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Institute for Photonics and Advanced Sensing

Quantum Magnetometer for Underwater Deployment

Chris Perrella, Kyle Netz, Andre Luiten

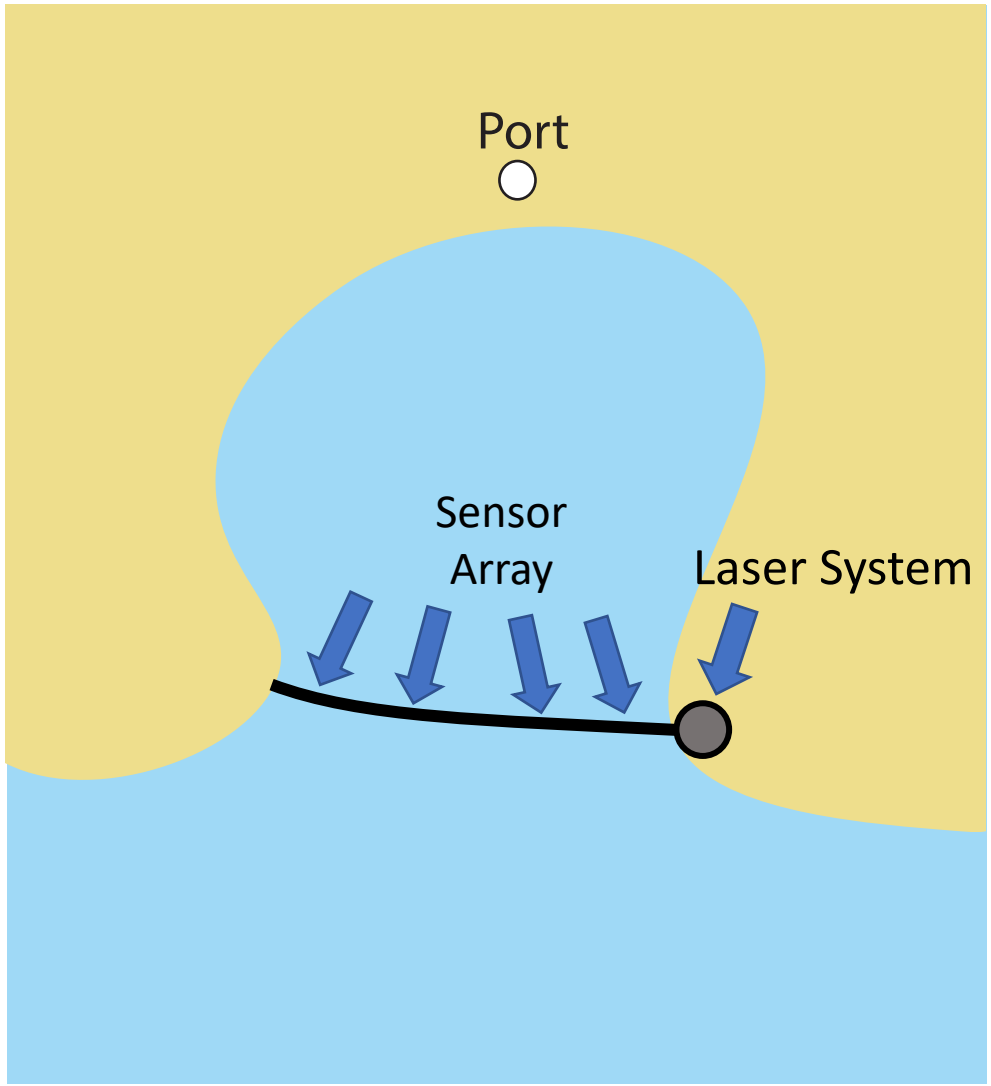
University of Adelaide

Ben Sparkes, Scott Foster

Defence Science and Technology Group

make history.

Barrier Network



- Seabed-mounted all-optical magnetic sensor array acting as a tripwire.
- Array suppresses geomagnetic noise
  - hard to do on airborne platform
- Standard undersea cabling
  - Can use telecom approaches
- All optical coms and power
  - Covert and simple

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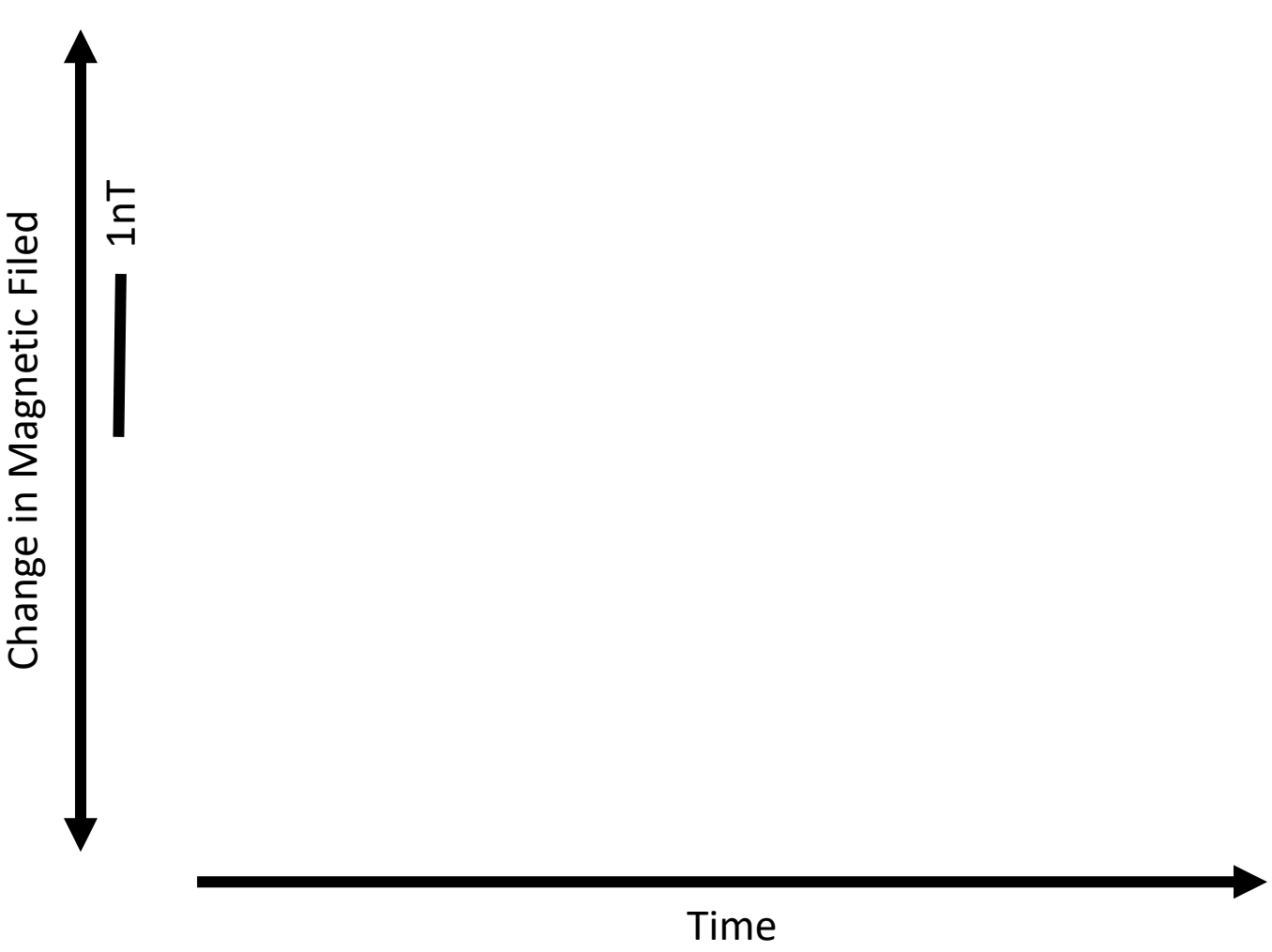
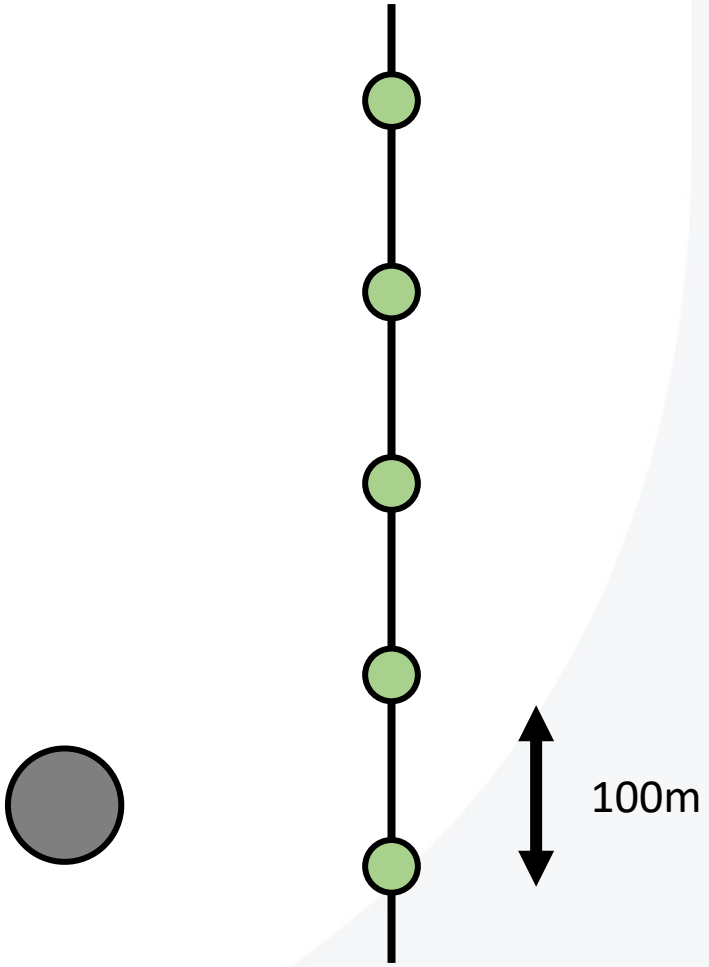
Barrier Network Example





