On the link between X-rays, accretion and the TeV emission in LS 5039

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We present a study of the X-ray and TeV lightcurve from LS 5039 in the context of a cold matter dominated jet model fed by accreted matter. We conclude that this source is likely powered by accretion, whose variations along the orbit affect the jet emission at X-rays and TeV energies.

Introduction

Microquasars are X-ray binaries with relativistic jets. The high-mass microquasar LS 5039 (Paredes et al. 2000), harboring an O type star and likely a black hole (Casares et al. 2005), turned out to be the first microquasar proposed to be a high-energy gamma-ray source due to its likely association with the EGRET source 3EG J1824-1514 (Paredes et al. 2000). Further theoretical studies supported this association (e.g. Bosch-Ramon & Paredes 2004), which could be extended to other EGRET sources (Kaufman Bernadó et al. 2002, Romero et al. 2003, Bosch-Ramon et al. 2006). Very recently, the Cherenkov telescope HESS detected LS 5039 at TeV energies (Aharonian et al. 2005), confirming the EGRET source association and leaving no doubt about the gamma-ray emitting nature of this object.

Recently, several works have pointed out that the dim X-ray emission following a pure power-law spectrum observed in this microquasar could be a hint of lack of accretion, hence pointing to a pulsar nature for the compact object (e.g. Martocchia et al. 2005, Dubus 2006). This work treats this issue accounting for the source phenomenology and few theoretical considerations. The detection of jets reaching ~1000 AU (Paredes et al. 2002), the mass funcion of the system, the lack of pulsed emission, the orbital radiation variability, and other observational and theoretical aspects strongly favor altogether the accretion scenario over the pulsar one.

Phenomenology

Jets reaching distances up to ~1000 AU have been detected in LS5039 with an upper limit on the half opening angle of 6º (see Fig. 1). Variable X-ray emission have been observed along the orbit (see Fig. 2; from Bosch-Ramon et al. 2005), presenting features that might be related to accretion through a slow equatorial wind (Paredes et al. 2006). A possible TeV peak appears at the same phase as the strongest X-ray peak: ~0.85 (Casares et al. 2005). A puzzling feature of the source is the lack of disk traces at X-rays, presenting only a power-law-like X-ray spectrum (e.g. Martocchia et al. 2005). No hint of pulsed emission has been found at any energy band so far. Regarding other interesting aspects of the source not so related to the accretion scenario, see e.g. Paredes et al. (2006).

Accretion-jet coupling and X-ray emission

Bosch-Ramon et al. (2006) developed a model in which the jet is dynamically dominated by cold protons and radiatively dominated by relativistic leptons, with an energy reservoir linked directly to accretion. The magnetic field energy density and the non-thermal particle maximum energy along the jet depend on the cold matter energy density and the particle acceleration/energy loss balance, respectively, and the amount of relativistic particles within the jet is restricted by the efficiency of the shock transferring energy to them. The model takes into account the external and internal photon and matter fields, as well as the jet magnetic field, all of them interacting with the jet relativistic particles and producing emission from radio to very high energies. This model has been applied to LS5039 (Paredes et al. 2006), and its computed and observed spectral energy distributions (SEDs) are presented in Fig. 3.

To apply the model to LS 5039, the accretion in the system was to be modeled to reproduce roughly the smooth X-ray observed lightcurve (see Figs. 2). The accretion from an inhomogeneous wind slower than those typically found in O type stars (see e.g. Ribó et al. 2006), with the occurrence of streaming (Leahy 2002), is required to obtain the X-ray lightcurve. The computed accretion rate curve and the X-ray lightcurve are shown in Fig. 4. Such wind would also allow to fulfill the gamma-ray energetic requirements, being consistent with the fast stellar rotational velocities and strong tidal forces in the system (Casares et al. 2005). A slow wind can lead to the formation of an accretion disk, which would smooth the X-ray changes along the orbit, yielding smaller variations than those expected in the fast wind accretion scenario (Reig et al. 2003), as observed.

Discussion

We conclude that available phenomenological knowledge on the source, altogether with some reasonable assumptions about the stellar wind, point to accretion powering emission in LS 5039. The compact object, likely a black hole, would accrete matter from a slow inhomogeneous wind, possibly produced at the equator due to fast rotation and tidal forces. Under such conditions an accretion disk could be formed, required in the paradigm of jet formation in microquasars. The puzzling fact is still the lack of disk traces in the spectrum at X-rays though it may be explained by the fact that energy is carried in a non radiative form (via advection and the jet), being the disk radiatively inefficient at X-rays. It is interesting to remark that, in such context, it could be asked how the jet in LS 5039 transfers efficiently jet kinetic energy to gamma-rays, the dominant spectral band. We note that this might be related to the optically thin radio spectrum observed in this source (Martí et al. 1998), perhaps associated with very efficient particle acceleration at jet middle scales (Paredes et al. 2006). Turning back to the lack of disk X-ray features, it is worth mentioning that accretion physics is still a very open field, and the debate concerning accretion disk properties is still on-going (see e.g. Miller et al. 2006).

