Standard Model's Panacea

Axion Searches with the CAST-CAPP Haloscope

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Dictionary

Definitions from Oxford Languages · Learn more

panacea

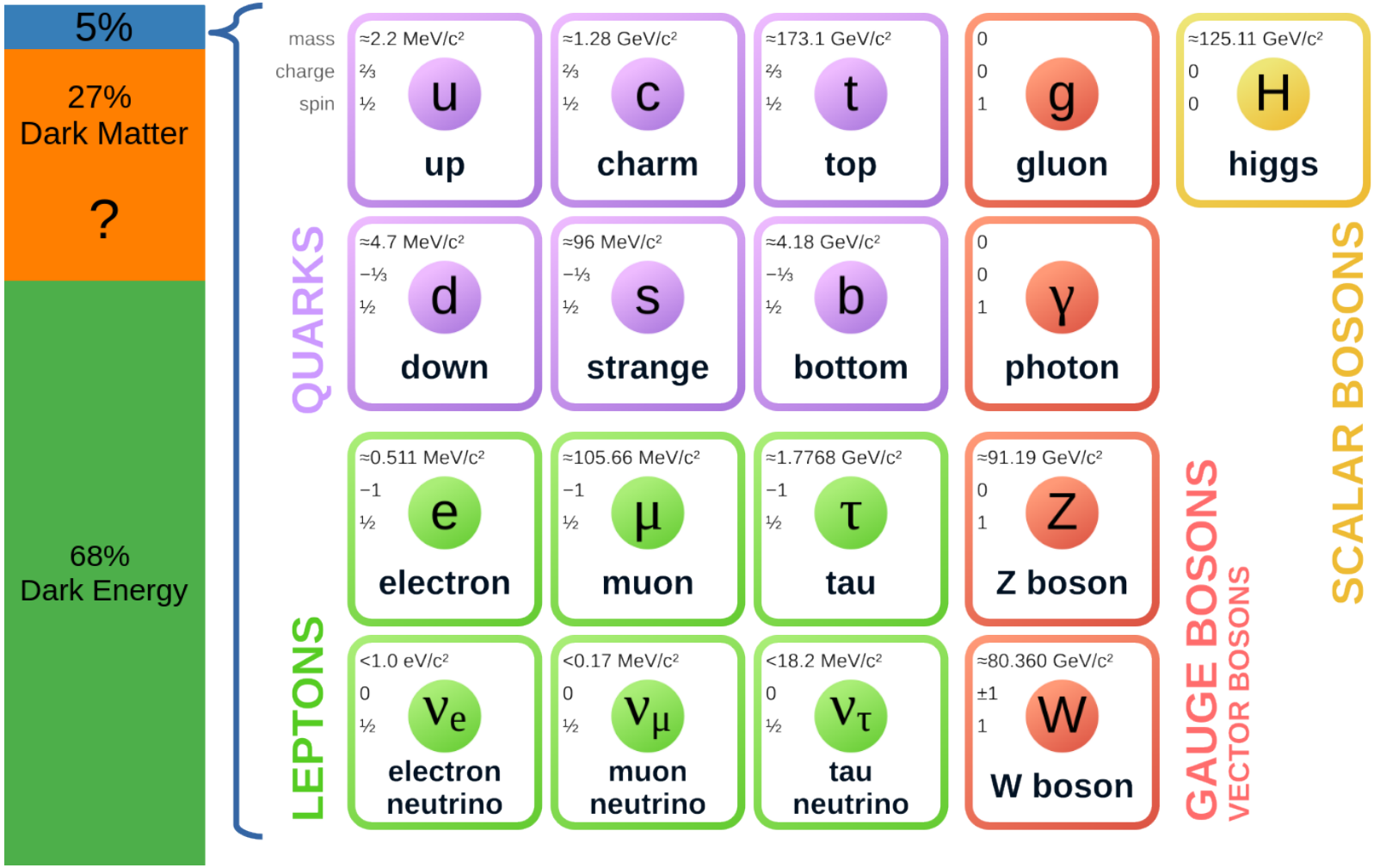
/ˌpanəˈsiːə/

noun

a solution or remedy for all difficulties or diseases.
"the panacea for all corporate ills"

