Results of the Rosetta mission before perihelion

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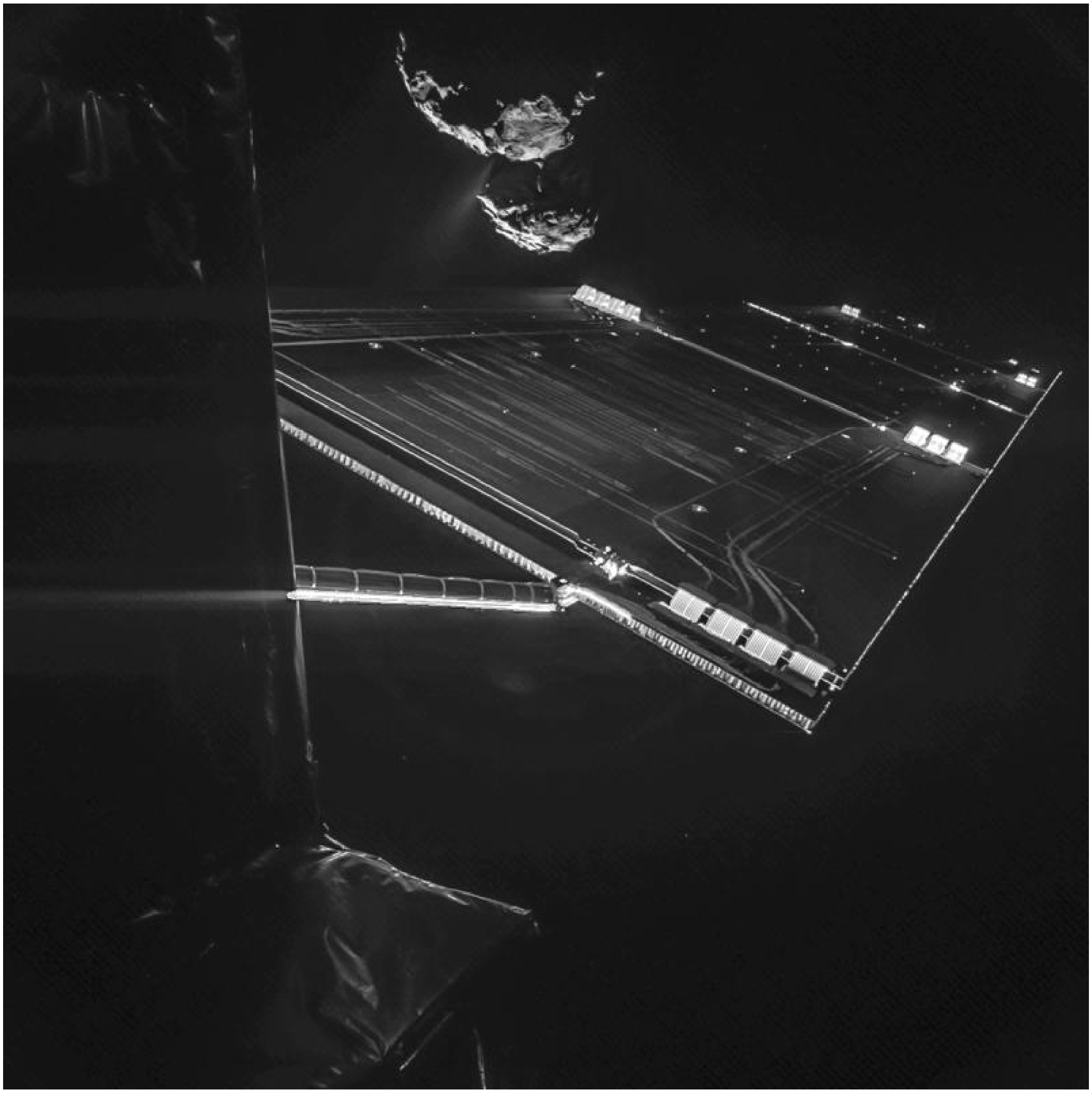

Astronomy & Astrophysics is publishing a special feature of 46 articles that present the results obtained by the Rosetta mission before the comet 67P/Churyumov-Gerasimenko reached its perihelion.

