Astron. Astrophys. 263, 361–366 (1992)

ASTRONOMY
AND
ASTROPHYSICS

Influx of interplanetary bodies onto Earth

Zdeněk Ceplecha

Astronomical Institute of the Czechoslovak Academy of Sciences, 251 65 Ondřejov Observatory, Czechoslovakia

Received March 24, accepted May 10, 1992

Abstract. The recent discovery of several asteroids in the 10- to 100- m size range by the Spacewatch Telescope has linked the flux data for large meteoroids with the range for asteroids. Cumulative number fluxes and incremental mass fluxes are given in Figs. 1 and 3 as functions of mass. The total influx of interplanetary bodies and dust to the Earth in a wide mass range from 10^{-21} kg to 10^{15} kg results in 1.7×10^{8} kg per year for the entire Earth's surface. The two most important mass ranges responsible for this influx are: 10^{12} kg - 10^{15} kg (occupied mostly by stony or carbonaceous bodies) and 10^{4} - 10^{7} kg (mostly small inactive comets). Meteoroids with masses below 1 kg form only an insignificant contribution to the total mass influx: their dust component is the most important, but still adds only a few percent at most to the total mass influx. The influx is also sorted according to different types (dust, ablation, meteorites, explosive impacts) which depend on the body composition. The average time between two consecutive impacts of large bodies is also presented. The almost unknown bodies in the 10 to 100 m size range prove to be the second most important contributor to the Earth mass and their study deserves the fullest attention in the near future.

Key words: asteroids – comets – meteoroids – dust: flux – ablation – impact

1. Introduction

The statistics of interplanetary bodies coming to the Earth in the 10 to 100 m size range (10^{5} to 10^{10} kg) were not known until the year 1990. The recent discoveries of several such bodies by the Spacewatch Telescope (Rabinowitz 1991a,b) filled this gap sufficiently to extend the mass range for meteoroids known from photographic fireball networks (upper mass limit of 10^{4} kg, Ceplecha 1988). In the past many authors have tried to estimate the total interplanetary matter arriving on the Earth by extrapolating results from quite a limited size-range of bodies to all masses, on simply assuming a constant population index.

In this paper I will use observations by different methods in different mass intervals to produce a single distribution curve of the numbers of interplanetary bodies coming to the whole Earth surface per year, valid for a mass range of 10^{-21}–10^{15} kg: 36 orders of magnitude! The cumulative number statistics within individual mass intervals are rather uncertain in the vicinity of both borders of any interval and only superpositions of observations from different methods and mass ranges reduces the uncertainties. Extrapolations outside limits defined by actual data are forbidden in any analysis. There are three important rules which should be adopted in such an investigation: a) Any interval useful to measure relative count rates should not include the smallest observable events, where the sensor omits the majority of them; b) Equivalently,any interval should not include the largest observable events, where again only a few are actually recorded; c) Individual events should have individually determined masses. If only a total effect relying on kinetic energy is recorded and the mass is estimated according to an average velocity, then the dependence of mass on velocity makes the cumulative number curve appear steeper. (In other words, more populated ranges of smaller bodies with high velocity are added to the ranges of a few larger bodies with low velocity, unresolved because they share the same average kinetic energy).

Note: I will often use the term "mass" (with notation m) in the sense of "initial mass", i.e. mass before entering the atmosphere (with notation m_∞).

2. Observational material

A summary of the observational data on fluxes used in this paper is presented in Table 1. The data for small masses were analyzed by Grün et al. (1985) and I adopted their values for the range 10^{-21} to 10^{-10} kg without changes. These include the space probe data with full internal consistency. Moreover the two fluxes from Pegasus at 9.3×10^{-11} and at 5.8×10^{-10} kg correspond well to the fluxes of the smallest radar meteors at 2.8×10^{-9} kg.

The flux data for meteoroid masses typical for photographic and television recording were analyzed by Ceplecha (1988) and I adopted these values from 2×10^{-6} to 10^{3} kg without changes. The mass of each meteoroid in my 1988 paper was determined individually from its light curve and instantaneous velocities. The same paper joins four different overlapping mass ranges of observations and uses their superpositions for different meteoroid populations. This also makes possible some insight into the problems of the origin of interplanetary bodies of different dimensions inside this mass range. This paper also revised the absolute value of the mass scale. I use here this mass scale for all data obtained by "atmospheric recording" of meteoroids, i.e. for photographic, television and radar meteors.

