
International
axion observatory
IAXO
COLOR BY
TECHNICOLOR
Starring
Javier Redondo
Zaragoza U
MPP Munich
Directed by
ALFRED
ITCHCOCK
Screenplay by
JOHN MICHAEL
HAYES
Y54-337 REAR WINDOW
REAR WINDOW Y54-337

questions . . .

questions . . .

meV mass axions

questions . . .

meV mass axions

axion dark matter

questions . . .

meV mass axions

Axion-like particles

axion dark matter

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hidden photons

questions . . .

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questions . . .

meV mass axions

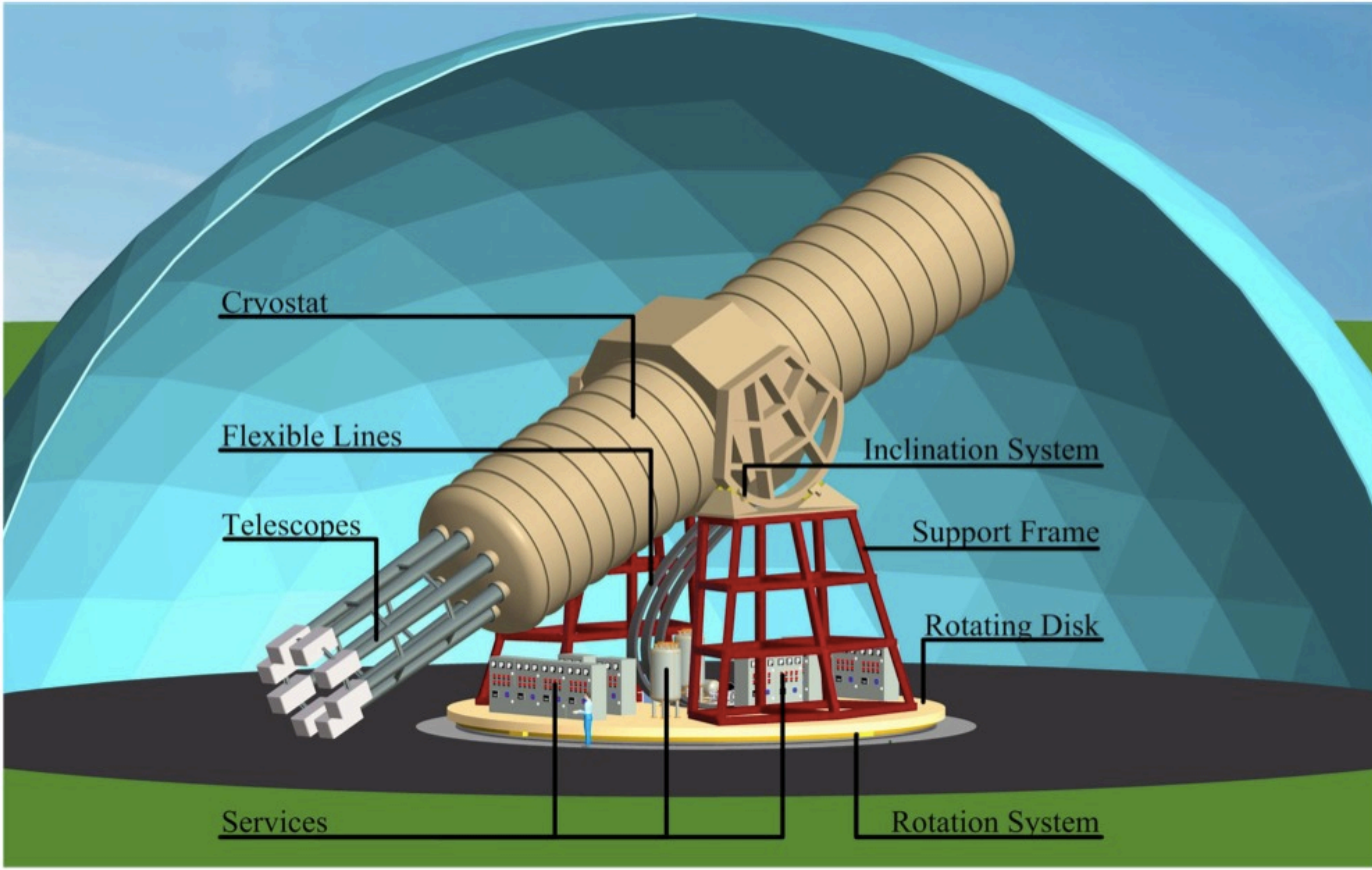
Axion-like particles

axion dark matter

hidden photons

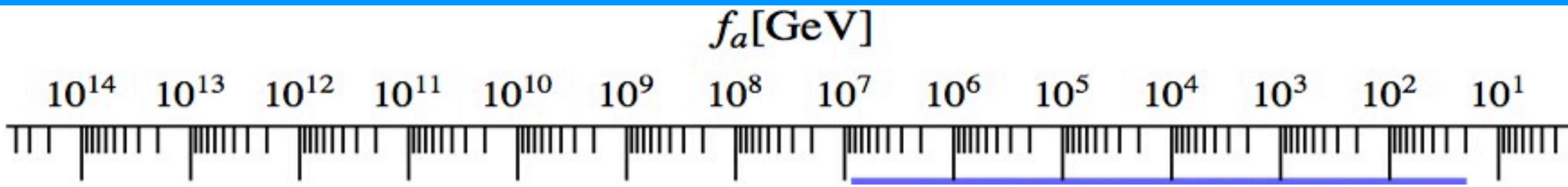
the answer? the largest magnet ever to serve axion physics

IAXO Conceptual design report, Armengaud et al. JINST 9 T05002



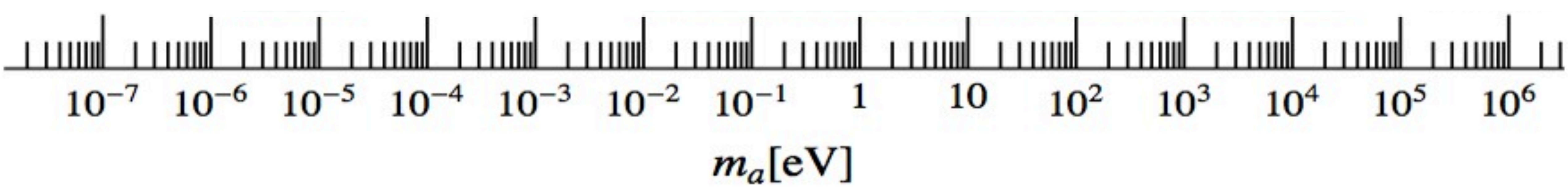
Axion dark matter

Preskill, Abbot, Dine 1983



- Axion DM scenarios

tuned (anthropic?) | ok | tuned



Pre inflation PQ

$$\Omega_{\rm aDM} h^2 \simeq \theta_I^2 \left(\frac{80\,\mu\mathrm{eV}}{m_a}\right)^{1.19}$$

Wantz, Shellard 2010

Axion dark matter

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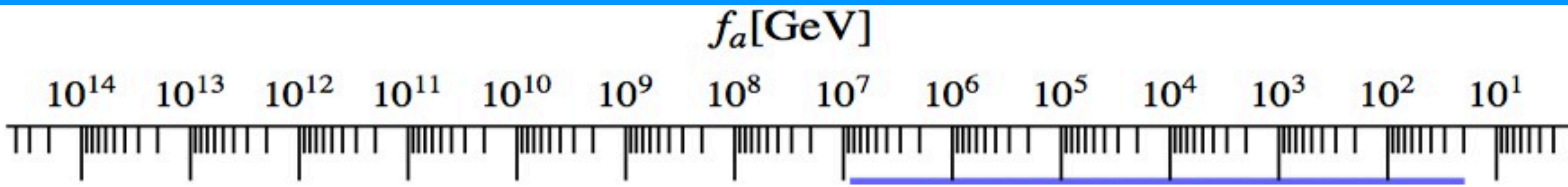

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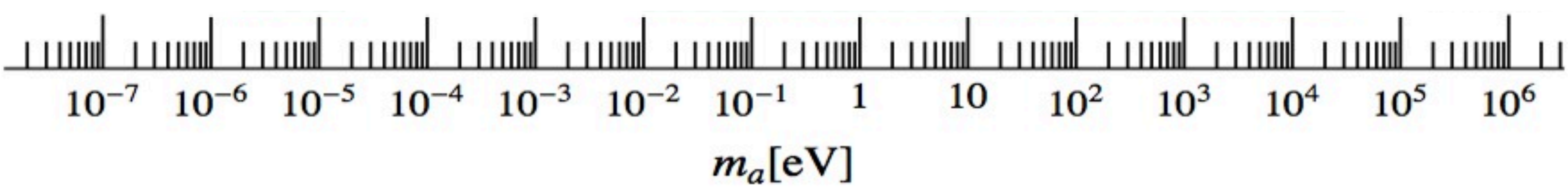

Post-inflation PQ (N=1)

strings+unstable DW's

Kawasaki, Saikawa, Sekiguchi 2014

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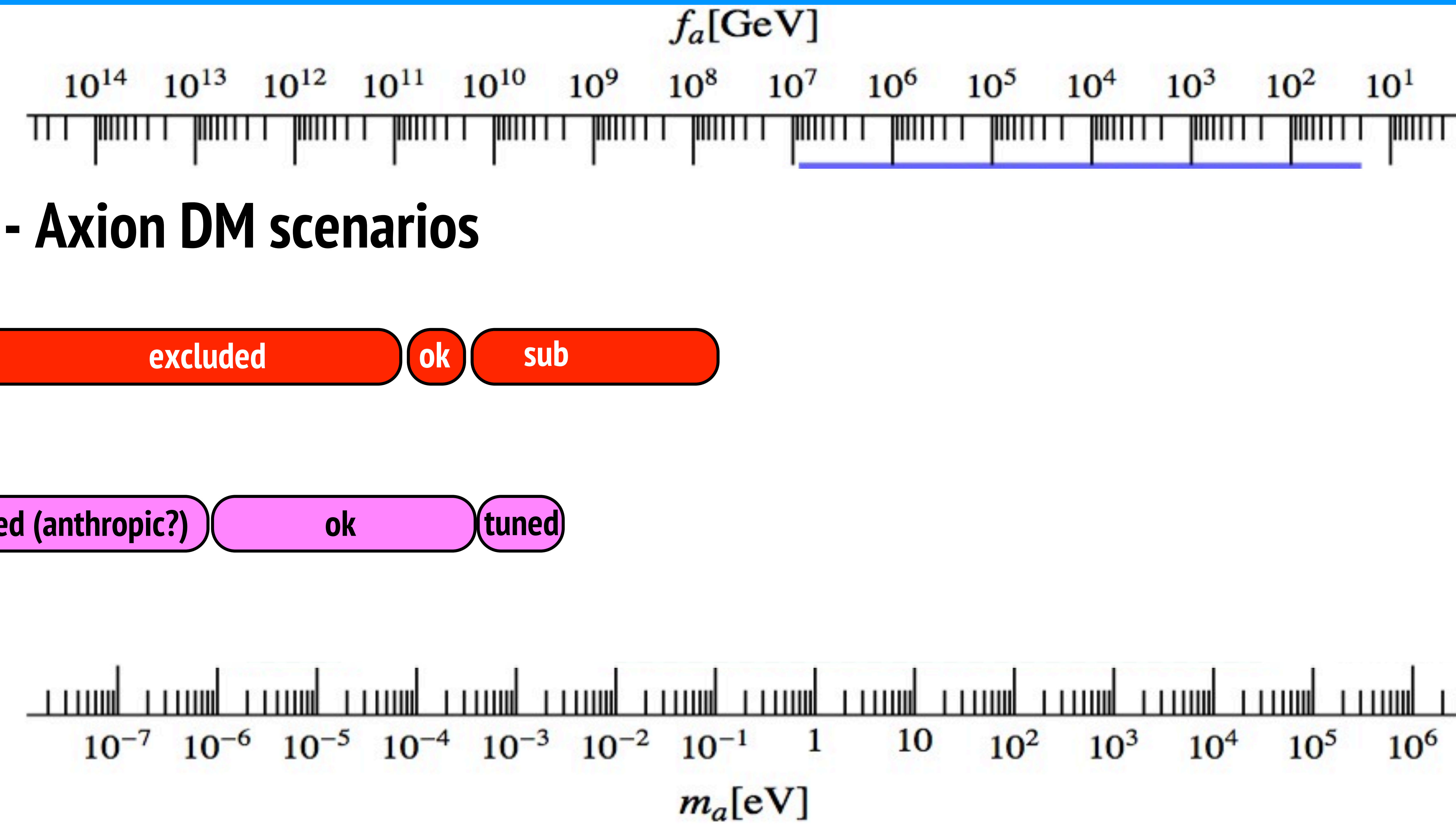

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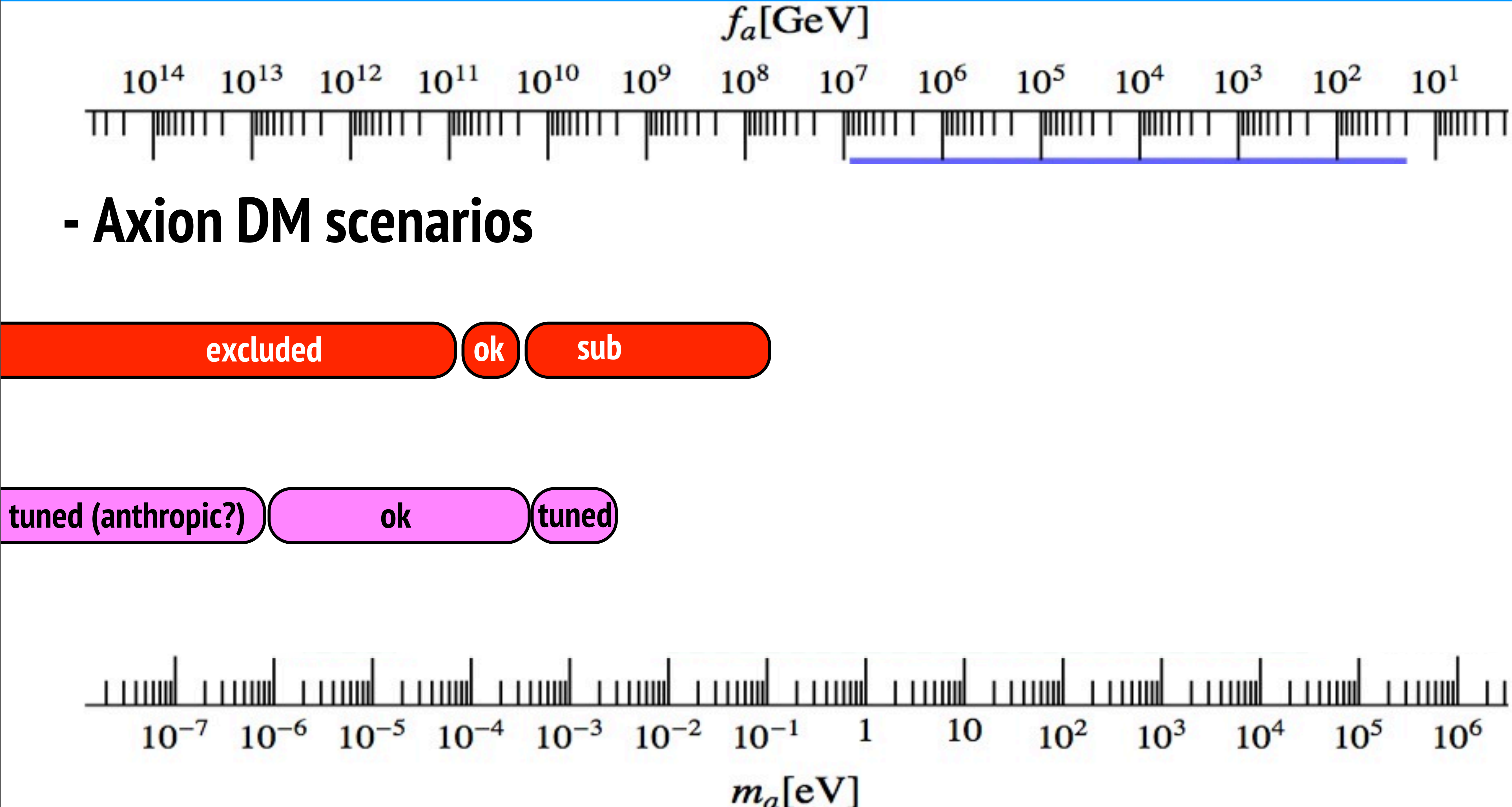

