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The Herschel Planetary Nebula Survey: HerPlaNS

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1. HerPlaNS

The Herschel Planetary Nebula Survey HerPlaNS is a ~200 hours Herschel open time program dedicated to the investigation of a sample of 11 Planetary Nebulae (PNe). The aim of this program is to study the spatial distribution and chemical composition of the cold dust and gas components by means of far-IR imaging and spectroscopy data and to investigate the energetics of the gas-dust systems as function of the location in the nebula using spatially resolved spectroscopy data. The unprecedented wavelength range explored combined with the sensitivity and resolution of the Herschel instruments provide a novel view of these objects and complement the greater picture that has been previously drawn from X-ray, Optical to mid-IR data.

2. Observing strategy

HerPlaNS makes use of the full observing capabilities of the two Herschel instruments PACS and SPIRE. The combined PACS and SPIRE observations consist of:

- Photometry maps covering the full extent of the planetary nebulae in 5 bands (70μm, 160μm, 250μm, 350μm and 500μm).
- Full range spectroscopy, at one to two different locations on the PN, covering a wavelength range from 70μm to 672μm.
- Spectral line maps at higher resolution (with PACS and for two PNe) around 8 emission lines: [OIII] 52μm, [NIII] 57μm, [OI] 63μm, [OIII] 88μm, [NII] 122μm, [OI] 146μm, [CII] 157μm and [NII] 205μm.

3. First Results: the case of NGC 6781

3a. Photometry

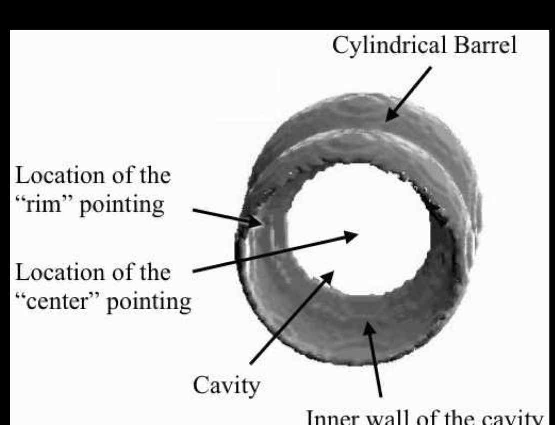

Fig.1: 3D iso-density surface model by Schwarz & Monteiro (2006). NGC 6781 is an evolved bipolar PN with a central star of ~110kK a DAO spectral type (Frew 2008) and ~1kpc away (Schwarz & Monteiro, 2006). This object is H_2 rich (Kastner et al. 1996) but there is no detection of X-ray emission (Kastner et al. 2012).

