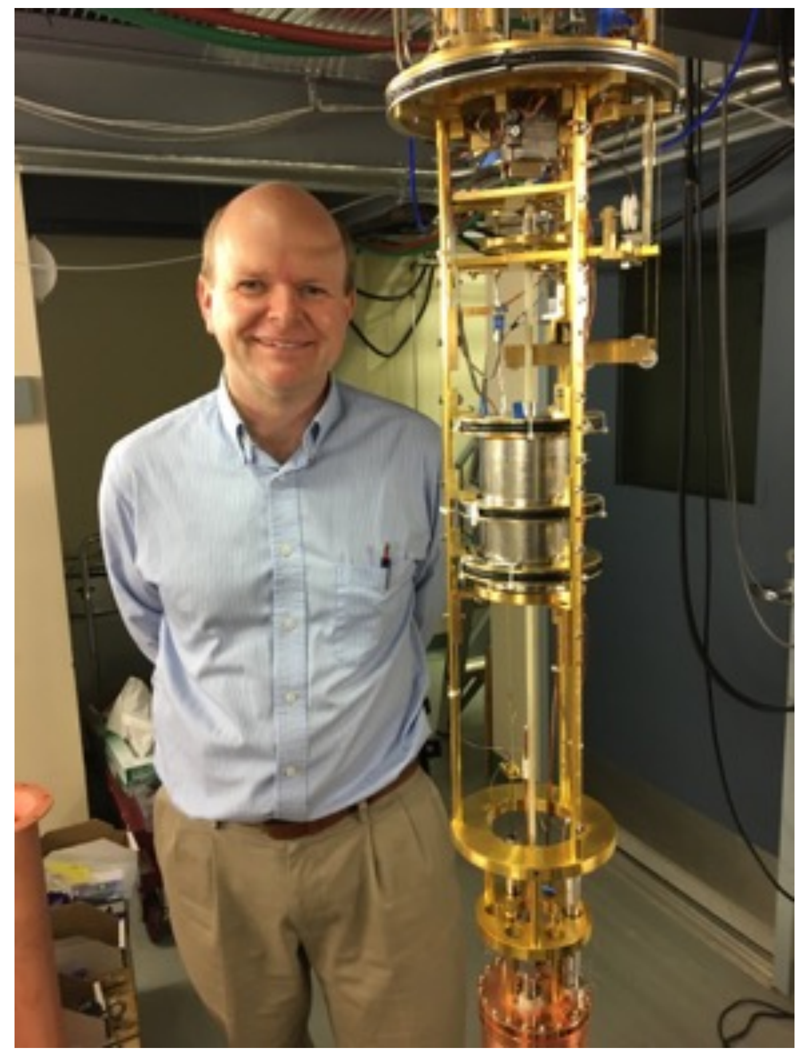
Overview of axions, axion-like particles

Ed Daw
The University of Sheffield



The Strong CP problem

Standard model symmetry group is $\underline{SU(3)} \times \underline{SU(2)} \times \underline{U(1)}$

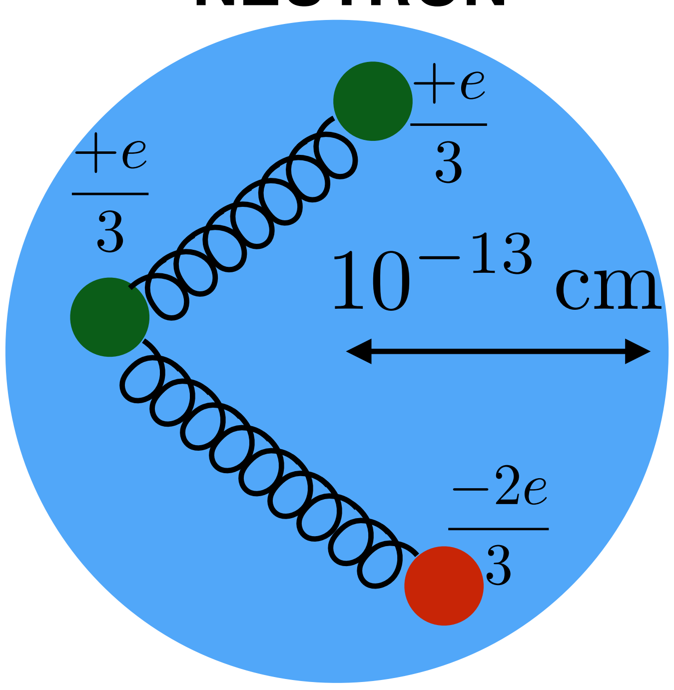
$SU(3)$	$SU(2)$	$U(1)$
NON-ABELIAN	**NON-ABELIAN**	**ABELIAN**
CP CONSERVING!	**CP VIOLATING**	**CP CONSERVING**

$$\mathcal{L}_{\rm CPV} = \frac{(\Theta + \arg\det M)}{32\pi^2} \vec{E}_{\rm QCD} \cdot \vec{B}_{\rm QCD}$$

Evidence for CP conservation in the SU(3) strong interactions from multiple measurements of neutron and nuclear electric dipole moments. For example, neutron EDM < 10^{-26} e-cm.

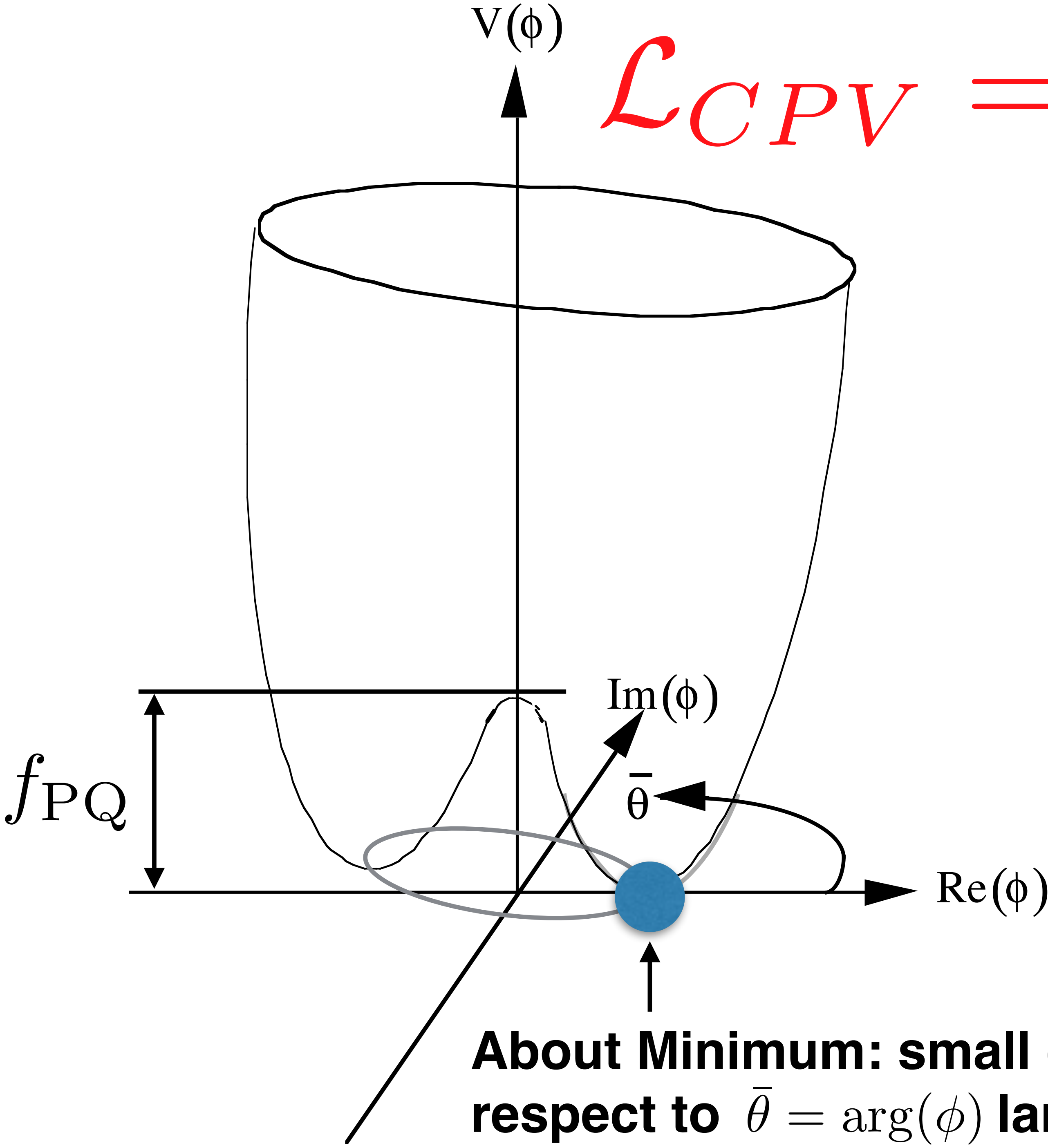
Even simple dimensional arguments show that this is unexpected. Why do the intricate SU(3) QCD interactions conserve CP when the less intricate SU(2) QED interactions do not? This is the strong CP problem.

