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OPTICAL TRAIL WIDTH MEASUREMENTS OF FAINT METEORS

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Abstract. We report results from two station, short-baseline (<100 m) high resolution measurements of faint meteors (limiting meteor magnitude +9) with the goal of measuring their optical trail widths. Meteors were observed using two 0.40 m Newtonian telescopes (field of view ~0.4 degrees) equipped with image intensifiers. Both telescopes were vertically oriented in a fixed mount and pointed to the same field of view. One system used a gated image intensified camera allowing the transverse velocity component to be measured. The widest trail captured, out of a total of 34 common events measured by both optical systems, had a full-width to half-maximum of 1.37 ± 0.71 m. The widest trail overall was captured by the gated system only, and was found to have a full-width of ~10 m. The brightness variation across this trail was found to be best represented by a Lorentzian. Most trails were smaller than our resolution limit and hence we could only place upper limits on their optical width. These were generally less than 1 m after correction for instrumental effects. Four meteors were found to have heights near 65 km and very low transverse velocities. These may be indicative of a largely unreported high density asteroidal component at these faint meteor magnitudes.

Keywords: Meteor, meteor heights, meteor velocities, optical, trail width

1. Introduction

Previous observations of meteor trail widths (Hawkins and Whipple, 1958; Cook et al., 1962) have produced results which suggest that the optical trail width for relatively bright (mainly +5 and brighter) meteors are larger than would be expected if the meteoroid were ablating as a single body. Measurements of meteor trail width for fainter meteors may thus provide direct evidence for the dustball theory (Hawkes and Jones, 1975) and could also add insight into the fragmentation and ablation process for small, submicrogram meteoroids. Measurements of initial trail radii are crucial to the correction of radar observations as meteors whose initial radii are comparable to the radar wavelength being employed will be heavily attenuated (Ceplecha et al., 1998). The trail radii are also a key initial input parameter in collisional and plasma models of meteors and meteor trail evolution (Dyrud et al., 2002).

2. Equipment

These data were collected over a total of six nights spread out over two observing runs in September 2003 and in May 2004, at the Elginfield Observatory (43°15′51 N, 80°46′20 W). Two identical f/4.5, 0.40 m aperture Newtonian telescopes were used, each having an effective field of view of ~0.48 × 0.34 degrees. The two telescopes were vertically oriented in a fixed mount, and pointed at the zenith. The separation between the two telescopes was 27.5 and 105.2 m for the September, 2003 and May, 2004 observing runs, respectively. One of the telescopes was coupled with a gated digital image intensified CCD camera (QImaging Extended Blue Intensified Retiga). The pixel dimensions of the gated camera were 676 × 518, with a resolution of 2.2 arc s/pixel. The main advantage of the gated camera is the ability to gate the image intensifier multiple times in a single CCD exposure. This records a meteor as a series of "dots" rather than a continuous trail, and allows for direct measurement of the velocity of the meteor as well as allowing a search for meteor wake to be made. For this experiment, the intensifier was gated at a frequency of 374.8 ± 0.4 Hz with a 1:4 on:off cycle yielding an effective exposure time of 0.5 ms per gated image. The Intensified Retiga had a limiting stellar magnitude of +12. Our other telescope was coupled to an NTSC video rate image intensified CCD sensor (ITT NightCam model 380i). The pixel dimensions of the video system were 720×480 pixels, and the resolution was ~2.4 × 2.6 arc s/pixel. The CCD was used in an interlaced mode with 60 video fields (or 30 complete video frames) per second. The limiting stellar magnitude of the video camera system was +13.

3. Data Reduction

Meteors were identified from NTSC digital video tape data using MeteorScan 280c (Gural et al., 2002). A total of 87 meteors were detected, and of these, 56 were captured by both camera systems. The low number of dual detections is due to the difference in sensitivity, as well as a slight offset of the two fields of view.

Width measurements were made using two different methods. The first involved a direct measurement of the full-width at half-maximum (FWHM) of the intensity profile across the meteor trail. This method was useful for examining the core brightness of the intensity profile. For those meteors which were detected by both camera systems, the parallax of the meteor was measured and heights obtained. Typical errors in individual height measurements were ~1–2 km. The results are summarized in Table I. For comparison with the video data, the FWHM of a star of similar brightness is included. We assume the point spread function (PSF) of the meteor trails will typically be smaller than stars of comparable brightness due to the much shorter exposure times for meteor trails. Thus the stellar widths actually represent an upper limit that can be attributed to the seeing (1–2 pixels) and instrumental blooming. Any remaining spread we attribute to physical width of the optical trail. The remaining spread for each meteor was calculated by subtracting the FWHM of a star of similar brightness from the FWHM of the meteor trail. The measured heights for each meteor were used to convert this correction from units of pixels to meters, which can be seen in the last column of Table I.

