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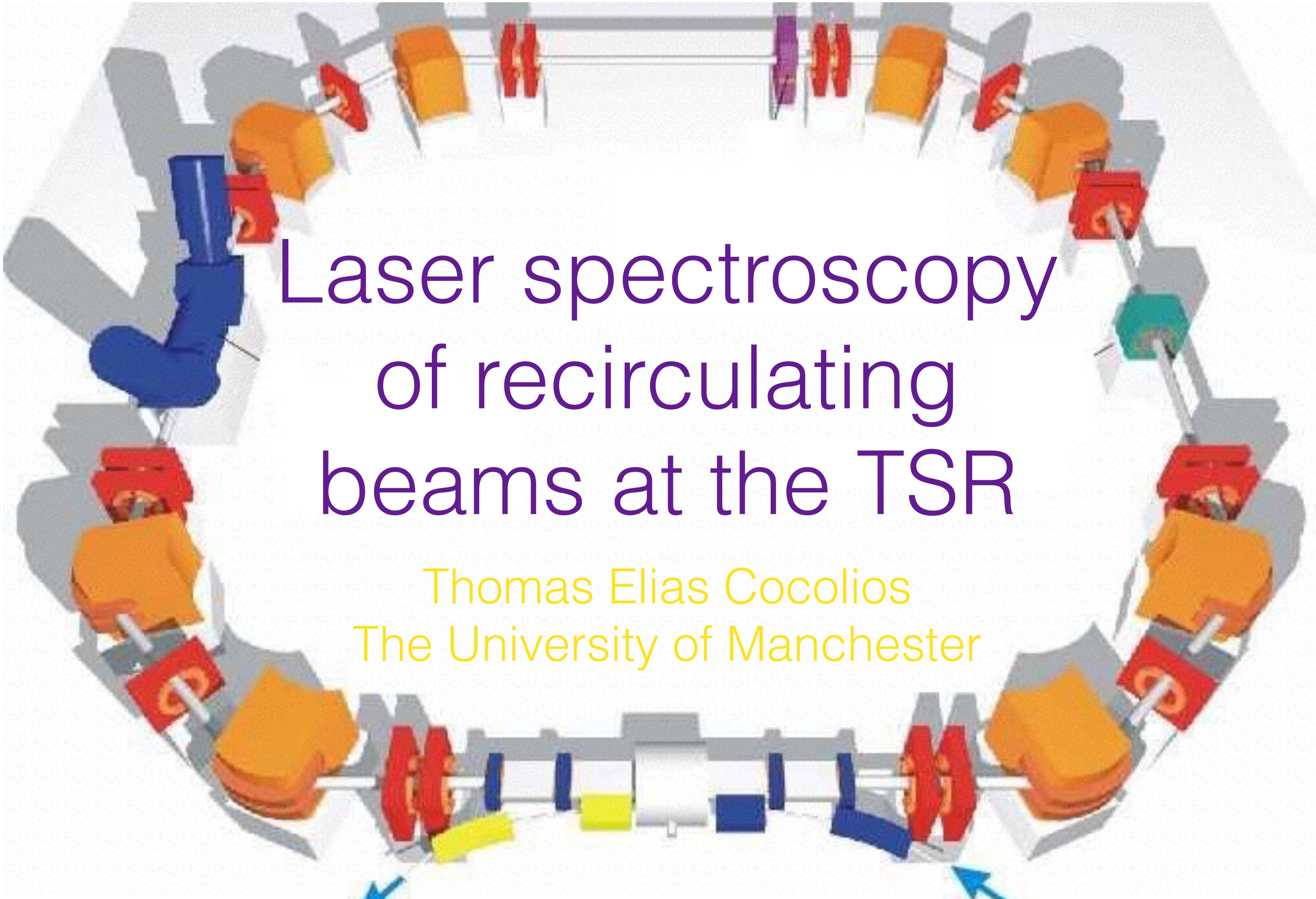

