Charge exchange measurements with neutral Hydrogen using the X-ray Quantum Calorimeter (XQC)

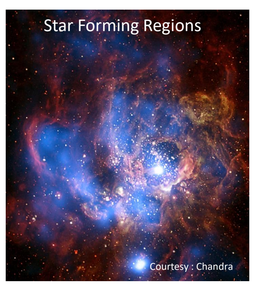
LTD-18
#239-308

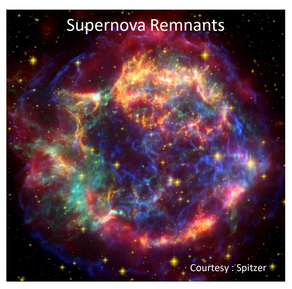
C. V. Ambarish[1], N. Christensen[1], F. Jaeckel[1], D. McCammon[1], A. Roy[1], D. Wulf[1], D. Seely[2], V. Andrianarijaona[3], C. C. Havener[4]

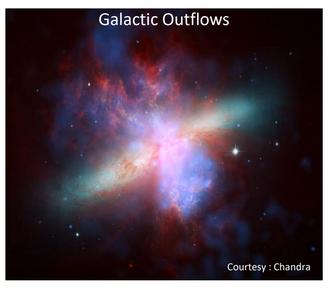
[1]University of Wisconsin-Madison [2]Albion College [3]Pacific Union College
[4]Oak Ridge National Laboratory

1. Introduction – Why study Charge Exchange?

- Highly-charged ions colliding with neutral atoms tend to accept an electron from the atom in a process known as **Charge Exchange (CX)**. The electron is accepted into an excited state which then de-excites back to ground state thus emitting an X-ray photon.
- CX is ubiquitous in astronomy. Wherever we have hot gas (with highly charged ions) interfacing with cold gas (with neutral atoms), we can have CX. Examples of such X-ray emission include

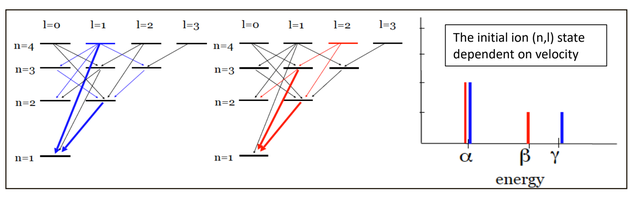




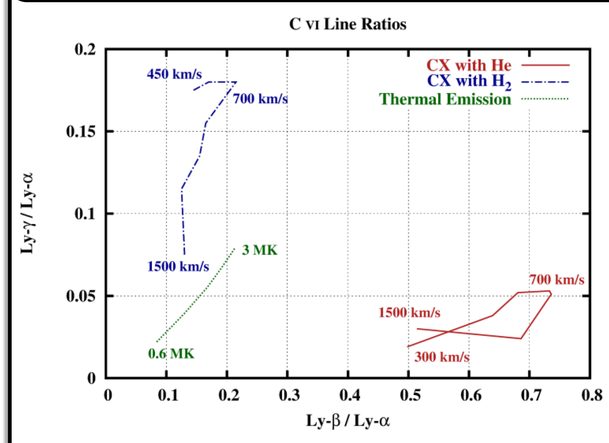


- Modelling charge exchange emission is hard because the partial cross-sections and hence the X-ray line strengths depends on the relative velocity of the ion and the atom. The relative velocity dictates the (n,l) quantum state after the collision.

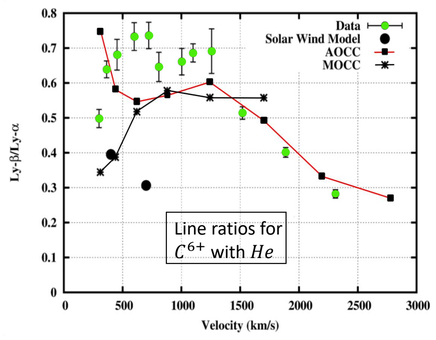
Different angular momentum state can give rise to different spectral lines and line-ratios because of selection rules.



