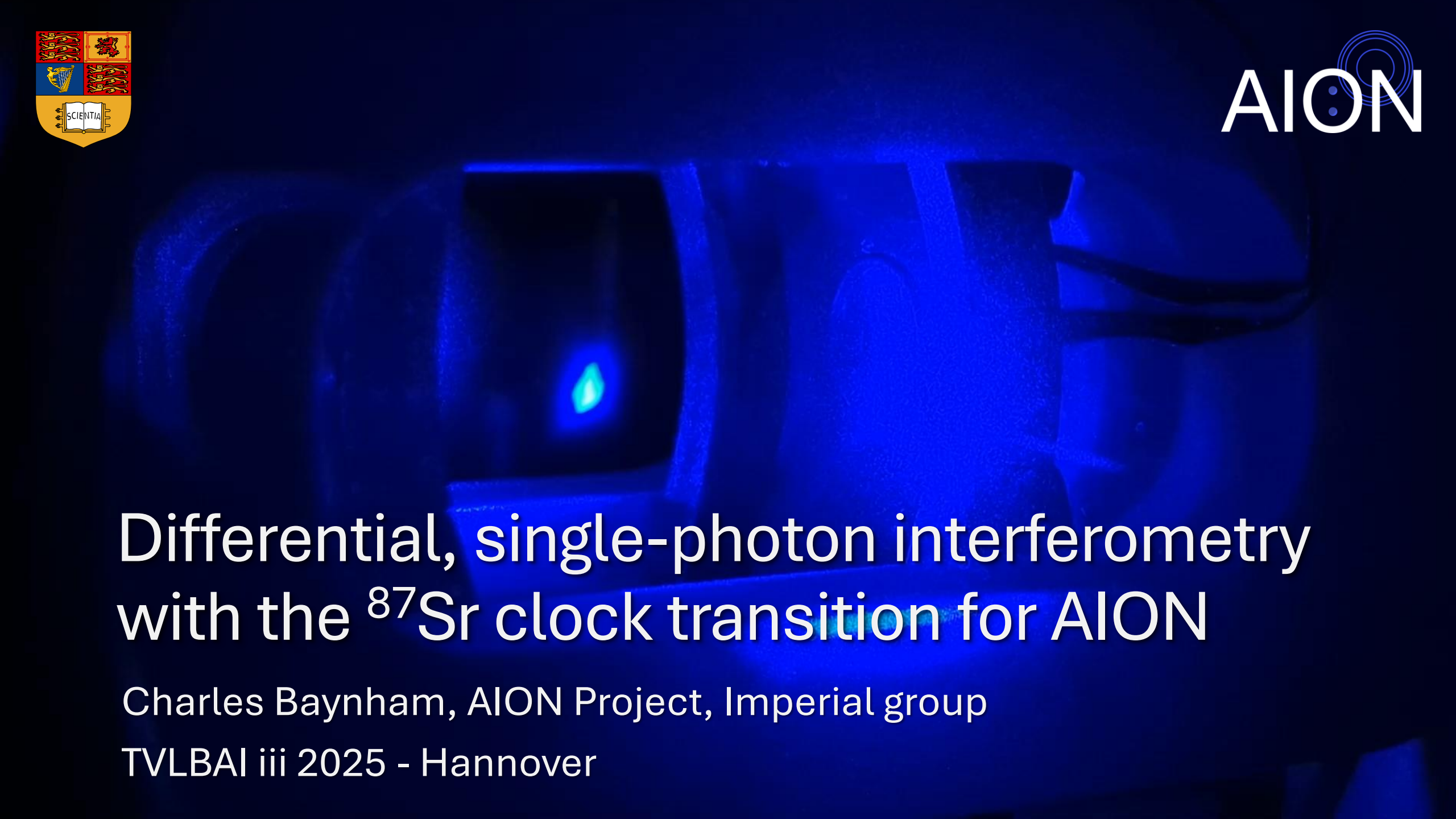


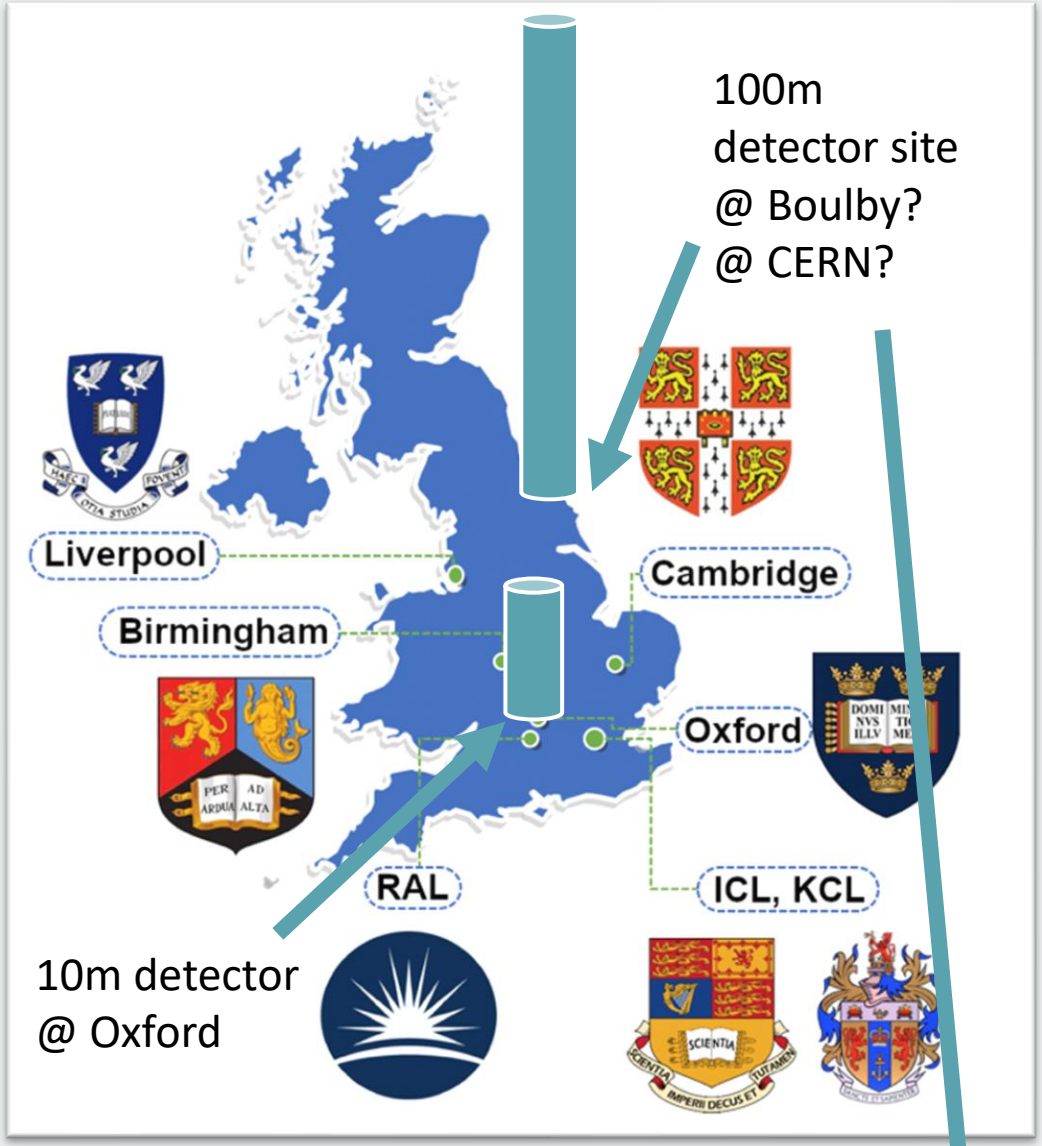
Differential, single-photon interferometry with the ^{87}Sr clock transition for AION

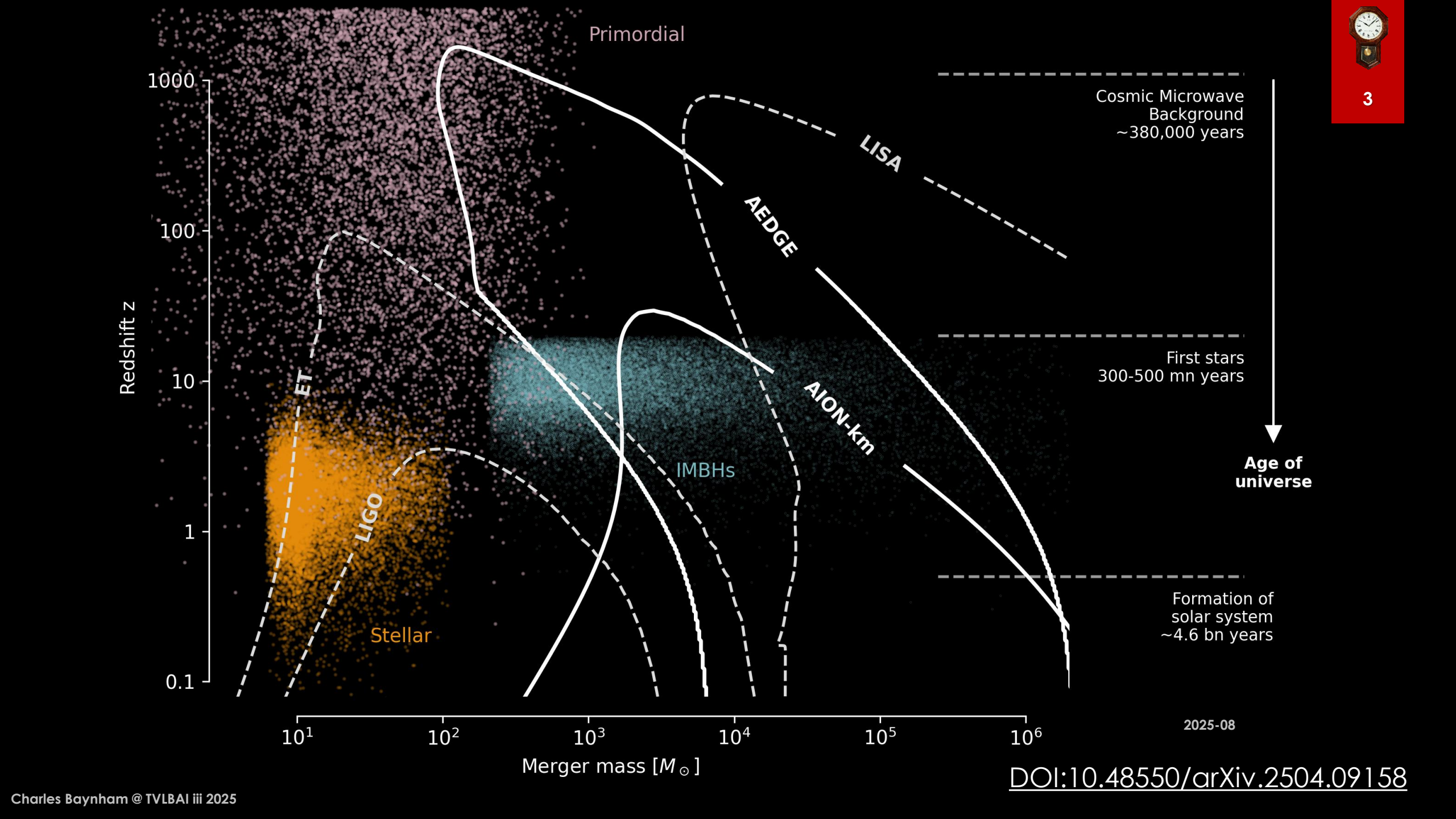
Charles Baynham, AION Project, Imperial group

