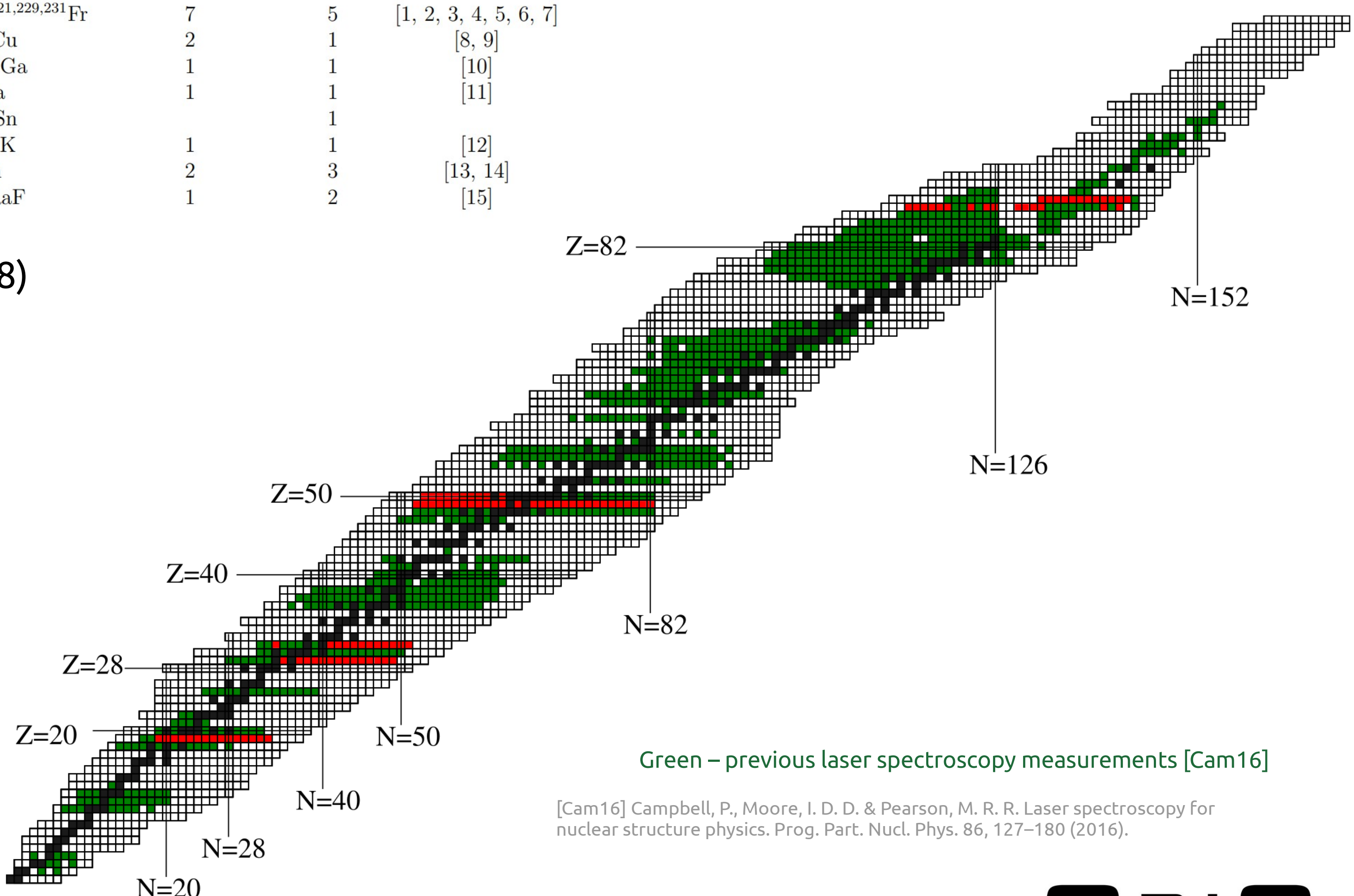
Status report from the CRIS collaboration (INTC-SR-098)

Adam R. Vernon
(K.U. Leuven)
On Behalf of the CRIS collaboration

Overview of CRIS measurements from run 2

Experiment Number	Isotopes	Papers Published or Submitted	PhD Students	References
IS471	$^{202-207,211,214,218-221,229,231}$Fr	7	5	[1, 2, 3, 4, 5, 6, 7]
IS531	$^{64,66,68-78}$Cu	2	1	[8, 9]
IS571	$^{65,67,75,79-82}$Ga	1	1	[10]
IS594	$^{222-233}$Ra	1	1	[11]
IS613	$^{104-111,113}$Sn		1	
IS620	$^{38-47,50-52}$K	1	1	[12]
IS639	$^{101-131}$In	2	3	[13, 14]
IS657	$^{223-226,228}$RaF	1	2	[15]

(see INTC-SR-098)

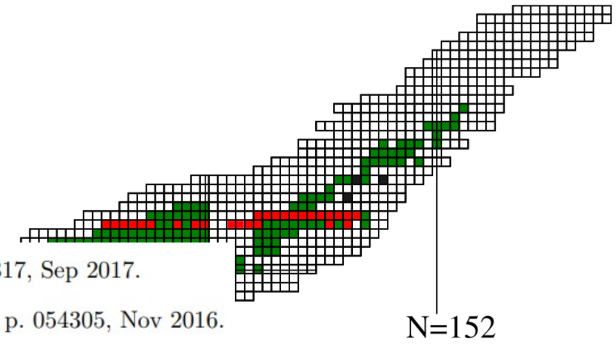


Green – previous laser spectroscopy measurements [Cam16]

[Cam16] Campbell, P., Moore, I. D. D. & Pearson, M. R. R. Laser spectroscopy for nuclear structure physics. Prog. Part. Nucl. Phys. 86, 127–180 (2016).

Overview of CRIS measurements from run 2

Experiment Number	Isotopes	Papers Published or Submitted	PhD Students	References
IS471	$^{202-207,211,214,218-221,229,231}$Fr	7	5	[1, 2, 3, 4, 5, 6, 7]
IS531	$^{64,66,68-78}$Cu	2	1	[8, 9]
IS571	$^{65,67,75,79-82}$Ga	1	1	[10]
IS594	$^{222-233}$Ra	1	1	[11]
IS613	$^{104-111,113}$Sn		1	
IS620	$^{38-47,50-52}$K	1	1	[12]
IS639	$^{101-131}$In	2	3	[13, 14]
IS657	$^{223-226,228}$RaF	1	2	[15]



Work on Fr, Ra and Ga has concluded in 2018

[1] S. G. Wilkins, K. M. Lynch, *et al.* *Phys. Rev. C*, vol. 96, p. 034317, Sep 2017.

[2] G. J. Farooq-Smith, T. E. Cocolios, *et al.* *Phys. Rev. C*, vol. 94, p. 054305, Nov 2016.

[3] K. M. Lynch, T. E. Cocolios, *et al.* *Phys. Rev. C*, vol. 93, p. 014319, Jan 2016.

[4] R. P. de Groote, I. Budinčević, *et al.* *Phys. Rev. Lett.*, vol. 115, p. 132501, Sep 2015.

[5] I. Budinčević *et al.* *Phys. Rev. C*, vol. 90, p. 014317, Jul 2014.

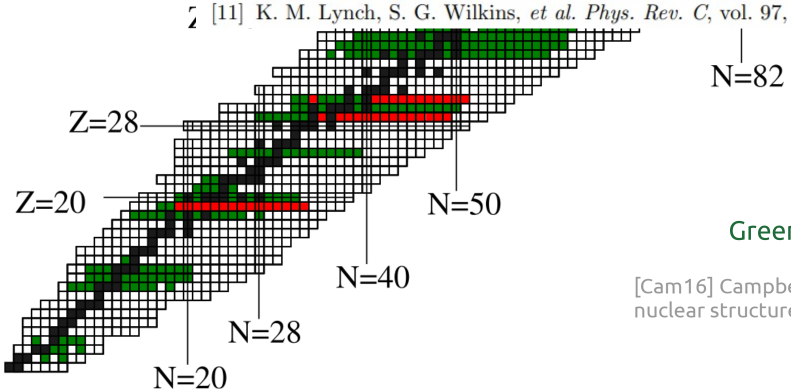
[6] K. M. Lynch *et al.* *Phys. Rev. X*, vol. 4, p. 011055, Mar 2014.

