Boletim da Sociedade Astronômica Brasileira, **35**, no. 1, 308-312

Modeling outbursts of the dwarf nova EX Draconis as mass transfer events

Wagner Schlindwein[1,2] & Raymundo Baptista[1]

[1] Universidade Federal de Santa Catarina (UFSC)
[2] Instituto Nacional de Pesquisas Espaciais (INPE)
e-mail: `wagner.schlindwein@inpe.br, raybap@gmail.com`

Abstract. Ex Draconis is an eclipsing dwarf nova with an orbital period of 5.04 h that shows outbursts with moderate amplitude ($\simeq 2$ mag) and a recurrence timescale of $\simeq 20$ d. Dwarf novae outbursts are explained in terms of either a thermal-viscous instability in the disc or an instability in the mass transfer rate of the donor star (MTIM). We developed simulations of the response of accretion discs to pulses of enhanced mass transfer, in the context of the MTIM, and applied them to model the light curve and variations in the radius of the EX Dra disc throughout the outburst. We obtain the first modeling of a dwarf nova outburst by using χ^2 to select, from a grid of simulations, the best-fit parameters to the observed EX Dra outbursts. The observed time evolution of the system brightness and the changes in outer disc radius along the outburst cycle are satisfactorily reproduced by a model of the response of an accretion disc with viscosity parameter $\alpha = 4.0$ and quiescent mass transfer rate $\dot{M}_2(\text{quiescence}) = 6.0 \times 10^{16}$ g/s to a pulse of width $\Delta t = 3.0 \times 10^5$ s (~ 3.5 d) where the mass-transfer rate increases to $\dot{M}_2(\text{outburst}) = 1.5 \times 10^{18}$ g/s.

Resumo. Ex Draconis é uma nova-anã eclipsante com período de 5.04 h que mostra erupções com amplitude moderada ($\simeq 2$ mag) e com um intervalo de recorrência de $\simeq 20$ d. Erupções de novas-anãs são explicadas ou em termo de uma instabilidade termo-viscosa no disco ou de uma instabilidade na taxa de transferência de matéria da estrela doadora (MTIM). Desenvolvemos simulações da resposta de discos de acréscimo a pulsos de matéria aumentada, no contexto do MTIM, e aplicamos para modelar a curva de luz e as variações no raio do disco de EX Dra ao longo da erupção. Obtivermos a primeira modelagem de erupções em novas-anãs usando o χ^2 para selecionar, em um grid de simulações, a combinação de parâmetros de melhor ajuste às erupções observadas de EX Dra. A evolução temporal observada do brilho do sistema e as mudanças no raio externo do disco ao longo do ciclo da erupção são reproduzidas satisfatoriamente por um modelo da resposta de um disco de acréscimo com parâmetro de viscosidade $\alpha = 4.0$ e taxa de transferência de matéria em quiescência $\dot{M}_2(\text{quiescência}) = 6.0 \times 10^{16}$ g/s a um pulso com largura $\Delta t = 3.0 \times 10^5$ s (~ 3.5 d) onde a taxa de transferência de matéria é aumenta para $\dot{M}_2(\text{erupção}) = 1.5 \times 10^{18}$ g/s.

Keywords. Accretion, accretion discs – Stars: dwarf novae – Methods: numerical

1. Introduction

In dwarf novae, a late-type star (the secondary) transfers matter to a white dwarf companion through an accretion disc. Dwarf novae show recurrent outbursts at days-months timescales, in which the accretion disc increases in brightness by factors 20-100. Two models compete for the explanation of the causes of these outbursts. The disc instability model (DIM, Cannizzo 1993; Lasota 2001; Hameury 2020) explains the outbursts in terms of a thermal-viscous instability in the disc that causes it to cyclically transition between a cold and low viscosity state (quiescence) and a hot and high viscosity state (outburst). On the other hand, the mass transfer instability model (MTIM, Bath 1972, 1975; Bath & Pringle 1981) explains the outbursts in terms of the response of a disc with constant (and high) viscosity to sudden increases in the mass transfer rate from the secondary.

