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The Red Rectangle as a Peculiar Evolved Binary

Hans Van Winckel
Instituut voor Sterrenkunde, KULeuven, Celestijnenlaan 200B, 3001 Leuven (Heverlee), Belgium

Abstract. Since the discovery paper, back in 1975, the Red Rectangle nebula around its central bright object HD 44179, has remained a very popular object of study over a wide wavelength domain. Its former role as proto-typical example of a proto-planetary nebula has changed in the recent years, and the object is now understood as an evolved object in a binary orbit. The binary is not in contact any longer, but during the former cool giant phase, interaction must have been severe. The inner structure of the object is a binary with a period of 318 $\pm$ 3 days in an eccentric orbit (e=0.37), surrounded by a stable circumbinary disc in Keplerian rotation. This presence of a disc is suspected in many other post-AGB binaries, but it is the circumstellar chemistry and the nebular morphology that makes the Red-Rectangle unique.

1. Introduction

During this conference the specific talks of individual objects showed a bewildering richness of individual peculiarities, not only of Planetary Nebulae (PNe), but also on objects in the previous evolutionary phase: the proto-planetary nebulae (PPNe). Clearly, much has to be learned still from these individual objects, but an even bigger challenge lies in the study on how these individual objects are linked by evolutionary channels. The significance of the enigmatic individual objects in the broader picture of stellar evolution is not clear.

One of those well studied, but poorly understood, objects is the Red-Rectangle (RR in what follows) nebula observed around the central bright object HD 44179 (m(v) $\sim$ 8.8). The nebula with its peculiar morphology was identified by Cohen et al. (1975) while the strong IR emission ($F_{IR}/F_{UV-VIS} \sim 33$) was detected during the IR Sky survey (Price & Walker 1976). Since then, the RR was often dubbed a 'proto-typical' C-rich proto-planetary nebula with a bipolar morphology. In this contribution, I will give an overview of the recent studies on this popular object (355 references in ADS in September 2003) which shows that this enigmatic object is far from being understood.

2. Binary characteristics

The inner structure of the nebula is well resolved with present day observational facilities and consists of an optically thick dust disc or torus seen almost edge-on with optically bright scattering lobes on both polar regions (e.g. Roddier et al.

1995; Osterbart et al. 1997; Bond et al. 1997). The disc formation antedated the recent C-rich phase, since the cooler parts are O-rich (Waters et al. 1998) and the suspected longevity was confirmed by the detection of Keplerian rotation in CO interferometric maps, which yield a total central mass of the binary of 0.9 $M_\odot$ and an uncertain disc mass of 0.04 $M_\odot$ (Bujarrabal et al. 2003, see also these proceedings).

Both central bright lobes are about 0.″14 apart, indicating a disc geometric total thickness of about 100 A.U., assuming a distance of 710 pc (Men'shchikov et al. 2002). The spectra of these scattering lobes do, however, indicate radial velocity changes with an orbital period of 318 days and a high eccentricity of e=0.37 with F(M)= 0.052 $M_\odot$ and a sin i = 0.34 A.U. (Waelkens et al. 1996, revised numbers). The spectrum of the object is consistent with an F-type object of about 7500K (Van Winckel et al. 1995).

The orbit is remarkable since, assuming the evolved star went through an AGB evolution, its dimensions would have been bigger than the current orbit and recent binary population synthesis calculations show that systems with periods $\leq$ 3000 days are circularised by stable Roche Lobe overflow or tidal interaction by the time the primary reaches the post-AGB evolutionary stage (Pols et al. 2003). Clearly, an eccentricity pumping mechanism (e.g. Artymowicz et al. 1991; Soker 2000) has to be invoked to understand the high eccentricity of the RR and some other binary post-AGB stars (Van Winckel et al. 1995).

There is evidence for a small HII region from radio observations (Jura et al. 1997) and very weak [NII] emission, which inspired Men'shchikov et al. (2002) to postulate the companion to be a He-WD. If true, the previous evolution of the RR system would be even more complicated. Note that shocks can also produce a small HII region and there is evidence for high velocity ($\sim$ 100 km s^{-1} gas in the wings of the H_α emission, so a more likely companion of the system is an un-evolved main sequence star.

3. Nebula

The RR is a famous IR-source with C-rich circumstellar material: the object is best known for the strong PAH bands in the near and mid-IR (Russell, Soifer & Willner 1987) and also for its strong extended red emission (ERE), associated with C-rich reflection nebulae. The ERE has been detected also in HII regions, diffuse Galactic ISM and dusty ISM of external galaxies (e.g. Smith & Witt 2002). The ERE is exceptionally strong in the RR and it even determines the morphology of the nebula: in pure scattered light, the nebula is remarkably spherically symmetric, while only in the ERE emission the bipolar structure is well apparent. Figure 1 gives a good representation of the wavelength dependence of the RR on HST-PC images of the blue F456M and red F622W filter (Cohen et al. 2004). No evidence for concentric rings (see Su et al. these proceedings) were found.

