



## ***The Bright Bolide of 15 June 2017 - An Analysis Based on reports by the Public***

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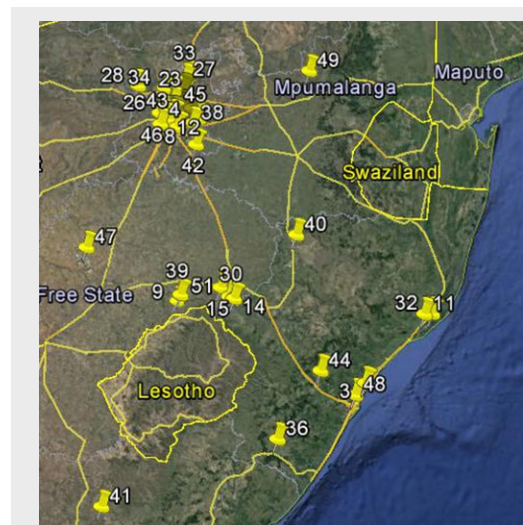
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### **Introduction**

On the early morning of 2017 June 15, as thousands of South Africans were on their way to work, a spectacular bolide was widely observed from the Eastern Cape, Kwazulu-Natal, Free State, Gauteng and Mpumalanga provinces. This event was the brightest since the super-bolide of 2009 November 21 (Cooper 2011) and the Daytime Bolide of 2013 March 12 (Cooper 2013), which had estimated total impact energies of 18.0 kT and 0.1 kT respectively (Chamberlin 2017). Reports of the brightness vary but the bolide probably peaked somewhere between magnitude -13 to -15, just too faint to be classified as a super-bolide (see Cooper 2017). This article summarises the bolide from the various eyewitness accounts received, all of which were followed up and analysed in order to determine the probable path across South Africa and a footprint for any possible meteorites that may have resulted if the bolide survived its passage through the atmosphere. All times are given in South African Standard Time (SAST).

### **Scope of visibility**

The author investigated fifty separate eye witness accounts of visual sightings by members of the public, including two sequences of video footage of the bolide. The locations of all the reports were plotted in number sequence as received and are reproduced as Figure 1. The geographical spread in visibility ranged from as far south as Dordrecht, Eastern Cape to as far north as Dullstroom, Mpumalanga. Observers from Welkom and Richards Bay were able to observe the fireball as it travelled northwards respectively low above their eastern and western horizons, and those in the south eastern Free State saw the fireball travel above their heads moving in a north-north-easterly direction.



**Figure 1**

*Locations of all 50 sighting reports. Numbers are in the sequence they were received. Due to congestion in Gauteng, not all numbered locations are visible.*

Good reports were received from the Northern Drakensberg area, and it was also in this area that sounds associated with the meteor were heard. A large fraction of the sightings was from Gauteng, which witnessed the demise of the object to the south east, and a number of these sightings were useful to help define the northern limit of the visible meteor.

## Important eye witness accounts

Those reports deemed to be of highest scientific value were investigated in detail, and the locations are shown in Figure 2.

