SMITHSONIAN CONTRIBUTIONS TO ASTROPHYSICS

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Number 14

Discrete Levels of Beginning Height of Meteors in Streams

By A. F. Cook

Number 15

Yet Another Stream Search Among 2401 Photographic Meteors

By A. F. Cook, B.-A. Lindblad, B. G. Marsden, R. E. McCrosky, and A. Posen

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A. F. Cook

Discrete Levels of Beginning Height of Meteors in Streams[1]

Introduction

Ceplecha (1968) plotted the photographed meteors reduced by McCrosky and Posen (1961) and not identified as members of streams, with beginning height as ordinate and velocity outside the atmosphere as abscissa. His Figure 1 exhibits the basic result. He found three ridges of maximum density of points. The lowest of these he designated as Class A, the highest as Class C, and an intermediate maximum apparent only from 27.5 to 43.7 km sec^{-1} as Class B. His Class C showed two peaks, one below 41.8 km sec^{-1} and the other above it, and he designated these regions as Classes C_1 and C_2, respectively.

Ceplecha favored the interpretation that the differences in beginning height were due solely to variations in density of the meteoroid. Subsequent studies by McCrosky and Ceplecha (1970) and by the author (in preparation) provide plots of log $(1/K_m)$ versus log V_∞, where K_m is a coefficient in the deceleration equation for meteors and V_∞ is the velocity of the meteoroid outside the atmosphere. The three classes appear in these plots too. However, the separation is not enough to explain fully the separations of Ceplecha's discrete levels. He also found that meteors of Class A had trajectories shorter than those of Class C, which implies that they have larger values of Jacchia's (1955) fragmentation index χ. This provides the explanation for the remainder of the separation of beginning heights.

It appears, therefore, that we may be able to use Ceplecha's classes to separate streams of meteors according to the density of the meteoroids. Ceplecha (1968) has already done this for some streams. Lindblad (1971b) subsequently analyzed the meteors of McCrosky and Posen (1961) statistically to identify several new streams. Identifications of streams from more restricted groups of meteors had previously been made by Whipple (1954), Jacchia and Whipple (1961), Southworth and Hawkins (1963), and Lindblad (1971a). McCrosky and Posen (1959) identified streams from the same sample as did Lindblad (1971b). The present paper considers these additional streams as well as the better known ones classified by Ceplecha.

Criteria for Reality of Streams

We accept as real only those streams that show four meteors, or three meteors and an associated comet, in McCrosky and Posen's (1961) list or those that are already well known. This is almost the criterion recommended by Lindblad (1971b). Inasmuch as most of the observations used by McCrosky and Posen were obtained from 1952 to 1954, there is little assurance that all these streams recur annually. Incidentally, for the purposes of this paper, the Cyclids (Southworth and Hawkins, 1963) are regarded as the product of observational selection, caused by the earth's enhanced collisional cross section, for meteoroids in orbits nearly the same as that of the earth; they are not counted as a stream. Application of these criteria yields 39 optical streams. Of these, 1 does not appear in the observations, 12 do not show enough meteors to permit classification (this point will be discussed further below), and 11 exhibit such extreme character that some remark about their densities can be made in spite of the

A. F. Cook, Smithsonian Institution Astrophysical Observatory, Cambridge, Massachusetts 02138.

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TABLE 1.—*The three Taurid streams of Lindblad (1971b)*

Name	Lindblad's duration	q	a	e	i	ω	Ω	π	Radiant (Eq. 1950) RA	Dec.	V_G (km sec^{-1})	No. of meteors
N. ι Aquarids*	21 Aug.–20 Sept.	0.33	2.00	0.83	4°.0	300°	161°	101°	354°	+ 1	31	3
Piscids	25 Sept.–19 Oct.	0.40	2.06	0.80	3.4	291	199	130	26	+14	29	9
Taurids	19 Sept.–21 Nov.	0.33	1.99	0.83	3.3	119	29	148	40	+13	31	91

* McCrosky and Posen (1961) identify two additional members on 27 July and 18 August, which would raise the number of meteors to five and extend the duration back to 27 July. The author concurs in these identifications.

small number of meteors involved. We are left with 15 streams that are sufficiently abundant to be unambiguously classified.

Classification of Streams

The logical method of classification is to begin with the most abundant stream and continue with decreasing numbers until it is evident that we are approaching uncertain ground.

1. The most abundant stream is the extended one of the Taurids, which are 105 in number and are usually divided into a northern and a southern component. Lindblad's search does not make this division but instead subdivides the stream into three overlapping parts according to the sun's longitude $L_\odot$. The elements q, a, i, ω remain constant as $L_\odot$ increases, while Ω and π progress steadily from part to part of the stream (here q is the distance at perihelion, a the semimajor axis, i the inclination, ω the argument of perihelion, Ω the longitude of the ascending node, and π the longitude of perihelion). There is a reversal of nodes as Lindblad switches from predominance of the northern branch to that of the southern branch. Table 1 presents the details of the Taurid streams found by Lindblad. It is apparent that the total activity extends over almost 4 months, growing steadily until the maximum at about 1 November given by McKinley (1961). Figure 1 exhibits the distribution of beginning heights of this stream.

The heights for Ceplecha's Classes C_1, B, and A are marked in Figure 1. The coincidence of the maximum with Class C_1 is evident, as are also the rather abrupt decline in numbers at greater beginning heights and the straggling tail to lower beginning heights. If the distribution were symmetrical, we might hope that as few as $3^2=9$ meteors would suffice to classify a stream. The process that causes

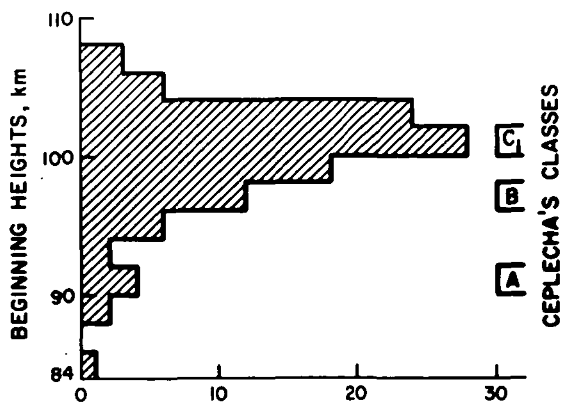

FIGURE 1.—Distribution of beginning heights for the extended stream of the Taurids.

