Axions and the like with an emphasis on ALPS-II.

Light particles beyond the Standard Model from broken symmetries

Babette Döbrich
International Niccolo Cabeo School
Ferrara, May 21st 2014

Outline

> Brief intro to Axions & Axion cosmology

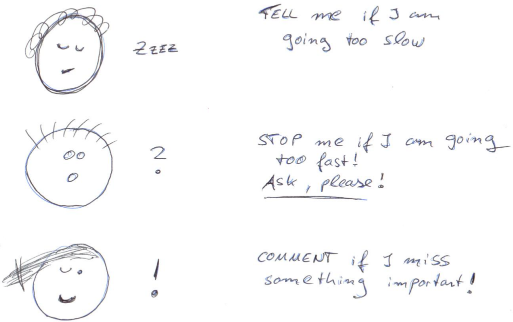
> Other light weakly interacting stuff & the search for them

> An example: the ALPS-II experiment

> More on selected ultralight Dark Matter setups

> Take home

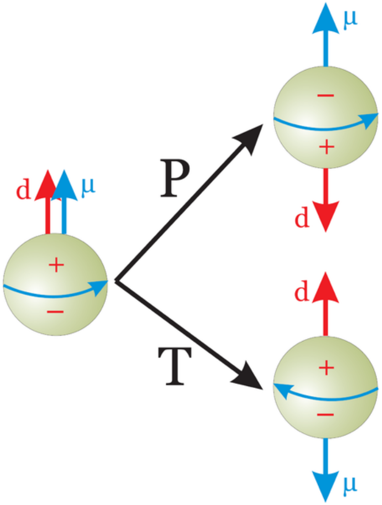
First things first: Niccolo Cabeo SCHOOL



Disclaimer

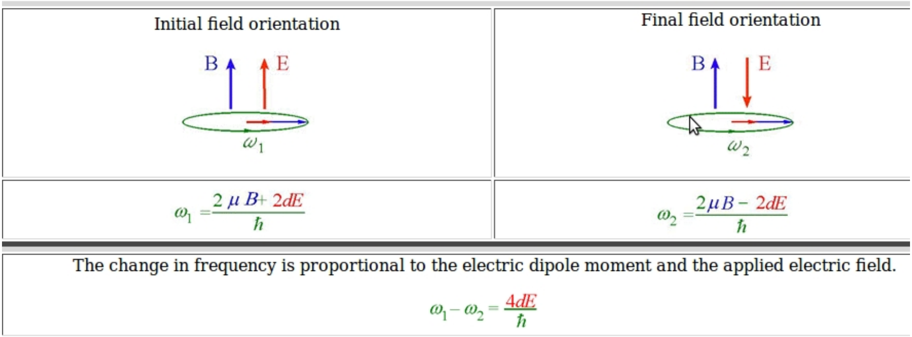
- I am no expert in all I say (e.g. cosmology) → refs
- school → profit for everybody (including me ;-))

Axions in brief see, e.g. Weinberg QFT Vol. II, & Raffelt: Stars as lab. & 0807.3125



- through non-trivial vacuum: QCD embodies the so-called Θ term: $\mathcal{L}_\Theta \sim \Theta \alpha_s G^a_{\mu\nu} \tilde{G}^{a,\mu\nu}$ cf. S. Scherer lecture
- with electroweak contribution $\bar{\Theta} = \Theta + \mathrm{Arg}\det M$, M quark mass matrix
- physical observable: Neutron EDM ($\vec{E}^a \vec{B}^a$ is CP violating)

Axions in brief see, e.g. Weinberg QFT Vol. II, & Raffelt: Stars as lab. & 0807.3125



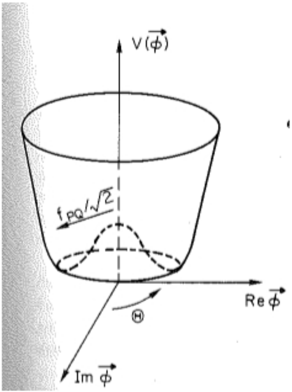
- via Lamor precession: $|d_\mathrm{n}| \lesssim 10^{-26} e$cm, but naively much larger $e/2m_N \sim 10^{-14} e$cm
- $\rightarrow \bar{\Theta} \lesssim 10^{-10} \rightarrow$ **naturalness problem** ($\bar{\Theta}$ is a sum and $M_{ij} \neq 0$)

graphic taken from

http://oldwww.phys.washington.edu/users/wcgriff/romalis/EDM/

Axions in brief see, e.g. Weinberg QFT Vol. II, & Raffelt: Stars as laboratory & 0807.3125

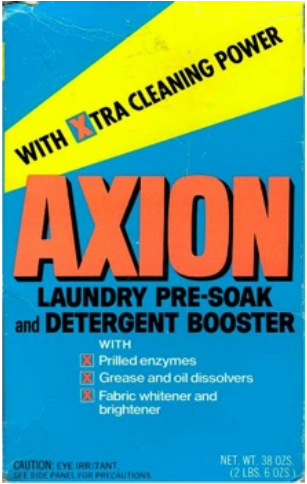
[Figure taken from Kolb/Turner]



- make $\bar{\Theta} \equiv a(x)/f_a$ dynamical and it relaxes to zero through potential

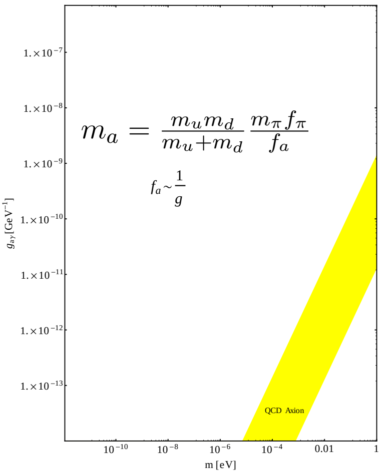
  Peccei & Quinn, 77

- can be realized if a global $U(1)_{\mathrm{PQ}}$ is spontaneously broken, the axion is the phase (Goldstone boson) of this symmetry Weinberg, Wilczek, 78



- make $\bar{\Theta} \equiv a(x)/f_a$ dynamical and it relaxes to zero through potential
  Peccei & Quinn, 77
- can be realized if a global $U(1)_{\mathrm{PQ}}$ is spontaneously broken, the axion is the phase (Goldstone boson) of this symmetry Weinberg, Wilczek, 78
- originally: $f_a \sim$ electroweak, quickly excluded e.g. astrophysical
- 'invisible axion models': KSVZ (no tree level coupl to e^-) and DFSZ

Axions in brief see, e.g. Weinberg QFT Vol. II, & Raffelt: Stars as laboratory & 0807.3125

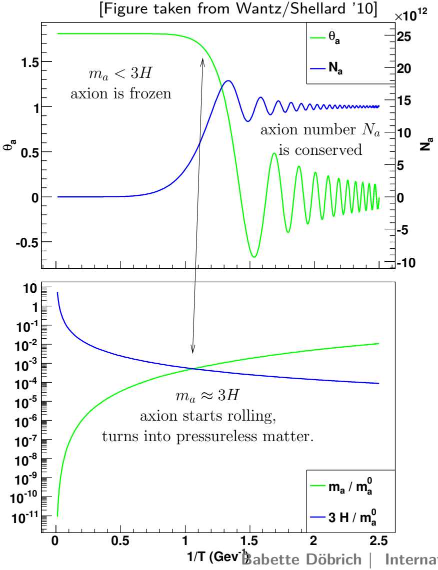


[good reading: 9506229 Sikivie's Pooltable]

- make $\bar{\Theta} \equiv a(x)/f_a$ dynamical and it relaxes to zero through potential

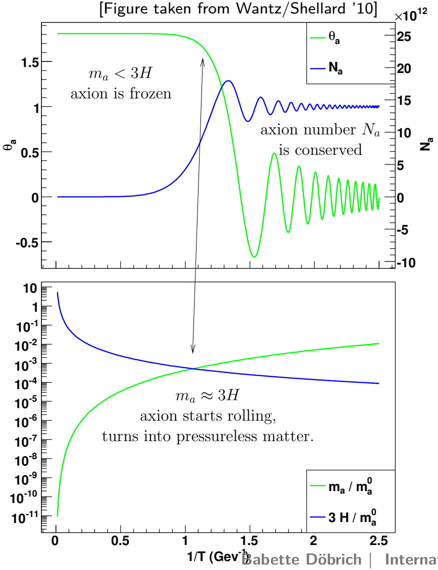
  Peccei & Quinn, 77
- can be realized if a global $U(1)_{\rm PQ}$ is spontaneously broken, the axion is the phase (Goldstone boson) of this symmetry Weinberg, Wilczek, 78
- originally: $f_a \sim$ electroweak, quickly excluded e.g. astrophysical
- 'invisible axion models': KSVZ (no tree level coupl to e^-) and DFSZ
- $m \sim 1/f_a \rightarrow$ pseudo-Goldstone boson (explicit symmetry breaking)
- couple to photons through quark $\triangle$

Axion cosmology in brief see, e.g. Kolb & Turner: Early universe



- $\ddot{\Theta} + 3H\dot{\Theta} + m^2(T)\Theta = 0 \rightarrow$ EOS non-rel DM
- low m Axion $\rightarrow$ CDM candidate (lifetime > age of universe) misalignment

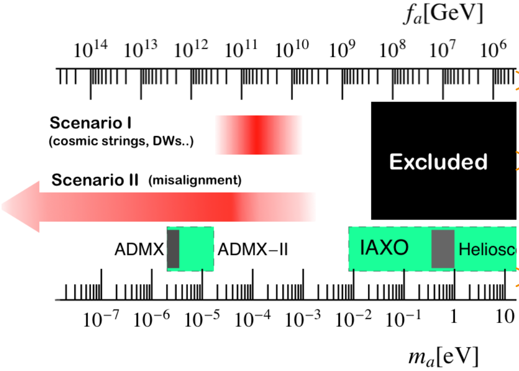
Axion cosmology in brief see, e.g. Kolb & Turner: Early universe



- $\ddot{\Theta} + 3H\dot{\Theta} + m^2(T)\Theta = 0 \rightarrow$ EOS non-rel DM
- low m Axion $\rightarrow$ CDM candidate (lifetime > age of universe) misalignment
- DM abundance dep. on Θ_{initial} (free in principle)

