ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

R&D on Cryogenic & Superconducting Detectors for Low Energy Events

Australian Government
Australian Research Council

THE UNIVERSITY of ADELAIDE

Australian National University

THE UNIVERSITY OF MELBOURNE

SWINBURNE

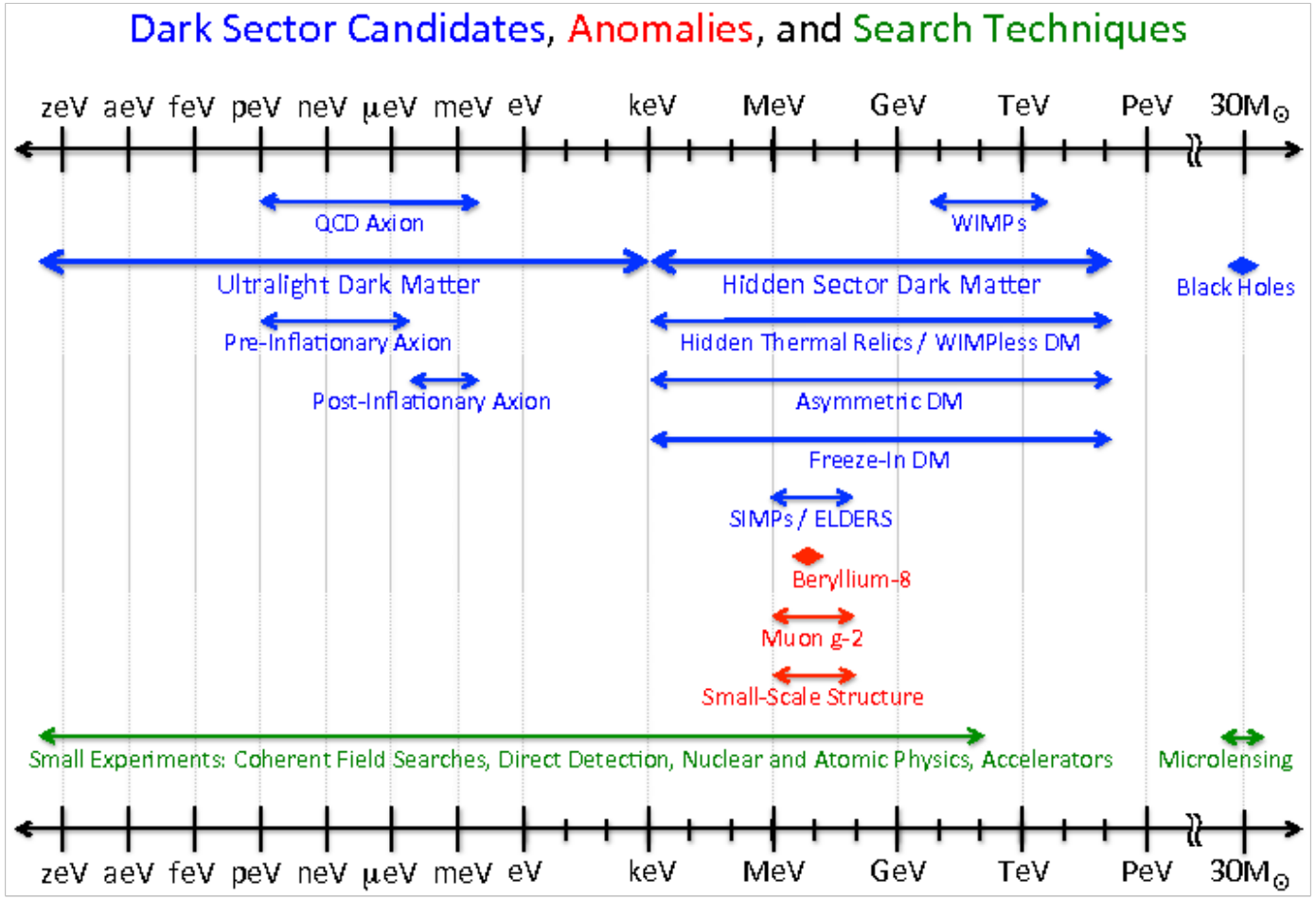
THE UNIVERSITY OF SYDNEY

THE UNIVERSITY OF WESTERN AUSTRALIA

Summary

- Dark matter candidates
- Axion detection
- WIMP detection
- Energy thresholds
- Current methods
- Some new detector ideas…

Dark Matter Candidates



https://arxiv.org/abs/1707.04591

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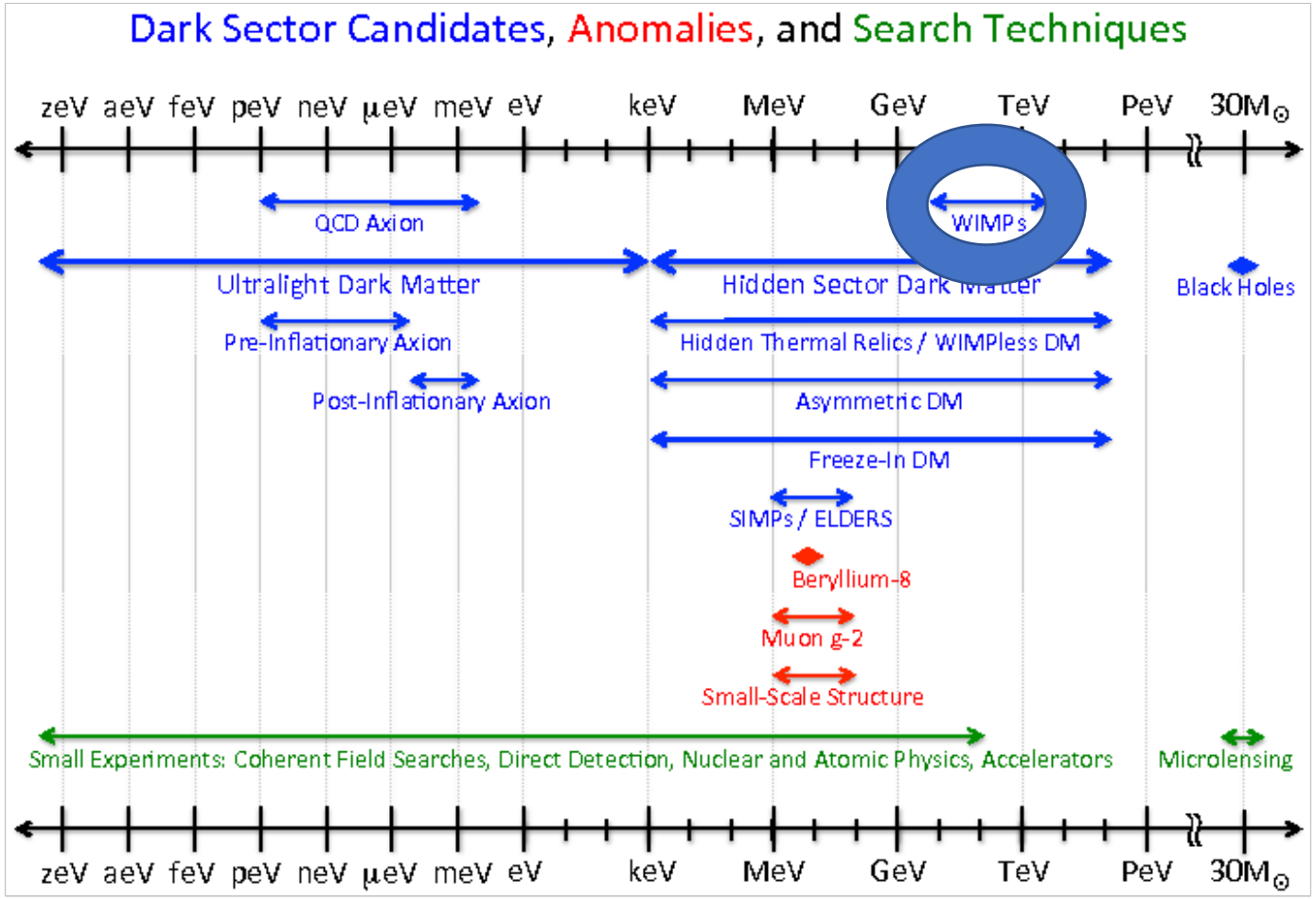

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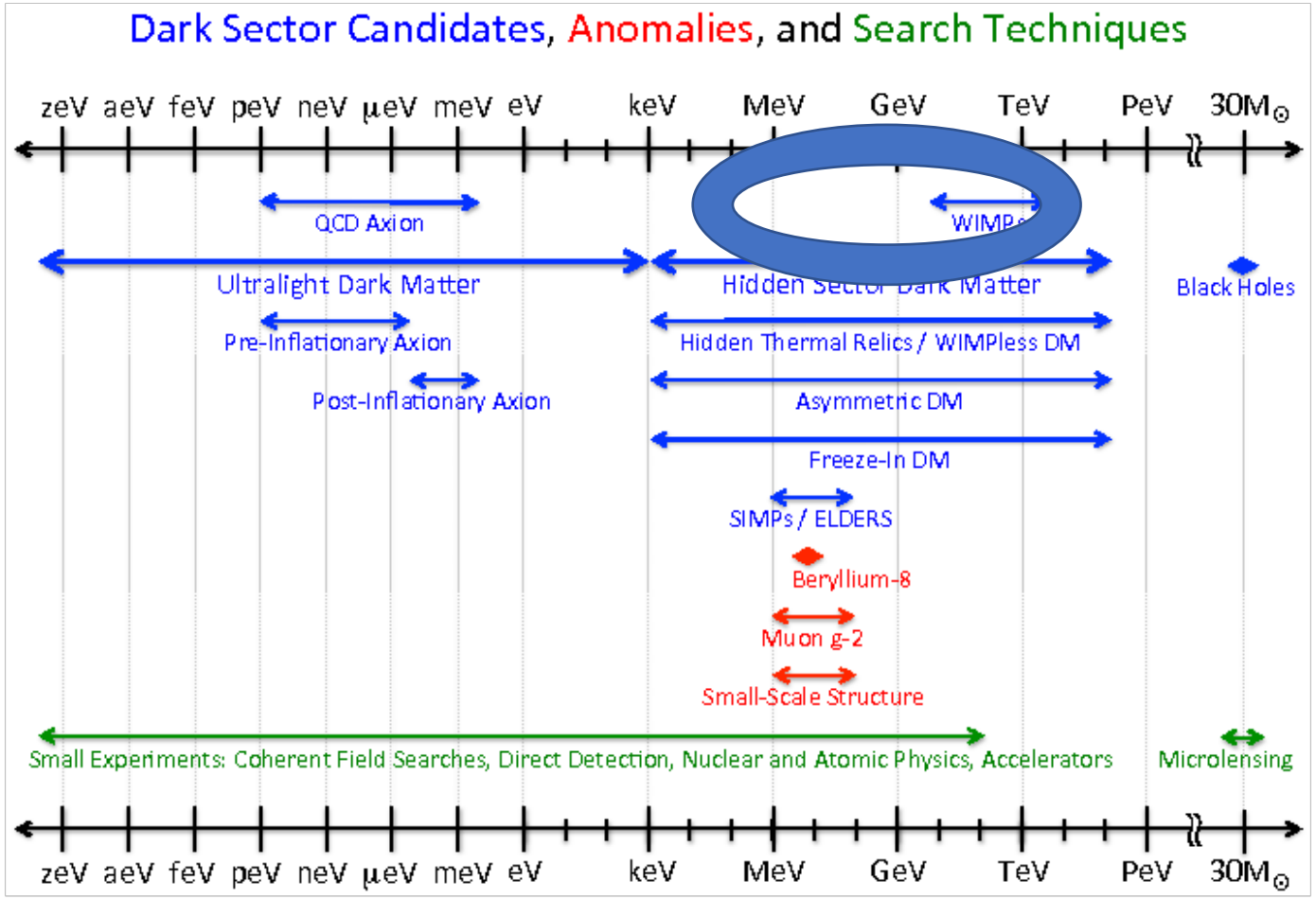