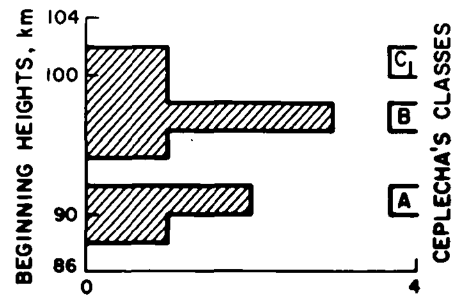

FIGURE 2.—Distribution of beginning heights for the Piscids.

skewing toward the lower heights implies, however, that 9 meteors will be insufficient. Inasmuch as Lindblad has segregated 9 of these Taurids as Piscids, we can examine their distribution as shown in Figure 2. They appear to suggest Class B, but since it is evident that three mavericks at lower beginning heights could account for this appearance, we conclude that more than 9 meteors are required to classify a stream unambiguously.

2. The Geminids are 77 in number and are displayed in Figure 3. This shower is plainly of Class B. Again we see the skew tail to lower beginning heights.

3. The Orionids, displayed in Figure 4, are 49 in number. They are plainly of Class C_2 and do not show the skew distribution.

4. The Perseids with 45 meteors are shown in Figure 5. Again these are clearly of Class C_2 and the distribution is symmetric.

5. The Andromedids (which from the current direction of the radiant have been called ϵ Piscids) number 33 meteors. The distribution appears in Figure 6 and is clearly bimodal with peaks at

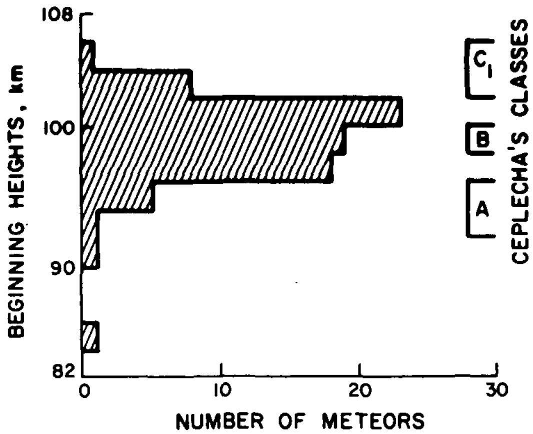

FIGURE 3.—Distribution of beginning heights for the Geminids.

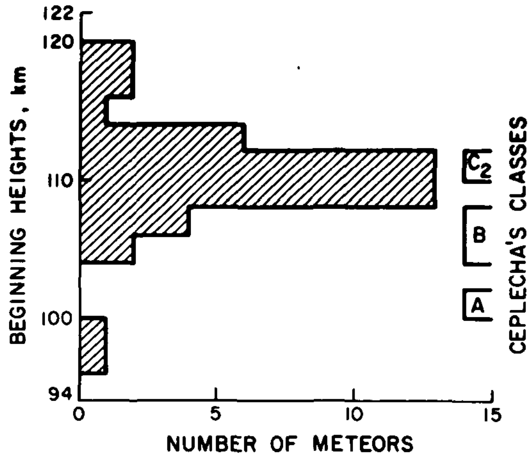

FIGURE 5.—Distribution of beginning heights for the Perseids.

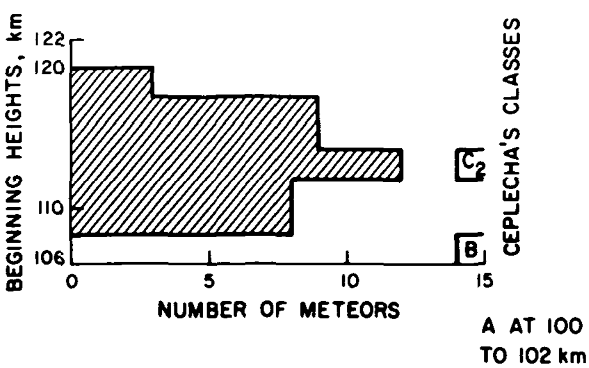

FIGURE 4.—Distribution of beginning heights for the Orionids.

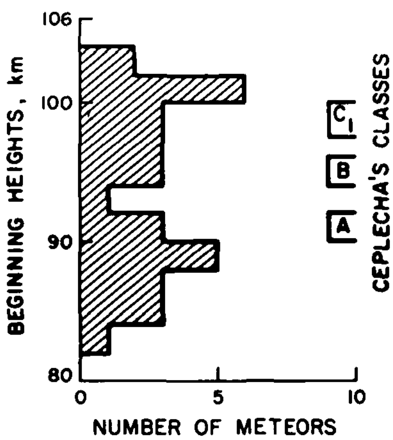

FIGURE 6.—Distribution of beginning heights for the Andromedids.

Classes C_1 and A or lower. These peaks are delineated well enough for us to conclude that 16 meteors are more than sufficient to classify a stream with one peak, whereas we have already seen that 9 meteors are apparently insufficient.

6. The δ Leonids, newly discovered by Lindblad (1971b), contribute 24 meteors to our sample. Figure 7 exhibits a bimodal distribution with peaks at Classes C_1 and A. The peaks are well defined so that we conclude that 12 meteors are sufficient to classify a stream with one peak. Since 9 meteors appear to be insufficient, we adopt 10 meteors as a working lower limit for well-defined classification unless we see what appears to be a bimodal distribution; in such a case the working least number of meteors will be 20.

7. The δ Aquarids number 22 meteors. Figure 8 exhibits the distribution of beginning heights. Noise in the distribution is noticeable, but it seems clear that the stream is of Class B.

8. The α Capricornids with 21 meteors are shown in Figure 9. The Class is C_1 (although B cannot be

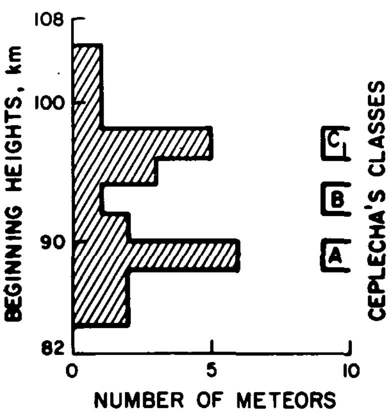

FIGURE 7.—Distribution of beginning heights for the δ Leonids.

