PHYSICS FRONTIER CENTER

JOINT QUANTUM INSTITUTE

81 years of Francium

TRIUMF Colloquium

27 February 2020

Luis A. Orozco

www.jqi.umd.edu

UNIVERSITY OF MARYLAND 18 56

NIST

ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ.

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

			Ti = 50	Zr = 90	? = 180.
			V = 51	Nb = 94	Ta = 182.
			Cr = 52	Mo = 96	W = 186.
			Mn = 55	Rh = 104,4	Pt = 197,1.
			Fe = 56	Rn = 104,4	Ir = 198.
			Ni = Co = 59	Pl = 106,6	Os = 199.
H = 1			Cu = 63,4	Ag = 108	Hg = 200.
	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112	
	B = 11	Al = 27,4	? = 68	Ur = 116	Au = 197?
	C = 12	Si = 28	? = 70	Sn = 118	
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?
	O = 16	S = 32	Se = 79,4	Te = 128?	
	F = 19	Cl = 35,5	Br = 80	I = 127	
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204.
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207.
		? = 45	Ce = 92		
		?Er = 56	La = 94		
		?Yt = 60	Di = 95		
		?In = 75,6	Th = 118?		

Д. Менделѣевъ

Tentative System of Elements, Mendeleev 1869

The periodic table of elements

Reihen	Gruppo I. — R^2O	Gruppo II. — RO	Gruppo III. — R^2O^3	Gruppo IV. RH^4 RO^2	Gruppo V. RH^3 R^2O^5	Gruppo VI. RH^2 RO^3	Gruppo VII. RH R^2O^7	Gruppo VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

Mendeleev 1871

Only the atomic weight known.

Moved the elements around to make their chemical properties similar.

Named eka- (ekasilicon, *germanium*; ekaaluminium, *gallium*, ekaboron, *scandium*) and predicted some properties for those elements missing but that should in the table.

People started looking for eka-caesium.

Periodic Table of Elements

based on Mendeleev's Periodic Law

0	I	II	III	IV	V	VI	VII	VIII		
	H 1.01									
He 4.00	Li 6.94	Be 9.01	B 10.8	C 12.0	N 14.0	O 16.0	F 19.0			
Ne 20.2	Na 23.0	Mg 24.3	Al 27.0	Si 28.1	P 31.0	S 32.1	Cl 35.5			
Ar 40.0	K 39.1	Ca 40.1	Sc 45.0	Ti 47.9	V 50.9	Cr 52.0	Mn 54.9	Fe 55.9	Co 58.9	Ni 58.7
	Cu 63.5	Zn 65.4	Ga 69.7	Ge 72.6	As 74.9	Se 79.0	Br 79.9			
Kr 83.8	Rb 85.5	Sr 87.6	Y 88.9	Zr 91.2	Nb 92.9	Mo 95.9	Tc (99)	Ru 101	Rh 103	Pd 106
	Ag 108	Cd 112	In 115	Sn 119	Sb 122	Te 128	I 127			
Xe 131	Ce 133	Ba 137	La 139	Hf 179	Ta 181	W 184	Re 180	Os 194	Ir 192	Pt 195
	Au 197	Hg 201	Ti 204	Pb 207	Bi 209	Po (210)	At (210)			
Rn (222)	Fr (223)	Ra (226)	Ac (227)	Th 232	Pa (231)	U 238				

Dobereiner's triads

Known to Mendeleev

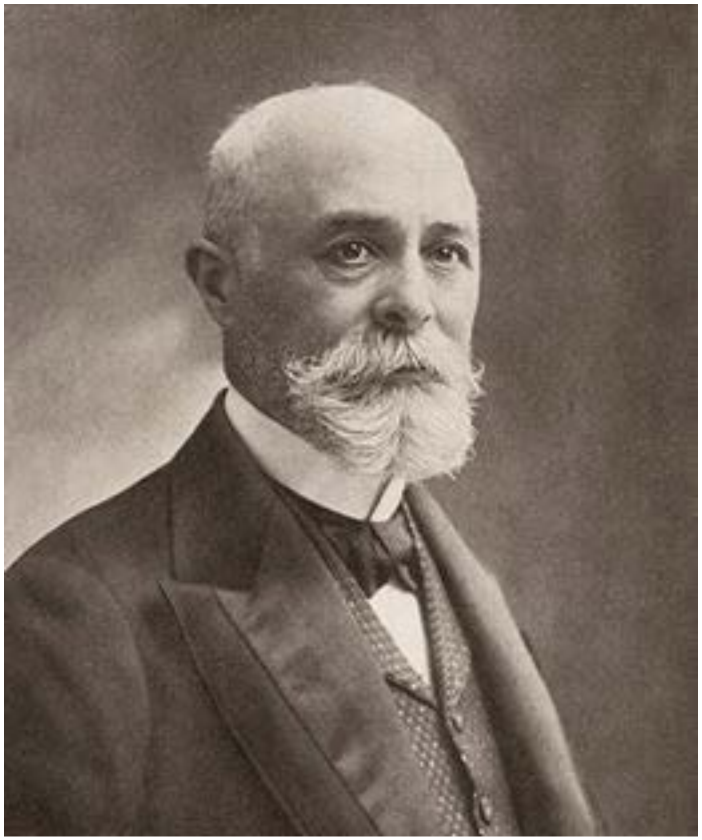
Lanthanide series

Actinide series

Known to Ancients

Radioactivity: Something probabilistic in nature

February 27 1896

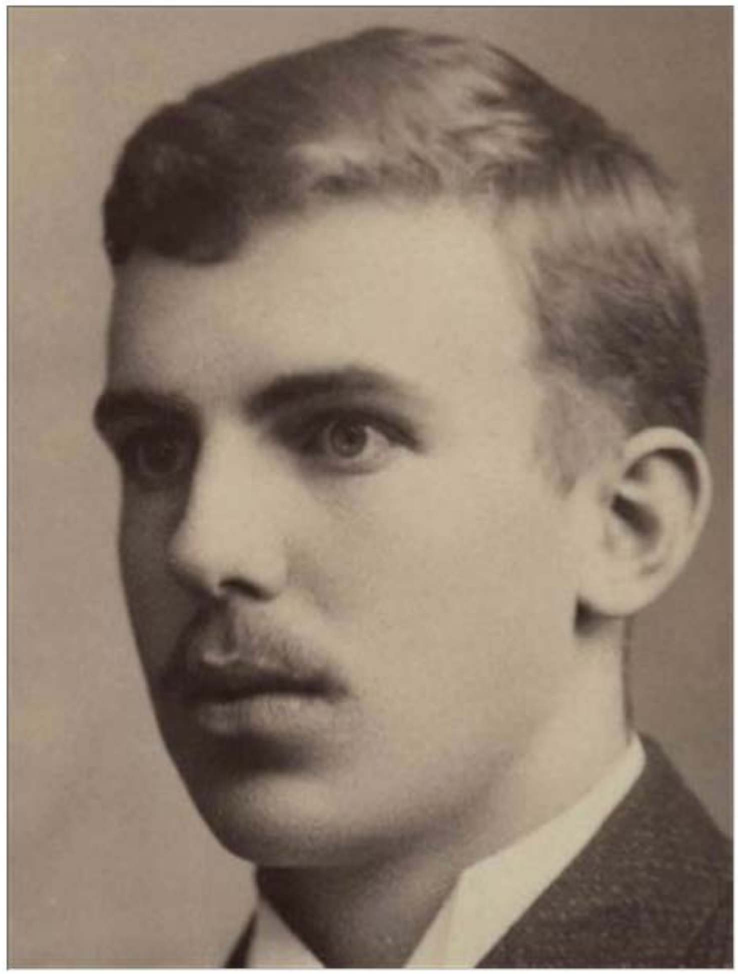


Henry Becquerel

Pierre Curie

Marie Curie

Rutherford discovers there are two kinds of rays in radioactivity (α, β)



Ernest Rutherford

Rutherford determines ~1910

- Alpha particle is a helium nucleus
- Beta particle is an electron

The researchers focus on:

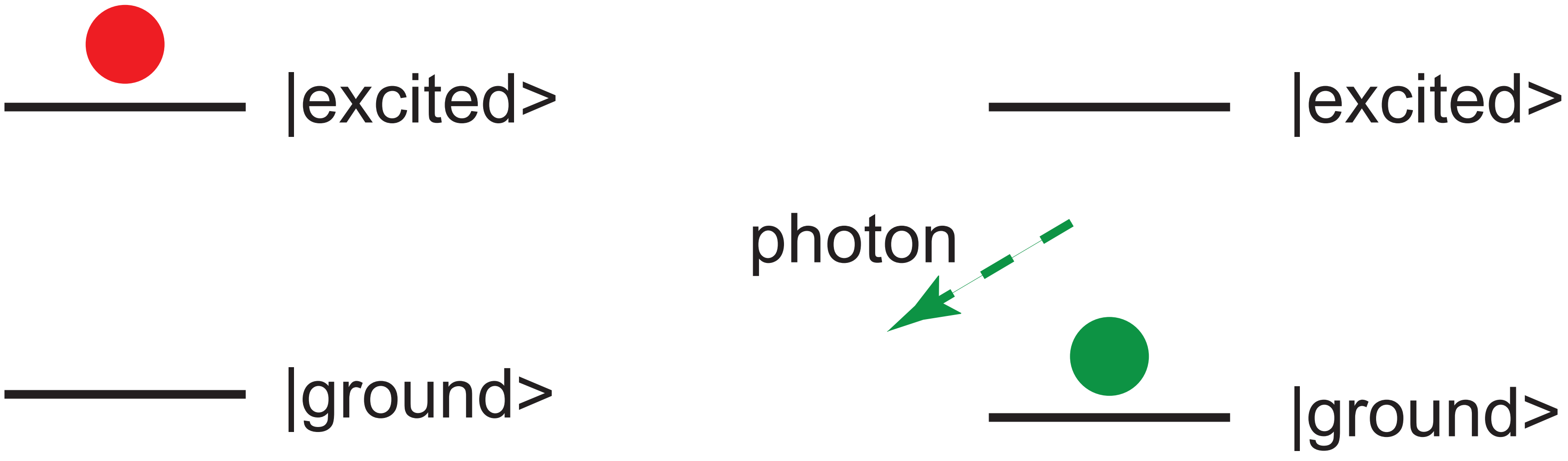
- How quickly an element decays?
- How it decays (alpha or beta)?

