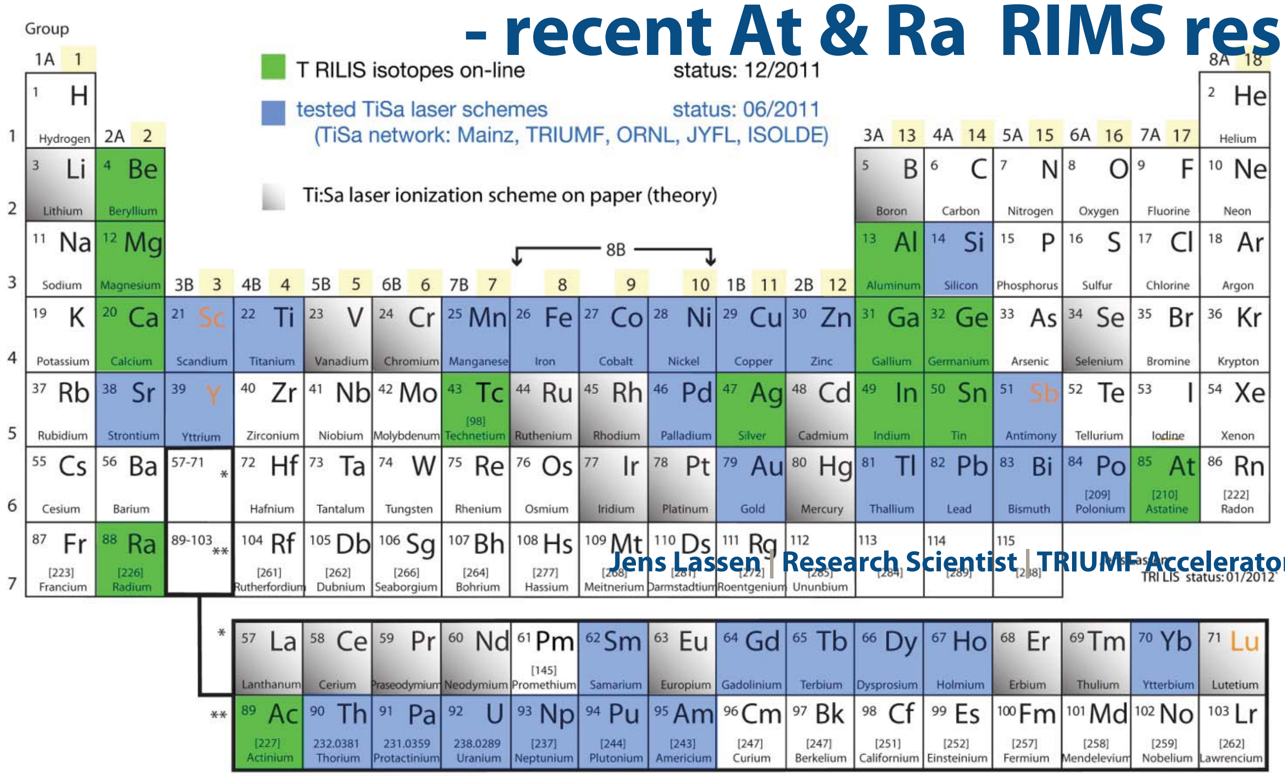
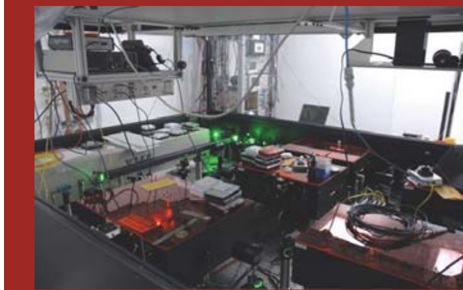
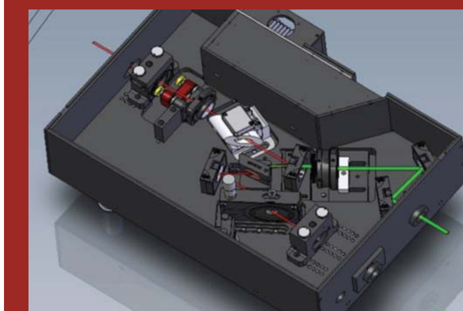
TRIUMF
Canada's National Laboratory for Particle and Nuclear Physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

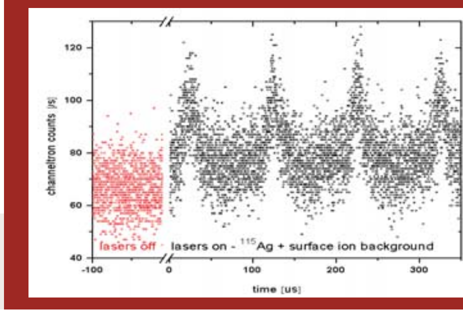
T Resonant Ionization Laser Ion Source - recent At & Ra RIMS results



Jens Lassen | Research Scientist | TRIUMF Accelerator Division







ISAC science forum 01Feb2012

Collaborations:

ORNL-HRIBF (Y. Liu), GANIL (N. Lecesne), CERN-ISOLDE (S. Rothe, V. Fedoseev)

Mainz U (Prof. K. Wendt), TU Darmstadt, U Applied Sciences Oldenburg

Current students:

U Guelph, FHO Emden, U Manitoba, TU Darmstadt

Funding: Government of Canada through NRC, NSCERC

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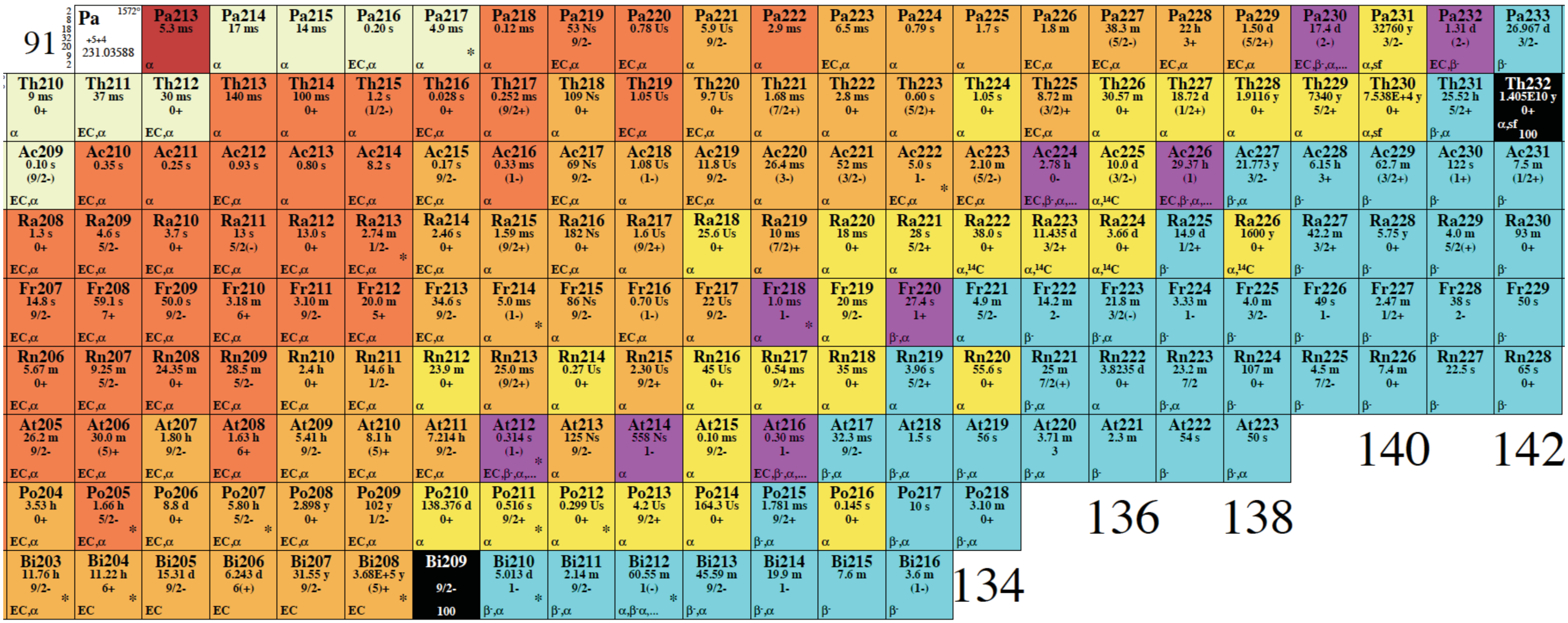
the neighbourhood UC$_x$ based

