Fundamental Structure and Interactions of Ionic Tin

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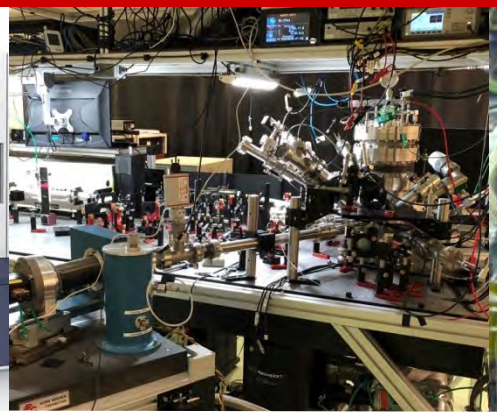
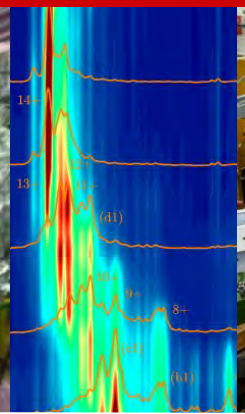
ARCNL
ADVANCED RESEARCH CENTER FOR NANOLITHOGRAPHY

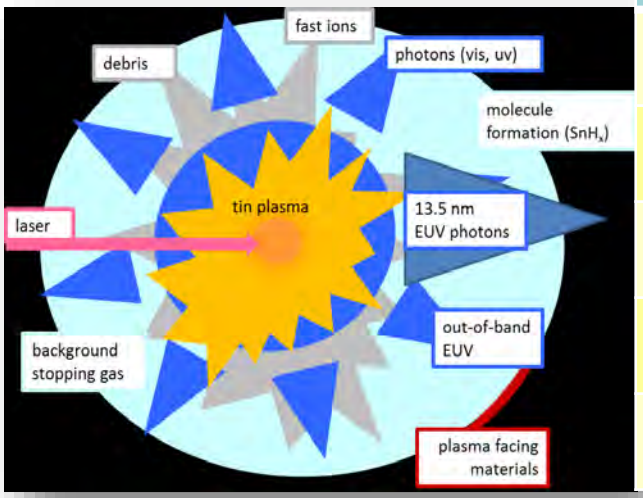
FOM NWO FOM Institute AMOLF Universiteit van Amsterdam VU Vrije Universiteit Amsterdam Gemeente Amsterdam Provincie Noord-Holland ASML

university of groningen
2014 | 400 years
zernike institute for advanced materials





outline

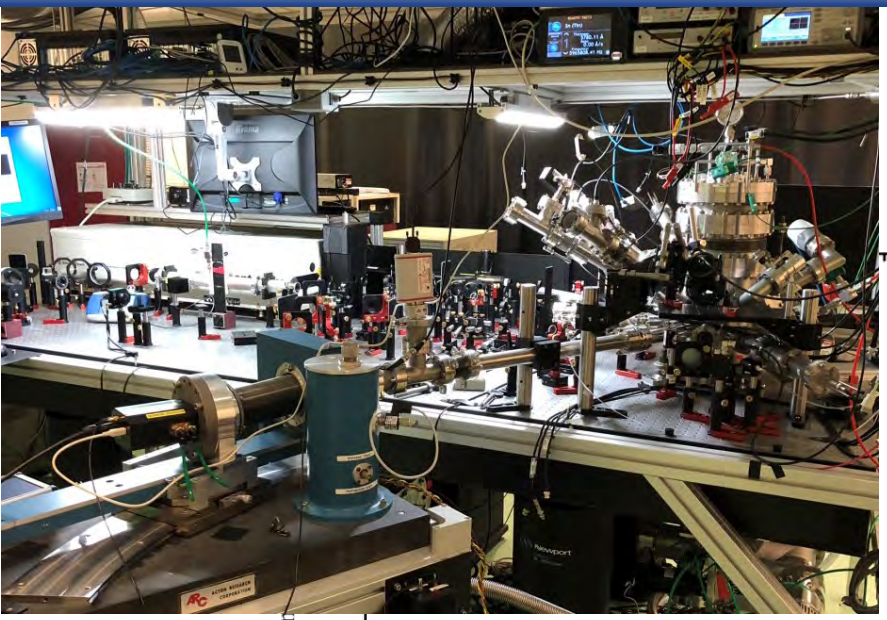


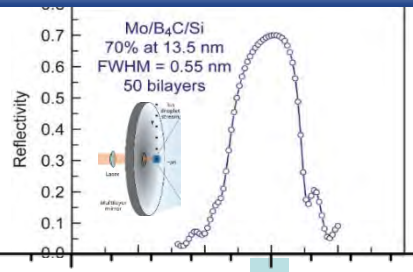
progress on atomic physics aspects
EUV line identifications in Sn^{13+}, Sn^{14+}, and Sn^{15+} ions
13.5-nm EUV light: the double magic of Sn ions
Optical depth as a single, pertinent scaling-law parameter
Sn ion scattering on Mo and Ru: experiments versus SRIM
charge exchange cross sections for ions traversing H_2 gas

the local collaborators

Alex Bayerle, Lars Behnke, Zoi Bouza, Laurens van Buuren, Mart Johan Deuzeman, Diko Hemminga, Harry Jonkman, Roeland Kamp, Sybren Koeleman, Dmitry Kurilovich, Bo Liu, Randy Meijer, Walewein Noordam, Lucas Poirier, Subam Rai, Joris Scheers, Ruben Schupp, John Sheil, Otte Tjepkema, Francesco Torretti, Joël Zwart, Ronnie Hoekstra, Wim Ubachs, Oscar Versolato

