SUBSURFACE TEMPERATURE OF COMET 67P/C-G FROM ROSINA/DFMS? A. Luspay-Kuti[1], M. Hässig[1,2], S. A. Fuselier[1], H. Balsiger[2], U. Calmonte[2], S. Gasc[2], A. Jäckel[2], L. LeRoy[2], M. Rubin[2], T. Semon[2], C. Tzou[2], J. J. Berthelier[3], J. De Keyser[4], B. Fiethe[5], U. Mall[6], H. Rème[7], A. Bieler[2,8], M. Combi[8], T. Gombosi[8], O. Mousis[9], K. E. Mandt[1]. [1]Space Science and Engineering Division, Southwest Research Institute (6220 Culebra Rd., San Antonio, TX 78238; aluspaykuti@swri.edu), [2]Physikalisches Institut, University of Bern (Sidlerstr. 5, CH-3012 Bern, Switzerland), [3]LATMOS (4 Avenue de Neptune F-94100 SAINT-MAUR, France), [4]Space Physics Division, BIRA-IASB (Ringlaan 3, B-1180 Brussels, Belgium), [5]Institute of Computer and Network Engineering (IDA), TU Braunschweig (Hans-Sommer-Straße 66, D-38106 Braunschweig, Germany), [6]Max-Planck-Institut für Sonnensystemforschung, (Max-Planckstrasse 2, 37191 Katlenburg-Lindau, Germany), [7]Université de Toulouse; UPS-OMP; IRAP (9 Avenue du colonel Roche, BP 44346, F-31028 Toulouse cedex 4, France), [8]University of Michigan (Space Research Building, 2455 Hayward Street, Ann Arbor, MI 48109, USA), [9]Université de Franche-Comté, Institut UTINAM, CNRS/INSU (UMR 6213, Observatoire des Sciences de l'Univers de Besancon, France)

Introduction: Cometary nuclei are believed to closely reflect the composition of planetesimals in the solar nebula. They carry important information about the prevalent conditions in the protoplanetary disk before and during planet formation. The detailed composition of cometary nuclei is therefore one of the most important yet still unknown aspects in the understanding the formation of the Solar System.

The recent arrival of the Rosetta spacecraft at comet 67P/Churyumov-Gerasimenko (67P) provides an unmatched opportunity to study this Jupiter-family comet in extreme detail. This opportunity includes understanding the composition, evolution, and possibly origin of comets. Rosetta has shown that the shape of the nucleus of 67P is complex, resembling that of a rubber duck, with a smaller and a larger lobe connected by a narrower neck. Measurements of the major outgassing species H_2O, CO_2 and CO revealed a strongly heterogeneous coma, with large diurnal variations, and possible indications of seasonal effects [1]. Though volatile abundances relative to H_2O in the nucleus are not directly reflected to observed abundances in the coma [e.g. 2], measurements of the coma could reveal various structural and physical characteristics of the nucleus.

In this study, measurements of coma volatiles are employed to try to infer shallow subsurface nucleus temperatures of the poorly illuminated, southern winter hemisphere of comet 67P.

Method: ROSINA/DFMS (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis/Double Focusing Mass Spectrometer) measurements obtained on September 18 are used for the analysis. These measurements cover the southern, poorly illuminated latitudes of 67P down to ~50° S. Heterogeneity of the coma has been demonstrated for the same time period [1], allowing for the study of possible correlations between the major and minor outgassing molecules. Relative concentrations of volatile species are derived from spectral fits to mass peaks from ROSINA/DFMS. For the time period of interest, clear signals well above background were obtained for the following species: H_2O, CO_2, CO, HCN, CH_4, C_2H_4, and C_2H_3 (likely a fragment of C_2H_y). The temperature-dependent latent heat of sublimation of each species, along with their sublimation temperatures are calculated via the Clausius Clapeyron equation [3] for a pressure range of 10^{-10} to 10^{-6} Pa.

Results and Discussion: Figure 1 shows the relative intensity profiles as a function of time for various coma molecules observed by ROSINA/DFMS, along with the view of the comet by the spacecraft for the times of maxima. All species trend together through the first peak at 13:30 UT. The species in this peak likely originate from the neck region (Fig. 2). There is a second peak in the CO, C_2H_3 and CO_2 profiles at 17:40 UT (bold dashed line in Fig. 1) that is not reflected in the H_2O or HCN profiles. This peak shows that the compositional heterogeneity of the coma [1] is not limited to H_2O, CO and CO_2. Here, we divide volatiles into two groups based on their intensity profile over the entire time interval in Figure 1. The first group trends with H_2O and the second group trends with CO_2. The peak in the CO_2 profile and the deep minimum in H_2O occur when the neck region is effectively blocked from Rosetta's view by the bigger lobe [1] (Fig. 2). Hence, the source region of the species in group 2 at the time of the 1st peak is in the warmer neck region. Though, the 2nd peak most likely originates somewhere from the southern, poorly illuminated winter hemisphere at the bottom of the bigger lobe (Fig. 2). The sublimation temperatures of group 2 (CO, CO_2, C_2H_y hydrocarbons) volatiles are clearly below that of group 1 (H_2O and HCN) volatiles. This is indicative of hemispheric differences in outgassing, and temperature variations in the comet. H_2O and HCN sublimation is nearly minimal at the time of the 2nd peak (Fig. 1; bold dashed line), which suggests that near-surface temperatures are sufficient to sublimate CO_2, but too low to sublimate HCN and H_2O (blue horizontal line in Fig. 1). If this were indeed the case, then group 2 ices would be stratified in the nucleus according to volatility. The temperature at the bottom of the sublimating layer is higher than the sublimation temperature of CO (Fig. 2).