[7] K. T. Flanagan, K. M. Lynch, *et al.* *Phys. Rev. Lett.*, vol. 111, p. 212501, Nov 2013.

[10] G. J. Farooq-Smith *et al.* *Phys. Rev. C*, vol. 96, p. 044324, Oct 2017.

[11] K. M. Lynch, S. G. Wilkins, *et al.* *Phys. Rev. C*, vol. 97, p. 024309, Feb 2018.

126

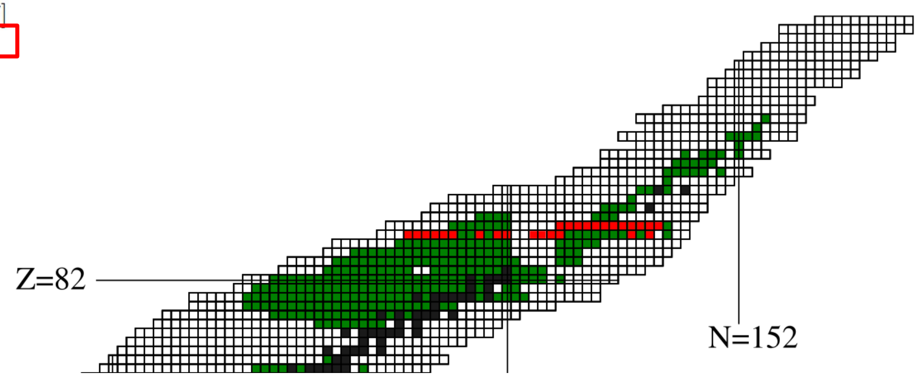


Green – previous laser spectroscopy measurements [Cam16]

[Cam16] Campbell, P., Moore, I. D. D. & Pearson, M. R. R. Laser spectroscopy for nuclear structure physics. Prog. Part. Nucl. Phys. 86, 127–180 (2016).

Overview of CRIS measurements from run 2

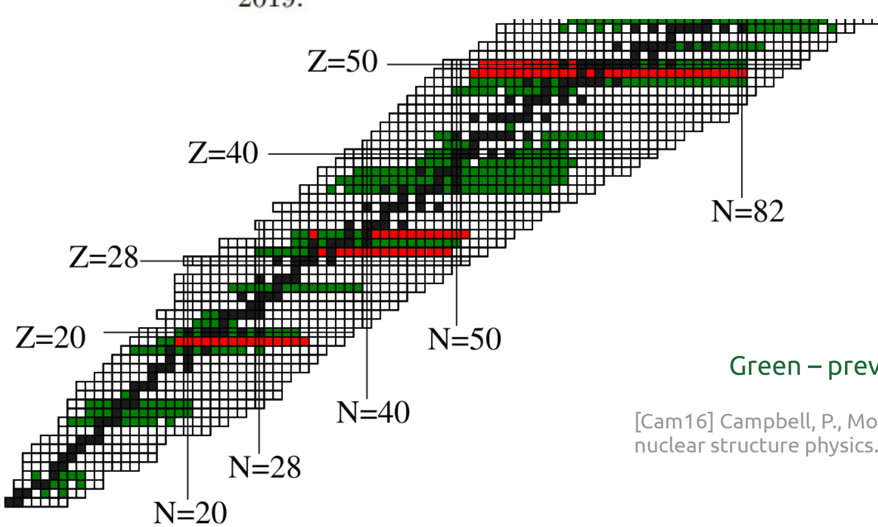
Experiment Number	Isotopes	Papers Published or Submitted	PhD Students	References
IS471	$^{202-207,211,214,218-221,229,231}$Fr	7	5	[1, 2, 3, 4, 5, 6, 7]
IS531	$^{64,66,68-78}$Cu	2	1	[8, 9]
IS571	$^{65,67,75,79-82}$Ga	1	1	[10]
IS594	$^{222-233}$Ra	1	1	[11]
IS613	$^{104-111,113}$Sn		1	
IS620	$^{38-47,50-52}$K	1	1	[12]
IS639	$^{101-131}$In	2	3	[13, 14]
IS657	$^{223-226,228}$RaF	1	2	[15]



Work on Cu concluded and publications submitted

[8] R. P. de Groote *et al. Phys. Rev. C*, vol. 96, p. 041302, Oct 2017.

[9] R. P. de Groote *et al. Accepted for publication in Nature Physics*, vol. arXiv 1911.08765, 2019.

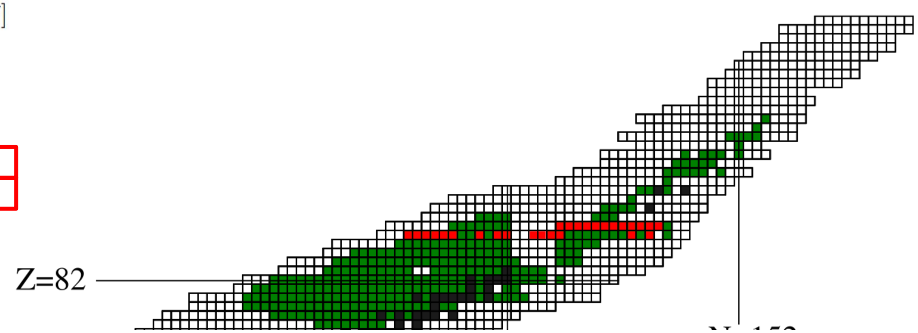


Green – previous laser spectroscopy measurements [Cam16]

[Cam16] Campbell, P., Moore, I. D. D. & Pearson, M. R. R. Laser spectroscopy for nuclear structure physics. Prog. Part. Nucl. Phys. 86, 127–180 (2016).

Overview of CRIS measurements from run 2

Experiment Number	Isotopes	Papers Published or Submitted	PhD Students	References
IS471	$^{202-207,211,214,218-221,229,231}$Fr	7	5	[1, 2, 3, 4, 5, 6, 7]
IS531	$^{64,66,68-78}$Cu	2	1	[8, 9]
IS571	$^{65,67,75,79-82}$Ga	1	1	[10]
IS594	$^{222-233}$Ra	1	1	[11]
IS613	$^{104-111,113}$Sn		1	
IS620	$^{38-47,50-52}$K	1	1	[12]
IS639	$^{101-131}$In	2	3	[13, 14]
IS657	$^{223-226,228}$RaF	1	2	[15]



[12] A. Koszorús, X. F. Yang, *et al. Phys. Rev. C*, vol. 100, p. 034304, Sep 2019.

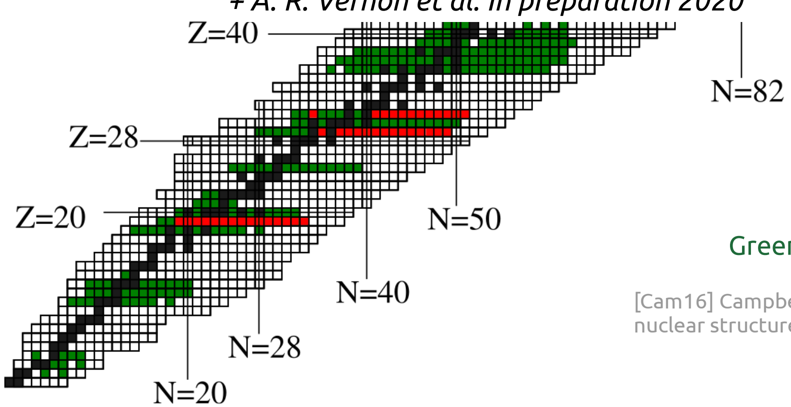
[13] R. F. Garcia Ruiz, A. R. Vernon, C. L. Binnersley, B. K. Sahoo, *et al. Phys. Rev. X*, vol. 8, p. 041005, Oct 2018.

[14] B. K. Sahoo, A. R. Vernon, R. F. G. Ruiz, *et al. New Journal of Physics*, 2020.

