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Spiral Waves and Shocks in Discs around Black Holes: Low Compressibility and High Compressibility models

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ABSTRACT

Some authors have concluded that spiral structures and shocks do not develop if an adiabatic index $\gamma > 1.16$ is adopted in accretion disc modelling, whilst others have claimed that they obtained well defined spirals and shocks adopting a $\gamma = 1.2$ and a $M_2/M_1 = 1$ stellar mass ratio. In our opinion, it should be possible to develop spiral structures for low compressibility gas accretion discs if the primary component is a black hole. We considered a primary black hole of $8M_\odot$ and a small secondary component of $0.5M_\odot$ to favour spiral structures formations and possible spiral shocks via gas compression due to a strong gravitational attraction. We performed two 3D SPH simulations and two 2D SPH simulations and characterized a low compressibility model and a high compressibility model for each couple of simulations. 2D models reveal spiral structures existence. Moreover, spiral shocks are also evident in high compressibility 2D model at the outer disc edge. We believe that we could develop even well defined spiral shocks considering a more massive primary component.

Key Words : Accretion Discs – Black Holes – CV – Radial Shocks – Spiral Structures

I. INTRODUCTION

Several papers have been dedicated to the problem of the accretion flow around a compact object (Monaghan 1992; Matsuda et al. 1990, 1992; Meglicki et al. 1993; Whitehurst 1994; Simpson 1995).

We are also interested in accretion disc structure and dynamics in close binary systems and we have performed some 3D SPH simulations in the last 10 years (Molteni et al. 1991; Lanzafame et al. 1992, 1994ab; Belvedere et al. 1993, 1994; Lanzafame and Belvedere 1997, 1998).

Recent papers by our group (Lanzafame et al. 2000, 2001) showed that initial angular momentum and energy of the injected stream at the inner Lagrangian point L1 are critical as to develop well defined spiral structures in the bulk of accretion discs of CV, and possible spiral shocks at the outer edge, concluding that high angular momentum and energy values support these structures.

Weak spiral shocks are usually masked by the shadowing effect of the artificial viscosity in the bulk of the gas particles in particular in 3D models (Monaghan 1985; Monaghan and Lattanzio 1985) and for $\gamma = 1.01$ at least. In fact Yukawa et al. (1997) performed 3D SPH simulations and obtained spirals for $\gamma = 1.2$ and $M_2/M_1 = 1$, but they did not obtained spirals for $\gamma = 1.01$, whilst we did in Lanzafame et al. (1997 and 1998), even if in our models we did not consider SPH particle injection coming from the inner lagrangian point L1. So, we are generally limited to the strong shocks case. These structures are generally better defined in 2D models than in 3D ones. Moreover, low compressibility models are limited because of the low resolution as a consequence of the low particle concentration. On the other hand, in high compressibility models, the smoothing effect of the artificial viscosity is stressed because of the high particle concentration. Chakrabarty (1992) theoretically and Bisikalo et al. (1999) via computer simulations claimed that spiral structures and shocks do not develop if an adiabatic index $\gamma > 1.16$ is adopted in accretion disc modelling. These last results are in evident contrast with each other.

We have singled out in Lanzafame et al. (2000) and in Lanzafame et al. (2001) which geometrical and dynamical conditions at the L1 point support spiral structures and shocks development in the disc as far as high compressibility disc particles are concerned. Now, we believe that in close binary systems in which the primary is a compact massive object such as a black hole and the secondary is a low mass star, we have enough initial energy and angular momentum at L1, and a wide and deep primary potential well, that are quite favourable conditions in order to develop well defined spiral structures, and eventually spiral shocks, independent of gas compressibility. Furthermore, we think that a lot of perturbations should come out as far as low compressibility 2D models are concerned, because the disc itself has to enlarge throughout the orbital plane. As a consequence, strong collisional events should develop throughout the disc along the injection stream path due to interactions of the injected stream particles, that become quickly supersonic after the injection due to the strong gravitational acceleration, with particles of both disc bulk and disc edge themselves.