Post-inflation PQ (N=1)
strings+unstable DW's

Post inflation PQ (N>1)
strings+long-lived DWs

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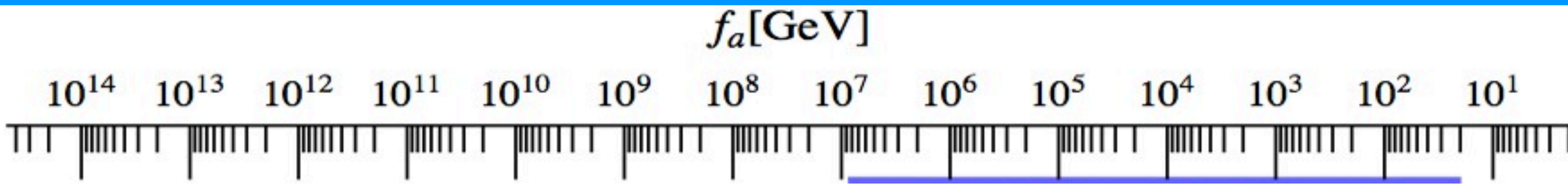
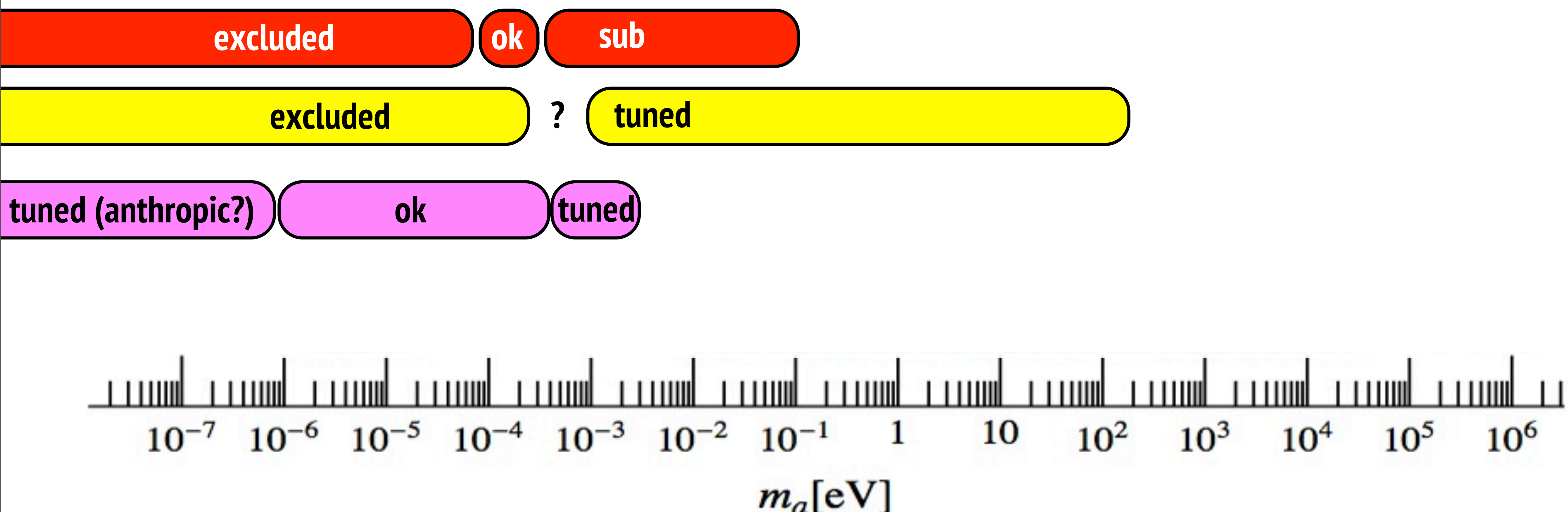


- Axion DM scenarios



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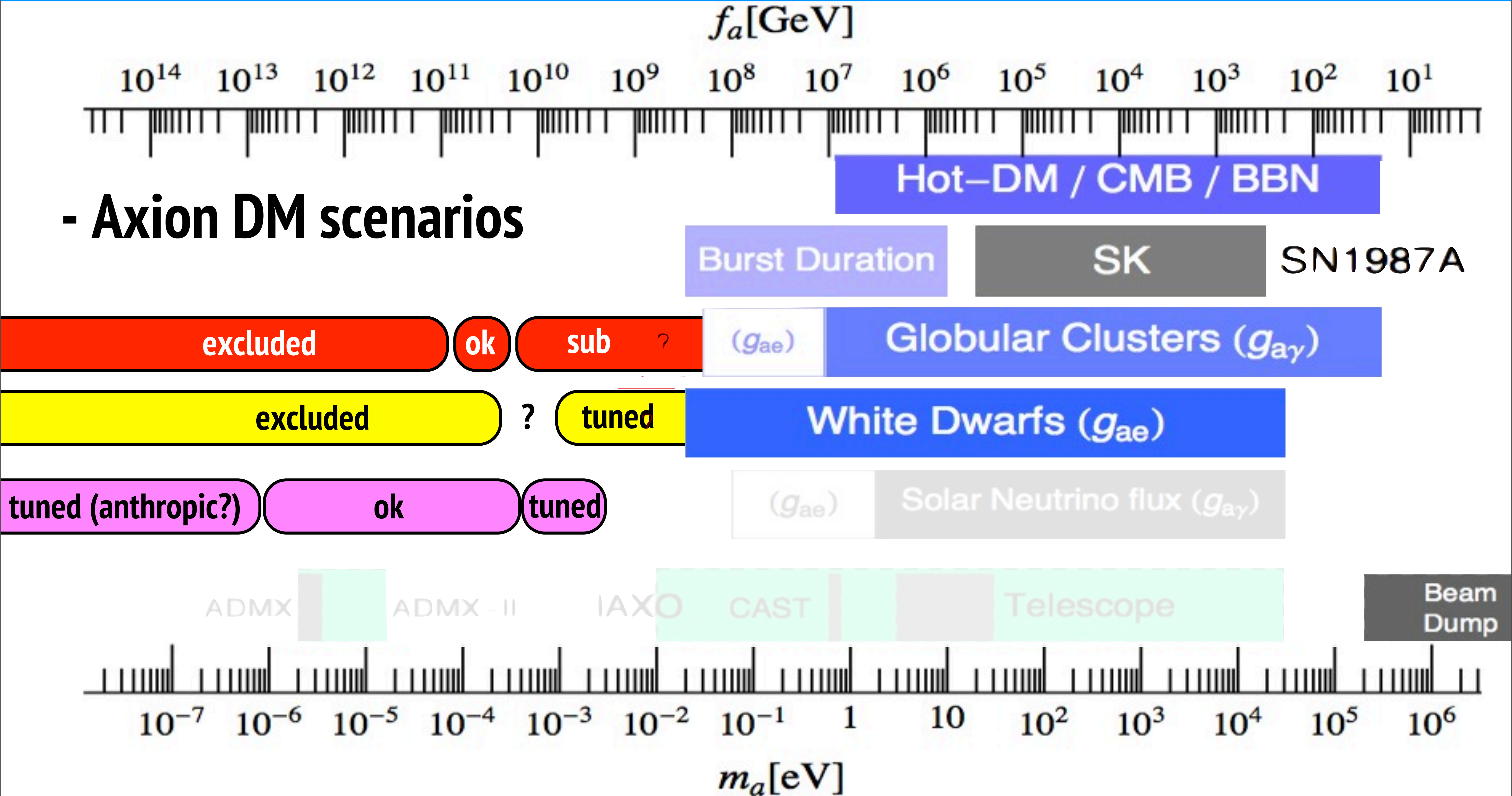

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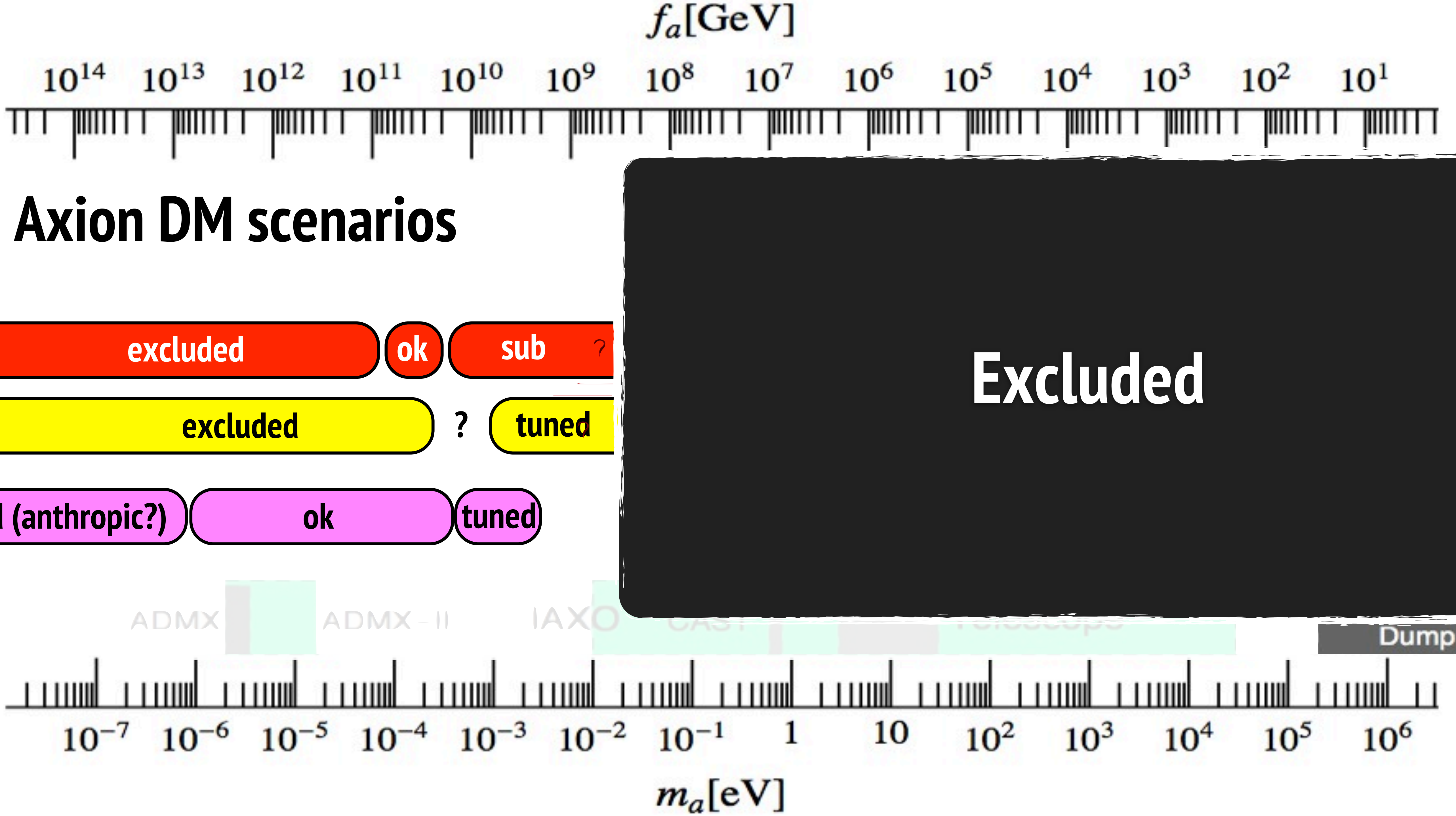

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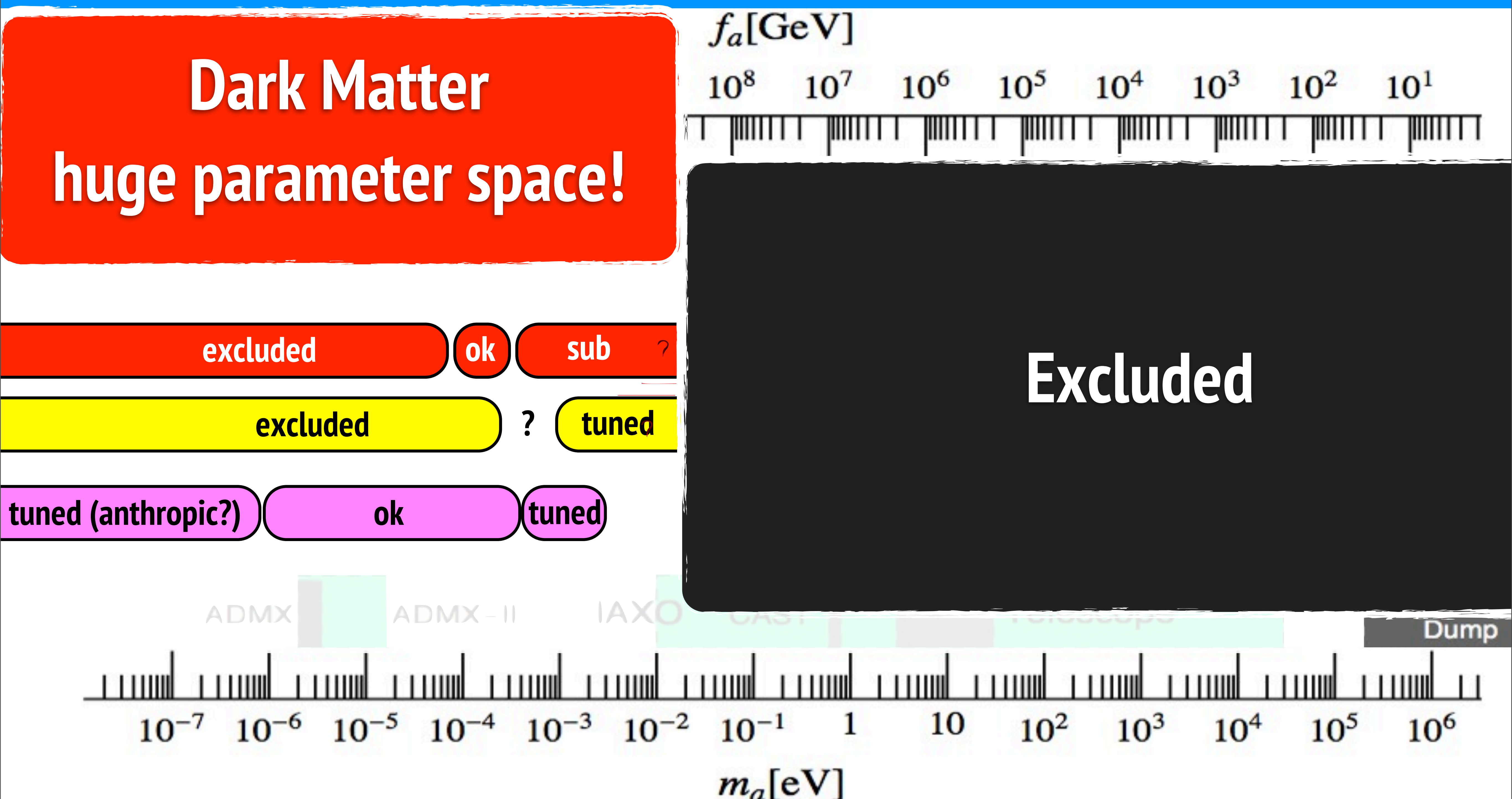
Dark Matter
huge parameter space!



