents are predicted at nearly any mass!



H. Baer, presentation at 5th Patras Workshop on Axions, WIMPs and WISPs, 2009

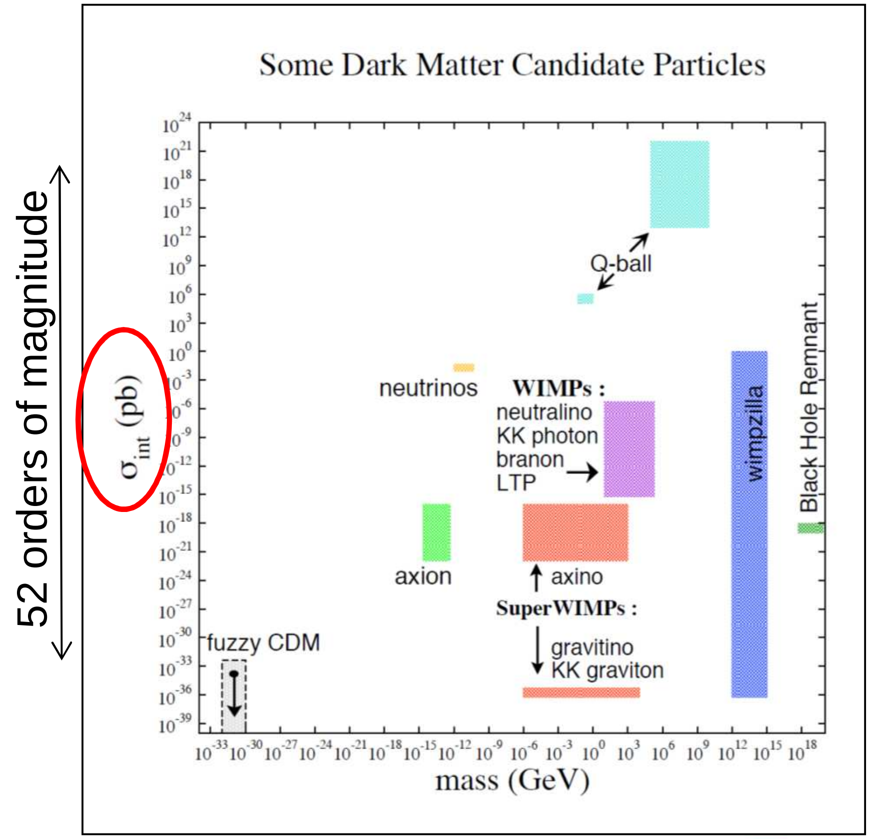
52 orders of magnitude

What does theory tell?

Where to expect physics beyond the standard model?

- **>** Main road of particle physics:
  New phenomena should show up at mass scales beyond the present experimental reach.
  - Experiments at the high energy and high intensity frontiers.
- **>** Another option:
  New phenomena could show up at low or moderate mass scales, but today‘s experiments have not reached a sufficient sensitivity.

  Is there a low energy frontier of Weakly Interacting Slim Particles (WISPs)?



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What theory tells about WISPs

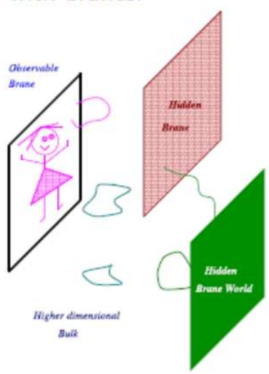
A *hidden sector* of particle physics could exist very well:

These particles would be uncharged with respect to electroweak and strong interactions and hence appear to be “dark”.

- The unification of forces requires extended gauge structures which led to singlets charged under some new gauge group. Thus GUTs or string theories can‘t avoid a hidden sector.

– Light hidden U(1)s . . . – 9

- Embeddings of the standard model in string compactifications often contain even several hidden sector U(1) gauge factors (cf. consistency conditions, e.g. tadpole/anomaly cancellation), e.g.
  - in type II string theory with branes:



A. Ringwald (DESY) SLAC, September 2009

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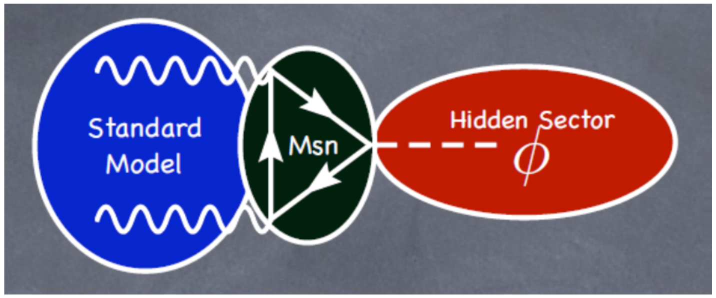
- The unification of forces requires extended gauge structures which led to singlets charged under some new gauge group. Thus GUTs or string theories can't avoid a hidden sector.
- Gauge hierarchy problem:
  how could one understand the huge difference between the electroweak scale of 10^2 GeV and the Planck scale of 10^{19} GeV?
  A hidden sector introducing a dynamical SUSY breaking could take care for this.
- There could be complex physics within the hidden sector with new forces and charges.

What theory tells about WISPs

Particles from a *hidden sector* could interact in different manners with standard model particles:

- By gravitation (dark matter in the universe).
- By heavy messengers charged under the Standard Model and the hidden sector.



- Standard model particles could be charged also under the hidden sector.
  This would result in fifth forces.

What theory tells about WISPs

Top-down calculation of axion and axion-like particle properties:

http://www.arxiv.org/abs/1206.0819v1

CERN-PH-TH/2012-153
DESY 12-058

The type IIB string axiverse and its low-energy phenomenology

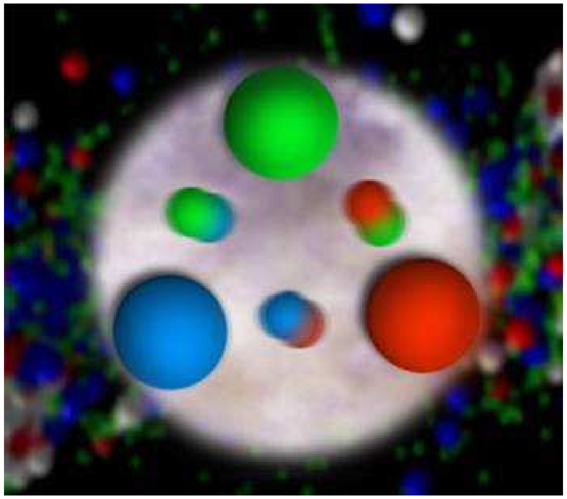
Michele Cicoli[♣*], Mark D. Goodsell[◇†] and Andreas Ringwald[♠‡]

We study closed string axions in type IIB orientifold compactifications. We show that for natural values of the background fluxes the moduli stabilisation mechanism of the LARGE Volume Scenario (LVS) gives rise to an axiverse characterised by the presence of a QCD axion plus many light axion-like particles whose masses are logarithmically hierarchical.

Moreover, we show how models can be constructed with additional light axion-like particles that could explain some intriguing astrophysical anomalies, and could be searched for in the next generation of axion helioscopes and light-shining-through-a-wall experiments.

The first WISP example

- The neutron has a strange property:
  It consists of three charged quarks, but does not show any static electric dipole moment.



http://www.lbl.gov/Science-Articles/Archive/sabl/2006/Oct/3.html

  Why do the wave functions of the three quarks *exactly* cancel out any observable static charge distribution in the neutron?

- The neutron has a well measured magnetic dipole moment.
  Hence the existence of an electric dipole moment would be equivalent to a CP-violation in QCD.

- Why does QCD conserve CP?

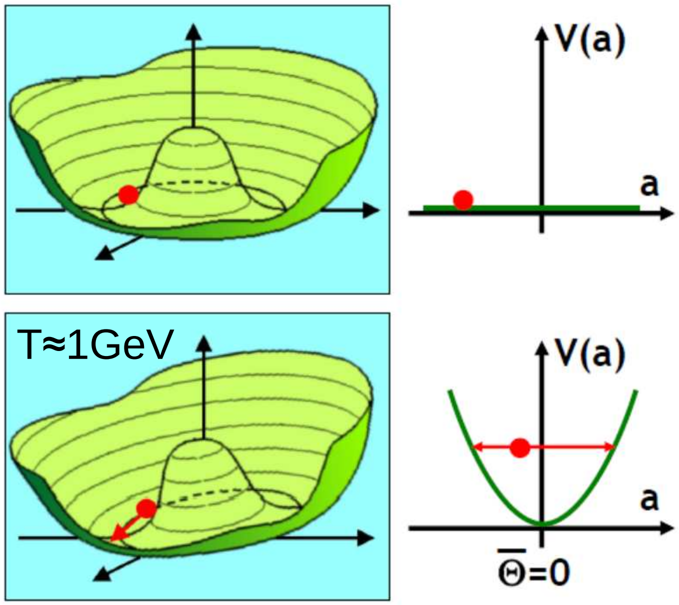
The first WISP example

CP violation in QCD (the size of the neutron's electric dipole moment) is described by a angle Θ. There are no theoretical bounds on Θ, but from the missing neutron dipole moment $\Theta < 10^{-9}$ is concluded.

Is this "just-so", a "fine-tuning" of QCD? This would be very unsatisfying.

The theoreticians approach:
try to find a dynamic explanation!

<u>Peccei-Quinn 1977:</u>
Θ takes an arbitrary value by spontaneous symmetry breaking at a certain high energy scale f_a and roles down by non-perturbative QCD effects to its very small value observed in QCD at low energies.



S. Hannestaad, presentation at 5th Patras Workshop on Axions, WIMPs and WISPs, 2009

Intoducing the axion

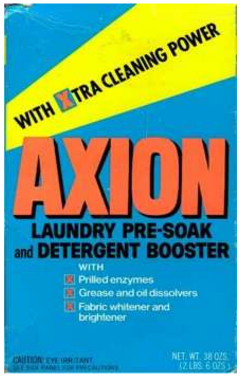
Wilczek and Weinberg independently noticed 1978:

The oscillations of Θ constitute an axion-field (christened by Wilczek).

Summary:

One can explain the CP conservation in QCD,
if a new particle, the axion, exists.
This implies new physics at a high energy scale f_a.

The axion "cleans" QCD.



άξιον = worthy, deserving

An unresolved issue in the SM

F. Wilczek at "Vistas in Axion Physics", Seattle, 26 April 2012
(see http://www.int.washington.edu/talks/WorkShops/int_12_50W/People/Wilczek_F/Wilczek.pdf)

- The gauge sector is tightly principled and brilliantly successful.
- The flavor sector is looser. It … requires many phenomenological input parameters.
  It's most striking success … is the KM theory of T violation. But there is a serpent in the garden:
- The overall phase of the quark mass matrix is physically meaningful.
  In the minimal standard model, this phase is a free parameter, theoretically. Experimentally it is very small.
- This is the most striking *unnaturality* of the standard model, aside from the cosmological term.
  It does not seem susceptible of anthropic "explanation".

An unresolved issue in the SM

How to solve the riddle of CP conservation in the SM:

- More detailed measurements on CP effects,
  for example measure nEDM, pEDM and dEDM.

- Search for axions to probe this explanation for CP conservations
  or similar WISPy particles to probe the existence of a
  low energy frontier.

WISPy particles

New particles could come in different flavors:

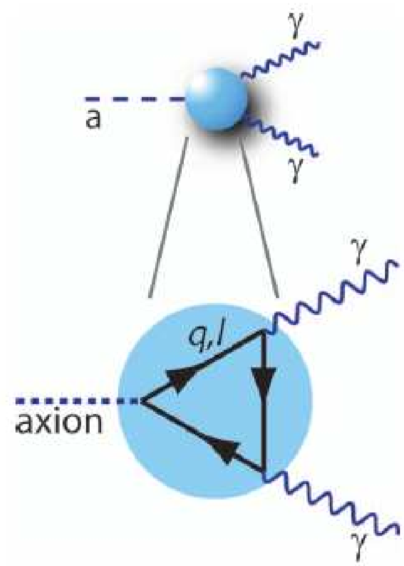
> The QCD axion: the light cousin of the π^0.

- Mass and the symmetry breaking scale f_a are related:
  $m_a = 0.6\text{eV} \cdot (10^7\text{GeV} / f_a)$

- The coupling strength to photons is
  $g_{a\gamma\gamma} = \alpha \cdot g_\gamma / (\pi \cdot f_a)$,
  where g_γ is model dependent and O(1).
  Note: $g_{a\gamma\gamma} = \alpha \cdot g_\gamma / (\pi \cdot 6 \cdot 10^6\text{GeV}) \cdot m_a$

- The axion abundance in the universe is
  $\Omega_a / \Omega_c \sim (f_a / 10^{12}\text{GeV})^{7/6}$.

  $f_a < 10^{12}\text{GeV}$
  $m_a > \mu\text{eV}$



The Search for Axions, Carosi, van Bibber, Pivovaroff, Contemp. Phys. 49, No. 4, 2008

WISPy particles

Axions

- could explain the CP conservation in QCD.
- could provide a significant part or even all of the dark matter.
- could provide a portal to physics at the 10^{12} GeV scale.
- couple extremely weakly to standard model particles challenging any experimental attacks.

WISPy particles

New particles could come in different flavors:

> The QCD axion: the light cousin of the π^0

> Axion-like particles (ALPs)

- Mass and coupling strength to photons are unrelated.

WISPy particles

New particles could come in different flavors:

- The QCD axion: the light cousin of the π^0
- Axion-like particles (ALPs)
- Hidden photons (HPs)
  - Massiv neutral vectorbosons like the QED photon

$$\mathcal{L} \supset -\frac{1}{4}F^{(\mathrm{vis})}_{\mu\nu}F^{\mu\nu}_{(\mathrm{vis})} - \frac{1}{4}F^{(\mathrm{hid})}_{\mu\nu}F^{\mu\nu}_{(\mathrm{hid})} + \frac{\chi}{2}F^{(\mathrm{vis})}_{\mu\nu}F^{(\mathrm{hid})\mu\nu} + m^2_{\gamma'}A^{(\mathrm{hid})}_{\mu}A^{(\mathrm{hid})\mu} + A^{(\mathrm{vis})}_{\mu}j^{\mu}$$

M. Cicoli, M. Goodsell, J. Jaeckel, A. Ringwald, JHEP 1107 (2011) 114

WISPy particles

New particles could come in different flavors:

- The QCD axion: the light cousin of the π^0
- Axion-like particles (ALPs)
- Hidden photons (HPs)
- Mini-charged particles
  - Charged under the “hidden sector QED”.

WISPy particles

New particles could come in different flavors:

- The QCD axion: the light cousin of the π^0
- Axion-like particles (ALPs)
- Hidden photons (HPs)
- Mini-charged particles
- More scalar particles
  - The Chameleon: its mass is related to the energy density of its surrounding.

$$\phi_{\min}(\rho_{\mathrm{m}}) = \Lambda \left(\frac{n M_{\mathrm{Pl}} \Lambda^3}{\beta_m \rho_m}\right)^{\frac{1}{n+1}}$$

$$m(\phi)^2 = V''_{\mathrm{eff}}(\phi) = \frac{n(n+1)\Lambda^{n+4}}{\phi^{n+2}}$$

WISPy particles

> Example: the landscape of axion-like particles.

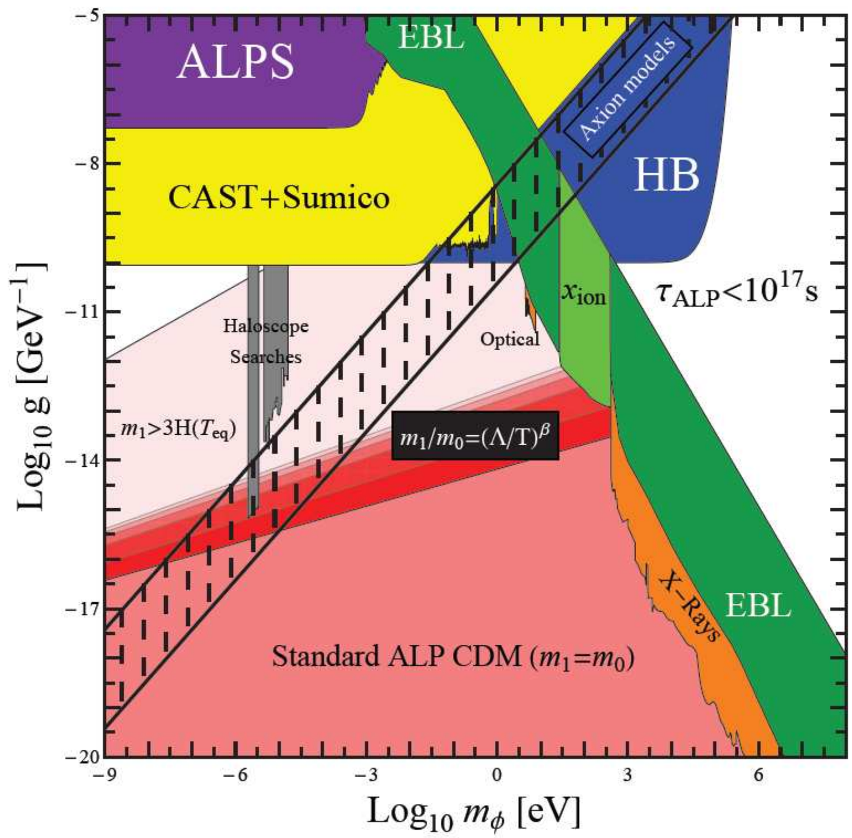
Due to their non-thermal production light ALPs could be the constituent of cold dark matter.

PREPARED FOR SUBMISSION TO JCAP
DESY 11-226; MPP-2011-140; CERN-PH-TH/2011-323; IPPP/11/80; DCPT/11/160

WISPy Cold Dark Matter

Paola Arias[a,b] Davide Cadamuro[c] Mark Goodsell[a,d] Joerg Jaeckel[e] Javier Redondo[c] Andreas Ringwald[a]

arXiv:1201.5902v1 [hep-ph]



What theory tells on WISPs: summary

- A low energy frontier with a zoo of WISPs could be there.
- String theory inspired extensions of the standard model expect hidden photons and axion-like particles.
- WISPs could provide solutions to questions like
  - What is the origin of CP conservation in QCD?
  - What are the constituents of dark matter?
- However, there are many theories on the market.
- Are there any observations hinting at WISP physics?

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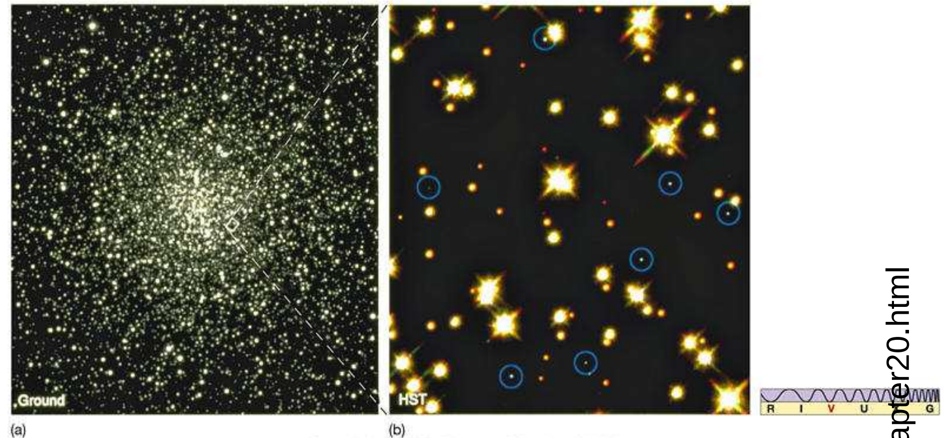
Open questions: white dwarfs

> White dwarfs

- Old burned-out stars.
- Final stage of 97% of all stars.
- Mass < 1.4 M_{sun}
- Thermally cooling down to black dwarfs (takes longer than the age of the Universe).



