INTERPRETING A DWARF NOVA ERUPTION AS MAGNETIC FLARE ACTIVITY

Noam Soker\textsuperscript{1} and Saeqa Dil Vrtilek\textsuperscript{2}

ABSTRACT

We suggest that the radio emission from the dwarf nova SS Cyg during outburst comes from magnetic activity that formed a corona (similar to coronae found in magnetically active stars), rather than from jets. We base our claim on the recent results of Laor & Behar, who found that when the ratio between radio and X-ray flux of accretion disks in radio-quiet quasars is as in active stars, \( \frac{L_r}{L_x} \lesssim 10^{-5} \), then most of the radio emission comes from coronae. Using observations from the literature we find that for SS Cyg during outburst \( \frac{L_r}{L_x} < 10^{-5} \). This does not mean jets are not launched during outbursts. On the contrary, if the magnetic activity in erupting accreting disks is similar to that in stars, then mass ejection, e.g., as in coronal mass ejection, is expected. Hence magnetic flares similar to those in active stars might be the main mechanism for launching jets in a variety of systems, from young stellar objects to massive black holes.

1. INTRODUCTION

In a recent detailed and elegant study, Laor & Behar (2008) present a correlation between radio and X-ray emission over some 15 orders of magnitude, from magnetically active stars to radio quiet AGN. The correlation they observe is consistent with \( L_r = 10^{-5}L_X \), a correlation known as the Güdel-Benz relation in magnetically active stars (Güdel & Benz 1993). This suggests that the source of the radio emission in these highly diverse objects may be related. Indeed Laor & Behar (2008) suggest that in radio quiet AGN the source of radio emission is coronae above accretion disks. Suzaku observations of the dwarf nova (DN) SS Cyg (Ishida et al. 2008) provide spectral evidence for thermal plasma distributed on the disk during outburst analogous to the Solar corona. Suggestions for the presence of coronae above accretion disks are not new (e.g., Galeev et al. 1979; Done & Osborne 1997; Wheatley &

\textsuperscript{1}Department of Physics, Technion–Israel Institute of Technology, Haifa 32000, Israel; soker@physics.technion.ac.il

\textsuperscript{2}Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138; saku@head.cfa.harvard.edu
Mauche 2005), and the connection between coronae and jets were proposed in the past (e.g., Fender et al. 1999; Markoff et al. 2005). The results of Laor & Behar (2008) and Ishida et al. (2008) put the presence of coronae in accretion disks on solid ground. The correlation does not hold for radio loud AGN, where most of the radio emission comes from jets, and systems show $L_r \gg 10^{-5}L_X$. Laor & Behar (2008) find that some galactic black hole (GBH) binaries also reside close to this correlation. This implies that the common practice of attributing radio emission of accreting neutron stars and black holes (BH) to emission from jets (e.g., Dunn et al. 2008) should be done with caution, if we assume that these systems are analogous with AGN (e.g., Markoff 2006). It is correct to attribute the radio emission to jets in some cases, as in SS 433 (Miller-Jones et al. 2008), but not necessarily in all binaries.

Jets are not usually observed in cataclysmic variables (CVs), among them DN. In CVs a white dwarf (WD) accretes mass from a companion via an accretion disk. In many other astrophysical systems accretion disks are known to launch jets. The absence of jets in CVs impose strong constraints on some jet launching models (Soker 2007). For example, no jets are observed in intermediate polars (DQ Her systems). These are cataclysmic variables where the magnetic field of the accreting WD is thought to truncate the accretion disk in its inner boundary. This magnetic field geometry is the basis for some jet-launching models in YSOs (e.g., Shu et al. 1991). Why then are no jets observed from intermediate polars?

Theoretical arguments (Soker & Lasota 2004), and at least one observation (Retter 2004) claimed that jets might be present in CVs when the accretion rate is high. High accretion rates result in longer diffusion time for photons (radiation) from the disk, and might leave time for the energy to be channeled to kinetic (Soker & Lasota 2004) or magnetic (Soker 2007) energy. Soker (2007) proposed that in some cases jets are launched in a manner similar to coronal mass ejection (CME) in the sun. Instead of a dynamo and buoyant magnetic flux tubes as in the sun, in accretion disks the kinetic energy of the gas in the accretion disk is transferred, e.g., by shock waves, to thermal energy. The thermal energy builds pressure that inflates magnetic flux loops above the disk, and from there on the activity is analogous to solar flares. It is also possible that the kinetic energy is transfered directly to the magnetic field. This model predicts that some burst activity must precede the magnetic activity. The idea that jets are launched by magnetic fields reconnection events similar to that in the sun is not new, e.g., de Gouveia Dal Pino & Lazarian (2005; de Gouveia Dal Pino 2006).

