Mem. S.A.It. Vol. 82, 145

Memorie della

Astrophysical jets: what can we learn from solar ejections?

M. Massi[1] and G. Poletto[2]

[1] Max Planck Institute for Radio Astronomy, Auf dem Huegel 69, D-53121 Bonn, Germany
e-mail: mmassi@mpifr-bonn.mpg.de
[2] INAF – Arcetri Astrophysical Observatory, Largo Fermi 5, I-50125 Firenze, Italy
e-mail: poletto@arcetri.astro.it

Abstract. Ejections from the Sun can be observed with a higher resolution than in any other astrophysical object: can we build up on solar results and apply them to astrophysical objects? Aim of this work is to establish whether there is any analogy between solar ejections and ejections in microquasars and AGNs. Briefly reviewing jets properties from these objects and from the Sun, we point out some characteristics they share and indicate research areas where cross-breeeding between astrophysical and solar research is likely to be productive. Preliminary results of this study suggest, for instance, that there may be an analogy between blobs created by tearing instability in current sheets (CSs) associated with solar coronal mass ejections (CMEs) and quasi periodic ejections of plasma associated with large radio outbursts in microquasars.

Key words. Sun: coronal mass ejections (CMEs) – Galaxies: jets – Magnetic reconnection

1. Introduction

Radio and X-ray observations of microquasars show the occurrence of two types of jets with completely different characteristics. The first type, referred to as steady jet, is a quasi-steady slowly moving continuous ejection emerging from an optically thick (flat or inverted radio spectrum) radio core region. The second type of jet, referred to as transient jet, shows up with an optically thin radio outburst and features a sequence of bright regions moving at superluminal speeds (Fender et al. 2004; Massi 2010). The formation of steady jets is recognized to be mediated by large-scale open magnetic fields threading the rapidly rotating accretion disks around compact objects (i.e. jets are accelerated by magneto-centrifugal forces, Blandford & Payne 1982). The transient radio jets, are instead related to shocks (Marscher & Gear 1985; Türler 2010). These shocks seem to be caused by relativistic plasma travelling in the slowly moving pre-existing steady jet, established during a previous phase. In other words the two jets seem to be inter-related (Fender et al. 2004). How does the steady-to-transient jet transition occur? A possible mechanism triggering the switch could be magnetic reconnection. In analogy with solar flares, magnetic energy is probably built-up and accumulated over long time scales during the steady jet phase and then dissipated over very short time scales in explosive events (Komissarov 2006). Such

Send offprint requests to: M. Massi

events occurring in the central engine, close to the black hole and accretion disk, can be the source of ejections/flaring events possibly causing shocks (Massi 2010). Solar ejections have been observed with a higher resolution than attainable in any other astrophysical objects. Are there analogies between ejections in different objects? In the following we briefly illustrate microquasar and AGN ejections (Sec. 2) and solar ejections (Sec. 3) highlighting properties they may share. Our conclusions are summarized in the last Section (Sec. 4).

2. Microquasars and AGNs

2.1. Quiet and active coronas in accretion disks and the Sun

Numerical simulations show that during the *low/hard* X-ray state, corresponding to the radio steady jet, a corona, similar to the solar corona, is present around the accretion disk. Starting with a differentially rotating torus threaded by toroidal magnetic fields, the simulations show that magnetic flux buoyantly escapes from the disk and creates loop like structures similar to the solar coronal loops (Machida et al. (2000), Yuan et al. (2009) and references there). As for the solar corona, magnetic fields are likely to play a fundamental role, although, as shown by Zhang et al. (2000), there is a factor 500 between a) the magnetic fields of the inner regions of an accretion disk around a stellar mass black hole and the active regions of the Sun and, b), the temperatures of the accretion disk coronae and the solar corona. The accretion disk corona is likely to be heated from small-scale reconnection events, in a scenario analogous to the microflare heated solar corona suggested by e.g. Parker (1963); Benz & Krucker (1998); Krucker & Benz (2000). Also, large coronal loops can emerge at the surface of the differentially rotating accretion disc where, because of the ensuing shear of the large magnetic structure, more energetic reconnection phenomena may be triggered. As far as transient ejections are concerned, Yuan et al. (2009) built an MHD model for ejections in Sgr A*, based on the analogy between astrophysical jets and coronal mass ejections (CMEs). Yuan et al. (2009) argue that the passage of these high speed plasmoids through the steady jet may indeed form shocks which show up as bright knots embedded in the steady continuous jet.

