THESE ASTEROIDS THAT GRAZE THE EARTH

Definition and classification of the different categories of objects

by Michel-Alain Combes

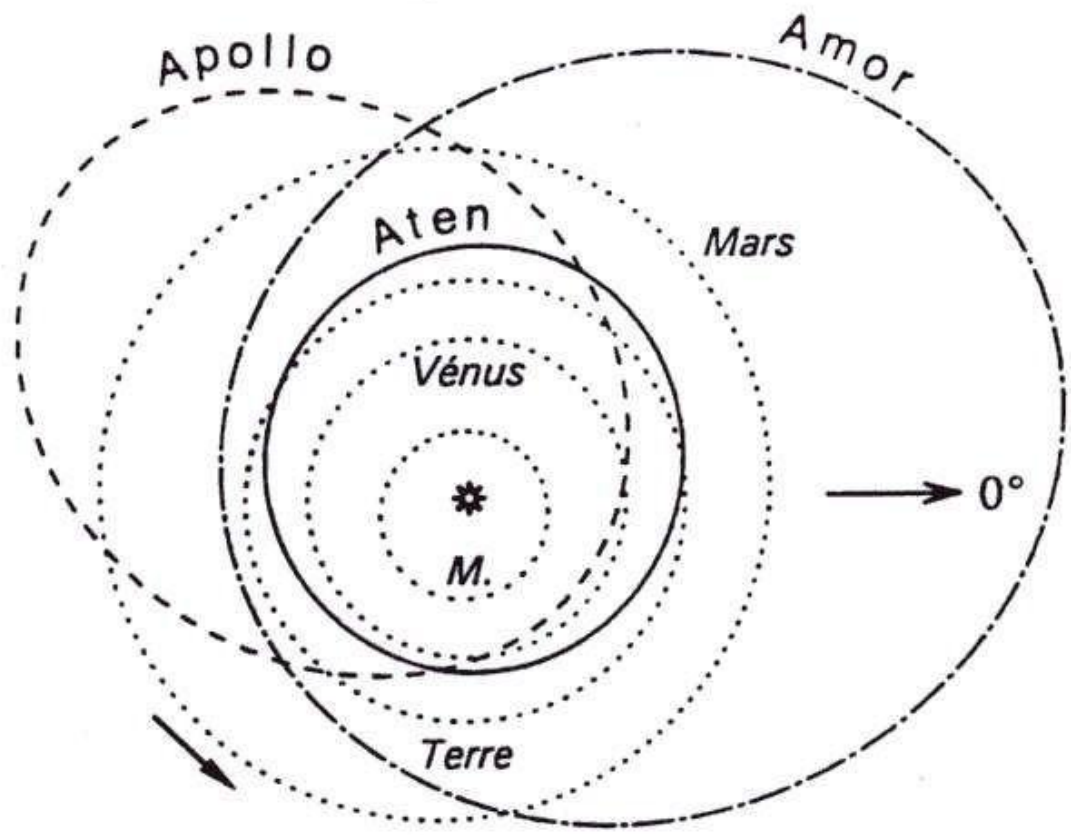
(Translated by Anne-Marie de Grazia)

We call NEA (standing for Near-Earth Asteroids) those whose inferior perihelic distance is less than 1.30 AU (=Astronomical Unit = mean distance between the Earth and the Sun over one Earth orbit).

We call PHA (for Potentially Hasardous Asteroids) those whose minimal distance to the Earth orbit (MOID) is <0.050 UA and whose absolute magnitude is (H)<22.1 (corresponding to a mean diameter of over 130m, but comprised between 100 and 200 meters according to their physical type and their albedo (this being the measure of how strongly an object reflects the light from light sources, where in most cases we are dealing with the Sun). These are the ones which we are seeking to identify and list exhaustively, in order to destroy (or deflect) them eventually, if the need should arise.

As of the end of April 2010, we know of **7000 NEA** and of over **1100 PHA.** That is, nearly **1 NEA out of 6 is also a PHA,** which is a very high percentage.

Since 1979, we have come to recognize **three** different types of NEA:
- the **Aten** type, which are NEA whose mean circulation takes place inside the Earth orbit (**a** being inferior to 1.000 AU);
- the **Apollo** type, which are NEA penetrating the Earth orbit at perihelion (**a** being superior to 1.000 AU and **q** inferior to 1.000 AU);
- the **Amor** type, which are NEAs whose perihelion is between 1.000 and 1.300 AU).

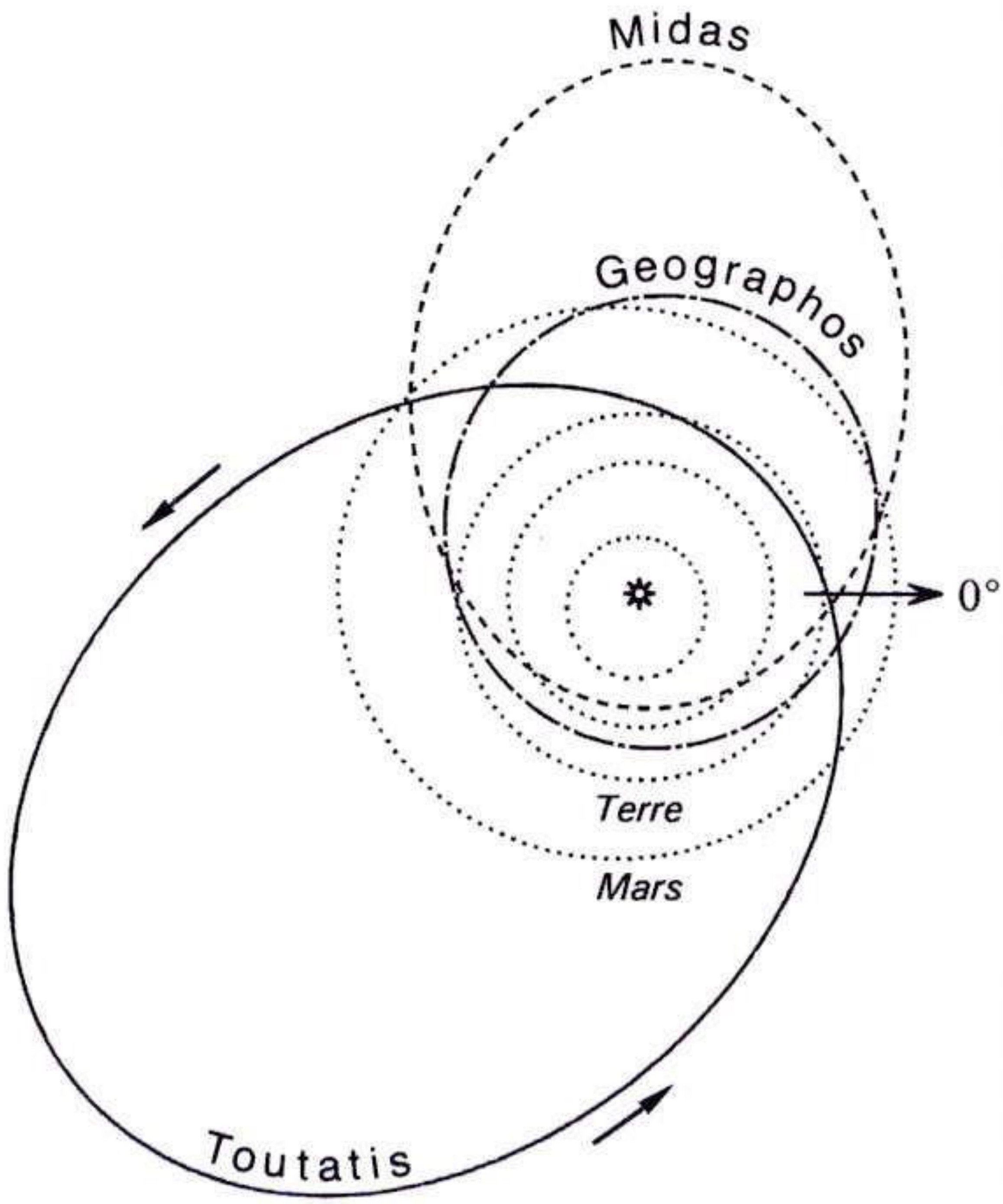


(Figure quanta2010-doc 01= the three types of NEAs)
(Terre=Earth)

The figure shows the orbits of the three objects which give their names to a certain type of NEA: **Aten, Apollo** and **Amor.** These are not the largest of their types when one considers their diameter. Only the NEAs of the Aten and Apollo types can cross the Earth orbit. They are called the **Earth-crossers.**

It is important to point out that several types of objects of the Amor type become at times Apollo types, due to the increase of their eccentricity which allows them to have **q** < 1.000 AU, and inversely, some Apollo objects can become of the Amor type. Certain objects whose movement is in libration with the Earth movement also cross over from the Aten to the Apollo type, and the reverse. Their half-major-axis is slightly inferior or superior to **a** = 1.000 AU at some times. This classification according to three types is therefore only valid for the present time. In order to differentiate between these orbits, which can be of considerably different dimensions, one distinguishes **four subtypes** for the Apollo and Amor types, in function of the value of the half-major-axis **a**, it being understood that the Aten type is also a sub-type, as it is based upon a particular value of **a**. These are:

Sub-type 1 concerning itself with the objects whose mean orbit circulates between the orbits of Earth and Mars (**a** between 1.000 and 1.523 AU);
Sub-type 2 which concerns itself with objects whose mean orbit circulates between Mars and the main ring of asteroids (**a** between 1.524 and 2.064 AU);
Sub-type 3 which concerns itself with the objects whose mean orbit circulates within the principal asteroid ring and which are therefore members of this ring (**a** comprised between 2.065 and 3.582 AU);
Sub-type 4 which concerns itself with some rare asteroids whose mean orbit circulate outside this main ring (**a** > 3.582 AU).