In a recent paper Körding et al. (2008) attributed radio emission in an outburst of SS Cyg to jets. Here we argue in §2 that the radio emission in SS Cyg is more likely to come from a corona that was formed during the outburst. The same activity could have launched jets, or more generally, collimated outflows, as we argue in §3. Fender et al. (1999; also Markoff et al. 2005) proposed that the base of the jet and the corona are the same region.
Our idea goes beyond this identification, and we argue that the acceleration mechanism of the jet is similar to solar magnetic activity. Our results are not in contradiction with the results of these works. Our claims are aiming at identifying the acceleration process of the jet. To put our claim on a broader view, in §4 we discuss some related systems.

2. THE OUTBURST BEHAVIOR IN SS CYG

2.1. Radio and X-ray fluxes

Körding et al. (2008) conducted radio observation of SS Cyg in its April 2007 outburst. The peak radio luminosity at 8.6 GHz reached a value of $\sim 1$ mJy, and then declined to $\sim 0.3$ mJy in a short time. It then continued slowly to decline. We take the average outburst radio emission to be $\sim 0.3$ mJy. This gives a radio flux of $F_{\text{radio}} \approx 3 \times 10^{-17}$ erg cm$^{-2}$ s$^{-1}$.

No X-ray observations were conducted during the April 2007 outburst, and Körding et al. (2008) refer to X-ray observations at previous outbursts. Wheatley et al. (2003) followed the X-ray emission from SS Cyg in its October 1996 outburst and analyze the X-ray emission as coming from two sources. Strong emission from the boundary layer (the boundary of the accretion disk and the WD), with a maximum flux of $L_{\text{BL}} \approx 3.6 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$. (The fluxes here include their correction of a factor of 1.8 to include the total X-ray emission). This emission is obscured, because of high optical depth, during most of the outburst (Patterson & Raymond 1985a, b). Wheatley et al. identify another source, the residual, which they interpret as extended emission, possibly coronal. The residual X-ray emission flux is $F_{\text{ex}} \approx 2.5 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$.

Okada et al. (2008) find the X-ray luminosity of the September 2000 outburst to be $\sim 0.3$ that in quiescence. Taking the quiescent flux from Wheatley et al. (2003), the September 2000 outburst X-ray luminosity is $\approx 3 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$. The ASCA flux in the 0.8 – 10 keV band reported by Baskill et al. (2005) was higher than the quiescent one: $4 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ in the outburst versus $2 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ in quiescence. Similar X-ray outburst fluxes were observed in the past (e.g., Nousek et al. 1994).

Over all, we find the ratio of radio to residual X-ray emission (the X-ray emission that is not attributed to the boundary layer by Wheatley et al. 2003) during outburst to be

$$\frac{F_{\text{radio}}}{F_{x}} \approx 10^{-6}. \quad (1)$$

For a distance of 166 kpc to SS Cyg (Harrison et al. 1999) the residual X-ray luminosity is $L_{x} \approx 10^{32}$ erg s$^{-1}$. We can now place the eruptive SS Cyg on the radio vs. X-ray luminosity
seminal plot ($L_r$ vs. $L_x$ plane) of Laor & Behar (2008). We do this in Figure 1. The radio and residual X-ray luminosities of SS Cyg at outburst put it where the magnetically active stars are.

The total flux at maximum, dominated by the extreme UV (Wheatley et al. 2003), is $F_{\text{tot}} \simeq 3 \times 10^{-8}$ erg cm$^{-2}$ s$^{-1} \sim 10^3 F_x$. A bolometric to X-ray ratio of $\sim 10^3$ is also observed in magnetically very active stars, i.e., in the activity saturation regime (Pizzolato et al. 2003). This further suggests that what we observe in the outburst of SS Cyg is a magnetic outburst, similar to flares on very active stars.

2.2. Time delay and kinetic energy

Wheatley et al. (2003) find that for SS Cyg the X-ray rise occurs $\sim 1$ day after the visible. Most of the initial X-ray rise is due to the emission from the boundary layer, and not from a corona. For that, we cannot tell when X-ray emission from the corona starts. The radio emission, which we attribute to the corona, is delayed also by $\sim 1$ day after the visible (Körding et al. 2008). This suggests that coronal emission starts after an instability in the disk has set in. In our model, kinetic and gravitational energy released in the disk lead to magnetic activity, rather than magnetic activity increasing the accretion rate.