EUV emisssion



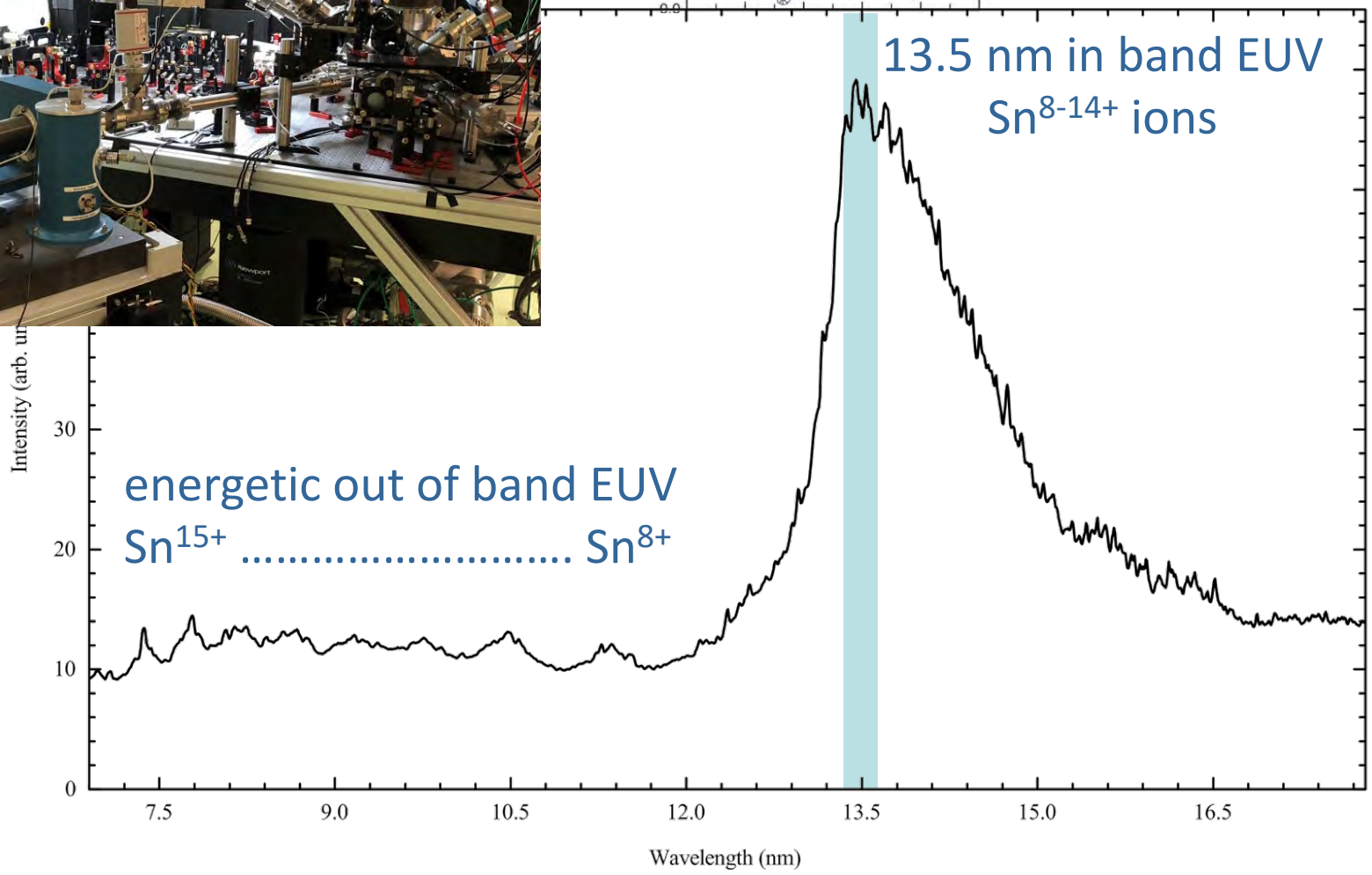


13.5 nm in band EUV

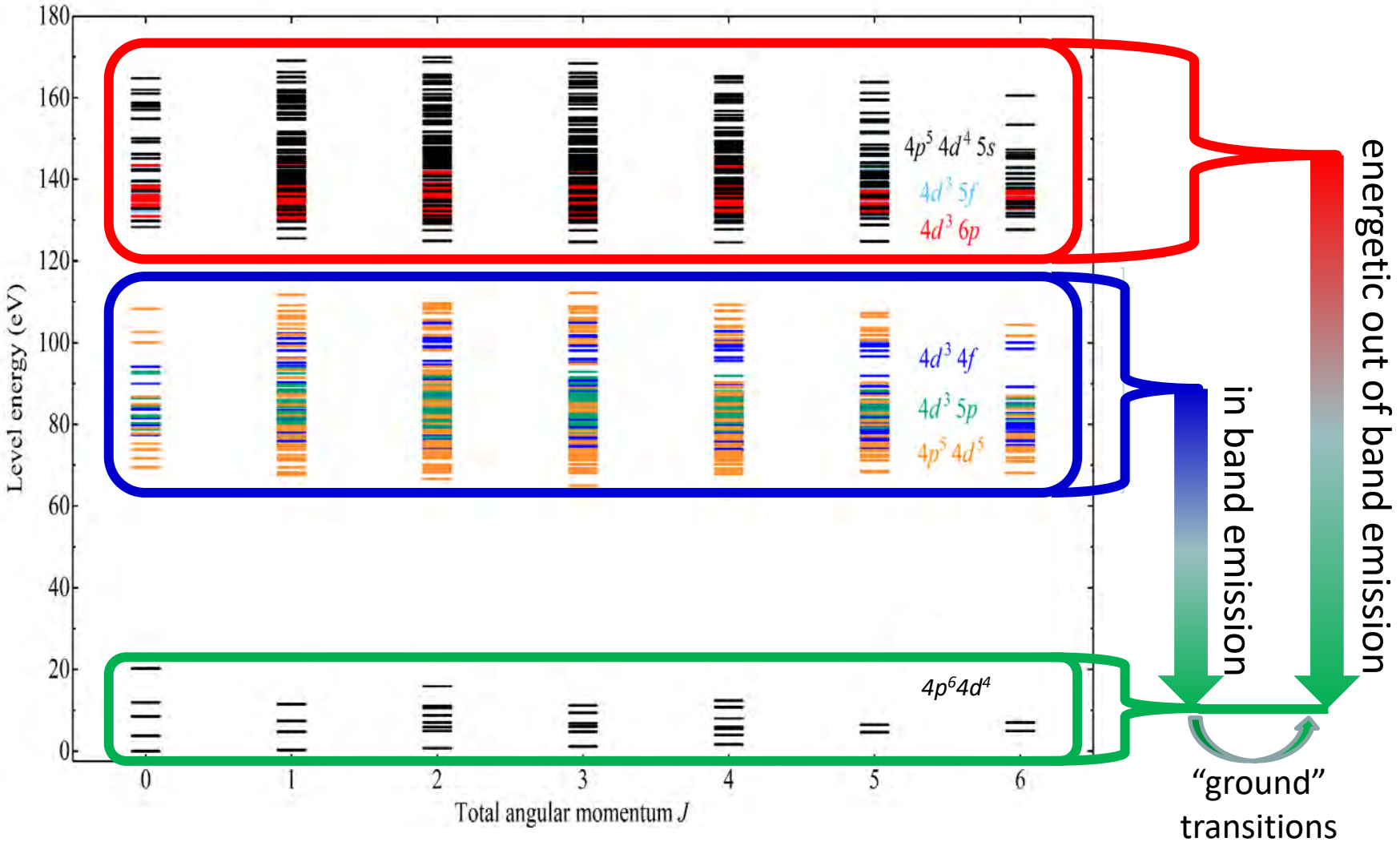
Sn^{8-14+} ions

energetic out of band EUV

Sn^{15+} ..... Sn^{8+}



atomic origins of EUV light: Sn^{10+}



A. Windberger et al., Phys. Rev. A **94**, 012506 (2016); F. Torretti et al, Phys. Rev. A **95**, 042503 (2017)

In-EBIT spectroscopy

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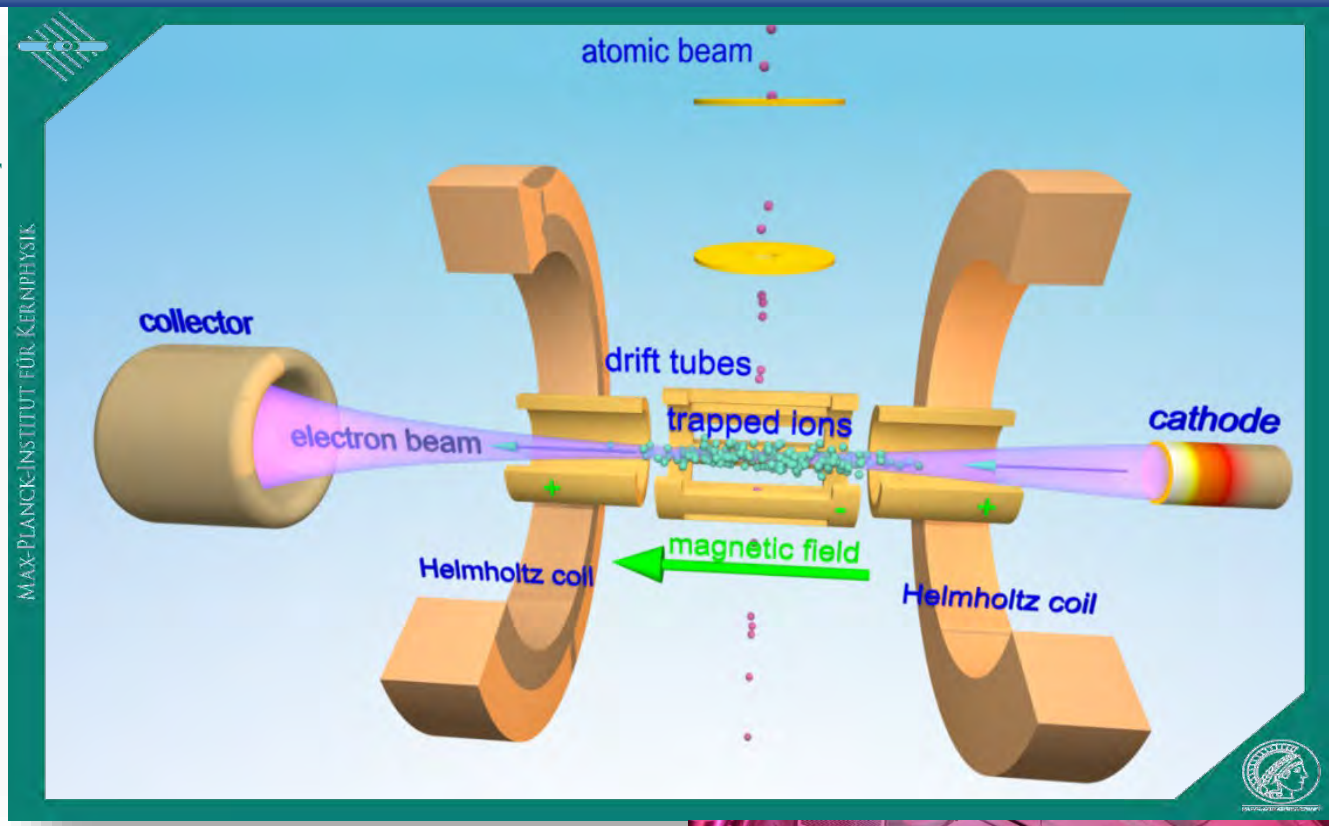