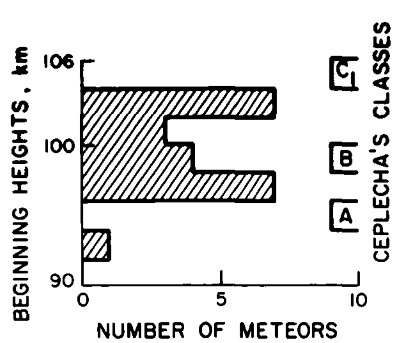

FIGURE 8.—Distribution of beginning heights for the δ Aquarids.

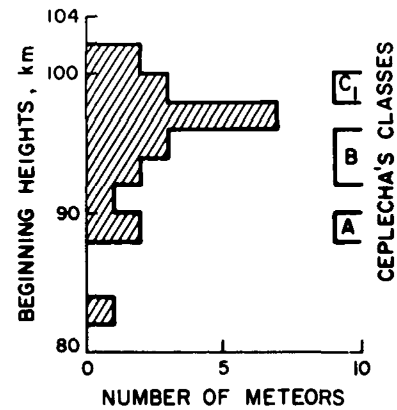

FIGURE 9.—Distribution of beginning heights for the α Capricornids.

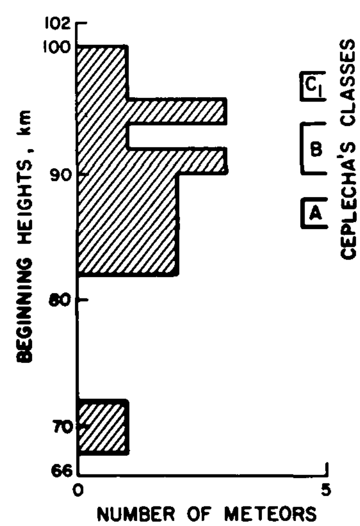

FIGURE 10.—Distribution of beginning heights for the σ Leonids.

excluded), with a skew tail on the distribution to lower heights.

9. The σ Leonids with 19 meteors are exhibited in Figure 10. This stream was discovered by Southworth and Hawkins (1963). It appears to be Class B (although Class A cannot be entirely ruled out). We note two very low heights observed, which suggest skewness to lower heights in this case.

10. The Quadrantids with 17 meteors are shown in Figure 11. This stream is clearly Class B.

11. The τ Herculids number 15 meteors. Figure 12 shows their distribution; the stream is plainly of Class A or lower with a suggestion of a skewness to greater heights. The stream was discovered by Southworth and Hawkins (1963).

12. The δ Arietids with 14 meteors were discovered by McCrosky and Posen (1959). Figure 13 exhibits the distribution. The stream is of Class A (or possibly B), with considerable noise in the distribution.

13. The Southern ι Aquarids with 13 meteors are exhibited in Figure 14. They are plainly of Class A. It should be noted that the orbit of the Southern ι Aquarids is very different (a much larger semimajor axis and a somewhat smaller distance at perihelion) from the Taurid-like orbit of the Northern ι Aquarids; it also produces a geocentric velocity

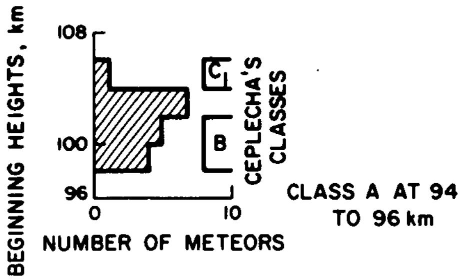

FIGURE 11.—Distribution of beginning heights for the Quadrantids.

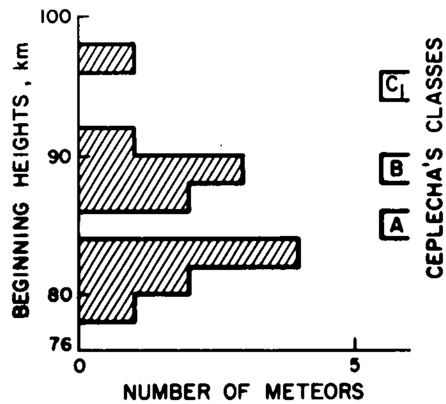

FIGURE 13.—Distribution of beginning heights for the δ Arietids.

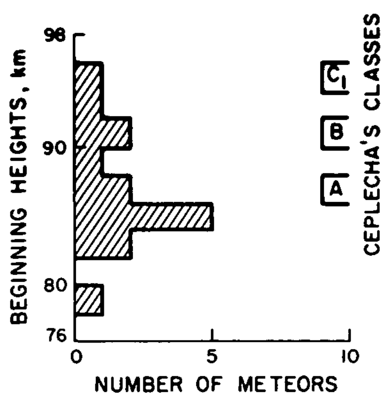

FIGURE 12.—Distribution of beginning heights for the τ Herculids.

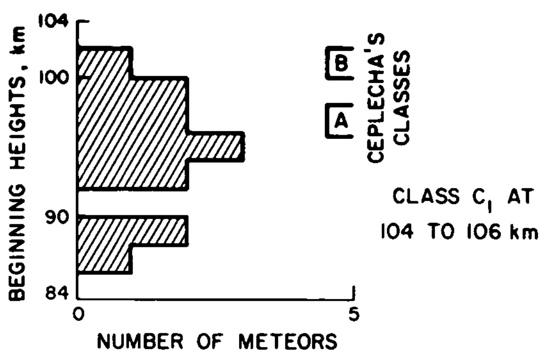

FIGURE 14.—Distribution of beginning heights for the Southern ι Aquarids.

some 5 to 10 km sec^{-1} higher for the Southern ι Aquarids than for the Northern ι Aquarids.

14. The χ Orionids with 12 meteors are shown in Figure 15. They are of Class C_1. The two very low meteors have abrupt beginnings and thus are not really comparable to the others. The χ Orionids were first reported by Whipple (1954).

