Europlanet TA Scientific Report

PROJECT LEADER

Project number: 21-EPN-FT1-015	
Name: Steven Bromley	
Home Institution: Auburn University	
TA Facility visited: Electron induced fluorescence laboratory-EIFL (SK)	

Project Title: *Characterizing electron impact induced UV-Optical emission of simple molecules relevant to atmospheres of small solar system bodies*

Scientific Report Summary.

The goal of the 2022 visit was to study and measure the electron-impact induced emission from dissociation and/or ionization of CO and CO_2 between 0 – 100 eV electron energy. These experiments are part of a longer-term plan to characterize the electron-impact-induced emission features of oxygen-containing molecules found in cometary environments. These data are expected to be used in future modelling and analyses of data acquired *in situ* during the Rosetta mission to comet 67P/Churyumov-Gerasimenko. We aim to understand the conditions in the inner coma and how electron-impact-induced emission features can probe the physical and chemical processes occurring in the near-nucleus coma environment.

During the first half of the visit, we measured electron-impact spectra of CO_2 gas at multiple electron energies. Electron impact of CO_2 can give rise to emission from CO, CO^+, CO_2^+, and excited states of C and O atoms. Since the probabilities of the different reaction channels depend strongly on the collision energy, these spectral features offer a way to diagnose the conditions of plasmas containing CO_2. The collected spectra and threshold measurements are in reasonable agreement with the limited data in the literature.

During the second half of the visit, we measured electron-impact spectra of CO gas at numerous electron energies. Many of the spectral features for neutral CO, CO^+, and atomic C and O were characterized, as a function of electron energy, for the first time. Given the time-consuming nature of the measurements, data analysis and additional measurements will continue remotely.

Full Scientific Report on the outcome of your TNA visit

Dissociative electron impact excitation reactions can provide a remote diagnostic of neutral gases and the physical environment of atmospheres around planets and small bodies in our solar system. The spectral signatures of the excited collision products are unique to each species and span the UV, visible, and infrared ranges. Previous experiments on electron impact of H_2O (Bodewits et al 2019) showed clear spectral differences between photo-excitation, photodissociation, and electron impact collisions with water vapour. The efficiency of the electron impact dissociative & ionizing excitation, determined by the energy-dependent cross section, provides a remote diagnostic of the emitters in astrophysical plasmas. This process and its unique spectral signatures have been used to confirm a tenuous O_2 atmosphere around Callisto, in the near-nucleus coma of comet 67P/Churyumov-Gerasimenko, and the atmosphere of Ganymede (Roth et al. 2021).

In electron impact, CO_2 produces strong emission from its cation, CO_2^+ (Ajello 1971b), and both CO and CO_2 produce strong emission from the "Comet Tail Bands" of CO^+ (Ajello 1971a). At lower collision energies beneath the threshold of CO^+ formation, the Cameron bands of CO (ultraviolet wavelengths) are excited, and electron impact collisions have been inferred from UV observations of the Cameron bands in the atmosphere of Mars (Ajello et al 2019). In most comets, CO_2 and CO are second in abundance to water vapour. Both CO and CO_2 have lower sublimation temperatures compared to H_2O, and can sublimate from cometary nuclei at large heliocentric distances. The threshold of the strongest electron-induced emission of these species (either CO_2^+ from CO_2, or CO^+ from CO) are relatively low and can be excited in the comae of comets at large heliocentric distances. Compared to their neutral counterparts, these cations emit in wavelength ranges that are accessible from ground-based observatories. Thus, these species are of particular interest to planetary and cometary science.

During our visit to the EIF lab at Comenius University, we focused on measuring (1) the electron-impact induced emission spectra of the gases CO and CO_2 and the excited collision fragments, and (2) the emission cross sections for the important spectral features. For (1), we set a fixed electron beam energy and scanned the CCD camera across the spectral range of interest. A sample of our collected spectra is shown in Figures 1 & 2, which show the electron-impact spectra of CO_2 and CO at 50 eV electron energy. At 50 eV, almost every feature in the CO_2 data can be identified as bands of the cation CO_2^+. In the CO spectrum (Fig. 2), the strongest features are from the cation CO^+. We also measured the spectra at multiple electron beam energies below and above known thresholds (e.g. the threshold for CO^+ formation, ~17 eV, 100 eV), and we identified emission bands of neutral CO. These bands are well-characterized in the ultraviolet beneath ~300 nm, but many of the emission cross sections for features at visible/near-IR wavelengths are not available. In many cases, cross sections are limited to a single value, typically 100 eV electron beam energy. The spectra also show emission lines of atomic O and atomic C in the near-IR.