Standard Model

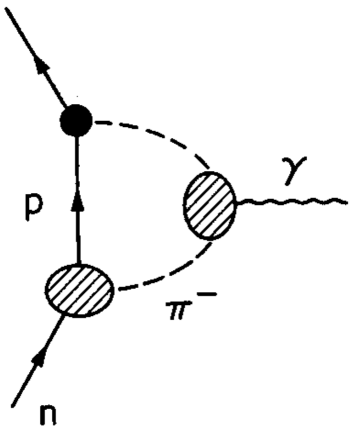
- Best model to date that describes fundamental particles' dynamics
- BUT incomplete model



Strong CP Problem

- Standard Model admits CP violating term in QCD sector

$$\mathcal{L} = \frac{-\theta g_s^2}{32\pi^2} G \cdot \widetilde{G}$$



Phys. Lett. B 88 (1979) 123

- QCD predicts neutron EDM (arXiv:hep-ph/9908508v4)

$$\frac{d_n}{e\,\text{cm}} = (2.4 \pm 1.0) \times 10^{-16}\ \theta$$

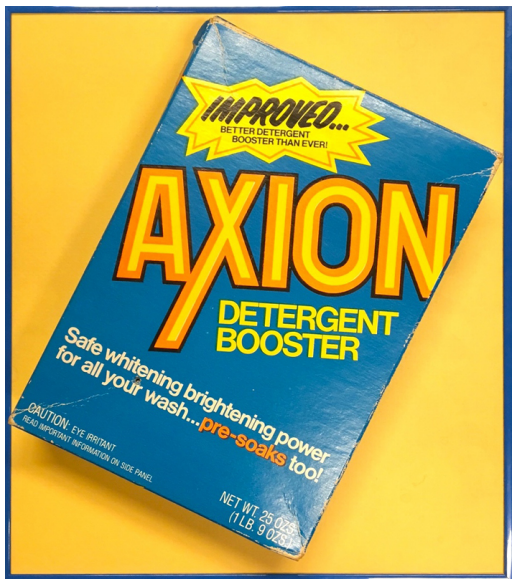
- Experiment: $\frac{d_n}{e\,\text{cm}} < 1.8 \times 10^{-26} \Rightarrow \theta \lesssim 10^{-10}$
- Why is θ so close to zero? Fine-tuning problem

Axions

- Solution by Peccei & Quinn: make θ zero dynamically with axion field

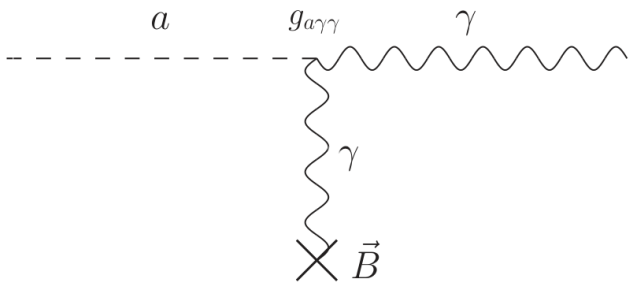
$$\mathcal{L}_a = \frac{1}{2}(\partial_\mu a)^2 + \frac{g_s^2}{32\pi^2}\left(\frac{a}{f_a} - \theta\right) G \cdot \widetilde{G} + \cdots$$

- Various models for how axions couple to matter
- f_a axion decay constant
- Axion mass, coupling $\propto {f_a}^{-1}$
- If ${f_a}^{-1}$ small $\rightarrow$ Candidate for Dark Matter



Experimental Detection

- Axions couple to EM field
- Detection: conversion $a \to \gamma$ inside cavity with static external magnetic field $\vec{B}$



arXiv:1210.3196

- Cavity resonance mode at photon energy = axion mass
- Axion conversion power at resonance

$$P \propto g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B^2 V$$

  - B^2: want powerful magnets
  - V: want larger cavities
  - ${m_a}^{-1}$: harder to convert heavy axions
- Problem: heavier axion $\to$ shorter wavelength $\to$ smaller cavity

CAST-CAPP Haloscope

- CERN Axion Solar Telescope
- 9T magnetic field from LHC prototype dipole magnet
- CAST Helioscope (2003-2017) $\rightarrow$ CAST-CAPP & CAST-RADES Haloscopes (2019-)

