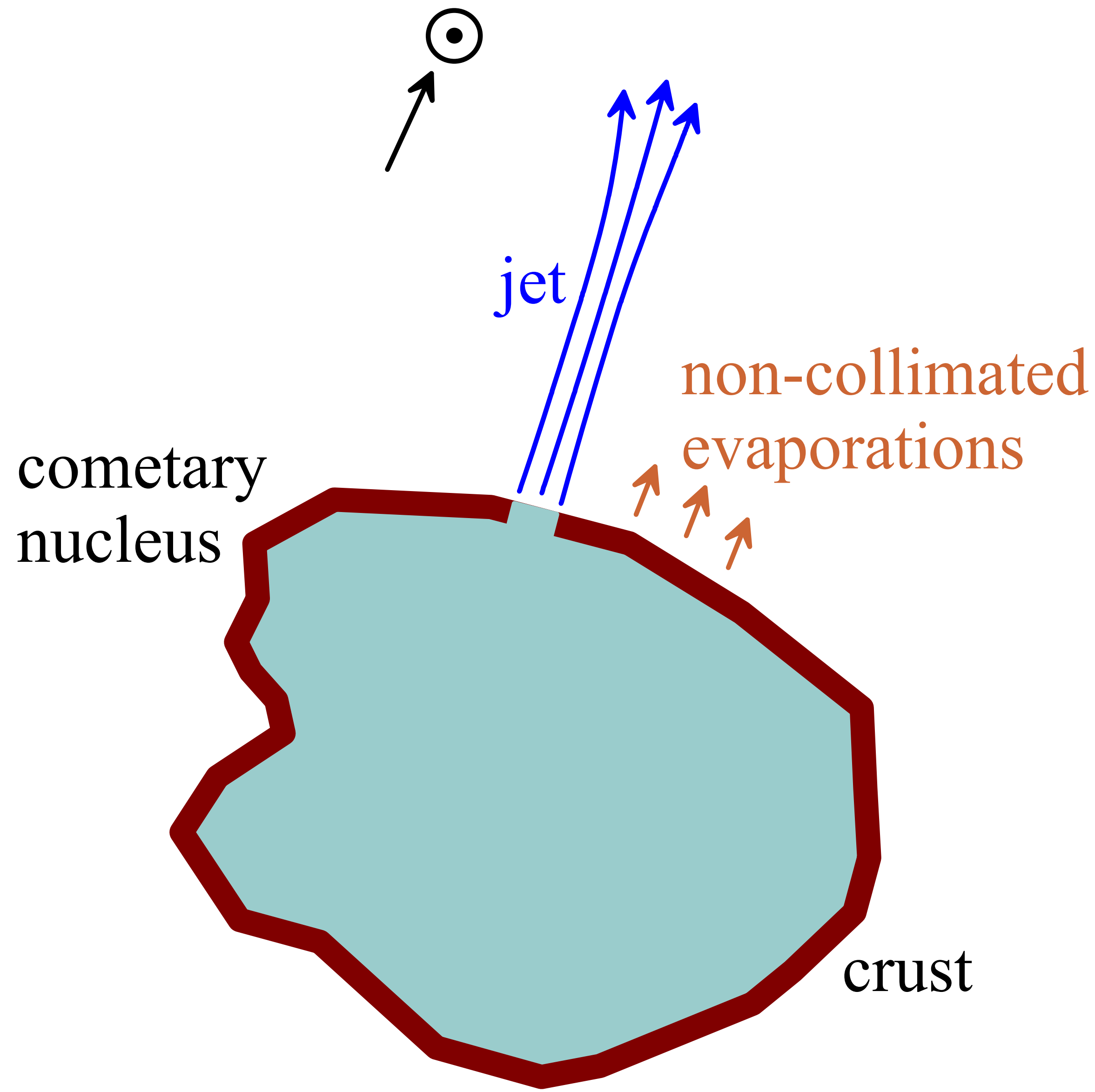
Ejection and motion of dust particles.
Split comets.

Ejections from comets



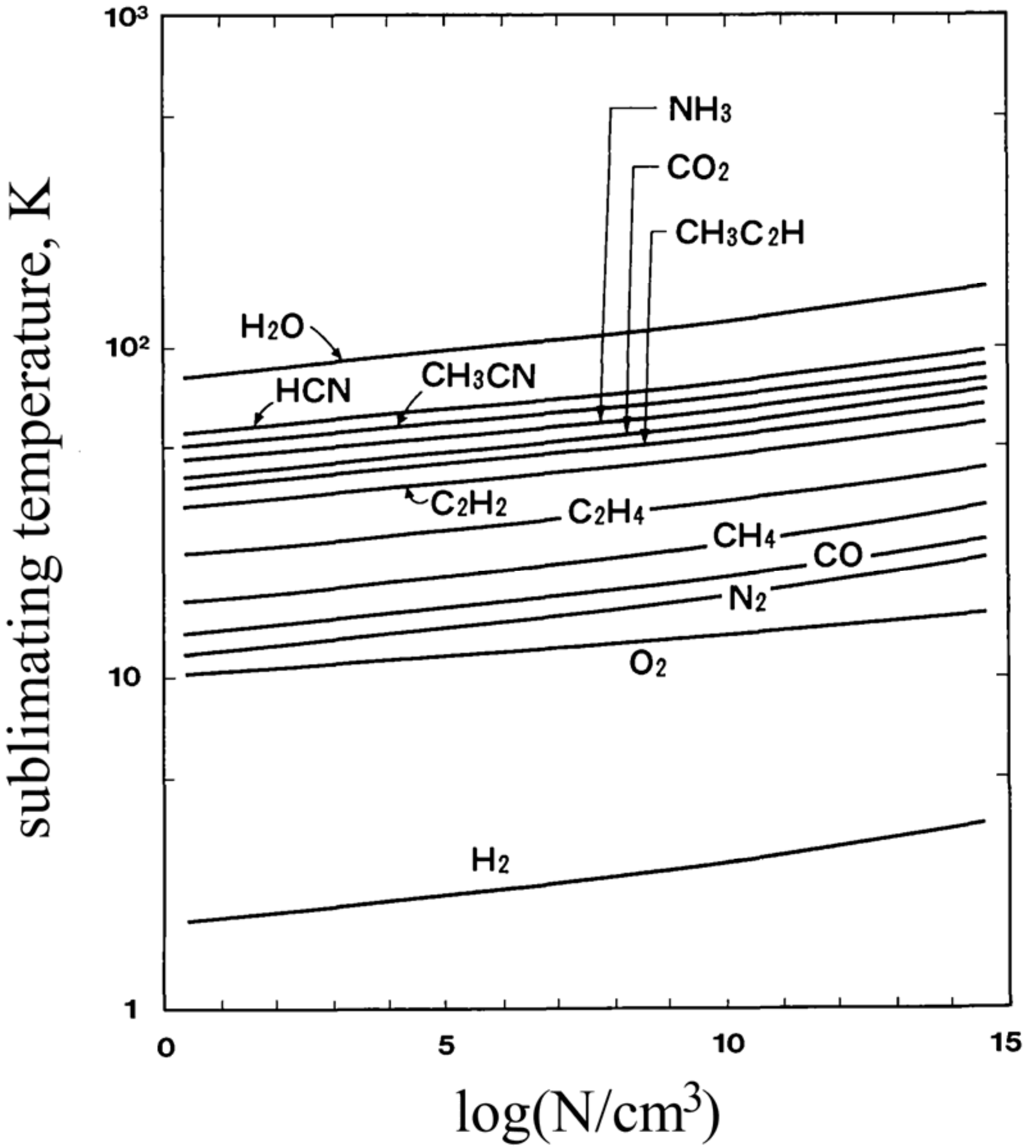
Three types of activity:

(1) dominated by the sublimation of H_2O through the porous mantle;

(2) strong collimated outflows (jets) with H_2O and strong contribution of super-volatiles CO and CO_2; particles are accelerated by gas drag force.

(3) episodic outburst activity (with H_2O, CO, and CO_2)

Sublimating temperature of spices of comets



In general, the sublimating is accompanied with condensation. However, at present, the density of the gases in the Solar system are very low. So, the minimal values of density in the Figure on the left has to be considered.

Nevertheless, in vicinity of the nucleus, this condition does not necessarily hold true.

About 10 – 100 km above the surface, the dust particles move only under influence of gravity and radiation pressure.

Motion of dust depends on so-called β parameter. This parameter is equal to the ratio of two forces, namely, the sun-radiation pressure F_{pr} to gravitation force F_g from the Sun:

$$\beta = \frac{F_{pr}}{F_g}$$

Radiation pressure force F_{pr} is defined as follows:

$$F_{pr} = \frac{E_o\, S_p\, Q_{pr}}{4\pi\, c\, R^2}$$

Where, E_o is the mean solar radiation, Q_{pr} – the scattering efficiency for radiation pressure, S_p – geometric cross section of the particle, R – distance from the Sun to the particle.

Gravitation force F_g is defined as follows:

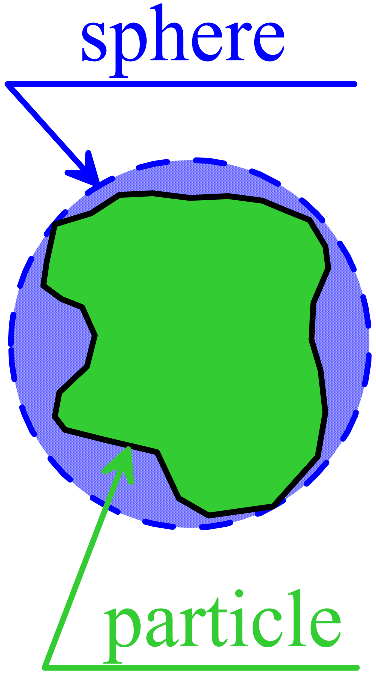
$$F_g = G \frac{M_o \, m_p}{R^2}$$

Where, M_o – mass of the Sun, m_p – mass of the particle, G – the gravitational constant, R – distance from the Sun to the particle.