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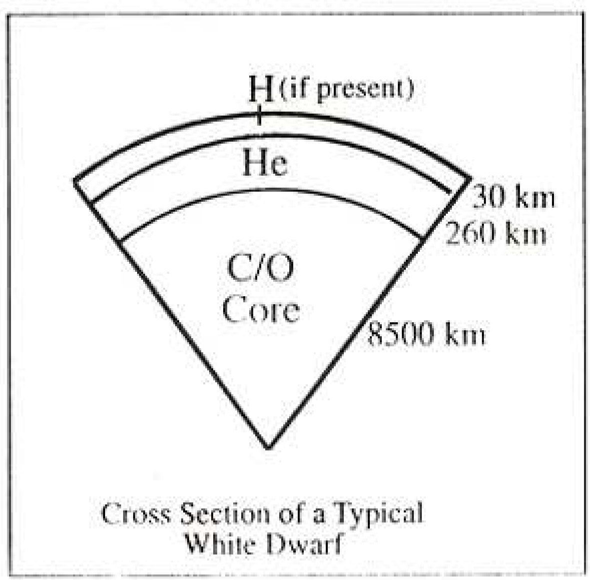
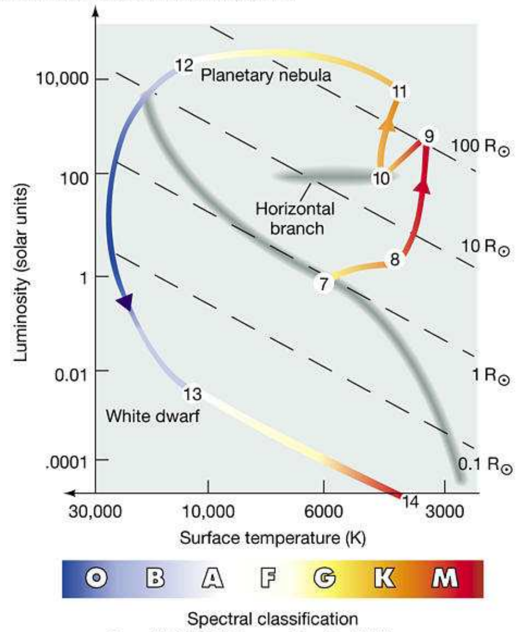
> Most simple star one could think of!

- Composition
- Physics

http://universe-review.ca/I08-25-whitedwarf.jpg





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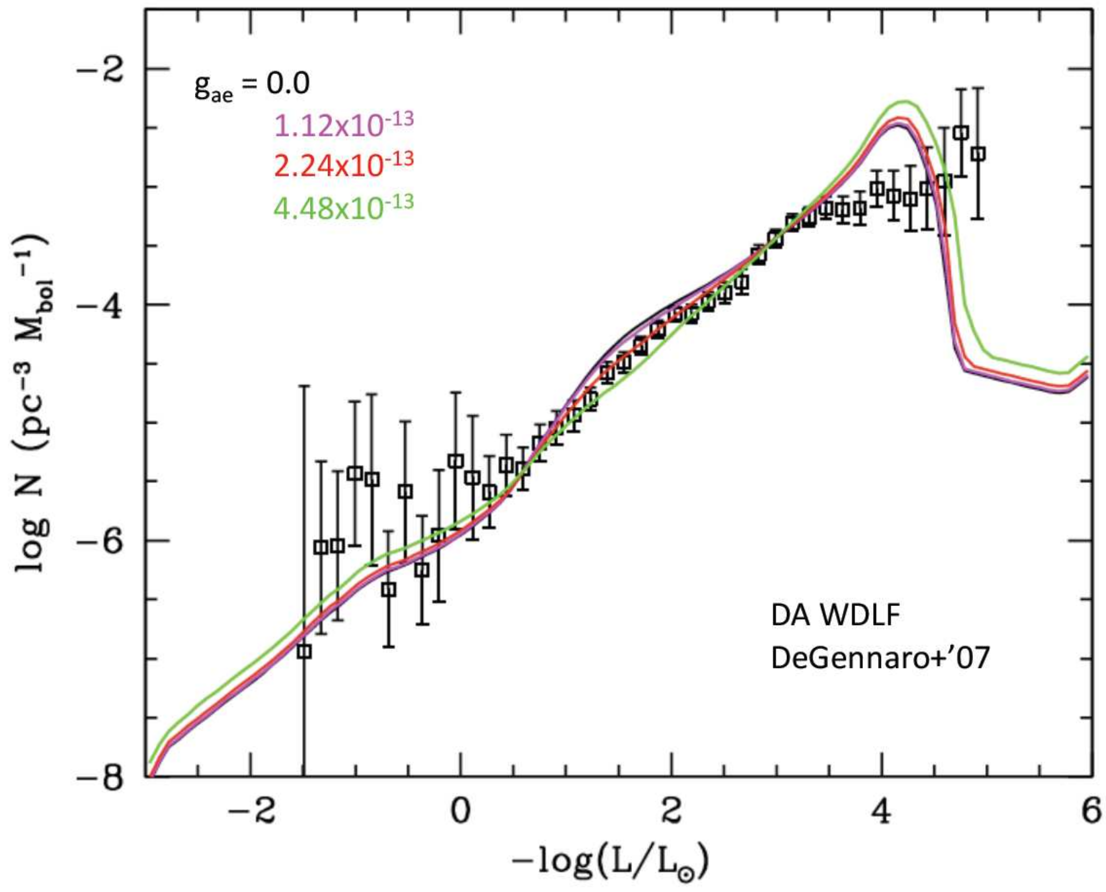
http://physics.uoregon.edu/~jimbrau/astr122/Notes/Chapter20.html

Open questions: white dwarfs

- White dwarfs cool too fast!
  - Observed in individual cases.
  - Seen in samples.
- Is there an unknown energy loss channel at work?
  - Emission of axions?

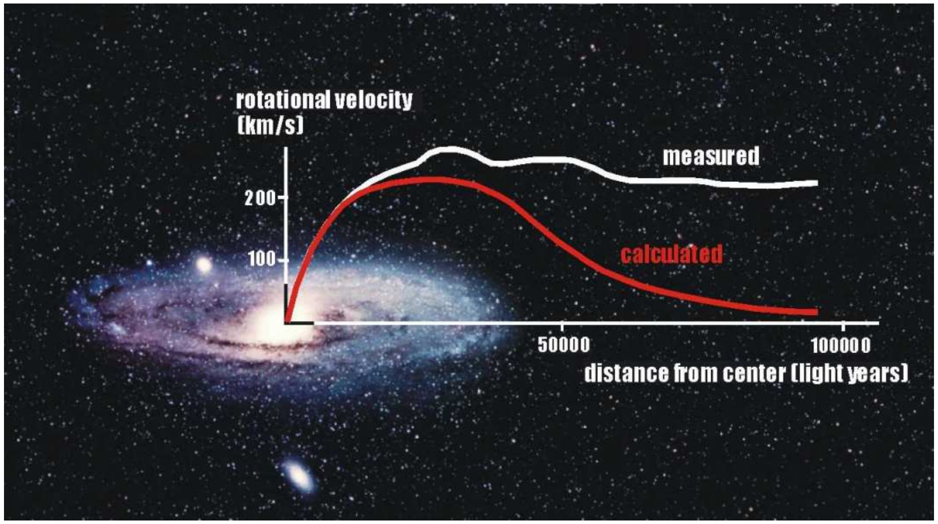
… Naturally, the uncertainties that still remain, both observational and theoretical, still prevent to claim the existence of such interaction. A systematic analysis aimed to discard any possible conventional solution is under way …



White dwarfs as physical laboratories: the axion case (J. Isern), 7th Patras Workshop on Axions, WIMPs and WISPs, http://axion-wimp.desy.de, see http://arxiv.org/abs/arXiv:1204.3565

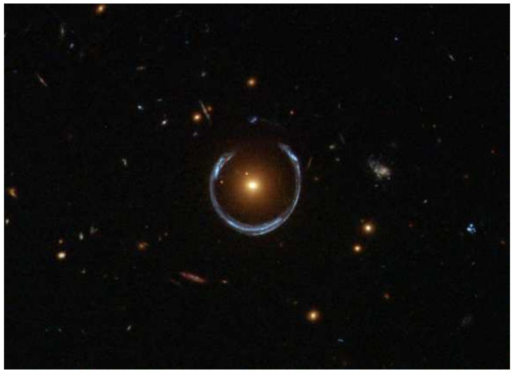
Open questions: dark matter

- Dark matter seems to dominate the dynamics of galaxies and clusters of galaxies.
  - Rotation curves of galaxies



http://cdms.phy.queensu.ca/Public_Docs/Pictures/Rotationcurve_3.jpg

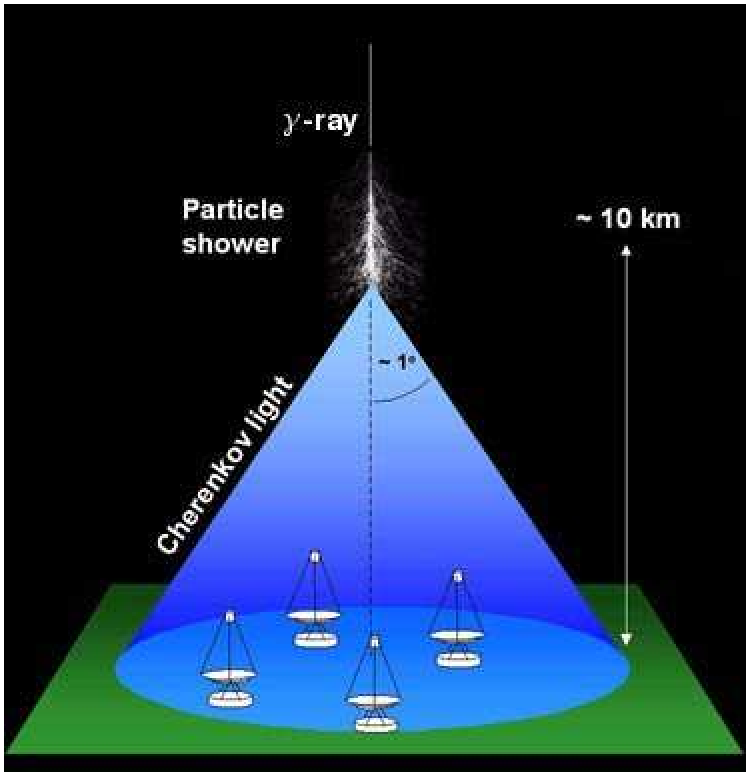
  - Gravitational lensing

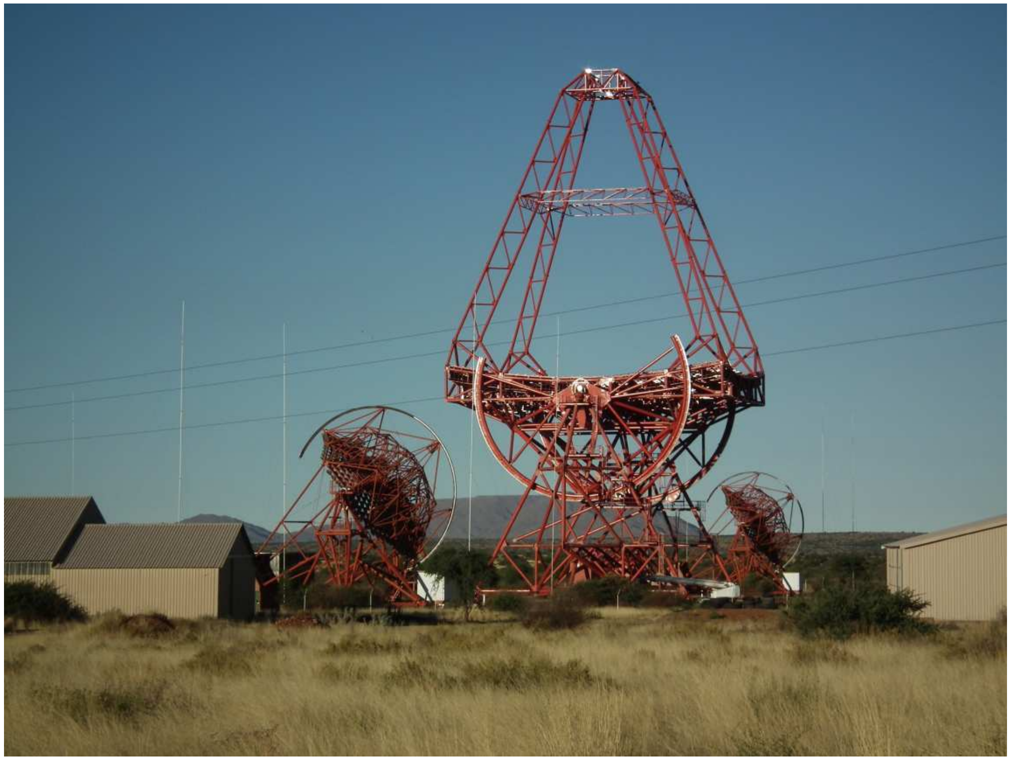


http://apod.nasa.gov/apod/ap111221.html

Open questions: TeV γ propagation

TeV photons from active galactic nuclei at cosmological distances are detected by Imaging Air Cherenkov Telescopes (IACTs).





http://www.dur.ac.uk/~dph0www4/ground.php

http://www.mpi-hd.mpg.de/hfm/HESS

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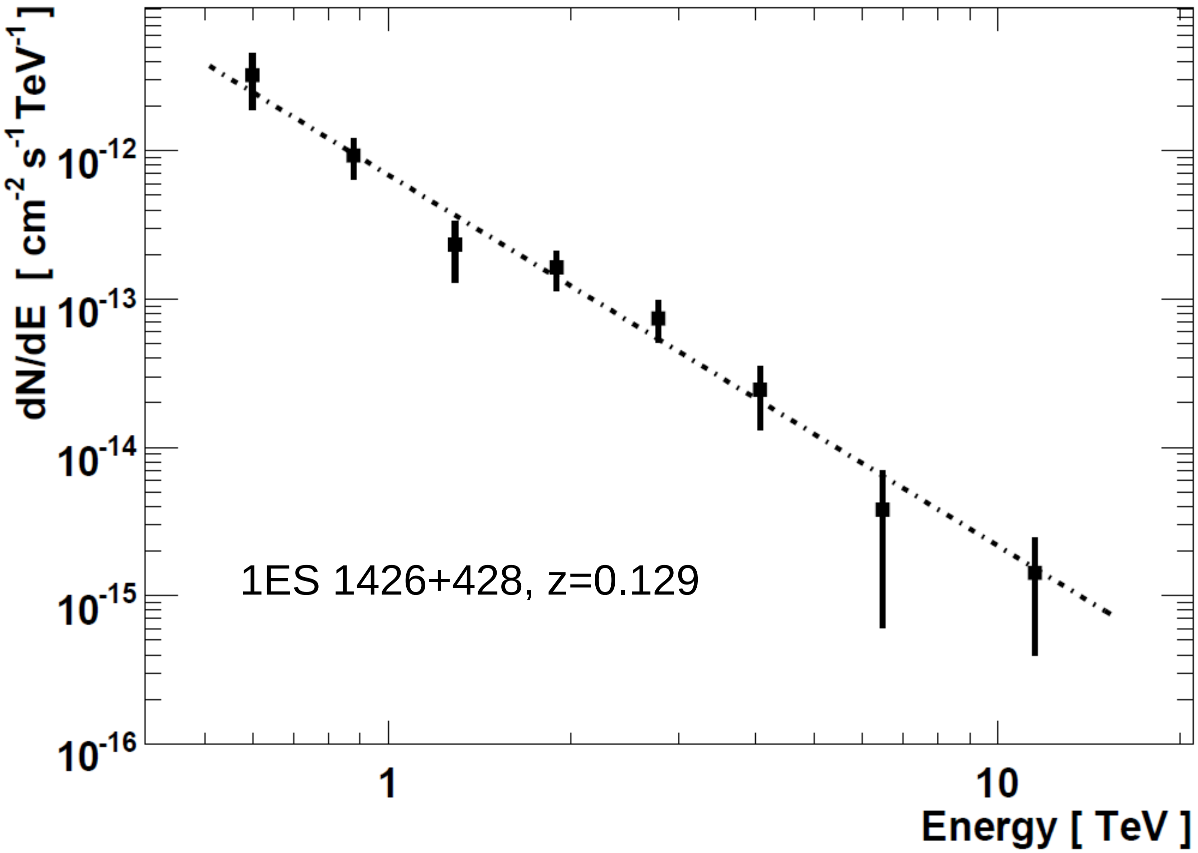


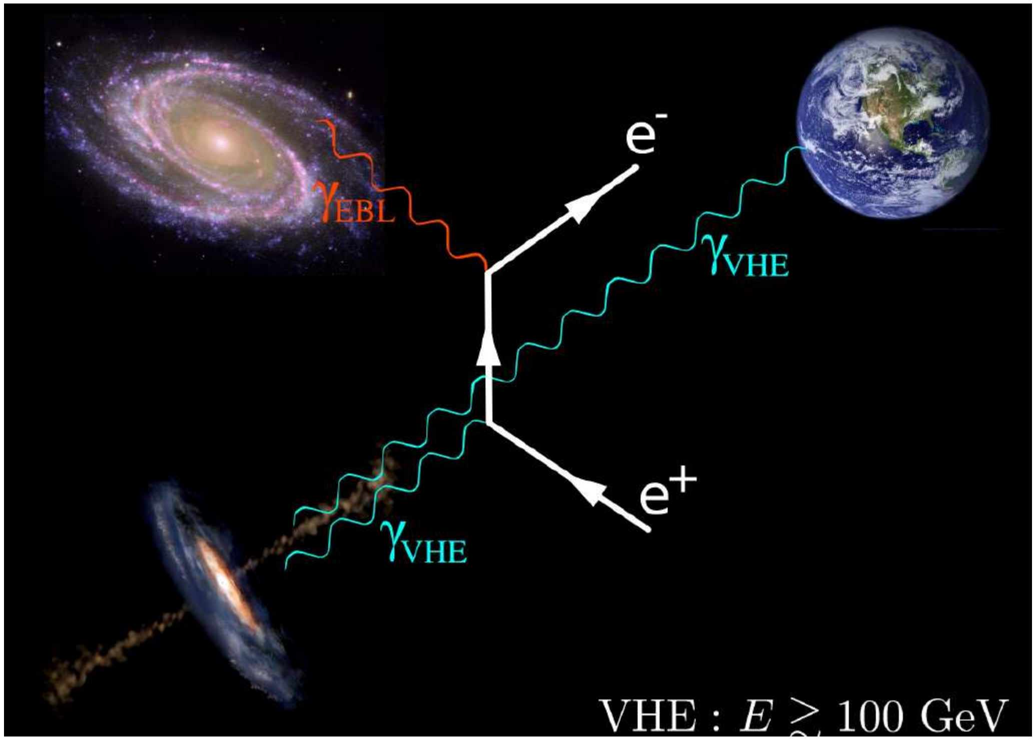
A&A, 475, L9, 2007,
arXiv:0709.4584v1 [astro-ph]

Open questions: TeV γ propagation

TeV photons should be absorbed by e^+e^- pair production due to interaction with the extragalactic background light (EBL):

$\gamma_{TeV} + \gamma_{eV} \rightarrow e^+ + e^-$

M. Meyer, 7th Patras Workshop on Axions, WIMPs and WISPs, 2011



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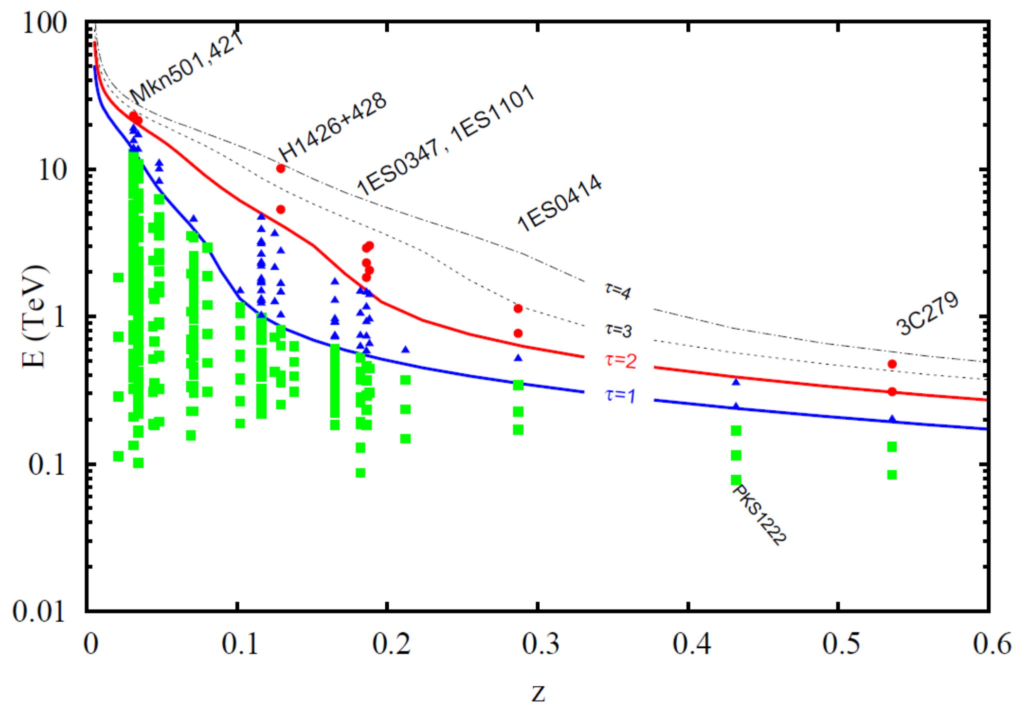
However, the TeV spectra of distant galaxies extend deep into the optical thick regions.

