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Assessment the area of accretion curtains from fast aperiodic time variability of Intermediate Polars

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Results of a study of the fast timing variability of the magnetic cataclysmic variable (mCV) EX Hya are presented. It was shown that one may expect the rapid flux variability of mCVs to be smeared out at timescales shorter than the cooling time of hot plasma in the post shock region of the accretion curtain near the WD surface. Estimates of the cooling time and the mass accretion rate, thus provide us with a tool to measure the density of the post-shock plasma and the cross-sectional area of the accretion funnel at the WD surface. We have probed the high frequencies in the aperiodic noise of one of the brightest mCV EX Hya with the help of optical telescopes, namely SALT and the SAAO 1.9m telescope. We place upper limits on the plasma cooling timescale $\tau < 0.3$ sec, on the fractional area of the accretion curtain footprint $f < 1.6\times10^{-4}$, and a lower limit on the specific mass accretion rate $\dot{M}/A > 3$ g sec^{-1} cm^{-2}. We show that measurements of accretion column footprints via eclipse mapping highly overestimate their areas. We deduce a value of $\delta r/r < 10^3$ as an upper limit to the penetration depth of the accretion disc plasma at the boundary of the magnetosphere.

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Intermediate polars is compact binary systems with magnetic white dwarfs (WD) as an accretor. In IPs the accretion disk is partially destroyed by the magnetic field of the white dwarf in its vicinity. On the disk inner edge the matter is captured by the WD magnetic field and continue to fall onto its surface through the magnetically channeled flow, which usually referred as "accretion columns" (see, e.g. Ghosh & Lamb, 1978). The geometry and size of accretion columns are important for defining the energy release processes of the falling matter. In turn the accretion column geometry depends on the interaction process between the white dwarf magnetic field and the accretion disk matter. The latter could give us an additional information on the magnetic properties of the disk.

Processes of the energy release in Intermediate Polars and Polars are known – an accreted matter is decelerated and heated up in a stationary shock wave near the white dwarf surface. After what a hot plasma between the white dwarf surface and shock wave is cooling down due to an optically thin emission (see, e.g. Aizu, 1973). It was shown by Langer et al. (1981) that position of the shock wave is unstable and should to oscillate. This instability in turn should lead to quasi periodical oscillations (QPOs) of X-ray and optical flux in IPs and Polars. A characteristic time of QPOs is defined by the matter density in the accretion column under the shock wave. Thus the using QPOs can be one of very convenient and easy ways to study accreted matter properties near the WD surface. Note, that such QPOs were found in several Polars, but not in any of known IPs. An absence of QPOs in IPs is probably connected with additional heating or cooling mechanisms, stabilizing the shock front position.

It is well known the the accretion flux near the white dwarf surface contains broad band variability spectrum Revnivtsev et al. (2010). In our study, to determine parameters of the accretion flow and columns near the WD surface we used the peculiar features which should arise in such luminosity variability power spectrum of IPs.

We have shown qualitatively that the variability of the accretion flow should be smeared out on the time scale shorter than the plasma cooling time in the hot zone between the stationary shock wave and white dwarf surface. In order to check an expected variability suppression we performed 1D and 2D hydrodynamical simulations of the accretion processes in the accretion channel near the white dwarf surface. In these simulations the accretion flow with a predefined variability power spectrum fall down in the gravitation field to the WD surface inside the channel with impenetrable walls. As a result a large number of lightcurves were produced in these simulations. The subsequent analysis showed that the power spectrum of resulted lightcurves corresponds to the power spectrum of the accretion flow at low frequencies and dumped at high frequencies (see left panel of Fig. 1). Our simulations showed as well that the smearing of the variability take place exactly on the plasma cooling time scale, which is proportional to the specific accretion rate in the accretion column $\dot{M}/A$, where A is accretion column footprint area and $\dot{M}$ is accretion rate on to the WD surface (Semena & Revnivtsev, 2012). Thus the specific accretion rate for IPs can be measured by the analysis of a variability of their luminosity.

This approach was used to determine the specific accretion rate and characteristic size of the accretion channel for two well-known intermediate polars – EH Hya and LS Peg.

For EX Hya system, we analyzed power spectra of X-ray and optic lightcurves, which were obtained from the data of *RXTE* and *XMM-Newton* observatories in X-rays (Semena & Revnivtsev, 2014) and from data of 10-m and 1.9-m telescopes of the South African Astronomical Observatory

(SAAO) in optics (Semena et al., 2014).