The β parameter is equal to:

$$\beta = \frac{E_o \, S_p \, Q_{pr} \, R^2}{4\pi \, c \, G \, M_o \, m_p \, R^2} = \frac{E_o}{4\pi \, c \, G \, M_o} \frac{S_p \, Q_{pr}}{m_p}$$

The left factor depends is a constant; whereas, the right one is defined by particles properties. One can simplify it as follows.



One can express the particle characteristics m_p and S_p through the radius of the circumscribing sphere. Indeed,

$$m_p = 4/3\,\pi\, a^3\, \rho\, \rho_{pack},$$

where, a is radius of the circumscribing sphere, ρ – material density, and ρ_{pack} – packing density.

$$S_p = g_p\, S_{cs} = g_p\, \pi\, a^2,$$

Where, g_p is the ratio of geometric cross section of the particle to that of the circumscribing sphere, S_{cs} – geometric cross section of the circumscribing sphere.

Thus, the right factor in the definition of the β parameter can be written as follows:

$$\frac{S_p\, Q_{pr}}{m_p} = \frac{Q_{pr}\, \pi\, a^2\, g_p}{4/3\, \pi\, a^3\, \rho\, \rho_{pack}} = \frac{3\, Q_{pr}\, g_p}{2\, d\, \rho\, \rho_{pack}}$$

Final form of the expression for the parameter β is as follows:

$$\beta = \frac{3E_o}{8\pi\, c\, G\, M_o} \frac{Q_{pr}\, g_p}{d\, \rho\, \rho_{pack}}$$

Where, d denotes the diameter of particles.

However, in the literature, the case of spherical particles is often considered. That case could be obtained in assumption of $g_p = 1$ and $\rho_{pack} = 1$.

On practice, the computation of the β parameter is not quite simple. The problem is that the most interested case of cometary dust particles is the micron-sized particles. Because they are comparable with wavelength, the scattering efficiency for radiation pressure Q_{pr} strongly depends on wavelength λ. Thus, the correct expression for β parameter must imply the variance of Q_{pr} with λ. It is as follows:

$$\beta = \frac{3E_o}{8\pi\, c\, G\, M_o} \frac{g_p}{d\, \rho\, \rho_{pack}} \int_{\lambda_{min}}^{\lambda_{max}} Q_{pr}(\lambda)\, F(\lambda) d\lambda$$

Where, $F(\lambda)$ is the normalized spectrum of the solar radiation. It can be well approximated by spectrum of radiation emitted by black body at T = 5777 K.

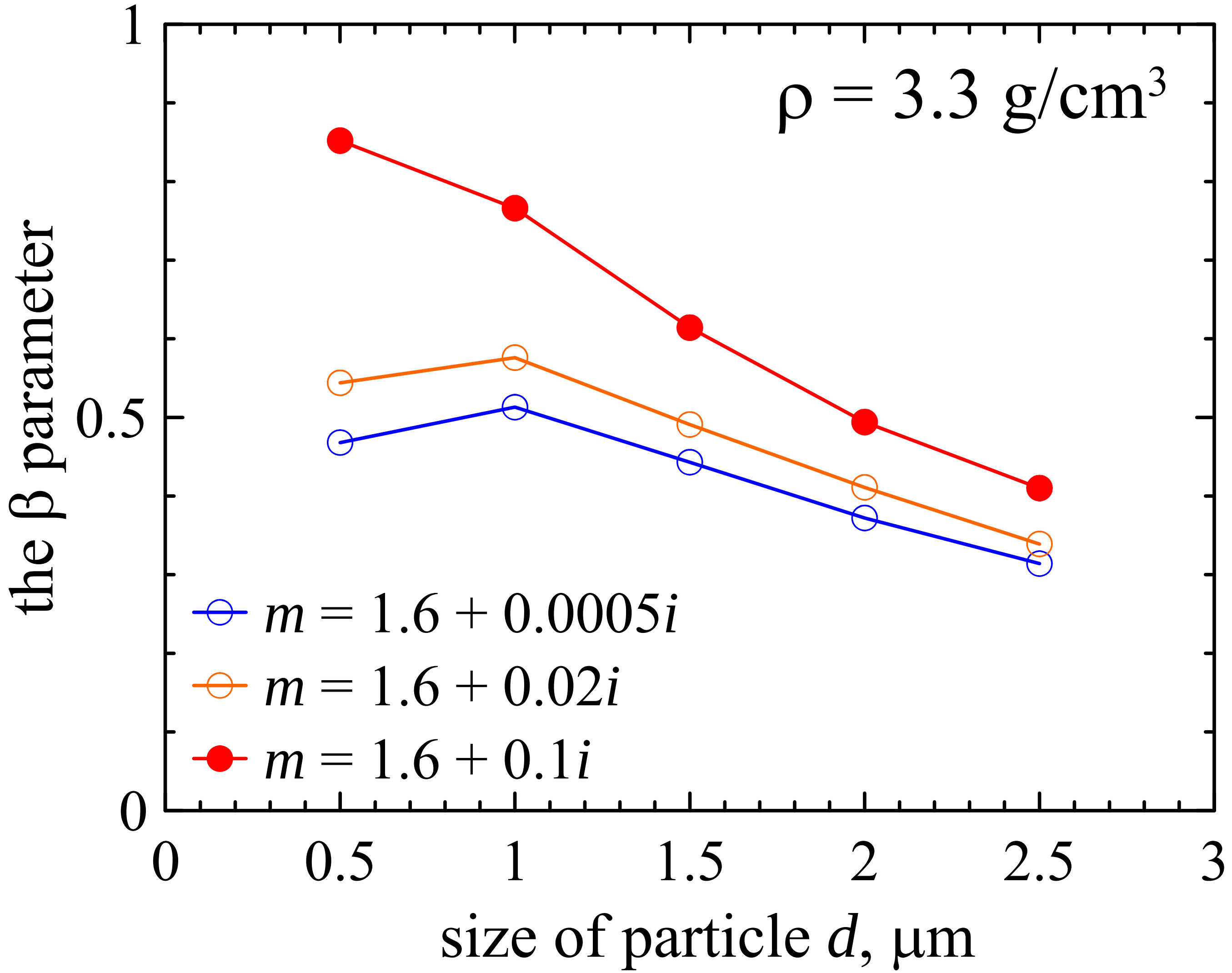
The range of wavelength λ could be considered from $\lambda_{min} = 0.25$ μm to $\lambda_{min} = 2.5$ μm.

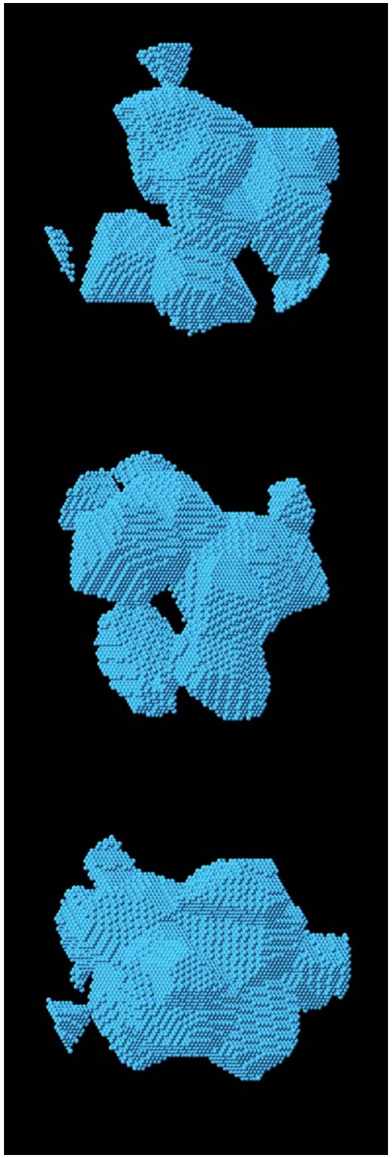
The scattering efficiency for radiation pressure Q_{pr} needs to be computed with one of technique. In this course we use the DDA.

E_o specifies full energy emitted by the Sun (in entire spectrum), it is equal to 3.827×10^{26} Watts.

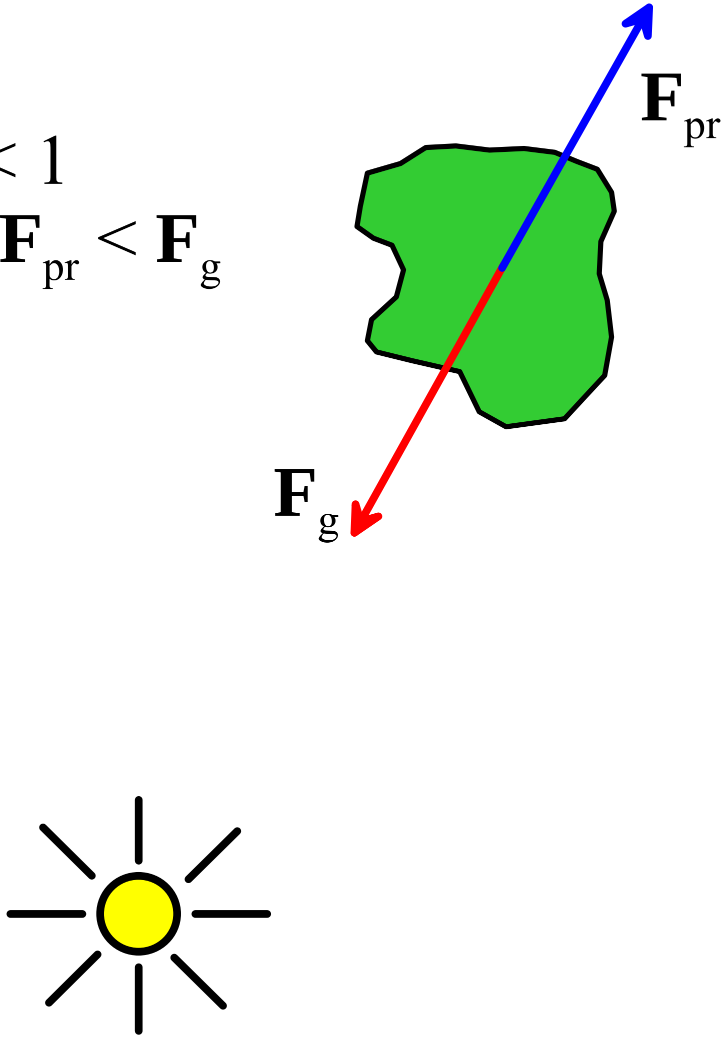
Material density ρ for silicates is about 3.3 g/cm^3, for organic material – 2–2.5 g/cm^3, and for water ice $\leq$ 1 g/cm^3.

