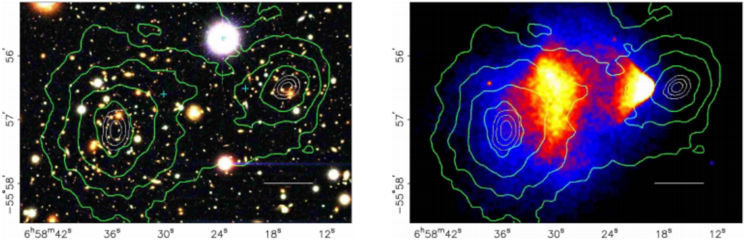
CERN

(Opportunistic) direct search for axion Dark Matter

Babette Döbrich

We have yet to understand what 80% of matter is made of

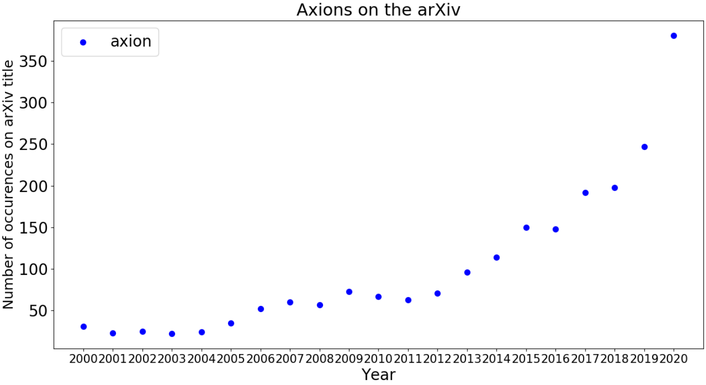
The bullet cluster might be the most famous evidence for the need for Dark Matter



but most importantly: evidence exists on multiple scales:
CMB, structure formation, galaxy rotation curves...

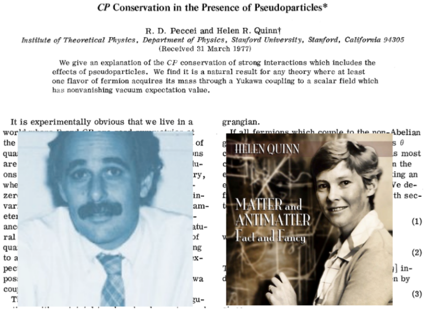
A prime goal of particle physics to find out what Dark Matter is

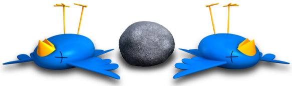
Community interest explodes in something called ‘the axion’



The Axion was not invented to be the Dark Matter!

More details already given in talks e.g. by J. Jäckel (Tuesday) and B.M. Schäfer (Monday)

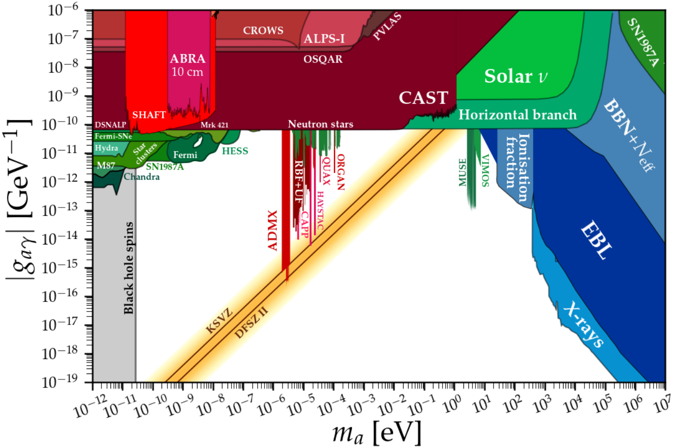




but Axions (or more generally axion-like particles (ALPs)) which must be extremely weakly interacting can be the Dark Matter or a portal to it!

