Laboratory Aeronomy by Electron Impact of CO and CO_2 for Analysis of Mars' MUV Dayglow

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Abstract

- We present our laboratory program which allows for measurement of optically allowed *and* forbidden emissions by electron impact occurring in planetary atmospheres.
- We have calculated from laboratory spectra accurate emission cross sections of the Cameron Band system of CO ($a\,^3\Pi \rightarrow X\,^1\Sigma^+$; 180–260nm), important in Mars' ionosphere, resulting from direct excitation of CO and dissociative excitation of CO_2.
- Determining the cross sections will establish a set of fundamental physical constants for electron impact codes to be used in the accurate analysis of MUV spectra in current and future missions to Mars and other terrestrial bodies.

Observational Motivations

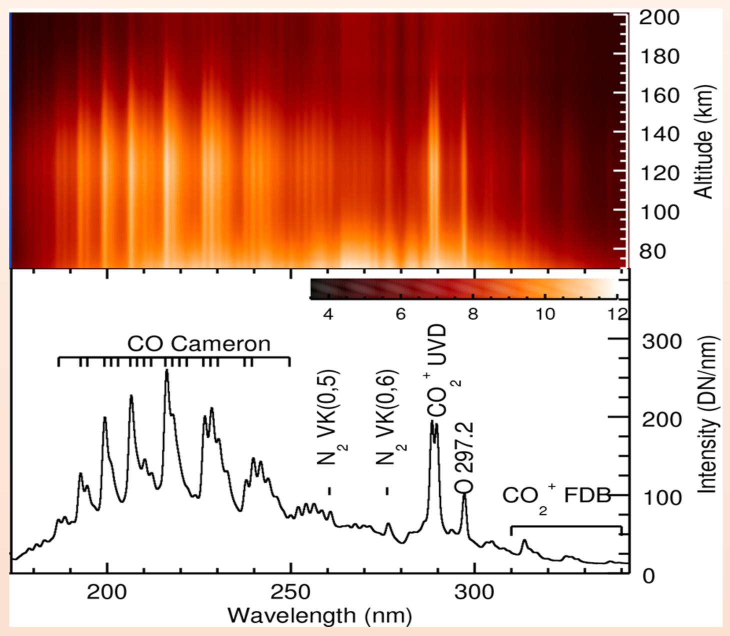

Fig. 1 MAVEN IUVS MUV observations for Mars Orbit 100; emission spectrum shown for altitude 150 km [Jain et al. 2015].

- Martian UV dayglow emission is a response of the upper atmosphere to solar cycle XUV variation, solar winds, and magnetospheric plasma flow.
- Collisional excitation by electron impact on atmospheric molecules, namely CO_2, is one mechanism responsible for certain features in Martian UV Dayglow. CO_2 comprises 96% of Mars' and Venus' atmospheres
- 2017 laboratory spectra [Ajello et al. 2017] compare closely with Mars data from MAVEN IUVS and Mars Express SPICAM, though different for each gas, with some discrepancies (Fig. 2.).
- 2017 results for Cameron Band cross sections by e+CO and e+CO_2 at 30 and 100 eV differ from model values by a factor of 17.