NEUTRON



The Peccei Quinn Mechanism Axions and ALPs

$$\mathcal{L}_{CPV} = \overline{\mathbf{\Theta}}\mathbf{E.B}$$

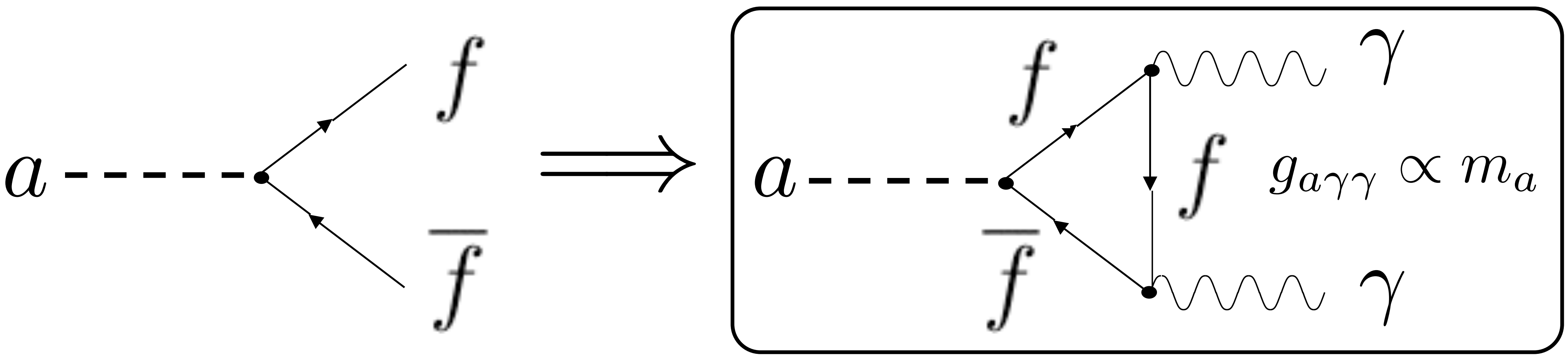


$$\overline{\mathbf{\Theta}} = 0$$

About Minimum: small curvature (hence small mass) with respect to $\bar{\theta} = \arg(\phi)$ **large curvature (hence large mass) with respect to** $\mathrm{Re}(\phi)$

Axion Phenomenology

The axion is a pseudoscalar; has the same quantum numbers as the π^0, and the same interactions, but with strengths scaled to the axion mass



$$f_{PQ} \propto \frac{1}{m_a} \qquad \Omega_{PQ} \propto \frac{1}{m_a^{\frac{7}{6}}}$$