TVLBAI iii 2025 - Hannover

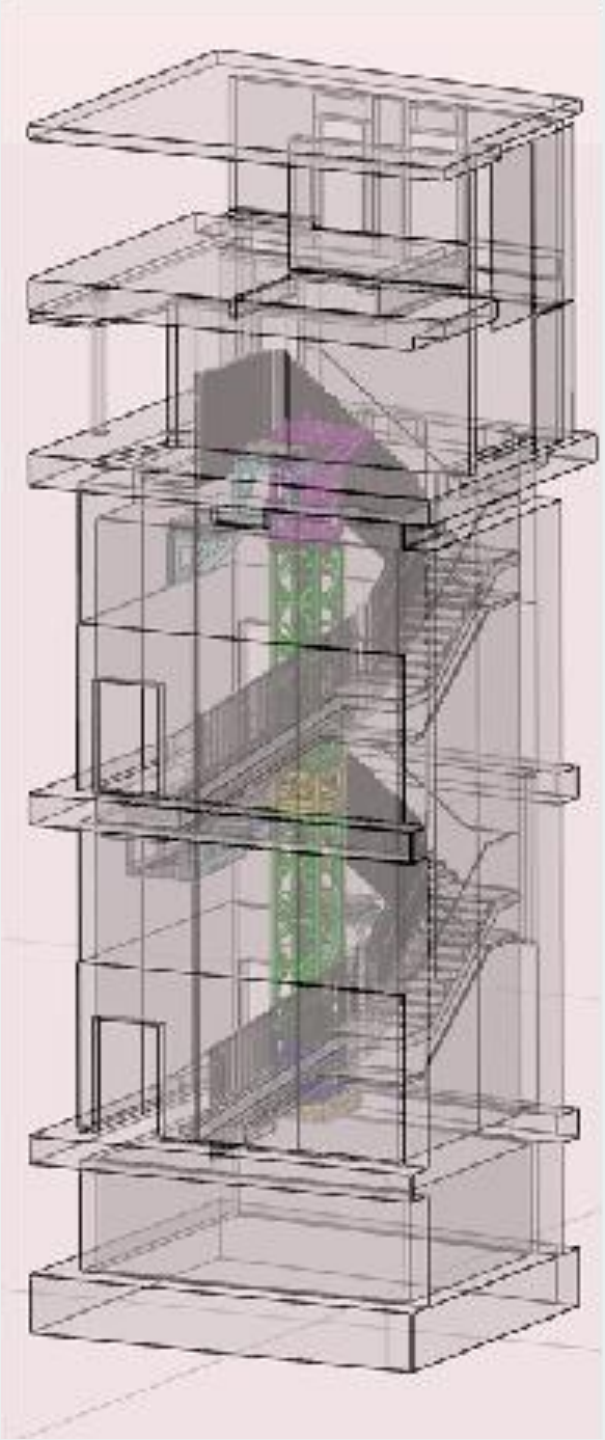
AION

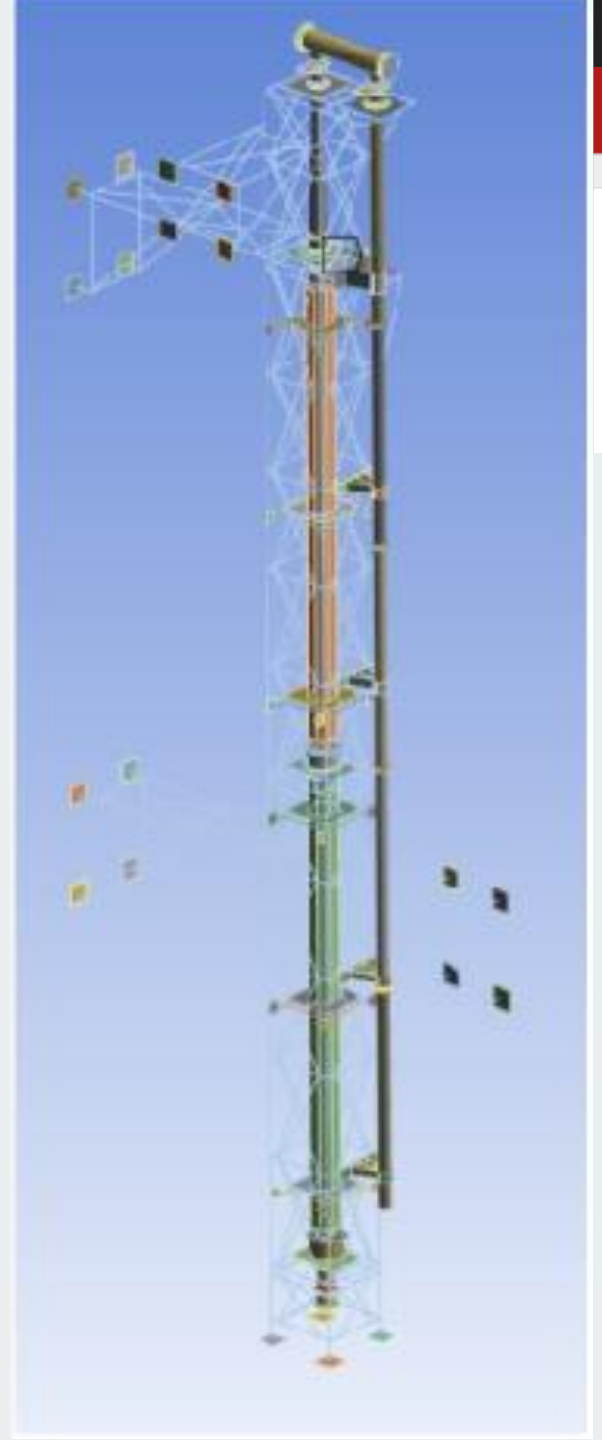
Atom Interferometer Observatory Network





DOI:10.48550/arXiv.2504.09158





Cornell University

We gratefully acknowledge support from th

arXiv > physics > arXiv:2508.03491

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[Submitted on 5 Aug 2025]

AION-10: Technical Design Report for a 10m Atom Interferometer in Oxford

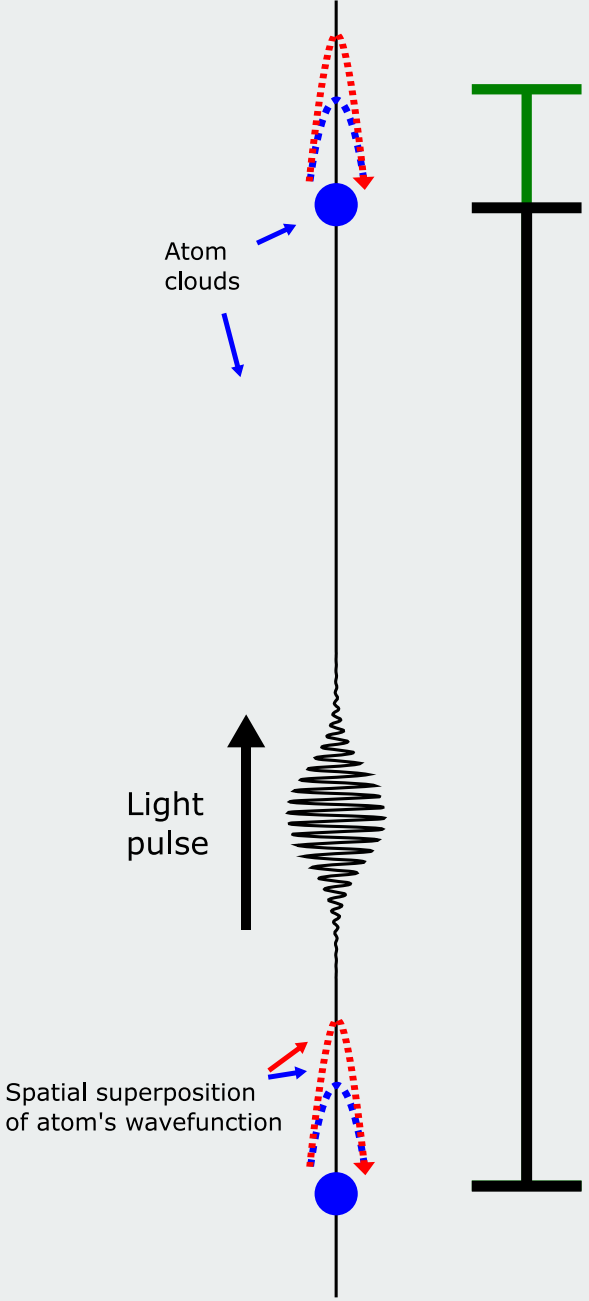
K. Bongs, A. Brzakalik, U. Chauhan, S. Dey, O. Ennis, S. Hedges, T. Hird, M. Holynski, S. Lellouch, M. Langlois, B. Stray, B. Bostwick, J. Chen, Z. Eyler, V. Gibson, T. L. Harte, C. C. Hsu, M. Karzazi, C. Lu, B. Millward, J. Mitchell, N. Mouelle, B. Panchumarthi, J. Scheper, U. Schneider, X. Su, Y. Tang, K. Tkalčec, M. Zeuner, S. Zhang, Y. Zhi, K. Clarke, A. Vick, C. F. A. Baynham, O. Buchmüller, D. Evans, L. Hawkins, R. Hobson, L. Iannizzotto-Venezze, A. Josset, D. Lee, E. Pasatembou, B. E. Sauer, M. R Tarbutt, T. Walker, L. Badurina, A. Beniwal, D. Blas, J. Carlton, J. Ellis, C. McCabe, G. Parish, D. Pathak Govardhan, V. Vaskonen, T. Bowcock, K. Bridges, A. Carroll, J. Coleman, G. Elertas, S. Hindley, C. Metelko, H. Throssell, J. N. Tinsley, E. Bentine, M. Booth, D. Bortoletto, C. Foot, N. Callaghan, C. Gomez-Monedero, K. Hughes, A. James, T. Leese, A. Lowe, J. March-Russell, J. Sander, J. Schelfhout, I. Shipsey, D. Weatherill, D. Wood, S. N. Balashov, M. G. Bason, K. Hussain, H. Labiad, P. Majewski, A. L. Marchant, D. Newbold, Z. Pan, Z. Tam, T. C. Thornton, T. Valenzuela, M. G. D. van der Grinten, I. Wilmut

Engineered design for 10m tower available on arXiv:

DOI:10.48550/arXiv.2508.03491

- Mechanical stability
- Magnetic field control
- Vacuum design
- Optics delivery
- Detection
- Construction plan
- …and more

See DOI:10.1116/5.0172731



$$T = (L + \delta L)/c$$

$$T = L/c$$

- 2 (or more) separate atom interferometers
- Direct measurement of changes in the flight time of light pulses
- Single arm -> No phase noise from laser
- Think of this as two freefall atomic clocks

