

# Bright Perseid fireball with exceptional beginning height of 170 km observed by different techniques

Pavel Spurný, Lukáš Shrbený, Jiří Borovička, Pavel Koten, Vlastimil Vojáček, and Rostislav Štork

Astronomical Institute, Academy of Sciences, 25165 Ondřejov, Czech Republic  
e-mail: pavel.spurny@asu.cas.cz

Received 17 December 2013 / Accepted 28 January 2014

## ABSTRACT

We report multi-instrumental observation of a bright fireball belonging to the Perseid meteor shower, which was recorded simultaneously by 11 all-sky photographic cameras, one high-resolution 300 mm photographic camera, two digital all-sky cameras, one wide-field digital camera, and two analog image-intensified video cameras on 12 August in 2012 at 22:29:46 UT. An exceptional beginning height of 170 km makes this fireball the highest Perseid ever observed and the highest meteor ever observed with precise atmospheric trajectory and heliocentric orbit not belonging to the Leonid shower. Moreover, one spectral video camera recorded the spectrum of the fireball. The spectrum shows only atmospheric emissions of O, N, and N<sub>2</sub> above 130 km. Below 110 km, the spectrum is not markedly different from other Perseid fireballs. The spectrum of the persistent train was also recorded, and a double-station observation of the persistent train provided its vertical and horizontal motion.

**Key words.** meteorites, meteors, meteoroids

## 1. Introduction

Beginning heights of meteors deduced from photographic observations range approximately from 70 km to 120 km (Ceplecha 1958). The television and photographic observations of the Leonid shower in 1995 and 1996 carried out by Fujiwara et al. (1998) showed that the beginning height of fast meteors could be at heights around 160 km and probably depends on the sensitivity of the observing system. It was confirmed and extended by Spurný et al. (2000a), who reported beginning heights of 1998 Leonids up to 199 km, depending on initial mass and the observing system. Spurný et al. (2000b) analyzed the radiation type of the highest Leonid meteors and suggested that light emitted above 130 km is probably not connected with thermal 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.

They divided the appearance of high-altitude meteors into three distinct phases: diffuse, intermediate, and sharp. The sharp phase was connected to the ablation process. The light emitted during the diffuse phase cannot be explained by the standard ablation theory, so a new type of radiation has to be considered. Brosch et al. (2001), Hill et al. (2004), Popova et al. (2007), and Vinković (2007) all suggest that the thermalization of particles sputtered from the meteoroid surface creates a cascade of collisions in the high-altitude atmosphere, which then produces the radiation of high-altitude meteors. The sputtering is effective for high-velocity meteors and is negligible in the case of meteor velocities below 30 km s<sup>-1</sup>. Both model light curves and theoretical shapes of the moving bodies were in very good agreement with observations.

High-altitude meteors (beginning heights above 130 km) were observed predominantly in the Leonid meteor stream (meteor velocity 71 km s<sup>-1</sup>) (Fujiwara et al. 1998; Spurný et al. 2000a,b; Koten et al. 2006), but also among  $\eta$ -Aquariids

(67 km s<sup>-1</sup>), Perseids (60 km s<sup>-1</sup>), Lyrids (45 km s<sup>-1</sup>) (Koten et al. 2001), and Orionids (68 km s<sup>-1</sup>) (Olech et al. 2013). Here we report a Perseid fireball with a higher beginning than any of these meteors except Leonids. We provide a precise trajectory, orbit, and the spectrum. The evolution of the persistent train is also discussed.

## 2. Instrumental data

Regular all-sky observations of fireballs were carried out by Automated fireball observatories (AFO) at 11 stations in the Czech Republic (Spurný et al. 2007). During the activity of selected meteor showers, analog image-intensified video cameras were used at two stations with narrow (50 degrees) fields of view (Koten et al. 2004). We report observing a bright fireball, EN120812, belonging to the Perseid meteor shower, which was recorded simultaneously by 11 all-sky photographic cameras on 12 August 2012 at 22:29:46 UT. By chance it also flew very favorably into the field of view of image-intensified video cameras at both videostations. The fireball was also recorded by one high-resolution 300 mm photographic camera (only the terminal part of the trajectory), two digital all-sky cameras, and one wide-field digital camera. Moreover, one spectral video camera recorded the spectrum of the fireball and its persistent train. Locations of the stations and projection of EN120812 on the ground are shown in Fig. 1, and basic details describing all cameras used in the final work are listed in Table 1. For the measurement, the films were scanned with a photogrammetric scanner at the resolution of 5000 dpi, and the analog signal of the video cameras was digitized on a PC in real time. In addition to direct photographic imaging, each AFO is equipped with a fast photometer with a sampling rate of 5000 samples/s and -1 mag sensitivity limit (for a moonless night). Therefore, we have very detailed information about the light curve of the fireball when it