Interest in the observational testing the two models declined from the 1990s onward as a result of the widespread acceptance of DIM as the correct explanation. Two arguments were crucial in establishing the dominance of DIM, both based on the hypothesis that the mass transferred from the secondary is deposited on the outer edge of the disc, in the position of the bright spot. Based on this hypothesis, it can be predicted that (i) a sudden increase in the mass transfer rate would inevitably lead to an increase in bright spot luminosity, and (ii) the MTIM mechanism could only produce outside-in outbursts of the disc because the excess matter would always be deposited on the outer edge of the disc. The existence of inside-out outbursts of the disc and the absence of observational support for the increase in bright spot luminosity at the beginning of the outbursts were taken as arguments against MTIM (Warner 1995, and references therein).

However, numerical simulations of accretion discs show that when the gas stream is significantly denser than the disc material, the stream "penetrates" the disc and allows matter to be deposited in its inner regions (giving rise to inside-out outbursts), while drastically reducing the emission in the bright spot (i.e., without producing any increase in its luminosity, Bisikalo et al. 1998a,b; Makita, Miyawaki, & Matsuda 2000). Additionally, strong observational support in favor of MTIM has emerged, in recent years, from a series of experiments monitoring the evolution of the brightness distribution of dwarf novae accretion discs throughout outbursts (Baptista & Catalán 2001; Baptista et al. 2007; Baptista 2012; Baptista, Borges, & Oliveira 2016), as well as the inference of high values for viscosity in discs of quiescent dwarf novae – inconsistent with DIM predictions (Baptista & Bortoletto 2004; Baptista 2012; Baptista, Borges, & Oliveira 2016). These results made it clear that there is a significant group of dwarf novae, the outbursts of which are incompatible with DIM and are presumably produced by the MTIM mechanism, leading to the conclusion that the two mechanisms coexist, probably in distinct subgroups of dwarf novae (Baptista 2012).

Ex Draconis (EX Dra) is an eclipsing dwarf nova with an orbital period of 5.04 h that shows outbursts with moderate amplitude ($\simeq 2$ mag) and a recurrence timescale of $\simeq 20$ d (Baptista, Catalán, & Costa 2000). The spectroscopy studies of Billington, Marsh, & Dhillon (1996); Fiedler, Barwig, & Mantel (1997);

Smith & Dhillon (1998) led to a 'spectroscopic' model for the binary based on measurements of the radial velocity of the secondary ($K_2 \simeq 210 - 220\,\mathrm{km\,s^{-1}}$) and the emission lines ($K_1 \simeq 163 - 176\,\mathrm{km\,s^{-1}}$, associated with the orbital movement of the primary), and the rotational broadening of the secondary ($v \sin i = 140\,\mathrm{km\,s^{-1}}$). Baptista, Catalán, & Costa (2000) presented and discussed a set of light curves of EX Dra in quiescence and outburst. The quiescent eclipse light curves were used to derive the geometry of the binary. The photometric and spectroscopic models of the binary are consistent with each other within the uncertainties.

Baptista & Catalán (2001) analyzed the light curves from Baptista, Catalán, & Costa (2000) with the eclipse mapping technique (Horne 1985; Baptista 2016). Eclipse maps show evidence of the formation of a spiral arm in the disc in the early stages of the outburst, and reveal how the disc expands during the rise phase until it fills most of the primary Roche lobe at light maximum. During the decay phase, the disc becomes progressively fainter until only a small bright region remains around the white dwarf at minimum light. Analysis of the radial brightness temperature distributions indicates that most of the disc appears to be in a steady state during quiescence and at the maximum of the outburst, but not during the intermediate stages. As a general trend, the mass accretion rate in the outer regions is larger than in the inner disc in the ascending branch, while the opposite is maintained during the descending branch. Fitting opaque steady disc models to radial temperature distributions allows estimating accretion rates of $\dot{M} = 10^{-7.7\pm0.3}\,\mathrm{M_\odot\,yr^{-1}}$ ($1.6^{+1.6}_{-0.8} \times 10^{18}\,\mathrm{g\,s^{-1}}$) at the outburst maximum and $\dot{M} = 10^{-9.1\pm0.3}\,\mathrm{M_\odot\,yr^{-1}}$ ($5.0^{+5.0}_{-2.5} \times 10^{16}\,\mathrm{g\,s^{-1}}$) in quiescence (Baptista & Catalán 2001).

