*Planetary Nebulae in our Galaxy and Beyond*
*Proceedings IAU Symposium No. 234, 2006*
*M. J. Barlow & R. H. Méndez, eds.*

doi:10.1017/S1743921306002961

# High spatial resolution study of the inner environment around two young planetary nebulae with [WR] central stars

**E. Lagadec[1,2] and O. Chesneau[2]**

[1]University of Manchester, UK
email: eric.lagadec@manchester.ac.uk

[2]Observatoire de la Côte d'Azur, France

**Abstract.** We present observations of the dusty emission from the young planetary nebulae Hen 2-113 and CPD-56°8032 obtained with VLT/NACO, VLTI/MIDI. Our NACO observations of Hen 2-113 reveals the presence of a diabolo-shaped structure. The L′ and M′ flux from the central source, show a strong infrared excess close to the central star and this source is resolved at a scale of about 150 mas. This infrared excess is explained by emission from a cocoon of hot dust with mass $\sim10^{-9}$ $M_\odot$ at $\sim$900 K. The central source is no longer visible with MIDI in the N-band and the nebula is fully resolved by a 8m telescope in this band. The dusty environment of CPD-56°8032 is much more compact, dominated by a bright, barely resolved, core whereas visible unpublished HST images shows that the nebula has an amazing complexity. From MIDI 8.7-$\mu$m acquisition images (dominated by PAH emission), the extension and geometry of the core have been estimated. Moreover, high SNR fringes at low level have been detected with projected baselines between 40 and 45 meters. This clear signal is interpreted in terms of the bright inner rim of a dusty disk exposed to the flux from the Wolf-Rayet star. The geometrical parameters of the N-band flux distribution are well constrained by means of simple geometrical models and a simple radiative transfer model has been developed to extract the physical parameters of the disc. The PA angle of the disk agrees well with the HST/STIS observations of De Marco *et al.* (2002), but the inferred inclination is much less (i$\sim$30°).

**Keywords.** techniques: high angular resolution, techniques: interferometric, stars: AGB and post-AGB, planetary nebulae: individual (Hen 2-113, CPD-56°8032)

## 1. Introduction

We present observations of the dusty emission from the young planetary nebulae Hen 2-113 and CPD-56°8032 (hereafter HEN and CPD respectively) obtained at the Very Large Telescope with the adaptive optics device NACO and the interferometric recombiner MIDI. The central stars of these two objects are of spectral type [WC10] ($T_{\rm eff}\sim 25000$ K and mass-loss rate of $\sim10^{-7}$ $M_\odot$ yr$^{-1}$) and these objects are located at similar distances making the detection of any differences in their close environment of great interest. Moreover, their dusty environments exhibit a dual dust chemistry with the simultaneous spectral signatures of warm carbon rich and cool oxygen rich dust.

## 2. Hen 2-113

Despite the careful study of the fundamental parameters of the CSs by De Marco and collaborators (De Marco *et al.* 1997), the morphology of the nebula of HEN was poorly known until the HST observations by Sahai *et al.* (2000). These authors showed that HEN exhibits a complex geometry, roughly bipolar with two bright, knotty, compact ring-like

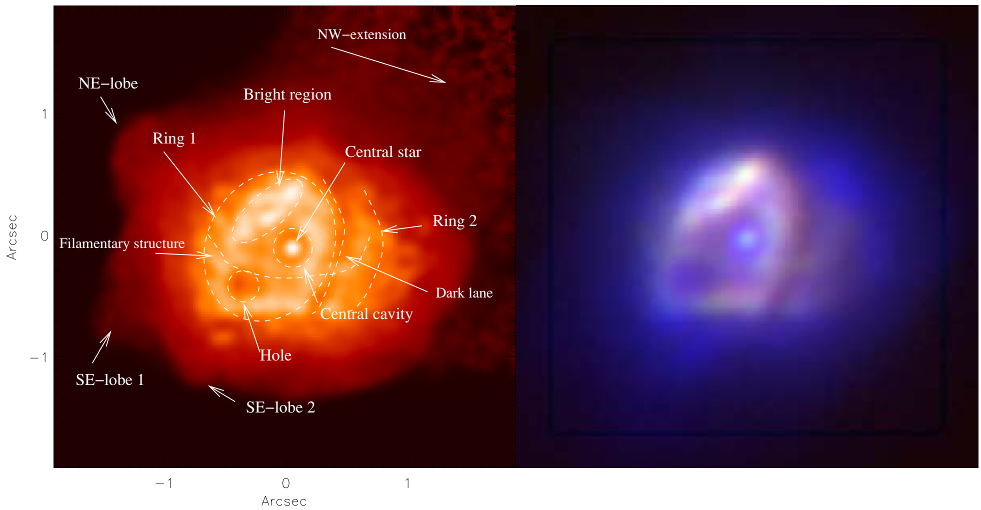


**Figure 1.** On the left, deconvolved L′ NACO image of HEN showing the complexity of its morphology; on the right, three color image of HEN showing the presence of a tilted diabolo-shaped structure inside the nebula.

structures around the central star. This compact structure is embedded in a larger and fainter spherically symmetric structure. Beside exhibiting dual-dust chemistry like CPD, its complex, multi-lobal geometry also suggests binarity.

