Recordings of 'sprites' by video meteor detection cameras

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This paper describes a series of 'sprites' serendipitously recorded by video cameras belonging to NEMETODE,[1] a UK-based meteor observation network operated by members of the British Astronomical Association's Meteor Section for the purpose of determining radiants and orbital characteristics of meteors. The results from these 2013 July captures (including data from a number of other sources) are presented and discussed. Recommendations are also given for operators of current and future video meteor detection systems.

Equipment and methods

The author operates three Watec 902H mono cameras with Computar aspherical 8mm f/0.8 lenses from Ravensmoor, Cheshire as part of NEMETODE.[1] The cameras are aligned on azimuths of 067°, 104° and 358° at elevations ranging from 44° to 67°. Detection and recording are accomplished by SonotaCo's *UFO Capture* software[2] running on Windows XP PCs that are synchronised to ±0.1s via an NTP server. For operational reasons the cameras are rotated through 90° so that the bottom of the recorded field of view is actually the left hand side. The system operates every night[3,4] and the latest configuration is detailed on the NEMETODE website.[1]

Overview of sprites

Cumulonimbus thunderstorm clouds typically have a base altitude of 5 km and lightning discharges can occur within clouds, between clouds or between a cloud and the ground.

Sprites are large-scale, short duration (<100ms) transient, luminous electrical discharge events at altitudes of 55–80 km[5] (*i.e.* within the mesosphere). They appear, often in clusters, as reddish-orange flashes above thunderstorm clouds, and are triggered by the more commonly observed lightning discharges. The first known observation dates back to the early 18th century. Since then there have been occasional reports, the frequency of which has increased during the 20th century, particularly from pilots flying aircraft above thunderstorm clouds. It was not until 1989 that they were first captured photographically.

NEMETODE recordings of sprites

The first NEMETODE sprite was recorded on 2013 July 23 at 02:06:16.8 UT by the azimuth 104° Ravensmoor camera. A further three sprites were recorded by the azimuth 067° Ravensmoor camera later that day at 22:38:52.3 UT, 22:42:06.7 UT and 22:45:23.7 UT. Composite still images and videos are available on the NEMETODE website.

Although a comparable volume of atmosphere is continuously monitored by the other full time NEMETODE participant, Alex R. Pratt in Leeds, his station was clouded out on this occasion and hence no sprites were recorded by his camera.

Analysis

The NEMETODE video cameras operate at 25 frames per second. By inspecting the individual de-interlaced video fields (50 per second, 20ms per field) the event duration can be estimated. Although the fields are lower resolution, rapidly occurring structural changes within the 2013 July 23 02:06:16.8 sprite can be seen (see Figure 1).

The sprites recorded later that day are shown in Figure 2. Unfortunately, the camera elevation was such that only the diffuse

