The Diffuse Interstellar Bands
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A Catalog of Diffuse Interstellar Bands in Fullerene-Containing Planetary Nebulae

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Abstract. Large fullerenes and fullerene-based molecules have been proposed as carriers of diffuse interstellar bands (DIBs). The recent detection of the most common fullerenes (C_{60} and C_{70}) around some Planetary Nebulae (PNe) now enable us to study the DIBs in fullerene-rich space environments. We have studied the presence of DIBs in the optical spectra (∼3300-9400 Å) of two fullerene-containing PNe (Tc 1 and M 1-20). Special attention is given to DIBs which are found to be unusually intense in fullerene-containing PNe; several of these DIBS have not previously been reported. Fullerenes larger than C_{60} (and C_{70}) and multishell fullerenes may be possible candidate carriers for the unusual DIBs seen in fullerene-rich environments.

Keywords. Astrochemistry, circumstellar matter, planetary nebulae: general

1. Introduction

The identification of diffuse interstellar bands (DIBs) has been very elusive since they were first discovered by Heger (1922). Since then, more than 380 bands have been identified (e.g., Hobbs *et al.* 2008). Most of the DIBs are located in the 4000 to 10000 Å wavelength range. Different complex carbon-based molecules - e.g., cabon chains, polycyclic aromatic hydrocarbons (PAHs), and fullerenes - have been proposed as DIBs carriers (see e.g., Cox 2011 for a review). In addition, fullerene-based molecules such as hydrogenated fullerenes (Cataldo & Iglesias-Groth 2009) and multishell fullerenes (Iglesias-Groth 2004) may explain the UV absorption band at 217 nm.

Fullerenes (C_{60} and C_{70}) have recently been detected in space: in planetary nebulae (Cami *et al.* 2010; García-Hernández et al. 2010, 2011a, 2012a), reflection nebulae (Sellgren *et al.* 2010) and the two least H-deficient R Coronae Borealis (RCB) stars (García-Hernández *et al.* 2011b,c).

The recent detection of fullerenes in PNe with normal H-abundances (García-Hernández *et al.* 2010) suggests that large fullerenes may be formed as decomposition products of hydrogenated amorphous carbon (HAC) dust, and that fullerenes may be very common around evolved stars. We have searched for DIBs in two planetary nebulae containing fullerenes, accompanied or not by PAH molecules.

2. Sample selection and optical observations

Both PNe Tc 1 and M 1-20 show fullerenes in their Spitzer Space Telescope spectra, but only M 1-20 has clear PAH emission bands (García-Hernández *et al.* 2010). Tc 1 has

