# DV AQUARII REVISITED

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ABSTRACT. This work presents a new solution for the close binary system DV Aqr (HD 199603, HR 8024) based on archival International Ultraviolet Explorer observations, ground-based photometric light curves and radial velocity data. The solution is obtained as the best fit of the theoretical model to all these observations simultaneously. Roche geometry of the binary system is assumed and a grid of the newest Kurucz models of stellar atmospheres is used in the calculations.

**Key words**: Stars: close binary; stars: individual: DV Aqr.

## 1. Introduction

The energy flux distributions, light and radial velocity curves of a binary contain information about the basic parameters of the system. To obtain these parameters a separate treatment of different types of data is usually made. In this work all observations are analyzed simultaneously giving only one set of model parameters. For this purpose we construct models which allow us to calculate energy flux distributions, light curves in different wavelengths, and radial velocity curves, according to prescriptions given by Połubek (1998). The main properties of the model are the following:

- Roche model is assumed for the system geometry,
- irradiation effect is taken into account,
- synchronous rotation of both components is assumed,
- newest Kurucz (1996) models of stellar atmospheres are included.

We use a differential correction scheme to derive the basic parameters of the system. This scheme is equivalent to the chi-square value minimization procedure (cf. Numerical Recipies in Fortran, Chapter 15):

$$\chi^2 = \sum_k^{N_{\rm obs}} \left( \frac{C^{\rm obs}(k) - C^{\rm cal}(k,\vec{p})}{\sigma_k} \right)^2 ,$$

where $\vec{p} = (p_1, p_2, ..., p_{\rm Npar})$ is the vector of model parameters , $C^{\rm obs}(k)$ and $C^{\rm cal}(k,\vec{p})$ correspond to the observed and theoretical values of different types of data, respectively; $\sigma_k$ is the error of $k$-th point and $N_{\rm obs}$ is the number of observations. The vector $\vec{p}$ must include, in general, geometrical parameters of the system, as well as parameters describing the radiation field. Our choice of $\vec{p}$ is the following:

$$\begin{aligned} \vec{p} &= (d, T^P_{\rm eff}({\rm pole}), T^S_{\rm eff}({\rm pole}), q, \mathcal{U}^P, \mathcal{U}^S, i, M_{\rm tot}, \\ &\quad P, E(B-V), \gamma, v_{\rm turb}, \left[\frac{m}{H}\right]), \end{aligned}$$

where $d$ is the distance to the system, $T^P_{\rm eff}$(pole) and $T^S_{\rm eff}$(pole) are polar temperatures of the primary and secondary components of the binary system, respectively, $q$ is the mass ratio, $\mathcal{U}^P$ and $\mathcal{U}^S$ are the surface physical potentials of the components, $i$ is the binary inclination angle, $M_{\rm tot}$ is the total mass of the system, $P$ is the orbital period, $E(B-V)$ is the colour excess, $\gamma$ is the radial velocity of the barycentre, $v_{\rm turb}$ is the turbulent velocity, and $\left[\frac{m}{H}\right]$ is the metallicity. In our case

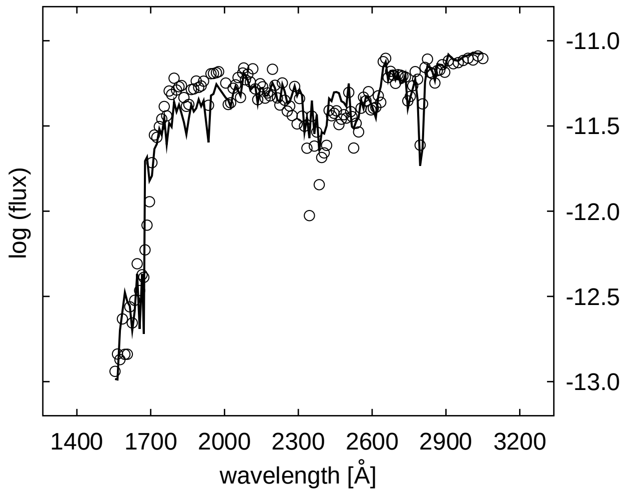


Figure 1: Observed (symbols) and synthetic (solid line) flux distributions of DV Aqr.

the minimization of chi-square $\chi^2$ must be achieved by an iterative scheme. We have to find corrections $\vec{\Delta p}$, which added to the current approximation of the sys-

Table 1: Archival IUE observations of DV Aqr.

| image identifier | dispersion | aperture | date and time | integration time in seconds |
|---|---|---|---|---|
| SWP52093 | low | large | 1994-09-12 07:44:38 | 359.5 |
| LWP29159 | high | large | 1994-09-12 08:00:38 | 2159.7 |
| SWP52160 | low | large | 1994-09-20 07:50:30 | 119.5 |

tem parameters $\vec{p}_{\rm cur}$ give smaller value of $\chi^2$.