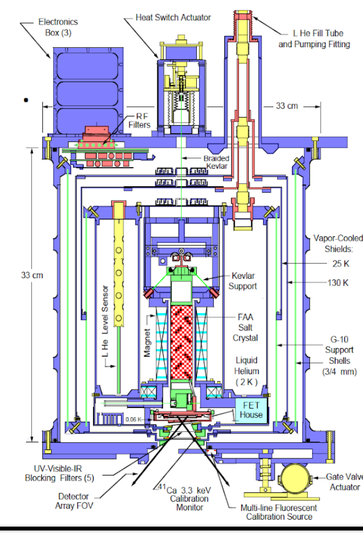
2. Previous Measurements



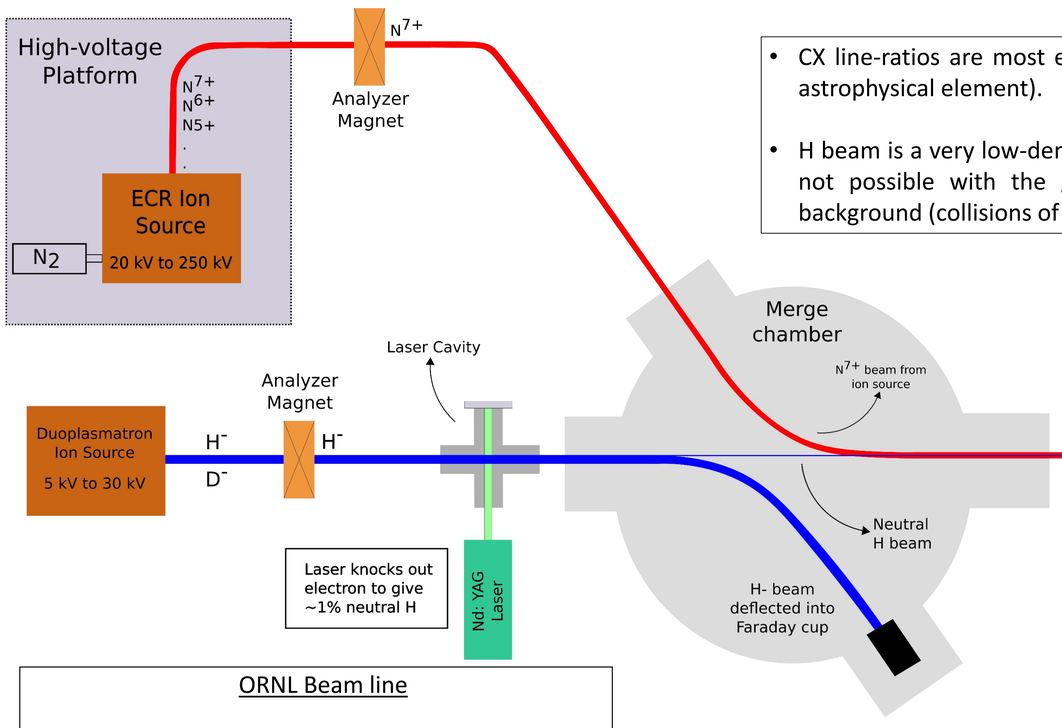
- Different spectral line ratios are plotted for charge exchange of C^{6+} . The heavy and non-trivial dependence on relative velocity is very clear.
- Good news is charge exchange spectra with different neutral atoms (and thermal emission) are very different. So, line ratios can help identify the process.



- X-ray lines are measured by our modified sounding rocket payload XQC, a silicon thermistor microcalorimeter.
- XQC was hooked up to the beamline and a gas cell was used as a stationary target.
- Data and theoretical models shown for C^{6+} with He for a range of velocities.
- Predictions very poor for low relative velocities which are the region of astrophysical interest.



