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Accretion and mass loss in young stellar objects

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Abstract. T Tauri Stars are young (1-10 Myr), low-mass (≤ 2 $M_\odot$) stars. They are called Classical T Tauri stars (CTTSs), when they are still accreting mass from a circumstellar disk, and Weak-lined T Tauri stars (WTTSs), when accretion has ceased. Signs of outflows, in the form of jets and winds, can be observed in CTTSs through different components of the [OI]6300 Å emission line, which makes the analysis of this line an important tool to understand the star-disk system evolution. We analyzed a sample composed of 12 stars, including 4 CTTSs, 6 WTTSs, and 2 A0-type stars. To be able to retrieve the outflow components of the [OI]6300 Å emission line, it is necessary to remove telluric and photospheric contributions from the observations. After obtaining the circumstellar contribution, we will decompose the [OI]6300 Å line to analyze its properties. Finally, we plan to characterize the regions where jets and winds originate, their relation with the accretion process, and compare our results with similar works from the literature.

Resumo. Estrelas T Tauri são estrelas jovens (1-10 Ma) de baixa massa (≤ 2 $M_\odot$). Elas são chamadas de estrelas T Tauri Clássicas (ETTCs), se possuem sinais de acreção de matéria de um disco circunstelar, e de estrelas T Tauri Fracas (ETTFs), quando a acreção terminou. Sinais de ejeção de matéria, na forma de jatos e ventos, podem ser observados através de várias componentes em emissão da linha de [OI]6300 Å, o que torna o estudo desta linha importante para entender a evolução de sistemas disco-estrela. Analisamos uma amostra de 12 estrelas, sendo 4 ETTCs, 6 ETTFs e 2 estrelas de tipo espectral A0. Para recuperar as componentes do vento na linha de emissão de [OI]6300 Å, é necessário remover contribuições telúricas e fotosféricas dos espectros observados. A partir do espectro circunstelar obtido, realizaremos a decomposição da linha de [OI]6300 Å a fim de analisar as propriedades de suas componentes. Por fim, esperamos caracterizar as regiões de origem de jatos e ventos e suas relações com o processo de acreção, e comparar nossos resultados com análises semelhantes na literatura.

Keywords. Stars: winds, outflows – Stars: variables: T Tauri – Stars: formation

1. Introduction

T Tauri Stars are young (1 – 10 Myr) low-mass (≤ 2 $M_\odot$) stars with strong magnetic fields (∼ 2 kG, Johnstone et al. 2014), which are formed in giant molecular clouds. Due to conservation of angular momentum, during the gravitational collapse of a cloud core, a circumstellar accretion disk is formed with the star. When the young stars are still accreting mass, they are called Classical T Tauri Stars (CTTSs), and if they no longer exhibit signs of accretion, they are referred to as Weak-lined T Tauri Stars (WTTSs). The young accreting systems also present outflows in the form of jets and winds, which are ubiquitous during star formation (Hartmann, Herczeg, & Calvet 2016).

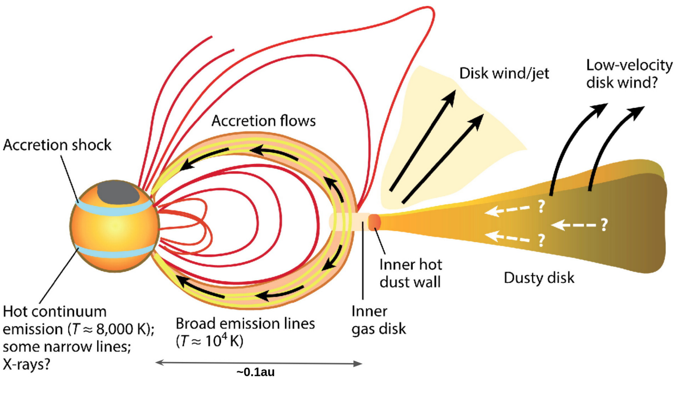

Figure 1. Schematic view of the magnetospheric accretion and ejection processes, showing the inner disk region and the stellar magnetic field (in red) (Hartmann, Herczeg, & Calvet 2016).

The magnetospheric accretion model, illustrated in Figure 1, is nowadays the accepted paradigm to describe CTTSs. According to this model, the stellar magnetic field is strong enough to truncate the circumstellar disk at a few stellar radii from the star and carry the ionized gas from the disk to the star, through magnetospheric accretion columns, until it shocks at the stellar surface. The magnetospheric accretion model may also include outflows in the form of stellar and disk winds and jets, mostly originating from the inner disk region. Outflows are important in star formation, since they extract angular momentum from the disk, allowing accretion to proceed. A way to investigate the outflows characteristics is to analyze forbidden lines, such as the [OI]6300 Å emission line, which are formed in low-density regions, like winds and jets (McGinnis et al. 2018). Owing to the relationship between outflows and mass accretion, the analysis of the [OI]6300 Å line helps us understand star formation and evolution. In order to retrieve the wind component of the [OI]6300 Å line profiles, it is necessary to perform a series of decontamination procedures on the observed spectra.

