Welcome to the course:

Small bodies in the Solar system I

The course is devoted to comets.
It includes 14 lectures, 6 exercises, and a project.

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Exercises – by Antti Penttilä (e-mail: Antti.I.Penttila@helsinki.fi)

We allow to miss 1 lecture and 1 exercise without a penalty.
However, absence on the lecture is not an excuse (!) at future exam. The same holds for home exercises – all of them have to be completed.
An extra absence will lead to an additional task.

Schedule of the lectures:

08.09.2010: 10-12 (D115)
09.09.2010: 10-12 (D104)
29.09.2010: 10-12 (D115)
30.09.2010: 10-12 (D104)
06.10.2010: 10-12 (D115)
13.10.2010: 10-12 (D115)
20.10.2010: 10-12 (D115)
03.11.2010: 10-12 (D115)
10.11.2010: 10-12 (D115)
17.11.2010: 10-12 (D115)
24.11.2010: 10-12 (D115)
01.12.2010: 10-12 (D115)
08.12.2010: 10-12 (D115)
15.12.2010: 10-12 (D115)

Introduction

In general, the term "comet" has two meanings:

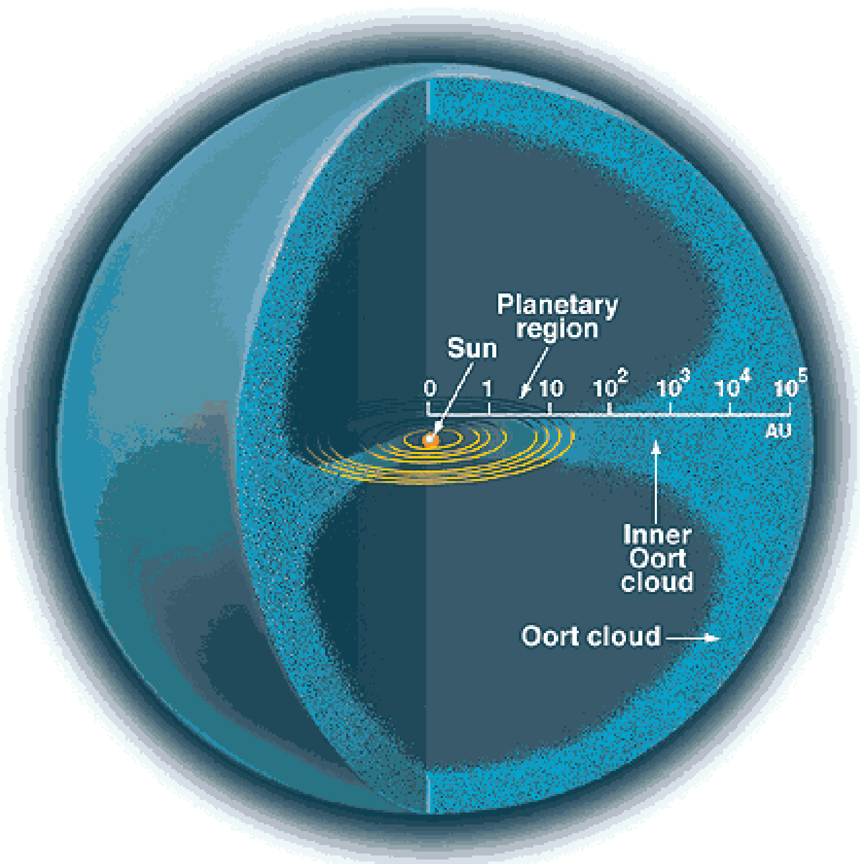
(1) small body containing volatiles, so, its approaching to the Sun causes certain atmosphere-like activity;

(2) phenomenon caused by sublimation of volatiles while small body is approaching to the Sun (whereas, the small body is referred to nucleus).

It is believed that comets are planetesimals, i.e., remnants of proto-planetary disk for the Solar system.

It is believed that comets have been formed in relative vicinity to the Sun (the area of the Solar system) because only there the materials were dense enough.
However, later, comets have been moved in outer region due to gravitational perturbations caused by rapidly-formed gaseous planets Uranus and Neptune.

At present, the most of comets is located in the outer region of the Solar system.



The outer region of the Solar system is called as the Oort cloud on behalf of Dutch astronomer Jan Hendrik Oort (1900 – 1992).

The inner boundary of the Oort cloud is assumed to be at about 1000 AU; whereas, the cloud extends till 100000 AU.

