

Spectroscopic characterization of the star PDS 70

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Abstract. This work presents a detailed spectroscopic analysis of the T Tauri star PDS 70, focusing on the determination of its atmospheric parameters and the characterization of its lithium abundance. Using high-resolution data obtained with the HARPS spectrograph, line ratio methods and spectral synthesis were applied to estimate the effective temperature, surface gravity, metallicity, and projected rotational velocity of the star. The lithium abundance was determined through spectral synthesis in the region of the 6707.8 Å line. The results indicate an effective temperature of 4176 ± 15 K, a surface gravity of $\log g = 3.62 \pm 0.05$, a metallicity of $[Fe/H] = -0.11 \pm 0.02$, and a $v \sin i$ of 16.49 ± 0.04 km s⁻¹. The lithium abundance ($A(Li) = 3.18 \pm 0.59$) confirms the youth of PDS 70 and is consistent with previous studies of T Tauri stars with similar mass and age. These results reinforce the classification of PDS 70 as a pre-main sequence star, highlighting its importance as a natural laboratory for the study of star and planet formation. The consistency of the obtained values with the literature validates the applied methodologies and contributes to the understanding of the physical processes governing the evolution of young stars and their planetary systems.

Resumo. Este trabalho apresenta uma análise espectroscópica detalhada da estrela T Tauri PDS 70, com foco na determinação de seus parâmetros atmosféricos e na caracterização de sua abundância de lítio. Utilizando dados de alta resolução obtidos com o espectrógrafo HARPS, foram aplicados métodos de razão de linhas e síntese espectral para estimar a temperatura efetiva, gravidade superficial, metalicidade e velocidade de rotação projetada da estrela. A abundância de lítio foi determinada por meio da síntese espectral na região da linha de 6707,8 Å. Os resultados indicam uma temperatura efetiva de 4176 ± 15 K, uma gravidade superficial de $\log g = 3,62 \pm 0,05$, uma metalicidade de $[Fe/H] = -0,11 \pm 0,02$ e uma velocidade de rotação projetada de $16,49 \pm 0,04$ km s⁻¹. A abundância de lítio ($A(Li) = 3,18 \pm 0,59$) confirma a juventude de PDS 70 e está em concordância com estudos anteriores em estrelas T Tauri de massa e idade semelhantes. Esses resultados reforçam a classificação de PDS 70 como uma estrela pré-sequência principal, destacando sua importância como um laboratório natural para o estudo da formação estelar e planetária. A consistência dos valores obtidos com a literatura valida as metodologias aplicadas e contribui para o entendimento dos processos físicos que governam a evolução de estrelas jovens e seus sistemas planetários.

Keywords. Techniques: spectroscopic – Stars: pre-main sequence – Protoplanetary disks

1. Introduction

The formation and evolution of planetary systems are intrinsically linked to the physical properties of their host stars. In this context, the T Tauri star PDS 70 (V1032 Cen) represents a benchmark system for the study of young stellar objects. Located in the Scorpius-Centaurus association, PDS 70 was first identified as a pre-main sequence star with infrared excess by Gregorio-Hetem et al. (1992).

The system hosts a transition disk with a large cavity, within which two accreting protoplanets, PDS 70b and PDS 70c, have been directly imaged (Keppler et al. 2018; Isella et al. 2019). Recent observations have further characterized the environment, detecting water in the inner disk (Perotti et al. 2023). However, despite the intense scrutiny, fundamental atmospheric parameters of the host star—specifically surface gravity ($\log g$) and metallicity ($[Fe/H]$)—remain debated in the literature, with varying results reported by different authors (e.g., Maldonado et al. 2015; Steinmetz et al. 2020).

In this work, we present a detailed spectroscopic analysis of PDS 70 using high-resolution optical data. Our main objective is to refine the stellar parameters and determine the Lithium abundance to robustly confirm the star's evolutionary stage and provide a solid baseline for planet formation models.

2. Methodology

In this work, we combined high-resolution optical spectroscopy with spectral synthesis techniques to characterize the star PDS 70. The following sections describe the data acquisition, the reduction process, and the Bayesian framework adopted to derive the atmospheric parameters and the Lithium abundance.

2.1. Observations and Data Reduction

We analyzed 38 high-resolution spectra ($R \sim 115,000$) of PDS 70 obtained with the HARPS spectrograph, available in the ESO public database. The data cover the period between 2018 and 2020. We selected only spectra with a Signal-to-Noise Ratio (SNR) greater than 10. The data reduction was performed using standard routines in IRAF. First, we applied Doppler corrections to the rest frame using the radial velocities provided by the Cross-Correlation Function (CCF) files. Subsequently, the spectra were combined using a weighted average to increase the SNR and normalized using cubic splines to fit the continuum level.

