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ISUAL far-ultraviolet events, elves, and lightning current

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[1] The Imager of Sprites and Upper Atmospheric Lightnings (ISUAL) often recorded events that have significant far-ultraviolet (FUV) emissions in the spectrophotometer but have no discernible transient luminous events (TLEs) in the imager. These FUV events likely are dim TLEs. To confirm the conjecture, lightning emissions were simulated and proved to be completely absorbed by the atmosphere. The FUV emission of the FUV events follows the lightning OI emission within 1 ms, similar to the characteristics of elves. After analyzing the imager-$N_2$1P brightness of the elves and their FUV intensity, a linear correlation was found, which is consistent with the work of Kuo et al. (2007). The intensity of the FUV events ranks among the dimmest elves and is less than 1×10^4 photons/cm^2. Combining all the information, the FUV events are identified as dim elves that eluded the detection of the ISUAL imager. Also from the detection limits of the ISUAL spectrophotometer (SP) and the imager, for the before-the-limb elves the detection number of SP is found to be nearly 16 times higher than that of the imager. This result is consistent with a related factor of ~13 that was inferred from the U.S. National Lightning Detection Network (NLDN) peak current distribution for the negative cloud-to-ground lightning. Hence the ISUAL spectrophotometer can be used to perform elve survey, to infer the peak current of the elve-producing lightning, and possibly to be used to deduce other lightning parameters. Evidence is also found for the existence of multielves, which are FUV events from the M-components or the multiple strokes in lightning flashes.

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1. Introduction

[2] The study of the lightning spectrum has been a continuous effort for over a century. In the early 1900s, *Pickering* [1901] and *Slipher* [1917] were the first to provide an accurate determination of lightning emission lines. Since then, the lightning spectrum lines were tabulated with ever increasing precision. The observations showed that the lightning spectrum contains emission lines of neutral hydrogen atoms (HI), neutral nitrogen atoms (NI), singly ionized nitrogen atoms (NII), neutral oxygen atoms (OI), and cyanogens (CN) [*Orville and Henderson,* 1984]. Some of the lightning emissions are greatly attenuated in the atmosphere, such that any lightning FUV emissions with wavelengths less than 286 nm have not been identified in the ground-based observations [*Orville,* 1977, p. 282 and references therein]. Moreover, *Prucitt* [1963] found that the excitation temperature of NII in a lightning channel ranges from 24200 to 28400 K implying that the lightning current produces a high-temperature channel with temperatures hotter than 24000 K.

[3] Transient luminous events (TLE) like sprites, elves, halos, and jets above thunderstorms are luminous emissions resulting from collisions of energetic electrons with atmospheric species [*Franz et al.*, 1990; *Inan et al.*, 1991; *Boeck et al.*, 1992; *Wescott et al.*, 1995; *Fukunishi et al.*, 1996; *Fernsler and Rowland*, 1996; *Inan et al.*, 1996, 1997; *Pasko et al.*, 1997, 2002; *Veronis et al.*, 1999; *Barrington-Leigh et al.*, 2001; *Su et al.*, 2003]. The major emissions in TLEs include the nitrogen first positive band ($N_2$1P), the nitrogen second positive band ($N_2$2P), the nitrogen first negative band (N_2^+1N), and the FUV N_2 Lyman-Birge-Hopfield (LBH) band. From analyses of ISUAL (Imager of Sprites and Upper Atmospheric Lightning) [*Chern et al.*, 2003]

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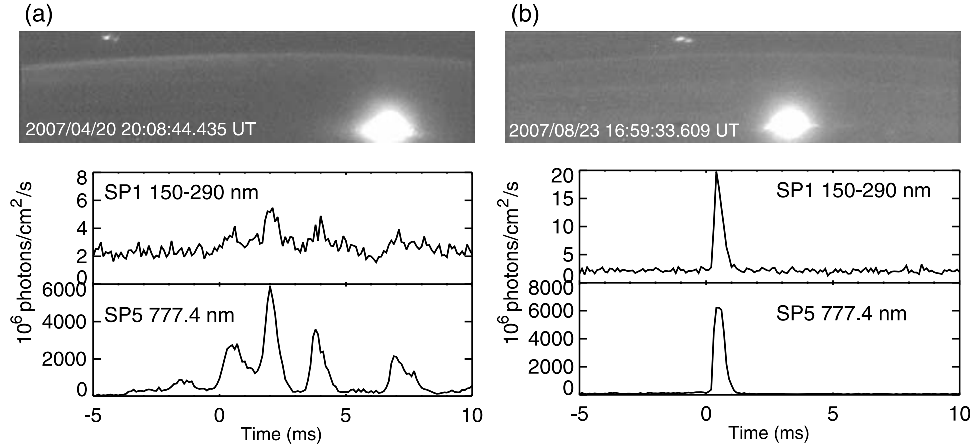

