Physical evolution of short-period comets

Sławomira Szutowicz

Space Research Centre PAS

LHB meeting, Kraków 23-26 June 2013

Cometary evolution

- In each perihelion passage the outer layers of the nucleus are heated what leads to mass loss and differentiation of these layers.

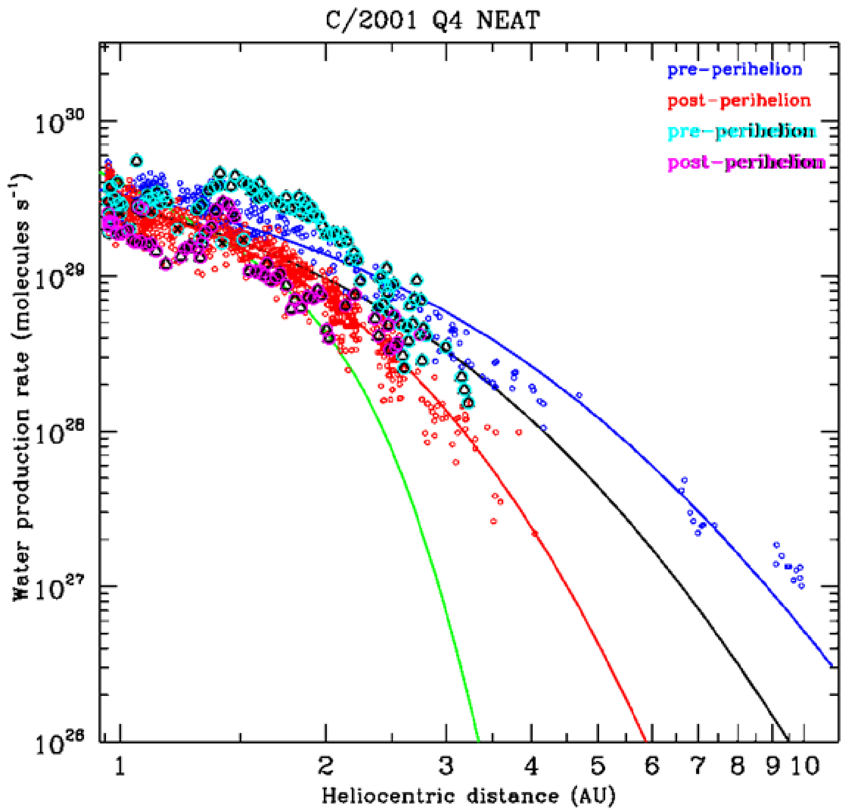
- The mass is lost due to process of volatile sublimation

- Outgassing from more or less non-uniformly distributed active regions over the nucleus produce a measurable orbital perturbation, i.e. nongravitational acceleration.

NG force:

- can cause a delay or an advance in the perihelion passage.
- varies with time
- make it impossible to track orbits accurately backwards (or forwards) in time more than a few centuries.

