The ORGAN Experiment: Results, Status and Future Plans

Ben McAllister, Aaron Quiskamp, Paul Altin, Maxim Goryachev,
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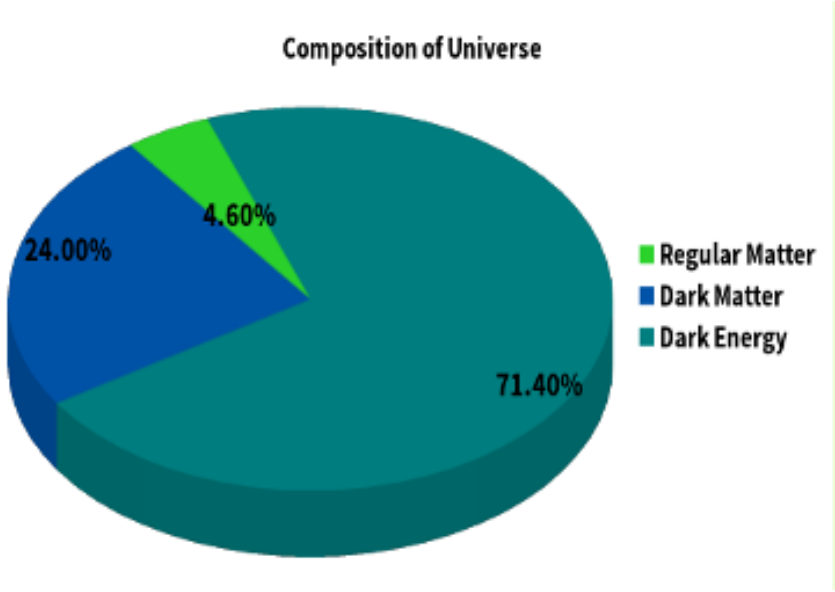
Overview

- General Introduction
- ORGAN
  - Run Plan
  - Phase 1a
  - R&D/Future Phases
- ORGAN-Q

Dark Matter

- Most of Universe made of DE, DM
- What is DM?
    - Doesn't interact with light
    - Has mass
    - ~5x as much as the regular matter
    - New particles?



Axions

- Light boson first proposed in ‘70s as consequence of solution to the strong CP problem
- Strong CP problem in quantum chromodynamics
- There exist natural CP violating terms within the QCD Lagrangian

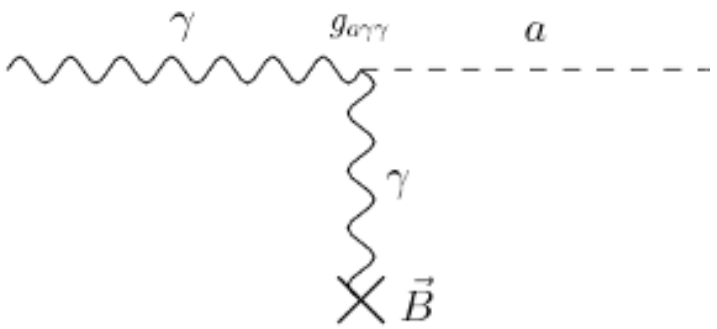
$$\mathscr{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{n_f g^2 \theta}{32\pi^2}F_{\mu\nu}\tilde{F}^{\mu\nu} + \bar{\psi}(i\gamma^\mu D_\mu - me^{i\theta'\gamma_5})\psi$$

- Key point: if θ is non-zero, CP symmetry is violated, and measurable effects would occur
- Specifically, neutron would develop electric dipole moment

Axions

- It was later realized that for a certain range of masses (neV to meV) axions could comprise dark matter
- They are a neat candidate since they solve the strong CP problem
- Have various interesting couplings to standard model particles

  e.g. photons



- Experiments attempt to exploit this coupling

ORGAN Introduction

- High mass axion haloscope collaboration
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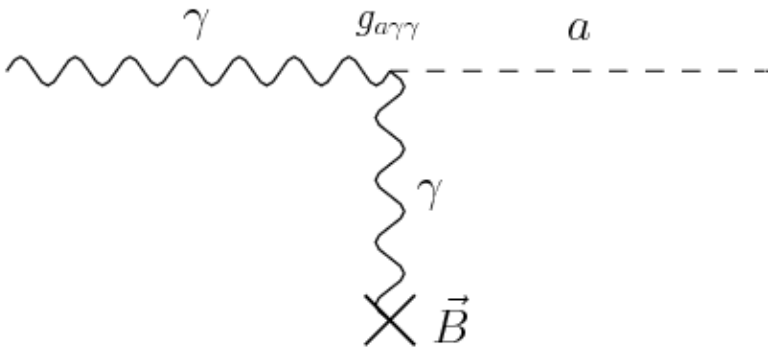

$$\hbar\omega_a \approx m_a c^2 + \frac{1}{2} m_a v_a^2$$

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

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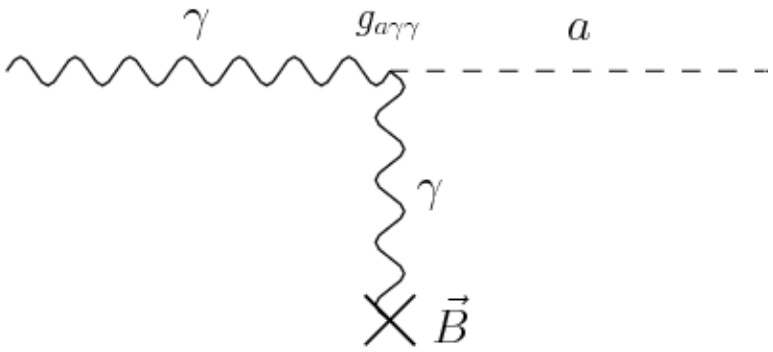

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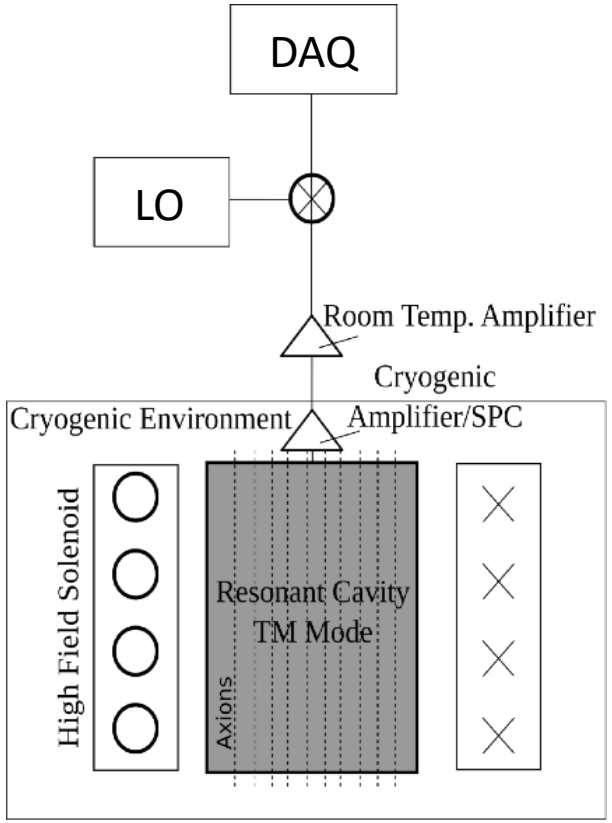

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- Many cavities together
- The Oscillating Resonant Group AxioN Experiment

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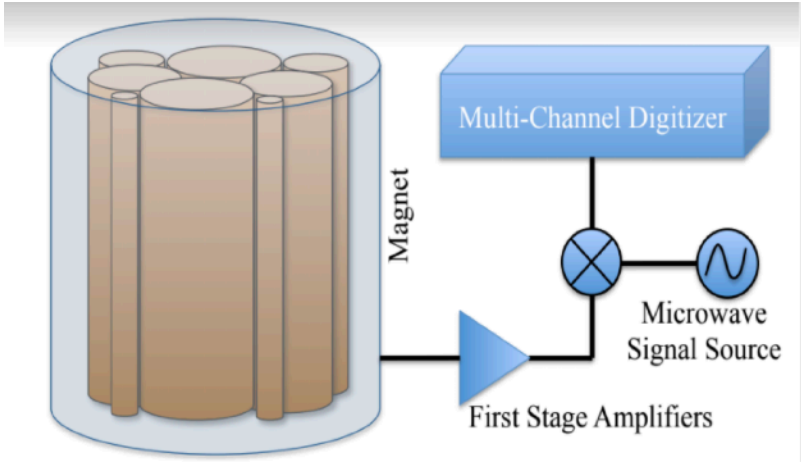

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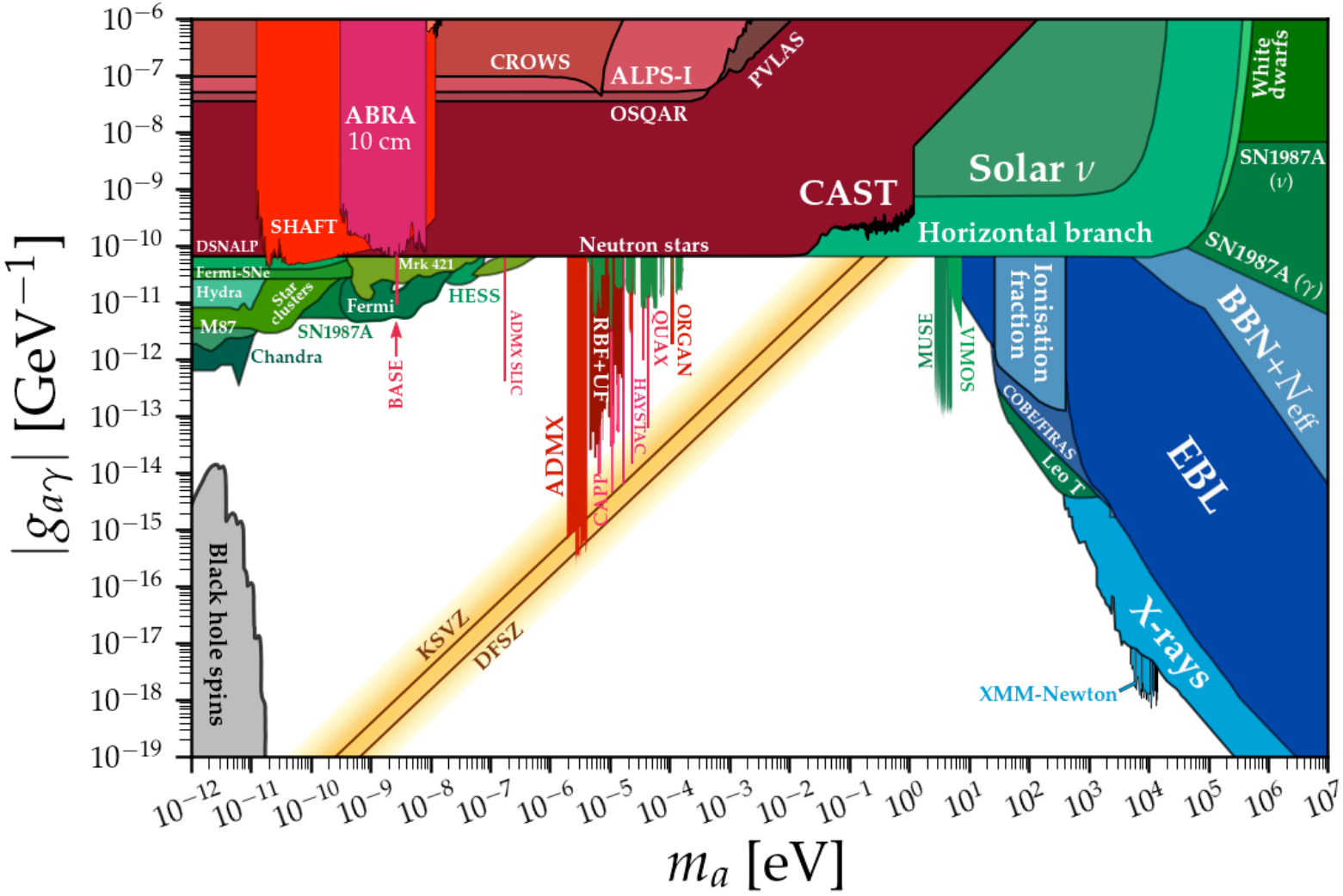
    - Josephson Junction results
    - High mass range relatively unexplored



