Meteor head echoes from high power radar

A. Hajduk and P. Hanisko

Astronomical Institute of the Slovak Academy of Sciences, Interplanetary Matter Division, Dúbravská cesta 9, 842 28 Bratislava, The Slovak Republic

Received: July 14, 1997

Abstract. Diurnal variation of meteor head echoes around the vernal and autumnal equinox obtained from 1609 head echoes reduced from the original film records of the Springhill Meteor Observatory high-power radar is analysed and discussed. Occurence rate of head echoes in the sporadic periods is clearly dependent on the apex motion by a factor of 5:1 during the vernal equinox days and 2.5:1 during the autumnal equinox days. However, the level of the head echo occurence in autumn is twice as high as in spring days. The radial velocity distribution of head echoes implies two distinct velocity groups centred at 15 km s^{-1} and 35 km s^{-1}, more pronounced in the spring sample. Possible geometrical influences on the occurence of head echoes are discussed.

Key words: meteors – radar meteor head echoes – sporadic head echoes, apex dependent

1. Introduction

The meteor head echo phenomenon was observed and first desribed by McKinley and Millman (1949) analysing film records from the radar equipment of the Springhill Meteor Observatory. The authors ascribed the rapid motion of the thin reflection preceeding the rough body echo (usual meteor echo) to ionized wave front moving with the velocity of the meteor body through the atmosphere in front of the meteoroid itself. Reflection from this faint ionized column on the range-time radar record is called head echo. Two typical examples of meteor head echoess of the approaching and receding head echoes, respectively, on the range-time record of the high-power radar of the Springhill Meteor Observatory from the periods analysed in this paper, are shown in Fig. 1 and Fig. 2.

In spite of the fact that the phenomenon of a meteor head echo is known for a long time, and that many attempts have been made to explain this phenomenon, or at least to contribute to the explanation of this effect, there is up to now no satisfactory explanation of the head echo phenomenon. As a plausible explanation can be considered the theory suggested by Hawkes and Jones (1975, 1978) and Jones and Webster (1991) according to which meteoroid fragments produce water cluster ions or similar molecular ions, which are effective in removing the ionization in a short time. Then the ablation mechanism of individual grains,

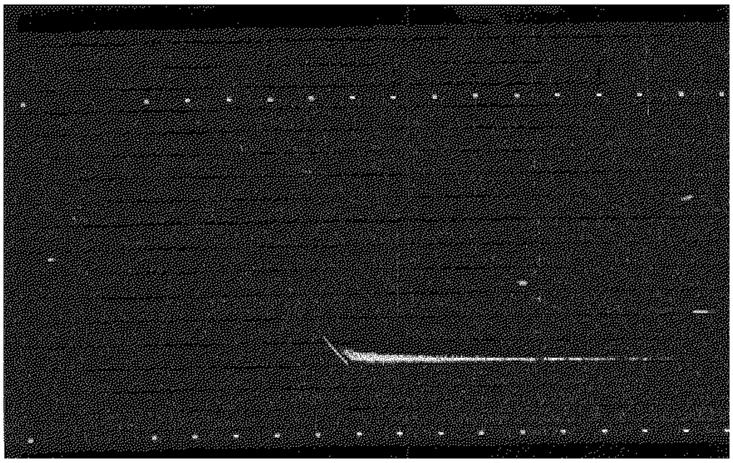


Figure 1. Example of a meteor head echo followed by a body echo on the range-time record of the Springhill Meteor Observatory high power radar. Range is indicated by 20 km lines, time markers are given in seconds. The record is from March 17, 1959: the head echo appears at 09 h 02 m 07.2 s, R = 127 km, lasting for 0.5 s and approaching 27 km; it is followed by an approaching body echo of 8.5 s duration. There are some other short duration echoes on the record.

