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First evidence of the possible detection of diffuse circumstellar bands in AGB descendants

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Abstract. The short transition phase between asymptotic giant branch stars (AGB; when circumstellar envelopes rich in small organic molecules are efficiently created) and planetary nebulae (PNe) represents a most active phase of molecular synthesis. Different complex organic molecules - e.g., polycyclic aromatic hydrocarbons and fullerenes - have been proposed as carriers of the enigmatic diffuse interstellar bands (DIBs). If the DIBs arise from such large carbon-based molecules, then they are also expected to be present in the circumstellar shells around C-rich AGB descendants; i.e., post-AGB stars and young PNe. Diffuse circumstellar bands (DCBs) in absorption have been unsuccessfully search for more than 40 years; the main difficulty being to distinguish the DCBs from the DIBs. Here we present a detailed DIB radial velocity analysis and a complete search of diffuse bands towards three young PNe (Tc 1, M 1-20, and IC 418) containing fullerenes. Interestingly, we report the first possible detection of two DCBs at 4428 and 5780 Å in the fullerene-rich circumstellar environment around PN Tc 1. This possible detection of DCBs in an environment rich in fullerenes and fullerene-related molecules could provide a link between fullerene compounds and some of the DIB carriers.

Key words. Astrochemistry — Line: identification — circumstellar matter — ISM: molecules — planetary Nebulae: individual: Tc 1, M 1-20, IC 418

1. Introduction

The identification of the carriers of the diffuse interstellar bands (DIBs) represents one of the most enigmatic problems in the interstellar medium (ISM). Different complex carbon-based molecules – e.g., carbon chains, polycyclic aromatic hydrocarbons (PAHs), and fullerenes – have been proposed as DIB's carriers (see, e.g., Cox 2011, for a review). If the DIBs arise from large gas phase molecules, then they are also expected to be present in other carbon-rich space environments like circumstellar shells around stars.

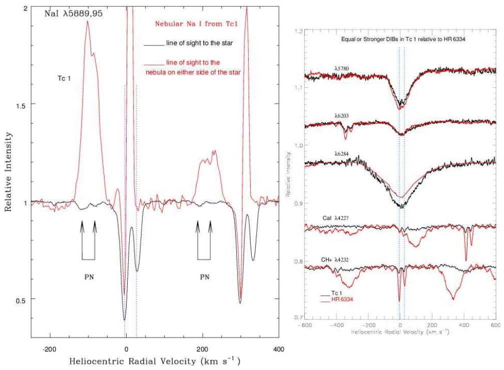

Fig. 1. The left panel displays Na I D lines observed towards PN Tc 1 central star (black) and average of two positions in the nebula 2.7 arcsec away from the central star on either side (red) (from Williams et al. 2008). The dashed blue lines indicate the interstellar Na I D components at -6.8 and $+25$ km s^{-1}. The right panel displays a selection of stronger DIBs in Tc 1 (in black) relative to the nearby comparison star HR 6334 (in red). The CH^+ and Ca I profiles at the bottom show the two interstellar components at -6.8 and $+25$ km s^{-1}. The carrier(s) of these DIBs are enhanced in the sight line to Tc 1 and they may be ionized species.

Diffuse circumstellar bands (DCBs) in absorption have been unsuccessfully studied for more than 40 years. DCBs are absent in the dusty circumstellar envelopes (with or without PAH-like features) of AGB/post-AGB stars, as well as in the atmospheres of cool stars and Herbig Ae/Be stars. Thus, the conventional wisdom is that there are no diffuse bands in circumstellar environments.

The unambiguous detection of DCBs would have a strong impact on diffuse bands theories; for example, they can be compared to the presence of the proposed diffuse band carriers mentioned above.

2. Unusually strong DIBs

We followed the list of DIBs measured in the high-S/N HD 204287 spectrum (Hobbs et al. 2008) to search for them in the VLT/UVES spectra of Tc 1 and M 1-20, as well as in the NOT/FIES spectrum of IC 418. We identified 20, 12, and 11 DIBs in Tc 1, M 1-20, and IC 418, respectively.

The Tc 1 optical spectrum displays two interstellar clouds lines (see Fig. 1). Interestingly, some DIBs are found to be unusually strong towards Tc 1 (at 4428, 5780, 6203, 6284, and 8621 Å). Their strengths in Tc 1 are higher than those in the comparison star HR 6334 (Fig. 2).

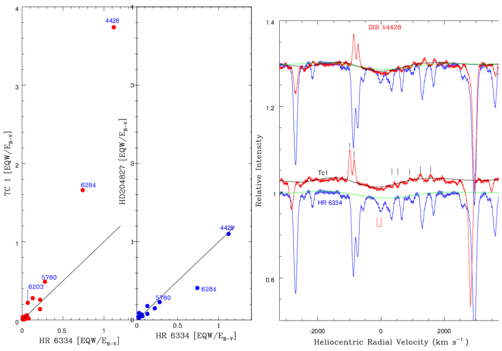

Fig. 2. The left panel displays plots of EQW/E(B-V) of Tc 1 with respect to (w.r.t.) HR 6334 and HD 204827 w.r.t. HR 6334. For Tc 1, we find five unusually strong DIBs (those at ~4428, 5780, 6203, 6284, and 8621 Å), which deviate from the linear relation. The right panel displays the profiles of the 4428 Å feature in Tc 1 (red) and in the comparison star HR 6334 (blue). The minimum seems to be blue-shifted in Tc 1 (see Díaz-Luis et al. 2015 for more details).

