Spectrophotometry of T Tau Stars in the Cha 1 Star Formation Region

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ABSTRACT: The variability mechanisms in T Tau stars are complex, influenced by accretion, dust, starspots etc – which requires multiband coverage over time. *The innermost regions can only be probed via spectroscopy and variability.* We analyse 25 years of spectra and photometry of 3 T Tau stars in Cha 1: CT, VZ an WW Cha, to complete a set of 6 observed during a simultaneous TESS and ground-based campaign. We present the data, Lomb-Scargle periodograms, emission line profile variability and colours, and further work to compare to the other 3 programme stars.

BACKGROUND/DATA: Our team received time on ESO and SMARTS telescopes during TESS observations in May-June 2019. We expanded our data to include archival TESS, ESO and other data covering 2000-2023 (Table 1). Our program builds on results from analyses of CR, VW and WX Cha (Zsidi+ 2022a,b; Fiorellino+ 2022) (Table 2), to analyse a representative sample from Cha 1 (d~179±11 pc), one of the closest star formation regions. *We show results for CT Cha as an example.*

Tab-1: Instrumt	Details	$\lambda\lambda$ nm	Nobs/cadence	period	Public?
ESO/spec	2-55 km/s resoln	345-1020	97 obs	2000-23	yes
TESS/phot	broadband	600-1000	30 min	2019,21,23	yes
ASASSN/phot	Broadband g,V	403-587	1-few days	2000-date	yes
ATLAS/phot	Broadband c,o	412-826	1-few days	2022-date	yes
ANDICAM/phot	Broadband IJHK	750-2300	1 day	5-6/19	no
NEOWISE/phot	Broadband W1,W2	3.4,4.6μm	6 months	2014-24	yes

Tab-2 Star	Ref	Dist pc	Mass $M_\odot$	Mdust/ $M_\oplus$	Log $\dot{M}/M_\odot$ /yr	Age Myr	Disk I deg	Disk Rad au
CR Cha	Zsidi+ 22a	185.	1.4	198.	-8.41	0.9±0.1	33±5	94±4
VW Cha	Zsidi+ 22b	188.	0.75, 0.57	…	-6 to -7	1.0,1.5	44±17	32±2
WX Cha	Fiorellino+ 22	191.	0.5,0.2	10.	-6.69	1.05 ±0.15	87±31	…
CT Cha	this work	190.	0.9 ±0.2	13.	-7.52	1.55 ±0.35	45±7	65±4
VZ Cha	this work	191.	0.5	60.	-7.14	1.3±0.2	50±5	57±3
WW Cha	this work	189.	1.9	630.	-6.28	0.35 ±0.15	40±6	139±5

We show photometry and spectral epochs for CT Cha in Fig. 1. The photometry is crucial to measure Ha and other fluxes, because all spectra except XSHOOTER are not flux-calibrated.

