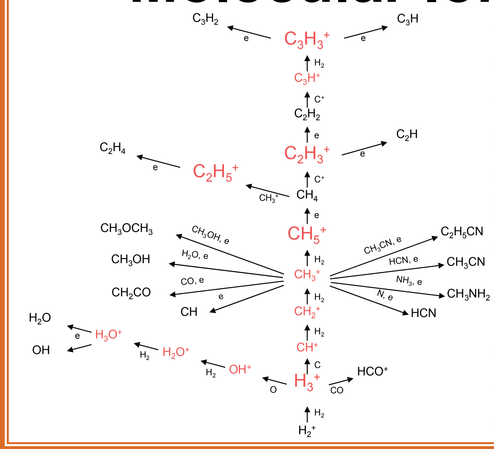
Sensitive, Cooled, Resolved, Ion BEam Spectroscopy: SCRIBES

Michael Porambo, Holger Kreckel, Andrew Mills, Manori Perera, Brian Siller
Department of Chemistry, University of Illinois at Urbana-Champaign, Urbana, IL 61801
Benjamin J. McCall
Departments of Chemistry and Astronomy, University of Illinois at Urbana-Champaign, Urbana, IL 61801

Molecular Ion Astrochemistry



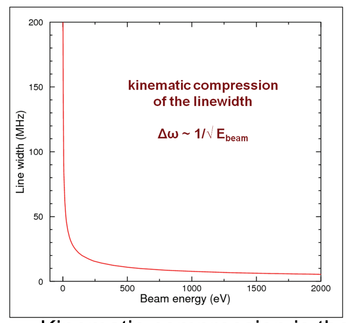
- Molecular ions play major roles in interstellar chemistry
- Spectroscopy is the main tool for identifying relevant chemical species in astronomical environments; therefore, high resolution laboratory spectra are important in advancing astrochemical research.

  HCO^+, HOC^+, NH^+ — SOFIA, Herschel.

  CH_5^+, $C_2H_5^+$, $C_3H_3^+$ — Precursors of common molecules in the interstellar medium.
- SCRIBES is a technique to acquire the rovibrational spectra of such targets.

Key Features of SCRIBES

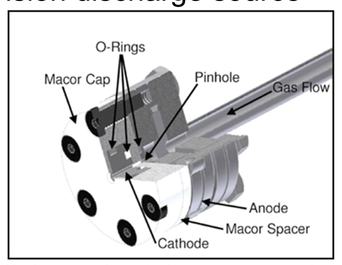
- Narrow linewidth due to kinematic compression.[1]
- Ion-neutral discrimination from the 90 benders, modulation technique.
- Optical cavity around drift region enhances spectroscopic signal.
- Mass identification using the TOF mass spectrometer and Doppler splitting.
- Low rotational temperature can be achieved using supersonic expansion discharge source.
- Characterization of the ion beam using mass spec.
- Frequency comb provides calibration to within 1 MHz.
- Major disadvantage: low ion column density.



Kinematic compression is the compression of absorption linewidth with increasing beam velocity.

Ion Source

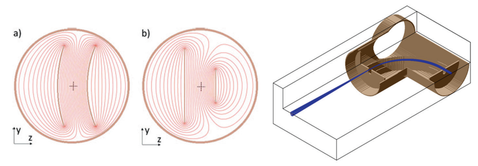
- Source chamber pressure of typically 10^{-5} Torr.
- Currently using cold cathode source.
- Electric glow discharge struck in quartz tube between two floated electrodes.
- Variables studied include the source's hole diameter, electrode voltages, ballast resistance, inlet gas pressure
- Plans to introduce supersonic expansion discharge source



Schematic of the supersonic expansion discharge source.[2]

Ion Optics

- Ions are extracted with 4 kV potential.
- Deflector plates allow steering.
- Einzel lens focuses ions into fast beam.
- A special 90 double-focusing design electrostatic bender is used to divert and collimate the ion beam into the overlap region

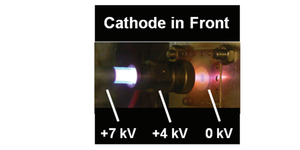


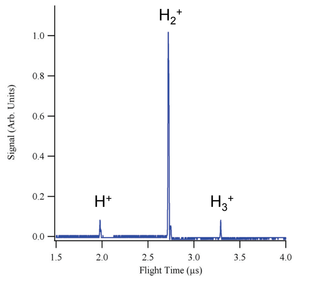
SIMION models of the 90 bender.[3] A): Spherical bender b): Cylindrical bender, such as the type used in SCRIBES.