Axion cosmology in brief see, e.g. Kolb & Turner: Early universe

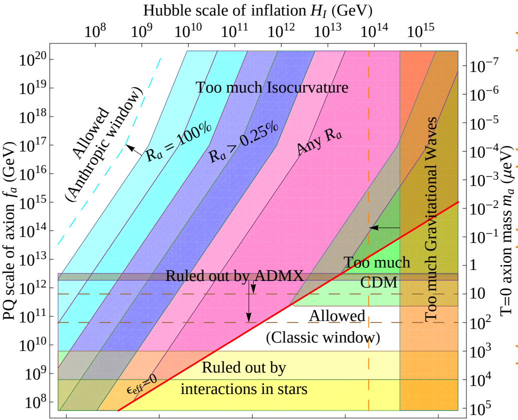
[Figure taken from 1311.5341]



- $\ddot{\Theta} + 3H\dot{\Theta} + m^2(T)\Theta = 0 \rightarrow$ EOS non-rel DM
- low m Axion $\rightarrow$ CDM candidate (lifetime $>$ age of universe) misalignment
- DM abundance dep. on Θ_{initial} (free in principle)
- crucial: phase transition f_a can in principle occur before or after inflation $H_I/(2\pi)$
- omitted: axionic strings, domain walls

Axion cosmology in brief see, e.g. Kolb & Turner: Early universe

[Figure taken from Hertzberg et al '08]



red line $f_a = H_I/(2\pi)$

when H_I known $\rightarrow$ small prefered region

- $\ddot{\Theta} + 3H\dot{\Theta} + m^2(T)\Theta = 0 \rightarrow$ EOS non-rel DM
- low m Axion $\rightarrow$ CDM candidate (lifetime > age of universe) misalignment
- DM abundance dep. on Θ_{initial} (free in principle)
- crucial: phase transition f_a can in principle occur before or after inflation $H_I/(2\pi)$
- omitted: axionic strings, domain walls
- isocurvature, H_I from BICEP2 $\rightarrow$ constraints (literature manifold)

Outline

> Brief intro to Axions & Axion cosmology

> Other light weakly interacting stuff & the search for them

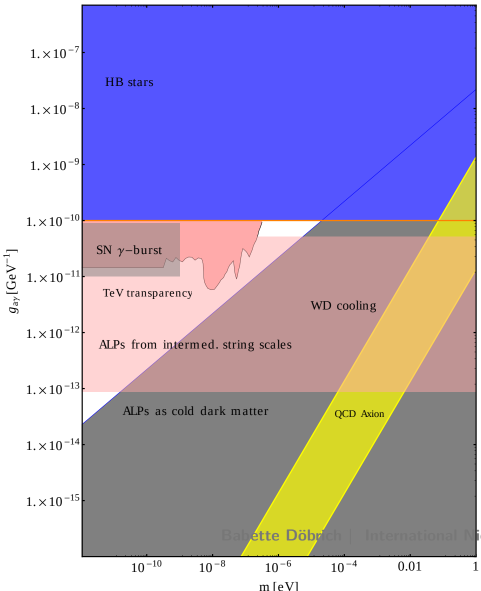
> An example: the ALPS-II experiment

> More on selected ultralight Dark Matter setups

> Take home

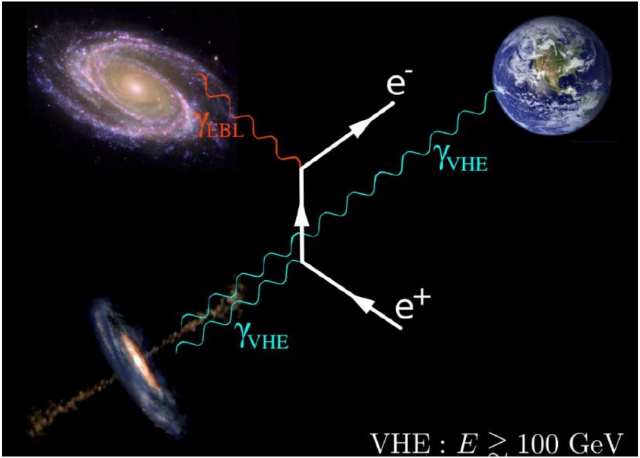
Pseudoscalar coupling plane: Axions and ALPs

[excerpt pseudoscalar γ coupling plane]



- Focus on $g_{\phi\gamma}$
  $\mathcal{L}_{\mathrm{int,PS}} \sim g_{\phi\gamma}\phi\, F_{\mu\nu}\tilde{F}^{\mu\nu}$
- PS-Photon coupling many constrains already, **external field needed** $\sim g\phi\vec{E}\vec{B}$
- QCD Axion, m_a & g tied, is a hard nut to crack, coupling tiny
- (m, g)-plane: axion-*like* particles (other broken sym, extra DOFs strings)
  - astrophysics indic.: TeV γs $\rightarrow$ next slide [1302.1208] + White Dwarf cooling hint [1204.3565],[1304.7652]

‘TeV transparency’



Pic: courtesy of M.Meyer

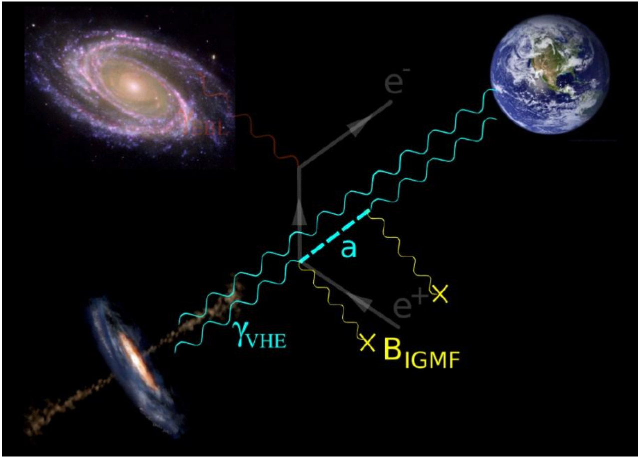
e.g. [1302.1208]

EBL acts as ‘wall’!

EBL=extragalactic ba

background light

‘TeV transparency’



Pic: courtesy of M.Meyer

e.g. [1302.1208]

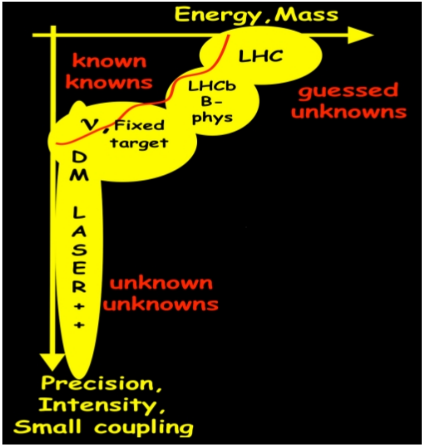
EBL acts as ‘wall’!

ALPs can traverse!

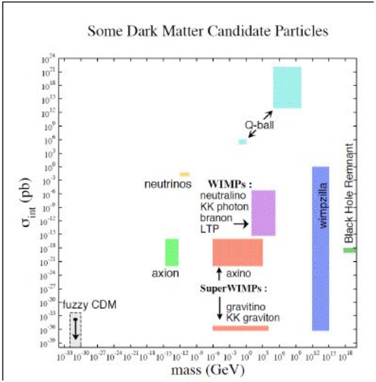
Other weakly interacting slim particles (WISPs)

Physics beyond SM needed
DM, DE, QG...

[courtesy of J.Jaeckel]

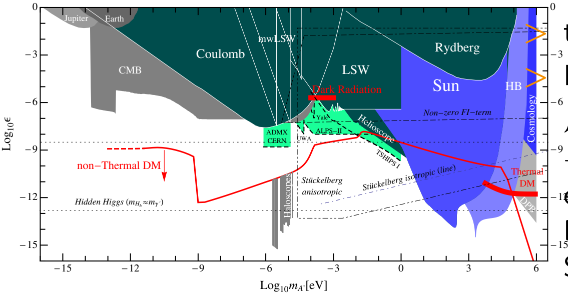


> axions and ALPs dubbed 'WISPs' [1311.0029]
> typically class of experiments



[taken from]

Other weakly interacting slim particles (WISPs)



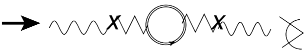
- axions and ALPs dubbed 'WISPs' [1311.0029]
- typically class of experiments
- Hidden/Dark Photons

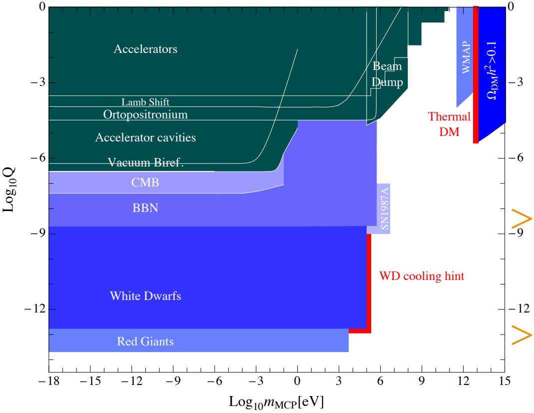
$$\mathcal{L} \sim \chi F_{\mu\nu} X^{\mu\nu} + \frac{m_{\tilde{\gamma}}^2}{2} X_\mu X^\mu$$

$\rightarrow$ extra U(1) with mass, experimentally **no need for B-fields**, oscillation process, Stückelberg or Hidden Higgs

- HPs e.g. from string scenarios [1206.0819], vector DM possible [1201.5902]

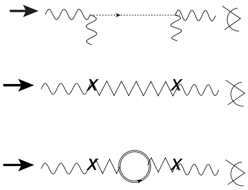
Other weakly interacting slim particles (WISPs)





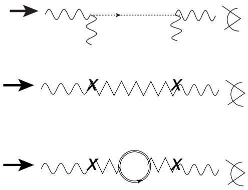
- axions and ALPs dubbed 'WISPs' [1311.0029]
- typically class of experiments
- Hidden/Dark Photons
  $\mathcal{L} \sim \chi F_{\mu\nu}X^{\mu\nu} + \frac{m^2_{\tilde{\gamma}}}{2}X_\mu X^\mu$
  $\rightarrow$ extra U(1) with mass, experimentally **no need for B-fields**, oscillation process, Stückelberg or Hidden Higgs
- HPs e.g. from string scenarios [1206.0819], vector DM possible [1201.5902]
- minicharged particles
  $\mathcal{L}_{\mathrm{int}} \sim e\bar{\psi}\not{A}\psi + e_{\mathrm{h}}\bar{h}\not{X}h$,
  minicharge $Q = \chi e_h/e$

experimental focus: photon-WISP vertices



- paradigmatic example with B-field: Axion/ALP, MCPs
- paradigmatic example without B-field: hidden photon

experimental focus: photon-WISP vertices



> paradigmatic example with B-field: Axion/ALP, MCPs

> paradigmatic example without B-field: hidden photon

> more? chameleons [1306.4326] & light scalar particles of massive gravity (connected to Dark Energy?)