In the solar case, the kinetic luminosity of the wind $\sim 2 \times 10^{27}$ erg s$^{-1}$ is about equal to the average X-ray luminosity. Applying the same relation to SS Cyg, i.e., taking the kinetic outflow to be equal to the residual X-ray luminosity, we get the kinetic energy of the outflow to be $\sim 10^{-3}$ the energy released in the outburst. If the outflow is equal to the Keplerian velocity at the WD surface, $\sim 3000$ km s$^{-1}$, we find the mass loss rate to accretion rate to be $\sim 10^{-3}$. This ratio is typical for weak jets. Namely, it is possible that weak jets are launched by the coronal magnetic activity.

We further note that in some cases, like the BH candidate Cygnus X-1, the power of the jets is about equal to the bolometric X-ray luminosity (Russell et al. 2007). This points to an ejection mechanism similar to that of the solar wind, assuming that a large fraction (but not all) of the X-ray emission is due to a corona.

The radio luminosity of Cyg X-1 is $10^{-8}$ times the X-ray luminosity, which is typical for many GBH systems and some solar regions (Laor & Behar 2008). As this is the case for solar microflares, it is not unlikely that the explanation for the outflow is indeed a solar like activity. The above ratio of $L_r/L_x \simeq 10^{-8}$ is much lower than in magnetically active stars. However, Wood et al. (2005) found that the kinetic energy of the wind decreases for more magnetically active stars. The ratio of the average radio luminosity of the quiet sun (Drake
Fig. 1.— The position of different objects in the $L_r$ vs. $L_x$ plane (from Laor & Behar 2008, beside SS Cyg). GBHs, ULX, and RQQ stand for Galactic black holes (in the hard state), ultraluminous X-ray sources, and radio quiet quasars, respectively. The square is the location of SS Cyg during eruption. The location of SS Cyg in this plane hints that its eruption is connected to magnetic flares.
et al. 1993) to the average solar X-ray luminosity is \( \sim 3 \times 10^{-7} \). Therefore, it is possible that the highest ratio of outflow kinetic energy to X-ray luminosity is obtained by activity similar to the less active regions of the suns, where radio emission can get as low as \( L_r \simeq 10^{-8}L_x \) (Güdel & Benz 1994). Indeed, microflares can heat the corona and supply the energy to the wind (Moore et al. 1999).

3. THE AMPLIFICATION OF THE MAGNETIC FIELD IN THE OUTBURST

Following the previous section and building on the behavior of the solar magnetic field, we consider magnetic fields with coherence lengths much smaller than the radius of the disk \( r \), rather than the large scale magnetic field that is used in many jet-launching models. We take the magnetic pressure to be limited by the thermal pressure of the disk, \( P_B \simeq P \), and approximate the thermal pressure from the hydrostatic equation in the vertical direction \( z \):

\[
dP/dz = -\rho(GM/r^2)(z/r),
\]

where \( r \) is the radial coordinate in cylindrical coordinates, \( \rho \) is the density, and \( M \) is the mass of the central accreting object. This gives for the magnetic pressure

\[
P_B \sim P \simeq \rho \frac{GM}{r} \left( \frac{H}{r} \right)^2,
\]

where \( H = \epsilon r \sim 0.1r \) is the scale height of the disk in the \( z \) direction. The Alfven speed \( v_A^2 = (2P_B/\rho) \) is then

\[
v_A \sim \frac{H}{r} v_{esc} \ll v_{esc},
\]

where \( v_{esc} = (2GM/r)^{1/2} \) is the escape velocity from the disk at radius \( r \). The inequality implies that the magnetic fields do not contain enough energy to expel large quantities of gas at high speeds. If a corona is formed, the typical temperature associated with this value of \( v_A \) is

\[
T_{corona} \sim 5 \times 10^6 \left( \frac{r}{R_{WD}} \right)^{-1} \left( \frac{H}{0.1r} \right)^2 K
\]

where for the WD mass and radius we took \( M_{WD} = 1M_\odot \) and \( R_{WD} = 0.01r_\odot \), respectively. A hot corona can be marginally formed under these conditions, and only very close to the WD.