The number of “typical” comets (size ~1 km) is about $\sim 10^{12}$

Density is 1 comet per 4190 AU^3, or in cube with side of 16 AU.

Orbital motion of a comet in the Oort cloud can be disturbed by neighbor stars and, occasionally, the comet may be directed toward the inner part of the Solar system. Indeed, while the outer boundary of the Oort cloud lies at about ½ parsec, circum-solar sphere with radius of 3 parsecs contains 11 stars.

Thus, a comet leaves the Oort cloud and starts very long journey to the Sun. Such a comet (i.e., with aphelion at $10^4 - 10^5$ AU) is referred to a dynamically fresh comet or new comet.

When approaching the Sun, motion of the comet is perturbated. This happens even not because close encounters with the planet, which might not occur. It is due to the fact that the comet has a barycentric motion (i.e., around the center of mass of the Solar system) when it is far away and a heliocentric motion when it is close; whereas, the distance of the barycenter from the Sun is of the order of the relative mass of Jupiter.

After a passage through the inner Solar System, it is unlikely that the semi-major axis remains of order 10^4 AU. It either decreases to 10^3 AU or the orbit becomes hyperbolic (i.e., comet leaves the Solar system forever).

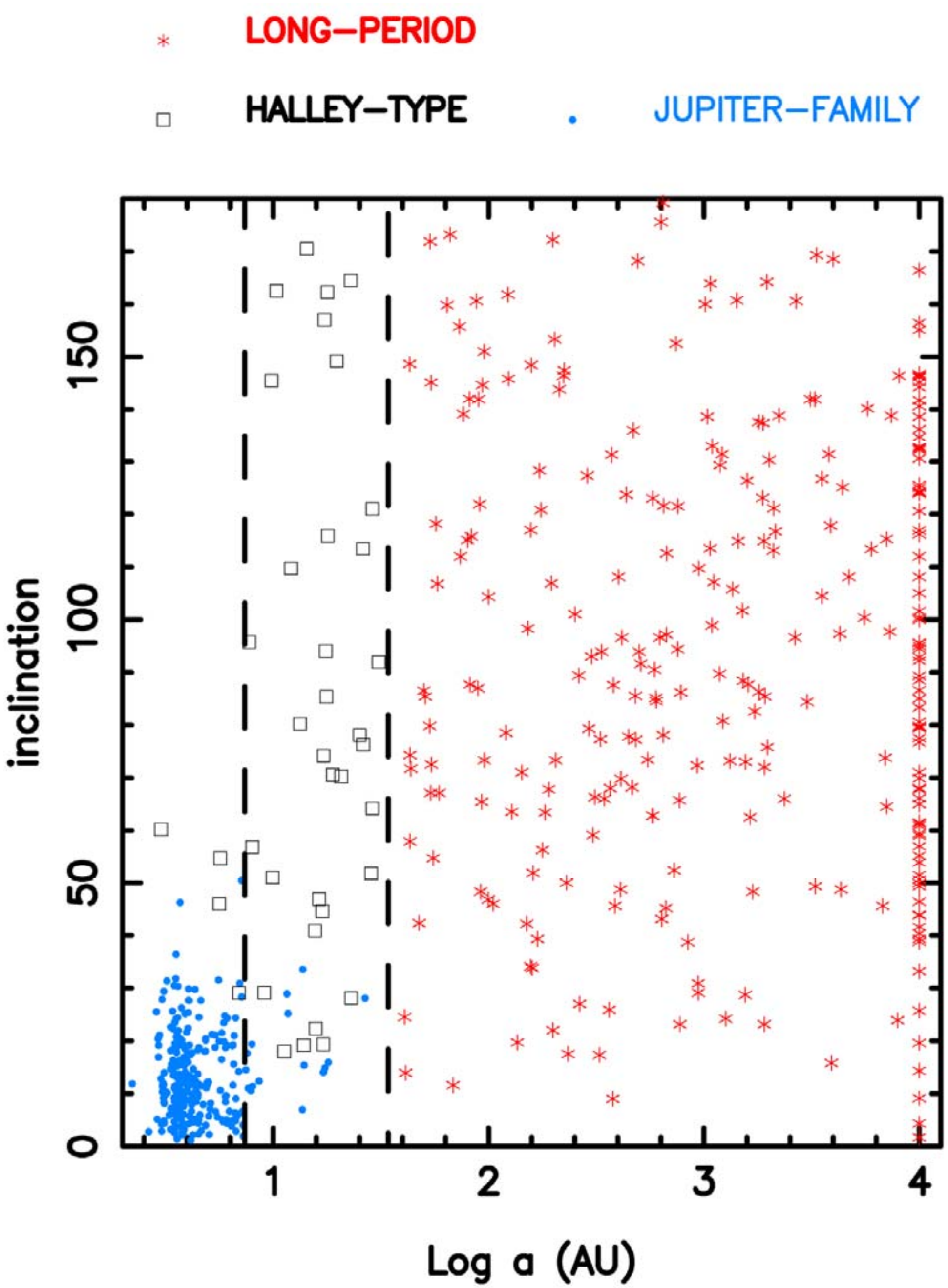
One can classify the comets basing on their orbital period P:

- Long period comets with $P > 200$ years;
- Short period comets with $P \leq 200$ years.

The threshold of 200 years is arbitrary, and has been chosen mostly for historical reasons.

Obviously, dynamically fresh comets form a sub-class of Long period comets.

Short period comets are subdivided in Jupiter family (JFCs) with $P < 20$ years and Halley-type (HTCs) with $20 \leq P \leq 200$ years.



Evolution of orbits

While orbit of a comet is getting smaller, its inclination is also being decreased.

For JFCs:

(a) $i \leq 30^{\circ}$

(b) the absence of retrograde comets

Nomenclature of comets

In order to distinguish one comet from another, each of them is marked with an unique tag. The currently accepted nomenclature (valid since 1995) is based on dynamics of comets.
An example of tag for a comet is as follows:

C/1989 Y1 (Skorichenko-George)

In general, the first symbol specify the orbital period of the comet. It is "C" if the comet belongs to the Long period comets and "P" – to the Short period comets. However, if the period exceeds 30 years, the comet is marked initially with symbol "C", even when the period is less than 200 years.
Other first symbol: "D" – lost or disintegrated, "X" – unknown orbit, "A" – object misclassified as a comet

The number after slash designates year of discovery.

Symbol the next after year specifies a time period of the discovery according to the table:

	Jan	Feb	Mar	Apr	May	Jun
01-15	A	C	E	G	J	L
16-31	B	D	F	H	K	M
	Jul	Aug	Sep	Oct	Nov	Dec
01-15	N	P	R	T	V	X
16-31	O	Q	S	U	W	Y

The final number indicates a discovery number within a given time period.

The words in parenthesis present a proper name of the comet, which are generally surnames of discoverers (up to 3 persons).

However, there are some exceptions when comets are named for:

(a) a person who calculated their orbits (comets 2P/Encke and 27P/Crommelin);

(b) observatory, laboratory, or project where or within the discovery have been done (comets C/2007 N3 (Lulin), C/2001 Q4 (NEAT), and C/2008 R3 (LINEAR));

(c) spacecraft (comet P/2008 N4 (SOHO)).

When a new short period comet passes perihelion twice, it obtains a permanent sequence number. For instance, the comet C/2008 R3 (LINEAR) will change its name in about 80 years to something like:

643P/LINEAR

The number in front of symbol “P” is being associated with given comet forever; even if the comet will be lost or disintegrated.

Old nomenclature of comets

Before 1995, comets have been tagged as follows. First, newly discovered or a detected short periodic comets was obtaining a temporarily tag as follows:

1984e

here, the number 1984 presents a year of discovery or detection; whereas, symbol “e” indicates order of appearance. If the number of observed comets exceeds 26, the symbol was extended by adding a number “1”. For instance, 27-th comet observed in 1984 would be tagged as 1984a1; 28-th comet as 1984b1, etc.

Only a few years later, a comet was obtaining its permanent tag.

For instance, the permanent tag for comet 1984e was as follows:

1985 XIII

here, the number 1985 specifies year of perihelion passage; whereas, number XIII – its order.

Obviously that such a nomenclature is an extremely misleading, since a periodic comet obtains a new tag in each apparition.

For instance, comet 1984e, 1985 XIII is 21P/Giacobini-Zinner with orbital period of 6.6 years.
It is known also as: 1992 IX, 1979 III, 1972 VI, 1966 I, 1959 VIII, 1946 V, 1940 I, 1933 III, 1926 VI, 1913 V, and 1900 III.
One can easily assess “a convenience” of this nomenclature.

