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On the mechanisms leading to orphan meteoroid streams

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ABSTRACT

We analyse several mechanisms capable of creating orphan meteoroid streams (OMSs) for which a parent has not been identified. OMSs have been observed as meteor showers since the XIXth century and by the *IRAS* satellite in the 1980s. We find that the process of close encounters with giant planets (particularly Jupiter) is the most efficient mechanism to create them: only a limited section of the stream is perturbed and follows the parent body on its new orbit, while the majority of the meteoroids remain in their pre-encounter orbit or in an intermediate state, breaking the link with their parent body. Cometary non-gravitational forces can also contribute to the process since they cause the comet to drift away from its stream. However, they are not sufficient by themselves to produce an OMS. Resonances can either split or confine a stream over a long time (>1000 yr). Some meteoroid streams may look like OMSs since their parent comet is dormant or not observable (e.g. long period). Even if new techniques succeed in linking minor objects to meteoroid streams, OMSs will still exist simply because cometary nuclei are subject to complete disruption leading to their disappearance.

Key words: celestial mechanics – comets: general – meteors, meteoroids.

1 INTRODUCTION

Meteoroid streams in the Solar system have been basically understood as a consequence of the ‘dirty-snowball’ nature of cometary nuclei proposed by Whipple (1950): dust particles dragged by the sublimating ices spread along all or part of the cometary orbit under the influence of non-gravitational forces (NGFs). Their detection in the Solar system remains difficult and presently results from the records of meteor showers (Jenniskens 2002), and from infrared and visible observations of the sky (Sykes et al. 1986; Reach et al. 2000; Ishiguro et al. 2003). The detailed investigation of the evolution of meteoroid streams was prompted by the difficulties in correctly predicting meteor storms. This has become an important issue for the space agencies as meteor storms may represent a threat to artificial satellites and manned space missions. It was progressively realized that the dynamical evolution of the meteoroid streams can be very complex, and is totally decoupled from that of their parent body, once the particles are released. Kondratieva & Reznikov (1985) and later McNaught & Asher (1999) were the first to correctly compute the position of the Leonid stream and the timing of the storms. They were followed by other groups who extensively modelled the physical processes involved in the generation of the meteoroid streams (Lyytinen & Van Flandern 2000; Vaubaillon, Colas & Jorda 2005a,b). These methods are obviously based on the knowledge of the orbit of the parent body. However, only a small number of me-

eteor showers are associated with a known parent body, generally a comet but also an asteroid in a few cases (Kresáková 1987; Hughes & Williams 2000). The known parent may have disappeared, such as in the case of the comet 3D/Biela leaving an ‘orphan’ meteoroid stream (in short, OMS), the Andromedids. Jopek, Valsecchi & Froeschlé (1999) showed that the dynamics of the Quadrantids and δ -Aquarids streams is compatible with the hypothesis of a common progenitor, even though they look decorrelated today. This points out that a meteoroid stream can be associated with a parent body even if there is no obvious link between the two. True OMSs, that is, without known progenitors, were detected by the *IRAS* satellite and reported by Sykes & Walker (1992). Their table II lists eight of them and their fig. 5 illustrates a single case.

This paper focuses on the mechanisms responsible for the creation of OMSs. Section 2 provides an overview of the approach carried out in this study. Sykes & Walker (1992) explicitly mentioned that close encounters between a meteoroid stream and a giant planet, namely Jupiter, could be an efficient way of creating OMSs. In particular, they wrote: ‘detailed dynamical modelling will be required to determine whether and to what extent these orbital perturbations shift trail particle orbit’. This is exactly what is performed in Section 3. In addition, we consider the influence of the resonances on the dynamics of the streams in Section 4. NGFs acting on the cometary parent body and on meteoroids are of different types. We discuss their influence in Section 5. Sykes (1988) mentioned the disruption of comets as an explanation of the existence of the zodiacal dust bands observed by *IRAS*. We examine this possibility for the creation of OMSs, in Section 6. Finally in Section 7, we present some

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cases of apparent OMSs, that is, current meteoroid stream without observable cometary parent body.

2 GENERAL DESCRIPTION OF THE METHOD

Our analysis of OMSs is based on the modelling of the creation and the evolution of meteoroid streams developed by Vaubaillon et al. (2005a,b). Meteoroids are ejected from the sunlit hemisphere of an icy cometary nucleus whenever its heliocentric distance r_h is less than 3 au. The ejection velocity is computed from the model of Crifo & Rodionov (1997). The evolution of the stream in the Solar system is followed taking into account the gravitational attractions of the Sun, of the nine planets and of the Moon (their ephemeris are taken from the JPL DE406 model), as well as the radiation pressure force and the Poynting–Robertson (PR) effect (Burns, Lamy & Soter 1979). Extensive numerical simulations are performed in order to realistically represent the creation and evolution of meteoroid streams over some 20 to 30 returns of the parent body. Five bins of size in the range [0.1, 100] mm are chosen, and 10^6 to 4×10^6 test particles per stream were numerically followed; a meteoroid bulk density of 1000 kg m^{-3} was assumed. The program was run on 5 to 50 processors on IBM SP3 and IBM SP4 computers located at CINES (France).

