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A Possibility of Using Doppler Tomography to Indicate the Presence of Fluctuations and Structure Formations in Accretion Binary Systems

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Abstract.

To confirm our theoretical results for the arising of some kind of structure formations locally in the accretion discs, we need from observational evidence, also. It is known that the tomogram can show some features of flow structures. The Doppler tomography (DT) technique is a rather power tool for studying of binary star systems, including accretion flow, because of difficulty to spatial resolved of the binary system component trough direct observations. In this paper we present how this method works and how useful we may employ the receiving data to get to the requisite proofs. The required observational data used in Doppler tomography are sets of velocity-resolved line profiles covering a variety of phases around the binary orbit. We point here DT is a method that can be used to reorganize the observational data to draw up a right picture of line-forming regions in a binary star system. We may use the combination of Doppler shifting and binary rotation, which gives sufficient information for the shape of Doppler maps.

1 Introduction

Many rapidly rotating single and binary stars change little during the course of a single rotation or orbit. The spots on single stars can persist for many days, while cataclysmic variable stars may stay in outburst for over 100 orbits and in quiescence for ten times longer still [1]. However, for the observer, orbital rotation can cause considerable variability both in flux and spectra. This arises from a combination of changes in aspect angle and visibility, caused by geometrical effects, and the rotation of all velocity vectors with the binary orbit. Without these effects we would know considerably less than we do about such stars, however the complex variability can be hard to interpret.

Doppler tomography was developed in the late 1980's by Keith Horne and Tom Marsh, who aimed to exploit the kinematical information contained in the observed line profiles and recover a model-independent map that spatially resolves the distribution of line emission in the binary [2]. It was recognized that the observed line profiles at orbital phase provide a projection of the accretion flow along the line of sight given sufficient observed projections these profiles can than be inverted into 2D images.

Image reconstruction, is one of the typical problems in astronomy where the situation is rather specific because astronomical objects are very distant and can be viewed from a single direction only. The tomography is the method of image restoration, applied in astronomy.

Doppler tomograms provide snapshots of the accretion geometry in a wide range of systems. In many cases, data sets covering several orbits are averaged together to provide a time-averaged image of the accretion flow in the co-rotating frame. Given that in principle only half an orbit is required for the reconstruction of a well constrained tomogram, a sequence of Doppler maps can track the evolution of systems on timescales of order their orbital period and longer. The Doppler Tomography is an alternative indirect imaging method [3] based on the atomic line emission such as the strongly emission by accretion disc.

2 The Base Operations

The Doppler-broadened line profile offers a projection of the velocity distribution onto the observer's line of sight, while rotation of the binary presents the observer with a continuously varying sequence of velocity projections. This combination of Doppler shifting and binary rotation provides sufficient information for the assembly of 2 dimensional Doppler maps.

With Doppler tomography, a 2D data set consisting of a time series of line profiles is inverted into a 2D Doppler tomogram. Since the dataset provides us with projected radial velocities of the emitting gas, the Doppler tomogram one reconstructs the distribution of the line emission in the binary in a velocity coordinate frame [4].

In the Doppler tomogram coordinate frame, each line source is characterized by its inertial velocity vector in the orbital plane, $V = (V_x, V_y)$, where the binary center of mass is at the origin, the x-axis points from the accretor to the donor and the y-axis points in the direction of motion of the donor, as viewed in the co-rotating frame of the binary.

Each source then traces a sinusoidal radial velocity curve as a function of the orbital phase (φ)centered on the systemic velocity of the binary (γ).

$$V(\varphi) = \gamma - V_x \cos 2\pi\varphi + V_y \sin 2\pi\varphi \tag{1}$$

The observed line profiles are the projection of the radial velocities and intensities of all velocity vectors considered:

$$(v_r, \varphi) = \int I(V_x, V_y) + g(V - v_r) dV_x dV_y \tag{2}$$

with $g(V - v_r)$ describing the line profile intensity at a Doppler shift $V - v_r$ and $I(V_x, V_y)$ the Image value of the Doppler map at the corresponding velocity grid point.

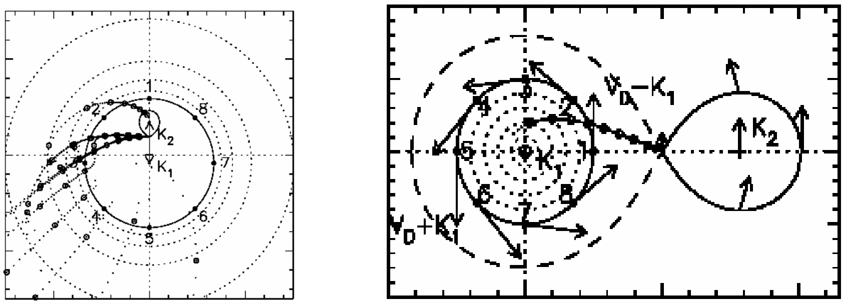
It is seen at the Figure 1 which illustrates the Doppler coordinates compared with position coordinates.

