WP AION-Upgrades

- How do we reach the sensitivity required to enable the science goals?

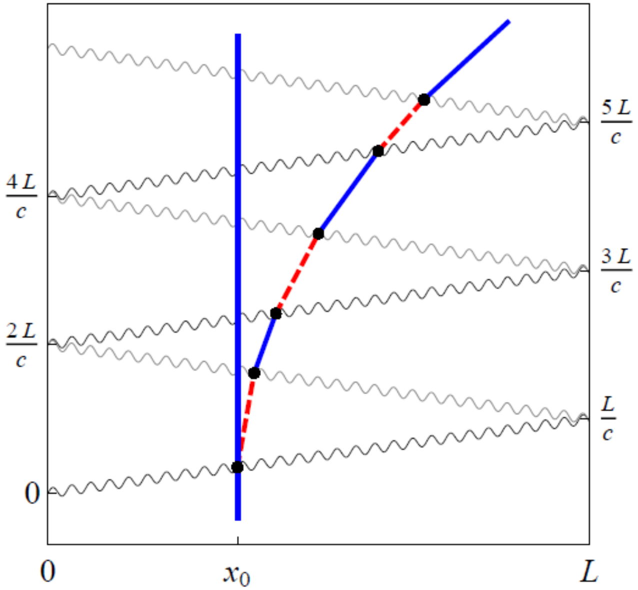
Tasks to define work areas:

- Task 1: Large momentum transfer
- Task 2a: Atom preparation
- Task 2b: Spin Squeezing

Aim to demonstrate significant advancements prior to AI-100/1000

WP AION-Upgrade Task 1: LMT

- To address propagation delay → single photon LMT on clock transition
- Meeting MAGIS/AION goals → need 10-100x LMT increase over SOTA



Graham, *et al.*, PRL (2013)

WP AION-Upgrade Task 1: LMT

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Work in Task 1

Enable LMT and minimise errors:

- Single photon gradiometry on narrow line to suppress spont. emission
- Beam quality (wavefront, shaping, filtering)
- Robust and high fidelity schemes, composite
- Launching and collimation/cooling schemes

Demonstrate in laboratory and translate to AI-10

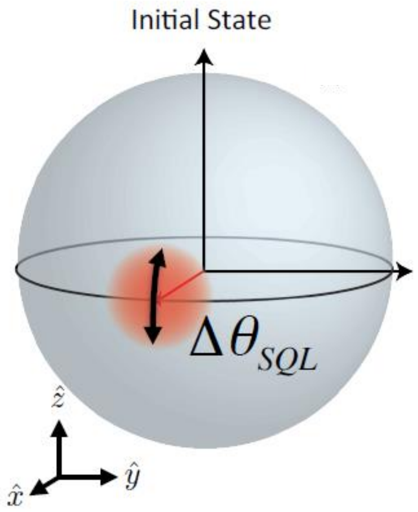
Estimated budget for Task 1

- 36 months of RF time, £100k/year: £300k
- Capital: £550k

Worked capital example:	
Laser systems for cooling and interferometry	£260,000
Experimental control and electronics	£70,000
Optical equipment	£50,000
Vacuum system and camera	£110,000
Test and measurement	£60,000
Total	**£550,000**

- Will require in-kind capital and staff (est >£2M)

WP AION-Upgrade Task 2



Need to shrink θ

Design goals for 5e-19 /rt(Hz) strain sensitivity in AI-100:

- Task 2a: Atom Preparation
  - Prepare 10^9 atoms at < 100 nK within 10 s; transport from sidearm to AI tube
- Task 2b: Spin Squeezing
  - Realise 20 dB of metrologically useful squeezing on the clock transition

