Observations of Nebulae Ejected by Massive Stars with PACS

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Abstract

In the context of the Mass-loss from Evolved StarS guaranteed time key program, we will obtain PACS imaging and spectroscopic observations of nebulae associated with Luminous Blue Variable and Wolf-Rayet stars. Descriptions of the observations and preliminary results are presented. More specifically, photometric maps of the LBV candidate Hen 3-519 are presented, as well as a preliminary study of the spectrum of the Luminous Blue Variable Wra 751.

Introduction

LBV stars represent a short time stage (~10^4 - 10^5 yr) in the evolution of massive stars with initial mass > 40 $M_{\odot}$. An early-type O star evolves into a WR star by loosing a significant fraction of its initial mass. One way to loose mass is through the stellar winds. These last years, the mass-loss rates of O stars have been strongly revised downwards (Fullerton et al. 2006). This enlights the key role played by episodes of extreme mass-loss in an intermediate evolutionary phase (LBV or Red Supergiant phase). Most LBVs are surrounded by ejected nebulae. The main characteristics of these stars are their photometric variability, from giant eruptions ≥ 2 mag to small oscillations of ~ 0.1 mag, their high luminosity ~10^6 $L_{\odot}$ and their high mass-loss rate ~10^{-5} –10^{-4} $M_{\odot}yr^{-1}$ (Humphreys & Davidson 1994). Progressively the outer layers of the star are removed revealing a 'bare core' and the star becomes a WR.

WR stars are hot, luminous objects with strong broad emission lines in the optical due to stellar winds. These winds have smaller mass-loss rates than LBV winds but higher velocities, up to 3000 km s^{-1}. They interact with the material ejected during the LBV phase, creating circumstellar bubbles which have been observed around many WR stars. Nebulae have been found around one third of the Galactic WR stars in the optical (Marston 1997).

There are many questions about the nebulae around LBVs and WR stars which have not yet been answered. We still do not know when exactly and how these nebulae are formed, what causes the strong mass-loss phase to start and what leads to the giant eruptions observed in some LBVs. Also, important quantities such as the dust mass and composition or the gas CNO abundances are very uncertain. Infrared studies of LBV nebulae have revealed that they contain dust and CO (McGregor et al. 1988, Hutsemékers 1997, Nota et al. 2002). In the past infrared observations of these object have been done using near-infrared ground base telescopes as well as IRAS, ISO and Spitzer space observatories. With Herschel we are able to study these nebulae in the full far-infrared with a high angular and spectral resolution for the first time.

Our project with Herschel

Our project is a part of the Herschel Guaranteed Time Key Program entitled MESS – Mass-loss of Evolved StarS (Groenewegen et al. 2010, in prep). The aim of this project is the detailed study of the gas and the dust in the circumstellar environments around LBVs and WR stars, so as to determine their properties. The accurate photometric maps of the far infrared emission provided by the instruments on-board Herschel will give us detailed informations on the basic parameters of the dust shells. The combination of spectroscopic observations with optical data will provide accurate C,N,O abundance determinations. Depending on the observed features, we could also be able to make dust mineralogy, estimate the mass and the location of the molecular gas and study the formation process of dust in these nebulae.

Targets in the accepted proposal of the MESS Key Program include LBVs, LBV candidates and WR stars. PACS imaging will be done for all of them, mainly in the scan map mode, while for the brightest nebulae PACS or SPIRE spectroscopy will be performed.

Photometric Observations: The case of the LBV candidate He 3-519

He 3-519 is located in the Carina spiral arm of our Galaxy near some of the most well known LBVs. Hoffleit (1953) discovered that a shell nebula surrounds He 3-519 and Henize (1976) found that its spectrum was similar to AG Car. Stahl (1986, 1987) noted spectroscopic similarities to Ofpe/WN9 and published a [N II], λ 6584, CCD image of the circumstellar nebulae. Davidson et al. (1993) suggested that it may be a post-LBV object and Smith et al. (1994) classified it as a WN 11 star, considering its nebulae as WR ring nebulae, rather than its progenitor.

A first series of observations were carried out on 25-12-2009 using the Photo Array Camera and Spectrometer (PACS, Poglitsch et al. 2010, in press). The scan map observing mode was used. For each of the two filters (B, R) two scan maps were taken with a scanning angle of 90 deg between them. Finally, our data consists in four scan maps (there are two arrays, the blue and the red), at 75 μm, 110 μm and 170 μm (2 maps). The data reduction was performed using Herschel Interactive Processing Environment (HIPE) and following the basic data reduction steps. Figure 1 shows a RGB image of the nebula around He 3-519, which is a combination of two PACS scan maps at 75 μm (B) and 110 μm (G) with a Spitzer image at 24 μm from the archive (R), and the nebulae in the optical region (Hα). The two images reveal a similar nebula shape, though in the Ha image the nebula appears to be more elliptical and have a thin shell structure. The nebulae in the infrared RGB image appears to have a more complicated structure. The nebula diameter is approximately 75 arcsec in the 24 μm and 80 arcsec in the 75 μm. At the Hα image the nebula has a diameter of about 60 arcsec.