2. Method of Numerical Calculations

We developed a computational code to simulate the response of accretion discs to pulses of enhanced mass transfer, in the context of the MTIM. We postulate the existence of variations in mass transfer rate, however, we do not attempt to explain their nature.

In our simulations, we adopted the same procedure as most disc simulations according to DIM, describing the behavior of the disc only in the radial direction. This is justified by the usual explanation that asymmetries in the distribution of mass in the azimuthal and vertical directions of the disc are eliminated faster than radial asymmetries, given the typical azimuthal (Keplerian) velocities of ~ 1000 km/s, the local sound speed of ~ 10 km/s (which determines the propagation of vertical disturbances in the disc), and the radial velocity of viscous flow ~ 1 km/s.

The program is written in C programming language and is based on the work of Ichikawa & Osaki (1992), the last simulation of the MTIM model found in the literature. For more details on the basic procedure for calculating the temporal evolution of the accretion disc, see Ichikawa & Osaki (1992). It should be noted that the viscosity expression (ν) assumed by Ichikawa & Osaki (1992) includes an additional 2/3 factor for the α-prescription of Shakura & Sunyaev (1973) ($\nu = \alpha c_s H$, where c_s is the speed of sound and H is the height scale). The code adopts cgs units, assumes a nonmagnetic primary, and initially starts from an already formed disc, which is a thin stationary disc. This last assumption helps reduce the computational time required.

The developed program was validated by testing its ability to reproduce the results obtained by Pringle (1981) and Ichikawa & Osaki (1992). To reproduce the analytical solutions of Pringle (1981), we adopted the binary parameters of the dwarf nova V4140 Sgr (Borges & Baptista 2005), a fixed viscosity of $\nu = 2.0 \times 10^{14}\,\mathrm{cm^2\,s^{-1}}$, and sliced the disc into 100 concentric annular rings that extend up to 0.8 of the inner Lagrangian radius (R_{L_1}). Initially we deposit 10^{21} g of matter in a ring at a radius of 9.55×10^9 cm and let the system evolve over time. The result of this test is shown in Fig. 1.

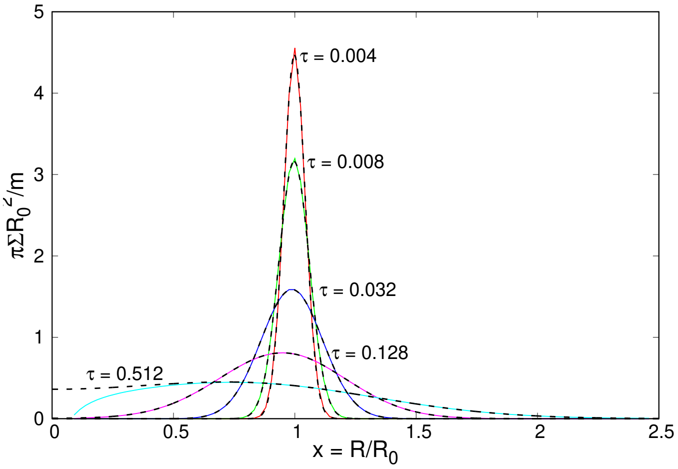

Figure 1. Test of the viscosity efficiency in our simulations. A ring of mass m placed in a Keplerian orbit at $R = R_0$ spreads under the action of viscous torques. The surface density Σ is shown as a function of $x = R/R_0$ and the dimensionless time variable $\tau = 12\nu t R_0^{-2}$, with $\nu = const$. The solid curves represent the solutions obtained through our simulations, while the dashed curves are the analytical solutions obtained by Pringle (1981).

