Transient Upper Atmospheric Plasmas: Sprites and Halos

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***Abstract*— Sprites and halos are two types of the so-called transient luminous events occurring in the upper layers (40–90 km) of the earth atmosphere. Their spectacular appearance is due to the optical emissions from mesospheric plasmas caused by the electric breakdown of the high-altitude rarified air. While halos look like flattened diffuse flashes of light appearing between 80 and 85 km, sprites exhibit a sharp transition between the upper diffuse and lower plasma streamer regions, as observed in one of the images shown here.**

***Index Terms*— Geophysics, geoscience and remote sensing, meteorology, nuclear and plasma sciences, plasmas.**

TRANSIENT luminous events (TLEs) are impressive flashes of light that occur at mesospheric/lower ionospheric altitudes in connection with lightning storms taking place in the midlatitude troposphere (0–17 km). In the 1920s, Wilson [1] postulated their existence, but they were not discovered until 1989 [2]. In the 25 years since the first TLE recording, scientists have come to understand many different features of sprites, halos, and other types of TLEs, such as blue jets and giant blue jets. It is now clear that the formation of mesospheric plasmas due to the TLE activity is directly connected to the electrical (lightning) activity in the lower layer of the earth atmosphere. In particular, though the quasielectrostatic origin of sprites and halos is nowadays readily accepted, many uncertainties remain about their inception [3] and development [4] in an atmospheric density gradient environment, different to the constant pressure/density ambient of laboratory electric discharges. In this paper, we show images of the transient mesospheric plasmas produced by sprites and halos.

We recorded images of sprites and halos from August to November 2013 during the season of electric thunderstorms in Europe. The two photos presented were taken with the high-sensitivity charge coupled device (CCD) camera of our new instrument called GRAnada Sprite Spectrograph and Polarimeter developed by our group and recently fielded in the Calar Alto Observatory (2168 m above sea level) in Southeastern Spain. Sprites and halos usually occur over a mean horizontal distance of 25 km from the parent lightning strike. A set of nine different sprites exhibiting striking features is seen emerging from a halo (Fig. 1), serving as the initial stage of sprite generation, formed at an approximate altitude of 80 km and about 500-km distant from the observatory. The observed vertical structuring in the three sprites shown in the center of Fig. 1 responds to the interplay between three physical time scales: 1) the net dissociative attachment time scale (τ_a); 2) the ambient dielectric relaxation time (τ_d) scale (inversely proportional to the ambient ion and electron conductivities); and 3) the time scale for the development of an individual electron avalanche into a streamer (τ_s) [5]. As reported in [5], the interplay between these three parameters creates three unique altitude regions visible in the three sprites shown in the center of Fig. 1: 1) the top diffuse region ($\tau_d < \tau_a$, $\tau_d < \tau_s$); 2) the transition region ($\tau_d > \tau_a$, $\tau_d < \tau_s$) in the middle is characterized by strong attachment of ambient electrons before the onset of the electrical breakdown; and 3) the streamer region ($\tau_d > \tau_a$, $\tau_d > \tau_s$) in the bottom is also characterized by the strong attachment as well as by individual electron avalanches and local inhomogeneities evolving into streamers. Due to the 33-ms exposure time of our camera, the fast moving sprite streamers (with speed of about 10^7 m/s) are observed as tendrils in Fig. 1. A set of column (left/center sides), carrot (center/right sides), and wishbone-like (left side) sprites are recorded in the image shown in Fig. 2 where there is no halo.

Contrarily to the lightning optical emissions from excited nitrogen and oxygen atoms and atomic ions, the very intense visible optical emissions from sprites and halos are controlled by the electron impact excitation of nitrogen (N_2) molecules and the radiative and quenching of the N_2 electronically excited states [6]. In particular, while halos (at approximately 80 km) emit only a reddish diffuse light associated to the first positive group (1PG) of N_2, sprites emit in red (upper part, 80–55 km) due to the 1PG of N_2 and in blue (lower part, 55–30 km) due to the second positive group (2PG) of N_2 since the emitting states of 1PG and 2PG N_2 are quickly quenched below 55 and 30 km, respectively.

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Fig. 1. Sprites emerging from a halo seen as a diffuse disc of light with a diameter of up to 100 km. Sprite plasma streamers are visible as filaments due to the low speed of the imaging system. This photo was taken from Calar Alto Observatory (37°13'25"N 2°32'46"W) placed 2168 m above sea level in Southeast Spain at 19:43:38.285 UT, November 15, 2013, using a 33 frames/s high sensitivity CCD 1/3" camera equipped with a f1:1.4 16-mm focal length lens covering a field of view of 19°. The bright flash in the bottom part corresponds to the causating parent lightning located at 40° 36' latitude and 1° 80' longitude (close to Balearic Islands, Spain). The optical intensity (brightness) of halos and sprites is, respectively, 10^6 and 10^7–10^8 Rayleigh (R) (1 R is 10^{10} photons/m^{2}s). The night sky is 250 R and auroras can reach 10^6 R. The global occurrence rate of sprites and halos is 0.5 sprites/min and 0.4 halos/min.

Fig. 2. Column and carrot type sprites taken at 20:40:38.239 UT, November 15, 2013 using the same camera and from the same location as the photo shown in Fig. 1. The typical dimensions of sprites are 40–80 km vertical length with diameters of up to 30–40 km. The distant lights in the bottom of the image correspond to nearby villages. The causating parent lightning was at 40° 37' latitude and 1° 72' longitude (close to Balearic Islands, Spain).

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