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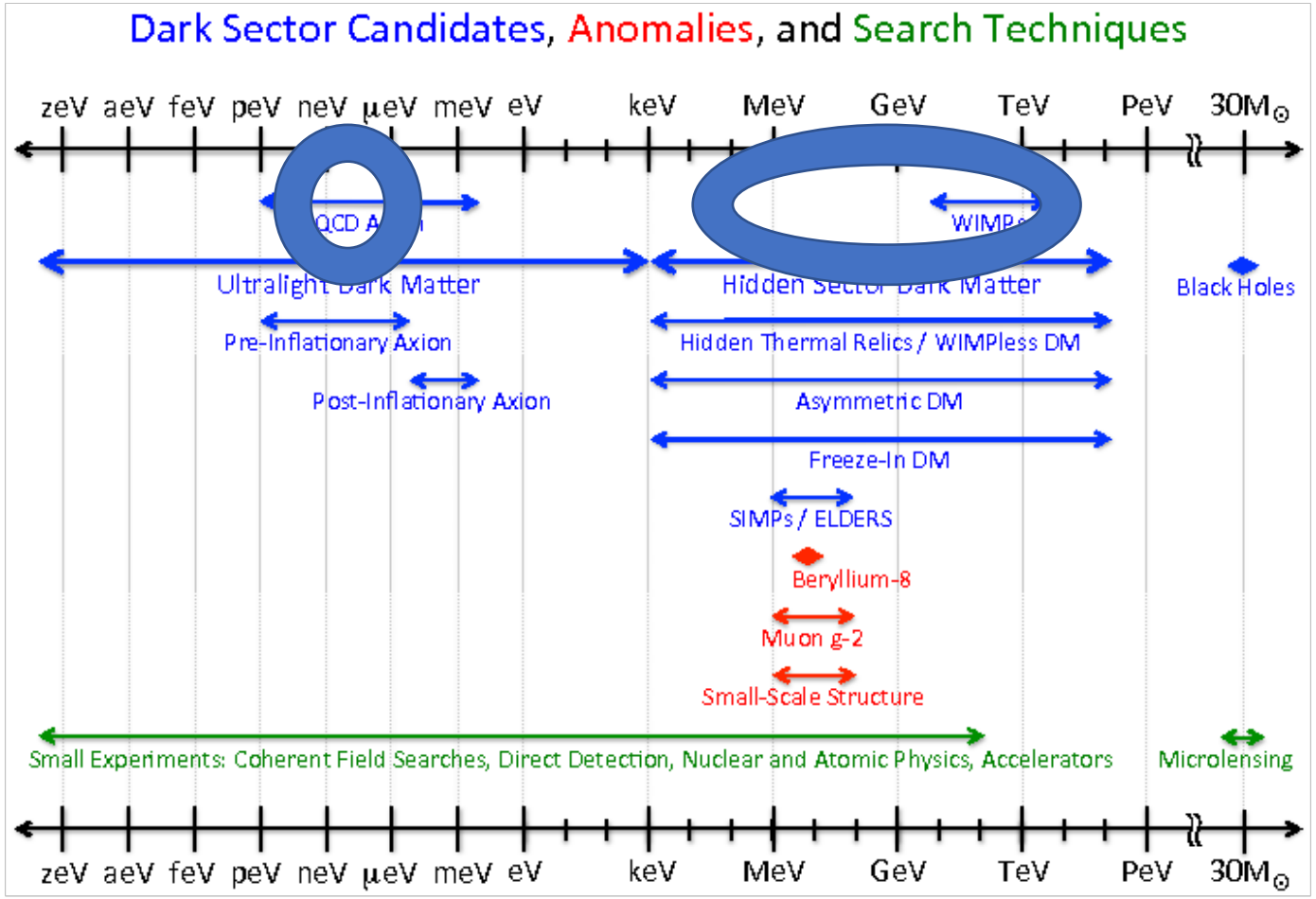

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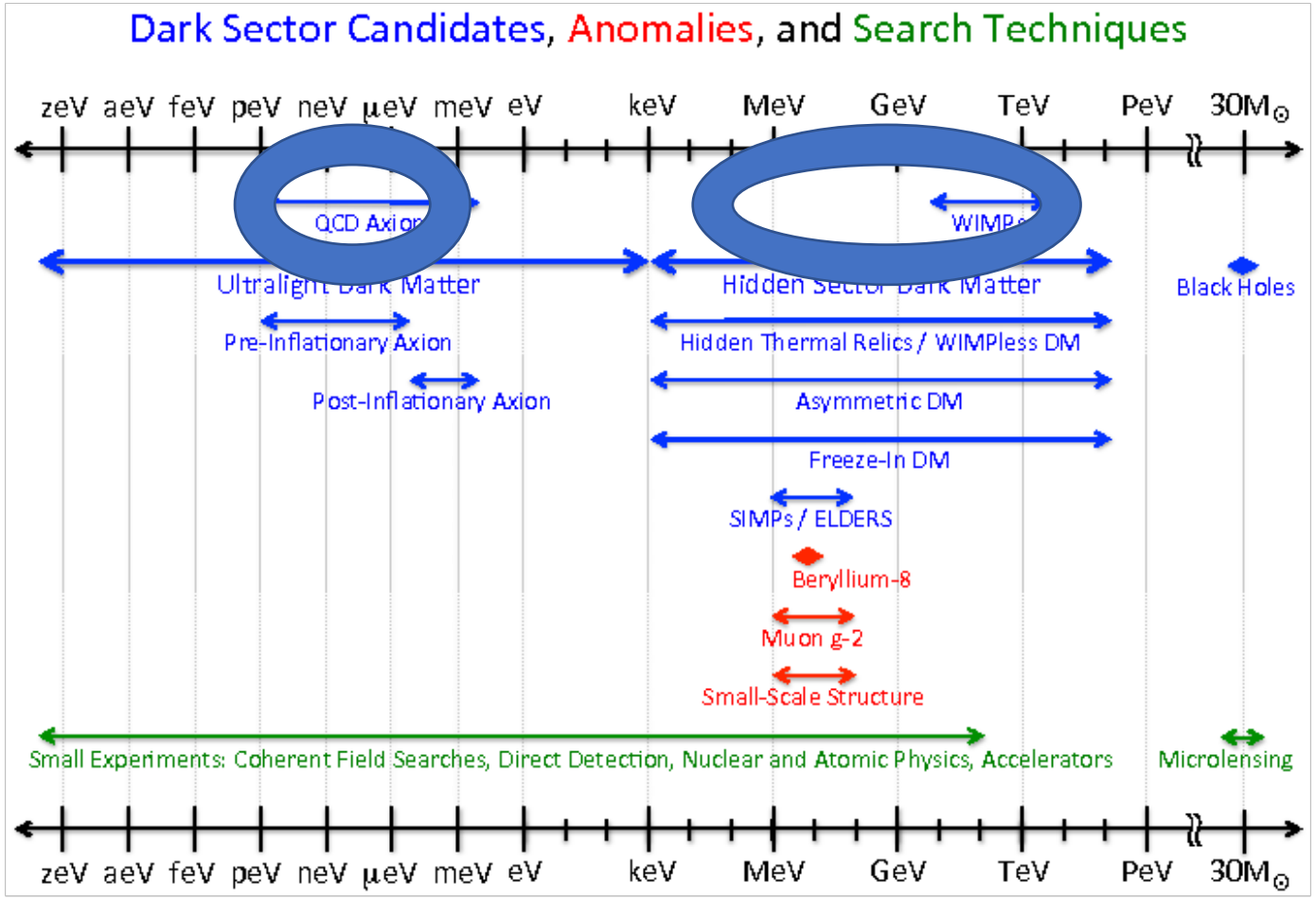

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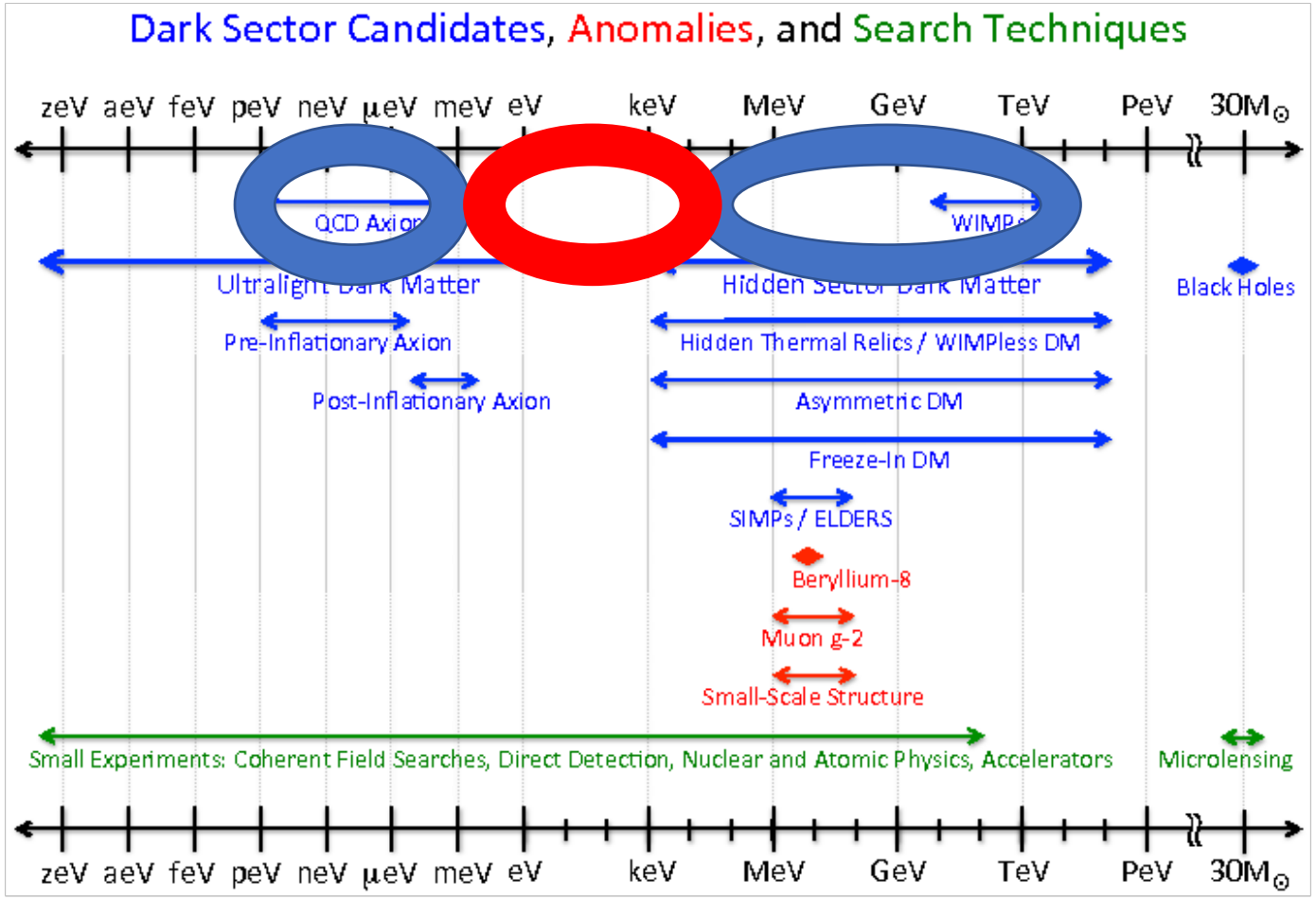

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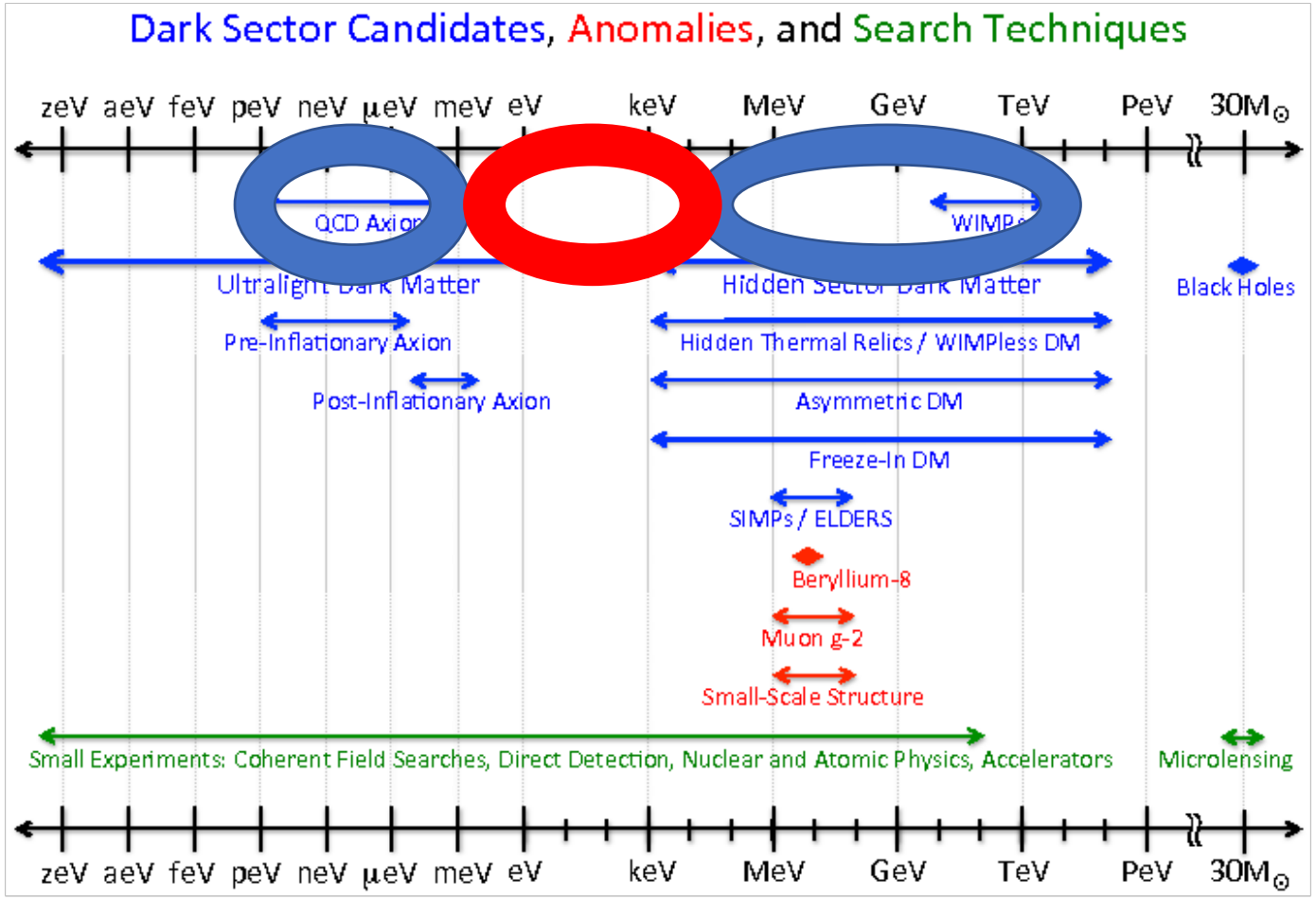