EBIT group:
J. Crespo López-Urrutia
And coworkers

electron impact excitation of trapped Sn ions in charge states 7 - 20+

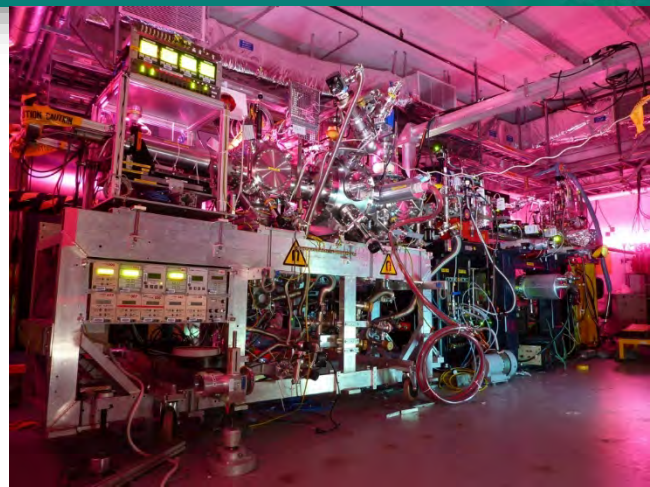
theory

ISAN Troitsk
A. Ryabtsev

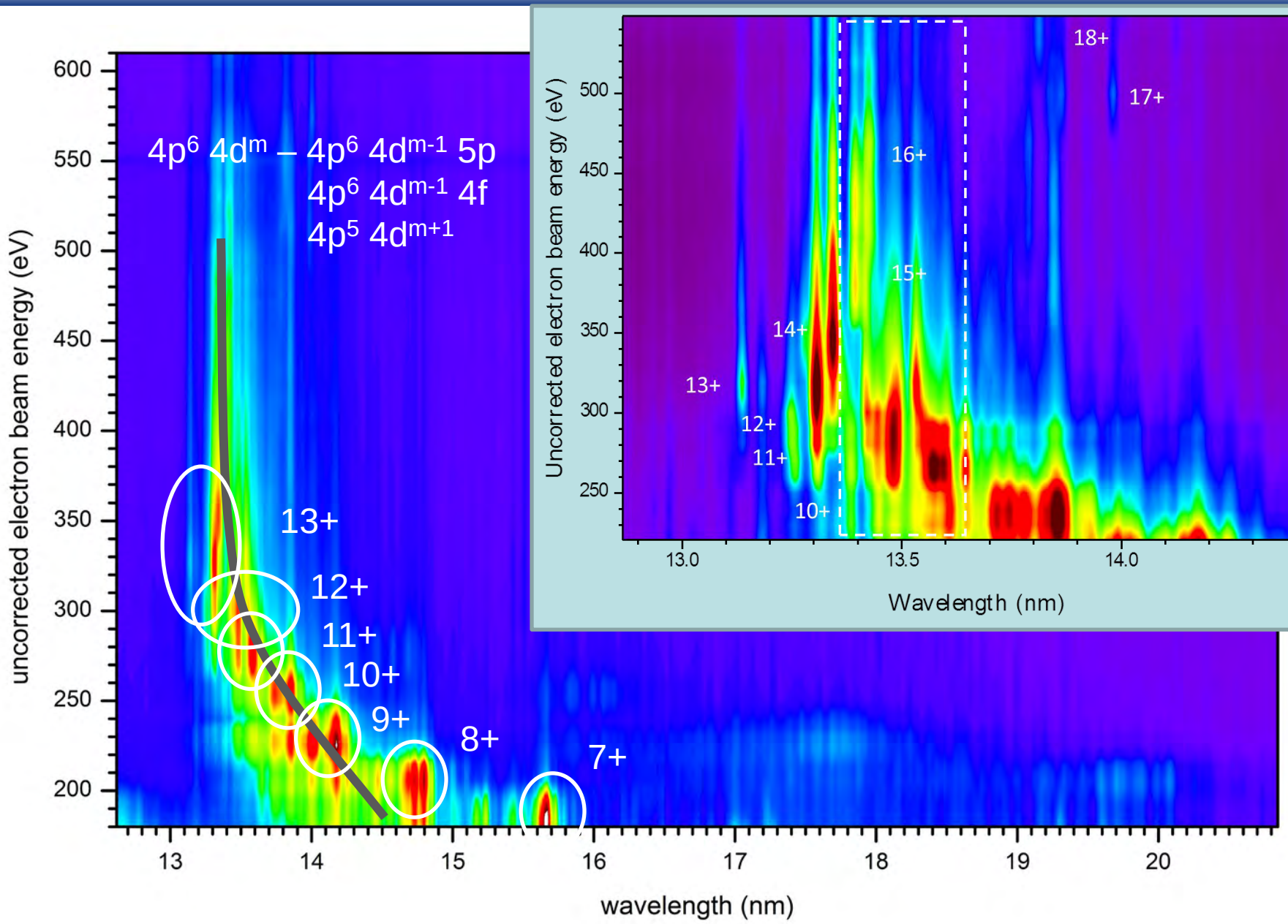
School of Chemistry
E. Eliav and U. Kaldor

university of groningen
Van Swinderen Institute
A. Borschevsky

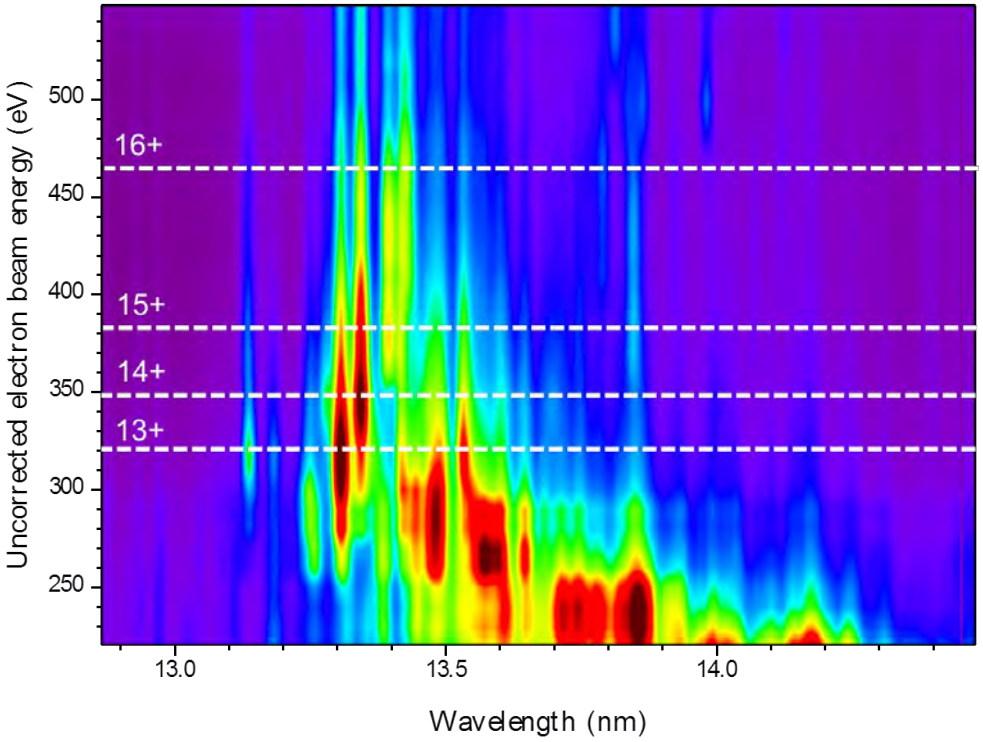
UNSW AUSTRALIA
School of Physics
J. Berengut and E. Kahl

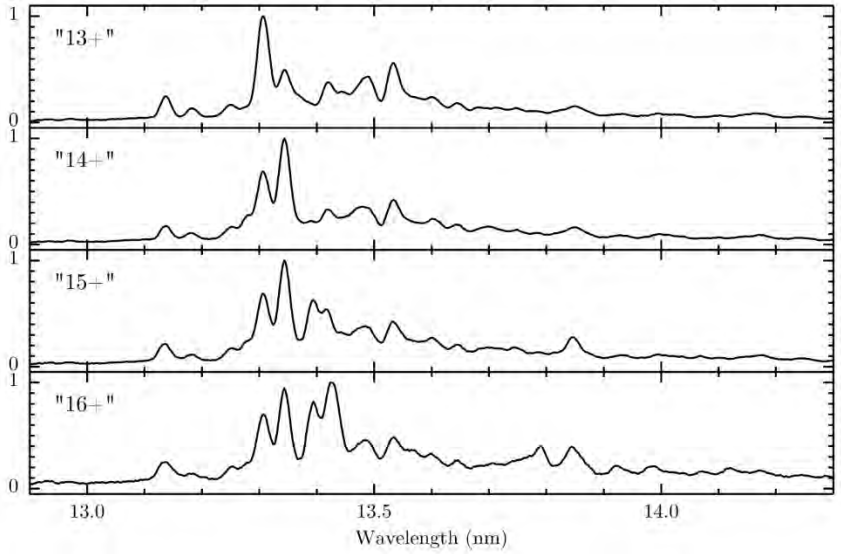


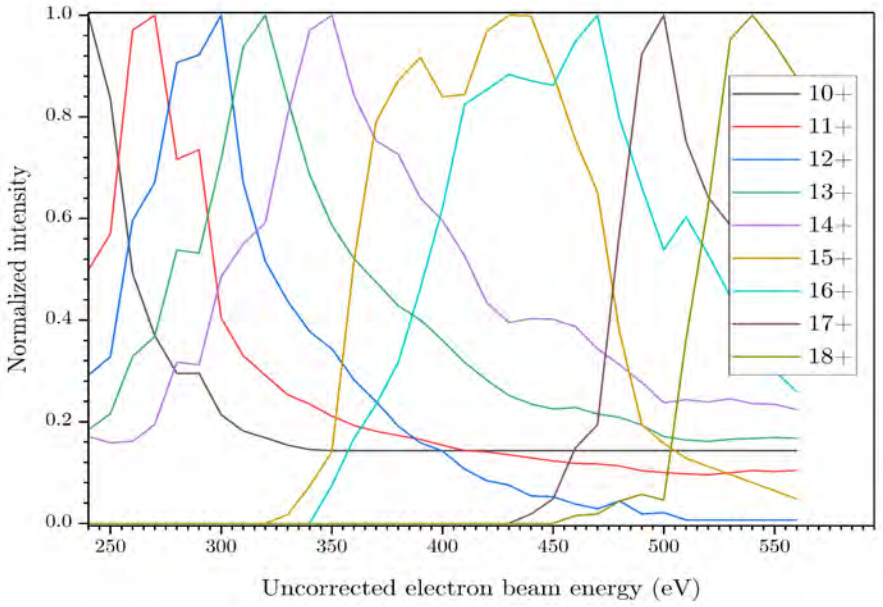
the tin serendipidity



charge state and intensity line-outs







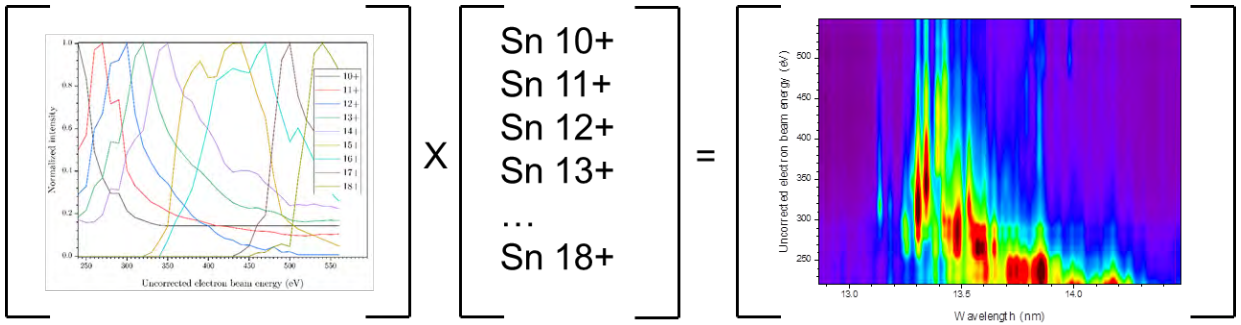
Sn^{15+} and Sn^{16+} are relevant for in-band EUV emission
single spectra obtained from line-outs
BUT: spectra are a mix of charge states