+ A. Koszorus et al. In preparation 2020

+ A. R. Vernon et al. In preparation 2020

Articles for neutron-rich K and In submitted and in preparation
Plans to propose further measurements in run 3



Green – previous laser spectroscopy measurements [Cam16]

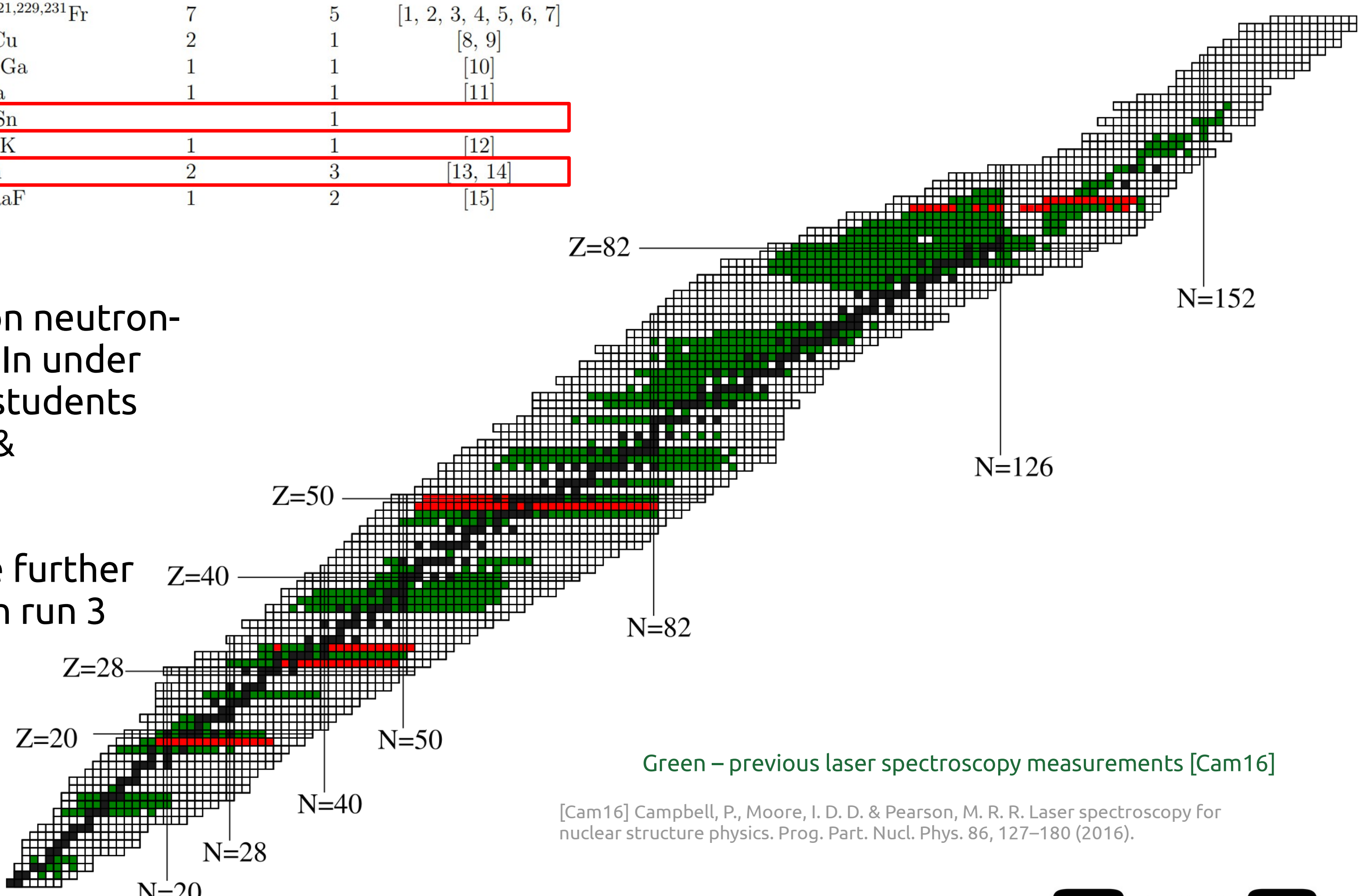
[Cam16] Campbell, P., Moore, I. D. D. & Pearson, M. R. R. Laser spectroscopy for nuclear structure physics. Prog. Part. Nucl. Phys. 86, 127–180 (2016).

Overview of CRIS measurements from run 2

Experiment Number	Isotopes	Papers Published or Submitted	PhD Students	References
IS471	$^{202-207,211,214,218-221,229,231}$Fr	7	5	[1, 2, 3, 4, 5, 6, 7]
IS531	$^{64,66,68-78}$Cu	2	1	[8, 9]
IS571	$^{65,67,75,79-82}$Ga	1	1	[10]
IS594	$^{222-233}$Ra	1	1	[11]
IS613	$^{104-111,113}$Sn		1	
IS620	$^{38-47,50-52}$K	1	1	[12]
IS639	$^{101-131}$In	2	3	[13, 14]
IS657	$^{223-226,228}$RaF	1	2	[15]

Measurements on neutron-deficient Sn and In under analysis by PhD students F. P. Gustafsson & C. M. Ricketts

Plans to propose further measurements in run 3



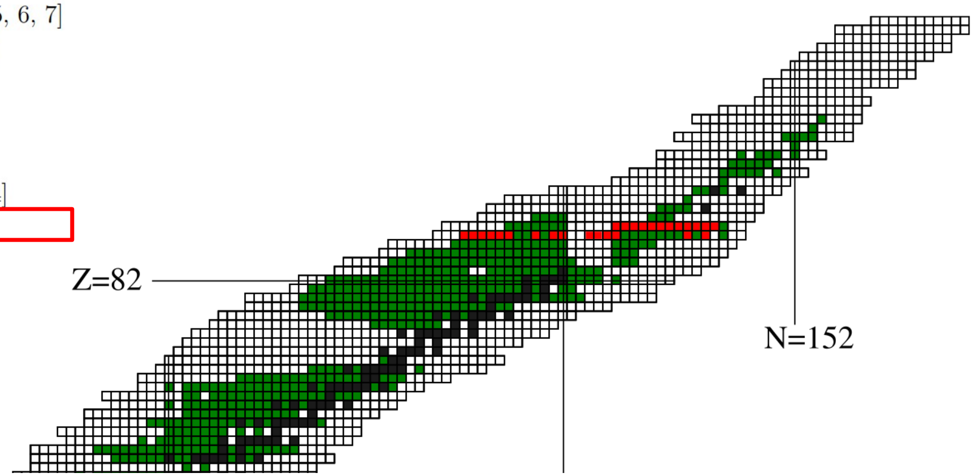
Green – previous laser spectroscopy measurements [Cam16]

[Cam16] Campbell, P., Moore, I. D. D. & Pearson, M. R. R. Laser spectroscopy for nuclear structure physics. Prog. Part. Nucl. Phys. 86, 127–180 (2016).

CRIS

Overview of CRIS measurements from run 2

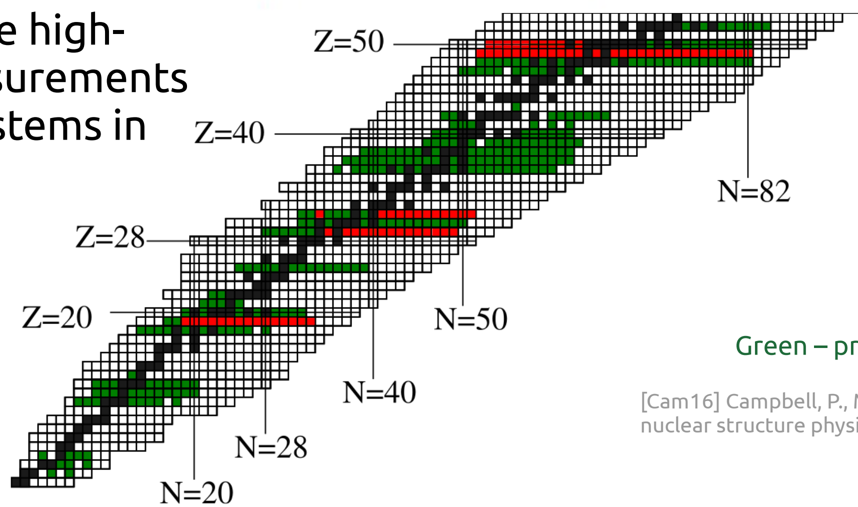
Experiment Number	Isotopes	Papers Published or Submitted	PhD Students	References
IS471	$^{202-207,211,214,218-221,229,231}Fr$	7	5	[1, 2, 3, 4, 5, 6, 7]
IS531	$^{64,66,68-78}Cu$	2	1	[8, 9]
IS571	$^{65,67,75,79-82}Ga$	1	1	[10]
IS594	$^{222-233}Ra$	1	1	[11]
IS613	$^{104-111,113}Sn$		1	
IS620	$^{38-47,50-52}K$	1	1	[12]
IS639	$^{101-131}In$	2	3	[13, 14]
IS657	$^{223-226,228}RaF$	1	2	[15]



[15] R. F. G. Ruiz, R. Berger, *et al.* *Submitted to Nature*, vol. arXiv 1910.13416, 2019.