For (2), measuring absolute cross sections, we adopted a systematic procedure. Using the overview spectra, we deduced the most probable identifications of the spectral features. With the photon detector set at a fixed wavelength, we scan the electron beam energy to measure relative cross sections, which will later be normalized and scaled to precisely known emission cross sections in literature. Interestingly, many of the molecular bands in the spectra have multiple thresholds, as shown as by the measured relative cross section of the CO_2^+ feature (Figure 3). In a similar measurement of a CO^+ Comet Tail band (455 nm, Figure 4), our measured thresholds are consistent with data available in literature. For both sets of experiments (CO and CO_2), the spectra were far richer in features than anticipated. While we are able to identify many features by comparison to theoretical models and other experiments, the cross section measurements for every feature could not be completed in a single visit. We will continue to collaborate with the EIF laboratory remotely to measure the remainder of the cross sections. It is expected that a manuscript detailing our cross section measurements on CO and CO_2 will be submitted to the Astrophysical Journal Supplement Series in the coming year.

References

1. D. Bodewits *et al* 2019 *ApJ* **885** 167
2. Roth, L., Ivchenko, N., Gladstone, G.R. et al. 2021, Nature Astronomy 5, 1043-1051.
3. M. Ajello, 1971a, The Journal of Chemical Physics, 53, 7.
4. M. Ajello, 1971b, The Journal of Chemical Physics, 53, 7.
5. Ajello et al 2019, Journal of Geophysical Research: Space Physics, 124, 2954-2977

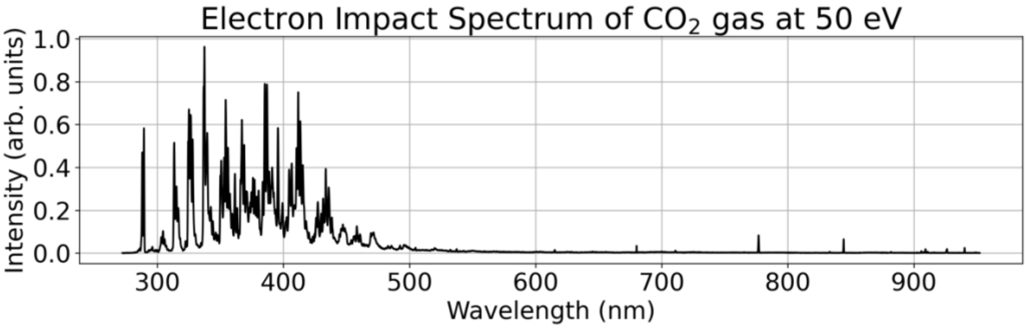


Figure 1: Measured electron impact-induced emission spectrum of CO_2 gas at 50 eV electron energy with a 100 micron slit size. Faint atomic features are visible in the near-IR. The emission between 280 and 500 nanometers is primarily from the cation CO_2^+.

