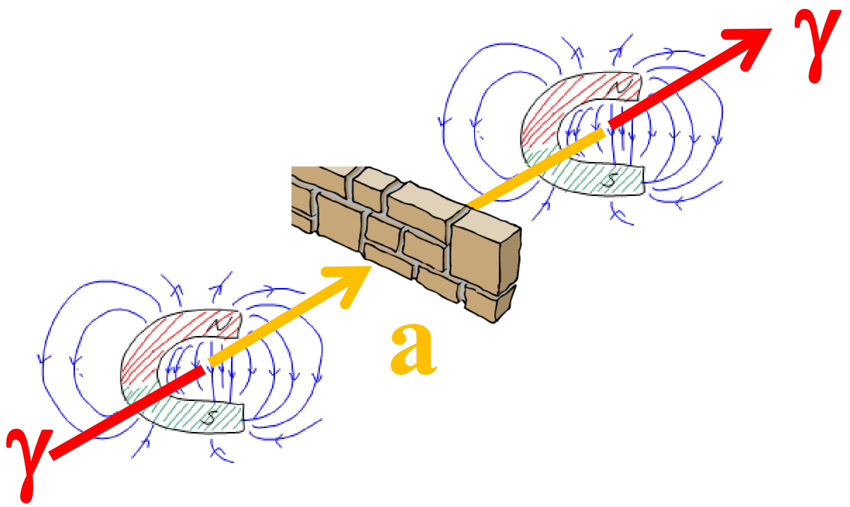
Any Light Particle Searches at DESY

Axel Lindner

DESY Summer Student Lecture,
August 9th, 2019



HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

DESY.

Beyond the Standard Model of particle phyiscs?

The standard model (SM) of particle physics is

- extremely successful, but
- does not provide answers to crucial questions (a selection):
  - How to integrate non-zero neutrino masses? } Here the SM fails!
  - What are dark matter and dark energy?
  - How to explain the baryon-antibaryon asymmetry of the universe? } Cosmology
  - Why is the Higgs so light?
  - Why is CP conserved in QCD?
  - Why is the vacuum energy so tiny? } Fine tuning

Where to look for beyond-SM-Physics?

Wherever you can! An exemplary selection:

- Laboratory experiments
  - Energy frontier
  - Precision frontier
  - Rare decays
  - Light-through-walls
- Astrophysics
  - Stellar evolutions, light propagation
  - Dark matter searches
- Cosmology
  - CMB, gravitational waves

Where to look for beyond-SM-Physics?

Wherever you can! An exemplary selection: energy reach

- **Laboratory experiments**
  - Energy frontier — 10 TeV (LHC)
  - Precision frontier — 10^2 TeV (BELLE II, model dependent)
  - Rare decays — 10^3 TeV (Mu3e, model dependent)
  - Light-through-walls — 10^5 TeV (axions, model dependent)
- **Astrophysics**
  - Stellar evolutions, light propagation — 10^5 TeV (axions, model dependent)
  - Dark matter searches — 10^9 TeV (axions, model dependent)
- **Cosmology**
  - CMB, gravitational waves — 10^{12} TeV (inflation, model dependent)

Compare:
Planck scale 10^{16} TeV, 10^{-43} s after the big bang.

Where to look for beyond-SM-Physics?

Wherever you can! An exemplary selection:	energy reach
> Laboratory experiments	
▪ Energy frontier	10 TeV (LHC)
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> Cosmology	
▪ CMB, gravitational waves	10^{12} TeV (inflation, model dependent)

Outline

- An introduction to axions and axion-like particles
- Axions and ALPs in the sky?
- Experimental approaches
  - ALPS II at DESY in Hamburg
  - IAXO and MADMAX
- Summary

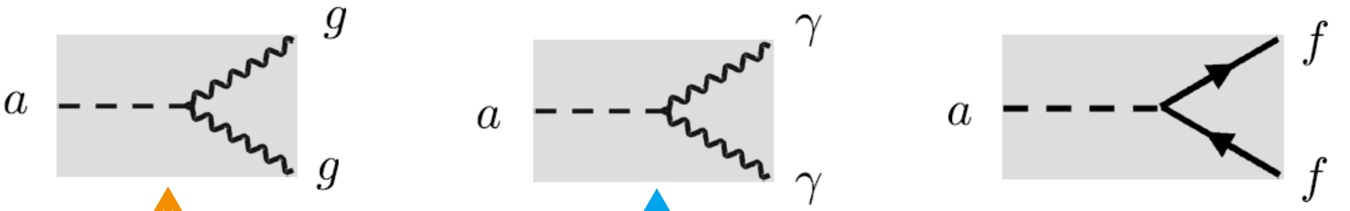
The QCD axion

Mass and coupling determined by one energy scale

With the PQ symmetry breaking scale $f_{a:}$

- Mass: $m_a = 0.6\ \text{eV} \cdot (10^7\text{GeV} / f_a)$
- Couplings ~ $1/ f_a$ (hence ~ m_a)

$$\mathcal{L} \supset -\frac{\alpha_s}{8\pi}\frac{C_{ag}}{f_a}\, a\, G^b_{\mu\nu}\tilde{G}^{b,\mu\nu} - \frac{\alpha}{8\pi}\frac{C_{a\gamma}}{f_a}\, a\, F_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{1}{2}\frac{C_{af}}{f_a}\partial_\mu a\, \overline{\psi}_f\gamma^\mu\gamma_5\psi_f$$



CP conservation in QCD

Exploited in most experiments

Courtesy A. Ringwald

Axion-like particles (ALPs)

More than one QCD axion

PHYSICAL REVIEW D 81, 123530 (2010)

String axiverse

Asimina Arvanitaki,[1,2] Savas Dimopoulos,[3] Sergei Dubovsky,[3,4] Nemanja Kaloper,[5] and John March-Russell[6]
[1]*Berkeley Center for Theoretical Physics, University of California, Berkeley, California, 94720, USA*
[2]*Theoretical Physics Group, Lawrence Berkeley National Laboratory, Berkeley, California, 94720, USA*
[3]*Department of Physics, Stanford University, Stanford, California 94305, USA*
[4]*Institute for Nuclear Research of the Russian Academy of Sciences, 60th October Anniversary Prospect, 7a, 117312 Moscow, Russia*
[5]*Department of Physics, University of California, Davis, California 95616, USA*
[6]*Rudolf Peierls Centre for Theoretical Physics, University of Oxford, 1 Keble Road, Oxford, England*
(Received 22 October 2009; published 28 June 2010)

- *String theory suggests the simultaneous presence of many ultralight axions possibly populating each decade of mass down to the Hubble scale 10^{-33} eV. Conversely the presence of such a plenitude of axions (an "axiverse") would be evidence for string theory.*

JHEP
Published for SISSA by Springer
Received: July 13, 2012
Accepted: September 17, 2012
Published: October 22, 2012

The type IIB string axiverse and its low-energy phenomenology

Michele Cicoli,[a,b] Mark D. Goodsell[c] and Andreas Ringwald[d]
[a]*Abdus Salam ICTP, Strada Costiera 11, Trieste 34014, Italy*
[b]*INFN — Sezione di Trieste, Trieste, Italy*
[c]*CERN, Theory Division, CH-1211 Geneva 23, Switzerland*
[d]*Deutsches Elektronen-Synchrotron, DESY, Notkestraße 85, 22607 Hamburg, Germany*
E-mail: mcicoli@ictp.it, mark.goodsell@cern.ch, andreas.ringwald@desy.de

- *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.*

ALPs

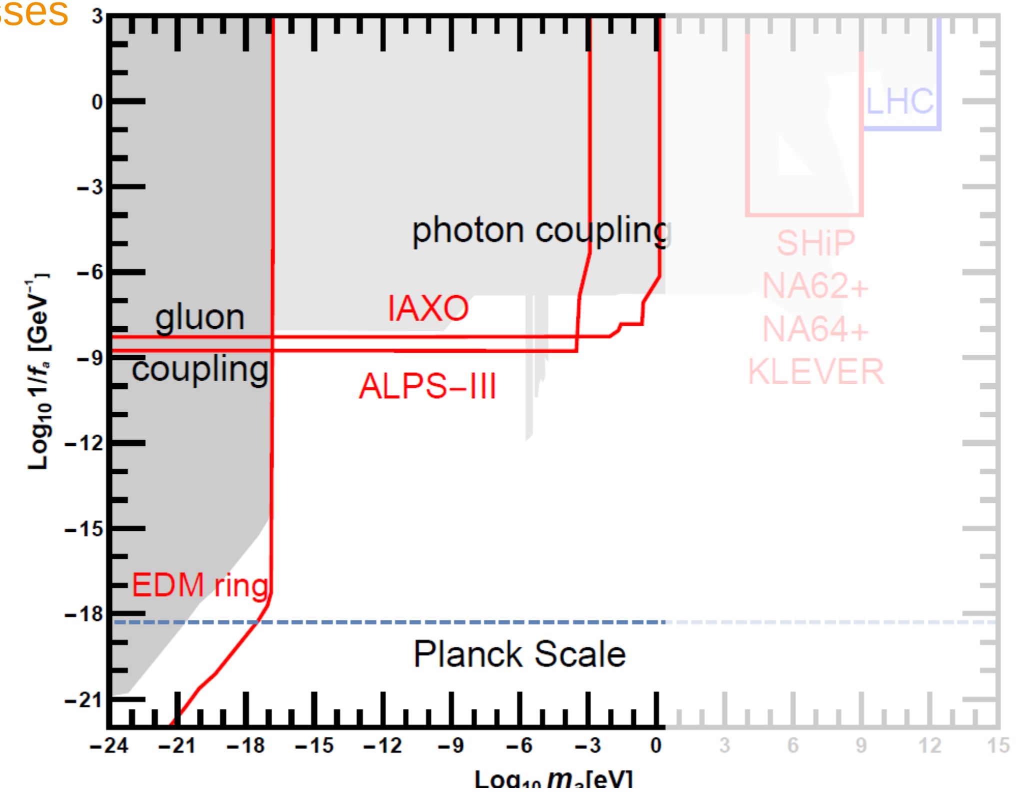
> don’t solve the problem of CP conservation of QCD,

> have couplings ~ 1/ f_{alp} , but m_{alp} and f_{alp} are not related.

Axion and axion-like particles (ALPs)

Here: only low masses

Roughly m < 1 eV

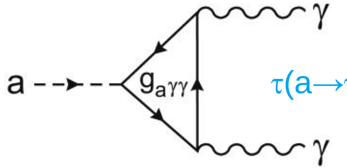


Courtesy J. Jäckel

Axions and axion-like particles (ALPs)

How to look at low masses: exploiting photon couplings

Axion decay to two photons

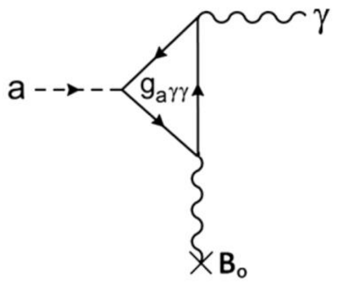


$\tau(a\rightarrow\gamma\gamma) \approx 1.3\cdot10^{25}s\cdot\ (10^{10}GeV^{-1}/g_{a\gamma\gamma})^2\cdot(m/eV)^3$

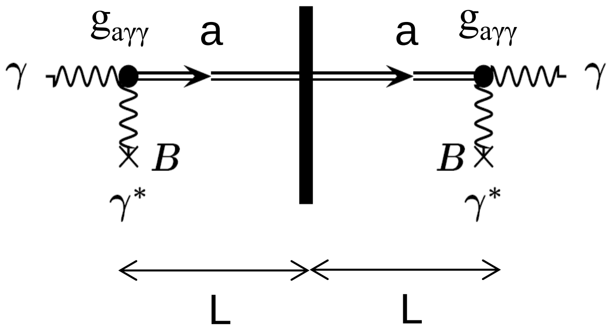
Axions and axion-like particles (ALPs)

How to look at low masses: exploiting photon couplings

Primakoff-like axion conversion



and light-shining-through-walls.



