Accretion Shocks in Young Stars: the Role of Local Absorption on the X-ray Emission

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Abstract. We investigate the X-ray emission from accretion shocks in classical T Tauri stars, due to the infalling material impacting the stellar surface. Several aspects in both observations and models of the accretion process are still unclear: the observed X-ray luminosity of the post-shock plasma is below the predicted value, the density vs temperature structure of the shocked plasma, with increasing densities at higher temperature, is opposite of what expected from simple accretion shock models. To address these issues we performed numerical magnetohydrodynamic simulations describing the impact of an accretion stream onto the stellar surface and considered the local absorption due to the surrounding medium. We explored the effects of absorption for different viewing angles and for the He-like line triplets commonly used for density diagnostic. From the model results we synthesize the X-ray emission from the accretion shock, producing maps and spectra. We perform density and temperature diagnostics on the synthetic spectra, and we directly compare our results with the observations. Our model shows that the X-ray fluxes detected are lower than expected because of the local absorption. The emerging spectra suggest a complex density vs temperature distribution proving that a detailed model accounting for a realistic treatment of the local absorption is needed to interpret the observations of X-ray emitting accretion shocks.

1. Introduction

Accretion processes onto classical T Tauri stars (CTTSs) are believed to generate shocks at the stellar surface due to the impact of supersonic downflowing plasma. Although current models of accretion streams provide a plausible global picture of this process, several aspects are still unclear.

First of all, the evidence that the density inferred by the OVII triplet is lower that the value derived from the Ne IX triplet (Brickhouse et al. 2010) appears as a puzzling result in the context of current models of shocks. Another open issue in this context is the evidence that the mass accretion rate derived in the X-ray band is always significatively lower than the values obtained in the other bands (e.g. order of magnitude lower than the optical values, see Curran et al. 2011). Furthermore, the observed X-ray luminosity in accretion shocks is, in general, well below the predicted values. A possible explanation is related to a significant absorption of the emission due to the thick surrounding medium. In this work we focus on the synthesis of the X-ray emission in accretion shocks of young stellar objects (YSOs) and on the effects of the local absorption on its observability.

2. Method

With the aim of explaining the open issues presented above taking advantage of detailed numerical models, we consider a 2D magnetohydrodynamic (MHD) model describing an accretion stream propagating through the atmosphere of a CTTS and impacting onto its chromosphere. The model includes all the relevant physics, namely the gravity, the thermal conduction, the radiative cooling, and a realistic description of the unperturbed stellar atmosphere (from the chromosphere to the corona). From the 2D simulations (performed using the PLUTO code, Mignone et al. 2007), we derived the 3D maps of the relevant parameters (density, temperature,) to synthesize the X-ray emission emerging from the hot slab produced by the accretion shock, exploring different density profiles of the accretion stream (accounting also for non uniform streams with a density of 10^{12} cm^{-3} on axis and a radial decreasing profile; see also Romanova et al. 2004). In particular, considering a specific cell of the source, we take into account the column density for each cell along the line-of-sight (LOS), using the absorption coefficient of Balucinska-Church & McCammon (1992). Then we add all the contributions of each cell to derive the X-ray image and spectrum. The synthesis includes the local absorption by the thick surrounding medium and the Doppler shift of lines due to the component of plasma velocity along the LOS. We explore the effects of absorption on the emerging X-ray spectrum, considering different inclinations of the accretion stream with respect to the observer (Bonito et al. in prep. 2014). The final products of this approach are the images and the spectra in the X-ray band (in the range $0.3 - 1$ keV). In particular, we derived the spectra focusing on the lines (e.g. OVII and Ne IX) from which it is possible to perform density diagnostic from the line ratio, as made for TW Hya by Brickhouse et al. (2010).

3. Results

The spectra and images synthesized from our numerical models as detailed explained in the previous section allow us to compare our model results with the observations with the aim of explaining the so far unsolved open issues described above. First of all, we derived from our numerical simulations the density vs temperature distribution and performed the density diagnostics usually made for the observations. The main result of our investigation is that the simplistic scenario of a plane-parallel stratified structure of the shock and post-shock region (with increasing density for decreasing temperature) fails to be valid as the distribution of the density with the temperature is quite complex. Therefore, a detailed numerical model is required to properly describe the complex region of the accretion slab.

We also performed a spectral analysis of the X-ray emitting region and we found, as expected, that when the local absorption is taken into account the flux if lower (see Fig. 1). We also investigated the effect of different geometry and found a higher flux emerging from higher inclinations with respect to the LOS (compare red and blue lines in Fig. 1).