Axion Sources for Lab Searches

LAB

PVLAS

ALPS/ALPS2*

OSQAR

CASCADE*

ARIADNE*

HALO

ADMX*

X3*

CAPP/CULTASK*

CASPER

FUNKY

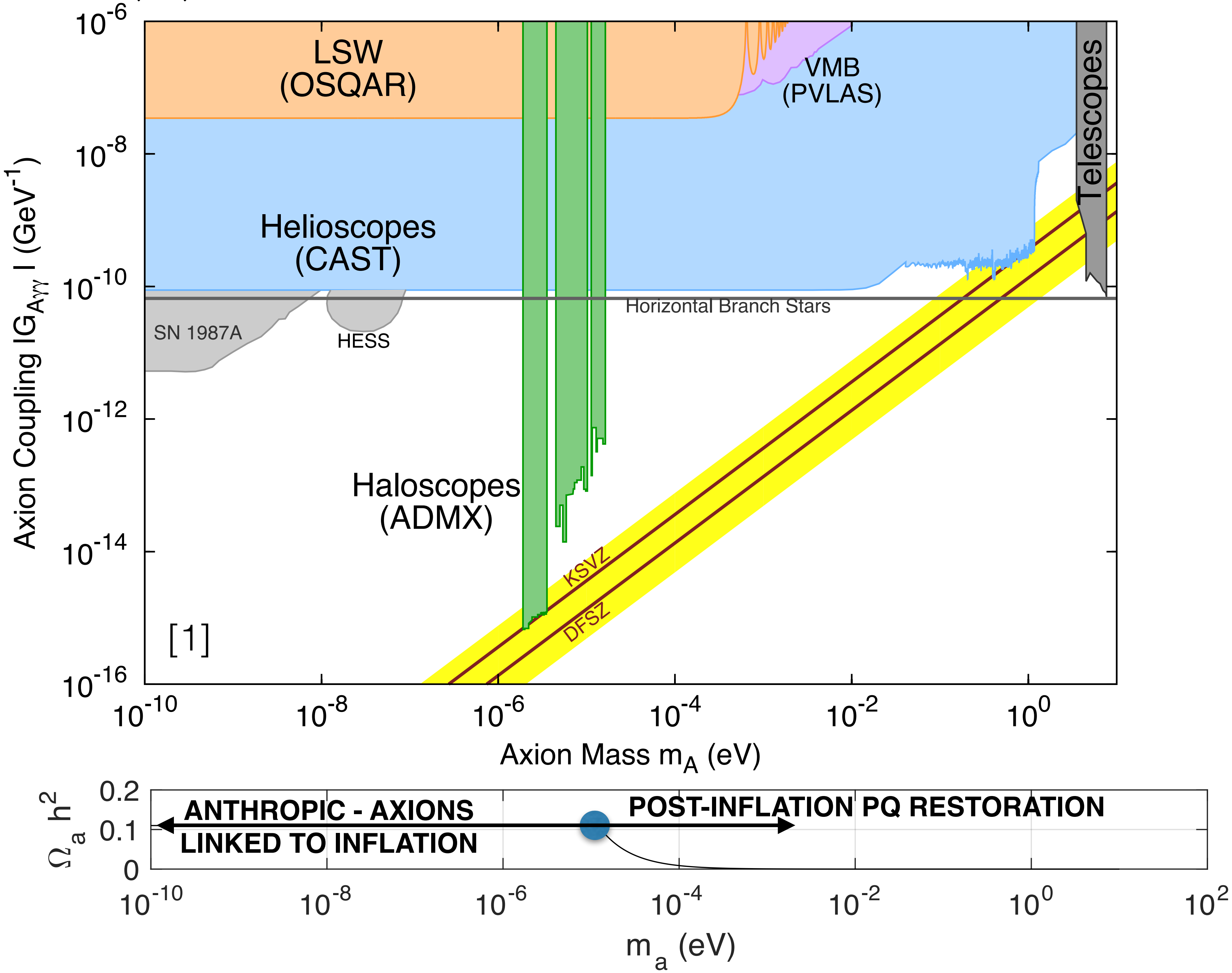
MADMAX

SUN

CAST

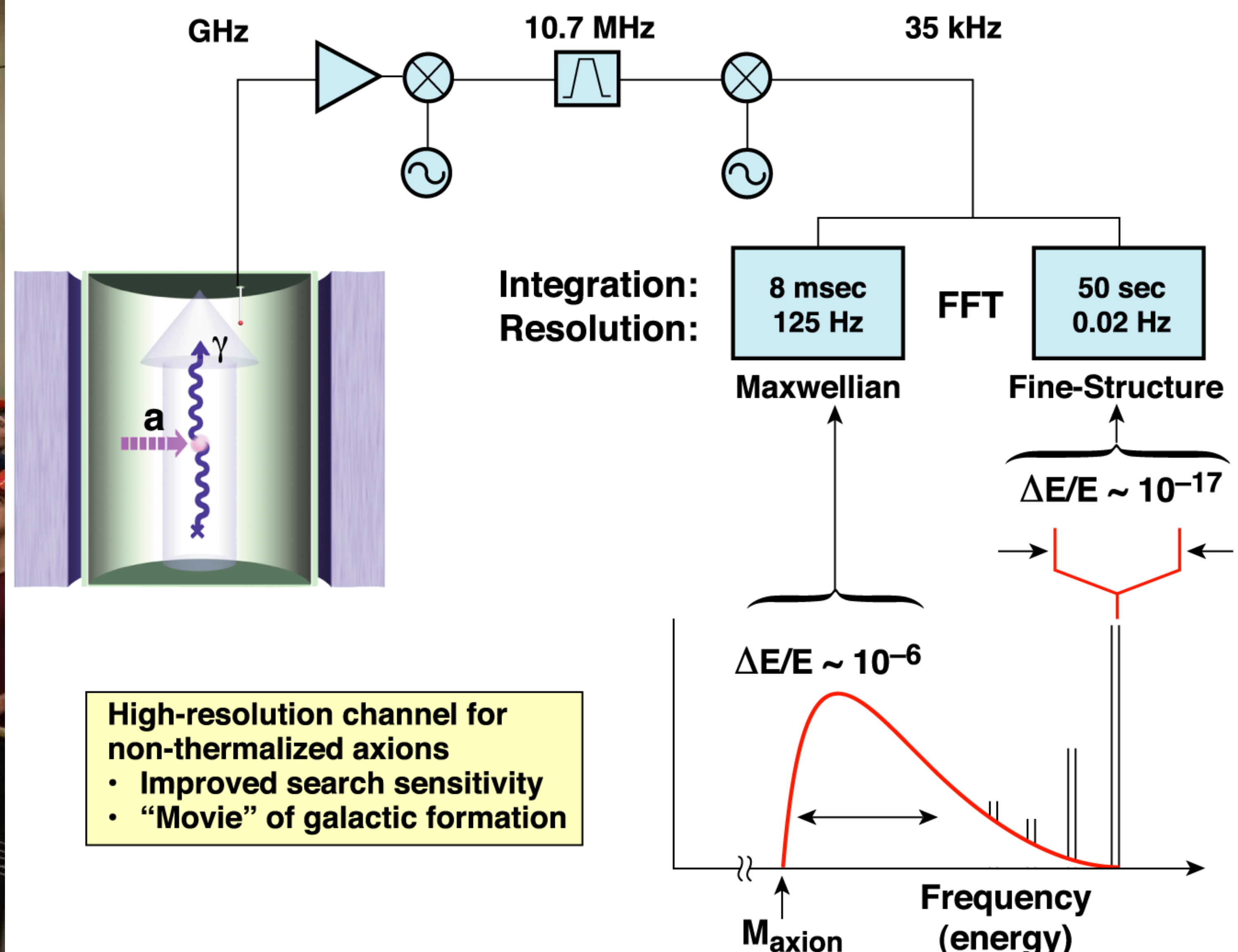
IAXO*

$g_{a\gamma\gamma}$ vs. m_a parameter space



[1] K.A. Olive et al. (Particle Data Group), Chin. Phys. C, 38, 090001 (2014) and 2015 update
2016 revision by A. Ringwald, L. Rosenberg, G. Rybka,

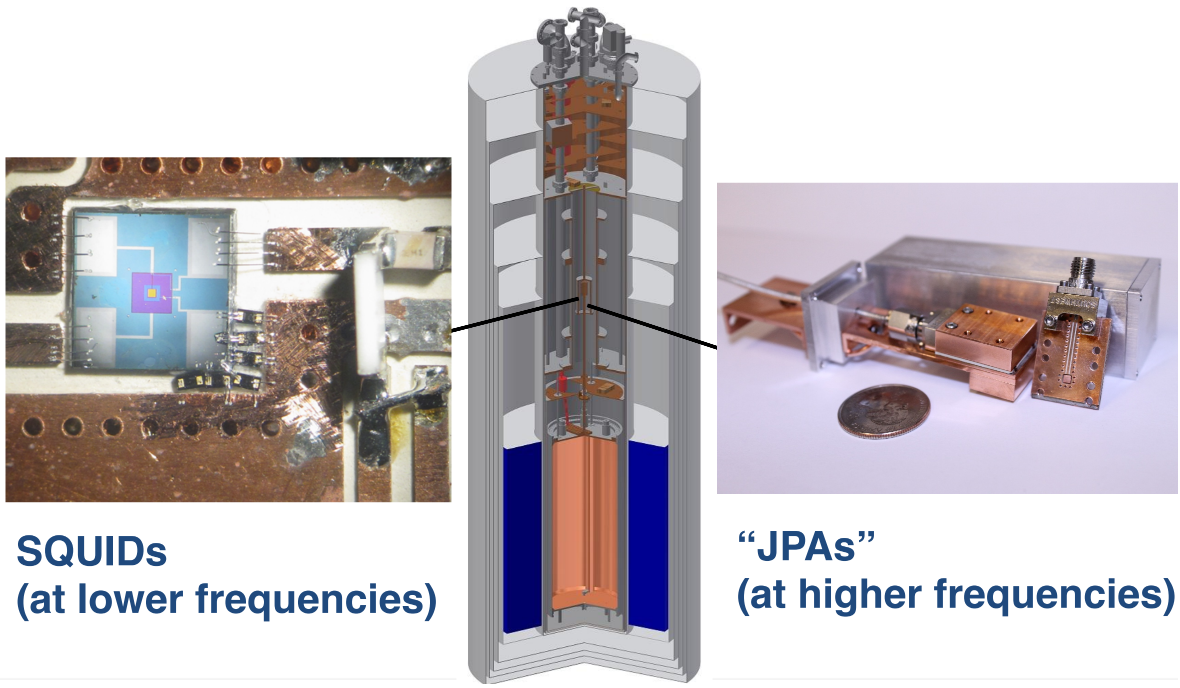
Resonant Cavity Detectors - **ADMX**

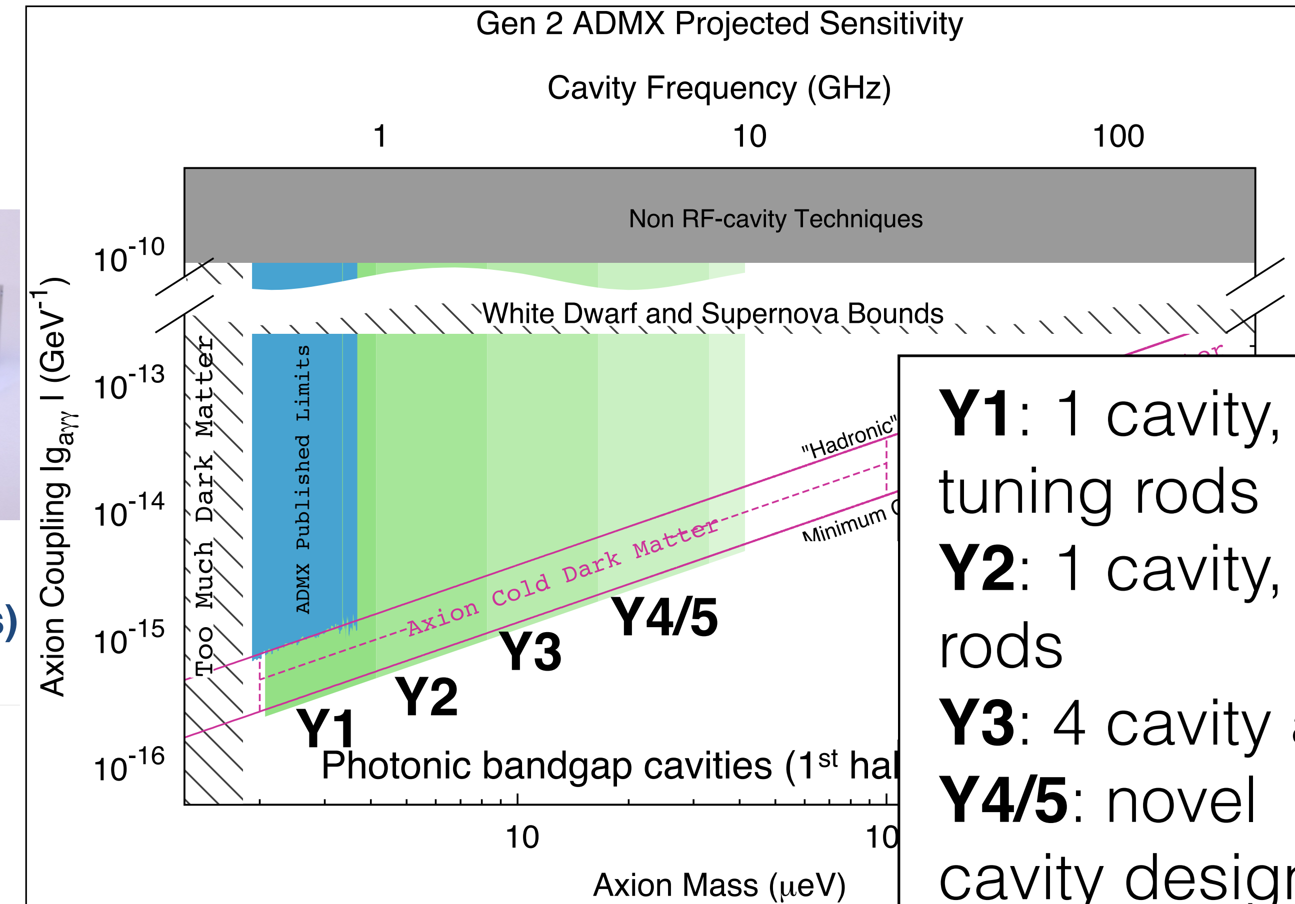


QUANTITY IN BRACKETS IS

$$P_\gamma = \left(\frac{g^2_{a\gamma\gamma} \rho_a \hbar^2}{m_a^2 c} \right) 2\pi c^2 \varepsilon_0 B_0^2 V f_{010} \nu_a Q$$

