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PF191012 Myszyniec – highest Orionid meteor ever recorded

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ABSTRACT

On the night of Oct. 18/19, 2012, at 00:23 UT, a −14.7 mag Orionid fireball occurred over northeastern Poland. The precise orbit and atmospheric trajectory of the event are presented, based on the data collected by five video stations and one photographic Polish Fireball Network station. The beginning height of the meteor is 168.4 ± 0.6 km, which makes the PF191012 Myszyniec fireball the highest ever observed, well-documented meteor not belonging to the Leonid shower. The ablation became the dominant source of light of the meteor at a height of around 115 km. The thermalization of sputtered particles is suggested to be the source of radiation above that value. The transition height of 115 km is 10−15 km below the transition heights derived for Leonids and might suggest that the material of Leonids is more fragile and probably has smaller bulk density than that of Orionids.

Key words. meteorites, meteors, meteoroids

1. Introduction

For many years it was commonly accepted that meteor ablation starts at a height of around 130 km. This was justified by the trajectories obtained from photographic and video double station observations, which indicated that the vast majority of meteor events emit their light at heights between 70 and 120 km (Ceplecha 1968).

The television and photographic observations of the Leonid shower in 1995 and 1996 carried out by Fujiwara et al. (1998) showed that the fastest meteors could start at heights of 130−160 km. This was quickly confirmed by Spurný et al. (2000a), who reported several 1998 Leonid fireballs with beginning heights at 150−200 km. Spurný et al. (2000b) analyzed the radiation type of the highest Leonid meteors and suggested that light emitted over 130 km might be due to processes not connected with ablation. All high-altitude meteors from their sample showed comet-like diffuse structures above 130 km, which evolved into typical moving droplets at normal heights. Spurný et al. (2000b) divided the light curves of high-altitude meteors into three distinct phases: diffuse, intermediate, and sharp. The sharp phase was connected with well-known ablation processes. The light emitted during the diffuse phase cannot be explained by standard ablation theory and a new type of radiation has to be taken into account.

The source of the meteor radiation above 130 km was not recognized until the mid-2000s. At that time Hill et al. (2004), Popova et al. (2007), and Vinković (2007) suggested that thermalization of sputtered particles could be the source of diffuse radiation from high-altitude meteors. Both model light curves and theoretical shapes of the moving bodies were in very good agreement with observations.

Up to that date the extreme heights of meteors were recorded only for Leonid fireballs. That was not surprising because Leonids are characterized by one of the highest entry velocities among all meteor showers. However, Koten et al. (2001, 2006) found that high-altitude meteors could be found among sporadic meteors and Lyrid, Perseid, and η-Aquariid showers. Still, among the highest meteors (with beginning height $h_{\rm b} > 160$ km), almost all events were recognized as Leonids. There was no single high-altitude Orionid meteor in that sample, which was surprising because Orionids are characterized by high geocentric velocity.

In this paper we report a detection of the PF191012 Myszyniec fireball belonging to the Orionid shower, which is one of the highest meteors ever observed.

2. Observations

The main goal of the Polish Fireball Network (PFN) project is to regularly monitor the sky over Poland to detect bright fireballs occurring over the whole territory of the country (Olech et al. 2005; Żołądek et al. 2007, 2009; Wiśniewski et al. 2012). It is kept by amateur astronomers associated with the Comets and Meteors Workshop (CMW) and coordinated by astronomers from the Copernicus Astronomical Center in Warsaw, Poland. Presently, there are 18 video and three photographic fireball stations belonging to PFN, which operate during each clear night.

On the night of Oct. 18/19, 2012, at 00:23:12 UT, five video stations and one photographic station of the PFN recorded a bright, −14.7 mag fireball belonging to the Orionid shower. The basic properties of the stations contributing the data to this work are listed in Table 1. Figure 1 shows images of the fireball captured by the photographic station in Siedlce and the video station in Błonie.

All video stations contributing to this paper work in PAL interlaced resolution (768 × 576 pixels), with 25 frames per second

Table 1. Basic data on the PFN stations which recorded the PF191012 Myszyniec fireball.