3 CLOSE ENCOUNTERS WITH THE PLANETS

The first studies of the influence of close encounters with a giant planet (namely Jupiter) on meteoroid streams were performed by Kazimirchak-Polonskaya, Belyaev & Terent'-Eva (1972) for the α -Virginids and α -Capricornids, followed by Carusi, Kresak & Valsecchi (1981) for the case of the comet 39P/Oterma and Carusi, Valsecchi & Kresakova (1982) for the case of the comet D/1770 L1 Lexell. They showed that the configuration of the stream in the Solar system becomes rapidly very complicated as a result of the perturbation. A close encounter with a giant planet is certainly the most efficient way to separate a comet from its associated stream for two main reasons. First, a close encounter is able to completely change the orbit of any small body in the Solar system, and the more massive the planet is, the more drastic the change of the orbit will be. Secondly, a close encounter cannot upset the whole meteoroid stream because it is spread along the cometary orbit (in a first approximation). As stated in the Introduction, Sykes & Walker (1992) have already mentioned this mechanism as a natural explanation of the OMSs that they have discovered.

3.1 Close encounters with Jupiter

As the most massive planet of the Solar system, Jupiter is indeed likely to be the key player in the formation of OMSs. As an example, we consider here the case of the comet 67P/Churyumov-Gerasimenko, which we have already extensively studied in the framework of the *Rosetta* mission (Vaubaillon, Lamy & Jorda 2005). We focus here on the consequences of its close encounter with Jupiter, which occurred in 1959, on its associated meteoroid stream. Fig. 1 illustrates the decorrelation between the post-encounter trail created during the 1976 return and the complex system of trails which resulted from the evolution of the pre-encounter meteoroids released during the 1947 return; clearly, some of the densest sections of this system may well appear as OMSs. This situation is readily understood by the fact that once the comet is injected on its new orbit, the new stream created during the next perihelion passage remains in the vicinity of the nucleus, while the bulk of the pre-existing stream remains close to the original cometary orbit or in

some intermediate orbits. The only common feature of these streams is that they pass close to the location of the encounter. Fig. 2 shows that the configuration of the trails further depends on the size of the meteoroids. Generally, the largest particles follow the nucleus on its new orbit (and tend to slowly spread outside the cometary orbital plane as pointed out by Vaubaillon et al. 2005), while the smallest ones quickly spread in the orbital plane. Fig. 3 provides details of the encounter itself. Initially, the meteoroids are trailing the nucleus (upper left-hand panel). The close encounter causes the formation of a loop – as first pointed out by Carusi et al. (1982) – since the giant planet passes behind the nucleus, that is, right in the middle of the trail, and since the importance of the perturbation depends on the distance to the planet. The loop keeps expanding while the comet is on its way to its new perihelion, and then the trail splits as a result of the increasing difference between orbital elements of the sub-trails. The three arrows in Fig. 3 point to three such subtrails. Eventually, the situation evolves to that illustrated in Fig. 1 (right-hand panel). The exact consequences very much depend on the miss distance. Carusi et al. (1981) have studied the case of Oterma, where the perturbation is not as drastic as in the case of 67P or as in the case of Comet Lexell (Carusi et al. 1982). For a single comet, several configurations are even possible since any Jupiter family comet (JFC) can experience several encounters with the planet. While close encounters with a planet certainly appear as the most natural mechanism for creating OMSs as envisioned by Sykes & Walker (1992), it does not systematically work. If the encounter is too violent, the meteoroids are spread out in the Solar system, their spatial density drastically decreases, and any structure becomes difficult, if not impossible, to detect. On the contrary, Vaubaillon, Jorda & Lamy (2006) have shown that, if the encounter is smooth enough, a reversal process occurs so that a potential OMS may remain spatially dense for a certain time, thus enhancing its detectability.

3.2 Close encounters with other giant planets

Close encounters with other giant planets are expected to have the same kind of consequences as those with Jupiter. Since the water–ice outgassing process starts at roughly 3 au, only those comets having $q < 3$ and $Q > 8$ au are in practice able to produce a meteoroid stream that can be perturbed by giant planets other than Jupiter. This is the case of, for example, 55P/Tempel-Tuttle, the parent body of the Leonid meteor shower. Williams (1997) has shown that Uranus plays a significant role in the evolution of this comet and its meteoroid stream. But in general, encounters with other giant planets tend to be less frequent, because of the dominant role of the JFCs and their continuous interaction with Jupiter.

Telluric planets can also affect the orbit of a minor body (Andreev, Terentjeva & Bayuk 1990), but again the probability of such an event is less than that with giant planets, since the sphere of influence directly depends on their mass. They are indeed unable to create OMSs but can cause gaps in a meteoroid stream, as already reported by McNaught & Asher (2002), Vaubaillon (2002), and illustrated in Fig. 4 for the case of the Leonid meteoroid stream (Vaubaillon 2003). These gaps are, however, much smaller than those caused by Jupiter, as reported by Scholl & Froeschlé (1988).

