Study of Venusian lightning light curves interpreting previous observations based on Planetary Lightning Detector observations and simulation modeling

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Planetary lightning observations provide critical data for atmospheric research, providing insights into convection, atmospheric composition, and volcanic activity. However, the light curves and time constants of lightning discharges on Venus remain unexplained. There is currently no consensus regarding the existence of Venusian lightning. Although the Lightning and Airglow Camera (LAC) onboard Akatsuki recorded long-duration light curves exceeding 50 milliseconds, and ground-based telescopes have captured images of lightning discharges on Venus' s nightside, limitations in exposure time and sample size render it inconclusive whether these observations represent scattered light from short-duration discharges lasting hundreds of microseconds or from long-duration discharges lasting hundreds of milliseconds. Consequently, the absence of detailed information on Venusian lightning light curves and time constants impedes accurate determination of discharge energy and frequency, complicating efforts to clarify charge-separation mechanisms and to perform comparative analyses with meteorological parameters.
This study aims to detect Venus lightning and analyze its light curve to obtain new insights into planetary lightning. The Planetary Lightning Detector was newly developed with a time resolution of 2 msec, surpassing the 50 msec exposure time of CCDs used in previous ground-based studies, and was installed on the 1.6-m Pirka Telescope at Hokkaido University. The PLD simultaneously observed light curves at two wavelengths. It utilizes waveform correlation to achieve high-precision discrimination between daytime background light, noise, and lightning flashes. To analyze the observed waveforms, a new three-dimensional light-scattering model for the light curve was developed that incorporates distributions of cloud particle size and composition. This model reproduced the light curves by including, for the first time, the time-delayed photon-scattering process within Venus cloud structures.

PLD observations on Venus were compared with model results and with the long-duration light curves of 50 msec reported in previous studies. In 2022, Venus was observed for approximately 300 min using the PLD. Four events were identified that exceeded 4.8 times the standard deviation in the peak value of the lightning observation wavelength light curve, and these were considered lightning candidates. The FWHM of these event waveforms exhibited a spike-like profile with a time resolution of 2 msec or less on the PLD. Although direct waveform comparisons with the Venus model used in this study were not possible, the results aligned with light curves showing a maximum FWHM of 1.5 msec at altitudes above 10 km. The energy of the spike-shaped waveform was approximately 10^9 J, consistent with previous studies. Observations and modeling suggest that the typical time constant for Venusian lightning is less than 2 msec, which is significantly shorter than the 50 msec FWHM observed by LAC. Modeling the LAC observations as scattered light from single discharges lasting hundreds of microseconds indicated that a cloud density 700 times the nominal value would be required. Given the range of number density fluctuations inferred from prior infrared observations and the energy required for the light source, it is difficult to explain the LAC observations solely in terms of cloud scattering. These findings suggest that the waveform observed by LAC does not represent typical lightning but rather indicates a long-period discharge.

Keywords: Venus, Lightning, Ground-based telescope, Scattering model for lightning light curve