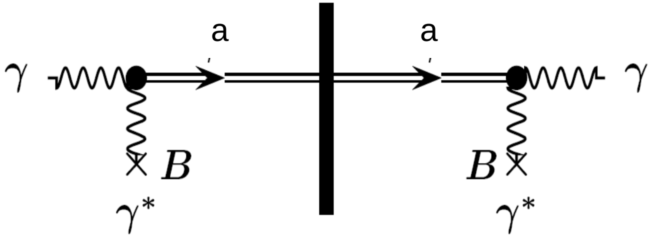
P(γ→a→γ) ~ $(g_{a\gamma\gamma} \cdot B \cdot L)^4$

ALPS II: P(γ→a→γ) ≈ 10^{-36}

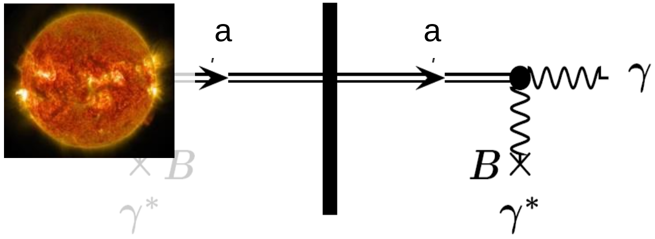
Sub-eV axions and axion-like particles (ALPs)

How to look: three kinds of axion/ALP sources

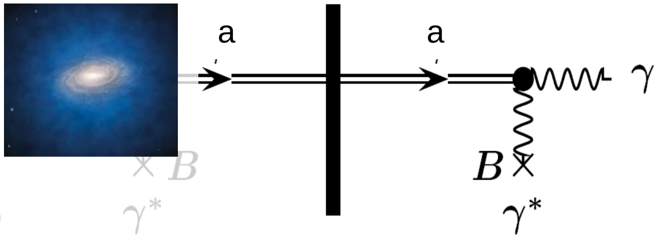
- **Purely laboratory experiments**
  “light-shining-through-walls”,
  optical photons



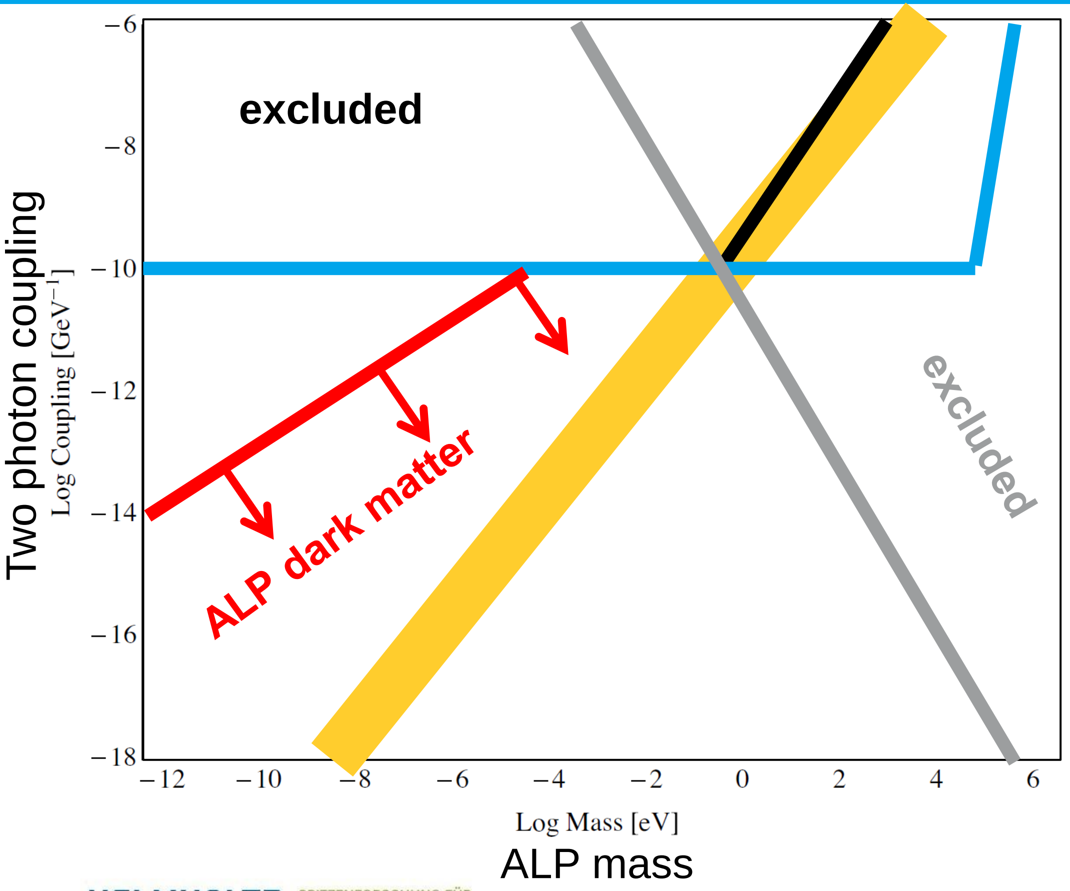
- **Helioscopes**
  ALPs emitted by the sun,
  X-rays,



- **Haloscopes**
  looking for dark matter constituents,
  microwaves.



The big picture: ALPs



QCD axion range

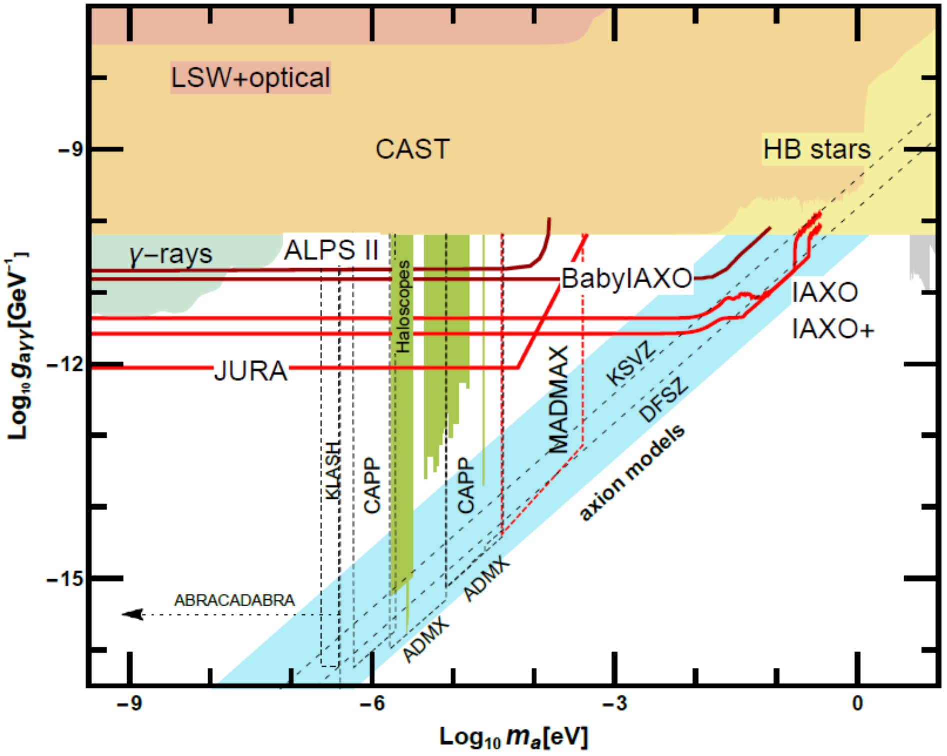
Excluded by WISP experiments

Excluded by astronomy (ass. ALP DM)

Excluded by astrophysics / cosmology

Axions or ALPs being cold dark matter

The big picture: ALPs



A European Strategy Towards Finding Axions and Other WISPs

K. Desch[1], *B. Döbrich*[2], *I. Irastorza*[3], *J. Jaeckel*[4], *A. Lindner*[5], *B. Majorovits*[6], *A. Ringwald*[5],
[1]Physikalisches Institut, Uni. Bonn, Nußallee 12, D-53115 Bonn, Germany
[2]CERN, 1 Esplanade des Particules, CH-1211 Geneva 23, Switzerland
[3]Departamento de Fisica Teorica, Uni. de Zaragoza, Pedro Cerbuna 12, E-50009, Zaragoza, Spain
[4]Institut für Theoretische Physik, Uni. Heidelberg, Philosophenweg 16, D-69120 Heidelberg, Germany
[5]DESY, Notkestraße 85, D-22607 Hamburg, Germany
[6]Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 Munich, Germany

ESPP update process, December 2018
https://indico.cern.ch/event/765096/contributions/3295758/

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- Axions and ALPs in the sky?
- Experimental approaches
  - ALPS II at DESY in Hamburg
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Dark matter production in the present universe

Dark matter production in the present universe

Dark matter with masses below 1 MeV could still be produced (thermally) in our universe today:

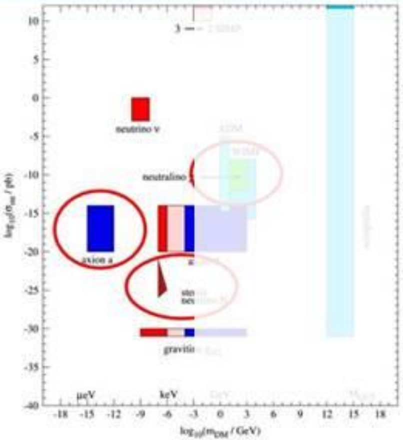
- axions, ALPs
- sterile neutrinos.

Next lecture: learn about axions, ALPs, stars and photons!

Dark matter candidates: where to focus experimentally?

Selection criteria:

- Are experimental options in reach to either
  - identify dark matter candidates in laboratory experiments,
  - find directly of indirectly the particles composing the dark matter halo we are living in?
- Does the theory explain "just" dark matter or is it embedded in a more general extension of the standard model of particle physics?



Dark matter detection (Laura Baudis), http://iopscience.iop.org/article/10.1088/0954-3899/43/4/044001

Axions and ALPs in the sky

Hints from astrophysics?

- Stellar evolutions
- Propagation of TeV photons
- Photon propagation in magnetic fields
- Supernovae

Axions and ALPs in the sky

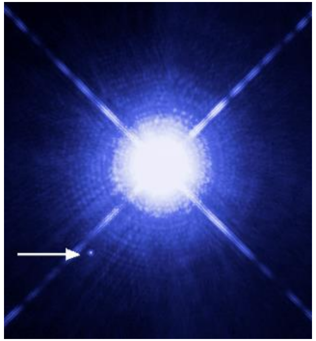
Stellar evolutions

- Extra energy loss beyond SM expectations
  is indicated by stellar developments.

Axions and ALPs in the sky

Stellar evolutions

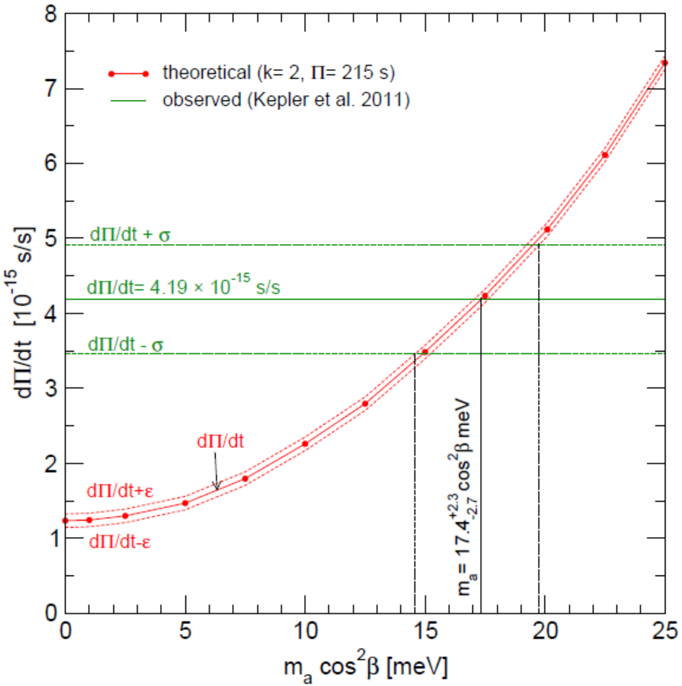
- Extra energy loss beyond SM expectations
is indicated by stellar developments.
- Example:
white dwarf stars.



The change of frequency of a pulsating DA white dwarf measures its cooling rate.

Data indicate that the white dwarf cools “too fast”.

