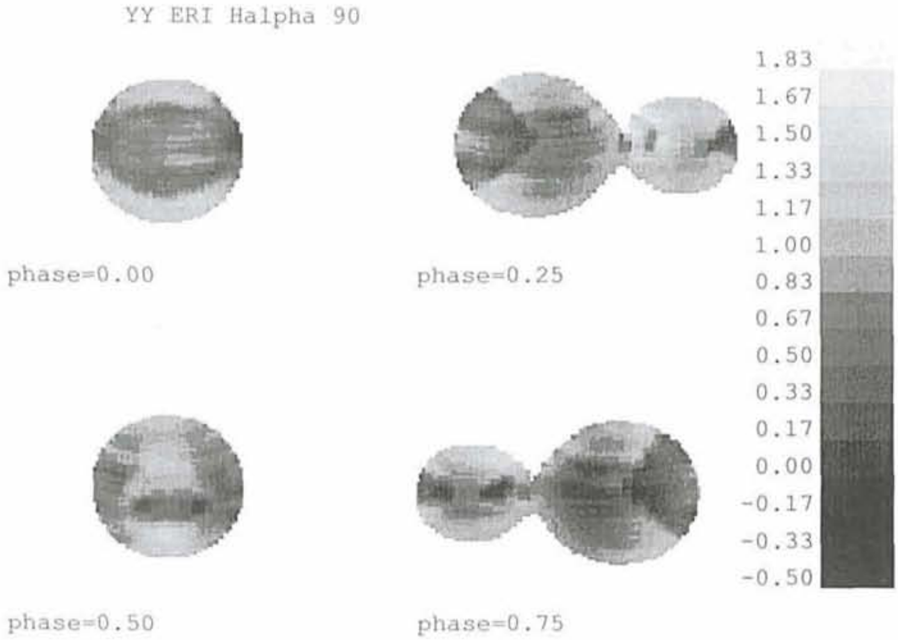

Figure 5: *Doppler imaging surface maps of YY Eri.*

hence the use of the appropriate model atmospheres. However, on a more qualitative ground, we know that darker tones correspond to colder areas; from a first rough estimate S = 1.83 corresponds to 350 K above the mean and S = 0.5 to 400 K below.

The similarity between the photometric and spectroscopic maps is evident, at least with reference to the distribution on a large scale. In both cases the fitting of the data requires a smooth non-uniform temperature distribution with the stellar poles hotter than the backs and the equators. Therefore we can say that the models from photometry and spectroscopy are at this level fully consistent. On the other hand, the detailed analysis of the surface features requires a less simple treatment, that we are still developing. Even in absence of spots we have a T distribution over the surface, which implies a variation of the line equivalent width and affects the reference values of S (i.e. the value corresponding to the unperturbed photosphere). To disentangle this effect from the actual brightness variation we are undertaking the computation of local profiles by means of model atmospheres.

3. Discussion and Conclusions

The Doppler imaging was already successfully applied to less rapidly rotating objects by other people, but as far as we know never to W UMa stars. With this experience we intended to examine if it is also possible to obtain new information about these capricious, rapidly rotating objects. The reason for this approach was clear. From the measurements of visible light curve, UV and X we know that these binaries are seats of magnetic activity. Furthermore, it is generally believed that high AML is controlling the evolution of these binaries towards the single-star stage, involving mass transport from the secondary to the primary component. Nobody presently understands how this mass transport takes place and how it is interacting with magnetic, tidal and Coriolis forces. It can be hoped that from a better survey of the brightness inhomogeneities on the surface, a better insight in the origin of these inhomogeneities, and related large-scale motions, can be obtained.

Our first results are encouraging for a further development of the application of this method. However, we feel that the next step will most probably require the use of the 3.6-m telescope, to have the possibility of enlarging the observable sample and of analysing less strong (and simpler) spectral lines.

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Are the Nebulae Around R Coronae Borealis Stars Evolution or Ejection Related?