With the basis of the simulations verified, we expanded the horizon of the MTIM simulations (Schlindwein 2021). First, we investigated the influence of the radial dependence of the viscosity parameter α and found that α increasing in radius provides a faster outburst decline. We also found that $\alpha \geq 1$ are necessary to describe the fast outburst declines in dwarf novae. It is worth emphasizing (Baptista & Schlindwein 2022), that the value of α inferred from the decline time of an outburst depends on the assumed model: In DIM, the decline of the outburst is due to the propagation of a cooling wave toward the center of the disc with velocity $R/t = v_{DIM} \sim \alpha c_s$, where R is the radius of the disc and t is the observed decay time com $c_s \simeq 10$ km/s. Velocities $v_{DIM} \sim 1$ km/s imply values $\alpha_{DIM} \sim 0.1$. On the other hand, in MTIM the decline is due to the viscous flow of the mass in the disc with velocity $R/t = v_R \sim 12\alpha c_s H/R$, where v_R ($\simeq 1$ km/ s) is the radial drift velocity. Therefore, for the same observed ratio R/t we have,

$$\frac{R}{t} \sim \alpha_{DIM} c_s \sim 12\alpha_{MTIM} c_s \frac{H}{R} \quad \longrightarrow \quad \alpha_{MTIM} \sim 10\alpha_{DIM}, \tag{1}$$

with $H/R \sim 10^{-2}$ (thin disc approximation). Thus, for a given outburst, the α value inferred with the MTIM assumption is an order of magnitude larger than with the DIM assumption.

For a high-viscosity disc ($\alpha \geq 1$), the shape of the outburst is highly correlated with the shape of the pulse of enhanced mass. We adopt a pulse of the form,

$$\dot{M}_2 = \dot{M}_2^i + (\dot{M}_2^p - \dot{M}_2^i) \exp\left[-\frac{1}{2}\left(\frac{t - t_p}{\Delta t_p/\sqrt{2\ln 2}}\right)^4\right], \tag{2}$$

where $\dot{M}_2^i$, $\dot{M}_2^p$, t_p and Δt_p are the initial and pulse mass transfer rates, the pulse center instant and their full width at half maximum, respectively, which creates a plateau during the peak of the outburst while preserving the smooth transitions at the start/end of the pulse.

We investigated the influence of how and where matter is deposited in the disc during the enhanced mass phase on the properties and shape of the outburst, to find that enabling the penetration of the gas stream into the accretion disc (up to the circularization radius, R_{circ}) allows a significantly better description of the variations in disc radius observed during the outburst. For this, the accretion stream as modeled by Hessman (1999) was used from the tabulated data of Lubow & Shu (1975, 1976).

Finally, the disc emission was computed adopting both the blackbody and gray atmosphere (e.g., Tylenda 1981) assumptions, which allows us to take into account emission from optically thin disc regions.

3. Application

We apply our simulations to describe the variations in brightness and radius throughout the outburst of the dwarf nova EX Dra. Fig. 2 shows the historical visual light curve of EX Dra (constructed from observations made by amateur astronomers from the AAVSO and VSNET) obtained from the superposition of observations covering 14 outburst cycles, aligned according to the start of the rise to maximum. The crosses indicate measurements of outbursts at the epoch of observations of Baptista & Catalán (2001), while the dots are measurements of outbursts at other epochs. Only outbursts with amplitude and duration similar to those covered by the authors' observations were included. A median filter with a width of 10 points was applied to the data in this set (blue points with error bars). Filled circles mark the epochs of the observations of Baptista & Catalán (2001) and indicate the corresponding R-band out-of-eclipse magnitudes. These are typical type B (inside-out) outbursts, with comparable rise and decline timescales (Smak 1984; Warner 1995). It has been observed that EX Dra also shows lower-amplitude outbursts, and outbursts for which the rise is significantly faster than the decline. For the outbursts shown in Fig. 2, the rise from quiescence to maximum takes about 3 d, followed by a plateau phase of about 6 d. The declining branch lasts for 3-4 d, after which the star goes through a low-brightness state during 4-5 d before recovering its quiescent brightness level.