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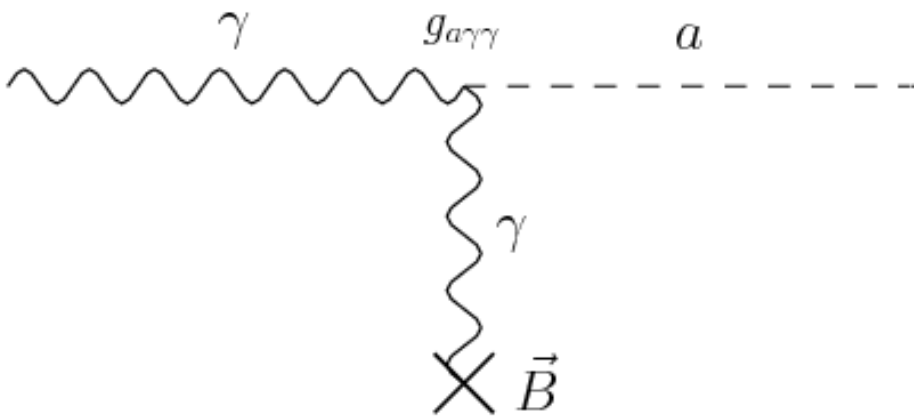

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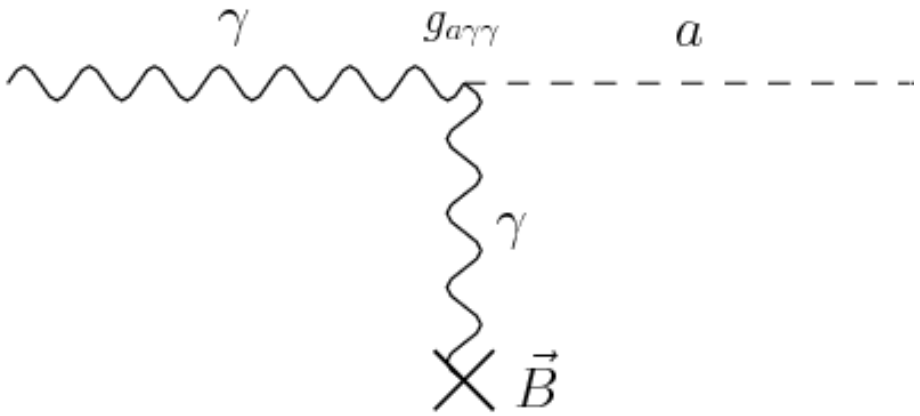

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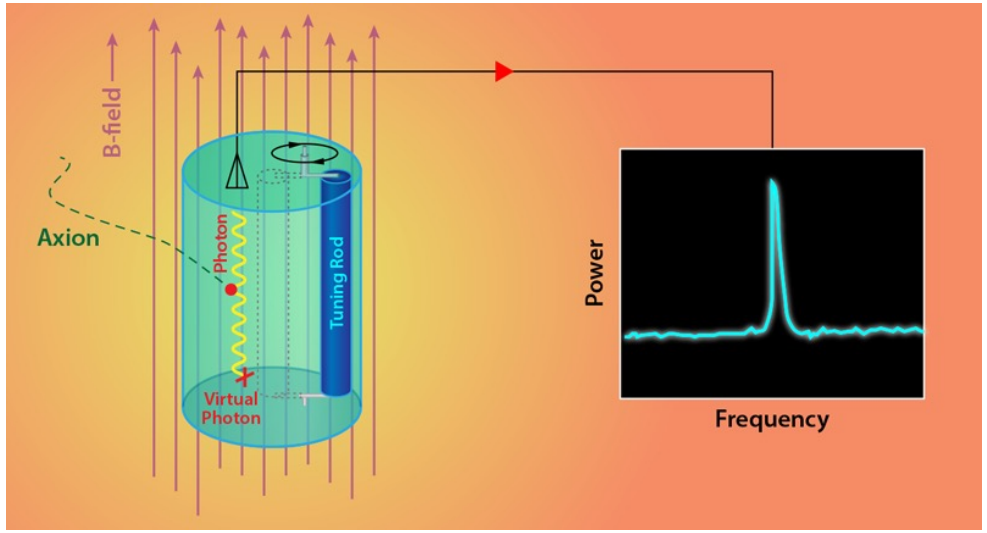

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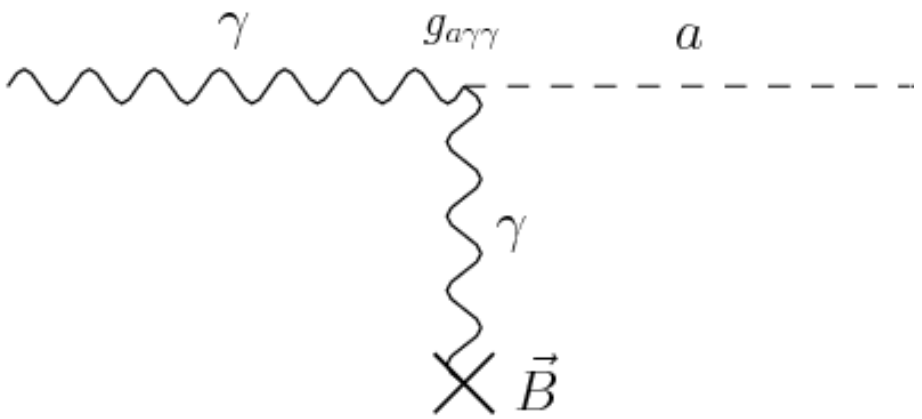

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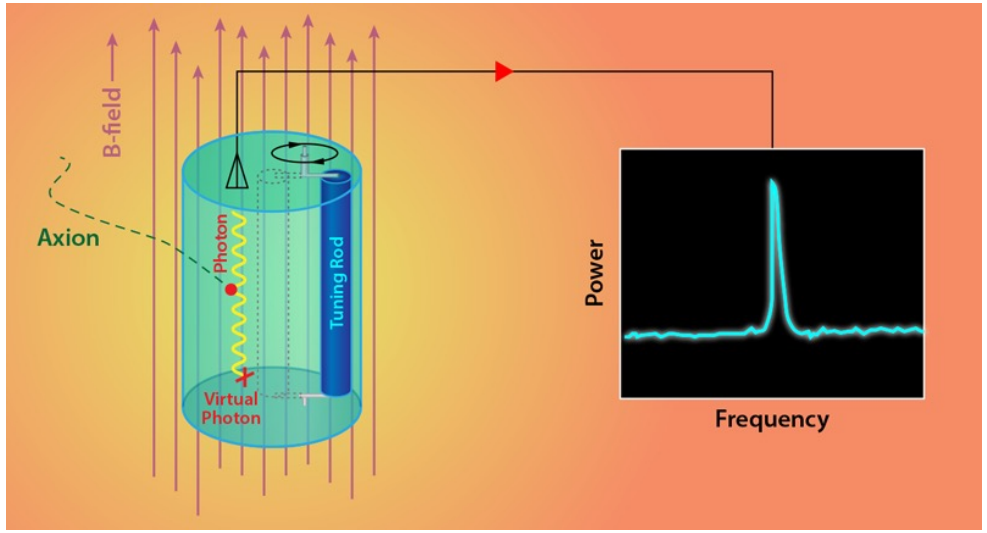

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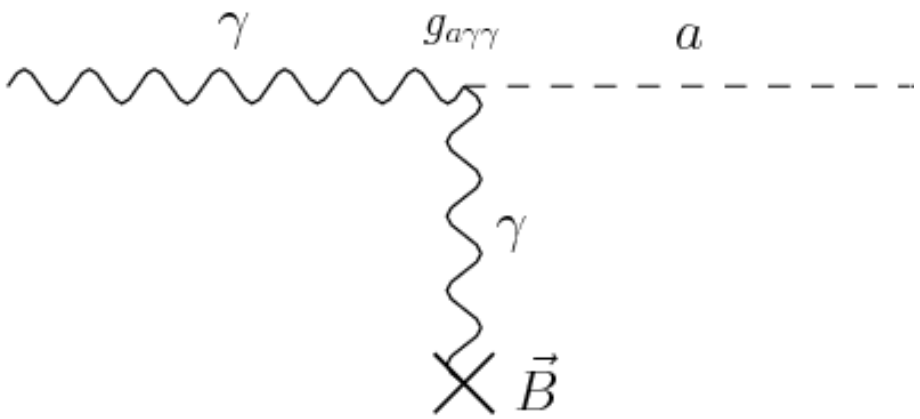

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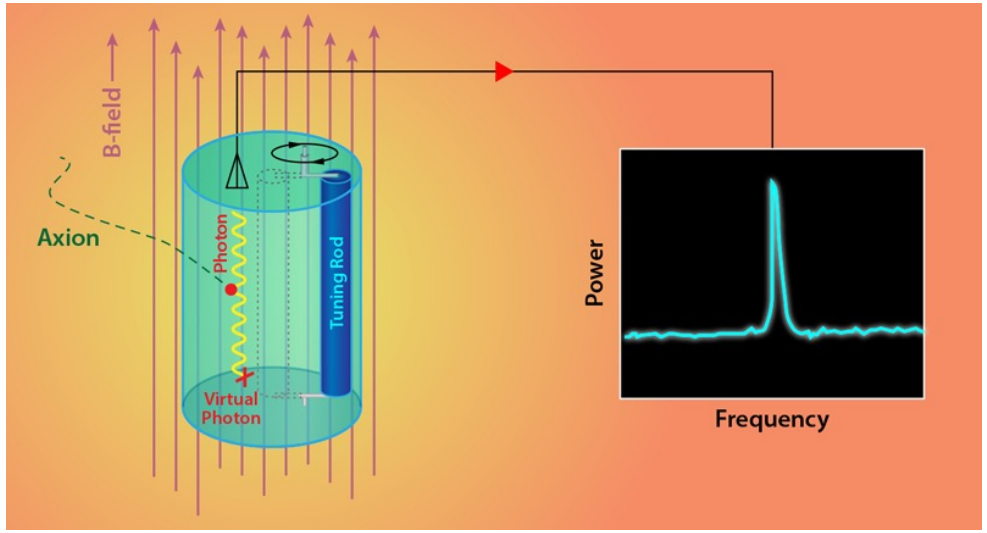

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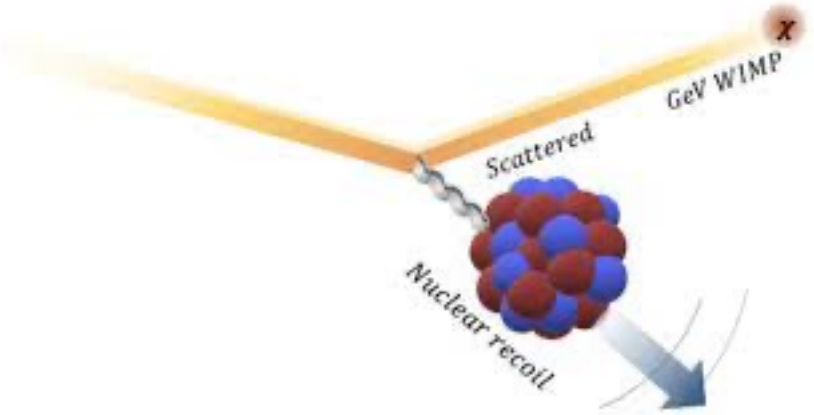

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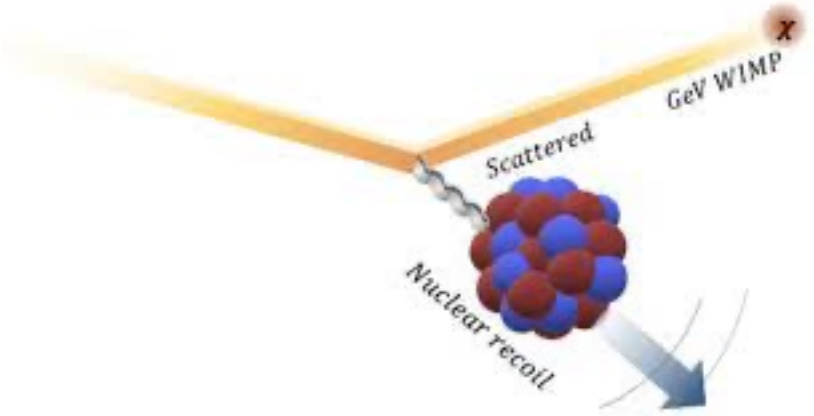