Present and future hide-outs of (low-mass) axions

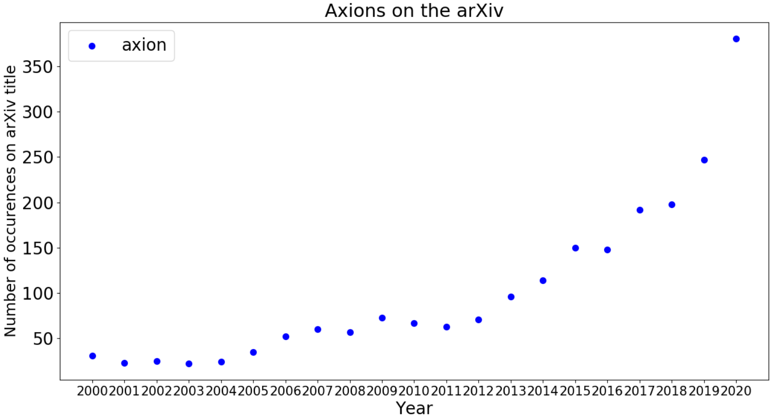
limit compilation (and disclaimer) by C O'Hare `https://github.com/cajohare/AxionLimits`



QCD axion lives on yellow line
an ALP almost anywhere.

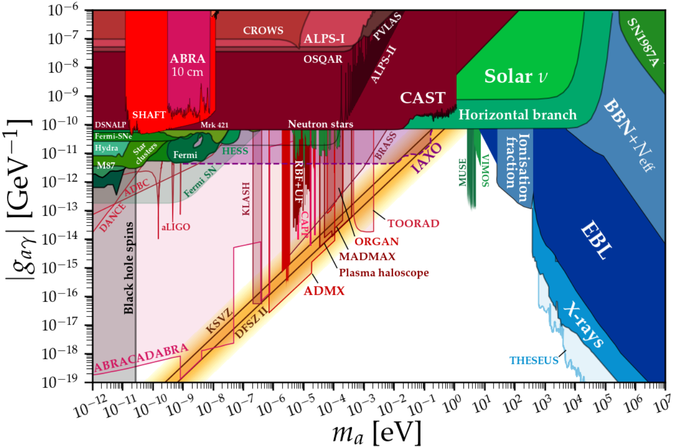
Present and future hide-outs of (low-mass) axions

limit compilation (and disclaimer) by C O'Hare `https://github.com/cajohare/AxionLimits`



Present and future hide-outs of (low-mass) axions

limit compilation (and disclaimer) by C O'Hare `https://github.com/cajohare/AxionLimits`



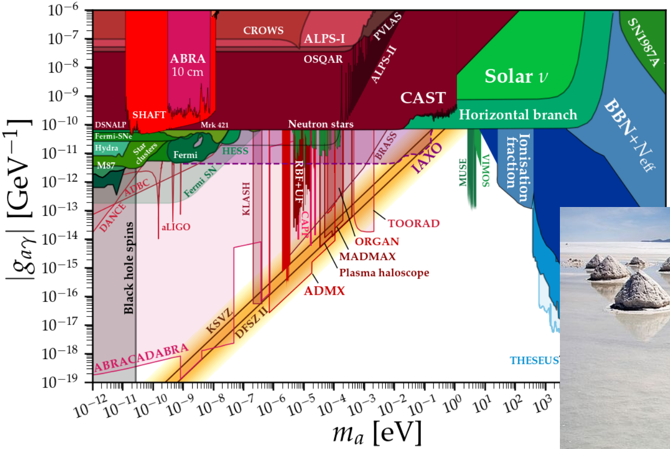
QCD axion lives on yellow line

an ALP almost anywhere.