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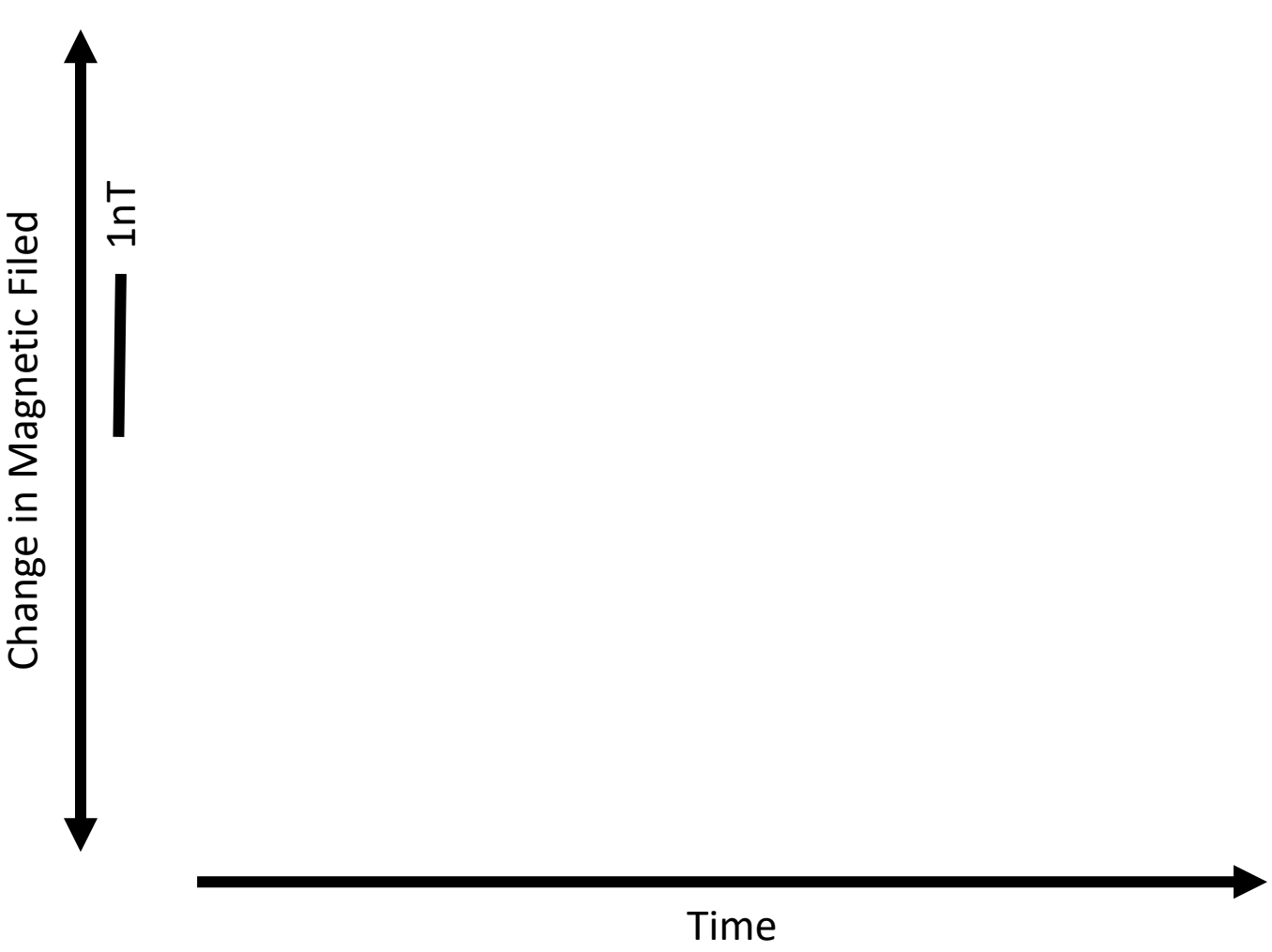
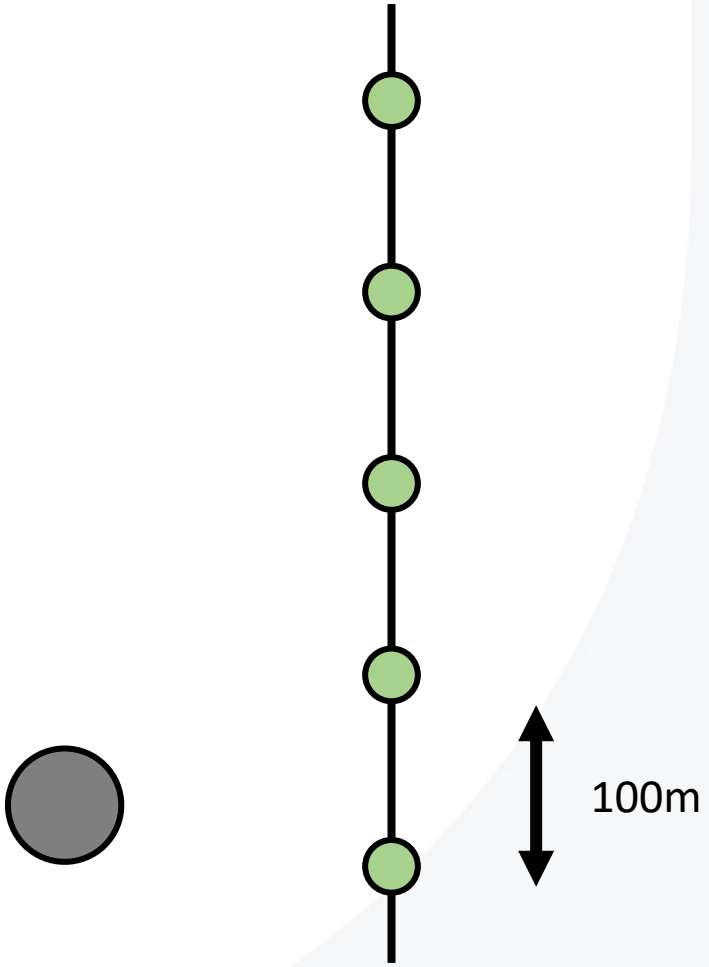
Barrier Network Example





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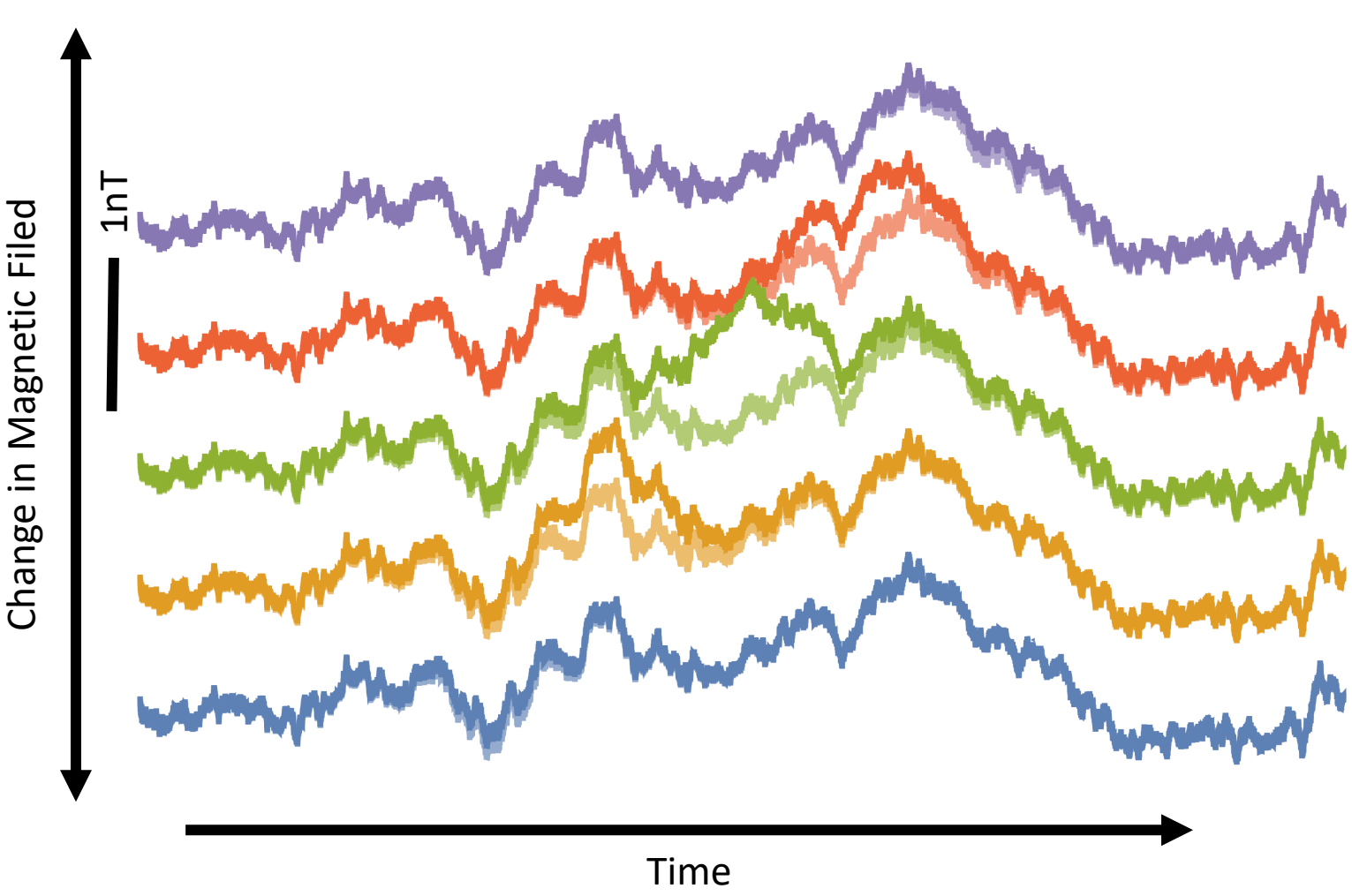
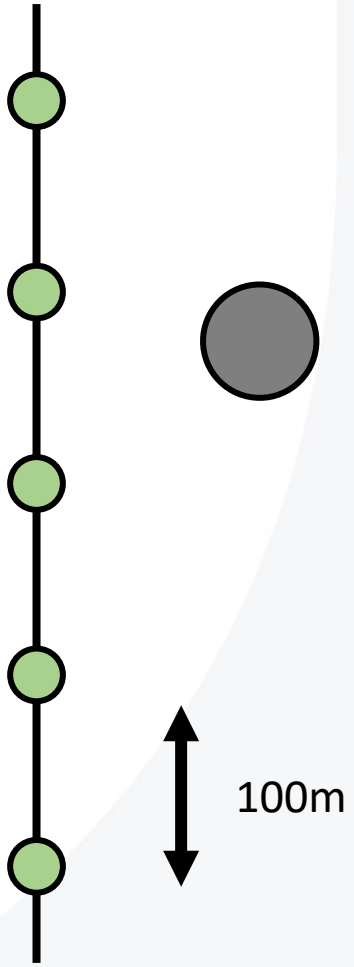
Barrier Network Example





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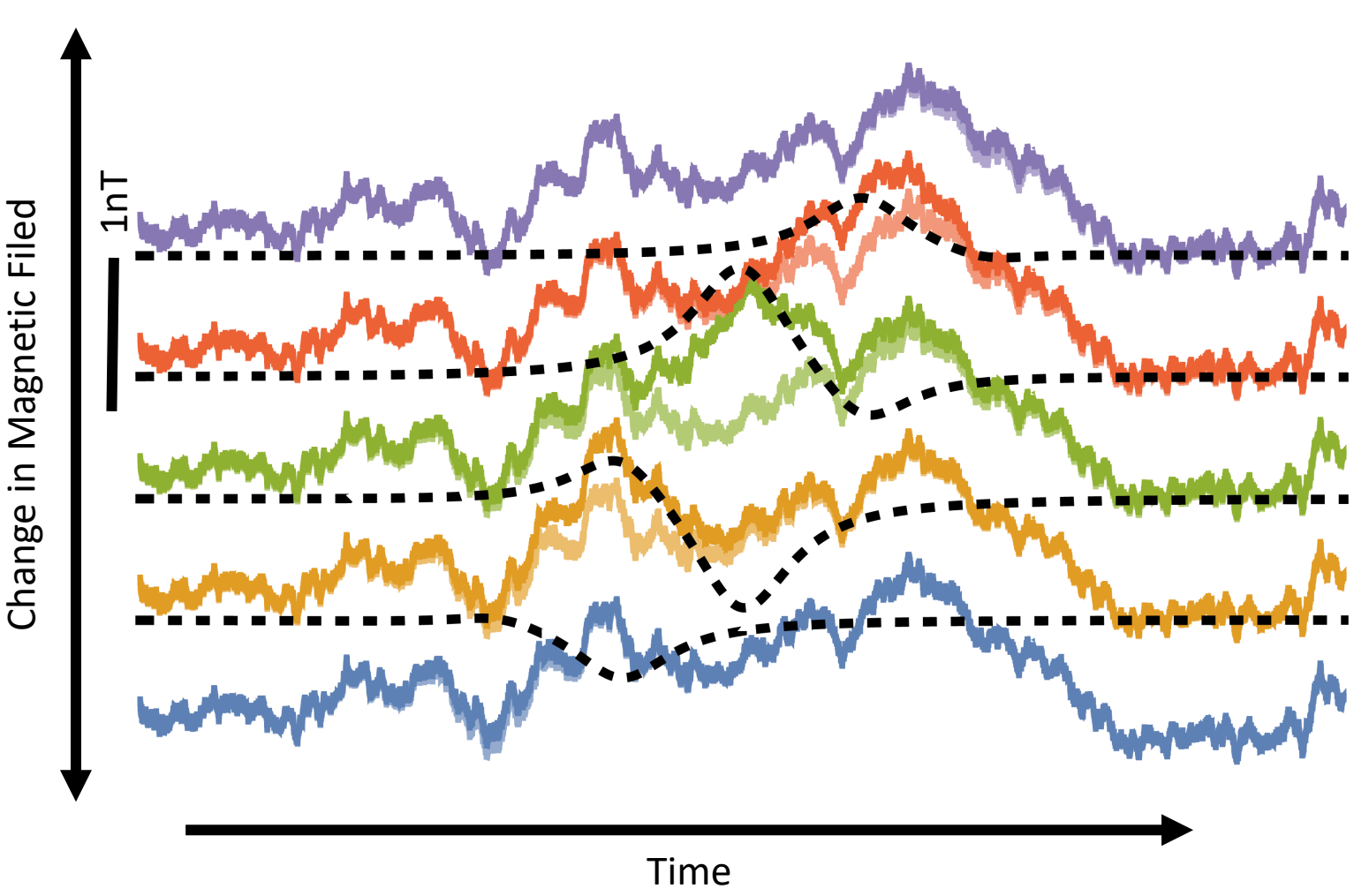
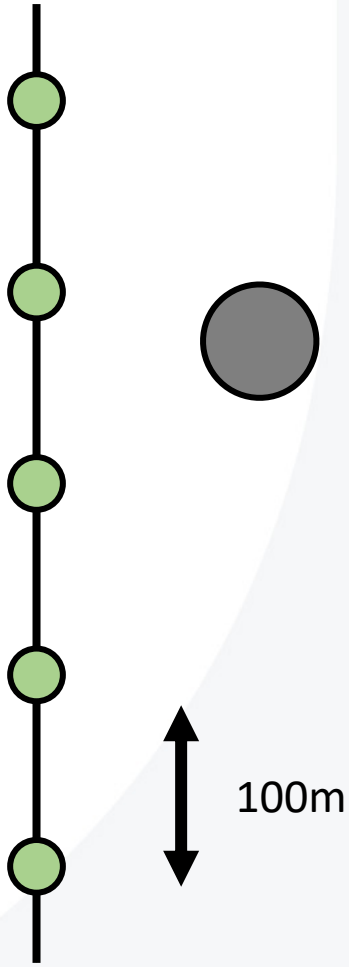
Barrier Network Example