Shining Light on Modifications of Gravity

Philippe Brax,[1] Clare Burrage[2] and Anne-Christine

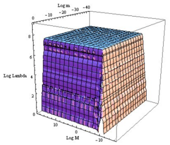
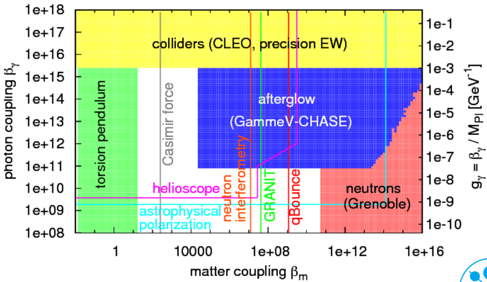
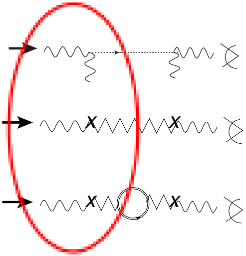


Figure 3. The constraint of the ALPS experiment on the m, M, Λ parameter space. All regions below the surface are excluded. The parameters are measured in units of GeV.

In Figure 3 the constraint of the ALPS experiment is shown in the three dimensional parameter space (m, M, Λ). We see th... almost all of the interesting range the constraint on Λ is that of the conformally coupled axion-like particle case $\Lambda \lesssim 10$ GeV.



experimental focus: photon-WISP vertices



Shining Light on Modifications of Gravity

Philippe Brax,[1] Clare Burrage[2] and Anne-Christine

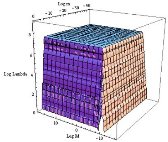
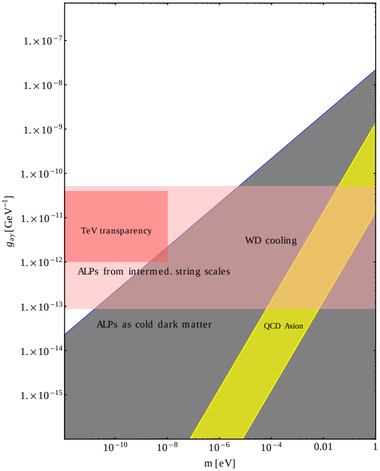


Figure 3. The constraint of the ALPS experiment on the m, M, Λ parameter space. All regions below the surface are excluded. The parameters are measured in units of GeV.

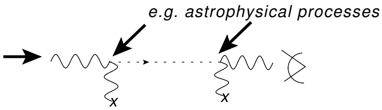
In Figure 3 the constraint of the ALPS experiment is shown in the three dimensional parameter space (m, M, Λ). We see that in almost all of the interesting range the constraint on Λ is that of the conformally coupled axion-like particle case $\Lambda \lesssim 10$ GeV.

- paradigmatic example with B-field: Axion/ALP, MCPs
- paradigmatic example without B-field: hidden photon
- more? chameleons [1306.4326] & light scalar particles of massive gravity (connected to Dark Energy?)
- experimental access through essentially four basic categories: differ in origin of the observed photon



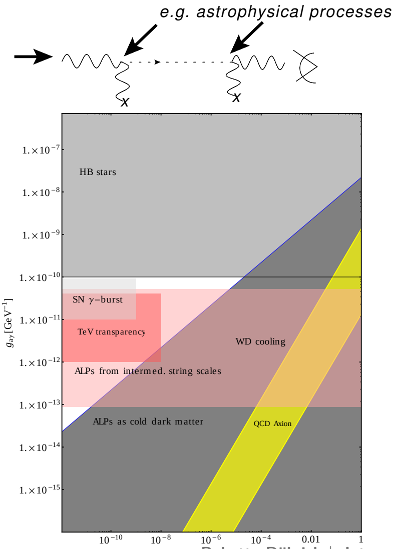
- paradigmatic example with B-field: Axion/ALP, MCPs
- paradigmatic example without B-field: hidden photon
- more? chameleons [1306.4326] & light scalar particles of massive gravity (connected to Dark Energy?)
- experimental access through essentially four basic categories: differ in origin of the observed photon
- in the following, focus on *part of ALP parameter space* for clarity, pointing out just some examples

1) WISP/Axion Limits from astro/cosmo



- exploit astro/cosmo phenomena, e.g. stellar evolution, CMB imprints... [→ G.G. Raffelt]
  - ☺ access to disjunct & remote parts of parameter space
  - ☹ indirect probe, sometimes model dependent

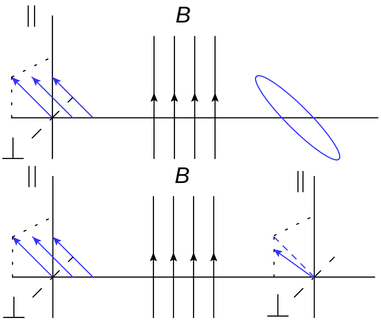
1) WISP/Axion Limits from astro/cosmo



- exploit astro/cosmo phenomena, e.g. stellar evolution, CMB imprints... [→ G.G. Raffelt]
  - ☺ access to disjunct & remote parts of parameter space
  - ☹ indirect probe, sometimes model dependent
- paradigmatic: SN γ-burst 1987 excludes part of the TeV transparency hint
- HB stars (stellar evolution) wide parameter range (stars would cool too quickly)

1) WISP/Axion Limits from astro/cosmo

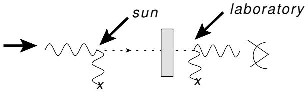
virtual intermediate particles



real intermediate particles

- exploit astro/cosmo phenomena, e.g. stellar evolution, CMB imprints... [→ G.G. Raffelt]
  - ☺ access to disjunct & remote parts of parameter space
  - ☹ indirect probe, sometimes model dependent
- paradigmatic: SN γ-burst 1987 excludes part of the TeV transparency hint
- HB stars (stellar evolution) wide parameter range (stars would cool too quickly)
- polarization of quasars e.g. [1309.6114], recall $\mathcal{L} \sim g\phi\vec{E}\vec{B}$ (also labrelevant)
- ...

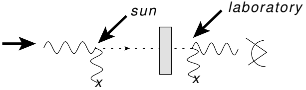
2) WISPs/Axions from our sun (Helioscopes)

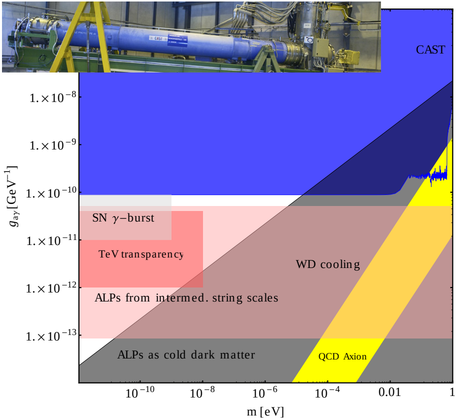


- natural photon source: sun
  → Helioscope [Sikivie '83]

see cast.web.cern.ch/CAST

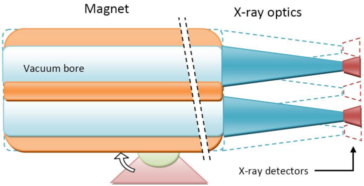
2) WISPs/Axions from our sun (Helioscopes)

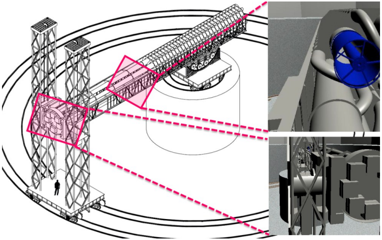




- natural photon source: sun
  $\rightarrow$ Helioscope [Sikivie '83]
- paradigmatic CERN Axion Solar Telescope CAST
  [arXiv:1209.6347]
  - ☺ broadband, rather sensitive, reaches QCD axion band
  - ☹ dependent on flux at source (nontunable and slightly model dep.)

2) WISPs/Axions from our sun (Helioscopes)

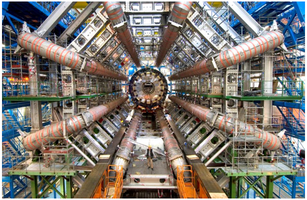




- natural photon source: sun
  $\rightarrow$ Helioscope [Sikivie '83]
- paradigmatic CERN Axion Solar Telescope CAST
  [arXiv:1209.6347]
  - ☺ broadband, rather sensitive, reaches QCD axion band
  - ☹ dependent on flux at source (nontunable and slightly model dep.)
- CAST at 'peak sensi': future: International Axion Observatory, $\sim$ 5T, 20m IAXO? [1302.3273,1401.3233] 2 OOM improv. $g \sim 10^{-12}$GeV^{-1}

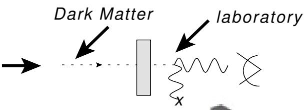
from Science: Vol. 342 no. 6158 pp. 552-555

'vs'

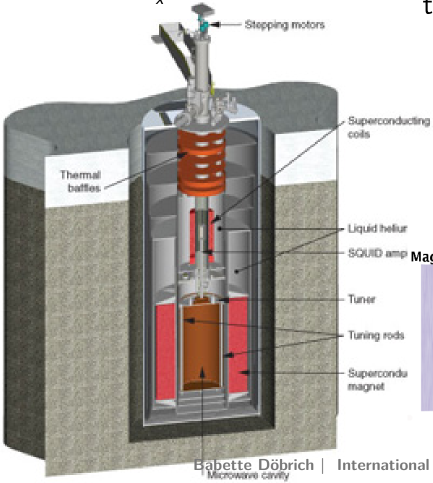


In the age of the 27-kilometer-long atom smasher and the 50,000-tonne underground particle detector, the Axion Dark Matter Experiment (ADMX) hardly looks grand enough to make a major discovery. A modest 4-meter-long metal cylinder, it dangles from a wall here at the University of Washingtons Center for Experimental Nuclear Physics and Astrophysics, as shiny and inscrutable as a tuna hung up for display. A handful of physicists tinker with the device, which they are preparing to lower into a silolike hole in the floor. The lab itself, halfway down a bluff on the edge of campus, is far from the bustle of the university. Yet ADMX researchers will soon perform one of the more important and promising experiments in particle physics.

