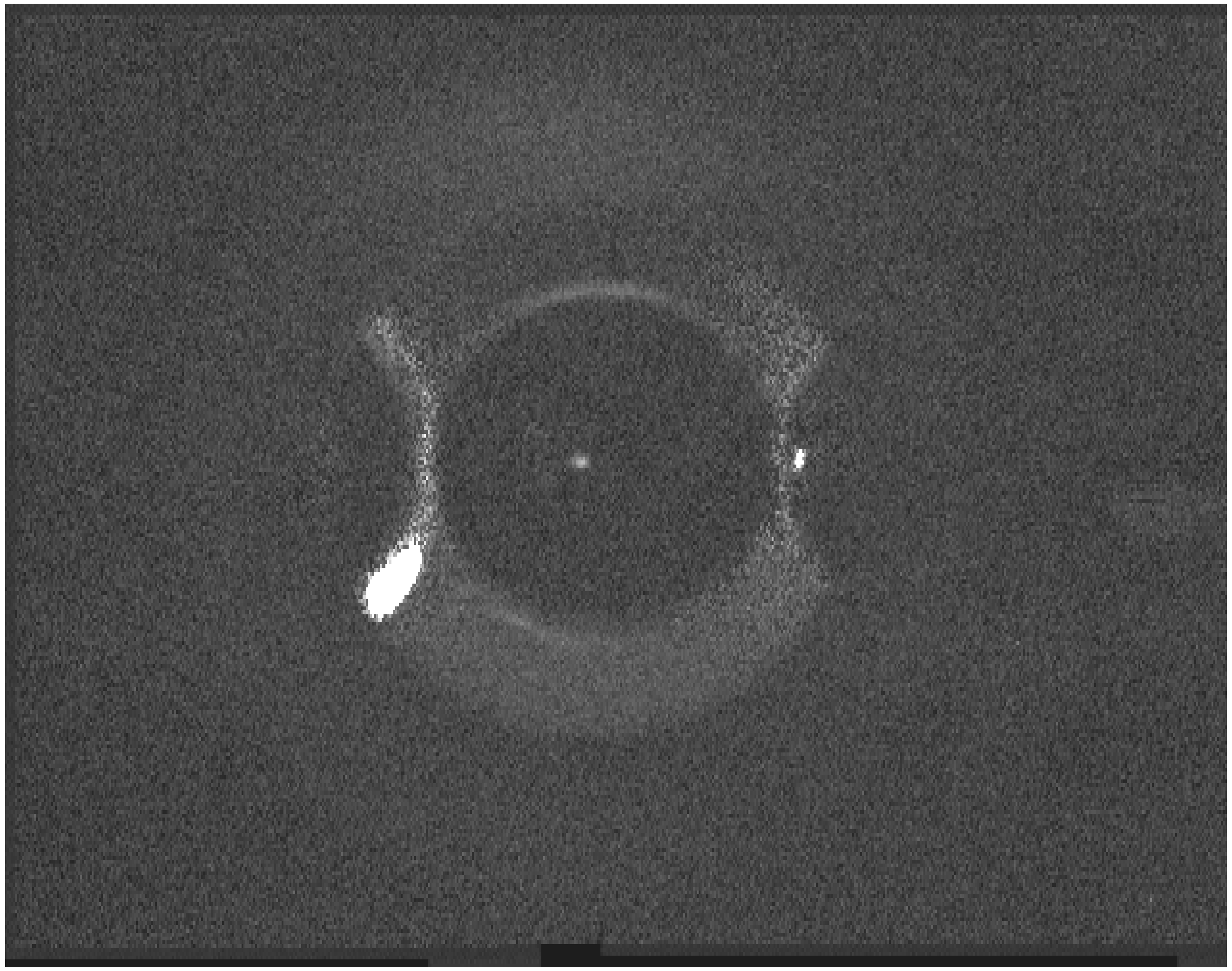
Argonne NATIONAL LABORATORY

... for a brighter future

Progress on the Search for EDM in Ra-225

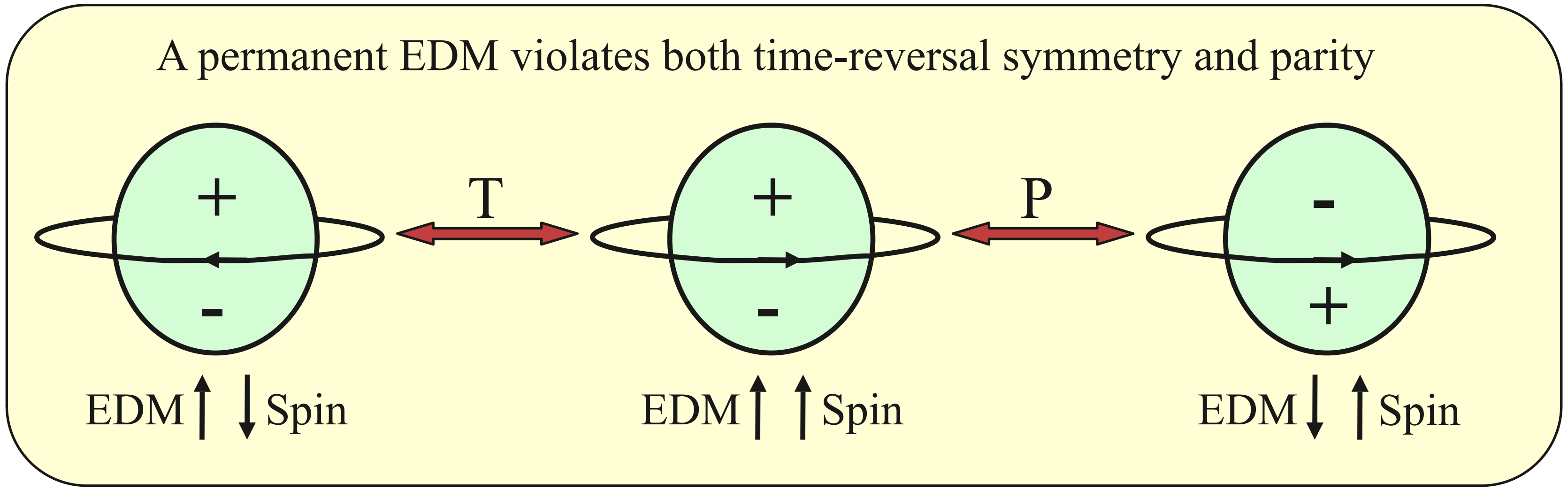


W. L. Trimble, I.A. Sulai, P. Mueller, I. Ahmad, K. Bailey, W. Korsch, B. Graner, J. P. Greene, T. P. O'Connor, R. J. Holt, Z.-T. Lu

U.S. Department of Energy

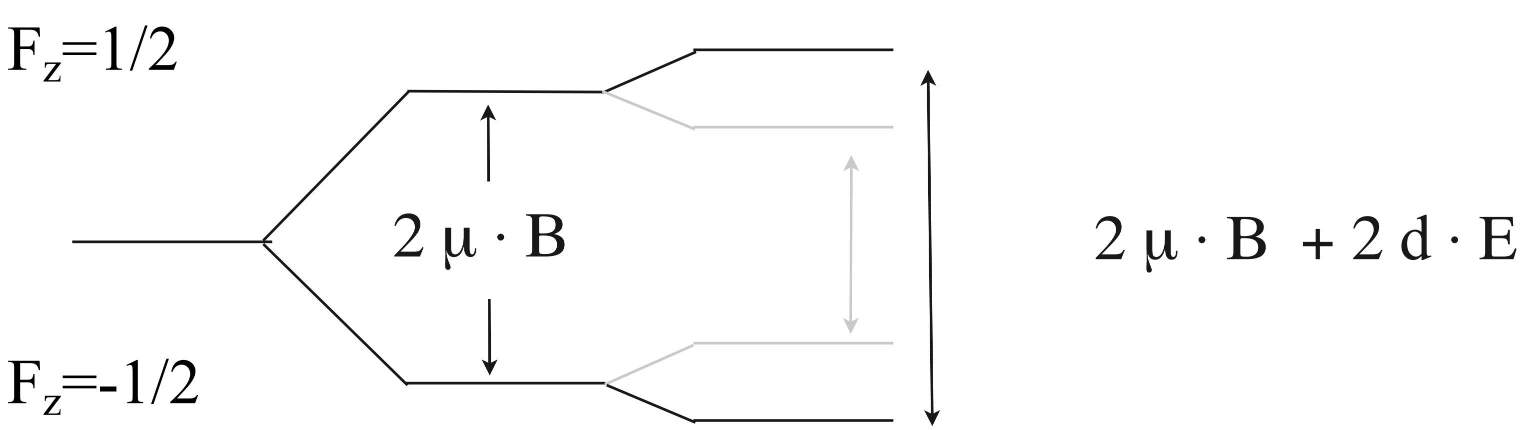
THE UNIVERSITY OF CHICAGO

Atomic EDM Violates Both P and T and appears as a perturbation to NMR



Ra is diamagnetic
(like Rn, Xe, Hg)
EDM measurements sensitive to
Schiff moment of nucleus