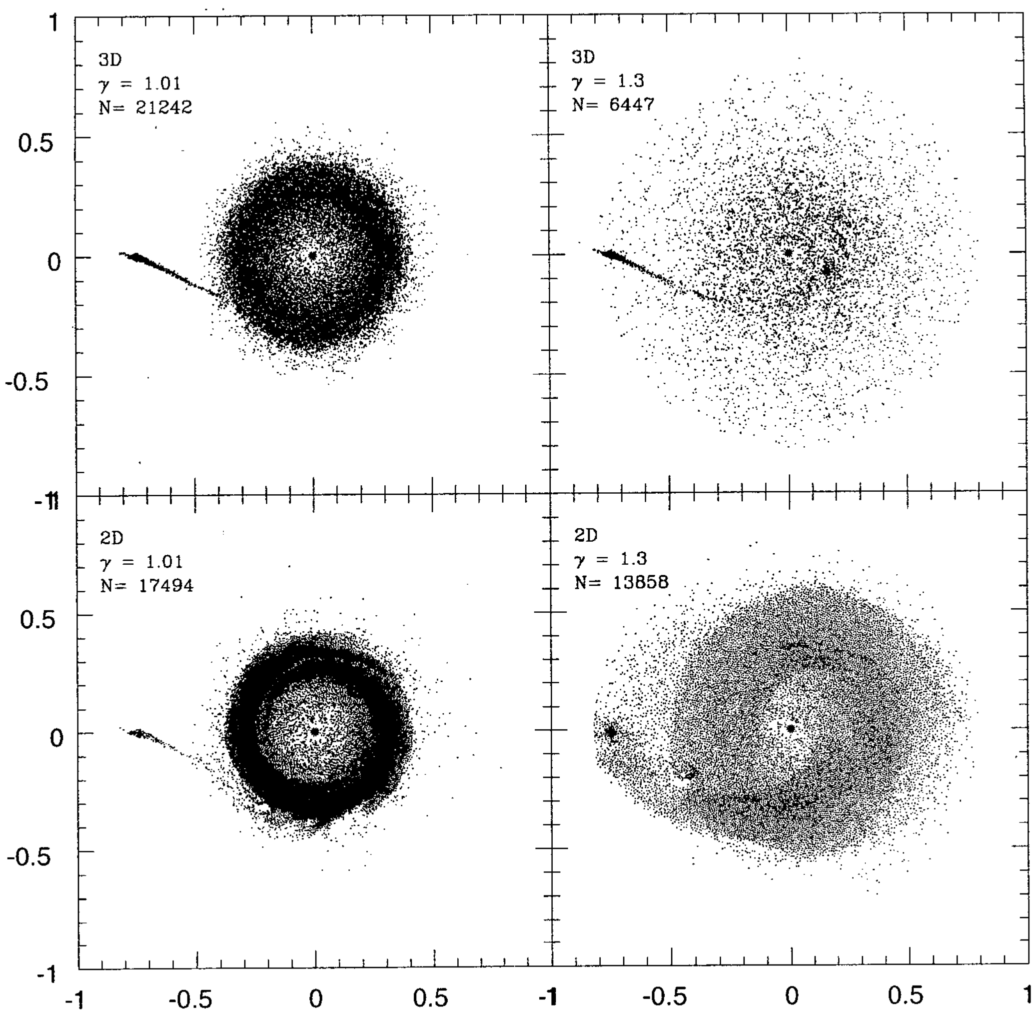

Fig. 1 — XY plot of 4 SPH models in stationary conditions. γ value and N = total particle number are reported.

II. MODELS AND RESULTS

Two 3D and two 2D simulations were performed. A low γ value ($\gamma = 1.01$) and a high γ value ($\gamma = 1.3$) were adopted in both 3D and 2D simulations. The close binary parameters are: $M_1 = 8M_\odot$, $M_2 = 0.5M_\odot$, stellar separation $R_{12} = 1.E6\ Km$, a quasi-sonic injection velocity at the L1 point $v_0 = 12\ Km\ s^{-1}$ and a gas temperature at the same point $T_0 = 1.E4$ K. Kernel width (resolution length) $h = 0.005$ of the separation of the two stellar component. For the model equations and the physical meaning of our parametrization in terms of the adiabatic index γ, we refer the reader to Lanzafame et al. (1994a).

As in Molteni et al. (1991) and Lanzafame et al. (1992), we have considered quasi-polytropic structures adopting the above-mentioned γ values and simulated the physical conditions at the inner and at the outer disc edges.

The graphical analysis of the four models (Fig. 1) shows, after reaching stationary conditions, the evident lack of spiral structures in the 3D models, due to the heavy shadowing effect of the artificial viscosity, as widely discussed in our previous papers. So, in 3D, subsonic or sonic injection SPH models at L1 cannot spontaneously produce any spiral structures. Of course, the 3D model with $\gamma = 1.3$ produces worse results because of the low gas compressibility.

Instead, 2D models, where the shadowing effect of the artificial viscosity is lighter, can show two dominant spiral structures. For the 2D high compressibility model, the spiral structures located at the outer edge are well defined and impressive, and there is also evidence of radial shocks. The first spiral shock – on the outer edge of the injected stream – comes out from the interaction of part of the injected stream flow revolving around the primary and interacting with itself. Instead, the second spiral shock comes out from the collisional interaction of the injected stream flow with the circumstellar envelope around the primary star.

As for the 2D low compressibility model, the two large spiral fronts are radially subsonic because they are very hot, and come closer to the primary producing a clearly not isotropic accretion onto the black hole. The disc is really wide and fills up the primary Roche lobe. The outer edge of the disc extends outwards producing a well defined halo of spiralling particles till to the inner lagrangian point L1, so pushing away the injected stream particles and disturbing the injection process itself. We monitored the structure of the overall disc for several orbital periods during the stationary phase, and observed persistent compressed supersonic particle lumps coming from the L1 point, flowing into the disc bulk and locally perturbing other environmental subsonic disc particles. In stationary conditions, the overall halo of outer edge disc particles invades the L1 point permanently, so we think that local and temporary statistical reduction in fluid density (not necessarily particle density) can produce these supersonic density lumps. The total number of these small lumps can vary between more or less one and two dozens for each orbital period.

The philosophy of these results suggests that spiral shocks can occur even in low compressibility accretion disc models where the compact object is a very massive black hole of $20 \div 40 M_\odot$ against a low mass secondary component whose mass is $\leq 1 M_\odot$. Of course, this implies a very long cpu computer time because of the extremely high SPH particle number spiralling into the primary Roche Lobe. The huge effort in performing this model will be done in the next future, even if we will not refer to a known close binary system.

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