The second method involved summing up the total intensity along the entire major axis of the meteor trail, and moving this pixel wide "box" across the trail to produce a width profile. This second method yields greater widths if there are short duration light curve irregularities with measurable transverse deviation from the trail, as suggested in some of the meteors analyzed by Fisher et al. (2000). In this way we may examine the trail for evidence of a bright core with fragments ablating on either side. Very few meteor trails showed significant width relative to stellar profiles. Of particular note, however, is a meteor recorded at 08:00:47 UT on October 1, 2003 by the gated camera which shows an extended total width to the background of more than 16 m, assuming a height of 90 km. This trail, which was too faint to directly measure the height or the FWHM using the first method, has sufficient width that we can characterize the form of the light production across the trail. This was found to be best fit with a Lorentzian of the form $8.56/(1+(x/6.62)^2)$ in units of meters. All other trails had too few points across their intensity profile to allow any meaningful fits to be attempted.

Figure 1 shows the height distribution of the 34 (of 56) meteors from our sample for which we were able to make height measurements. The mean height is 83 km, as there were no very high meteors (above 115 km) detected. However, a large population of high altitude meteors as proposed by Olsson-Steel and Elford (1987) should have been detected providing their trail widths were not exceptionally large or optical brightness very low. Note that there are quite a few events at heights ~65–75 km. To our knowledge these are the lowest heights ever measured for meteors in this magnitude range (+8 to +9).

Meteor velocities were measured for all meteors captured as a relatively clear series of dots on the gated camera for which height measurements were available (20 meteors in total). It should be noted that this measurement

TABLE I

Summary of Trail Width Measurements: observations made on Sept. 30 and Oct. 1, 2003, and May 13, 17, 19, and 27, 2004

Time (EDT)	Video meteor FWHM (pixels)	Error (pixels)	Star FWHM (pixels)	Gated meteor FWHM (pixels)	Error (pixels)	Height (km)	Height δ (km)	Corrected video meteor FWHM (m)
Sep-03								
1:47:04	3.16	0.77	2.68	2.80	0.96	65.2	1.7	0.50
3:31:30	na	na	na	3.92	1.41	88.0	3.1	na
3:37:07	na	na	na	5.87	0.77	104.4	6.6	na
3:45:05	3.29	0.73	2.68	2.33	0.58	111.7	11.1	0.88
3:50:06	3.73	0.78	2.68	2.88	0.43	83.5	2.6	0.88
4:13:09	3.29	0.97	2.68	2.24	0.00	110.9	3.9	0.65
4:17:53	4.23	1.13	2.68	2.98	0.94	70.4	1.2	0.96
4:41:41	2.86	0.96	2.68	2.56	0.32	93.0	5.0	0.12
5:11:29	3.87	1.06	2.68	3.69	1.09	80.9	2.7	0.75
5:13:29	na	na	na	3.36	0.59	64.5	1.5	na
5:18:20	3.56	0.68	2.68	2.35	0.48	65.6	1.0	0.35
5:24:23	3.32	0.53	2.68	3.67	0.49	107.9	8.2	0.42
1:50:16	2.95	0.91	2.90	na	na	67.2	1.2	−0.54
2:41:26	2.75	0.52	2.89	2.70	0.65	80.7	3.0	−0.92
3:21:42	3.72	1.28	2.90	2.81	0.91	77.4	3.1	−0.03
3:36:45	na	na	na	2.62	0.29	67.0	1.3	na
3:41:43	5.55	0.64	2.89	6.49	1.33	105.7	3.9	1.37
4:00:43	na	na	na	na	na	66.3	1.9	na
4:05:30	2.46	0.45	2.89	na	na	82.7	3.0	−1.03
4:26:19	4.84	0.80	2.90	5.18	0.78	81.4	2.8	0.58
May-04								
4:22:24	3.03	0.65	3.23	2.88	0.47	83.0	0.9	−0.78
2:15:42	4.06	0.54	3.23	na	na	74.6	0.4	0.20
0:47:30	3.53	0.76	3.24	2.66	0.48	97.6	2.8	0.24
1:01:34	3.55	0.85	3.24	3.02	0.80	81.5	0.5	−0.20
1:19:57	na	na	na	2.89	0.82	68.7	1.7	na
1:59:56	3.63	0.98	3.24	na	na	79.3	0.5	0.04
23:05:29	4.14	0.76	3.24	3.15	1.00	95.8	2.4	0.60
23:07:18	3.13	0.39	3.23	na	na	86.6	0.6	−0.71
23:19:37	3.09	0.65	3.23	na	na	87.5	0.7	−0.67
1:10:42	na	na	na	2.90	0.64	78.2	0.4	na

