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16/11/21

Direct Dark Matter Detection and Novel Directional Searches

UCL

COLLABORATIVE WORK

HEP

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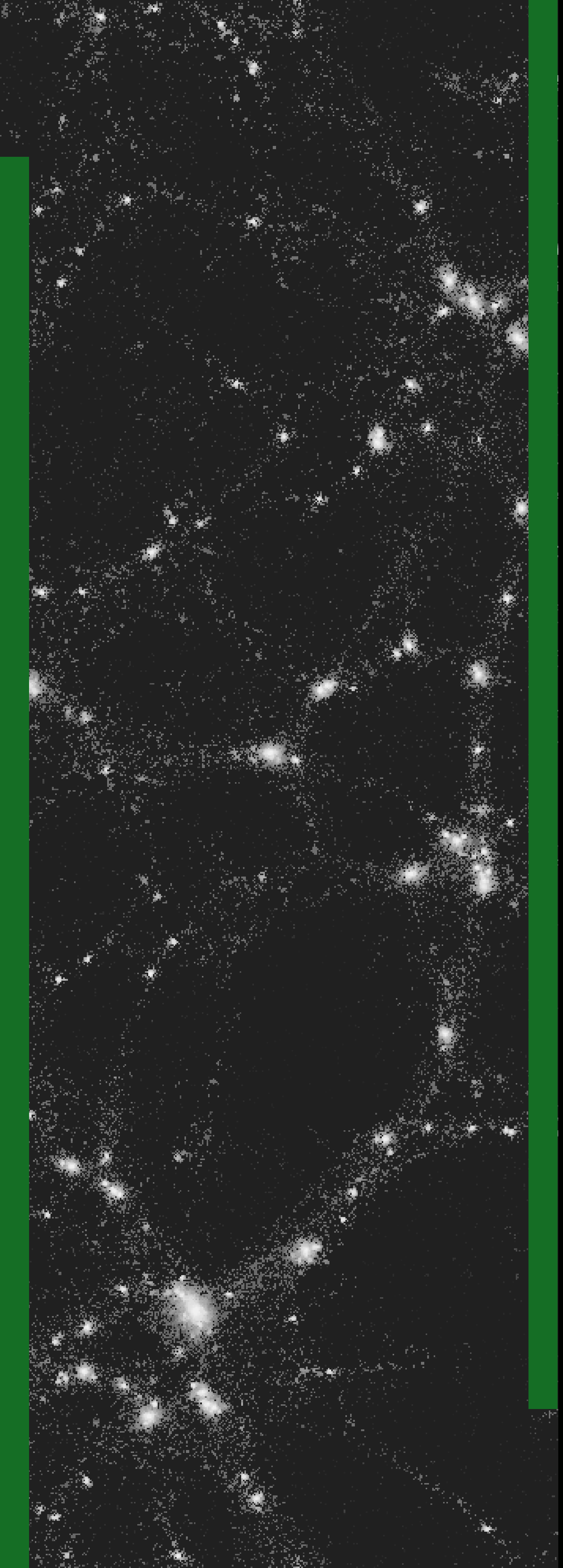
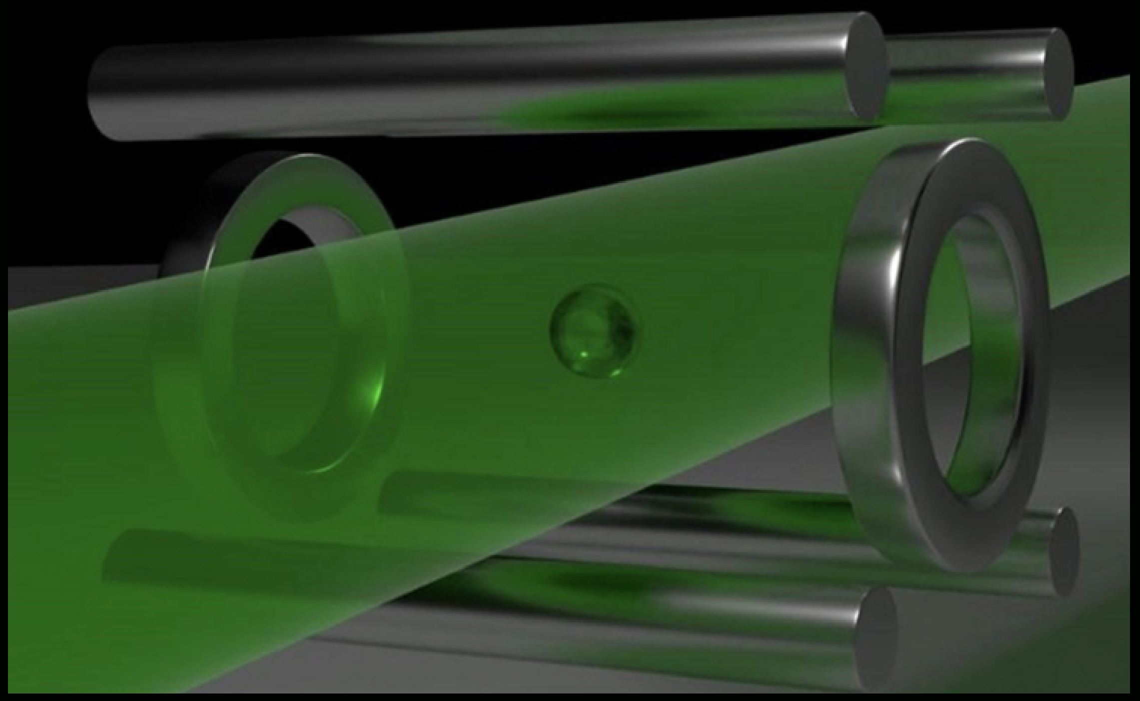