Articles submitted for RaF

Plans to propose high-resolution measurements of molecular systems in run 3



Green – previous laser spectroscopy measurements [Cam16]

[Cam16] Campbell, P., Moore, I. D. D. & Pearson, M. R. R. Laser spectroscopy for nuclear structure physics. Prog. Part. Nucl. Phys. 86, 127–180 (2016).

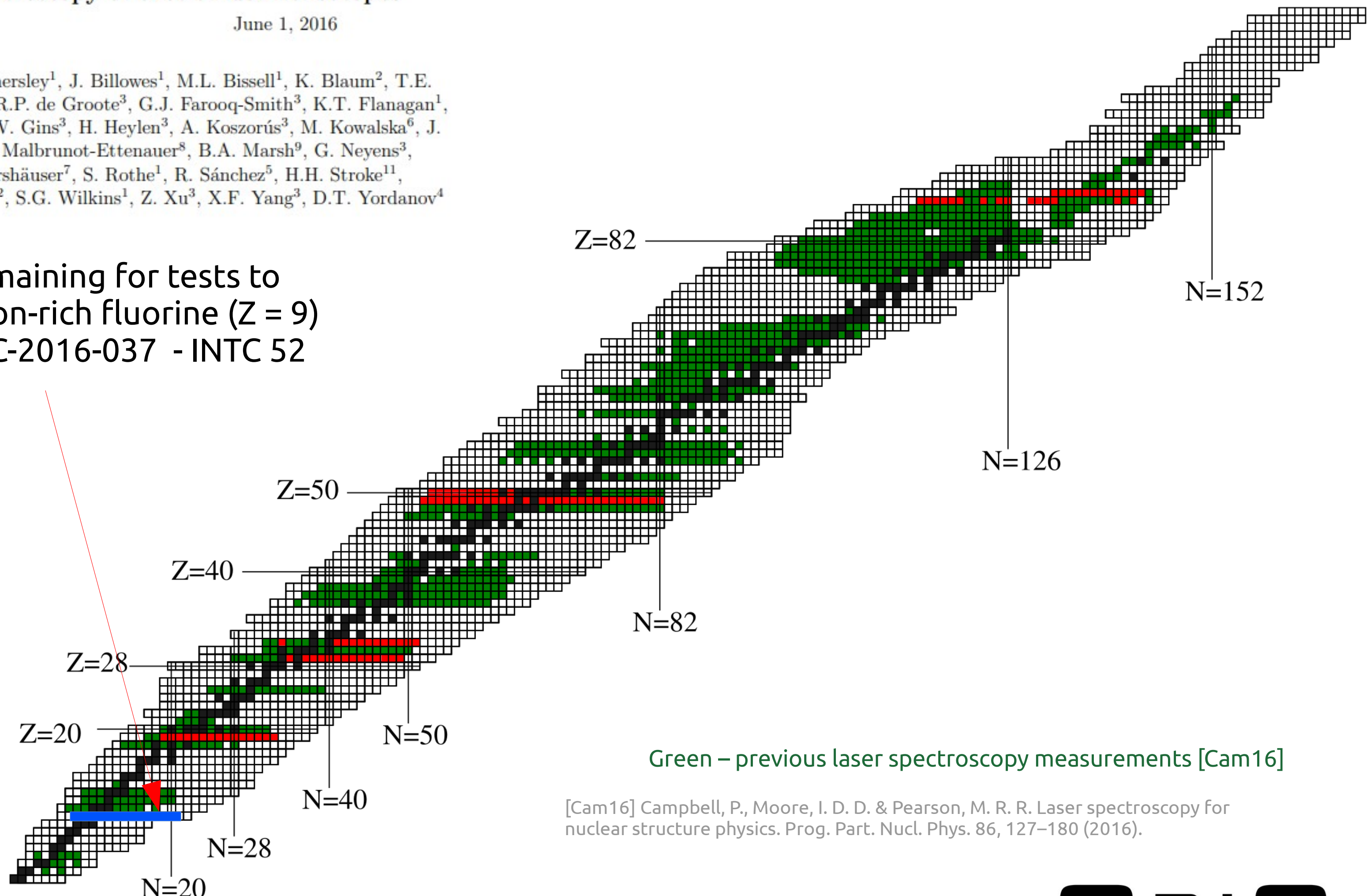
Overview of CRIS measurements from run 2

Towards laser spectroscopy of exotic fluorine isotopes

June 1, 2016

R.F. Garcia Ruiz[1], C.L. Binnersley[1], J. Billowes[1], M.L. Bissell[1], K. Blaum[2], T.E. Cocolios[3], T. Day Goodacre[1], R.P. de Groote[3], G.J. Farooq-Smith[3], K.T. Flanagan[1], S. Franchoo[4], W. Geithner[5], W. Gins[3], H. Heylen[3], A. Koszorús[3], M. Kowalska[6], J. Krämer[7], K.M. Lynch[8], S. Malbrunot-Ettenauer[8], B.A. Marsh[9], G. Neyens[3], R. Neugart[2,10], W. Nörtershäuser[7], S. Rothe[1], R. Sánchez[5], H.H. Stroke[11], A.R. Vernon[1], K.D.A. Wendt[12], S.G. Wilkins[1], Z. Xu[3], X.F. Yang[3], D.T. Yordanov[4]

13/13 shifts remaining for tests to measure neutron-rich fluorine (Z = 9)
I171 CERN-INTC-2016-037 - INTC 52

