Fundamental interactions studies by laser trapping methods

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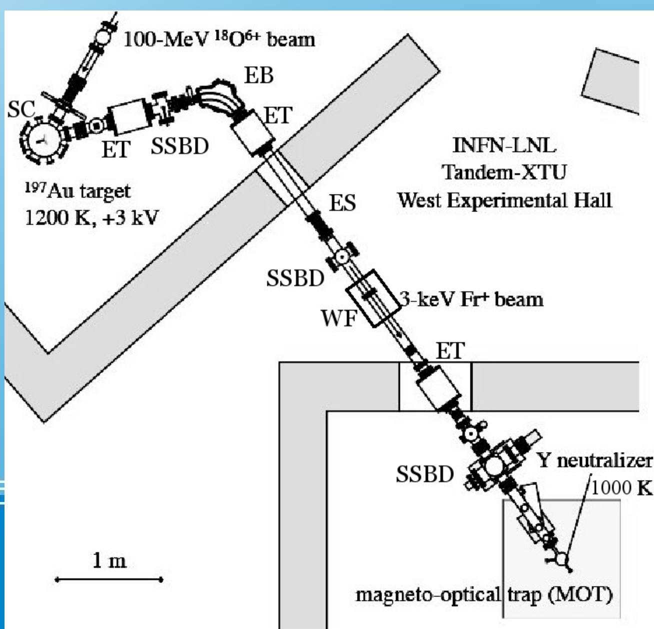

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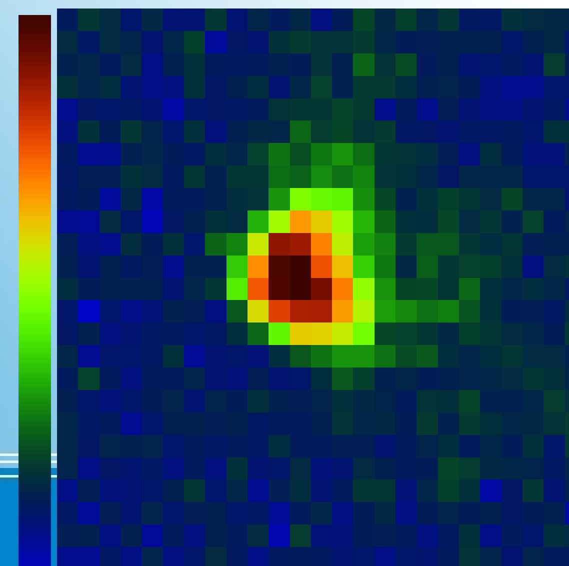

SPES-Nusprasen Workshop, Pisa – February 2, 2018

Outline

- Laser Spectroscopy as a precision tool for fundamental and nuclear physics
- Laser trapping of radioactive neutral isotopes
- Perspectives (and proposals?)

INTRODUCTION

À la découverte des Observables

Meetup **HumanTalks** Paris Décembre 2017

List of atomic observables for nuclear studies

→ **Hyperfine structure**

$$\Delta E_{HFS} = \Delta E_{dipole} + \Delta E_{quadrupole}$$

$$= \frac{A}{2}C + \frac{B}{4}\frac{\frac{3}{2}C\left(C+1\right) - 2IJ\left(I+1\right)\left(J+1\right)}{IJ\left(2I-1\right)\left(2J-1\right)}$$

$$A = \frac{\mu_I B_e(0)}{JI}$$

$$B = q_e Q_S \left\langle \frac{\partial^2 V}{\partial z^2} \right\rangle$$

$$C = F(F+1) - J(J+1) - I(I+1)$$

$$\frac{A}{A'} \simeq \frac{\mu}{\mu'}\frac{I'}{I} \qquad \frac{B}{B'} \simeq \frac{Q_s}{Q_s'}$$

3682 Vol. 42, No. 18 / September 15 2017 / Optics Letters

Letter

Optics Letters

Observation of $7p\,^2P_{3/2} \rightarrow 7d\,^2D$ optical transitions in 209 and 210 francium isotopes

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List of atomic observables for nuclear studies

→ **Hyperfine anomalies**

$$A = A_{point}(1+\epsilon_{BR})(1+\epsilon_{BW})$$

$$\frac{A}{A'} = \frac{A_{\rm point}\,(1+\epsilon_{\rm BW})\,(1+\epsilon_{\rm BR})}{A'_{\rm point}\,(1+\epsilon'_{\rm BW})\,(1+\epsilon'_{\rm BR})} \approx \frac{\mu I'}{\mu' I}\left(1+{}^{A}\Delta^{A'}\right)$$

Hyperfine anomalies in Fr: boundaries of the spherical single particle model

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(Dated: July 2, 2015)

We have measured the hyperfine splitting of the $7P_{1/2}$ state at the 100 ppm level in Fr isotopes (^{206g,206m,207,209,213,221}Fr) near the closed neutron shell (N = 126 in ^{213}Fr). The measurements in five isotopes and a nuclear isomeric state of francium, combined with previous determinations of the $7S_{1/2}$ splittings, reveal the spatial distribution of the nuclear magnetization, i.e. the Bohr-Weisskopf effect. We compare our results with a simple shell model consisting of unpaired single valence nucleons orbiting a spherical nucleus, and find good agreement over a range of neutron-deficient isotopes ($^{207-213}$Fr). Also, we find near-constant proton anomalies for several even-N isotopes. This identifies a set of Fr isotopes whose nuclear structure can be understood well enough for the extraction of weak interaction parameters from parity non-conservation studies.

List of atomic observables for nuclear studies

→ **Isotope shift**

→ **Mean square nuclear charge radii**

$$\delta\nu^{A,A'} = \delta\nu^{A,A'}_{\text{mass shift}} + \delta\nu^{A,A'}_{\text{field shift}}$$

$$\delta\nu^{A,A'}_{\text{mass shift}} = \frac{m^{A'} - m^{A}}{m^{A} m^{A'}} (N + S)$$

$$\delta\nu^{A,A'}_{\text{field shift}} = \frac{Ze^2}{6h\epsilon_0} \Delta \left|\psi_e(0)\right|^2 \delta\left\langle r^2\right\rangle^{A,A'}$$

$$\left\langle r^2\right\rangle = \frac{3}{5} r_0^2 A^{\frac{2}{3}}$$

$$\left\langle r^2\right\rangle \approx \left\langle r^2\right\rangle_0 \left(1 + \frac{5}{4\pi}\left\langle\beta_2^2\right\rangle\right)$$

PHYSICAL REVIEW A **90**, 052502 (2014)

Isotope shifts in francium isotopes $^{206-213}$Fr and ^{221}Fr

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(FrPNC Collaboration)
(Received 4 June 2014; published 7 November 2014)

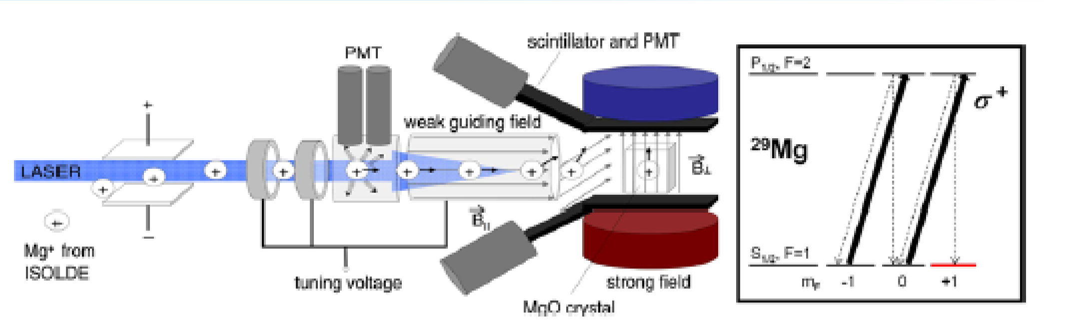
We present the isotope shifts of the $7s_{1/2}$ to $7p_{1/2}$ transition for francium isotopes $^{206-213}$Fr with reference to ^{221}Fr collected from two experimental periods. The shifts are measured on a sample of atoms prepared within a magneto-optical trap by a fast sweep of radio-frequency sidebands applied to a carrier laser. King plot analysis, which includes literature values for $7s_{1/2}$ to $7p_{3/2}$ isotope shifts, provides a field shift constant ratio of 1.0520(10) and a difference between the specific mass shift constants of 170(100) GHz amu between the D_1 and D_2 transitions, of sufficient precision to differentiate between *ab initio* calculations.

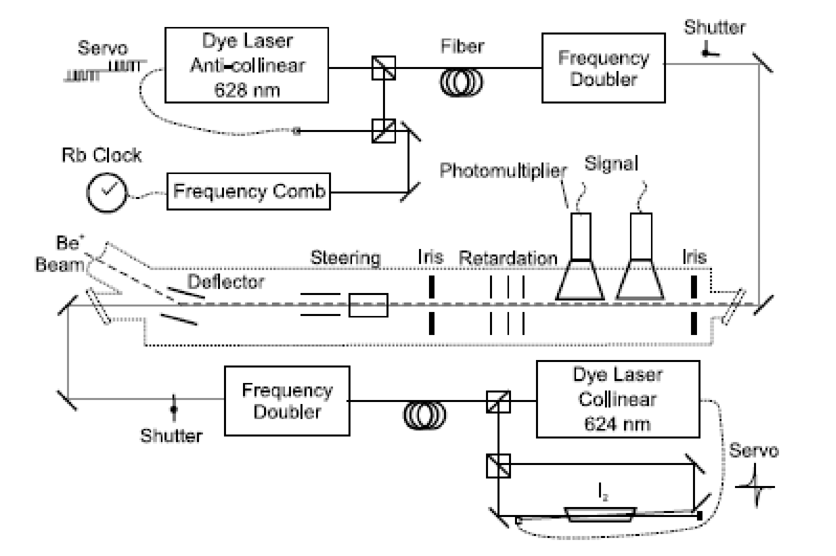
→ **Quadrupole deformation parameter**

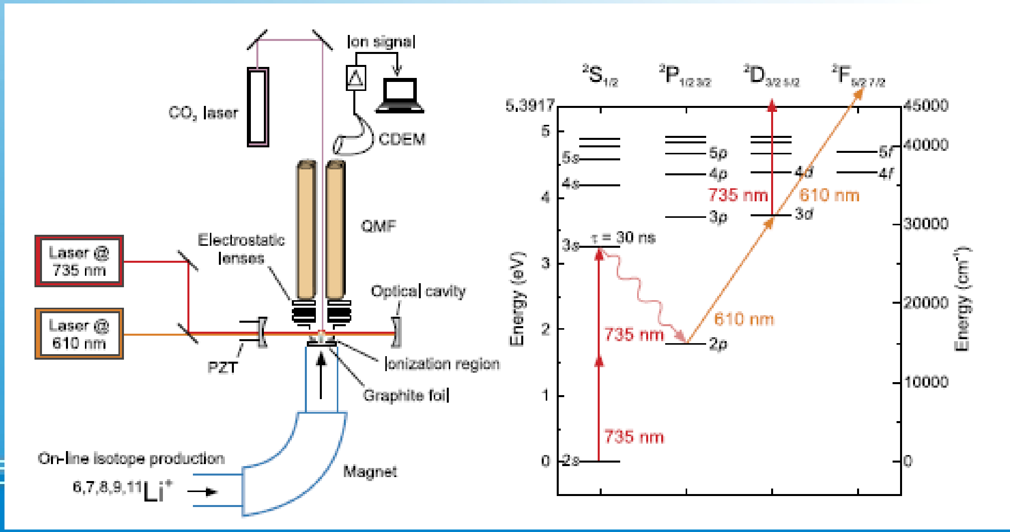
$$Q_s = \frac{3\Omega^2 - I(I+1)}{(I+1)(2I+3)} Q_0$$

$$Q_0 = \frac{3}{\sqrt{5\pi}} Z e R^2 \left\langle\beta_2\right\rangle \left(1 + 0.36\left\langle\beta_2\right\rangle\right)$$

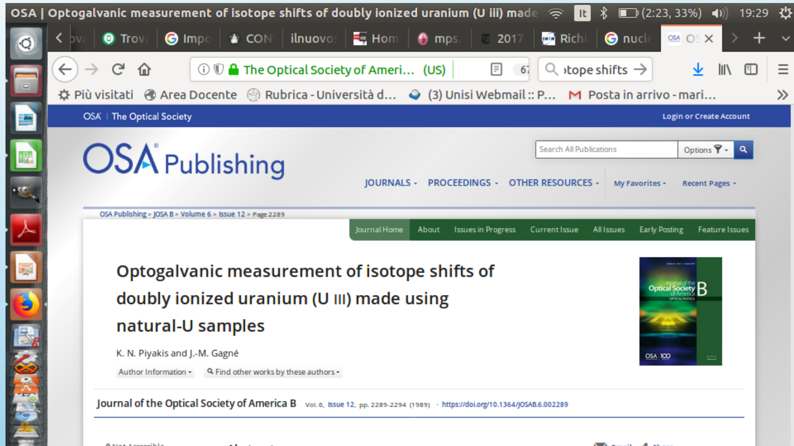
List of atomic observables for nuclear studies







List of atomic observables for nuclear studies



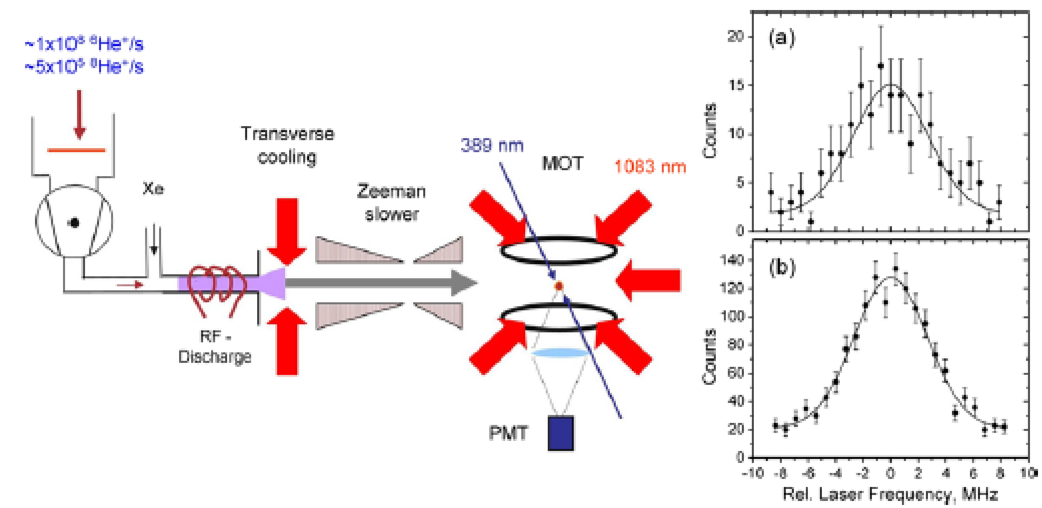
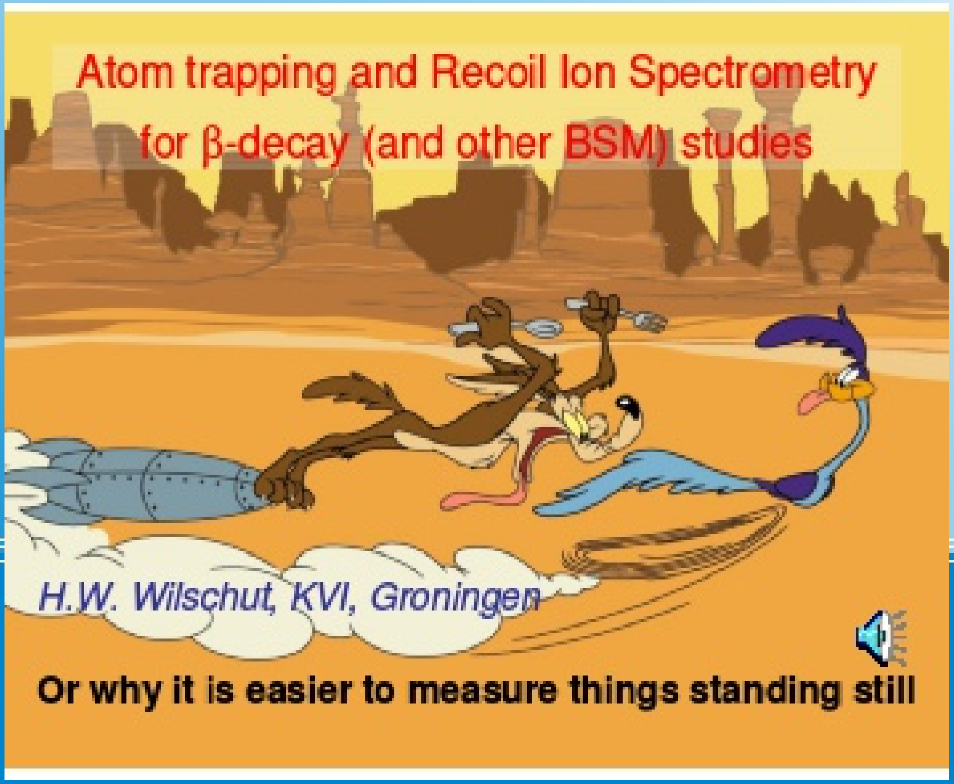