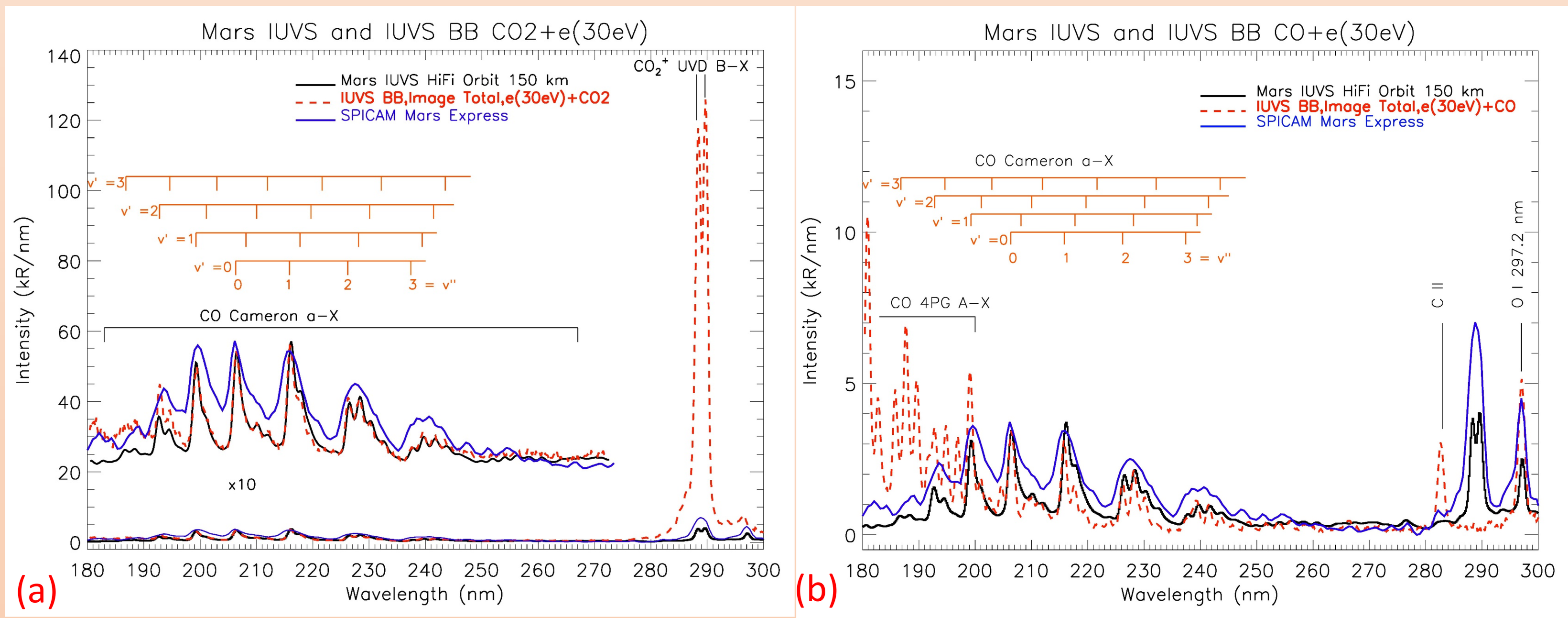

Fig. 2 (a) e(30eV)+CO_2 and (b) e(30eV)+CO laboratory spectra from 2017 compared to Mars data from MAVEN and Mars Express. Key features have been identified and used for calibration and normalization of raw laboratory spectral data.

Experimental Methodology

- Laboratory setup unique in the world for measuring optically forbidden transitions, shown in Fig. 3. Large vacuum chamber allows for measurement of optically-forbidden transitions with mean free path of 1 m or greater.
- MAVEN IUVS BreadBoard (flight spare) equipped with FUV (110-190 nm) and MUV (190-350 nm) sensing capabilities, shown in Fig. 4.
- Measure electron impact fluorescent spectra at discrete electron energies (20, 30, 50 and 100 eV) at various pressures depending on the target molecule (e.g. CO emission spectra are pressure dependent). Experimentation underway.
- Cross sections calculated (*preliminary results*) for Cameron Bands at 30 and 100 eV using known UVD on-center cross section [*Avakyan, et al. 1999*].
- Glow profile from 0-30 cm radial distance imaged (Fig. 7.)

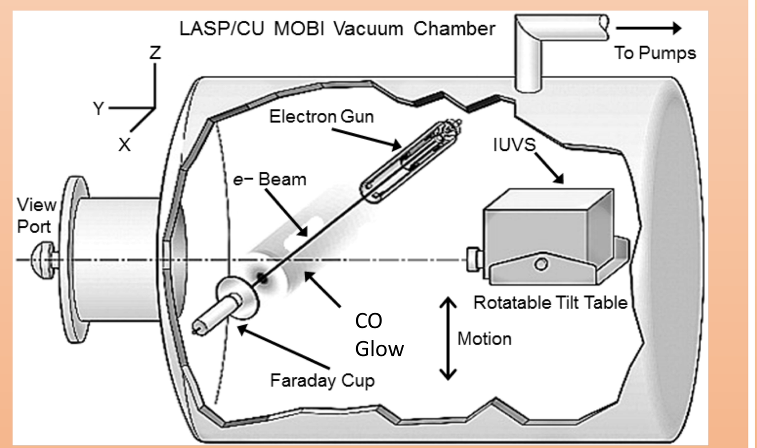

Fig. 3 Schematic of the CO glow experiment. MOBI Vacuum Chamber, ~1.5 m diam. x 1.8 m length, housing static CO, CO_2 gas environments, IUVS, and a 0.3 m electrostatic electron gun [*Ajello et al. 2017*].

