Mass distribution of the Lyrid meteoroid stream from forward-scatter meteor observation

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Abstract. Lyrid meteoroid stream data obtained by a forward-scatter radio equipment in 1992–1996 are analyzed and discussed from the point of view of the mass distribution of meteoroids in the stream. The mass exponent of the Lyrids was found to be $s = 1.93$ which is a higher value than the value derived from previous backscatter observations and is in a substantially better agreement with the population index r resulting from visual observations.

Key words: meteoroid streams – Lyrids – forward-scatter system

1. Introduction

A forward-scatter radio equipment for meteor observations has been operating in Italy (baseline Budrio–Lecce) since 1992. The observations are carried out systematically during the activity of selected meteor showers and sporadic periods. The Lyrid meteor shower is monitored by the equipment regularly and partial results depicting the shower activity in 1994 and 1995 were published by Porubčan et al. (1995, 1996). The shower has shown a distinct maximum only for overdense echoes, while the flux of underdense echoes appears to be very variable and rather poorly discernable from the sporadic background. A conspicuous feature of small particles (very short duration echoes, < 0.1s) following the overall trend of activity of the overdense echoes was observed in 1994. However, the 1995 data did not confirm this spectacular feature in the shower activity. Mass distribution of particles in the Lyrid stream based on backscatter radar observations from Ondřejov in 1980–1985 was studied by Porubčan and Šimek (1988). Since then no additional radio data concerning the mass distribution of the Lyrid meteoroids are available and forward-scatter observations on the baseline Budrio – Lecce provided an opportunity for such a study.

2. Equipment and observations

The CNR forward-scatter radio system in Italy utilized for meteor observations has the transmitting station at Budrio (44.6° N, 11.5° E) near Bologna and receiving station at Lecce (40.3°, 18.2° E) in Southern Italy. The distance between both stations is of about 700 km. The system is operating on CW transmitting frequency of 42.7 MHz with a fixed modulating tone at 1 kHz and 1 kW mean power. In the 1992–1993 Lyrid campaign, the system was operating at a lower mean power of about 100 W. The transmitting and receiving Yagi antennas consisting of 5 elements are horizontally and vertically polarized with an elevation angle of 15° along the Budrio – Lecce direction (azimuth from the north 127°.

The Lyrid observation was carried out in each year (1992–1996) continuously for about a week starting few days prior to maximum and covering the shower activity. However, in some years, interruptions in the observation due to technical problems with the equipment appeared, or in some cases the observation was seriously influenced by ionospheric disturbances. As the data thus obtained were not reliable, from the studied set were eliminated. In 1993, a new receiving station at the Modra Observatory, Slovakia (48.3° N, 17.3° E) was experimentally set in operation during the Lyrid period. The aim of the experiment was establishing a new baseline and to transmit signal simultaneously in two mutually nearly rectangular directions (Budrio – Lecce and Budrio – Modra), with a possibility to monitor meteor flux in different baseline orientations. The first result of the experiment has been presented by Cevolani et al. (1996). The activity of the Lyrid meteor shower obtained from the forward-scatter data, considering geometrical factors influencing detection of shower echoes and with respect to the above experiment of transmitting the signal in two directions, will be published later.

3. Mass Distribution

In a study of the contribution of a meteoroid stream to the flux of interplanetary dust it is necessary to analyze the relative numbers of meteoroids of various sizes. The relation between the number of particles N having masses in the interval $m, m + dm$ is presented by the differential mass exponent s as

$$dN_m \sim m^{-s}\, dm \tag{1}$$

and integrating (1) the number of particles with mass m and greater is

$$N_m \sim m^{-(s-1)}. \tag{2}$$

Kaiser and Closs (1952) showed that the echo duration of an overdense meteor trail is proportional to the electron line density and inversely proportional to the diffusion coefficient assuming that the decay of the echo is caused by ambipolar diffusion only. For overdense echoes, the mass distribution exponent s which characterizes the mass distribution of meteoroids is given by the formula (Kaiser and Closs 1952).

$$N_c \sim T_D{}^{-3(s-1)/4}, \qquad (3)$$

where T_D is the duration of an overdense echo controlled by diffusion (valid for short duration echoes occuring at great heights) and N_c is the cumulative number of echoes with the duration T_D or greater.

At lower heights the duration is affected by a second mechanism of reducing the electron line density of a meteor trail, which was previously attributed to attachment of free electrons to neutral air particles. Baggaley (1972), Baggaley and Cummack (1974), Nicolson and Poole (1974), McIntosh and Hajduk (1977) have presented that the attachment is not a dominant factor for ionization loss of meteor trails and Jones et al. (1990) have shown that a series of chemical reactions involving ozone is likely to be more important than the electron attachment.

In order to be able to compare a consistence of the mass distribution exponent obtained from forward-scatter data with that from backscatter (Porubčan and Šimek 1988), in the first step (a) we strictly treated the forward-scatter Lyrid observations by the same procedure as was applied in the previous analyses, i.e. considering the effect of the electron attachment mentioned above. Then, in the next step (b) the data were analyzed without a correction for the attachment.