2.2. Stellar Parameters and Abundances

The atmospheric parameters (T_{eff} , $\log g$, $[Fe/H]$, and $v \sin i$) were determined using the spectral synthesis method implemented in the iSpec framework (Blanco-Cuaresma et al. 2014). We utilized the M00G radiative transfer code (Snedden 1973) integrated with MARCS model atmospheres (Gustafsson et al. 2008) and the

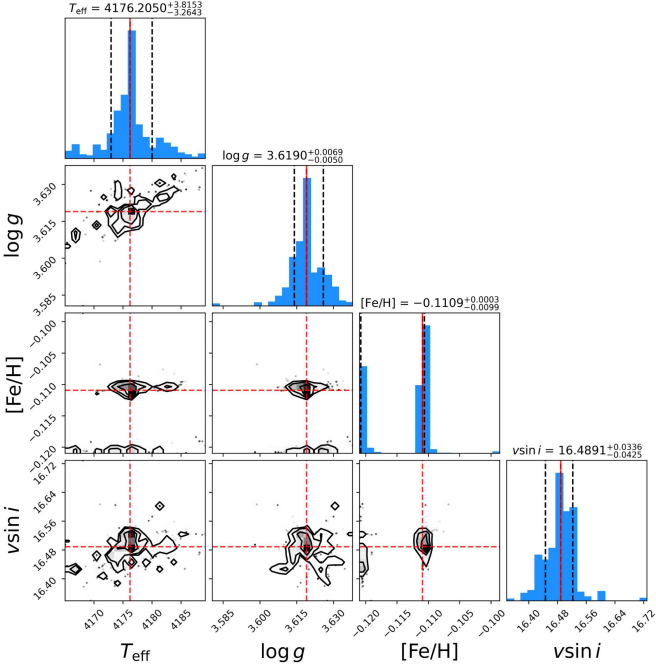


FIGURE 1. Posterior distributions and correlations for the atmospheric parameters of PDS 70 obtained from the MCMC analysis. The red lines indicate the median values.

VALD atomic line list. Solar abundances were adopted from Grevesse et al. (2007).

To handle parameter degeneracy and estimate robust uncertainties, we employed a Bayesian approach using Markov Chain Monte Carlo (MCMC) simulations via the emcee package, which implements the Affine Invariant Ensemble Sampler (Goodman & Weare 2010). The analysis focused on the spectral window between 595 nm and 615 nm, a region rich in Fe I and Fe II lines sensitive to temperature and gravity. Finally, the Lithium abundance, $A(\text{Li})$, was derived by fitting the synthetic spectrum to the observed Li I resonance doublet at 6707.8 Å.

3. Results and Discussion

The atmospheric parameters were derived using a Bayesian approach. The MCMC simulations showed efficient convergence after approximately 100 iterations. Figure 1 displays the corner plot with the posterior distributions and correlations between the parameters. The analysis yielded an effective temperature of $T_{\text{eff}} = 4176 \pm 15$ K and a surface gravity of $\log g = 3.62 \pm 0.05$, values that are consistent with a pre-main sequence status. Notably, we found a subsolar metallicity of $[\text{Fe}/\text{H}] = -0.11 \pm 0.02$, which aligns with the results from Swastik et al. (2021) and challenges earlier assumptions of solar composition for PDS 70. The projected rotational velocity was determined as $v \sin i = 16.49 \pm 0.04$ km s $^{-1}$.

The Lithium abundance was determined by synthesizing the Li I resonance doublet at 6707.8 Å. As shown in Fig. 2, the synthetic model fits the observed absorption profile remarkably well. We derived an abundance of $A(\text{Li}) = 3.18 \pm 0.59$ dex. This high Lithium content is a robust indicator of youth, consistent with T Tauri stars in the Sco-Cen association, and confirms that PDS 70 has not yet depleted its initial lithium through mixing processes.

Finally, the H α emission profile was analyzed to assess the accretion activity. We measured a width at 10% of maximum

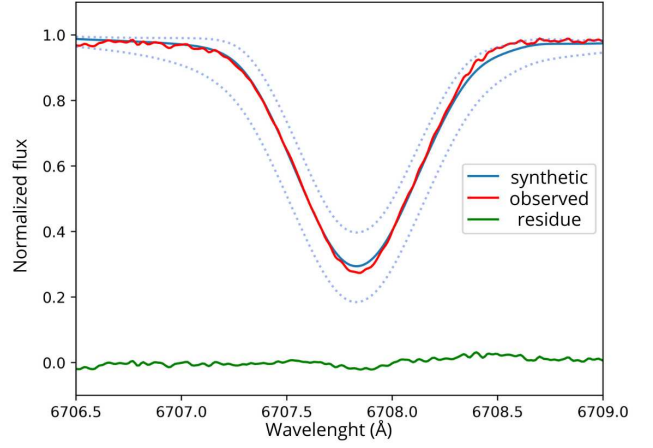


FIGURE 2. Spectral synthesis of the Li I line at 6707.8 Å. The red line represents the observed HARPS spectrum, while the solid blue line shows the best-fit synthetic model ($A(\text{Li}) = 3.18$). The dotted blue lines indicate the 1 σ uncertainty limits. The green line at the bottom shows the residuals.

intensity ($W_{10\%}$) of 5.26 Å (~ 240 km s $^{-1}$). According to the criterion proposed by White & Basri (2003), stars with $W_{10\%} < 270$ km s $^{-1}$ are classified as Weak-line T Tauri Stars (WTTS). Our data, therefore, support the classification of PDS 70 as a WTTS, suggesting a phase of weak or residual gas accretion from the disk.

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