(Figure quanta2010-doc02 = the Sub-types)
(Terre=Earth)

The figure shows the orbits of sub-type 1 (**Geographos**), another of sub-type 2 (**Midas**) and a third of sub-type 3 (**Toutatis**). We see clearly that the sizes of these orbits, and therefore their period of revolution vary widely.

Finally, concerning the **origins of the NEA,** we distinguish **planetary** NEAs, which are **true asteroids,** probably fragments of larger planetary objects broken up after collisions in space, and **cometary** NEAs, which are nuclei of **dead** or **sleeping** comets, of an asteroidal appearance.

We know some objects that have displayed a cometary behavior at some periods, but which today are asteroids, as they no longer display any cometary behavior that can be discerned. They are catalogued both as comets and as asteroids.

The orbits of NEAs

Nearly **7000 NEAs** are known at the end of April 2010.Their orbits may be very different so far as concerns their half-major-axis, their eccentricity, their inclination, their perihelion and their orientation in space. But we must be well aware that nothing is immutable and that these elements vary with time.

Type Aten. We know some **600** NEAs (**8%** of the total) which circulate on average inside the Earth orbit (**a** < 1.000 AU and **P** < 1.00 year). We observe them near aphelion, when they are not obscured by the solar light. Several of these objects can graze Venus, and even Mercury, and they are the major impactors of these planets.

Type Apollo. More than **3500** objects (**50 %** of the total) have been counted. They divide themselves into three sub-types with a marked predominance of objects with a mean orbit situated between Earth and Mars (sub-type 1), even if these large orbit objects are rather rnumerous. Their eccentricities are quite variable, they can be weak for the sub-type 1 objects, whereas they are always strong for the sub-type 3 objects. Eccentricities of **e** > 0.70 are not rare, many being made of **fragments of HEPHAISTOS.**

Type Amor. Nearly **2900** objects (**42%** of the total) do not penetrate inside the Earth's orbit at the present time, but get close to it at perihelion. The majority are members of main ring (sub-type 3), but we know of numerous objects circulating between Earth and Mars (sub-type 1) on a weakly excentric orbit. Many of these are easily accessible from Earth and may be exploited in the future by our descendants when they run out of mineral resources.

The sub-types. Sub-types 1, 2 and 3 are very common, but sub-type 4 is rare. It is only relevant to a few external NEAs of cometary origin and with unstable orbits. These objects have been recently captured from larger orbits, and their present orbits, which are quite provisory, are destined to evolve considerably during the coming millennia.   It is generally thought that their periodicity will be reduced and that they will become asteroids of the main ring. In a few rare cases, they may be expelled from the Solar system, or be reinjected into a comet pool (such as the Oort Cloud and the Kuiper Belt).

Physical composition of the NEAs

Since the beginning of the 1970s, astronomers have arrived at a fundamental insight: the existence of **several physical types** of asteroids, that can be associated with certain types of well-known meteorites. This result is quite logical insofar as we know that there is a **continuity between the two kinds.** Some fifteen different physical types have been inventoried.

The types **S** (silicated objects) and **C** (carbonated) are the main ones, but NEAs have also been found of other types, notably the **M** type (metallic) and **V** (objects originating from Vesta). Cometary NEAs are principally of the **C** or **D** types, but some indeed seem to be of an S type, for they could be covered over with a thin silicated layer. The question also occurs whether some NEAs of cometary origin, which have been recently injected into the inner Solar system, might not be totally composed of ice.

A multiple origin for the NEAs.

In the light of the research done in the 1970s, we know that a double solution must be taken into account for the origin of the NEAs: one **planetary** and one **cometary.** In fact, to those distinct origins must be added a third, which coexists with the two others: **mixed objects,** which are in the same time planetary and cometary.

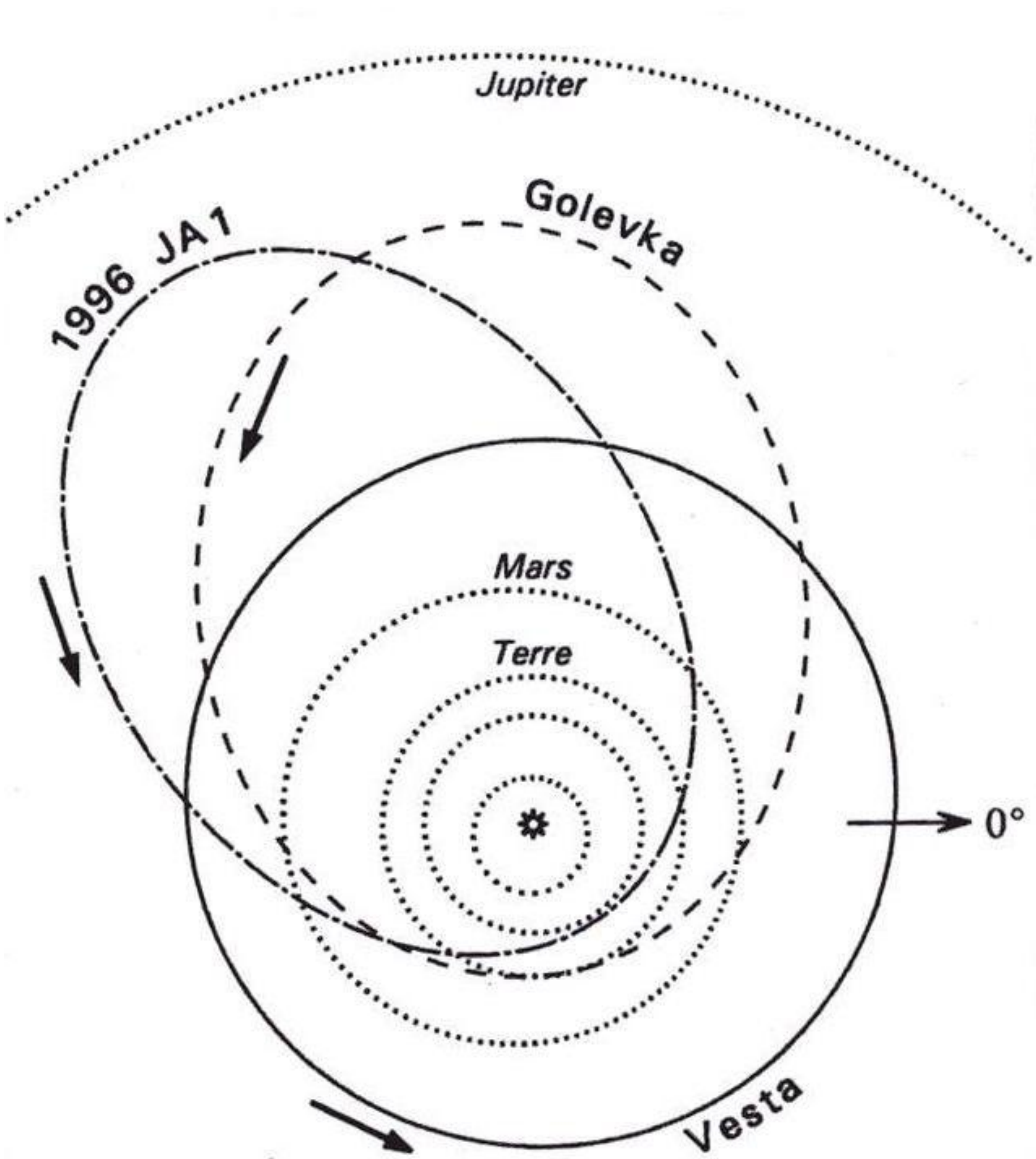
It was long thought that the planetary NEAs existed in a proportion of 3 to 4 (75%), with 1 to 4 (25%) for the cometary ones. Today, this ratio is considered too high. The experts tend in majority towards a ratio of 60/40, the number of cometary objects having probably been underestimated.

But besides the double origin, we know **several mechanisms of renewal** which allow a system to auto-generate itself and to planetary impactism to have lasted for four billion years and will do so for a long time to come. I shall now say a word about these different types of mechanisms.

Asteroid splinter NEAs. Some large, or glancing collisions do not result in total fragmentation of the target asteroid (the most massive of the two), but there ensue ejections of matter chipped off the surface and sent into space. Following such impacts, asteroid **splinters** become **autonomous** objects, sometimes propelled into the Solar system onto orbits which are considerably different from those of the parent body. Thus, certain recognized NEAs are known to have been in a relatively recent past (a few million years) an integral part of larger asteroids. Vesta purveys an excellent example, being the only differentiated asteroid of the type V (V for Vesta) and the parent body of eucrites. We know several NEAs with identical physical characteristics which are splinters which can reach a diameter of one kilometer, but the size of which is more generally hectometric. Of course, there exist also innumerable objects of a decametric or metric size, but these remain undetectable with our present technology, unless they approach very closely to Earth.