OUTLINE



Software package creation

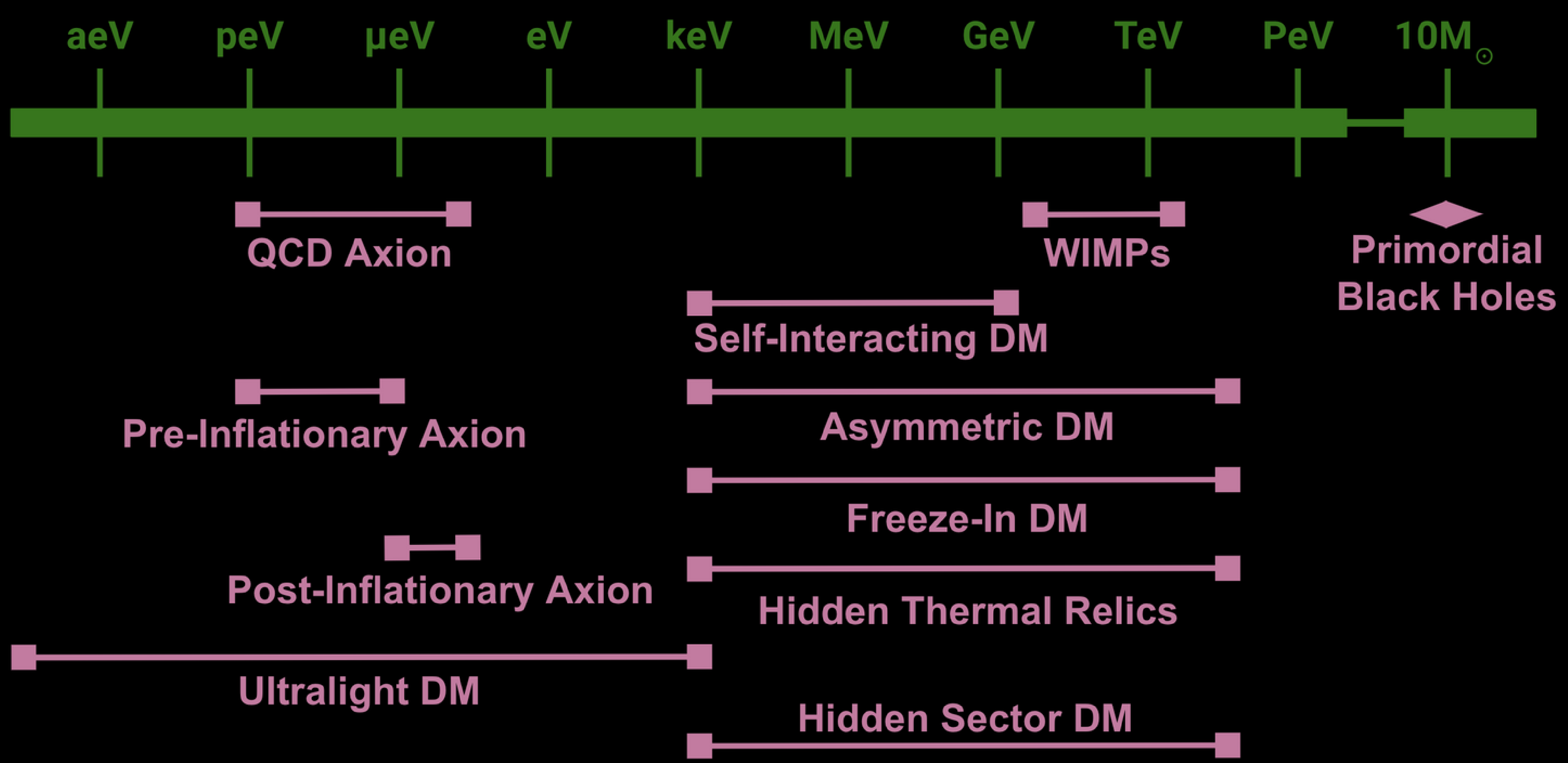
Optical tweezer experimental design and construction