Figure 1. Two examples of the Imager of Sprites and Upper Atmospheric Lightning (ISUAL) mystic far-ultraviolet (FUV) events; the trigger times are (a) 20 April 2007 2008:44.435 UTC and (b) 23 August 2007 1659:33.609 UTC. No elve is apparent from the image frame, but the ISUAL SP1 indicates that both events have FUV emissions.

observed events it is known that elves, sprites and gigantic jets (during the fully developed jet stage) emit FUV emissions [*Mende et al.*, 2005; *Kuo et al.*, 2005a, 2005b, 2007, 2009; *Liu et al.*, 2006, 2009]. *Frey et al.* [2007] have shown photometric data of an ISUAL recorded halo, but provided no further discussion on the characteristics of its FUV emission. Also, *Kuo et al.* [2007] have modeled the $N_2$1P-brightness of elves versus the peak current of the causative lightning using a finite difference time domain (FDTD) method, and the relation has been validated.

[4] Among the ISUAL recorded events, we often notice a special subset of events that have no discernible transient luminous events (TLEs) in the imager frames except for the bright lightning but have a significant associated FUV signal (Figure 1). For these events, the lightning OI signal is followed by the FUV emission within 1 ms. The nature of these events remains illusive and they are identified as the "mystic FUV events" or simply the FUV events in the following discussion.

[5] One reason to carry out the ISUAL experiment on the FORMOSAT-2 satellite is to observe TLEs from space with much reduced atmospheric interference. Indeed in the early phase of the ISUAL experiment, the FUV emissions of TLEs had been successfully found [*Mende et al.*, 2005]. However, due to the severe absorption of short-wavelength photons, the TLE FUV emissions still suffer various degrees of atmospheric attenuation. Since the lightning occurs at altitudes of ~10 km or lower, the FUV emissions of lightning will be highly attenuated and are not expected to be detectable by ISUAL.

[6] In this article, the ISUAL spectrophotometer (SP) data and results from previous TLE and lightning studies will be used to establish that the FUV events are dim elves which have eluded the detection of the ISUAL imager. The FUV intensity of several well-defined elves will also be computed. For the ISUAL elves, the relation between the imager-$N_2$1P brightness and the associated FUV intensity will be established. How the result can be used to infer the peak current of the elve-producing lightning, to perform elve survey, and to explore other lightning characteristics will be discussed.

2. Instrument Settings and the Data Set

[7] ISUAL contains three sensor packages: an intensified CCD imager, a six-channel spectrophotometer (SP) and a dual-module array photometer (AP) [*Chern et al.*, 2003]. The field of view (FOV) of the ISUAL imager is 20°(H) × 5°(V). The images analyzed in this article were obtained through a 653–754 nm filter ($N_2$1P) with a frame integration time of 29 ms. The ISUAL SP has the same bore-sighted FOV as the imager, and registers six band-passing photometric variations of an event with a 10 kHz sampling rate. Only the SP1 and the SP5 data are used in this study. The SP1 is equipped with a FUV filter (150–290 nm) to detect photons from the N_2 LBH band. The SP5 channel has a narrow band filter centered at 777.4 nm for the detection of the lightning OI emission. The ISUAL AP contains two blue (370–450 nm) and red (530–650 nm) modules and the sampling rate is 20 kHz for the first 20 ms of the AP data collection. Each AP module has 16 multianode photometers that provide the temporal and spatial variations of lightning or TLE emissions along the vertical direction. [*Chern et al.*, 2003; *Fukunishi et al.*, 2004].

[8] To keep the effective detection threshold approximately constant, the gain settings of the ISUAL SP and imager varied from year to year. Hence we choose only the data set recorded during the year of 2007 for this study. However, the results obtained from analyzing the data recorded in other years should be consistent. Moreover, in order to correlate the lightning (SP5) and the FUV emissions, only the before-the-limb events are used. For the ISUAL observation, the before-the-limb events are ~2700 km to ~3000 km away from the spacecraft.