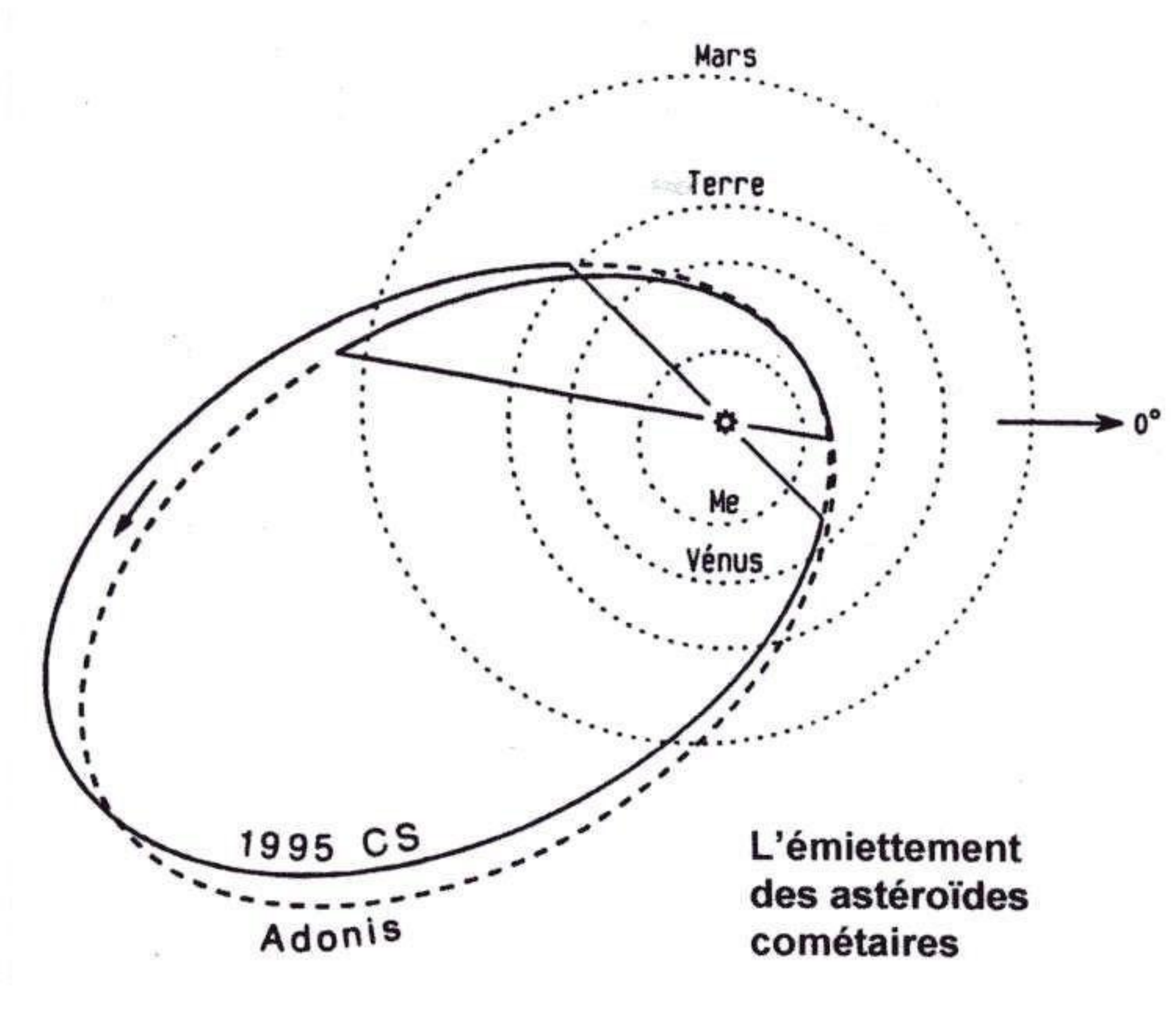
(Figure qanta2010-doc 03 = asteroid splinters)

NEAs which are fragments of broken up asteroids. We have seen with Vesta that splinters can acquire autonomy and become themselves asteroids and later, eventually, NEAs. But there is a second catastrophic scenario. The collision can be such that the target asteroid is **totally shattered.** Tens of thousands of fragments replace the desintegrated mother planet. Some will remain grouped and form a family of asteroids which might contain several hundred members of kilometric



size and thousands of hectometric size. We have long known of such **families**. Each comprises a variable number of members the three **characteristic elements** of which (the major-half-axis, eccentricity and proper inclination) remain inside a rather narrow bracket. But at the moment of disintegration of the parent body, numerous fragments gain their autonomy and become totally independant, and quite soon it becomes impossible to match them with the other members of the family.

An almost constant crumbling. Another important phenomenon which must be taken into consideration when one studies the origin of NEAs is **crumbling.** All returns to dust, in space as everywhere else. Cometary as well as real asteroids fragment and crumble off. We know of several pairs of NEAs with very similar characteristic orbits which broke off from each other only very recently (a few thousand years at most in some cases), without any major commotion, as the orbital elements have remain the same. Only their orientation in space varies, natural dispersion occurring at the rate of 4 degrees per millennium for the longitude of the ascending node and for the longitude of the perihelion.



Among the most striking cases, we may cite **Icarus** and **Talos,** two asteroids of equivalent size, **Adonis** and **1992 SK,** two true asteroids recently separated, probably as a result of a collision in space.

(Figure quanta2010-doc04 = crumbling of cometary asteroids)

Two great groups: planetary and cometary NEAs.

To sum up the important problem of the origin of NEAs, we can say that they divide into two large groups: planetary and cometary NEAs. Planetary NEAs are considered to be objects resulting from the relatively recent fragmentation (for practically no NEA has a life expectancy superior to 100 million years) of asteroids of the principal ring (2.06-3.58 AU) which, originally, did not reach inside the orbit of Mars.

Cometary NEAs are considered to be nuclei of comets which have lost all their volatile elements. In some cases, these may be **sleeping comets,** whose nucleus is provisorily inactive because it is surrounded by a “carapace” of dust or of an opaque substance which makes all activity of a cometary type impossible. We know that the **active** life expectancy of comets with a very short period (less than 12 years) is extremely short on the astronomic scale. It amounts to **tens of thousands of years for nuclei of a kilometric size** and to only thousands of years for those of a hectometric size. Cometary nuclei survive therefore under an asteroidal aspect for several million years, if the nucleus is sufficiently resistant to avoid fragmentation or crumbling following close approaches to the planets.

Several factors allow us to distinguish between the two populations composing the three types of NEAs: Aten, Apollo and Amor. We think particularly that the physical types S, M and V pertain to true asteroids and physical types C and D to cometary nuclei. We base our propositions generally on orbital elements, a very strong eccentricity and a very sharp inclination being indications of a cometary origin. We believe that a great majority of the numerous NEAs which evidence strong variation in their light curves are vestiges of objects which broke up at the occasion of collisions. Whether they are right or not, astronomers still believe (despite P/Halley) that cometary nuclei are more or less spherical as a general rule (which allows for exceptions) and that they display only minimal variations in brightness.

The important number of observed active comets with a very short period forces us to admit, as a principal consequence, the existence of a very high number of cometary NEAs, 100.000 being of more than a 100m diameter according to the numbers considered (250,000 NEAs of which 40% of a cometary origin). Yet, we must point out that we still are ignorant of the precise proportion of comets having a truly solid nucleus, capable of surviving as asteroids while avoiding the total **sublimation** of their matter (notably ice and frozen gases), as well as **fragmentation,** which is a fairly common phenomenon for comets.

This problem of the double origin of NEAs is very important. Owing to differences in composition and in destiny, the consequences are not the same when Earth collides with a true asteroid or with a cometary nucleus.

The diameters of NEAs and PHAs.

The NEAs are **very small objects** relative to the large planets and even to the main asteroids, which are more than 100km in diameter. The average approximate diameters of asteroids can be calculated using **their absolute magnitude H.** It is an average, because asteroids generally, and NEAs in particular, can have any shape at all. All asteroids of **planetary** origin are broken off pieces and therefore shapeless fragments, and those of **cometary** origin are nuclei of degassed comets which are not necessarily spherical, even if they display a less irregular light curve than that of the true asteroids.

This absolute magnitude H represents the brightness which would belong to an asteroid situated at 1.00 AU (150 MK) from both Earth and Sun, in a zero phase angle. It is an important parameter, from which one can caculate all other magnitudes and diameters, and which experts strive to determine with a maximum precision (to the 1/100 of magnitude when possible).

Equivalence of absolute magnitudes H – mean diameters d (in km)

Formula for **approximate** calculation of mean diameters: **log d = C — H/5**
where **C** = variable constant according to the physical type and **H** = absolute magnitude