We assume α constant and with a high value (≥ 1), and a variable deposit of the accretion stream on the disc. We allow the stream to penetrate the disc up to its shortest distance from the primary (R_{min}). This parameter is obtained from the computational trajectories of Lubow & Shu (1975) and can be approximated by the expression,

$$\frac{R_{min}}{a} = 0.0488 q^{-0.464}, \qquad (3)$$

with an accuracy of 1% in the range $0.05 < q < 1$. The radius of the shortest distance (R_{min}) is always smaller than the radius of circularization (R_c). The stream penetration radius (R_J) is given by the radius where the gas stream density equals the disc mid-plane density. The outer disc radius at each step along the outburst is defined as the corresponding tidal truncation radius. We adopted a tidal truncation constant of $c\omega = 30\,\mathrm{rad/s}$ (Eq. 5 from Ichikawa & Osaki 1992) so that the quiescent disc radius coincided with the value obtained by Baptista, Catalán, & Costa (2000) ($R_d = 0.51 \pm 0.04\, R_{L_1}$). Since the EX Dra outburst presents a plateau during the maximum (Fig. 2), we adopted a pulse of enhanced mass with the format described in Eq. 2. For local emission from the accretion disc, we consider both the blackbody and gray atmosphere models. The resulting spectra were convolved with the V and R passband responses to generate the corresponding magnitude versus time curves. The binary parameters listed in Table 5 of Baptista, Catalán, & Costa (2000) were used.

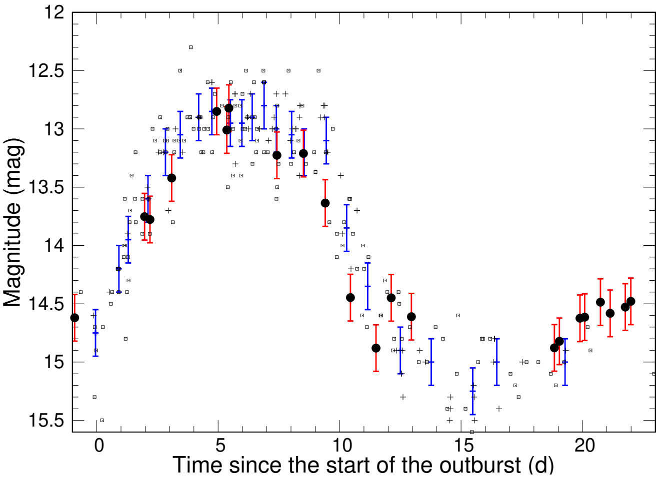

Figure 2. Superposition of visual outburst light curves of EX Dra, constructed from observations made by the AAVSO and the VSNET. The x-axis is time relative to the onset of the outburst. Crosses indicate measurements of the outbursts at the epoch of the observations of Baptista & Catalán (2001), while small dots are measurements of outbursts at other epochs. The blue points with error bars are the result of applying a median filter to this data set. R-band out-of-eclipse magnitudes from observations of Baptista, Catalán, & Costa (2000) are shown as filled circles along with their uncertainties.

We built a grid with 1000 outburst models, covering a range of values for the input parameters quiescent mass transfer rate, $\dot{M}_2^i (= 2, 4, 6, 8, 10 \times 10^{16}$ g/s), mass transfer rate during the maximum of the pulse, $\dot{M}_2^p (= 1.0, 1.5, 2.0, 2.5, 3.0 \times 10^{18}$ g/s), pulse duration, $\Delta t_p (= 2.5, 2.75, 3.0, 3.25, 3.5 \times 10^5$ s), and viscosity parameter, $\alpha (= 1, 2, 3, 4, 5, 6, 7, 8)$. The value of $\dot{M}_2^i$ is determined by the magnitude in quiescence, and that of $\dot{M}_2^p$ is defined by the magnitude during the plateau. The value of Δt_p is determined by the full width at half maximum of the outburst and the duration of the plateau. The rise timescale is determined by the pulse shape and the value of Δt_p. The value of α is determined by the timescale of outburst decline. The best-fitting outburst model to the observations was found by calculating the χ^2 of the fit for each grid model. Figs. 3 and 4 show the best-fit simulations for the cases of blackbody and gray atmosphere local emission, respectively.

