SF2A 2018
P. Di Matteo, F. Billebaud, F. Herpin, N. Lagarde, J.-B. Marquette, A. Robin, O. Venot (eds)

FLARING ACTIVITY ON THE DISK OF CLASSICAL T TAURI STARS: EFFECTS ON DISK STABILITY

S. Colombo[2,3,1], S. Orlando[2], G. Peres[1], F. Reale[1], C. Argiroffi[1], R. Bonito[2], L. Ibgui[3] and C. Stehlé[3]

Abstract. Classical T Tauri Stars (CTTSs) are young stellar objects surrounded by a circumstellar disk with which they exchange mass and angular momentum through accretion. Despite this process is a crucial aspect of star formation, some issues are still not clear; in particular how the material loses angular momentum and falls into the star. CTTSs are also characterized by strong X-ray emission. Part of this X-ray emission comes from the heated plasma in the external regions of the stellar corona with temperature between 1 and 100 MK. The plasma heating is presumably due to the strong magnetic field (Feigelson and Montmerle, 1999) in the form of high energetic flares in proximity of the stellar surface. This energetic phenomena may influence the circumstellar environment. Recently, Reale et al. (2018) proved that long flares may connect the disk to the stellar surface. Moreover a study of Orlando et al. (2011) has shown that an intense flare close to the disk may strongly perturb its stability, inducing accretion episodes. Starting from these lines of evidence, here we investigate the effects of multiple flares with low-to-medium intensity on the disk stability, and check if they may be responsible for triggering accretion episodes. To this end, we developed a 3D magnetohydrodynamics model describing a CTTS surrounded by an accretion disk subject to intense flaring activity. The flares occur randomly in proximity of a thick disk. We found that the flaring activity determines the formation of a hot extended corona that links the disk to the stellar surface. In addition, the flares strongly perturb the disk and trigger accretion phenomena with a mass accretion rate comparable with those inferred by X-ray observations.

Keywords: Classical T Tauri Star, Accretion, MagnetoHydrodynamics, Flares

1 Model

We adopted the model described in Orlando et al. (2011). The model describes a rotating magnetized CTTS surrounded by a thick quasi-Keplerian disk. The CTTS is assumed to have a mass of $M_* = 0.8M_\odot$ and a radius of $R_* = 2R_\odot$. The initial magnetosphere is assumed to be force-free, with a topology given by a dipole and an octupole, with both magnetic moments aligned with the rotation axis of the star. The magnetic moments are choosen in order to have a magnetic field of $\approx 1kG$ at the surface of the star.

The model solves the time dependent MHD equations in a 3D spherical coordinates system (R, θ, ϕ), taking into account the effects of gravitational force from the central star, the magnetic-field-oriented thermal conduction, the disk viscosity, the coronal heating (using a phenomenological heating term) and the radiative losses from optically thin plasma.

The calculation is performed using PLUTO, a modular Godunov-type code for astrophysical plasmas (Mignone et al. 2007).

2 Results and Conclusions

We investigated the effects of an intense flaring activity localized in proximity of the accretion disk of a CTTS. We explored cases with different density of the disk and different levels of flaring activity. Fig. 1 shows a

[1] Universitá degli Studi di Palermo
[2] INAF - Osservatorio Astronomico di Palermo
[3] LERMA - Sorbonne University, Paris

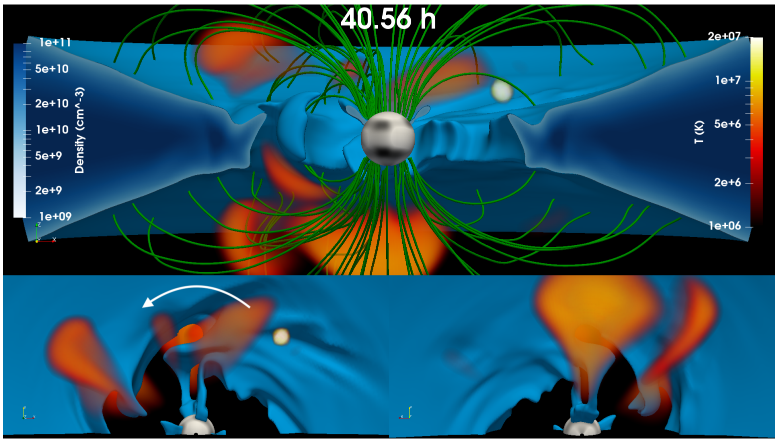

Fig. 1. Snapshot of the simulation after 40.56 hours of evolution. The figure is composed by three panels: on top an edge on view of the system, on bottom left and right the two pole on views. The cutaway view of the star-disk system shows the mass density (blue) and sampled magnetic field lines (green). A 3D volume rendering of the plasma temperature is over-plotted in log scale in each panel and shows the flaring loops (red-yellow), linking the inner part of the disk with the central protostar. The color-coded density logarithmic scale is shown to the left of the top panel, the analogously coded temperature scale is to the right. The white arrow indicates the direction of rotation of the system.

representative snapshot of the simulation used as reference case. The code gives as result the 3D distribution of all the MHD quantities. Our results lead us to the following conclusions. First, the coronal activity due to a series of small-to-medium flares occurring in proximity of the disk surface heats up the disk material to temperatures of several million degrees. Part of this hot plasma is channelled and flows in magnetic loops which link the inner part of the disk to the central protostar; the remaining part of heated plasma is poorly confined by the magnetic field and escapes from the system, carrying away mass and angular momentum. Moreover, the circumstellar disk is heavily perturbed by the flaring activity. In the aftermath of the flares, disk material evaporates in the outer stellar atmosphere under the effect of the thermal conduction. As previously stated by Orlando et al. (2011) overpressure waves are generated, by the heat pulses, in the disk at the footpoints of the hot loops forming the corona. The overpressure waves travel through the disk distorting its structure. Possibly the overpressure waves reach the side of the disk opposite to where heat pulses were injected. There, the overpressure waves can push the disk material out of equilibrium to form funnel flows which accrete disk material onto the protostar. We found that the effects of the overpressure waves are larger in disks less dense and for higher frequency of flares. The accretion process starts about 20 hours after the first heat pulse, namely a timescale much shorter than that required by the disk viscosity to trigger the accretion (Romanova et al. 2002).

Lastly, the accretion columns generated by the flaring activity on the disk have a complex dynamics and a lifetime ranging between few hours and tens of hours. They can be perturbed by the flaring activity itself; for instance a flare occuring close to an accretion column can disrupt it or, otherwise, increase the amount of downfalling plasma.

PLUTO is developed at the Turin Astronomical Observatory in collaboration with the Department of Physics of Turin University. We acknowledge the "Accordo Quadro INAF-CINECA (2017) the CINECA Award HP10B1GLGV and the HPC facility (SCAN) of the INAF Osservatorio Astronomico di Palermo,for the availability of high performance computing resources and support. This work was supported by the Programme National de Physique Stellaire (PNPS) of CNRS/INSU co-funded by CEA and CNES. This work has been done within the LABEX Plas@par project, and received financial state aid managed by the Agence Nationale de la Recherche (ANR), as part of the programme "Investissements d'avenir" under the reference ANR- 11-IDEX-0004-02.

References

Mignone, A., Bodo, G., Massaglia, S., et al. 2007, ApJS, 170, 228

Orlando, S., Reale, F., Peres, G., & Mignone, A. 2011, MNRAS, 415, 3380
Romanova, M. M., Ustyugova, G. V., Koldoba, A. V., & Lovelace, R. V. E. 2002, ApJ, 578, 420