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The 1995 outburst and possible origin of the α-Monocerotid meteoroid stream

J. Rendtel,[1] P. Brown[1,2] and S. Molau[1,3]

[1]*International Meteor Organization, PF 600118, D-14401 Potsdam, Germany*
[2]*Department of Physics, University of Western Ontario, London, Ontario, N6A 3K7, Canada*
[3]*Archenhold-Observatory Berlin, Alt-Treptow 1, D-12435 Berlin, Germany*

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ABSTRACT

A short-duration outburst of the α-Monocerotids was observed on 1995 November 22 between 01:15 and 01:45 UT. The highest equivalent zenithal hourly rate (EZHR) occurred in the 5-min interval 01:25–01:30 UT, reaching a value of 420 ± 50. The peak time derived from the available data is 1995 November 22, 01:28 UT ± 3 min, or $\lambda_{\odot} = 239\overset{\circ}{.}320 \pm 0\overset{\circ}{.}002$ (J2000). The FWHM of the peak as derived from a Gaussian fit to the rate profile amounts to $0\overset{\circ}{.}016$ in solar longitude or 22 min. The population index, r, is found from visual magnitude estimates to be $r = 2.36 \pm 0.17$. The radiant for the shower has been determined from video observations to be $\alpha = 117° \pm 3°$, $\delta = +1° \pm 2°$. The potential orbits associated with this radiant for plausible entry velocities suggest that the shower is not associated with C/1943 W1 (Van Gent–Peltier–Daimaca or 1944 I) as first suggested by Kresák. The most probable parent is a small comet with a 10-yr period and a node very near the Earth.

Key words: celestial mechanics, stellar dynamics – comets: individual: C/1943 W1 – meteors, meteoroids.

1 INTRODUCTION

The diverse nature of the formation and evolution of meteoroid streams leads naturally to unique properties for each. The large nodal width of the Geminid and Taurid streams and the periodic nature of the Leonid and Giacobinid streams are cases in point. Attempts to classify meteoroid streams (e.g., Plavec 1954) have met with limited success, and many properties of even well-known streams remain mysteries.

One of the most unusual meteor showers on record is that of the α-Monocerotids (Kronk 1988). This stream was first detected visually in 1925 (Olivier 1926) by several observers on the east coast of the USA. The remarkable aspect of the shower was its brief duration and intensity, with 37 meteors seen in 15 min. A similar recurrence in 1935 (Olivier 1936a) was witnessed in Asia with more than 100 shower meteors being observed in 20 min. Based on these two occurrences, Olivier (1936b) suggested a 10-yr period for the stream. Although nothing was reported in 1945 or 1955, Kresák (1958) analysed the available visual records in detail and suggested a possible association with C/1943 W1 (Van Gent–Peltier–Daimaca or 1944 I). This association, if real, would be particularly interesting as the orbit of C/1943 W1 (Marsden & van Biesbroeck 1963) is hyperbolic, although Marsden & van Biesbroeck suggest the poor quality of the cometary observations was a more likely explanation for the hyperbolicity than an out-of-Solar system origin.

The paucity of data surrounding the outbursts in 1925 and 1935, including an accurate radiant or velocity, has made the task of identifying a parent difficult. The 10-yr periodicity seemed to have been verified when another outburst was observed by at least two observers on the west coast of the USA on 1985 November 21 (Ducoty 1986). In a period of only 4 min, 27 meteors appeared from the shower with another seven in the next 12-min interval. No photographic or radar records of any of these past outbursts exist.

Based on the apparent 10-yr period, expectations were raised of another possible outburst in 1995 (Kresák 1993; McBeath 1994; Jenniskens 1995; Beech, Brown & Jones 1995). Here we report on activity from the shower which was widely observed from Europe in the early morning hours (UT) of 1995 November 22. The entire display lasted less than 1 h and the bulk of the outburst was contained in a 20-min interval centred about 01:28 UT, 1995 November 22. In contrast to the older records, the 1995 outburst was recorded with several different techniques (Rendtel 1995). We present the results obtained by the MOVIE video system (Molau 1995) and from a number of European visual observers who reported their data immediately to the International Meteor Organization (IMO), and compare these with past observations. The radiant of the stream has been accurately determined, as has a complete profile of the flux for the 1995 outburst.