Infrared observations of HEN were obtained with VLT/NACO, VLTI/MIDI, VLT/ISAAC and TIMMI at the ESO 3.6m telescope. We also attempted to detect and study small scales structures in the mid-IR with the long baseline interferometer MIDI/VLTI but the nebula appeared over-resolved with 46m baselines so that no interferometric data could be recorded. HEN exhibits a clear 1″ torus-like structure superimposed to a more diffuse environment visible in the L′ (3.8-$\mu$m), M′ (4.78-$\mu$m) and 8.7-$\mu$m bands. Our ISAAC and TIMMI observations indicates that the PAHs are mostly concentrated towards the bipolar lobes of the nebula. We interpret the two ring-like structures as due to the projection of the lobes of a diabolo-shaped structure observed nearly pole-on.

Photometry of the central star in the L′ and M′ bands indicates that it is respectively ∼300 and ∼800 times brighter than predicted by stellar models (De Marco *et al.* 1997). Moreover, the central object appears resolved in the L′ band, with a measured FWHM of about 155 mas. Simple calculations indicate that this infrared excess can be explained by emission from hot dust grains. A dust mass of $\sim 10^{-9}$ $M_\odot$ with T∼900 K can account for this infrared excess. By a totally independent way (fitting of the SED), Sahai *et al.* (2000) indicated the possible presence of hot dust (T∼900 K and $M \sim 10^{-9}$ $M_\odot$) inside the nebula. This is a clear evidence that dust is still continuously created in the present wind of the [WC] star. This kind of dusty structures could be common to PPNe and PNe as it as been mentioned that color measurements in other PNe observed with adaptive optics on Keck indicate the presence of hot dust close to the CS among a few of them (Sánchez-Contreras *et al.*, these proceedings).

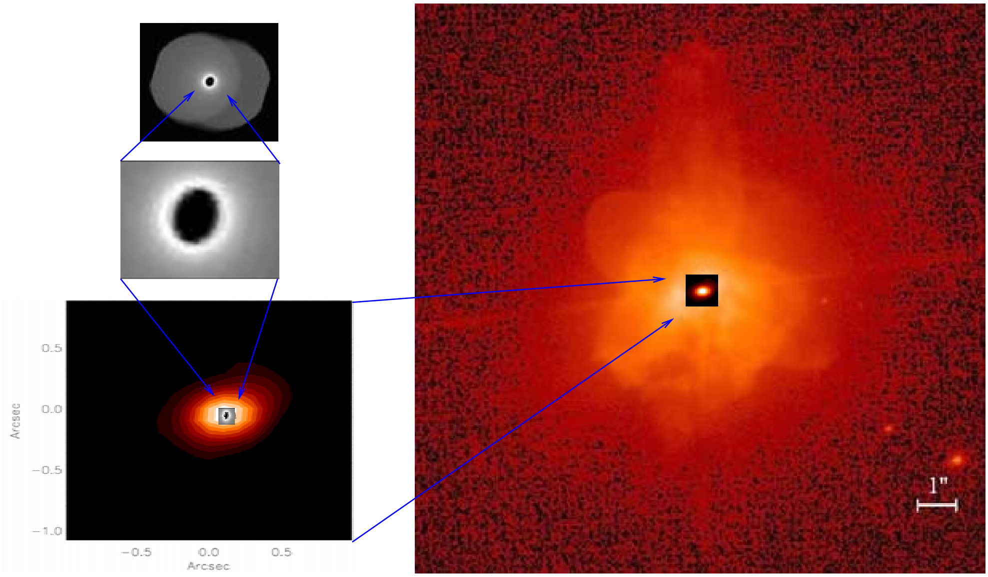


**Figure 2.** Sketch representing the different spatial scales of our observations of CPD. On the right, the nebula as observed with the HST, on the left bottom corner, the inner dusty structure observed by MIDI aquisition image, above the inner rim of the disc and the disc models as observed by MIDI

## 3. CPD-56°8032

De Marco, Barlow & Cohen (2002), presented the first direct evidence for an edge-on disk/torus around CPD, as revealed by HST/STIS spectroscopy. Their HST spectra show a spatially resolved continuum split into two bright peaks separated by 0″.10 and interpreted to be stellar light reflected above and below an obscuring dust disc. They deduced a disc thickness of 134 AU at 1.35 kpc (De Marco *et al.* 1997).

