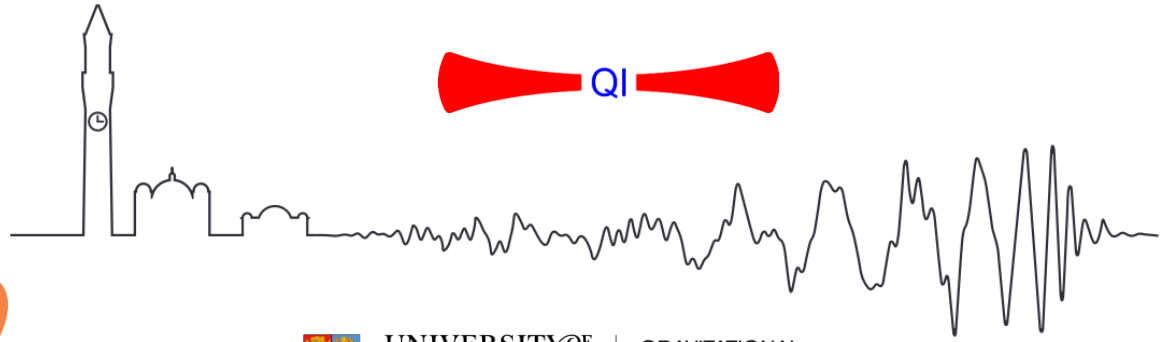
LIDA:
First results and future prospects

Joscha Heinze (speaker),
Artemiy Dmitriev, Alex Gill, Jiri Smetana, Tiangliang Yan, Vincent Boyer, and Denis Martynov



since 1966 Rencontres de Moriond

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UKRI Engineering and Physical Sciences Research Council

Laser-**I**nterferometric **D**etector for **A**xions: First results and future prospects

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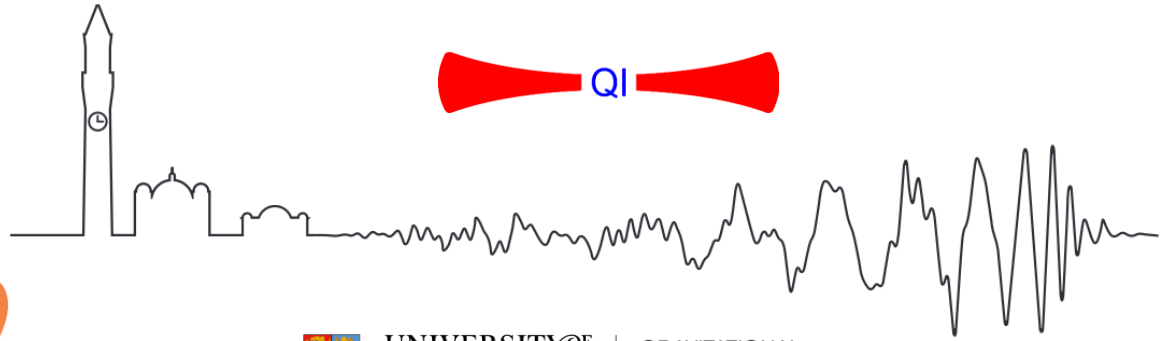

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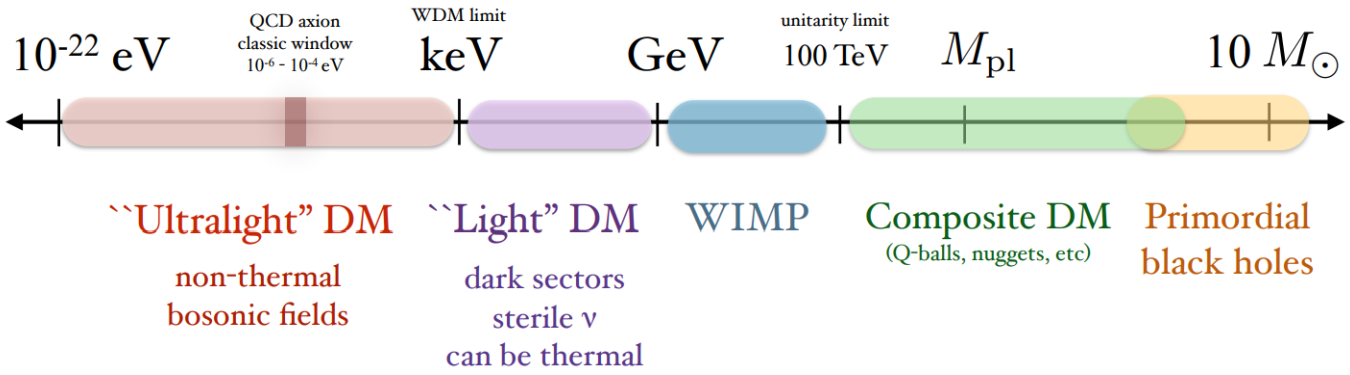
Mass range



T. Lin, arXiv:1904.07915 (2019)

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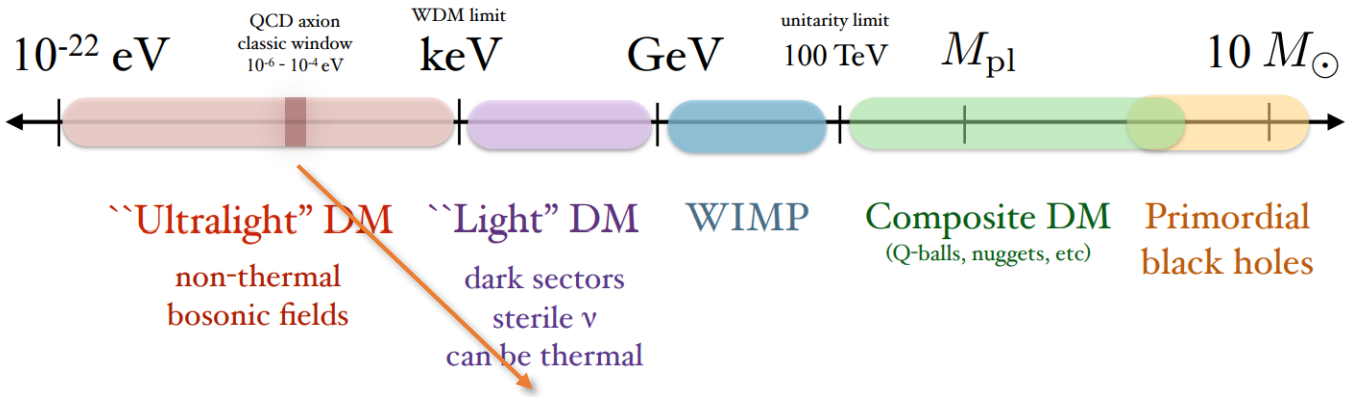
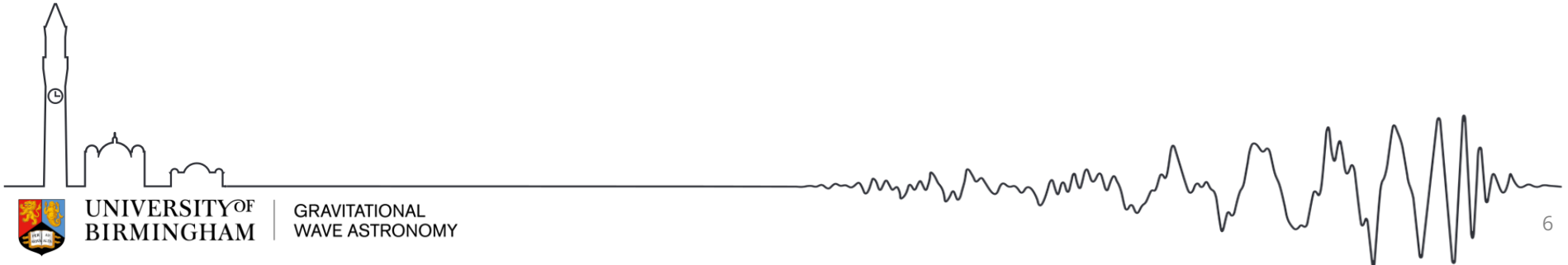


Wave-like: $a(t) = a_0 \sin(\Omega_a t)$

T. Lin, arXiv:1904.07915 (2019)

Operating principle



Operating principle

- Directly detect axions and axion-like particles ($10^{-16} - 10^{-8}$ eV).

