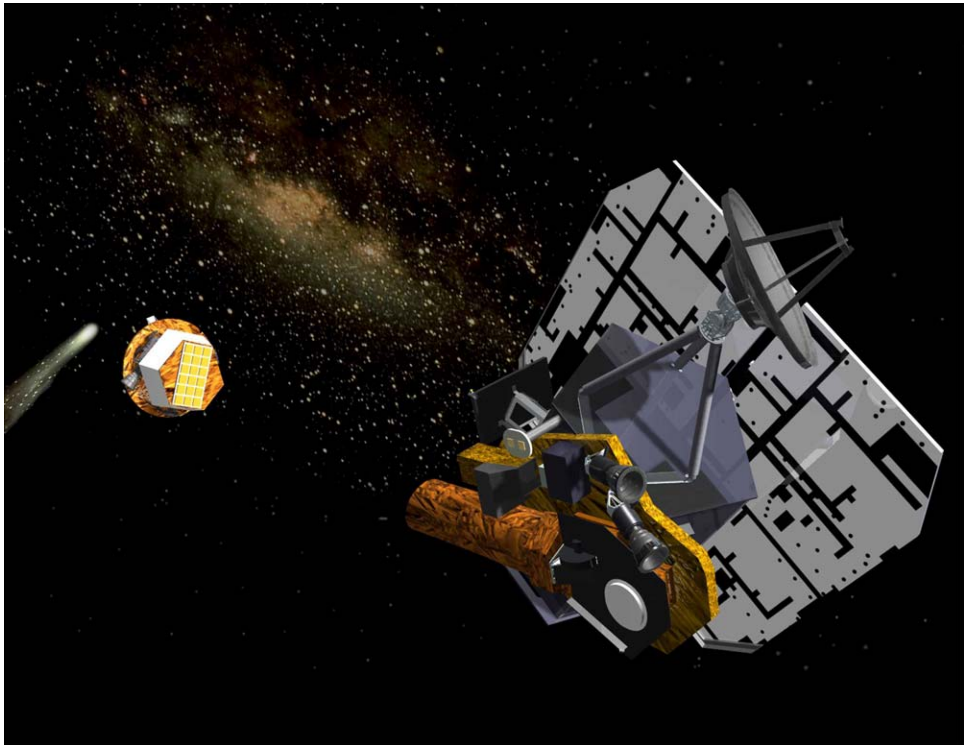
In situ studies of comets (3)

Studies carried out in vicinity of comets with help of spacecraft play an extremely important role in cometary physics.

The main advance of such studies is that the number of assumptions on cometary particles is substantially reduced in comparison with ground based observations.

So far, only six comets have been visited by spacecrafts:

21P/Giacobini-Zinner	1985	International Cometary Explorer (ICE);
1P/Halley	1986	VeGa-1, 2; Giotto; ICE; Suisei; Sakigake;
26P/Grigg-Skjellerup	1992	Giotto
19P/Borrelly	2001	Deep Space 1
81P/Wild 2	2004	Stardust
9P/Tempel 1	2005	Deep Impact



(7) Deep Impact

Spacecraft for excavation the material in comet 9P/Tempel 1.

Deep Impact (the flyby probe) flew near the nucleus (at distance of 500 km) with velocity of ~10.3 km/s.

Both the closest approach (the flyby probe) and crash (impactor) on July 4, 2005.

On July 4, 2005, heliocentric distance of the comet was 1.51 AU.

Deep Impact consists of two main sections, the 370-kg copper-core "Smart Impactor" that impacted the comet, and the "Flyby" section, which imaged the comet from a safe distance during the encounter.

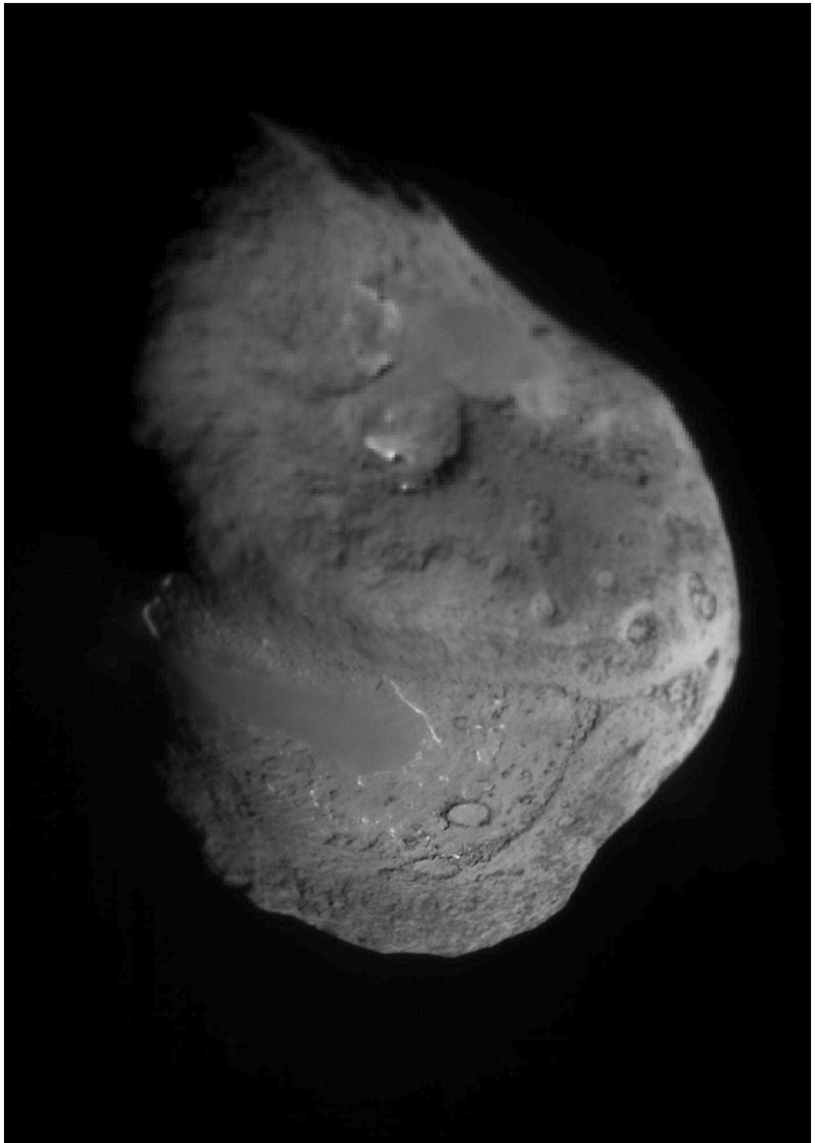
The flyby section was equipped with Medium Resolution Imager (with a filter wheel), High Resolution Imager (with a filter wheel), Spectral Imaging Module (1.05–4.8 μm).

The impactor was equipped with Medium Resolution Imager (without filters). The final image was taken 3.7 seconds before impact.

The split of the impactor and flyby section happenedon June 29.