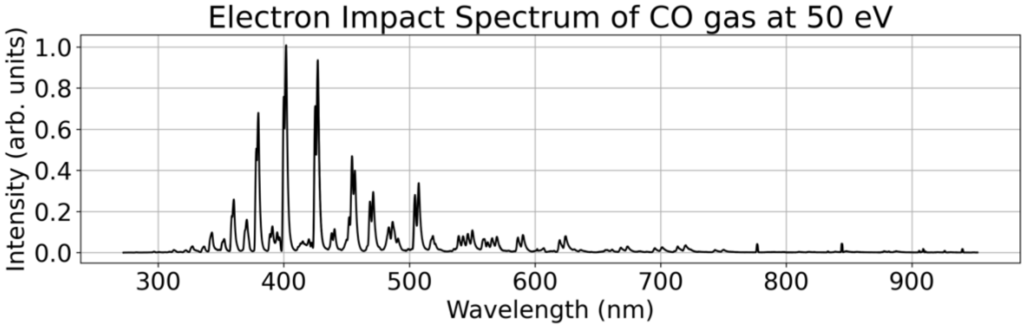


Figure 2: Measured electron impact-induced emission spectrum of CO gas at 50 eV electron energy with a 400 micron slit size. Faint atomic features are visible in the near-IR. The emission between 300 and 650 nanometers is primarily from the cation CO^+.

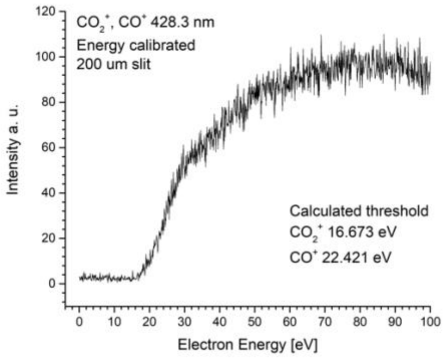


Figure 3: Measured relative emission cross section of the blended CO_2^+ / CO^+ band at 428.3 nm from electron impact of CO_2 gas. Multiple thresholds are visible in the cross section as a function of collision energy, indicating that the feature is a likely blend of CO_2^+ and CO^+ emission bands. The thresholds are consistent with theoretical values calculated from the known dissociation and excitation energies.

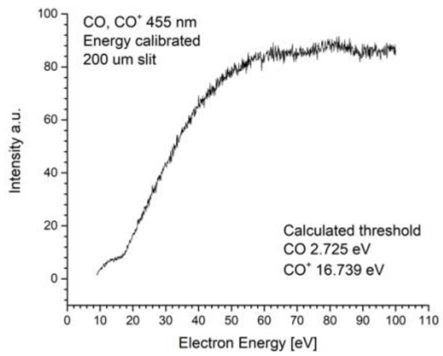


Figure 4: Relative emission cross section of a CO^+ comet tail band (455 nm) from electron impact of CO gas. The threshold of CO^+ emission (16.74 eV) is consistent with the value in the literature within the experimental uncertainties.

Figure 5: Visiting postdoc Steve Bromley and PhD student Barbora Stachova discussing the electron impact spectrum of CO gas at 100 eV electron beam energy.

Expected Publications

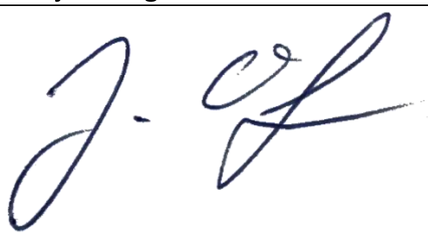
We plan to pursue a publication of the measured cross section data and spectra in *The Astrophysical Journal Supplement Series*, with the projected title "Emissive dissociation and emissive ionization cross sections of CO and CO_2 from threshold to 100 eV"

- Host confirmation

Please can hosts fill in/check this table confirming the breakdown of time for this TA project:

Dates for travel to accommodation for TA visit (if physical visit by applicant)	Start Date of TA project at facility	Number of lab/field days spent on TA Visit pre-analytical preparation	Number of days in lab/field site for TA Visit	Number of days spent in lab for TA Visit data analysis	End Date of TA project at facility	Dates for travel home (if physical visit by applicant)
Departed: 17-07-22 Arrived: 25-07-22	25-07-22	0	10	0	07-08-22	Departed: 07-08-22 Arrived: 07-08-22

The host is required to approve the report agreeing it is an accurate account of the research performed.

Host Name	Juraj Országh
Host Signature	
Date	10-08-2022

- Project Leader confirmation

Do you give permission for the full version of this TA Scientific Report (in addition to the 250 word summary) to be published by Europlanet 2024 RI on its website and/or public reports? YES

Project Leader Name	Steven Bromley
Project Leader Signature	
Date	07-08-2022