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PRE-MAIN SEQUENCE STARS

Spectroscopy of nine eruptive young variables using TANSPEC

ARPAN GHOSH[1,3,*], SAURABH SHARMA[1], JOE P. NINAN[2], DEVENDRA K. OJHA[2], A. S. GOUR[3], RAKESH PANDEY[4], TIRTHENDU SINHA[5], AAYUSHI VERMA[1], KOSHVENDRA SINGH[2], SUPRIYO GHOSH[6] and HARMEEN KAUR[7]

[1]Aryabhatta Research Institute of Observational Sciences (ARIES), Manora Peak, Nainital 263001, India.
[2]Department of Astronomy and Astrophysics, Tata Institute of Fundamental Research (TIFR), Mumbai 400005, India.
[3]School of Studies in Physics and Astrophysics, Pandit Ravishankar Shukla University, Raipur 492010, India.
[4]Physical Research Laboratory, Navrangpura, Ahmedabad 380009, India.
[5]Satyendra Nath Bose National Centre for Basic Sciences (SNBNCBS), Salt Lake, Kolkata 700106, India.
[6]University of Hertfordshire, Hatfield AL10 9AB, UK.
[7]Center of Advanced Study, Department of Physics, DSB Campus, Kumaun University, Nainital 263001, India.
*Corresponding author. E-mail: arpan@aries.res.in

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Abstract. In recent times, 3.6m Devasthal Optical Telescope (DOT) has been installed with an optical to near infra-red spectrograph, TANSPEC, which provides spectral coverage from 0.55 to 2.5 microns. Using TANSPEC, we have obtained a single epoch spectrum of a set, containing nine FUors and EXors. We have analysed line profiles of the sources and compared them with the previously published spectra of these objects. Comparing the line profile shapes with the existing theoretical predictions, we have tried to interpret the physical processes that are responsible for the current disc evolution and the present accretion dynamics. Our study has shown the importance of time-evolved spectroscopic studies for a better understanding of the evolution of the accretion a mechanisms. This in turn can help in the better characterization of the young stars displaying episodic accretion behavior.

Keywords. Eruptive young stellar objects—FUors—EXors.

1. Introduction

The phenomenon of episodic accretion first came to light in 1936 when FU Ori, located in the B35 dark clouds in the Orion star-forming region, underwent an outburst of >5 magnitudes from its historical V band magnitude of 16 (Wachmann 1954). Herbig (1966) first proposed that this phenomenon of episodic accretion represents an important stage in the formation of low mass stars (mostly having masses $\leq 1\ M_\odot$ with few exceptions with masses between 2 and 3 $M_\odot$, Hartmann *et al.* 2016). Observationally, it has been found that the phenomena of episodic accretion span the entire pre-main sequence (PMS) evolutionary stage starting from class 0 to class II stages (Safron *et al.* 2015). The time span of these events is extremely short (∼months to ∼decades) compared to the millions of years spent in the formation stages. This makes these events extremely rare with around 30 sources have been discovered till date. These events though very small in timescales, are capable of delivering significant amounts of matter onto the central source (Vorobyov & Basu 2006). The brightness variations exhibited in an episodic accretion event are easily noticeable in observations taken before and during the outburst. Figure 1 shows one such example with the pre-outburst and post-outburst optical images of Gaia 20eae, a newly discovered member of young stars displaying episodic accretion behavior. Sources displaying episodic accretion are bi-modally classified into FUors and EXors. FUors named after FU Ori, undergo outburst of 4–5 magnitudes in optical

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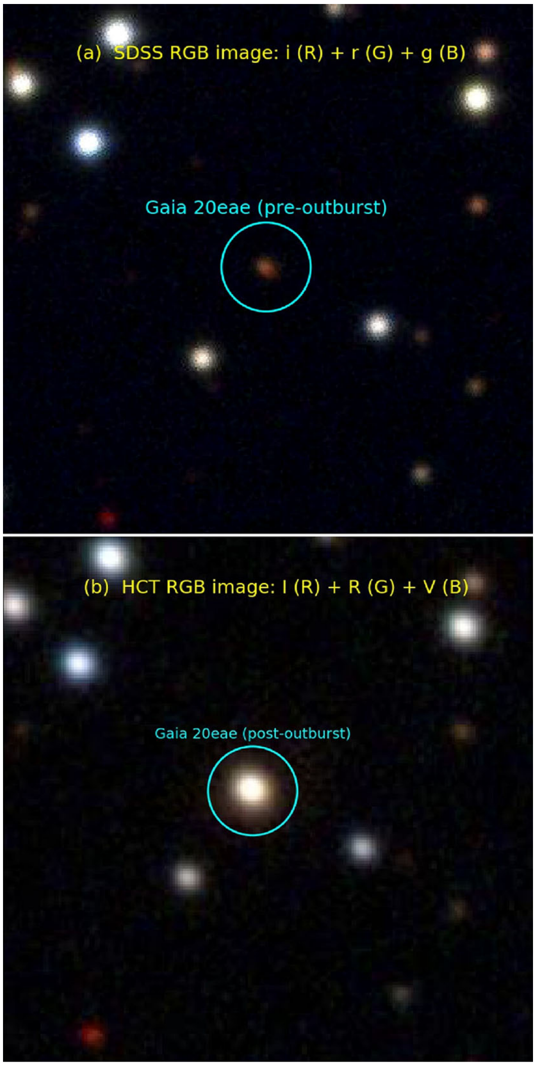