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$$\mathcal{L} = \frac{g_{a\gamma}}{4} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

Lagrangian $\mathcal{L}$
a: axion field
$g_{a\gamma}$: coupling coefficient
F: electromagnetic field-strength tensor

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Lagrangian $\mathcal{L}$

wave equation for electric field $\boldsymbol{E}$

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$$\Rightarrow \quad \frac{\partial^2 \boldsymbol{E}}{\partial t^2} - \nabla^2 \boldsymbol{E} = g_{a\gamma} \dot{a} (\nabla \times \boldsymbol{E}) \quad \Rightarrow$$

wave equation for electric field $\boldsymbol{E}$

$$\Delta\phi = g_{a\gamma}[a(t) - a(t-\tau)]$$

phase difference $\Delta\phi$ between left- and right-handed circular polarisation

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wave equation for electric field $\boldsymbol{E}$

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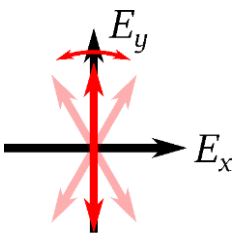
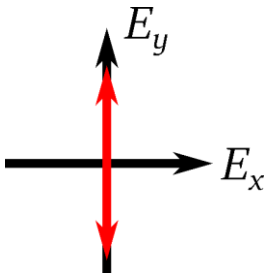
phase difference $\Delta\phi$ between left- and right-handed circular polarisation

Observable effect:
Rotation of linear polarisation!

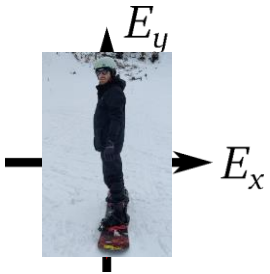


Signal generation



Input: linear s-polarisation.

Signal generation



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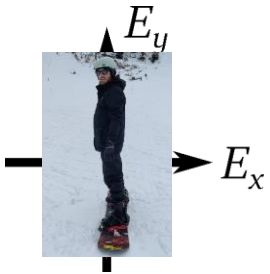

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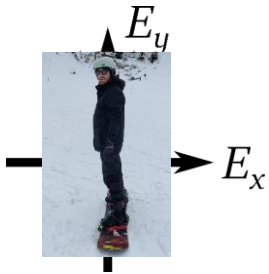

Effect: polarisation rotation.

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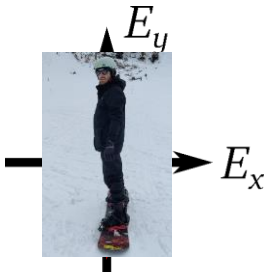

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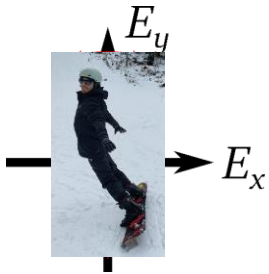

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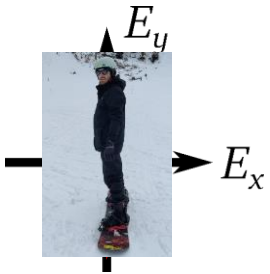

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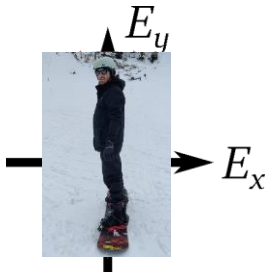

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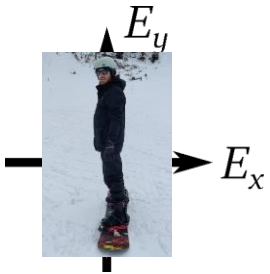

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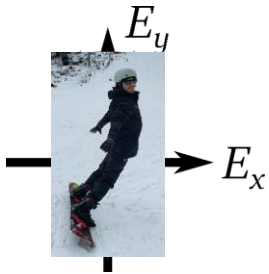

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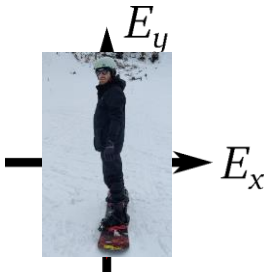

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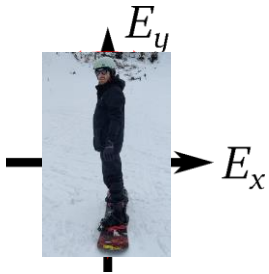

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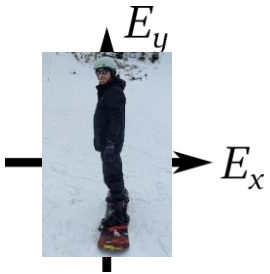

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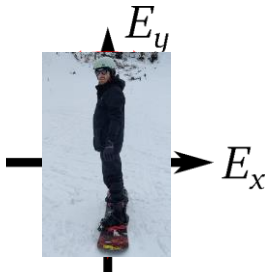

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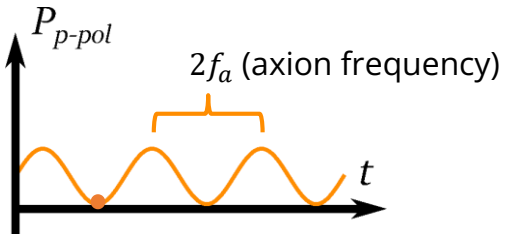
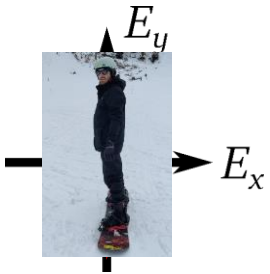


Output: signal in p-polarisation.

Signal generation



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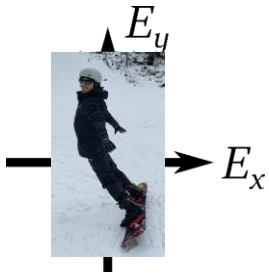

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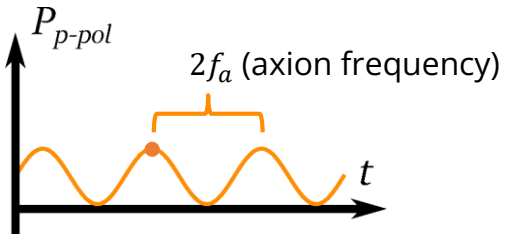

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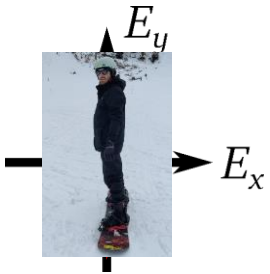

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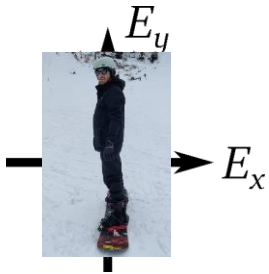

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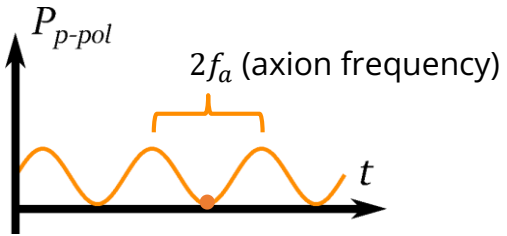

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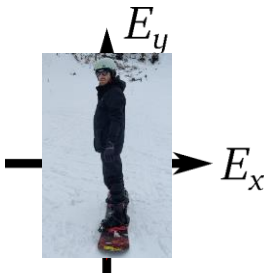