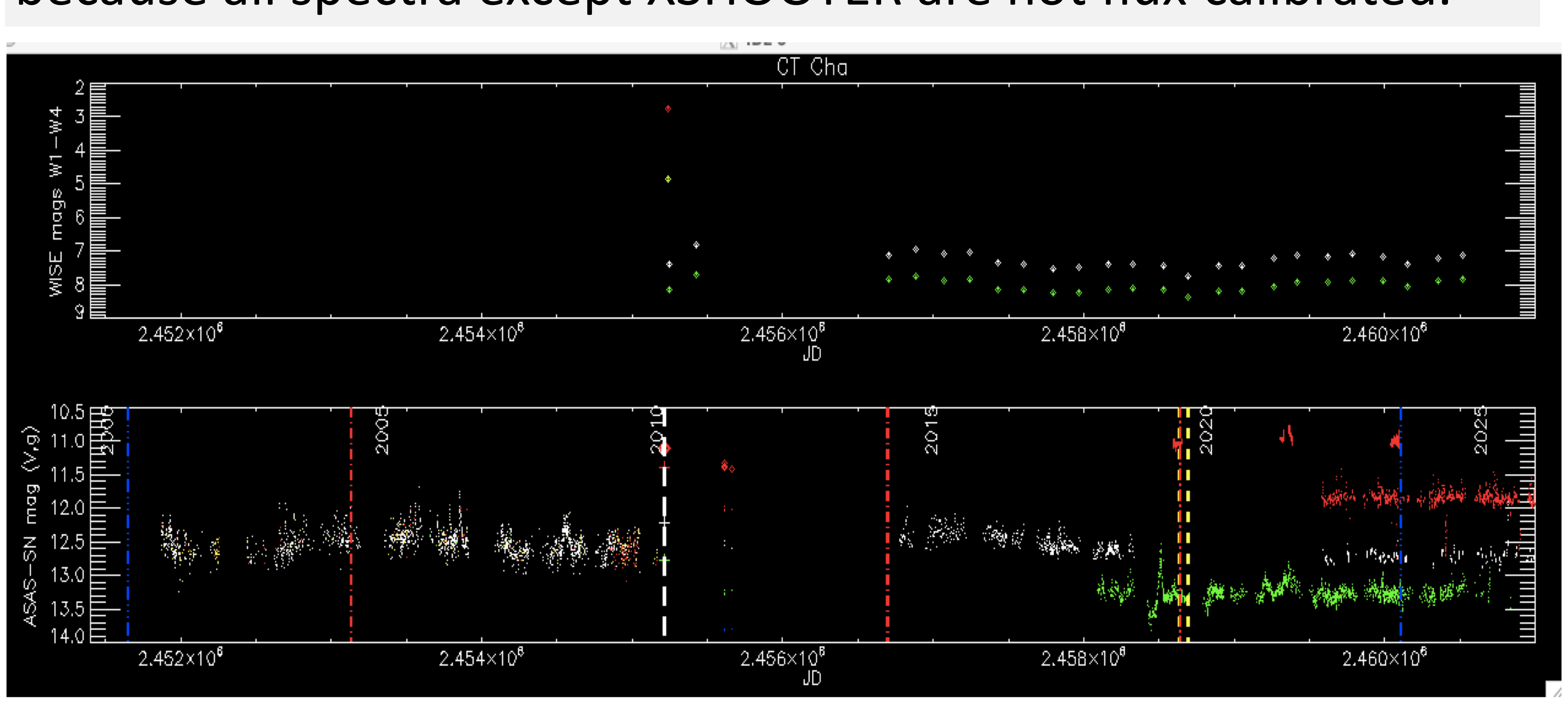

Fig 1. Main photometry (mag) and spectral time sampling for spectra for CT Cha, by Julian Day. Top: NEOWISE. Green, white: 3.4, 4.6μm. One-epoch yellow, red: 12, 22μm. Bottom: White dots – ASAS-SN V (2001-12), ATLAS c (2022-25). Green dots: ASAS-SN g. Red dots: ATLAS o. Topmost red curves: TESS. Isolated photometry is shown for 2010-14. Vertical lines: spectra. Yellow-dashed: VLT/ESPRESSO. Red dot-dashed: ESO 2.2/FEROS. Blue dot-dashed: VLT/UVES. White-dashed: VLT/XSHOOTER with calculated photometry (v,V,o,TESS, low to high, during a 0.3-0.4 mag outburst). Significant outbursts/dips can be seen outside of the 2019 TESS+ESO campaigns.

A light curve and Lomb-Scargle periodogram from TESS indicate period-icity (Fig. 2).

