Fullerenes and fullerene-related molecules in the circumstellar environment of evolved stars

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Abstract

The recent detection of the most common fullerenes (C_{60} and C_{70}) in the circumstellar environment of evolved stars like planetary nebulae (PNe) has raised the idea that other forms of carbon such as hydrogenated fullerenes may be widespread in the Universe and it has permitted to study the DIBs towards fullerene-rich space environments for the first time. In particular, here we present: i) the first possible detection of two diffuse bands of circumstellar origin (diffuse circumstellar bands, DCBs) at 4428 and 5780 Å around PN Tc 1; and ii) the non-detection of fullerene-related molecules such as hydrogenated fullerenes (fulleranes like $C_{60}H_{36}$ and $C_{60}H_{18}$) in the 3-5 µm spectral range of C_{60}-rich PNe. Our non-detections together with the (tentative) fulleranes detection in a proto-PN suggests that fulleranes may be formed in the short transition phase between asymptotic giant branch (AGB) stars and PNe but they are quickly destroyed by the UV radiation field from the central star.

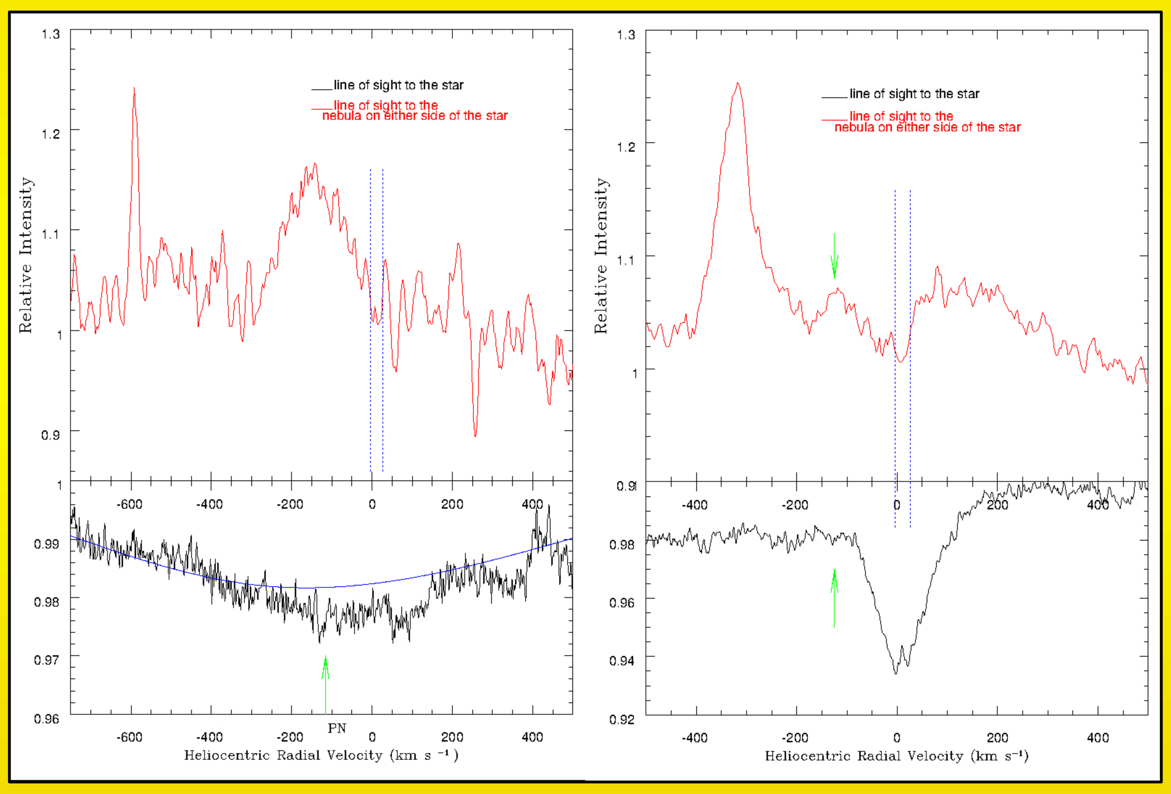

Figure 1: Profiles of the broad 4428 Å band (left panel) and of the 5780 Å feature (right panel) towards Tc 1 central star (black) and average of two sight lines to the nebular position on either side of the nebula (from Williams et al. 2008). Note the coincidence in velocity of the profile centre of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