2 RADIANT, GEOCENTRIC VELOCITY AND PROBABLE ORBITS FOR THE α-MONOCEROTIDS

For the determination of the radiant we have two data sources: the precise recordings of the MOVIE video and a number of visual meteor plots obtained before and after the activity burst as well as at the very beginning of the rate increase. All available meteor trails (video and visual) have been measured and analysed with the RADIANT program (Arlt 1992). The radiant positions of both samples yield radiants which are several degrees north-west of the position reported in previous returns (Kresák 1958) of $\alpha = +132.^\circ 5$, $\delta = -8.^\circ 4$. The most accurate radiant results from the video meteor sample, and is located at $\alpha = 117° \pm 3°$, $\delta = +1° \pm 2°$ which is the location of the intersections of the backward prolongations of 28 video-recorded meteor trails (Fig. 1).

We may determine an estimate for the value of V_∞ from consideration of the possible orbits for differing entry velocities. Table 1 shows the variation in orbital elements using the best estimate for the radiant. The orbit is very sensitive to V_∞ as well as to the position of the radiant. In particular, the values for the semimajor axis and eccentricity are strongly varying functions of the radiant position. All orbital solutions with $V_\infty > 64$ km s^{-1} are hyperbolic. For our radiant, the possible solutions most resembling cometary orbits have $V_\infty > 54$ km s^{-1}, with the most probable solutions having $64 > V_\infty > 60$ km s^{-1}. The 10-yr periodicity suggests a value for the semimajor axis near 4.6 au, making 61 km s^{-1} our most probable entry velocity (see Section 4). Other possible radiants within the formal uncertainty of our observed radiant position lead to orbits that are similar to those shown in the table in the elements i (inclination), ω