Thanks to the high spatial resolution images of the HST, we discovered that the nebular structure is much more complex than anticipated: the X-shaped nebula is formed by a sequence of discrete mass-loss episodes, probably confined by the presence of the long lived disc. These mass-loss events form a complex pattern of nested parabola which terminate on the bicone edges in large, limb-

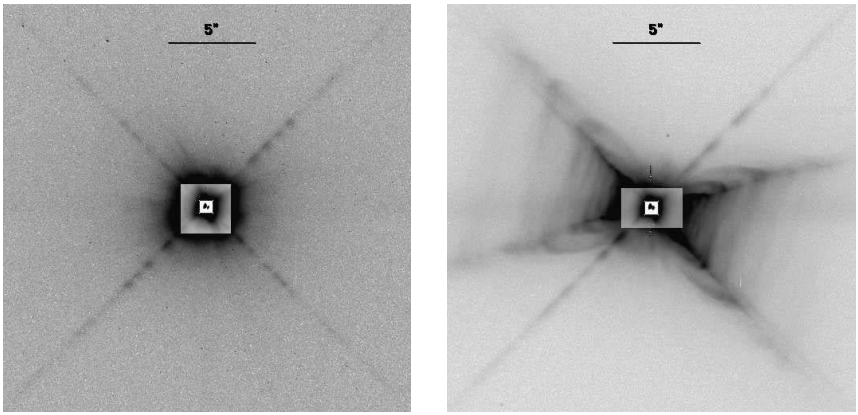


Figure 1. The striking morphology difference between a blue image (HST filter F467M) and a red image (F622W). The first filter samples only scattered light, while the red filter is centred on the Extended Red Emission, photoluminescence of a yet unknown carrier.

brightened vortices. The edges are connected with linear features perpendicular to the radius vector and give the nebula a ladder-like structure. The total extend of the nebula is some 2' on the sky and the dynamical age of the extended nebula is estimated to be about 14000 years (Cohen et al. 2004). Similar structures were found by Icke (2002) in detailed modelling of a spherically symmetric intermittent wind of cooling gas which is focused by an oblique shock. Weak H_α emission, which is indeed observed on the long symmetry axis of the nebula, is also predicted by this model (e.g. Cohen et al. 2004).

4. Circumstellar Chemistry

Besides the continuum ERE emission and the mid-IR PAH emission complexes, the circumstellar chemistry is very rich and the carriers of many additional spectral features completely unknown.

The circumstellar chemistry is complex and molecular components are observed in a broad wavelength range. The identified bands include the UV CO Cameron bands (likely to come from CO_2 dissociation); UV OH-bands; Ca H and K emission; CH^+ optical line emission; superposed on the broad ERE emission, many narrow complexes are found, which display a profile change with a decrease in FWHM with increasing distance from the central object. Some of these features converge, both in wavelength and in profile, to narrow Diffuse Interstellar Bands. Finally CO_2 gas phase absorption was detected in the IR. A more complete overview is given in Van Winckel et al. (2002) and references therein.

The nebula is weak in pure rotational line diagnostics. The very narrow CO profile (Bujarrabal et al. 2003); the inferred presence of very large grains (Jura et al. 1995) and the presence of cool strongly crystalline silicates (Waters

at al. 1998) are also best explained by long-term processing of the dust in the circumstellar disc. Note that even macrostructures might have been observed (Jura & Turner, 1998).

5. Conclusion

Although the inner structure of the RR, with its edge-on Keplerian disc surrounding a binary central star, is suspected to be similar in more objects (see Van Winckel 2003), the complex circumstellar chemistry, involving both C and O-rich components, make the RR nebula quite unique.

References

Artymowicz, P., Clarke, C. J., Lubow, S. H., & Pringle, J. E. 1991, ApJ, 370, L35

Bujarrabal, V., Neri, R., Alcolea, J., & Kahane C. 2003, preprint

Bond H.E., Fullton L.K., Schaefer K. et al. 1997, in IAU Symp. 180 "Planteary Nebulae", 211

Cohen, M., Anderson C. M., Cowley A. et al. 1975, ApJ, 196, 179

Cohen, M., Van Winckel, H., Bond H. E., & Gull T. R. 2004, AJ, submitted

Icke, V. 2002, in IAU symp 209, in press.

Jura, M., & Turner, J., 1998, Nature, 395, 144

Jura, M., Balm , S. P., & Kahane, C. 1995, ApJ, 453, 721

Jura, M., Turner, J., & Balm, S.P. 1997 ApJ, 474, 741

Men'shckikov, A. B., Schertl, D., Tuthill P. G., Wigelt, G., & Yungelson, L. R. 2002, A&A, 393, 867

Osterbart R., Langer N., & Weigelt G. 1997, A&A, 325, 609

Pols, O. R., Karakas A. I., Lattanzio J. C., Tout C. A., 2003, In ASP conf. Ser.: Symbiotic Stars, in press

Price, S. D., & Walker, R. G. 1976, AFGL-TR-0208 Environemental Research papers

Roddier F., Roddier C., Graves J.E., & Northcott M.J. 1995, ApJ, 443, 249

Russell, R. W., Soifer, B. T., & Willner, S.P. 1987, ApJ, 220, 568

Smith, T. L., & Witt, A. N. 2002, ApJ, 565, 304

Soker, N. 2002, ApJ, 570, 369

Van Winckel, H. 2003, ARA&A, 41, 391

Van Winckel, H., Waelkens, C., & Waters, L. B. F. M., 1995, A&A, 293, L25

Van Winckel, H., Cohen, M., & Gull T. R. 2002, A&A, 390, 147

Waelkens, C., Van Winckel, H., Waters, L. B. F. M., & Bakker, E. J. 1996, A&A, 314, L17

Waters, L. B. F. M., Waelkens, C., & Van Winckel, H. et al. 1998, Nature, 391, 868