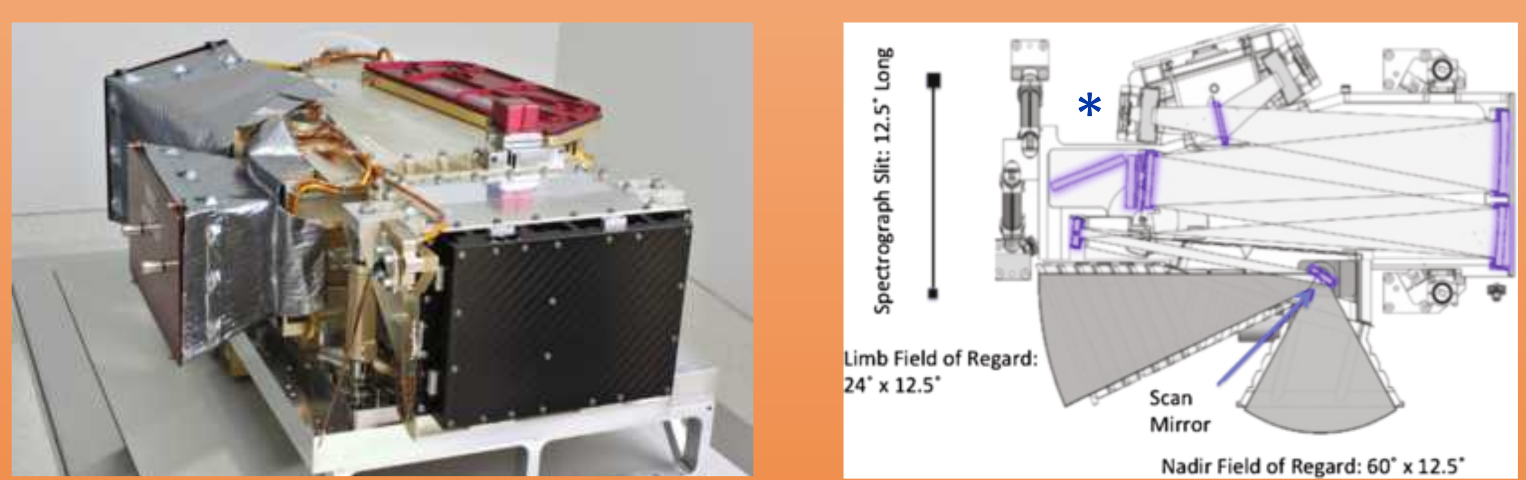

Fig. 4. (a) IUVS instrument. (b) Cross section of IUVS depicting optical path and elements (* = MUV detector).