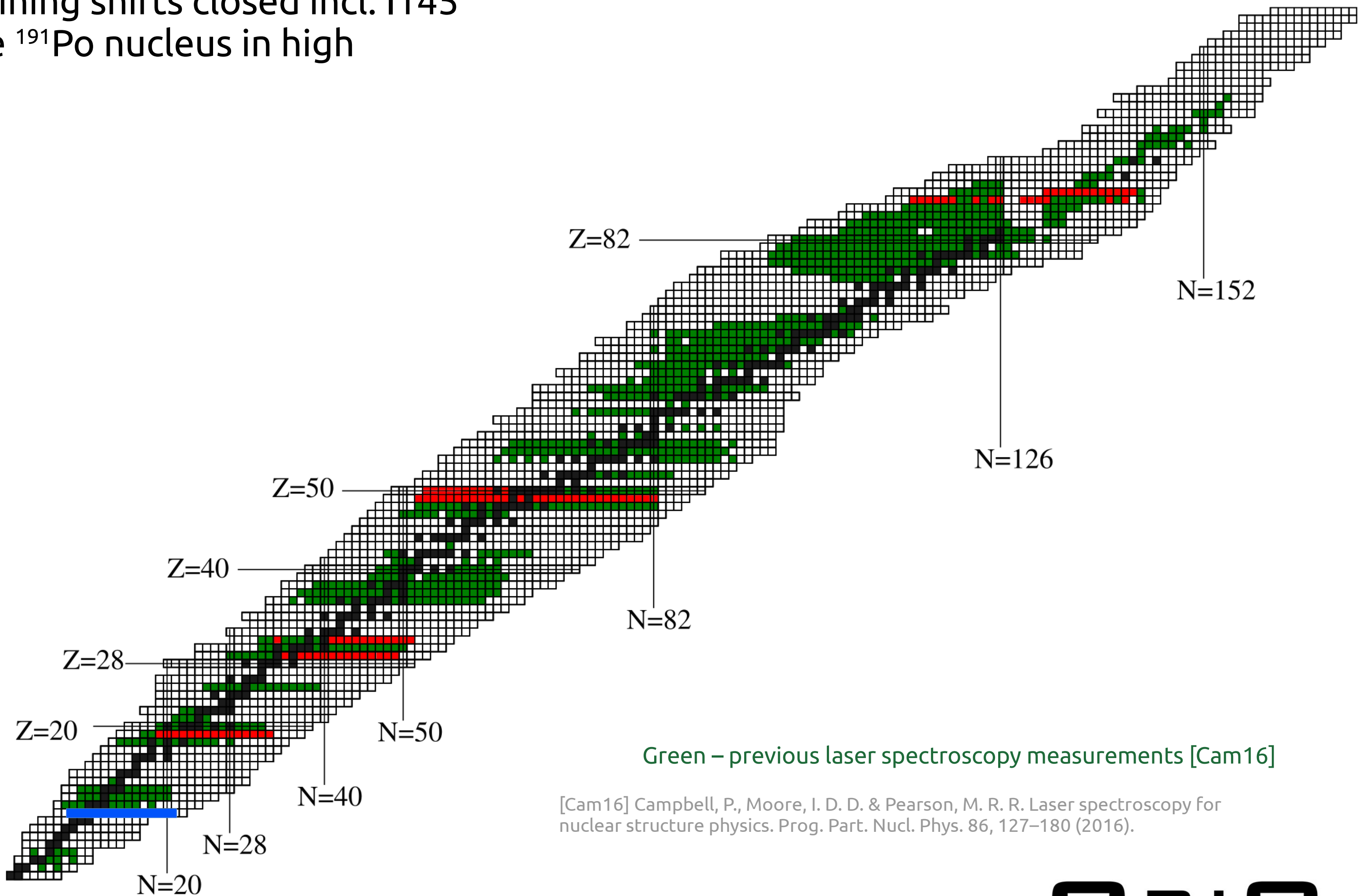


Green – previous laser spectroscopy measurements [Cam16]

[Cam16] Campbell, P., Moore, I. D. D. & Pearson, M. R. R. Laser spectroscopy for nuclear structure physics. Prog. Part. Nucl. Phys. 86, 127–180 (2016).

Overview of CRIS measurements from run 2

All other remaining shifts closed incl. I145
LoI to measure ^{191}Po nucleus in high resolution

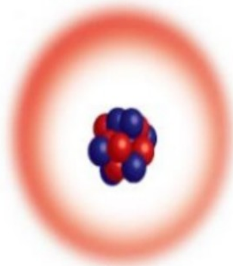


Green – previous laser spectroscopy measurements [Cam16]

[Cam16] Campbell, P., Moore, I. D. D. & Pearson, M. R. R. Laser spectroscopy for nuclear structure physics. Prog. Part. Nucl. Phys. 86, 127–180 (2016).

Laser spectroscopy of exotic fluorine isotopes

- Shifts outstanding on the joint LoI (I171 CERN-INTC-2016-037) with COLLAPS submitted in 2016 – Spokesperson R. F. Garcia Ruiz
- Fluorine one proton outside of $Z = 8$ shell closure of oxygen
- ^{17,23,25}F isotopes described as weakly bound proton halo states outside of doubly-magic cores (^{16,22,24}O) [Hag10]
- ^{18}F ($Z = N = 9$) and ^{24,26}F sensitive probes of proton-neutron interactions [Kan14,Lep13]
- Quantum Monte Carlo methods are now able to calculate electromagnetic properties in the oxygen region [Lon18]
- Charge radii demonstrated to be uniquely sensitive to components of the nuclear force in chiral EFT calculations of ^{16}O [Eks19]
- <u>An important nuclear many-body system but challenging to measure with laser spectroscopy</u>



[Kan14] Kanada-En'yo, Y. & Kobayashi, F. Mixing of parity of a nucleon pair at the nuclear surface due to the spin-orbit potential in 18F. Phys. Rev. C 90, 054332 (2014).
[Lep13] Lepailleur, A. et al. Spectroscopy of 26F to probe proton-neutron forces close to the dripline. Phys. Rev. Lett. 110, 082502 (2013).
[Eks19] Ekström, A. & Hagen, G. Global Sensitivity Analysis of Bulk Properties of an Atomic Nucleus. Phys. Rev. Lett. 123, (2019).
[Hag10] Hagen, G., Papenbrock, T. & Hjorth-Jensen, M. Ab-initio computation of the F17 proton halo state and resonances in A=17 nuclei. Phys. Rev. Lett. 104, (2010).
[Lon18] Lonardoni, D. et al. Properties of Nuclei up to A=16 using Local Chiral Interactions. Phys. Rev. Lett. 120, (2018).
[Lon20] Lonardoni, D. et al. Article with Fluorine in preparation

Laser spectroscopy of exotic fluorine isotopes

- Experimental challenges:
  - Transitions from atomic or ionic ground states at extreme-UV wavelengths (~93 nm)
  - Fluorine is highly reactive and readily forms molecules (e.g. F_2, AlF_3, RaF_2 …)
  - Light elements more sensitive to beam energy instabilities and require high precision measurement of isotope shift (<1 MHz)
  - PSB yields only measured for ^{17}F (1.1x10^5 ions/s using a SiC target)
  - As fluorine has only one stable isotope beam time is needed to test the isotope shift sensitivity of transitions

Laser spectroscopy of exotic fluorine isotopes

- Technical questions to be answered online (in 7 shifts of radioactive beams and 6 shifts of stable beam):

  ISOLDE measurements:
  - Yield measurements of neutron-rich $F^{\pm}$ with SiC target
  - Bunching efficiency tests with ISCOOL

- Plan I: Measurements on bunched F^{+} with pulsed lasers
  - Spectroscopy from metastable F states with CRIS
  - ^{18}F (Z = N = 9) measurement (10^5 ions/s expected yield)
    → Rough isotope shift sensitivity, new Q and μ moments
  - Charge radius of ^{17}F proton halo nucleus
  - Scheme isotope shift sensitivity, studying systematic uncertainties and laser ionization sensitivity test with contaminated beam for neutron-rich F isotopes

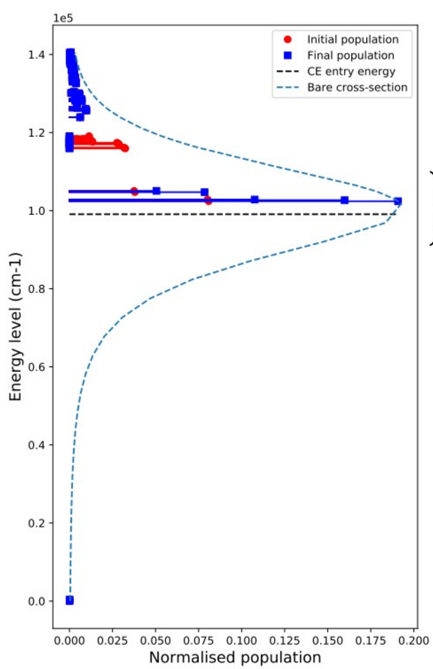
  If F^{+} bunching is not possible:
- Plan II: continuous beam alternatives
  - Re-ionization cross section measurements and technique development (COLLAPS needed)
- Plan III: F^{-} alternatives
  - ISOLDE- Yield checks of F^{-}
  - Electron detachment cross section measurements (COLLAPS needed)

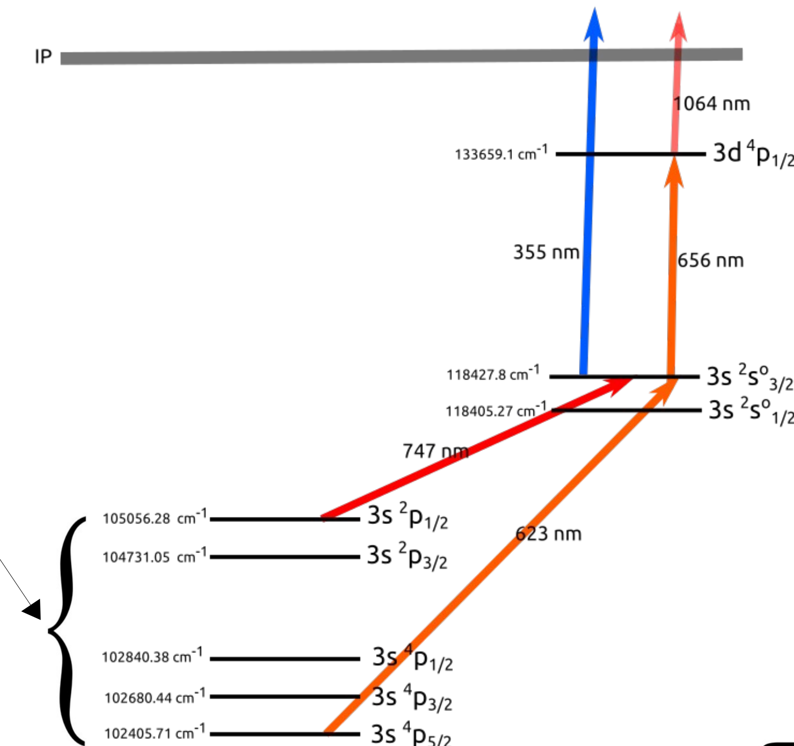
  (Plans II & III can be tested with stable beam from ISOLDE)