Post-inflation PQ (N=1)
strings+unstable DW's

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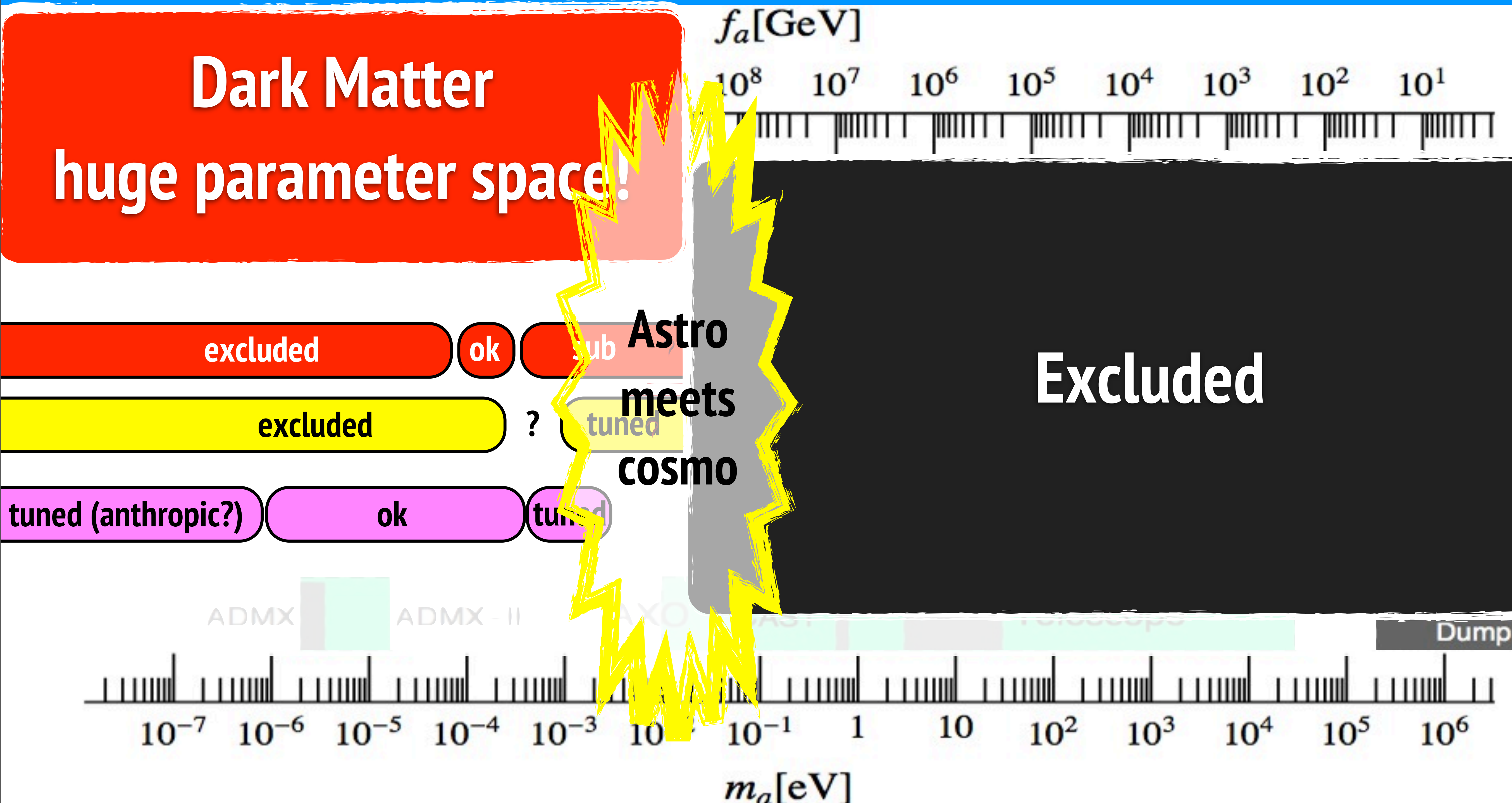

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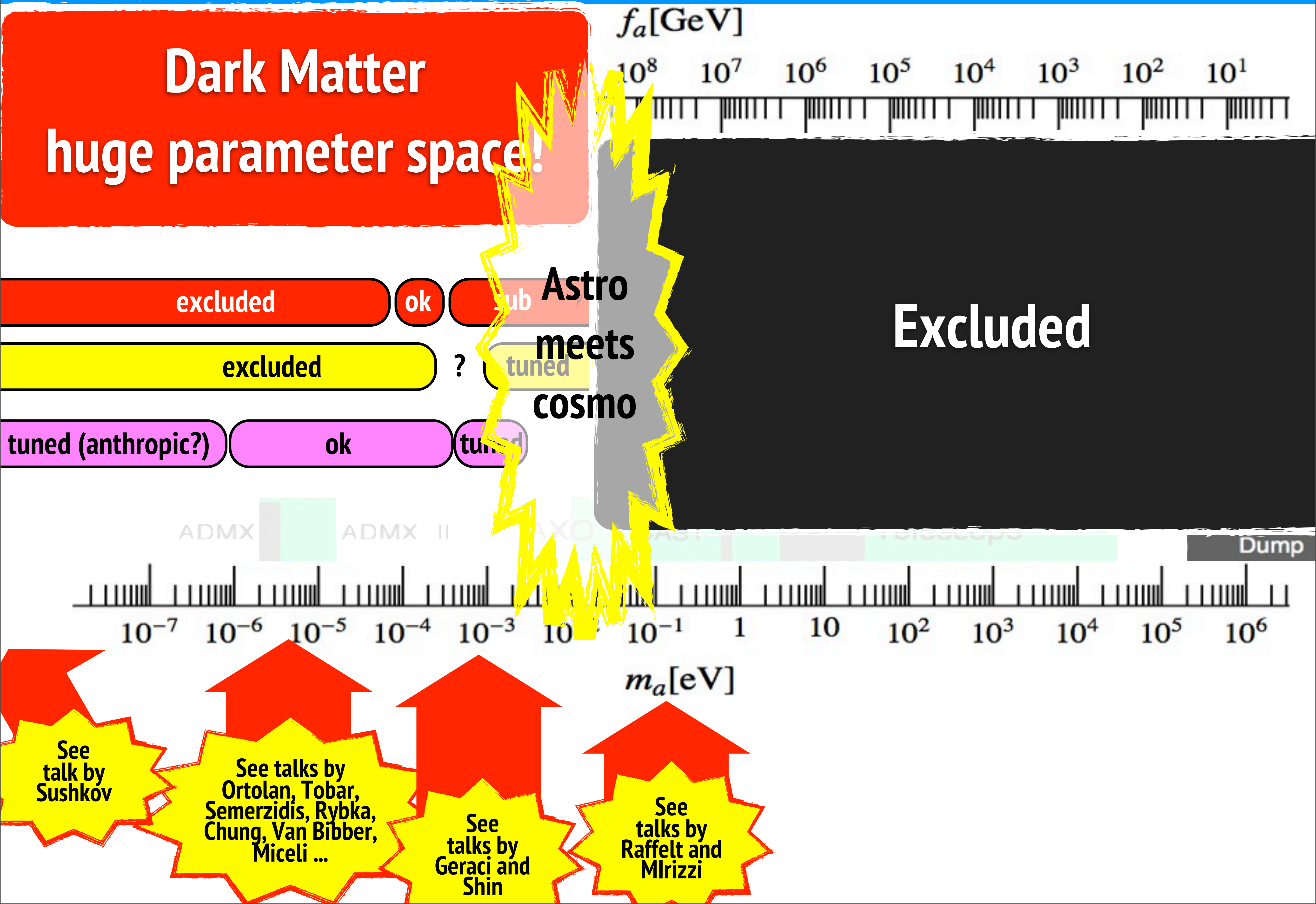


Hints, constraints and models ... any preference?

See also Giannotti's talk!

Tip of the Red Giant branch (M5)

$$g_{ae} = C_{ae}\frac{m_e}{f_a} = (2 \pm 1.5) \times 10^{-13}$$

Viaux, PRD 2011

White dwarf luminosity function

$$g_{ae} = C_{ae}\frac{m_e}{f_a} = (1.4 \pm 1.4) \times 10^{-13}$$

Bertolami, JCAP 2014

Cassiopeia A: neutron star cooling

$$g_{an} = C_{an}\frac{m_n}{f_a} = (3.8 \pm 3) \times 10^{-10}$$

Leinson, JCAP 2014

SN1987A

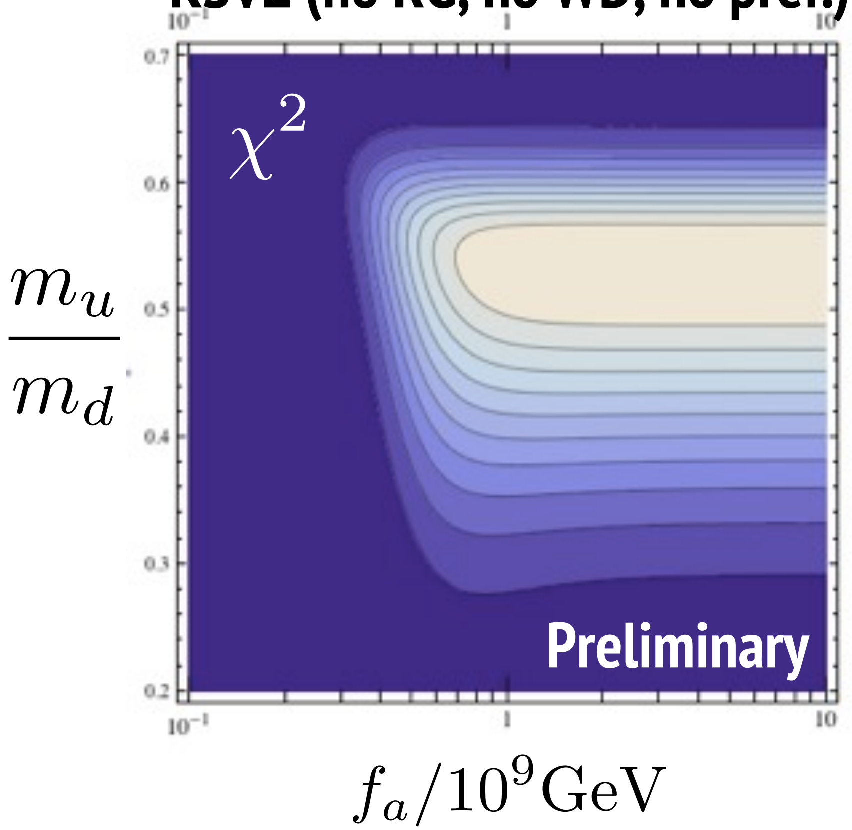
$$g_{ap} = C_{ap}\frac{m_p}{f_a} < 0.8 \times 10^{-10}$$

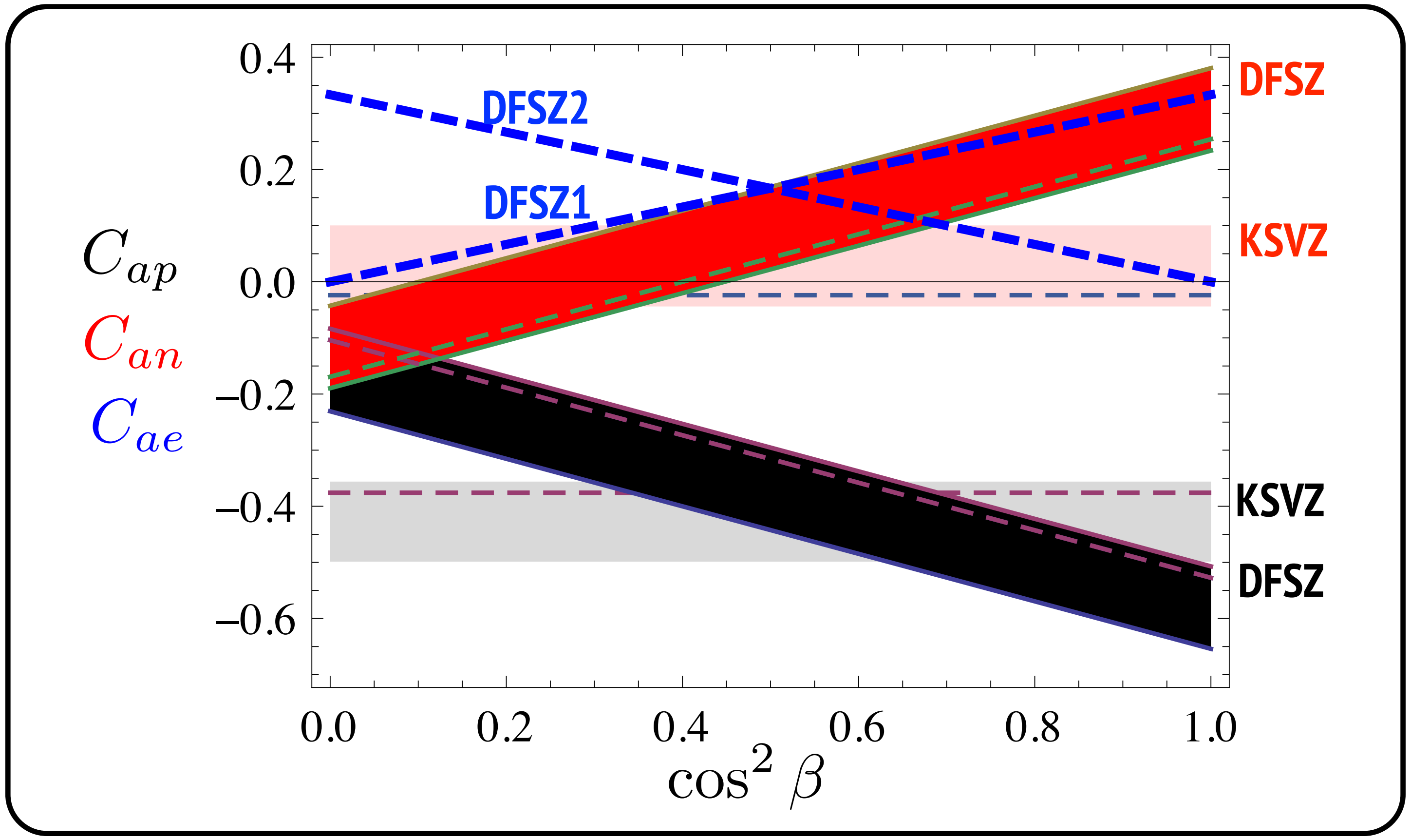
Raffelt Lec. Not. Phys. 2008 and ... see Mirizzi's talk on thursday!

Hints, constraints and models ... any preference?

