FLUORESCENCE SPECTRUM OF $^{12}CO^+$ AND $^{13}CO^+$ IN COMETS. P. Rousselot[1], E. Jehin[2], D. Hustemékers[2], C. Opitom[3], J. Manfroid[2], P. Hardy[1,4], [1]Institut UTINAM, UMR 6213 CNRS-Univ. Franche-Comté, BP 1615, F-25010 Besançon Cedex, France (e-mail address: philippe.rousselot@obs-besancon.fr), [2]STAR Institute, Univ. Liège, Allée du 6 Août 19c, 4000 Liège, Belgium, [3]Institute for Astronomy, Univ. Edinburgh, Royal Observatory, Edinburgh EH9 3HJ, UK, [4]LICB, UMR 6303 CNRS-Univ. Bourgogne, 9 Av. A. Savary, BP 47870, F-21078 Dijon Cedex, France

Introduction: Despite the fact that CO can be an abundant species in comets (relative production rate compared to water varying between 0.3 and 26% [1] or even more in the unusual case of C/2016 R2 (PansSTARRS)), its ionization product, CO^+, presents usually faint emission lines. A few comets, mainly C/2016 R2, have nevertheless been observed with bright CO^+ emission lines appearing in the optical range. Such emission lines offer the opportunity to perform a good modeling of this fluorescence spectrum, leading to the possibility of measuring the $^{12}C/^{13}C$ isotopic ratio for this species. It is the goal of the development of a new $^{12}CO^+$ and $^{13}CO^+$ fluorescence model.

The model: The CO^+ emission lines observed in the optical range belong to the comet tail system, i.e. to the $A^2\Pi_i$-$X^2\Sigma^+$ electronic transition. We developped a fluorescence model taking into account the first six vibrational levels of these two electronic levels, as well as the $B^2\Sigma^+$ electronic level. These later transitions with the ground electronic state can also influence the relative populations of the $X^2\Sigma^+$ state. Thanks to accurate wavelengths obtained from laboratory experiments for both $^{12}CO^+$ and $^{13}CO^+$ it has been possible to model the emission lines belonging to the main bands ((5,0), (4,0), (3,0), (2,0), (1,0)) with a high accuracy for these two isotopologues, by assuming that they have similar transition probabilities.

Observations: The synthetic spectra obtained with our fluorescence model have been compared to spectra of the comet C/2016 R2 obtained with the Ultraviolet-Visual Echelle Spectrograph (UVES) mounted on the ESO 8.2 m UT2 telescope of the Very Large Telescope (VLT). A total of five different observing nights were used, corresponding to February 11, 13, 14, 15 and 16, 2018. One single exposure of 4800 s of integration time with two different settings simultaneously was obtained during the first three nights and one exposure of 3000 s for the two last ones. We used a narrow 0.44" slit with a slit height varying between 8" and 12" corresponding to about 14,500 to 21,750 km at the distance of the comet (geocentric distance of 2.4 au). The resolving power was R~80,000. The average heliocentric distance was 2.76 au and the heliocentric velocity was 6 km s^{-1}. As explained in [2], the data were reduced using the ESO UVES pipeline, combined with custom routines to perform the extraction and cosmic ray removal, and were then corrected for the Doppler shift due to the relative velocity of the comet with respect to the Earth.

Results: Our fluorescence spectrum fits well the observational 1D spectra, averaged for each setting along the whole slit and the different observing nights to obtain a better signal-to-noise ratio. The (5,0), (4,0), (3,0), (2,0), (1,0), (3,2), (1,1), and (1,2) bands of the $A^2\Pi_i$-$X^2\Sigma^+$ electronic transition located between 3590 and 5670 Å are clearly visible with a good signal-to-noise ratio. Fig. 1 presents an example of the quality of our modeling for the (1,1) band, $A\Pi_{3/2}$-$X^2\Sigma^+$ transition (average spectrum for the nights February 11, 13, 14).

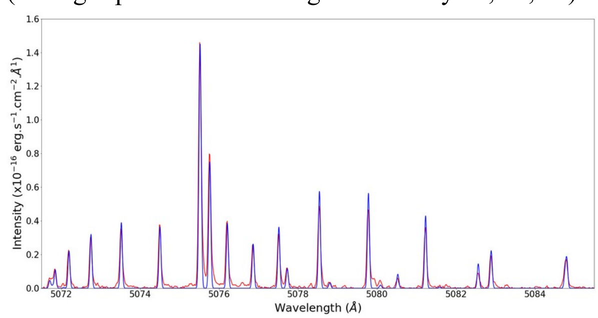

Fig.1: Comparison of our fluorescence model (in blue) with the observational spectrum of C/2016 R2 for the (1,1) band (in red).

Thanks to our model we can both compute new values for the fluorescence efficiency factors (compared to the one published by [3]) and the Swings effect that affects these values. Because our model can also predict the position and intensities of the $^{13}CO^+$ emission lines it can be used to measure the $^{12}C/^{13}C$ ratio in CO^+ ions. Even if these lines are weak and close to the noise level a coaddition of a few tens of $^{13}CO^+$ emission lines, compared to the coaddition of the corresponding $^{12}CO^+$ lines allows us to derive efficiently the $^{12}C/^{13}C$ isotopic ratio for this species. We will present these new results during the meeting.

References: [1] Dello Russo N. et al. (2016) *Icarus, 278*, 301–332. [2] Opitom C. et al. (2019) *A&A, 624,* id.A65, 14 pp. [3] Magnani L. and A'Hearn M.F. (1986) *ApJ, 302*, 477-487