COLTRIMS Measurements of Charge Exchange with Highly Charged Ions and Simple Molecules

S. Bromley[1*], M. Fogle[1], C. Sosolik[2], J. Marler[2], P. Stancil[3], G. Brown[4], S. Porter[5], M. Leutenegger[5]
[1]Auburn University, Department of Physics, Auburn AL
[2]Clemson University, Department of Physics and Astronomy, Clemson SC
[3]University of Georgia, Department of Physics and Astronomy and Center for Simulational Physics, Athens GA
[4]Lawrence Livermore National Laboratory, Livermore CA
[5]NASA Goddard Space Flight Center, Greenbelt MD
*sjb0068@auburn.edu

Presented to the AtomDB Workshop and Advanced Spectroscopy School
3-5 August 2020

Solar Wind Charge Exchange

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

Where *A* = highly charged ions (HCIs) of C, N, O, Ne, Mg, S, Si, P, Fe, … and *B* represents common astrophysically relevant neutrals (H, H_2, He, CO, CO_2, etc.). Several theoretical treatments are available for calculating cross sections of this process and producing the subsequent xray cascade spectra: e.g. Multi-channel Landau-Zener or Atomic Orbital Close Coupling [1]. These cross sections and other tools are available in the KRONOS database hosted by UGA. Following CX with a bare ion, the populated l-states are degenerate, and though they have no effect on the *positions* of CX emission lines, their populations do affect intensities and thus diagnostic line ratios. These theoretical treatments are approximate and must be benchmarked against measured spectra.

Cold Target Recoil Ion Momentum Spectroscopy (COLTRIMS)

COLTRIMS is technique for studying collisions and fully resolving the collision dynamics by capturing all collision products. We cross a cold, neutral gas jet with a highly charged ion beam, and extract the momentum transfer from measured times-of-flight and spatially-resolved detections of both the HCI charge state(s) and the slow ions produced by CX. Our team incorporates an xray microcalorimeter to measure the xray spectra from which the *l*-distribution of initial capture states can be extracted. Given the timing resolution of our apparatus, we will resolve both single- and multi-electron capture events.

HCI Source *COLTRIMS* *Xray Detector* *Theory*

- **Post-CX HCIs via TOF and position sensitive MCP**
- **Post-CX slow ions (e.g. H^+) via TOF and MCP**

} ***n*-distribution from momentum transfer**

- **Time-resolved xray spectra (NASA Goddard Microcalorimeter, ~6eV array-averaged resolution)**

} ***l*-distribution**

Experimental Program

We will measure xray spectra and relative CX cross sections for the following systems with collision velocities spanning a range typical of the solar wind (200 – 800 km/s):

- **A^{q+} + B: A = Ne^{10+}, Mg^{12+}, Si^{14+}, P^{15+}, Fe^{16+}**
- **B = H, H_2, He, (time permitting CO/CO_2)**

Impact on Xray Observations

Our measurements will address standing issues with interpretations of CX emission spectra. By tuning the beam energy with CUEBIT, we can measure energy-dependent CX cross sections for both single- and multi-electron capture. The COLTRIMS apparatus is operable with any gas target and will be used to measure cross sections for common neutrals. The observed spectra and measured cross sections will enable direct benchmarking of theoretical models of CX emission for both simple molecules (H) and multielectron targets (H2, He, CO, etc). These results can help reduce uncertainties in currently available xray observations (CHANDRA, XMM), as well as provide highly accurate atomic data for future high-resolution xray emissions such as the upcoming Arcus telescope.

Projected Timeline

- *Aug/Sep 2020: Finish Machining + Assembly of Deflection Schemes*
- *Fall 2020: Electronics + Detector testing; HCI beam extraction testing*
- *Spring 2021: Relocate + Setup COLTRIMS apparatus at CUEBIT*
- *Summer 2021 - Onward: CX Measurements with H2/He targets.*
- *Future (time permitting) CX measurements of CO/CO_2 targets.*

Funding Provided NASA-APRA GRANT #80NSSC19K0679

References

[1] Mullen *et al.,* ApJ **844**, 7 2017.
[2] M. F. Gu, Can. J. Phys. **86**, 675, 2008.
[3] Lyons, Cumbee, and Stancil, ApJS **232**, 27 2017.
[4] Kulkarni *et al.* RSI **88**, 083306 2017