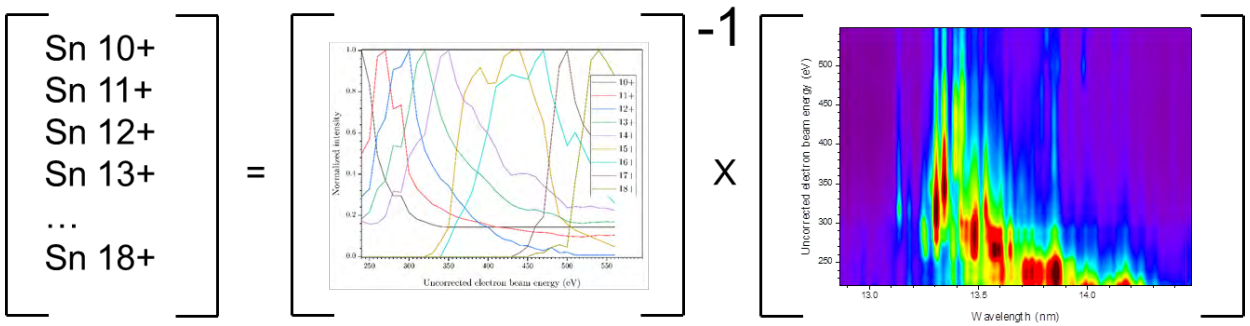
J. Scheers et al, under review

charge state resolved spectral reconstruction

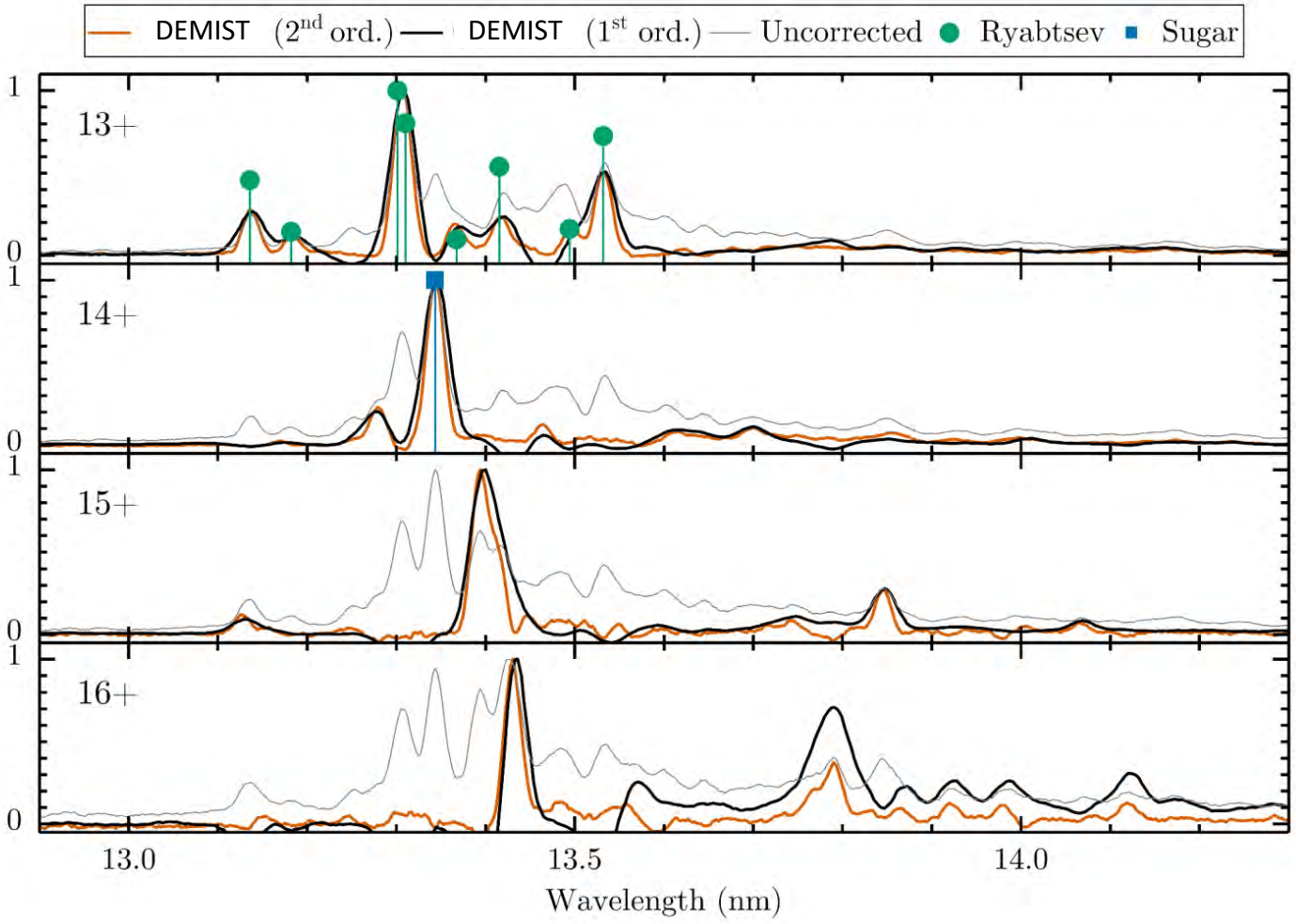
DEMIST

DEconvolution using Matrix Inversion of SpecTra



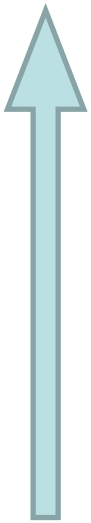


charge state resolved spectra



J. Scheers et al, under review

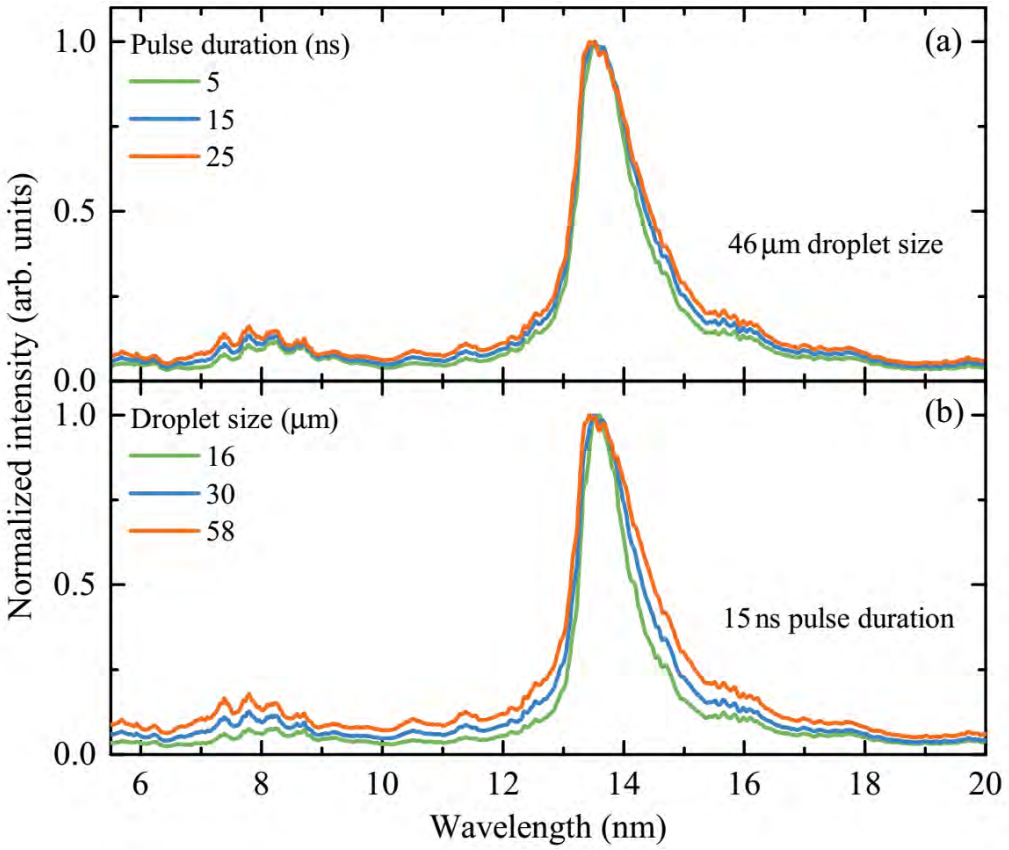
the double magic structure of tin ions



next talk by James Colgan

F. Torretti et al, under review

Line shape and opacity



$$L_\lambda = B_\lambda \left(1 - e^{-\tau_\lambda}\right)$$

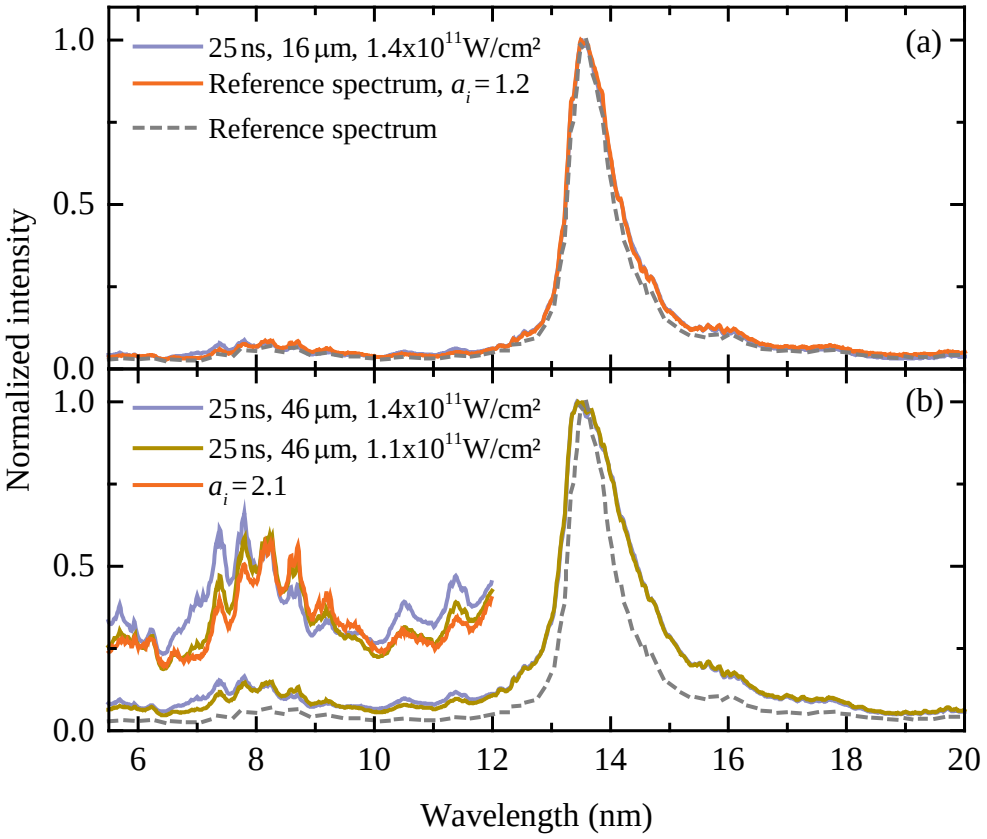
$$\tau_\lambda = -\ln\left(1 - \frac{L_\lambda}{B_\lambda}\right)$$