Laser spectroscopy of recirculating beams at the TSR

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TSR@ISOLDE Workshop 2015

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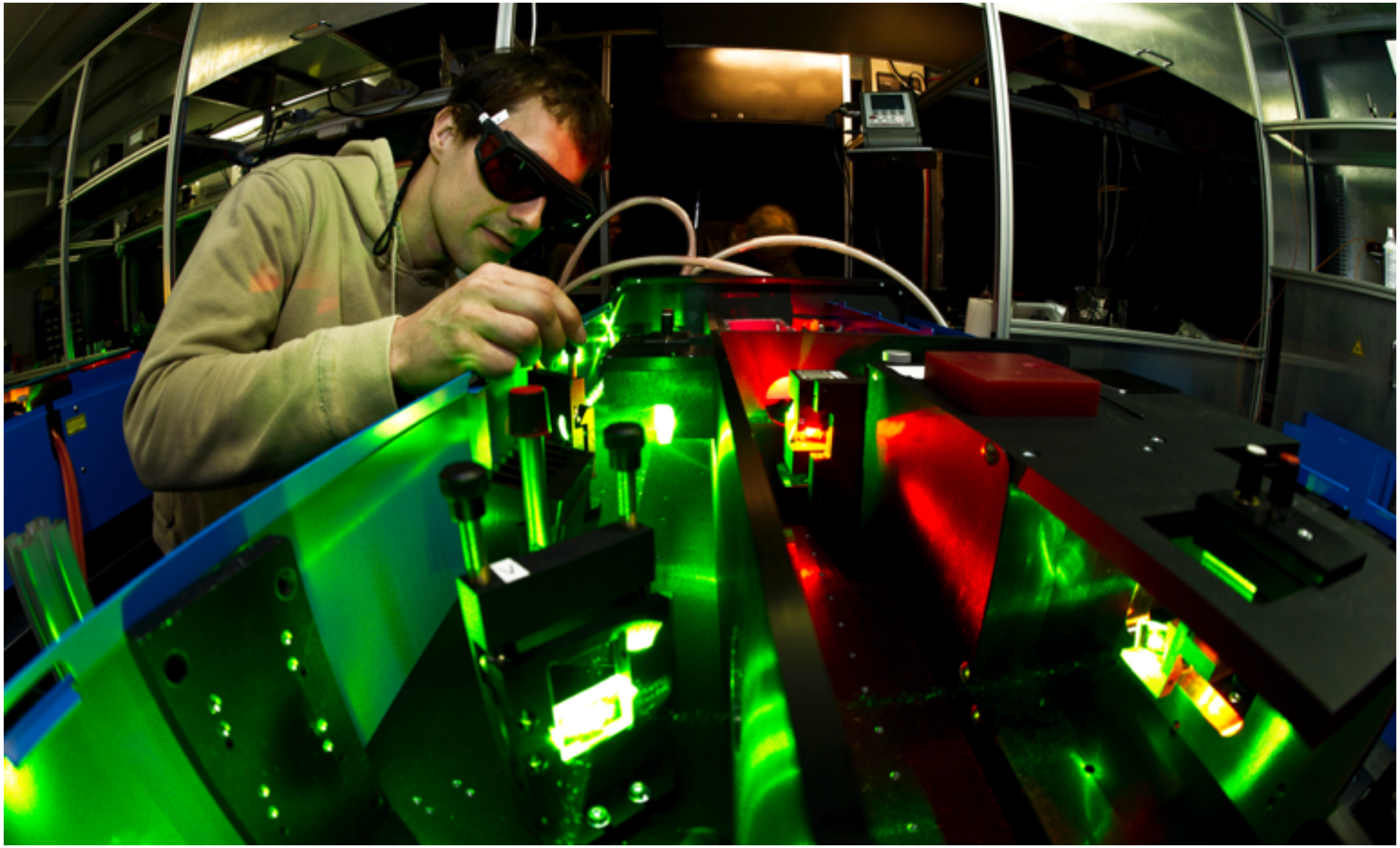
Outline

- Basics of laser spectroscopy
- In-ring studies
  - Highly-charged ions
  - Mono-atomic beams
  - Recirculation
- Out-of-ring interests



Laser spectroscopy

Shedding light on the nucleus

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Hyperfine Structure

- Interaction between nuclear spin and atomic angular momentum lifts the atomic magnetic substate degeneracy: ***F*** = ***I*** + ***J***

- The substate deviate from the original level energy according to the electromagnetic nuclear moments:

