Wave density configuration via the vorticity patterns formation in accreting binary stars systems

Daniela Boneva

Space Research and Technology Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria

Emails: danvasan@space.bas.bg, dany_sr97@hotmail.com

Introduction

In binary stars with accretion disc, vortices may arise in conditions of tidally interacting flows – which is a common process in this type of stars. After they have appeared, the vortices could propagate globally throughout the disc.
Why we study vortices? As a result of some disc instability, they are responsible for the angular momentum transportation. Further they could be considered as sources of brightness variability of the object.
We present our theoretical investigations on the local behavior of vorticity formations in accreting flow of binary stars. The vortices are considered as non-single patterns that are moving along with the flow, interacting with the matter there – maintained by gas - dynamical laws. The vortex - flow density relation factor is suggested. Then we study of how much its values are relative to the stability of the vortices themselves and to the entire accretion disc structure.
Further dynamics of the disc matter could result in the situation when a single vortex meets other vortical formations. According to the physical conditions and parameters, these vortices could merge forming a new bigger tick composition. In the second case, they could stay as individual vortices, which are held in a cluster and moving as a whole configuration, as a density wave. The current considerations are made for close binary stars with tidally interacting flows. We consider the accretion disc flow with already established vortex configuration on the radial direction.

Theoretical background

conditions for vortex formation ⇒

- Baroclinic term is non-zero: $\nabla\rho \times \nabla p \neq 0$ → source of vorticity in the vorticity equation (K&B 2003)
- $E_{init} > 10^{-3}\, E_{Kepl}$ → anticyclonic vortices form and merge; cyclonic vortices shear out (Bracco et al. 1999)

vortices strength and longevity ⇒

- Reynolds number $Re \geq 10^4 \div 10^5$ → maximum vorticity or Vortex life-time - 60 orbital periods.
- there is a radial variation of the background temperature: $T \sim 1/r^{-n}$ → larger background temperature gradients; higher background temperatures (Petersen + 2007)

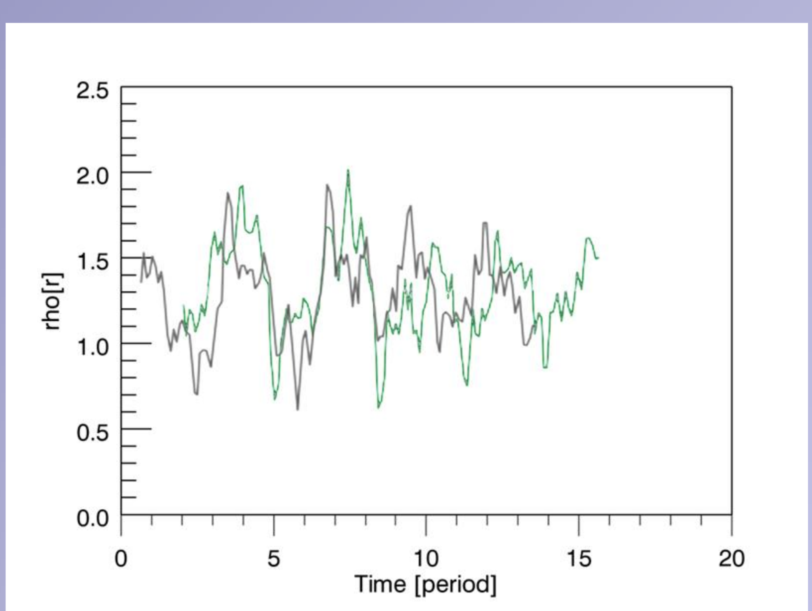
Vortex concepts and models

Vortices are non-isolated patterns:

• moving along with the flow and interacting with the surrounding matter

Since we have the vorticity formation with some density ρ_{vort} and radius R_{vort}, which is interacting with the disc flow matter, while moving through it with a variable velocity v_{vort}. The disc matter has a different density ρ_{disc} (which is equivalent to the disc's surface density) and radius R_{disc}. Since the vortex is not an isolated formation and it is moving among the fluid matter, we can write the relative terms for the density, radius and velocity:

$$\rho_r \approx \frac{\rho_{disc}}{\rho_{vort}}\,;\quad r_r \approx \frac{R_{disc}}{R_{vort}}\,;\quad v_r \approx \frac{v_{flow}}{v_{vort}}\,.$$



The contrast between the densities of the vortex and disc could reach the average value of ~ 1.8. This vortex - flow density relation we call: density factor (from Bisikalo et al. 2001) and it is ~ $\boldsymbol{\rho_r}$ (fig.1). The variations of the relative term of density v/s period of rotation: Figure 1.