2.2. Quasi periodic oscillations (QPOs) in astrophysical objects

Quasi periodic oscillations of 20 min, observed around the supermassive black hole Sgr A*, modulating large NIR/X-ray flares lasting about 100 min, have been ascribed to an active region (AR) in the inner orbit of the accretion disk. More precisely, an AR within an accretion disk seen at high inclination, is supposedly located in an orbit with a rotation period of 20 minutes and is able to survive for 100 minutes (since 5 cycles have been observed), giving rise to the observed QPOs (Eckart et al. 2006, 2008). Can we compare the total lifetime of the QPOs in Sgr A* with the durations of the long lasting solar CMEs?

Similar kind of QPOs, i.e. related to the inner orbit of the accretion disk, have been observed also in stellar mass black holes (Stella & Vietri 1998). In these cases, milliseconds QPOs result because of the smaller orbit. However, in three X-ray binaries different kind of QPOs have been observed in radio and X-rays. They are closely related to large radio outbursts and have quite long timescales, i.e. minutes/hours. During the decay of a radio outburst a variety of 22−120 min oscillations were observed at radio wavelenghts in V404 Cyg (Han & Hjellming 1992). Radio oscillations of 30−84 min were observed in LS I +61°303 during the decay of radio outbursts (Peracaula et al. 1997), whereas Harrison et al. (2000) observed oscillations of 30 min in X-rays during the onset of a radio outburst. In GRS 1915+105 Fender et al. (1999) observed at radio wavelengths similar long-term QPOs associated with a large optically thin outburst. Simultaneous QPOs observations of GRS 1915+105 in X-rays, infrared and radio wavelengths have been interpreted as periodic ejections of plasma with subsequent replenishment of the inner accretion disk. The estimated mass of these blobs ejected every few tens of minutes are on the order of $\sim 10^{19}$g (see references in Mirabel & Rodríguez 1999). As to AGNs, QPOs of 55 minutes have been associated with the flat spectrum radio quasar 3C 273 (Espaillat et al. 2008) and QPOs of 60 minutes have been observed in the narrow-line Seyfert 1 Galaxy RE J1034+396 (Gierliński et al. 2008). Rani et al. (2010) recently found evidence for QPO of 15 minutes in the blazar S5 0716+714. These observations in V404 Cyg, LS I +61°303 and GRS 1915+105 of 20−120 min oscillations related to large outbursts and associated to periodic ejections of plasma, naturally lead us to questions like: Is there any evidence for periodic minor solar ejections related to large CMEs?

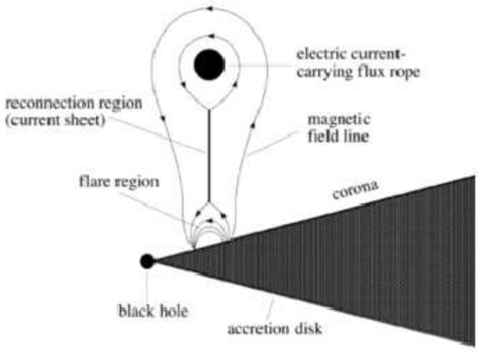

Fig. 1. The CME bubble is connected to the low-lying loops via an extended current sheet (Yuan et al. 2009).

3. Solar ejections

3.1. Coronal mass ejections (CMEs)

Mass ejections on the Sun have been recognized recently to be far more numerous than previoulsy predicted and their size and energy span over several order of magnitudes, from the mini X-ray polar jets to the spectacular *Coronal Mass Ejections (CMEs)*: events where the ejection of mass is unambiguously observed as an enhanced density structure moving outwards through the solar corona and the heliosphere. The average mass of a CME is on the order of 10^{15} g, and the speed can reach up to nearly 3000 km s^{-1} with an average value of 450 km s^{-1}. The highest kinetic energy of CMEs is $10^{32} - 10^{33}$ erg, with an average of (2 - 3) 10^{30} erg. The lifetime of CMEs is not well defined, as it depends on the level where they are observed: often CMEs are associated with well identifiable solar disk phenomena, that last several hours, while coronal manifestations of CMEs can be observed for days. Heliospheric CMEs, called ICMEs (Interplanetary CME), can be followed over longer times. Depending on the phase of the solar activity cycle, the frequency of occurrence of CMEs varies between a few events/day and a few events/week. As we said, there is a whole family of ejections, in the Sun. We may ask whether they originate from the same physical processes or whether they include different physical processes. Because CMEs' mass, kinetic energy (Vourlidas et al. 2002) and width (at least between 20 and 120 degrees, Robbrecht 2009), follow a power-law distribution, most likely there is a continuous distribution of mass ejections, from the largest to micro-events, i.e. CMEs are scale-invariant events. This result hints to a common physical origin for CMEs, likely to be identified with magnetic reconnection and subsequent energy release. This raises a question: Can astrophysical mass ejections be accounted for by the same mechanism?