Results and Discussion

2019 Laboratory Program – Replication Study

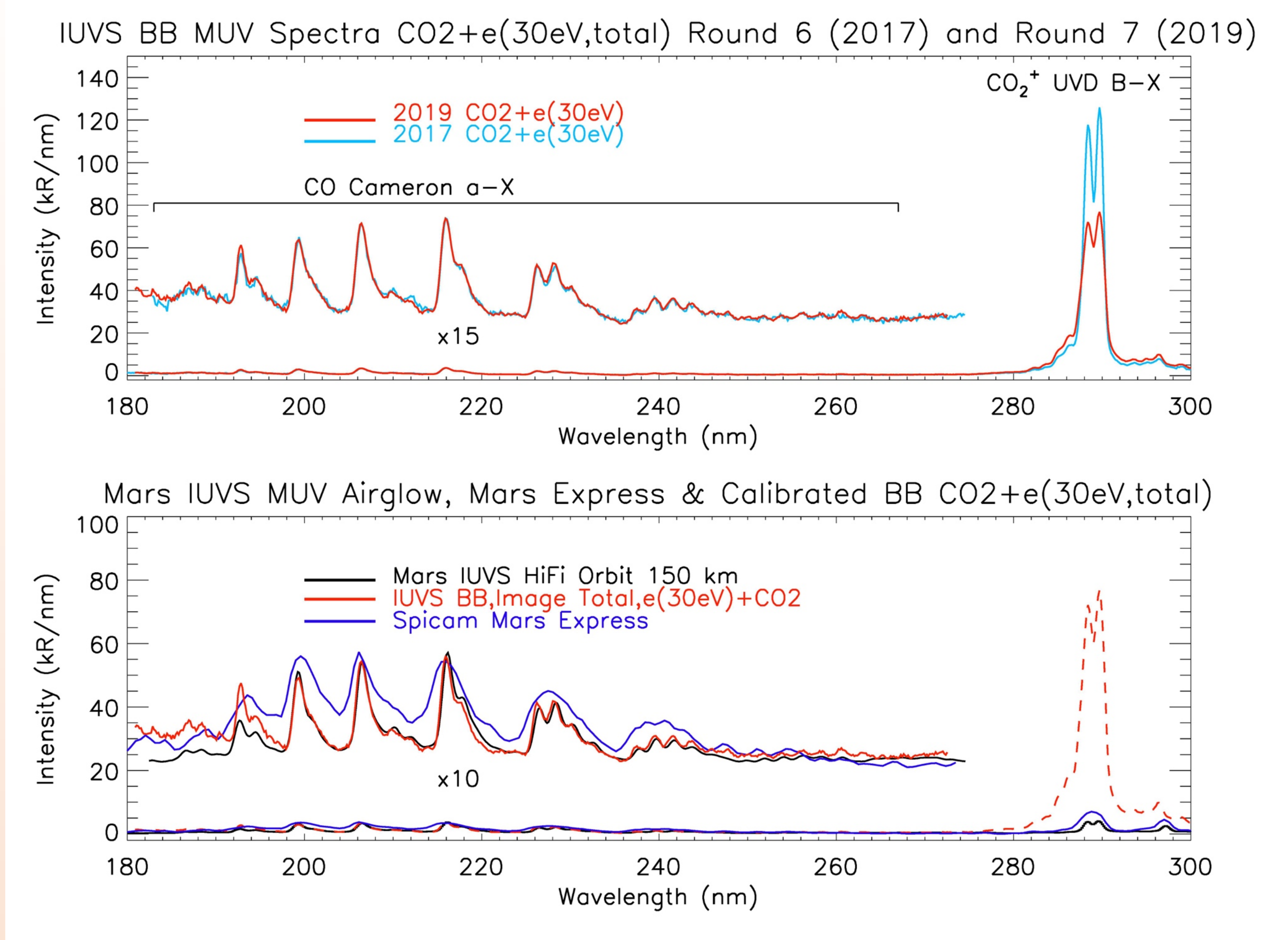

Fig. 5. (a) Comparison of our 30eV laboratory MUV spectra from 2017 and 2019 experimental work. Note the decrease in UVD-to-Cameron Band ratio. (b) 2019 laboratory MUV spectrum compared to MAVEN IUVS and MEx SPICAM observations.

Implications on Planetary Atmospheres

- We are seeing that there must be a prevalence of CO_2 dissociation on Mars rather than CO direct excitation.
  - This is likely true for Venus as well, as the Venusian dayglow compares closely with that of Mars.
  - Dominant process: $CO_2 + e_{ph}(E > 11.5\ eV) \rightarrow CO(a^3\Pi) + O + e_{ph}$
- Brighter laboratory CO_2^+ UVD suggests that the electrons at Mars have have energy lower than 30 eV.
- Latitudinal, altitudinal, and seasonal limb profiles of Mars MUV dayglow may need to be adjusted according to our results.

Model Comparisons

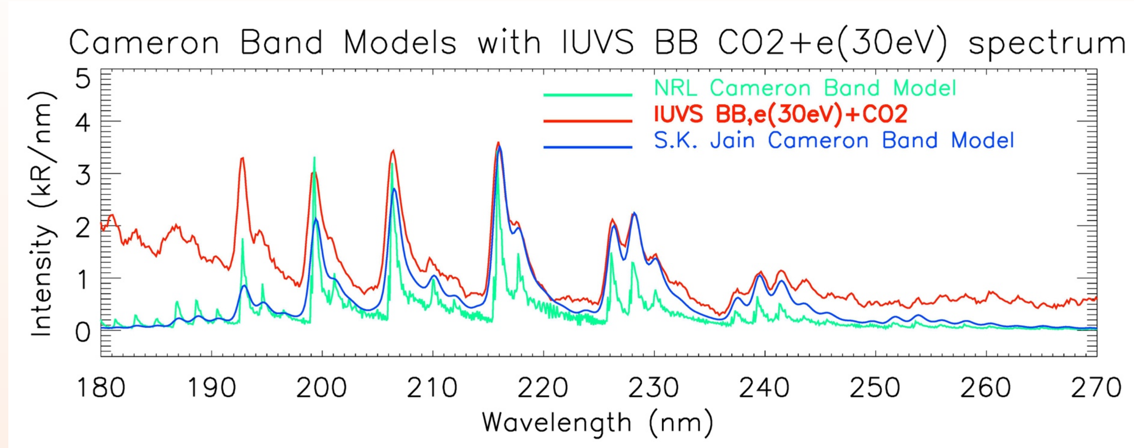

Fig. 6. Laboratory CO_2+e(30eV) spectrum compared to Cameron Band computational models (unpublished) [*Jain c. 2019, Evans c. 2019*]. Model predictions based on flight data.