The β parameter computed for agglomerated debris particles is shown in the figure below.





The motion of particle in the space is defined by two forces: gravitation and radiation pressure.



if $\beta < 1$
then $\mathbf{F}_{pr} < \mathbf{F}_{g}$

$$m\mathbf{a} = \mathbf{F}_g + \mathbf{F}_{pr}$$

However, if the β parameter is known, one can replace $\mathbf{F}_{pr}$ as follows:

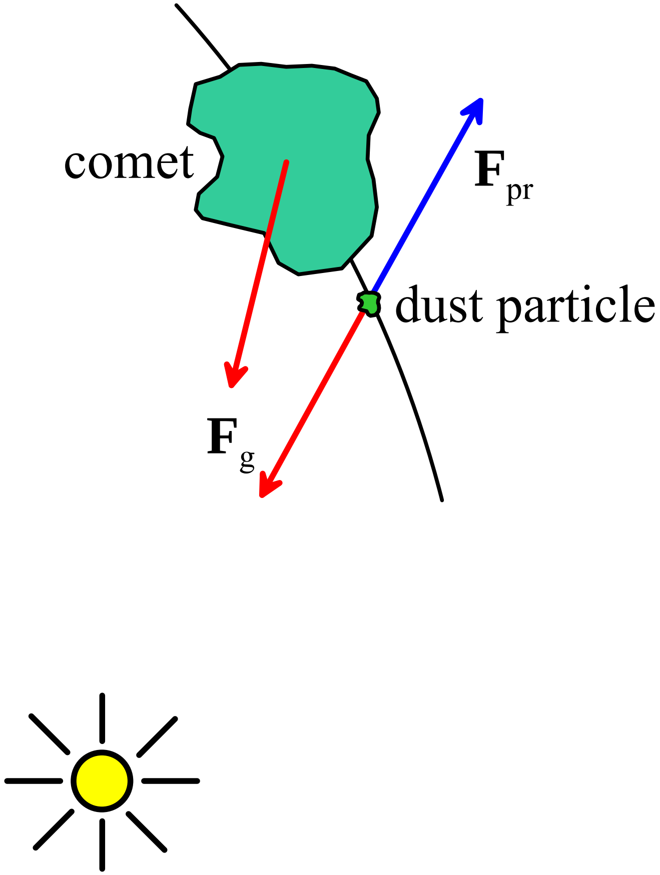
$$m\mathbf{a} = \mathbf{F}_g - \beta\mathbf{F}_g$$

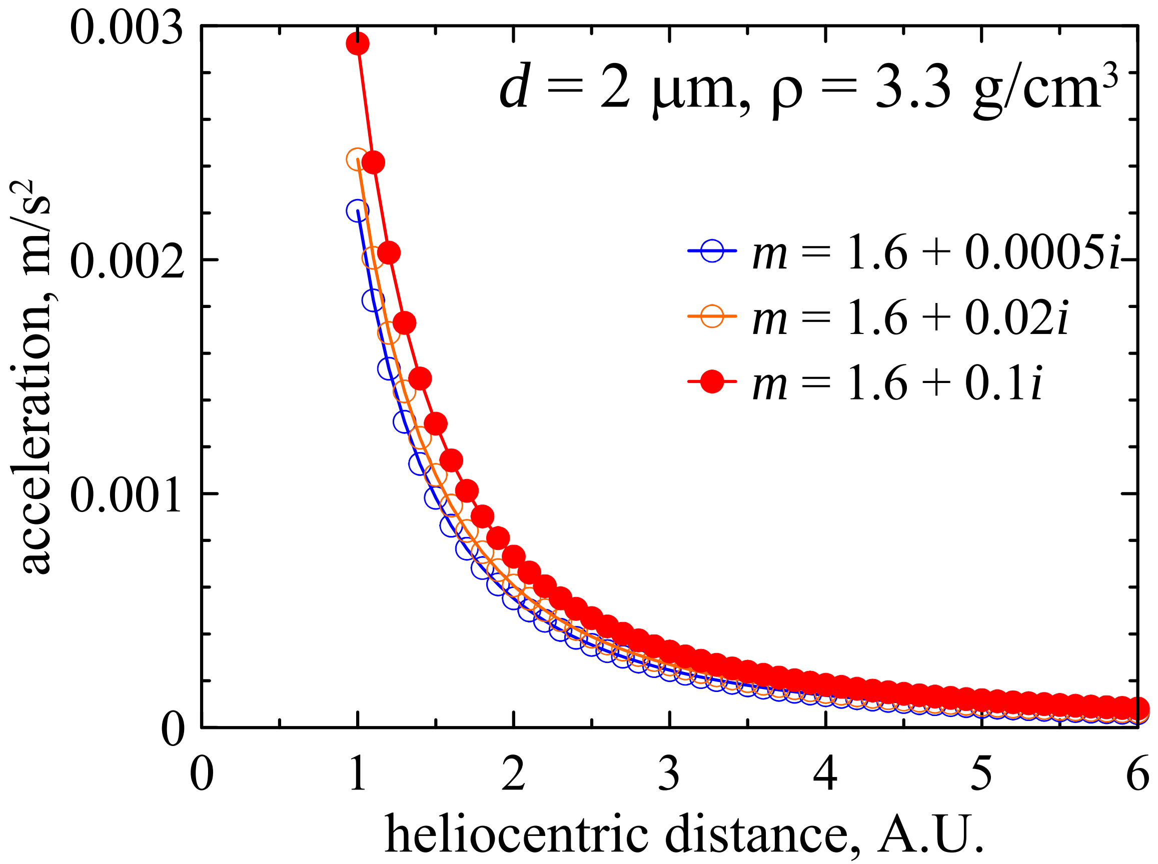
In order to further simplify this expression, one can replace factor $\mu = 1 - \beta$:

$$m\mathbf{a} = \mu\mathbf{F}_g$$

$$\beta = 1 - \mu$$

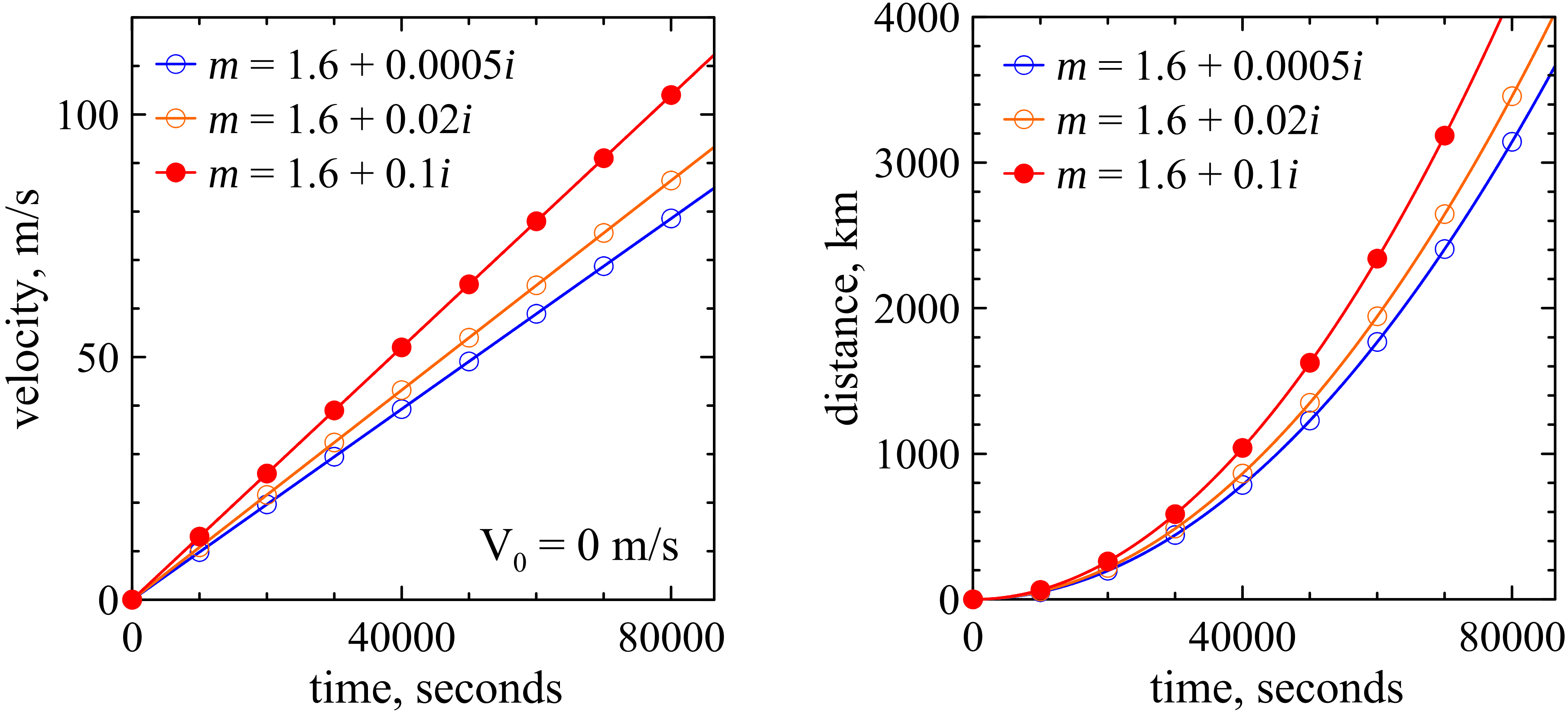
Radiation pressure force acts on motion of dust particles is weakly, but this impact is persistent.





