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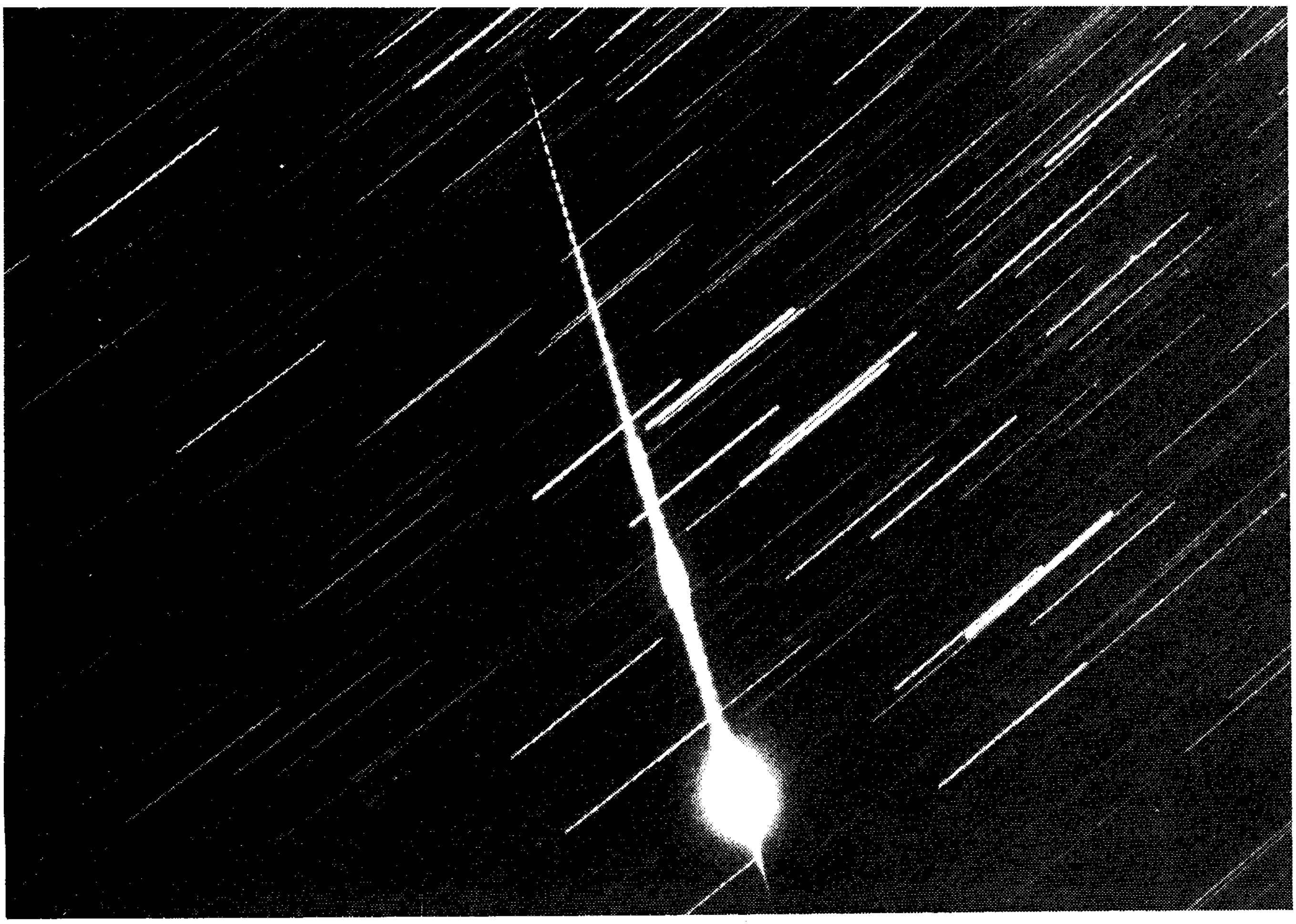

This spectacular κ-Cygnid fireball was in Delphinus, photographed with a Canon T-70 camera by the Dutch observer Robert Haas from Rognes, Southern France, appeared at $0^h34^m53^s$ UT in the night of August 11-12.

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Contents

Useful Information

The April Issue *(WGN 22:2)*

The *April issue* will be a thick issue and will be mailed during the first week of April. Contributions are due on *March 11* at the latest. They should be sent to *Marc Gyssens.*

WGN Subscription/IMO Membership 1994

The subscription rate for Volume 22 (1994) of the *Bimonthly Journal* is 25 DEM for six issues which are anticipated to contain over 250 pages in total. A combined subscription with the *Report Series* and *FIDAC News* costs 60 DEM. You can also become a Supporting Member by paying at least 15 DEM extra.

Administrative Correspondence

Ordering *IMO* publications is done in the same way as paying subscription/membership fees. Complaints about not receiving *WGN* or changes of address should be sent to *Paul Roggemans.*

All addresses can be found on the inside of the back cover.

In Memoriam

Lubor Kresák, 1927–1994

Andrea Carusi, President IAU Commission 20

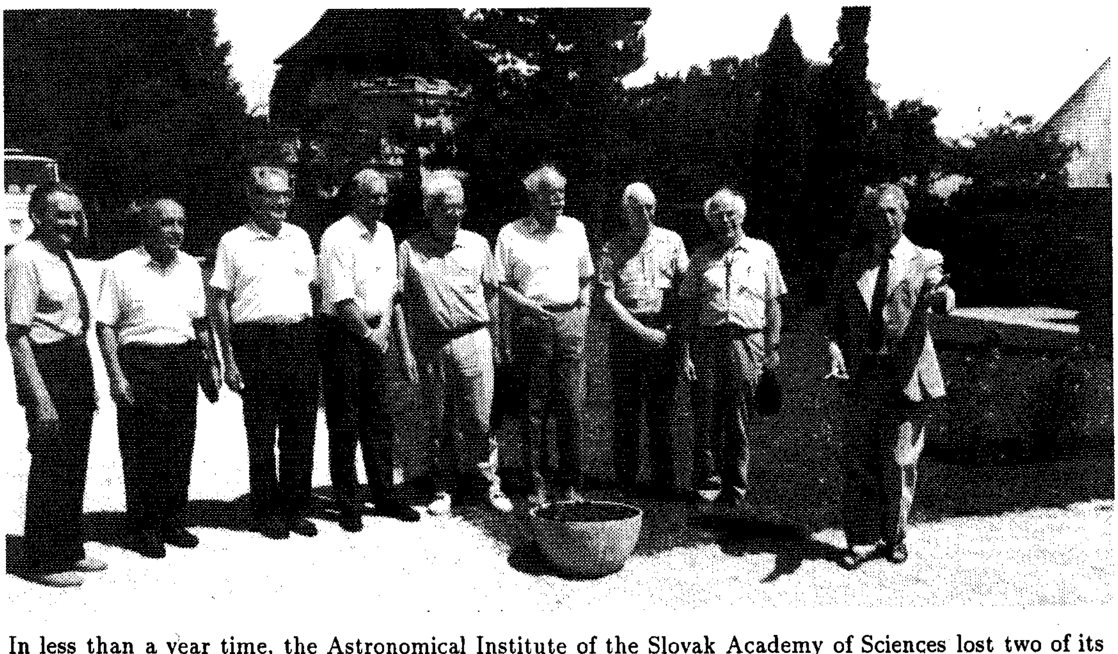
Professor Lubor Kresák died on January 20, 1994, in Bratislava, Slovakia. The news of his death went rapidly through computer networks, leaving everybody astonished: Professor Kresák was such a prominent scientist and wonderful person that everyone working in his and related fields has been really shocked by the loss.

Lubor Kresák was born on August 23, 1927, in Topol'čany, Slovakia. He received the RNDr. title at the Charles University, in Prague, in 1951, discussing the thesis "Structure, mass and age of the Comet Halley meteoroid stream." Subsequently, he was affiliated to the Czechoslovak Academy of Sciences, with the CSc. title, in 1957; was Docent at the Comenius University, in Bratislava, in 1962; was DrSc. at the Czechoslovak Academy of Sciences in Prague, in 1967; and finally became Professor at the Charles University in Prague, in 1992. He first worked at the Skalnaté Pleso Observatory, in 1951–1955, and then entered the Astronomical Institute of the Slovak Academy of Sciences in Bratislava. He was External Lecturer of Astronomy at the Comenius University since 1956, and Corresponding Member of the Slovak Academy of Sciences since 1968.

Professor Kresák was very much involved in the coordination of international activities: he was Acting President of IAU Commission 22 (Meteors and Meteorites) in 1961; became Vice-President, and then President of IAU Commission 20 (Position and Motion of Minor Planets, Comets, and Satellites) in 1970–1973 and 1973–1976 respectively, was elected Vice-President of the IAU in 1979, a post he held until 1985; was Vice-President, and then President, of the IAU Commission 15 (Physical Studies of Comets, Minor Planets, and Meteorites) in 1982–1985 and 1985–1988. He was also an Associated Member of the Royal Astronomical Society since 1987, and Corresponding Member of the Czechoslovak Academy of Sciences, since 1989.

Professor Lubor Kresák worked mainly in the field of solar system minor bodies. He was a very skilled observer; at the Skalnate Pleso Observatory in 1946, he observed an exceptional outburst in activity of the Giacobinids. Professor Kresák also discovered two comets: P/Tuttle-Giacobini-Kresák, in 1954, and Kresák-Peltier, in 1954. One asteroid carries his name: (1849) Kresák. Lubor married Margita in 1954, also an astronomer, and they had a daughter, Katka.

The work done by Lubor Kresák on small bodies, especially comets and meteoroids, has been very influential on all the fields that he dealt with. Especially noteworthy was his ability to treat both the observational and the dynamical aspects of problems equally successfully, so as to get the most from the observations and, at the same time, make clear to himself and his colleagues what were the limits beyond which the conclusions could not be pushed. In this respect, he has left several important catalogues concerning short-period comets: one in cooperation with the ITA, concerning orbital evolution and observational circumstances, another in cooperation with the IAS, on orbital evolution over a somewhat longer time-span, and finally that in cooperation with his wife Margita, on absolute magnitudes.



In less than a year time, the Astronomical Institute of the Slovak Academy of Sciences lost two of its most eminent members: Jan Štohl and Lubor Kresák. On this photograph taken at the Smolenice Symposium in July 1992, we see *(from left to right)* Kresák, Babadzahnov, Ceplecha, Williams, Belkovich, Lindblad, Elford, Keay, and Štohl.

Lubor Kresák also worked very successfully in many fields related to minor bodies, such as: interrelations between comets and asteroids, observational biases, ensemble of available observations, and general conclusions on their statistical significance, to name but a few. Lubor Kresák published almost 200 scientific papers.

But as important as his scientific contributions to astronomy have been, his personal qualities were also outstanding: he was an excellent teacher, who educated practically all astronomers in Slovakia. He was known by practically everybody in the field as a kind and helpful friend, and for that will be missed by everybody.

In the last fifteen years, Giovanni B. Valsecchi and myself have had the unique opportunity to work very closely with him: we owe to Lubor most of our training in the field of cometary dynamics, and will always remember the wonderful time spent with him in very open and wide discussions, not only on scientific topics.