Rosetta is a cornerstone mission of the ESA space science program. The spacecraft was launched on 2 March 2004 and reached its target in August 2014 after a ten-year journey. The spacecraft's target, comet 67P/Churyumov-Gerasimenko (67P), is a short-period comet with a period of 6.55 years and a low orbital inclination. Its perihelion distance is 1.24 AU and its aphelion distance 5.68 AU. Rosetta reached 67P at about 3.5 AU from the Sun and entered into the comet's orbit to follow 67P on its way toward the Sun. The Rosetta spacecraft consists of an orbiter and a lander, Philae, which was deployed to the comet's surface on 12 November 2014. Unlike the previous cometary space missions that only passed by their targeted comets, Rosetta orbits a comet for the first time and follows its path toward perihelion to witness the cometary activity awakening.

The articles published in this *A&A* special feature cover a variety of themes in cometary science and revolutionize the field in many ways.

A first direct result from Rosetta was the opportunity to see the comet nucleus directly. The nucleus exhibited a surprising, "duck-like" shape that was very different from predictions (Preusker et al.). Was this shape a consequence of the comet's formation and collision history or of its progressive erosion? Researchers have also wondered for a long time about the structure of comet. How does the composition of the nucleus relate to that of the coma, how does the comet evolve, and of course, how have comets formed: are they possibly the building blocks of planets? With its wealth of data, Rosetta provides some answers to these long-standing questions.

The comet has, of course, been monitored from the ground, and its activity has been close to what was expected, with gradual increase during its approach to the Sun (Zaprudin et al.). It became clear that most of the activity was coming from dust jets in the Hapi region, i.e., in the "neck" between the two lobes of the comet (Lin et al., Lara et al.). The analysis of data acquired by the suite of instruments on Rosetta enabled an extensive characterization of the comet's activity and of its gaseous coma (Feldman et al., Biver et al., Lee et al., Bieler et al.). Theoretical considerations have shown that the variation in the comet's spin rate could be explained by the loss of about one meter of comet material at each orbit around the Sun (Bertaux). Only about 6% of the surface needs to be active to match the observed water production rates at perihelion (Keller et al.). To explain the observed dust trail, dust (mostly in the form of millimeter-sized grains) needs to be released from the comet's surface at very low velocities (Soja et al.). This is only possible if surface dust has very low tensile strength, one thousand times less than that of a dust layer assembled from micrometer-sized grains. One solution is that the nucleus formed through the gravitational collapse of an ensemble of millimeter- to centimeter-sized aggregates (Gundlach et al.).

Rosetta's observations of the comet nucleus show a young surface covered by a dusty coating and possibly heterogeneous composition between the two lobes (El-Maarry et al.). A wide variety of terrains and morphologies is observed, including elevated roundish features that betray degassing conduits, which in turn indicate that there are large primordial voids inside the nucleus (Auger et al.). Thousands of boulders are identified and show multiple evidence that the whole surface has been reshaped by airfall (Pajola et al., Thomas et al.). The measurement of inclinations of slopes enables a determination of the tensile strength of comet material. It is extremely low, pointing again to slow formation by gentle accretion of porous aggregates (Groussin et al., A32).

The interior of the comet has also been probed by Rosetta. Laboratory experiments predict a vertical stratification with an uppermost porous mantle of refractory dust over a layer of hard ice formed by recondensation or sintering. In agreement with this prediction, the comet surface is dark and "dusty" but shows meter-sized bright patches of dirty water ice (Pommerol et al.). Strong diurnal variations in the submillimeter and millimeter emission also indicate very low thermal inertia values, which are compatible with a highly porous, loose, regolith-like surface, and they suggest some vertical structure within the upper few centimeters of the surface (Brouet et al., Schloerb et al., Choukroun et al.). While the radar observations between the Rosetta spacecraft and the Philae lander are difficult to interpret, they do suggest that the permittivity and dielectric constant change below the surface (Ciarletti et al.).

