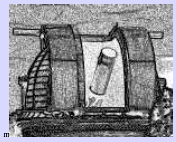
AA Dor – An Eclipsing sdOB - Brown Dwarf Binary



Thomas Rauch

[1]Dr.-Remeis-Sternwarte, Sternwartstraße 7, D-96049 Bamberg, Germany
e-mail: Thomas.Rauch@sternwarte.uni-erlangen.de
[2]Institut für Astronomie und Astrophysik, Universität Tübingen, Germany

AA Dor is an eclipsing, close, post common-envelope binary (PCEB) consisting of a sdOB primary star and an unseen secondary with an extraordinary small mass ($M_2 \approx 0.066\,M_\odot$) – formally a brown dwarf. The brown dwarf may have been a former planet which survived a CE phase and has even gained mass.

A recent determination of the components' masses from results of NLTE spectral analysis and subsequent comparison to evolutionary tracks shows a discrepancy to masses derived from radial-velocity and the eclipse curves. Phase-resolved high-resolution and high-SN spectroscopy was carried out in order to investigate on this problem.
We present results of a NLTE spectral analysis of the primary, have a close look onto the emission component seen in Hβ, and discuss possible evolutionary scenarios.

Spectral Analysis

In a recent spectral analysis of AA Dor, Rauch (2000) determined $T_{\rm eff} = 42\,$kK and log g = 5.2 (cgs). The photospheric abundances are shown in Figure 1.

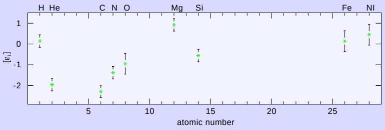


Figure 1. Photospheric abundances of the primary of AA Dor. Note the clear indications of gravitational settling and radiative levitation.

Although Rauch (2000) used advanced model atmospheres for the spectral analysis of the primary, a "g problem" appeared — there is no realistic agreement in the mass-radius relation between his results and the solution of a mass function f(m) and light-curve analysis (Figure 2) — an intersection is found only at $M_1 < 0.2\,M_\odot$ (within error limits) which seems to be too low for a sdOB star.

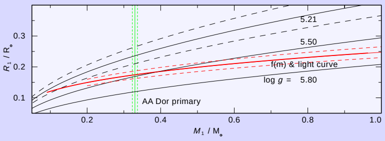


Figure 2. Mass-radius relation for the primary of AA Dor. Obviously, the solution from f(m) and light curve does not intersect with the result (log g = 5.21) of Rauch (2000) and the mass value ($M_1 \approx 0.330\,M_\odot$) determined from comparison to evolutionary models. The dashed lines indicate the error ranges. log g = 5.5 would be necessary to achieve a sufficient agreement.

On the "g problem"

Possible reasons for the discrepancy described above may be too optimistic error ranges in Rauch (2000) or in the analysis of light curve and radial-velocity curve, or that the theoretical evolutionary models of Driebe et al. (1998) are not appropriate in the case of AA Dor since these are post-RGB models for non-CE stars.

Hilditch et al. (2003) have recently verified previous results of light-curve analysis with even smaller error ranges.

Since the decrement of the hydrogen Balmer series is a sensitive indicator for log g, 107 high-resolution échelle spectra with short exposure times (180 sec) have been taken in Jan 2001 with UVES (UV-visual échelle spectrograph)) attached to the ESO VLT. Rauch & Werner (2003) determined from these a rotational velocity of $v_{\rm rot} = 47$ km/sec. The co-added spectrum is shown in Figure 3.

Additional medium-resolution longslit spectra have been taken at the 2.3m telescope at SSO in Sept 2003 with the DBS (double beam spectrograph). Figure 3 shows the synthetic spectrum of our final model in agreement with the observation while a higher log g results in a worse fit.