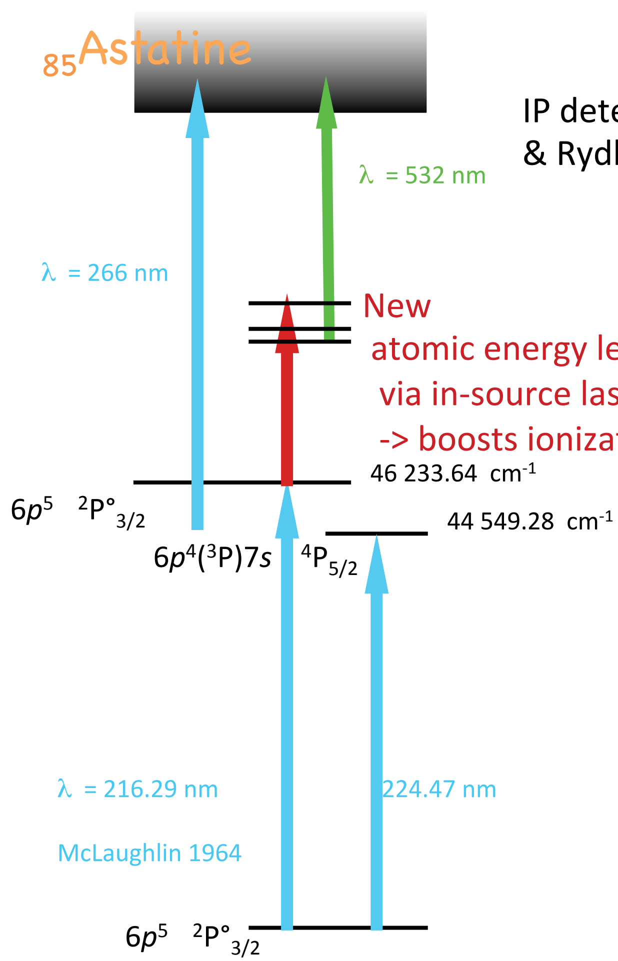


With p+ on target -> massive Fr background

without p+ -> only long lived isotopes -> clean Ra, Ac beams of select isotopes

e.g. A=225

At 1964-2010 …. McLaughlin data
2010-2011 the new "status quo"

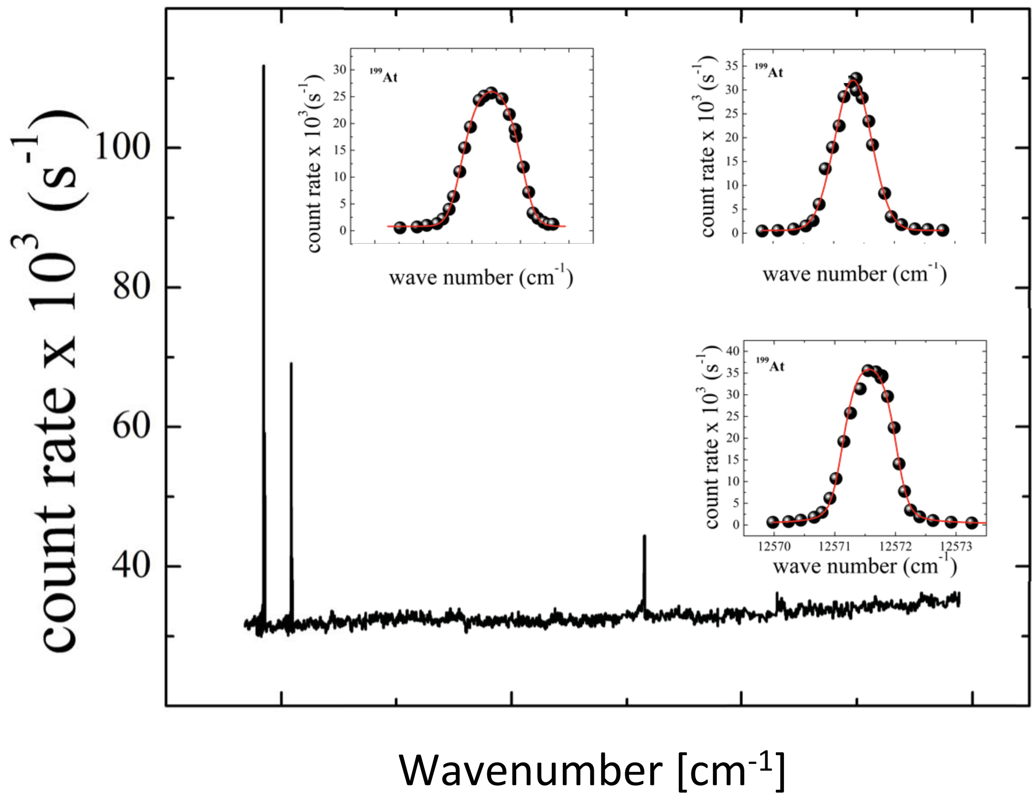


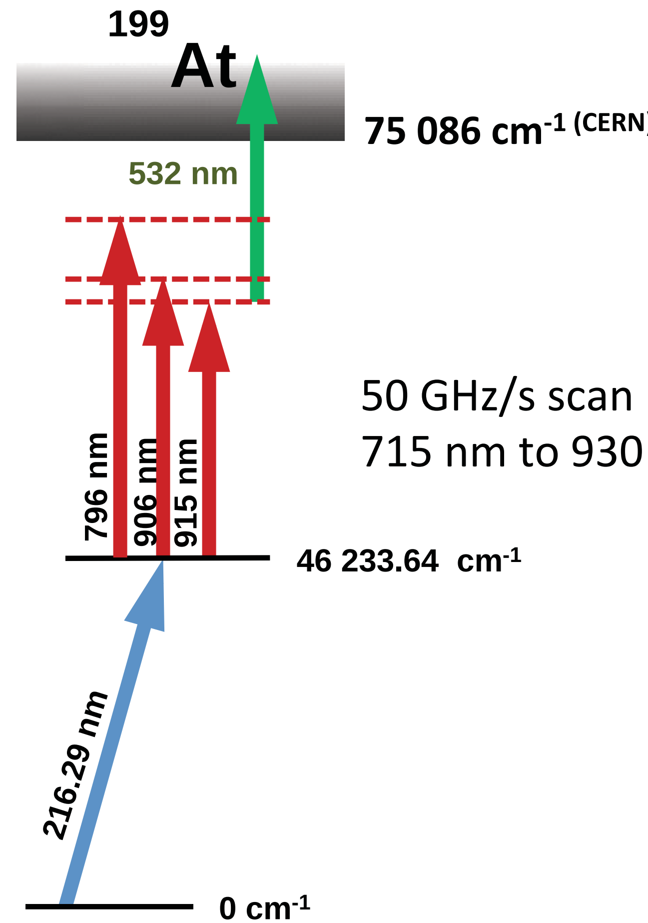
IP determination (CERN) via UV-UV scan
& Rydberg series convergence (winter 2011)

New
atomic energy levels
via in-source laser resonance ionization spectroscopy (3 from TRIUMF 1 from CERN)
-> boosts ionization efficiency 50x

Configuration	Term	J	Level (cm^{-1})	Ref.
$6p^5$	$^2P°$	3/2	0.0	M64a
$6p^4(^3P)7s$	^4P	5/2	44549.3 ?	M64a
		3/2	46233.6 ?	M64a
At II ($^3P_2$)	*Limit*			

[M64a] R. McLaughlin, J. Opt. Soc. Am. 54, 965 (1964)





50 GHz/s scan
715 nm to 930 nm

TRIUMF yield measurements:

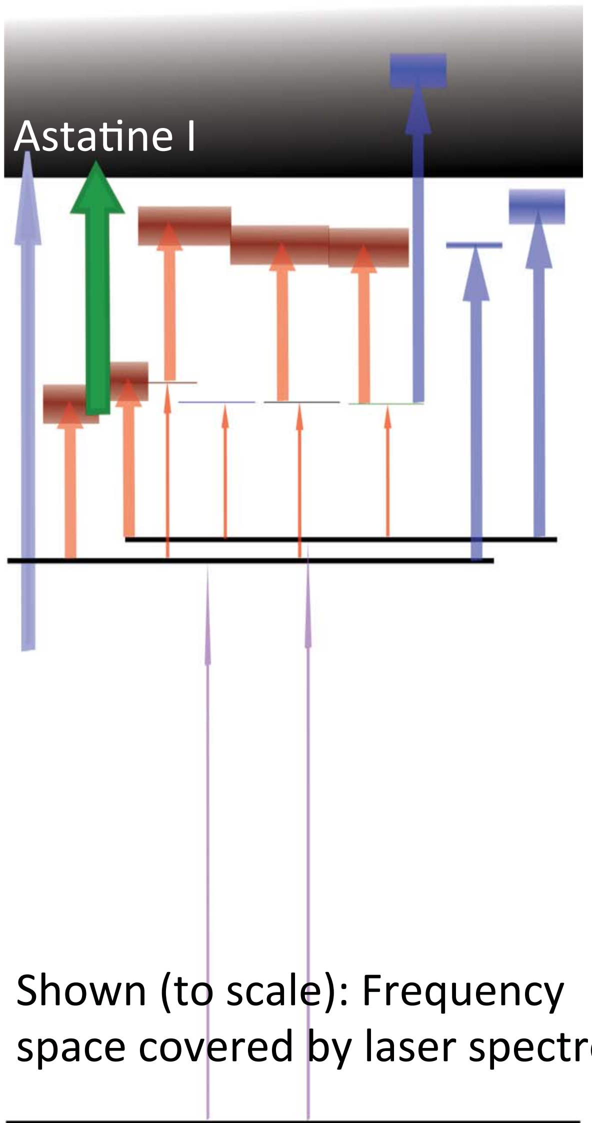
At isotope	Yield (UV,UV)	Yield (UV, IR, 532nm)
199	$1x10^3$ s^{-1}	$5x10^4$ s^{-1}
218	70 s^{-1}	$3x10^3$ s^{-1}

Three new energy levels found
50 x increase in yield

J. Lassen et al., to be published

Winter 2011: S1237 At in-source spectroscopy (2 shifts only) ^{199}At… 34 new atomic energy levels

TRIUMF TRILIS



Shown (to scale): Frequency space covered by laser spectroscopy

So far no autoionizing states

NEW: 24 measured 3rd excited states (even parity)

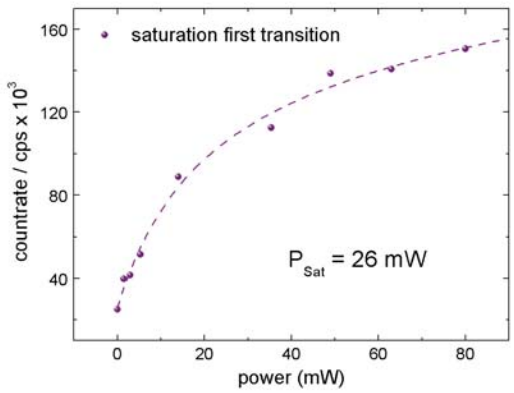
NEW: 8 measured 2nd excited states (odd parity)

Data evaluation in progress (in collaboration with atomic theory)
Obtained wavenumber uncertainty about (0.5 – 1) cm^{-1}

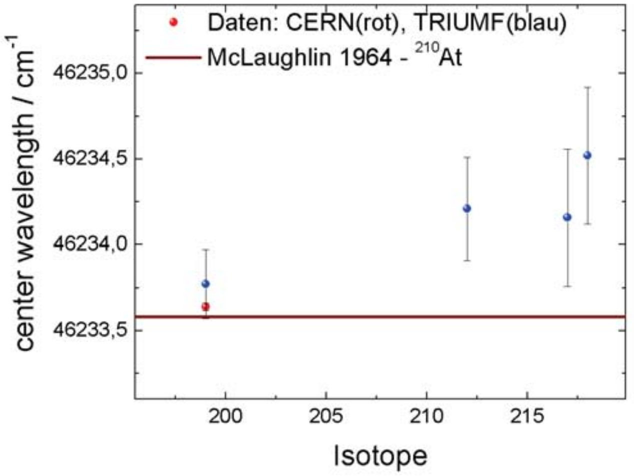
(to be published)

Saturation of optical transitions
Optical isotope shift measurements

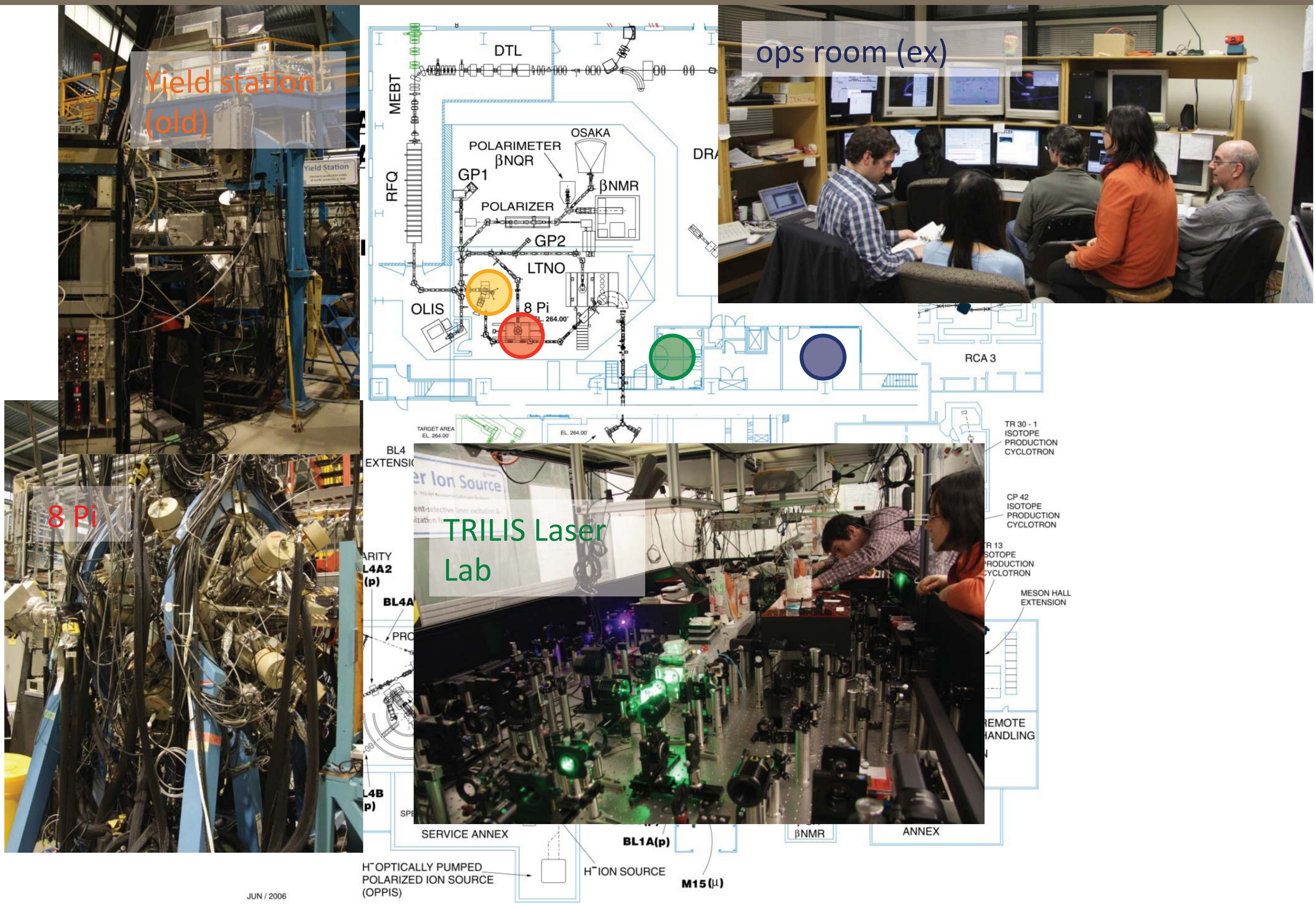
- Saturation measurement for first transition (approx. 26mW)
- Saturation for second transitions
- (approx. 100mW)



