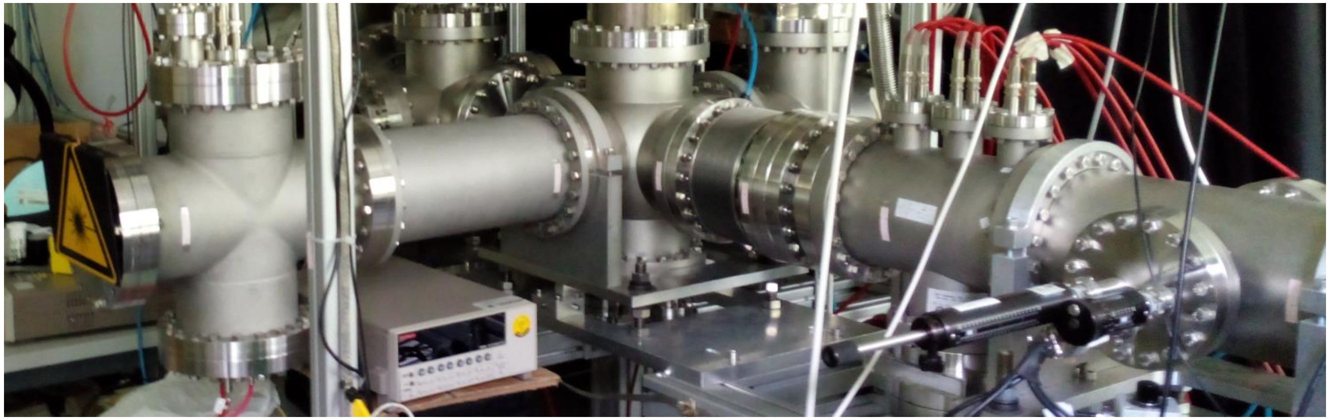
Towards Laser Cooling of Negative Ions

Elena Jordan*, Giovanni Cerchiari,
Aurélien Chevaleyrias, Alban Kellerbauer
Max Planck Institute for Nuclear Physics, Heidelberg