Document mis au point par Michel-Alain Combes

Magnitude absolute visual H	**Type E**	**Types V et R**	**Type S**	**Type M**	**Type C**	**Type C**	**Types C et T**	**diameters standards**
	3.30	3.40	**3.50**	3.55	3.70	**3.80**	3.90	**constant**
	~0.34	~0.26	**~0.15**	~0.11	~0.06	**~0.04**	~0.02	**albedo**
13.0	5.0	6.3	7.9	8.9	12.6	15.8	20.0	
13.2	4.6	5.8	7.2	8.1	11.5	14.5	18.2	
13.4	4.2	5.2	6.6	7.4	10.5	13.2	16.6	
13.6	3.8	4.8	6.0	6.8	9.5	12.0	15.1	
13.8	3.5	4.4	5.5	6.2	8.7	11.0	13.8	
14.0	3.2	4.0	5.0	5.6	7.9	10.0	12.6	type S = 5.0 km
14.2	2.9	3.6	4.6	5.1	7.2	9.1	11.5	type C = 10.0 km
14.4	2.6	3.3	4.2	4.7	6.6	8.3	10.5	
14.6	2.4	3.0	3.8	4.3	6.0	7.6	9.5	
14.8	2.2	2.8	3.5	3.9	5.5	6.9	8.7	
15.0	2.0	2.5	3.2	3.5	5.0	6.3	7.9	
15.2	1.8	2.3	2.9	3.2	4.6	5.8	7.2	
15.4	1.7	2.1	2.6	3.0	4.2	5.2	6.6	
15.6	1.5	1.9	2.4	2.7	3.8	4.8	6.0	
15.8	1.4	1.7	2.2	2.5	3.5	4.4	5.5	
16.0	1.3	1.6	2.0	2.2	3.2	4.0	5.0	type S = 2.0 km
16.2	1.2	1.4	1.8	2.0	2.9	3.6	4.6	type C = 4.0 km
16.4	1.1	1.3	1.7	1.9	2.6	3.3	4.2	
16.6	1.0	1.2	1.5	1.7	2.4	3.0	3.8	type S = 1.5 km
16.8	0.9	1.1	1.4	1.5	2.2	2.8	3.5	type C = 3.0 km
17.0	0.8	1.0	1.3	1.4	2.0	2.5	3.2	
17.2	0.7	0.9	1.1	1.3	1.8	2.3	2.9	
17.4	0.7	0.8	1.0	1.2	1.7	2.1	2.6	type S = 1.0 km
17.6	0.6	0.8	1.0	1.1	1.5	1.9	2.4	type C = 2.0 km
17.8	0.6	0.7	0.9	1.0	1.4	1.7	2.2	
18.0	0.5	0.6	0.8	0.9	1.3	1.6	2.0	type S = 800 m
18.2	0.5	0.6	0.7	0.8	1.1	1.4	1.8	type C = 1.6 km
18.4	0.4	0.5	0.7	0.7	1.0	1.3	1.7	
18.6	0.4	0.5	0.6	0.7	1.0	1.2	1.5	
18.8	0.4	0.4	0.5	0.6	0.9	1.1	1.4	
19.0	0.3	0.4	0.5	0.6	0.8	1.0	1.3	type S = 500 m
19.2	0.3	0.4	0.5	0.5	0.7	0.9	1.1	type C = 1.0 km
19.4	0.3	0.3	0.4	0.5	0.7	0.8	1.0	
19.6	0.2	0.3	0.4	0.4	0.6	0.8	0.9	
19.8	0.2	0.3	0.3	0.4	0.5	0.7	0.9	
20.0	0.2	0.3	0.3	0.4	0.5	0.6	0.8	type S = 300 m
20.2	0.18	0.2	0.3	0.3	0.5	0.6	0.7	type C = 600 m
20.4	0.17	0.2	0.3	0.3	0.4	0.5	0.7	
20.6	0.15	0.19	0.2	0.3	0.4	0.5	0.6	
20.8	0.14	0.17	0.2	0.2	0.3	0.4	0.5	
21.0	0.13	0.16	0.2	0.2	0.3	0.4	0.5	type S = 200 m
21.2	0.12	0.14	0.18	0.2	0.3	0.4	0.5	type C = 400 m
21.4	0.11	0.13	0.17	0.19	0.3	0.3	0.4	
21.6	0.10	0.12	0.15	0.17	0.2	0.3	0.4	
21.8	0.09	0.11	0.14	0.15	0.2	0.3	0.4	
22.0	**0.08**	**0.10**	**0.13**	**0.14**	**0.2**	**0.3**	**0.3**	**Limit of PHAs**
22.2	0.07	0.09	0.11	0.13	0.18	0.2	0.3	

22.4	0.07	0.08	0.10	0.12	0.17	0.2	0.3	type S = 100 m
22.6	0.06	0.08	0.10	0.11	0.15	0.19	0.2	type C = 200 m
22.8	0.06	0.07	0.09	0.10	0.14	0.17	0.2	
23.0	0.05	0.06	0.08	0.09	0.13	0.16	0.2	
23.2	0.05	0.06	0.07	0.08	0.11	0.14	0.18	
23.4	0.04	0.05	0.07	0.07	0.10	0.13	0.17	
23.6	0.04	0.05	0.06	0.07	0.10	0.12	0.15	
23.8	0.04	0.04	0.05	0.06	0.09	0.11	0.14	
24.0	0.03	0.04	0.05	0.06	0.08	0.10	0.13	type S = 50 m
24.2	0.03	0.04	0.05	0.05	0.07	0.09	0.11	type C = 100 m
24.4	0.03	0.03	0.04	0.05	0.07	0.08	0.10	
24.6	0.02	0.03	0.04	0.04	0.06	0.08	0.09	
24.8	0.02	0.03	0.03	0.04	0.05	0.07	0.09	
25.0	0.02	0.03	0.03	0.04	0.05	0.06	0.08	type S = 30 m
25.2	0.018	0.02	0.03	0.03	0.05	0.06	0.07	type C = 60 m
25.4	0.017	0.02	0.03	0.03	0.04	0.05	0.07	
25.6	0.015	0.019	0.02	0.03	0.04	0.05	0.06	
25.8	0.014	0.017	0.02	0.02	0.03	0.04	0.05	
26.0	0.013	0.016	0.02	0.02	0.03	0.04	0.05	type S = 20 m
26.2	0.012	0.014	0.018	0.02	0.03	0.04	0.05	type C = 40 m
26.4	0.011	0.013	0.017	0.019	0.03	0.03	0.04	
26.6	0.010	0.012	0.015	0.017	0.02	0.03	0.04	
26.8	0.009	0.011	0.014	0.015	0.02	0.03	0.04	
27.0	0.008	0.010	0.013	0.014	0.02	0.03	0.03	
27.2	0.007	0.009	0.011	0.013	0.018	0.02	0.03	
27.4	0.007	0.008	0.010	0.012	0.017	0.02	0.03	type S = 10 m
27.6	0.006	0.008	0.010	0.011	0.015	0.019	0.02	type C = 20 m
27.8	0.006	0.007	0.009	0.010	0.014	0.017	0.02	
28.0	0.005	0.006	0.008	0.009	0.013	0.016	0.02	
28.2	0.005	0.006	0.007	0.008	0.011	0.014	0.018	
28.4	0.004	0.005	0.007	0.007	0.010	0.013	0.017	
28.6	0.004	0.005	0.006	0.007	0.010	0.012	0.015	
28.8	0.004	0.004	0.005	0.006	0.009	0.011	0.014	
	Type	**Types**	**Type**	**Type**	**Type**	**Type**	**Types**	
	E	**V et R**	**S**	**M**	**C**	**C**	**C et T**	
The smallest known NEAs have **H = 30.0** and a mean diameter of the order of **5 mètres**								
Zones in yellow and light blue above concern mean diameters above 200 meters								
Zones in light green concern mean diameters between 200 and 20 meters								
Zones in yellow at bottom concern mean diameters below 20 meters								
Objects of type C are considered to have a diameter double of those of type S								
NEAs with MOID < 0.050 UA and H < 22.1 are PHAs (Potentially Hazardous Asteroids)								
The mean value (type S) is **130 meters.** Extremes go from 80 to 300 meters								
All diameters in this charts are only **ballpark figures,** of course.								

(Document quanta 2010-doc05 = chart of equivalence H/d)

It is at this level that **the distinction between NEAs and PHAs** is made. An NEA can have any diameter, and we discover now minuscule objects with H > 25, which amounts to barely thirty meters. **A PHA must have H < 22.1,** which corresponds to an **average diameter of 130 meters** for an S type object, but **in a bracket of 80 to 300 meters,** as shown on the chart of diameters.

Among the known NEAs, three only have a mean diameter greater than 15 km. These are **Ganymed,** by far the largest, which is around 40 km, **Eros,** which has a mean diameter of 23 km (with a major axis of 33 km) and **Don Quixote,** a cometary asteroid of about 20 km. All three are of the Amor type and do not present a danger to Earth in the present time. A few other objects of the Apollo and Amor types are **between 5 and 10 km.** We are still discovering NEAs with a diameter of 3 km and more. All these asteroids, most of which are destined to strike a planet sometime in the future, can cause enormous damage should their final target happen to be Earth.

The probable number of NEAs.

There are several methods to calculate the number of NEAs and each specialist swears by his own. While results may vary in detail, a constant inevitably emerges: their total number is very high, and the smaller the objects, the more numerous they are. The following numbers can be obtained for the numbers of NEAs:
5 km NEAs = 20
1 km NEAs = 1500
500 m NEAs = 20 000
100 m NEAs = 250 000
50 m NEAs or less = several millions

The XXI century will see the discovery of **tens of thousands of NEAs over 100 m** and should become able to locate the quasi-totality of those whose diameter is close to 1 kilometer. On the other hand, despite the fact that some experts seem to believe it possible, it appears utopian to aim for a nearly complete inventory of the 500 m objects. Some will remain unknown for many more centuries, and one must also consider that their **renewal** is constant. There will always be "new ones."

The possible approaches of NEAs to Earth

We understand by **possible approaches** (the **MOID,** for Minimum Orbit Intersection Distance), the distance **between the orbits** of Earth and of the asteroid or comet in question. At an astronomical scale, this minimal distance, constantly variable in time, can be attained fairly often, or at least approached closely. One must know that certain NEAs approach Earth very closely, other not, even among the Aten and Apollo objects which cross the Earth's orbit.

There exists a special list that is constantly kept up-to-date by the **Minor Planet Center.** Since 1970, I have been watching the possible approaches for all known NEAs. The time when objects such as **Apollo** (MOID = 0.025 AU) or even Adonis (MOID = 0.013 AU) still figured among the first ten is far gone already. At the end of 2009, **the one thousanth** approach amounted to 0.011 AU. Today, in order to make the "top ten," an NEA must be on an orbit of **quasi-collision** (MOID < 0.0010 AU) of 150,000 km, or 1/1000 AU, an insignificant distance on the astronomical scale).

Some objects in the one kilometer range, such as **1994 PC1** and **Oljato** plus a few others, such as **Midas, Toutatis** and **Phaethon** (related to the considerable meteoritic swarm of the Geminides), herald great danger to Earth in the middle term (several thousand years) and may have to be destroyed in order to avoid a catastrophe of which civilisation could only recover with difficulty.

The very close real approaches of NEAs

More specifically, the Minor Planet Center keeps up-to-date a list of all **real observed approaches inferior to 0.0100 AU** (1.5 MK). This list enriches itself almost monthly, but it deals in the quasi-totality of cases of approaches by objects of H > 25.0, that is, with an diameter inferior to 30 m.