The lack of a disk radiation bump at the lowest energy part of the X-ray spectrum remains to be explained, but it is just one in front of the numerous problems that pulsar scenario faces. Strongly collimated jets cannot be explained in the pulsar scenario, and although the lack of pulsed radiation could be due to the pulsar orientation or smearing, the mass function is a strong hint of the black hole nature of the compact object. The accretion model seems more suitable to reproduce the X-ray and TeV variability than the colliding wind model, for which few variability would be expected. The strong photon field from the star would likely cool the wind precluding further TeV radiation in the shock region. Although further observations are required to clarify whether the proposed scenario is indeed the one at work, this appears to be more natural when explaining the overall observational findings of LS 5039.

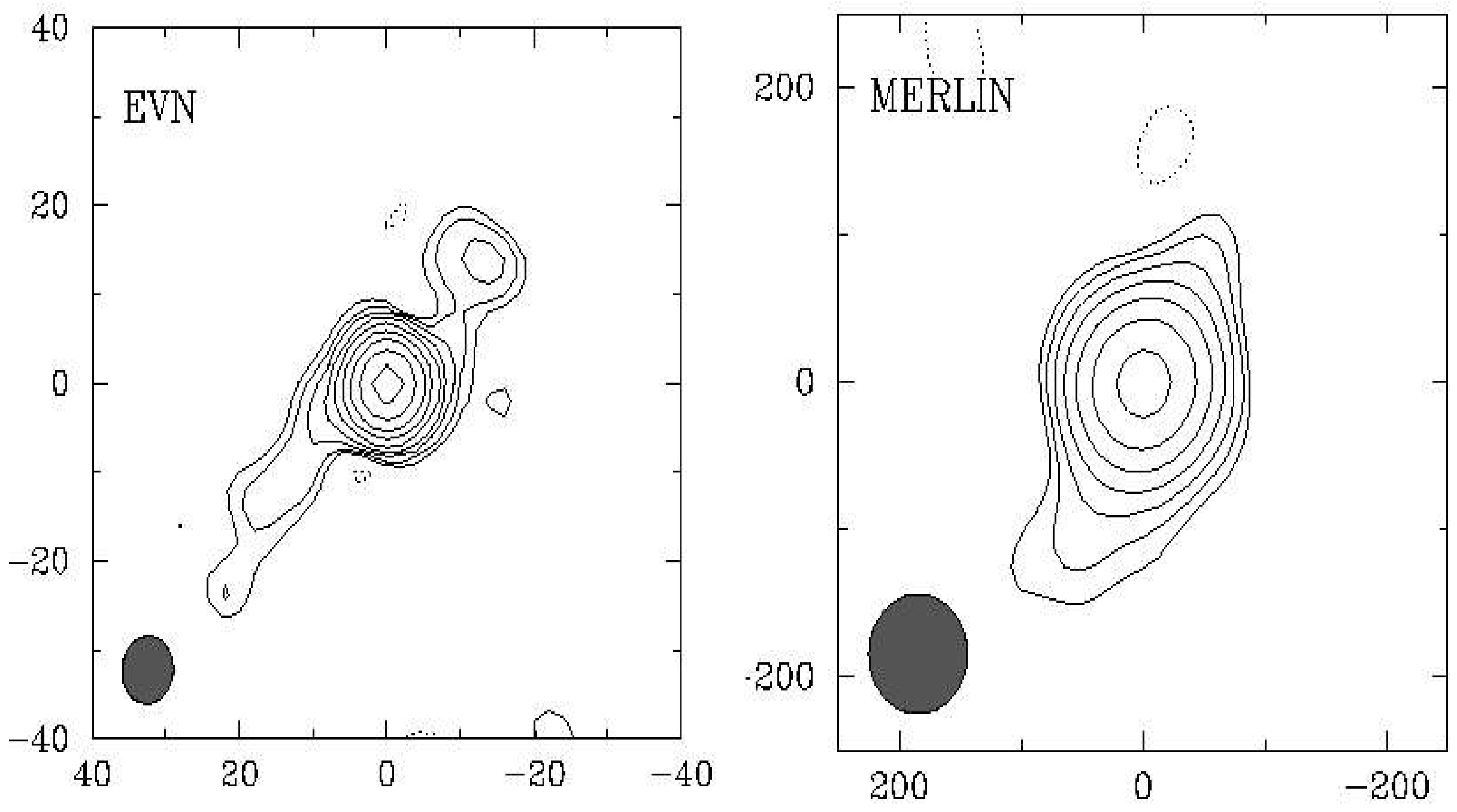

Fig. 1 Radio images of LS 5039 presented by Paredes et al. (2002). Note the jet collimation in the EVN radio map and the jet extension in the MERLIN one (LS 5039 is located at 2.5 kpc, Casares et al. 2005). The counter-jet is also clear in the EVN image. When comparing with other radio maps from the literature, The orientation of the jet seems to be independent of the orbital phase that. altogether with the strong collimation, would not be the case if they were powered by an anisotropic process like, e.g. colliding winds (see Dubus 2006).