**Table 1.** Photographic, video, and digital cameras that recorded the EN120812 Perseid and were used in this work.

	Regular all-sky	Regular wide-field	Image-intensified video (Ondřejov)	Image-intensified video (Kunžak)	Image-intensified spectral video	DSLR all-sky	DSLR all-sky	DSLR wide-field
Camera	AFO	300 mm	Panasonic SX50	Panasonic NVS88	Panasonic NVS88	Canon EOS 5D Mark II	Canon EOS 550D	Canon EOS 550D
Type	f	f	a	a	a	d	d	d
Lens	3.5/30	3.5/300	1.4/50	1.4/50	1.4/50	3.5/8	3.5/5	3.5/8
Resolution	...	...	768 × 576	768 × 576	768 × 576	5616 × 3744	5184 × 3456	5184 × 3456
FOV (deg)	180	45 × 30	50	50	50	180	180	120 × 90

**Notes.** DSLR stands for digital single-lens reflex camera; type “f” stands for photographic film, “a” for analog, and “d” for digital record; resolution is in pixels; FOV is field of view. Image-intensified cameras were equipped with the same image intensifier Mullard XX1332 and were operated at a frame rate of 25 frames per second. The spectral video camera was equipped with a grating with 600 grooves/mm, and exposure time of all DSLR cameras was 31.5 s.



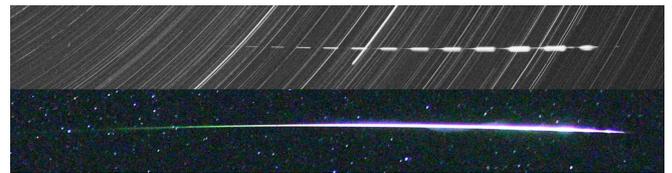
**Fig. 1.** Schematic display of the places where the EN120812 Perseid was recorded and projection of its atmospheric trajectory on the map of part of the Central Europe. Dark circles mark stations where the EN120812 fireball was recorded by the AFO, black crosses mark other detections. The other detections are as follows: 300 mm photographic camera, image-intensified video, image-intensified spectral video, and all-sky DSLR camera at Ondřejov; image-intensified video and all-sky DSLR camera at Kunžak; wide-field DSLR at Mt. Pancíř.

was brighter than this sensitivity limit. We have never recorded such a bright fireball with so many different instruments, so it gave us a unique opportunity to get complex and reliable results about this fireball, and for the first time, we can also compare these results obtained independently from different kinds of instruments for one meteor.

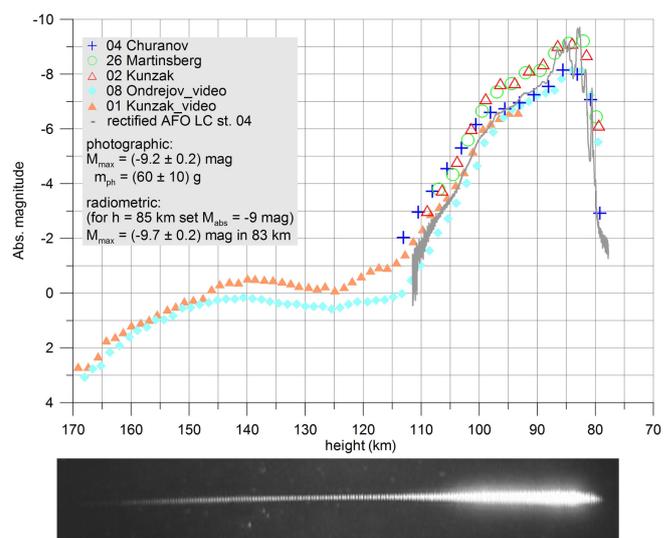
The results are based on five best all-sky and one hi-res photographic images, three video records (including one spectral), and three digital images plus 14 digital images of the persistent train.