(a) *Attachment.* In the view of previous considerations the mass distribution exponent s was found following the approach used in Šimek (1987) and Porubčan and Šimek (1988) from the cumulative counts of echoes in respective duration groups using of an adaption of equation (3) by McIntosh and Šimek (1974) for the variable mass exponent s in the form

$$log\ N_c = -\frac{3}{4}\left[s_0 - 1 + s_1\ log\ T_D + s_2(log\ T_D)^2\right] log\ T_D + const. \qquad (4)$$

The observed echo duration T_A was related to T_D according to the formula given by (Plavcová 1965)

$$T_D = T_A\ exp[B_0 T_A (T_D/T_0)^{1/4}], \qquad (5)$$

where B_0 is a function of the air density and is the attachment rate for a given height and T_0 is the overdense echo duration corresponding to the geocentric velocity V_g and characteristic height H. For B_0, Bibarsov (1970) derived the relation

$$B_0 = exp(-0.1612\,H + 11.49) \qquad (6)$$

Following McKinley (1961) the height of maximum echo duration is related to the geocentric velocity and electron line density as

$$H_{max} = 82 + 49\ log\ V_g - 4.4\ log\ \alpha_{max}, \qquad (7)$$

the diffusion coefficient D is given by

$$log\, D \;=\; 0.067\, H - 5.6 \tag{8}$$

and T_0 in the case of a forward-scatter equipment is given as

$$T_0 = 7 \times 10^{-17} \cdot \frac{\alpha}{D} \cdot \lambda^2\; sec^2\, \phi, \tag{9}$$

where λ is the wave length and 2ϕ is the forward-scatter angle.

Adapting for the Lyrids the characteristic height of H = 96 km, the geocentric velocity of $V_g = 47.08$ km/s we get $B_0 = 0.019$, the diffusion coefficient $D = 6.8$ m^2/s and $\alpha_{max} = 2.8 \times 10^{15}$ el/m. Furthermore, substituting for $\lambda = 7$ m and $\phi = 75^o$, $T_0 = 21$ s. The durations T_D corresponding to given T_A were obtained from (5).

(b) *Diffusion.* Being aware of the fact that the change of slope in the cumulative duration distribution of overdense meteor echoes cannot be ascribed to attachment of free electrons to air molecules, but to some chemical reactions involving ozone (Jones et al. 1990), the mass distribution exponent was found from formula (3) considering the ambipolar diffusion for sole process by which the density of the plasma decayes. The s was found from the formula adopted in the form

$$log\; N_c \;=\; -\frac{3}{4}\,[s-1]\;\; log\, T + const. \tag{10}$$

where T is the observed duration (referring to T_A in (a)).

4. Analysis

The Lyrid meteoroids mass distribution exponent s was derived from five consecutive returns of the shower in 1992 - 1996. Although the 1993 data are from the baseline Budrio – Modra, these were also in the analysis included in order to compile as much data from the Lyrid FS observation as possible. The most representative part of the shower activity is the densest part about the maximum. Therefore, the analysis was confined to the stream width of one degree in solar longitude at the maximum. The mean Lyrid maximum obtained from radar observations covering 18 returns of the shower over 30 years (Porubčan et al. 1989) was found at the solar longitude of 31.5^o (equinox 1950.0) and, therefore, the data from the solar longitude interval 31.^{o}0 - 32.^{o}0 were analyzed. The data were divided according to the observed echo durations T_A into 15 sets covering the duration range 0.3 - 30 s, where the last set referred to the echoes of $T_A \geq 30$ s.

The observed echo counts were corrected for the sporadic background by substracting the corresponding sporadic echo counts from the period of the maximum. For sporadic, the counts observed on the first day of observation in respective years were taken. The cumulative echo counts of the duration sets were obtained by combining all five years and normalized to 1000.

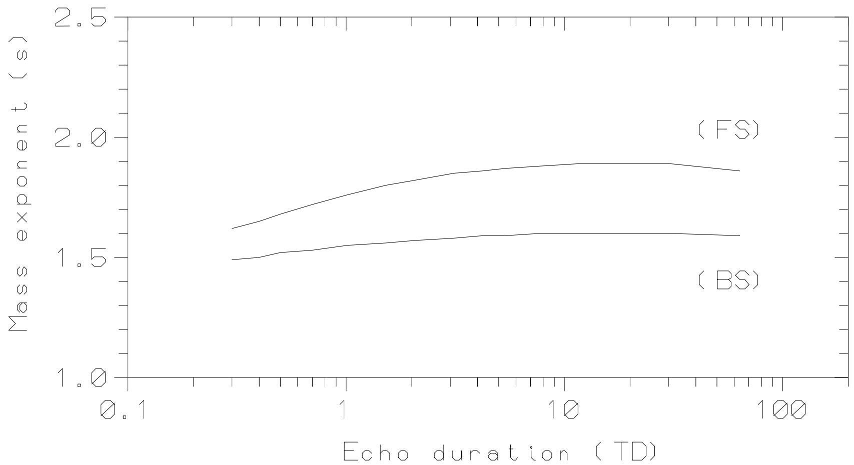

Figure 1. Mass distribution exponent s of the Lyrid meteoroids. FS – forward-scatter data obtained on the baseline Bologna–Lecce (1992-1996). BS – backscatter data from the Ondřejov Observatory (1980-1985).