Paul trap experimental design

Background characterisation and reduction

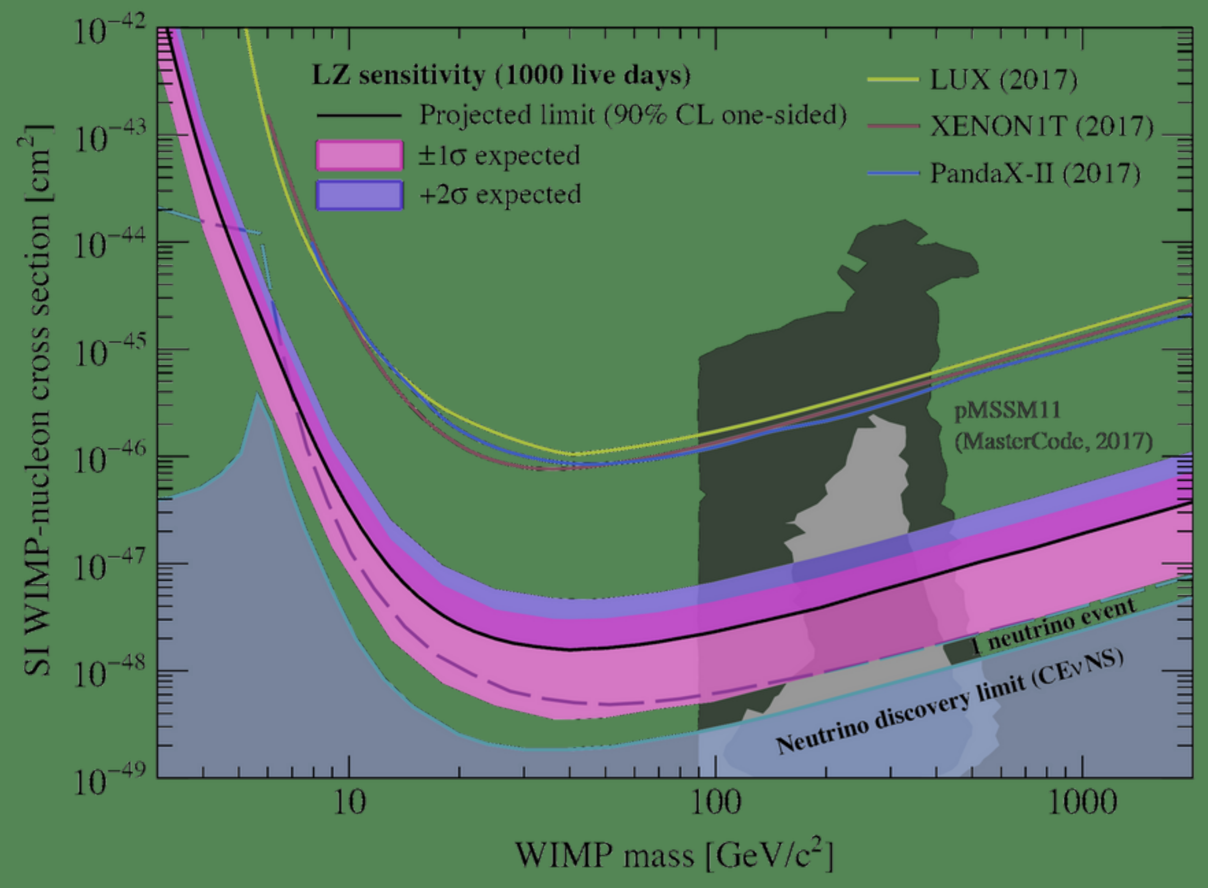
Setting initial limits

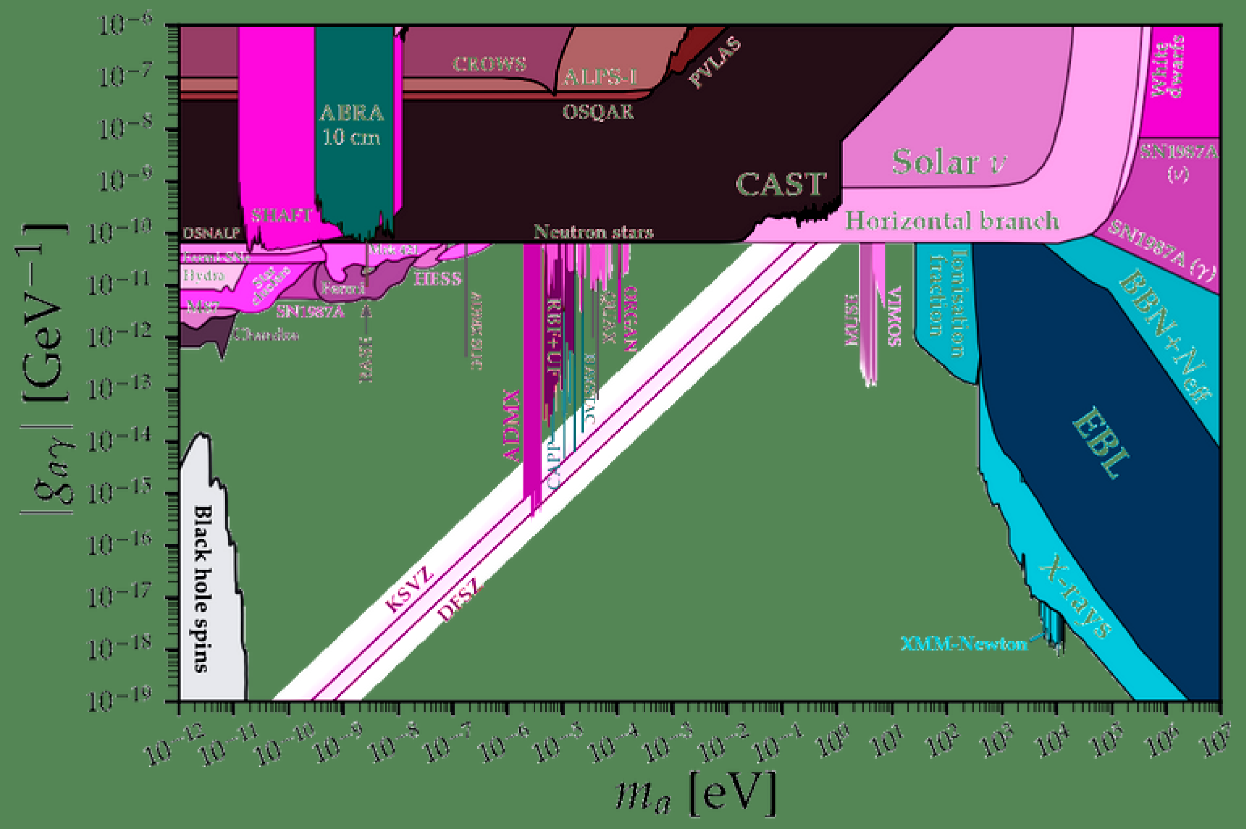
Future searches

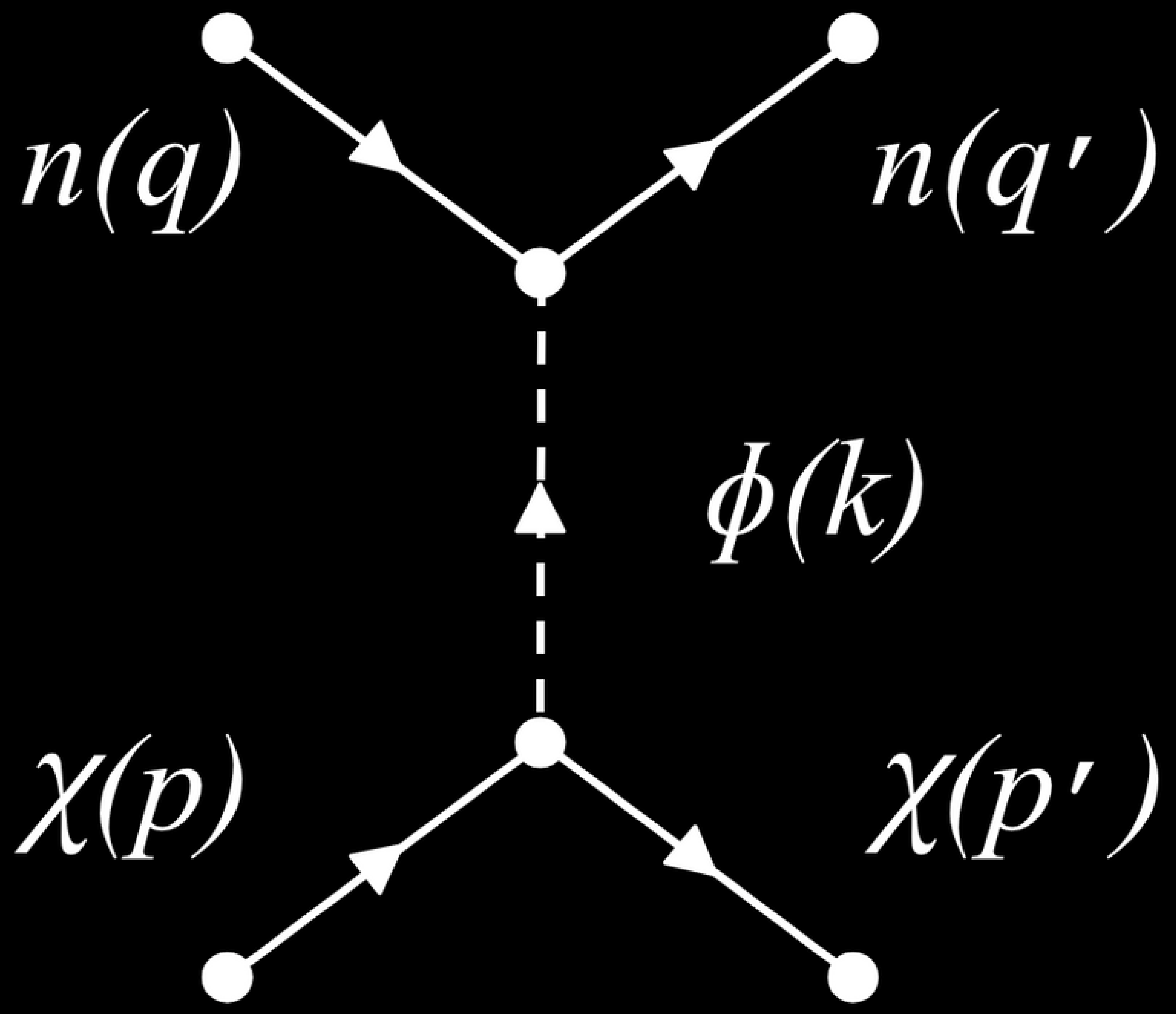


DARK MATTER CANDIDATES

DIRECT DETECTION LIMITS







SELF INTERACTING DM

$$\mathscr{L} \supset -g_\chi \phi \chi^* \chi - g_n \phi \bar{n} n$$

- One theoretically motivated candidate for self-interacting DM is a class of model known as DM 'nuggets'
- Contain a number of constituents, N_χ
- Interact with standard model particles via a light mediator, ϕ (mass $m_\phi \leq$ eV)

