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On radar measurements of the terrestrial mass accretion rate of meteoroids

L. FOSCHINI
Istituto FISBAT/CNR - Via Gobetti 101, 40129 Bologna, Italy

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Summary. — Radar data recorded during 1993 and 1994 by using the forward-scatter meteor radar of the National Research Council (CNR), enable us to obtain a measurement of the terrestrial mass accretion rate in the cosmic dust mass range 10^{-12} to 10^{-7} kg. This value results to be $5.4 \cdot 10^{7}$ kg per year and is in good agreement with previous estimates obtained from other authors (LOVE S. G. and BROWNLEE D. E., *Science*, **262** (1993) 550). Calculations are possible only by taking into account some statistical data series and extrapolation toward higher mass ranges appears to be misleading.

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Investigation of the influx of meteoroids into Earth is very important in many contexts. For example, it allows to optimize models of meteoroid population and quantifies meteoroid collision hazards for spacecraft. With the term *meteoroid* it is customary to indicate any cometary or asteroidal body with mass between 10^{-9} and 10^{7} kg, as specified in 1961 by the *International Astronomical Union Nomenclature Committee*. Nevertheless, in order to obtain a more complete knowledge on interplanetary matter, it is necessary to extend the mass range to 36 orders of magnitude (from 10^{-21} to 10^{15} kg) [1], and to use different observational techniques and methods as, for instance, detectors on rockets, glacial accumulations, studies of microcraters on lunar specimens and collecting areas on artificial satellites, *i.e.*, the *Long-Duration Exposure Facility* (LDEF) satellite [2]. At the upper limit of the mass range, where larger meteoroids could be confused with smallest asteroids, a powerful observational mean is given by the Spacewatch Telescope [3]. Meteoroids with mass between 10^{-9} and 1 kg and more, are detected by visual, photographic and radar observations. Radar provides an important tool because of the continuous monitoring independent of meteorological conditions, daylight and moonlight. However, radar meteor fluxes, based on individually determined masses are rarely published, since the relationship between ionization efficiency and meteoroid mass is not well known.

During the last years, several studies were carried out on main meteor showers by using the CNR bistatic forward-scatter radar Bologna-Lecce (*e.g.*, [4-7]). From 1993, improved instruments made it possible to detect meteors with electron line density $q \geqslant 10^{12}$ el/m, corresponding to meteoroids with initial mass of about 10^{-8} kg [7, 8].

Although data from Bologna-Lecce radar give not absolutely calibrated meteor fluxes, it is possible to make some statistical evaluation, after imposing some restrictive hypotheses: first, the meteoroid influx into Earth is considered uniform in space and time; second, the mass index s, that is varying in dependence on the shower and on the echo duration (and hence on the meteoroid mass [9]), is considered constant and equal to a mean value. The number of meteors per surface and time unit with mass between m and $m + \mathrm{d}m$, that is the flux density of meteoroids $\mathrm{d}\phi$, is

$$\mathrm{d}\phi = km^{-s}\,\mathrm{d}m\,, \tag{1}$$

where k is a parameter to be determined, that depends on utilized instrumental apparatus, and s is the mass index.

To calculate the parameter k it is necessary to consider the total number of meteors detected by radar in a mass range from m_0 (minimum detectable mass, in our case 10^{-8} kg) to m_1 (maximum detectable mass, virtually infinite). By knowing the collecting area and time, it is possible to obtain the mean flux density of meteoroids with mass equal to or greater than m_0:

$$\phi_{m \geqslant m_0} = \lim_{m_1 \to \infty} \int_{m_0}^{m_1} km^{-s}\,\mathrm{d}m\,. \tag{2}$$

After integrating the second member of eq. (2) it is possible to obtain the parameter k, by taking into account that the mass index is generally greater than 1:

$$k = \phi_{m \geqslant m_0}(s-1)\, m_0^{s-1}\,. \tag{3}$$

From data recorded during 1993 and 1994 by the CNR meteor radar (table I) it is possible to calculate the mean value of the terrestrial mass accretion rate in the mass range of the cosmic dust ($10^{-12} \leqslant m \leqslant 10^{-7}$ kg). Comparative results in the same range are available from Love and Brownlee [2].

TABLE I. – CNR *forward-scatter meteor radar data recorded during* 1993 *and* 1994.

Starting hour and day	Ending hour and day	Total hours	Total meteors	Main shower
19 - 08/08/1993	18 - 30/08/1993	528	103 254	Perseids
21 - 20/10/1993	08 - 27/10/1993	156	37 222	Orionids
10 - 02/12/1993	11 - 14/12/1993	290	16 482	Geminids
00 - 20/04/1994	23 - 25/04/1994	144	32 351	Lyrids
18 - 25/07/1994	10 - 31/07/1994	137	56 156	δ-Aquarids
11 - 04/08/1994	08 - 14/08/1994	238	87 768	Perseids
21 - 10/11/1994	01 - 23/11/1994	293	68 083	Leonids
16 - 02/12/1994	03 - 24/12/1994	516	210 253	Geminids
—	—	2302	606 569	total

The mean flux density of meteoroids is obtained from the total number of meteoroids (606 569) recorded from the radar collecting area A ($6 \cdot 10^9$ m^2, [10]) during the monitoring time Δt (2302 hours):

$$\phi = \frac{N}{A\,\Delta t} = \frac{606569}{(6\cdot 10^9)\cdot(2302\cdot 3600)} = 1.22\cdot 10^{-11}\,\mathrm{m}^{-2}\,\mathrm{s}^{-1}\,. \tag{4}$$