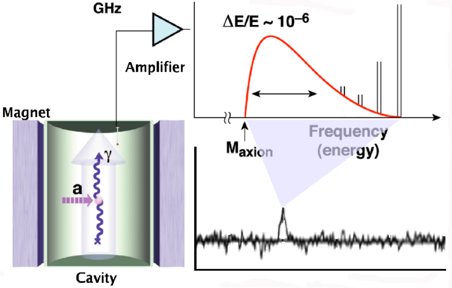
3) Dark Matter Axions/WISPs (Haloscopes)



> Axions & WISPs $\rightarrow$ dark matter candidate $\rightarrow$ Haloscope [Sikivie '83] resonant technique $f_{\text{cavity}} \sim m_{\text{axion}}$



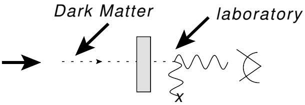
ADMX status cf [1403.5332]

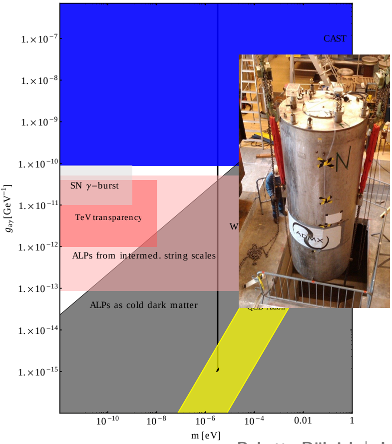


taken from learner.org

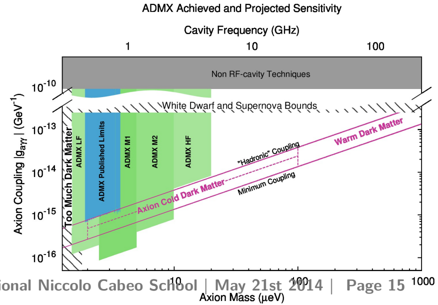
taken from [0807.3125]

3) Dark Matter Axions/WISPs (Haloscopes)

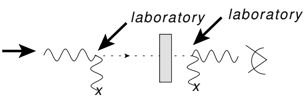




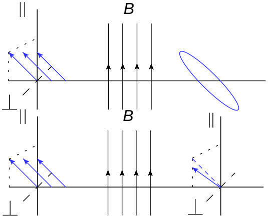
- Axions & WISPs → dark matter candidate → Haloscope [Sikivie '83] resonant technique $f_{\text{cavity}} \sim m_{\text{axion}}$
- paradigmatic for axions: ADMX and ADMX-HF
  - ☺ VERY sensitive
  - ☹ so far very narrow band



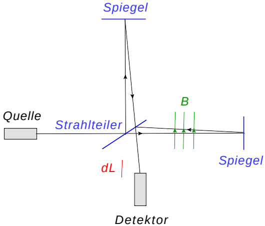
4) “Homemade” WISPs/ pure laboratory setups



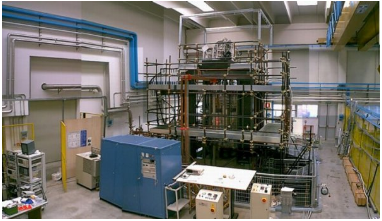
> light-shining-through-a wall, polarization measurements [PVLAS, 1301.4918] & interferometry

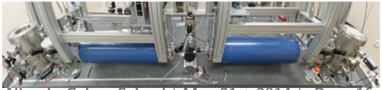


(also QED)

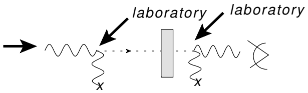


[0904.0216]



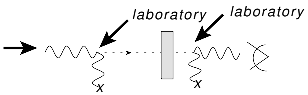


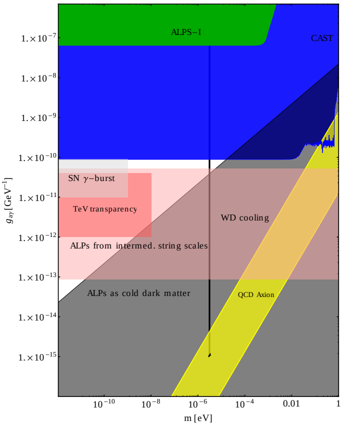
4) “Homemade” WISPs/ pure laboratory setups



- light-shining-through-a wall, polarization measurements [PVLAS, 1301.4918] & interferometry
- ideal for WISP-search: LSW
  - ☺ full control over WISP production, least model-dep.
  - ☹ “until soon” non-competitive

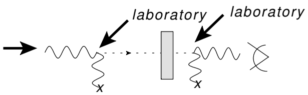
4) "Homemade" WISPs/ pure laboratory setups

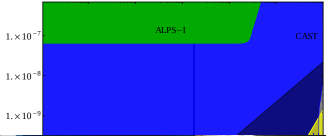


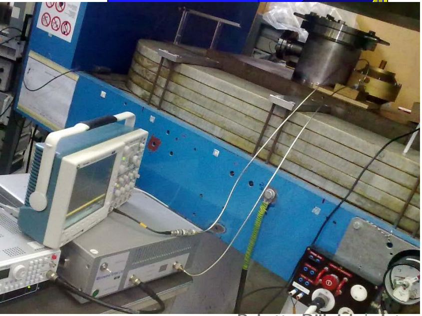


- light-shining-through-a wall, polarization measurements [PVLAS, 1301.4918] & interferometry
- ideal for WISP-search: LSW
  - ☺ full control over WISP production, least model-dep.
  - ☹ "until soon" non-competitive
- paradigmatic for optical LSW: ALPS-I [arXiv:1004.1313] (cf. also OSQAR CERN & FERMILAB setups)

4) “Homemade” WISPs/ pure laboratory setups



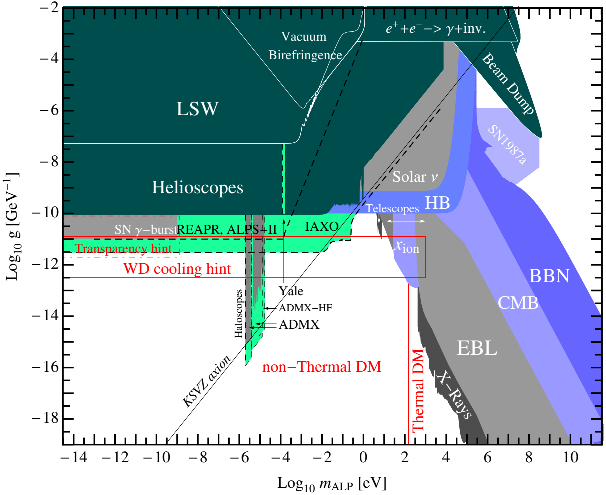




- light-shining-through-a wall, polarization measurements [PVLAS, 1301.4918] & interferometry
- ideal for WISP-search: LSW
  - ☺ full control over WISP production, least model-dep.
  - ☹ “until soon” non-competitive
- paradigmatic for optical LSW: ALPS-I [arXiv:1004.1313] (cf. also OSQAR CERN & FERMILAB setups)
- microwave-through-the-wall experiments at CERN [arXiv:1310.8098] (sensitive at lower mass, “inherent resonant regeneration” (will be explained later))

Comprehensive ALP parameter space

whole story see e.g. Essig et al. [arXiv:1311.0029]



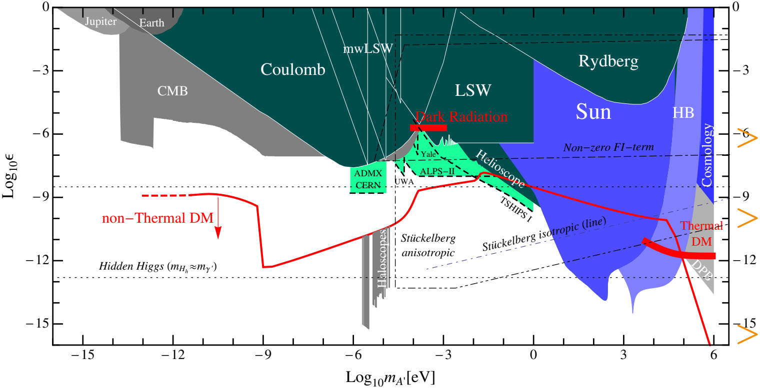
colored regions:

- Dark green = experiments
- blue: astrophysical/ cosmological
- gray: astronomical
- light green: planned exp.
- red: favored parameter regions

(Almost) Comprehensive HP parameter space

plot misses interesting pheno region μ g-2

whole story see e.g. [arXiv:1311.0029]



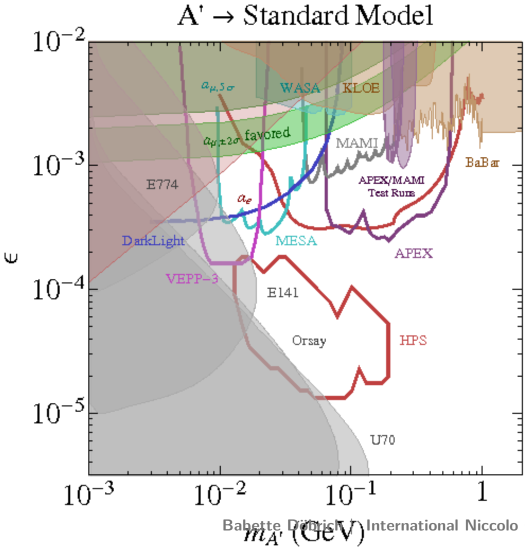
colored regions:

