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Flare-like outbursts from loading of the jets?

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Abstract. I discuss the possibility of observing the collapse of the accretion disk by detecting the emission of the disk matter if part of it is expelled from the centre as a wind-like outflow. I suggest that when the resulting flare is considered in connection with existing shock-in-jet models, certain kinds of orphan flares and their relations to multifrequency flares followed by new jet components can be understood in the context of jet launching. In this early report of an ongoing study I describe our first approach for this problem, outline the central signatures one could expect from this kind of an event, present the few quantitative results obtained so far, and discuss the observational tests in preparation.

Key words. Accretion Disks; Active Galactic Nuclei; Microquasars; Outflows.

1. Introduction

Many characteristics of flaring in active galactic nuclei (AGNs) and microquasars are best explained with relativistic motion of the radiating regions in jets. Especially for microquasars the variability is often best explained by variations in the structure of the accretion disk and the jets; as discussed by many authors in this volume, the connection between the disk and the large-scale jets is well established even if the details are not yet fully known.

Our starting point is the general model proposed, in slightly differing forms, for both the microquasars and AGNs (see Mirabel & Rodríguez 1998; Marscher et al. 2002, and references therein). The connection between the accretion disk and the jets in AGN and microquasar objects is discussed by many authors in this volume; in general the scenario is believed to work along the following lines: part of the accretion disk breaks off, and while some of the inner hot matter falls beyond the event horizon the outer parts get injected into the jet where the magnetic fields and pressure gradients collimate and accelerate the plasma into a narrow, relativistic flow.

Especially in AGNs the jet becomes visible in the radio maps far away from the black hole at the radio core (see, *e.g.*, Marscher 2008, and references therein), where the flow presumably passes through a standing shock that compresses the plasma and accelerates the particles, thus creating a bright multifrequency flare, often including a strong gamma-ray outburst (Jorstad et al. 2009). After this flare, a new component becomes visible in the jet, moving away toward the downstream (Savolainen et al. 2002; Chatterjee et al. 2008). Furthermore, Marscher et al. (2002) have also established the connection between the collapse of the accretion disk – seen as a dip in the X-ray emission – and the core flare and a new jet component.

We add one component to this scenario to see if we can improve our understanding of the similarities and differences between microquasar and AGN objects and better quantify some of the open accretion and ejection parameters. We ask: if part of the collapsing disk matter escapes both the black hole and the jet, could we detect it? If part of the matter is indeed blown away, and if we could detect that, we would be able to better model not only the flaring behaviour, but also the general dynamics and the energy budget in these systems; for example, the accretion rate and its relation to the power of the jets.

Observationally this study was motivated by the observations and idea of Miller-Jones et al. (in preparation), who found that certain double-peaked flares in the microquasar Cygnus X-3 are best explained by treating the first flare as a product of a violent outbreak of disk wind, later followed by a second flare when a new jet element – launched from the centre during the first flare – becomes visible further away in the jet. Here we seek to generalise that idea by stydying the possibility that the same general scenario could also scale up to some AGN objects.

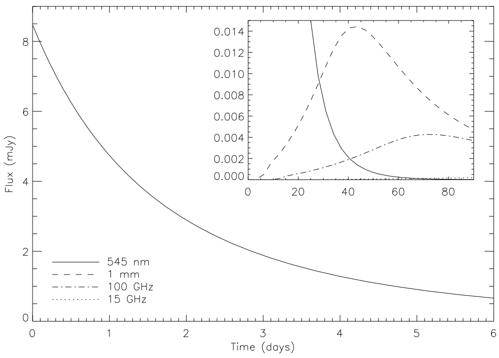

Fig. 1. Example lightcurves from a thermal flare in BL Lacertae for optical (solid line) and three radio frequencies as given in the plot. The dimmer and slower radio flares are only visible in the small panel showing the micro-Jansky level peaks months after the optical mJy-level flare. See text for details. From Tammi & Hovatta (2010).

2. Thermal flare in the centre

In Tammi & Hovatta (2010) we used a very simplified model to see if a thermal flare with reasonable parameters can, even in principle, match the observations. We took a ”spherical cow” approach, describing the radiating plasma as a homogeneous sphere expanding at a constant speed, and computed the blackbody and the bremsstrahlung spectra as functions of time.

For the zeroth-order calculation we used isotropic and homogeneous pair plasma (temperature of the order of 10^5–10^7 K and mass 1–10 $M_\odot$), beginning to expand at a speed of 0.1–0.5 c from an initial radius of 1.5–3 Schwarzschild radii. The volume inside the black hole event horizon was taken into account when calculating the initial plasma parameters, but later it was deemed negligible compared to the total volume of the relativistically expanding sphere. The plasma cooled only from the adiabatic expansion; radiation losses were omitted in this first approach due to short expansion timescales and low energies of the particles.

For a crude comparison with observations we checked what (if anything at all) could be seen from BL Lacertae ($z = 0.069, M_{\rm BH} \approx 10^8\,M_\odot$). Using collapsing mass of $10\,M_\odot$ in temperature 10^5 K within the initial radius of 1.5 Schwarzschild radii, starting to expand at constant speed of 0.4 c. The result, shown in Fig. 1, was an optical flare rising within hours from zero to 8.5 mJy and declining in a few days approximately proportionally to $e^{t/2}$. At radio frequencies, however, the peak flux was two to three magnitudes fainter and the flare duration was months; nothing that could be detected, especially in an already rapidly varying source. With this simple radiation model, also the X-rays were missing due to the relatively low temperature of the plasma (and no inverse Compton scattering in the model at this point). So for BL Lac the result was a short, a few days long orphan flare seen only at optical wavelenghts. Preliminary comparison to the lightcurves from the Tuorla Observatory Blazar monitoring programme and the Kanata telescope sho many examples of similar flares observed (detailed comparison is in progress).