$$H = \vec{\mu} \cdot \vec{B} \pm \vec{d} \cdot \vec{E}$$



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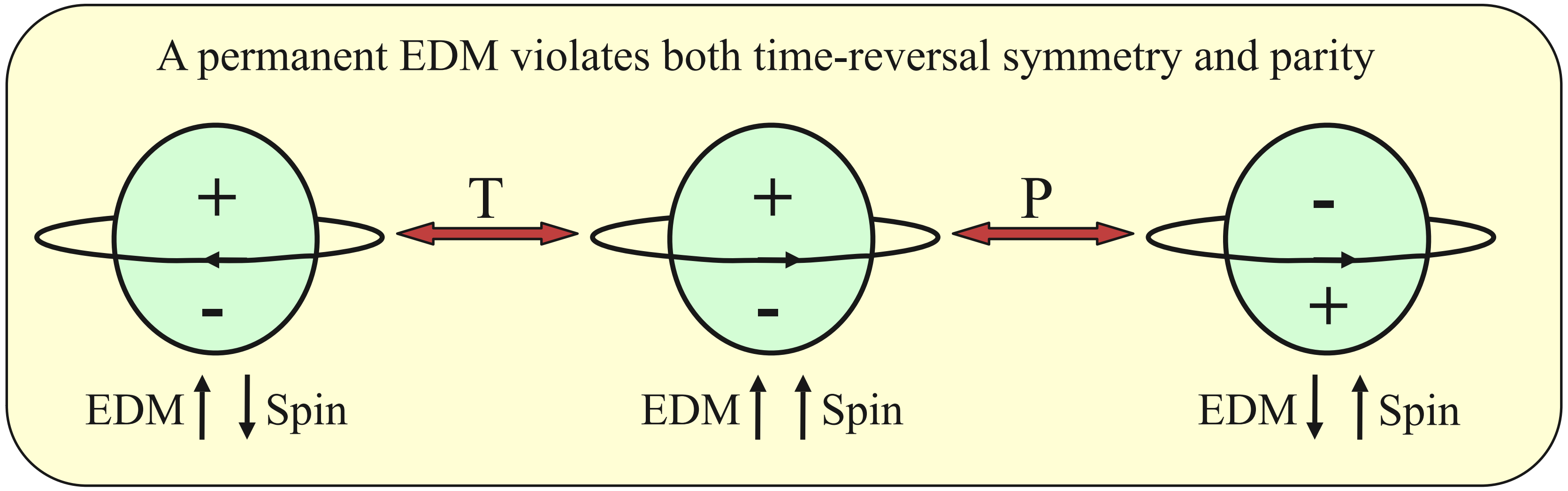

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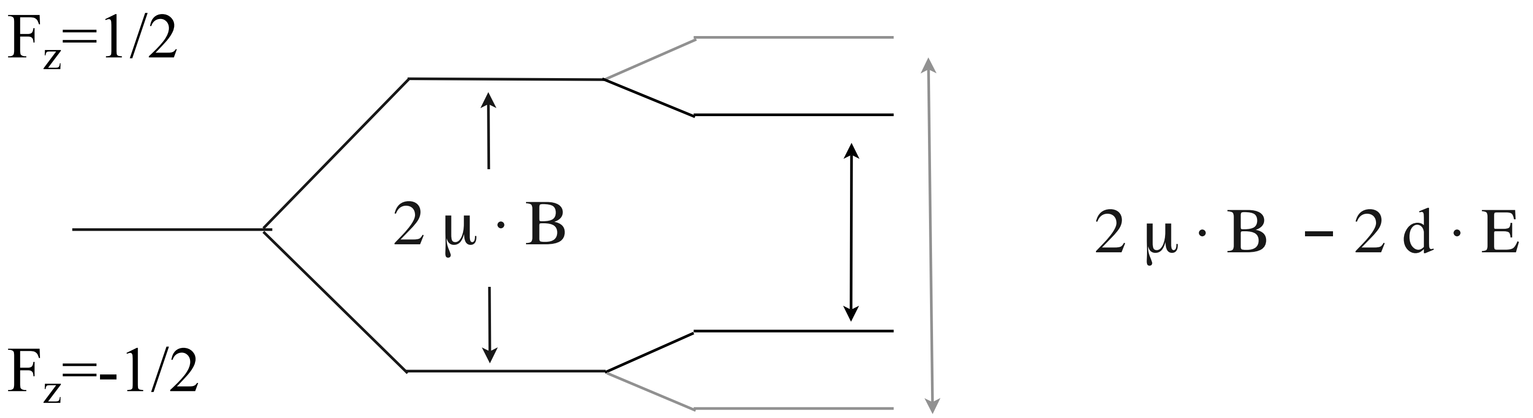
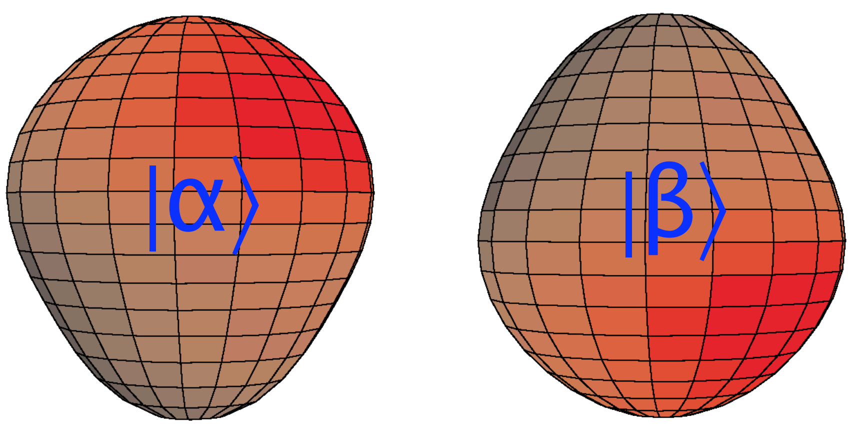
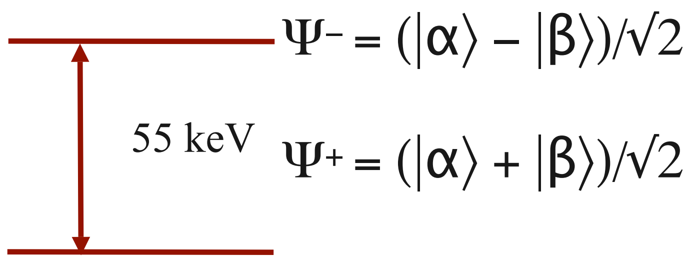


Radium-225 has enhancement of observable effect of symmetry-violation over stable nuclei

- Large intrinsic Schiff moment due to octupole deformation
- Closely spaced parity doublet
- Relativistic atomic structure

Haxton & Henley (1983)
Auerbach, Flambaum & Spevak (1996)
Engel, Friar & Hayes (2000)





Skyrme Model	Isoscalar	Isovector	Isotensor
SkM*	1500	900	1500
SkO'	450	240	600

Enhancement Factor: EDM (^{225}Ra) / EDM (^{199}Hg)

Schiff moment of ^{199}Hg, de Jesus & Engel, PRC72 (2005)
Schiff moment of ^{225}Ra, Dobaczewski & Engel, PRL94 (2005)

^{226}Ra Source

238U 4.5 Gy —α, β→ 226Ra 1600 years —α→ 222Rn 3.8 days —α→ Po, At, Bi —α, β→ 206Pb stable

I = 0

Permits testing of trap, lasers

^{225}Ra Source

229Th 7300 yr —α→ 225Ra 15 days —β→ 225Ac 10 days —α→ Fr, At, Rn… ~ 4 hours —α, β→ 209Bi stable

I = 1/2

- 2 mCi ^{225}Ra sources available from ORNL

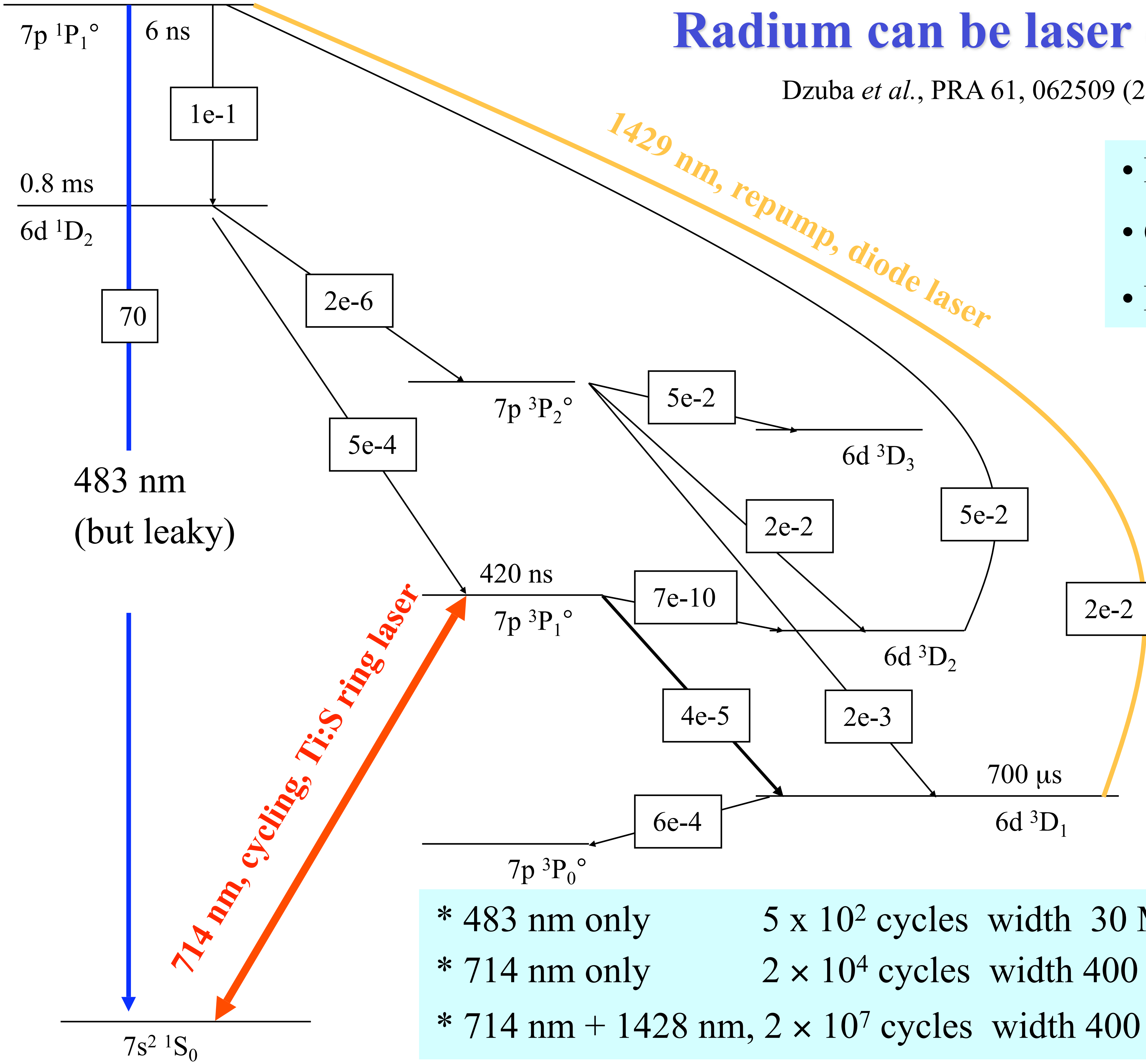
competing with experimental cancer therapies using ^{213}Bi, ^{225}Ac

