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A *Herschel* study of PNe

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This poster presents our on-going analysis of the PNe that have been observed so far with *Herschel*. These observations are part of the MESS Key Programme, which is looking at mass loss from evolved stars in the Galaxy. The PNe we present include NGC 6720, NGC 6853 and NGC 7293. The high spatial resolution of the PACS images allows almost direct comparison of the sub-mm dust to H_2 images of the molecular gas, in particular for NGC 6720 and NGC 6853. The talk of Peter van Hoof will present the theoretical modeling NGC 6720; in this poster we include more detail on the reduction of *Herschel* data and present the latest PACS and SPIRE images for a closer inspection. We also discuss our future analysis, which will include a study of the spatial distribution of the material within the nebulae.

A Herschel Study of PNe

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★★★--ABSTRACT--★★★

Grains play an important role in the physics and chemistry of planetary nebulae (PNe). In this poster we present Herschel images of the dust around PNe, taken as part of the MESS Key Programme, which is looking at mass loss from evolved stars in the Galaxy. Van Hoof et al. (2010) studied the formation of H_2 grains in NGC 6720; the strikingly similar morphology of the PACS images and the ground-based H_2 images suggests an intimate link between the dust and gas. In this poster we present these maps for a closer inspection and introduce the most recent Herschel images of NGC 6853 and NGC 7293. We also outline our future analysis, which will include a study of the spatial distribution of the material within the nebulae. *Due to the extremely early submission requirement for posters of this conference, the final poster will be more complete than what you are reading right now.*

★★★--NGC 6720--★★★

NGC 6720 is an evolved, oxygen-rich bipolar PN seen nearly pole-on. Molecules such as H_2 and CO have been detected (Beckwith et al. 1978; Huggins & Healy 1986). The central star has exhausted hydrogen shell burning and is now on the cooling track. As a result the outer halo is recombining. NGC 6720 is very similar to the Helix nebula, which seems to be further advanced along the same evolutionary path (O'Dell et al. 2007).

H_2 images of NGC 6720 show that most of the H_2 resides in high density knots in the inner ring (Speck et al. 2003). H_2 will have formed in the dense AGB wind, the question then is whether (i) the H_2 survived in knots which formed before the gas was ionised, or (ii) the H_2 survived in the ionised region or (iii) the H_2 was destroyed and then formed again within the knots.

When we compare a Calar Alto H_2 image with a PACS 70μm image–Fig. 1–we find that within the ring and in the halo of this PN, the dust and the H_2 gas have very similar morphologies. *This could be observational evidence that H_2 forms on grain surfaces.* The three scenarios for the formation of H_2 were analysed with the help of the Herschel and other data, and Cloudy models, by van Hoof et al. (2010). They concluded that the most plausible scenario is that the H_2 resides in high density knots which were formed after the recombination of the nebula began. This could occur via hydrodynamical instabilities due to the low temperature of the recombining gas. H_2 formation in such knots is expected to be substantial after the central star's luminosity dropped 1000-2000 years ago, and may still be ongoing.

These results are the subject of a talk by van Hoof at this conference. Here we show–Fig 1–the PACS and SPIRE images for your closer inspection.

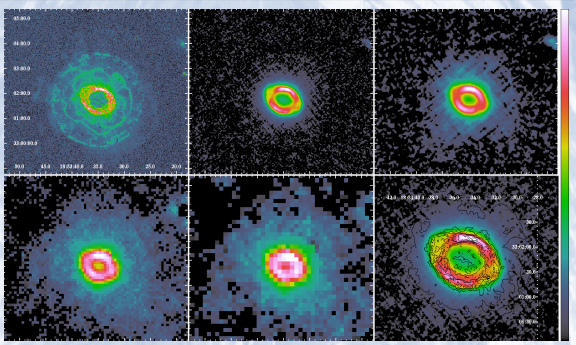
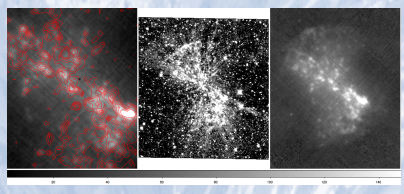


FIG 1. Top, left to right: H_2 2.12μm, PACS 70μm, PACS 160μm. Bottom, left to right: SPIRE 250μm, 350μm, and PACS 70μm with overlaid H_2 contours. N up, E left. It is apparent that the PACS and H_2 images have extremely similar morphologies, as do also (within the differing spatial resolution) the PACS and SPIRE images. This appears to be observational evidence that the H_2 has formed on grain surfaces in this nebula. A similar result was obtains by Habart et al. (2003) for the ρ Ophiuchi molecular cloud, suggesting that H_2 forms on PAH surfaces. The presence of PHAs in NGC 6720 cannot be fully excluded but seems unlikely. Hence our observations are the first indication for H_2 formation on O-rich dust grains in an astrophysical environment.