Figure 1. Optical RGB pre-outburst and post-outburst images of Gaia 20eae, a newly discovered episodically accreting young star. The pre-outburst RGB is generated from the g, r and i filter images obtained from SDSS archive. Post-outburst RGB is generated from optical observations in V, R and I filters taken from the 2m Himalayan Chandra Telescope. Image source: Ghosh *et al.* (2022).

wavelengths that lasts for several decades to even ∼100 years and show absorption features in their spectra. EXors, named after Ex Lupi, on the other hand, undergo smaller magnitude outbursts of 2–3 magnitudes in optical lasting for a few years and displaying emission features in their spectra (Hartmann & Kenyon 1996; Hartmann 1998).

Various models have been put forward to explain the enhancement of the accretion rate leading to episodic accretion. Zhu *et al.* (2009) proposed the throttle mechanism to explain the outbursts. According to this model, the disc is replenished from the infalling envelope at a different rate than the rate at which the matter is transported to its inner regions resulting in the pile up of material, which is subsequently released causing outburst. Another model, initially proposed by Bell & Lin (1994) and later improved upon by Armitage *et al.* (2001), postulates that the phenomena of episodic accretion events are self-regulated. According to this theory, if the inward transport of matter within the disc is sufficiently high, it results in the ionization of the gas (mainly hydrogen) causing a rapid rise in opacity. This leads to heat being trapped within the disc that develops into a runaway situation during which the inner disc is emptied out. The third model proposes about the perturbation of the circumstellar disc by an eccentric binary companion at periastron (Bonnell & Bastien 1992; Reipurth 2004). Fourth scenario, envisages the idea of accretion of a large 'gas blob' from the circumstellar disc to the central source (Vorobyov & Basu 2005). The fifth and final model is centred around the idea of disc-magnetosphere interactions in 'weak propeller' regime to explain the weak 'EXor type' outbursts (D'Angelo & Spruit 2010; D'Angelo 2012).

Spectroscopic studies of sources exhibiting episodic accretion are crucial, as the line profile shapes offer vital clues about the physical processes that are undergoing at their current stage of evolution. The sources classified as FUors and EXors broadly affirm their respective spectroscopic behavior, but their photometric behavior is quite diverse with different rise and decay timescales to and from their maximum brightness. Lately, several sources have been discovered, which show intermediate behavior to that of FUors and EXors (Audard *et al.* 2014). In recent times, Gaia photometric alert system has provided invaluable contribution towards identifying new eruptive young stars (Hodgkin *et al.* 2013). From the Gaia alerts, four new members of eruptive variables have been discovered: Gaia 17 bpi (Hillenbrand *et al.* 2018), Gaia 18dvy (Szegedi-Elek *et al.* 2020), Gaia 19ajj (Hillenbrand *et al.* 2019) and Gaia 20eae (Ghosh *et al.* 2022). Among them, Gaia 17bpi and Gaia 18dvy exhibited properties similar to FUors, whereas Gaia 19ajj resembled EXor. Gaia 20eae displayed intermediate behavior to that of FUors and EXors.

In this paper, we discuss our findings based on a set of nine eruptive young variables that were classified either as FUors or EXors (Audard *et al.* 2014). These sources are well-studied with their optical and near-infrared (NIR) spectra available in the literature. Recently, TIFR-ARIES Near Infrared Spectrometer (TANSPEC, Sharma *et al.* 2022) was commissioned on the 3.6m telescope at Devasthal, Nainital, India (Kumar *et al.* 2018). This instrument has a very unique capability

Table 1. Log of photometric and spectroscopic observations (telescope/instrument: 3.6m DOT TANSPEC)

Date	JD	Source name	Slit size	Exposure (s × frames)
12 Nov 2020	2,459,166	FU Ori	$0.'5$	150 × 4
23 Oct 2020	2,459,146	XZ Tau	$0.'5$	120 × 4
24 Oct 2020	2,459,147	V2492 Cyg	$0.'5$	150 × 8
12 Nov 2020	2,459,166	V2494 Cyg	$0.'5$	150 × 6
10 Nov 2020	2,459,164	V1180 Cas	$1.'0$	150 × 8
10 Nov 2020	2,459,164	V899 Mon	$1.'0$	150 × 3
29 Oct 2020	2,459,152	V960 Mon	$0.'5$	150 × 6
29 Oct 2020	2,459,152	V1118 Ori	$0.'5$	180 × 12
29 Oct 2020	2,459,152	V733 Cep	$0.'5$	180 × 12

to do medium resolution ($R \sim 2750$) spectroscopy from optical to NIR bands in a single shot. Thus, observing eruptive young variables through TANSPEC, we can compare their spectral properties both in optical and NIR bands with the previously published spectra. This is very crucial to understand the physical processes responsible for episodic accretion and their evolution. The paper is arranged as follows: Section 2 describes about the observation and data reduction details. Section 3 describes the results and in Section 4, we conclude this paper based on our results.

