A Multi-Wavelength Study of T Tauri Stars

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Abstract. We present results from a multi-wavelength study of T Tauri stars (TTS). This study is important for understanding the activity and evolution of young stars of different ages. Optical observations of blue/redshifted absorption features are indicative of out/in-flows suggesting the presence of stellar winds and/or accretion. Constraints on the modelling are provided by the analysis of variability in the spectral features. The associated timescales have been used to differentiate between wind and infall regions and to help understand the boundary between out/in-flows around TTS. In addition, the UV spectroscopic analysis has recently been improved using collisional-radiative atomic models, resulting in more accurate determination of the atmospheric structure and physical properties of TTS and highlighting potential problems with the analysis methods. Our study of X-ray data has also revealed the connection between UV and X-ray emission which might be explained by solar-like coronal activity at a much higher level. Upcoming observations from XMM will allow a more complete examination of the detailed spectra.

Keywords: Stars: T Tauri, X-rays, UV, Outflows, Accretion - X-rays: Stars - Instruments: ROSAT, XMM-Newton

1. Optical

TTS have long been known to be variable in the optical and ultraviolet. They show pronounced activity with brightness variations ranging from less than one hour (possibly flares) to years. Irregular variations are also common, but for many TTS they are superimposed on more regular variations. As the study of TTS properties grew deeper and wider, various aspects of their variability have emerged as main topics of analysis. More recently the wide availability of high resolution spectroscopy in the optical opened up the possibility of examining the variability in the shape of the line profiles. Blue and redshifted absorption features were observed in various TTS, indicative of out/in-flows and suggesting the presence of stellar winds and/or accretion. The Balmer and Na I D blueshifted absorption components present the clearest evidence that a strong wind is present (see Figure 1a). Almost 80% of classical TTS show similar

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blueshifted absorption in at least one line, the most common being Hα (Alencar & Basri 2000). Redshifted absorption components in the line profiles (inverse P Cygni profiles), are the clearest spectral evidence that infall of material is occurring (Figure 1b). In a few TTS these two types of profile have been found simultaneously, indicating both out- and in-flow. In recent years many attempts have been made to explain these characteristics and this variability. For example, stellar wind models have been developed with the objective of explaining the observed blueshifted absorption spectral features. Observations of red displaced absorption features have led to the development of accretion models. The associated timescales of the variations, and correlations between the equivalent widths and fluxes of different lines, have been used as tools to investigate the relationship between different line formation regions and provide new constraints for the models (see e.g Lago & Gameiro 1998).

2. Atomic Physics

In observational and predictive studies of TTS spectral data an accurate atomic collision database is required to assist with interpretation. Previous model simulations and spectroscopic diagnostic analyses have often relied on lower quality atomic data or have been subject to uncertainty due to the simplifying assump-
tions involved. In this work we have improved the accuracy of such data by utilising the Collisional-Radiative Models implemented in the Atomic Data and Analysis Structure (ADAS, Summers 1994). For example, we have included an improved treatment of effects such as finite plasma electron density and its influence on ion population structure and ionisation/recombination processes (Brooks et al. 1999). We have also included the effects of metastable states on the level population distribution. Within the framework of the ADAS project we are extending such models for analysis of the higher resolution data from XMM and HST-STIS. We hope to remove uncertainties when the accretion/wind models are confronted with the observations.

3. Ultraviolet

The UV is an especially valuable spectral range for the study of TTS. It includes emission lines indicative of temperatures from a few $10^4$ K up to $2 \times 10^5$ K hence allowing the study of plasma in different physical conditions. In this context, emission measure (EM) and differential emission measure (DEM) techniques are powerful tools which provide insight into the structure of the atmosphere at these temperatures. Using ADAS we have analysed IUE data of a sample of TTS in order to derive their EM distributions (Brooks et al. 1999, 2000). In one case we also studied the DEM distribution (BP Tau). This resulted in an improvement of the determination of the atmospheric structure of individual TTS, together with more accurate estimates of the electron densities and the extension and volume of the emitting regions. It also highlighted possible problems with the physical assumptions underlying the analysis methods. An example EM distribution is shown in Fig. 2 for CV Cha.

Note that the SiIII and OIII forbidden lines cannot be brought into agreement with the general trend for any density. This result is a common feature of the stars in our sample. It is indicative of the existence of problems with either the atomic data used, the accuracy of the observed fluxes or a failure in the physical assumptions underlying the analysis method. In a recent work (Brooks et al. 2000) we made several tests, including e.g. analysis of opacity effects, alteration of elemental abundances, which suggested that plasma dynamic effects or the presence of two separate emission regions could be the cause of such discrepancies. We are currently investigating these issues further.

4. X-rays

In the X-ray range, our analysis of ROSAT data has been combined with the IUE data to reveal the connection between UV and X-ray activity amongst different TTS that might be explained by solar-like coronal activity but at a much higher level (e.g. flares, hot spots). The emission is found to be variable in many cases and appears consistent with thermal emission from an optically thin, solar-like coronal plasma. We have used these data to study the variability and clarify the high temperature structure in TTS (Costa et al. 2000). The data were fitted with a two-temperature model of an optically thin plasma in collisional equilibrium with one component around $10^6$ K and the other around $10^7$ K. However, despite the success of these fits to the low resolution spectra we
Figure 2. Volume Emission Measure loci plotted against temperature for CV Cha using the method of (Jordan et al. 1987). A fairly smooth trend is evident through the OI, SiII, CII, SiIV and CIV. The SiIII line which lies above the general trend is blended with OI and this probably signifies imperfect separation of the components. The forbidden lines of SiIII and OIII do not appear to fall into agreement with the general trend.

expect the data from the higher resolution instruments on board XMM to focus attention on the uncertainties in the adopted atomic models and data, as the IUE and HST observations have done in the UV. In fact XMM will reveal the X-ray high resolution spectra of TTS for the first time. In Fig. 3, where we have simulated the XMM-EPIC spectra for V410 Tau, several lines which constitute important diagnostic tools for the conditions in very high temperature plasmas are clearly prominent e.g. OVII, OVIII, NeIX, NeX and FeXXV-XXIV.

5. Conclusions

Multi-wavelength spectroscopic studies of TTS (from the optical to X-rays) are an essential tool for investigating their atmospheric properties and activity and for testing/improving the theoretical models. The optical provides important information on plasma flows into and from TTS atmospheres in addition to the atmospheric structure in lower temperature regions. Conversely, the UV and X-ray regions provide information on the higher temperature plasmas and also allow examination of critical boundaries between optically thick and thin
regions. The combination of the three wavelength regions allows determination of the entire atmospheric structure from the photosphere through to the corona. In this poster we have shown a few examples of our current multi-wavelength research at CAUP. Future prospects for these fields of research appear promising with upcoming data from XMM, recent observations with HST-STIS and large ground based telescopes (e.g. VLT). The possibility of simultaneous observations of events on TTS in the optical, UV and X-ray ranges will become available with XMM. They will most certainly provide unique constraints on the underlying mechanisms responsible for the energy production. One of the main goals of this study will be to determine if the mechanisms behind the optical, UV and X-ray activity are related, or if they have a separate origin.

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References

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