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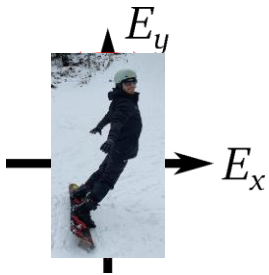

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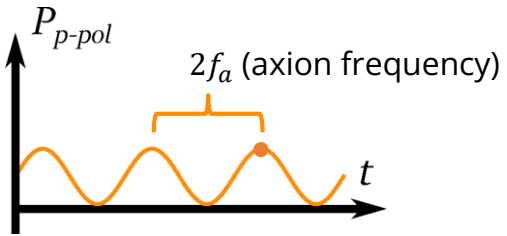

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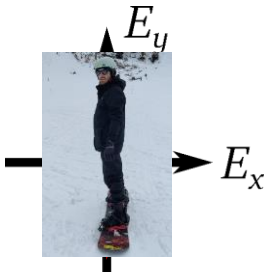

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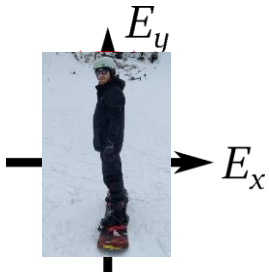

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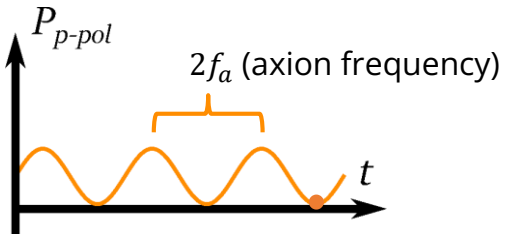
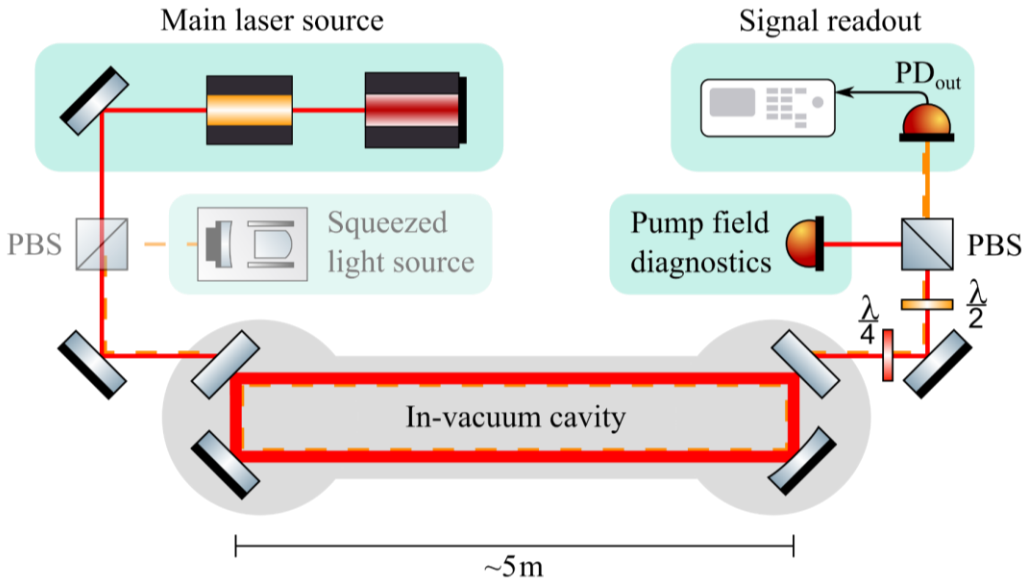


Output: signal in p-polarisation.

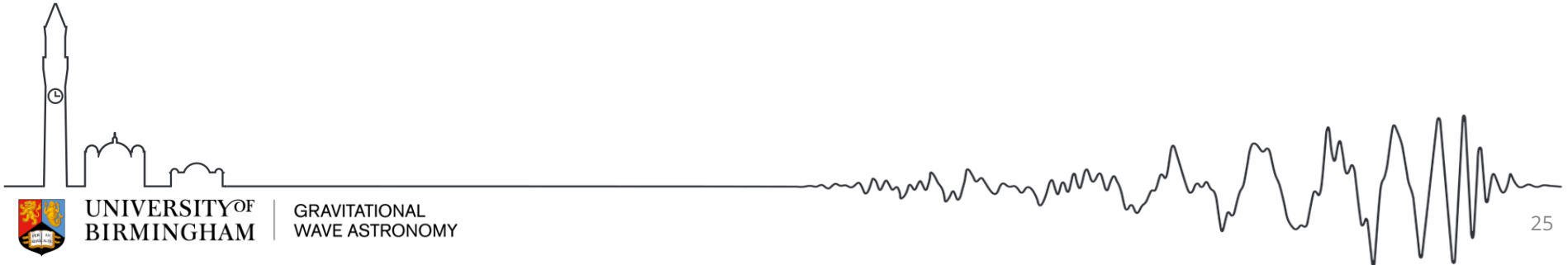
Detector design



Tabletop demonstration:

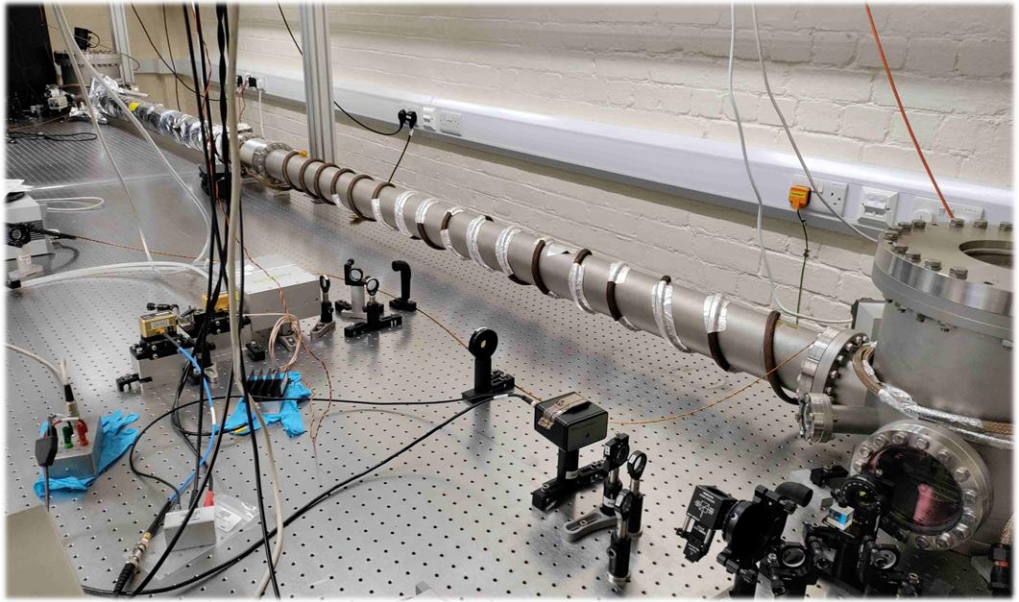
- **200 kW** intra-cavity power to enhance signal
- **5 m** baseline to increase interaction time
- vacuum system
- **6 months** integration time for larger signal-to-noise ratio
- **squeezed light** to reduce quantum noise by up to 10 dB

Status and first results



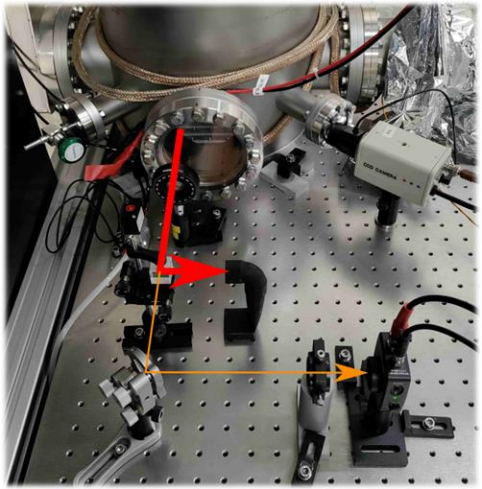
LIDA in the lab

- 5 m long vacuum system!

