Other projects in the same mass range

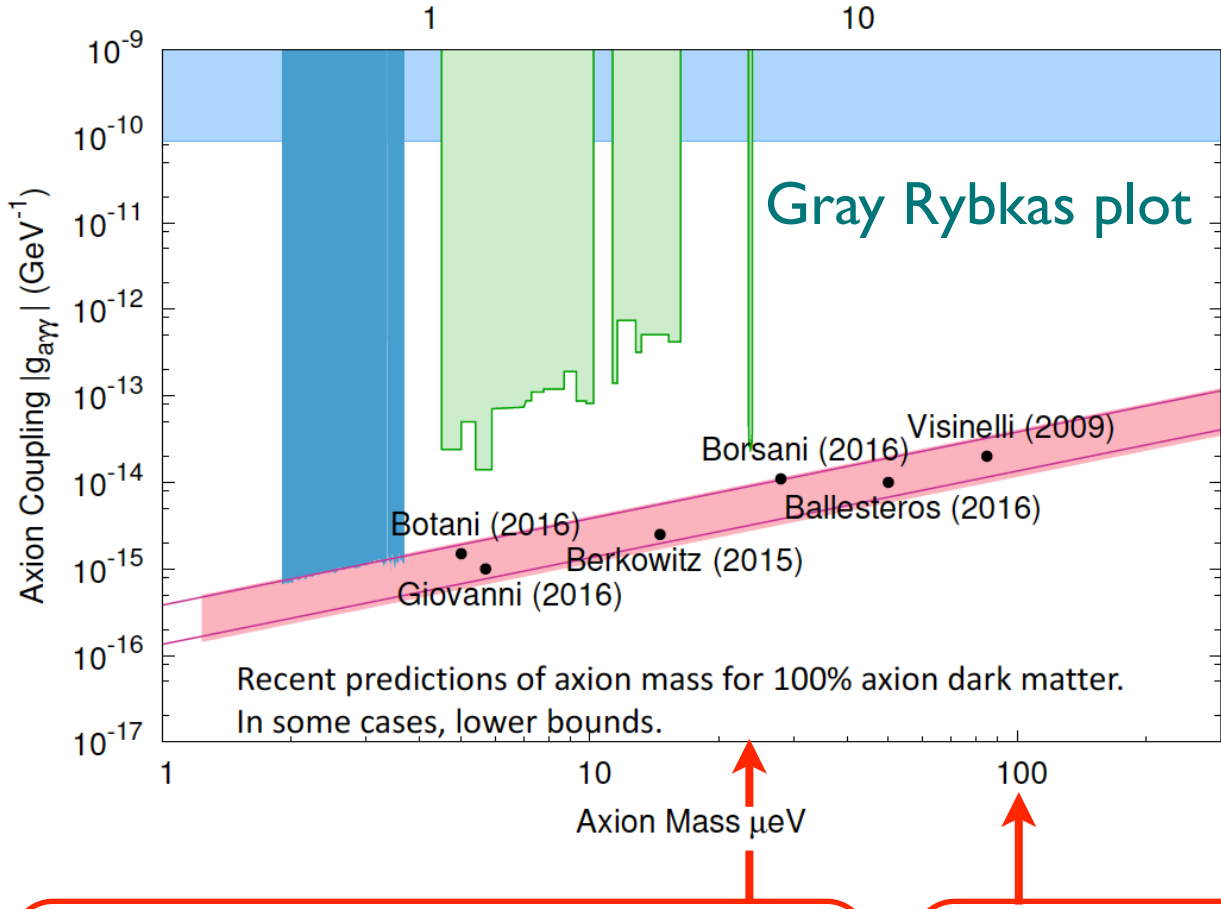
Frank Steffen

Theory Group
Max Planck Institute for Physics
Munich, Germany

MADMAX Workshop
DESY Hamburg, Oct 19, 2017

➔ Andreas Ringwalds talk

What is the axion dark matter mass?



Exploiting lattice results on topological susceptibility of [Borsanyi et al. `16]:

$$m_A = 26.2 \pm 3.4\,\mu\text{eV}$$

[Klaer,Moore `17]

"axion from hell"
[Javier Redondo]

SMASH
[Ballesteros et al., PRL'16]

anomalous Josephson junct.
[Beck, PRL'13 & PDU'15]

What is the axion dark matter mass?

! warning: highly controversial !

[Beck, PRL'13 & PDU'15]

Possible resonance effect of axionic dark matter in Josephson junctions

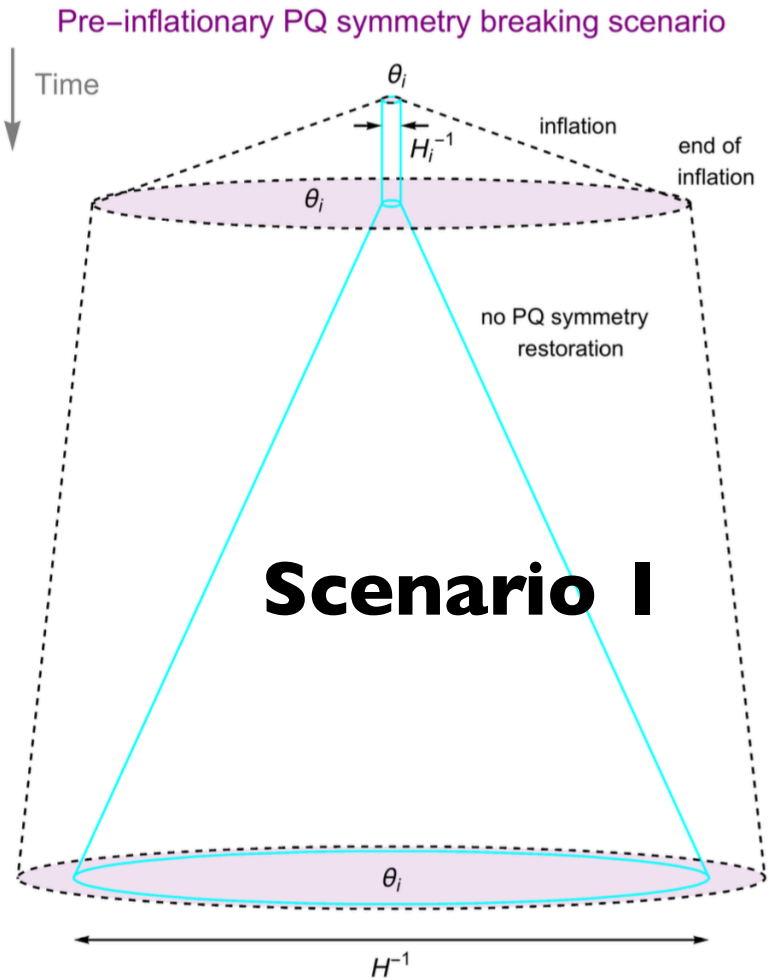
Christian Beck
Isaac Newton Institute for Mathematical Sciences, University of Cambridge, 20 Clarkson Road, Cambridge CB3 0EH, UK, and School of Mathematical Sciences, Queen Mary University of London, Mile End Road, London E1 4NS, UK

We provide theoretical arguments that dark matter axions from the galactic halo that pass through the earth may generate a small observable signal in resonant S/N/S Josephson junctions. The corresponding interaction process is based on uniqueness of the gauge-invariant axion Josephson phase angle modulo 2π and is predicted to produce a small Shapiro step-like feature without externally applied microwave radiation when the Josephson frequency resonates with the axion mass. A resonance signal of so far unknown origin observed in [C. Hoffmann et al. PRB 70, 180503(R) (2004)] is consistent with our theory and can be interpreted in terms of an axion mass $m_a c^2 = 0.11\text{meV}$ and a local galactic axionic dark matter density of 0.05 GeV/cm^3. We discuss future experimental checks to confirm the dark-matter nature of the observed signal.

Anomalous effect observed in Josephson junctions

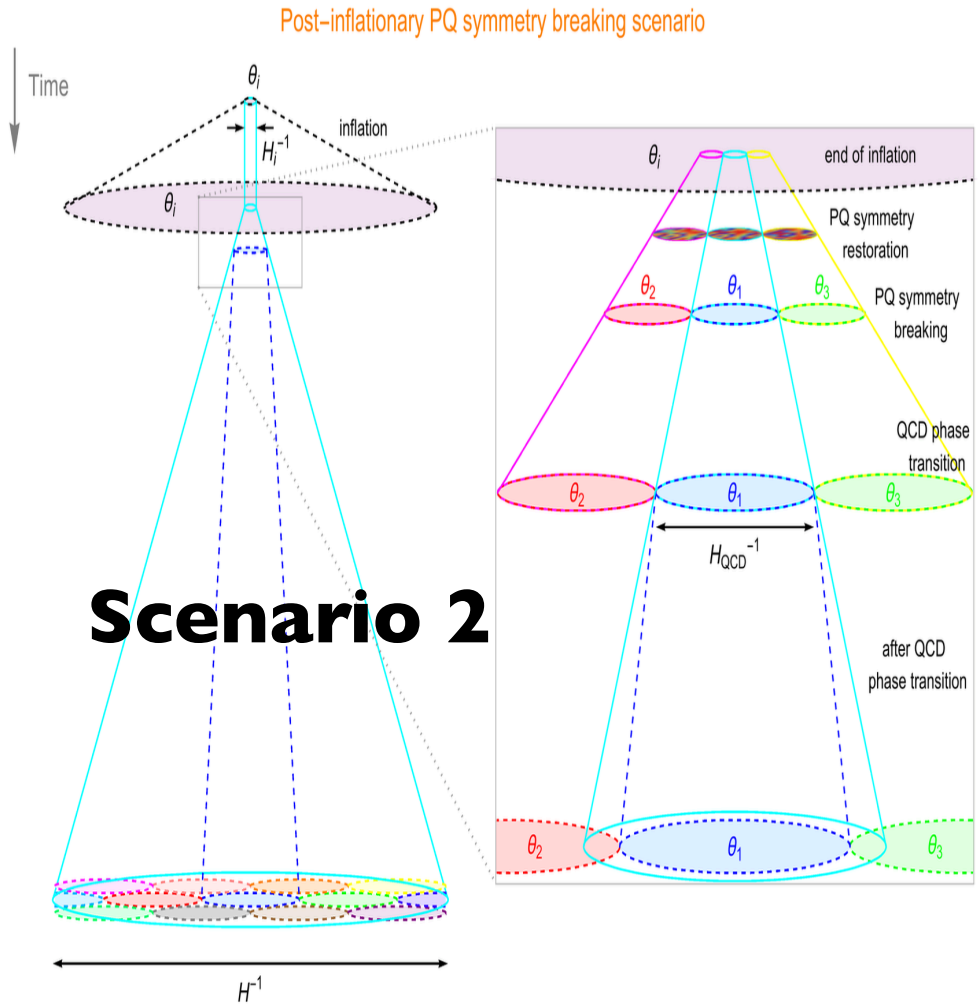
➔ Andreas Ringwalds talk

What is the axion dark matter mass?