- Test source: 300 nCi ^{226}Ra - invaluable for testing

Radium can be laser cooled

Dzuba *et al.*, PRA 61, 062509 (2000)

- Linewidth ~ 400 kHz
- Cooling 7 μK, 14 mm/s
- B gradient ~ 1 G / cm



* 483 nm only	5×10^2 cycles	width 30 MHz (leaks to D-levels)
* 714 nm only	2×10^4 cycles	width 400 kHz
* 714 nm + 1428 nm,	2×10^7 cycles	width 400 kHz

Statistical Limit
(we can do it)

$$\delta d = \frac{h}{2E\sqrt{\tau N \varepsilon T}}$$

Near term

$N = 1 \times 10^4$ atoms
$E =$ 100 kV/cm
$\tau =$ 100 seconds
$T =$ 10 days
$\varepsilon =$ 50%

$\delta d = 1 \times 10^{-26}$ e cm

- | d(^{199}Hg) | < 3×10^{-29} e-cm (95% C.L.) Griffith *et al., PRL 102 (2009)*

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$\delta d = 1 \times 10^{-26}$ e cm

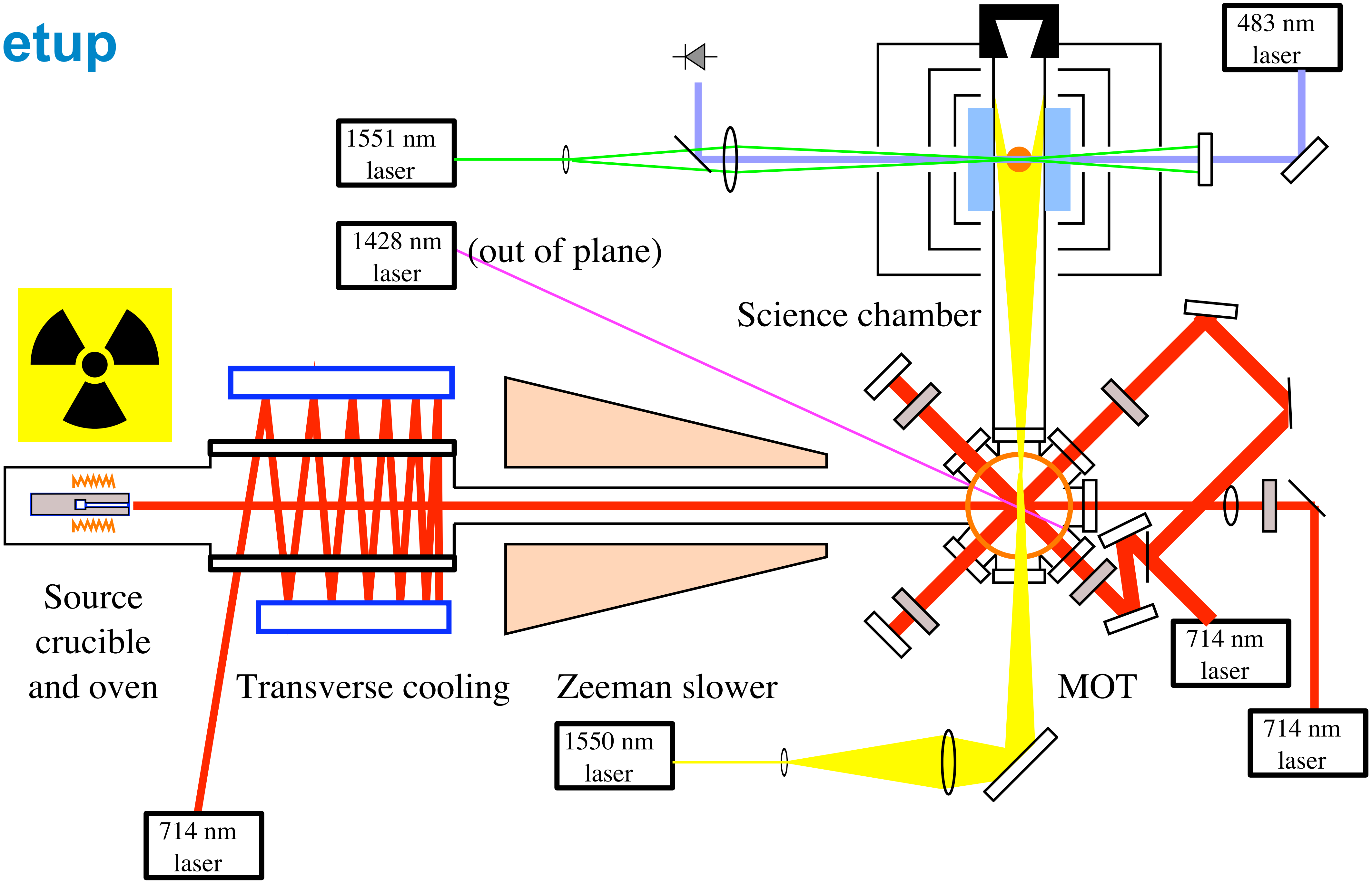
Long term

$N = 1 \times 10^6$ atoms
$E = 100$ kV/cm
$\tau = 100$ seconds
$T = 100$ days
$\varepsilon = 50\%$

$\delta d = 3 \times 10^{-28}$ e cm

- $|d(^{199}Hg)| < 3 \times 10^{-29}$ e-cm (95% C.L.) Griffith *et al., PRL 102 (2009)*

Setup



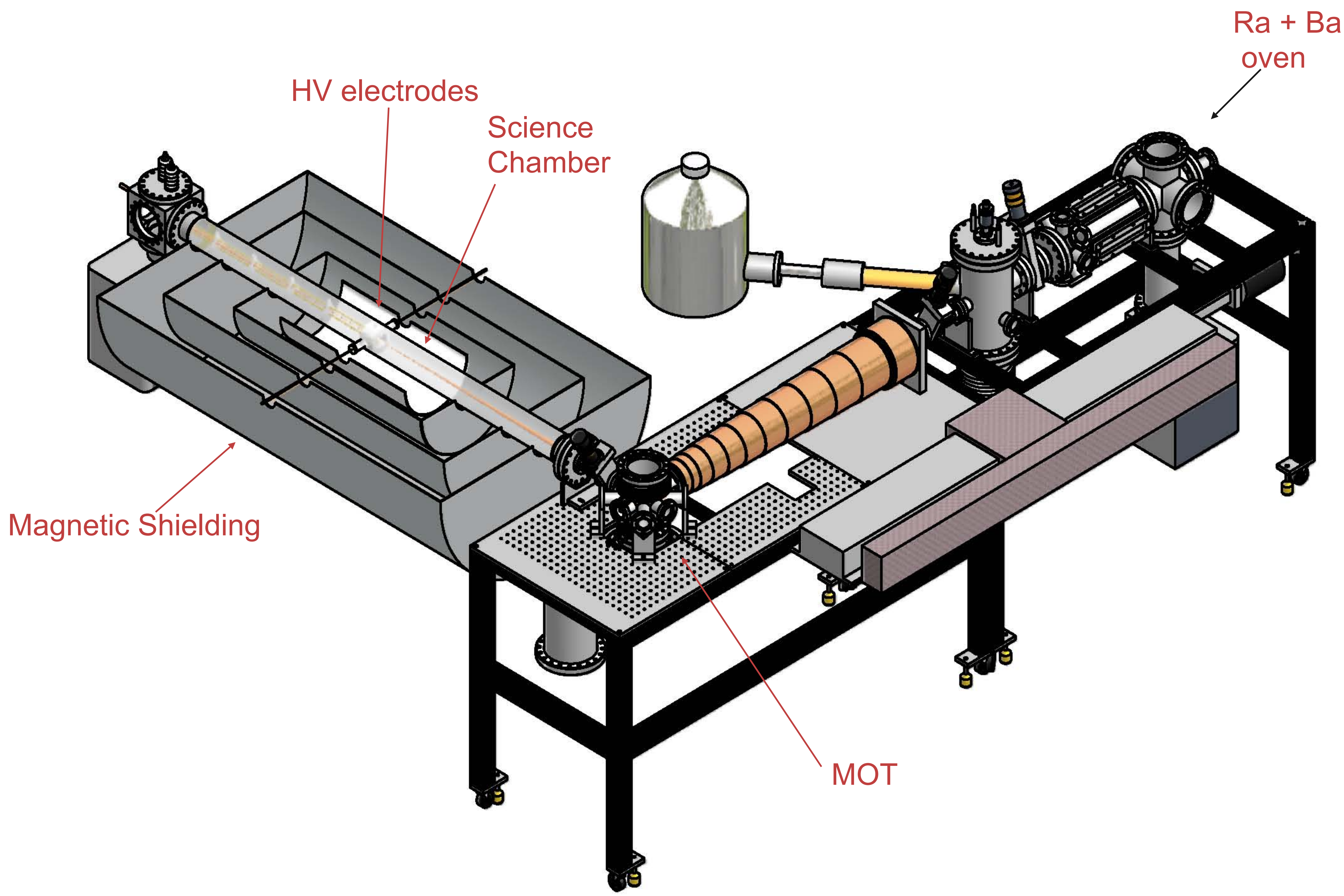
Technical targets:

Efficient transfer from Magneto-Optical Trap to Optical Dipole Trap (summer 2009)

Target vacuum: 10^{-10} Torr so that atoms remain in optical trap for > 100 seconds

Target number: > 10,000 atoms in optical dipole trap for NMR measurement

Experimental setup



300 ng radium sources are treated with great care here.