2. Observation and data reduction

We have carried out our observations using the 3.6m Devasthal Optical Telescope (DOT) located at Devasthal, Nainital (latitude = $29°21'39''.4$ N, longitude = $79°41'03''.6$ E, altitude = 2450 m) with the newly commissioned TANSPEC instrument (Sharma *et al.* 2022). TANSPEC has two spectroscopic modes: higher resolution cross-dispersed mode (XD) and a lower resolution prism mode, with simultaneous wavelength coverage from optical to near-infrared bands, i.e., 0.55–2.5 μm. We have taken our observation with the XD mode. The XD mode provides a median resolution (R) of $\sim$2750 across the orders in $0''.5$ slit and about 1500 in $1''.0$ slit. We have used both the $0''.5$ and $1''.0$ slits for our observations. Table 1 contains the list of objects that we have observed along with the slit information and exposure time. We have followed the standard observing procedures, while obtaining spectra of each source. Each source was nodded along the slit at two positions and multiple exposures of the source at each position were taken to obtain the spectra. Our observation strategy was driven by the motto of obtaining high signal-to-noise-ratio (SNR) spectrum of our sources. The maximum exposure time given to obtain one spectrum was limited to 3 min. This was done so as to cancel out the telluric emission lines from the consecutive frames taken at alternate nod positions. We have also observed a nearby telluric standard star of A0V spectral type for telluric correction. We have also observed the argon and neon lamps for wavelength calibration and the tungsten lamps for flat fielding. These calibration and arc lamps were observed for each source and target. The obtained spectrum is then processed, extracted and flat-fielded using the pyTANSPEC pipeline[1] developed for reducing the TANSPEC XD mode spectrum. The obtained output spectrum is then telluric-corrected using the standard IRAF[2] module of SPLOT. After telluric correction, the resultant output was normalized using the CONTINUUM module of IRAF. Finally, the different orders of continuum normalized spectra are added up to generate the total spectrum of a single source. Spectra of each of the observed source is provided in Figure 2. Various absorption and emission features are seen. There are gaps in our spectrum, which is due to the atmospheric absorption windows due to the broad H_2O and OH bands.

3. Results and discussion

In the following subsections, we will be discussing the properties of the optical to near-infrared spectral lines found in the TANSPEC spectra (cf. Figure 2) of our studied sample of FUors/EXors. Figure 3 shows the

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[1] https://github.com/astrosupriyo/pyTANSPEC.

[2] IRAF is distributed by National Optical Astronomy Observatories, USA, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with National Science Foundation for performing image processing.