Mass loss of water ice by sublimation



Typical long-period comet

Q ~ 10^{29} mol s^{-1} →

~ 3000 kg s^{-1}

Typical Jupiter-family comet

Q ~10^{28} - 10^{27} mol s^{-1} →

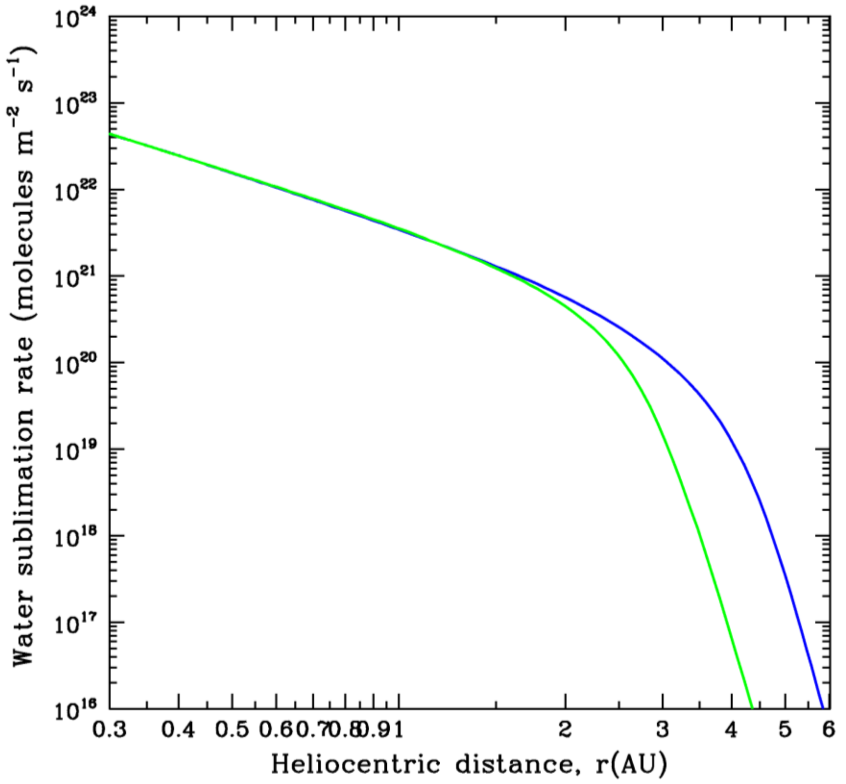
~ 300 - 30 kg s^{-1}

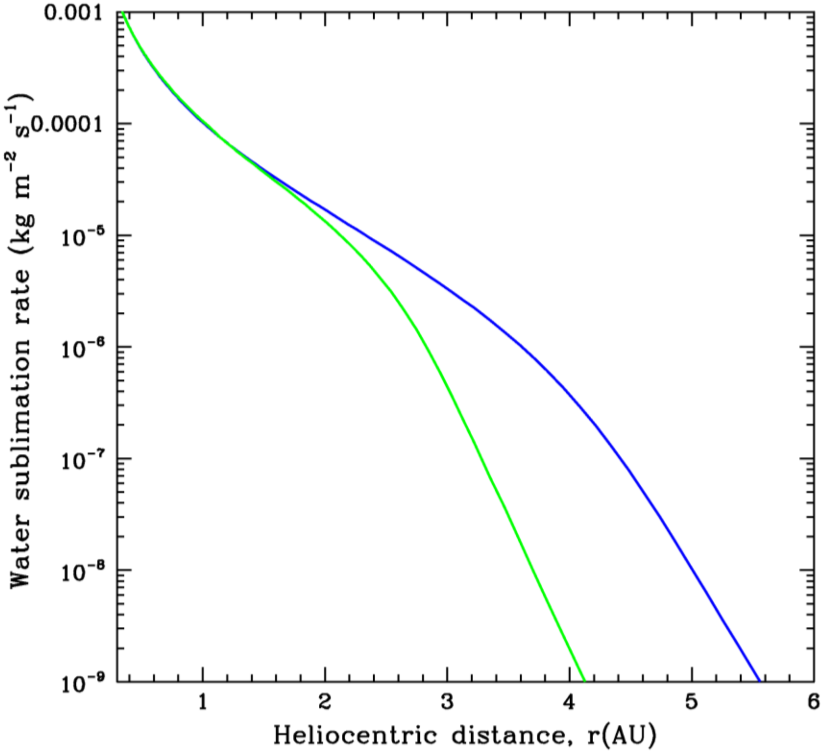
Water production rate versus heliocentric distance

Theoretical curve of water production rate per unit area:

-) isothermal case (green)

-) all latitudes equally active, spin axis perpendicular to the orbital plane (blue)