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Barrier Network – Requirements

- Operable underwater
  - Low to zero electrical load
  - Fibre optic connection
- Low SWAP allowing many to be deployed along single fibre line
- All optical coms and power desired

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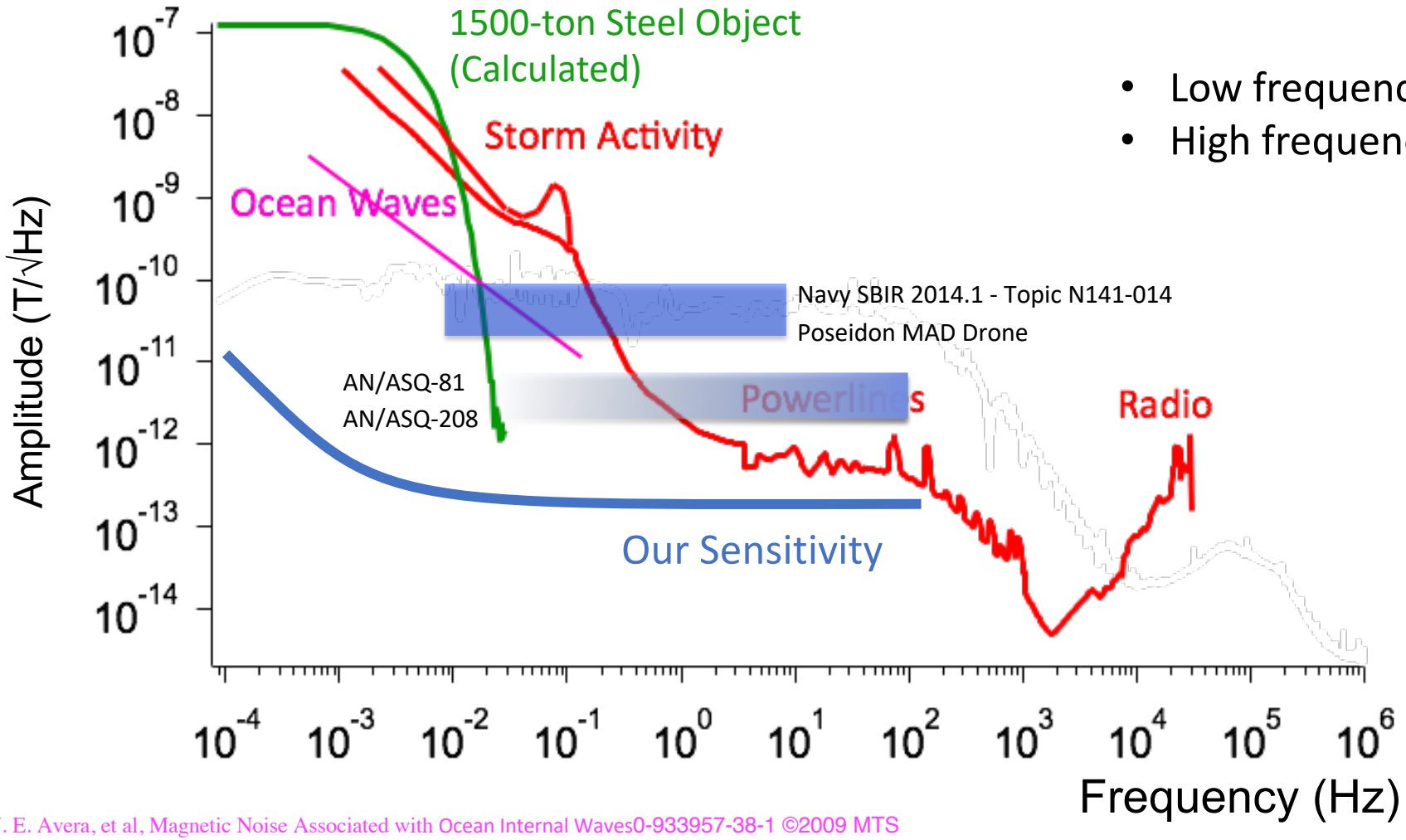
The Challenge .....



- Low frequency performance key.
- High frequency could be useful for signatures.

W. E. Avera, et al, Magnetic Noise Associated with Ocean Internal Waves0-933957-38-1 ©2009 MTS

Catherine Constable GEOMAGNETIC TEMPORAL SPECTRUM in Encyclopedia of Geomagnetism and Paleomagnetism Editors, David Gubbins and Emilio Herrera-Bervera

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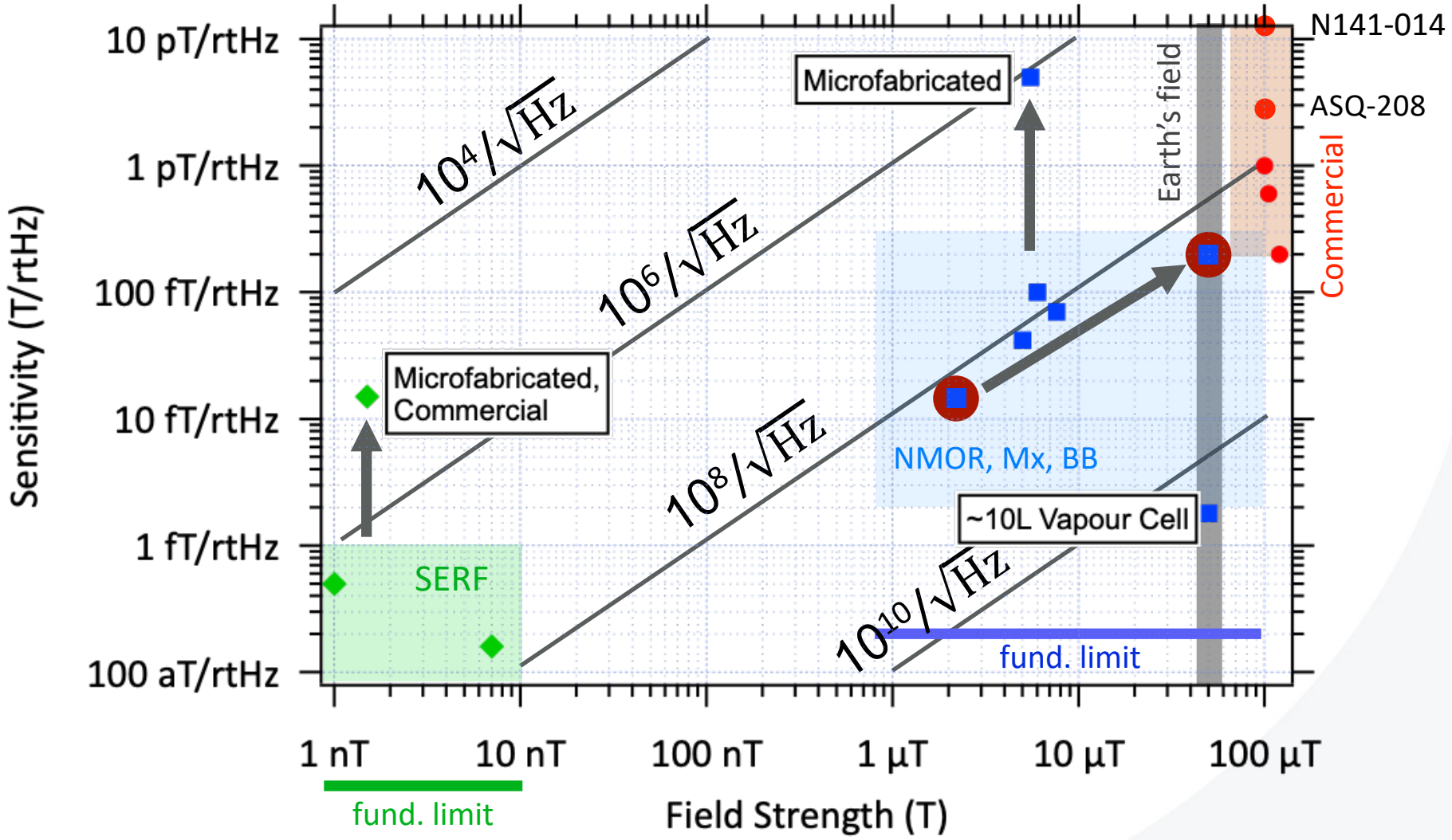
Summary of OPAM Performance



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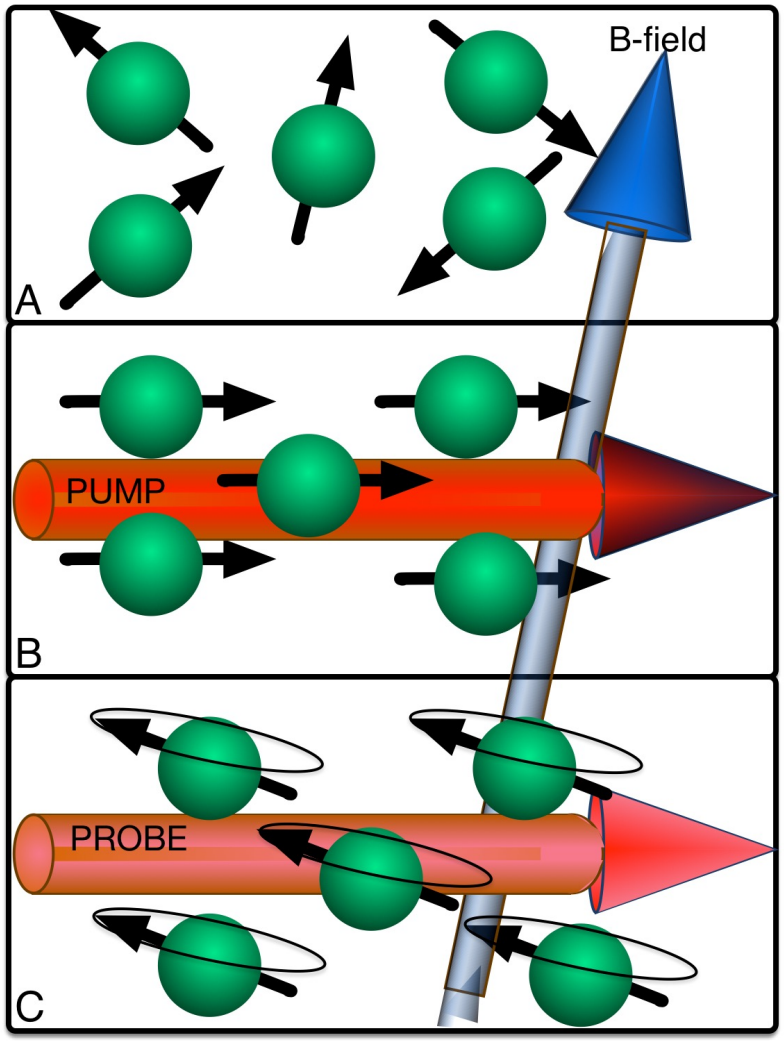
Conceptual Idea



- Unpolarised atoms.
- Atoms oriented by optical pump.
- Magnetisation evolves at a rate determined by magnetic field.
- Optical probe detects evolution through polarisation rotation.