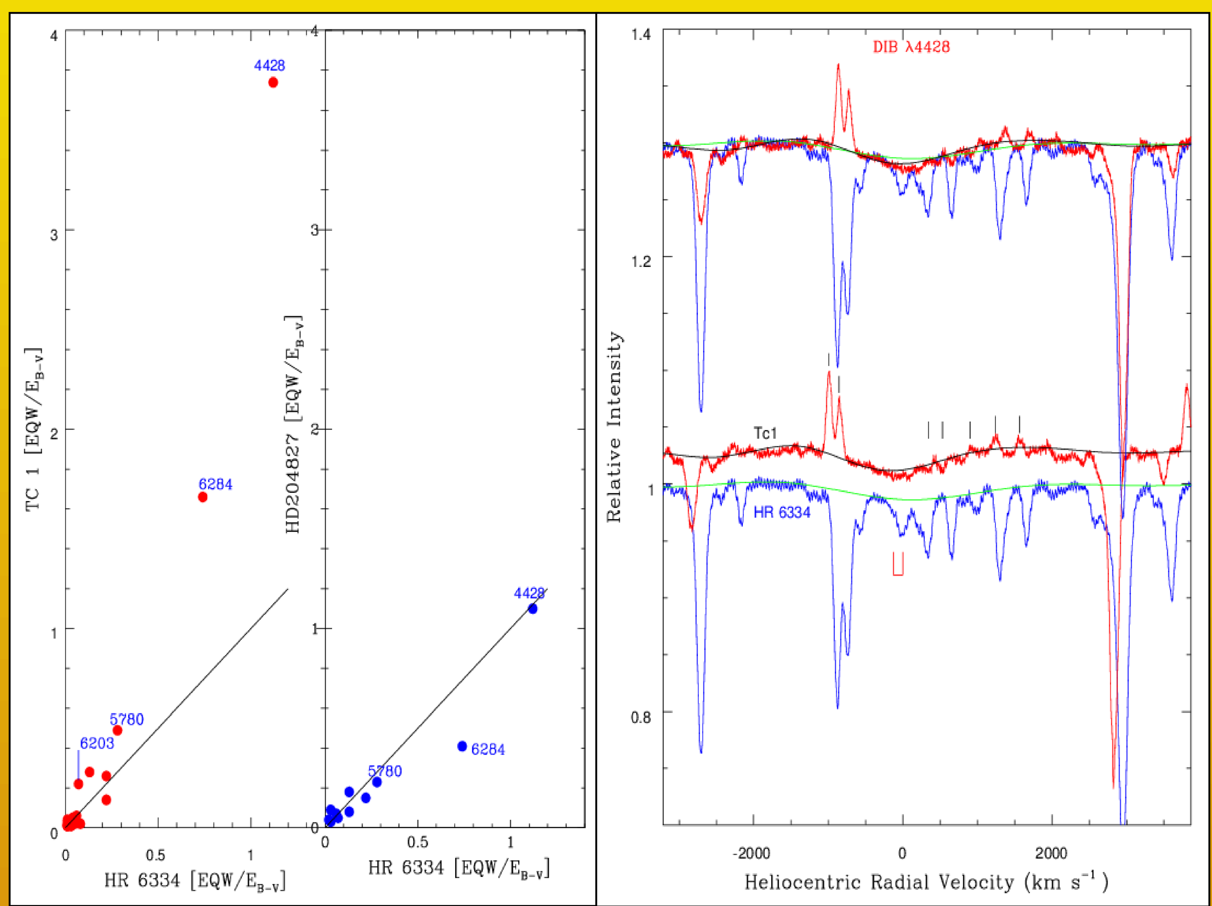

Figure 2: The left panel displays plots of EQW/E(B-V) of Tc 1 with respect to (w.r.t.) HR 6334 and HD 204827 w.r.t. HR 6334. For Tc 1, we find five unusually strong DIBs (those at ~4428, 5780, 6203, 6284, and 8621 Å), which deviate from the linear relation. The right panel displays the profiles of the 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.

1. A search for diffuse circumstellar bands

Our high-quality VLT/UVES (S/N > 300) spectra for PN Tc 1, together with its high radial velocity (in the range from −83 to −130 kms^{-1}; Williams et al. 2008), have permitted 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 (blue-shifted) at the Tc 1 nebular velocity (-125 kms^{-1}) and the broad 4428 Å feature in Tc 1 seems to be also blue-shifted (at -126 kms^{-1}) (see Figs. 1 and 2; see also Díaz-Luis et al. 2015 for more details).