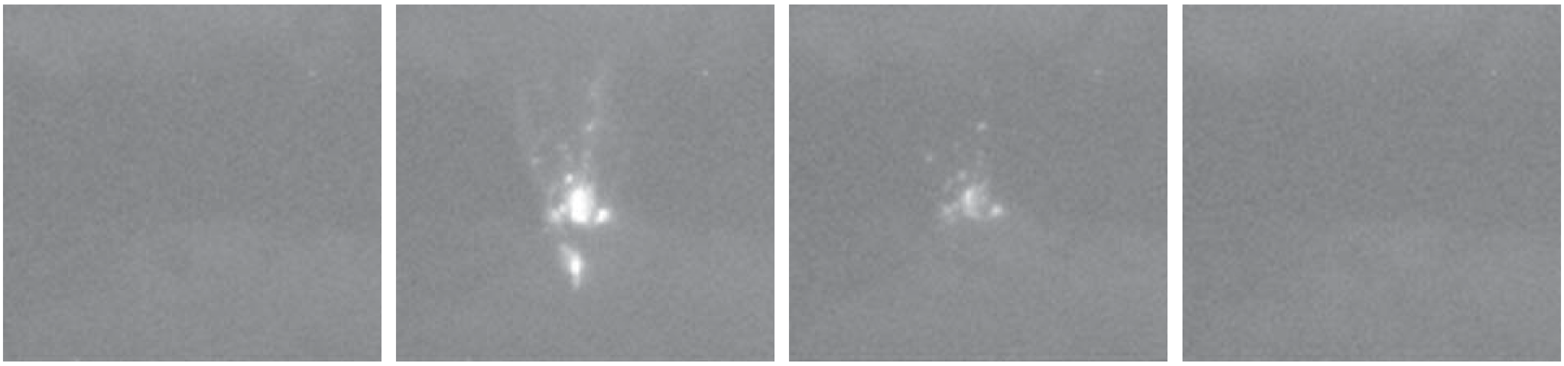

Figure 1. Individual sequential fields (each of 20ms duration) from the azimuth 104° Ravensmoor camera, cropped, rotated and enhanced showing the evolution of the 2013 July 23 02:06:16.8 UT sprite event. The star-like object in the upper right hand corner is a hot pixel. The streamer between the core of the sprite and the region around the hot pixel is faintly visible in the first field while the last field shows a very faint residual glow. The shape is characteristic of a red 'carrot' sprite. The diffuse sprite halo (if one was present) is obscured by intervening cloud.

Figure 2. Cropped, rotated and enhanced composite images of the diffuse tops of the three sprites recorded during the evening of 2013 July 23 by the azimuth 067° Ravensmoor camera at (from left to right) 22:38:52.3 UT, 22:42:06.7 UT and 22:45:23.7 UT. The final event (right hand panel) shows a combination of ‘column’ and ‘carrot’ sprites.

Table 1. Measured elevations and azimuths of the sprites observed from NEMETODE Ravensmoor on 2013 July 23

Time of sprite (UT)	*Maximum elevation (°)*	*Left hand azimuth (°)*	*Right hand azimuth (°)*	*Average azimuth (°)*
02:06:16.8	28.90	093.98	100.48	097.23
22:38:52.3	22.25	064.68	070.48	067.58
22:42:06.7	23.89	065.09	070.79	067.94
22:45:23.7	24.40	059.89	067.28	063.59

tops of the sprites were captured. While some structural detail is visible, the main bodies of each sprite are missing. The first three events are ‘carrot sprites’ while the fourth is a combination of ‘carrot’ and ‘column’ sprites.

SonotaCo’s *UFO* software suite[2] includes an analysis package (*UFO Analyser*) that allows accurate (<0.03°) positional measurements to be made of features within the images. This is achieved by knowing the precise azimuth, elevation, rotation and lens characteristics of each camera system, which are determined by comparing the stars within the field of view against an astrometric catalogue. While no stars are visible in the sprite images, analysis of meteor images (containing background stars) for prior and subsequent nights demonstrates that the camera housings had not moved in the interim and hence azimuth and elevation measurements for the sprites based on previously determined camera orientation parameters may be considered accurate. The results are given in Table 1.

Additional observation

On 2013 July 23 a sprite was captured by the Ash Vale station of the UKMON[6] Video Meteor Network with a timestamp of 22:38:52.4 UT. A composite image was subsequently posted on Twitter.[7] This observation led to a press release from the University of Bath[8] and to an article in the media.[9] The temporal similarity of this recording with that of the second sprite recorded from Ravensmoor suggested that the same object had been imaged from two locations, thus potentially allowing the sprite location to be triangulated.

While the location of the Ash Vale camera was known, the azimuth, elevation, rotation and lens characteristics were not. No stars are visible in the Ash Vale sprite image but the same Twitter feed contains an image of a bright sporadic meteor from 2013 June 30 at 23:36:59.6 UT.[10] The stars of Auriga, Perseus, Cassiopeia and Andromeda are clearly visible in this image.

The horizon features in both UKMON Twitter images were compared and found to be in identical positions with respect to the frame edges, confirming that the camera had not moved during the intervening period. Astrometry was therefore applied to the image of the sporadic meteor in order to characterise the relationship between pixel location and azimuth and elevation. The measured extremities and averages of the pixel positions of the sprites could then be converted to values for azimuth and elevation and these are given in Table 2. The average azimuth is consistent with UKMON’s ground track image of the sprite posted on Twitter.[11]

Location of lightning progenitor events

Sferics are radio emissions from lightning discharges, with each one having a unique waveform. As well as allowing the polarity of the lightning discharge to be determined, comparison of the precise arrival time of these unique waveforms at widely separated antennae enables the location of the discharge to be inferred.

A number of systems are currently in operation including ATDNET[12] and Meteorage[13] and the typical positional accuracy is ±2.5 km.[12] The Meteorage system has higher sensitivity during periods of darkness[14] and is therefore the preferred data source. Data from both systems were kindly provided by Dr Martin Füllerkrug of the University of Bath,[15] a leading sprite researcher, and the results are given in Table 3. Unfortunately there was no retrievable sferic data for the third event from ATDNET or Meteorage, hence the location could not be determined. Two sferics (very close in time and location) were recorded for the fourth event by the ATDNET system.