3. Lightning FUV Emissions and Atmospheric Absorption

[9] To be certain that the lightning FUV emission cannot reach the ISUAL instrument, we performed a simulation of

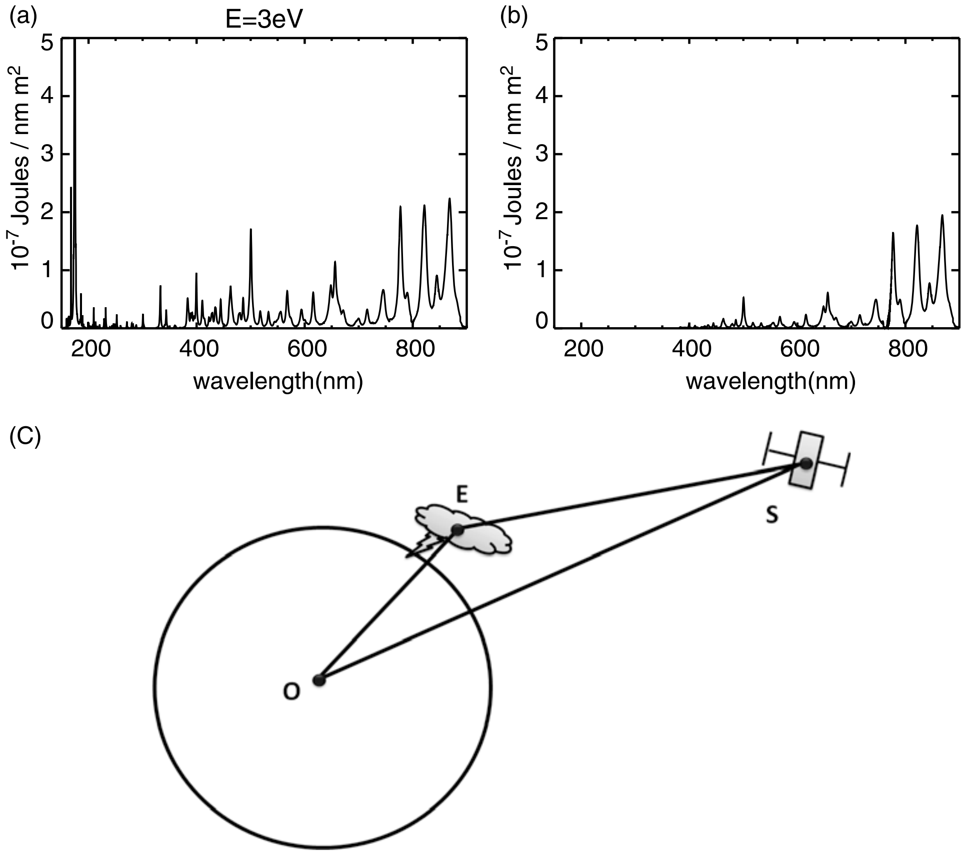

Figure 2. (a) Theoretical lightning emission spectrum. (b) Lightning emission spectrum under the atmospheric absorption. (c) The observation geometry for lightning occurred before the Earth limb. E denotes the lightning, which is assumed to be at a 10 km altitude above the ground. S denotes the location of FORMOSAT 2 satellite.

the lightning FUV transmission in air using the experimental transitional level data for the atomic and molecular species and the transmittance of the upper atmosphere.

[10] We assume that the lightning current heats up the channel to a temperature of 30000 K and that the lightning channel is in thermal equilibrium. In such a high-temperature environment, the emission intensity from a transition from level k to level i can be written as $\varepsilon_{\rm line} = (1/4\pi)h\nu A_{\rm ki}\, N_{\rm k}$, where h is the Planck constant and ν is the frequency of the emitted photon. The number density of atoms in energy level k, N_k, is $N_k = (Ng_k/B(T))exp(-\varepsilon_k/k_BT)$, where k_B is the Boltzmann's constant, N is the total number density of atoms, and B(T) is the partition function $B(T) = \sum_j g_j \exp(-\varepsilon_j/kT)$ [*Orville,* 1977, p. 295]. The statistical weights of level k (g_k), excitation energies (ε_k) and the Einstein coefficient (A_{ki}) are obtained from NIST data (National Institute of Standard and Technology) [*Ralchenko et al.*, 2008]. After taking into account the Lorentz broadening due to atomic and molecular collisions, the theoretical lightning spectrum is shown in Figure 2. The integrated emission intensity for the wavelengths range between 160 and 290 nm is 6.7×10^{-11} Joules/cm^2, or 6.7×10^7 photons/cm^2.