Radium oven

Zeeman slower

Stern man

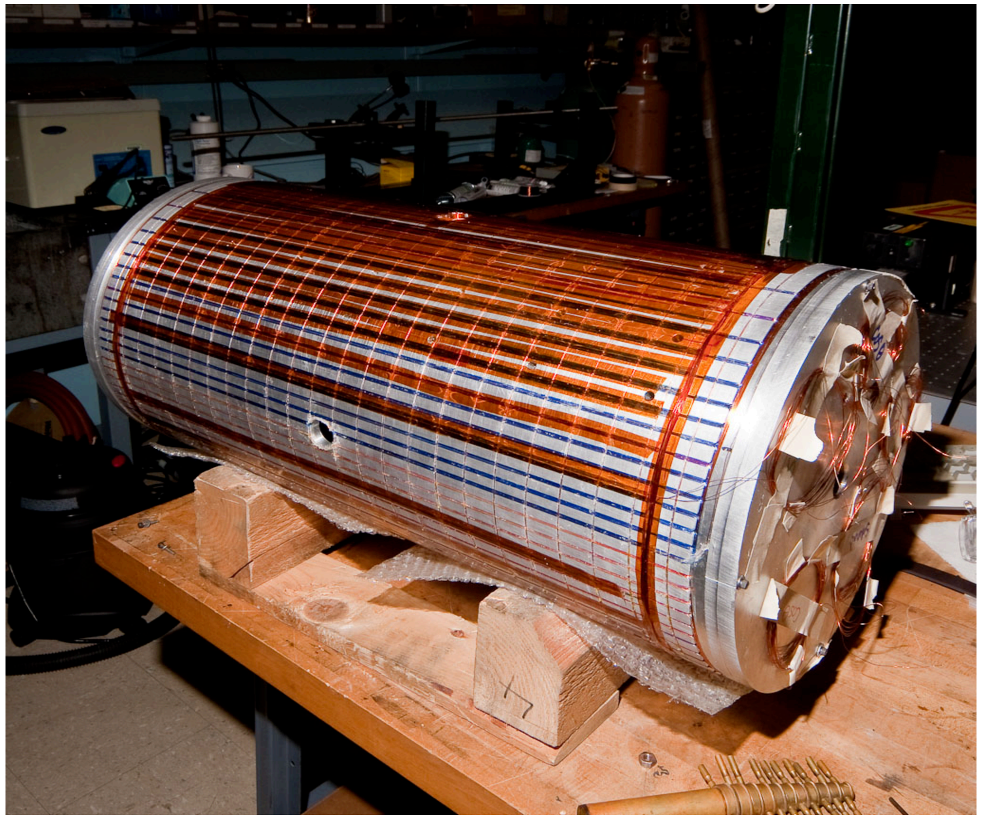
Geiger counter

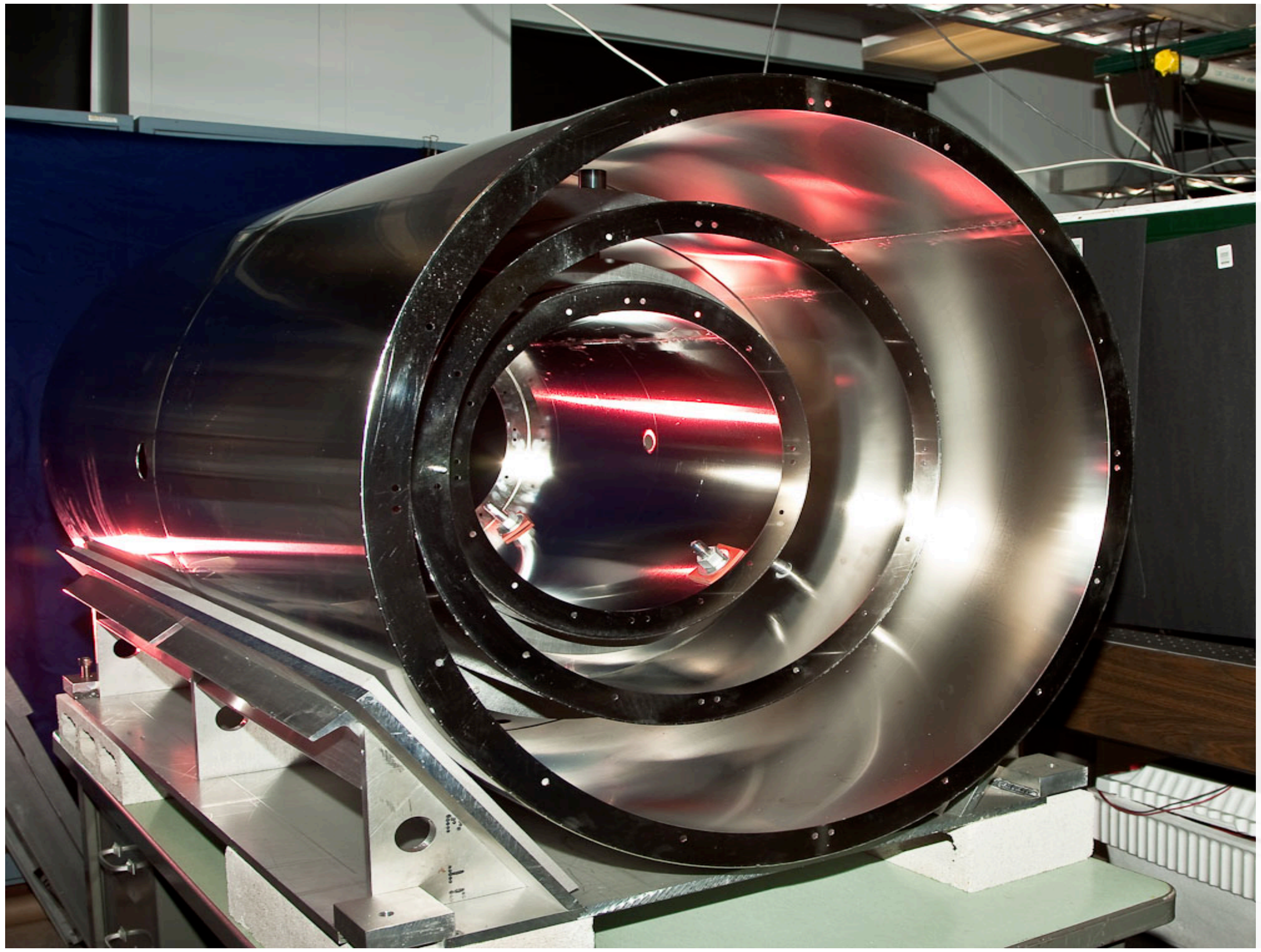
Photo credit: Z-T Lu

Special thanks to our health physicists Paul Niquette and Lee Sprouse.

Magnetic Field Shielding and Generation

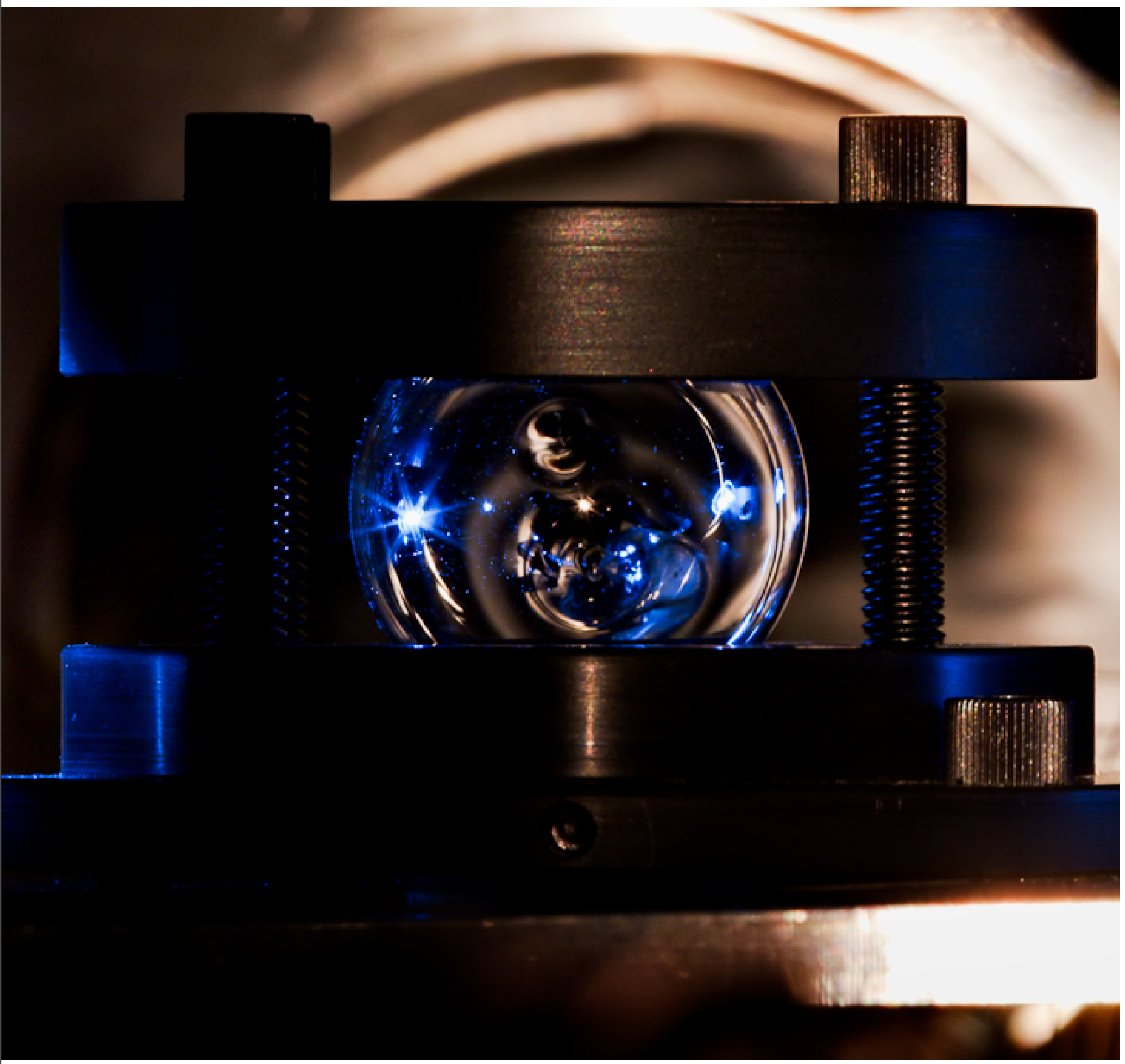
3-layer mu metal shield
3×10^4 shielding factor

