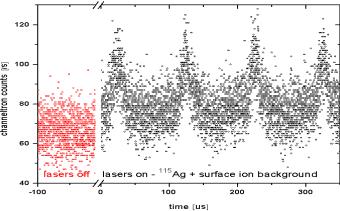
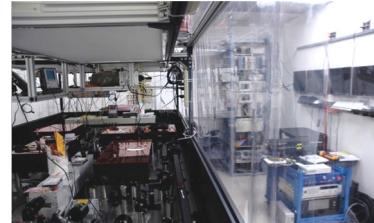


# resonance ionization laser ion source polarized beams & collinear fast beam laser spectroscopy

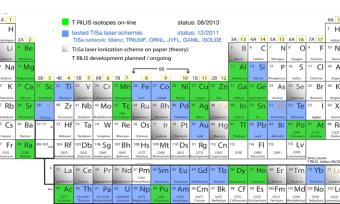
accelerator div facilities & R&D for the ISAC & ARIEL RIB program



Jens Lassen & Ruohong Li | TRIUMF Accelerator Division

acknowledgements to funding agencies: NSERC, NRC, CFI

Universities: Simon Fraser, Manitoba, Oldenburg, Darmstadt, Heidelberg, Emden-Leer, Mainz  
collaborators @ ISOLDE, Leuven, Mainz , GANIL, JYFL, Nagoya, ORNL & TiSa Network



Raeder et al. "An ion guide laser ion source for isobar-suppressed rare isotope beams" Rev.Sci.Instrum. 85(3) 033309 (2014) DOI 10.1063/1.4868496

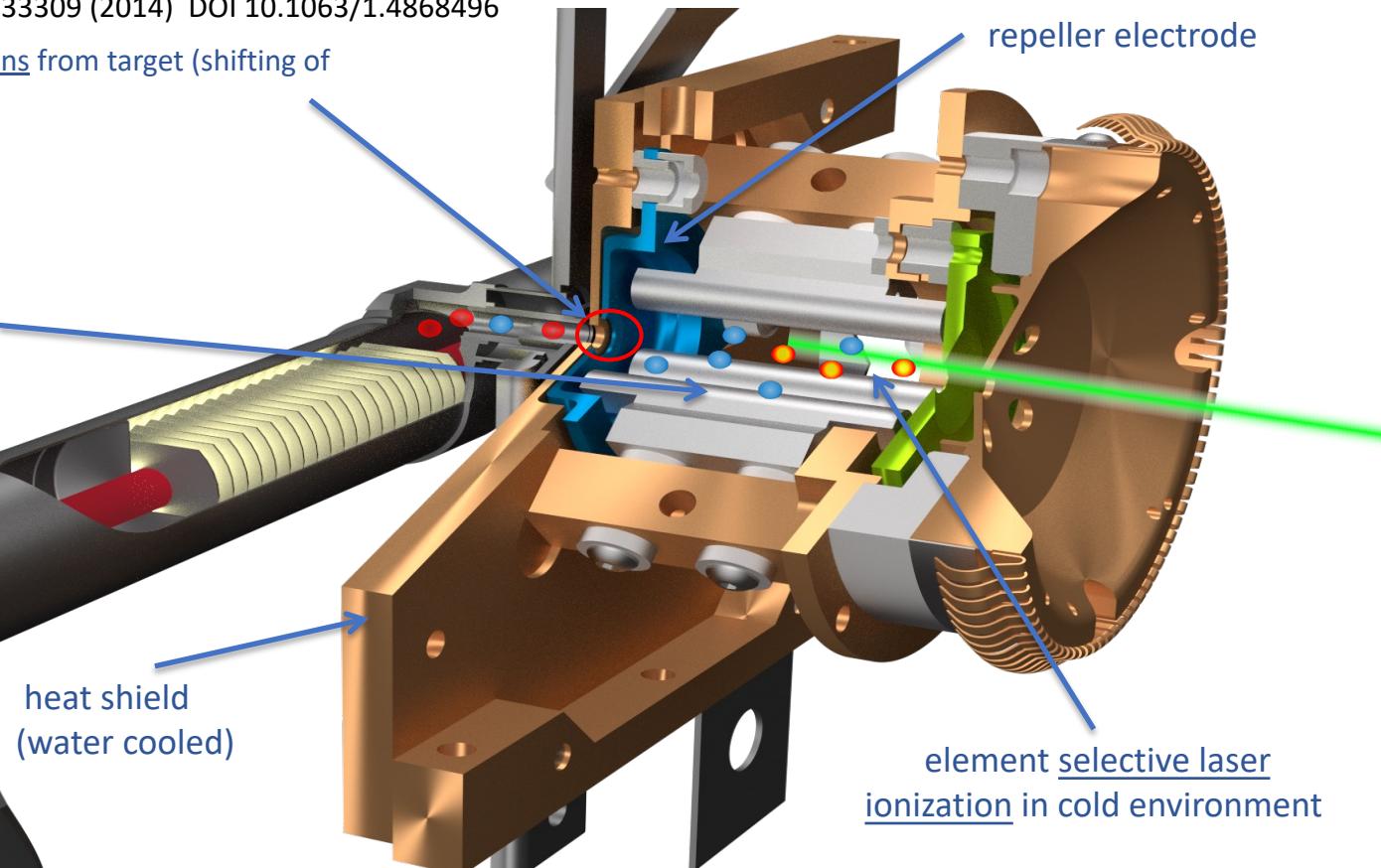
potential barrier to suppress ions from target (shifting of target and repeller voltages)

