



HAL
open science

H₂O and O₂ Absorption in the Coma of Comet 67P/Churyumov-Gerasimenko Measured by the Alice Far-Ultraviolet Spectrograph on Rosetta

B. A. Keeney, S A Stern, M F A'Hearn, Jean-Loup Bertaux, L M Feaga, P D Feldman, J Wm Parker, E Schindhelm, A J Steffl, M Versteeg, et al.

► **To cite this version:**

B. A. Keeney, S A Stern, M F A'Hearn, Jean-Loup Bertaux, L M Feaga, et al.. H₂O and O₂ Absorption in the Coma of Comet 67P/Churyumov-Gerasimenko Measured by the Alice Far-Ultraviolet Spectrograph on Rosetta. 48th Lunar and Planetary Science Conference, Mar 2017, The Woodlands (Texas), United States. pp.LPI Contribution No. 1964, id.1275. insu-04613355

HAL Id: insu-04613355

<https://insu.hal.science/insu-04613355>

Submitted on 16 Jun 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

H₂O AND O₂ ABSORPTION IN THE COMA OF COMET 67P/CHURYUMOV-GERASIMENKO MEASURED BY THE ALICE FAR-ULTRAVIOLET SPECTROGRAPH ON ROSETTA.

B. A. Keeney¹, S. A. Stern¹, M. F. A'Hearn², J.-L. Bertaux³, L. M. Feaga², P. D. Feldman⁴, J. Wm. Parker¹, E. Schindhelm¹, A. J. Steffl¹, M. Versteeg⁵, and H. A. Weaver⁶

¹Southwest Research Institute, Department of Space Studies, Boulder, CO 80302, USA, bkeeney@gmail.com, ²Department of Astronomy, University of Maryland, College Park, MD 20742, USA, ³LATMOS, CNRS/UVSQ/IPSL, 78280 Guyancourt, France, ⁴Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218, USA, ⁵Southwest Research Institute, San Antonio, TX 78238, USA, ⁶Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA.

Introduction: One of the most surprising results from the Rosetta mission to Comet 67P/Churyumov-Gerasimenko (67P/C-G) has been the persistent detection of O₂ in the coma [1,2] by the Double Focusing Mass Spectrometer (DFMS) of the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA). Not only does this represent the first detection of O₂ in the coma of a comet [1], but O₂ is the fourth most abundant species in the coma of 67P/C-G [1,3].

Alice is a lightweight and low-power far-ultraviolet (FUV) imaging spectrograph located aboard the Rosetta orbiter [4]. Its characterization of the coma of 67P/C-G has typically used emission lines from CO and atomic hydrogen, oxygen, carbon, and sulphur [5,6]. Here we present novel observations that have detected H₂O and O₂ in absorption against the FUV continuum of bright stars located near the comet's nucleus.

Other Rosetta instruments are capable of directly measuring the abundance of H₂O and CO/CO₂ in the coma of 67P/C-G, most notably the Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) [7], and the Microwave Instrument for the Rosetta Orbiter (MIRO) [8], but only Alice and ROSINA are capable of directly measuring O₂. This makes the observations reported herein an important and unique confirmation of the initial O₂ detections. Complicating matters, however, is the fact that Alice, VIRTIS, and MIRO are remote sensing instruments that probe a line of sight near the comet's nucleus, while ROSINA samples the coma's composition *in situ* at the spacecraft location.

Stellar Appulse Observations: Over the course of Rosetta's orbital escort mission, Alice probed the sunward coma of 67P/C-G in absorption 30 times using FUV-bright stars located along lines of sight near the nucleus as background sources. Each of these stars was later re-observed when they were far from the nucleus to characterize their intrinsic stellar spectra, allowing an identification of the absorption features in the original appulse observations that originated in the coma.

There are two varieties of Alice stellar appulse observations, which we term "targeted" and "archival".