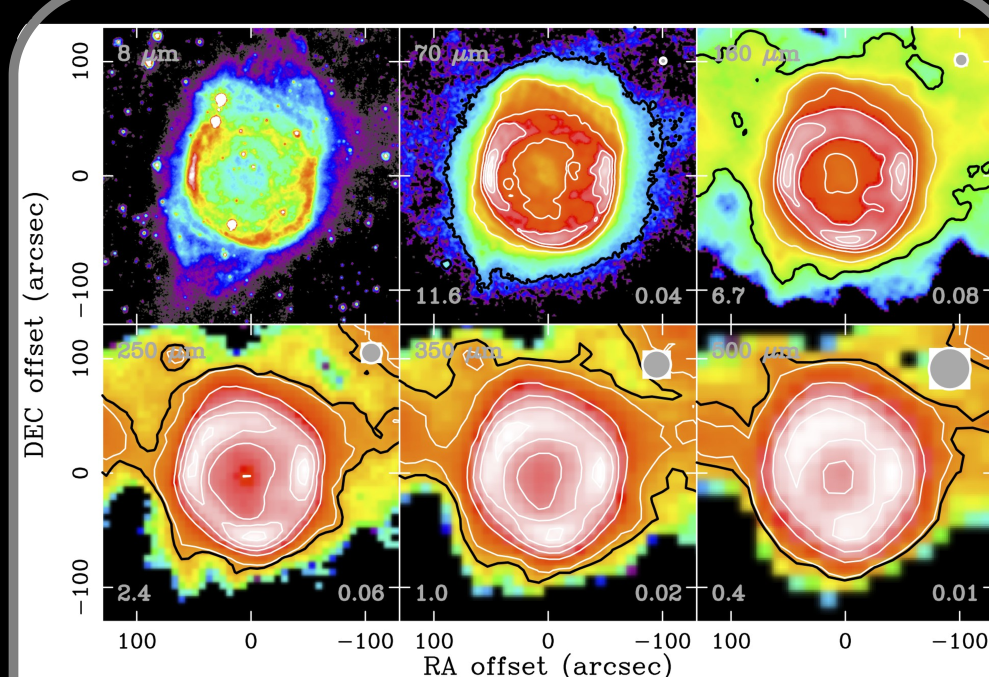

Fig.2: [Top left] Spitzer-IRAC map at 8μm followed by Herschel-PACS and -SPIRE broadband maps. Peak brightness is indicated at the bottom left corner, one σ noise at bottom right and beam size at top right. Contours are drawn for 90, 70, 50, 30 and 10% of the peak in white and in black is the 3 σ detection. Dust continuum within the ring like structure is resolved even at the longer SPIRE wavelength of 500μm.

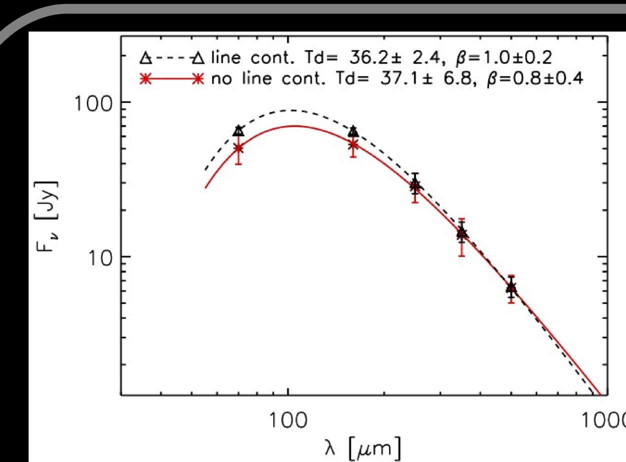

Fig.3: Modified black body fit ($\sim\lambda^{-\beta}B_\nu(T_{dust})$) to the total photometry derived with aperture photometry from the 5 PACS and SPIRE images. The red line is the fit to the data (stars) with line contribution, as estimated from spectroscopy data, subtracted while the dashed black line is the fit to the total flux (triangles) with line contamination. This shows that despite line flux contamination, dust temperature determination is still robust. This is because line contamination is low. The β value around 1 suggests the presence of carbon type dust.

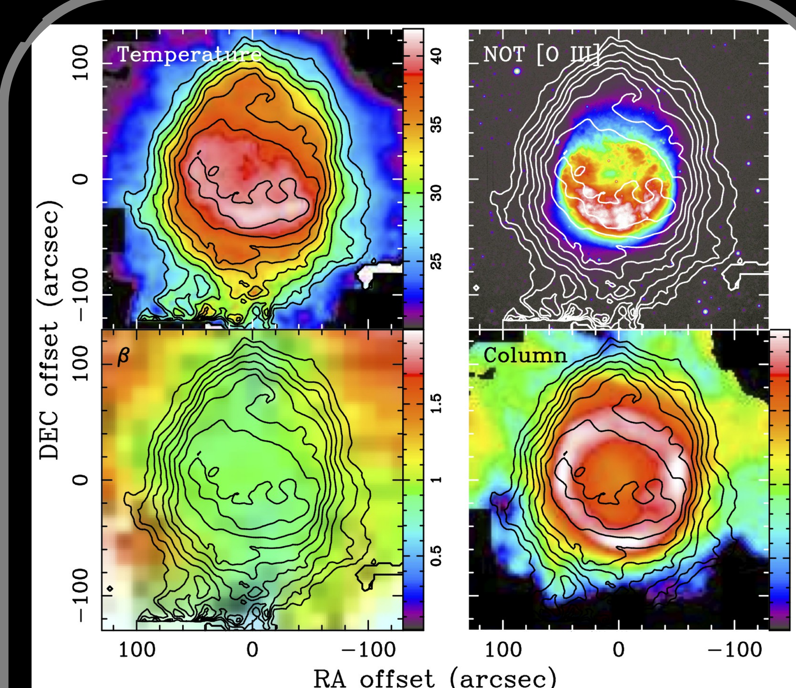

Fig.4: [Top left] dust temperature (T_{dust}) map derived from fitting the 5 Herschel maps with a power-law dust emissivity ($\sim\lambda^{-\beta}B_\nu(T_{dust})$) in K with contours for 40 to 26K with 2K intervals. [Top right] T_{dust} contours drawn on the [OIII] λ5007 map from the NOT. [Bottom left] the power law index β. [Bottom right] dust column density in $M_\odot$/pix.