RFQ ion guide for radial confinement of laser ions

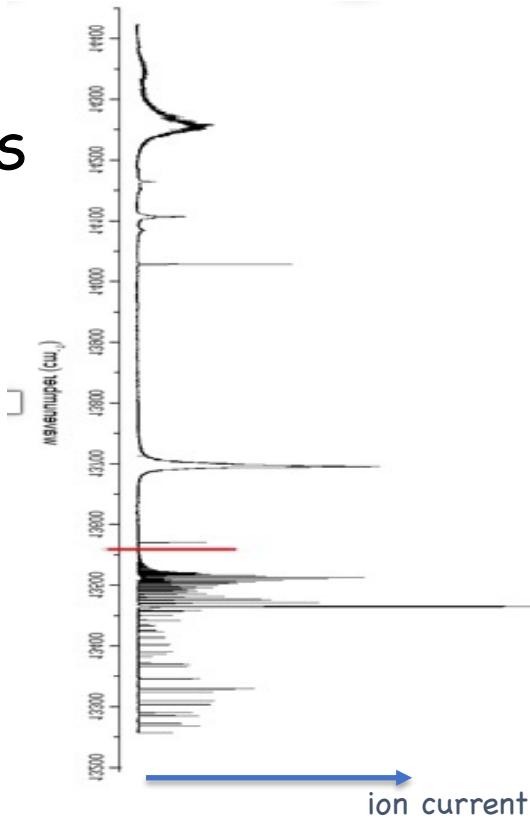
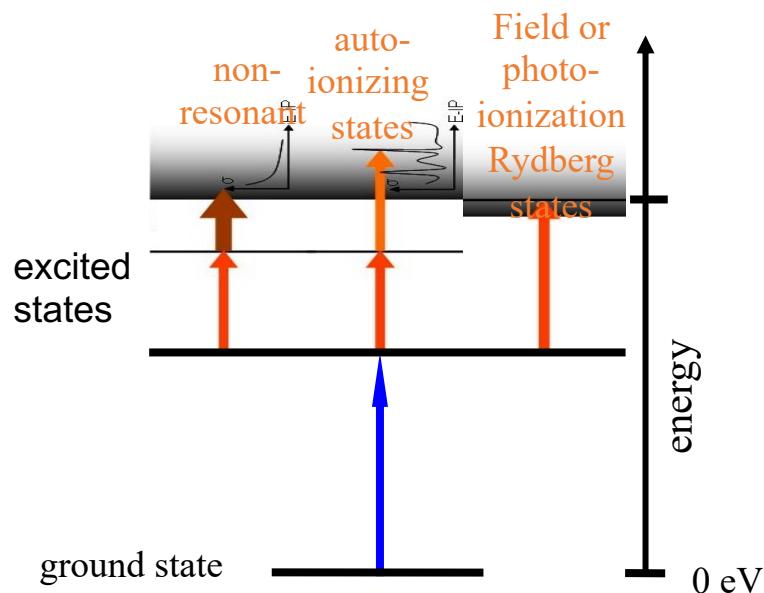
500 MeV p<sup>+</sup>

heat shield  
(water cooled)

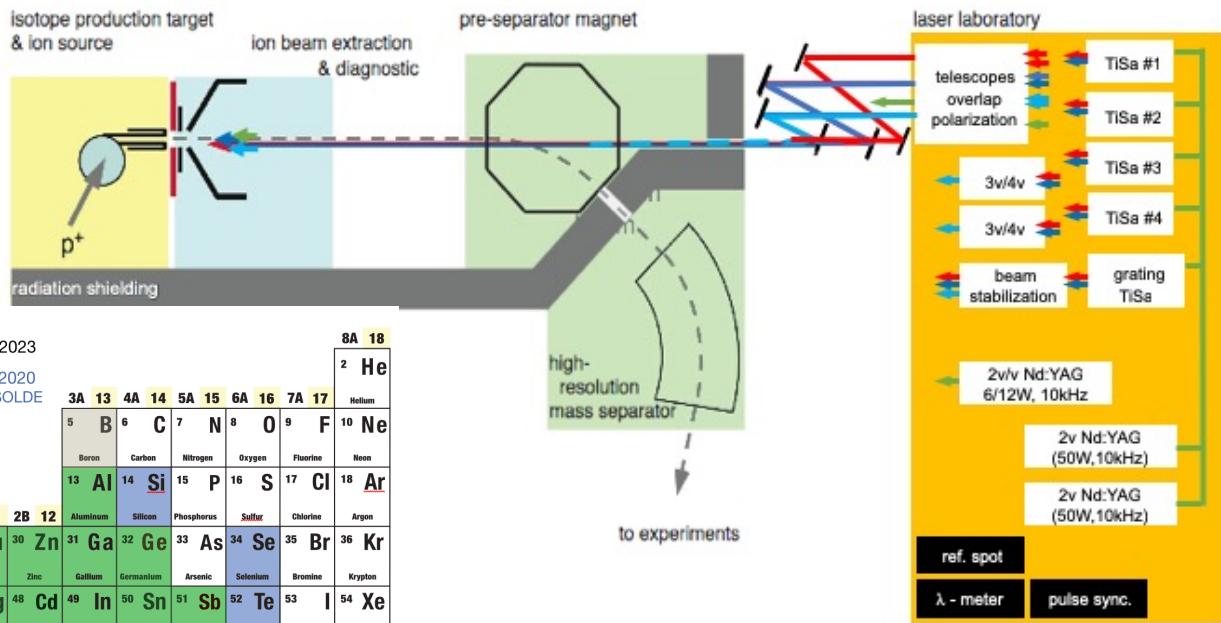
element selective laser ionization in cold environment