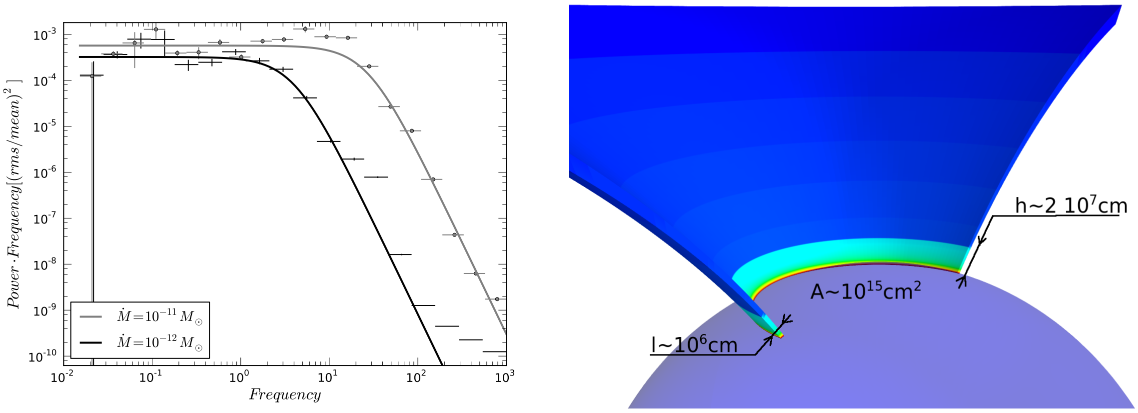

Figure 1: (left panel) Power spectra of the light curves produced in the hydrodynamic simulations with the different mean specific accretion rate. (right panel) Schematic view of the accretion flow near the white dwarf surface of EX Hya deduced from the analysis of its light curve variability

To obtain an intrinsic power spectrum of EX Hya we carefully took into account different background noise properties of observations carried out with different telescopes. We were able to extract high signal to noise intrinsic power spectra of EX Hya up to 5 Hz frequency. No prominent variability suppression was found in the received power spectrum. However, we obtain a lower limit on the power spectrum dumping frequency which in turn gave an upper limit on the specific accretion rate in the system $\dot{M}/A < 3g/cm^2$.

In a combination with the X-ray eclipse profiles (Mukai et al., 1998) these measurements allowed us to estimate a geometry of the accretion channel. It was shown that the accretion channel has a shape of a thin curtain with the footprint area $\sim 10^{15}$ cm^2 and thickness only $\simeq 10^6$ cm (see right panel of Fig. 1).

This value of the accretion channel thickness is much smaller that the one usually used in the most of theoretical models. At the same time it is close to the estimates made in some theoretical works considered accretion disk interaction with the magnetic field (Lovelace et al., 1995; Campbell, 2010). The thin accretion curtain indicates that the zone in the accretion disk where the matter is captured by the magnetic field is also small. In turn this indicates on the speed of a magnetic field propagation into the accretion disk is small as well as an effectiveness of a magnetic field dissipation in the disk.

If we assume that coupling region at the boundary of magnetosphere has a similar value $\delta r/r < 10^{-3}$ in the case of accreting neutron stars, then we can estimate the fractional area of the neutron star accretion column $A/4\pi r_{ns}^2 < 10^5$. Such a small fractional area of the column should result in very high mass flux and thus should have strong influence on the column structure.

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DISCUSSION

Marina Romanova: 3-D simulations show that the hot spot is inhomogeneous, where the higher energy expected in the inner parts of the spots. Is it possible that the size of the spots is larger at low frequencies.

Andrey Semena: The temperature of the matter under the shock wave should be the same for inner and outer parts of the flow (therefore both parts should have same continuum energy spectra). The break in the power spectrum is determined by the part of the flow, which give the most part of the system luminosity - most dense inner regions. That mean that accretion curtain could have larger area, but most part of the accretion flux goes through the small cross-section area.

Pavel Kaigorodov: Is the curtains optically thin or thick?

Andrey Semena: Accretion curtain is optically thin under the shock wave ($\tau < 0.3$ for the largest path under the shock wave) and also it is optically thin above the shock wave.