The MTIM model with a pulse given by Eq. 2 and with high viscosity provides a satisfactory description of the observations of the outbursts in EX Dra, reaching values of χ^2 very close to unity. The best-fit values of $\dot{M}_2^i$ and $\dot{M}_2^p$ are consistent with the quiescence and outburst accretion rates inferred from the radial brightness temperature distributions of Baptista & Catalán (2001) within the respective uncertainties. The inferred values for α are high, but consistent with the range of values inferred by Mantle & Bath (1983) from the decline of outbursts in dwarf novae. Furthermore, the amplitude of the outburst in V passband is larger than that in the R passband, in accordance with observations. To our knowledge, this is the first time that a simulation

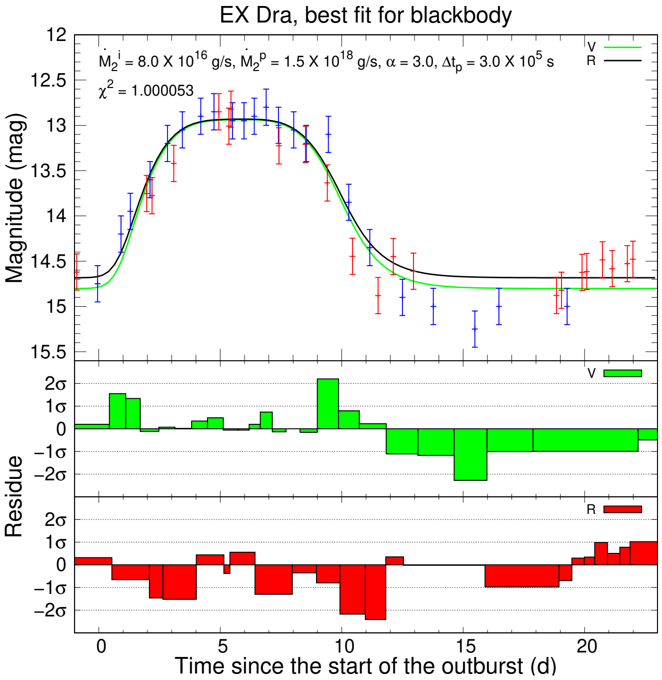

FIGURE 3. Best-fit simulation in the case of local blackbody emission. The input parameters for this simulation are shown in the body of the figure together with the χ^2 value of the fit. *Upper panel:* The points with error bars are the same as in Fig. 2. The solid lines are the magnitudes in the V (green) and R (black) passbands of the simulated accretion disc. *Bottom panels:* Show the fitting residuals.

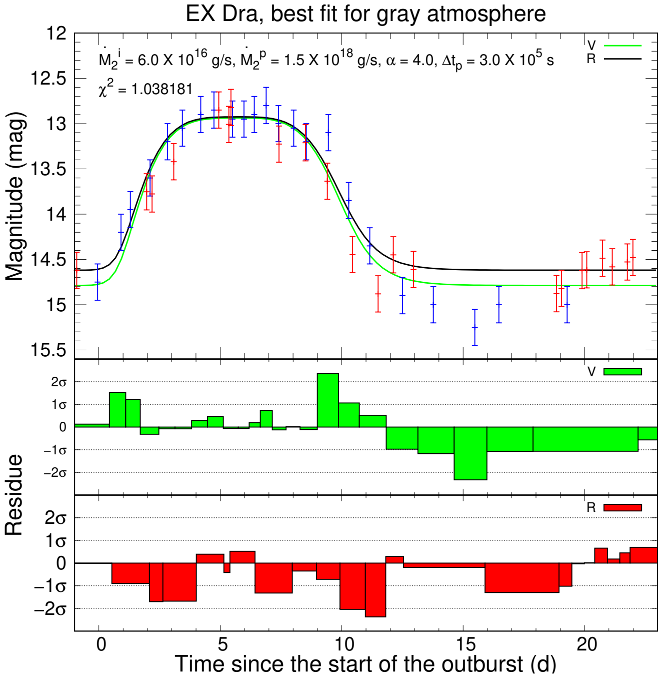

FIGURE 4. Best fit simulation in the case of local emission by gray atmosphere. The notation is similar to that of Fig. 3.

of dwarf nova outbursts has been directly compared with observational data using a χ^2 test. Typically, data and simulations are plotted in different figures in the literature, as DIM simulations do not describe the quiescence of objects well.