CRIS

Laser spectroscopy of exotic fluorine isotopes

- Plan I: Measurements on bunched F^{+} ions to test isotope shift sensitivity
  - $Na + F^{+} \rightarrow Na^{-} + F$ populates ~5 metastable states ($^{4}P_{5/2}$ lifetime and hfs known [Lev07]) with several transitions in 600-900 nm range which will work
  - Plans at CRIS to test these transitions with offline ion source for efficiency and moment sensitivity – radii will require radioactive beams

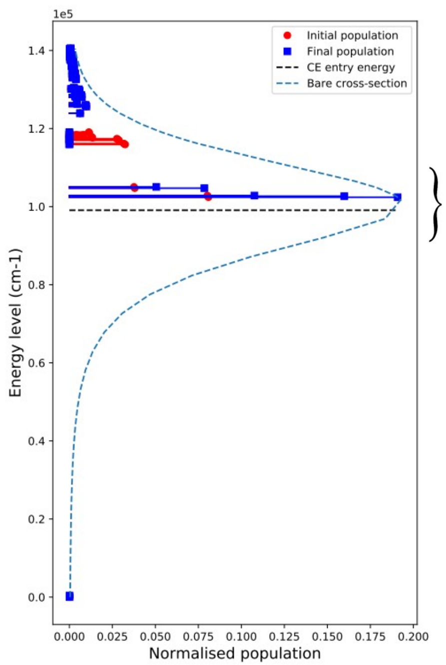


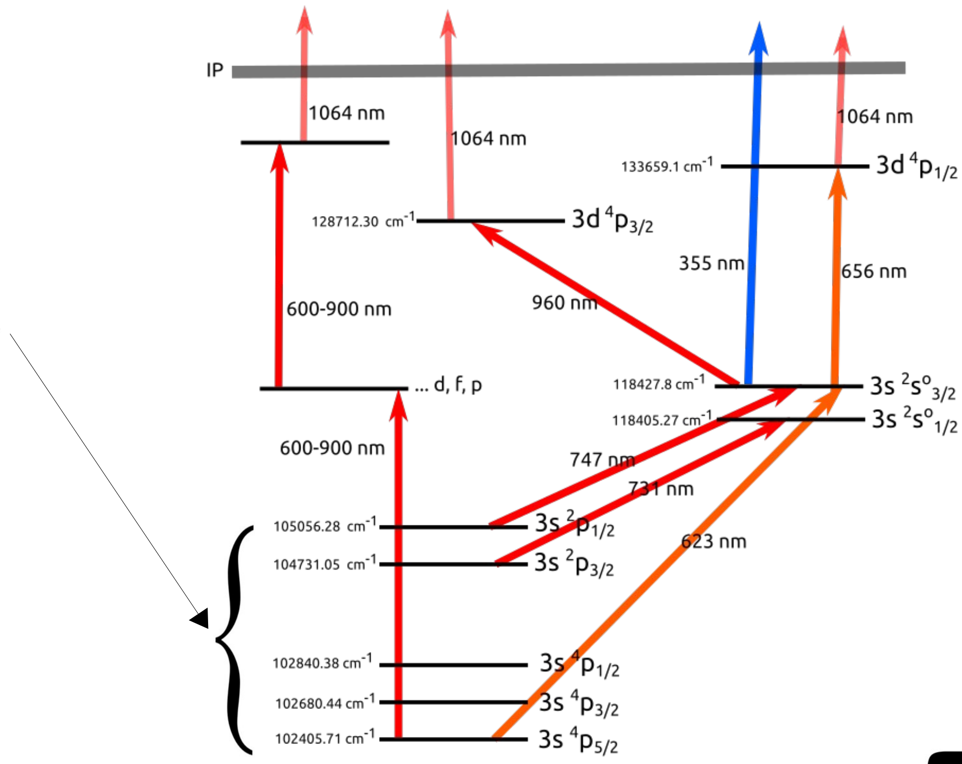


[Lev07] Levy, C. D. P. D. P. et al. Feasibility study of in-beam polarization of fluorine. NIM A 580, 1571–1577 (2007).

Laser spectroscopy of exotic fluorine isotopes

- Plan I: Measurements on bunched F^+ ions to test isotope shift sensitivity
  - Na + F^+ → Na^- + F populates ~5 metastable states ($^4P_{5/2}$ lifetime and hfs known [Lev07]) with several transitions in 600-900 nm range which will work
  - Plans at CRIS to test these transitions with offline ion source for efficiency and moment sensitivity – radii will require radioactive beams





[Lev07] Levy, C. D. P. D. P. et al. Feasibility study of in-beam polarization of fluorine. NIM A 580, 1571–1577 (2007).

Laser spectroscopy of exotic fluorine isotopes

Relevant developments with CRIS since 2016:

- Expansion in laser scheme capabilities
  - 3x simultaneous laser steps with narrowband or broadband Ti:Sa or dye range (500-900 nm transitions) + non-resonant steps from 355-1064 nm possible

Laser spectroscopy of exotic fluorine isotopes

Relevant developments with CRIS since 2016:

- Expansion in laser scheme capabilities
  - 3x simultaneous laser steps with narrowband or broadband Ti:Sa or dye range (500-900 nm transitions) + non-resonant steps from 355-1064 nm possible

- ✓ **M2 Ti:Laser and freq. Doubling cavity (735 – 975 nm 368 nm - 487 nm)**
- ✓ **Matisse dye/Ti:Sa laser and freq. Doubling cavity (550 – 1050 nm, 275 nm - 525 nm)**
- ✓ **Injection seeded Ti:Sa laser system + doubling + tripling (215 nm … 870 nm)**
- ✓ **Pulse dye amplification system**
- ✓ **Stabilized HeNe and Diode lasers**

} **Narrow band (< 50 MHz)**

- ✓ **Industrial Nd:YAG laser (13 W, 1 kHz, 120 ns)**
- ✓ **Two Ti:Sa cavities (~1.5 W, 1 kHz)**
- ✓ **Three 100 Hz Nd:YAG Litron laser systems + Two Brilliant 20 Hz Nd:YAG**
- ✓ **Cobra Pulsed-dye laser (line-width ~ 2 GHz)**
- ✓ **Two Spectra Pulsed-dye laser systems (line-width ~ 30 GHz)**

} **broad band (1-30 GHz)**

~ 20 laser systems in operation (207-1000 nm)

Laser spectroscopy of exotic fluorine isotopes

Relevant developments with CRIS since 2016:

- Expansion in laser scheme capabilities
  - 3x simultaneous laser steps with narrowband or broadband Ti:Sa or dye range (500-900 nm transitions) + non-resonant steps from 355-1064 nm possible

