ON FROZEN VOLATILES IN COMETS, AND THEIR SUBLIMATION. Rita Schulz, ESA Research and Scientific Support Department, ESTEC, Postbus 299, 2200 AG Noordwijk, The Netherlands, rschulz@rssd.esa.int.

Introduction: A comet approaching the Sun can be considered an excellent planetary laboratory in which the sublimation of ice-dust mixtures into vacuum can be studied without any obstructing boundaries. The development of cometary activity is undoubtedly related to most complex physico-chemical processes in the surface layer of the nucleus and in the inner coma. These processes form the atoms, molecules and ions making up the composition of the gas coma as we know it from decades of remote-sensing observations. Great effort has been put into trying to infer the composition of the comet nucleus from that of the coma by chemical modeling, starting with simple gas chemistry and later introducing more complex hydrodynamic-chemical models [1]. A number of processes were identified that are capable of altering the initial composition of volatile material sublimating from the nucleus surface and/or subsurface. However, we do not know enough yet to draw any conclusions, which would allow confirming or discarding one of these mechanisms or unambiguously inferring the physico-chemical nature of a comet nucleus. For this we need measurements, at least for one comet nucleus and its near-nucleus environment. Key information is expected from the Rosetta rendezvous mission with Jupiter-family comet 67P/Churyumov-Gerasimenko. Hence, we need to exploit this mission to find the clues required for determining the properties of cometary nuclei from coma observations. Ideas how this can be achieved from parallel measurements will be presented.

Comet Nucleus Composition: The key to the origin of comets and possibly to the formation and evolution of the solar system is the composition of the comet nuclei. Although no ground-truth measurements of this composition exist, much could be inferred from spectroscopic observations of active comets mainly at infrared and radio wavelengths. Of the about 45 molecules, radicals or ions identified as coma species, about 25 are likely to have sublimated from nucleus ices [2]. To date only very few direct measurements exist from comet fly-by missions. However, the availability of very large telescopes in combination with advanced new instrument technology, particularly in the infrared, provides nowadays the opportunity to attempt direct measurements of the surface composition of cometary nuclei also from ground. Spectroscopic observations in the near-infrared region between 1.4 µm and 2.5 µm are sensitive to absorption bands of water and hydrocarbon ices. A number of searches for spectral signatures diagnostic of surface ices have already been conducted for minor bodies in the outer solar system, in particular for Centaurs and TNOs. The results are rather promising with a number of frozen volatiles detected [3]. A few near-infrared spectra of comet nuclei have also been published opening the opportunity to take a glimpse at the surface a comet from ground [4] [5]. However, owing to the faintness of a bare comet nucleus the observations merely allow to derive the nucleus reflectance spectrum. A near-infrared spectrum of a comet nucleus can only be compositionally diagnostic if the reflected light from the nucleus is measured with a high enough signal-to-noise to render a clear distinction between absorption bands and noise patterns. Therefore, to ensure the correct interpretation of such data it is essential to compare them with the results of space missions. There is an infrared spectrometer on Rosetta, which will obtain spectra of the nucleus of comet 67P/Churyumov-Gerasimenko from the orbiting spacecraft [6]. These spectra will serve as a reference to what spectroscopic features would in principle be observable in this comet from ground if there were no constraints in sensitivity. In practice it is however rather unlikely that a diagnostic infrared spectrum of the comet will be obtained by ground-based telescopes in the near future. The infrared spectra obtained by Rosetta should therefore be used for comparison with ground-based spectra of bright comet nuclei, which will undoubtedly be available at the time of the Rosetta encounter.

Water Ice: The measured water production rates in comets suggest that water ice is the most abundant frozen volatile of a comet nucleus. Nevertheless, water ice deposits on the nucleus surface have up to now been directly detected only once, on the surface of comet 9P/Tempel by the infrared spectrometer on board the Deep Impact mission [7]. The Stardust mission to comet 81P/Wild 2 did not carry an instrument capable of searching for water ice and the infrared spectrometers on board the Vega and Deep Space 1 missions were searching for, but did not find any evidence for absorption bands of water ice in comet 1P/Halley or 19P/Borrelly. This is very surprising, not only because water ice must be present in every comet nucleus and was expected to be detected, but also because water ice grains were...
dragged from the surface or at least from very close to the surface by gentle sublimation of volatiles, which in turn would support the presence of deposits of icy grains on the nucleus surface that may be made up of either pure water ice or be a mixture of water ice and non-volatile or less volatile species. Closer to the Sun icy grains are extremely difficult detect, because inside 2 AU the icy component sublimes within 1-2 hours forming a secondary source for water and its decay products. Nevertheless, when produced under non-steady state conditions icy grains can be detected; and indeed the observations of the fresh coma material ejected from the nucleus of comet 9P/Tempel within the first 1.5 hours after the impact led to the detection of disintegrating icy grains [11]. It was demonstrated that the mass loss during and immediately after the impact was probably not in form of gentle water sublimation [12] and the detection of disintegrating icy grains proved the long standing assumption that the water in comets does not exclusively sublimate directly from the comet nucleus, but is also ejected in form of small icy grains at least during outbursts [11]. The only way to find clear evidence that can solve the question on how water ice is deposited in comet nuclei (at least close to the surface) and how it is released under different conditions is to focus certain measurements of the Rosetta mission on this topic. The nucleus activity of the target comet has to be monitored along the orbit from the onset of the nucleus activity to perihelion and also during outbursts that may occur along its path. Details will be given on the capabilities of the Rosetta payload to tackle the question of water ice deposits as well as the release and characterisation of icy grains.

**Evidence from coma observations:** The monitoring of the Rosetta target comet will include parallel compositional measurements in the coma by various instruments opening the opportunity to cross-correlate the values obtained by the different measurement techniques. The remote-sensing instruments on board the Rosetta orbiter work on the same principle as respective telescope instrumentation. The results can therefore further be correlated with parallel measurements from ground or the HST. The OH abundance and its relation to the water production will be of particular interest, as OH is regarded as a direct daughter product of water the most reliable measure for the overall activity of a comet from ground. However, the spacecraft measurements will also identify parent molecules other than water and provide quantitative information on chemical reaction chains in the near-nucleus region by which the daughter species accessible from ground are eventually produced. A link between the coma chemistry uncovered by the space mission and the abundance of daughter species observed from ground can therefore be established if parallel ground-based monitoring is available. This will be of utmost importance for being able to transfer what we learn from Rosetta also to other comets.

**Conclusions:** A complete characterization of a comet will only be possible if cold samples of the surface and the interior of the nucleus are brought back to Earth for detailed analysis. As this will definitely not be the case in the foreseeable future, the physical properties and composition of comet material has to be disclosed by other means. Rosetta will conduct a great number of important measurements which should provide major pieces to the puzzle. However, only if the results of all measurements can be put into mutual context will we be able to draw a consistent picture of the physico-chemistry of cometary matter and its relation to the solar nebula at the time of comet formation. It is therefore crucial to develop theoretical and experimental methods by which the results of measurements can be explained on the basis of the rules of physics, chemistry and mineralogy. Laboratory experiments have already become of growing importance for the interpretation of astronomical data and the preparation of space missions. The investigations include production, processing and analysis of cometary analogues as well as experimental and theoretical techniques for studying photochemical reactions and infrared signatures of mineralogical compounds. The interpretation of experimental results on cometary analogue material by theoretical investigations helps to prepare us for what to expect from the data we are about to collect. Once the spacecraft data are available the picture will reverse in that the knowledge gained from the space missions will bear refined theories and trigger further experiments that will help to secure even more pieces to the puzzle.

**References:**