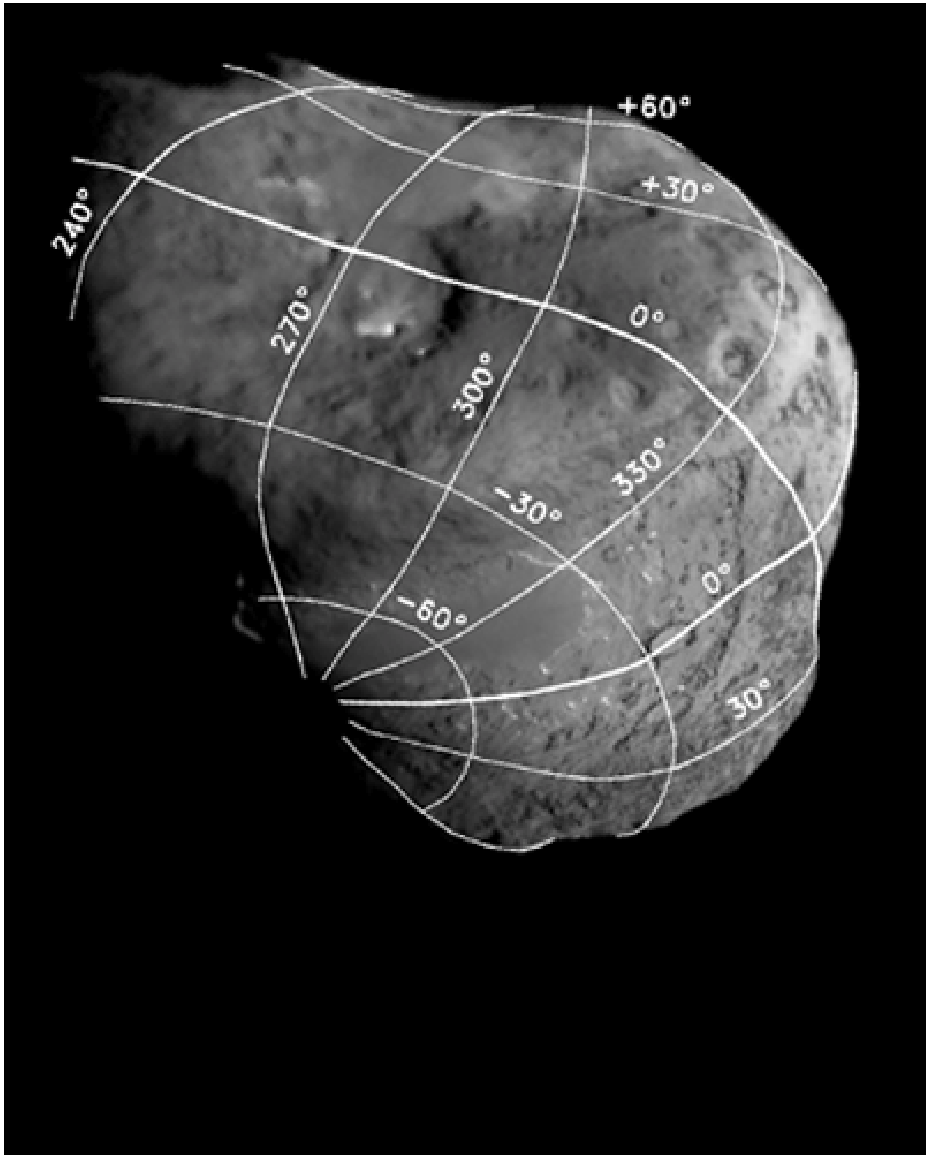
Kinetic energy was equivalent of 4.7 tons of trinitrotoluene.

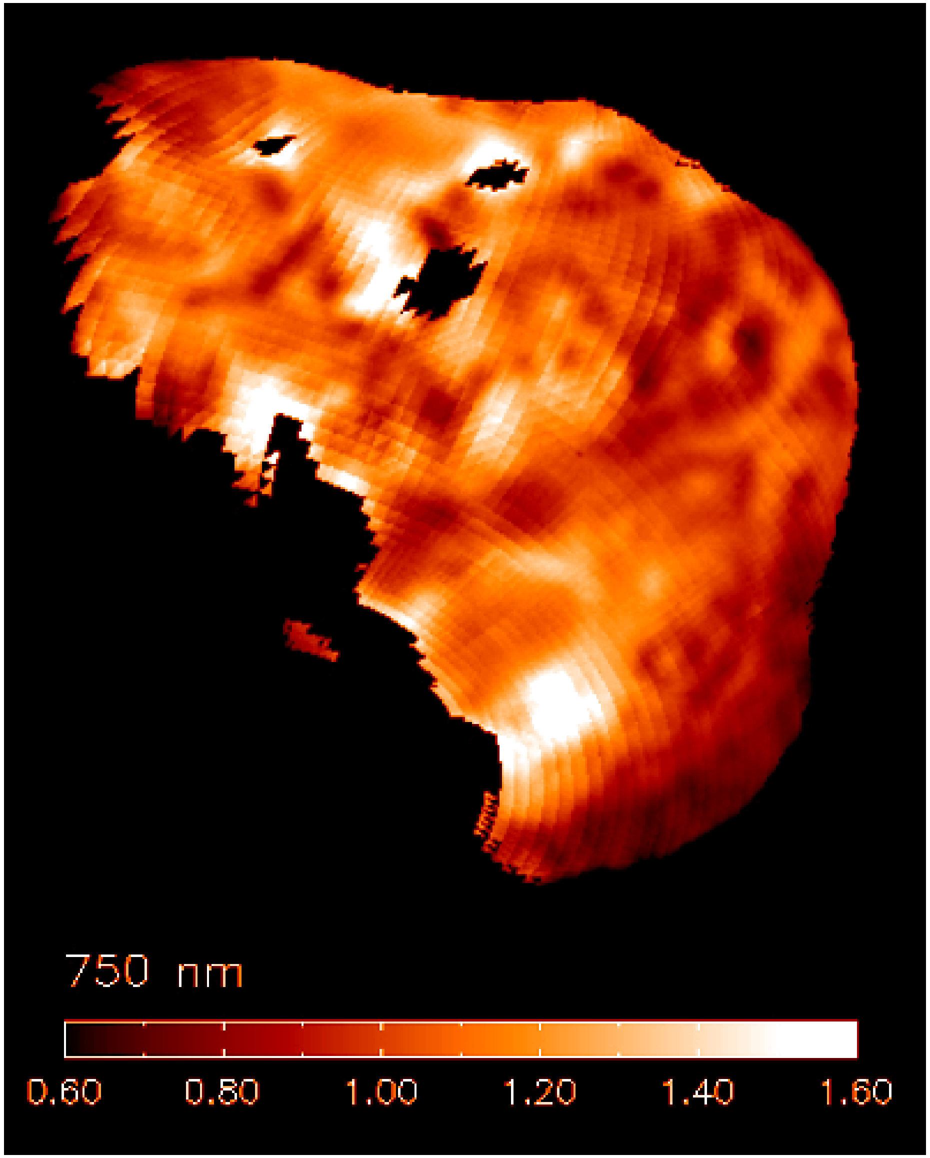
Nucleus of comet 9P/Tempel 1.