[11] Because of the severe absorption and scattering of high-frequency photons in air, the FUV atmospheric transmittance has to be treated properly. We assume that the lightning (E) is 10 km above the ground and is 2600 km away from the satellite (S). The observation geometry is shown in Figure 2c. We use the Lambert's law $T(\lambda, \mathrm{H}) = \exp(-L(\mathrm{H})\sigma(\lambda))$ to compute the FUV atmospheric transmittance, which is a function of event altitude (H) and emission wavelength (λ); where L(H) is the integrated atmospheric species density in units of cm^{-2} along the line of sight between the satellite and the lightning, $\sigma(\lambda)$ are the absorption or the scattering cross sections in units of cm^2 for the major atmospheric species including oxygen (σ_{O_2}) [*Minschwaner et al.*, 1992; *Yoshino et al.*, 1992; *Amoruso et al.*, 1996], ozone (σ_{O_3}) [*Molina and Molina*, 1986; *Burrows et al.*, 1999], and molecular Rayleigh scattering ($\sigma_{scatter}$) [*Jursa*, 1985].

[12] With the atmospheric attenuation, the lightning spectrum profile is reduced to that shown in Figure 2b. The lightning FUV photon flux is down to 1.0×10^{-11} photons/cm^2 at the ISUAL altitude of 891 km. This means that there is no chance for the ISUAL detector to see the lightning FUV emissions.

4. FUV Emissions From Dim Elves

[13] From ISUAL observations, sprites, elves and gigantic jets are all found to have FUV emissions. Spectral data of the mystic FUV events indicate that the FUV emission

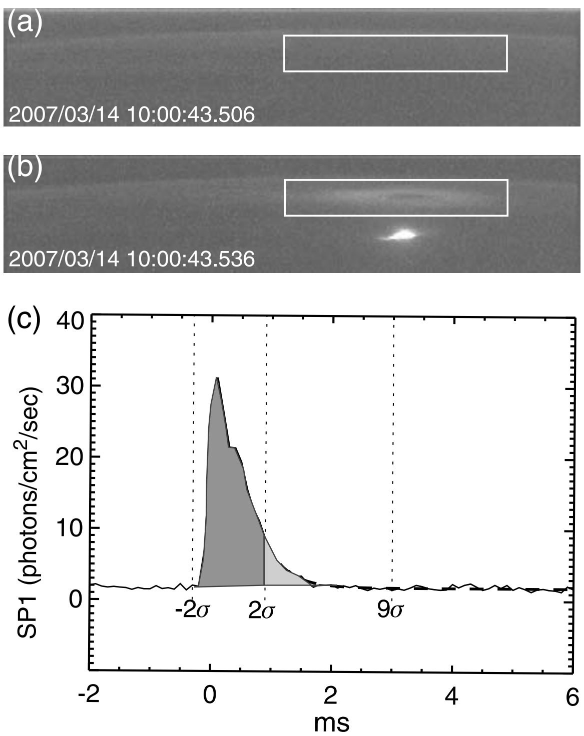

Figure 3. A before-the-limb ISUAL elve on 14 March 2007 1000:43.550 UTC. (a) The pretrigger frame, (b) the trigger frame, and (c) the associated SP1 FUV signal around the trigger time.

follows the lightning signal within 1 ms. For sprites, the typical time delay between the causative lightning and the FUV emission is about 1.5–4.0 ms [*Rodger*, 1999; *Kuo et al.*, 2005b]. Generally, gigantic jets are not accompanied by lightning [*Kuo et al.*, 2009]. Thus dim sprites and gigantic jets can be ruled out as the possible candidates of the mystic FUV events. Thus these mystic FUV events are either dim elves or halos. There are no easy ways to discriminate halos from elves using only the FUV emissions. However, the FUV intensity of elves is greater than that of halos due to the atmospheric absorption [*Kuo et al.*, 2008] and furthermore, the occurrence frequency of elves is also an order of magnitude higher than that of halos [*Chen et al.*, 2008]. By neglecting the potential contribution of halos, the incurred errors are expected to be negligible. Therefore we can reasonably assume that the mystic ISUAL FUV events are mainly dim elves produced by the low peak current lightning. These elves are too dim to be discernible in the imager data [*Kuo et al.*, 2007], but their FUV emissions are unambiguously detected by the ISUAL spectrophotometer which has a higher sensitivity than the low-light-level imager.

[14] Though, it is difficult to find the associated lightning data for the FUV events from the existing lightning networks to verify our conjecture. However, it had been shown previously that the elve brightness, which is deduced from the imager data taken through a 653–754 nm band filter ($N_2$1P band), is closely related to the peak current of the causative lightning [*Kuo et al.*, 2007, Figure 18a]. Hence if, for elves, there is a functional relationship between the intensity of the SP1-FUV emission and the imager-$N_2$1P brightness, then the intensity of the FUV emission becomes another gauge for the peak current of the causative lightning. Thus the conjecture can be confirmed if and only if all the FUV events have weak FUV emissions. Therefore the imager-$N_2$1P brightness and the SP1-FUV intensity of several well-identified elves are computed.