The situation is less clear for the fullerene PNe M 1-20 and IC 418 but at least the ~4428 Å DIB is unusually strong in both PNe.

3. A search for diffuse circumstellar bands

The detection of DCBs can only be made by measuring the radial velocities of the circumstellar and interstellar components. Our high-quality (S/N > 300) spectra for PN Tc 1, together with its high radial velocity (in the range from -83 to -130 km s^{-1}; Williams et al. 2008), permit us to search for the possible presence of DCBs; the low S/N and low radial velocity prevent any search for DCBs towards M 1-20 and IC 418, respectively. Interestingly, we detect a weak 5780 Å absorption feature (blueshifted) at the Tc 1 nebular velocity (-125

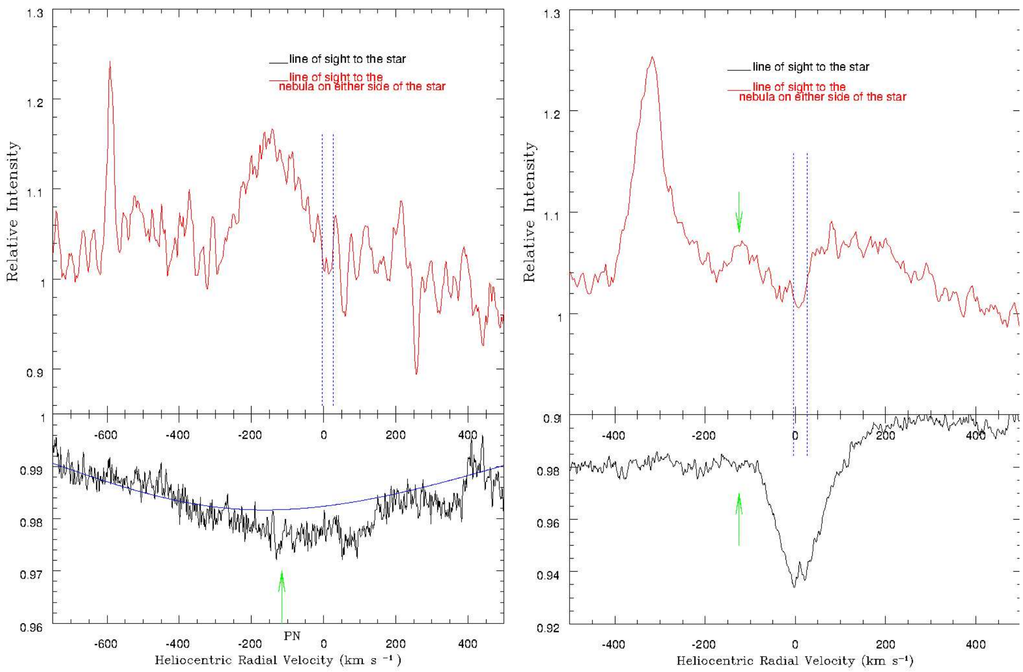

Fig. 3. Profiles of the broad 4428 Å band (left panel) and of the 5780 Å feature (right panel) towards Tc 1 central star (black) and average of two sight lines to the nebular position on either side of the nebula (from Williams et al. 2008). Note the coincidence in velocity (marked by green arrows) of the profile centre of the broad 4428 and of the weak 5780 Å circumstellar absorptions and the corresponding nebular emissions.

km s^{-1}) and the broad 4428 Å feature in Tc 1 seems to be also blue-shifted (at −126 km s^{-1}) (see Fig. 3). Figure 3 shows the correspondence of blueshifted nebular emission features with λ4428 and λ5780 absorptions, which suggests a circumstellar (nebular) nature for the carrier(s) (see Díaz-Luis et al. 2015 for more details).

4. A fullerene–diffuse band connection?

An unusually strong 4428 Å feature seems to be a common characteristic towards fullerene PNe, reinforcing the speculation of a possible fullerene–DIB connection. Our detection of DCBs at 4428 and 5780 Å in an environment rich in fullerenes and fullerene-related molecules would inevitably provide a link between fullerene compounds and the DIB carriers. Photo-absorption theoretical models of several large fullerenes (carbon onions like $C_{60}@C_{240}$, $C_{60}@C_{240}@C_{540}$) predict their strongest optical transitions very close to 4428 and 5780 Å (Iglesias-Groth 2007), suggesting that they are possible carriers. Recent experimental studies demonstrate that fullerenes would react with polycyclic carbon, graphene-like structures, and PAHs, forming a rich family of fullerene-based molecules such as fullerene/PAH clusters and endohedral metallofullerenes (Dunk et al. 2013). In short, fullerenes in their multifarious manifestations, may help solve the long-standing problem of the identification of some of the DIB carriers.

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