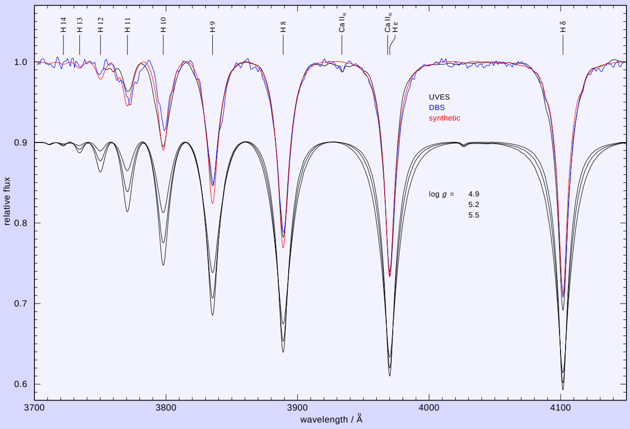


Figure 3. Optical spectra (UVES & DBS) of AA Dor compared to a synthetic spectrum (Rauch 2000, $T_{\rm eff} = 42\,$kK, log g = 5.2, $\mathrm{He/H} = 8.0\cdot10^{-4}$, $\mathrm{C/H} = 1.5\cdot10^{-6}$, $\mathrm{N/H} = 3.0\cdot10^{-6}$, $\mathrm{O/H} = 6.4\cdot10^{-5}$, $\mathrm{Si/H} = 8.8\cdot10^{-6}$ by number). Positions of hydrogen Balmer lines are indicated. The lower three synthetic spectra (from H+He models) demonstrate the log g dependence.
The UVES and the synthetic spectra are convolved with a Gaussian with 3.3 Å (FWHM) in order to match the resolution of the DBS spectra. Note that a higher log g than 5.2 would result in too broad lines.

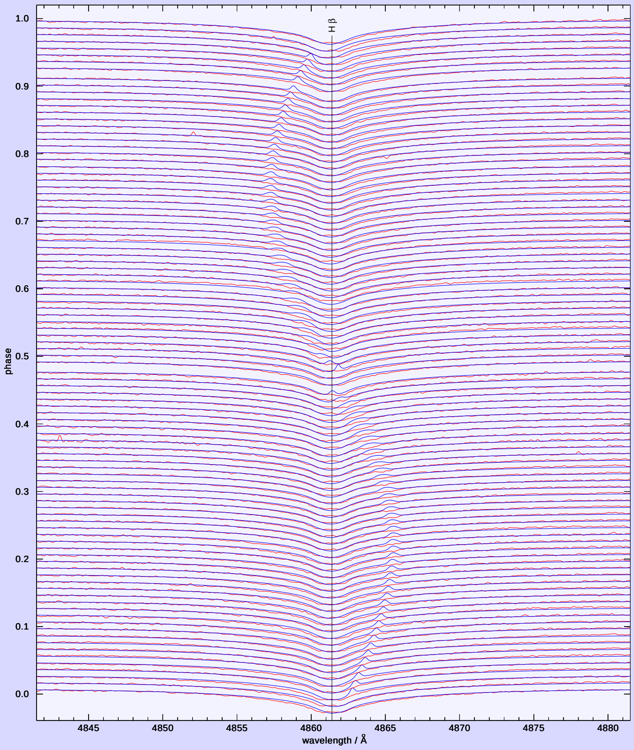


Figure 4. Section of the UVES spectra around Hβ compared to phase-dependent synthetic spectra (rotation, orbital motion, transit and occultation of the secondary are considered). A weak Hβ emission is used to represent the secondary's radiation and to show the effect of orbital motion. It is obvious that the emission component in Hβ is phase dependent but clearly not coming from the secondary.

Phase Dependence of Hβ

Prominent emission components are detectable in the line cores of Hα and Hβ (Rauch 2000). Due to the unknown phase of the observations, the emission has been assumed to have its origin in the reflection from the secondary.

A close inspection of our UVES spectra (Figure 4) shows that the emission component in Hβ is phase dependent, but certainly does not stem from the secondary. It is more likely that it is formed in the wind of the primary which is interacting with the secondary's wind (the hemisphere towards the primary is heated up to 15 - 20 kK).

Evolutionary Scenario

Due to the low mass of the system, all scenarios (e.g. Paczynski 1980, Hilditch et al. 1996, Rauch 2000) have a severe problem – loss of orbital energy and angular momentum, i.e. when the secondary once started to spiral-in during the CE phase, there might be no way to avoid its collision with the core of the primary.

Recently, Eggleton & Kiseleva-Eggleton (2002) proposed a scenario which appears not generally to end up with a merger described above:

In the case of AA Dor, the binary would start with
$M_1 \approx 1.0\,M_\odot$, $M_2 \approx 0.05\,M_\odot$, $P \approx 20\,$d.
The secondary spins up the primary on its way up the giant branch and thus, there will be a substantial mass loss combined with minimum angular-momentum loss. RLOF starts when the system arrives at
$M_1 \approx 0.3\,M_\odot$, $M_2 \approx 0.05\,M_\odot$, $P \approx 60\,$d.
Since the envelope mass is now $\approx 0.05\,M_\odot$, it may be expelled by the secondary without spiraling in to the core of the primary.

Results

The surface gravity (log g = 5.21) determined by Rauch (2000) is verified. Thus, the reason for the disagreement in the mass-radius relation for the primary is still unclear.

We can not identify any spectral feature of the secondary in the optical spectrum. The emission in the line core of Hβ comes from the primary, its phase dependence is likely due to an interaction of the stellar winds of both components.

References

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