Code	Site	Longitude [°]	Latitude [°]	Elev. [m]	Camera	Lens	Remarks
PFN42	Błonie	20.6223 E	52.1888 N	86	Tayama C3102-01A1	Computar 4 mm $f/1.2$	flash saturated
PFN32	Chełm	23.4982 E	51.1355 N	194	Mintron MTV-12V8HC	Computar 3.8 mm $f/0.8$	end not detected
PFN06	Kraków	19.9425 E	50.0216 N	250	Mintron MTV-23X11C	Ernitec 4 mm $f/1.2$	low altitude
PFN38	Podgórzyn	15.6817 E	50.8328 N	369	Tayama C3102-01A1	Computar 4 mm $f/1.2$	low altitude
PFN43	Siedlce	22.2833 E	52.2015 N	152	Canon EOS 350D	Samyang 8 mm $f/3.5$	photo with shutter
PFN20	Urzędów	22.1456 E	50.9947 N	210	Tayama C3102-01A1	Ernitec 4 mm $f/1.2$	short path

Table 2. Orbital elements of the PF191012 fireball compared to the mean orbit of the Orionid shower and orbit of comet 1P/Halley.

	α_G [deg]	δ_G [deg]	V_G [km s^{-1}]	$1/a$ [1/AU]	e	q [AU]	ω [deg]	Ω [deg]	i [deg]	D'
PF191012	93.00(6)	14.89(14)	66.9(8)	0.0652(69)	0.961(40)	0.605(13)	79(3)	25.85089(1)	162.3(3)	
Orionids	92.5	15.7	66.8	0.0689	0.961	0.576	81.90	27.70	164.00	0.0283
1P/Halley	–	–	65.9	0.0550	0.967	0.582	111.80	58.10	162.26	0.0587

Notes. All values are in J2000.0 equinox.

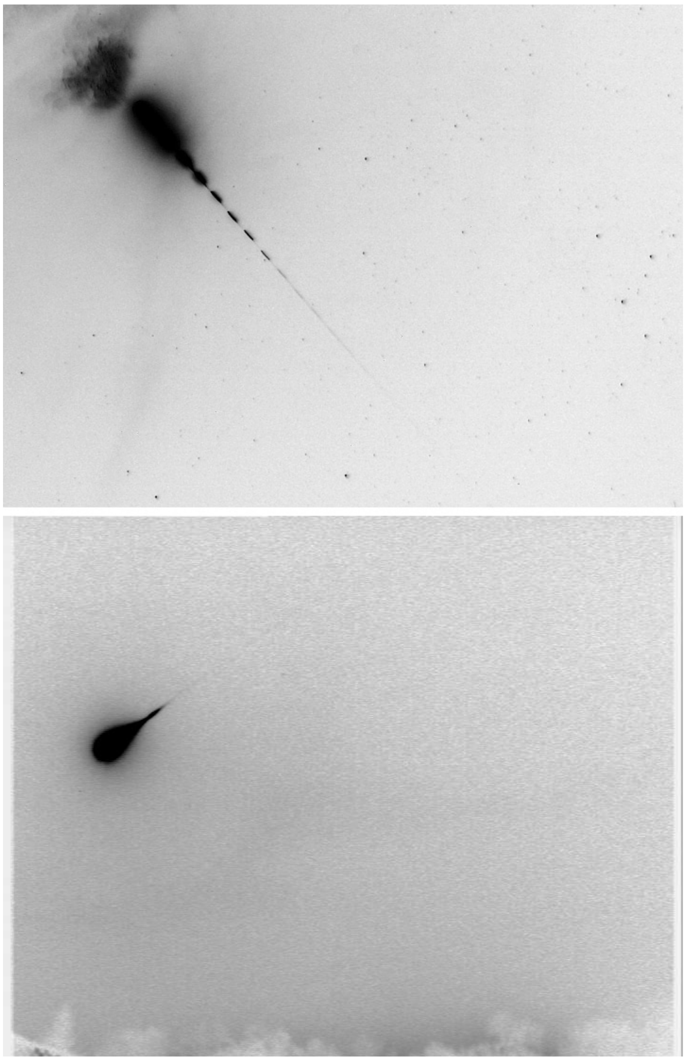

Fig. 1. Images of the PF191012 Myszyniec fireball recorded at Siedlce PFN43 (*upper panel*) and Błonie PFN42 (*lower panel*) stations.

offering 0.04 s temporal resolution. The photographic station in Siedlce works in reduced resolution of 2496 × 1664 pixels, with 30 s exposure times at ISO 1600. The frequency of rotating shutter is 10.68 Hz.