Scenario 1

[Saikawa]



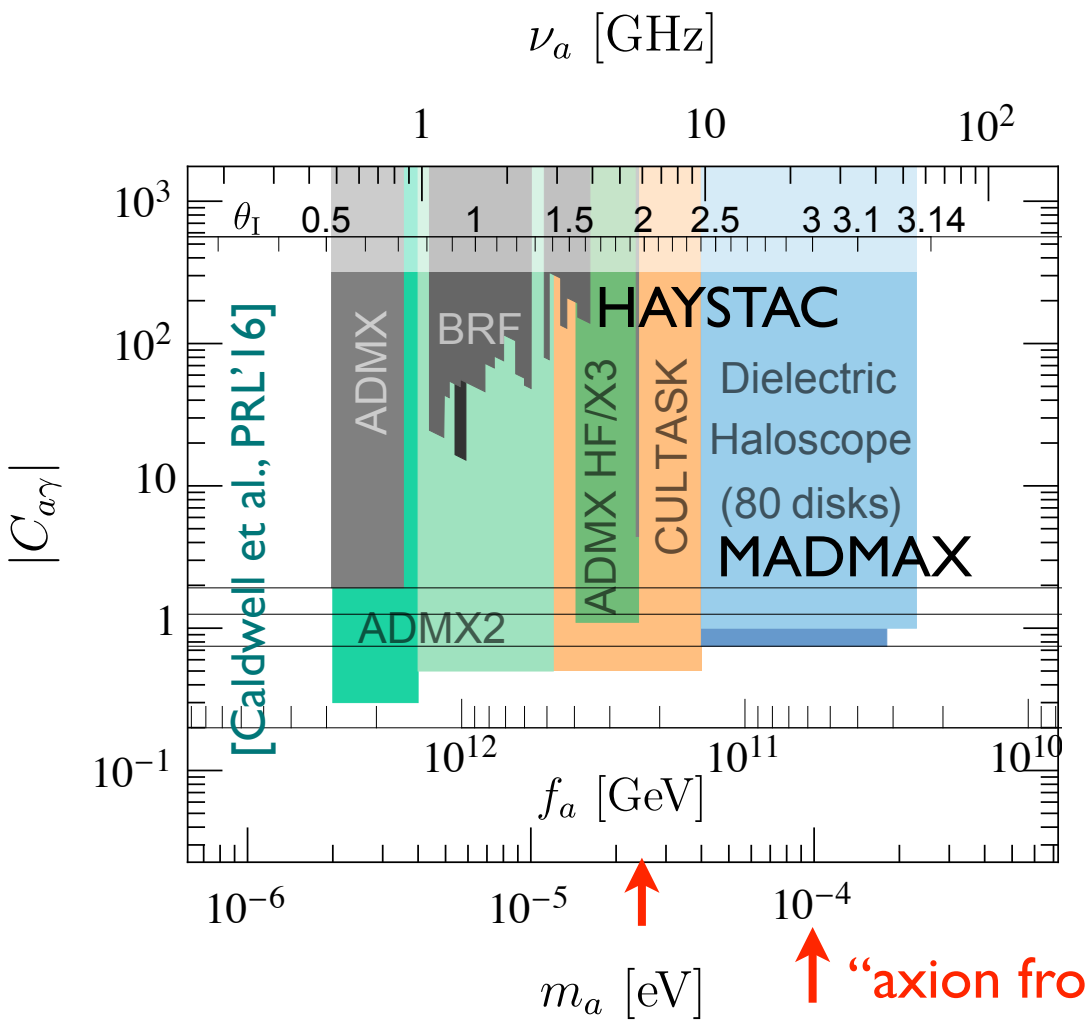
Scenario 2

[Saikawa]

Without observation: theory uncertainty stays

➔ Andreas Ringwalds talk

What is the axion dark matter mass?



"axion from hell"

← Scenario 1

accidental inital misalignment

$m_A > 100\ \mu eV$

Scenario 2

average inital misalignment

but computational challenge

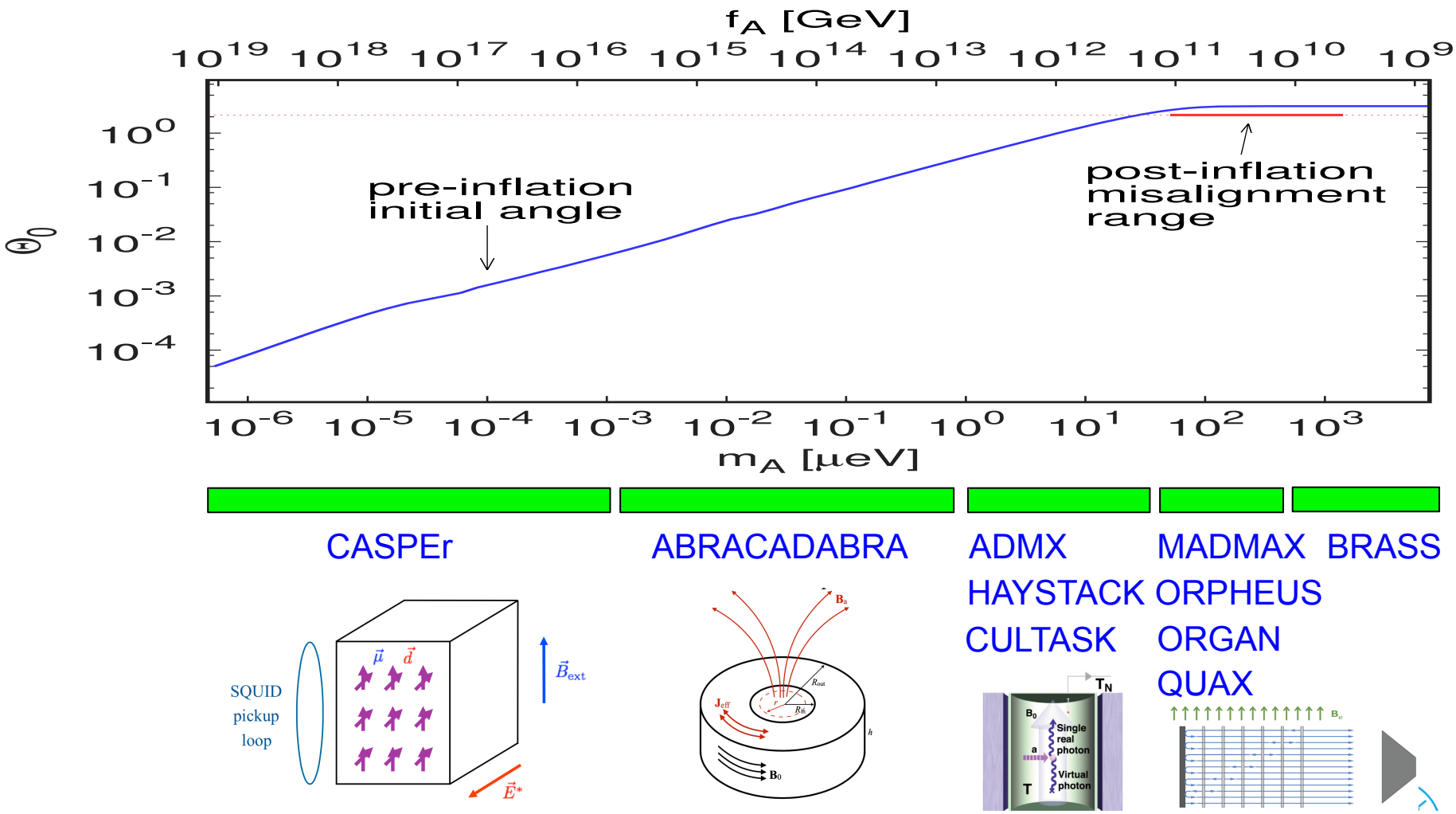
$$m_A = 26.2 \pm 3.4\,\mu\text{eV}$$

$$g_{a\gamma} = -\frac{\alpha}{2\pi f_a} C_{a\gamma} = -2.04(3) \times 10^{-16}\ \text{GeV}^{-1} \left(\frac{m_a}{1\,\mu\text{eV}}\right) C_{a\gamma}$$

$$C_{a\gamma} = \frac{\mathcal{E}}{\mathcal{N}} - 1.92(4)$$ ← another theory uncertainty