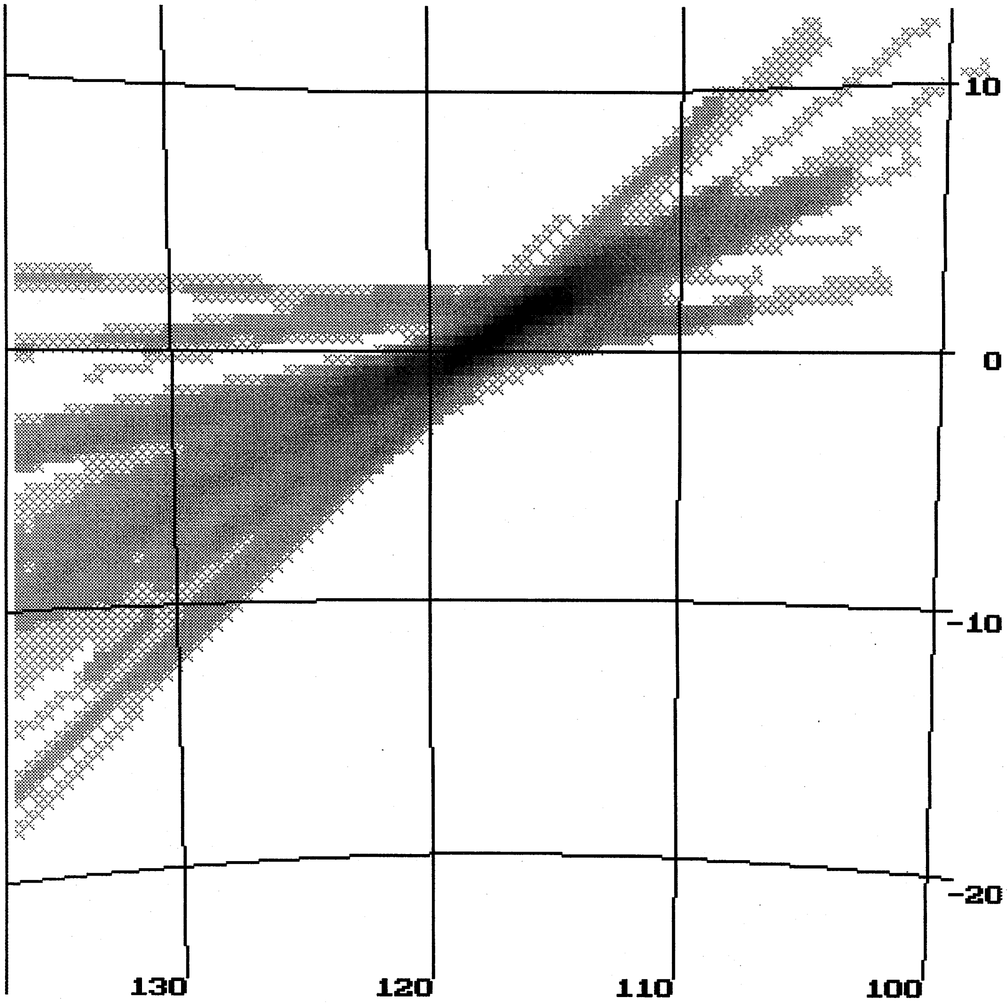

Figure 1. Radiant of the α-Monocerotids obtained from meteors recorded with the MOVIE video equipment by S. Molau. The radiant position is at $\alpha = 117° \pm 3°$, $\delta = +1° \pm 2°$. The visual plot produces a radiant at $\alpha = 111°$, $\delta = +3°$.

Table 1. Orbits for the α-Monocerotids using an apparent radiant of $\alpha = 117°$, $\delta = +1°$ and differing values for the velocity (given in km s^{-1}). All angular values refer to J2000.0 and all distances are in au. The orbit of C/1943 W1 (Van Gent–Peltier–Daimaca, VGPD) is shown for comparison as given by Marsden & van Biesbroeck (1963).

V_∞	a	e	$i°$	$\omega°$	$\Omega°$	q	Q
64	∞	1.012	133	90	59.3	0.49	∞
63	16	0.9702	133	93	59.3	0.48	31
62	6.8	0.9322	132	96	59.3	0.46	13
61	4.3	0.8984	131	100	59.3	0.44	8.2
60	3.2	0.8686	131	103	59.3	0.42	6.0
59	2.6	0.8430	130	107	59.3	0.40	4.7
58	2.2	0.8214	129	111	59.3	0.38	3.9
57	1.9	0.8037	128	115	59.3	0.36	3.4
56	1.6	0.7899	127	118	59.3	0.35	2.9
55	1.5	0.7796	125	122	59.3	0.33	2.6
54	1.3	0.7726	124	126	59.3	0.31	2.4
VGPD	∞	1.0039893	136.2	32.94	58.6	0.87	∞

(argument of perihelion) and q (perihelion distance); these showing extreme variations of $\pm 10°$, $\pm 15°$ and ± 0.1 au respectively over the entire uncertainty box.

3 MAGNITUDE AND ACTIVITY DATA

The visual magnitude data (1105 meteors) yield a mean population index of $r = 2.36 \pm 0.17$ for the entire outburst period. The method for determining r is described by Koschack (1995). The population index, r, is defined as the ratio of the true number of meteors in magnitude class $M_V + 1$ to the number in class M_V. The proportion of shower meteors brighter than 0 mag was small, and no fireballs were reported. The complete lack of any truly bright meteors, despite the large numbers recorded, is another outstanding property of the stream in 1995 as well as in past outbursts (Ducoty 1986; Olivier 1936a).

For the determination of high flux within time intervals considerably shorter than 1 h, the term 'equivalent ZHR' (EZHR) has been introduced (Rendtel 1994). The EZHR is a modification of the usual zenithal hourly rate (ZHR) which is defined as

$$\mathrm{ZHR} = \frac{N r^{6.5 - lm}}{\sin(H_{\mathrm{rad}})\, T_{\mathrm{eff}}}, \qquad (1)$$

where N is the number of shower meteors in the effective observing time T_{eff}, H_{rad} is the angular altitude of the radiant and lm is the stellar limiting magnitude. The EZHR is similar to the ZHR but determined for much shorter periods, the length of which are such that a statistically significant number of meteors are included (typically of order 10 or more).