Fig. 5 compares the evolution of the disc radius as estimated by Baptista & Catalán (2001) with the prediction of the best-fitting models in Figs. 3 and 4. It is worth noting that, while Baptista & Catalán (2001) estimated the disc radius from the point in the radial distribution where the intensity equals the maximum intensity of the bright spot in quiescence, the simulations estimate the value of R_d from the radius of truncation of the accretion disc. These definitions are different and can lead to different results throughout the outburst. Despite this, the best-fit models provide a good description of the variations observed in the disc radius throughout the outburst, with differences at the maximum level of 2-σ in a couple of cases.

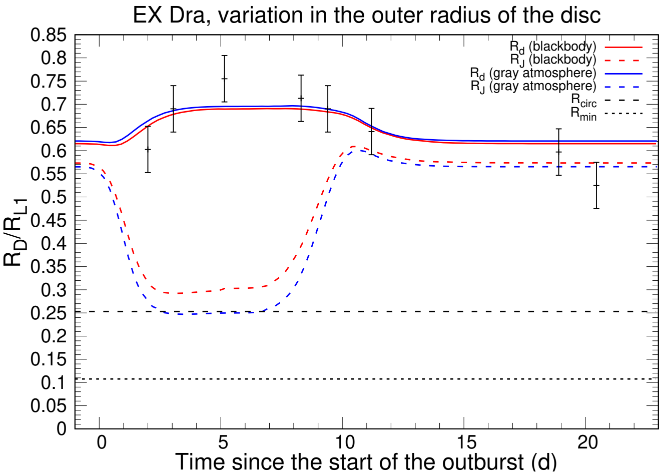

FIGURE 5. Comparison of the variation in the outer radius of the disc from our simulations with the observational results of Baptista & Catalán (2001). The points with error bars are the measurements of Baptista & Catalán (2001), while the red and blue lines represent the case of local emission by blackbody and gray atmosphere, respectively – with the solid line being the outer radius of the disc and the dashed line being the radius of stream penetration. The black dashed and dotted lines mark the value of the circularization radius and the minimum radius of Lubow & Shu (1975), respectively.

Our models predict an almost imperceptible shrinkage in the radius of the disc at the start of the outburst and an almost immediate increase in R_d, with the maximum radius being reached just before maximum brightness. The existence of gas stream penetration into the disc eliminates the marked initial reduction in R_d present in the Livio & Verbunt (1988) and Ichikawa & Osaki (1992) simulations and provides a variation consistent with observations. The amplitude of the R_d variation in our simulations is smaller than that observed. This may be due to differences between the definitions of R_d in Baptista & Catalán (2001) and that of the simulation program, or to a different format than that adopted for depositing the stream on the disc. In this second case, a more realistic treatment requires an analytical description of the interaction between the stream and disc particles based on 3D simulations of the accretion stream. There is still no work in this regard in the literature. Alternatively, Buat-Ménard, Hameury, & Lasota (2001) suggest that it is possible to reproduce larger amplitude variations in the disc radius throughout the outburst by reducing the exponent of the radial dependence of the tidal effect term.

4. Conclusion

In this work, we present the results of the development of a simulation program for the response of accretion discs to pulses of enhanced mass transfer, in the context of MTIM. Our program resumes simulations with MTIM based on the work of Ichikawa & Osaki (1992), the last publication on the subject found in the literature. The developed program was validated by reproducing the results obtained by Pringle (1981) and Ichikawa & Osaki (1992).

With the basis of the simulations verified, we expanded the horizon of the MTIM simulations, where we noticed that $\alpha \geq 1$ are necessary to describe the outbursts in dwarf novae – in the case of EX Dra, a $\alpha = 3.0 - 4.0$ was found. As explained by Baptista & Schlindwein (2022), a viscosity parameter larger than unity implies in some scenarios: if viscosity arises from hydrodynamic turbulence, this implies that either the turbulence is anisotropic or that the turbulence is supersonic; in case viscosity arises from magnetic stresses, this implies that the magnetic energy density is larger than the thermal energy density. Furthermore, it was shown that the shape of the pulse is highly correlated with the shape of the outburst, and that it is important to consider gas stream penetration into the accretion disc. Finally, the emission from the accretion disc was considered both as a blackbody and as a gray atmosphere in our simulations.

