Detection of Hydrogen cyanide (HCN) and Ammonia (NH_3) in Comet 67P/Churyumov-Gerasimenko

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Introduction

- Comets are relatively unprocessed remnants of our early solar system. Their small size means a lack of internal heating and thus their original compositions remains nearly unchanged. Study of the chemical composition of comets may provide answers to questions about the formation and evolution of our solar system including how volatiles were distributed and delivered to the inner planets[1,2].
- Comets are mainly classified into two categories: short orbital period (<200 years) Jupiter-family comets(JFCs), originating from the Kuiper belt, and the long orbital period Oort cloud comets (OCCs), originating from the Oort Cloud.
- Despite the fact that JFCs are underrepresented in the compositional analysis of comets in the near-IR, it is crucial for cometary science to distinguish between primitive and post-formation processing effects in comets by comparing the chemical composition of JFCs and OCCs, which have different dynamical histories due to their varied orbital periods.
- 67P was the first ever comet where a man-made spacecraft was landed. In November 2014, the Philae lander from the Rosetta mission, by the European Space Agency (ESA), made its touchdown on the surface of Comet 67P[3].
- This work is focused on the detection of HCN and NH_3 which are in the range of 3.00 - 3.04 µm.

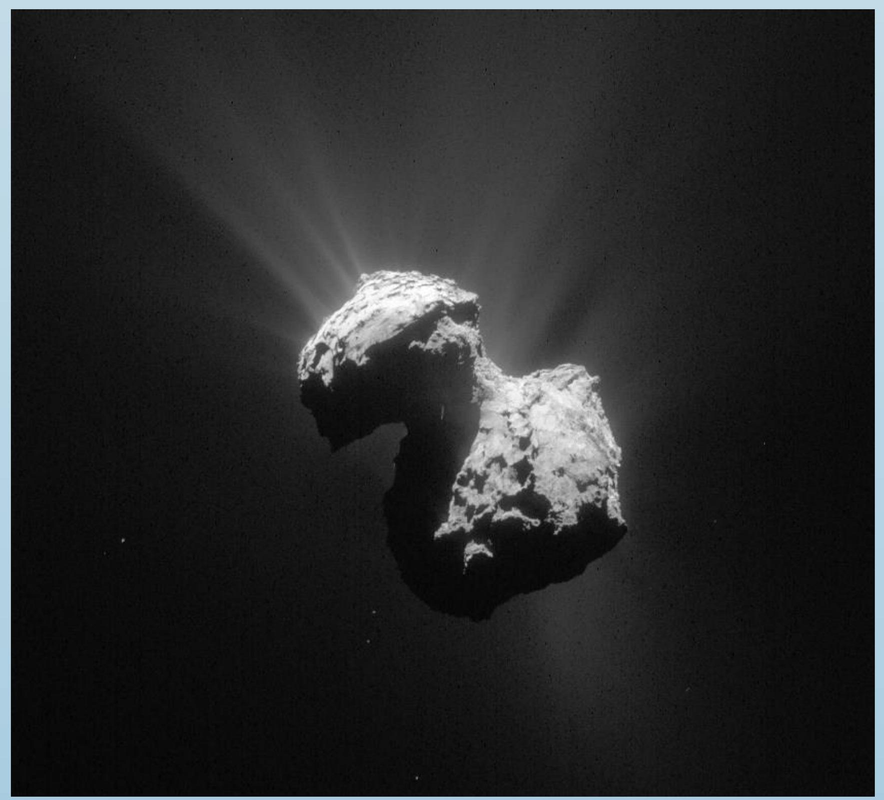