3. Calculations

The astrometry in the photographic image recorded at the PFN43 Siedlce station was performed using Astro Record 3.0 software (de Lignie 1997). The accuracy of the meteor path determination reached 10 arcmin. In the case of the video data, the modified Turner method was used as described in Olech et al. (2006). For the video images, the accuracy of the astrometry varied from 9 arcmin for the PFN42 Błonie station to 11 arcmin at the PFN32 Chełm station. The stations at Kraków, Podgórzyn, and Urzędów were located too far from the meteor to use their data in the final calculations.

The trajectory and orbit of the PF191012 Myszyniec fireball was computed using PyFN software written by Żołądek (Żołądek 2012). PyFN is written in Python with usage of SciPy module and CSPICE library. For the trajectory and orbit computation, it uses the plane intersection method described by Ceplecha (1987).

The PyFN software accepts data in both MetRec (Molau 1999) and UFOAnalyzer (SonotaCo 2009) formats and allows for semi-automatic searches at double-station meteors. Once the trajectory and orbit are computed, they can be compared to other orbits in the database using the Drummond criterion D' (Drummond 1979). Moreover, PyFN allows computation of the mean D' value in the vicinity of the meteor, which can be used for searching for new meteor showers as demonstrated by Żołądek & Wiśniewski (2012).

4. Results

Table 2 lists the radiant parameters and orbital elements of the PF191012 fireball computed from our data and compared to the mean photographic orbit of the Orionid shower and the orbit of comet 1P/Halley (Lindblad & Porubcan 1999). Both the radiant and orbital elements clearly show that there is no doubt that the PF191012 fireball belongs to the Orionid shower. It is also confirmed by the value of D' criterion, which in both cases is significantly smaller than 0.105 and thus indicates that all discussed bodies are related.

The trajectory and radiant parameters derived from the data collected in three PFN stations are summarized in Table 3. Additionally, Fig. 2 shows a map of northeastern Poland with the location of the Siedlce, Błonie, and Chełm stations, as well as the luminous trajectory of the PF191013 fireball.

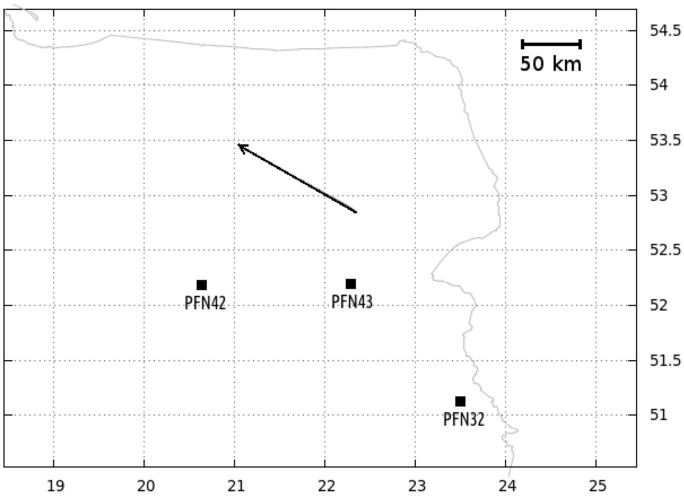

Fig. 2. Luminous trajectory of the PF191013 fireball over northeastern Poland and the location of the three PFN stations, whose data were used in calculations.

Table 3. Basic trajectory and radiant data of the PF191013 Myszyniec fireball

2012 Oct. 19, T = $00^h23^m12^s \pm 1^s$ UT			
Atmospheric trajectory data			
	Beginning	Max. light	Terminal
Height [km]	168.4 ± 0.6	77.7 ± 1.0	69.4 ± 0.6
Long. [°E]	22.336 ± 0.005	21.186 ± 0.020	21.040 ± 0.002
Lat. [°N]	52.865 ± 0.004	53.385 ± 0.010	53.463 ± 0.007
Abs. mag	1.5 ± 1.0	−14.7 ± 1.0	−1.0 ± 0.5
Slope [°]	42.4 ± 0.5	41.5 ± 0.5	41.4 ± 0.6
Duration [s]		2.19 ± 0.04	
Length [km]		148.4 ± 0.8	
Stations		Siedlce, Błonie, Chełm	
Radiant data (J2000.0)			
	Observed	Geocentric	Heliocentric
RA [°]	92.71 ± 0.13	93.00 ± 0.06	–
Dec [°]	15.08 ± 0.09	14.89 ± 0.14	–
Vel. [km s^{-1}]	68.0 ± 0.7	66.89 ± 0.76	41.51 ± 0.82

