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The α-Monocerotids meteor outburst: the cross section of a comet dust trail

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Abstract. One minute counts obtained during the meteor outburst of α-Monocerotids on November 22, 1995, are analyzed in order to examine the possibility of filamentary structure in the stream profile. None is found. It is argued that far-comet type outbursts are due to the Earth's passage through the dust trail of a long period comet, thus offering a direct means of studying such comet dust trails. Hence, the meteor stream activity curve is the first accurate cross section of dust densities through a comet dust trail. © 1998 Elsevier Science Ltd. All rights reserved

Introduction

Two thousand six hundred years after Chinese astronomers described a sudden outburst of meteors, and must have wondered about its origin, an important step has been made in understanding the cause of these far-comet type meteor outbursts. That oldest known record is from the year 7 of Duke Zhuang of Lu (March 23, 687 BC in our calender), when it was written that "in the middle of the night, stars fell like rain" (Lovell, 1954; Tian-shan, 1977). This transient increase in meteor rates has since been identified as a manifestation of the Lyrid meteor stream, debris of comet C/1861 G1 Thatcher. Even today, the Lyrids are known for their occasional meteor outbursts. which happen at times when the parent comet is not near perihelion. That characterizes "far-comet type" meteor outbursts, which differ in that sense from the "near-comet type" outbursts that are associated with the return of the comet to perihelion (Kresák, 1993; Jenniskens, 1995a). There are no known streams that have both types of outbursts. We will discuss why that may be.

Closer inspection shows that far-comet type meteor outbursts do not occur at random. Guth (1947) noted that the Lyrid outbursts typically occur when Jupiter or Saturn are in conjunction with the node of the stream. Recently, we generalized this observation to other streams with far-comet type outbursts by noting that outbursts are seen in years when both Jupiter and Saturn are at certain positions in their orbit. The favorable configurations correspond to similar displacements of the Sun from the barycenter of the solar system (Jenniskens, 1997). The Sun's reflex motion is thought to reflect the displacement of a trail of dust with respect to the Earth's orbit. When the trail is directed in the Earth's path, a meteor outburst can occur (Kresák, 1958). A return of one such far-comet type outburst was predicted for November 22, 1995, when the planets would be at much the same position as during a previous event in 1935 (Jenniskens, 1995b). An outburst of α-Monocerotids did indeed occur (Marsden, 1995), and provided the first detailed observations of these natural phenomena. We were able to measure the orbits of a number of α-Monocerotids and found that these particles had a long orbital period, confirming the hypothesis that the outbursts are caused by a trail of dust in the orbit of a long period comet that is brought in the path of the Earth by planetary perturbations (Jenniskens *et al.*, 1997).

In this light, the meteor stream activity profile of the α-Monocerotid outburst is a cross section of particle density through one particular dust trail. Here, we examine the activity profile for the possible presence of filamentary structure. Such filamentary structure has been reported elsewhere in the literature, and, if true, implies that ejection velocities derived from the width of IRAS dust trails (e.g. Sykes *et al.*, 1990) are overestimated.

The α-Monocerotid activity profile

Shortly after 01 h UT, on November 22, 1995, rates of the α-Monocerotid stream started to climb from a low zenith hourly rate of ZHR = 5, attributed to the annual stream, to a rate as high as ZHR = 500 half an hour later (Jenniskens *et al.*, 1997). At the peak, uncorrected rates were typically 5 α-Monocerotids per minute.

Several observers reported that the rates did not seem

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to be constant during the peak. After initial high rates, a lull in activity was reported before rates increased again. Borovicka and Spurný, 1995 reported a double maximum in the meteor stream activity profile, with a sharp increase in rates on the leading branch and a sub-minimum at the centroid of the shower. Similarly, Simek (1996) reported two sharp peaks in the radar data, with variations on a scale of 3–5 min. Rendtel (1995) noted that the sudden increase started at 1 h 13 min ± 2.4 min UT, with possibly a gradual variation across Europe. Total numbers of individual counts are too low, however, to be certain about the statistical significance of such features in the individual activity profiles.