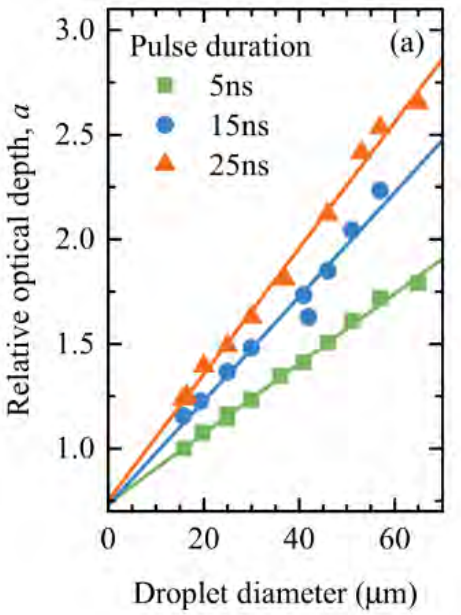
$$\tau_{\lambda,i} = a_i\, \tau_{\lambda,0}$$

$$\frac{L_{\lambda,i}}{B_{\lambda,i}} = 1 - \left(1 - \frac{L_{\lambda,0}}{B_{\lambda,0}}\right)^a$$

Ruben Schupp et al., Appl. Phys. Lett. **115**, 124101 (2019)

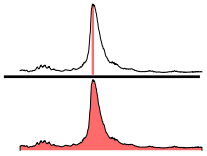
Relative opacity scaling of Nd:YAG LPP

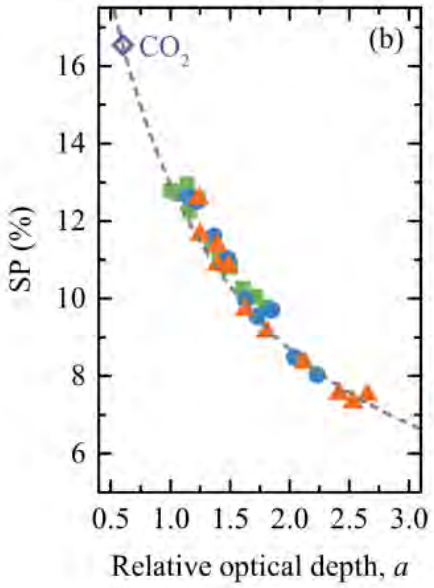




Spectral purity:

$$\mathrm{SP} = \frac{E_{2\%\mathrm{EUV},2\pi}}{E_{\mathrm{EUV},2\pi}} =$$





ZERNIKELEIF @ university of groningen / zernike institute for advanced materials

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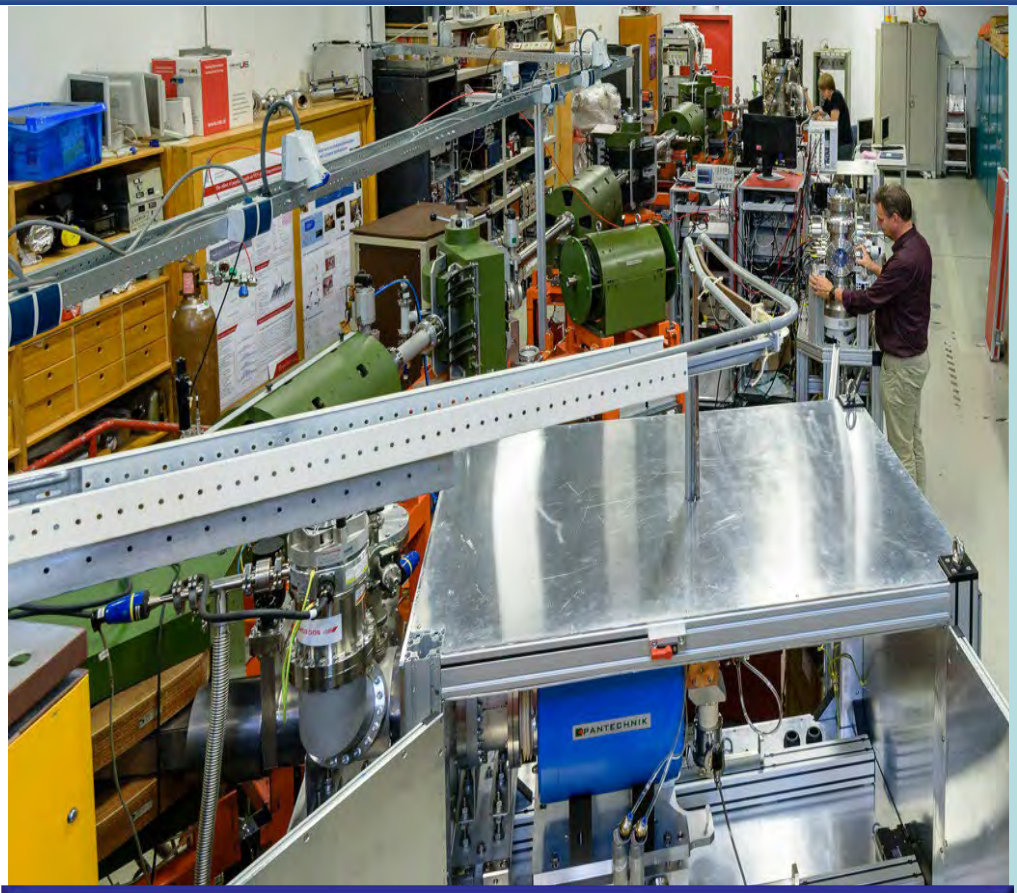
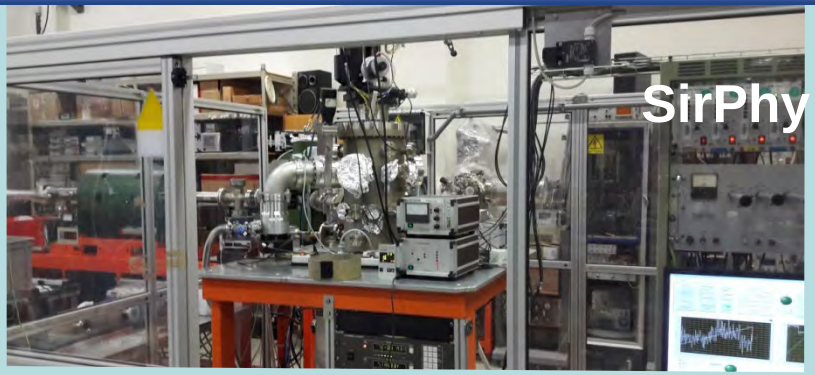
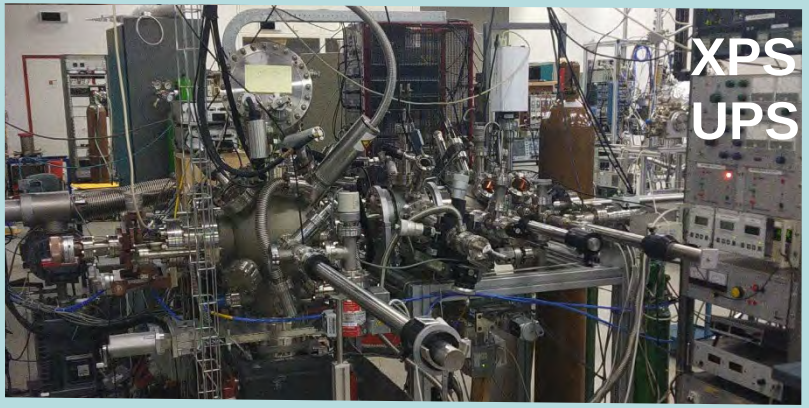
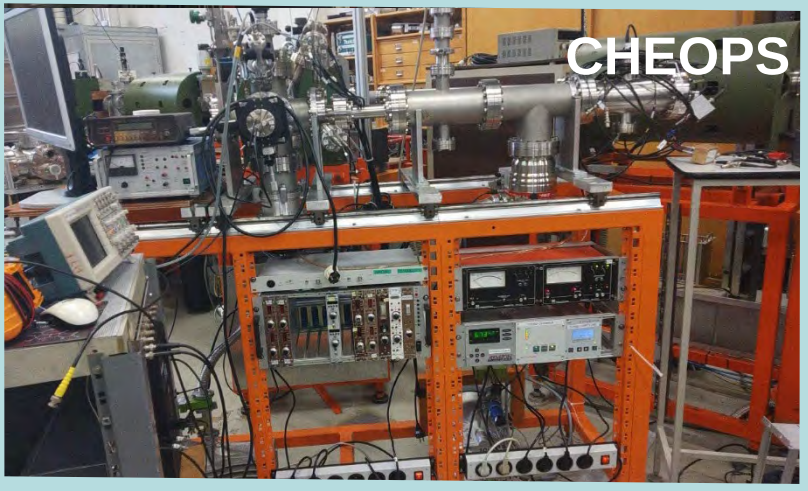