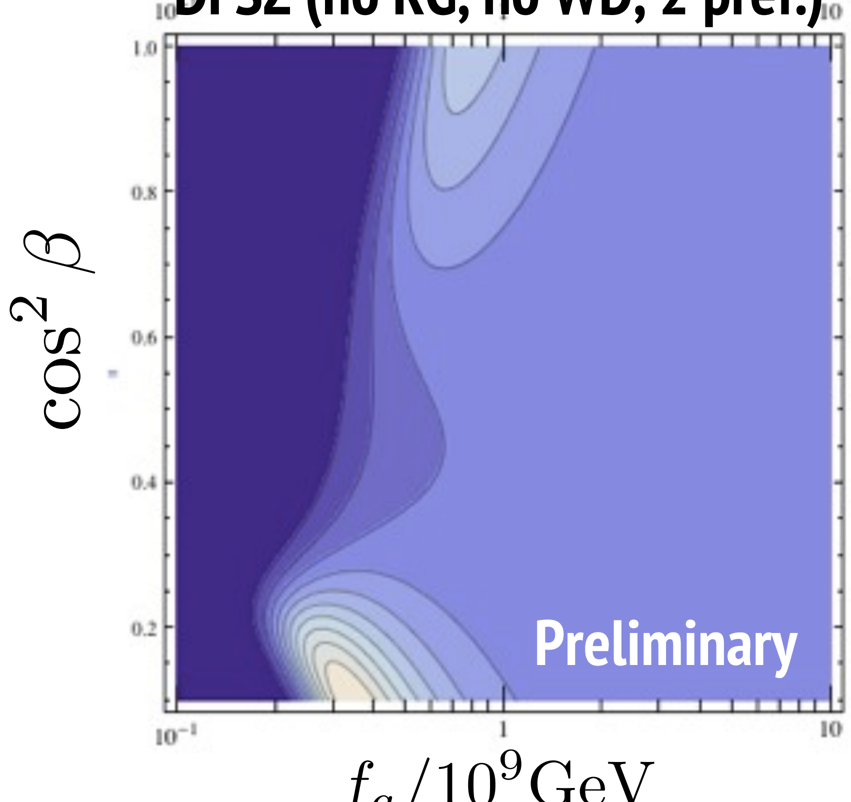
See also Giannotti's talk!

KSVZ (no RG, no WD, no pref.)

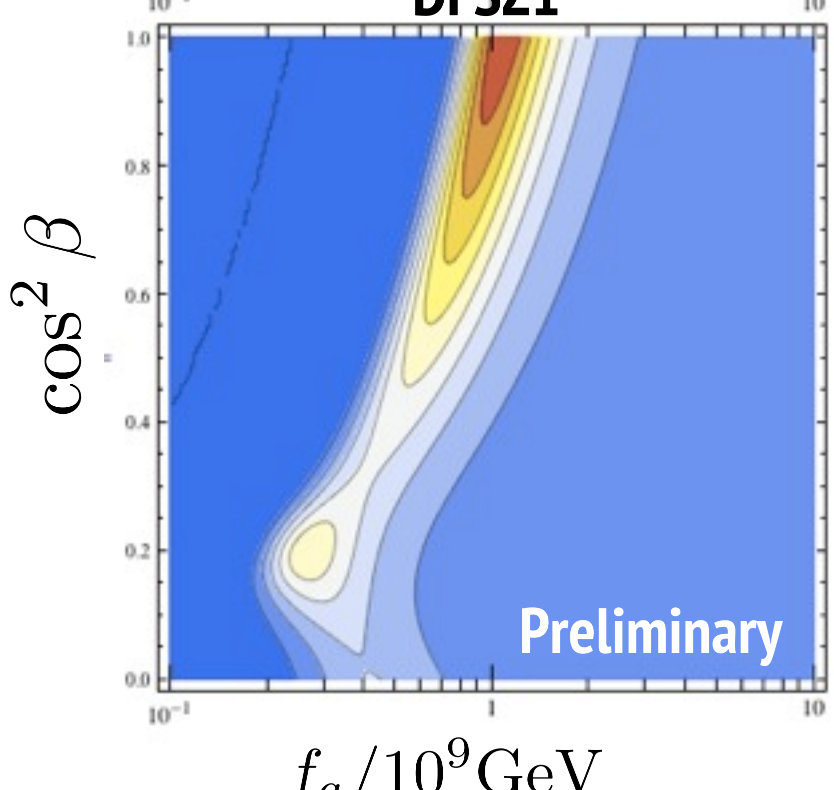




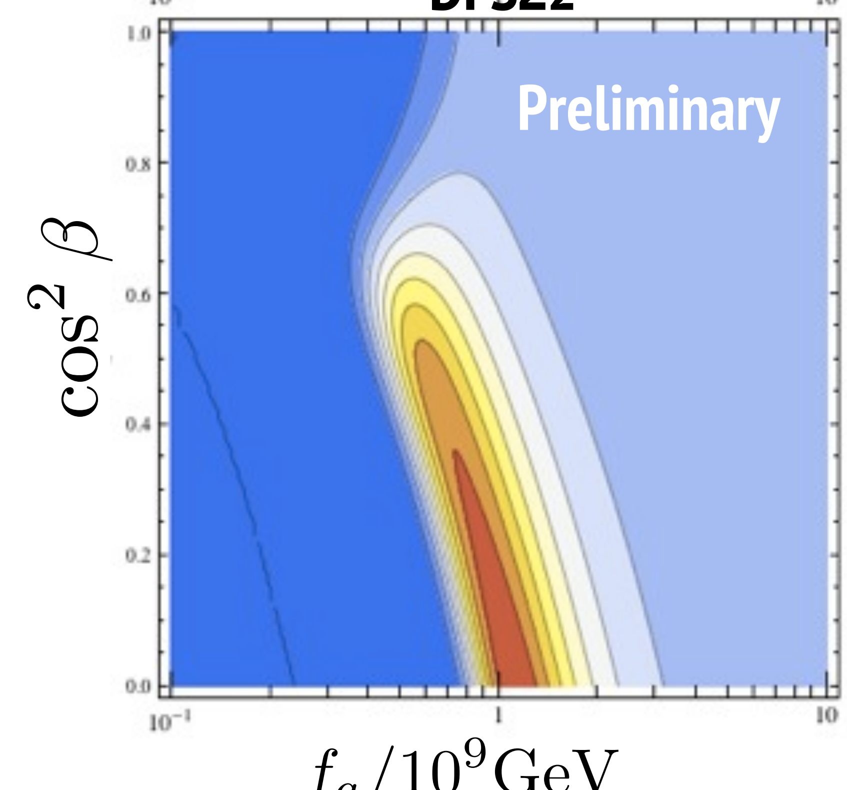
DFSZ (no RG, no WD, 2 pref.)



DFSZ1



DFSZ2

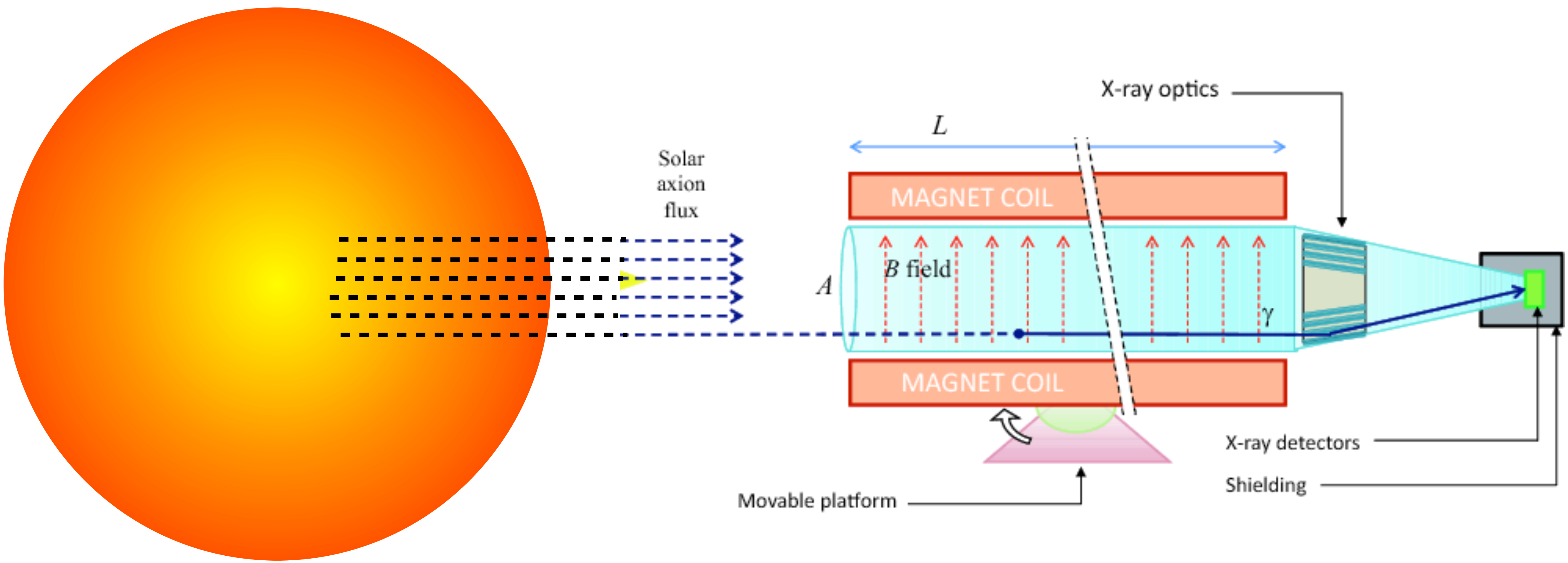


Helioscopes

Sikivie PRL 1983

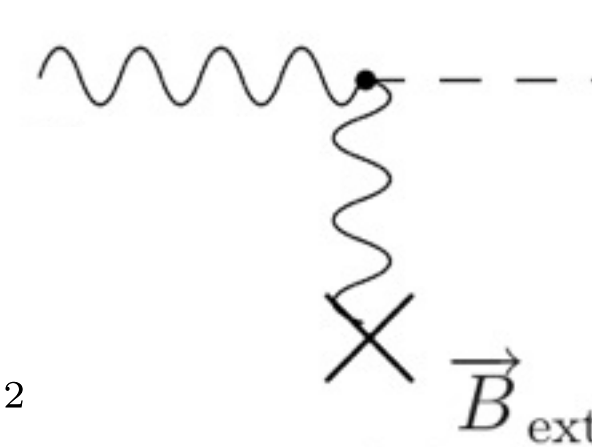
The Sun is a copious emitter of axions!

convert into X-rays **focus** **detect**



Conversion probability

$$P(a \leftrightarrow \gamma) = \left(\frac{2 g_{a\gamma} B_T \omega}{m_a^2}\right)^2 \sin^2\left(\frac{m_a^2 L}{4\omega}\right)$$

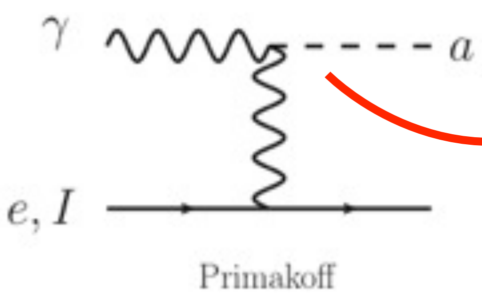


$m_a \to 0, P \to \left(\frac{g_{a\gamma} B_T L}{2}\right)^2$ $\qquad$ $m_a \to \text{large}, P \to \left(\frac{2 g_{a\gamma} B_T \omega}{m_a^2}\right)^2$

Axions from the Sun

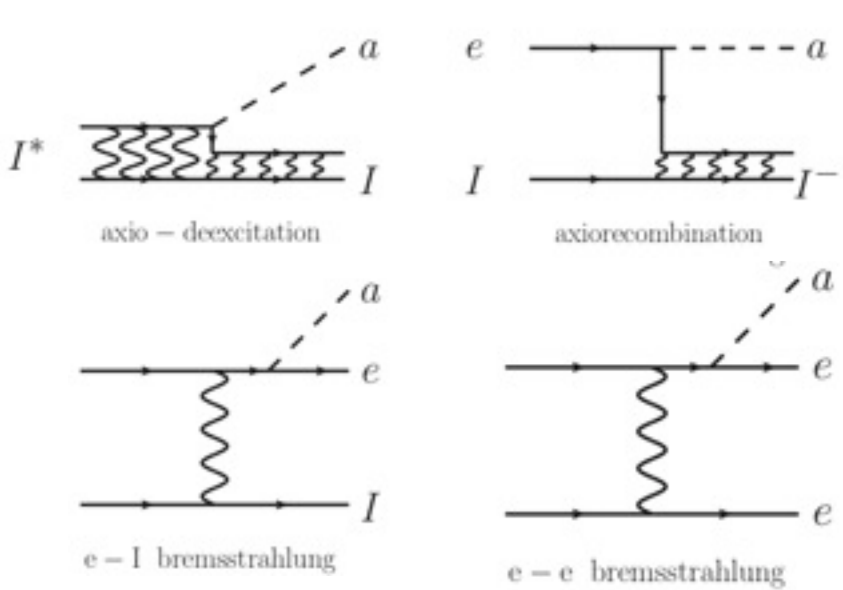
JR, JCAP 2013

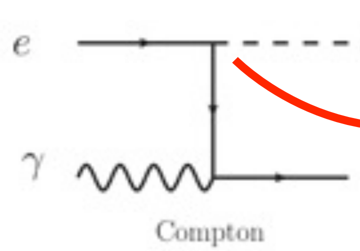
Hadronic axions (KSVZ)



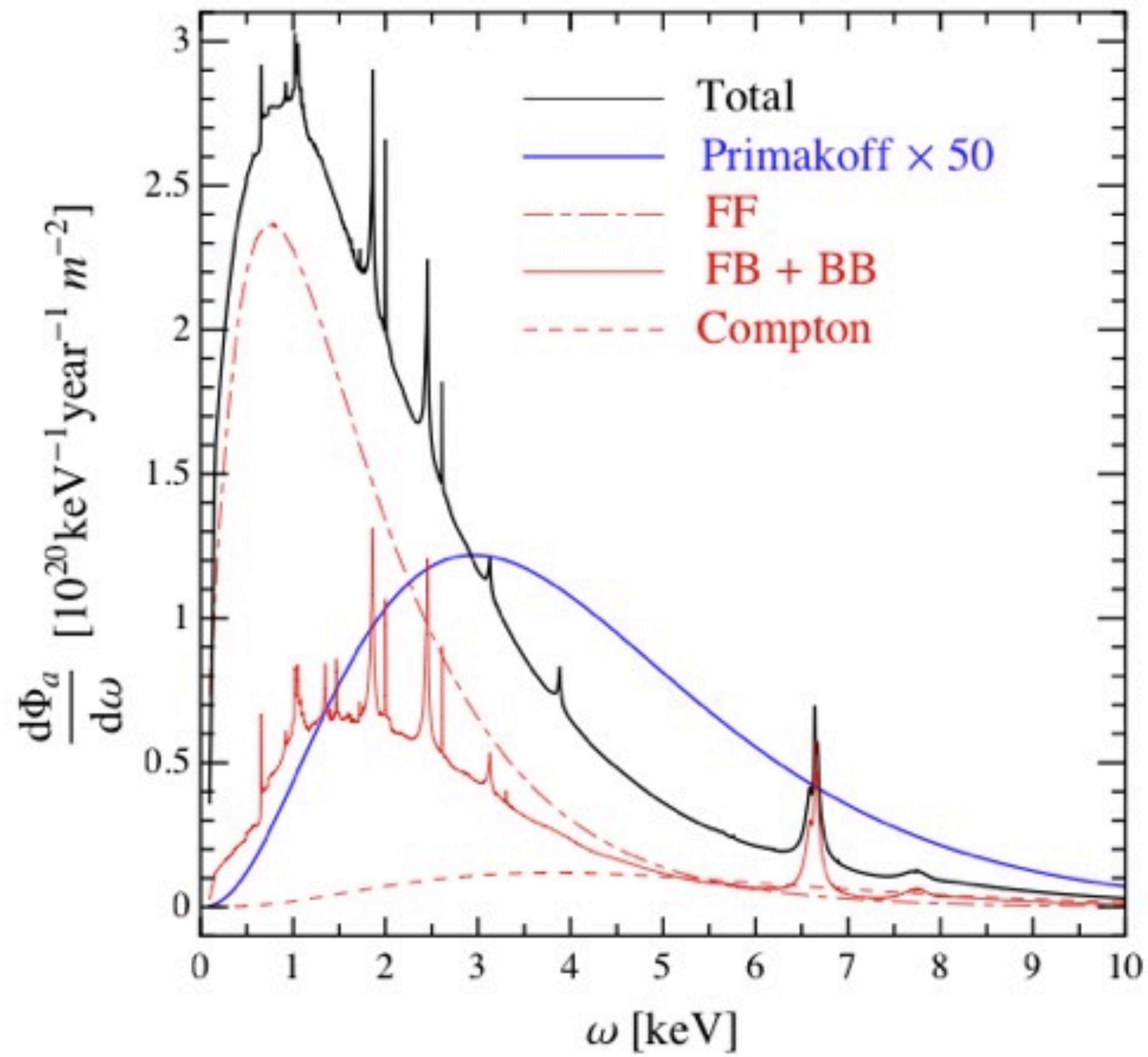
$$\underbrace{\frac{C_\gamma \alpha}{2\pi f_a}}_{g_{a\gamma}} \frac{F_{\mu\nu}\widetilde{F}^{\mu\nu}}{4} a$$

