Ra atoms and ions: production and spectroscopy

Testing the Standard Model in Heavy Nuclei

H.W. Wilschut

TRIμP group

TRIμP =Trapped Radioactive Isotopes, μ-laboratories for fundamental Physics

KVI - University of Groningen - The Netherlands

university of groningen

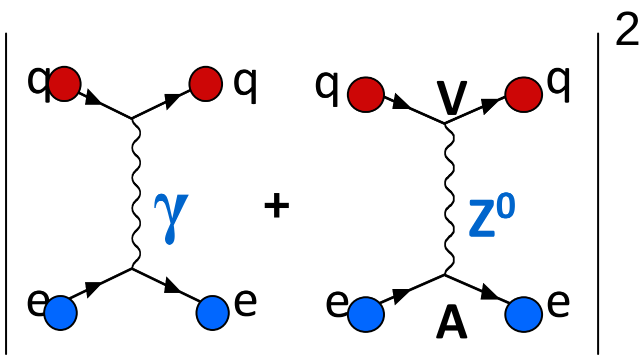
FOM

KVI

“Violating” Moments

- Atomic parity violation:
  P odd

$$APV \propto \left\langle p_{1/2} \middle| \hat{h}_W \middle| s_{1/2} \right\rangle \propto R(Z) Z^2 Q_W$$



Isotope range

$Q_W = -N + (1-4\sin^2\theta_W)Z$ + rad. corr. + “new physics”

Atomic spectroscopy

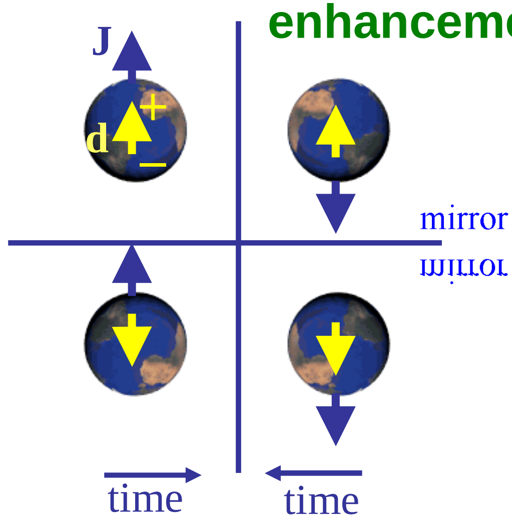
- Electric dipole moment:
  P odd and *T* odd

$$\vec{d} = 2\sum_M \frac{\left\langle K \middle| \hat{\vec{D}} \middle| M \right\rangle \left\langle M \middle| \hat{H}_{PT} \middle| K \right\rangle}{E_K - E_M}$$

Z and deformation enhancements

BSM

Degeneracy enhancement

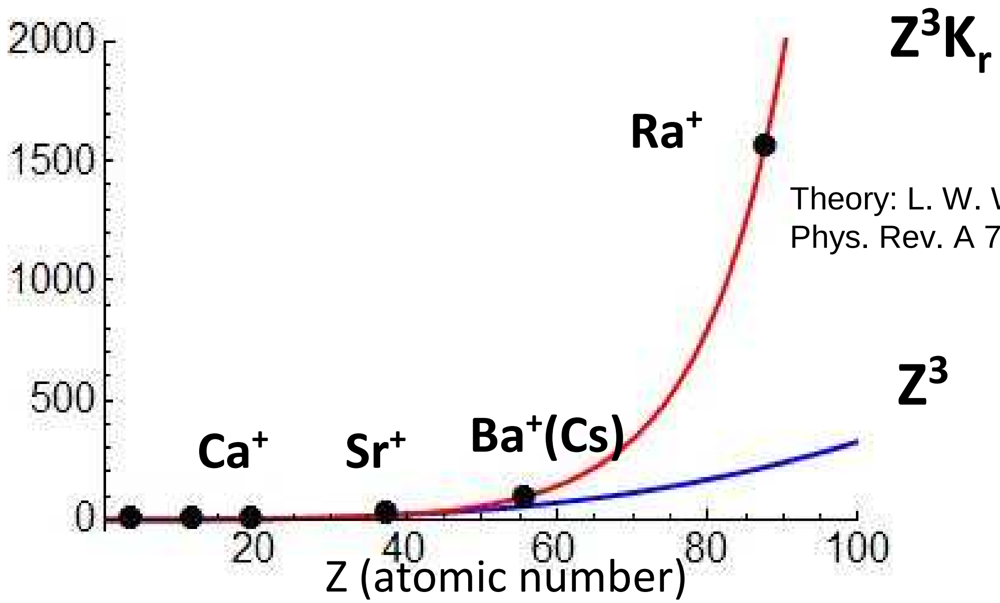


Ra ion for APV

The Bouchiat & Bouchiat (1974) “faster than Z^3-law” says:

$\langle nS_{1/2} | H_W | nP_{1/2} \rangle \propto K_r Z^3$ where K_r is a relativistic factor

$\langle nS_{1/2} | H_W | nP_{1/2} \rangle$ [arb. units]