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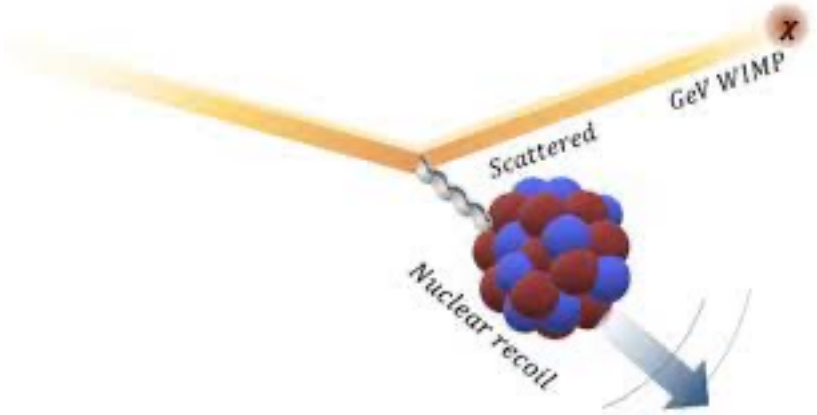

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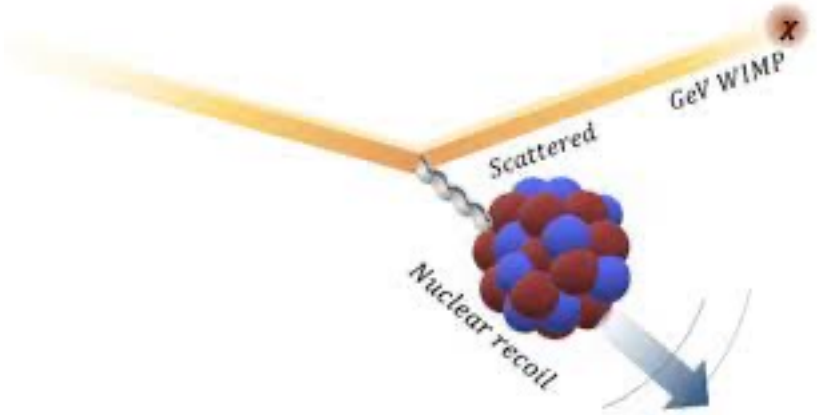

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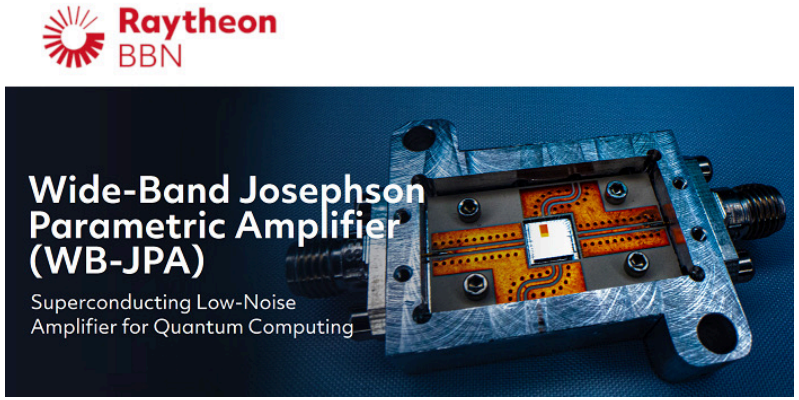

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- Not many good detectors around the μeV – meV energy range of high interest…

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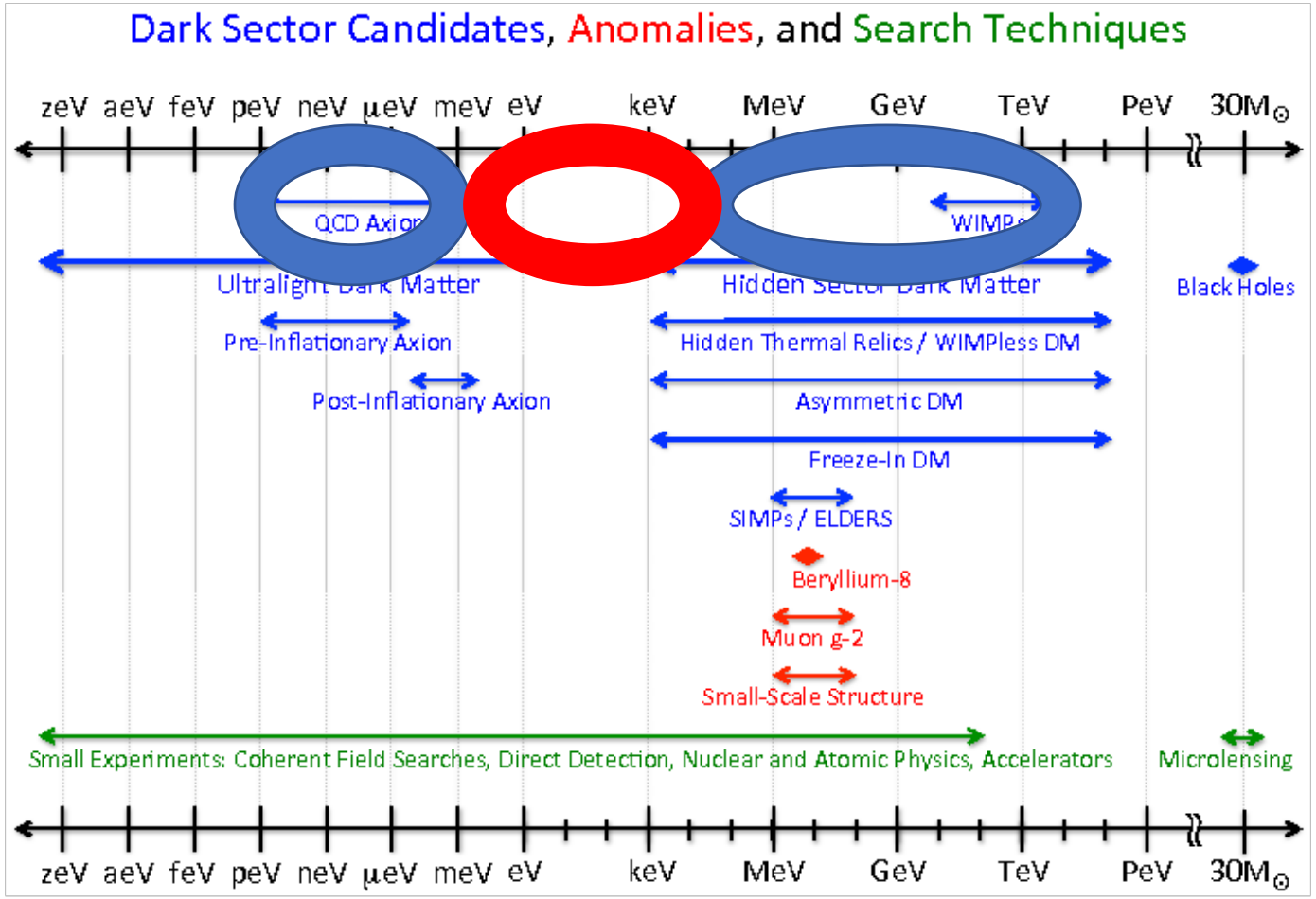

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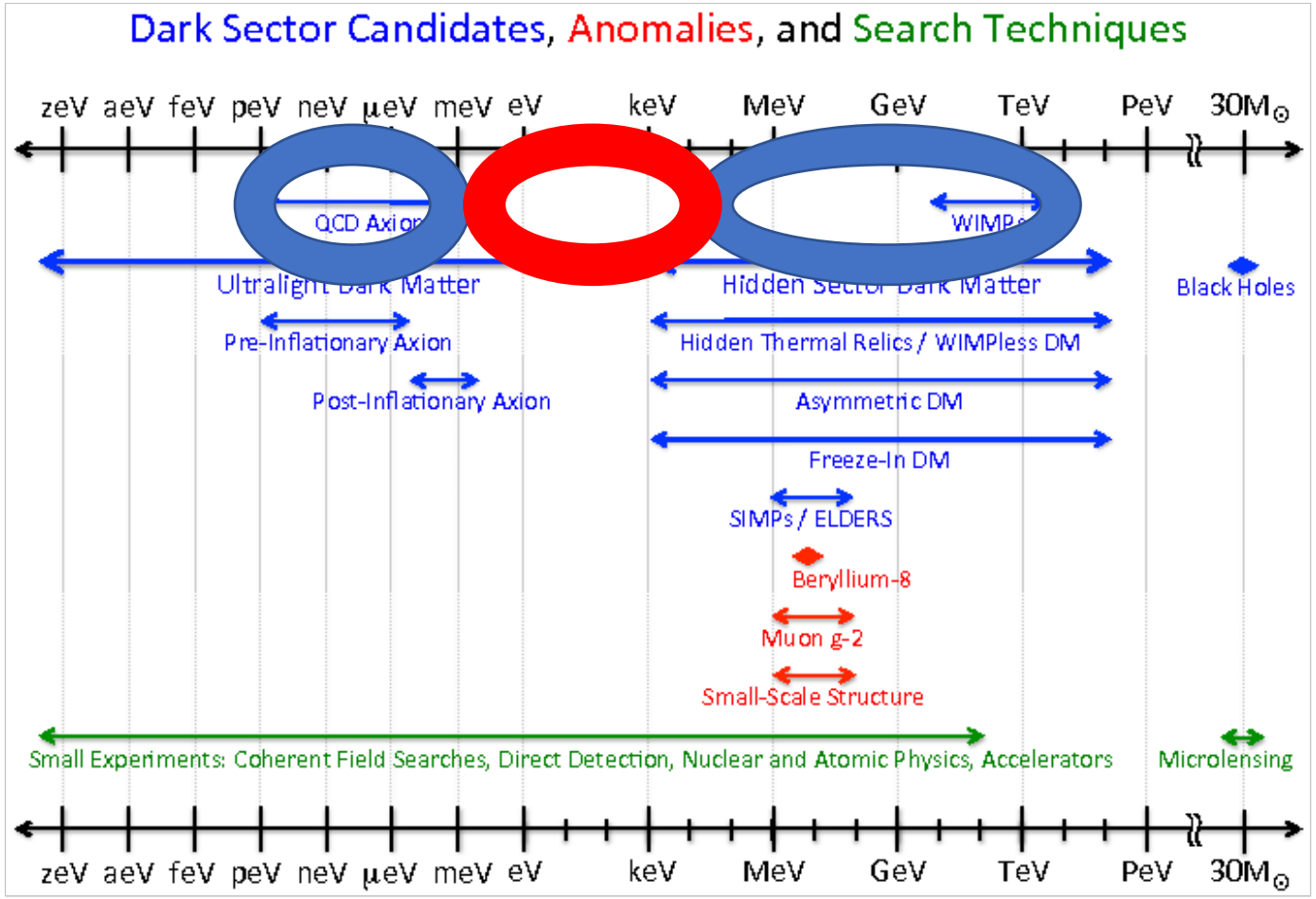

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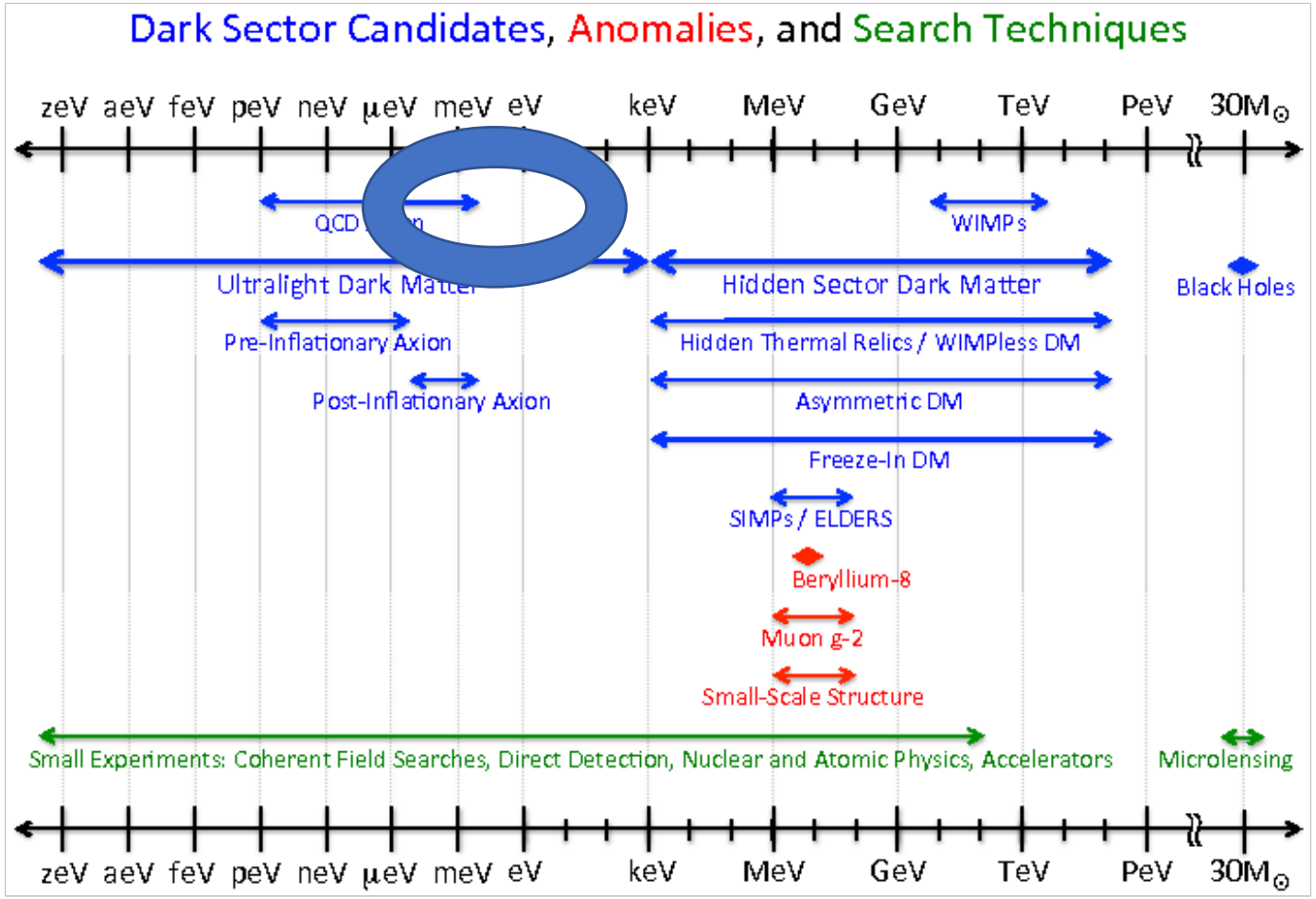

