A Comprehensive Analysis of Optical Emissions in Exposed Lightning Channels

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The Atmosphere Space Interactions Monitor (ASIM) was installed on the International Space Station (ISS) on April 13, 2018. The ASIM included the Modular Multispectral Imaging Array (MMIA), designed to study the optical signals of atmospheric electrical phenomena [1]. The ASIM-MMIA's photometers, with their unprecedented high-sampling frequency of 100 kHz, and its high spatial resolution cameras, offering 400 × 400 meters per pixel, provide a unique opportunity to analyze light emissions from lightning-induced plasmas from space. ASIM photometers operate in the near UV line at 337 nm ± 2 nm (PH1), the UV band at 180–230 nm (PH2), and the neutral atomic oxygen multiplet at 777.4 nm ± 2.5 nm (PH3). Additionally, the MMIA instrument features two filtered cameras operating at 12 frames per second, one in the near UV (CHU1, 337 nm ± 2 nm) and the other in the neutral atomic oxygen multiplet (CHU2, 777.4 nm ± 2.5 nm).

In this study, we examine the optical signal from exposed lightning flashes that reaches the MMIA without interference from cloud scattering. We combine an electrodynamical model of hot air plasmas in lightning discharges [2,3] with computations of synthetic spectra of lightning-like discharges [4]. The electrodynamical model calculates the temporal and radial evolution of plasma parameters and chemical species. We ran different simulations of lightning-like discharges between 0 km and 16 km altitude, varying input energy, initial radius, initial mass, and humidity. We use a simplified model to estimate the peak current corresponding to each input energy. We then post-process the output of the electrodynamical model following the method in [4], providing the temporal evolution of the emitted spectra. In particular, we calculate the synthetic emissions of a 1 km portion of a flash propagating at the velocity of an intra-cloud burst at 12 km in the 777.4 nm and the 337 nm channels. Finally, we compare the simulated peaks in the photon fluxes with the observations of exposed flashes provided by ASIM-MMIA.

Preliminary results are shown in Figure 1. The first panel of Figure 1 shows the 777.4 nm simulated photon flux peak (black stars) and the photon flux peak of exposed lightning observed by ASIM-MMIA (red dots) versus the lightning flash peak current. A positive relationship between the photon flux peak and the peak current can be observed in both the simulations and observations. The second panel of Figure 1 shows the results at the 337 nm spectral line. Our results indicate that the thermal (due to ions, black stars) 337 nm optical emission of hot plasmas in exposed lightning can only be detected by ASIM-MMIA if the electric peak current is approximately above approximately 40 kA (about 76 J/cm input energy). Our electrodynamic model for the hot lightning plasma does not consider streamers in lightning so that the computed 337 nm optical emissions (black stars in bottom panel of Figure 1) that are thermal (due to ions) 337 nm emissions take values different that those observed by ASIM-MMIA. We hypothesize that the 337 nm photon flux detected by ASIM-MMIA from lightning discharges with a peak current below 40 kA is exclusively emitted by streamers, while more energetic lightning flashes can produce detectable emissions in the 337 nm line from the excitation of ions (OII and NIII) [4].

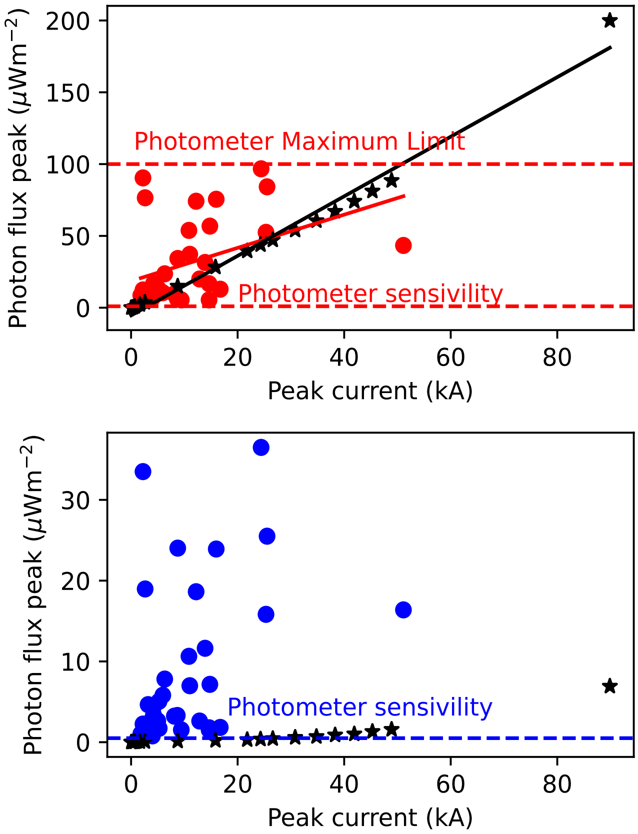

Figure 1: The first panel shows the 777.4 nm simulated photon flux peak (black stars) and the photon flux peak of exposed lightning observed by ASIM-MMIA (red dots) versus the lightning flash peak current. The red line represents a linear fit to the red dots, whereas the black line represents a linear fit to the black stars. The second panel shows the 337 nm simulated photon flux peak (black stars) and the observed photon flux peak of exposed lightning (blue dots). The peak current in the observations is provided by a ground-based lightning location system.

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