## 2. Observational material

Observational material used in our analysis consists of:

- International Ultraviolet Explorer spectra listed in Table 1;
- B and V light curves of Okazaki & Yamasaki (1985);
- radial velocity curve of the primary component taken from Paffhausen & Seggewiss (1976).

Orbital phases are calculated assuming the ephemeris given by Strohmeier (1965):

$$\text{Min.I} : \text{HJD}2426160.500 + 1\overset{\rm d}{.}575531 \times \text{E}.$$

## 3. Analysis

Okazaki & Yamasaki (1985) found photometric value of the mass ratio $q = 0.6$ and our first solution assumes this value.

Table 2: Parameters of DV Aqr.

| Parameter | Value |
|---|---|
| $d$ | 91 pc ± 12 pc |
| $T^P_{\rm eff}$(pole) | 7905 K ± 320 K |
| $T^S_{\rm eff}$(pole) | 6056 K ± 240 K |
| $q$ | 0.6 * |
| $\mathcal{U}^P$ | 1.474E15 ± 0.085E15 cgs |
| $\mathcal{U}^S$ | 2.255E15 ± 0.181E15 cgs |
| $i$ | 83°.18 ± 0°.11 |
| $M_{\rm tot}$ | 2.76 ± 0.04 $M_\odot$ |
| $P$ | $1\overset{\rm d}{.}575531$ * |
| $E(B-V)$ | 0.04 ± 0.03 |
| $\gamma$ | 10.0 km s$^{-1}$ ± 2.3 km s$^{-1}$ |
| $v_{\rm turb}$ | 2.0 km s$^{-1}$ * |
| $[\frac{m}{H}]$ | 0.0 * |

*) assumed value

Model parameters derived from the best fit procedure are shown in Table 2. Table 3 gives additional

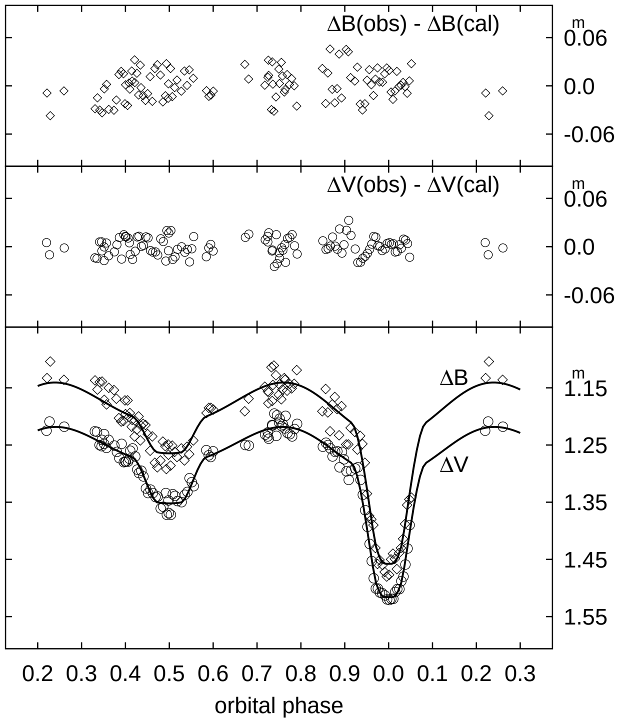


Figure 2: Lowest panel shows B and V light curves of DV Aqr (open symbols) with the best fit synthetic curves (solid lines). Upper two panels show the residuals.

information about the binary system. Observed energy flux distributions, light curves and radial velocity curve are marked in Figures 1 – 3 as open symbols, while solid lines represent theoretical values. DV Aqr appears to be a detached system just as in the solution of Okazaki & Yamasaki, but model parameters of our solution are significantly different from those of Okazaki & Yamasaki. In contrast, light curves minima are flat in our solution (see Figure 2) and dimensions of secondary component are considerably smaller. Our estimate of the inclination angle is $i = 83\overset{\circ}{.}18$, while Okazaki & Yamasaki give $i = 70°$.

To check quality of the solution we compare the rms residuals of the light curves. For scatter of the observations from synthetic light curves Okazaki & Yamasaki report $\sigma_{\Delta V} = 0.019$ mag and $\sigma_{\Delta B} = 0.033$ mag for $V$

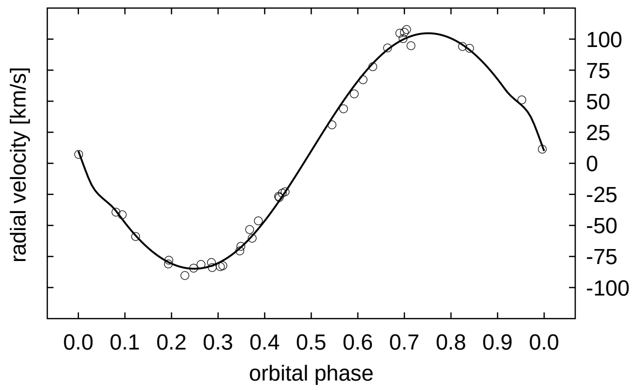


Figure 3: Observed radial velocities (open symbols) and the synthetic curve of the best fit solution (solid line).

