Modeling the heartbeat state in the microquasar IGR J17091-3624

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Abstract

Microquasar IGR J17091-3624 exhibits faint, quasi-periodical outbursts of the period between 5 and 70 seconds and regular amplitudes, frequently referred to as the 'heartbeat state'. These outbursts are plausibly explained by the accretion disk instability, driven by the dominant radiation pressure. Similar models have already been proposed to discuss the behaviour of another, much brighter microquasar, GRS 1915+105. In the current work, we use our hydrodynamical code GLADIS (Global Accretion Disk Instability Simulation) to model these 'heartbeat' outbursts. We compare our results o the observational data from SWIFT XRT and we investigate the link bewteen the development of the disk instability and strength of massive wind launched from the source. We discuss the properties of this wind and compare them with the results of spectral analysis.

Microquasar IGR J17091-3624 - artistic view

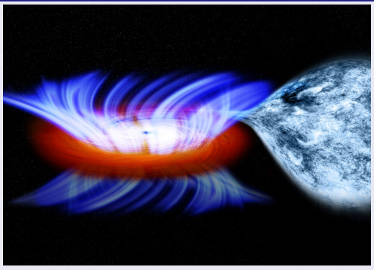


Figure: http://chandra.harvard.edu/photo/2012/igr/

Radiation pressure instability

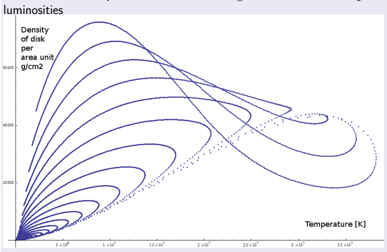
The accretion disk is thermally and viscously

$$\frac{\partial \dot{M}}{\partial \Sigma} < 0 \quad (1)$$

(Lightman Eardley 1974 , Meyer Meyer-Hofmeister 1981) Condition for radiation pressure instability (Janiuk, Czerny, Siemiginowska 2002)

$$\frac{\partial \ln \Sigma}{\partial \ln T} < 0 \quad (2)$$

Results for stationary model for $M = 10M_{\odot}$ for several sub-Eddingtonian luminosities



The greater the accretion rate the larger is the size of unstable region in disk accretion rate the larger is the size of unstable region in disk

Theory of outbursts - hydrodynamics

The mass conservation equation:

$$\frac{\partial \Sigma}{\partial t} = \frac{1}{2\pi r}\frac{\partial \dot{M}}{\partial r} \quad (3)$$

$$\dot{M} = -2\pi r \Sigma v_r \quad (4)$$

The angular momentum conservation:

$$\dot{M}\frac{d}{dr}(r^2\Omega) = -\frac{\partial}{\partial r}(2\pi r^2 T_{r\phi}) \quad (5)$$

We define ν as the kinematic viscosity (α - disk theory)

$$T_{r\phi} = \alpha PH = (3/2)\Omega\nu\Sigma \quad (6)$$

From mass and angular momentum conservation equations 5 and 6 we obtain the final formula on the evolution of the surface density of disk: **7**

$$\frac{\partial \Sigma}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}(3r^{1/2}\frac{\partial}{\partial r}(r^{1/2})\nu\Sigma) \quad (7)$$

The radial velocity is given by:

$$v_r = -\frac{3}{\Sigma}r^{-1/2}\frac{\partial}{\partial r}(\nu\Sigma r^{1/2}) \quad (8)$$

In the disk we may have radiative cooling as well as convection, advection and diffusion. In our model we neglect the effects of convection and heat diffusion and assume the same equation as in

$$\frac{\partial \ln T}{\partial t} + v_r\frac{\partial \ln T}{\partial \ln r} = \frac{4-3\beta}{12-10.5\beta}(\frac{\partial \ln \Sigma}{\partial \ln r} - \frac{\partial \ln H}{\partial \ln r} + v_r\frac{\partial \ln \Sigma}{\partial \ln r}) + \frac{Q_+ - Q_-}{(12-10.5\beta)PH} \quad (9)$$