Non hadronic (DFSZ, e-coupling!)





$$\underbrace{\frac{C_e m_e}{f_a}}_{g_{ae}} i\bar{e}\gamma_5 e\, a$$



$$g_{ae} = 10^{-13}$$
$$g_{a\gamma} = 10^{-12}$$

typical of non-hadronic meV mass axions

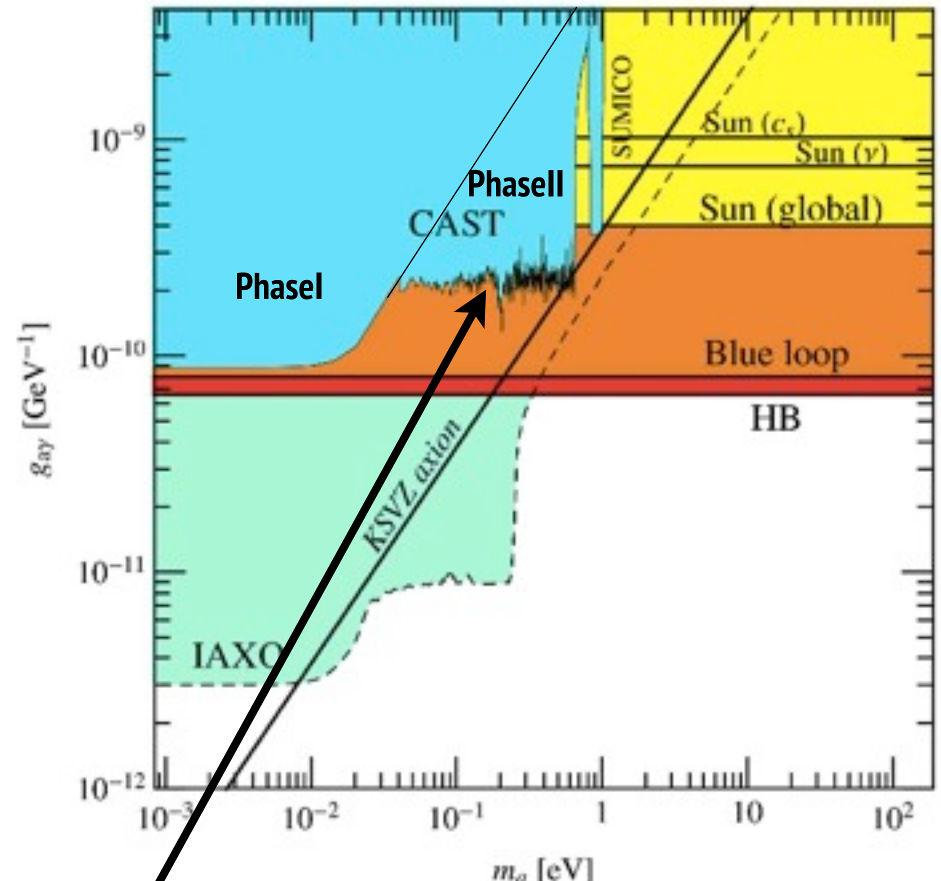
CAST Helioscope

CAST (LHC dipole 9.3 m, 9T)

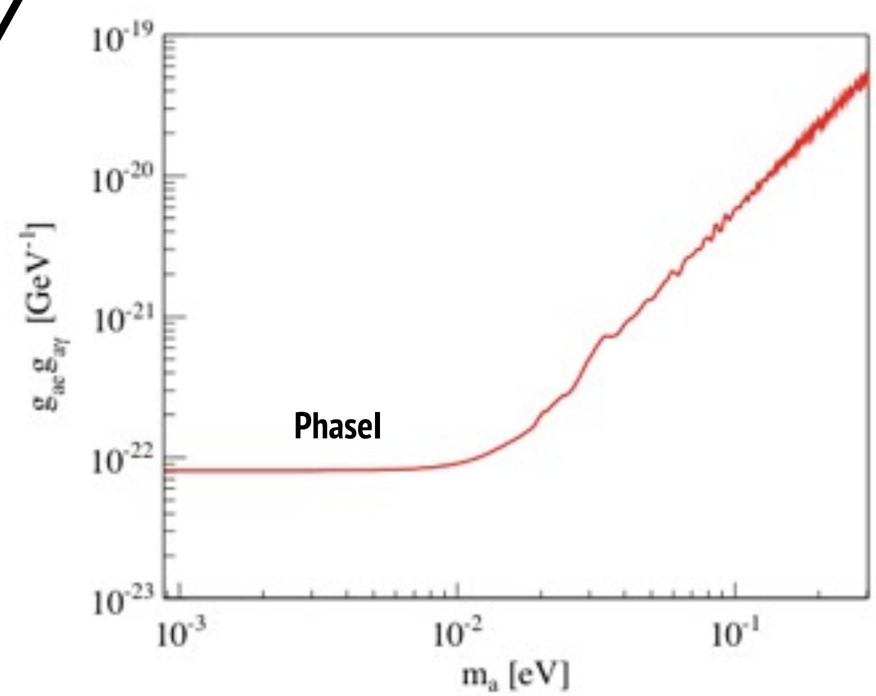
- 1~2 h tracking/day (sunset,dawn)
- 3 Detectors (2 bores)
  CCD, Micromegas
- X-ray optics
- He gas for large masses

$$P(a \leftrightarrow \gamma) = \left(\frac{2g_{a\gamma}B_T\omega}{m_a^2 - m_\gamma^2}\right)^2 \sin^2\left(\frac{(m_a^2 - m_\gamma^2)L}{4\omega}\right)$$

hadronic axions



non-hadronic axions



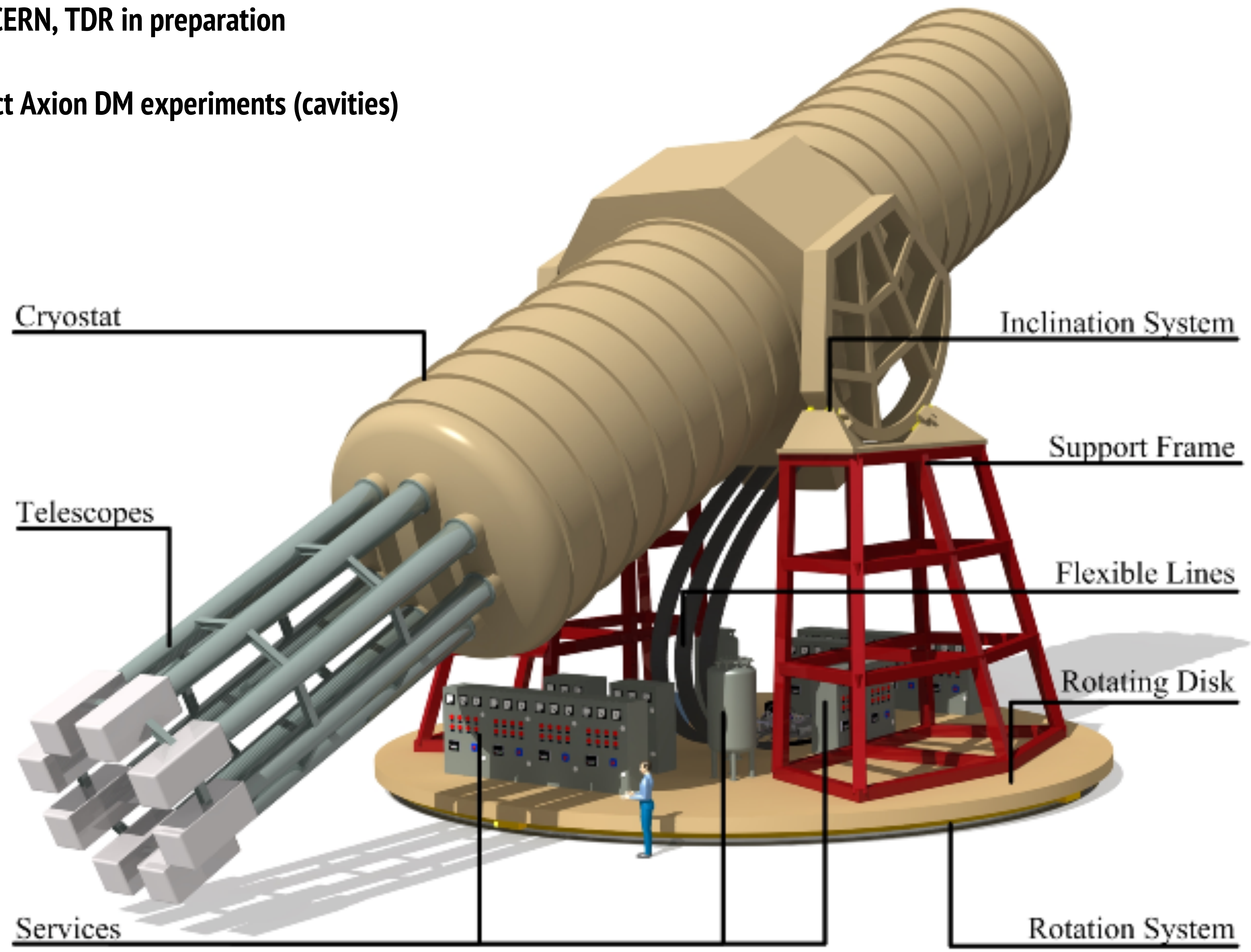
Next generation (proposed) IAXO

Boost parameters to the maximum

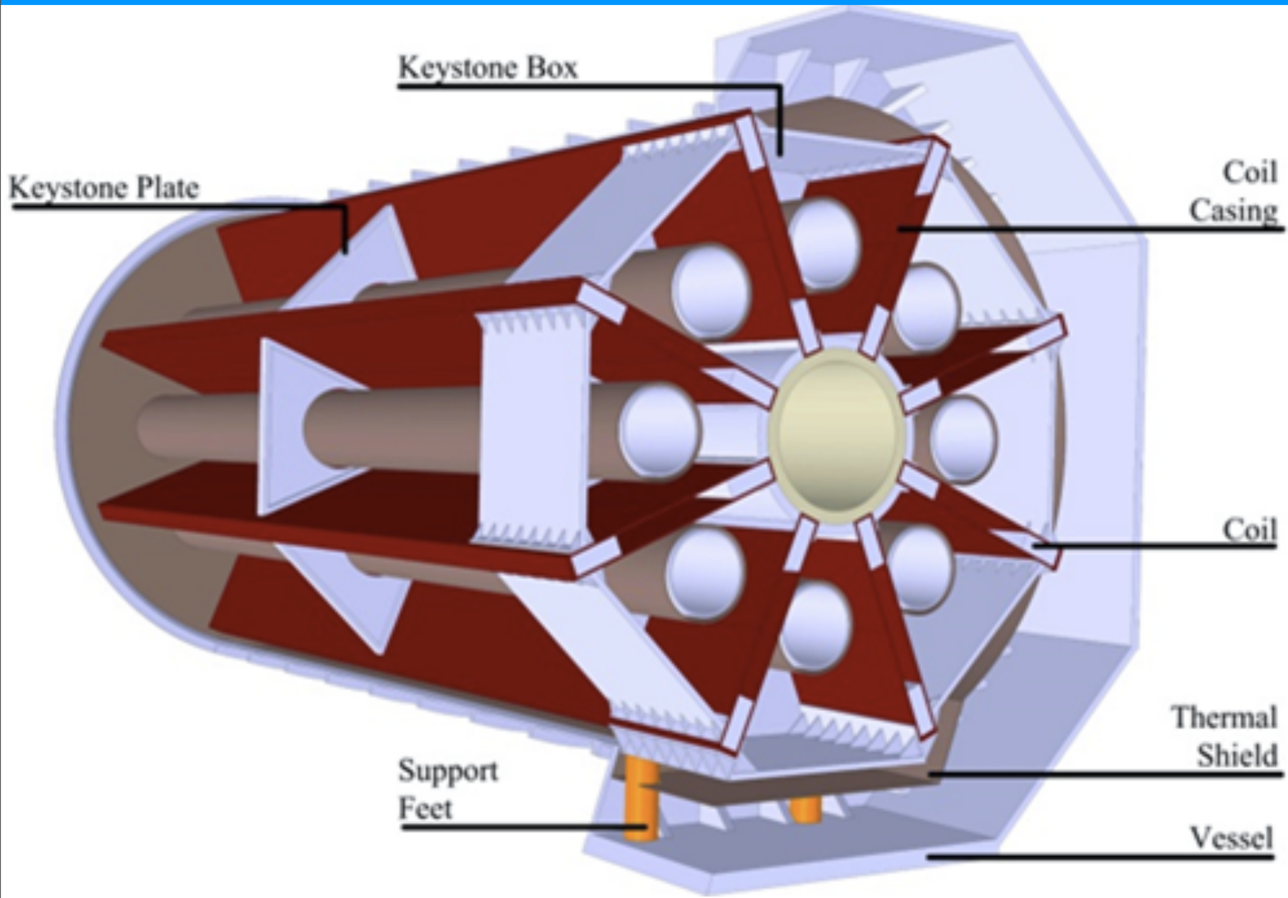
-NGAG paper JCAP 1106:013,2011
-Conceptual design report IAXO 2014 JINST 9 T05002
-LOI submitted to CERN, TDR in preparation

-Possibility of Direct Axion DM experiments (cavities)

Large toroidal 8-coil magnet L = ~20 m
8 bores: 600 mm diameter each
8 x-ray optics + 8 detection systems
Rotating platform with services



IAXO magnet (under development)

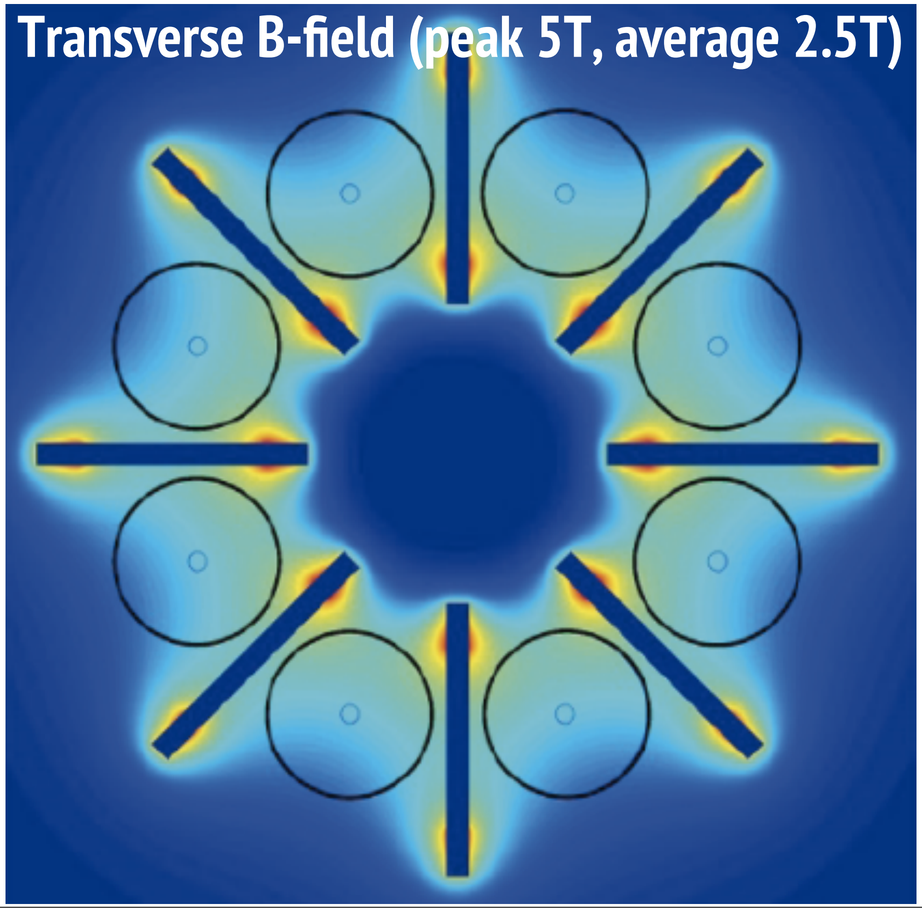


IAXO magnet concept presented in:

IEEE Trans. Appl. Supercond. 23 (ASC 2012)

Adv. Cryo. Eng. (CEC/ICMC 2013)

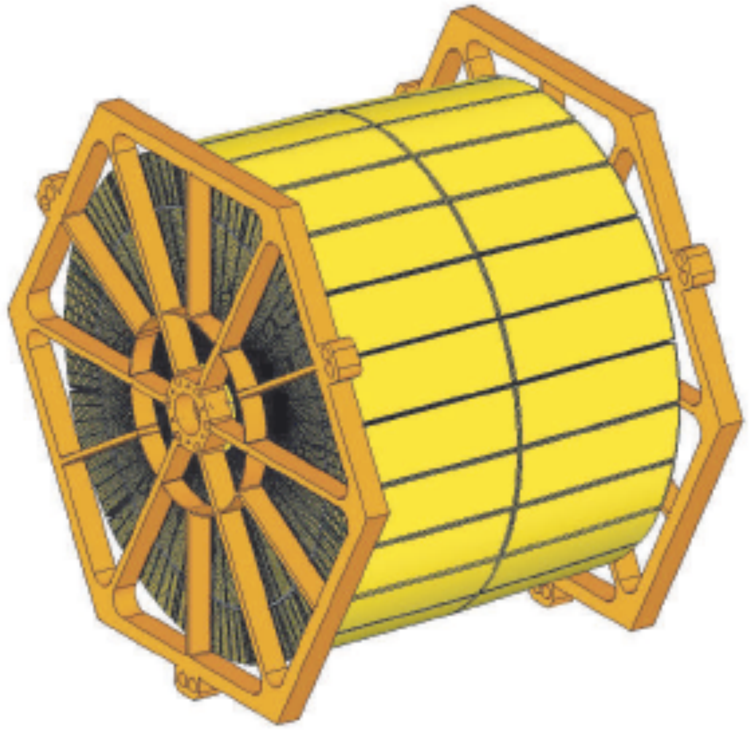
IEEE Trans. Appl. Supercond. (MT 23)

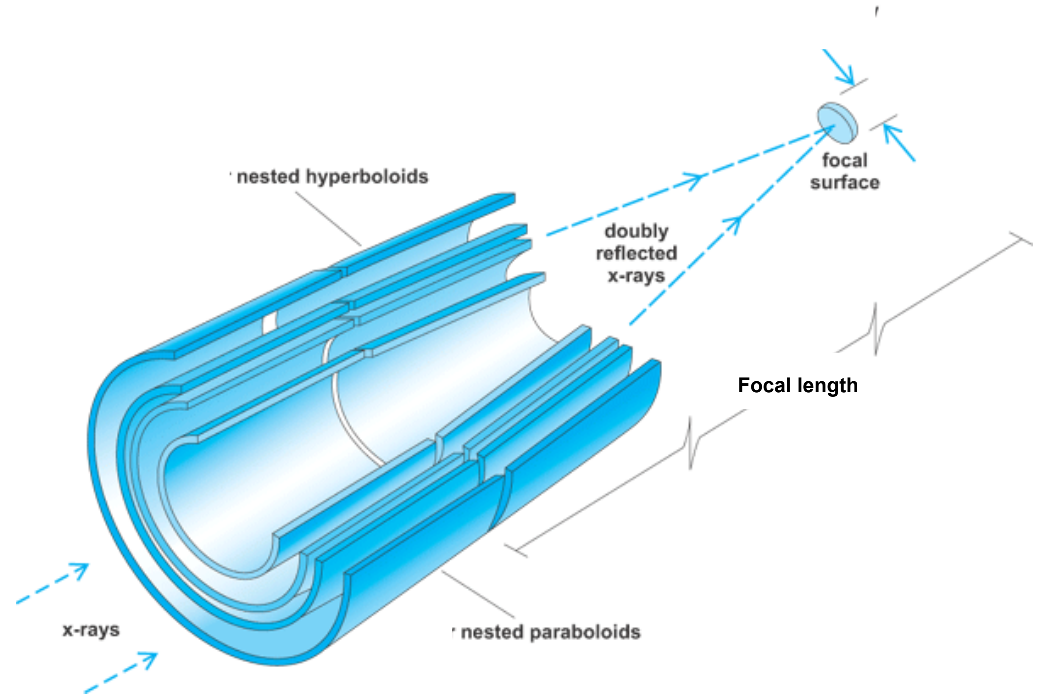


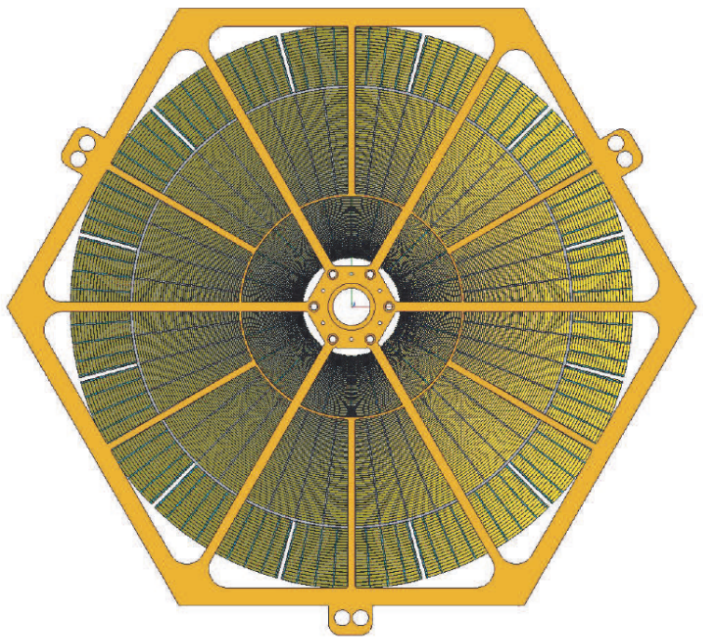
Property		*Value*
Cryostat dimensions:	Overall length (m)	25
	Outer diameter (m)	5.2
	Cryostat volume (m^3)	$\sim$ 530
Toroid size:	Inner radius, R_{in} (m)	1.0
	Outer radius, R_{out} (m)	2.0
	Inner axial length (m)	21.0
	Outer axial length (m)	21.8
Mass:	Conductor (tons)	65
	Cold Mass (tons)	130
	Cryostat (tons)	35
	Total assembly (tons)	$\sim$ 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 $\times$ 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)	$\sim$150
	at 60-80 K (kW)	$\sim$1.6

IAXO optics

- IAXO optics conceptual design
AC Jakobsen et al, Proc. SPIE 8861 (2013)
- NuSTAR optics groups LLNL, Columbia U., DTU Denmark all in IAXO





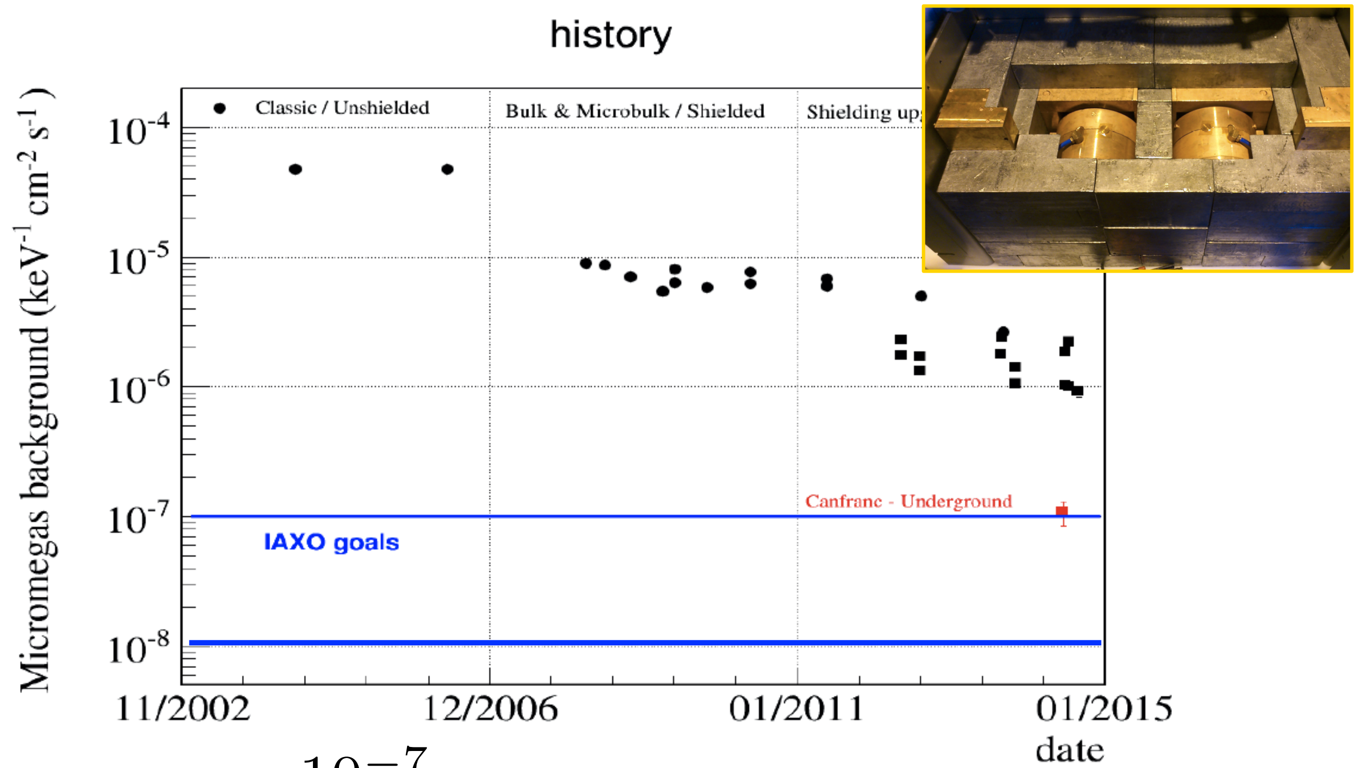


Telescopes	8
N, Layers (or shells) per telescope	123
Segments per telescope	2172
Geometric area of glass per telescope	$0.38\ \mathrm{m}^2$
Focal length	5.0 m
Inner radius	50 mm
Outer Radius	300 mm
Minimum graze angle	2.63 mrad
Maximum graze angle	15.0 mrad
Coatings	W/B_4C multilayers
Pass band	1 – 10 keV
IAXO Nominal, 50% EEF (HPD)	0.29 mrad
IAXO Enhanced, 50% EEF (HPD)	0.23 mrad
IAXO Nominal, 80% EEF	0.58 mrad
IAXO Enhanced, 90% EEF	0.58 mrad
FOV	2.9 mrad

IAXO detectors

Goal background level for IAXO: $\dfrac{10^{-7} \rightarrow 10^{-8}}{\mathrm{keV\,cm^2\,s}}$

- **Small Micromegas-TPC chambers:**
  - Shielding
  - Radiopure components
  - Offline discrimination

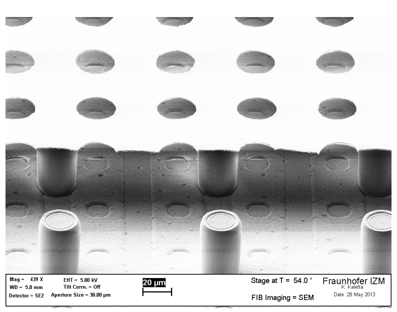


Already demonstrated: $\dfrac{8 \times 10^{-7}}{\mathrm{keV\,cm^2\,s}}$ **(in CAST 2014 result)** $\dfrac{10^{-7}}{\mathrm{keV\,cm^2\,s}}$ **(underground at LSC)**

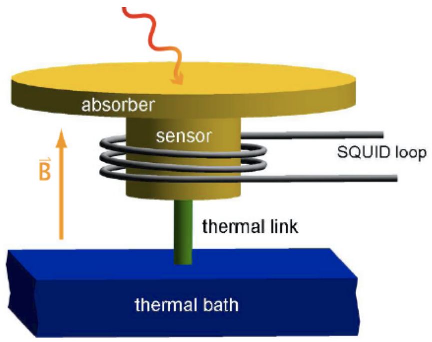
See talk by García wednesday!