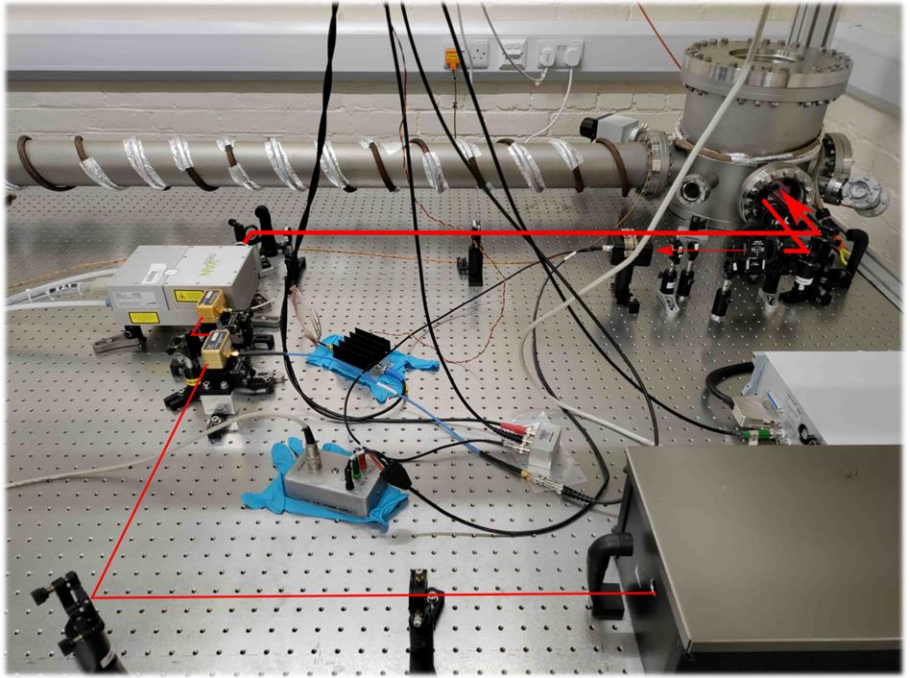


LIDA in the lab

- 5 m long vacuum system!
- Input and readout setup!



Readout



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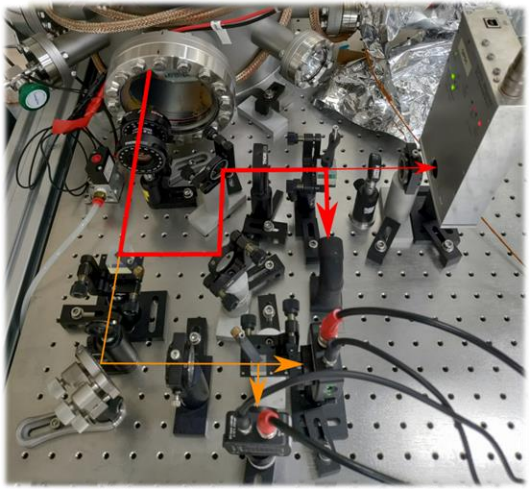

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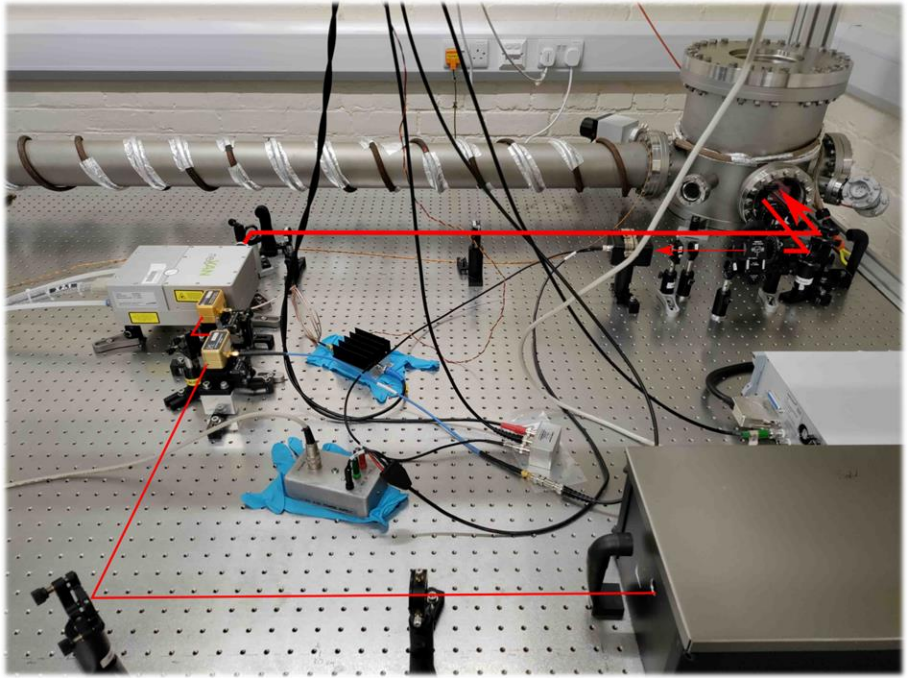


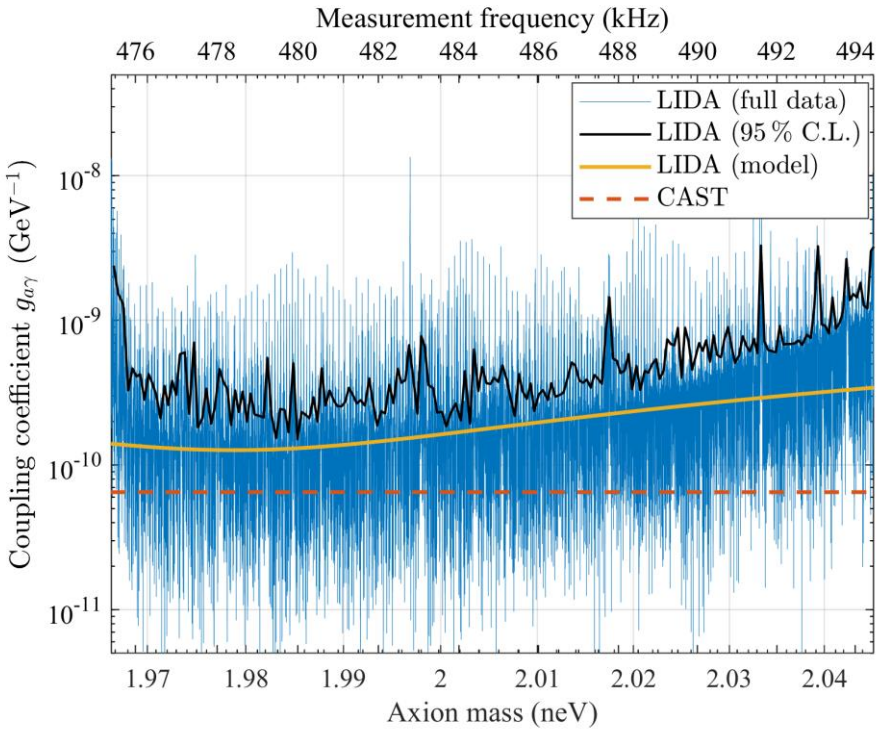
Input

1st science run

	First run
Input pump power	12 W
Intra-cavity power	118 kW
Measurement time	85 h
Squeezing level	–
Detuning	478 kHz