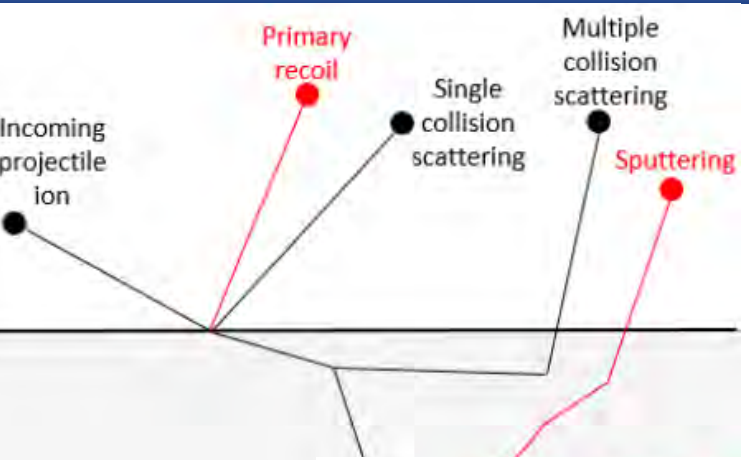


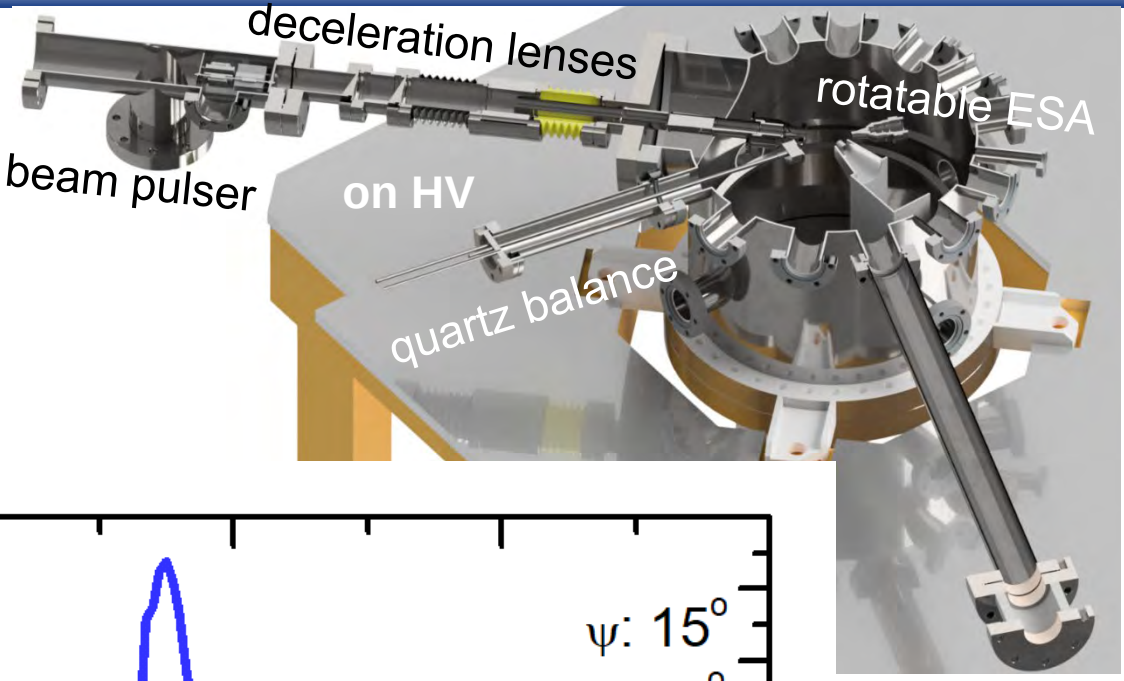


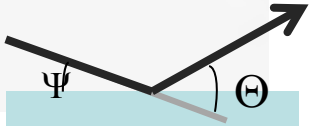


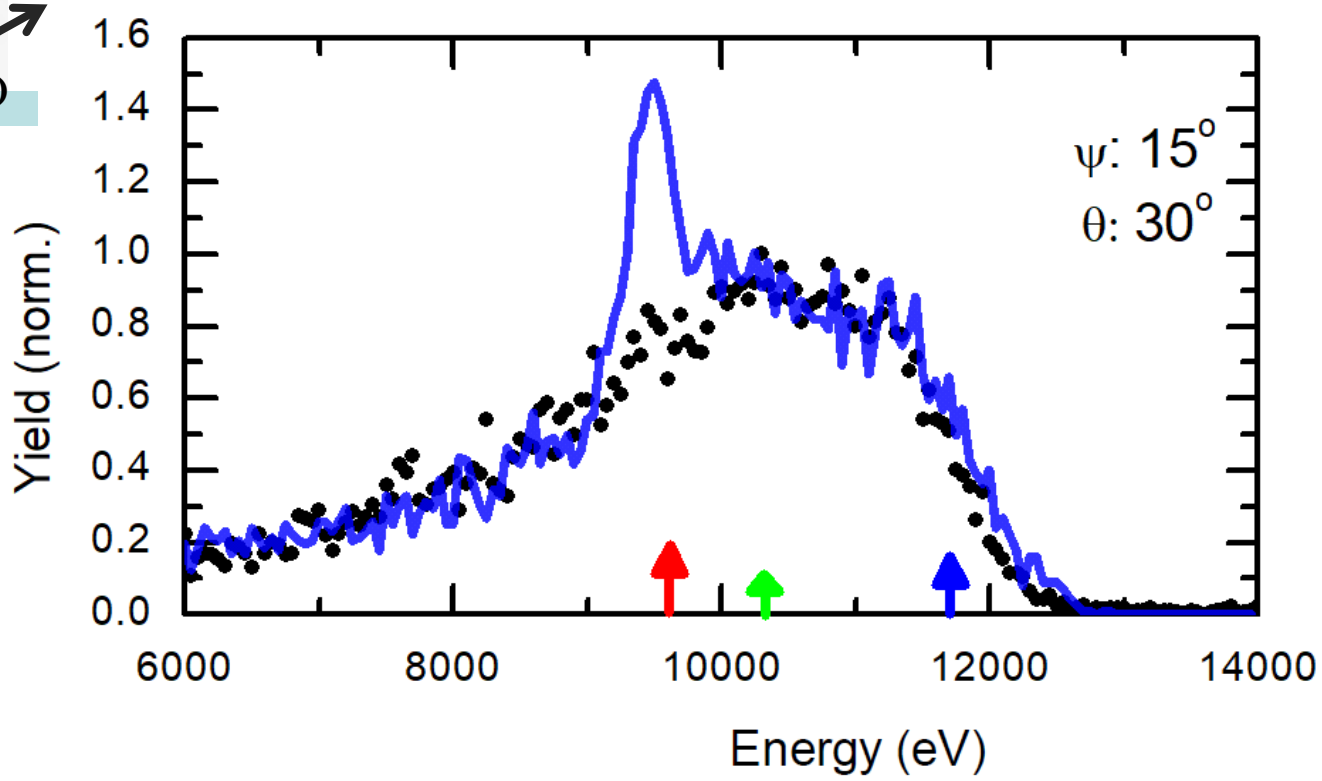
ZERNIKELEIF facility:
low-energy, mass and charge state selected
A^{q+} ion beam facility
with a full suite of auxiliary equipment

14 keV Sn^{2+} - Mo: benchmarking SRIM









tests of “SRIM – experiment difference”

original experiment: 14 keV Sn^{2+} - Mo		
incoming charge state	$Sn^{1+ - 4+}$	as 14 keV Sn^{2+}
energy	5 – 30 keV	as 14 keV Sn^{2+}
ion species	He^{1+}, Ne^{1+}	no difference between exp. and SRIM
	$Xe^{1+ - 2+}$	as 14 keV Sn^{2+}
	Kr^{2+}	larger difference than 14 keV Sn^{2+}
outgoing charge state	neutrals	TOF: Single-Collision peak absent
target	Ru	larger difference than 14 keV Sn^{2+}

SRIM heavy-heavy, slow interactions to be revisited?