Radiation pressure force acts on motion of dust particles is weakly, but this impact is persistent.

Agglomerated debris particles with $d = 2$ μm, $\rho = 3.3$ g/cm^3 at $R = 1.5$ A.U.

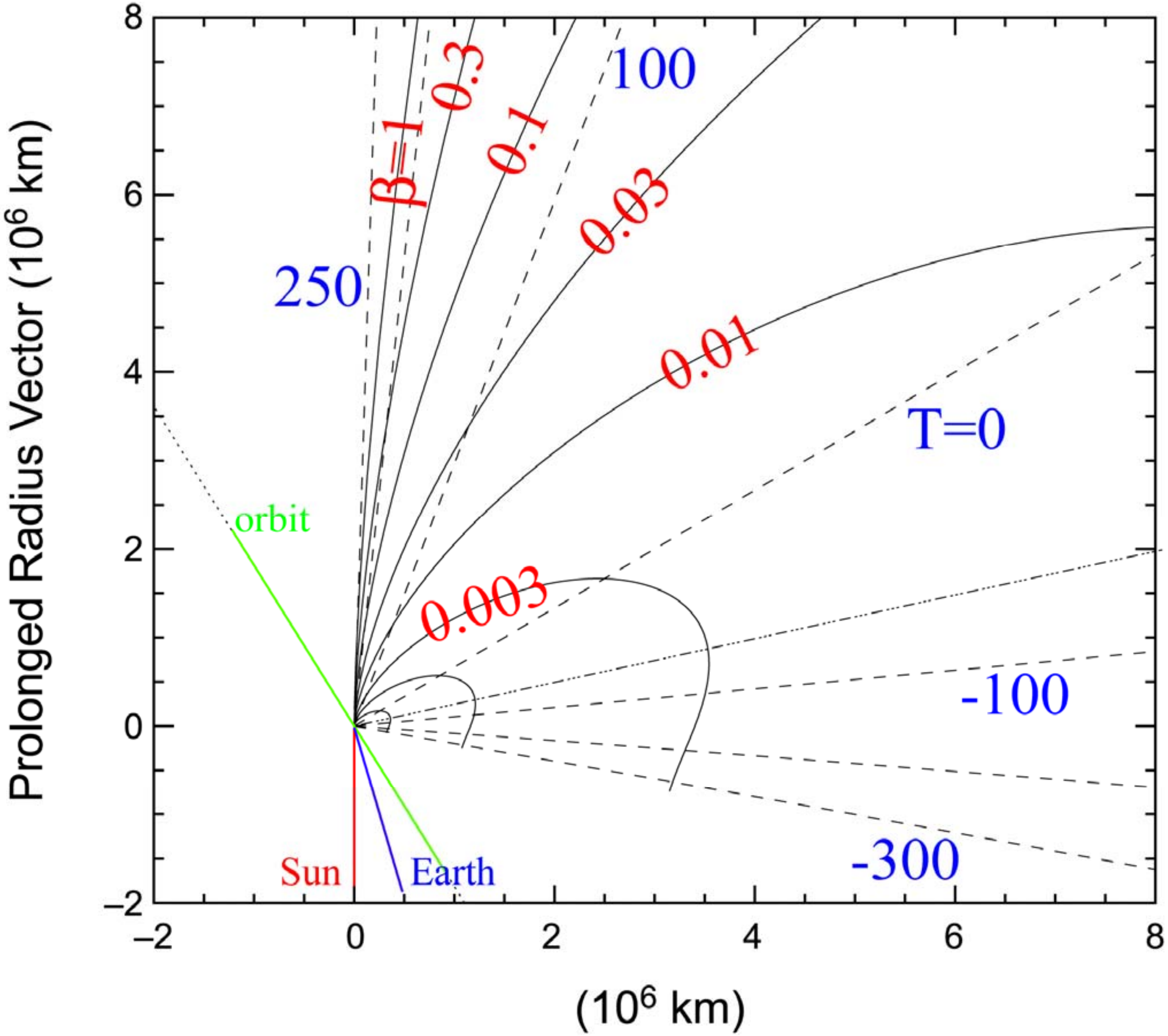


Two important terms in dynamics of cometary dust are synchrones and syndynes.

Synchrone – a line which is formed by dust particles all ejected at the same time and characterized by any μ value will be distributed at a later observation time. Synchrones can be approximated by radial lines, all diverging from the comet nucleus.

Syndyne – a line which is formed by dust particles characterized by the same μ value ejected at any time will be distributed at a later observation time. Syndynes can be approximated by spirals tangent to the prolonged radius vector, the Sun-comet nucleus vector.

Examples of synchrones and syndynes lines computed for C/1995 O1 (Hale-Bopp) on 3 January 1998, V_0 = 0 m/s.

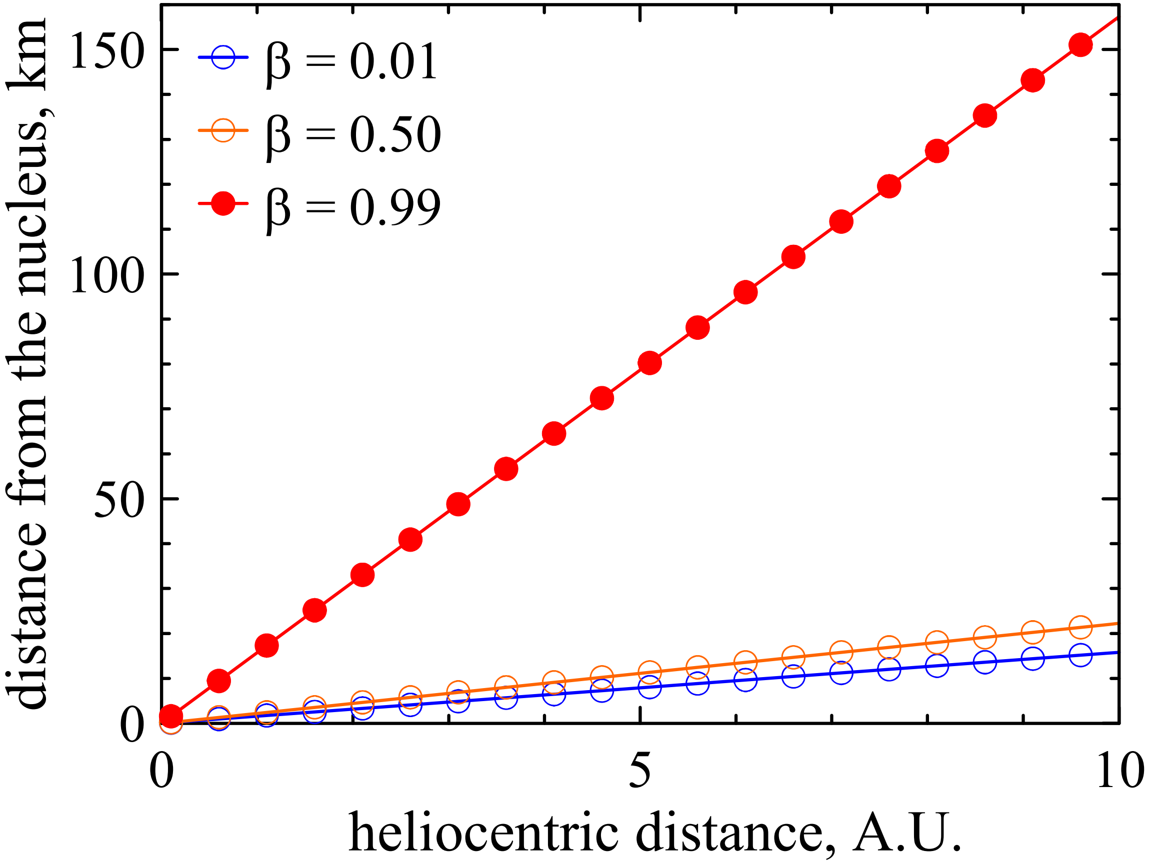


When the ejection velocity is very small, cometary nucleus might have effect on the motion trajectory of dust particles because they remain some time in vicinity of the nucleus.

One can estimate the distance from the nucleus to the point where the gravitation forces from the Sun and the nucleus are equal to each other.

Estimation is done for comet 1P/Halley, m = 2.2×10^{14} kg.