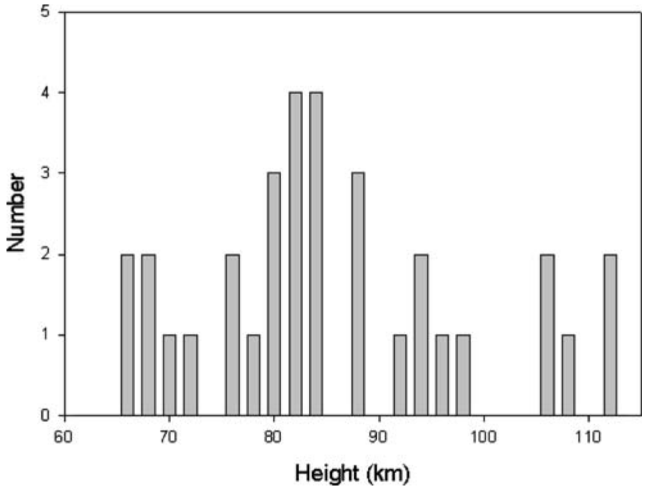

Figure 1. Height distribution of meteors in the sample.

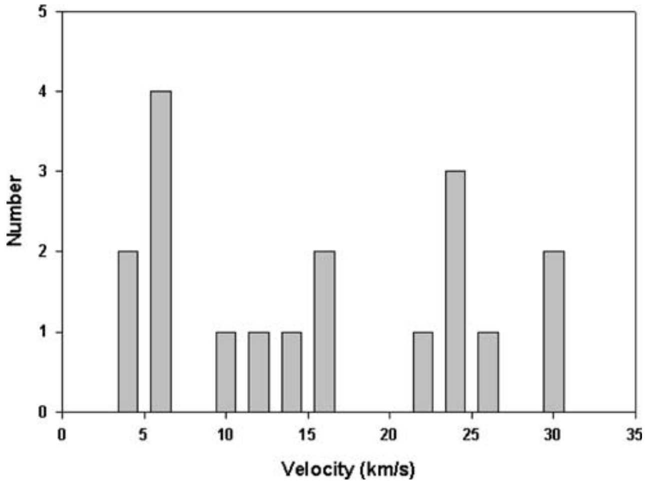

Figure 2. Velocity distribution.

represents only the transverse (sky plane) component of the true velocity; the actual velocities will be larger. Figure 2 is a plot of the velocity distribution with an average error per measured meteor velocity of 0.6 km/s. The lowest velocities (~5 km/s) generally correspond to the low height population (below 70 km).

Meteor magnitudes were measured only for those meteors which were clearly gated (showing little or no wake between dots) so that standard differential stellar photometry techniques could be used (total number = 11). The absolute magnitude range was found to be ~ + 6.5 to + 10.