scattering potentials

$$U = \frac{Z_1 Z_2}{r} \chi\left(\frac{r}{a}\right)$$

Bohr

$\chi = e^{-r/a}$

$$a = \frac{1}{\left({Z_1}^{2/3} + {Z_2}^{2/3}\right)^{1/2}}$$

TFM-F

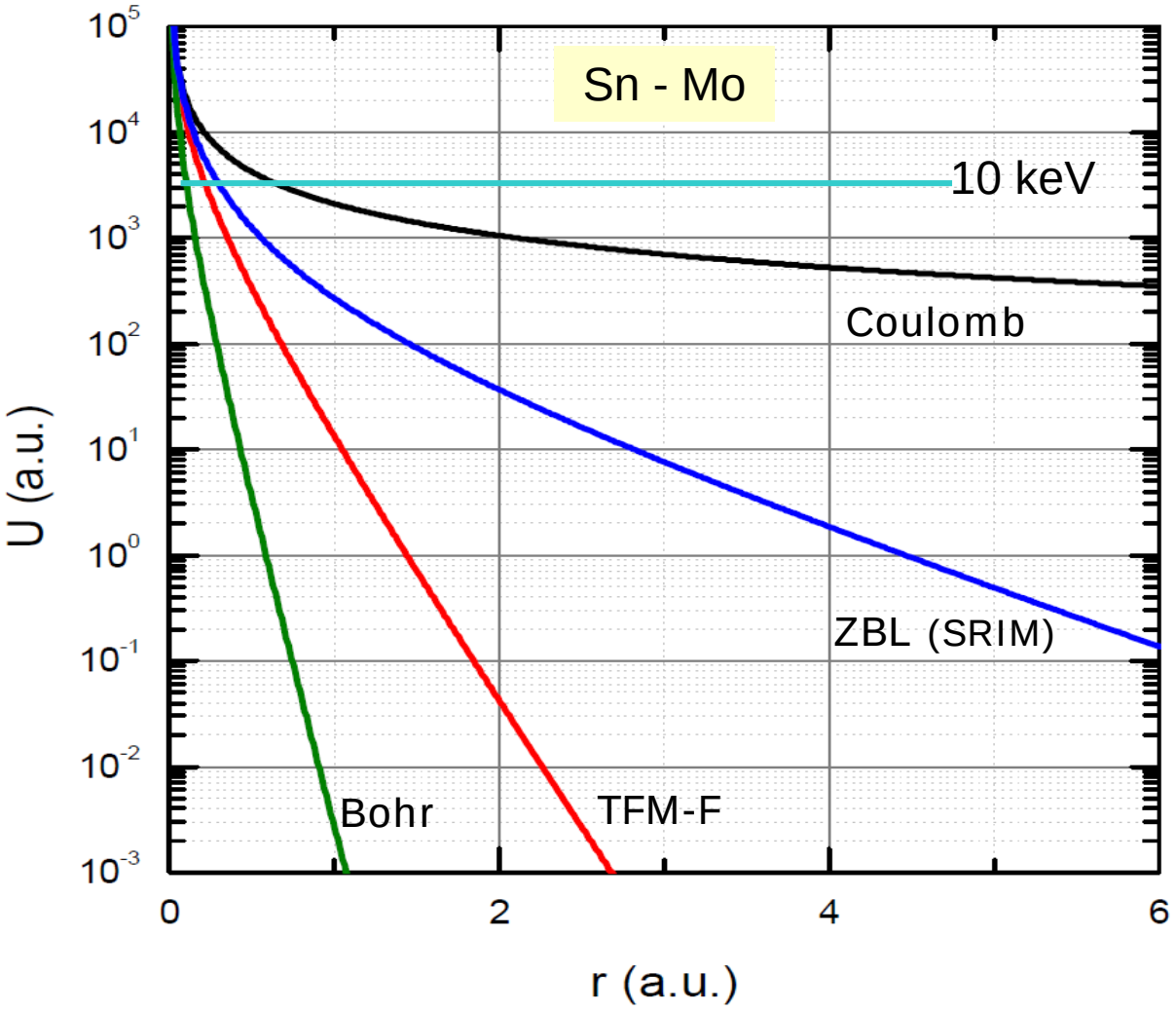
$$\chi = 0.35e^{-3r/a} + 0.55e^{-1.2r/a} + 0.1e^{-6r/a}$$

$$a = \frac{0.8853}{\left({Z_1}^{2/3} + {Z_2}^{2/3}\right)^{1/2}}$$

ZBL (SRIM)

$$\chi = 0.1818e^{-3.2r/a} + 0.5099e^{-0.9423r/a} + 0.2802e^{-0.4028r/a} + 0.2817e^{-0.2016r/a}$$

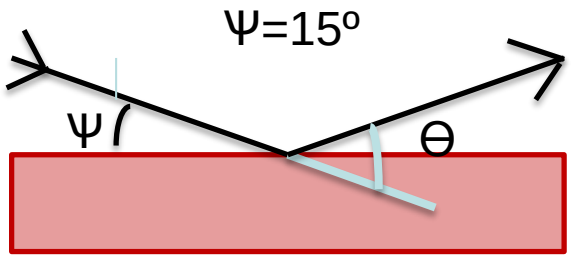
$$a = \frac{0.8853}{{Z_1}^{0.23} + {Z_2}^{0.23}}$$