The activity from the α-Monocerotids in 1995 started from below background and quickly reached high levels. The principal activity began at 01:13 UT ± 3 min, November 22, when the EZHR rose from below 50 to about 200 within less than 4 min. After 01:35 UT the rates fell as fast as they had risen, but with some remaining activity lasting until about 02:10 UT ($\lambda_\odot = 239\overset{\circ}{.}35$).

Data for the peak period have been split into intervals of 3–5 min length for this analysis (760 meteors in total). This allows the determination of the peak time to an accuracy of about 3 min.

Various sampling periods for the determination of the ZHR profile have been applied. Time resolutions of 3 to 6 min yielded smooth profiles (see Fig. 2 for 3-min shifts of the averaging interval), while a shift by 1.5 min (Fig. 3) hints at some structure in the ascending portion of the profile. Such structure in outburst profiles has been seen before, such as during the 1946 Giacobinid storm (Lovell 1954). However, this structure can be confirmed only when all available data are combined. These short time-steps of 1.5 min are less than the length of the count intervals, and thus the information becomes statistically noisy as evidenced by the larger error margins in Fig. 3, and the information gained becomes marginal. We note, however, that the dip which occurs in Fig. 3 at $\lambda_\odot = 239\overset{\circ}{.}319$ was specifically mentioned by observers Borovička & Spurný (1995).

The EZHR profile from Fig. 2 is remarkably symmetric. Using only activities above the sporadic background, a least-squares fit to a Gaussian of the form

$$\mathrm{EZHR} = A \left\{ \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2} \left(\frac{\lambda_\odot - \lambda_{\odot\,\mathrm{max}}}{\sigma} \right)^2 \right] \right\} \qquad (2)$$

produces excellent agreement with the observed profile. The resulting solution yields a value for $\sigma = 0\overset{\circ}{.}0070 \pm 0\overset{\circ}{.}0008$ and a value for the constant, A, of 7.627 ± 0.44. This solution is shown in Figs 2 and 3 as the solid line. The EZHR maximum occurred at $\lambda_\odot = 239\overset{\circ}{.}320 \pm 0\overset{\circ}{.}002$ (J2000), or on November 22, 01:28 UT ± 3 min. The full width at half-maximum (FWHM) of this Gaussian profile is only 22 ± 2 min or $0\overset{\circ}{.}016$ in solar longitude.

Knowledge of the population index r and probable atmospheric entry velocity (V_∞) permits a rough calculation of the stream number density S. Here we give values of S for $V_\infty = 61$ km s^{-1} which is the most probable entry velocity (see Section 4). The peak EZHR of 420 corresponds to a number density for meteoroids of mass at least 10^{-3} g [about $M_V = +3.5$ and brighter using the relation given by Verniani (1973)] of $(50 \pm 25) \times 10^9$ km^{-3}, or 50 meteoroids in a cube of 1000-km edge length. The particle flux, Φ, of meteoroids of mass at least 10^{-3} g is then $\Phi = (3 \pm 1.5) \times 10^{-6}$ km^{-2} s^{-1}. Assuming that saturation effects are not important, the flux to a limiting magnitude of +6.5 and equivalent limiting mass of roughly 10^{-5} g is $\Phi = (4 \pm 2) \times 10^{-5}$ km^{-2} s^{-1}.

These figures are comparable to the peak number density found in the 1991 Perseid peak (Rendtel et al. 1995), but lower than the number densities derived from the maxima of the Quadrantids and Geminids.