$$V(r) = (-)\, \frac{g_\chi g_n e^{-r m_\phi}}{4\pi r}$$

1

SIMULATIONS

2

CALIBRATION

3

DAQ AND DATA STREAMING

4

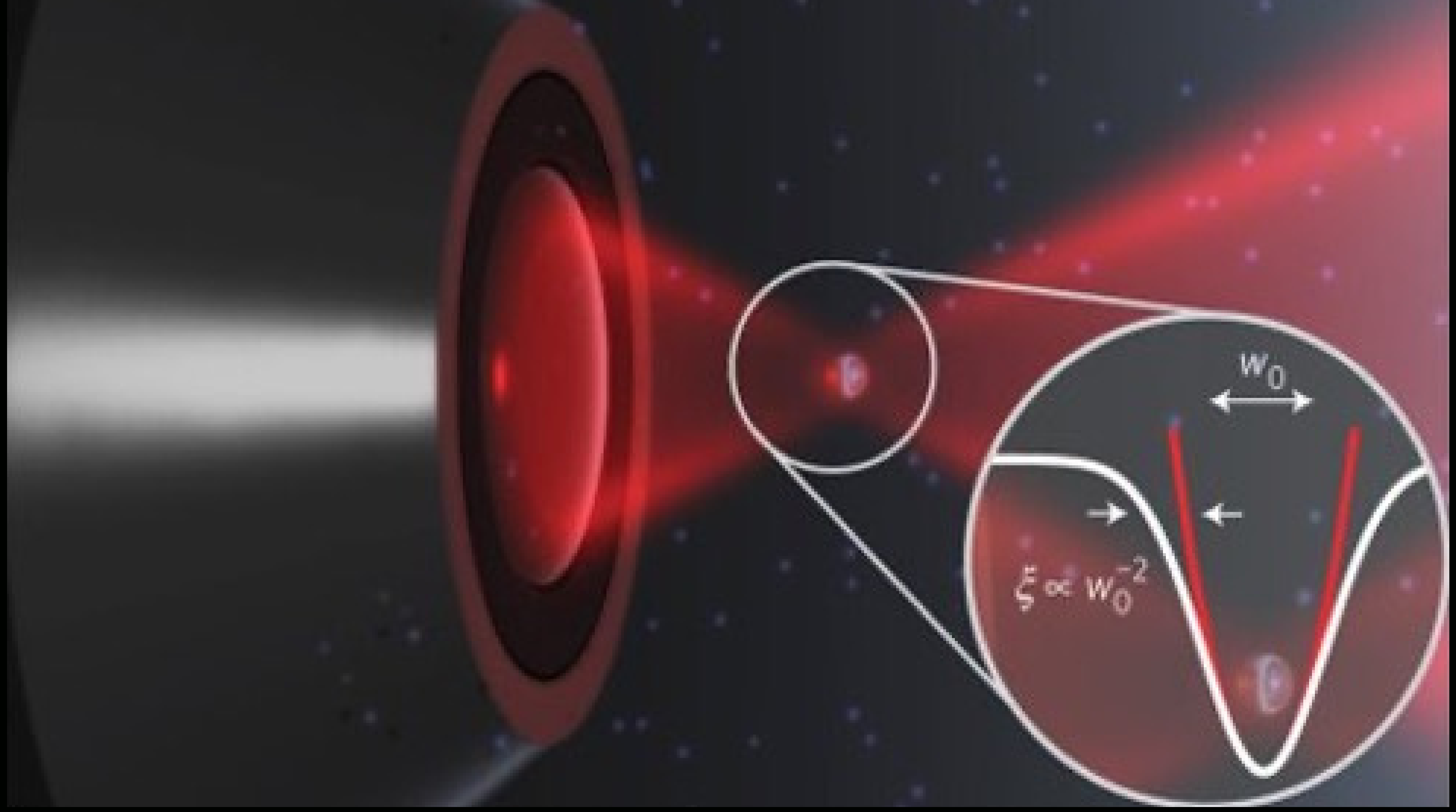
PUSLE FINDING AND CATEGORISATION

5

STATISTICAL ANALYSIS

QS PACKAGE

FIBER-COUPLED ND:YAG 1064 NM LASER



$$m\ddot{q} = -m\gamma\dot{q} + F_{Gr} + F_{Dr} + F_{fluct}$$

Gradient Force

Driving Force

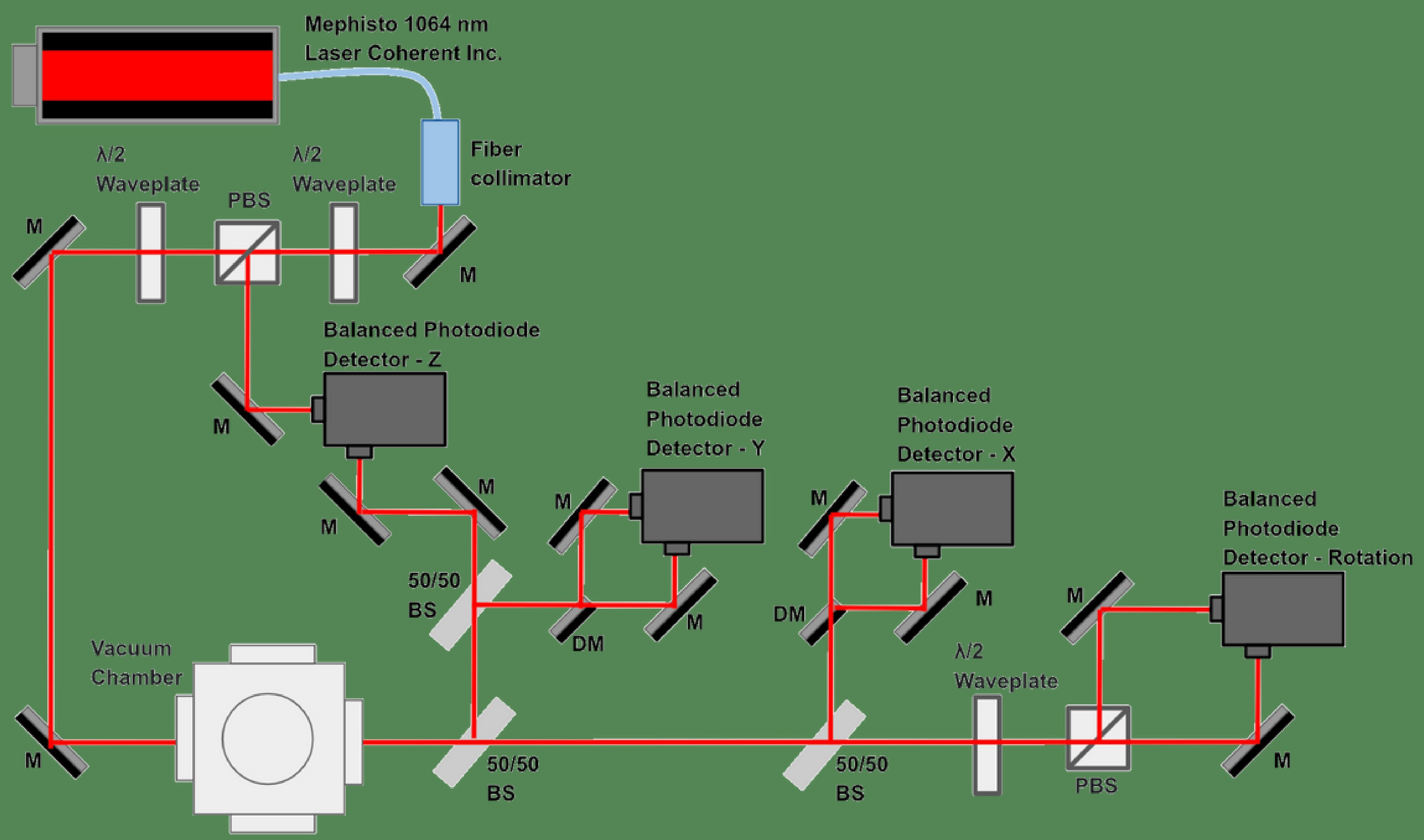
Fluctuating Force

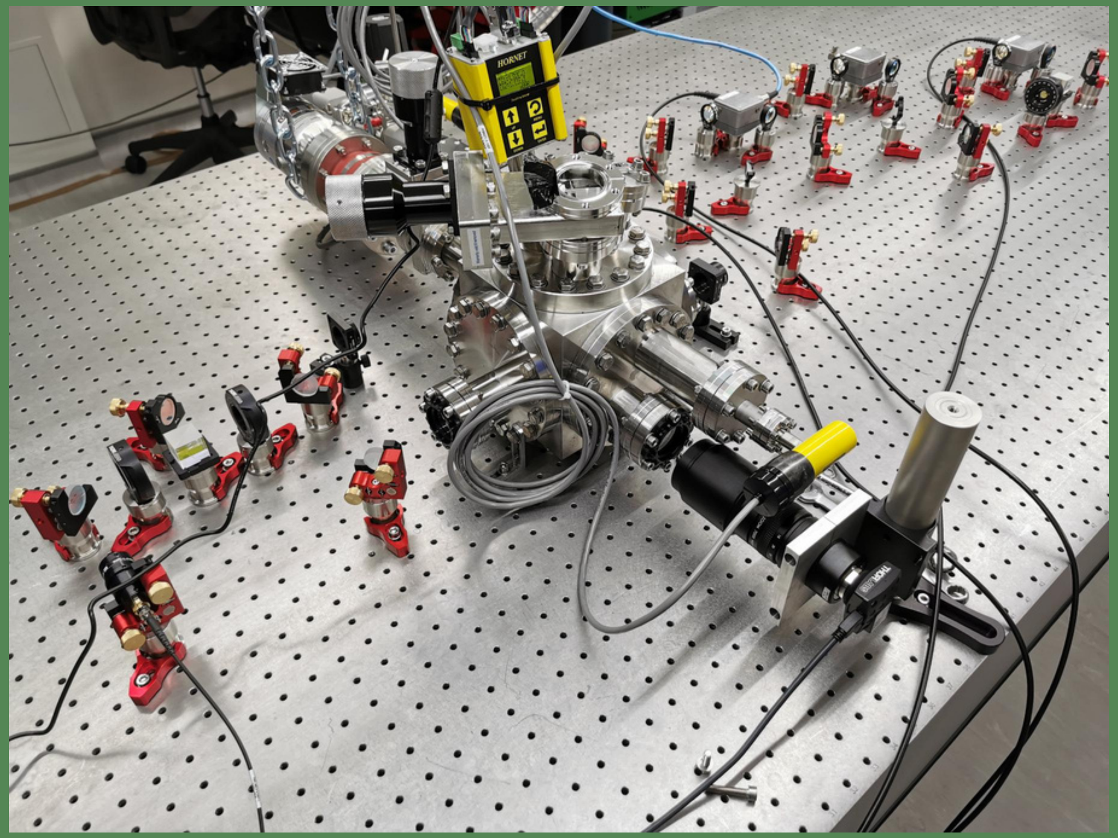
Trapping potential formed through focusing of EM fields to the focal point of an optical lens

Interference of the incident light rays occurs at this focal point

$$\langle \vec{F} \rangle = \frac{\alpha'}{2} \langle \nabla |\vec{E}|^2 \rangle$$