3. Current Setup

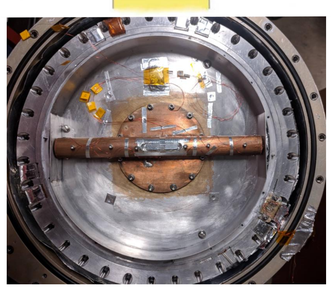


- CX line-ratios are most essential for H atom (most abundant astrophysical element).
- H beam is a very low-density target, such a measurement was not possible with the gas cell since we were limited by background (collisions of ions with atoms in UHV).

<u>ORNL Beam line</u>

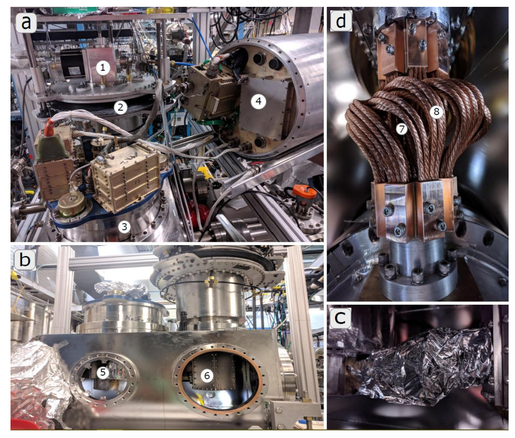
- 1-50 µA of ion current
- 200 nA of neutral H beam from 20 µA of H^- beam.
- Relative velocities spanning entire range of astrophysical interest – 20 km/s to 2000 km/s

XQC



<u>Modifications</u>

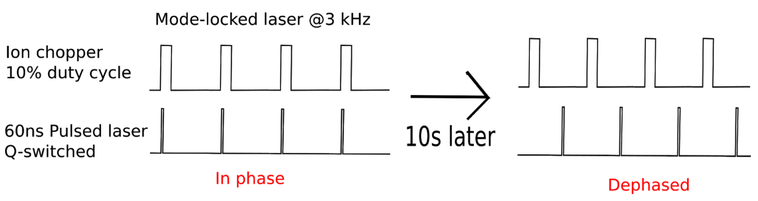
1. To improve the background, a beam tube at 2K has been added. At these temperatures, all atoms have sticking co-efficient of 1, so a 6" 3mm beam tube decreases background by 10^4.
2. The detectors are now 3cm from the beamline compared to 23 cm before which improves the solid angle by a factor of 59.
3. Three IR blocking filters have been removed improving transmission by a factor of 1.75 which is significant especially at the low energies.
4. To keep the beam-tube cold and improve the liquid helium hold times, a 2 stage vibrations isolated GM cryocooler has been added.



1. Cryocooler cold head
2. Bellows for gaseous helium
3. XQC payload
4. Electronics section for XQC
5. 50K shield on XQC aft end
6. 50K plates on cryocooler
7. 2K copper braids
8. 50K copper braids

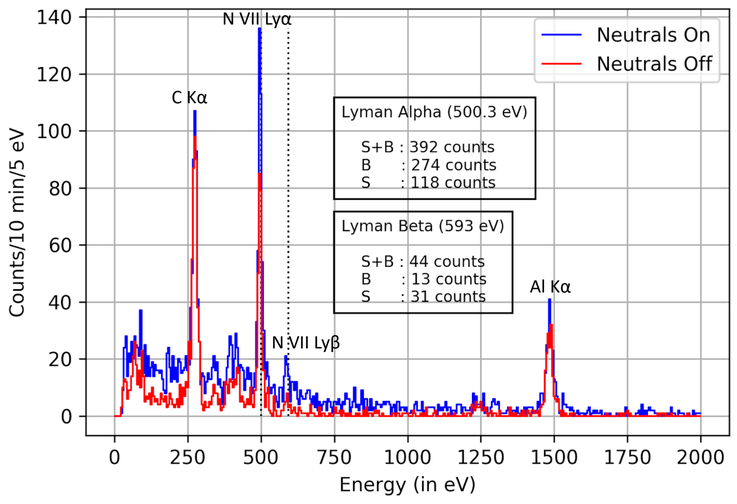
4. Results and Spectra

To distinguish the signal from background, we measure spectra both when the ion beam and neutral beam are in phase as well as when they are out of phase (to measure background from both sources).