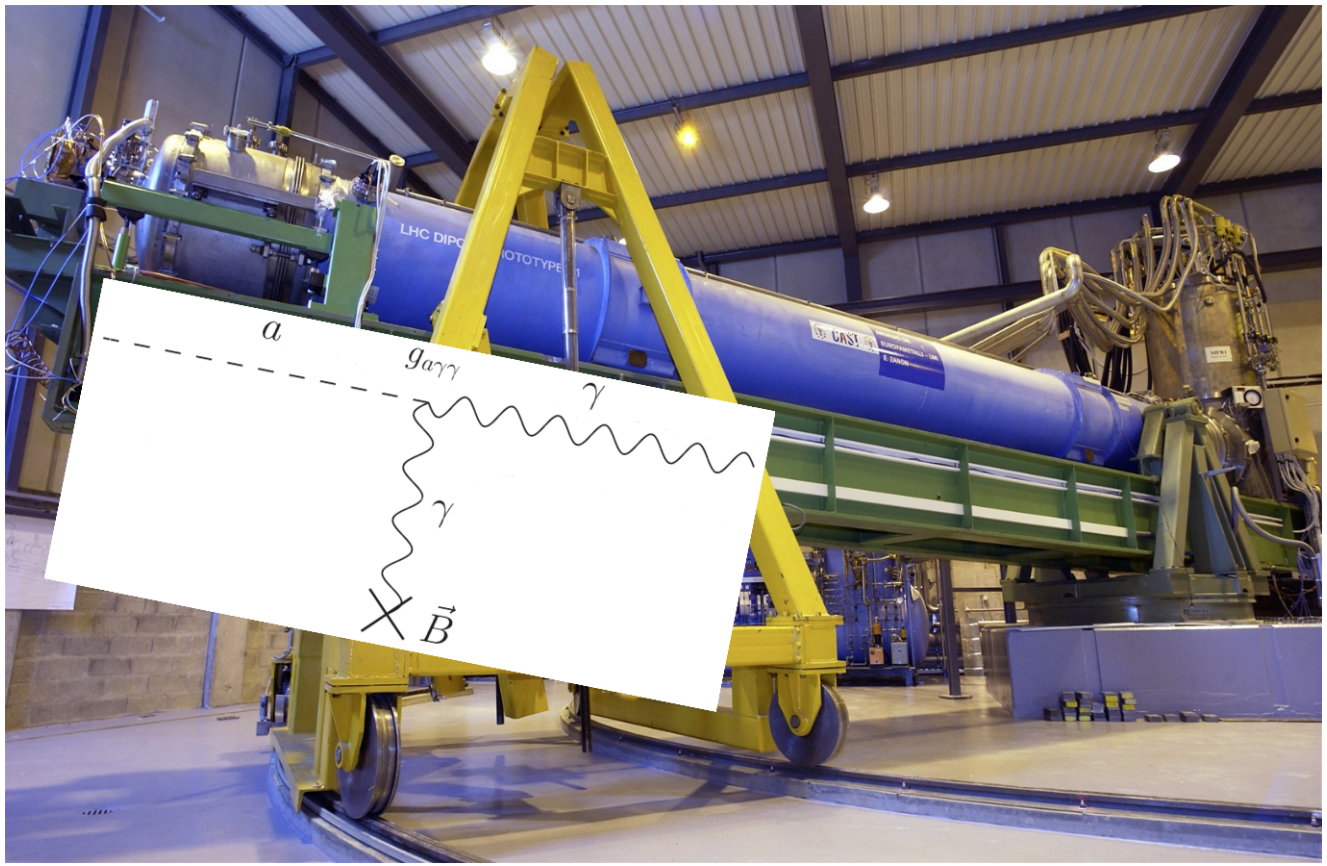


Image Credit: CAST

Helicopter for Scale

Image Credit: My friend, Jack Stevenson-Perkins

CAST Cavities

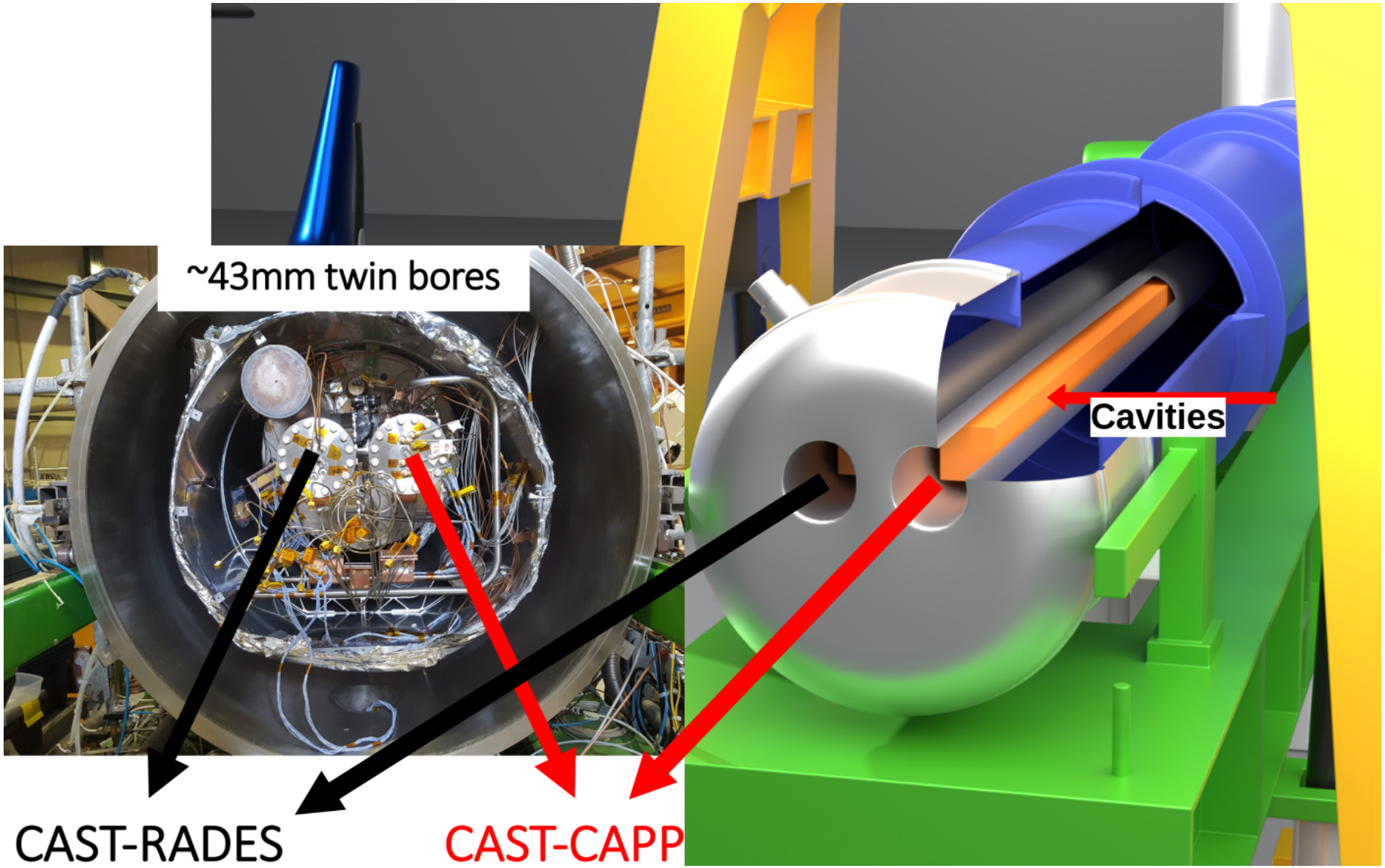


Image Credits: Left: CAST Right: My friend, Jack Stevenson-Perkins

Cavities design

- Four $23 \times 25 \times 390$ mm rectangular cavities in series
- Resonance wavelength tuned by strips driven with piezoelectric motor
  - Scan for signals over a range of axion masses
- Signals amplified then combined coherently by phase-matching
  - Combines four cavities into one effective cavity
  - Larger effective volume with same resonance frequency