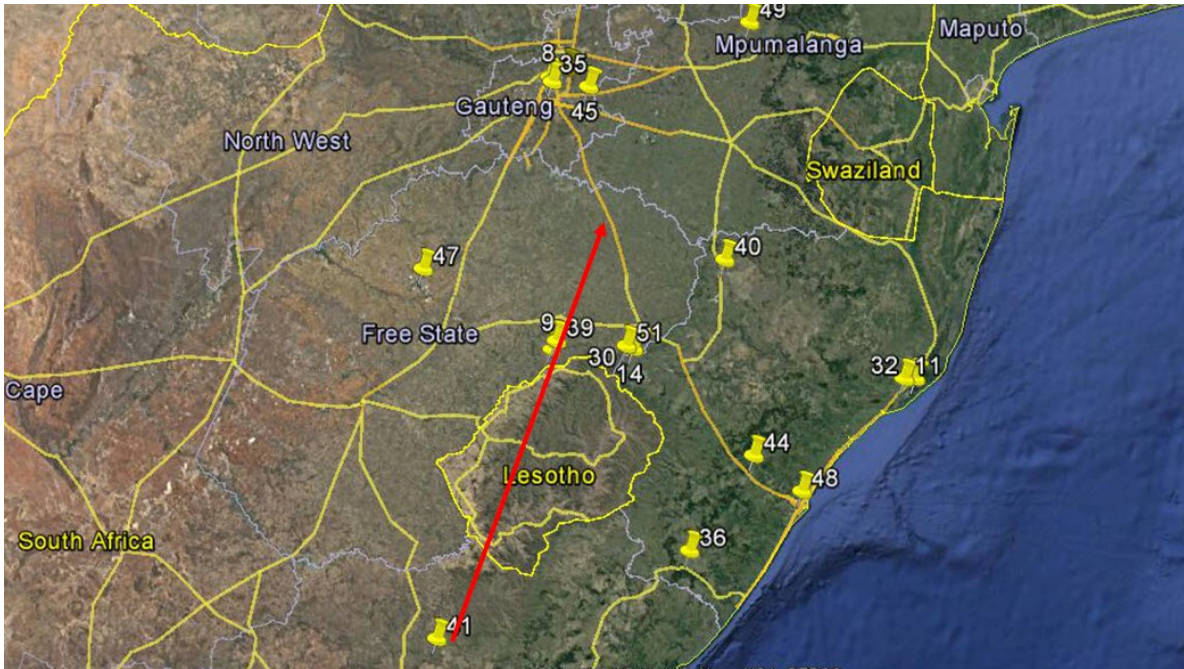


Figure 2 Locations of important reports, from which conclusions were arrived at to determine probable path (red arrow).

- Hennie Pelsler (location 41) was driving northwards on the R392 to Dordrecht. He saw the meteor high above to the right and behind the driver's side window, and disappeared behind the horizon in direction NNE. Duration was given as 3 seconds. This sighting was also the most southerly. While several reports are available which enable a determination of the end of the visible meteor, the entry point into the atmosphere could not be accurately ascertained. However Mr Pelsler's report does indicate the process of ablation had already commenced over the south-eastern Cape.
- Ronald Nair (36) was driving westwards on the N2, just after Harding and before the right hand turn onto R56 to Umzimkulu. The meteor was seen passing left to right about half way up the view in front of him. He described it as a huge ball of fire followed by flames which lit the dark sky, mostly yellow, but also orange and red.
- Slightly further north in KZN, Warren Hale (44) was driving almost due west on the N3 at Woodlands, Pietermaritzburg. He first saw the meteor in azimuth  $258^\circ$ , which is north of location 41 and the point of entry into the atmosphere, and it disappeared behind a ridge at azimuth  $320^\circ$ . The meteor was visible for 3 seconds.
- Letitia Veltman (9) was situated at Fouriesburg in the Free State, where she saw the meteor directly overhead and moving in direction NNE. The observation that the meteor passed overhead is an important pivot for the trajectory at this point.

Several useful reports were obtained from the eastern Free State and KZN Drakensberg regions.

- Wiseman Kurauone (30) was standing alongside the D119 at the turn-off to Hlalanathi. He was facing the opposite direction waiting for his lift to work when the sky lit up, and he turned round to see the object passing over Hlolela peak moving towards the direction of Montusi. The author visited the site and photographed the terrain in order to measure the altitude and azimuth of start and end points. The meteor was bright with a yellow tail, and it looked like flames were coming off the tail. It gave a terminal burst and suddenly disappeared, after which he thought it would hit the peak at the summit of Oliviershoek Pass. The duration was roughly 3-5 seconds and about two minutes later he heard sounds like thunder which caused the ground to vibrate. Innocent Miya was riding his bicycle along the same road (D119) on his way to work. He gave a similar description to Wiseman.
- Several staff at the Cavern (51) witnessed the visible passage, and again the author was able to interview those who saw it. Sakhile Mlangeni saw it through a window facing azimuth  $\sim 280^\circ$ . I measured the altitude as  $28^\circ$  moving left to right through a gap just below the tree line. The arc of travel was too small to discern its heading. Phelelani Mlangeni was finishing his shift on night watch, and had just turned the outside lights off under the thatched shelter between the tennis courts and bowling green at the hotel. As he was heading out he saw the bright light above the roof of the shelter, but immediately took cover in surprise. As a consequence he did not see the direction relative to the hotel buildings, but I ascertained the altitude as  $45^\circ$  in azimuth  $240^\circ$  at the moment he saw it.
- Several other Cavern staff members including Thokoza Mofokeng, Nomusa Mthetwa, Joseph Masabalala, Vuyisile Radebe, and Mbuyiseni Miya saw it from the main road in the Amazizi village, moving from the direction of Orion Mont Aux Sources hotel towards Hlalanathi. A minute or so later they experienced sounds and shaking like an explosion.

