



A new cometary fluorescence model for CN and its isotopologues

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The CN radical is a well known species in cometary spectra. It was first identified in 1881 in the bright comet C/1881 K1 also known as comet Tebbutt (Huggins, 1881) thanks to its bright near-UV emission band, observed at that time as two emission lines located at 387 and 388.3 nm. This relative ease of observation of this band has allowed the abundance of CN to be measured in many comets, contributing to the establishment of cometary taxonomic groups (see e.g. A'Hearn et al., 1995). It also offers the possibility of measuring the ¹⁴N/¹⁵N and ¹²C/¹³C isotopic ratio of this species and its parent molecule (Arpigny et al., 2003 ; Manfroid et al., 2009 ; Bockelée-Morvan et al., 2015). The main contributor to CN is HCN but it is not the only one, this radical also being produced by dust grains or by other parent molecules ejected from the nucleus (Fray et al., 2005 ; Hänni et al., 2020).

A quantitative study of CN abundance requires modeling its fluorescence spectrum and a good knowledge of the different transition probabilities. Arpigny (1964) showed that the CN spectrum cannot be explained by a Boltzmann distribution but rather by solving a system of steady-state equations describing a resonance-fluorescence excitation mechanism. A first fluorescence model was published by Tatum & Gillespie (1977) who calculated the radiance of the (0,0) band at 388 nm as a function of the heliocentric velocity. A similar model was performed by Mumma et al. (1978), but with a different Einstein-A coefficient and solar spectrum (integrated over the solar disk), leading to significantly different results. More detailed fluorescence models were published later by Schleicher (1983), Tatum (1984), Zucconi & Festou (1985), Kleine et al., (1994) and Schleicher (2010). Some of these models include the three main isotopologues (¹²C¹⁴N, ¹³C¹⁴N, ¹²C¹⁵N). More recently Paganini & Mumma (2016) published a model covering infrared and optical wavelengths for the main isotopologue ¹²C¹⁴N.

All these models rely heavily on the data available in the scientific literature regarding transition probabilities. Thanks to an improved line list for radiative transitions between the first three electronic levels of CN we decided to develop a new CN fluorescence model. The calculation method for this large data set is presented in Kozlov et al. (2024) and the complete data (energy levels and transition probabilities between and within electronic level) are available in the ExoMol database¹. Our model can be compared with the high-resolution spectra obtained with the UVES spectrometer at VLT for different comets, over the last two decades.

To model the CN emission spectrum of comets, both in the optical and infrared domains, it is necessary to consider the first three electronic levels : X²Σ⁺, A²Π_i and B²Σ⁺. These states produces three band systems : the red system (A-X), the violet system (B-X) and the LeBlanc system (B-A). The main (0,0) emission band observed in comets at 388 nm belongs to the violet system. These three electronic transitions, as well as the different transitions inside them, are taken into account in

the ExoMol data used in our model.

Our model is based on a steady-state equilibrium. We used the formalism developed by Zucconi & Festou (1985), that is, we reduced the system of equations to the number of levels of the ground electronic state (X), which led to the calculation of the relative populations of the levels of this state. The relative populations of the upper state are then derived from these ground state populations, since they are several orders of magnitude smaller than the ground state relative populations.

The results of this new model will be presented and compared to observational data obtained with the UVES spectrometer at VLT. This modeling is in good agreement with the observational data. Fluorescence efficiency – g factors – will also be presented, for the three main isotopologues.

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¹<https://www.exomol.com/>