G117−B15A

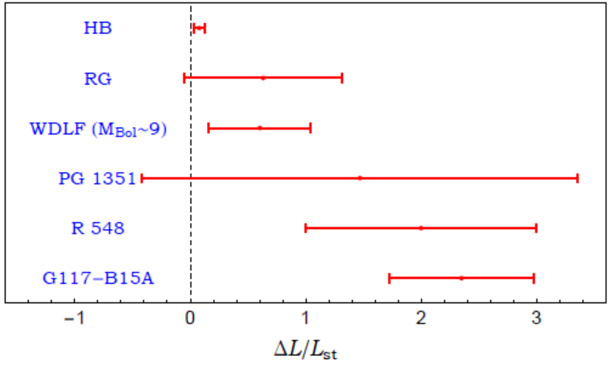


https://arxiv.org/abs/1205.6180

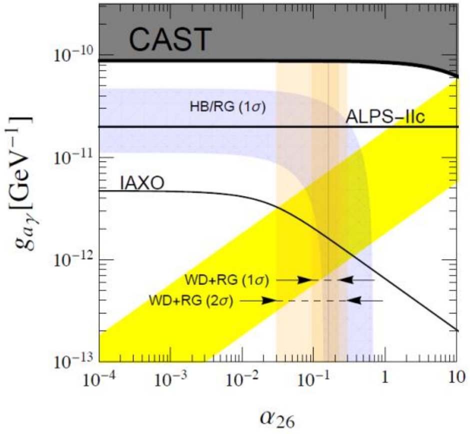
Axions and ALPs in the sky

Stellar evolutions

- Extra energy loss beyond SM expectations
  is indicated by stellar developments.
- Such losses can be explained consistently
  by the emission of axions coupling to photons and electrons.
  Light ALPs would also work.



M. Giannotti, I. Irastorza,
J. Redondo, A. Ringwald,
http://arxiv.org/abs/1512.08108



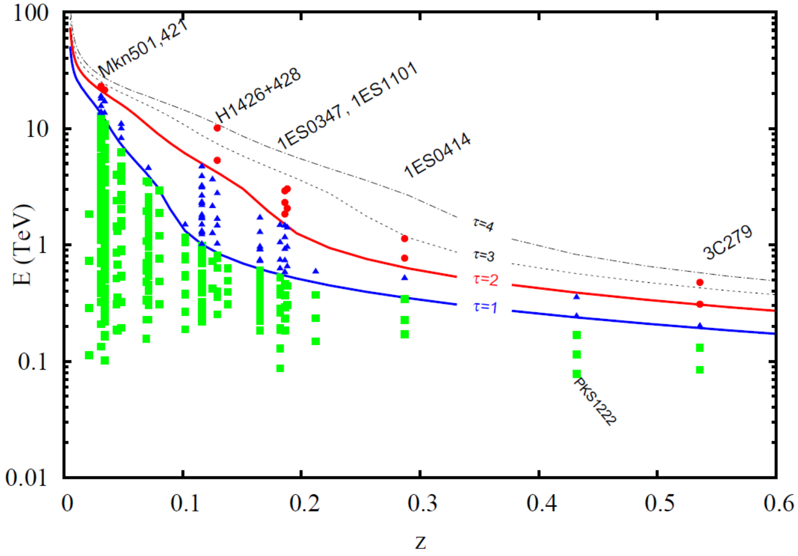
M. Giannotti, I. Irastorza,
J. Redondo, A. Ringwald, K. Saikawa
https://arxiv.org/abs/1708.02111

Axions and ALPs in the sky

Propagation of TeV photons

Anomalous transparency of the universe to TeV photons:

> TeV photons might not be absorbed in the intergalactic space due to $\gamma+\gamma \rightarrow e^+e^-$ scattering as predicted by QED.



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

Axions and ALPs in the sky

Propagation of TeV photons

Anomalous transparency of the universe to TeV photons:

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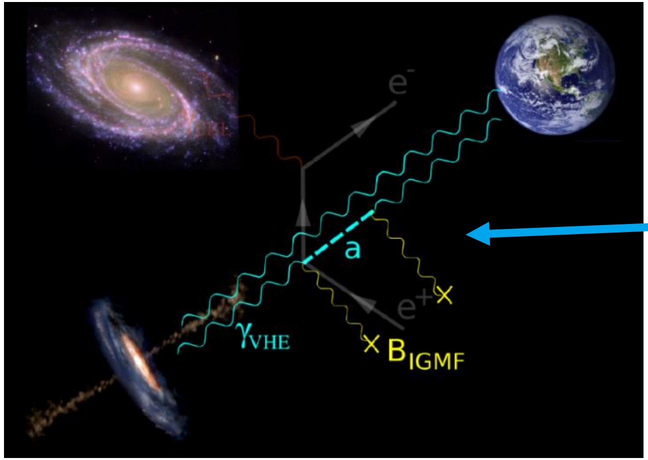
- This could be explained by axion-like particles.



TeV photons in the universe

might convert in magnetic fields to ALPs via their two-photon coupling.

Such ALPs might convert back to photons in the vicinity of earth.

Axions and ALPs in the sky

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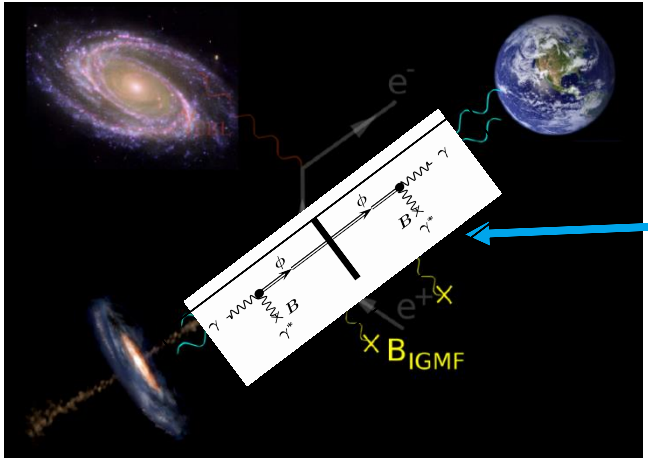

TeV photons in the universe:

"Light-shining-through-the-wall" of extragalactic background light?

Axions and ALPs in the sky

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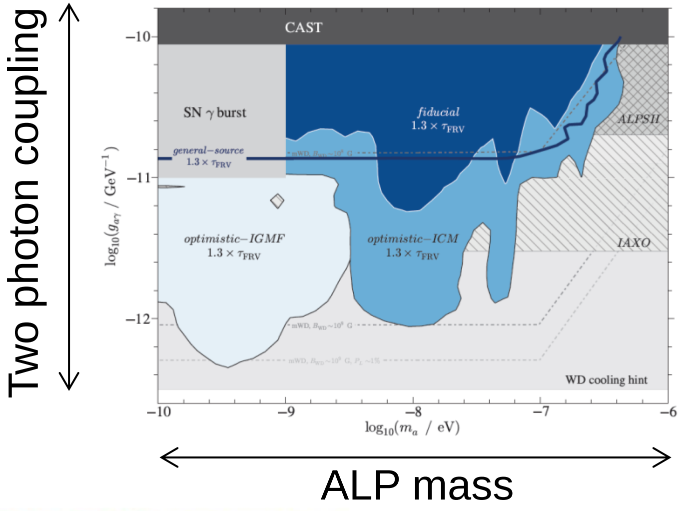


A very similar axion-photon coupling as derived from stellar developments is required!

M. Meyer, D. Horns, M. Raue,
arXiv:1302.1208 [astro-ph.HE], Phys. Rev. D 87, 035027 (2013)

S. V. Troitsky,
arXiv:1612.01864 [astro-ph.HE], JETP Lett. 105 (2017) no.1, 55

Axions and ALPs in the sky

Propagation of TeV photons

ALPs to explain an unexpected high transparency of the universe for TeV photons:

PROCEEDINGS OF SCIENCE

Hints for an axion-like particle from PKS 1222+216?

https://arxiv.org/abs/1409.4401

Advantages of axion-like particles for the description of very-high-energy blazar spectra

https://arxiv.org/abs/1503.04436

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Sensitivity of the Cherenkov Telescope Array to the detection of axion-like particles at high gamma-ray opacities

https://arxiv.org/abs/1410.1556

PHYSICAL REVIEW D **86,** 075024 (2012)

Hardening of TeV gamma spectrum of active galactic nuclei in galaxy clusters by conversions of photons into axionlike particles

https://arxiv.org/abs/1207.0776

PHYSICAL REVIEW D **93,** 045014 (2016)

Towards discrimination between galactic and intergalactic axion-photon mixing

https://arxiv.org/abs/1507.08640

Axion-like particles and the propagation of gamma rays over astronomical distances

https://arxiv.org/abs/1612.01864

Axions and ALPs in the sky

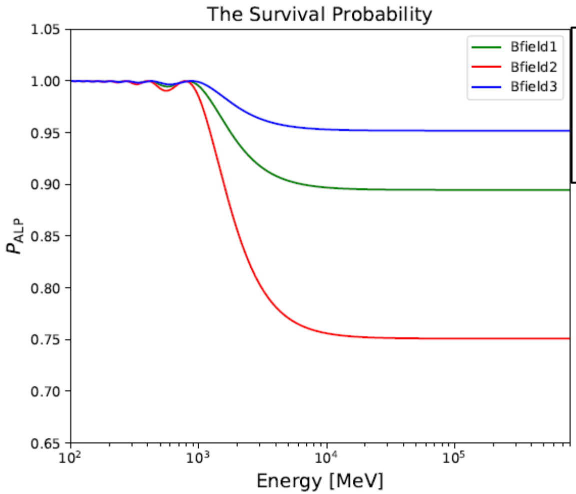
Photon propagation in magnetic fields

Photon spectra might be changed due to photon-ALP conversion in magnetic fields (10.1103/PhysRevD.97.063003, Zi-Qing Xia et al.):

$$P_{\mathrm{ALP}} = 1 - P_{\gamma\to a} = 1 - \frac{1}{1+E_c^2/E_\gamma^2}\sin^2\left[\frac{g_{a\gamma}B_{\mathrm{T}}l}{2}\sqrt{1+\frac{E_c^2}{E_\gamma^2}}\right]$$

where the characteristic energy E_c is defined as

$$E_c = \frac{\left|m_a^2 - w_{\mathrm{pl}}^2\right|}{2g_{a\gamma}B_{\mathrm{T}}},$$



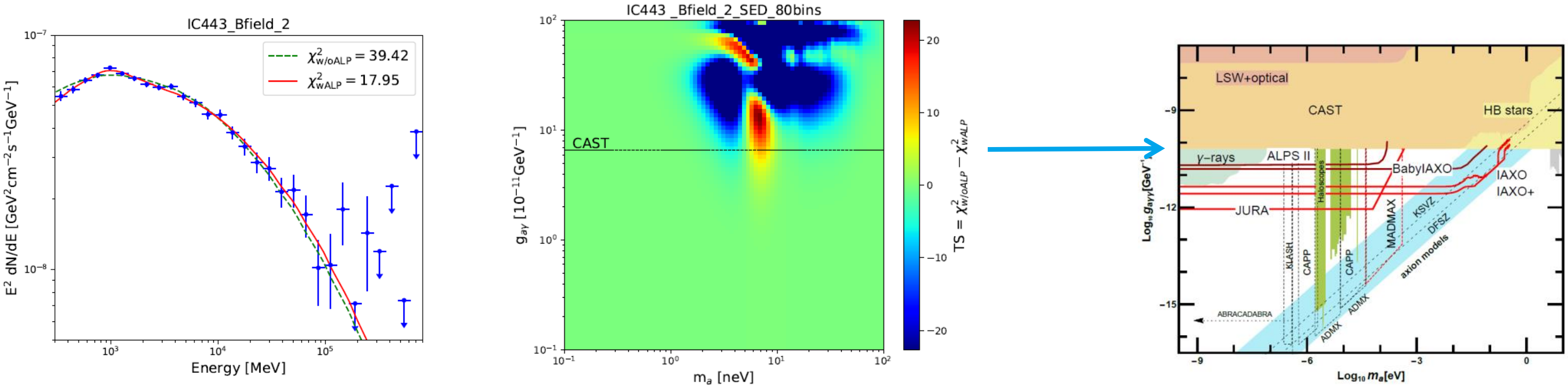
SNR IC443, 1.5 kpc
$m_a = 6.6\cdot10^{-9}$eV
$g_{a\gamma\gamma} = 1.3\cdot10^{-10}$GeV^{-1}

Spectral modulations might hint at the existence of ALPs!