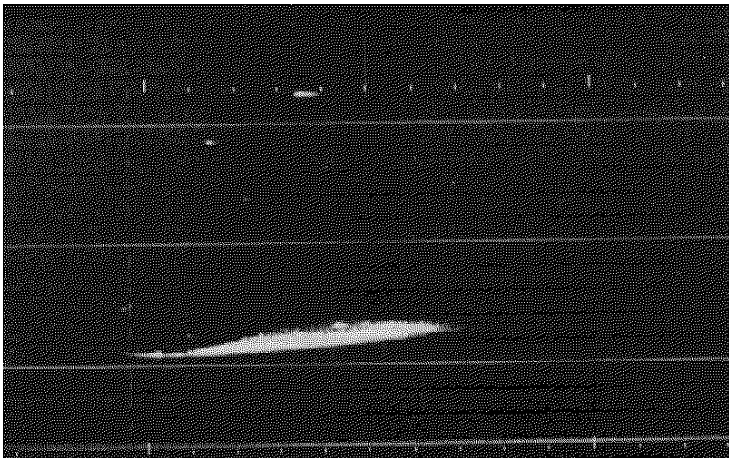


Figure 2. Example of a meteor head echo from March 9, 1967 showing an approach (at the beginning) and recesion, followed with a receding body echo as in Fig. 1. The point of a minimum distance corresponds to 01 h 28 m 00 s at $R_0 = 106$ km.

separated from the meteoroid body could be responsible for the expanding head of the ionized trail. They also have found the dependence on the occurence of the head echoes on the geocentric velocity of meteoroids. However, because of controversal observations of the head echo rates for various meteor shower periods, (Hajduk 1972, Hajduk and Galád 1995) the explanation of the head echo phenomenon is still open and futher analyses are very desirable.

2. Equipment and observational data

A megawatt pulse radar transmitter utilized for meteor research at the Springhill Meteor Observatory, with a peak power of 2 MW at a frequency of 32.7 MHz, using a $\lambda/4$ dipole for the antenna, has been operated since 1961. Details on the equipment were described by Neale (1966). The equipment was operating mostly during the periods of selected meteor showers; however, sporadic periods are satisfactorily covered also taking into account the observed average meteor echo rates of 2 000 per hour. A part of these unique data, in original film records is thanks to the donation of the Herzberg Institute of Astrophysics in Ottawa now located at the Astronomical Institute of the Slovak Academy of Sciences. Only a small part of about 5 per cent of all the high-power radar data have been analysed so far as a consequence of the enormous amount of about 10^7 meteors recorded on the film records.

The present analysis is based on the material of about 25 000 meteors, of which 1 609 meteor head echoes have been recognized in the sporadic periods around the vernal (Feb. 11 – Apr. 11) and autumnal (Sept. 1 – 30) equinox. The data are summarized in Table 1.

To each head echo the following parameters have been determined: the date and time of occurence, the beginning range R_h (km), the change in range $\Delta\ R_h$ (km), the duration $\Delta\ T_h$, the type (approaching, recceding, U type) and comments. Head echoes with $\Delta\ R_h < 3$ km have been excluded from the sample because of high uncertainty and possible mixture with drifting meteor echoes of quite different origin as shown by Hajduk and Prikryl (1976) and Lindblad and Hajduk (1984).

As it is seen from the summary values in Table 1 the head echo diurnal or hourly rates are about 2.2 times larger in the autumn period than in the spring period. The diurnal variation in the two periods is shown in Fig. 3 and 4, respectively. It is evident that the occurence of head echoes follows the regular diurnal variation of meteors as a consequence of the motion of the apex of the Earth on the sphere with the maximum rate close to 6:00 EST and with the minimum at about 18:00 EST. The amplitude of the variation is nearly the same in both periods, the level being twice as high in the autumn, which again agrees with the regular seasonal variation of meteor echo rates. From these aspects we can say that the occurence of head echoes follows the apex motion on the sphere.

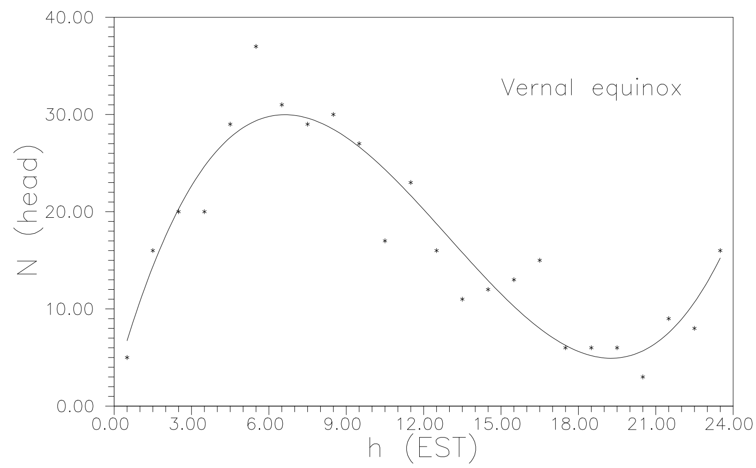
Table 1. Occurence of head echoes in the spring and autumnal periods from the high-power radar of the Springhill Meteor Observatory data