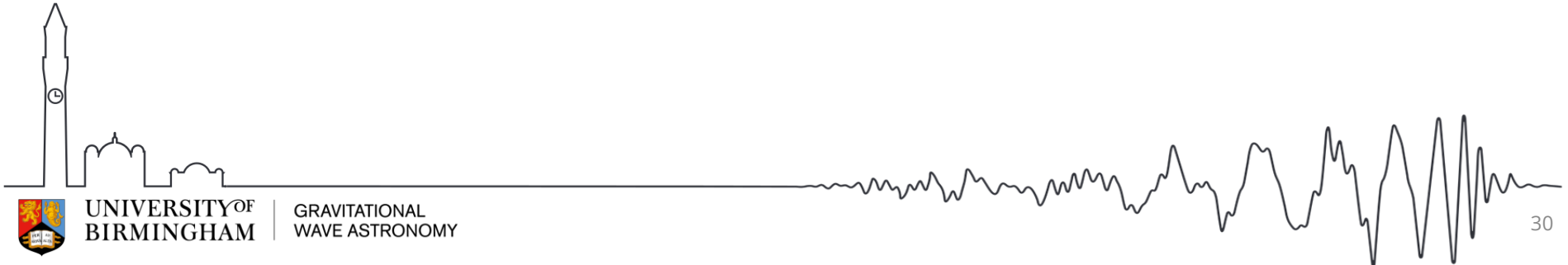
Peak sensitivity: $\mathbf{1.51 \times 10^{-10}\,GeV^{-1}}$

Avg sensitivity: $\mathbf{3.2 \times 10^{-10}\,GeV^{-1}}$



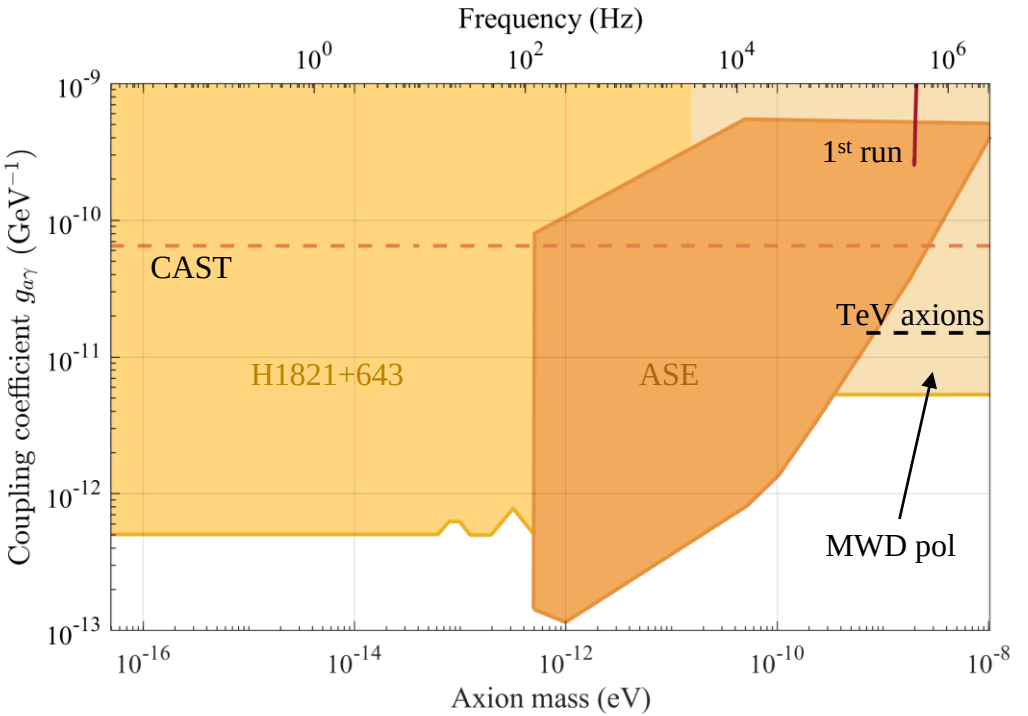
Published: J Heinze, et. al., arXiv:2307.01365 *(Accepted by PRL)*

Prospects for LIDA



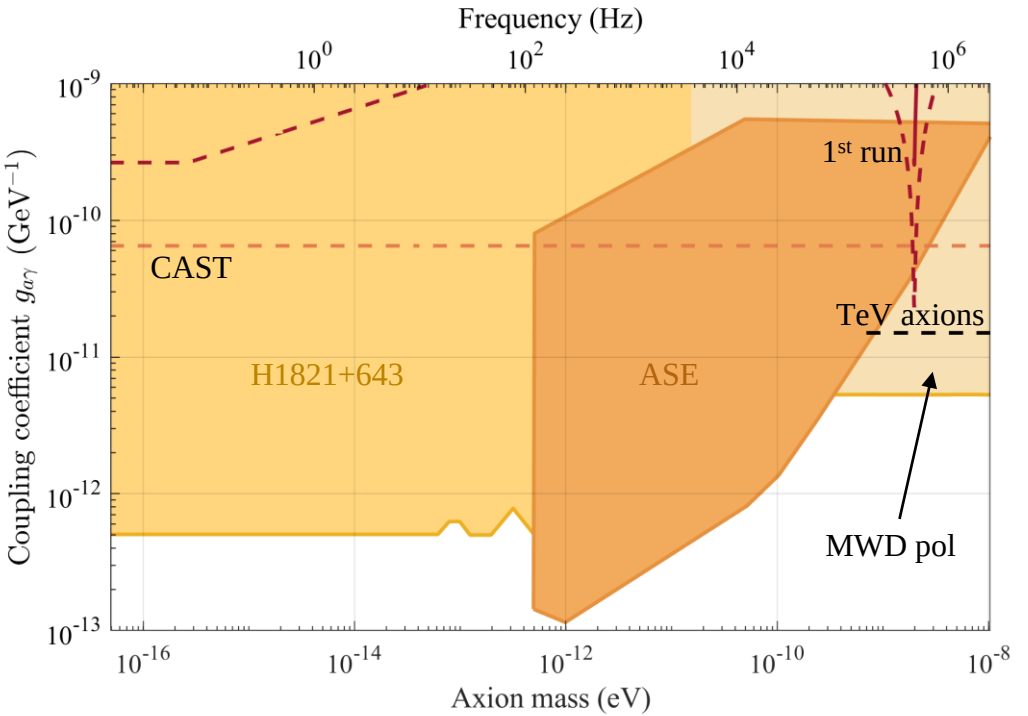
Prospects for LIDA

	First run	Next run
Intra-cavity power (kW)	118	?
Measurement time	85 h	?
Squeezing level (dB)	–	?
Detuning	478 kHz	?