Further reports were analysed as the bolide moved through the Free State:

- Nduduzo Gumede (40) observed the meteor to the west from Newcastle. From his description of the path relative to landmarks seen from his location, I ascertained the end of the visible meteor in azimuth  $280^\circ$ , which together with those of locations 8 and 35 enable a tentative estimate for the point at which the meteor had ceased to emit visible light.
- Sandor Horvath (47) from Welkom had a good view of the passage moving northwards low in the east. From a sketch provided the azimuths of start and end point relative to local landmarks are roughly  $144^\circ$  to  $90^\circ$ . This places the end of the visible meteor a little further south of the points determined from Locations 8, 35 and 40.

The vast majority of reports were from Gauteng, where most probably thousands witnessed the demise of the bolide towards the northern end of its path. The most reliable reports were:

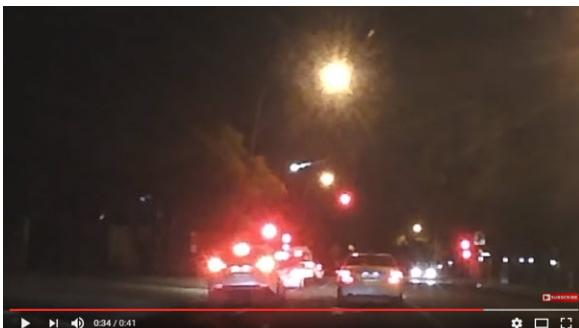
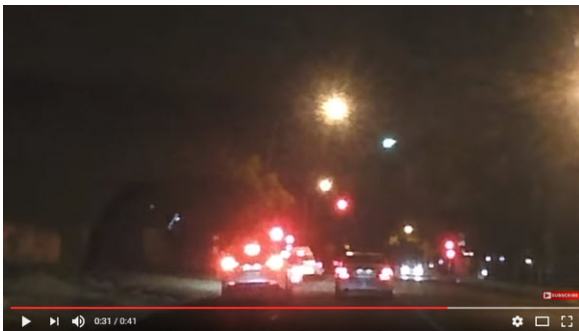
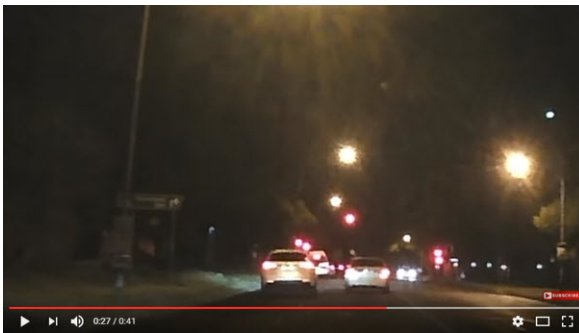
- Ruan Kuhn (45) saw the meteor from the intersection of Cowles Street and Main Reef Road, Springs while waiting for a change in the traffic lights. The object disappeared at low altitude to the south of his location, which led him to believe the object must have fallen nearby.

- Brendan Orsmond (8) had a ringside seat over Johannesburg from atop of his office block in Braamfontein, Gauteng, and was able to give a detailed description of the path which after measurement enabled determination of the northern limit of the visible meteor. The value arrived at is in good agreement with those from locations 35 and 40.