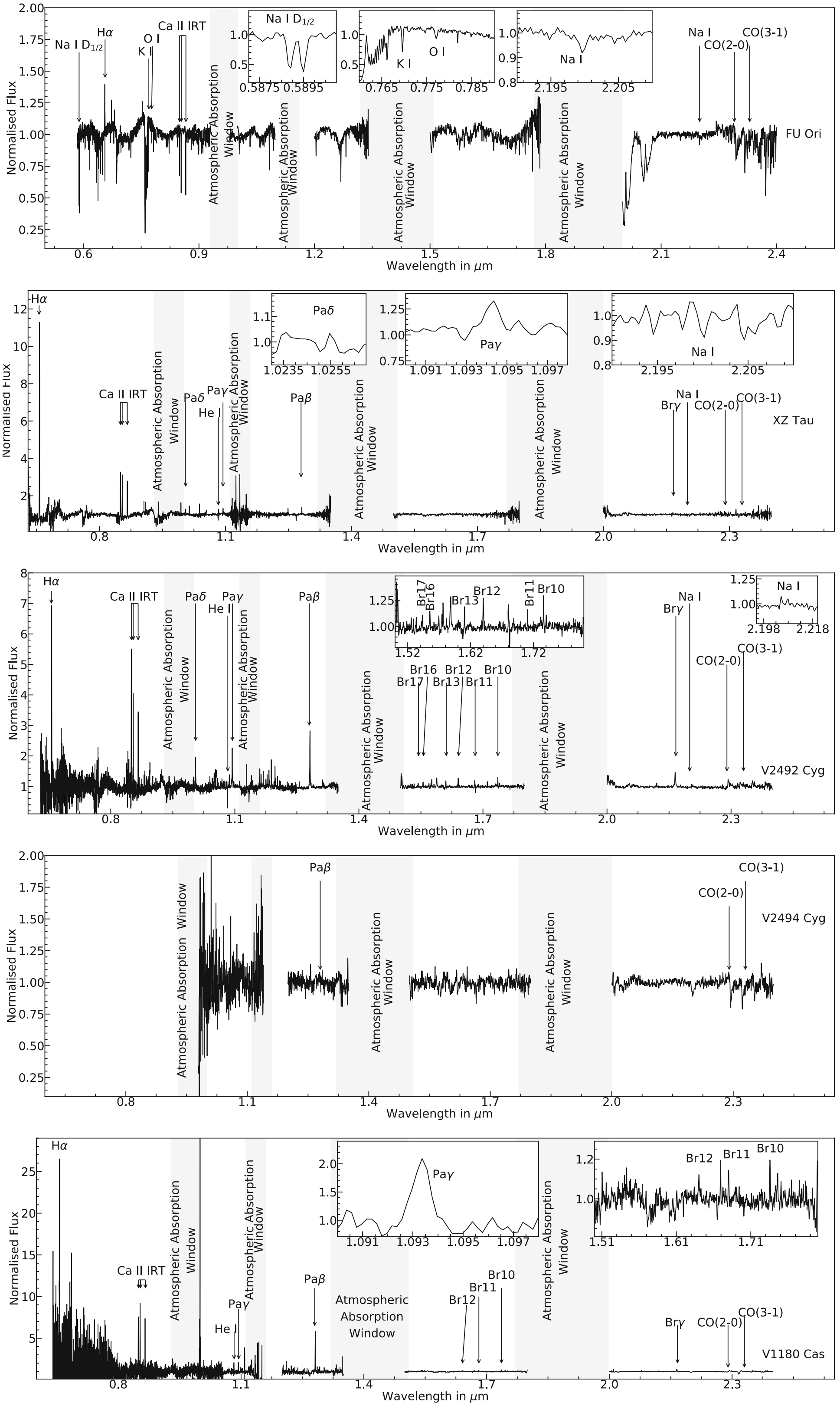

Figure 2. Spectra of the young eruptive variables observed with TANSPEC. The lines, which have been discussed in the present study are marked. The Paschen and Brackett series lines are abbreviated as 'Pa' and 'Br', respectively. The shaded grey regions denote the atmospheric absorption window in our spectrum.

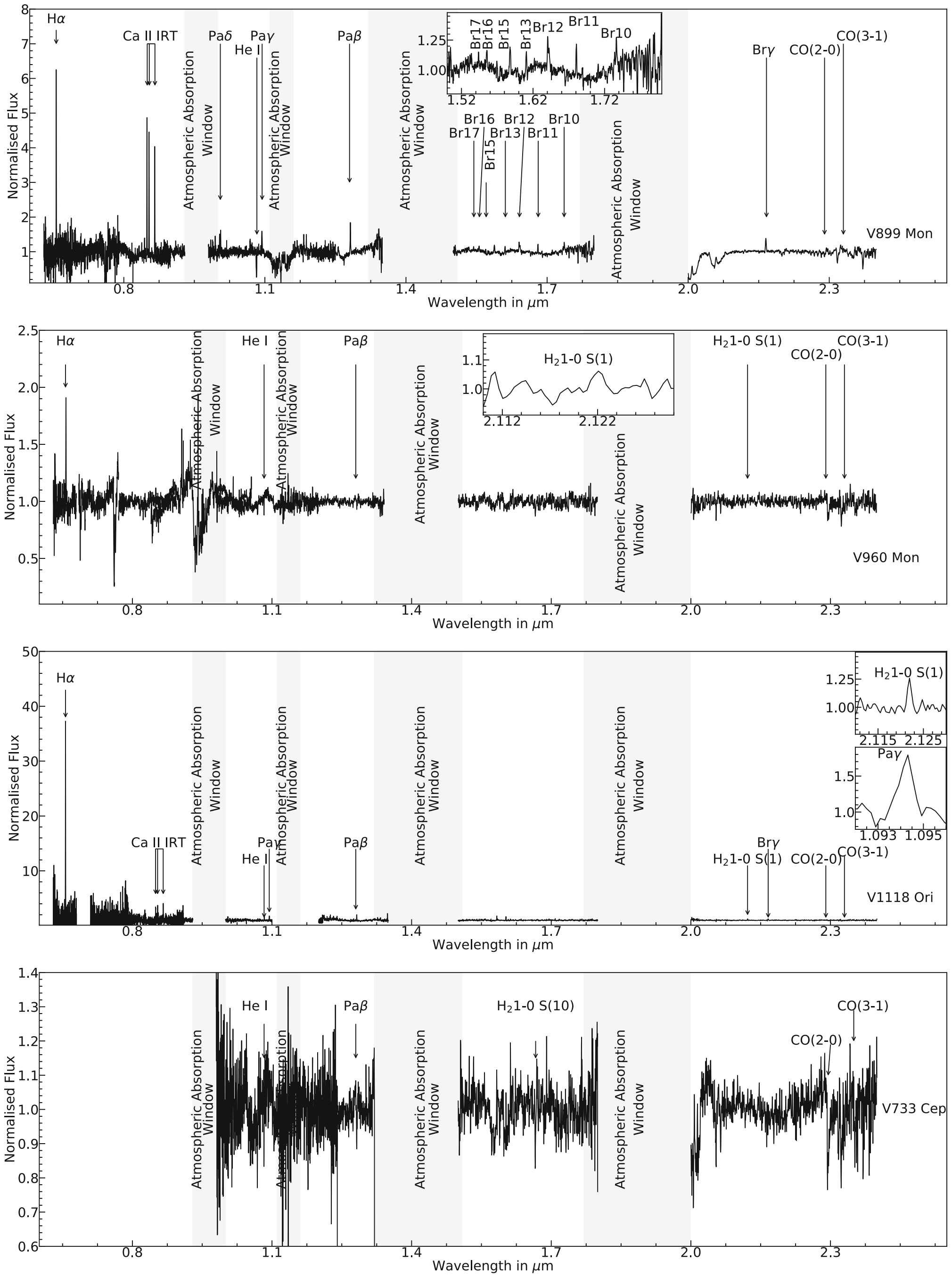

Figure 2. Continued.

zoomed-in version of the most common lines that are discussed in this paper.