Escape velocity is of 2.3 m/s

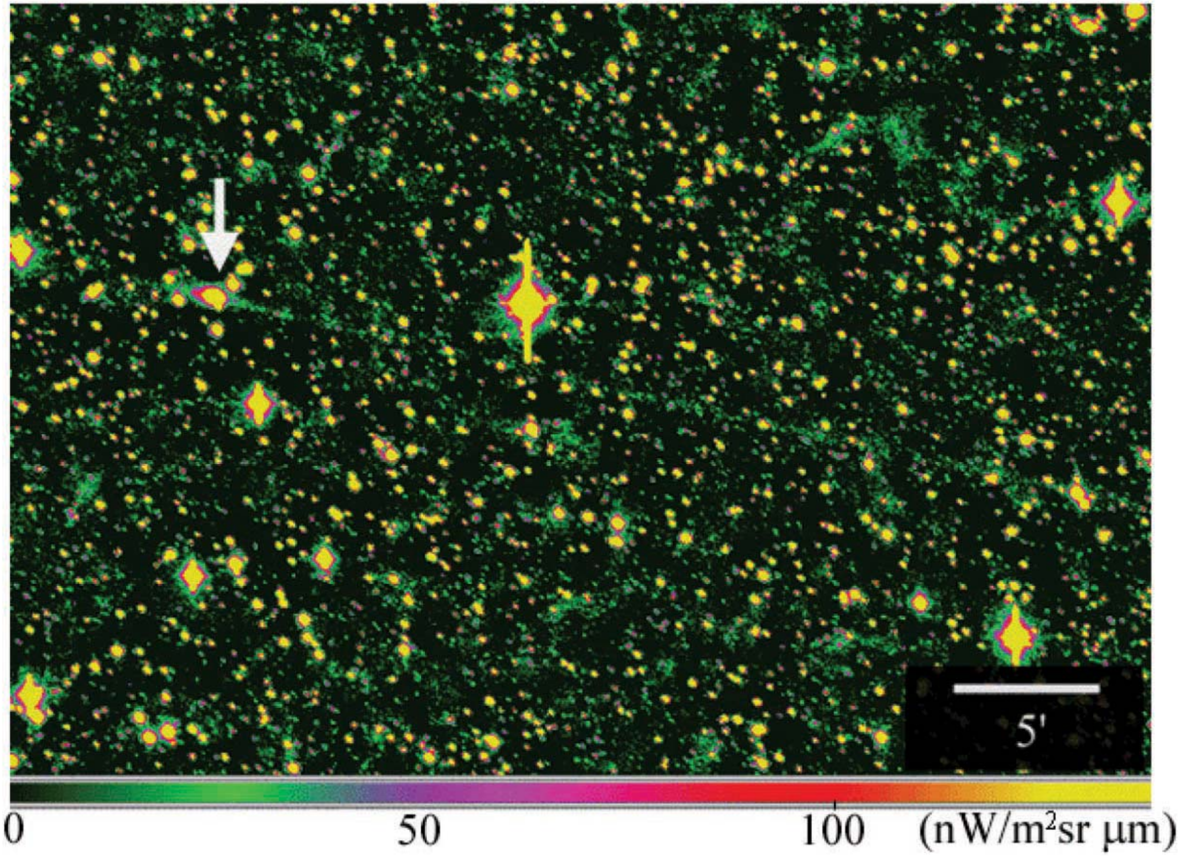


Dust trails is a stream of large particles (~1 mm and larger) which have been ejected at low velocity. Dust trail particles simply follow the nucleus in its orbiting motion. Obviously, their motion is not disturbed by radiation pressure force.

As of a day, dust trail structures along the orbits of nine short period comets (Encke, Pons-Winnecke, Tempel 1, Tempel 2, Kopff, Schwassmann-Wachmann 1, Gunn, and Churyumov-Gerasimenko, Wild 2) were successfully detected.

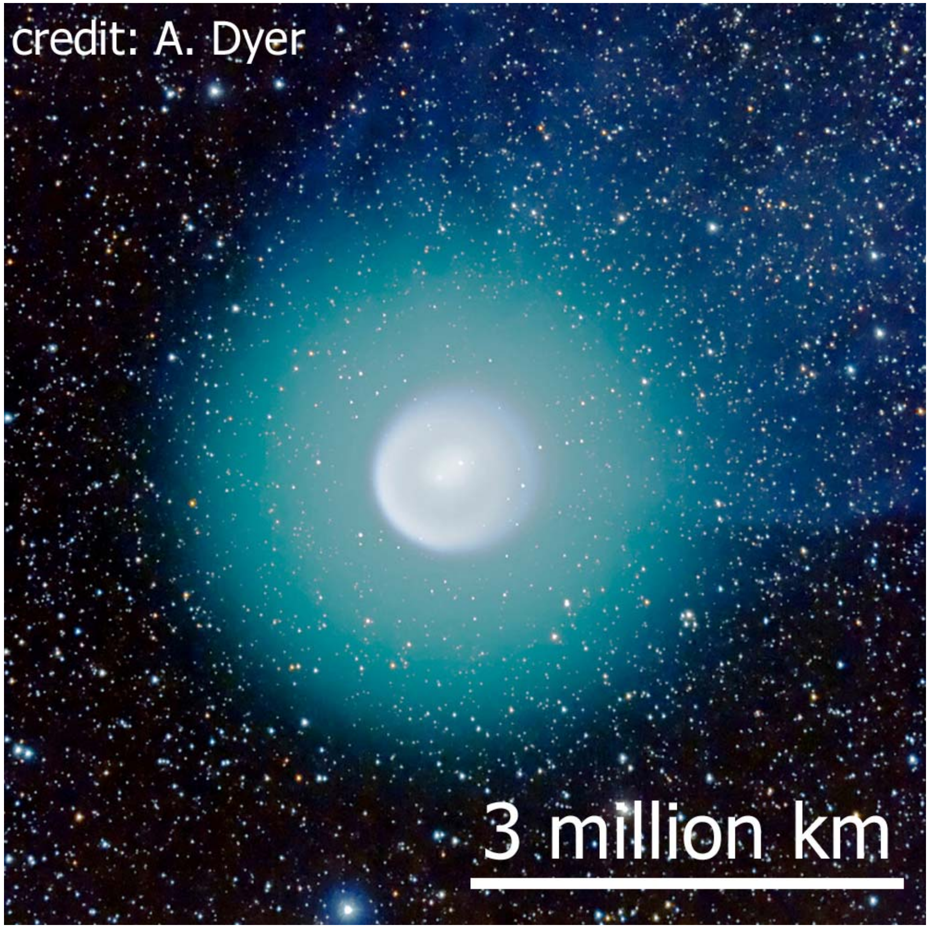
Dust trails are quite challenging objects for study. Only very large ground-based telescopes could be used for their observations. However, the dust trails are quite dangerous for space mission. For instance, when approaching to the comet Wild 2, Stardust spent about 0.8 days in the dust trail of this comet.

Comet dust trails are responsible for meteor outbursts and storms.



Dust trail image of the comet 81P/Wild 2 observed 2003, February 3. The coma is located at the position indicated by the arrow. The classical dust tail composed of small grains spreads toward the upper left, and the dust trail extends toward the lower right.

In the case of outburst activity the particles are immediately accelerated to very large velocities (~500 m/s). Therefore, the impact of radiation pressure could be not important at early stages of coma evolution.



Comet 17P/Holmes after explosion in 2007

Then, initial conditions of the outburst play an extremely important role.

For instance, if particles are accelerated by gas drag produced by an explosive event, the velocity of a particle with size a should depend on a^{-1}.

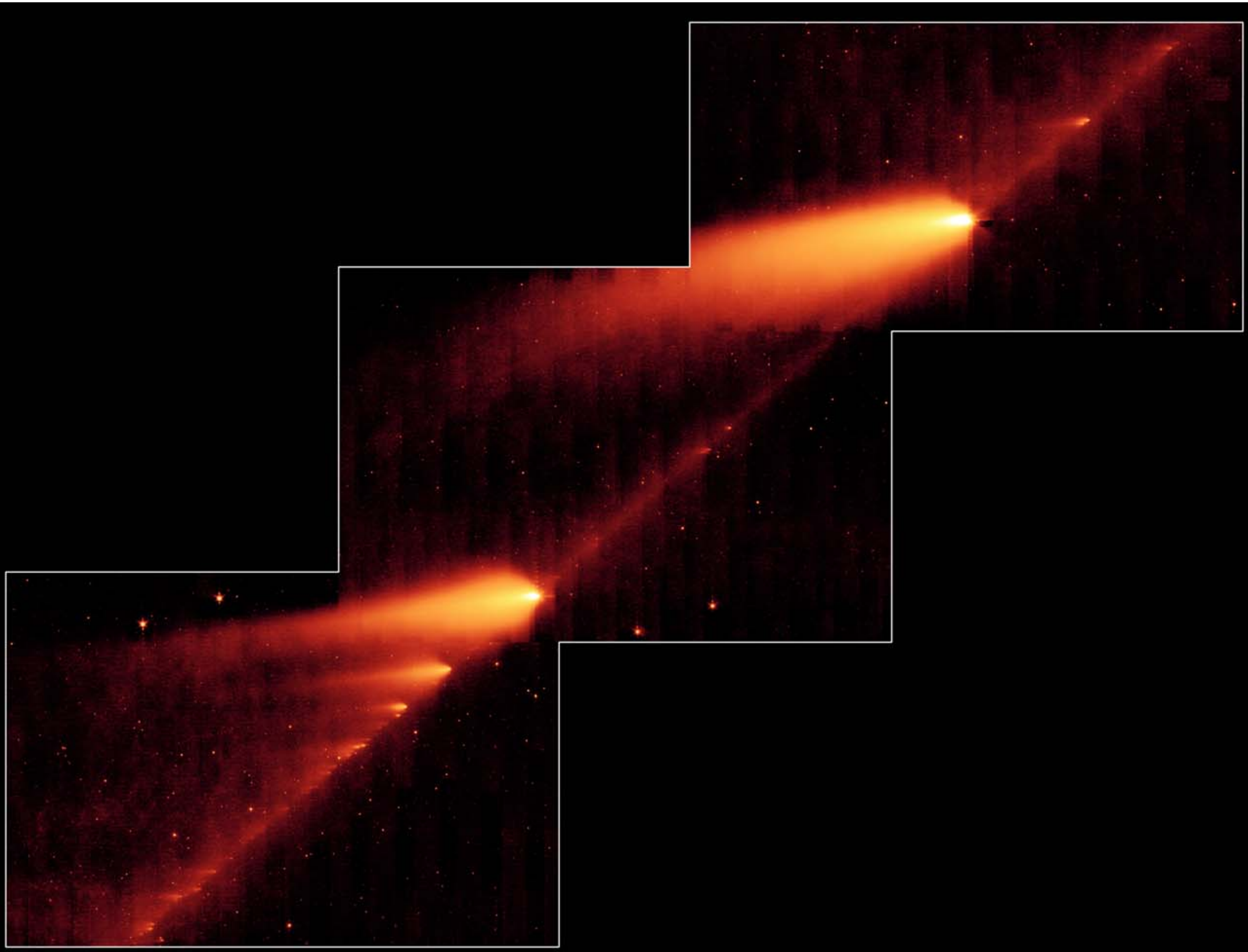
Split comets appear as multiple comets with two or more components arising from the same parent and initially moving in very similar orbits. Each sub-comet reveals own coma and tail.