While observing in Spain during the outburst, we had a similar experience, but were well aware of the low number statistics in each observing interval. Hence, in order to establish the true nature of these fluctuations, we set out to compare 1 min counts of various groups of observers at locations in Spain to those in the eastern and middle parts of Europe. True filamentary structure in the meteor stream is expected to show up as statistically significant enhancements of rates over a Gaussian mean profile on a scale much less than the width of the profile. Also, these structures should have a significant spatial extend, sufficient to show up at all observing locations, which are about 2000 km apart.

The observations

Figure 1 summarizes the available 1 min counts of α-Monocerotids in the period from 1 h UT until 2 h UT. Individual counts of observers are seldom higher than 7 min^{-1} and do not provide enough statistical accuracy. Hence, the data are grouped according to the longitude of the observing site (Spain: −4°W v.s. Middle and Eastern Europe: +15°E) and in two groups of typical meteor brightness (visual: -1^m to $+3^m$ versus radio meteor-scatter and video observations: $+3^m$ to $+7^m$). Figure 1 shows four groups of data, which will now be discussed separately.

Our observations in Spain consist of visual, photographic and TV image intensifier counts, which were obtained at four different locations 50–100 km apart during a dedicated field expedition that was organized by the Dutch Meteor Society (DMS), with participation of members of SOMYCE, the Spanish Meteor Society (Betlem *et al.*, 1996; Jenniskens *et al.*, 1997). Observers that contributed counts are listed in Table 1. Irregular fields of cirrus clouds have affected these data to various degrees, especially during the rising branch of the activity curve. Ignoring the periods with more than two magnitudes of extinction, we added the observed numbers in 1 min bins. Gaps in each sequence of counts were replaced by the mean count of other observers in the region. The result is shown in the upper two curves in Fig. 1. The Calar Alto counts are added to those of nearby Alcudia-de-Guadix. No smoothing is applied to the counts. No correction is made for observing conditions (i.e. limiting magnitude, radiant altitude, or cloud cover). Note that the radiant altitude did not vary significantly during the short span of the outburst, and the rates should be proportional to the dust density in the meteoroid stream. Error bars are the square root of the number of observed meteors in each bin.

These results are compared with counts from observers in Middle and Eastern Europe that are listed in Table 1 (third curve in Fig. 1). The dataset is limited to observations obtained during clear weather and under constant sky conditions. Hence, this curve is not affected by cloud cover or limiting magnitude changes. Data were kindly made available by the observers directly (A. Latini, S. Molau), or were taken from Borovicka and Spurný (1995) and Znojil and Hornoch (1995). The curve also includes counts from the image intensified video camera system MOVIE of Molau at Argenau Observatory (Berlin, Germany) because, with a 60° field of view, that system is

Table 1. Summary of observations

Observer	Location	$N_{\alpha Mo}$	T_{eff} (min)	Type
H. Betlem	Spain, Alm.	28	21	V
K. Hornoch	Czech Rep.	50	61	V
O. van Mill	Spain, Alm.	83	50	V
P. Jenniskens	Spain, Cal.	51	61	V
K. Jobse	Spain, Zaf.	11	43	TV
M. Langbroek	Spain, Cal.	57	61	V
A. Latini	Italy	48	61	V
J. van't Leven	Spain, Zaf.	16	43	TV
F. Mol	Spain, Alm.	52	31	V
J. Nijland	Spain, Alc.	57	19	V
K. Miskotte	Spain, Alc.	86	24	V
S. Molau	Germany	37	61	TV–MOVIE
S. Molau	Germany	18	61	TV–TV1
V. Pijl	Spain, Alm.	76	30	V
J. Borovicka/J.Spurný	Czech Rep.	94	51	V
P. van Tongeren	Spain, Alm.	42	32	V
I. Yrjölä	Finland	141	61	MS–VCR
A. Zoete	Spain, Alm.	41	35	V

$N_{\alpha Mo}$: number of α-Monocerotids detected between 1 and 2 h UT on Nov. 22, 1995. T_{eff}: elective observing time. Type: V = visual, TV = video, MS = meteor-scatter. Notes: Alc. = Alcudia-de-Guadix, Alm. = Almedinilla, Cal. = Calar Alto Observatory, Zaf. = Zafarraya.