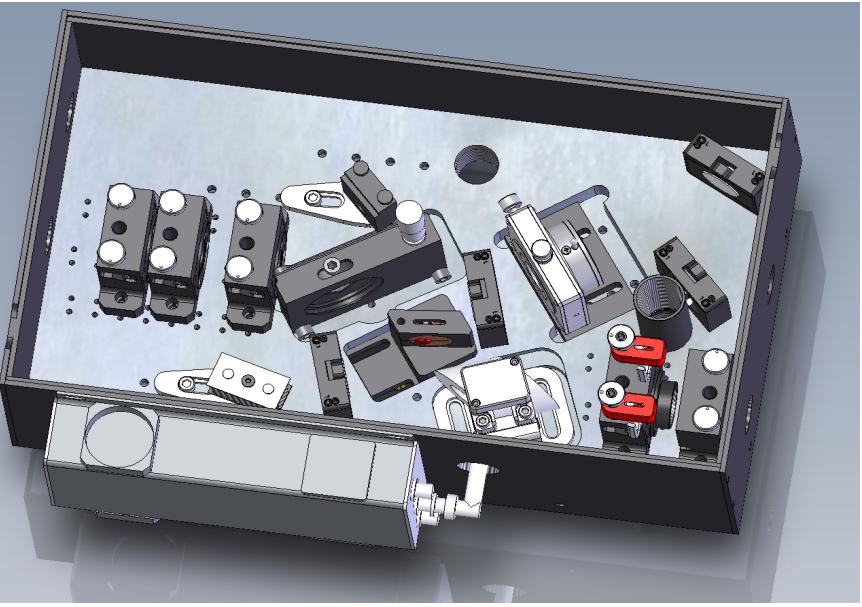
need for atomic spectroscopy  
to search for AI  
to map IS & HFS



sample spectrum Sb with Rydberg series and autoionizing states



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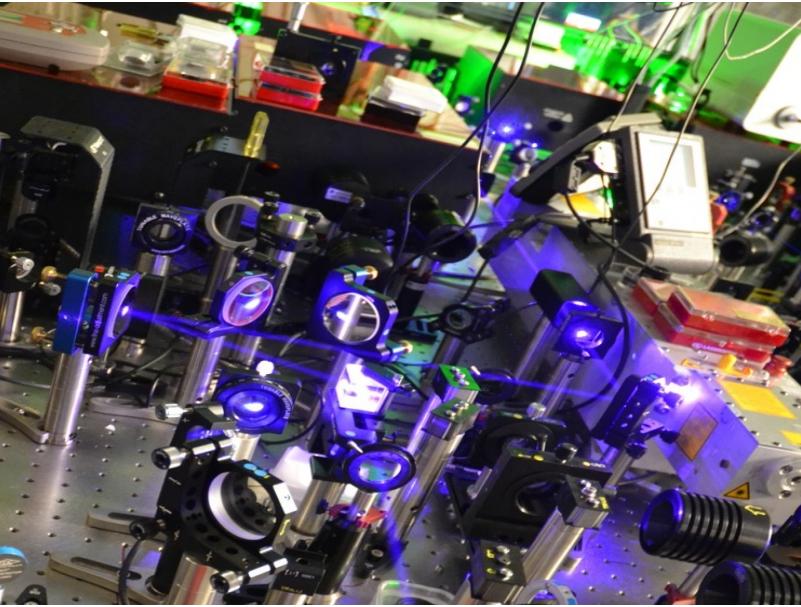
#### laser system specifications:

10kHz rep. rate, Q-switched

linewidth: < 5GHz (as low as 600 MHz)

wavelength: 690-990 nm

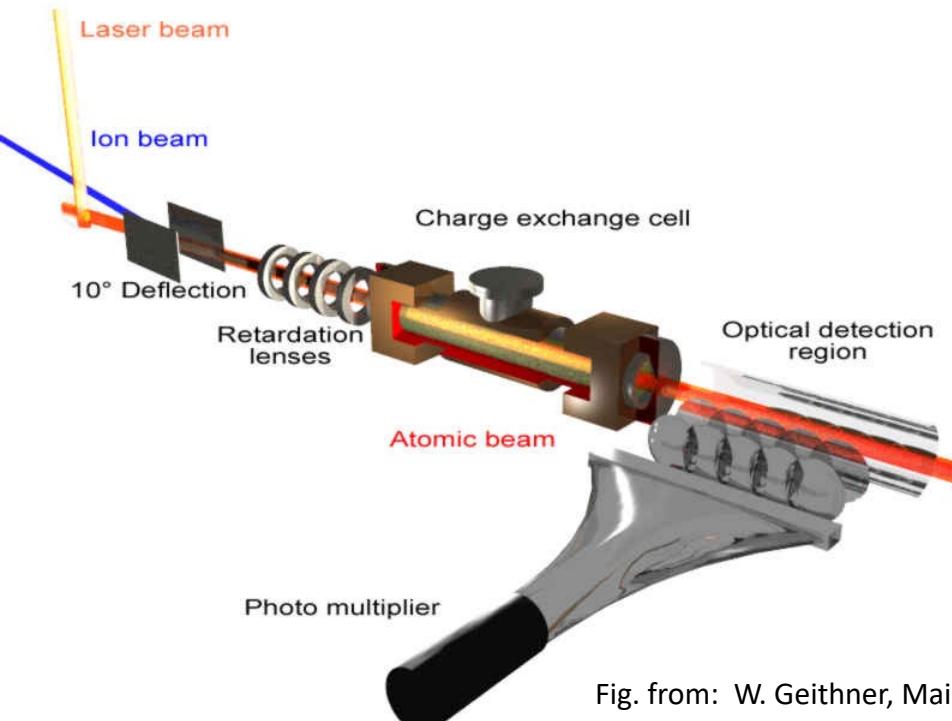
power: 2/5W IR @ 10/20W, 10kHz pump



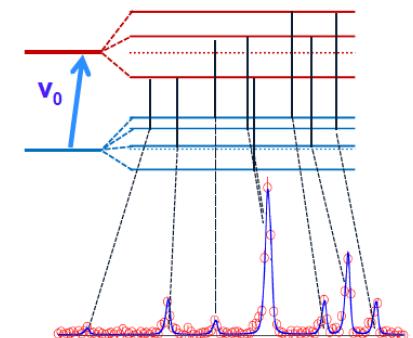
laser developments:  
TiSa lasers MK7 (ALIS)  
pump lasers (soon) as commercial ns systems disappear

laser excitation schemes  
laser spectroscopy of AI states  
HFS & IS of heavy isotopes

collinear spectroscopy → highest selectivity (Doppler-free)  
→ highest sensitivity (velocity bunching)



insensitive to isobaric contamination  
independent of  $t_{1/2}$



sensitive detection  
upgrades i.p.