From CA O'Hare's Axion Limit Plotting Tool

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    - Phase 1 - targeted 1 GHz scans ~month(s) scale
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- Some auxiliary experiments

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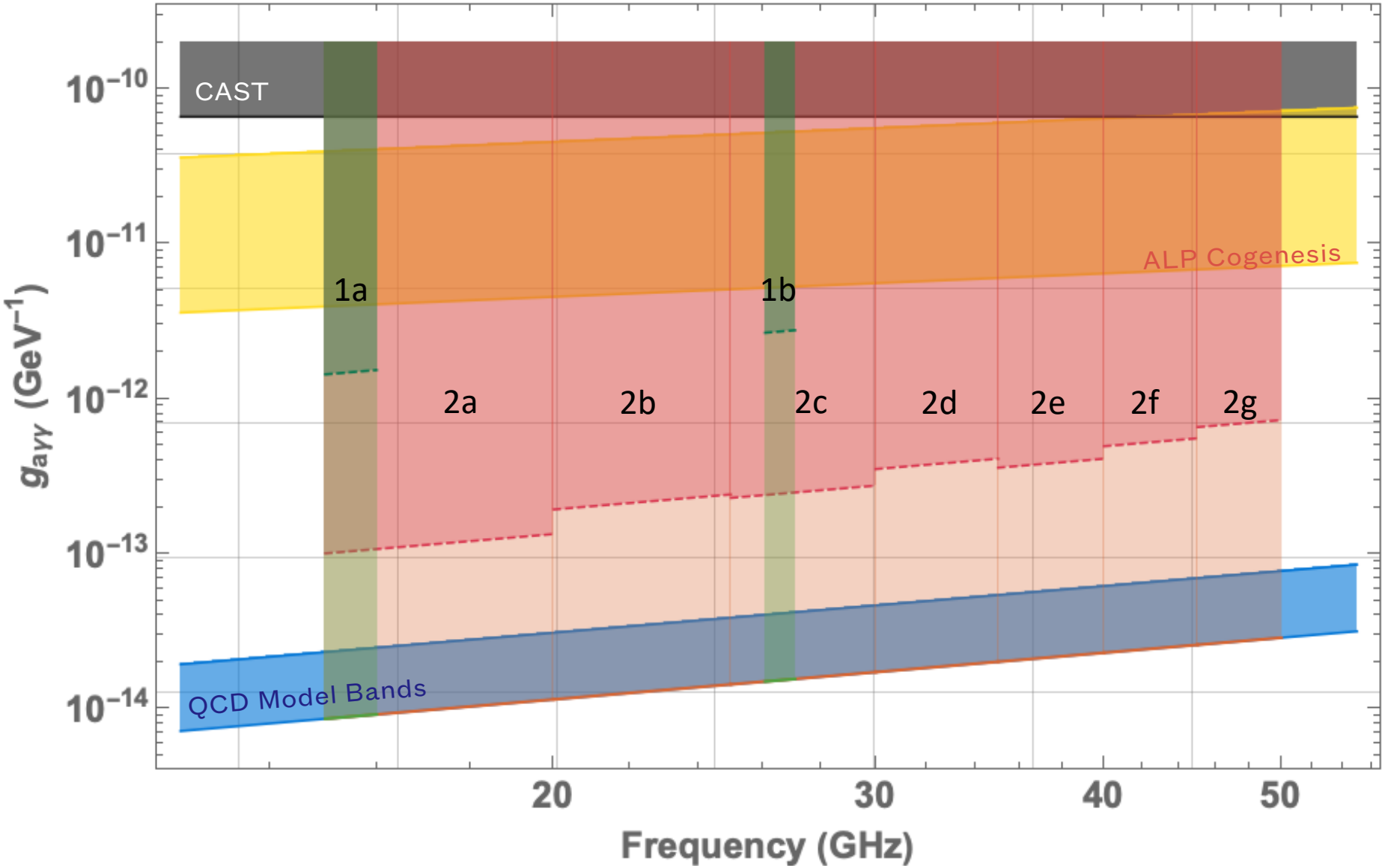
  - Low noise amplification/photon counting readout
  - Data acquisition and analysis

Run Plan



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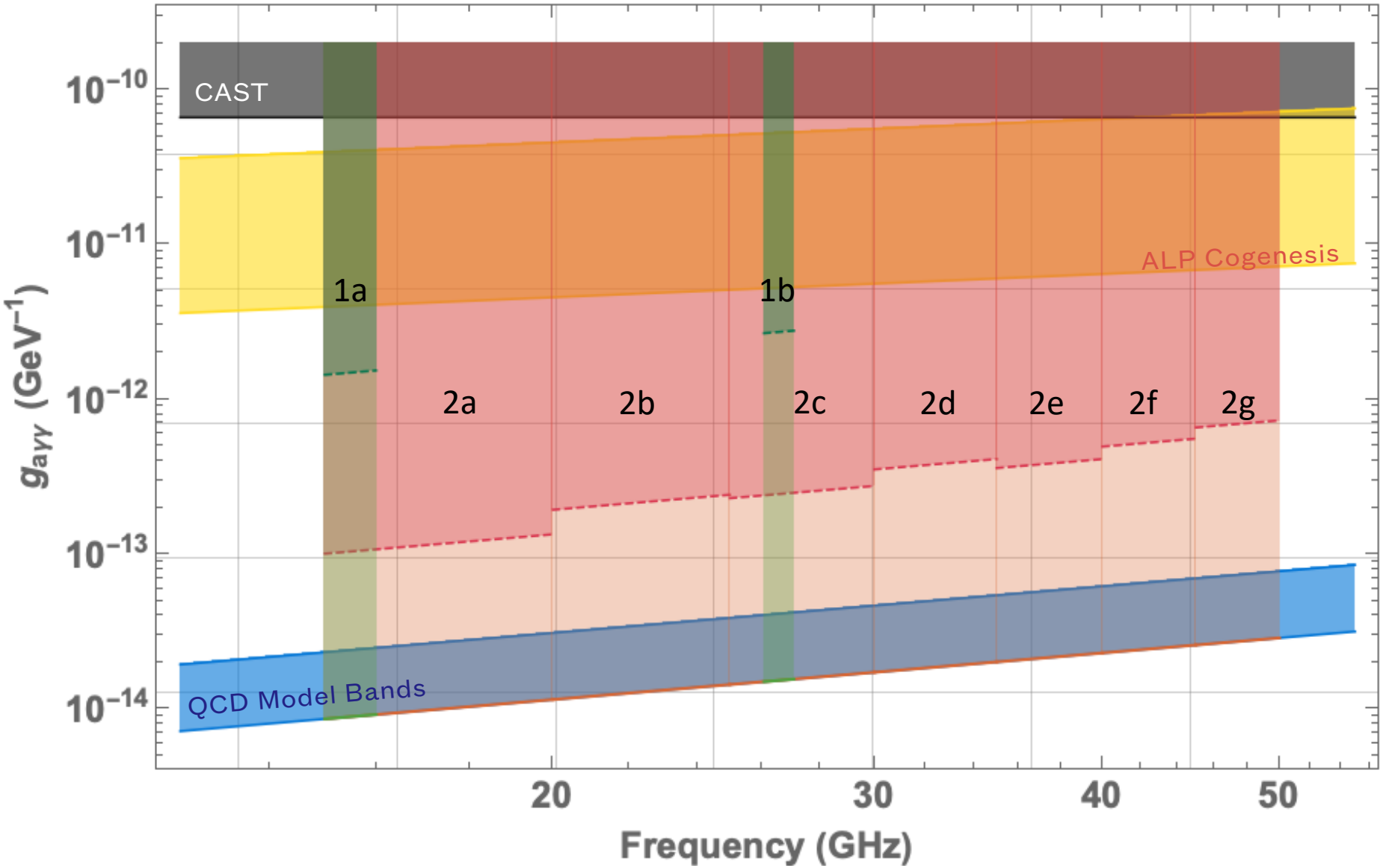

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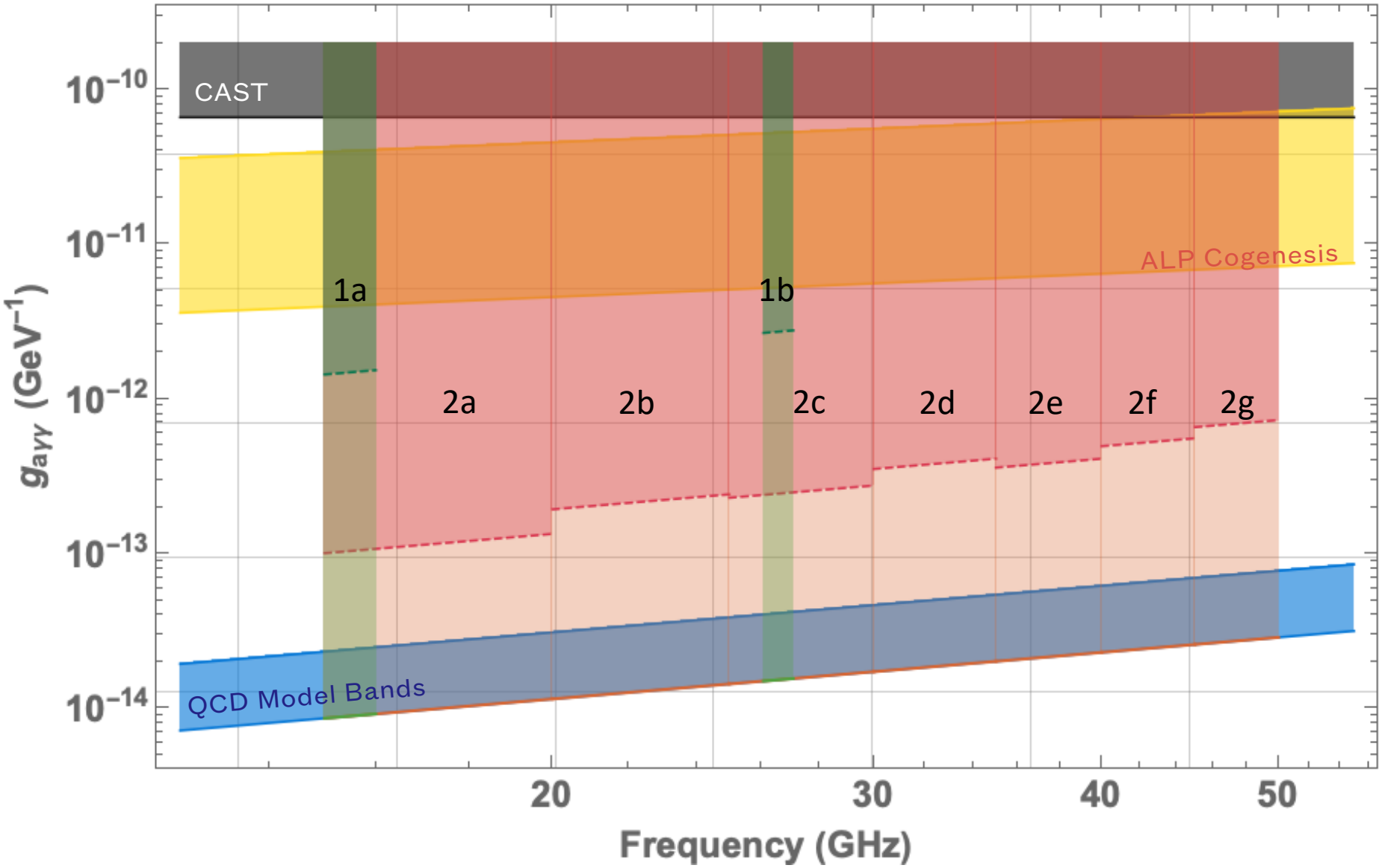