4 MEAN MOTION RESONANCES

A meteoroid is in a mean motion resonance with a planet when its orbital period is equal to a fraction of that of the planet. Depending on the resonance itself, the consequence is to confine the meteoroids,

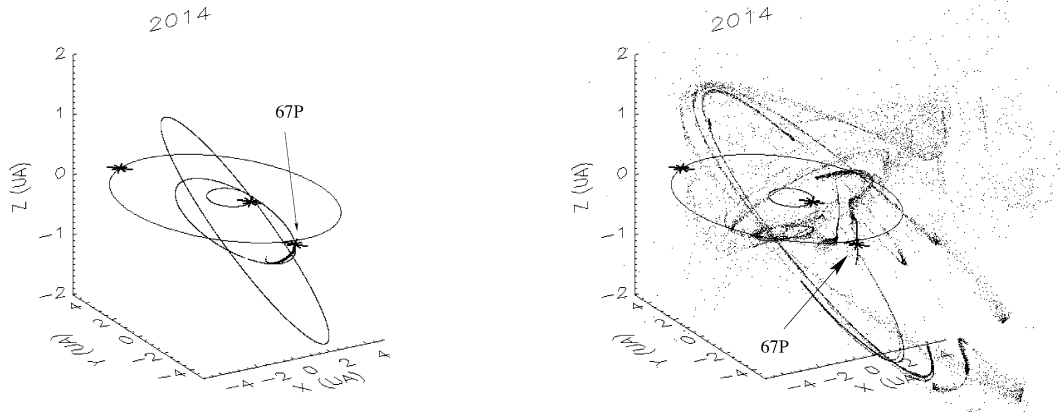


Figure 1. Three-dimensional view of the meteor streams associated with comet 67P/Churyumov-Gerasimenko at the time of the rendezvous with the *Rosetta* spacecraft in 2014. The reference frame is heliocentric with the X- and Y-axis in the ecliptic (J2000) plane and the unit is au. The orbits of Jupiter, of the comet and of the Earth are plotted and their locations are shown by stars. The two panels illustrate the consequences of the close encounter of the comet with Jupiter which occurred in 1959. Each of them, as well as the subsequent figures, is a plot of the location of a given meteoroid trail at a given time (here in 2014). Left-hand panel: the meteoroid trail ejected in 1976, that is, after the close encounter. The particles are trailing the nucleus and are spatially dense. The two orbits of the comet, pre- and post-encounter are displayed. Right-hand panel: the meteoroid trail ejected in 1947, that is, before the close encounter. Note that many meteoroids are still in the pre-1959 orbit. Some do follow the comet since they are located very close to the nucleus. Some others are on intermediate orbits.