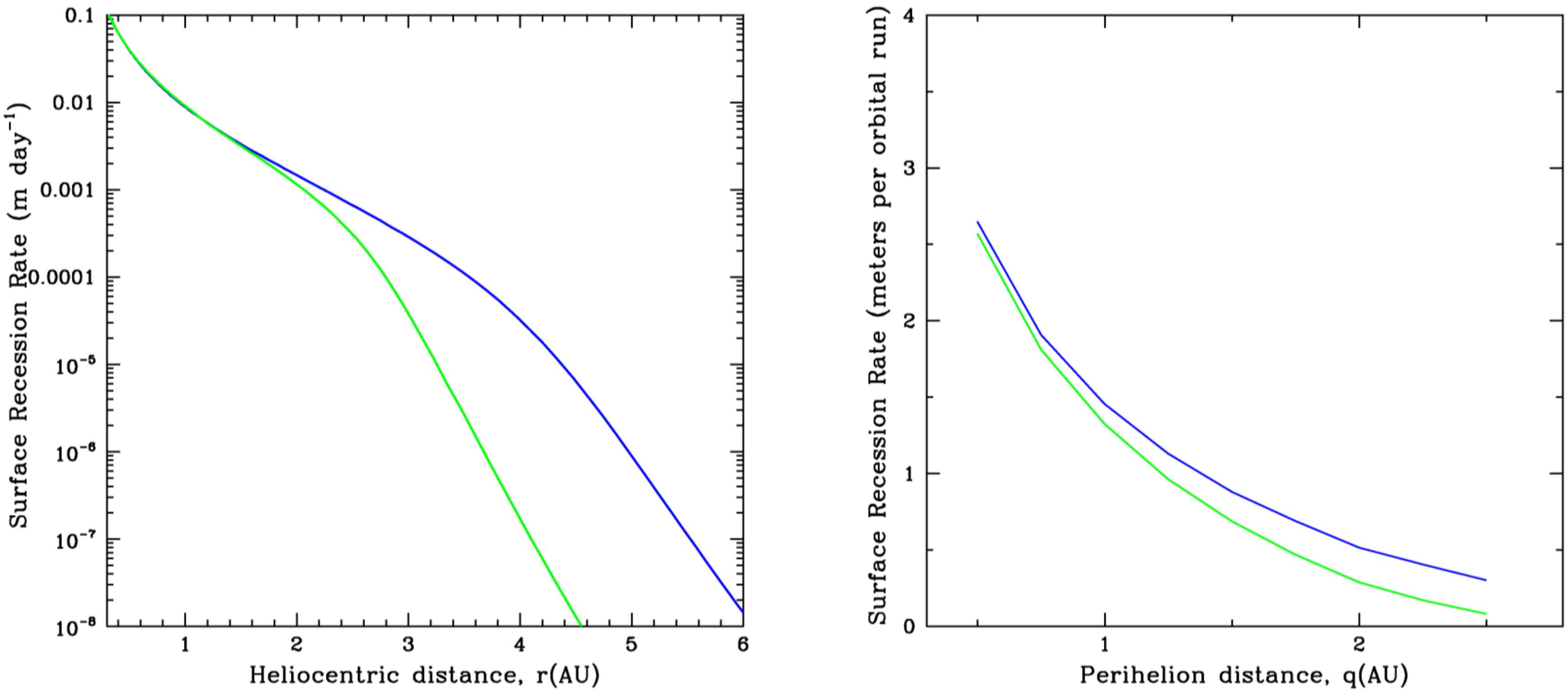




for outgassing ~ 300 - 30 kg s^{-1} at q~1.4 AU → active area ~ 0.6 – 0.06 10^7 m^2

then assuming nuclear radius of JFC ~ 1.5 km → active fraction ~ 20 - 2 %

Erosion rate due to sublimation



per day

per orbital revolution

for density = 1000 kg m^{-3}

mass loss about 1000 kg m^{2} per revolution
on orbit with q~1.4 AU

The sublimation of ices may develop different dust mantles → different fractions of surface are active through the comet lifetime

Dust mantle increases in thickness due to the sub-dust sublimation of ice, and episodically can be blown. The latter is expected when the gas pressure at the ice–dust interface rises.

The existence of crusts, inactive areas on cometary nuclei, was shown by the spacecraft images of the comets.

Cometary fading

1) disrupted comet

random disruption or splitting due to, e.g., thermal stresses, internal gas pressure, fast rotational, impacts by other small bodies, or tidal disruption

2) dormant comet

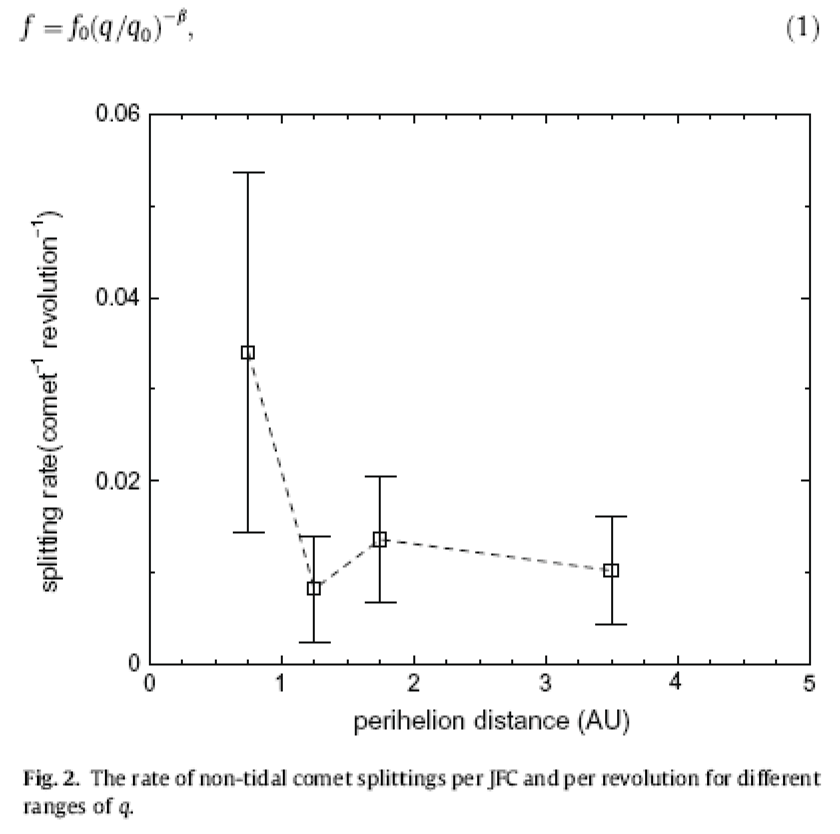
formation of a nonvolatile crust or mantle on the nucleus surface;
has lost the ability to generate a detectable coma;
perturbed to a smaller perihelion distance might be reactivated.