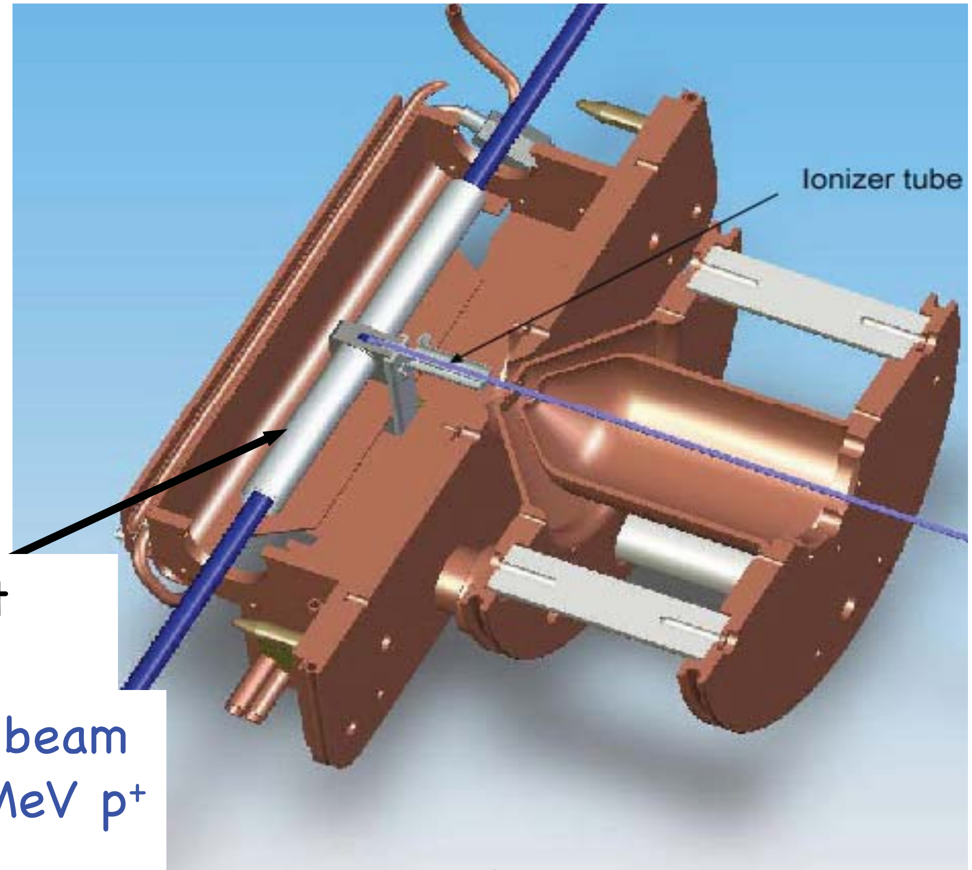
- Optical isotope-shift of first transition (216 nm) isotopes 199, 212, 217 & 218 detected



Saturation of optical transitions
Optical isotope shift measurements

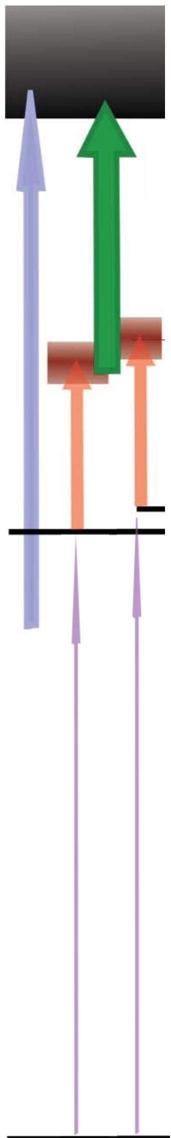


thick target - hot cavity ISOL technique



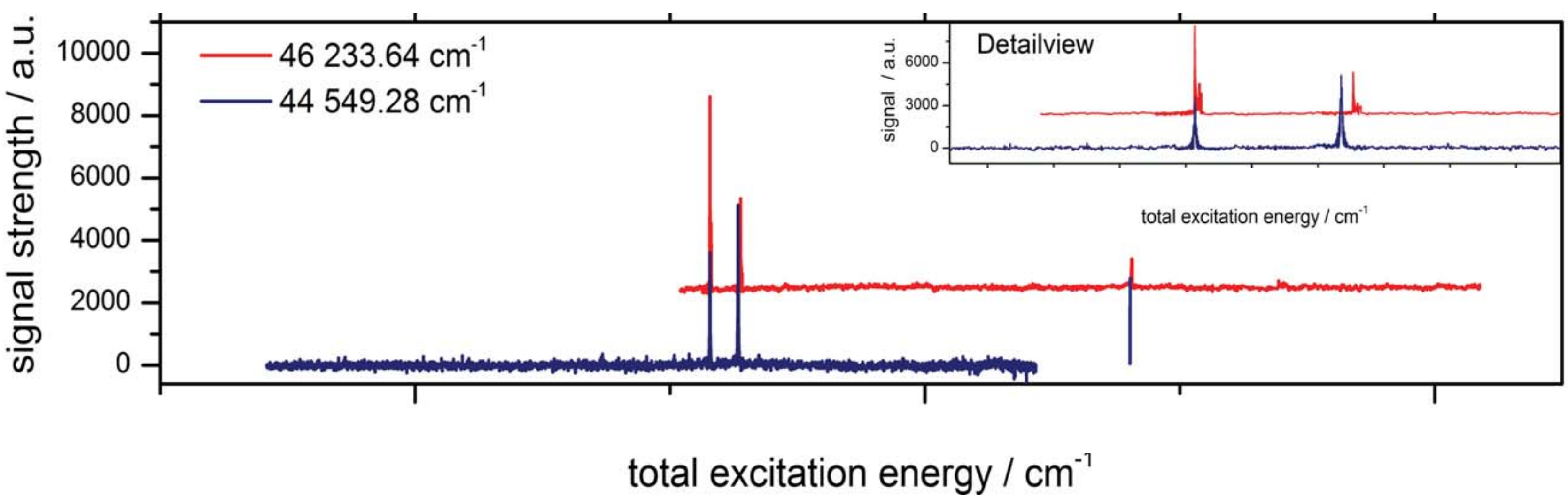
ISOL: isotope separator on-line

Scan for 2nd excited states – red I

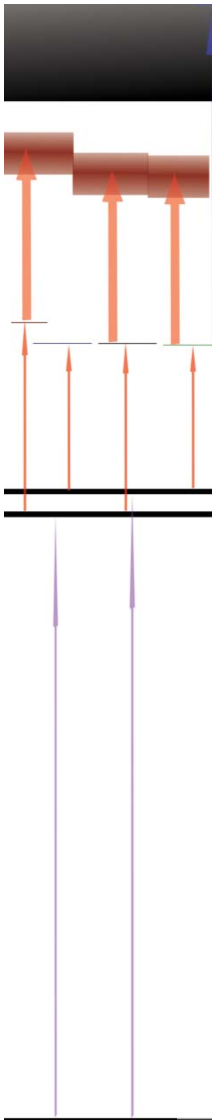


- Scan for SES from both first excited states
  - First scan last year, now repeated and second scan done,
  - 701nm transition was difficult to reach with the grating laser, therefore checked with conventional TiSa
- 6 transitions & 4 levels