ADMX II Reach



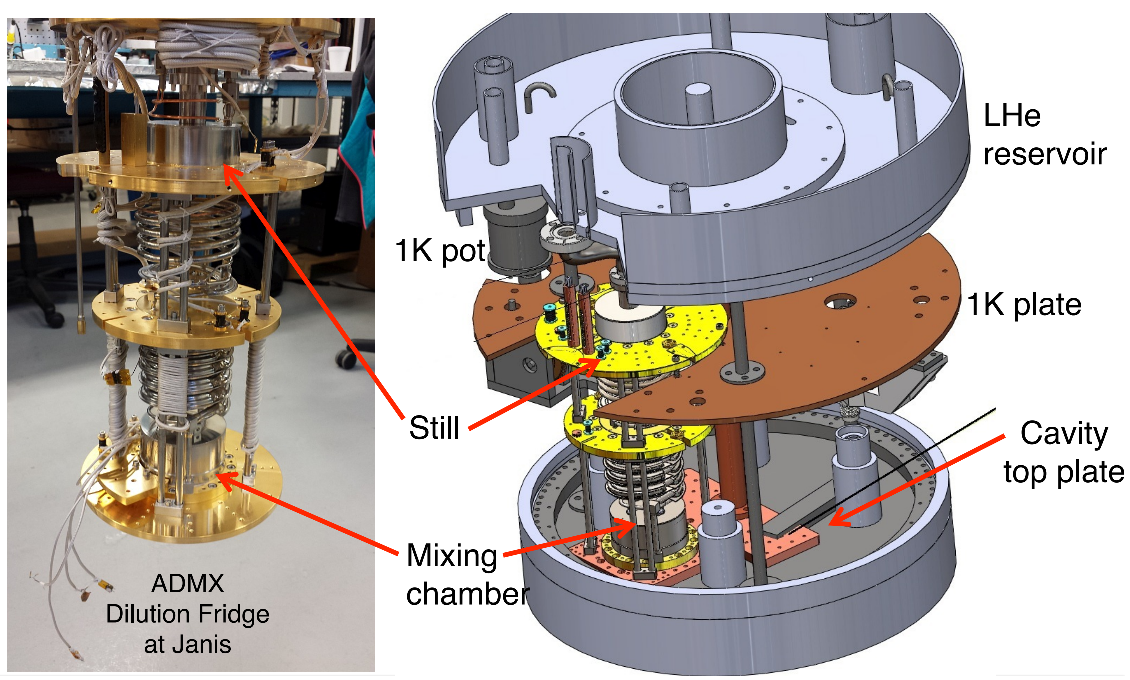


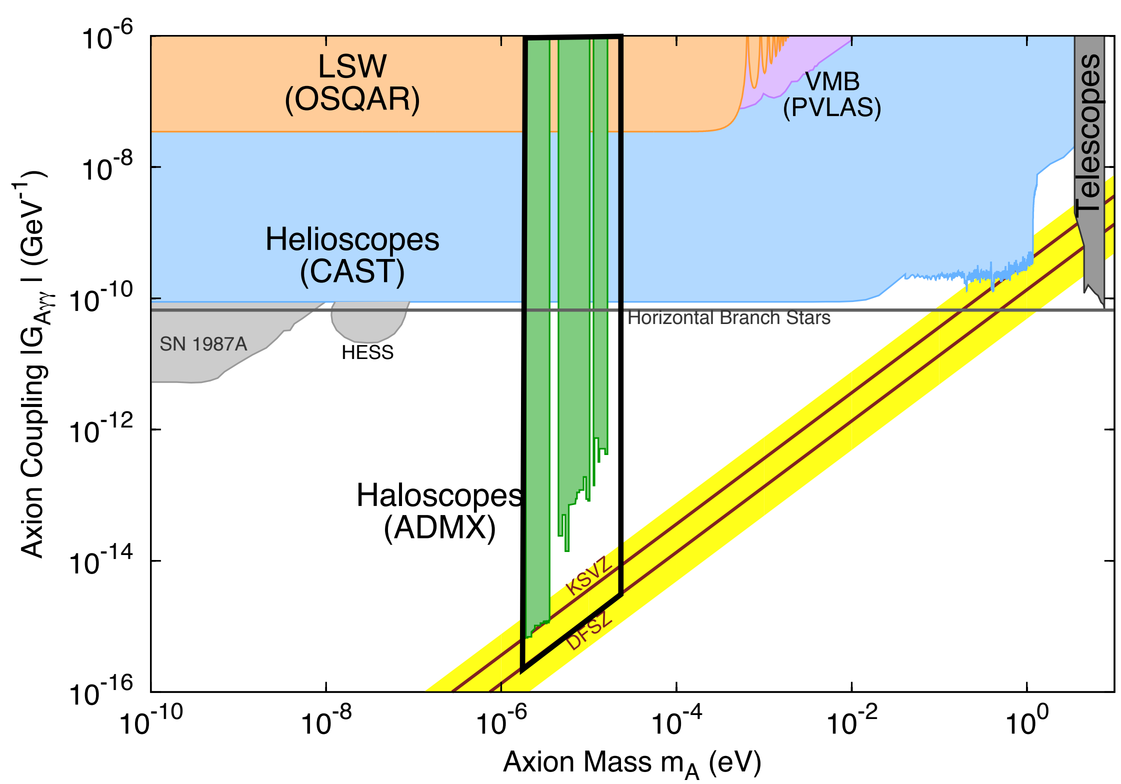
Y1: 1 cavity, 2 tuning rods

Y2: 1 cavity, more rods

Y3: 4 cavity array

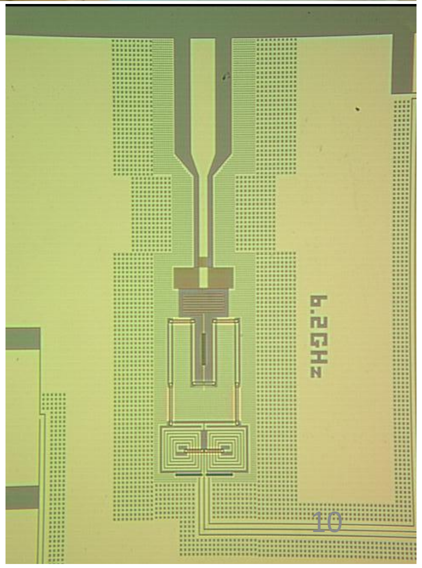
Y4/5: novel cavity designs



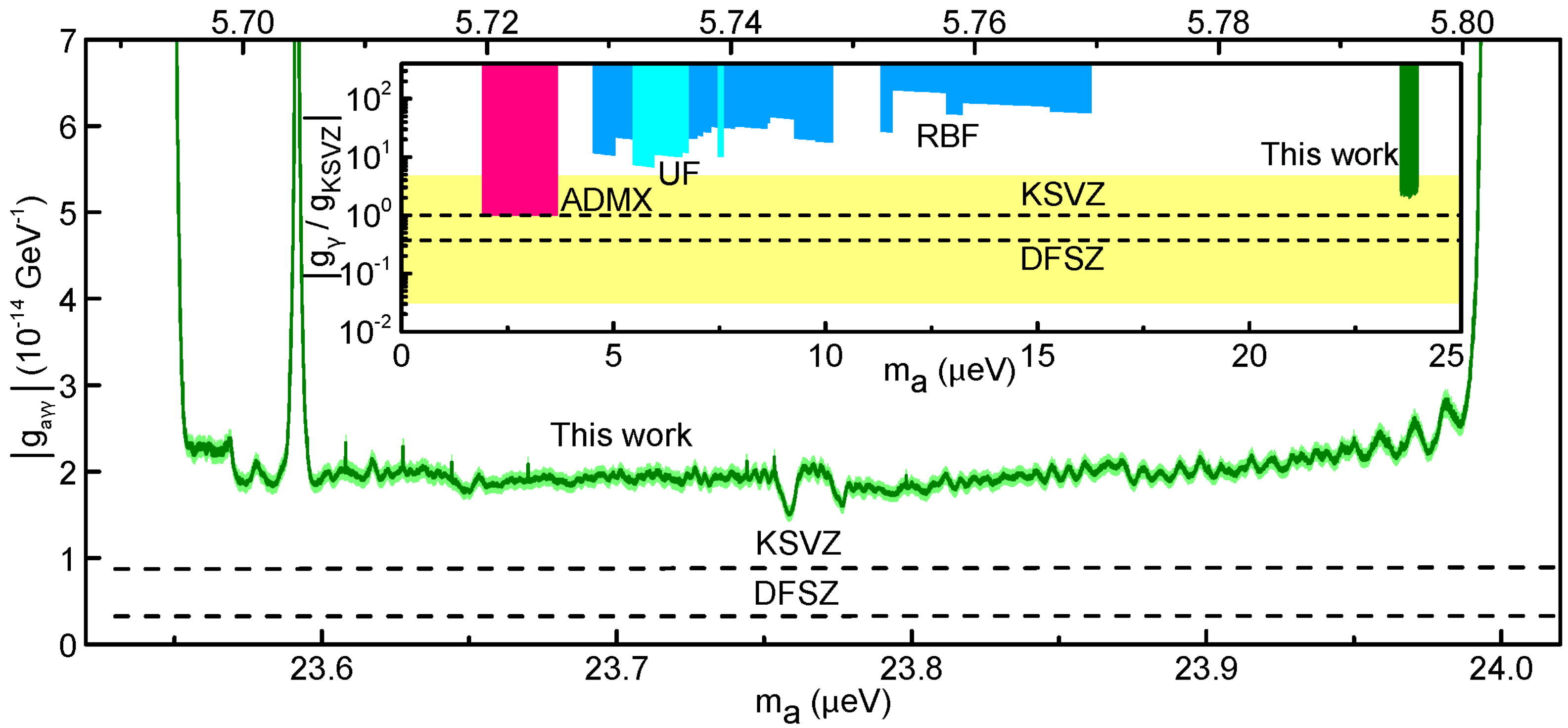


X3 - Yale (formerly ADMX-HF)