Glow Profile and Lifetime

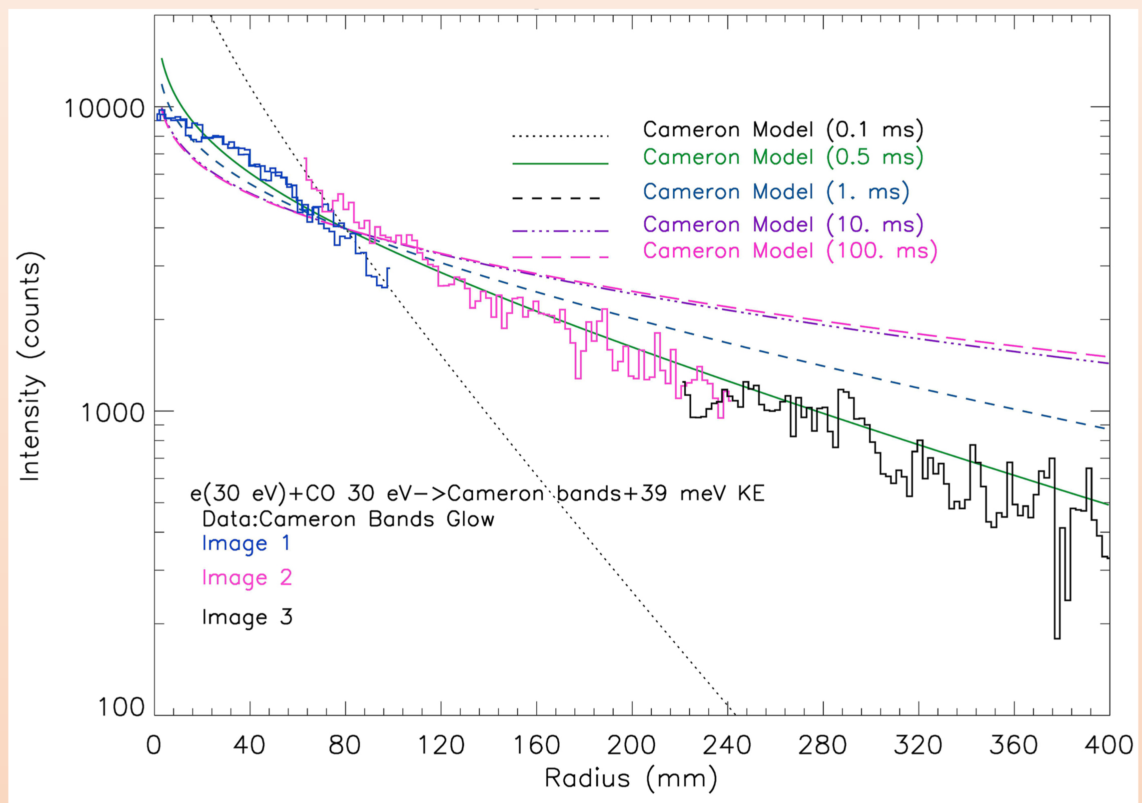

Fig. 7. Cameron Band emission intensity as a function of radial distance from electron beam. Glow model profiles overlain. [*Ajello et al. 2017*]

Emission Cross Sections for CO ($a\,^3\Pi \rightarrow X\,^1\Sigma^+$)

- We have calculated the cross sectional areas of the Cameron Band system from 180-250 nm at 30 and 100 eV (Table 1.)
- UVD-to-Cameron Band ratio was used to calculate Cameron Band cross sections based on literature UVD cross section value.
- Preliminary results, if real, cause a deficiency in Cameron Band production compared to Mars IUVS observations.

