Soft X-rays from DG Tau: A physical jet model

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DG Tau is a classical T Tauri star (CTTS) showing an unusual X-ray spectrum, best described by two thermal components with different absorption columns. The soft X-rays are less absorbed than the hard, presumably coronal, component [4]. This rules out stellar accretion as the origin of the soft photons, which is a standard model for CTTS and successfully explains the emission in e.g. TW Hya [5]. Instead, the observations of DG Tau require an emission region above the circum-stellar absorption layer. A good candidate is the jet of DG Tau, which is resolved in X-rays out to a few arcseonds using *Chandra* [3]. Additionally there is a 30 AU offset between the hard, coronal and the softer X-ray emission of the central source [7].

The jet has also been observed in the optical with *HST*/STIS. It consists of components with different velocities, where the faster components reach up to 600 km/s and they are more collimated than the slower components. This can be traced in Hα and forbidden sulfur and oxygen lines [1]. The outermost wind is a molecular outflow [2].

We suggest that the soft, unresolved X-rays originate from shocks in a narrow, fast inner wind component bracketted by slower outflows as observed in the optical (Fig. 1, left). The geometry is cylindrical with the shock at the cylinder base. The outflowing matter is heated to X-ray emitting temperatures in the shock front and cools radiatively within the post-shock cooling length d_{cool}, where faster velocities v_{shock} lead to higher temperatures and larger d_{cool} [6]. Several scenarios can lead to the formation of the shock: Stationary collimation shocks, wind shocks or internal

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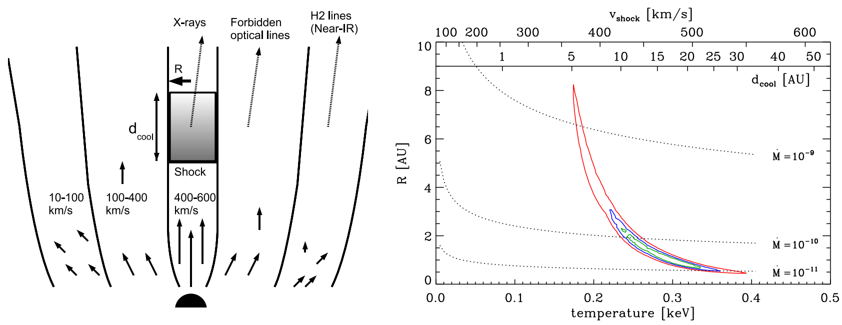

Fig. 1 *left:* Sketch of our model. The innermost and fastest component of the outflow passes through a shock front. The cooling zone has a cylindrical geometry. *right:* Estimated dimensions of the shock for a density $10^5/\mathrm{cm}^3$. The contours encircle the 68%, 90% and 99% confidence regions.

working surfaces caused by unsteady launching velocities are possibilities. Using all available X-ray data from *Chandra* and *XMM-Newton* we fit a two temperature model. We explore the parameter space of the soft component, keeping the values for the hard emission fixed. Unfortunately the temperature is not very well constraint, because there is –as always– an ambiguity between soft emission and extra absorption (Fig. 1).

We divide the observed volume emission measure by the density taken from optical observations and by d_{cool} to obtain the shock area with radius R (Fig. 1, right).

As a result we find that our model successfully describes the observed spectra. In all cases the dimensions of the shock are only a few AU, below the resolution limit of the optical observations. Thus it is possible that the X-ray shock cannot be seen in the optical data. From v_{shock} and the radius of the cylinder base the mass flux can be estimated: $10^{-10} M_{\mathrm{sun}}/\mathrm{yr}$ are sufficient to explain the emission; this is at least three orders of magnitude below the total mass loss in the jet.

The high extinction towards the central source allows the spatially distributed emission to be detected in DG Tau, but it is possible that emission from a jet base also contributes in other CTTS to the observed spectra. A grating spectrum of the soft emission could help to narrow down the errors on our results significantly.

References

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