The search for dark matter - more lamp posts

Peter Quinn
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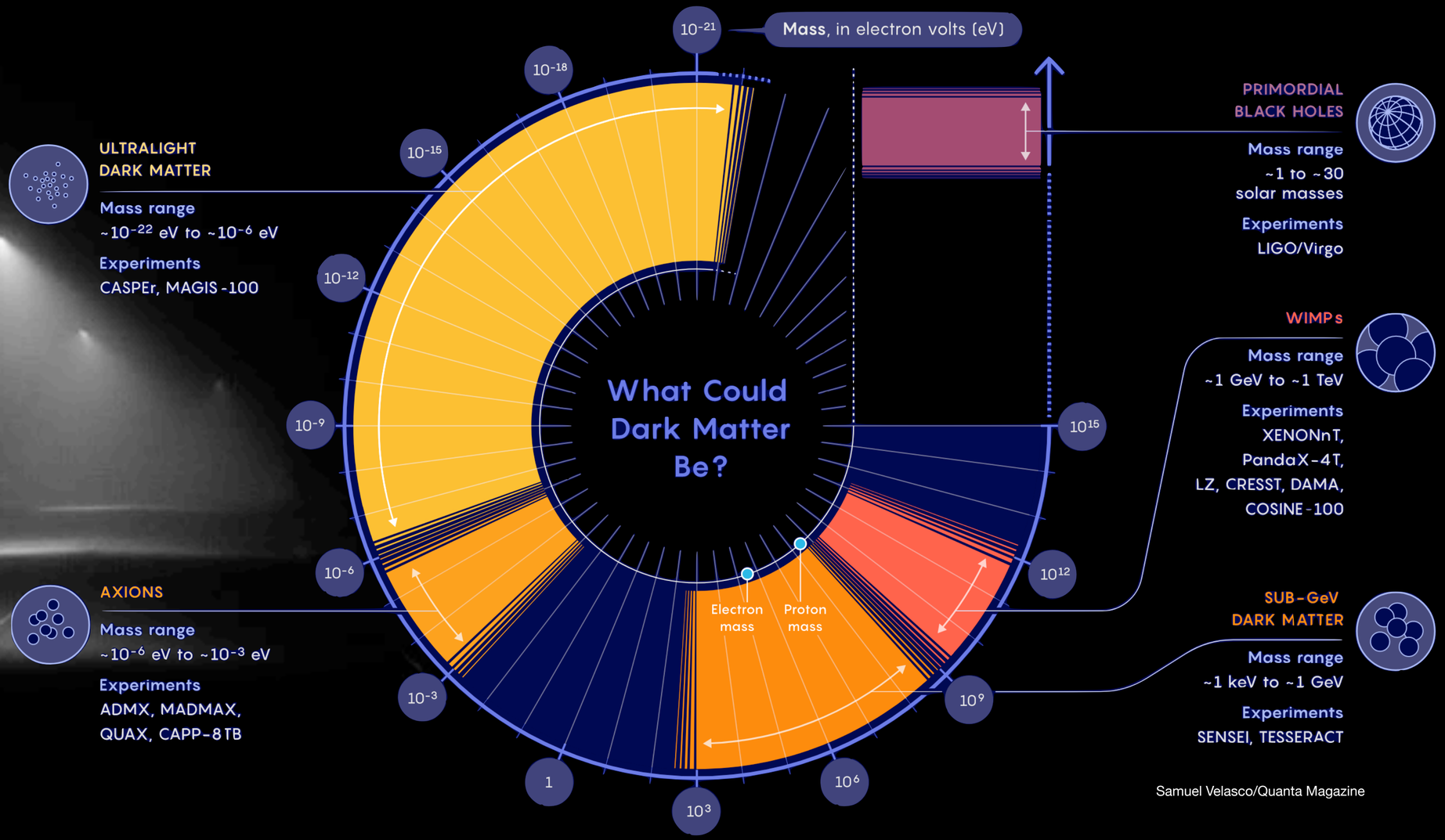
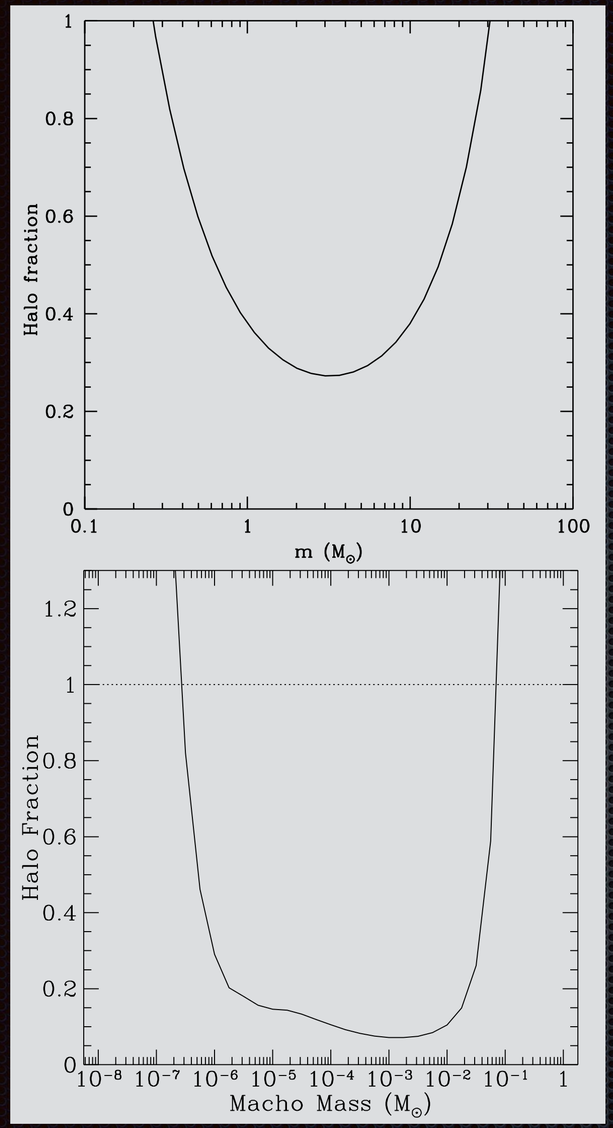
Where is it?