Y	M	D	$N_{head\,+}$	$N_{head\,-}$	$\sum N_{head}$
1958	2	18	23	12	35
1958	2	19	25	8	33
1958	2	26	18	14	32
1958	3	19	25	11	36
1958	3	20	22	11	33
1958	3	28	22	9	31
1959	3	7	10	27	37
1959	4	10	31	8	39
1959	4	11	34	10	44
1967	3	9	53	11	64
1967	4	11	53	6	59
$\sum N_{head}$		11 days	316	127	443
1957	9	1	73	17	90
1957	9	23	83	11	94
1957	9	24	48	19	67
1957	9	30	66	32	98
1958	9	6	60	18	77
1958	9	13	76	10	86
1958	9	14	67	15	82
1958	9	20	75	5	80
1959	9	3	59	18	69
1959	9	4	74	18	92
1961	9	12	88	3	91
1962	9	28	118	5	122
1965	9	28	112	6	118
$\sum N_{head}$		13 days	999	167	1166

(Each day contains a 24 h period)

More interesting is the variation of the relative rates of head echoes in comparison with normal meteor echo rates. Figures 5 and 6 show the diurnal variation of the relative head echo rates for the same two periods of the vernal and autumnal equinox as in Figs. 3 and 4. The amplitude of variation is approximately the same, 2:1 for the morning vs. evening hours, however, the proportion of head echoes to meteor echoes is not constant but of about 1.5 times greater during the whole day in the autumnal period than in the spring period.

As it follows from the above observational data the head echo phenomenon varies proportionaly to the incident flux of meteoroids entering the Earth's atmosphere, however, this dependence is not linear.



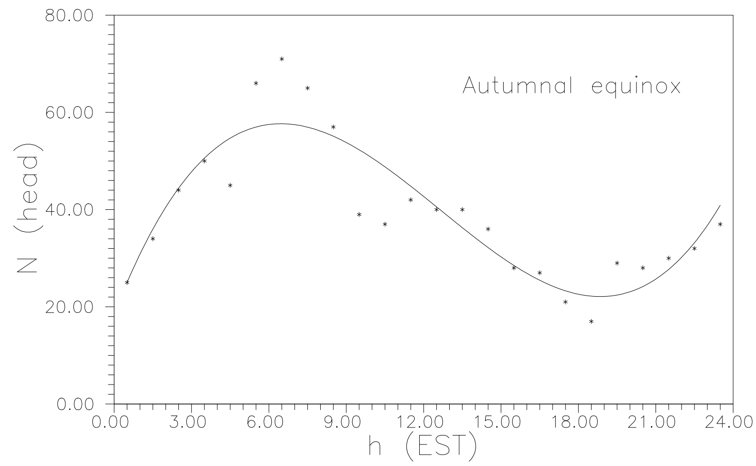
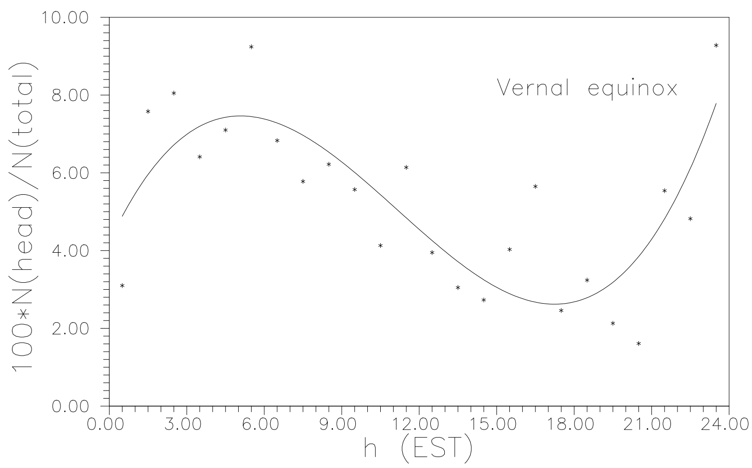


Figure 3. and 4. Diurnal variation of head echo hourly counts N for the periods given in Table 1