An effect with more than 4 σ ?

Systematics discussed include

- source effects,
- energy calibration
- extra galactic background light.

D. Horns, M. Meyer, JCAP 1202 (2012) 033



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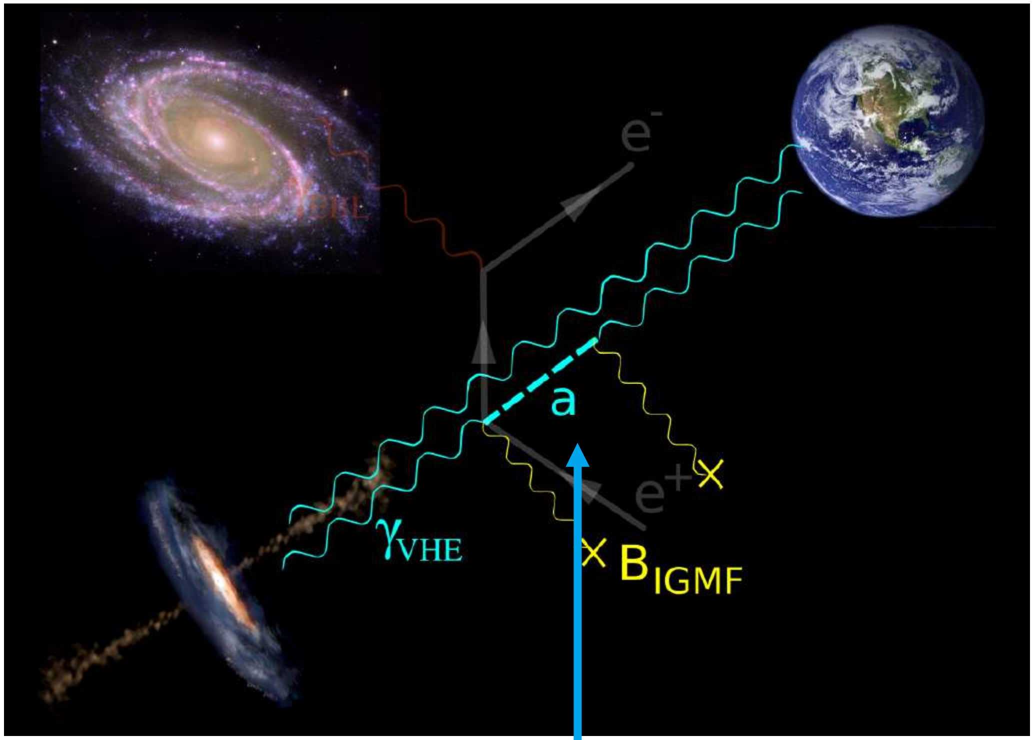
Is a new particle involved?

A Weakly Interacting Slim Particle, a WISP?

M. Meyer, 7th Patras Workshop on Axions, WIMPs and WISPs, 2011



TeV photons may “hide”

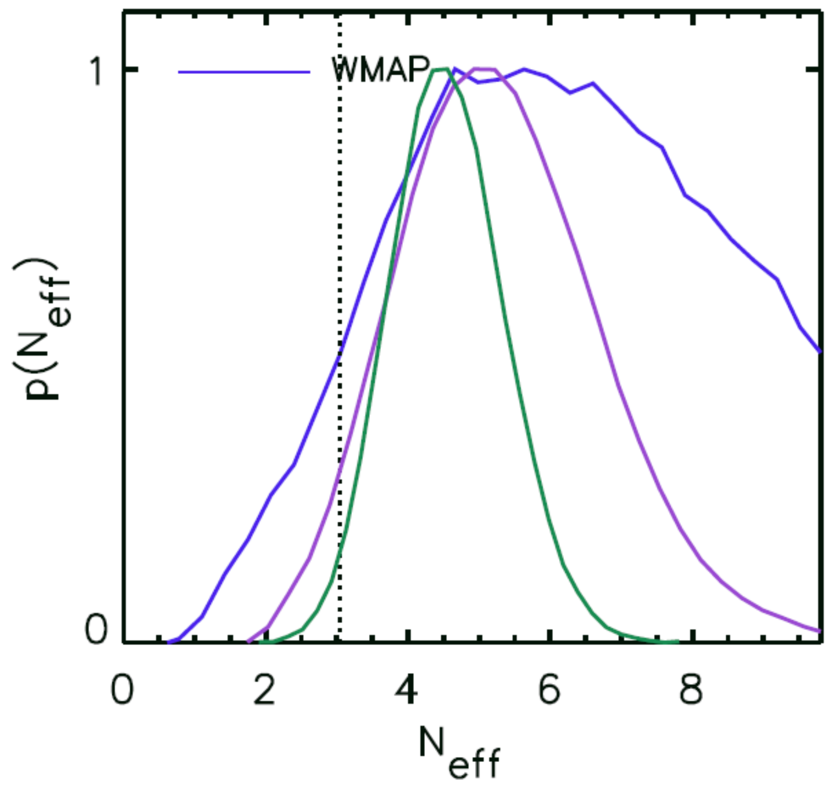
Open questions: CMBR analysis

The WMAP-7, ACT and other data find for the number of relativistic species:

$N_\nu = 4.56 \pm 0.75$

(expected from SM physics: 3.04)

This could indicate a new neutrino
(not considering the significance for a moment)
but could equally well hint at
a WIPSy hidden sector photon.

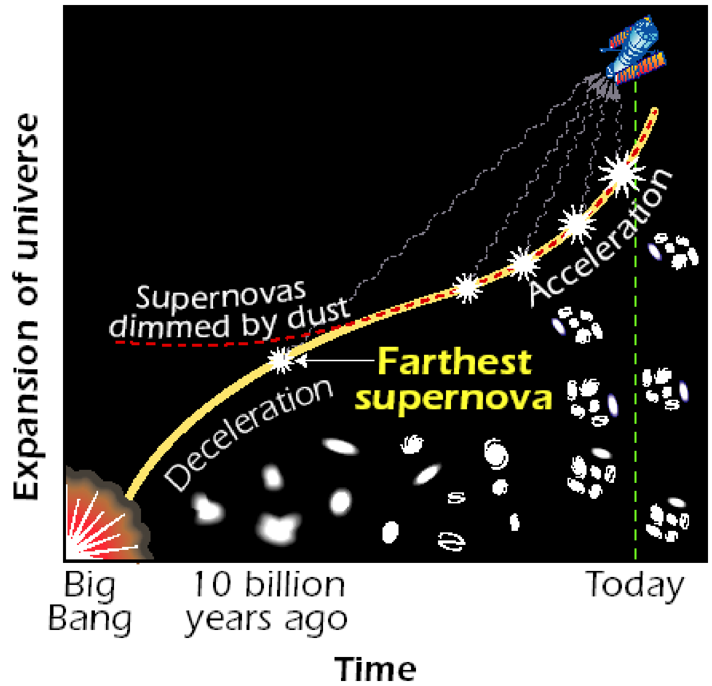


arXiv:1009.0866v1 [astro-ph.CO]

Open questions: dark energy

- Dark energy drives the Universe apart.

- It might be attributed to a new kind of scalar field corresponding to very light particles.



The cosmological constant problem, *S. Weinberg*, Rev. Mod. Phys. 61, 1–23 (1989)	ute to the effective cosmological constant. In order to keep $\rho_V < 10^{-48}$ GeV^4, we need the scalar field adjustment to cancel the effect of gravitational and electromagnetic field fluctuations down to frequencies 10^{-12} GeV; for this purpose we must have $m_\phi < 10^{-12}$ GeV. A field this light will have a macroscopic range: $\hbar/m_\phi c \gtrsim 0.01$ cm.

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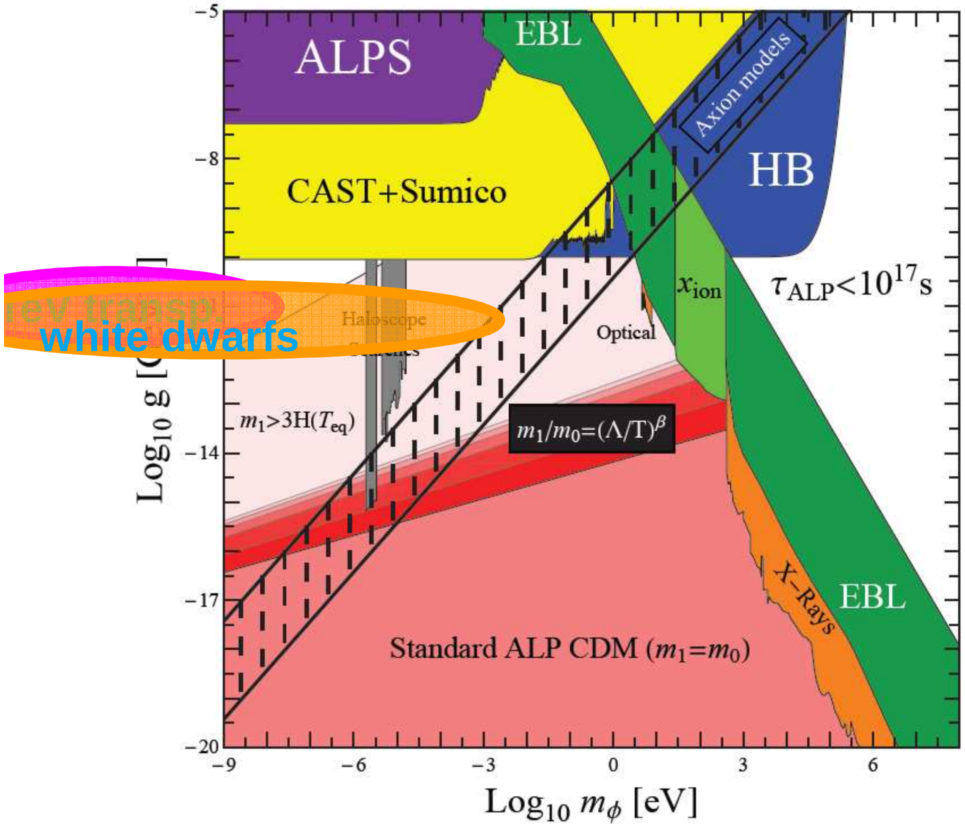
A new particle habitat (1) ?

- Probably (some / most of ?) the “open question” phenomena point at physics beyond the standard model.
- There could be a hidden sector of very Weakly Interacting Slim Particles (WISPs).
- Single WISPs could explain different phenomena:

Phenomenon	WISPy explanation	WIMPy explanation
Solar phenomena	Chameleon, ALP	
White dwarf cooling	Axion, ALP	
TeV transparency	ALP	
CMBR neutrino number	HP, Chameleon (?)	
Dark matter	Axion, ALP, HP	yes
Dark energy	Chameleon	

- Is there a consistent picture?

The big picture: axion-like particles



PREPARED FOR SUBMISSION TO JCAP
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WISPy Cold Dark Matter

Paola Arias[a,b] Davide Cadamuro[c] Mark Goodsell[a,d] Joerg Jaeckel[e] Javier Redondo[c] Andreas Ringwald[a]

arXiv:1201.5902v1 [hep-ph]

With one ALP one could explain dark matter, the TeV photon transparency and the white dwarf energy loss phenomenon!

A new particle habitat (2) ?

- Some WISPs (axion-like particles or chameleons) could solve different phenomena in one go!

- Although a sound proof for WISPs is still missing …
  - but may come soon with PLANCK data, white dwarf cooling or the TeV photon transparency of the universe …
- … there is sufficient interest to think of experiments **directly** searching for WISPs.

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Experimental WISP searches

WISPs masses below ≈ 1 MeV

- Hidden photons don't decay into electron/positron pairs.
  - Hardly any access in collider or beam dump experiments.
- Coupling of the QCD axion to standard model particles too low to utilize collider or beam dump experiments
(the "invisible axion").
- Need a new technique for particle physics at the low energy frontier!
  - This presentation!

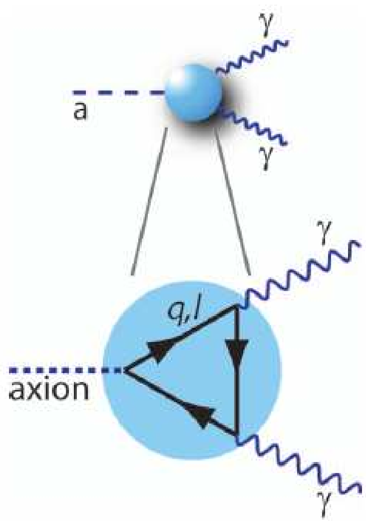
WISPs masses above ≈ 1 MeV

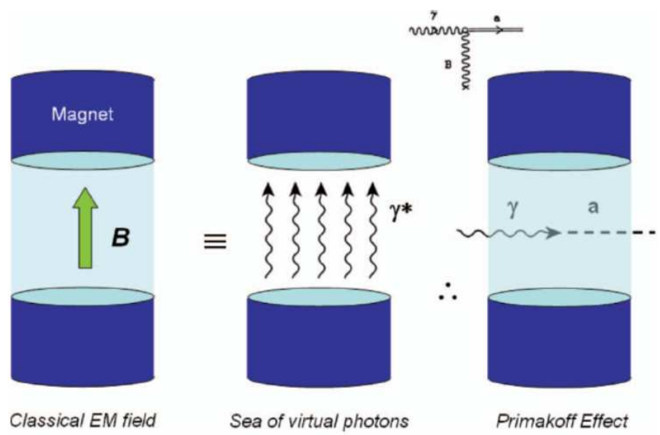
- Hidden photons could decay into electron/positron pairs.
  - Possibility to search for HPs in beam dump experiments.
- Coupling of the QCD axion to standard model particles large enough to allow for sensible searches at collider or beam dump experiments.
- Ongoing experiments and plans for new ones.
  - Not covered here

Seeing the "invisible": Primakoff effect

- Axion and axion-like particles (ALPs): exploit the coupling to photons.
  - photon + photon ↔ ALP
    photon + ALP → photon
  - photon + (virtual photon) → ALP
    ALP + (virtual photon) → photon

    A virtual photon can be provided by an electromagnetic field.

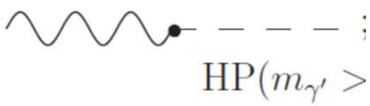




The Search for Axions,
Carosi, van Bibber, Pivovaroff,
Contemp. Phys. 49, No. 4, 2008

Seeing "invisible" WISPs

- Neutral scalar or pseudoscalar WISPs: exploit the Primakoff effect
- Neutral vectorbosons ("hidden sector photons" HP):
  exploit mixing with "ordinary" photons.



Seeing “invisible” WISPs

- Neutral scalar or pseudoscalar WISPs: exploit the Primakoff effect
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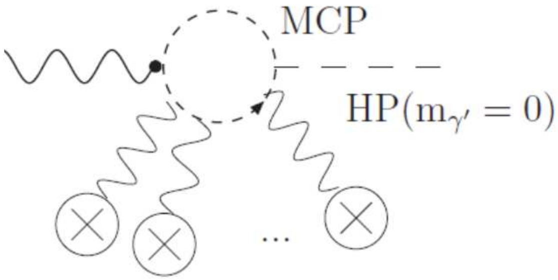

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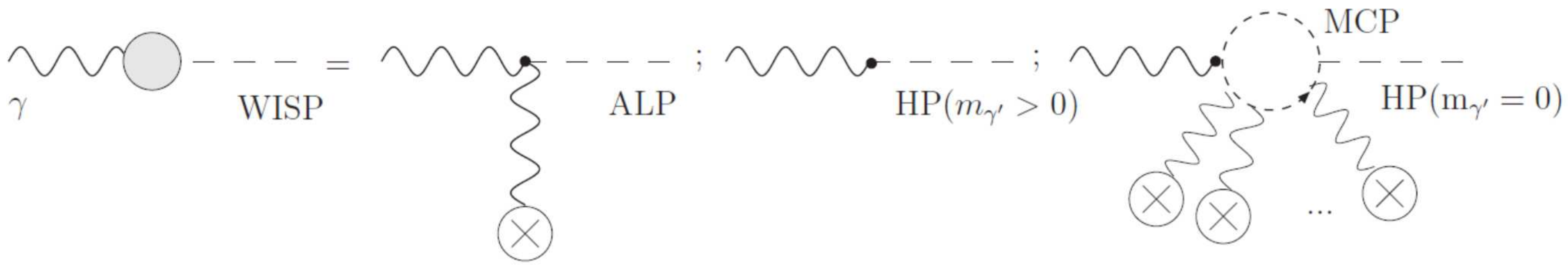


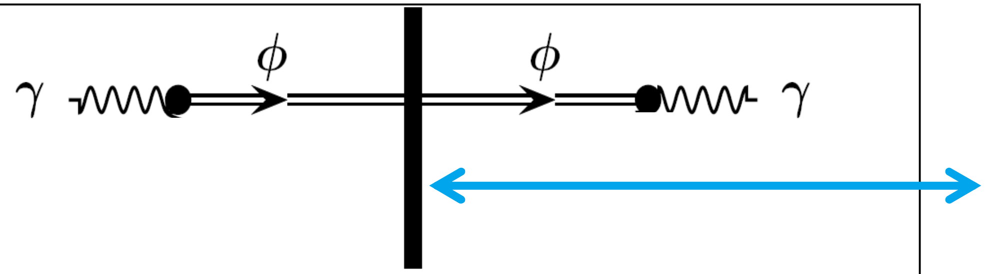
Axion-Like Particles, Hidden Photons, MiniCharged Particles

- Most experiments: exploit the coupling of WISPs to photons. Photon beams usually provide a very “clean” environment.

Shining WISPs through walls

- Basic idea: due to their very weak interaction WISPs may traverse any wall opaque to Standard Model constituents (except ν and gravitons).
  - WISP could transfer energy out of a shielded environment
  - WISP could convert back into detectable photons behind a shielding.

"Shining-through-a-wall"



Okun 1982, Skivie 1983, Ansel'm 1985, Van Bibber et al. 1987

steel wall, cryostat,
earth's atmosphere,
stellar body,
intergalactic background light,
….