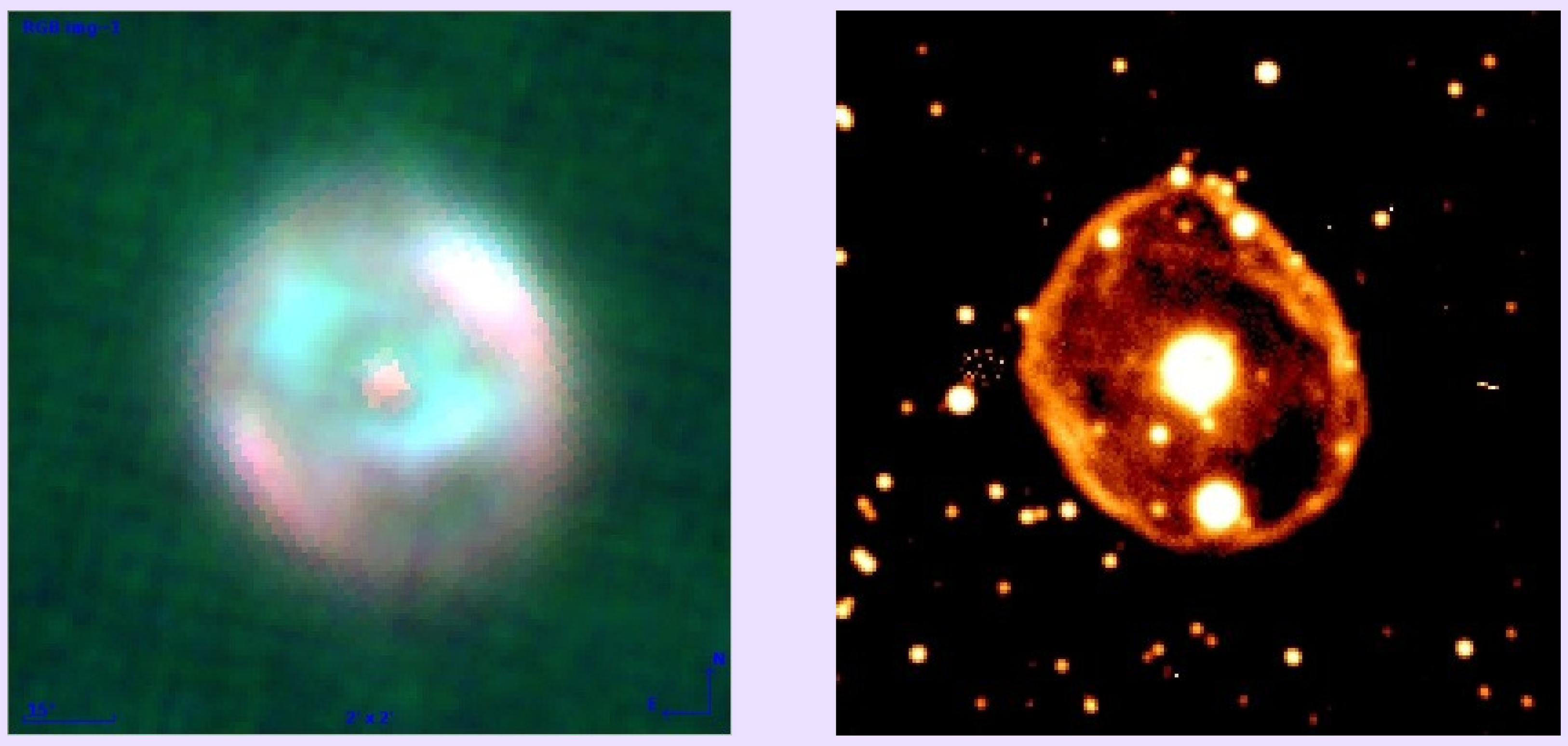

Figure 1. The nebulae around He 3-519: an RGB image, R is a Spitzer image at 24 μm, G is the PACS 110 μm image and B is the PACS 75 μm image (on the left) and the Hα image (on the right). North is up and east is on the left. The dimensions of both images are 2 x 2 arcmin.