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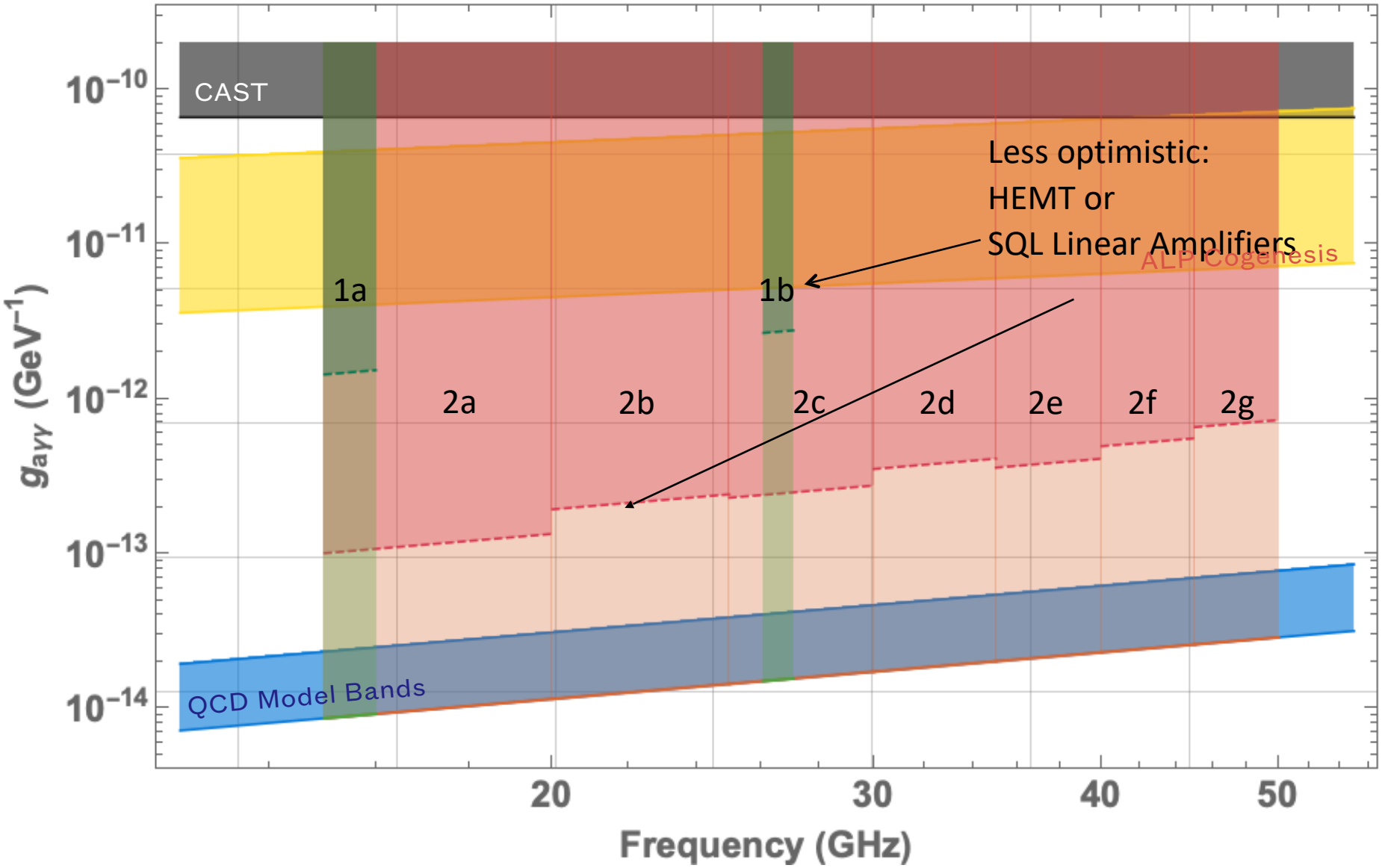

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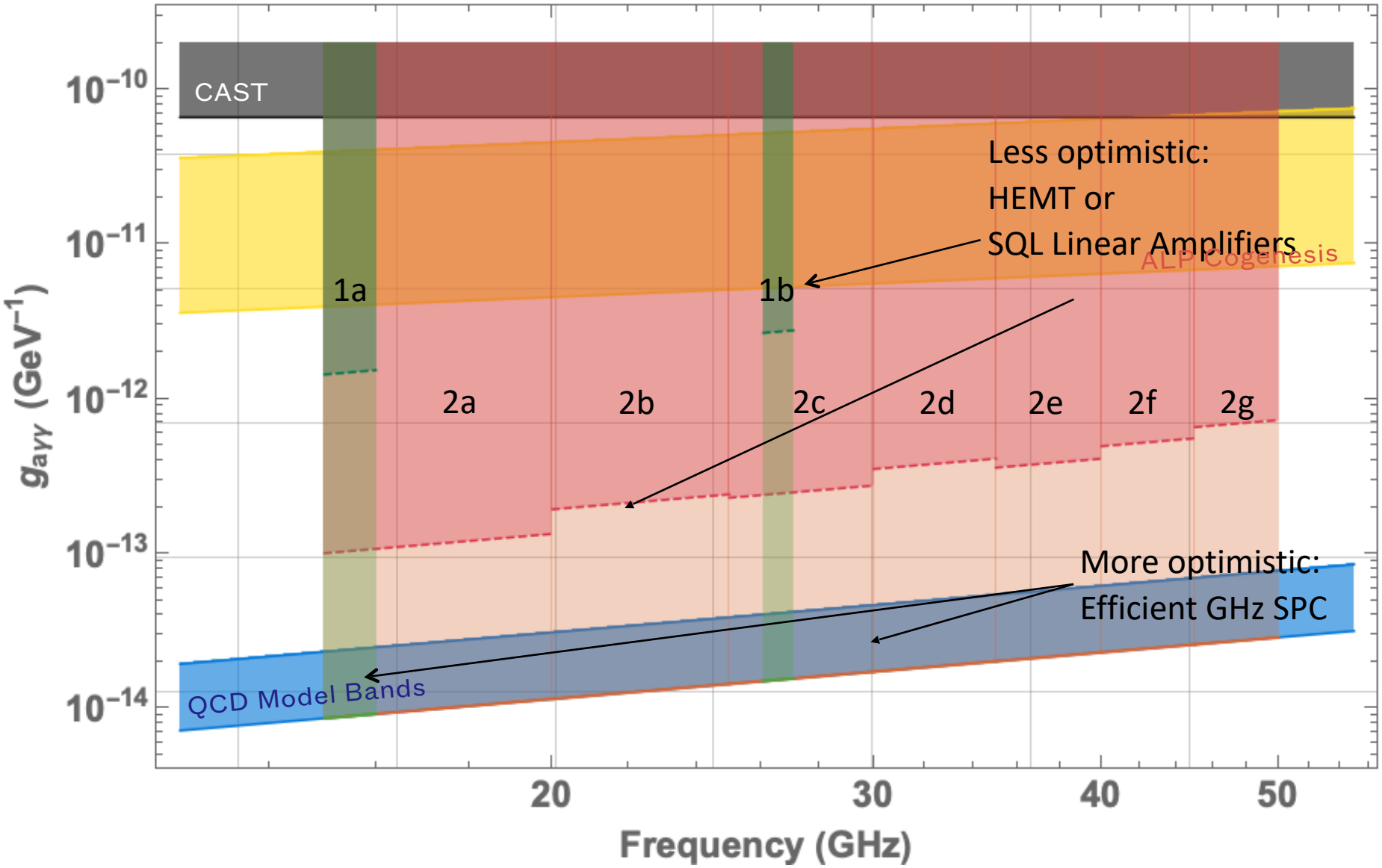

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Phase 1a

- Targeted scan around 15 GHz
- Commenced in 2021, now complete

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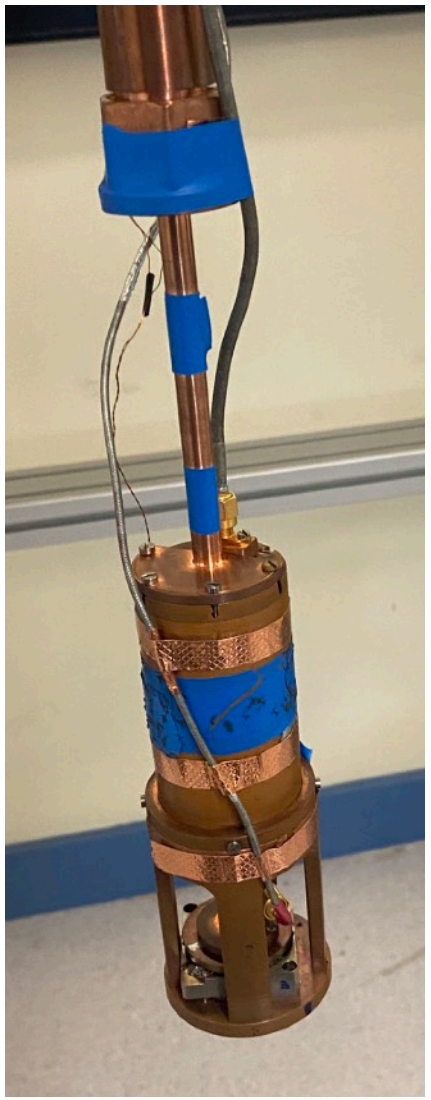

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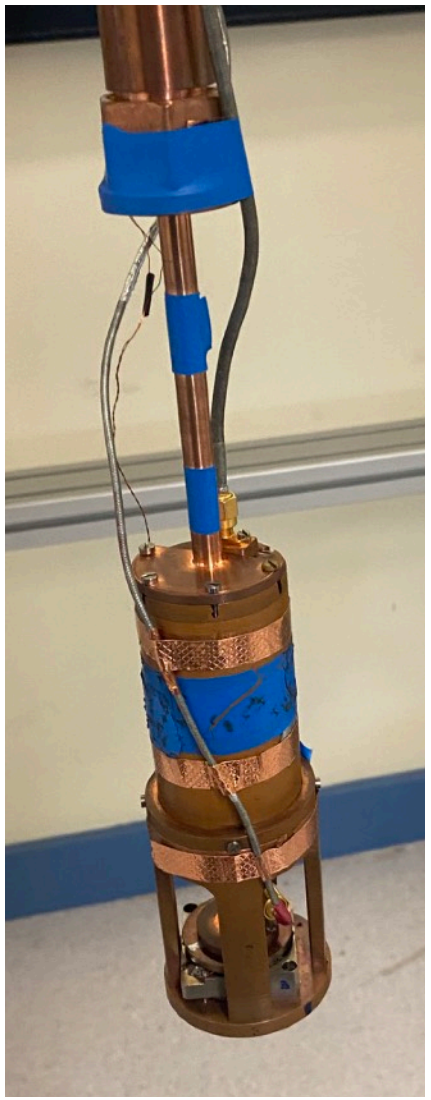
- Zero-dead-time FFT on FPGA (from ANU)