We observed CPD with VLTI/MIDI with single telescopes providing a resolution of 250 mas at 8.7 $\mu$m and in interferometric mode using the UT2-UT3 47m baseline, providing a typical spatial resolution of 20 mas. We made also use of unpublished HST/WPC2 images in the F435 and F606 filters. The visible HST images exhibit a complex multilobal geometry dominated by a few faint lobes for which a counterpart is not always found. The farthest structures are located more than 6″ from the star. The mid-IR environment of CPD is dominated by a compact source, barely resolved by a single UT telescope in a 8.7-$\mu$m filter ($\Delta\lambda$=1.6 $\mu$m, contaminated by PAH emission).

The infrared core is almost fully resolved with the three 40-45m projected baselines, ranging from –5° to 51°, but smooth oscillating fringes at low level have been detected in dispersed visibilities. This clear signal is interpreted in terms of a ring structure which would define the bright inner rim of the equatorial disc. Geometric models allowed us to retrieve the main geometrical parameters of the disc.

The disc geometry consists in a circular bright inner rim and a rapidly decreasing, although important, flux in the outer regions. A reasonably good fit to the visibilities curves is reached with an achromatic and elliptical truncated Gaussian profile with a radius of 97±11 AU, an inclination of 28±7° and a PA for the major axis of –15°±7°.

We performed radiative transfer simulations using the continuum radiative transfer code MC3D (Wolf *et al.* 1999), restricted to carbon-rich dust (i.e. to the close vicinity of the star). The goal was to get a good estimate of the physical parameters of the inner

https://doi.org/10.1017/S1743921306002961 Published online by Cambridge University Press

rim based on the simultaneous constraints of the visibilities, MIDI spectra and the SED. These models show that the disc is mostly optically thin in the N-band and highly flared, witnessing an advance stage of dissipation, probably as a result of the recent evolution of the central star through the [WR] stage (Fig 2).

## 4. A short comparison of these two environments

HEN and CPD offer a unique opportunity to compare two different nebulae ejected from central stars presenting striking similarities. The central stars are both of [WC10] type, with very similar temperature and luminosity, putting them onto tracks of stars at 0.62 $M_{\odot}$. At large scales, their environments observed by the HST are quite different. The nebula around HEN is more compact and perhaps simpler than the one seen around CPD although both exhibit a complex multi-lobal geometry. Despite its compactness, HEN presents a ring-like structure which is resolved by a single 8m telescopes from $L'$ to N band, whereas CPD is definitely only barely resolved at 8.7 $\mu$m (probably due to the presence of PAHs) and harbors a compact disc in the vicinity of the central star.

In this context, the question of the dynamical age of the nebulae is of importance. The development of a compact and complex planetary nebula is a fast event compared to the life-time of their parent stars and it is possible that the differences reported for HEN and CPD nebulae are solely due to the age of the ejection, the nebula of CPD being younger in this case than HEN since the dusty core is more compact. On the other hand, it does not explain why some lobes seen in the HST images of CPD are so extended, reaching $6''$ from the central star, whereas the lobes from HEN are at most at $3''$ from the star.

Dust formation (in particular episodic dust formation) might be the result of binary interaction as is the case of the massive stars WR104 and WR98a (Tuthill *et al.* 1999; Monnier *et al.* 1999, 2002). The presence of circumstellar or circumbinary discs is another signature of the possible presence of an unseen companion orbiting CPD and HEN.

In the case of [WR] CSPNe, De Marco & Soker (2002) put forward the speculative hypothesis that they result from a merger which dictated the change between oxygen-rich and carbon-rich chemistries as well as a departure from the AGB. In this scenario, the stars are currently single (we note that no [WC] CSPN is known to be in a binary system) and the discs would be a signature of their binary past. In this scenario the newly formed dust seen around HEN (Lagadec *et al.* 2006) would not be triggered by a companion but intrinsically formed in the wind of the [WR] star.

**Acknowledgements**

This work is the result of a fruitful collaborations involving Arnaud Collioud, Orsola De Marco, José de Freitas de Pacheco, Sebastian Wolf, Albert Zijlstra, Mikako Matsuura, Agnès Acker, Geoffrey Clayton, Bruno Lopez and Alexander Rothkopf.

## References

De Marco, O., Barlow, M. J., & Storey, P. J. 1997, MNRAS, 292, 86
De Marco, O., Barlow, M. J., & Cohen, M. 2002, ApJ, 574, L83
De Marco, O., & Soker, N. 2002, PASP, 114, 602
Lagadec, E., Chesneau, O., Matsuura, M., *et al.* 2006, A&A, 448, 203
Monnier, J. D., Tuthill, P. G., & Danchi, W. C. 1999, ApJL, 525, L97
Monnier, J. D., Tuthill, P. G., & Danchi, W. C. 2002, ApJL, 567, L137
Sahai, R., Nyman, L.-A., Wooten, A. 2000, ApJ, 543, 88
Tuthill, P. G., Monnier, J. D., & Danchi, W. C. 1999, Nature, 398, 487
Wolf, S., Henning, Th., & Stecklum, B. 1999, A&A, 349, 839

https://doi.org/10.1017/S1743921306002961 Published online by Cambridge University Press