10^{36} in particle mass



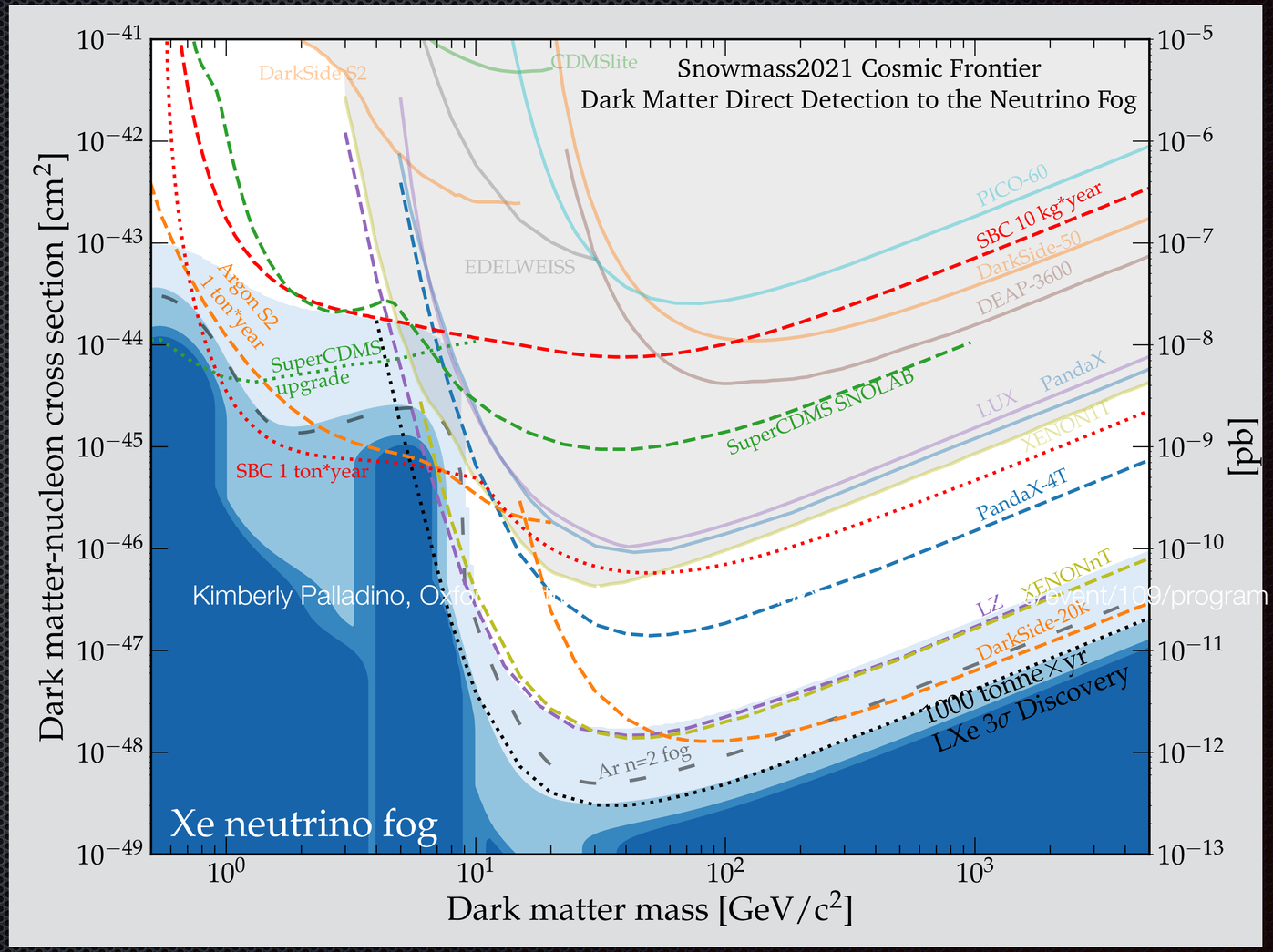
Samuel Velasco/Quanta Magazine

The search - MACHOs and WIMPs



- Paczynski 1986 microlensing and DM *ApJ* **304**, 1-5
- MACHO, OGLE and EROS collaborations
- CDMS, XENON, PANDAX, DAMA/LIBRA …
- New southern hemisphere WIMP experiment

Alcock et.al. 1996
arXiv:astro-ph/9604176
Alcock et.al. 2000
arXiv:astro-ph/0011506



