Short paper

The Isle of Lewis fireball of 2013 October 14

William Stewart

On the evening of 2013 October 14 several fireballs were reported over the British Isles. One was observed and photographed to the north of the Isle of Lewis, Scotland at 19:30 UTC. This paper details the observation and provides an analysis based on the photographs that were taken.

Observation

The fireball was fortuitously recorded on 2013 October 14 at 19:30 (all times UTC) by Byron Griffiths (BG) who was taking a series of images of an auroral display from 58°12'28" N, 06°17'41"W, altitude 3m, near Branahuie on the Isle of Lewis. The sky was clear with a very small amount of scattered cloud to the north. The lunar phase was 80% (magnitude –11.4, elevation 22° in the SSE). BG was using a tripod-mounted Canon EOS 7D fitted with a 50mm lens. Each exposure was 5 seconds at f/2.8 at ISO 1000 and the camera was pointed just east of north.

The exposure interval was 1 second (controlled via a remote shutter release with a built-in timer) and the offset between the camera's onboard clock and UTC has been accounted for, but only to the nearest minute. (This was a consequence of the unknown drift rate of the camera's onboard clock[1] and the 15 days that elapsed from when the images were taken to when the offset was measured.) A composite of the two consecutive images, which were the subject of a number of media reports,[2] is shown in Figure 1. Clearly the event was observed very close to the horizon and the effects of atmospheric extinction and refraction make the fireball appear dimmer and higher in the sky than would have otherwise been the case.

A review of online fireball reporting sites[3,4,5] did not reveal any other observations at a time or location consistent with BG's images. This may be due to the cloud cover that lay over Scotland at the time (see Figure 2) and the remote nature of the location. Of note however is Douglas Scott's observation from Inverness[4] in which he describes a vivid turquoise fireball at an angle of 40°, slightly brighter than Venus, of duration 5–7 seconds to his northwest. The time is reported as 'approx 18pm GMT' and the fireball is reported as travelling 'South to North, Left to Right'.

Another report from Inverness,[3] elements of which bear an uncanny resemblance to the previous report, gives a time of '16pm GMT' and the trajectory as being 'North to South' for a duration of '6–7 seconds' at an angle of 40°. It is not clear if this is the same observer reporting the same observation on two online systems.

Table 1. Measured values of azimuth and elevation of key features in Byron Griffith's fireball images

Feature	*Azimuth*	*Observed elevation*	*Corrected elevation*
Detection	18.618°	5.138°	4.976°
Gap start	16.281°	3.474°	3.257°
Gap end	15.257°	2.700°	2.441°
Extinction (behind headland)	12.806°	0.891°	0.471°

Corrected elevations take account of atmospheric refraction

Figure 1. Composite of Byron Griffiths' two images of the same fireball. The gap in the trail is due to the 1 sec interval between consecutive exposures. The field of view (H×V) is approximately 24°×16° and the stars visible in the image are from a somewhat obscure part of the sky centred on RA 7h 20m, Dec +39°, bordered by Lynx, Auriga and Gemini. The streetlights in the image are the village of Col and the fireball is seen to disappear behind the headland. The brightest stars in the image have a typical apparent magnitude (taking account of atmospheric extinction) of +5.5.

The azimuth and observable range are consistent with the 19:30 event, though the reported times and directions of travel are significantly different and mutually inconsistent. The author is not aware of any other reported observations of this event.

Analysis

Key features in the fireball trail were measured against stellar positions in each of BG's images using *Stellarium* V0.12.2, configured to BG's location and altitude and set to the time of the event. Bennett's formula

$$R = \cot(OE + 7.31/(OE + 4.4)) \quad [1]$$

where R is the refraction in arcminutes and OE is the Observed Elevation, was applied in order to correct for atmospheric refraction.[6] The results are given in Table 1.