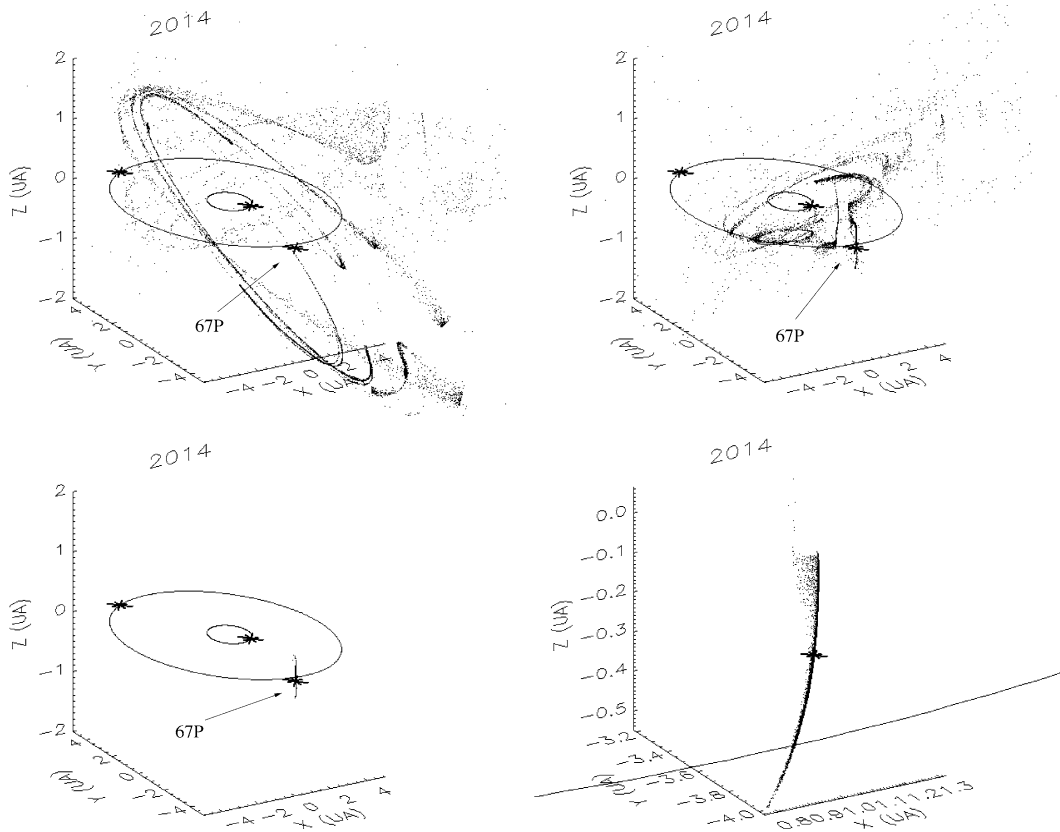


Figure 2. Illustration of the influence of the size of the meteoroids on the configuration of an OMS. The display is similar to the right-hand panel of Fig. 1 (same reference frame), but the size range of the meteoroids has been divided in three intervals: [0.1, 0.5] mm (upper left-hand panel), [1, 5] mm (upper right-hand panel), and [10, 100] mm (bottom panels, the right-hand one being a zoom). Large particles are ejected with low ejection velocities and are less sensitive to non-gravitational forces (Section 5) than small ones. As a consequence, they tend to more or less follow the nucleus in its new orbit. On the contrary, small particles remain in the pre-1959 orbit. They were too far from the nucleus at the time of the encounter, and therefore did not experience it. Medium-size particles are on intermediate orbits.

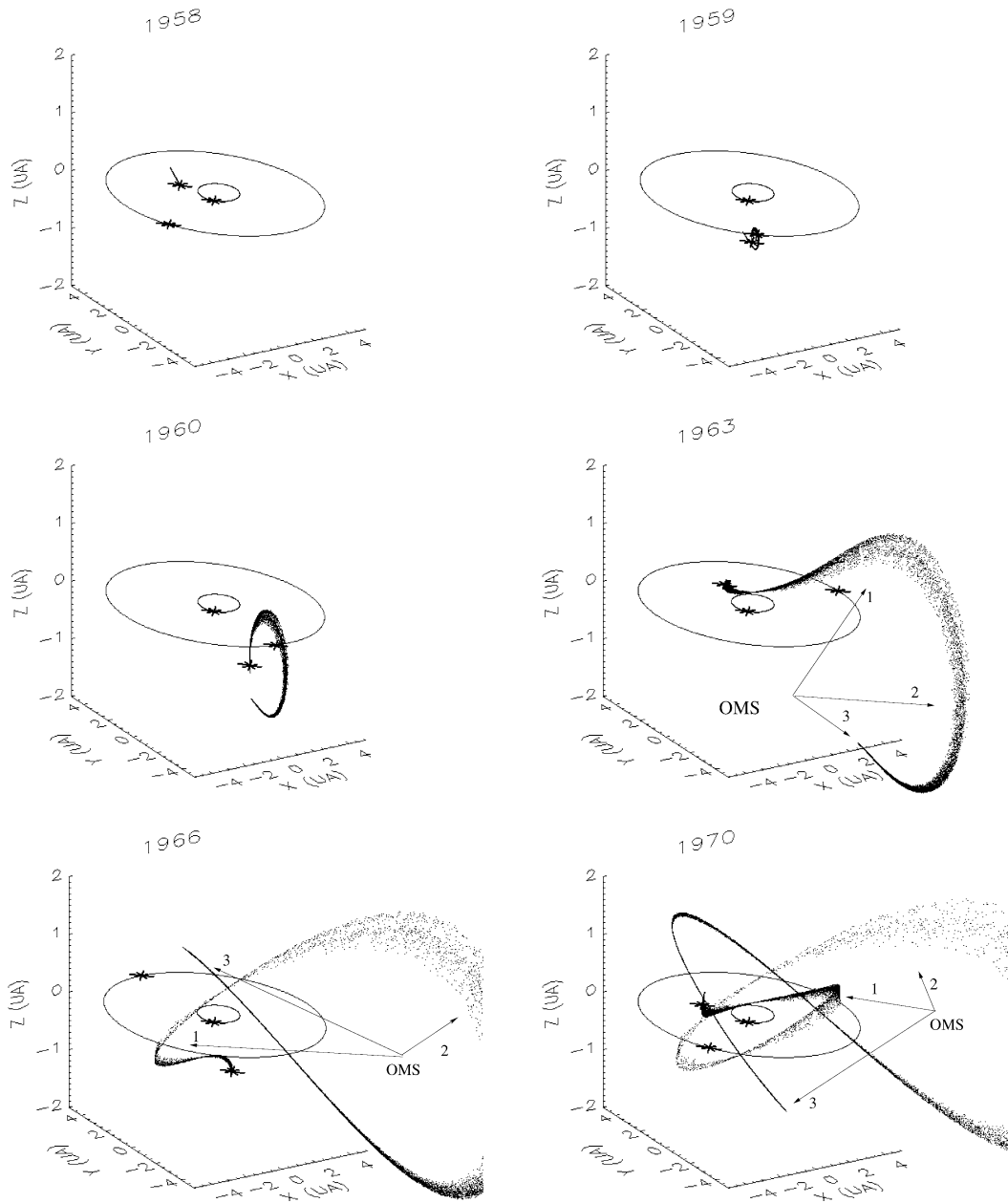


Figure 3. Details of the close encounter between Jupiter, comet 67P/Churyumov-Gerasimenko and its associated meteoroid stream. The display is similar to the right-hand panel of Fig. 1. It shows the evolution of the trail ejected in 1947 (same as Fig. 2) at six different epochs between 1958 and 1970 on the six panels. Possible OMSs are the sections of the trail which no longer have an orbit similar to that of the comet. The three arrows point to such subtraills.

or on the contrary, to keep them out of certain region of the phase space. Usually, the effect of a resonance can be seen only after several thousands years, but some processes are much faster.