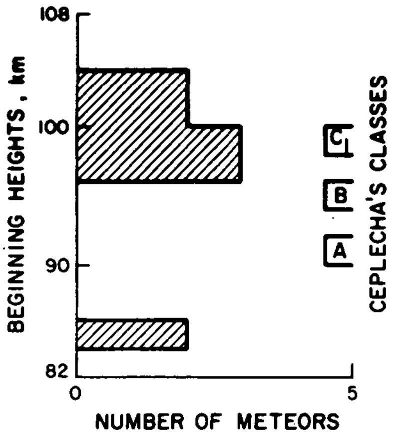

FIGURE 15.—Distribution of beginning heights for the χ Orionids.

15. The χ Scorpiids with 11 meteors are newly discovered by Lindblad (1971b). Figure 16 exhibits the distribution of beginning heights. It appears to fit Class B with a broad distribution. The isolated meteor at great height may be a badly reduced interloper.

16. The κ Cygnids number 10 meteors and the distribution of heights is shown in Figure 17. While we might classify this stream as C_1, there is a suggestion of a double peak, i.e., C_1 and A. The meteors are too few to delineate a bimodal distribution, so that we must treat this stream as unclassifiable.

One stream, the μ Sagittariids with four meteors, is so extreme in beginning heights that we can classify it as Class A or lower. This stream is newly discovered by Lindblad (1971b). Two other streams, the October Draconids with two meteors and the Monocerotids with three, are so extreme that we can classify them as higher than Class C_1. The latter stream was first reported by Whipple (1954). Finally, the Leonids with five meteors are so extreme that they can be classified as higher than C_2.

Seven streams are sufficiently extreme that Class A can be ruled out: Lyrids with five meteors, η Aquarids with seven, o Serpentids with four, κ Aquarids with five, ϵ Geminids with seven, Leo Minorids with three, and σ Hydrids with six. Of these streams, the o Serpentids are newly discovered by Lindblad (1971b), the κ Aquarids by Lindblad (1971a); the ϵ Geminids and Leo Minorids were discovered by McCrosky and Posen (1959), and the σ Hydrids by Jacchia and Whipple (1961).

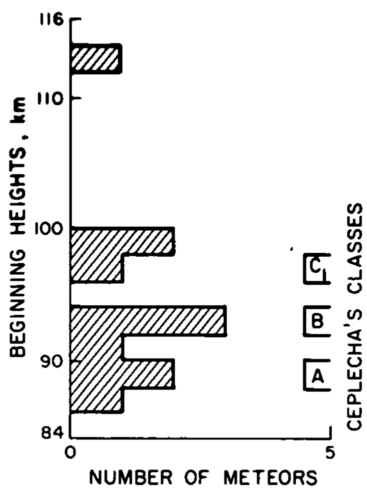

FIGURE 16.—Distribution of beginning heights for the χ Scorpiids.

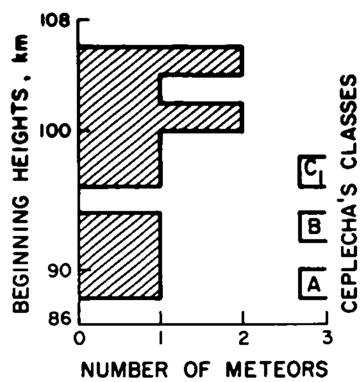

FIGURE 17.—Distribution of beginning heights for the κ Cygnids.

The 11 streams that remain are too poorly represented in our sample to be classified: δ Cancrids (7 meteors), Coma Berenicids (7 meteors), Northern Virginids (including Northern λ Virginids) (6 meteors), κ Serpentids (4 meteors), μ Virginids (7 meteors), α Scorpiids (5 meteors), α Boötids (8 meteors), ϕ Boötids (6 meteors), θ Ophiuchids (4 meteors), α Triangulids (4 meteors), and Pegasids (5 meteors). Of these streams, the δ Cancrids, μ Virginids, α Scorpiids, and α Triangulids are newly discovered by Lindblad (1971b); the α Boötids, ϕ Boötids, and θ Ophiuchids were discovered by Southworth and Hawkins (1963), and the Coma Berenicids, κ Serpentids, and Pegasids by McCrosky and Posen (1959).

Finally, one optical stream is well known and has not been observed in the list of McCrosky and Posen (1961): the Corona Australids. It is a Southern Hemisphere shower.

Table 2 summarizes the foregoing results of classification.

Associated Comets

Table 2 includes in its last column the currently preferred identity of the parent comet of each stream. If we confine our attention to comets now accessible to observation, we find two streams above C_1, one above C_2, two C_1, two C_2, one not A, and one A. P/Comet Halley contributes two streams, so that the classification of the η Aquarids as not A is redundant and should be preempted by the classification of the Orionids as C_2. If we consider the one comet known to have disappeared (P/Comet Biela), we find its stream exhibits Classes A and C_1 together. If we consider the one comet no longer in an orbit accessible to observation (1770 I Lexell), we find its stream to be of Class A or lower. One comet's stream cannot be classified (1819 IV, Blanplain).

Discussion

Four salient points command attention:

1. Meteoroids of Ceplecha's Class A have a density of about 1.2 g cm^{-3}, approaching that of Type I carbonaceous chondrite meteorites (2 g cm^{-3}) (McCrosky and Ceplecha, 1970; Cook, in preparation).

2. Whipple and Stefanik's (1966) model for the redistribution of ices within the nuclei of comets by radioactive heating might lead naturally to gravitational compaction of the less volatile material in the interior, a natural explanation of Ceplecha's Class A and of carbonaceous chondrites of Type I (although rather large nuclei would be required in the latter case). Meteoroids of Classes C_1 and C_2 would then be the low-density residual framework left after evaporation of the volatile ices from the outer shell.

3. Millman, Cook, and Hemenway (1971) find that faint Perseid meteors exhibit spectra ranging from the traditional atomic-line spectra of vaporized meteoroids to almost entirely atmospheric radiations or an extended continuum or both followed by an interval of radiation from atomic lines of meteoric elements lower along the trajectory. This type of behavior seems the most probable cause for the skew distribution toward lower heights because the Super-Schmidt cameras with X-ray film do not photograph the nonblue part of the atmospheric radiations or the continuum, but do respond to those in blue to ultraviolet from the meteoric vapors.