Experimental Projects

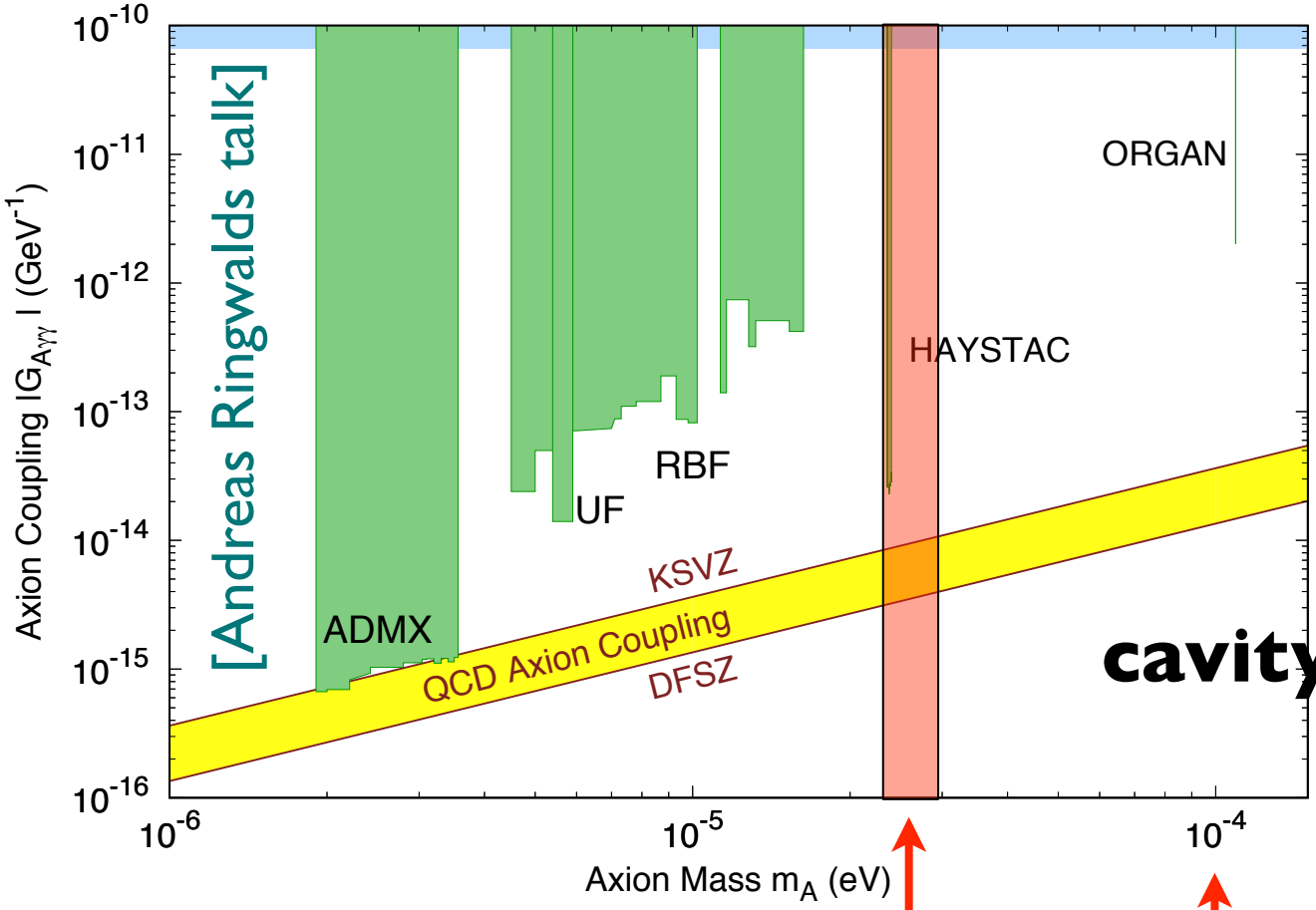
$$m_a = 5.70(6)(4)\,\mu\text{eV}\left(\frac{10^{12}\,\text{GeV}}{f_a}\right)$$



[Slide from Andreas Ringwalds talk at PASCOS 2017]

➔ Andreas Ringwalds talk

Existing exclusion limits today



CAST

helioscope

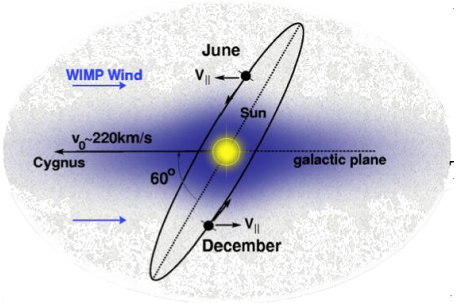
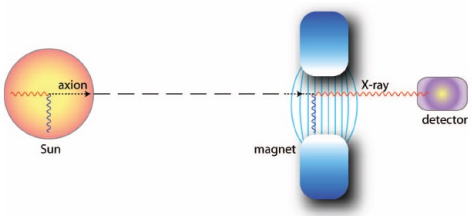
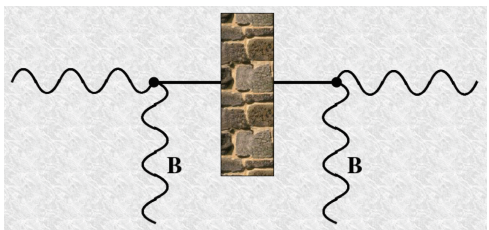
cavity haloscopes

"axion from hell"

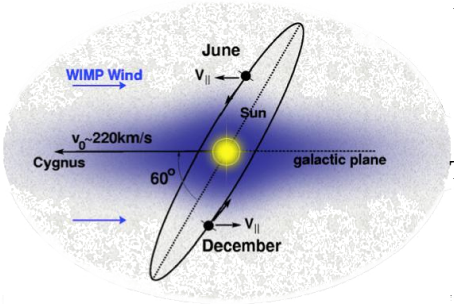
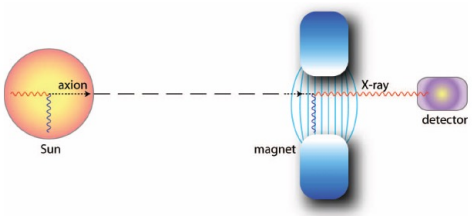
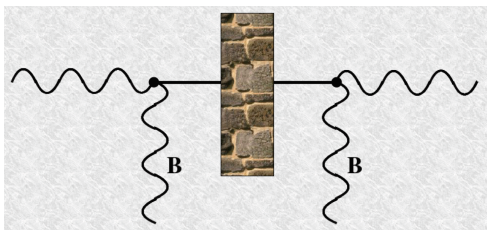
$m_A = 26.2 \pm 3.4\,\mu\text{eV}$

[Klaer, Moore,'17]

Axion Search Experiments

• Dark Matter Axions 	cavity haloscopes spin couplings magnetized mirror dielectric haloscope	ADMX, HAYSTAC, ORGAN, CULTASK/CAPP, ORPHEUS CASPEr, QUAX BRASS MADMAX + LC-circuit + ABRACADABRA
• Solar Axions 	helioscopes	CAST, TASTE, miniIAXO, IAXO
• Laboratory Axions 	light shining through wall 5th force/torsion balance	ALPS, ALPS II ARIADNE

Other projects in the same mass range

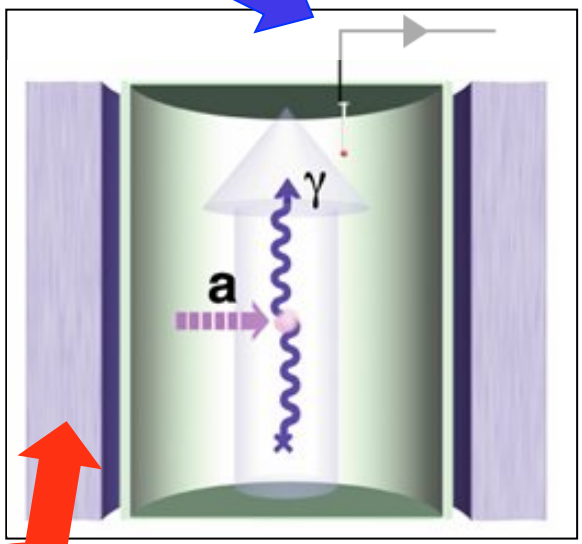
• Dark Matter Axions 	cavity haloscopes spin couplings magnetized mirror dielectric haloscope	ADMX, HAYSTAC, ORGAN, CULTASK/CAPP, ORPHEUS CASPEr, QUAX BRASS MADMAX + LC-circuit + ABRACADABRA
• Solar Axions 	helioscopes	CAST, TASTE, miniIAXO, IAXO
• Laboratory Axions 	light shining through wall 5th force/torsion balance	ALPS, ALPS II ARIADNE

Cavity Haloscopes

$$\frac{s}{n} = \frac{P_{sig}}{kT_S} \cdot \sqrt{\frac{t}{\Delta\nu}}$$

Integration time limited to ~ 100 sec

* *Dicke, 1946*



System noise temp.