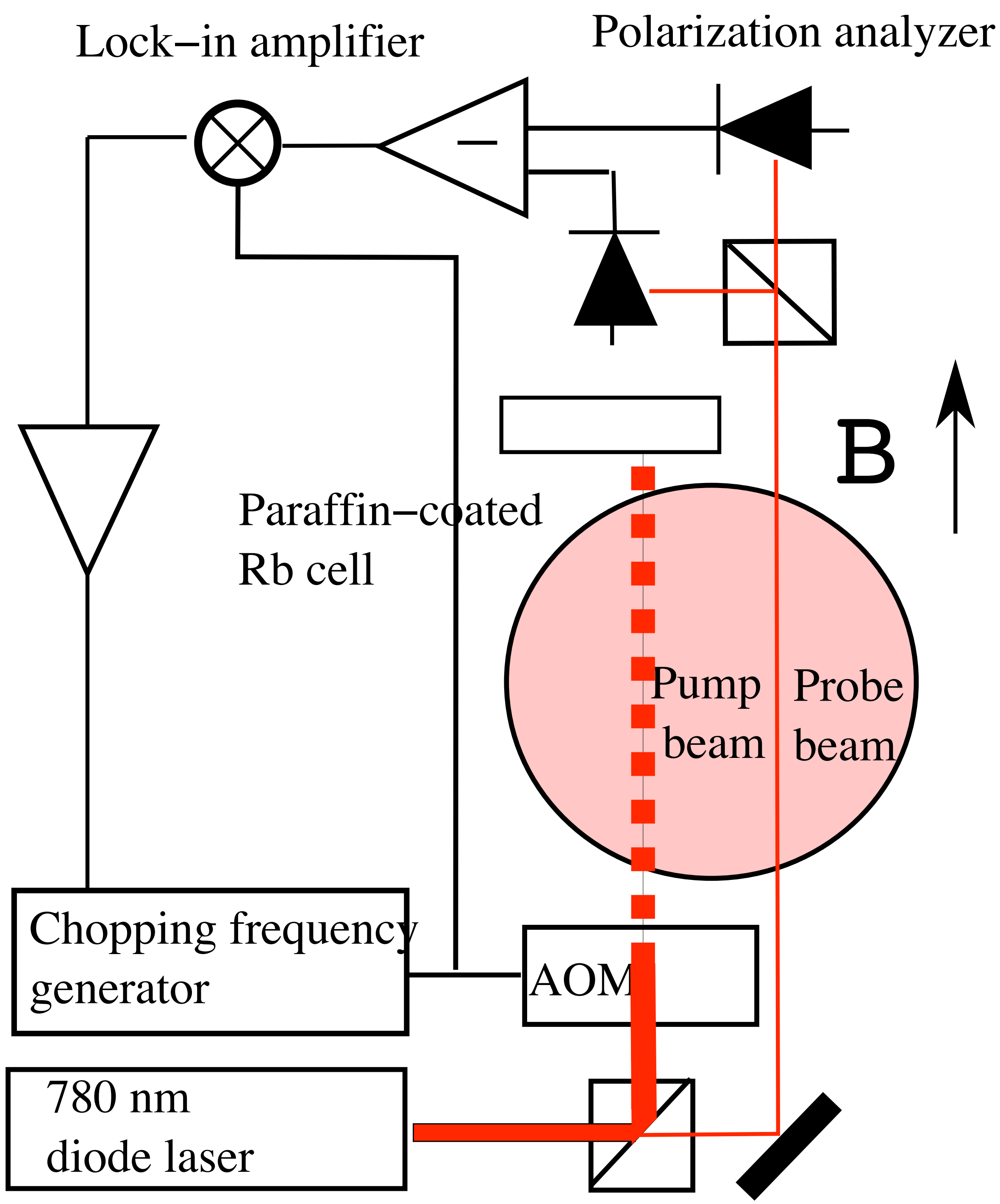




Cosine theta Coil to generate bias B field
B = 10mG
B gradient < 10μG/cm

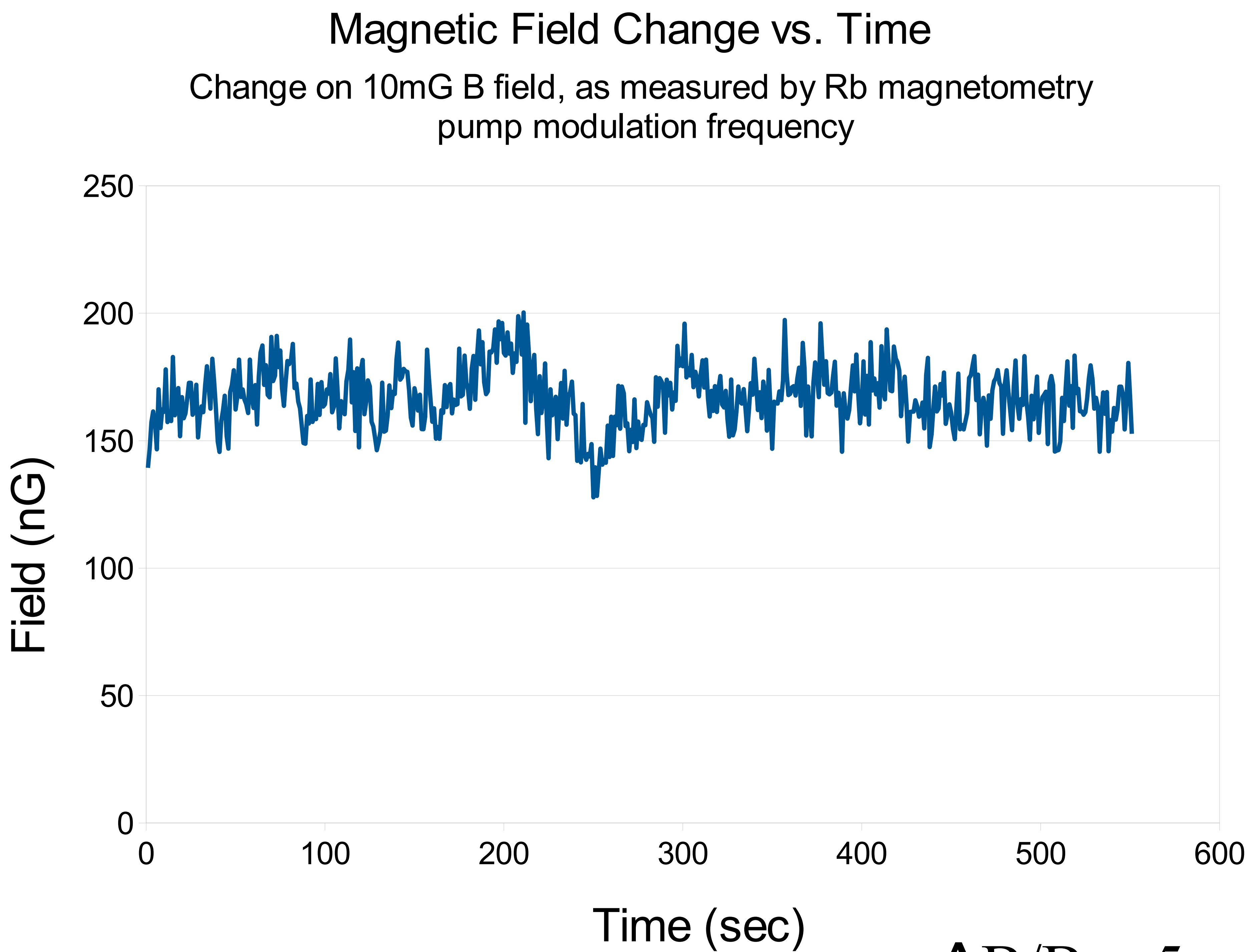
Magnetometry





Initial measurement: two vapor cell magnetometers
Improved measurement: Yb co-magnetometer