From the President

Jürgen Rendtel

Another year with many meteor astronomical highlights has passed. In 1993 we lived to see another high activity Perseid peak in August, and unusual Orionid rates before the normal maximum in October. Despite all the collected data and the developed models, there are surprises time and again. Therefore it remains open what is going to happen in 1994: will there be another Perseid outburst at all, or will Leonid rates start to increase, perhaps? The possible Perseid storm also led to new kinds of contacts with other organizations, like NASA. *These relations can be expected to continue to flourish in the future, because we obviously still do not know enough about the structure of meteoroid streams and the* IMO *is in a unique position to provide valuable data.*

The atmosphere of the 1993 IMC *in Puimichel, France, left much time for the participants to talk with each other. This is a part of my message in last year's note. I think that such talks also initiate contacts necessary for the further development of all techniques of meteor observation. Photographic and radio meteor work are, in my opinion, the branches which can be expected to provide promising results in the near future. It was also decided at this years* IMC *that the 1994* IMC *will be held in Bulgaria, a country where very active groups have been contributing good data for many years. I hope to seeing many* IMO *members at this* IMC *as well.*

A newly elected Council has held office since January, 1994. I wish to thank the members of the first IMO *Council for their work. Of course, in these five years we all had to learn how to manage our organization and this process will continue. A smaller Council can be expected to work more effectively. On the other hand, having fewer people, we need more feedback from all members to keep the* IMO *an organization that you like to participate in.*

I wish all IMO *members and friends a successful and healthy New Year. Good luck with your personal plans and with your meteor related projects!*

From the Editor-in-Chief

Marc Gyssens

Of course, I cannot but agree with the words of our President and join him in wishing you the very best for 1994. Unfortunately, the year did not start well with the unexpected death of Lubor Kresák. On behalf of the IMO, *President Jürgen Rendtel offered his condolences to Dr. Kresák's colleagues and family.*

Turning to the present issue, I have to apologize for the unusual delay. The delay has been caused by an illness afflicting your editor-in-Chief that has put my out of action for a couple of weeks. Partly to limit the delay and partly for logistical reasons, I have decided to produce a normal-sized issue for February. As a consequence, several contributions had to be postponed again. I want to assure the unfortunate authors of these contributions, however, that the April issue will again be a thick issue, at which time the present backlog will be eliminated.

For WGN, *every new year means a new attempt to further improve our journal. Last year, we introduced the refereed section, which contributed very meaningfully to our journal as the article in this issue by Luis Bellot on the determination of the population index shows. At the same time, however, we are also concerned about our many subscribers who may not (yet) have sufficient mastery of the field of meteor astronomy to fully comprehend these technical articles. For these people, Rainer Arlt has decided to initiate a "Frequently Asked Questions" section, beginning with this issue. Questions that you may have that are suitable for this section may be sent either to me or directly to Rainer (all addresses on the inside back cover). Both of us hope that the new section, together with the letter section, will be a forum for all subscribers and members in which information can not only be exchanged, but also obtained.*

From the Treasurer

Ina Rendtel

1. Gifts from members and subscribers

In 1993 the following people paid more than required for their membership or subscription or for the publications they ordered. Their financial contribution helped greatly to finance the production of *WGN*. Gifts are welcome and help to keep the subscription low for those who cannot afford to pay more than 25 DEM.

The donators were:

> Per Aldrich, Peter Aneca, Ben Apeldoorn, ASH Polaris, Lars Bakman, Ragnar Bödefeld, Erik Bredael, Peter Brown, Carl De Pooter, Oscar Cervera Garcia, Luc Gobin, Roberto Gorelli, Marc Gyssens, Trond Erik Hillestad, André Knöfel, Masahiro Koseki, Joseph Lemaire, Michael Luciuk, Alastair McBeath, Javier Mendez Alvarez, Paul O'Brien, Michael Olason, Ghislain Plesier, Urijan Poerink, Ina Rendtel, Jürgen Rendtel, Philip Roberts, Paul Roggemans, Hans Salm, Hans-Georg Schmidt, Ulrich Sperberg, Christian Steyaert, Enrico Stomeo, Leonard Tomko, Masayoshi Ueda, Jeroen Van Wassenhove, Luc Vanhoeck, Roger Venable, Peter Wright, Zidian Wu, Yasuo Yabu.

2. Exchange of publications with currency-controlled countries

Last year, several members arranged an exchange subscription to *WGN* with colleagues in currency-controlled countries. We hope that as a result everybody received the publications he or she expected. If you have not received what you ordered, please report such facts to the Treasurer.

For 1994, the following arrangements are possible for subscribers wishing to help their colleagues in currency-controlled countries:

- *Czech Republic:* Order the Atlas Brno (gnomonic) for 5 DEM from the *IMO* and for every 5 copies sold cover the subscription of a Czech reader. As orders are booked by the *IMO* and copies have to be sent from Brno, this procedure may take up to 3 months. If you ordered an atlas and did not receive it in 3 months, please inform the Treasurer.
- *Hungary:* Order the Proceedings of the *1989 IMC* from the *IMO* for 12 DEM and help our Hungarian friends to cover their subscription. Copies can be ordered through the *IMO* treasurer.
- *Other currency-controlled countries, such as Russia, the Ukraine, Rumania, Slovakia, Bulgaria, Tadjikistan, etc.:* It is possible to make donations to the *IMO* fund for assistance to members from currency-controlled countries (for a subscription or for a publication), or you can help by paying for a specific person with whom you made an agreement for some exchange. If you want to obtain a specific publication, for instance Russian astronomical journals, the Minor Planets Ephemerids for 1991, 1992, etc., contact the Secretary-General who will try to arrange this exchange.

3. Complaints about not receiving ordered publications

In general, we receive very few complaints, but every now and then it may happen that parcels disappear or are destroyed in the mail. If you do not receive what you ordered from or through the *IMO* in about 3 months after your order was placed, do not hesitate to contact the Treasurer. It may happen that something goes wrong in our administration, due to misunderstandings, or because of unclear orders.... Sometimes we receive money without any clue regarding the purpose or sender!

Letters to WGN

compiled by Marc Gyssens

Radio reflection duration and visual magnitude, and other issues

The controversy surrounding this subject triggered by an initial letter from George Zay in last year's December issue (WGN 20:6, p. 210) *continues to bring reactions. Below is a sceptical reaction by Vladimir Znojil, not only to this subject, but also to other controversial issues treated recently in* WGN.

I was surprised when reading several articles and opinions in recent issues of *WGN* and I would like to say something regarding these issues, now that I have a little time due to the Christmas holiday season.

Radio reflection duration and visual magnitude

The relation between radio reflection duration and visual magnitude was a subject of my thesis. I had at my disposal a huge collection of thousands of telescopic and visual meteors and radar echos, observed in the period 1972–1973. The results were published by my co-authors and I in three articles [1–3].

As to the statistics: the results obtained agreed well with data gathered by B.A. Lindblad [4] and D.W.R. McKinley [5]. On the other hand, it was also apparent that exact dependencies between the characteristics involved and which might be valid in individual cases do not hold in general. The relation proposed by J.-M. Wislez [6]) is good, but does not take into account the macro-turbulence of the upper atmosphere and wind streams in it. Nevertheless, their result can also be obtained even in situations where the meteor is recorded by radar more than 1 s after the visual sighting, as is proved by correlation diagrams in the other references quoted.

Nevertheless, there remains a dispersion of around 2 magnitudes in brightness for meteors with the same reflection duration, even in a relatively homogeneous meteor sample containing only meteors from a single shower, while the errors of visual magnitude estimates are altogether generally below 0.5 magnitudes for experienced observers.

Moreover, I view the attempt to obtain exact radar and visual observations of individual meteors as entirely useless. After all, both methods are in principle based on statistics, so we must respect this limitation. The radar observations of good quality derived from several stations are generally in a good agreement with the telescopic data (e.g., [7]) in whose mass range I work.

Curved meteors

I have encountered the characterization "curved" in connection with the path of a meteor seen during a visual observing several times, but I judge that it is necessary to refer such meteors to the place where they belong: among ghosts, goblins, and parasite radiants. To see this, it suffices to realize what energy it would take for a substantial diversion of flight direction.

Although it is true that phenomena such as explosions and asymmetric evaporation of part of the meteoroid can divert the flight direction a bit (as proved by some rare photographs), the diversions are always small (at most of the order of tens of arc minutes). There is probably just one case among thousands of meteors in our archives in which a change of direction can be considered proven: the case relates to the Orionids of 1966, observed from 2 stations by 5 telescopic observers in total, in the close vicinity of the radiant. The calculation proved that the deviation in flight direction in this case was around $40' \pm 10'$. Other curved meteors were proven to be optical illusions of single observers, caused by motion of the observer or motion of his eyes. On the other hand, I would like to note that I see nothing of interest in this single established case of a curved meteor.

Illustrating a meteor stream

D.W. Hughes [8] qualifies as "erroneous" the way in which the structure of a meteor stream in the solar system is depicted in a whole series of publications. It is clear that, factually (the slowing down of the motion and the related "concentration" of meteoroid positions in aphelion and the increasing dispersion of orbits in the aphelion), Hughes is right. Of course, one must ask the question to which extent illustrations such as Figure 5 are useful for a beginner to help him in visualizing a meteor stream. Moreover, I am convinced that the picture sketched by Hughes does not represent the whole story. The substantial part of the differences among heliocentric trajectories obtained by photographic methods are due to errors caused by insufficiently accurate measurements of meteor velocities. Errors in these measurements influence the aphelion dispersion of the stream considerably. I am quite convinced that the pictures presented would have looked rather different if the statistically relevant deconvolutions. would have been carried out first.

Variations of the population index during sharp Perseid maxima

My last comment refers to the editorial postscript following the article by A. Grishchenyuk [9] in which the significance of the decrease of the population index during the Perseid maximum is questioned based on the global analysis by R. Koschack, R. Arlt, and J. Rendtel [10]. An examination of this analysis will immediately show two problems: on the one hand, the itemizing of the intervals in which the population indices were classified was done in a rather mechanical way, taking little account of the changes in the hourly rate, and on the other hand, the method used to estimate the population index has a relatively low accuracy when compared with methods based on a calibration with the sporadic background or on the general model of magnitude distribution. Rather accurate estimates of the population index and, in particular, its variation can be obtained by combining various methods, even from rather humble observation material. As a matter of fact, the population indices of the Perseids obtained by V. Znojil [11] were estimated in this way.

The reality of significant changes in the population index during sharp Perseid maxima are substantiated by telescopic observations led by Pravec in which the sharp maxima of the Perseids did not appear (preliminary information) revealing that the hourly rates of telescopic meteors were lower than that found in normal maxima. This absence of faint Perseids was really present in both 1992 and 1993. It was as conspicuous as the change in average brightness of visual Perseids during those sharp maxima. It should be noted that during those periods, average brightnesses of sporadic meteors remained nearly unchanged. Therefore, explaining the results of Grishchenyuk's work (and similar studies) as the result of ignoring faint meteors is hardly acceptable.

[1] Znojil V. et al., *Bull. Astron. Inst. Czechosl.* 31, 1980, pp. 14–25.
[2] Znojil V. et al., *Bull. Astron. Inst. Czechosl.* 32, 1981, pp. 1–19.
[3] Znojil V. et al., *Bull. Astron. Inst. Czechosl.* 36, 1985, pp. 44–56.
[4] Lindblad B.A., *Smithson. Contr. Astrophysics* 7, 1963, p. 27.

[5] McKinley D.W.R., "Meteor Science and Engineering", McGraw-Hill, New-York, 1961.
[6] Wislez J.-M., *WGN* 21, 1993, p. 244.
[7] Znojil V. et al., *Bull. Astron. Inst. Czechosl.* 32, 1982, pp. 201–210.
[8] Hughes D.W., *WGN* 21, 1993, pp. 254–258.
[9] Grishchenyuk A., *WGN* 21, 1993, pp. 283–284.
[10] Koschack R., Arlt R., Rendtel J., *WGN* 21, 1993, pp. 152–167.
[11] V. Znojil, *WGN* 20, 1992, pp. 244–247.

Vladimir Znojil, January 1, 1994

Editor's comment: *I will not comment on Dr. Znojil's remarks regarding the relationship between radio reflection durations and visual magnitudes nor will I add anything more to the subject of curved meteors—after all, there has been said very much already on these subjects in* WGN.

Regarding the way in which a meteoroid stream should be depicted, I am quite confident that Dr. Hughes does not advocate replacing the oversimplified representations in most books by the figures and diagrams in his article. The point Dr. Hughes wanted to make—and in my opinion a very valid point indeed—is that this oversimplified picture also lives in the mind of most meteor amateurs and thus can lead to false interpretations and conclusion when, for instance, considering the possibility of a meteor storm. Of course the question to what extent dispersion of meteoroid orbits near the aphelion of the parent body's orbit is due to errors in photographic measurements remains interesting.

