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PRESENTACIÓN MURAL

Hydrodynamical study of outbursts in protostellar accretion discs

M. Orellana[1,2] & M. R. Schreiber[1]

(1) Departamento de Física y Astronomía, Universidad de Valparaíso, Chile
(2) Facultad de Ciencias Astronómicas y Geofísicas - UNLP, Argentina

Abstract. Low mass young stellar objects (YSOs) occasionally display large scale luminosity fluctuations The standard explanation for these outbursts are global thermal instabilities in the accretion disc which occur if the inner regions are sufficiently hot for hydrogen to become ionized. However, early models (e.g. Bell & Lin 1994) require extremely low values of the viscosity parameter α to reproduce the observed time scales. Armitage et al. (2001) suggested that this issue might be resolved by combining a magnetically layered intermediate disc, gravitational instabilities in the outer disc, and thermal instabilities in the innermost disc. We intend to test this hypothesis by combining one-dimensional convective, vertical structure models with 1D time-dependent, radial diffusion models for the evolution of the disc in the vicinity of the star. Here we comment on our first results.

Resumen. Objetos estelares muy jóvenes, de baja masa, ocasionalmente presentan fluctuaciones a gran escala en su luminosidad. La explicación aceptada en forma estándar para estos "estallidos" es la propagación de inestabilidades térmicas en el disco de acreción, las cuales ocurren en las regiones internas donde la temperatura puede ser lo bastante alta como para ionizar el hidrógeno. Los primeros modelos (ej. Bell & Lin 1994) requieren sin embargo de valores extremadamente bajos del parámetro de la viscocidad α para poder reproducir las escalas de tiempo observadas. Armitage et al. (2001) han sugerido que este problema podría sortearse al combinar un disco estratificado en zonas intermedias, con inestabilidades gravitacionales en regiones exteriores y las inestabilidades térmicas en su parte central. Nos hemos propuesto testear esta hipótesis combinando modelos unidimensionales verticales con convección y modelos de la estructura radial dependientes del tiempo para la evolución de las propiedades físicas del disco en las cercanías de la estrella. En esta contribución comentamos sobre nuestros primeros resultados.

1. Eruptive phenomena in YSOs: Basic observational properties

Most pre-main sequence stars exhibit irregular brightness variations during the early phases of stellar evolution. Some objects, called EXors and the FUors (named after the prototypes EX Lupi and FU Orionis respectively) show more pronounced semiregular eruptions. In 1936 the prototype FU Orionis brightened by 6 mag within a year and since then remained essentially constant. Subsequent discoveries of this eruptive variables led to generally interprete them, from statistical grounds, as recurrent events which happen to protostars approx. every 10^4 years (see e.g Hartman 2009). On the basis of spectral features additional objects have been proposed as members of the class.

EXors normally remain at minimum light, but are subject to relatively brief (a few months to a few years) flare-ups of several magnitudes amplitude. The outbursts of EX Lup are repetitive. Historical data show that the variations were irregular and the star sometimes remained inactive at minimum light (B 14.7 mag) for years. Between 1995 and 2005 there were at least 4 outbursts reaching mV=11.5 to 10.8. with an average duration of these outbursts of 127 days (Herbig, 2008).

The large extinctions and far-infrared emission of many eruptive YSOs suggest that they are still experiencing infall from protostellar envelopes. The estimated accretion rates during the peak of outbursts being some 10^{-4} $M_\odot$ yr^{-1}, are too large to be sustained for long. Adittionally, the measurement of rotational velocities in spectroscopic lines has confirmed the presence of a Keplerian accretion disc. See Hartmann (2009) for a complete review of the topic.

2. Thermal instabilities in accretion discs and their numerical study

A ring of the disc is in thermal equilibrium when the vertically integrated heating rate (Q^+) and the surface cooling rate (Q^-) are in balance. In active discs the heat is provided by viscous friction, whereas the cool is radiative. In Figure 2 we show the caracteristic S-curve which is the locus of equilibrium points in the $\Sigma{-}T_{\rm eff}$ plane for a distance $r \sim 0.1$ AU from the center of a solar mass star, taken here as a typical YSO. Along the central branch of the S the equilibrium is not stable, and this unstable region can trigger a limit-cycle behaviour causing the disk to switch between the lower and upper stable branches. This disk instability model has been successfully used to explain dwarf nova outburts occuring in some Cataclysmic Variables if a switch in α between a hot and a cold state is assumed[1].

It is usual to describe a disc as composed of concentric rings orbiting a central star at Keplerian angular speed. If we assume the disc to be geometrically thin and optically thick, we are allowed to decompose the disc equations in to their vertical and radial components. In the code by Hameury et al (1998), the hydrostatic vertical structure is solved for steady accretion flows, and stored into a grid. In this 1+1D scheme, for a given α, surface density Σ and central ($z = 0$)

[1] This is the original context for which Hameury et al (1998) developed their code. We have considered the same prescription for $\alpha(T_c)$. Note that in our aplication, as we consider a non-binary YSO, tidal torques are not present.