Differential atom interferometry

Imperfect overlap of wavepackets

Phase of laser imprinted during pulses

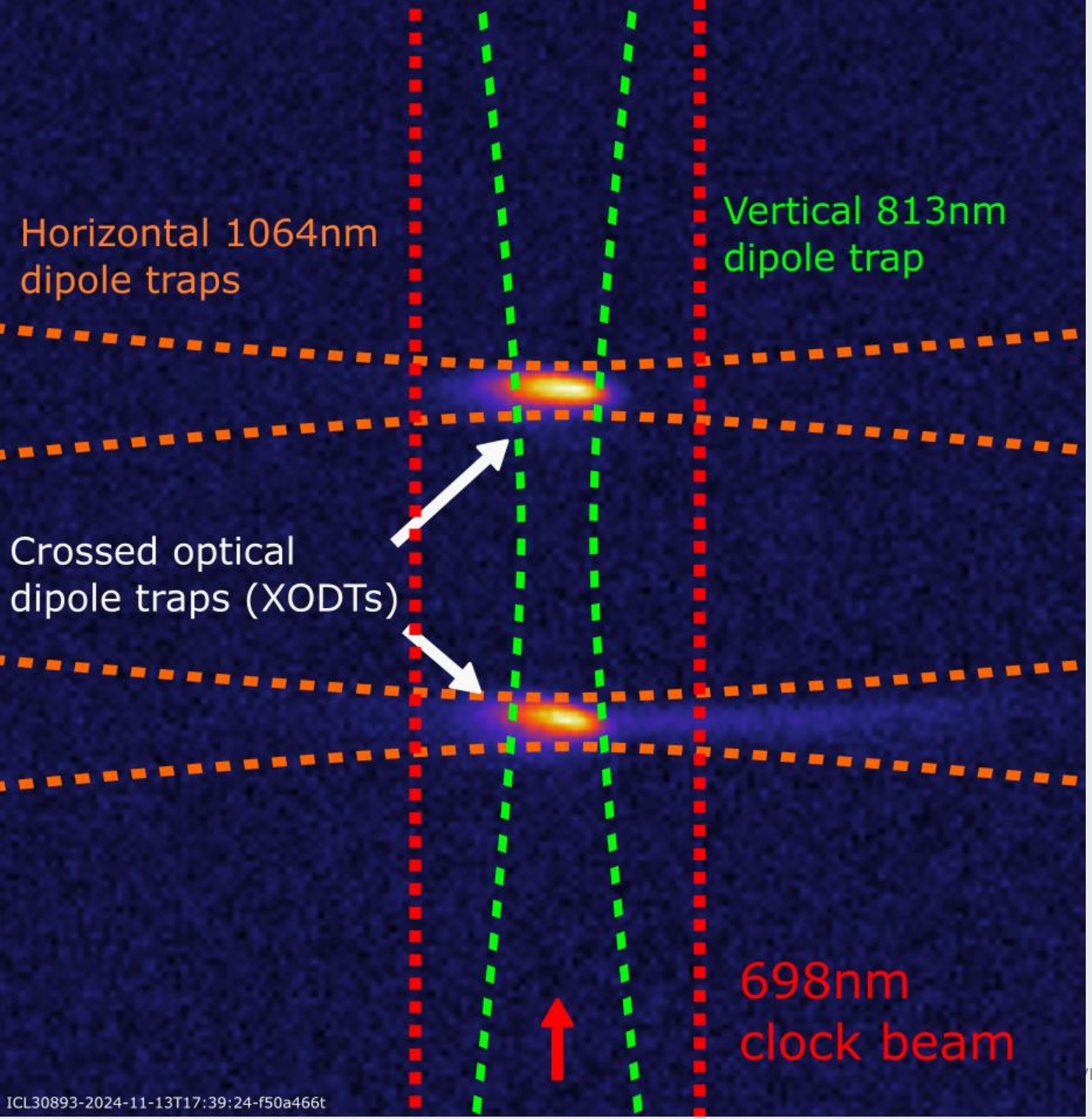
$$\phi = \phi_{prop} + \phi_{sep} + \phi_{laser}$$

$$\phi_{prop} = \frac{1}{\hbar}\int (L - E)\, dt$$

Classical Lagrangian for movement in a gravitational field in a rotating frame

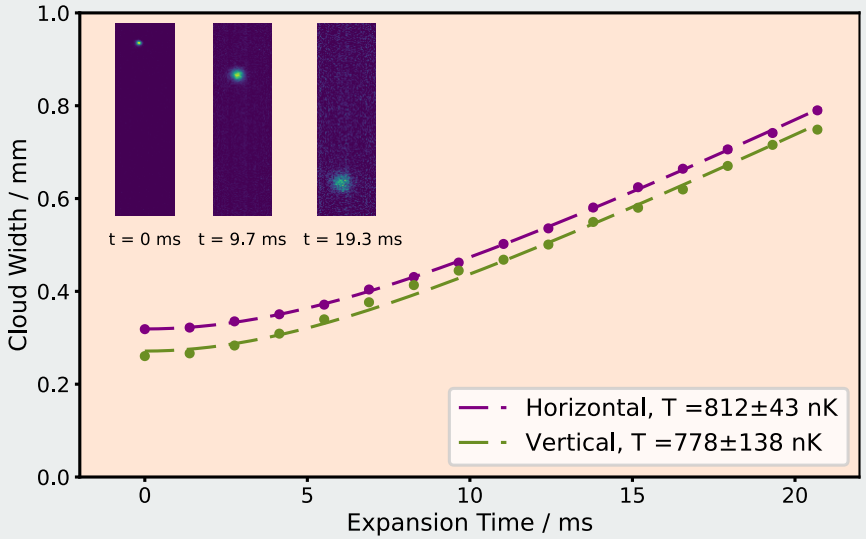
Energy of optical transition

$$\rightarrow \quad \frac{d|\psi\rangle}{dt} = -\frac{iE}{\hbar}|\psi\rangle$$



The experiment at ICL

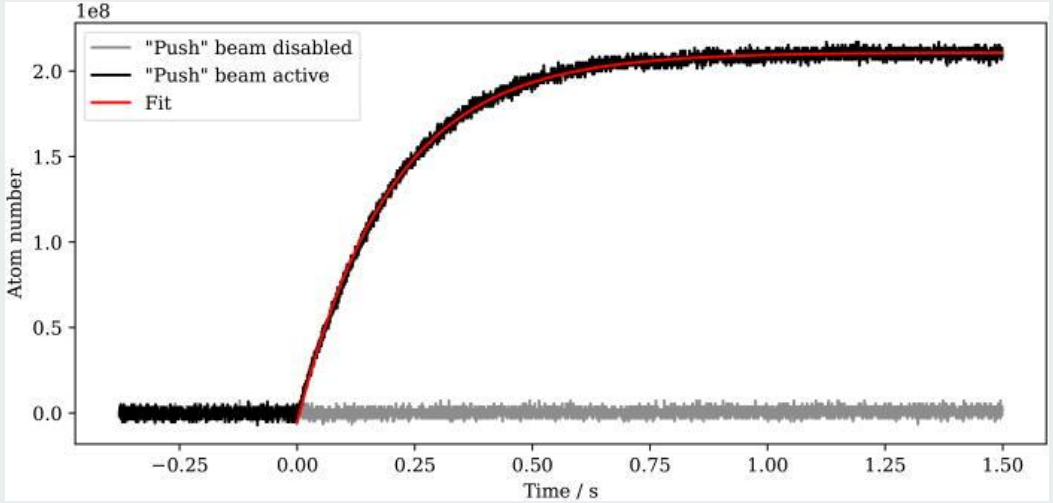
- 87-Sr atoms in two crossed, far off-resonant dipole traps
- Common clock laser interrogates both clouds



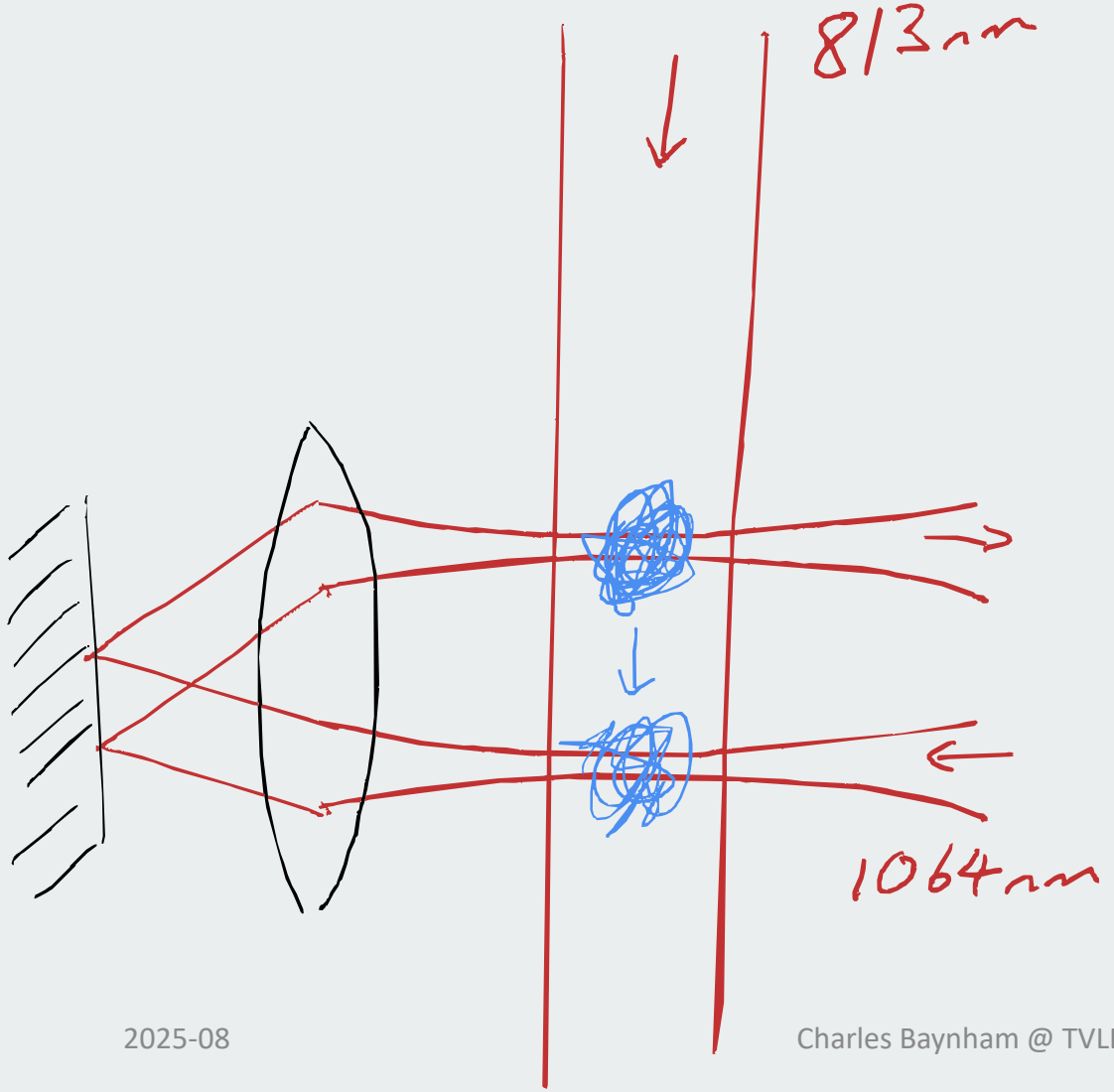
AVS Quantum Sci. 6, 014408 (2024)
https://doi.org/10.1116/5.0180043

Drop

Blue MOT | Modulated red MOT | Narrowband red MOT | Upper dipole trap | Lower dipole trap | Spin polarization | Velocity slicing | Differential interferometry | State readout