3.1 *FU Ori*

FU Ori is the first observed member of the class of young stellar objects (YSOs) displaying episodic accretion behavior as it underwent a brightening of >5 magnitudes from its historical magnitude of ∼16 magnitude in V band in the year 1936 (Wachmann 1954). It has since then faded by ∼1/2 magnitude in the next 40 years (Herbig 1977). It is located in the B35 dark nebula present in the Orion star-forming region. FU Ori, being the first prototype of the category of episodic accreting YSOs and that of FUor sub-group, its spectrum serves as a reference for all other potential new episodically accreting YSOs and FUors in general.

CO bandheads in K: Spectroscopically, FUors display an absorption feature, while EXors exhibit an emission feature in the (2–0) and (3–1) CO bandheads.

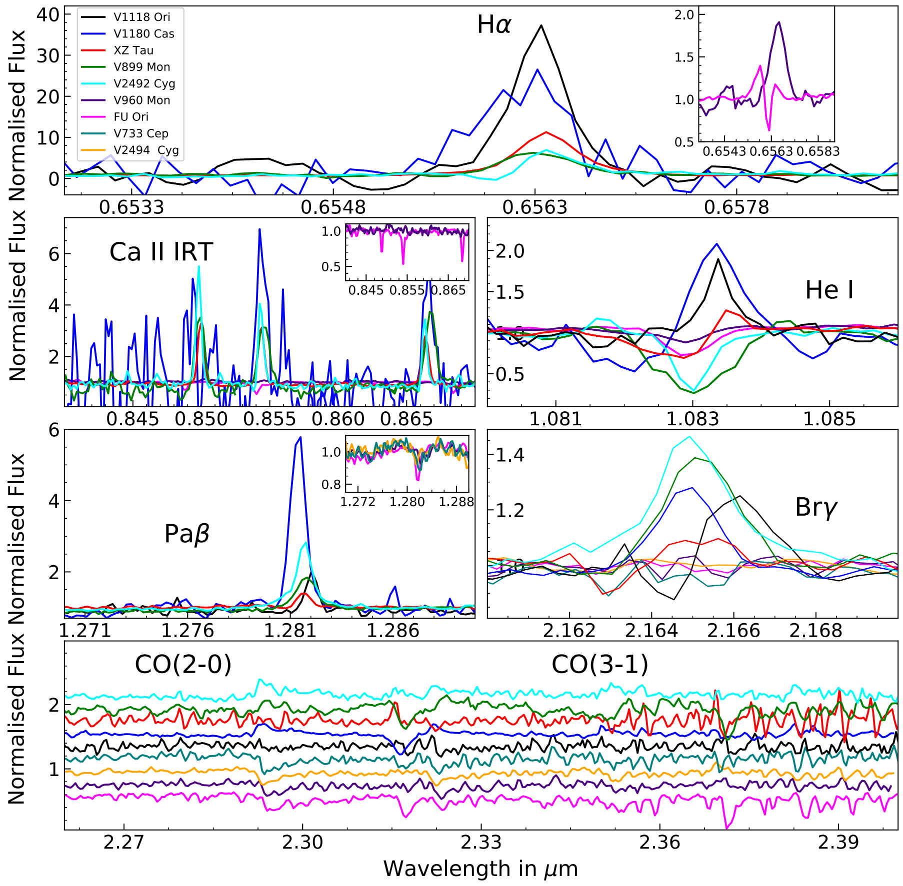

Figure 3. Zoomed line profile of the important lines that are discussed in this paper.

FU Ori, being the first prototype of FUors display deep absorption bands in CO bandheads. The origin of such deep absorption features in CO bandheads along with the absence of Brγ emission in the spectrum can be attributed to the boundary layer accretion mechanism, which is different from magnetospheric accretion regime. In the boundary layer accretion model, the accretion rate is so high that the ram pressure of the inflowing matter in the disc breaks through the magnetic pressure, with matter accreting onto the central PMS star in the disc mid-plane (Hartmann & Kenyon 1996).

Metallic lines: The spectrum of FU Ori contains absorption feature of the metallic lines of Na I at 2.206 μm. However, the metallic line of Ca at 2.256 μm is absent in our spectrum of FU Ori. Previously, Connelley & Reipurth (2018) have reported weak presence of both these metallic lines in their spectrum of FU Ori. Lorenzetti *et al.* (2009), by their continuous NIR spectroscopic monitoring have shown that the metallic line of Na I likely originates in regions close to that of the CO bandheads and generally, follows the profile of the latter, i.e., if the CO bandheads are in absorption, the Na I lines will be in absorption and vice versa.

1.083 μm He I: In our spectrum of FU Ori, He I line at 1.083 μm displays a prominent absorption feature. The absorption feature in He I is indicative of the outflowing winds generated due to accretion (Edwards *et al.* 2003).