- Dark green = experiments
- blue: astro-physical/ cosmological
- gray: astro-nomical
- light green: planned exp.
- red: favored parameter regions

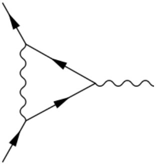
(Almost) Comprehensive HP parameter space

colored regions:

plot misses interesting pheno region μ g-2

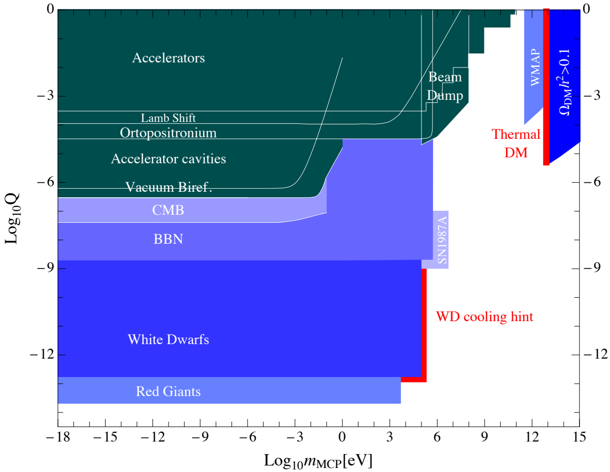


]



Comprehensive MCP parameter space

whole story see e.g. [arXiv:1311.0029]



colored regions:

- Dark green = experiments
- blue: astrophysical/ cosmological
- gray: astronomical
- light green: planned exp.
- red: favored parameter regions

Outline

- Brief intro to Axions & Axion cosmology
- Other light weakly interacting stuff & the search for them
- **An example: the ALPS-II experiment**
- More on selected ultralight Dark Matter setups
- Take home

ALPS-I (2010) and upgrades towards ALPS-II

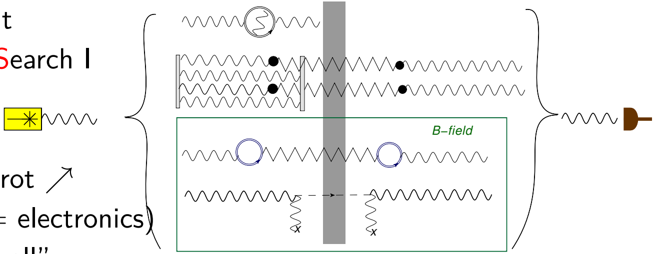
Any Light

Particle Search I

Fabry Perot ↗

resonator (= electronics)

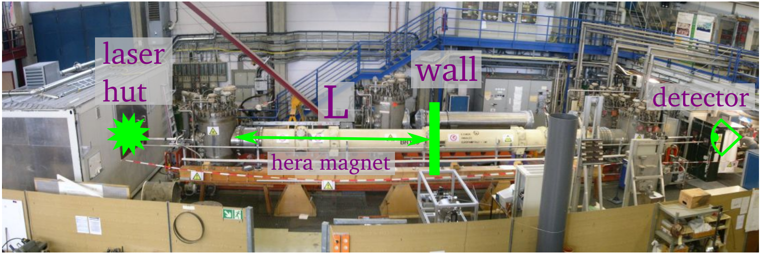
before "wall"



9m, 5T

HERA

dipole

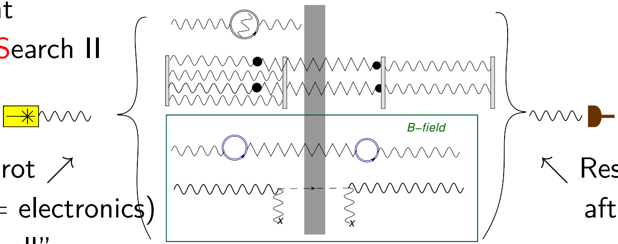


Phys. Lett. B **689**, 149 (2010)

ALPS-I (2010) and upgrades towards ALPS-II

Any Light
Particle Search II

Fabry Perot ↗
resonator (= electronics)
before "wall"



↖ Resonator
after "wall"

Upgrades from ALPS-I to ALPS-II

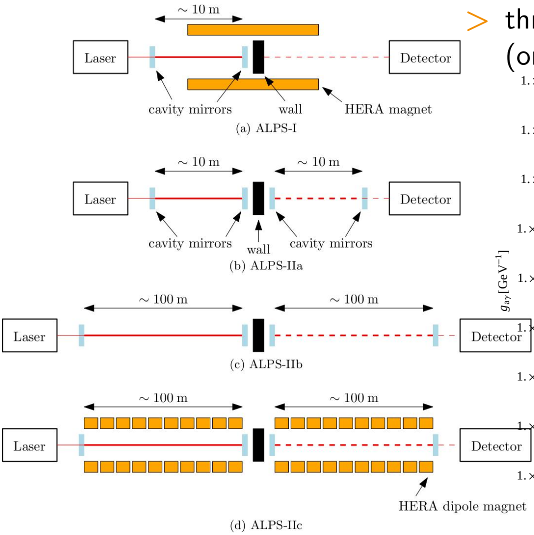
1) more photons → enhanced probability
2) better single photon detection

1) *coupled* cavities → resonant regeneration (photon self-interference)
2) Transition Edge Sensor - superconducting edge

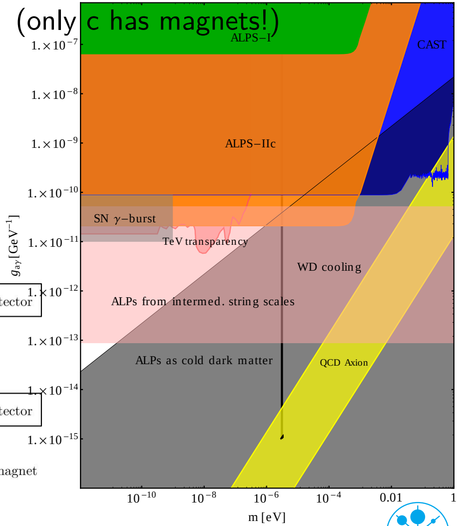
ALPS-I (2010) and upgrades towards ALPS-II

3) More (magnetic) length

3) more HERA dipoles (20)!
enhance length → tunnel



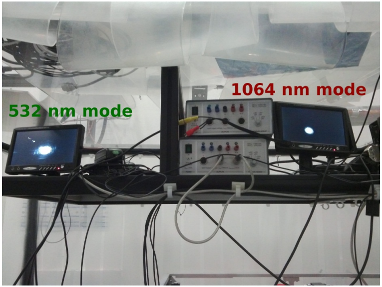
> three stages ALPS-II **a**,b,c (only c has magnets!)



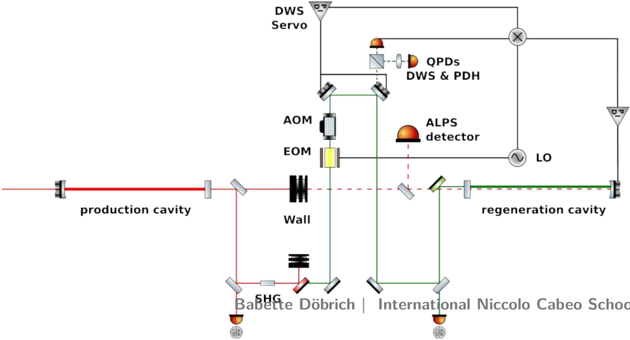
Status [1309.3965] for Optics, Detector, Magnets

- three stages ALPS-II **a**,b,c (only c has magnets!)
- **Optics:** high-finesse cavity 1064nm across 10m

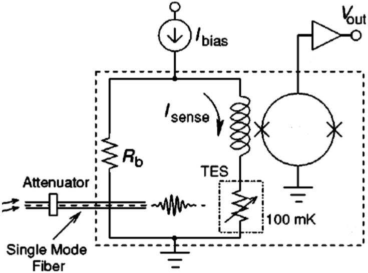
Status [1309.3965] for Optics, Detector, Magnets

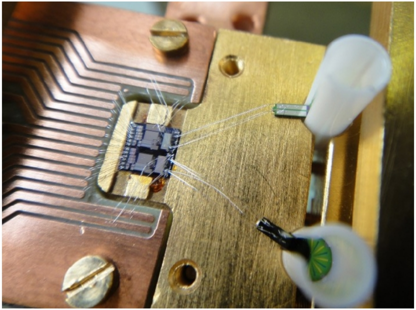


- three stages ALPS-II **a**,b,c (only c has magnets!)
- **Optics:** high-finesse cavity 1064nm across 10m
- **Optics:** locking principle with infrared & green at 1m testsetup

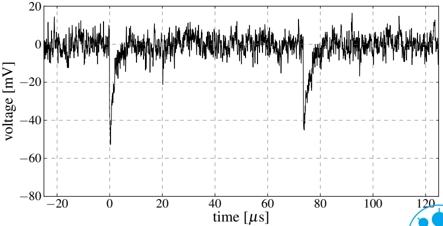


Status [1309.3965] for Optics, Detector, Magnets

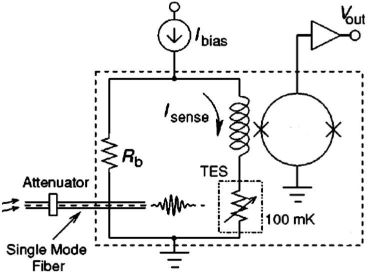


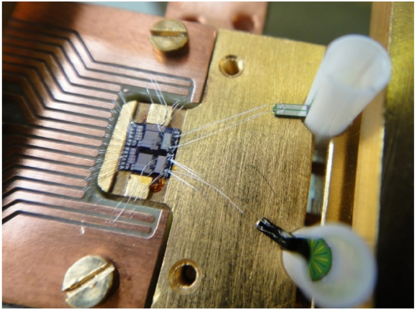


- three stages ALPS-II **a**,b,c (only c has magnets!)
- **Optics:** high-finesse cavity 1064nm across 10m
- **Optics:** locking principle with infrared & green at 1m testsetup
- **Detector:** transition edge sensor (superconductor at T_{crit}) [1309.5024]