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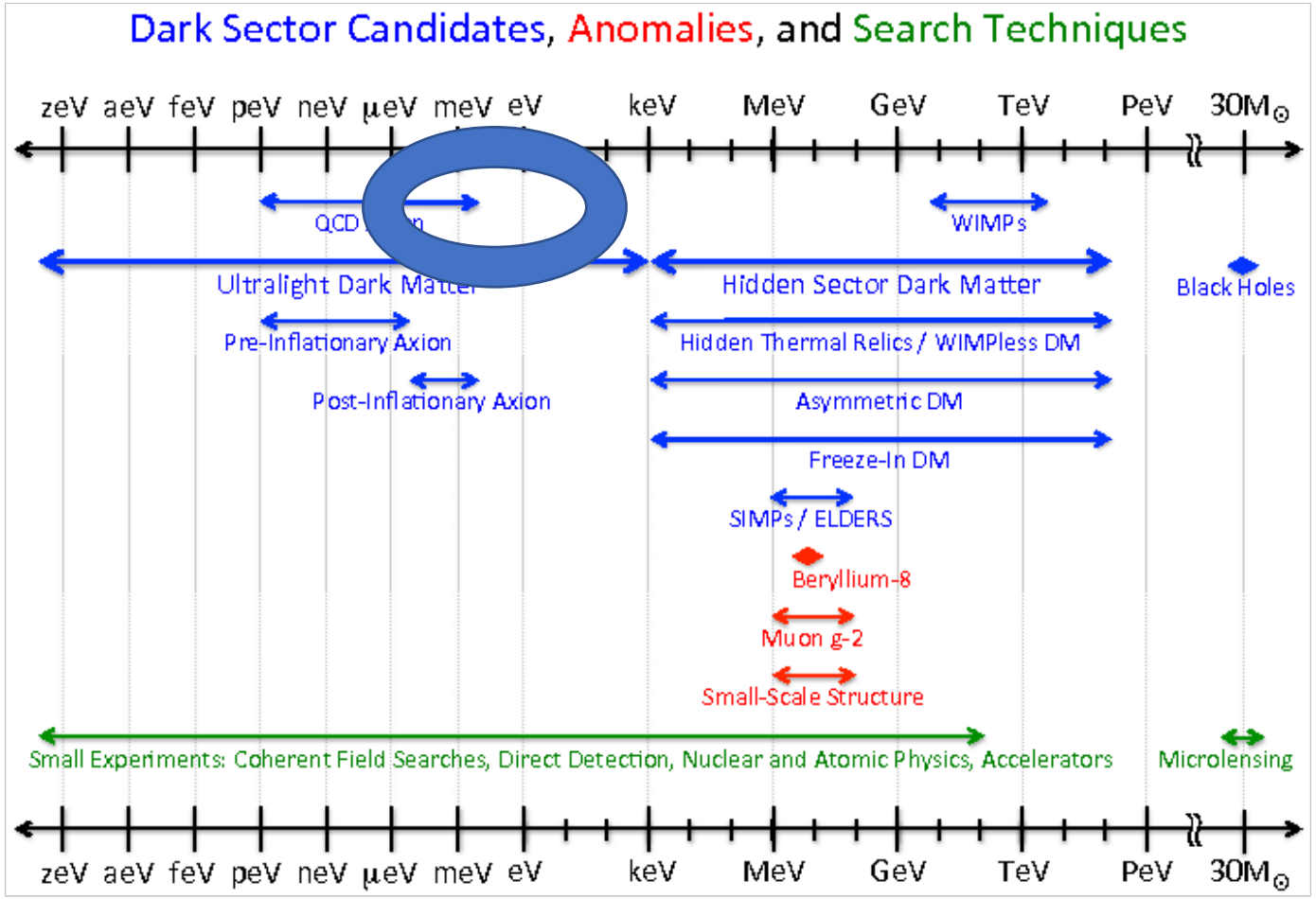
- The kinds of technologies we need for future of both fields might be the **SAME**



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Low Energy Threshold Detectors

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- Can we apply them to high mass axions, or low mass WIMPs?

SIS Josephson Junctions

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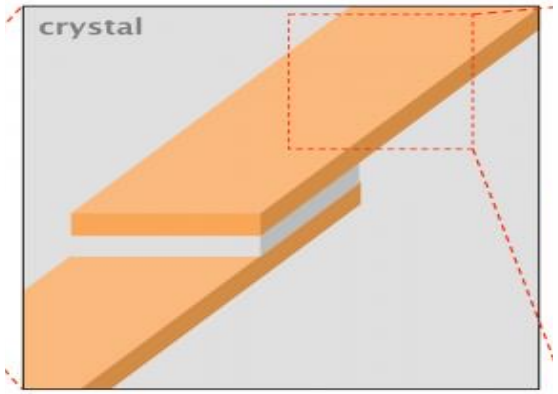
- Layer of superconductor – insulator – superconductor

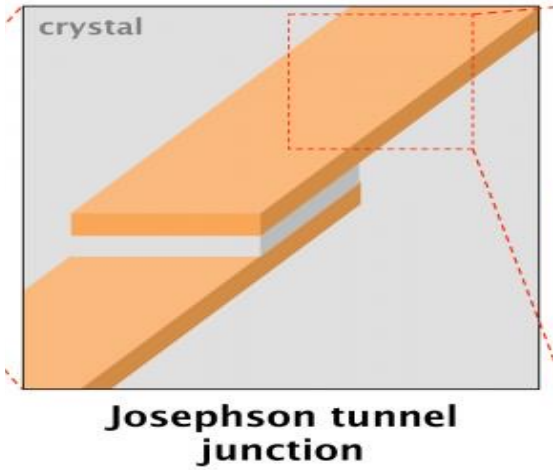


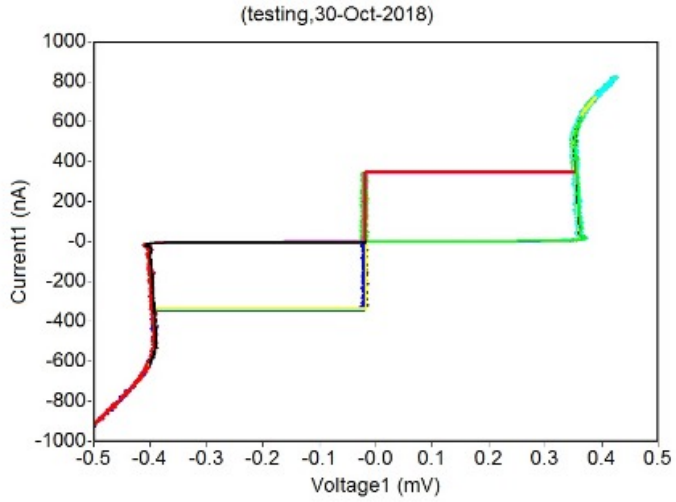
Josephson tunnel junction

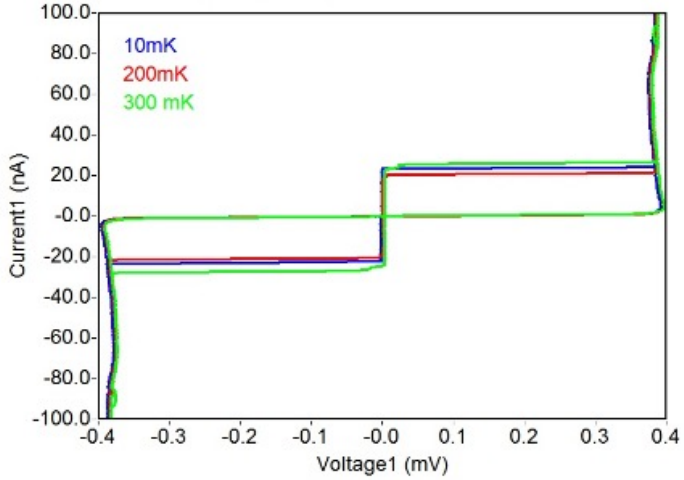
L. S. Kuzmin *et al*., *IEEE Transactions on Applied Superconductivity*, 2018

SIS Josephson Junctions

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







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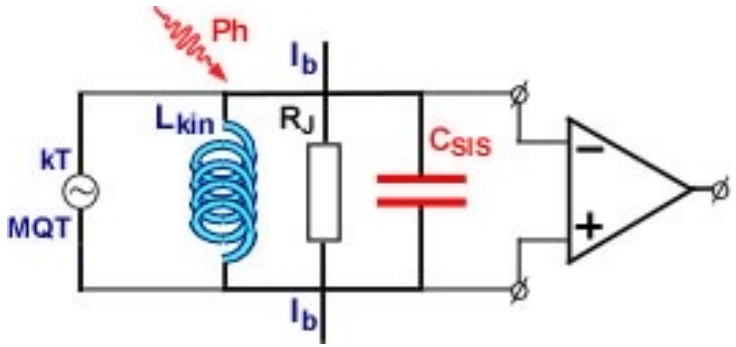