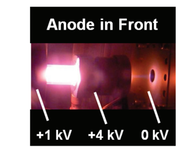
- While ions are diverted by the bender, neutral species are not.

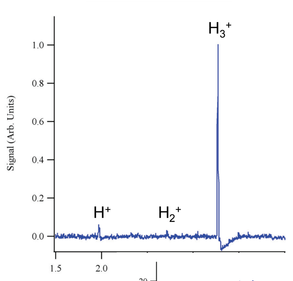
Recent Improvements

- Attempting to acquire spectrum of rovibronic Meinel bands of N_2^+ to test the instrument sensitivity.
- Redesigned cold cathode ion source to allow for water cooling, sideways introduction of the precursor gas.
- Recently modified the cold cathode source to run in "reverse bias"; i.e., the ions are extracted from the anode.

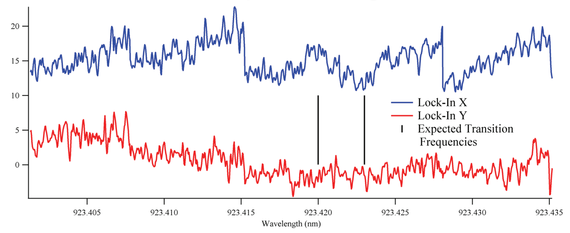




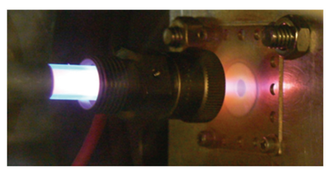




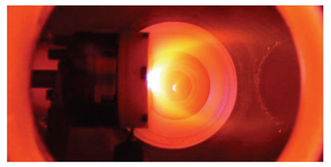
- Mass spectral studies of a hydrogenic plasma in this configuration revealed that a significant amount of H_3^+ was formed.
- The presence of H_3^+ implies that ion collisions occur.
- This indicates that N_2^+ should be experiencing collisions too.
- Most sensitive technique tried yet—NICE-OHMS—performed.