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Phase 1a

- ~3.5 weeks of data
- ~600 cavity positions
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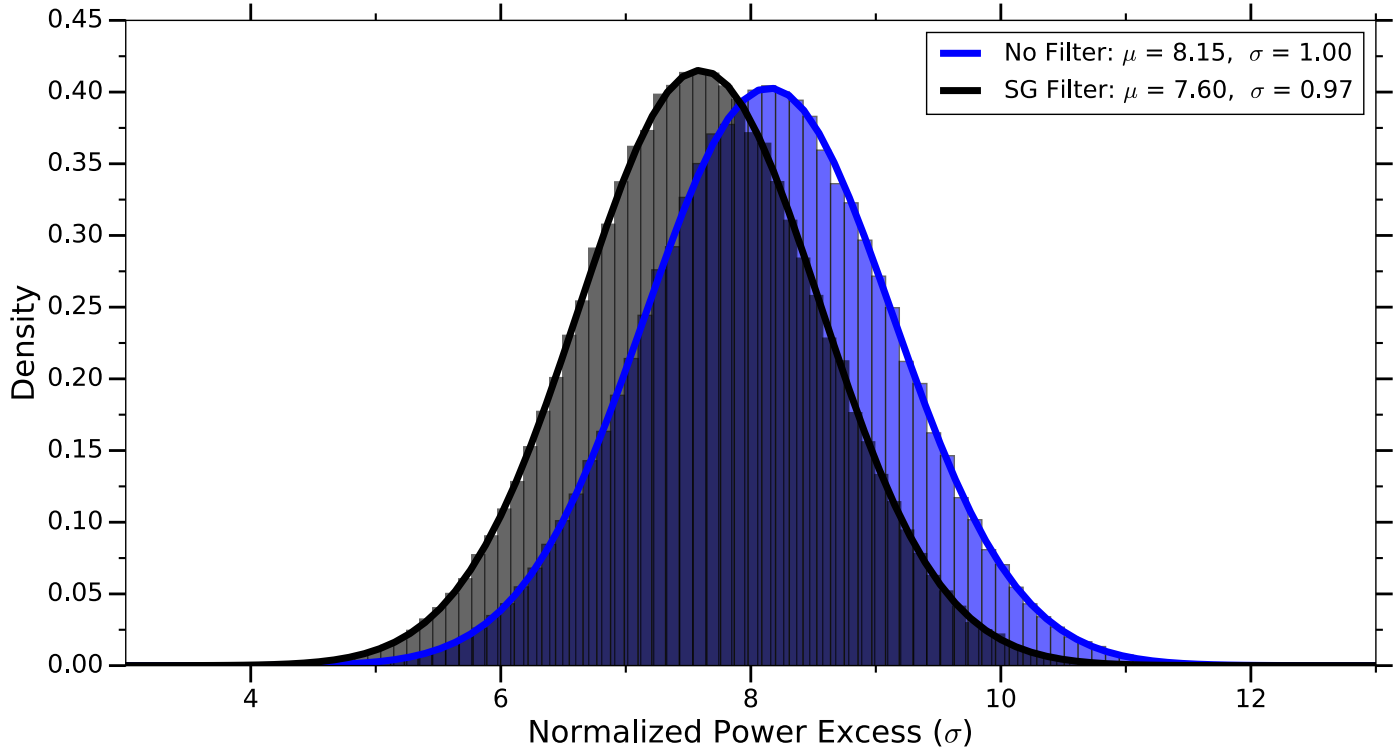

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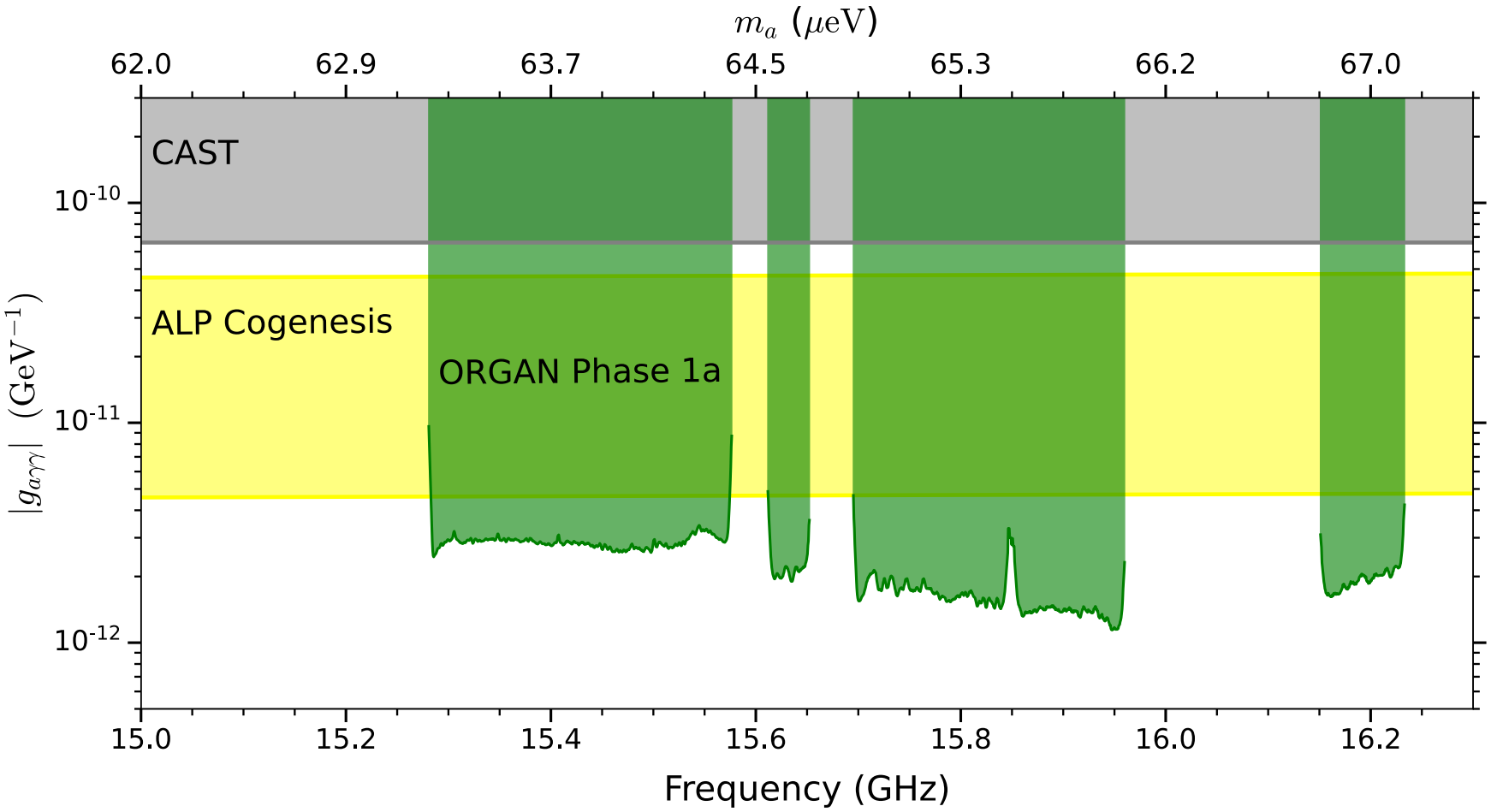

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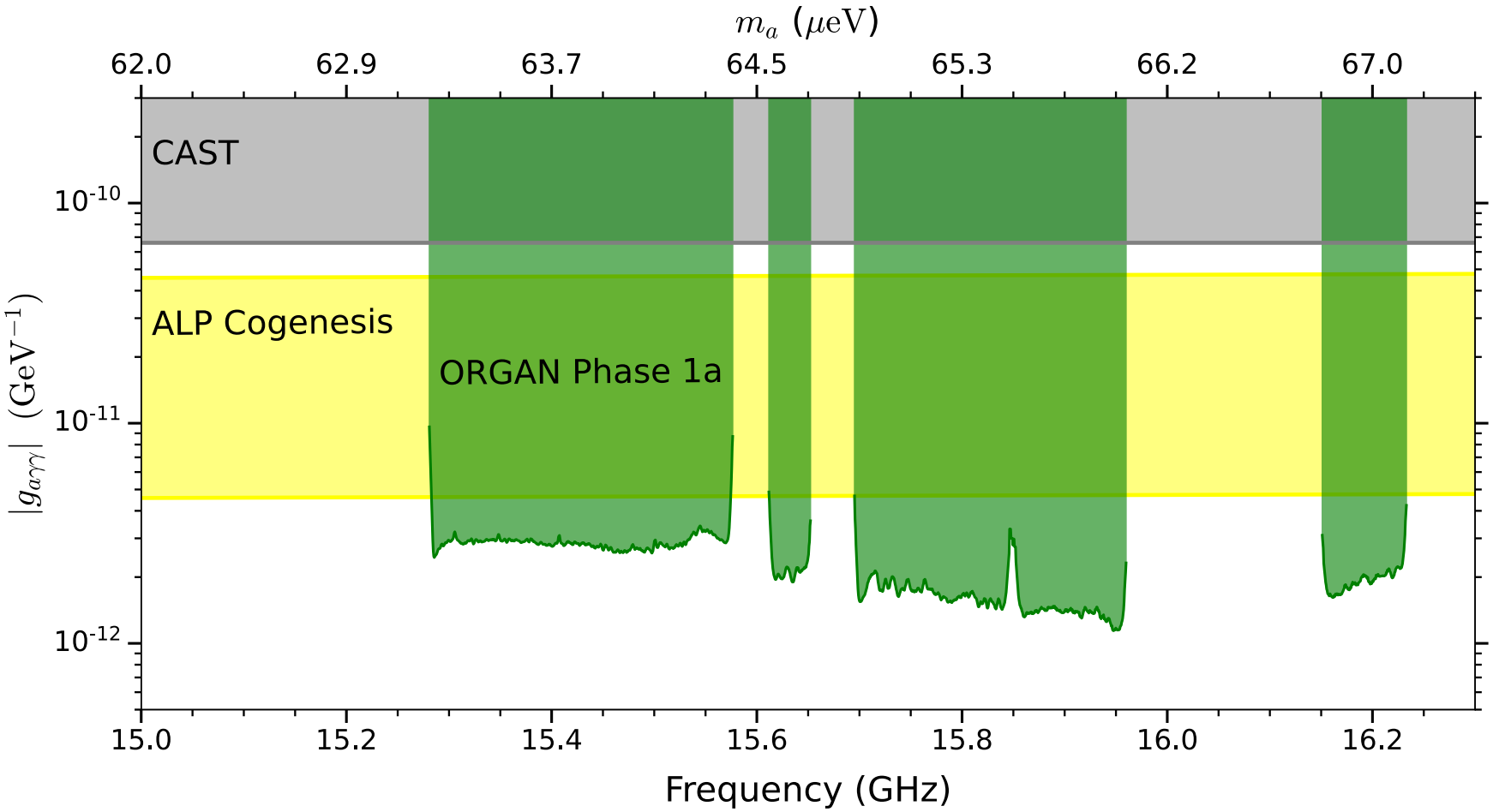
Phase 1a