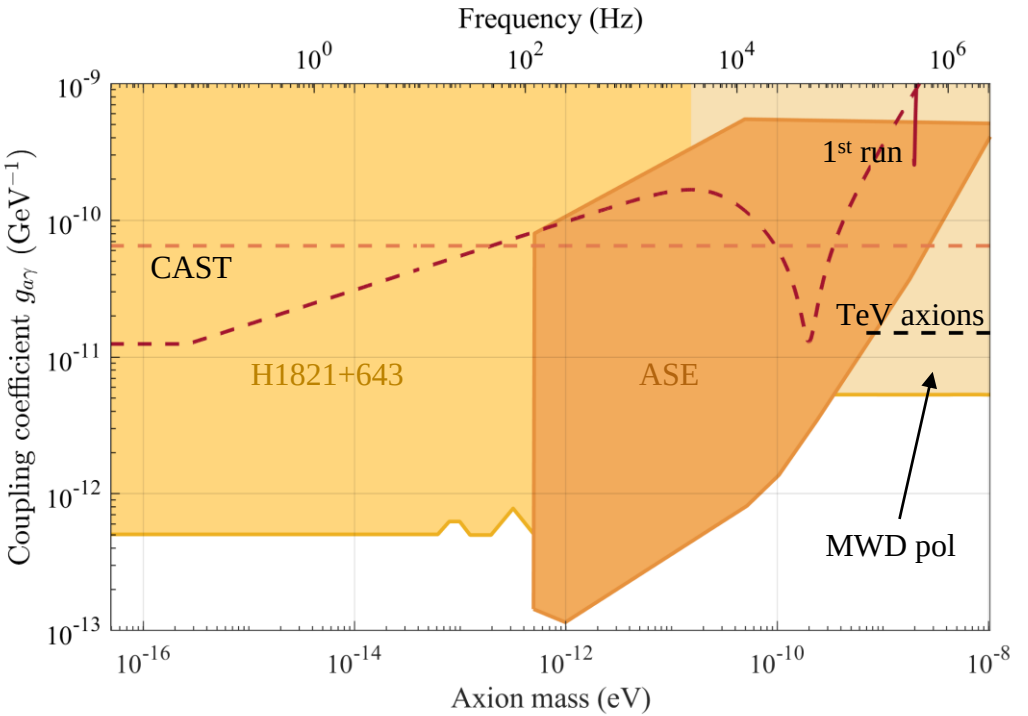
Prospects for LIDA

	First run	Next run
Intra-cavity power (kW)	118	200
Measurement time	85 h	6 months
Squeezing level (dB)	–	10 dB
Detuning	478 kHz	478 kHz



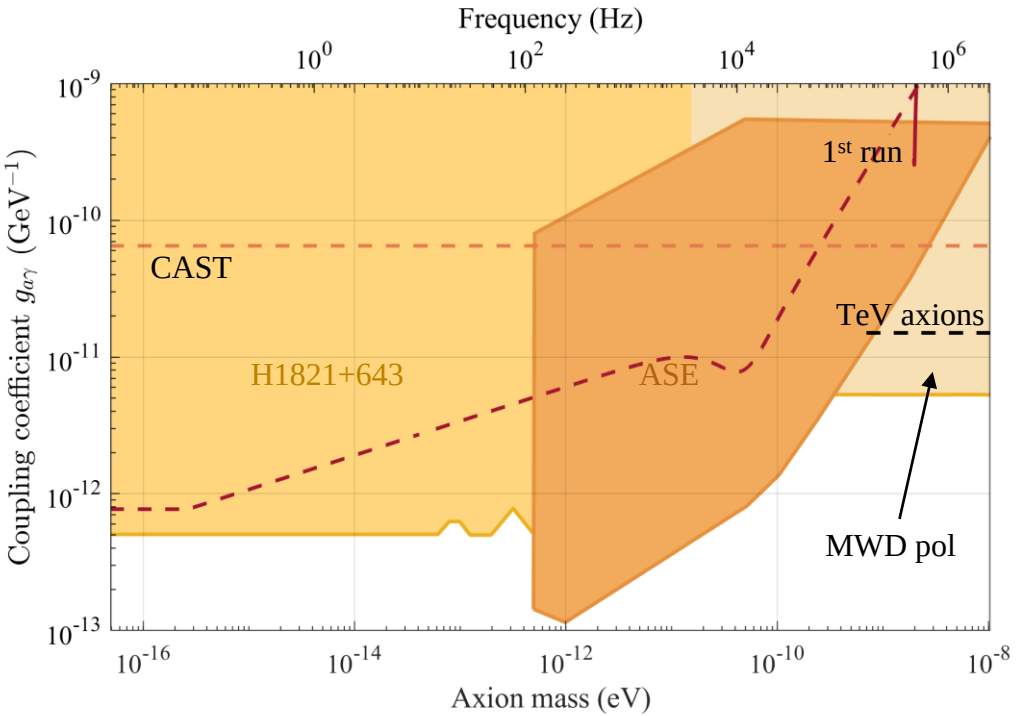
Prospects for LIDA

	First run	Next run
Intra-cavity power (kW)	118	200
Measurement time	85 h	6 months
Squeezing level (dB)	–	10 dB
Detuning	478 kHz	48 kHz



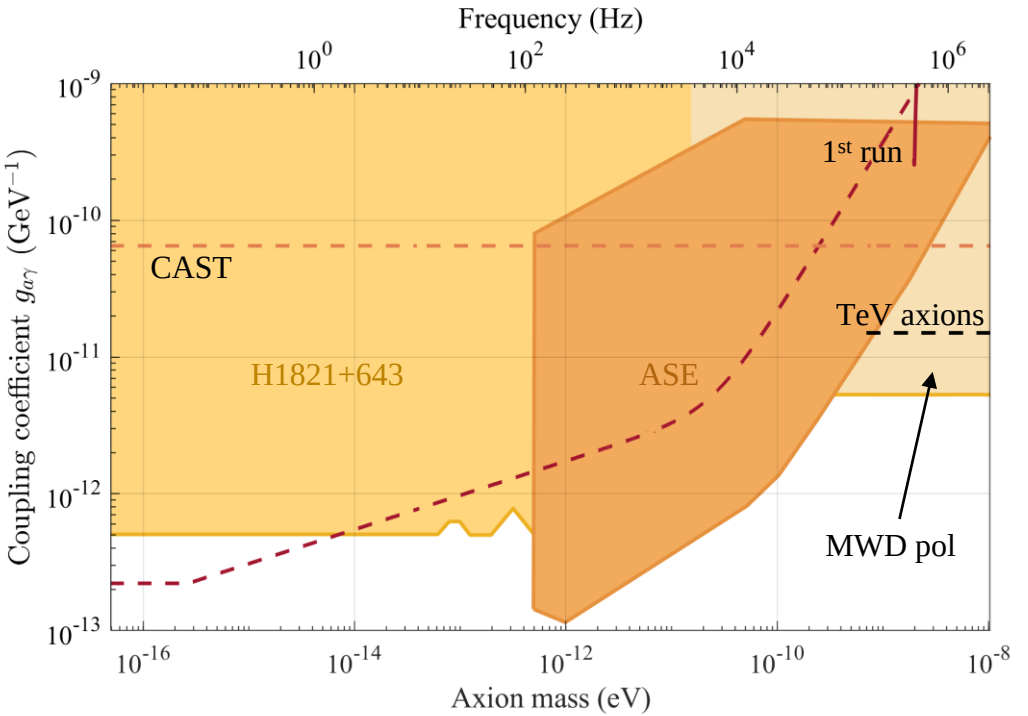
Prospects for LIDA

	First run	Next run
Intra-cavity power (kW)	118	200
Measurement time	85 h	6 months
Squeezing level (dB)	–	10 dB
Detuning	478 kHz	10 kHz



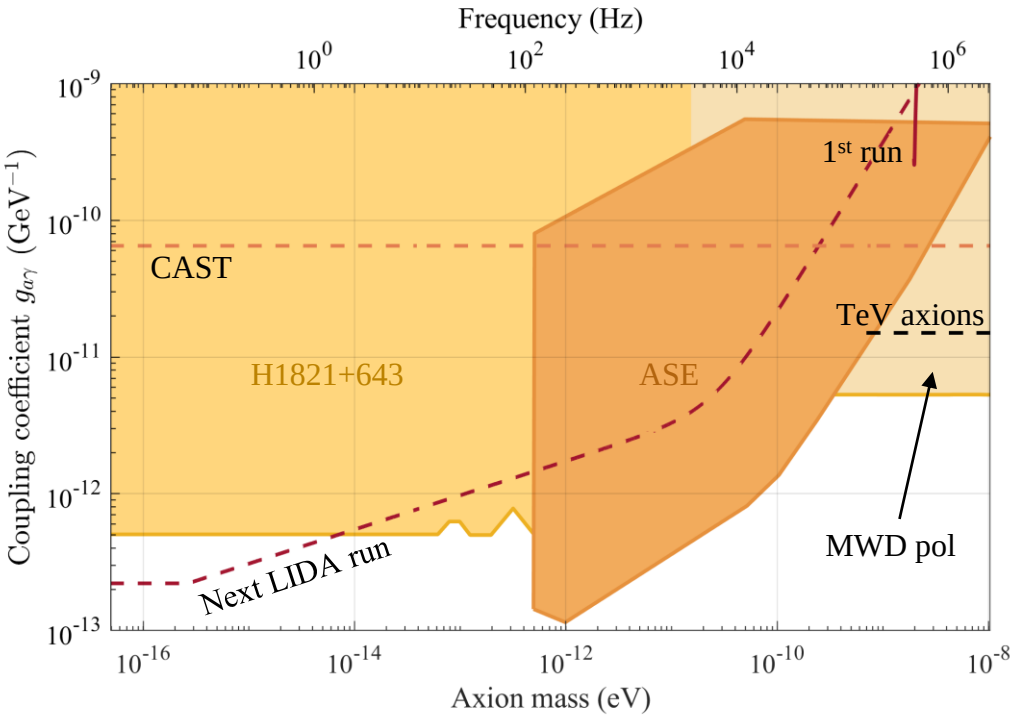
Prospects for LIDA

	First run	Next run
Intra-cavity power (kW)	118	200
Measurement time	85 h	6 months
Squeezing level (dB)	–	10 dB
Detuning	478 kHz	0 kHz