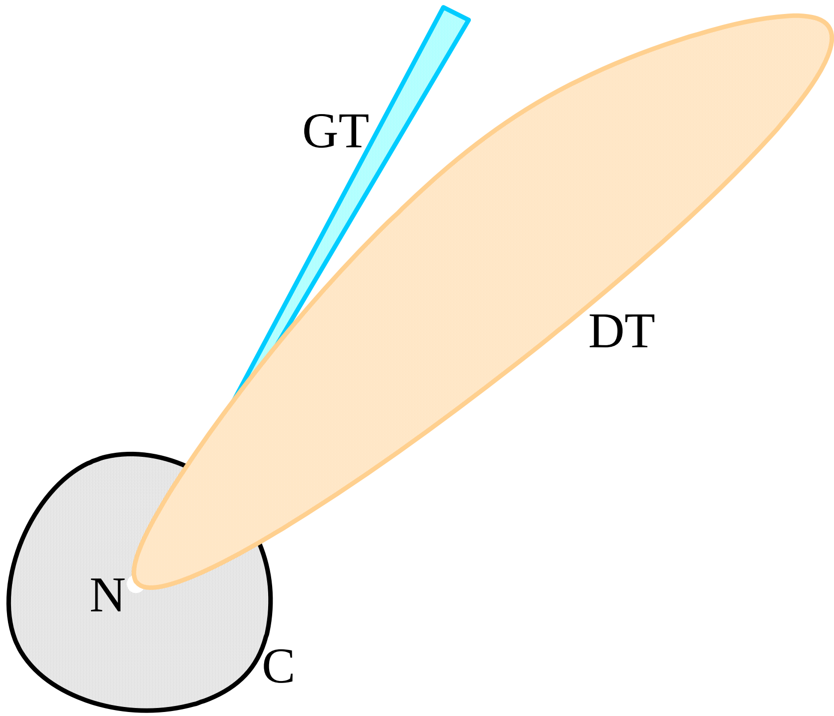
Appearance of comets: low activity

Appearance of comets: moderate activity

Appearance of comets: high activity

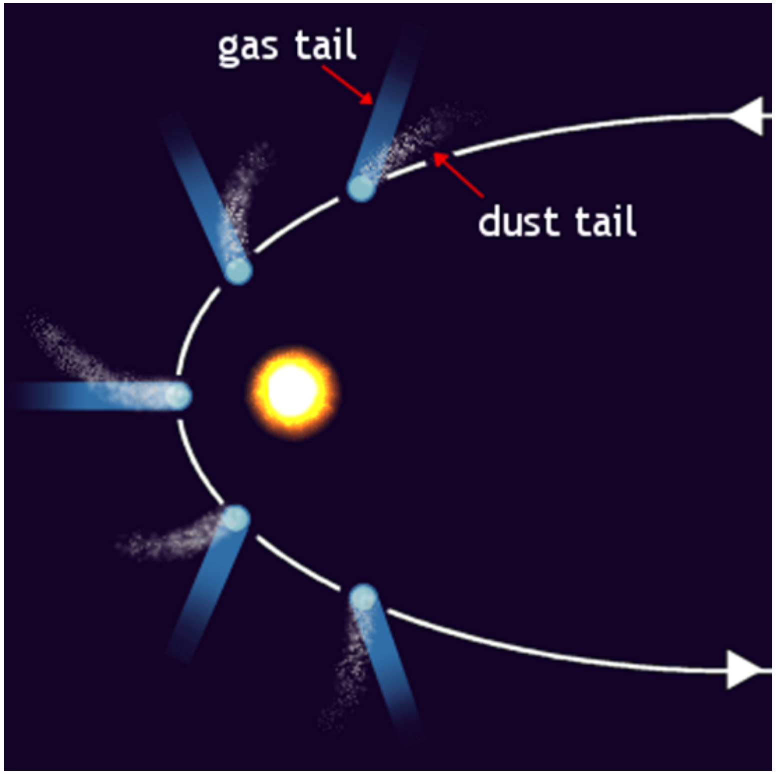
False impression on optical thickness of coma

Schematic picture of a comet



N: nucleus	< 50 km (invisible)
C: coma	up to a few millions km
GT: gas tail (type I)	up to 4 AU
DT: dust tail (type II)	up to a few AU

In the most of cases, tails are oriented in anti-sunward direction.