$A = (\boldsymbol{\mu} \,.\, H_0) / (I \,.\, J)$

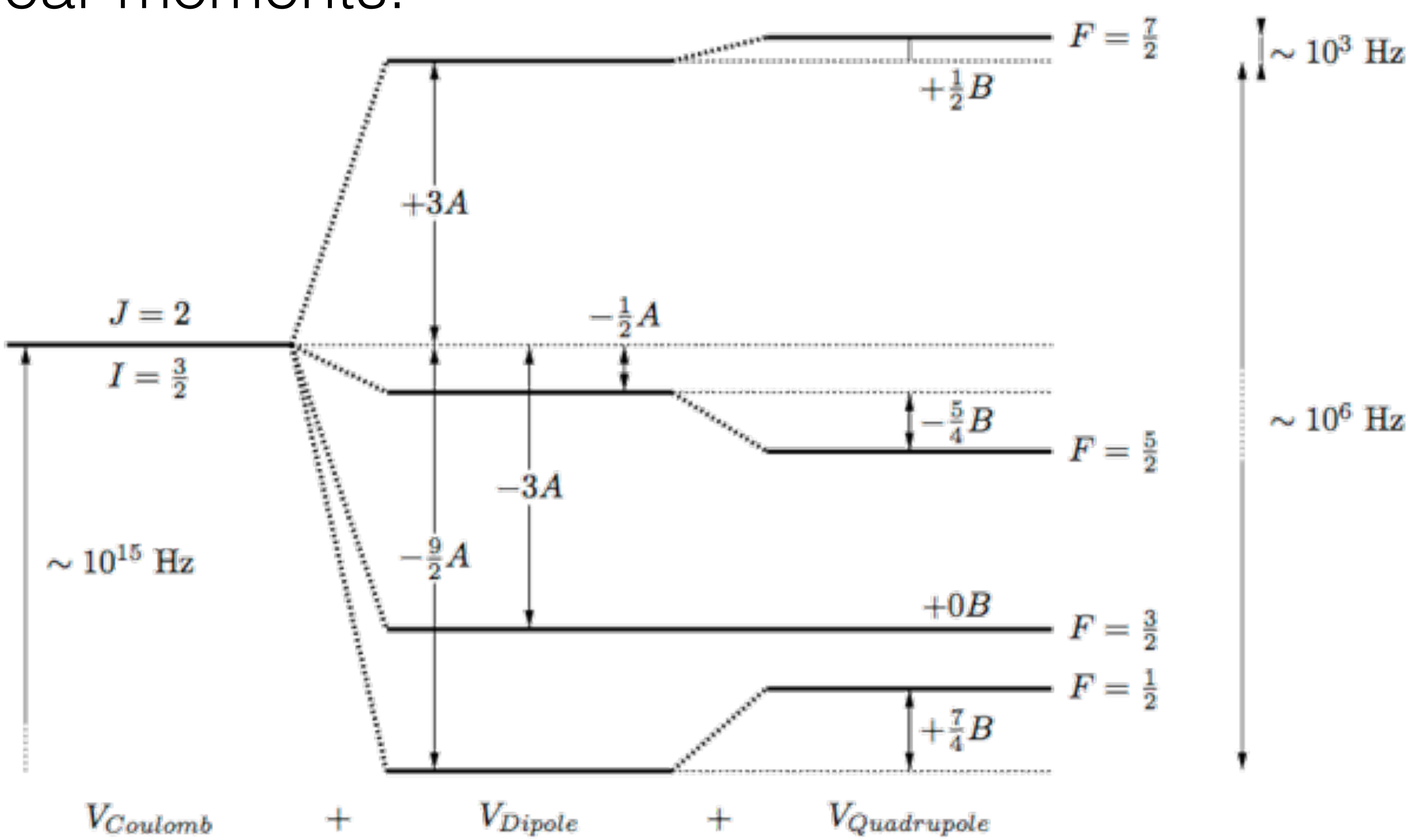
$B = e \,.\, \mathbf{Q_s} \,.\, \Psi_{zz}$

$\Delta E = K \,.\, A / 2$

$\quad + f(K) \,.\, B$

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

Relative measurement!



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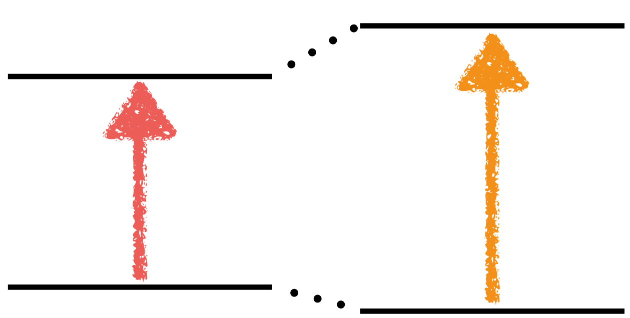
Isotope Shift

- The nucleus is not a point charge and its distribution influences the atomic levels.
- The study of atomic transitions across and isotopic chain may reveal the changes in charge distribution.

$$\partial v = \mathbf{M} \,.\, \Delta A / A^2 + \mathbf{F} \,.\, \partial \langle r^2 \rangle$$