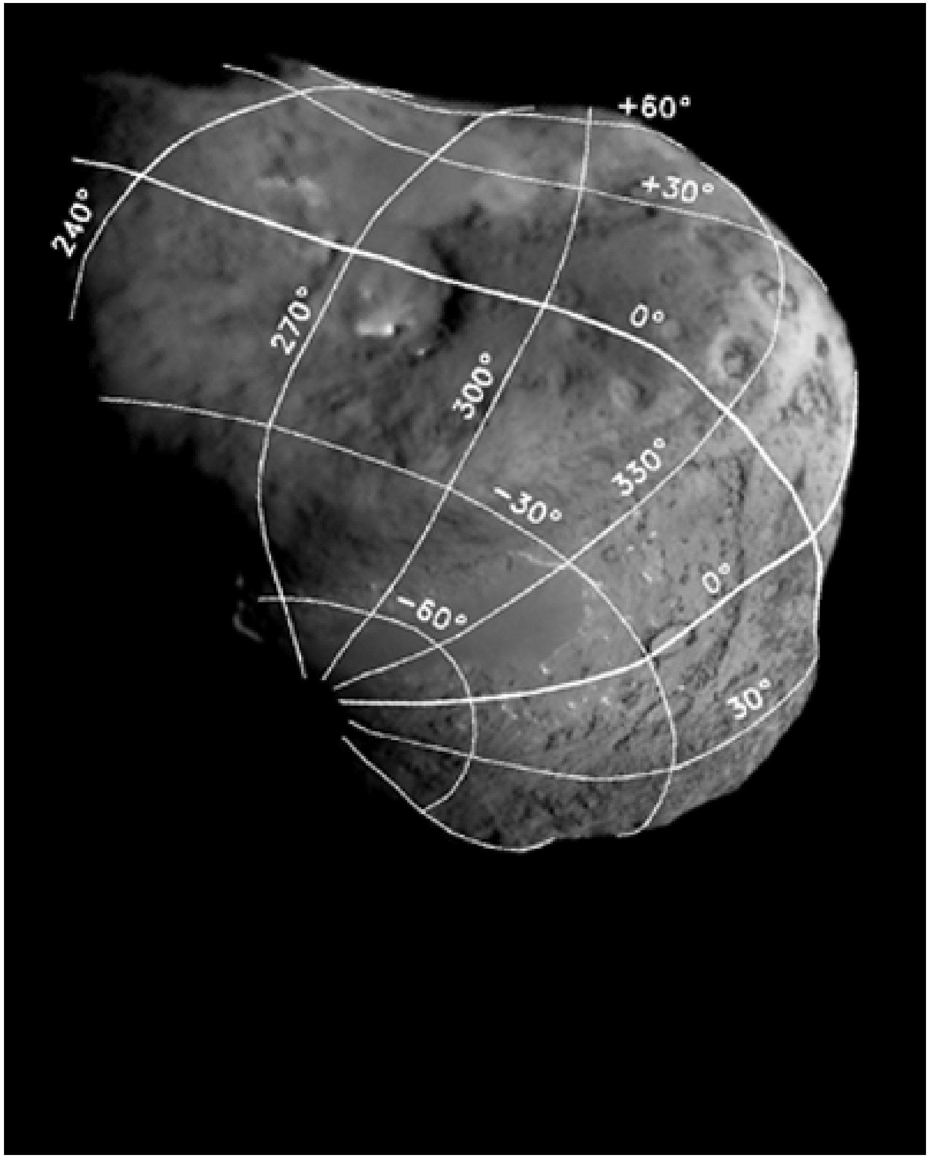
Size:	7.6 $\times$ 4.9 km
Density:	~0.6 g/sm^3
Rotational Period:	40.7 hours
Albedo:	~4%

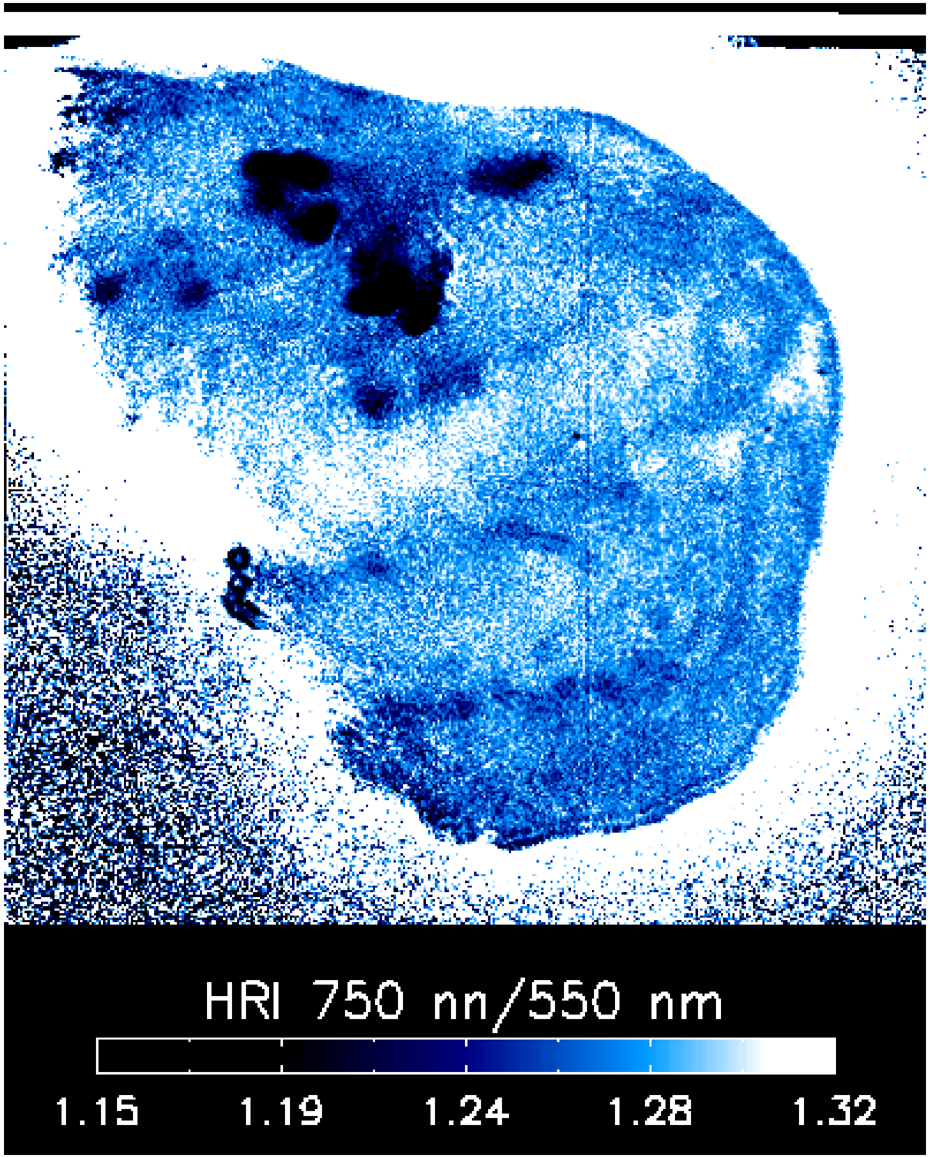
Variations of albedo through surface of the nucleus (1.00 = 4%)