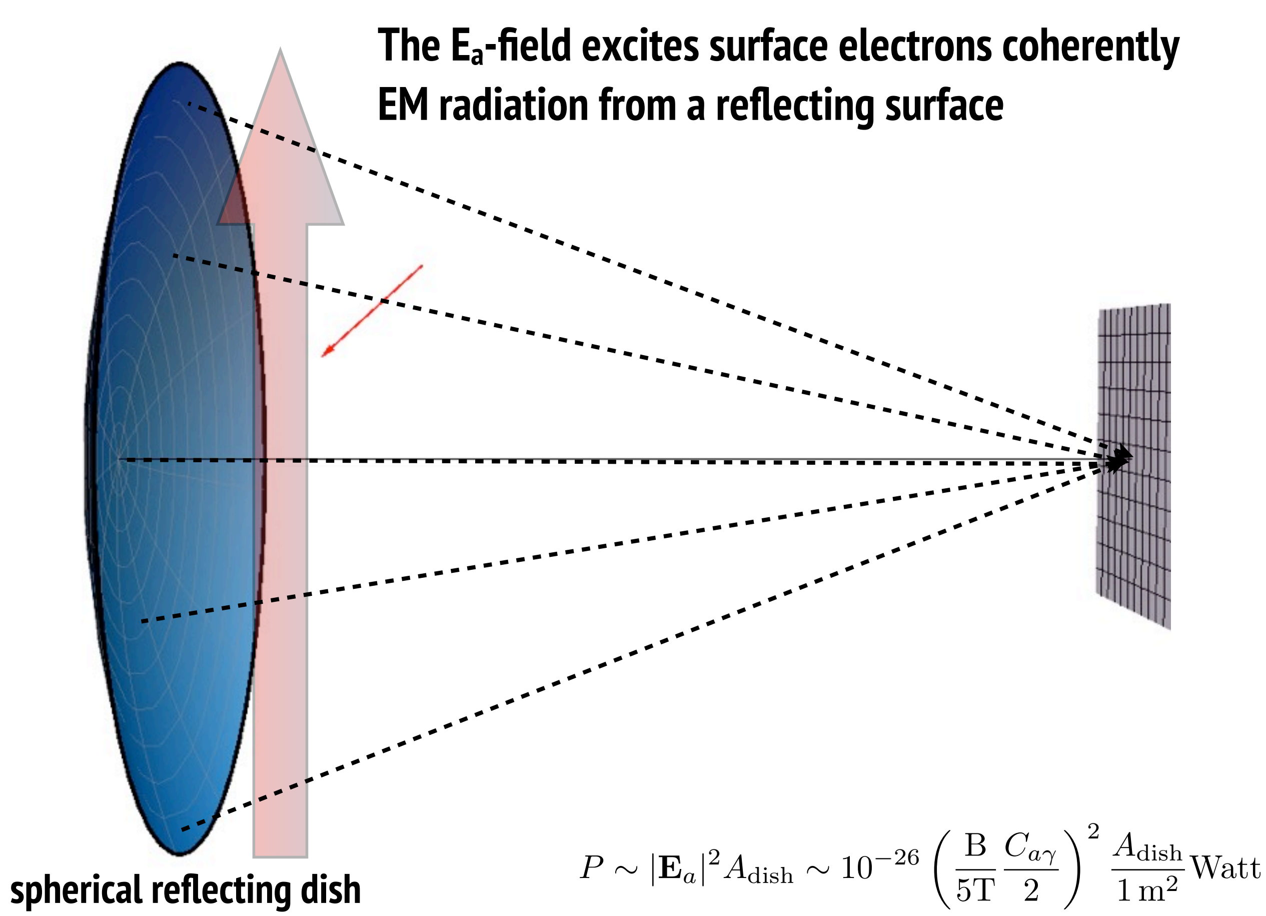
- Probes the 5-25 GHz (20-100 μeV) axion mass region.
- Uses a 25 mK dilution refrigerator.
- Uses a highly uniform 9 T magnet.
- Uses Josephson Parametric Amplifiers (JPAs)

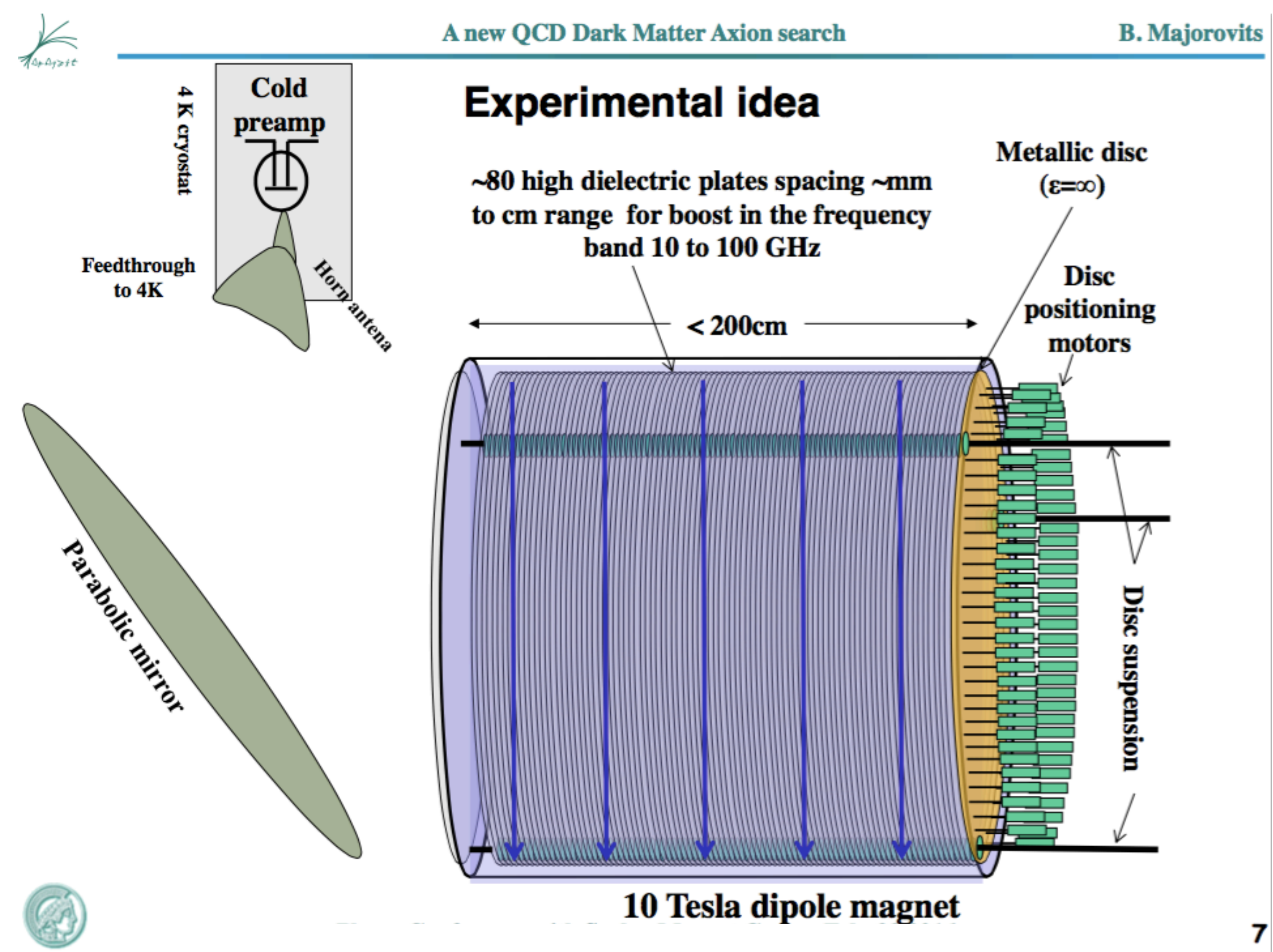


[From a talk by Tim Shokair for X3 collaboration, 2015.]