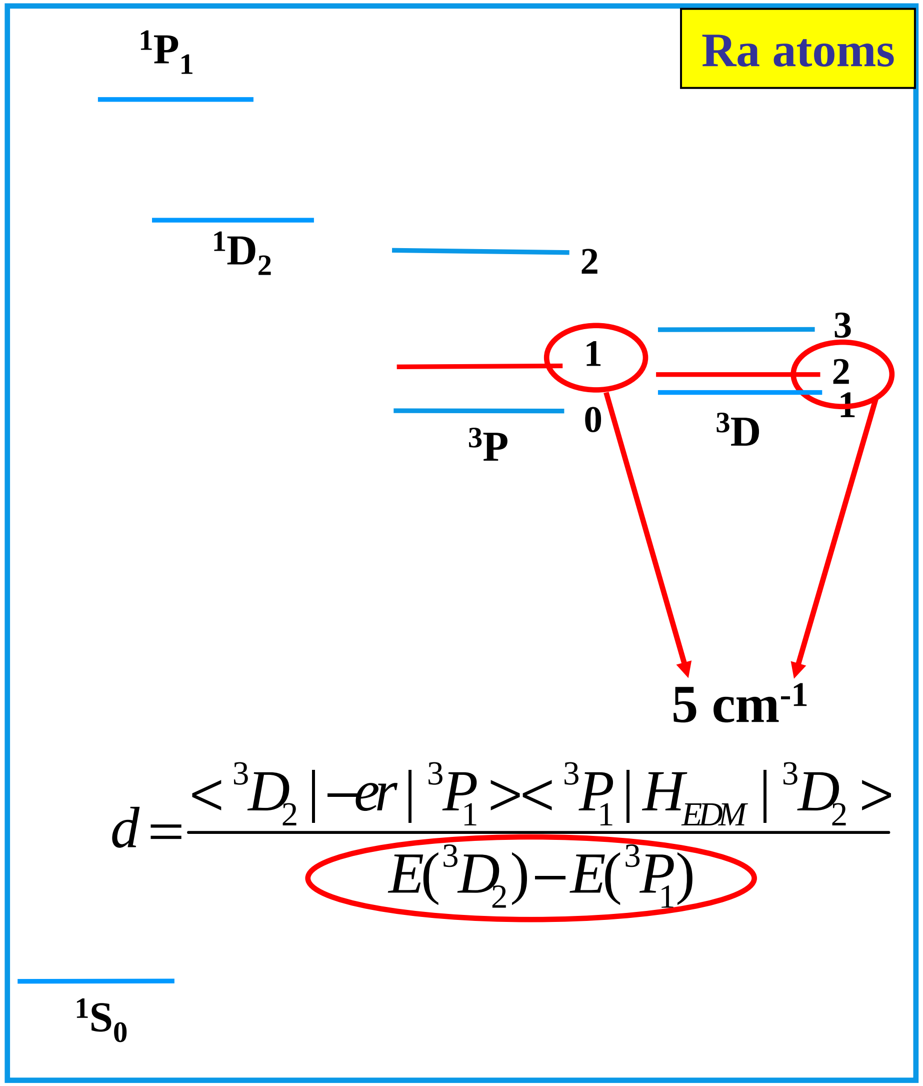
Theory: L. W. Wansbeek et al., Phys. Rev. A 78, 050501(R) (2008).

$E1_{APV}$ effect in Ra^+ is 20 times larger than for Ba^+, and 50 times larger than for Cs (Wiemann)

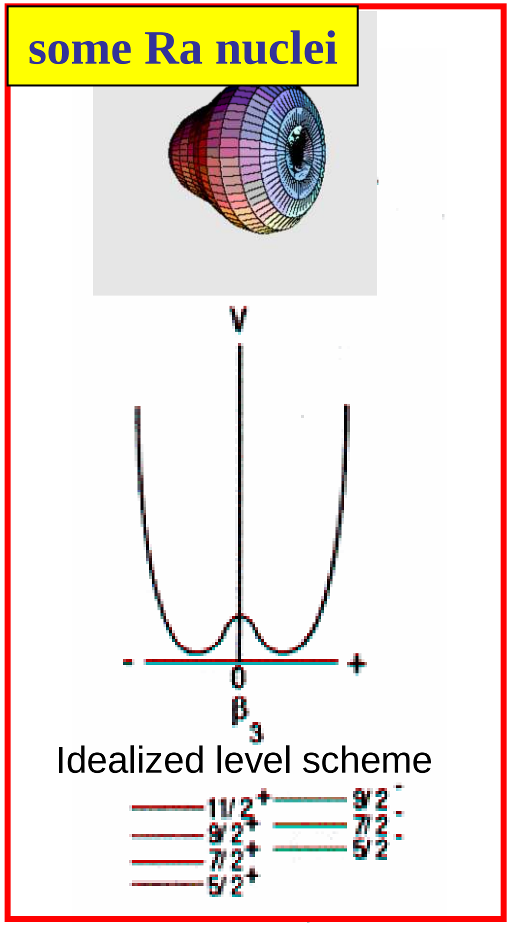
- Ra^+ is a superior APV candidate:

➞ In 1 day, a 5-fold improvement over Cs appears feasible!