1928 George Gamow explains alpha decay as a tunneling process

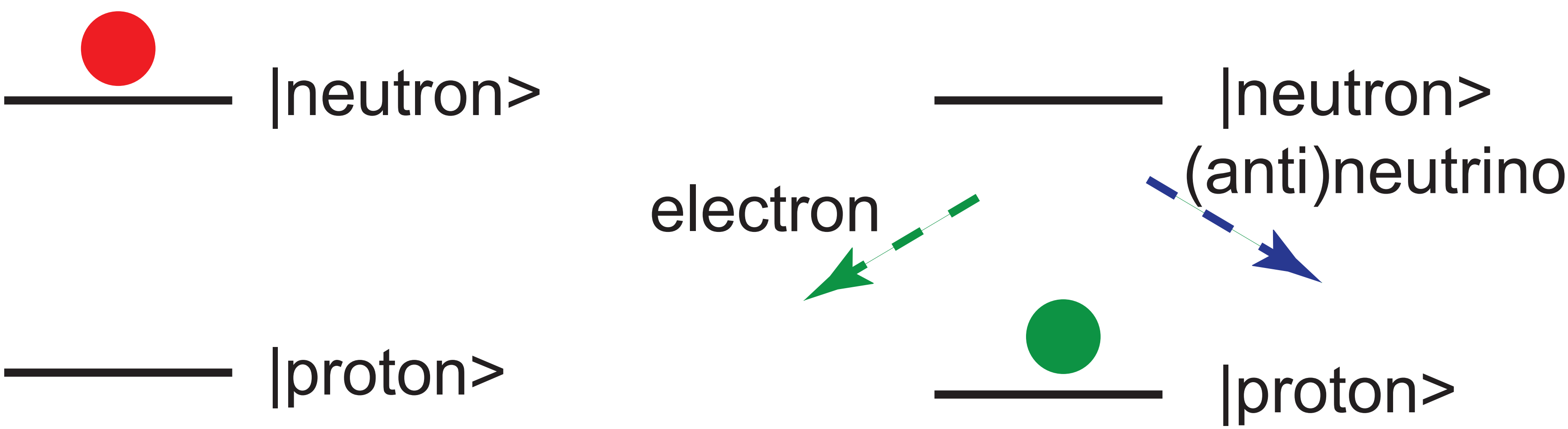
Beta decay theory by Enrico Fermi in 1934, it is just spontaneous emission.

Enrico Fermi

Spontaneous emission



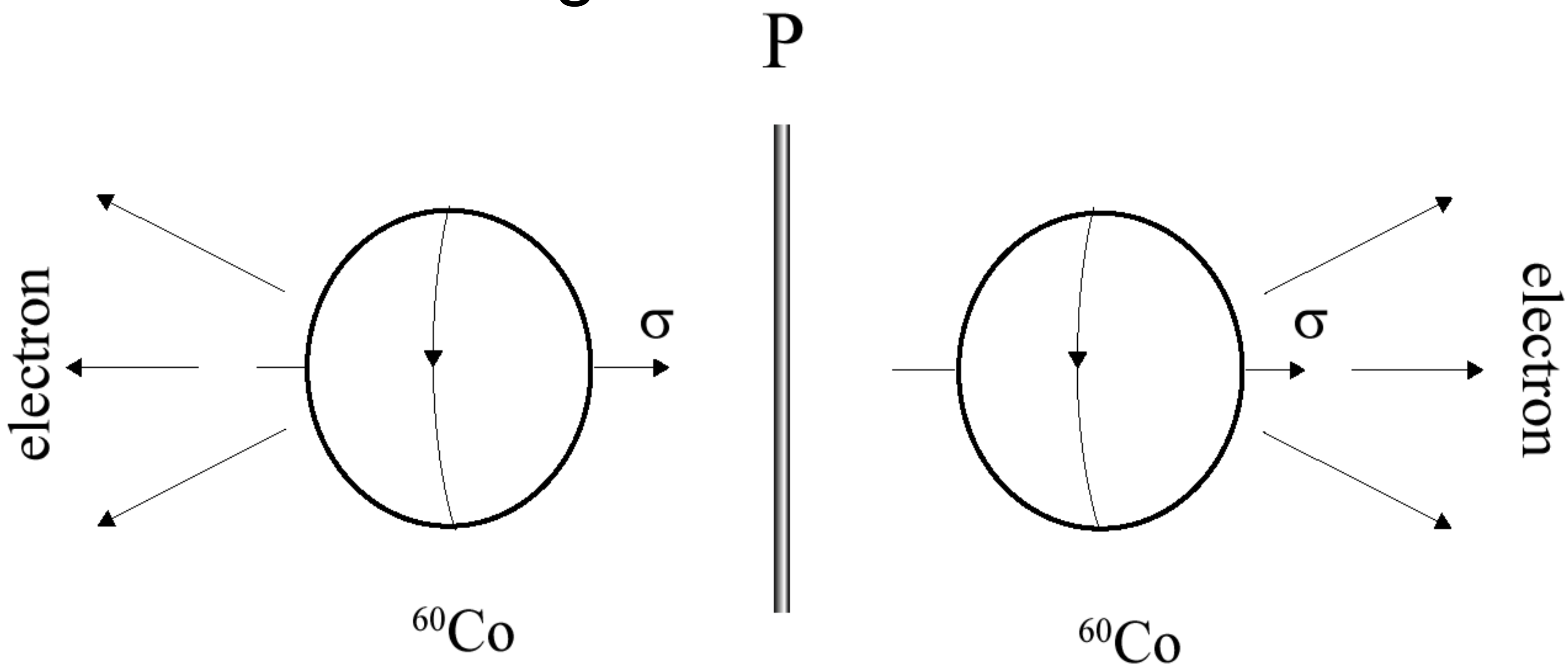
Beta decay



Nature does not have Parity symmetry (1956), C. N. Yang and T. D Lee.

Change x to –x; y to –y and z to –z

From right hand to left hand



The NBS-Columbia Experiment

- The weak interaction changes the flavor of a particle: a down quark becomes an up quark, converting a neutron into a proton.

- The inverse process a proton becomes a neutron is the beginning of the solar cycle.

- The weak interaction violates parity and charge-parity (1964).

- Neutrinos have mass and oscillate (~1990-2010).

- …

The discovery of Francium

First report of eka-caesium

D. K. Dobroserdov, a soviet chemist, claims to have found eka-caesium. In 1925 he observed weak radioactivity in a sample of K and incorrectly concluded that eka-caesium was contaminating the sample (it came from ^{40}K)
He published his predictions of the properties of eka-caesium, which he named Russium after his home country. He abandoned any pursue of element 87.

In 1926 Gerald J. F. Druce and Frederick H. Loring (UK) analyzed X ray spectra of manganese sulfate and presumed to see eka-caesium, they proposed alkalinium.

Time Magazine February 1930

Science: Alabamium

Monday, Feb. 17, 1930

▸ **Subscriber content preview. or Log-In**

+ Share

Of the 92 elements which the late great Russian Dmitri Ivanovitch Mendelèeff (1834-1907) predicates with his Periodic Law, 16 have been discovered since 1894.* Two remain to be isolated—eka-iodine and eka-cesium.† Last week Dr. Fred Allison and Edgar Jackson Murphy of Alabama Polytechnic Institute at Auburn, Ala., reported that they had "evidence of considerable weight for the presence" of eka-cesium in certain salts they had reduced from lepidolite, a form of mica, and pollucite, a mineral consisting chiefly of cesium, aluminum and silicon. When they break down their salts they will get a...

(They wanted to call it Virginium). Report retracted later.

Horia Hulubei and Yvette Cauchois analyzed pollucite (the mineral that was analyzed by Fred Allison of Virginum) in 1936 using X ray spectra and they presumed they were from element 87, They announced it and proposed Moldavium. By 1937 there was criticism of their work but they were supported by Jean B. Perrin who sided with them, but later changed his mind.

Marguerite Perey (1909-1975)

- Born in Villemomble, east of Paris, youngest of 5 children.
- She studied at Lycée Victor Duruy.
- She wanted to study medicine, but the dead of her father made her look for something more immediate.
- Studied in a vocational college chemistry laboratory technician.
- The Curies often hired the top student from the school as an assistant, and Perey at 19 was called in for an interview.