Finally, Frank Louw (49) was driving south on the R540 between Dullstroom and Belfast, and confirmed the visible meteor did not reach this far north, but must have burned out to the south. Most importantly, looking south he saw the object moving to his right, further constraining the angle of the path of the fireball.

### Images from video recordings

In addition to the many visual reports, two sequences of video were obtained showing the passage of the visible meteor. Both sequences captured the latter parts of the path, including the bright flash, disintegration and burning out of the meteor, but neither captured the initial entry into the atmosphere.



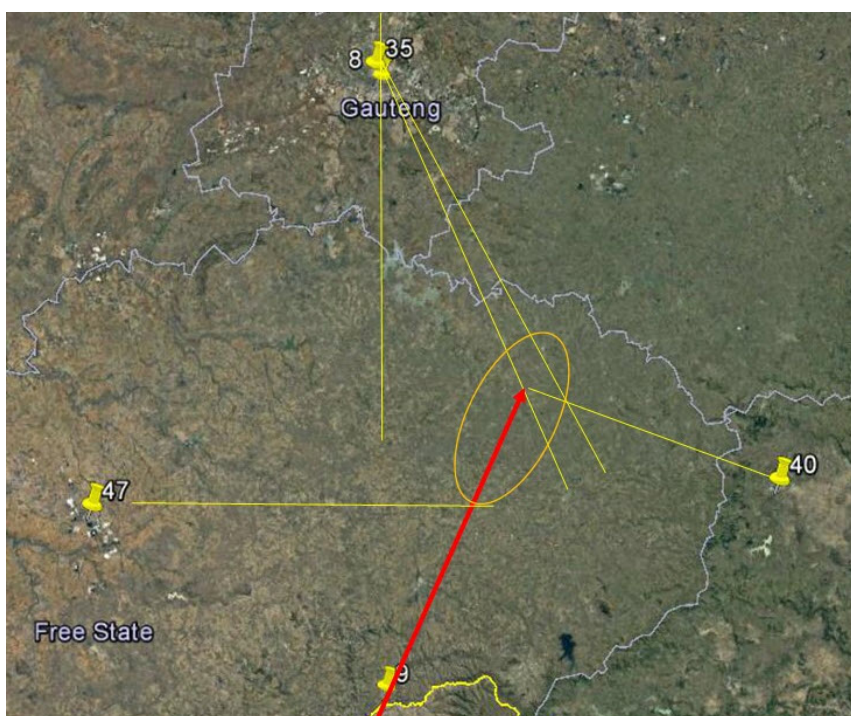
**Figure 3**  
Screen grabs from dashcam footage at location 35

**Figure 4**  
Screen grabs from security camera footage at location 50

- Location 35 was footage from a vehicle dashcam. Knowing the area well I managed to isolate the exact location in Greenside, Johannesburg. The author visited the site and calibrated still images captured from the footage to give the start and end coordinates of the meteor. There is no time associated with the appearance of the meteor at upper right, but it descends to the lower left, and the duration of passage is around 8 seconds. Image captures are shown in Figure 3.
- Location 50 is from a security camera located in Chloorkop, Gauteng. It has the time imprinted, and the meteor enters upper right and descends towards lower left at a shallow angle. The time of appearance is 06h04m23s, the bright flash occurs at 06h04m27s, and the visible meteor ends at 06h04m29s. The calibration status of the time is not known. Image captures are shown as Figure 4.

## Reconstruction of the path from visual and video records and potential footprint for meteorite falls

Determining the path of the bolide is important in projecting a forward trajectory and potential fall site of any meteorites assuming it survived its passage through the atmosphere. The probable path as derived from eye witness accounts is shown in Figure 2. The entry point into the atmosphere is indeterminate, as none of the accounts appear to have witnessed the start of the visible path with sufficient accuracy. The point of entry was certainly to the south of Dordrecht in the Eastern Cape, and a little to the east of that location according to the account from location 41. The accounts from locations 9, 30, 40, 47 and 51 are important to understanding the path of the meteor. Location 9 was sure the meteor passed overhead, while estimates of the altitude from locations 30 and 51 indicate the meteor had already descended to an altitude of about 30-40 km at about the point it passed over Fouriesburg. The accounts from locations 8, 40 and 47, and accurate measurements from the dashcam (35) enable a reasonable understanding of the termination of the visible meteor and the azimuths derived therefrom are shown in Figure 5. There is a good coincidence between locations 8, 35 and 40, which indicate the end of the visible path occurred in the northern Free State, near to the towns of Frankfort or Cornelia. While the point derived from location 47 is a little further south, it at least indicates the meteor must have passed the town of Reitz in the Free State.