Akerib et.al. 2022 arXiv:2203.08084

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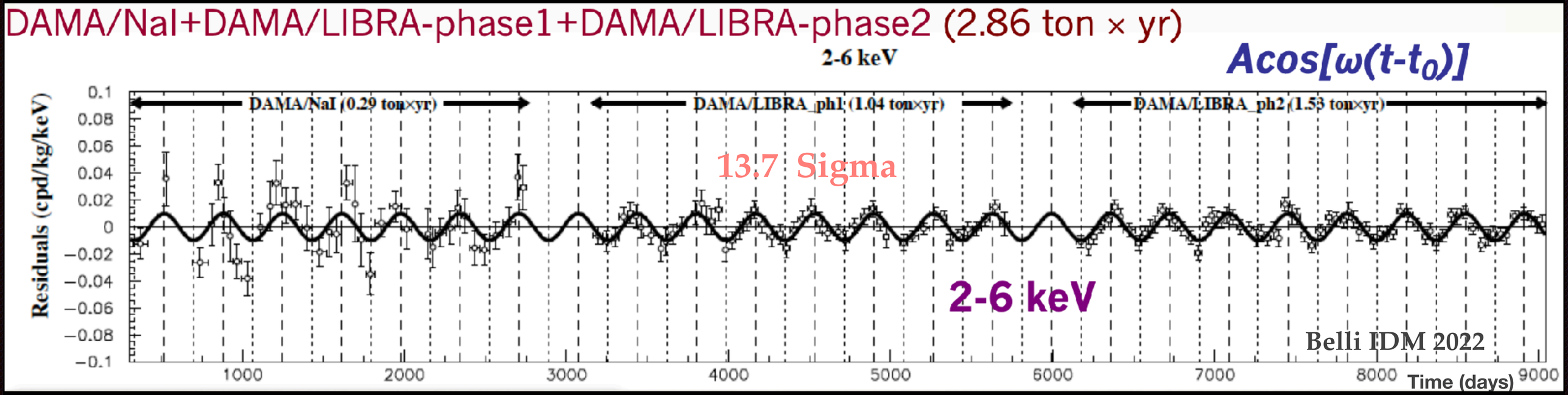
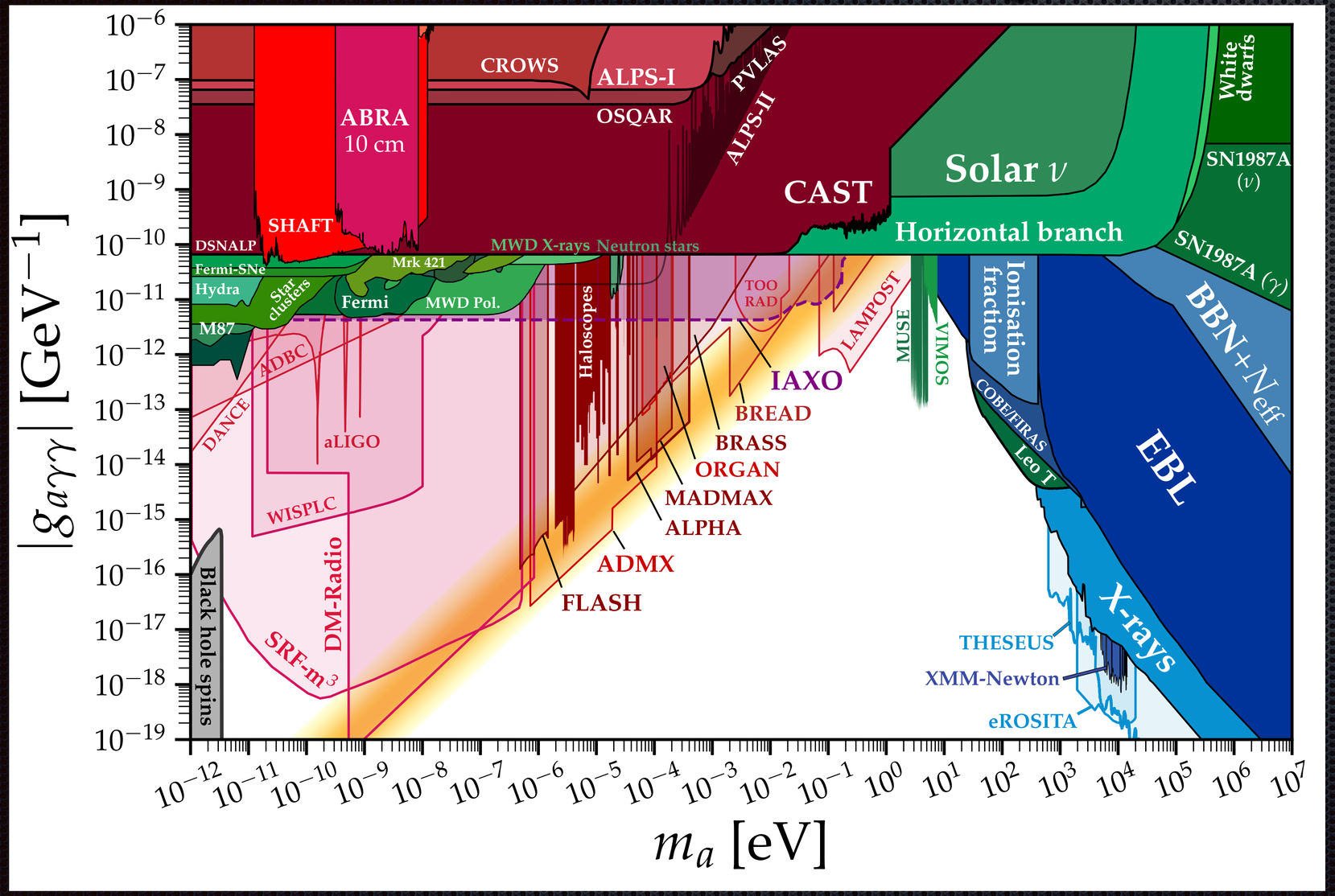


Kimberly Palladino, Oxford, Patras Meeting 2022 indico.him.uni-mainz.de/event/109/program

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Southern hemisphere “DAMA experiment”
Elisabetta Barberio, University of Melbourne, $35m ARC centre of excellence, Stawell Vic, 1km depth

The Axion: advantage and opportunity



Snowmass 2021 White Paper Axion Dark Matter, Jaeckel et.al. , 2022, ArXiv 2203.14923