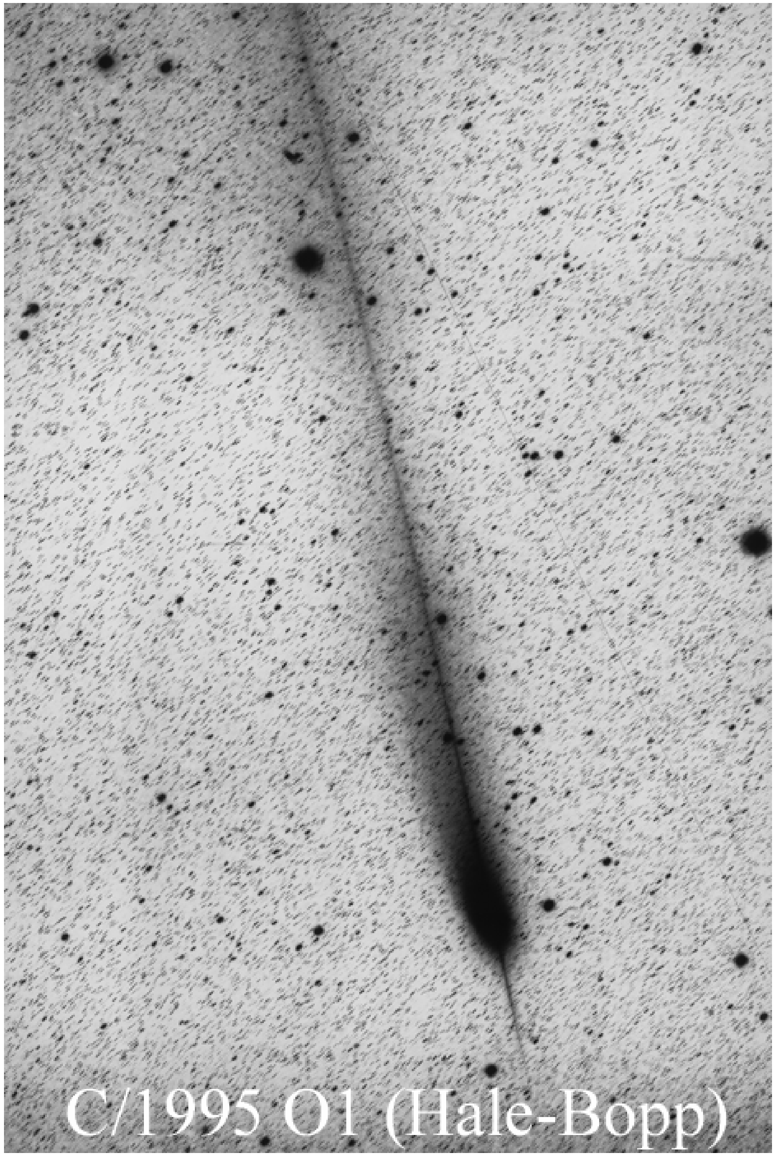


Ion (or gas) tail is deflected by solar wind. However, there is no direct interaction between solar wind particles and cometary gas molecules. The deflection happens due to a curvature of magnetic field caused by ion atmosphere around a nucleus.

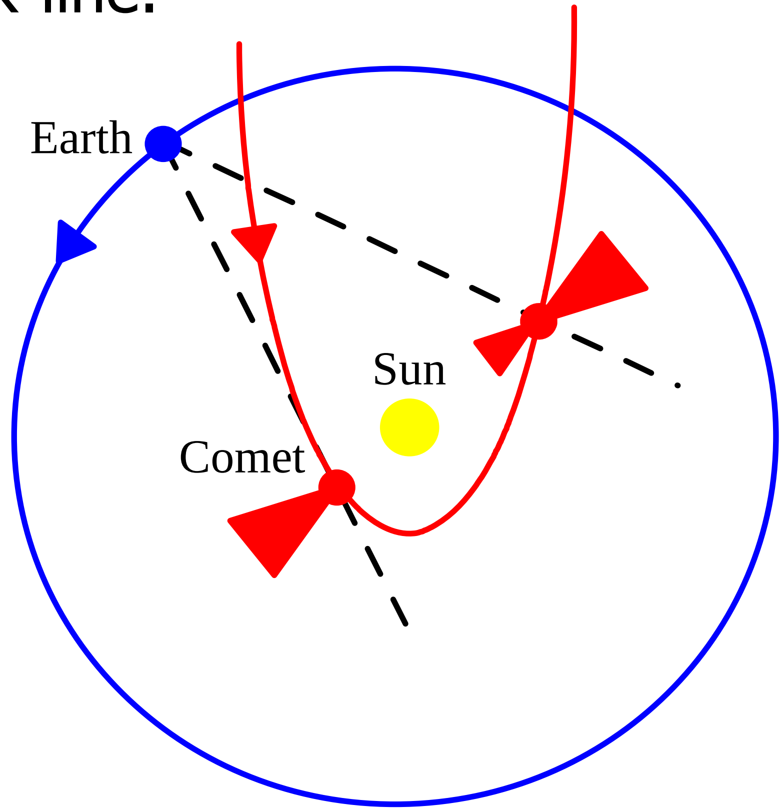
Dust tail is deflected by radiation pressure. The force acts in the direction opposite to the gravity force; its effect is similar to “a decrease” of the Sun mass. Thus, a particle moves along orbit with smaller curvature than nucleus.