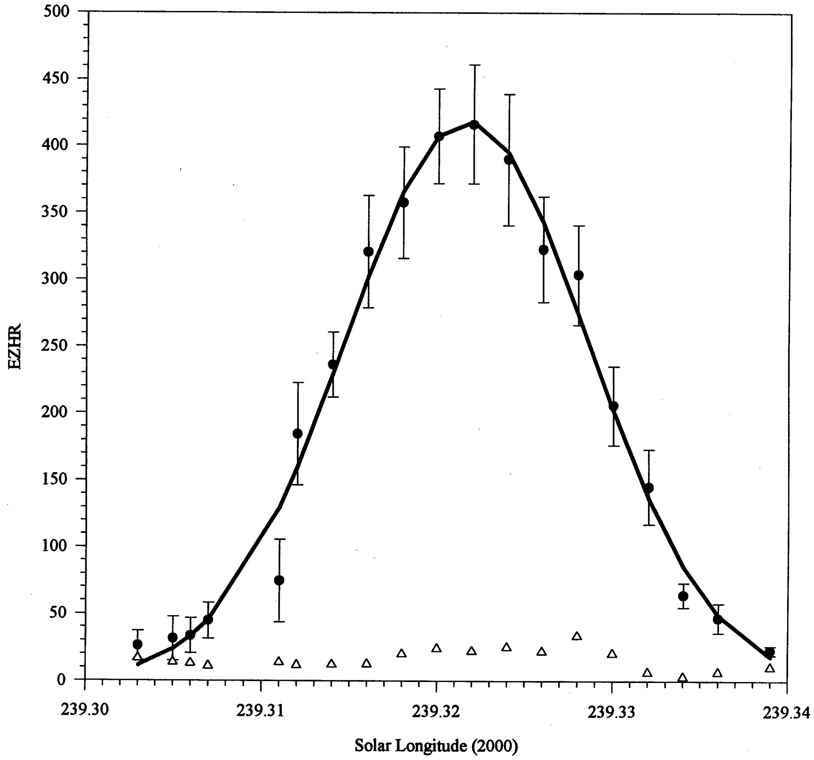

Figure 2. Mean activity profile of the α-Monocerotids on 1995 November 22. The length of the averaging interval was 0°.004, with the intervals shifted by 0°.002, or 3 min. The peak occurred at $\lambda_\odot = 239°.320 \pm 0°.002$, or November 22, 01:28 UT. The solid line corresponds to the Gaussian fit described in the text. The ● symbols show shower activity while the △ are sporadic rates. The error margins are the standard deviation of the individual EZHRs used to compute the average for any point, with each value weighted by the reciprocal of its total correction value.