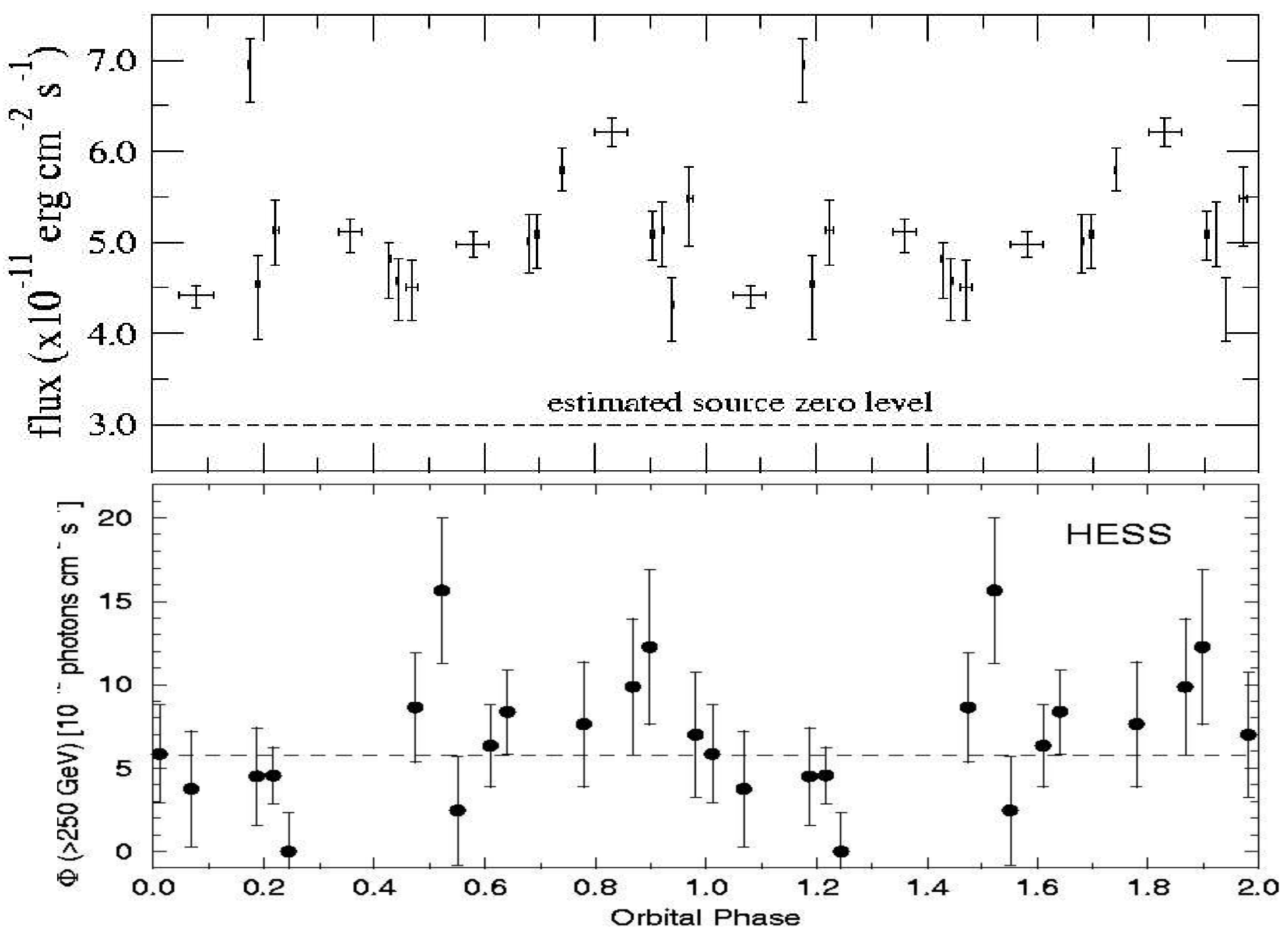

Fig. 2 Top: The X-ray lightcurve for two orbits adapted from Bosch-Ramon et al. (2005). Bottom: The lightcurve in the TeV range put in phase by Casares et al. (2005). In the X-ray curve there is a marginal peak at phase 0.3, and a clear one at phase 0.8, at which TeV emission also appers to peak. This could be explained by accretion through an inhomogeneous slow wind.

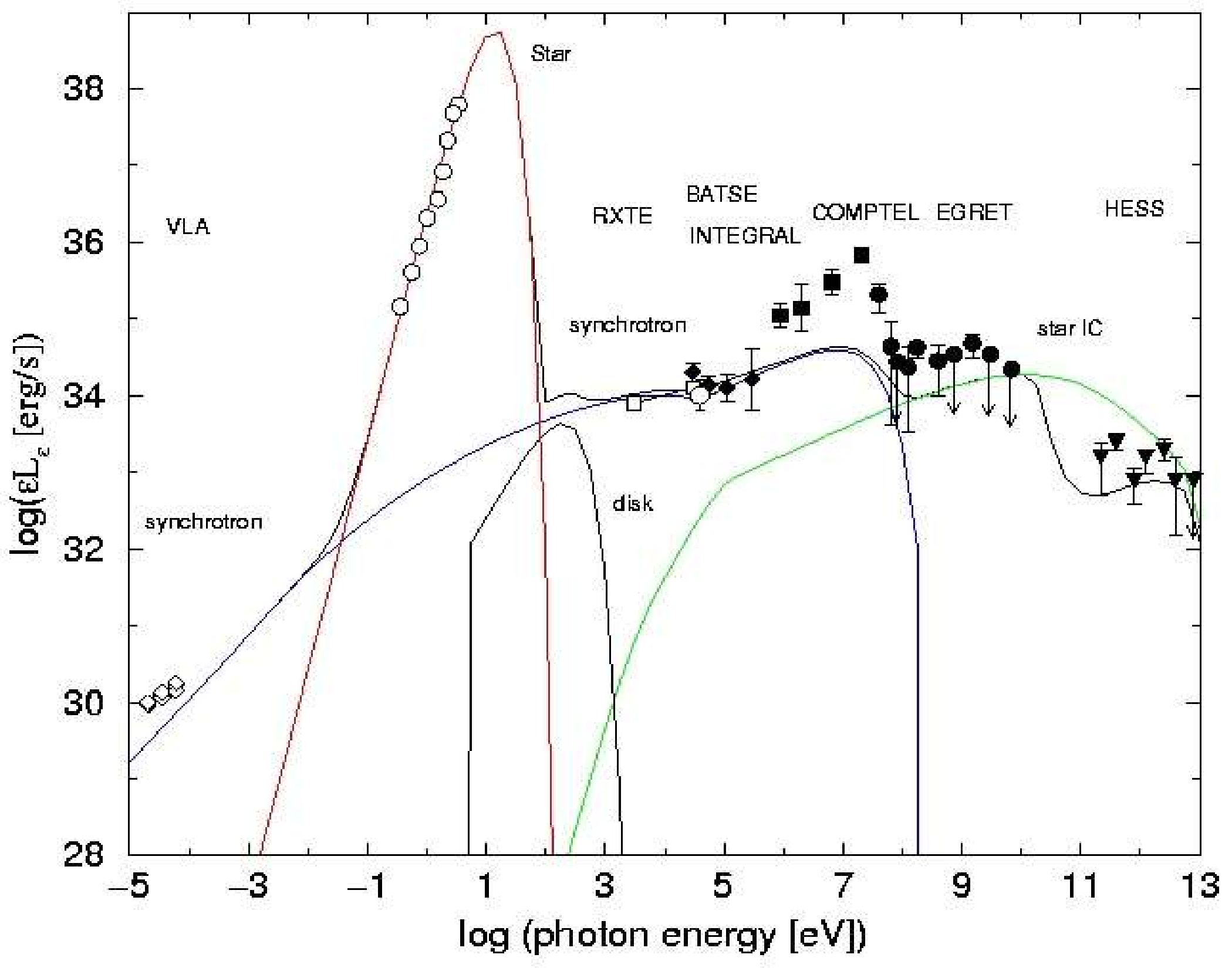

Fig. 3 Computed SED and the data obtained at different energies for LS 5039 (it is not a statistical fit). The radio, the X-ray and the soft gamma-ray band are dominated by non thermal synchrotron emission from the jet, whereas high energy and very high energy gamma-rays are produced via IC emission. Note the effect of a weak disk peaking at ~100 eV, only noticeable below 1keV. Emission detected by COMPTEL could have been affected by unnoticed gamma-ray sources in the several degree error box of this instrument.