Basics of most direct WISP searches

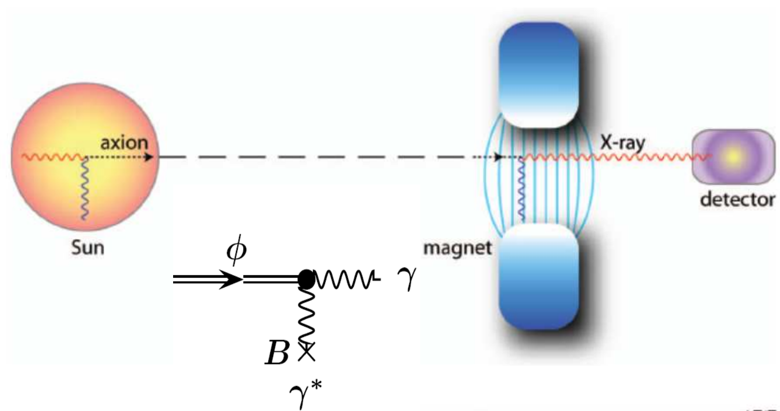
- Exploit the coupling of WISPs to photons.
  - Do strong sources like the sun or intense laser beams create WISPs?
  - Do WISPs create light in an otherwise dark environment?
  - Do WISPs induce oscillation or light polarization effects?
- Look for energy leaking through a very well shielded environment.
  - Dark closed box in the laboratory.
  - The earth atmosphere (X-rays from the sun)
  - Stellar bodies (sun, white dwarfs)
  - The intergalactic space (TeV photon transparency)
- Three possibilities:
  - Indirect: some energy seems to leave a shielded environment.
  - Indirect: phenomena like oscillation patterns, light polarization effects.
  - Direct: energy (photons) appears in a shielded environment.

Direct WISP searches

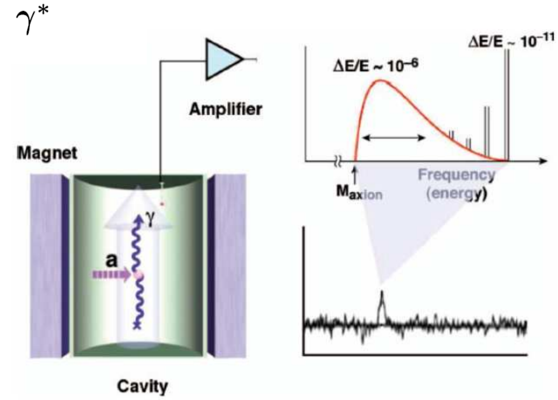
Use three kinds of (possible) WISP sources:

1. Make the WISPs yourself in the laboratory:
   Offers full control on production and detection of WISPs;
   no excuses for theory!

2. The sun as a strong natural WISP emitter: helioscopes.



3. Ambient dark matter WISPs: haloscopes.



The Search for Axions, Carosi, van Bibber, Pivovaroff, Contemp. Phys. 49, No. 4, 2008

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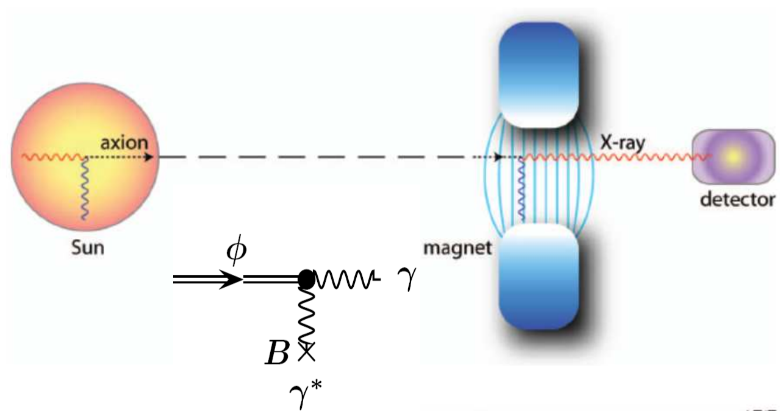

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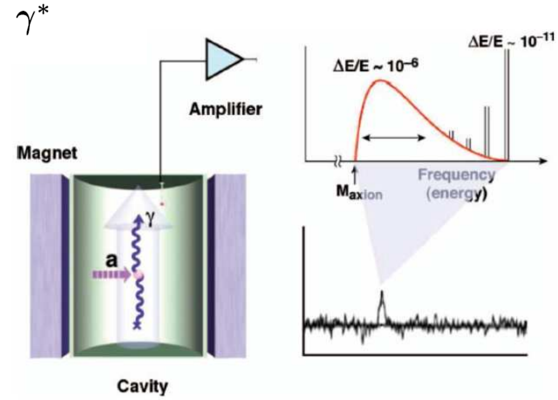


Theoretical uncertainty

"Invisible" WISPs in the laboratory

"Light-shining-through-a-wall" (LSW)

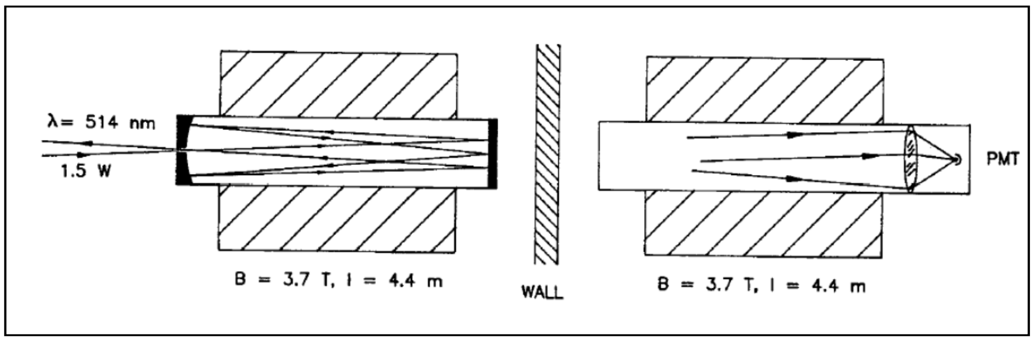
For ALPs:

P(B field) / P(beam dump) = $10^6 \cdot (mm/\lambda_{abs}) \cdot (B/T)^2 \cdot (L/m)^2$

Okun 1982, Sikivie 1983, Ansel'm 1985, Van Bibber et al. 1987

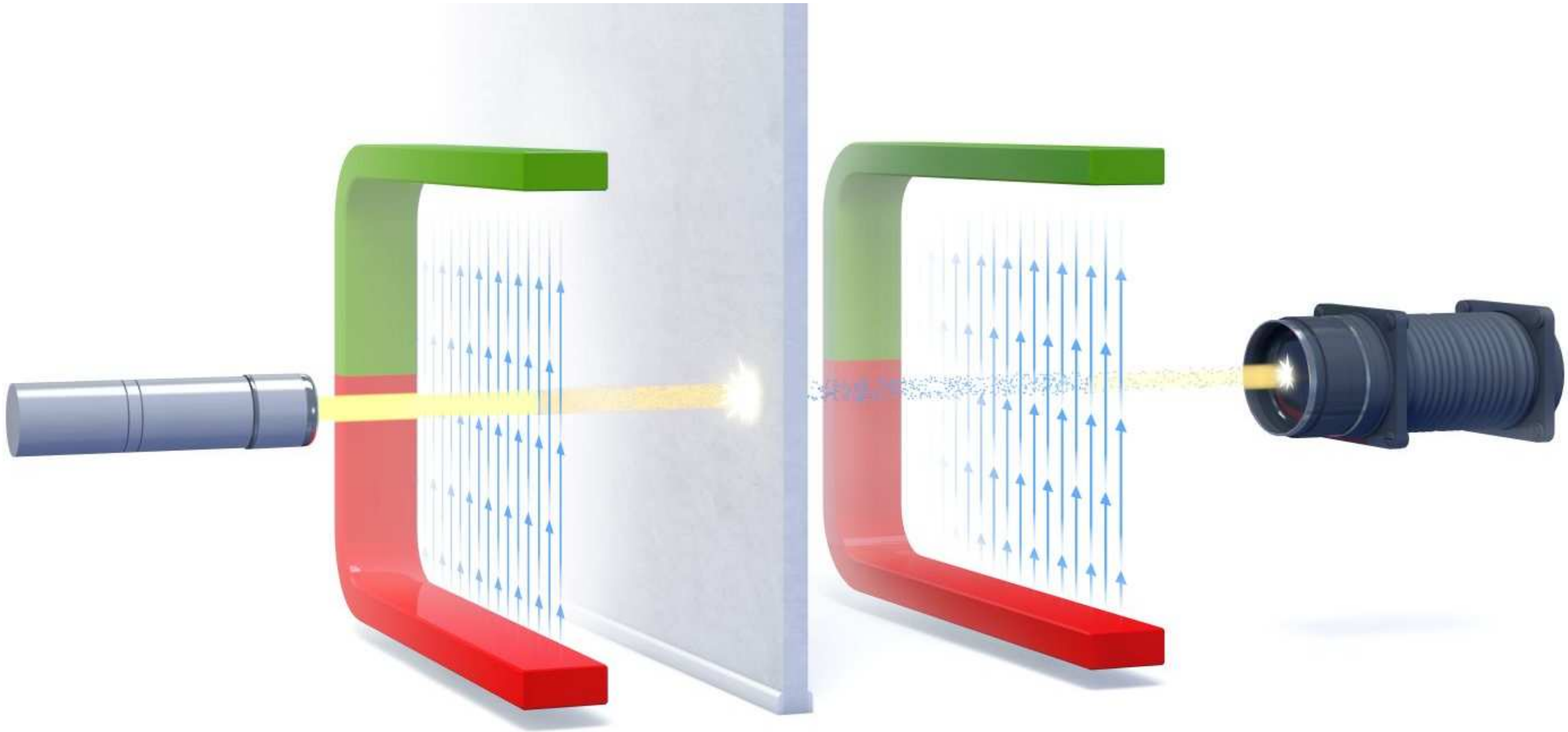
(A. Ringwald, J. Redondo, arXiv:1011.3741v1 [hep-ph])

Note:
$P_{\gamma\to\Phi\to\gamma} \sim (BLg)^4$



G. Ruoso et al.
(BFRT Experiment),
Z. Phys. C 56 (1992) 505

Light-shining-through-a-wall



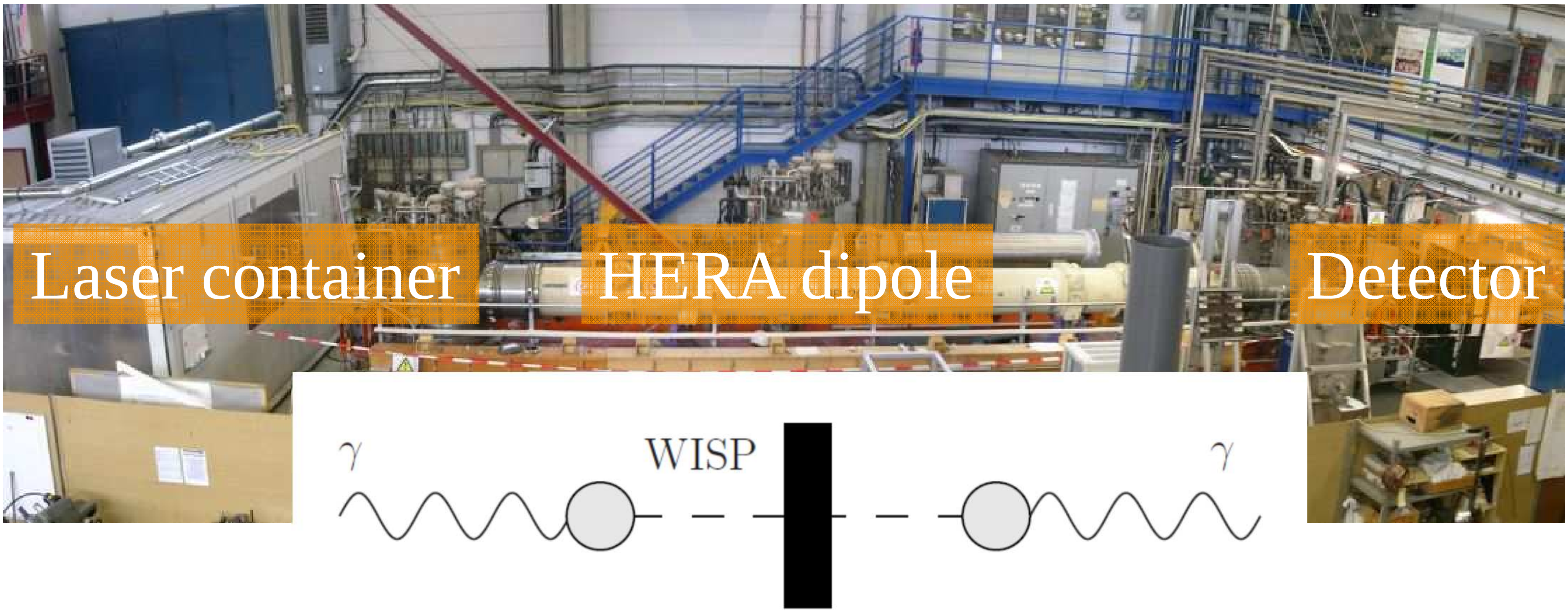
A selection of WISP experiments

- Light-shining-through-a-wall in the laboratory
  - ALPS at DESY
  - OSQAR at CERN
  - REAPR in the US
  - First results using microwaves
- Helioscopes searching for WISPs from the sun
  - TSHIPS at Hamburg
  - CAST at CERN
  - The IAXO proposal
- Haloscopes searching for axionic dark matter
  - ADMX in the US
  - Next steps searching for axionic dark matter: Tore Supra?
- Crazy stuff

ALPS @ DESY in Hamburg

The ALPS Experiment

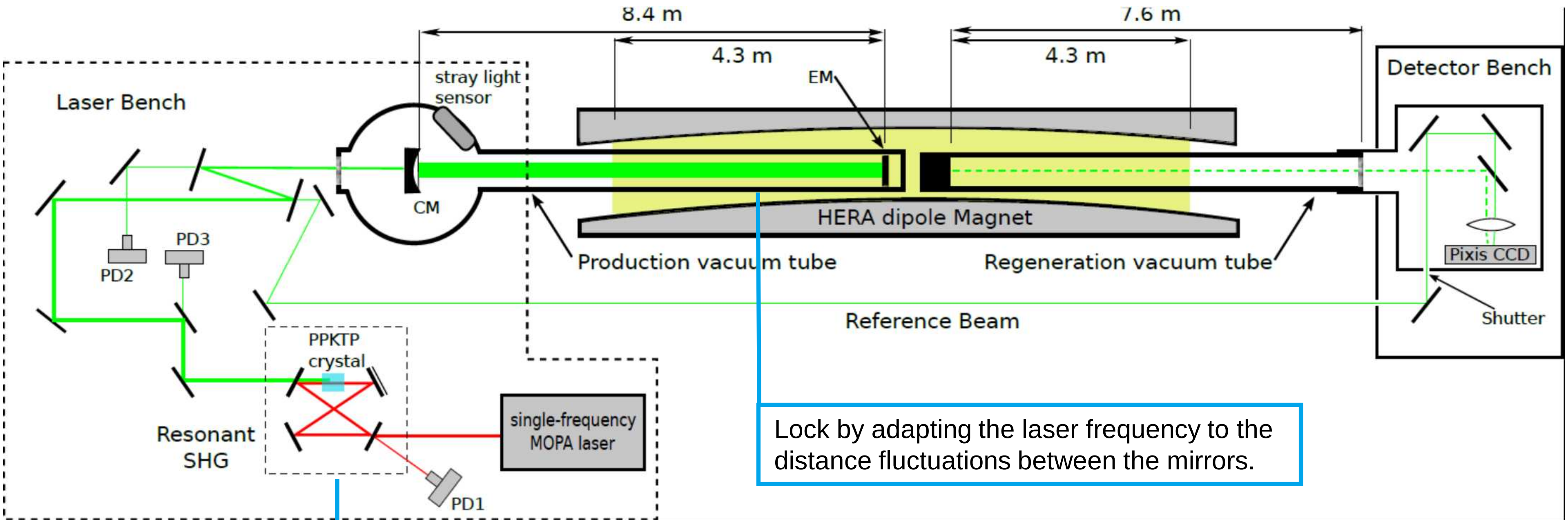
Any Light Particle Search @ DESY: ALPS-I concluded in 2010



"Light-shining-through-a-wall" (LSW)

The ALPS-I experiment

- New: realize an optical resonator inside the HERA dipole!



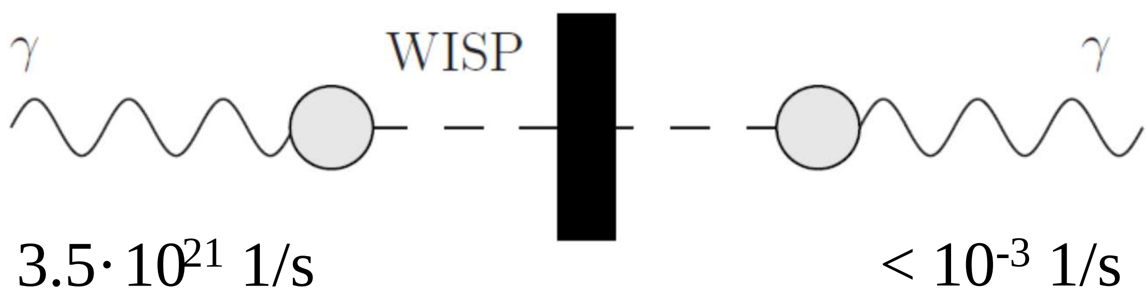
Lock by adapting the distance between the mirrors to the variations of the laser frequency.

- Limitation: power density on the mirrors of ≈ 50 kW/cm^2 (532 nm).

ALPS-I results

(PLB Vol. 689 (2010), 149, or http://arxiv.org/abs/1004.1313)

> Unfortunately, no light was shining through the wall!



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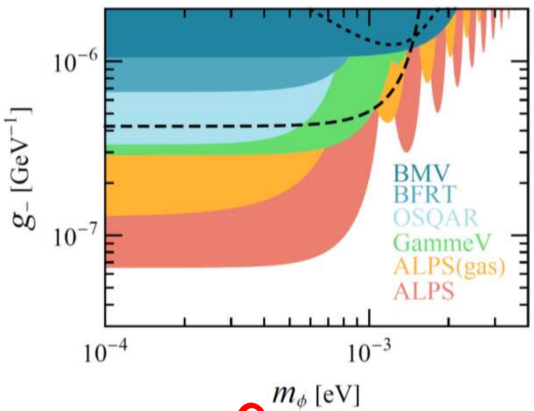
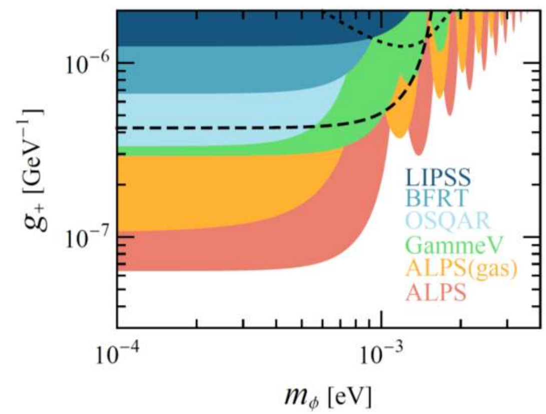
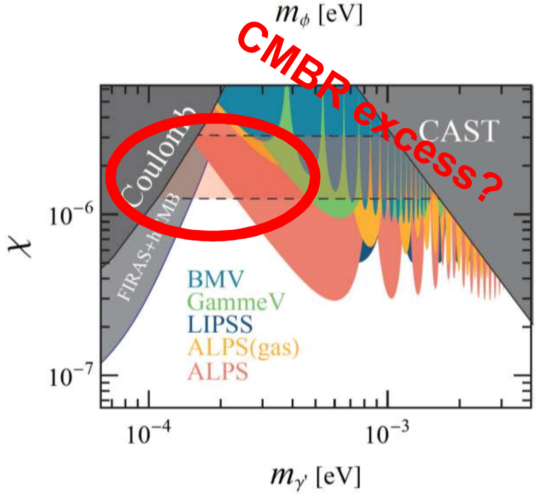


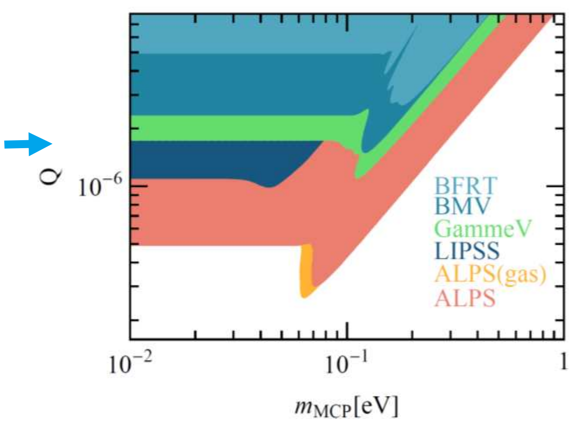
pseudoscalar
and
scalar
axion-like particles





hidden sector photons
and
minicharged particles

Filling a gap remaining from astrophysics and other experiments!