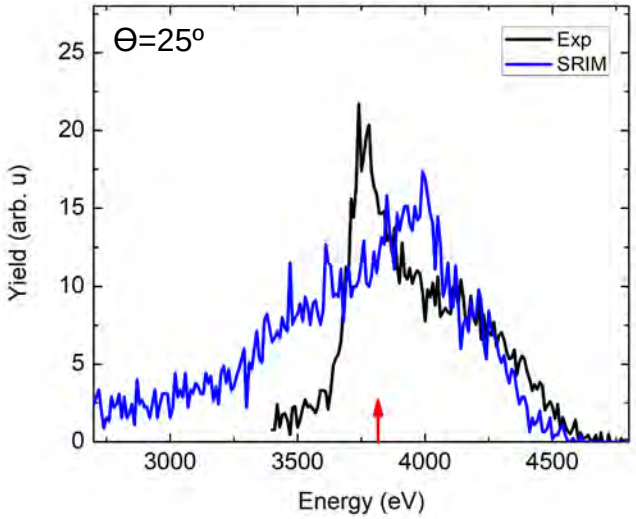


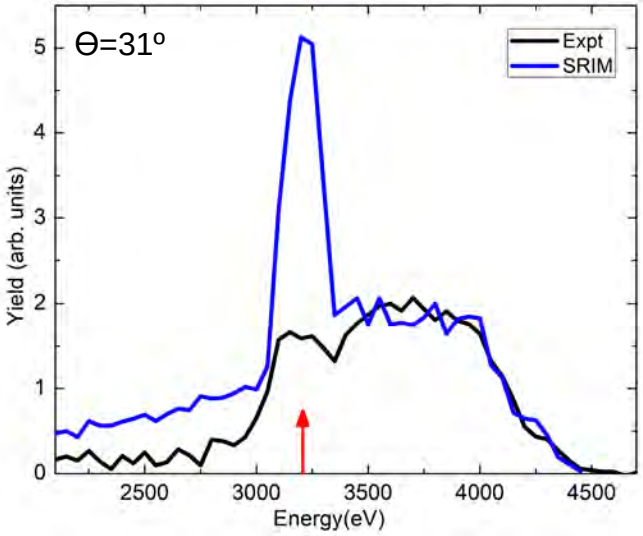
next step: SRIM → SDTrimSP-2D

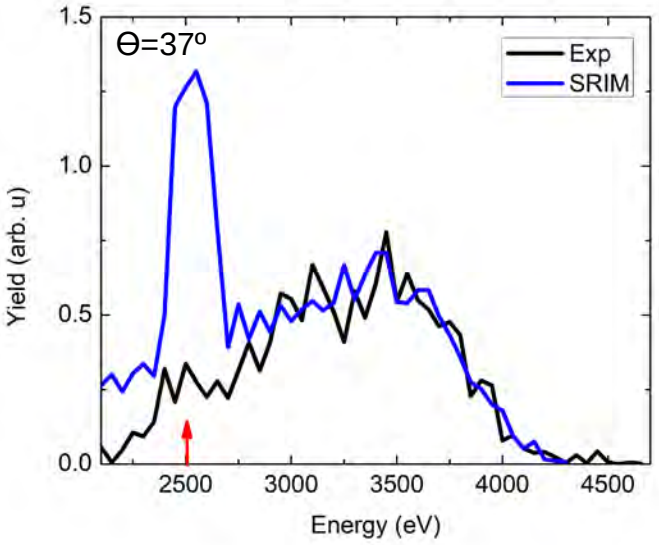
7 keV Kr+ on Cu

Similar $\frac{Target\ mass}{Projectile\ mass}$

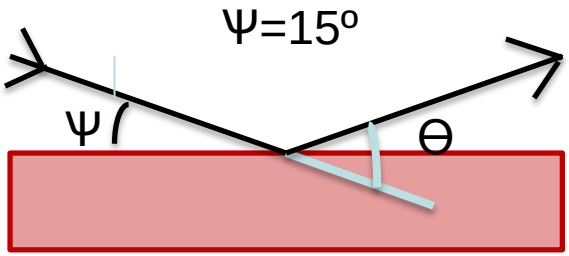


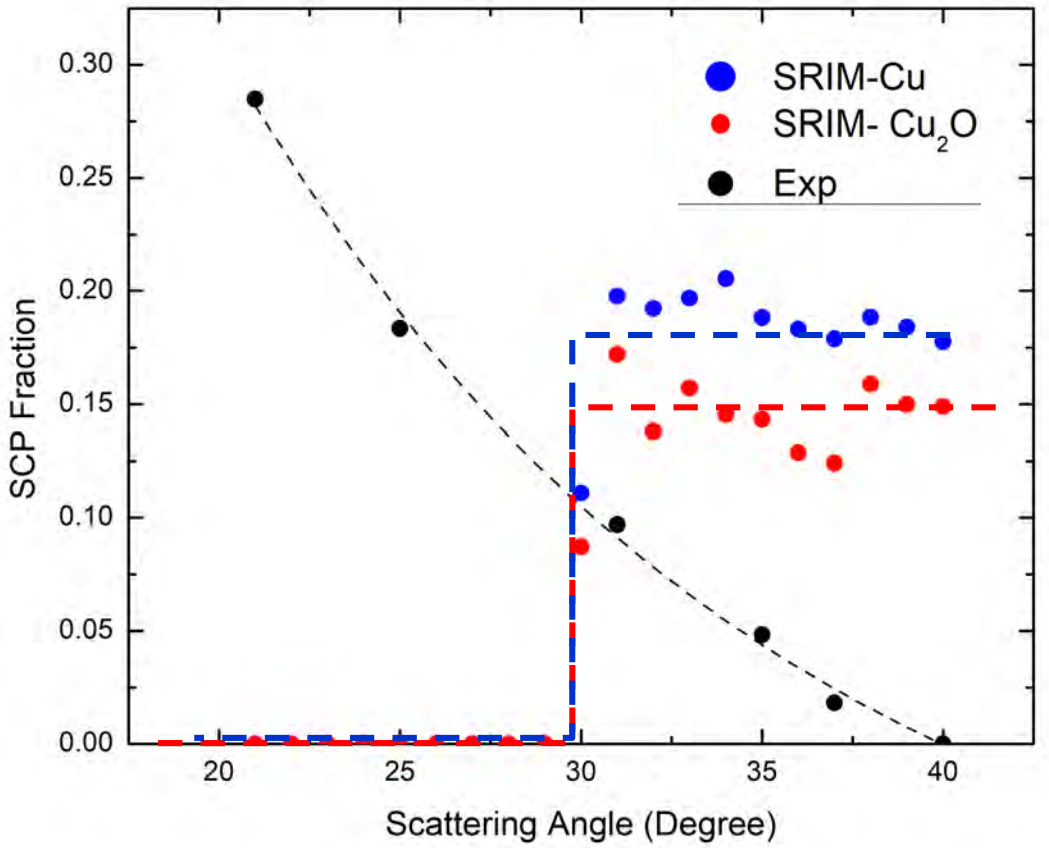






Single-collision peak strength





ion – H_2 gas interactions: H^+/H_2^+

one-electron capture

$$A^{q+} + B \rightarrow A^{(q-1)+*} + B^+$$

autoionizing double capture

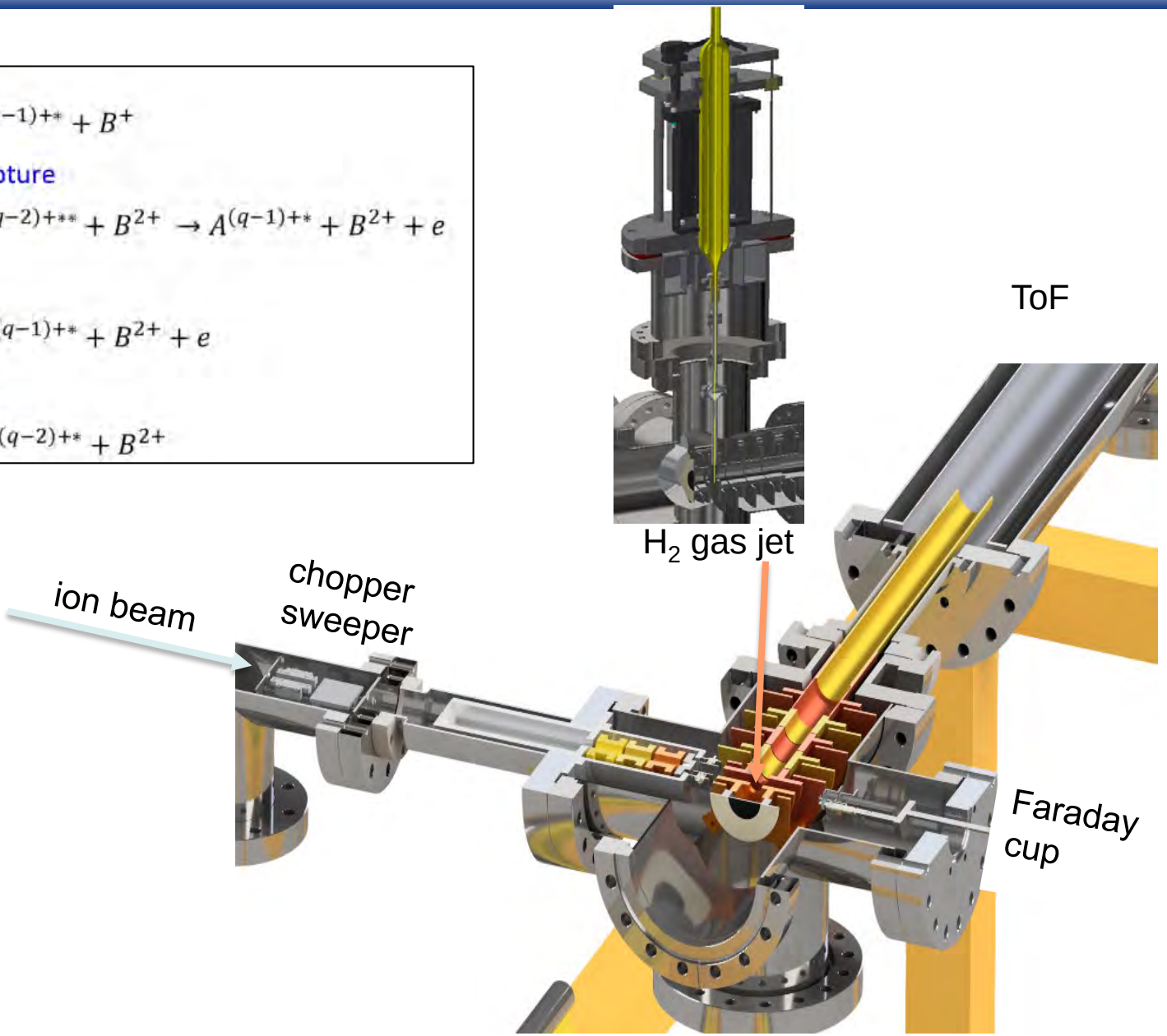
$$A^{q+} + B \rightarrow A^{(q-2)+**} + B^{2+} \rightarrow A^{(q-1)+*} + B^{2+} + e$$

transfer ionization

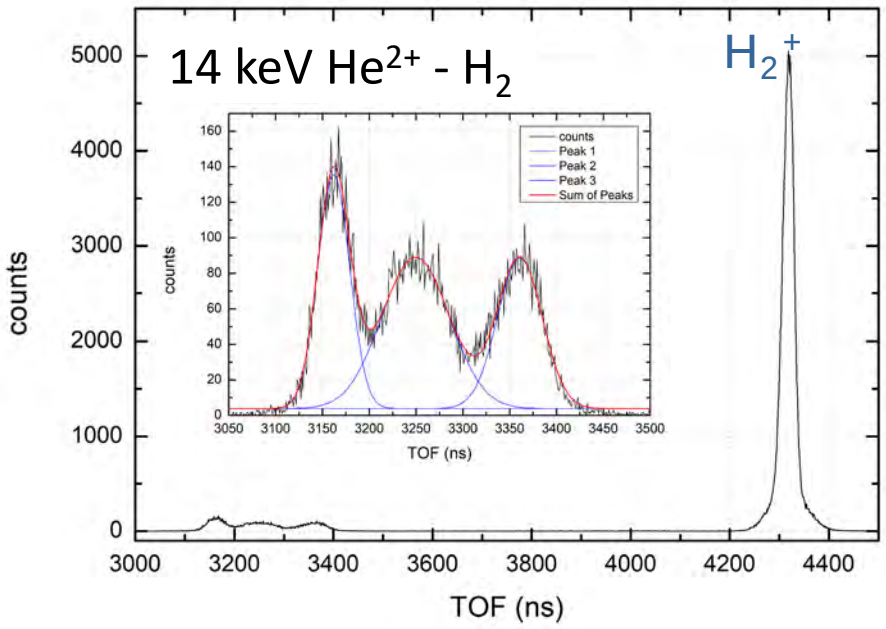
$$A^{q+} + B \rightarrow A^{(q-1)+*} + B^{2+} + e$$

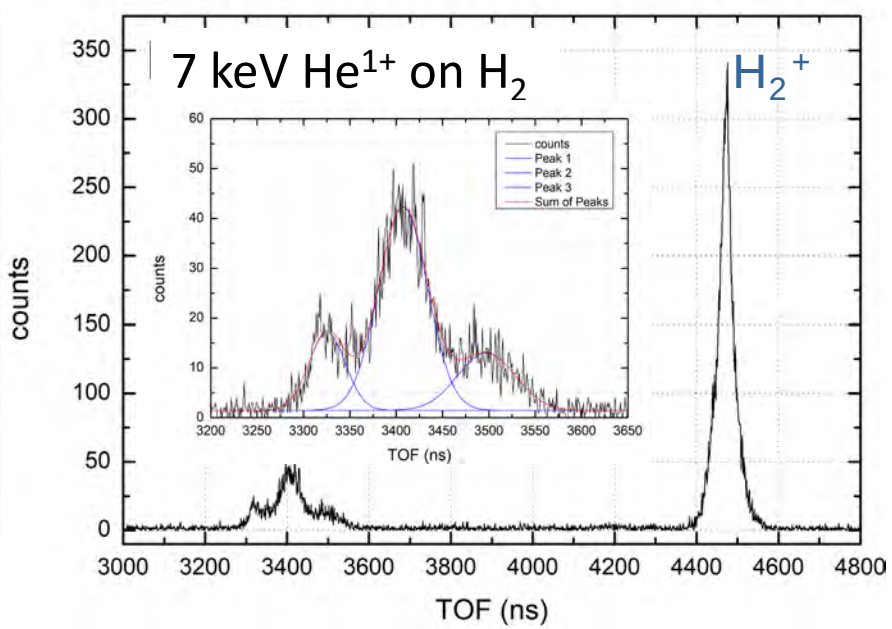
bound double capture

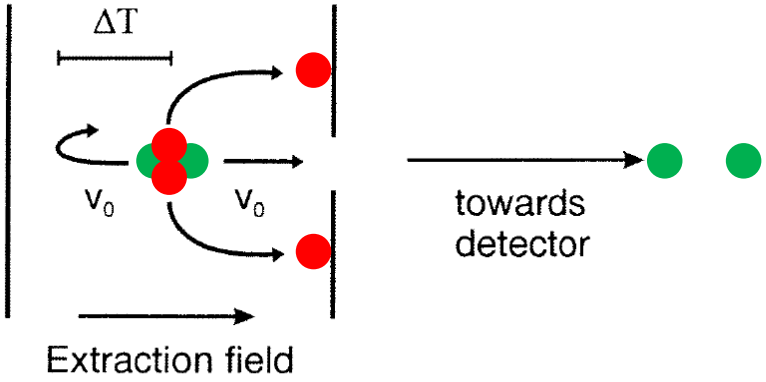
$$A^{q+} + B \rightarrow A^{(q-2)+*} + B^{2+}$$



Very first ToF spectrum of H^+/H_2^+







ready for Sn ion experiments

conclusions

Progress on unraveling fundamental atomic physics aspects	
TOPIC	PROGRESS
atomic structure line identifications	new method “charge state specific spectra” EUV line identifications in $Sn^{13+-15+}$ ions
13.5-nm in band EUV light	driven by the double magic structure of Sn ions
line shapes and opacity	relative optical depth: a single, pertinent scaling-law parameter
Sn ion – solid interactions	missing Single Collision peak SRIM description flaw assess potential effects via Kr – Cu
Sn ions traversing H_2 gas	set up commissioned and operational for charge exchange and H_2 fragmentation