Finally, I want to make clear that in my comment on Mr. Grishchenyuk's article I did not question whether or not the decrease of the population index was real: I merely wanted to point out to the reader that another study yielded another conclusion and present some possible explanations for the discrepancy. Most likely, the analysis of the data obtained during the successful 1993 Perseid campaign will resolve the controversy. Also, I want to point out that in this issue's refereed section, Luis Bellot presents a refined method to compute the population index. This method was able to explain unexpected variations in the population index in a global analysis of the Quadrantids in which the authors of the analysis strongly suspected that the variations were spurious. Whether or not this new method is able to shed some light on the Perseid results, however, I did not examine.

Global analysis and the sporadic background

Often, the sporadic background is used to "calibrate" the results of shower analyses. George Spalding points out below that this aspect has been neglected in the global analyses of the IMO.

I would like to suggest that in all future detailed reports of major shower activity to be published in the pages of *WGN* the contemporaneous sporadic or background activity is also analyzed and reported as a useful control and comparison.

In recent years, the peak zenithal hourly rate deduced for the Quadrantids, Perseids, and Geminids in *WGN* reports has tended to be well above what tends to be quoted in the literature. In certain cases this may be ascribed to real enhancements in activity; however, the methods used in assessing shower rates may also be a contributing factor to some overcorrection.

Sporadic rates vary diurnally, and also seasonally, and there are of course random variations in activity. Subject to these caveats, however, the background sporadic rates are probably relatively stable from year to year, and therefore a useful control on the data.

The corrected sporadic hourly rate should probably lie between 2 and 25 meteors per hour, depending on time of day and year. Hence if the rates are computed as consistently much more than 30 per hour, I would be suspicious that some overcorrection for both sporadic and shower rates has occurred.

Overcorrection could result from *(i)* too high values used for the population index r, *(ii)* pessimistically quoted limiting magnitudes, and *(iii)* high perception of the observer.

As an example, I have recently seen some Japanese observations of the 1994 Quadrantids. The observational data itself is excellent. However the reporters have computed Quadrantid ZHR values of well over 200 meteors per hour from this material. However, analogous correction of their non-Quadrantid meteor rates would result in figures of typically 40 or 50 meteors per hour—quite unrealistic in my view. Therefore, I would submit that the quoted Quadrantid ZHRs are probably a factor of at least 2 too high. Hence, the contemporaneous sporadic data have given us a clue to overcorrection of shower rates.

Hence I hope that my opening suggestion is acceptable as a plausible means by which the analyst and the reader of the papers can assess the quality and accuracy of corrected shower rate data.

George Spalding, January 13, 1994

Below is a reply to George Spalding's suggestion by Rainer Arlt and Jürgen Rendtel, two prominent authors of global IMO *analyses.*

The comment of George Spalding emphasizes a problem which is well known from the analyses carried out recently. The procedures of the *VMDB* do include the calculation of the sporadic rate for each observer. In previous reports the average HR was explicitly listed (see, e.g., [1]). This was left out in more recent reports for reasons we will now explain. The term "sporadic meteor" is not well defined. The exact use of the *IMO* shower list could allow the definition of a sporadic rate. However, this is difficult during the peak period of a major shower. Most observers will report only shower and non-shower meteors. For example, a considerable number of Aquarids will contribute to the number of non-Perseids during the Perseid maximum night. Additionally, this effect depends on the observer's latitude. On one hand, this is caused by another elevation of the same radiant(s), and on the other hand there may be other radiants above the horizon. The latter case holds during the Geminid maximum for observers at northern and southern latitudes, respectively. Moreover, the reliability of associating shower members is lower during high activity. The effect of accidentally incorrect associated meteors will influence the sporadic rate much more than the major shower rate.

These considerations show that the sporadic background is not as appropriate for scaling the shower rates as it seems at first glance. Nevertheless, when we analyzed rates of a meteor shower, we check extraordinarily high or low ZHRs by, among other things, the observer's sporadic rate. Sometimes, unfortunate limiting magnitude estimates might have lead to overcorrected rates. The introduced perception coefficients, expressed as shifts in the limiting magnitude, are an attempt to solve this problem. This, however, requires that all observers providing data for the peak period have been active in the intervals chosen for this reduction as well. Unfortunately, this condition is only partly fulfilled, because many observers restrict their efforts to the night of the maximum.

[1] Roggemans P., "The Perseid Meteor Stream in 1988: A Double Maximum!", *WGN* 17:4, August 1989, pp. 127–137.

Rainer Arlt and Jürgen Rendtel, February 2, 1994

Frequently Asked Questions on Observing Methods

compiled by Rainer Arlt

How reliable is meteor angular velocity estimate in degrees per second?

As shower association with both the counting and plotting methods depends on the meteor angular velocity, observers should try to estimate the velocity during their observation. In the past, step scales from zero to five were used, now a direct estimation in degrees per second is recommended. It turned out that the estimates of medium experienced observers have scatter of 30 to 50%. The statistical uncertainty of the estimates, therefore, is the same as that of step scales, however, the systematic error is smaller. (There is no definition on how wide the steps of the speed scale are and what is the offset from zero for the first step.) Remember that the maximum angular speed is about 40°/s due to purely geometrical reasons; most meteors do not exceed 25°/s. Note that the maximum observable speed of a shower with a geocentric velocity of about 35 km/s is 20°/s. Capricornids and κ-Cygnids will hardly be faster than 10°/s. Such values restrict the range of speed estimates; reliability should be sufficient for shower association after some dozens of meteor sightings.

I could hardly distinguish the various components of the Aquarids or the Taurids. How should I note this on the observing form?

Associating a meteor with a double or multiple radiant seems to be possible only when observing fields near the radiants are employed and meteors are plotted. There is no chance of resolving the showers when the counting method is used. The human mind turns out to be quite poor at constructing great circles in the sky. You may test this for yourself the next time you see a satellite, which moves on a great circle as it traverses the sky. Try to predict its location 40° ahead and watch the satellite's motion. It will probably move several degrees off your prediction. This 40° is about the distance between Deneb (α Cygni) and Altair (α Aquilae) or between Regulus (α Leonis) and Procyon (α Canis Minoris).

If observing the shower complex is not the main goal of your watch, do not try to distinguish the components, unless you make plots. Although meteor plots are rather uncertain graphs of the meteor's path, you can associate the shower members by objective criteria after the observation. Meteor plots are still urgently needed to follow the branches of multiple radiants.

Please do not report meteor numbers of single branches in addition to total numbers of the complex. If there is a combined shower rate and rates for its branches on your observing form, all branch meteors will be put into the combined shower class to avoid misinterpretations during later analyses with respect to the total number of meteors belonging to the complex. In the case of the Taurids, either note the Northern and Southern Taurids or the Taurids in total. Do not report all three. If you simply count the meteors during the Perseids, you may report total rates for the Aquarids and Capricornids only.

About 25% of the sky was covered by houses and trees. Does this affect the cloud factor?

The answer is simple: no. The field of view has a diameter of about 100°. The number of meteors being detected outside this field is very low compared to the number of meteors seen in the field. If you find a part of the sky to watch which has a diameter of 100°, and it is not covered by clouds or terrestrial objects, your cloud factor will be 1.00, independent of the clouds of any size around your field.

Some people, however, observe from balconies. They only see half of the celestial sphere at best. Although the diameter of the observing field does not exceed 90° between the horizon and the roof, the horizontal width of the field is certainly larger than 100°. The error is really very small if we set the cloud factor (more generally: the coverage correction) to 1.00 also in these cases. I have watched several years from my balcony and have not noticed any loss in activity which would need correction.

Visual Observers' Notes: March–April 1994

Jeff Wood

In March and April, only the δ-Pavonids and the April Lyrids are active among the major showers. However, these months are characterized by a whole host of minor streams that makes observing, especially after midnight, most interesting when rates in dark skies can reach over 20 meteors per hour on occasions. As well, there is the unusual number of brilliant fireballs that emanate out of the Scorpius, Libra, Centaurus and Virgo regions. Two of these, seen on March 18, 1983, and April 6, 1975 were recorded as −19 and −15 respectively!

Table 1 lists some of the meteor showers to be seen in March and April 1994. Table 2 shows moonlight and observing conditions. The illuminated part of the Moon is always given for 0^h UT on the date indicated. The dates of the phases of the Moon are also given in UT.

Table 1 – A list of some of the meteor showers to be seen in March–April 1994.

Shower	Activity	Max	Radiant			Drift		V_∞	r	ZHR
			α	δ	Diam.	$\Delta\alpha$	$\Delta\delta$			
Virginids	Feb 01–May 30	several	195°	−04°	15°/10°			30	3.0	5
θ-Centaurids	Jan 23–Mar 12	Feb 01	210°	−40°	6°	+1.°1	−0.°2	60	2.6	
δ-Leonids	Feb 05–Mar 19	Feb 16	159°	+19°	8°	+0.°9	−0.°3	23	3.0	3
γ-Normids	Feb 25–Mar 22	Mar 14	249°	−51°	5°	+1.°1	+0.°1	56	2.4	8
δ-Pavonids	Mar 11–Apr 16	Apr 07	308°	−63°	10°/15°	+1.°2	+0.°1	59	2.6	13
Scorpid/Sagittarids	Apr 15–Jul 25	several	260°	−30°	15°/10°			30	2.3	10
Lyrids	Apr 16–Apr 25	Apr 22	271°	+34°	5°	+1.°1	0.°0	49	2.9	var
π-Puppids	Apr 15–Apr 28	Apr 23	110°	−45°	5°	+0.°6	−0.°2	18	2.0	var
α-Bootids	Apr 14–May 12	Apr 26	218°	+19°	8°	+0.°9	−0.°1	20	3.0	3
η-Aquarids	Apr 19–May 28	May 03	336°	−02°	4°	+0.°9	+0.°4	66	2.7	50

Table 2 – Moonlight and observing conditions in March–April 1994.

Date	k	Date	k
Friday February 25	0.98+	Friday April 01	0.73−
Friday March 04	0.58−	Friday April 08	0.08−
Friday March 11	0.02−	Friday April 15	0.14+
Friday March 18	0.27+	Friday April 22	0.80+
Friday March 25	0.91+	Friday April 29	0.86−

New Moon:	March 12, April 11, May 10
First Quarter:	March 20, April 19, May 18
Full Moon:	February 26, March 27, April 25
Last Quarter:	March 4, April 3, May 2

1. Virginids

This shower is very complex and is active from February 1 through to May 30. There are many subradiants and submaxima. Observers are encouraged to continue the project outlined in the Visual Observers' Notes for January and February 1994 [1].

2. γ-Normids

This shower is often misnamed the Corona Australids due to a transcription error by the great New Zealand meteor worker R. McIntosh in 1935. The γ-Normids are active from February 25 through to March 22. A variable maximum of 3 to 15 meteors per hour occurs on March 14. They are fast meteors and are best seen from the southern hemisphere in the pre-dawn hours. With favorable Moon conditions, the *IMO* urgently requires observations of this stream. Observers should locate their field center no more than 40° away from the radiant and plot all possible γ-Normids seen. If observers wish to monitor both the δ-Pavonids and the γ-Normids, the field center must be located around $\alpha = 270°$ and $\delta = -55°$.

Table 3 – Radiant positions of the γ-Normids.

Date	α	δ	Date	α	δ
Feb 25	234°	−53°	Mar 14	249°	−51°
Mar 03	237°	−52°	Mar 19	254°	−50°
Mar 08	242°	−52°	Mar 22	258°	−50°

3. δ-Pavonids

The δ-Pavonids are thought to have been formed from the debris of Comet P/Grigg-Mellish (1907 II). Observations to date indicate that the shower produces variable activity with rates at maximum varying in the range of 5 to 15 meteors per hour. With the radiant reaching its greatest altitude in the southern hemisphere skies in the pre-dawn hours, the δ-Pavonids should provide moon-free viewing for most of their period of activity except from March 22 to 31. The δ-Pavonids appear to have several sub-maxima during the period March 30 to April 10, apart from the major maxima that occurs on the morning of April 7. With this in mind, southern-hemisphere observers are encouraged to give the δ-Pavonids particular attention in 1994. They should locate their field center no more than 40° away from the radiant and ensure that all meteors seen are plotted.