Axions and ALPs in the sky

Photon propagation in magnetic fields: conflicting results!

Galactic SNR (10.1103/PhysRevD.97.063003, Zi-Qing Xia et al.):



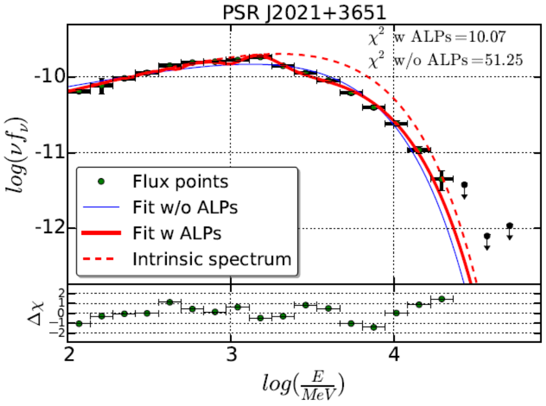
Evidence for ALPs from IC443?

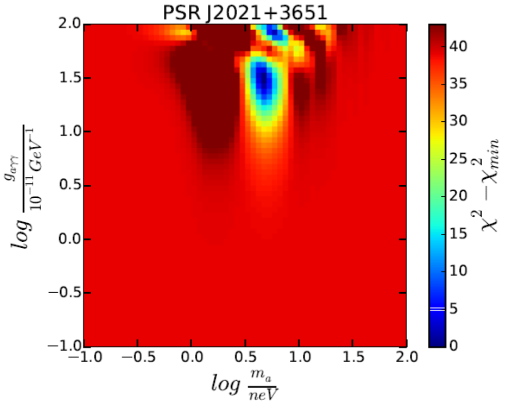
No ALPs indications from W44 and W51C, method checked with close SNRs.

Axions and ALPs in the sky

Photon propagation in magnetic fields: conflicting results!

Galactic pulsars (J. Majumdar *et al* JCAP04(2018)048):





Pulsar name	N_0 $[10^{-9}\mathrm{MeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}]$	Γ_1	E_{cut} [GeV]	$g_{a\gamma\gamma}$ $[10^{-10}\,\mathrm{GeV}^{-1}]$	m_a [neV]
J1420-6048	0.0016(2)	1.74(4)	5.4(6)	1.7(3)	3.6(1)
J1648-4611	0.0028(2)	0.88(3)	3.4(2)	5.3(9)	4.3(1)
J1702-4128	0.13(3)	0.9(1)	1.0(2)	4.4(2)	8.1(5)
J1718-3825	0.024(2)	1.48(4)	2.1(1)	2.4(3)	8.9(2)
J2021+3651	0.18(1)	1.45(3)	3.5(1)	3.5(3)	4.4(1)
J2240+5832	0.005(1)	1.5(1)	2.4(6)	2.1(4)	3.7(3)

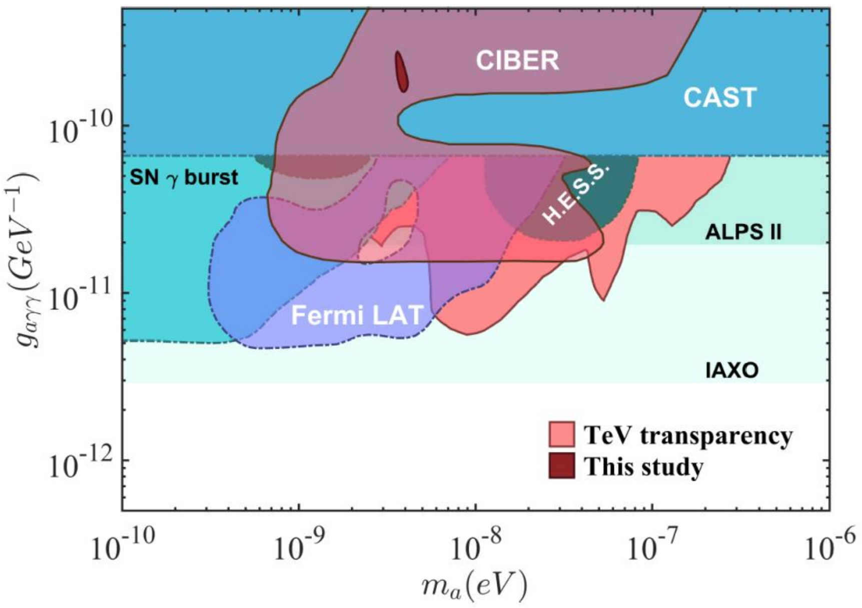
Pulsars selected according to the magnetic field strength along the line of sight.

Method checked with close pulsar.

Axions and ALPs in the sky

Photon propagation in magnetic fields: conflicting results!

Galactic pulsars (J. Majumdar *et al* JCAP04(2018)048):



Surprising agreement with SNR analyses!

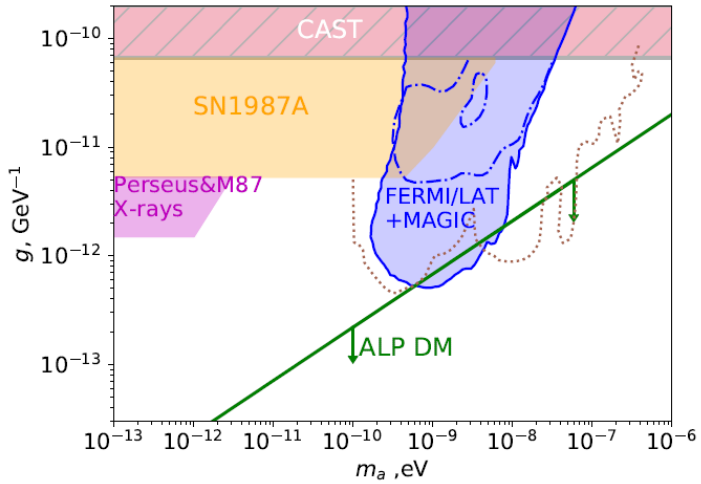
Conflict to other exclusions!

Do we understand astrophysics?

Axions and ALPs in the sky

Photon propagation in magnetic fields: conflicting results!

NGC 1275, Perseus cluster (D. Malyshev et al, arXiv:1805.04388 [astro-ph.HE]):



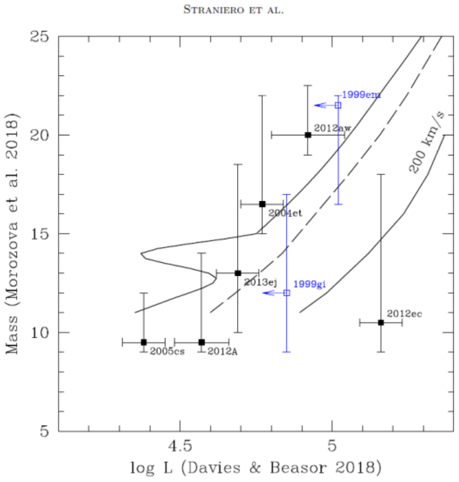
No evidence for ALPs! “Galactic hints” are excluded!

Do we understand astrophysics?

Axions and ALPs in the sky

Supernovae

seem to be a bit too dim compared to expectations from the mass of progenitor stars:



O. Straniero et al, arXiv:1907.06367 [astro-ph.SR]

Axions / ALPs in reach of ALPS II and IAXO might solve the problem!

Do we understand astrophysics?

Axions and ALPs in the sky

Hints from astrophysics?

- Stellar evolutions
- Propagation of TeV photons
- Photon propagation in magnetic fields
- Supernovae

Nothing conclusive yet, but lot's of interesting data.

Strive for model independent measurements: ALPS II at DESY!

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Experiments (possibly) located at DESY in Hamburg

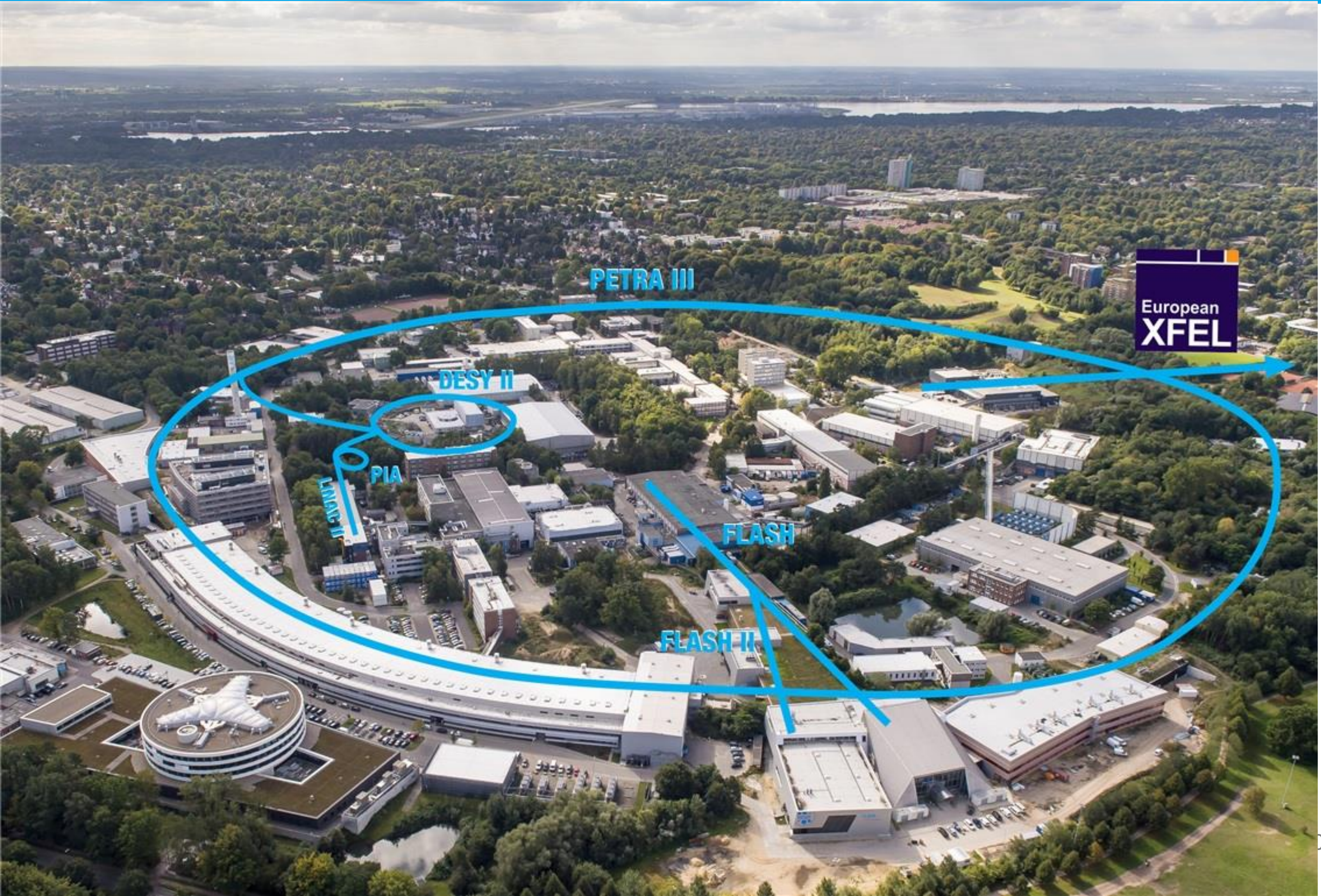
Name	Type	Sens (10^{-11} GeV^{-1})	Location	Status	Reference
ALPS II	LSW	2, m < 0.1 meV	DESY	construction	https://arxiv.org/abs/1302.5647

Name	Type	Sens (10^{-11} GeV^{-1})	Location	Status	Reference
IAXO (babyIAXO)	$g_{a\gamma\gamma}$	0.5, m < 10 meV, axion 1 < m < 3000 meV	DESY	evaluated	https://arxiv.org/abs/1401.3233

Name	Type	ALP / axion mass range	Location	Status	Reference
MADMAX	dish, dielect. booster	Axion, $4 \cdot 10^{-5}$ to $4 \cdot 10^{-4}$ eV	DESY	preparation	https://arxiv.org/abs/1901.07401

These are to be complemented with other experiments (see haloscope mass range for example)!

DESY in Hamburg



Axion physics:

Opportunity to have particle physics experiments on-site complementing participation in remote experiments (ATLAS, CMS, BELLE II).

