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Developing a New Taxonomy for Comets Based on Updated Molecular Abundances

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Abstract

We present revised results for the main molecular species (H_2O, C_2H_6, CH_3OH, HCN, C_2H_2, NH_3, CH_4, H_2CO, CO) in twenty comets observed with NIRSPEC, starting from 1999. The new results, obtained using updated models and procedures, demonstrate the necessity and the importance of having a complete, consistent and unbiased sample for obtaining a reliable comet taxonomy; comet 67P will be discussed in this context.

1. Introduction

Knowing the chemical composition of cometary nuclei is fundamental to understanding the formation and evolution of matter within the early Solar System ([1]). Comets probably formed from the icy and dusty material present in the protoplanetary disk at diverse distances from the young Sun (between 5 and 30 AU) and, after their formation, they were scattered by gravitational interactions with forming giant planets into the Kuiper Belt and the Oort cloud ([2]), where they remained frozen and mainly unaltered until today.
For this reason, these small bodies are considered among the least modified objects of our Solar System and, depending on their heritage, their composition is expected to reflect the chemical and physical conditions that could have affected part of the material in the protoplanetary disk.
Since 1985, more than 60 cometary nuclei have been investigated using ground-based high resolution infrared spectrometry in the region between 2 and 5 μm, and many efforts have been made to create a reliable classification of these bodies ([1,3]).
Considering that data analysis techniques and molecular and atmospheric models have been continuously changed and improved over the last decades, it emerges that a chemical classification of comets based on their previously retrieved chemical composition may be affected by systematic uncertainties that were introduced by different reduction and retrieval approaches.
We collected all the available spectra in a comprehensive database, and using a robust and common set of analytical tools we can now correct for discrepancies in reduction methodologies and apply a reliable statistic to the results.

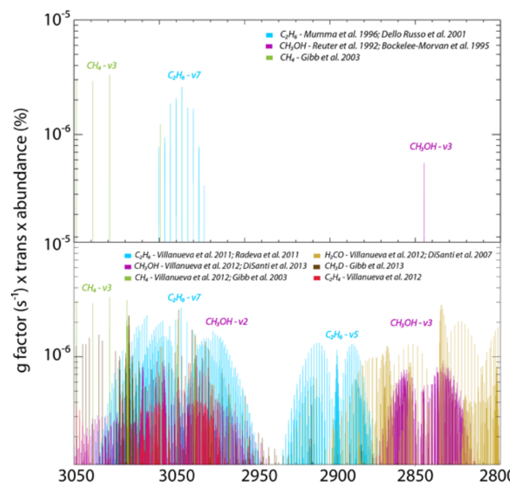

Figure 1. Comparison between molecular models used to interpret cometary spectra, before (upper plot) and after 2011 (bottom plot) (adapted from [4])

2. Results

At the moment, we have extracted updated rotational temperatures, production rates and mixing ratios (MR) for twenty comets; in this process we have corrected for irregularities in the previous data and have introduced values not reported in the past due to the lack of specific molecular models (Figure 1). From our analysis it is clear that for comets observed before 2011 the difference between our results and the previous ones can be dramatic, as for example for comet C/1999 S4 (Figure 2, upper limits are 3-σ); as expected, the differences tend to be smaller for comets observed after 2011, even if in some cases we still can see some discrepancies between our updated results and the previous ones (Figure 3).

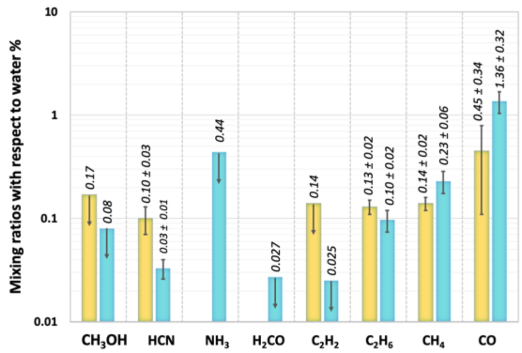

Figure 2. Comet C/1999 S4: comparison between previous ([5], yellow bars) and new MR (cyan bars).

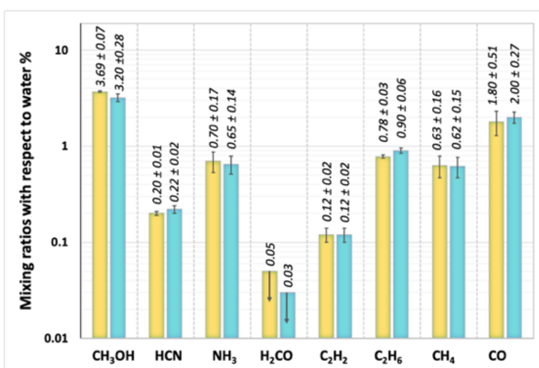

Figure 3. Comet C/2007 W1: comparison between previous ([6], yellow bars) and new MR (cyan bars).

With the new results we started to implement a statistical analysis for these objects (Figure 4), trying to understand: 1) how the individual molecular species are distributed among nuclei, 2) if there are obvious ways to group comets into families, and 3) if there exists a correlation between comet composition and protoplanetary disk models; comet 67P will be discussed in this context.

Soon we will include in our analysis ortho-to-para ratios and nuclear spin temperatures, and isotopic abundances. The final goal is to collect all the possible information that we can retrieve from each spectra and to apply data mining techniques to infer a chemical taxonomy for these bodies.

3. Summary and Conclusions

We present updated results for rotational temperatures, production rates and mixing ratios for twenty comets observed with NIRSPEC since 1999. Our new analysis is unique, since it employs an automated procedure, limiting the human error factors, and it makes use of the latest fluorescence quantum models, updated with the most recent molecular parameters. Moreover, we modeled the atmospheric features using very accurate recently developed tools, and the new results show clearly the importance in updating previous values, especially for comets observed before 2011 (which constitute over half of the database). We are now able to explore the properties of each comet to obtain some hints about its origins. Moreover, we can now try to apply data mining techniques to the new results to explore trends and similarities among different comet populations and to finally build a firm comet taxonomy based on volatile composition.

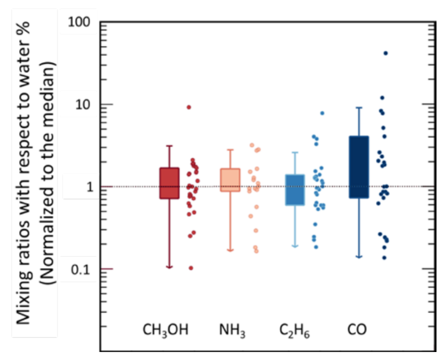

Figure 4: Boxplot distributions of MR in comets (relative to water and normalized to the median value of each molecule).

Acknowledgements

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