2. Goals

The observed spectra around the [OI]6300 Å line contain both telluric lines, originating from the Earth's atmosphere, and photospheric lines, from the stellar surface. The main goal of this work is to retrieve the outflow contribution to the [OI]6300 Å line, by removing the telluric emision and absorption lines, as well as the photospheric lines in the [OI]6300 Å spectral region. With the outflow component of the [OI]6300 Å line, we should be able to identify and characterize the jet and wind contributions in each line profile. Finally, we plan to compare our results with similar analysis from the literature.

3. Methods

The spectra were obtained with the VLT (ESO) FLAMES multi-object spectrograph (Pasquini et al. 2002). Our sample is composed of 12 stars, consisting of 4 CTTSs, 6 WTTSs, and 2 A0-type stars, according to the classification by Venuti et al. (2014). The removal of telluric and photospheric lines was accomplished through python scripts, which were originally developed by Castelões (2022), following a sequence of steps. First, telluric emission lines were removed by subtracting a sky spectrum from the stellar spectra. To remove the telluric absorption lines, we divided the stellar spectra by a template, created combining the spectra of two A0 stars, which do not present photospheric lines in the [OI]6300 Å line region. At last, we removed the photospheric contribution by subtracting from the CTTS spectra, a WTTS spectrum of the same spectral type as the CTTS.

After removing telluric and photospheric lines from the CTTS spectra, we searched for the presence of residual [OI]6300 Å emission originating in winds and jets. We considered a real detection when the emission line peak was found at the 3σ level with respect to the continuum and presented a FWHM larger than the spectral resolution. Through the analysis of these emission lines, we can study the kinematics of the star-disk system.

4. Results

In Figure 2, we observe the decontamination process of telluric emission and telluric absorption lines in the spectrum of the CTTS CSIMon-804. On the left, the sky spectrum (in blue) shows the telluric emission, identified in red in the stellar spectrum. The stellar spectrum after the removal of the telluric emission line is shown in black. On the right, the telluric absorption lines from the combined A0 stellar spectra can be seen in blue, and we show in black the CTTS spectrum after telluric decontamination.

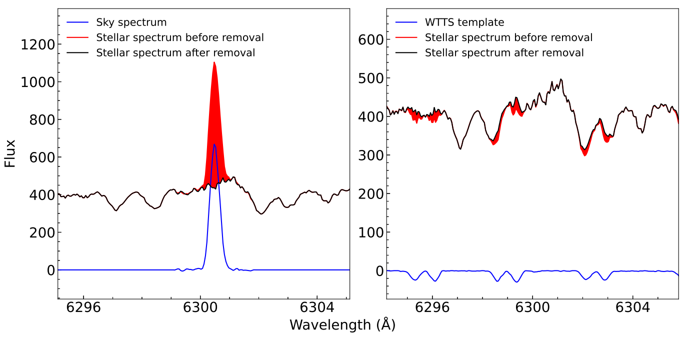

Figure 2. Decontamination process of telluric emission lines (left) and telluric absorption lines (right) from the spectrum of the CTTS CSIMon-804.

Figure 3 shows an example of the removal of photospheric lines from the CTTS spectrum of CSIMon-804. The spectra of CTTSs are often veiled, presenting shallow photospheric lines. The veiling corresponds to an extra continuum coming from the accretion shock region of the CTTS and has to be added to the WTTS spectrum before subtraction. In Fig. 3, the spectrum of a veiled WTTS of the same spectral type as the CTTS is shown in red, overplotted to the CTTS spectrum (in black). In blue, we see the final decontaminated spectrum, that can be used to analyze the outflow contribution to the [OI]6300 Å emission line.

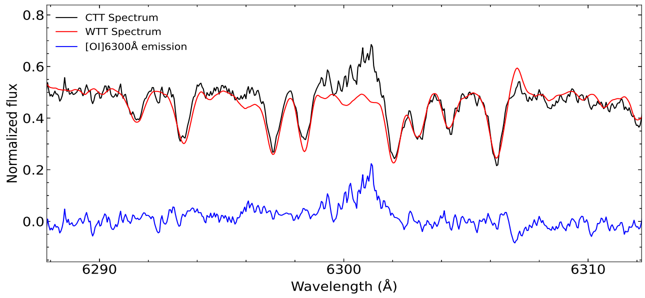

Figure 3. Removal of the photospheric contribution from a spectrum of the CTTS CSIMon-804

5. Conclusion

The [OI]6300 Å emission line decontamination process, which includes the removal of telluric and photospheric lines, produced preliminary satisfactory results. During each step, it was possible to identify the contribution of the telluric and photospheric components present in the stellar spectra, as well as to remove them. By obtaining the circumstellar line profile, we can now decompose the [OI]6300 Å line into high-velocity components, originating from jets, and low-velocity components, originating from disk winds. We will then do a kinematic analysis of these components to characterize their regions of origin and their relations with the accretion process. Finally, to determine the method's efficiency, we will compare our results with similar analysis from the literature.

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