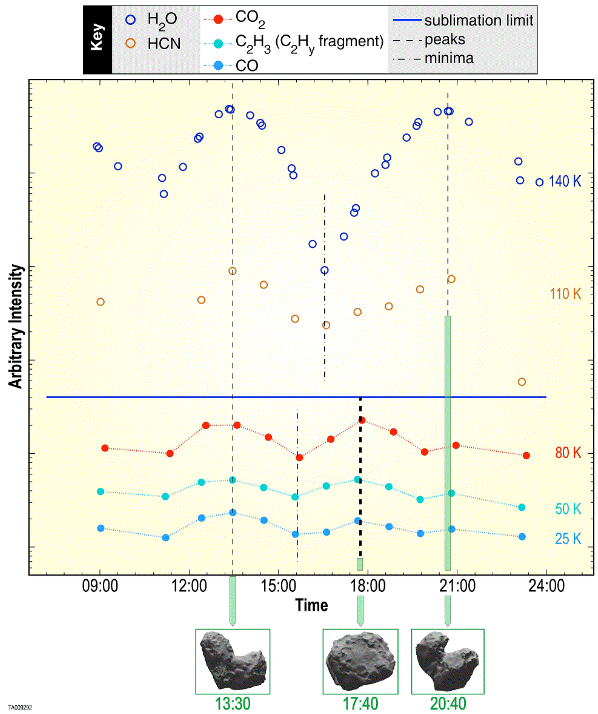

Figure 1. Profiles of volatile species in the coma on September 18. Maxima and minima are marked by vertical lines. The blue line marks the sublimation threshold in the near-subsurface of the southern, winter hemisphere. Shape model credit: ESA/Rosetta/MPS for OSIRIS TEAM MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA.

Based on the preliminary results, the intensity profile of CH_4 (T(CO) < T(CH_4) < T(C_2H_y)) does not seem to fit the above picture. Sublimation of pure ices from successively deeper crystalline ice layers suggests that CH_4 should follow the group 2 volatiles. Instead, CH_4 trends with group 1 volatiles over the time period examined. Possible explanations include compositional heterogeneities within the nucleus. The compositional differences in the 3rd peak in Fig. 1 at 20:40 UT may indicate also such heterogeneity. In particular, the lack of maxima of group 2 molecules despite the sublimation of the least volatile component (H_2O) may suggest that each peak in the signal reflects outgassing from different source regions. Another possible explanation of the CH_4 discrepancy may be that the nucleus is composed of a mixture of clathrate hydrates and pure volatile condensates [4-6].

Conclusions: Diurnal variations of various volatile species detected in the coma of 67P may provide a way to estimate the winter-hemisphere subsurface temperatures of 67P. Preliminary results suggest that a significant temperature difference may be present between the topmost subsurface layers of the two hemispheres. Furthermore, these measurements indicate a notable temperature drop between the surface and the uppermost sublimating layer.in the winter hemisphere. Such results are in agreement with observations by the Microwave Instrument for the Rosetta Orbiter (MIRO) [7].

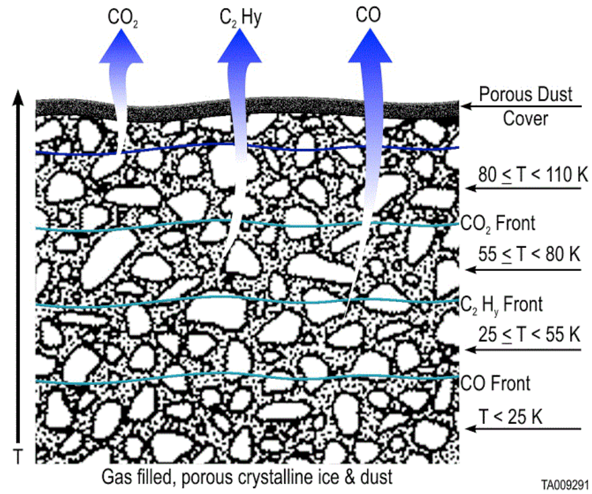

Figure 2. Possible temperature boundaries and layered structure of the southern-hemisphere nucleus inferred from the time-variability of coma volatiles.

The time variation of volatiles in the coma of 67P may bear implications for compositional heterogeneity within the nucleus. Analysis of additional observations is required to conclude with confidence on the underlying cause of the heterogeneity of the coma signal. Such an attempt is currently underway, and may provide important clues about the composition and evolution of 67P.

References: [1] Hässig M. et al. (2014) *Science* In Revision. [2] Huebner W. F. and Benkhoff, J. (1999) *Space Sci. Rev.* 90, 117. [3] Huebner W. F. et al. (2006) *ISSI Report.* [4] Mousis O. et al. (2012) *ApJL* 757, 146. [5] Mousis O. et al. (2010) *Faraday Discussions* 147, 509. [6] Marboeuf U. et al. (2010) *ApJL* 708, 812-816. [7] Gulkis S. et al. (2015) *Science,* in press.