Ancillary measurement of magnetic fields with Rb



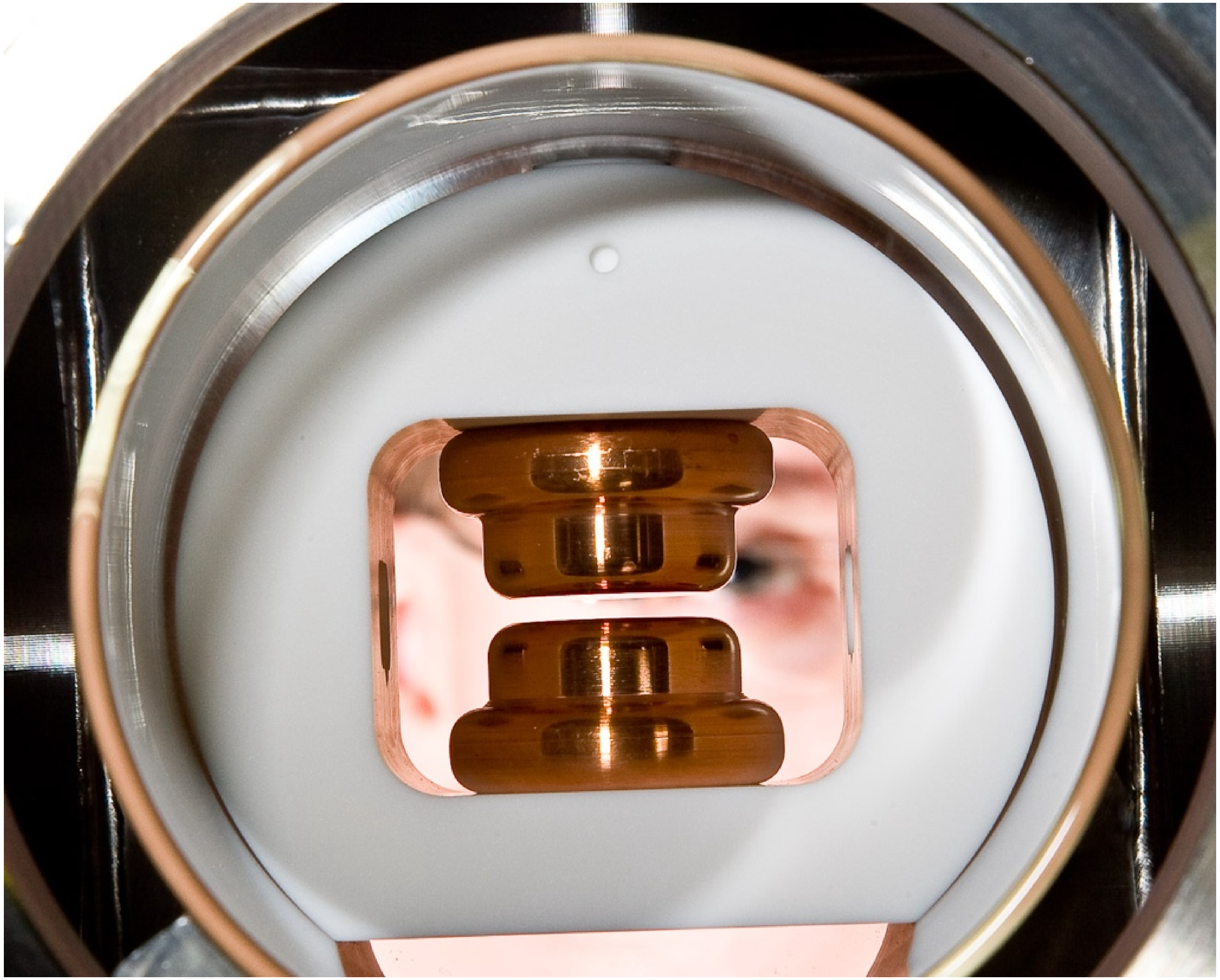
$$\Delta B/B = 5 \times 10^{-6}\ \mathrm{Hz}^{-1/2}$$

Target magnetic measurement sensitivities

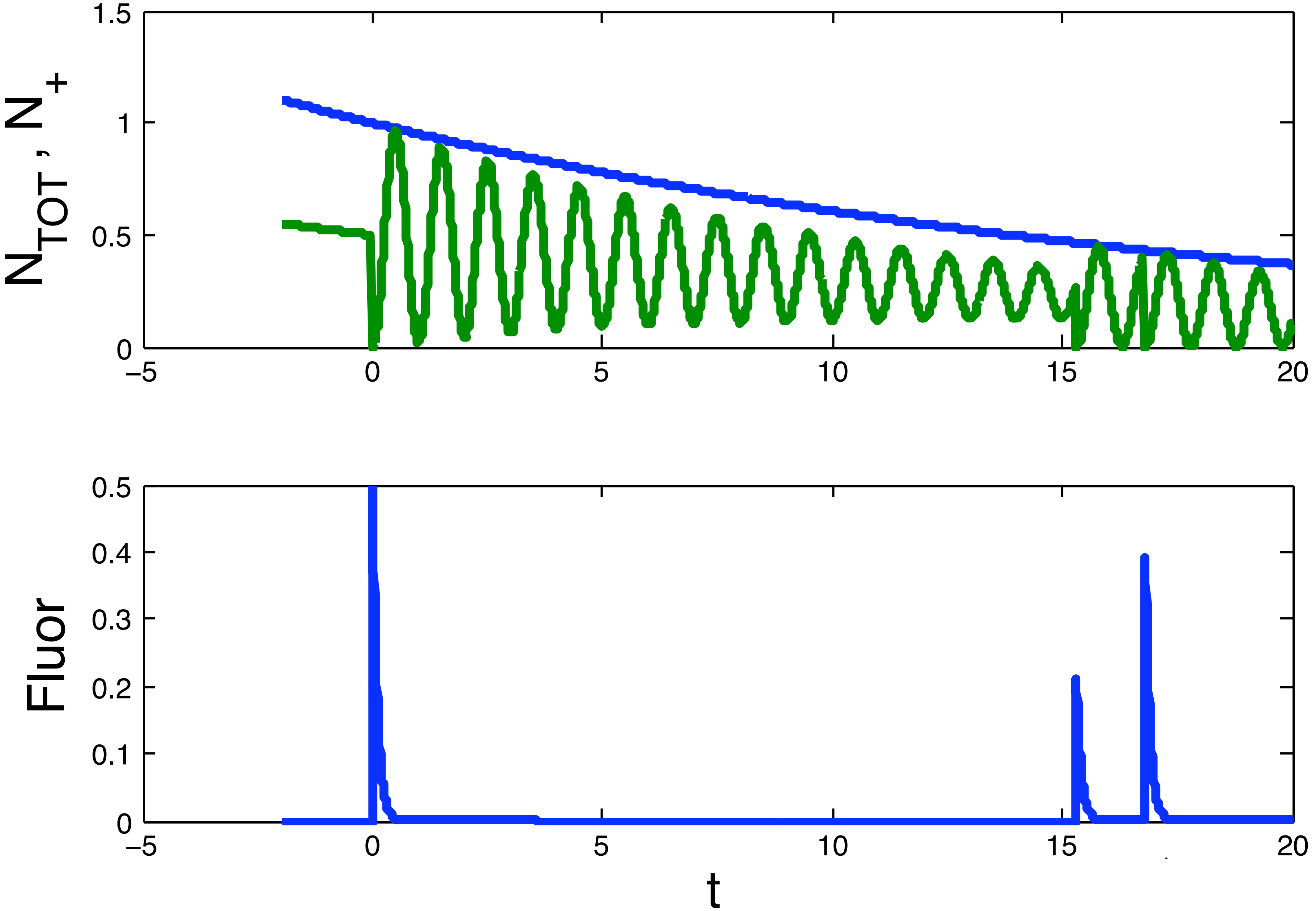
Species		$\Delta B/B$	ΔB
Ra	100 sec. statistical. N = 30,000	10^{-5}	10^{-7} G
Rb cell	100 sec.	5×10^{-7}	10^{-10} G
Ra	2-week half-life (5000 shots) statistical	10^{-7}	10^{-9} G
Rb cell	Systematic target	5×10^{-9}	10^{-11} G

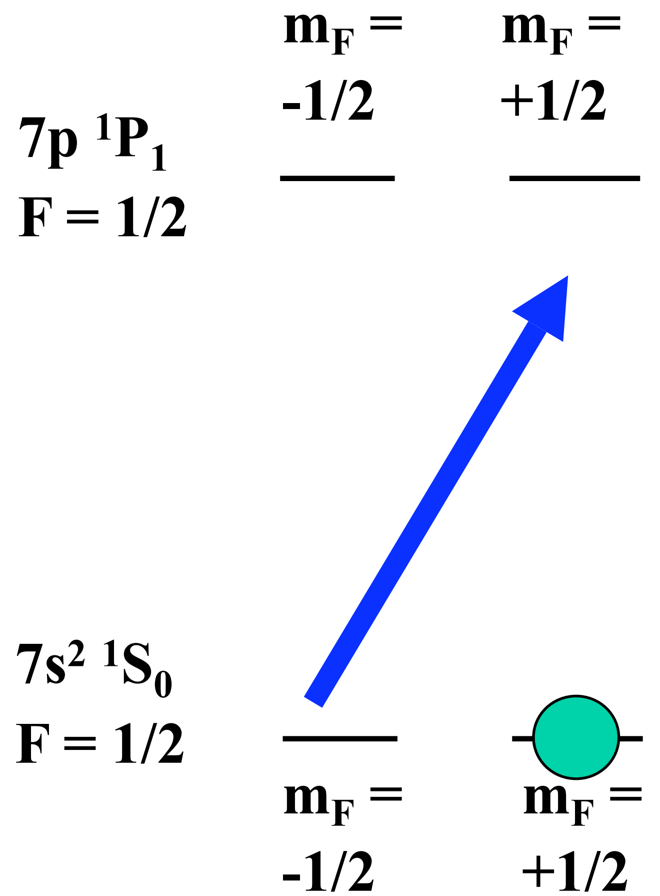
100 kV / cm -- done.