2. Non-detection of fullerene-related molecules such as hydrogenated fullerenes in C_{60}-rich PNe

VLT/ISAAC 2.9-4.1 µm spectroscopy of the fullerene PNe M 1-20 and Tc 1 (see Fig. 3) shows the non-detection of the strongest bands of hydrogenated fullerenes (fulleranes such as $C_{60}H_{18}$, $C_{60}H_{36}$, $C_{70}H_{38}$, and a fullerane mixture) at ~3.44, 3.51 and 3.54 µm (see Fig. 4). The expected fluxes are higher than the 2σ upper limits for M 1-20 and Tc 1. On the contrary, Zhang & Kwok (2013) have (tentatively) detected fulleranes in the proto-PN IRAS 01005+7910; three strong C-H stretching bands at 3.48, 3.51, and 3.58 µm are apparently present in its ISO spectrum with fluxes that are comparable to the one of the 3.3 µm feature. This may suggest that if fulleranes are present in M 1-20 and Tc 1, then they seem to be much less abundant than C_{60} and C_{70}, and can be formed in the short transition phase between AGB stars and PNe but they are quickly destroyed; e.g., by the quick increase of UV radiation from the central star (see Díaz-Luis et al. 2016 for more details).

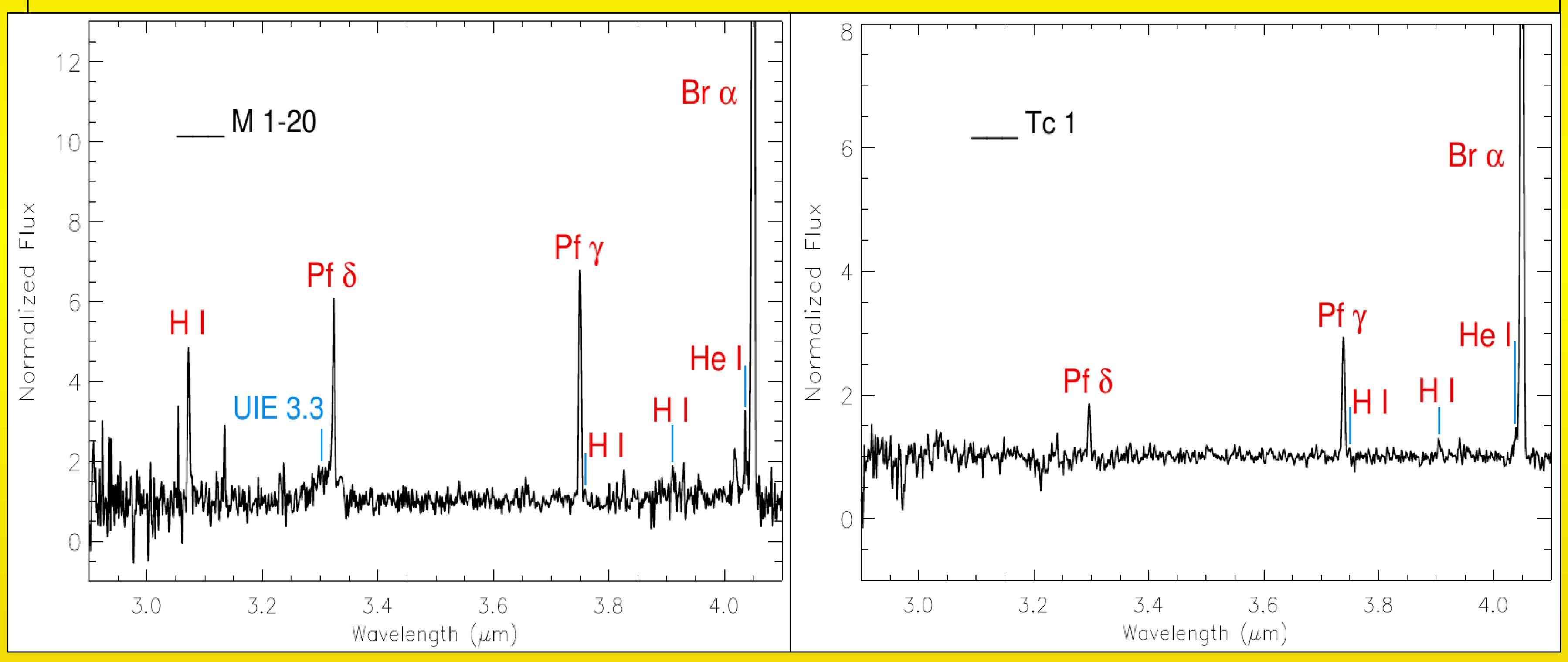

Figure 3: VLT/ISAAC spectra of the PNe M 1-20 (left panel) and Tc 1 (right panel). The UIE feature at 3.3 µm is indicated.