The flux data for large masses were published by Rabinowitz (1991a) at the ACM'91 Conference in Flagstaff. The lowest mass covered by these data was based on the single discovery of 1991 BA. Later, more low mass objects were discovered by the Spacewatch Telescope (1991 TT, 1991 TU, 1991 VA) and I have received the revised unpublished values of fluxes directly from

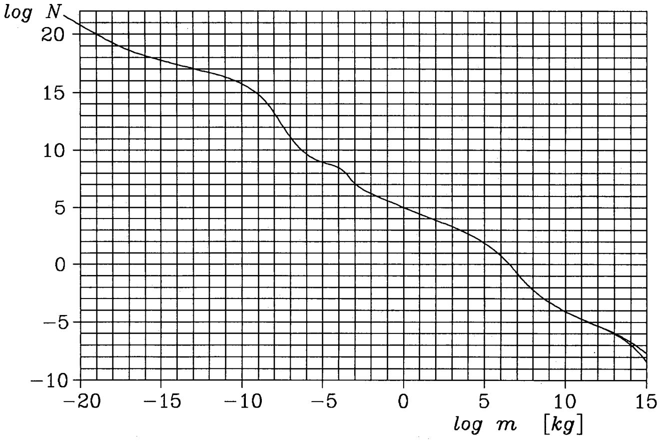

Fig. 1. Logarithm (base 10) of the cumulative number, N, of interplanetary bodies with mass equal or greater than m coming to the Earth is plotted against logarithm of the mass m. The lower curve at $\log m = 14$ and 15 is from the data of Shoemaker et al. (1990); the upper curve is the adopted average (see text)

Table 1. Observational flux-data on Earth-crossing interplanetary bodies

Mass range (kg) from	to	method	author
10^{-21}	10^{-9}	lunar microcraters space probes	Grün et al. (1985)
10^{-16}	6×10^{-10}	space probes	Naumann (1966) Hoffman et al. (1975a,b) Grün & Zook (1980)
3×10^{-9}	3×10^{-6}	radar meteors	Elford et al. (1964) Verniani & Hawkins (1965)
10^{-6}	10^{4}	photographic and television meteors	Ceplecha (1988)
8×10^{5}	10^{15}	asteroid discoveries by Spacewatch	Rabinowitz (1991a,b)
10^{12}	10^{15}	photographic Earth-crossing asteroids	Shoemaker et al.(1990)

Rabinowitz (1991b). He announced me that he will include these new values into the final version of his ACM'91 paper. He estimated the errors in $\log m$ as ± 0.5 and the errors in the computed log of the cumulative flux as mostly between +0.2 and -0.4. I have applied these data of cumulative fluxes directly within the mass range from 8×10^5 to 10^{12} kg, where Rabinowitz presents five discrete values.

The flux data published by Shoemaker et al. (1990) for the biggest asteroidal bodies crossing the Earth's orbit are based on statistics of all known bodies discovered and followed by photographic methods. These data differ from the data of Rabinowitz only close to the extreme limit of 10^{15} kg, where both analyses are based on very few cases and the completeness depends strongly on each newly discovered body. Thus I used two sets of cumulative fluxes for the mass range from 10^{12} to 10^{15} kg: an average based on average fluxes from both analyses, and another following the fluxes given by Shoemaker.

For masses less than 10^{-6}, the fluxes derived from television meteors are too low for smooth extension into the region of space-probe data, as already mentioned in Ceplecha (1988). If the condition of individually determined masses is kept, the entire gap in the flux data between 10^{-6} kg and 10^{-9} kg is accessible only to radar observations of meteors. But absolutely calibrated radar meteor fluxes based on individually determined masses were rarely published; most of the papers contain only population indices determined in a very narrow mass interval so that masses are only defined statistically. This is the same situation as with visual telescopic observations of meteors or with lunar craters. I was able to find one exception: the data from the Harvard-Smithsonian Radio Meteor Project, which is included in Table 1. The correction of the masses used by Verniani & Hawkins (1965) to the scale used for photographic and television meteors also in the present analysis means: $\log m$ (new) $= \log m$ (old) $- 0.5$. The threshold value of the smallest meteoroids observed by Elford et al. (1964) must be corrected as well. This value depends very much on velocity and resulted in 2.8×10^{-9} kg for 20 km/s when the above correction is applied.

The discrepancy between the flux data from television and radar observations of meteors may have a simple reason: the luminous efficiency at atmospheric entry significantly decreases for masses smaller than 10^{-6} kg. But the ionization efficiency is also not so well known and moreover its value depends on luminous efficiencies derived for higher masses. Much more should be done in meteor physics to solve these questions. In any case the fluxes in the mass range of 10^{-6} to 10^{-9} kg are the least certain of all the flux data given in this paper.