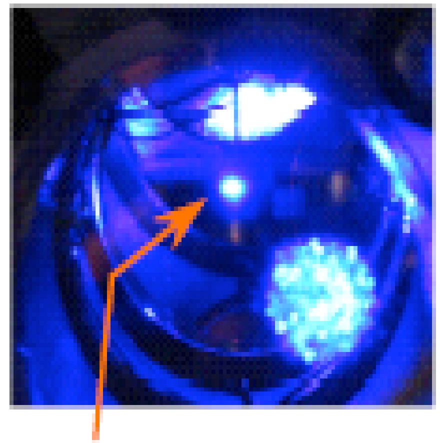
Fig. 6.8 Experimental setup for the isotope shift measurements of He isotopes (*left*) as explained in the text. The *upper plot* (a) at the *right* shows the very first spectrum recorded solely with the first ^{8}He atom in the MOT obtained within 0.4 s. The *lower figure* (b) shows an integrated spectrum over 30 atoms, resulting in a line center fitting uncertainty of 110 kHz and a $\chi^2 = 0.87$ assuming a simple Gaussian profile. Figure modified from [18], ©The Royal Swedish Academy of Sciences. Reproduced by permission of IOP Publishing. All rights reserved

RADIOACTIVE ATOM TRAPPING



Atom trap features

Typical MOT parameters:



trapped atoms

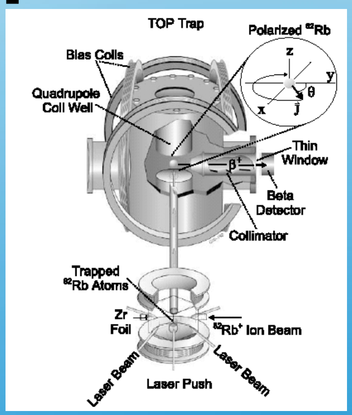
Diameter of Laser Beams	1 cm
Power/Laser Beam	10 mW
Detuning of Laser Frequency	1 Γ
Magnetic Field Gradient	10 Gauss/cm
Number of trapped Atoms	10^9
Peak Density of trapped Atoms (Limited by Fluorescence)	10^{11} atoms/cm^{-3}
Temperature (below Doppler Limit)	10 μK
Phase Space Density $\rho\Lambda^3$	10^{-6}

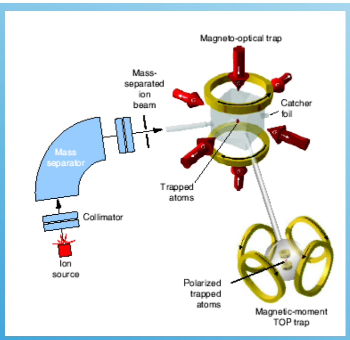
Why to trap radioactive atoms?

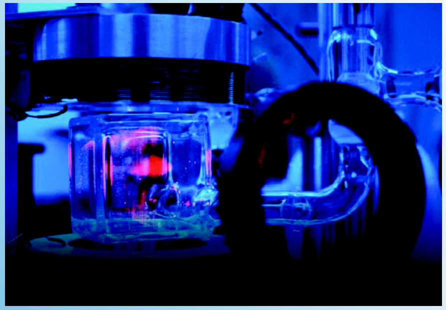
A) Because it is a way of studying nuclear physics and fundamental processes by atomic physics tools

→ β DECAY

$$\frac{d^2W}{d\Omega_e d\Omega_\nu} \sim 1 + a\frac{\boldsymbol{p}\cdot\boldsymbol{q}}{E} + b\Gamma\frac{m_e}{E} + \langle \boldsymbol{J}\rangle \cdot \left[A\frac{\boldsymbol{p}}{E} + B\,\boldsymbol{q} + D\frac{\boldsymbol{p}\times\boldsymbol{q}}{E}\right] + \langle \boldsymbol{\sigma}\rangle \cdot \left[G\frac{\boldsymbol{p}}{E} + Q\,\langle \boldsymbol{J}\rangle + R\,\langle \boldsymbol{J}\rangle \times \frac{\boldsymbol{p}}{E}\right]$$







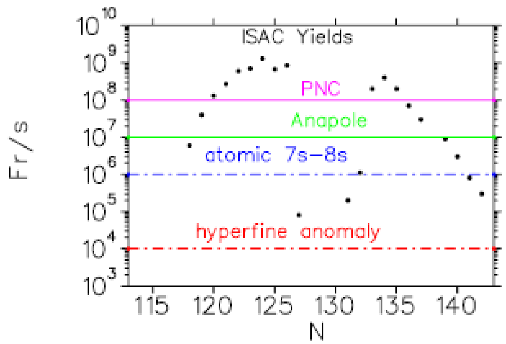
➡ ATOMIC PARITY NON CONSERVATION

→ STANDARD MODEL CHECK

B) Because it becomes possible to perform spectroscopy on rare species

Trapped radioactive isotopes

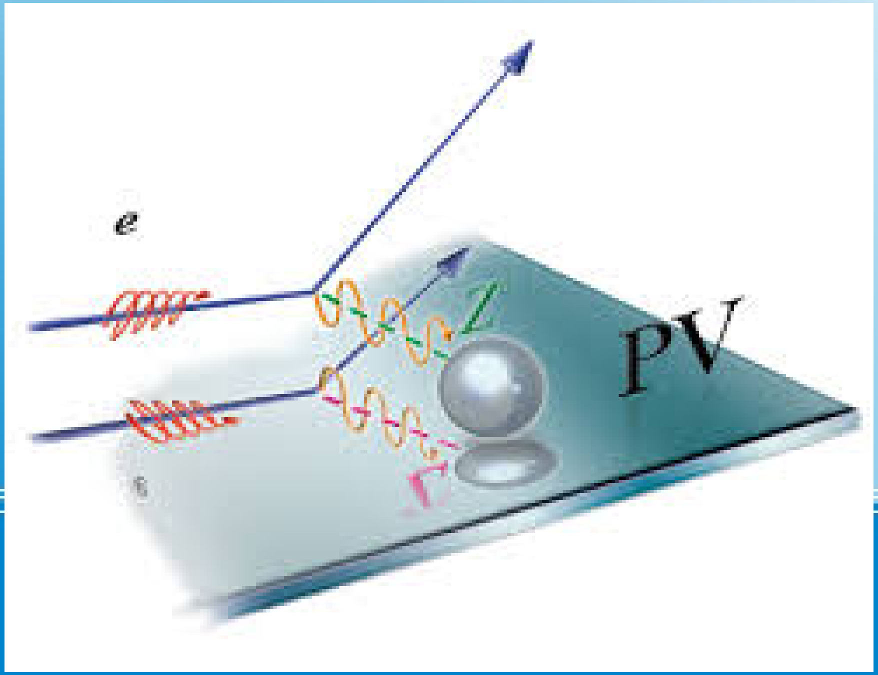
Element	Group/facility	Measurement	Trapped atom number
^{8}He	Berkeley	Halo structure	
^{21}Na	Berkeley	β decay asymmetry parameter	4 10^4
^{37,38}K	TISOL - TRIUMF	β decay asymmetry parameter	6 10^3
^{37,38}K	Wisconsin	β decay asymmetry parameter	-
^{79}Rb	Stony Brook	Preparation of Fr experiment	80
^{82}Rb	Los Alamos	Beta – spin correlation function	10^6
^{84}Rb	Los Alamos	fermion-fermion and fermion-boson collision dynamics at T=0	
^{81}Kr	Berkeley	Map of groundwater movement	
^{135,137}Cs	Los Alamos	Ultrasensitive detection	
$^{209\text{-}211}$Fr	Stony Brook	Atomic Parity Violation	10^4
$^{209\text{-}211}$Fr	LNL	Atomic Parity Violation	10^4
$^{209\text{-}211}$Fr	CYRIC/RIKEN	Electron Electric-Dipole-Moment Search	?
^{221}Fr	Colorado/LBNL	Atomic Parity Violation/EDM	10^2
$^{206g;206m;207;209;213;221}$Fr	TRIUMF	Hyperfine anomaly	Max 10^5
^{225}Ra	Trijp/KVI	Permanent EDM	
^{225,226}Ra	Argonne	Atomic EDM	



$^{207-213}$Fr and $^{220-223}$Fr have optical PNC experiments possible

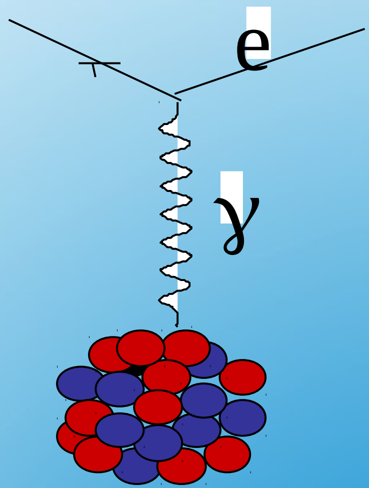
"The Fr experiment at CYRC. Sendai is now going on, and last year. we finally observe the Fr-MOT at last, although the estimated number of Fr atoms was still limited compared with your experiment at LNL. "

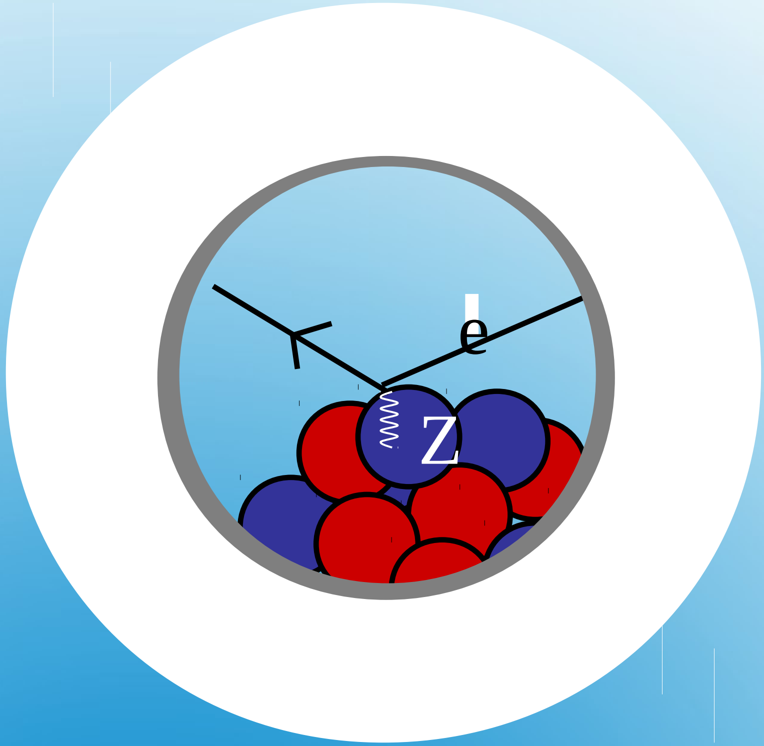
ATOMIC PARITY NON CONSERVATION



Atomic parity violation

RELEVANT ELECTRON - HADRON PROCESSES





$$A_{em} \propto \frac{e^2}{p^2}$$

$$A_W \propto \frac{e^2}{p^2 + M_{Z_0}^2 c^2}$$

p is the momentum transfer
(inversely proportional to the Bohr radius)

$$p \sim m_e \alpha c$$

Atomic parity violation

Different transition probabilities for two mirror - image experiments

The amplitude A_W contains a part that is odd under space reflection and gives rise to a left - right asymmetry A_{LR} by interference with A_{em}.

$$P_{L/R} = \left| A_{em} \pm A_W^{odd} \right|^2$$

$$A_{LR} = \frac{P_L - P_R}{P_L + P_R} \simeq 2\mathrm{Re}\,\frac{A_W^{odd}}{A_{em}}$$

$$\alpha^2 \left(\frac{m_{e^-}}{M_{Z_0}} \right)^2 \sim 10^{-15}$$

Atomic parity violation

Completely hopeless? No!

There are 2 factors of enhancement:

A. The so - called Z^3 law

- For valence electrons belonging to penetrating orbitals, the orbitals are deformed in the vicinity of the nucleus, where electrons "see" a Coulomb potential generated by a charge Ze. The orbital radius is given by a_0/Z, in such a way that p^2 is enhanced by Z^2.
- The various nucleons add for their contributions coherently: the number of nucleons grows as Z

Atomic parity violation

B. The second source comes from the possibility of exciting highly forbidden transitions like

$$nS_{1/2} \Rightarrow (n+1)S_{1/2}$$

in alkalis. The electromagnetic selection rules strictly forbid the electric dipole transition; dipole magnetic transitions M_1 are allowed by the symmetry, not by the change in radial number.

$$M_1 \approx 4 \times 10^{-5} \frac{\mu_B}{c}$$

The weak interaction associated with the boson exchange breaks this rule and gives rise to a parity violating electric dipole amplitude $E^{(PV)}_1$:

$$E_1^{PV} \approx 10^{-11} ea_0$$

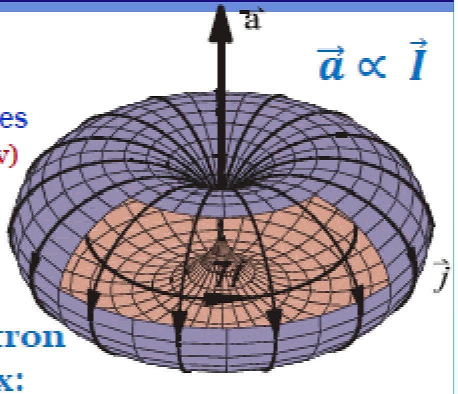
$$Im\, E_1^{pv}/M_1 \simeq 0.5 \times 10^{-4}$$

Nuclear parameters deducible by laser spectroscopy

→ **Nuclear anapole moment**
→ **Weak charge**

Nuclear anapole moment (NAM)

- 1959: Concept of Nuclear Anapole Moment:
  (Ya. B. Zel'dovich & V. G. Vaks)
- 1980: Detectable through atoms and molecules
  (V. V. Flambaum, I. B. Khriplovich & O. P. Sushkov)
- 1997: Reported to be observed in Cs PNC
  (C. S. Wood et al, Science 275, 1759 (1997))



Current distribution seen by an electron has definite chirality due to spin helix:

$$\vec{A}(\vec{R}) = \frac{1}{c}\int \frac{\vec{j}(\vec{r})}{|\vec{R}-\vec{r}|}\, d^3r$$

Weak charge

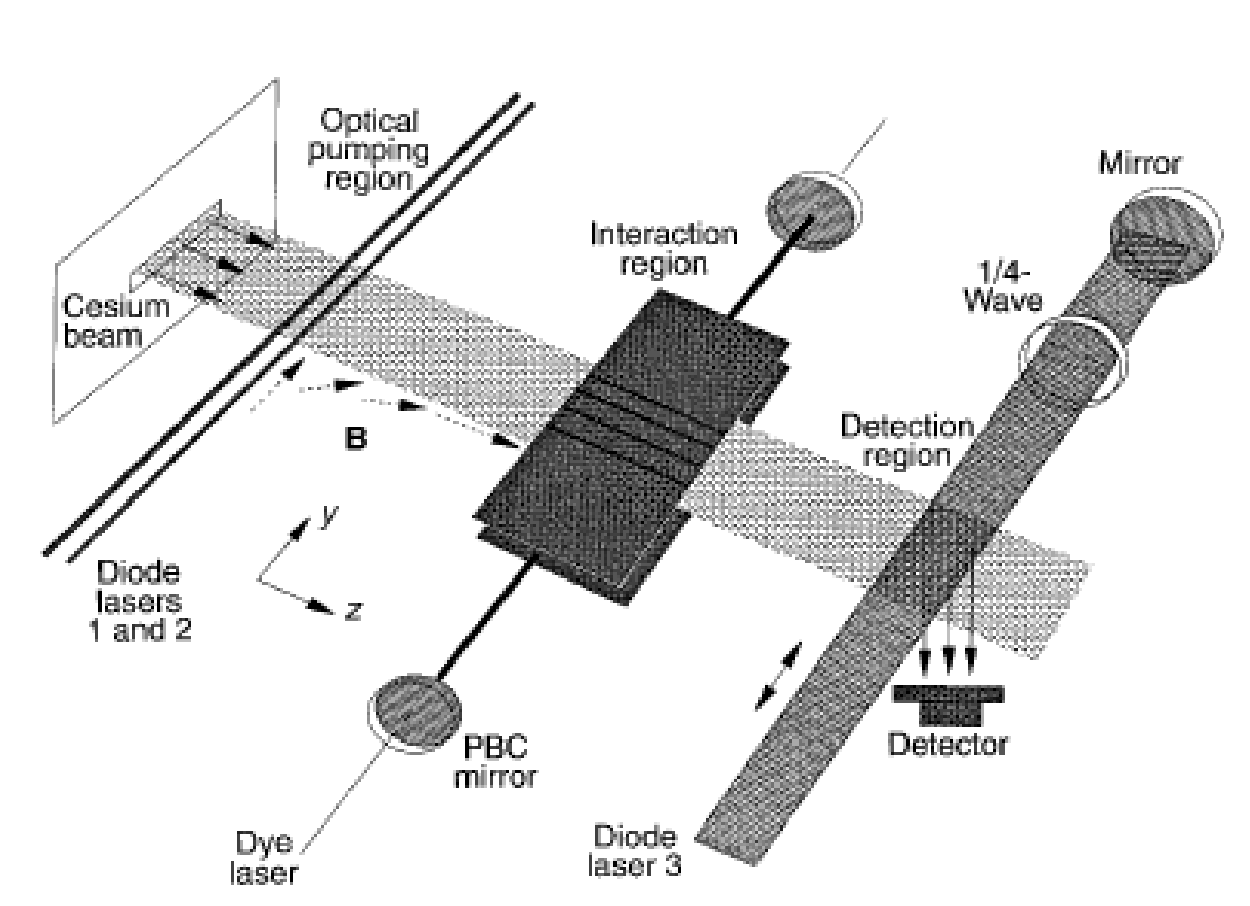
Weak charges of quarks in the nucleus add coherently, therefore, at the tree level of SM:

$$Q_W^{SM} = -N + Z\,(1 - 4\,Sin^2\,\theta_W) \approx -N$$

With the permission of B. Sahoo

APV Cs measurements

To obtain an observable that is first order in the APNC amplitude, it is possible to apply a dc electric field *E* that also mixes *S* and *P* states. This field gives rise to a “Stark induced” E1 transition amplitude that is typically 10^5 times larger than *A*PNC and can interfere with it.