RILIS laser ion source pulsed beam  
→ gated detection

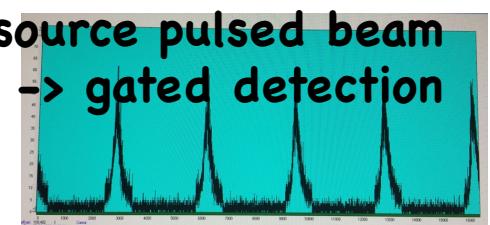
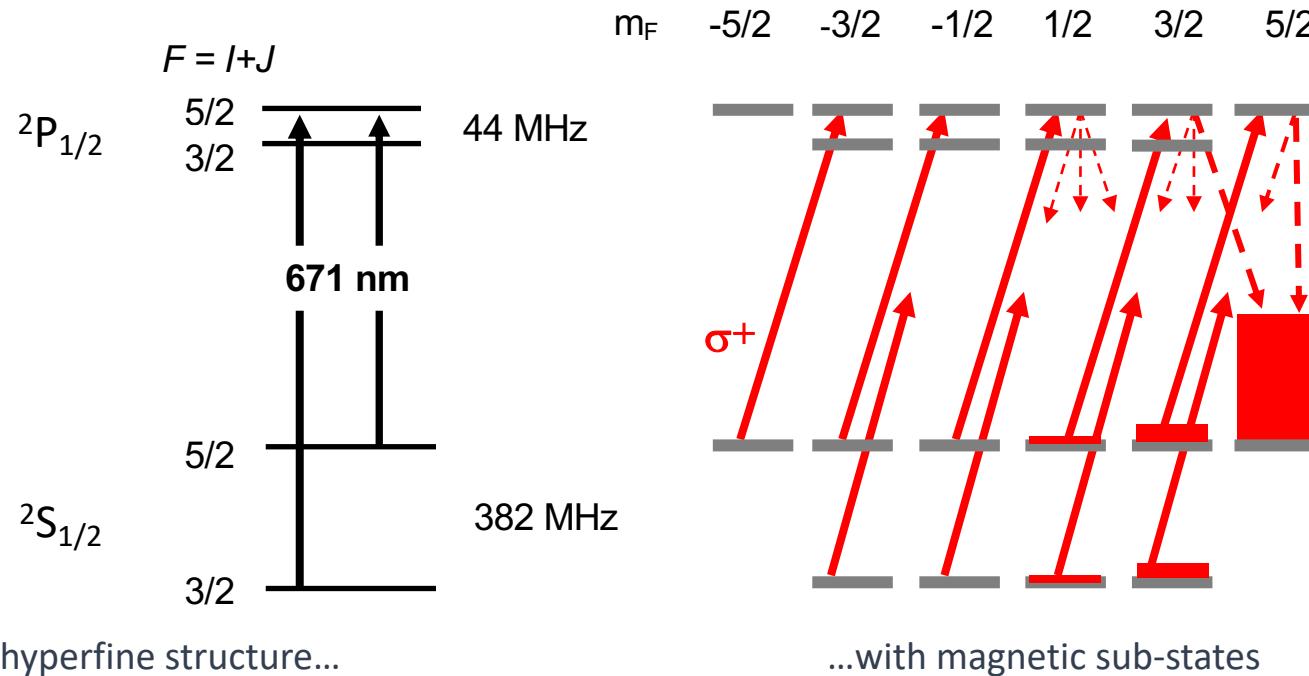
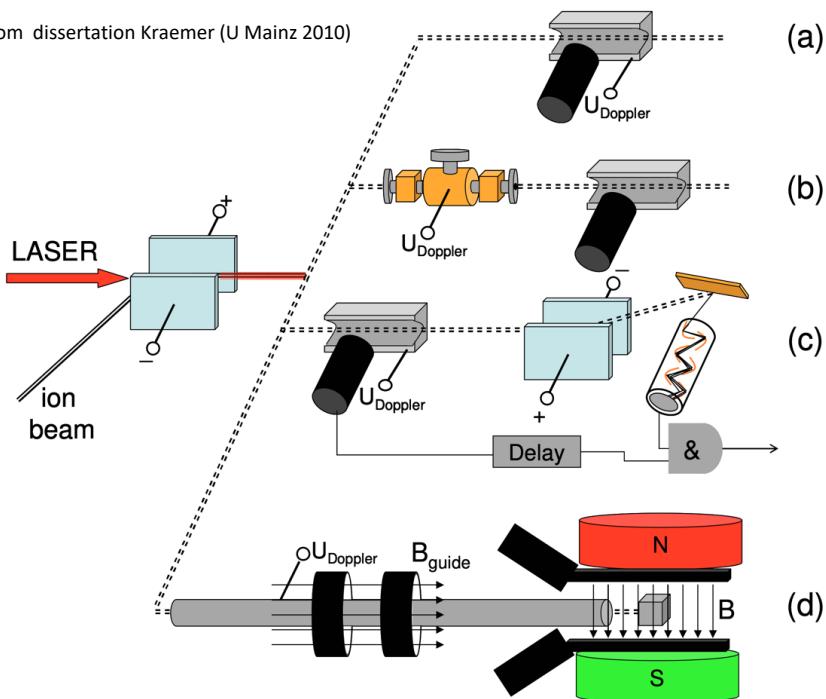


Fig. from: W. Geithner, Mainz U.