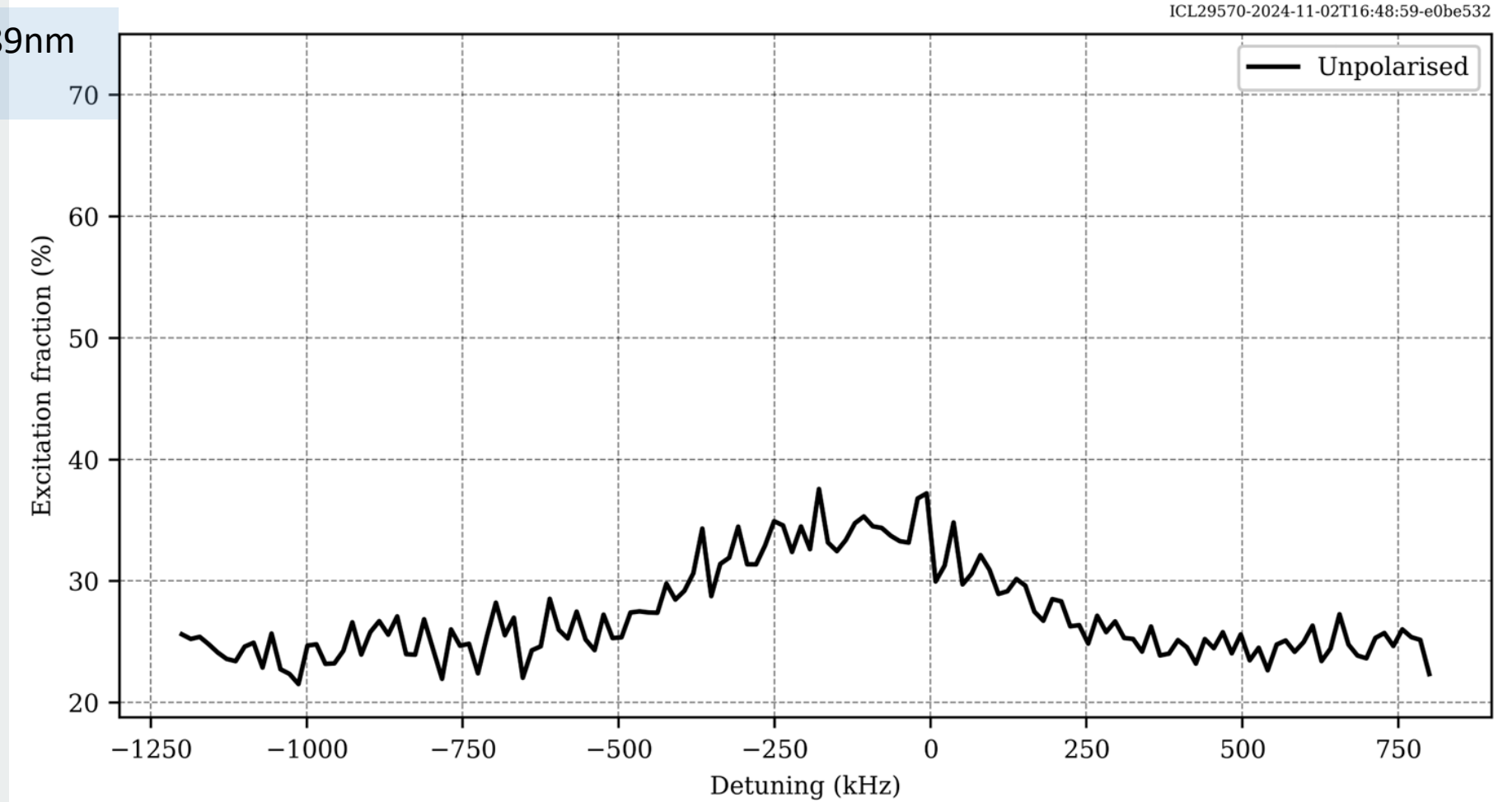


AVS Quantum Sci. 6, 014409 (2024)
https://doi.org/10.1116/5.0172731


813nm
1064nm


t = 10.0 ms

Spectroscopy with 689nm
$^1S_0$ -> $^3P_1$ transition



See e.g. Ludlow, Andrew D. *The strontium optical lattice clock: optical spectroscopy with sub-Hertz accuracy*. University of Colorado, 2008.

Spectroscopy with 689nm
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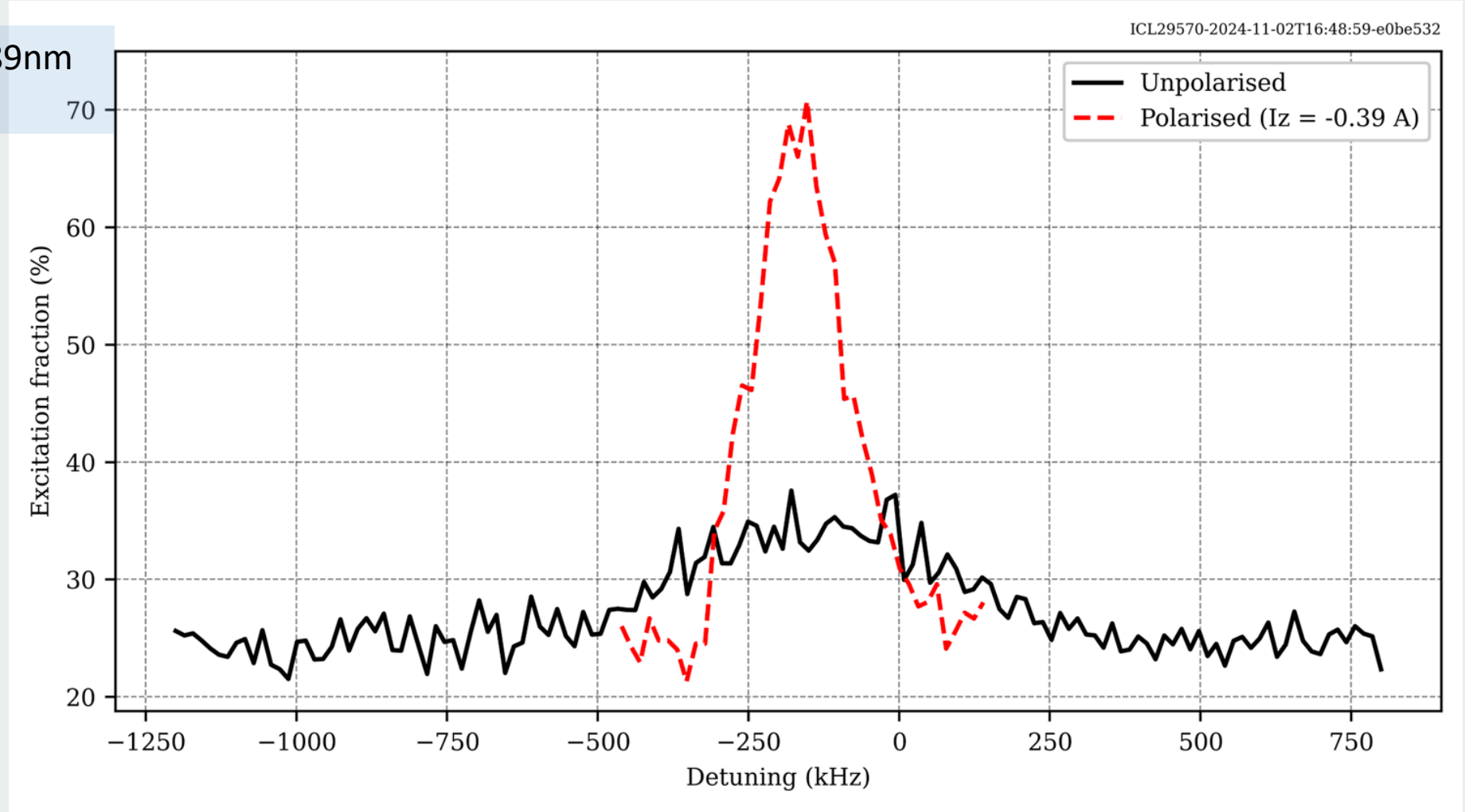

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Spectroscopy with 689nm
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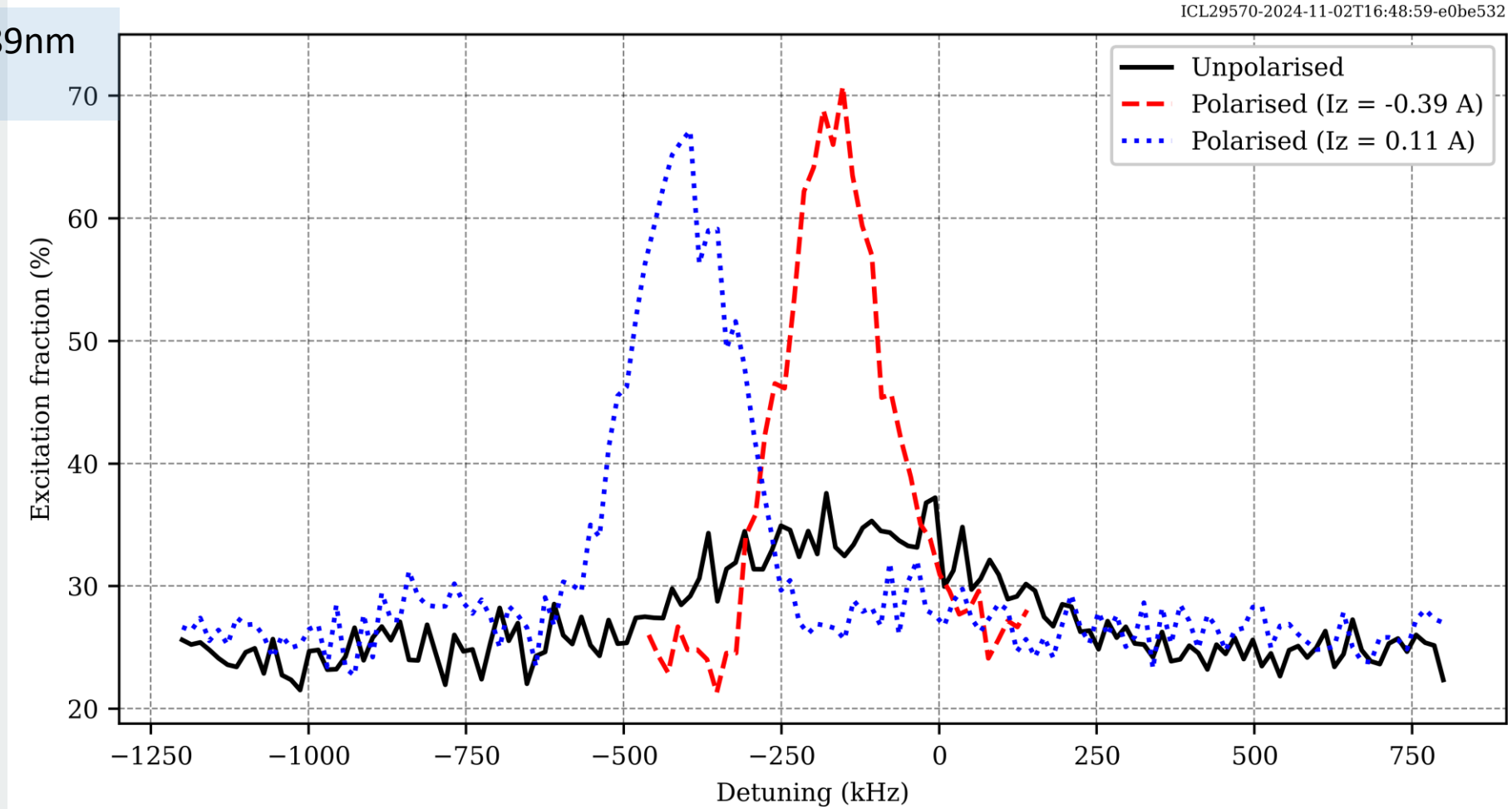