$$R \propto \left|A_{Stark} + e^{i\theta} E_1^{APNC}\right|^2$$
$$\propto \quad A_{Stark}^2 + kA_{Stark} Im(E_1^{APNC})$$

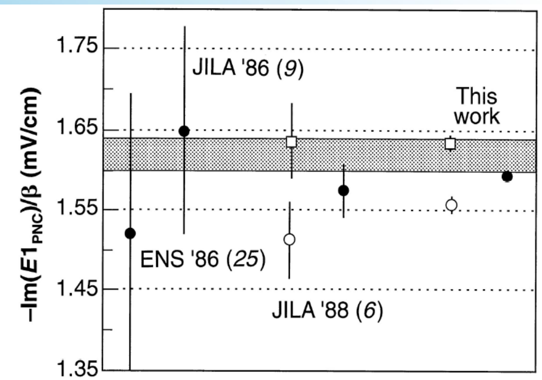


Figure 4. Historical comparison of cesium PNC results. The squares are values for the 4-3 transition, the open circles are the 3-4 transition, and the solid circles are averages over the hyperfine transitions. The band is the standard-model prediction for the average, including radiative corrections. The ±1σ width shown is dominated by the uncertainty of the atomic structure.

C.S.Wood et al., Science 275(1997)1759

APV Yb measurements

Parity violation in atomic ytterbium: experimental sensitivity and systematics

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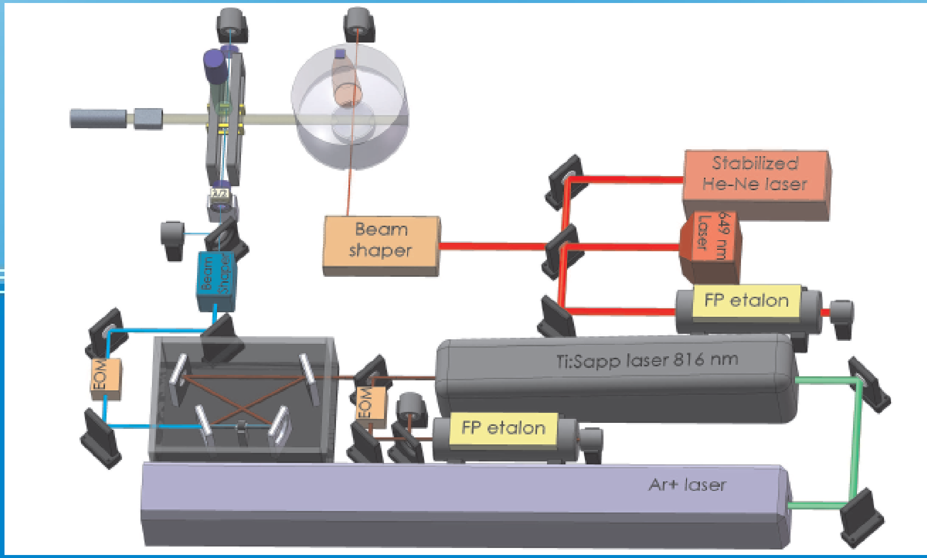
(Dated: June 19, 2017)

We present a detailed description of the observation of parity violation in the $6s^2\,{}^1S_0 \rightarrow 5d6s\,{}^3D_1$ 408-nm forbidden transition of ytterbium, a brief report of which appeared earlier. Linearly polarized 408-nm light interacts with Yb atoms in crossed **E**- and **B**-fields. The probability of the 408-nm transition contains a parity violating term, proportional to $(\boldsymbol{\mathcal{E}} \cdot \mathbf{B})[(\mathbf{E} \times \boldsymbol{\mathcal{E}}) \cdot \mathbf{B}]$, arising from interference between the parity violating amplitude and the Stark amplitude due to the E-field ($\boldsymbol{\mathcal{E}}$ is the electric field of the light). The transition probability is detected by measuring the population of the ${}^3P_0$ state, to which 65% of the atoms excited to the ${}^3D_1$ state spontaneously decay. The population of the ${}^3P_0$ state is determined by resonantly exciting the atoms with 649-nm light to the $6s7s\,{}^3S_1$ state and collecting the fluorescence resulting from its decay. Systematic corrections due to E-field and B-field imperfections are determined in auxiliary experiments. The statistical uncertainty is dominated by parasitic frequency excursions of the 408-nm excitation light due to imperfect stabilization of the optical reference with respect to the atomic resonance. The present uncertainties are 9% statistical and 8% systematic. Methods of improving the accuracy for the future experiments are discussed.



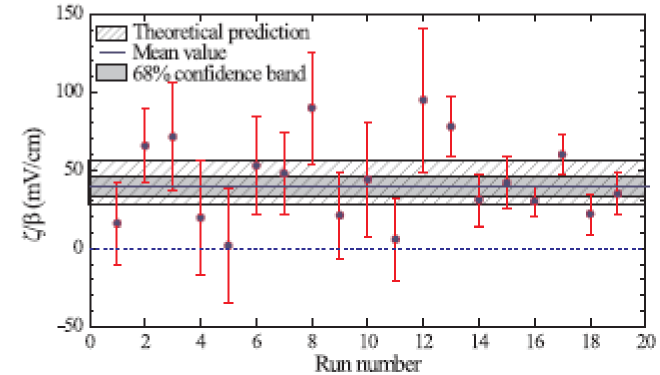


FIG. 8: (color online) The PV interference parameter ζ/β. Mean value: $39(4)_{\rm stat.}(3)_{\rm syst.}$ mV/cm, $|\zeta| = 8.7 \pm 1.4 \times 10^{-10}\ ea_0$.

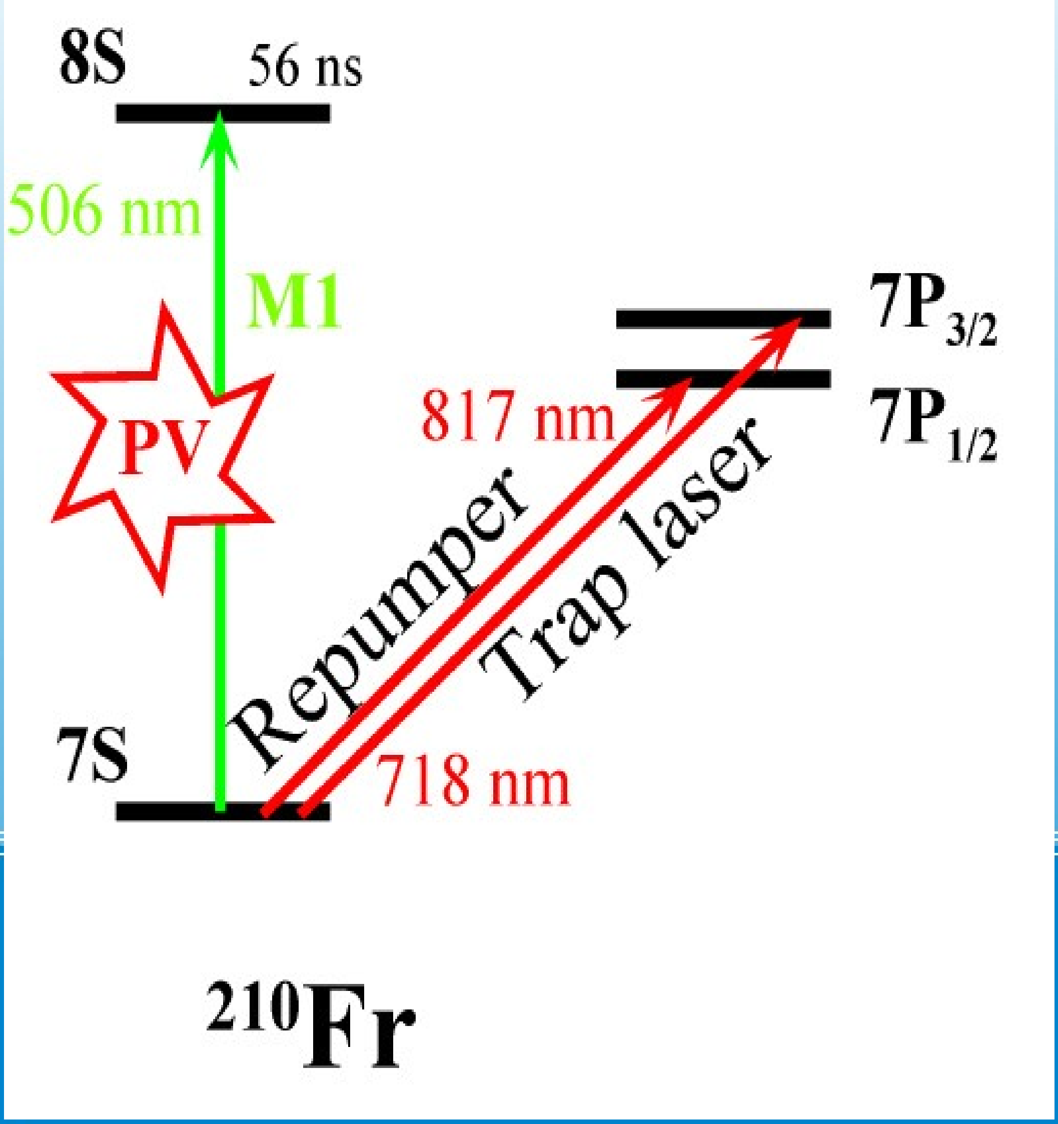
Atomic parity violation roadmap

A possible experimental approach:

1. Capture Fr atoms in a MOT
2. Accumulate and cool in the MOT
3. Transfer to a second trap (purely optical)
4. Establish a "coordinate system" by dc electric field, dc magnetic field, k vector of the exciting laser
5. Excite 7S to 8S using a build up cavity and detect using the 7S to 7P transition.
6. Reverse the coordinate axis.
7. Change isotope.

"Towards" APV measurement

$$\vec{d}^{\,\mathrm{eff}}_{F,F'} = -\alpha\vec{E} - i\beta\vec{\sigma}\wedge\vec{E} + M_1'\vec{\sigma}\wedge\vec{k} - iIm(E_1^{PV})\vec{\sigma}$$



preliminary measurement
of the ratios
α/β, β/M_1, M_1/M_1^{hf}:
in the MOT cloud
to "calibrate" APV

Expected signal to noise ratio

- Fr production rate in Legnaro: up to 10^6 ions/s.
- Trapping efficiency $\sim 10^{-2} \Rightarrow N = 10000$ atoms in 1 mm^3 (0.01 mm^3) (optical dipole trap).
- **Laser intensity: 100 mW/mm^2**, enhanced by a factor $\zeta = 1000$ with a Fabry-Perot cavity (cf. Boulder) $\Rightarrow P/S = 10$ kW/cm^2.
- Fluorescence detection efficiency: $\eta \sim 10\%$.

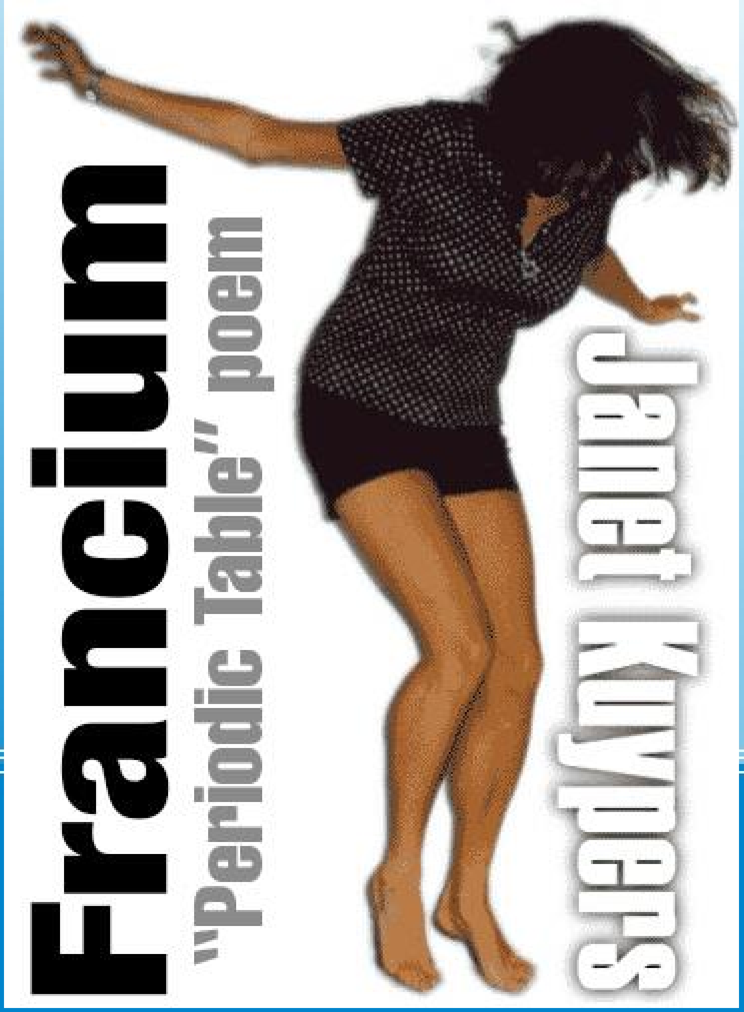
$$S/N = \Im m E_1^{pv} \sqrt{\frac{4\pi}{3\hbar c} \frac{1}{\hbar \Gamma} \frac{P}{S}} \eta N \sqrt{t} = 0.009 \sqrt{t(s)} \quad (1 \text{ for } t = 3 \text{ hours})$$

How can we improve S/N ?