The other major gap in the flux data occurs between 10^4 and 8×10^5 kg. This gap had been much wider before the Spacewatch observations became available. The fluxes just outside this gap on both sides point to the significance of these bodies for the total Earth influx. Systematic observations within this mass range are highly desirable. The observed cumulative fluxes on either side of the gap agree well enough to interpolate them for masses inside the gap. In any case values of fluxes inside this mass range are more reliable than the flux values inside the mass range of radar observations of meteors.

3. Earth influx of interplanetary bodies

3.1. Cumulative influx and population index

The resulting cumulative number fluxes of interplanetary bodies onto the Earth derived from the data of Table 1 are given in Fig. 1. The fluxes across this vast range of masses cannot be expressed by a simple power law, which may suggest many different interlaced populations of different origin, as was already demonstrated for bodies with masses from 10^{-6} to 10^4 kg.

If we define the population index α as: $N(m) \propto m^{-\alpha}$, we can derive such indices from Fig. 1. The results are shown in Fig. 2. The fluxes contain at least three parts with high values of α centered near $\log m = 7, -3.5, -8$. If we take the critical value of $\alpha > 5/6$ (Dohnanyi 1970), then there are three mass ranges with unstable populations: $\log m = (-9.5, -6)$, $(-4, -2.5)$ and $(5, 9.5)$. The first of these regions is inside the range of radar meteor data, the second inside the SuperSchmidt photographic range and the last, at the smallest bodies observed by Spacewatch.

The first region corresponds to the situation where the losses of particles caused by the Poynting-Robertson effect outweigh the collisional gains of particles from bigger bodies (Grün et al. 1985, Leinert & Grün 1988).

The second region at $\log m = -3.5$ corresponds to the mass range where meteor showers are the most distinct phenomena. These meteoroids originate from a limited number of comets. At the start they closely follow the orbit of their parent comet, which

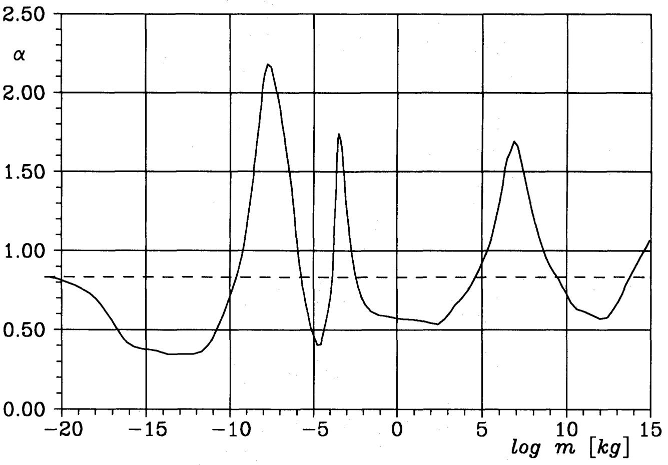

Fig. 2. Population index α against logarithm of the mass *m*. The dashed horizontal line corresponds to the critical value derived by Dohnanyi (1970). Values above this critical limit belong to unstable populations

makes them easily recognized among sporadic meteors. But soon their orbits are perturbed and spread to such an extent that they cannot be distinguished from the sporadic background.

The third region corresponds to the majority of small cometary fragments (small inactive comets) as already proposed by Kresák (1978) and Rabinowitz (1991). Evidently comets need to have masses of at least 10^9 kg to be active.

3.2. *Incremental mass flux*

From Fig. 1 we can derive the incremental mass flux, d*m*, to the whole surface of the Earth per year and per mass interval of one order, i.e. per $\mathrm{d}(\log m) = 1$. This is given in Fig. 3. The most important masses for the mass influx onto the Earth are 10^{13} - 10^{15} kg. Even more massive bodies might prove to be more important, but Shoemaker's (1990) data show a maximum at 10^{14} kg, hopefully the last maximum in the trend towards larger masses. The second biggest maximum of incremental mass influx reaches almost the same value as the biggest and it belongs to bodies with masses of 10^6 kg. These bodies, with dimensions on the order of 10 meters, are the least known in the solar system. Just recently the Spacewatch telescope opened the way to their direct study. The research of these bodies deserve full attention in the coming years.