Gas tail is more straight in appearance than dust tail.

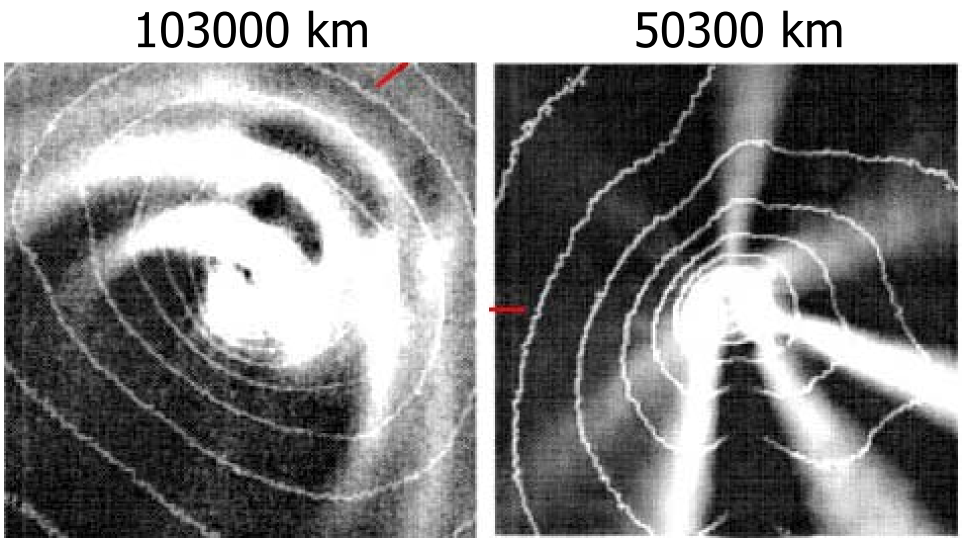
Dust antitails (Neck-lines)



In some cases, dust tails retain the memory of the dust ejection over long time-period. If simultaneously a perihelion passage happens, one can observe a remnants of dust tail as a neck-line.



Inner structure of coma



Comet C/1995 O1 (Hale-Bopp)

Inner coma reveal extremely bright and highly collimated fluxes of dust particles. Depending on their shape, they are called as jets or arcs.

A distinctive feature of jets is high velocity of dust particles (~ 100 m/s).

Interestingly, the number of jets is limited (less than ten).

Dust particles forming jets are accelerated by gas.

In addition to jets, coma includes non-collimated dust fluxes which are much less accelerated (order of magnitude?)

Composition of comets

Comets consist of three abundant components:

1. Mg-rich silicates;
2. Organic material (no one knows exactly what it is; but something composed of carbon, oxygen, hydrogen, and nitrogen)
3. Volatiles, preferentially water ice (about 70-90% by mass). However, super-volatiles, such as, carbon monoxide (CO) and carbon dioxide (CO_2) also appear in considerable amount; up to 30% and 6%, correspondingly.

An important parameter characterizing cometary activity is the dust-to-gas ratio. This parameter significantly vary for different comets. However, for a given comet, it may also change significantly with time. The range is from 0.1 to more than 1.

Loss of material by a comet

For example, we will consider comet 1P/Halley.

The total mass of the comet is of 2.2×10^{14} kg.

According to Singh et al. (1994), near perihelion, it losses about 27500 kg of volatiles and 14800 kg of dust per sec; altogether, 42300 kg/s.

Near the Sun (R < 2 AU), the comet was from October 26, 1985 till May 27, 1986, i.e., 214 days, or 1.85×10^{7} s.
During this time period, the comet have lost about 7.8×10^{11} kg.