Pure mass effect
Scales as A^{-2}

Size/shape effect
Scales as Z

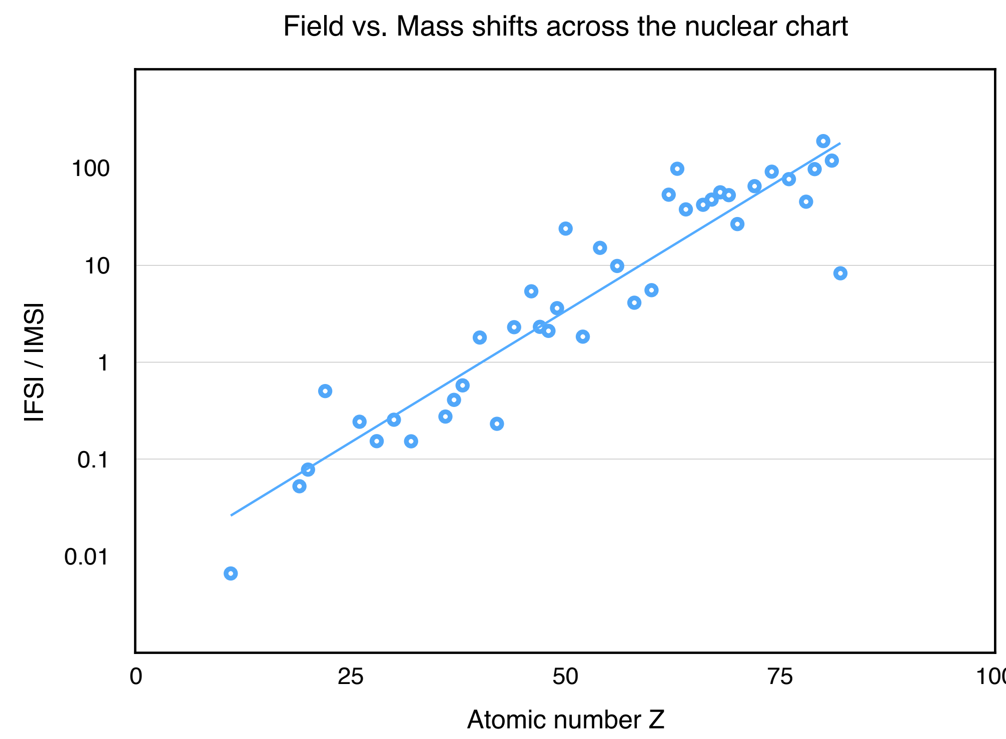
The atomic limit 1

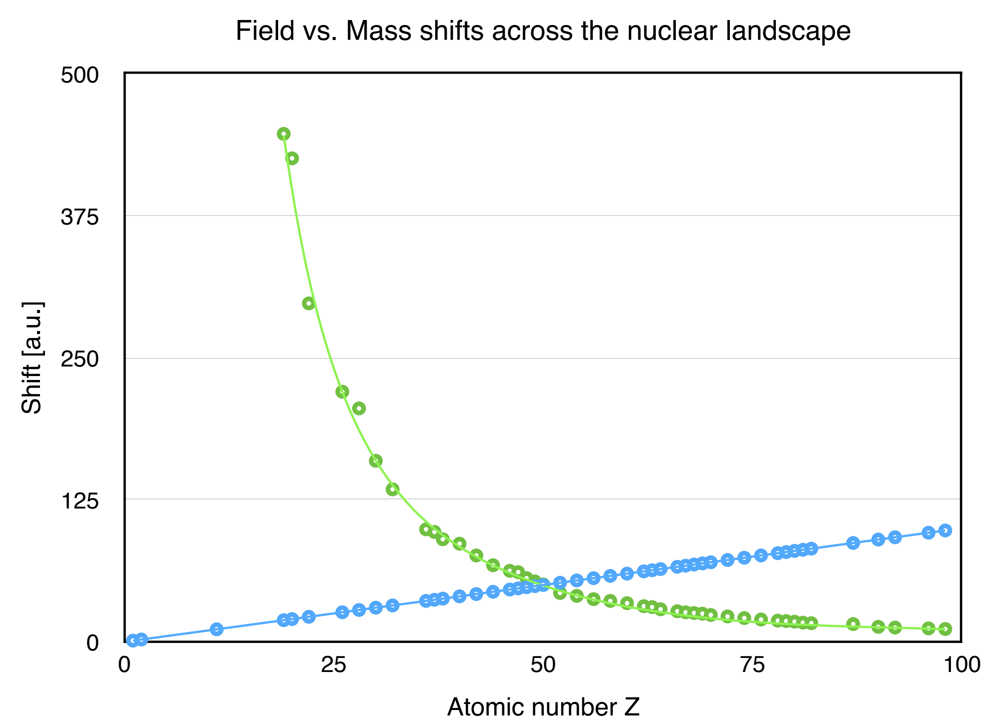
- The atomic **M** & **F** parameters can be determined exactly for **up to 3 electrons**.

see e.g. Yan & Drake, PRL 91:113004 (2003).

- Heavier systems must rely on models with large assumptions and sometimes questionable convergence.

see e.g. Dzuba, Johnson & Safronova, PRA 72:022503 (2005), Cheal, Cocolios & Fritzsche, PRA 86:042501 (2012).