We used data from Baptista & Catalán (2001) to model the light curve and variations in disc radius at EX Dra throughout the outburst. Our simulations provide a good description of the brightness variations of EX Dra throughout the outburst and reproduce the corresponding variations in the disc radius reasonably well. It is worth highlighting that this is the first time that a simulation of outbursts in dwarf novae is directly compared with observational data with the χ^2 test. Typically, data and simulations are plotted in different figures in literature papers, as DIM simulations do not describe the behavior in quiescence well. The values of the mass transfer rates inferred by our model for quiescence (8.0×10^{16} g s^{-1} – blackbody, and 6.0×10^{16} g s^{-1} – gray atmosphere) and outburst maximum (1.5×10^{18} g s^{-1} – blackbody and gray atmosphere) are compatible with those inferred by Baptista & Catalán (2001) – $5.0^{+5.0}_{-2.5} \times 10^{16}$ g s^{-1} in quiescence and $1.6^{+1.6}_{-0.8} \times 10^{18}$ g s^{-1} at the outburst maximum.

Acknowledgements. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. WS acknowledges financial support from CNPq/Brazil (Proc. 300343/2022-1). WS is grateful for the discussions on numerical methods with Leandro Roza Livramento.

References

Baptista R., Catalán M. S., Costa L., 2000, MNRAS, 316, 529
Baptista R., Catalán M. S., 2001, MNRAS, 324, 599
Baptista R., Bortoletto A., 2004, AJ, 128, 411
Baptista R., Santos R. F., Faúndez-Abans M., Bortoletto A., 2007, AJ, 134, 867
Baptista R., 2012, MmSAI, 83, 530
Baptista R., 2016, in Boffin H. M. J., Hussain G., Berger J.-P., Schmidtobreick L., eds, Astronomy at High Angular Resolution, Astroph., and Space Science Library, Springer-Verlag, Switzerland, p. 155
Baptista R., Borges B. W., Oliveira A. S., 2016, MNRAS, 463, 3799
Baptista R., Schlindwein W., 2022, AJ, 163, 108
Bath, G. T. 1972, ApJ, 173, 121
Bath, G. T. 1975, MNRAS, 171, 311
Bath, G. T., & Pringle, J. E. 1981, MNRAS, 194, 967
Buat-Ménard V., Hameury J.-M., Lasota J.-P., 2001, A&A, 366, 612
Billington I., Marsh T. R., Dhillon V. S., 1996, MNRAS, 278, 673
Bisikalo D. V., Boyarchuk A. A., Chechetkin V. M., Kuznetsov O. A., Molteni D., 1998a, MNRAS, 300, 39
Bisikalo D. V., Boyarchuk A. A., Kuznetsov O. A., Chechetkin V. M., 1998b, ARep, 42, 621
Borges B. W., Baptista R., 2005, A&A, 437, 235
Cannizzo, J. K. 1993, ApJ, 419, 318
Fiedler H., Barwig H., Mantel K. H., 1997, A&A, 327, 173
Hameury J. M., 2020, Adv. Space Res., 66, 1004
Hessman F. V., 1999, ApJ, 510, 867
Horne, K. 1985, MNRAS, 213, 129
Ichikawa S., Osaki Y., 1992, PASJ, 44, 15
Lasota, J.-P. 2001, New A Rev., 45, 449
Livio M., Verbunt F., 1988, MNRAS, 232, 1P
Lubow S. H., Shu F. H., 1975, ApJ, 198, 383
Lubow S. H., Shu F. H., 1976, ApJL, 207, L53
Makita M., Miyawaki K., Matsuda T., 2000, MNRAS, 316, 906
Mantle V. J., Bath G. T., 1983, MNRAS, 202, 151
Pringle J. E., 1981, ARA&A, 19, 137
Schlindwein W., 2021, PhD thesis, UFSC
Shakura N. I., Sunyaev R. A., 1973, A&A, 24, 337
Smak J., 1984, AcA, 34, 161
Smith D. A., Dhillon V. S., 1998, MNRAS, 301, 767
Tylenda R., 1981, AcA, 31, 127
Warner, B. 1995, Camb. Astrophys. Ser. Vol. 28, Cataclysmic Variable Stars, Cambridge Univ. Press, Cambridge