The University of Bath also operates the Wideband Digital Low-frequency Receiver,[16] a device that is sensitive to the sudden enhancement of background radio noise associated with sprites (and which can therefore be used as a sprite proxy measure). Dr Füllerkrug provided data-plots from this receiver and these can be used to characterise not only the sprite duration but also the time delay between a progenitor lightning discharge event and a sprite. This system detected all four sprites and plots from this receiver are available on the NEMETODE website.[1]

Table 2. Derived azimuths and elevations of the sprite observed from UKMON Ash Vale on 2013 July 23

Time of sprite (UT)	*Left hand azimuth (°)*	*Right hand azimuth (°)*	*Average azimuth (°)*	*Minimum elevation (°)*	*Maximum elevation (°)*	*Average elevation (°)*
22:38:52.4	011.41	013.76	012.58	11.44	15.02	13.23

Table 3. Meteorage and ATDNET data for lightning discharges that occurred within ±0.5s of sprites recorded by Ravensmoor on 2013 July 23

Time of lightning (UT)	*Latitude of lightning*	*Longitude of lightning*	*Source*
02:06:16.89	52° 45' 37"	00° 32' 43" W	Meteorage
22:38:52.39	53° 52' 44"	00° 40' 27" E	Meteorage
22:45:23.40	53° 55' 38"	00° 33' 53" E	ATDNET
22:45:23.42	53° 56' 05"	00° 32' 45" E	ATDNET

Results

Dr Füllerkrug has emphasised that not all sprites can be attributed to a particular detected lightning discharge. In addition the lateral displacement between progenitor discharges and their associated sprites can be as much as 50 km,[17] though during discussion with the author, Dr Füllerkrug pointed out that the distribution can be assumed to be Gaussian and that in most cases the lateral displacement is likely to be under 10 km.[18]

Working on the assumption that the sprite occurred along the measured azimuth at a distance from Ravensmoor equivalent to that of the progenitor lightning discharge allows the sprite location to be estimated from the azimuths listed in Table 1. Trigonometry then allows the maximum altitude and diameter to be estimated.

A more accurate estimate of the position of the 2013 July 23 22:38:52.3 sprite can be triangulated using the average azimuths detailed in Tables 1 and 2, leading to a location of 53° 42' N, 00° 12' W. The combined results for maximum altitude and diameter are shown in Table 4.

The triangulated position of the 2013 July 23 22:38:52.3 sprite and the location of the progenitor lightning discharge are within 40 km of each other, within previously discussed values.[17] Attention is drawn to the diameter of the sprites, further reducing the lateral displacement.

A review of the sferics detected by the ATDNET system shows multiple events in close proximity in time and location to the second sprite event.[19,20] This, combined with the similarity in azimuth, elevation and time for the second, third and fourth sprites, suggests they all occurred in close proximity to each other. An assumption that the distance of the 22:42:06.7 UT sprite from Ravensmoor was midway between that of the 22:38:52.3 and 22:45:23.7 sprites leads to maximum altitude and diameter values of 94 km and 23 km respectively.

The results in Table 4 have a significant range of values, a factor that is primarily a consequence of the uncertainty in the distance from Ravensmoor. Of particular concern is the maximum altitude value 103 km for the 22:45:23.7 event.[5] The values for the 22:38:52.3 event are likely to be the most accurate as they are based on a known triangulated location.

Table 4. Estimated details of sprites recorded from Ravensmoor based on the azimuths from Table 1 and the distances to the lightning discharges in Table 3

Details for the 2013 July 23 22:38:52.3 event are based on the triangulated position of the sprite.

Time of sprite (UT)	*Distance from Ravensmoor (km)*	*Maximum altitude (km)*	*Diameter (km)*
02:06:16.8	140	77	18
22:38:52.3	197	81	22
22:45:23.7	228	103	32

In conversation, Dr Füllerkrug has highlighted an interesting aspect of the fourth sprite in that the assumed progenitor lightning discharge had a negative polarity whereas sprites, in the vast majority of cases, are associated with positive polarity discharges. In addition, the delay of ~250ms between the lightning discharge progenitor and the sprite is difficult to explain.[18]

In all of the Ravensmoor recordings there is evidence of a sprite on at least four successive fields, indicating that the sprite duration was >40ms. The 22:42:06.7 and 22:45:23.7 events have evidence on at least five successive fields (indicating a duration >60ms) though these images appear to show a cluster of concurrent (or almost concurrent) sprites – the longer duration may therefore be explained by there being more than one sprite.