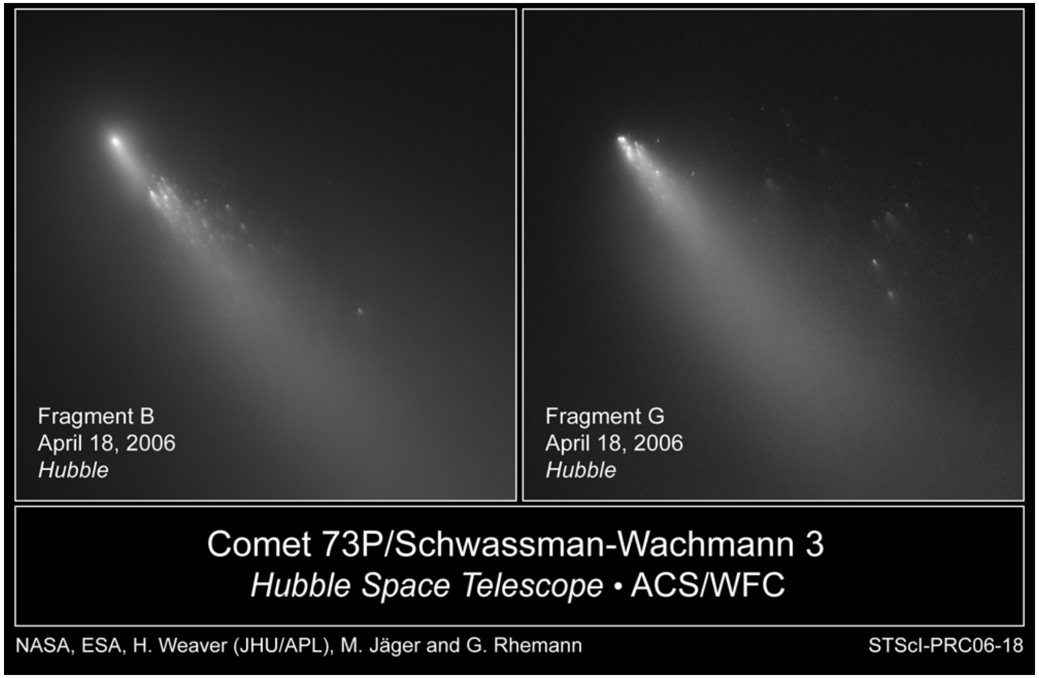
Thus, the comet needs to revolve 282 times around the Sun in order to lose all its material. Taking into account the orbital period 75 years, one can estimate a life time of the comet as 21150 years.

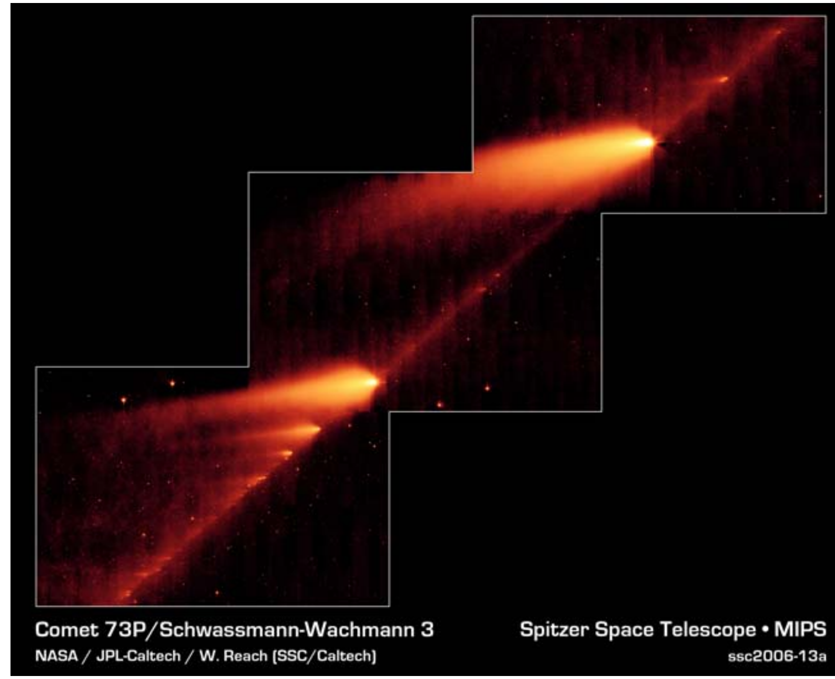
“Death” of comets

However, it is very unlikely that a comet may completely evaporate. More probable scenario is as follows. After all volatiles in sub-surface layer have been sublimated, the nucleus gets a crust consisting of refractory materials and the comet becomes similar to asteroid.