### 3. Atmospheric trajectory and orbit

Figures 2 and 3 show the fireball and its light curve, respectively. The exceptionally long atmospheric trajectory (145 km) was determined with high accuracy. The standard deviation of any arbitrary point on the luminous trajectory is 31 meters when we take all the records into account and 18 meters for photographic records alone. The deviations of individual positions measured on photographic and video records from the computed fireball trajectory are presented in Fig. 4. Terminal heights determined from different techniques are within 1 km (see Table 2). The lowest value is from image-intensified video

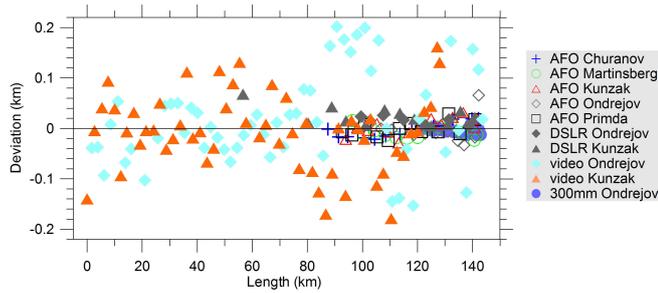


**Fig. 2.** Comparison of fireball images from different techniques. The upper picture shows the detail of the fireball from the closest site equipped with photographic all-sky camera (Churáňov), the bottom picture is taken from the nearest DSLR record (Pancíř). The photographic camera contains a rotating shutter that results in an interrupted meteor trail.

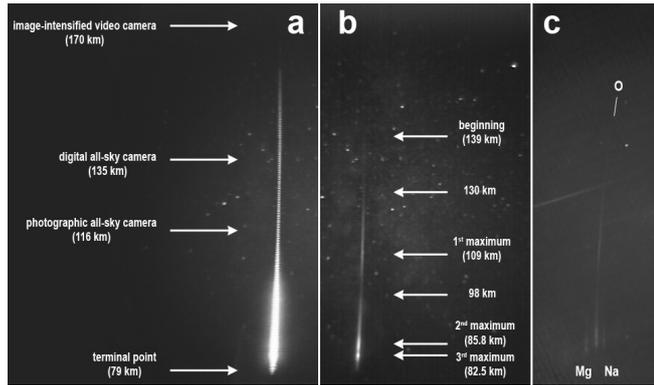


**Fig. 3.** Light curves from different stations. Absolute magnitudes (100 km distance) are plotted here as the function of the height. Rectified AFO light curve means that the original data were corrected for the distance and the zenith distance (due to change of sensitivity of the radiometer (Spurný et al. 2012)) of the fireball. The lower image shows the fireball composition from Ondřejov video record.

cameras at 78.6 km. The fireball terminated suddenly which contrasts to its beginning. The beginning heights strongly depend on the sensitivity of the detector (see Table 2 and Fig. 5a), which has been studied and demonstrated for other meteors in Spurný et al. (2004). The image-intensified video cameras detected the Perseid at the height of 170.2 km as a meteor of +3 mag. This is the highest Perseid ever observed (160.7 km was the highest Perseid observed by our cameras so far) and one of the highest meteors ever observed by image-intensified cameras (Koten et al. 2006). The highest meteors ever observed optically were Leonids in 1998 with the maximum observed height of 199 km



**Fig. 4.** Deviations of individual positions measured on photographic and video records from the computed fireball trajectory.



**Fig. 5.** Heights of trajectory and persistent train and spectrum of persistent train. **a)** Composed image of the Perseid fireball from Ondřejov video record; **b)** persistent train 1 s after the fireball passage; **c)** spectrum of the persistent train 1 s after the fireball passage: only oxygen line is present in the higher altitudes, magnesium and sodium are present at lower altitudes.

(Spurný et al. 2000a). The beginning heights from digital all-sky and photographic all-sky cameras are 135 and 116 km, respectively. Other atmospheric parameters did not differ from regular Perseid meteors: initial velocity  $59.81 \pm 0.05 \text{ km s}^{-1}$ ; geocentric velocity  $58.61 \pm 0.05 \text{ km s}^{-1}$ ; geocentric radiant: right ascension  $47.607 \pm 0.014^\circ$ , declination  $59.547 \pm 0.007^\circ$ . Atmospheric trajectory and heliocentric orbit parameters are collected in Table 2.

The initial mass of  $60 \pm 10 \text{ g}$  of the EN120812 was determined from the photometry of three photographic and two video records (Fig. 3). Determination of the photometric masses depends very strongly on the luminous efficiency,  $\tau$ , which is very difficult to derive for such fast meteors as the Perseids. For the initial velocity of  $59.81 \text{ km s}^{-1}$ , a value of  $\log \tau = -11.91$  (c.g.s. units with  $I = 1$  for 0 stellar magnitude) was used (Ceplecha & McCrosky 1976), which corresponds to 1.8% of the total kinetic energy of mass loss. There is a small discrepancy in maximum brightness: the photographic film is more sensitive in the blue part of the spectrum (where Ca II line is presented) in comparison to the CCD detectors of our video cameras. This is probably the reason the maximum brightness from AFOs is by about 1 mag higher than from video cameras. The saturation near maximum brightness of the fireball may be the explanation for lower maximum brightness at the nearest AFO station Churáňov.