[15] Figures 3a and 3b are the pretrigger and the trigger frames of a before-the-limb elves on 14 March 2007. The rectangles mark the regions selected to compute the background and the integrated brightness for this elve in the imager data. The imager brightness of an elve can be obtained through the method of differential photometry, by subtracting the background of the region of interest in the pretrigger frame from the intensity of the same region in the trigger frame. The process of obtaining the FUV intensity of an elve is more elaborate. As shown in Figure 3c, the photometric peak from the SP1 channel is dissected into two regions for a more precise analysis. The photometric data within two standard deviations (2σ; σ is obtained from the IDL-Interactive Data Language function GAUSSFIT and is the width of the waveform) of the peak, the dark gray region, is summed directly. The second region, the light gray area, contains photometric data between 2 to 9 σ from the peak. The photometric trace in this region shows a substantial fluctuation and is curve fitted before performing the summation. The dashed line is the result of the curve fitting with an exponential function $f = B_0 e^{B_1 x} + B_2$, where the coefficients are extracted from curve fitting. The sum of the photometric counts in these two regions is the integrated SP1-FUV intensity of an elve.

[16] After excluding the events whose imager data are contaminated by lightning, only 72 before-the-limb elves are selected for analysis from the year of 2007. As shown in Figure 4a, the imager-$N_2$1P brightness (Λ_{IMG}) and the SP1-FUV intensity (Λ_{SP1}) exhibit a tight correlation for the well-identified elves. A curve fit, the solid line in Figure 4a, shows that there is a linear dependence between these two data sets. The functional form of the correlation is $\Lambda_{IMG} \sim 25.5\Lambda_{SP1}$, and the correlation coefficient of the fit is 0.93. The SP5–777.4 nm intensity of the causative lightning is derived in the same way as that for the FUV emission. Figure 4b indicates that the SP1-FUV intensity of all the FUV events is less than 1×10^4 photons/cm^2. This result points out that, comparing with the well-identified elves, the FUV events are dim FUV emitters and generally initiated by relatively weak causative lightning. This result also implies that the mystic FUV events are dim emitters at the other photometric bands. Hence, the identification of the mystic FUV events as dim elves initiated by low peak current CG lightning is well grounded.

[17] To confirm the relationship between the imager-$N_2$1P brightness (Λ_{IMG}) and the SP1-FUV intensity (Λ_{SP1}) of elves, we use the electromagnetic FDTD model to simulate the intensity of those emissions that would be seen in the ISUAL SP1 channel and the imager-$N_2$1P band [*Kuo et al.*, 2007]. The simulation result is displayed as the dashed line in Figure 4a, and gives a clear demonstration that the imager-$N_2$1P brightness of an elve is indeed proportional to its SP1-FUV intensity, though with a different linear form of $\Lambda_{IMG} \sim 16.0\Lambda_{SP1}$. The discrepancy between the observed and the theoretical relations can be readily resolved by noting that the gains of the ISUAL imager and SP under the

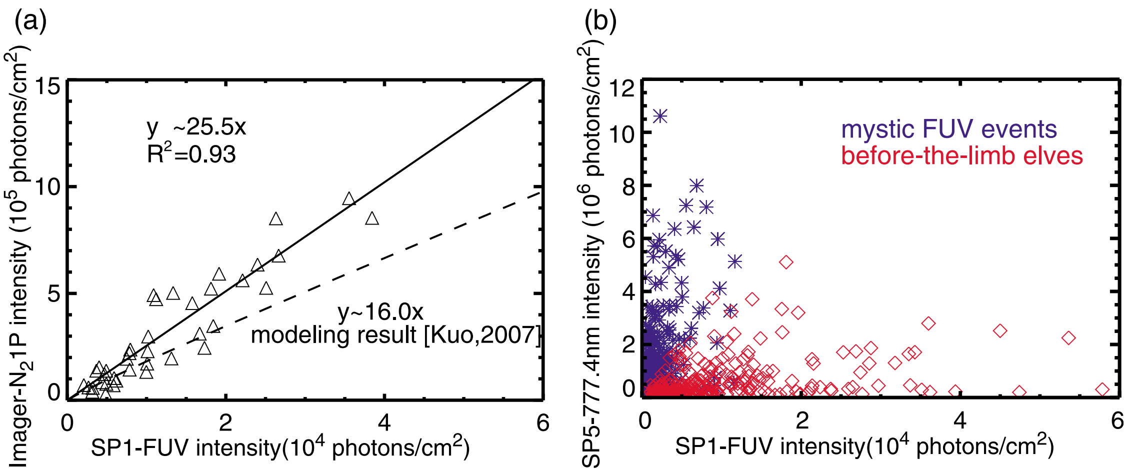

Figure 4. (a) The correlation between the ISUAL imager-$N_2$1P brightness and the ISUAL SP1-FUV intensity for elves. (b) The distribution of the ISUAL SP1 and SP5 intensities of the before-the-limb elves (red diamonds) and the mystic FUV events (blue asterisks).