Analysis of the list of real approaches. This list has become plethoric and the record has been beaten several times. For instance, the historic approach of **Hermes** on October 30, 1937 (0.0049 AU = 0.73 MK), which held the absolute record for over a half-century, no longer figures among the closest approaches. First beaten by **Asclepius** in March 1989 (0.0046 AU = 0.69 MK), the record was shattered by **1991 BA,** an NEA of less than 10 m diameter, in January 1991 (0.0011 AU = 0.165 MK)

Two other objects of the same caliber have bettered it in the following years: **1993 KA2** in May 1993 (0.0010 AU = 0.150 MK) and **1994 XM1** in December 1994 (0.0007 AU = 0.105 MK). Again, this record has been bettered twice, first by **2003 SQ222** in September 2003 (0.00056 AU = 0.084 MK) and finally by **2004 FU162** in March 2004 (0.00009 AU = 0.013 MK).

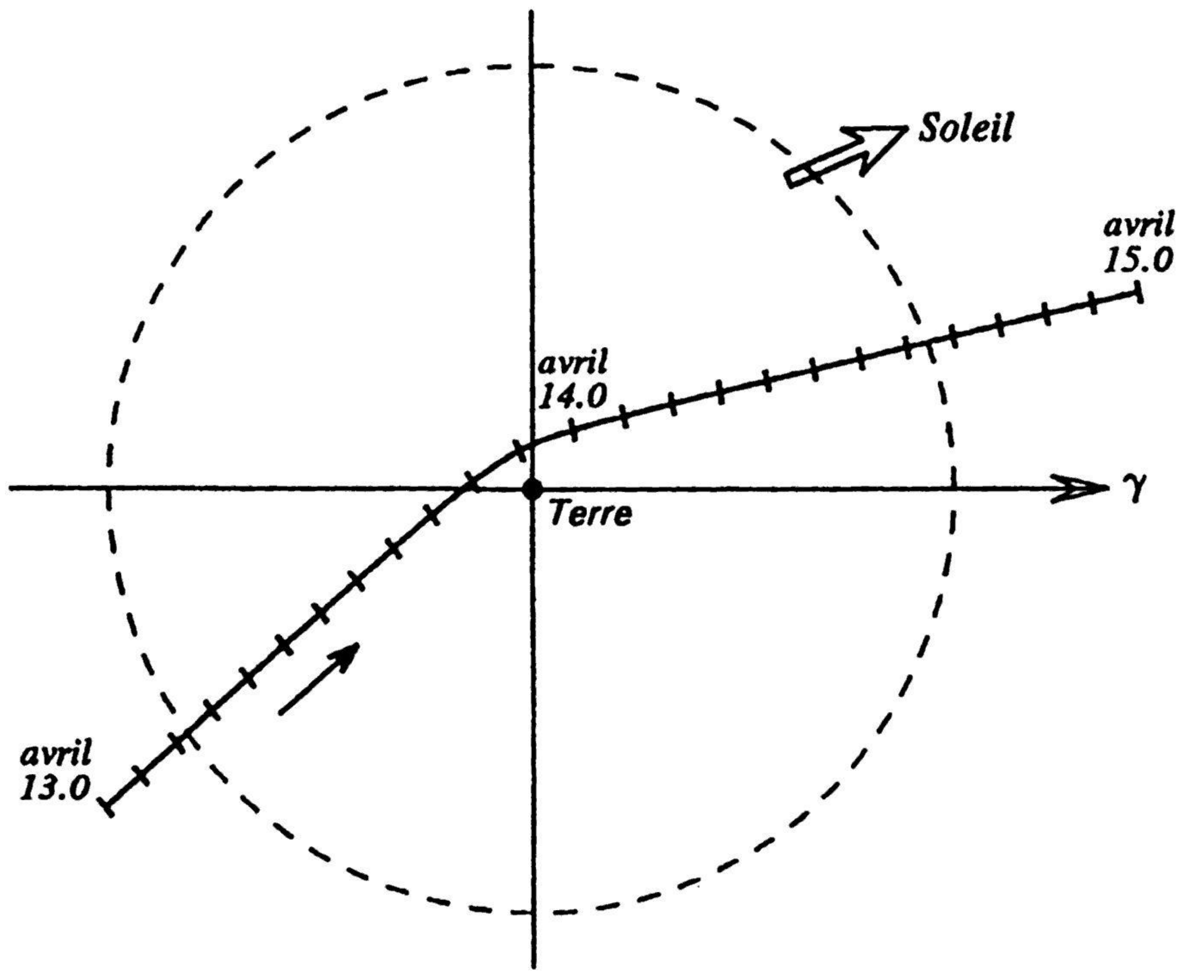
Going all the way to the announced impact of **2008 TC3** on October 7, 2008, an object of a few meters diameter discovered only one day before (on October 6th) which disintegrated above Northern Sudan without causing any damage. But one must insist on the fact that these recent record approaches concern insignificant objects, of only a few meters diameter.

We must remember that on August 10, 1972, the famous **meteorite** grazed the Earth surface **at an altitude of 58 km,** skipping on the Earth atmosphere before taking off into space again. It was an NEA of some 15m which did not receive a provisory designation, as it was observed during several tens of seconds only. This record will never be beaten, as it constitutes practically the minimal possible approach. An approach of less than 50 km would necessarily result in disintegration or impact.

The approach of **1994 PC1** in January 1933: 0.0075 AU, i.e. 1.12 MK, is the closest approach of NEA of a diamter superior to 1 km in the twentieth century. Yet it was not discovered on approach, despite the fact that it was an easy object for that time (its approach has been calculated retroactively). This shows that very dangerous objects have long escaped even the most qualified observers. Delporte and Reinmuth, the two tenors of that time, together with all their colleagues, also missed **Toutatis** the following year, not having been able to distinguish it from the mass of anonymous objects which had left their imprint on the photographs.

Apophis, the asteroid that brings fear. This asteroid, discovered in June 2004 and known at first under the provisory appellation 2004 MN4, turned out to be of extraordinary interest. It has the closest calculated approach of all the known NEAs of below 50 m of this century. On April 13 2029, at 21h43' UT, it will approach to a distance of 0.00023 AU, that is 33,600 km from the Earth’s center, which is less that 28,000 km from the surface, an absolute record for a PHA. It will then be visible to the naked eye, like a small star of magnitude 3 or 4. Its diameter is of the order of **400 m** (H = 19.2, the photometric value still considered by the Minor Planet Center). Radar measurements give a somewhat smaller diameter: 270

m (with H = 19.7). New observations will be necessary to decide. In fact, Apophis could well be an elongated object like Eros or Geographos.



(Figure quanta2010-doc 06 = the approach of Apophis in 2029)
(Terre=Earth; Soleil=Sun)

Apophis, who was the god of evil and destruction in Egyptian mythology (under the Egyptian name of Apep) is an NEA (and also a PHA) of the Aten type (**a** = 0.922 AU). Following its grazing approach to Earth, it will become, under the eyes of astronomers, an Apollo type NEA (with **a** = 1.125 AU). This object is the best example of the manner in which an NEA can go from one type to another following a very close approach to a planet. Calculations have shown that **Apophis** has had 4 very close approaches to Earth (between 0.024 and 0.032 AU) in the XX century, without as much as having been discovered, and that it will have yet 4 more during the XXI century. It is a "fear-bearing asteroid," that could be regarded as an "external enemy." Some think that the important perturbations which it will experience in April 2029 could precipitate it onto Earth at its next passage, in 2036, a very small probability, or that it could even disintegrate thereafter, if it is of a cometary constitution. We still know nothing about its origin and its structural configuration. On the astronomic scale, it is clear that its days are counted, to Earth's detriment, during the coming centuries, if nothing is done by our successors to deviate or to destroy it.

The life expectancy of NEAs.

The frequency of **terrestrial impactism** is linked principally to the life expectancy of NEAs. This latter is short on the astronomic scale, much inferior to the presumed age of the Solar System. This is also logical, when one considers that asteroids are broken up objects, and often are broken up more than once. The average life-expectancy of objects penetrating inside the orbit of Mars, the **Mars-crossers,** is estimated more or less at 100 MY, with extremes which can go from ca 1 MY to 1000 MY. A Mars-crosser has therefore an average life-expectancy that is 50 times inferior to the age of the Solar system at its present stage of evolution. The Apollo and Aten type objects, the **Earth-crossers,** have a life expectancy that is ten times shorter than the Mars-crossers and several astronomers who have done simulations about them give them only 10 MY on the average as independant objects.

These ages, which give only an order of magnitude, have been obtained through comparisons with the age of meteorites. One can calculate with a fair approximation the duration of the exposition of these objects to the cosmic rays, a duration which corresponds to their age as autonomous objects in space since the last fragmentation from which they issued. For ordinary chondrites (of the types H, L and LL) which represent the majority of the NEAs, the bracket of probable ages goes from less than 1 MY to 50 MY. It seems that the life expectancy of siderites, which are much less subject to fragmentation, due to their greatly superior resistance, is considerably higher, and in many cases superior to 100 MY. These ages are coherent with what we know about the very long term of the evolution of orbits. Practically, no NEA can exist for more than 100 MY without suffering a collision with one of the four interior planets, with the Moon, or with any of the millions of asteroids of the main ring.

Rate of individual elimination. About **1 NEA out of 2 crosses the Earth's orbit,** which amounts to some 125,000 objects of an average diameter over 100 m. By combining the data concerning the total numbers of NEAs and those of their average life expectancy, we can obtain the rate of individual elimination of an NEA according to its orbital type, its absolute magnitude, and its diameter.

Individual Elimination of NEAs		
And their final destination		
(average between several calculation methods)		
Final destination	**% hypothesis**	**% hypothesis**
	High	**Low**
Mars	15	7.5
Earth	**20**	**10**
Venus	10	5
Mercure	5	2.5
Sun	15	25
Others (planets, asteroïds, satellites)	5	5
Expulsion onto non NEA orbits	10	20
Disintegration and/or crumbling	20	25
In the high hypothesis, the four planets account for 50 % of total.		