Table 4 – Radiant positions of the δ-Pavonids.

Date	α	δ	Date	α	δ
Mar 11	296°	−65°	Apr 05	307°	−63°
Mar 21	301°	−64°	Apr 10	309°	−63°
Mar 31	305°	−63°	Apr 15	311°	−62°

4. April Lyrids

The Lyrids are active from April 16 to 25 reaching a maximum of between 10 and 15 meteors per hour on April 22. On a few occasions, the most recent being in 1982, rates have been much higher almost reaching 100 meteors per hour. The Lyrids' parent body is Comet P/Thatcher (1861 I). In 1994, the Lyrids are heavily affected by the Moon. Observations should only be made if the limiting magnitude exceeds +5.5.

Table 5 – Radiant positions of the Lyrids.

Date	α	δ	Date	α	δ
Apr 16	265°	+34°	Apr 22	271°	+34°
Apr 19	268°	+34°	Apr 25	274°	+34°

5. α-Scorpids

The α-Scorpids are one of the major components of what Hoffmeister called the Scorpio-Sagittarius complex of showers. This ecliptic stream is active from March 26 to June 4 with a broad maximum of between 4 and 8 meteors being reached during early May. The α-Scorpids are well known for the many brilliant yellow, orange and green fireballs they produce. Few, however, leave a persistent train.

With a velocity V_∞ of 35 km/s, and several other Scorpio-Sagittarid radiants active in the same region of the sky, especially in May and early June, special care needs to be taken when recording and classifying these meteors. Observers should plot all possible α-Scorpids seen. They should center their field of view no more than 30° from the radiant.

Table 6 – Radiant positions of the α-Scorpids.

Date	α	δ	Date	α	δ
Mar 26	236°	−21°	May 05	246°	−24°
Apr 05	238°	−21°	May 15	249°	−25°
Apr 15	241°	−22°	May 25	252°	−25°
Apr 25	244°	−23°	Jun 04	254°	−26°

6. π-Puppids

The π-Puppids are a young meteor shower having been recorded only over the last 20 years. Their parent body is comet P/Grigg-Skjellerup. The π-Puppids are a periodic shower occurring in great numbers every five years. Rates therefore range from almost zero up to 40 per hour. The last strong activity was in 1987.

The π-Puppids are a southern hemisphere shower and are best seen during the early evening hours. They are very slow meteors and often have a yellow-orange hue. Many fireballs are produced.

With the Full Moon occurring on April 25, the shower's viewing conditions are adversely affected in 1994. In spite of this, observers are encouraged to watch for members of the shower to confirm or deny a strong return in 1994. They should center their field no more than 40° from the radiant and plot all possible π-Puppids seen unless the rate exceeds 10 per hour when counts are permitted.

Table 7 – Radiant positions of the π-Puppids.

Date	α	δ	Date	α	δ
Apr 17	106°	−44°	Apr 23	110°	−45°
Apr 20	108°	−45°	Apr 26	112°	−46°

7. Theoretical radiants of 1863 Antinous and 1981 Midas

The Earth has a closest approach to the orbit of the minor planet *1863 Antinous* on April 6 (distance: 0.178 AU). Possible meteors have a V_∞ of 19.6 km/s and should radiate from $\alpha = 204°$, $\delta = +32°$ (April 6), $\alpha = 212°$, $\delta = +31°$ (April 16) [2].

A closest approach with the orbit of *1981 Midas* occurs on March 20 (distance: 0.001 AU). Possible meteors have a V_∞ of 30.1 km/s and a radiant at $\alpha = 205°$, $\delta = +35°$ (March 10), $\alpha = 213°$, $\delta = +34°$ (March 20) [2].

The orbits of both asteroids come close to that of the Earth's and the values of V_∞ make it possible to observe showers related to one or both objects. Due to the close approach and the high V_∞, 1981 Midas is the more favored candidate. The theoretical radiant positions provide northern hemisphere observers with the better viewing conditions though they can be observed in both hemispheres in the evening skies.

It should be noted that the theoretical radiant positions may differ somewhat from the actual observed ones by some degrees. This means that it is impossible to carry out shower associations and obtain ZHRs using standard observing procedures. What needs to be done is to investigate whether or not there is a significant radiant in the vicinity of the predicted one. In order to do this, observers should center their field of view at a distance of less than 20° from the predicted radiant position and plot all meteors seen that radiate from an area of about 25° around the predicted radiant position onto the Atlas Brno gnomonic charts. The X,Y-coordinates of the plots should be measured (see [3]) and reported in the table format described in the Aquarid Project (see [4]). Please, of course mention the chart number.

In 1994, the *IMO* requests that observers watch the 1863 Antinous radiant from April 3 to 21 and 1981 Midas from March 7 to 22.

All possible meteors from these radiants should be plotted.

Table 8 – Radiant positions of possible 1863 Antinous shower.

Date	α	δ	Date	α	δ
Mar 27	195°	+33°	Apr 11	208°	+32°
Apr 01	199°	+33°	Apr 16	212°	+31°
Apr 06	204°	+32°	Apr 21	216°	+31°

Table 9 – Radiant positions of possible 1981 Midas shower.

Date	α	δ	Date	α	δ
Mar 05	201°	+36°	Mar 20	213°	+34°
Mar 10	205°	+35°	Mar 25	217°	+34°
Mar 15	209°	+35°	Mar 30	220°	+33°

8. α-Bootids

This shower can be seen from April 14 to May 12. With a maximum on April 26 most of its period of activity is affected by the Moon.

Table 10 – Radiant positions of the α-Bootids.

Date	α	δ	Date	α	δ
Apr 16	207°	+20°	Apr 28	218°	+19°
Apr 20	211°	+20°	May 02	222°	+19°
Apr 24	214°	+19°	May 06	225°	+18°

References

[1] J. Wood, M. Gyssens, "Visual Observers' Notes: January–February 1994", *WGN* 21:6, December 1993, pp. 249–252.

[2] Duncan Olsson-Steel, "Theoretical Meteor Radiants of Recently Discovered Asteroids and Comets and Twin Showers of Known Meteoroid Streams", *Australian Journal of Astronomy*, April 1988, pp. 93–101.

[3] R. Koschack, "Comments for Visual Observers", *WGN* 18:6, December 1990, pp. 197–198.

[4] R. Koschack, J. Rendtel, "Aquarid Project 1989", *WGN* 17:3, June 1989, pp. 90–92.

Change of address

Please note that the author's address has changed. The correct address can be found on the inside back cover.

Telescopic Observers' Notes: March–April 1994

Malcolm J. Currie

The year 1993 ended in keeping with the rest of the year with few telescopic observations. This is disappointing as the moonlight in 1993 favored many of the major showers. The most notable recent data being those of of Chris Hall (8.5 × 44 binocular, 5°6 field, lm +10) from Stoke in the English Midlands. Chris ignored the gloomy weather forecast on the night of Geminid maximum; skies cleared after midnight, and Chris was rewarded with 27 meteors in 2^h53, of which almost half appear to have been Geminids. This confirms recent results that the Geminids currently give the best telescopic show of the year.

Forthcoming events

The year 1994 is not going to be favorable for the major showers, so I should like telescopic observers to focus on the minor showers this year. March and April are not reknown for spectacular meteor activity and indeed the sporadic rate reachs its low tide. These months have been neglected by most optical observers for this very reason. One has to trawl the archives over a few years to get more than a handful of reports. Yet this paucity of meteors, somewhat surprisingly, can be one of the attractions to the enterprising observer. A campaign of a few hours observing each clear dark night could well reveal previously unknown radiants, especially if made after midnight local time and away from the celestial equator. Shorter sessions might suggest tantalizingly of a new radiant, but for the statistics to be significant, long sessions are really needed. The lower sporadic rate will help to discriminate weak showers too. Choose from charts from either a northern group: 54–69; or from an equatorial set: 122–130; but do not mix charts from the sets. Do not use adjacent charts, but rather work with pairs displaced by about 30°, for example, 61 and 64. As the night progresses choose another pair east of the current field centers.

These same equatorial charts will also permit you to study the best-known minor shower of this period—the *Virginids*. This is in fact composed of numerous weak and temporally overlapping showers clustered around the ecliptic that last from February to May. The showers are famed for their slow, long meteors. Their moderate speed increases their probability of being observed telescopically, and the showers are rich in faint meteors. Several maxima have been claimed to exist, presumably due to the separate radiants. There is great uncertainty as to the durations and locations of these components. Indeed historical radiant information has many conflicts. This may reflect on the transient properties of certain sub-centers and/or the density of the radiants and observational errors making shower discrimination very difficult. Only by careful plotting by numerous *IMO* visual and telescopic observers over many years will it be possible to find out the true behavior of this shower. Alastair McBeath's analysis of just 69 meteors [1] shows what can be achieved even from cloudy Britain. Observers at more southern latitudes should see even more Virginids.

The observing strategy is slightly different from the radiant hunting in that at least three fields should be used. This is because an apparent radiant seen from several field centers is far less likely to have arisen by chance alignments. In March charts 124, 125, and 126 are preferred, and in April the best ones are 125, 126, and 128 to follow the eastward motion of the Virginid complex. It should be possible to combine Virginid and shower-hunting investigations for most of the night. In March you can also follow the decline of the *δ-Leonids*. Use chart 159 as well to locate its radiant more accurately. Remember to take care to plot the meteor paths as carefully as you can, especially the orientation; shower rates are low so make every meteor count.

Southern observers might also like to tackle the δ-Pavonids during April's dark time. Their radiant is elongated and may contain distinct sub-centers. Visually, sub-maxima have been recorded, lending weight to that speculation. Careful plotting should resolve major sub-components. One pair of field centers are $\alpha = 268°$, $\delta = -35°$ and $\alpha = 176°$, $\delta = -65°$. If the altitudes of the field centers permit, centers closer to the radiant than these are desirable.

Moonlight interferes badly with the Lyrid shower. Pre-dawn sessions after the moon has sunk low or set are possible. Suitable charts are 69 and 84. Some data from 1971 suggests that the shower is active telescopically a week before it is seen visually. This can be checked. However, because of the radiant's motion substitute chart 83 for 84 for observations before April 18.

References

[1] A. McBeath, "UK Visual Results for the Virginids, 1988–1992", *WGN* 20:6, 1992, pp. 227–237.

Recently Discovered Earth-Grazing Asteroids

Dirk Artoos

There might *possibly* be very sharp shower activity from the recently-discovered asteroids listed in Table 1. In all instances, the closest approach is at less then 0.1 AU.

Table 1 – Orbital data for the asteroids 1993 VA, 1993 UC, and 1993 VW.

El.	1993 VA	1993 UC	1993 VW
q	0.8228459 AU	0.8239747 AU	0.8741161 AU
a	1.3710674 AU	2.4408678 AU	1.6955121 AU
e	0.3998501	0.6624255	0.4844530
Ω	133°61469	165°92721	231°33417
ω	336°09972	322°93392	280°90988
i	7°41287	25°76144	8°68228
P	1.61 year	3.81 year	2.21 year

For 1993 VA, I found the closest approach to the Earth to be on March 12 ($\lambda_\odot = 351°38$, eq. 2000.0) at a distance of 0.08407 AU, with a low velocity $V_\infty = 15.74$ km/s and a radiant at $\alpha = 16°49$ and $\delta = -17°57$.

For 1993 UC, I found the closest approach to the Earth to be on March 12 ($\lambda_\odot = 352°08$) at a distance of 0.0882 AU, with a velocity $V_\infty = 23.34$ km/s and a radiant at $\alpha = 35°71$ and $\delta = -43°16$.

For 1993 VW, I found the closest approach to the Earth to be on April 19 ($\lambda_\odot = 28°97$) at a distance of 0.06335 AU, with a low velocity $V_\infty = 16.45$ km/s and a radiant at $\alpha = 49°31$ and $\delta = -07°23$.

Source: M.P.E.C. 1993-U11; 1993-WO3, 1993-YO3

However, do not forget to watch for activity from well-know earth-grazing asteroids (Table 2).