We turn now to an outburst, where the mass accretion rate substantially increases. Consider a rapid stochastic dissipation of the kinetic energy of the gas in the disk. This can occur through shock waves, i.e., transfer of kinetic energy to thermal energy, and through transfer of kinetic energy directly to magnetic fields. In the case of shock waves the gas will cool via two processes. Radiative cooling via diffusion of photons, and adiabatic cooling.
When the diffusion time scale is longer than the adiabatic expansion time scale, the orbital kinetic energy of the gas in the disk is transferred mainly to vertical motion (perpendicular to the disk plane), that can lead to the formation of jets (Torbett 1984; Torbett & Gilden 1992; Soker & Regev 2003; Soker & Lasota 2004). This is the thermally launched jet model (Soker 2007).

Soker & Lasota (2004) found the minimum accretion rate required to launch jets from WDs in the thermally launched jet model to be

$$\dot{M}_b \gtrsim 10^{-6} \left(\frac{\alpha_d}{0.1}\right)^{-1} M_\odot \text{ yr}^{-1},$$

(5)

where $\alpha_d$ is the disk-viscosity parameter. Due to several uncertainties, the limit in equation (5) can be as low as $\sim 10^{-7} M_\odot \text{ yr}^{-1}$. This limit is compatible with the result of Retter (2004), who argued for a detection of jets in the transition phase (few months post-outburst) of nova V1494 Aql. Considering that $\alpha_d$ can be much lower, and taking into account some observations of jets in super-soft X-ray sources (see discussion in Soker & Lasota 2004), this limit can be as low as $\sim 10^{-8} M_\odot \text{ yr}^{-1}$. The accretion rate at peak luminosity in the eruptions of SS Cyg is $\sim 10^{-8} M_\odot \text{ yr}^{-1}$ (Wheatley et al. 2003). This limit implies that if rapid dissipation of the orbital kinetic energy occur, then a large fraction, or even most, of this energy will be channelled to accelerate gas in the vertical direction.

The vertically accelerated gas can stretch magnetic field lines and amplify the magnetic fields (Soker 2007). The strong magnetic fields lead to a second acceleration stage, where after the primary outflow stretches magnetic field lines, the field lines reconnect and accelerate small amount of mass to very high speeds. This double-stage acceleration process might form highly relativistic jets from BH and neutron stars, as well as jets from brown dwarfs and stars.

Here we raise the possibility that the magnetic fields might be amplified by an $\alpha\Omega$ dynamo, in addition to a pure stretching in the vertical direction. The amplification of magnetic fields by turbulence dynamo, and the acceleration of gas by reconnection in accretion disk coronae was considered before by de Gouveia Dal Pino & Lazarian (2005). Here we attribute a major role to the differential rotation velocity and the dissipation of the kinetic energy of the disk material. We also do not require the presence of a global field, but rather consider many small scale flares.

In stars, the $\alpha$ effect (not to confuse with the $\alpha_d$ for disk viscosity) is attributed to the convection, while in galaxies it can come from supernovae and other stars, or from the dynamics of magnetic field lines themselves (Beck et al. 1996). Basically, local heating (e.g. OB associations and supernova) in the galaxy can drives the $\alpha$ effect. Here the local heating is done by small shocks (Soker & Regev 2003), which can then grow to larger volumes. This
result in a rapid increase in the thermal pressure, and the acceleration of gas, mainly in
the vertical direction, but locally in other directions. This motion can play the role of the
α effect. Within the disk the accelerated gas move at a fraction of the Keplerian speed
(only the outer layers can be accelerated to the escape speed): \( v_t = \beta v_{\text{Kepl}} \). If we take the
coherence length of the field to be \( H = \epsilon r \), then \( \alpha = \min(\Omega H, v_t) \) (Beck et al. 1996, sec.
4.4). If \( \beta \gtrsim \epsilon \simeq 0.1 \), then the magnetic growth time is (Beck et al. 1996, sec. 4.4)

\[
\tau_B \simeq \left( \frac{H}{\alpha \Omega} \right)^{1/2} \simeq \Omega^{-1}.
\]

In the eruption phase the Alfven speed is about equal to the Keplerian speed, and by
equation (4) (taking \( H \simeq r \)) a very hot corona is formed up to a distance of \( r \simeq \text{few} \times 10R_{\text{WD}} \)
(somewhat cooler corona can be formed at larger distance as well). The magnetic field growth
time at these radii is \( \tau_B \simeq \Omega^{-1} \simeq 5(r/30R_{\text{WD}})^{3/2} \text{ min}. \) This is much shorter than the rise
time of the outburst at different bands (spanning several hours to a day; Körding et al. 2008;
Wheatley et al. 2003).