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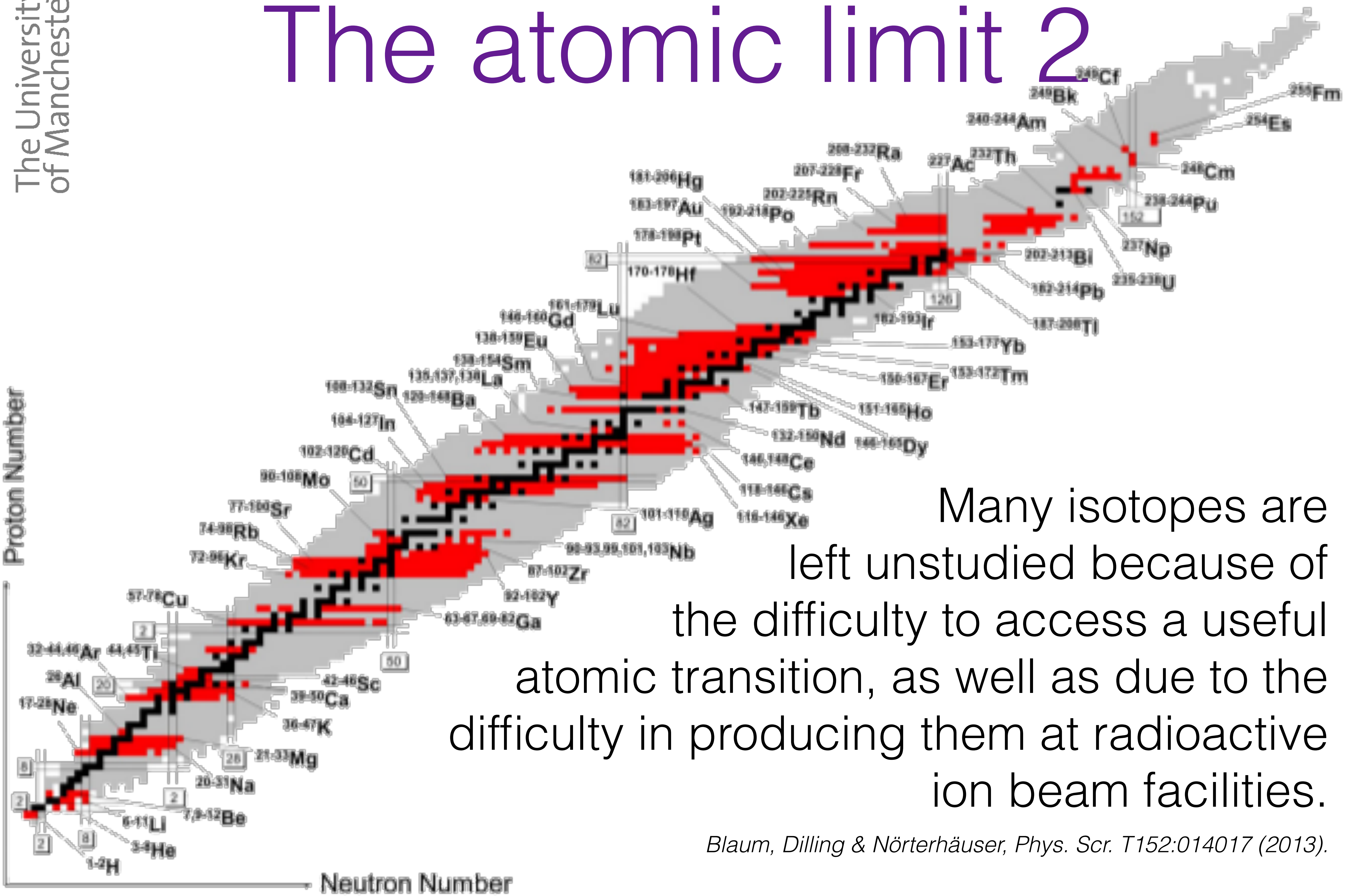
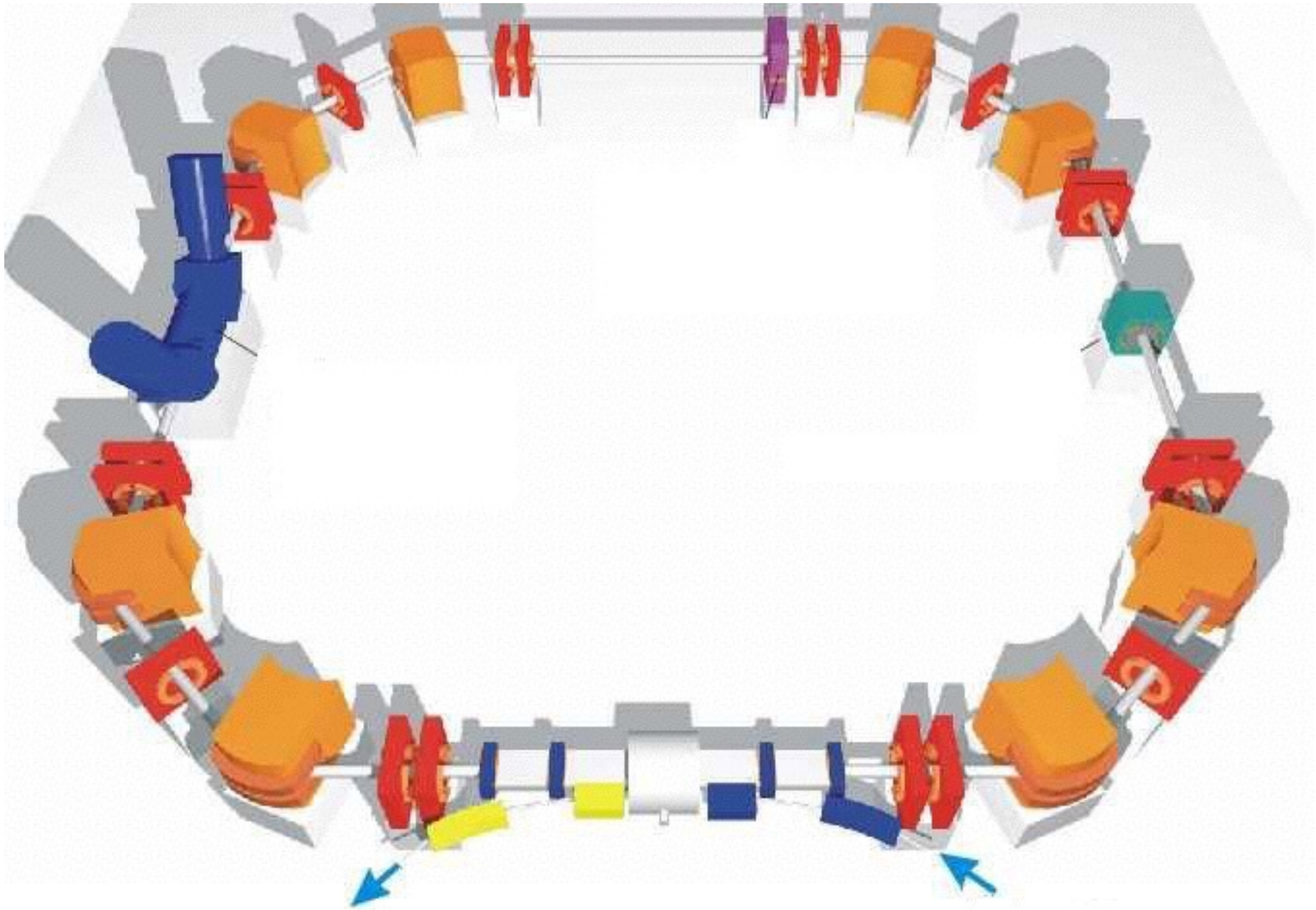
The atomic limit 2