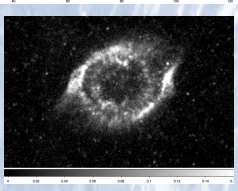


FIG 2. Top, left to right, NGC 6853: a zoom on the PACS 70μm image with H_2 contours overlaid–clearly the correspondence between the two is very good; H_2 image; and PACS 70μm image, both with a wider view. H_2 image credit: Gatley, M. Merrill, National Optical Astronomy Observatory. Bottom: SPIRE 250μm image of NGC 7293.

★★★--NGC 7293 and NGC 6853--★★★

NGC 7293–the Helix–is well-known for its cometary knots–so called because of their head+tail shapes. These can be found in many other types of nebulae, such as star-forming regions and supernovae. H_2 images of the knots were studied by Matsuura et al. (2009), who found that the H_2 is present only in knots, and concluded that H_2 formed during the AGB phase can survive through to the PN stage. *On Fig 2 we will show the the SPIRE 250 μm image and PACS 70 μm image, the latter will be compared to an H_2 image (kindly donated by A. Speck). The PACS and H2 maps are still to be produced.*

NGC 6853–the Dumbbell is also a very knotty nebula, and on the H_2 images these knots have a very radial-streaming appearance. Its knots were studied by O'Dell et al. (2002) from *HST* data. These knots do not have the cometary appearance of those of NGC 7293, although radial tails are found in the knots further out from the central star. On Fig 2 we show the PACS 70μm image together with an H_2 image. As with NGC 6720, the PACS and the H_2 images show a very striking similarity in the appearance of the knots, although the PACS images shows none of the radial-streaming morphology (whether because it is not there or because it is too faint, we have not yet established). A close association of the dust and gas is thus found here also.

Data Reduction

A quick word on data reduction. The Herschel data were processed though their respective pipelines. These have not yet come to full maturity, although the instrumental corrections are essentially all done. For the PACS images, removing the so-called 1/f noise is a process that is still being tested; imperfect removal of this background results in artificial structures in the images (the striping in the NGC 6720 images above are an example of this). We expect to be able to better these maps once the removal of the 1/f noise is a more mature process.

★★★--The Next Step--★★★

Our work is not yet done! A handful more PNe are part of the MESS programme and are yet to be observed. We are also turning the PACS images into ratio maps. The ratio of the 70μm and 160μm data provides information on the temperature structure of the nebulae. Before making these ratios one must deconvolve PACS images with their respective PSFs (the resolution of the 160μm data is worse than the 70μm) and then rebin them to the same spatial sampling. Our knowledge of the PSF of PACS is almost in a state where one can do this quantitatively. But as a sampler of what such ratio maps will look like, in Fig 3 we show a preliminary 70/160μm map of NGC 6720. Comparing to the 70μm map, you can see that the two are very similar, although differences in where the ratio peaks in the ring can be found. Brighter on this image means warmer dust.

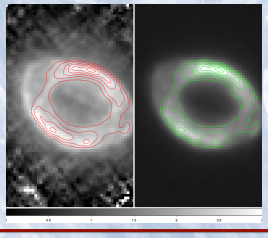


FIG 3. NGC 6720 70/160μm ratio map (left) and 70μm map (right). Contours of the 70μm image brightest parts have been overlaid on the ratio map for ease of comparison. Brighter on the ratio image means warmer dust.

References: van Hoof et al., 2010, A&A (arXiv:1005.1502) accepted; Beckwith et al. 1978, ApJ, 219, 133; Huggins & Healy 1986, MNRAS, 220, 33P; O'Dell et al. 2007, AJ, 134, 1679; , Speck et al. 2003, PASP, 115, 170; Matsuura et al. 2009, ApJ, 700, 1067; O'Dell et al., 2002, AJ, 123, 3329