- Simultaneous solution of two fundamental problems: CP violation and the origin of dark matter
- QCD "favoured" regions from 10^{-6} eV to 10^{-3} eV
- Weak axion photon coupling $g_{a\gamma\gamma}$ implies long lifetimes (> 10^{33} years) but axion can be "stimulated" to decay via a magnetic field (Primakoff effect) Sikivie 1983, PhysRevLett.51.1415
- Resonant (cavity, plasma) $F \sim B^2$ conversion of axions as well as non-resonant (vacuum) conversion $F \sim B^2(k_a)$
- Axion mass $\sim 10^{-6}eV \rightarrow \lambda_{Compton} \sim 1m$ human sized resonant cavities
- Axion energy $\sim 10^{-6}eV - 10^{-3}eV$ 240 MHz - 240 GHz photons = Radio Astronomy opportunity
- Most of the parameter space above the model predictions (orange) will be covered in less than 10 years

Axion Dark Matter Experiment ADMX
University of Washington

Radio Astronomy searches


GBT NRAO


VLA NRAO


MeerKAT SARAO


Parkes

Radio Astronomy searches

- Primakoff: $F \sim B^2 V$
- Resonant Conversion in neutron star magnetospheres ($\omega_p \sim \omega_a$)
  - Large B, small V
  - Individual pulsars, dwarf galaxies, galactic centre
  - Foster et.al. 2022 (2202.08274); Zhou et.al. (2209.09695); Quinn, Tremblay and Hobbs 2023, 700MHz - 4 GHz
- Non-resonant conversion ($k_B \sim k_a$)
  - Small B, large V
  - MW global B field, external galaxies and clusters of galaxies - Kelley PhD UWA 2019
  - Kelley and Quinn 2017 (1708.10399) - overly optimistic
  - Weak cosmic fields + unknown small scale spatial structure of **B** makes axion signal very weak/uncertain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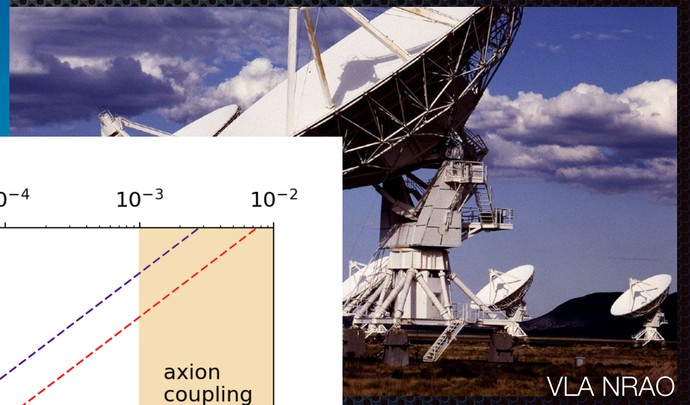