Ra for EDM



$$d = \frac{\langle {}^3D_2 | -er | {}^3P_1 \rangle \langle {}^3P_1 | H_{EDM} | {}^3D_2 \rangle}{E({}^3D_2) - E({}^3P_1)}$$



Electron EDM enhanced > 10 ^{4}

V. A. Dzuba et al. Phys. Rev. A, 61, 062509 (2000)

Nucleon EDM enhanced ≈ 10^2

J. Engel et al. Phys. Rev. C, 68, 025501 (2003)

Nuclei with J=1/2 (213, 225)

Radioactive radium: because of their special properties

The relevant isotopes of radium

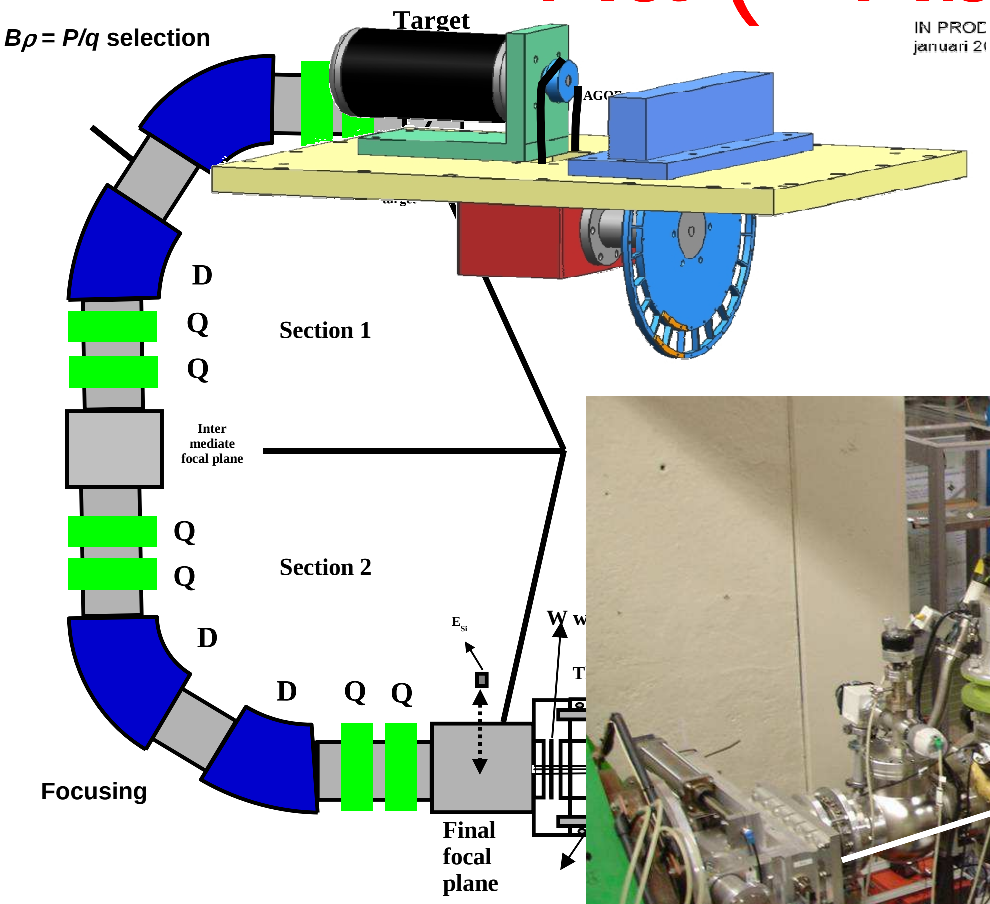
Recently produced on-line for Spectroscopy

Available off-line (EDM)

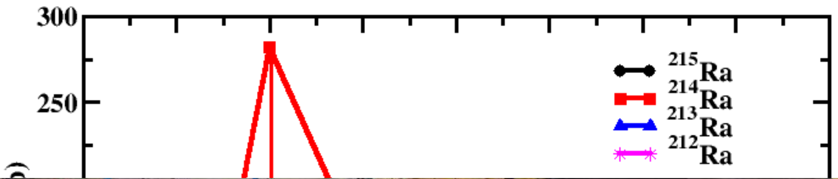
	Lifetime	Spin
209	4.6(2) s	5/2
211	13(2) s	5/2
212	13.0(2) s	
213	2.74(6) m	1/2
214	2.46(3) s	
221	28.2 s	5/2
223	11.43(5) d	3/2
224	3.6319(23) d	
225	14.9(2) d	1/2
226	1600 y	
227	42.2(5) m	3/2
229	4.0(2) m	5/2