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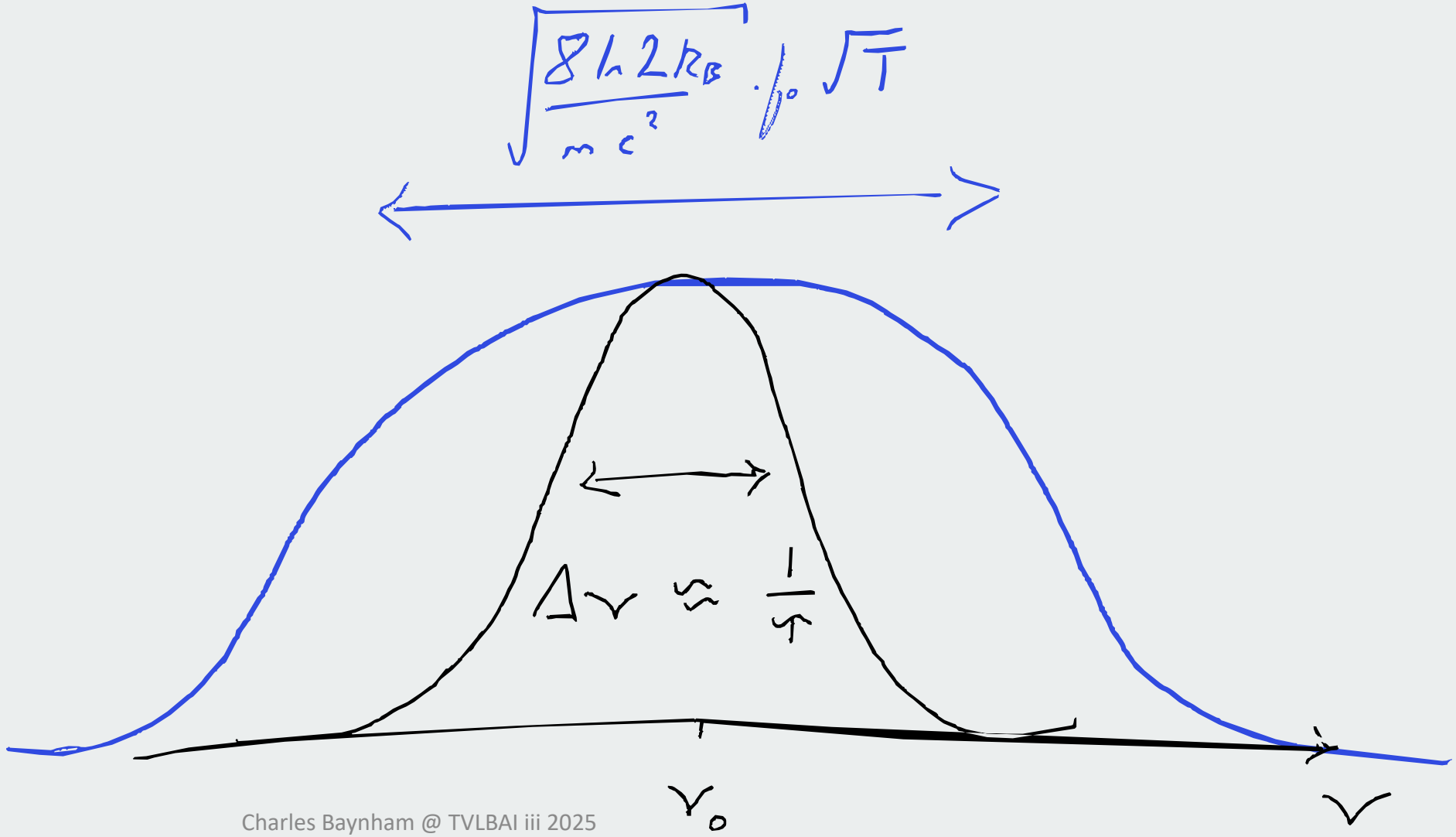
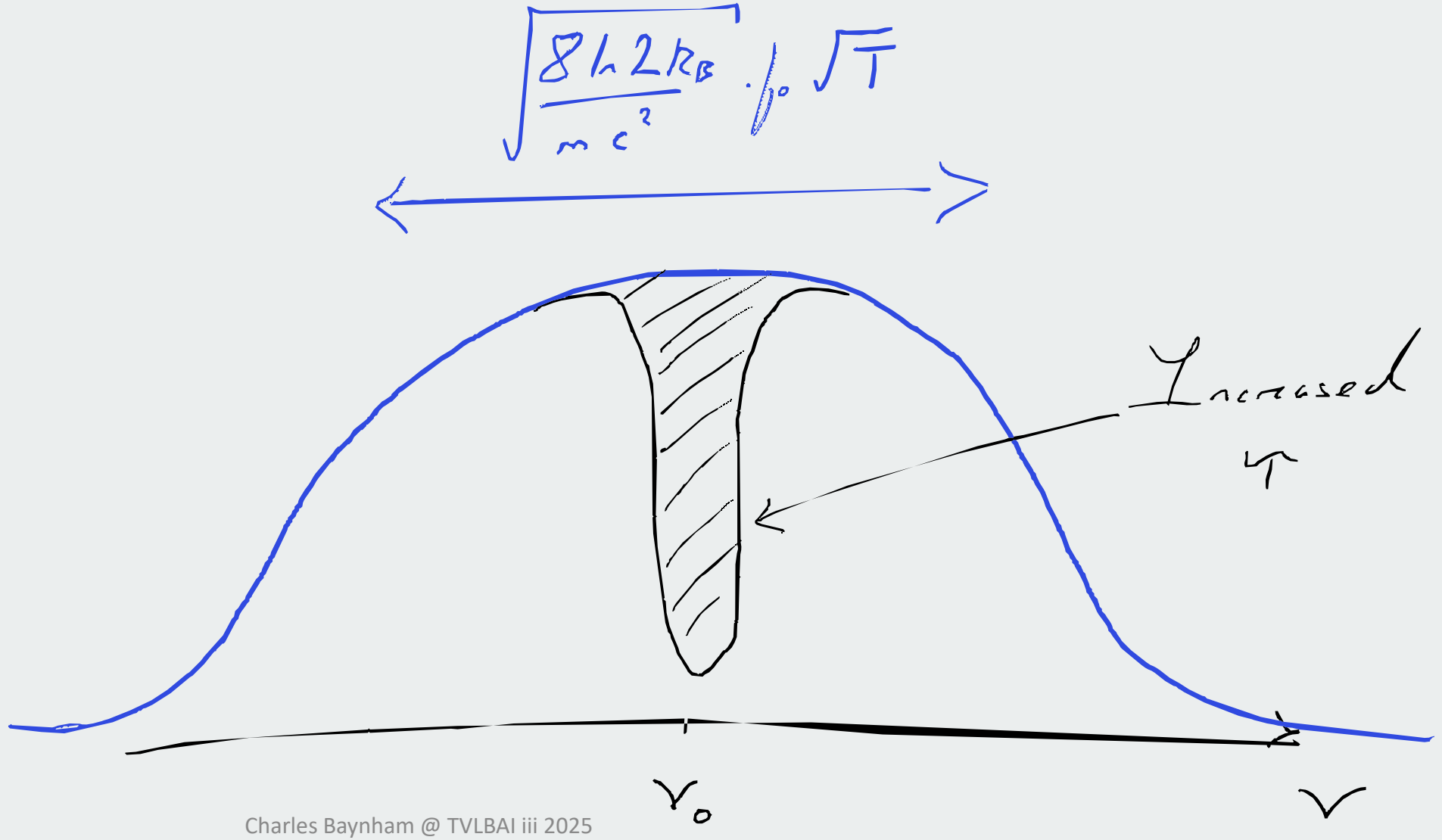
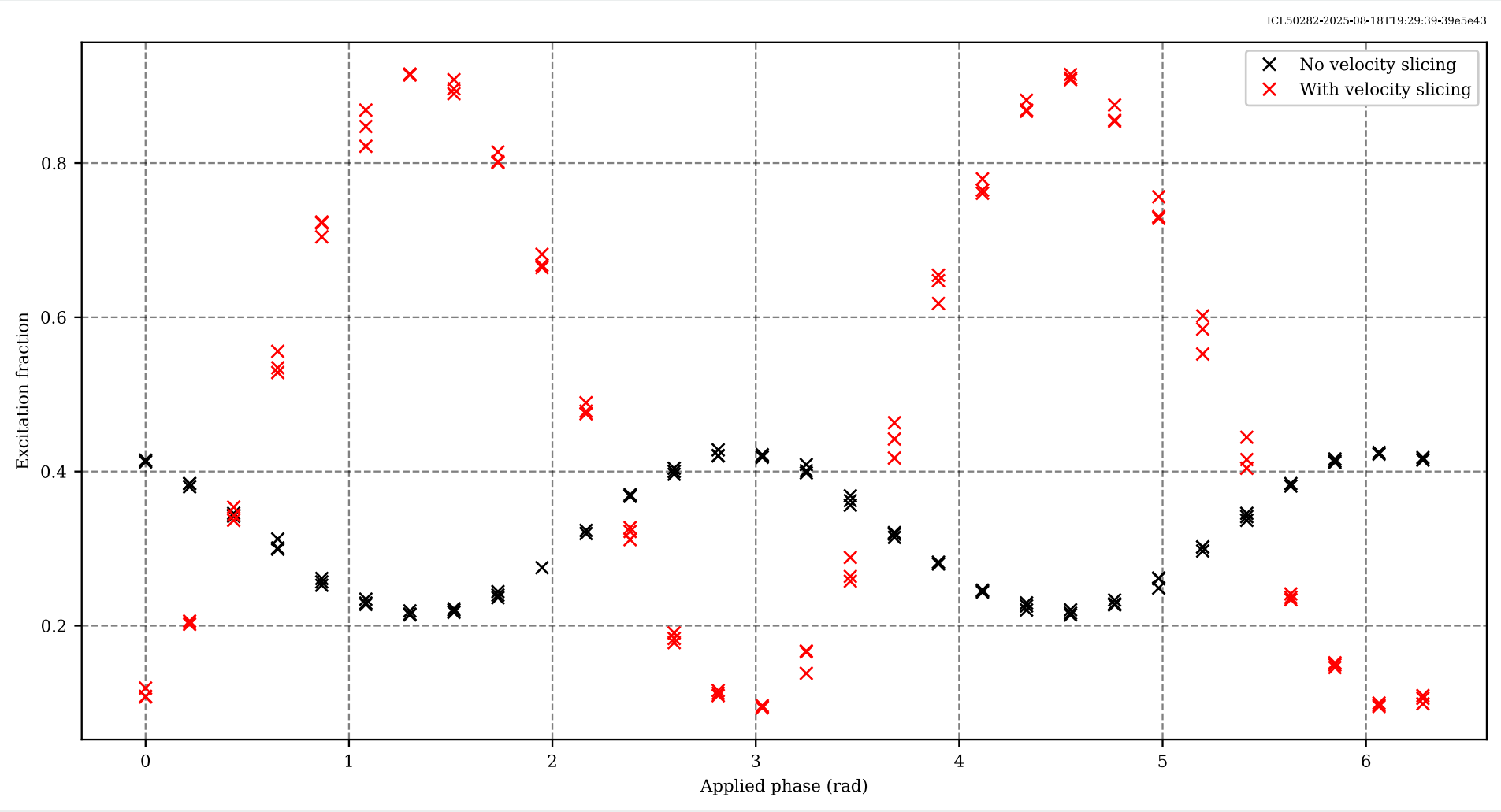
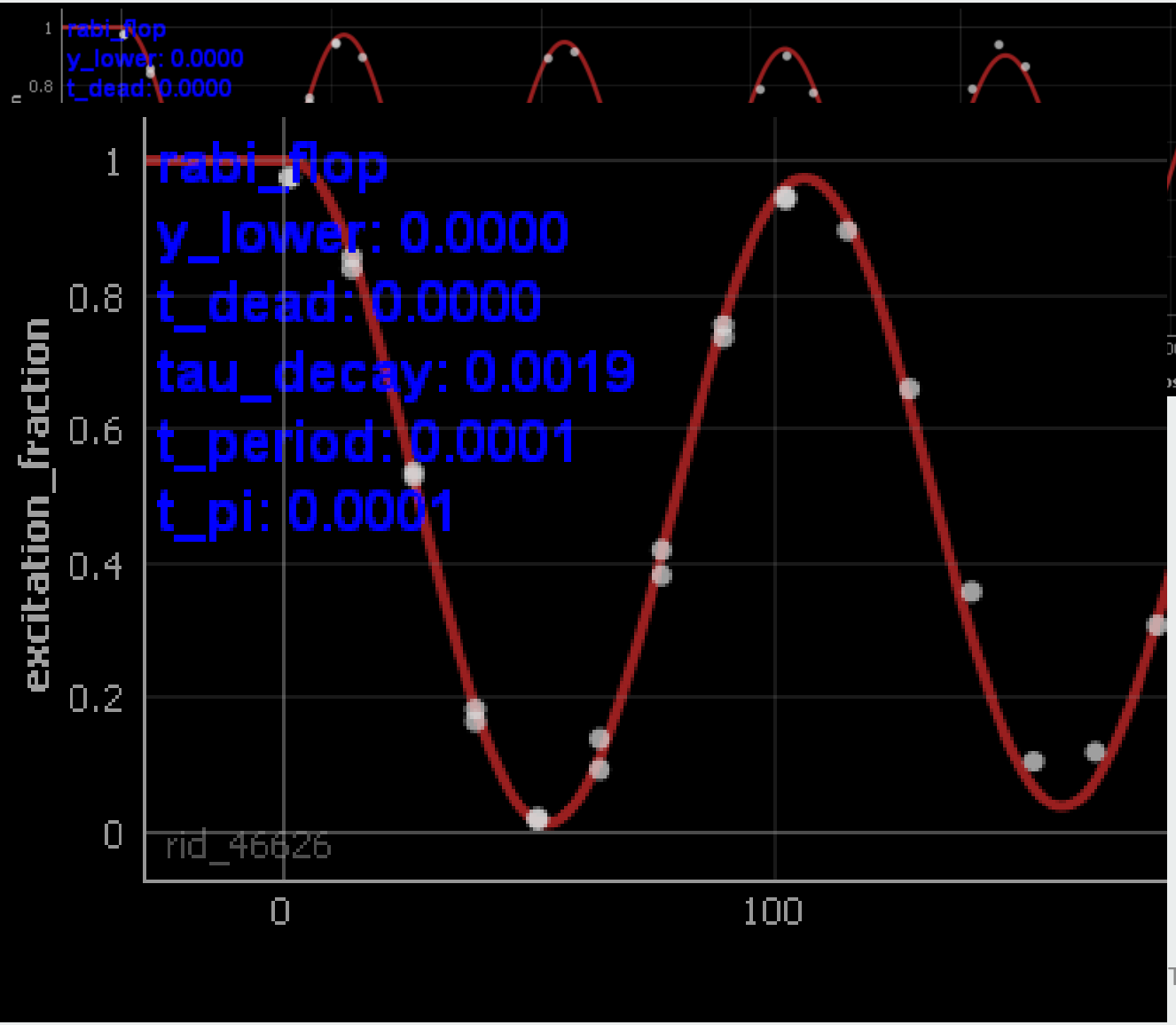