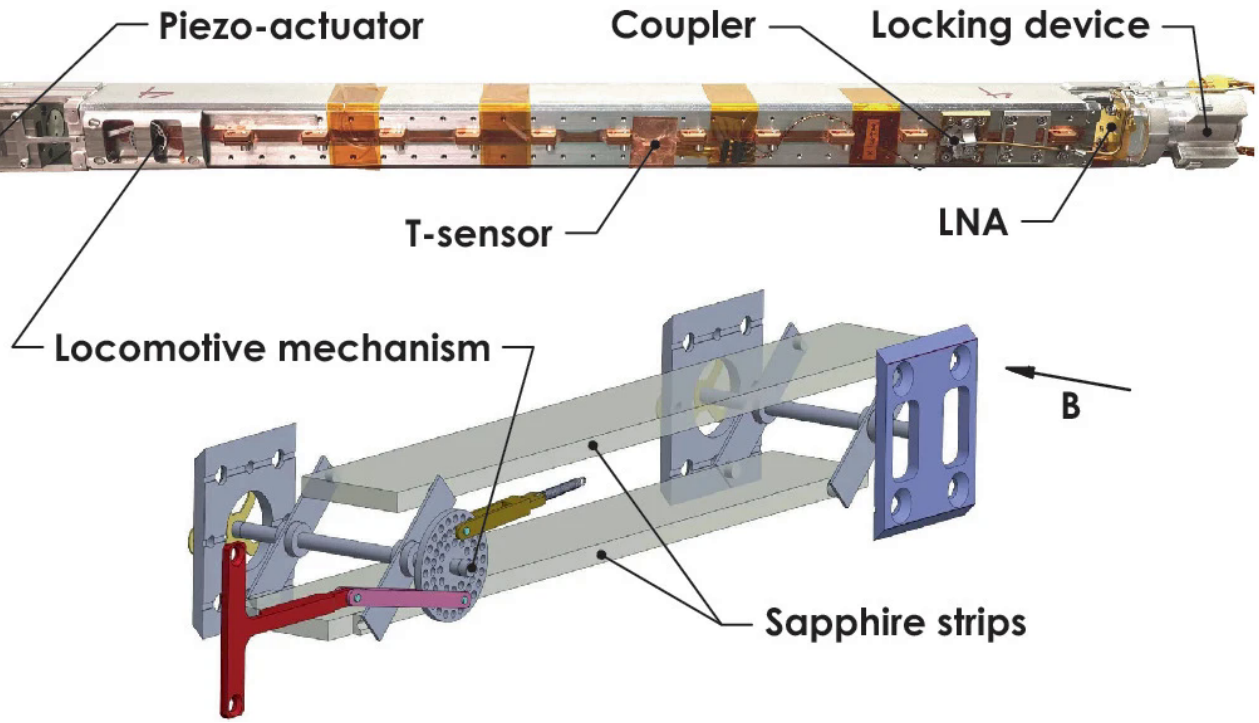
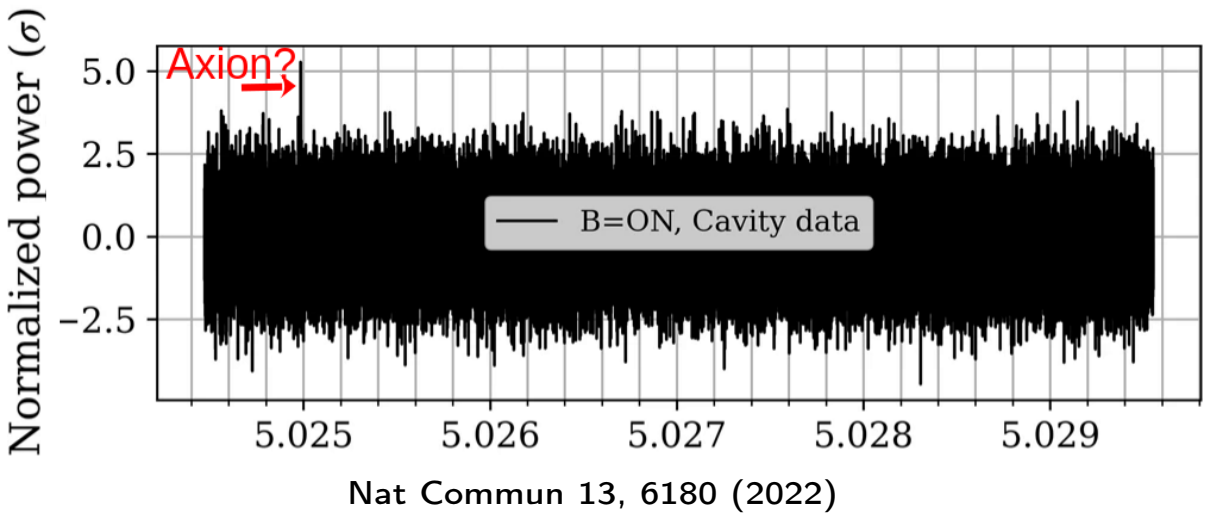