Relation: factor value ↔ stability of the vortices ↔ entire disc's structure: *$1 < \rho_r < 1.8$ → vortices exist and*

$\rho_r \approx 1$ → stable flow, decayed vortices

Vortex – vortex interaction

→ vortices merger

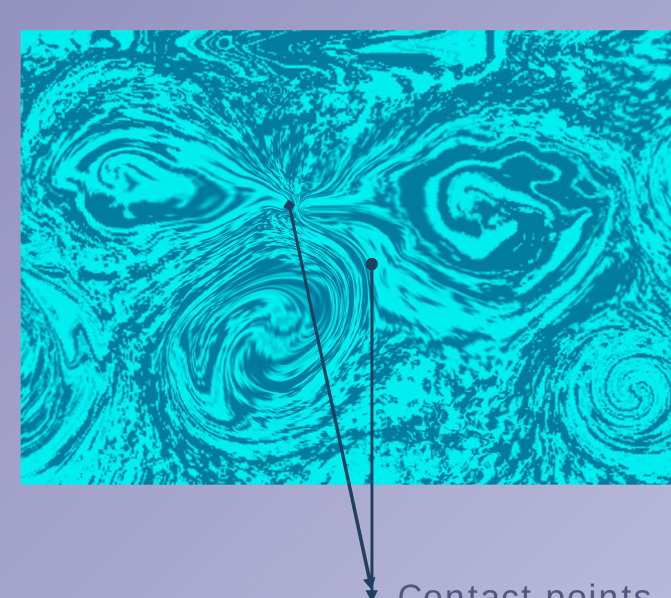


Figure 2. Visualization of the initial step of the vortex – vortex merger process.

→ vortices composition

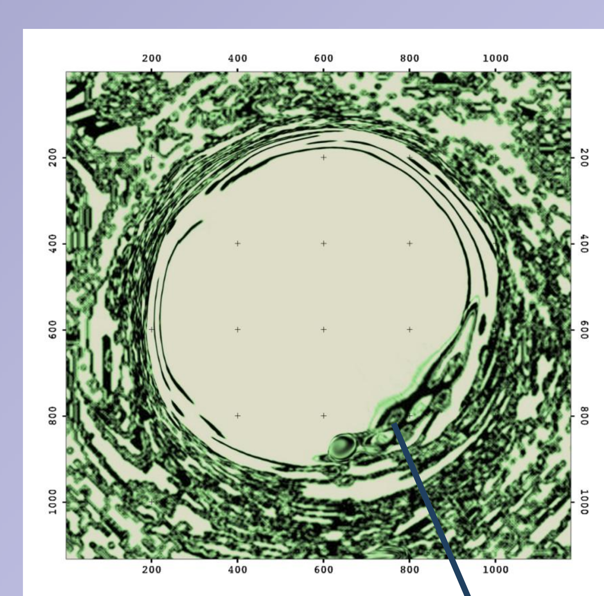
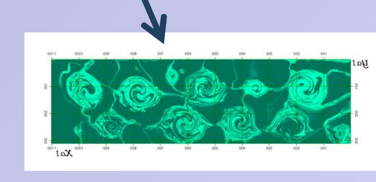


Figure 3. The simulation presents the development of small vortex formations along to the inner part of the accretion disc (Boneva 2017)



Wave pattern formation

The matter flux on the radial direction also changes in dependence on the velocity and density of the moving formation:

$$\rho_{vort} v_{vort} \sim F_{flux}$$

Reference:

Bisikalo, D.V., Boyarchuk, A.A., Kil'pio, A.A. Kuznetsov O. A., Chechetkin V. M., (2001), Astron. Rep., V. 45, Issue 8, pp 611
Boneva, D., 2017, Proceeding of SES'2017, p.79, ISSN 1313 – 3888
Bracco, A., Chavanis, P. H., Provenzale, A., & Spiegel, E. A. 1999, Phys. Fluids, 11, 2280
Klahr, H., P. Bodenheimer. ApJ, 2003, 582, 869-892
Petersen, M.R., G.R. Steward, K. Julien. Ap J., 2007, 658:1252-1263

Acknowledgments

• This work was initiated in part at Aspen Center for Physics - summer program 2017 and supported by a grant from the Simons Foundation.

• Thanks to Heloise Meheut for the useful discussion!