In the low hypothesis, they account for only 25 %.
For some researchers, the Sun's part would be superior to the values given here.

(Document quanta2010-doc07 = rate of individual elimination of NEAs)

The part attributed to each planet is necessarily rather unpredictable and varies according to the methods and the data that are utilised, but certain constants emerge. The four interior planets gather all together **50% of the total** (Mars 15%, **Earth 20%,** Venus 10% and Mercury 5%). The 50% left over spread themselves the following way: Sun 15%, asteroids, Moon and satellites 5%, disintegration and crumbling 20%, expulsion into an exterior orbit 10%.

These numbers are only orders of magnitude. The example of the **Comet of Aristotle,** which spawned the **Kreutz group,** inspires some experts to think that the Sun's part could be more important than 15%. Some simulations seem to show that the combination of solar attraction and chaotic orbit might lead some asteroids and incomplete comets to a **direct collision** with the Sun (**q** then becoming very close to 0.001 AU), or to disintegration in the near solar environment and to the formation of a constantly renewed **cosmic dust.** It is possible that the Sun's part and the part of expulsion have been underestimated, in such a way that the Earth would no longer be the receiver of 20% of the existing Aten and Apollo type NEAs, but of **only 10%** (low hypothesis). If such were the case, the frequency of impact would have to be reduced by a factor of 2, but the higher hypothesis still seems more likely.

The problem of minuscule NEAs. We understand by **minuscule asteroids** those whose absolute magnitude H > 22,0. It appears that these must be treated differently from the others. Their number is enormous: several million NEAs of 50 m, a number that is embarrassing to specialists, but one which must absolutely be taken into consideration. It is no less than **cosmic dust** on an astronomic scale. If there existed no process of destruction, every decade should see a terrestrial impact, which is contradicted by two centuries of observation.

In fact, there are three destruction mechanisms which enter into play: disintegration and crumbling in space and destruction in the Earth's atmosphere, mechanisms which are much more efficient in the case of small objects than for those which are of a hectometric or a kilometric size, especially because of the fact that these are very often made up of cometary fragments, the structural cohesion of which is weak. A mere close approach to a planet can lead to severe fragmentation, even total disintegration. Moreover, it turns out that minuscule objects are **condemned to crumbling** when they penetrate Earth's atmosphere and cross only very rarely all of the atmospheric layers.

The numbers I am giving in this section are variable with time, the disintegration of a comet (such as the one of Aristotle, genetrix of the Kreutz group) or of a centaur (such as **Hephaistos**) being capable of seriously increasing for several hundred thousand years the number of objects in the immediate environment of Earth. One may practically use the term of "astronomic pollution." We can see this clearly today with the **Taurid Complex,** a vast flow of minuscule objects circulating on similar orbits, related to a common progenitor.

The rate of elimination may appear too high to some experts. In my opinion, this is not the case. We know that NEAs renew themselves constantly, especially the cometary types, through the introduction into the close solar system of objects coming from the Kuiper Belt or the Oort cloud. These are often half-planetary, half-cometary objects, the cohesion of which does not survive a close approach to one of the larger planets (especially Jupiter, but also Saturn, Uranus and Neptune) and which fragment themselves into a multitude of smaller objects. But we know since the beginning of the 1990s that the older members of the Kuiper Belt, which often go through the intermediary type of **centaurs,** can exceed **100 km** in some cases, and that their fragments can well exceed 10 km. A 3 km diameter must be considered exceptional, as we have seen with the fragments of **Hephaistos,** several of which exceed this diameter.

Rate of collisions with Earth. Present data leads one to think that about 1 Aten and Apollo NEA out of 5 will collide with Earth (in 1982, I gave the ratio of 1 out of 3, because of the under-estimation of the role of the Sun and of expulsion). The combination of new information with what I considered before, concerning the rate of individual elimination, allows one to know the frequency of collisions on the whole Earth, and on the dry or submerged parts of the globe.

Frequency of collisions of NEAs with Earth					
According to diameter					
(**in years**, objects ***entering the atmosphere***)					
Diameter of NEA	**Number of NEAs**	**Individual elimination life : 10 MA**	**Earth With 20 % of impacts**	**Earth surface submerged surface**	**emerged surface**
		1/…	1/...	1/...	1/...
50 m	10 000 000	*-1*	*-5*	*-10*	*-20*
100 m	150 000	70	**350**	500	1200
300 m	15 000	700	**3500**	5000	12 000
500 m	5000	2000	**10 000**	15 000	35 000
1 km	1000	10 000	**50 000**	70 000	170 000
5 km	10	1 000 000	**5 000 000**	7 000 000	17 000 000
The number of earth-crossers is less by half than the total number of NEAs					
Earth-crossers are asteroïds of the types Aten et Apollo					
Minuscule objects (less than 100 mètres) are condemned to crumbing					
and disintegration. *They rarely cross into the Earth atmosphere*					
Numbers given are ballpark figures,variable with time					

(Document quanta2010-doc08 = rate of collisions for different diameter categories).

We can accept, in consideration of the present data (always as indicators of orders of magnitude) about objects **penetrating the atmosphere** that, **on average:**

- 1 NEA of 100m collides with Earth every 350 years, the ocean every 500 years and the land every 1200 years;
- 1 NEA of 300m collides with Earth every 3500 years, the ocean every 5000 years and land every 12,000 years;
- 1 NEA of 500 m collides with Earth every 10,000 years, the ocean every 15,000 years and land every 35,000 years;
- 1 NEA of 1 km collides with Earth every 50,000 years, the ocean every 70,000 years and land every 170,000 years.

I must point out that these are objects **penetrating into the atmosphere,** not those which actually hit the ground, who are evidently less numerous, insofar as **fragmentation,** and even **disintegration** are common occurrences, especially for small objects. Which is fortunate, if one contemplates the danger presented by an oceanic impact.

Energy at impact of NEAs.

We know the approximate diameter of NEAs, as well as their probable density. It is possible therefore to calculate **their kinetic energy** at impact by using the classic formula: $Ek=1/2mv^2$. This kinetic energy being equal to the half-product of mass by the square of impact velocity. Velocity is therefore an important factor, as velocity multiplied by two results in a kinetic energy multiplied by four. We know that all listed NEAs are on direct orbits and therefore their speed at the distance of Earth to the Sun cannot be superior to 42.1 km/s (parabolic velocity of Earth). In fact, their speed at (vector radius) r = 1.00 AU is comprised between 25km/s (NEAs of the Aten type) and 38km/s (NEAs of the Apollo type, with **a** > 2.50AU and **e** > 0.70).

The **geocentric velocity** of an NEA is a relative speed resulting from the combined respective speeds of the object and of Earth (the latter varying between 29.3 and 30.3km/s because of the slight eccentricity of the Earth orbit). This geocentric velocity corresponds to the speed at the moment of impact (more or less, for one must also take into account the acceleration due to terrestrial attraction). We admit as an average **a speed at impact of 20km per second,** yet with extremes which can reach 10 and 35 km/s depending on the geometry of the orbits. We must suppose that, starting with a certain mass (several tens of thousands tons, i.e. about 20 m in diameter), NEAs experience practically no braking any longer when crossing the atmosphere and retain therefore a very high fraction (9/10) of their initial velocity.

Cinetic Energy of NEAs				
Accordingto their diameter and their physical type				
(impact speed : 20 km/s – energy in joules)				
Diameter	**Carbonated NEAs**	**Silicated NEAs**	**Mixed NEAs**	**Metallic NEAs**
of NEA	**type C**	**type S**	**type S**	**type M**
in km	density 2.5	density 3.5	density 5.0	density 7.8

0.1	2.6 × 10^17	3.7 × 10^17	5.2 × 10^17	8.2 × 10^17
0.2	2.1 × 10^18	2.9 × 10^18	4.2 × 10^18	6.5 × 10^18
0.3	7.1 × 10^18	9.9 × 10^18	1.4 × 10^19	2.2 × 10^19
0.4	1.7 × 10^19	2.3 × 10^19	3.4 × 10^19	5.2 × 10^19
0.5	3.3 × 10^19	4.6 × 10^19	6.5 × 10^19	1.0 × 10^20
0.6	5.7 × 10^19	7.9 × 10^19	1.1 × 10^20	1.8 × 10^20
0.7	9.0 × 10^19	1.3 × 10^20	1.8 × 10^20	2.8 × 10^20
0.8	1.3 × 10^20	1.9 × 10^20	2.7 × 10^20	4.2 × 10^20
0.9	1.9 × 10^20	2.7 × 10^20	3.8 × 10^20	6.0 × 10^20
1.0	2.6 × 10^20	3.7 × 10^20	5.2 × 10^20	8.2 × 10^20
2.0	2.1 × 10^21	2.9 × 10^21	4.2 × 10^21	6.5 × 10^21
3.0	7.1 × 10^21	9.9 × 10^21	1.4 × 10^22	2.2 × 10^22
4.0	1.7 × 10^22	2.3 × 10^22	3.4 × 10^22	5.2 × 10^22
5.0	3.3 × 10^22	4.6 × 10^22	6.5 × 10^22	1.0 × 10^23
6.0	5.7 × 10^22	7.9 × 10^22	1.1 × 10^23	1.8 × 10^23
7.0	9.0 × 10^22	1.3 × 10^23	1.8 × 10^23	2.8 × 10^23
8.0	1.3 × 10^23	1.9 × 10^23	2.7 × 10^23	4.2 × 10^23
9.0	1.9 × 10^23	3.7 × 10^20	3.8 × 10^23	6.0 × 10^23
10.0	2.6 × 10^23	3.7 × 10^23	5.2 × 10^23	8.2 × 10^23
20.0	2.1 × 10^24	2.9 × 10^24	4.2 × 10^24	6.5 × 10^24
30.0	7.1 × 10^24	9.9 × 10^24	1.4 × 10^25	2.2 × 10^25
40.0	1.7 × 10^25	2.3 × 10^25	3.4 × 10^25	5.2 × 10^25
50.0	3.3 × 10^25	4.6 × 10^25	6.5 × 10^25	1.0 × 10^26