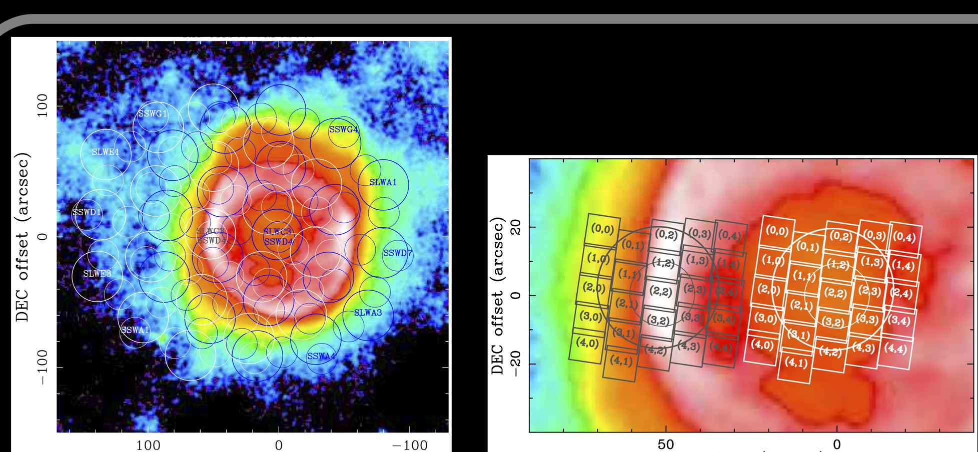

Fig.5: Overlaid on the PACS 70um map, [Left] SPIRE spectroscopy footprint (SSW and SLW) for the central (blue) and rim (white) pointing, [Right] PACS spectroscopy footprints for the central (white) and the rim (gray) pointing. Location of the SPIRE SSW and SLW central bolometers is also shown for comparison.

3a. Spectroscopy

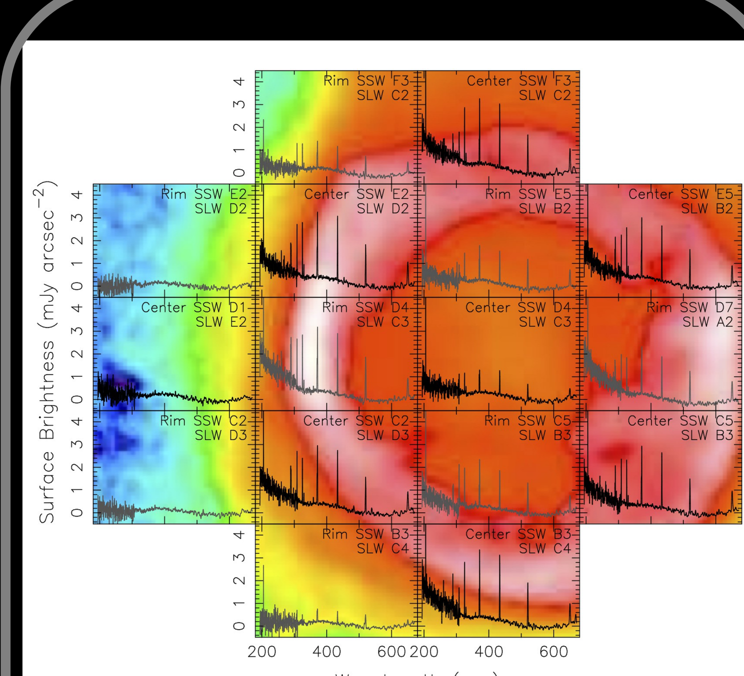

Fig.6: Combined SPIRE SSW+SLW spectra (in black) for spatially overlapping bolometers. The spectra are plotted as function of the location in the nebula over the 70μm PACS photometry map. We can see that the SPIRE spectrum is rich in molecular lines with the emission being brighter in the ring like region which indicates the presence of a colder and denser environment within the barrel walls.