The third maximum in Fig. 3 is one order of magnitude lower than the second, and it belongs to meteoric dust at 10^{-9} kg, as already recognized by Grün et al. (1985) and Leinert and Grün (1990). The fourth maximum is quite small and located at mass of $10^{-3.5}$ kg, just inside the mass range of Super-Schmidt photographic meteors and also visually observed meteors.

In the past, limited mass ranges have been used to compute the total influx of interplanetary bodies onto the Earth. When based on data from mass ranges near the third ("dust") or fourth ("visual meteor") maxima, they gave much lower values than reality. Combining the dust and visual meteor data was not very helpful in this respect. The photographic observations of fireball networks (McCrosky 1968; McCrosky & Ceplecha 1969; Halliday et al. 1984, 1989; Ceplecha 1988) were the first which pointed to the much higher total influx of interplanetary bodies onto the Earth than estimated by extrapolations from previous observations of fainter meteors.

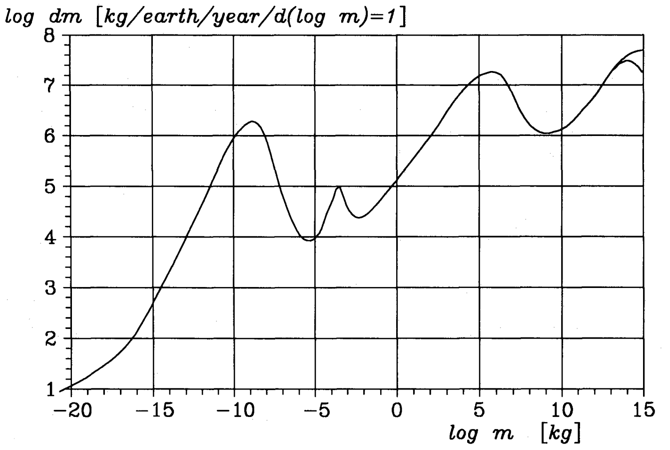

Fig. 3. Logarithm of the incremental mass flux, d*m*, (the incremental interval is chosen as one order of mass) against logarithm of the mass *m*. The lower curve at $\log m = 14$ and 15 belongs to data of Shoemaker et al. (1990); the upper curve is the adopted average

3.3. *Earth atmosphere and surface*

All interplanetary bodies encountering Earth bring their mass ultimately to its surface. However, it may be of some interest to know what fraction of this mass is altered by the atmosphere (ablation) and what fraction strikes the surface either at low velocity (meteorites) or high velocity (explosive craters). A simple heating and ablation theory (Ceplecha & Padevět 1961, Pecina & Ceplecha 1983) was used in this paper for such a purpose (Ceplecha & Padevět 1961, Pecina & Ceplecha 1983). The theory of meteorite impacts used here was taken from Ceplecha (1987).

Before ablation starts, the heating of the body during its atmospheric entry continues with time until the surface temperature of the body, T_B, reaches the "ablation" value (I adopted 2460 K) and ablation takes then over most of the energy exchange. This happens at a height h_B, where the air density is ρ_B. The velocity of the body v_B at this height can be computed from

$$1+\frac{v_\mathrm{B}^3 m_\infty^{1/3} b \cos z \, \ln(v_\mathrm{B}/v_\infty)}{4\varepsilon K T_\mathrm{B}^4}=0, \tag{1}$$

where ε is the Stefan-Bolzmann constant, $K = \Gamma A \delta^{-2/3}$ is the shape-density coefficient of the body (0.5 in c.g.s units for stones), Γ is the drag coefficient, δ the bulk density of the body, A the shape factor $A = Sm^{-2/3}\delta^{2/3}$, S the head cross-section of the body, m_∞ is the initial mass and v_∞ is the initial velocity before the atmospheric entry, z is the zenith distance of the direction of the body flight (the average value $2/\pi$ was used) and b is the air density gradient. In solving this equation and the following, the variability of b with height was taken into account. I solved this equation for the unknown v_B. When this equation has no solution, the body does not ablate at all (small dust particles). Its impact velocity v_s on the surface is then

$$v_\mathrm{s} = \sqrt{g m_\infty^{1/3}/(K\rho_\mathrm{s})}, \tag{2}$$

where g is the gravitational acceleration and ρ_s the air density at the Earth's surface.