3/7/2014

EGAS46 conference, Lille

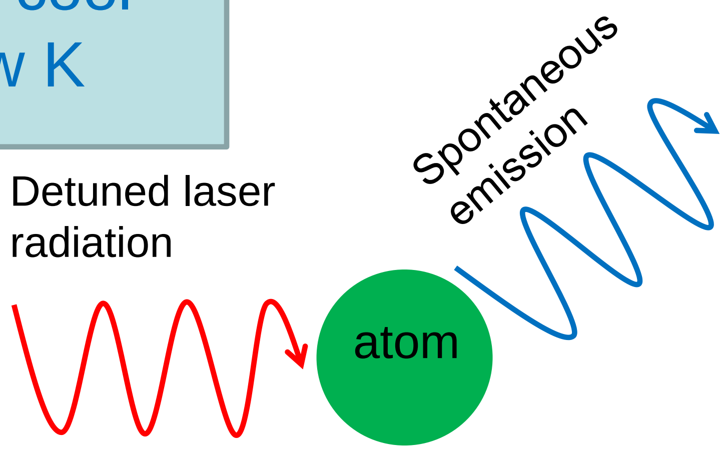
Motivation

Key technique for cooling of positive ions and atoms

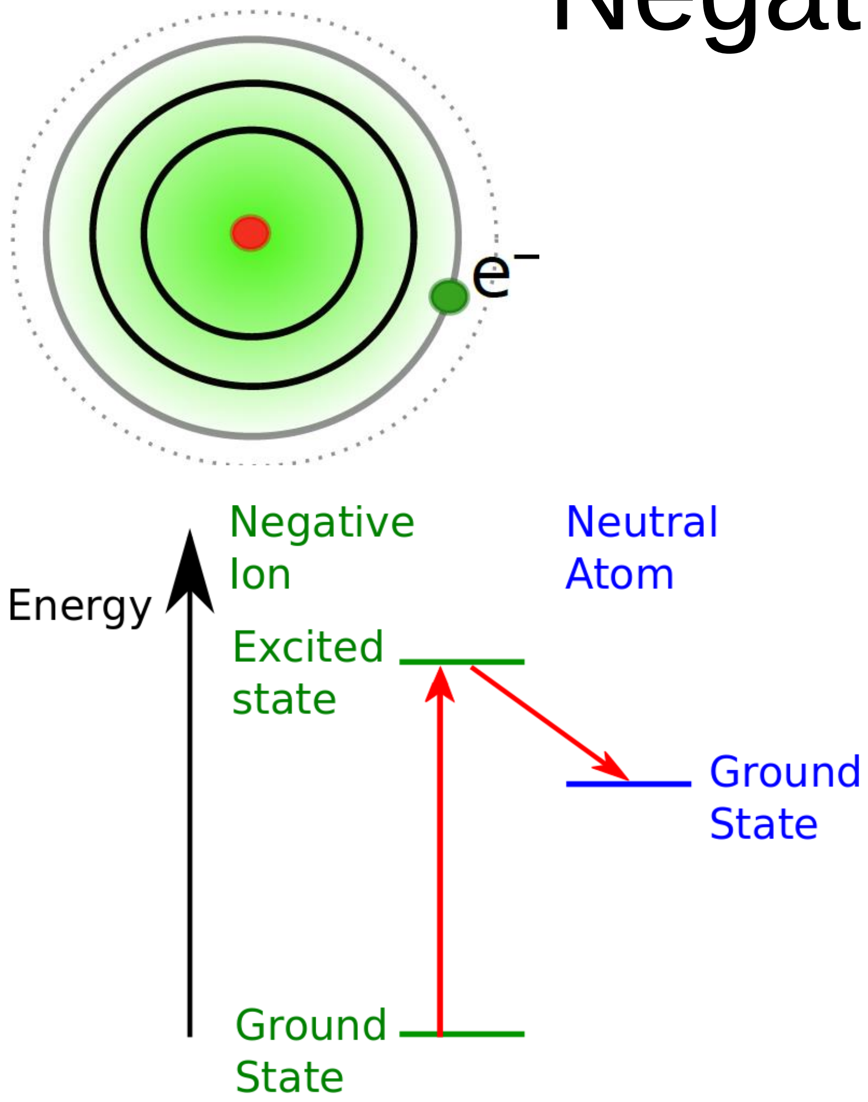
- Positive ions (1978 by Wineland and Dehmelt)
- Neutral atoms (1985 by Chu)
- Negative Ions ?