The targeted appulses were instances where a bright star was intentionally observed because it was located near the nucleus, whereas the archival appulses were serendipitously observed to be near the nucleus. The seven targeted appulses were all observed between 2015 Dec 25 and 2016 Feb 9 at heliocentric distances of $R_h = 1.97\text{-}2.33$ AU and impact parameters of $\rho = 6\text{-}18$ km. By contrast, the many archival appulse candidates were observed much more uniformly throughout the mission. Since we were ultimately limited in the number of stars we could re-observe, we selected the 23 archival appulses that occurred closest to perihelion (2015 Aug 13). These had R_h ranging from -1.75 to 1.98 AU (negative values indicate pre-perihelion observations) and $\rho = 1\text{-}20$ km.

We searched for optically-thin absorption from H₂O and O₂, along with eight other species previously identified in the coma of 67P/C-G [3]. An example fit can be found in Figure 1, which shows best-fit individual and ensemble absorption profiles compared to the normalized stellar flux in the top panel, and the fit residual in the bottom panel. By "normalized" we mean that the intrinsic shape of the stellar spectrum has been removed prior to the fit. Acceptable fits were found for 24 of the 30 appulses.

A suite of forward-modeled Monte Carlo simulations was used to assess the reliability of these fits as a function of signal-to-noise ratio, S/N, H₂O column density, $N(\text{H}_2\text{O})$, and relative abundance, O₂/H₂O. These simulations revealed that the best-fit values of $N(\text{H}_2\text{O})$ and O₂/H₂O were somewhat biased with respect to the input values, and that the formal fitting uncertainties were too small. We were able to statistically correct for these deficiencies to derive "adopted" values of $N(\text{H}_2\text{O})$ and O₂/H₂O that are well-calibrated.

Results & Conclusions: The top panel of Figure 2 shows the adopted values of $N(\text{H}_2\text{O})$ as a function of R_h compared to measurements from VIRTIS-H (the high spectral resolution channel of VIRTIS) taken at similar R_h and ρ as our stellar appulses [9]. The good agreement between the Alice and VIRTIS-H column

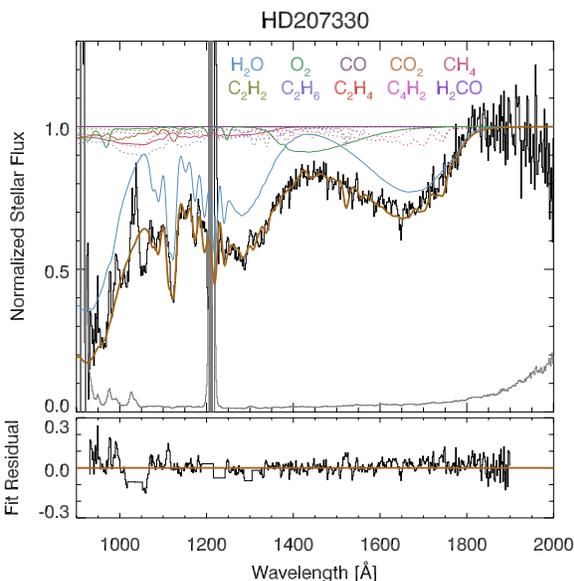


Figure 1: Example absorption-line fit to the archival appulse of HD 207330. *Top:* The normalized stellar flux and 1σ uncertainty, with best-fit ensemble absorption (solid brown line) overlaid. Absorption from individual species is shown with solid (H_2O , O_2 , CO , CO_2 , CH_4) or dashed (C_2H_2 , C_2H_6 , C_2H_4 , C_4H_2 , H_2CO) lines. *Bottom:* The residual of the ensemble fit.