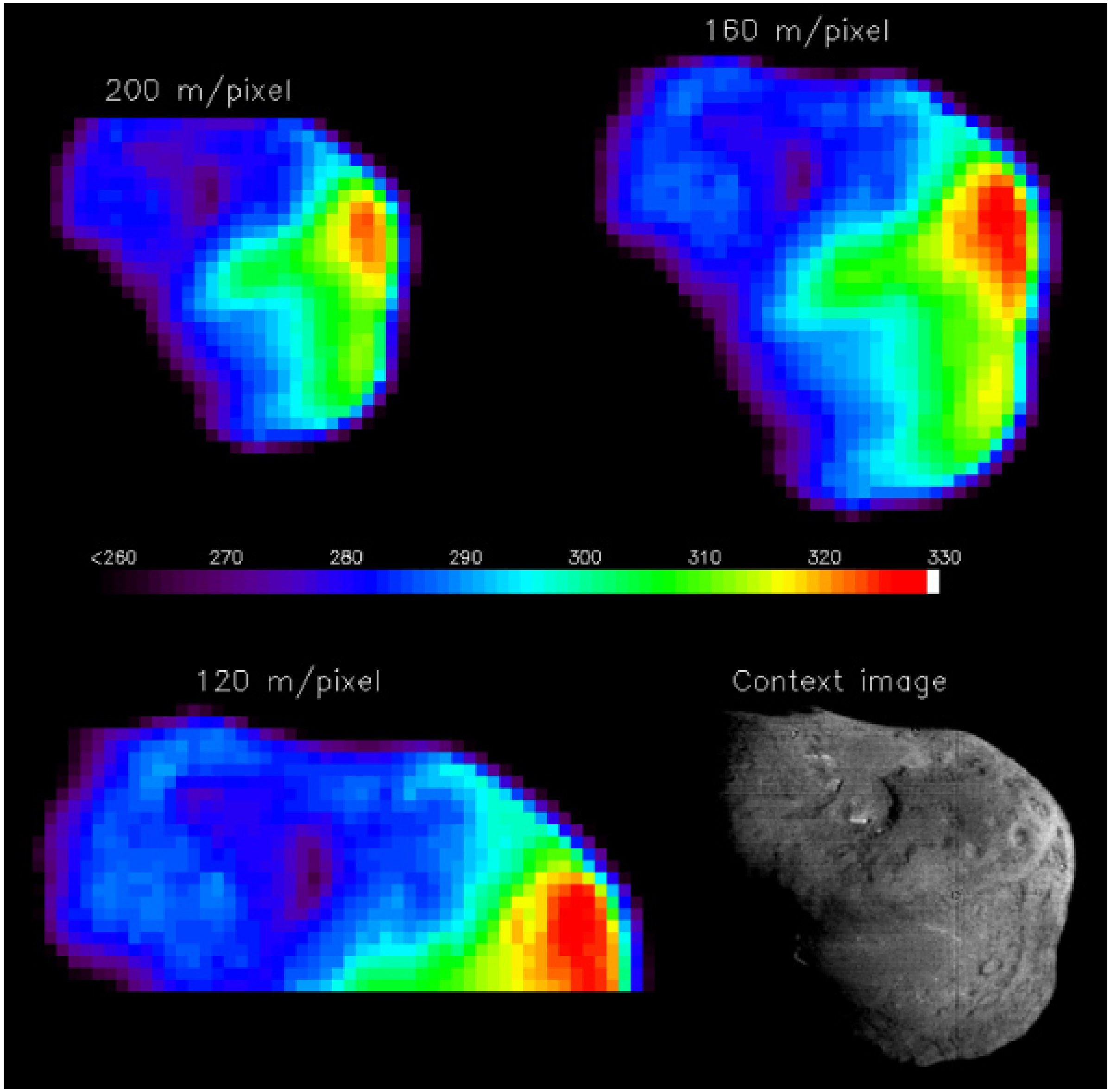


Variations of the color index I_{750} / I_{550}

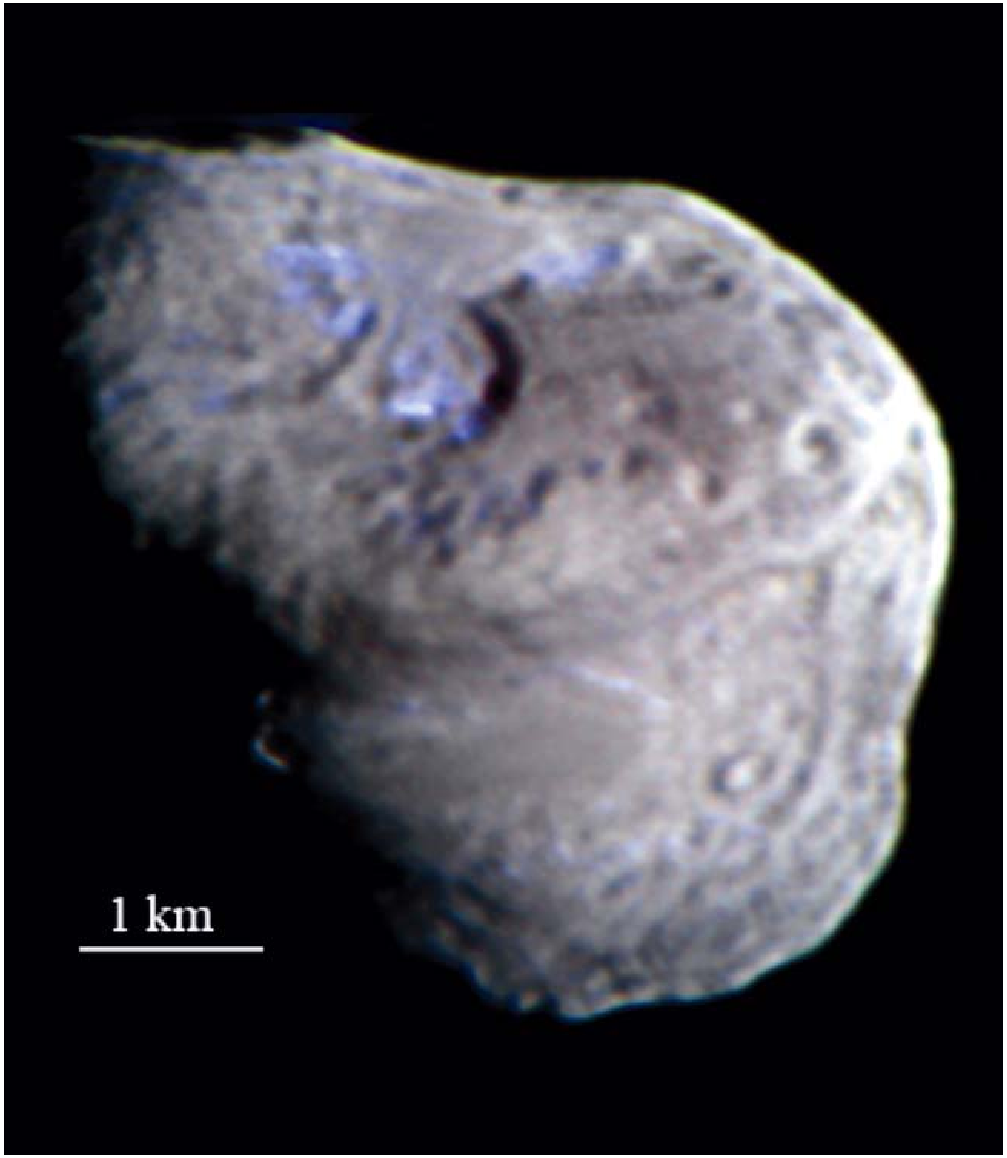




Temperature of surface of comet 9P/Tempel 1



Water ice on surface of comet 9P/Tempel 1 (blue in appearance)