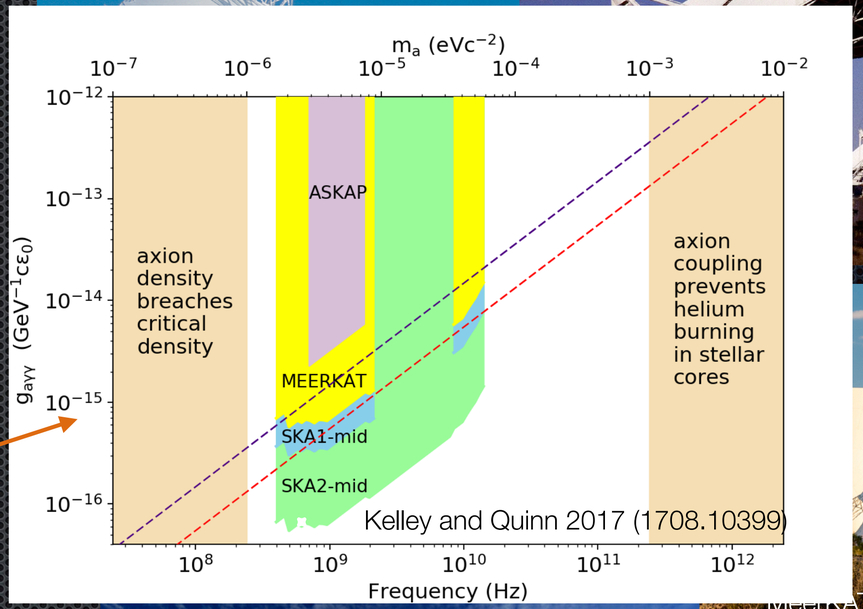

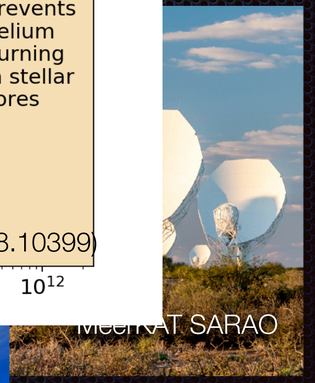

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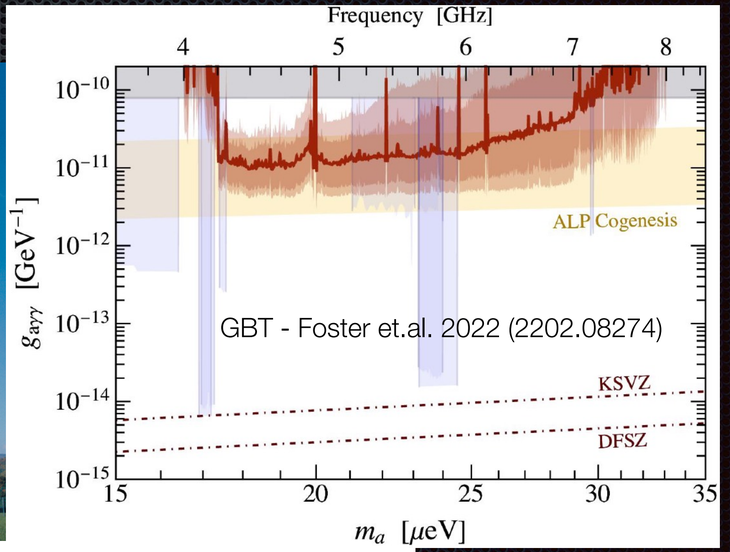
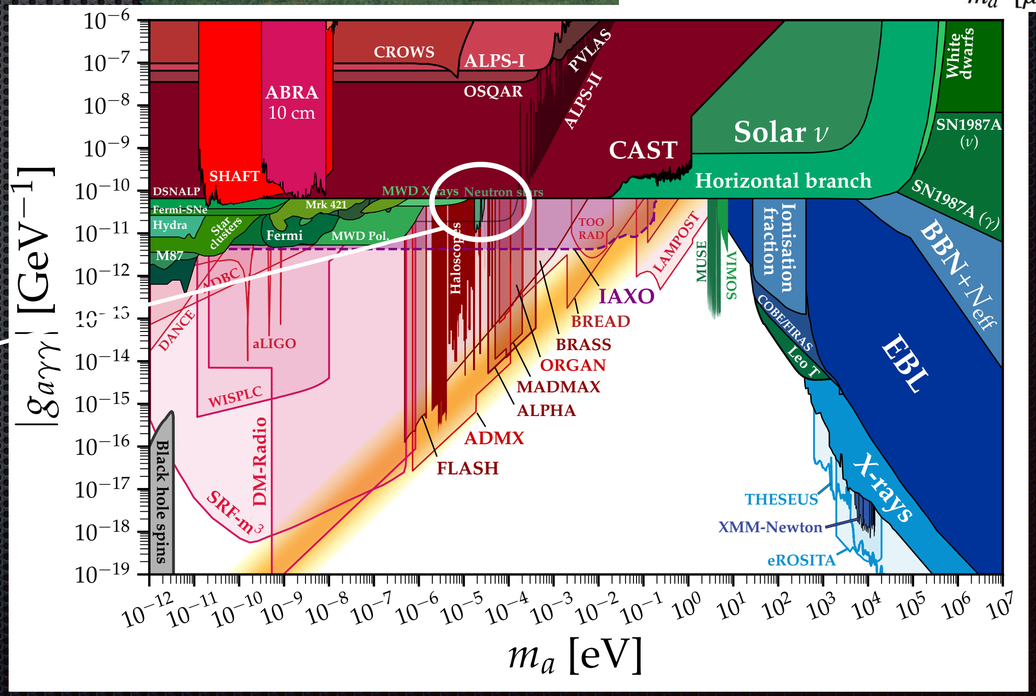
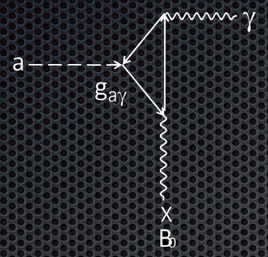
- Upper limits from observations of neutron stars $g_{a\gamma\gamma} \leq 10^{-11}$
- Recent downgrade of expected NS fluxes (Battye et.al. 2021, 2107.01225)
- Are there any prospects for a useful observational astronomy constraint on QCD axions?