Lycée Victor Duruy 7th Arr. Paris, for girls opened 1912

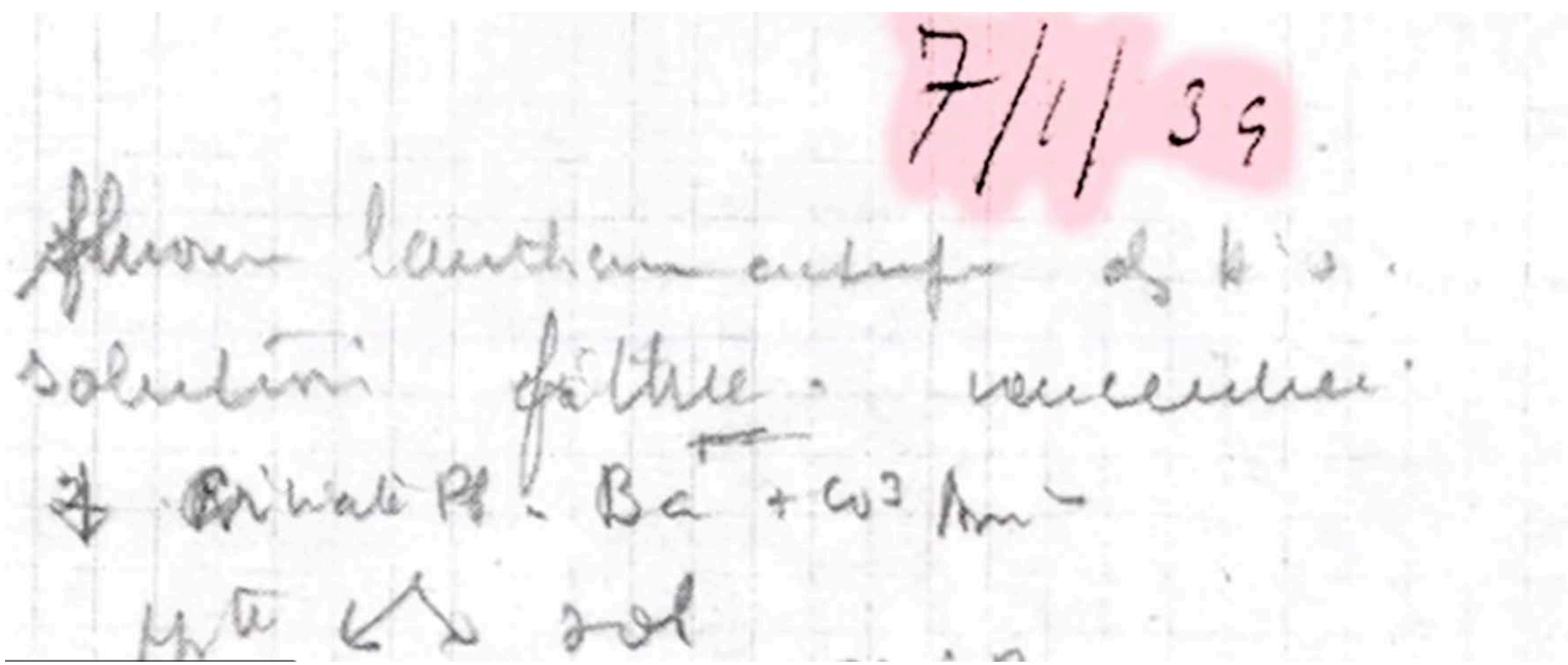
Her first impression of Marie Curie in 1924. "Without a sound, someone entered like a shadow. It was a woman dressed entirely in black. She had gray hair, taken up in a bun, and wore thick glasses. She conveyed an impression of extreme frailty and paleness." A secretary, Perey thought — then realized she was in the presence of Curie herself.

"I left this dark house, persuaded that it was for the first and last time. Everything had seemed melancholy and somber, and I was relieved to think that I would undoubtedly not return there."

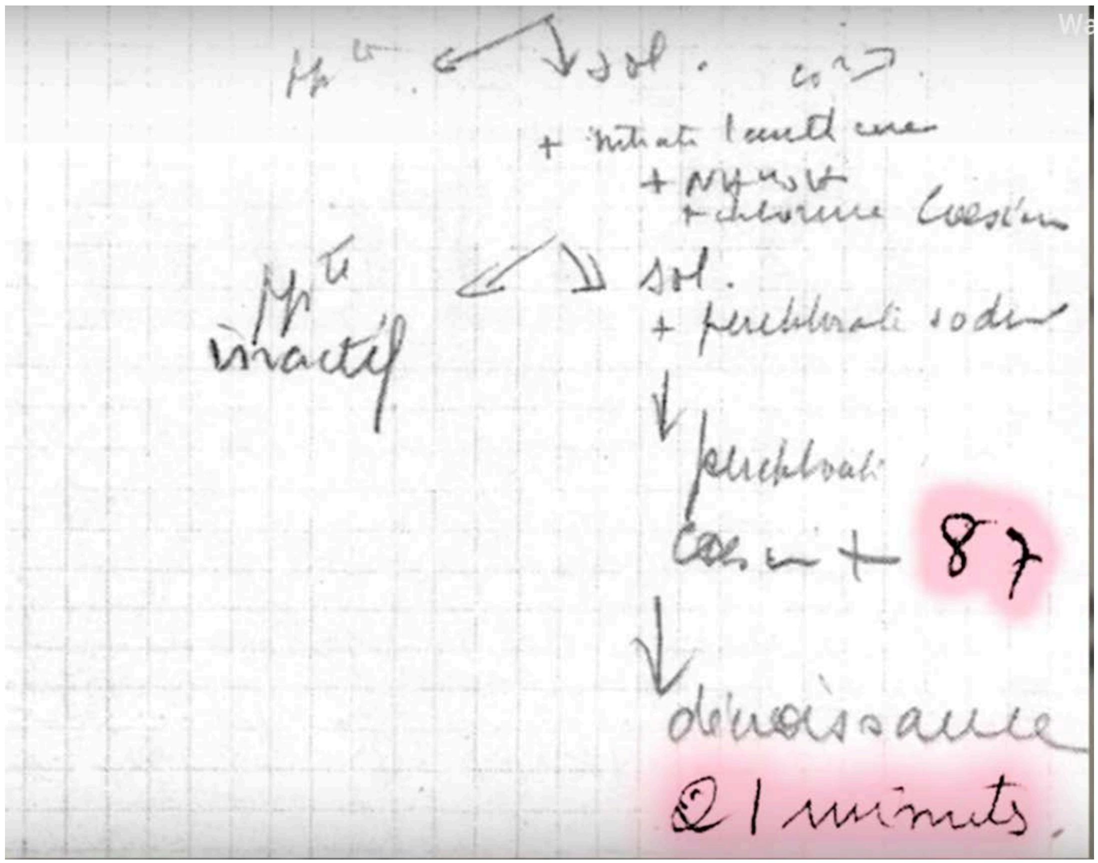
In the garden of the Institut du Radium (1930)

At the Institut du Radium

- Purified a mineral (about ten tons) in about ten years containing actinium (a few milligrams).
- She discovered that the actinium had two decays after she finished the purification, one at 220 KeV corresponding to actinium and the other at 80 KeV of the daughter with half-life of 21 minutes.



- Saw that the activity of the daughter behaved like an alkali as it precipitated with some cesium salts.
- She was doing nuclear chemistry of the highest quality.



Discovery of Francium as a product of alpha decay of actinium in 1939 (Marguerite Perey)

$$^{227}_{89}\mathrm{Ac} \longrightarrow {}^{223}_{87}\mathrm{Fr} + {}^{4}_{2}\alpha$$

Eka-caesium
(Mendeleeff)

Marguerite Perey, Institut du Radium, Paris~1939

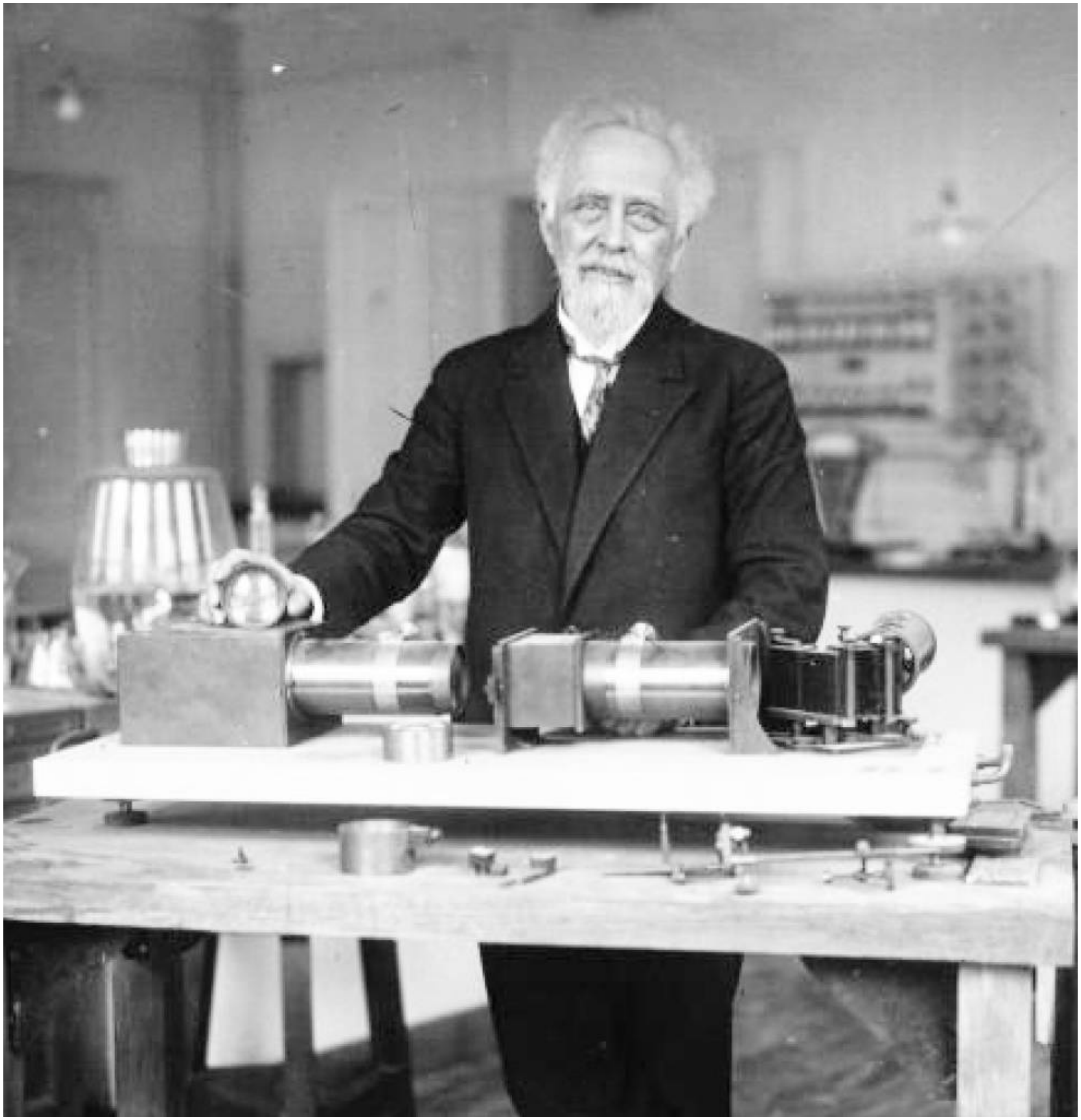
Comptes rendus a L'Academie de Sciences, **208**, 87 (1939)
Séance du 9 Janvier 1939

RADIOACTIVITÉ. — *Sur un élément 87, dérivé de l'actinium.* Note de M[lle] MARGUERITE PEREY, présentée par M. Jean Perrin.