To summarize, in this section we examined a chain of events starting with some disk
instabilities that lead to enhanced mass accretion rate (Lasota 2001). Local dissipation of
orbital kinetic energy of the disk material, e.g., via shocks, lead to local expansion of many
regions in the disk (Soker & Regev 2003), because radiative cooling proceeds on a time
scale longer than the expansion time (Soker & Lasota 2004). The gas motion in the disk
can amplify magnetic fields by stretching magnetic field lines, or by being the source of the
α effect in an αΩ dynamo. These magnetic fields are likely to behave similarly to stellar
magnetic fields (Laor & Behar 2008). Namely, they can be the main radio source and can
eject material by reconnecting in the disk corona (de Gouveia Dal Pino & Lazarian 2005).
When collimated, the ejected gas becomes jets.

4. RELATED OBJECTS

Several authors (e.g. Nipoti et al 2005; Massi 2005) have pointed out that X-ray binaries,
and in particular the subset within them that are called microquasars, show evidence for
radio-loud and radio-quiet states similar to that observed in AGN. The obvious analogy
is that radio-loud systems emit strong jets and radio quiet systems do not. SS 433 is a
complicated object, but shows that in cases where jets are strong radio sources the ratio of
radio to X-ray emission can be \( L_r/L_x \gg 10^{-5} \). On July 11, 2003, the ratio of radio to X-ray
emission from the core was \( (L_r/L_x)_{\text{core}} \simeq 2 \times 10^{-5} \) (Migliari et al. 2005; Miller-Jones et al.
2008). The radio contribution outside the core was 0.54 times that in the core. At other
times X-ray and radio measurements are not performed simultaneously, but we note that the core X-ray emission is $\sim 0.025 - 0.25$ times that in July 11, 2003 (Migliari et al. 2005), while the total radio emission is larger (Miller-Jones et al. 2008) by factor of $\sim 2$. Over all, for most of the time in SS 433, the radio to X-ray ratio is $L_r/L_x \sim 10^{-4} - 10^{-3}$. This ratio resides between radio quiet and radio loud AGN.

In Table 1 we list the $F_r/F_x$ ratios of a few X-ray binaries associated with micro-quasars that are listed as “radio-loud” by Massi (2005). We determine the majority of our ratios from numbers obtained from Figures 2 and 6 of Gallo, Fender, & Pooley (2003; hereafter GFP03). Where available, for each object we give the range from each of the the states: quiescent, hard, soft, and transient. GFP03 note that the quiescent state is dominated by jets, no jets are observed in the hard state, and jets again in the soft and transient state. The majority of the ratios do lie below 1.e-5 as noted by Loar & Behar (2008). Nevertheless, as GFP03 note, many of these systems do show jets. The reason is that the accretion disks around neutron stars and GBHs has a substantial fraction of their emission in the X-ray band. Disks around stars and massive BH emits mainly in the IR to UV bands. The strong thermal X-ray emission from disks around neutron stars and GBHs (X-ray binaries) reduces the ratio of $L_r/L_x$. The inner region of disks around WDs contribute to the X-ray emission, particularly from the boundary layer. The ‘trick’ in SS Cyg in eruption is that the optical depth to the boundary layer becomes very large, such that the energy is radiated from a larger area at longer wavelengths. This allows the detection of the residual X-ray emission, which is assumed to come from the coronae.

Not only are the disks in X-ray binaries strong x-ray emitters, but the observed luminosity is strongly influenced by the geometry of the system. This is because the flux comes from a small region towards the center of the disk that can be easily obscured by flared edges of the disk, if observed edge on. We conclude that the observed X-ray flux from X-ray binaries is not a reliable measure of the X-ray flux from the disk corona. Hence the ratio $F_r/F_x$ can not be used as an indicator for jet formation.

5. SUMMARY AND DISCUSSION

Magnetically active stars follow the Güdel-Benz relation ($L_r \simeq 10^{-5} L_X$; Güdel & Benz 1993). In a recent paper Laor & Behar (2008) found this correlation to hold over some 15 orders of magnitude, from magnetically active stars to radio quiet AGN. For strong jets to be present in AGN $L_r \gg 10^{-5} L_X$.

The new finding of Laor & Behar (2008), and the observations of Ishida et al. (2008)
of disk coronae formed during an outburst of SS Cyg, motivated us to examine whether the radio emission found in the outburst of the dwarf nova SS Cyg by Körding et al. (2008) is due to magnetic flaring as well.