Many isotopes are left unstudied because of the difficulty to access a useful atomic transition, as well as due to the difficulty in producing them at radioactive ion beam facilities.

Blaum, Dilling & Nörterhäuser, Phys. Scr. T152:014017 (2013).



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The solution!

Highly-charged ions

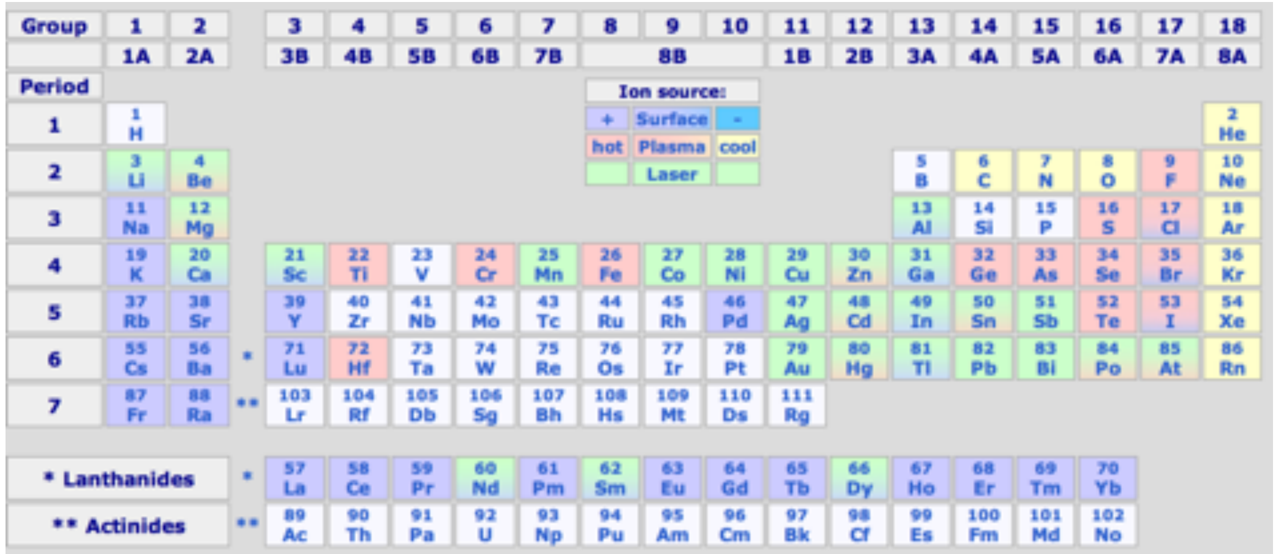
- Phase 1: EBIS-produced beams with **A/q ~ 4**.
  - Li-like with A/q ∊ [2.5; 4]: $^{9\text{-}12}$C, $^{12\text{-}16}$N, $^{13\text{-}20}$O
  - **Atomic parameters can be calculated exactly**
  - Some atomic transitions are known in the deep UV => high velocity in the TSR provides **Doppler correction** into the visible range.

Limited to elements lighter than Ni.