Fireballs typically become visible at an altitude of 110 km. From the corrected elevation given in Table 1, the re-entry commencement point can therefore be estimated as being 1250 km to the NNE of the observer at 68° 34' N, 03° 25' E, over the sea to the west of Norway. Clearly the fireball was travelling westwards but in the absence of definitive observations from other locations it is not possible to infer if the subsequent path was towards, away or orthogonal to the observer. The apparent angle is 38° to the horizon, remarkably close to the 40° reported in the possible visual observations.[3,4] Assuming

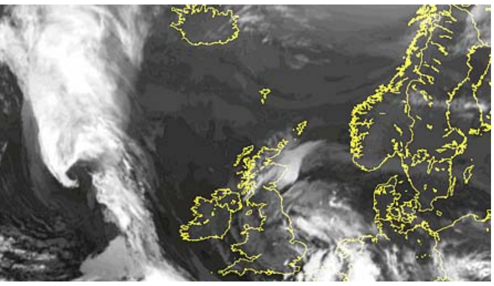

Figure 2. 10.8μm infrared satellite image showing cloud cover over and to the N of the British Isles on 2013 Oct 14 at 19:00 UTC *(courtesy Sat24.com/ Eumetsat/Met Office).*

the trajectory was orthogonal, the fireball penetrated to an altitude below 11 km approximately 125 km to the WNW of the re-entry commencement point. The nearest landmass is over 300 km from this point and it is highly likely that any surviving fragments would have landed in the Norwegian Sea.

As can be seen from Figure 1, the fireball continued to brighten until it disappeared behind the headland. The pixel values in the image are saturated (pixel value 255; BG was capturing images in 8 bit jpg format). A line profile of pixel values (average of red, green and blue channels), orthogonal to the fireball trail and crossing at the brightest point, was taken and a normal distribution curve fitted in order to estimate what the values would have been had the pixels not saturated. This is shown in Figure 3, left. A similar approach was adopted for the stars 65 Aur, DU Lyn, 71 Gem and HIP 37369 (the latter of which is shown in Figure 3, right) that are relatively close to the fireball and which have known apparent magnitudes (taking account of atmospheric extinction). The maximum apparent magnitude can then be inferred via a comparison of the areas under the curves of the fireball and the four reference stars, and was determined to be –2.2 ±0.8.

This value will be an underestimate for two reasons. Firstly, the light from the stars had 5 seconds (the length of each exposure) to build up on the pixels in the image whereas the fireball, due to its movement across the sky, would have had much less time (the focal length, short exposure duration and high declination mean that the effects of star trailing due to the Earth's rotation can be ignored).

The interval between exposures was 1 second and during that period, the fireball traversed the gap shown in Figure 1. This was measured as 214 pixels. The fireball peak width at the base from Figure 3 is 29 pixels. Assuming the trajectory was orthogonal to the observer (hence no corrections to account for foreshortening), the saturated pixels were therefore exposed to the brightest part of the fireball for a duration of 0.136s which is 1/37 of the total exposure time. Assuming a linear detector response a correction factor of ×37 may therefore be applied to the area shown in Figure 3, left, which raises the maximum apparent magnitude to –6.1.

A second correction should be applied to account for atmospheric extinction. Towards the zenith we are looking through 1 air mass and a correction is required for objects at lower elevations, particularly near the local horizon. Using Rozenberg's Equation[7]

$$\text{Air Mass} = 1/[\cos z + 0.025 \exp^{(-11 \cos z)}] \qquad [2]$$

where z is the zenith angle (90°–Corrected Elevation), the total air mass at an elevation of 0.471° (from Table 1) is calculated to be 31. Assuming each air mass leads to a drop in magnitude of 0.28,[8] the maximum apparent magnitude through a single air mass is calculated as –14.6.