If the solution for v_B from equation (1) exists, we can find the air density ρ_B at the height below which the body starts to ablate

$$\rho_{\rm B} = 4\varepsilon T_{\rm B}^4/v_{\rm B}^3. \quad (3)$$

In the ablation regime, we are interested in the terminal mass $m_{\rm E}$, which is defined as the mass which remains after being decelerated to a terminal velocity $v_{\rm E}$, where ablation ceases. I used $v_{\rm E} = 3$ km/s. The terminal mass is then given by

$$m_{\rm E} = m_\infty \exp(\tfrac{\sigma}{2}(v_{\rm E}^2 - v_{\rm B}^2)), \quad (4)$$

where σ is the ablation coefficient (0.014 s^2/km^2 for stones, 0.042 for carbonaceous material). The impact velocity $v_{\rm s}$ is then given by

$$v_{\rm s} = \left[v_{\rm E}^2 \exp\left(\frac{2K(\rho_{\rm E} - \rho_{\rm s})}{b m_{\rm E}^{1/3}} \right) + \frac{g m_{\rm E}^{1/3}}{K \rho_{\rm s}} \right]^{1/2} \quad (5)$$

where $\rho_{\rm E}$ is the air density at the terminal point given by

$$\rho_{\rm E} = \rho_{\rm B} + \frac{(\mathrm{Ei}(\frac{\sigma v_{\rm B}^2}{6}) - \mathrm{Ei}(\frac{\sigma v_{\rm E}^2}{6}))\, m_\infty^{1/3} b \cos z}{2K \exp(\frac{\sigma v_{\rm B}^2}{6})} \quad (6)$$

such that $\mathrm{Ei}(x) = \int_{-\infty}^{x} u^{-1} \exp(u) \mathrm{d}u$ is the exponential integral.

If the body is not decelerated to $v_{\rm E} = 3$ km/s before it reaches the surface (i.e. very big bodies), its impact velocity is greater than this value and is given by

$$v_{\rm s} = \left[\frac{6}{\sigma} \mathrm{Ei}^{-1} \left(\mathrm{Ei}(\frac{\sigma v_{\rm B}^2}{6}) - \frac{2K(\rho_{\rm s} - \rho_{\rm B}) \exp(\frac{\sigma v_{\rm B}^2}{6})}{m_\infty^{1/3} b \cos z} \right) \right]^{1/2}, \quad (7)$$

where $\mathrm{Ei}^{-1}(x)$ is the inverse function to $\mathrm{Ei}(x)$ (Pecina 1986).

Using the above equations we can sort all the mass influx to the Earth into three categories: the mass which comes unchaged by ablation (d), the ablated mass (a), and the terminal mass after ablation (t). We can further sort the terminal mass into two categories: the mass which falls down as meteorites (m), and the mass which impacts the surface in an explosive way (e). The lowest velocity for which the impact starts to be explosive is given by equating the kinetic energy of the body to the energy necessary for its complete evaporation. The range of this value for stones is between 3 and 4 km/s. For practical purposes I took 3 km/s, the same value as for the end of ablation. The function of impact velocity with mass (see Fig. 4 plotted for stony bodies) is so crude that this assumption has practically no influence on the resulting total mass influx of meteorite and explosive events.

Figure 4 also shows that the protection by the Earth's atmosphere against explosive impacts of stony bodies is effective only below 10^5 kg. For masses of 10^6 kg the protection is partial, i.e., against high velocity bodies. Stony bodies more massive than 10^7 kg impact the surface explosively for all initial velocities. For carbonaceous bodies the situation is similar except the border is shifted two orders higher to larger masses with a steeper velocity gradient. Thus the protection against carbonaceous bodies is much more effective. Cometary bodies with masses under 3×10^{11} kg (initial velocity of 28 km/s) do not impact the Earth surface explosively, while bodies with mass of 10^{12} kg and greater do, although their terminal mass at impact is 4×10^{10} kg and greater.

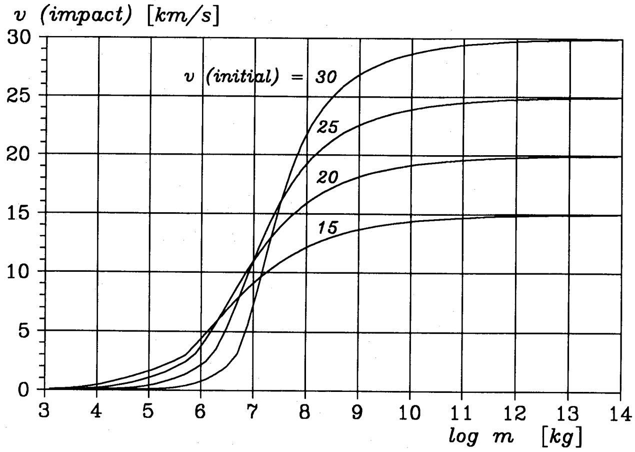

Fig. 4. Impact velocity on the Earth surface, v(impact), against logarithm of the initial mass m, for different initial velocities and for stony composition of the body