Afin de connaître avec précision l'évolution de l'activité du rayonnement β émis par l'actinium privé de ses dérivés, nous en avons suivi l'accroissement, en nous efforçant de mesurer le plus tôt possible après la dernière purification l'activité β propre à l'actinium, avant que celle de ses successeurs intervienne.

…

Nous sommes donc amenée à penser que cet élément *radioactif naturel*, de période 21 minutes, a le numéro atomique 87 et dérive, par rayonnement α, de l'actinium; soit que l'actinium possède un faible embranchement α, ou qu'il soit un mélange de deux isotopes se désintégrant l'un par rayonnement β, l'autre par rayonnement α.



Jean B. Perrin, founding father of CNRS

- She was given a fellowship to study her PhD at La Sorbonne, which she finished in 1946.
- Professor at Strasbourg, head of Nuclear Chemistry (1949).
- First woman elected as a corresponding member of the French Academy of Sciences (1962).

Veronique Greenwood, “My Great-Great-Aunt Discovered Francium. and It Killed Her.” New York Times Magazine Dec. 3, 2014; photographs provided by Jean Trouchaud.

Marguerite Perey in her office in Strasbourg

The origin of the name

- 1939 Perey proposes Actinium K
- 1946 Perey proposes Catium (Objected by Irène Joliot Curie)
- 1949 Francium (Fa later changed to Fr) making the second element named for the country (Gallium).

The entrance to atomic physics

HERMAN YAGODA
New York University,
Washington Square East,
May 19, 1932.

The Ultimate Lines of Element 87

TABLE II. *Red lines of neutral ekacaesium.*

N_a	λ_a	N_b	λ_b	λ_a/λ_b
$1^2S-2^2P_2$: $\lambda_a/\lambda_b=0.010860N_a+2.0001$				
37	7800.30	29	3247.548	2.40190
55	8521.15	47	3280.67	2.59738
87	(7150)	79	2427.96	(2.9449)
$1^2S-2^2P_1$: $\lambda_a/\lambda_b=0.012014N_a+1.9830$				
Rb	7947.63	Cu	3273.964	2.42753
Cs	8943.6	Ag	3382.89	2.64378
87	(8104)	Au	2675.95	(3.0282)

H. Yagoda, Physical Review 40, 1017 (1932)

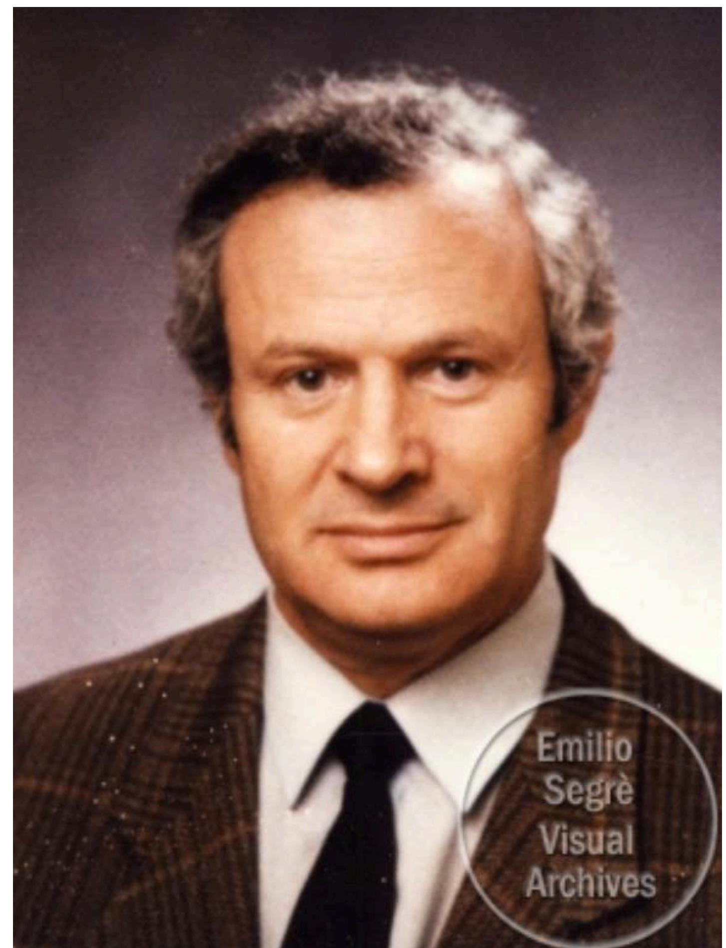
C. R. Acad. Sc. Paris, t. 286 (16 mai 1978) Série B — 253

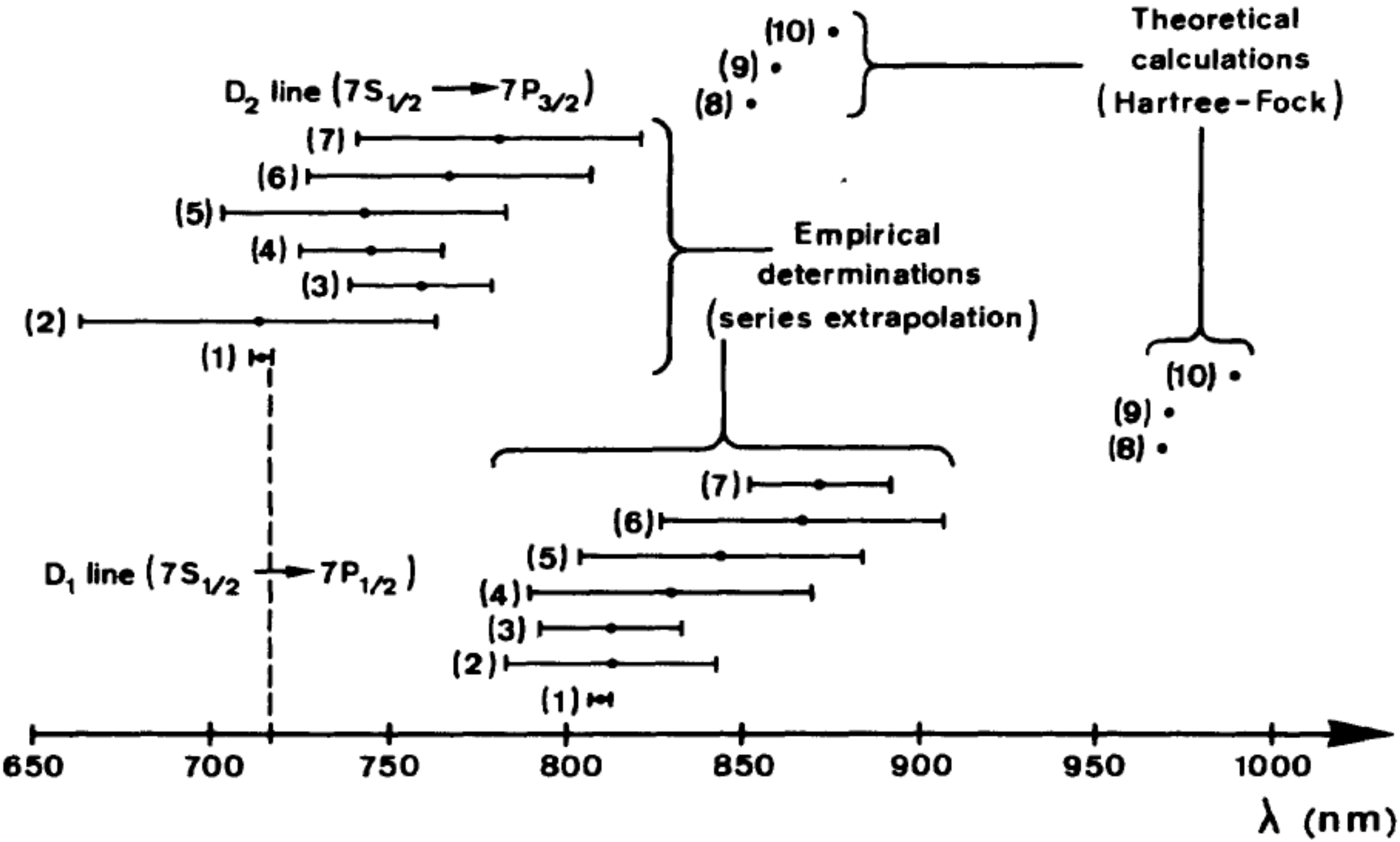
SPECTROSCOPIE ATOMIQUE. — *Première mise en évidence d'une transition optique dans l'atome de francium.* Note (*) de Sylvain Liberman, Jacques Pinard, Hong Tuan Duong, Patrick Juncar, Jean-Louis Vialle, Pierre Jacquinot, Membre de l'Académie, Gerhard Huber, François Touchard, Stephan Büttgenbac' Annie Pesnelle, Catherine Thibault, Robert Klapisch et Collaboration ISOLDE.

Sylvain Liberman
(1934-1988)

Found the D2 line of Fr (718 nm), working at CERN.