Image Credit: CAST

Signal Analysis

- Data from 4.774–5.434 GHz (19.74–22.47 μeV) in 200kHz intervals
- Fourier transform $\rightarrow$ signal is peak in frequency domain



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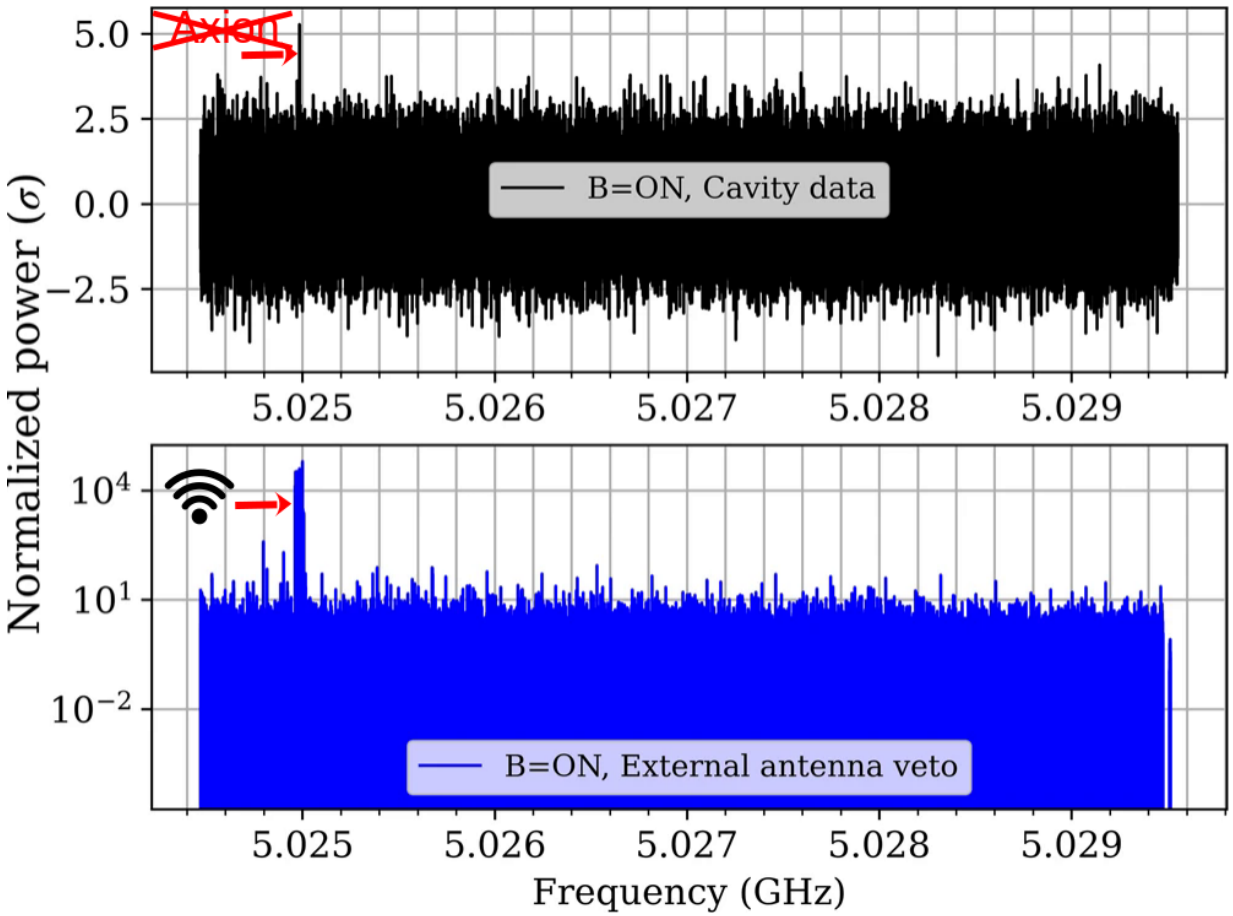
Signal Analysis

- Data from 4.774–5.434 GHz (19.74–22.47 μeV) in 200kHz intervals
- Fourier transform $\rightarrow$ signal is peak in frequency domain
- Veto external EM signals (5GHz Wi-Fi!)