Table 2 – Possible meteor activity from earth-grazing asteroids in March, April, and May 1994.

Name	$\lambda_\odot$	α	δ	V_∞	d	Date
Geographos	353°49	194°01	+34°	16.15 km/s	0.08045	Mar 13
Midas	357°17	213°6	+33°61	30.10 km/s	0.00038	Mar 17
Aristaeus	10°49	29°59	−36°58	21.14 km/s	0.0103	Mar 31
Bacchus	11°16	351°09	+21°97	16.1 km/s	0.06751	Apr 1
Apollo	51°98	233°08	−07°54	20.3 km/s	0.03126	May 12

Meteor Summer School Announcement

Oleg Belkovich, Kazan University

We are going to organize on behalf of the *IMO* a summer school for radio observers at the Kazan University in Russia. We can admit up to 20–30 people. The cost would be about 20 dollars per day including meals and lodging, and will not depend on the number of participants. We can organize lectures on meteor astronomy and the theory of radar and forward scatter observations of meteors (in English); as well there will also be room for a cultural program. The event will be held in July or August 1994 over a period of 10–15 days. All participants have to come to Moscow where our representative will meet them and distribute train tickets to Kazan (return tickets costs about 15 USD). The Kazan University is the center of meteor research in Russia. There are about 30 people working in meteor astronomy and in meteor communications system design. The sophisticated meteor radar works continuously. I would ask all the people interested in taking part in the summer school to contact me before April 15 and answer the following questions:

1. Which period(s) is (are) most convenient for you?
2. What subject in meteor astronomy would you like to have as a lecture?

Please communicate via electronic mail only. My address is `oleg@astro.kazan.su`.

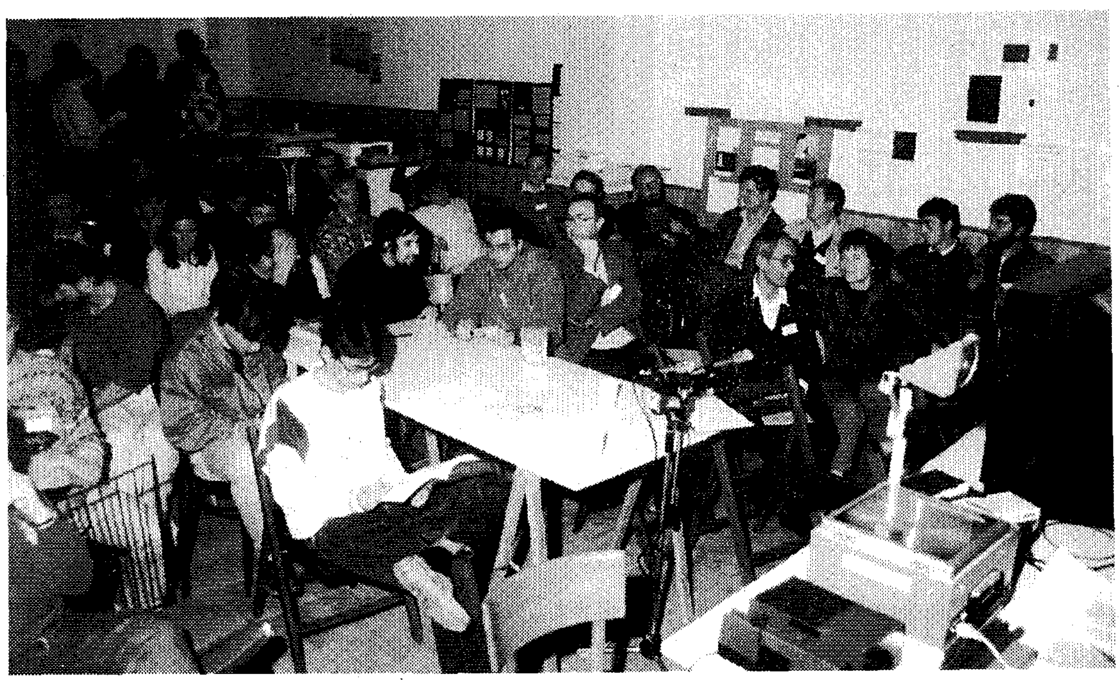


Figure 1 – In between lectures at the 1993 *IMC* in Puimichel. Clearly recognizable in the foreground, reading, is Luis Bellot, author of the following article. On the other side of the table, we see two professional participants, Dr. Ibadov and Dr. Terentjeva.

Progress in Meteor Science

Articles in this section have been formally refereed by at least one professional and one experienced, knowledgeable amateur meteor worker, and deal with global analyses of meteor data, methods for meteor observing and data reduction, observations with professional equipment, or theoretical studies.

Dependence of the Population Index on the Radiant Zenithal Distance

Luis Ramón Bellot Rubio

By integrating the differential equation system of the single-body meteor theory which describes meteor flight in the atmosphere, we show that the population index r depends on the radiant zenithal distance z_R. When z_R is large, r diminishes, requiring correction in order to obtain reliable number density profiles. A new method is proposed to correct the population index when $z_R \neq 0°$. Its application to the problem of the 1992 Quadrantids raised by Rendtel et al. [1] shows that corrected values of r vary from $r = 2.32$ to $r = 2.44$ between $\lambda_\odot = 283.^\circ 00$ and $\lambda_\odot = 283.^\circ 23$.

1. Introduction

One of the most important parameters when analyzing a shower is the population index r, which gives information about the mass distribution inside the stream. The spatial number density ρ is computed from r and its reliability strongly depends on the correct determination of r. Therefore it is necessary to obtain good values for r if we want to derive accurate density profiles.

In particular, we need real population indices, i.e., those which are free from observational conditions and which represent the actual physical particle distribution of the stream in space. Recently, a global analysis of the 1992 Quadrantids [1] has raised a very important question: does the value of r depend on the radiant zenithal distance? If this is indeed the case, we should correct the estimates of r obtained from observational data, since we would be using population indices affected by external conditions; useless to derive further structural parameters (such as mass index and number densities).

In the analysis by Rendtel et al. [1], an increase of r from $r = 2.1$ to $r = 2.4$ during a period of only six hours is discussed. The authors suggest as a possible explanation that the change is not due to a real increase in smaller particles inside the stream, but most probably a result of a dependence on entry angle of the transformation process of the particle's kinetic energy into visible radiation. Such a hypothesis is based on the fact that the radiant moved from a zenithal distance $z_R \approx 70°$ at the beginning of the period to $z_R \approx 30°$ at the end of the period.

To find out whether the suggested explanation is true or not, the first step is obtaining the intensity I radiated by a given particle as a function of the entry angle in the atmosphere. From the experimental point of view, the problem is very difficult to solve, since it requires that the meteors enter at different radiant zenithal distances but with all other conditions held exactly the same; something which never happens in practice. Therefore the only approach to the problem is the theoretical one.

In principle, r can depend on the radiant zenithal distance because, if $z_R \neq 0°$, the meteoroid finds a gradient of atmospheric density which is much smaller than that for the case $z_R = 0°$. As a consequence, the mass loss is slower and the particle emits less energy in the form of visible radiation. Due to the change in brightness (equivalently, in magnitude), r also changes.

In this paper, we present the physical theory of meteors and its application to developing a new method which corrects the population index when z_R is different from zero. We conclude by considering the variation of r during the maximum of the Quadrantids in 1992.

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WGN, the Journal of the International Meteor Organization, Vol. 22, No. 1, February 1994, pp. 13–26.

In this paper, we present the physical theory of meteors and its application to developing a new method which corrects the population index when z_R is different from zero. We conclude by considering the variation of r during the maximum of the Quadrantids in 1992.

2. Meteoroid-atmosphere interaction: the single-body theory

In order to calculate the magnitude m of a meteoroid of mass M which moves with velocity v entering the atmosphere at angle z_R with respect to the normal, it is necessary to obtain the intensity I emitted in each instant. To this end we will use the single-body theory [2], together with some results from the physics of rarefied gases.

The single-body theory describes the deceleration, mass loss and luminosity of a nonfragmenting particle which moves in the atmosphere. There are strong evidences in favor of quasi-continuous fragmentation during the flight of visual meteors [3]. Trying to explain some features of the light curve of faint meteors, Jacchia [4] proposed a porous dustball structure for meteoroids. The behavior of such meteoroids would differ from that of compact, nonfragmenting particles as regards the maximum intensity emitted. Nowadays, the dustball hypothesis is widely accepted by meteor scientists, but surprisingly our knowledge of the structure of cometary meteoroids is still very incomplete [5, 6]. For this reason, we prefer to use the single-body theory as a first approximation to our problem, in spite of the fact that there exists a model for the ablation of dust-ball meteoroids [6]. By applying the single-body theory we will obtain less accurate results, but in any case the general trend of the solution will be correct.

Suppose that the radiation intensity I of the meteor is a fraction τ of the kinetic energy of mass dM evaporated during time dt. This hypothesis has been confirmed by means of photometric and spectroscopic observations. Then the luminosity equation of the single-body theory turns out to be

$$I = \tau \left(-\frac{dM}{dt} \right) \frac{v^2}{2}, \tag{1}$$

where I represents the energy radiated in a solid angle of 4π sterad per unit time. We measure I in erg/s. The dimensionless coefficient τ is called the luminous efficiency and it typically ranges between 3×10^{-4} and 2×10^{-2}.

The coefficient τ does seem to depend on the velocity of the meteoroid and perhaps also on other parameters such as mass. However, no conclusive results are available so far. For faint meteors with $v > 24$ km/s, it was customary to use the so-called model B of Öpik, which assumes $\tau = \tau_0 v^n$ and $n < 0$. Observational values of n are contradictory, which demonstrates that this model is too simple. Consequently, we decided to adopt the following experimental determination of τ [7]:

$$\tau(v) = \begin{cases} 6.04 \times 10^{-4} \, (v - 8.8)^{-0.35} & \text{if } v \leq 16 \text{ km/s;} \\ 0.024 \, (v + 8.8)^{-1} & \text{if } v > 16 \text{ km/s,} \end{cases} \tag{2}$$

where v is in km/s.

From equation (1) it is evident that we need to know the mass loss dM/dt and the instantaneous velocity v to obtain the intensity I. These parameters are computed from the two last equations of the single body theory.

Let us suppose that the momentum loss $M dv$ by the meteoroid is a fraction Γ of the momentum carried by the oncoming air flow. The particle intercepts during time dt a mass $S\rho v dt$, S being the midsectional area of the meteoroid and ρ the atmospheric density. Thus the deceleration equation of the single-body theory reads

$$M \frac{dv}{dt} = -\Gamma S \rho v^2. \tag{3}$$

The drag coefficient Γ may be less or greater than unity. The latter situation occurs when many colliding atmospheric molecules or evaporated molecules rebound from the body surface and gain a reactive moment in the direction of $\vec{v}$.

The energy expended in ablation of meteoric material comes from the kinetic energy of the impinging molecules. We will assume that a fraction Λ of the kinetic energy $\frac{1}{2}S\rho v^3 dt$ of the oncoming air flow is used in evaporating the meteoric mass dM during time dt. Under such a hypothesis, the mass loss equation of the single body theory can be written as

$$\frac{dM}{dt} = -\Lambda\frac{S\rho v^3}{2Q}, \tag{4}$$

where Λ is called the heat transfer coefficient and Q is the latent heat of vaporization in erg/g. Unlike the drag coefficient Γ, Λ must be less than unity because the energy expended in ablating the meteoroid cannot be greater than the total kinetic energy input.

In order to eliminate S in equations (3) and (4), we introduce the shape factor A, defined as

$$A \equiv \frac{S}{V^{2/3}} = SM^{-2/3}\delta^{2/3},$$

where δ and V are the density and volume of the particle. If the shape of the body does not change during the flight, A is a constant equal to 1.21 for a sphere.