Projections!!! with

Present and future hide-outs of (low-mass) axions

limit compilation (and disclaimer) by C O'Hare `https://github.com/cajohare/AxionLimits`



QCD axion lives on yellow line
an ALP almost anywhere.
Projections!!! with
more than a grain of salt

Luca Galuzzi via Wikimedia Commons

Main search types & where to learn from true experts

1. **Produce** an axion, then detect it: light shining through walls T12.2 T12.3 T12.1 T12.5 also beam dump, LHC (at higher masses) T12.4 T12.6 T12.7 T12.8 T12.9
2. look for axions from a **natural source**, most prominently solar axion searches: CAST, (baby-)IAXO (see e.g. T10.3 T10.4 T19.7 T20.8)
3. **assume that axions are THE Dark matter** (normally assume they are all of Dark Matter), infer their presence (e.g. T70.5 T70.6 T70.7 T70.8 T70.9)

Main search types & where to learn from true experts

1. **Produce** an axion, then detect it: light shining through walls T12.2 T12.3 T12.1 T12.5 also beam dump, LHC (at higher masses) T12.4 T12.6 T12.7 T12.8 T12.9
2. look for axions from a **natural source**, most prominently solar axion searches: CAST, (baby-)IAXO (see e.g. T10.3 T10.4 T19.7 T20.8)
3. **assume that axions are THE Dark matter** (normally assume they are all of Dark Matter), infer their presence (e.g. T70.5 T70.6 T70.7 T70.8 T70.9)

typically different in ability to probe vast mass-/coupling- scales

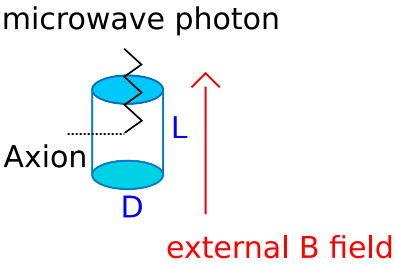
Main search types & where to learn from true experts

1. **Produce** an axion, then detect it: light shining through walls T12.2 T12.3 T12.1 T12.5 also beam dump, LHC (at higher masses) T12.4 T12.6 T12.7 T12.8 T12.9
2. look for axions from a **natural source**, most prominently solar axion searches: CAST, (baby-)IAXO (see e.g. T10.3 T10.4 T19.7 T20.8)
3. **assume that axions are THE Dark matter** (normally assume they are all of Dark Matter), infer their presence (e.g. T70.5 T70.6 T70.7 T70.8 T70.9)

typically different in ability to probe vast mass-/coupling- scales

click-able links above ... I exploit my privileged long talk
to elaborate more on point 3 and what we do about that at CERN

A poor (wo-)man's axion haloscope



- figure of merit: $F \sim g^4 m^2 B^4 V^2 T_{\mathrm{sys}}^{-2} \mathcal{G}^4 Q$
- typically high-field solenoids, several Tesla
- typically few-/sub- Kelvin
- scanning: tune in steps $\sim$ size of axion width
- resonance quality Q worth to push up to $\sim 10^6$
- design requirement $\mathcal{G}$: cavity modes: right direction/ well spaced/ correctly coupled

The pioneers & ‘old hands’ - ADMX

Bartram et al: Axion Dark Matter eXperiment: Run 1B Analysis

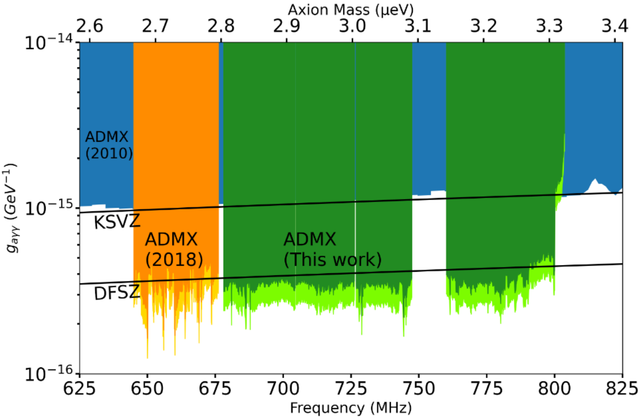
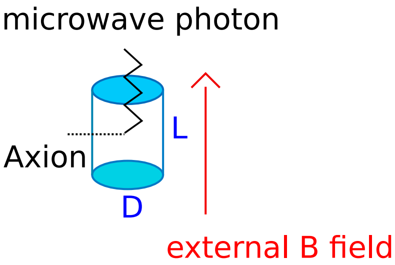