Froeschlé & Scholl (1986) have studied how the 2:1 resonance with Jupiter influences the dynamics of a stream located close to it. The meteoroid stream splits, and the particles eventually gather along several arcs of reversed orbits (compared to the initial one). Though Scholl & Froeschlé (1988) did not find any real case to validate their prediction, this mechanism can certainly be invoked to explain OMSs. The case of the Quadrantids is of particular interest, since it is located close to the 2:1 resonance with Jupiter. Jopek et al. (1999) have shown that this stream and the North and South

δ -Aquadrids probably belong to the same complex. Because of the high eccentricity of the Quadrantids, Kozai resonance can also play an important role in this splitting process. The exact mechanism leading to such a splitting has not been worked out by these authors, but their result is in line with the work of Babadzhanov & Oubrov (1993), though they did not consider the same parent body, that is, the asteroid 2003 EH1 instead of the comet 96P/Machholz. Nowadays, Asteroid 2003 EH1 is indeed right in the middle of the stream, as discovered by Jenniskens (2004), and could be a potential progenitor. Sekanina & Chodas (2005) have recently pointed out that these two objects could both result from the fragmentation of a more massive precursor and that they now form a complex system, the Machholz

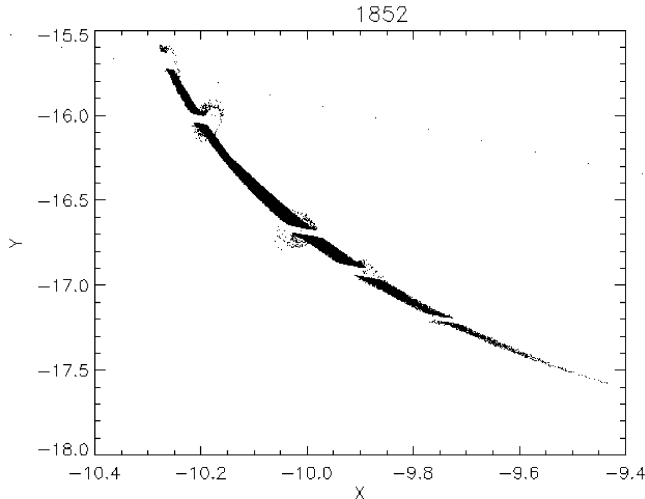


Figure 4. Gaps created in a Leonid meteoroid stream ejected in 1767, as seen in 1852 after five close encounters with the Earth. The reference frame is the same as that in Fig. 1, but the view here is two-dimensional (X – Y), and is centred on the trail.

complex, which besides the above three streams, includes groups of sunskirting comets discovered by the LASCO coronagraphs (Lamy et al. 2006).

The Perseids meteoroid stream exhibits the same kind of feature. Indeed, Wu & Williams (1995) have reported the existence of gaps in the distribution of the orbital elements of some Perseids meteors. Their dynamical considerations point to resonances with giant planets on a short time-scale (150 yr), that is, of the order of the period of the comet 109P/Swift-Tuttle.

Asher & Emel’yanenko (2002) have shown that the June Bootids experienced the influence of a 2:1 resonance with Jupiter, but the other way around as the resonance tends to trap the meteoroids. The same behaviour was found by Asher, Bailey & Emel’yanenko (1999) as an explanation of the 1998 Leonid meteor storm: some meteoroids ejected during the 1333 return of the comet 55P/Tempel-Tuttle and trapped into the 5:14 resonance were responsible for the unexpected meteor storm of 1998. Even if Vaubaillon et al. (2005b) later proposed that some other streams may have also been responsible for this event, there is no doubt that the resonance did confine the particles. The relevant time-scale here is about tens of revolutions at least, that is, very fast compared to the other cases already discussed.

In conclusion of this section, we can say that mean motion resonances can be responsible for the creation of OMSs on large time-scales ($> 10^3$ yr), as well as for the confinement of the meteoroids on small time-scale ($< 10^3$ yr), enhancing their detectability as structures in the Solar system.

5 NON-GRAVITATIONAL FORCES

Depending on its physical properties, a minor body in the Solar system experiences several NGFs which slightly deviate its orbital motion from the Kepler orbit. In particular, cometary orbits are modified by the outgassing process (Whipple 1950). A meteoroid will rarely experience any outgassing, unless it is large enough (> 1 m) and freshly ejected from the nucleus. If such a process occurs, it lasts a very short time in comparison to the age of a stream. However, radiative forces, such as the radiation pressure, the PR drag and the Yarkovski force (for a review, see Burns et al. 1979) are known

to control the dynamical evolution of meteoroids. The Yarkovski–Radzievski effect to name it correctly (Radzievskii 1952) is usually considered when studying the long-term evolution of asteroids (Brož et al. 2005).