From (3) and (4), by considering a mean mass index equal to 1.86, as obtained by the variation of s against echo durations for selected meteor showers and sporadic background [11] (fig. 1), it is possible to obtain the parameter k

$$k = \phi(s-1)\, m_0^{(s-1)} = 5.3\cdot 10^{-16}\,\mathrm{kg}^{(s-1)}\,\mathrm{m}^{-2}\,\mathrm{s}^{-1}\,. \tag{5}$$

Now, using (2) and considering that $m_0 = 10^{-12}$ kg and $m_1 = 10^{-7}$ kg, it is possible to calculate the mean flux density in the considered range

$$\phi_{m_0 \leq m \leq m_1} = \frac{k}{(s-1)}\left(m_0^{(1-s)} - m_1^{(1-s)}\right) = 3.4\cdot 10^{-8}\,\mathrm{m}^{-2}\,\mathrm{s}^{-1}\,. \tag{6}$$

From (6) it is easy to obtain the number of particles falling down on the total Earth surface ($A_\mathrm{E} = 5.15\cdot 10^{14}\,\mathrm{m}^2$) every year

$$N = \phi_{m_0 \leq m \leq m_1} \cdot A_\mathrm{E} \cdot \Delta t = 5.4\cdot 10^{14}\,. \tag{7}$$

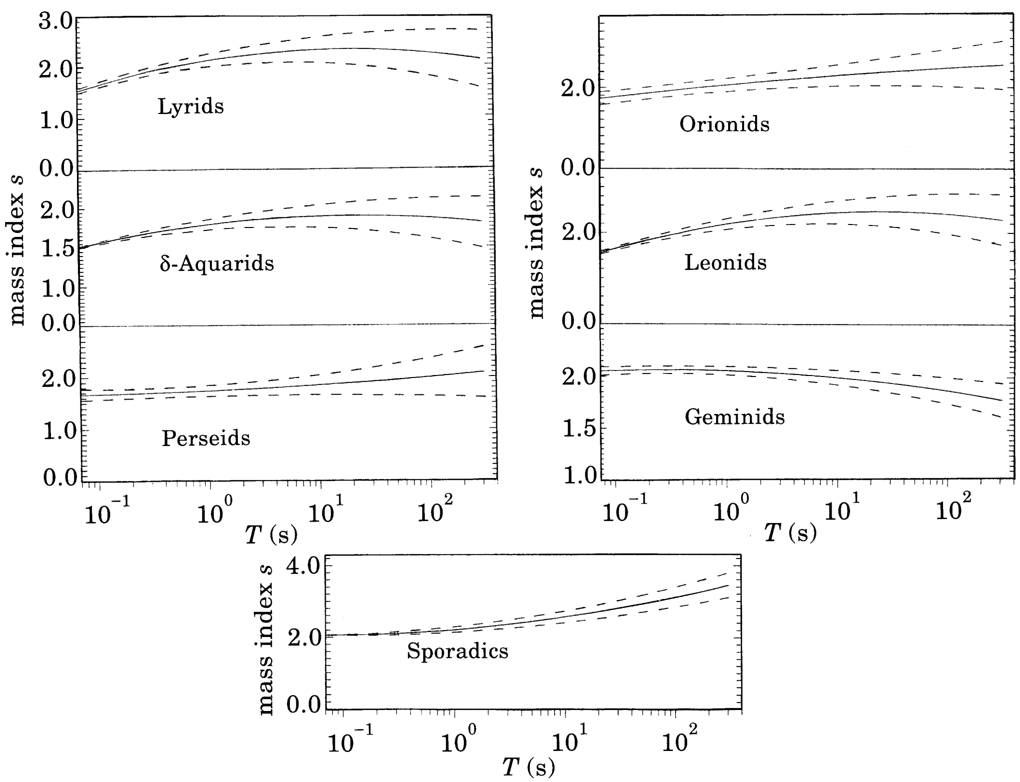

Fig. 1. – Mass index *vs.* echo durations [11].

Now it is necessary to know the mass distribution of cosmic particles in the considered range: in this case an inverse-exponential–type distribution is taken into account [12] and the number N_0 of meteoroids with mass m_0 is supposed to be equal to the total number N, given by (7). Then, it is possible to evaluate the mean value of the terrestrial mass accretion rate

$$M = N \int_{m_0}^{m_1} \exp[-m]\, dm = 5.4 \cdot 10^7 \text{ kg/y} . \tag{8}$$

Love and Brownlee [2], using the LDEF satellite data, found a value of $4 \cdot 10^7$ kg per year.

The present results, even if preliminary, highlight the importance of carrying out observational campaigns as long as possible in order to deepen our knowledge on meteoroid distribution function. To evaluate any extrapolation, it is extremely important to take into account the mass distribution and the mass index value, since both depend on mass range. In this case, the inverse-exponential type distribution is preferred, being particularly proper for underdense meteors, with duration lower than 1 s (about 10^{-7} kg), and hence lower masses are thought to maintain the same distribution. It seems misleading to extrapolate these results to greater mass ranges, unless one knows the distribution function of overdense meteors, which surely differs from the inverse-exponential–type distribution [12].

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