The Enigma of AA Dor

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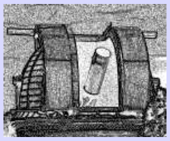

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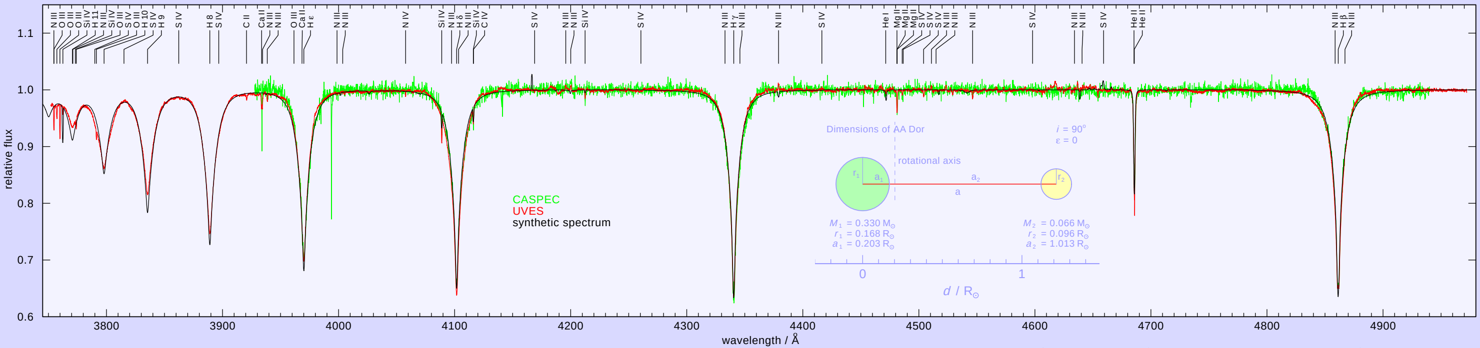

Fig. 1 Optical spectra of AA Dor compared to a synthetic spectrum (Rauch 2000, final model, $T_{\rm eff} = 42$ kK, $\log g = 5.2$, $He/H = 8.0 \cdot 10^{-4}$, $C/H = 1.5 \cdot 10^{-6}$, $N/H = 3.0 \cdot 10^{-6}$, $O/H = 6.4 \cdot 10^{-5}$, $Si/H = 8.8 \cdot 10^{-6}$ (by number)). Positions of spectral lines which are identified in the UVES spectrum are indicated. Note that He I 4471 Å is slightly too deep in the theoretical spectrum which indicates a slightly lower He/H ratio and/or a slightly higher $T_{\rm eff}$. C II 3920.68 Å is newly identified in the UVES spectrum and thus, the evaluation of the C II / C III ionization equilibrium will improve the determination of $T_{\rm eff}$.

Abstract

AA Dor is a close binary ($P = 0.26$ d) consisting of an sdOB primary star and an unseen secondary with an extraordinary small mass (Fig. 1). Based on the assumption that the primary component has a mass of $M_1 = 0.5\,M_\odot$, Hilditch et al. (1996) found that the cool secondary with $M_2 = 0.086\,M_\odot$. is in excellent agreement with lowest mass ZAMS models of Dorman et al. (1989).
In a recent spectral analysis (Rauch 2000) of the primary, based on high-resolution CASPEC and IUE spectra, $M_1 = 0.330\,M_\odot$, has been derived from comparison of $T_{\rm eff}$ and log g to evolutionary tracks of post-RGB stars (Driebe et al. 1998) and $M_2 = 0.066\,M_\odot$. has subsequently been calculated from the system's mass function. Thus, the secondary is possibly a planet which may have survived a common envelope phase and has even gained mass ("late case B mass transfer", Iben & Livio 1993). However, a reason for the discrepancy between these masses and those derived from the radial-velocity and the eclipse curves (Kilkenny et al. 1979) is not known. Two possible reasons are the inaccuracy of the theoretical models by Driebe et al. (1998) for AA Dor and the error range for the photospheric parameters in Rauch (2000). This analysis was hampered by the long exposure times (some hours) and hence, a large orbital velocity coverage (the observed line profiles were broadened by the star's rotation as well as by a smearing due to orbital motion within the observations).
We present results of a new spectral analysis of the primary which is based on phase-resolved high-resolution and high-SN spectroscopy with UVES@VLT (ESO).

Observations

In order to make progress and to minimize the effects of orbital motion, 105 UVES (attached to the ESO VLT) spectra had been taken on Jan 8, 2001 with an exposure time of 180 sec each. We achieved a resolving power of 48 000. The spectra cover a complete orbital period of AA Dor. They were subject to the standard reduction provided by ESO.
The S/N ratio of the single spectra is partly up to 30. In Fig. 1 we show the co-added spectrum: All 105 spectra were shifted to rest wavelengths, then co-added and subsequently binned to 0.045 Å (3 wavelength points). Although the S/N of the co-added UVES spectrum is about 200, no chemical element could be identified which had not been identified in other spectra before.

Radial velocity determination

The phase dependent radial velocity is determined by fitting Lorentzians to He II 4686 Å, Mg II 4482 Å, Si IV 3760, 4089 Å, and the H Balmer series. During this procedure the smearing due to orbital motion during the exposure was neglected because the exposure time was very short compared to the complete period. Then, the derived velocity curves were fitted by sine curves in order to determine their periods, amplitudes, and T_0 (Fig. 2).

