

# Analysis of the Pioneer Venus Large Probe Neutral Mass Spectrometer Data Yields New Insights into the Composition of Venus' Atmosphere

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**Introduction:** We present a new analysis of mass spectral data obtained by the Pioneer Venus (PV) Large Probe Neutral Mass Spectrometer (LNMS) (Hoffman et al. 1980, Mogul et al. 2021), which sampled the atmosphere across the altitudes of 64–0.2 km. To analyze the LNMS data, we constructed an analytical model that accounts for spectrometer performance at each altitude, provides CO<sub>2</sub> abundances in units of density (kg/m<sup>3</sup>), and retains the resolving power of the LNMS through use of a targeted data-fitting routine.

**Methods:** The LNMS data were judiciously normalized to account for impacts of the descent. Data-fitting yielded measures of peak shape (full width half maximum, FWHM), accounted for shifts in the mass scale, and included isobaric species. Densities (kg/m<sup>3</sup>) for CO<sub>2</sub> were obtained using standard curves constructed from published control data. Statistical uncertainties were obtained from the pre-sampling data; errors were propagated throughout the calculations.

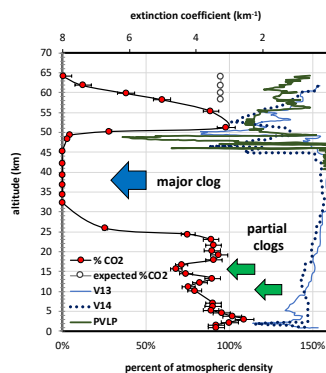
**Results & Discussion:** Performance of the LNMS was assessed by tracking several species. Comparison of the calculated peak shapes for CH<sub>3</sub><sup>+</sup>, <sup>40</sup>Ar<sup>+</sup>, and <sup>136</sup>Xe<sup>+</sup> revealed (1) a linear correlation ( $R^2 > 0.99$ ) between FWHM and  $m/z$  at each altitude, consistent with Mogul et al. (2021), and (2) that no anomalous operations of the LNMS were noted throughout the descent, including between 50–25 km, where the inlets were clogged by aerosols, and at the higher atmospheric pressures and temperatures at <20 km. We also tracked the ionization and fragmentation of CO<sub>2</sub>. Values for CO<sup>18</sup>O<sup>+</sup> ( $0.44 \pm 0.03\%$ ), <sup>13</sup>CO<sub>2</sub><sup>+</sup> ( $1.3 \pm 0.1\%$ ), <sup>13</sup>CO<sub>2</sub><sup>++</sup> ( $0.033 \pm 0.002\%$ ), and CO<sub>2</sub><sup>++</sup> ( $2.6 \pm 0.1\%$ ) are similar though slightly higher than NIST values. Fragments, isotope ratios (<sup>13</sup>C/<sup>12</sup>C & <sup>8</sup>O/<sup>16</sup>O), and isobars will be discussed.

In **Fig. 1**, we provide the CO<sub>2</sub> altitude profile (red circles) expressed as a percent of the atmospheric densities, which were calculated per Seiff et al. (1985). Densities for CO<sub>2</sub> fluctuated greatly over the descent as observed during the clog (large blue block arrow in **Fig. 1**). During optimal intake rates, our analyses yield a CO<sub>2</sub> density of  $1.36 \pm 0.27$  kg/m<sup>3</sup> at 51.3 km which is  $98 \pm 19\%$  of the atmospheric density ( $1.38$  kg/m<sup>3</sup>), while densities of  $14.9$ – $21.1$  kg/m<sup>3</sup> between  $23.0$ – $17.9$  km are  $\sim 91 \pm 4\%$  of the atmospheric values ( $16.7$ – $23.3$  kg/m<sup>3</sup>). Per **Fig. 1** (green block arrows), at <17 km, CO<sub>2</sub> densities temporarily deviated from the atmospheric profile

to yield ‘dips’ or decreases of  $\leq 30\%$  and  $\leq 25\%$  between 16.7–13.3 km and 13.2–7.0 km, respectively.

These observations are consistent with partial and rapidly-clearing clogs occurring at <17 km due to particulate/aerosol species. In **Fig. 1**, comparison of the CO<sub>2</sub> profile to the scattering coefficients measured by Venera 13 and 14 (Grieger et al. 2004) and the PV Large Probe (Ragent et al. 1985) shows that *increases* in particle densities (or cross sections) between  $\sim 50$ – $46$  and  $\sim 17$ – $2$  km match where CO<sub>2</sub> densities *decrease* between 50–25 and 16.7–5.3 km. Interpretations of the LNMS mass data *within this context* will be presented.

**Conclusions:** Our forthcoming results provide new insights into the composition of Venus' atmosphere. Densities for CO<sub>2</sub> increase towards the surface and are suggestive of surface outgassing (Cordier et al. 2019); impacts on the N<sub>2</sub> profile will be presented. The partial obstructions of the LNMS at <17 km are likely important considerations for future missions. Re-analysis of the LNMS data, therefore, may assist in revealing the past, present and/or future habitability of Venus' clouds.



**Figure 1.** Altitude profiles for %CO<sub>2</sub> (relative to atmospheric densities; red circles) and the volumetric scattering coefficients (upper x-axis, reversed scale) measured by Venera 13 (solid blue line), Venera 14 (dotted black line), and the Pioneer Venus (PV) Large Probe (solid thick green line); block arrows represent areas of partial blockage of the inlets, expected CO<sub>2</sub> values are provided  $\geq 58$  km (circles), and error bars represent the propagated error.

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