**Figure 5**  
Probable end location of visible meteor over north-eastern Free State

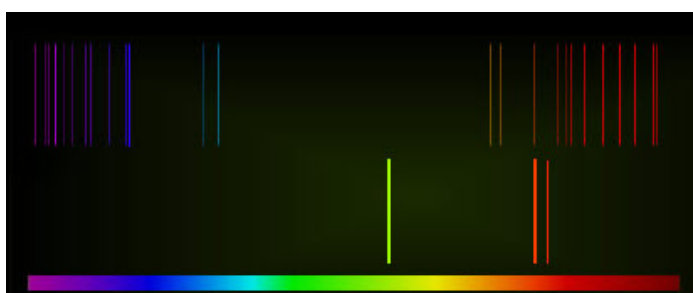
The two sets of video footage indicate the meteor started to disintegrate at least several seconds before end of the visible passage, and these smaller fragments continue to ablate well after the disintegration. This fact is evident in the lower image of Figure 3 and the centre image of Figure 4. It should also be born in mind that the object entered earth's atmosphere at a shallow angle of about 20°, and so probably experienced severe heating due to passage through a large air mass. It is therefore likely that the object, with a pre-atmospheric size of 10-100 cm assuming a magnitude of -13 to -15, may have burned up entirely during its flight. If any fragments did survive, and based on the probable path and northern visible limit derived from the eye witness accounts, meteorites might be possible somewhere in the north-eastern Free State or south-western Mpumalanga.

## Characteristics of the visible meteor

The time of passage was quoted variably from 05h55 to 06h05 SAST, the general consensus being just after 06h00. Ronald Nair was very certain about his time being 06h03, and the footage from the security camera has the time imprinted on it as 06h04. Again the estimates of the duration of the visible meteor vary considerably, from 2-3 seconds being the shortest, to 15 seconds being the longest. However, in terms of the shorter reported durations, it is probable the observers only saw a small part of the overall passage. The meteor was visible for 8 seconds in the dashcam footage, though it is not clear how long it was visible before it entered the frame

Estimates of the brightness of such events are normally highly subjective, and very often over-estimated. One reason for this is the absence of suitable celestial objects at similar brightness for comparison. While most agreed the object was very bright, and some said it lit up the sky, there were only four direct references. One observer from near Durban quoted 'very bright, could be described as nearly as bright as the sun', while the remaining three, all in Gauteng said 'brighter than the full moon', 'similar intensity to full moon', and 'close to that of the full moon'. One report also commented 'It made a few flashes so the brightness was more intense at some points than others'. From this I conclude the brightness may have peaked somewhere between magnitude -13 to -15, though this cannot be confirmed for certain.

The observation of colour in meteors is similarly subjective, and depends on a number of factors. Firstly light is emitted due to excitation of metals which emit light on return to their ground state, the specific wavelengths depending on the metals involved. Typical colours emitted by meteors (Rendtel 1993) are blue-violet from calcium and magnesium, yellow-green from sodium and iron, and red from silicon. The brightest emission lines in meteor spectra are normally the H and K lines from calcium. Secondly, very energetic processes during entry of the body into the atmosphere cause excitation of atmospheric gas molecules, which then radiate light in the visible region, for example green from oxygen and red from nitrogen. Persistent green meteor trains (see Figure 6) have been shown to be due to the forbidden line of atomic oxygen at 557.7 nm (Evans 2003), and this emission is catalysed by the presence of sodium in the meteor (Beech 1987).