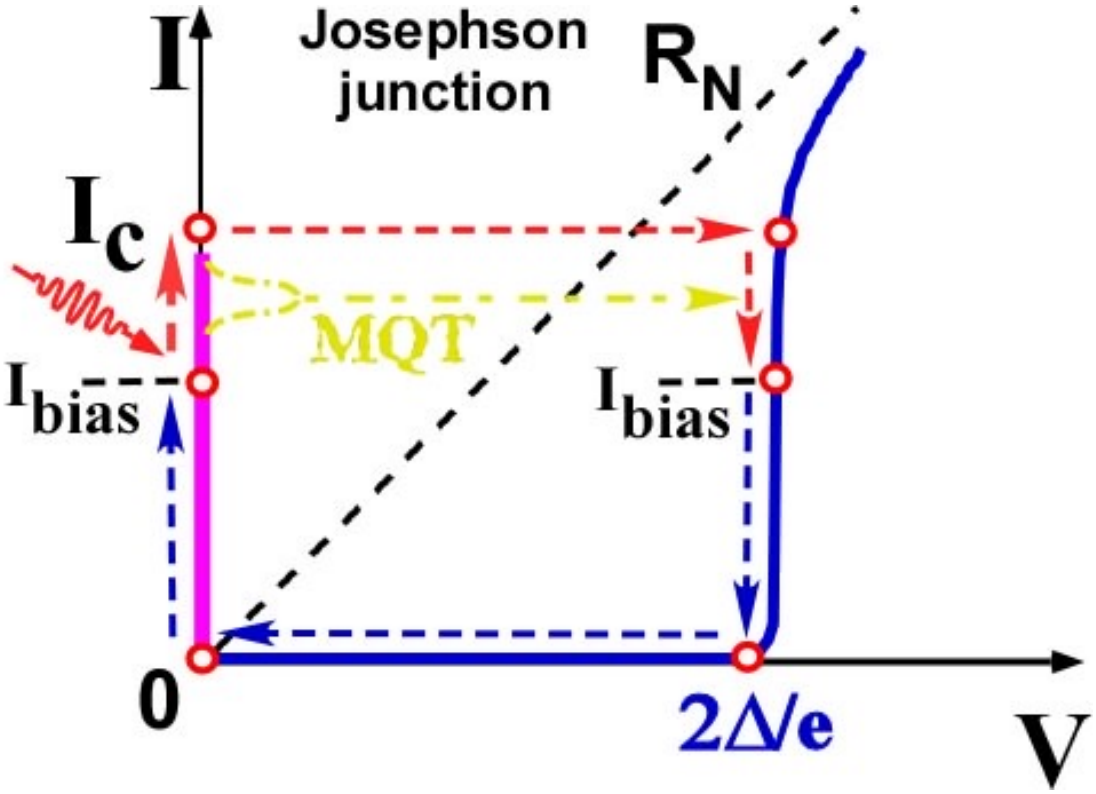

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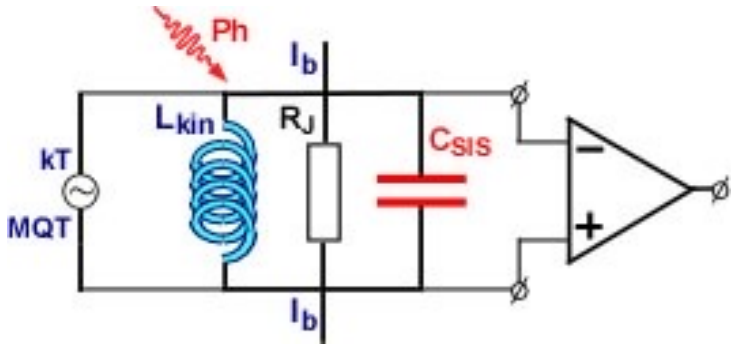
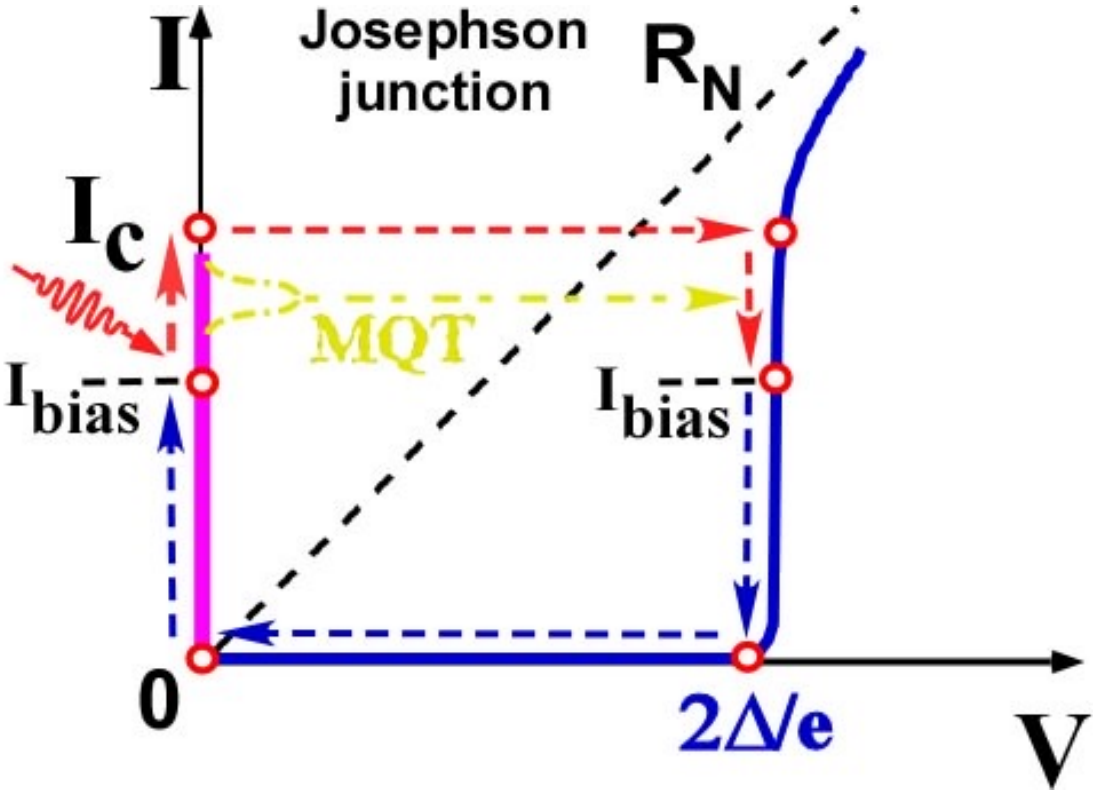
- 10s of μeV+ energy thresholds
- Gets easier at higher energy…





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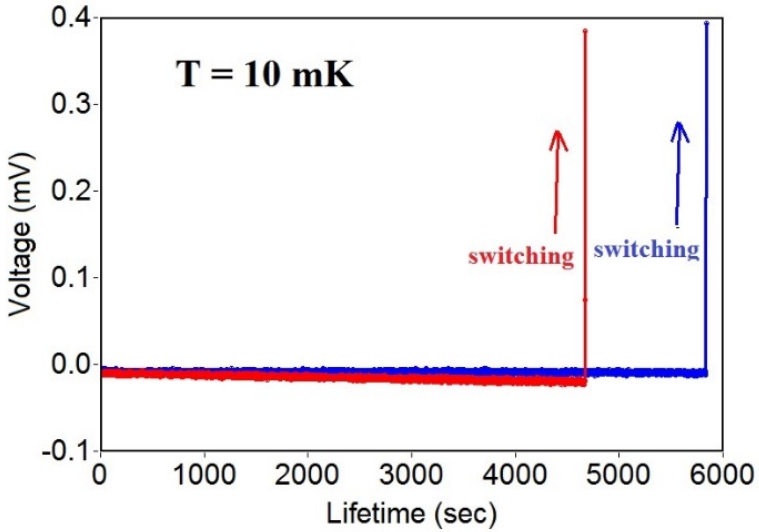
- Dominant issue – balance dark counts and efficiency



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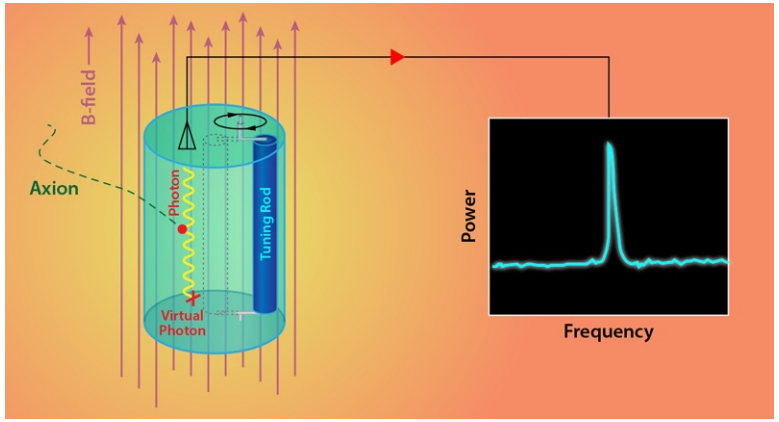

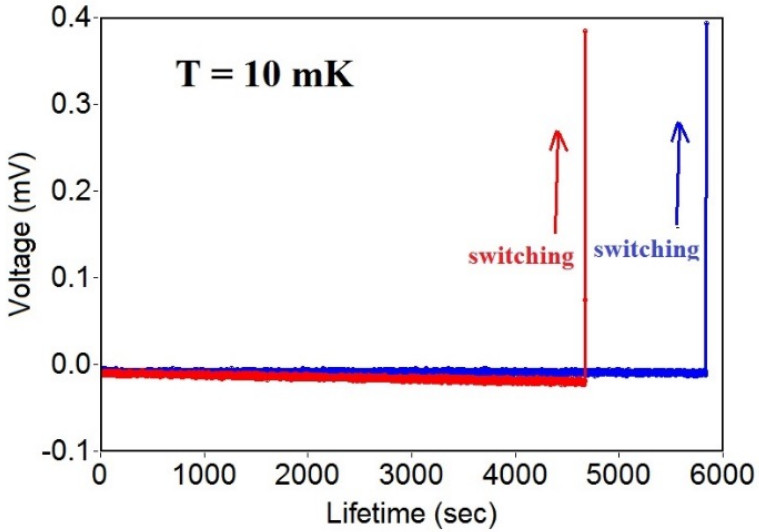

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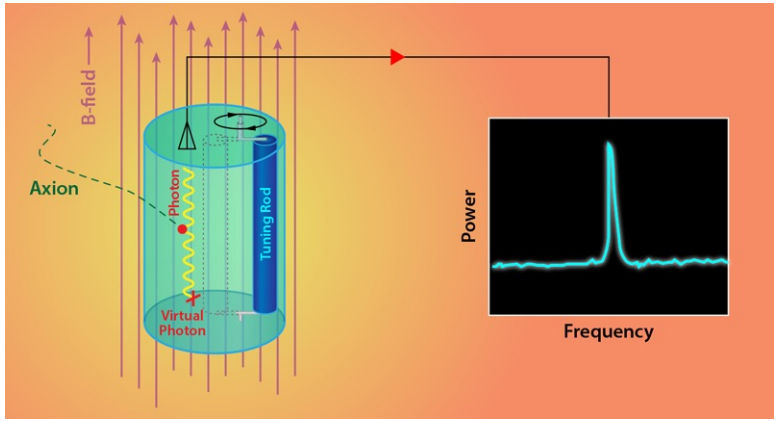
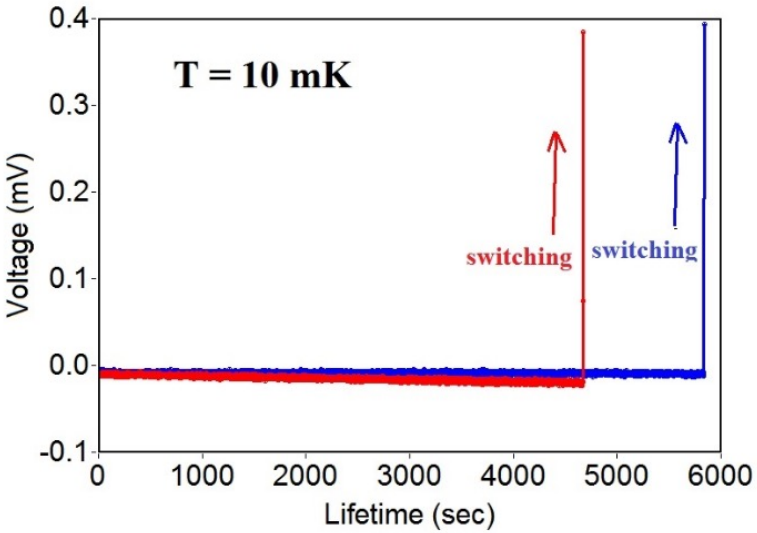
- For axions - need to couple it to cavity – impedance matching issue
- Can it be used for WIMPs?
- How to couple the recoil energy into the JJ current?





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- Some samples from Chalmers at UWA node under testing for axions
- One group reporting some good tentative results (0.3 efficiency)
- Can also probably make these at Swinburne!
- Is there interest for something like this?

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SNSPDs

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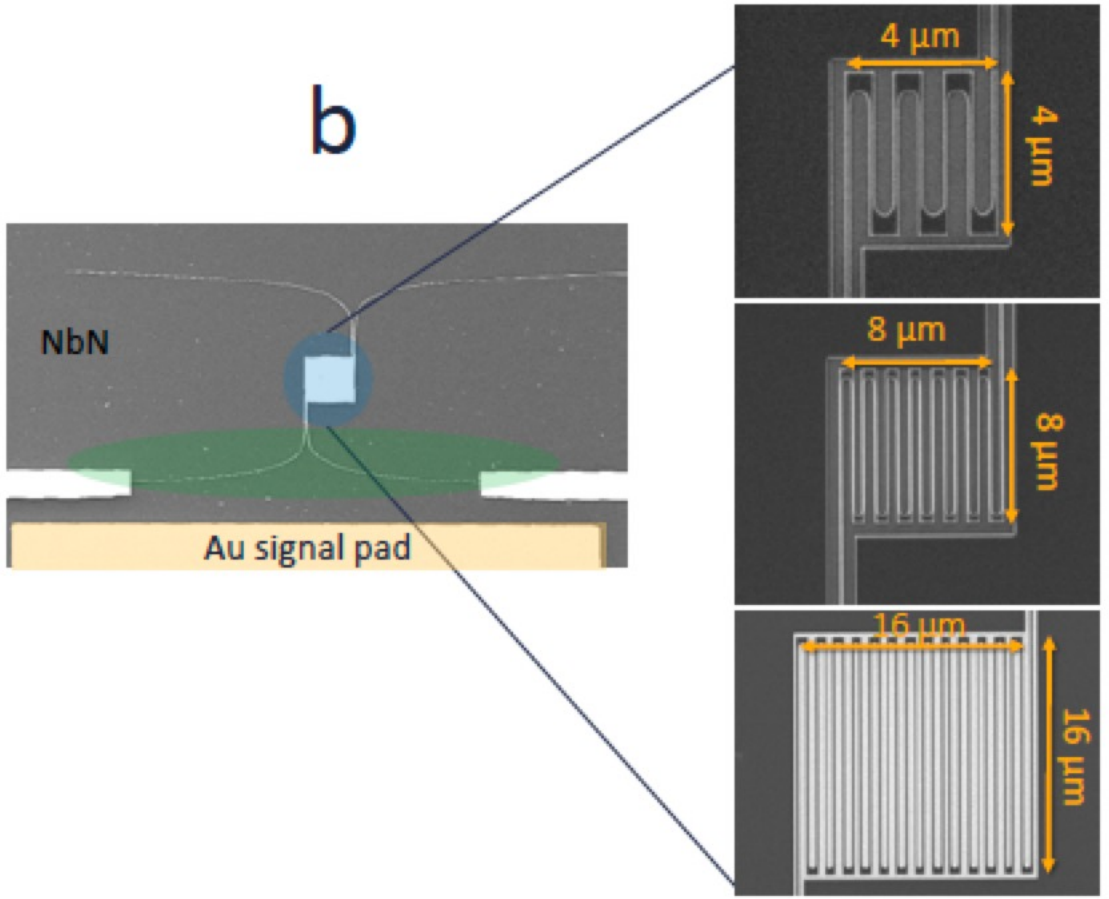
- Superconducting nanowire single photon detector