Dish reflector searches





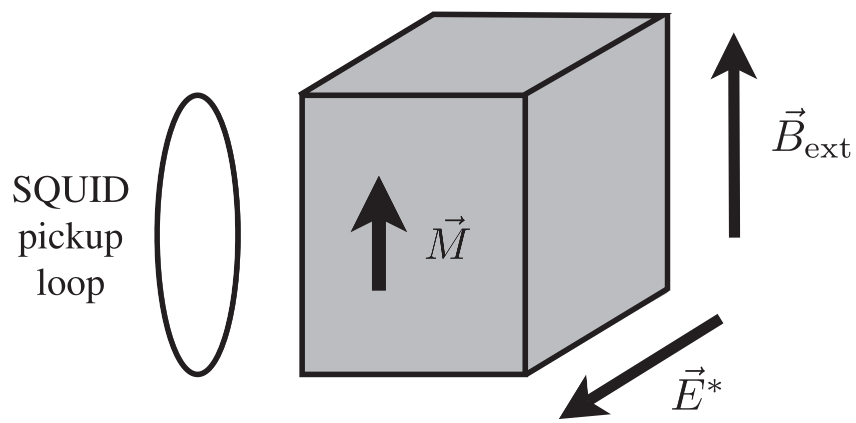
From talk by Javier Redondo, Bela Majorovits,
Warsaw Workshop on Non-Standard Dark Matter, June 2016

Disc reflector idea employed by proposed MADMAX, FUNKY

Nuclear EDM Searches

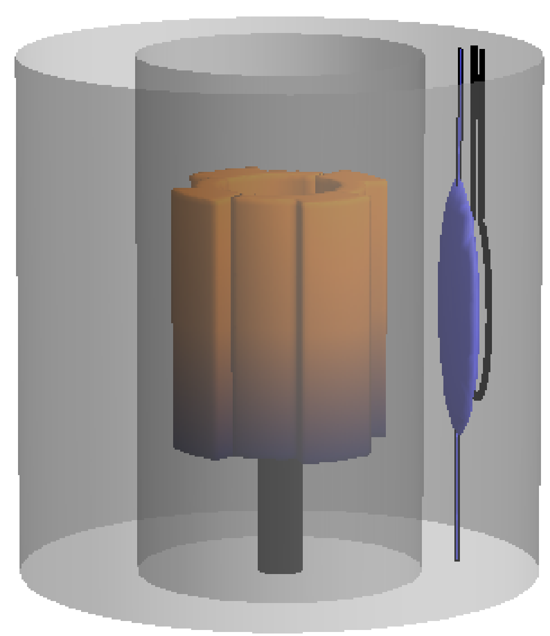
CASPER is a search for axion to nucleon coupling generating an oscillating EDM in a sample. Sensitive to KSVZ axions,

$$m_a \leq 10^{-9}\,\mathrm{eV}$$



PHYS. REV. X **4,** 021030 (2014)

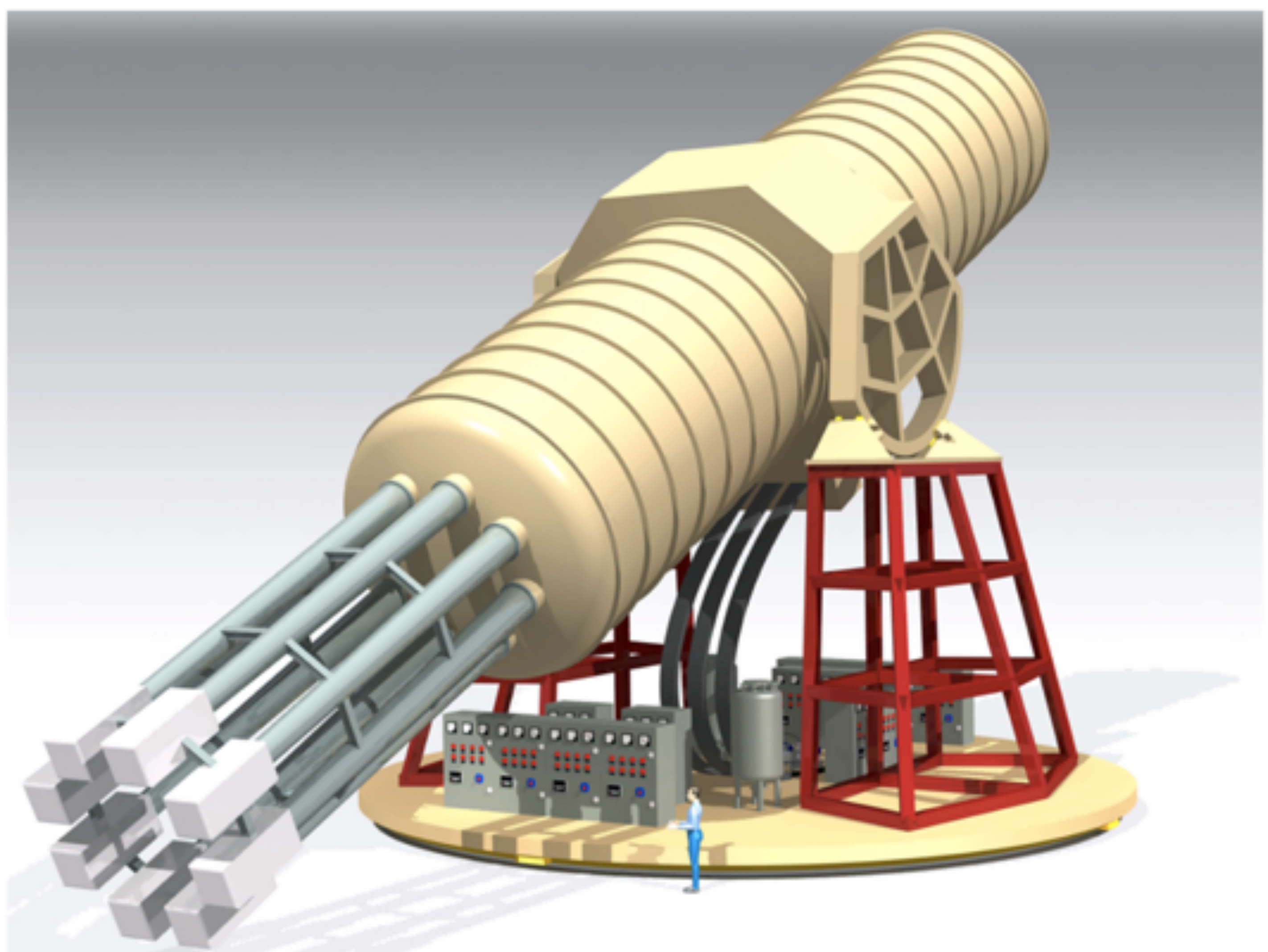
ARIADNE is a search for short-range axion mediated forces between a source mass and an NMR sample.