- Gaps to be filled in future phases
- Better sensitivity



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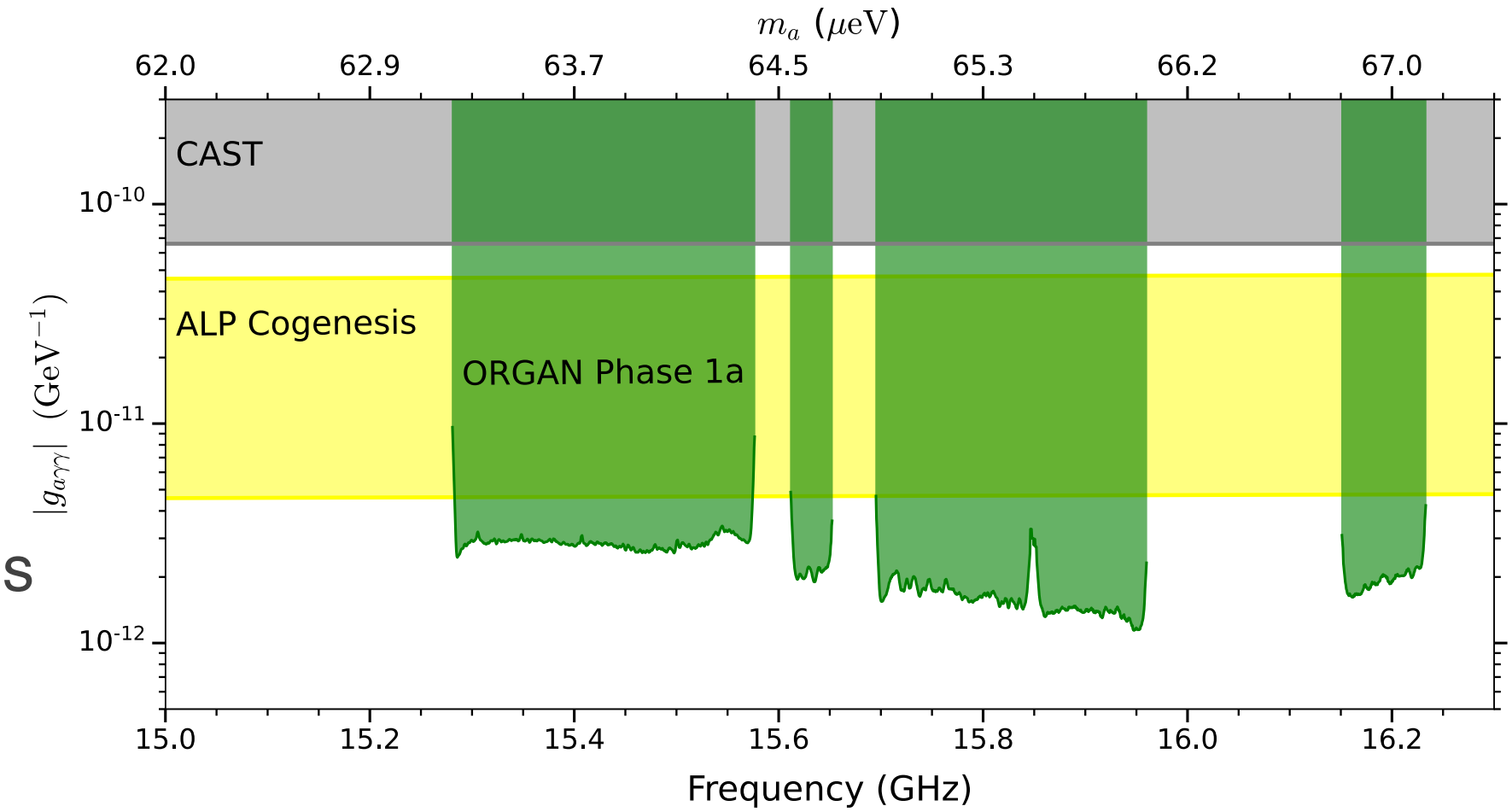
- Published now in Science Advances



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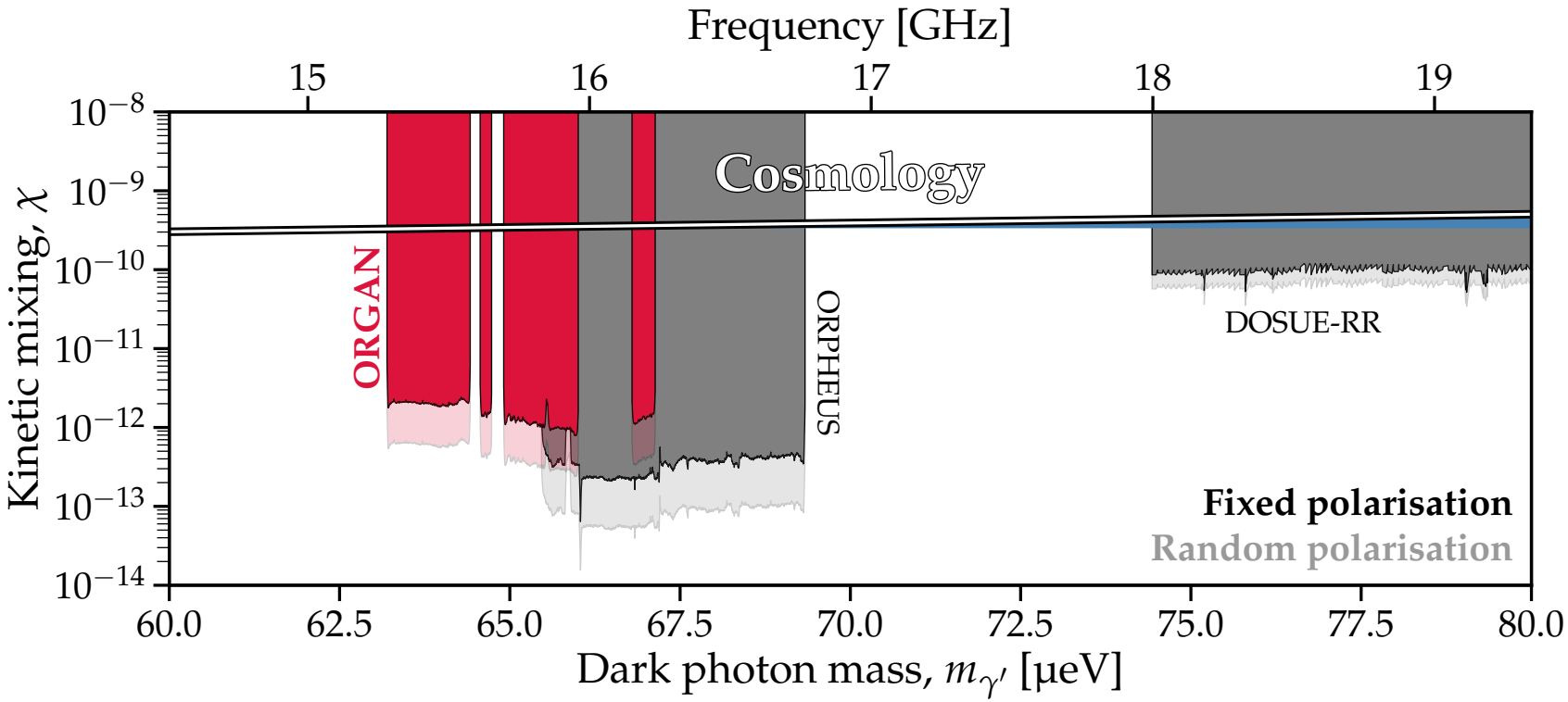
Phase 1a

- Also limits on dark photons and scalar dark matter (thanks Ciaran O'Hare



https://arxiv.org/abs/2212.01971

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- 26-27 GHz

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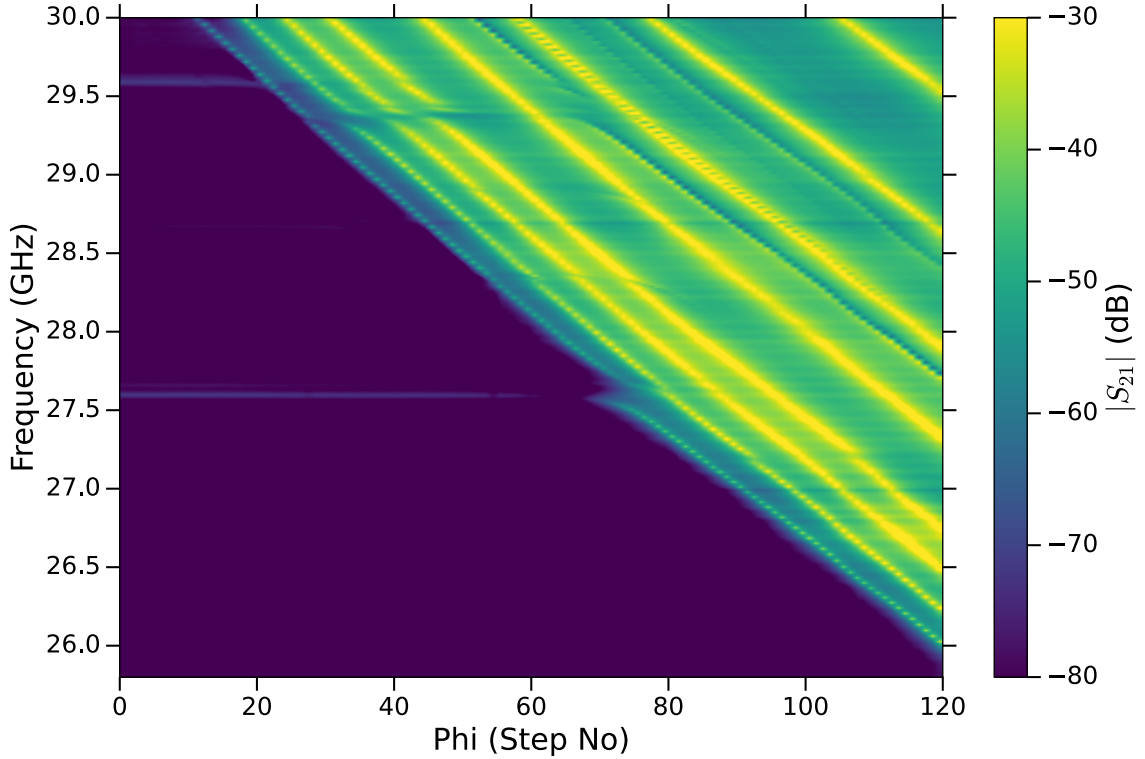

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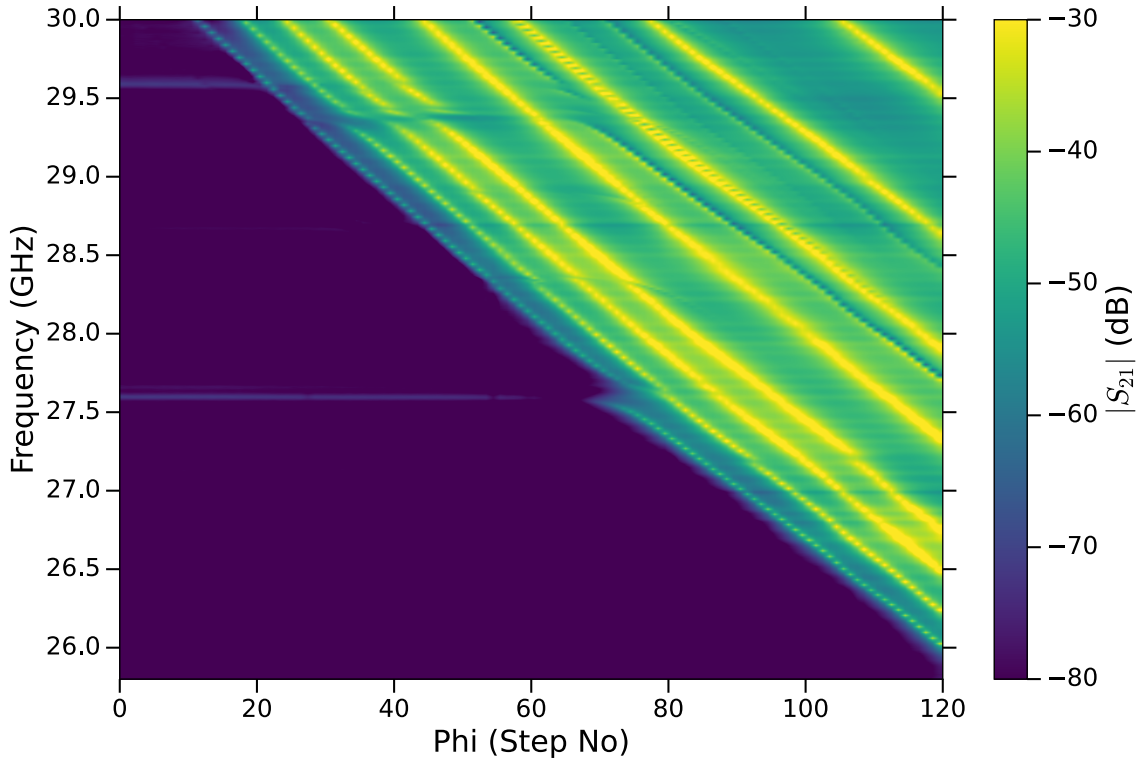

