What determines the formation and stability of disks in binaries with intermediate separations?

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ABSTRACT

Subject headings: ? — ? — ? —

1. Introduction

1.1. Bondi-Hoyle accretion and disk impact parameter

the orbital motion of the system modifies the BH accretion about a fixed object by adding an acceleration which is perpendicular to the direction of the flow. A “backflow” will then develop aimed towards a point between the seconday’s original and current positions; the captured material is accelerated on average towards a retarded position. The time-scale associated with the wind capture scales up with r_b/v_w. The distance, D, that a cell of gas will have moved due to acceleration will thus be $1/2 a_c t^2 \cos\alpha$, where α is the angle between the flow velocity and the acceleration vector.

In an inertial reference frame co-rotating with the secondary at t_0, the companion accelerates towards the primary at $r_s\Omega^2$, and the projection relative to the incoming flow velocity take the form

$$r_s\Omega^2 \frac{v_s}{\sqrt{v_s^2 + v_w^2}}. \tag{1}$$

Given that acceleration of captured material occurs over a time scale

$$\frac{r_b}{\sqrt{v_s^2 + v_w^2}}, \tag{2}$$

the offset scales up with

$$\frac{v_s^3 r_b^2}{2r_s(v_s^2 + v_w^2)^{3/2}}\hat{\mathbf{r}}. \tag{3}$$

This implies the backflow returns at some small distance from the secondary and will then proceed into a prograde orbit about the secondary. In summary, D falls off with the orbital radius supporting the fact that disks start small (section 3).

(4)

2. Model and initial set-up

We model the formation of disks in binaries numerically by solving the equations of hydrodynamics in three-dimensions. In non-dimensional conservative form these are given by

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \tag{5}$$

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla)\mathbf{v} = -\frac{1}{\rho}\nabla p - \Phi \tag{6}$$

where ρ, p and $\mathbf{V}$ are the gas density, thermal pressure and flow velocity, respectively. We use an isothermal equation of state, thus $\gamma = 1$. In (6)

$$\Phi = -\frac{G m_s}{\sqrt{r + \epsilon}}, \tag{7}$$

where ϵ is a gravity softening radius which is 4 cells long.

We solve these equations using the adaptive mesh refinement (AMR) numerical code *AstroBEAR2.0*[1] which uses a single step, second-order accurate, shock capturing scheme (Cunningham et al. 2009; Carroll-Nellenback et al. 2011). While AstroBEAR2.0 is able to

[1]https://clover.pas.rochester.edu/trac/astrobear/wiki

compute several microphysical processes, such as gas self-gravity and heat conduction, we do not consider these in the present study.

We use *BlueHive*[2] –an IBM massively parallel processing supercomputer of the Center for Integrated Research Computing of the University of Rochester– and *Ranger*[3] –a Sun Constellation Linux Cluster which is part of the TeraGrid project– to run simulations for an average running time of about 1 day/orbit using 64–512 processors.

2.1. Initial conditions

Our computational domain is a $2.5r_B^3$ cube. Wind boundary conditions (section 2.1.1) are set at the $-x$ and $+y$ domain faces, and outflow only conditions are set in all other faces. The primary, the center of mass of the system and the secondary are located at ($-r_p$,0,0), (0,0,0), and (r_s,0,0), respectively. The primary simulates an AGB star with a mass of 1.5 $M_\odot$, a spherical constant wind with speed $v_w = 10\,\mathrm{km\,s^{-1}}$ and mass-loss $\dot{M} = 1^{-5}\,M_\odot\,\mathrm{yr}^{-1}$. The secondary simulates a main sequence star, or a white dwarf, with 1 $M_\odot$, in a circular orbit about the primary. We use a reference frame that co-rotates with the secondary, thus Coriolis terms are calculated. The resolution of the simulations as well as other relevant model parameters in shown in table 1.

2.1.1. Wind solution

Initially, we set all grid cells using the wind solution which has a constant temperature of 1000 K and a density given by

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[2]https://www.rochester.edu/its/web/wiki/crc/index.php/ Systems#Blue_Gene.2FP

[3]https://www.xsede.org/web/guest/tacc-ranger

$$\frac{\dot{m}_p}{4\pi(\mathbf{x}_p - \mathbf{x})^2 v_w}, \tag{8}$$

where $\mathbf{x}_p$ and $\mathbf{x}$ are the primary's orbital position and an arbitrary grid cell position, respectively. We calculate the velocity field of the wind solution by solving for the characteristics that leave the surface of the primary, $\mathbf{x}_p(t_r)$, at a *retarded* time $t_r = t - |\mathbf{x}|/v_w$, with a velocity vector pointing towards $\mathbf{x}$. We assume: (i) that $v_w > |\mathbf{v}_s|$, where $\mathbf{v}_s$ is the secondary's orbital velocity. This condition is is true for the a and v_w explored (se table 1). (ii) that the distance from the primary's surface to $\mathbf{x}$ is larger than r_p, which for the parameters explored restricts the distance between the secondary and the grid's boundaries.

As time goes from t_r to t the primary covers a circular segment of radius r_p which starts at $\mathbf{x}_p(t_r)$, and has a displacement vector $\mathbf{d} = \mathbf{x} - \mathbf{x}_p(t_r)$. We calculate the wind normal, $\hat{\mathbf{n}}$ so that

$$(v_w \hat{n} + \mathbf{v}_p(t_r)) \times \mathbf{d} = 0, \tag{9}$$

$$\hat{n} \times \mathbf{d} = \frac{-1}{v_w} \mathbf{v}_p(t_r) \times \mathbf{d}. \tag{10}$$

The wind velocity from the primary is then

$$\mathbf{v}_w = v_w \hat{\mathbf{n}} + \mathbf{V}_p(t_r), \tag{11}$$

which yields a better approximation of the retarded time

$$\tau_r = t - |\mathbf{x}|/|\mathbf{v}|. \tag{12}$$

We iterate these computations 10 times/cell and then add the velocity contribution from the rotating frame.

2.1.2. Wind injection

We continually set the wind solution (above) to the grid cells corresponding to the $-x$ and $+y$ domain faces. This is consistent with both the location of the primary and the direction that the stellar wind enters the grid. After each iteration in the wind solution computations, however, we account for the acceleration caused by the secondary's gravity on the characteristic trajectories of vector fields which leave the primary's surface at t_r. We allow the mass of the secondary to ramp up during one wind crossing time, $2.5 r_B/v_w$, in order to make the transition between the initial wind solution (where no gravity effects are considered) and the injected wind one.

2.2. Simulations

We carry out two simulations corresponding to stellar separation of 10 and 20 AU.

3. Results

3.1. a

4. CONCLUSIONS

We have carried out 3D

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