Ca II infra-red triplets: Ca II infra-red triplet (IRT) in the spectrum of FU Ori is found to be in absorption. The absorption feature in the spectrum of FU Ori can be explained by the disk wind models of Hartmann *et al.* (1990). These wind models describe about the various observed line profile shapes in terms of outflowing wind densities, temperatures and velocity fields.

O I 7773 Å: The O I line at 7773 Å has a high ionization state of ∼9 eV, which prevents its formation in the photosphere of cool stars and it is believed to form in the broad component regions (BCRs) that correspond to the warm gas in the envelope and is therefore, believed to act as a tracer for disc turbulence

(Hamann & Persson 1992). This likely explains the observed absorption feature at 7773 Å.

K I: We have also detected blue-shifted absorption feature in the metallic line of potassium, K I at 7699 Å. This line is an indicator of the disc winds from FU Ori (Hartmann 1998).

Hα: Hα profile exhibited by the spectrum of FU Ori is very complex. It displays a primary peak along with a blue-shifted secondary peak, which is greater than the primary peak. The observed line profiles can be explained in terms of the wind models of Hartmann *et al.* (1990). The most likely wind models that can simultaneously explain the observed Ca II IRT and Hα are Models 3(I) and 4(I) presented in Table 1 of Hartmann *et al.* (1990), where the regions from which, these winds arise, likely have temperatures ranging between 5000 K and 10,000 K.

Na I D$_{1/2}$: The spectrum of FU Ori also displays the absorption profile in the Na I D lines. With the resolution of TANSPEC, we can resolve the doublet lines of sodium. The absorption feature is typical and is indicative of the outflowing winds. The observed blue-shifted Na I D lines place a further qualitative constraint on the mass loss rate to be 10^{-7} $M_\odot$ yr^{-1} or greater (Hartmann *et al.* 1990).

3.2 *XZ Tau*

XZ Tau is a Classical T Tauri (CTT) star of spectral type M3 located in the L1551 dark cloud of Taurus star-forming region. It has been classified as an EXor type variable by Lorenzetti *et al.* (2009) based on its photometric and spectroscopic evolution. During our observation, the brightness of XZ Tau was ∼13.2 mag in V band. This enabled us to obtain the spectrum of XZ Tau from TANSPEC. We can identify several spectroscopic features, some of which are in absorption, while the rest are in emission. The main spectral features that we can identify are summarized below.

CO bandheads in K band: We can identify very weak absorption CO overtone features of (2-0) and (3-1) transitions in our spectrum. Previously, Lorenzetti *et al.* (2009) reported the bandheads to be in absorption in their low resolution ($R \sim 250$) spectra. This weakening of the CO overtone feature as observed in our spectra can be attributed to the change (increase) in the stellar temperature, resulting in increased irradiation of the inner disc, which decreases the strength of the CO bandheads (cf. Figure 7 of Calvet *et al.* 1991). This variation in the CO bandhead features months of timescales, which were previously reported by Lorenzetti *et al.* (2009).

2.2 μm Na I: The atomic line Na I has an ionization potential of 5.1 eV, which is very low, hence it is believed to have originated at the inner part of the circumstellar disc, which are capable of shielding the ionizing photons (Lorenzetti *et al.* 2009). The Na I line in the spectrum of XZ Tau is found to be in absorption. This reinforces our understanding that the Na I and the CO bandheads have a common origin (McGregor *et al.* 1988).

2.165 μm Brγ: Brγ line is an important tracer for magnetospheric accretion in the NIR regime (Connelley & Reipurth 2018). Brγ line in the spectrum of XZ Tau displays a P Cygni profile hence, it can be assumed that the accretion process in XZ Tau is likely to be of magnetospheric origin along with outflowing winds from regions close to the accretion columns.

1.28 μm Paschenβ: Hydrogen recombination line of Paschenβ is another diagnostic tracer of accretion as this line in the spectrum is believed to originate in the magnetospheric accretion columns (Folha *et al.* 1997). In the spectrum of XZ Tau, we note that the Paschenβ line displays a P Cygni profile, which again can be attributed to the outflows originating from the regions close to the magnetospheric accretion columns.

1.083 μm He I line: The He I line at 1.083 μm is produced due to resonant scattering from the meta-stable Helium atoms and is an excellent diagnostic probe for the outflowing winds from YSOs (Edwards *et al.* 2003). The EUV to X-ray radiation formed due to the accretion results in the formation of the meta-stable triplet state of Helium atoms, which then, resonant scatter the 1.083 μm photons resulting in a strong absorption signal in the spectrum. Our spectrum of XZ Tau exhibit absorption trough at 1.083 μm indicative of the outflows generated due to the magnetospheric accretion. Previously, Antoniucci *et al.* (2017) reported a complicated profile of the He I line in their high resolution spectra. We have not observed any such complicated profile in our spectrum. The non-detection can either be attributed to the lower resolution of our spectrum being unable to resolve those features or to the change in the structure of the outflowing wind.

Ca II IRT line: Emission feature in the infra-red triplet lines of Ca II in YSOs is thought to originate from the active chromospheres and the magnetospheric accretion funnels (Hamann & Persson 1992; Muzerolle *et al.* 1998). In our spectra of XZ Tau, the Ca II IRT are found to be in emission, indicative of the magnetospheric accretion process, being the agent behind the accretion of matter from the circumstellar disc to the central pre-main sequence star of XZ Tau.