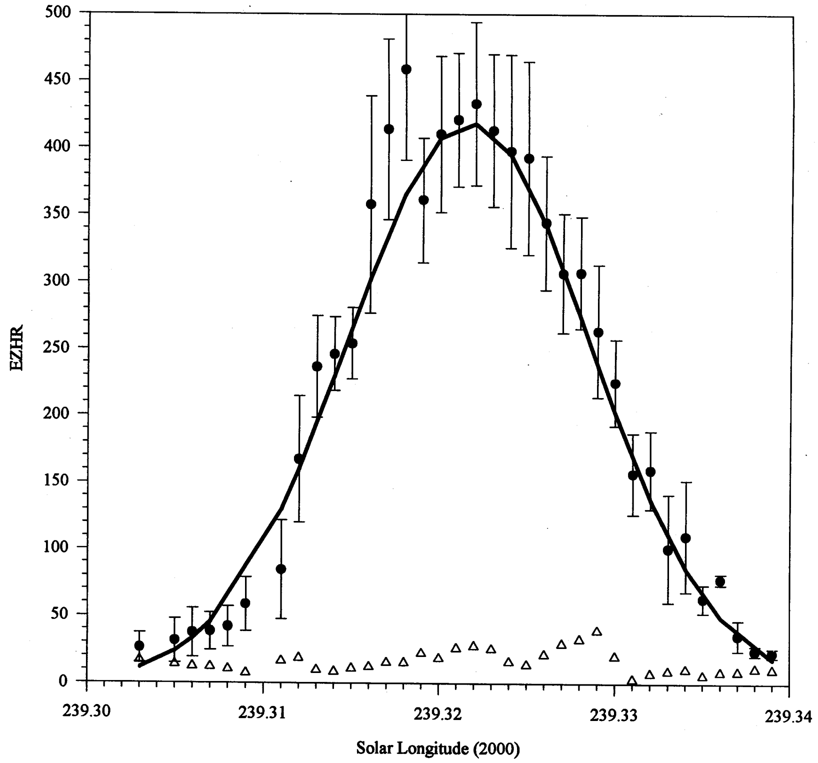

Figure 3. Mean activity profile of the α-Monocerotids on 1995 November 22 with a higher time resolution. The length of the averaging interval was 0°.002, and the intervals were shifted by 0°.001, or 1.5 min. There are indications of structure in the profile over spatial extents of order 3000 km, but this still needs confirmation and is at the limits of the information that can be derived from the included data. Symbols are the same as in Fig. 2.

4 DISCUSSION

The 1995 outburst of the α-Monocerotids further strengthens the 10-yr periodicity first suggested by Olivier. However, the fact that the 1995 event fits the 10-yr periodicity does not preclude other outbursts in years well away from the middle of a decade. In the data files of the IMO (1988 to 1995) there are no observations closer than 3 h from the position of the peak. The apparent faint character of the meteors suggests that other outbursts could easily be missed.

Indeed, the values of the expected peak times based on a 10-yr period given in Table 2 show that the chances of a similar event passing unnoticed are quite large: the radiant reaches sufficient elevations only after local midnight, and the Moon further narrows the effective interval.

Based on the foregoing information, an association with C/1943 W1 seems unlikely. None of the possible orbital solutions in Table 1 is close to the best available orbit for the comet, with the argument of perihelion and the perihelion distance, in particular, showing large differences from the cometary values. The cometary orbital solution is almost certainly in error to some degree as discussed earlier, but there seems no reasonable means of eliminating the large discordance between the two. The original linkage between the stream and C/1943 W1 was made by Kresák (1958) using orbital solutions based on possible radiant positions determined by inexperienced observers which differed by more than 20° from one another and which we now know to be in error. Comparison of all test orbits in Table 1 with catalogued comets and near-Earth asteroids revealed no potential associations.

The 10-yr periodicity is also difficult to reconcile with C/1943 W1 as the parent to the stream. Jovian perturbations of the meteoroids might be expected to produce slight changes in the nodal distances of some particles every 12 yr, possibly just enough to make the stream Earth-intersecting. Such a general effect is widely recognized as important in stream evolution (cf. Levin et al. 1972; Hughes, Williams & Fox 1981). The lack of bright meteors accompanying these outbursts is consistent with this notion, as smaller stream meteoroids have broader nodal distributions as a result of higher initial ejection velocities, and these would be the easiest to perturb into Earth-crossing orbits as a result. If such a process is taking place, activity might be expected for a few years on either side of the year corresponding to the largest nodal change for the meteoroids. A recurrence, even at a lower level, of the α-Monocerotids in 1996 would lend support to this notion. If such is the case, the parent is still more likely to be an unknown comet (probably of long period), rather than C/1943 W1.

Table 2. Times of the return of the $\lambda_{\odot} = 239\overset{\circ}{.}32$ position and phase of the Moon in the years of the suspected returns when a 10-yr period of outbursts is assumed. Possible returns in 1945 and 1975 were completely lit by a nearly full Moon; 1935 had some moonlight interference. The age of the Moon refers to days after new Moon.