The light curves determined from Martinsberg and Kunžak records are almost identical. The maximum photographic brightness of  $-9.2 \pm 0.2 \text{ mag}$  was observed at the height of 85 km. The absolute calibration of the radiometric light curve was performed with the help of photographic records. The brightness at the height of 85.0 km was set to  $-9 \text{ mag}$  (averaged brightness in the

**Table 2.** Beginning and terminal heights observed by different techniques, basic atmospheric data, and radiants and orbital elements (J2000.0) of the EN120812 Perseid fireball.

Type of camera	$h_B$ (km)	$h_E$ (km)	Length (km)
Photographic all-sky	116.0	79.2	58.7
Photographic high-res	...	79.1	20.5
Digital all-sky	135.0	79.4	88.6
Image-intensified video	170.2	78.6	145.2
Spectral video	154.4	78.6	120.3

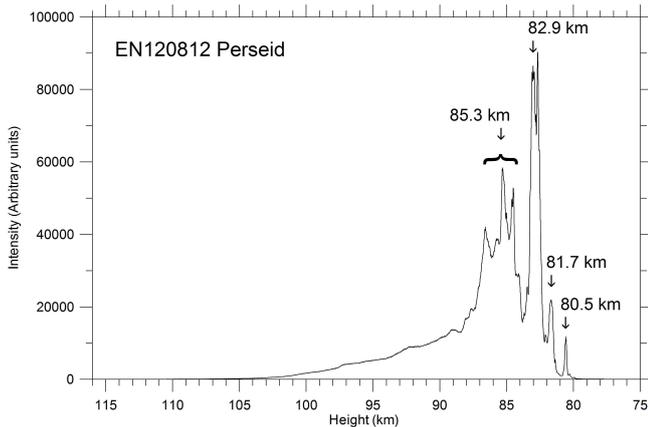
	Beginning	Max. light	Terminal
Height (km)	$170.18 \pm 0.09$	82.7	$78.6 \pm 0.03$
Velocity ( $\text{km s}^{-1}$ )	$59.81 \pm 0.05$	...	$55 \pm 1$
Long. ( $^\circ\text{E}$ )	$14.4436 \pm 0.0003$	13.505	$13.45656 \pm 0.00008$
Lat. ( $^\circ\text{N}$ )	$49.5036 \pm 0.0002$	48.785	$48.74671 \pm 0.00005$
Abs. mag (mag)	$3.0 \pm 0.3$	$-9.7 \pm 0.2$	$-1.0 \pm 0.3$
Slope (deg)	$38.554 \pm 0.007$	...	$38.959 \pm 0.007$
Duration (s)		2.5	
Length (km)		$145.23 \pm 0.06$	
Initial mass (g)		$60 \pm 10$	
PE coefficient/type		-5.48/IIIA	

	EN120812	IAU MDC	109P
$\alpha_R$ (deg)	$46.756 \pm 0.014$	...	...
$\delta_R$ (deg)	$59.552 \pm 0.007$	...	...
$v_\infty$ ( $\text{km s}^{-1}$ )	$59.81 \pm 0.05$	...	...
$\alpha_G$ (deg)	$47.607 \pm 0.014$	...	...
$\delta_G$ (deg)	$59.547 \pm 0.007$	...	...
$v_G$ ( $\text{km s}^{-1}$ )	$58.61 \pm 0.05$	...	...
$v_H$ ( $\text{km s}^{-1}$ )	$41.48 \pm 0.05$	...	...
$a$ (AU)	$29 \pm 3$	25	26.3
$e$	$0.967 \pm 0.004$	0.962	0.964
$q$ (AU)	$0.9545 \pm 0.0002$	0.952	0.958
$\omega$ (deg)	$151.90 \pm 0.07$	151.3	153.0
$\Omega$ (deg)	$140.41914 \pm 0.00001$	139.6	139.4
$i$ (deg)	$110.89 \pm 0.03$	113.3	113.4

**Notes.** Heights and lengths for different techniques are rounded to 100 m. Mean orbit of the Perseid stream based on the data of the IAU Meteor Data Center Catalog of precise photographic orbits and the orbit of the parent comet 109P/Swift-Tuttle in the passage of 1992 are also presented.

heights from 84.5 to 85.5 km is  $-9 \text{ mag}$ ). The maximum radiometric brightness is then  $-9.7$  at the height of 82.7 km and corresponds to a short flare at  $22:29:46.6637 \pm 0.0005 \text{ s UT}$  (mean time of maximum intensity from nine independent radiometric records) that is not resolved in photographic records.