$\sqrt{\frac{8 \ln 2 k_B}{m c^2}} \cdot f_0 \sqrt{T}$
$\Delta\nu \approx \frac{1}{\tau}$
ν_0
ν

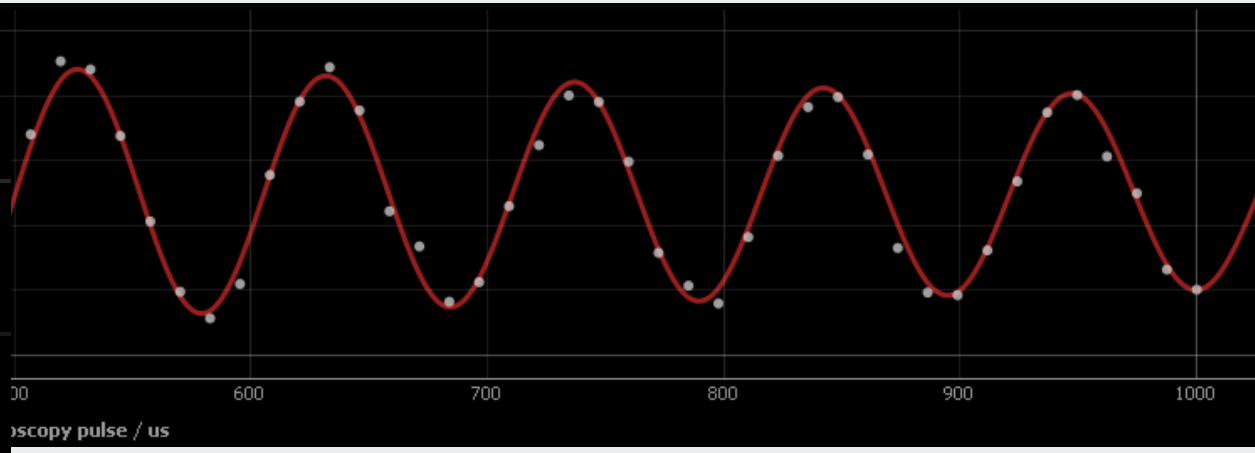

$\sqrt{\frac{8\ln 2 k_B}{mc^2}} \cdot f_0 \sqrt{T}$
Increased
T
ν_0
ν



200us slicing pulse
=> ~15nK velocity slice

Chirped Rabi flop



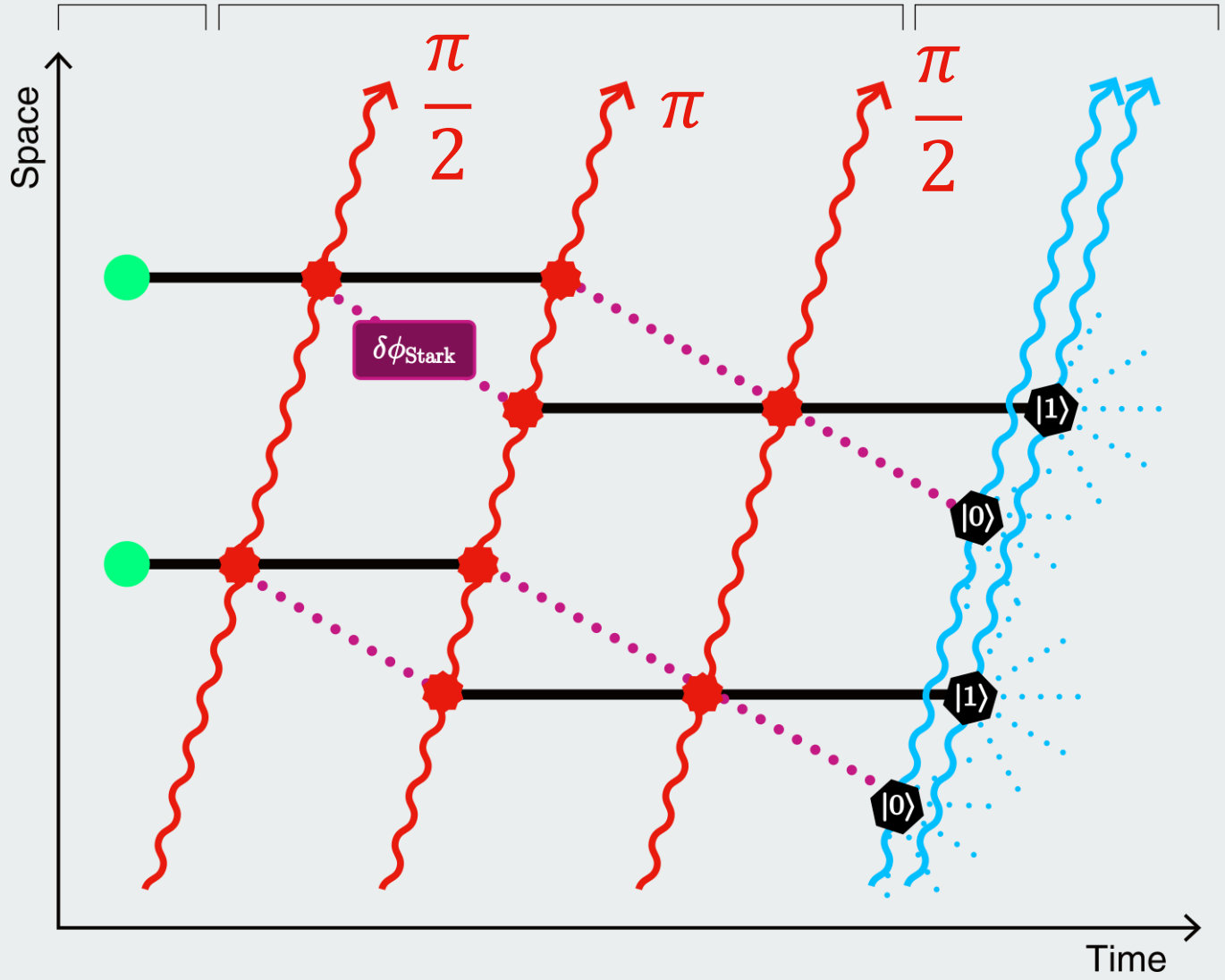


97% contrast

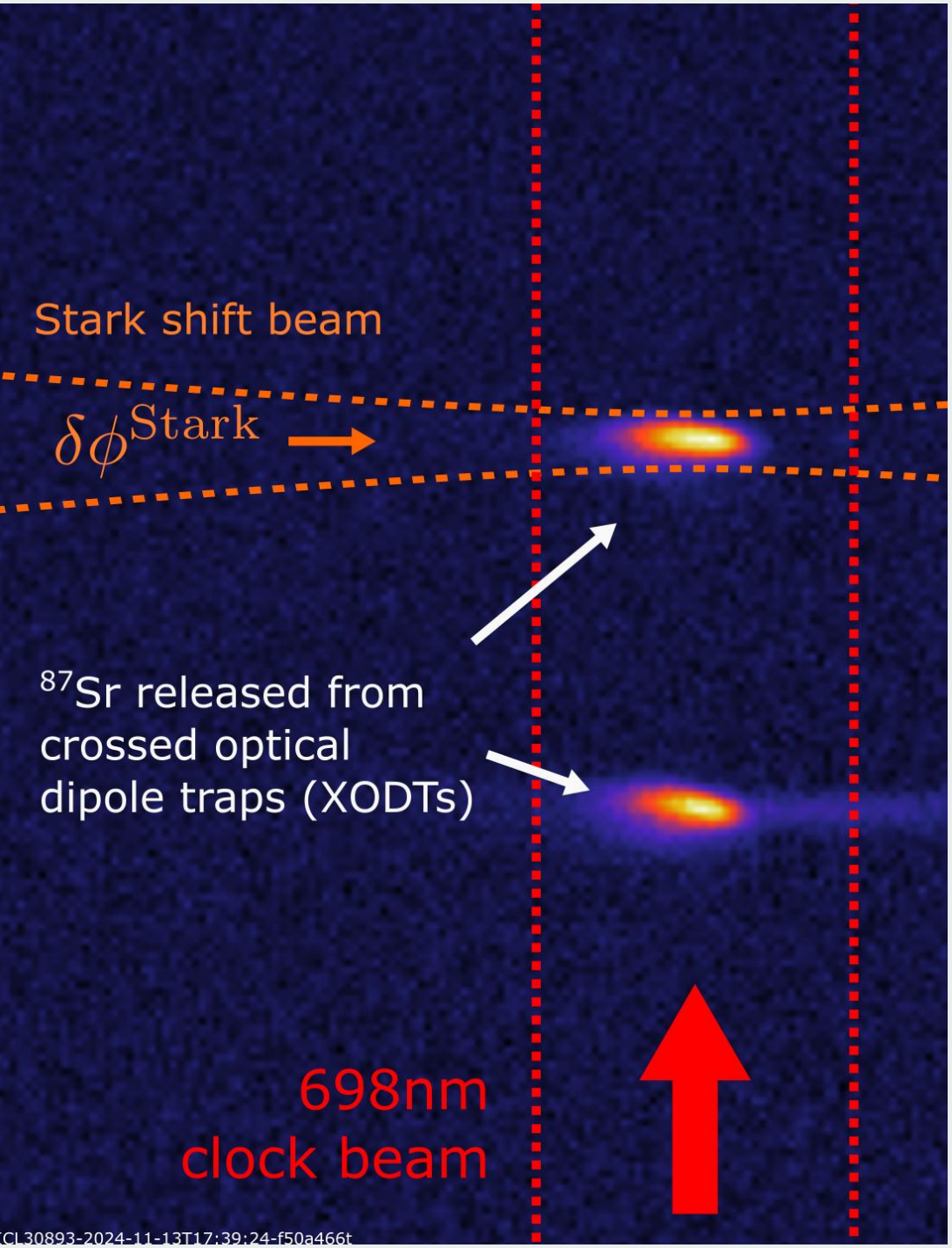
Coherence time = 1.9ms

$= 38\pi$

Blue MOT | Modulated red MOT | Narrowband red MOT | Upper dipole trap | Lower dipole trap | Spin polarization | Velocity slicing | Differential interferometry | State readout