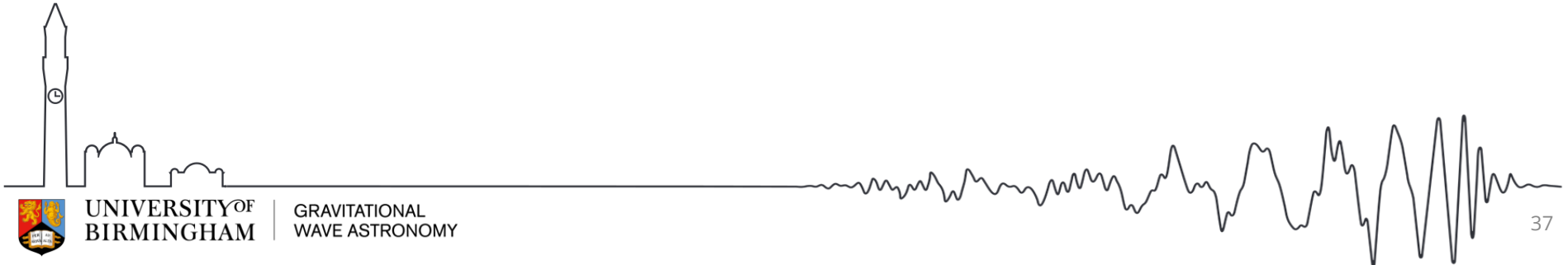


Prospects for LIDA

	First run	Next run
Intra-cavity power (kW)	118	200
Measurement time	85 h	6 months
Squeezing level (dB)	–	10 dB
Detuning	478 kHz	0 kHz

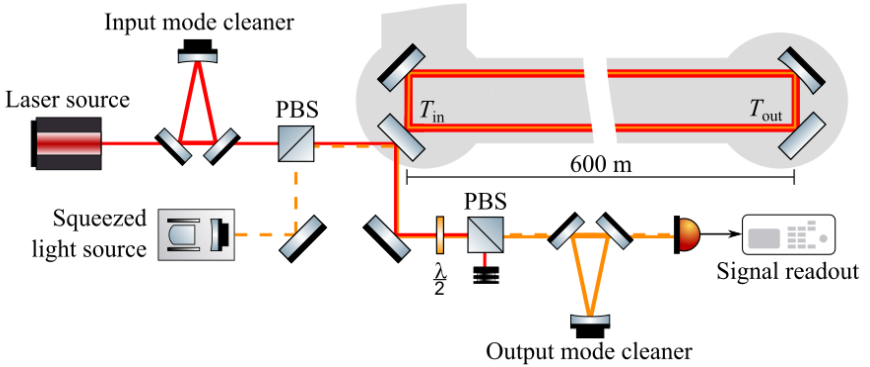


Proposal for GEO600



GEO600 → DarkGEO

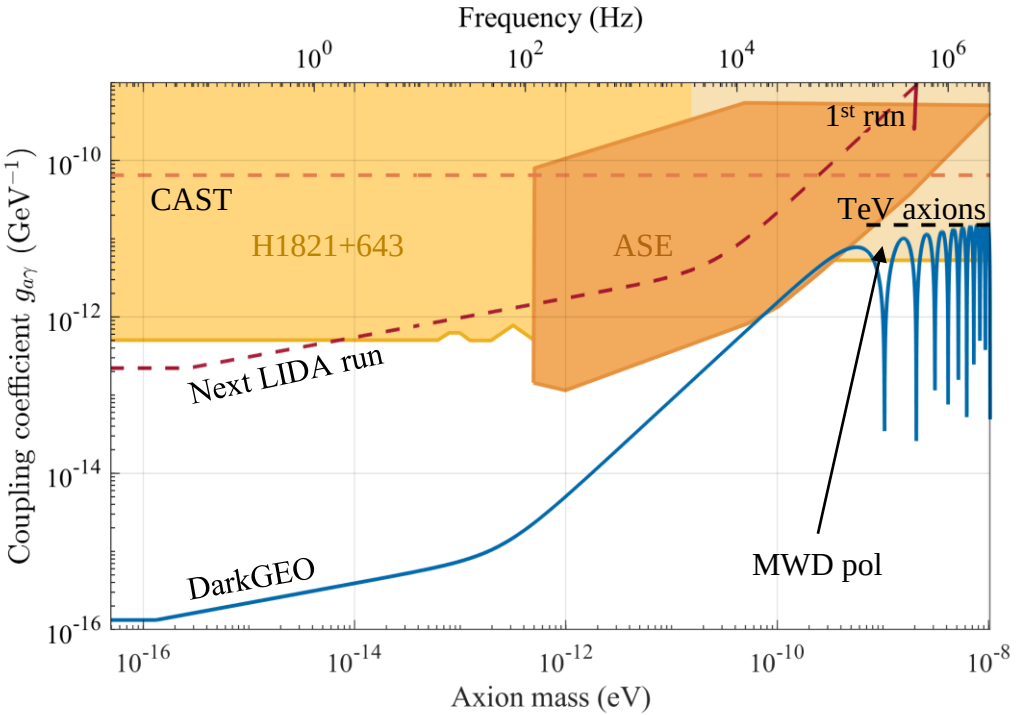
GEO600: close to Hanover, Germany (credit: geo600.org)



Published: J Heinze, et. al., arXiv:2401.11907 (2024)

DarkGEO prospects

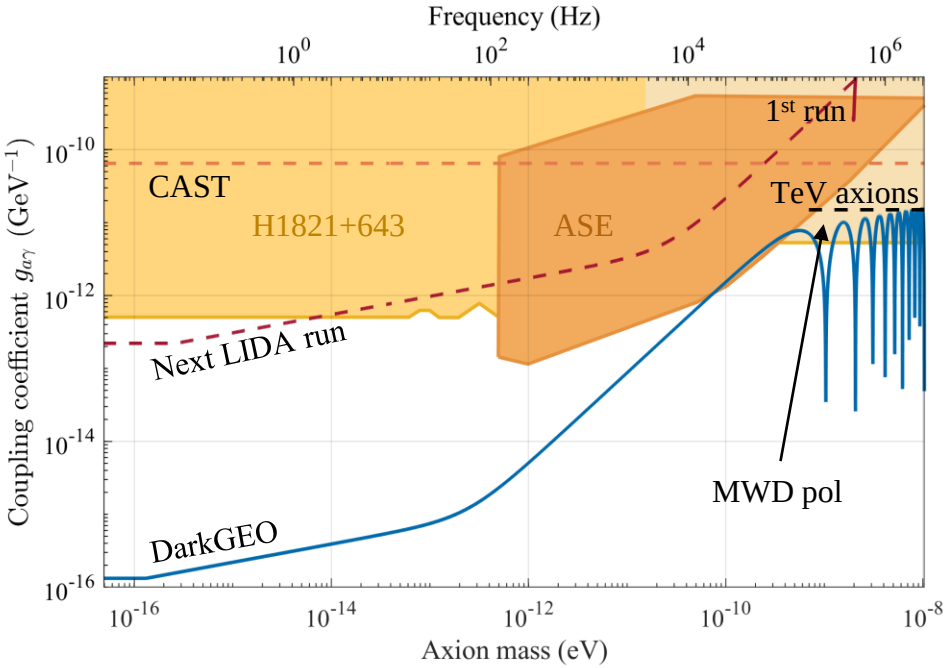
	First LIDA	Next LIDA	DarkGEO
Power (kW)	118	200	10,000
Meas time	85 h	6 months	1 year
Squeezing (dB)	–	10 dB	10 dB
Detuning	478 kHz	0 kHz	0 kHz