Wind model

The mass loss rate (propably in the verical direction is equal to the ratio of the locally generated flux in the accretion disk, with a fraction determined by f_{out}, to the energy change per particle, $\dot{m}_z = F_{tot}(1-f_{out})/(\Delta E/m_p)$. The local flux is given by the Equation (10) of the standard accretion disk theory

$$F_{\rm tot} = \frac{3GM\dot{M}}{8\pi r^3}f(r) \quad (10)$$

We assume f_{out} as a simple smooth rational function:

$$f_{out} = \frac{1}{(1+A\dot{m}^2)} \quad (11)$$

We assume that this relation holds also in the hydrodynamical computations. The energy change per particle is on the order of virial energy, $\Delta E = BkT_{vir} = BGM/r$, with $B \sim 1$, so expressing the mass loss rate in terms of local variables, in the units of [g s^{-1} cm^{-}2], we have a final formula:

$$\dot{m}_z(r) = B\frac{3}{4}\frac{1}{r}\Sigma v_r f(r)(1-f_{out}) \quad (12)$$

with f_{out} given by Equation 11.

Microquasar IGR-J-17091-3624

- Heartbeat at the period between **5** and **70** seconds - possible by radiation pressure instability
- Moderately bright transient X-ray binary
- Peak flux level at **20** mCrab in the range **20 − 100** keV
- Discovered by INTEGRAL/IBIS in **2003** (Kuulkers et. al. Astron. Telegram. **149**)
- Was searched in archival data of previous missions (TTM-Kvant,BeppoSAX)
- At the end of January **2011** Swift/BAT reported renewed activity of IGR-J-**17091**; 28 February 2011 started a long monitoring campaign
- **2011** outbursts increased to **120** mCrab
- IGR-J-**17091-3624** presents fast and ionized wind observed during the soft spectral state
- Similatities between IGR-J-**17091-3624** and GRS-**1915+105**

Simultaneous observations of IGR-J-17091-J-3624 with Chandra and RXTE show the presence of wind during some of the heartbeat states

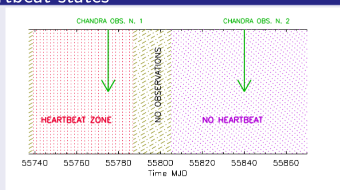
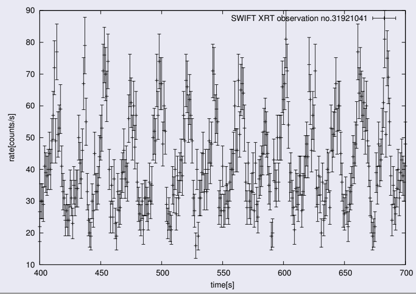


Figure: The timeline sketch in Figure XX shows the periods in which the flare-like events named "heartbeat" have been detected or not in the lightcurve of IGR J17091-3624. For this purpose we analized the data taken during the SWIFT/XRT observation campaign of the 2011 outburst and two CHANDRA observations (MJD=55775 and MJD=55840, respectively). The first CHANDRA observation did not show any detectable wind. Simultaneous radio observations did not detect jets. The second CHANDRA observation on the contrary shows a strong and fast wind. Also in this case, simultaneous radio observations did not detect jets.