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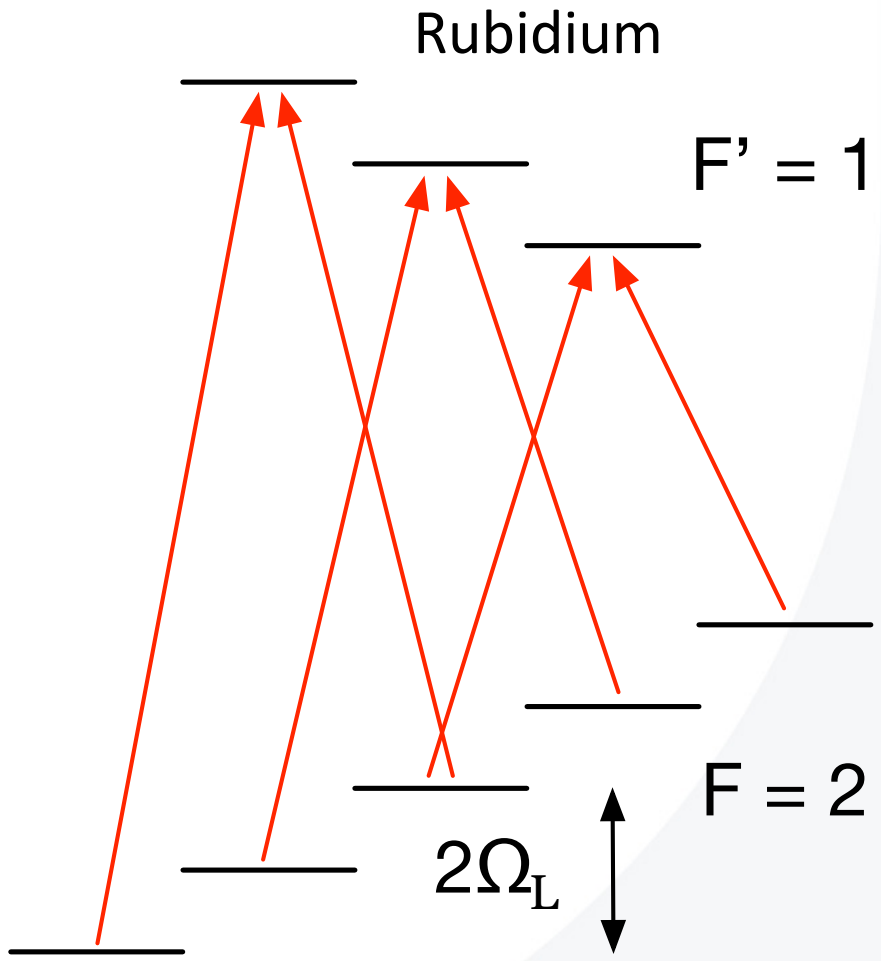
Measuring the Larmor Frequency

- Optical pumping generates circular birefringence
- Circular birefringence has time dependence of $2\Omega_L$
- Optical polarization rotation is modulated at $2\Omega_L$

$$\Omega_{\mathrm{L}} = \frac{m_F \mu_B g_F B}{\hbar}$$



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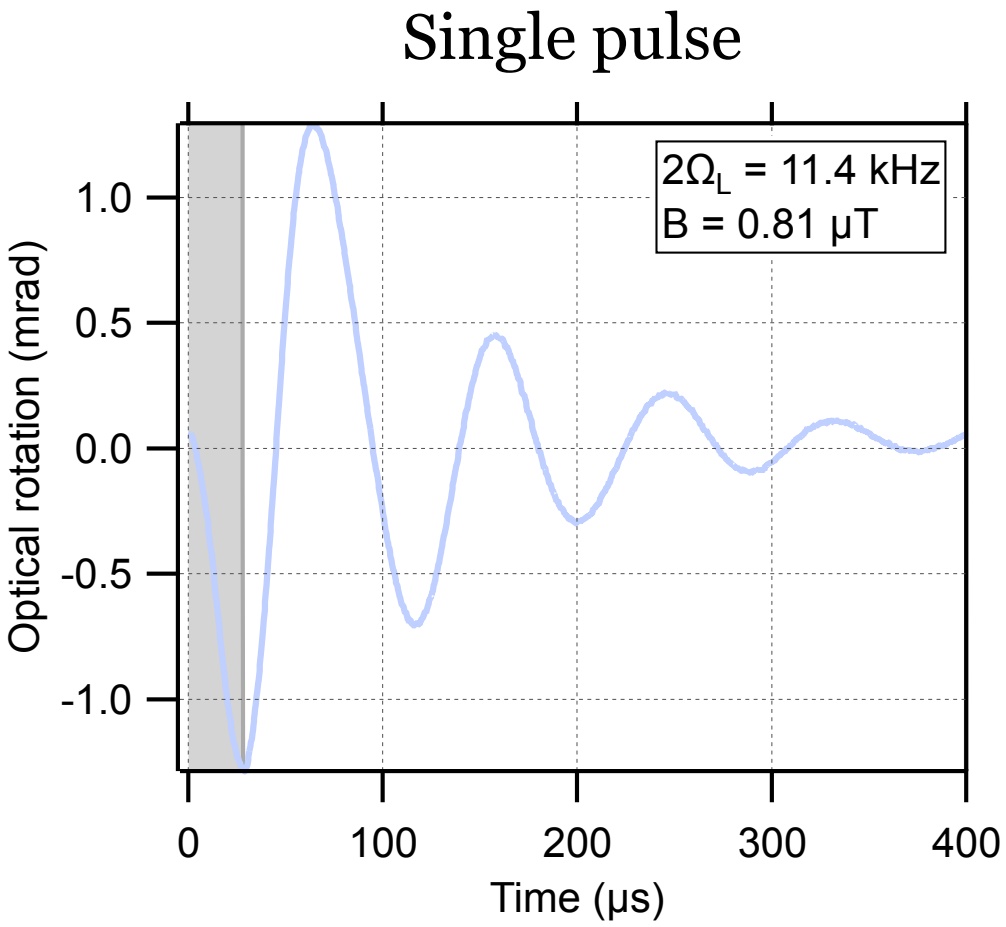
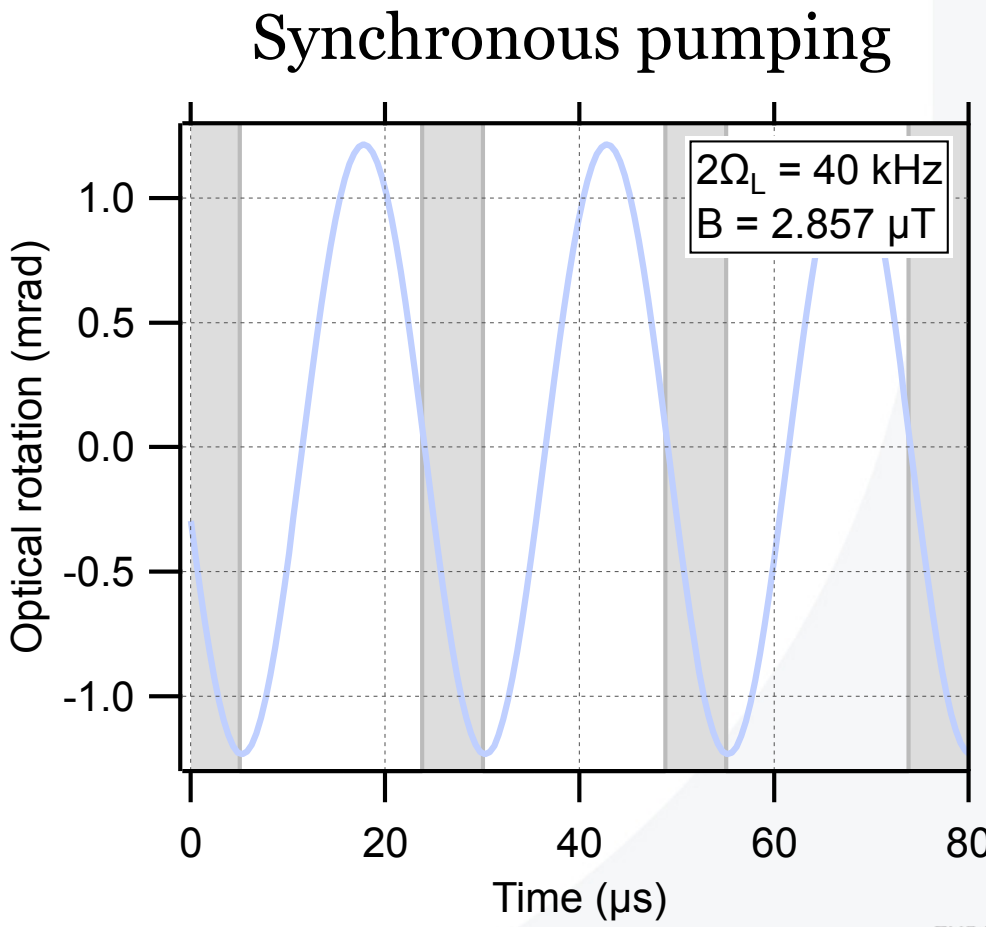
Pumping Atomic Vapour