- electro-optic modulator (EOM) puts 381 MHz sidebands on laser frequency,  
 $\rightarrow$  both ground state hyperfine levels are pumped

from dissertation Kraemer (U Mainz 2010)



(not shown: collinear RIS)

polarizer operation:  
3 different elements with about 1200h /y

Figure 3.5.: Principle of collinear laser spectroscopy and the different possible extensions. (a) shows the classical optical detection with ions. The tuning voltage is applied to the mirror in the optical detector. (b) combines the optical detection with a charge exchange to perform spectroscopy with atoms. To increase the signal to noise ratio the optical detection can be combined with a subsequent particle counting, shown in (c). In the case of short-lived radioactive nuclei the  $\beta$ -asymmetry detection can be applied after optical pumping with  $\sigma$  polarized light in a guiding field as it is shown schematically in (d).

development goals: new spin polarized species  
requires collinear laser spectroscopy

# nuclear moments & shapes from atomic hyperfine-structure i.e. laser spectroscopy

- ❖ Nuclear spin  $I$
- ❖ Magnetic dipole moment  $\mu$
- ❖ Electric quadrupole moment  $Q$
- ❖ Changes in the mean square charge radii  $\delta\langle r^2 \rangle$

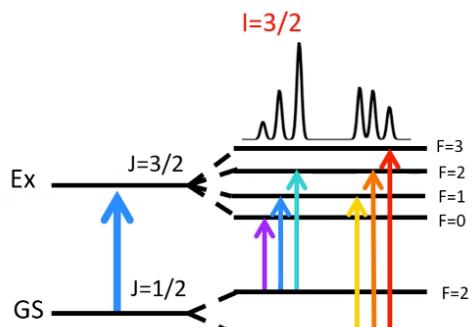
$$\Delta E = A \cdot K/2 + B \cdot \{3K(K+1)/4 - I(I+1)J(J+1)\}/\{2(2I-1)(2J-1)IJ\}$$

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

$$A = \frac{\mu_I B_J}{IJ}$$

$$B = eQV_{zz}$$

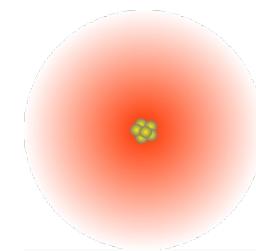
$$\delta\nu^{AA'} = M \frac{m_{A'} - m_A}{m_A m_{A'}} + F \delta\langle r^2 \rangle^{AA'}$$



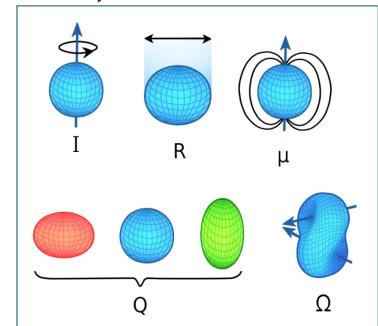
Atomic parameters either form calculations or

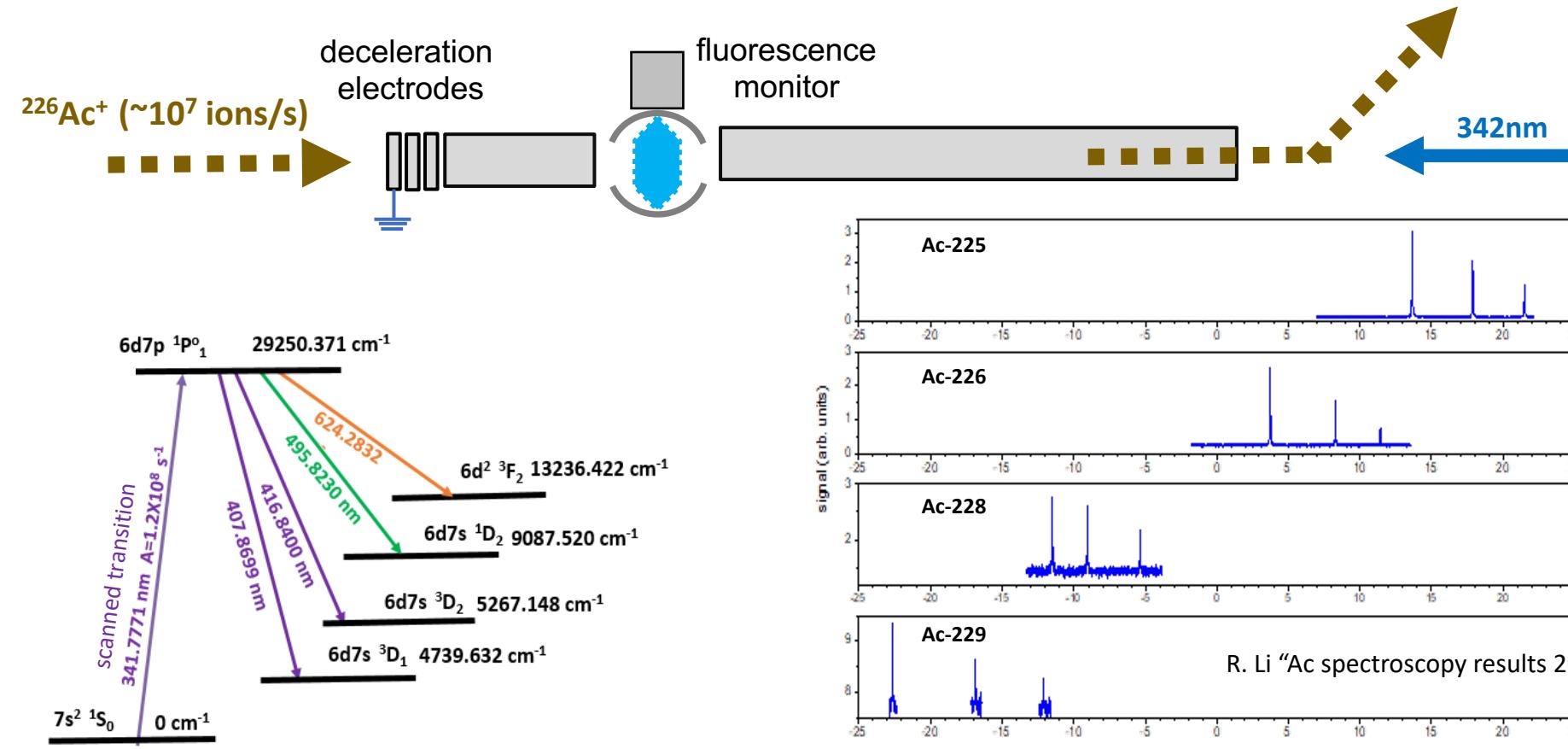
$$\mu = \frac{AI}{A_{ref} I_{ref}} \mu_{ref}$$

