Atlas of cometary lines obtained from high-resolution optical spectra of comets C/2002 T7 (LINEAR) and C/2016 R2 (PanSTARRS). P. Hardy[1,2], E. Jehin[3], P. Rousselot[2], D. Hutsemékers[3], J. Manfroid[3], [1]LICB, UMR 6303 CNRS-Univ. Bourgogne, 9 Av. A. Savary, BP 47870, F-21078 Dijon Cedex, France (e-mail address : pierre_hardy@etu.u-bourgogne.fr), [2]Institut UTINAM, UMR 6213 CNRS-Univ. Franche-Comté, BP 1615, F-25010 Besançon Cedex, France, [3]STAR Institute, Univ. Liège, Allée du 6 Août 19c, 4000 Liège, Belgium

Introduction: As leftovers of the Solar System formation, comets are often considered as fossils containing clues about the formation of our star, its planets, and other small bodies. At optical wavelengths, spectra of comets are composed of emission lines mainly produced from fluorescence-resonance of cometary radicals, ions, and atoms (the so-called "daughter" cometary species) added to the scattered solar light from the dust grains. Using high-resolution optical spectra of two comets, we produced an atlas of emission lines occurring in cometary environments.

Observations: C/2002 T7 (LINEAR) is a bright long-period comet that was observed in 2004 at small heliocentric and geocentric distances (respectively 0.68 and 0.61 au) [1], with the VLT/UVES spectrometer. A slit width of 0.45" and two different settings were used, the DIC1 (346/580 nm) and the DIC2 (437/860 nm) in order to cover the whole optical range (from 304 to 1040 nm).

C/2016 R2 (PanSTARRS) was observed with the same spectrometer in 2018 [2] at a larger heliocentric distance (2.76 au). The spectrum spans 330-1000 nm.

In both cases, data were reduced using the ESO UVES pipeline. Cosmic rays were removed, and spectra were shifted in the Earth frame, by considering the geocentric velocities.

Detection and identification of emission lines: The small heliocentric and geocentric distances of C/2002 T7 (LINEAR) coupled with the high-resolution of the UVES spectrometer (R~100,000) led to one of the best cometary optical spectra ever obtained, containing thousands of emission lines.

After dust continuum subtraction using the solar spectrum of Kurucz [3], we studied the cometary emission lines by developing an automatic line detection, and by identifying them using high-resolution molecular line lists found in the Exomol database [4], derived from recent fluorescence models, or more generally found in the literature.

Sky emission lines observed by VLT/UVES in 2001 [5] were used to confirm the cometary nature of detected emission lines.

Emission lines of CO^+ and N_2^+ ions were analyzed thanks to the spectrum of comet C/2016 R2 (PanSTARRS), because those species are much brighter in this comet compared to most of other comets.

Results: We present an atlas of cometary emission lines, containing 22,000 detected emission lines. Among those, approximately 75% were successfully identified as radicals (C_2, NH_2, C_3, OH, CH, NH), ions (OH^+, CH^+, H_2O^+, CO^+, N_2^+) or atoms ([OI], [CI], [NI], NaI, FeI, NiI). Figure 1 represents a small region of the atlas, where C_2, NH_2, and unidentified lines are indicated.

On the other hand, 25% of detected lines could not be identified. By comparing our atlas with former atlas (such as [6] and [7]) we observe that, even if the number of identifications increases thanks to a better resolution and a greater spectrum coverage, the proportion of unidentified lines among the detected ones stays roughly the same. Moreover, most of unidentified bands are found in all atlases. This indicates that some molecular species are yet to be identified in cometary optical spectra.

Identifying those bands should be the priority as it will improve our understanding of physical and chemical processes occurring in the coma.

Our atlas of emission lines will certainly be useful in the cometary community to analyze spectra, but also for astronomers working in visible spectrometry. A free, interactive website displaying our atlas is currently in preparation.

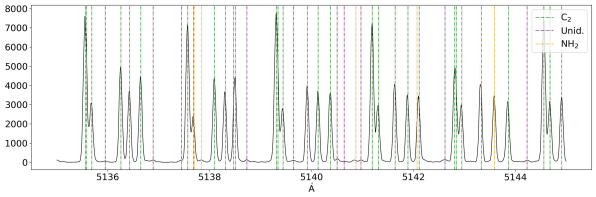

Figure 1 : Spectrum of C/2002 T7 (LINEAR) between 5135 and 5145 Angstroms. Lines of C_2 and NH_2 are respectively indicated by green and orange lines. Purple lines indicate unidentified emission lines.

References:

[1] Hutsemékers et al. (2008) *A&A, 490, L31-L34.* [2] Opitom, C. et al. (2019) *A&A, 624, A64.* [3] Kurucz R. L. (2005) *Mem. S.A.It Suppl., vol. 8, 189.* [4] Tennyson, J. et al. (2016) *Journal of Molecular Spectroscopy, 327, 73-94.* [5] Hanuschik R. W. (2003) A&A 407, 1157-1164. [6] Cochran A. L. and Cochran W. D. (2002) Icarus, 2002, vol. 157, 2, 297–308. [7] Cambianica et al. (2021), A&A, 656, A160.