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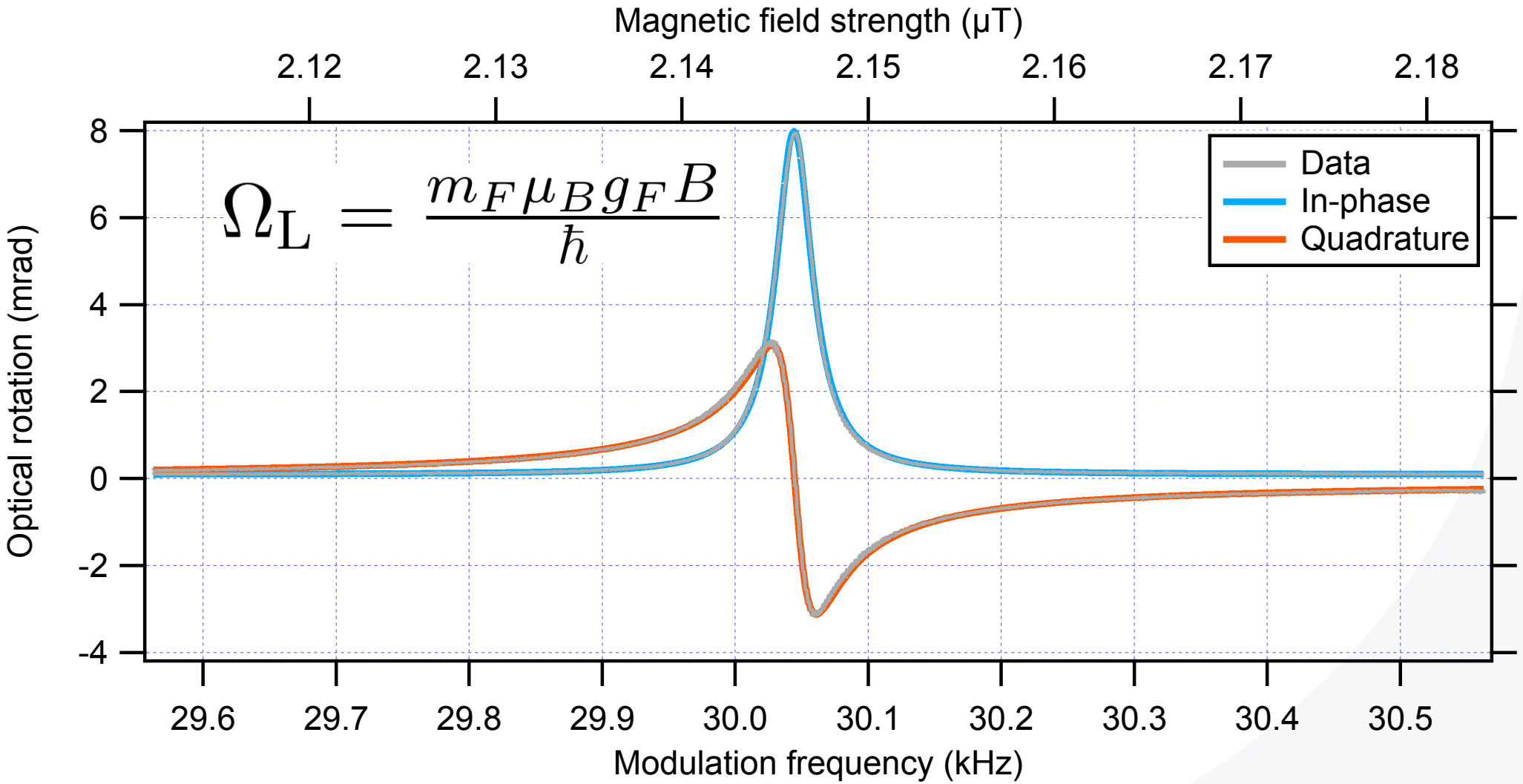
Conventional Measurement – Low Field



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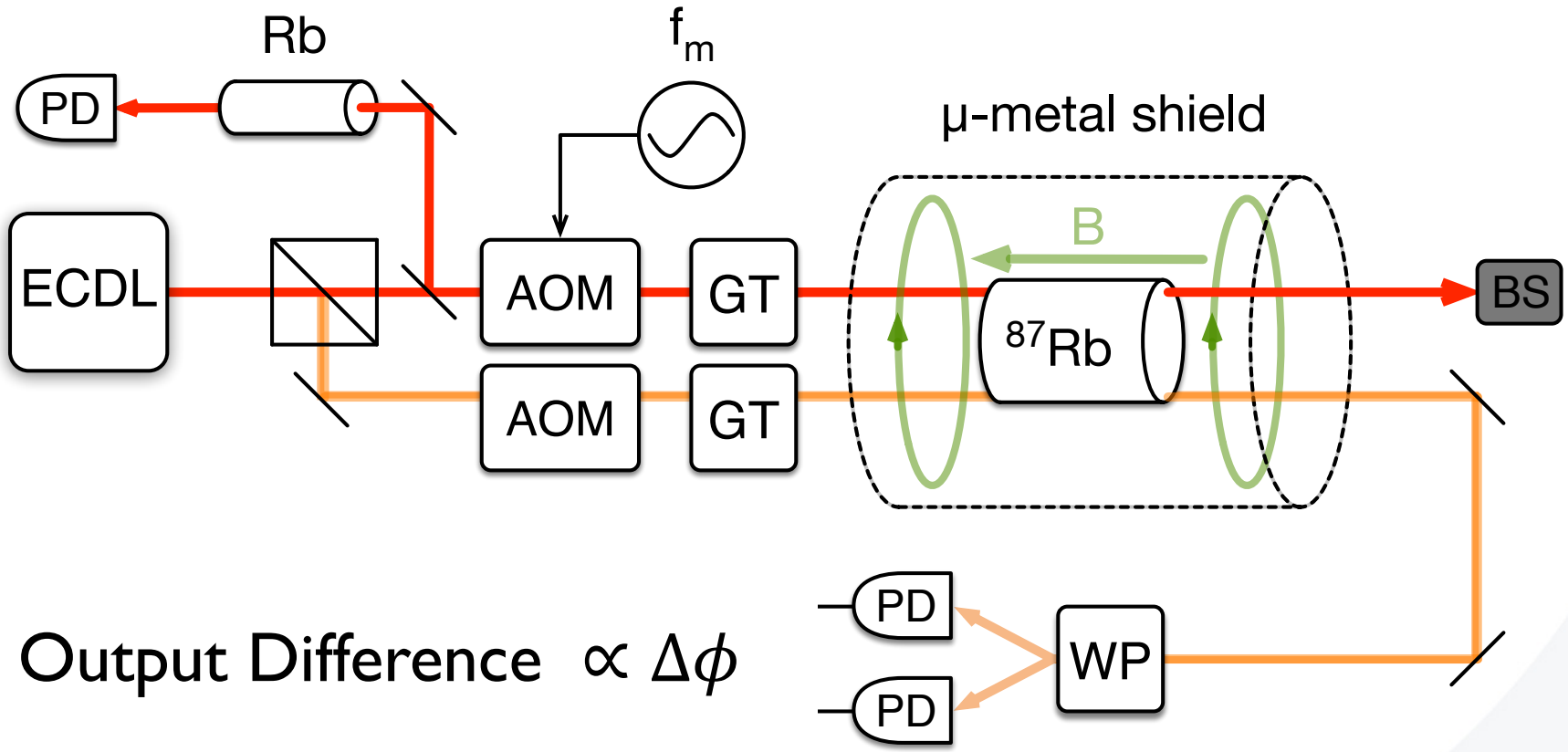
Measurement Technique



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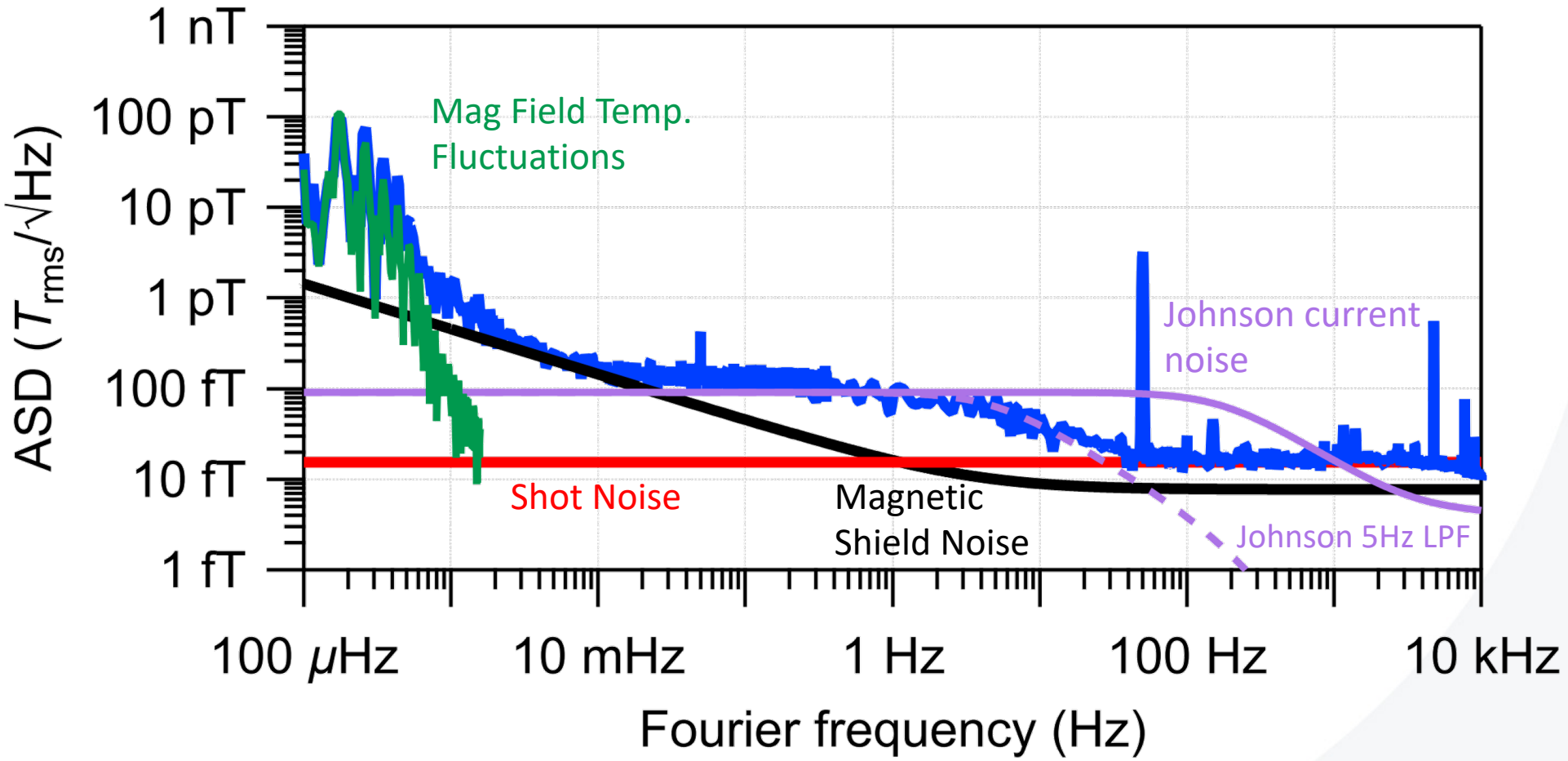
Indoor Performance