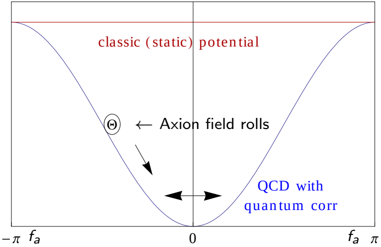
FIG. 17. Exclusion plot for Run 1B, shown in green. Dark green represents the region excluded using a standard Maxwell-Boltzmann filter, whereas light green represents the region excluded by an N-body filter [42].

Interlude: Why large masses are harder to test

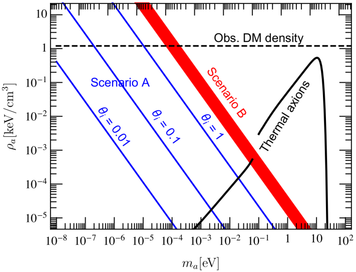


- figure of merit: $F \sim g^4 m^2 B^4 V^2 T_{\rm sys}^{-2} \mathcal{G}^4 Q$
- naively: large $m \to$ higher resonance $f \to$ lower dimension
- $Q \sim \frac{V}{\delta S}$ Volume to surface ratio: gets bad at low Volumes

Interlude: Why large masses are interesting to test



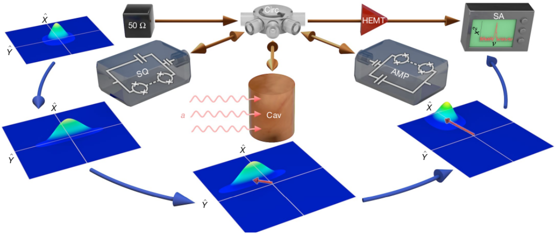
↓ time

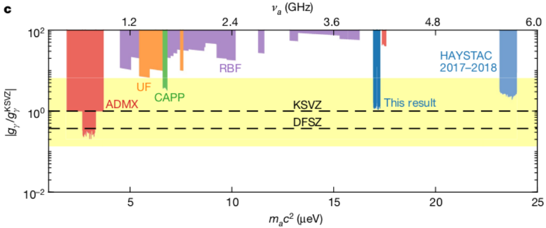


- axion mass depends on initial misalignment angle & inversely proportional to symmetry breaking scale
- large axion masses test the ‘post-inflationary’ axion, in which the axion mass can be more ”easily” predicted

  (average of possible initial conditions, whereas otherwise one unknown initial condition stretched by inflation)
- scenario B: m prediction somewhat possible

Notable progress at large m: going 'beyond' quantum uncertainty

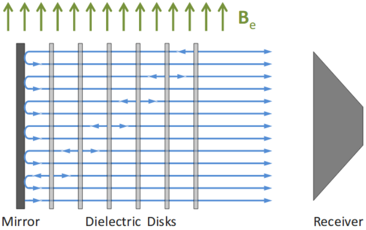


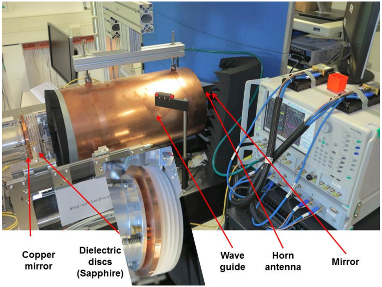


Bakes et al. Nature volume 590, pages 238–242(2021)