**Figure 6**

*Colours emitted due to neutral and singly ionised molecular nitrogen (upper lines) and neutral oxygen (lower lines) The green emission of oxygen at 557.7 nm is prominent. The colour is analogous to that seen in the aurora, which is also due to the decay of excited oxygen atoms to a lower energy state.*

The light emitted by the meteor may be subsequently affected by which process predominates, extinction effects due to altitude, and variable perception by the observer. Furthermore these factors may also vary along the length of the path, as the meteor loses kinetic energy and descends in altitude. In terms of the eye witness accounts green (35%) was most often mentioned in terms of the body of the meteor, followed by white (18%), blue (15%), yellow (15%), red and orange (17% combined). Fewer commented on the colour of the trail, with only nine cases, these being green (2), blue (2), yellow (2), orange (2) and red (1). I also looked at the colours seen from different locations along the path; so at the southern end Ronald Nair saw it as yellow/orange, while only slightly more north Warren Hale saw it as distinctly green. Around mid-passage at Fouriesburg, Letitia Veltman saw the colour of the meteor overhead as bright white. Moving further northwards Sandor Horvath in Welkom witnessed green. The greatest number of reports were from Gauteng, and here blue, white, but most often green were the predominant colours seen. Bearing in mind the aforementioned subjectivity, there does not appear to be any significant shift in overall colour perception along the path of the meteor.

Two observers may have witnessed nearly the whole passage of the bolide. Mark Sliep observed from Gauteng, saying 'first saw it as a small glowing dot that grew into a big fireball with a tail, big enough to see debris falling from it and burning up as they fell. The main ball was slightly brighter than a full moon with a greenish tinge to it'. Frank Louw was driving due south near Dullstroom and reported 'I saw what first looked like a bright white light not moving fast. I pointed to its direction showing my wife. We saw it first as a single light ball but as it reached the horizon it broke up into several pieces.

## **Audible sound reports**

Sounds associated with the passage of bright meteors may be normal or anomalous (Vinkovic et al 2002) and include:

1. Rumbling, similar to that of distant thunder.
2. Single or recurring sharp cracking noises.
3. Fizzing or hissing sounds, known as electrophonic noise.

The first two (normal) occur sometime after the visible passage depending on the distance of the fireball from the observer at the time of the event, while electrophonic noise (anomalous) occurs simultaneously with the visual observation. Type 1 sounds due to acoustic waves may be detected audibly, and seismically if they are ground-coupled (Edwards et al 2008), in which case it feels like the ground is shaking. In regard to this event only Type 1 sounds were reported, mainly from locations in the eastern Free State and northern Drakensberg regions as follows:

- A loud bang was heard at Hlalanathi (14), where Mary Walker said it caused the windows to rattle.
- Standing waiting for his lift, Wiseman Kurauone (30) saw the meteor and about two minutes later heard sound 'like thunder which caused the ground to vibrate'.
- At the Cavern (51) many staff heard sound like distant thunder, Megan Bedingham said it caused the windows to shake, and Jackie Ponsford thought it was actual thunder.
- Closer to the path at Phutaditjhaba (25), Mpho Mafika said the meteor was followed by a thunder-like sound. At the same location Modikadika Motaung reported 'a thunderous sound that lasted for like 10 seconds, it was really loud'.

- At Fouriesburg, which was apparently right underneath the path, Letitia Veltman (39) 'heard two deep 'boom' sounds, like massive explosions, but far away. These sounds were heard about 2 minutes after the visible flash'.

## Conclusions

Based on the foregoing analysis, it appears a small fragment of asteroid entered earth's atmosphere at 06h04 SAST, at a shallow angle of around 20°. The duration of visible passage was >8 seconds, during which time the meteor probably reached about magnitude -13 to -15 in a bright flash near the end of its path, and disintegrated several seconds before finally burning out. The point of entry was most likely to the south of Dordrecht in the Eastern Cape, passed overhead near Fouriesburg and the visible path ended somewhere near the towns of Frankfort or Cornelia in the north-eastern Free State. If any fragments persisted, they might have deposited as meteorites in the area of the north-eastern Free State or south-western Mpumalanga.

## Acknowledgements

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