(Document quanta2010-doc09 = impact energy of NEAs)

This chart gives us, in joules the kinetic energy for NEAs of varying diameters and for four typical densities: 2,5 for the carbonated objects (type C), 3,5 for the typical aeroliths (type S), 5,0 for the sideroliths (also type S) and 7,8 for the siderites (type M). The speed at impact considered is 20 km/s. The chart shows clearly that NEAs have a kinetic speed which is far from negligible. This energy, for an object which we suppose spherical (which is far from the general case) increases by a factor of 1000 when the diameter increases by a factor of 10. So that an NEA of 1km, of type S, density 3.5 (aeroltihs) with an impact velocity of 20 km/s has a kinetic energy Ek=3.7 x 10^{20} joules. A body ten times smaller (100m) has a kinetic energy of Ek=3.7 x 10^{17} joules and one ten times larger (10km) has a kinetic energy Ek=3.7 x 10^{23} joules. Eros, with a supposed mean diameter of 24 km and a density of 4.0 has a kinetic energy Ek = 5.8 x 10^{24} joules, whichy is an amount vastly superior to the total energy liberated by all the purely terrestrial cataclysms known to us from the past and the present.

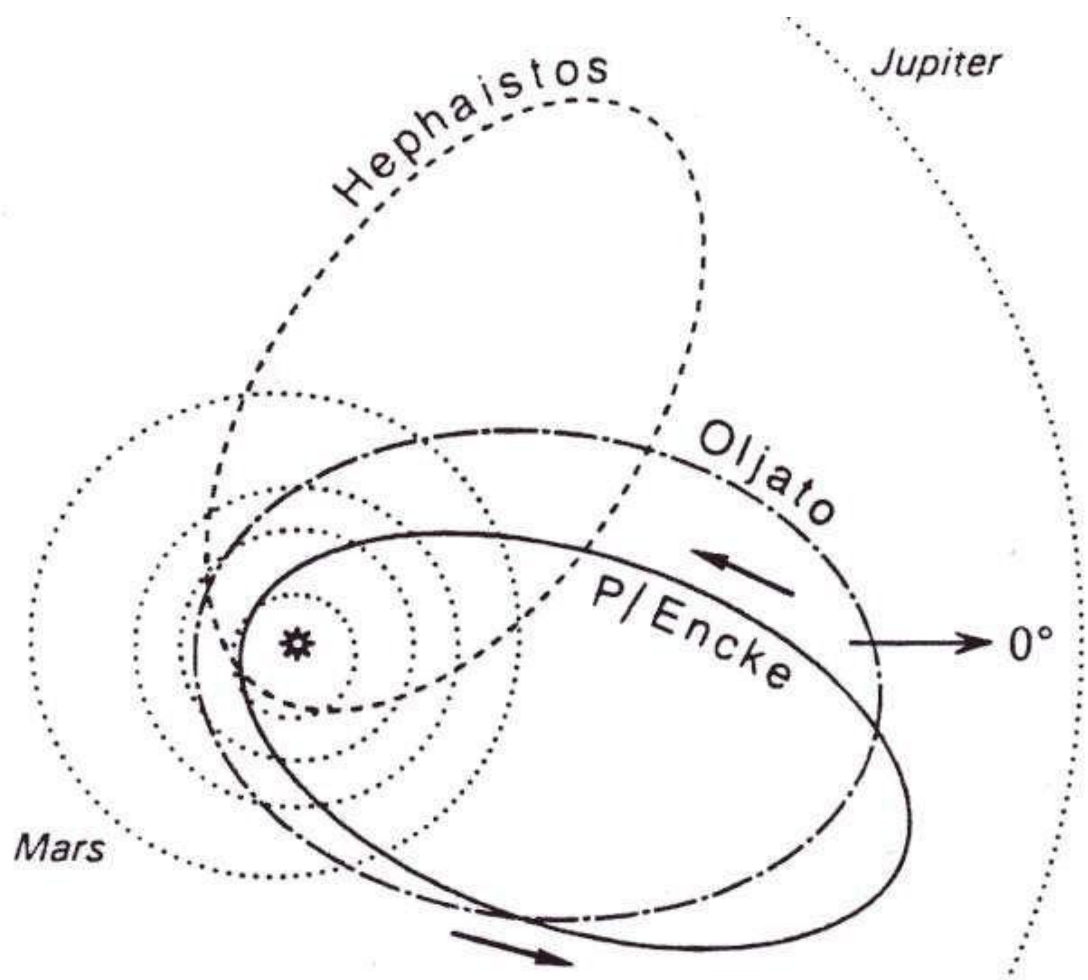
Impact=instantly liberated "extraterrestrial" energy. We are aware of the fantastic amount of energy that can be liberated by an NEA of 2 or 3 km when it hits Earth. Especially, we must not forget one thing: the energy liberated by an NEA is practically instantaneous (a matter of seconds), whereas an earthquake lasts a few seconds, a hurricane several days and a volcanic eruption several weeks. An NEA of the S type of 2 km can provoke an earthquake largely superior to all known terrestrial cataclysms through its kinetic energy of 2.9 x 10^{21} joules. An NEA of 3km diameter and of the M type, meaning a metallic object, has a kinetic energy in the order of 2.2 x 10^{22} joules. Finally, a large NEA of 5 km, of which we know several, has an energy of 5 x 10^{22} joules, which is equivalent to practically 1000 times the energy released by the Chile earthquake of 1960, the strongest known.

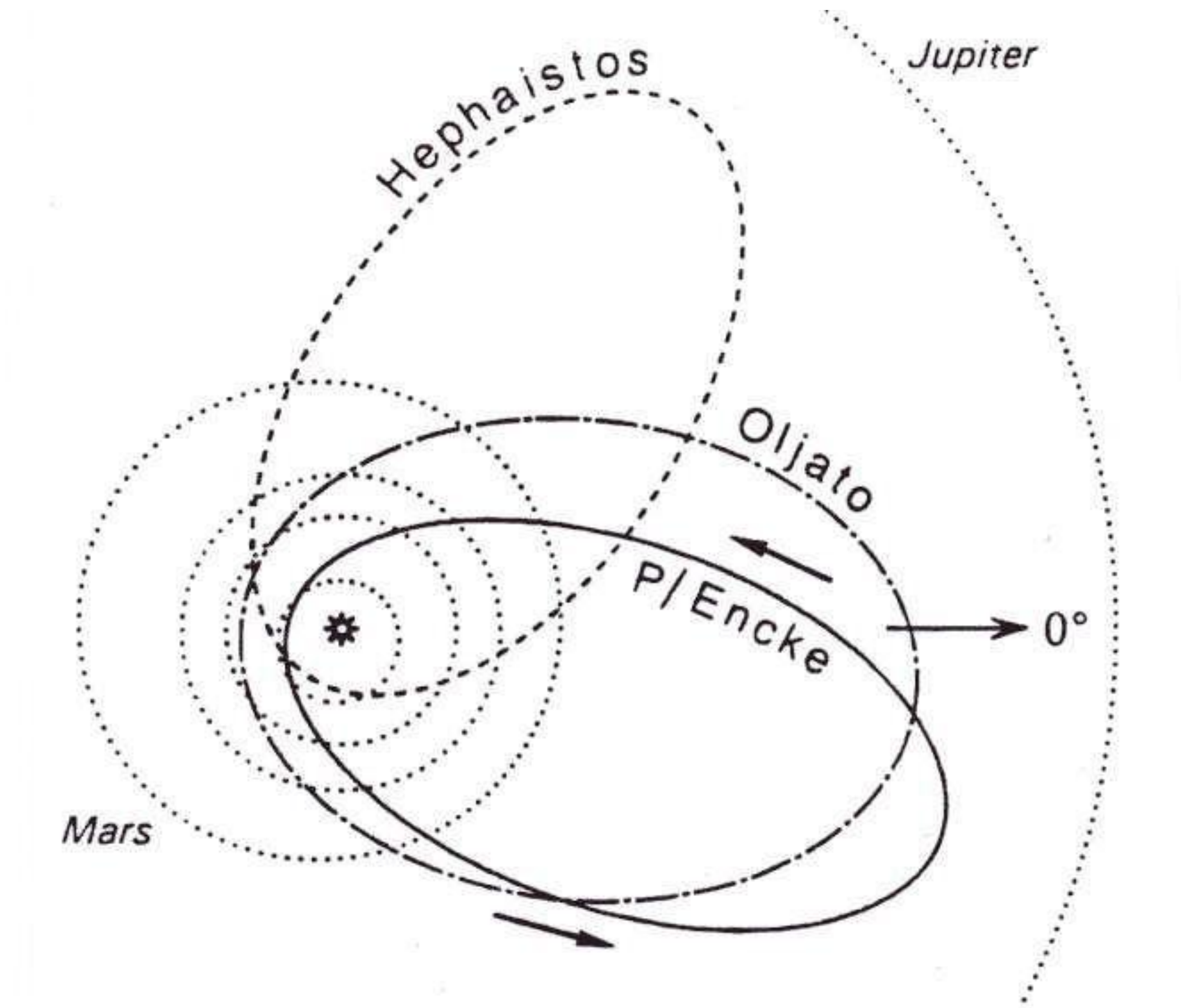
Another important conclusion: the kinetic energy of an NEA of a mean diameter of 600m is not superior to the energy released in great terrestrial cataclysms. All impacts of NEAs of this size and smaller, which are by far the most numerous, are therefore events which remain of a quite secondary importance in the energetic domain and their conseqeences are relatively small on the terrestrial scale (I am not speaking of course of human and economic consequences).