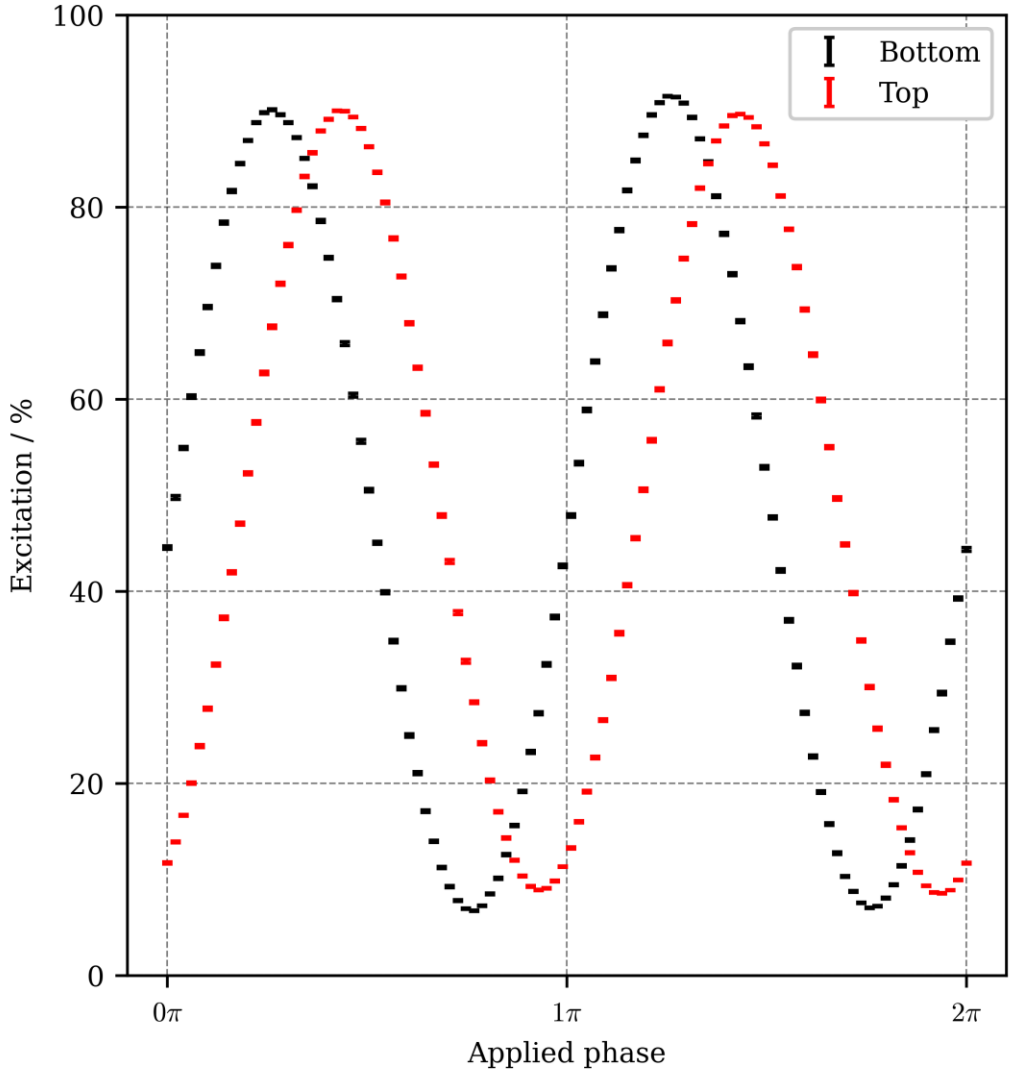


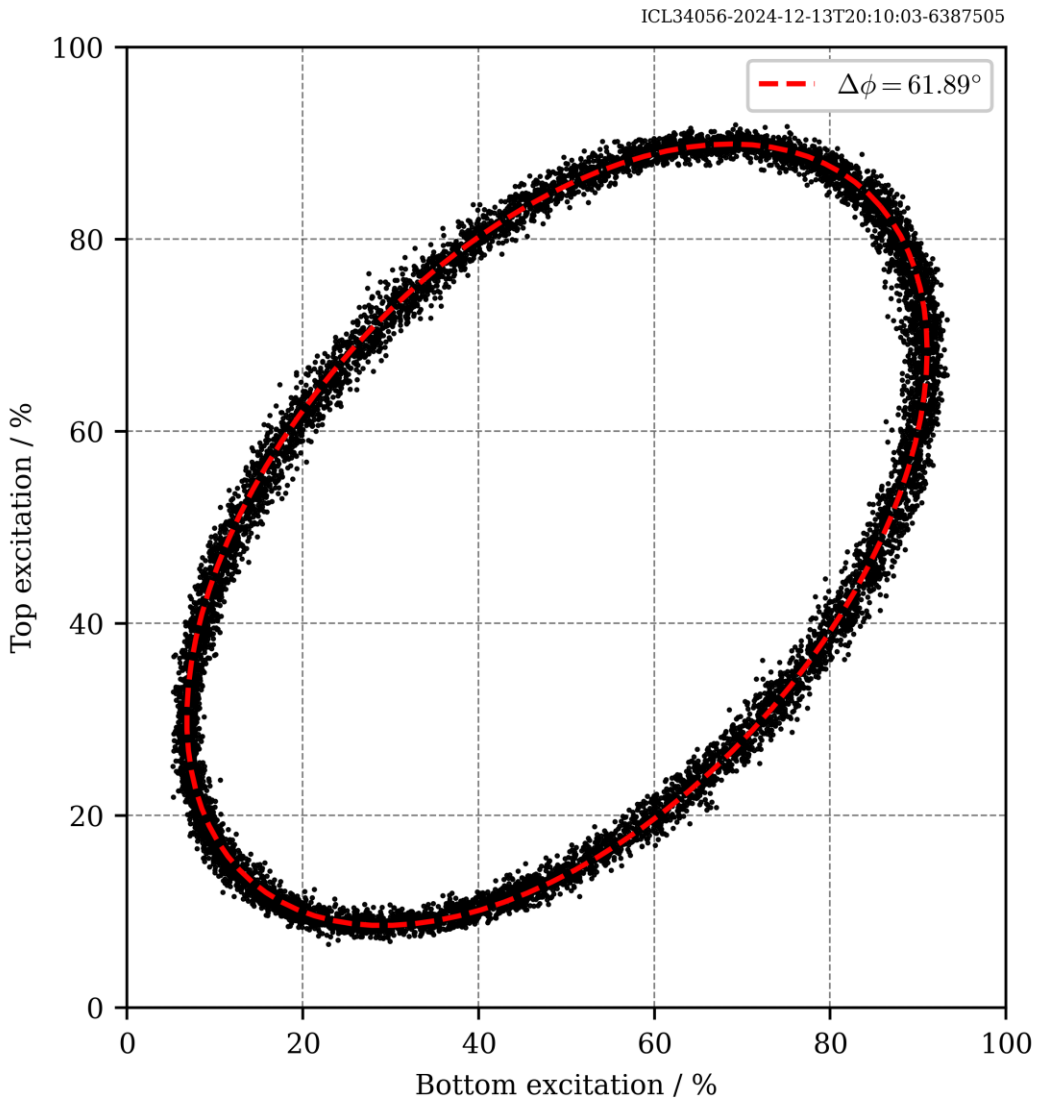
Applied differential phase



- A Stark shifting beam controllably shifts the ground state's energy:
  - Detuned by −80 MHz from the $^1S_0$ F = 9/2 to $^3P_1$ F ′ = 11/2
  - Pulsed for ~30us during interferometry