Spurný et al. (2000b) divided the appearance of high-altitude meteors into three distinct phases: diffuse, intermediate, and sharp. Diffuse structures, observed above 130 km, are connected with sputtered particles and their subsequent thermalization. The sharp phase is connected with classic meteor ablation. The image-intensified video record of EN120812 shows the distinct diffuse appearance of the meteor with a comet-like tail down to the altitude of 139.1 km and a slightly diffuse appearance down to 130.0 km, where the meteor quickly starts to transform to the usual point-like object. This intermediate phase is visible down to 124 km, and then the meteor looks like a distinct point leaving the persistent train. The wake is visible from 112.5 km. It closely resembles the behavior of Leonids described in Spurný et al. (2000b).



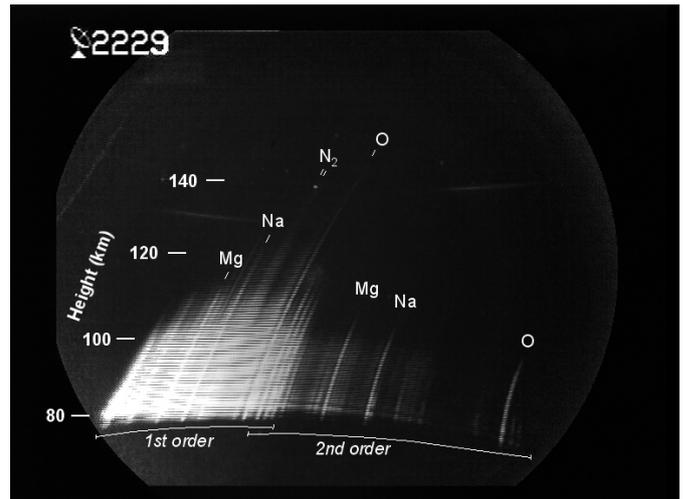
**Fig. 6.** Light curve of EN120812 recorded by AFO at station Churáňov. Duration of the flares: 80 ms of the flare around 85.3 km (three 10–20 ms flares are part of this wide flare), 30 ms at 82.9 km (3.5 ms flare corresponding to the fireball maximum brightness is part of this flare), 15 ms at 81.7 km, and 10 ms at 80.5 km.

The altitude where the ablation starts to be the dominant source of light should be clearly visible in the part of the light curve where the slope of the light curve changes significantly (Koten et al. 2006). The light curve of EN120812 (Fig. 3) shows two such points at the heights of 125 and 114 km. Based on the comparison to the spectrum (see below), the first height (125 km) is connected with the start of ablation of volatile part (Na) and the second height with the start of intensive evaporation. When we compare the altitude of EN120812, where the ablation starts to be dominant (according to the light curve), with other meteors we can sort meteor showers as follows: 125 km for  $71 \text{ km s}^{-1}$  Leonids (Spurný et al. 2000a,b; Koten et al. 2006), 115 km for  $68 \text{ km s}^{-1}$  Orionid (Olech et al. 2013), and 125 km for  $60 \text{ km s}^{-1}$  EN120812 Perseid.

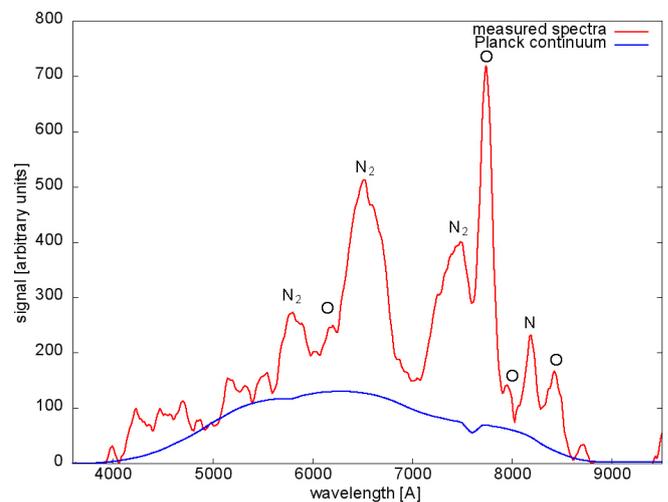
The orbit of EN120812 is one of the most precise photographic orbits ever determined for a Perseid fireball. Orbital elements are presented in Table 2, together with the mean photographic orbit of Perseids (Svoreň et al. 2006) and the orbit of the parent comet (Marsden et al. 1993). On the basis of  $D_{\text{SH}}$  criterion, which serves for comparing two heliocentric orbits (Southworth & Hawkins 1963), we conclude that the orbit of the EN120812 Perseid is a typical orbit of photographic Perseids only with slightly smaller inclination of the orbit to the ecliptic.  $D_{\text{SH}}$  of the EN120812 orbit and the mean orbit is 0.02. Svoreň et al. (2006) identified 17 filaments inside the Perseid meteoroid stream on the basis of the IAU Meteor Data Center Catalog of photographic orbits. We compared the orbit of our Perseid with the filaments and found that filament M has the most similar elements ( $D_{\text{SH}} = 0.02$ ). The filament M is the most numerous (43%), and its orbital elements are very similar to the mean orbit and the parent comet ( $D_{\text{SH}} = 0.03$  for the comet and EN120812). Other filaments with similar elements ( $D_{\text{SH}} = 0.04$ ) are F, K, and R.