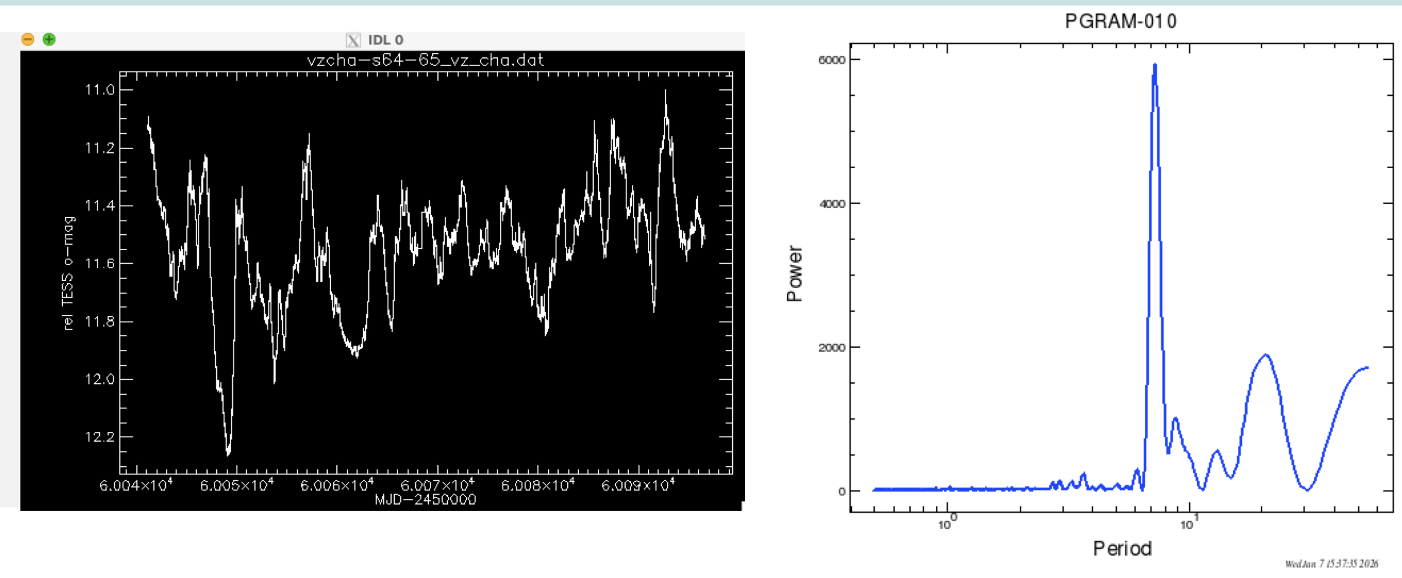

Fig. 2. Left: Light curve from TESS for periods 64-65 (May-June 2023). Right: Long-Scargle periodogram, indicating a periodicity of 7.25 days.

Colours can reveal whether dust extinction is present, help to construct spectral energy distributions to calibrate spectra and constrain models for accretion rates and spectral holes (Figs 3-4).

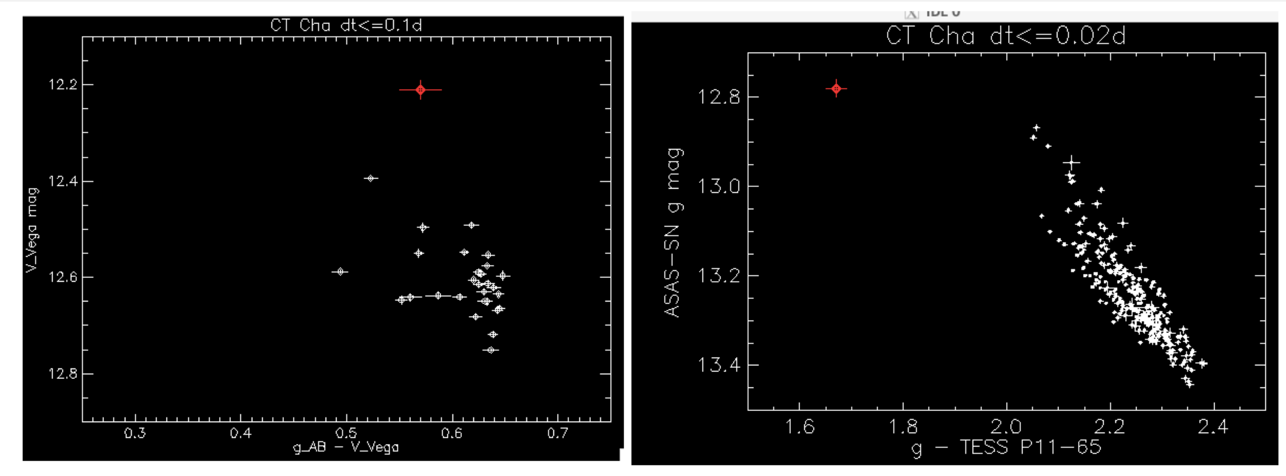

Fig. 3. Left: g-V vs V. Right: g-TESS vs. g. Both are consistent with dust extinct-tion.