ALPS II: aiming for “first light” in 2020 @ DESY in HH

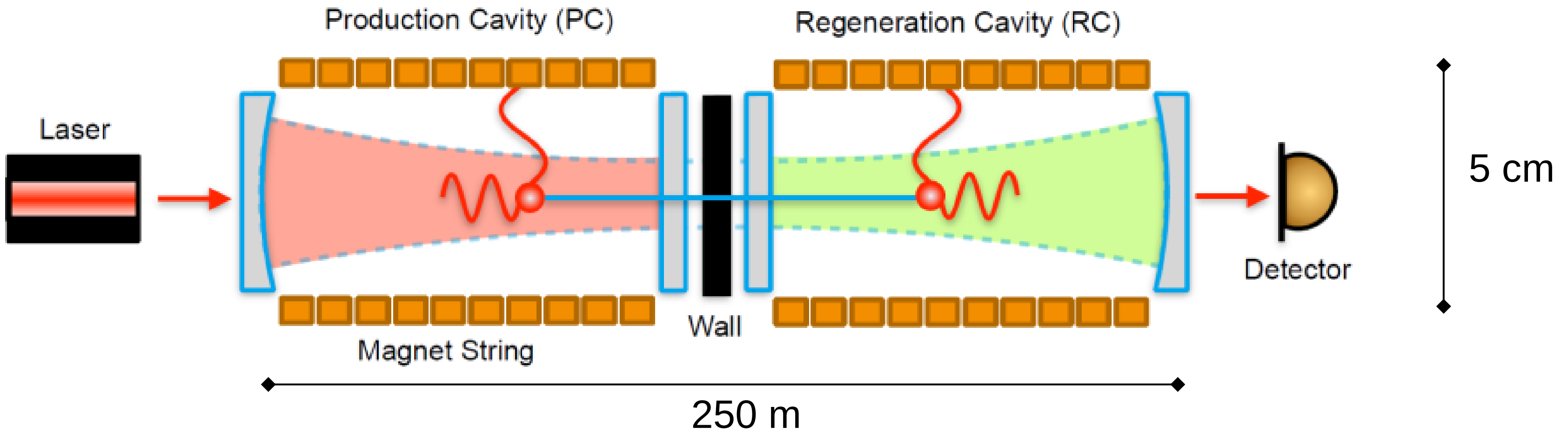
Collaboration

ALPS II main contributions				
Partner	**Magnets**	**Optics**	**Detectors**	**Infrastructure**
DESY	X	X	X	X
AEI Hannover		X		
U. Cardiff		X		
U. Florida		X	X	X
U. Mainz			X	

Significant funding support also by the

HEISING-SIMONS FOUNDATION

ALPS II @ DESY in Hamburg: construction underway!



10+10 dipole magnets from the HERA proton accelerator

Production cavity and regeneration cavity, mode matched

$$P_{\gamma\to\phi\to\gamma} = \frac{1}{16}\cdot\mathcal{F}_{PC}\mathcal{F}_{RC}\cdot(g_{a\gamma\gamma}Bl)^4 = 6\cdot 10^{-38}\cdot\mathcal{F}_{PC}\mathcal{F}_{RC}\cdot\left(\frac{g_{a\gamma\gamma}}{10^{-10}GeV^{-1}}\frac{B}{1\,T}\frac{l}{10m}\right)^4$$

ALPS II main components: magnets from HERA

- 12+12 dipoles from HERA, each 5.3 T on 8.8 m.
- To be straightened to achieve ≈ 50 mm aperture from 35 mm (600 m bending radius)

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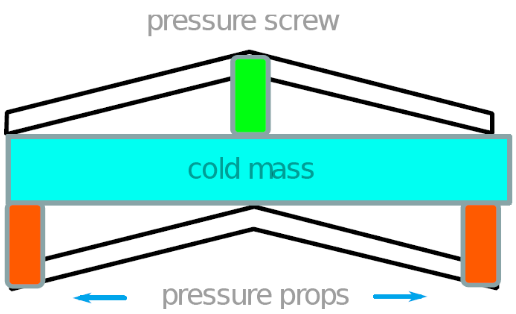
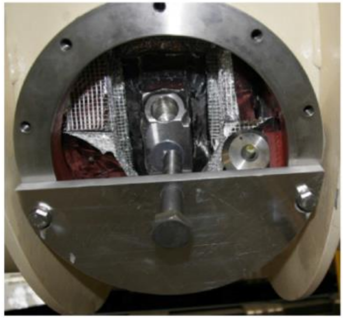
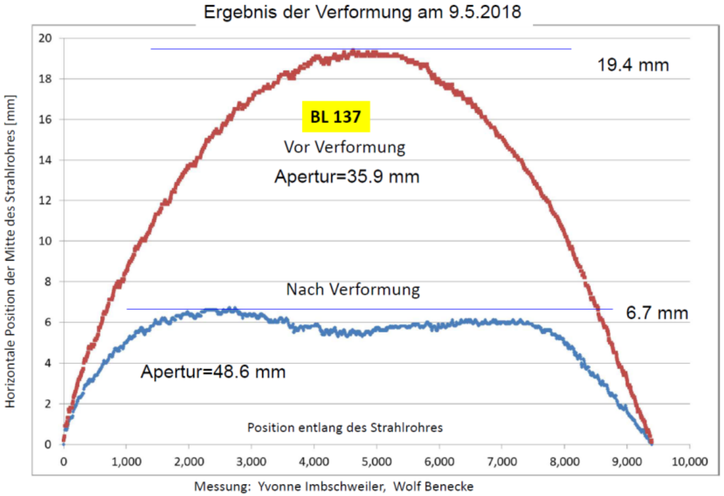
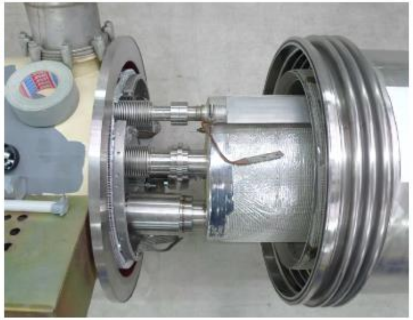






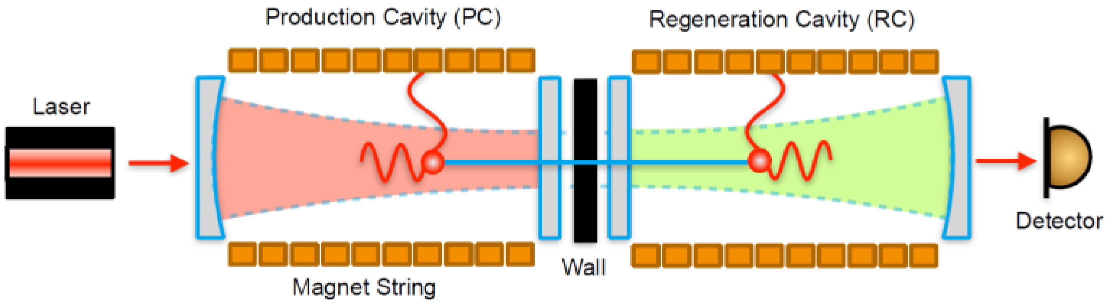
ALPS II main components: magnets from HERA

- 12+12 dipoles from HERA, each 5.3 T on 8.8 m.
- To be straightened to achieve ≈ 50 mm aperture.
- 21 magnets modified successfully (out of 21).
- The HERA tunnel is cleared.



Dieter Trines

ALPS II main components: optics adapted from LIGO



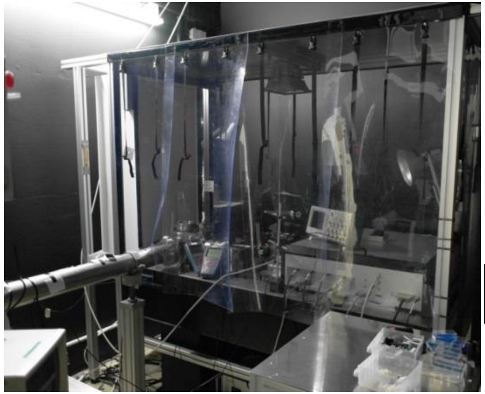
Jan H. Põld
Aaron D. Spector

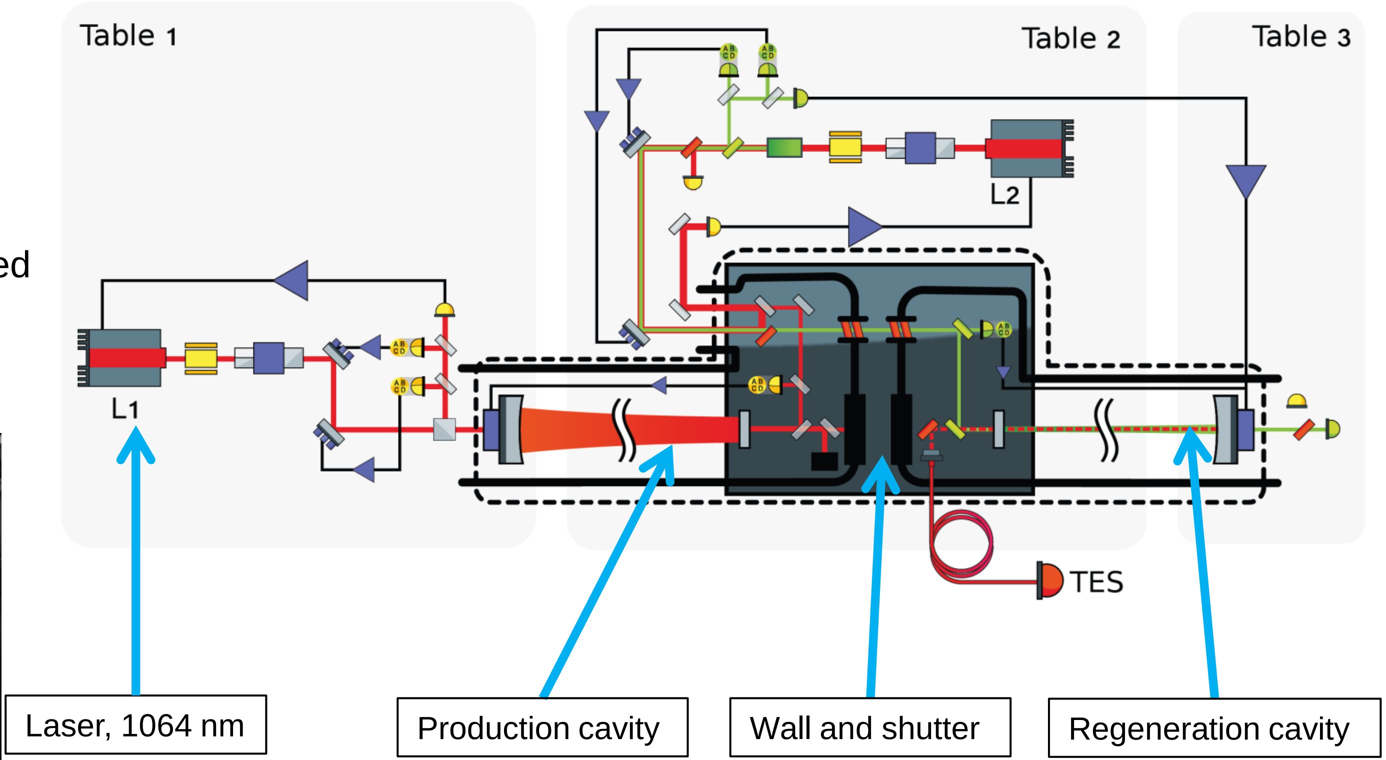
- Mode-matched optical resonators before ("PC") and behind ("RC") the wall.
- Relative angle between PC and RC less than 5 µrad.
- Each about 100 m long, need to compensate seismic noise.
- Power built-up PC: 5,000: 150 kW circulating power.
- Power built-up RC: 40,000: length relative to light wavelength stabilized to 0.5 pm.