4. Whipple and Stefanik pointed out that many smaller comets that separate from large comets are short lived, as would be expected if only a piece of the ice-impregnated surface peeled off. If a comet cracks all the way through, then some core is left to hold the ice-impregnated surfaces together, which matches the behavior of P/Comet Biela. To complete the picture for that comet, we need only conjecture that the icy surface layers either peeled or were exhausted at the last observed return.

These considerations lead naturally to several ideas. Two inert pieces disguised as small asteroids may yet remain. The exposure of both core and impregnated surface layers would explain the observed bimodal A and C_1 distribution. A similar explanation would follow for the δ Leonids, although no comet has ever been observed in that orbit.

Furthermore, the presence of some ice in an old cometary core is to be expected because, of the ice sublimed by the sun, some would evaporate away but some would diffuse inward and redeposit as frost on the cold interior. In this context, we may understand the A classification of the meteors from the very faint Comet 1930 VI, Schwassmann-Wachmann 3. Recovery of this comet is desirable. B. G. Marsden (private communication) indicates that the next opportunity will come in 1979. Finally, the lower density of Class B streams com-

TABLE 2.—*Optical meteor streams classified according to Ceplecha's (1968) system*

Name	Duration	Radiant (Eq. 1950) RA	Radiant (Eq. 1950) Dec.	V_G (km sec^{-1})	Number of meteors	Ceplecha's class	Comet
Quadrantids	2–3 January	299°	+49°	42	17	B	
δ Cancrids	13–21 January	126	+20	28	7	—	
Coma Berenicids	13–23 January	187	+19	64	7	—	
N. Virginids	3 Feb.–12 March	173	+ 5	36 }	6	—	
N. λ Virginids	4–15 April	210	−10	32 }			
δ Leonids	5–19 February	159	+19	23	24	A+C_1	
Corona Australids	14–18 March	245	−48	—	0	—	
σ Leonids	21 March–13 May	195	− 5	20	19	B*	
κ Serpentids	1–7 April	230	+18	45	4	—	
μ Virginids	1 April–12 May	221	− 5	29	7	—	
α Scorpiids	11 April–5 May	235	−21	34 }	5	—	
	9–12 May	247	−24	35 }			
α Boötids	14 April–12 May	218	+19	23	8	—	
φ Boötids	16 April–12 May	240	+51	16	6	—	
Lyrids	21–22 April	271	+34	47	5	not A	1861 I, Thatcher
η Aquarids	3–12 May	340	− 2	67	7	not A	P/Halley
τ Herculids	19 May–14 June	228	+40	18	14	A or lower	1930 VI, Schwassmann-Wachmann 3
χ Scorpiids	27 May–20 June	246	−12	23	11	B	
θ Ophiuchids	4–16 June	266	−28	30	4	—	
o Serpentids	9–25 June	274	−11	30	4	not A	
μ Sagittariids	22 June–6 July	268	−15	23	4	A or lower	1770 I, Lexell
α Capricornids	15 July–10 Aug.	304	−10	25 }	21	C_1**	1954 III, Honda-Mrkos-Pajdušáková
	4–9 August	317	−17	28 }			
S. ι Aquarids	19 July–6 Aug.	320	−15	35 }	12	A	
	5–22 August	348	−10	41 }			
S. δ Aquarids	21 July–8 Aug.	340	−16	43 }	22	B	
N. δ Aquarids	5–25 August	347	+ 1	40 }			
Perseids	8–15 August	46	+57	60	45	C_2	1862 III, Swift-Tuttle
κ Cygnids	10 Aug.–6 Oct.	273	+61	22	10	—	
N. ι Aquarids	27 July–20 Sept.	354	+ 1	31	5 }		
Piscids	25 Sept.–19 Oct.	26	+14	29	9 } 105	C_1	P/Encke
S. Taurids } N. Taurids }	19 Sept.–21 Nov.	40	+13	31	91 }		
Andromedids	31 Aug.–2 Nov.	10	+ 6	27	33	A+C_1	P/Biela
κ Aquarids	11–28 September	338	− 5	20	5	not A	
October Draconids	9 October	276	+49	21	2	above C_1	P/Giacobini-Zinner
Orionids	14 Oct.–7 Nov.	95	+16	67	53	C_2	P/Halley
ε Geminids	16–27 October	102	+27	70	7	not A	
Leo Minorids	22–24 October	162	+37	62	3	not A	1739, Zanotti
Pegasids	29 Oct.–12 Nov.	344	+19	16	5	—	1819 IV, Blanplain
α Triangulids	7–12 November	22	+30	21	4	—	
Leonids	15–20 November	152	+23	71	5	above C_2	P/Tempel-Tuttle
N. χ Orionids	4–13 December	83	+26	28	4 } 12	C_1	
S. χ Orionids	7–14 December	85	+16	28	8 }		
σ Hydrids	4–15 December	128	+ 2	58	6	not A	
Geminids	4–16 December	111	+32	37	77	B	
δ Arietids	8 Dec.–2 Jan.	54	+25	17	14†	A**	
Monocerotids	10–17 December	104	+10	42	3	above C_1	1917 I, Mellish

* Class A cannot be entirely ruled out. ** Class B cannot be entirely ruled out. † 12 northern, 2 southern.

pared with that of Class A may be due to comets so small that their cores were gravitationally compacted to a density of only about 0.6 g cm^{-3}. We then assume that their ice-impregnated low-density surfaces have been completely removed. Again, the cores would have accumulated some frost from ice that sublimed and diffused inward. These comets would now be very faint or would be disguised as asteroids. It is perhaps not surprising that no comets have been detected in association with streams of Class B.

In this context, it is difficult to believe that a stream as rich as the Geminids does not still have a parent body. The configuration and shortness of period of the orbit make it the only reasonable candidate for a search for such a body among the streams of Class B.