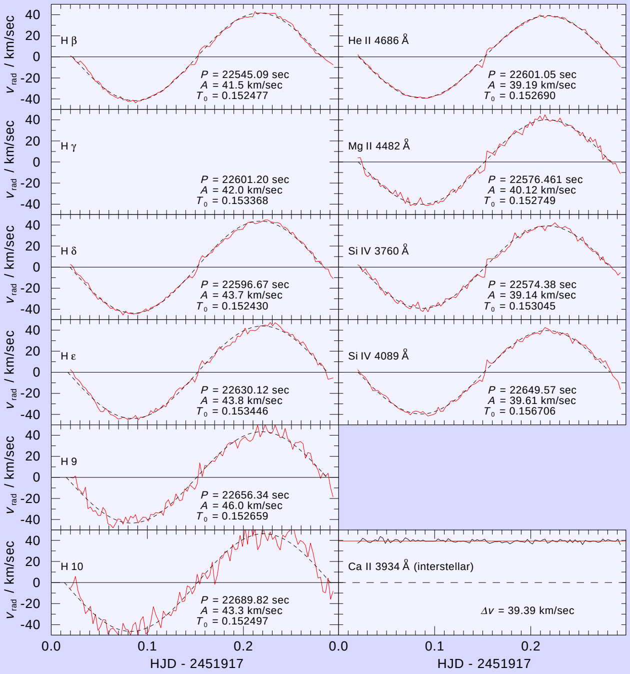

Fig. 2 Radial-velocity curve of AA Dor measured from the individual lines. He II 4686 Å and Mg II 4482 Å have the sharpest observed line profiles while the Balmer lines are much broader and the S/N ratio is decreasing towards the higher series members. Ca II 3934 Å is measured for comparison – this gives a zero point for the motion of AA Dor relative to the Earth. Note the velocity jumps close to T_0 which are the result of the transit of the cooler star!

Since the observed He II 4686 Å line is the sharpest line in the optical spectrum (Rauch 2000), we achieve the best fit to a theoretical sine curve with the velocity curve measured from this line. Mg II 4482 Å is also sharp but much weaker and the Balmer lines are much broader and the S/N is lower. The measured amplitude of the velocity curve appears to be larger for the higher Balmer lines. This is clearly an effect of the lower S/N.
From the result of He II 4686 Å we adopt $P = 22\,601.05$ sec and $A = 39.19$ km/sec. The period is 0.02% longer than given by Kilkenny et al. 1991 (22 597.0 sec from photometric data of 27 eclipses). A higher radial-velocity amplitude of $A = 40.8$ km/sec has been measured by Hilditch et al. (1996), also from observations of He II 4686 Å.

Rotational velocity determination

In order to determine the rotational velocity of the primary, we have selected six spectra with minimum $v_{\rm rot}$ and co-added these. Since the resolution of the spectra is better than 0.1 Å (at the position of He II 4686 Å), we checked whether it is necessary to consider the fine structure of He II 4686 Å. In Fig. 3 we show that the fine-structure splitting results in a wider line profile and cannot be neglected because the helium abundance may be strongly overestimated.

We calculated a grid of H+He composed NLTE model atmospheres in the relevant parameter range and performed a χ^2 test to determine the rotational velocity. The best agreement is found at $T_{\rm eff} = 44$ kK, $\log g = 5.5$, $He/H = 0.0007$, and $v_{\rm rot} = 43$ km/sec. However, Rauch (2000) has determined $T_{\rm eff} = 42$ kK from He, C, N, and O ionization equilibria which are very sensitive indicators for $T_{\rm eff}$ and thus, we keep $T_{\rm eff} = 42$ kK and $\log g = 5.2$ fixed. Then $v_{\rm rot} = 45$ km/sec and $He/H = 0.0008$ yield the best fit.

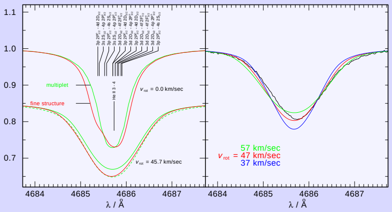

Fig. 3 Left: Theoretical line profiles of He II 4686 Å calculated from models with $T_{\rm eff} = 42$ kK, $\log g = 5.2$, and $He/H = 0.0008$ (Rauch 2000). The red lines show the profile which is calculated with fine structure splitting (components are indicated). For the green lines, He II 4686 Å is calculated as one multiplet. Note that the deviation is larger than the spectral resolution (0.1 Å) of our observation. At the bottom, the profiles are convolved with a rotational profile ($v_{\rm rot} = 45$ km/sec) and compared to a theoretical line profile (dashed, without fine structure splitting) calculated from model with a 50% higher helium abundance ($He/H = 0.0012$)
Right: Comparison of a theoretical line profile ($T_{\rm eff} = 42$ kK, $\log g = 5.2$, and $He/H = 0.0008$) convolved with rotational profiles of 37, 47, and 57 km/sec with the observation.

Results and Discussion

The determined rotational velocity of $v_{\rm rot} = 47$ km/sec suggests, that AA Dor performs a bound rotation (45.7 km/sec), not surprising in this relatively close system. The radius of the cool component is almost the same size like Jupiter but its mass is about 70 times higher. Thus, it lies formally within the brown-dwarf mass range (0.013 - 0.08 $M_\odot$). However, the idea of Rauch (2000), that it may have been a planet which has survived the common envelope phase and even has gained mass, needs further numerical simulations of the common envelope phase to be verified.

References

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