In this way, the three basic equations of the single body theory become

$$I = \tau\left(-\frac{dM}{dt}\right)\frac{v^2}{2}; \tag{5}$$

$$\frac{dv}{dt} = -\Gamma A\delta^{-2/3}\rho M^{-1/3}v^2; \tag{6}$$

$$\frac{dM}{dt} = -\frac{\Lambda A}{2Q}\delta^{-2/3}\rho M^{2/3}v^3. \tag{7}$$

The meteor height above the Earth's surface, h, is obtained from the following auxiliary condition:

$$\frac{dh}{dt} = -v\cos z_R. \tag{8}$$

The atmospheric density ρ appears in equations (6) and (7). If we use an exponential model, i.e.,

$$\rho(h) = \rho(h_o)e^{-bh},$$

and Λ and Γ are assumed to be constant, the system (6)–(8) has an analytical solution [2]. However, the atmosphere is far from exponential and the coefficients Λ and Γ change during the flight by more than 80%. A better approximation for ρ is the density of the U.S. Standard Atmosphere of 1976 [8]. Also, the coefficients Λ and Γ play a vital role because they describe a very important part of the meteoroid-atmosphere interaction. In order to study the variation of the meteor intensity with the entry angle, we should take them into account.

As already mentioned, Γ represents the fraction of the atmospheric molecules' momentum transferred to the meteoroid, and Λ the fraction of the oncoming air flow kinetic energy which is used in ablating the body. The efficiency of these processes depends, for example, on the number of atmospheric or evaporated molecules in front of the meteoroid. When this number is high, molecules reflected or evaporated from the surface collide with impinging molecules and they protect the particle from some of the impacts. Therefore a thermal and aerodynamical shielding which diminishes Γ and Λ is set up. In general, we can write

$$\Gamma = \alpha_\Gamma\,\Gamma_\infty;$$
$$\Lambda = \alpha_\Lambda\,a_e,$$

where α_Γ and α_Λ are known as aerodynamic and thermal shielding coefficients, respectively. In the above equations, Γ_∞ is the value of Γ in the absence of shielding. The accommodation coefficient a_e was approximated by Levin [9] using the Langmuir and Compton theory of elastic molecular collisions, and turns out to be

$$a_e = \frac{(3+\mu_*)\,\mu_*}{(1+\mu_*)^2},$$

with $\mu_* \equiv \mu_a/\mu_m$, the ratio of the relative masses of atmospheric and meteoric molecules. According to Saidov and Šimek [10], we may use $\mu_m = 30.8$, whilest μ_a is obtained from the U.S. Standard Atmosphere for each height h.

If a body has hypersonic velocity in a given medium (in our case, the air), the oncoming molecules may flow around it in certain ways. We then say that the body moves in different flow regimes. The coefficients α_Γ and α_Λ are determined by the flow regime in which the meteoroid moves. The flow regime is specified by the so-called Knudsen number Kn, defined as the ratio of the mean free path l_r of the reflected molecules in a frame fixed to the body and the characteristic dimension of the particle (for example, its radius R). However, when defining l_r one should remember that there is an enormous difference between the velocities of the reflected and oncoming atmospheric molecules: while the former are supposed to move with the thermal velocity $\bar{v}_r$ corresponding to the meteoroid surface temperature T, the latter move with velocity v in the meteoroid's reference frame. As $\bar{v}_r \ll v$, the collisions between reflected and oncoming molecules are very numerous and the actual mean free path l_r is smaller than that obtained when the only processes accounted for are the collisions between reflected molecules. Thus we may write

$$l_r = \frac{\bar{v}_r}{n_i v \sigma_\circ},$$

where n_i and v are the number density and velocity of the oncoming molecules (which coincides with the meteoroid velocity in the selected frame), $\sigma_\circ$ the collision cross section for atmospheric molecules ($\sigma_\circ = 4.28 \times 10^{-15}$ cm^2), and

$$\bar{v}_r = \left(\frac{8kT}{\pi m_a}\right)^{1/2}. \tag{9}$$

As usual, k stands for the Boltzmann constant, m_a being the mass of the atmospheric molecules.

Explicitly, the Knudsen number is given by

$$Kn \equiv \frac{l_r}{R} = \frac{\bar{v}_r}{n_i v \sigma_\circ R}.$$

The number density entering the expression for Kn can be obtained from the U.S. Standard Atmosphere. As regards T, we will follow Lebedinets and Portnyagin [11] for the case of large enough meteoroids:

$$T = \frac{\Lambda \rho v_\circ^3 R}{8\lambda\left(\frac{R}{x_\circ}\coth\frac{R}{x_\circ} - 1\right)} + T_\circ. \tag{11}$$

In the above equation, $v_\circ$ represents the initial velocity of the body, λ the thermal conductivity of the meteoric material, and $x_\circ$ the depth of heat penetration, defined as

$$x_\circ = f\sqrt{\frac{H^*}{v_\circ \cos z_R}},$$

where H^* stands for the atmospheric density scale height, and $f \approx 0.045$ cm s$^{-1/2}$.

During the first part of the trajectory, the meteoroid heats up from T_o (outer space temperature, approximately 280 K) to the fusion temperature T_f. We will assume $T_f = 2580$ K [12]. Once this point is reached, all the energy brought in by the oncoming flow goes into evaporation, and $T \approx T_f$.

Let us return to the problem which led us to define Kn: the calculation of Γ and Λ. Following Bronshten [2], under any flow regime the coefficient Γ is equal to that given by Barantsev [13]:

$$\Gamma = \Gamma_o + (\Gamma_\infty - \Gamma_o)\Phi(x).$$

Here, Γ_o and Γ_∞ represent the value of Γ when $Kn = 0$ and $Kn = \infty$, respectively. In the case of a sphere, $\Gamma_o = 0.46$ and $\Gamma_\infty = 1.15$ [2, 14]. In the above equation, x and Φ are defined by

$$x = \frac{\log Kn + a_*}{\sigma_*};$$

$$\Phi(x) = \frac{1}{2}\left(1 + \operatorname{erf}\frac{x}{\sqrt{2}}\right),$$

where $a_* = 0.88 \pm 0.26$ and $\sigma_* = 0.77$ for many bodies.[1]

If $Kn \geq 3$, the meteoroid moves in the *first collisions regime* [15]. In such a regime, the only significant effect producing shielding is the collision of atmospheric molecules reflected from the body surface with oncoming molecules (thus diminishing the net rate of impacts over the meteoroid), and α_Λ can be obtained from

$$\alpha_\Lambda = 1 - \varepsilon\sqrt{\frac{8}{\pi}}\frac{1}{Kn}\frac{g'_\Lambda}{g_{o\Lambda}},$$

where $g_{o\Lambda}$ is the flux of energy in the absence of shielding, g'_Λ the increment due to first collisions and ε a parameter determined from comparison with experiments ($\varepsilon = 1.6$ [13]). Values for g'_Λ and $g_{o\Lambda}$ in the case of a sphere can be found either in [2] or [13].

If $Kn < 3$ and $\rho R < 5 \times 10^{-8}$ g/cm^2, the meteoroid moves in the *transition regime*. In this regime, encounters of evaporated molecules with impinging atmospheric molecules are no longer negligible and

$$\alpha_\Lambda = \frac{1}{1+k}, \tag{12}$$

with

$$k = \bar{\eta}\xi\frac{a_e}{2Q}\mu_* v^2. \tag{13}$$

In the above equation, $\bar{\eta}$ represents the fraction of evaporated molecules which participate in the shielding, which does depend on l_e/R. Furthermore, l_e is the mean free path of the evaporated molecules (taking into account the difference between the velocities of evaporated and oncoming molecules, as before) in a frame which moves with the particle:

$$l_e = \frac{\bar{v}_e}{n_i v \sigma_d}.$$

We compute $\bar{v}_e$ from equation (9) by writing m_m instead of m_a. The collision cross section for meteoric molecules, σ_d, amounts to $\sigma_d = 5.6 \times 10^{-11}\, v^{-0.8}$ [16] if v is in cm/s.

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[1] In the above equation, the function erf is defined by $\operatorname{erf} y = \frac{2}{\sqrt{\pi}}\int_0^y e^{-t^2}dt$.

Bronshten gives $\bar{\eta}$ for a sphere when $1/8 \leq l_e/R \leq 4$. Since this range is too small, we will extrapolate $\bar{\eta}$ with

$$\bar{\eta} = \begin{cases} 0.488\,(l_e/R)^{-1/4} & \text{if } l_e/R < 1/8; \\ 0.302\,(l_e/R)^{-5/3} & \text{if } l_e/R > 4. \end{cases} \tag{14}$$

The factor ξ appearing in equation (13) takes into account the fact that some colliding molecules are pushed toward the particle and transfer their kinetic energies to it. Approximately, $\xi = 0.33$ [2].

The meteoroid enters the *intense evaporation regime* when $Kn < 3$ and $\rho R \geq 5 \times 10^{-8}$ g/cm^2. For a cylindrical body, the value of the coefficient Λ turns out to satisfy [17]

$$\Lambda = e^{-\Lambda \frac{\xi v^2}{3Q}}. \tag{15}$$

This scenario is far from complete: the range $5 \times 10^{-10} \leq \rho R \leq 5 \times 10^{-8}$ g/cm^2 is not described satisfactorily by any model. Bronshten recommends the use of equation (12) together with (13) while $\rho R < 5 \times 10^{-8}$ g/cm^2, but this produces a discontinuity in Λ when the particle begins to move in the intense evaporation regime and we switch to equation (15). Moreover, the shape of the meteoroids could be very different from that of a cylinder, so equation (15) could produce erroneous values for Λ. In order to overcome these problems, we will only analyze particles small enough not to reach the intense evaporation regime.

3. Calculation of the intensity emitted by a meteoroid

We can now perform a numerical integration of the equation system (6)–(8) and obtain the intensity I as a function of t and z_R. The initial conditions read

$$\begin{aligned} v(t=0) &= v_\circ; \\ M(t=0) &= M_\circ; \\ h(t=0) &= h_\circ. \end{aligned}$$

For each instant t, the height h and the atmospheric density $\rho(h)$ are calculated. With them, we determine the Knudsen number Kn in order to find out the flow regime in which the meteoroid moves. Then we can select the correct Λ and Γ coefficients. The last step is the calculation of $M(t)$, $v(t)$, and dM/dt, which allows us to compute I with the help of τ.

We use cubic splines to interpolate the U.S. Standard Atmosphere. The differential equation system is solved with a fourth-order Runge-Kutta algorithm of constant step size ($\Delta t = 0.005$ s). Figure 1 shows the results of the integration for a particle with mass $M_\circ = 0.28$ g, $v_\circ = 41$ km/s and $z_R = 0°$. We set $h_\circ = 180$ km since at this height the mass loss is negligible.

Some physical parameters of the meteoroids are either characteristic of the stream under analysis or not well known. At first sight, one could think that these uncertainties affect the intensity I in such a way that no general results can be extracted from the calculations. However, this is not the case because we are interested in magnitude differences, not in the absolute value of I. This ensures that the uncertainties cancel out for meteoroids of the same stream, and also that the results are valid for streams of different physical properties.

A good illustration of the above-mentioned problem is the effect of the luminous efficiency τ. The value of I strongly depends on the value of τ. We adopted experimental values of τ which lie in the lower limit of the interval $3 \times 10^{-4} \leq \tau \leq 2 \times 10^{-2}$. For this reason, we will obtain small intensities, but τ acts as a scale factor and thus cancels out when we compute the difference of magnitudes.

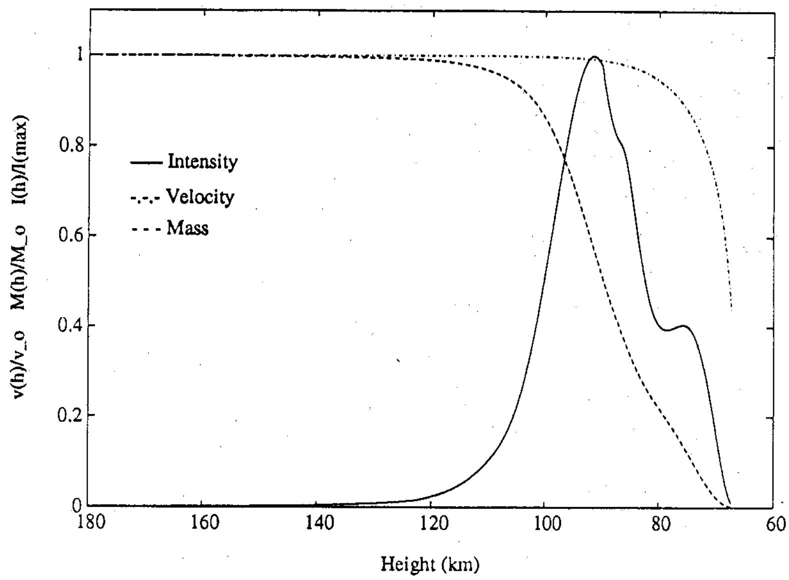

Figure 1 – Mass loss, deceleration, and intensity of a meteoroid with initial parameters $M_o = 0.28$ g, $v_o = 41$ km/s and $z_R = 0°$ in the single-body-theory approximation. The maximum intensity is $I_{max} = 1.92 \times 10^9$ erg/s.