SNSPDs

- Superconducting nanowire single photon detector
- Similar to SIS junction
- Simple meander of superconducting wire

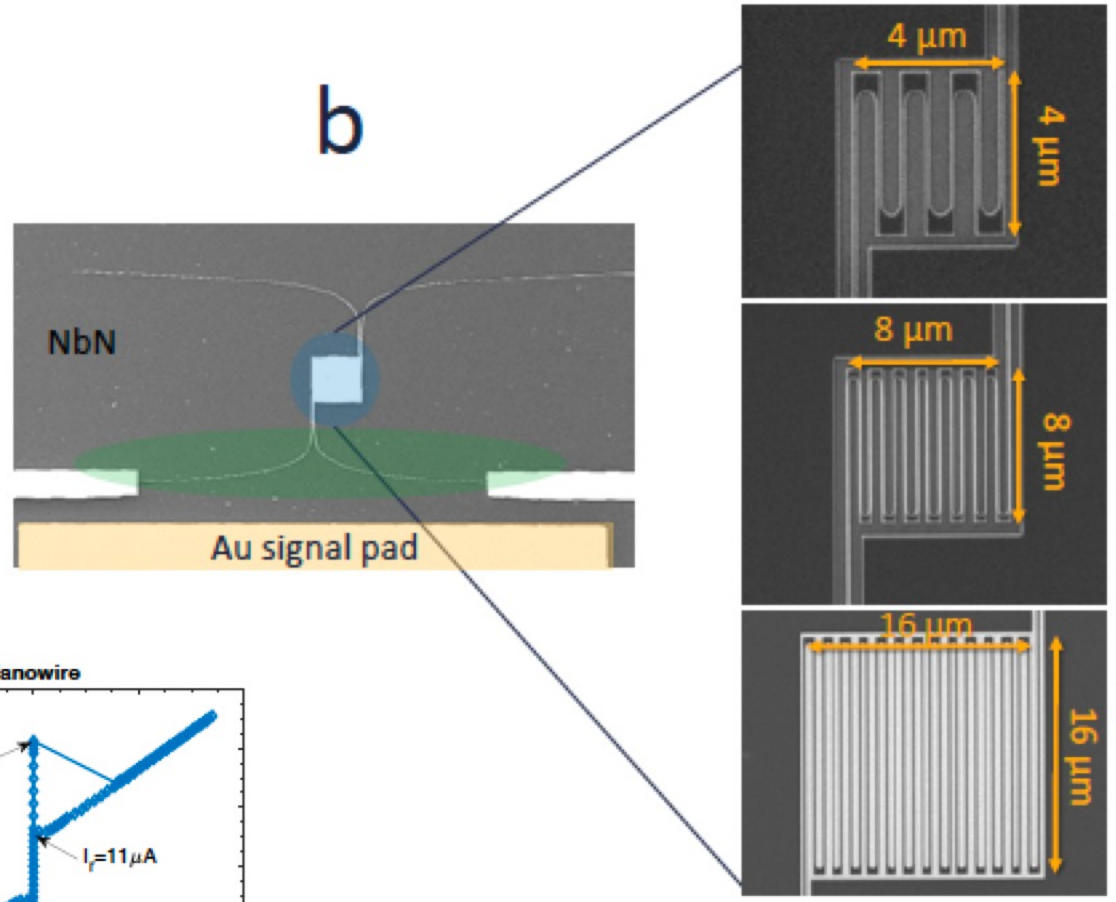


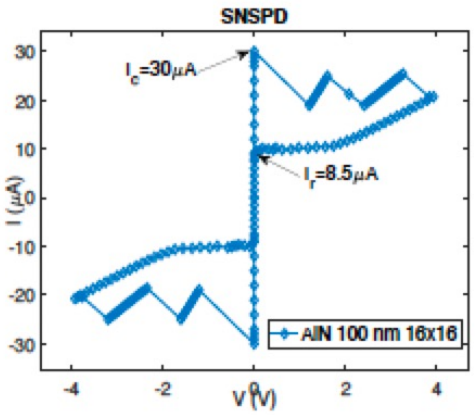
Nicolo Petrini, Masters Thesis, MIT, 2019.

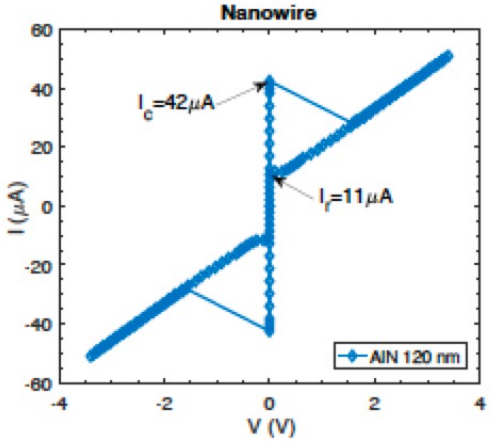
ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

SNSPDs

- Superconducting nanowire single photon detector
- Similar to SIS junction
- Simple meander of superconducting wire
- IV curve different to SIS junction







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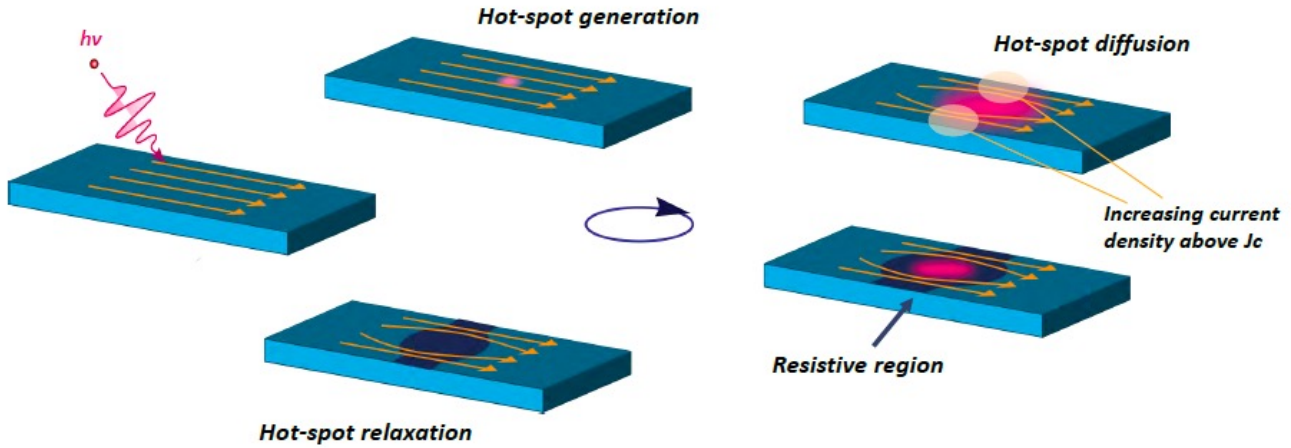

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SNSPDs

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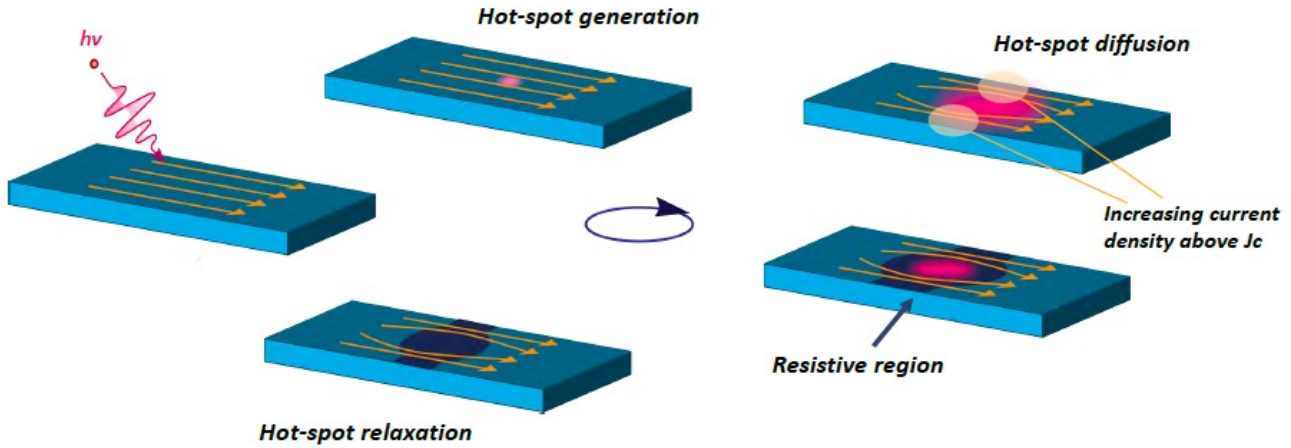
- Energy thresholds ~eV at present



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- Well established technology at ~eV energy photon absorption
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ID281 Superconducting Nanowire Series

The very best in single-photon detection, with ultra-stable performance

- Near-ideal detection efficiency: can exceed 95%
- Highly precise timing and low noise, true latch-free operation
- Ultrafast and photon-number resolving detection
- Mix and match up to 16 detectors, with options for rack-mounted systems

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Overview | Specifications | Applications | Resources

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

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- Can also make these at Swinburne (collaborating with others on this now)

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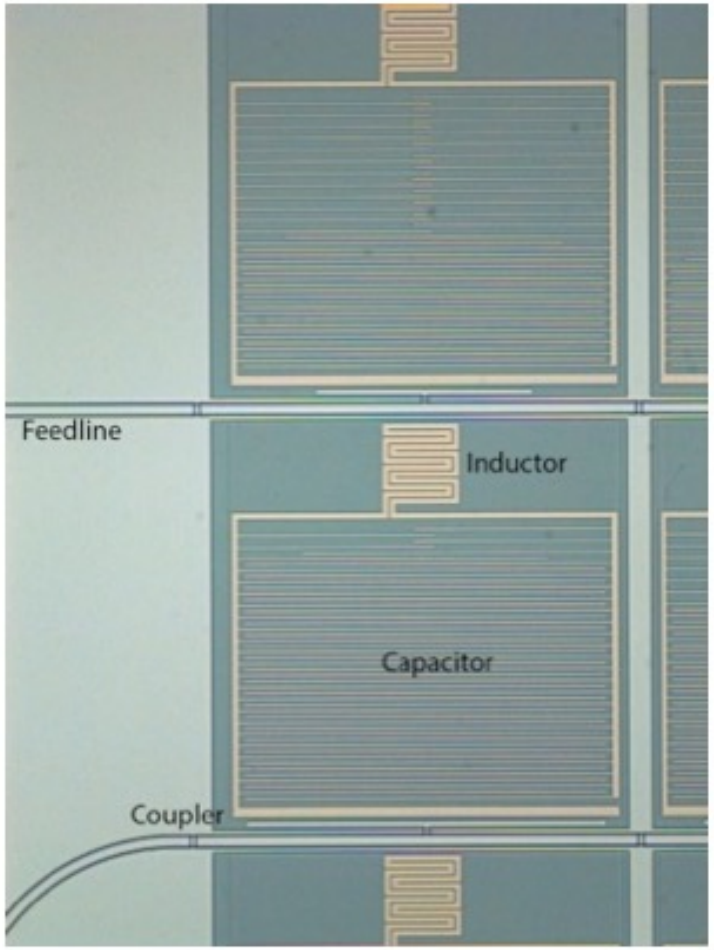