$T_S = T_{phys} + T_N$

T_{Quant} *~ 48 mK @ 1 GHz*

Gen2: Dilution Fridge + Quantum-limited amps

$$P_{sig} \sim (B^2 V\, Q_{cav} C_{010})(g^2 m_a \rho_a)$$

Magnet size, strength $B^2V \sim \$$

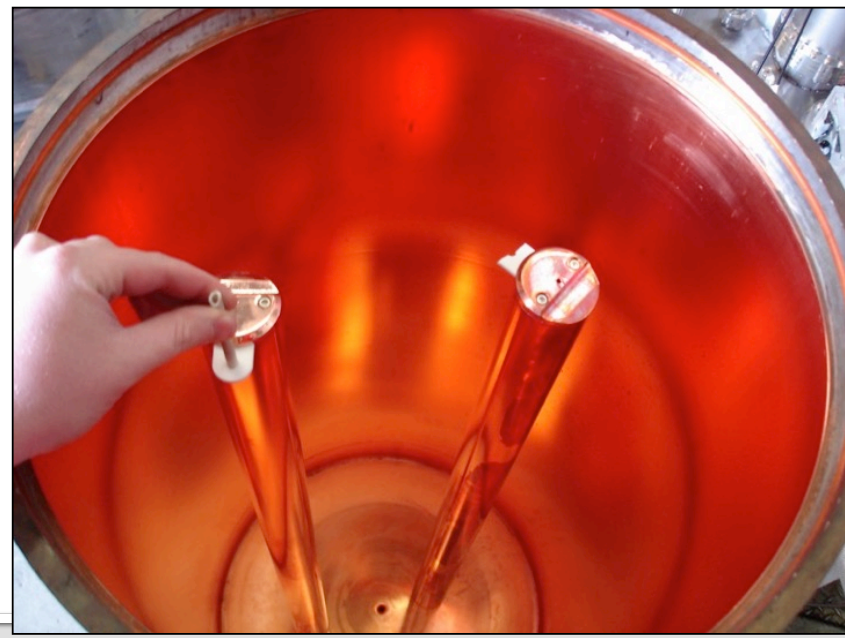
~ 10^{-23} *Watts for ADMX*

[Slide from Gianpaolo Carosis talk at PASCOS 2017]

Cavity Haloscopes towards higher axion mass values

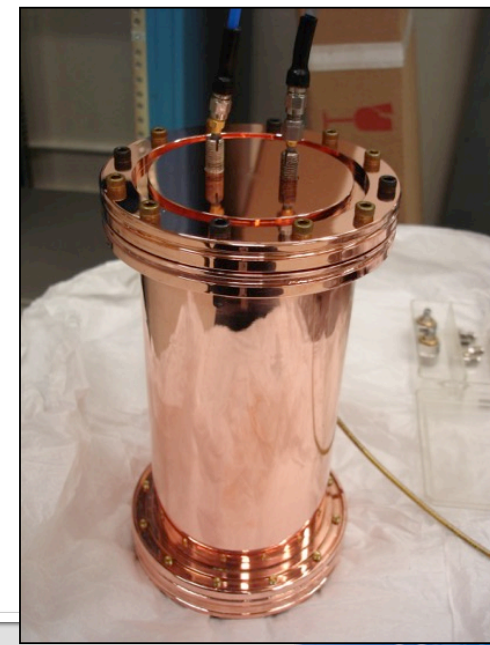
- Scaling single cavity to higher frequencies (f) – Volume ~ $(f)^{-3}$!
- Quality factor also goes down as frequency increases ($Q_L \sim 10^5 \cdot (f)^{-2/3}$)
- Need to move to multi-cavity array's.

Frequency ~ 540 MHz
Q_L – 100,000
Axion Mass ~ 2 μeV
Volume – 135 liters



16" diameter

Frequency ~ 2.4 GHz
Axion Mass ~ 9 μeV
Q_L – 60,000
Volume ~ 2.6 liters



5" diameter

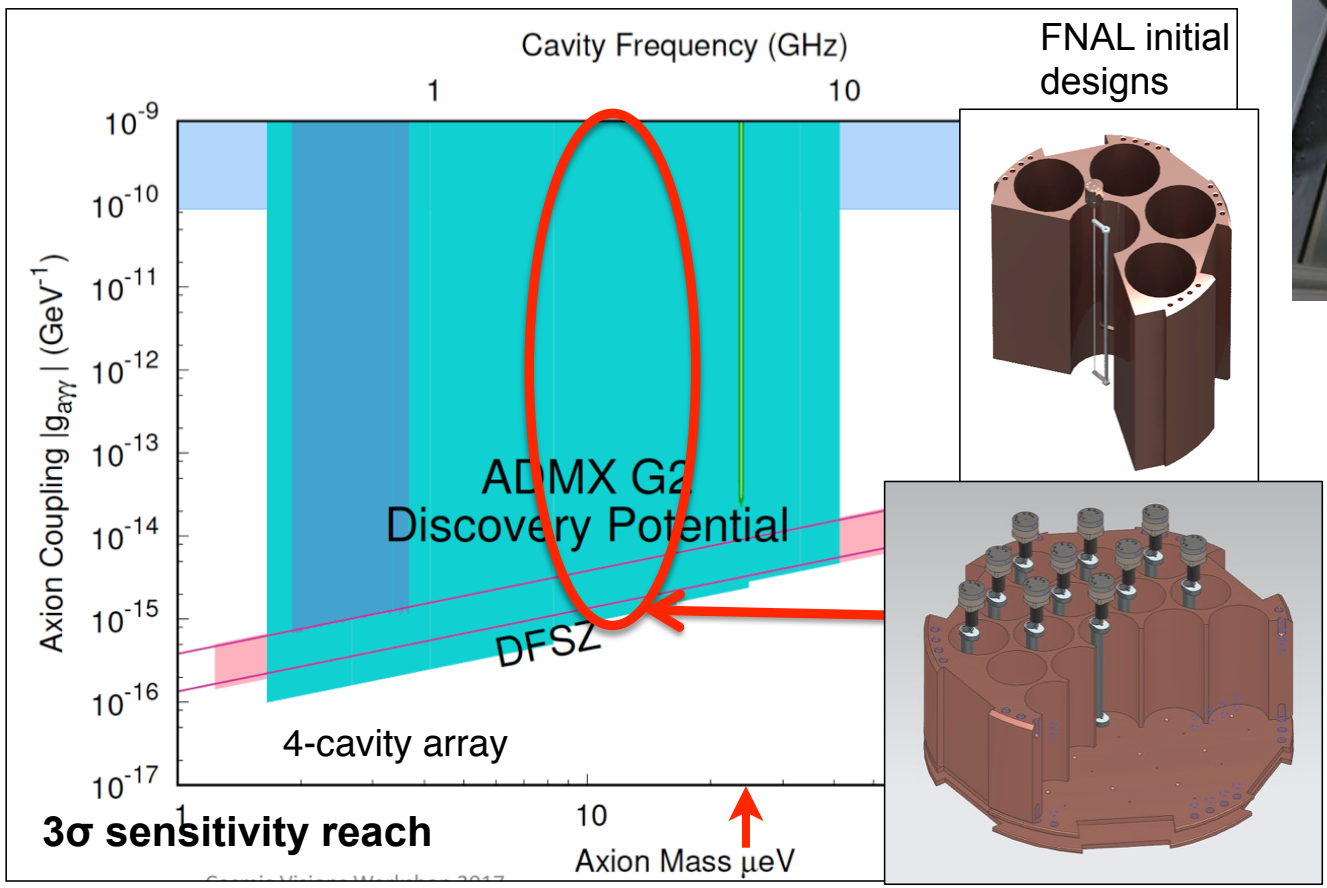
Frequency ~ 10 GHz
Axion Mass ~ 36 μeV
Q_L – 25,000
Volume – 0.025 liters

1" diameter

[Slide from Gianpaolo Carosis talk at PASCOS 2017]

ADMX future - multi-cavity arrays

ADMX Science Prospects (2-6 GHz)