Until today, no technique to cool negative ions below a few K

Need:
- Two level system
- High spontaneous emission rate



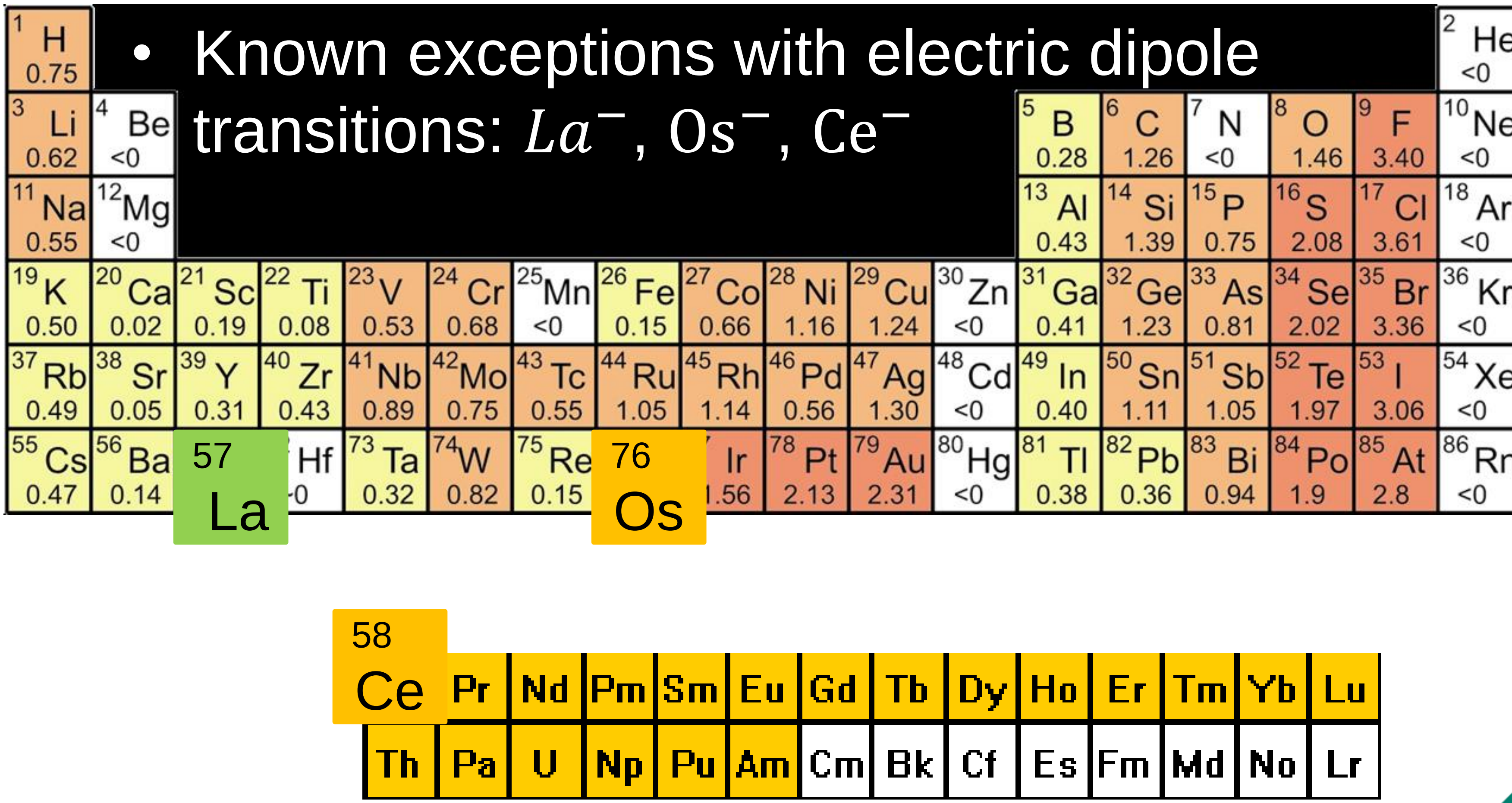
Negative Ions



- Bound mainly by correlation and by polarization effects
- Few, if any, bound excited states
- Even when there are excited states, there are generally no optical transitions

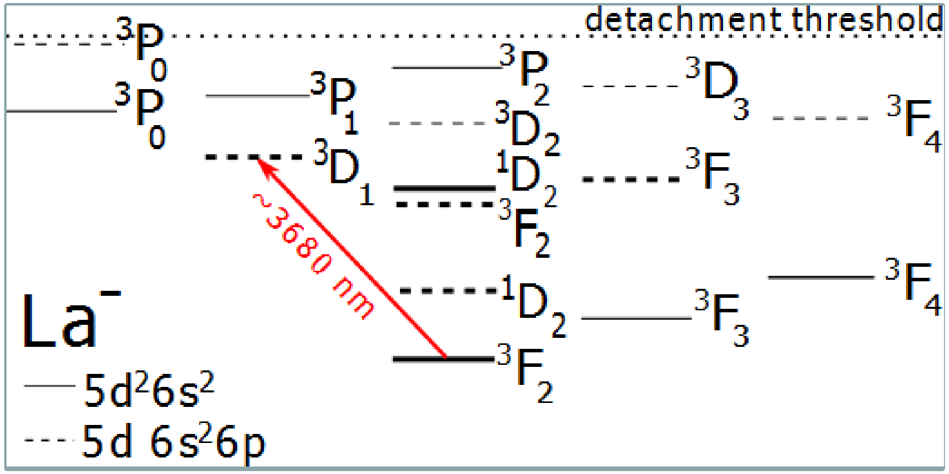
Negative Ions

- Known exceptions with electric dipole transitions: La^-, Os^-, Ce^-

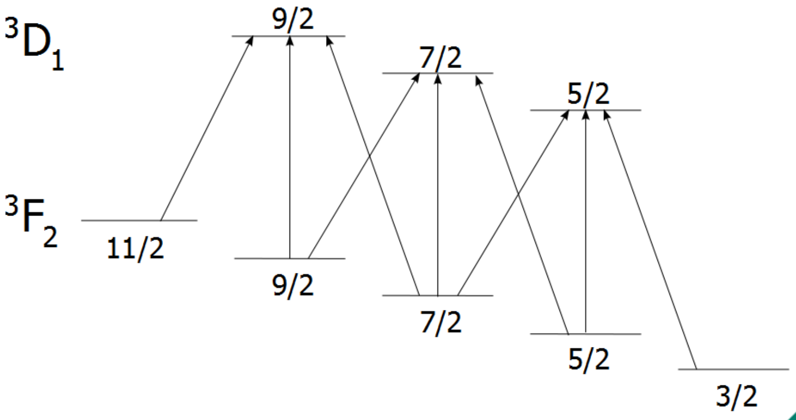


Predictions for La$^-$

- RCI calculations predict:
  - Transition rate 100 times higher than for Os$^-$
- Closed transition (decays back >99.98%)