D. POLLACCO, Department of Physics and Astronomy, St. Andrews University, Scotland

The R Coronae Borealis (R CrB) stars are a rare group of cool hydrogen-deficient supergiants whose light variations are characterized by dramatic fading of up to visual mag. 9 and a slow recovery to maximum. Spectroscopically they appear to be extremely hydrogen-deficient and carbon rich. Their evolutionary history has been the source of much controversy. Mixing scenarios for single AGB stars (Schönberner, 1986) have been unable to reconcile the observed photospheric abundances with model predictions. Recently two rather exotic scenarios have emerged that address this problem:

- *The last thermal pulse scenario* (Renzini, 1979, 1981 and Iben et al., 1983). Calculations have shown that if a white dwarf suffers a thermal pulse it may be intense enough to re-ignite a helium-burning shell sending the star towards the AGB for a second time ('Born again' AGB star). The R CrB stars are suspected to be at this stage. This process is accompanied by large-scale mixing of the photosphere. Although the computational work is great it does appear that the time spent at the AGB is

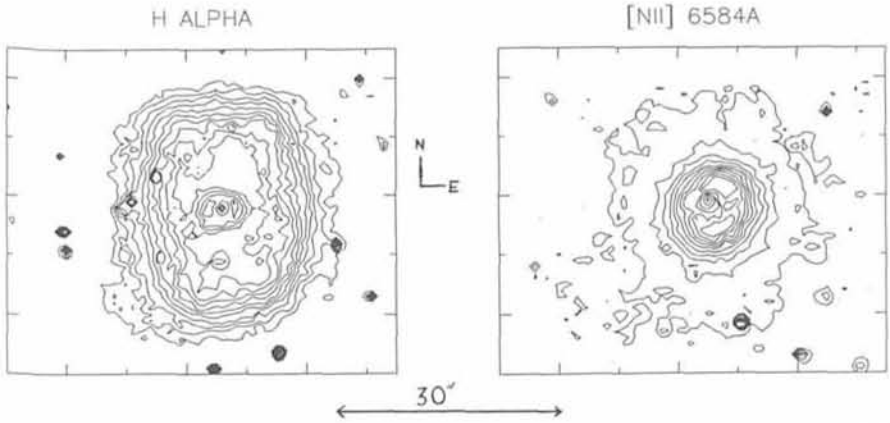

Figure 1a/b: *Narrow-band images of V 348 Sgr and its surrounding nebula taken with the ESO/MPI 2.2-m telescope in 1987. In each case there are ten contours equally spaced between the sky level and the peak flux in the central nebula. These images are continuum subtracted – although differences in the PSF through the different filters and images show that some stellar residue remains.*

strongly mass dependent and even for the lowest mass objects may be too short to account for the suspected R CrB lifetimes. Subsequent evolution is via a Schönberner track to the white dwarf configuration.

- *The merged white dwarf scenario* (Webbink, 1984). It is thought possible that a double degenerate binary consisting of He and CO white dwarfs may lose sufficient angular momentum by gravitational radiation/material ejection to allow the system to merge within a Hubble time. In these circumstances it is expected that the lighter He dwarf will be smeared around the other producing the observed abundances.

The first clues to the evolutionary status of the R CrB stars may have been found by Herbig (1949, 1968) who while observing the proto-type R CrB in deep minima found possible evidence of [O II] λ3727/9Å emission. These lines only occur in low-temperature and density material and suggest that R CrB may be surrounded by a low-surface brightness nebula. IRAS observations of R CrB have revealed the presence of a huge fossil dust shell (Walker, 1986) some 8 pc in diameter. Gillett et al. (1986) tried to understand the heating of the shell but concluded that the stellar and interstellar radiation fields are far too feeble to account for the observed shell temperature.

The hot R CrB stars are thought to be similar to the R CrB stars but have much higher photospheric temperatures (Pollacco, 1989, Pollacco and Hill, 1991). The brightest member of this class, V 348 Sgr, is known to be surrounded by a faint nebula. Figure 1a/b shows the nebula's morphology as observed through Hα and [NII] λ6584Å narrow-band filters using the ESO/MPI 2.2-m telescope remotely from Garching. These images are continuum subtracted and show an amazing morphology difference (normally images of PN in these ions display roughly similar structures). Spectroscopy obtained with the AAT (Fig. 2) shows the nebula to be of low excitation. An analysis of this indicated that helium is heavily overabundant, while simple and more complicated modelling failed to predict the observed nebular ionization and extent at the inferred surface temperature of the central star (~20,000 K: Schönberner and Heber, 1986). However, convergence was achieved using black-body models (the limiting case) if the stellar temperature was raised by some 10,000 K (Pollacco et al., 1990). UV spectra do not give any indications of another body in the system, so we are forced to accept that V 348 Sgr must have been hotter in the recent past (the recombination timescale of the nebula is 120–2300 yr). We conclude that V 348 Sgr is rapidly evolving towards the red supergiant region of the HR diagram – probably the R CrB region.