Indeed, the short period comets reveal substantially less activity than the long period ones. The same holds true for the Jupiter family comets and Halley-type comets. For instance, comet 26P/Grigg-Skjellerup (5.3 years) has the dust production for 200 times less than comet 1P/Halley (75 years).

Comet 2P/Encke (3.3 years) is an absolute “champion” among comets with low activity. The comet is observed at least since 1786 (68 periods). Its nucleus is visible in ground-based observations.



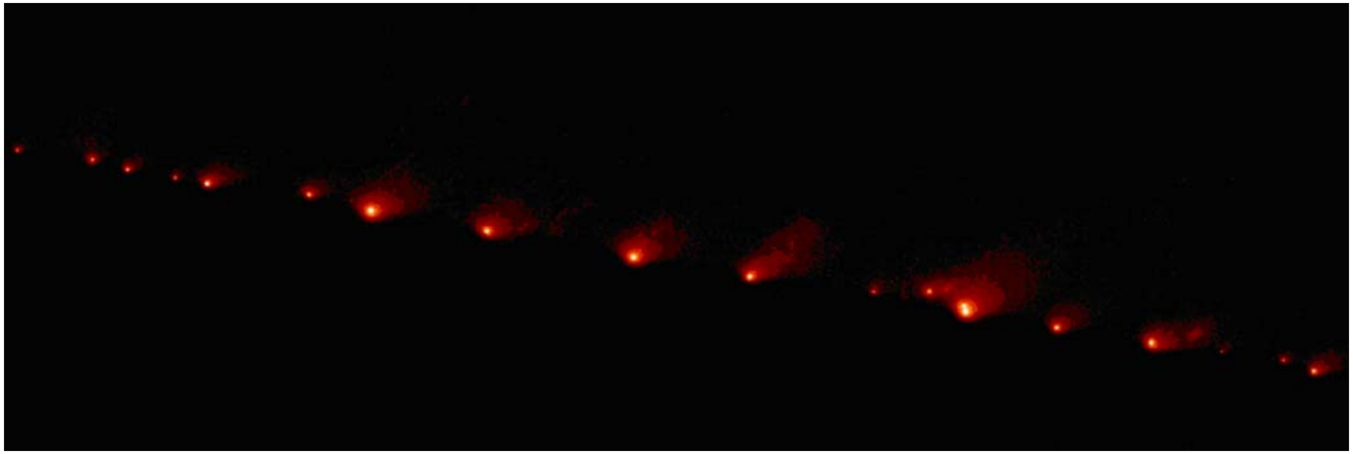


Comet may disappear due to disintegration caused by a gravitational interaction with a big planet (most likely Jupiter). Such a disintegration is being observed currently for comet 73P/Schwassmann-Wachmann. In 1995, the nucleus of this comet (~1.1 km across) was split into five large pieces. However, at present, there are already 66 fragments.

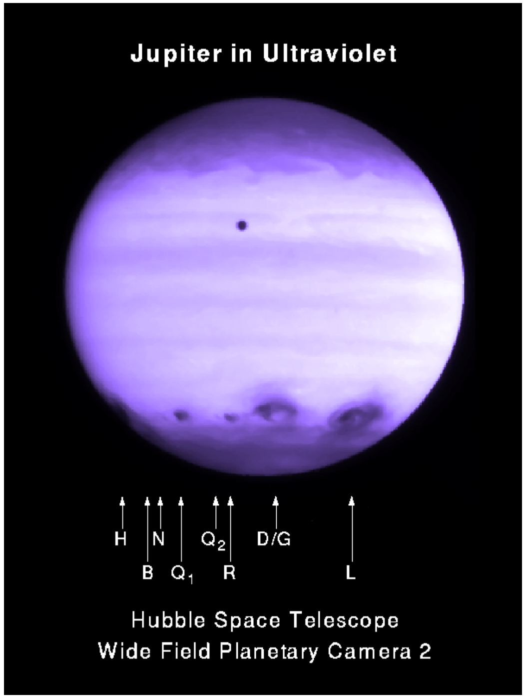
The death of comet 3D/Biela through disintegration have been observed in 1846–1859.

Finally, comet may die due to a collision with planet (or the Sun). In 1994, such event was indeed observed for comet D/1993 F2 (Shoemaker-Levy). The comet was orbiting Jupiter! The tidal forces pulled the comet apart in more than 20 fragments.

On July 16–22 of 1994, the fragments collided with Jupiter.



D/1993 F2 on May 17, 1994



After impact