Spectroscopic Observations: The spectrum of the LBV WRA 751

WRA 751 was identified as a galactic LBV by Hu et al. (1990). Hutsemékers and Van Drom (1991) found that it is surrounded by a ring nebulae of ~22 arcsec in diameter. De Winter (1992) detected a cool dusty circumstellar shell around WRA 751 with strong emission in the far-IR. Voors et al. (2000) derived many properties of the circumstellar dust around WRA 751 by modeling their ground-based infrared imaging around 10 μm and ISO spectroscopic observations: the distribution of emission is roughly spherical, the dust shell is detached and elongated, there is neutral gas outside the dust region and ionized gas only in the inner part of the dust region which contains on average large grains.

The observations were carried out using the Photo Array Camera and Spectrometer in the SED mode. The final spectrum is shown in Figure 2, along with an optical Hα image of the nebula. The lines [NIII] λ 57.3 μm, [OI] λ 63 μm and λ 145 μm, [OIII] λ 88 μm, [NII] λ 122 μm and λ 205 μm and [CII] λ 158 μm are clearly visible with the [NII] λ 122 μm being the strongest one. The presence of these lines shows that gas around WRA 751 is highly ionized. Voors et al. (2000) using ISO spectroscopic data detected only the two lines [OIII] λ 88 μm and [NII] λ 122 μm, in the waveband 40-140 μm, and not so strong. The absence of the line [OI] λ 63 μm was really surprising for them, considering the fact that the central star has a temperature of about 20,000 K. Apart from these nebular lines and the dust continuum, no other features are detected. More details will be given in Vamvatira-Nakou et al. (2010, in prep.).

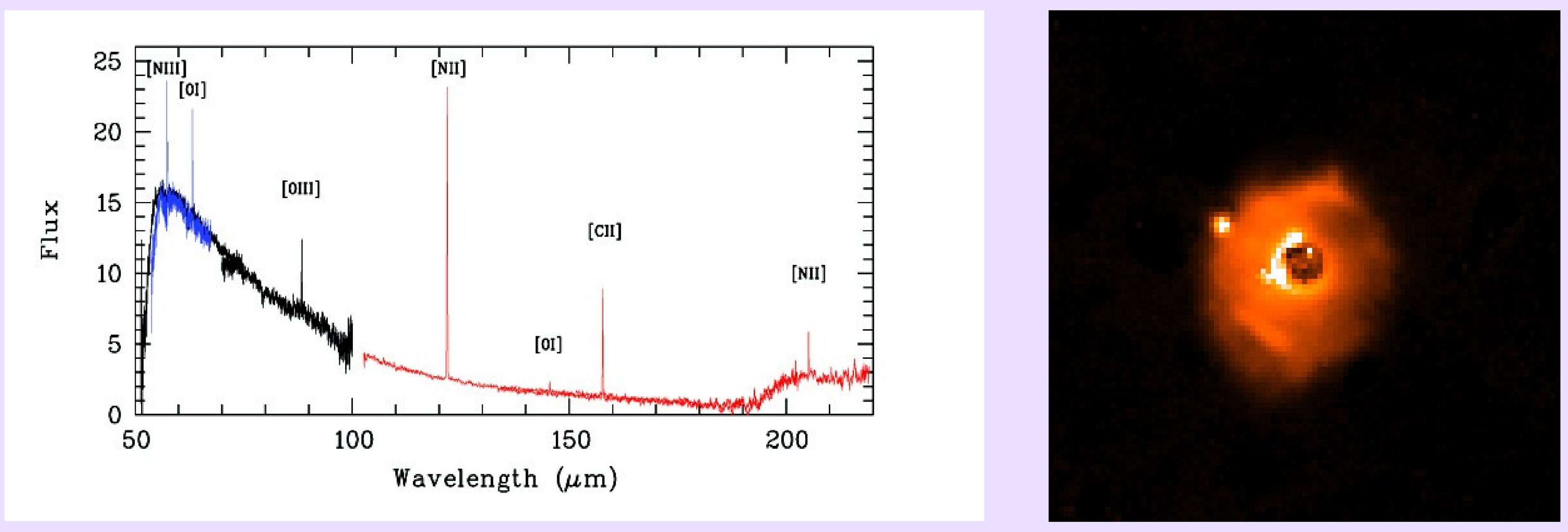

Figure 2. PACS spectrum of WRA 751 (preliminary reduction). Indicated are the lines [NIII], [OI], [OIII], [NII] and [CII] (on the left) and an Hα image of the nebula with dimensions of 1 x 1 arcmin (on the right).

Conclusion – Future work

Although the results presented in the previous paragraphs are very preliminary, it is clear that Herschel data with their high spectral and angular resolution give us additional informations about the structure and the composition of the nebulae around evolved massive stars.

Our future work consists in analysing the photometric and spectroscopic Herschel data for each one of our targets and combining them with data taken in other spectral regions, so as to identify where exactly the dust is located with respect to the gas and to derive precise measurements of dust and gas parameters and properties. By comparing the results found for our targets we should be able to answer important questions about the origin of the nebulae and the evolution of massive stars in general.

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