laboratory and the space environments are different as reported by *Mende et al.* [2005]. The ISUAL instruments were well calibrated in the laboratory before launch but not on low-Earth orbit. The microchannel plate based ISUAL imager and the photomultiplier based SP exhibit different responses when they were moved to the low-temperature space environment. *Mende et al.* [2005] noted that, because the microchannel plate is more sensitive to temperature changes, the on-orbit ratio between the imager-$N_2$1P brightness and the SP4-$N_2$1P intensity of elves is 25/18; even though both instruments have the same band pass and were laboratory calibrated to give the same intensity. Here, the ratio of the observed and the simulated imager-$N_2$1P brightness of an elve came out to be 25.5/16.0, which is consistent with the result reported by *Mende et al.* [2005].

[18] The relation between the imager-$N_2$1P brightness of elves and the lightning peak currents has been reported by *Kuo et al.* [2007, Figure 18a]. Here we have further established the relation between the imager-$N_2$1P brightness of an elve and its SP1-FUV intensity. Clearly, the SP1-FUV intensity of an elve can also be used as a gauge to estimate the peak current of the causative CG lightning. Now we have two tools to extract the peak current of the elve-producing CG lightning from space.

[19] Is it possible to infer some physical characteristics of lightning from the ISUAL SP5–777.4 nm signal? *Adachi et al.* [2009] reported an analysis of ten ISUAL sprites and found that the sprite-associated SP 777.4 nm luminosity was correlated to the current moment after applying a scaling factor of ~0.82 MR/kA km. As was discussed in section 3, the lightning OI emission intensity depends on the total number of the excited oxygen atoms in the discharge channel. As the charge increases or the lightning path lengthens, more atoms will be excited. Because the charge moment is the time integration of the current moment, the time-integrated SP5–777.4 nm intensity provides a good measure of the associated charge moment change. To correlate the ISUAL lightning OI emission and the SP1-FUV intensity (peak current), we calculate the time-integrated SP5–777.4 nm intensity using the method discussed in section 4. The distribution of the causative lightning OI emission (SP5) versus the SP1 intensity of elves, as shown in Figure 4b, is similar to that of the peak currents versus the charge moment changes for the lightning as discussed by *Goei and Cummer* [2005]. The distribution indicates that large-charge-moment lightning does not necessarily have a high peak current. To explore the possible physical reason behind this feature, the SP5–777.4 nm signal characteristics for two extreme types of events were further analyzed: the Group 1 events having large SP5–777.4 nm intensity (>4 × 10^6 photons/cm^2) but small SP1 intensity, and the Group 2 events having small SP5–777.4 nm intensity but large SP1 intensity (>2 × 10^4 photons/cm^2). The average duration of the SP5–777.4 nm emission for the Group 1 events is found to be 2.06 ms (t_1), whereas that for the Group 2 events is 1.05 ms (t_2). Assuming that the return stroke propagation velocity (v) and the removed charge (Q) are nearly the same for these events, and neglecting the effect of cloud morphology, the longer emission duration for the Group 1 events implies that these events have longer discharge channels (dL_1), smaller peak currents ($I_1 = Q/t_1$), and larger charge moment changes ($Q\ dL_1$). Contrarily, the Group 2 events have shorter lightning channels (dL_2), larger peak currents ($I_2 = Q/t_2$), and smaller charge moment changes ($Q\ dL_2$).

5. Undercounted Elves in the ISUAL Imager Survey

[20] Compared to the ISUAL imager, the ISUAL SP1 is a more sensitive instrument for detecting elves. Naturally it has to be asked whether the ISUAL SP1 can be used to determine the undercounting factor for elves in the ISUAL imager survey [*Chen et al.*, 2008]. We use the before-the-limb elve events in 2007 for this study. Let N_{img} be the number of the before-the-limb elves in 2007 from the imager survey, and N_{SP1} be the number of FUV events that have the characteristics of elves in the SP1-FUV and SP5 emissions. N_{SP1} would be the number of detected elves if ISUAL SP1 is used as the survey tool. The average of the

Table 1. Number of the Before-the-Limb Elves From the Imager and the Spectrophotometer (SP1) Surveys for the Months of January and July 2007

2007	Elves From the Imager (N_{img})	Elves From the SP1 (N_{SP1})	N_{SP1}/N_{img}
January	30	431	14.4
July	70	1357	19.4

ratio N_{SP1}/N_{img} is ~16 for the 2007 ISUAL data set. This means that if we use the SP1 as the elve survey instrument, then the occurrence rate of the before-the-limb elves will be 16 times higher than that based on the imager survey [*Chen et al.*, 2008].