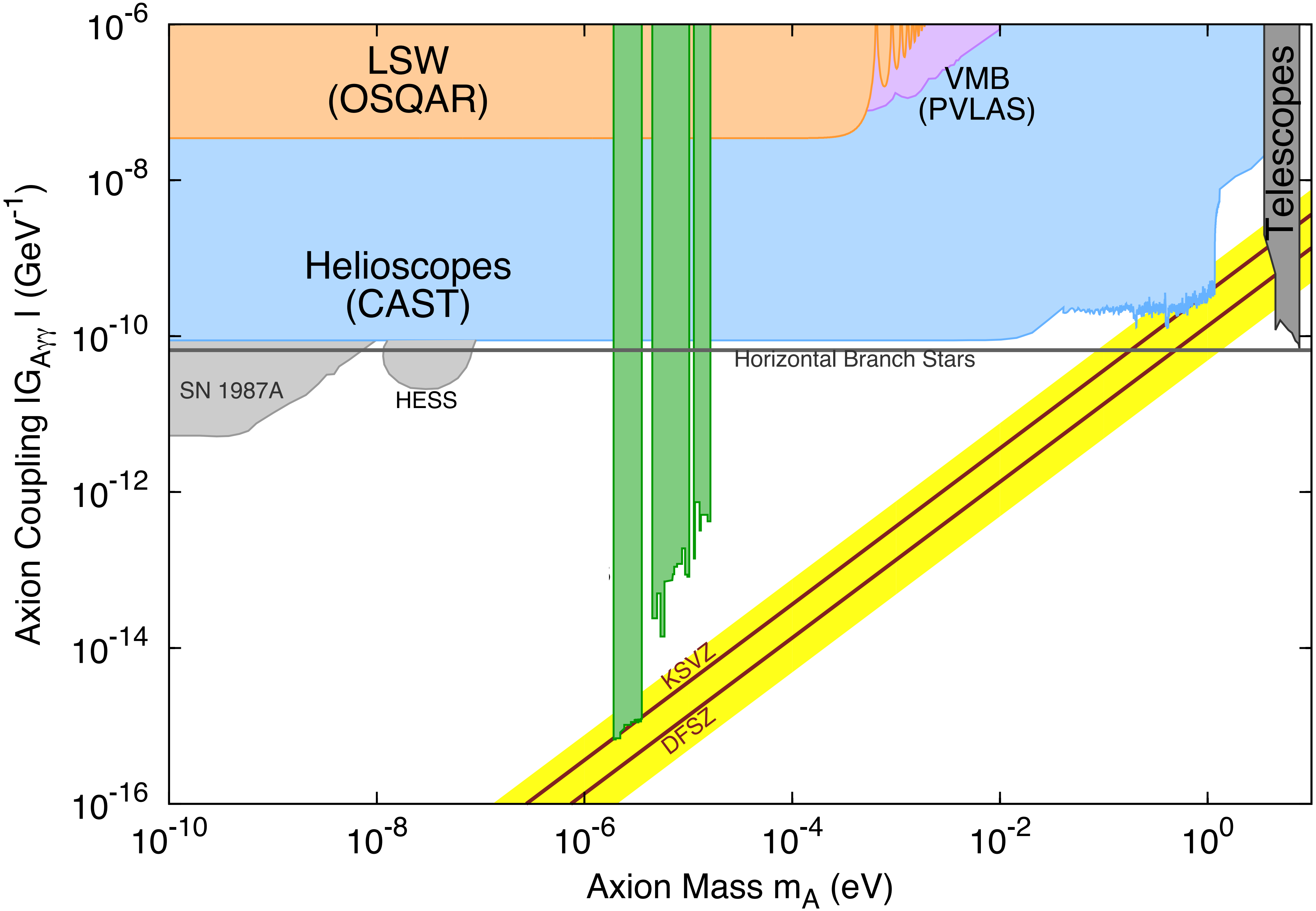


IAXO

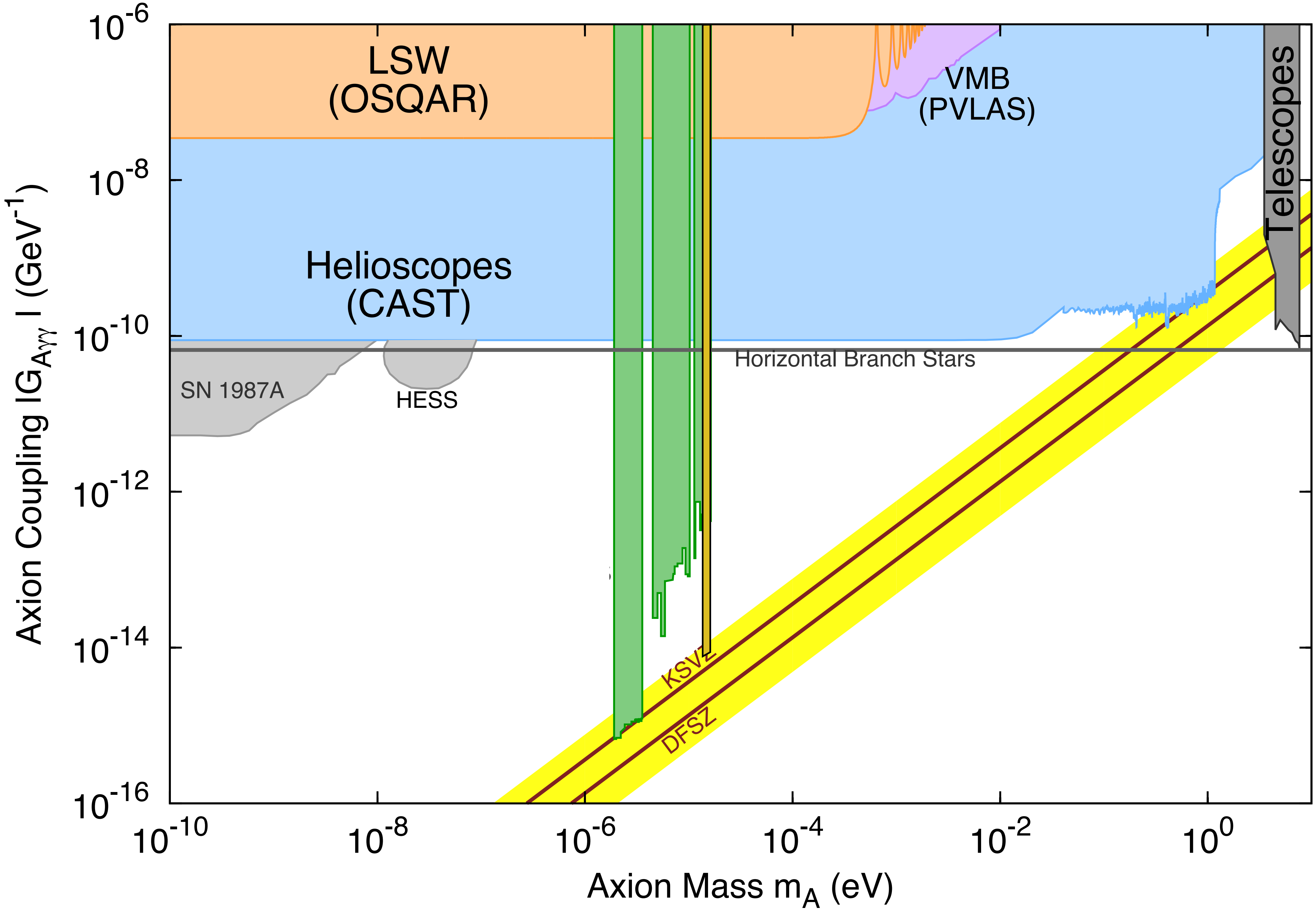
See Talk by Igor Irastorza TODAY (Tuesday), Elisa Ruiz-Choliz on Thursday

A proposed large scale axion haloscope, with a greatly increased axion conversion volume, new electronics, and a very large high-field magnet. Projected sensitivity to DFSZ/KSVZ axions above 0.01eV.





LSW
(OSQAR)
VMB
(PVLAS)
Telescopes
Helioscopes
(CAST)
Horizontal Branch Stars
SN 1987A
HESS
KSVZ
DFSZ
Axion Coupling $|G_{A\gamma\gamma}|$ (GeV^{-1})
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^{0}
Axion Mass m_A (eV)



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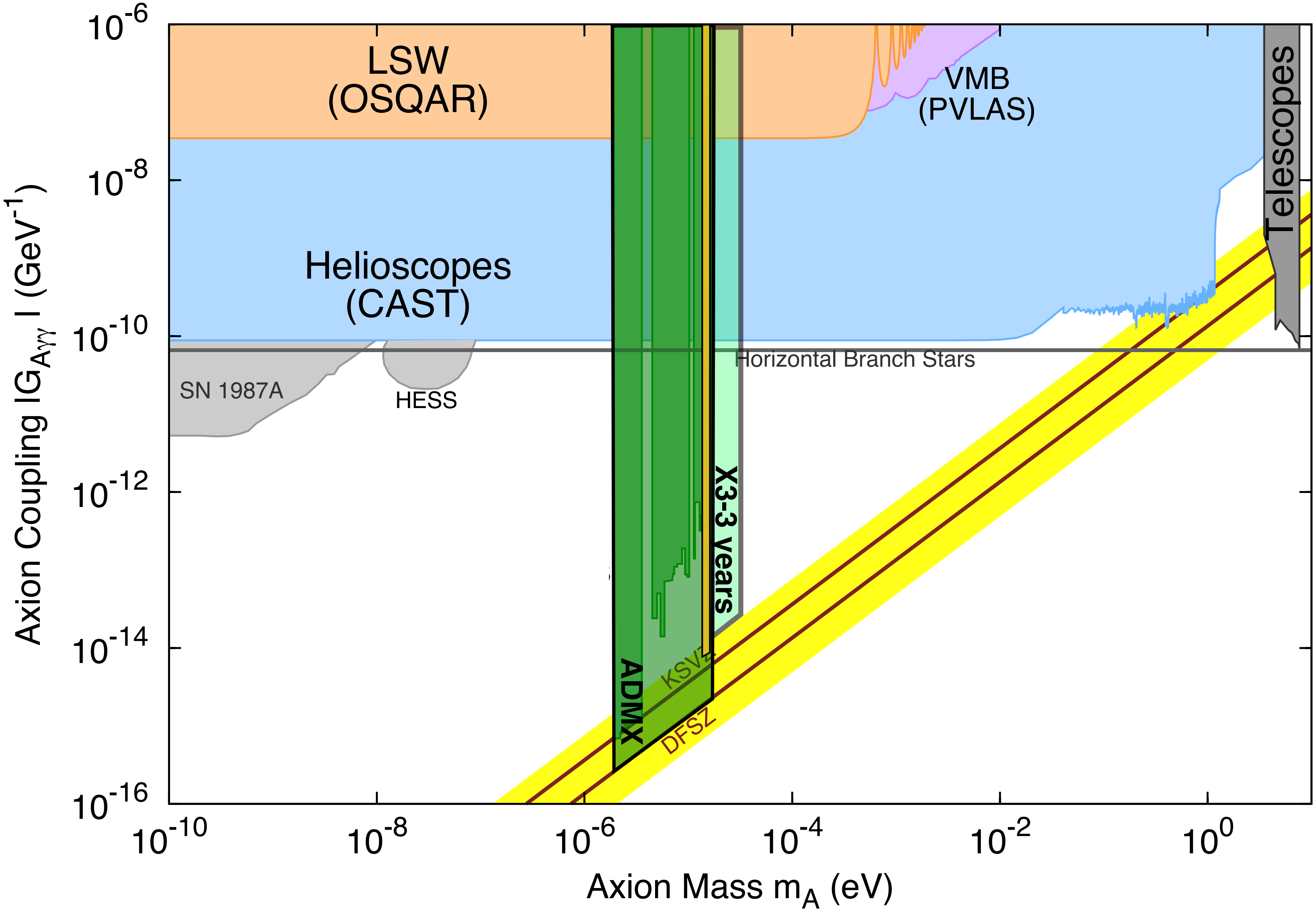