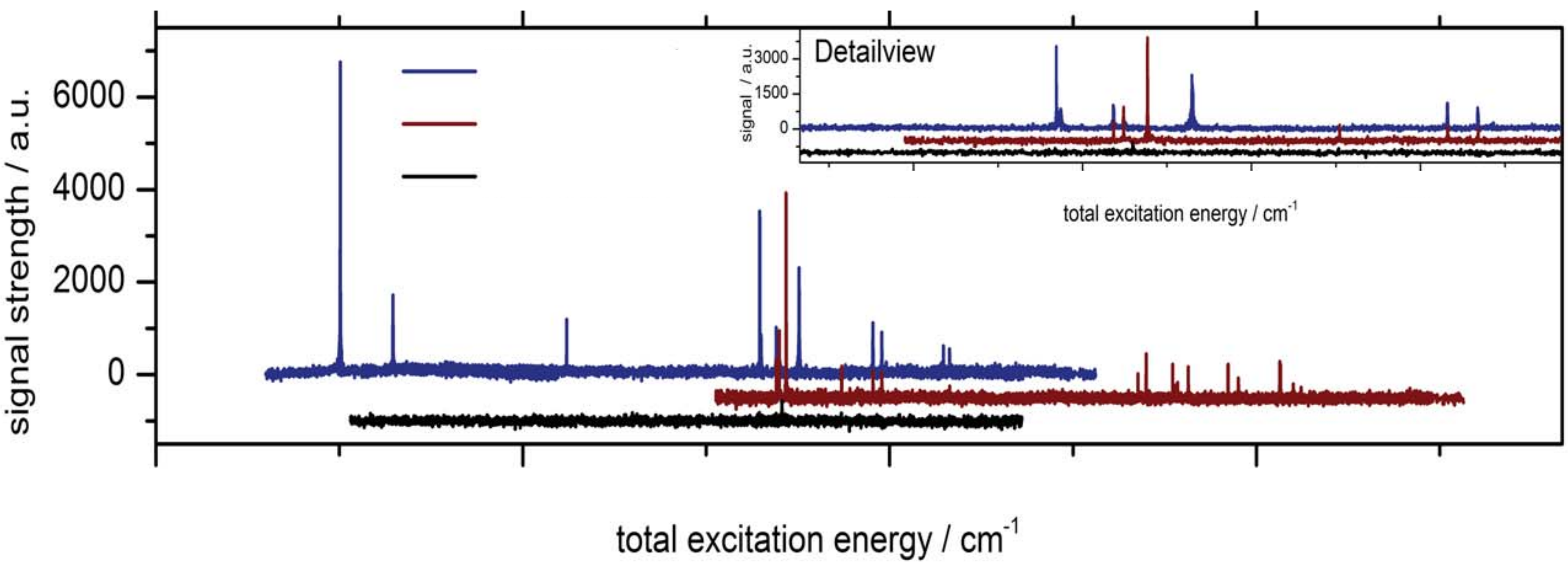
→ SES @57277 cm^{-1} (224+785nm) seen @ CERN in spring 2011 has to be corrected by ~10cm^{-1}



Scan for Third Excited States – red II



- Scan for TES from three of the four identified SES
  - Grating-Ti:Sa fundamental, temporal alignment from 720 – 900 nm possible
  - Ionization via one of the red steps
- 29 transitions and 24 levels



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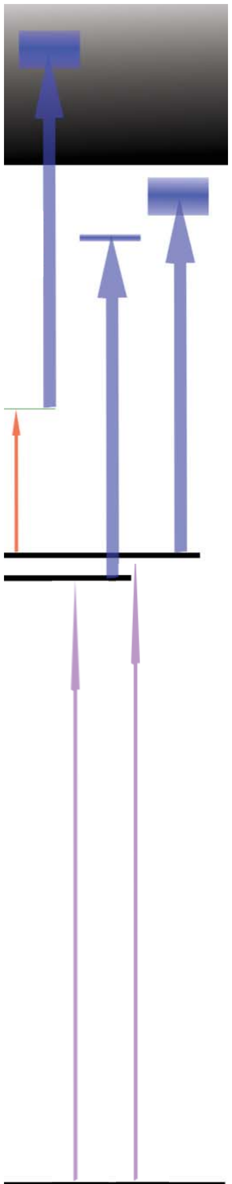
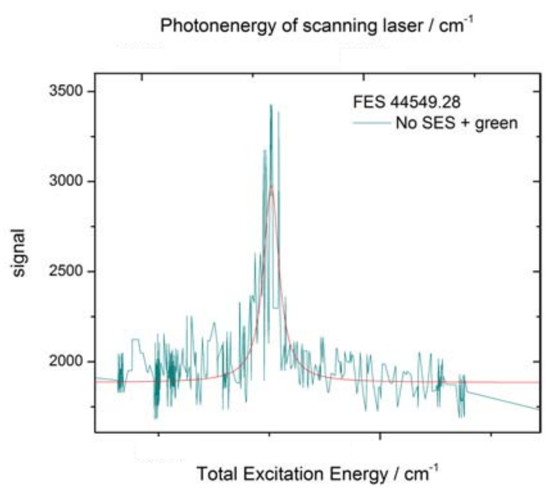
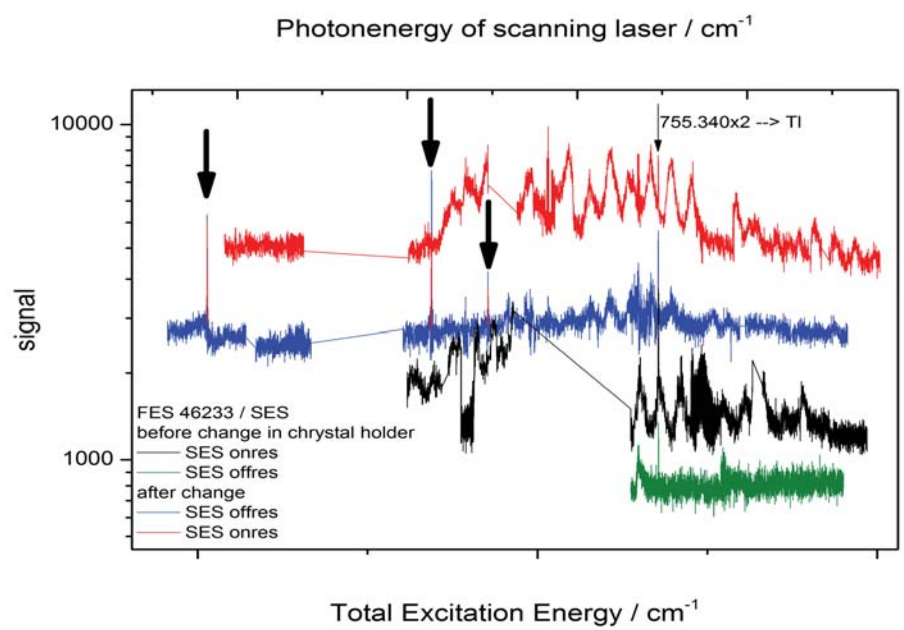
Scan for 2nd excited states & AI – blue I

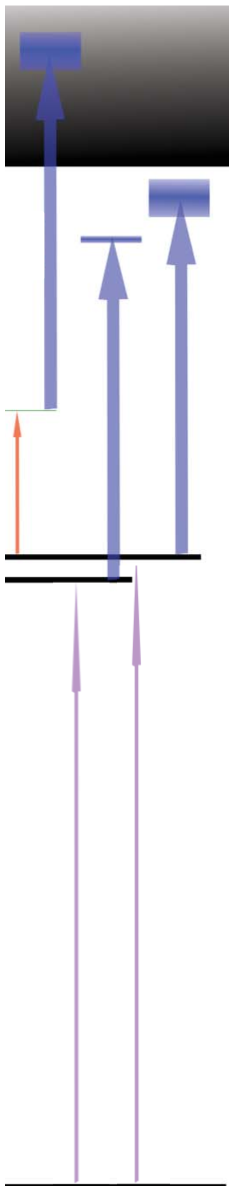


- Blue scan (frequency doubled) from FES & SES
  - Periodic structure due to non-resonant ionization and power fluctuation of the grating laser
  - Blue also increased the background (not UV wavelength dependent), presumably Tl
  - Pointing stability without active stabilization of blue Ok for about 20-40 nm fundamental, then signal drops fast due to steering