Hα: The spectrum of XZ Tau exhibits an emission feature in Hα. This emission feature in Hα likely points toward a combination of accretion process, hot spots, magnetic field topology, etc., in XZ Tau (Alcalá *et al.* 2014).

3.3 *V2492 Cyg*

V2492 Cyg also known as PTF 10nvg is a Class I pre-main sequence star that underwent its first recorded outburst in 2010 (Aspin 2011). It has displayed a highly variable photometric behavior since then, transitioning with it to outburst state in 2016–2017 (Munari *et al.* 2017). It has continued to show its highly variable behavior after this latest episode of outburst. The physical origins of the variability observed in V2492 Cyg has been attributed to be driven by both UXor-type extinction[3] and EXor-type accretion (Hillenbrand *et al.* 2013; Giannini *et al.* 2018; Ibryamov & Semkov 2021). A paper describing about the detailed evolution of the various spectral features from previous outbursts till present times is currently under preparation. The spectral lines that we have obtained from our TANSPEC spectrum of V2492 Cyg are the CO bandhead features in K band, 2.2 μm Na I, 2.165 μm Brγ, 1.28 μm Paschenβ, 1.083 μm He I, Ca II IRT and Hα.

3.4 *V2494 Cyg*

V2494 Cyg is located in the L1003 dark cloud of the Cygnus OB7 star-forming complex at a distance of 800 pc (Magakian *et al.* 2013). V2494 Cyg was spectroscopically classified as an FUor source owing to its similarity with the spectrum of FU Ori by Reipurth & Aspin (1997). The source was faint during our observation with a magnitude of ~17.5 mag in zr band of Zwicky Transient Facility (ZTF) and therefore, we could only obtain the NIR spectrum of V2494 Cyg.

The prominent lines visible in our spectra are the CO bandhead features in K and Paschenβ. A detailed analysis of the spectral line features and their evolution will be described in a separate upcoming paper.

3.5 *V1180 Cas*

V1180 Cas is variable star located in the dark cloud Lynds 1340 in the star-forming region in Cassiopei, located at a distance of 600 pc from the Sun. It was identified by Kun *et al.* (1994) as a variable young star based on its strong Hα emission. V1180 Cas, similar to V2492 Cyg exhibits highly variable photometric behavior that can be attributed to a combination of extinction and accretion rate changes (Mutafov *et al.* 2022). The main spectral features of V1180 Cas as obtained from TANSPEC are described below.

CO bandheads in K: The CO bandheads in the spectrum of V1180 Cas are in emission, implying the strong irradiation from the central pre-main sequence star to the inner part of the circumstellar disc (Calvet *et al.* 1991).

2.165 μm Brγ: In the NIR regime of the spectrum of T Tauri stars, Brγ is an important signature of the magnetospheric accretion (Connelley & Reipurth 2018). The spectrum of V1180 Cas also exhibits a strong Brγ emission line.

Hydrogen recombination lines of Brackett series in H band: The spectrum of V1180 Cas several Brackett series hydrogen recombination lines with all of them being found to be in emission. We can identify the Brackett (12-4), Brackett (11-4) and Brackett (10-4) recombination lines.

1.28 μm Paschenβ: The Paschenβ line in the spectrum of V1180 Cas is in emission. The Paschenβ line profile observed in V1180 Cas is similar to that observed in the case of V2492 Cyg implying similar physical processes governing its evolution.

1.083 μm He I: The He I line at 1.083 μm exhibits a P Cygni profile in the spectrum of V1180 Cas. P Cygni profile as observed in the spectrum therefore, signifies the heavy mass loss via outflowing winds from the innermost regions of the disc from where the accretion onto the PMS star is occurring (Edwards *et al.* 2003).

Ca II IRT lines: The Ca II IRT lines are found to be in emission therefore, indicating magnetospheric accretion of matter from the circumstellar disc.

Hα: The Hα line in the spectrum of V1180 Cas is in emission and is considerably stronger in strength compared to that observed in V2492 Cyg and XZ Tau.

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[3] UXor-type variability arises due to occultation of the central YSO by the matter present in the circumstellar disc.

3.6 *V899 Mon*

V899 Mon is located in the Monocerous R2 region of our galaxy at a distance of about 905 pc (Lombardi *et al.* 2011). It was reported as an episodic accretion candidate by the Catalina Real Time Survey (CRTS) when it underwent an outburst in 2010 and the subsequent spectrum of the source displayed strong Hα and Ca II IR triplet lines, which confirmed it to be an YSO (Wils *et al.* 2009). V899 Mon is peculiar kind of YSO exhibiting episodic accretion behavior. During its 2014 outburst, V899 Mon displayed properties intermediate to that of FUors and EXors (Ninan *et al.* 2015). Spectroscopically, it displayed P Cygni profile in Hα and Ca II IRT, while the prominent NIR lines (1.083 μm He I and CO bandheads in K band) were found to be in absorption. After the 2014 outburst, V899 Mon has been steadily transitioning toward its quiescent state. Recent spectroscopic observations made by Park *et al.* (2021), reveals transition of the P Cygni profile of Hα and Ca II IRT into emission feature. The NIR CO bandhead features also transitioned into emission. We will be discussing about the detailed evolution of the various spectral features and the likely physical processes governing their evolution in a separate paper that is currently under preparation. The prominent spectral features of V899 Mon that we have observed with TANSPEC are CO bandheads in K, 2.165 μm Brγ, several Hydrogen recombination lines in H band like Br10 at 1.736 μm, Br11 at 1.681 μm, Br12 at 1.641 μm, B13 at 1.611 μm, Br15 at 1.571 μm, Br16 at 1.556 μm and Br17 at 1.544 μm. Several Paschen series lines were also detected in the spectrum like the Paschenβ, Paschenγ at 1.094 μm and Paschenδ at 1.005 μm. We have also detected the 1.083 μm He I, the IR triplet of Ca II and Hα in the spectrum.