- Higher laser power, BUT: – heating due to photon scattering
  – photoionization from $8S$ and $7P$.
- Higher Fr^+ Rate: $\geq 4 \cdot 10^9$ ions/s at the ISOLDE facility.
  $\Rightarrow S/N = \mathbf{0.55} \sqrt{t(s)}$

In 9 hours we can get $S/N = 100$

THE LNL EXPERIMENT



(Bad) facts about francium

	Mass no. (*A*)	Half-life
Fr	202	0.34 s
	203	0.55 s
	205	3.85 s
	206	15.9 s
	207	14.8 s
	209	50 s
	211	3.1 min
	213	34.6 s
	220	27.4 s
	223	21.8 min
	224	3.3 min
Fr	225	4.0 min
	226	48 s
	227	2.47 min
	228	39 s
	230	19.1 s
	232	5 s

Fr has no stable isotopes

The longest lifetime is 22min

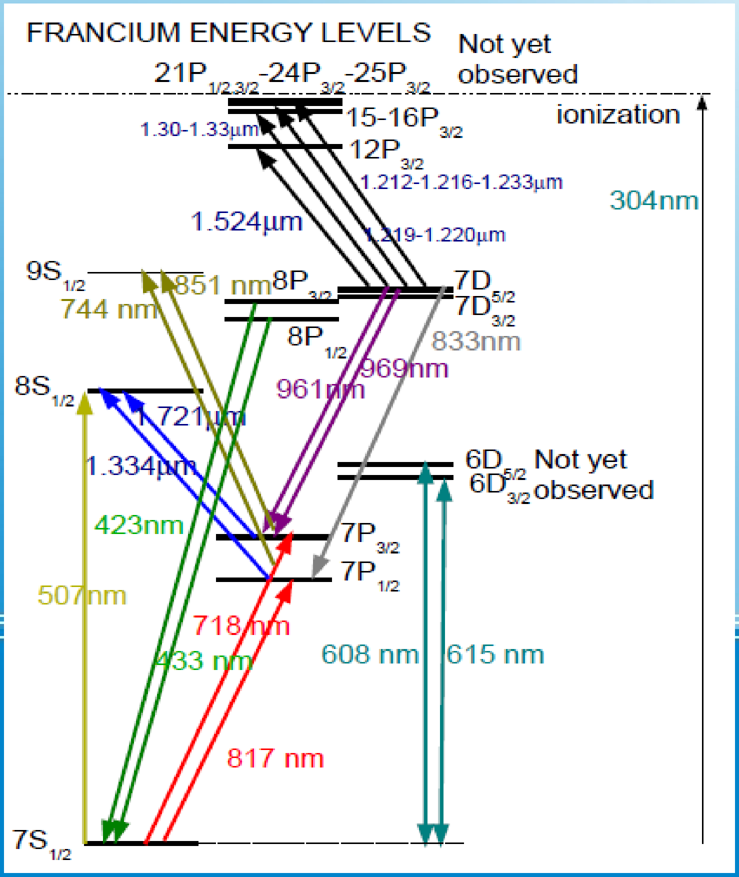
There is at most a tea spoon of francium in the whole Earth at any given time

⇒ continuos production and trapping for further studies is necessary

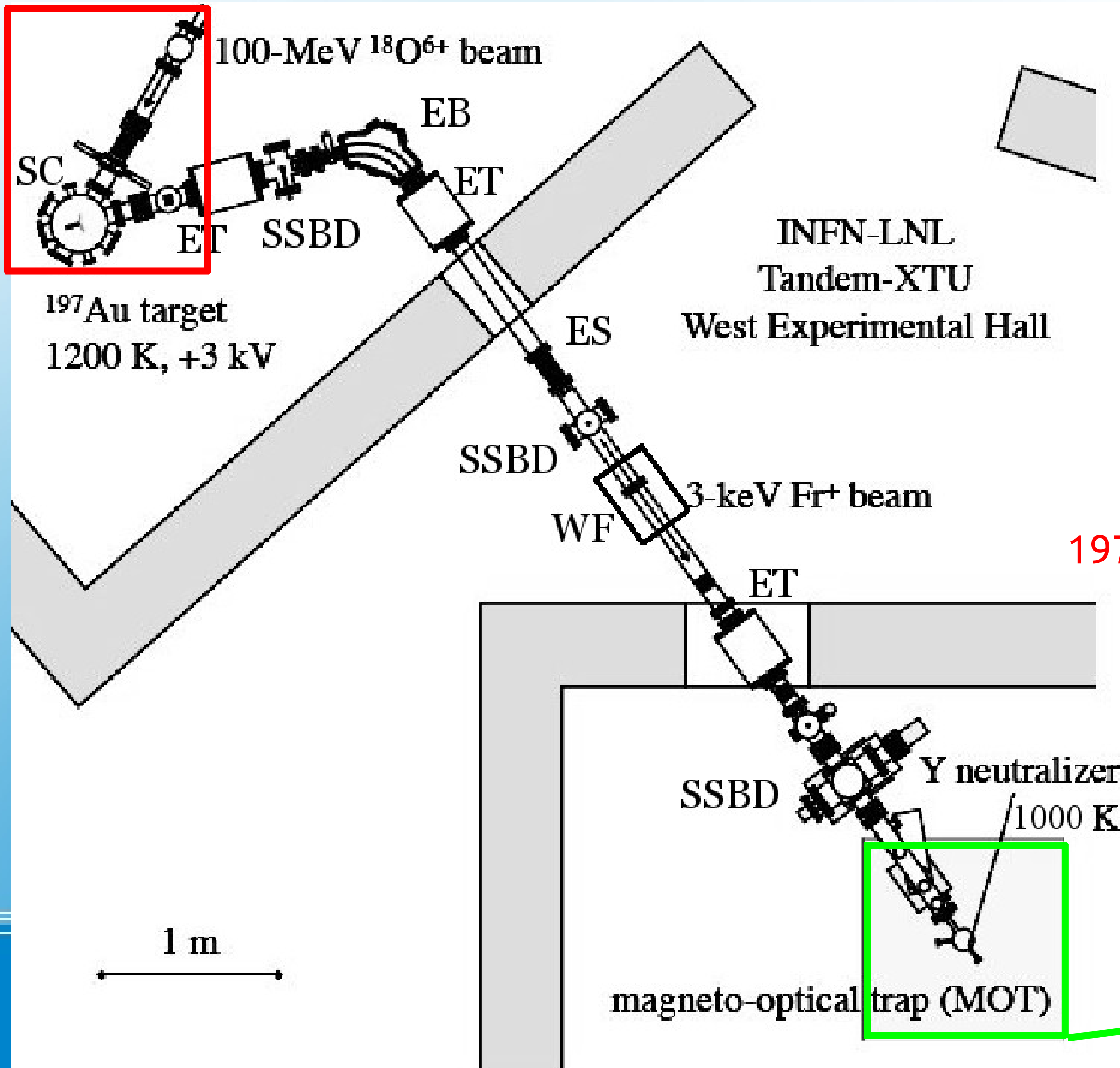
^{210}Fr → 3.2 min

(Interesting) facts about francium

spectroscopically poorly known
"simple" electronic structure
several isotopes suitable for trapping
enhanced P and T violations (Z=87)



The "traprad"/"francium"/"wade" experiment



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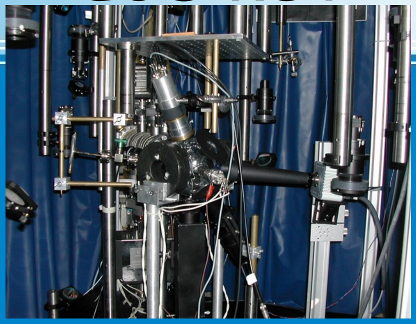
INFN L.N.L.

Fr production

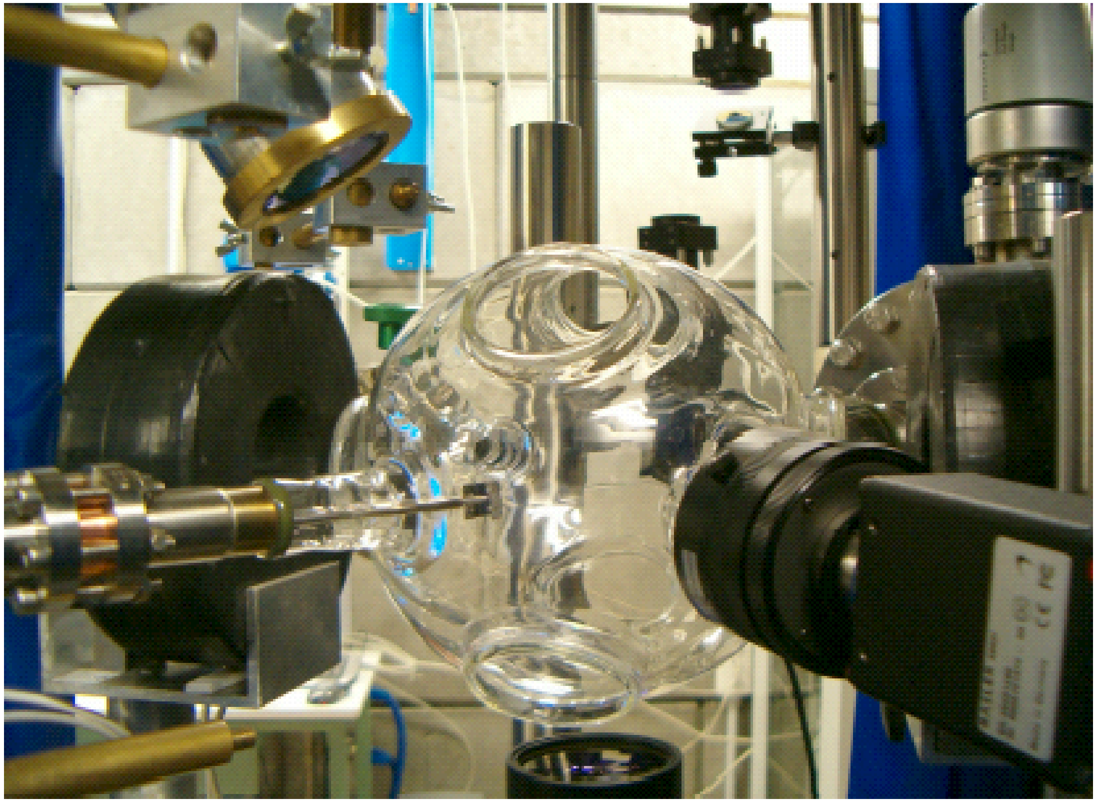
$^{197}Au + ^{18}O \rightarrow xn + ^{215-x}Fr$

Fr^{+} (and Rb^{+}) transport at 3 keV



Eur Phys J ST 150 389 (2007)

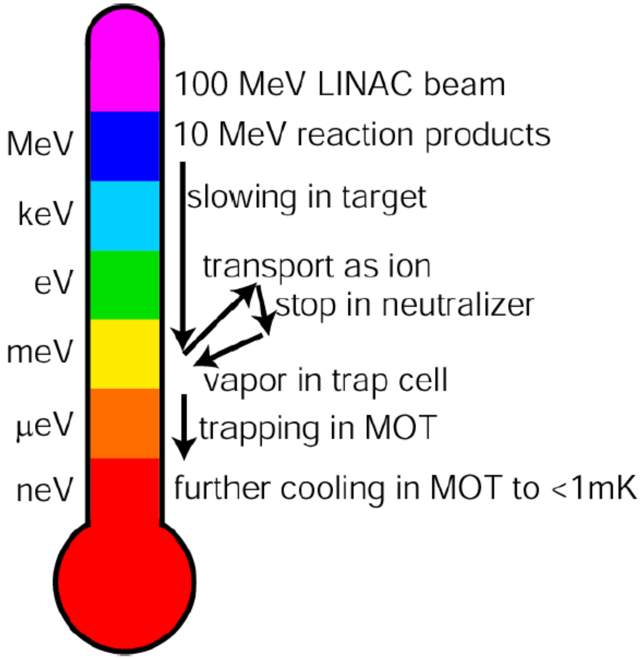
The MOT cell



$\phi_{Au} = 5.1$ eV

$\phi_{Y} = 3.1$ eV

$I_{Fr} = 4.1$ eV



$$\frac{n_+}{n_a} = \frac{g_+}{g_a} \exp\left(\frac{\phi - I}{k_B T}\right)$$

Francium trapping

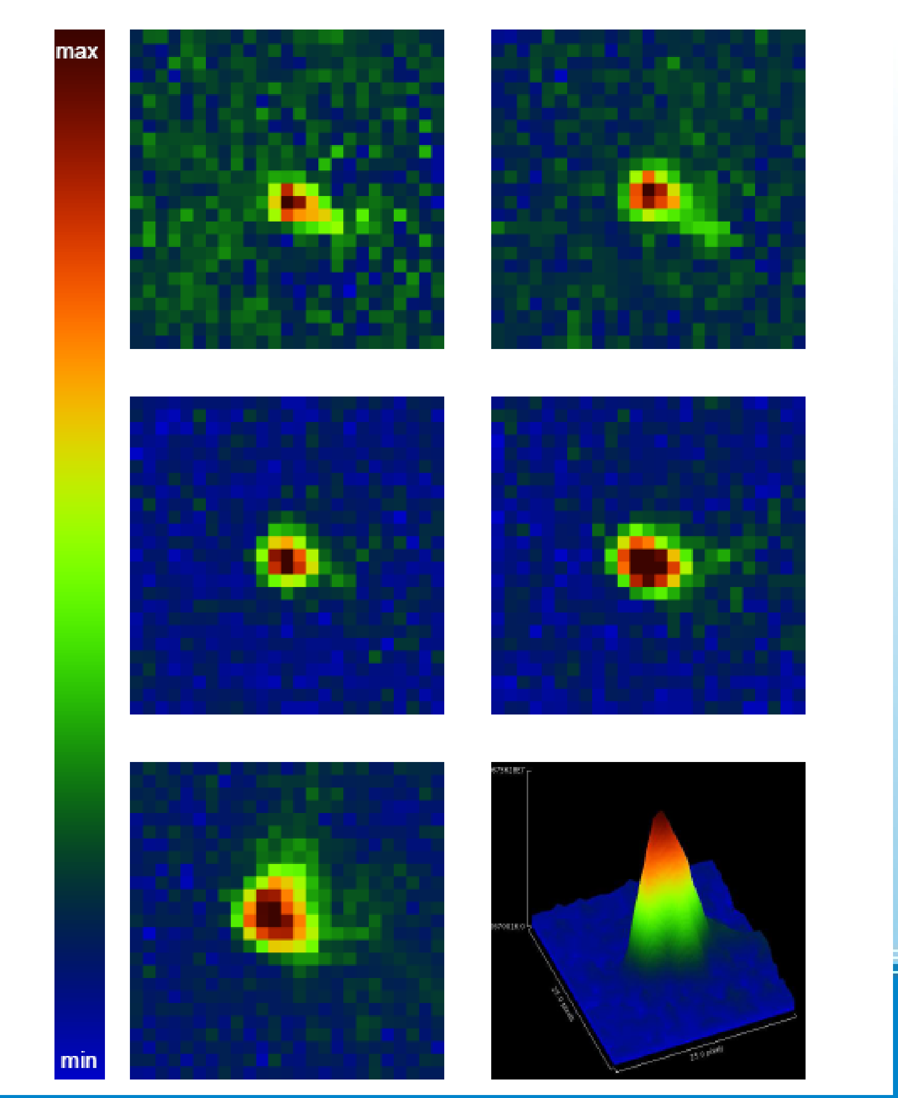
220 atoms

450 atoms

560 atoms

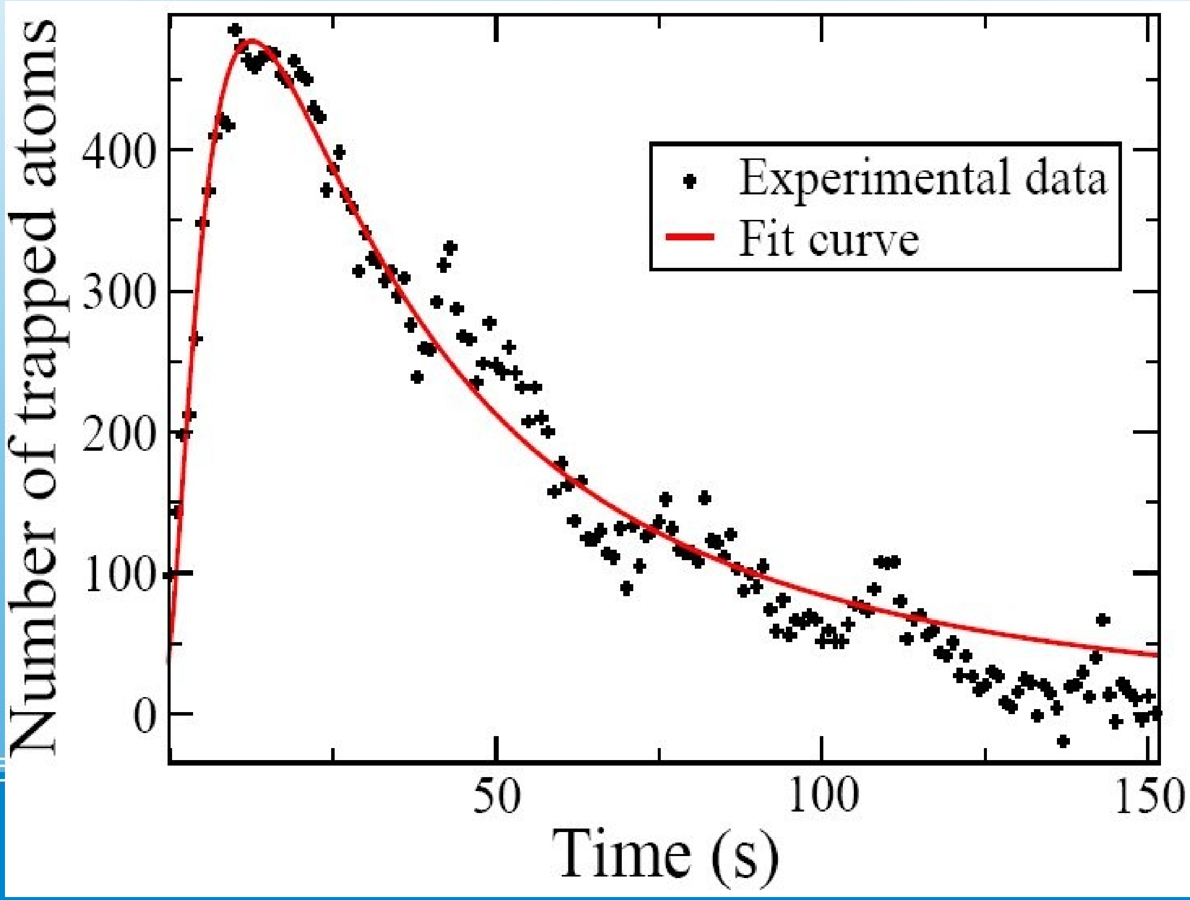
930 atoms

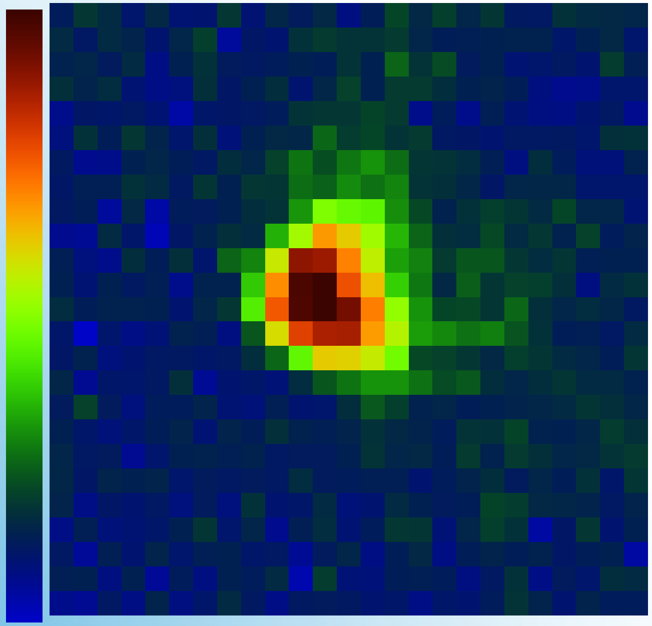
1100 atoms

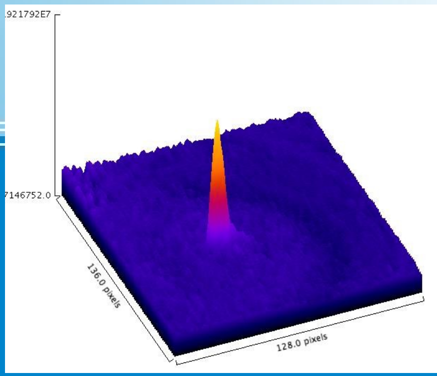


Francium trapping

accumulation in the cold yttrium and fast release
by suddenly switching on the heating of neutraliser