The positions of all these components is fully specified if the projected orbital velocities of the two stars, K_1 and K_2, and the orbital phase are known. The overall scale is set by $K_1 + K_2$; their ratio, which is the mass ratio $q = K_1/K_2 = M_2/M_1$, defines the detailed shape of the stream and Roche lobe. The orbital phase sets the orientation of the image, and if it is not known the image will be rotated by an unknown amount relative to the "standard" orientation shown in Figure 1 (based on figure of [5]).

Although velocity coordinates simplify the picture of line profile formation, it is simple enough to invert into position coordinates – this is how originally it is computed Doppler images.

The method of Doppler tomography was developed to unravel the emission line variations of cataclysmic variable stars (CVs) [1]. CVs are short period binary stars, with orbital periods typically between 1.5 and 10 hours, which are beautifully set up to allow us to study accretion. The stellar components of the binary, a white dwarf and a low-mass main-sequence star, are faint, and their semi-detached configuration means that the geometry is entirely specified by the mass ratio and orbital inclination alone.

Unfortunately, CVs are far too small to be resolved directly – they typically subtend $< 10^{-4}$ seconds of arc at Earth – and we can learn nothing of their structure from direct imaging. Instead we must turn to more indirect methods, which are "eclipse mapping" and "Doppler tomography". Eclipse mapping relies on the



(a) Doppler coordinates (b) Position coordinates

Figure 1. Schematic comparison of two coordinate systems of CVs. The scheme includes the Roche lobe filling companion star, the mass transfer stream and accretion disc around WD.

geometrical information contained in eclipse light curves; Doppler Tomography uses the velocity information contained in Doppler-shifted light curves.

3 The Results, Relating to Accretion Discs

Doppler tomograms provide snapshots of the accretion geometry in a wide range of systems [4]. In many cases, data sets covering several orbits are averaged together to provide a time-averaged image of the accretion flow in the co-rotating frame. A sequence of Doppler maps can track the evolution of systems on timescales of order their orbital period and longer. Load up with an adequate long data-set we can thus construct real-time movies of the changing accretion dynamics in binary systems. The dwarf novae and X-ray transients are felicitous targets for such time-lapsed tomography experiments.

The Doppler tomography can be very useful for tracing the structure of the disk surface when it is seen at a sufficiently large inclination. Similar techniques have been used recently to study detached binaries and multiple stars. All these methods are based on the fact that the line spectrum of the source is affected by the radial velocity of its individual components with respect to the observer [6].

It is relatively straightforward to identify and resolve bulge sites such as the extended accretion disc, the gas stream and its impact on the outer disc, the magnetically channeled flow in polars and emission from and around the mass donor star. Spatial asymmetries in the emissivity of the accretion disc map into similar structures in the inside-out Doppler projection of that disc. Since each of these sites has a completely different position-velocity relation, it would be impossible to reconstruct the equivalent position image without wide detailed assumptions concerning the (unknown) translation between velocity and position.

In disc accreting systems, tomograms have demonstrated that in many cases accretion disc flows are highly asymmetric. The interaction between the infalling stream and the outer edge of the disc manifests itself in a prominent bright spot as well as more extended disc asymmetries downstream (Figure 2). With Doppler maps, we have the prospect of studying this interaction in detail using a range of different lines.

Apart from imaging the geometry and dynamics of the accretion flow in a wide range of settings, Doppler tomography can also be used as a means toward the determination of basic system parameters. In particular, a contribution from the donor star is commonly observed in high-mass transfer rate CVs, polars and X-ray binaries.