Over the past 150 years: at least 42 split comets producing several hundred (>400) fragments in more than 100 splitting events. Two of the split comets have disappeared completely; another one was destroyed during its impact on Jupiter.

Two types of split comets are known from observations:

Type A: The split comet has a few (usually two) components. The primary fragment is the one that remains “permanent”; the secondary can be minor (~10–100 m), short-lived, or persistent for a longer time (years to centuries).

Type B: The split comet has many (more than 10) components that could arise from a single or a short sequence of fragmentation events. The fragments are short-lived (possibly of small size), and no primary component can be identified.

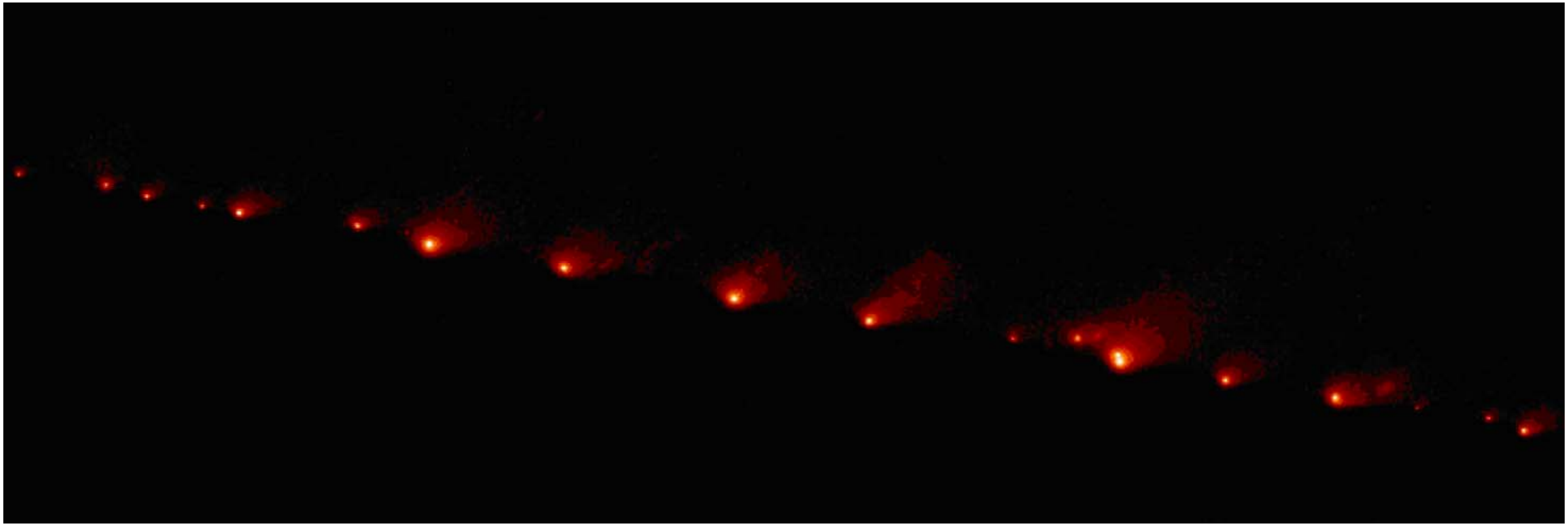


Comet 73P/Schwassmann-Wachmann 3

Spitzer Space Telescope • MIPS

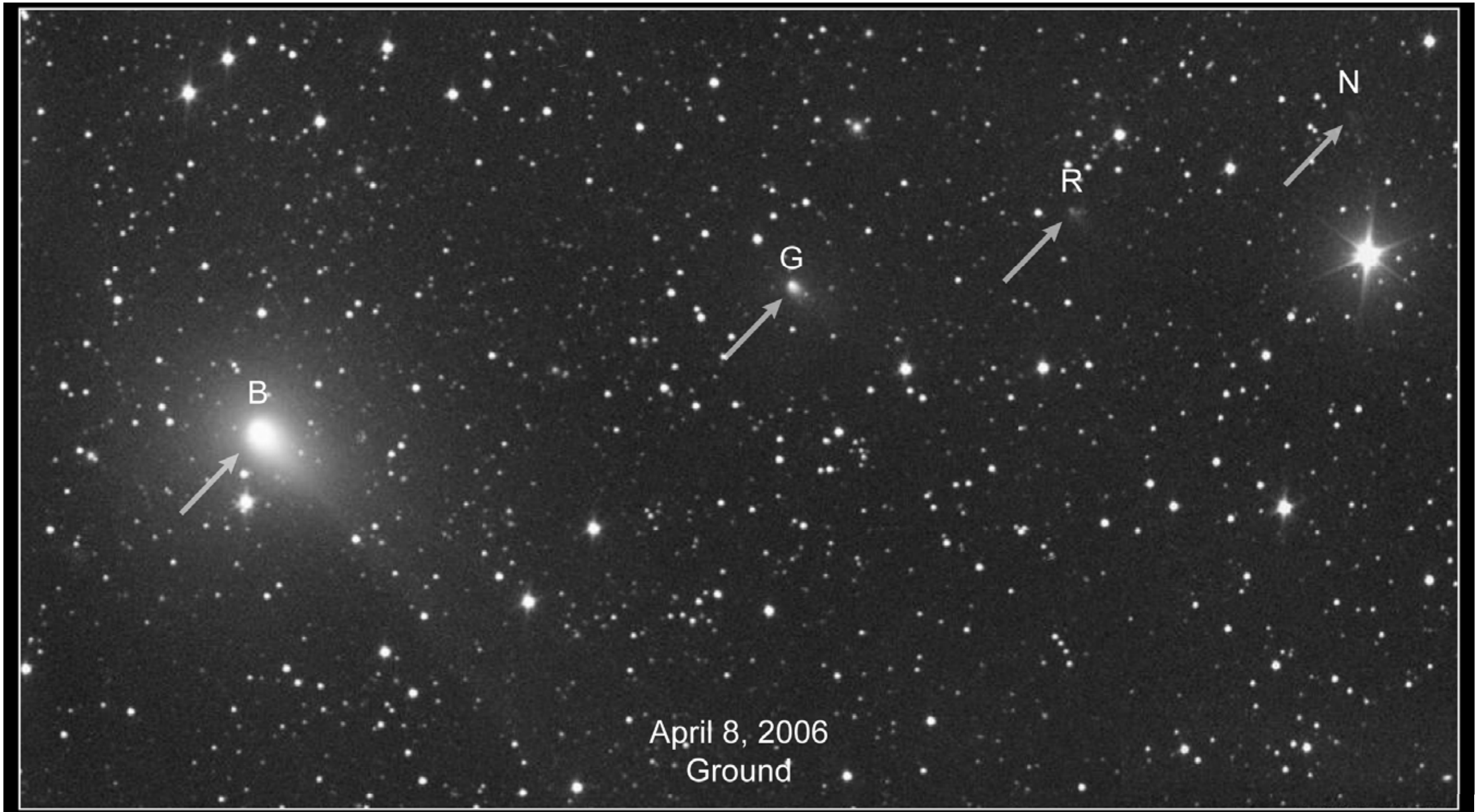
NASA / JPL-Caltech / W. Reach (SSC/Caltech)

ssc2006-13a



Split comet D/1993 F2 (Shoemaker-Levy) on 17 May 1994.

The fragments are denoted with the designation and name of the parent comet [given by the International Astronomical Union (IAU)], followed by upper-case letters beginning with the letter A for the component that passes perihelion first. This fragment is supposed to be the primary component. However, cases of misidentified primaries exist (for instance, 73P/Schwassmann-Wachmann 3A and C, the latter being the primary).