	Z	A	1	2	3	4	5	6
C	6	9	9	4.5	3	2.25	1.8	1.5
	6	10	10	5	3.33	2.5	2	1.66
	6	11	11	5.5	3.66	2.75	2.2	1.83
	6	12	12	6	4	3	2.4	2
	6	13	13	6.5	4.33	3.25	2.6	2.16
	6	14	14	7	4.66	3.5	2.8	2.33
	6	15	15	7.5	5	3.75	3	2.5
	6	16	16	8	5.33	4	3.2	2.66
	6	17	17	8.5	5.66	4.25	3.4	2.83
	6	18	18	9	6	4.5	3.6	3
	6	20	20	10	6.66	5	4	3.33
	6	22	22	11	7.33	5.5	4.4	3.66

Mission Beam Impossible

- ISOLDE is famous for its wide variety of beams.
- ISOLDE is equally famous for its gaps in the periodic table of elements
- Many beams are best extracted as molecular beams, *e.g.* CO_2, Cl_2, XF_x



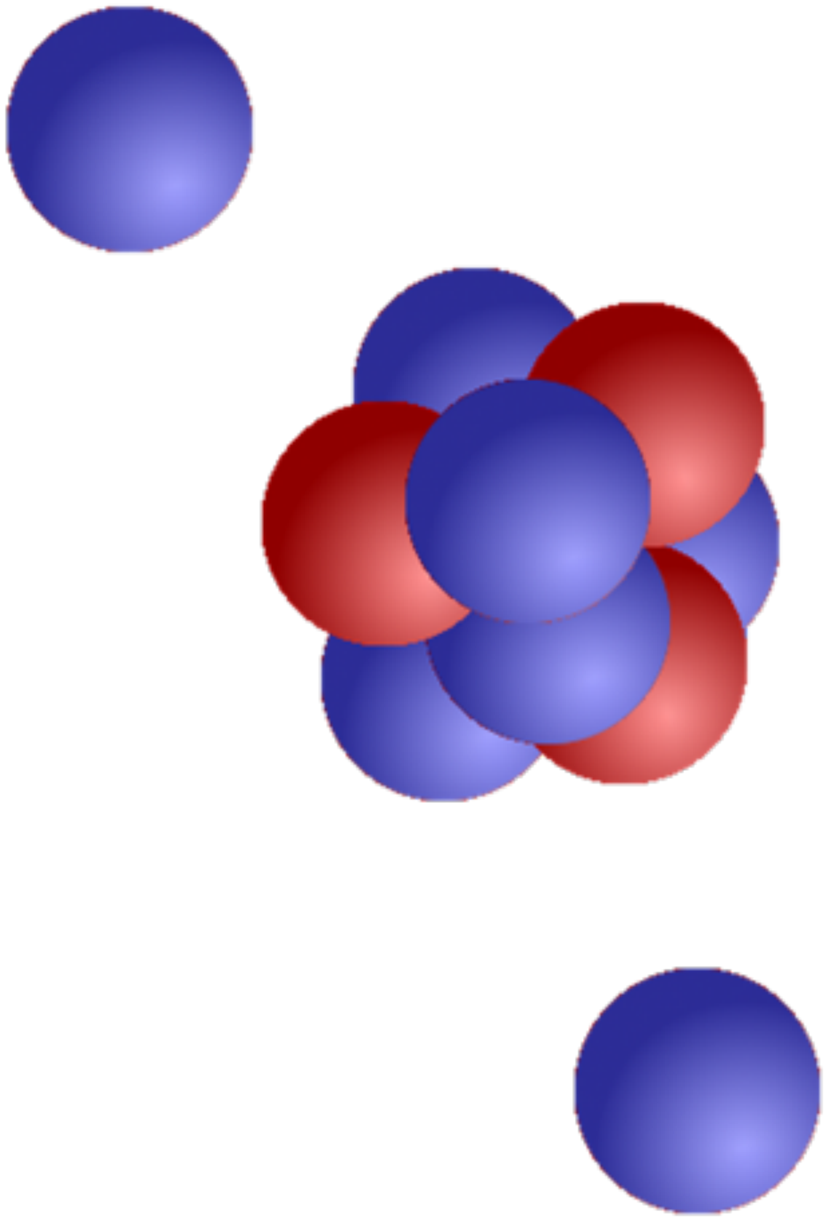
Molecules can be broken down in the EBIS and delivered as mono-atomic ions.

Recirculating beams

- Recirculating the beams increases the interaction between the ions and the laser beam dramatically without the losses associated with optical pumping.

- Transitions of interest may start from a metastable state and may be depopulated after the first interaction

  => Repopulate with the electron cooler?