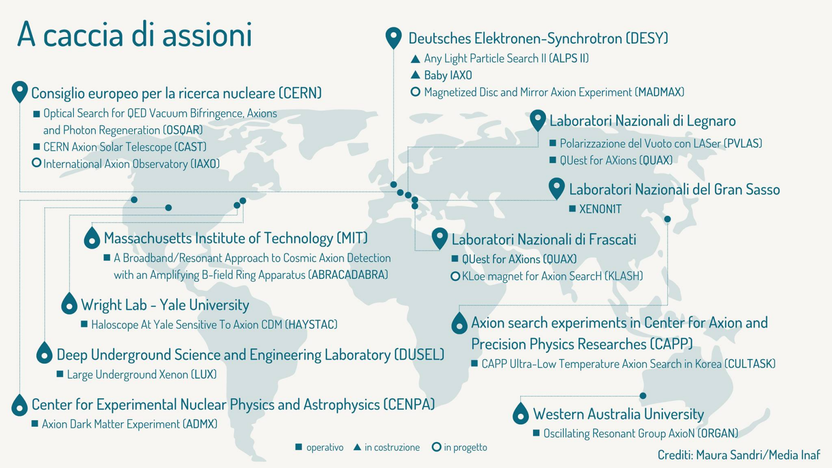
The biggest european contender - MADMAX

- constructively combine axion emission at dielectric surface by choice of plate separation $\rightarrow$ allows to probe 'large' axion DM mass
- amongst challenges: 9T dipole with 1.35m bore





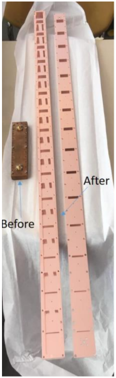
That's not all... (incomplete, but nicely prepared)

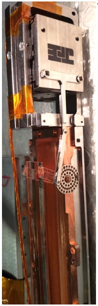


Some comments

- CAPP Korea: quite a wide program: tuning all the different knobs to enhance sensitivity
- QUAX (running)/ KLASH (proposed): italian-based: photon and spin-interactions
- CASPEr (Mainz): NMR-like
- BRASS (Hamburg, proposed): broadband dish instead of resonator
- ...

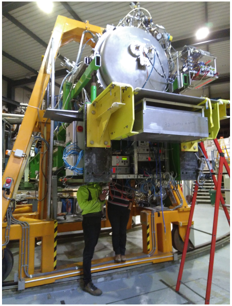
The opportunists - RADES & CAPP-CAST





2018-2021 ⟶

in CAST LHC dipole



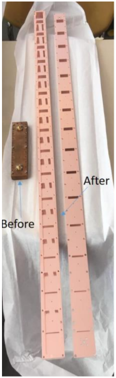
⟵ true dedication:

hands-on and heads-in

(80% of us: this is 'hobby'!)

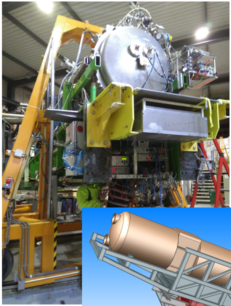
cavity R&D to search DM axions in **dipole magnets**

The opportunists - RADES & CAPP-CAST

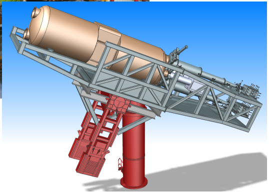


2018-2021 ⟶ in CAST LHC dipole

RADES: long term ⟶ babyIAXO (lower frequ)



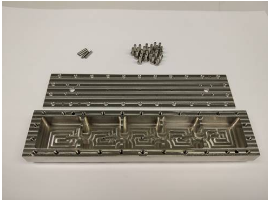
← true dedication: hands-on and heads-in (80% of us: this is 'hobby'!)



cavity R&D to search DM axions in **dipole magnets**

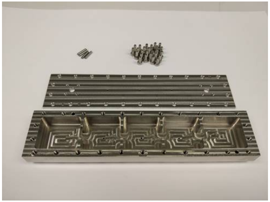
see e.g. Alvarez-Melcon et al, JHEP 07 (2020) 084

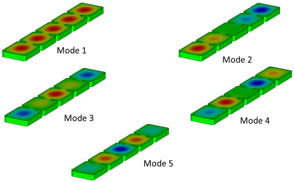
Basic idea of RADES: E pluribus unum JCAP 05 (2018) 040