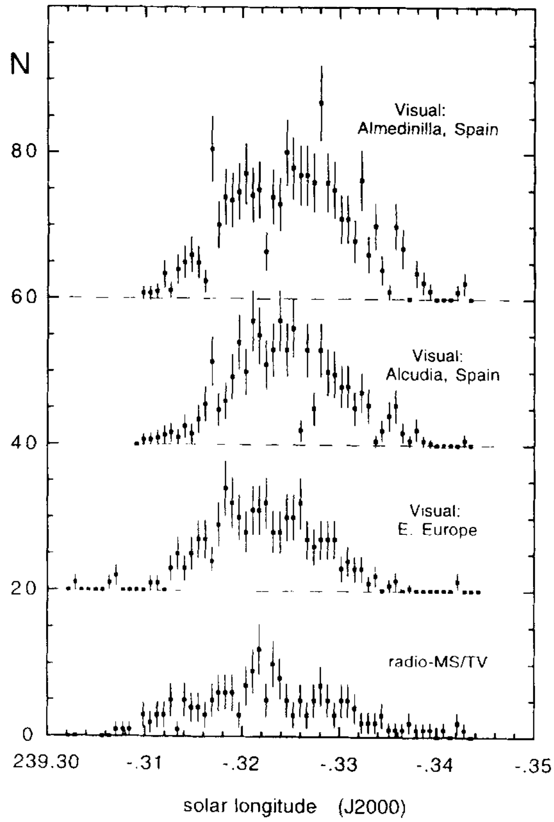

Fig. 1. Sum of 1 min counts of α-Monocerotids by four groups of observers in the period between 1 and 2 UT on Nov. 22, 1995

sensitive to relatively bright meteors in the range of visual meteors.

The final curve consists of radio meteor-scatter (MS) observations and of narrow field video imaging. These systems are sensitive to smaller meteoroids than the visual observers. While the visual observers detect particles typically in the range 0.01–0.001 g, these systems detect particles in the range 0.001–0.0001 g. The MS counts are from I. Yrjölä (Kuusankoski, Finland), while the video counts are from a second video camera of S. Molau and from video systems by K. Jobse and M. de Lignie that were operated from locations in Zaffarraya and Almedinilla during our field expedition.

Results

No strong variations in the stream profiles are observed, not even due to the varying cloud cover for the observers in Spain. This is consistent with the large relative abundance of bright meteors in the stream, as a result of which the rates are not much affected by the cirrus clouds (Jenniskens *et al.*, 1997).

A smooth Gaussian curve fits through the error bars of all four curves. The full width at half-maximum (FWHM) of the visual meteors is $0.014 \pm 0.001^\circ$, corresponding to 3.6×10^4 km along the Earth's path. Outlyers in the Almedinilla and Alcudia curves are due to bright meteors that were counted several times by the various observers in the group. Cloud cover may account for some of the low counts. There is no evidence of filamentary structure in the stream profiles.

The centroid of the peak seen in Spain is slightly later than in Eastern Europe (solar longitude $\lambda_\odot = 239.326^\circ$ versus 239.322° J2000). Only part of this difference (0.002°) can be due to the longitude difference of the observing sites. We can not exclude that some effect is due to the influence of cloud cover present in the Spanish data during the rising part of the activity curve.

More importantly, there are no features in the activity curve derived from observations in Middle and Eastern Europe that are seen again in Spain at the expected later time of 0.002° in solar longitude.

The curve of faint meteors (bottom curve) has perhaps a slightly earlier onset than that of the visually observed meteors (Jenniskens *et al.*, 1997) and may be slightly broader, with FWHM = 5.4 (versus 3.6) $\times 10^4$ km. The broadening is consistent with Whipple's model for particle ejection, where the smaller particles are ejected with 47% higher ejection velocities (Whipple, 1951).

Discussion

The trajectories of ten α-Monocerotid meteors were recorded from two or more sites, which allows triangulation (Jenniskens *et al.*, 1997). The orbits calculated from this were found to have a long orbital period ($P > 140$ yr at the 98% certainty level). This corroborates with the long orbital period of the only two known parent bodies of streams with far-comet type outbursts: the $P \sim 415$ yr period of C/1861 G1 Thatcher and the $P \sim 2500$ yr period of C/1911 N1 Kiess (Marsden and Williams, 1992). This suggests that the general conclusion holds that far-comet type outbursts are due to the dust trail in the orbit of long-period comets. The alternative, that the α-Monocerotid outbursts are due to a dust cloud of $P = 10$ yr orbital period (Rendtel *et al.*, 1996), can now be excluded.