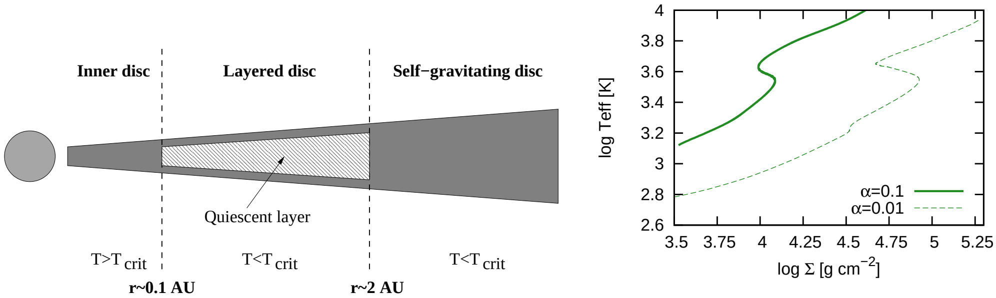

Figure 1. Illustration of the radial structure of the disc in the layered disc model (from Armitage et al. 2001). At small radii the temperature exceeds $T_{\rm crit}$ allowing the transport of angular momentum by Magneto-Rotational Instability (MRI) turbulence (i.e. the inner disc is active). At the right: computed equilibrium S-curves for $r \sim 0.1$ AU.

temperature T_c, there exists a unique solution describing the vertical structure for a fixed annuli. Radial-time dependent equations are then solved using the grid to compute the thermal imbalance.

Here we only need to consider the innermost region of the accretion disc, where the thermal instabilies can arise, and so fixed the outer radius as a fraction of AU. This inner part is fed by the outer disc which according to the layered disk model by Armitage et al (2001) can provide during long timescales ($\sim 10^4$

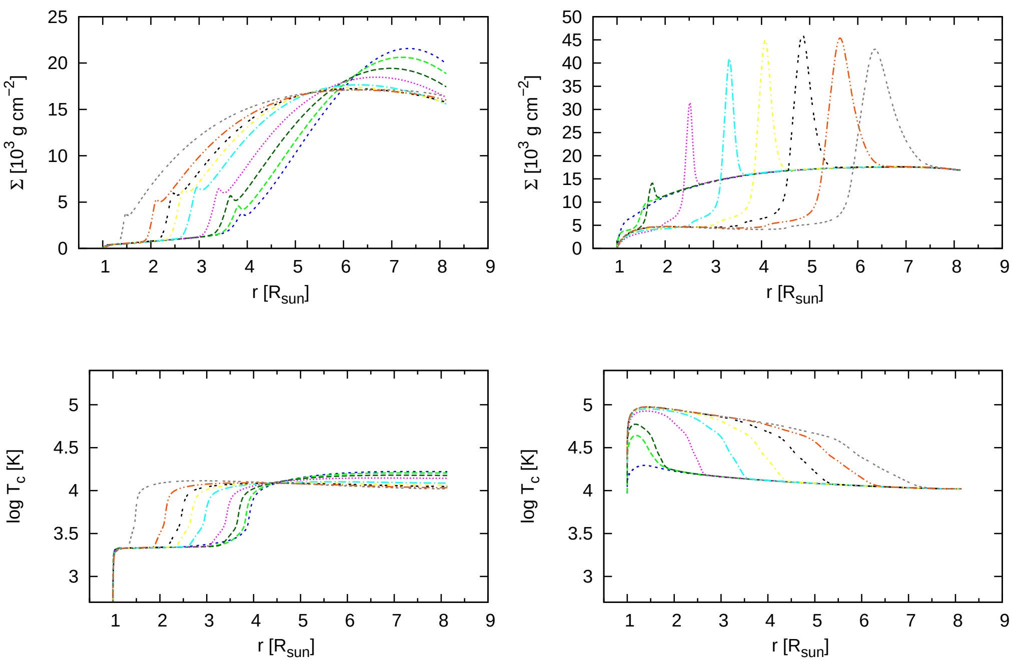

Figure 2. Typical radial profiles of the surface density and central temperature during the propagation of a cooling (left) and heating (right) fronts. Different colors are used for clarity. Separation between curves is ∼10 days.

yr) an infall rate of $\dot{M} \sim 10^{-6}$ M$_\odot$ yr^{-1}. We used this value as input parameter for an implementation of the aforementioned code which conveniently adapted for this scenario. For illustration, a sketch of the layered disc model is shown in the Figure 1.

3. Preliminary results and prospects

In Figure 2 some of the obtained radial profiles of central temperature and surface density are shown. As an example of an outburst light curve predicted by our model we show in Figure 3. the evolution of the visual magnitude M_V for a young star with accretion rate $\dot{M} = 5 \cdot 10^{-7}$ M$_\odot$ yr^{-1}, and an inner disc extending up to ~ 8 R$_\odot$. The magnitude is computed assuming that each annulus of the disc emits as a blackbody. Our first results are promissing. The time scales of the predicted light curves resemble those of some EXor systems, in particular, those of Ex Lup and V114 Ori (e.g. Herbig, 2008 and references therein) seem attainable to our calculations. The mass accretion rate is by far the essential parameter. In a minor degree, the location of the matter injection place and so the radial extent of the disc may also affect the amplitude of the brightness variation. We expect to reproduce EXor and FUor visual light curves by assuming dramatic changes of the mass supply from the outer disc as suggested by the layered disc model.

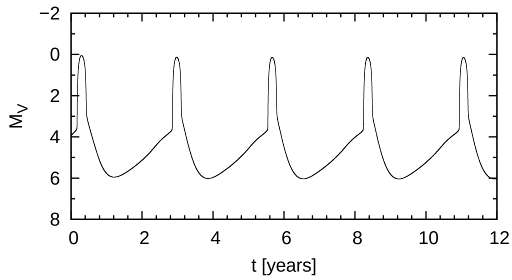

Figure 3. Example of an obtained optical light curve for a protostar with solar properties.

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