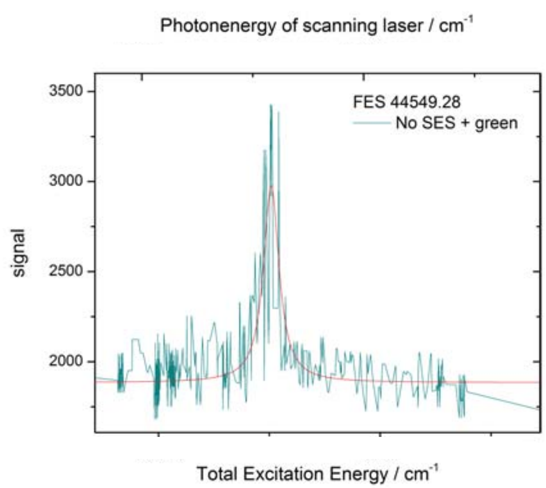


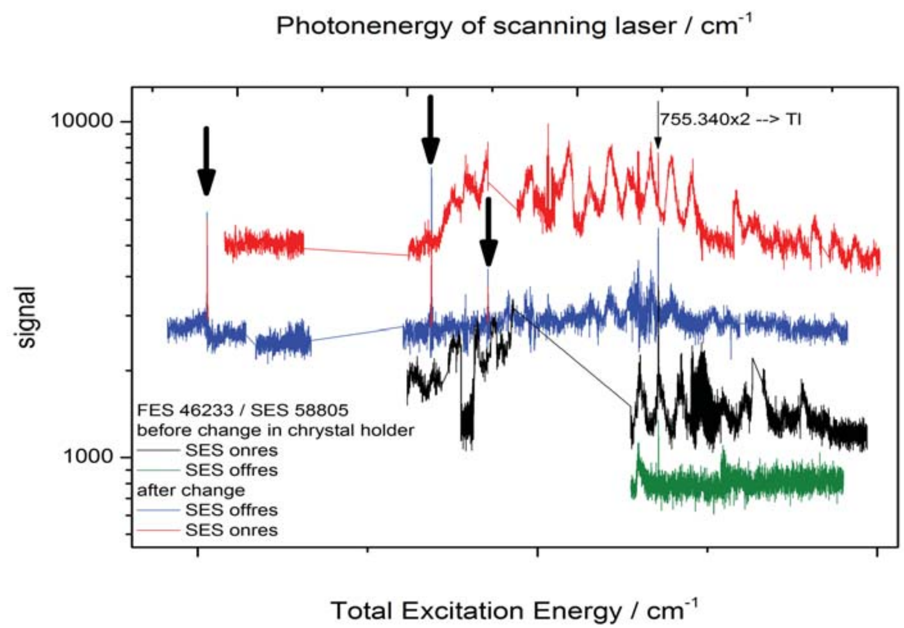
Scan for SES & AI states – blue II



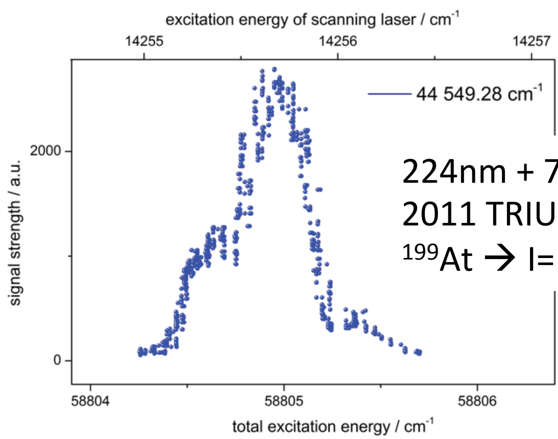
- Scanning region limited to tuning range of doubling crystal
  - Scanning time slowed down significantly due to calibration requirements

  -> continued laser development required (theses: J. Grueneisen & T. Quenzel) work in progress
- Up to now: 4 transitions and 4 levels for SES, no AI state seen
- Additionally one Tl transition at 755.34nm x 2 was observed

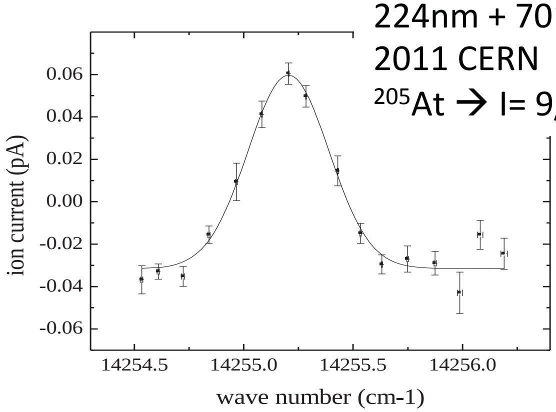




Outlook: HFS & isotope shifts



224nm + 701nm
2011 TRIUMF
^{199}At → I= (9/2-)



224nm + 701nm
2011 CERN
^{205}At → I= 9/2-

Outlook & work to do:

(i) Hyperfine structure & optical isotope shift measurements

(ii) 223, 225 At for EDM experiments

Indication of HFS for the 701nm transition starting from the 44549 cm-1 FES (224nm)

- Not visible in ISOLDE/CERN scan from spring 2011

To be investigated

Radium – new element for TiSa RIMS

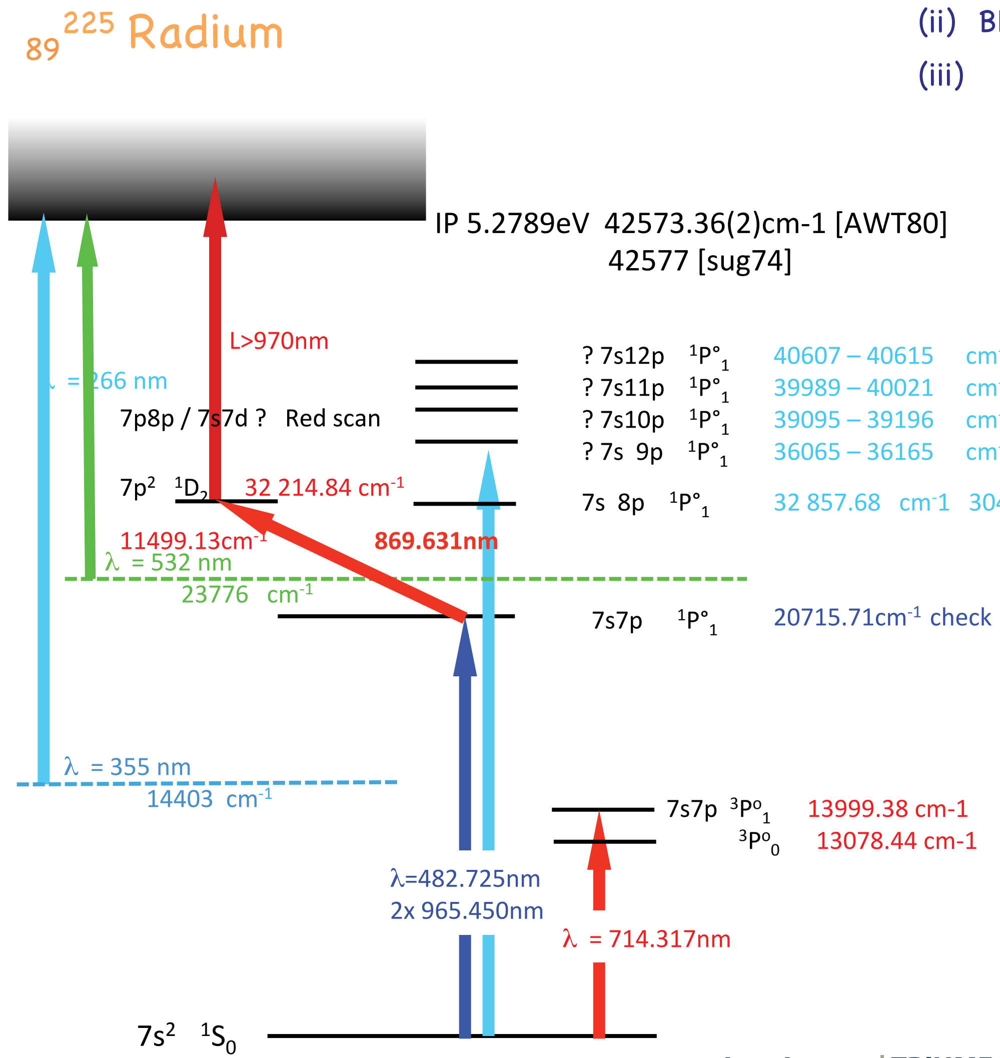
(i) IR scan for new states … 482/IR/532, 304/IR (AI)