In conclusion, it is desirable to review the classifications for reliability and the individual streams for certainty of their existence. The adopted classifications appear to the author to be unassailable for 10 streams (Taurids, Geminids, Orionids, Perseids, Andromedids, δ Leonids, Quadrantids, τ Herculids, Southern ι Aquarids, and χ Orionids). These are distributed two each over the possible classifications—A (including A or lower), B, C_1, and C_2. There is room for the possibility that the $A+C_1$ distributions may be uniform and broad without a minimum at B. Nevertheless, all the arguments made above can be put forward on the basis of these streams alone.

It is therefore desirable to classify as many other streams as possible. Another stream (δ Aquarids) is almost as securely classified as the 10. Three more streams have somewhat uncertain classifications (α Capricornids, σ Leonids, and δ Arietids). It might be tempting but not very good practice to take note of Ceplecha's failure to find the ridge at Class B down to lower velocities among the sporadic meteors and move the σ Leonids to Class A. Similarly, the possibility of Class B would then be ruled out for the δ Arietids. One stream is of very uncertain classification (χ Scorpiids). If the Class $A+C_1$ has in fact a broad uniform distribution without a minimum at B, the χ Scorpiids would become unclassifiable.

It does not seem important to comment in this vein on the classification of the extreme cases among the less numerous streams except to draw attention to the three streams whose existence is most open to doubt: the θ Ophiuchids, o Serpentids, and μ Sagittariids. All these radiants come from a diffuse region of general activity in June and early July in Scorpius, Sagittarius, Ophiuchus, and Serpens. While more than one stream must contribute to this activity, the computer programs of Hawkins and Southworth and of Lindblad may have arbitrarily grouped these meteors to yield the three listed streams of only four meteors each.

Special suspicion attaches to a stream associated with Comet 1770 I, Lexell, because it only came close to the sun twice (in 1770 and 1776), having passed close to Jupiter in 1767 and 1779. The existence of a detectable stream almost 2 centuries later is rather dubious.

It would be convenient to be rid of these streams since the μ Sagittariids are Class A or lower and Comet Lexell was an embarrassing 5 magnitudes brighter than Comet 1930 VI (Schwassmann-Wachmann 3) and thus not a good candidate for a nearly exhausted comet. Evidently, further study of individual radiants and velocities of meteors in June and early July in Scorpius, Sagittarius, Ophiuchus, and Serpens is desirable.

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Abstract

Of the 26 streams of meteors classified according to Ceplecha's discrete levels of beginning height, 13 are associated with known comets. Comet Biela produced in the Andromedids a double-peaked distribution (Classes A and C_1). Apparently no known comets produce a stream of Class B. Consideration of Whipple and Stefanik's model of an icy conglomerate nucleus with radioactive heating and redistribution of ice leads to association of Ceplecha's Class C with the residue of the ice-impregnated surface of a cometary nucleus after sublimation of the ices, and of Ceplecha's Class A with the core of a cometary nucleus. Class B meteoroids are then to be associated with less dense cores of smaller cometary nuclei that have lost their surfaces and are too small to have been observed. Furthermore, the density of Class A meteoroids (1.2 g cm^{-3}) is so close to that of Type I carbonaceous chondrites (2 g cm^{-3}) as to suggest that the latter come from old cores of very large nuclei of comets, an idea originally proposed by McCrosky and Ceplecha.

It is suggested that two inert objects that look like asteroids may yet remain from the two pieces observed at the last return of P/Comet Biela. The recovery of Comet 1930 VI, Schwassmann-Wachmann 3, at its return in 1979 is urged since it is the only available comet producing a shower (τ Herculids) of Class A. A search for an asteroidal object or a very small comet in the orbit of the Geminids is also urged as the best chance of finding an object that produces meteoroids of Class B. Further study of the distribution of radiants and velocities of meteors in June and early July in Scorpius, Sagittarius, Ophiuchus, and Serpens is required to sort out the true structure there, if indeed one exists.

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B. G. Marsden, R. E. McCrosky,
and A. Posen*

Yet Another Stream Search Among 2401 Photographic Meteors

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Smithsonian Institution
Astrophysical Observatory

Cambridge, Massachusetts

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A. F. Cook, B.-A. Lindblad, B. G. Marsden, R. E. McCrosky, and A. Posen

Yet Another Stream Search Among 2401 Photographic Meteors

Introduction

Observations made from two stations in New Mexico with the Baker Super-Schmidt cameras have provided a large body of homogeneous data on meteors. McCrosky and Posen (1959) undertook the original search for streams in these data by plotting the radiant of each meteor on an Aetoff equal-area chart for the month in which the meteor occurred. The 12 charts were then inspected for areas of maxima of density of points. Quite stringent conditions were applied to the number of meteors within a particular size of circle and a particular number of days. Subsequently, McCrosky and Posen (1961) published the individual orbits and trajectories. Most of these meteors were reduced by an approximate graphical method (McCrosky, 1957). The others were much more accurately reduced (Jacchia and Whipple, 1961; Hawkins and Southworth, 1961; Jacchia, Verniani, and Briggs, 1967).

Recently, Lindblad (1971b) made a new search with a computer program of Southworth and Hawkins (1963) that operates by comparing orbits of meteors. He also compared the results of this search with earlier ones by computer program among smaller numbers of meteors (Southworth and Hawkins, 1963; Lindblad, 1971a) and with others by inspection of smaller samples (Whipple, 1954; Jacchia and Whipple, 1961). Cook (1970) has combed these lists and applied as the criterion of membership that there be at least four meteors, or three meteors and an associated comet identified by Lindblad's (1971b) search. Alternatively, a stream was accepted if it had been independently established by previously observations or searches. Cook raised doubts as to the existence of three streams in Serpens, Ophiuchus, and Sagittarius in June and July.