OPTICAL TWEEZER THEORY





EXPERIMENTAL REQUIREMENTS

Trapping Optics

Vacuum and Optical Trap

Detection System

TRAPPING AND DETECTION

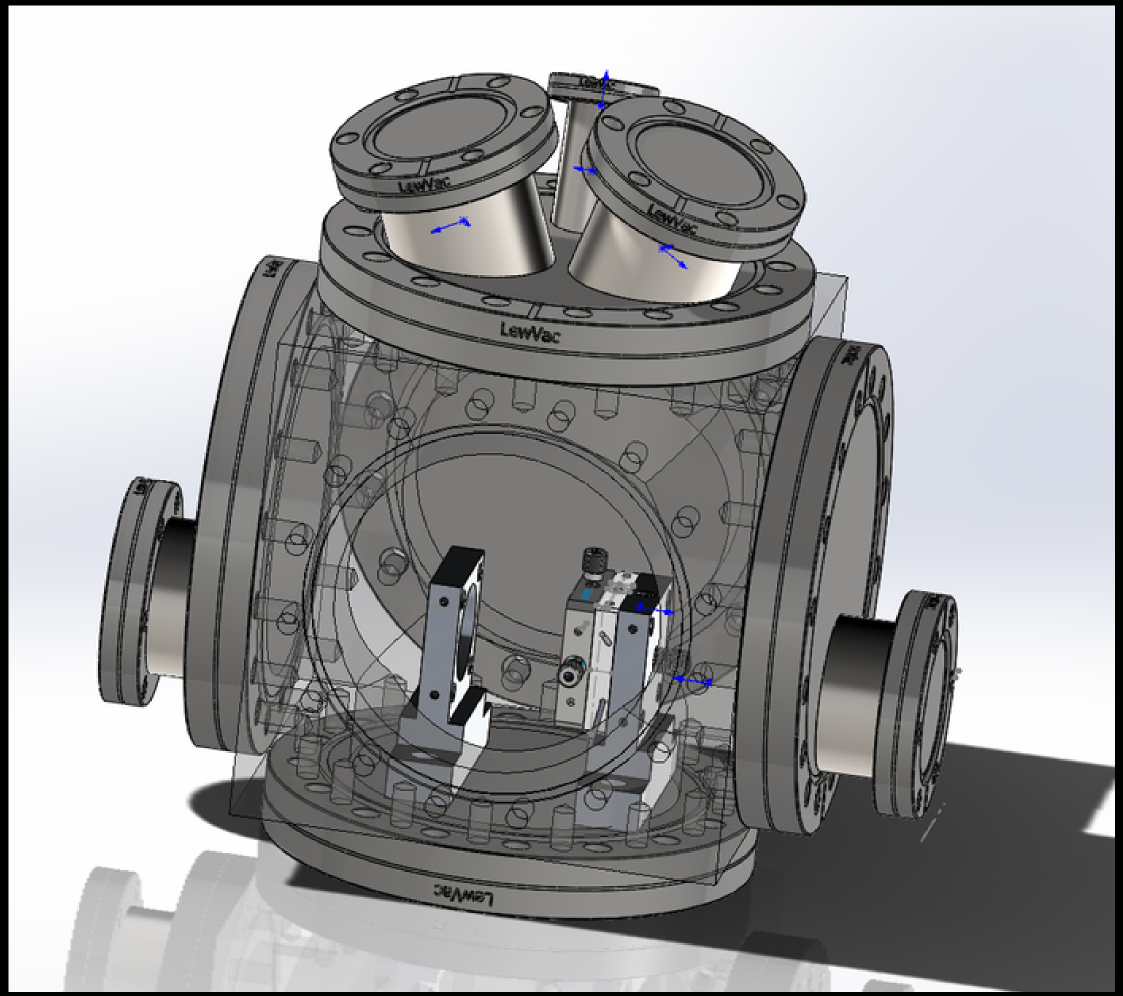
Reduction of cantilever movement

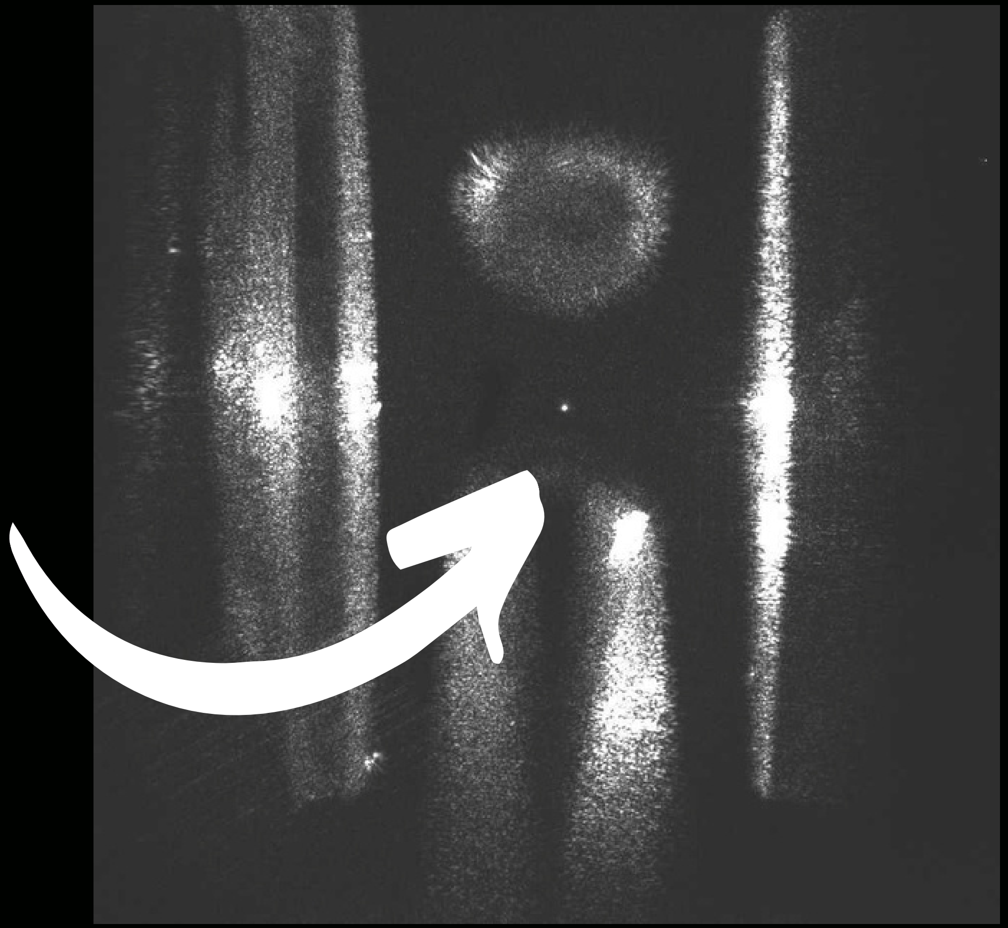
Laser power controlled

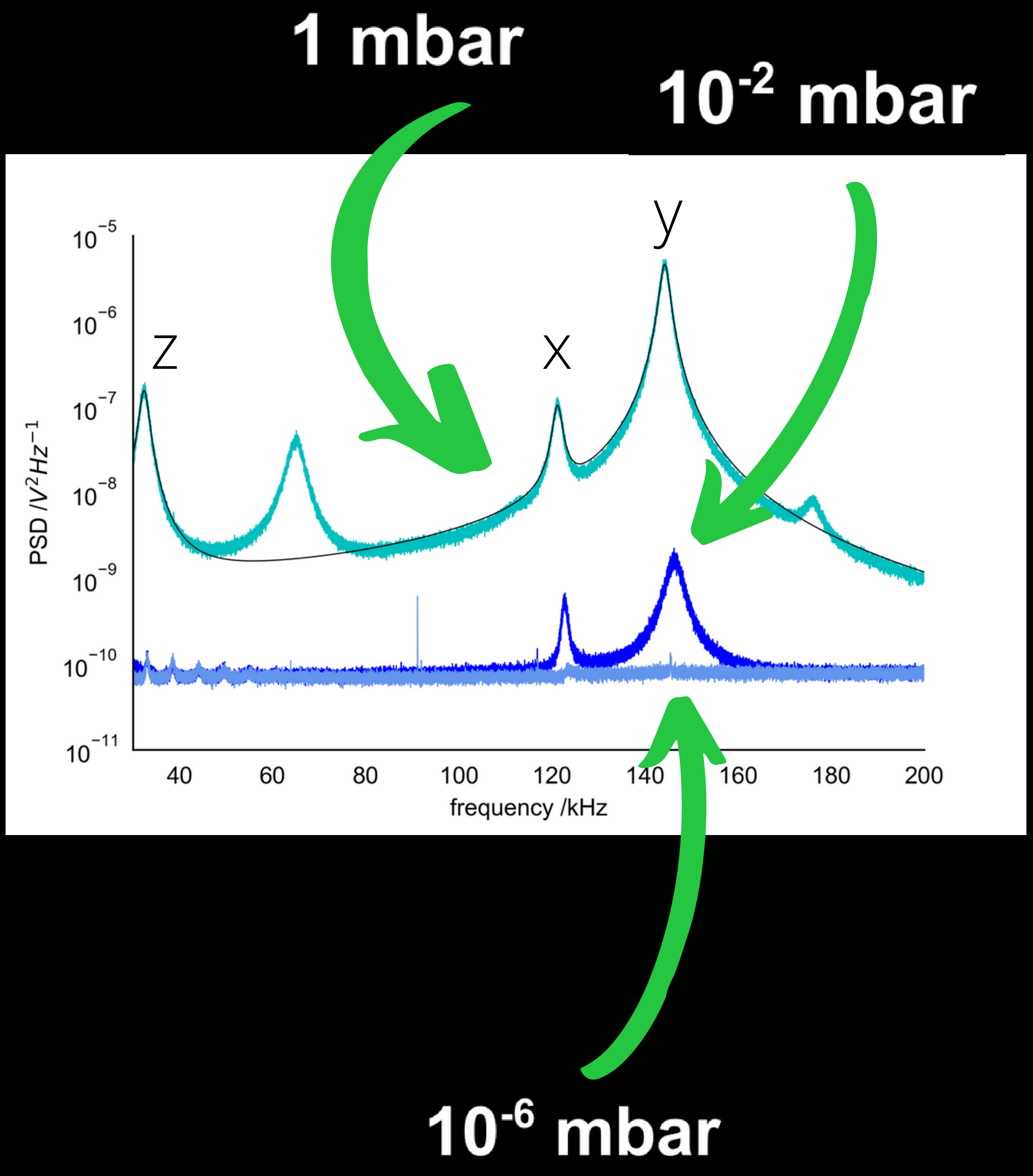
Feedback cooling and calibration