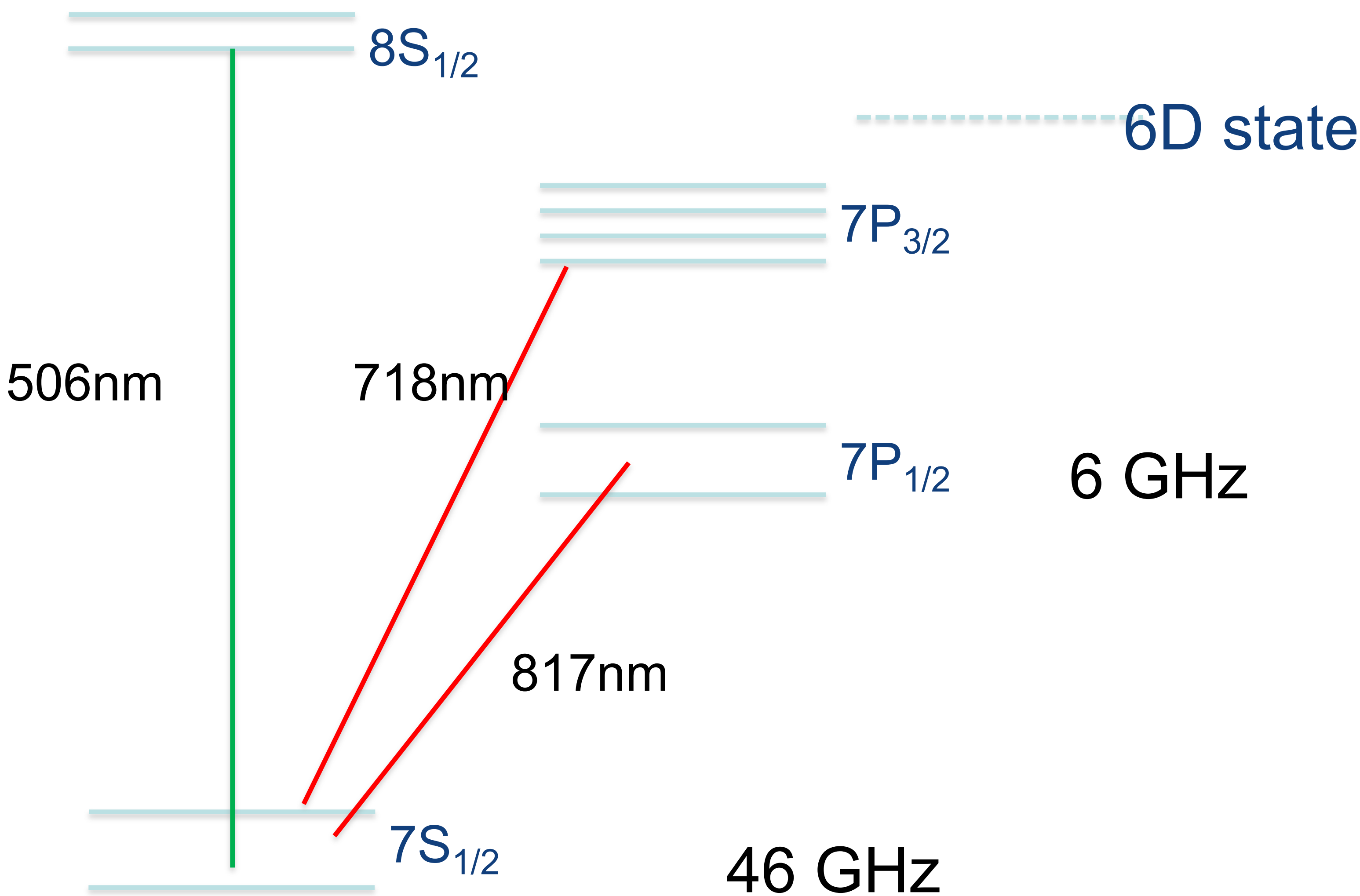
Try to find a Euro coin between Paris and Marseille





A highly sensitive method of detection coupled with a laser atomic beam experiment using on-line-produced Fr isotopes, has permitted finding and measuring the first optical resonance line of this element and its wavelength: $\lambda = 717.97 \pm 0.01$ nm. A high-resolution optical study has been undertaken, which has led to the determination of the hyperfine structure and isotope shifts for isotopes of mass number 208 to 213.

Francium Atomic Energy Levels

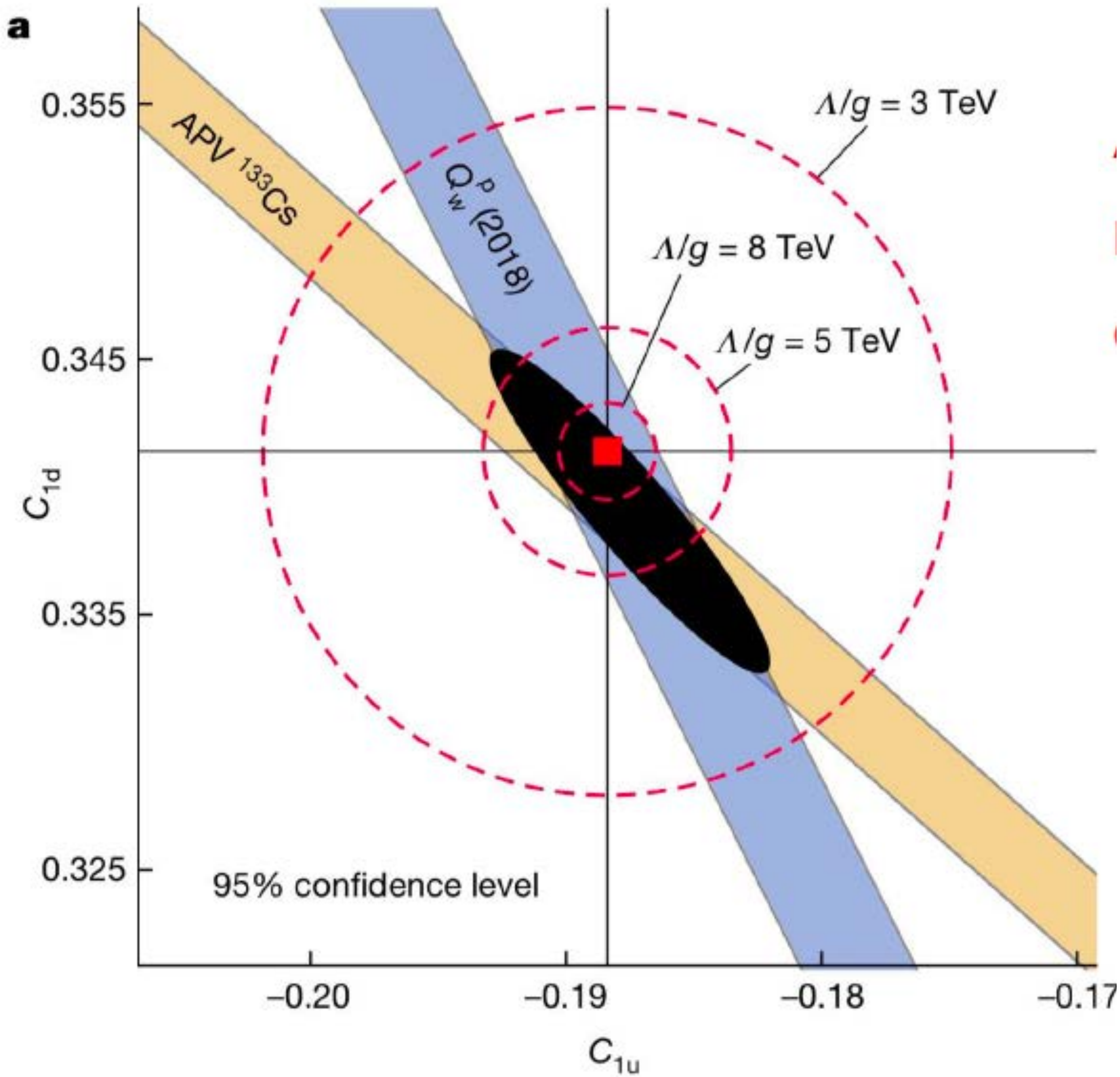


Francium at Stony Brook

Measure Atomic Parity non Conservattion and compare to predictions of the SM and study if the weak interaction gets affected by the presence of lots of nucleons.

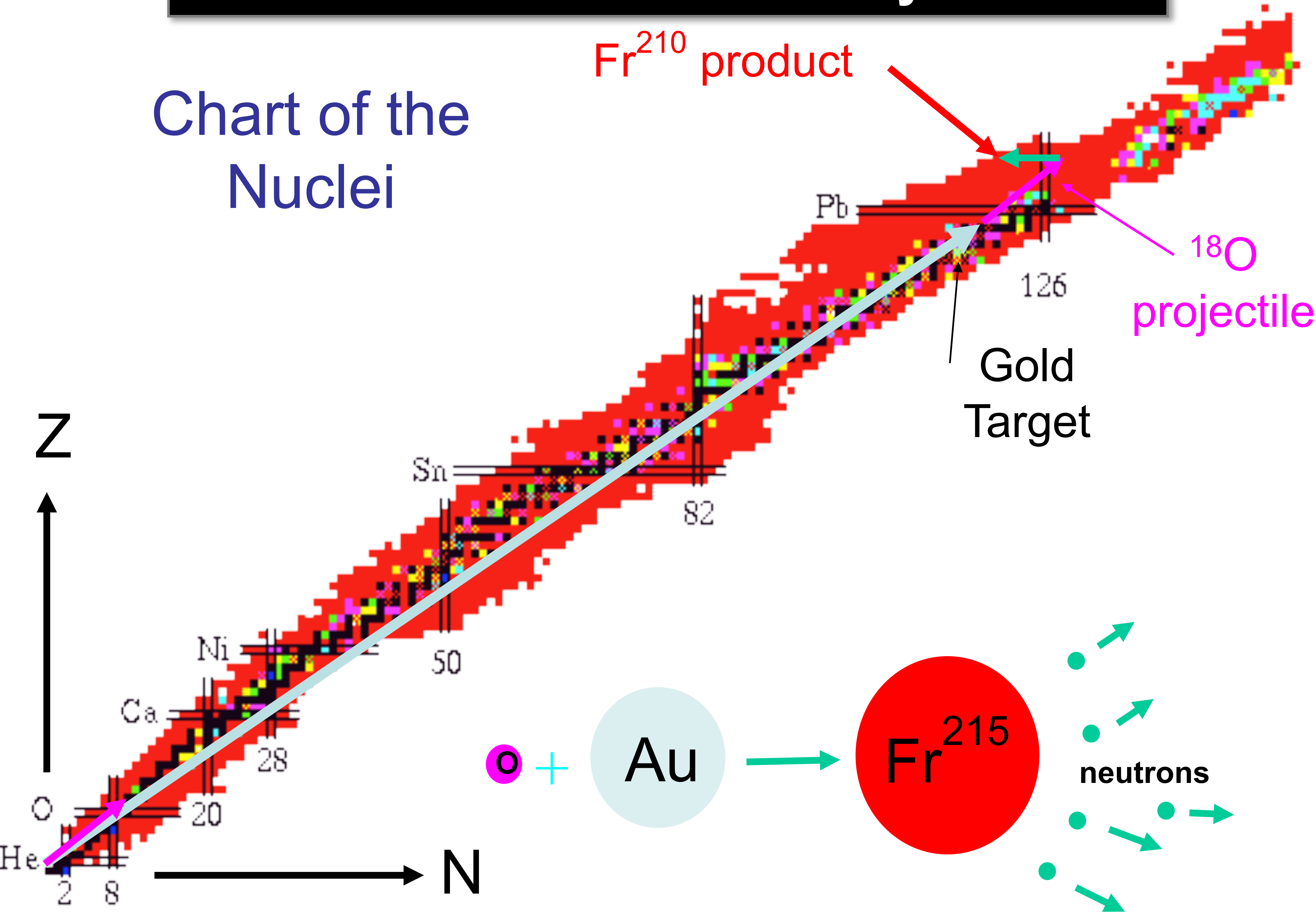
Use a heavy atom as the measurements scale faster than Z^3 and $Z^{8/3}$