Table 1. Emission cross sections for the Cameron Bands produced by electron impact on CO and CO_2 from various model and laboratory calculations; previous laboratory work has failed to properly measure the full Cameron Band spectrum due to insufficient allowance of mean free path for long-lived CO ($a\,^3\Pi$) state. Therefore, uncertainties in previous calculations have been high. * = value corrected since publication; + = preliminary results

	e+CO	e+CO_2
Lee and Ajello (2019 data)+	*analysis underway*	7.54×10^{-18} cm² at 30 eV
Lee and Ajello (2017 data)+	4.3×10^{-18} cm² at 30 eV	5.7×10^{-18} cm² at 30 eV 1.4×10^{-17} cm² at 100 eV
Erdman and Zipf (1983)	1.5×10^{-16} cm² at 11 eV	2.4×10^{-16} cm² at 80 eV
Simon et al. (2009)	1.89×10^{-16} cm² at 10 eV	2.4×10^{-16} cm² at 80 eV
Ajello (1971b)	1.4×10^{-17} cm² at 11 eV *	1×10^{-17} cm² at 80 eV

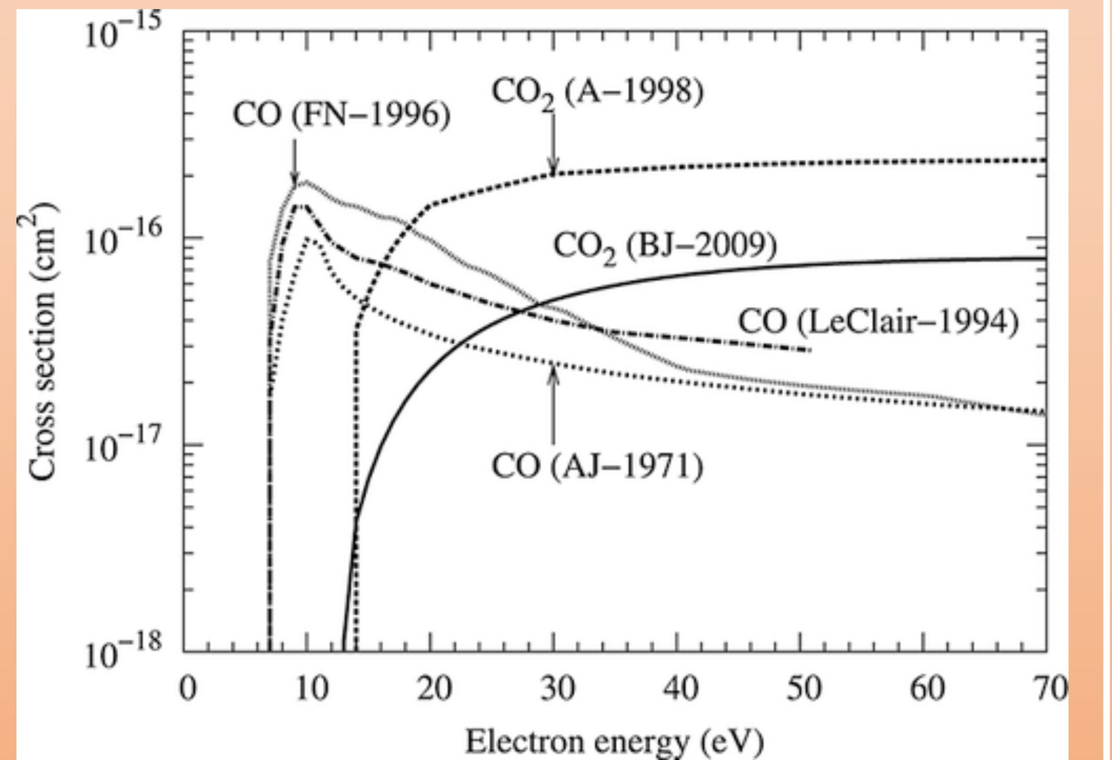

Fig. 8. Cross sections for the production of CO ($a\,^3\Pi$) as a function of electron energy from electron impact on CO, CO_2. [*Bhardwaj and Jain, 2013*]. Necessary corrections from original sources have been made.

Summary

- Planetary atmospheres show prevalence of forbidden transitions (Cameron Bands at Mars and Venus, LBH at Earth), which can only be measured by our experimental apparatus.
- Comparisons between laboratory spectra from electron impact on CO and CO_2 gases, computational models, and Mars observations indicate prevalence of a CO_2 dissociation process on Mars. Electron energies likely lie below 30eV.
- Calculated emission cross sections, averaged over the two laboratory datasets, suggest a deficiency in Cameron Band production compared to Mars.

Going Forward

- Further experimentation on major planetary gases at low energy, spectroscopy with thermal manipulation in vacuum chamber, photon bombardment spectroscopy (planned through January 2020)
- Model confirmations and forward modeling (AURIC and Trans-Mars integrated and kinetic codes) to better understand atmospheric processes
- Manuscript in preparation on Cameron Band cross sections and CO_2 dissociation mechanism as a dominant process on Mars

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