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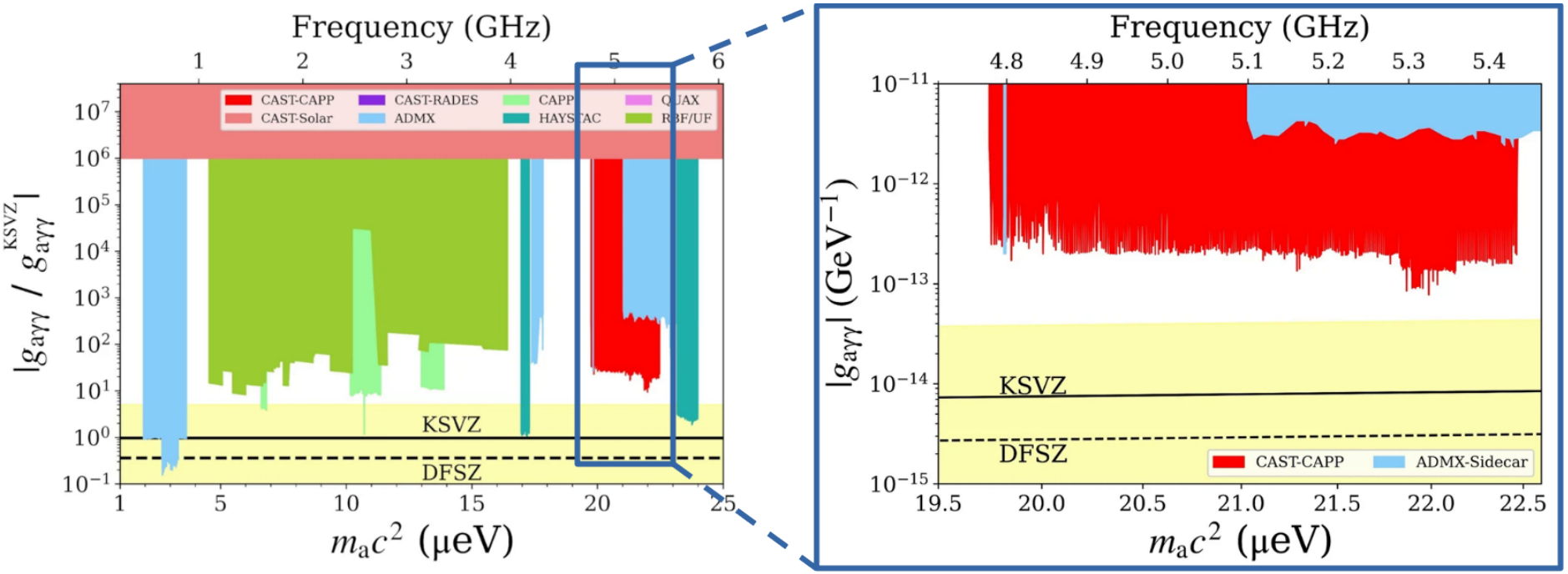
Results

- DM axion mass is unknown; open mass range $10^{-6}\text{eV} < m_a < 10^{-2}\text{eV}$
- Coloured regions of parameter space excluded by experiments
  - Red region from CAST-CAPP with ~2 years' data
- Data excludes new region of phase space



Exclusion at 90% in parameter space Nat Commun 13, 6180 (2022)

Summary

- Axions as solution to Strong CP problem can be DM candidate
  - Could solve both problems simultaneously!
- Search by conversion to photon via coupling to strong $\vec{B}$ field
- CAST-CAPP: modified CAST helioscope
  - four phase-matched cavities increase effective volume
  - fast tuning mechanism with piezoelectric motors
- No axions yet ...
- Plan to increase search range up to 1GHz (4.6–5.8 GHz)
- Scalable number of cavities for even higher frequencies

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