Winds in R Coronae Borealis Stars

Geoffrey C. Clayton (Louisiana State University), T.R. Geballe (Gemini Observatory) & L. Bianchi (JHU)

Introduction – The RCB stars are a small group of hydrogen-deficient carbon-rich supergiants which undergo spectacular declines in brightness of up to 8 magnitudes at irregular intervals (Clayton 1996,PASP, 108, 225). RCB star atmospheres are extremely deficient in hydrogen but very rich in carbon. Dust is apparently forming within a couple of stellar radii of the stars, which have $T_{eff} \sim$ 5000 – 7000 K. RCB stars are very rare. Only about 35 are known in the Galaxy (Clayton 1996). Their rarity may stem from the fact that they are in an extremely rapid phase of the evolution toward white dwarfs. Understanding the RCB stars is a key test for any theory that aims to explain hydrogen deficiency in post-Asymptotic Giant Branch stars. There are two major evolutionary models for the origin of RCB stars: the Double Degenerate and the Final Helium Shell Flash (Iben et al. 1996, ApJ, 456, 750). The former involves the merger of two white dwarfs, and in the latter a white dwarf/evolved Planetary Nebula (PN) central star is blown up to supergiant size by a final helium flash.

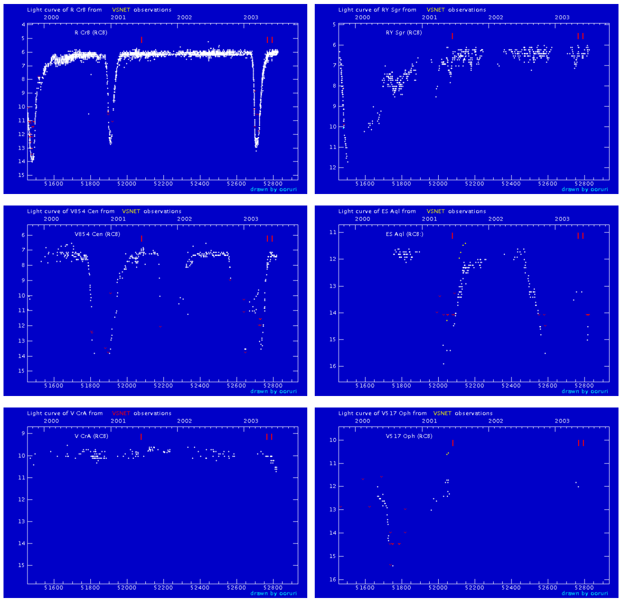

Figure 1 – VSNET lightcurves for the RCB stars whose He I λ10830 spectra are shown in Figure 2. The lightcurves cover the last 4 years. The epochs of the spectroscopic observations are marked in red. There seems to be a correlation between recent dust formation activity and the strength of the blue-shifted He I absorption. Declines occur when dust forms in front of the stellar photosphere as shown in Figure 4.