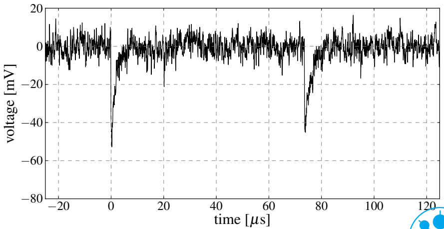


Status [1309.3965] for Optics, Detector, Magnets

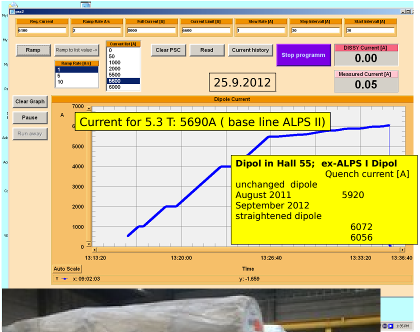




- three stages ALPS-II **a**,b,c (only c has magnets!)
- **Optics:** high-finesse cavity 1064nm across 10m
- **Optics:** locking principle with infrared & green at 1m testsetup
- **Detector:** transition edge sensor (superconductor at $T_{\rm crit}$) [1309.5024]

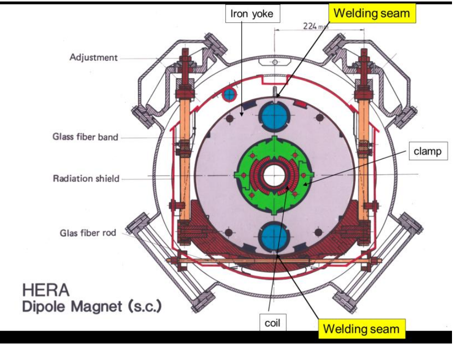


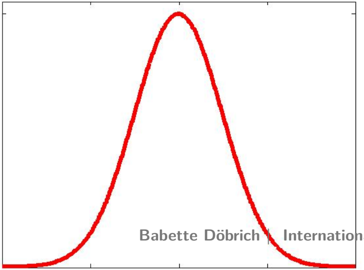
Status [1309.3965] for Optics, Detector, Magnets



- three stages ALPS-II **a**,b,c (only c has magnets!)
- **Optics:** high-finesse cavity 1064nm across 10m
- **Optics:** locking principle with infrared & green at 1m testsetup
- **Detector:** transition edge sensor (superconductor at T_{crit}) [1309.5024]
- **Magnets:** 'magnet straightening' (with spare magnets!) working just fine

Why straightening? Aperture constraints



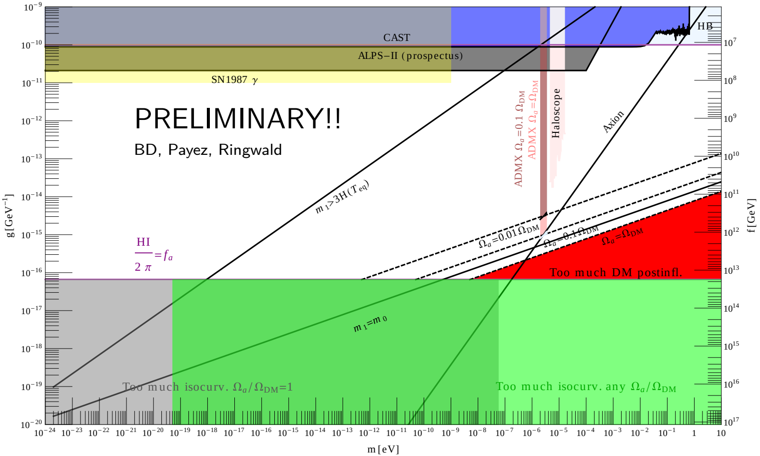


- $PB_{PC} = 5000$ for IR, $PB_{RC} = 40000$ for IR
- pipe aperture limits PB due to clipping
- **large** aperture for ALPS-IIa and b (HERA straight)
- ALPS-IIc $\rightarrow$ effective aperture 35mm limits to 4+4 dipoles (not enough) at proposed PB but "true" aperture larger (55mm)
- reestablish "true aperture" with pressure props

Outline

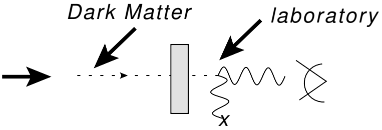
- Brief intro to Axions & Axion cosmology
- Other light weakly interacting stuff & the search for them
- An example: the ALPS-II experiment
- **More on selected ultralight Dark Matter setups**
- Take home

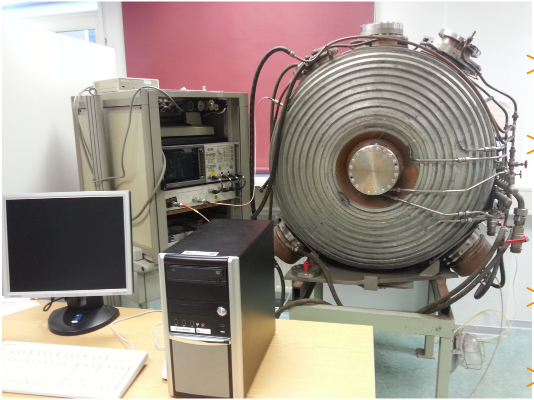
March $\rightarrow$ BICEP 2, can have sizable implications...
see also Hertzberg et al. [0807.1726] and MANY others



and for Hidden Photons... Jaeckel, Redondo, Ringwald... and certainly more

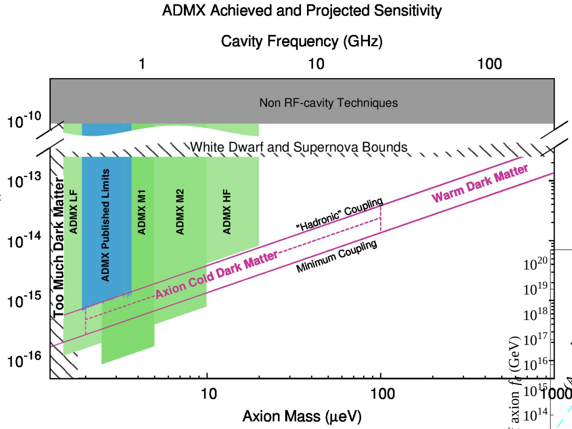
BUT theory is ‘flexible’, let’s do experiments!





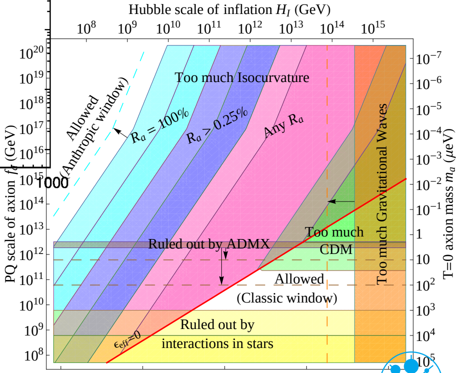
- 208 MHz HERA proton cavity as Haloscope
- phase 1 (ongoing) $\rightarrow$ **hidden photons** search at 'nominal cavity resonances'
- phase 2 $\rightarrow$ cavity tuning, $\sim 60\%$ of 200-500 Mhz
- phase 3 $\rightarrow$ B field? HUGE V! H1 (supra 1.15T), Hermes (norm. cond. ~1T), CERN M1 (3T)
- add. problem: geometry factor! ($\angle$ B, A)
- not sensitive to QCD axions

Further Haloscopes at higher masses?



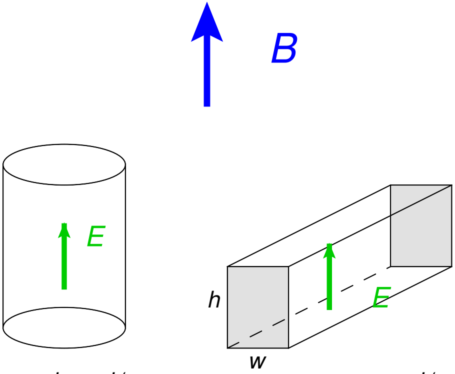
Pic from ADMX homepage

- existing experiments & ADMX HF leave out high masses, classical axion window



[Hertzberg et al]

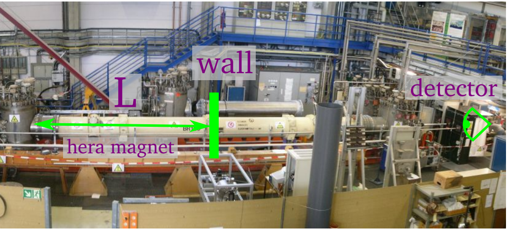
Further Haloscopes at higher masses?



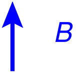
$d \sim pi/m$ $w \sim pi/m$

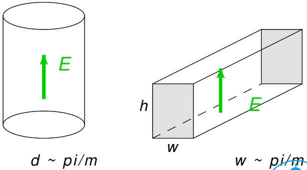
- existing experiments & ADMX HF leave out high masses, classical axion window
- decouple resonant frequency from V [1110.2180], long rectangular cavities? perfect for dipoles
- under construction... [Irastorza, Redondo; Gimeno, Gallego]
- problems: close mode spacing... and more

3rd life of HERA dipoles? w F. Schaefer, E. Kreysa (MPIfR) & more

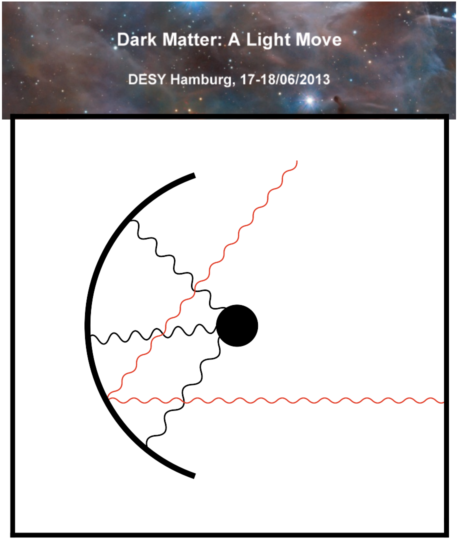


- magnets straightening working & magnet ready at test stand, 5.3 T, 27l volume
- waveguide H11 basic mode in OFHC (copper) beam pipe at ~3.2 GHz? (limits exist already)
- long term → rectangular cavity inside?