- retain large volume at high resonance frequencies using a division into subcavities
- sub-cavity scale sets resonance scale

Basic idea of RADES: E pluribus unum JCAP 05 (2018) 040



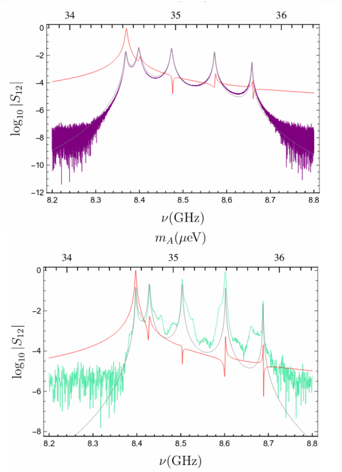


↑

ext. B-field

- retain large volume at high resonance frequencies using a division into subcavities
- sub-cavity scale sets resonance scale
- N of subcavities = N of modes: not all cavity modes couple to the axion, but we can find one, here 'mode 1'!

Basic idea of RADES: E pluribus unum JCAP 05 (2018) 040

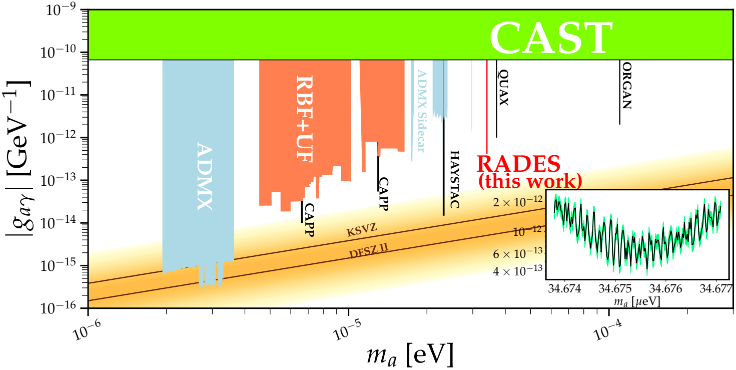


- retain large volume at high resonance frequencies using a division into subcavities
- sub-cavity scale sets resonance scale
- N of subcavities $=$ N of modes: not all cavity modes couple to the axion, but we can find one, here 'mode 1'!
- (mode mixing at big N & tuning solved)

modest but brand-new: RADES **preliminary** not through CAST procedure

CAST collaboration, forthcoming (main analyst: S. Arguedas Cuendis)

→ strongest result to date above 30μeV



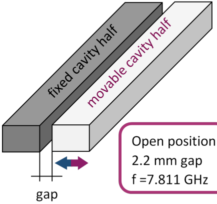
Conclusions

- the axion warrants to build some **strategic** (Dark Matter) experiments that cover large chunks of parameter space (like MADMAX, babyIAXO)
- there is also space for **opportunistic** searches that might just be 'lucky' to 'hit' the right axion mass (or target it in case of prediction). RADES is an example for that, long-term plans of these studies aimed at exploiting the babyIAXO magnet (that is then strategic)
- remain optimistic that within (few) decades, a final word on axions is spoken
- happy to take questions now or later: babette@cern.ch
- **thanks to the RADES/CAST teams + CERN technical support + ERC 802836 AxScale**

backup RADES tuning

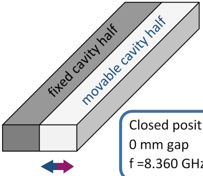
courtesy of Jessica Golm, see talk T70.9

Mechanical tuning by changing the distance of cavity halves

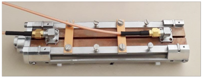


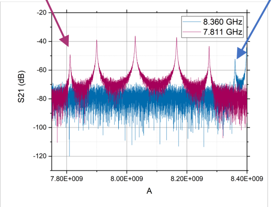
Open position
2.2 mm gap
f =7.811 GHz

Tuning range:
550 MHz



Closed position
0 mm gap
f =8.360 GHz





CERN

home.cern