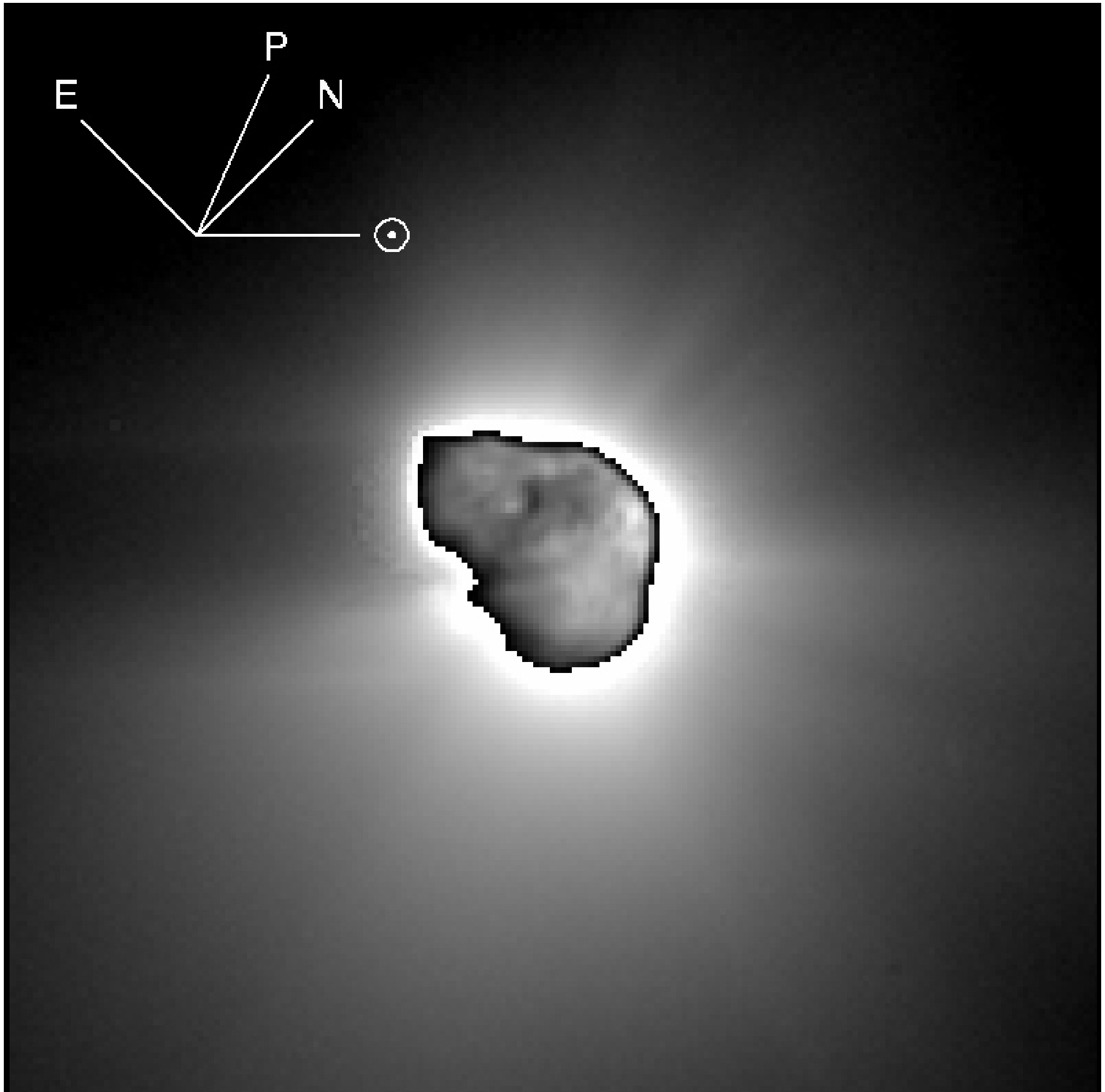


Using images of the nucleus obtained at wavelengths of 1.5 and 2.0 μm (the water ice absorption bands), one can locate the ice-rich area.

The ice-rich areas take a small fraction of the surface, only 0.5%.

Ice-rich areas are simultaneously the coldest ones.

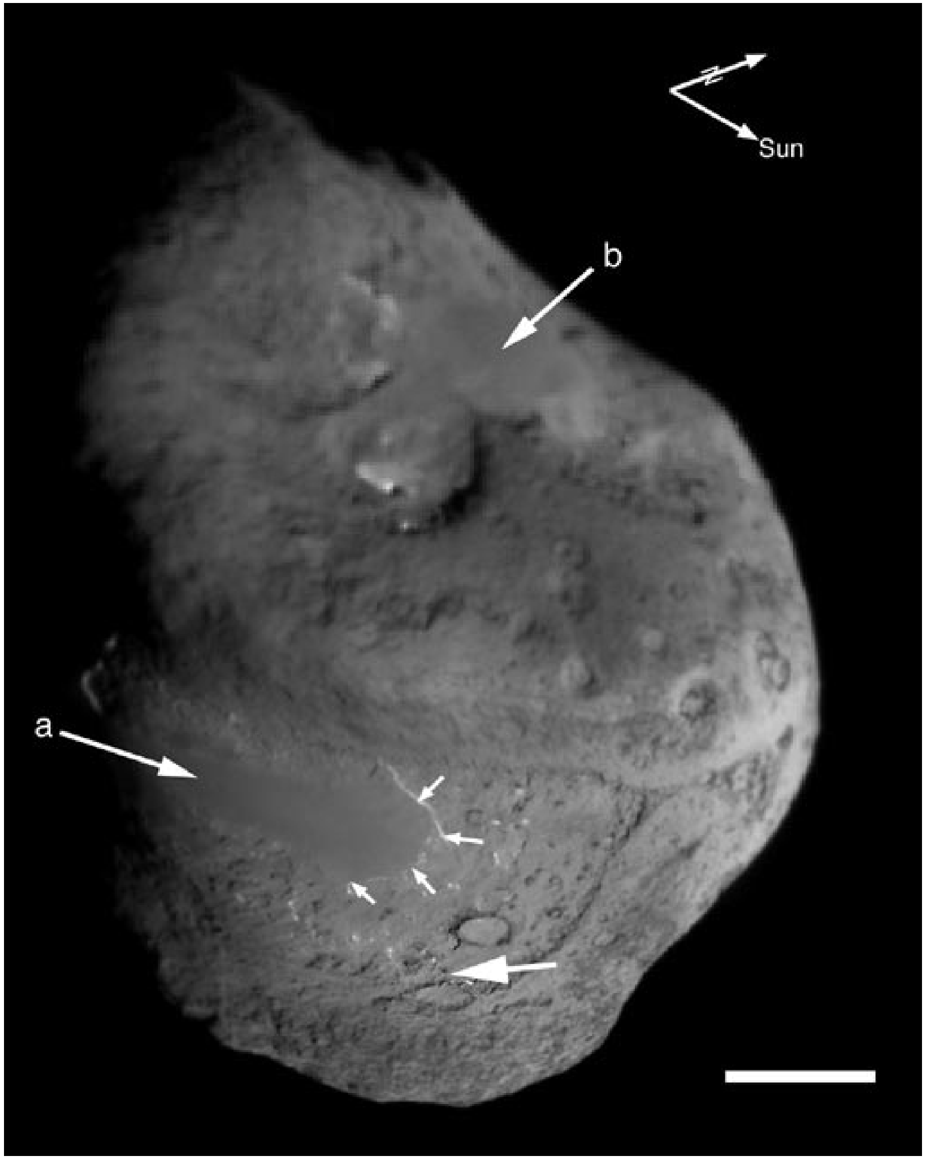
Pre-impact jet activity of comet 9P/Tempel 1



Comet 9P/Tempel 1 revealed 9 jets.

It seems that one of them was originated from night side of the nucleus.