Weak PV electron-quark couplings

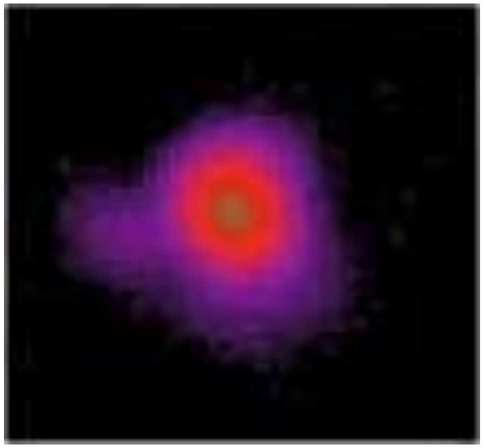


Q_{weak} 2018

How did we make Fr at Stony Brook ?



A Brief History of Francium at Stony Brook with Gene D. Sprouse

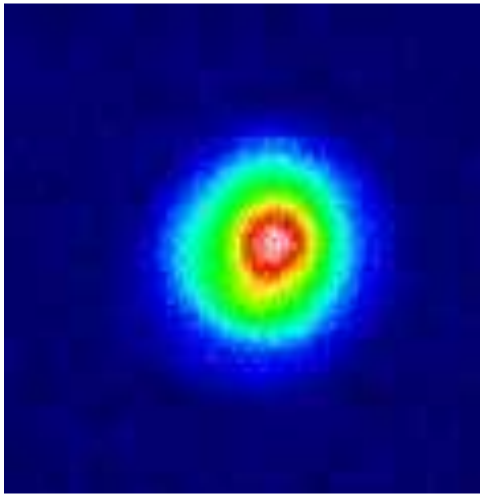


2,000 atoms
Fr MOT

1991-94: Construction of 1st production and trapping apparatus.

1995: Produced and Trapped Francium in a MOT.

1996-2000: Laser spectroscopy of Francium.



250,000 atoms
Fr MOT

2000-2002: High efficiency trap.

2003: Spectroscopy.

2004: Lifetime of 8S level.

2007: Magnetic moment ^{210}Fr .

PHYSICAL REVIEW A, VOLUME 62, 052507

Energies and hyperfine splittings of the 7D levels of atomic francium

J. M. Grossman,* R. P. Fliller III, T. E. Mehlstäubler,† L. A. Orozco, M. R. Pearson, G. D. Sprouse, and W. Z. Zhao‡
Department of Physics and Astronomy, State University of New York, Stony Brook, New York 11794-3800
(Received 5 May 2000; published 12 October 2000)

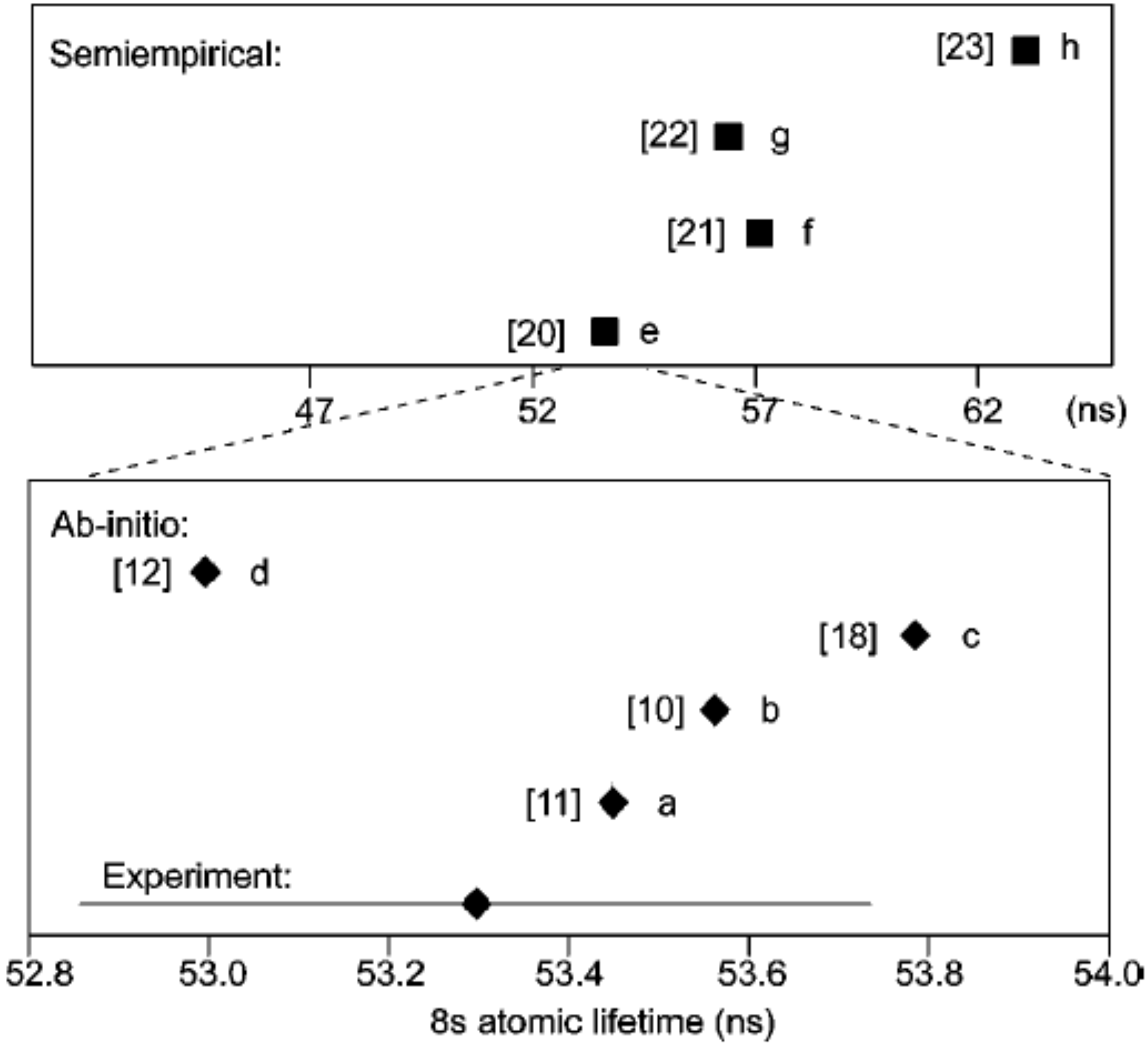
TABLE IV. Comparison of measured and predicted center-of-gravity energy difference to ground state

Source	$E(7D_{3/2})$ (cm^{-1})	$E(7D_{5/2})$ (cm^{-1})
This work	**24 244.831(4)**	**24 333.298(4)**
Ref. [28] (MBPT)	24 235(120)	24 325(120)
Ref. [3] (MBPT)	24186	24275
Ref. [27] (MBPT)	24253	24343
Ref. [29] (second order QDF)	24 244.03(3)	24 332.93(3)
Second-order QDF, using δ from [13]	24 244.070	24 332.766
Third-order QDF, using $E(nD_J)$ from [13]	24 244.303	24 334.211

Theory from 20% (1978) to about $1/10^5$ (2000).

PHYSICAL REVIEW A **71**, 062504 (2005)