International conference on HYPERFINE interactions and their applications

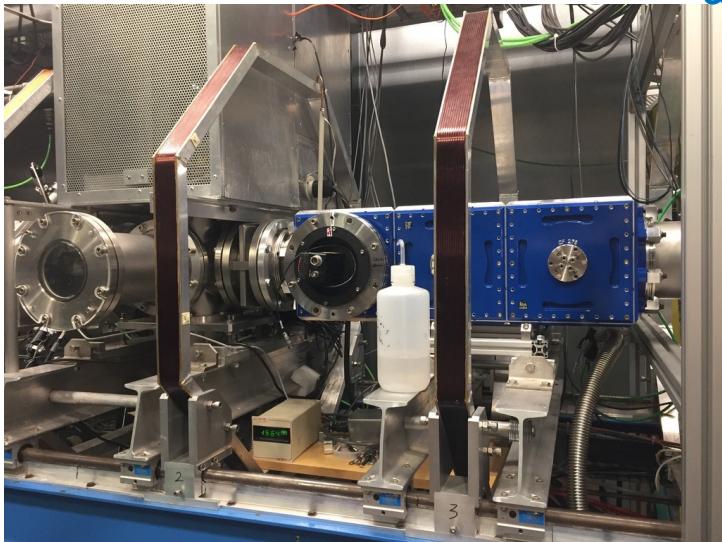


$\times 10^5$

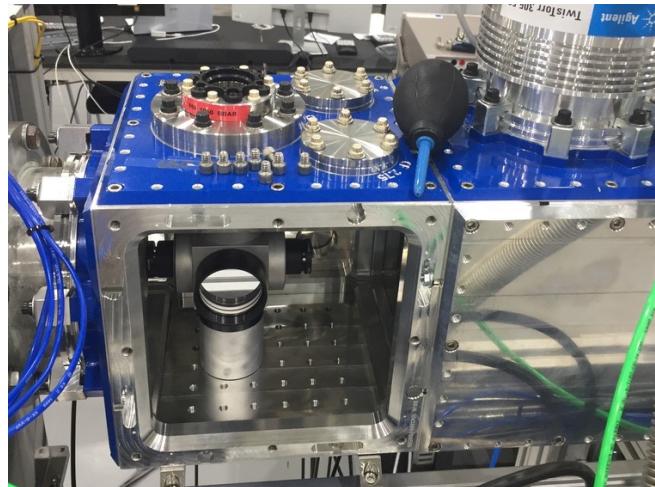




for custom detection setups  
& quick re-configuration to polarized beams operation



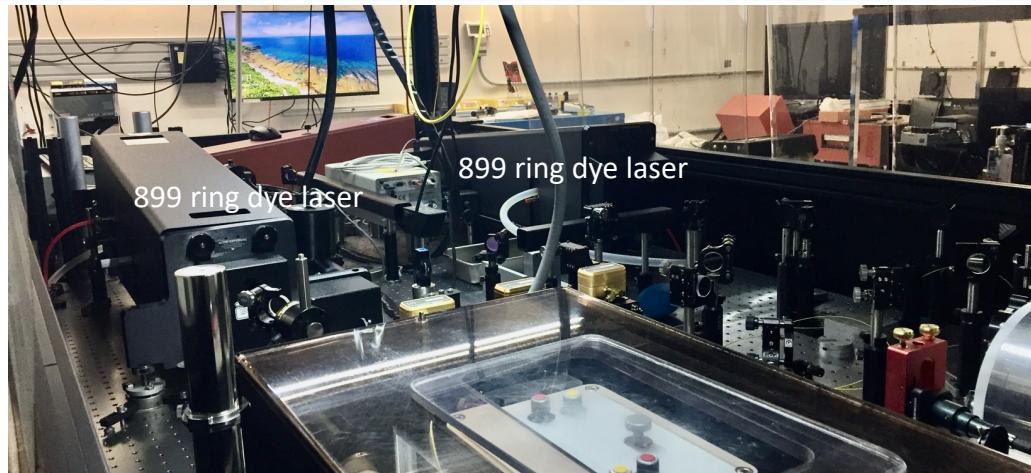
vacuum separated charge exchange cell  
& versatile user-section for detection setups



uv – optical detection region for At  
(MSc. Katarina Preocanin)