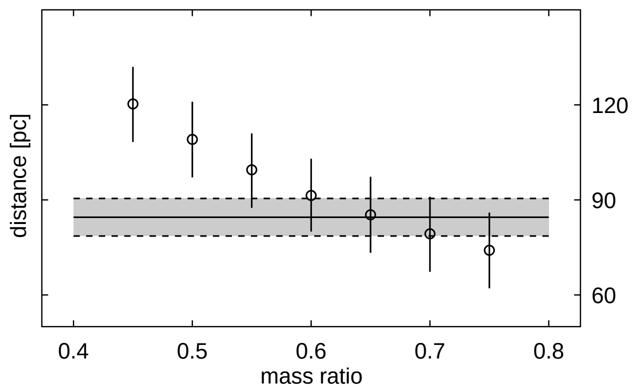


Figure 4: Distance to the DV Aqr as a function of mass ratio. Solid line corresponds to the Hipparcos parallax of the system.

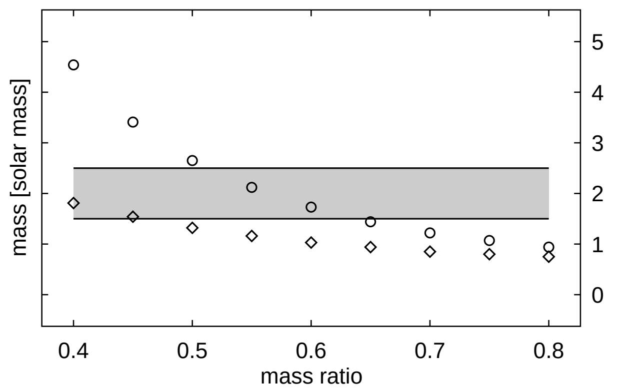


Figure 5: Mass of primary (circles) and secondary (diamonds) component of DV Aqr as a function of mass ratio. Shaded region corresponds to mass range of $\delta$ Scuti variable stars.

Table 3: Other characteristics of DV Aqr.

| | | Primary | Secondary |
|---|---|---|---|
| Roche potentials | | 3.467 | 8.603 |
| Radius* | | | |
| | pole | 0.345 | 0.144 |
| | point | 0.384 | 0.146 |
| | side | 0.357 | 0.144 |
| | back | 0.371 | 0.145 |
| Radius** | | | |
| | pole | 2.756 | 1.149 |
| | point | 3.067 | 1.164 |
| | side | 2.854 | 1.154 |
| | back | 2.963 | 1.162 |
| Temperature | | | |
| | pole | 7905 | 6059 |
| | point | 7613 | 6289 |
| | side | 7815 | 6052 |
| | back | 7721 | 6035 |
| $\log g$ | | | |
| | pole | 3.803 | 4.334 |
| | point | 3.585 | 4.312 |
| | side | 3.742 | 4.327 |
| | back | 3.676 | 4.315 |

*) fractional radius (in separation units)
**) radius in solar units

and $B$ bands, respectively. Our solution is much better since $\sigma_{\Delta V} = 0.011$ mag and $\sigma_{\Delta V} = 0.018$ mag.

In the next step we search for a photometric value of the mass ratio, $q$. For this purpose, a sequence of solutions is calculated for different values of $q$ in the range from 0.4 to 0.8. In all cases we get a detached configuration. However, no unique minimum can be reached. Thus, photometric value of $q$ cannot be determined with reasonable accuracy.

Alternative way to find the mass ratio is the following. Different values of $q$ give different values of distance to the system. Figure 4 shows a distance to DV Aqr as a function of $q$. The solid line represents the Hipparcos (ESA 1997) data, viz. $d = 84.5 \pm 6.0$ pc. As can be seen from this comparison, the value of $q$ consistent with the Hipparcos distance is in the range from 0.55 to 0.8.

Additional constraint on the mass ratio may be secured from $H_\beta$ observations of DV Aqr (Kilambi 1975). These data suggest that the binary system contains a pulsating star of $\delta$ Scuti type. Mass of such a star must be in the range from 1.5 to 2.5 $M_\odot$ (cf. Gautschy & Saio 1995). Figure 5 shows masses of the primary and secondary components as a function of $q$. Formal errors of the mass determinations are small (they are comparable to the size of symbols used in Figure 5). As can be seen, the secondary component may be a $\delta$ Scuti variable only for $q < 0.45$. It is inconsistent with the mass ratio determination from the Hipparcos parallax. This indicates that only the primary component may be a $\delta$ Scuti variable. In this case the mass of the primary component lies in the range from 1.5 to 2.5 $M_{\odot}$ for $q = 0.50 - 0.65$. This indicates that the Okazaki & Yamasaki value of $q$ is reasonable estimation of the mass ratio.

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