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Modeling of the CO^+ emission spectrum in comet C/2016 R2 (PanSTARRS)

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Abstract

The long period comet C/2016 R2 (PanSTARRS), discovered on 2016 September 7 by the PansSTARRS telescope, presented an unusual composition. Most of the emission lines due to radicals usually abundant in comets (such as C_2, CN, C_3) appeared to be faint while unexpected strong emission lines due to N_2^+ and CO^+ ions were clearly apparent in the spectra obtained in the optical range (some fainter CO_2^+ emission lines were also present). It is the first comet with such bright N_2^+ emission lines but also the brightness and abundance of CO^+ lines allow to study this ion in great details. We obtained in February 2018 high resolution spectra with the ESO 8-m Very Large Telescope and the UVES spectrograph, that allowed us to obtain a CO^+ spectrum with an unprecedented signal-to-noise ratio. We also developed a fluorescence model for CO^+ to model these spectra. We will present these observations, their modeling and a first estimate of the $^{12}C/^{13}C$ isotopic ratio for CO^+ ions in comet C/2016 R2. It is the first measurement of such a ratio with ground-based telescopes, the only related measurement published so far being done in situ in the coma of comet 67P/Churyumov-Gerasimenko by the ROSINA instrument on-board the Rosetta spacecraft for CO and CO_2 molecules [6][3].

1. Introduction

The CO^+ and H_2O^+ ions are dominant in the tail of a comet. This is due to the fact that water molecules as well as carbon monoxyde and carbon dioxyde are the dominant species in comets. In somes cases it is possible to observe bright CO^+ emission lines even in the inner coma. This was the case for the long period comet C/2016 R2 (PanSTARRS) which presented an unusual spectrum, dominated by N_2^+ and CO^+ emission lines in the optical range [2][5][7].

Such bright emission lines offered the possibility of testing the modeling of CO^+ emission spectrum and also to measure the $^{12}C/^{13}C$ isotopic ratio in CO^+.

2. Observations

Five hours of Director's Discretionary Time, with the Ultraviolet-Visual Echelle Spectrograph (UVES) mounted on the ESO 8.2 m UT2 telescope of the Very Large Telescope (VLT) were allocated to observe C/2016 R2. A total of five exposures were obtained on February 11, 13, 14, 15 and 16, 2019, with two different dichroics covering the spectral range from 326 to 1060 nm. We used a 0.44 arcsec wide slit providing a resolving power R$\sim$80,000. The exposure times was 4800 s for dichroic #1 and 3000 s for dichroic #2 while the heliocentric distance was 2.75 au at the time of the observations [5].

Fig. 1 presents the average spectrum obtained with the dichroic #1 in the spectral region corresponding to a bright CO^+ band, after a complete data processing. In this spectrum the continuum, including the sunlight reflected by the cometary dust grains, was removed using a BASS2000 solar spectrum whose slope was corrected to match that of the comet. The Doppler shift due to the relative velocity of the comet with respect to the Earth was also corrected.

3. Model of the CO^+ spectrum

The CO^+ emission lines appearing in the optical range belong to the comet tail system, i.e. to the $A^2\Pi_i$-$X^2\Sigma^+$ transition. We developed a model based on these two electronic levels. We considered the vibrational levels up to $v = 5$ for the $X^2\Sigma^+$ state and $v = 6$

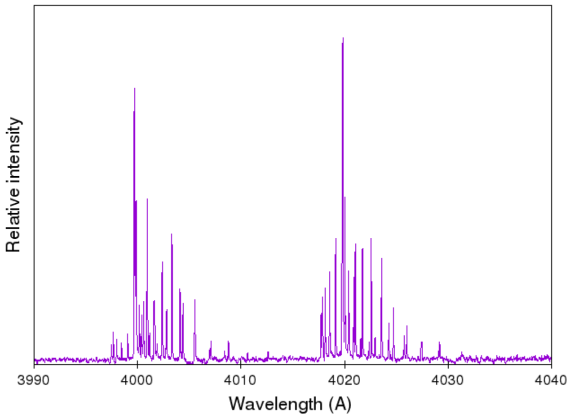

Figure 1: Average UVES spectrum of the (3,0) band of CO^+ around 4000 Å.

for the $A^2\Pi_i$ state, each of them with all the energy levels corresponding to the rotational quantum number $N \leq 10$.

We computed the equilibrium population for CO^+ ions receiving a solar flux at the heliocentric distance and velocity of the comet, with a method similar to the one presented in [4].

4. $^{12}C/^{13}C$ isotopic ratio in CO^+

The $^{12}C/^{13}C$ isotopic ratio was measured in different objects of the solar system, including comets. The terrestrial value is 89 and is similar to the one measured in other solar system objects (Sun, Venus, the Moon, Mars, Jupiter, Saturn, Titan, Neptune, meteorites, IDPs). This ratio is larger than the value of $\sim$68 measured in the local interstellar medium, that may result from a ^{13}C enrichment since the formation of the Solar System. For the comets such measurements mainly come from the C_2 and CN radicals and the HCN molecule (the CN coming mainly from HCN). The ratios published so far for these species are in the range $\sim$80-110, in agreement with the terrestrial value but with large error bars (see [1] for more details). In situ measurements obtained in the coma of comet 67P were published recently, for the CO, CO_2, C_2H_4 and C_2H_5 molecules [3][6], the CO_2 appearing slightly enriched in ^{13}C compared to solar abundance.

Our high resolution and high signal-to-noise spectra of CO^+ permitted to measure the $^{12}C/^{13}C$ isotopic ratio. Because no $^{13}CO^+$ emission line can directly be observed on our average spectrum we coadded all the $^{13}CO^+$ lines corresponding to a bright $^{12}CO^+$ line. Such a coaddition, based of a few tens of lines, is the only possibility to get enough signal-to-noise for mesuring the $^{12}C/^{13}C$ isotopic ratio. At the end we managed to detect the $^{13}CO^+$ emission lines and to derive an estimate of the $^{12}C/^{13}C$ ratio in CO^+. Our preliminary result is that this ratio is compatible with the terrestrial value.

5. Conclusion

Thanks to the comet C/2016 R2, and to our high resolution and high signal-to-noise spectra, it is possible to test accurately the modeling of CO^+ emission spectrum. It is also possible to measure the $^{12}C/^{13}C$ isotopic ratio in this species for this comet and others with bright ionic tails, opening a new way to access to this important measurement. Our preliminary result in C/2016 R2 is in agreement with the terrestrial value.

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