Active program of development. Clear roadmap for improvement

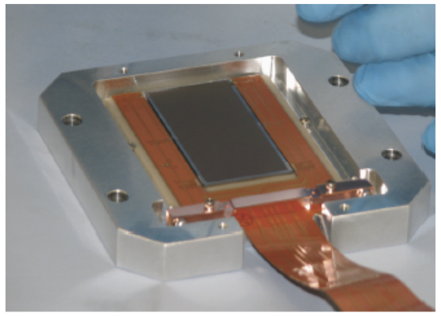
- **Gridpix/InGrid,**



- **MMC**



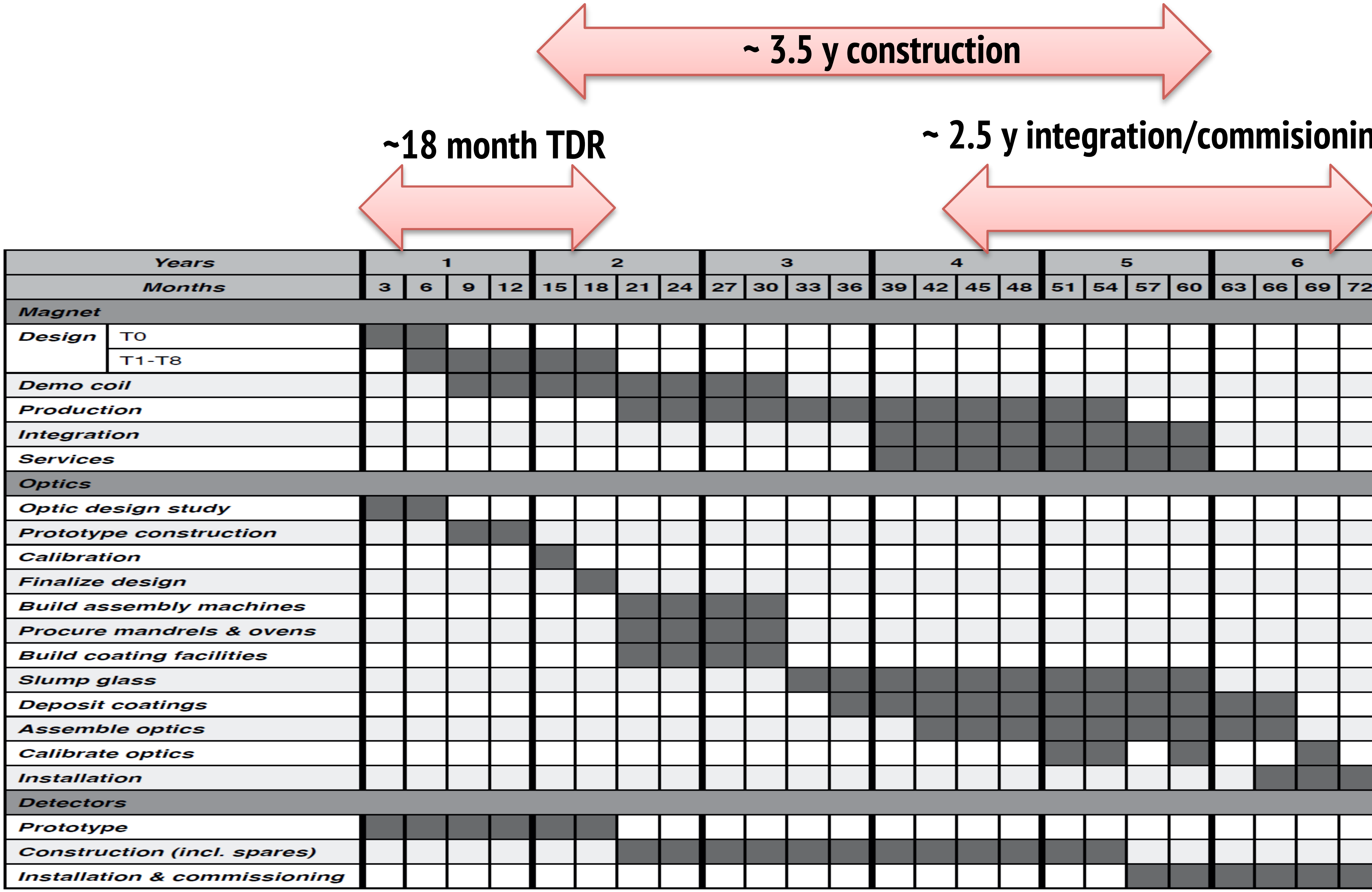
- **Low noise CCDs**



See talk by Desch tomorrow

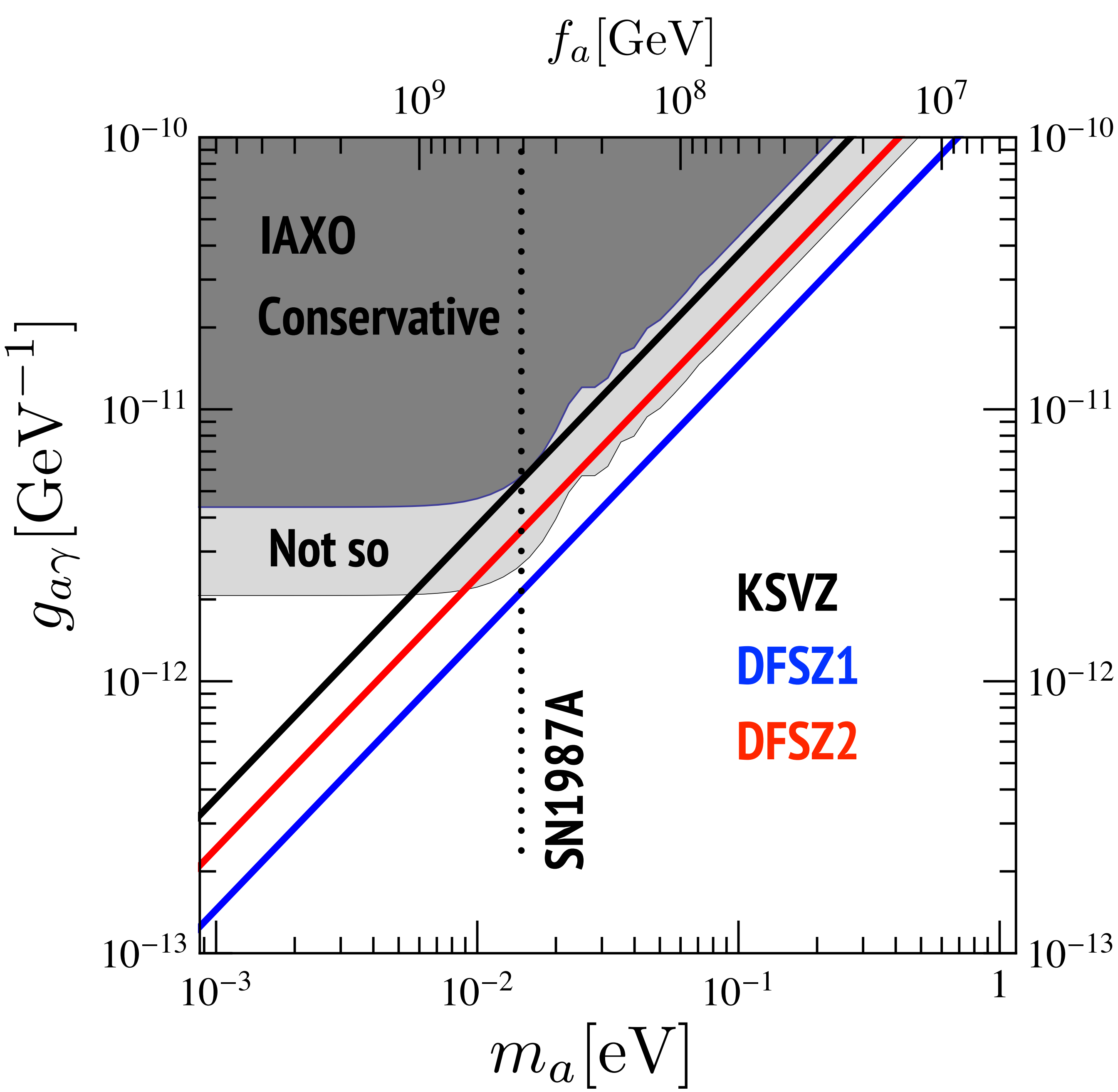
See poster by Desch tomorrow

IAXO timeline

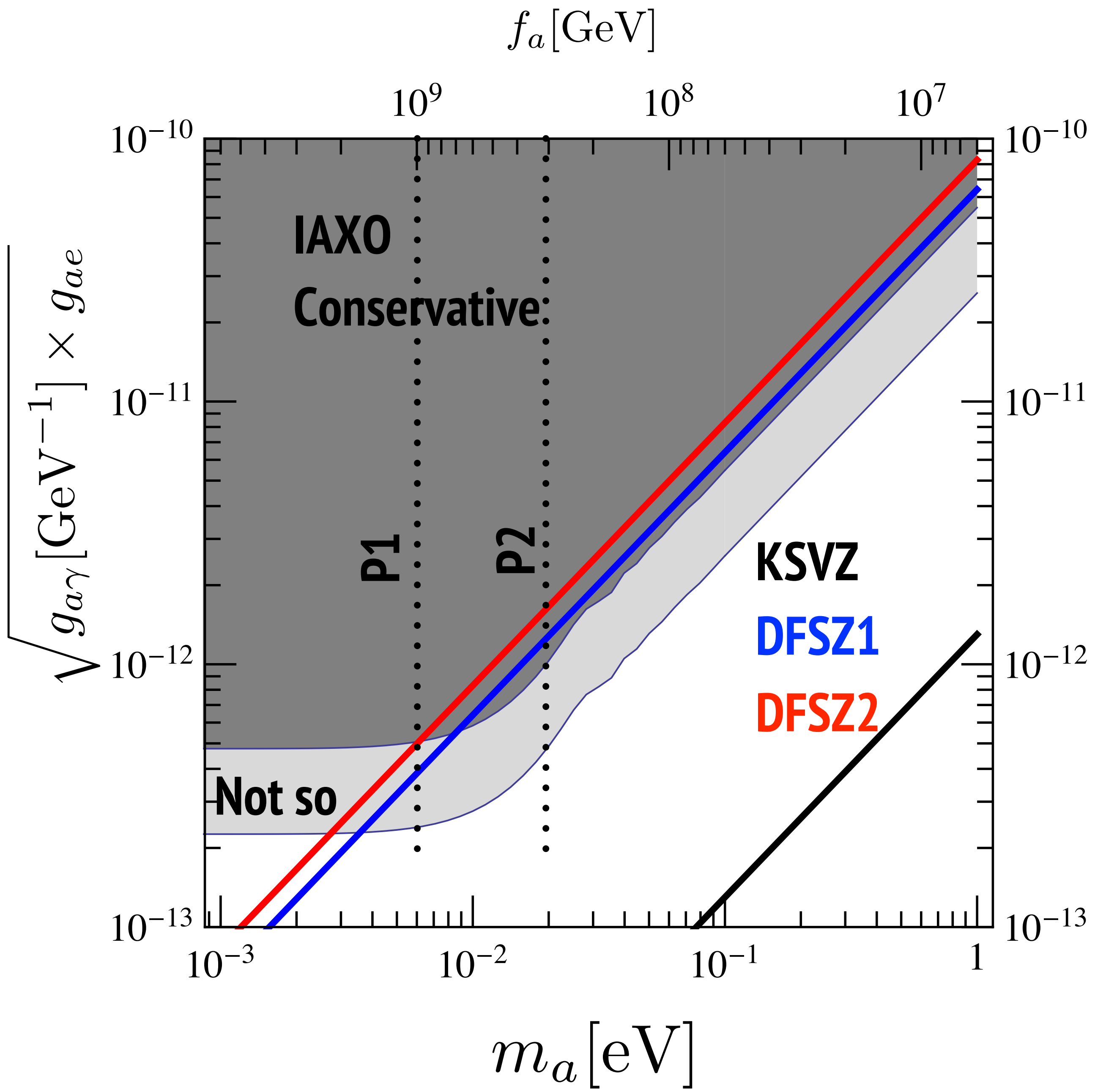


Physics reach: Axions (preliminary)

Hadronic axions (KSVZ)



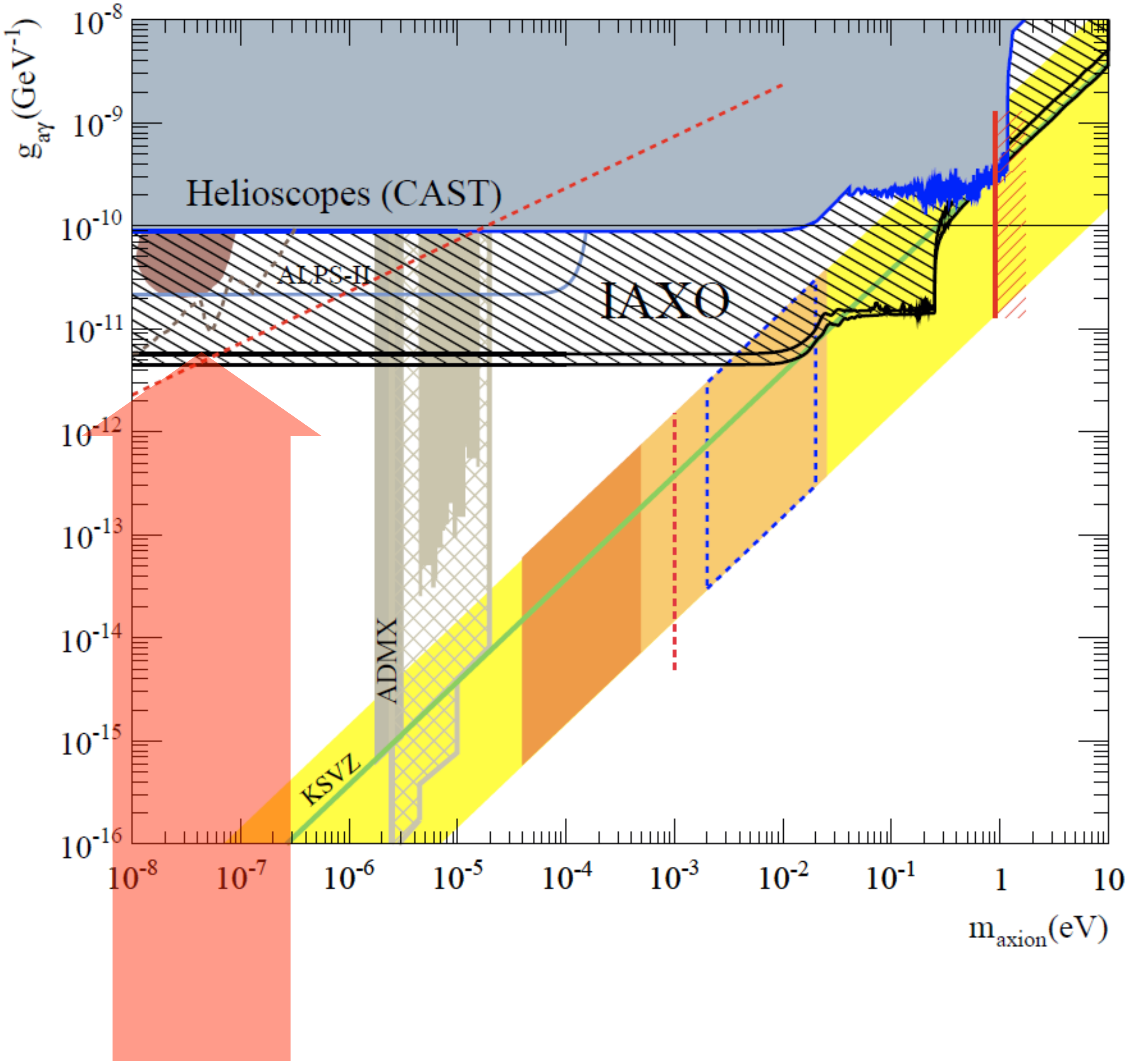
Non hadronic (DFSZ, e-coupling!)



Possibility to unveal the hints in DSFZ P1, P2!

Physics reach: Axions-like

Axion-like particles easing gamma-ray propagation across the universe?



See talks by Roncadelli, Giannotti, Troitsky, Meyer

IAXO will cover the exciting parameter space !