ALPS II main components: optics adapted from LIGO

Laser:

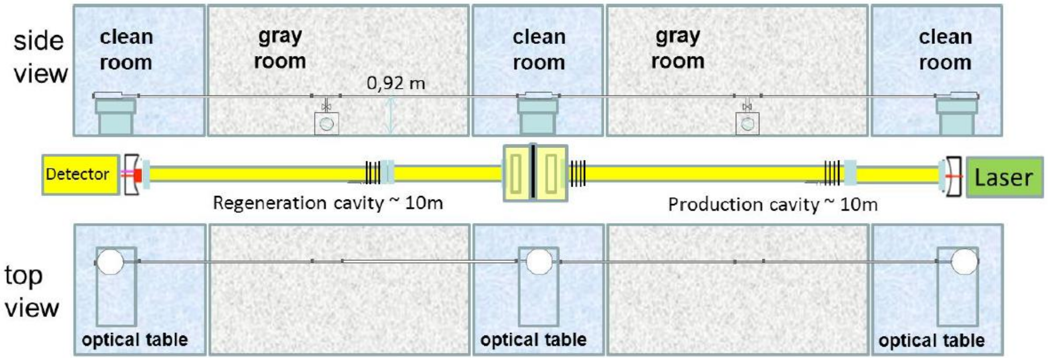
- developed for LIGO,
- based on 2 W NPRO by Innolight/Mephisto (Nd:YAG, neodymium-doped yttrium aluminium garnet),
- 1064 nm, 35 W, $M^2<1.1$

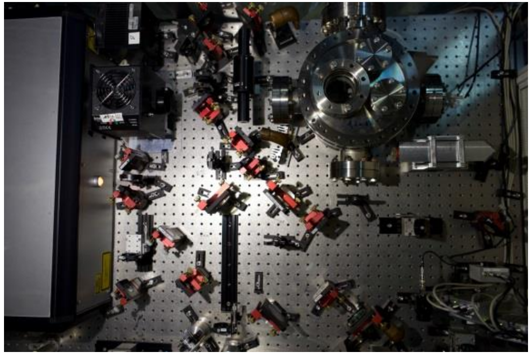


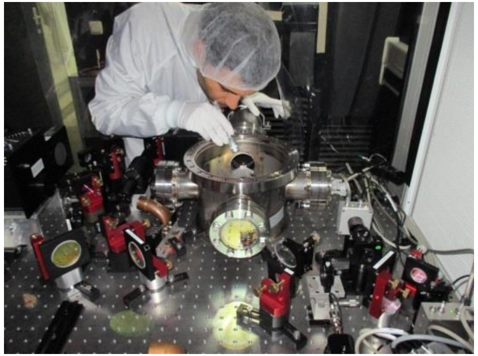


ALPS II main components: optics

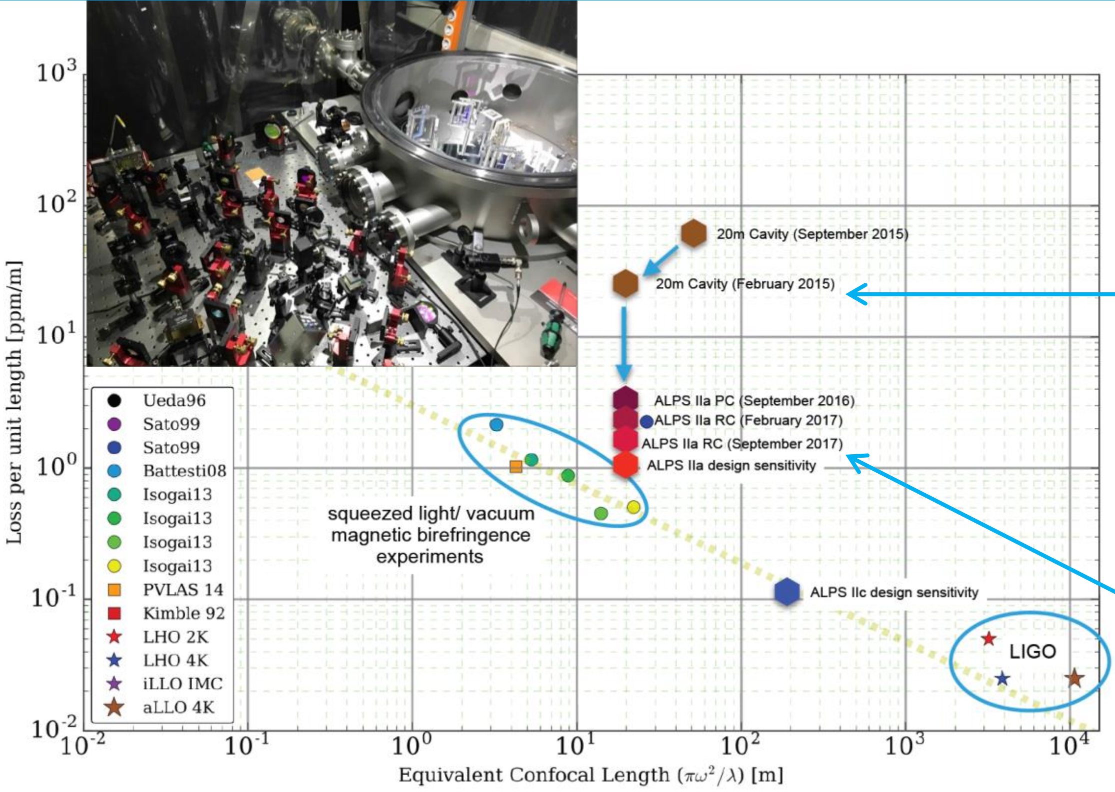
The optics is developed in a 20 m long dedicated lab “ALPS IIa“.



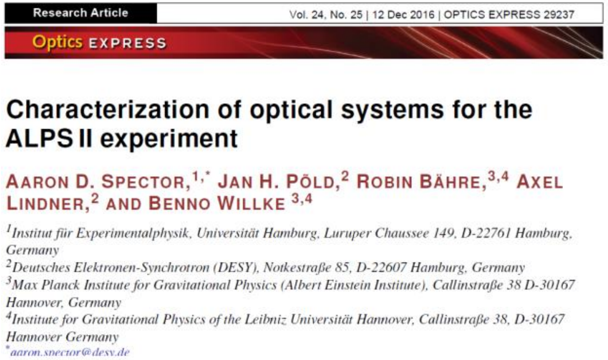




ALPS II main components: optics status summary



plot from LIGO T-1400226-v6



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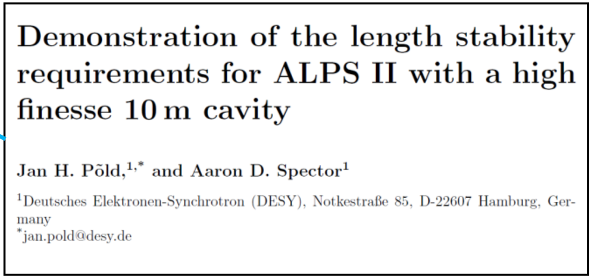
Optics EXPRESS

Characterization of optical systems for the ALPS II experiment

AARON D. SPECTOR,[1,*] JAN H. PÕLD,[2] ROBIN BÄHRE,[3,4] AXEL LINDNER,[2] AND BENNO WILLKE[3,4]

[1]Institut für Experimentalphysik, Universität Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany
[2]Deutsches Elektronen-Synchrotron (DESY), Notkestraße 85, D-22607 Hamburg, Germany
[3]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Callinstraße 38 D-30167 Hannover, Germany
[4]Institute for Gravitational Physics of the Leibniz Universität Hannover, Callinstraße 38, D-30167 Hannover Germany
*aaron.spector@desy.de



Demonstration of the length stability requirements for ALPS II with a high finesse 10 m cavity

Jan H. Põld,[1,*] and Aaron D. Spector[1]

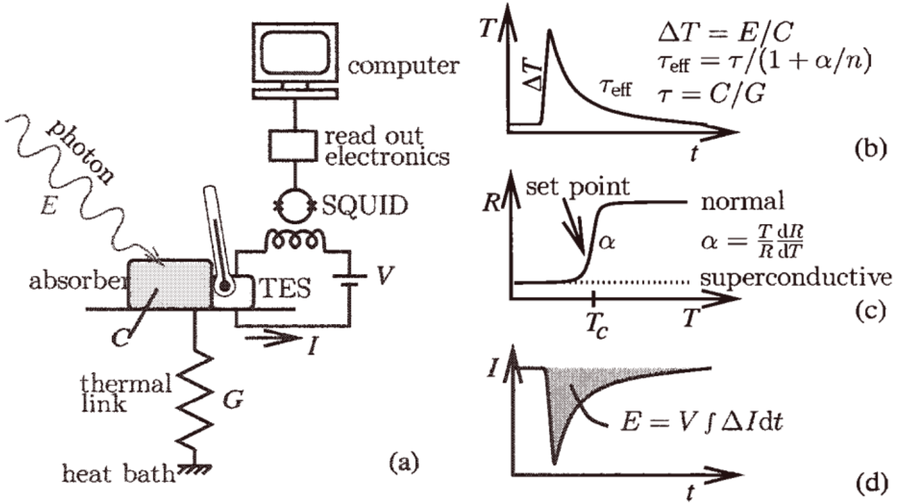
[1]Deutsches Elektronen-Synchrotron (DESY), Notkestraße 85, D-22607 Hamburg, Germany
*jan.pold@desy.de

https://arxiv.org/abs/1710.06634

ALPS II main components: detectors

DESY:

- Transition edge sensor (TES) operated at 80 mK.



$\Delta T \approx 100\ \mu K$

$\Delta R \approx 1\ \Omega$

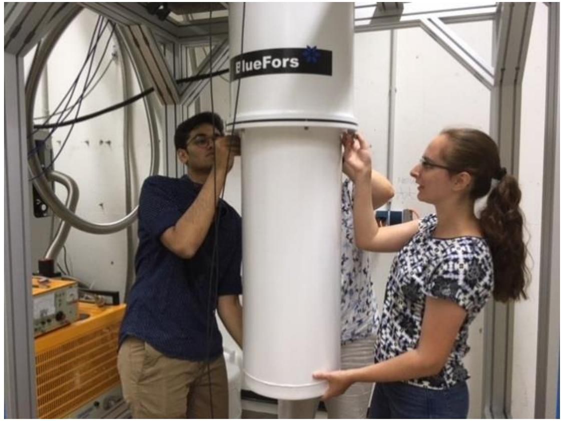
$\Delta I \approx 70\ nA$

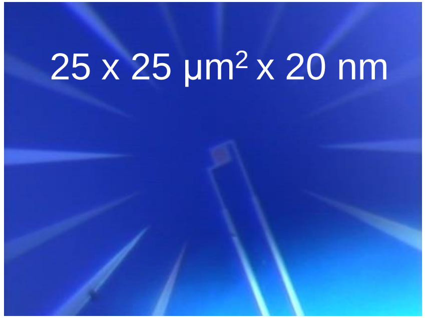
Friederike Januschek

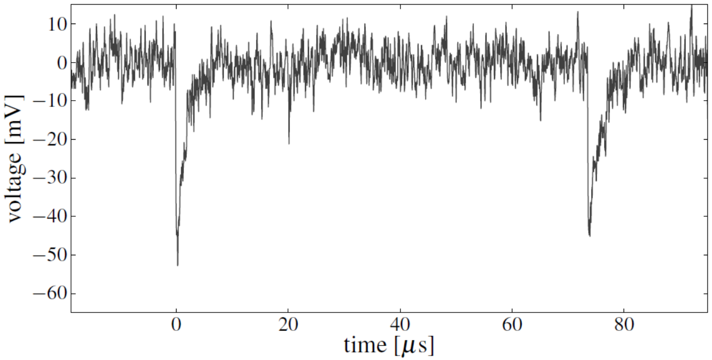
ALPS II main components: detectors

DESY:

- Transition edge sensor (TES) operated at 80 mK.
- Single 1064 nm photon detection demonstrated:
  - 5% energy resolution
  - 10^{-4} counts/s intrinsic background
- R&D is resuming with a new cryostat in summer 2018.







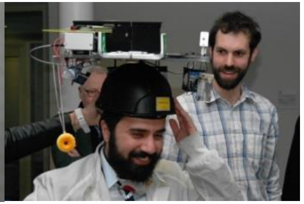
ALPS II @ DESY in Hamburg

Results and schedule

Results:

- Axions and ALPs:
  none (no data run yet …)
- Publications:
  5 on optics and detector developments;
  several conference contributions.
- People (since 2012):
  8 Ph.D. theses completed,
  about 6 to come,
  5 postdocs left for a next career step.