20 kV over 2mm vacuum gap
50 pA leakage currents observed

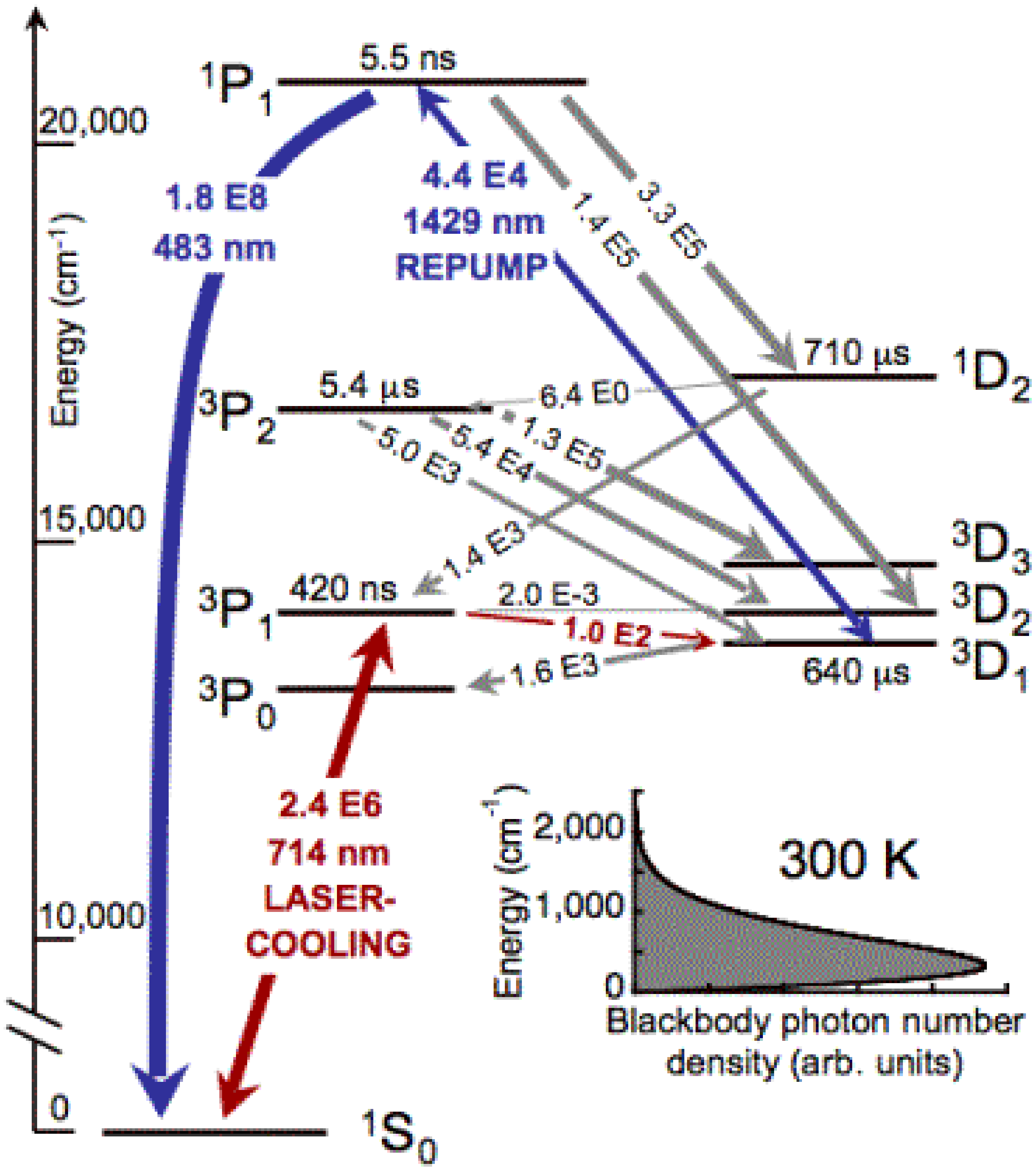


Transverse optical pumping of trapped radium optical readout of NMR





Measurements from the radium MOT so far

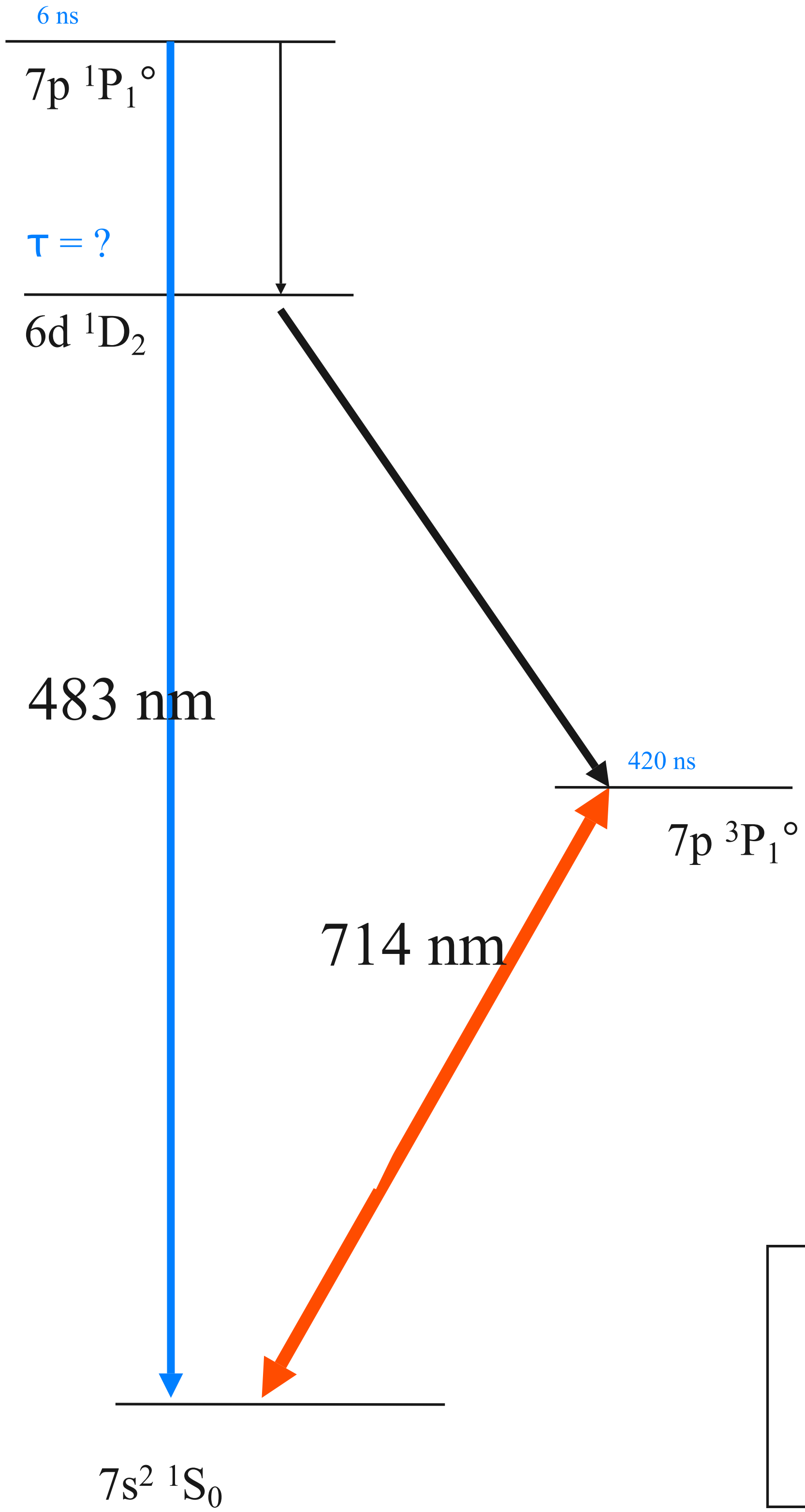


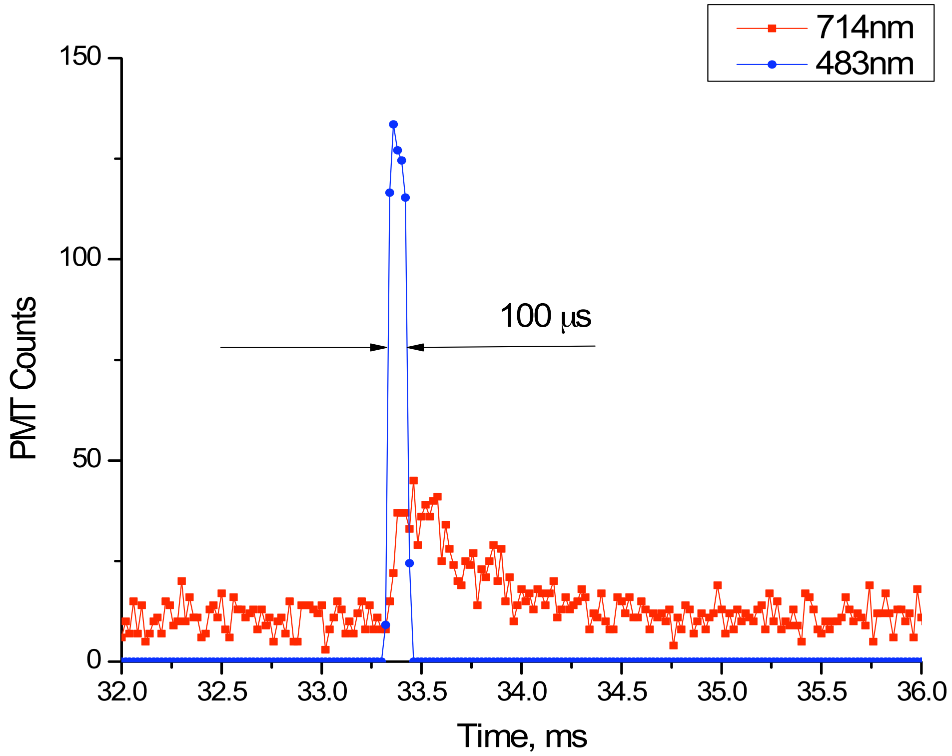
Lifetime of $^3P_1$ cooling level
Scielzo et al. (PRA, 73, 010501(R) (2006))