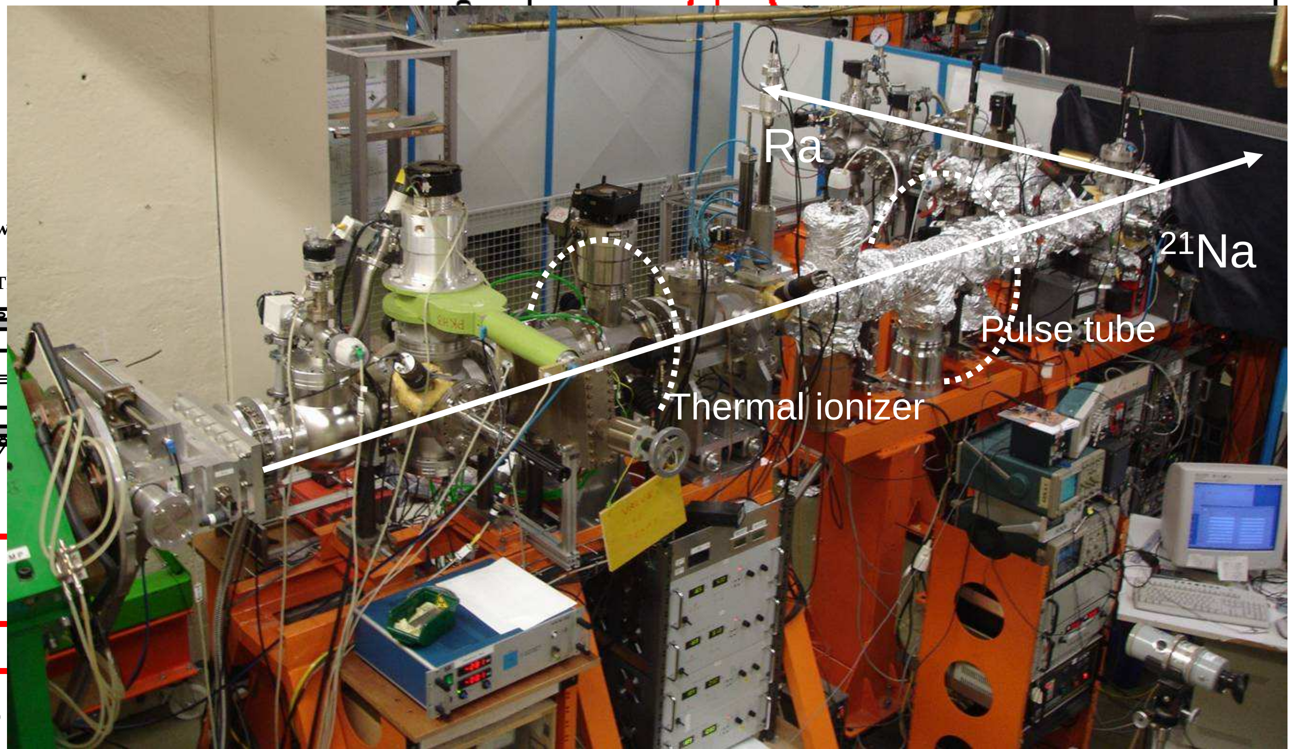
$\Delta N \approx 10!$

$^{210\text{-}214}$Ra (^{80}Rb) production



^{206}Pb + ^{12}C ⟶ ^{212,213,214}Ra





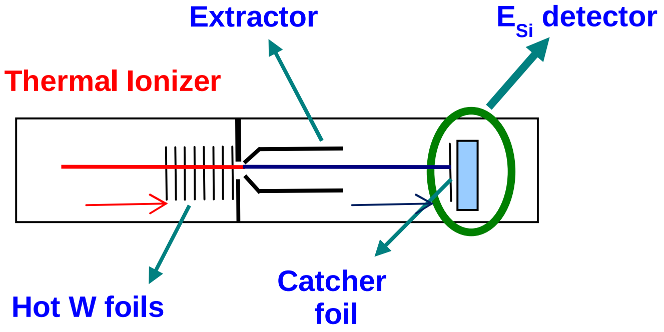
^{206}Pb (^{12}C,xn)^{210,211}Ra

^{82}Kr (d,4n) ^{80}Rb @ 25

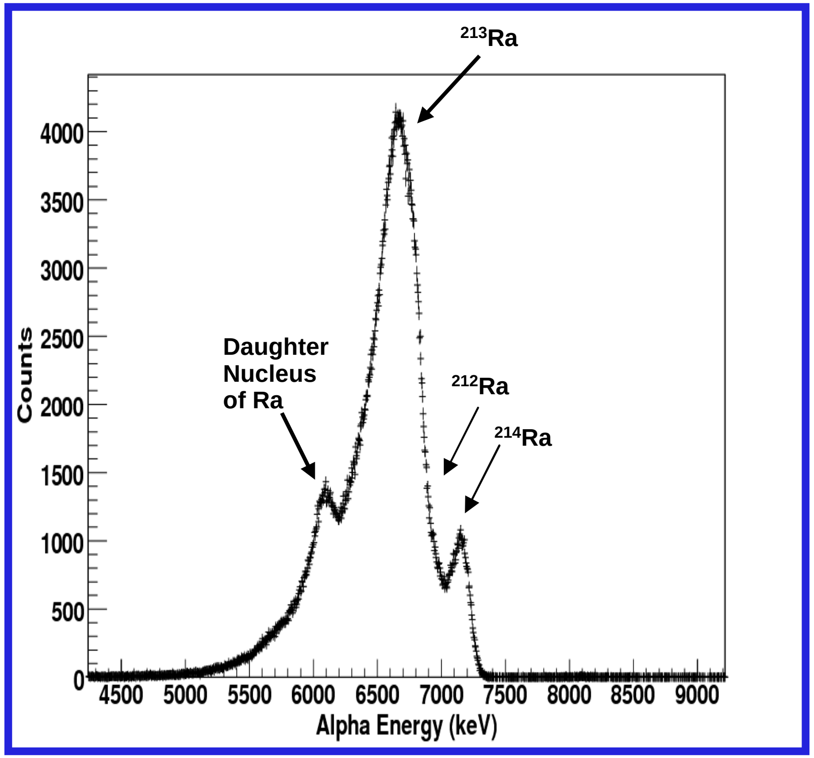
4 mg/cm^2
(thickness)