N. Wilson, et al (2019). *Physical Review Applied*, *11*(4), 044034.

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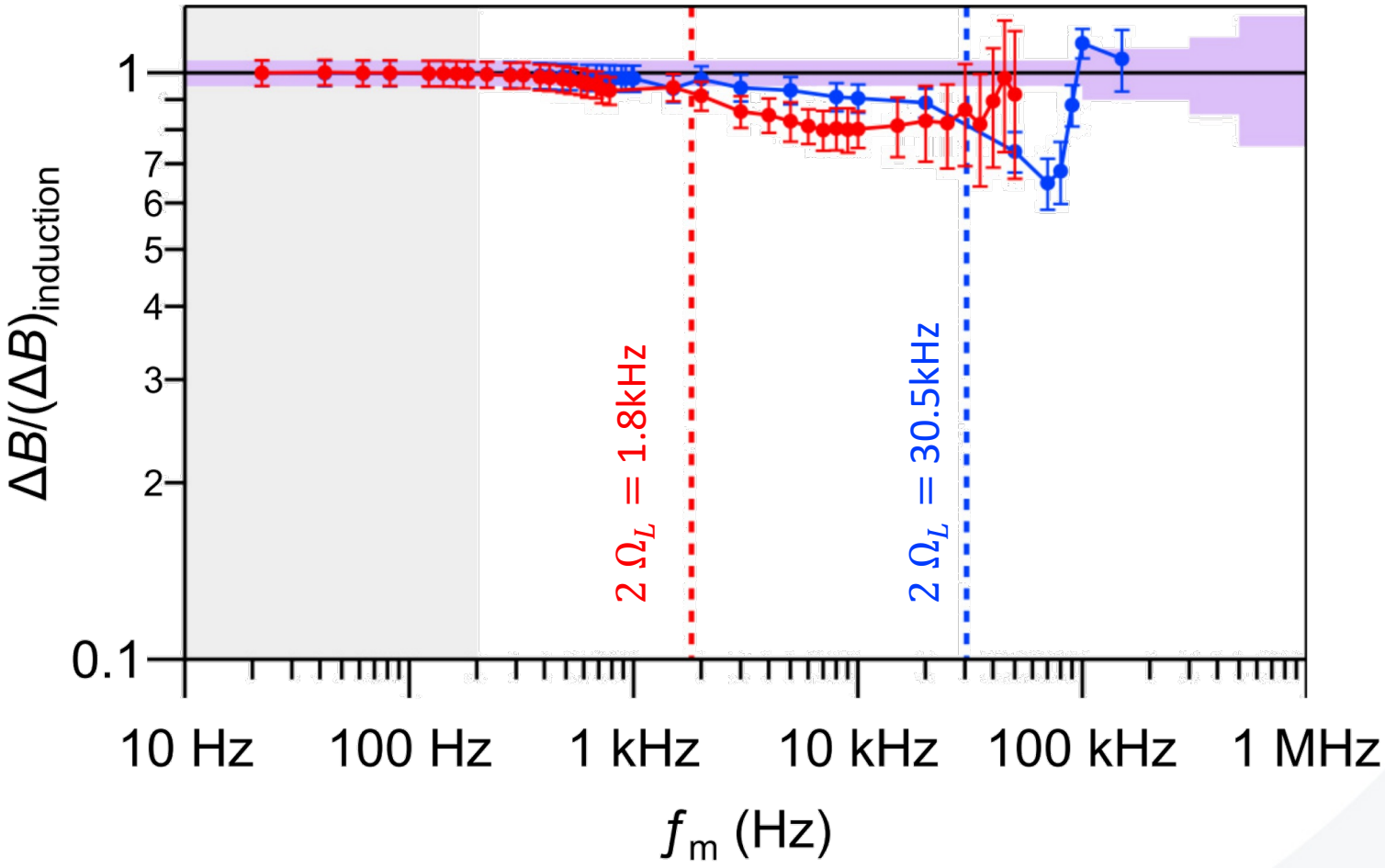
Indoor Performance



N. Wilson, et al. (2020). *Physical Review Research*, *2*(1), 1–9

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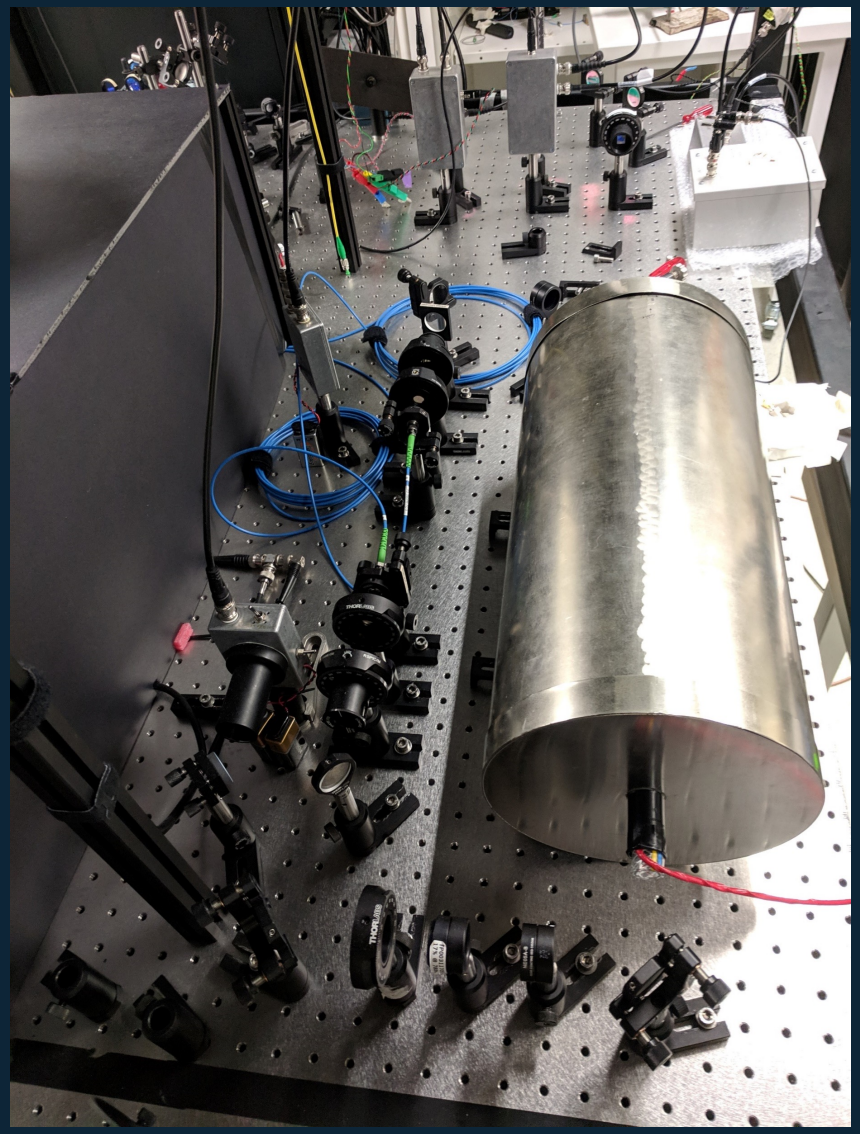
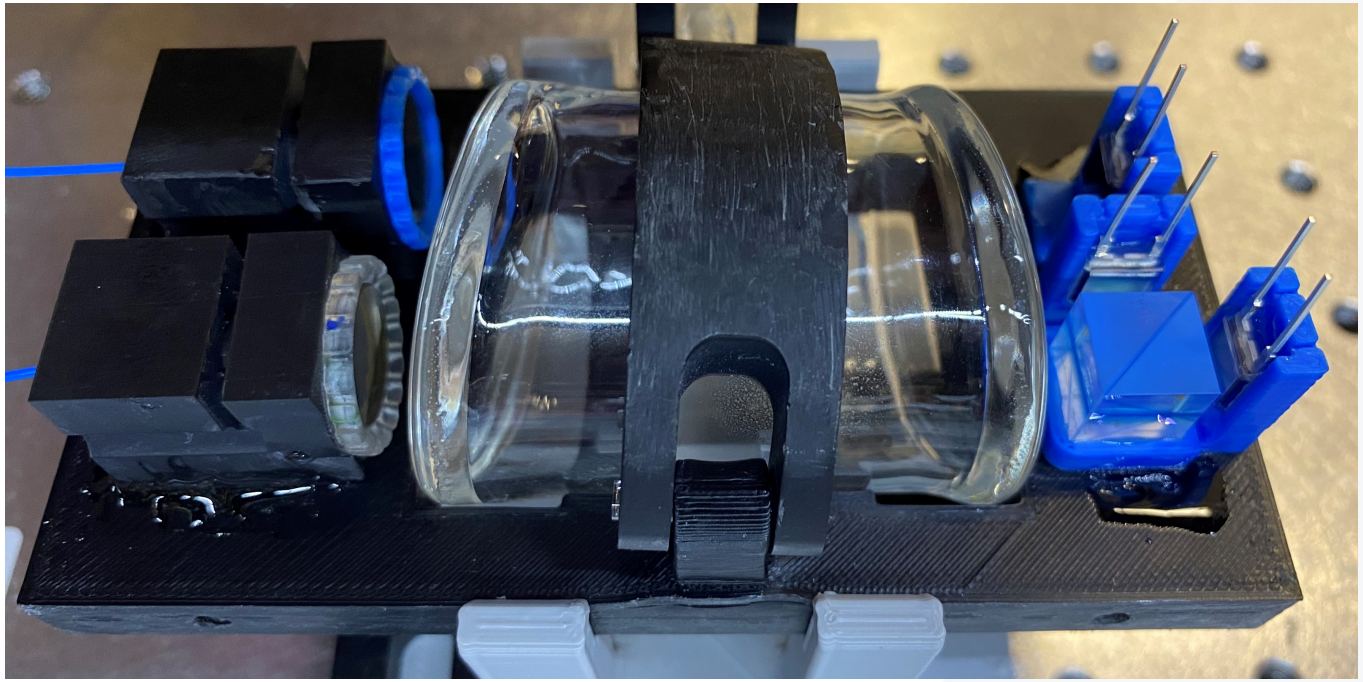
Lab-Based Sensor (2019)



Deployable Sensor (2021)

55 mm



150 mm

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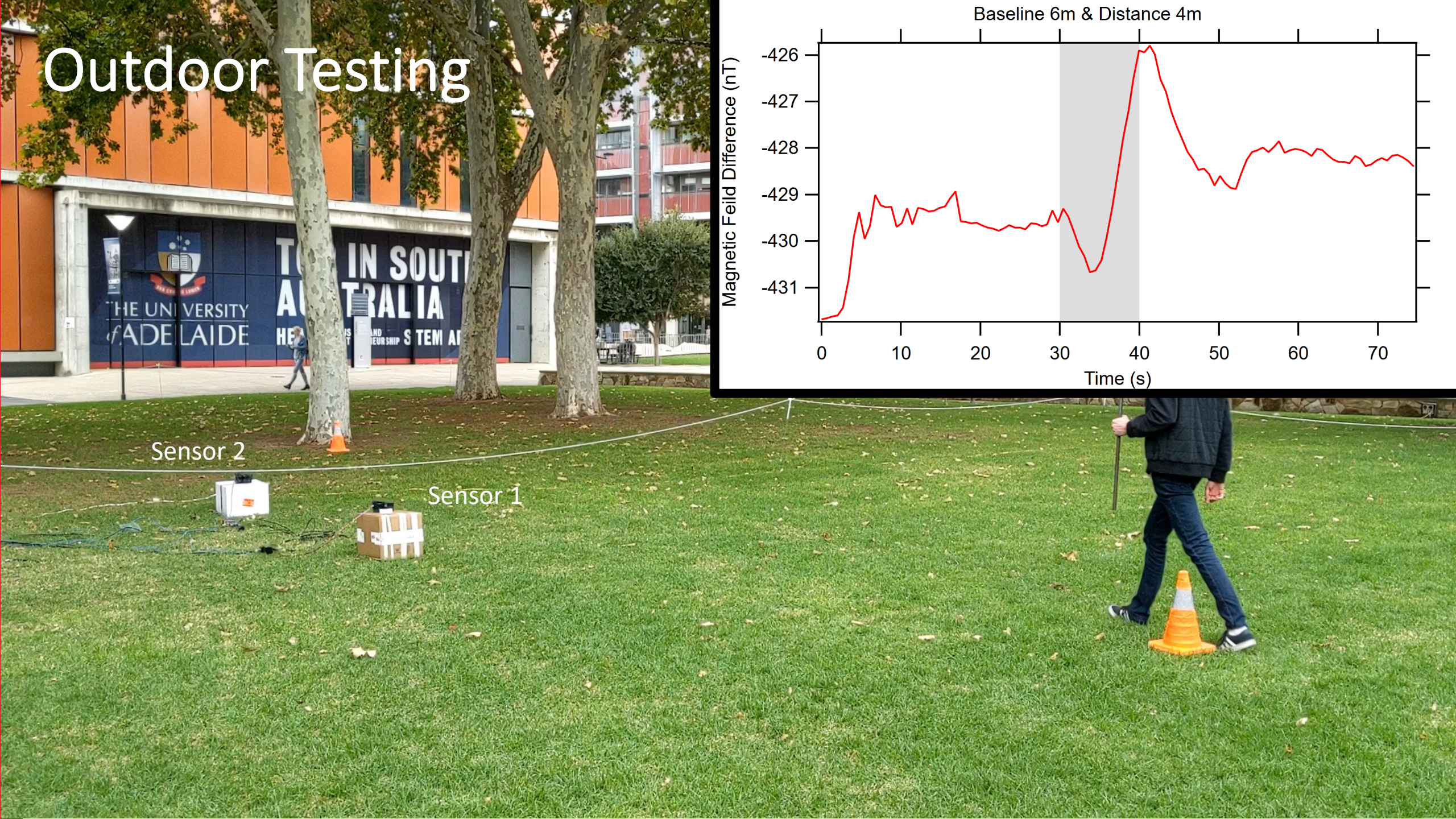
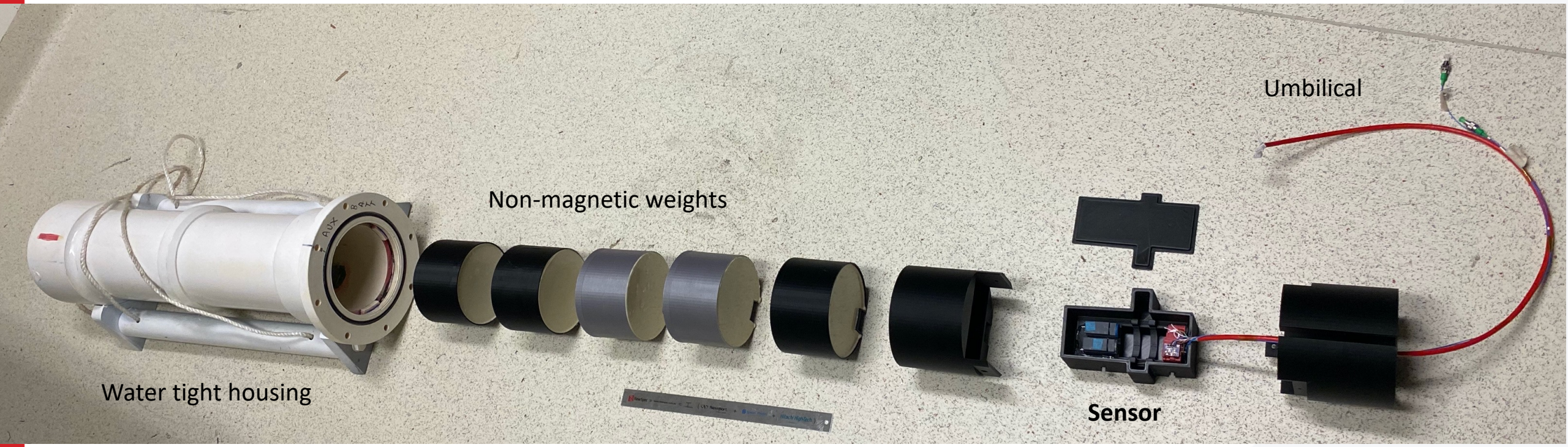
Outdoor Testing (2021)