Finding U(1)'s of a Novel Kind @ desY (FUNKY)

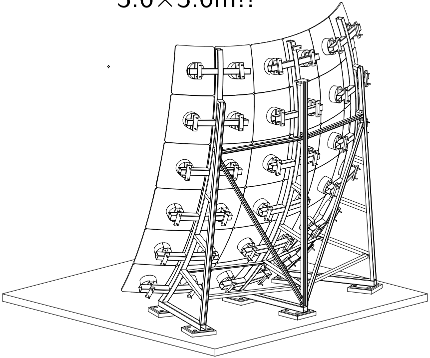


- faster but less sensitive: broadband search w/o resonant enhancement: collect light at center of reflecting sphere w or w/o B-field Jaeckel/Redondo more info:[1212.2970] and [1308.1103]

Finding U(1)'s of a Novel Kind @ desY (FUNKY)

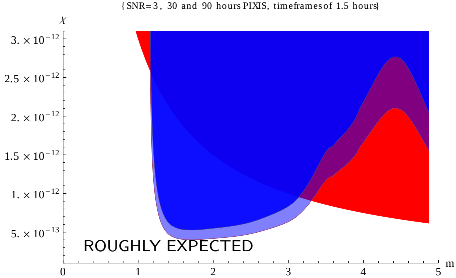
[with R.Engel (KIT), M.Kowalski (Berlin & DESY Zeuthen) and others]
supported by HAP, see [1311.5341]

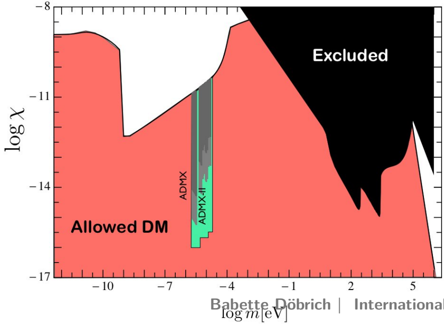
3.6×3.6m!!



- faster but less sensitive: broadband search w/o resonant enhancement: collect light at center of reflecting sphere w or w/o B-field Jaeckel/Redondo more info:[1212.2970] and [1308.1103]
- first setup @ KIT with AUGER spare in the visible foreseen for mid/end 2014,

Finding U(1)'s of a Novel Kind @ desY (FUNKY)





- faster but less sensitive: broadband search w/o resonant enhancement: collect light at center of reflecting sphere w or w/o B-field Jaeckel/Redondo more info:[1212.2970] and [1308.1103]
- first setup @ KIT with AUGER spare in the visible foreseen for mid/end 2014,
- expected sensitivity for hidden photons (1.5-3) eV down to $\chi \lesssim 10^{-12}$
- difficult with magnet... but we'll see

Outline

- Brief intro to Axions & Axion cosmology
- Other light weakly interacting stuff & the search for them
- An example: the ALPS-II experiment
- More on selected ultralight Dark Matter setups
- **Take home**

Subjective physics and politics sum up

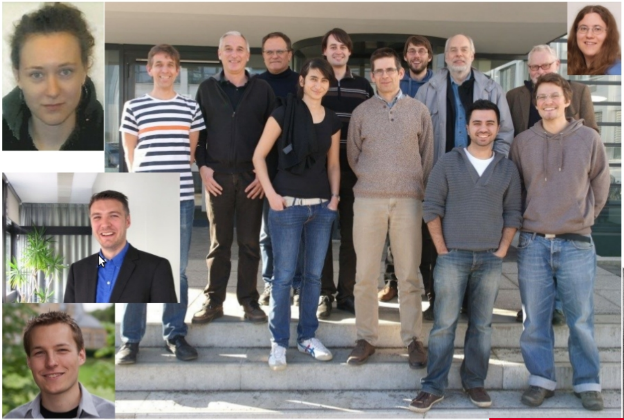
Theory and experiments for light & weakly coupled particles

- broken symmetries $\rightarrow$ potential for very light particles and weakly interacting particles axions & WISPs (DM candidates)
- Axion well motivated, particularly DM. Other WISPs plausible in BSM extensions, techniques are similar
- Experiments (non-comprehensive list): manifold, interdisciplinary, fun :-)

Prospect

- Axion DM Q can be 'definitely' answered (if not $\Omega_a \ll \Omega_{DM}$), finite parameter space, WISP physics case could sharpen
- large funding in Korea for axions (KAIST), ADMX new data, setups emerging in many places around the globe (depends on LHC 14TeV & WIMP DM searches...)

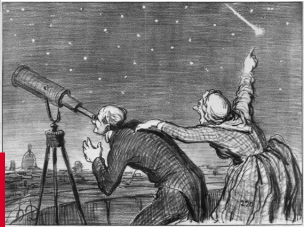
Thank you for your attention



ALPS-II collaboration

TDR arXiv:1302.5647

Qs at any time
babette.doebrich@
desy.de

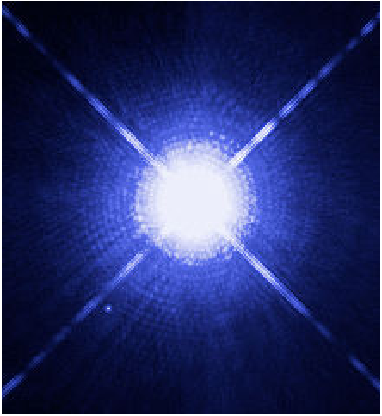


BSM - don't miss!

More? $\rightarrow$ Backup

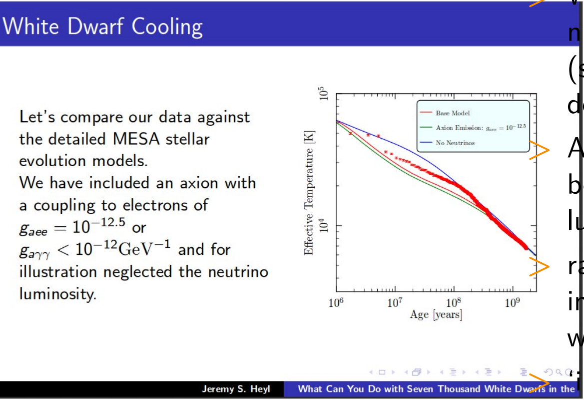
Bonus material

White Dwarf cooling [e.g. 1304.7652]



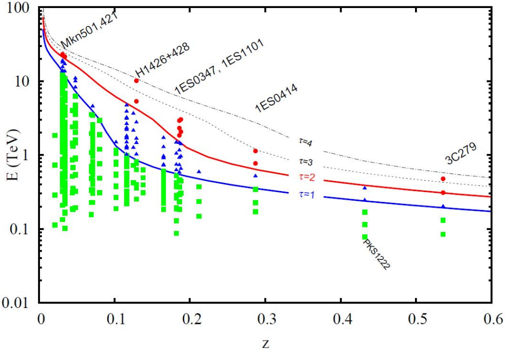
- White Dwarfs have no nuclear energy source (stabilized by electron degeneracy)
- Axions with $g_{ea} \sim 10^{-13}$ fit better the white dwarf luminosity function
- rate of pulsation of individual stars fits better with axions
- 'independent hints'

White Dwarf cooling [e.g. 1304.7652]



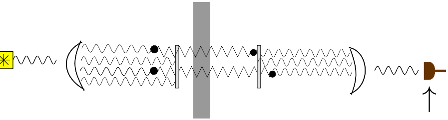
- White Dwarfs have no nuclear energy source (stabilized by electron degeneracy)
- Axions with $g_{ea} \sim 10^{-13}$ fit better the white dwarf luminosity function
- rate of pulsation of individual stars fits better with axions
- 'independent hints'
- Jeremy Heyl at LaB workshop: not consistent with his data? [1209.4901]

TeV transparency [e.g. 1201.4711] M. Meyer, D. Horns et al



- fit spectral sample (left from [e.g. 1201.4711]) in optically thin region
- extrapolate into thick region
- not 'compatible with fit' at $\sim 4\ \sigma$
- explanation through secondary processes difficult (cascade would wash out the intrinsic variability of the source)

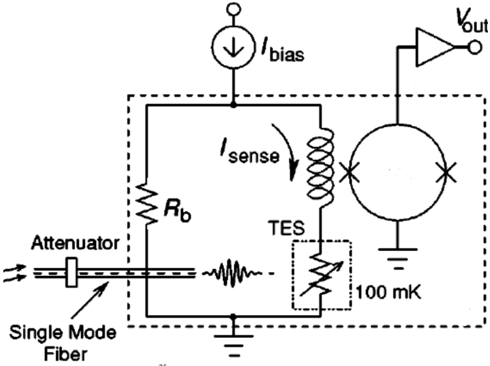
Detector requirements and TES working principle

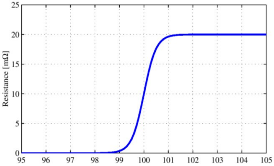


- Experimental needs
  - low rates of single infrared photons (<1/h)
  - high quantum efficiency (PIXIS: 1.2%)
  - low background

Detector requirements and TES working principle

pic ad.: Miller Appl.Phys.Lett. 83/4





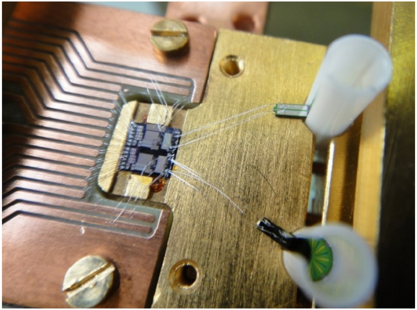
- Experimental needs
  - low rates of single infrared photons ($<1/\mathrm{h}$)
  - high quantum efficiency (PIXIS: 1.2%)
  - low background
- TES working principle
  - TES = superconducting absorber at transition T
  - fiber $\rightarrow$ guide light there
  - Photon absorption $\rightarrow$ current change $\rightarrow$ pick up by SQUID