[21] Interestingly, the ratio N_{SP1}/N_{img} also varies from month to month. As shown in Table 1, the ratios N_{SP1}/N_{img} for January and July are 14.4 and 19.4, respectively. The larger July–ratio means that more elves have gone undetected in the ISUAL imagery survey for July 2007. The larger undercounting ratio in July than that in January should be expected, since the median lightning peak current in July is lower than that in January [*Orville and Huffines*, 2001].

[22] The undercounting ratio for the before-the-limb elves can also be estimated from the detection limits of the ISUAL Imager and SP1. The elve event on 14 March 200710:00:43.550 UTC, Figure 3b, is a typical before-the-limb elve with an event distance of ~2700 km. At this distance, the resolution of an imager pixel is 2 km. Assuming the diameter of an elve is around 200 km [*Kuo et al.*, 2007], then this elve will be projected into an imager area with a width of ~100 pixels and a height of ~10 pixels. The standard deviation of the imager intrinsic noise (σ_{img}) is known to be 10 kR [*Kuo et al.*, 2007]. Only the imager pixels with counts greater than $3\sigma_{img}$ can be discriminated in an image frame. Therefore the typical detection limit for the ISUAL imager is 3.4×10^4 photons/cm^2, which is equivalent to the elve imager-$N_2$1P flux induced by a CG lightning with a peak current of 150 kA [*Kuo et al.*, 2007].

[23] In Figure 5, the average standard deviation of the SP1 noise (σ_{SP1}) in 2007 is chosen as a reference. If the peak value of the SP1 signal is larger than $3\sigma_{SP1}$, then the minimum detectable intensity of an elve in the SP1 is 660 photons/cm^2. This corresponds to elves that are induced by CG discharges with a peak current of 110 kA. Using the peak current distribution of the NLDN lightning during 1989 to 1993 as reported by *Wacker and Orville* [1999], the number ratio of –CG flashes with peak current greater than 110 kA ($N_{I>110kA}$) and –CG with peak current greater than 150 kA ($N_{I>150kA}$), $N_{I>110kA}/N_{I>150kA}$, is ~13, in good agreement with the N_{SP1}/N_{img} ratio.

[24] A previous study has established the imager detection limit of the limb-viewing elves to be 80 kA [*Kuo et al.*, 2007]. This means that it is easier to discern elves using the imager than using the SP1 for a limb-viewing configuration, for the edge-on view would create a larger integrated column intensity in the imager while the intensity stays the same for the SP1 regardless of the viewing configuration. But, for the before-the-limb elves, the luminosity of an elve is projected into a wide imager area resulting in a smaller column intensity compared to that for the limb-viewing