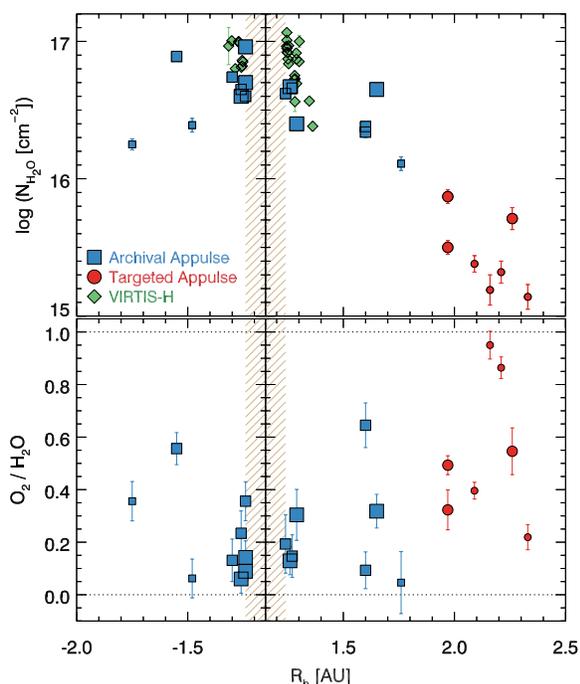


Figure 2: Adopted values of $N(\text{H}_2\text{O})$ (*top*) and $\text{O}_2/\text{H}_2\text{O}$ (*bottom*) as a function of R_h . The $N(\text{H}_2\text{O})$ values are compared to values measured by VIRTIS-H near perihelion [9]. Symbol sizes for the appulse observations signify confidence in the measurement. Heliocentric distances in the beige hatched region are smaller than the perihelion distance of 1.24 AU.

densities suggest that the adopted $N(\text{H}_2\text{O})$ values are reasonably robust. Further, if a Haser model is used to estimate H_2O production rates from these column densities, they agree reasonably well with values from the VIRTIS-M [10,11] and MIRO [12,13] instruments.

The bottom panel of Figure 2 shows the adopted values of $\text{O}_2/\text{H}_2\text{O}$ as a function of R_h . The O_2 abundances derived from the Alice appulse observations are considerably larger than those reported by ROSINA, which found $n(\text{O}_2)/n(\text{H}_2\text{O}) = 3.85 \pm 0.85\%$ on average, with no measured values $>20\%$ [1]. Therefore, half of the values measured by Alice are higher than any value measured by ROSINA.

But Alice is a remote sensing instrument, while ROSINA makes measurements *in situ* at the spacecraft location. One way to overcome the ambiguities inherent in directly comparing these measurements is to use a three dimensional coma model [2] that accounts for the irregular shape of the nucleus of 67P/C-G and non-uniform production on the surface of the nucleus. This model is designed to reproduce all ROSINA-DFMS measurements of H_2O , CO_2 , CO , and O_2 for data taken through Feb 2016. It finds an O_2 production rate with respect to H_2O of 2% near perihelion [2], once again considerably lower than our adopted values.

However, when integrated along the appropriate line of sight this same model has difficulty reproducing the VIRTIS-H measurements of $N(\text{H}_2\text{O})$ taken near perihelion [9], over-estimating them by a factor of ≈ 4 [2]. This suggests that $\text{O}_2/\text{H}_2\text{O}$ may be under-estimated by this same factor in their model, but even if that were the case it would not explain the full difference in the Alice and ROSINA measurements. Further work is clearly needed to reconcile these two estimates of the O_2 abundance in the coma of 67P/C-G.

Acknowledgements: Rosetta was an ESA mission with contributions from its member states and NASA. The Alice team acknowledges continuing support from NASA JPL through contract 1336850 to the Southwest Research Institute.

References: [1] Bieler, A. et al. (2015) *Nature*, 526, 678. [2] Fougere, N. et al. (2016) *MNRAS*, 462, S156. [3] Le Roy, L. et al. (2015) *A&A*, 583, A1. [4] Stern, S. A. et al. (2007) *Space Sci. Rev.*, 128, 507. [5] Feldman, P. D. et al. (2015) *A&A*, 583, A8. [6] Feldman, P. D. et al. (2016) *ApJ*, 825, L8. [7] Coradini, A. et al. (2007) *Space Sci. Rev.* 128, 529. [8] Gulkis, S. et al. (2007) *Space Sci. Rev.* 128, 561. [9] Bockelée-Morvan et al. (2016) *MNRAS*, 462, S170. [10] Migliorini, A. et al. (2016) *A&A*, 589, A45. [11] Fink, U. et al. (2016) *Icarus*, 277, 78. [12] Gulkis, S. et al. (2015) *Science*, 347, 709. [13] Biver, N. et al. (2015) *A&A*, 583, A3.