Detector requirements and TES working principle

National Institute of Advanced Industrial Science and Technology AIST

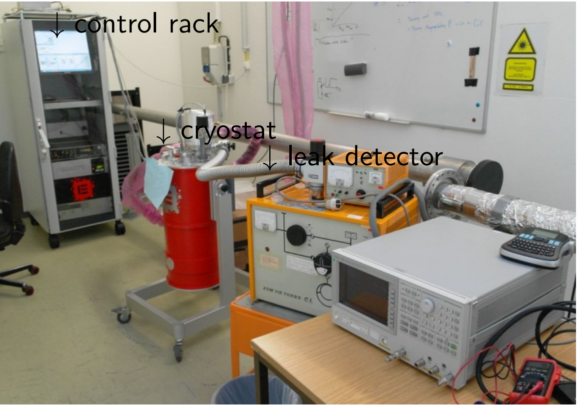
NIST National Institute of Standards and Technology U.S. Department of Commerce

PTB



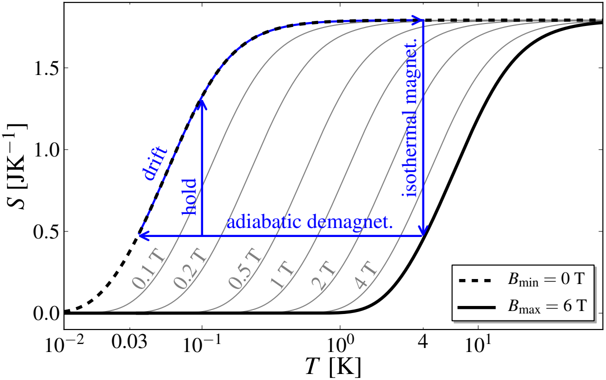
- Experimental needs
  - low rates of single infrared photons ($<1/h$)
  - high quantum efficiency (PIXIS: 1.2%)
  - low background
- TES working principle
  - TES = superconducting absorber at transition T
  - fiber $\rightarrow$ guide light there
  - Photon absorption $\rightarrow$ current change $\rightarrow$ pick up by SQUID
  - TES from NIST (and AIST) coated e.g. Tungsten ($\sim$ 100mK) or Ti/Au ($\sim$ 200mK), readout PTB

Milli-Kelvin environment



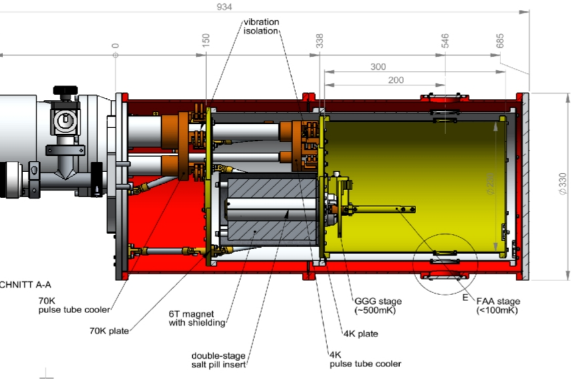
- 'Entropy' mK environment
  - dry (helium confined) & compact (only water & electricity)
  - time at <100mk: 48h
  - recharge time 1h

Milli-Kelvin environment



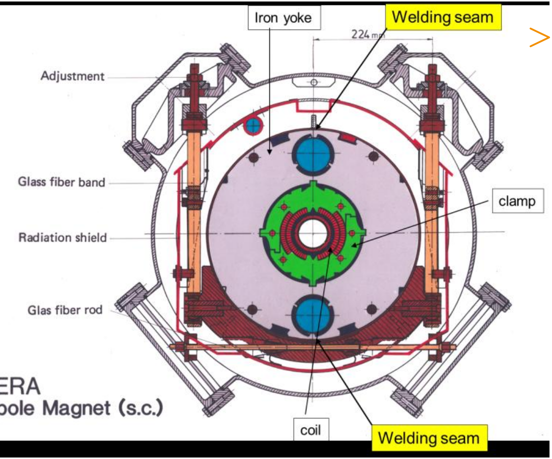
- 'Entropy' mK environment
  - dry (helium confined) & compact (only water & electricity)
  - time at <100mk: 48h
  - recharge time 1h
- working principle
  - 4K pulse-tube stage
  - isothermal magnetization, adiabatic demagnetization

Milli-Kelvin environment



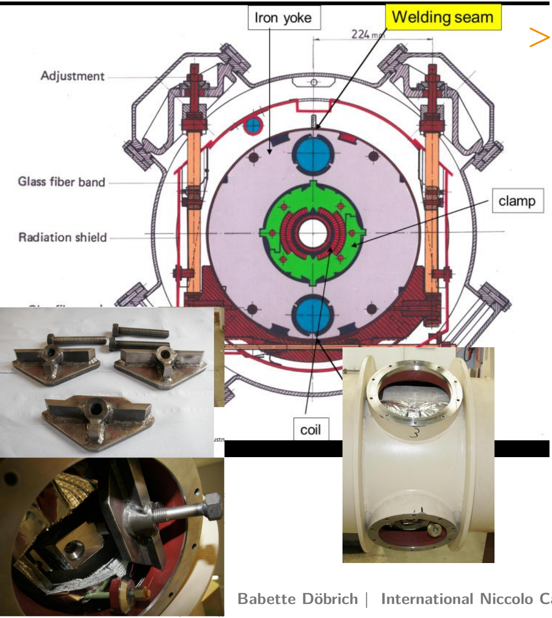
- ‘Entropy’ mK environment
  - dry (helium confined) & compact (only water & electricity)
  - time at <100mk: 48h
  - recharge time 1h
- working principle
  - 4K pulse-tube stage
  - isothermal magnetization, adiabatic demagnetization

Magnet straightening in a (very small) nutshell



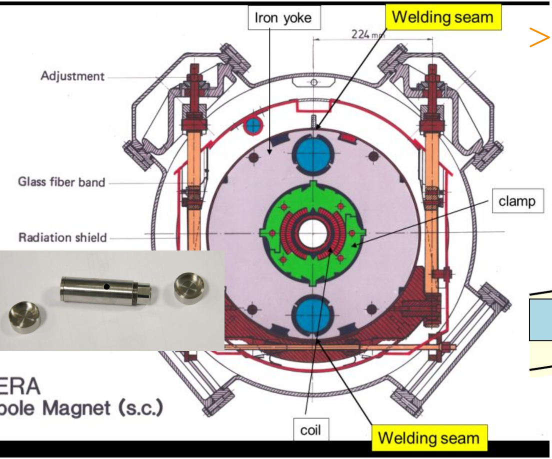
- howto
  - force on cold mass

Magnet straightening in a (very small) nutshell

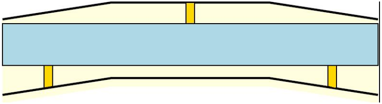


- howto
  - force on cold mass
  - pressure screws at lower flanches

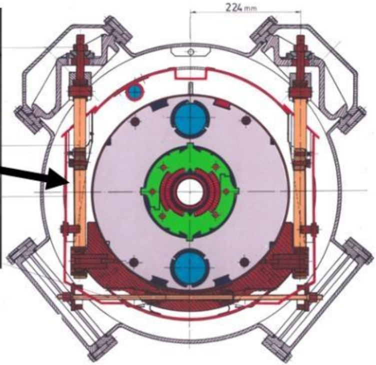
Magnet straightening in a (very small) nutshell



- howto
  - force on cold mass
  - pressure screws at lower flanches
  - pressure prop at middle and ends



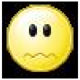
Magnet straightening in a (very small) nutshell



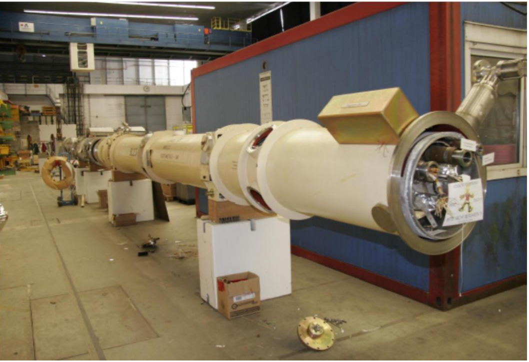
- howto
  - force on cold mass
  - pressure screws at lower flanches
  - pressure prop at middle and ends
  - requires modified suspensions

Magnet straightening in a (very small) nutshell

- howto
  - force on cold mass
  - pressure screws at lower flanches
  - pressure prop at middle and ends
  - requires modified suspensions
- good to know

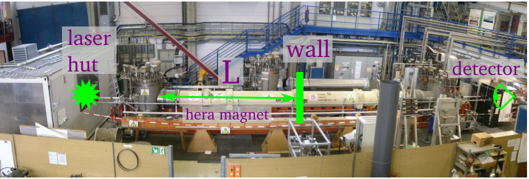


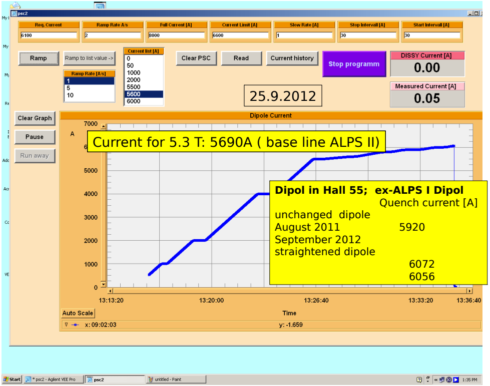
Magnet straightening in a (very small) nutshell



- howto
  - force on cold mass
  - pressure screws at lower flanches
  - pressure prop at middle and ends
  - requires modified suspensions
- good to know
  - first tests with “PR” magnet (non-functional)

Magnet straightening in a (very small) nutshell





- howto
  - force on cold mass
  - pressure screws at lower flanches
  - pressure prop at middle and ends
  - requires modified suspensions
- good to know
  - first tests with “PR” magnet (non-functional)
  - real-life tests with ALPS-I magnet (hall 55)

Magnet straightening in a (very small) nutshell

- howto
  - force on cold mass
  - pressure screws at lower flanches
  - pressure prop at middle and ends
  - requires modified suspensions
- good to know
  - first tests with "PR" magnet (non-functional)
  - real-life tests with ALPS-I magnet (hall 55)
  - ultimate setup: 24 spare magnets at Reemtsma
  - even reversible