[S.M. O'Malley and D.R. Beck, Phys.Rev. A 81,032503 (2010)]
[L.Pan and D.R. Beck, Phys.Rev. A 82,014501 (2010)]

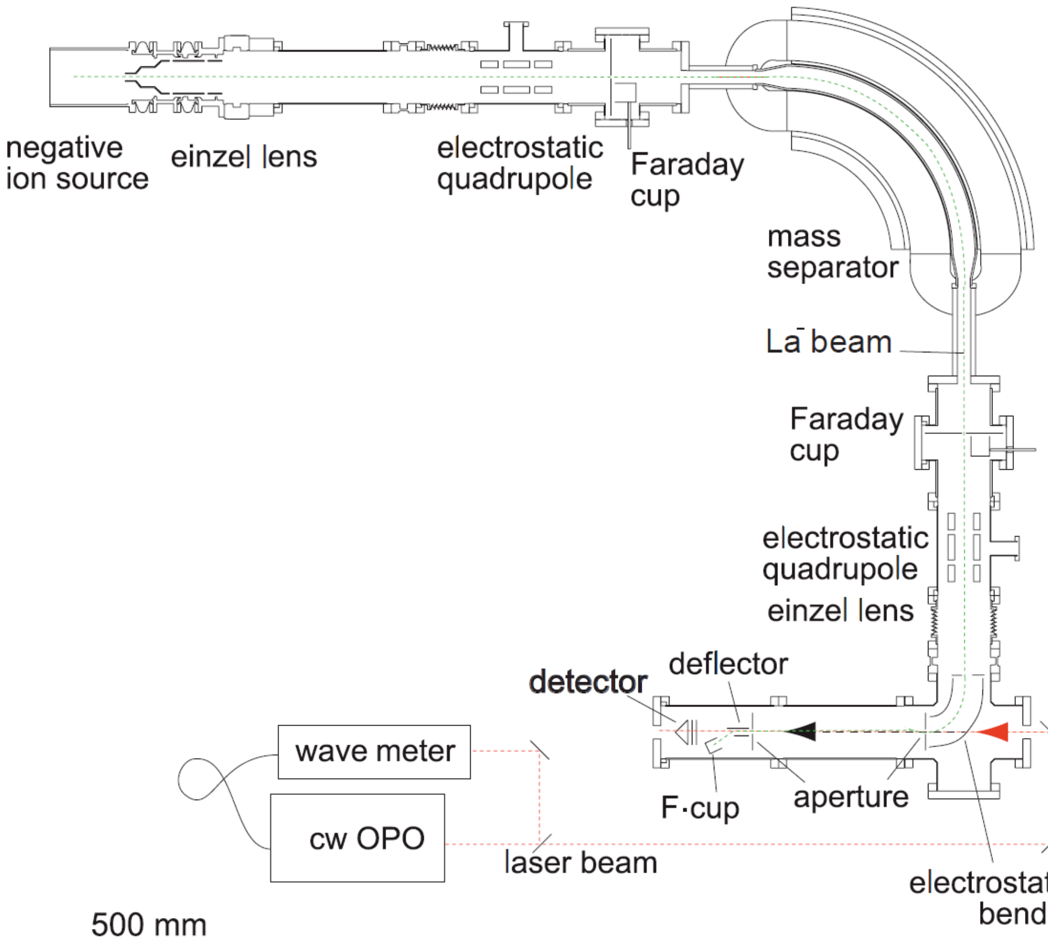


- Nuclear spin 7/2

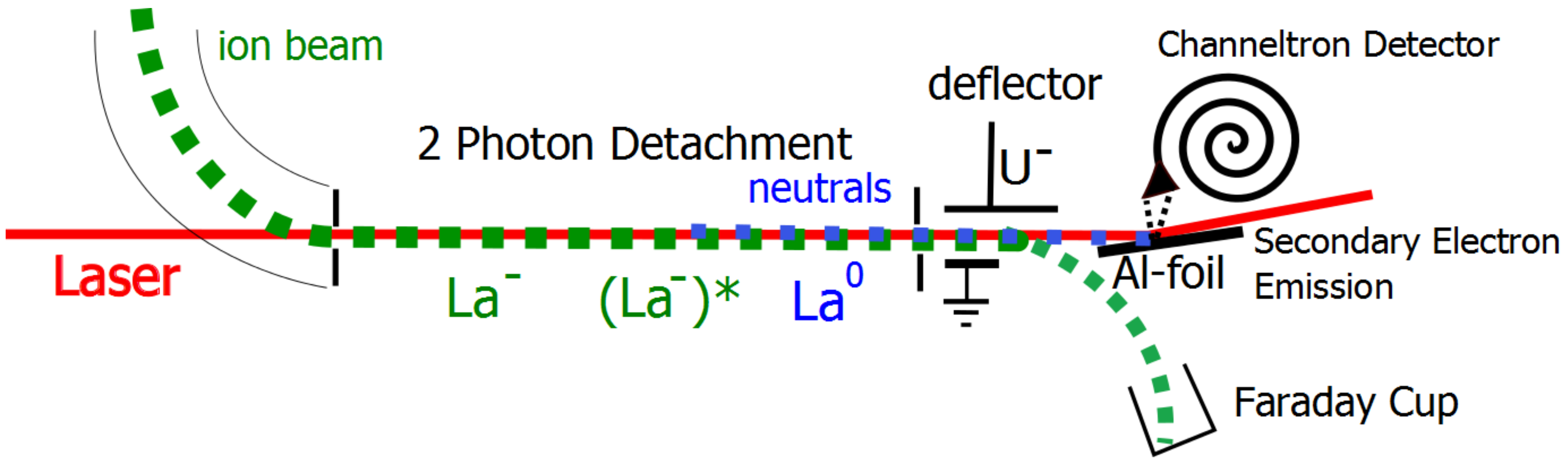
→ 9 Hyperfine transitions

Experimental Setup

- Middleton type ion sputtering source
- Mass separator magnet
- 1-100 pA La^- in spectroscopy part
- Laser bandwidth <1 MHz



Collinear Spectroscopy Setup



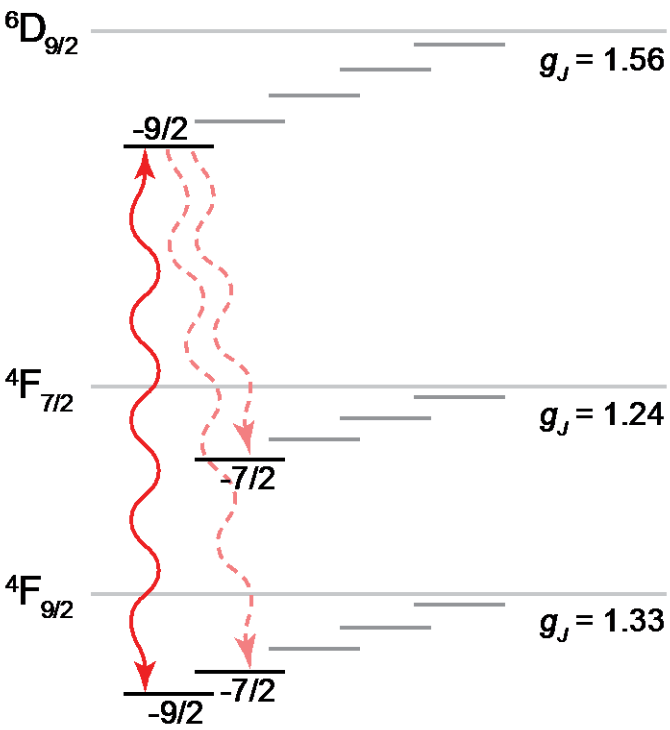
Measurement principle:

- Superimpose ion beam and laser beam
- Scan laser frequency
- Detect neutralized atoms

Measurements on Os^-

Os^-

- Transition frequencies measured and confirmed
- Measurements outcome
  - Low cooling rate:
    Einstein coefficient $\approx 330\ s^{-1}$ equivalent to 3 min from 4K
  - Metastable “dark” states
    2 additional lasers required



[U. Warring et al., Phys. Rev. Lett. 102 (2007) 043001]

Spectroscopic Results for La$^-$

La$^-$

- Counts of neutral atoms on detector
- Background:
  - Dark counts
  - Stripping on apertures
  - Thermal excitation in ion source