We reexamined McCrosky and Posen's charts and could not confirm the three streams involved (θ Ophiuchids, o Serpentids, and μ Sagittariids). All three radiants lie within a diffuse maximum in the distribution that was recognized long ago by Hoffmeister (1948), who called it the Scorpius-Sagittarius System. We also found from the charts eight additional concentrations of meteors as candidate stream radiants. The present paper discusses these results further and concludes that independent evidence exists for the reality of the θ Ophiuchids but not for that of the o Serpentids or the μ Sagittariids and that after appropriate screening, four of the candidate radiants are eliminated, thus yielding four streams (Camelopardalids, δ Draconids, o Draconids, December Leo Minorids), of which three have been previously reported and one is new (o Draconids) and is associated with Comet 1919 V Metcalf.

o Serpentids, μ Sagittariids, and θ Ophiuchids

Two of the three streams that could not be confirmed on the charts of McCrosky and Posen were found to have only four meteors by Lindblad (1971b) and have not been found by others. We therefore reject the existence and classification of these streams in Cook's (1970) list. They are the o Serpentids and the μ Sagittariids. The latter has been associated with Comet 1770 I Lexell, which

A. F. Cook, B. G. Marsden, and R. E. McCrosky, Smithsonian Institution Astrophysical Observatory and Harvard College Observatory, Cambridge, Massachusetts 01238. *B.-A. Lindblad, Lund University, Lund, Sweden. A. Posen, Smithsonian Institution Astrophysical Observatory, Cambridge, Massachusetts* 01238.

made only two relatively close perihelion passages in 1770 and 1776 between two close encounters with Jupiter in 1767 and 1779. It is unlikely that many meteoroids from the comet would have escaped a close encounter with Jupiter in 1779. The encounter at that time would have effectively left the meteoroids' velocity vectors forming a sheet, as it would also the orbits. Subsequent encounters with Jupiter would have exploded this sheet of orbits into a third dimension in both space and vector velocity. The absence of new meteoroids as input should have left no detectable stream unless the original one were so very dense as to have figured prominently in historical records in 1770, 1775, or 1776.

The θ Ophiuchids, on the other hand, were originally detected by Southworth and Hawkins (1963) and confirmed by Lindblad (1971a). Combination of these meteors with those of Lindblad (1971b) yields seven meteors from McCrosky and Posen's (1961) sample alone. Examination of their individual orbits suggests that they do indeed form a common stream, but we retain only four of them as conforming to it. Furthermore, Hoffmeister (1948) reported that the diffuse Scorpius-Sagittarius System develops a relatively sharp and more intense radiant at nearly the same position from 6 to 16 June. Table 1 presents all the relevant information.

A final argument that might be made for the o Serpentids is to regard them as Northern θ Ophiuchids, although the relatively high inclination is against this. Also, the μ Sagittariids might be regarded as late χ Scorpiids. This would greatly weaken the apparent connection with Comet Lexell. The failure of these streams to appear in the earlier searches or to be noted by Hoffmeister in comparison with the θ Ophiuchids argues against their reality.

Camelopardalids, δ Draconids, o Draconids, and December Leo Minorids

Eight candidate clusters of radiants were found on McCrosky and Posen's charts. Four contained only three meteors each, and no comet with a similar orbit could be found. Another cluster showed six meteors with orbits that grouped two, two, one, and one. Four were accepted as streams. The first of these, the Camelopardalids, was detected in Lindblad's (1971b) search but, along with several other minor unconfirmed streams, was not listed. A

TABLE 1.—*The θ Ophiuchids*

Meteor no.	Day	Month	Year	Radiant (Eq. 1950) RA	Dec.	V_G (km sec^{-1})	a	q	ω	Ω	ι	π	Beginning height (km)
7782	8.26	6	53	266°	−31°	28.0	2.36	0.40	109°	257°	8°	6°	93.1
7808	8.38	6	53	266	−27	30.1	3.42	0.365	111.0	257.2	3.1	8.2	92.5
7895	16.31	6	53	266	−29	24.8	3.11	0.538	92.2	264.8	4.5	357.0	96.9
7899	16.31	6	53	269	−26	27.4	2.86	0.465	100.9	264.8	4.9	5.7	90.2
Adopted	8–16	6	53	267	−28	26.7	2.90	0.460	101.4	262.3	4.2	3.5	
Hoffmeister	6–16	6	37	270	−30								

TABLE 2.—*The Camelopardalids*

Meteor no.	Day	Month	Year	Radiant (Eq. 1950) RA	Dec.	V_G (km sec^{-1})	a	q	ω	Ω	ι	π	Beginning height (km)
6881	14.30	3	53	122°	+64°	8.0	1.76	0.99	191°	353°	9°	184°	78.3
6882	14.30	3	53	113	+63	6.4	1.53	0.99	187	353	7	180	78.3
10342	26.28	3	54	129	+73	7.2	1.54	1.00	183	5	9	188	78.5
10514	7.35	4	54	153	+77	8.4	1.56	0.99	162	17	12	179	85.3
Adopted	14/3–7/4			118.7	+68.3	6.8	1.534	0.974	185.0	359.0	8.2	184.0	

group of four meteors listed in Tables 2 forms a well-defined stream, originally reported by Jacchia and Whipple (1961) as their Association No. 37. Kresák and Porubčan (1970) have named this stream the Camelopardalids. It is exceptional because of its low geocentric velocity. In this connection, we wish to point out an error in McCrosky and Posen's (1961) list. The right ascension of the radiant of meteor no. 10514 should read 153°, not 53°.

The second of these, the δ Draconids, was originally reported by Jacchia and Whipple (1961) as their Association No. 45. Table 3 gives the details of these meteors.

The next stream, the ο Draconids, is new; only three meteors and an associated comet establish the identification. Table 4 gives the details. The identication with Comet 1919 V Metcalf seems quite secure.

The final stream, the December Leo Minorids, had been previously reported by Whipple (1954) as his Association VII. We suggest that McCrosky and Posen's (1959) Leo Minorids be called the October Leo Minorids to distinguish between these two streams. Details are given in Table 5. With six meteors, this is the most abundant of the four streams presented in Tables 2 to 5. Meteor No. 2578 is reported by Whipple (1954) among 144 meteors photographed with small cameras and is included to establish an orbit from an accurately reduced meteor. The orbit bears a strong resemblance to that of the Coma Berinicids in January.

It should be noted that the ο Draconids were all observed in 1952 and 1953 and may not be an annual stream. The spread over 18 days and the distance of the comet's orbit from the earth's provide a strong argument for a broad annual stream. The δ Draconids were observed in two successive years and spread over 20 days, so that while they may not recur annually, it would seem reasonable to expect them to do so. The December Leo Minorids (Table 5) were discovered in somewhat earlier observations and presumably do return annually.