The meteoroid entered the atmosphere at a height of 168.4 ± 0.6 km, which makes it the highest Orionid meteor ever observed. The initial velocity and absolute magnitude were 68.0 ± 0.7 km s^{-1} and 1.5 ± 1.0, respectively. These data come from PFN32 Chełm station, where the beginning of the meteor was recorded. The earliest phase of the luminous path was located outside the field of view of the images from PFN42 Błonie station. The meteor entered this field at height of 162.8 ± 0.6 km.

Although some kind of diffuse structure of the meteor shape at high altitude is visible in both Błonie and Chełm data, it can be explained by the combination of high angular velocity of the bolide and interlace effect on 0.04 s temporal resolution data.

The first trace of the path of the meteor in the photo taken by PFN43 Siedlce station is located at a height of 152.0 ± 0.5 km. Due to the lack of shutter breaks on the green path recorded in the height range 128−152 km, we conclude that this part of the recorded light comes not from the meteor itself but from its persistent train.

The first clear shutter break is detected at a height of 128 km. At this point the color of the meteor changes from green to white-yellow. Below the height of 100 km, the color changes again and the meteor starts to show a white-blue hue.

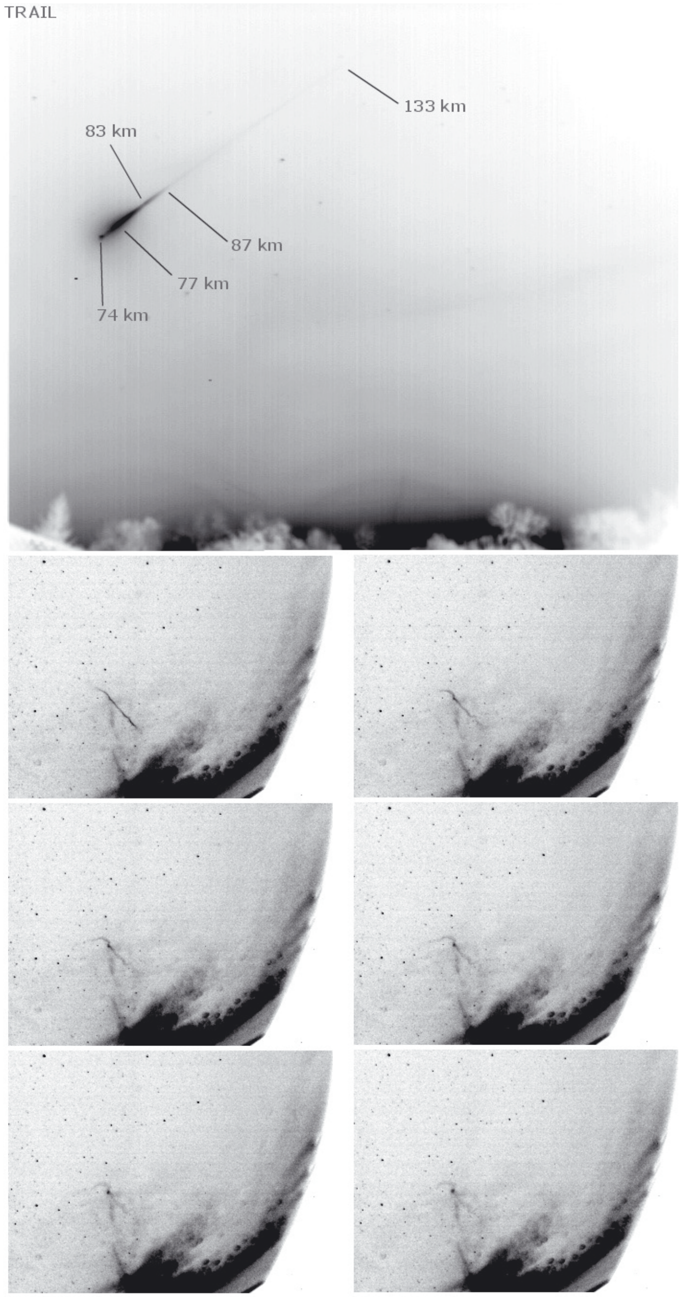

Fig. 3. Persistent train of the PF191013 fireball recorded at video frames in PFN42 Błonie station (*upper image*) and six consecutive 30-s exposures obtained in PFN43 Siedlce station.