Physics interest

As proposed in the ISOL-SRS programme to the STFC

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Halo structure & Magicity

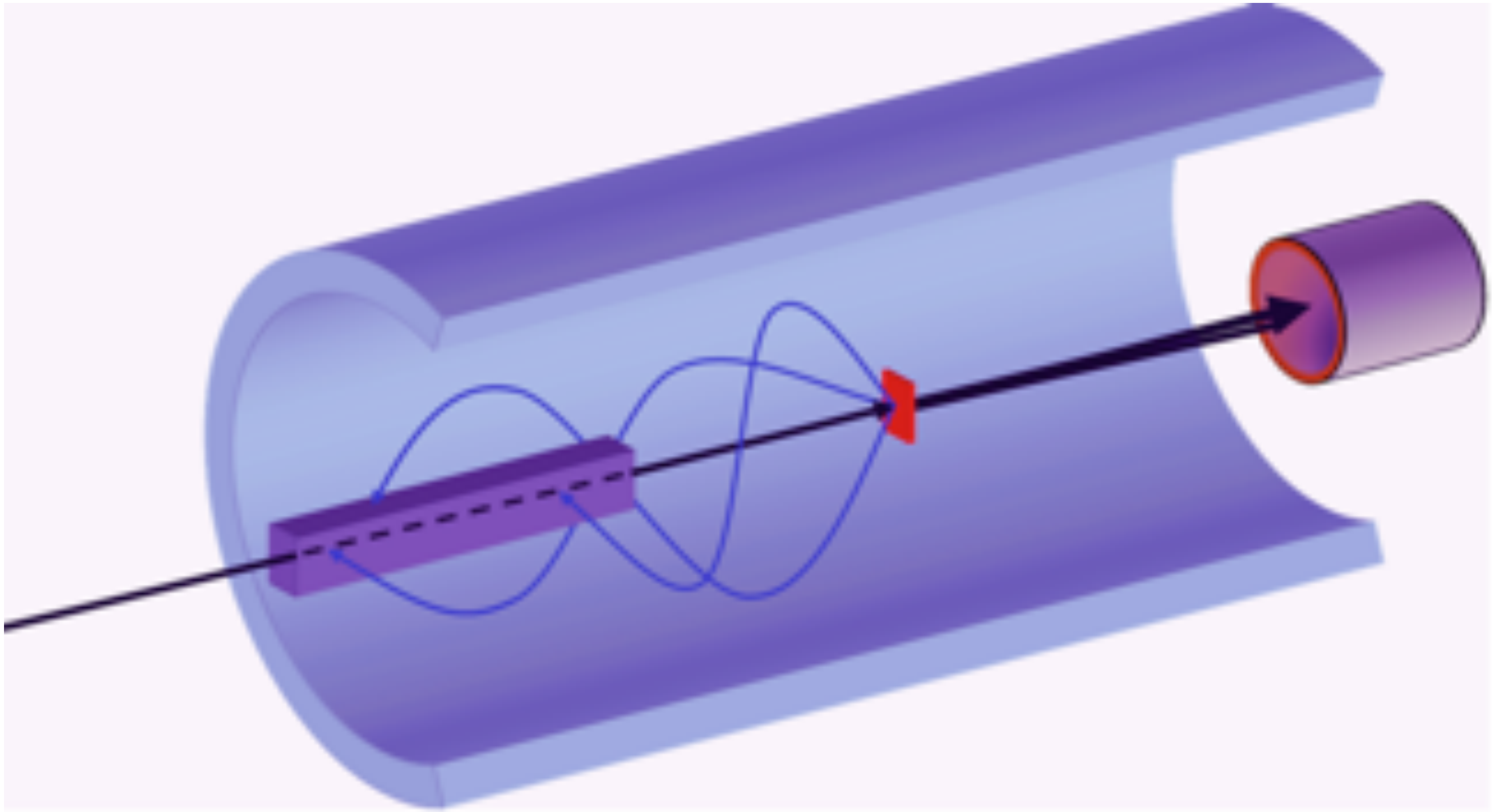
- $^{9\text{-}12}C$, $^{12\text{-}16}N$, $^{13\text{-}20}O$ are accessible at the TSR for laser spectroscopy.

- Those isotopes may present halo structures at the border of existence, and the study of the charge radii along the chain is an observable providing insight into this phenomenon.

e.g. He: P. Mueller et al., PRL 99:252501 (2007) ; Li: R. S·nchez et al., PRL 96:033002 (2006) .

- New magic numbers are found away from stability amongst these isotopes and the study of electromagnetic nuclear moments can help shed light on this phenomenon.

e.g. N=16: A. Ozawa et al., PRL 84:5493 (2000) .



Out-of-ring interest

There is more than spectroscopy to the lasers

Polarised beams

- Nucleon transfer reactions provide many observables on nuclear states, one of which is the angular momentum l of the state of interest.

- Transfer reactions with polarised beams provide additional information from which j^{π} can be deduced.

- Laser spectroscopy can be applied to polarise beams of isotopes, provided the ions can be irradiated multiple times. The recirculation will offer this possibility.

Outlook

- Laser spectroscopy of Li-like ions provides reference information for extended studies on isotopic chains.
- Molecular break-up in EBIS gives access to mono-atomic ion beams from extracting 'impossible' beams.
- Laser spectroscopy could be applied to polarise ion beams for transfer reactions.
- A user group is being established, lead by Kieran Flanagan (Manchester).