Outdoor Testing



Underwater Housing



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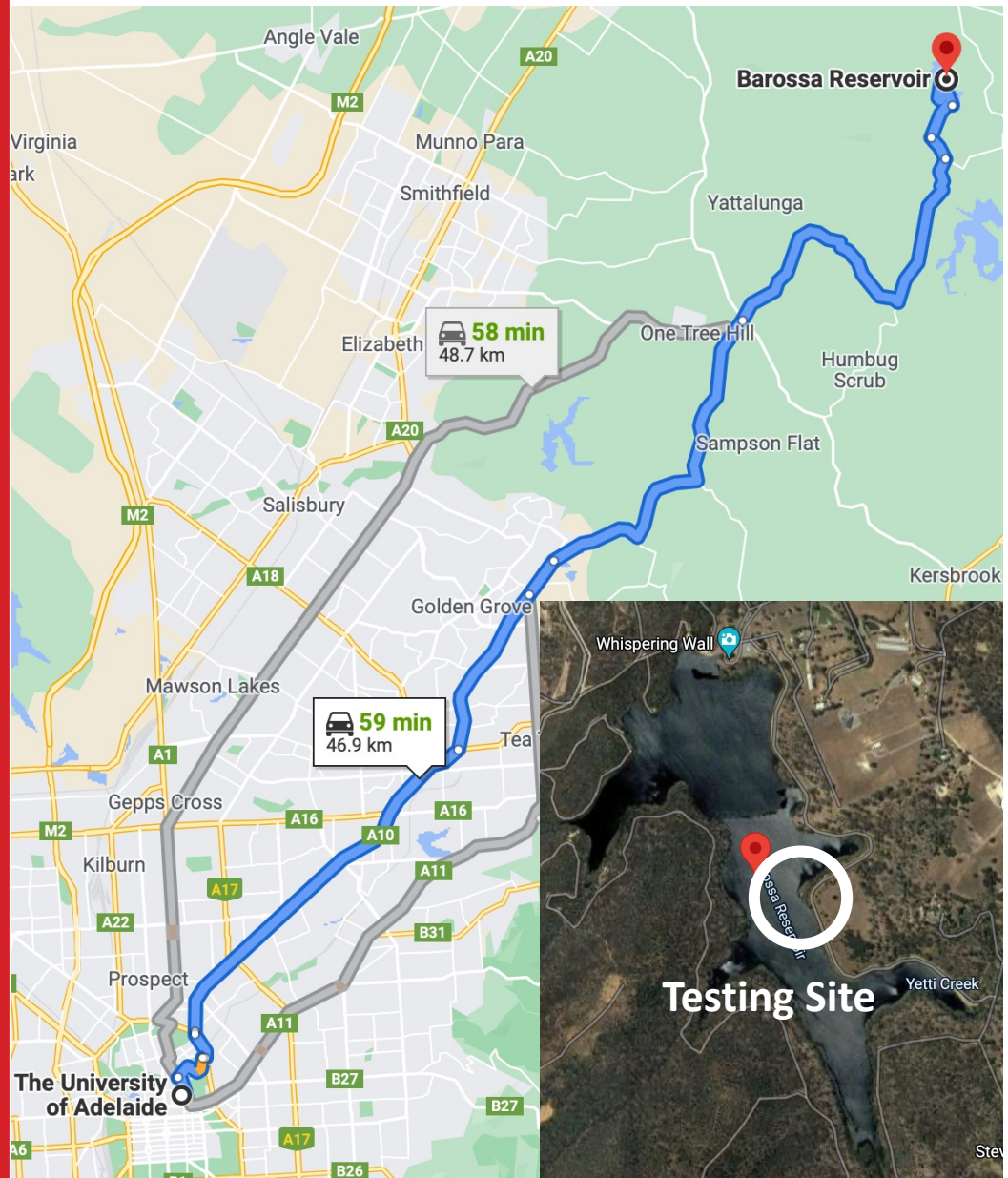
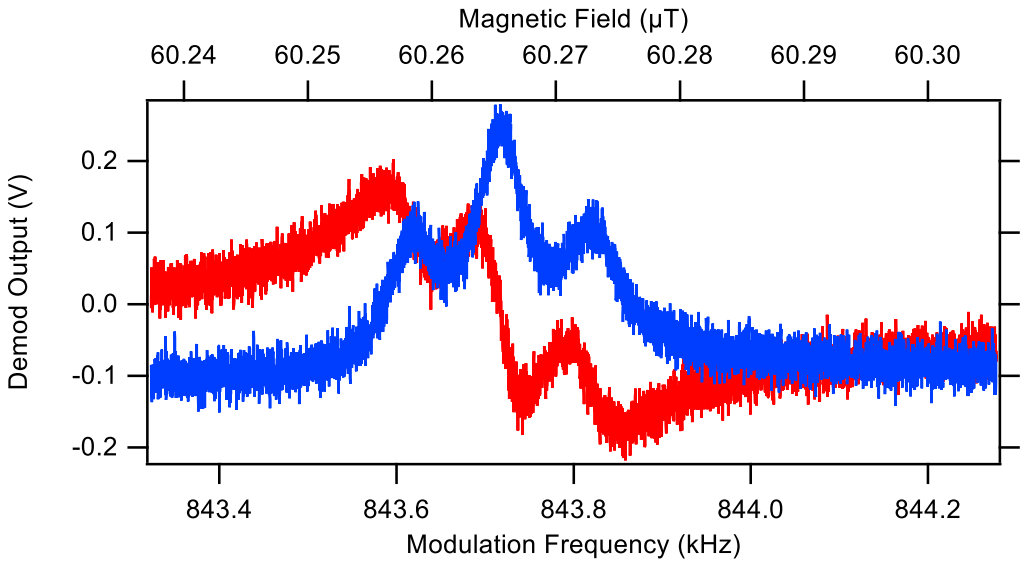
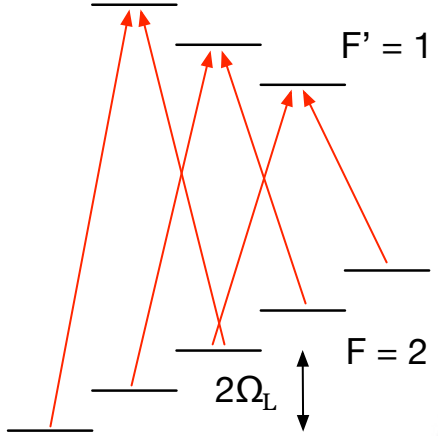
Barossa Reservoir Trials (2022)



Outdoor Noise Floor





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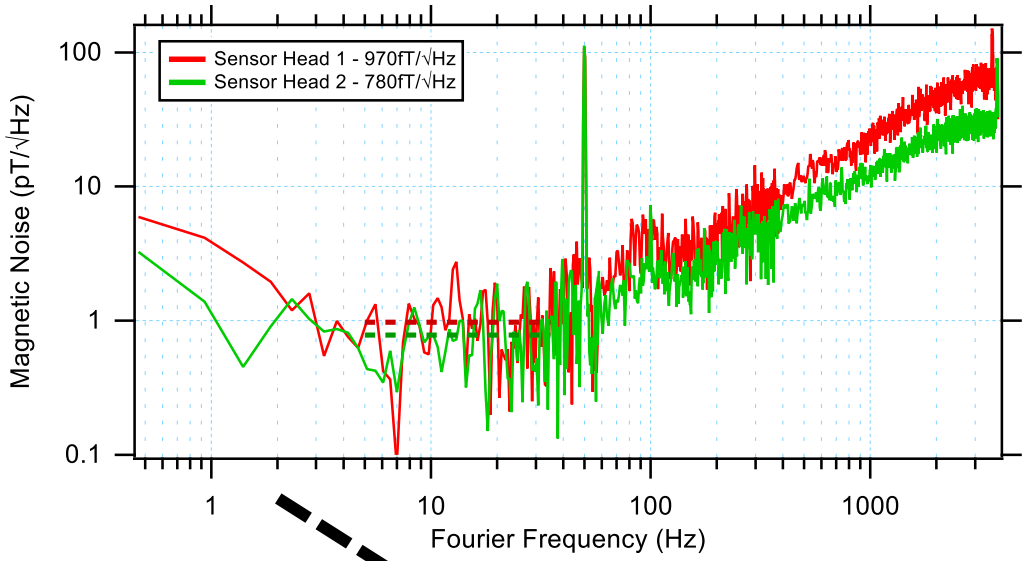
Outdoor Noise Floor