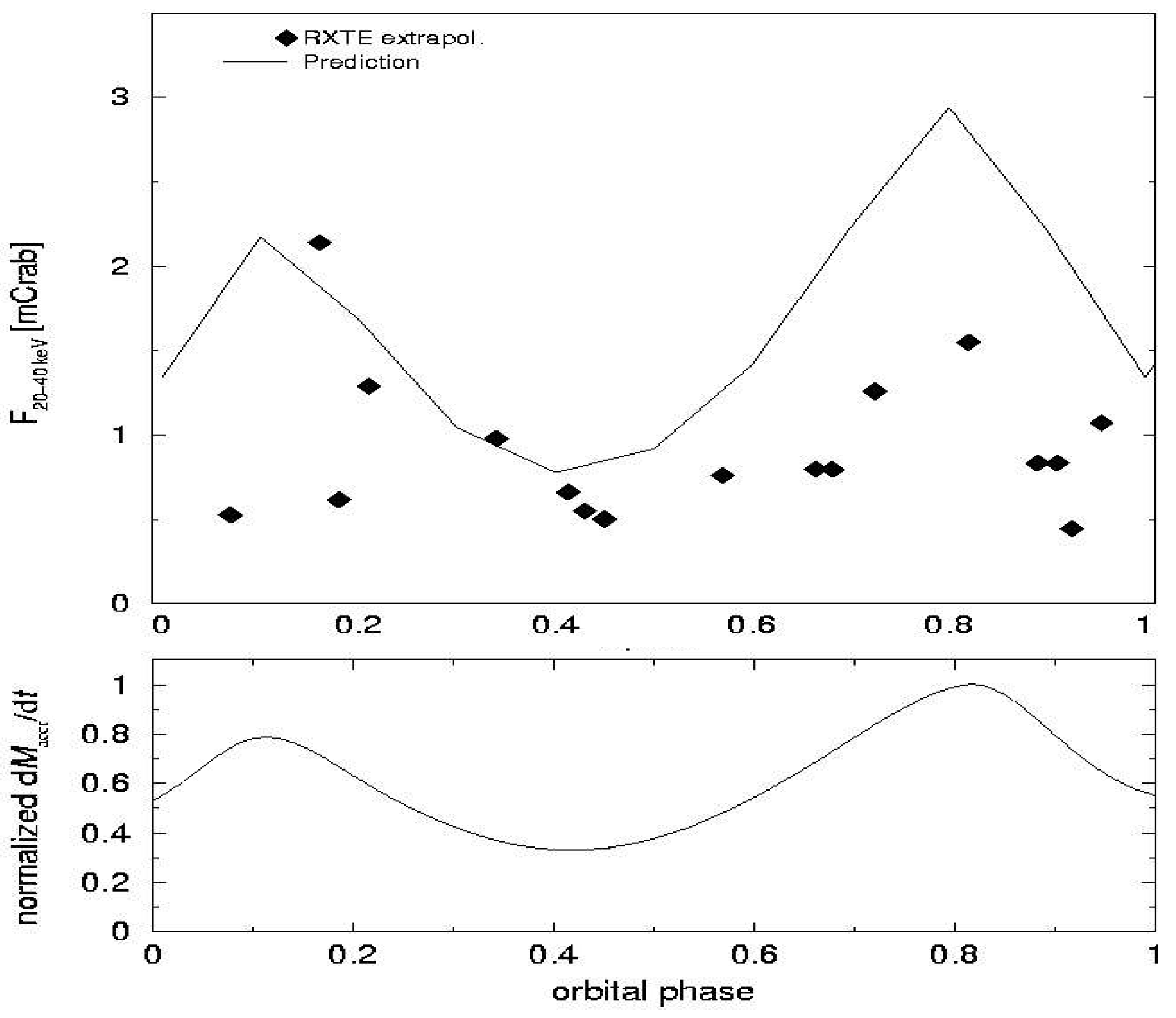

Fig. 4 At the top, comparison at hard X-rays of the RXTE lightcurve (extrapolated to 20-40 keV) and the computed one. Below, the computed accretion is shown.

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