Lyytinen & Van Flandern (2000) took into consideration the seasonal effect of this force in their model of the Leonid: the net effect is to increase the spreading of the particles and to lower their spatial density.

The first effect of the radiation pressure is to increase the semi-major axis of the meteoroids, compared to the parent comet. The second effect is to shift the location of the resonances (Liou & Zook 1996). The difference between the semimajor axes of a comet and a meteoroid having $\beta = 0.01$ amounts to 0.022 au in the case of the 2:1 Jovian resonance. In the case of a comet and its meteoroid stream trapped in the same resonance, their semimajor axes will be different and their orbital evolutions will eventually appear uncorrelated. The internal resonances are located towards the Sun, relative to the parent body. Adding the fact that the PR drag tends to decrease the semimajor axis, it is likely that a comet trapped in an internal resonance will loose its meteoroid stream by the combined effect of the radiation pressure and the PR drag, thus leading to the creation of an OMS.

The above scenario will generally take place on a long time-scale ($> 10^3$ yr). But the combined effect of different non-gravitational forces, cometary NGF on the one hand and meteoroid NGF on the other hand, can accelerate the separation between a comet and its stream. Indeed, a comet may experience large NGF during a return, and its orbital parameters may thus evolve over a single revolution, whereas those of its meteoroids remain more or less the same. Fig. 5 illustrates the case of the comet 7P/Pons-Winnecke, the parent body of the June-Bootid meteor shower, and its associated meteoroid stream. The non-gravitational acceleration components A_1 and A_2 of this comet are of the order of 10^{-10} and 10^{-11} (Rocher 2004), respectively, and they cause a drift of the comet away from its stream. The scale of the figure reveals that the effect is small (compared to that of a close encounter for example), but it can increase due to the

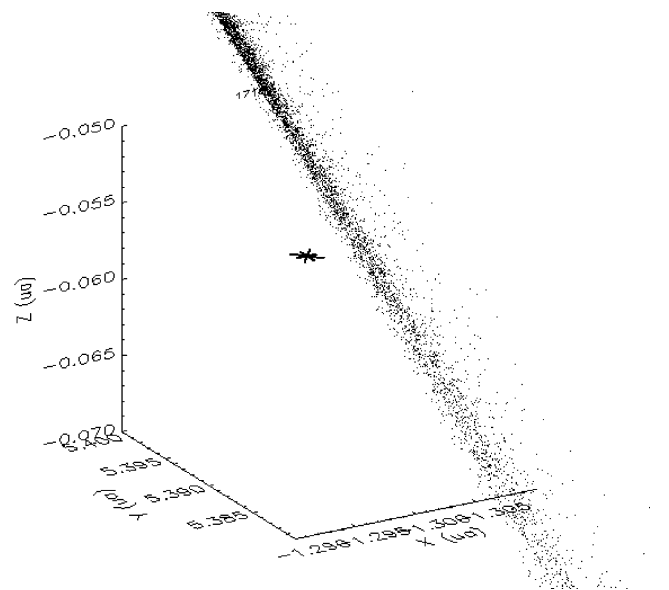


Figure 5. Close-up view of the June-Bootids meteoroid stream and its parent body, the comet 7P/Pons-Winnecke (star). In the absence of non-gravitational forces, the comet would be located in the densest part of the stream.

possible cumulative action of the NGF on the cometary orbit at each return. Another consequence is to widen the meteoroid stream as a whole, since new trails are generated at each return.

In summary, it is unlikely that non-gravitational forces totally separate the stream from the comet in such a way that they look unrelated. However, they can help in the creation of an OMS if, for instance, a close encounter with a giant planet occurs just after the comet has drifted away from the stream, since the separation between the two will cause different perturbations.

6 DISRUPTED COMETS

OMSs may be naturally created by the physical breakup of their parent cometary nucleus. Several processes may lead to fragmentation: tidal disruption, rotational splitting, breakup due to internal gas pressure, or even collisions with other bodies. Granting that cometary disruption is quite common (Chen & Jewitt 1994), and that the majority of the fragments completely ‘disappear’ sooner or later, that is, within time-spans of hours to years (Boehnhardt 2002), we do have here a straightforward and efficient process to create OMSs. There are indeed several cases of known meteoroid stream for which the parent cometary nucleus is known to have broken apart, the detection of these streams being achieved, for instance, by the observation of meteor showers.

A first example is the Andromedids associated with the lost comet 3D/Biela (Herschel 1872) known to have experienced a complete disruption as two fragments were observed during the 1846 and 1852 apparitions which were subsequently never recovered. The comet is thus considered definitely lost leaving an OMS, the Andromedids, which is the only present observable proof of the past existence of its parent. Fig. 6 shows the configuration of this stream in 1905 together with the hypothetical location of the comet if it had not broken up.

A second example is the Phoenicids generally associated with the lost comet D/1819 W1 Blanpain. However, according to the work of Foglia et al. (2005) and Jenniskens & Lyytinen (2005), the asteroid 2003 WY25 also appears to be associated with this stream, and could be the (now inert) nucleus of the comet.

