A new near-IR C_2 linelist for improved chemical analysis of hydrogen deficient carbon-rich giants

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Abstract. Diatomic carbon (C_2) is ubiquitous in astronomical environments, from comets and stars to translucent clouds and the interstellar medium. In particular, the C_2 bands (mainly the Ballik-Ramsay and Phillips transitions) are an important source of opacity in the near-IR region of carbon stars such as the hydrogen deficient carbon-rich (HdC) or R Coronae Borealis (RCB) stars. Present C_2 linelists are still not accurate enough (e.g., in wavelength positions) to model the near-IR spectra of HdC and RCB stars, strongly limiting our ability to properly model their complex spectra and to extract the elemental (an isotopic, when possible) abundances of key elements like C, N, O, F, etc. Very recently, a new near-IR C_2 linelist (including both Ballik-Ramsay and Phillips systems, among others) have been generated by the ExoMol project (Yurchenko et al. 2018; see `www.exomol.com`). The synthetic spectrum constructed for the benchmark HdC star HD 137613, using this new C_2 linelist, provides an unprecedented match to its high-resolution (R∼50,000) observed spectrum. The new C_2 linelist is thus expected to significantly improve the near-IR chemical analysis for HdC and RCB stars but also for normal carbon stars (e.g., C-rich AGB and dwarf stars) and even Solar System bodies like comets.

1. The C_2 molecule

Diatomic carbon (C_2) is an abundant molecule in a wide variety of astrophysical environments, including interstellar and translucent clouds, comets, cool carbon stars (normal and asymptotic giant branch (AGB) stars), (proto-)planetary nebulae,, and even our own Sun. Indeed, the C_2 spectra are commonly used to determine the $^{12}C/^{13}C$ isotopic ratio in carbon stars (Zamora et al. 2009) and comets (Stawikowski & Greenstein 1964).

In particular, the C_2 molecule is an important source of opacity in the near-IR region of carbon stars (especially through the Ballik-Ramsay and Phillips transitions) such as the enigmatic hydrogen deficient carbon-rich (HdC) or R Coronae Borealis (RCB) stars (see e.g., Lambert & Rao 1994 for a review). Previous C_2 linelists were still not accurate enough (e.g., in wavelength positions) to model properly the near-IR spectra of HdC and RCB stars (e.g., García-Hernández et al. 2009, 2010), severely limiting our ability to measure the elemental an isotopic abundances of key elements like C, N, O, F, etc., which are essential to unveil the scenario of their origin.

2. The new C_2 linelist

Very recently, accurate linelists for the C_2 molecule have been reported by the ExoMol project (Yurchenko et al. 2018[1]). They cover the rovibronic transitions between the eight lowest electronic states, which include several C_2 band systems (see Figure 1 in Yurchenko et al. 2018). Motivated by the spectroscopic APOGEE survey (Majewski et al. 2017), here we are mainly interested in the H-band (1.5−1.7 μm), which is mainly affected by the Ballik-Ramsay and Phillips systems. Figure 1 shows the C_2 lines from the Ballik-Ramsay and Phillips systems in the H-band (from 1.5 to 1.6 μm).