The values of T_A were corrected for the attachment process presented in section 2 as (a) and corresponding T_D were found. Followingly, the Lyrid mass distribution exponent s was obtained by solving equation (4) (similar as in Porubčan and Šimek 1988) in the form

$$s \; = \; 1.758 + 0.223 \, log \, T_D - 0.091 \, (log \, T_D)^2. \qquad (11)$$

The result obtained exhibits a moderately increasing mass exponent s towards long-duration echoes and a comparison of both the backscatter and forward-scatter result is shown in Fig.1. The mass exponent of the sporadic background shows also a slowly increasing tendency with the increasing echo duration (0.3 - 30 s), having a mean value $s \sim 2.3$ over a large interval of the overdense echoes.

An application of formula (3) resp. (10) to the same set of data, i.e. without taking into account attachment resulted in a higher value of the mass distribution exponent $s = 1.93$ and distribution of the cumulative numbers N_{cum} vs. echo duration is plotted in Fig.2.

5. Discussion and conclusions

The forward-scatter observation of the Lyrid meteor shower in 1992-1996 on the Bologna-Lecce baseline provided an opportunity to examine the mass distribution of meteoroids in the stream and to compare the result with similar backscatter data.

To verify reality of the result derived from FS and its applicability in the field, the data were treated by the same procedure as applied to backscatter observation of the Lyrids at the Ondřejov Observatory in 1980-1985 (Porubčan

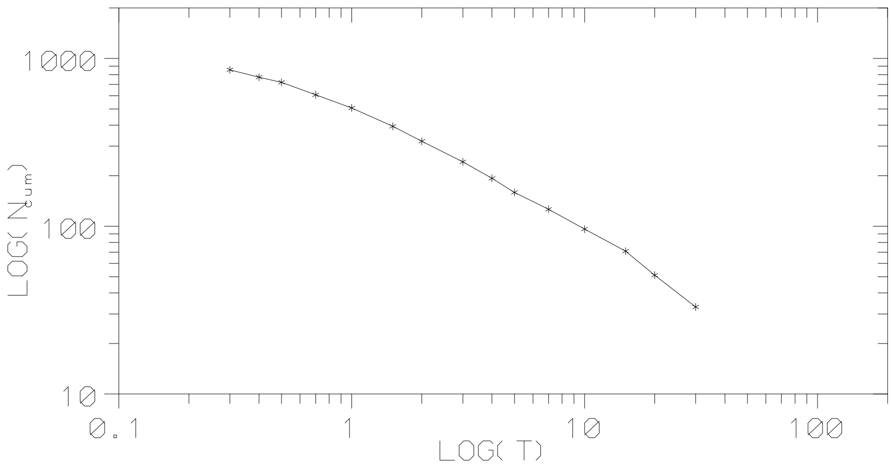

Figure 2. Lyrid meteor shower of 1992-1996 observed by the FS system on the baseline Bologna - Lecce: Distribution of the cumulative number of echoes N_{cum} with respect to the observed echo duration T.

and Šimek 1988), i.e. considering the attachment process. The mass distribution exponent derived from the central part of the shower (solar longitude $31° - 32°$) as a function of the observed echo duration in the range from 0.3 to 30 s exhibits a moderately increasing trend with the echo duration (Fig. 1) giving $s \sim 1.76$ for the echo duration of about one second. A similar tendency is apparent for the sporadic background echoes with $s \sim 2.3$ in the substantial part of the overdense echo counts (0.7 - 5.0 s). The forward-scatter observation provides a slightly higher value of s than the backscatter radar ($s \sim 1.58$, Porubčan and Šimek 1988). There is also observed a similar difference for the sporadic background echoes with $s \sim 2.2$ obtained from backscatter observation (Šimek 1987). As the interpretation of a forward-scatter observation is complicated by various geometrical and propagation factors (Baggaley 1979) for a conclusive explanation of the difference further analyses and comparisons of other observations would be desirable.

Taking into account conclusions of the studies about the chemical processes in the meteor zone cited in section 2 disproving a dominant role of the attachement of the free electrons to neutral air molecules in decaying of the meteor trails at lower heights, the Lyrid mass distribution exponent was derived from non-reduced observed echo durations and formula (10). The resulting value of $s = 1.93$ is higher than the value obtained from both the backscatter and forward-scatter data allowed for the attachment and is substantially closer and consistent with the corresponding population index r ($s = 1 + 2.5\, log\, r$) known from a series of visual observations derived for the Lyrids, e.g. by Kresáková (1969) with $r = 2.88$. If the mass exponent is derived from the echo duration $T \geq 1s$, i.e. closer to visual meteors, our analysis gives $s = 2.05$ which means

$r = 2.63$ and is still in a better consistence with the visual observations. With respect to our result we can conclude that the Lyrid mass exponent derived considering diffusion for sole process responsible for a meteor echo decay provides more realistic results, as far as the mass distribution exponent concerns, than the previously stressed role of the attachment of the free electrons to neutral particles.

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