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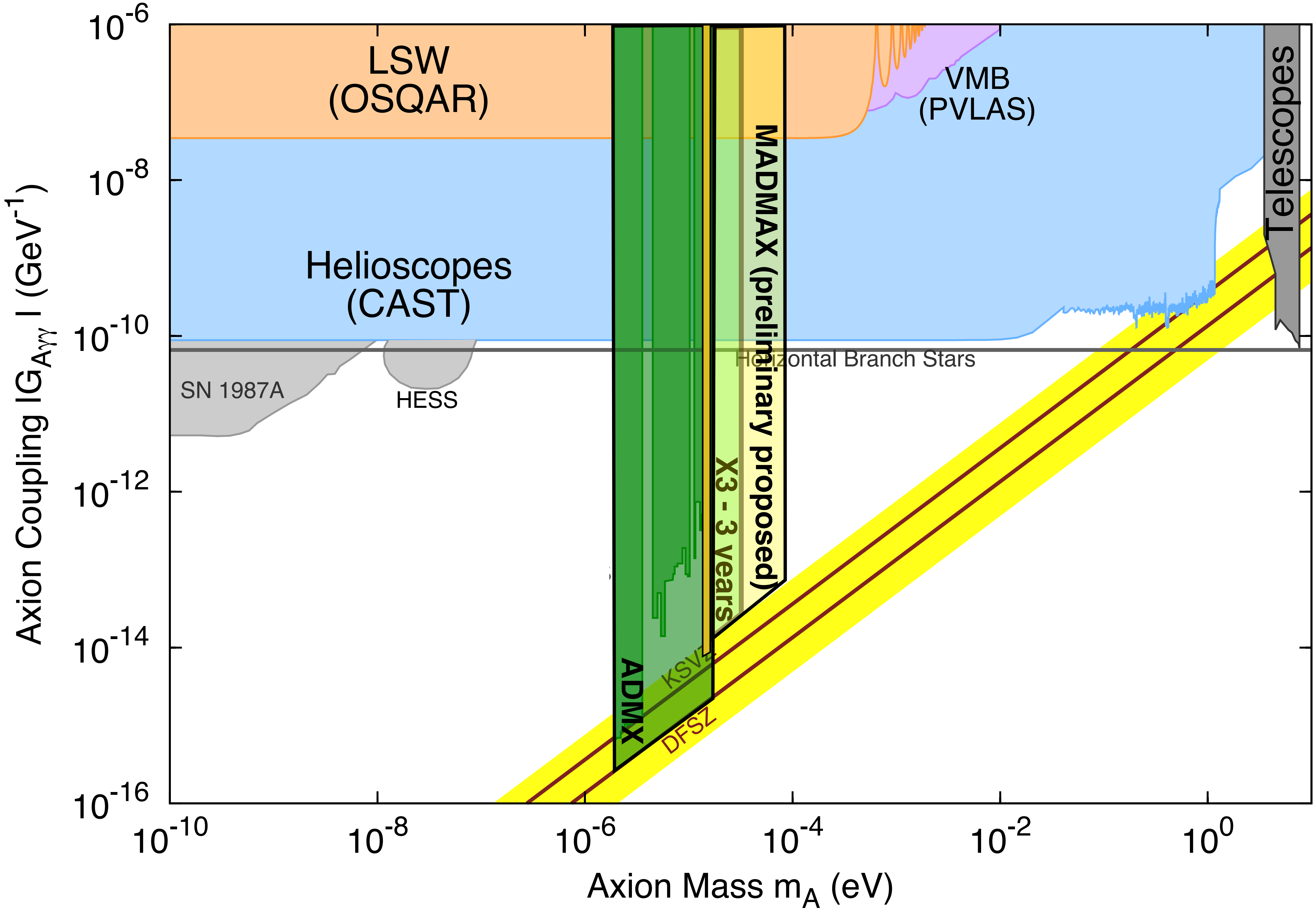

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MADMAX (preliminary proposed)
X3 - 3 years
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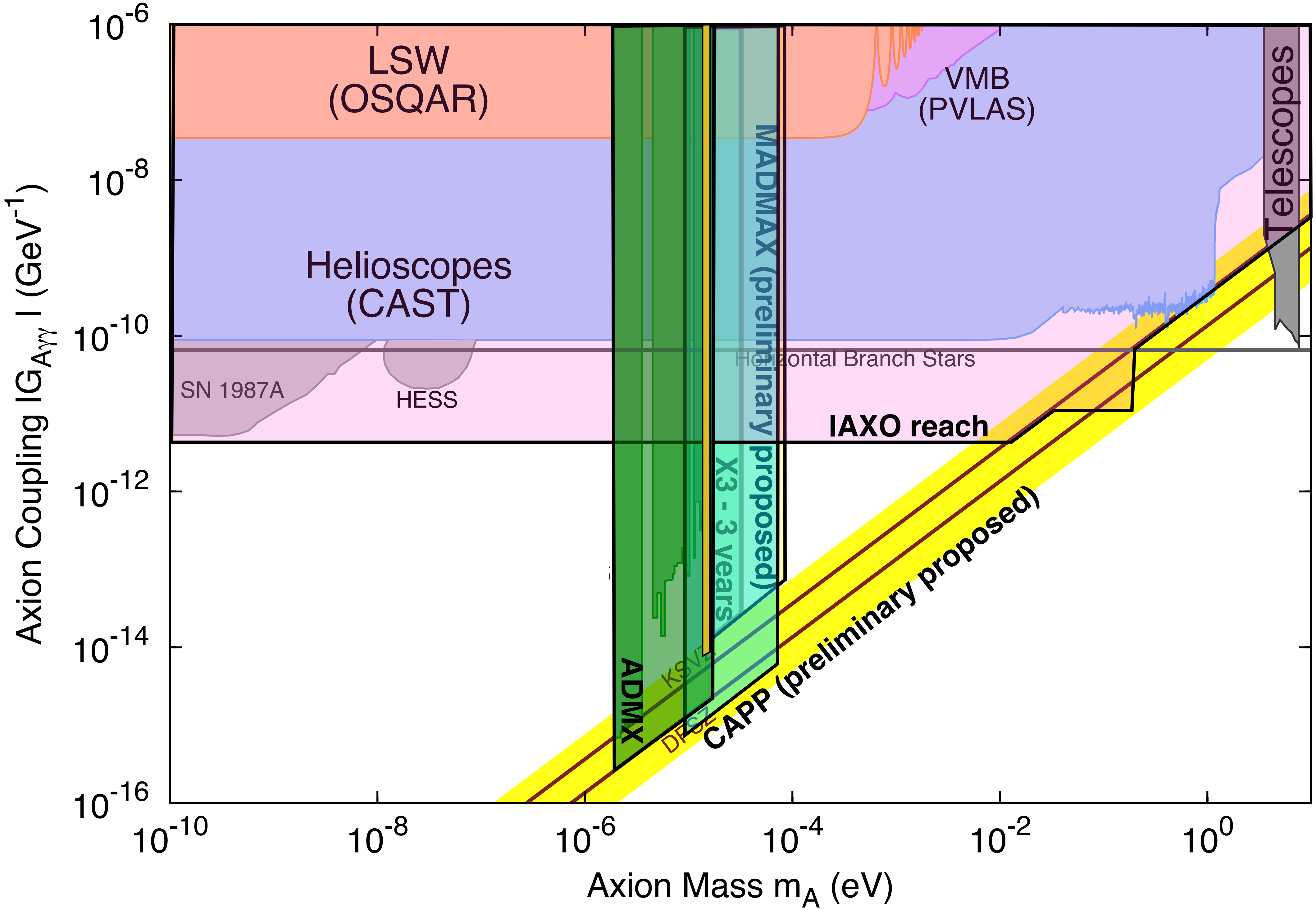
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Conclusions

ADMX2 running imminent.

X3 first results available (preliminary).

Other cavity searches ramping up.

‘Mirror’ searches promising.

IAXO greatly increase reach of haloscopes into axion territory.

NMR / spin precession methods developing

Real prospects for axion discovery as rate of coverage of mass range ramps up.