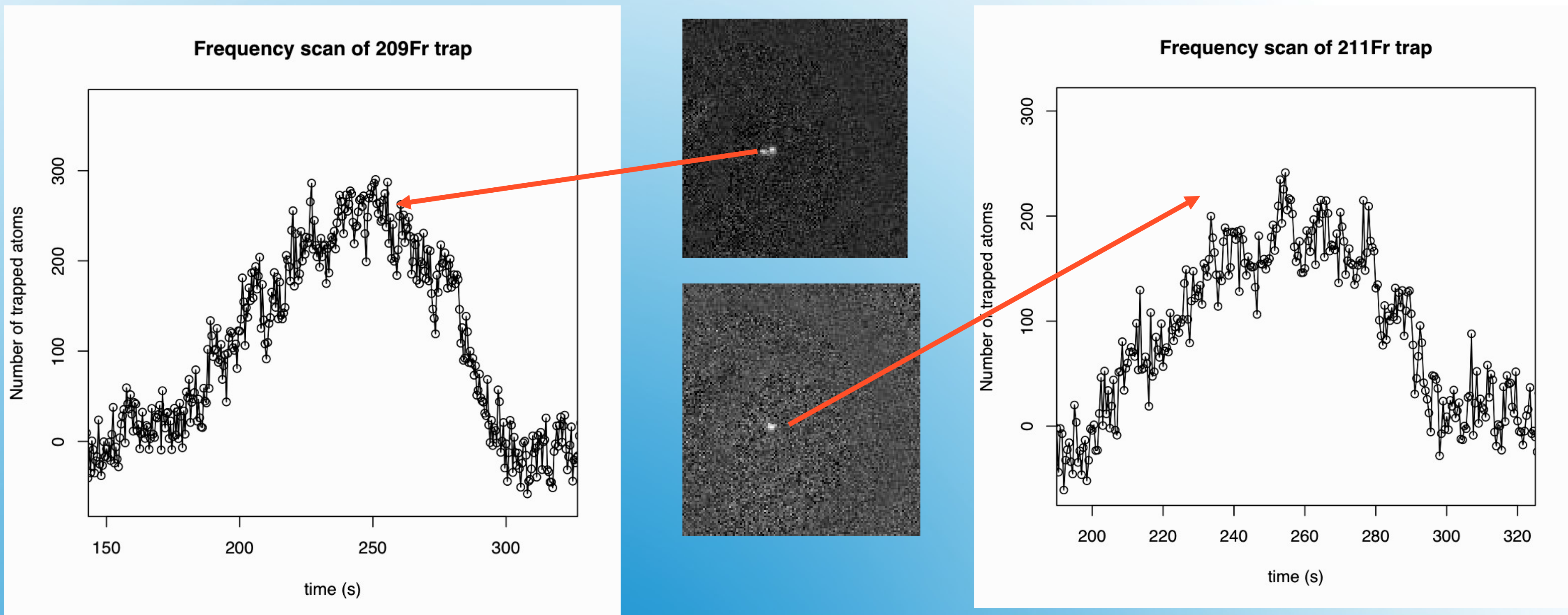






up to 10000 atoms

Other Fr isotopes (209, 211)



PRECISION MEASUREMENTS ON THE FRANCIUM LEVELS

Precision measurements

April 1, 2009 / Vol. 34, No. 7 / OPTICS LETTERS 8

Accurate measurements of transition frequencies and isotope shifts of laser-trapped francium

S. Sanguinetti,[1,*] R. Calabrese,[2] L. Corradi,[3] A. Dainelli,[3] A. Khanbekyan,[4] E. Mariotti,[4] C. de Mauro,[4] P. Minguzzi,[1] L. Moi,[4] G. Stancari,[2] L. Tomassetti,[2] and S. Veronesi[4]

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[2]*Dipartimento di Fisica dell'Università degli Studi and Istituto Nazionale di Fisica Nucleare, Sezione di Ferrara, Via Saragat 1, 44100 Ferrara, Italy*

[3]*Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, Viale dell'Università 2, 35020 Legnaro (PD), Italy*

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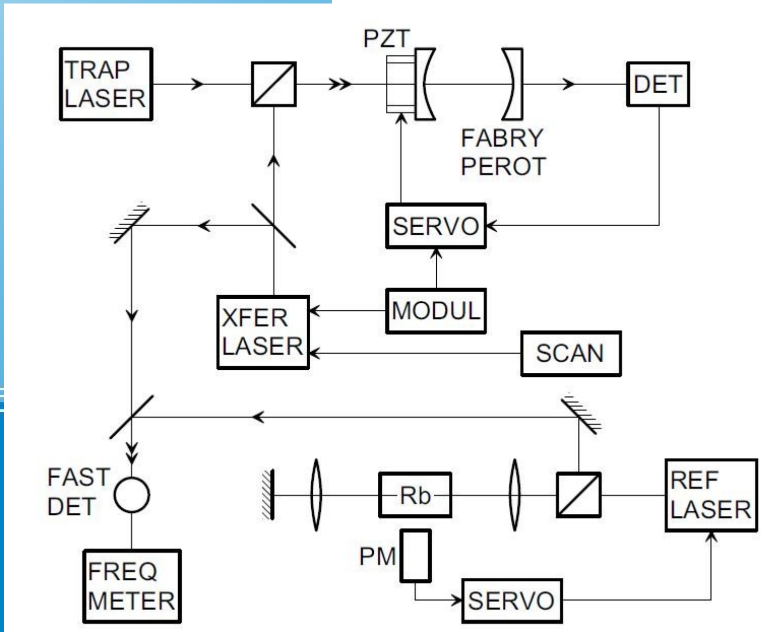
Corresponding author: stefano.sanguinetti@df.unipi.it

008; revised January 23, 2009; accepted February 9, 2009;
9, 2009 (Doc. ID 104610); published March 17, 2009

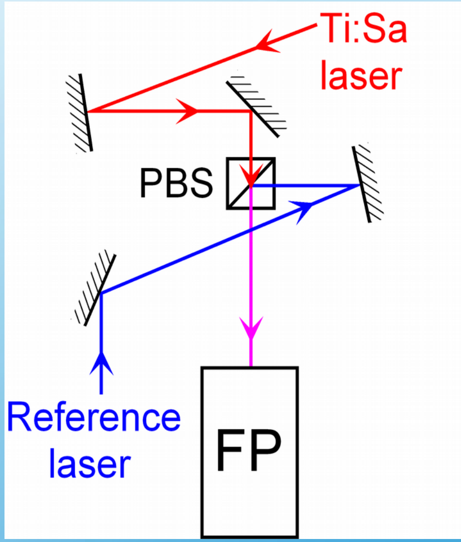


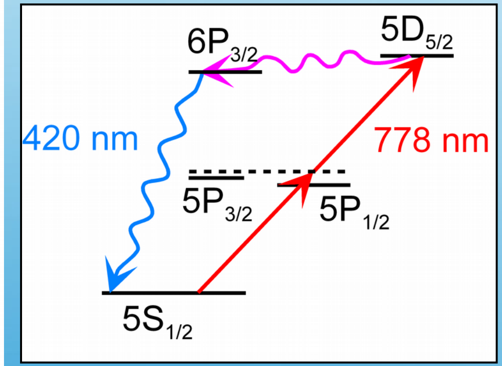
We compare the frequency of 2 lasers transmitted by a confocal FP cavity (finesse 200, FSR 2 GHz) .....

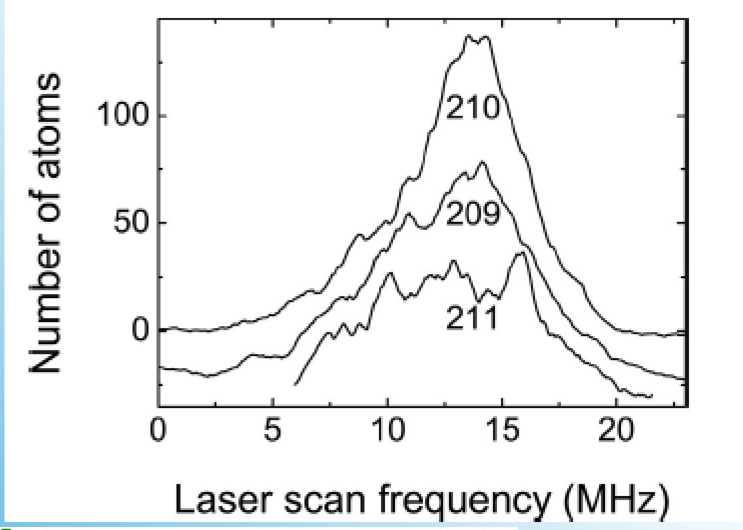
....Measuring the beat signal with a frequency meter (accuracy better than 300 kHz)

Precision measurements

Secondary frequency standard: Rb 5S – 5D$_{5/2}$ 2 photon transition (@ 778 nm) measured with 8 kHz accuracy







Accuracy:

Calibration	➠ 5 MHz
Fabry-Perot maxima	➠ 2 MHz
Refractive index of air	➠ 2 MHz
TOTAL	➠ 9 MHz

Isotope	209	210	211
Trapping freq. (GHz)	417415.0914(90)	417412.4493(90)	417412.6303(90)
Repumping freq. (GHz)	366897.43(5)	366898.70(5)	366895.57(5)

DETECTION OF LINES BY CHANGE IN TRAPPED ATOM NUMBERS

Detection results (Rb)

IOP PUBLISHING MEASUREMENT SCIENCE AND TECHNOLOGY

Meas. Sci. Technol. 24 (2013) 015201 (8pp) doi:10.1088/0957-0233/24/1/015201

Detection of excited level population transfer in an MOT through the measurement of trapped atom number

L Moi[1], G Batignani[1], A Khanbekyan[1], K Khanbekyan[1], C Marinelli[1], E Mariotti[1], L Marmugi[1], L Corradi[2], A Dainelli[2], R Calabrese[3], G Mazzocca[3], L Tomassetti[3] and P Minguzzi[4]

[1] CNISM, Physics Department, University of Siena, via Roma 56, 53100 Siena, Italy
[2] INFN—Laboratori Nazionali di Legnaro, viale dell'Università 2, 35020 Legnaro (PD), Italy
[3] University of Ferrara and INFN, via Saragat 1, 44122 Ferrara, Italy
[4] CNISM, Physics Department, University of Pisa, largo Pontecorvo 3, 56127 Pisa, Italy

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Measurement Science and Technology's Outstanding Paper awards for 2013
http://iopscience.iop.org/0957-0233/25/7/070201

Detection results (Rb)

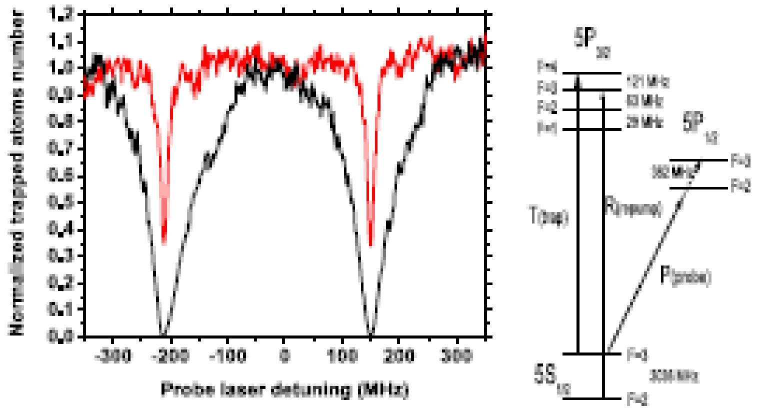

Figure 2. (Left) Relative variation of the trapped ^{85}Rb atoms as a function of the Ti:Sa laser detuning with respect to the D_1 line involving hyperfine level $F_g = 3$. The black and red lines denote the signal obtained with 3.5 mW and 35 μW, respectively. (Right) A simplified scheme of the involved levels.

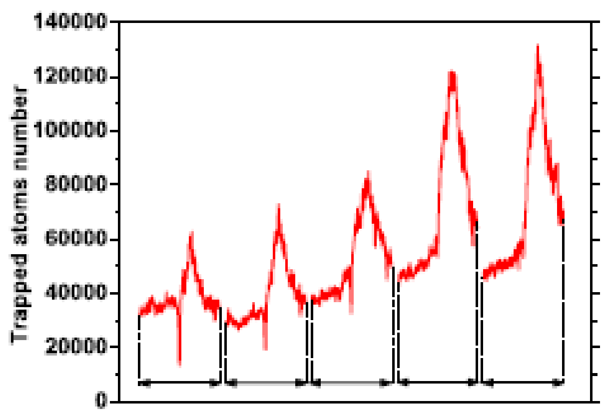

Figure 6. Variation of the trapped ^{85}Rb atom number as a function of the Ti:Sa laser detuning with respect to the D_2 line involving hyperfine level $F_g = 2$. The curves in the graph shows the effect of increasing Ti:Sa intensity (from left to right) on the observed signal. Each 600 MHz wide scan of the Ti:Sa laser frequency is marked by black arrows.

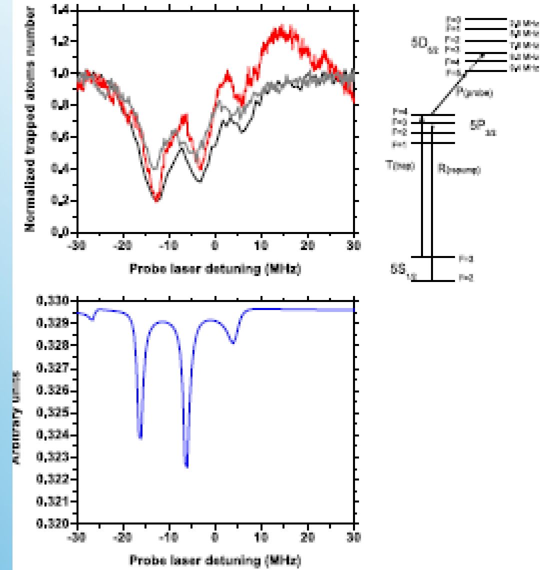

Figure 9. (Top) Relative variation of the number of trapped ^{85}Rb atoms as a function of the Ti:Sa laser detuning with respect to the $5P_{3/2}$ ($F_g = 4$) $\rightarrow$ $5D_{5/2}$ at 8 mW (black curve), 1 mW (grey curve) and 35 μW (red curve) (left). (Right) Simplified scheme of the involved Rb atom levels. (Bottom) Numerical simulation of occupation probability as a function of the probe laser detuning.