3. Radial velocities and the occurence of head echoes. Discussion of results

Radial velocity of each head echo can easily be determined from the recorded change in the range and the corresponding time as $v_{h,\,rad} = \Delta\, R_h / \Delta\, T_h$. The number distribution of radial velocities from 12 km s^{-1} up to 71 km s^{-1} with the step of 1 km exhibits a fairly large scatter from a few head echoes up to 84 head echoes in different groups. However, in the mean numbers of head echoes for 5 km s^{-1} intervals as seen in Figures 7 and 8 two distinct groups of $v_{h,\,rad}$ can be recognized at 16 km s^{-1} and 25 km s^{-1} which may possibly correspond



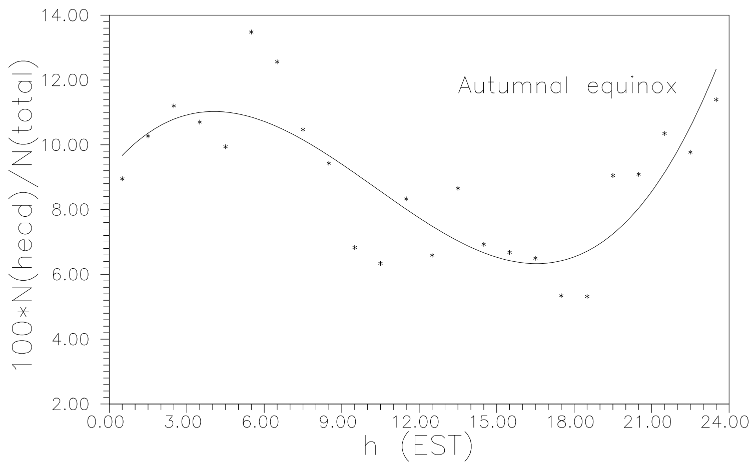
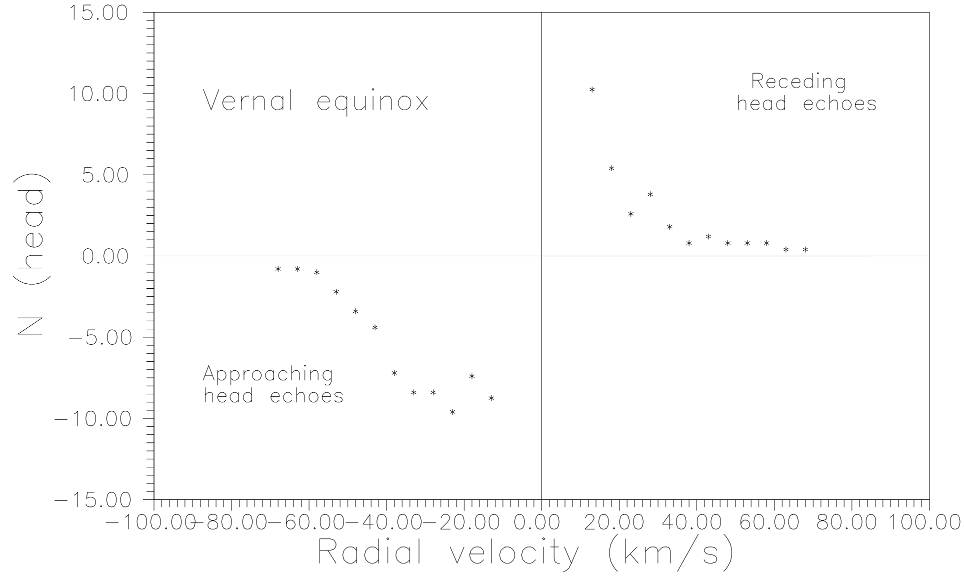


Figure 5. and 6. Diurnal variation of the relative number of head echoes to the total number of all meteor echoes for the two periods given in Table 1.

to the two maxima of the geocentric velocities of sporadic meteors at 36 km s^{-1} and 63 km s^{-1} (McKinley 1961), respectively.