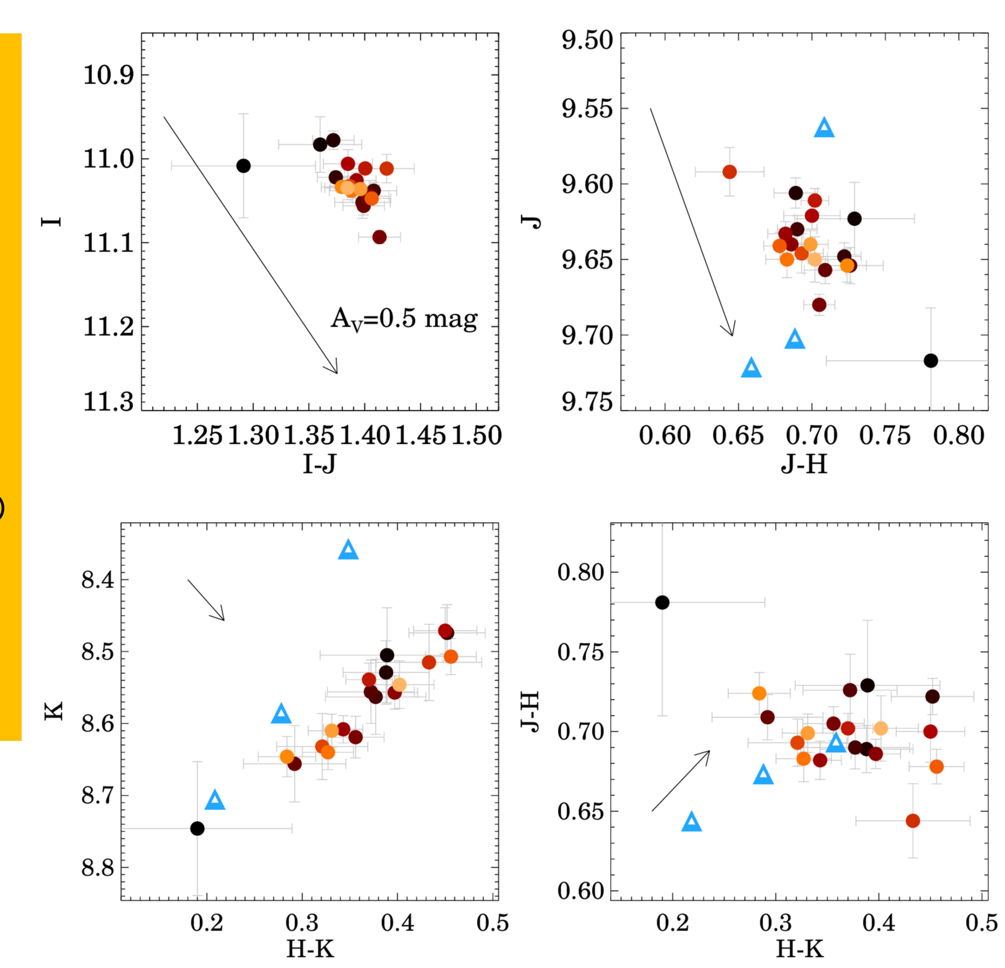

Fig. 4. IJHK colours for CT Cha from June 2019. Lighter colours = later data. Arrows: Cardelli+ (1988) for A_V=0.5. Triangles: Carpenter+ (2001) models for accretion rate log($\dot{M}/M_\odot$)= -8.5 (/yr), and inner holes of 1, 2, 4$R_\odot$ (upper R to lower L). H-K vs K is anomalous, and is not consistent with dust extinction.

Emission line variability reveals wind component dynamics, and can change significantly (Fig. 5).