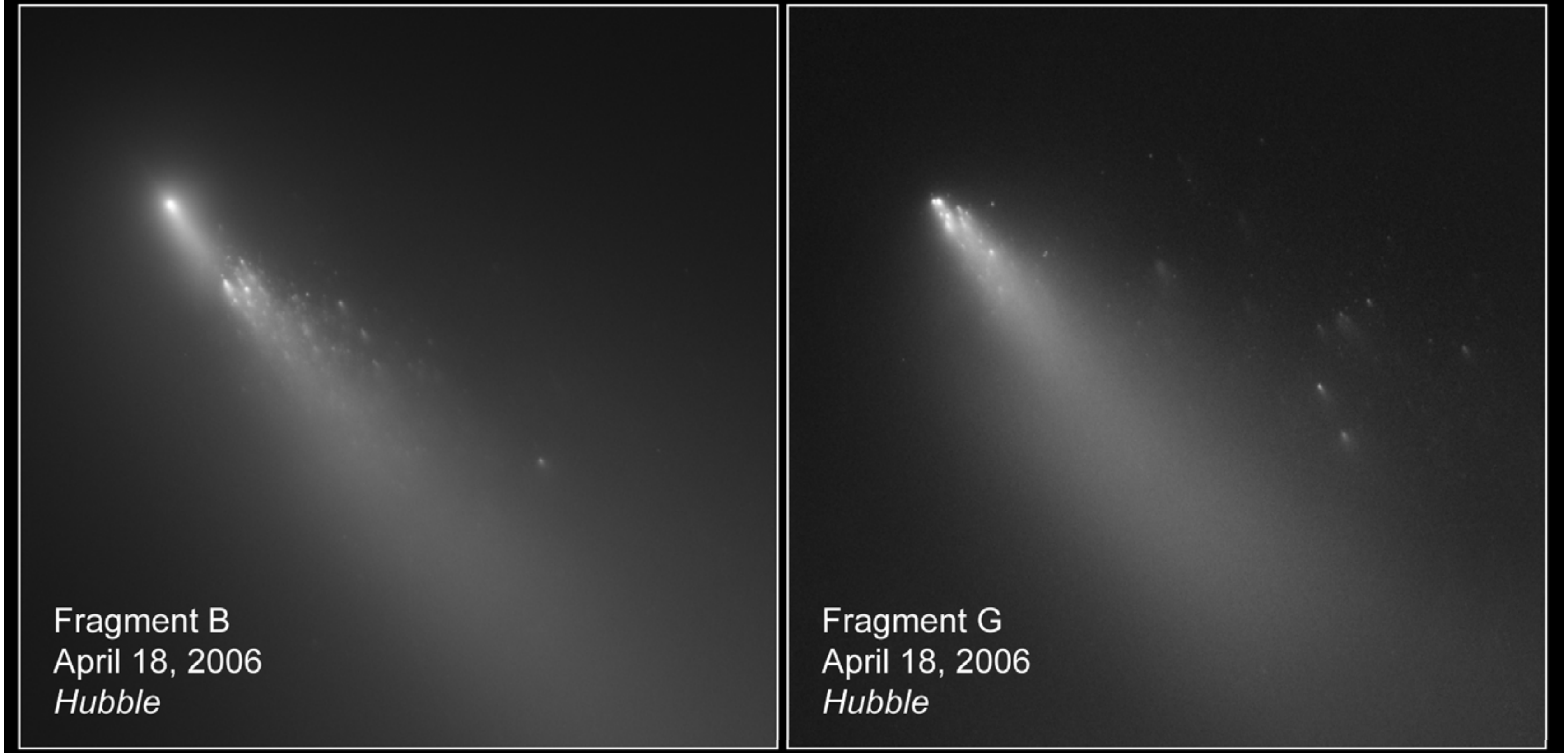
April 8, 2006
Ground

Comet 73P/Schwassman-Wachmann 3

Hubble Space Telescope • ACS/WFC

NASA, ESA, H. Weaver (JHU/APL), M. Jäger and G. Rhemann

STScI-PRC06-18

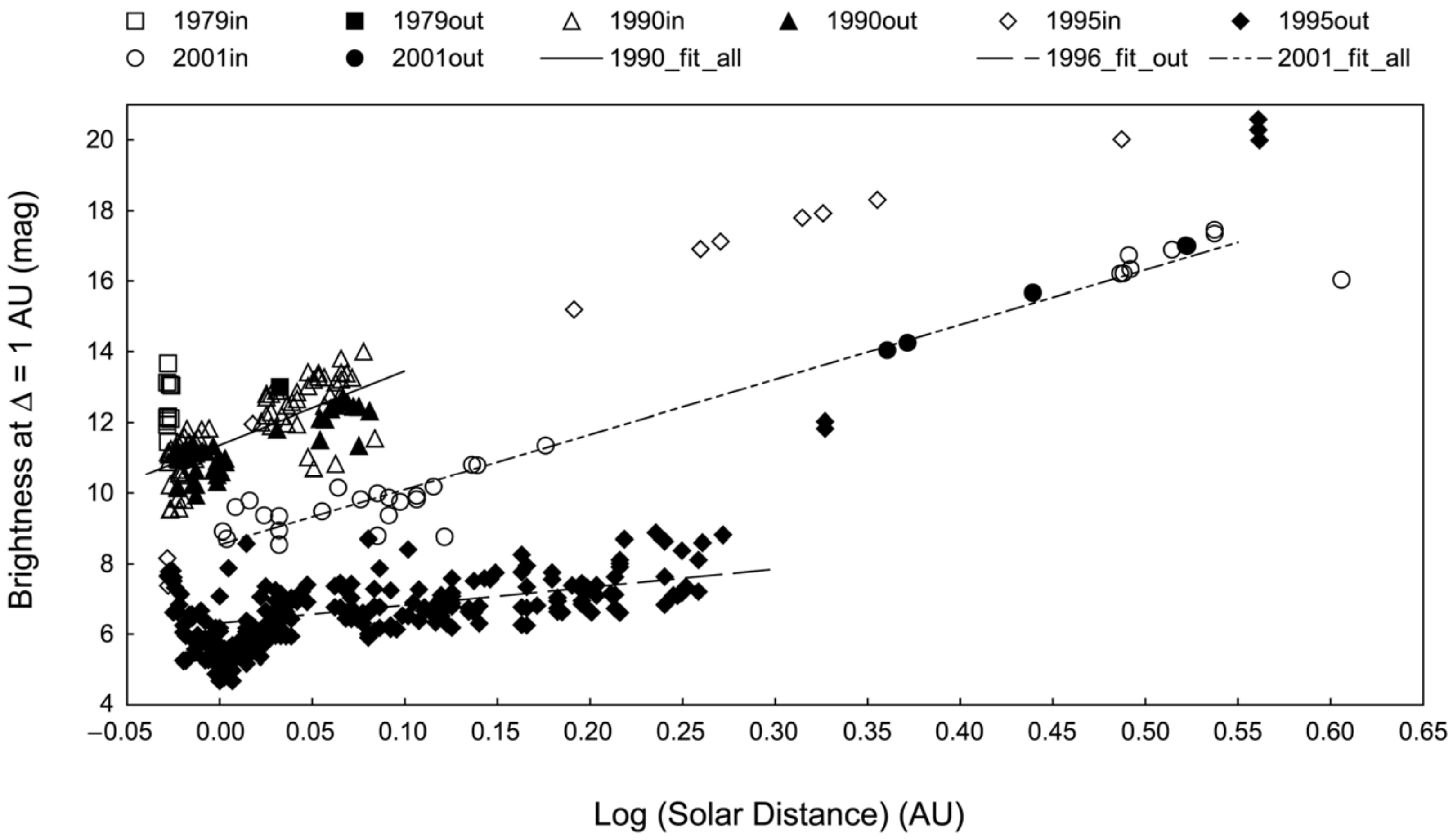


Comet 73P/Schwassman-Wachmann 3

Hubble Space Telescope • ACS/WFC

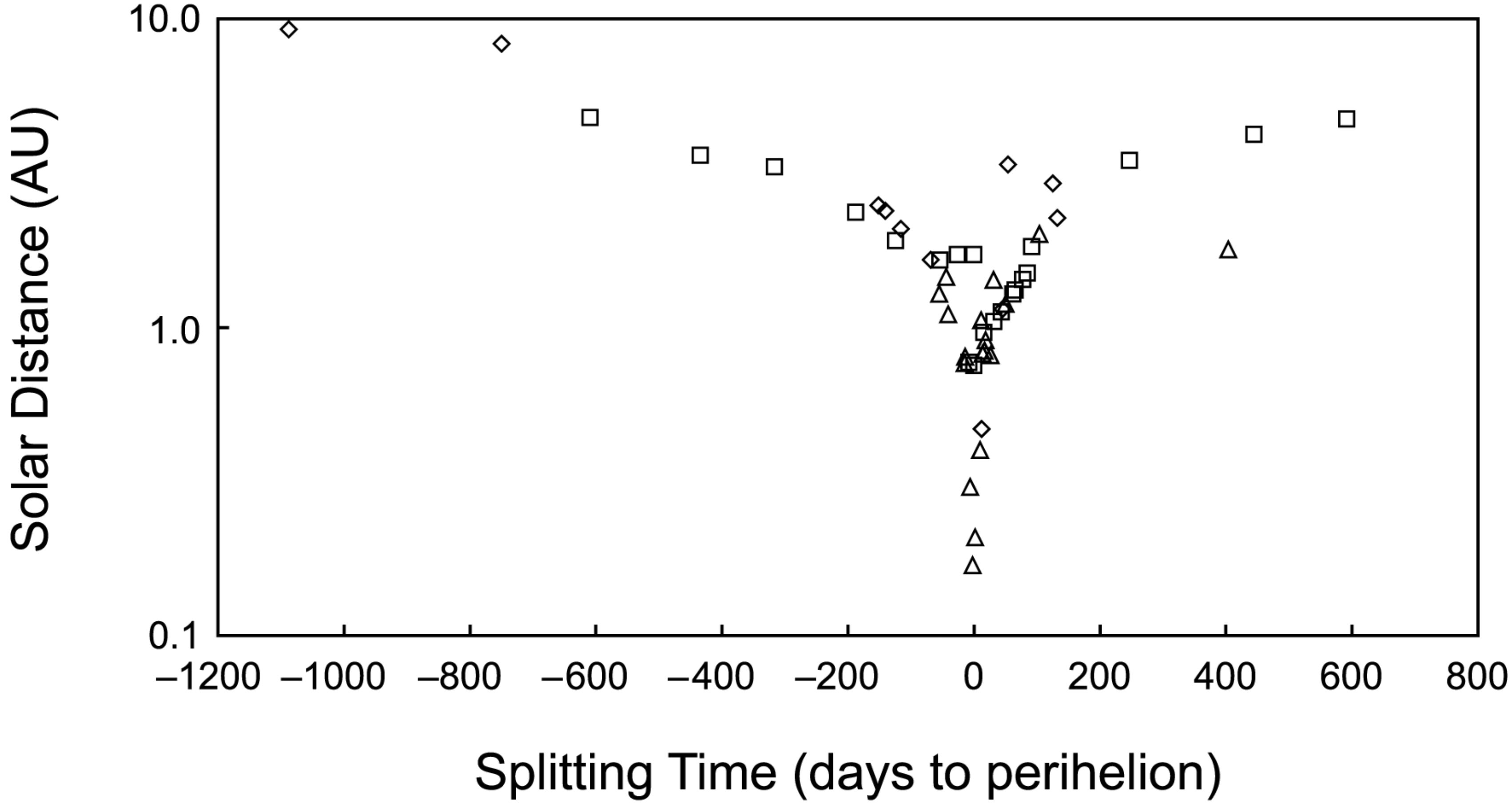
NASA, ESA, H. Weaver (JHU/APL), M. Jäger and G. Rhemann STScI-PRC06-18

Long term variations in brightness of comet 73P/Schwassmann-Wachmann caused by its splitting. Disintegration began in 1995 shortly after perihelion passage; brightening for 7–8 magnitudes.