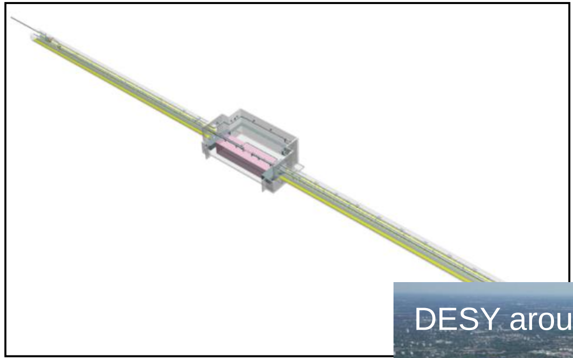
Jan Dreyling-Eschweiler

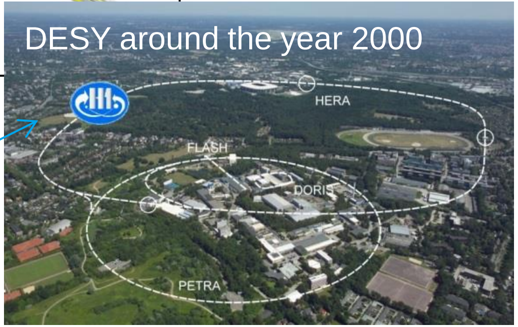


Reza Hodajerdi

Schedule and site:

- Start data taking in the HERA tunnel in 2020.

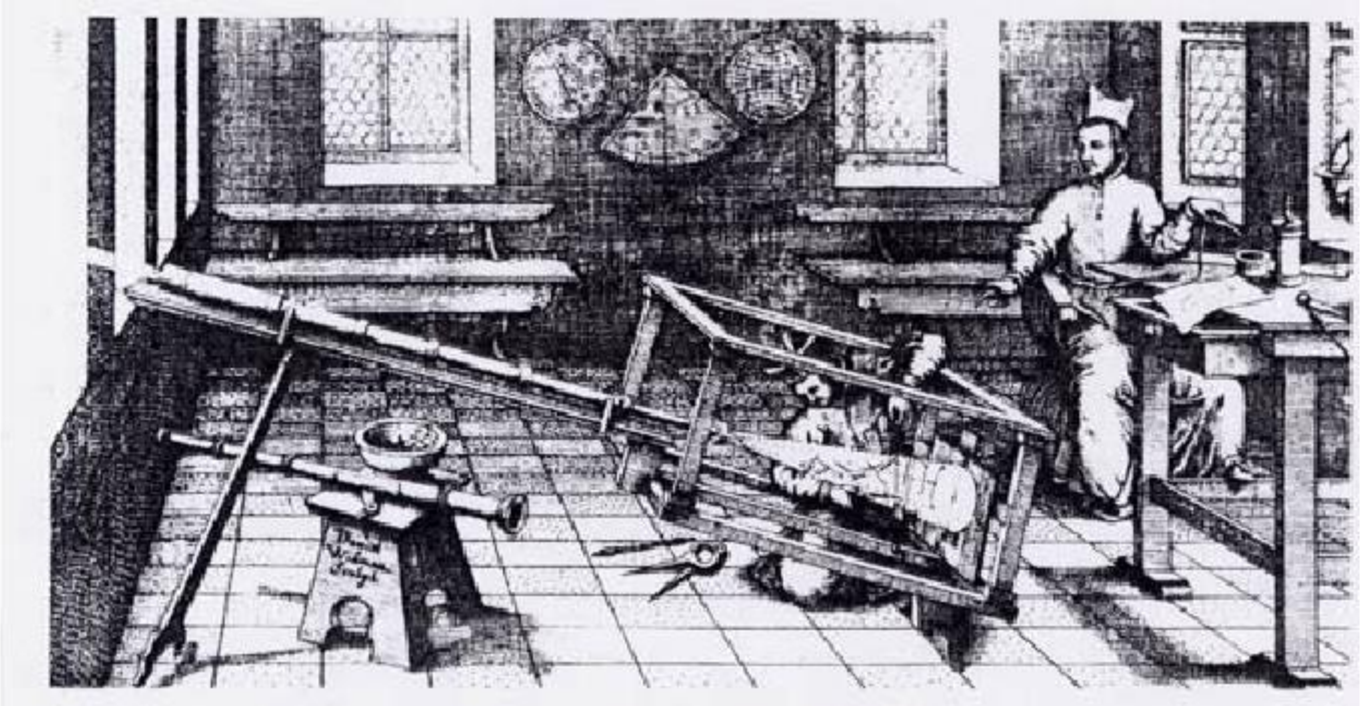




HERA hall North
(former H1 experiment at HERA)

Axions from the sun

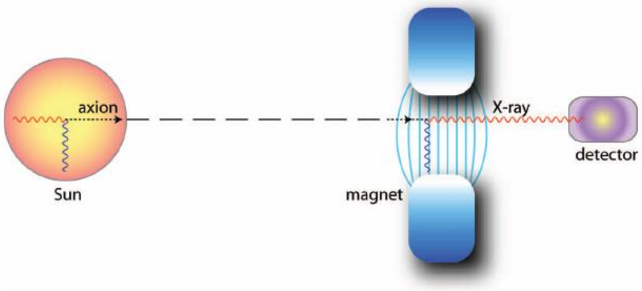
Helioscopes

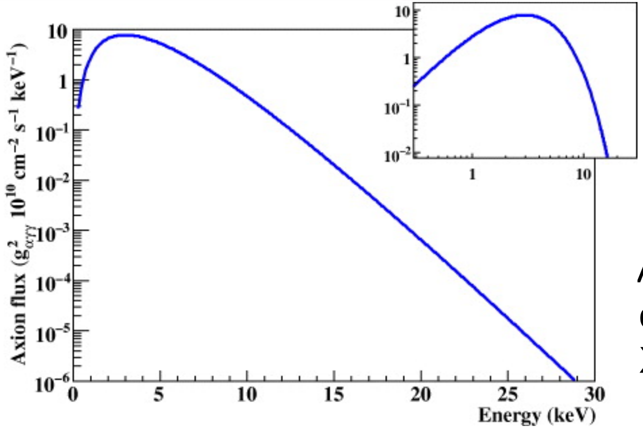


Father Christoph Scheiner
(1575 – 1650)

Axions from the sun: CAST at CERN

LHC prototype magnet pointing to the sun.



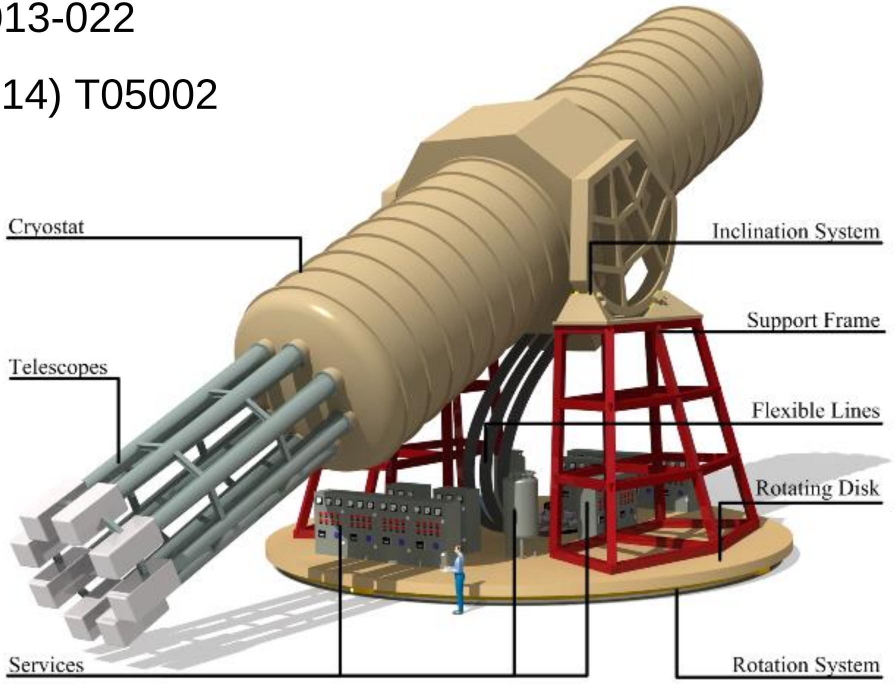


Axions or ALPs from the center of the sun would come with X-ray energies, thermal spectrum.

International Axion Observatory IAXO

Baseline

- IAXO Letter of Intent: CERN-SPSC-2013-022
- IAXO Conceptual Design: JINST 9 (2014) T05002



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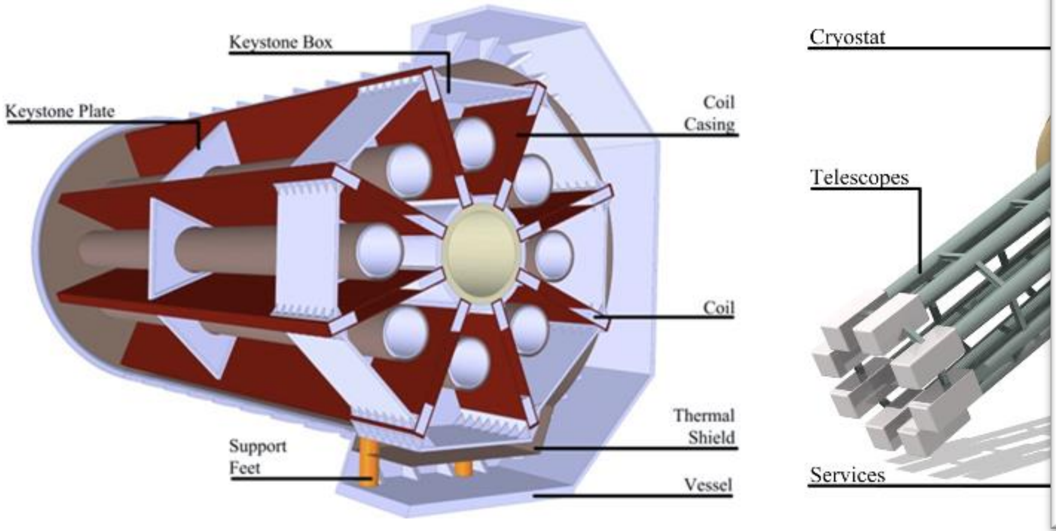


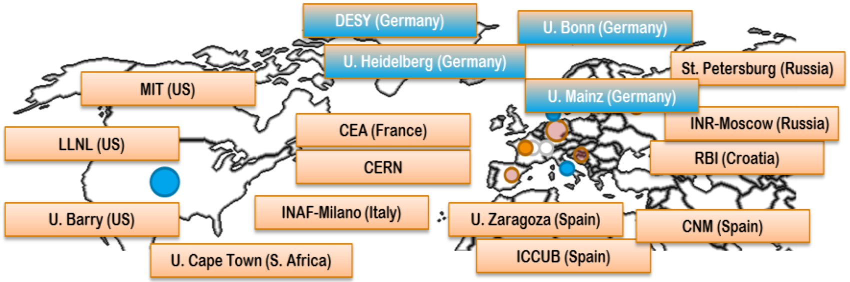
Property		*Value*
Cryostat dimensions:	Overall length (m)	25
	Outer diameter (m)	5.2
	Cryostat volume (m^3)	~ 530
Toroid size:	Inner radius, R_{in} (m)	1.0
	Outer radius, R_{out} (m)	2.0
	Inner axial length (m)	21.0
	Outer axial length (m)	21.8
Mass:	Conductor (tons)	65
	Cold Mass (tons)	130
	Cryostat (tons)	35
	Total assembly (tons)	~ 250
Coils:	Number of racetrack coils	8
	Winding pack width (mm)	384
	Winding pack height (mm)	144
	Turns/coil	180
	Nominal current, I_{op} (kA)	12.0
	Stored energy, E (MJ)	500
	Inductance (H)	6.9
	Peak magnetic field, B_p (T)	5.4
	Average field in the bores (T)	2.5
Conductor:	Overall size (mm^2)	35 × 8
	Number of strands	40
	Strand diameter (mm)	1.3
	Critical current @ 5 T, I_c (kA)	58
	Operating temperature, T_{op} (K)	4.5
	Operational margin	40%
	Temperature margin @ 5.4 T (K)	1.9
Heat Load:	at 4.5 K (W)	~150
	at 60-80 K (kW)	~1.6

International Axion Observatory IAXO

Summary

Collaboration:

- 17 Institutes from 8 countries.
- Formal collaboration founding 03 July 2017 at DESY.
- DESY has offered to host IAXO.