Fireball magnitudes are normalised to an absolute value defined as their apparent magnitude if they appeared at the zenith at an altitude of 100 km (that is, through a single air mass). The absolute magnitude at a distance of 100 km was calculated using the formula:

$$m_{100} = m_{obs} - (2.512 * \log L_{inc}) \qquad [3]$$

where m_{100} is magnitude at a distance of 100 km, m_{obs} is the observed magnitude and L_{inc} is the increase in luminosity given by the formula:

$$L_{inc} = (d/100)^2 \qquad [4]$$

where d is the distance (in km) between the observer and the meteoroid.

Again assuming the fireball trajectory was orthogonal to the observer and was hence at a range of 1250 km, the absolute magnitude is calculated to be –20.1.

The overall fireball trail shown in Figure 1 extends for 1326 pixels from the start until it disappears behind the headland. Comparing this length to the number of pixels across the previously described 1 second gap (214 pixels) gives an overall duration of 6.2 seconds, a value that is consistent with the aforementioned visual observations. Assuming the trajectory was orthogonal to the observer places a lower limit on the average velocity of the fireball during re-entry of 25.7 km/s.

In order to quantify how much the calculated absolute magnitude could be in error as a consequence of assumptions in the value of 'd' used in Equation 4, the author considered the case where the parent meteoroid had the maximum possible geocentric velocity for a solar system bounded particle at the radius of the Earth's orbit (72km/s).[9] Taking this value in conjunction with the observed duration and assuming a trajectory parallel to the Earth's surface gives an estimated maximum range from the previously given re-entry commencement point of 446 km. Applying this figure to a trajectory that is at an angle of 45° towards and away from the observer yields alternate values of 'd' of 986 km and 1602 km respectively, which in turn lead to absolute magnitude values of –19.6 and –20.6 respectively.

The author also considered the implications of the fireball's initial visibility being at an altitude less that 110 km, perhaps as a consequence of atmospheric extinction resulting from the distance to the observer. If the altitude was halved to 55 km the range, assuming an orthogonal trajectory, would also be halved from 1250 to 625 km. The absolute magnitude would therefore be –18.6. The author therefore concludes that reasonable assumptions for errors in the value of 'd' do not have a significant impact on the

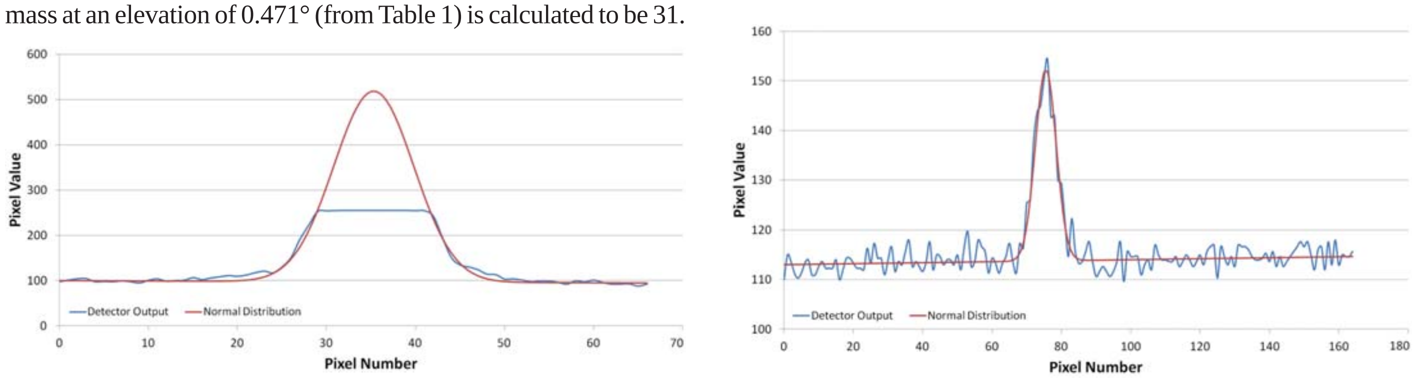

Figure 3. Fit of normal distribution curves to *(left)* an orthogonal slice through brightest region of Isle of Lewis fireball of 2013 October 14, and *(right)* a slice through star HIP 37369 (apparent magnitude 7.18) from the same image.

derived absolute magnitude.