3.4. Cumulative mass influx and time spans

Cumulative mass influx is given in Fig. 5. Here M denotes all mass influx of bodies with mass greater than the mass m. Two levels of the cumulative influx are evident: the first one belongs to bodies bigger than about 10^{10} kg, the other to bodies bigger than about 10^3 kg. The ratio of masses at these two levels is less than 2. This reflects the situation that high masses are most important for the total mass influx to the Earth. In the range below 10^3 kg there is little additional mass coming to the Earth in comparison with masses above this.

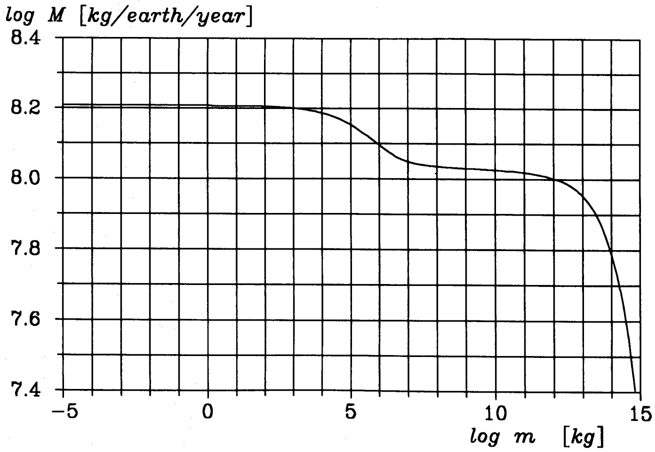

Fig. 5. Logarithm of the cumulative mass, M, of interplanetary bodies with mass equal or greater than m is plotted against logarithm of the mass m

We can also plot another cumulative mass influx by accumulating masses in the opposite sense, starting with the smallest masses. In Fig. 6 this cumulative mass influx, i.e. influx of all masses less than a given mass m, is denoted $M<$, and is plotted against $\log T$, the average time span between two consecutive events having the mass m. In the dust region this cumulative flux increases up to a level of 4×10^6 kg per year for the whole Earth surface. The next rise on this curve corresponds to masses in the fireball range up to the small Spacewatch objects leveling at

6×10^7 kg per year for the whole Earth surface already during the time span of one year! Only very large objects add some significant amount of mass more, but they need the time span of more than million years.

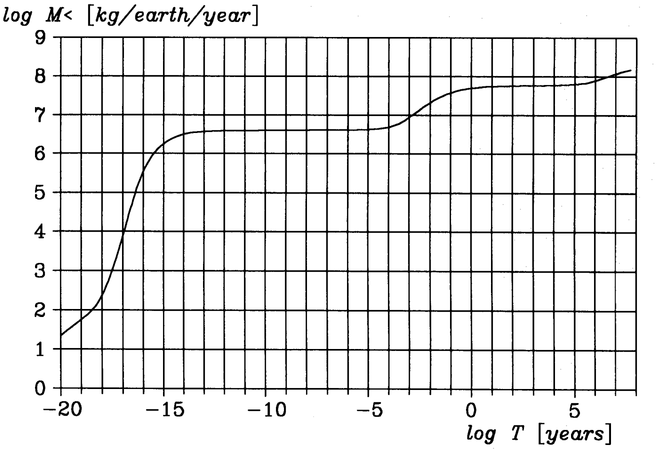

Fig. 6. Logarithm of the cumulative mass, $M<$, of interplanetary bodies with mass equal or less than m coming to the Earth is plotted against logarithm of T, the average time between two consecutive events of mass equal or less than m

From Fig. 1, we can also determine the average time interval between two consecutive events of the same mass. (The inverse of "number of events per year" is equivalent to "average number of years between consecutive events".) From the point of view of potential danger of meteoroid impacts, these results are interesting particularly for bigger masses. They are given in Table 2, where T denotes the average time interval between two consecutive events having masses inside the same logarithmic interval of 1 (0.5 both sides of the given initial mass m_∞). The values of terminal masses m_t are given for three models: stones (ordinary chondrites), carbonaceous material and cometary material. Formulae used are given in section 3.3. The numerical values of average velocity v_∞, bulk density δ, ablation coefficient σ and shape-density coefficient K, necessary for computing the terminal mass m_t are given in Table 3 of the next section. They were taken from data derived for photographic fireballs.