The absence of filamentary structure on the stream activity profile allows the assumption that the width of the stream reflects the ejection velocities of the grains from the comet nucleus. Dispersive effects from planetary perturbations are likely to put the particles outside of the outburst component and are not likely contribute to the observed width. The width of the α-Monocerotid trail compares well with the estimated width of the comet Tempel 2 dust trail observed by IRAS, which measures 3.6×10^4 km near the comet, increasing by about 30% within 3° mean anomaly of the comet (Sykes *et al.*, 1990). Indeed, most of the particle ejection from the nucleus is near perihelion and given that the physical mechanism of particle ejection does not vary between short and long period comets, the trail width should be comparable with that of short period comets. Models of IRAS dust trails point at ejection velocities of typically 1–10 m s^{-1} (Sykes *et al.*, 1990; Sykes and Walker, 1992). In the Sykes *et al.* model, the width of the α-Monocerotid trail corresponds to an ejection velocity of 7 m s^{-1} for 1 mg grains, assuming emission at perihelion (Sykes *et al.*, 1990). In that case, filamentary structure on a 3 min timescale can be caused only if ejection velocities perpendicular to the comet orbital plane are less than 1 m s^{-1}.

Why there are two types of meteor outbursts?

Let us address the question of why there are two types of meteor outbursts while no stream is known to show both. In our opinion, there is a fundamental difference in the mechanism that causes the dust to wander far enough away from the orbit of the parent comet. Note that the comet orbit is described by the osculating orbital elements at given epoch. We now think that far-comet type meteor outbursts are due to gravitational perturbations on the individual orbits, which cause a periodic motion of the ascending or descending node relative to the Earth's orbit (see graphs in Wu and Williams (1993)). This cyclic motion follows the Sun's reflex motion around the barycenter (Jenniskens, 1997) and has a semi-period of 60 yr due to the dominating contribution by Jupiter and Saturn. Because of the relatively long period, this effect is noticeable only for long and intermediate period comets.

For short period comets, on the other hand, this perturbation will probably lead to a rapid smearing of the dust profile into a wider component. A dispersion of the meteoroid stream in this manner would result in an activity profile characterized by an exponent $B \approx 1$, as observed for the "background component" in some of the activity curves of outbursts of Draconids, Andromedids and Leonids (Jenniskens, 1995a). Indeed, these components may have their cause in this effect.

Near-comet type outbursts, on the other hand, are not due to a direct passage of the Earth through an IRAS dust trail. If that would be the case, fluxes should be orders of magnitude higher than observed (Sykes *et al.*, 1990; Kresák, 1993). The peak dust density derived for the P/Tempel-2 trail close to the comet would result in a peak ZHR $= 4 \times 10^7$ meteors per hour for an encounter velocity of $70\,\mathrm{km\,s^{-1}}$. Past Leonid storms are thought to have peaked at best around ZHR $= 10^5$ (Jenniskens, 1995a). This is why we suggest that, in the case of "near-comet" type outbursts, the Earth passes a sheet of dust that emanates from the dust trail. That sheet has a high dust density only near the comet position. The concept of comet dust sheets was nicely confirmed by a series of near-comet type outbursts of the Perseid stream in recent years.

Similar sheets should also exist in association with long period comets. However, the dust in these sheets spreads much more rapidly along the comet orbit as a result of large variations in orbital period caused by small ejection velocities. In this way, the dust density can fall below the detection level, which can be the reason why long-period comets do not typically show near-comet type meteor outbursts.

We conclude that near-comet type outbursts are typically due to short-period and intermediate period comets ($P < 200$ yr), while far-comet type outbursts are due to long period comets. In the latter case, the Earth crosses the comet dust trail itself, although not necessarily through the center. Hence, observations of far-comet type outbursts offer a means of studying the dust trail of long period comets. The present observations of the α-Monocerotid stream provide the first detailed cross section of the dust density in such a comet dust trail.

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