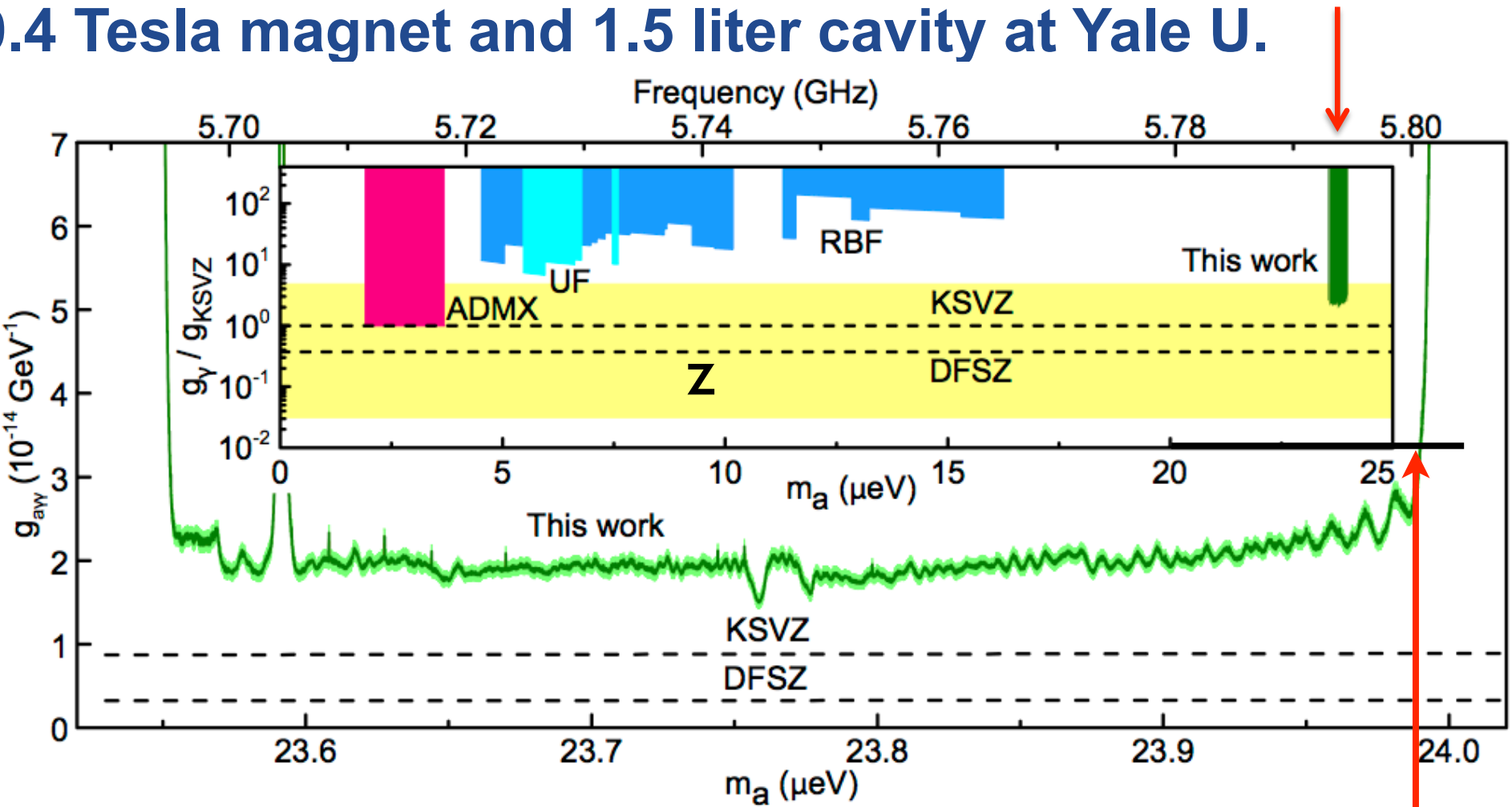


FNAL initial designs

[Slide from Gianpaolo Carosis talk at PASCOS 2017]

HAYSTAC (ADMX-HF)

9.4 Tesla magnet and 1.5 liter cavity at Yale U.



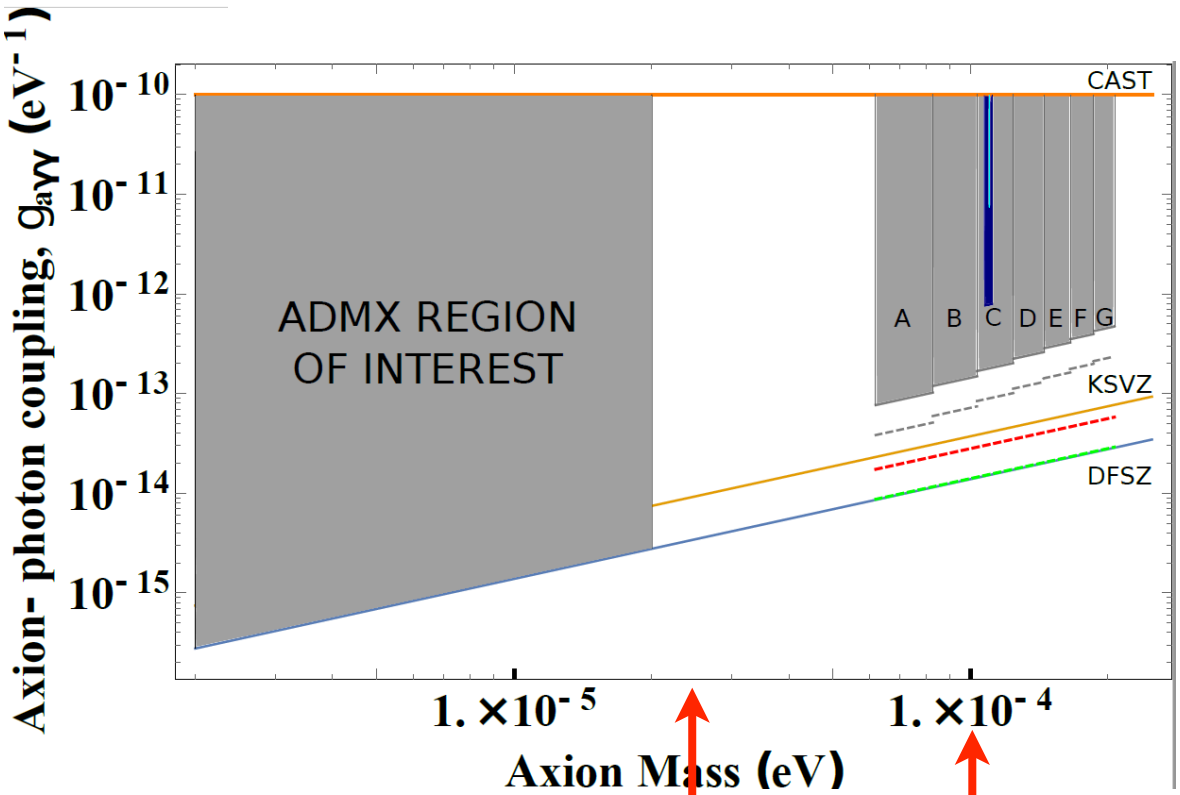
$m_A = 26.2 \pm 3.4\,\mu\text{eV}$

[Klaer, Moore,'17]

cf. [1706.00209]

ORGAN

Oscillating Resonant Group AxioN Experiment



2018-2025

SQL Amps
14 T magnet

magnet upgraded to 28 T
squeezed state amplifiers

$m_A = 26.2 \pm 3.4\,\mu\text{eV}$
[Klaer, Moore,'17]

"axion from hell"
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anomalous Josephson junct.
[Beck, PRL'13 & PDU'15]

ORGAN

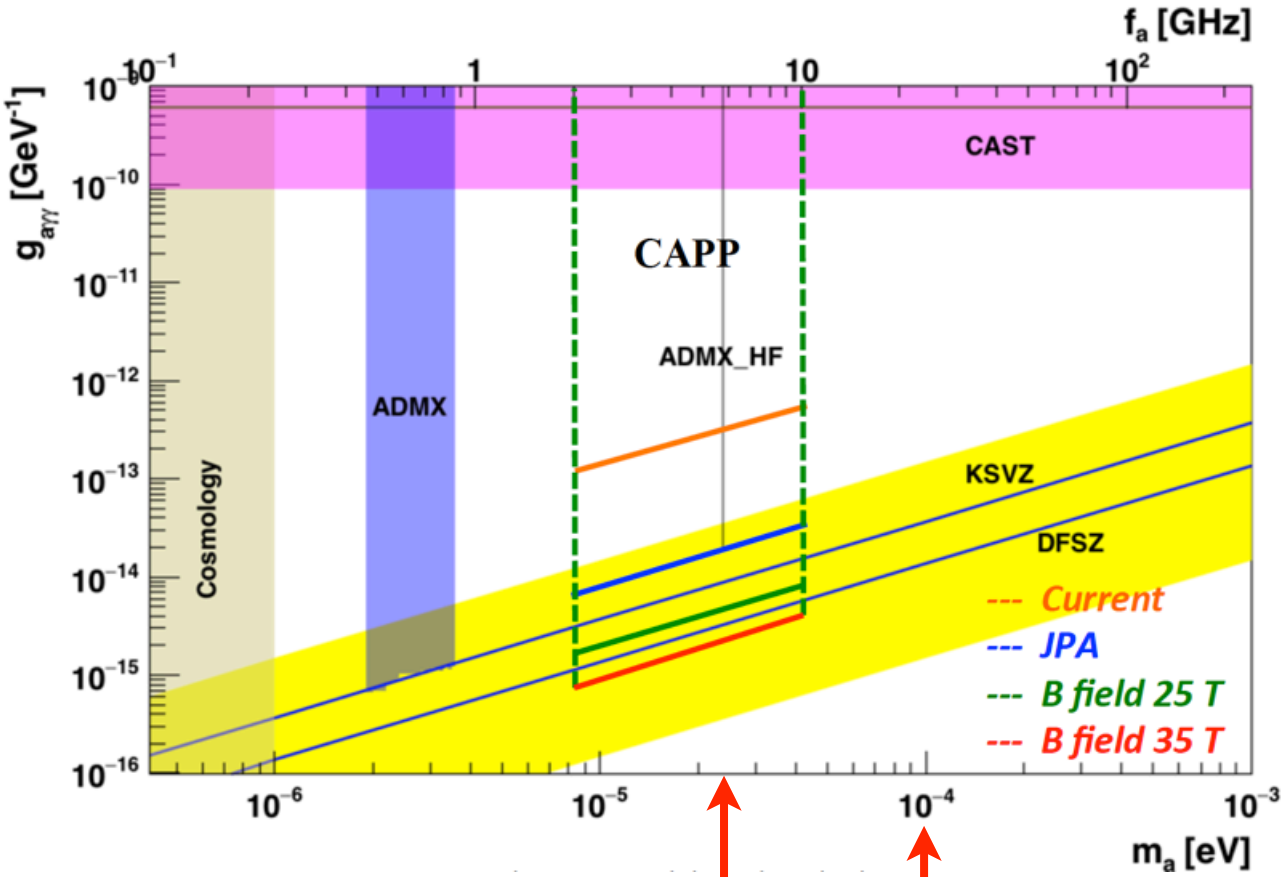
cf. [1706.00209]

- Pathfinding Run
  - m_a = 110 μeV (i.e. 26.531 GHz), 2.5 neV wide
  - TM_{020} mode (i.e., higher order mode)

Mode	Form Factor	Volume (cm^3)	Geometry Factor (Ω)
TM_{010}	0.69	1.45	386.5
TM_{020}	0.13	7.78	744.6
TM_{030}	0.053	18.87	1244.3