PLB 689 (2010), 149

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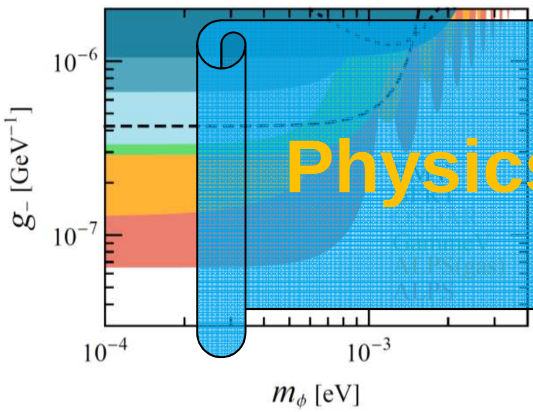

pseudoscalar
and
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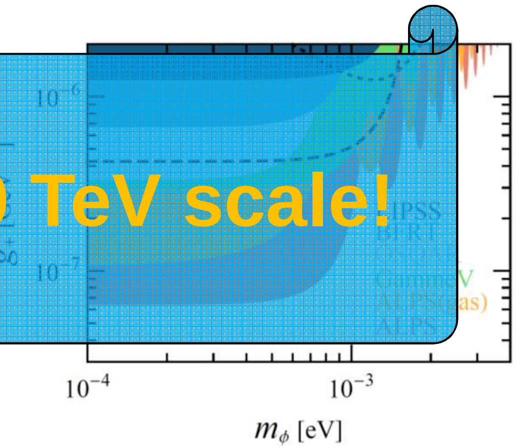
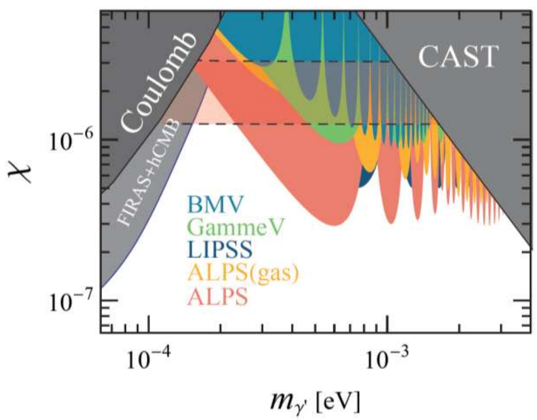
Physics at the multi 10 TeV scale!





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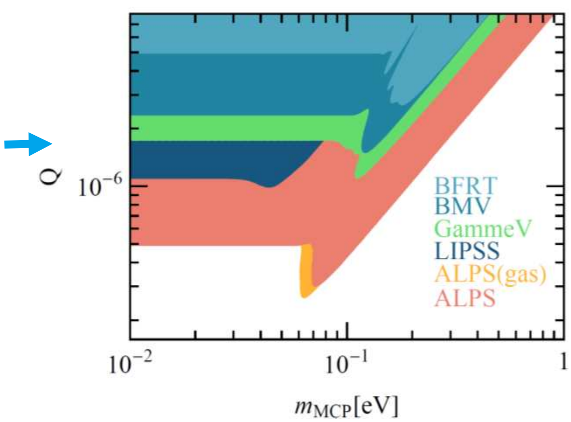


PLB 689 (2010), 149

Prospects for ALPS-II @ DESY

- Laser with optical cavity to recycle laser power, switch from 532 nm to 1064 nm, increase effective power from 1 to 150 kW.
- Magnet:
  upgrade to 12+12 straightened HERA dipoles instead of ½+½ used for ALPS-I.
- Regeneration cavity to increase WISP-photon conversions, single photon counter (superconducting transition edge sensor?).

All set up in a clean environment!

The ALPS-II reach

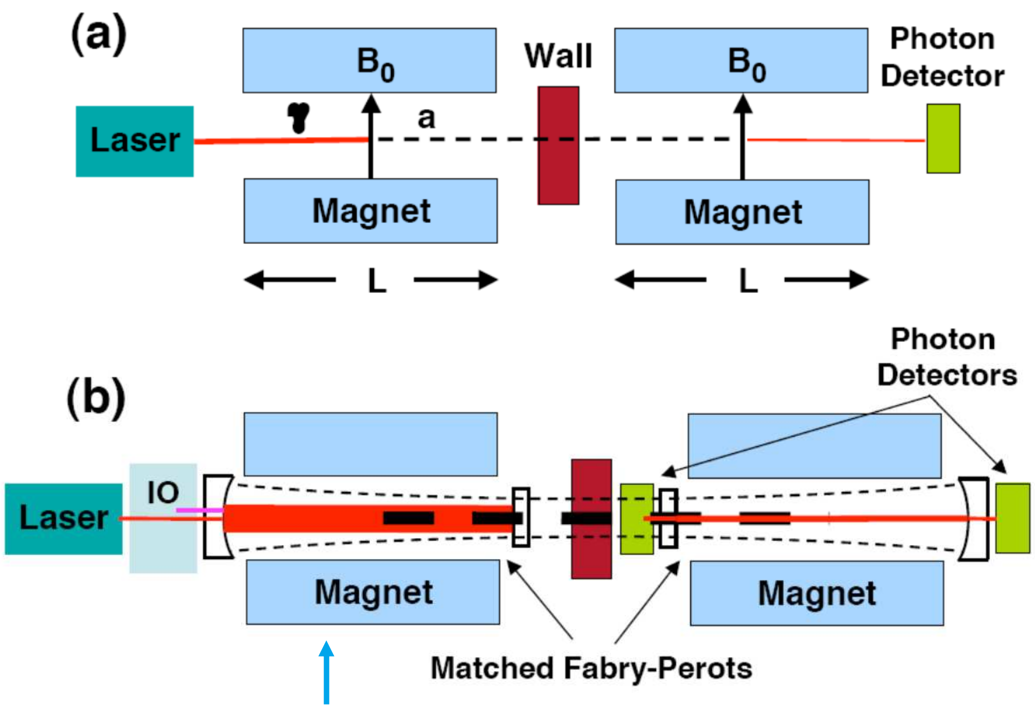
Parameter	Achieved at ALPS-I	Aimed for at ALPS-II	Sensitivity to ALP coupling g	Sensitivity gain compared to ALPS-I
Effective Laser power LP	1 kW	150 kW	$g \sim LP^{-1/4}$	3.5
Rel. photon number flux n	1 (532nm)	2 (1064 nm)	$g \sim n^{-1/4}$	1.2
Magnetic length BL	0.5+0.5 HERA dipole	12+12 HERA dipoles	$g \sim 1/BL$	24.0
Detector Efficiency QE	0.9	0.9	$g \sim QE^{-1/4}$	1.0
Detector Noise DC	[illegible]	[illegible]	[illegible]	[illegible]
Power built-up in a regeneration cavity PB	[illegible]	[illegible]	[illegible]	14.1
Total for ALP searches				**2,500**
Total for HP searches				100

Three oders of magnitude in the ALP coupling constant!

The ALPS-II preparations

> Done in 2011:

- New 20 m long cleanroom laser laboratory ready for use in HERA-West.
- First tests towards the new optical system.
  Implementation of a second cavity in the regeneration part of the experiment to enhance the conversion probability WISP→ photon.



Realized at ALPS-I

"Resonantly enhanced Axion-Photon Regeneration"
P. Sikivie, D.B. Tanner , Karl van Bibber. *Phys.Rev.Lett.98:172002,2007.*

(also F. Hoogeveen, T. Ziegenhagen, DESY-90-165, Nucl.Phys.B358)

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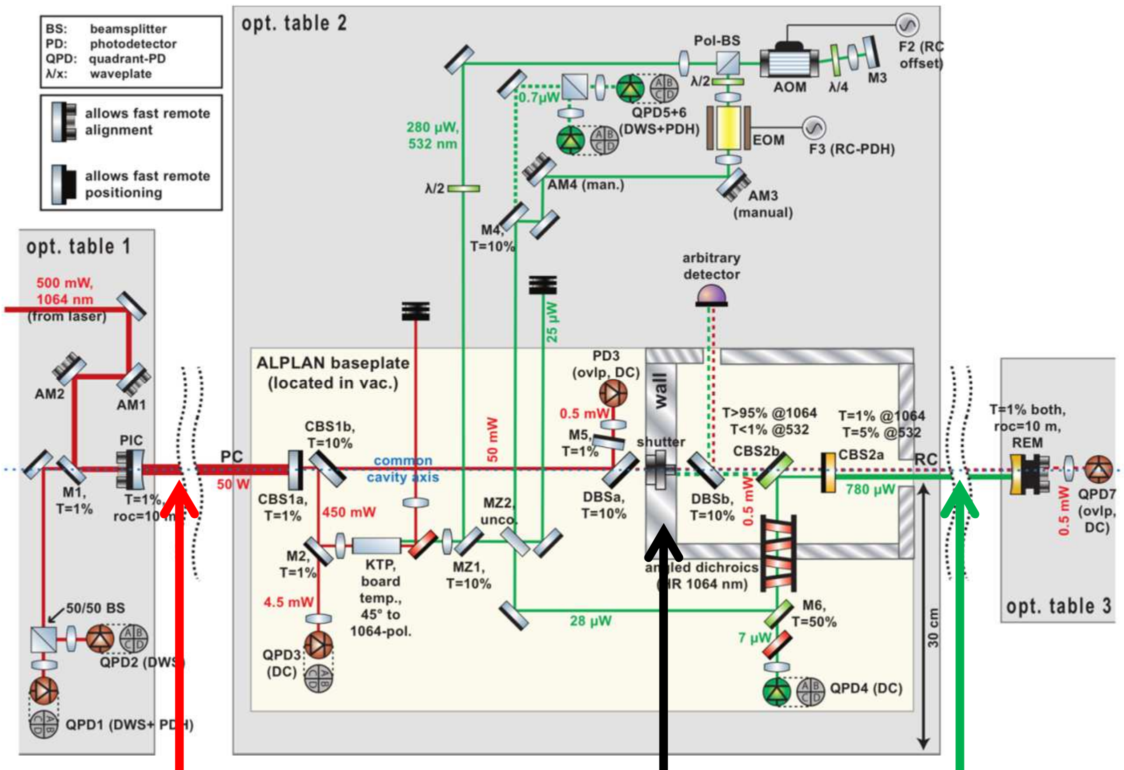


Production cavity, infrared

Wall

Regeneraton cavity, locked with green light.

The ALPS-II preparations

> Done in 2011:

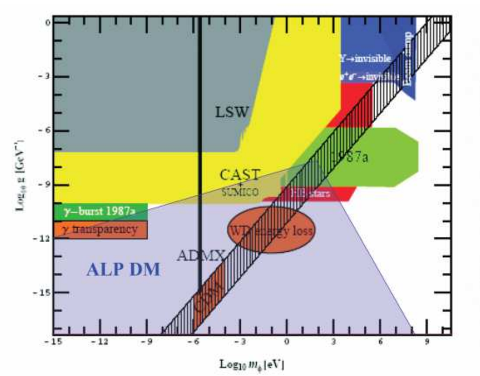
- New 20 m long cleanroom laser laboratory ready for use in HERA-West.
- First tests towards the new optical system.
- New partnership with Italian groups (G. Cantatore), PTB, NIST on the development of a superconducting Transition Edge Sensor.
- First successful tests to straighten HERA dipole magnets!

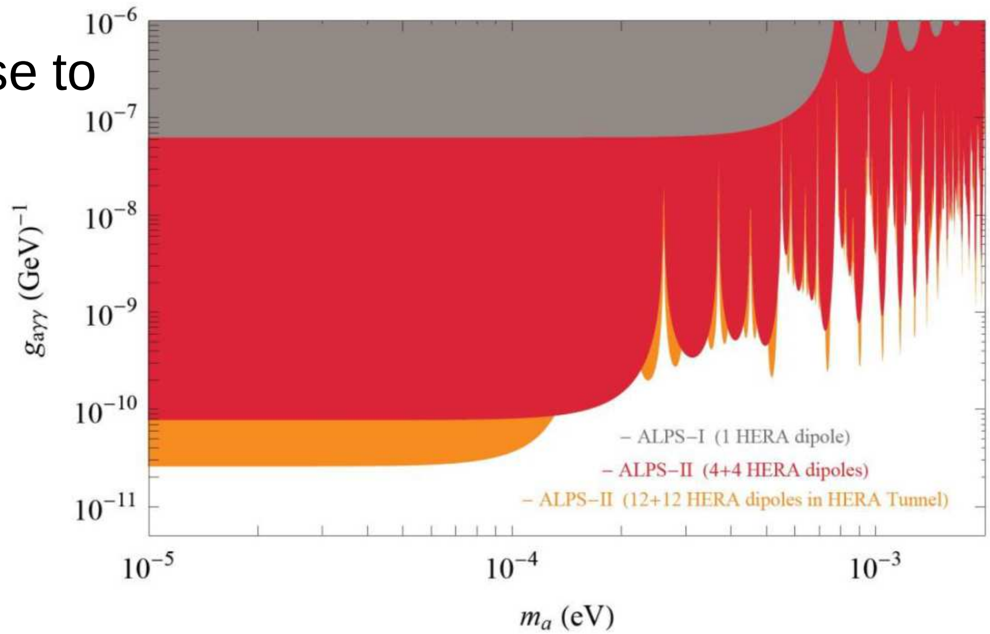
Eff. dipole aperture		Max. # of dipoles		B·L (Tm)	
		HERA	LHC	HERA	LHC
35 mm	(HERA)	2·4		187	
40 mm	(LHC)	2·6	2·4	281	514
50 mm	(HERA almost straight)	2·10		468	
55 mm	(HERA straight)	2·12		562	

HERA dipoles are competitive with LHC dipoles!

The ALPS-II potential and summary

- Goal: reaching the region close to 10^{-11} GeV^{-1} in 2017 to probe astrophysical phenomena.





- Main challenges:
  - Getting the optical system running (at present no show stopper found)
  - Getting the HERA dipoles straight (at present no show stopper found)
  - Getting a TES detector running (first success)
  - Setting up a 260 m long system (surveys under way, decision expected for 2015)

The fun of collaborating in ALPS

- DESY:
  Babette Döbrich, Jan Dreyling-Eschweiler, Klaus Ehret, Samvel Ghazaryan, Reza Hodajerdi, Friederike Januschek, Ernst-Axel Knabbe, Axel Lindner, Dieter Notz, Javier Redondo (jetzt MPI), Andreas Ringwald, Jan Eike von Seggern, Dieter Trines
- Hamburg university / observatory Bergedorf:
  Dieter Horns, Günter Wiedemann
- AEI Hannover:
  Robin Bähre, Tobias Meier, Benno Willke
- LZH Hannover / neoLASE:
  Maik Frede

Theory **Exp. Particle physics** **Accelerator physics**

ALPS

Astronomy **Astroparticle physics** **Laser physics**

Surface physics

Beyond ALPS-II

- On the longer run one could strive for an ALPS-III:
  - New dipoles based on developments for LHC energy upgrade: B = 13T, aperture 100 mm: gain in B·L by a factor of about 10
  - Increasing the cw laser power to a few MW.
  - Reach for ALP couplings down to 10^{-12} GeV^{-1}!
  - However, only light ALPs with masses below 0.1 meV could be searched for!

$$P_{\gamma\to\phi}(B,\ell,q) = \frac{1}{4}\,(g\,B\,\ell)^2\ F(q\ell) \qquad F(q\ell) = \left[\frac{\sin\left(\frac{1}{2}q\ell\right)}{\frac{1}{2}q\ell}\right]^2$$

  - Do new short pulse high power lasers offer new opportunities? If focused, they provide very strong albeit short magnetic fields.

Beyond ALPS-II

- Crucial parameters:

Experiment	Photon flux (1/s)	Photon E (eV)	B (T)	L (m)	B·L (Tm)	Mass reach (eV)
ALPS-I	$3.5 \cdot 10^{21}$	2.3	5.0	4.4	22	0.001
ALPS-II	$1 \cdot 10^{24}$	1.2	5.3	106	562	0.0002
"ALPS-III"	$3 \cdot 10^{25}$	1.2	13	400	5200	0.0001
European XFEL	$< 10^{18}$	$1 \cdot 10^{4}$	5.3	106	562	0.01
PW laser	10^{20} 1/pulse	2.3	10^{6}	10^{-5}	10	0.5

New ideas to exploit PW lasers welcome!