Observational data

Obtaining the data:

- SWIFT mission
- X-Ray data from termal radiation of the disk - XRT
- **0.2 − 10** keV
- HEASOFT - High Energy Astrophysics SOFTware v.**6.15**
- XRT pipeline
- XSELECT extracting



Spectral modeling

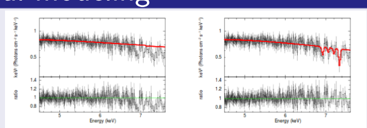


Figure: Fe lines in X-Ray spectrum, Fe lines in X-Ray spectrum (King et. al. 2012)

- From the spectral modeling we have column density $0.475 \cdot 10^{22}$ to $1.14 \cdot 10^{22}$ cm^{-2}
- We can compute column density of wind from our model

$\dot{m}$	$\dot{M}$ [g s^{-1}]	$\Delta\dot{M}_{wind}$ [g s^{-1}]	ρ_{wind} [g cm^{-3}]	N_H [cm^{-2}]	$\frac{\dot{M}_{wind}}{\dot{M}}$	error
0.07985	$1.073 \cdot 10^{18}$	$9.43 \cdot 10^{16}$	$2.52 \cdot 10^{-12}$	$2.68 \cdot 10^{21}$	0.0879	0.1463
0.1	$1.344 \cdot 10^{18}$	$1.97 \cdot 10^{17}$	$5.26 \cdot 10^{-12}$	$5.58 \cdot 10^{21}$	0.146	0.135
0.1248	$1.677 \cdot 10^{18}$	$3.37 \cdot 10^{17}$	$8.81 \cdot 10^{-12}$	$9.56 \cdot 10^{21}$	0.2009	0.1127

Results of the disk/wind model, for assumed parameters A= **15**, $M = 6M_{\odot}$, $R_{max} = 1000R_{Schw}$

Model with and without wind

- $M = 6M_{\odot}$
- Accretion rate between **0.04** and **0.1** Eddington
- Amplitude (maximal luminosity / minimal luminosity) below **9**
- Wind parameter change period and range of outbursts significantly

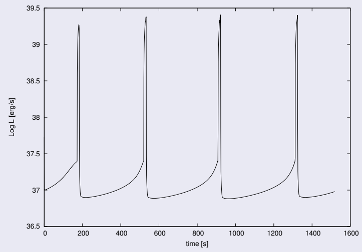


Figure: Without wind and $\dot{m} = 0.1$

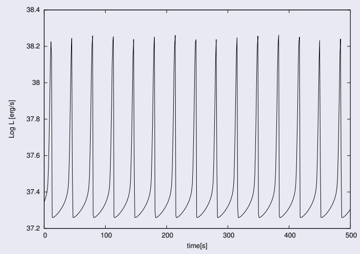


Figure: With wind strength parameter A = **15** and $\dot{m} = 0.1$:

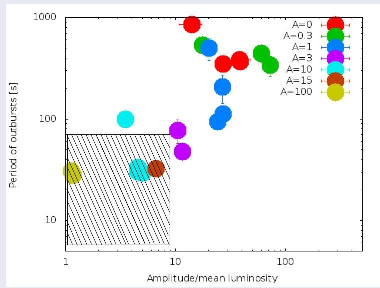
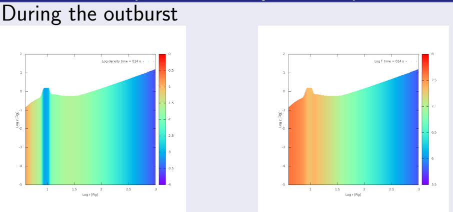


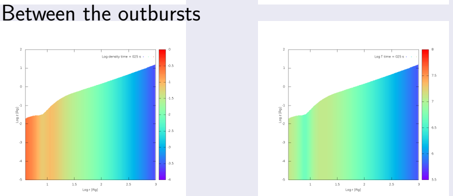
Figure: Grid of models, $\dot{m} = 0.1$

Accretion disk profile - density and temperature

During the outburst



Between the outbursts



- Lightman Eardley 1974 ApJ, vol. 187, p.L1
- Meyer Meyer-Hofmeister 1981 AA , 104, L10
- Janiuk, Czerny, Siemiginowska 2002 ApJ vol. 576 pp.908â922
- King et. al. 2012 ApJ Letters, Vol. 746, Issue 2, art. id. L20, 5 pp.