  - HEMT-based amplification
  - 7 T magnet
- Future Prospects
  - 7y funding secured
  - Josephson parametric amplifiers -quantum-limited
  - 14 T/28 T superconducting magnet
  - pipe organ-like arrangement of thin long resonant cavities

CULTASK & CAPP Projected Sensitivity



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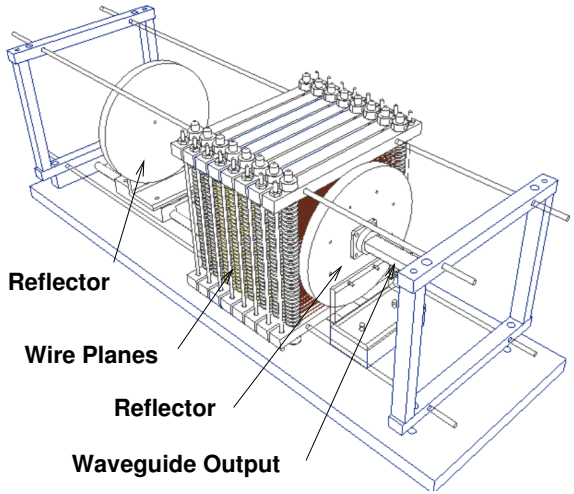
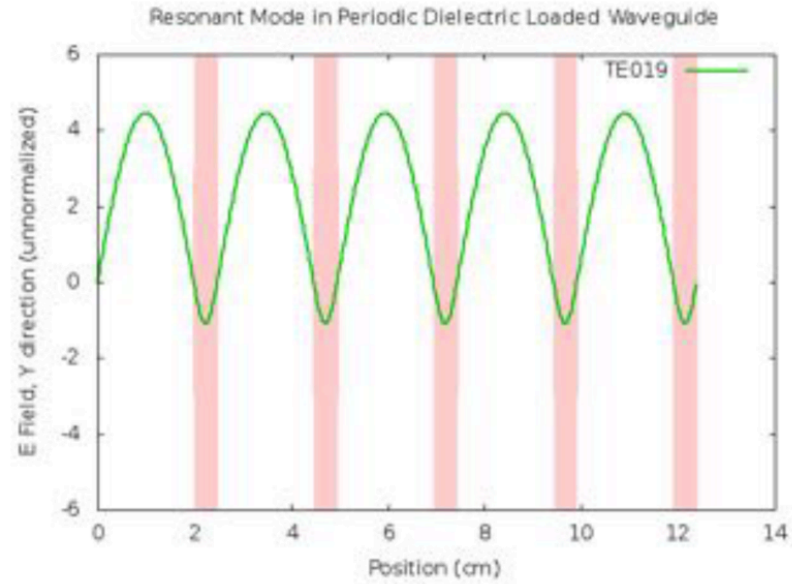
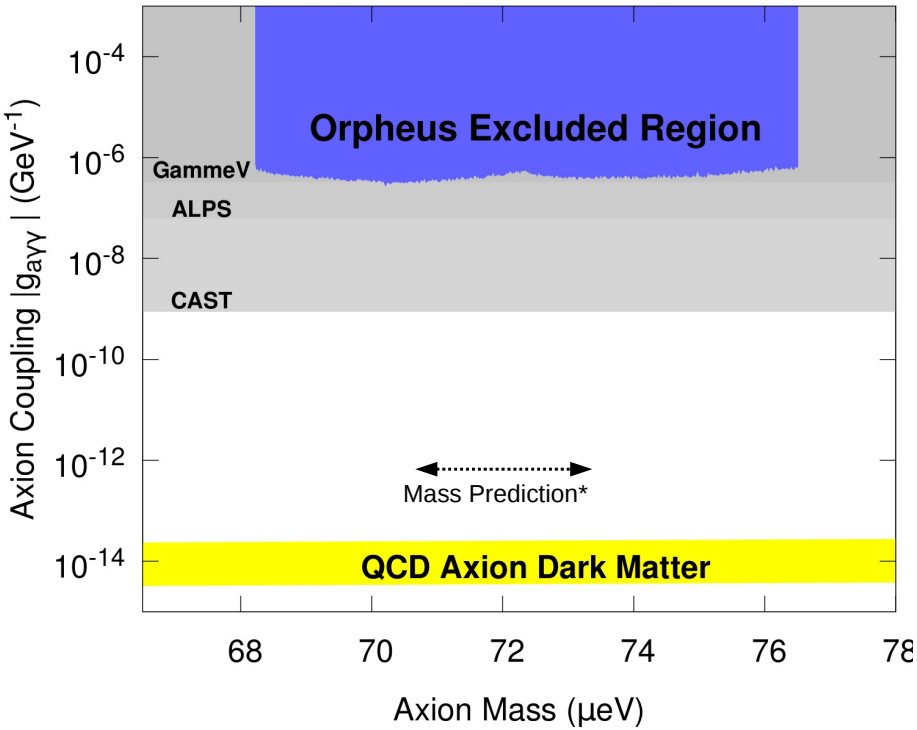
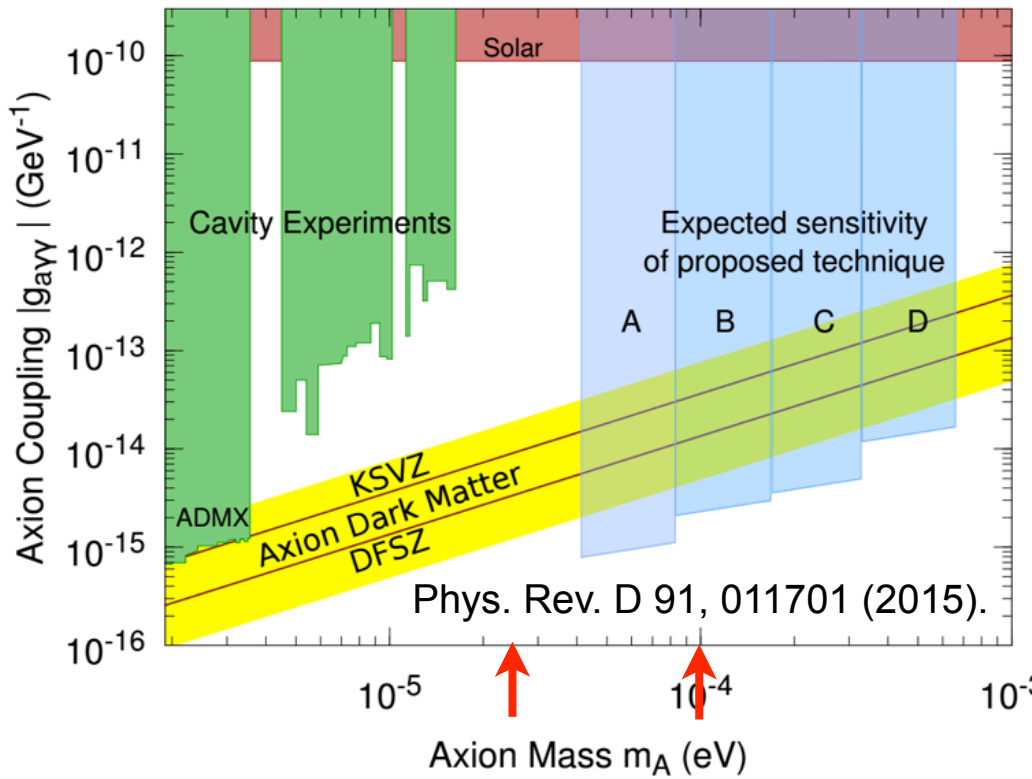
ORPHEUS