Upgrade task 2a: Atom preparation

- High-flux ^{87}Sr source: 10^{11} slow atoms/second
  - State of the art: 10^9 atoms/second
- Big ^{87}Sr “blue” MOT: 10^{11} atoms
  - State of the art: 5×10^8 atoms
- Narrow-line cooling of 10^{10} atoms to 1 uK in dipole trap (+ optical pumping)
  - State of the art: 10^7 atoms
- Evaporative cooling of 10^9 atoms to < 100nK
  - State of the art: 2×10^5 atoms
- Horizontal transport over 50 cm with heating < 100 nK
  - State of the art: few uK heating

Upgrade task 2b: Spin squeezing

- Apply 20 dB spin squeezing on “clock” transition
  - Option 1: Cavity – either weak measurement or one axis twisting (“cavity feedback”)
  - Option 2: Interactions – e.g. through Rydberg dressing
- Squeezing must be metrologically useful
  - Low dephasing and decoherence
- Squeezing must not induce too much heating (< 100 nK)
  - Cavity: Challenging due to dipole forces from cavity spatial mode; Rydberg: untested
- Squeezing must be compatible with 10^9 atoms
  - Cavity: large cavity mode volume; Rydberg: must avoid inelastic collisions
- Squeezing must be compatible with transport, lattice launch and delta-kick lens
  - Preserve squeezing in magnetic sublevels, then transfer to clock states in AI tube?
- Detection noise < 10^{-6} to measure squeezed population distribution

Upgrade task 2: Budget estimate

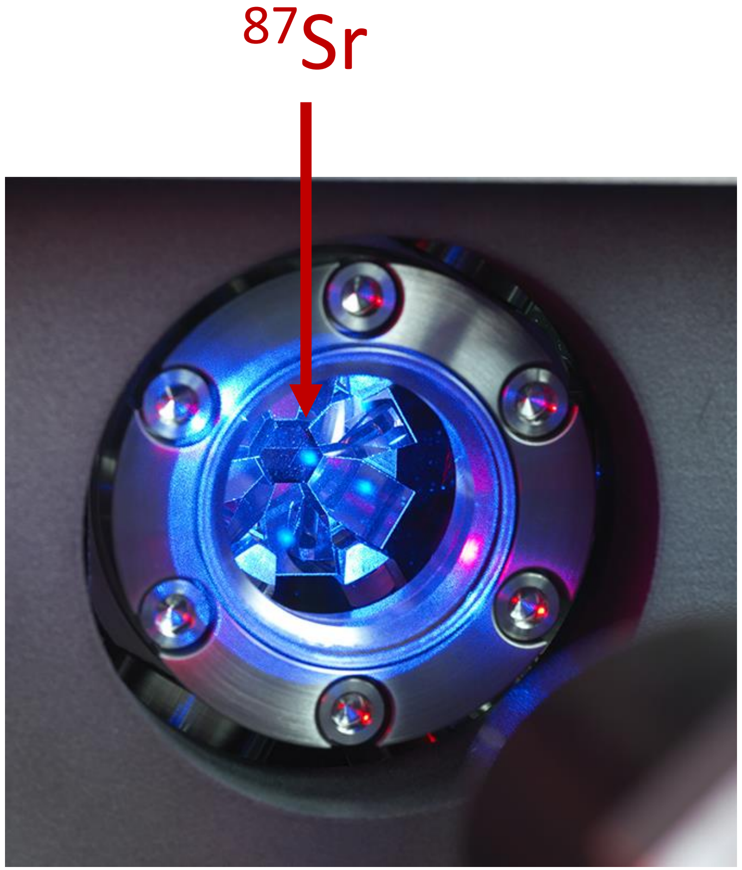
Labour: £600k

£600k = 2 PDRA staff at £100k/yr each
+ in kind contributions (e.g. students)

Capital: £1.0M

See table below

Laser systems for cooling	£605,000
Laser stabilisation ("clock" laser + stability transfer)	£580,000
Experimental control and electronics	£125,000
Vacuum system, camera and squeezing cavity	£140,000
Test and measurement	£100,000
Estimated in-kind contributions from hosts	-£550,000
Total capital budget	£1,000,000



But this is only 10^7 atoms…