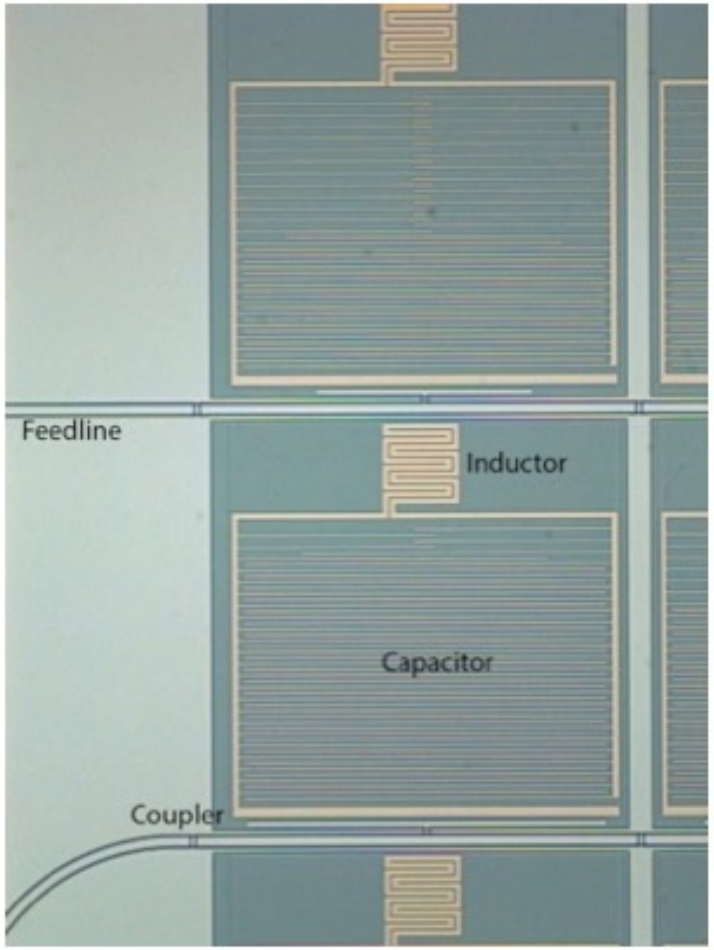
Mazin Lab, UCSB

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

MKIDs

- Microwave Kinetic Inductance Devices
- Similar to SNSPD, but different detection methodology
- Length of superconductor, coupled to resonant circuit
- Relies on kinetic inductance

$$L_K = \left(\frac{m_e}{2n_s e^2}\right)\left(\frac{l}{A}\right)$$



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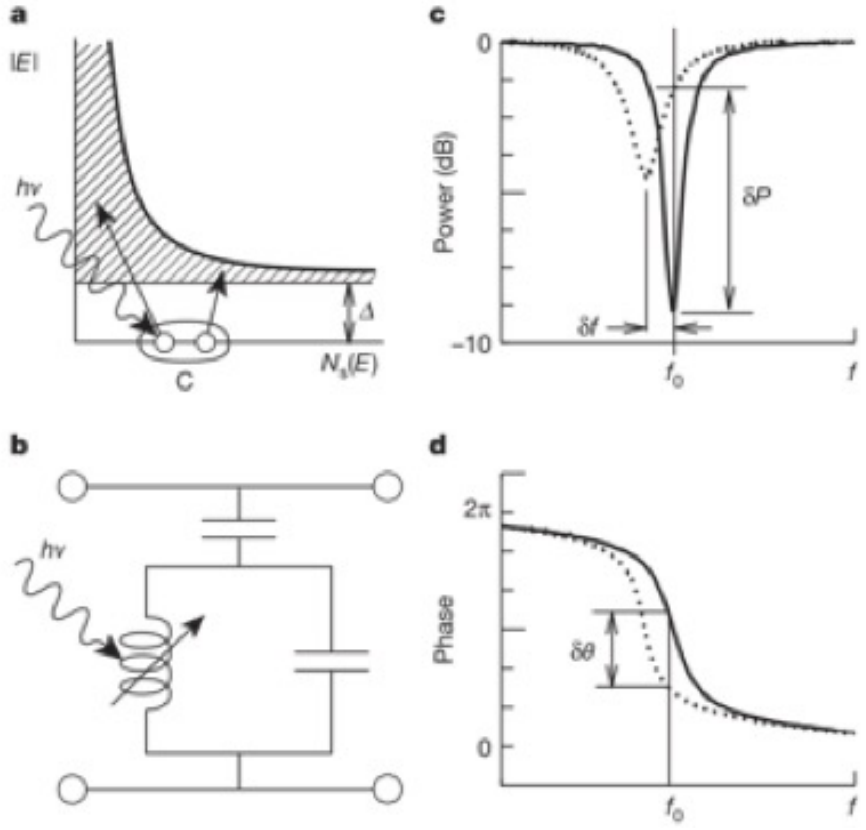

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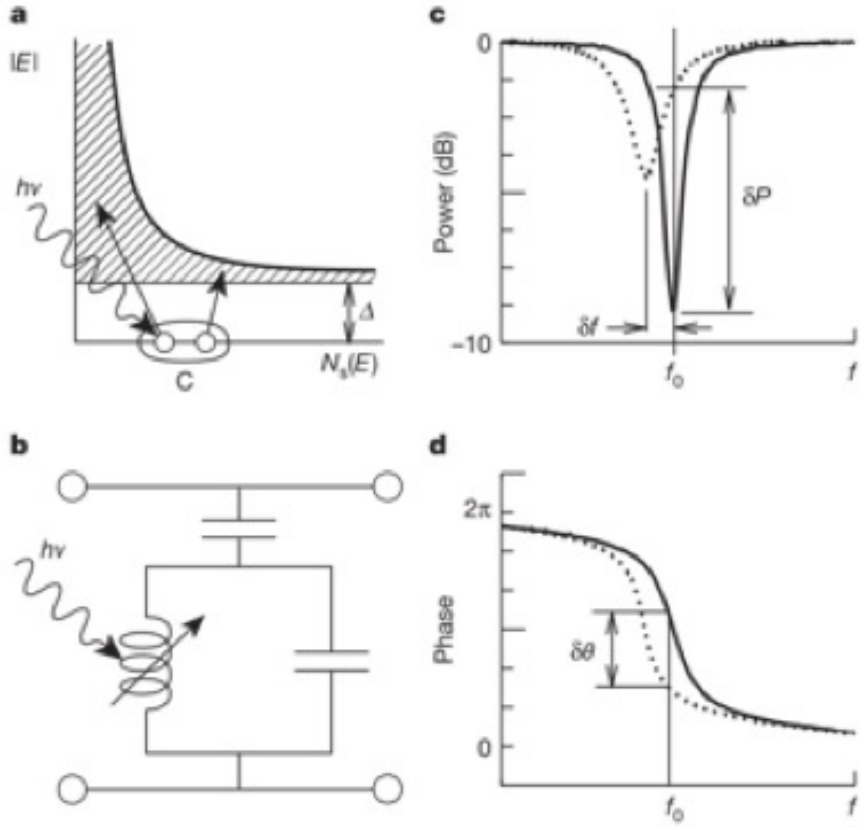

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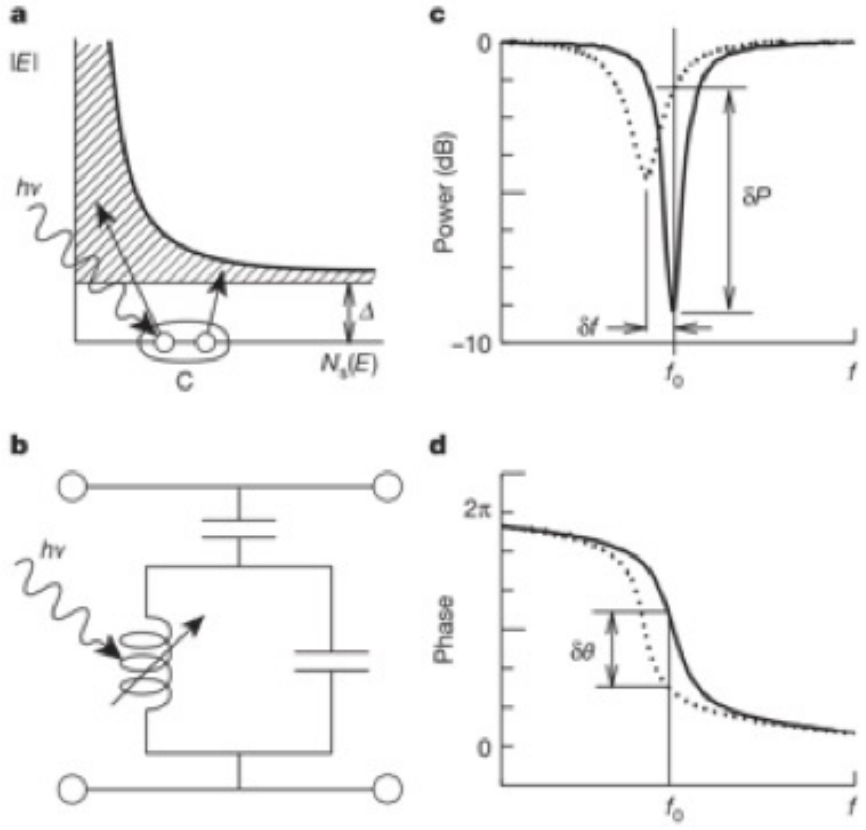
- Can measure energy by size of shifts
- Have been developed from 10s of GHz to X-ray and beyond
- Potentially 100s of μeV+



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- Similar to SNSPD – direct absorption of particle into the superconductor

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- How to couple to axion detectors?
- How to couple to WIMP detectors?

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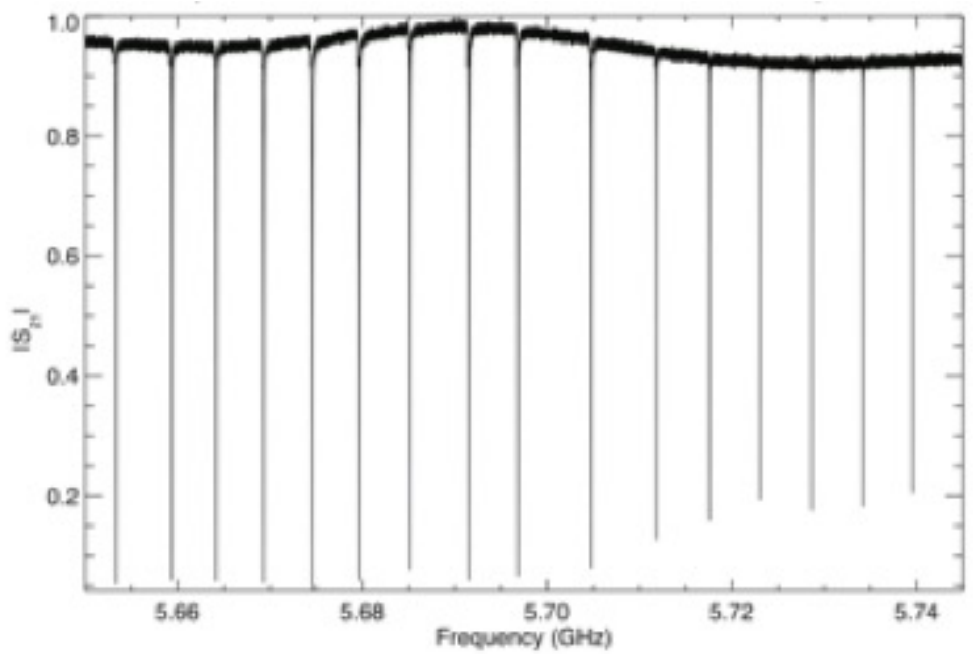
- So maybe can be made bigger by having arrays



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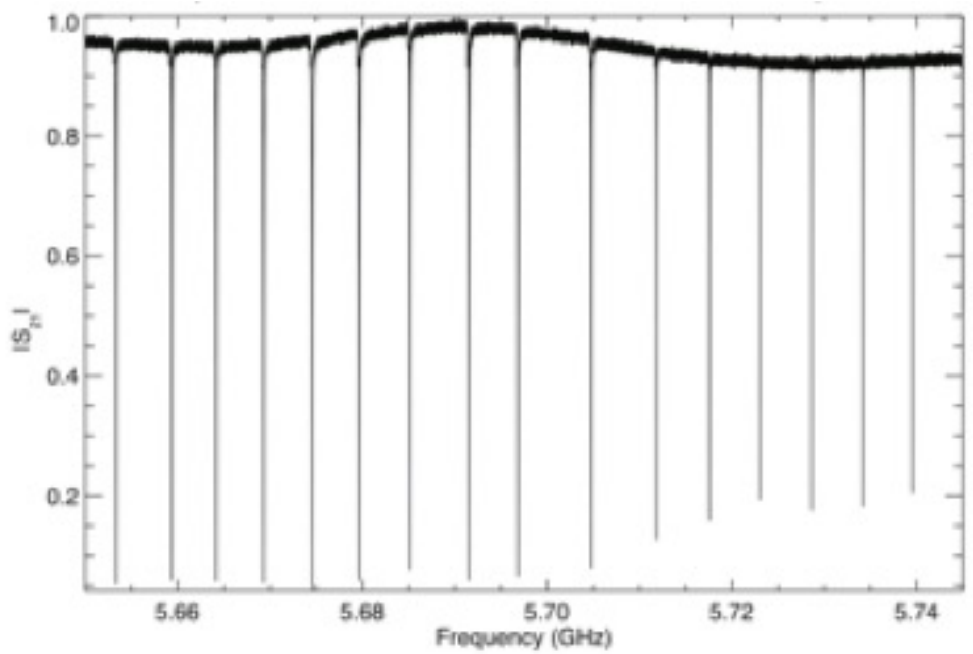
- Can also (probably) make these at Swinburne



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Conclusions

- We are not so different after all…
- Some superconducting cryogenic R&D options
- Actively spinning up CDM capacity in this area
- Open questions:
  - Which is the best device?
  - How best to couple to WIMPs/axions?
- Open to collaborations and interested parties!