The very small values of terminal masses for cometary material originate from cases, when the body slows down to the terminal velocity of 3 km/s before impacting the surface. High initial velocity and the big value of ablation coefficient make the computed remnant mass negligible. In fact we do not know physical phenomena in case of big bodies composed of such a loose material. Severe fragmentation may cause that the terminal masses are very small also for initial masses of 10^{12} kg and bigger.

The regime of explosive impact on the Earth's surface is denoted in Table 2 by the dividing line. We can use Table 2 for indirect identification of the composition of bodies in the initial mass range from 10^5 to 10^7 kg (dimensions of the order of 10 m). If these bodies were ordinary meteoritic stones, we would expect 20 impacts on the Earth each year with explosive craters of dimesions from 10 to 100 m. Even taking into account the ocean surface, this clearly is not the case. If these bodies were carbonaceous, we would expect 20 meteorite falls each year with masses close to 10 tonnes and non-explosive craters of the dimensions of several meters. But this also seems too far from what is known about observed meteorite falls. The idea that these bodies are mostly small inactive comets (Kresák 1978, Rabinowitz 1991) seems to be independently verified in this indirect fashion. An admixture of stony bodies to this system could form only a few percent at most. The problem of nature of these bodies can be more clarified by using several indirect methods (e.g. deep see sediments, lunar soil), but the direct observation of these bodies in close future would be the best solution.

Table 2. Average time T between two consecutive events of masses m_i: $\log m_\infty - 0.5 < \log m_i < \log m_\infty + 0.5$; m_t is the terminal mass

		material			
$\log m_\infty$ kg		stony $\log m_t$ kg	carbonaceous $\log m_t$ kg	cometary $\log m_t$ kg	$\log T$ year
15		15.00	14.99	14.92	7.30
14	reg-	14.00	13.99	13.80	6.41
13	ion	12.99	12.97	12.52	5.75
12	of	11.98	11.94	10.60	5.23
11	ex-	10.96	10.86	-5.8	4.59
10	plo-	9.91	9.70	-6.8	3.88
9	sive	8.83	8.31	-7.8	2.96
8	im-	7.64	6.44	-8.8	1.78
7	pa-	6.34	4.75	-9.8	0.19
6	cts	5.07	3.75	-10.8	-1.25
5		4.04	2.75	-11.8	-2.18

3.5. *Total Earth influx of interplanetary bodies*

The total influx of all interplanetary bodies to the Earth across the mass range from 10^{-21} kg to 10^{15} kg resulting from Fig. 3 is

1.7×10^8 *kg per year for the entire Earth surface.*

This value does not change much in case we take the flux for large bodies according to Shoemaker (the lower curve at the highest masses in Fig. 2.): 1.4×10^8 kg per year per Earth surface. In any case these values are one order of magnitude higher than those derived from extrapolations of smaller body data (e.g. Hughes 1978). Most of the influx comes from bodies more massive than 10^3 kg. Impacts of bodies in the mass ranges from 10^4 to 10^7 kg (perhaps mostly cometary bodies) and bigger than 10^{12} kg (stony or carbonaceous asteroidal bodies) are most important. A very rough guess of the total flux of interplanetary bodies by McCrosky & Ceplecha in 1969 (based on the first results from photographic fireball networks), i.e. 10^8 kg per year per Earth surface, is surprisingly close to that found here with reliable data for masses up to 10^{15} kg.

Knowledge of the relative strength of different populations among all the bodies coming to the Earth is available only for the mass range from 10^{-6} kg to 10^4 kg. Thus it is not possible to make a complete study of what part of the total influx rate comes to the surface as unchanged dust, as meteorites, as ablated material and as explosive impacts (see section 3.3). We can simplify the problem by assuming that bodies accros the whole studied mass range have a single "average" composition. Properties of the mass increase of the Earth with this assumption valid are evident from Table 3.