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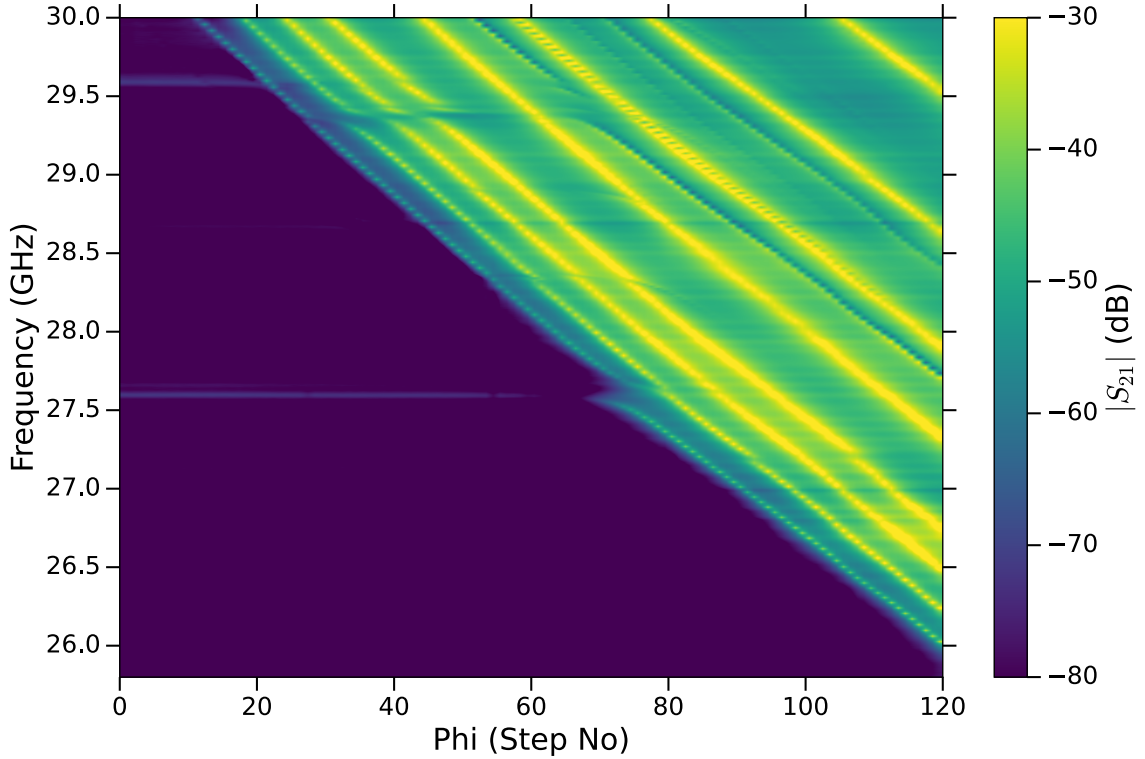
- Will investigate novel readout, superconducting coatings while we wait…



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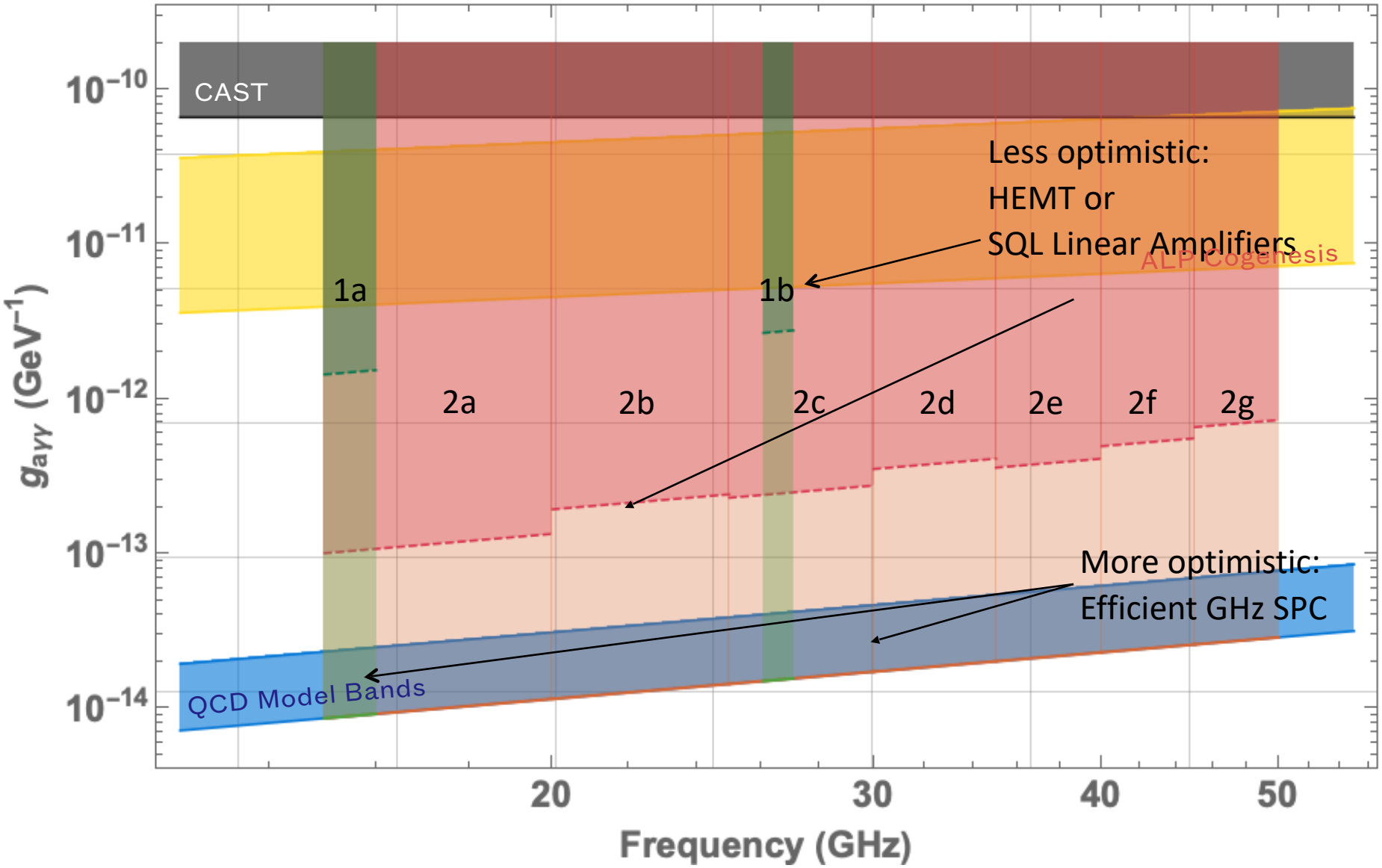

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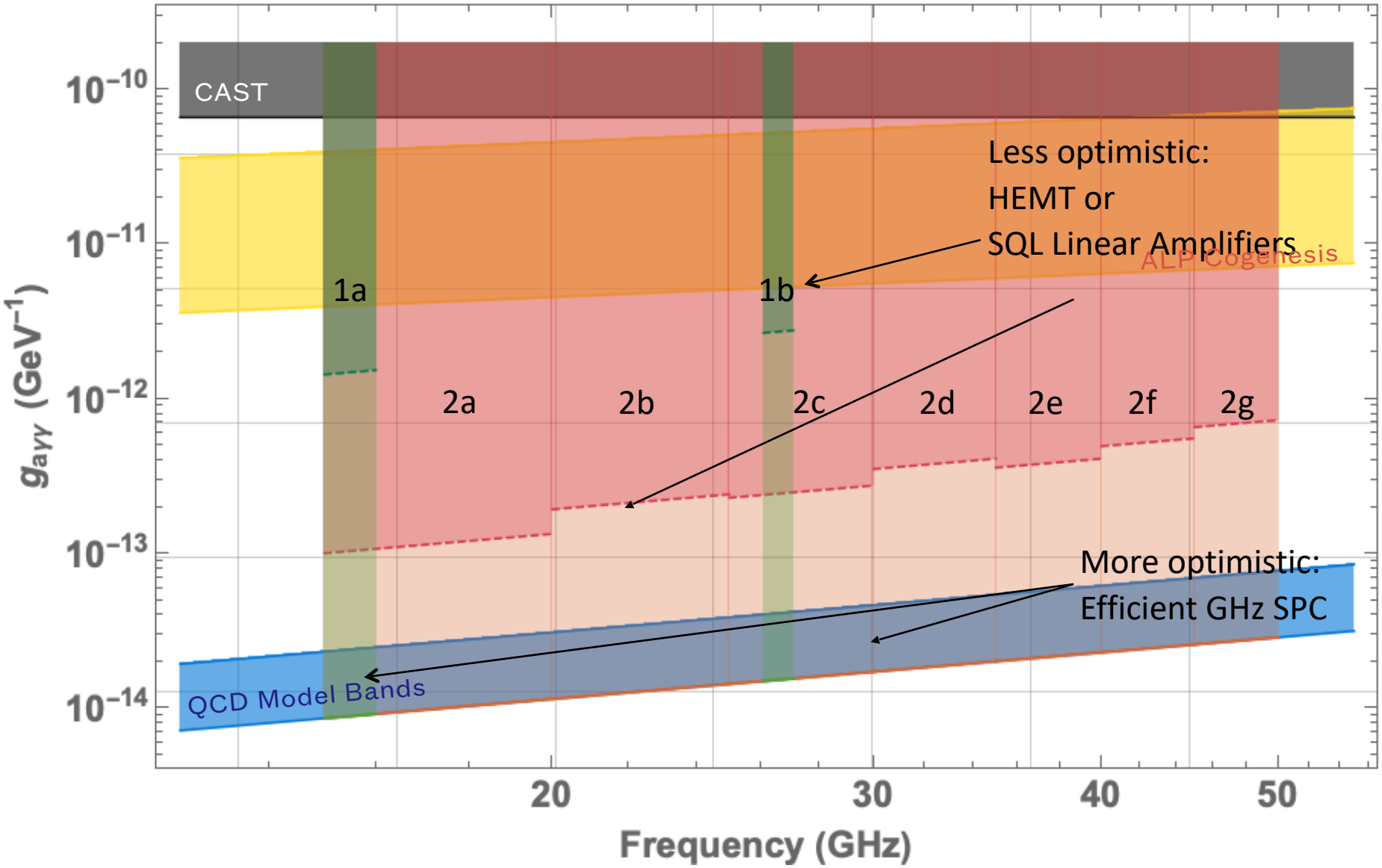