Differential interferometry

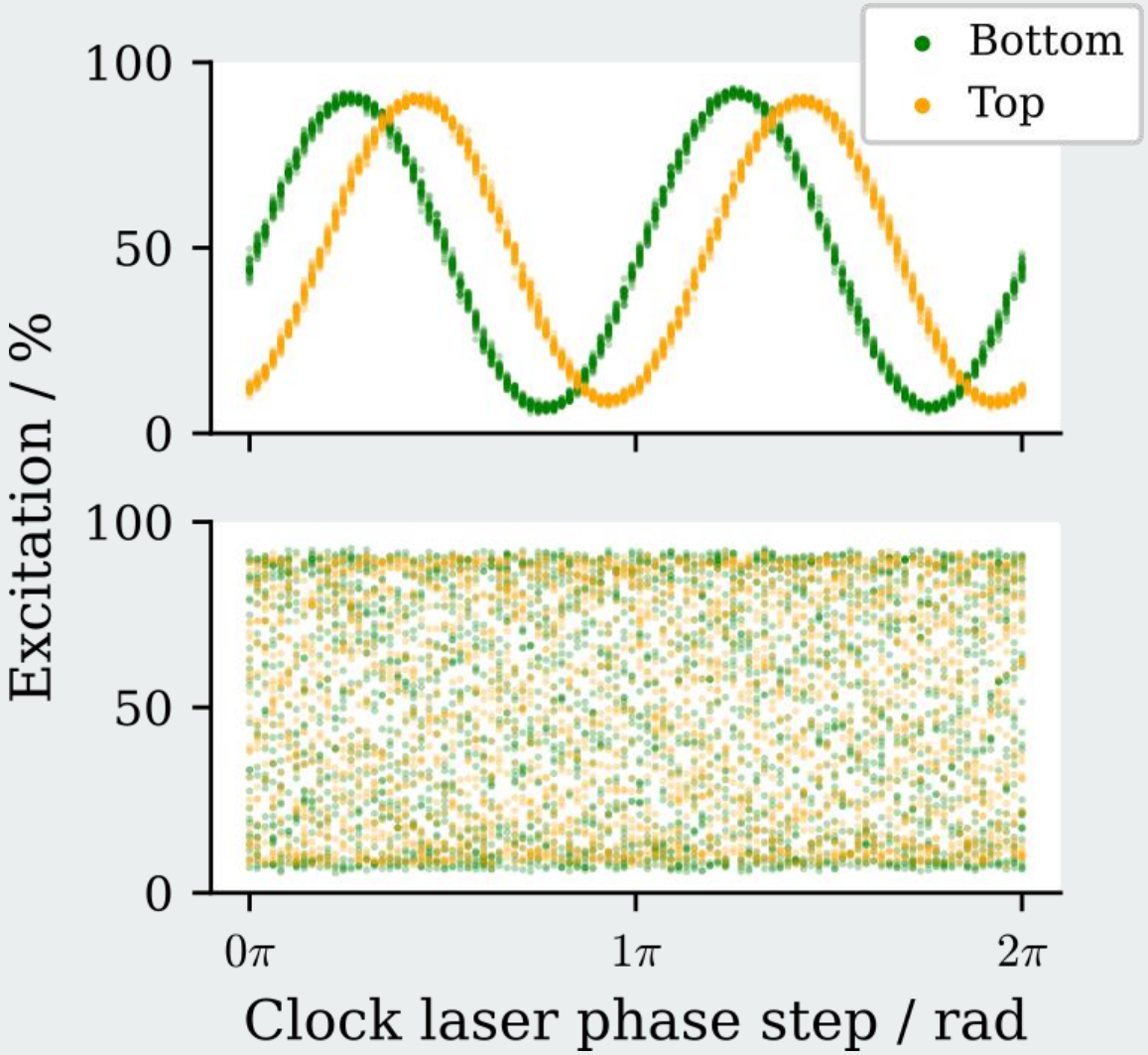


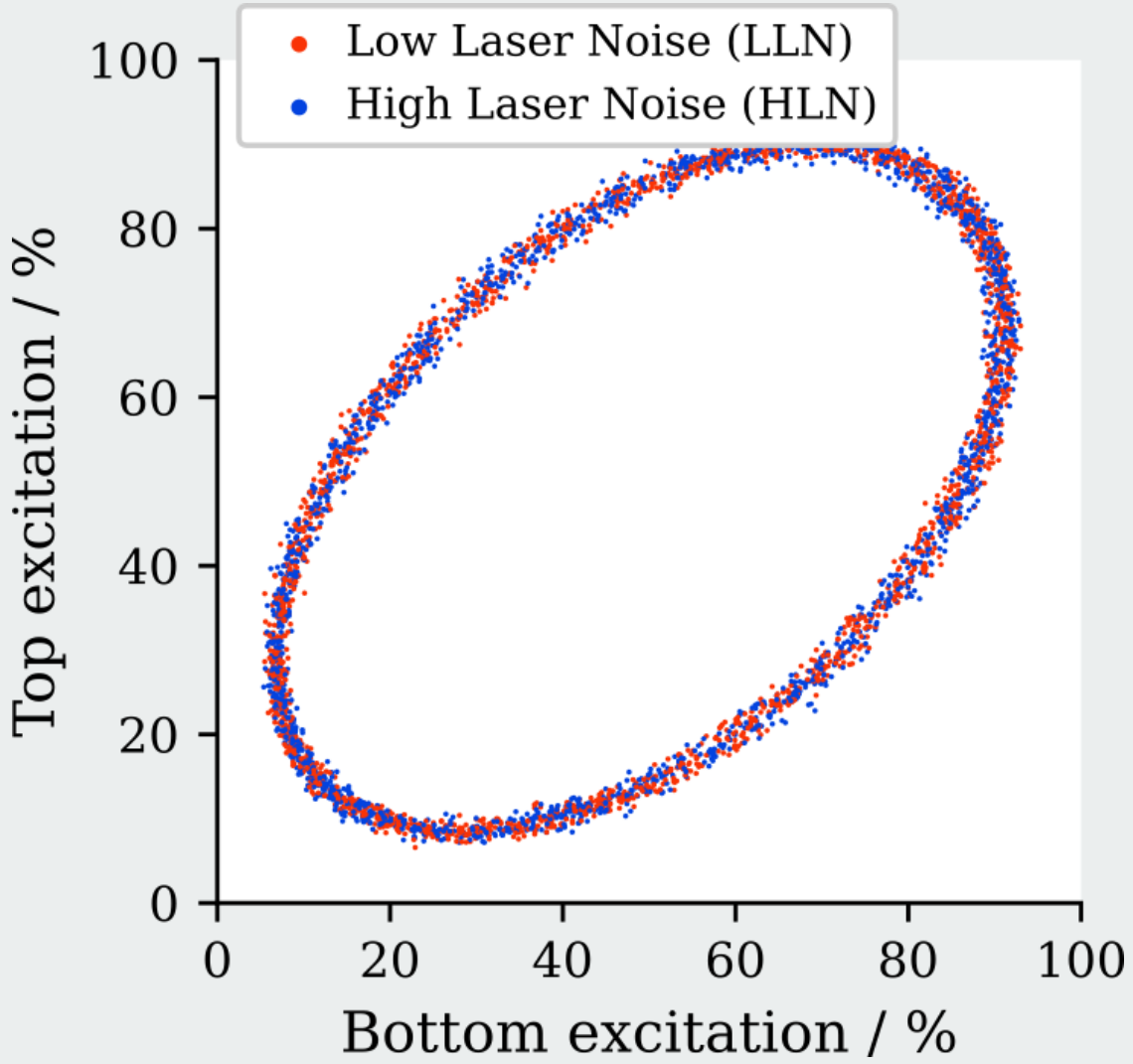


~80% contrast

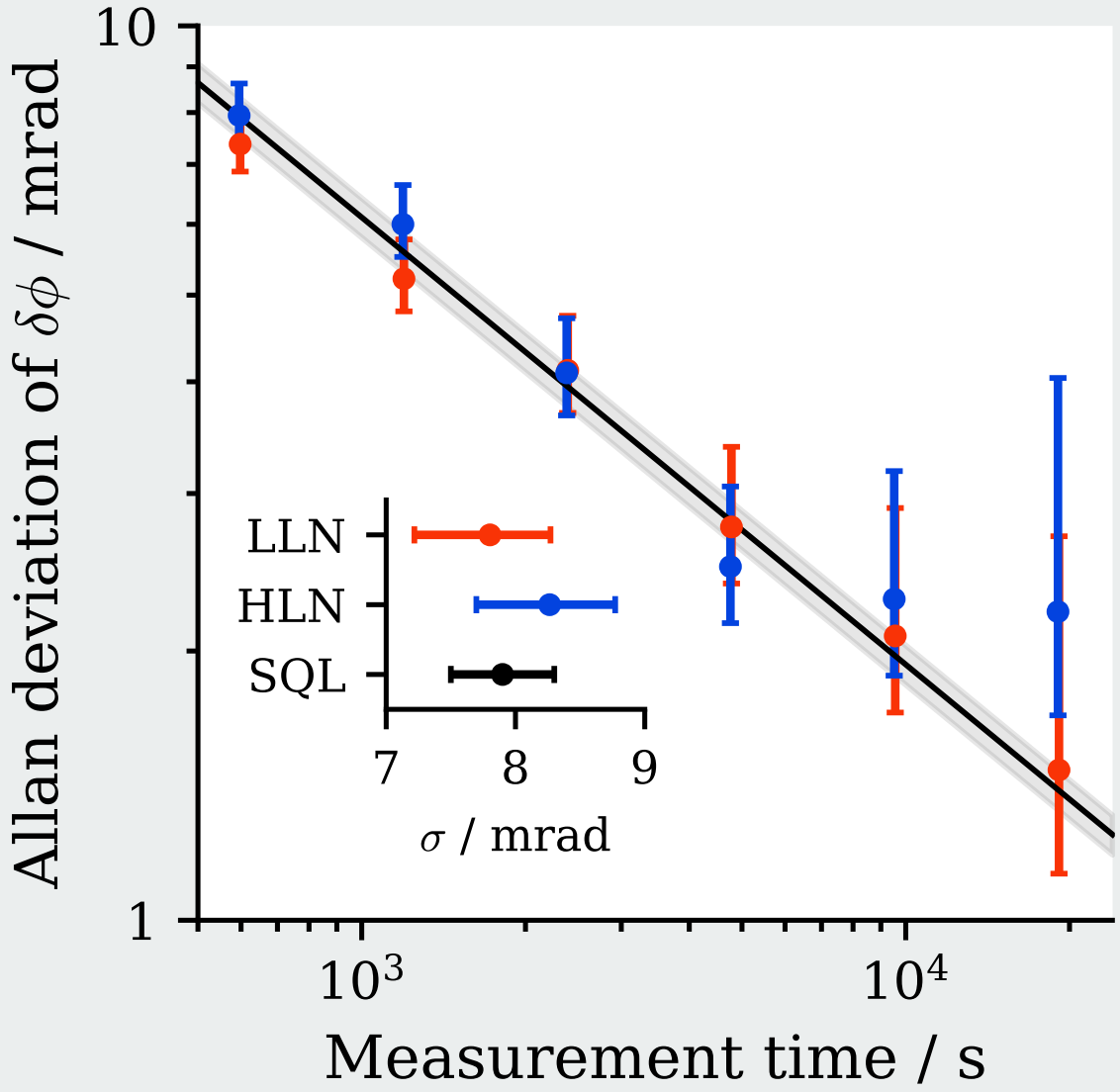
61.89 deg phase shift

Noise injection



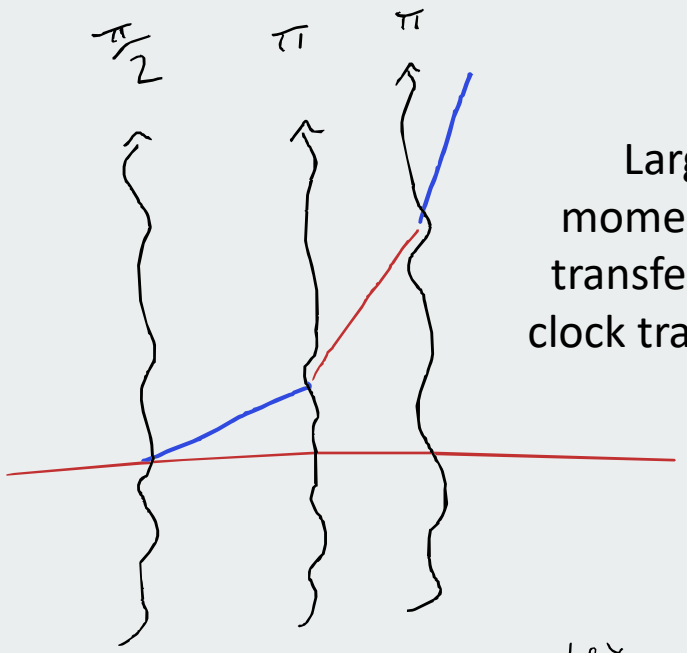


Quantification of noise rejection

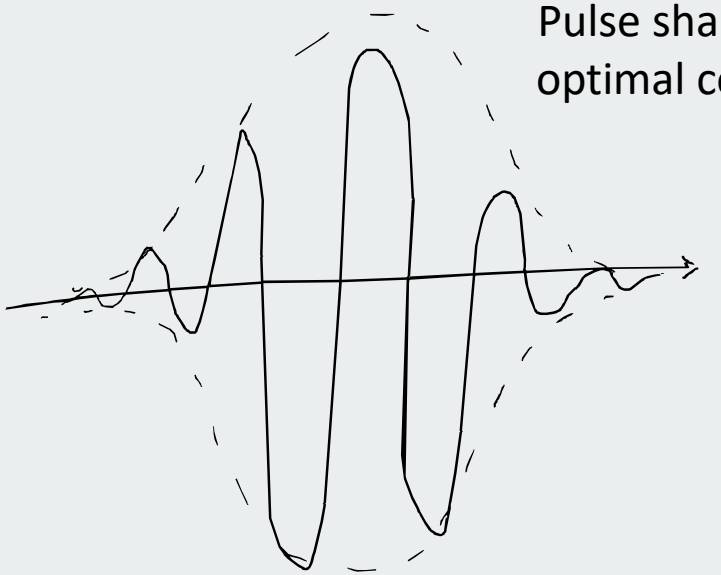


- Absorption imaging =>
  - 1280(130) atoms in top trap
  - 1600(160) atoms in bottom trap
- Monte-Carlo simulation to estimate SQL limit:
  - 1000 datasets with 10,000 shots each
  - σ_{SQL} = 7.7(3) mrad

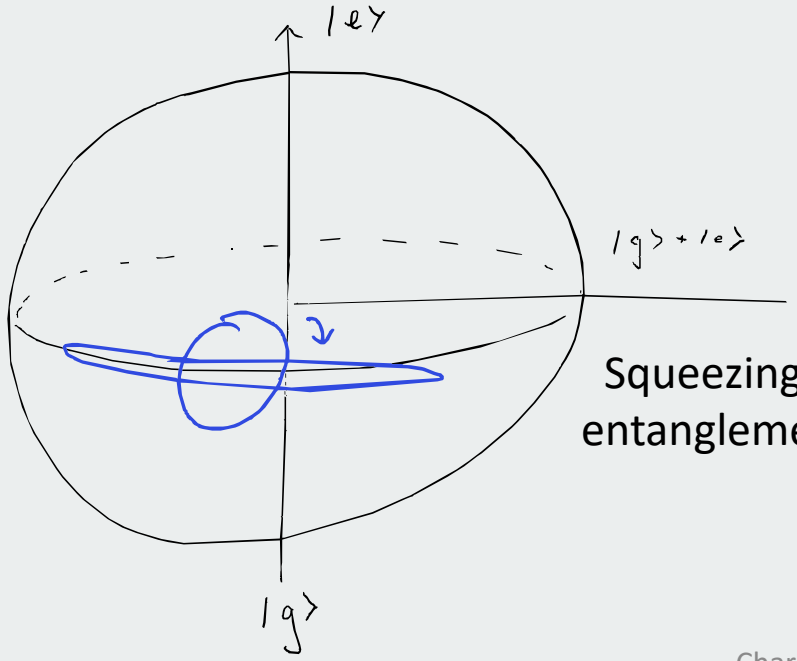
Future work



Large momentum transfer with clock transition

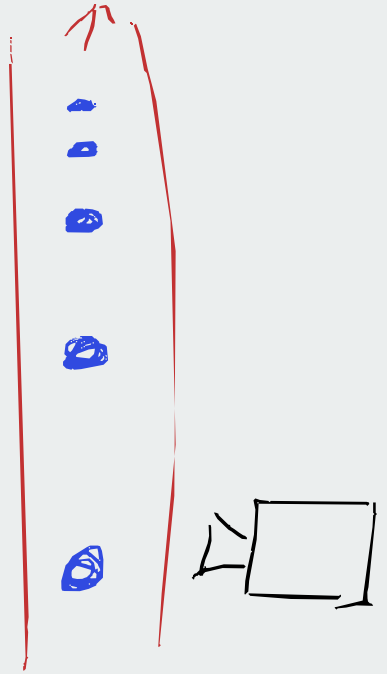


Pulse shaping / optimal control



Squeezing / entanglement

Continuous probing / interleaving



Dillen, Leonie, Ludo, Charles, Richard, David, Elizabeth, Alice, Tom and Oliver

The AION collaboration