#### 4. Physical properties and spectrum

We also studied the physical properties of the fireball. According to the PE criterion (Ceplecha & McCrosky 1976), the EN120812 Perseid consisted of soft cometary material (PE =  $-5.48$ , PE type IIIA) and did not differ from regular Perseid fireballs. This is also confirmed by the light curve profile. The detailed radiometric light curve from AFO shows numerous flares (see Fig. 6). These flares are probably connected with the fragmentation of



**Fig. 7.** First and the second orders of the video spectrum of the EN120812 Perseid. Different spectral lines begin at different heights.

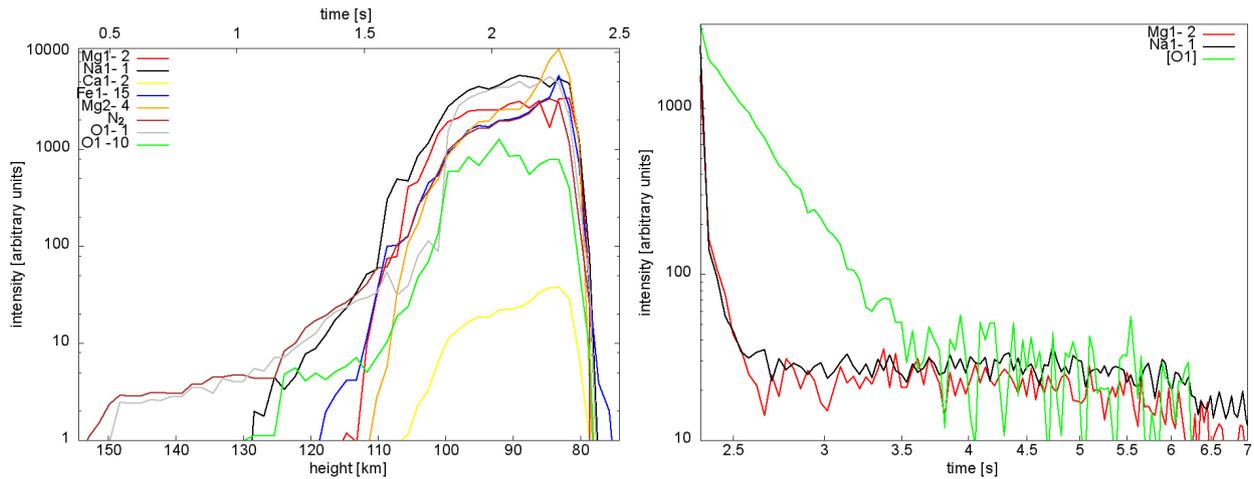


**Fig. 8.** Video spectrum at high-altitude. Figure shows sum of first 12 frames of the video record where spectral lines were evident. Heights were from 154.4 km to 130 km. The spectrum was not corrected for the spectral response of the camera.

the meteoroid and started at the height of 87 km under the dynamic pressure of 0.02 MPa. Macroscopic fragmentation is not visible on the video records (no visible fragments), but the heights of the flares correspond to the heights of the brightenings observed in the persistent train. The typical duration of the flares (from the beginning to the end) was 10–20 ms, although the brightest flare was only 3.5 ms long. A short duration of the observed flares very probably means that mostly small grains were released during these fragmentation events of the meteoroid.

Minor deceleration on the order of 5% was observed at the very end of EN120812. The deceleration was presented on too short a part of the trajectory to determine the ablation coefficient. The terminal velocity was approximately  $55 \text{ km s}^{-1}$ .