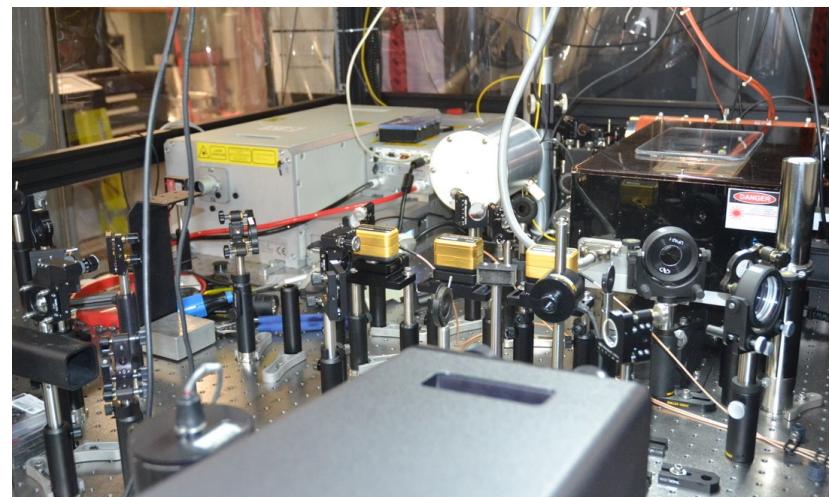
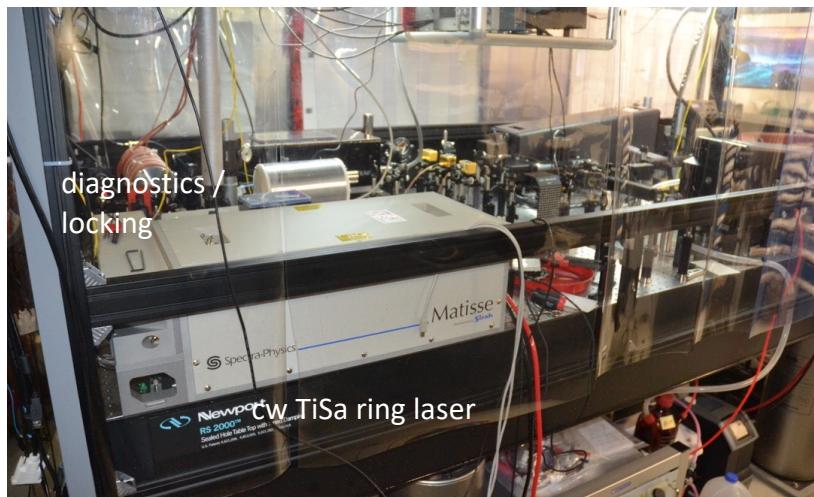
new CFBS beamline section & laser upgrades financed through  
NSERC experiment grants (R. Li, J. Lassen)

old collinear laser spectroscopy equipment & lab now RadMol (S. Ettenauer)



solid state laser (MatisseCS)  
and 2<sup>nd</sup> ring dye laser  
for polarizer  
& CFBS

2<sup>nd</sup> frequency doubler (wavetrain)



about 1000 h/a beam delivery

low energy  
radioactive ion beam



POLARIZER

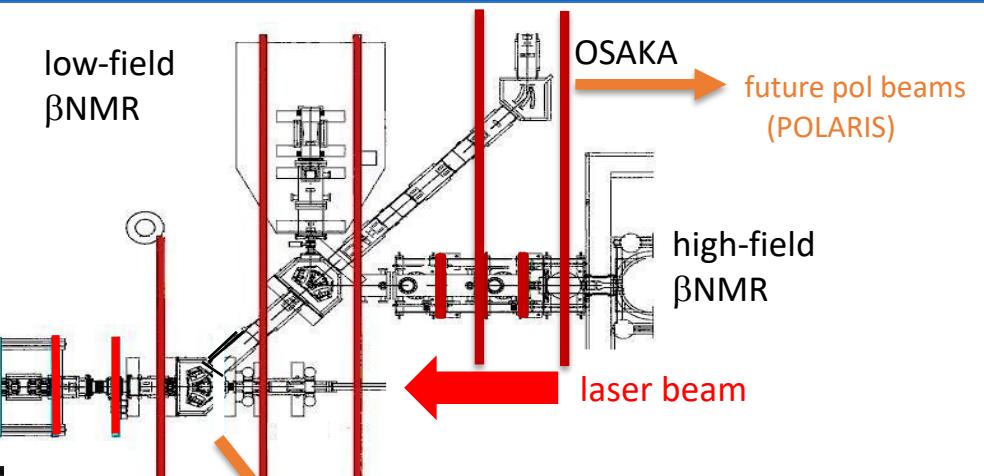
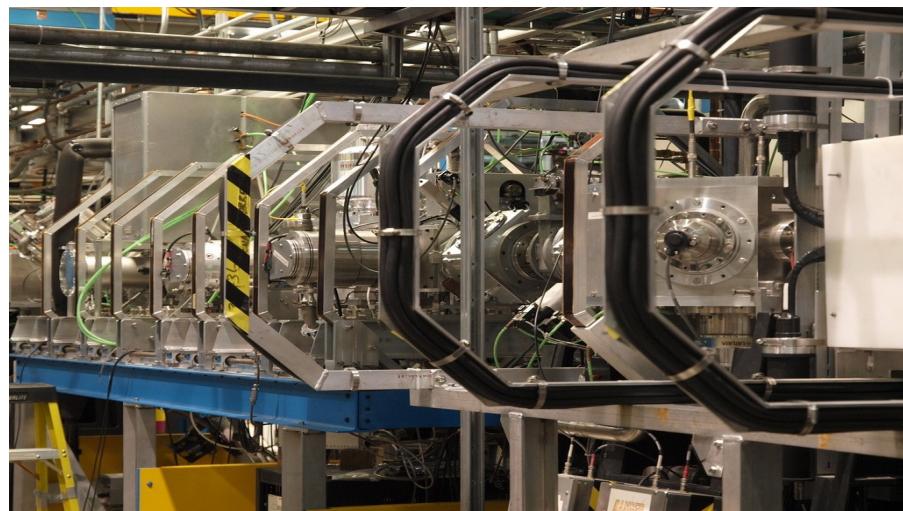
low-field  
 $\beta$ NMR