A selection of WISP experiments

- Light-shining-through-a-wall in the laboratory
  - ALPS at DESY (a certain emphasis will be put here)
  - OSQAR at CERN
  - REAPR in the US
  - First results using microwaves
- Helioscopes searching for WISPs from the sun
  - TSHIPS at Hamburg
  - CAST at CERN
  - The IAXO proposal
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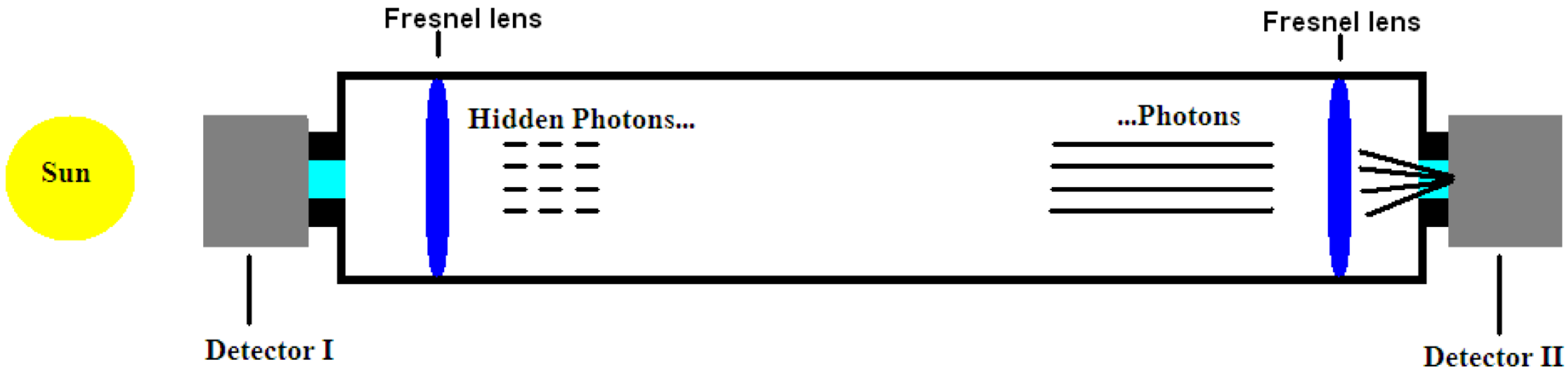
TSHIPS

Telescope for Solar Hidden Photon Search



- DESY
- Hamburger University (observatory Bergedorf)

TSHIPS-I status

- Close to start data-taking
  - 4.2 m long, 0.18 m diameter
  - Light collection by Fresnel lens
  - Cooled PM as detector
  - Attached piggyback to an existing telescope, alignment in progress
- Hope for “first light” in summer 2012.
- For more details see: http://arxiv.org/abs/1111.5797

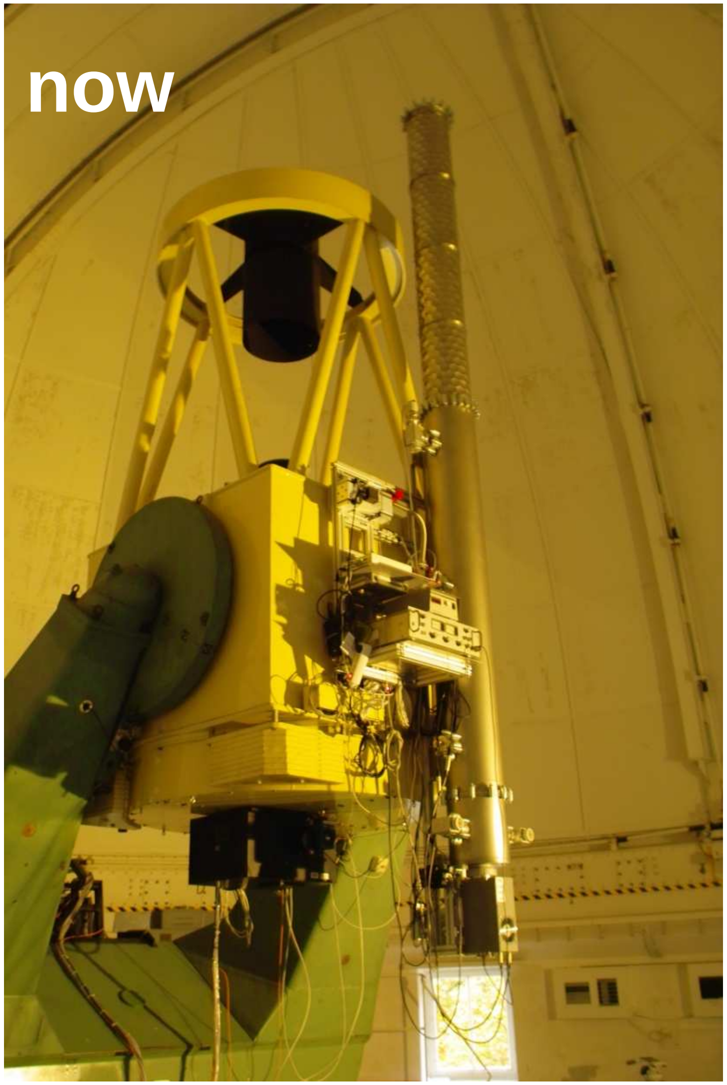
DESY 11-223; MPP-2011-139

Solar Hidden Photon Search

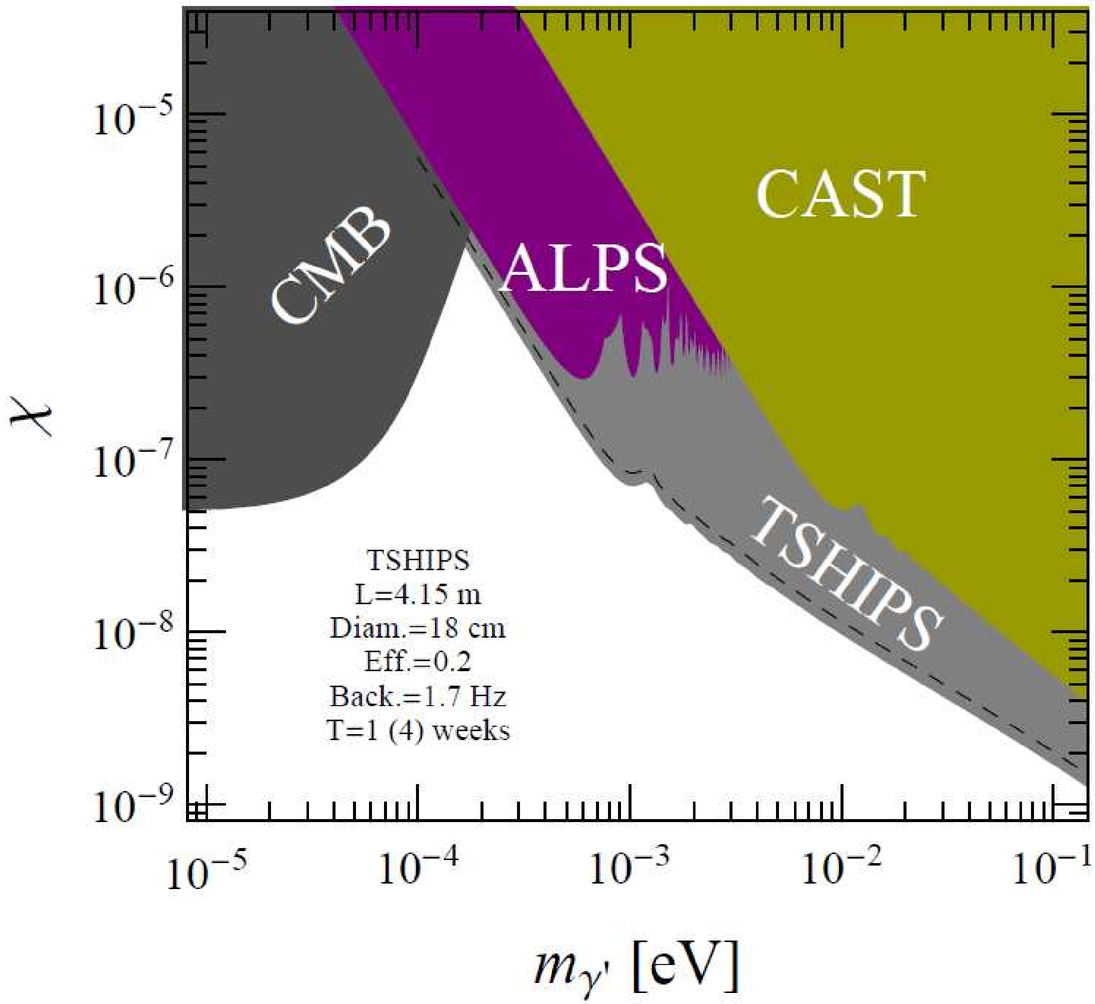
Matthias Schwarz[1], *Axel Lindner*[2], *Javier Redondo*[3], *Andreas Ringwald*[2], *Günter Wiedemann*[1]

[1]Hamburger Sternwarte, Gojenbergsweg 112, D-21029 Hamburg, Germany
[2]Deutsches Elektronen-Synchrotron DESY, Notketraße 85, D-22607 Hamburg, Germany
[3]Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 München, Germany

TSHIPS-I status



TSHIPS-I potential

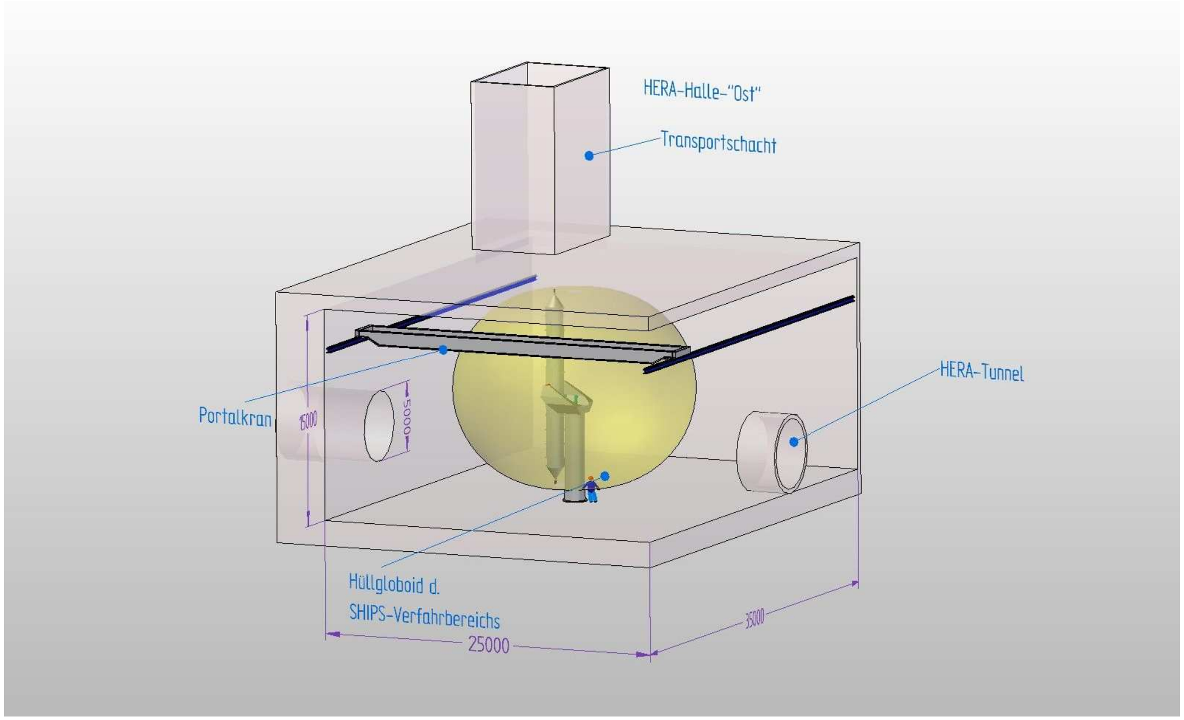


Significant improvement compared to present experimental sensitivities!

Search for hidden photons, hence no magnets required!

Future TSHIPS options

- Add 2nd detector system to allow for 24h observations of the sun to search for transient phenomena.
- Measure with CCDs for spatial resolution and higher sensitivities.
- A larger version in a HERA hall?

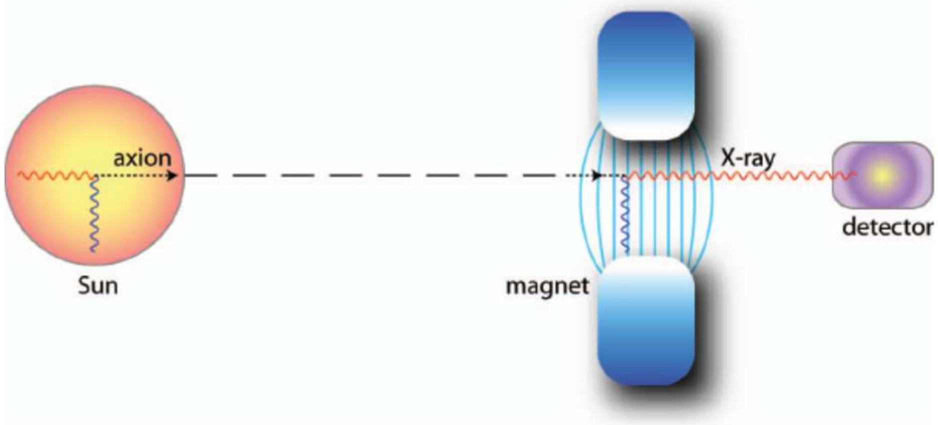


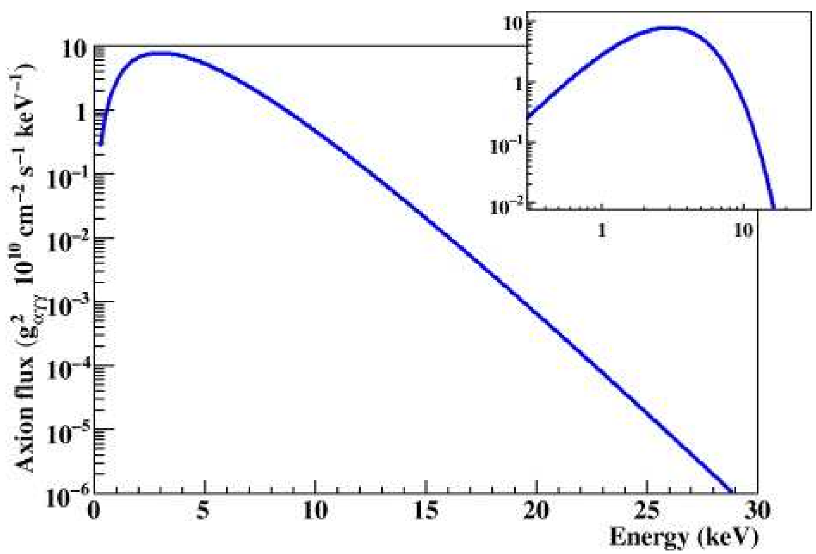
TSHIPS with a 13 m long, 1.25 m diameter tube:

- Volume factor 150 larger than TSHIPS-I

CAST: the dominating helioscope

- LHC prototype magnet pointing to the sun.





Axions or ALPs from the center of the sun would come with X-ray energies.

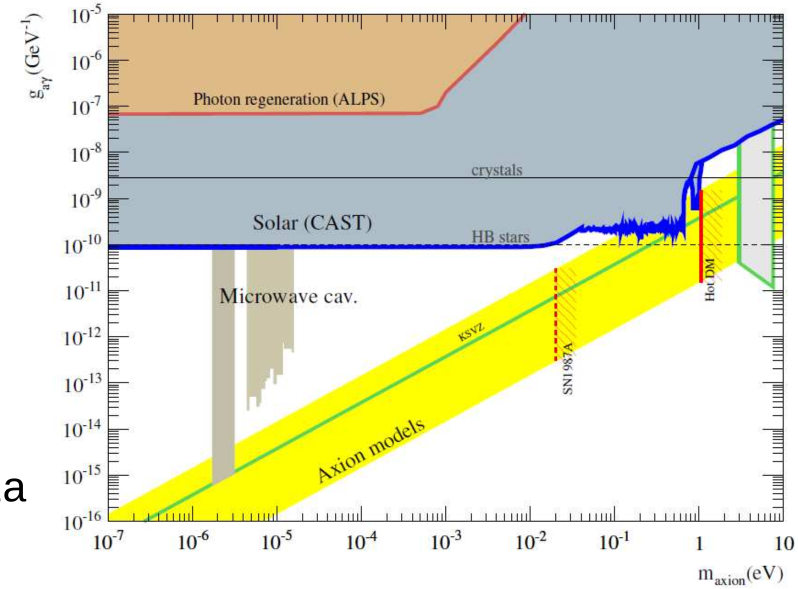
New J. Phys. **11** (2009) 105020

CAST: the dominating helioscope

> LHC prototype magnet pointing to the sun.

Unfortunately no hint for WISPs yet:

Courtesy of I. Irastorza

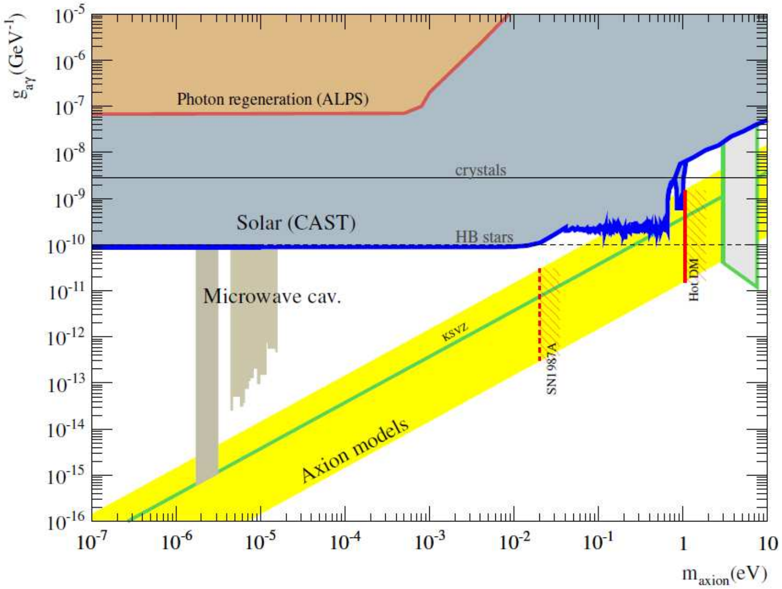


> Most sensitive experiment searching for axion-like particles.

- If an ALP is found, it would be compatible with known solar physics!

CAST: the dominating helioscope

> LHC prototype magnet pointing to the sun.



> Most sensitive experiment searching for axion-like particles.

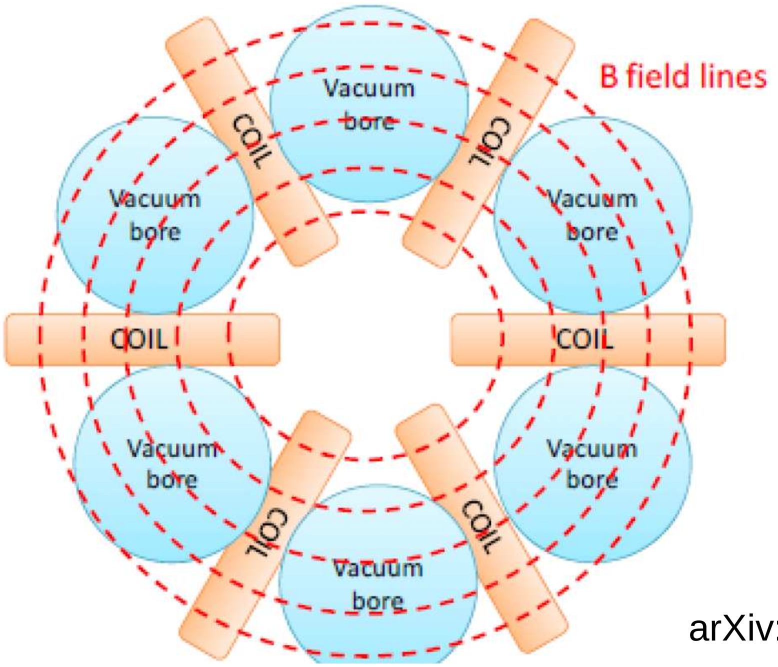
- If an ALP is found, it would be compatible with known solar physics!

> However, CAST does not strictly meet the "no excuse theorem".

- CAST has to assume ALP production in the sun.