Corrections to McCrosky and Posen's List of Orbits

We wish to point out two omissions in McCrosky and Posen's (1961) list of orbits of meteors. The

TABLE 3.—*The δ Draconids*

Meteor no.	Day	Month	Year	Radiant (Eq. 1950) RA	Dec.	V_G (km sec^{-1})	a	q	ω	Ω	ι	π	Beginning height (km)
3079	28.23	3	52	281°	+71°	23.2	2.66	0.998	178.5°	7.4°	34°.1	185°.9	87.6
3088	28.34	3	52	288	+68	23.3	2.938	0.989	167.6	7.6	37.2	175.2	99.8
7392	16.33	4	53	287	+66	25.1	2.717	0.994	167.3	26.0	41.2	190.3	93.8
7423	17.36	4	53	287	+66	29.0	7.95	1.00	169	27	45	196	101.0
Adopted	28/3–17/4			281	+68	26.7	2.770	0.996	171.1	13.7	37.5	184.8	

TABLE 4.—*The ο Draconids*

Meteor no.	Day	Month	Year	Radiant (Eq. 1950) RA	Dec.	V_G (km sec^{-1})	a	q	ω	Ω	ι	π	Beginning height (km)
7941	6.27	7	53	290°	+61°	29.3	3.18	1.01	193°	104°	49°	297°	101.5
8069	16.39	7	53	290	+65	29.3	3.43	1.01	186	114	49	300	101.2
3367	24.22	7	52	274	+59	24.9	4.06	1.01	192	121	39	313	89.1
Adopted	6–24	7		271	+59	28.6	∞	1.01	190	113	43	303	
Comet 1919V Metcalf				1/a = −0.001929				1.12	186	121	46	307	

TABLE 5.—*The December Leo Minorids*

Meteor no.	Day	Month	Year	Radiant (Eq. 1950) RA	Dec.	V_G (km sec^{-1})	a	q	ω	Ω	ι	π	Beginning height (km)
9559	12.40	12	53	153°	+32°	67.0	−4.51	0.61	254°	260°	140°	154°	117.6
9593	12.50	12	53	155	+35	62.4	8.77	0.58	261	260	132	161	107.9
2578	13.46	12	50	156	+35	65.0	−8.86	0.629	252.3	260.9	133.0	153.2	
5988	14.43	12	52	157	+33	59.4	2.59	0.51	275	262	132	177	104.6
6027	16.45	12	52	161	+32	62.7	6.44	0.61	258	264	134	162	111.6
9802	16.53	12	53	160	+32	60.3	2.83	0.56	269	264	133	173	110.8
6038	17.36	12	52	163	+30	60.5	2.30	0.59	267	265	136	172	109.5
Adopted	12–17	12		156.1	+34.6	63.7	∞	0.612	255.8	260.9	132.3	156.7	

κ Cygnids are listed as a shower, but no meteors are classified as such; we propose as members numbers 8413, 3568, 3652, 3787, 4325, 4472, 8763, and 8882, which were used by Cook (1970). Also, the η Aquarids were entirely omitted; we propose as members numbers 11861, 11929, 11938, 10145, 10138, 12094, and 12096, which were used by Cook (1970).

Members of the Andromedids

Lindblad (1971b) lists 33 Andromedids designated by him as Piscids (Stream No. 92) and used by Cook (1970). Examination of the charts of McCrosky and Posen shows that this stream starts in Pisces in September near the ecliptic west of the Taurid radiant (and overlapping that area at its western edge) and migrates northward through October, becoming entirely separate and, early in November, migrating toward the radiant of the great Andromedid showers. This progression enables us to identify five later Andromedids: meteor numbers 5332, 5335, 5339, 5382, and 5392. Four of these were grouped by Lindblad (1971b) into the α Triangulids, which thus is no longer an independent entity. The duration is thus extended to the 12th of November. There is a systematic trend with the longitude of the sun (i.e., with that of the earth) such that the perihelion moves out from the sun, the inclination increases, and the node and argument of perihelion vary in such a way as to keep the longitude of perihelion unchanged. Meanwhile those members with radiants south of the ecliptic appear to be a southern branch of the other stream designated Piscids (Stream No. 31) by Lindblad (1971b). These 14 meteors are numbers 3864, 4369, 4391, 4476, 4478, 4505, 4520, 4605, 8767, 8777, 8899, 4987, 5064, and 9134. The revised membership of the Andromedids consists of 24 meteors. Addition of these meteors to Cook's (1970) histogram does not alter the character of that distribution.

Revised Membership of the δ Arietids

Lindblad (1971b) lists 14 δ Arietids (called by him Northern δ Arietids) over the interval from the 8th of December to the 2nd of January. Seven of these meteors over the interval from the 8th to the 14th of December form a much more compact stream. They are numbers 5552, 5573, 5772, 5878, 5953, 9438, and 9486. These are adopted as the true members of the stream.

Classification of the Streams on Ceplecha's System

The θ Ophiuchids can be classified as not C on the basis of their revised membership, the Andromedids remain classified as A and C_1, and the Piscids (Stream No. 31 of Lindblad 1971b) can be classified as A and C_1, while the Camelopardalids can be classified as A and the December Leo Minorids as not A, on the basis of Ceplecha's (1968) system of classification in terms of beginning heights. The δ Draconids and the o Draconids cannot be classified. A separate classification for the ι Aquarids is required and is Class A. The Taurids remain C_1. The δ Arietids become not C_1. These revisions and additions apply to Cook's (1970) classification of streams. Finally, of course, the θ Serpentids, the μ Sagittariids, and the α Triangulids are to be deleted from Cook's list.

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Abstract

Two streams previously listed (one of them with a classification on Ceplecha's system in terms of beginning height) by Cook are shown probably not to exist, a possibility already pointed out by Cook. One stream that he questioned has been revised as to membership and it is then classified. Four streams are added to the list by our new search and one of these is classified. Previous reports exist for three of these streams, while one is new. The two Piscid streams of Lindblad and his α Triangulid stream are regrouped into two streams, one already called the Andromedids by Cook and the other still called the Piscids; the α Triangulids are absorbed into the Andromedids. The Piscids are classified along with the ι Aquarids. The classifications of the Taurids and the Andromedids remain unchanged.

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