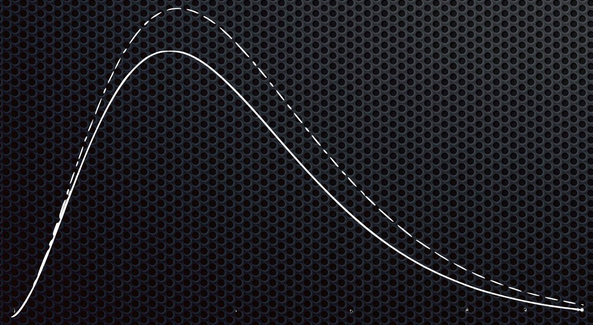


Early Universe possibilities

- Resonant Primakoff conversion $a \rightarrow \gamma$



  - $\omega_{plasma} \sim \sqrt{n_e} \sim (1+z)^{3/2}$
  - Universe acts like a tuneable cavity
  - $\omega_a = \omega_{plasma}$ at some $z = z_a > z_{recombination}$
  - 10^{-6} eV - 10^{-3} eV axions $z_a \sim 10^5 - 10^7$
  - Photons are heavily Compton scattered (thermalized) and add ΔT to CMB
  - $k\Delta T_a \sim E_a B^2 g_{a\gamma\gamma}^2 \delta t \neq f(z_a)$



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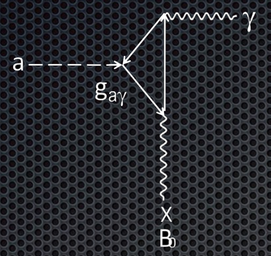

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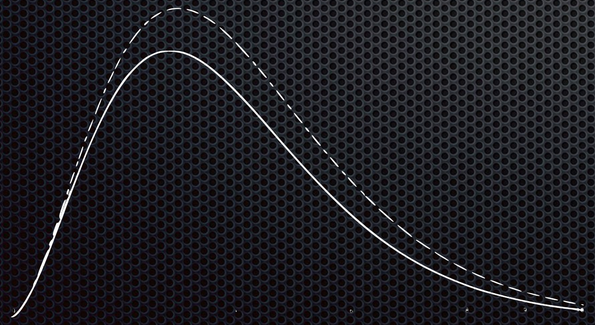
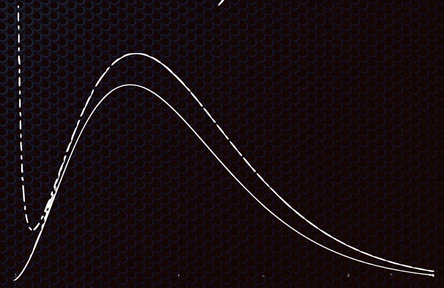


- Non-Primakoff conversion $a \rightarrow 2\gamma$

  - Axion 2 photon decay lifetime $\tau_a \sim E_a^{-3} g_{a\gamma\gamma}^{-2} >> t_{Hubble}$
  - $\#\ decays\ m^{-3} \sim \frac{n_a}{\tau_a} \sim (1+z)^3$
  - $\tau_a \rightarrow \frac{\tau_a}{\Sigma}$ (Caputo et.al. 2019, 1811.08436)

    $\Sigma_{CMB} = density\ of\ states = 2\left(e^{\frac{E_a}{6k(1+z)}} - 1\right)^{-1}$
  - $\Delta E \rightarrow \Delta T_{CMB} \quad z > z_{recomb}$
  - $\Delta E \rightarrow spectrum \quad z < z_{recomb}$



  - Spectral contribution rises to lower frequencies unlike CMB in Rayleigh-Jeans domain

New experiments

- New generation EoR detectors in the 40-90 MHz band could provide interesting constraints on possible low frequency CMB distortions for the decay of axions in the 10^{-3} eV range ($\nu_0 < 10^8\ Hz$)
- GINAN (Global Imprint from Nascent Atoms to Now) project 2023 (Ravi Subrahmanyan et.al.) 40 - 230 MHz

Shaped Antenna measurement of the background RAdio Spectrum
SARAS 3
Raghunathan et.al. 2021 (2104.03522)