3D directional reconstruction

Rotational detection



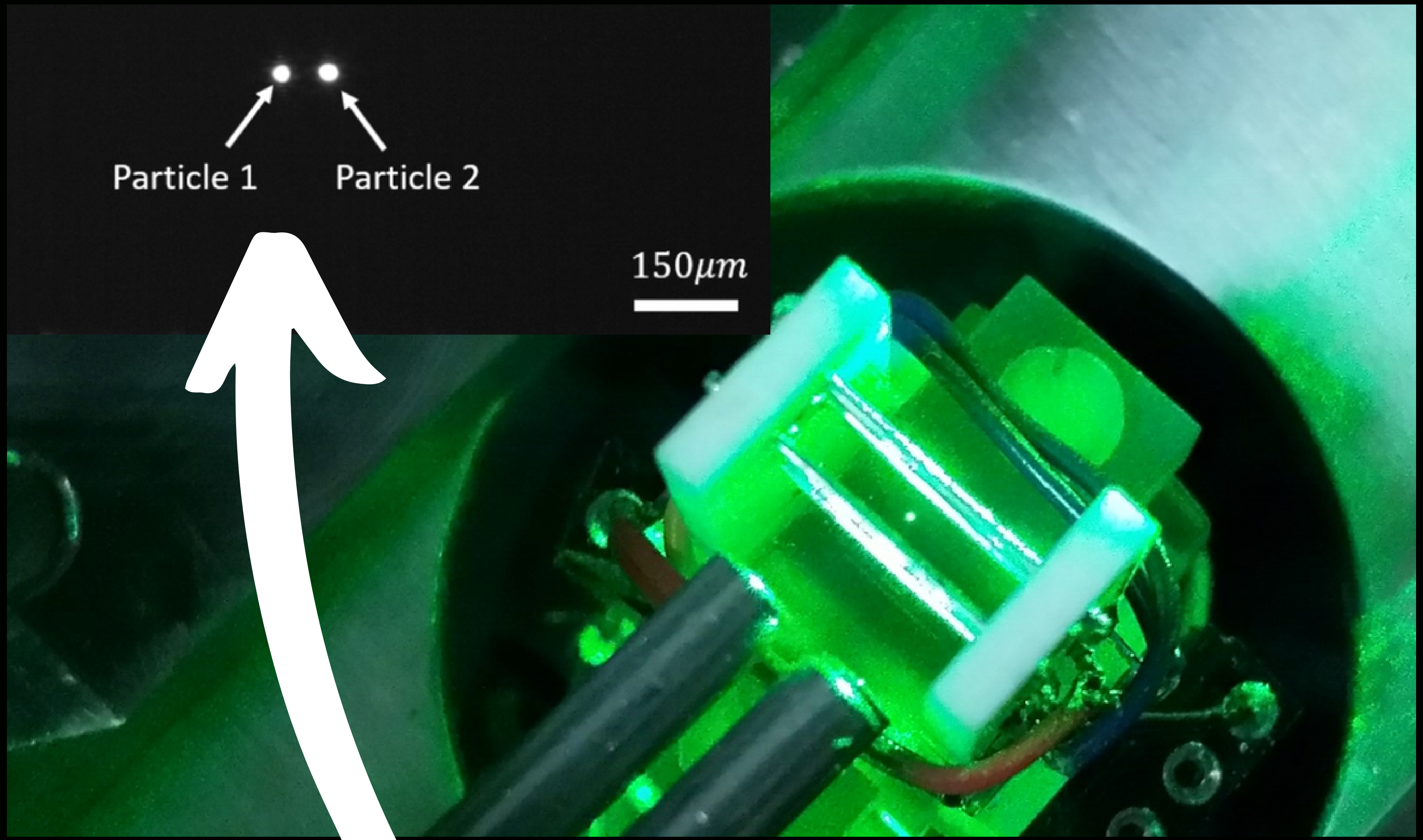




- Cooling through active feedback mechanism "velocity damping"
- Shown to cool to the quantum ground state*
- More effective than other methods of cooling**
- Calibration through application of harmonic driving force