Physics case + : Betelgeuse goes bang

If Betelgeuse is the next galactic SN …

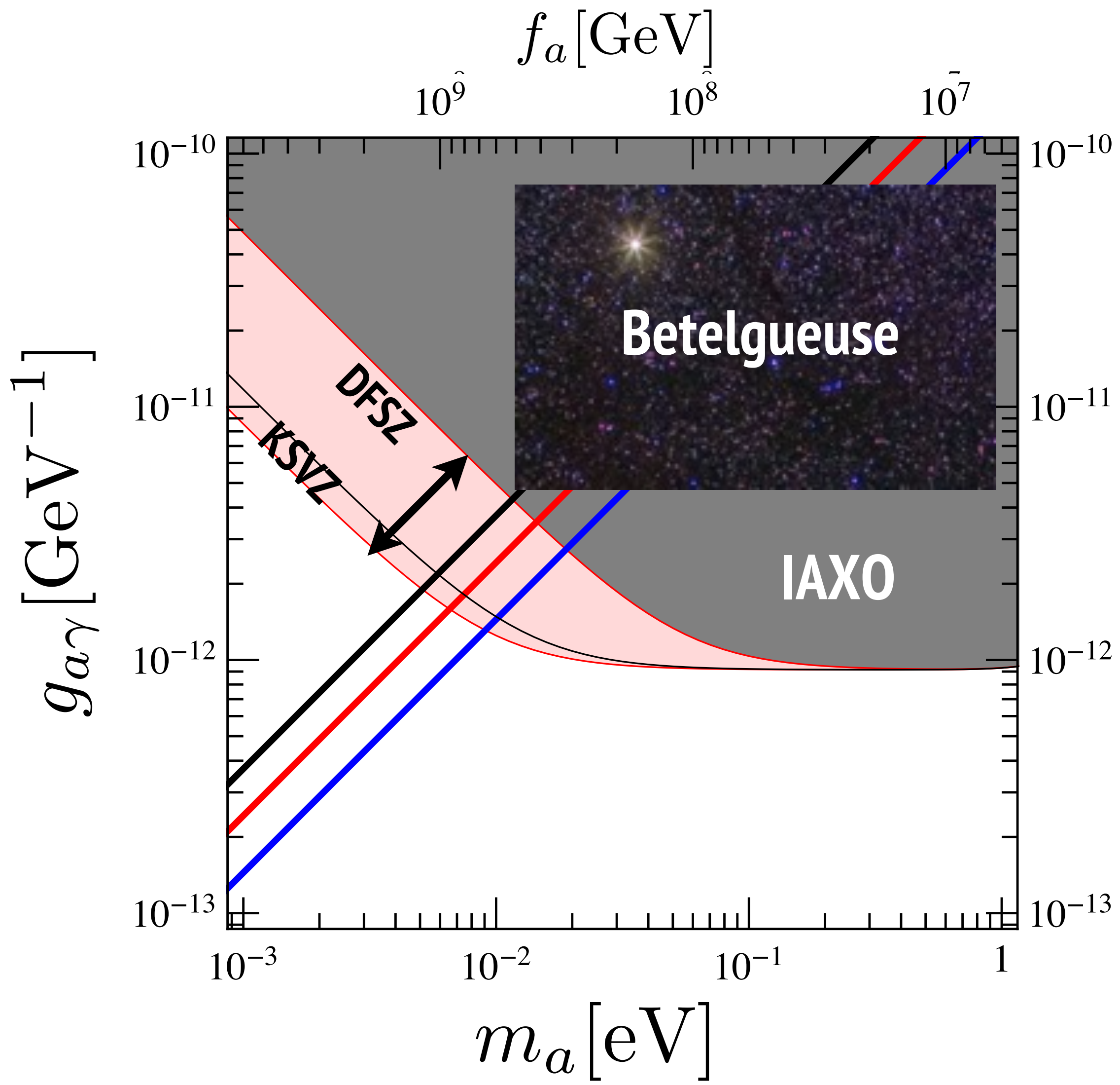
- up to 5 10^{14} a's (E~80 MeV) in 10 sec

- Early warning (Si nu's) to point

- check visibility

- 50-100 MeV detectors

- needs a boost ~30



Physics case + : Axion DM detectors @ IAXO

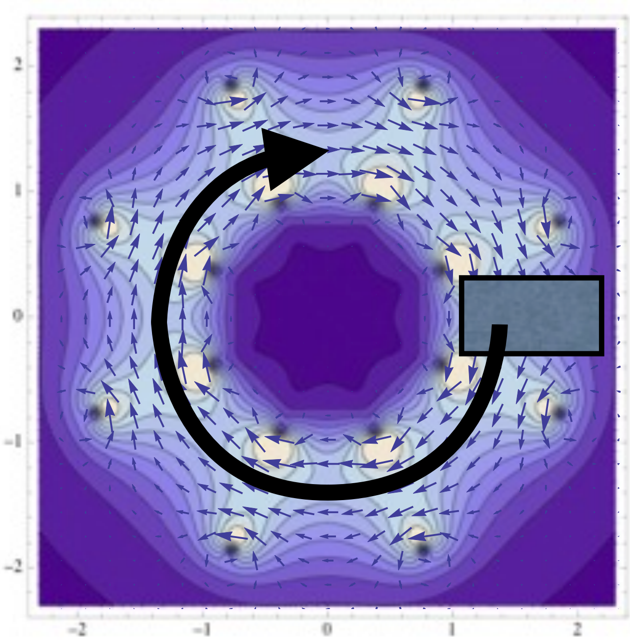
JR, talk at Patras 2014

DM detectors inside IAXO volume (see JR, talk at Patras 2014)

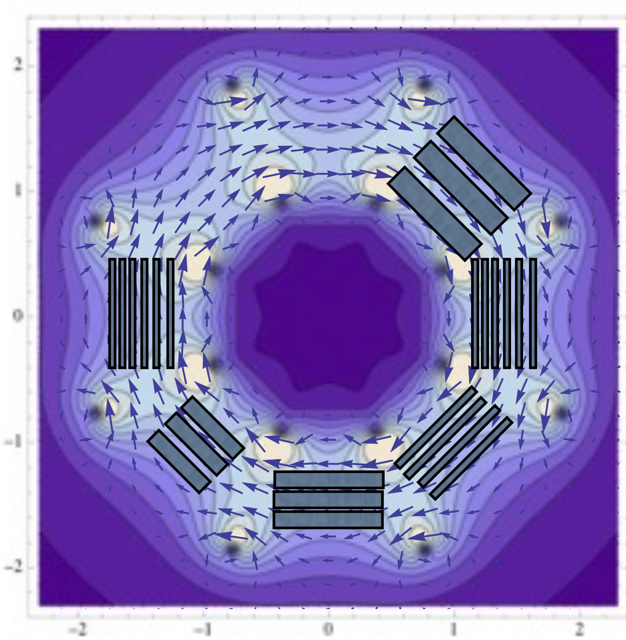
- huge magnetic volume

	ADMX 	ADMX-HF 	IAXO 	CAST 
B [T]	8	9	2.5 *	9
Dimensions [cm]	h,R=100,21	h,R=25,5	h,R*=2000,30	h,R=920,2.2
V [L]	140	2	8 x 1700	2 x 14
$P_{\mathrm{out}} \propto \lvert\mathbf{B}\rvert^2 V\ [\mathrm{T}^2\mathrm{L}]$	9000	160	8 x 35000	2 x 1100

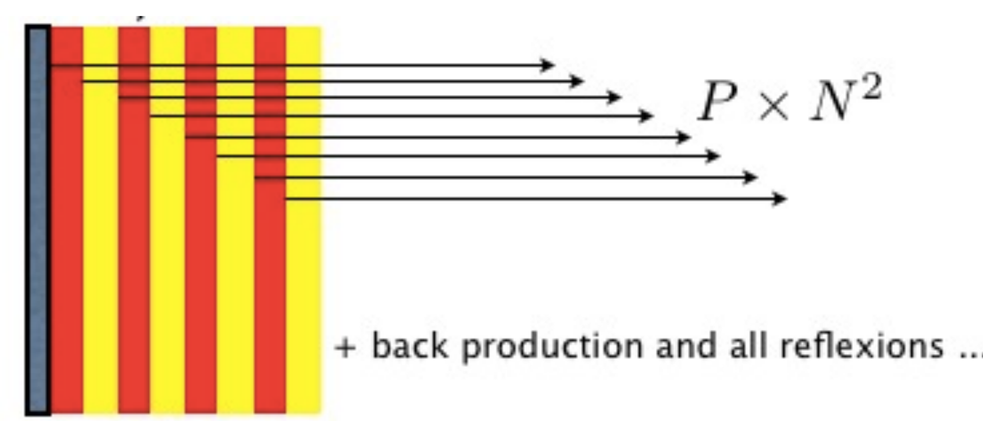
- Low masses



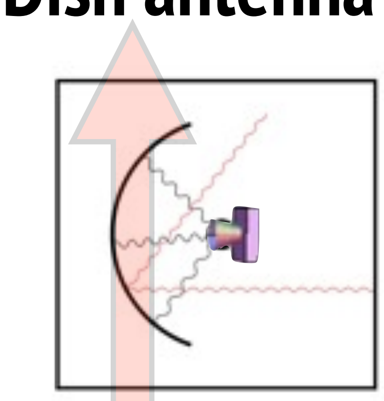
-High masses: long/flat cav's, combine)



- Dielectric filters



- Dish antenna (miniclusters)

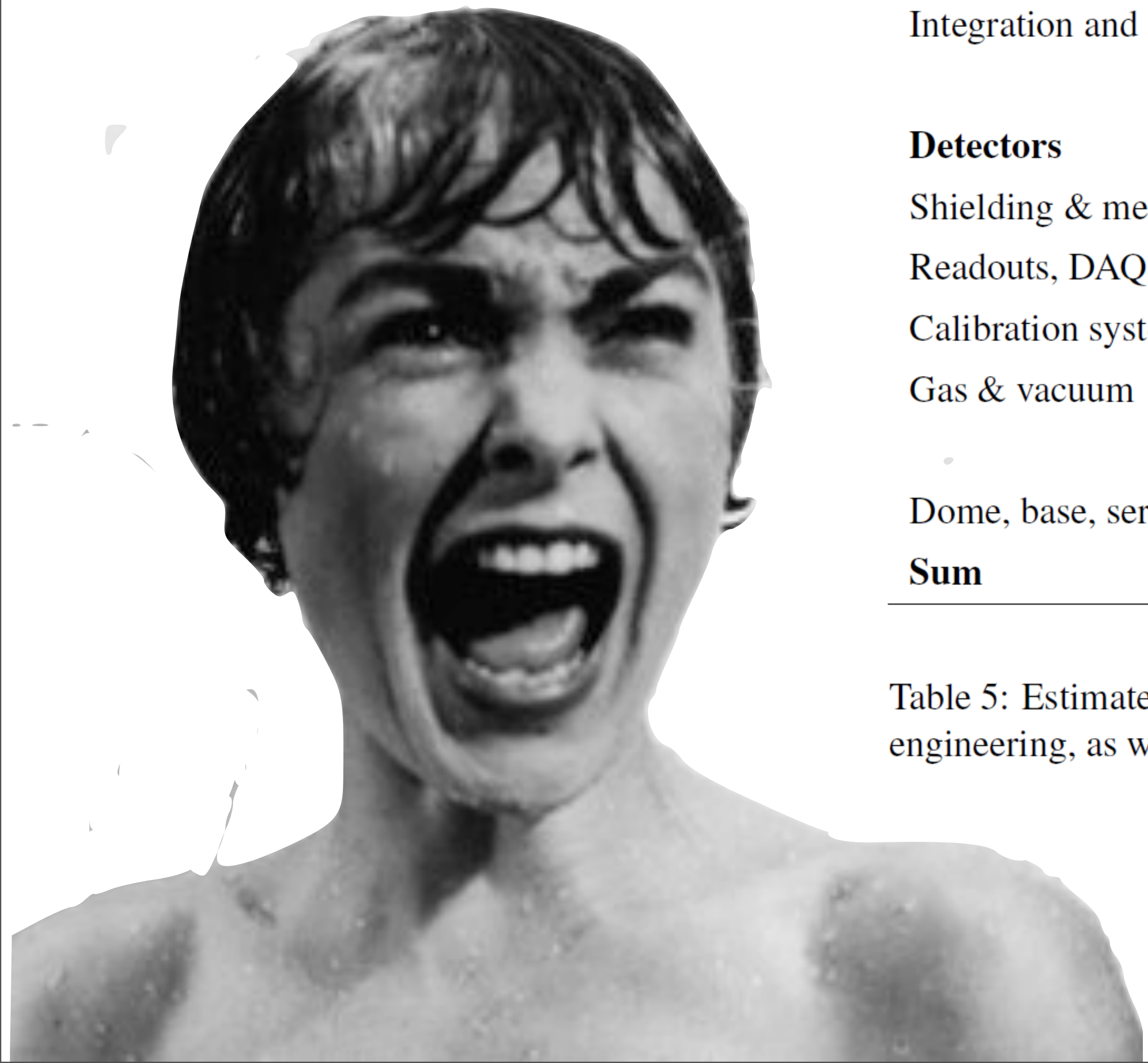


See talks by Tkachev, Sikivie, Prescod

IAXO costs

Item	Cost (MCHF)	Subtotals (MCHF)
Magnet		31.3
Eight coils based assembled toroid	28	
Magnet services	3.3	
Optics		16.0
Prototype Optic: Design, Fabrication, Calibration, Analysis	1.0	
IAXO telescopes (8 + 1 spare)	8.0	
Calibration	2.0	
Integration and alignment	5.0	
Detectors		5.8
Shielding & mechanics	2.1	
Readouts, DAQ electronics & computing	0.8	
Calibration systems	1.5	
Gas & vacuum	1.4	
Dome, base, services building and integration		3.7
Sum		**56.8**

Table 5: Estimated costs of the IAXO setup: magnet, optics and detectors. It does not include laboratory engineering, as well as maintenance & operation and physics exploitation of the experiment.



Conclusions

- Extraordinary physics case
  - meV axions (relevant in astrophysics?, (sub) dominant dark matter?)
  - Axion-like particles and gamma-ray transparency
  - Direct Axion DM detection (much to do!)
  - Next galactic supernova?
  - Others... HPs, MCPs ...

- Doable!, built upon CAST experience
  - key expertise covered (magnet, optics, detectors)

- New Physics case "white paper" soon

- **We are a few ... but**

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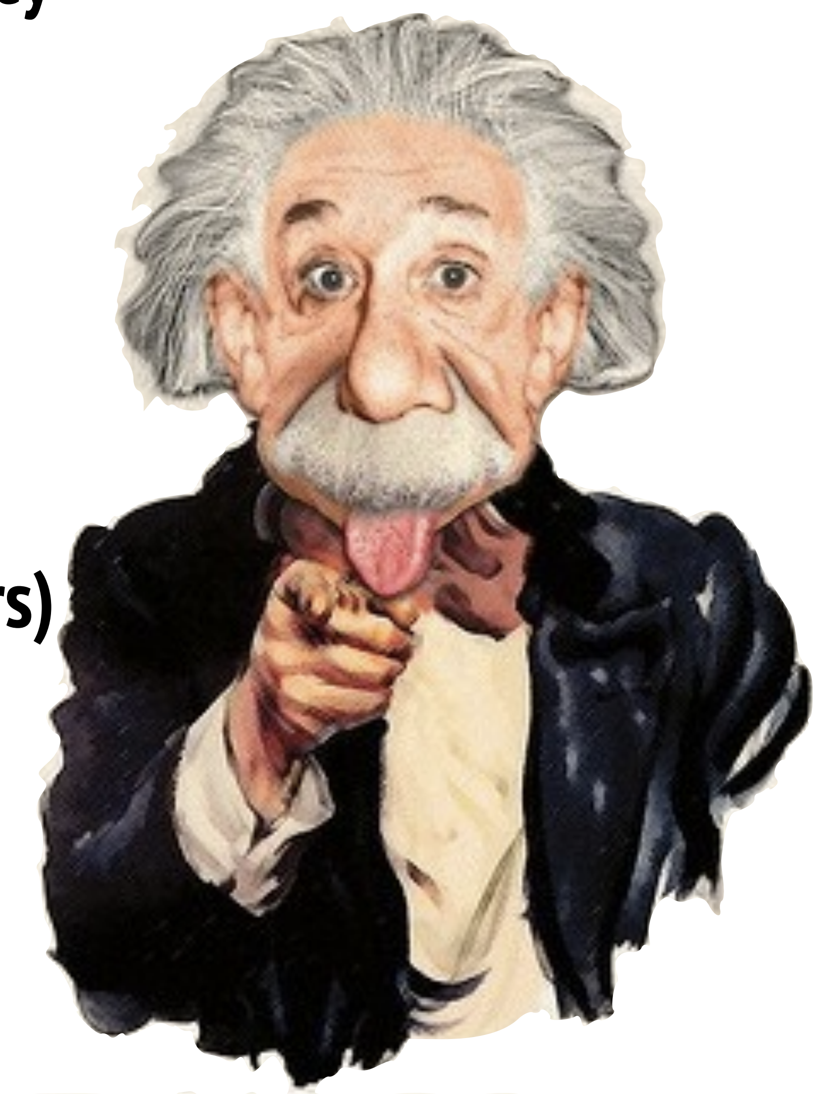

- **We are a few ... but** **WE NEED YOU!**