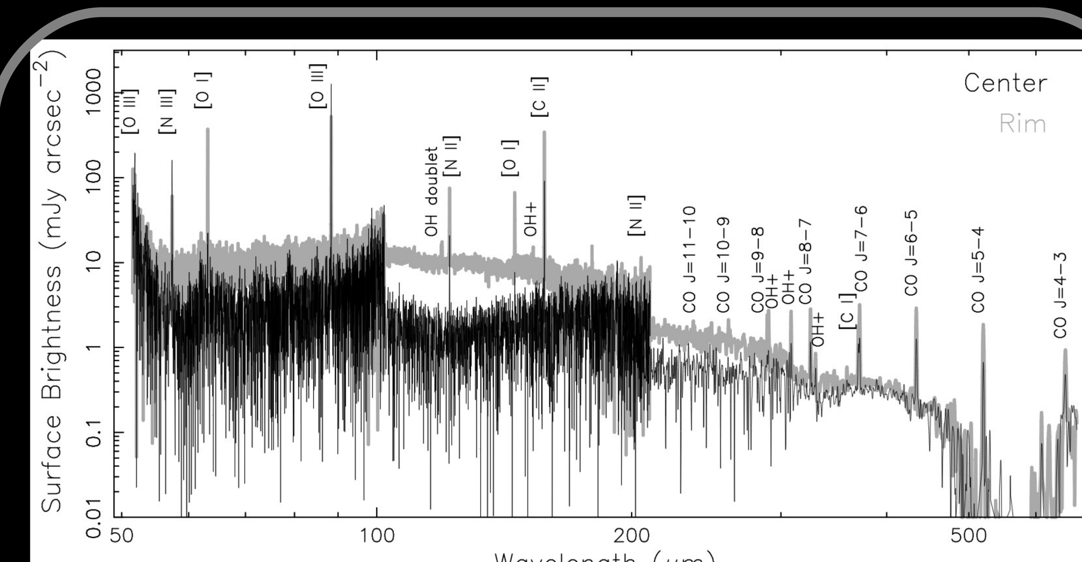

Fig.7: Full range PACS+SPIRE spectrum for the central (gray) and rim (black) pointing, extracted from the PACS central spaxel and SPIRE central bolometer. The spectrum is rich in atomic and molecular lines with a first detection of OH+ in emission in PNe. This is in line with the very high temperature of the central star (~110kK)

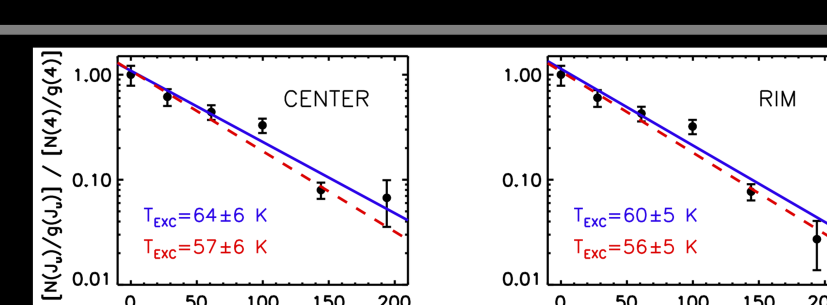

Fig.8: CO rotation diagrams from the 6 lowest detected transitions (Fig.7). The blue line fit uses all 6 transitions while the red line uses only the four best fitted lines. The CO excitation temperature is found to be higher than the estimated dust temperature of ~ 37K (Fig.3). This indicates that the dust and gas components are not quite thermalized if the emission arises from the same region or that the CO gas is emitted from a warmed inner part of the PN compared to the dust emission.