(ii) Blue scan 482/blue (RYD-IP)

(iii) 245-278 nm spectroscopy (3n)

IP_Ra(i) eV 42573.36(2)cm-1

355nm limit (2x TiSa@710nm): cm-1
266nm limit (2x YHP40): cm01



6d7p intruder ?????
37895 – 38048 cm-1

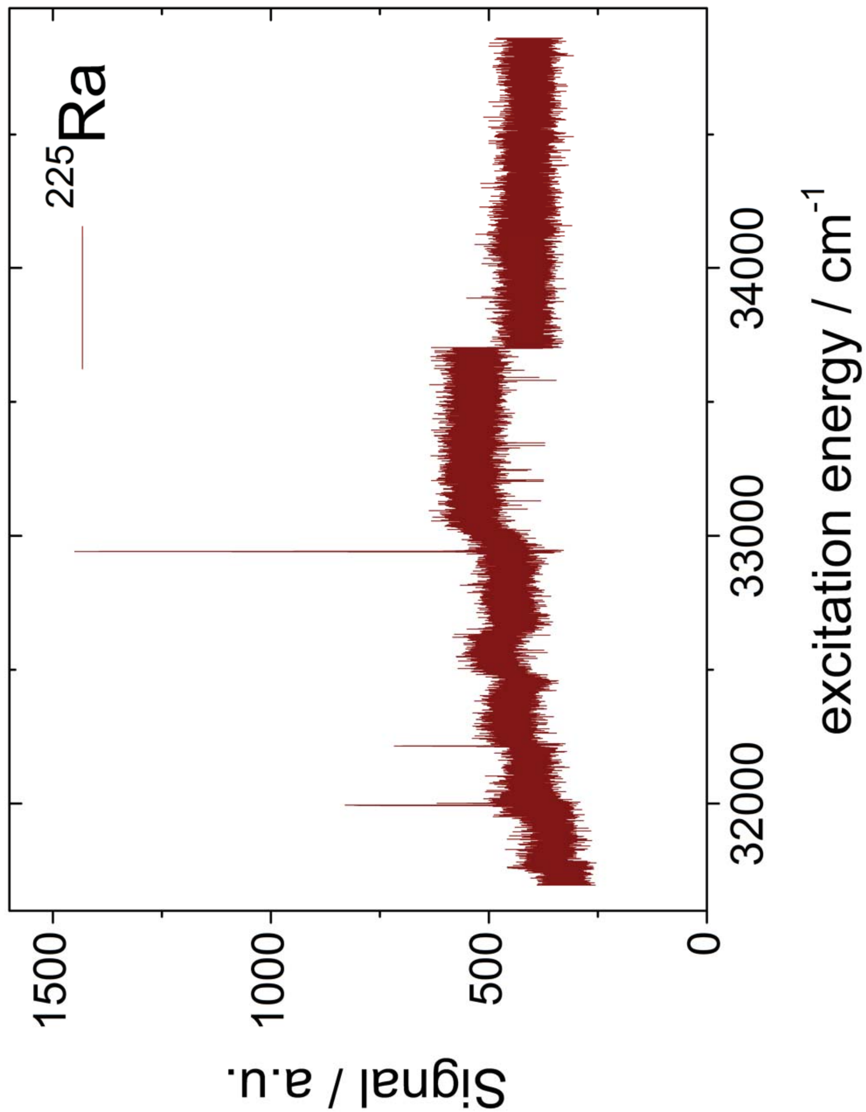
Sansonetti 17 energy levels, NIST (V4) 47 energy levels for Ra I.

J. Phys. B: Atom. Molec. Phys. **13** (1980) L133-L137.
LETTER TO THE EDITOR
Bound, 7snp 1P0l series in Ra I: measurements and predictions
J A Armstrongt, J J Wynnet and F *S* TomkinsS§
t IBM T J Watson Research Center, Yorktown Heights, New York 10598, USA
$ Chem. Division, Argonne National Laboratory, Argonne, Illinois 60439, USA Received 27 November 1979

Abstract. Absorption measurements of the 7s13p-7s52p 'P: Rydberg series in Ra I are presented. A revised new value of the first ionisation limit (42573.36*0.02cm-') is derived.
From these measurements and from a systematic trend in Ca I, **Sr** I and Ba I, a multichannel quantum defect theory **(MQDT)** analysis is used to predict the location of the 7s9p-7s12p and 6d7p 'P: states.

Russell PR1934
Rasmussen Zphys 1934

2^{nd} step scan -> best excitation scheme



First step *7s7p* ^{1}P° J=1 *20 715.71* cm^{-1}

Second steps, green for ionization

measured [cm^{-1}]	Literature [cm^{-1}]	
31 993.71	31 993.41	*7s7d* ^{3}D 2
32 000.84	32 000.82	*7s7d* ^{3}D 1
32 214.91	32 214.84	7p^2 ^{1}D 2
32 941.39	32 941.13	7p^2 ^{3}P 2

Best scheme

Signal enhancement laser/surface= 3-4

(without protons, low temperature target)

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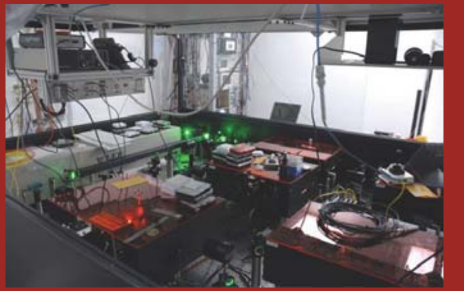
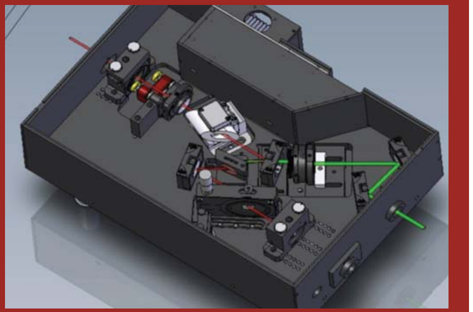
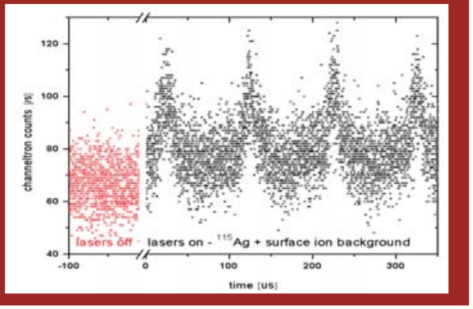
TRIUMF Resonant Ionization Laser Ion Source - recent At & Ra RIMS







Recent on-line developments – At & Ra

status 2/2012

Jens Lassen | Research Scientist | TRIUMF Accelerator Division

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Collaborations:
ORNL-HRIBF, GANIL, CERN-ISOLDE
Mainz U, TU Darmstadt, U Applied Sciences Olden