In order to test this scenario more thoroughly we (Pollacco et al., 1991) have used the NTT to search for faint nebulae around cool R CrB stars. Multiple images were obtained of UW Cen in very deep minima that clearly show the star to be surrounded by a faint (and small) nebula of unusual physical appearance (Fig. 3). The morphology consists of a fainter outer envelope of circular appearance while the central parts are dominated by a pair of reasonably collimated and diagonally opposed "jets" (I use this word lightly). Narrow-band imaging and spectra (Fig. 4) obtained with the NTT suggest that the nebular emission is dominated by a scattering component with no obvious signs of line emission (our detector had little efficiency at λ3720 Å). Despite the overwhelming excellence and hence enjoyment of using the NTT, this run was overshadowed by a certain student – who shall remain nameless – who found during a long slew that he was unable to control the contents of his stomach.

This structure is proving difficult to understand in the context of the evolutionary scenarios set out above. However, considering the ejection velocities implied by chromospheric lines (~200 km s^{-1}) observed during the decline to minimum, these structures could easily be produced within the theoretical age of the R CrB phase (Schönberner, 1977). Hence it is more likely that the jet structure is related to the process causing the minima. In line with this, Pollacco et al. (1991) suggest that in UW Cen and by implication all R CrB stars, there is also a jet in or close to the line of sight.

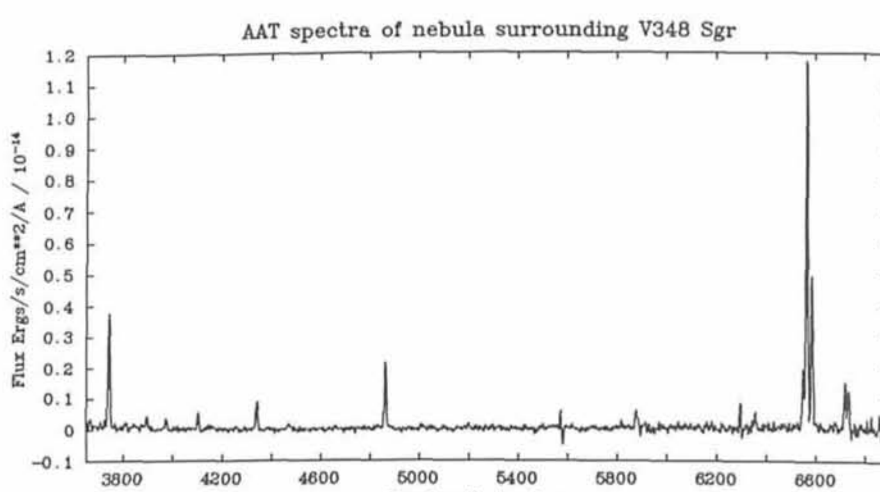

Figure 2: *Sum of 5 hr worth of IPCS spectra taken with the AAT in 1987. Note the relatively strong appearance of HeI λ5876Å which is not expected for a central source of this temperature (~20,000 K).*

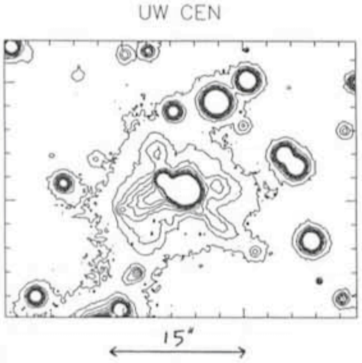

Figure 3: *NTT V band image of the classical R CrB star UW Cen obtained when the star was in a deep minimum. In this diagram there are ten contour levels equally spaced between the sky and 10 % of the peak stellar flux.*