In accreting WD and neutron stars the task of finding the ratio $L_r/L_x$ is more complicated, as the accreting gas near the boundary layer emits in the X-ray band. As we showed in section 4, the strong X-ray emission from the disks in X-ray binaries prevent us from using the ratio $L_r/L_x$ to learn about the presence of absence of a jet.

However, in the case of SS Cyg the high accretion rate during outburst obscures the boundary layer, and the residual X-ray emission observed by Wheatley et al. (2003) can be attributed to a corona. In §2 we found the ratio between the peak radio emission at outburst (Körding et al. 2008) and the residual X-ray emission at outburst (Wheatley et al. 2003) of SS Cyg to be $L_r/L_x \simeq 10^{-6}$. Note that the two measurements are in two different outbursts, but the outbursts peaks of SS Cyg are quite regular (Wheatley et al. 2003).

This finding leads us to suggest that most of the radio emission in the outburst of SS Cyg comes from a magnetically newly formed corona, and not from jets as argued by Körding et al. (2008). This does not mean that jets, or a collimated outflow, were not launched in the outburst. On the contrary, if the magnetic activity on the surface of accretion disks is similar to stellar magnetic activity, then ejection of mass is expected (e.g., de Gouveia Dal Pino & Lazarian 2005). Soker (2007) suggested that jets are launched in a manner analogous to stellar magnetic eruptions and coronal mass ejection. We have elaborated on this idea in §3. We do note that Fender et al. (1999) and Markoff et al. (2005) proposed that the base of the jet and the corona are the same region. We are not in dispute with their claim. We simply argue that processes similar to solar flares form the corona and accelerate the jets (de Gouveia Dal Pino & Lazarian 2005), and that this magnetic activity is the source of the radio emission in SS Cyg, rather than the already collimated outflow (jets).

The main assumption of the stellar-like magnetic activity is that local heating occurs in the regions of the disk close to the accreting object, in a manner described by Soker & Regev (2003): if the accretion rate is high enough such that radiative cooling occurs on a time scale longer than the expansion time scale, then the gas motion due to the local heating is mainly in the vertical direction. The critical mass accretion rate for WDs is $\sim 10^{-8} - 10^{-7} M_\odot \text{yr}^{-1}$ (Soker & Lasota 2004).

The vertical motion can stretch magnetic field lines and amplify the magnetic fields (Soker 2007). Here we considered the $\alpha\Omega$ dynamo (see also de Gouveia Dal Pino & Lazarian 2005 who considered a turbulence dynamo). Local velocities can be in all directions, not only vertical. We assumed that such a motion can play the $\alpha$ role in the $\alpha\Omega$ dynamo mechanism,
and concluded that the time scale for the amplification of the magnetic field is very short compared with the rise time of the outburst. It is very likely that the strong magnetic fields behave similarly to stellar magnetic fields (Laor & Behar 2008). We argued that these magnetic fields emit most of the radio emission observed by Körding et al. (2008) in the eruption of SS Cyg. The magnetic flares can also lunch jets, and might even be the main mechanism for lunching jets in variety of objects, from YSOs to massive BHs (Soker 2007).

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Table 1: Related Objects

| Source          | Fr/Fx  | State       | Jets | Reference          |
|-----------------|--------|-------------|------|--------------------|
| V404 Cyg        | 5.2e-5 | quiescent   | yes  | Gallo et al. 2003  |
|                 | 4.0e-6-1.0e-5 | hard     | no   | Gallo et al. 2003  |
| GX339-4         | 1.2e-5-6.3e-6 | quiescent | yes  | Gallo et al. 2003  |
|                 | 2.1e-8-2.7e-6 | hard     | no   | Gallo et al. 2003  |
| XTEJ1118+480    | 1.5e-6 | outburst    | yes  | Chaty et al. 2003  |
|                 | 2.4e-6 | hard        | no   | Gallo et al. 2003  |
| Cygnus X-1      | 7.5e-8-7.5e-7 | hard     | no   | Gallo et al. 2003  |
| Cygnus X-3      | 1.0e-7-1.5e-5 | soft     | yes  | Gallo et al. 2003  |
| GRS 1915+105    | 2.0e-9-5e-7  | transient  | yes  | Gallo et al. 2003  |
| SS433           | 1.0e-3-1.0e-4 | yes-steady | yes  | Miller-Jones et al. 2008 |
|                 | 1.0e-4     |            |      | Kotani et al. 1999 |