Modified viscosity in accretion disks

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Black holes surrounded by accretion disks are present in the Universe in different scales of masses, from microquasars, up to the Active Galactic Nuclei. The basic theory of a geometrically thin, stationary accretion is based on a simple albeit powerful α description which assumes the proportionality between non-diagonal stress tensor term $\tau_{r\varphi}$ and the total pressure. This model is thermally and viscously unstable, which leads to the limit-cycle oscillations if the accretion rate is high enough and part of energy is transported by advection. The thermal instability, due to radiation pressure domination in the inner hot areas of the accretion disk is called radiation pressure instability. Those oscillations found their observational confirmation in the X-ray flares of some microquasars like GRS1915+105 and IGR J17091-3624.

In our work we examined large grid of accretion disk models with generalized description of viscosity. One of the possibilities is assuming that only the gas pressure contributes to viscosity ($\tau_{r\varphi} = \alpha P_{gas}$), although this model does not lead to thermal instability. Assumption of $\tau_{r\varphi} = \alpha P$ for the known sources (Szuszkiewicz 1990) results in flares with very large amplitude and period. Between those two extremes there exists a continuum of effective models, described by the parameter μ ($\tau_{r\varphi} = \alpha P^{\mu} P^{1-\mu}$),which was the base of our model. The range of the oscillation limit cycle, in a global view, can be reduced by the magnetic field, having its possible effective description in value μ.
We developed the global, 1.5-D code GLADIS to model the lightcurves from the set of accretion disk parameters, like central BH mass, accretion rate and α. Introducing the μ parameter extends the family of possible limit-cycle lightcurve shapes, and increases the number of possible observables, leading to results independent from the spectral analysis.

We used this procedure to determine the mass of the intermediate mass black hole of HLX-1 and its accretion rate from the features of the observed flares, detected by the Swift X-ray satellite. Much greater accessibility and shorter characteristic timescales can help in the verification of the microquasars disk parameters; in this case the black hole spin can be another parameter influencing the X-ray flare timescale and amplitude.
In case of Active Galactic Nuclei such method should be introduced only indirectly, using the statistics and parameter distributions for the classes of objects.

Accretion disks - General picture

- Characteristic spectrum (diskbb) $T \sim r^{-3/4}$ & Eddington ratio
- Keplerian rotation, optically thick & geometrically thin disk
- The alpha prescription of Shakura & Sunyaev (1973)
- We propose the generalized model (Szuszkiewicz 1990), which can possibly include the stabilizing effect of strong magnetic field in disk (Sądowski 2016)

$$\tau_{r\phi} = \alpha P^{\mu} P_{\rm gas}^{1-\mu}$$

Models & Results

- GLADIS CODE (1.5D, viscous & thermal scales, Janiuk et. al 2002)
- Input parameters - M, mdot and μ
- Model equations:

$$\frac{\partial \Xi}{\partial t} = \frac{12}{y^2}\frac{\partial^2}{\partial y^2}\left[\Xi \nu\right],$$

where $y = 2r^{1/2}$ and $\Xi = 2r^{1/2}\Sigma$, and

$$\frac{\partial \ln T}{\partial t} + v_r \frac{\partial \ln T}{\partial r} = q_{\rm adv} + \frac{Q_+ - Q_-}{(12 - 10.5\beta)PH}$$

- Results of model grid:

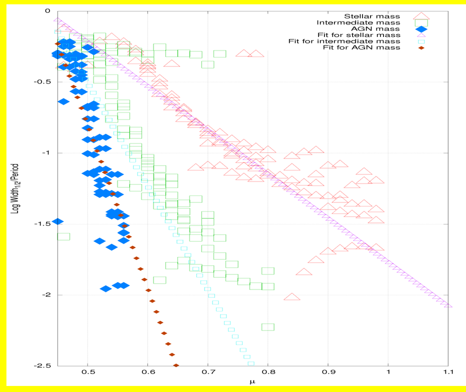


Fig. 1 Δ - μ correlation

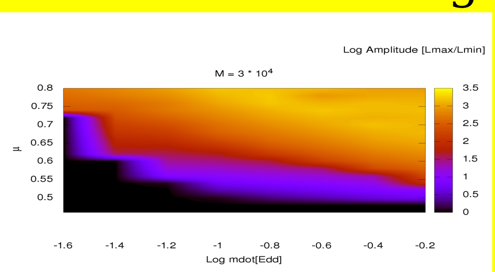


Fig. 2 Flare amplitude map

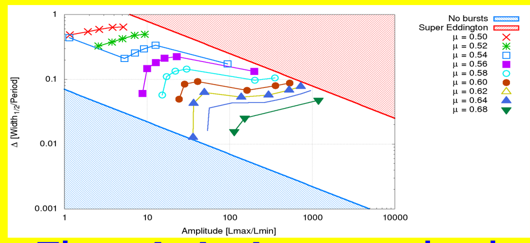


Fig. 4 Δ-A correlation

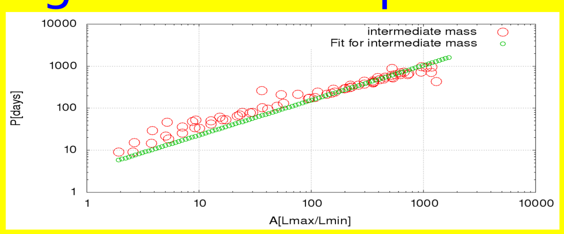


Fig. 3 P-A correlation

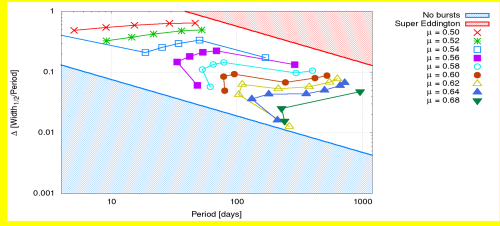


Fig.5 P-Δ correlation

Applications

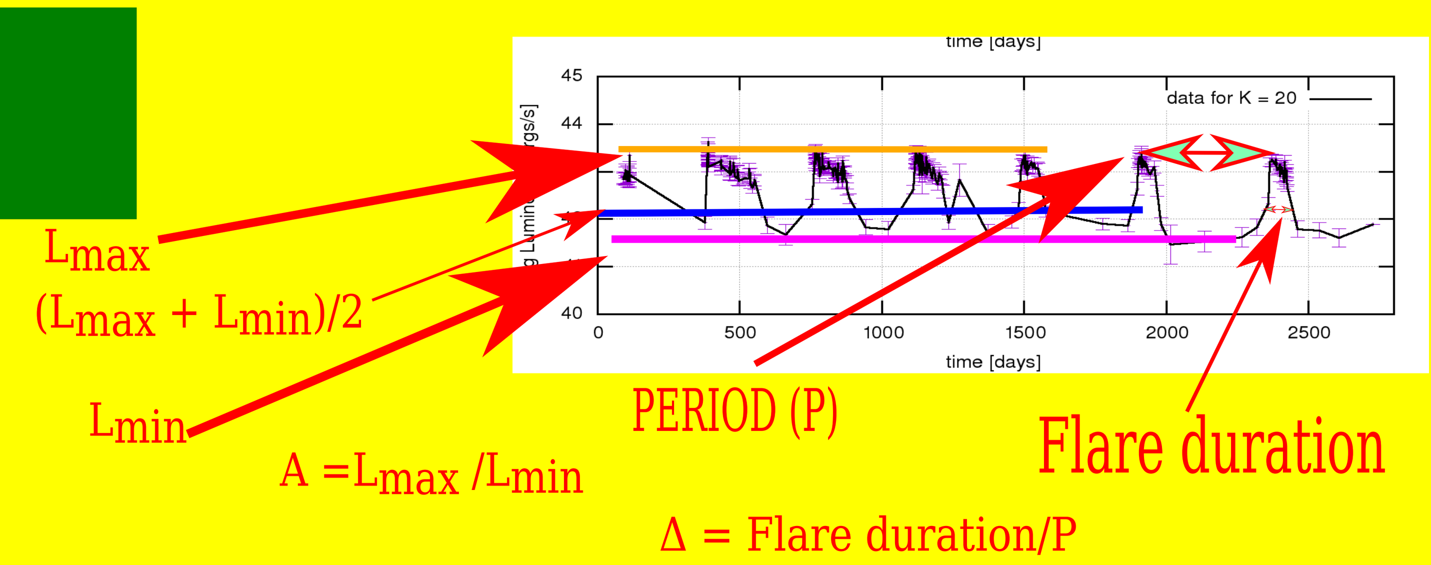
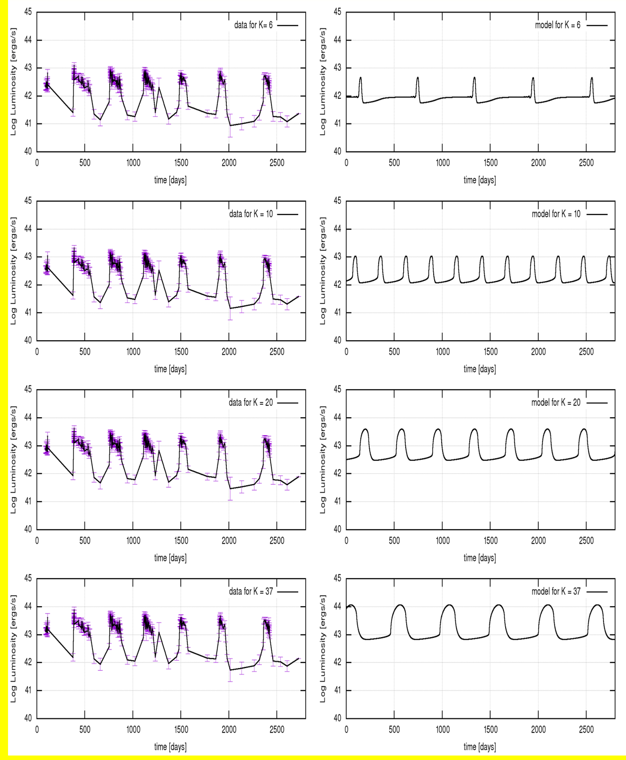