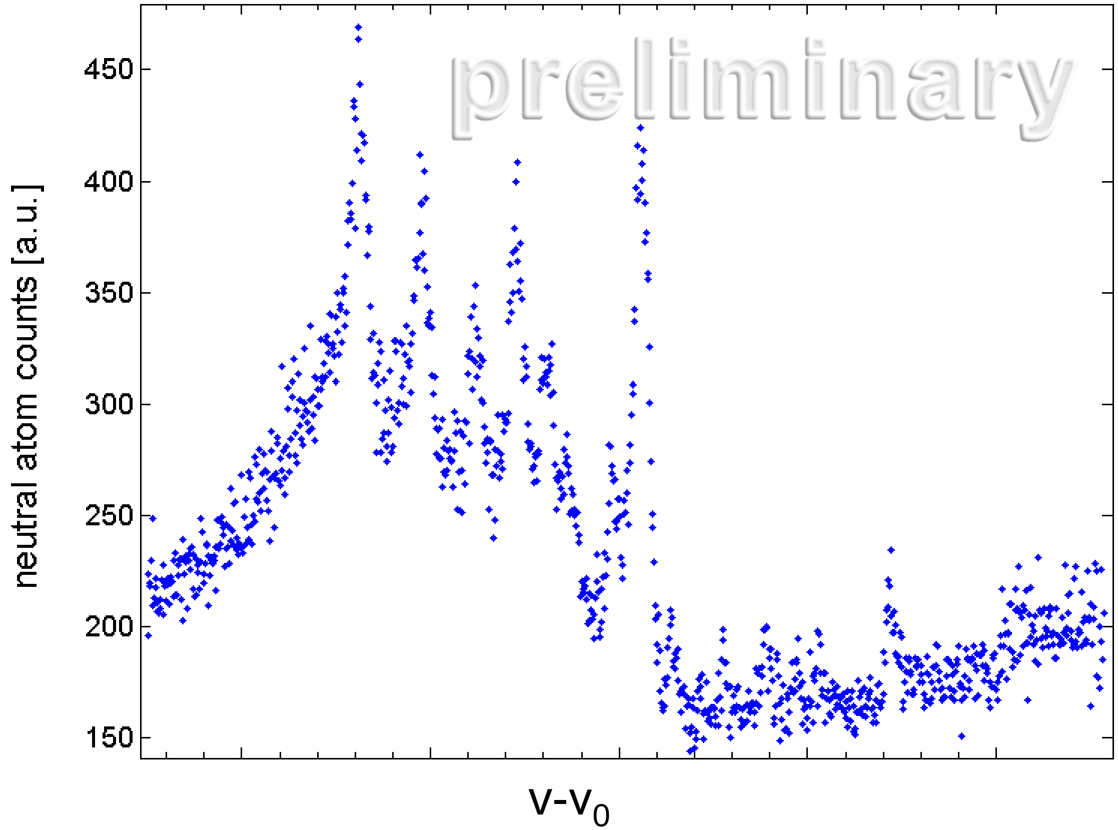
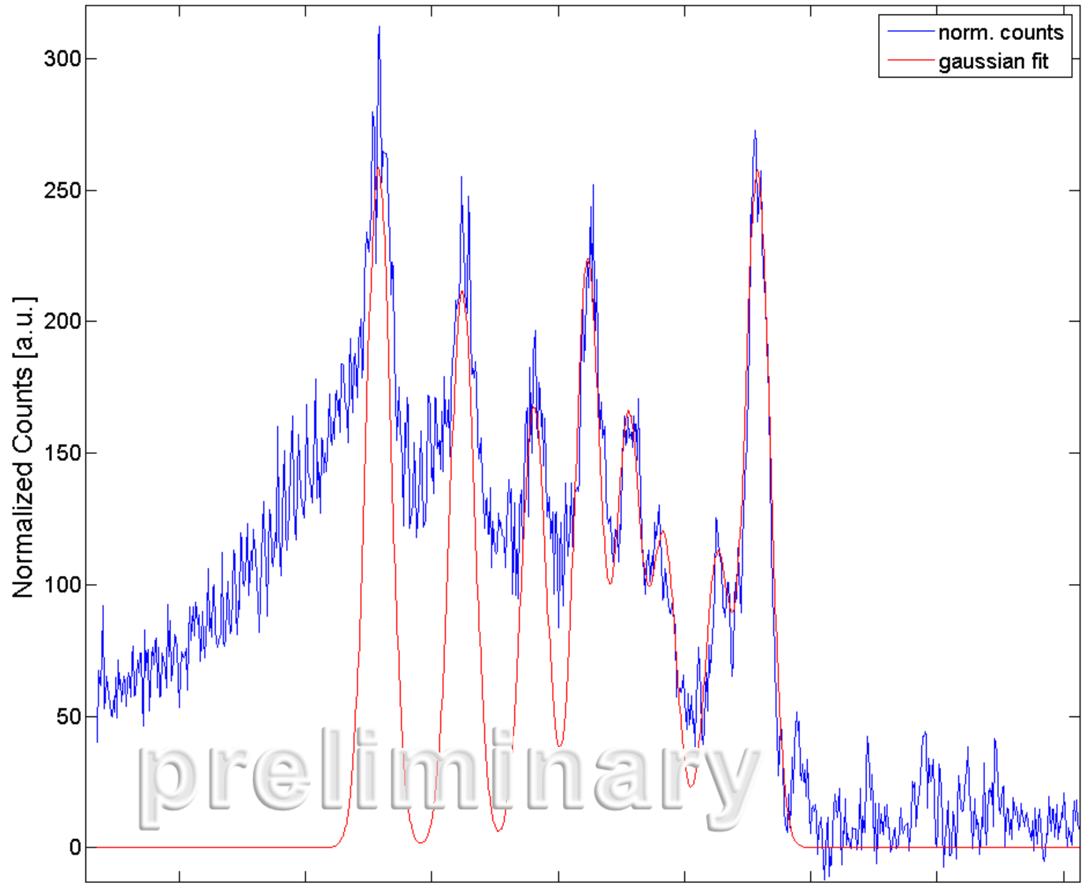