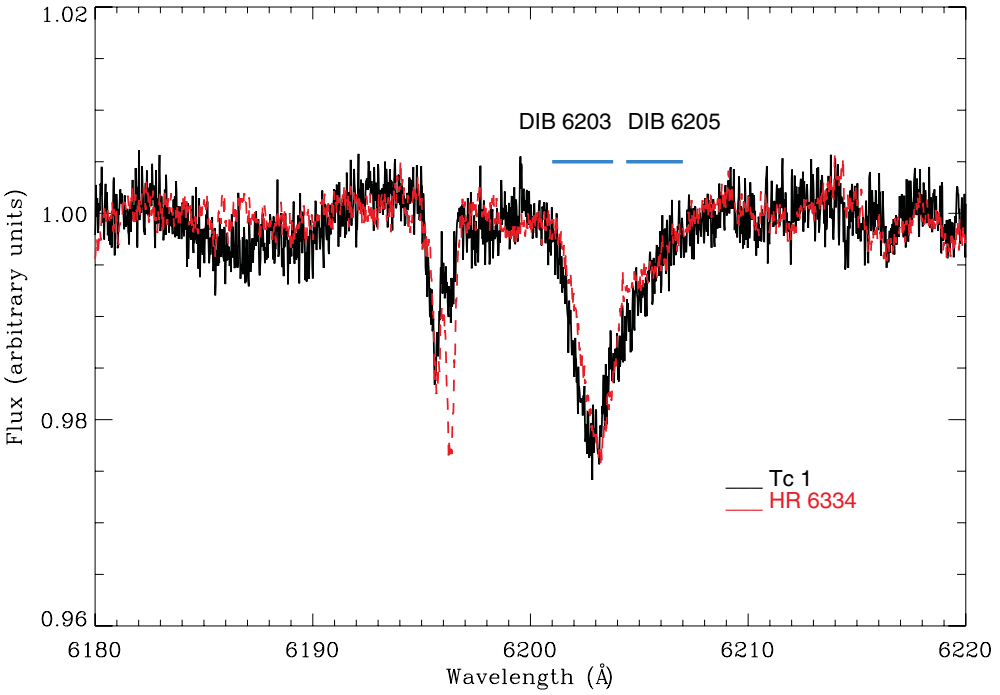

Figure 1. Spectra of Tc 1 (solid, black) and HR 6334 (dashed, red). The DIBs have been marked for identification. Note that HR 6334 displays a reddening (E(B-V)) about two times higher than in Tc 1.

a magnitude $B = 11.1$ and an extinction of $E(B-V) = 0.23$, while M 1-20, $B = 13.7$ and $E(B-V) = 0.80$

The optical observations were carried out between May-September 2011 at ESO/VLT (UT2), (Paranal, Chile) in service mode by using the UVES spectrograph. We covered the spectral ranges between ∼3300-4500, 5750-7500, and 7700-9400 Å using the 2.4 arcseconds slit with the standard setting DIC2 (390+760). This configuration gives a resolution of 15000 and an adequate interorder separation.

Nearby comparison stars were observed on the same dates with the same set-up. For Tc 1 we observed the nearby B1I-type star HR 6334 (B =5.1; $E(B-V) = 0.42$) and for M1-20 the B0I-type star HR 6716 (B =5.7; $E(B-V) = 0.22$). The spectra were processed using the UVES data reduction pipeline (Ballester *et al.* 2000) and the stellar continuum was fitted by using standard astronomical tasks in IRAF. For Tc 1, the total exposure time was 3 hours, obtaining a $S/N = 300$ in the continuum at 4000 Å, while for M 1-20, the total exposure time was 4 hours, obtaining a much lower S/N of about 20 at 4000 Å. As for the comparison stars, we achieved a $S/N > 450$ for both HR 6334 and HR 6716.

3. Results

The spectra were inspected and all the absorption stellar features and emission nebular lines were identified. We identified 21 bands that do not have stellar origin. All except 4 of the bands (3809.7, 3811.9, 4215.3 and 4217.9 Å) appear in the catalog of DIBs by Hobbs *et al.* (2008).

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In Figure 1, we present some of the DIBs detected in Tc 1. García-Hernández & Díaz-Luis (2013) already reported the unusually high intensity of the 4428 Å DIB in Tc 1 (and M 1-20), (see also García-Hernández, these proceedings) and they suggest a possible link of this DIB with the presence of fullerenes bigger than C_{60} and C_{70} (e.g., C_{80}, C_{240}, C_{320}, and C_{540}) and multishell fullerenes (buckyonions such as $C_{60}@C_{240}$ and $C_{60}@C_{240}@C_{540}$ in the circumstellar shell of Tc 1. This possible fullerenes - DIB connection was previously suggested by Iglesias-Groth (2007) from theoretical considerations. Interestingly, DIBs in fullerene-containing PNe are remarkably different from those in the fullerene RCB star DY Cen (García-Hernández *et al.* 2012b; see also García-Hernández, these proceedings).

When comparing the normalized equivalent width (EQW/E(B-V)) of several DIBs in Tc 1 with the reddened star HD 204827 (Hobbs *et al.* 2008), some of the DIBs (e.g., 6036, 6168, 6170, 6270 Å) show similar values, while the rest of DIBs show much higher values for Tc 1. The complex band at ∼6203 Å is especially noteworthy, in which the normalized EQW/E(B-V) is 2−3 times higher for Tc 1 than for the reddened star HD 204827 and for the comparison star HR 6334 (note that HR 6334 displays E(B-V) about two times higher than in Tc 1; see Fig. 1). Based on theoretical studies, Iglesias-Groth (2007) shows that both C_{240} and $C_{60}@C_{240}$ show their strongest transition around 6200 Å. Therefore, we speculate that the detection of an unusually intense 6203 Å band in Tc 1 may support the previous finding of García-Hernández & Díaz-Luis (2013) about the possible presence of fullerenes bigger than C_{60} (and C_{70}) and buckyonions in the circumstellar envelope of Tc 1.

The complete catalog of DIBs observed in Tc 1 and M 1-20 will be published elsewhere.

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