Another interesting case is that of comet 73P/Schwassmann-Wachmann 3, the parent body of the τ -Herculids meteor shower. In 1995, its nucleus broke up in at least five main fragments, and several of them have already been lost (Boehnhardt et al. 1995). The

largest fragment has been detected in 2001 (Toth, Lamy & Weaver 2005) and recovered in 2005 by Hergenrother, Marsden & Nakano (2005). The close encounter with the Earth that this comet will experience in 2006 will offer a unique opportunity for detecting other smaller fragments, but it is entirely possible that only the largest one is presently surviving and only for a few more revolutions. As a consequence, the τ -Herculids may well become an OMS sooner or later. Wiegert et al. (2005) found that, in spite of the close approach between the main fragments and the Earth in 2006, no meteor outburst is expected.

In general, we can say that a meteoroid stream can become an OMS when its parent comet breaks up in several fragments that are too faint to be detected. Such a scenario is expected to have occurred many times in the past and therefore supports the idea of the ubiquitous presence of OMSs in the Solar system. The link to a known body is possible only if at least one large fragment survives, but usually these fragments experience strong non-gravitational effects just after the breakup, and therefore drift away from the initial nucleus orbit (see also Section 5), thus complicating the identification.

7 APPARENT ORPHAN METEOROID STREAMS

7.1 Dormant or extinct comets

Some meteoroid streams are particular since their parent body is an asteroid, which is thought to be an extinct cometary nucleus. The Geminids and the Quadrantids are good examples and, respectively, associated with 3200 Phaethon and 2003 EH1 (Williams & Wu 1993; Jenniskens 2004). These streams are observed as meteor showers since the XIXth century, suggesting that their age amounts to several hundreds years. They were considered OMSs until the discovery of their parent asteroids and the realization of their association based on the similarity of their orbital elements. Since their orbits are relatively stable, we can understand that the nucleus remains roughly on the same orbit as the meteoroids once all the ice has sublimated away. This is also a necessary condition for the stream to be detected by other means than a meteor shower (e.g. infrared observation such as the *IRAS* survey). Fig. 7 displays the configuration of the Quadrantids and asteroid 2003 EH1. The meteoroids shown here were ejected at each return since 1704 AD. The parent body still remains in the middle of the stream, despite some

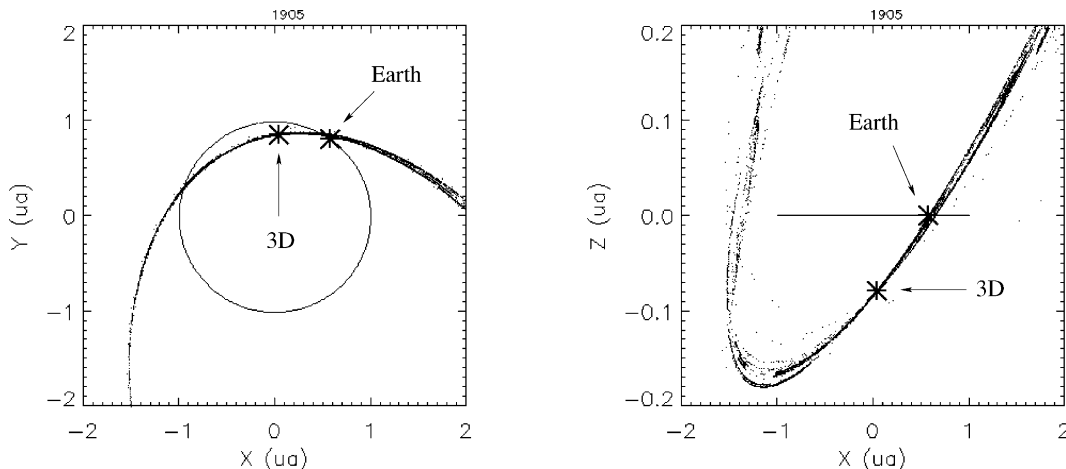


Figure 6. Configuration of comet 3D/Biela in 1905 (if the nucleus had not broken up) and the Andromedids in an ecliptic (J2000) heliocentric frame. The meteoroids trailing the nucleus are responsible for the mid-November meteor showers since they come very close to Earth.

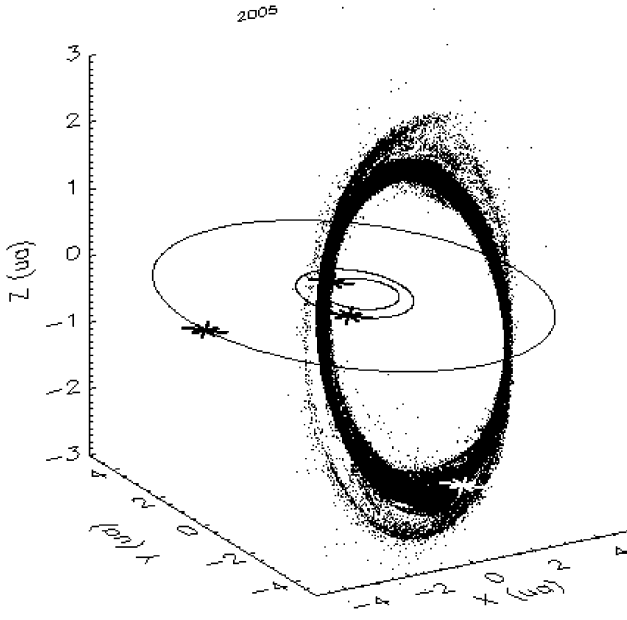


Figure 7. Configuration of the Quadrantid meteoroid stream ejected since 1704 and asteroid 2003 EH1 (white star), as seen in 2005. This presumed parent body is located inside the stream.