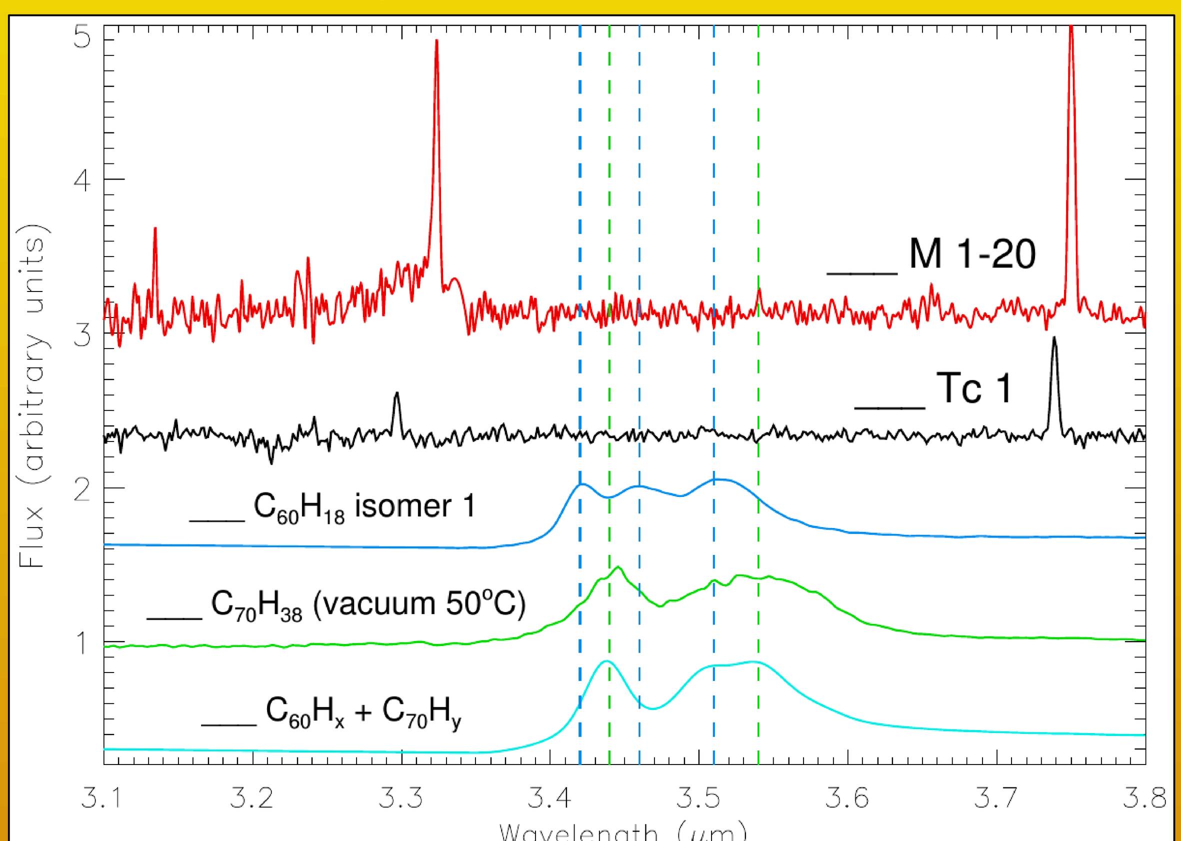

Figure 4: VLT/ISAAC spectra of M 1-20 and Tc 1, in comparison with the laboratory spectra of the fulleranes $C_{60}H_{18}$, $C_{70}H_{38}$, and $C_{60}H_x$+$C_{70}H_y$ in the 3.1-3.8 µm range. Note that the fullerane bands are marked with dashed lines.

3. Conclusions

Our detection of DCBs 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 $C_{60}@C_{240}@C_{540}$) predict their strongest optical transitions very close to 4428 and 5780 Å (Iglesias-Groth 2007), suggesting that they are possible carriers.

We report the non-detection of the strongest bands of fulleranes in the 3-4 µm spectra of two PNe. If fulleranes are present in both objects, then they seem to be much less abundant than isolated fullerene molecules and may be formed in the short transition phase AGB-PN. 3-4 µm spectroscopy in a larger sample of C-rich proto-PNe is encouraged.

References:

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