Lifetime measurement of the 8*s* level in francium



Uncertainty of 0.8 %

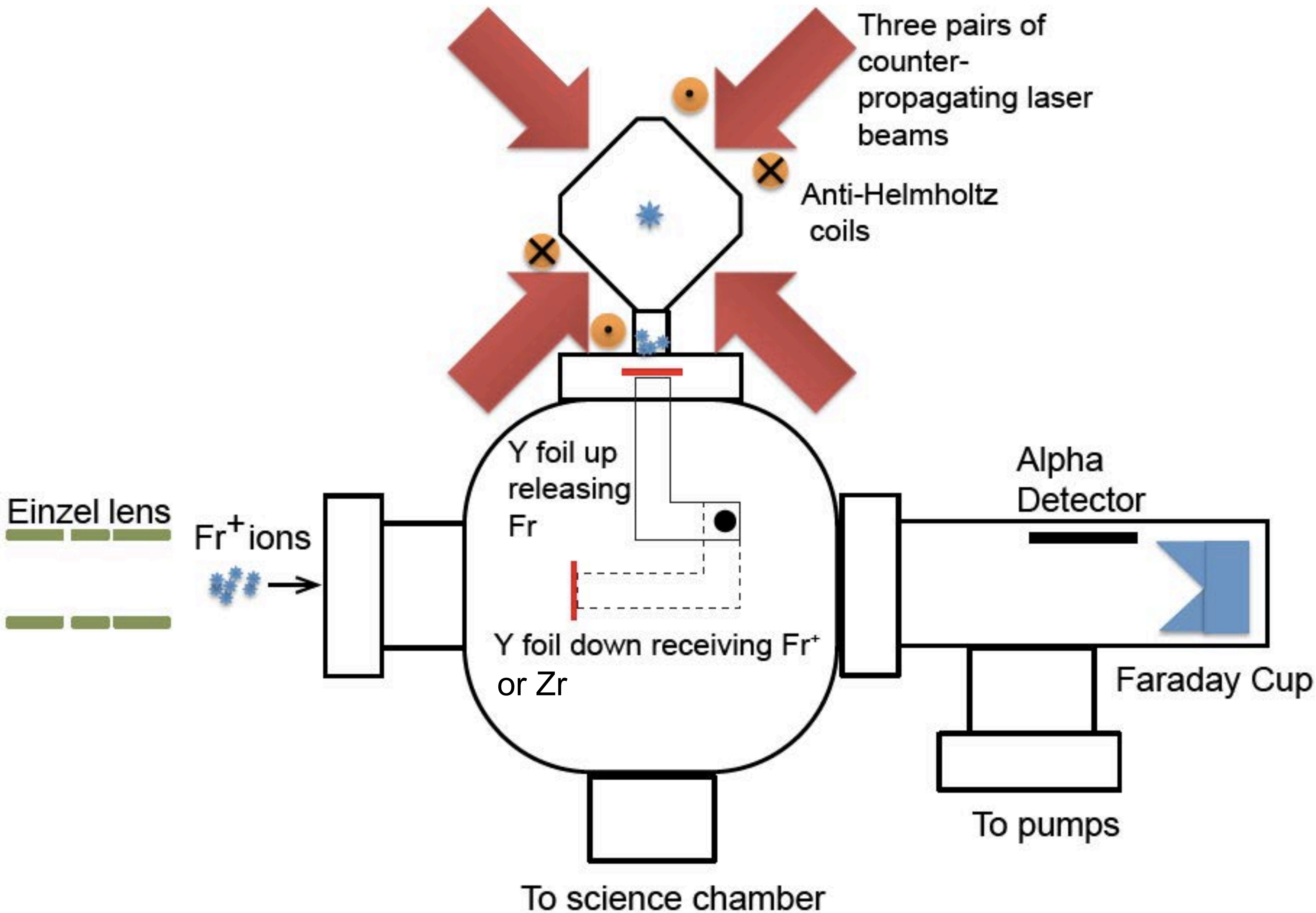
Francium at TRIUMF

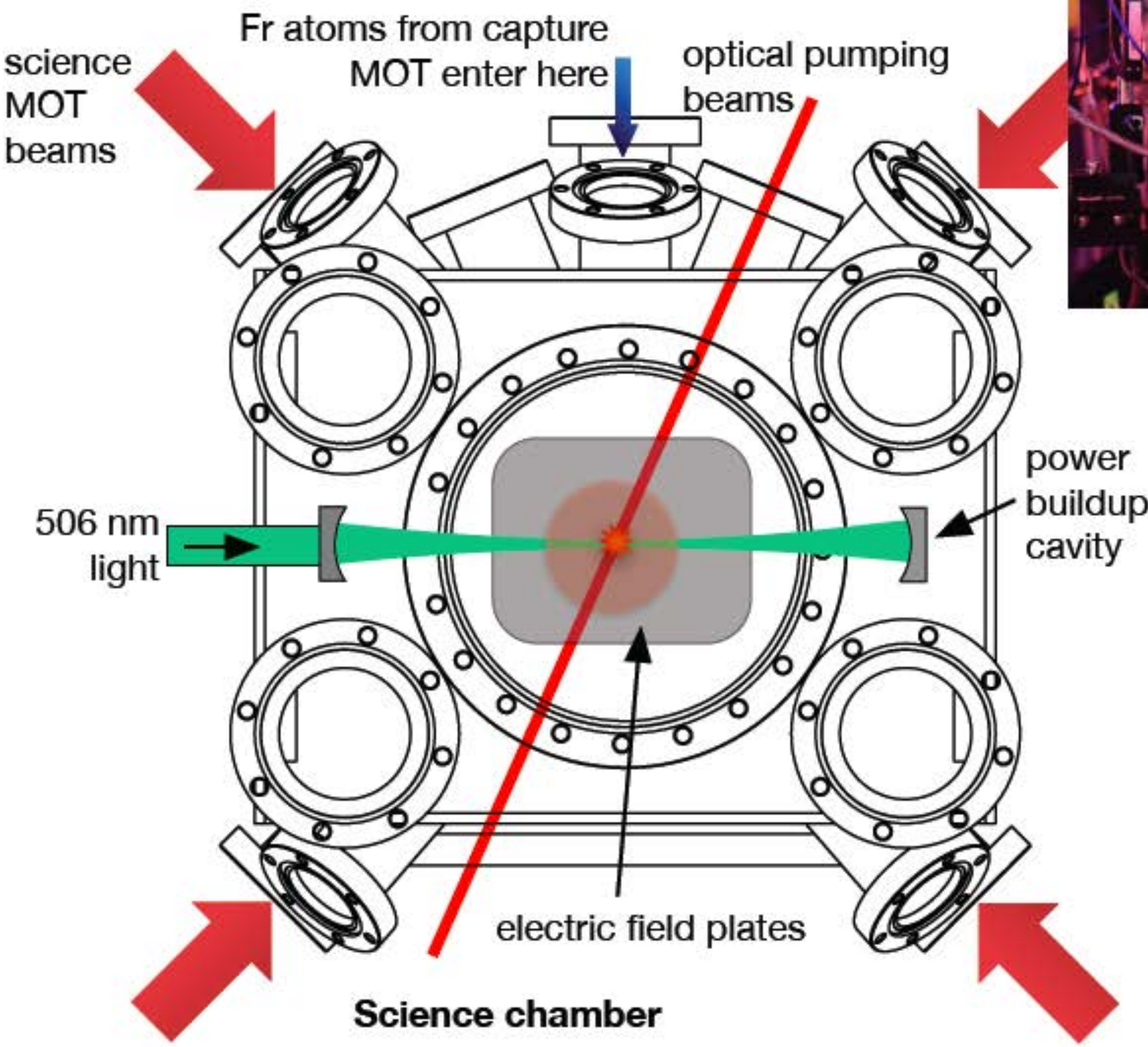
FrPNC Colaboration (Winter 2019-2020)

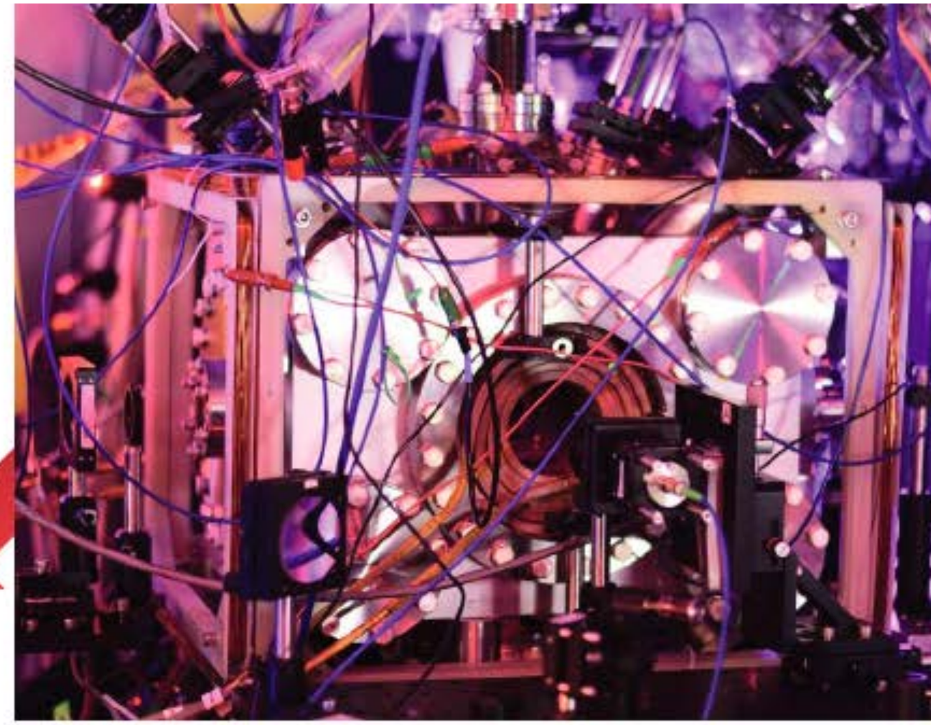
Seth Aubin; College of William and Mary, USA.
John A. Behr, Matt R. Pearson, Alexander Gorolov, Mukut R. Kalita; TRIUMF, Canada.
Victor V. Flambaum; University of New South Wales, Australia.
Eduardo Gómez; Universidad Autónoma de San Luis Potosí, México.
Gerald Gwinner SPOEKESPERSON Thimoty Hucko, Anima Sharma ; University of Manitoba, Canada.
Luis A. Orozco. Jeffrey D. Wack; University of Maryland, USA.
Yanting Zhao; Shanxi University, Taiyuan, China.

Work has been supported by: NRC, TRIUMF, and NSERC from Canada, DOE, and NSF of USA, y CONACYT from Mexico.