Current students:
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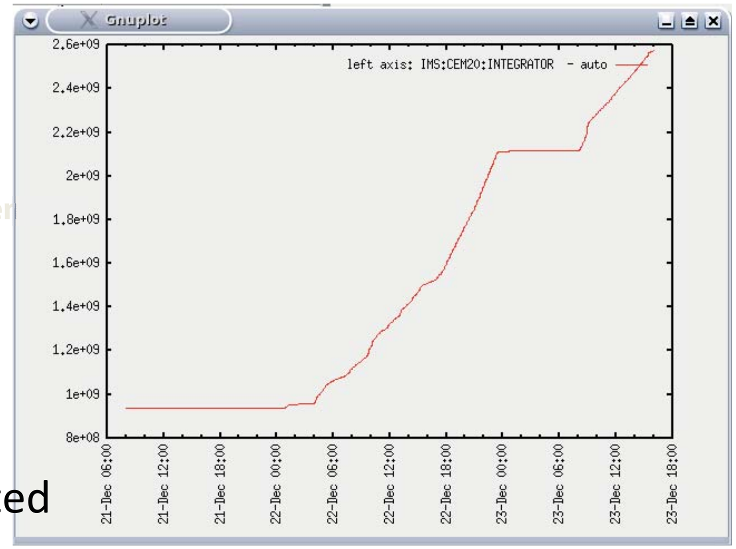
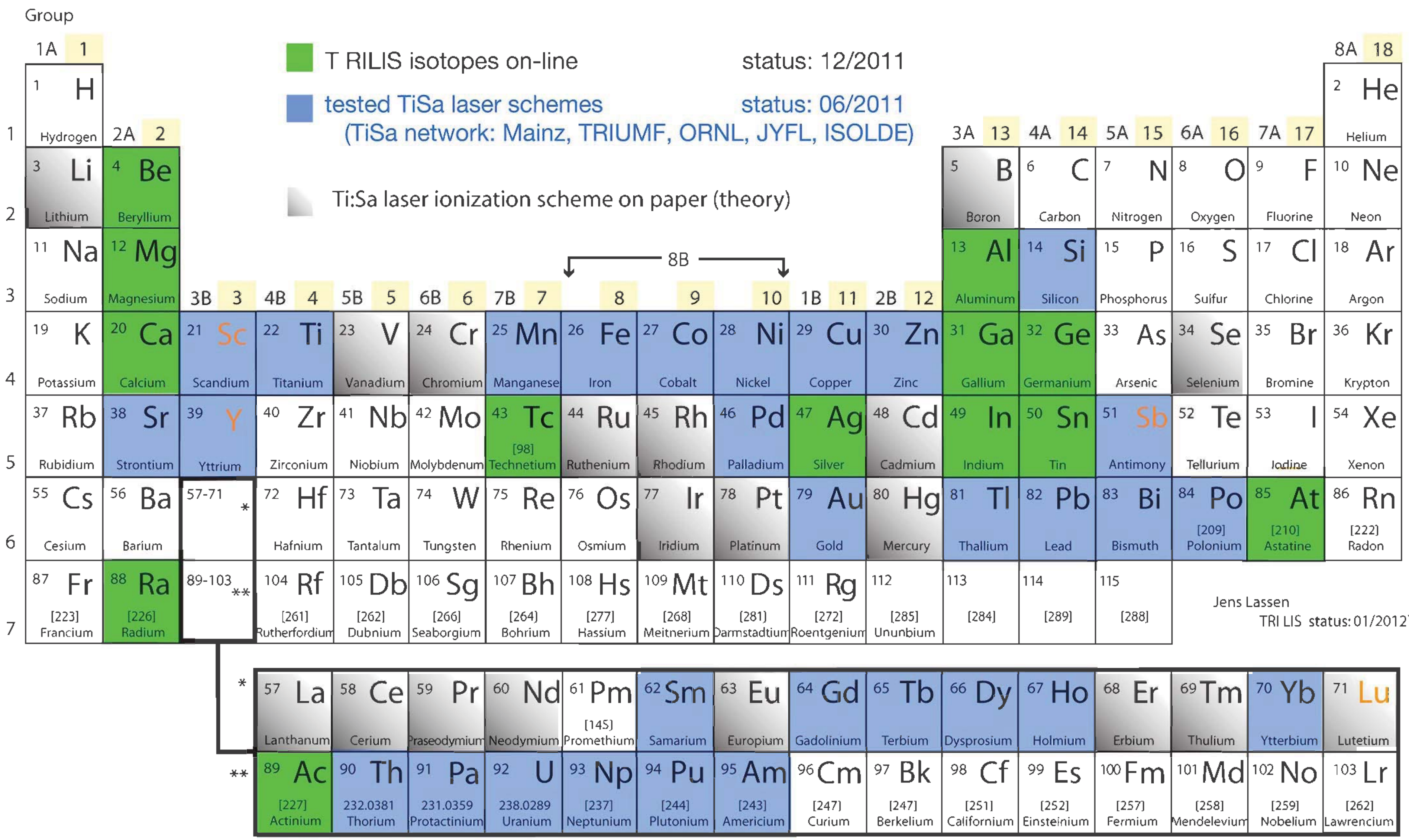


CEM20 with A=225 mass
=> approx. 3k Bq accumulated


Group
T RILIS isotopes on-line status: 12/2011
tested TiSa laser schemes status: 06/2011
(TiSa network: Mainz, TRIUMF, ORNL, JYFL, ISOLDE)
Ti:Sa laser ionization scheme on paper (theory)
1A 1
2A 2
3B 3
4B 4
5B 5
6B 6
7B 7
8B
8
9
10
1B 11
2B 12
3A 13
4A 14
5A 15
6A 16
7A 17
8A 18
1
2
3
4
5
6
7
1 H Hydrogen
2 He Helium
3 Li Lithium
4 Be Beryllium
5 B Boron
6 C Carbon
7 N Nitrogen
8 O Oxygen
9 F Fluorine
10 Ne Neon
11 Na Sodium
12 Mg Magnesium
13 Al Aluminum
14 Si Silicon
15 P Phosphorus
16 S Sulfur
17 Cl Chlorine
18 Ar Argon
19 K Potassium
20 Ca Calcium
21 Sc Scandium
22 Ti Titanium
23 V Vanadium
24 Cr Chromium
25 Mn Manganese
26 Fe Iron
27 Co Cobalt
28 Ni Nickel
29 Cu Copper
30 Zn Zinc
31 Ga Gallium
32 Ge Germanium
33 As Arsenic
34 Se Selenium
35 Br Bromine
36 Kr Krypton
37 Rb Rubidium
38 Sr Strontium
39 Y Yttrium
40 Zr Zirconium
41 Nb Niobium
42 Mo Molybdenum
43 Tc [98] Technetium
44 Ru Ruthenium
45 Rh Rhodium
46 Pd Palladium
47 Ag Silver
48 Cd Cadmium
49 In Indium
50 Sn Tin
51 Sb Antimony
52 Te Tellurium
53 I Iodine
54 Xe Xenon
55 Cs Cesium
56 Ba Barium
57-71 *
72 Hf Hafnium
73 Ta Tantalum
74 W Tungsten
75 Re Rhenium
76 Os Osmium
77 Ir Iridium
78 Pt Platinum
79 Au Gold
80 Hg Mercury
81 Tl Thallium
82 Pb Lead
83 Bi Bismuth
84 Po [209] Polonium
85 At [210] Astatine
86 Rn [222] Radon
87 Fr [223] Francium
88 Ra [226] Radium
89-103 **
104 Rf [261] Rutherfordium
105 Db [262] Dubnium
106 Sg [266] Seaborgium
107 Bh [264] Bohrium
108 Hs [277] Hassium
109 Mt [268] Meitnerium
110 Ds [281] Darmstadtium
111 Rg [272] Roentgenium
112 [285] Ununbium
113 [284]
114 [289]
115 [288]
Jens Lassen
TRI LIS status: 01/2012`
*
57 La Lanthanum
58 Ce Cerium
59 Pr Praseodymium
60 Nd Neodymium
61 Pm [145] Promethium
62 Sm Samarium
63 Eu Europium
64 Gd Gadolinium
65 Tb Terbium
66 Dy Dysprosium
67 Ho Holmium
68 Er Erbium
69 Tm Thulium
70 Yb Ytterbium
71 Lu Lutetium
**
89 Ac [227] Actinium
90 Th 232.0381 Thorium
91 Pa 231.0359 Protactinium
92 U 238.0289 Uranium
93 Np [237] Neptunium
94 Pu [244] Plutonium
95 Am [243] Americium
96 Cm [247] Curium
97 Bk [247] Berkelium
98 Cf [251] Californium
99 Es [252] Einsteinium
100 Fm [257] Fermium
101 Md [258] Mendelevium
102 No [259] Nobelium
103 Lr [262] Lawrencium

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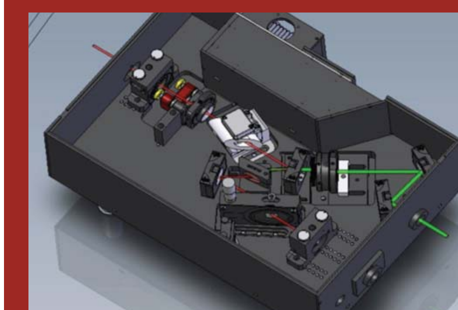

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