Variability model for the microquasar GRS 1915+105

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Abstract

We analyse the radiation pressure instability of the standard, optically thick disc and propose it as an explanation of the observed variability of the superluminal microquasar GRS 1915+105. The quantitative agreement with the observed outburst amplitudes is obtained under the assumption that substantial part of the energy is carried away by the jet.

1 Microquasar GRS 1915+105

The X-ray source GRS 1915+105 discovered by GRANAT observatory exhibits both the superluminal jet (Mirabel & Rodriguez 1994) and very complex variability pattern (Belloni et al. 1997). The outburst X-ray luminosity is about $10^{39}$ erg/s, being of the order of Eddington luminosity in case of stellar mass black hole system. The spectral analysis reveals the domination of disk-like component during the outbursts, and therefore the variability of the source may be connected with disk evolution.

2 Instability in the accretion disc

The local time behaviour of an accretion disk at a given radius is determined by the stability curve, i.e. the log $\dot{m}$ vs. log $\Sigma$ diagram constructed for a stationary disk, where $\dot{m}$ is the accretion rate and $\Sigma$ is the disk surface density. The parts of the curve with a negative slope describe the unstable branch and indicate

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the range of accretion rates resulting in time dependent disk behaviour at this radius. The unstable part corresponds to the radiation pressure dominated region; including the advection term results in stabilizing the solution.

The disc is unstable in the inner part. For the limited range of radii the limit cycle behaviour occurs and propagates outwards. The value of viscosity parameter does not change the outburst amplitude, but influences the duration of the limit cycle.

3 Jet ejection

The observations of microquasar outbursts require that the whole limit cycle should run between $\dot{m} \sim 0.01$ and $\dot{m} \sim 1.0$. In the model, the maximal disc luminosity is lowered under the assumption that jet ejected from the disc takes away a certain part of the total emitted power, depending on the $L/L_{Edd}$ ratio. We adopt a jet power parameterization similar to Nayakshin et al. (1999)

We assume that the heat generated within the disk at any radius is either stored temporarily within it or removed by: (i) radiation (ii) advection (iii) jet. As the spectral observations show the presence of hard X-ray tail, we also assume the existence of hot corona, with moderate contribution to the energy dissipation ($f_{cor} = 0.5$).

4 Theoretical lightcurves

We adopt the mass supply to the inner part of the disk as a model parameter and follow the time evolution of the disk under the radiation pressure instability, as described in Siemiginowska et al. 1996. The amplitude of the global outburst depends mostly on the shape of the stability curve in the innermost part of the disk. The duration of the limit cycle, on the other hand, is basically determined by the viscous timescale at the outer radius of the instability zone in a stationary model, i.e. on the stationary accretion rate, radial extension of the instability zone for that accretion rate and the viscosity parameter $\alpha$.

5 Summary

We used a physically viable instability due to radiation pressure to model the time dependent behaviour of the optically thick disk itself. The presence of the hot optically thin medium was accounted for by assuming assuming that a certain part of gravitational energy ($f_{cor} = 0.5$) is released in hot corona outside the disc. The mechanism operates for accretion rates above $\dot{M}_d/\dot{M}_{Edd} \sim 0.16$ which is in agreement with the observations of GRS 1915+105 - the source does not exhibit the outburst if the mean luminosity temporarily drops below $2.1 \times 10^{38}$ erg/s. The viscosity coefficient of order of 0.01 is appropriate to
Figure 1: An example of the stability curves calculated at $10 \, R_{Schw}$ for the mass of the central object equal $10M_\odot$ and viscosity parameter $\alpha$ equal 0.01. Green triangles show the solution obtained with the model of full vertical structure of a disc and the circles mark the standard analytic solution. The yellow line is obtained from the vertically averaged solution with appropriate scaling coefficients. Red continuous lines are the curves resulting from the vertically averaged equations: dotted line shows the effect of assumption that 50% of the gravitational energy is released in the corona outside the disc and the continuous line resulted from including the jet.
Figure 2: The lightcurves calculated for $M = 10M_\odot$, $\alpha = 0.01$ and four values of the external accretion rate: $0.6 \times 10^{-7}$, $0.8 \times 10^{-7}$, $1.0 \times 10^{-7}$ and $2.0 \times 10^{-7}[M_\odot/yr]$.
model the typical outburst duration. We conclude that the radiation pressure instability is a promising model of the basic instability mechanism underlying the observed variability of this microquasar.

6 References

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