3) extinct comet

loss of all volatiles

The end-state of Jupiter Family comet:

- -) extinct or dormant comet
- -) desintegration
- -) splitting – small chance per perihelion passage



$$f = f_0(q/q_0)^{-\beta}, \qquad (1)$$

Fig. 2. The rate of non-tidal comet splittings per JFC and per revolution for different ranges of q.

Average a JFC will experience a major splitting every 77 revolutions (Di Sisto et al. 2009)

They performed a series of numerical simulations of fictitious comets originated in the Scattered Disk and transferred to the Jupiter's region with a model that includes nongravitational forces, sublimation and splitting mechanisms.

The mean lifetime of JFCs with radii R > 1 km and q < 1.5 AU is found to be of about 150–200 revolutions.

Asteroids in cometary orbits

-Determining the fraction of dormant comets in the ACO population will provide important information for understanding the dynamics of the main belt and the end states of comet nuclei.

- Tisserand parameter T_J<3
-no signature of cometary activity
-orbits of those objects are dynamically unstable, implying that the population needs to be continually replenished.
-physical mechanism that deactivates comet nuclei, transforming a typical active comet into an asteroidal object , i.e. extinct or dormant comet.

Fraction of extinct comets in the asteroid population

-) the orbit shape, Tisserand parameter T_J<3
-) the albedo, known albedos of cometary nuclei are low

→ an asteroid in a comet-like orbit with a comet-like albedo is a good candidate to be extinct comet.

Mid-IR survey of 26 near-Earth and unusual asteroids (NEAs and UAs) in comet-like orbits by Fernandez Y. et al.(2005):

-) 64% +/- 5% of the 32 objects have comet-like albedos

-) Nearly all objects in the sample with T_J < 2.6 have comet-like albedos.

-) Of the almost five dozen known albedos among NEAs with T_J > 3, only 10% are comet-like

-) 4% of all known NEAs are extinct comets. This is consistent with the prediction of Bottke et al. (2002) and Morbidelli et al. (2002).

ALBEDOS OF ASTEROIDS IN COMET-LIKE ORBITS

Ferna´ndez Y, Jewitt and Sheppa (2005)