Geomag. Noise

Phase lock loop Noise

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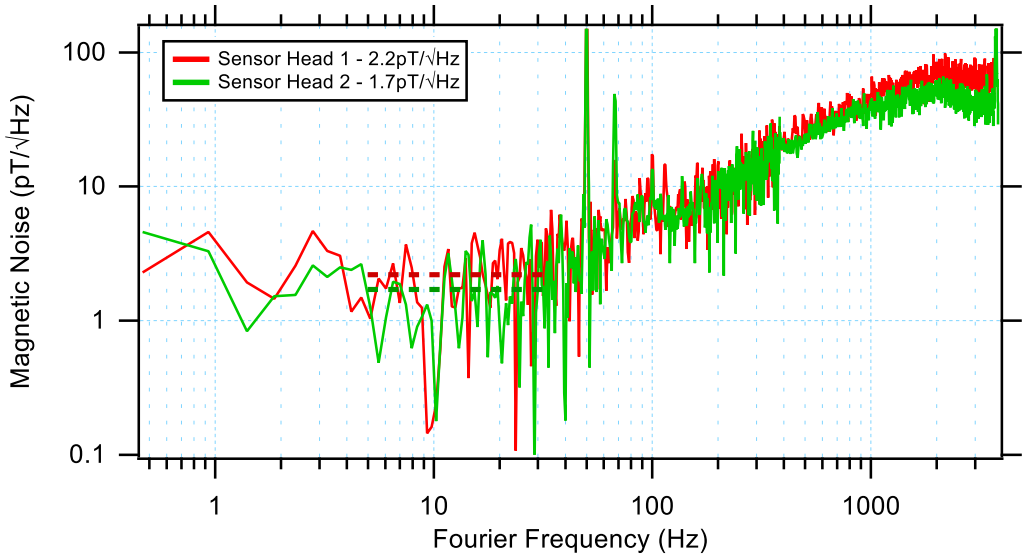
Barossa Reservoir Trials – Deployment

Barossa Reservoir Trials – RUV

Underwater Noise Floor



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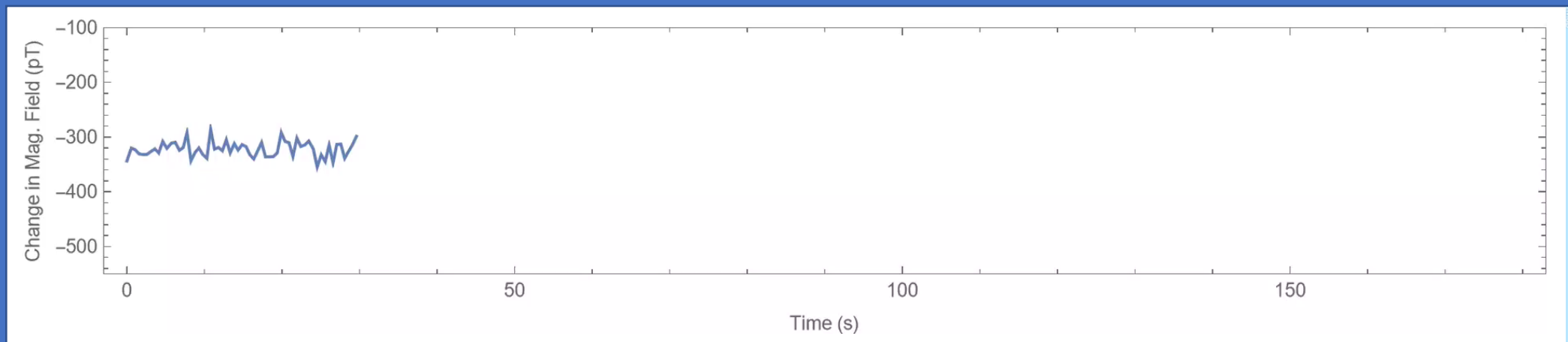
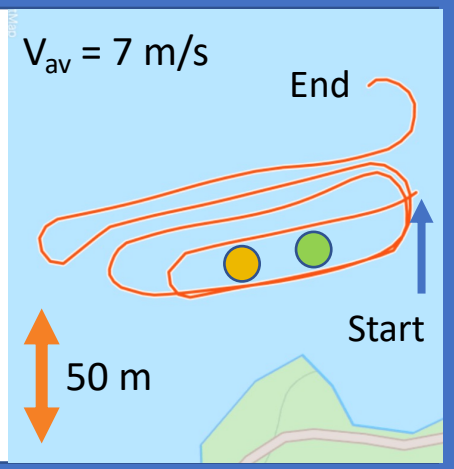
Barossa Reservoir Trials – Anomaly Detection

Sensor 1

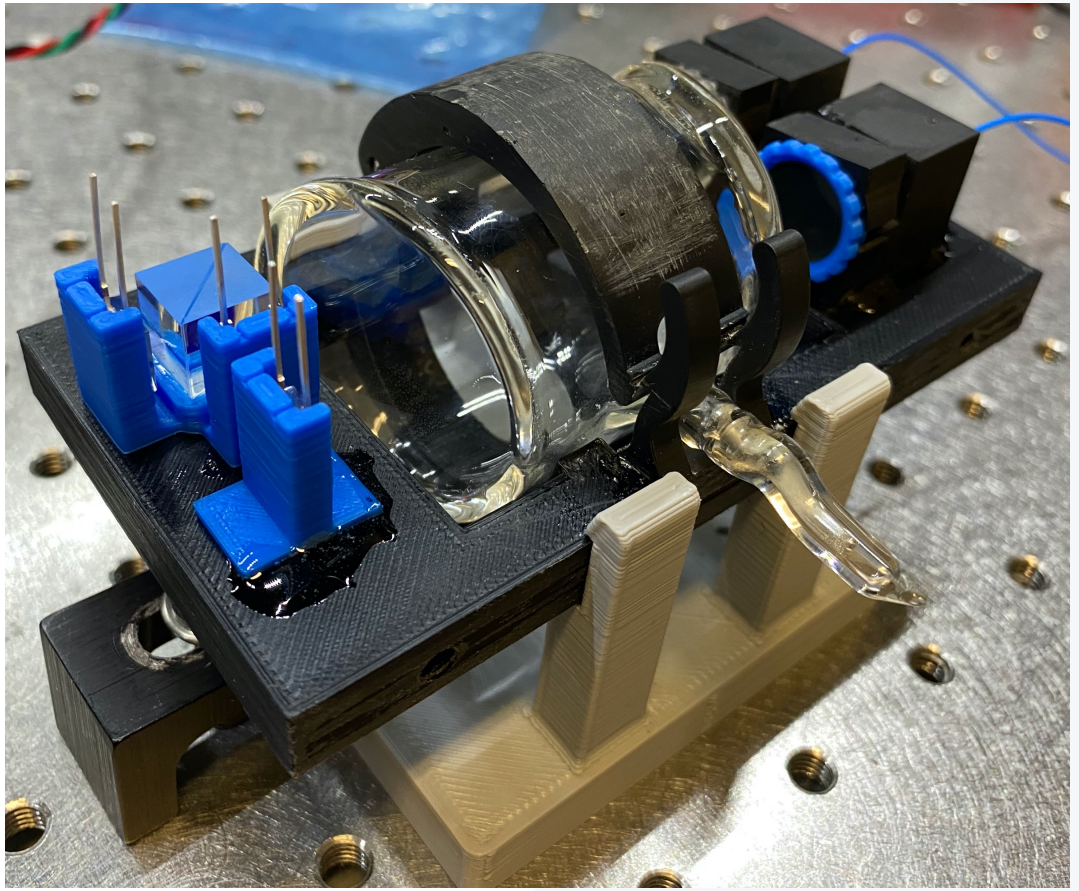
Sensor 2





Conclusions

- Lab demonstration achieved sensitivity of 20 fT/$\sqrt{\text{Hz}}$ at 2μT
- Indoor testing of miniature sensor head achieved sensitivity of 200 fT/$\sqrt{\text{Hz}}$
- Outdoor testing of miniature sensor head achieved sensitivity of 780 fT/ $\sqrt{\text{Hz}}$
- Underwater sensitivity of 1.2 pT/$\sqrt{\text{Hz}}$
- Detection of a RHIB at a distance of 40m



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Acknowledgements

- Defence Science and Technology Group:
  - Shane Wood, Marc Webber, Lachlan Jones,
    Dr Joanne Harrison, Next Generation Technologies Fund
- University of Adelaide:
  - Dr Rujie Li, Dr Nicolas Bourbeau Herbert
- Australian National Fabrication Facility Optofab Node:
  - Alastair Dowler, Lijesh Thomas

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Questions?

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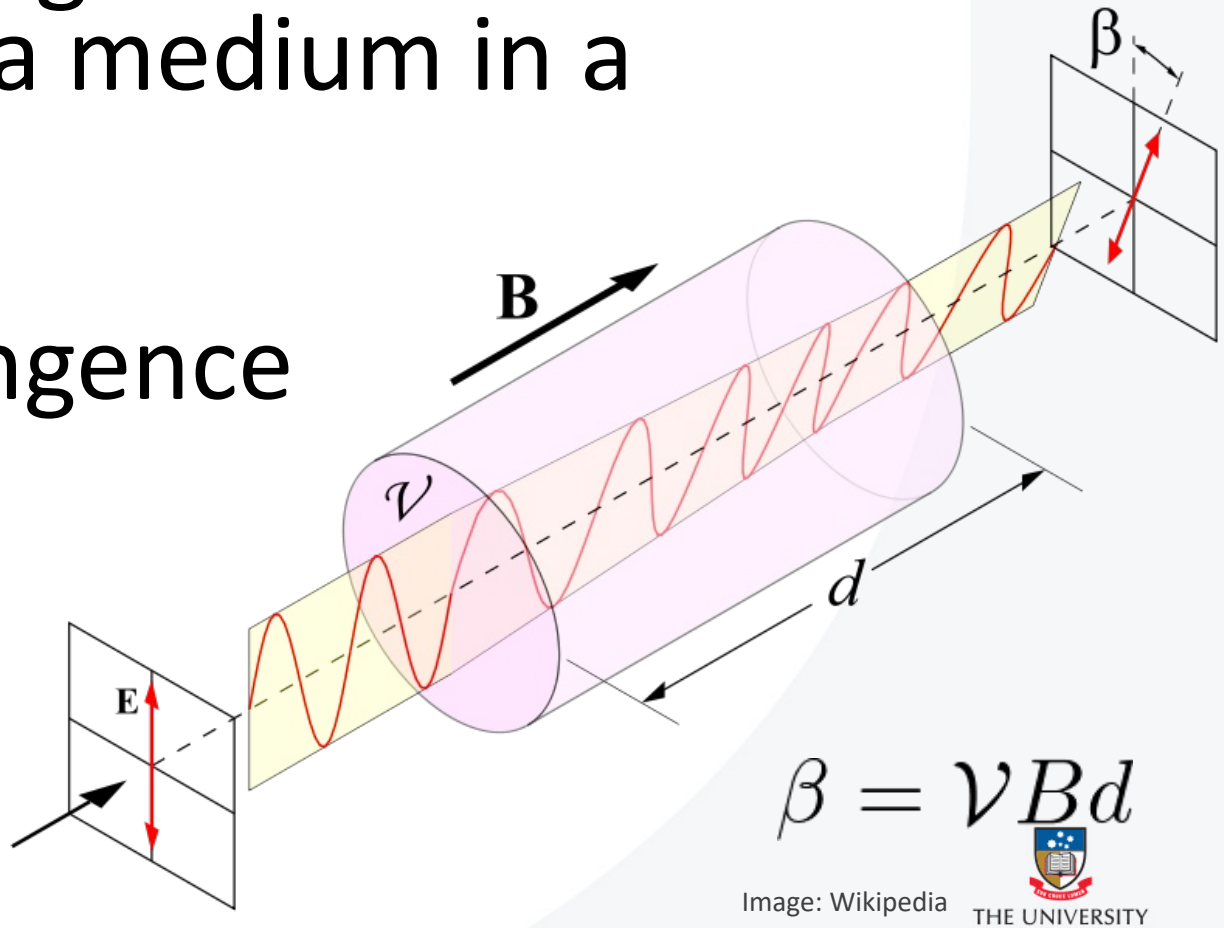
Probing: Faraday effect

- Plane of polarisation of light will be rotated when it travels through a medium in a magnetic field
- Result of circular birefringence



$$\beta = \mathcal{V} B d$$

Image: Wikipedia

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