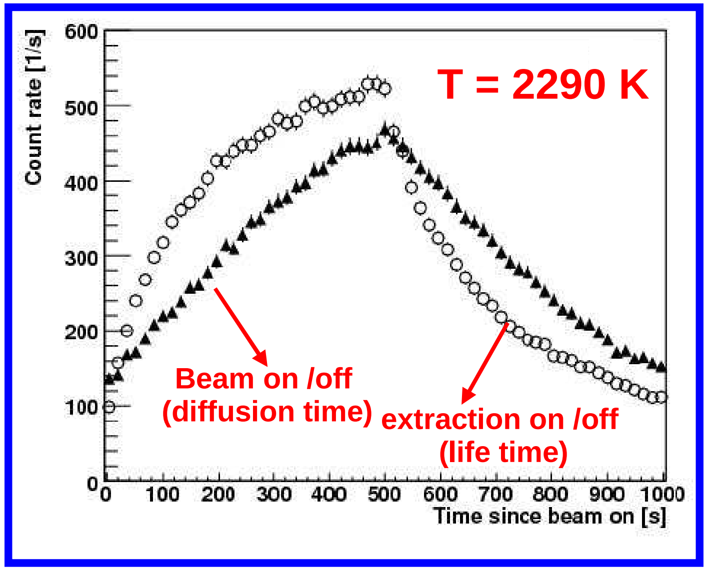
Thermal Ionizer

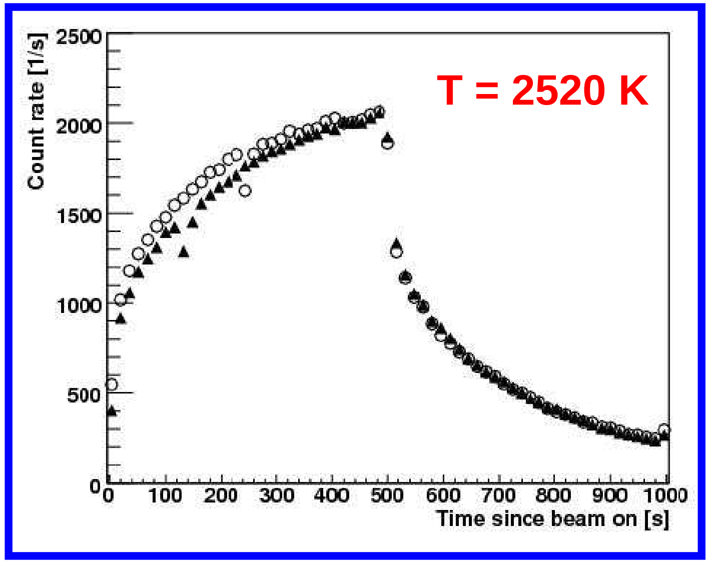
213Ra: 650/s/(pnA 206Pb)
P. Shidling et al.,
NIM A 606 (2009) 305