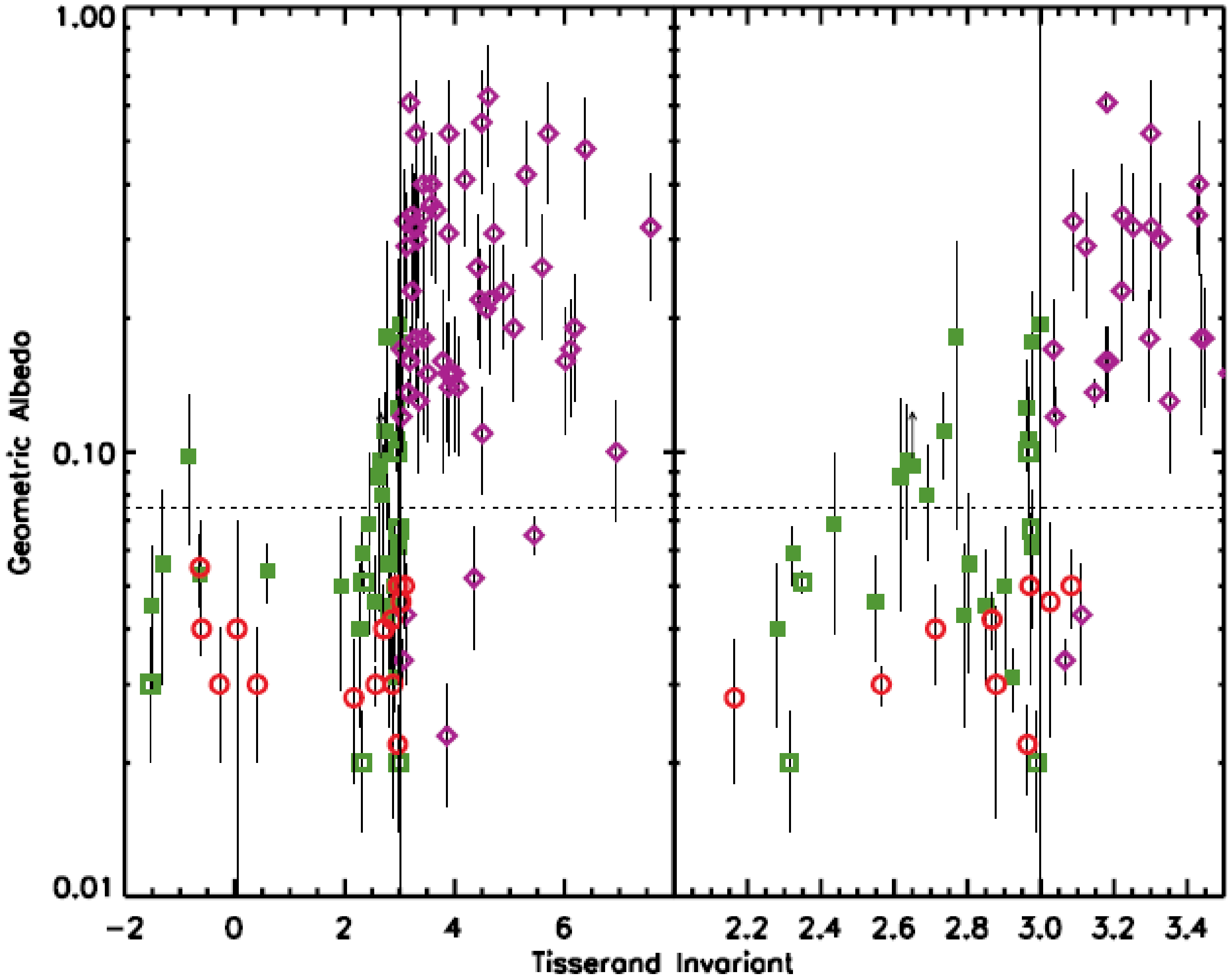


FIG. 3.—Plot of Tisserand invariant vs. known geometric albedos for $T_J < 3$ asteroids (*green squares*) and $T_J > 3$ asteroids (*purple diamonds*). Main-belt asteroids, Trojans, Cybeles, Hildas, Centaurs, and trans-Neptunian asteroids have been excluded; the plot shows only NEAs and UAs. Active cometary nuclei are represented by red circles. The 26 objects in our sample are represented by filled green squares; the six objects taken from the literature are represented by open green squares. The vertical line marks the dynamical boundary $T_J = 3$. There are 57 high-Tisserand albedos plotted, 56 of which are NEAs. The left panel shows the entire range of Tisserand values, and the right panel shows just the region near $T_J = 3$. The fraction of objects with comet-like albedos differs greatly from one side of the dynamical boundary to the other. A large fraction of the $T_J < 3$ objects have comet-like albedos. The $T_J > 3$ asteroid albedos come from the following sources: Morrison et al. (1976), Cruikshank & Jones (1977), Lebofsky et al. (1978, 1979), Green et al. (1985), Tedesco & Gradie (1987), Bell et al. (1988), Veeder et al. (1989), Tedesco (1992), Hudson & Ostro (1995), Mottola et al. (1997), Pravec et al. (1997), Harris (1998), Harris et al. (1998, 2001), Harris & Davies (1999), Tedesco et al. (2002), Benner et al. (2002a, 2002b), Delbó et al. (2003), Sekiguchi et al. (2003), and Müller et al. (2004). There are 14 cometary albedos plotted, taken from the list of Lamy et al. (2004) with 81P/Wild 2 added by Brownlee et al. (2004).

Fading problem

The distribution of the dynamically evolved, “captured” comets from the Oort cloud has been difficult to explain.

- a deficit in the number of comets observed in short-period orbits like that of comet Halley.

→

The model predicts two orders of magnitude more comets in short-period “Halley-type” orbits (periods of revolution $P < 200$ years) than are observed (i.e. Levison *et al*. (2002)

Different thermal histories of two different comets population could lead to different disruption rates →

- Nearly isotropic comets disrupt because of strong thermal gradients
- Jupiter Family comets survive because they are warmed more slowly.