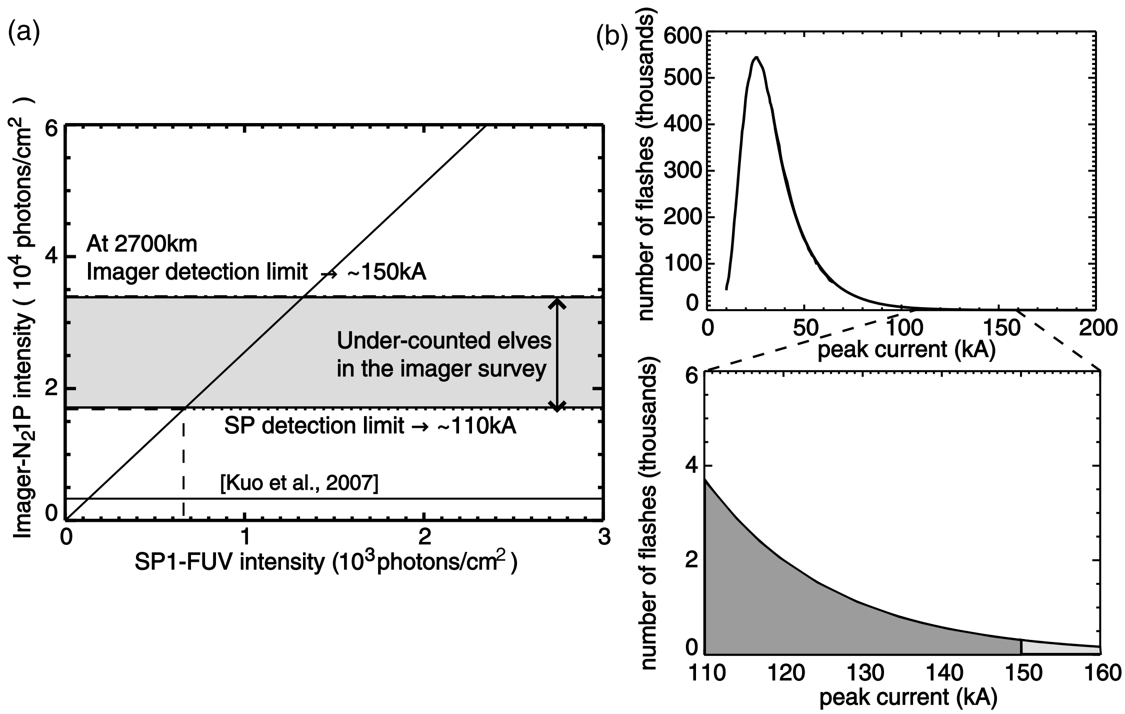

Figure 5. (a) Detection limit of ISUAL imager and the ISUAL SP1. (b) The peak current distribution of the NLDN lightning during 1989 to 1993 [*Wacker and Orville*, 1999]. The gray region in Figure 5a indicates these elves would be undetected in the ISUAL imager survey of TLEs.

case; therefore the SP1 is a better instrument to detect before-the-limb elves.

6. Multielves Events

[25] *Newsome and Inan* [2009] reported the possible detection of doublet and triplet elves using an instrument called PIPER (Photometric Imaging of Precipitation of Electron Radiation). They suggested that these multiple elve events with 0.1–0.2 ms time spacing are caused by either multiple strokes or electromagnetic pulse (EMP) reflection from the ground. If one assumes that the stroke originates at 10 km altitude, then the time difference between the electromagnetic wave that reflects from the ground and that directly reaching the lower ionosphere will be ~0.1 ms. Unfortunately, the time resolution of the ISUAL SP is 0.1 ms, which is barely able to resolve signals separated in time by 0.1–0.2 ms.

[26] Here, we report two kinds of multielves events which may be induced either by the M-components or multiple CG strokes of lightning. Figure 1a presents a possible multielve on 20 April 2007 2008:44.435 UTC from the ISUAL survey. There are three photometric peaks at 0.6, 2.0 and 4.0 ms after the event trigger. The time difference between the first and the second peak is about 1.5 ms. Thus we speculate that this multielves event on 20 April 2007 may have been caused by the M-components of the lightning [*Rakov and Uman*, 2003, p. 179 and references therein]. ISUAL also often records events that have a double-peaked feature in the SP1 and SP5 with a temporal separation of tens of milliseconds. The average interstroke time interval is 69.0 ms for the CG lightning [*de Miranda et al.*, 2003]. Hence we propose that the event with the individual elves separated by tens of milliseconds could have been induced by the multiple strokes in a lightning flash.

7. Conclusion

[27] By comparing the photometric characteristics of the ISUAL mystic FUV events and the well-identified elves that occurred before the limb, the FUV events were identified as dim elves that cannot be discerned from the ISUAL imager data. For the before-the-limb elves, the causative CG lightning ought to have a minimal peak current of 110 kA and 150 kA, respectively, to induce elves that are discernible in the ISUAL SP and imager. Using the ISUAL data set for the selected before-the-limb elves and FUV events recorded in 2007, the number of elves registered by the ISUAL SP is about 16 times higher than that from the imager survey. While using the peak current distribution of the NLDN lightning during 1989 to 1993, the –CG flashes with peak currents greater than 110 kA is ~13 times of that with peak currents of 150 kA or greater, which is in good agreement (18%) with the ISUAL ratio. Thus, for the before-the-limb elves, the ISUAL spectrophotometer is a more sensitive survey instrument than the ISUAL imager. The experimentally determined relation between the imager-$N_2$1P brightness and the SP1-FUV intensity of elves is consistent with the modeled result presented by *Kuo et al.* [2007], after the correction for the instrumental performance in the space environment was applied. Hence besides using the imager-$N_2$1P brightness of an elve to infer the peak current of the elve-causative CG lightning [*Kuo et al.*, 2007], the SP1-FUV intensity is an alternative gateway. Some FUV events were found to contain multiple peaks. They likely are multielve events induced by the M-components or the multiple strokes in lightning flashes.

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