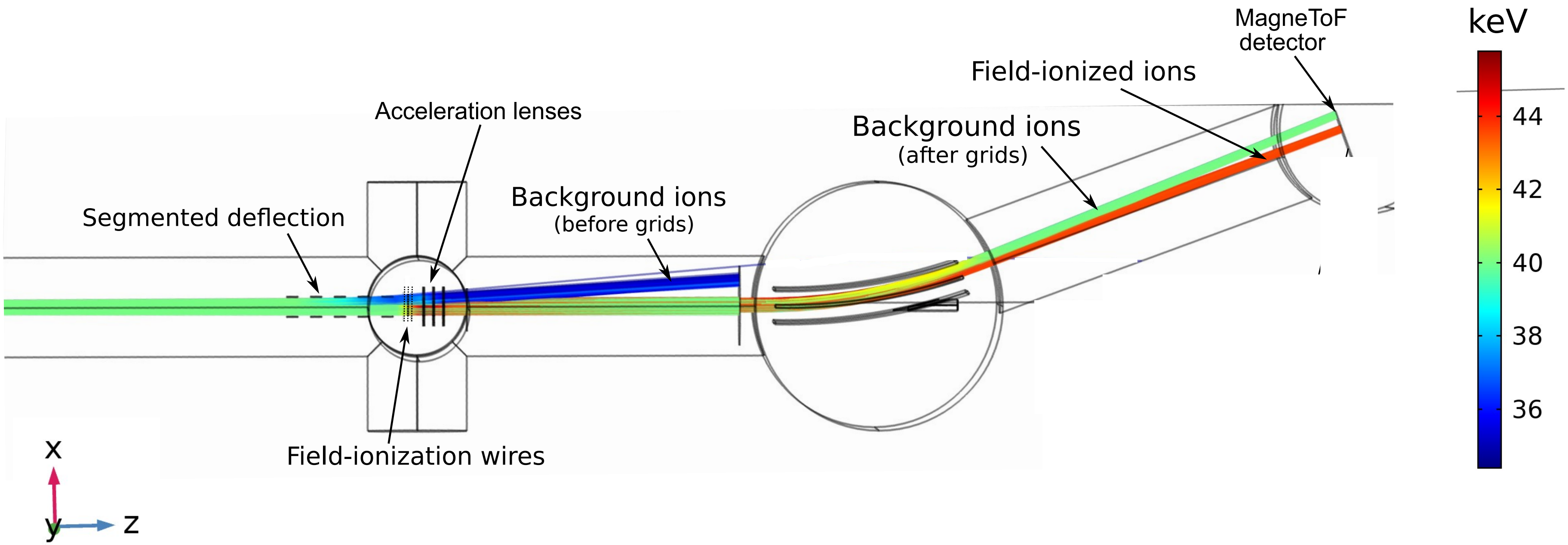
- Offline ablation ion source for pulsed beams of almost any element [Gar18]

- Precision (<1 MHz) isotope shift setup tests with light isotopes of $^{39-52}K$ [Kos19]
- β-decay assisted spectroscopy setup for background suppression

- Atomic theory developments for high accuracy field and specific mass shift factors benchmarked [Sah20]

[Sah20] Sahoo, B. K. , Vernon, A. R. et al. Analytic response relativistic coupled-cluster theory: the first application to indium isotope shifts. New J. Phys. 22, 012001 (2020).
[Kos19] Koszorús et al. Precision measurements of the charge radii of potassium isotopes. Phys. Rev. C 100, (2019).
[Gar18] Garcia Ruiz, R. F., Vernon, A. R. et al. High-Precision Multiphoton Ionization of Accelerated Laser-Ablated Species. Phys. Rev. X 8, (2018).

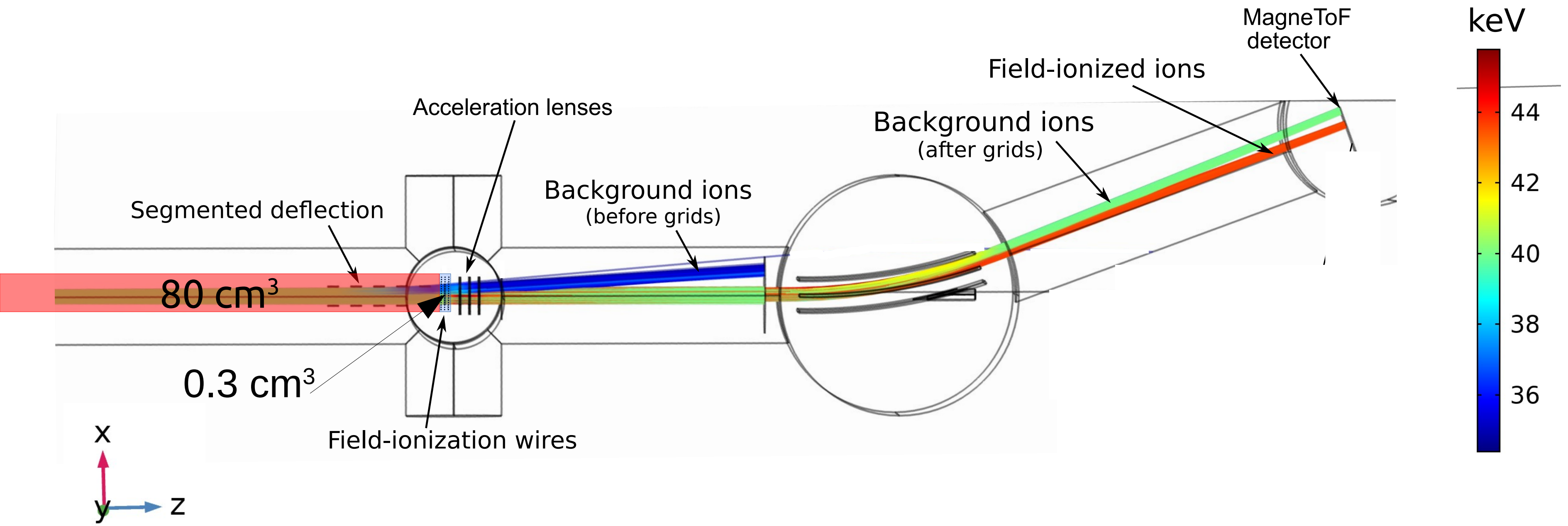
Laser spectroscopy of exotic fluorine isotopes



- Rydberg field-ionization setup tested with Zn and In
  - Increased background suppression
  - ISCOOL bunching times can be tested down to 0.1 ms

CRIS

Laser spectroscopy of exotic fluorine isotopes



- Rydberg field-ionization setup tested with Zn and In
  - Increased background suppression
  - ISCOOL bunching times can be tested down to 0.1 ms

Laser spectroscopy of exotic fluorine isotopes

Relevant developments with CRIS since 2016:

- Expansion in laser scheme capabilities
  - 3x simultaneous laser steps with narrowband or broadband Ti:Sa or dye range (500-900 nm transitions) + non-resonant steps from 355-1064 nm possible

- Offline ablation ion source for pulsed beams of almost any element [Gar18]

- Precision isotope shift tests with light isotopes of $^{39-52}K$ [Kos19]
- β-decay assisted spectroscopy setup for background suppression

- Atomic theory developments for high accuracy field and specific mass shift factors benchmarked [Sah20]

- Rydberg field-ionization setup tested with Zn and In
  - Increased background suppression
  - ISCOOL bunching times can be tested down to 0.1 ms

[Sah20] Sahoo, B. K. , Vernon, A. R. et al. Analytic response relativistic coupled-cluster theory: the first application to indium isotope shifts. New J. Phys. 22, 012001 (2020).
[Kos19] Koszorús et al. Precision measurements of the charge radii of potassium isotopes. Phys. Rev. C 100, (2019).
[Gar18] Garcia Ruiz, R. F., Vernon, A. R. et al. High-Precision Multiphoton Ionization of Accelerated Laser-Ablated Species. Phys. Rev. X 8, (2018).

Laser spectroscopy of exotic fluorine isotopes

We will try to answer the following questions with produced with bunched ^{19}F ($I^{\pi}=5/2^{+}$) using ablation this year to prepare:

1) What is the energy spread of fluorine produced by ablation?
   - ISCOOL may be needed for high-resolution studies

2) Study systematics to extract hfs and reduce beam energy dependence

3) Scheme testing for electric quadrupole and magnetic dipole moment sensitivity

4) Population and lifetime testing of metastable states

5) Total ionization scheme efficiencies and background rates

6) Testing for a sensitive Rydberg state field-ionization scheme

<u>Ultimately radioactive beam from ISOLDE will be needed to answer the most important questions → neutron-rich F yield, bunching efficiency and isotope shift sensitivity</u>

Thanks for listening!