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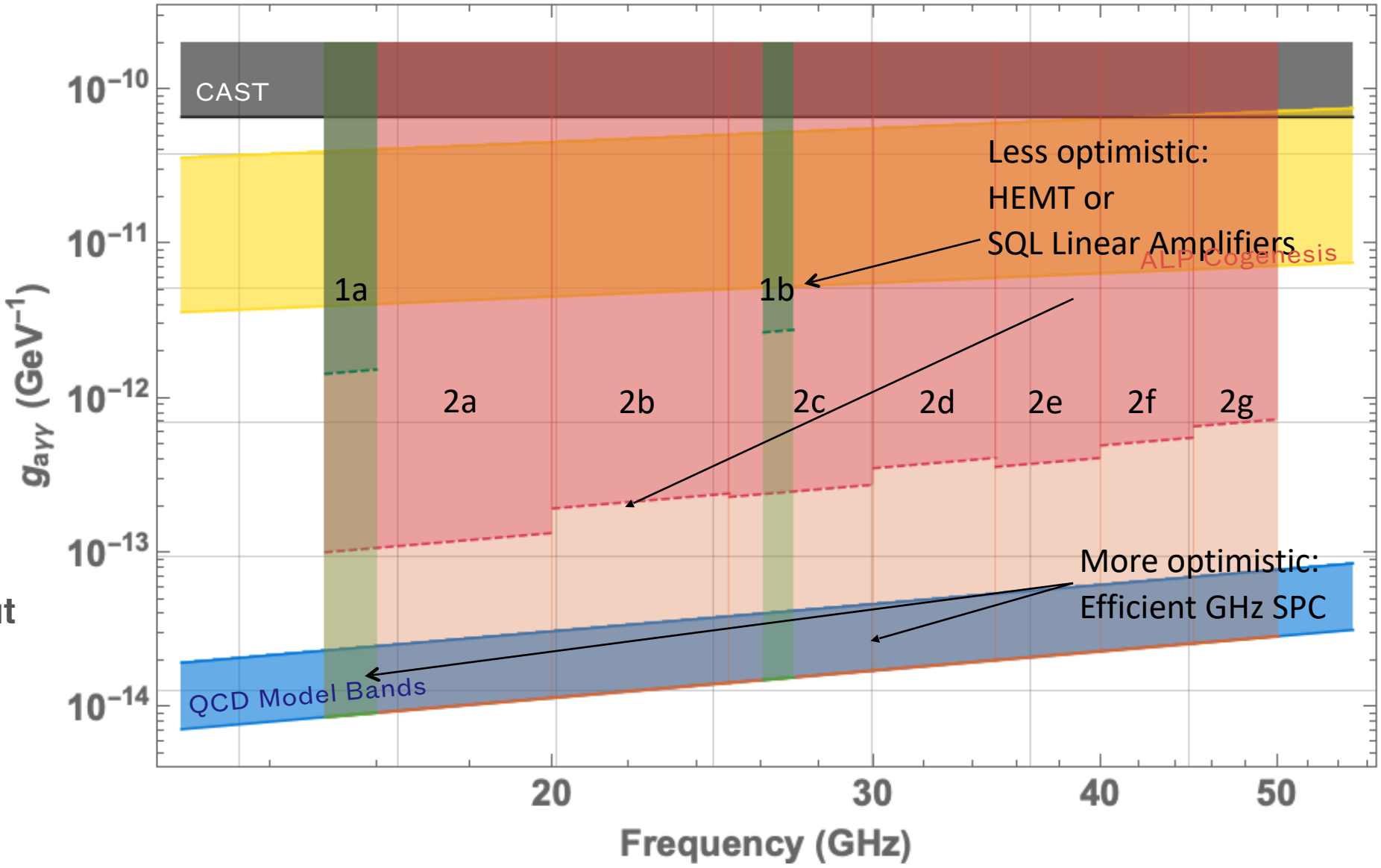

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R&D: Superconductors

- New collaborator within ORGAN
- Swinburne University of Technology - nanofabrication capacity

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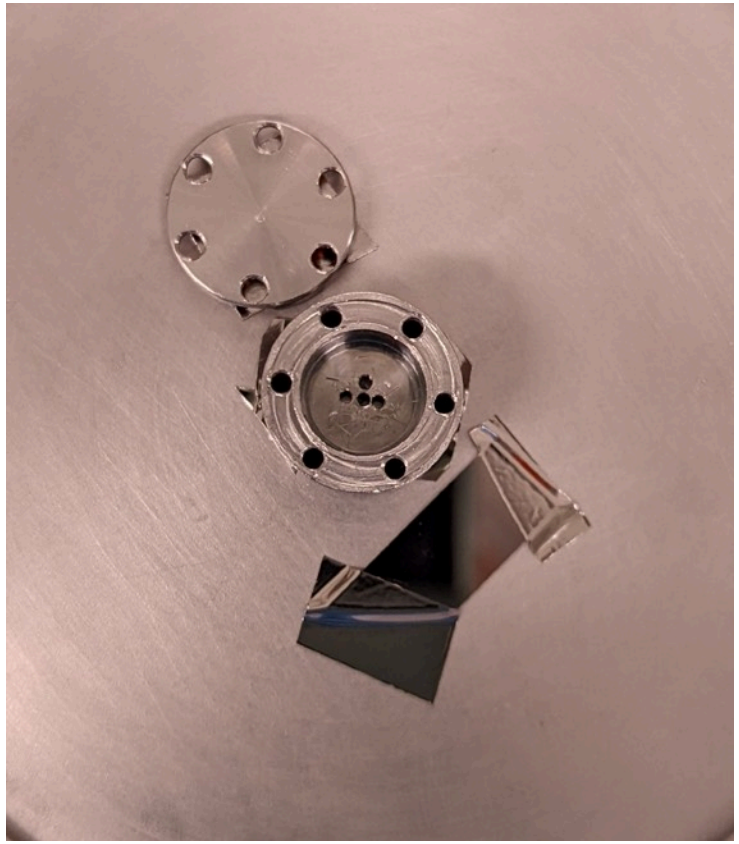

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- Single Photon Detection is superior to SQL linear amplification under the right conditions
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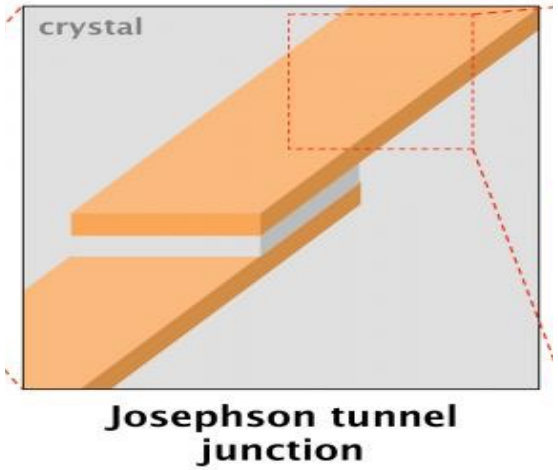
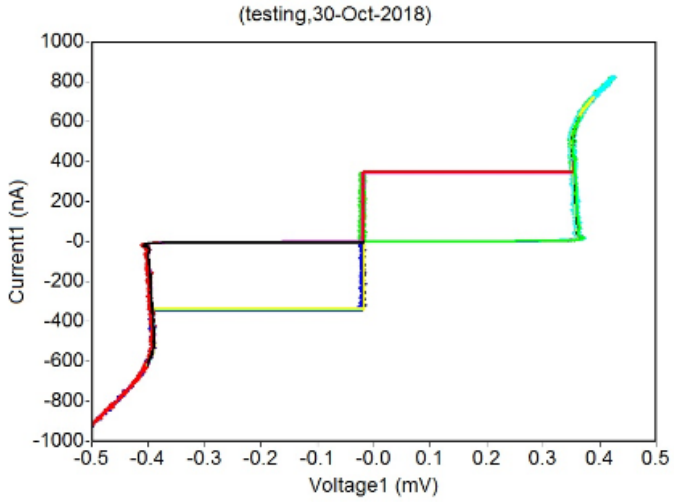
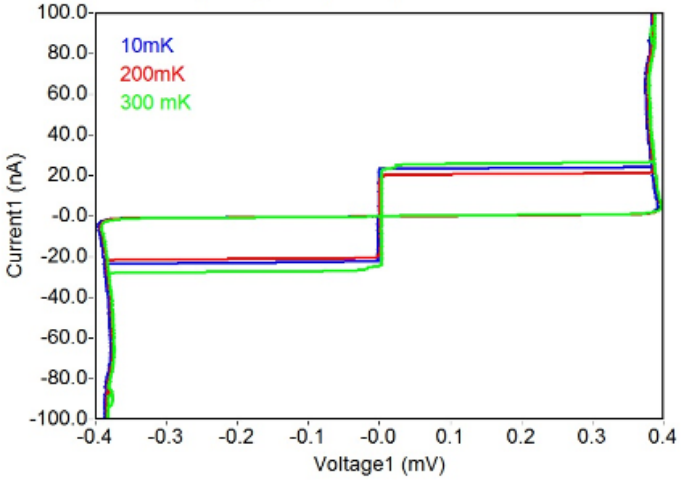
- For above parameters, with efficiency of 0.9: SQL about 50 times noisier
- Not a lot of options for GHz SPCs…but a few!

SIS Josephson Junctions

- Layer of superconductor – insulator – superconductor
- Exhibits Josephson effect: supercurrent across junction until critical current reached -> becomes resistive







L. S. Kuzmin *et al.*, *IEEE Transactions on Applied Superconductivity*, 2018

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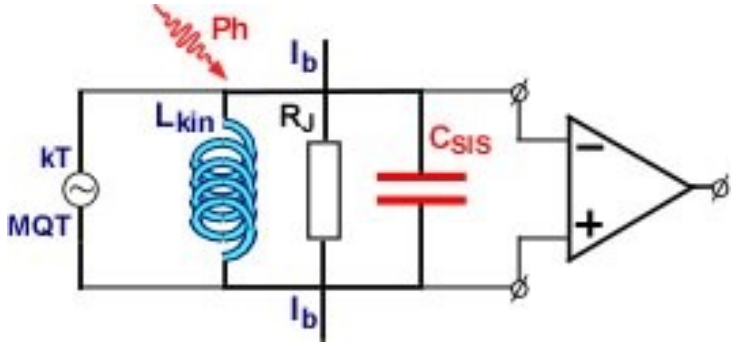
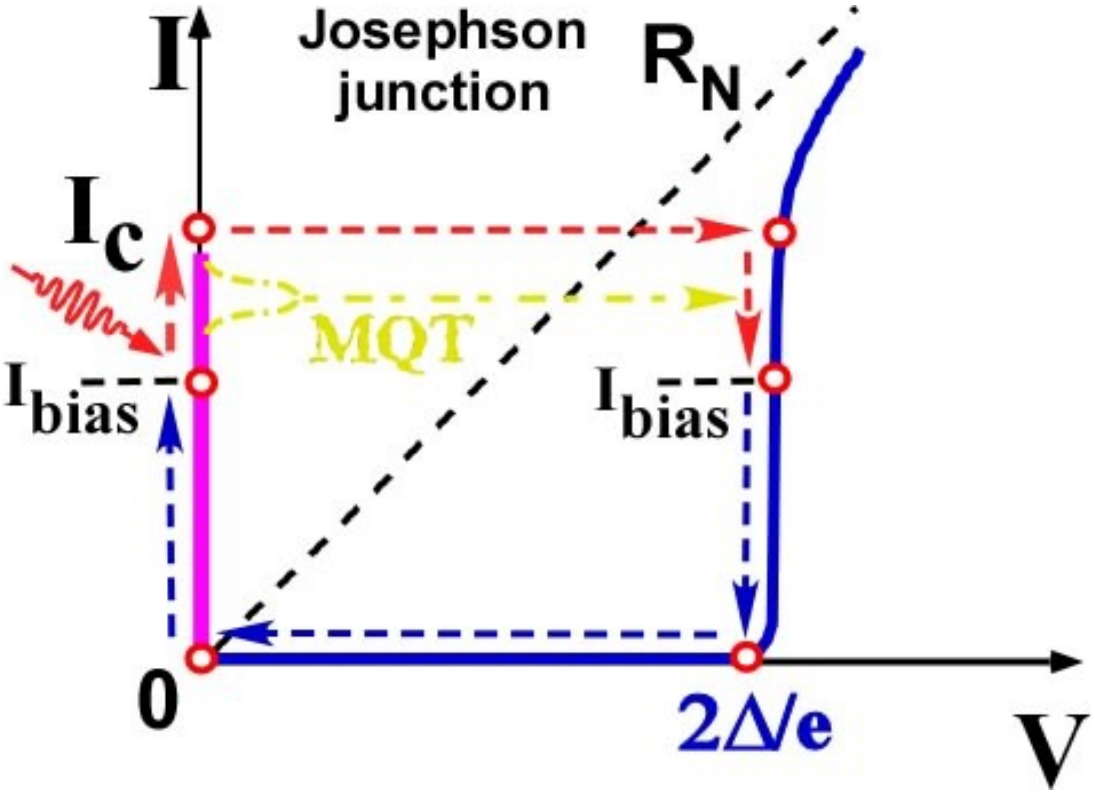
SIS Josephson Junctions

- Can be used as weak current sensor in the GHz range...in principle
- 10s of μeV+ energy thresholds
- Gets easier at higher energy…





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SIS Josephson Junctions

- Some samples from Chalmers at UWA node under testing for axions
- One group reporting some good tentative results (0.3 efficiency)
- Can also make these at Swinburne!