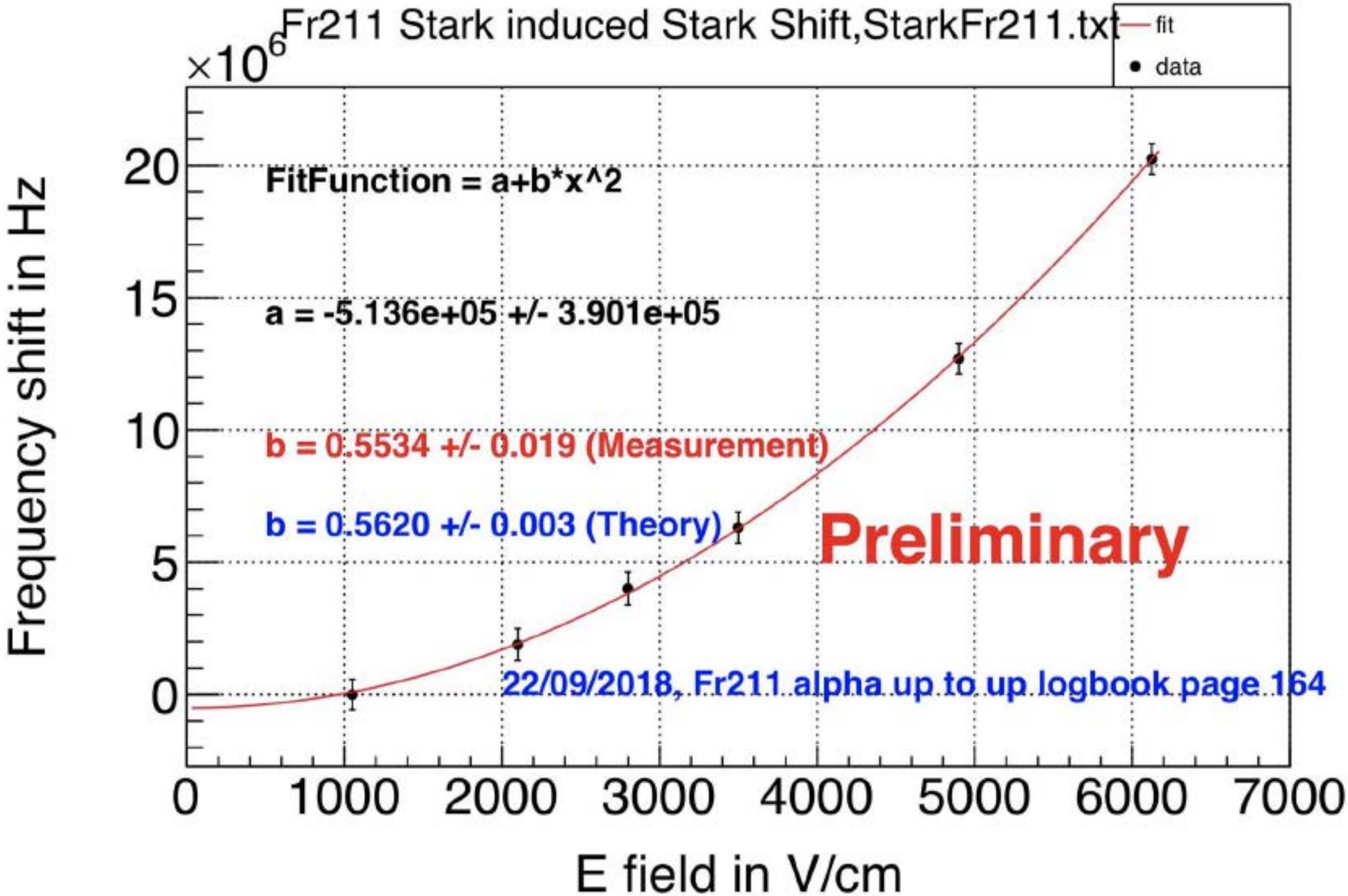
Fr Trapping Facility capture MOT




Fr atoms from capture
MOT enter here
science
MOT
beams
optical pumping
beams
power
buildup
cavity
506 nm
light
electric field plates
Science chamber



Fr 7s - 8s DC Stark effect



- We understand quantitatively the Fr atom. Energy levels, lifetime, hyperfine splitting, isotope shifts, etc.

- DC Stark induced transition 7s to 8s for scalar polarizability (measured) and for vector polarizability (observed).

- Closer to Weak interaction studies.

The method

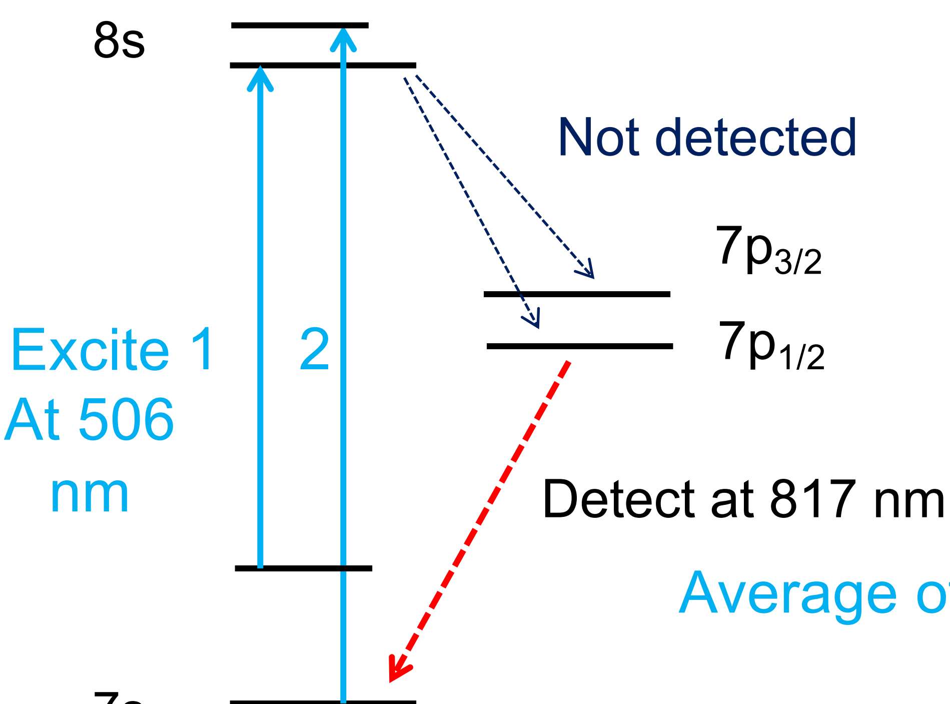
APNC with Stark-induced 7s → 8s transition in Fr

•Electric dipole forbidden.

•Small transition rate due to PNC effect.

•Use Stark Interference technique.

$$R \propto |A_{stark}+A_{PNC}|^2 \approx (A_{stark})^2 \pm 2Re(A_{stark}A_{PNC}^*)$$



Interference term changes sign upon parity reversal

$$S \approx 2(R^+ - R)/(A_{stark})^2$$
$$\approx 2A_{PNC}(A_{stark})$$

Average of 1 and 2: nuclear spin independent APNC

Difference of 1 and 2: Anapole

The apparatus:

We need a system of coordinates.

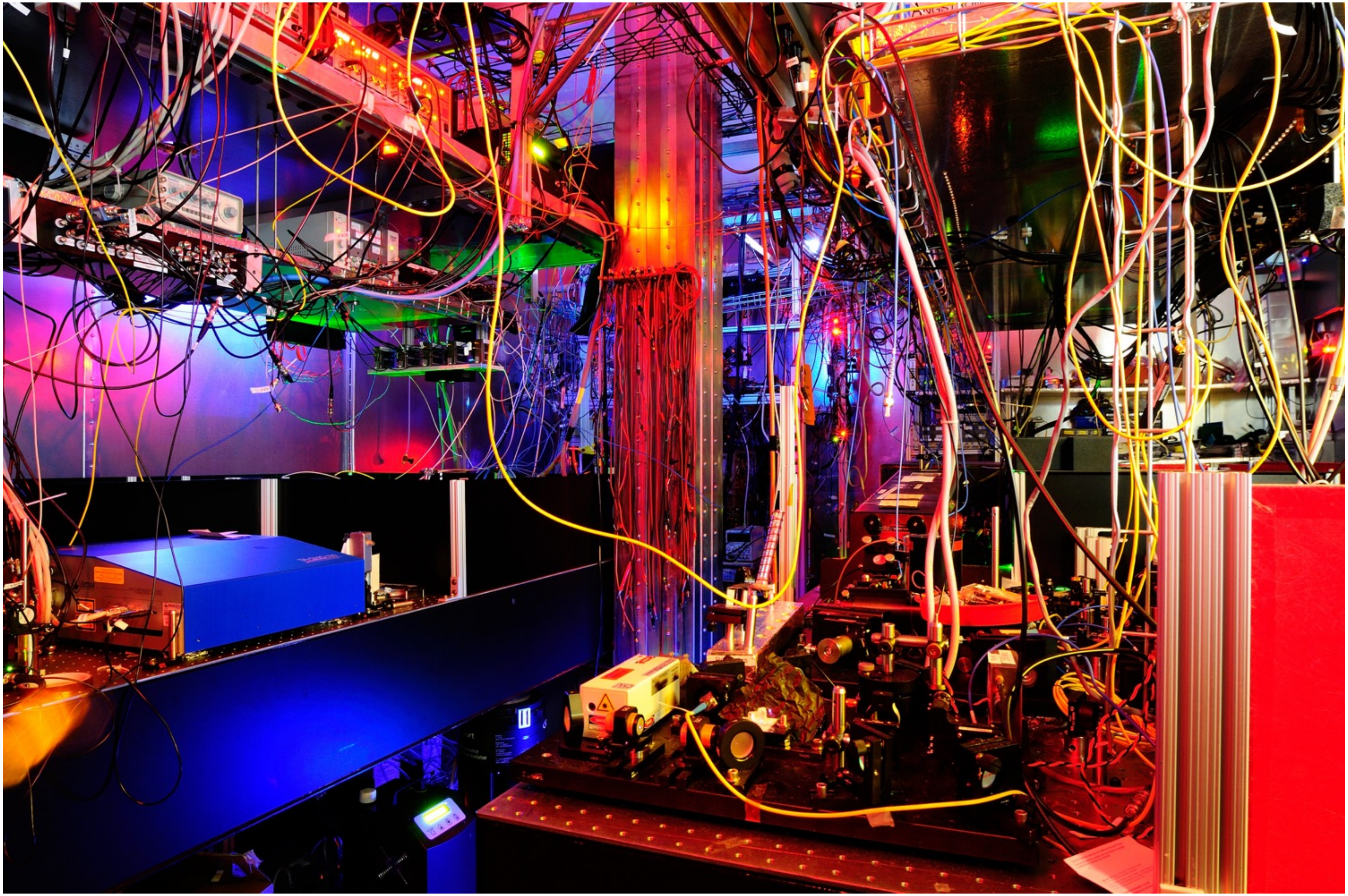
The observable (pseudoscalar, P odd, T even).

$$\vec{S} \cdot \vec{E} \times \vec{B}$$

E Electric Field for Stark Mixing

B Magnetic Field (needs to resolve the m sublevels)

S polarization of excitation light



Thank you very much

Happy 81^{th} birthday to Francium
and
Happy 50^{th} birthday to TRIUMF