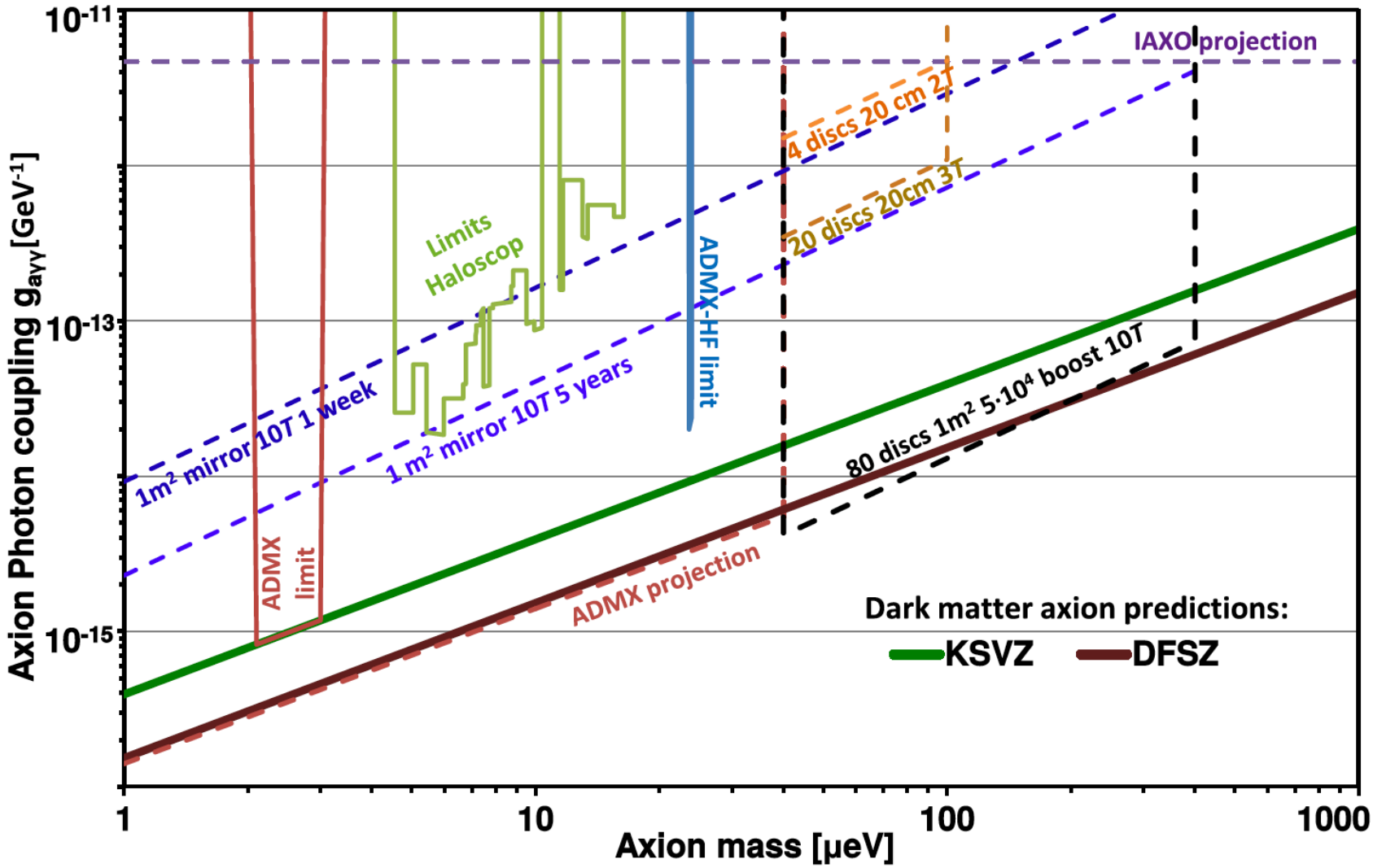






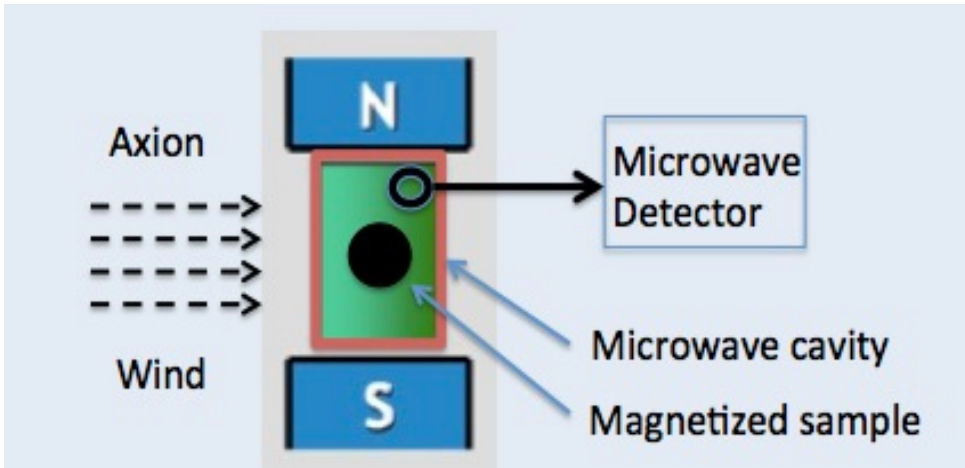
[Slide from Gray Rybka]

MADMAX


Axion Photon coupling $g_{a\gamma\gamma}$[GeV^{-1}]
10^{-11}
10^{-13}
10^{-15}
1
10
100
1000
Axion mass [μeV]
IAXO projection
4 discs 20 cm 2T
20 discs 20cm 3T
Limits Haloscop
ADMX-HF limit
1m² mirror 10T 1 week
1 m² mirror 10T 5 years
ADMX limit
ADMX projection
80 discs 1m² 5·10⁴ boost 10T
Dark matter axion predictions:
KSVZ
DFSZ

QUAX

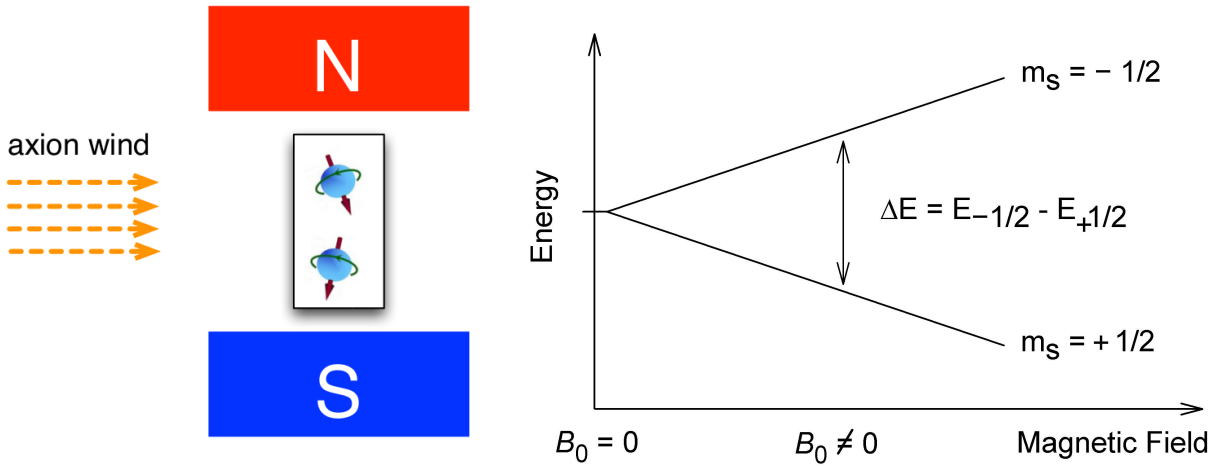
QUest for AXion Experiment



R. Barbieri et al., *Searching for galactic axions through magnetized media: The QUAX proposal* Phys. Dark Univ. **15,** 135 - 141 (2017)

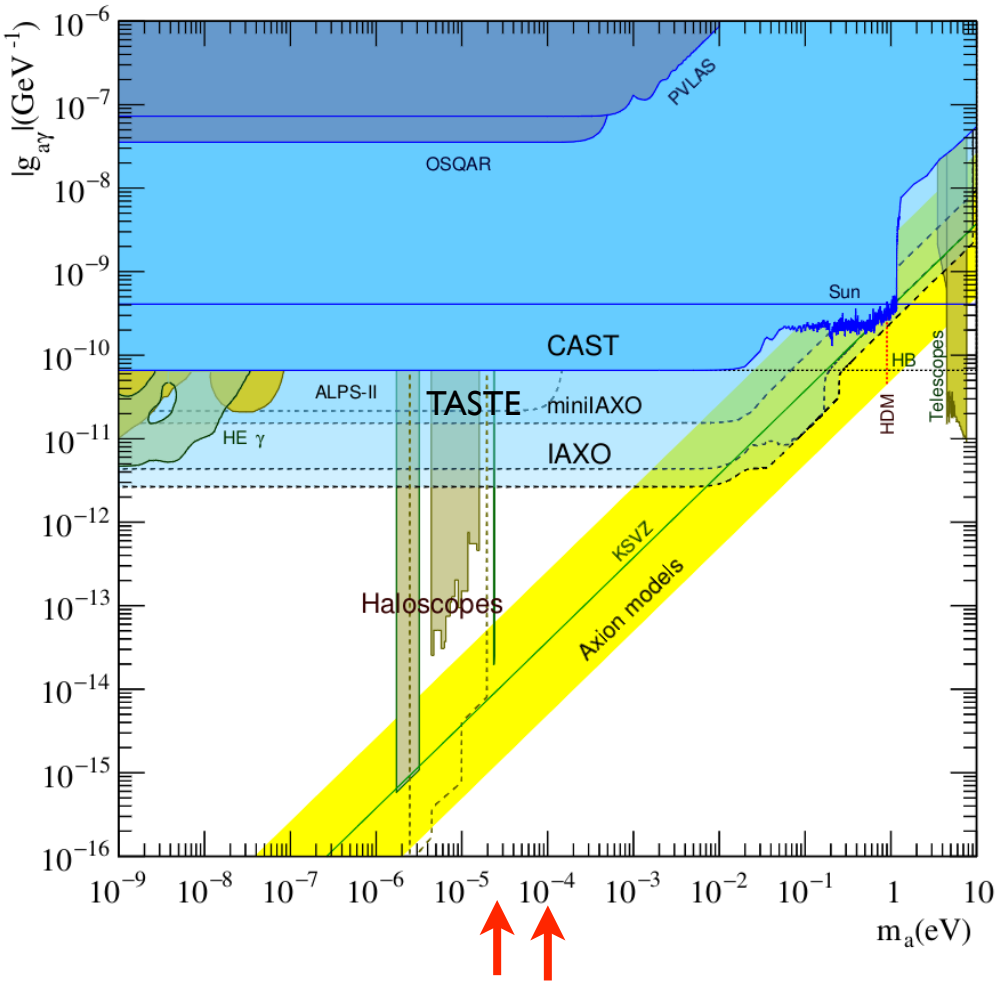
DSFZ specific

$m_A \sim 200$ μeV

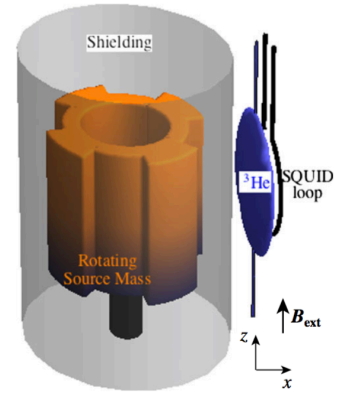


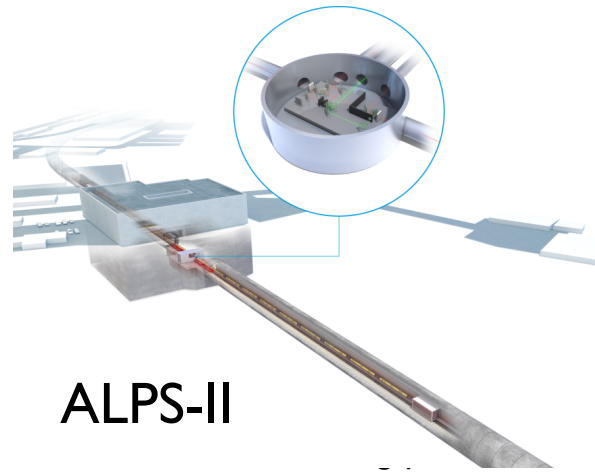
Sensitivity to the axion-electron coupling