With a geometric albedo of 6%, 67P is as dark as coal. The infrared and visible spectrum of the nucleus is generally featureless and reddish, which is compatible with an organic composition (Fornasier et al., Ciarnello et al., La Forgia et al.). Observations in the farultraviolet confirm that the surface is covered with a homogeneous layer of material and that surface ice is not ubiquitous in large abundances (Feaga et al.).

Measurements using mass spectrometers and remote sensing instruments have allowed the composition of the coma to be directly determined as a function of time. This information is precious for determining the depth from which the various molecules come from. For example, water production is weak in regions with low solar illumination, while CO2 is outgassing both from illuminated and non-illuminated regions, which indicate that unlike H2O, CO2 sublimates below the diurnal skin

(Bockelee-Morvan et al.). Minor species show a correlation with either H_2O or CO_2, but CH_4 shows a different, unexplained, pattern (Luspay-Kuti et al.). The comet also contains complex organic molecules and the large differences in relative abundances between summer and winter hemispheres point to a possible largescale evolution of the cometary surface (Le Roy et al.). Even ions were detected with this method, enabling the study of ion-neutral chemistry (Fuselier et al.). On 67P's surface, Philae's own mass spectrometer also successfully measured a ratio of CO/CO_2 that was substantially lower than some measurements in the coma, which indicates the significant heterogeneity of the nucleus (Morse et al.).

Rosetta also investigated the interactions of the coma and the solar wind (Broiles et al., Nilsson et al.), discovering a stronger-than-expected, highly turbulent, interaction (Clark et al.) and the presence of negatively charged nanograins (Gombosi et al.).

A surprise has been the discovery of at least four large grains with diameters between 10 and 50 cm orbiting the nucleus (Davidsson et al.), as well as millions of particles (Fulle et al.). From solar wind sputtering and the mass spectrometers measurements, it appears that this dust has the same Na abundance as carbonaceous chondrites (the most primitive meteorites) but is depleted in calcium and has excess potassium (Wurz et al.). Both compact particles and fluffy porous aggregates were found, with masses between 0.1 and 100 µg and velocities between 0.3 and 12 m/s (Della Corte et al.). No object larger than six meters was discovered in orbit around the nucleus (Bertini et al.). One millimeter-sized particle was found by Philae's dust detector. Its material properties are compatible with a porous particle with a low bulk density of about 0.25 g/cm^3 (Krüger et al.).

With its low density, high porosity, and low tensile strength, this comet seems fragile, and yet simulations of the collisional history in the solar system show that it is highly unlikely that it was formed as a 4 km-size body and that it survived the 4.5 billion year journey to us unaltered. Instead, it must be the fragment of a larger object that experienced one or several massive collisions (Morbidelli & Rickman). While the "neck" of the comet is the region where most of the jets originate, the erosion appears too limited to have excavated hundreds of meters of comet material. Instead, close inspection of the Rosetta images with theoretical models indicate that the two lobes of 67P's nucleus are derived from two distinct objects that formed a contact binary via a gentle merger (Rickman et al.).

The comet still holds many secrets. This A&A special feature interprets data acquired before the height of activity, i.e., before the comet reached perihelion on 13 August 2015. Already during that period, Rosetta noticed changes happening on the surface such as the growth of 100-meter large round features apparently associated with H_2O and/or CO_2 ices (Groussin et al., A36). The data collected during and after perihelion promises to be as rich in surprises.

More information: A&A special feature: Rosetta mission results pre-perihelion, *Astronomy & Astrophysics*, volume 583, November 2015. www.aanda.org/articles/aa/abs/ … ntents/contents.html

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