Fig.: Transition of La$^-$ at 7kV beam energy with 5 MHz binning

Spectroscopic Results

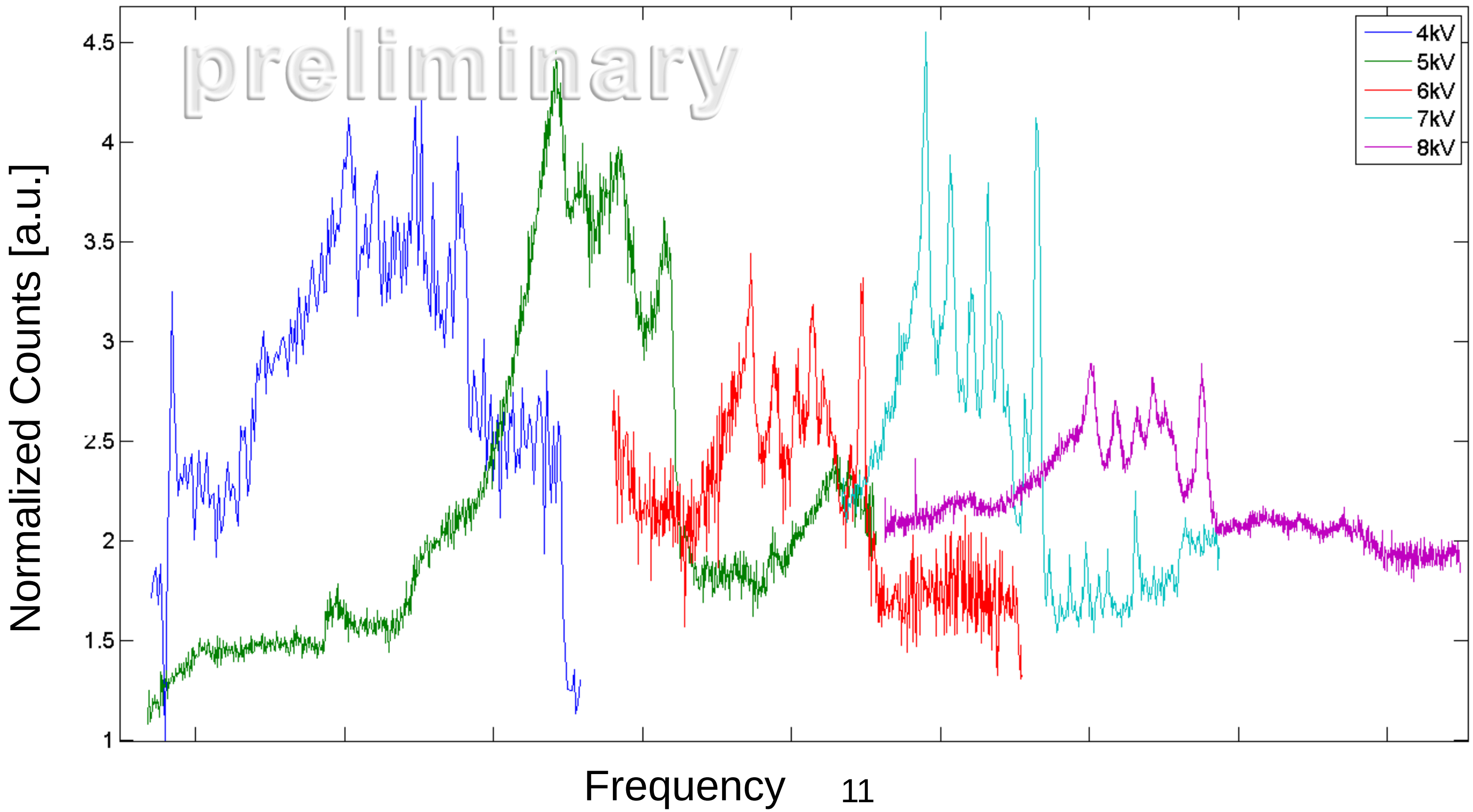
- Fit with Gaussian
- Hyperfine structure mostly resolved
- 8 of 9 expected peaks
- Transition width ≈ 2.3 GHz
- Peak width ≈ 70±25 MHz