CX-COLTRIMS EXPERIMENTAL LAYOUT

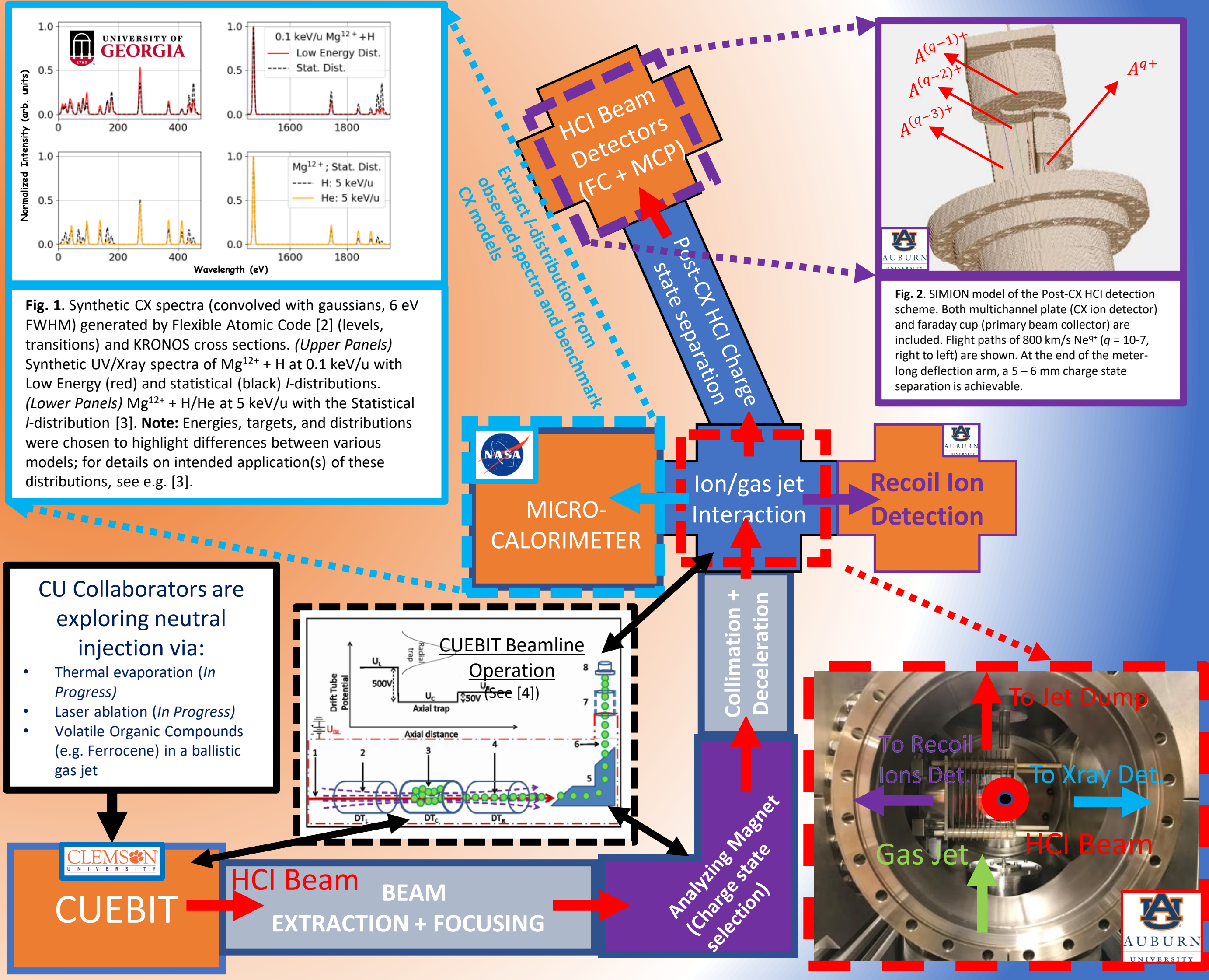

Fig. 1. Synthetic CX spectra (convolved with gaussians, 6 eV FWHM) generated by Flexible Atomic Code [2] (levels, transitions) and KRONOS cross sections. *(Upper Panels)* Synthetic UV/Xray spectra of Mg^{12+} + H at 0.1 keV/u with Low Energy (red) and statistical (black) *l*-distributions. *(Lower Panels)* Mg^{12+} + H/He at 5 keV/u with the Statistical *l*-distribution [3]. **Note:** Energies, targets, and distributions were chosen to highlight differences between various models; for details on intended application(s) of these distributions, see e.g. [3].

Fig. 2. SIMION model of the Post-CX HCI detection scheme. Both multichannel plate (CX ion detector) and faraday cup (primary beam collector) are included. Flight paths of 800 km/s Ne^{q+} (q = 10-7, right to left) are shown. At the end of the meter-long deflection arm, a 5 – 6 mm charge state separation is achievable.

CU Collaborators are exploring neutral injection via:

- Thermal evaporation (*In Progress)*
- Laser ablation (*In Progress)*
- Volatile Organic Compounds (e.g. Ferrocene) in a ballistic gas jet