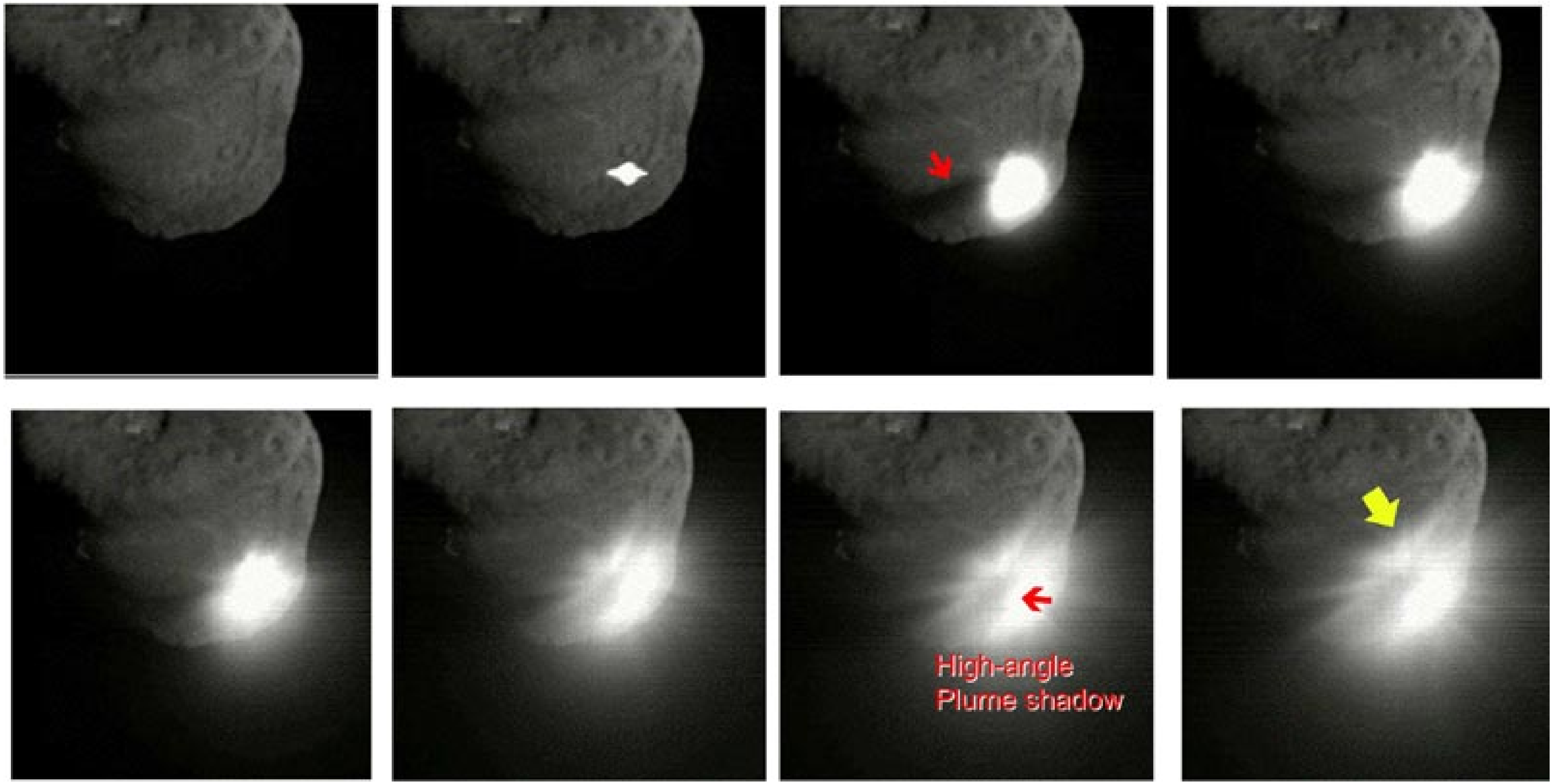
Morphology of the surface of comet 9P/Tempel 1



The scale bar is 1 km, and the two arrows above the nucleus point to the Sun and to the rotational axis of the nucleus.

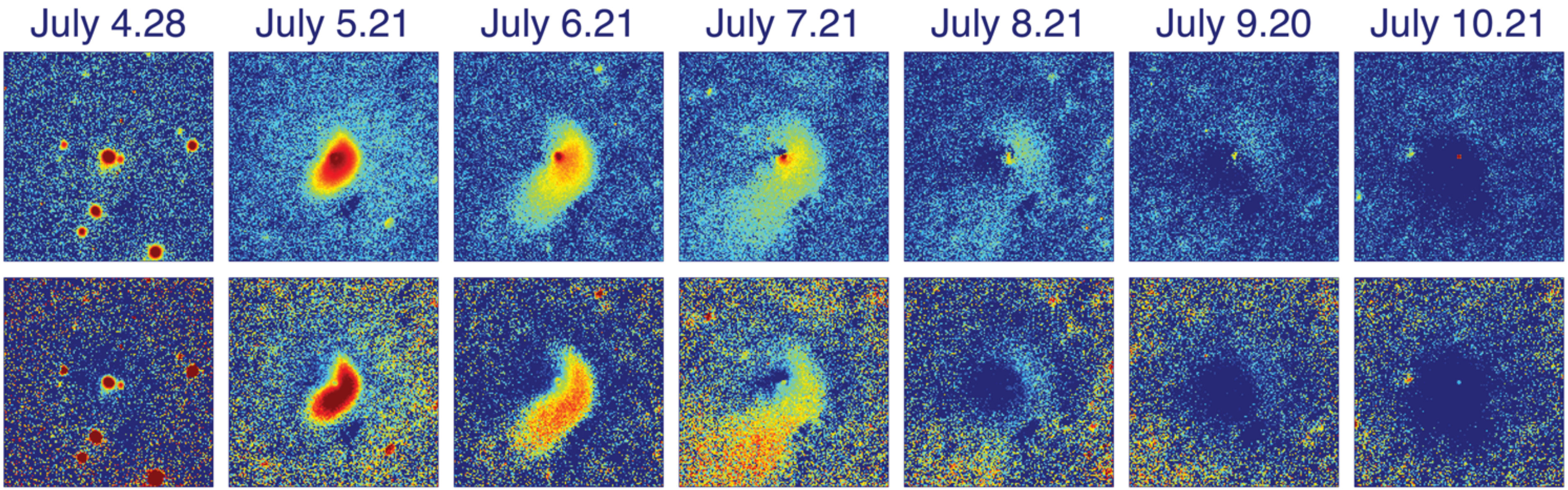
Arrows a and b point to the large, smooth areas. The small arrows highlight the scarp, bright due to the illumination angle, which shows the smooth area to be elevated above the extremely rough terrain.

Development of the ejecta plume



The time-delay between images is of 0.84 seconds.

Development of the ejecta plume (long scale)



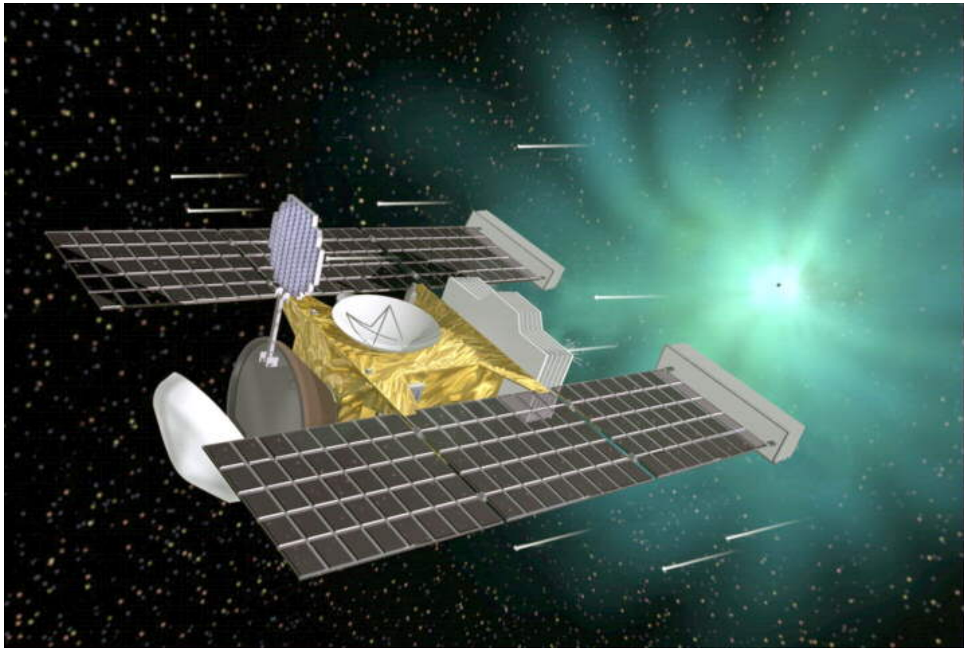
Daily sequence of ejecta plume images (upper row) obtained from ground-based observations. Each image is 120,000 km on a side. Image on July 4 was obtained 44 minutes after impact. Column density naturally decreases with distance from the nucleus as material moves outward. The bottom row presents images enhanced by removing a 1/ρ radial distribution (ρ is the projected radial distance as seen in the plane of the sky).

Ejected materials were moved with average velocity of 115 ± 16 m/s. Simultaneously, velocity of the leading part of the cloud was found to be 200 – 300 m/s.

