ULXs, Accretion Disk Fragmentation, and Super-Eddington Luminosities

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We suggest a new instability in disk/corona systems which leads to fragmentation of accretion disks in strong magnetic fields under radiation pressure and allows Super-Eddington radiation from the fragmented accretion disk.

§1. Introduction

Ultraluminous X-ray sources (ULXs) with observed luminosities of $10^{39.5}$ to 10^{41}erg/s and spectra fitted by multi-temperature black body radiation of temperatures 1-2 keV are thought to be black holes accreting mass from a late O type (Liu et al. 2002) stellar companion at high rate. In order not to exceed the Eddington limit the accreting black holes would have to be of intermediate mass, 50-100 $M_{\odot}$, while the observed disk temperatures are too high for such black hole masses (Makishima et al. 2000).

Various suggestions have been made to resolve this problem: Beaming into our direction (King et al. 2001), Kerr metric of spinning black holes allowing the disk to get closer to the black hole and be hotter (Ebisawa et al. 2003), slim disk accretion involving advective energy transport (Watarai, Mineshige and Mizuno 2002), alternative spectral fits (Miller et al. 2003).

§2. Super-Eddington radiation from accretion disks

Radiation pressure supported disks in magnetic fields are unstable against a "photon-bubble instability", in which overstable oscillations enhance vertical energy transport (Gammie 1998). In a non-linear version such radiation driven inhomogeneities can allow the escaping flux to exceed the Eddington limit and are suggested as resolution of the ULX problem (Begelman 2000, 2002). We here suggest that radiation pressure leads to a complete fragmentation of accretion disks in magnetic fields around black holes and that radiation escapes through the gaps between fragments at super-Eddington luminosity. Essential for the gap formation is the overlying disk corona into which gas of too low a density evaporates.

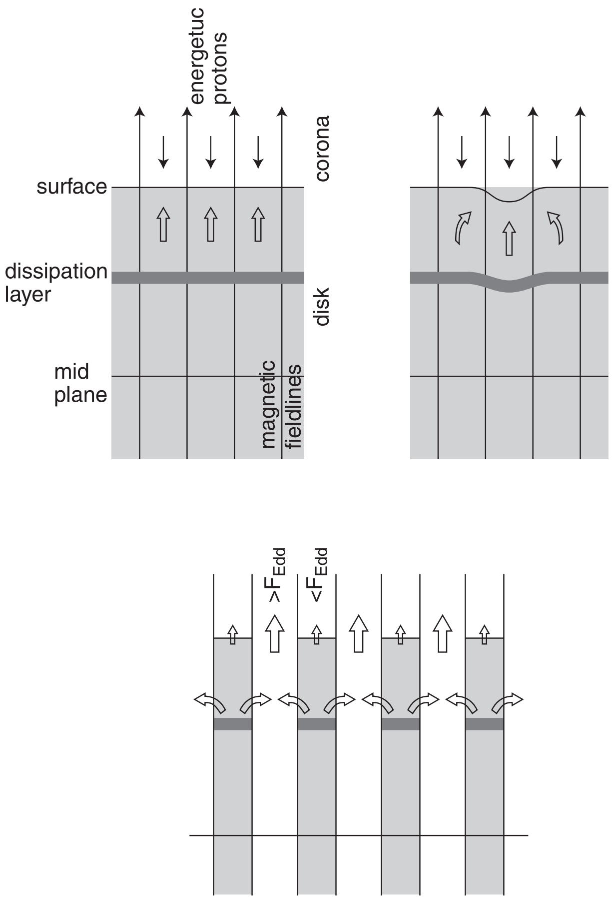

Fig. 1. Process of disk fragmentation

§3. Fragmentation instability

We shortly sketch the essentials. If magnetic pressure exceeds the gas pressure the magneto-rotational instability (Balbus & Hawley 1998) is quenched. Coronal magnetic fields penetrating the disk are sheared by Kepler motion of their foot points in the disk. This energy input is dissipated in the corona by reconnection instabilities. Dynamical reconnection in the low gas pressure coronal plasma predominantly accelerates ions in collision-free shocks. Because of its low density the coronal plasma radiates inefficiently. However the ions penetrate along field lines into the accretion disk to high optical depth depending on their energy. There they release their energy and heat the accretion disk. By radiation transport the energy travels to the surface where it is radiated away. For high accretion rate or a rapidly spinning black hole and close to the central accretor the energy input is high. As a result the radiation pressure dominates over gas pressure and supports the disk against gravity in the vertical direction. The higher the radiative flux F to the surface is the more vertically extended the disk becomes.

It is now important to note that the density at the transition between disk and corona above is uniquely determined by the coronal heating. At higher density gas is able to cool efficiently and condense into the disk. For lower density gas does not cool efficiently and is heated up to coronal temperatures (Meyer et al. 2000). For radiation pressure supported accretion disks this leads to fragmentation of the disk into individual blobs as shown in Fig.1.

A small decrease of surface density in one column lowers its density and thereby decreases the optical path length to the surface. As a result radiation from neighboring columns flows into this column and increases the radiation flux density F there. This further reduces the density in the column and matter evaporates into the corona. This leads to further inflow of radiative flux from the neighboring columns and further evaporation until the whole column has been evaporated. The neighboring columns cool very efficiently by sidewise radiative flow into the newly formed gap. Little radiation still diffuses through the large vertical optical depth to the surface and the flux there is diminished. Radiation pressure support decreases and the temperature inside the remaining column drops. The end result is a mixture of dense cool blobs circulating around the black hole heated from above by energetic particles and cooling sidewise with gaps in between through which then black body type radiation escapes even at super-Eddington rate if the accretion power requires it.

Fig. 2 schematically shows the magnetic interaction between blobs which releases the accretion energy in the corona. We note that a rapidly spinning black hole coupled to the blobs of the fragmented accretion disk by magnetic fields of in-falling matter would act in much the same way as Kepler rotation of accreting blobs as an input of energy.

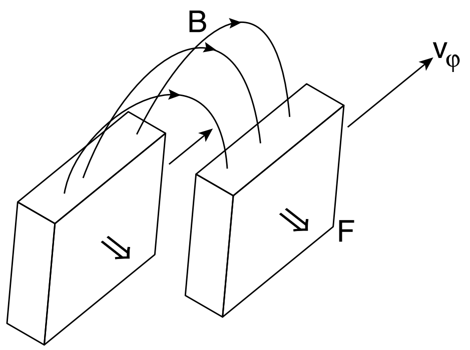

Fig. 2. Magnetic interaction of individual blobs

Where do the strong magnetic fields come from? We have already pointed out that the fragmentation leads to a remarkable drop of pressure in the blobs while the magnetic pressure remains unchanged. One can show that for a standard case it lowers the ratio of gas to magnetic pressure by more than a factor of 5. The high electrical conductivity prevents the escape of magnetic flux from the blobs on the accretion time scale.

§4. Final remarks

It might be noted that this fragmentation process eliminates the Lightman-Eardly instability of the radiation pressure supported disk theoretically expected, but observationally not evident. Further we note that a blobby disk of the kind suggested here is an ideal configuration for modeling quasi-periodic oscillations at near Kepler frequencies and has the potential to resolve many other problems.

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