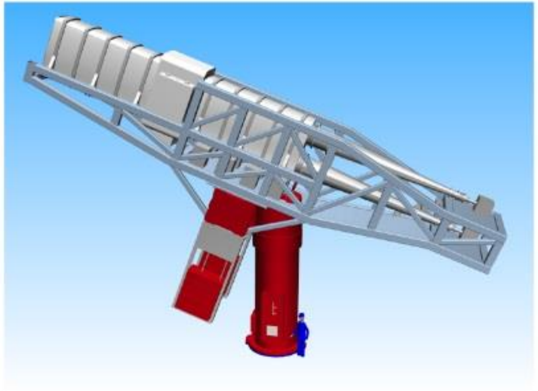


Experiment:

- Motivation:
  explore a well motivated axion parameter region (for example stellar evolutions) not accessible by other techniques.
- Approach:
  use experience gained at CAST (CERN) to optimize solar axion searches with dedicated magnets, X-ray optics and detectors.
- Timeline:
  prototype ready in 2021.
- Location:
  several options at DESY in Hamburg.

International Axion Observatory IAXO

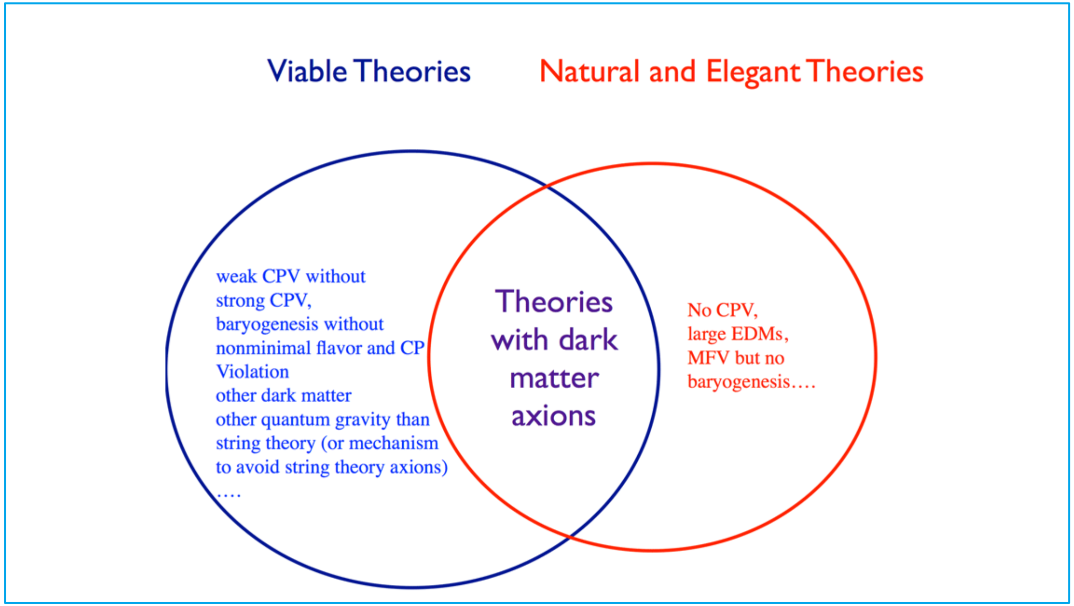
From babyIAXO to the full experiment



Free bore [m]	0.6
Magnetic length [m]	10
Field in bore [T]	2.5
Stored energy [MJ]	27
Peak field [T]	4.1

Dark matter axions

Haloscopes



Ann Nelson, University of Washington

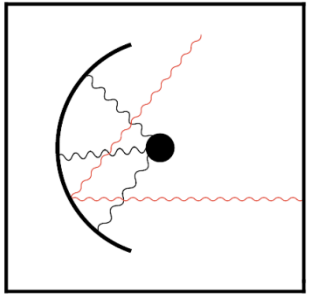
MAgnetized Disc and Mirror Axion eXperiment

Principle

Dish antenna: dark matter axions might convert to photons at the surface of a magnetic mirror.

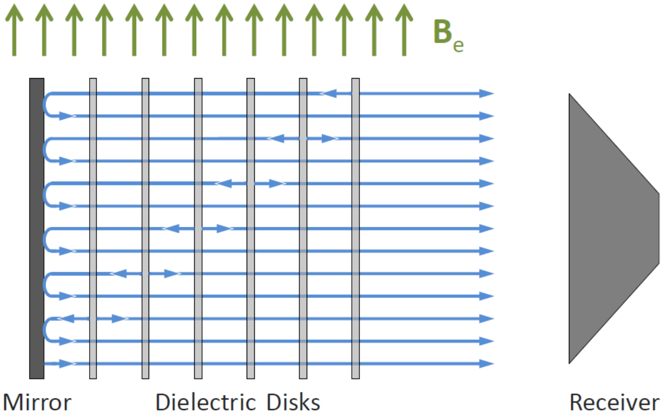
- The discontinuity of ε causes reflection.
- Such photons are emitted perpendicular to the surface.

D. Horns et al, JCAP04(2013)016



MADMAX: combines the dish antenna with a tunable resonating structure out of dielectric disks to boost the axion-photon conversion probability.

- Balance bandwidth and boost factor.
- Access dark matter mass range not reachable with techniques (microwave cavities).



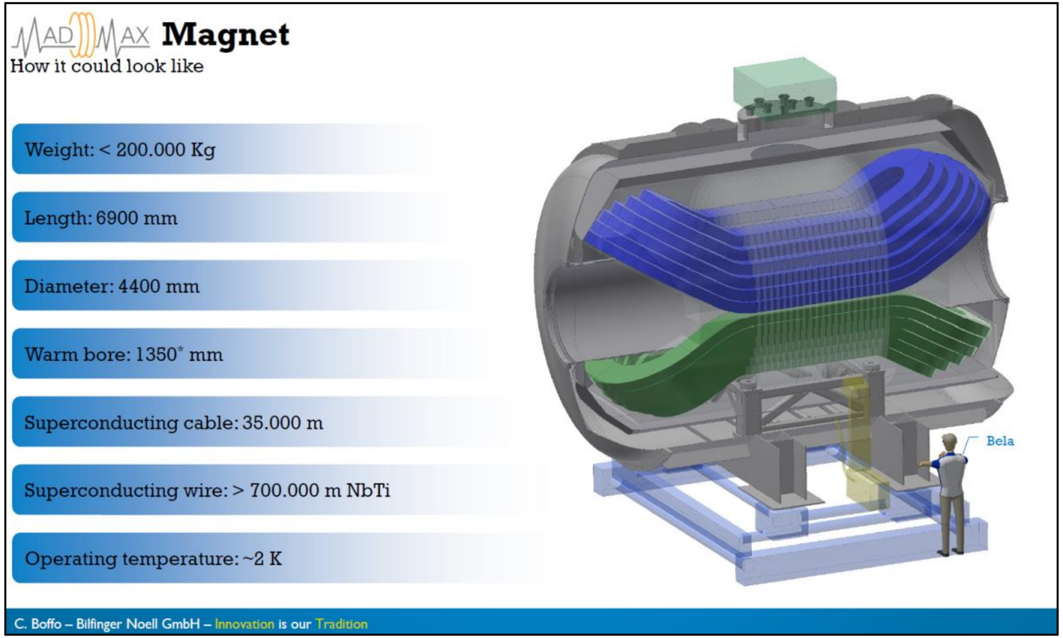
A. J. Millar et al., JCAP 061 (2017)

MAgnetized Disc and Mirror Axion eXperiment

R&D

Critical items:

- provide a large aperture strong dipole magnet to host the “booster” (dielectric disks).

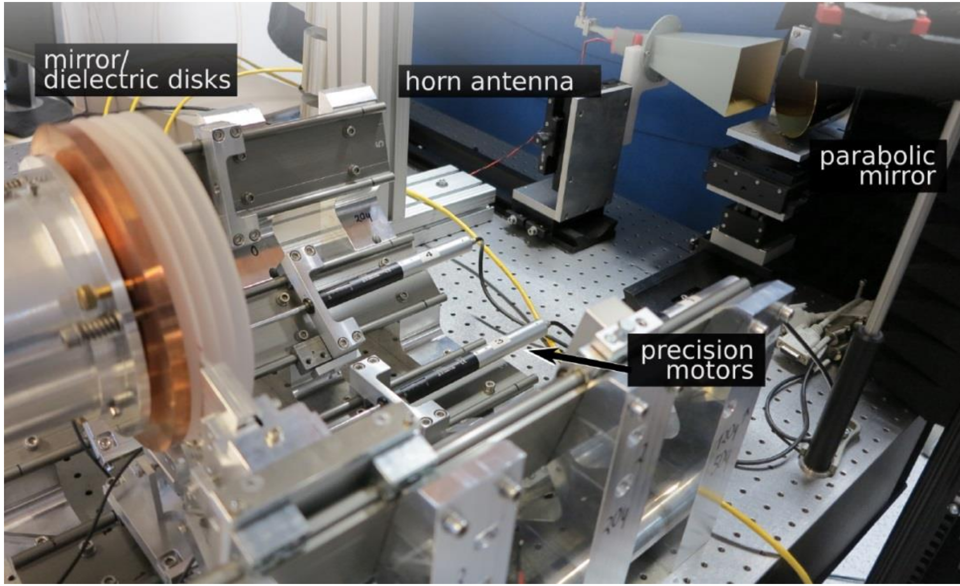


Studies ongoing by Bilfinger-Noell and CEA Saclay.

R&D

Critical items:

- provide a large aperture strong dipole magnet to host the “booster” (dielectric disks).
- Understand and construct the “booster”.
    - Up to 80 Sapphire or $LaAlO_3$ discs with $A=1m^2$ to be positioned with µm accuracy on 2 m.



Test setup at MPI Munich

MAgnetized Disc and Mirror Axion eXperiment

R&D

Critical items:

- provide a large aperture strong dipole magnet to host the “booster” (dielectric disks).
- Understand and construct the “booster”.
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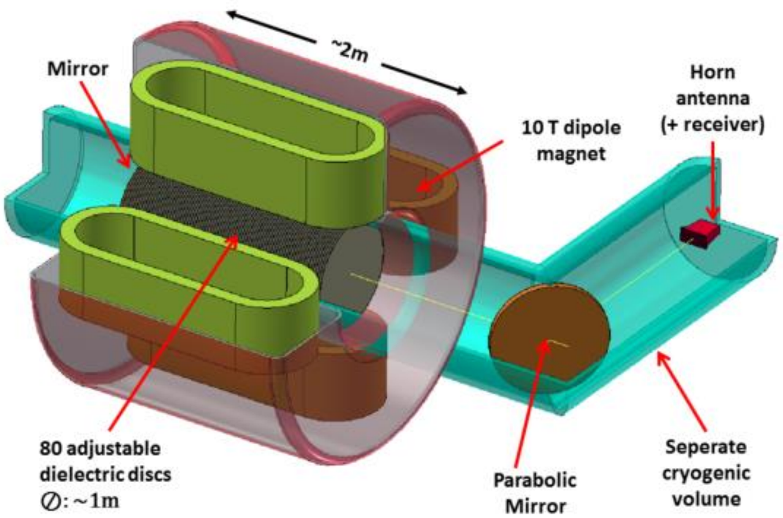

MAgnetized Disc and Mirror Axion eXperiment

Status

Collaboration:

- 8 Institutes from 3 countries.
- Formal collaboration founding 20 October 2017 at DESY.

Experiment:

- Motivation:
  look for well motivated axion dark matter (for example “SMASH”) in a mass region not accessible by present techniques.
- Approach:
  install a tunable “booster” of 80 dielectric disks inside a 2 m long dipole magnet providing $B^2 \cdot A = 100\ T^2m^2$.
- Timeline:
  prototype ready in 2022.
- Location:
  next to ALPS II in HERA North, funding proposal for infrastructure approved by Helmholtz.

Summary

Axion and axion-like particle physics

- is very well motivated by theory, cosmology and astro(particle)physics,
- ALPS II will be the first experiment probing the astrophysics hints on ALPs.

ALPS II

- construction has started aiming for “first light” in 2020
  to probe the hints for “beyond standard model physics” from astrophysics.

With IAXO and MADMAX in addition

- DESY might become (also) a center for experimental axion physics with
- some risks, but potentially high rewards!