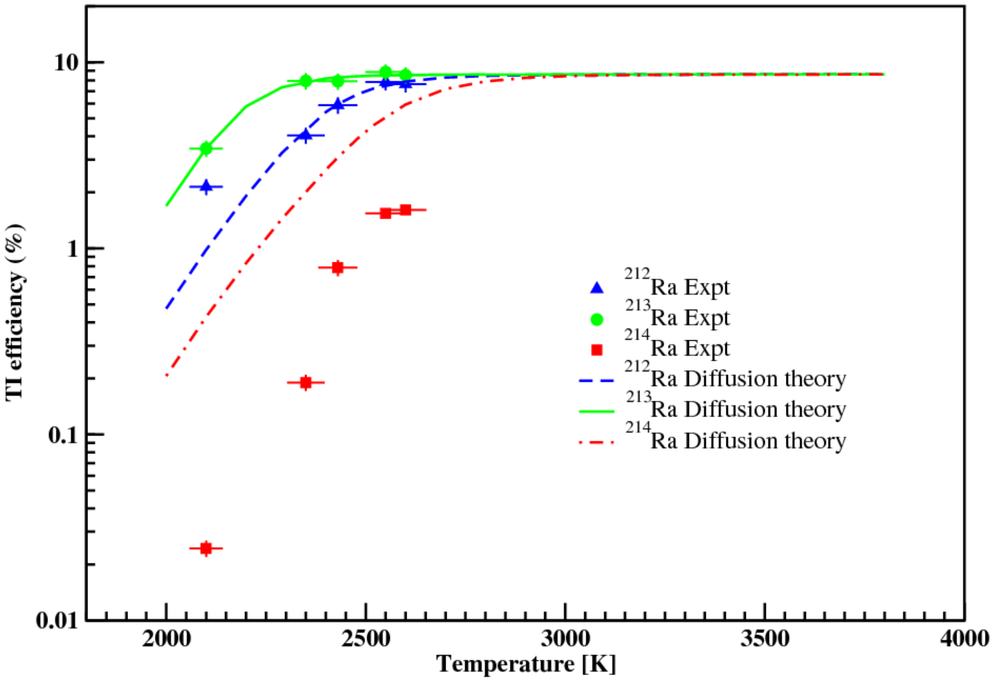
Alpha Spectrum after Thermal Ionizer







Thermal Ionizer Efficiency



Element	Temperature [K]	TI efficiency (%)	$T_{1/2}$ (s)
^{212}Ra	2100 - 2600	9 %	13
^{213}Ra	2100 - 2600	9 %	164.4
^{214}Ra	2100 - 2600	2 %	2.46
^{21}Na	2370 - 2780	55 %	22.49
^{20}Na	2380 - 2750	16 %	0.447
^{80}Rb	2400 - 2550	35 %	33.0

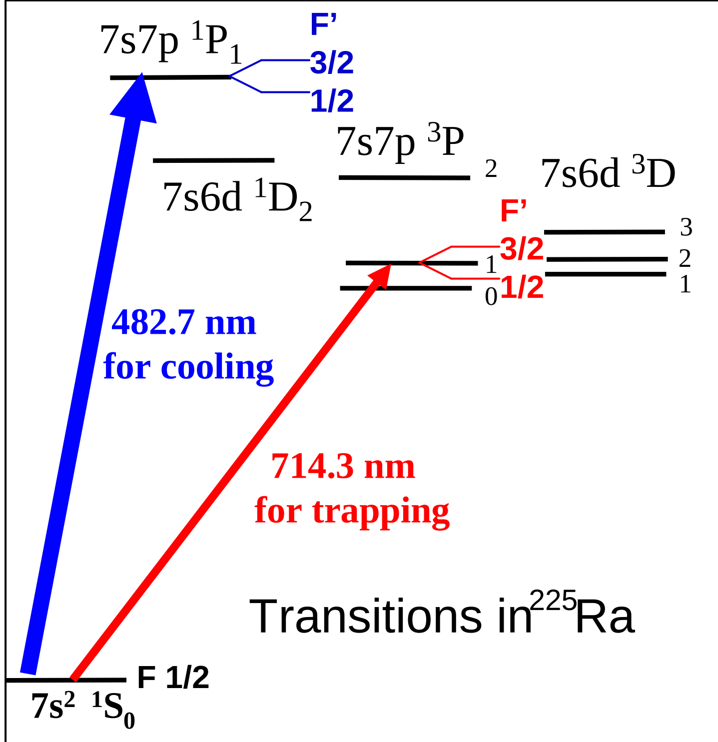
Measured diffusion efficiency two ways:
1) DC throughput
2) Dynamic time dependence