- Charging and discharging of particle through application of xenon UV flash lamp

COOLING AND CALIBRATION

*F. Tebbenjohanns et al., Phys. Rev. Lett., 2019
**A. Pontin, T. W. Penny and P.F. Barker, Phys. Rev. A, 2021



Co-levitated nanoparticles

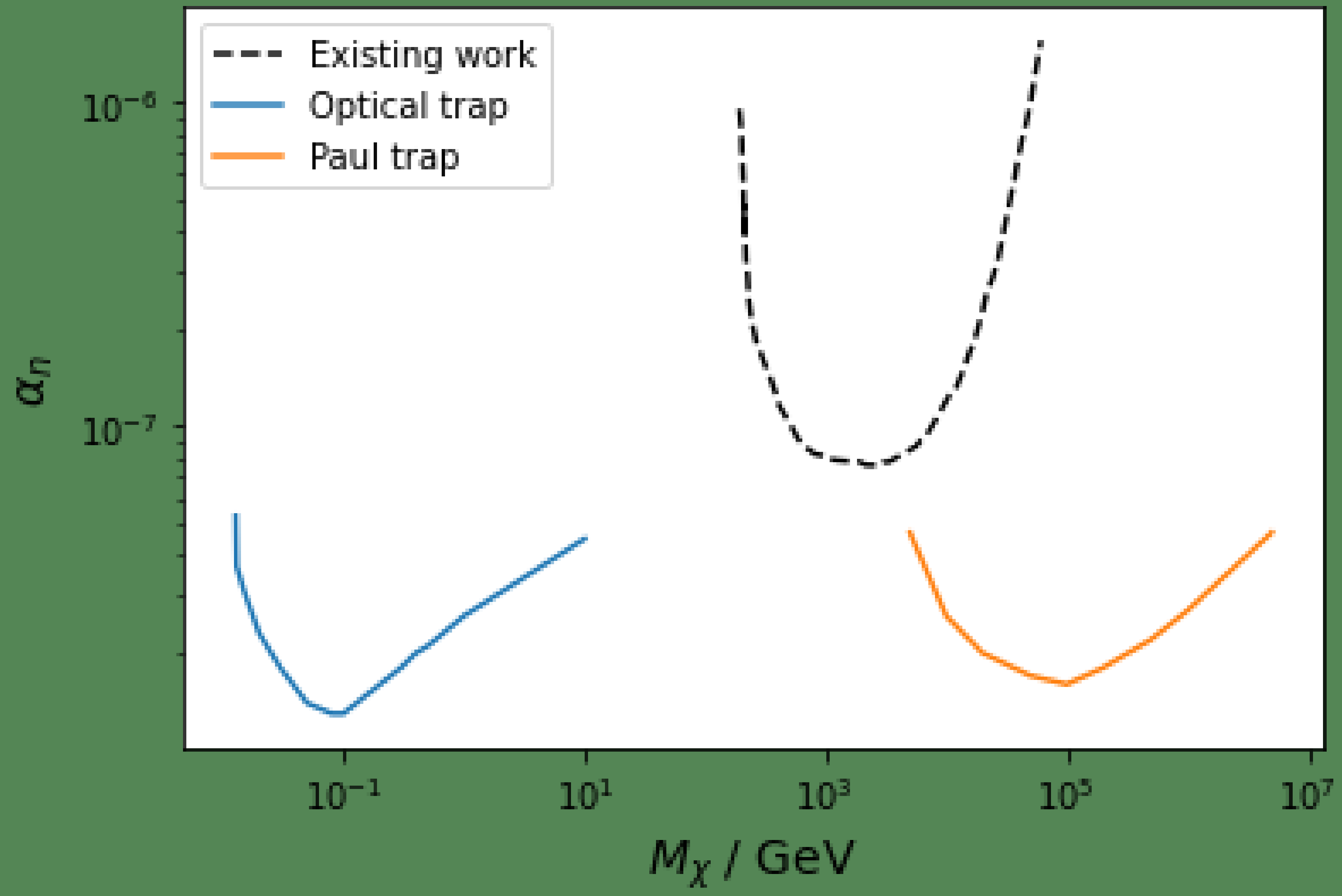
Particles O(100μm) in diameter have been trapped in vacuum using this method