Figure 1. *Picture taken from the ROSETTA mission by ESA[4].*

Observation and Data Reduction

- Comet 67P was at its perihelion (1.21 AU) on UT November 02, 2021. On UT 12th November, the comet 67P made its closest approach towards the earth at 0.418 AU and was around 0.42 AU from the earth on UT November 21.
- We observed 67P/Churyumov-Gerasimenko using the iSHELL spectrograph at the 3-m NASA Infrared Telescope Facility (IRTF)[5,6] on multiple dates between October 14 – December 15, 2021.
- For the comet data, we used the 0.75" wide slit using an ABBA nod sequence.
- We got our flux calibration using bright IR flux standard star using the 4" wide slit. The wider slit reduces signal loss, allowing for a more accurate measurement of the stellar continuum.
- During our reduction process, we canceled out the background thermal continuum, sky emission (lines and continuum), and instrumental biases to second order in airmass by combining the frames as A-B-B+A (comet-sky-sky+comet). The dark subtracted flats were added which then cleaned of cosmic-ray hits and hot pixels.

Results and Discussion

1. NH_3 and HCN from 67P in the context of JFCs, OCCs, and the Comet Population Measured at the Near-IR wavelengths

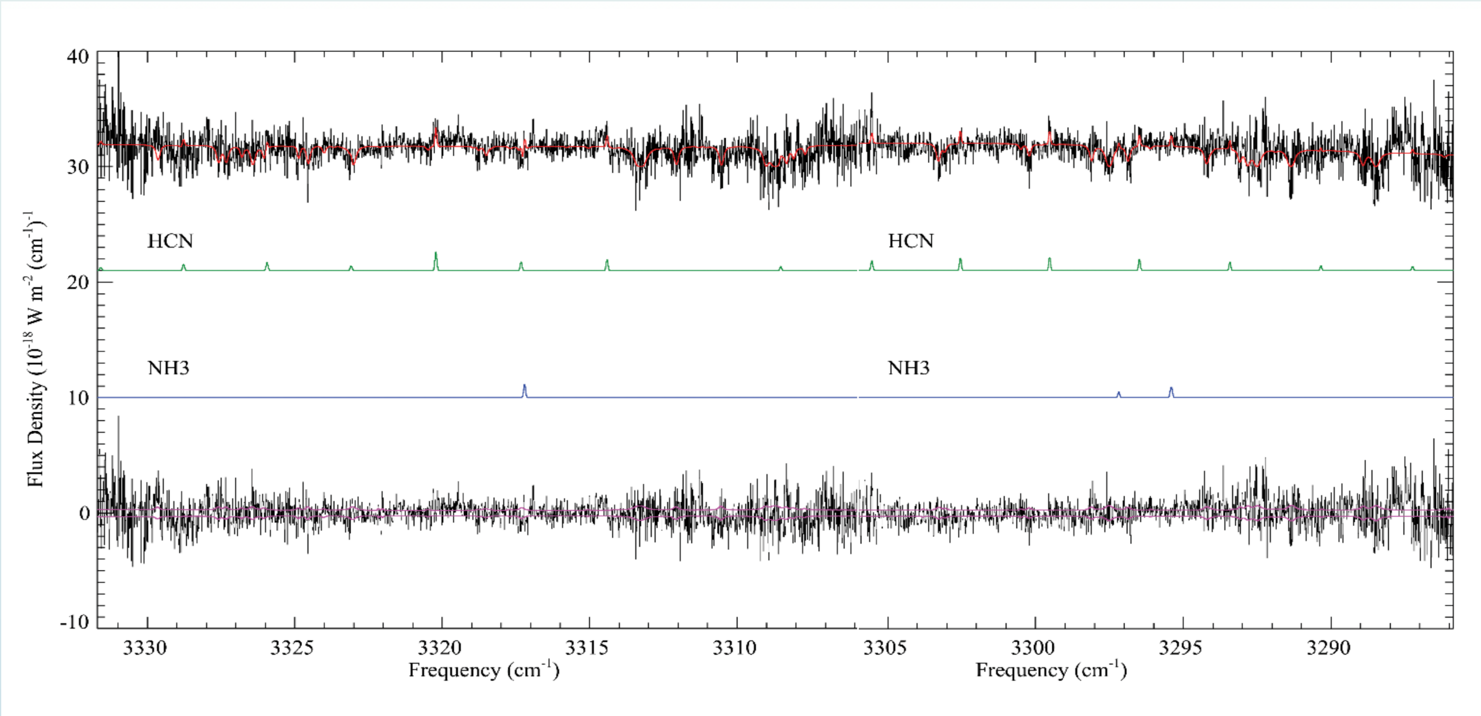

Figure 2. *Best fit fluorescent models of HCN, and NH_3 emission in 67P during the night of UT 2021, November 21. The observed spectra (black) are superimposed with the telluric model (red). The bottom plot indicates the residual superimposed with a 1σ noise envelope.*