P.D. Shidling et al. Equilibrium/dynamic method
To be published in NIMA

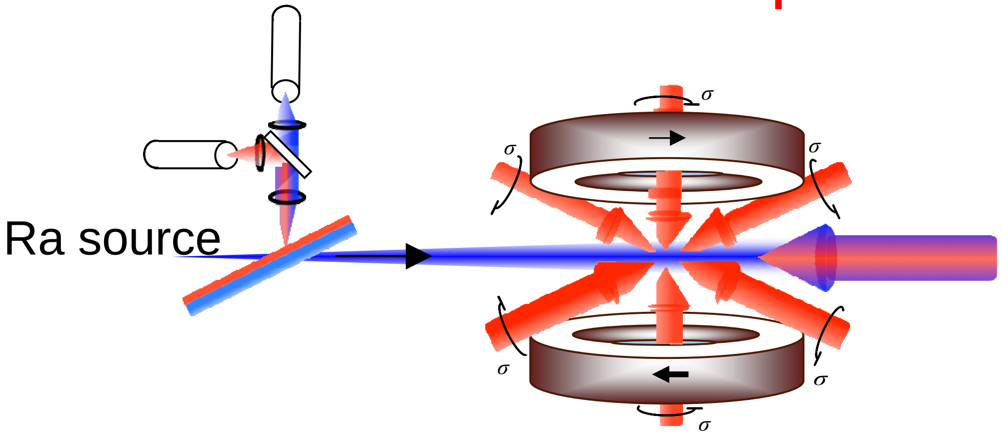
$$\alpha = \frac{D}{a^2 \lambda}$$

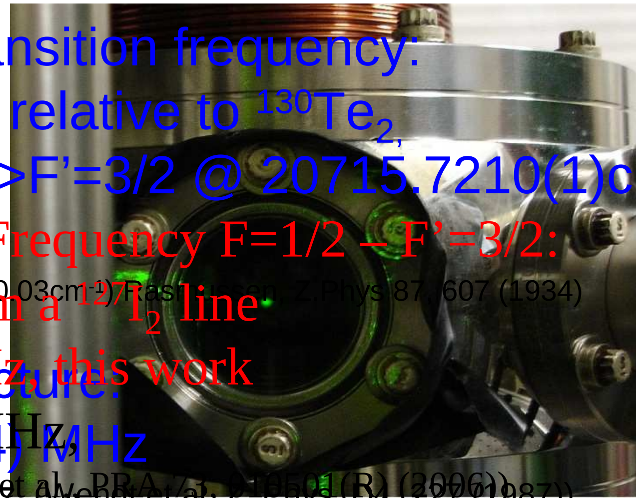
Ra EDM

step one collect them as a cold small sample



Scheme for trapping





Accuracy of transition frequency:

4 MHz relative to $^{130}Te_2$,

F=1/2->F'=3/2 @ 20715.7210(1)cm^{-1}

Absolute Frequency F=1/2 – F'=3/2:

Offset from a $^{127}I_2$ line

726(5)MHz, this work

702(30) MHz,

(N. D. Scielzo et al., PRA 73, 010501(R) (2006))

2100 MHz (0.03cm^{-1}) Rasmussen, Z. Phys 87, 607 (1934)

Hyperfine Structure:

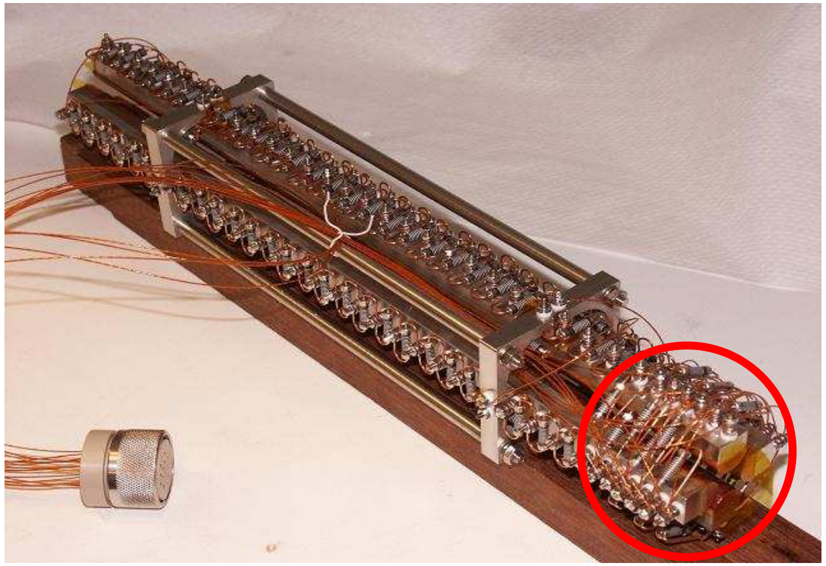
4198(4) MHz

4193(4)MHz (Wendt et al. Z. Phys. D4, 227 (1987))

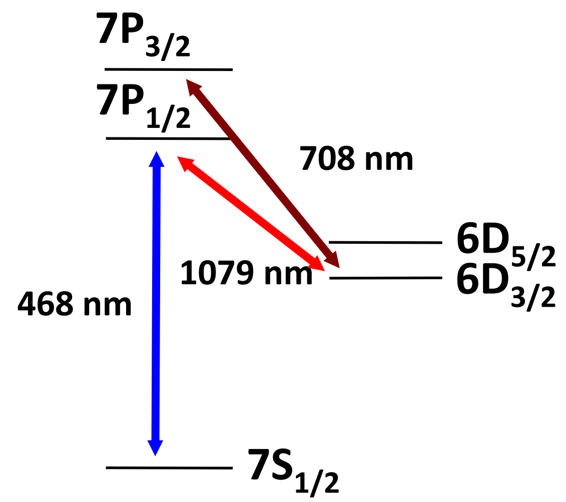
Following cooling scheme for Ba

S. De, U. Dammalapati, K. Jungmann, and L. Willmann, PRA 79 (2009) 041402 and Eur. Phys. J. D 53 (2009) 1

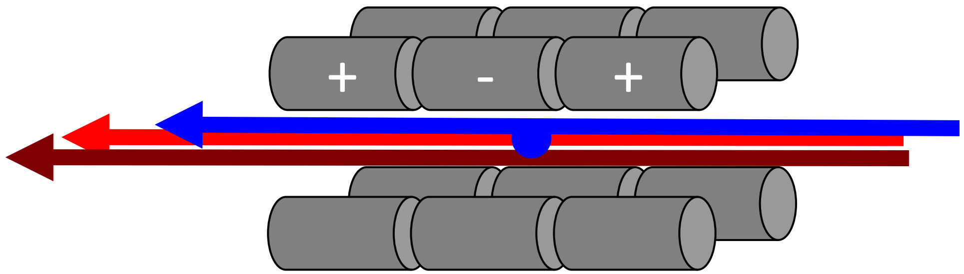
Steps towards APV of single Ra ions spectroscopy in Paul trap (atomic theory)