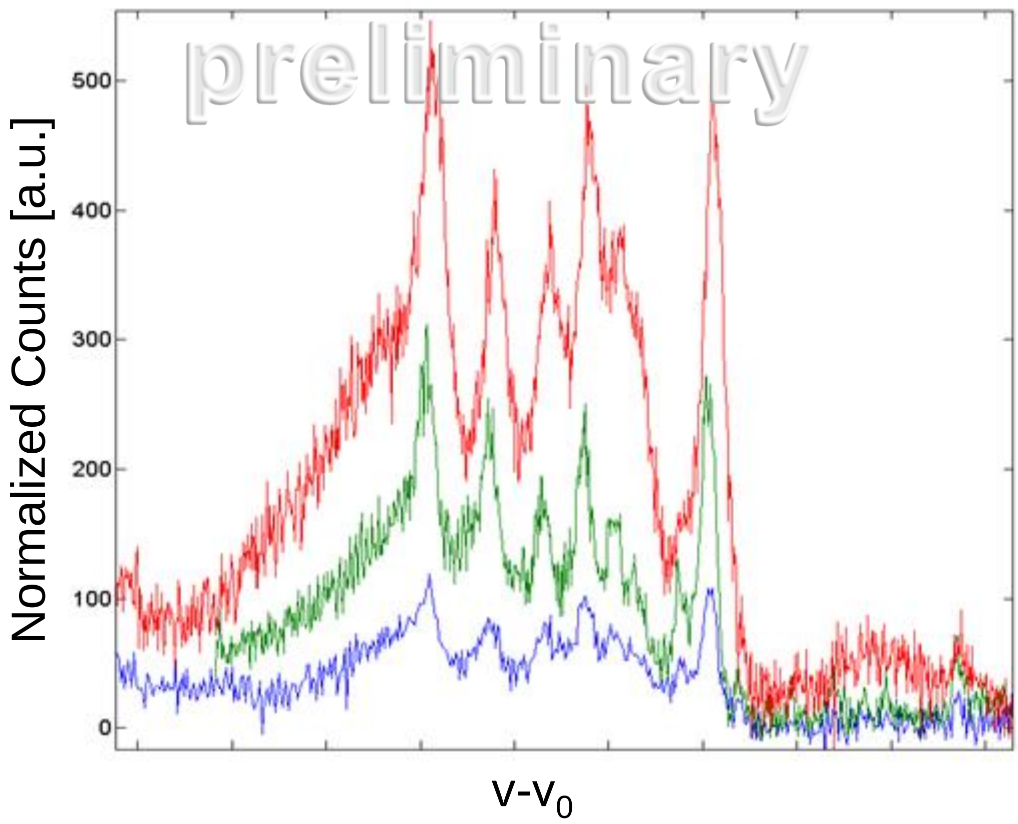
$\nu-\nu_0$

Doppler Correction

- Measure at various beam energies
- Extrapolation to 0 eV → Doppler free transition energy



Doppler Correction



- Data analysis ongoing
- Doppler free transition frequency with Doppler correction:

$$f = f_0 \frac{\sqrt{1+v/c}}{\sqrt{1-v/c}}$$

- Transition wavelength 3.1 µm

Summary

- Collinear ion beam spectroscopy
- Determined transition frequency between two bound states in negative La
- Partially resolved hyperfine splitting

Outlook

- Cross section measurement for the resonant transition
- Measure Zeemann splitting
- If possible: Laser cooling in Penning trap
- Sympathetic cooling of other negative species

Thanks to

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Thank you for your attention!