The NEAs and the HEPHAISTOS hypothesis.

The hypothesis, proposed by British neo-catastrophists, of the capture of **a large comet** in the inner solar system, several ten thousand years ago, is probably well-founded. The number of known asteroids resulting from the fragmentation and **ensuing crumbling of one single cosmic body** is constantly increasing. Especially as all of these ojects are rather easily identifiable, thanks to their very high eccentricity (generally in a bracket between 0.70-0.85) and their low inclination (between 0 and 12°), whereas the values of the major-half-axis are more spread out, as a consequence of varied perturbations. We know about 150 of these fragments and they form the **Hephaistos family** (from the name of the main object of the family, discovered in 1978 by L. Chernykh). Some members of the original family have been accelerated and their periodicity has decreased as a result, so that they have left the main ring (sub-types 3) to become sub-types 2, with **a** < 2.00 AU. They could belong to the **Herakles family** which comprises some 80 members already inventoried. One can expect to discover hundreds of new members of both families in the decades to come.

As for the **origin** of these thousands of know and yet-to-be-known objects,some astronomers now tend to believe in the capture of a **centaur** rather than in the capture of a giant comet arriving directly from the Kuiper Belt. This would be **HEPHAISTOS.** We know centaurs to be **mixed objects,** half-asteroids, half-comets and that **their fragments can be of a different nature,** which is less paradoxical than it may seem. Some **have had** a cometary activity, but not all. The **physical** type of these fragments is different according to their surface composition, and this is precisely what one observes with the verious inventoried fragments. One of the fragments of the **Hephaistos** family, by far not the largest, woke up after a long period of sleep during which it was but one cometary NEA among many - this may have happened after it suffered a collision in space. I am talking about **P/Encke,** the famous periodic comet which has been newly active for only three centuries and will be so for only a short time (two or three centuries maximum).

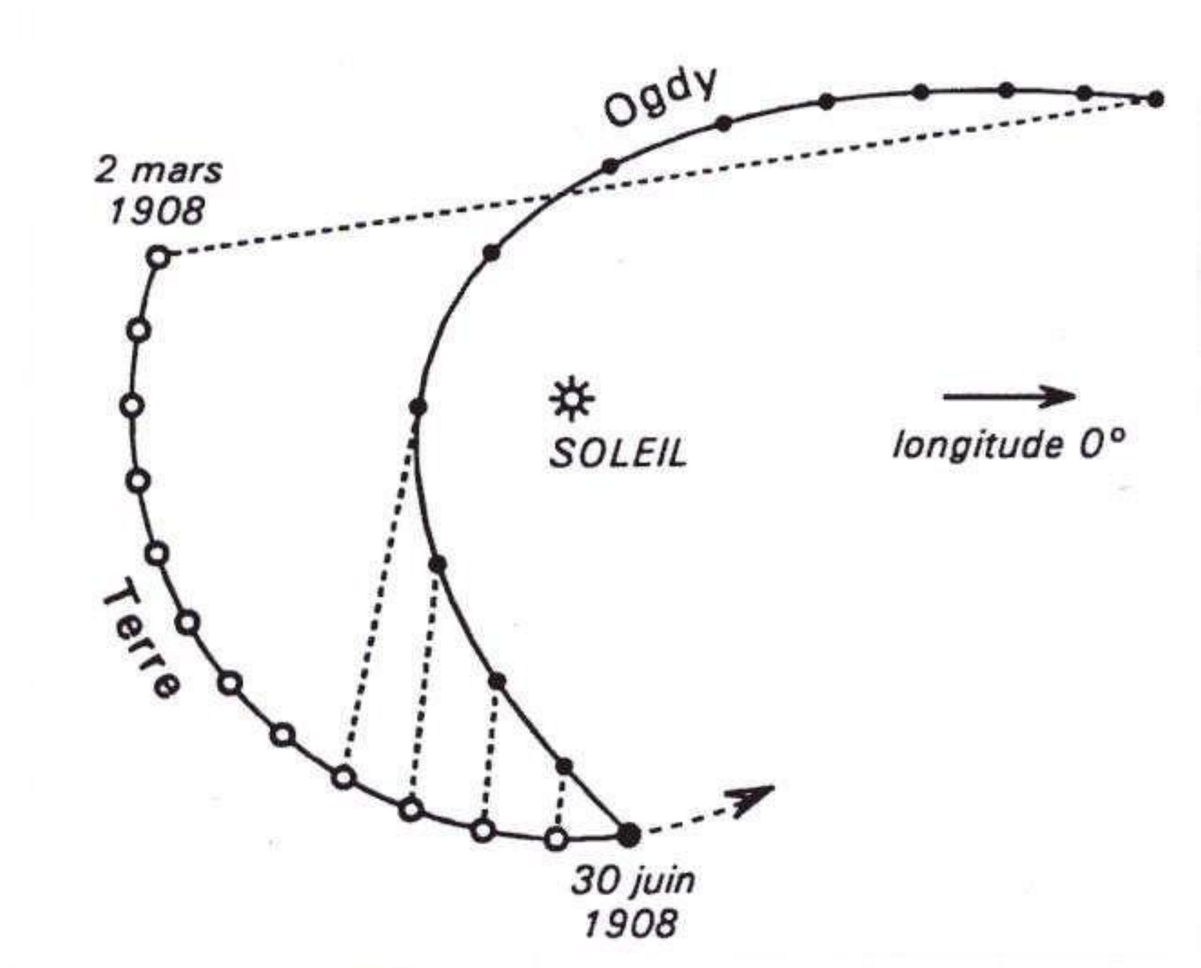

Jupiter
Hephaistos
Oljato
P/Encke
0°
Mars



(Figure quanta2010-doc10 = orbits of Hephaistos, P/Encke et Oljato)

The discoverty through calculations that **P/Encke** and **Oljato** were still forming, less than 10,000 years ago, one single object was an essential discovery in order to understand the complexity of our recent cosmic history. On top of the initial fragmentation, an **ulterior fragmentation** was added (with the formation of the **Hephaistos** and **Herakles** families) followed by a thorough **crumbling**, due to the very weak cohesion of certain fragments and to the very close approaches to planets which they were subjected to. But as the initial break-up was quasi-contemporaneous (on the astronomic scale), the process of disintegration is far from over, and is still going on under the eyes of the astronomers. Nevertheless, today the quasi-totality of the fragments generated by **Hephaistos,** the original former centaur, are now **asteroids,** and those who had a cometary activity are definitely degassed. We can expect the discovery of several hundreds of members in the kilometric and hectometric range, which goes to show that the terrestrial environment is literally **polluted** with debris of cometary disintegration. Luckily, our atmosphere is an effective protective screen against all the fragile matter of cometary origin and it is in a position to take care by itself of most of the clean-up.

It appears that ice fragments in the decametric range, as well as carbonated fragments (of type C) are doomed to quasi-complete disintegration. But others are composed of rocks (type S and even type E), with a cohesion that is considerably superior.
The Tunguska object, today baptised **Ogdy** (in the name of the fire god of the Tunguz), which disintegrated in the atmosphere above Siberia in 1908, might be one of them.



(figure quanta2010-doc11 = collision with Ogdy, the Tunguska object).
(Soleil=Sun; mars=March; juin=June)

Conclusion

The contribution of the specialized American surveys has a had a determining impact: it has revolutionized the search and discovery of NEAs since the beginning of the 1990s. In the heroic times, in the early 1950s, only 10 NEAs were known, along them Apollo, Adonis and Hermes. At the beginning of the 1980s, thanks to the investigations of Shoemaker and Helin, about a hundred were known. With the Spacewatch program and the CCD revolution, we passed into higher gear. Then, LINEAR, LONEOS, NEAT, Siding Spring, Catalina and Mt Lemmon did the rest. The 500th NEA was discovered in May 1998, the 1000th in April 2000, the 5000th in November 2007. Today, on average, we discover **two new NEAs a day** and we are close to knowing about 7000 NEAs.

WINNERS' LIST OF OBSERVATORIES FOR THE LAST TEN YEARS (2000-2009)

Observatoires et surveys ayant au moins 15 NEA à leur palmarès

Document établi par Michel-Alain Combes

Surveys and observatories	Code obs.	Nb de NEA	en 2000	en 2001	en 2002	en 2003	en 2004	en 2005	en 2006	en 2007	en 2008	en 2009
Discovery of NEAs			363	440	484	439	535	627	641	648	805	783
Spacewatch	691	498	26	17	8	40	64	79	91	43	76	54

LPL / Spacewatch II	291	**74**	0	5	14	17	6	3	8	2	10	9
LINEAR	704	**1954**	**258**	**278**	**286**	**235**	**304**	137	96	111	141	108
LONEOS	699	**267**	38	42	21	54	39	41	19	12	1	0
Catalina Sky Survey	703	**950**	13	0	1	8	47	**148**	157	187	156	233
Mt. Lemmon Survey	G96	**1134**	0	0	0	0	2	107	**177**	**227**	**333**	**288**
Siding Spring Sky Survey	E12	**332**	0	0	0	0	35	54	63	52	72	56
NEAT / MSSS	608	**112**	16	34	24	27	6	5	0	0	0	0
NEAT Palomar	644	**297**	0	58	119	41	20	33	22	4	0	0
Mauna Kea	568	**31**	8	4	1	0	5	7	3	2	1	0
La Sagra Sky Survey	J75	**19**	0	0	0	0	0	0	1	0	3	15
Only **Spacewatch** was operational before 1995 (since 1989)												
Catalina, **Mt. Lemmon** and **Siding Spring** are associated and their discoveries may be added												

(Figure quanta2010-doc12 = discoveries of NEAs in the past 10 years)