Disc's parameters and the accretion efficiency of two interacting binary stars: FU Ori and AG Dra

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Abstract. We investigate the accretion disc configuration around the primary star after the mass transfer being started in two binary stars (FU Ori and AG Dra). The interacting processes between the close components have an effect on the established formation. Using online data of the accreting flow parameters, the disc's structure models are suggested. As a result, the dependencies in disc's models of both: parameters against variations in the radius, and the model flux against wavelength are presented. We estimate the disc - accretion efficiency on the base of the obtained star/disc parameters.

Key words: stars: binaries; Accretion: Accretions discs; stars: individual: FU Ori, AG Dra

Introduction and model description

Binary stars with accretion discs offer large possibilities to investigate the physical properties and conditions of astrophysical objects. Studying the accretion disc behavior is important since the different accretion disc models could explain some peculiarities and variabilities in emissions, spectrum and brightness. As an example, the outbursts events may be produced by the mechanism that operates in part of the accretion disc (Bell & Lin 1994). The different temperatures in the inner or outer parts of the disc give in result different spectra, from optical to infrared spectrum (Hartmann & Kenyon 1996).

In this paper, we employ the model of D'Alessio and Merin (D'Alessio 1998, 1999) that works with the star's and discs main parameters. These physical disc models are the solution of two main calculations: the first one consists the influence of heating from the stellar radiation and from viscous dissipation due to accretion on the detailed vertical structure of the accretion disc. In the second one, the transfer equations are calculated in order to consider the emission maps of the disc for thermal and scattered light. In both computations all parameters are compatible for the calculations with the star and disc input parameters. The models involve the following assumptions: the energy is transported by radiation, convection and turbulent flux; heating is realized due to viscous dissipation and stellar flux irradiation; the disc is in a steady state (M = dM/dt=const); it is a geometrically thin disc ($H/R << 1$); the alpha viscosity parametrization (α) from Shakura & Sunyaev (1973) is used. The model of D'Alessio and Merin gives limitation values of: the primary star temperature $4000K - 10000K$, as well as of the central objects' mass, disc radius and accretion rate. To fit the model to the objects, we assume the stars and disc parameters, corresponding to these limitations. In section 1 we present a description and some observational details of the objects. The results are given in Section 2.

1. Objects' details

FU Ori belongs to type of variable young stellar objects FU Orionis, a class with exceptional increases in luminosity in optical brightness within 5 magnitudes or more (Herbig 1977). We accept the values for the disc inner radius $\sim 5R_{\odot}$, for outer radius of the inner high disc $\sim 1AU$, and the disc inclination angle $\sim 55°$. The FU Ori discs are observed to be quite massive and compact (Liu et al. 2018), about $10-20$ of the stellar masses and radii of tens of AU. A range of the disc masses is considered as $M_{disc} = 0.01, 0.1M_{\odot}$ and the characteristic radii are $Rc = 100AU$ and $20AU$. The mass of the FU Ori's primary is taken to be $\sim 1.1M_{\odot}$ and the mass of the FU Ori itself $\sim 0.5M_{\odot}$ (Hartmann & Kenyon 1996).

AG Dra is a classical type D symbiotic binary. The hot component of AG Dra is considered to be a white dwarf producing a high luminosity in order of $10^3L_{\odot}$ and temperature of about $1-2\times10^5K$. The mass of the hot component is found to be $Mh = 0.4 - 0.6M_{\odot}$ (Mikolajewska et al. 1995) for a distance of 2.5kpc, and $0.5M_{\odot}$, calculated by Tomov et al. (2000). For the radius of the white dwarf Mikolajewska et al. (1995) have obtained the values $R_{wd} \approx 0.06 - 0.08R_{\odot}$, supposed it is a sub-dwarf. The mass donor or the cool component of AG Dra is of early spectral type in the range K0-K4 with metal deficiency (Smith et al. 1996) and has also been classified as a Barium star. The mass of the giant was estimated as $1.5M_{\odot}$ by Kenyon & Fernandez-Castro (1987). The orbital period is estimated as $P_{orb} \approx 550days$ (Sion et al 2012).

2. Results

In this section, we calculate the disc model structures for each object separately.

The values of the targets parameters, presented in Section 1 are used. Some disc and the central stars parameters that need to fill up the model data are also added in the calculations. They are listed as follows: $\dot{M}$ - mass accretion rate of the model in $M_{\odot}/yr$; R_{disc} - maximum radius of the disc in AU; R_{hole} - inner radius of the disc in stellar radii; α - non-dimensional parameter for the viscosity according to the prescription from Shakura and Sunyaev (1973). The value ($\alpha = 0.01$) is used for these models (see Merin et al. (2004) for more details); M_{disc} - mass of the disc in solar masses. The value of this parameter is calculated by integrating the disc surface density over the inner to the outer radius; L_* - luminosity of the central star in solar units.