Table 1

Mixing Ratios (%, with respect to H_2O) of Primary Volatiles in 67P on UT 2021 November 21 Compared with Other Comets Observed at Near-IR Wavelengths

Molecule	Value in 67P	Mean Value among JFCs*	Mean Value among OCCs*	Mean Value among Comet Population*
HCN	0.25 ± 0.07	0.17 ± 0.03	0.22 ± 0.03	0.2 ± 0.02
NH_3	1.36 ± 0.14	0.59 ± 0.11	0.91 ± 0.30	0.80 ± 0.20

Notes. ** Values from Dello Russo et al. (2016) calculated from 30 comets measured at near-IR wavelengths between 1997 and 2013.*

2. Nitrile Ratio in the context of JFCs, OCCs, and the Comet Population

- The primary nitrogen-bearing compounds in comets are likely HCN and NH_3, but their mixing ratios are loosely linked.
- As a result, comets can be classified based on their total nitrogen mixing ratios (NH_3 + HCN)/H_2O, as well as the highly variable NH_3/HCN or amine/nitrile ratio.

Table 2

Nitrile Ratio Comparison between Comet Families and 67P Observed on November 21, 2021

Nitrile Ratio	Value in 67P	Mean Value among JFCs*	Mean Value among OCCs*	Mean Value among Comet Population*
N/H_2O ^{a}	1.60 ± 0.002	0.78 ± 0.11 (6)	1.12 ± 0.32 (11)	1.00 ± 0.21 (17)
NH_3/HCN	5.52 ± 1.68	4.90 ± 2.00 (7)	3.90 ± 1.20 (9)	4.30 ± 1.10 (16)

Notes. *^{a} $N/H_2O = (NH_3 + HCN)/H_2O$*
** Value from table 7 of Dello Russo et al. 2016. The number inside the parenthesis is the number of measurements used to obtain the mean.*

Results and Discussion

3. Comparing Results with ROSETTA Mission

- Ground-based remote sensing studies do not resolve a comet's nucleus (and hence do not allow for the identification of particular active regions on the surface), and the limited observation time available generally prevents sampling of a comet's entire surface throughout a rotation cycle[7].

Table 3

Mixing Ratios (%, with respect to H_2O) of Primary Volatiles in 67P on UT 2021 November 21 Compared with results from ROSETTA mission[9].

Molecule	iSHELL	Summer Hemisphere	Winter Hemisphere
HCN	0.25 ± 0.07	0.09	0.62
NH_3	1.36 ± 0.14	0.06	0.15
C_2H_2	0.14 ± 0.04	0.045	0.55