3.2. CME-associated current sheets

Models of solar ejections invoke topological changes of the magnetic field: for large CMEs the catastrophic loss of equilibrium of a magnetic flux rope stretches the preexisting magnetic configuration creating a Current Sheet (CS) (see Fig.1). Here we focus on the CME flux rope model of Lin & Forbes (2000) that has been invoked to explain episodic jets in black hole systems as well (Yuan et al. 2009). Indeed, CSs, at the model-predicted position, have been detected via spectroscopic analyses of solar data. Also, properties of the diffusion region around the CS (likely the CS itself is too tiny to be identified) have been derived: 1) the high electron temperatures seen at the CS site slowly decays after the CME passage over hours/days; b) a high kinetic temperature - on the order of a few units $\times 10^7$ K characterizes the diffusion region, slowly decaying and hinting to the presence of turbulence within the CS; c) **densities in the diffusion region seem to be up to one order of magnitude higher than ambient densities** (see, e.g. Poletto (2009); Schettino et al. (2010) and references therein). Continuing with our attempts to search for features shared by astrophysical and solar jets we may ask: is there any possibility to identify high temperature/density signatures associated with outward propagating astrophysical ejections? Can astrophysical blobs be interpreted in terms of reconnection? Analysis of the temporal behavior of the CME-associated diffusion regions, in the Sun, allowed us to detect *blobs* moving outward along the CS structure. **These outflowing features can be interpreted in terms of tearing instability within the CS.** Tearing instability promotes the formation of magnetic islands, usually identified with the above mentioned blobs. Reconnection is thus unsteady, or *bursty* (Tanuma & Shibata 2005).

4. Conclusions

This brief analysis of astrophysical and solar jets revealed a number of analogies among ejections events that differ by order of magnitudes in energy, size, mass. First attempts to bridge the gap between the Sun and other objects have focussed on applying a popular CME model to accretion disk jets. Other so far unexplored areas include the interpretation of minute time scale oscillations in terms of reconnection-related phenomena. Altogether this research area is still in its infancy, but appears to deserve more attention than got so far.

Acknowledgements. G. P. acknowledges support from ASI I/015/07/0.

References

Blandford, R.D. & Payne, D.G. 1982, MNRAS, 199, 883
Benz, A.O. & Krucker, O. 1998, Solar Phys., 182, 349
Eckart, A., et al. 2006, A&A, 450, 535
Eckart, A., et al. 2008, A&A, 479, 625
Espaillat, C., Bregman, J., Hughes, P., & Lloyd-Davies, E. 2008, ApJ, 679, 182
Fender, R. P., Belloni, T. M., & Gallo, E. 2004, MNRAS, 355, 1105
Fender, R.P., Garrington, S. T., McKay, D. J., et al. 1999, MNRAS, 304, 865
Gierliński, M., Middleton, M., Ward, M., & Done, C. 2008, Nature, 455, 369
Han, X., & Hjellming, R. M. 1992, ApJ, 400, 304
Harrison, F. A., Ray, P. S., Leahy, D.A., Waltman, E. B., & Pooley, G. G. 2000, ApJ, 528, 454
Komissarov, S.S. 2006, AIP Conference Proceedings, 856, 129
Krucker, O. & Benz, A.O. 2000, Solar Phys., 191, 341
Lin, J. & Forbes, T.G. 2000, JGR 105, 2375
Machida, M., Hayashi, M. R., & Matsumoto, R. 2000, ApJ, 532, L67
Marscher, A. P., & Gear, W. K. 1985, ApJ, 298, 114
Massi, M. 2010, arXiv:1010.3861
Mirabel, I. F., Rodríguez, L. F., 1999, ARA&A, 37, 409
Parker, E.N. 1963, ApJS, 8, 177
Peracaula, M., Martí, J., & Paredes, J. M. 1997, A&A, 328, 283
Poletto, G. 2009, Adv. in Geosciences, 14, 67
Rani, B., Gupta, A. C., Joshi, U. C., Ganesh, S., & Wiita, P. J. 2010, ApJ, 719, L153
Robbrecht, E., Berghmans, D., Van der Linden, R.A.M. 2009, ApJ, 691, 1222
Schettino, G., Poletto, G., & Romoli, M. 2010, ApJ, 708, 1135
Stella, L. & Vietri, M. 1998, ApJ, 492, L59
Tanuma, S., & Shibata, K. 2005, ApJ, 628, L77
Türler, M. 2010, arXiv:1010.0907
Vourlidas, A., Buzasi, D., Howard, R.A., Esfandiari, E. 2002, ESA-SP 506, 91
Yuan, F., Lin, J., Wu, K. and Ho, L.C. 2009, Mon. Not. R. Astron. Soc. 395, 2183
Zhang, S.N., Cui, W., Chen, W. et al. Science, 287, 123, 2000