The same phenomenon occurs with the meteoroid density δ. We choose $\delta = 0.27$ g/cm^3, but in reality meteoroids from different streams have different densities, ranging from 0.01 to at least 1.5 g/cm^3. However, the value of the density does not alter the results since δ behaves as a scale factor for I too. This can be easily proven by noting that $dv/dt \approx 0$ during most of the trajectory (whence δ does not influence the velocity too much) and that δ propagates from equation (7) to equation (5) as a constant.

The latent heat of vaporization Q does *not* behave as τ and δ since it modifies the heat transfer coefficient Λ in the transition regime (see equation (13)). Thus Q is a very critical parameter. During the calculations we use $Q = 8 \times 10^{10}$ erg/g, the representative value for stony and iron materials, but another value might be required for cometary meteoroids.

Numerical tests were performed to find out the dependence of the intensity I on the meteoroid surface temperature T, which turned out to be almost nonexistent. The reason for this is that T reaches the maximum value $T_{max} = 2580$ K at the early stages of the trajectory, far from the point of maximum intensity, and then remains constant (and no longer affects the Knudsen number). In order to compute T, we have to assume a value for the thermal conductivity λ. We select $\lambda = 2 \times 10^4$ erg cm^{-2} s^{-1} K^{-1}, which corresponds to friable stone. However, the knowledge of the correct λ-value is not very critical because of the already mentioned weak dependence of the intensity I on T.

Any modification of h_o, the expression for $\bar{\eta}$, or the limit between the transition regime and the first collisions regime do not alter the final results in a fundamental way. Together with the above comments, this suggest that the calculations are valid even if the meteor flight is in reality described by slightly different values. The only important unknown parameter is Q.

As was demonstrated by Koschack and Rendtel [18], the population index does not depend on the field of view selected for observing, and therefore is independent of the observer-meteoroid distance. This fact simplifies the problem, since we will only have to deal with absolute magnitudes. In general [19, 20] the observer uses the maximum brightness I_{max} of the meteors to estimate their magnitudes. Thus the absolute magnitude of a meteoroid of mass M_o and velocity v_o belonging to a shower with a radiant zenithal distance z_R is

$$m_{abs}(M_o, v_o, z_R) = 6.5 - 2.5 \log \frac{I_{max}(M_o, v_o, z_R)/4\pi d^2}{9.6 \times 10^{-9}}, \qquad (16)$$

in which we have converted I_{max} to energy flux (erg cm^{-2} s^{-1}). The coefficient $F = 9.6 \times 10^{-9}$ erg cm^{-2} s^{-1} is the flux of a +6.5 star and the distance d equals 10^7 cm.

By solving equations (5)–(8) we know $I_{max}(M_o, v_o, z_R)$, and the derivation of $m_{abs}(M_o, v_o, z_R)$ is then straightforward after (16). Tables 1, 2 and 3 show $m_{abs}(M_o, v_o, z_R)$ for certain values of M_o, $0° \leq z_R \leq 70°$ and $v_o = 25$, 41, and 60 km/s. Masses M_o have been selected in order to span a wide range, but do not enter the intense evaporation regime.

Table 1 – Absolute magnitudes m_{abs} for meteoroids with initial velocity $v_o = 25$ km/s. These are calculated from the maximum intensity emitted by the meteoroids in the single-body-theory approximation with the following model parameters: $\delta = 0.27$ g/cm^3, $Q = 8 \times 10^{10}$ erg/g, $\lambda = 2 \times 10^4$ erg cm^{-2} s^{-1} K^{-1}, and the luminous efficiency τ as given in [7]. The data in this table should only be used to find magnitude differences, since the uncertainties in the physical parameters of the meteoroids can lead to systematic errors in the values for m_{abs}, as explained in the text.

z_R (°)	M_o (g)				
	2.8×10^{-1}	7.0×10^{-2}	2.48×10^{-2}	9.55×10^{-3}	3.85×10^{-3}
0	2.47	3.36	4.30	5.29	6.26
5	2.47	3.36	4.31	5.29	6.27
10	2.47	3.37	4.32	5.30	6.28
15	2.48	3.38	4.34	5.32	6.30
20	2.49	3.40	4.36	5.35	6.33
25	2.50	3.42	4.40	5.39	6.37
30	2.51	3.46	4.44	5.44	6.42
35	2.53	3.50	4.50	5.50	6.48
40	2.56	3.55	4.56	5.57	6.55
45	2.59	3.62	4.65	5.66	6.64
50	2.62	3.70	4.74	5.76	6.74
55	2.66	3.80	4.86	5.88	6.86
60	2.72	3.93	5.01	6.03	7.01
65	2.81	4.10	5.19	6.21	7.20
70	2.96	4.31	5.41	6.44	7.43

Table 2 – Same as Table 1, for meteoroids with initial velocity $v_o = 41$ km/s.

z_R (°)	M_o (g)				
	2.8×10^{-1}	7.0×10^{-2}	2.48×10^{-2}	9.55×10^{-3}	3.85×10^{-3}
0	1.00	2.00	3.01	4.02	5.00
5	1.00	2.00	3.02	4.02	5.00
10	1.00	2.01	3.03	4.03	5.01
15	1.01	2.03	3.05	4.05	5.04
20	1.02	2.05	3.08	4.08	5.07
25	1.03	2.08	3.11	4.12	5.11
30	1.04	2.12	3.16	4.17	5.16
35	1.06	2.17	3.22	4.23	5.22
40	1.09	2.23	3.29	4.31	5.30
45	1.13	2.30	3.37	4.39	5.39
50	1.18	2.39	3.47	4.50	5.50
55	1.24	2.50	3.59	4.63	5.63
60	1.33	2.64	3.74	4.78	5.80
65	1.45	2.82	3.93	4.98	6.00
70	1.63	3.04	4.17	5.23	6.27

Table 3 – Same as Table 1, for meteoroids with initial velocity $v_o = 60$ km/s.

z_R (°)	M_o (g)				
	2.8×10^{-1}	7.0×10^{-2}	2.48×10^{-2}	9.55×10^{-3}	3.85×10^{-3}
0	−0.07	1.04	2.10	3.13	4.14
5	−0.07	1.04	2.10	3.13	4.14
10	−0.07	1.05	2.11	3.14	4.16
15	−0.06	1.07	2.13	3.17	4.18
20	−0.05	1.10	2.16	3.20	4.22
25	−0.03	1.13	2.20	3.24	4.26
30	−0.01	1.17	2.25	3.29	4.32
35	0.02	1.23	2.31	3.36	4.39
40	0.05	1.29	2.39	3.44	4.48
45	0.10	1.38	2.48	3.54	4.58
50	0.16	1.47	2.59	3.66	4.71
55	0.24	1.59	2.72	3.80	4.86
60	0.35	1.74	2.89	3.98	5.04
65	0.50	1.94	3.10	4.21	5.28
70	0.70	2.19	3.38	4.50	5.58

From these calculations it is obvious that meteors become fainter when z_R is large. However, the effect is smaller for massive meteoroids than for lighter ones and increases with velocity. As a consequence, there is a change in the population index. Figure 2 helps in understanding the variation of r with z_R. Imagine two ideal observers, both monitoring the same stream at the same time but from different places. Observer A sees the radiant with $z_R = 0°$ and Observer B with $z_R > 0°$. The magnitude distributions reported by them will be as in Figure 2. For Observer A, the magnitude difference between meteors of adjacent masses remains constant. Observer B gets decreasing magnitude differences for meteors of adjacent decreasing masses, but they are always larger than the constant value obtained by Observer A. As the number of particles in each mass group does not change with z_R, the final result is a fictitious reduction of r (slope of the regression line) for Observer B with respect to Observer A. The r-value given by Observer B has been modified by observational effects and thus does not represent the correct population index.

One could ask if this phenomenon is important enough to be reflected in visual data. Indeed, we expect the changes in the brightness caused by differing z_R to be as large as 1.5 magnitudes and hence significant; this topic deserves future research with the *VMDB* in order to find out whether an experimental confirmation is possible or not.

4. Correction of the population index

The mass index s is defined such that the cumulative number $\Phi(M)$ of particles with mass greater than M is proportional to M^{1-s}. Equivalently,

$$\frac{\Phi(M_1)}{\Phi(M_2)} = \left(\frac{M_1}{M_2}\right)^{1-s}.$$

Following Levin [9], the intensity radiated by a meteoroid can be written as

$$I = K \times v_o^a \times M_o^b \times \cos^c z_R,$$

with K a constant. Hughes [21] assumes $a = 3.91$, $b = 0.92$, and $c = 0$.

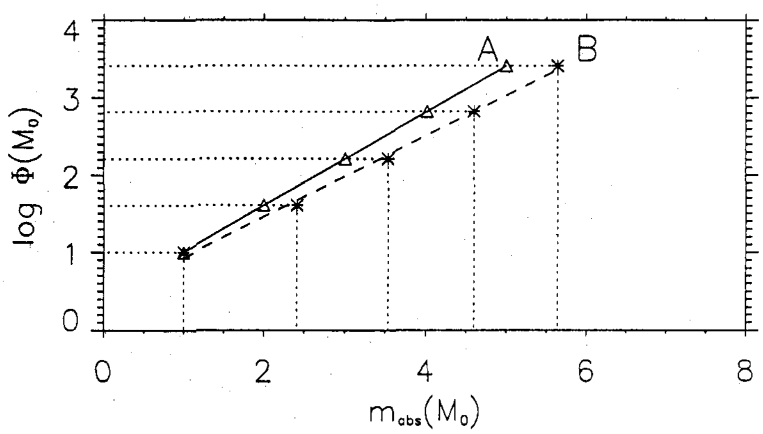

Figure 2 – Variation in the population index when $z_R > 0°$. In order to use the data from Table 1, we assume $v_\circ = 41$ km/s. Case A (triangles) represents the idealized magnitude distribution reported by an observer when $z_R = 0°$, and Case B (stars) is the corresponding magnitude distribution reported by another observer who monitors the same shower at the same time but sees the radiant at $z_R = 70°$. The cumulative number of meteors for each mass group, $\Phi(M_\circ)$, has been calculated from $r(z_R = 0°) = 4.00$, just to make the effect more evident. The points of Observer B are shifted to the left so that the first points for both observers coincide. While in Case A the magnitude class distance remains constant, in Case B it varies, and this produces a decrease of the population index (slope of the regression lines).

As $c = 0$ and there are no systematic dependences of velocity with mass significant enough to affect our considerations [22], two meteoroids belonging to the same stream have the same velocity and satisfy

$$\frac{I_1}{I_2} = \left(\frac{M_1}{M_2}\right)^b, \tag{17}$$

which, after some manipulations [18], leads to

$$s = 1 + 2.5\, b \log r, \tag{18}$$

with r the population index related to s.

The mass index s is an intrinsic characteristic of the stream which cannot depend on z_R. But $r = r(z_R)$, and thus any variation in z_R will produce a change in s except if $b = b(z_R)$ is not constant. From this reasoning we conclude that b is indeed a function of z_R.

