Planetary Nebulae: An Eye to the Future
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A Herschel study of Planetary Nebulae

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Abstract. We present Herschel PACS and SPIRE images of the dust shells around the planetary nebulae NGC 650, NGC 6853, and NGC 6720, as well as images showing the dust temperature in their shells. The latter show a rich structure, which indicates that internal extinction in the UV is important despite the highly evolved status of the nebulae.

Keywords. planetary nebulae: individual (NGC 650, NGC 6853, NGC 6720), infrared: ISM

1. Introduction

As part of the Herschel Guaranteed Time Key Project MESS (Mass loss of Evolved StarS) (PI Martin Groenewegen) we have imaged a sample of planetary nebulae (PNe) with the PACS (Poglitsch *et al.* 2010) and SPIRE (Griffin *et al.* 2010) instruments on board of the Herschel satellite (Pillbratt *et al.* 2010). A detailed description of the program can be found in Groenewegen *et al.* (2011) and an overview of the Herschel observations for PNe in van Hoof *et al.* (2012).

2. Data Reduction

All targets in this paper have been imaged in scan map mode. With PACS we have obtained images in the 70 and 160 μm bands, with SPIRE in the 250, 350, and 500 μm bands. PACS data were reduced up to level 1 within the data procession package HIPE (Ott 2010). The PACS images were made with the code Scanamorphos (Roussel 2011). The SPIRE images were reduced with the SPIRE pipeline. The images were convolved using the appropriate convolution kernels of Aniano *et al.* (2011) and rebinned to the pixel size of the longest wavelength image with flux conservation. These images were background subtracted before the ratios were taken. In order to convert the flux ratio images to temperature maps we determined the theoretical flux ratio at a given grain temperature by folding the grain emissivity of astronomical silicate or graphite (Martin & Rouleau 1991) with the PACS and SPIRE filter transmission curves in HIPE using the procedure outlined in the SPIRE Observer's Manual. We interpolated the flux ratio as a function of temperature for each pixel in the the flux ratio image to obtain the temperature map. The temperature maps based on the ratio PACS 70 / PACS 160 μm differs from PACS 160 / SPIRE 250 μm by about 10 K. The reason for this difference needs to be investigated further. Here we present the temperature maps based on the PACS 70 / PACS 160 μm ratio images.

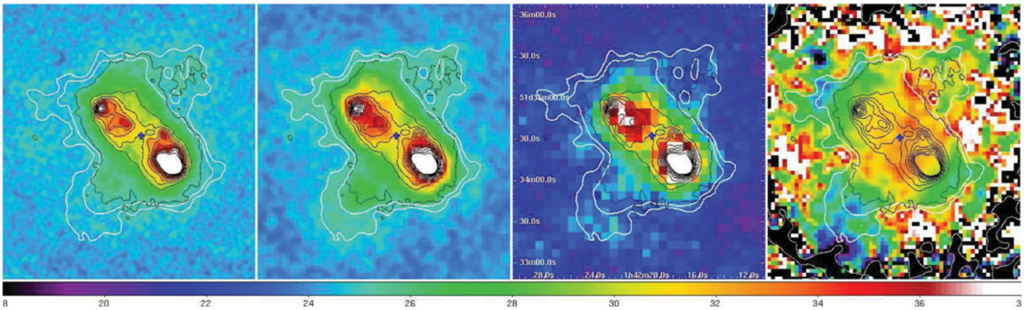

Figure 1. NGC 650, *from left to right*: PACS 70 and 160 μm, SPIRE 250 μm and the temperature map created from the PACS 70 / 160 μm ratio image. The black contours are of the PACS 70 μm inner region and the white contours of the fainter outer regions of the PACS 160 μm image. The blue cross marks the central star. The bar at the bottom shows the temperature scale.

3. Results

NGC 650 (the Little Dumbbell): in the temperature map of Fig. 1 the shadowing effect of the torus is clearly visible: the regions at the outer edge of the torus and beyond are clearly cooler than the dust in other directions. The dust grains are primarily heated by UV photons, either emitted by the central star, or diffuse emission from the gas (e.g., Lyα photons). Hence there must be substantial extinction of UV photons inside the torus. The measured flux values above 3 σ are 6.54, 5.61 and 1.27 Jy ($\pm$ 5%), at 70, 160, and 250 μm respectively.

NGC 6853 (the Dumbbell): in the temperature map of Fig. 3 in van Hoof *et al.* (2012), we see a strong correlation between the high-density regions and the colder dust. The hot patch towards the south appears to be real and has no counterpart in the north. Presumably this is material that is directly irradiated by the central star. The measured flux values above 3 σ are 83.45 and 56.0 Jy ($\pm$ 5%) at 70 and 160 μm respectively.

NGC 6720 (the Ring nebula): in Fig. 1 of van Hoof *et al.* (2012) we see that the halo is clearly detected in all 3 bands. The temperature map shows that the temperature is lower in the halo than inside the ring, because it is shielded from the starlight by the dense ring. The measured flux values above 3 σ are 54.70, 29.18 and 13.70 Jy ($\pm$ 5%), at 70, 160, and 250 μm respectively.

The similarity between the optical Hα and the FIR images, indicate that the gas and cool dust are well mixed in these objects.

The detailed match between the H_2 emission and the FIR dust emission, suggests the formation of H_2 on dust grains (van Hoof *et al.* 2010).

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