The spectrum (Fig. 7) was observed from the height of 154 km. At the beginning, only atmospheric emissions (O, N, N<sub>2</sub>) were present (see Fig. 8). This is consistent with a sputtering process, when a single sputtered atom excites many atmospheric atoms and molecules. A faint continuum with unclear origin is also present. To our knowledge, the present spectrum is the best meteor spectrum ever obtained at altitudes above 130 km. The



**Fig. 9.** Monochromatic light curves. Time 0 s corresponds to 22:29:44.4 UT, which is the first frame of the spectral video record. *Left:* monochromatic light curves of the fireball. Intensities on logarithmic scale are given as the function of the height and the time of the fireball. *Right:* three monochromatic light curves of the persistent train of the fireball (below 100 km altitude) from video record are given as the function of time. Both the intensities and the time are on a logarithmic scale.

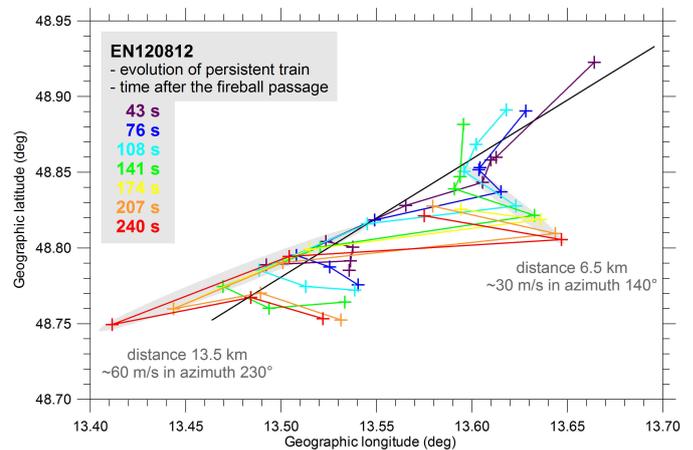
Na line (589 nm) appeared at 130 km. Other usual meteoric lines (Mg, Fe) appeared later at heights between 120 km and 110 km. Below 110 km the spectrum was not markedly different from other Perseid fireballs. At maximum, high temperature component lines (Ca II, Mg II) dominated. The monochromatic light curves of the fireball and of the persistent train of the fireball are presented in Fig. 9.

### 5. Persistent train

One second after the fireball passage, the train was visible in the image-intensified video record between the heights of 139 and 79 km. The heights of the 2nd and 3rd maxima of brightness of the persistent train and the meteor light curve correspond to each other (see Figs. 5 and 6) within a few hundred meters. The 1st maximum does not correspond to any feature in the light curve at 109 km.

The early train was formed by the forbidden O I 557 nm line in the upper part and Mg I, Na I, and the O I line in the lower part (see Fig. 5c). The quick initial decay of the Mg I and Na I lines was followed by a stable intensity lasting for about three seconds (Fig. 9), which can be ascribed to the recombination phase (Borovička 2006).

Evolution of the persistent train of this fireball was detected by digital still cameras and analog video cameras for almost 15 min. We present the reconstruction of the horizontal motion of the train from double-station observation in the first four minutes in Fig. 10 and single-station evolution in the first five minutes in Fig. 11. The maximum horizontal shift perpendicular to the atmospheric trajectory was 6.5 km at the height of 91 km. The corresponding mean speed was 27 m/s in the geographical azimuth 140 degrees (corresponding to wind direction 320 degrees). The maximum horizontal shift in any direction was a 13.5 km long drift in azimuth 230 degrees with corresponding mean speed 56 m/s. The highest speed of 81 m/s was measured in the first minute. These two maximum drifts are highlighted by gray ellipses in Fig. 10. Vertical evolution shows the upward motion along the whole train with speed up to 13.5 m/s (maximum rise was 2 km from the height of 86 km and was observed in first 2.5 min) with typical speeds around 2 m/s. The train was visible in the digital pictures between the heights of 99 and 84.5 km.



**Fig. 10.** Horizontal evolution of the persistent train. Projection of the atmospheric trajectory of EN120812 on the Earth's surface is shown by the black line. Maximum drifts of the persistent train are highlighted by gray ellipses.

Two features were observed: increase in brightness in three parts of the train (see arrows in Fig. 11) and the formation of a double trail. The heights of the three bright parts in Fig. 11 are 94, 91.5, and 90 km. The double trail was observed between 90 and 88 km and was about 5 km long. The mechanism of double trails was described by Kelley et al. (2013) and is connected with vortices in a convectively unstable trail.

### 6. Conclusions

We presented observation of the bright Perseid fireball recorded by different techniques. The main conclusions are summarized as follows.