Spectroscopic and photometric observations of R CrB stars at different points of their light curve suggest that the deep minima may be caused by an ejection of material in the line of sight with subsequent condensation producing an effect analogous to a solar eclipse ("the consortium of puffs model", Feast, 1986). As the dust clumps disperse, the star slowly returns to its former brightness. At maximum brightness many R CrB stars appear to vary with a ~40-day period and in the cases of RY Sgr and R CrB itself (the best studied objects) these oscillations are thought due to radial pulsations. R CrB stars are known to be surrounded by hot circumstellar shells (800 K) so that at IR wavelengths the shell flux becomes increasingly dominant until at L it is the outstanding contributor. Observations of RY Sgr show that the shell is powered by the stellar radiation field as it also displays the ~40-day variation and this continues despite the optical minima and with a similar magnitude. The shell pulsation is superimposed on a much longer period variation (1000–3000 days). Feast (1990) has found that optical declines are often associated with rising of bright periods in L flux and suggested that ejected material gathers in the shell until at some critical density condensation occurs. Stellar radiation pressure then drives the clumps to great stellar distance where upon they disperse. The long-term variation in L corresponds to a "refilling" of the shell by ejected stellar material (quasi-periodic relaxation oscillations). An implication of Feast's model is that ejected material is randomly expelled but Stanford et al. (1988) have found polarimetric evidence in support of a preferred plane of ejection. Feast (1990) rejects this scenario due to geometric considerations (no R CrB-like stars are known that do not display deep minima[1] and interprets the polarimetric data as indications of a grain collimation direction. This latter criticism could also be levelled at the jet model but Pollacco et al. point out that with a sufficiently large jet opening angle (and this seems valid in the case of UW Cen) the statistical occurrence of R CrB-like stars not displaying minima would be small. Both Stanford et al.'s and Feast's models imply some collimation mechanism is at work – be it non-radial pulsation (Stanford et al.) or a magnetic field (Feast).

Future observations of other R CrB stars in deep minima will allow us to confirm or reject this model and may shed light on the jet collimation mechanism. While the detection of extended line emission will lend strong support for Renzini's ideas.

This work is carried out in collaboration with C.N. Tadhunter (RGO), P.W. Hill (St. Andrews), L. Houziaux (Liège) and J. Manfroid (Liège).

[1] This statement may not be correct as it is becoming increasingly apparent that a good number of R CrB stars suffer minima only rarely – sometimes only at discovery.

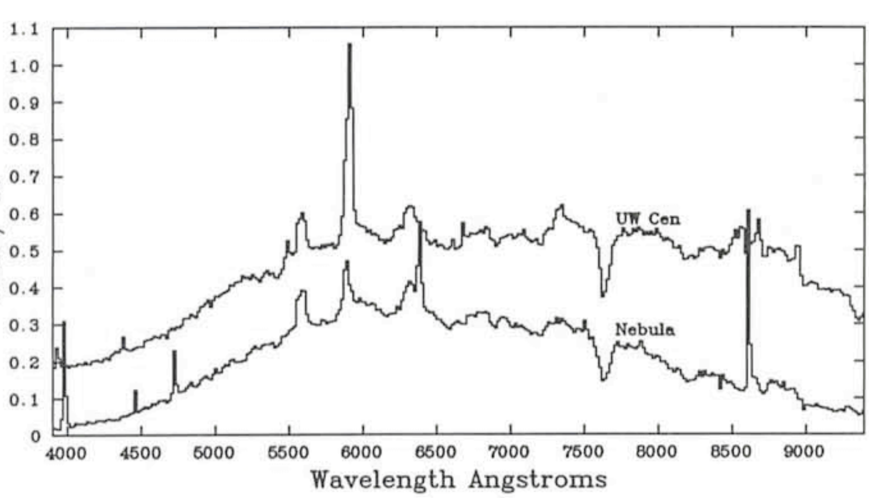

Figure 4: *EFOSC spectra obtained east-west through the central regions of Figure 3. The spectrum of the nebula is similar to that of the star but with a bluer energy distribution. This behaviour is indicative of a reflection nebula.*

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