Solar Axions & Laboratory Axions



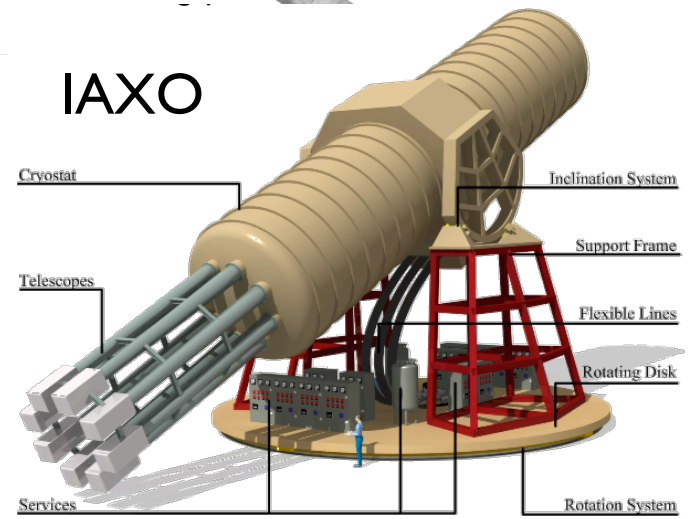
ARIADNE





ALPS-II

IAXO



No direct MADMAX competitors

Conclusions

- axion dark matter mass search range?

  $m_A = 26.2 \pm 3.4\,\mu\mathrm{eV}$ [Klaer, Moore,'17]

  Has the m_A ~ 100 μeV axion from hell gone back home?

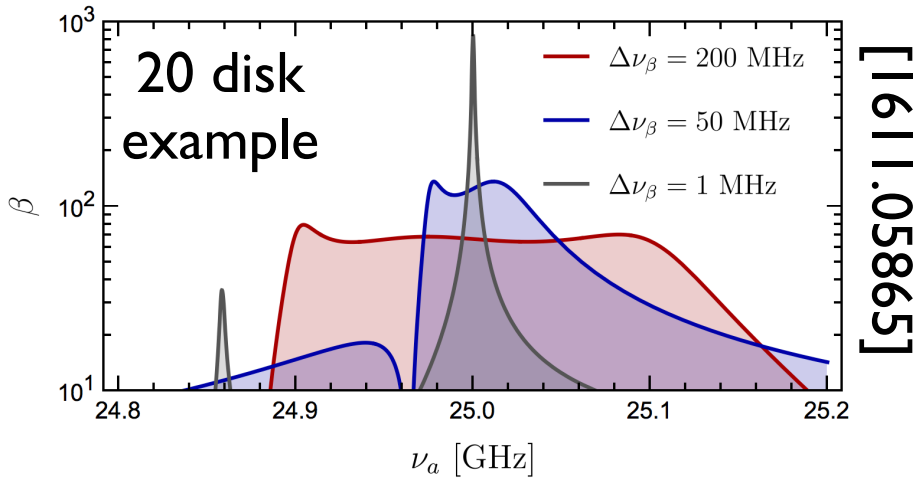
  ➔ Watch out for theory news!

- strongly growing exp. efforts to find the axion also towards m_A ~ 100 μeV

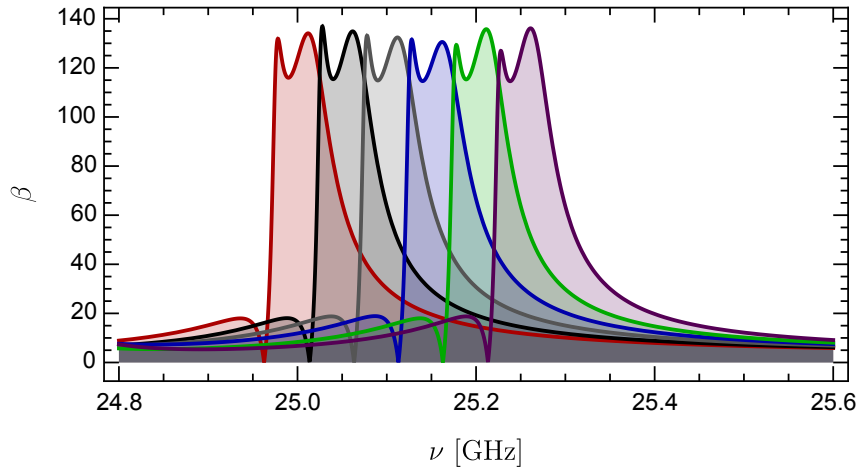
  HAYSTAC, ORGAN, CAPP, ORPHEUS, QUAX, ...

  ➔ Watch out for experimental news!

- MADMAX: unique potential with respect to seamless broadband m_A scans

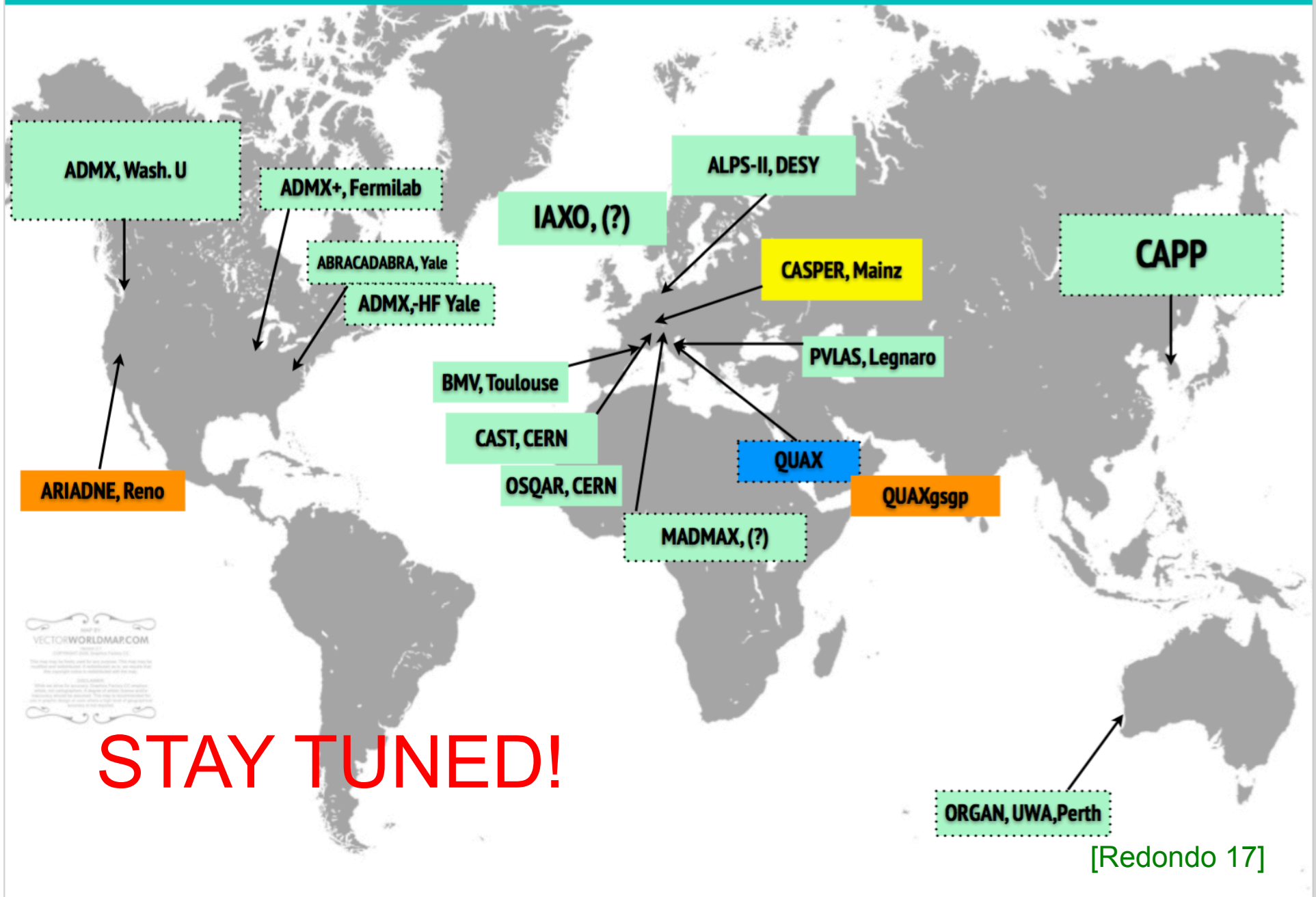


[1611.05865]



➔ Develop a clever MADMAX search strategy!

Lab experiments 2017



[Redondo 17]