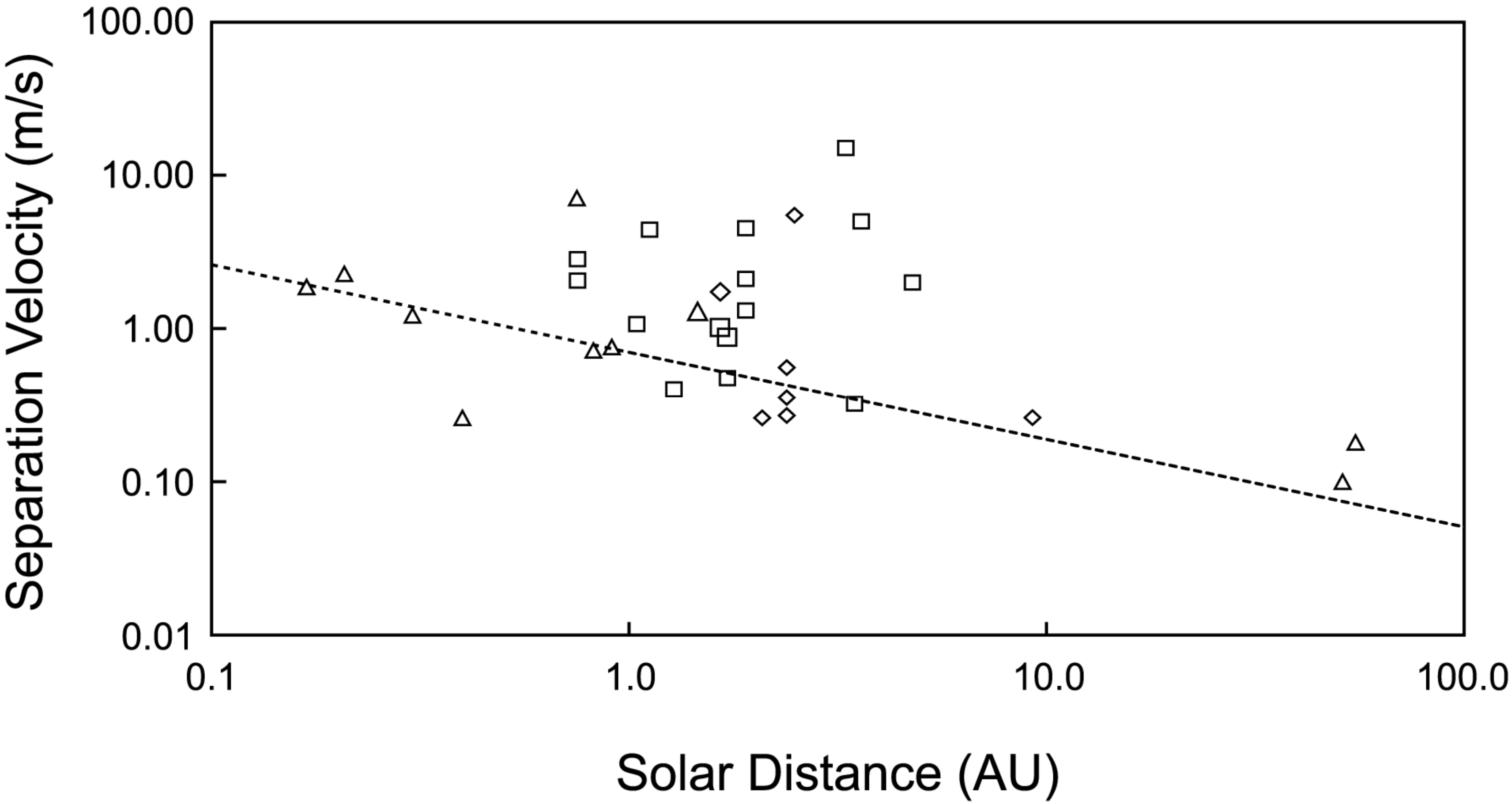
Open symbols before and filled after perihelion passage.

Some details on splitting of comets. Splitting events versus heliocentric distance and time before and after perihilion.



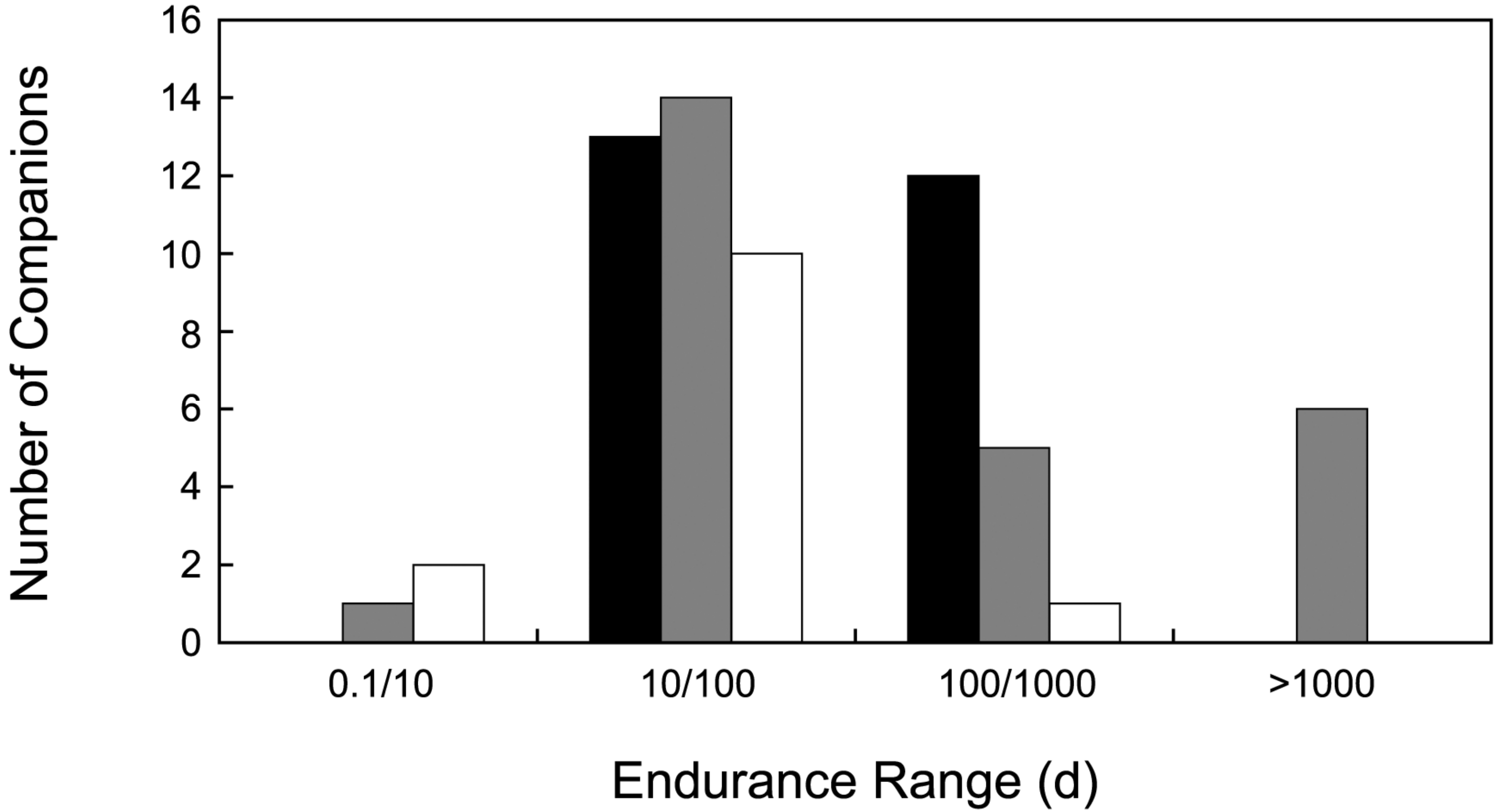
Nucleus splitting can occur at large heliocentric distances (certainly beyond 50 AU) for long-period and new comets and all along the orbit for short-period comets.

Some details on splitting of comets. Splitting velocity versus heliocentric distance.



The relative speed of the fragments shortly after the fragmentation event amounts from 0.1 to 15 m/s with the majority between 0.3 and 4 m/s.

Some details on splitting of comets. Histogram distribution of life-time of companions.



Colors used in the plot are as follows: short-period comets – black; long-period comets – gray; dynamically new comets – white.

References:

(1) Belton, M. J. S., (2010): Icarus, **210**, 881–897.

(2) Yamamoto, T., Nakagawa, N., Fukui, Y., (1983): Astron. Astrophys., **122**, 171–176.

(3) Ishiguro, M., Kwon, S. M., Sarugaku, Y., Hasegawa, S., Usui, F., Nishiura, S., Nakada, Y., Yano, H., (2003): Astrophys. J., **589**, L101–L104.

(4) Fulle, M., (2004): in Comets II, M. C. Festou, H. U. Keller, and H. A. Weaver (eds.), 565–575.

(5) Boehnhardt, H., (2004): in Comets II, M. C. Festou, H. U. Keller, and H. A. Weaver (eds.), 301–316.