For stony and carbonaceous bodies explosive impacts are the most important type of influx. They form two thirds of the total influx, the remaining third being ablated material originating

Table 3. Type of influx for different composition of the whole system (in kg per year for the whole Earth surface).

type of influx	stony	material carbonaceous	cometary
d	8.3×10^5	2.4×10^6	4.7×10^5
a	5.1×10^7	6.1×10^7	1.0×10^8
t	1.14×10^8	1.02×10^8	6.5×10^7
m	4.1×10^6	3.1×10^5	$8. \times 10^{-6}$
e	1.10×10^8	1.02×10^8	6.5×10^7
total	1.65×10^8	1.65×10^8	1.65×10^8
v [km/s]	18	16	28
σ [s^2/km^2]	0.014	0.042	0.1
δ [c.g.s.]	3.7	2.0	0.75
K [c.g.s.]	0.5	0.75	1.45

d: dust unchanged by ablation
a: mass ablated in the atmosphere
t: terminal mass left after ablation
m: meteorites (non-explosive impacts)
e: explosive impacts of bodies
δ is the bulk density of the material

from preceding atmospheric ablation of these impacting bodies. Meteorite falls form several percent of the total influx of stony bodies and few per mil of total influx of carbonaceous bodies. The dust component of the total influx behaves just opposite to the meteorite component: it forms a few percent of the total inlux of carbonaceous bodies and few per mil of total influx of stony bodies.

For cometary bodies, the ablated material is the most important type of influx. It forms two thirds of the total influx, the remaing third belonging to explosive impacts. There are practically no meteorites coming from a cometary source and the dust component is only few per mil of the total influx.

Acknowledgements. I am very much indebted to Dr. David Rabinowitz for his kind cooperation in affording me his flux data derived from new discovered interplanetary bodies in the 10 to 100 m size range before publication. His presentation at the ACM'91 conference in Flagstaff actually inspired this paper. I want to express my cordial thanks to Dr. Jaymie Matthews for his work on improving the language of the paper. This work has been supported by grant 30319 from the Czechoslovak Academy of Sciences.

References

Ceplecha Z., 1987, Bull. Astron. Inst. Czechosl. 38, 222

Ceplecha Z., 1988, Bull. Astron. Inst. Czechosl. 39, 221

Ceplecha Z., Padevět V., 1961, Bull. Astron. Inst. Czechosl. 12, 191

Dohnanyi J.S., 1970, J. Geophys. Res. 75, 3468

Elford W.G., Hawkins G.S., Southworth R.B., 1964, Radio Meteor Project, No.11, Harvard and Smithsonian Obs., Cambridge USA

Grün E., Zook H.A., 1980, Dynamics of Micrometeoroids in the Inner Solar System. In: Halliday I. McIntosh B.A. (eds.) Solid Particles in the Solar System. Reidel, Dordrecht, p.293

Grün E., Zook H.A., Fechtig H.,Giese R.H., 1985, Icarus 62, 244

Halliday I., Blackwell A.T., Griffin A.A., 1984, Sci 223, 1405

Halliday I., Blackwell A.T., Griffin A.A., 1989, Meteoritics 24, 173

Hoffmann H.J., Fechtig H., Grun E., Kissel J., 1975a, Planet Space Sci. 23, 215

Hoffmann H.J., Fechtig H., Grun E., Kissel J., 1975b, Planet Space Sci. 23, 985

Hughes D.W., 1978, Meteors. In: McDonnell (ed.) Cosmic Dust. Wiley, Chichester, p.123

Kresák L., 1978, Bull. Astron. Inst. Czechosl. 29, 135

Leinert Ch., Grün E., 1989, Interplanetary Dust. In: Schwenn R., March E. (eds.) Physics of the Inner Heliosphere I. Springer, Heidelberg, p. 207

McCrosky R.E., 1968, Smithson. Astrophys. Obs. Spec. Rep. 280

McCrosky R.E., Ceplecha Z., 1969, Photographic Networks for Fireballs. In: Millman P.E. (ed.) Meteorite Research. Reidel, Dordrecht, p. 600

Naumann R.J., 1966, The Near Earth Meteoroid Environment. NASA TND 3717

Pecina P., 1986, Bull. Astron. Inst. Czechosl. 37, 8

Pecina P., Ceplecha Z., 1983, Bull. Astron. Inst. Czechosl. 34, 102

Rabinowitz D.L., 1991a, ACM'91 Conference Proceedings. The Flux of Small Asteroids near the Earth. Lunar and Planetary Institute, Huston (in press)

Rabinowitz D.L., 1991b, New Discovered Asteroids in the 10 to 100 m size range. (Private communication)

Shoemaker E.M., Wolfe R.F., Shoemaker C.S., 1990, Asteroid and Comet Flux in the Neighborhood of Earth. In: Sharpton V.L., Ward P.D. (eds.) Global Catastrophes in Earth History, Geological Soc. of America, p.155

Verniani F., Hawkins G.S., 1965, Radio Meteor Project, No.12, Harvard and Smithsonian, Cambridge USA