IAXO proposal

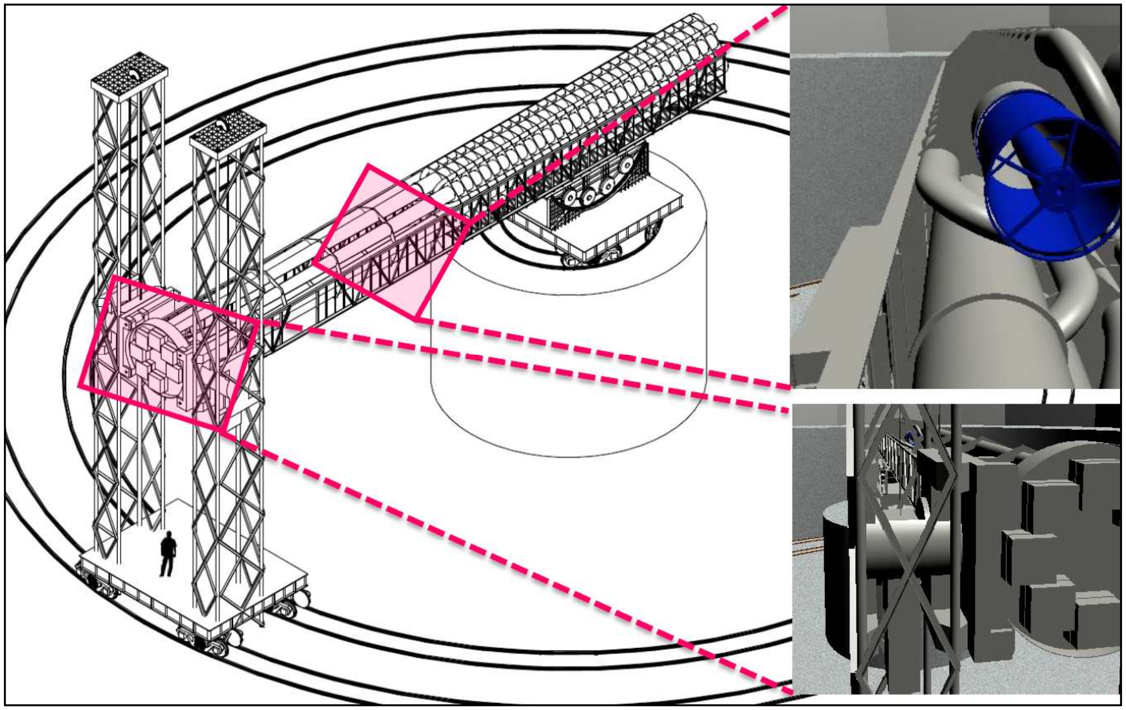
- The International Axion Observatory
  - CAST principle with dramatically enlarged aperture
  - Use of a toroid magnet similar to ATLAS?



arXiv:1103.5334v3 [hep-ex]

IAXO proposal

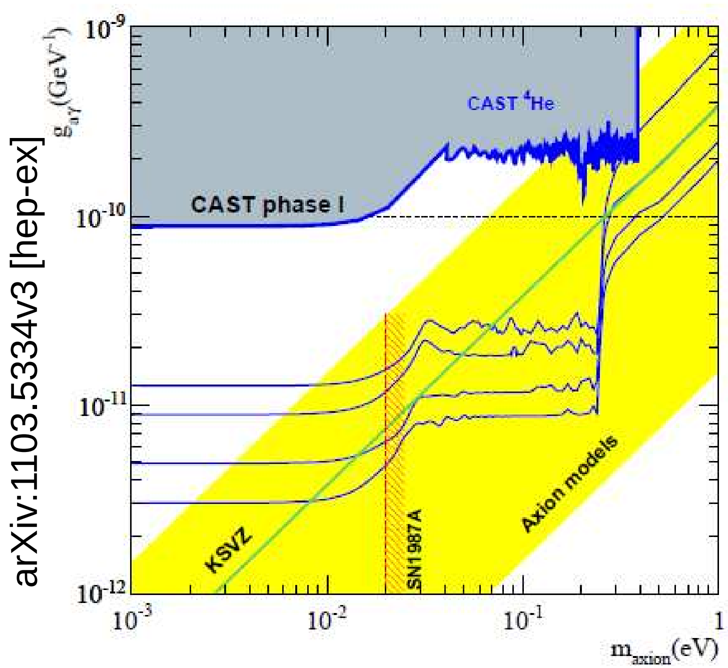
- The International Axion Observatory
  - CAST principle with dramatically enlarging the aperture
  - Use of toroid magnet similar to ATLAS?
  - X-ray optics similar to satellite experiments.



M. Pivovaroff (*LLNL*) , presentation at
Fundamental Physics at the Intensity Frontier, Rockville, 2011

IAXO proposal

- The International Axion Observatory
  - CAST principle with dramatically enlarging the aperture ← ALPS-I
  - Use of toroid magnet similar to ATLAS?
- IAXO could reach deep into the region where astrophysical phenomena might indicate the existence of ALPs.



← ALPS-II (but m < 0.2meV)

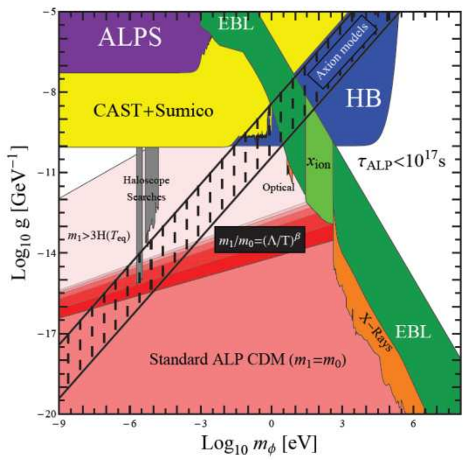
← "ALPS-III" dream (but m < 0.1meV)

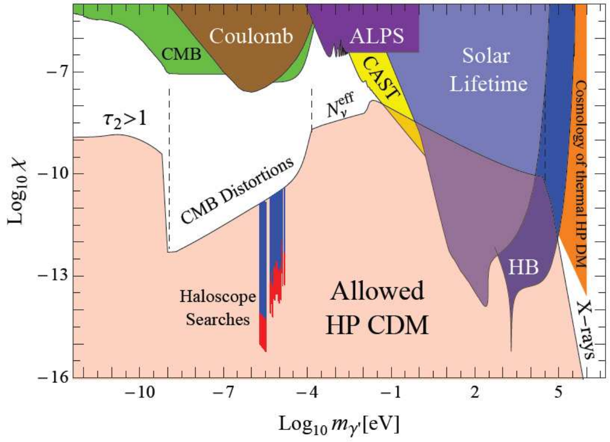
A selection of WISP experiments

- Light-shining-through-a-wall in the laboratory
  - ALPS at DESY (a certain emphasis will be put here)
  - OSQAR at CERN
  - REAPR in the US
  - First results using microwaves
- Helioscopes searching for WISPs from the sun
  - TSHIPS at Hamburg
  - CAST at CERN
  - The IAXO proposal
- Haloscopes searching for axionic dark matter
  - ADMX in the US
  - Next steps searching for axionic dark matter: Tore Supra?
  - Crazy stuff

Searches for WISPy cold dark matter

- Axions, axion-like particles and hidden photons could make up the dark matter in the universe.





PREPARED FOR SUBMISSION TO JCAP

DESY 11-226; MPP-2011-140; CERN-PH-TH/2011-323; IPPP/11/80; DCPT/11/160

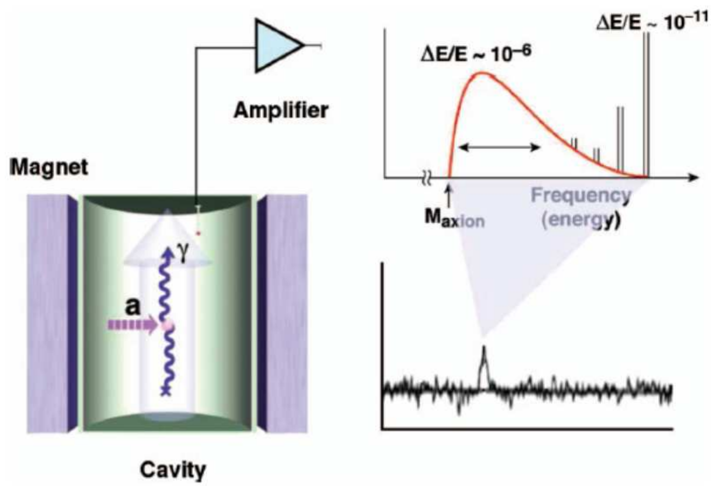
WISPy Cold Dark Matter

Paola Arias[a,b] Davide Cadamuro[c] Mark Goodsell[a,d] Joerg Jaeckel[e] Javier Redondo[c] Andreas Ringwald[a]

arXiv:1201.5902v1 [hep-ph]

Searches for WISPy cold dark matter

- Due to their low mass WISPy cold dark matter can not be detected by recoil techniques.
- WISPy dark matter particles have to convert into photons in a thoroughly shielded environment.
- The mass of the dark matter particle determines the energy to be detected. For axions it is in the microwave range.

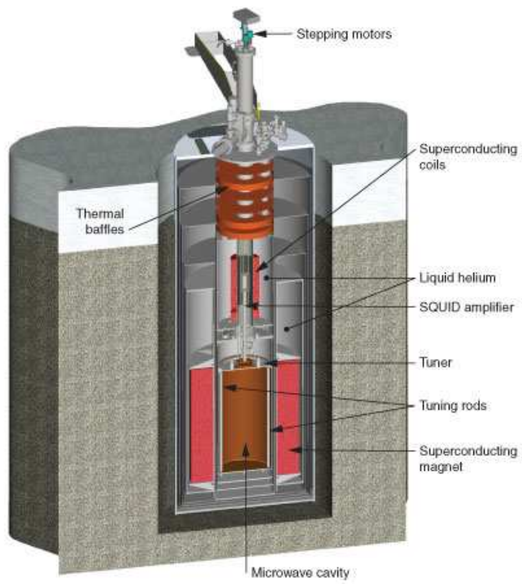


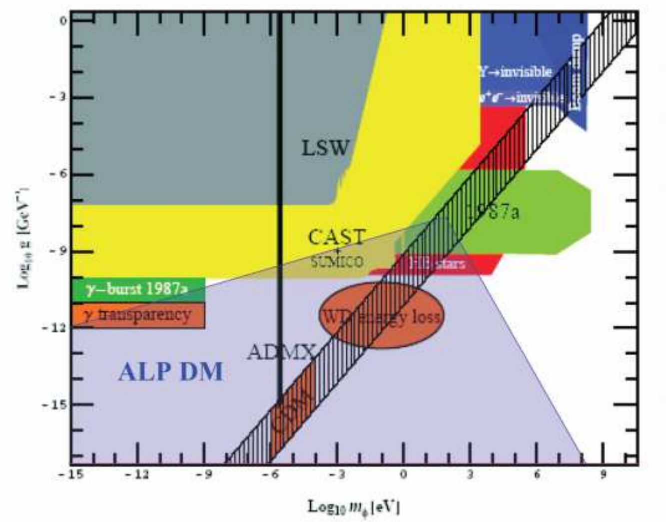
The Search for Axions, Carosi, van Bibber, Pivovaroff, Contemp. Phys. 49, No. 4, 2008

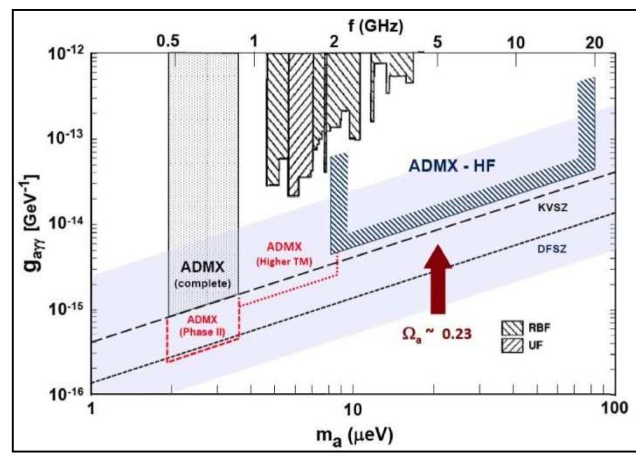
ADMX

- Existing experiment at Washington university.

The Search for Axions, Carosi, van Bibber, Pivovaroff, Contemp. Phys. 49, No. 4, 2008







G. Carosi (*LLNL*) , presentation at Fundamental Physics at the Intensity Frontier, Rockville, 2011

- ADMX-HF in preparation at Yale.
- Both experiments could probe a large part of the parameter space for dark matter axions!

Exploit the possibilties of other magnets

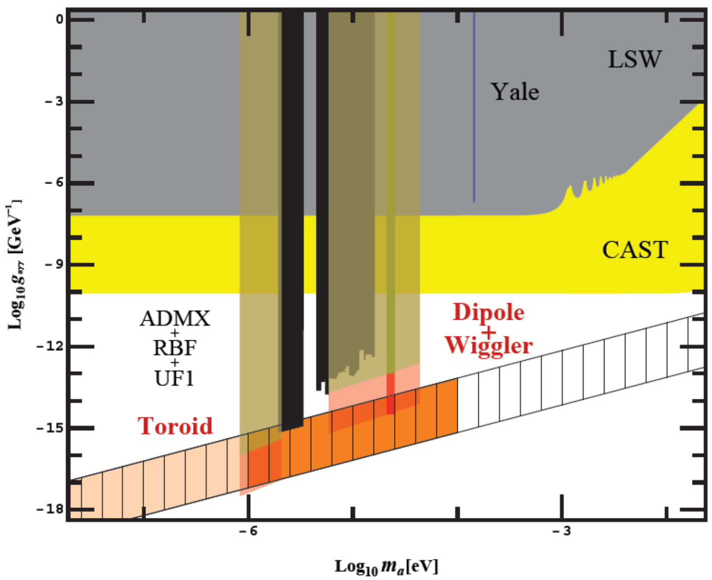
DCPT/11/110; DESY 11-163; IPPP/11/55

Phys.Rev. D85 (2012) 035018

arXiv:1110.2180v1 [physics.ins-det]

Prospects for Searching Axion-like Particle Dark Matter with Dipole, Toroidal and Wiggler Magnets

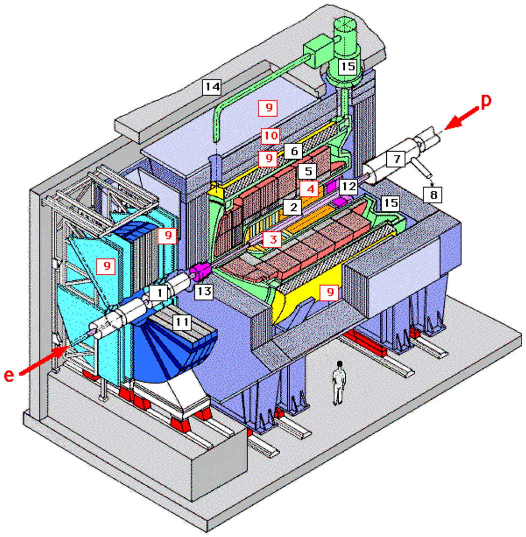
Oliver K. Baker[1], Michael Betz[2], Fritz Caspers[2], Joerg Jaeckel[3], Axel Lindner[4], Andreas Ringwald[4], Yannis Semertzidis[5], Pierre Sikivie[6], Konstantin Zioutas[7].



Experiments with toroid (IAXO),dipole and wiggler magnets could complement ADMX (using a solenoid).

Possibilities when combining forces

- Dark matter searched for by particle physicists and radio astronomers
  - MPIfR (A. Lobanov, R. Keller, M. Kramer)
  - DESY (A.L.,A. Lobanov, W.-D. Möller,A. Ringwald, J. Sekutowicz,D, Trines, A. Westphal)
  - IPPP Durham (J. Jaeckel)
- Combine accelerator cavities, detector magnets with receivers from radio astronomy?

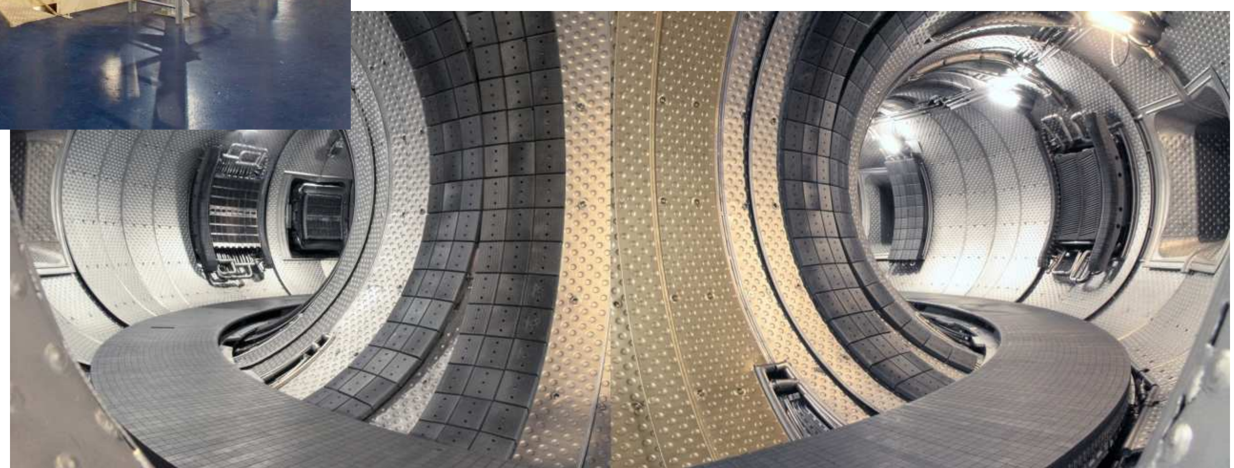


http://www.mpifr.de/div/electronic/content/receivers/21cm/fig_4.jpg

- Hope for a WISPDMX project proposal by the end of this year!

Use a tokamak magnet?

- Discuss options to use Tore Supra in Cadarache
  (many thanks to Konstantin Zioutas and Jean-Claude Vallet!)



Options with Tore Supra

- Use large magnetic volume equiped with microwave cavities to search for dark matter ALPs and axions.

Experiment	B (T)	V (m^3)	$B^2 \cdot V$ (Tm^3)
ADMX	8	1	64
Tore Supra	4	35	560

- However, Tore Supra cannot be (easily) cooled down to a few K.

- Questions
  - **Is the electromagnetic noise within the magnet tolerable?**
  - Is it possible to use the magnet as a cavity at its fundamental resonance at about 145 MHz (0.6 µeV)? What is the Q value here?
  - Is it possible to assemble a number of smaller cavities inside the magnet?
  - Does a broad spectral range search for dark matter make sense (Q=1)?

Options with Tore Supra

Next steps (thanks to Jean-Claude Vallet):

- First measurements of electromagnetic background planned for end of June.
- If everything works out, there might be a time slot in early 2013 for first searches for halo ALP dark matter.
  - Use large soft cavities made out of thin copper foil?
  - New concept of "inflatable" cavity tubes to use most of the Tore Supra magnetic volume?
- Are there (realistic) options to search for solar Chameleons?

It will be very exciting!
New options (again) by involving other communities.

http://www.iter.org/newsline/227/1196

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Conferences

02 Jul - 07 Jul, 2012
39th European Physical Society Conference on Plasma Physics (Joint meeting with ICPT)
Stockholm, Sweden

08 Jul - 12 Jul, 2012
39th IEEE Int'l Conference on Plasma Science (ICOPS2012)
Edinburgh, U.K.

27 Aug - 31 Aug, 2012
TOFE 2012 - Realizing new technologies for the age of fusion energy
Nashville, US

03 Sep - 14 Sep, 2012
6th International School on Fusion Technologies
Karlsruhe, Germany

17 Sep - 21 Sep, 2012
IPP Summer University on Plasma Physics and Fusion Research
Garching, Germany

24 Sep - 28 Sep, 2012
27th Symposium on Fusion Technology (SOFT) Conference
Liège, Belgium

08 Oct - 13 Oct, 2012
24th IAEA Fusion Energy Conference
San Diego, USA

18 Mar - 21 Mar, 2013
6th I'ntl Workshop on

iter newsline

15 Jun, 2012 - #227

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Focus On

Will tokamaks unveil the #1 mystery of the Universe?

-Robert Arnoux

Because of their large magnetized volume, tokamaks could be used to detect the elusive particles that are postulated to constitute dark matter/dark energy.

The more astronomers observe the Universe, the more matter they need to find to explain it all. Do "exotic particles" hold the key to the mystery? © A. Schaller (STScI)

A huge chunk of mass appears to be missing from the Universe. The billions and billions of galaxies that telescopes observe, the giant gas and dust clouds that float in the immensity of intergalactic space account for only a fraction of what is really there. The rest is invisible and remains undetectable.

The existence of a "dark matter" permeating the Universe and accounting for such gravitational phenomena as the rotational speed of galaxies or the "bending" of light around massive astronomical objects was inferred by cosmologists as early as the 1930s. Theories were established that remain unconfirmed to this day.

Decades later, observations of the accelerating expansion of the Universe led cosmologists to postulate the existence of another mysterious entity, a force whose nature can only be surmised— the so-called "dark energy".

It is generally estimated that the mass-energy content of the Universe is made up of approximately 74 percent dark energy, 22 percent dark matter and only 4 percent ordinary matter such as stars, planets, dust and intergalactic gas.