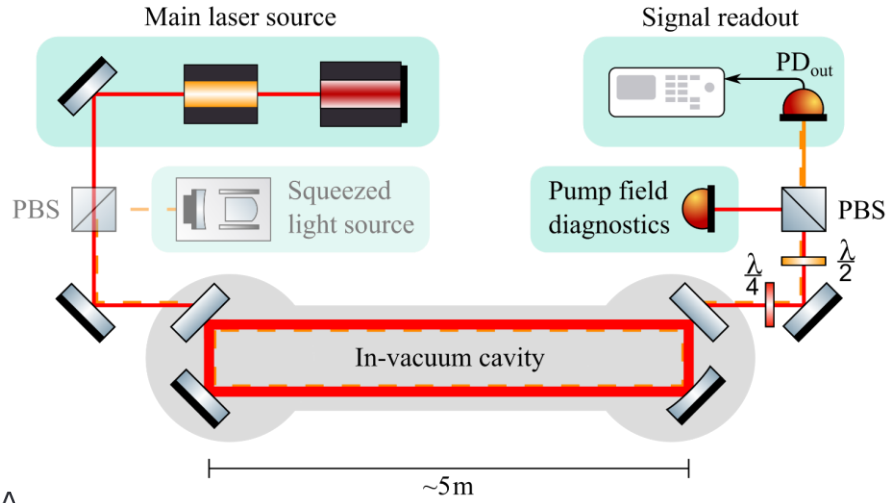
Published: J Heinze, et. al., arXiv:2401.11907 (2024)

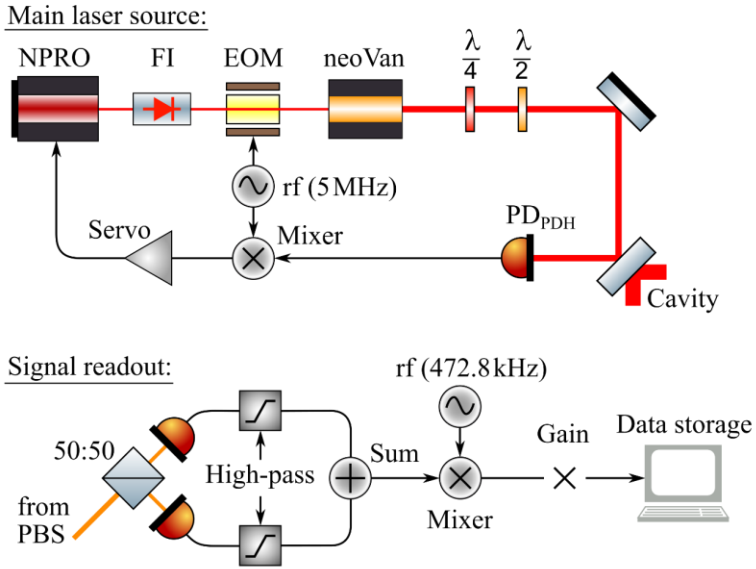
Summary

- **LIDA** is a **laser-interferometric detector for axions** sensitive to a rotation of linear polarisation!
- First science run yielded very **promising results**, paper submitted!
- **Prospects** to even probe unexplored regions in the next observing run at lower axion masses!
- **Challenge** to reduce detuning!
- **DarkGEO** could further boost the sensitivity by several orders of magnitude, paper in preparation!



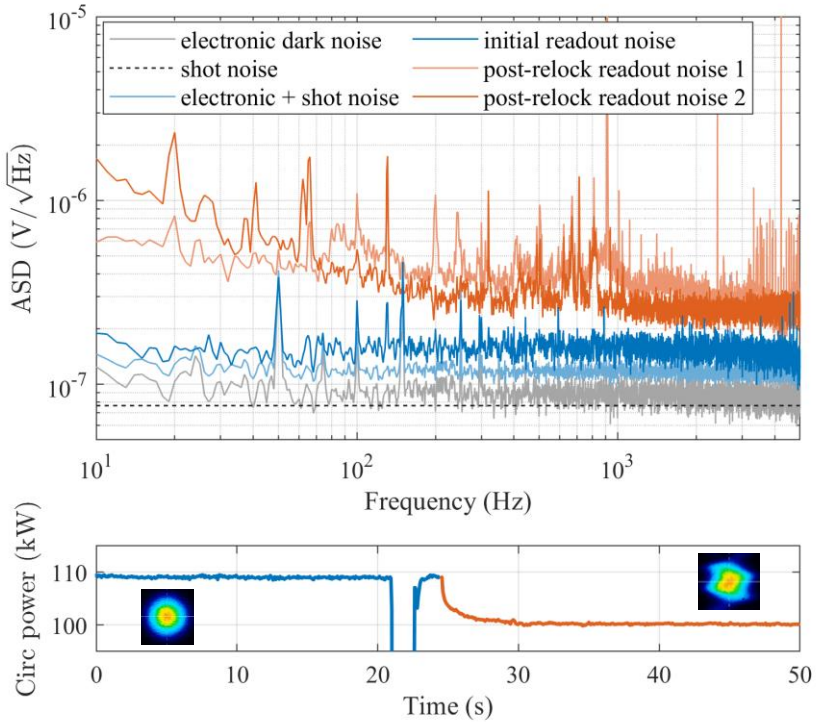
More detailed setup





EOM: electro-optic modulator, NPRO: non-planar ring oscillator, PBS: polarising beamsplitter, PD: photodetector, PDH: Pound-Drever-Hall, rf: radio-frequency generator

High-power effects



At high circulating power:

If disturbed, the cavity often changes “state” correlating with

- a reduction in circulating power,
- a distortion of the transmitted field,
- higher readout noise.

GEO600 → DarkGEO

GEO600: close to Hanover, Germany (credit: geo600.org)

Parameter (DarkGEO-I)	Value	Unit
Wavelength	1064	nm
Cavity roundtrip length	1.2	km
Input coupler transmissivity, T_{in}	20	ppm
Output coupler transmissivity, T_{out}	1	ppm
Cavity roundtrip loss, l_{rt}	20	ppm
Laser input power	210	W
Intra-cavity power, $P_{\mathrm{m,cav}}$	10	MW
Measurement time, T_{meas}	1	year
Main laser field polarisation	vertical	
Signal field polarisation	horizontal	

Parameter (DarkGEO-II/III)	Value	Unit
Wavelength	1064	nm
Cavity roundtrip length	1.2	km
Input coupler transmissivity, $T_{\mathrm{m,in}}$	45	ppm
Output coupler transmissivity, $T_{\mathrm{m,out}}$	1	ppb
Input coupler transmissivity, $T_{\mathrm{sig,in}}$	3000	ppm
Output coupler transmissivity, $T_{\mathrm{sig,out}}$	2.5	ppm
Cavity roundtrip loss, l_{rt}	45	ppm
Laser input power	460	W
Intra-cavity power, $P_{\mathrm{m,cav}}$	10	MW
Effective squeezing level	10	dB
Measurement time, T_{meas}	1	year
Detuning, β	0.13 (scanned)	
Main laser field polarisation	vertical	
Signal field polarisation	horizontal	

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