Detection results (Fr)

3682 Vol. 42, No. 18 / September 15 2017 / *Optics Letters* **Letter**

Optics Letters

Observation of $7p\,^2P_{3/2} \rightarrow 7d\,^2D$ optical transitions in 209 and 210 francium isotopes

S. Agustsson,[1] G. Bianchi,[1] R. Calabrese,[2] L. Corradi,[3] A. Dainelli,[3] A. Khanbekyan,[1,2] C. Marinelli,[1] E. Mariotti,[1,*] L. Marmugi,[4] G. Mazzocca,[2] L. Moi,[1] L. Ricci,[5] L. Stiaccini,[1] and L. Tomassetti[6]

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[2]*Department of Physics and Earth Sciences, University of Ferrara and INFN, via Saragat 1, 44122 Ferrara, Italy*
[3]*INFN-Laboratori Nazionali di Legnaro, Viale dell'Università 2, 35020 Legnaro (PD), Italy*
[4]*Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, UK*
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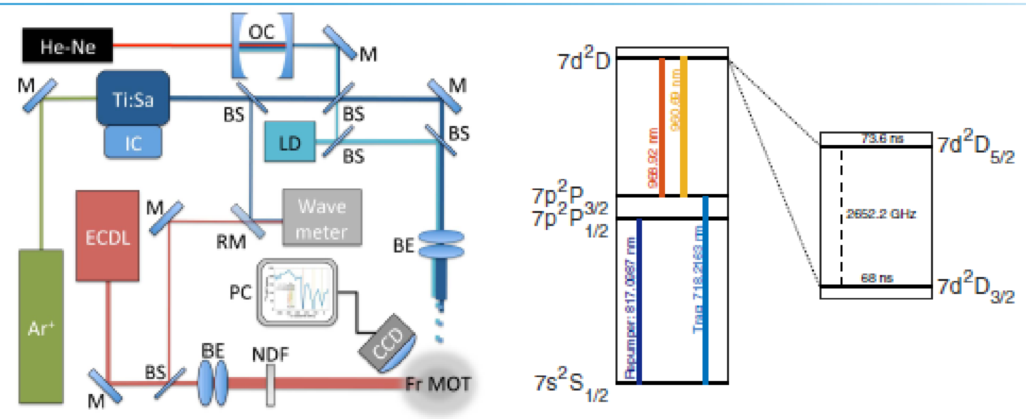
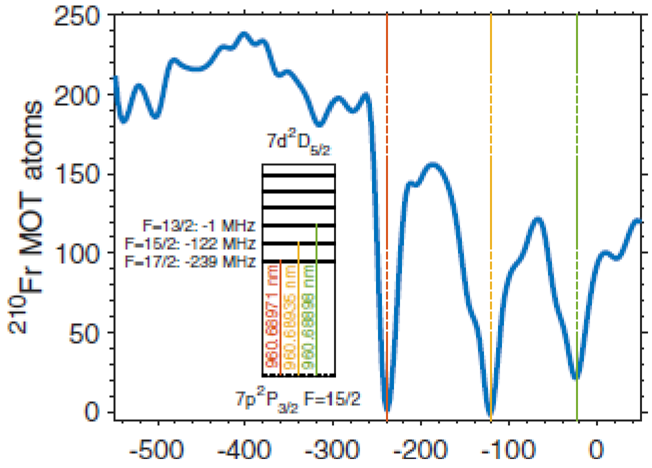
*Corresponding author: emilio.mariotti@unisi.it

Received 6 July 2017; accepted 1 August 2017; posted 7 August 2017 (Doc. ID 301826); published 15 September 2017



Detection results (Fr)



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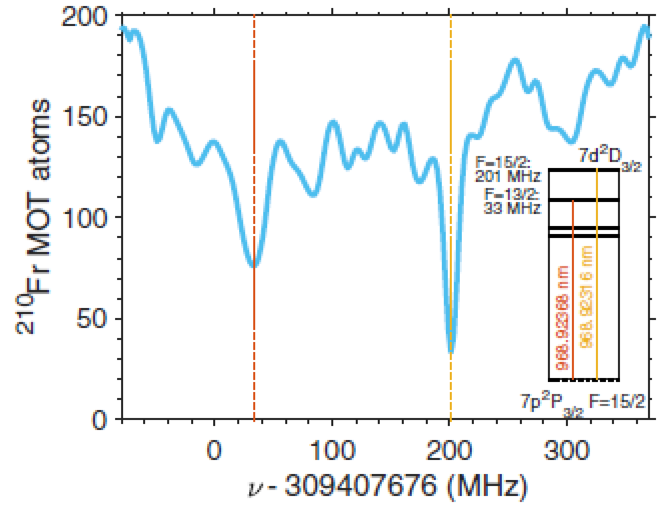


Fig. 3. ^{210}Fr $7p^2P_{3/2}(F = 15/2) \rightarrow 7d^2D_{5/2}(F' = 13/2, 15/2)$ optical transitions observed as MOT population depletion caused by a laser beam of the wavelength 968.9 nm, intensity 1.77 mW cm^{-2}. Inset: levels scheme according to [19,25,26].

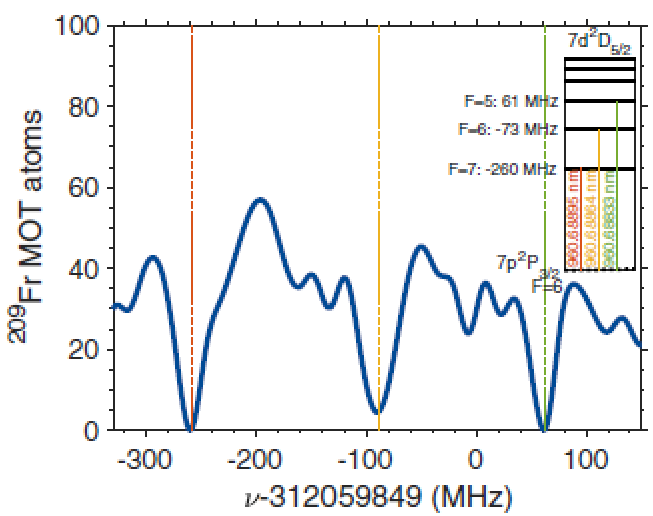


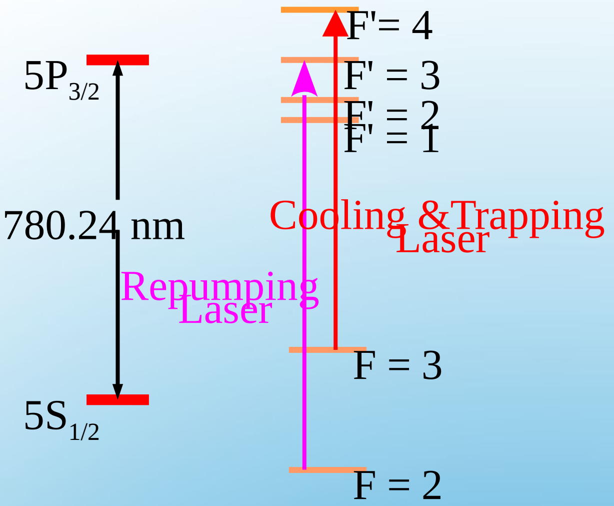
Fig. 4. ^{209}Fr $7p^2P_{3/2}(F = 6) \rightarrow 7d^2D_{5/2}(F' = 7, 6, 5)$ optical transitions observed as MOT population depletion caused by a laser beam of the wavelength 960.7 nm, intensity 2.1 mW cm^{-2}. Inset: levels scheme according to Eq. (1).

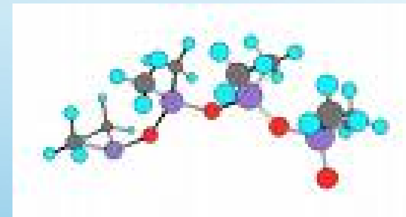
Table 1. $^{209}Fr\,7p^2P_{3/2} \rightarrow 7d^2D_{5/2}$ **Hyperfine Splittings**

Excited Level	Experiment (This Letter)	Theory (Eq. 1)
$F' = 7$	(−259 ± 10) MHz	(−260 ± 15) MHz
$F' = 6$	(−89 ± 10) MHz	(−73 ± 7) MHz
$F' = 5$	(+62 ± 10) MHz	(+61 ± 7) MHz

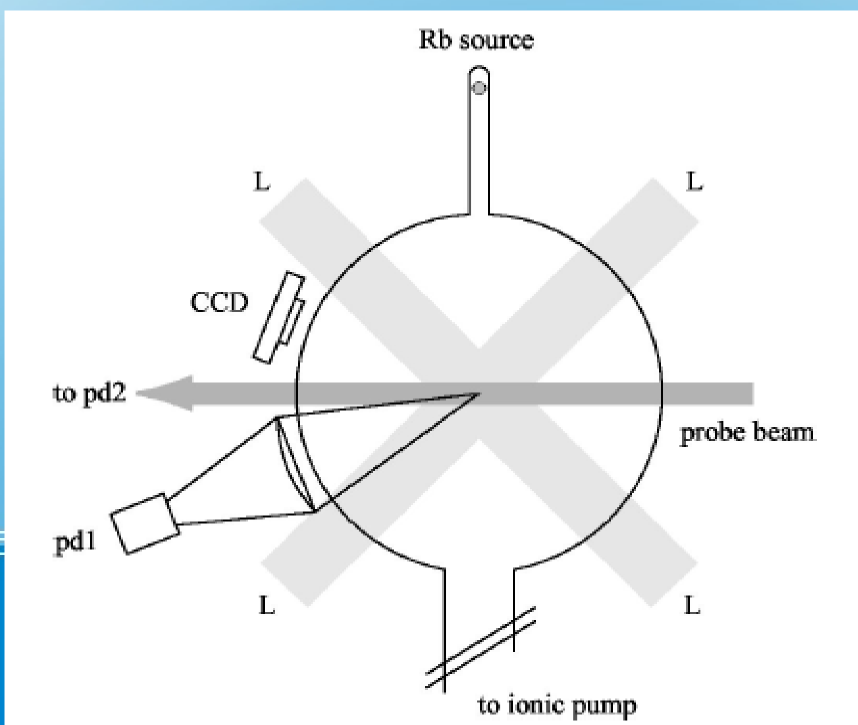
OPTIMIZATION OF TRAPPED ATOM NUMBERS

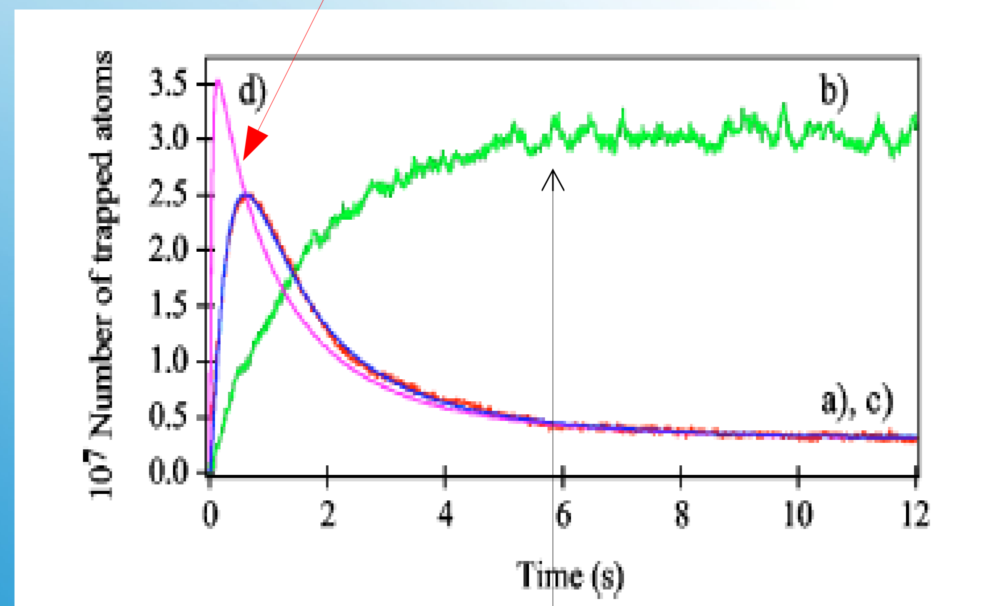
LIAD for MOTs





LIAD MOT loading





"Usual" MOT loading

S.N.Atutov et al. Phys.Rev. A 67, 053401 (2003)

Rb MOT loading from Yttrium

AIP | The Journal of Chemical Physics

Light desorption from an yttrium neutralizer for Rb and Fr magneto-optical trap loading

V. Coppolaro, N. Papi, A. Khanbekyan, C. Marinelli, E. Mariotti, L. Marmugi, L. Moi, L. Corradi, A. Dainelli, H. Arikawa, T. Ishikawa, Y. Sakemi, R. Calabrese, G. Mazzocca, L. Tomassetti, and L. Ricci

Citation: The Journal of Chemical Physics **141**, 134201 (2014); doi: 10.1063/1.4896609
View online: http://dx.doi.org/10.1063/1.4896609
View Table of Contents: http://scitation.aip.org/content/aip/journal/jcp/141/13?ver=pdfcov
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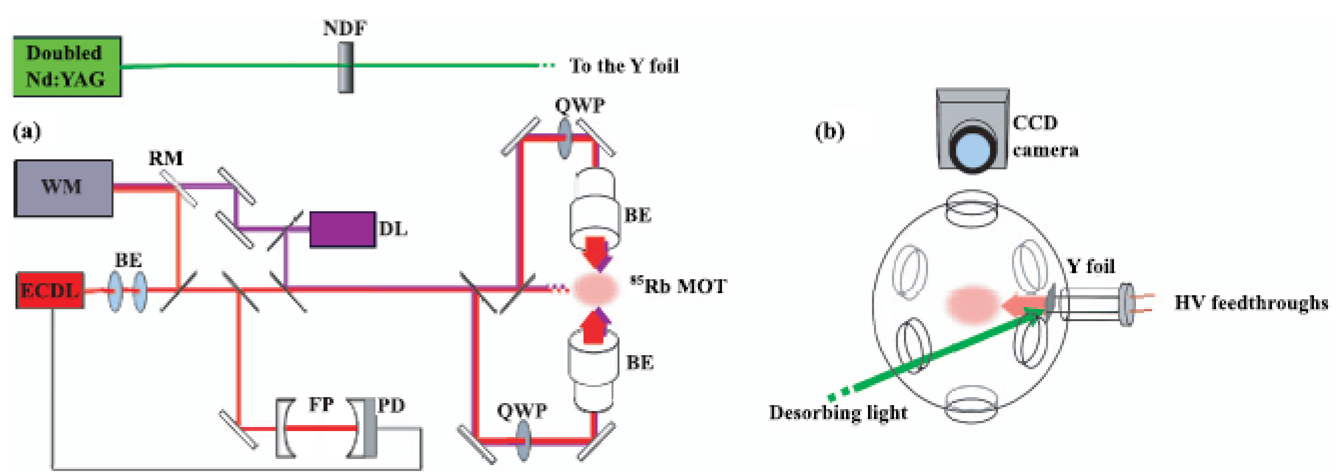


Fr LIAD MOT loading from Yttrium

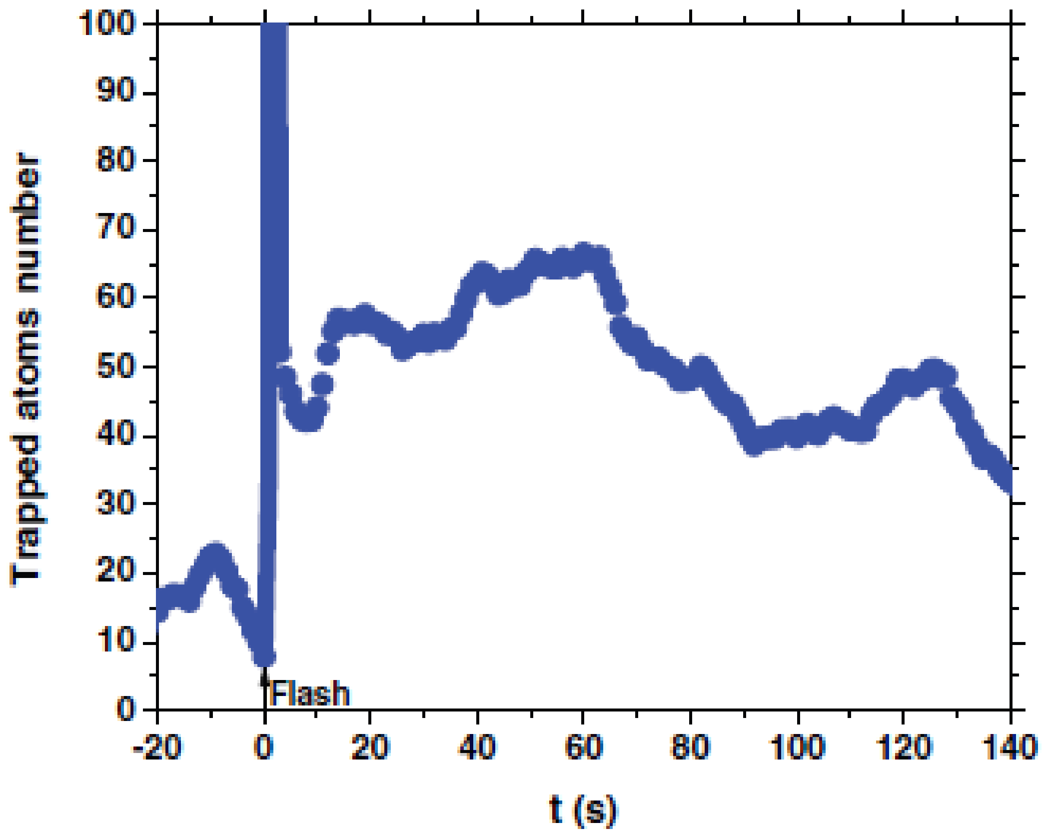


FIG. 8. Application of LIAD to Francium MOT loading.