possible perturbations by Jupiter at aphelion. No outgassing activity was detected either from 2003 EH1 or from Phaethon (Jenniskens 2004; Hsieh & Jewitt 2005). Since they are km-size objects, it is not surprising that only recent observational techniques and systematic surveys were able to detect them. In summary, extinct comets can lead to apparent OMSs, and the linkage is only possible if their orbits are stable enough, or by the calculation of association criteria as defined, for instance, by Valsecchi, Jopek & Froeschlé (1999).

7.2 Long-period comets

Long-period comets remain unobservable for decades once they pass their perihelion. Therefore, any associated meteoroid stream will appear as an OMS. Again in this case, the observation of meteor showers helps to detect and associate the streams and the comet. The most famous associations are the Lyrids and comet C/1861 G1 Thatcher (Porubcan, Stohl & Svoren 1992), and the Aurigids and comet C/1911 N1 Kiess (Guth 1936). Two other cases are the Halley-type comets C/1917 F1 Mellish associated with the Monocerotids meteor shower (Kresáková 1974; Lindblad & Olsson-Steel 1990) and the ϵ -Eridanids and the comet C/1854 L1 Klinkerfues (Vaubailon & Jenniskens 2006). Strictly speaking, these latter two cases are not long-period comets but only one return has been observed so far, and the next one is expected before 2061 for C/1854 L1 Klinkerfues. Further details of these showers and comets can be found in Jenniskens (2006). Table 1 lists all the meteor showers associated with comets which are presently unobservable. We can see that this phenomenon is far from being marginal, since 10 showers of this kind are known, among the 131 showers appearing in the International Meteor Organization meteor shower list.

Since the parent body cannot be observed, we can say that long-period comets and even Halley-type comets can be a source of apparent OMSs. The considerable distances between the meteoroids and their parent body imply that they are extensively spread in the Solar system. The resulting low spatial densities make their direct

Table 1. Associations between meteor showers and their parent comets which are presently unobservable (Kresakova 1986; Kresáková 1987; Hughes & Williams 2000). IMO is the International Meteor Organization.

Shower	IMO code	Parent comet
Leo Minorides	LMI	C/1739 K1 1739 (Zanotti)
Lyrids	LYR	C/1861 G1 Thatcher
Aurigids	AUR	C/1911 N1 Kiess
Monocerotids	MON	C/1917 F1 Mellish
α -Draconides	ODR	C/1919 Q2 Metcalf
δ -Cancriides	DCA	C/1931 P1 Ryves
σ -Hydrides	HYD	C/1943 W1 Van Gent-Peltier-Daimaca
ϵ -Geminides	EGE	C/1964 N1 Ikeya
η -Lyrids	ELY	C/1983 H1 IRAS-Araki-Alcock
ϵ -Eridanids	EED	C/1854 L1 Klinkerfues

detection, either in the visible or in the infrared, quite difficult. Actually, even the associated meteor showers are hard to detect, and only the trails formed during the last revolution are expected to possibly cause a remarkable outburst (Lyytinen & Jenniskens 2002). However, annual meteor showers are regularly observed (e.g. the Lyrids) and their observation is still the best way to study the associated streams.

7 CONCLUSION

Several mechanisms can lead to the creation of OMSs. The most efficient is a close encounter between a comet and a giant planet, that propels the parent body into a new, totally different orbit. Meteoroids ejected before the encounter and located far from the nucleus are not much perturbed and remain in the original orbit. This mechanism is fast.

Resonances can cause the stream to either split or be confined in certain regions of the Solar system, but this mechanism requires more time than a close encounter.

Cometary non-gravitational forces cause the parent body to drift away from its associated meteoroid stream. However, the effect is weaker than a close encounter and will require much more time to create an OMS. Non-gravitational forces acting on meteoroid make their orbits wider than that of the parent body, and shift the position of the resonances compared to the gravitation-only case.

Some meteoroid streams can appear as OMSs since their parent body is an asteroid (thought to be an extinct comet), a Halley-type or a long-period comet which was observed only once. Even if some new associations may be identified in the future, OMSs will always exist just because comets are subject to breakup.

Any combination of the above-mentioned effects will help creating an OMS. For example, we can imagine that first cometary NGF slightly separates a comet from a stream. Then a close encounter sends the comet on a totally different orbit. After several thousands years, some meteoroids can be trapped in a resonance and the resulting confinement enhances their spatial density and allows their detection as a stream, precisely an OMS, since the link between the parent bodies (if it has not disappeared in the mean time) would be hard to recognize because the orbits will look so different.

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