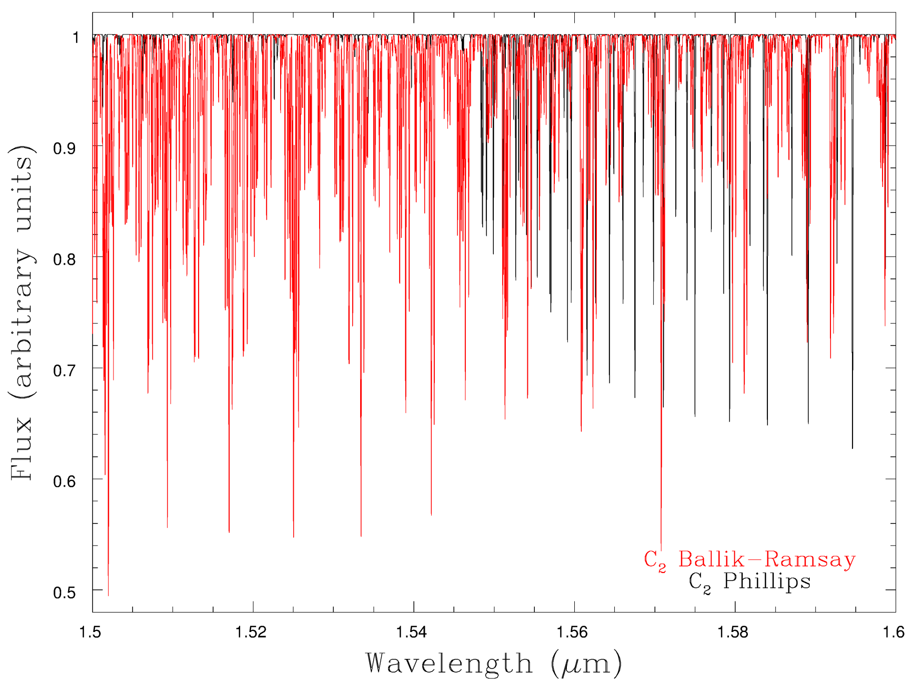

Figure 1. Synthetic H-band (1.5−1.6 μm) spectra (constructed for the benchmark HdC star HD 137613) for the C_2 Ballik-Ramsay (in black) and Phillips (in red) lines. Note that the C_2 lines from the Ballik-Ramsay system dominate towards the blue.

[1] See www.exomol.com.

3. The benchmark HdC star HD 137613

A high-resolution (R∼50,000) H-band spectrum of the HdC star HD 137613 - known to harbor a pletora of C_2 lines (García-Hernández et al. 2009) - was obtained in the H-band with the IGRINS spectrograph at the W. J. McDonald Observatory (USA). In order to test the new near-IR C_2 linelist, we constructed synthetic spectra appropiate for HD 137613 (see García-Hernández et al. 2009 for more details) and compared them to the observed IGRINS HD 137613 spectrum. Figure 2 shows that the HD 137613 synthetic spectrum, using the new C_2 ExoMol linelist, gives an excellent match to the observations.

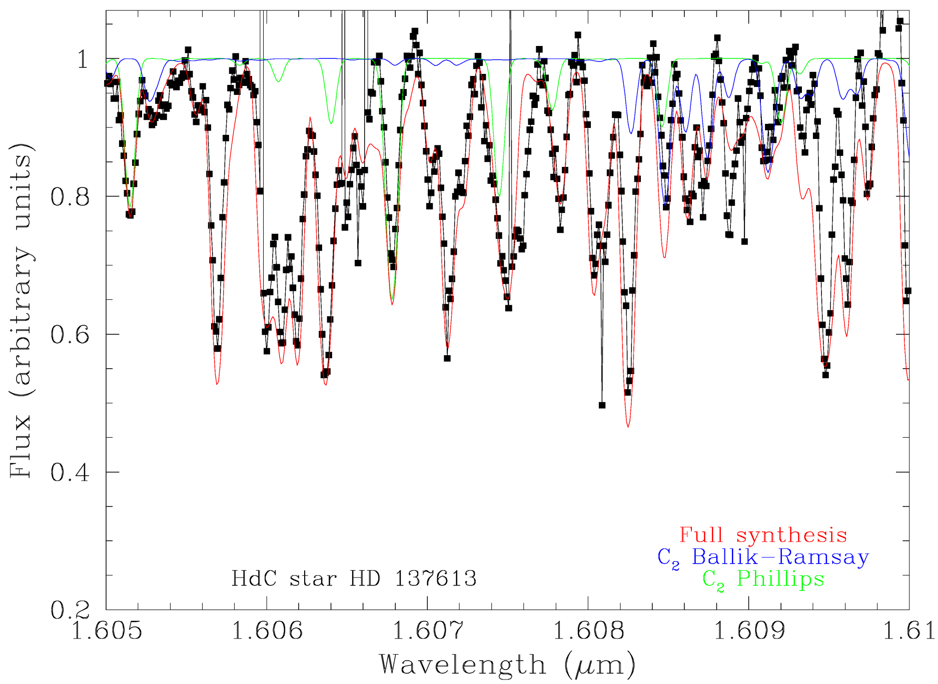

Figure 2. Best synthetic (red) and observed (black) spectrum in a small H-band region (1.605−1-610 μm) for the benchmark HdC star HD 137613. Synthetic spectra for the C_2 lines from the Ballik-Ramsay and Phillips systems are shown in blue and green, respectively. Note that the HD 137613 H-band spectrum is strongly dominated by the $^{12}C^{14}N$ molecule (also included in the full synthesis, among all the other CO and CN isotopologues).

4. Conclusion

By confronting the high-resolution near-IR observations of a hydrogen deficient carbon-rich giant with appropiate synthetic spectra, we conclude that the new C_2 ExoMol linelist is expected to greatly improve the chemical analysis from near-IR spectra in HdC and RCB stars but also in other types of cool carbon stars like C-rich AGB stars (and dwarfs) and even in Solar System bodies such as comets.

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