Fr MOT loading from PDMS

SCIENTIFIC REPORTS

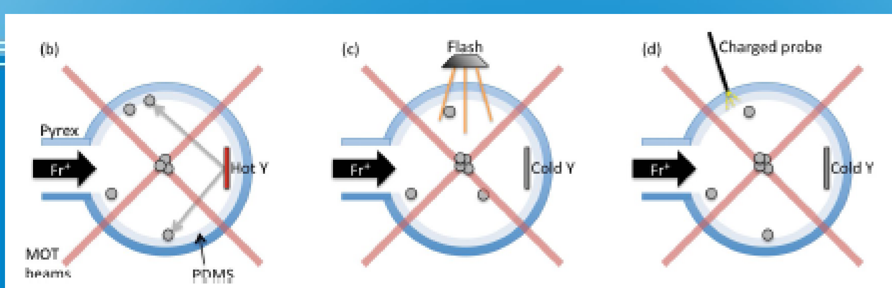
OPEN

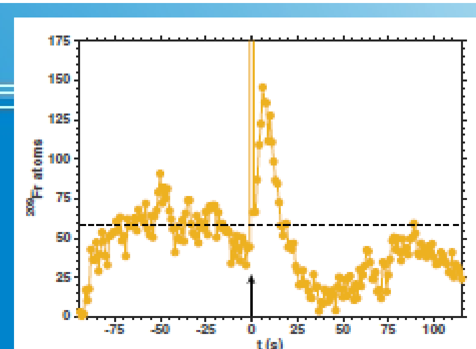
Enhanced Atomic Desorption of 209 and 210 Francium from Organic Coating

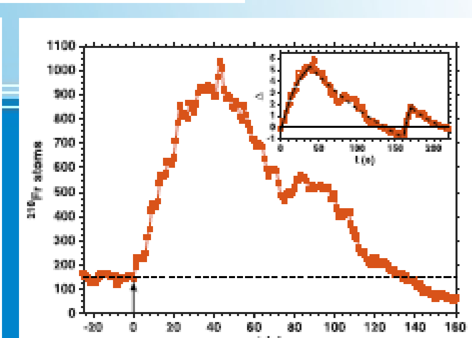
Received: 14 February 2017
Accepted: 12 May 2017
Published online: 23 June 2017

Steinn Agustsson[1], Giovanni Bianchi[1], Roberto Calabrese[2], Lorenzo Corradi[3], Antonio Dainelli[3], Alen Khanbekyan[1,2], Carmela Marinelli[1], Emilio Mariotti[1], Luca Marmugi[4], Leonardo Ricci[5], Leonardo Stiaccini[1], Luca Tomassetti[6] & Andrea Vanella[1]

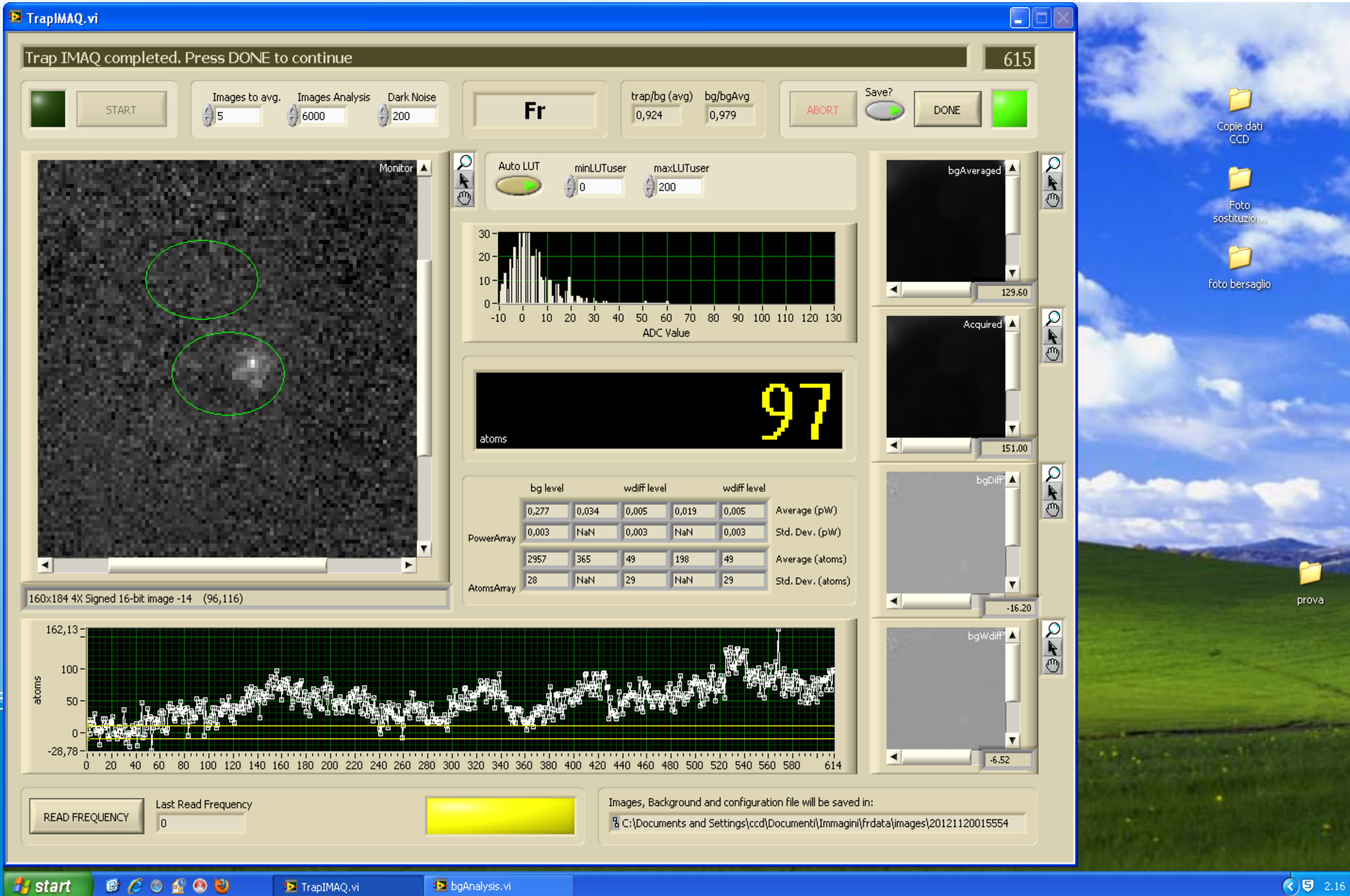
Controlled atomic desorption from organic Poly-DiMethylSiloxane coating is demonstrated for improving the loading efficiency of ^{209,210}Fr magneto-optical traps. A three times increase in the cold atoms population is obtained with contact-less pulsed light-induced desorption, applied to different isotopes, either bosonic or fermionic, of Francium. A six times increase of ^{210}Fr population is obtained with a desorption mechanism based on direct charge transfer from a triboelectric probe to the adatom-organic coating complex. Our findings provide new insight on the microscopic mechanisms of atomic desorption from organic coatings. Our results, obtained at room temperature so as to preserve ideal vacuum conditions, represent concrete alternatives, independent from the atomic species in use, for high-efficiency laser cooling in critical conditions.







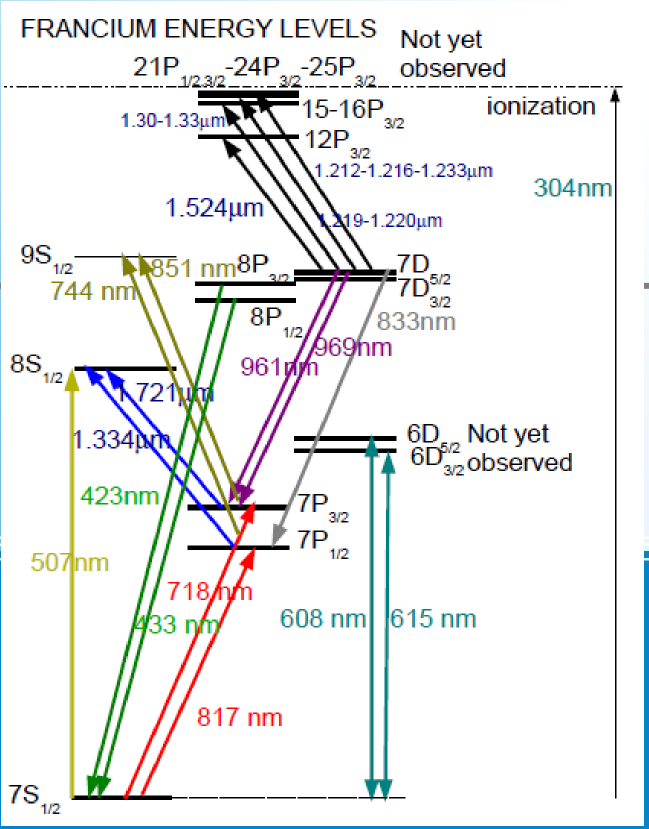
Room temperature neutralizer trap!



PERSPECTIVES

1. New spectroscopic measurements

- ENERGY LEVEL DETERMINATION
- LIFETIMES MEASUREMENTS
- COLLISIONAL STUDIES
- DIMER FORMATION



2. Gamma Ray Laser proposal

Physics Letters B 777 (2018) 281–285

Contents lists available at ScienceDirect

Physics Letters B

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PHYSICS LETTERS B

Coherent gamma photon generation in a Bose–Einstein condensate of ^{135m}Cs

Check for updates

Luca Marmugi [a], Philip M. Walker [b], Ferruccio Renzoni [a,*]

[a] Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, United Kingdom
[b] Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom

2. Gamma Ray Laser proposal

Physics Letters B 777 (2018) 281–285

Contents lists available at ScienceDirect

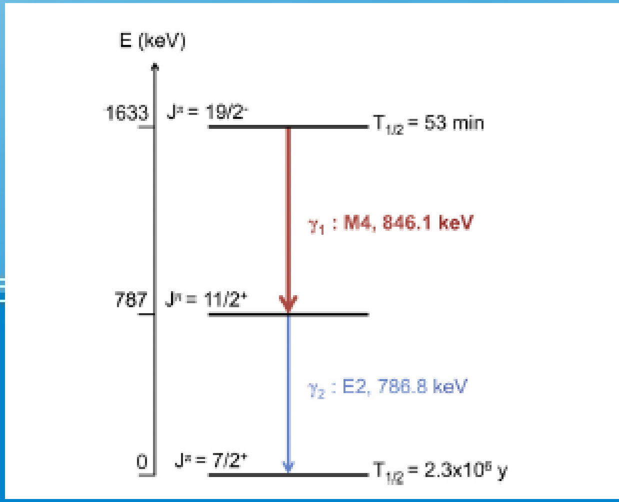
Physics Letters B

www.elsevier.com/locate/physletb

Coherent gamma photon generation in a Bose–Einstein condensate of ^{135m}Cs

Luca Marmugi[a], Philip M. Walker[b], Ferruccio Renzoni[a,*]

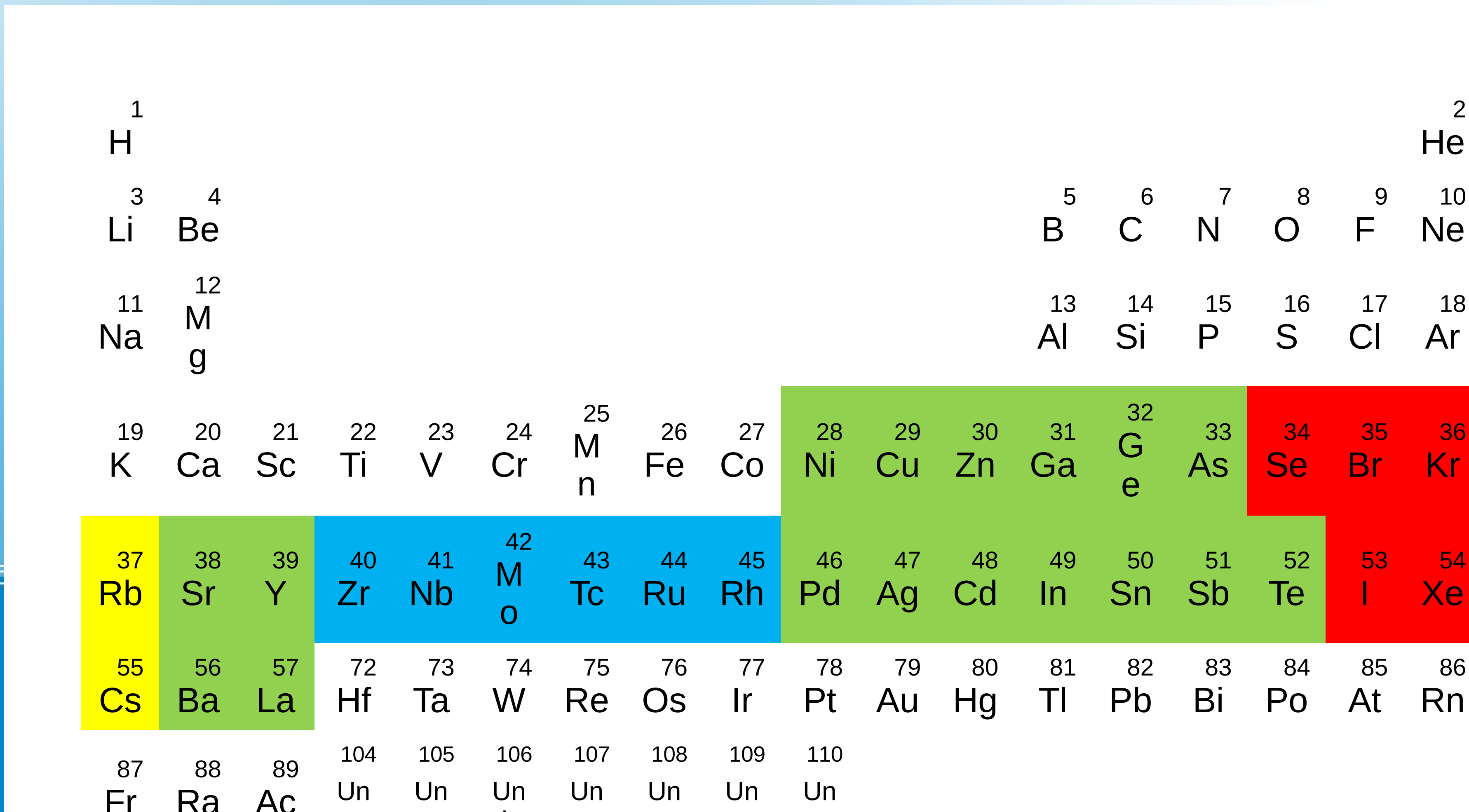
[a] Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, United Kingdom
[b] Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom



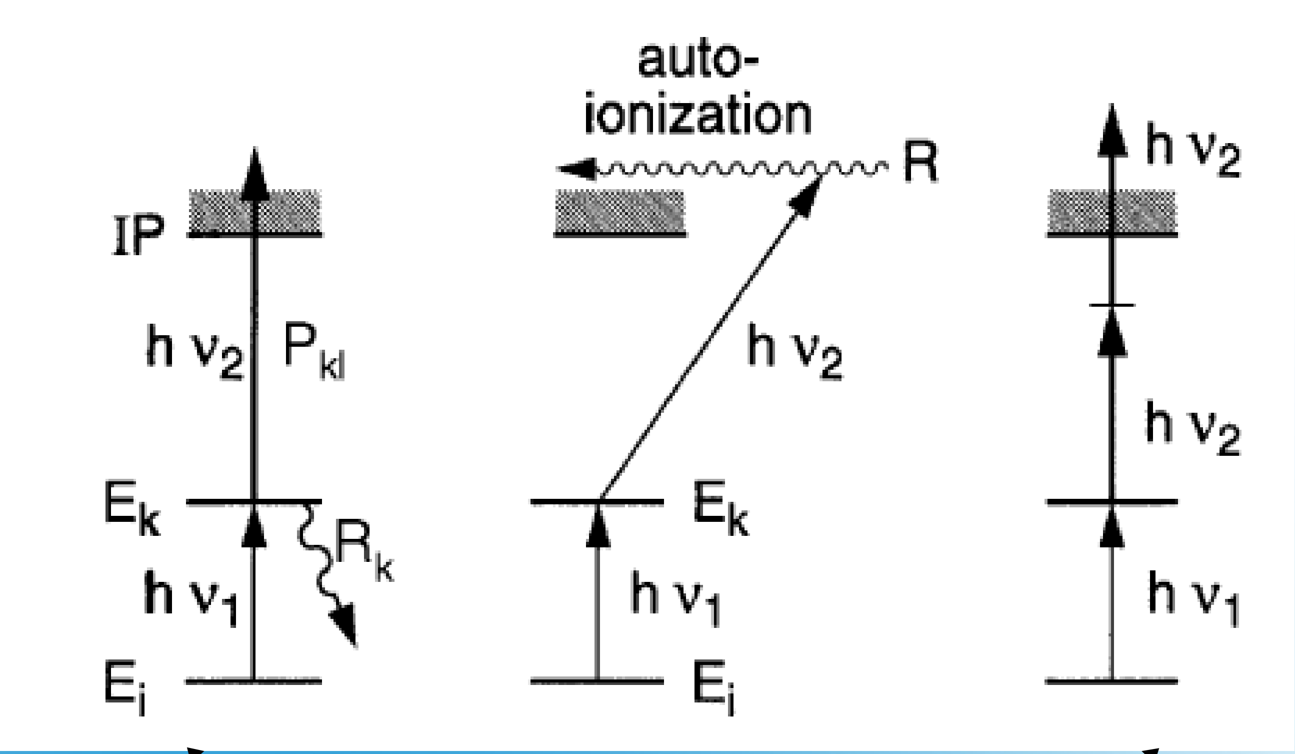
Our results demonstrate that a mechanism of collective decay occurs for a BEC of ^{135m}Cs isomers. The collective nature of the phenomenon is highlighted by the exponential dependence of the number of emitted photons with respect to the initial isomer density. The collective de-excitation relies on the coherence of the condensate being transferred to γ photons, and occurs at densities much lower than those required by the standard Dicke superradiance. The identified mechanism provides a promising route to the generation of coherent γ radiation, as the associated process can be realized with available technology. ^{135m}Cs ion beams can be generated by proton-induced fission of actinides. Afterwards, laser cooling and trapping can proceed as well established for ^{133}Cs and some of its isotopes [14]. The long lifetime of ^{135m}Cs allows for evaporation and creation of a BEC in an optical trap, along the lines of the procedure for stable cesium. As the collisional properties of ultra-cold ^{135m}Cs are not known, it is not possible to give an accurate estimate of the expected size of the BEC, and hence of the intensity of the γ photons burst. However, the present results indicate that exponential photonic generation occurs for a wide range of BEC densities. We therefore expect coherent emission to occur over a broad range of BEC size, thus demonstrating the validity of the proposed approach for coherent gamma-ray generation.