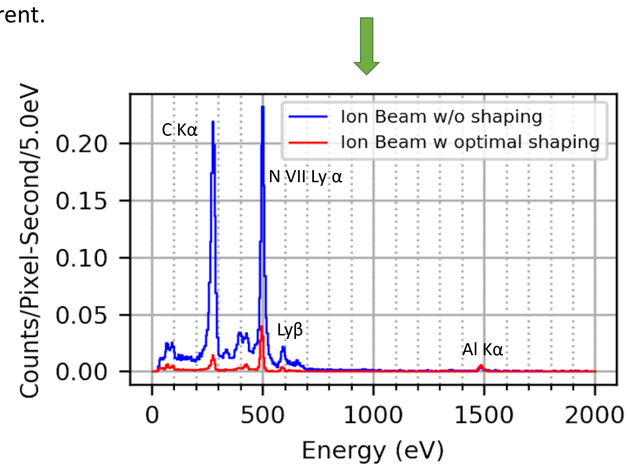


Final Spectra of N^{7+} ion beam on neutral H beam.

- N^{7+} at 100 kV
- H at 19 kV
- V_{rel} = 1000 km/s
- Laser Q-switched at 3 kHz

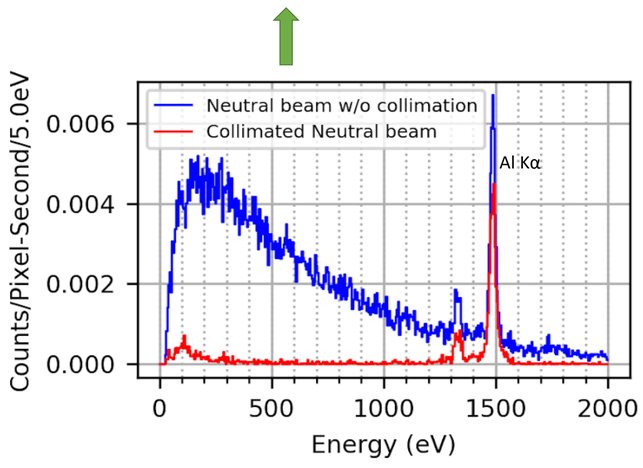


The first spectra showed a lot of C Kα, the cause of which was found to be improper shaping of the ion beam. The beam was optimally shaped using various slits and focusing elements along the beamline. The spectra below illustrates the difference in background for the same beam current.



Similar adjustments were done to get a collimated beam of neutrals. The spectra on the right shows the reduction in the background.

The neutral beam produces an order of magnitude lower background than the ion beam



5. Conclusions/Outlook

- The experiment to measure charge exchange has been demonstrated to work.
- There was a leak during the run which is why we had 10 mins of data which has been fixed, so we expect much better statistics for the next runs
- We plan on starting with the astrophysically relevant ions like Carbon, Nitrogen and Oxygen first and then moving over to explore less abundant but equally interesting elements like Silicon, Magnesium and Sulphur.

6. Acknowledgements

This work was supported in part by NASA grant NNH13ZDA00iN. The authors would also like to thank STP Boyd from the University of New Mexico for supplying us the GM cryocooler.

7. References

- *X-ray emission measurements following charge exchange between C^{6+} and He, X.* Defay et al, Phys. Rev. A 88, 052702 2013
- *X-ray-emission measurements following charge exchange between C^{6+} and H_2 , Fogle et al.* Phys. Rev. A **89**, 042705 2014