Super-Eddington luminosity from fragmented accretion disks

Friedrich Meyer

Max-Planck-Institut für Astrophysik, Garching, Germany

Abstract. In order to resolve the problem of apparent super-Eddington luminosities from accretion disks around black holes in super-luminous X-ray sources we propose that in strong magnetic fields under radiation pressure such disks fragment into individual magnetically aligned columns of cool disk gas and that radiation escapes through the gaps between them at super-Eddington luminosity.

1 Super-Eddington radiation from accretion disks

In order not to exceed the Eddington limit the ultra-luminous X-ray sources (ULXs) would have to be of intermediate mass, 50-100 $M_{\odot}$. But 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.

Radiation pressure supported disks in magnetic fields are unstable against a "photon-bubble instability", in which over-stable 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 (Meyer 2004). Essential for the gap formation is the heating in the overlying disk corona into which gas of too low a density evaporates.

2 Model

If magnetic pressure exceeds gas pressure the magneto-rotational instability (Balbus & Hawley 1998) is quenched. But there is still heating of disk gas: 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 a low gas pressure coronal plasma predominantly accelerates ions in collision-free shocks. At low density the coronal plasma radiates inefficiently. However the ions penetrate along field lines into the accretion disk to high optical depth. There they release their energy and heat the accretion disk. Radiation transports this energy 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 radiation pressure dominates over gas pressure and expands the disk against gravity in the vertical direction.

If now in an originally homogeneous disk one of the magnetic columns accidentally has a smaller density than its neighbors radiation will preferentially choose this pathway for escape thereby expanding it and lifting its upper part into a density regime for which evaporation into the corona occurs by the predominance of heating over cooling at low density. As a result the column looses mass and the process accelerates until the whole column is evaporated and a gap has formed. The radiation then escapes rather sidewise from the remaining columns and can easily surpass the Eddington luminosity.

An essential element in this fragmentation is thus that the density at the transition between disk and corona is determined by the coronal heating. At higher density gas is able to cool efficiently and remain in the disk. At lower density gas is heated up to coronal temperatures.

3 Discussion

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

In particular it may lead to understanding of the so called very high state in which Comptonization of disk photons by coronal electrons appears to produce a power law rather than a disk black body spectrum (Kubota and Done 2004). Mass equilibrium between disk and corona is reached when the rate of coronal ions stopped in the blobby disk equals the rate at which blob mass enters the corona by shearing away the blob skins through the radiative flux in the gaps. At higher accretion rate and luminosity more mass will reside in the corona until at very high rates coronal density is high enough to efficiently heat coronal electrons by electron ion collisions and radiate large parts of the coronal energy by Comptonizing cool disk photons instead through disk radiation directly.

References

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