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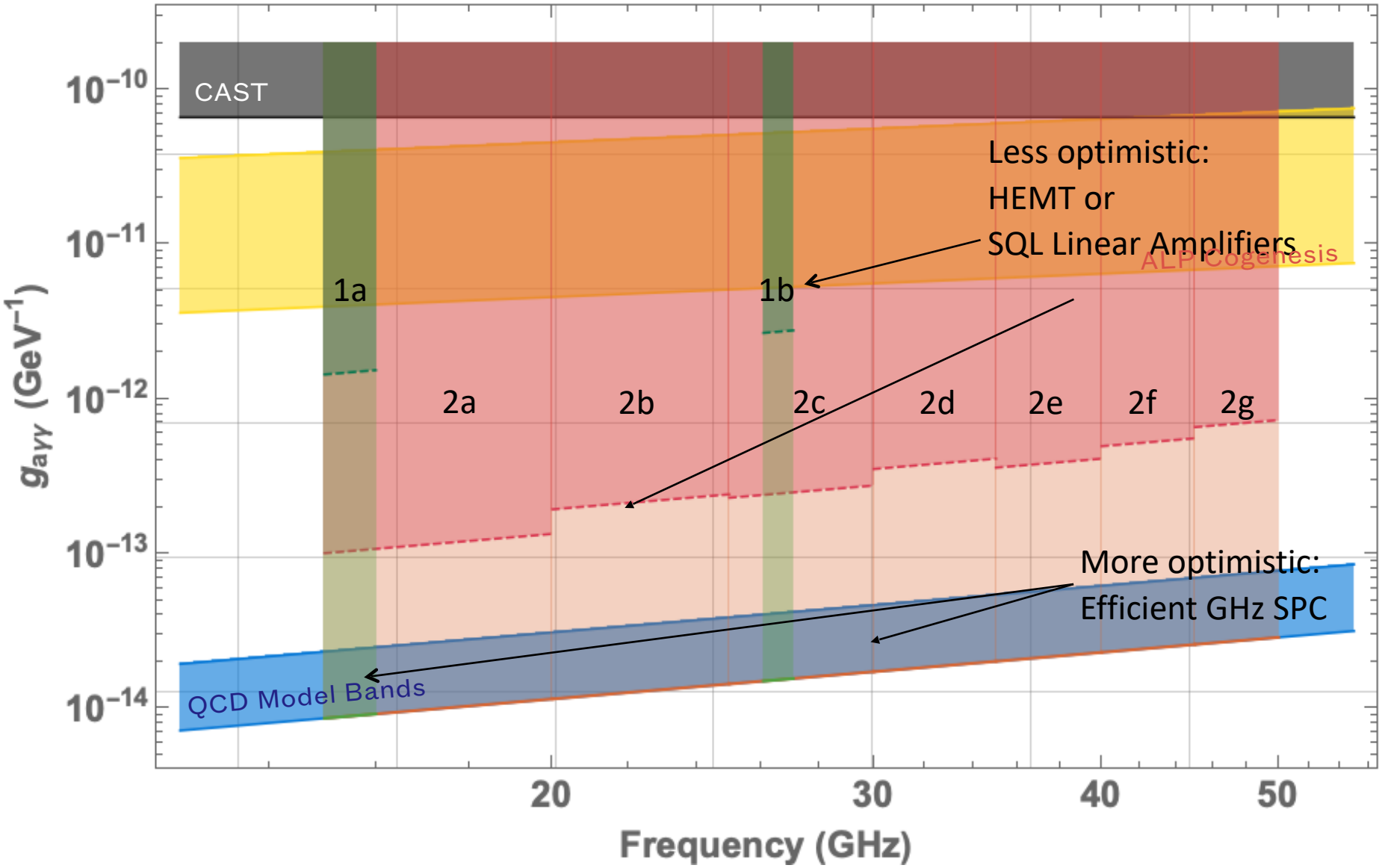

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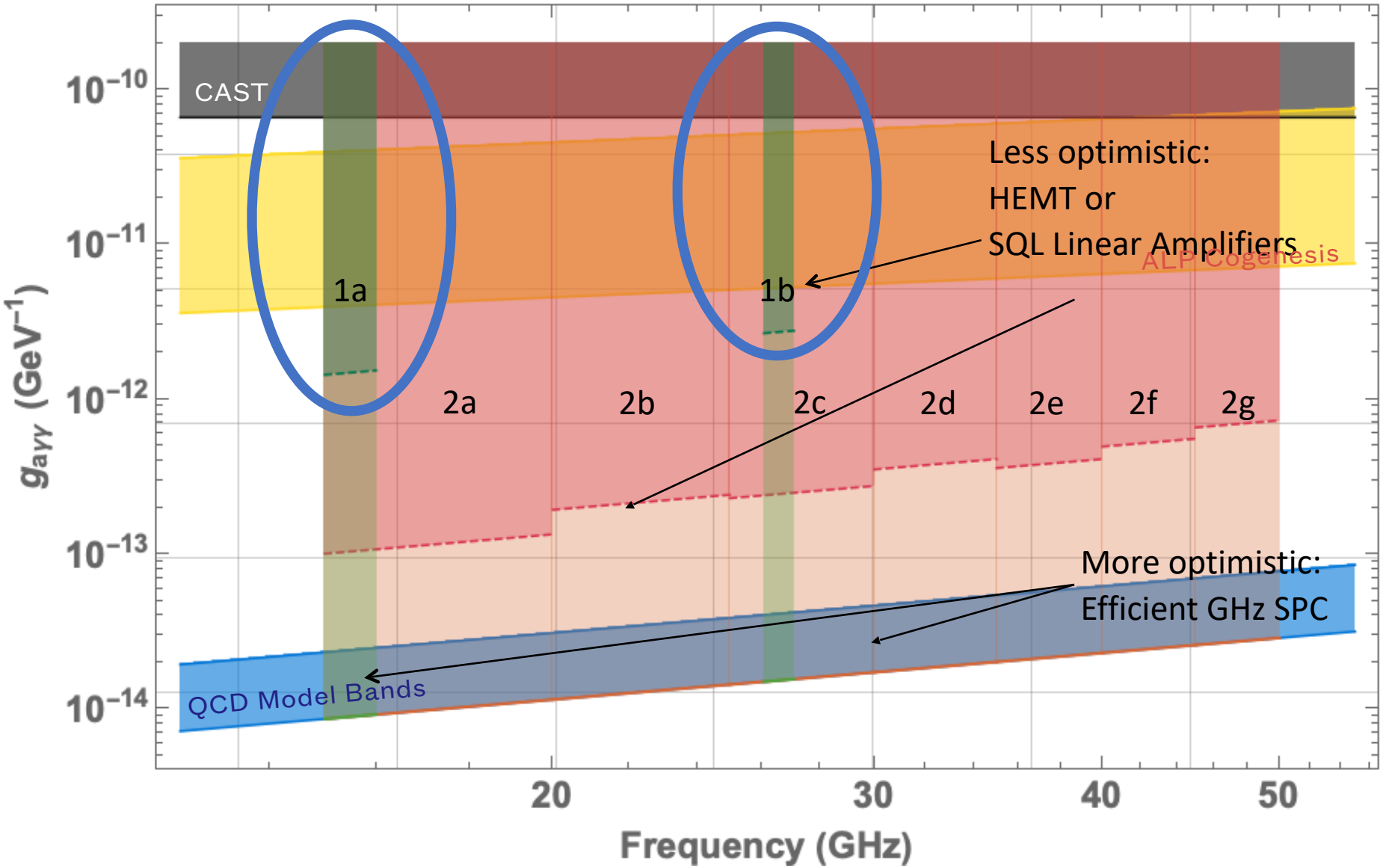

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    - Various mechanical/design feature improvements

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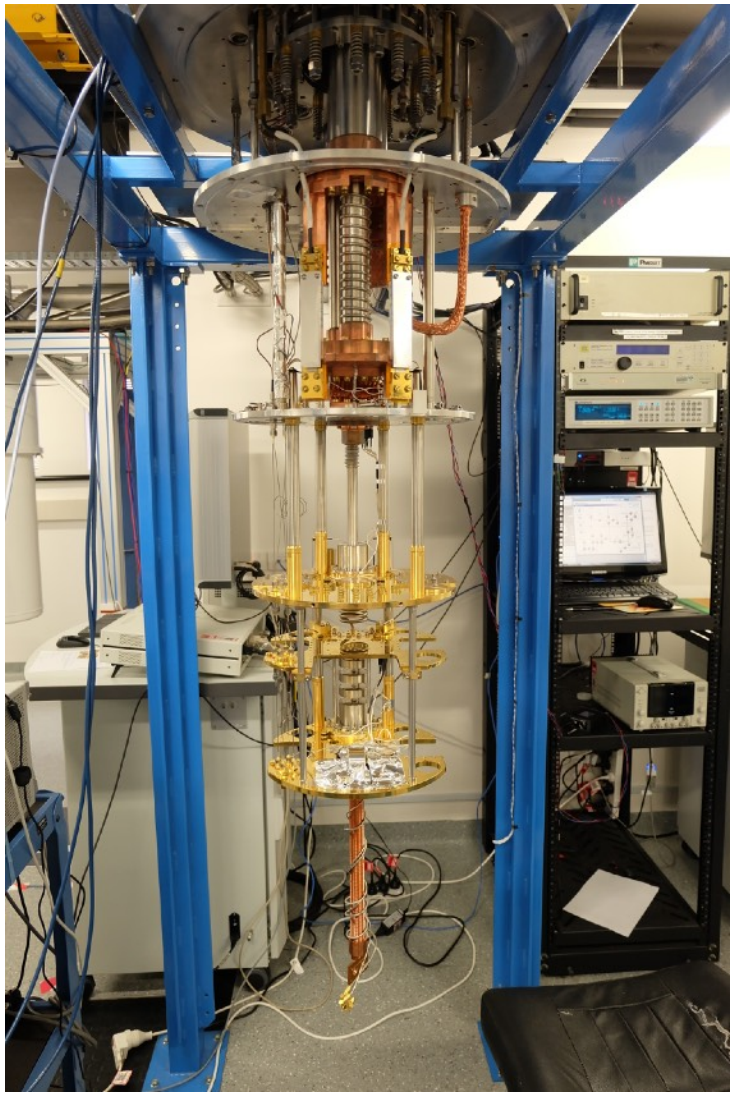
    - Various mechanical/design feature improvements
- Commence in 2023 in larger bore 7 T Magnet



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- Test transmission line and shielding options

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- 5-10 x KSVZ sensitivity
- Commencing 2023

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Conclusion

- ORGAN
  - High mass axion haloscope (15+ GHz)
- Run Plans
  - Phase 1a completed 2021/2022
  - Future phases commencing 2022/2023
  - Various avenues of R&D
- ORGAN-Q
  - Spin-off/testbed commencing 2023