Trapping of metallic particles of much higher density is possible, allowing probing of heavier dark nugget parameter space

Levitated particle arrays cooled to mK temperatures using sympathetic feedback cooling*

LINEAR PAUL TRAP

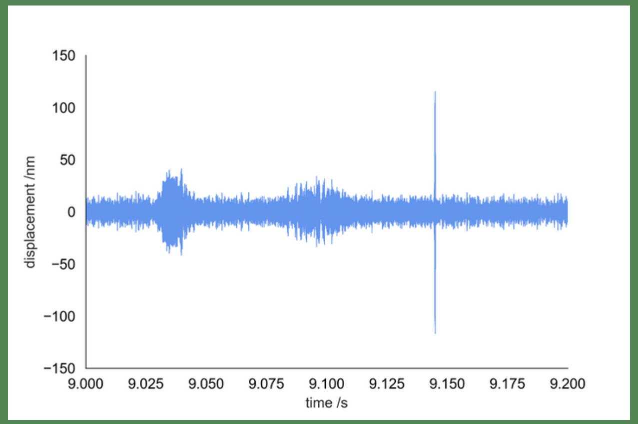
*T. W. Penny et al, Sympathetic cooling and squeezing of two co-levitated nanoparticles, 2021



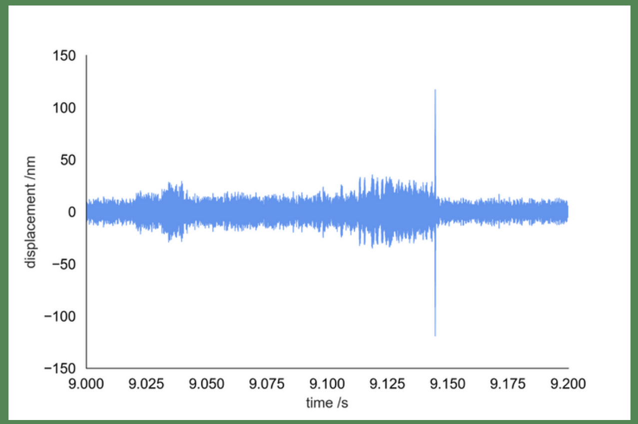
ROBERT JAMES

PROJECTED 90% DARK NUGGET SCATTERING SENSITIVITY

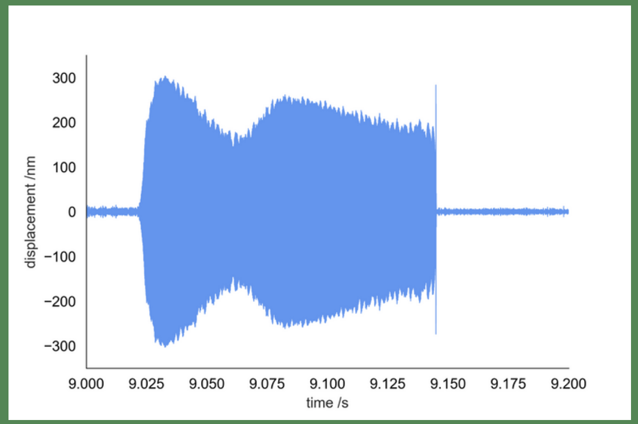
Background-free experiment with the observation of 0 events and a mediator mass of 0.1 eV



x - axis



y - axis



z - axis

IMPULSE LIKE INTERACTIONS

THERMAL NOISE

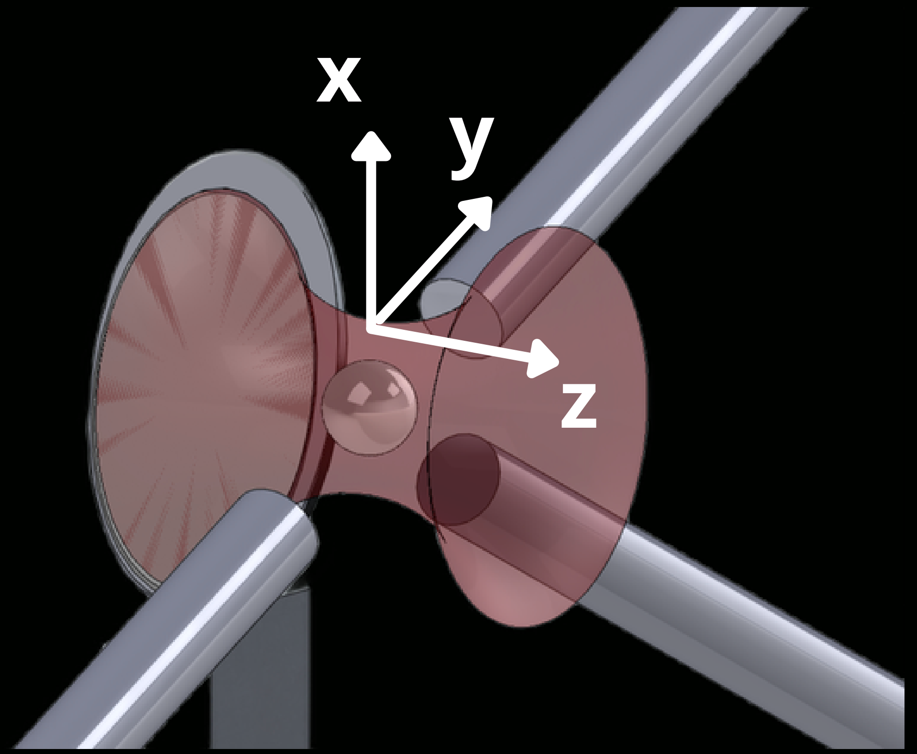
ELECTRONIC NOISE

SEISMIC NOISE

LASER NOISE

A background study is integral to the commissioning of the experimental setup

This will involve simulation code and pulse finding and categorisation



BACKGROUND CHARACTERISATION AND REDUCTION

PROJECT PLAN

1 Optically levitated nano-oscillator sensor

2 Electrodynamic micro-oscillator sensor

3 Multi-oscillator sensor arrays

4 Ultralight dark matter detection with levitated oscillators

5 Further theoretical investigation

ADDITIONAL SLIDES

SILICA NANOPARTICLES