While pre-impact water production rate was of 6×10^{27} molecules/s, the impact released up to 4×10^{32} molecules (about a day portion); which corresponds to about 1.3×10^{7} kg of ice or the equivalent of a cube about 23 m on a side.

Though the excess in other gas spices (i.e., CN, HN, C2, C3) was notable, it was significantly less than that for water ice.

In five days, production rates of all gases have returned to the pre-impact values.

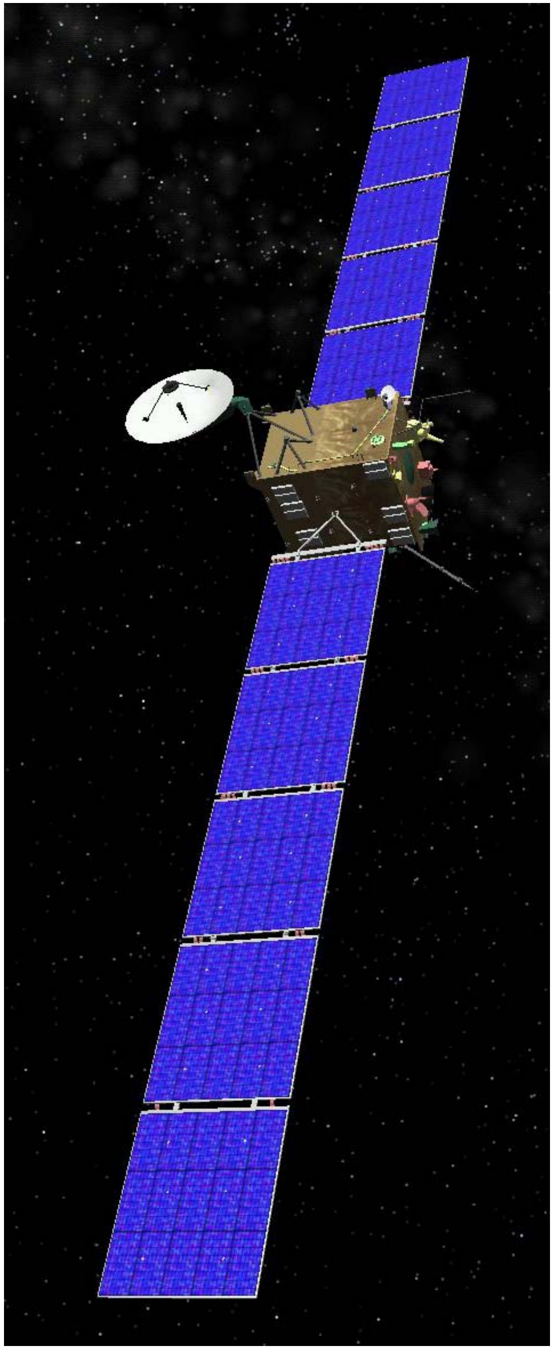


(8) Stardust NExT (New Exploration of Tempel 1)

Bonus mission of Stardust spacecraft to comet 9P/Tempel 1.

Primarily goal is to study the crater produced by Deep Impact.

The closest is expected on February 14, 2011.



(9) Rosetta

Spacecraft for complex study of comet 67P/Churyumov-Gerasimenko.

The spacecraft consists of two elements: orbiter and lander.

Schedule for the mission:

(a) The comet approach January – May 2014.
(b) Preliminary study of the comet August, 2014.
(c) Landing on the comet November 2014.

Terrestrial sampling of interplanetary dust particles (IDPs).

IDPs flying everywhere within the Solar system may enter the Earth stratosphere. Approximately 10^4 tons of interplanetary dust impact the atmosphere every year.

IDPs fall to the ground (sea) after some time (which depends on particle size). However, the most pristine dust particles could be collected in the stratosphere.

In 1970, Dr. D. Brownlee carried out the first successful collecting of IDPs, using a balloon-borne collector. Since 1974, IDPs are being collected with help of high-altitude airplanes U2, by Dr. D. Brownlee and his colleagues.

Airplane U2

dust collector

Collection is being made by inertial impaction of particles from airstream (>200 m/s) onto clean plastic surface coated with tar-like silicon oil. The number density of 10 μm particles in the stratosphere is 3×10^{-4} in m^{-3}.

Collectable stratospheric particles are usually limited to the 2-50 μm diameter range.

In the stratosphere, 10-μm particles fall with velocity of ~ 1 cm/s (i.e., 36 meters per hour or 864 meters per day).

Under good conditions (i.e., no contamination by volcanic particles), extraterrestrial particles contribute roughly 30% of all irregular particles larger than 5 μm.

Most extraterrestrial particles can be easily identified because they have chondritic elemental abundances (Mg, Al, Si, S, Ca, Fe, and Ni; in solar ratios) or contains fragments of such materials.

All particles can be split into two categories: those that melted (spheres; <10% of 10-μm particles) and those that did not melt.

Melted particles, also called as ablation spheres, found in the stratosphere can sub-divided onto:

(a) sulfide spheres (it is the most common type made of magnetite Fe_3O_4 and pyrrhotite FeS);
(b) non-chondritic spheres (depleted in Fe and enriched in Ca, Al, and Ti relative to chondritic abundance);
(c) metal mound silicate particles (spheroidal silicates covered with small mound of FeNi metal).

Non-melted particles, also referred to micrometeorites, found in the stratosphere can sub-divided onto:

(a) with chondritic abundances (within factor 3 for the 12 most abundant elements);
(b) with non-chondritic abundances (generally, single mineral grains).

Chondritic extraterrestrial particles are very fine grained.

By infrared transmission spectroscopy, chondritic IDPs can be divided onto three classes:

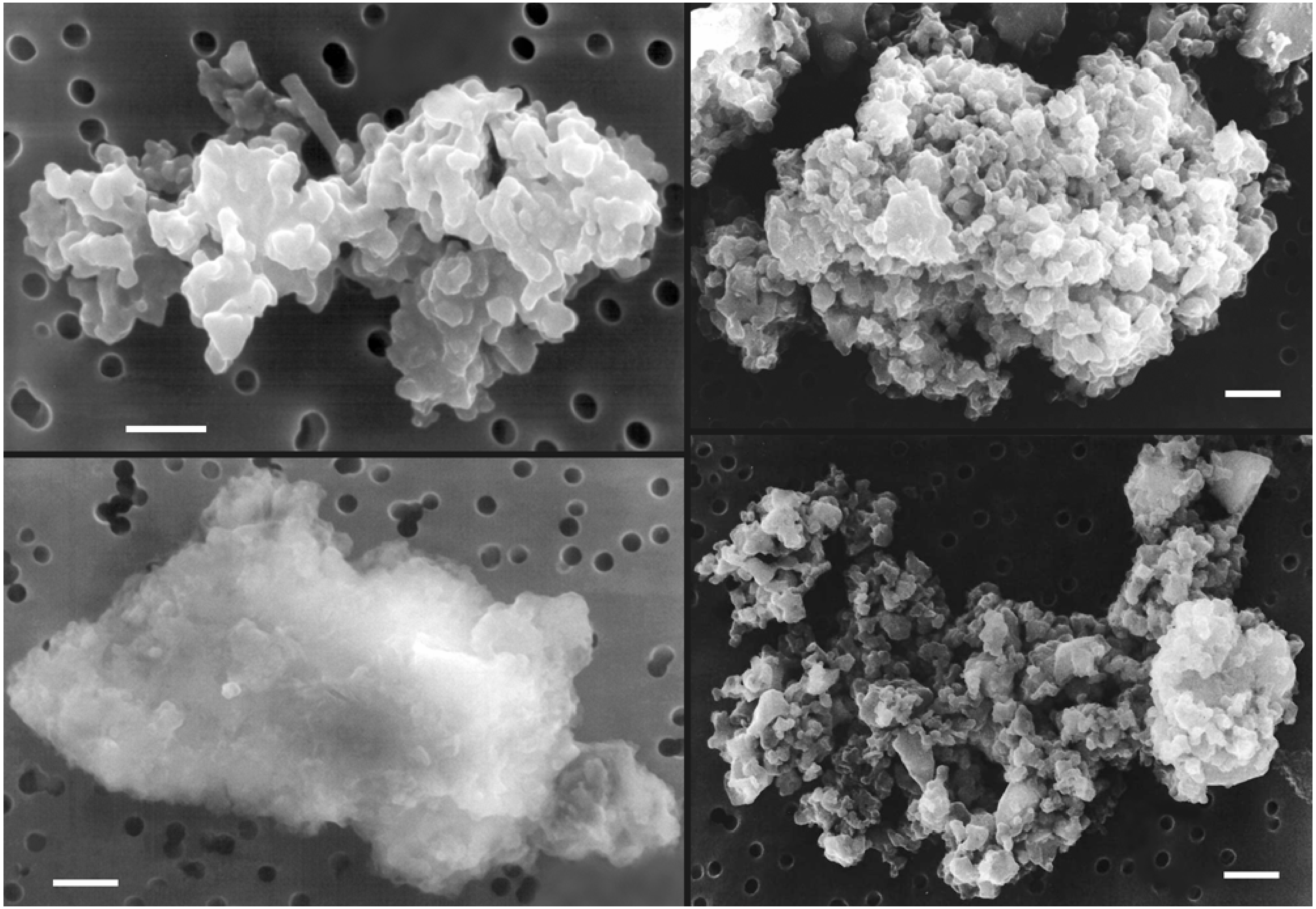
(1) those with spectra similar to olivine;
(2) those with spectra similar to pyroxene;
(3) those with spectra similar to hydrated silicates.