OSAKA

future pol beams  
(POLARIS)

high-field  
 $\beta$ NMR

laser beam



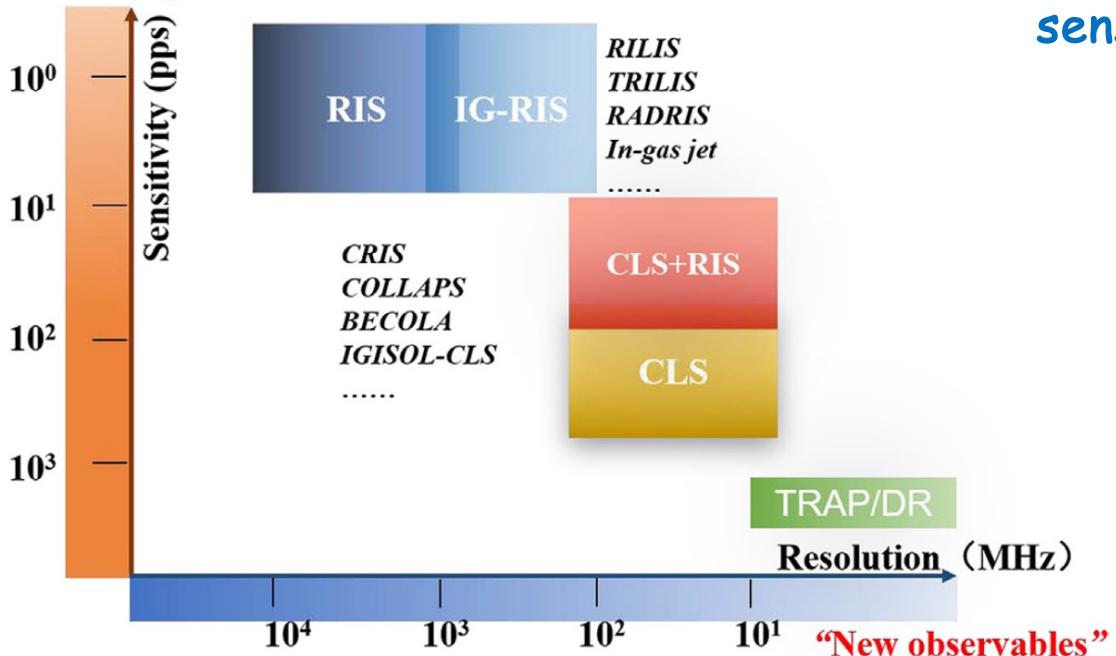
development axes:  
complement laser systems to allow for "user cfbs"  
develop new polarized species for bNMR, life- and nuclear sciences

investigate nuclear moments & shapes

future pol beams (GRIFFIN) develop a universal polarizer

deliver polarized beams of highest quality & availability  
from ISAC & ARIEL

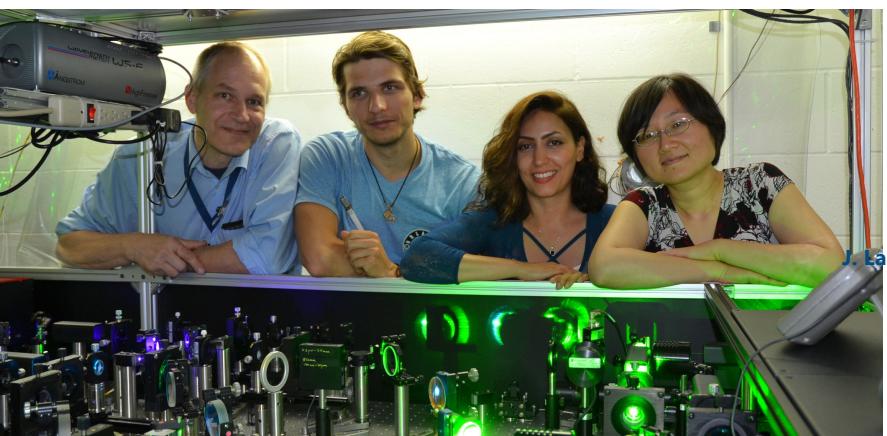
“Terra incognita”



sensitivity vs resolution frontier  
with current techniques

part of accelerator division RIB delivery infrastructure  
primary mission beam delivery & related R&D

## questions ? comments ?



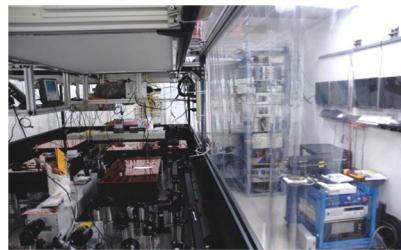
U Mainz, ISOLDE, Leuven, GANIL, JYFL, ORNL, Nagoya U, & TiSa Network

- more elements ✓
  - increased intensity & beam purity ✓
  - higher uptime (laser & techniques R&D) ✓
  - scientific interest in ✓
  - laser spectroscopy (atomic data) ✓
  - laser development ✓

**resource requirements:**  
machine shop access  
**design office support**  
**controls**

funding agencies: NSERC, NRC, CFI

**collaborators:**  
Simon Fraser U, U Manitoba, U Windsor, SMU  
U Oldenburg, TU Darmstadt, Hochschule Emden Leer,  
euven, GANIL, JYFL, ORNL, Nagoya U , & TiSa Network



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Simon Fraser | Toronto | Victoria | Winnipeg  
| York