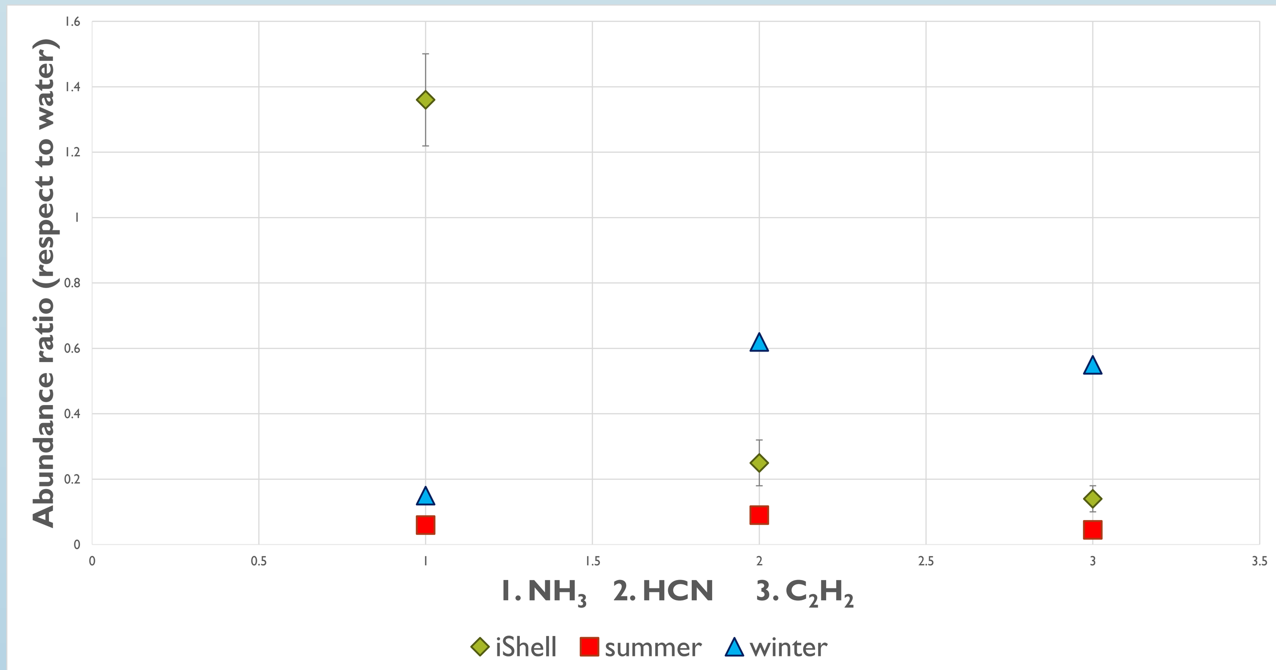

Figure 2. *Graphical representation of comparison on abundance ratio (in %) results from iSHELL instrument and Rosetta[9].*

Acknowledgments

The lead author would like to thank Dr. Erika Gibb, Younas Khan, Mohammad Saki and Chemeda Ejeta for their mentorship through learning the observing and reduction process. Also, huge thanks to the team of Society of Physics Student (SPS) for their generous funding towards our poster presentation for Physcon 2022 conference. Various co-authors gratefully acknowledge the generous support by the NSF Planetary Astronomy Program (NSF 2009910) and the NASA Missouri Space Grant Consortium. Data for this study were obtained at the NASA Infrared Telescope Facility (IRTF), operated by the University of Hawai'i under contract NNH14CK55B with the National Aeronautics and Space Administration (NASA).

References

[1]Bockelée-Morvan, D., Crovisier, J., Mumma, M. J., & Weaver, H. A. 2004, in Comets II, ed. M. C. Festou, H. U. Keller, & H. A. Weaver (Tucson, AZ: Univ. Arizona Press), 391
[2]Mumma, M. J., & Charnley, S. B. 2011, ARA&A, 49, 471
[3]The European Space Agency (ESA). (n.d). Rosetta timeline. https://www.esa.int/Education/Teach_with_Rosetta/Rosetta_timeline/
[4]The European Space Agency (ESA). (n.d). Comet on 7 July 2015 – NavCam. https://www.esa.int/ESA_Multimedia/Images/2015/07/Comet_on_7_July_2015_NavCam
[5]Rayner, J., Bond, T., Bonnet, M., et al. 2012, Proc SPIE, 8446, 84462C
[6]Rayner, J., Tokunaga, A., Jaffe, D., et al. 2016, Proc SPIE, 9908, 990884
[7]Khan, Y., Gibb L., E., Bonev P., B., et al. 2021, The Planetary Science Journal, 2, 20
[8]Dello Russo, N., Kawakita, H., Vervack, R. J., Jr., et al. 2016, Icar, 278, 201
[9]Roy, L. L., Altwegg, K., Balsiger, H., et al. 2015, A&A 583