- The EN120812 fireball is the highest Perseid ever observed and the highest meteor ever observed with precise atmospheric trajectory and heliocentric orbit that do not belong to the Leonid shower. Its beginning height recorded by analog image-intensified video cameras with sensitivity limit of +3 mag (absolute magnitude at that height) was 170.2 km.



**Fig. 11.** Evolution of persistent train. The pictures were taken 1 min to 5 min after the fireball passage. The white arrows denote the increase in brightness of the persistent train at 94, 91.5, and 90 km.

- The image-intensified video spectrum of EN120812 is the highest spectrum of a meteor ever obtained. This spectrum shows that only atmospheric emissions of O, N, and N<sub>2</sub> were present above 130 km and that the spectrum was not markedly different from other Perseid fireballs below 110 km.
- The atmospheric trajectory and orbit based on records from photographic, digital, and image-intensified video cameras belong to the most precise ever obtained for a Perseid meteor. The standard deviation of any arbitrary point on the luminous trajectory (approximated by a straight line) is 31 meters for all three techniques. The only difference is strong dependence of the beginning height on the sensitivity of the detector. The orbit is a typical orbit of photographic Perseids (with slightly smaller inclination of the orbit to the ecliptic), and it is similar to the orbit of the parent comet ( $D_{SH} = 0.03$ ).
- A double-station observation of first four minutes of the persistent train showed the upward motion along the whole train up to 13.5 m/s (typical speeds around 2 m/s) with maximum vertical drift of 2 km from the height of 86 km.

*Acknowledgements.* The authors are very indebted to Petr Horálek, who operated his digital cameras at Pancfř and who kindly provided his records of the fireball and its persistent train for measurements. This work was supported by the project RVO:67985815, by Praemium Academiae of the AS CR, and by GA ČR grants P209/11/P651, 205/09/1302, P209/11/1382. We also gratefully acknowledge helpful comments by the referee Dr. J. M. Madiedo.

## References

- Borovička, J. 2006, *J. Roy. Astron. Soc. Canada*, 100, 194
- Brosch, N., Schijvarg, L. S., Podolak, M., et al. 2001, *Meteor observations from Israel, Proc. of the Meteoroids 2001 Conf.*, 495, 165
- Ceplecha, Z. 1958, *Bull. Astron. Inst. Czech*, 9, 154
- Ceplecha, Z., & McCrosky, R. E. 1976, *J. Geophys. Res.*, 81, 6257
- Fujiwara, Y., Ueda, M., Shiba, Y., et al. 1998, *Geophys. Res. Lett.*, 25, 285
- Hill, K. A., Rogers, L. A., & Hawkes, R. L. 2004, *Earth Moon Planets*, 95, 403
- Kelley, M. C., Williamson, C. H. K., & Vlasov, M. N. 2013, *J. Geophys. Res. A*, 118, 3622
- Koten, P., Spurný, P., Borovička, J., et al. 2001, *Extreme beginning heights for non-Leonid meteors, Proc. Meteoroids 2001 Conf.*, 495, 119
- Koten, P., Borovička, J., Spurný, P., et al. 2004, *A&A*, 428, 683
- Koten, P., Spurný, P., Borovička, J., et al. 2006, *Meteor. Planet. Sci.*, 41, 1305
- Marsden, B. G., Williams, G. V., Kronk, G. W., et al. 1993, *Icarus*, 105, 420
- Olech, A., Żołądek, P., Wiśniewski, M., et al. 2013, *A&A*, 557, A89
- Popova, O. P., Strelkov, A. S., & Sidneva, S. N. 2007, *Adv. Space Res.*, 39, 567
- Southworth, R. B., & Hawkins, G. S. 1963, *Smithsonian Contrib. Astrophys.*, 7, 261
- Spurný, P., Betlem, H., van't Leven, J., et al. 2000a, *Meteor. Planet. Sci.*, 35, 243
- Spurný, P., Betlem, H., Jobse, K., et al. 2000b, *Meteor. Planet. Sci.*, 35, 1109
- Spurný, P., Borovička, J., & Koten, P. 2004, *Earth Moon Planets*, 95, 569
- Spurný, P., Borovička, J., & Shrbený, L. 2007, *Automation of the Czech Part of the European Fireball Network: Equipment, methods and first results, Proc. IAU Symp.*, 236, 121
- Spurný, P., Bland, P. A., Shrbený, L., et al. 2012, *Meteor. Planet. Sci.*, 47, 163
- Svorenř, J., Kařuchová, Z., & Jakubřík, M. 2006, *Icarus*, 183, 115
- Vinkovič, D. 2007, *Adv. Space Res.*, 39, 574