It is clear from Figure 1 that during the interval between first and second field (20ms), a significant volume of atmosphere was excited to the extent that visible light was emitted. Using date from Table 4 the height of the object in the second field (which has a measured elevation of the lowest observable part of 21.90°) is calculated (via trigonometry) as 21 km. The mechanism by which the atmospheric excitation occurred was therefore travelling at a speed in excess of $1.05e^6$ ms^{-1} (>Mach 3000 or 0.35% of the speed of light).

The second and third fields shown in Figure 1 clearly show small regions of particularly intense ionisation. Using the same technique as that used to calculate the overall height, these smaller regions have estimated sizes of between 500m and 1000m. No movement of these regions is discernible between fields two and three and the author therefore concludes that, within the limitations of the camera resolution, these regions did not move in a direction orthogonal to the line of sight.

Conclusions

On 2013 July 23 cameras belonging to NEMETODE recorded four separate sprites with altitudes ranging from 77 to 103 km and diameters between 18 and 32 km, providing optical confirmation of sprite proxies detected by the University of Bath Wideband Digital Low-Frequency Receiver. The first occurred in the vicinity of Grantham, Lincolnshire while the remaining three were over the North Sea, just offshore from the Humber Estuary. A lower limit of $1.05e^6$ $ms{-}^1$ has been placed on the speed of propagation of the atmospheric ionising mechanism. The observations also highlight areas of ongoing research regarding the relationship between the polarity of lightning discharge events and sprites, as well as the time delay between them.

In addition, images that are rapidly disseminated on social media platforms have been demonstrated to be of value when combined with other observations.

Discussion and recommendations

As of the time of writing (2013 August) there are known to be at least two dozen video systems in the British Isles that continuously monitor the night sky for meteors.[1] In this paper the author demonstrates that this deployed technology can also be used to capture useful scientific data relating to other (non-astronomical) phenomena in the upper atmosphere, with minimal impact on the observers' primary science goals. This approach of 'piggybacking' one area of research on top of an existing one is not unheard of in astronomical research: SETI (Search for Extraterrestrial Intelligence) investigators often mount their equipment on existing radio telescopes, commensally collecting the feed from wherever the telescope happens to be pointing.[21]

Operators of meteor imaging equipment (especially video) are therefore encouraged to deploy their equipment irrespective of forecast conditions and in particular during periods when thunderstorms are prevalent. The low light sensitivity of these systems combined with the typical frame rate (and even higher field rate for interlaced video cameras) makes them ideally suited for the capture of data that will be of use to researchers active in this area. As the number of meteor cameras increases, so too does the potential for productive collaboration between astronomers and researchers working on the electro-dynamic properties of the upper atmosphere, a region that is the focus of two upcoming space missions.[22,23]

An increase in the number of operational cameras also raises the probability that the same sprite will be imaged from multiple locations, thus facilitating a more accurate estimate of its location, altitude and size.

The likelihood of imaging sprites is enhanced by having a clear unobstructed line of sight to a distant thunderstorm. Consequently they will appear close to the horizon and operators should be mindful of checking the edges of their cameras' fields of view in any captured images. The fact that Ravensmoor cameras are rotated through 90° almost certainly led to the sprites being captured, as a normal orientation would have resulted in their being outside the field of view.

Finally, operators are encouraged to report their observations quickly as sferic data is often held on circular databases – rapid reporting allows this key information to be retrieved before it is overwritten. Dr Füllerkrug is a useful contact for such reports.

Acknowledgments

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The author wishes to note that the NEMETODE and UKMON sprite observations are not the first of their kind from the British Isles. Robert Cobain, who operates a video meteor detection system from Bangor, Co Down in conjunction with Armagh Observatory, had a potential capture on 2005 Jan 18[24] while Graham Roche had a capture from Dublin in 2011 Oct 26.[25] Nick James also recorded one from Chelmsford, Essex on 2011 Dec 13[26] while, more recently, a sprite was captured by the Meteor Detection Cameras of Armagh Observatory on 2013 Jul 25.[27] A list of known sprite captures within the British Isles is maintained on the NEMETODE website.[1]

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