Global sensitivity analysis of bulk properties of an atomic nucleus

Andreas Ekström[1] and Gaute Hagen[2,3]

[1]*Department of Physics, Chalmers University of Technology, SE-412 96 Göteborg, Sweden*
[2]*Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA*
[3]*Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA*

(Dated: October 8, 2019)

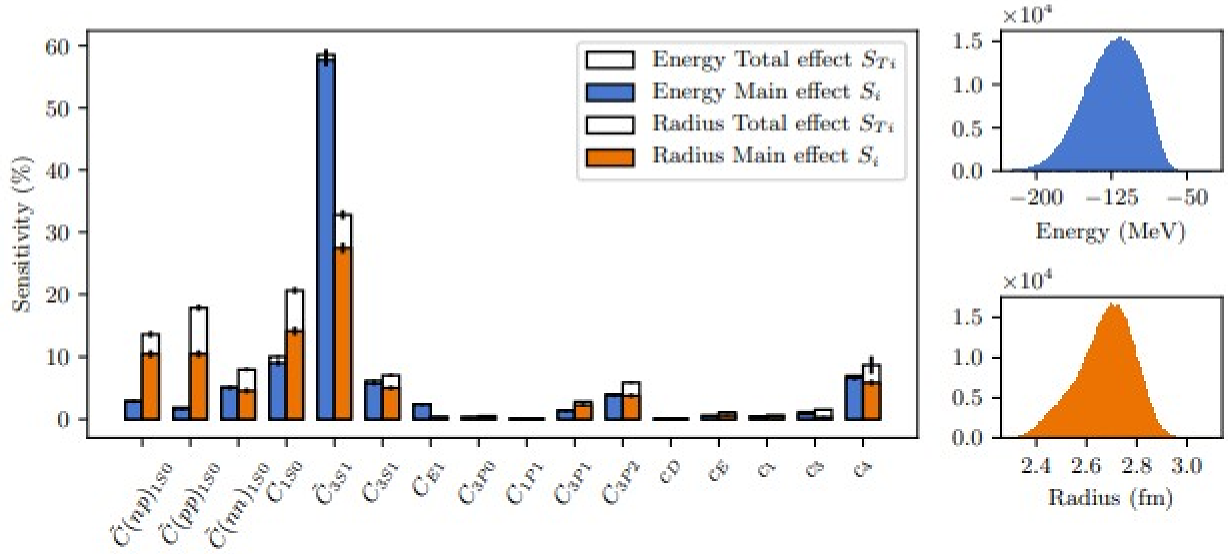


FIG. 3. (Color Online) (Left panel) Main and total effects (in %) for the ground-state energy (left bar) and charge radius (right bar) in ^{16}O, grouped per LEC. The main and total effects were computed from $(16+1)\cdot 2^{16} = 1,114,112$ quasi MC evaluations of the SP-CC(64) Hamiltonian. The vertical lines on each bar indicate bootstrapped 95% confidence intervals. A larger sensitivity value implies that the corresponding LEC is more critical for explaining the variance in the model output. (Right panels) Histograms of the ground-state energy (top) and charge radius (bottom) from which total variances are decomposed.

Table 1: Literature values for the ground-state properties of fluorine isotopes [30].

Nuclei	$T_{1/2}$	I^{π}	Yield (ions/μC)	μ[nm]	Q[b]	$< r^2 >^{1/2}$[fm]
^{17}F	64 s	$5/2^+$	$1.1 \times 10^{5\star}$	+4.7213(3)	0.076(4)	
^{18}F	110 m	1^+	$1.8 \times 10^{7*}$			
^{19}F	stable	1/2		+2.628868(8)		2.855(15)
^{20}F	11 s	2^+	$9.7 \times 10^{6*}$	+2.09335(9)	0.056(4)	
^{21}F	4 s	$5/2^+$	$9.4 \times 10^{5*}$	3.9194(12)	0.11(2)	
^{22}F	4 s	(4^+)	$3.1 \times 10^{4*}$	(+)2.6944(4)	0.003(2)	
^{23}F	2 s	$5/2^+$	$1.6 \times 10^{3*}$			
^{24}F	400 ms	$(1,2,3,4)^+$				
^{25}F	80 ms	$5/2^+$				
^{26}F	9.7 ms	(1^+)				

⋆ Yields available for PSB. * Yields available for SC

Working plan	Physics case /technical questions	Shifts
I	Yield measurements of F^+ exotic isotopes	—
I	ISCOOL bunching efficiency of F^+	—
I	Charge radii and gs moments of ^{18}F (N=Z=9)	
	−> Probe of sensitivity for different atomic transitions	3
I	Charge radius of the proton halo nucleus ^{17}F	2
I	Study of isotope shifts for $^{17,18,19}F$ by collinear resonance ionization	
	−> Probe of ionization schemes and study of systematic errors	
	−> Test of sensitivity of resonance ionization	2
II	Hyperfine structure measurements for ^{19}F by	
	state-selective re-ionization with a continuous F^+ beam	
	−> Measurements of re-ionization cross sections	(3)*
	−> Test of sensitivity for the technique	stable
III	Yield measurements of exotic F^- ions	—
	Measurement electro detachment cross sections	(3)*
	and state-selective re-ionization	stable

CRIS

Laser spectroscopy of exotic fluorine isotopes

- If F^+ ISCOOL efficiency is low we would have to try alternatives :
  - Plan II: Measurements on continuous F+ beam using state-selective ionization from optical pumping (e.g. 677 nm) – re-ionization cross sections need measurement - COLLAPS
  - Plan III: Measurements starting from F^- beam
    - Cross-section for electron detachment known up to 8 keV using a Ne or He cell (10^{-16}-10^{-15} cm^2 [Cow90]), with population of F* metastables states (e.g. 3s $^4P_{5/2}$) expected in the process

$$F^- + He \rightarrow \begin{cases} F^* + He + e, \\ F + He^* + e, \end{cases}$$

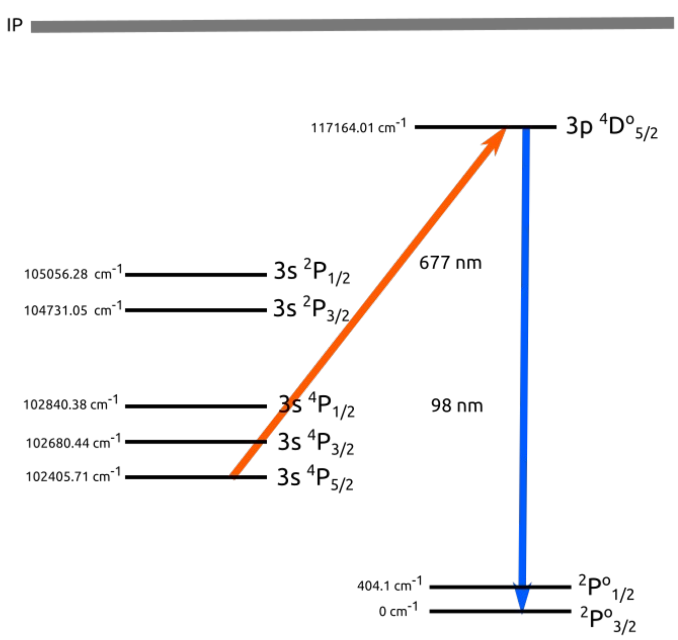
$$F^- + Ne \rightarrow \begin{cases} F^* + Ne + e, \\ F + Ne^* + e, \end{cases}$$

    - If F^- yield is much higher then measurements of detachment cross-section up to 40 keV can be made for future schemes - COLLAPS
    - If F^- can be bunched → Non-resonant pulsed laser photodetachment into S states? [Ber63]

[Cow90] Cowan, R. D., Hansen, J. E. & Dahl, P. Electron detachment and excitation processes in f−-he, ne collisions: Electron and optical emissions from excited f−and f states. J. Phys. B At. Mol. Opt. Phys. 23, 457–469 (1990).
[Ber63] Berry, R. S. & Reimann, C. W. Absorption Spectrum of Gaseous F-and Electron Affinities of the Halogen Atoms J. Chem. Phys. 38, 2724 (1963).

Laser spectroscopy of exotic fluorine isotopes

- 3 working plans to detect fluorine to answer these questions and test schemes:
  - Plan II: Measurements on continuous F^+ beam
    - If significant losses observed for F+ in the cooler buncher
    - Measurements using state-selective re-ionization: depopulated of excited state using 677 nm cw laser and then resonance detected by difference in ions produced using ionization cell



The CRIS collaboration

J. Billowes, T.E. Cocolios, B. Cooper, K.T. Flanagan, S. Franchoo, V. Fedosseev, B.A. Marsh, M. Bissell, R.P. De Groote, R.F. Garcia Ruiz, A. Koszorus, G. Neyens, H. Perrett, F. Parnefjord Gustafsson, C. Ricketts, H.H. Stroke, **A. Vernon,** K. Wendt, S. Wilkins, X. Yang

KU LEUVEN

MANCHESTER 1824

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

LPSC Grenoble

NEW YORK UNIVERSITY

[Thanks to Kara Lynch for the CRIS PowerPoint template]

And thanks to these funding bodies and organisations for allowing the research:

erc European Research Council
Established by the European Commission

belspo

BriX

ENSAR2

fwo Research Foundation Flanders
Opening new horizons

Science & Technology Facilities Council

ISOLDE

CERN