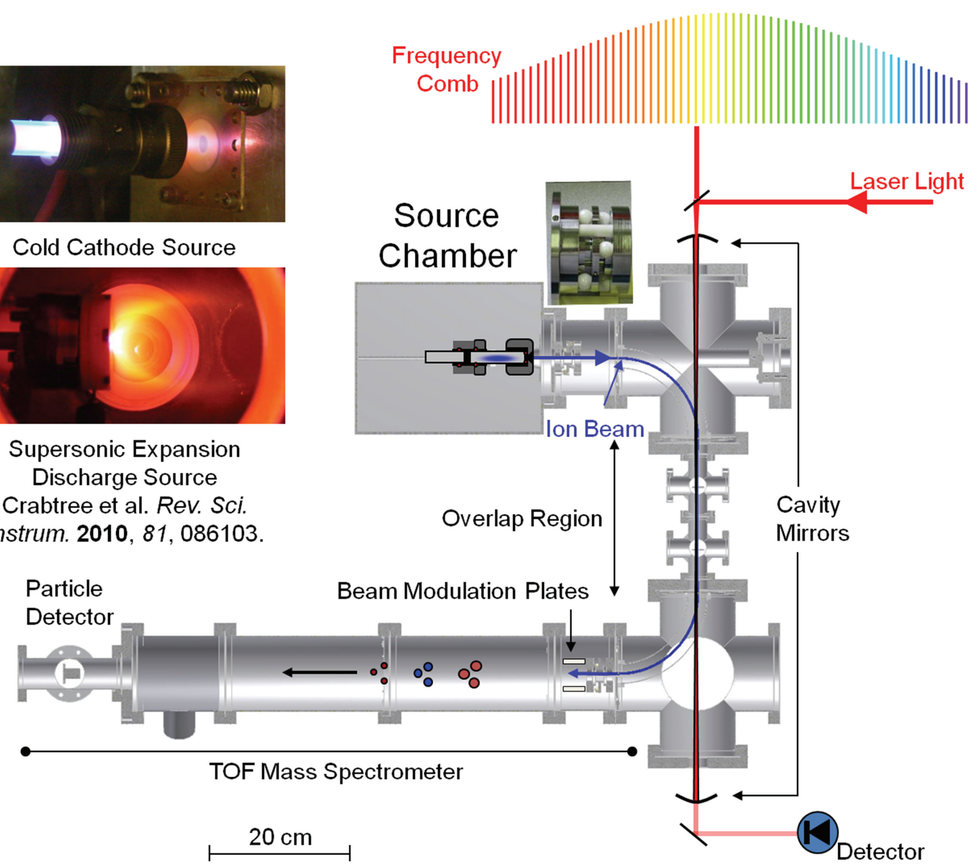
SCRIBES Experimental Layout



Cold Cathode Source



Supersonic Expansion Discharge Source
Crabtree et al. *Rev. Sci. Instrum.* **2010**, *81*, 086103.



Spectroscopy

- Region after first 90 bender where laser is overlapped with the ion beam.
- Laser used is a tunable Ti:sapphire (900–1100 nm).
- Laser couples into low finesse (~200) optical cavity.
- Two apertures are used to guide the beam for better overlap.
- The spectroscopic methods performed in order of increasing sensitivity:

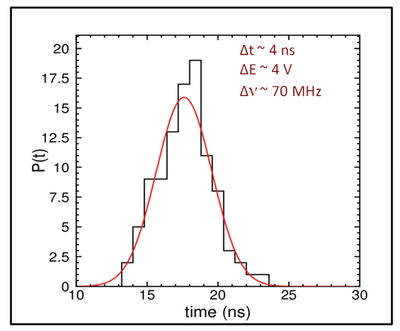
  Cavity Ringdown Spectroscopy (CRDS)

  Cavity Enhanced Velocity Modulation Spectroscopy (CEVMS)[4]

  Noise Immune-Optical Heterodyne Molecular Spectroscopy (NICE-OHMS).

Mass Spectrometer

- Used for mass identification and beam energy characterization.
- Pulser plates create packets of ions down the time-of-flight (TOF) drift tube that separate by m/z.
- The mass spectrometer allows calculation of the beam energy and the beam energy spread.



Mass spectral signals for molecular ions can be collected and analyzed in a histogram to obtain a measure of the ion beam's energy spread.

Future Work

- We are currently testing spectroscopic techniques on positive column discharge cell—please see Talk T08 tomorrow for this work and a discussion of optical heterodyne spectroscopy and NICE-OHMS. These studies will enhance our understanding of the sensitivity of the spectroscopy used in SCRIBES.
- We will continue attempts to acquire N_2^+ spectra. These spectra will aid in the optimization of the precision and sensitivity of the instrument.
- We plan to construct a difference frequency generation system using the Ti:sapphire laser and a Nd:YAG to study the vibrational spectra of molecular ions such as HN_2^+ in the mid-infrared. The method of combination differences will be used to obtain an indirect THz spectrum, to be compared with past studies.
- Mid-IR and indirect THz spectroscopy will be performed on astrophysically relevant molecular ions.

References and Acknowledgments

[1]Field, D. and Gray, M. D. *Phys. Rev. A* **1989**, *40*, 1976–1982.
[2]Crabtree, K. N.; Kauffman, C. A.; McCall, B. J. *Rev. Sci. Instrum.* **2010**, *81*, 086103.
[3]Kreckel, H.; Bruhns, H.; Miller, K. A.; Wåhlin, E.; Davis, A.; Höckh, S.; Savin, D. W. *Rev. Sci. Instrum.* **2010**, *81*, 063304.
[4]Siller, B M.; Mills, A. A.; McCall, B. J. *Rev. Sci. Instrum.* **2010**, *35*, 1266–1268.

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