Very interesting is the pronounced maximum of head echo occurence for the smallest radial velocities in the spring sample. According to the Jones' and Webster's theory the occurence of head echoes is proportional to the velocity of meteors (Jones and Webster 1991). This apparent discrepancy can be explained by a simple fact that small radial velocities do not necessarily correspond to the small geocentric velocities, as they depend on the geometry of the reflection. One of the intriguing points in the head echo theory is probably the question,



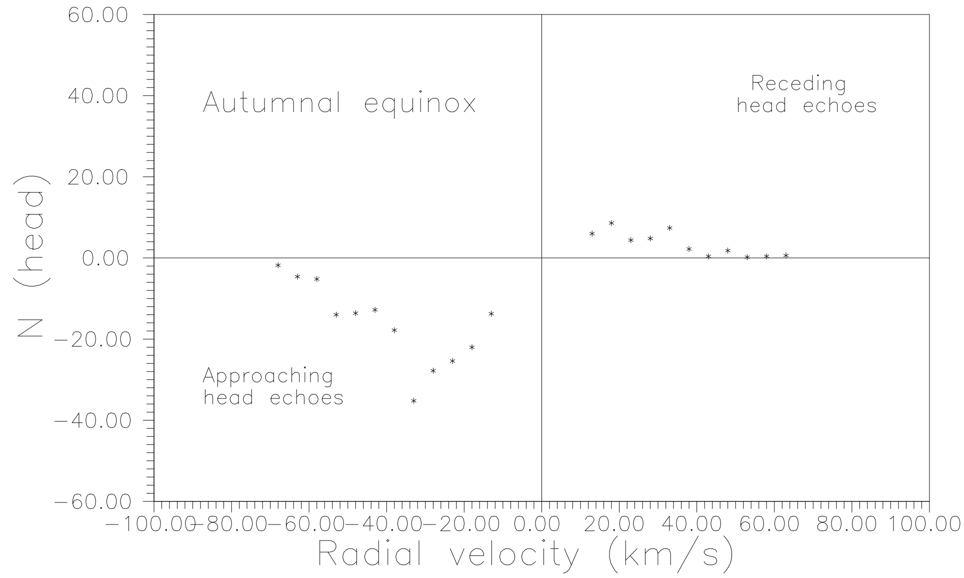


Figure 7. and 8. Radial velocity distribution of head echoes of different types for the periods given in Table 1.

how much the geometry of the reflection can contribute to the occurence of head echoes. Moreover, the lower is the distance to a meteor the higher is the sensitivity of the equipment and hence the possibility of recording the faint signal from the head echo. The examined range distribution of head echoes shows that ninety per cent of head echoes are recorded from the range interval of 90 – 130 km. In general the head echo rates are proportional to the total flux of meteoroids along the solar longitudes during the shower period however, some geometrical factors, especially the meteor trail orientation with respect to the condition of perpendicular reflection have been found to be responsible for the observed minima of the head echo occurence in the culmination times of some meteor showers (McIntosh 1963, Hajduk 1972).

If we accept the general relation between the meteor velocity and occurence of head echoes, as shown by Jones and Webster (1991) then it should be added that this is not the only relation between them. To determine the exact contribution of the trail orientation and its position with respect to the beam axis of the antenna as well as the contribution of the equipment sensitivity corresponding to the slant range to the meteoroid for the forming process of a head echo requires further statistical investigation. Such approach desires a study of head echoes of selected meteor showers with well defined velocities and known radiant positions. This should be the next step for explanation of the head echo phenomenon at all.

Acknowledgements. The authors wish to express their thanks due to the Herzberg Institute of Astrophysics and to Dr. Bruce McIntosh personally for providing them the unique observational material from the high-power radar of the Springhill Meteor Observatory. Our thanks are also due to the Grant Agency of the Slovak Academy of Sciences for grant No 1051/95.

References

Hajduk, A.: 1972, *Bull. Astron. Inst. Czechosl.* **23**, 35
Hajduk, A., Galád, A.: 1995, *Earth, Moon, Planets* **68**, 293
Hajduk, A., Prikryl, P.: 1976, *Bull. Astron. Inst. Czechosl.* **27**, 246
Hawkes, R.L., Jones, J.: 1975, *Mon. Not. R. Astron. Soc.* **173**, 339
Hawkes, R.L., Jones, J.: 1978, *Mon. Not. R. Astron. Soc.* **185**, 727
Jones, J., Webster, A.R.: 1991, *Planet. Space Sci.* **39**, 873
Lindblad, B.A., Hajduk, A.: 1984, *Bull. Astron. Inst. Czechosl.* **35**, 244
McIntosh, B.A.: 1963, *Can. J. Phys.* **41**, 355
McKinley, D.W.R.: 1961, *Meteor Science and Engineering*, McGraw-Hill, New York
McKinley, D.W.R., Millman, P.M.: 1949, *Can. J. Res.* **27**, 53
Neale, M.J.: 1966, *Can. J. Phys.* **44**, 1573