

## HIGH-RESOLUTION SPECTROSCOPY OF ASTROPHYSICALLY RELEVANT MOLECULAR IONS

O. ASVANY<sup>1</sup>, S. THORWIRTH<sup>1</sup>, P. C. SCHMID<sup>1</sup>, T. SALOMON<sup>1</sup> and S. SCHLEMMER<sup>1</sup>

<sup>1</sup> *I. Physikalisches Institut, Universität zu  
Köln, Zùlpicher Str. 77, 50937 Köln, Germany  
E-mail asvany@ph1.uni-koeln.de*

**Abstract.** High-resolution rovibrational and pure rotational spectra for molecular ions of astrophysical interest have been recorded in the Cologne laboratories. Recent examples include  $\text{CN}^+$ ,  $\text{CH}_2\text{NH}_2^+$ ,  $\text{CH}_3\text{NH}_3^+$ ,  $c\text{-C}_3\text{H}_2^+$ ,  $\text{l-CCCH}^+$ , and  $\text{HCCCO}^+$  (see references below for the first four molecular ions). These have been investigated using ion trap instruments which feature mass selection via quadrupole mass analyzers, long storage times in cryogenic 22-pole ion traps, and cooling of the ions via He buffer gas to temperatures as low as 4 K. Due to the low number of stored ions (typically less than  $10^5$ ), so-called action spectroscopic techniques have to be applied, in which the ion count is used as the spectroscopic signal. As the ion counting efficiency is close to unity, action spectroscopy can be very sensitive. Several such action spectroscopic schemes have been developed in-house during the last couple of years. Recent technical advances along this direction are demonstrated for the ions  $\text{l-CCCH}^+$  and  $\text{HCCCO}^+$  in this contribution. The advantage of using mass-selected, cryogenically cooled ions is that very clear spectroscopic information is obtained, with only a handful of lines, but which can be intense and have very narrow linewidth. This allows to obtain accurate frequency information and to resolve overlapping lines. An example of such an approach is the first rotational spectrum of protonated methylamine,  $\text{CH}_3\text{NH}_3^+$ , shown in the Figure below. For this prolate symmetric top molecule thirteen transitions between 80 and 240 GHz were detected in the ground vibrational state, covering  $J_K = 2_K - 1_K$  up to  $J_K = 6_K - 5_K$  with  $K = 0, 1, 2$ . A comparison with spectroscopic simulations reveals that this symmetric top molecule is not rigid, but exhibits torsional motion between the  $\text{CH}_3$  and  $\text{NH}_3$  subunits. This result and the other laboratory rotational data presented here will further support and guide radio-astronomical searches of these species in space. A first search of  $\text{CH}_3\text{NH}_3^+$  in the Sagittarius B2(N) and (M) regions was performed but unfortunately without a clear detection.

### References

- Thorwirth, S., Schreier, P., Salomon, T., et al.: 2019, *Astrophys. J. Lett.* **882**, L6  
Markus, C.R., Thorwirth, S., Asvany, O., and Schlemmer, S.: 2019, *PCCP* **21**, 26406  
Schmid, P. C., Thorwirth, S., Endres, C. P., et al.: 2022, *Frontiers in Astronomy* **8**, 805162  
Markus, C.R., Asvany, O., Salomon, S., et al.: 2020, *Phys. Rev. Lett.* **124**, 233401

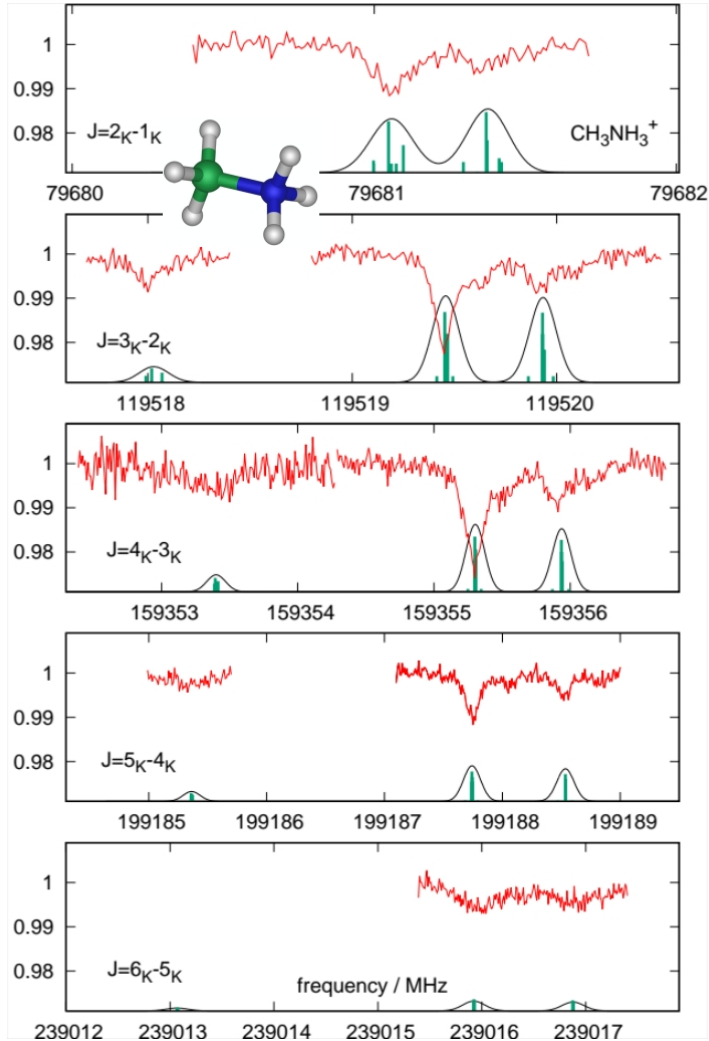


Figure 1: Measured rotational transitions  $J'_K \leftarrow J''_K$  ( $K = 0, 1, 2$ ) of  $\text{CH}_3\text{NH}_3^+$  (red trace). The simulations (green sticks indicate nitrogen quadrupole hyperfine structure and their convolution is given as black traces) are based on a simple rigid symmetric rotor model. Discrepancies between the simulated and measured spectra, in particular the blue-shifted shoulders for  $K = 0$  and  $1$  (red trace), are due to the neglect of torsional motion between the  $\text{CH}_3$  and  $\text{NH}_3$  subunits in the simulation. Figure taken from Schmid et al 2022.