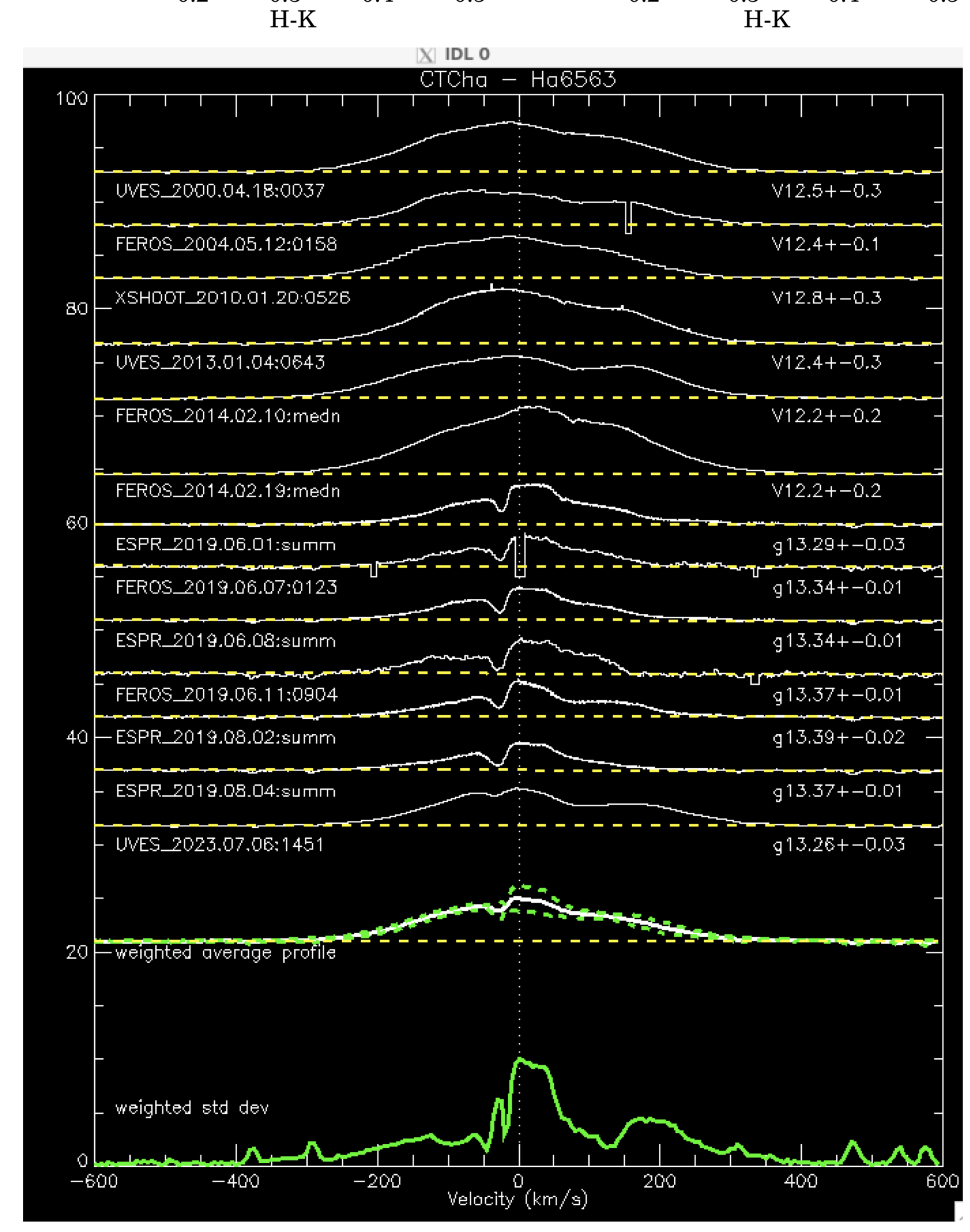

Fig. 5. H-alpha profile in velocity space for CT Cha from 2000-2023, from ESO VLT (ESPRESSO, UVES, XSHOOTER) and ESO 2.2m/FEROS. Most variability is for dv<50 km/s. Absorption was only evident in 2019.

DISCUSSION/FURTHER WORK: The spectra have been stacked and normalised by observation date. The g-magnitudes and colour-magnitude diagrams will permit us to construct spectral energy distributions to measure absolute line fluxes, and estimate accretion rates. The complete sample will provide a cross-section of variability mechanisms for the innermost regions (<1 au) of disks in Cha 1.

REFERENCES:

Cardelli+ 1988, ApJ; Carpenter+ 2001, AJ, 121, 3160; Fiorellino+ 2022 ApJ, 938, 93; Zsidi+ 2022a, A&A, 660, 108; Zsidi+ 2022b, ApJ, 941, 177