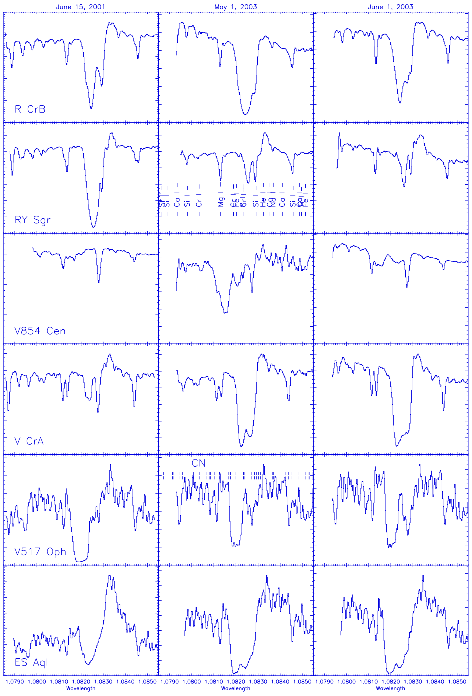

Figure 2 – We present new UKIRT CGS4 echelle spectra of the He I λ10830 line in RCB stars which provide the first strong evidence that all RCB stars have winds (Clayton et al. 2003, ApJ, in press (Sep. 20)). The new spectra show that all ten stars observed have P-Cygni or asymmetric blue-shifted profiles in the He I λ10830 line. The spectra are shown for six RCB stars at three epochs, June 2001, May 2003 and June 2003. Vacuum wavelengths are plotted. Other than He I, the spectra of the warmer RCB stars such as RY Sgr show mainly neutral atomic species while the cooler stars such as V517 Oph show many CN absorption bands. He I λ10830 varies significantly in strength and shape, both from star to star and on short and long timescales. For example, note the large change in the blue-shifted absorption of RY Sgr from 2001 to 2003, and in V854 Cen from May to June 2003. In all cases, the line indicates a mass outflow - with a range of intensity and velocity. The lower state of the He I λ10830 transition is 20 eV above the ground state. This state is metastable as its transition probability is very small. It can be populated by two mechanisms, photoionization/recombination or collisional excitation. Rao et al. (1999, MNRAS, 310, 717) estimate T $\sim$ 20000 K and $n_e = 10^{11}$–10^{12} cm^{-3}. In this regime, collisional excitation is important.

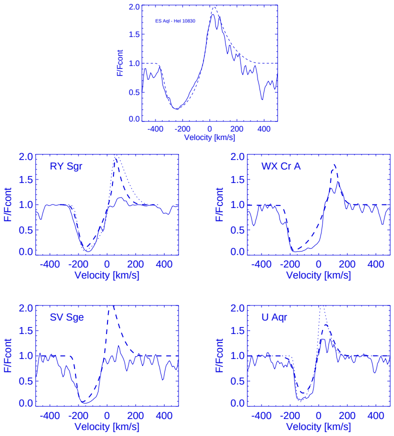

Figure 3 – The line profiles have been modeled with an SEI code to derive the optical depth and the velocity field of the helium gas. The results show that the typical RCB wind has a steep acceleration with a terminal velocity of V_∞ = 200-350 km s^{-1} and a column density of N $\sim 10^{12}$ cm^{-2} in the He I λ10830 line. The He I λ10830 line profiles of five stars in our sample are shown, in velocity scale, with their best fit model profiles. The main absorption structure is asymmetric and blue-shifted, indicating outflow, and the corresponding emission is probably masked by other lines. The interpretation of which parts of the profiles are the intrinsic He I line profiles becomes uncertain, and the two possible fits shown for RY Sgr and U Aqr show the range of uncertainty of the analysis in these cases. Zero velocity is the rest wavelength of the transition after the recession velocity of the star has been removed.

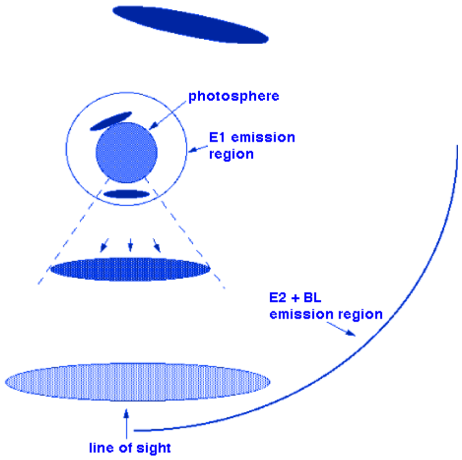

Figure 4 – A scenario for Near-Star dust formation in RCB stars. In this scenario, dust forms near the star and moves quickly away due to radiation pressure, expanding to cover the photosphere and parts of the emission regions. Small dust clouds may form during each pulsation cycle of the star. Declines only occur when a cloud forms along the line of sight. It has long been suggested that when dust forms around an RCB star, radiation pressure accelerates the dust away from the star, dragging the gas along with it.