Dark matter and dark energy hold the answers to our ultimate destiny. Will the Universe expand forever in all directions or will it eventually retract and end in a Big Crunch? The question is definitely worth pondering ...

Dr Jean-Claude Vallet, of CEA's Institut de Recherche sur la Fusion Magnétique (IRFM), is participating in the preliminary discussions with CERN and ESA on turning Tore Supra into a part-time dark matter detector.

There is a consensus among cosmologists and particle physicists that "exotic" particles are key to understanding dark energy and dark matter. Dubbed "chameleons" (they are able to change their own mass) and "axions" (in reference to the US detergent Axion because their existence may help to clean up some theory problems) these hypothetical particles have been assigned a set of properties that would explain the behaviour of the Universe. As of today, however, both chameleons and axions have escaped detection.

Now, there's big news on the cosmic front. Tokamaks—and specifically the CEA-Euratom machine Tore Supra in Cadarache, France—could play a decisive role in the detection of some of these elusive particles: the "solar chameleons" that may originate in the Sun, and the "relic axions" that were produced right after the Big Bang ...

Axions and chameleons are postulated to interact weakly with matter (they traverse it as if it didn't exist) and to change into photons via the "Primakoff effect" in the presence of an intense magnetic field. However, experiments aimed at confirming their existence, like the CERN Axion Solar Telescope (CAST) in Geneva, have failed, to this day, to detect either axions or chameleons.

Outline

- Introduction
- Could there be any low-mass-low-coupling particle physics?
  What theory tells and a visit to the WISP zoo …
- If it is possible: are there any hints?
  Some open questions in (astro)physics …
- A new particle habitat?
- Experimental WISP searches:
  basics, direct searches and future prospects.
- Some crazy ideas (skip it?)
- Advertisements
- Summary

Some freestyle after the WISP duty …

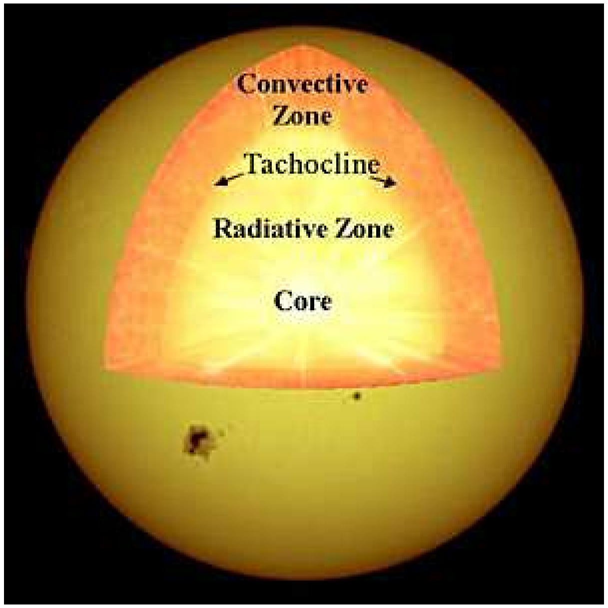
Chameleons have unique properties (by designing them as a dark energy candidate):

$$V_{\mathrm{eff}}(\phi) = M_\Lambda^4 + \frac{M_\Lambda^{n+4}}{\phi^n} + \frac{\beta_m \rho \phi}{M_{\mathrm{Pl}}}$$

- The chameleon mass depends on the energy density of its environment:
  - massless in intergalactic space to model long-range dark energy
  - heavy in dense objects to exponentially suppress fifth forces and escape experimental bounds.

Dark energy chameleons from the sun

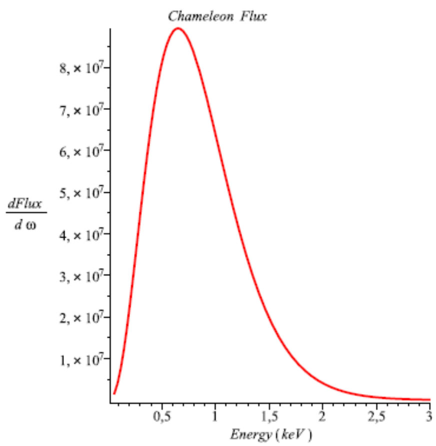
- Chameleon fields could make up the dark energy in the universe.
- At the sun's tachocline a strong magnetic field is expected.
  Here photons could convert
  to Chameleon particles which leave the sun.
- Chameleons with X-ray energies (energy larger than their mass in matter) traverse any wall similar to ALPs.
- They couple to two photons similar to ALPs (Primakoff effect).



http://news.stanford.edu/news/2002/january16/agusolar-116.html

Dark energy Chameleons from the sun

- Hence they could be detected in CAST-like helioscopes.



Detection Prospects for Solar and Terrestrial Chameleons

Philippe Brax,[1,*] Axel Lindner,[2] and Konstantin Zioutas[3]

arXiv:1110.2583v3 [hep-ph],
accepted by PRD

- However, Chameleons would originate from the tachocline at 0.7 R_{sun}. Present day helioscopes concentrate on the sun's center and have a small acceptance for the outer part of the sun.
- Have we overlooked Chameleons by now?

Some freestyle after the WISP duty …

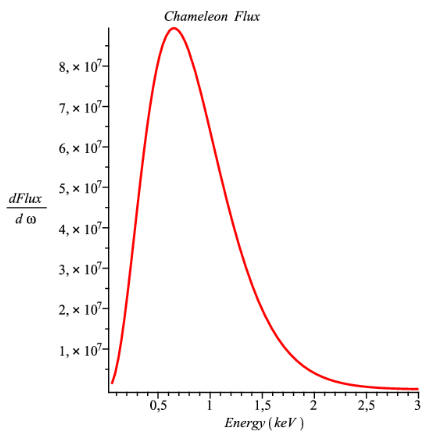
Chameleons have unique properties (by designing them as a dark energy candidate):

$$V_{\text{eff}}(\phi) = M_\Lambda^4 + \frac{M_\Lambda^{n+4}}{\phi^n} + \frac{\beta_m \rho \phi}{M_{\text{Pl}}}$$

- The chameleon mass depends on the energy density of its environment:
  - massless in intergalactic space to model long-range dark energy
  - heavy in dense objects to exponentially suppress fifth forces and escape experimental bounds.
- If the energy of a chameleon is smaller than its mass in matter, it is totally reflected.
- Similar to X-rays, the maximal reflection energy rises with rising incident angle.

A chameleon Gedankenexperiment

1. Chameleons are produced in the sun‘s tachocline with soft X-ray energies:



Detection Prospects for Solar and Terrestrial Chameleons

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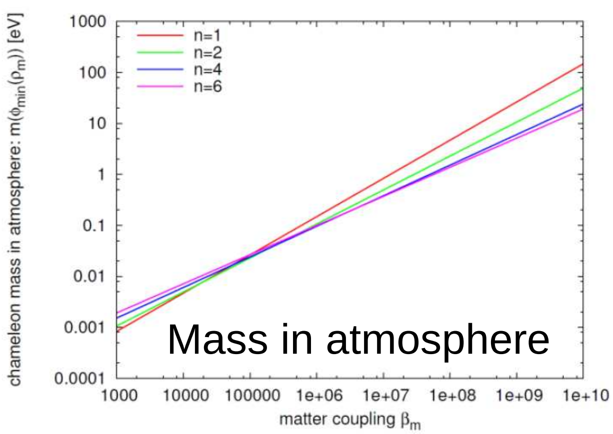
arXiv:1110.2583v3 [hep-ph], accepted by PRD

2. Chameleons with energies above 100 eV reach CERN / DESY.



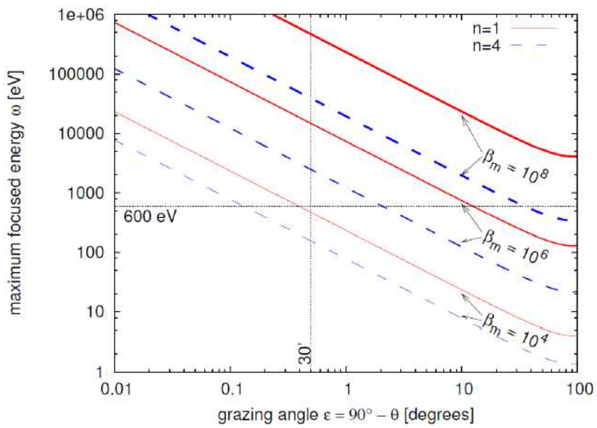
A chameleon helioscope

Keith Baker[1)], Axel Lindner[2)], Amol Upadhye[3)], Konstantin Zioutas[4)]

arXiv:1201.0079v1 [astro-ph.SR]

A chameleon Gedankenexperiment

3. The chameleons are focused by an grazing incident mirror (in air!) to enhance their flux.



A chameleon helioscope

Keith Baker[1), Axel Lindner[2), Amol Upadhye[3), Konstantin Zioutas[4)

arXiv:1201.0079v1 [astro-ph.SR]

4. The Chameleons are detected by their radiation-like pressure on a foil: Sensitivities below µW/m² are possible,while the chameleon flux from the sun could be up to 15 mW/m².

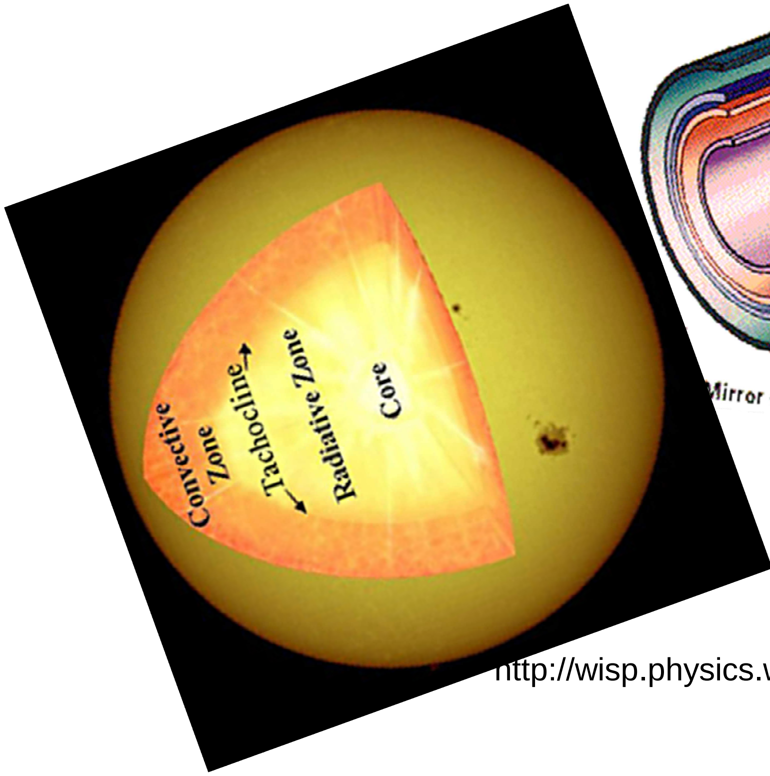
   A new method besides the Primakoff effect?

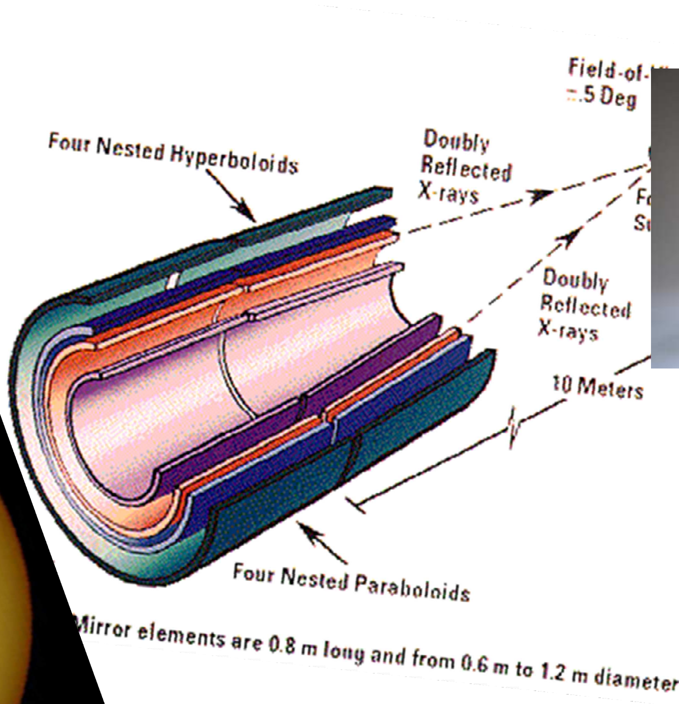
Detection of radiation pressure from solar chameleons

O. K. Baker [1), A. Lindner [2), Y. K. Semertzidis [3), A. Upadhye [4), K. Zioutas [5)

arXiv:1201.6508v1 [astro-ph.IM]

A chameleon Gedankenexperiment





http://www.umsl.edu/~physics/lab/lab-images/demos/Crookes_radiometer.jpg

http://wisp.physics.wisc.edu/astro104/lecture8/chandra_mirrors.gif

(jump to last slide)

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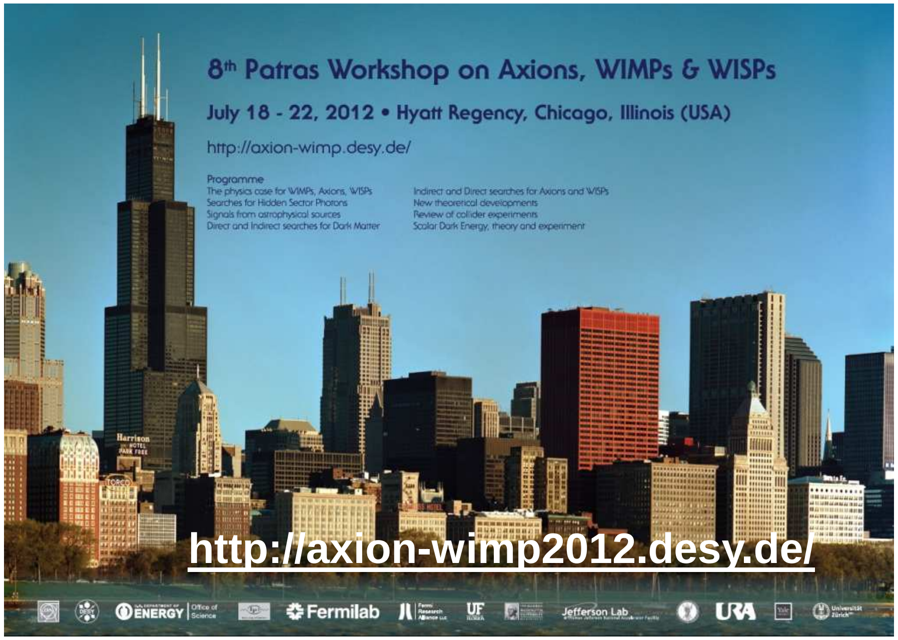
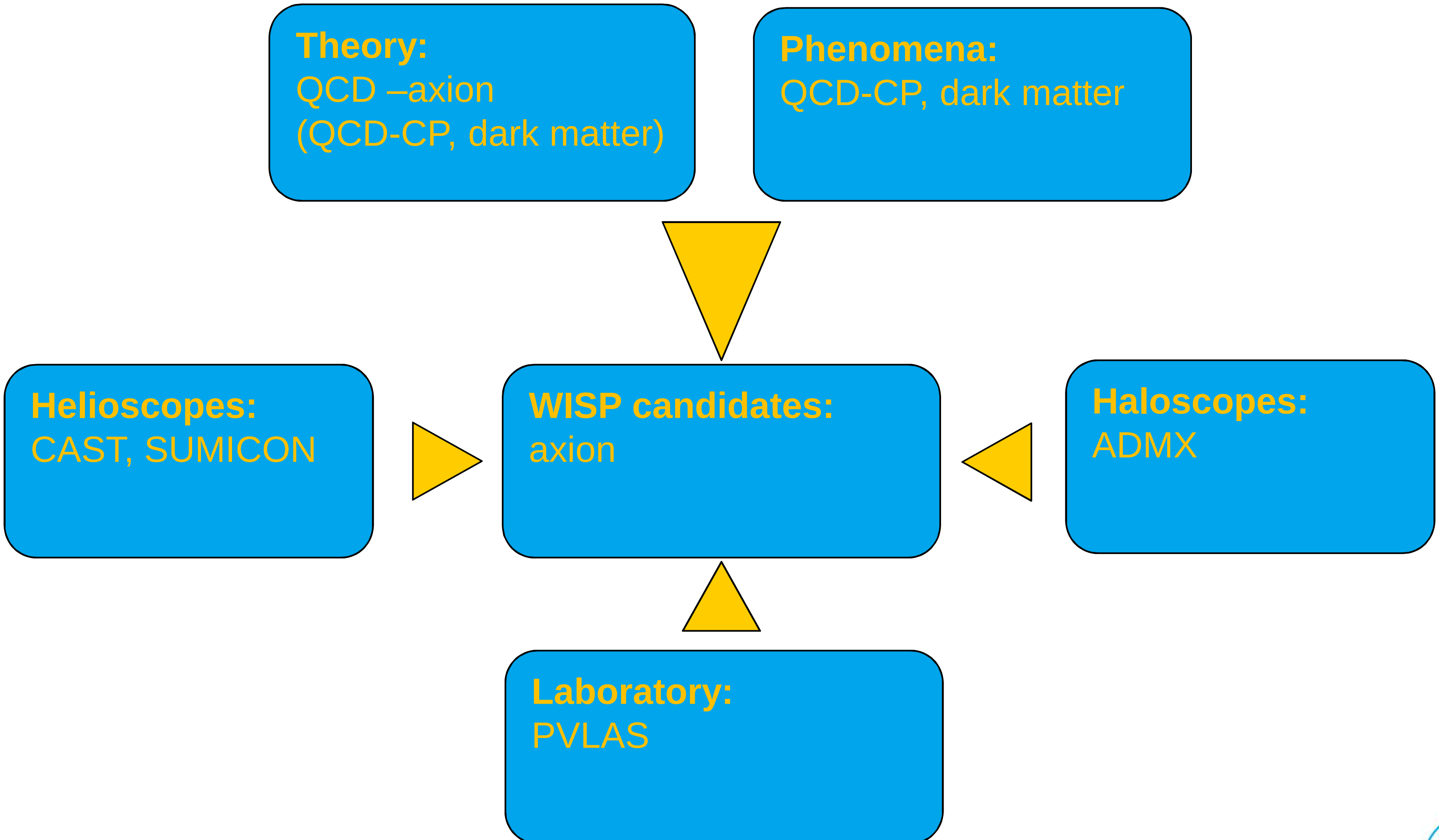
Some advertisement

> Join the Patras workshop series!



Summary

- WISP physics O(10) years ago (an oversimplified personal recollection).



PVLAS 2006

Summary

- WISP physics now (an incomplete selection).

Theory:
QCD –axion,
string-axivese, low energy effective theories

Phenomena
QCD-CP, dark matter, dark energy, sun, TeV transparency, white dwarfs, quasar light polarization, CMBR, …

Helioscopes:
CAST runs,
SUMICON,
TSHIPS

WISP candidates:
Axion, ALPs, hidden photons, minicharged, chameleons

Haloscopes:
ADMX, ADMX-II,
ADMX-HF

Laboratory:
ALPS, BMV, CHASE,
GammeV, LIPSS, OSQAR,
Q&A, REAPR…

Summary

- WISP physics: the next O(10) years:

- With the recent developments in theory and astrophysics phenomena we know were to go
  - for axion-like particles,
  - for hidden photons.
- Next generation experiments (LSW, helio- and haloscopes) should reach the required sensitivities.
  Sensitivities will jump by orders of magnitude!
- One should exploit carefully new options provided by high power pulsed laser systems or large existing magnets for example.

The next 10 years will decide on the future of WISP physics!

Come in and find out!