Without knowing the true trajectory of the fireball it is not possible to reliably estimate the radiant position, geocentric velocity or potential mass of the meteoroid and hence the author has made no attempt to do so.

Conclusions

On 2013 October 14 at 19:30 UTC a fireball with an absolute magnitude of the order of –19 was observed over the Norwegian Sea. The absolute magnitude and altitude penetration strongly suggest that this was a significant event and that fragments could have survived re-entry. While fortunate that it did not occur over a populated area, the uncertainties in the trajectory and the fact that it occurred far out to sea make the possibility of recovery of these potential fragments somewhat remote.

Acknowledgments

The author is deeply indebted to Byron Griffiths who willingly shared his images – without his generosity, much of this paper would not have been possible. Thanks also to Len Entwisle for researching other potential observations of this event and to Alex Pratt for his critical assessment of early drafts of this paper.

Address: c/o British Astronomical Association, Burlington House, Piccadilly, London W1J 0DU. *[ws@nemetode.org]*

References

1 Welty E. Z. *et al.*, ‘Instruments and Methods: Cameras as Clocks’, *Jnl of Glaciology* **59**, 214 (2013)
2 **http://www.bbc.co.uk/news/uk-scotland-highlands-islands-24532979**
3 **http://arpc65.arm.ac.uk/cgi-bin/fireballs/browse.pl**
4 **http://thelatestworldwidemeteorreports.blogspot.jp/**
5 **http://www.amsmeteors.org/fireballs/fireball-report/**
6 Bennett G. G., ‘The Calculation of Astronomical Refraction in Marine Navigation’, *Jnl of Navigation* **35**, 255–259 (1982)
7 Rozenberg G. V., *Twilight: A Study in Atmospheric Optics*, New York: Plenum Press, 1966, p.160
8 Schaefer B. E. , ‘Atmospheric Extinction Effects on Stellar Alighments’, *Jnl Hist Astron., Archaeoastron. Supp.*, **17**, S35 (1986)
9 Jenniskens P., *‘Meteor Showers and their Parent Comets’*, Cambridge University Press, 2006, p.40

Received 2013 November 21; accepted 2014 January 29

BAA Membership

The subscription rates for the 2013–2014 session are as follows:

Young Persons’ membership (22 years of age or under on 1st August) £19.00
Ordinary Members (23–64) £46.00
Senior Members (65 or over) £33.00
Affiliated Society £46.00

Members with 50 or more years’ continuous membership (Honorary Members), no charge

Family Membership:
Where both members are under 65 on 1st August £50.00
Where one or both members are 65 or over £35.00

Family Membership is available for two people living at the same address. Only one *Journal* and *Handbook* will be sent although both may attend meetings and have a vote.

Paper *Circulars* (if required):
UK & Europe £5.00
Rest of World £10.00

Postage
Overseas postage by surface mail for the *Journals* and *Handbook* is included in the above rates. To avoid postal delays and losses use of airmail is strongly recommended. Please add the following for airmail:

Europe (incl. Canary Is. & Turkey) £14.00
Rest of World £21.00

Overseas members may send a sterling cheque, arrange payment in sterling on a UK bank, or **pay by credit card using the BAA’s secure website www.britastro.org. Please note that we do not hold a continuous credit card facility, so your payment must be renewed every year.**

UK members are particularly asked to save administrative costs and time by paying their subscriptions by Direct Debit: please contact the Office for the necessary form.

Gift Aid
UK Income Tax payers are urged to complete a Gift Aid certificate for their subscriptions and other donations. To claim Gift Aid you must pay an amount of UK income tax and/or Capital Gains tax at least equal to the tax which we reclaim on your donations in the tax year (currently 25p for each £1 you donate).

Please request a Gift Aid form from the Office if you have not previously completed one. The BAA can claim a tax refund at any time during the year.