After initial oscillations, the magnitude of the meteor was monotonically increasing. At a height of 87 km the first small flare occurred. The second and main flare with the maximum absolute magnitude of −14.7 ± 1.0 was observed at a height of 77.7 km. The third and final flare occurred at 74 km. The final flare did not cause the complete disintegration of the body. A small fragment with a brightness of −1.0 ± 0.5 mag was observed over the next three video frames and disappeared at a height of 69 km. The appearance of the flares is concluded not from the light curve of the fireball but from the shape of the train recorded in the images from Błonie station (see upper panel of Fig. 3).

Koten et al. (2006) derived the empirical relations between the beginning height of the meteor and its photometric mass. The relations differed in slope between all meteors in their sample

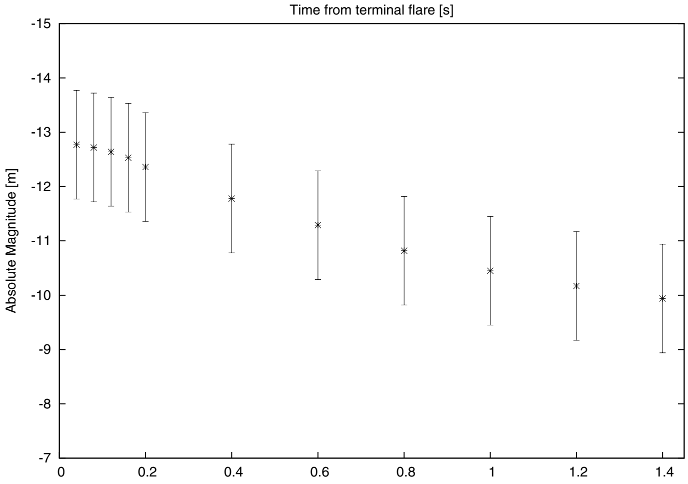

Fig. 4. Evolution of the absolute magnitude of the persistent train left by the PF191012 fireball.

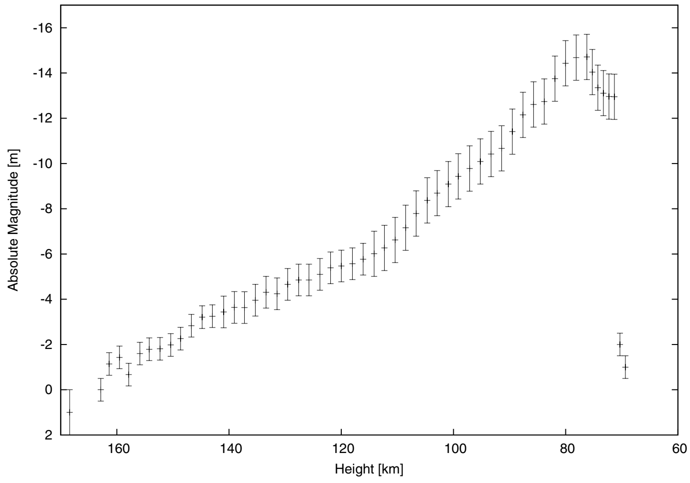

Fig. 5. Evolution of the absolute magnitude of the PF191012 fireball.

and high-altitude meteors from the Leonid shower. They suggested that for high-altitude meteors the steeper relation should be taken into account. However, all points for high-altitude Perseids, which are slower than Leonids, are located clearly below the steeper relation. Knowing that Orionids are also slower than Leonids, we decided to use the traditional relation given by their Eq. (1). According to this, the photometric mass of the PF191013 Myszyniec fireball is 360 ± 110 g.

The empirical relations of Koten et al. (2006) are only rough estimations; thus, we decided to calculate the initial mass of the meteoroid using the radiation equation of meteors (Ceplecha 1996). For determination of the luminous efficiency, we used the ReVelle and Ceplecha (2001) approximation for fast meteors. The resulting photometric mass is around 1500 g. Due to the ~1 mag error in brightness determination, it is only a rough estimate. The real value of the initial mass should be in the 600−3500 g range.