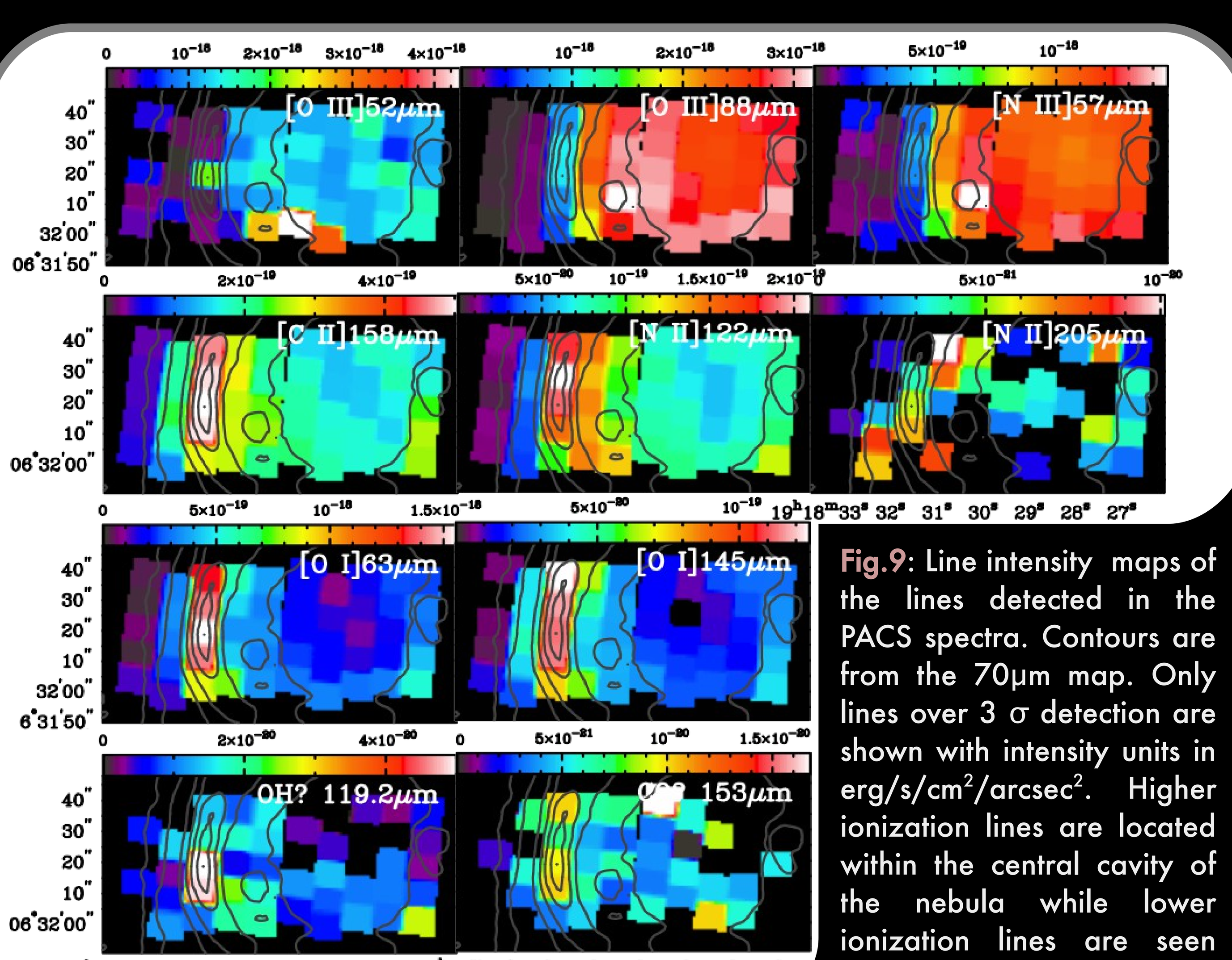

Fig.9: Line intensity maps of the lines detected in the PACS spectra. Contours are from the 70μm map. Only lines over 3 σ detection are shown with intensity units in erg/s/cm²/arcsec². Higher ionization lines are located within the central cavity of the nebula while lower ionization lines are seen within the rim region.