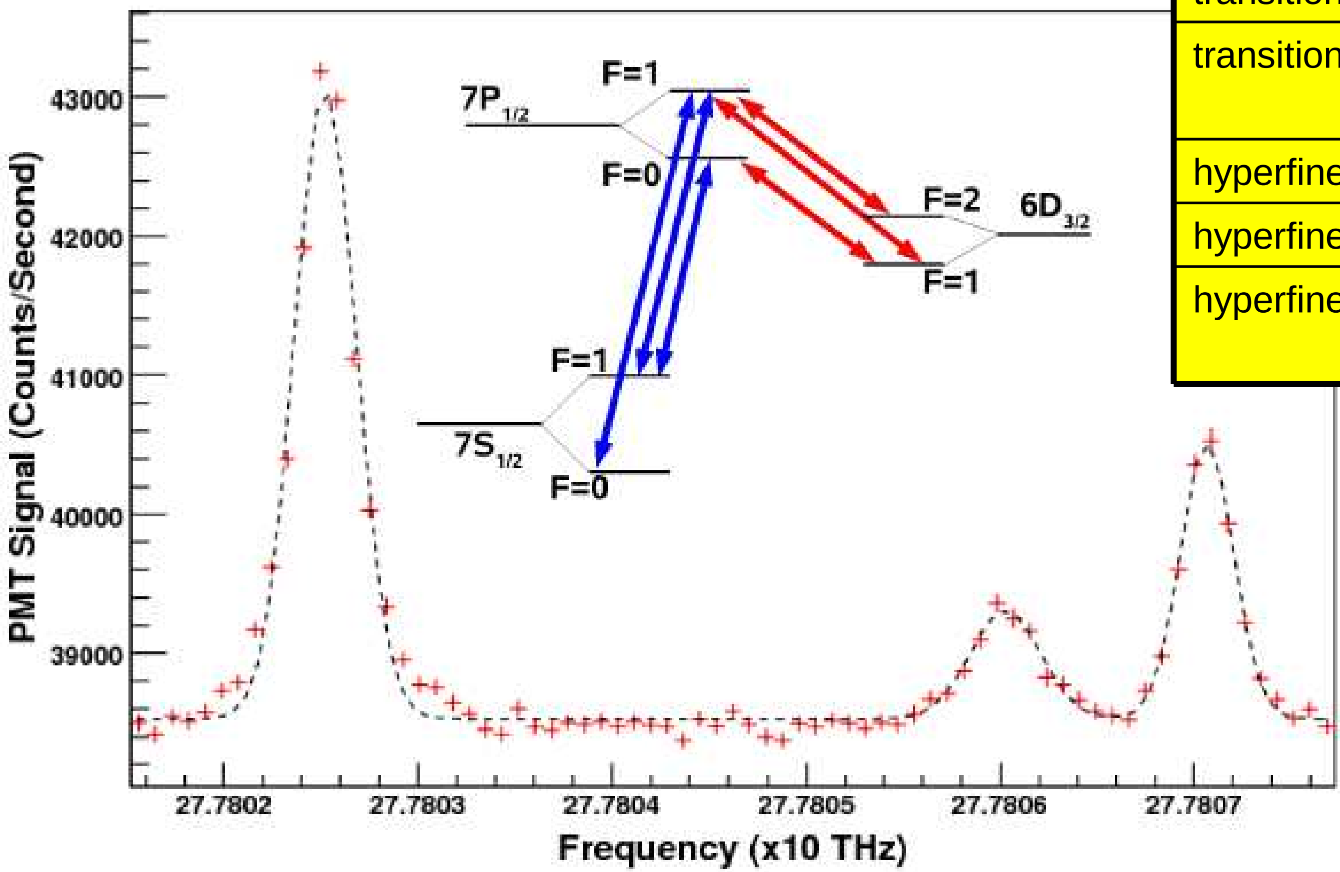
Radiofrequency Quadrupole (RFQ)



Simplified level scheme of Ra^{+}



First spectroscopy of Ra ions in Paul trap



transition	$7S_{1/2}$-$7P_{1/2}$	$^{212;214}$Ra.
transition	$6D_{3/2}$-$7P_{1/2}$	$^{212;214}$Ra first time
hyperfine	$7S_{1/2}$	^{213}Ra
hyperfine	$7P_{1/2}$	^{213}Ra
hyperfine	$6D_{3/2}$	^{213}Ra first time

O.O. Versolato et al.
arXiv:1003.5580

- Range of Ra isotopes available
- Radium ions – trapped – gas cooled

- New spectroscopy
- Next: single ion – laser cooled
- $\rightarrow$ APV measurement

Conclusions

TRIμP@KVI-DESIR-elsewhere

Home program

- Focus on very specific elements and isotopes
- TRIμP: alkalides and earth-alkalides (Na,Rb,Ra)
- Long-term program and developments (frequent access to beam)
- ENSAR approved: can service outside users

"Out-of-house" program

- Limited by manpower and funds
- Elsewhere only when
  - Availability superior:
    - If limited in dynamic range of Isotopes of an element
    - If intensity limits final statistics
    - Access chances
  - AGOR funding horizon is 2013