Because the radiation from the first thermal flare is unpolarized, and assuming that the intensity of polarised emission from elsewhere in the source does not change during the flare, the rise of the unpolarised radiation leads to a corresponding decrease of the polarisation. In Tammi & Hovatta (2010) we estimated for our BL Lac example a dip in the polarisation degree of about 10 % during the flare. A crude comparison to a preliminary data (showing an optical flare with increase in the flux of 8.5 mJy and drop of polarisation degree from 18 % to 11 %) was encouraging, but more good-quality data is needed before the model can be tested satisfyingly.

3. After the thermal flare

If the thermal flare is indeed related to the loading of the jet, we should expect a second flare when the matter that was injected in the jet (not to be confused with the matter causing the firts thermal flare) reaches the radio core as suggested, *e.g.*, by Marscher (2008). This multifrequency flare is then followed by a new component becoming visible and moving downstream in the jets in the VLBI maps (Savolainen et al. 2002; Chatterjee et al. 2008). From this point on the ejected plasma can be described using various shock-in-jet models.

As the mechanisms and the environments related to the first flare in the center and the second flare at the core of the jet are different, also the flares should differ from each other from spectral as well as temporal points of view. Firstly, with typical AGN parameters the sphere is optically thin for optical photons from the beginning, making the flare bright in the optical waveband almost immediately. Millimetre and radio flux, on the other hand, peak weeks to months later and reach flux levels of only small fractions of those of the optical peak. It is also important to notice that the timescales or radiative signatures of first flare would not be affected by similar Lorentz boosts or Doppler shifts than the flares in the jet.

Whereas a thermal flare would most likely be observed and interpreted as an optical flare without radio counterpart, the latter flare at the radio core is always expected to be bright throughout the spectrum. This means that depending on the observing frequency, the two events would be observed either as single- or double-peaked flares – at the radio and optical wavelenghts, correspondingly.

The time difference between the two connected (optical) flares would be determined by the distance of the black hole to the stationary core and the properties of the jet acceleration, and if the latter is constant in a given source, then also the separation of the two flares would be roughly the same for different flare pairs.

Finally, if the first flare loads the jet with matter, this could lead to the flux starting to rise already before the second flare. On one hand this is due to the particles in the plasma being energized by the strong magnetic turbulence near the center providing promising conditions for efficient second-order Fermi acceleration (Tammi & Duffy 2009), leading to gradually increasing synchrotron emissivity. On the other hand, the acceleration of the ”proto jet” emitting region as a whole leads to increased Lorentz boosting of the emitted radiation.

4. Discussion and conclusions

In its current stage the model for the first thermal flare and its connection to the flare in the core and a new VLBI jet component is very simplified abd many physical components are still missing; the current model is certainly not the accurate description of what we suggest to happen in the centre. It does, however, allow the first tests to be made. And based on these first test and very preliminary data, the general model presented here could work. It is, however, still too early to say anything about its plausibility in the context of AGNs in general.

In addition to the presented case for BL Lac, we have tested our toy model for different AGNs and microquasars. The results (in preparation) are promising: even with our very crude spherical-cow model we have been able to reproduce lightcurves similar to those observed both in AGN and microquasar objects. Some sources, however, seem to be completely beyond the scope of the flux levels and timescales obtainable with the present simple model. We are currently collecting multifrequency data for detailed testing and further development.

From the theoretical point of view, several recent observations have fuelled the motivation for the development of the model as an additional step for modelling the disk–jet connection. For example, Tombesi et al. (2010) found evidence of mildly relativistic expansive outflows in certain AGNs, suggesting that the initial expansion speeds used in this study could very well be reasonable (even though modelling the drivers behind the physical expansion have been far beyond the current scope of the model). Similarly, observations of Sagittarius A* seem to require at partially nonthermal emission from cooling electrons to explain the X-ray emission (omitted in this study) (Dodds et al. 2010); including synchrotron emission and improving the radiation modelling are the next steps in developing the model. This will also enable testing the X-ray emission, especially modelling the observed anticorrelation between the X-ray and radio fluxes (Chatterjee et al. 2009).

Furthermore, the physicality of the model will be improved by including different geometries and dynamics for the outflow, as well as taking into account the presence of, *e.g.*, the dust torus for AGNs and companion star in microquasar, as well as the differences in the density and composition of the environment and the matter in the coronae of the black hole and the accretion disk. Even though the expanding plasma is completely optically thin when the sphere reaches the Broad Line Region (taken to be $\sim$ 5 lightdays away from the centre, *e.g.* Cabetti et al. 2010), modelling the possible effects of the wind on the BLR clouds or the torus, together with studying the possibility that the dust in the torus could reprocess the optical flare photons, could provide interesting new directions for the research.

To conclude, based on the preliminary results and within the limits of currently available data we cannot rule out the possibility that in some microquasars and AGNs certain flares can be due to a thermal or partly thermal flare associated with the explosive event that also dismisses parts of the accretion disk and injects material into the jets. However, more data and improvements for the model are needed to satisfyingly estimate the feasibility of non-jet flares in these sources.

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