Molecular oxygen at comet 67P: Detection and origin

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Molecular oxygen was unexpectedly detected in the coma of comet 67P by the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA)/Double Focusing Mass Spectrometer (DFMS) instrument persistently, at a density ratio, υ_{O2}, relative to water between 1 and 10% [Bieler et al., *Nature*, 2015]. Independently, O_2 was remotely detected with Alice through the spectroscopic analysis of FUV emissions from the coma during gas outbursts with the Alice instrument [Feldman et al., *Astro.J. Lett.*, 2016]. During these extreme events, a density ratio υ_{O2} was found to reach very large values, larger than 50%. O_2 was later detected through absorption features during stellar occultations [Keeney et al., *MNRAS*, 2017]. This technique yielded a density ratio υ_{O2} between 11 and 68%, significantly higher than the values derived from ROSINA/DFMS. We present a new analysis of the detection of O_2 through a multi-instrument approach combining neutral density and composition from ROSINA, energetic electron intensity from Rosetta Plasma Consortium (RPC)/Ion and Electron Spectrometer (IES) and FUV emission brightness from Alice. This analysis is performed for nadir viewing over the shadowed nucleus in the northern hemisphere. The outcome seems consistent with the density ratio υ_{O2} from ROSINA/DFMS.

The presence of molecular oxygen at a comet was neither anticipated nor predicted. Since its detection at comet 67P, measurements from the Neutral Mass Spectrometer on board Giotto in the coma of 1P/Halley were found to be compatible with the presence of O_2 with a υ_{O2} around 4% [Rubin et al., *Astrophys. J. Lett.*, 2015]. Molecular oxygen has not only been detected unambiguously for the first time, but might be a rather common species having now been detected at a Jupiter family comet and at a comet from the Oort cloud. Its origin remains however an open debate. Beside a primordial origin which is compatible with the amount and trend of O_2 observed [e.g., Taquet et al. *MNRAS*, 2016; Mousis et al. *Astrophys. J.*, 2018], several mechanisms have been proposed, including the one based on Eley-Rideal (ER) reactions driven by energetic ions hitting the nucleus' surface [Yao and Giapis, *Nature Comm.*, 2017]. Combining estimates of the outgassing rate and ionization frequency from ROSINA and RPC dataset, even when generous assumptions are made the ER mechanism cannot generate the observed amount of molecular oxygen. Furthermore, the O_2 density observed by ROSINA/DFMS is found to be anti-correlated with the flux of energetic ions measured by RPC/Ion Composition Analyser (ICA) and driving the ER reactions [Heritier et al., *Nature Comm.,* 2018]. Recent ROSINA/DFMS observations of isotope oxygen ratios derived from water [Schröder et al., *A&A*, 2018] and from molecular oxygen shed new lights on the primordial origin.