EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Report on the outcomes of a Short-Term Scientific Mission[1]

Action number: **CA21126**

Grantee name: Silvia Tosi

Details of the STSM

Title: **Analysis of HAC emission in C_{60}-PNe**

Start and end date: 02/12/2024 to 20/12/2024

Description of the work carried out during the STSM

The study of fullerenes (C60 and C70) has attracted growing interest within the astrophysical community because they can explain several discrete unidentified infrared (UIR) features. Among the proposed formation processes for fullerenes (C60 and C70), the top-down processing/destruction of hydrogenated amorphous carbon (HAC) grains is considered one of the most plausible explanations. Consistent with this idea, HAC-like dust grains are proposed as potential carriers of the broad UIR plateau features (e.g., at 6–9 and 9–13 μm) commonly observed in fullerene-containing PNe. Indeed, the pioneering work of Gómez-Muñoz et al. (2024) on PN Tc 1 demonstrated that HAC-like grains can explain its broad UIR plateau features, supporting the HAC-C60 connection and the idea of HAC processing/destruction for fullerene formation.

This STSM served as a foundation for follow-up work on the Gómez-Muñoz et al. (2024) study of PN Tc 1, which was the first to incorporate the laboratory-derived optical constants (n and k) of HAC-like dust into photoionization modeling. Following the tasks outlined in the application form, the initial phase of the STSM focused on training with the CLOUDY photoionization code to incorporate HAC into synthetic SED modeling.

Subsequently, I investigated the uncertainties in the prescription of PN Tc 1 reported by Gómez-Muñoz et al. (2024). This included evaluating how changes in HAC grain sizes and the power-law grain size distribution affect the agreement between the synthetic SED and the observed Spitzer spectrum. I also analyzed how these variations influence the HAC grain abundance required to achieve consistency with the observational spectrum. To further explore PN Tc 1, I investigated how modifying the density distribution of grains within the nebular shell impacts the modeled spectrum.

[1] This report is submitted by the grantee to the Action MC for approval and for claiming payment of the awarded grant. The Grant Awarding Coordinator coordinates the evaluation of this report on behalf of the Action MC and instructs the GH for payment of the Grant.

Finally, I began extending this analysis to two additional sources, M1-12 and SaSt2-3, which also exhibit the broad plateau at 9–13 μm. The aim is to assess whether HAC can similarly account for this feature, as demonstrated by Gómez-Muñoz et al. (2024) for Tc 1.

Description of the STSM main achievements and planned follow-up activities

Building on the model of PN Tc 1 presented in Gómez-Muñoz et al. (2024), I explored the effects of assuming different grain sizes and tested various power-law indices for the grain size distribution on its IR spectral modeling. Specifically, the study considered grain distributions ranging from very small grains (0.001 μm to 0.01 μm) to larger grains (0.2 μm to 1.0 μm), with power-law indices of -2.5, -3.5, and -4.5.

Larger grains produced an emission peak with higher flux at longer wavelengths compared to smaller grains. This behavior may be linked to the fact that larger grains emit from regions farther from the central star (Bermudez-Bustamante et al. 2024) compared to smaller grains, contributing to redder wavelengths. Consistent with this, assuming a steeper grain size distribution (favoring smaller grains) enhanced the flux at shorter wavelengths.

Across all the scenarios explored, agreement between the synthetic spectrum and the Spitzer observations was preserved by adjusting the HAC grain abundance. Assuming very small grains did not significantly affect the model's agreement with observations. However, for larger grains, it was necessary to increase the HAC grain abundance by nearly a factor of two to maintain agreement. Nevertheless, the assumption of larger grains resulted in a poorer fit at wavelengths longer than 12 μm compared to both the very small grain distribution and the Gómez-Muñoz et al. (2024) model, causing a 30–40% flux mismatch between the synthetic and observed spectra at those wavelengths.

The Tc 1 model adopted by Gómez-Muñoz et al. (2024) assumes that grains follow the same distribution as the hydrogen density, spanning the entire nebula. As part of this STSM, I also investigated how the IR model changes when a step-like spatial distribution of the grains is assumed, with grains present only up to 30%, 50%, and 80% of the nebular radius. Confining the dust grains closer to the central star resulted in lower IR fluxes compared to a distribution spanning the entire nebula, requiring an increase in HAC grain abundance by up to 25% to match the synthetic flux with the Spitzer observations. Despite these changes, the HAC prescription for describing the broad plateau remained robust, requiring only minor adjustments to the HAC grain abundance.

The findings from this investigation, along with an exploration of HAC modeling in two additional sources that exhibit the broad plateau at 9–13 μm (M1-12 and SaSt2-3), will be presented in an upcoming publication.