The meteor left an extremely bright persistent train. Its peak brightness reached −13 mag. During the first phase the brightness of the train was decreasing at a rate of two magnitudes per second. The evolution of the train was recorded on 38 images (30 s exposure each) captured by the Siedlce station and is shown in Fig. 3. Additionally, the light curve of the train is presented in Fig. 4.

The evolution of the absolute magnitude of the meteor in the function of height is presented in Fig. 5. The oscillation of the magnitude of the meteor at high altitude has already been reported by Spurný et al. (2000a,b) and Koten et al. (2006) and is typical for high-altitude meteors. A clear change of the slope of magnitude increase is evident at a height of around 115 km. At this point the ablation process becomes the dominant source of light.

A detailed inspection of the light curve shows some differences between the Orionid fireball light curve and these obtained for faster Leonids. Vinković (2007) derived the theoretical light curves for high-altitude meteors for the beginning heights of 200 and 171 km. In both cases, at a high altitude of 145−160 km, one can see a slight change of the slope from the steeper to gentle one. However, this change is more pronounced in the lower meteor. In our case such a change is only barely visible at a height of slightly below 150 km. This can be understood by taking into account the fact that the amount of generated light in the sputtering process depends on the number of collisions and this number is lower for slower meteors. The light curve of the Orionid fireball should resemble Leonids' light curves obtained for higher meteors.

An additional and more pronounced change of the slope of the brightness of the PF191013 Myszyniec fireball is recorded at height of 115 km. It can be interpreted as a transition from the intermediate phase (where both sputtering and ablation work together) to the final (sharp) phase, where only the ablation process is responsible for generating the light. What is interesting, its that the obtained value of 115 km is 10−15 km below the transition heights derived for Leonids by Spurný et al. (2000b) and Koten et al. (2006). This may suggest that the material of Leonids is more fragile and probably has smaller bulk density. It is in agreement with recent results of Borovička (2007) or Babadzhanov & Kokhirova (2009).

Although adding some conclusions about the parent bodies from the single case of the high-altitude Orionid meteor is a speculative task, some simple facts could be derived. The bulk densities of the parent comet nuclei are known with high uncertainty (for 1P/Halley comet estimates vary from 0.2 do 1.5 g/cm^3 and for 55P/Tempel-Tuttle only a rough estimate of 0.5 g/cm^3 is derived; Sagdeev et al. 1988; Peale 1989). Additionally, both bulk and mineralogical densities of meteoroids may vary within one meteor shower by factor of 2−3, as shown by Babadzahanov & Kokhirova (2009). The valuable conclusions about the basic properies of meteor showers could only be determined from the study of a larger sample of high-altitude and typical Orionids.

As we already wrote, a relatively large amount of high-altitude Leonids compared to only one case of high-latitude Orionid meteor and the difference in transition height may suggest that Leonids have a smaller bulk density than Orionids. The difference of 10−15 km in transition height transforms into a factor of ~2 in difference in mineralogical density. However, this is true only for the particular Orionid fireball that we observed and not for all Orionids, whose mean mineralogical density is very similar to the mineralogical density of Leonids.

We end this paper with the banal statement that more valuable conclusions will be drawn only when we detect more high-altitude Orionids and compare the whole sample to a group of high-altitude Leonids. This is the perfect task not only for PFN but for all fireball networks worldwide.

5. Summary

In this paper we presented an analysis of the multistation observations of a bright fireball belonging the Orionid meteor shower. Our main conclusions are as follows:

- the meteor started on Oct. 18/19, 2012, at 00:23:12 UT, over the northeastern part of Poland and was detected by five video stations and one photographic station of the PFN;
- the orbital elements and radiant parameters of the meteor clearly show that it belongs to the Orionid shower;
- the fireball started at a height of 168.4 ± 0.6 km, which makes it the highest Orionid meteor ever observed and one of the highest meteors known;
- the initial brightness of the meteor was 1.5 ± 1.0 mag and was oscillating;
- the ablation became the dominant source of light at a height of around 115 km, where we noticed a clear change of slope of the magnitude increase;
- the fireball reached its maximum absolute magnitude of -14.7 ± 1.0 at a height of 77.7 ± 1.0 km;
- the persistent train left by the fireball had a maximum absolute magnitude of around -13 and was observed over the next 20 min both in video frames and photographic images.

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