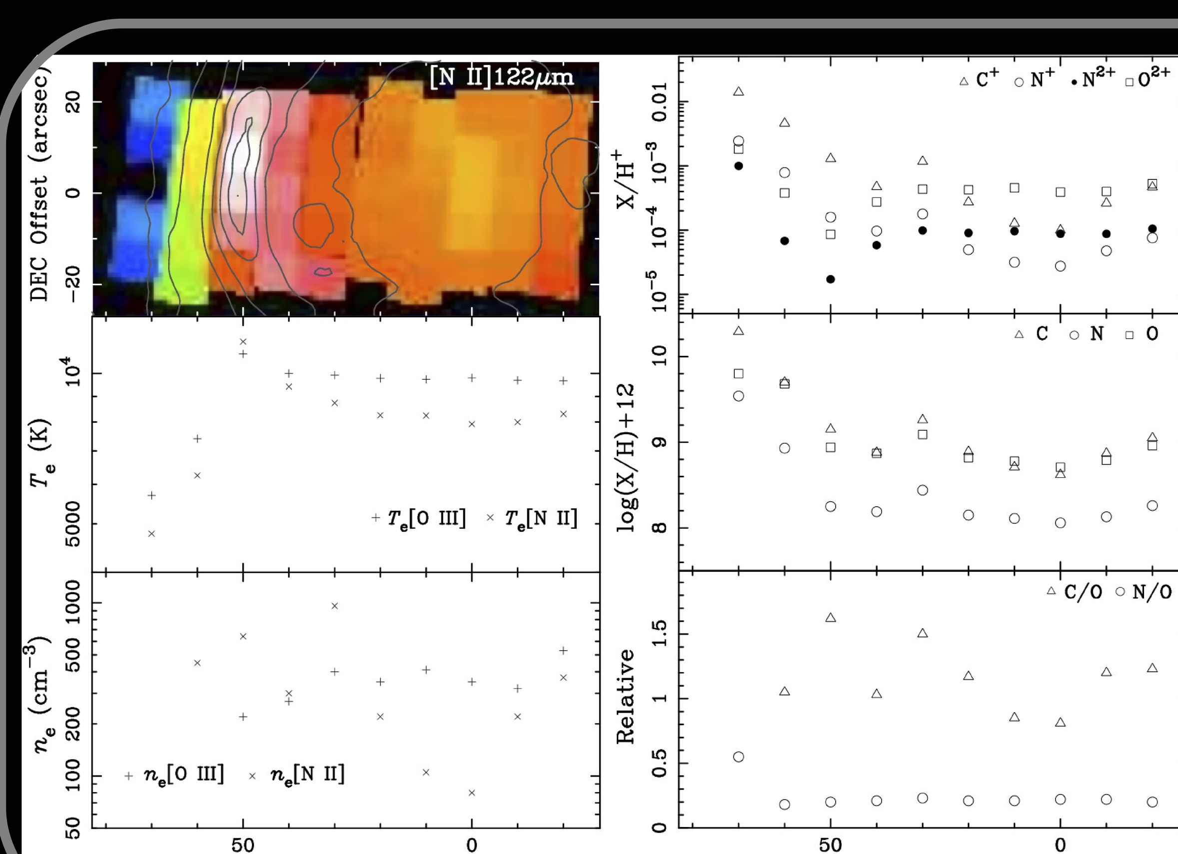

Fig.10: Electron temperature (T_e), Electron density (n_e) and abundance profiles across the RA direction of the observed region of NGC 6781 observed with PACS spectroscopy compared to the [NII] 122um line map (top left) with contours from the 70um PACS map. T_e is fairly constant in the central cavity with an increase and a peak temperature at the wall of the barrel with a fall off further out. N_e distribution shows a constant density of medium ionization gas while low ionization gas increases from the center outward with a peak at the barrel wall. Abundance profiles reveal the stratified structure of the nebula across the barrel cavity and barrel wall.

4. Conclusion

HerPlaNS data offer us a unique view of PNe. The combination of spatially resolved spectroscopy data with broad band imaging allow us not only to trace the dust and gas components of the nebula but to also to disentangle both components and quantify them. The broadband images of NGC 6781 trace the dust continuum distribution up to 500μm (Fig.2) while the spectroscopy data show us a rich atomic and molecular environment (Fig.7) with a first detection of OH^+ in emission in a PN. The resolved spectroscopy reveal the distribution of the ionized and molecular gas (Fig.6 and Fig.9) within the nebula and for the first time we clearly see the stratification of the different ionization layers in the nebula volume (Fig.10).

References: Frew, D. J., 2008, Ph.D. Thesis, Macquarie Uni., NSW, Australia/Kastner, J. H., et al. 1996, ApJ, 462, 777/Kastner, J. H., et al. 2012, ApJ, 144, 58/Schwarz, H. E., & Monteiro, H., 2006, ApJ, 648, 430

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