Fig.6 Lightcurve parametrization (of HLX-1): (P,A,Δ)



$$M[M_\odot] = 0.45 P[s]^{0.87} A^{-0.72} \left(\frac{\alpha}{0.02}\right)^{1.88}$$

$$\mu = 3/7 + \frac{-\log\Delta + 0.87\log(\frac{\alpha}{0.02})}{1.49 + 1.04\log P - 0.864\log A}$$

- Formulae connecting observables and model parameters (Grzędzielski et al. 2017); We can determine the black hole mass from the ligthcurve (Wu et al. 2016, Grzędzielski et. al. 2017)

Fig. 7 HLX-1 mass determination:
P = 400 days, Δ = 0.14,
M = 1.9 x 10^5
Eddington rate 9 -18%

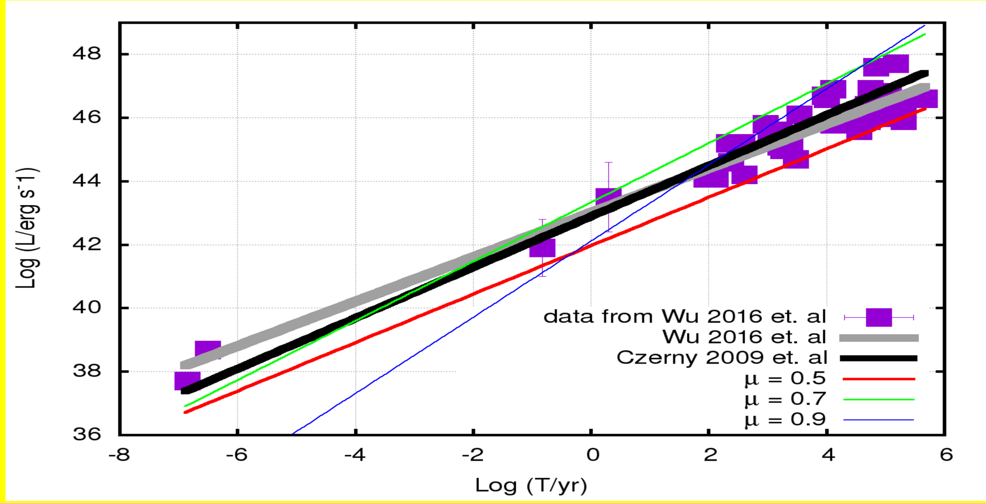


Fig. 8 Universal timescale-luminosity correlation. Points represent AGNs (Czerny et al. 2009), HLX-1, IGR J17091 and GRS1915 microquasars, lines represent the models (Wu et al. 2016, Grzędzielski et al. 2017)

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