By morphology, chondritic IDPs can be divided onto two classes:

(1) chondritic porous (i.e., CP) – cluster-of-grapes, average size of grains is ~ 0.3 μm.
(2) chondritic smooth (i.e., CS) – quite smooth on micron scale.

In some CPs, grains are single minerals. While, in others CPs, grains are composed of numerous different small crystals embedded in amorphous material.

Shape of IDPs



Images of interplanetary dust particles (IDPs), having probable cometary origin. The white line corresponds to 1 μm.

The most of CPs contain significant amounts of amorphous carbonaceous material and possibly amorphous silicates as well.

For CPs, the measured densities range from 0.7 to 2.2 g/cm^3.

Both CPs and CSs are highly-absorbing particles.

The principal difficulty is as follows. In general, IDPs are originated from both comets and asteroids; whereas, it is very hard to distinguish one type of particles from another by their exterior. Therefore, it is necessary to involve quite sophisticated methods in order to determine the origin of the collected IDPs.

One possible solution is as follows. Asteroidal and cometary dust particles enter the atmosphere with generally different velocities. For asteroidal dust, it is about 12 km/s; whereas, for cometary dust, it is about 19 km/s.
The difference in enter velocities leads to difference in the heating. At 12 km/s, 5 μm IDPs are heated to 400–500 K; and, at 19 km/s, to 800–900 K. The heating releases He. Therefore abundance in He can be directly related to the enter velocity.

Using such a technique, it was found that about 50% of IDPs have an asteroidal origin, and, at least, 20% came from comets.

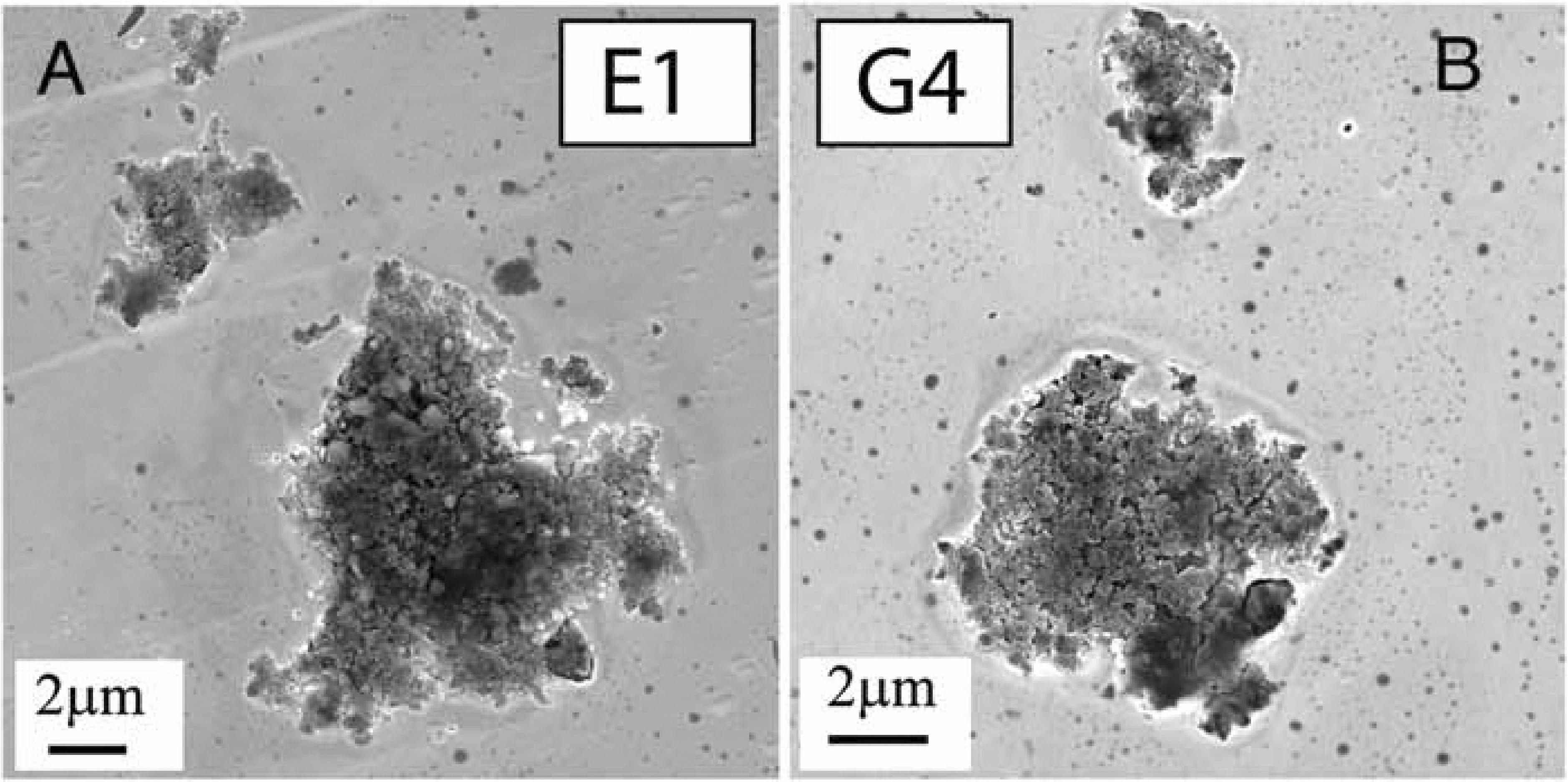
Even when cometary origin of a given IDP is determined, the parent body remains unknown.

However, the collecting of IDPs in the stratosphere can be dedicated to Earth passage through a cometary dust stream (tail or even coma).

In particular, calculations predicted that from 1 to 50% of the total flux of IDPs with sizes larger than 40 μm collected after Earth passed through dust stream of comet 26P/Grigg–Skjellerup in April 2003 would originate from this comet.

On April 30 – May 1, the collecting of IDPs originated from comet 26P/Grigg–Skjellerup have been carried out successfully.

IDPs originated from comet 26P/Grigg–Skjellerup



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