3. Lasers at SPES

- surface ionization mechanism
- laser ionization mechanism
- electron impact ionization mechanism



3. Lasers at SPES

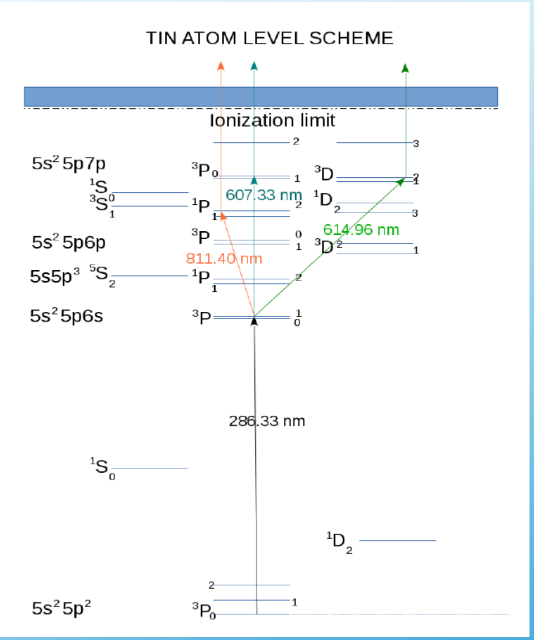


$$M^*(E_k) + h\nu_2 \longrightarrow M^+ + e^- + E_{kin}$$

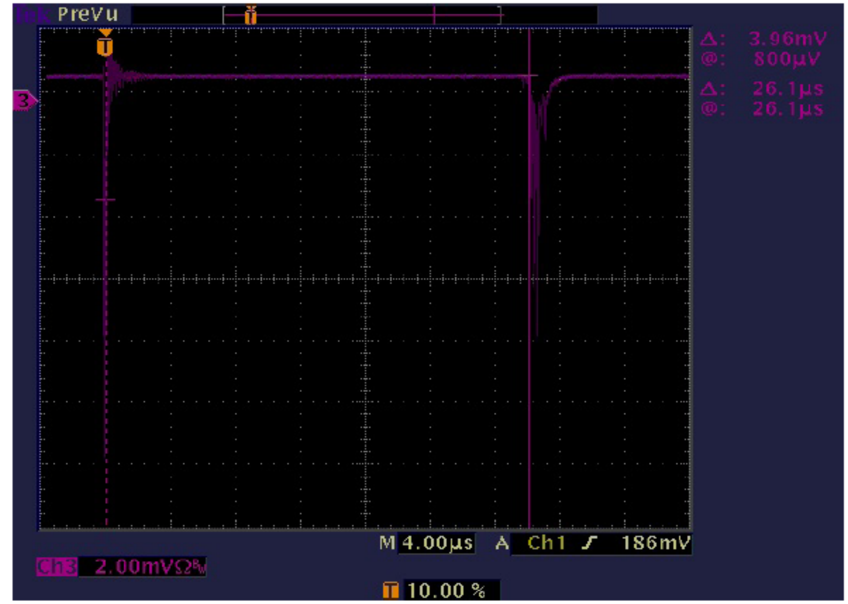
$$M^*(E_k) + 2h\nu_2 \longrightarrow M^+ + e^- + E_{kin}\,(e^-)$$

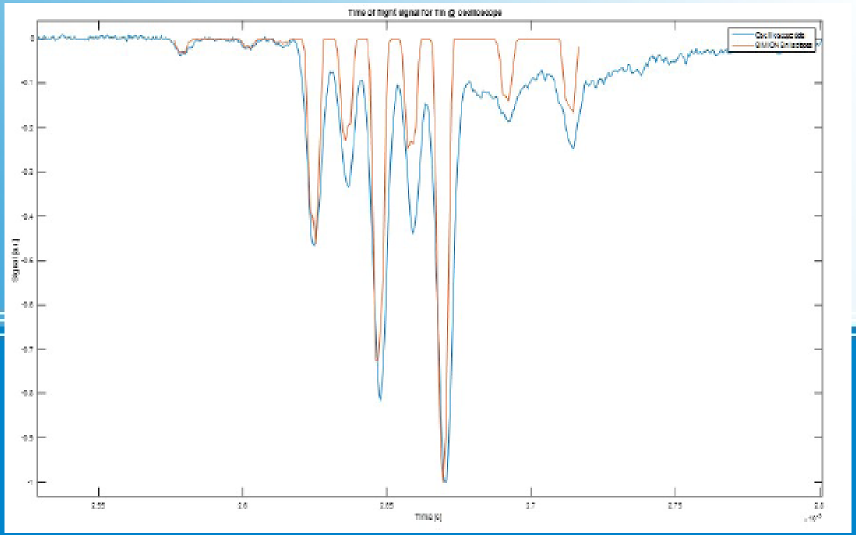
$$M^*(E_k) + h\nu_2 \longrightarrow M^{**} \rightarrow M^+ + e^- + E_{kin}\,(e^-)$$

3. Lasers at SPES



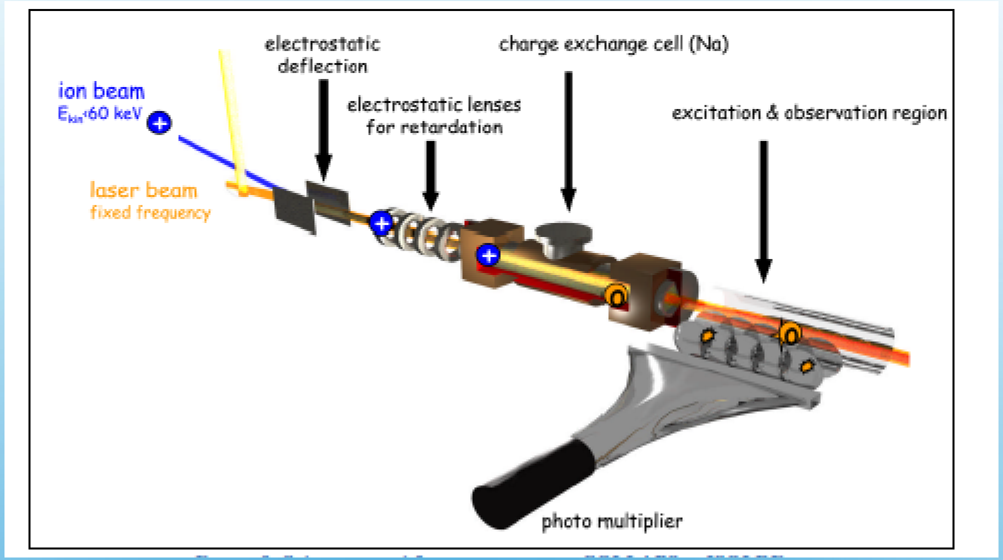
Isotope	Mass	Abundance
^{112}Sn	111.90	0.97
^{114}Sn	113.90	0.66
^{115}Sn	114.90	0.34
^{116}Sn	115.90	14.54
^{117}Sn	116.90	7.68
^{118}Sn	117.90	24.22
^{119}Sn	118.90	8.59
^{120}Sn	119.90	32.58
^{122}Sn	121.90	4.63
^{124}Sn	123.91	5.79

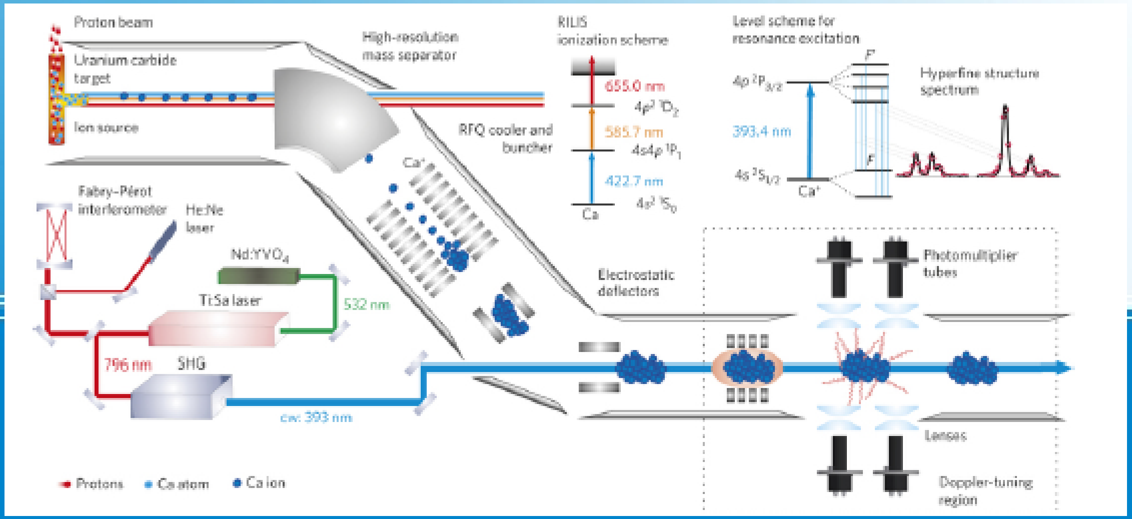




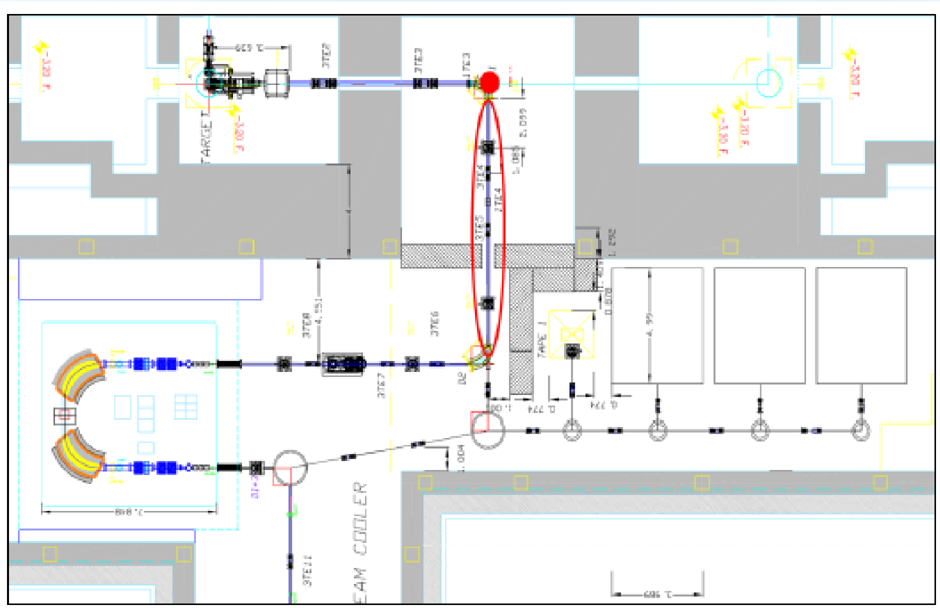
Journal of Instrumentation, 11 C09001 (2016)

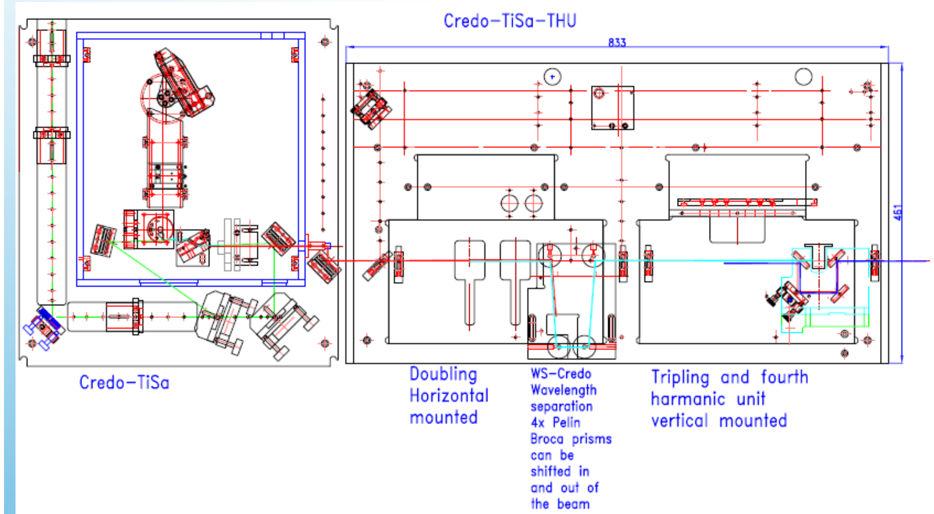
4. Collinear laser spectroscopy proposal

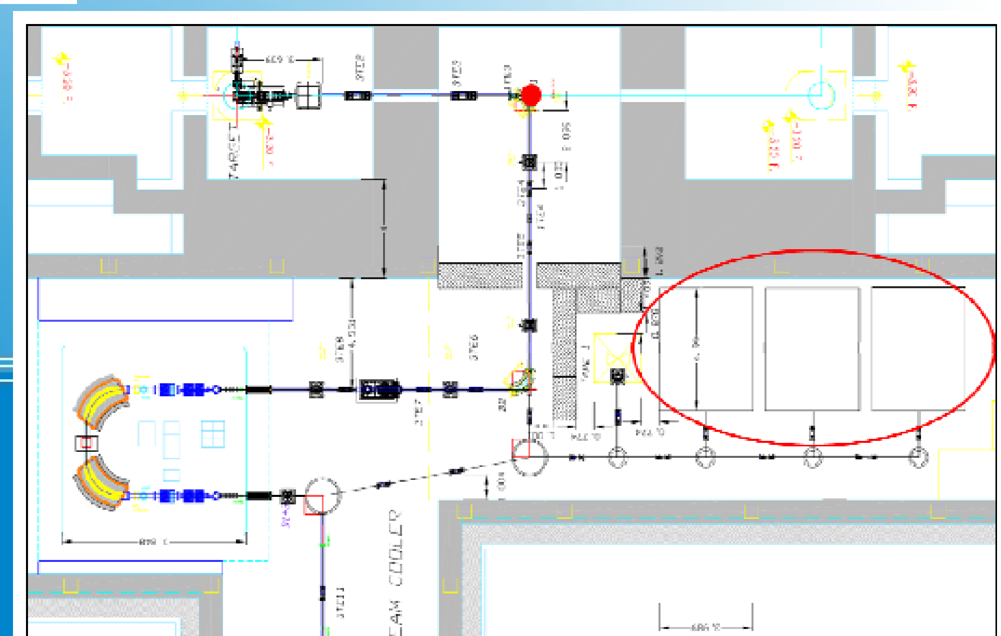




4. Collinear laser spectroscopy proposal







SPES laser group

Thank you very much for the patience!

(SPES lasers after national elections)