Since s does not depend on z_R, we have that

$$1 + 2.5\, b(0°) \log r(0°) = 1 + 2.5\, b(z_R) \log r(z_R),$$

and therefore we have found a method to correct the r-values if $z_R \neq 0°$:

$$r(0°) = r(z_R)^{b\,(z_R)/b\,(0°)}. \tag{19}$$

Here, $r(z_R)$ represents the population index value computed with the current *IMO* method from an observation carried out when the radiant zenithal distance was z_R. The value $r(0°)$ is the corrected value for $r(z_R)$ assuming that the radiant was placed on the zenith. Note that this correction standardizes the population index to the case in which $z_R = 0°$. Only corrected values can be compared with each other. Otherwise, the uncorrected population indices derived for any given interval from different places would differ as z_R would not be the same at every site.

In order to apply equation (19), we must know $b = b(z_R)$ for each velocity $v_\circ$. Equation (17) is linearized by taking decimal logarithms:

$$\log \frac{I_1}{I_2} = b \log \frac{M_1}{M_2}.$$

With the aid of the least squares method, b can now be determined.

Table 4 – Mass exponent b in the single-body-theory approximation as a function of z_R for some velocities $v_\circ$ using the data presented in Tables 1, 2, and 3.

z_R (°)	$v_\circ = 25$ km/s	$v_\circ = 41$ km/s	$v_\circ = 60$ km/s
0	0.822	0.867	0.910
5	0.822	0.868	0.911
10	0.825	0.870	0.913
15	0.828	0.873	0.916
20	0.833	0.877	0.921
25	0.839	0.883	0.927
30	0.847	0.890	0.935
35	0.856	0.899	0.943
40	0.866	0.909	0.954
45	0.877	0.920	0.966
50	0.892	0.933	0.979
55	0.910	0.947	0.994
60	0.928	0.962	1.011
65	0.946	0.979	1.030
70	0.964	0.999	1.050

Table 4 presents the results for several selected velocities, corresponding to those of Tables 1, 2, and 3. As one might expect, b increases when z_R is large since it has to compensate for the decrease in r. The average of b for the whole set of velocities amounts to $\bar{b} = 0.91$, almost exactly the same value as given by Hughes. Consequently, $\bar{b} = 0.92$ describes the mean behavior of the showers, but it cannot be applied to particular situations.

The above calculations have been carried out in the range $25 \leq v_\circ \leq 60$ km/s for each velocity, and the resulting mass exponents $b(z_R, v_\circ)$ can be approximated sufficiently accurately by the following function:

$$\begin{aligned} b(z_R, v_\circ) = {} & 0.67795 + 8.29 \times 10^{-3} v_\circ - 1.24 \times 10^{-4} v_\circ^2 + 8.455 \times 10^{-7} v_\circ^3 \\ & + 9.311 \times 10^{-4} z_R - 1.079 \times 10^{-4} z_R v_\circ + 3.262 \times 10^{-6} z_R v_\circ^2 \\ & - 2.836 \times 10^{-8} z_R v_\circ^3 - 6.74 \times 10^{-5} z_R^2 + 9.188 \times 10^{-6} z_R^2 v_\circ \\ & - 2.593 \times 10^{-7} z_R^2 v_\circ^2 + 2.188 \times 10^{-9} z_R^2 v_\circ^3 + 1.837 \times 10^{-6} z_R^3 \\ & - 1.563 \times 10^{-7} z_R^3 v_\circ + 4.0834 \times 10^{-9} z_R^3 v_\circ^2 - 3.282 \times 10^{-11} z_R^3 v_\circ^3, \end{aligned}$$

where z_R is in degrees and $v_\circ$ in km/s. Figure 3 shows the residuals obtained with the above approximation. The largest errors occur for low velocities, as well as for large radiant zenithal distances with $v_\circ = 60$ km/s. In this last case, it is preferable to use the b-values from Table 4.

We now discuss the application of the new method to global meteor shower analysis in the *IMO*. It has been customary to use

$$s = 1 + 2.5\, \bar{b} \, \log r(z_R),$$

which is obviously incorrect. The correct formula should read

$$s = 1 + 2.5\, b(z_R) \, \log r(z_R).$$

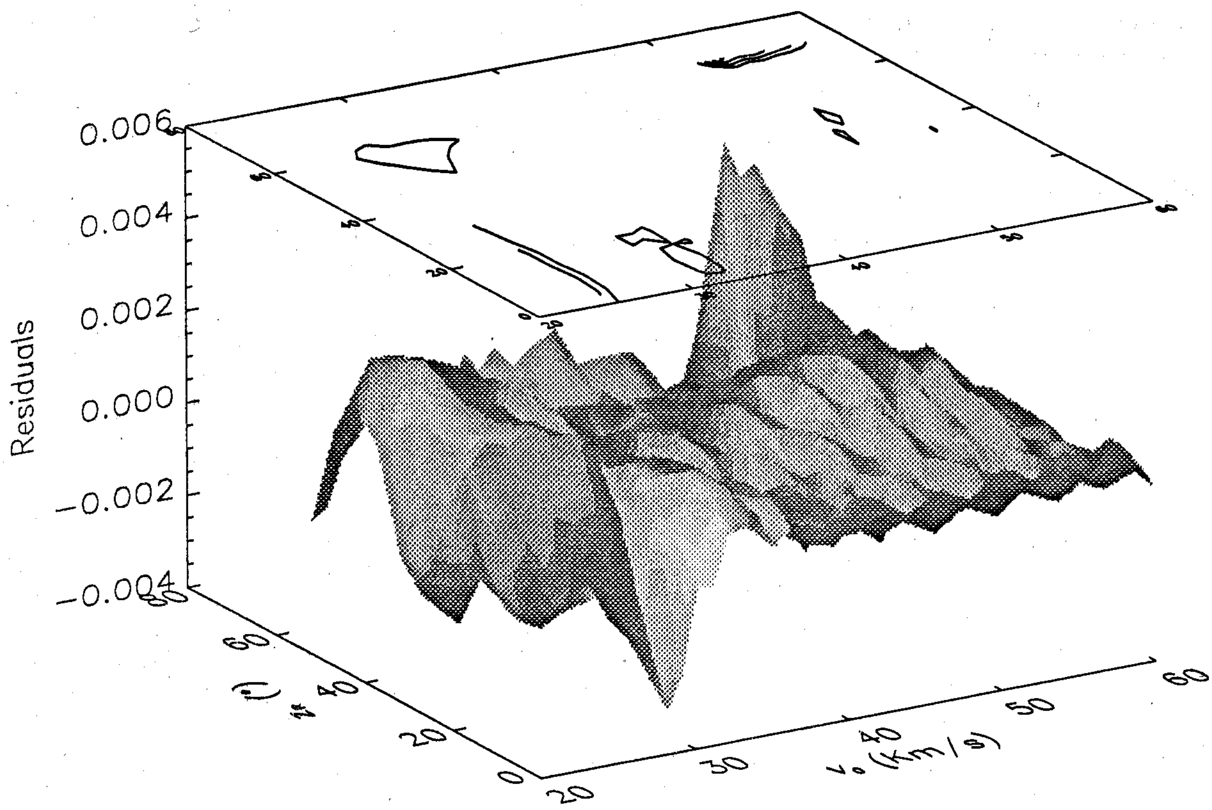

Figure 3 – Residuals for the approximation of the mass exponent. The top panel shows a contour map of the surface in order to make more evident the points of worst fit. Each line represents the limit of the area in which the residuals are greater than 0.001, 0.002, or 0.003. When only one line is present, the points corresponding to the enclosed area have residuals larger than 0.001 but smaller than 0.002, and so on.

In the same way, the zenithal hourly rates and the spatial number densities obtained so far are not representative of the streams, since they depend on z_R through r. Therefore we have to modify the r-profiles with equation (19) before using the usual formulae. Equation (19) produces small but non-negligible corrections: in extreme cases this may amount to three or four tenths.

Let us consider an example. Table 5 shows the population index values obtained during the 1992 Quadrantid maximum [1] and the corrected values assuming a linear variation of z_R with $\lambda_\odot$. The published r-profile varies from $r = 2.11$ to $r = 2.38$ between $\lambda_\odot = 283\overset{\circ}{.}00$ and $\lambda_\odot = 283\overset{\circ}{.}23$ (eq. 2000.0). If we use equation (19), the new profile changes, varying now from $r = 2.32$ to $r = 2.44$, and it may be regarded as constant within the error margins (the maximum difference is about 0.1, see Figure 4). These data suggest that there was not any statistically significant increase of the population index or, at least, that it was very small.

Table 5 – Population index profile during the 1992 Quadrantid maximum. The third column shows the values calculated in [1] and the fourth one the corrected values using equation (19).

$\lambda_\odot$ (2000.0)	z_R (°)	$r(z_R)$	$r(z_R \equiv 0°)$
283°.00	70	2.11 ± 0.09	2.36 ± 0.12
283°.03	65	2.11 ± 0.07	2.32 ± 0.09
283°.07	58	2.15 ± 0.05	2.33 ± 0.06
283°.11	50	2.21 ± 0.06	2.35 ± 0.07
283°.17	40	2.30 ± 0.06	2.39 ± 0.07
283°.20	35	2.34 ± 0.06	2.41 ± 0.06
283°.23	30	2.38 ± 0.11	2.44 ± 0.12

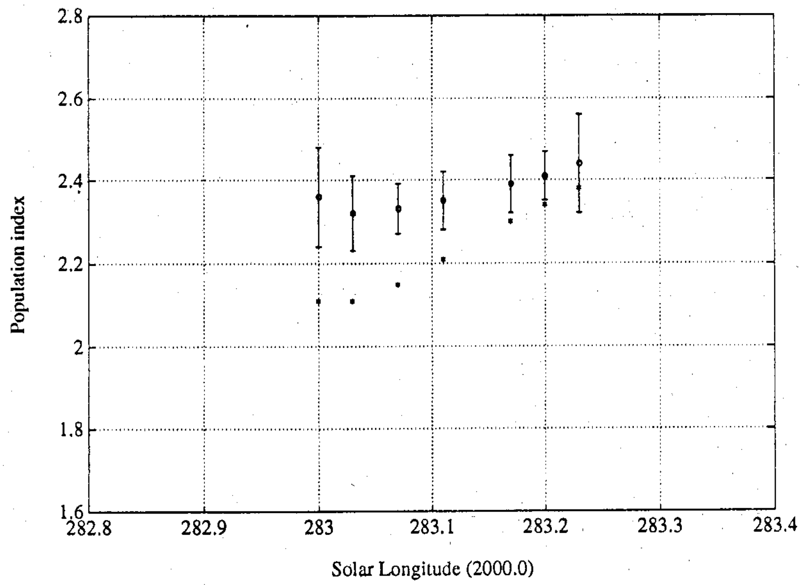

Figure 4 – Calculated and corrected population index profile for the 1992 Quadrantid maximum. Values from [1] are represented as stars, while corrected values are shown as circles.

5. Conclusions

After integrating the equation system which describes the interaction between meteoroids and atmosphere, we have proved that the population index depends on the radiant zenithal distance z_R. Consequently, it is necessary to correct the population index profiles before obtaining reliable zenithal hourly rates, mass indices or spatial number densities.

By using the invariance of s, we have developed a new method to correct the population index derived from visual data. To perform the correction, it is necessary to know $b = b(z_R, v_o)$ as accurately as possible. The single-body theory is used as a first approximation. The uncertainties in some physical parameters can be disregarded since we need relative values of the intensity I rather than absolute values. This is true for the luminous efficiency τ, the density δ, and the thermal conductivity λ of the meteoroids. The only uncertain parameter is the latent heat of vaporization Q, but we follow the usual approach and take the value appropriate for that of iron and stone. These facts ensure the validity of the given mass exponents $b(z_R, v_o)$. They would only improve if the quasi-continuous fragmentation model is used (together with a more precise knowledge of the structure of cometary meteoroids) or if a better value of Q becomes available.

The application of the derived method to the 1992 Quadrantid problem leads to a reduction of about 60% in the observed variation of r. This means that there was no significant increase of the population index between $\lambda_\odot = 283\overset{\circ}{.}00$ and $\lambda_\odot = 283\overset{\circ}{.}23$. The remaining small differences might be easily explained if the correction (19) is carried out for every individual estimate of the population index r.

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