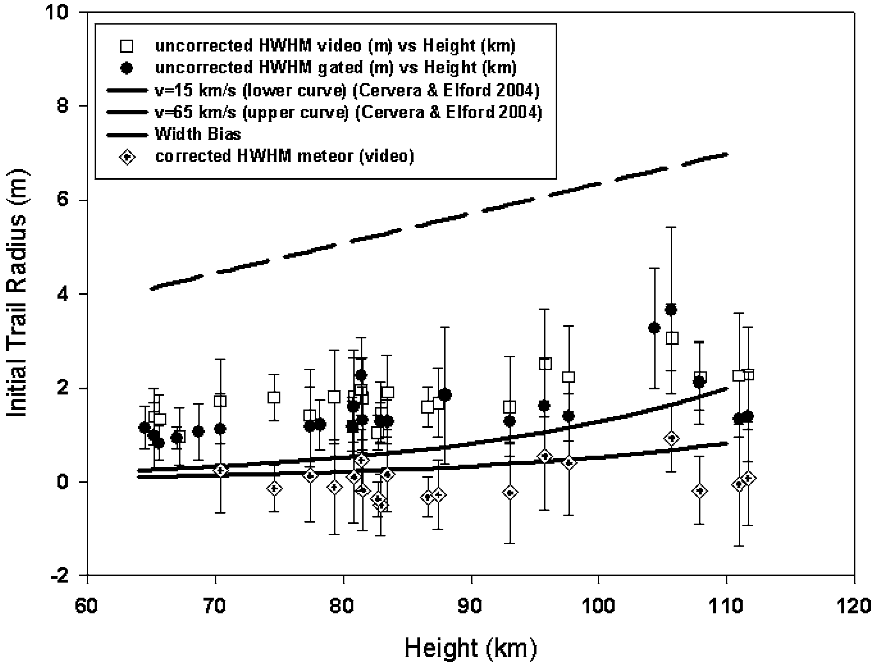

Figure 3. Height versus Initial Trail Radius. This figure displays our results along with predictions of trail radii versus height from Cervera and Elford (2004). Also included is our calculated width bias, which is an estimate of the widest trail radius we expect to be able to detect with our equipment. The uncorrected HWHM represent the trail radii without correcting for atmospheric and instrumental broadening, while the corrected HWHM have been corrected for such effects.

4. Discussion and Results

Figure 3 is a plot summarizing all the width measurements made for both the video and the gated images (using only the first width measurement technique). Note that the width measurements have been converted from full-width to half-width (trail radii) in order to compare to published results. The uncorrected trail radii represent an upper limit to the true radii as no corrections have been applied for widening caused by seeing and instrumental blooming. For comparison, an estimate of the widest meteor trail we expect to detect with our instrumental setup was determined by using the brightest meteor detected during our campaign, and summing its total intensity along the major axis of the trail in a rectangle three pixels wide. This total intensity was then spread out over successively larger and larger rectangular areas, until the average intensity per pixel dropped to within one standard deviation of the mean background (i.e., until it was just barely detectable). We defined this to be our width bias, which is shown in Figure 3 represented by the dashed line.

Also included are points representing the corrected trail radii values for which the radius of a star of similar peak intensity has been subtracted to account for the seeing and instrumental blooming. For comparison, there are two curves plotted among the data in this figure representing predicted initial trail radii at various heights with velocities of 15 and 65 km/s using the relation from Cervera and Elford (2004):

$$\log_{10} r_0 = 0.0194h - 1.96 + 0.6 \log_{10}(\upsilon/40) \tag{1}$$

where r_0 is the initial radius (root mean square width) of the meteor trail, h is the height in km, and υ is the velocity in km/s.

There were four events (5% of the total sample) which were found to produce light at very low heights (~65 km). Single body ablation modeling shows that meteoroids of this mass (less than a microgram) need to have very high heats of ablation to penetrate to this altitude. Indeed, almost the only means to model such deep penetrations is to assume material with properties comparable to solid iron. We adapted the ablation model of Rogers et al. (2004) submitted, to investigate what heights would be predicted for low velocity, high density meteoroid ablation. If iron (density 7800 kg/m^3) spherical particles are assumed, maximum luminosity is observed at a height of 68, 72, and 76 km for 10^{-4}, 10^{-5}, and 10^{-6} kg meteoroids.

These low events were also found to have very low transverse velocities ~5 km/s, and showed no evidence for significant width or measurable wake. Potentially, we are detecting a previously unseen large population of small, low velocity (and hence faint) meteors of largely iron composition. We do not know of any previous surveys (radar or optical) which would be expected to detect such a faint, low and slow meteoroid population.

5. Conclusions

In total, 87 meteor trails were examined, most of which showed little to no statistically significant width (i.e., width beyond that of a star of similar brightness). The widest trail found by directly measuring its corrected FWHM (method 1) was found to be 1.37 m ± 0.71. Using a slightly different method which involved summing up the total intensity along the meteor trail, we were able to look at meteors that had been too faint to be measured using method 1. As a result, we were able to determine that the widest trail captured (08:00:47 UT on October 1, 2003) had a corrected full width of ~10 m.

No meteors were detected at very high altitudes. The greater range to high meteors result in reduction of apparent brightness according to the inverse square law, and more high meteors will be lost in the unresolved background glow. It is possible that there is a second bias if the trail widths increase at great heights due to a larger mean free path. The four low events detected at ~65 km could represent a population of asteroidal material not yet previously detected. These meteors at low heights also had very low transverse velocities, characteristic of a low height population.

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