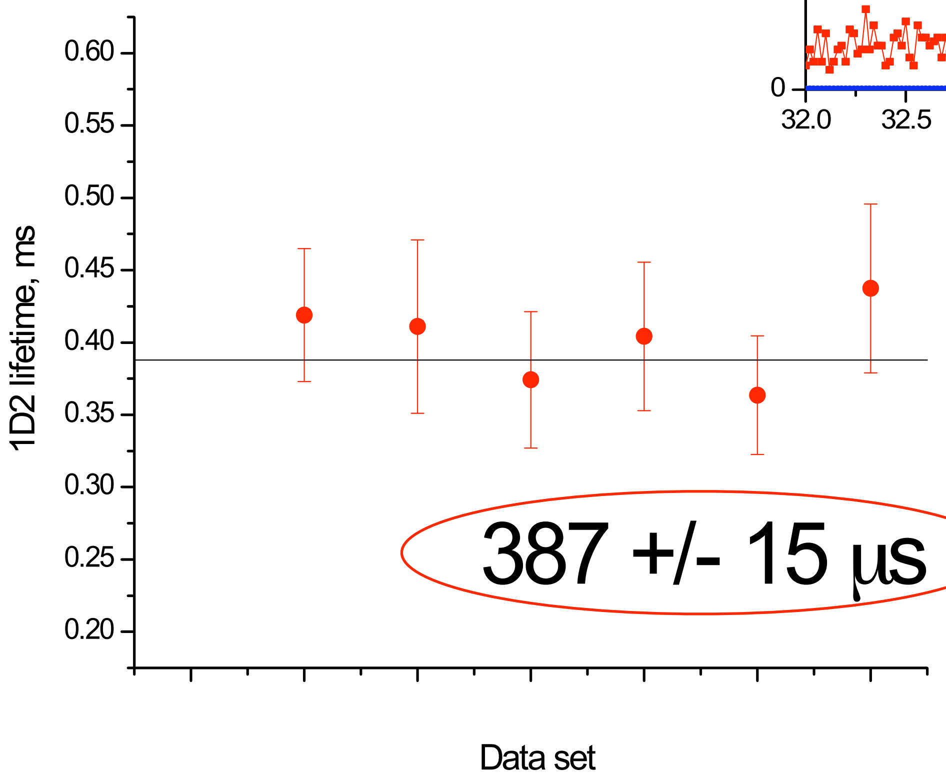
Blackbody repumping assisted magneto - optical trapping

Hyperfine Constants and Isotope Shift on $^3D_1$ – $^1P_1$ transition for ^{225}Ra and ^{226}Ra
Guest et al. (PRL 98, 093001 (2007))

Measurement of $^1D_2$ Lifetime



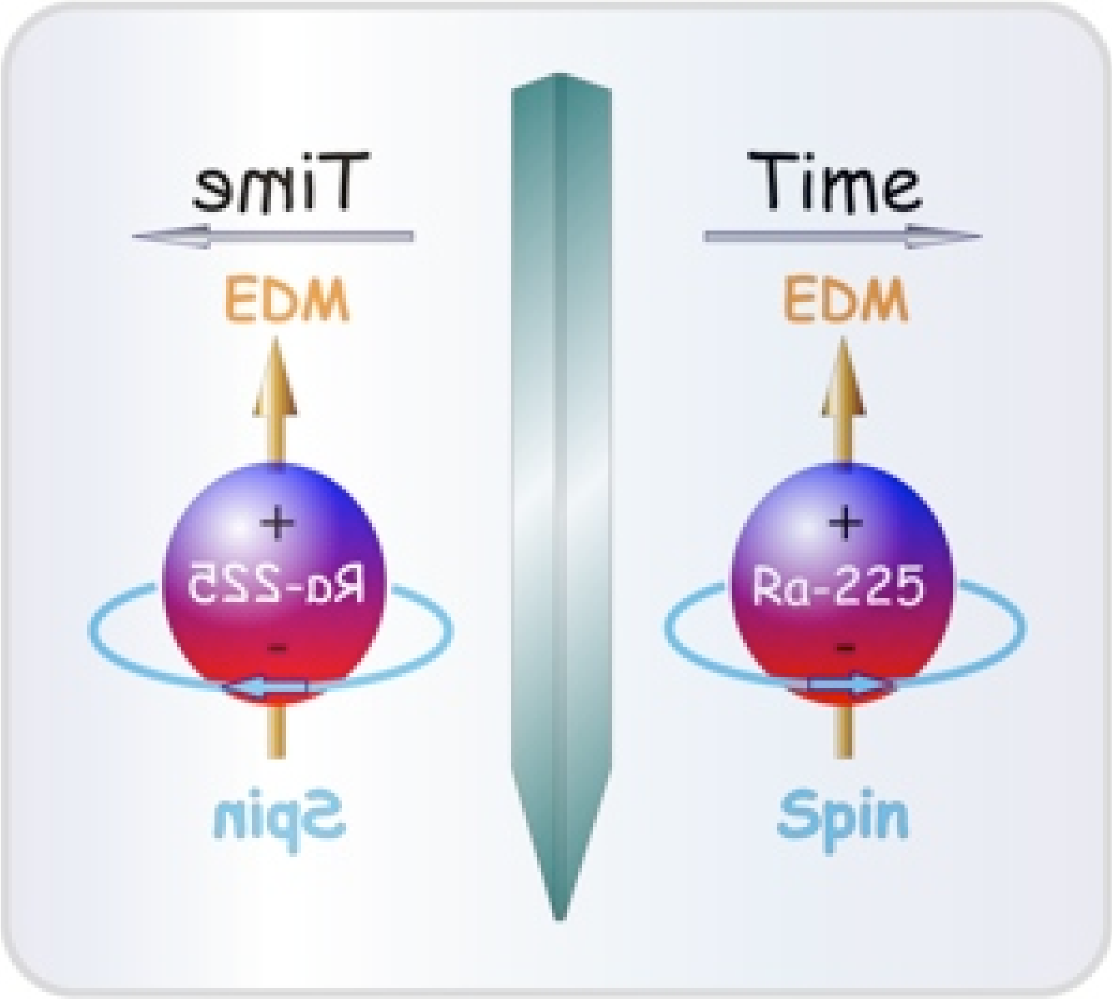




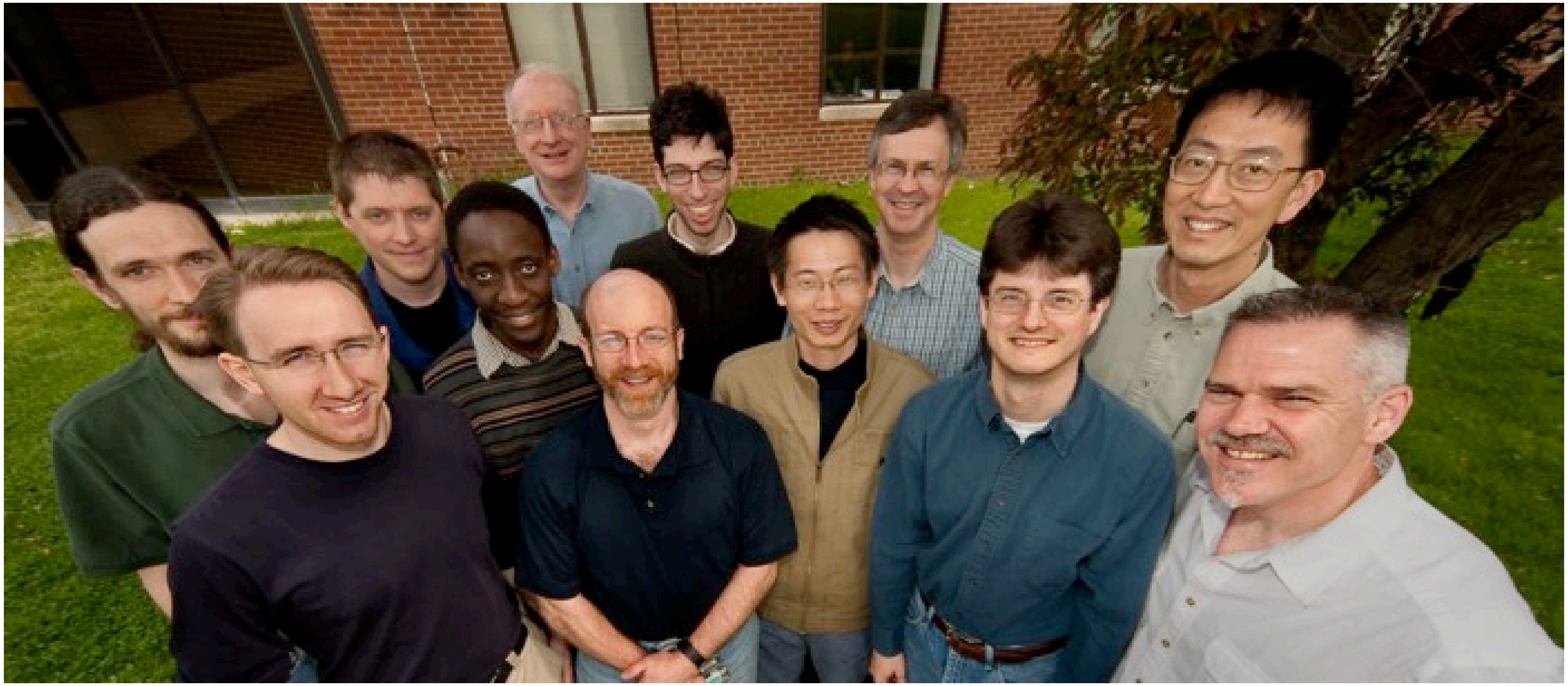
Theory:	
38 ms	Dzuba, PRA **61**, 062509 (2000)
0.126 ms	Dzuba, J. Phys. B **40**, 221 (2006)
1.37 ms	Bieron, E. J. Phys. **44**, 75 (2007)

The road ahead

- MOT size is now 15,000 ^{226}Ra; need 10,000 ^{225}Ra for first EDM
- Increase MOT storage time.
- Blue slowing -- up to 100x higher loading with the same source strength.
- After first measurement, stronger sources. 2-week half-life means online operation not necessary.



Atom Trap Trace Analysis (ATTA) at Argonne



William L. Trimble, Will Williams, Roy J. Holt, Kenneth Rudinger, Wolfgang Korsch, Z-T. Lu
Brent Graner, Ibrahim A. Sulai, Kevin G. Bailey, Bob Sun, Peter Mueller, Tom P. O'Connor

Not pictured: Irshad Ahmad, John Greene