On the other hand, a Doppler tomogram cleanly separates such donor emission from disc emission since emission from the Roche lobe-shaped donor stars maps onto a Roche lobe-shaped region along the positive V_y axis in Doppler tomograms (Figure 1b). This has the added advantage that the Doppler tomogram

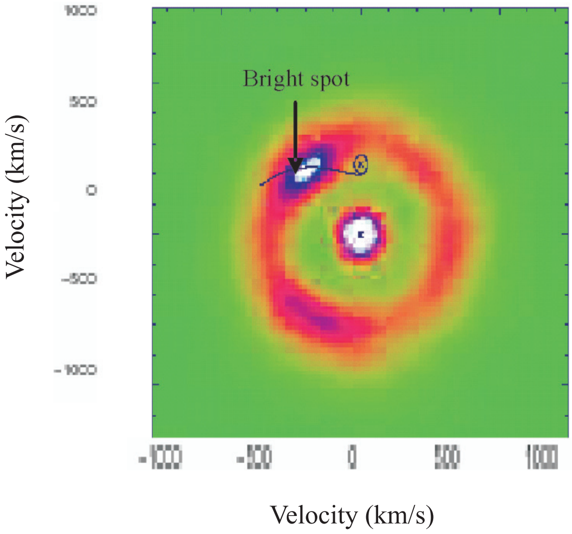


Figure 2. Doppler tomogram of U Gem. It is seen the bright spot. The cross near the system's center of mass denotes the location of the accreting white dwarf, a uncharacteristically strong emission-line source.

makes use of all the observed profiles at once and can thus identify very weak donor contributions that are too feeble to be identified in the individual line profiles. The main disadvantage of this method is that the emission traces only that part of the donor that is exposed to the ionizing radiation from the hot accretion flow, and thus is pointed toward the front side of the donor.

Cataclysmic variable stars produce strong optical emission lines, with double-peaked velocity profiles arising from the nearly-Keplerian orbital motion within the accretion disk [5]. In addition, there are S-wave components from emission-line regions on the companion star and in the accretion stream. What this means?

The nearly Keplerian velocity field of the disk gives rise to a distorted "inside-out" image of the disk in the doppler map. Each closed streamline in the disk maps into a closed loop in the doppler map, the doppler radius and azimuth at different positions around the loop being given by the velocity vectors at corresponding positions around the streamline. Gas flowing with constant velocity around a circular orbit will map into a circle with a radius equal to the flow speed. The disc's doppler image is inside-out because the outer rim of the disk, where the Kepler velocity is smallest, maps into the inner edge of the doppler image.

In the studying of the emission line profiles of close binaries accretion discs [7], it is view that the disc pattern is dominated by prominent spiral shock arms excited by the tidal forces of the secondary star. Using Doppler Tomography,

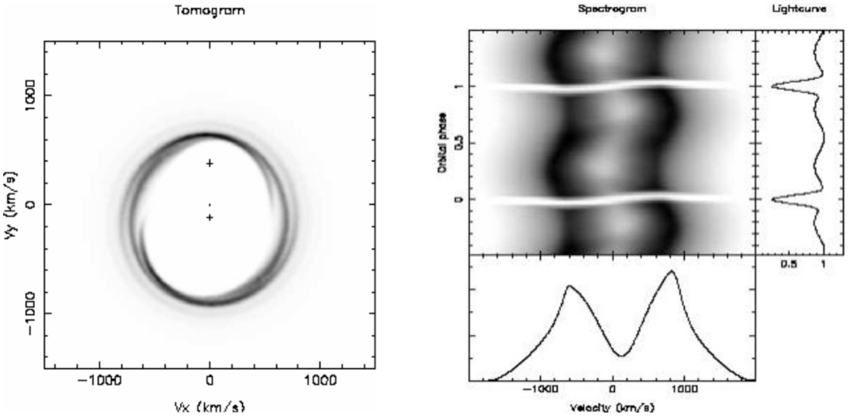


Figure 3. The distribution of line emission in velocity coordinates. Model for High Mach number; $\alpha = 0.01$ disc in a binary with $q = M_2/M_1 = 0.3$. The left panel shows the distribution of line emission in the V_xV_y plane. The crosses in the tomogram denote the projected radial velocity of the white dwarf (lower cross) and secondary stars. The right panel display the calculated emission line profiles for Hydrogen-like lines at an inclination of 80°. Here the line emission is produced across the whole disc height.

in the model for the high Mach number disc with CV (seen in Figure 3), it is found that the spiral shocks are very closely and cannot see clearly the separate fingerprints.

4 Conclusion

The base point in observationally examination of accretion systems is the detection of broad and strong emission lines. The supersonic accretion flows lead to complex and highly time-depended line profiles across the spectrum.

The theoretical simulations and results give rise to the same suggestion as in the observational results, obtaining from Doppler Tomography technique. Using the hydrodynamical and other non-linear theoretical methods we find that in the disc area there are conditions to form vorticity structures. But they are not enough to predict all variabilities of such systems.

By means of Doppler Tomography it becomes possible to corroborate the arising of such structures, especially spiral structures [8] and understand their evolution. The existence of spiral structures is theoretically examined and now the observations indicate the same results for the behavior of them.

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