2.1. Disc's model and structure for the two objects

To match the model of FU Ori, it was necessary to use a maximum disc temperature $T_{max} = 6420K$ (as in Zhu et al. (2007)), the central star mass is $\sim 0.3M_{\odot}$ and the mass accretion rate of the inner high disc is $\sim 2.4 \times 10^{-4}M_{\odot}yr^{-1}$.

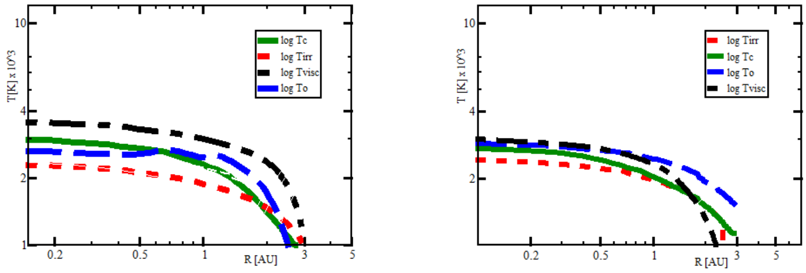

Fig. 1. Radial distribution of the effective temperature T [K] for an irradiated and a non-irradiated disc model, for FU Ori (left) and AG Dra (right). The plotted temperatures are in a logarithmic scale: midplane T_c for the irradiated disc (solid green line), T_{irr} - irradiation temperature (dotted red line), surface temperature T_o (dashed blue line) and T_{visc} - viscous effective temperature (dot-dashed black line).

The temperature of the disc midplane is calculated against the radius (Fig.1) and it declines at the larger radii ($> 1AU$). Following the data from the model, the temperatures are presented in a logarithmic scale.

The disc surface density is calculated as a function of radius and z. This distribution can be seen in Figure 2.

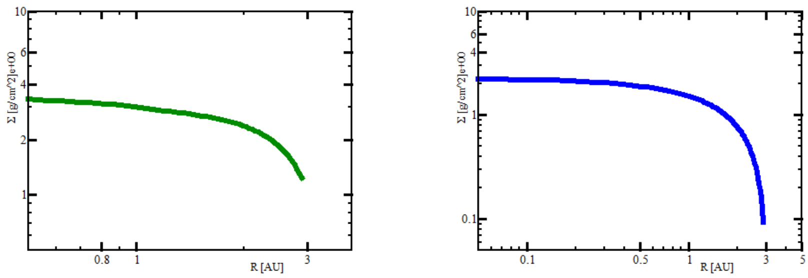

Fig. 2. Radial distribution of the surface density of an irradiated disc model for FU Ori (left) and AG Dra (right).

The disc and stellar parameters for both calculations are the same. The type of the distributions and the dependences against the radius are similar for both objects. The temperature distribution in the FU Ori disc has more abrupt decreasing slope than that in AG Dra. Compared with the density distribution of AG Dra, the surface density values distributed throughout the disc of FU Ori are seen to be higher. The difference is most likely related to the type of the objects, their ages and accretion activity.

2.2. Accretion efficiency of the two objects

In general, the efficiency η expresses the amount of energy gained from the matter with mass m, in units of its mass energy (Kolb et al. 2010). It measures how efficiently the rest mass energy, c^2 per unit mass, of the accreted material is converted into radiation. It is a useful measure that illustrates the power of accretion as an energy generator.
The accretion efficiency η_{acc} is defined by the expression:
$\eta_{acc} = \frac{GM_*}{R_* c^2}$, obtained by the expressions of accretion luminosity:

$L_{acc} = \frac{GM\dot{M}}{R_*}$ and $L_{acc} = \eta_{acc}\dot{M}c^2$

Following these equations and the values of the given above parameters, we calculate the accretion efficiency for both objects.

The obtained value for FU Ori is:
$\eta_{accr}[FUOri] = 1.21388 \times 10^{-7}$, which is $\approx 8.26\%$;

and for AG Dra we have:
$\eta_{accr}[AGDra] = 1.445105 \times 10^{-5}$, which is $\approx 0.7\%$

The estimated values of the accretion efficiency show that, as a younger stellar object, FU Ori posseses more accretion power, which could be converted into radiative energy.

Discussion and Conclusion

In this paper, the density and temperature structure have been calculated by the model, in which the given parameters of the central star are applied: mass, temperature, radius, a disc mass accretion rate and the viscosity parameter α. It is considered that the energy in the disc can be transported by radiation. The Spectral Energy Distribution (SED) for FU Ori and AG Dra expresses the model flux distribution in $[ergscm^{-2}s^{-1}]$ against wavelength (λ) in micron $[\mu m]$. These synthetic SEDs are obtained by solving the radiative transport equation and integrating the disc's emission (Castelli & Kurucz 2003). The flux maximum for FU Ori is at $\sim \lambda = 1-5\mu m$, while for the symbiotic binary AG Dra the maximum is at $\lambda \approx 0.1 - 1\mu m$. For both objects the flux decrease starts at $\sim \lambda > 200\mu m$. It illustrates the emission from the star. The disc, obtained as a solution of the applied model on the known parameters, is the result of the solution of detailed vertical structure equations for each disc annulus.

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