Year	$\lambda_{\odot} = 239\overset{\circ}{.}320$	Moon k	age
1925	Nov 21 0235 UT	+0.28	5
1935	Nov 21 1610 UT	−0.18	25
1945	Nov 21 0535 UT	−0.96	17
1955	Nov 21 1915 UT	+0.41	7
1965	Nov 21 0850 UT	−0.04	27
1975	Nov 21 2220 UT	−0.91	19
1985	Nov 21 1150 UT	+0.71	9
1995	Nov 22 0125 UT	−0.01	29

The previously observed returns of the α-Monocerotids occurred at the positions given in Table 3. Although the peaks are situated at somewhat different positions, there seems to be no systematic drift between the returns. The 1925, 1935 and 1985 event locations are potentially in error by some minutes as observers caught those displays in progress, no complete profile of activity having been obtained except for the 1995 return.

The 10-yr periodicity suggests that the most probable origin for the stream is from a parent with a semimajor axis (a) in the interval $4.49 < a < 4.80$ au. The periodic outbursts are probably associated with a return of the comet to the neighbourhood of the Earth and the Earth's passage near the cometary nodal point close to the time of the parent's passage, a situation similar to that for the π-Puppids (Hughes 1992) or the Draconids (Wu & Williams 1995). This would also explain, in part, the extremely narrow nodal width of the stream, the meteoroids not having had time to disperse out of the plane of the cometary orbit. It is instructive to note from Table 1 that the inclination of the stream for the most probable entry velocity associated with $4.49 < a < 4.80$ is such that the Earth passes almost perpendicular to the stream. This is probably the explanation for the Gaussian shape of the activity profile, with stream meteoroids concentrated within 20 000 km of the cometary orbital plane and limited diffusion out of this plane.

The stream has diffused so little that the parent must make extremely close passages to the neighbourhood of the Earth every decade or the stream would not be visible at all. Similar streams such as the π-Puppids or Draconids produce strong outbursts only when the parent comet has a nodal distance within less than 0.01 au of the Earth's orbit. Since no currently catalogued comet has an orbit even modestly similar to the most probable for the stream (i.e. with $V_{\infty} = 61$ km s^{-1}), such a comet must be faint to have escaped

Table 3. Peak times of past returns of the α-Monocerotids.

Year and UT	$\lambda_{\odot}$ J2000
1925 Nov 21 0410 UT	$239\overset{\circ}{.}38$
1935 Nov 21 1900 UT	$239\overset{\circ}{.}43$
1985 Nov 21 1147 UT	$239\overset{\circ}{.}32$
1995 Nov 22 0128 UT	$239\overset{\circ}{.}32$

detection. This object would also be very unusual as it would represent the only member of the Jupiter family of comets with a retrograde orbit. It may also pose a significant collision hazard with Earth.

5 CONCLUSIONS

Since their discovery, the α-Monocerotids have been observed on only four occasions. In other years the activity is very low, virtually undetectable, but some ZHRs of the order of 5 at $\lambda_\odot = 240°$ have been reported (Rendtel et al. 1995). A portion of the activity may simply be the result of sporadic contamination, but it cannot be ruled out that there is some permanent activity as well. The sudden outbursts observed in the past suggest that regular monitoring of the α-Monocerotids is worthwhile.

The activity profile of the 1995 outburst is Gaussian showing a FWHM of only 22 min and a peak EZHR of over 400. The best-fitting radiant from video observations is $\alpha = 117° \pm 3°$, $\delta = +1° \pm 2°$.

The Gaussian profile reflects the almost perpendicular passage of the Earth through the orbital plane of the stream and further strengthens the idea that the stream must be extremely young.

The association of the stream with C/1943 W1 (Van Gent–Peltier–Daimaca) does not seem viable using the best observed radiant from 1995 and most probable entry velocity.

Planetary perturbations may move the descending node for some stream meteoroids slightly every 12 yr from a nominal orbit with no nodal intersection with the Earth, and produce the stream. More likely is that the parent comet has a period of approximately 10 yr and we observe intense returns at times near the comet's passage through its node. Such a small comet could easily go undetected and might pose a significant collision hazard with the Earth, having an expected encounter velocity of approximately 60 km s^{-1}.

A temporal resolution of 2–3 min is the limit for averaging procedures from observers distributed over an area as large as a continent. There are indications in the 1995 outburst profile of spatial structures smaller than this scale, causing variations in activity between sites.

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