The effect on the observability of the post shock region due to a proper treatment of the local absorption, as made for the first time in this model, is found also to vary with the wavelength as the OVII density reduction is higher than 20%, being lower than 9% for NeIX. Therefore, we can conclude that local absorption prevents us from the observation of deeper and denser regions for more absorbed emitting regions as the absorption is higher for the softer part of this very complex region.

In conclusion, we developed and tested a method to derive the X-ray emission from accretion shocks and we synthesized the images and spectra from detailed numerical models to be directly compared with the observations.

The role of the local absorption is crucial as well as the role of the inclination with respect to the LOS. The comparison between the models results and the observations can help in explaining the open issues in this context.

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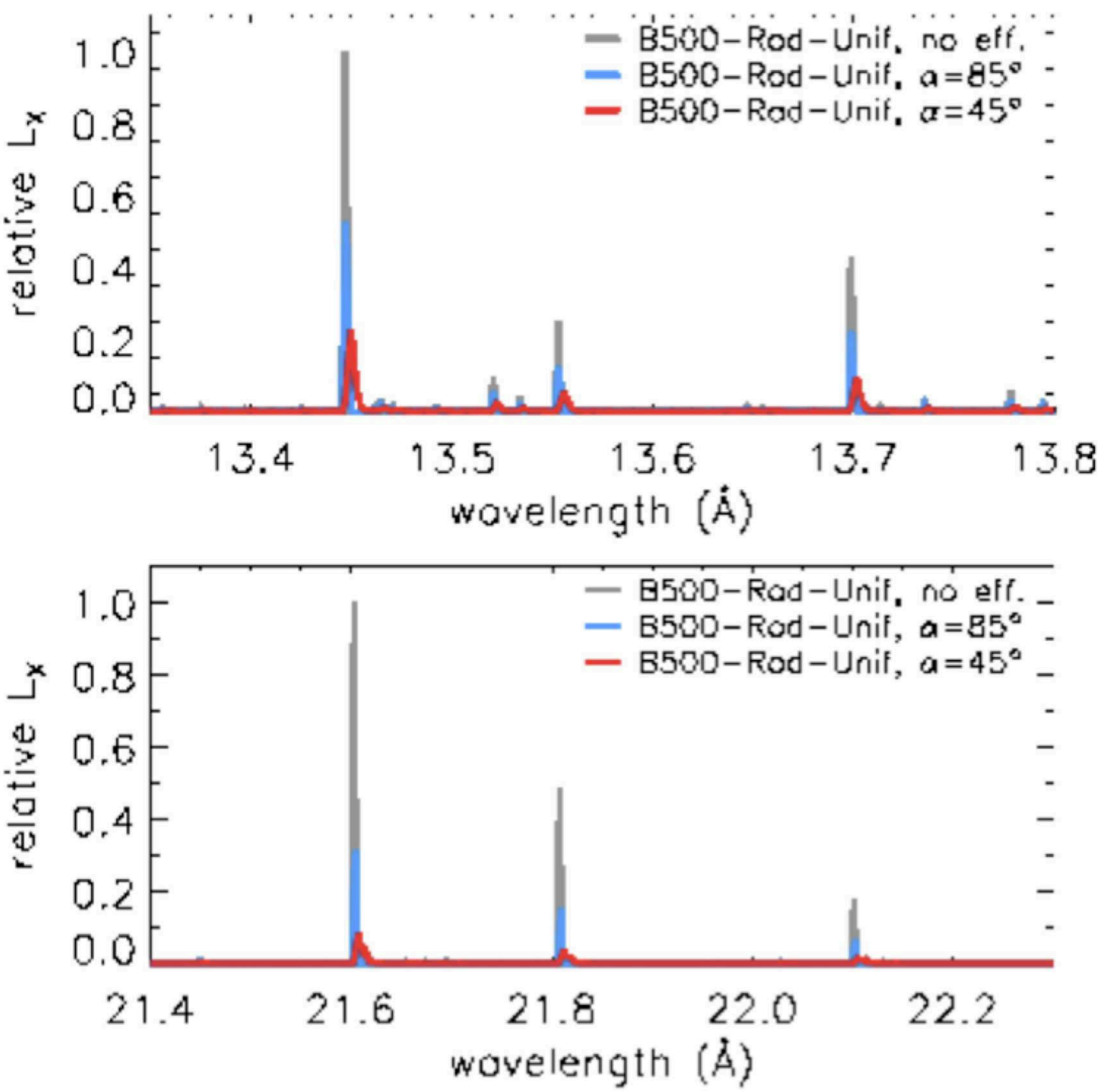

Figure .1: Spectra derived from the numerical simulations without (black line) and with