3.7 *V960 Mon*

V960 Mon is also known as 2MASS J06593158−0405277 is located in the Monocerous star-forming region of the galaxy at a distance of 450 pc. V960 Mon underwent its first recorded outburst in 2014 and has since been steadily fading from its peak brightness since then, typical of sources displaying FUOrionis behavior (Jurdana-Šepić & Munari 2016). The spectral characteristics exhibited by V960 Mon were also similar to that of FU Ori, the first member of the FUOrionis sub-class of episodically accreting young stars (Hillenbrand 2014; Reipurth & Connelley 2015). V960 Mon was, spectroscopically monitored after its 2014 outburst by Takagi *et al.* (2018). Their monitoring revealed gradual decline in the luminosity of the accretion disc post outburst due to decrease in accretion rate. Recently, Takagi *et al.* (2020) and Park *et al.* (2020) presented further spectroscopic monitoring results of V960 Mon. Their results indicate a gradual weakening of the wind features post outburst along with the presence of double-peaked line profiles indicative of Keplerian rotation. Spectroscopic monitoring further revealed that the spectrum of V960 Mon has become central star dominant.

The main spectral features that we have observed with our TANSPEC spectrum are the CO bandheads in K, 2.12 μm H_2 line, 1.28 μm Paschenβ line, 1.083 μm He I and the Hα. A detailed analysis of the observed line profiles of V960 Mon and the possible underlying physical processes will be described in an upcoming paper.

3.8 *V1118 Ori*

V1118 Ori has been classified as belonging to the EXor sub-group of eruptive young variables. It underwent its first recorded outburst in 2006 after which it remained in quiescence for almost a decade, following which it again underwent an outburst during 2015–2016 period (Giannini *et al.* 2017). V1118 Ori again underwent an outburst during 2019, which lasted almost for a year and by February 2020, it had transitioned back to its quiescent phase (Garcia *et al.* 2020). We have obtained our spectrum of V1118 Ori on 29 October 2020. In the following, we will discuss about the spectral line profiles that we have obtained.

CO bands in K: In our spectrum of V1118 Ori, the CO bandheads are found to display a weak absorption profile. Previously, Lorenzetti *et al.* (2015) and Giannini *et al.* (2016, 2017) have reported that the CO bandheads to be in emission. The weak bandheads possibly hint toward the change in the inner structure of the circumstellar disc as the CO bandheads in emission is thought to arise from the warm gas in the innermost part of the disc powered by active accretion (Najita *et al.* 1996; Lorenzetti *et al.* 2009; Kóspál *et al.* 2011). In the case of XZ Tau, the presence of 2.2 μm Na I in absorption helped to definitively conclude about the weak absorption in the CO bandheads. However, the spectrum of V1118 Ori lacks the Na I line, hence we refrain from inferring anything from the observed bandhead features, rather more time-series spectroscopy of this source is required to understand the evolution of CO bandheads.

2.165 μm Brγ: The Brγ line our spectrum of V1118 Ori is found to display a P Cygni profile. Presence of P Cygni profile in Brγ points toward heavy outflow from the regions close to accretion as Brγ is an important tracer of accretion in the NIR (Connelley & Reipurth 2018).

H_2 lines in K: We have detected the H_2 (1-0) transition feature to be in emission in our spectrum of V1118 Ori. H_2 lines are absent in the spectrum of FUors with V960 Mon to be an exception (Park *et al.* 2020). However, H_2 lines are seen in several EXors, like ESO$-$Hα 99 (Hodapp *et al.* 2019), V346 Nor (Kóspál *et al.* 2020), Gaia 19bey (Hodapp *et al.* 2020), etc. Emission feature in H_2 (1-0) is indicative of the outflows in young stars (Davis *et al.* 2003, 2010; Bally *et al.* 2007).

Hydrogen recombination lines of Paschen series: Hydrogen recombination lines in emission are an important diagnostic tracer of the magnetospheric accretion (Folha *et al.* 1997). In our spectrum of V1118 Ori, Paschenβ and Paschenγ line display a prominent emission profile, thereby indicating magnetospheric accretion to be the main accretion process in V1118 Ori.

1.083 μm He I: The 1.083 μm He I line in our spectrum of V1118 Ori is found to be in emission. The emission feature we have observed, was seen previously in the spectrum of V1118 Ori, as reported by Lorenzetti *et al.* (2015) during the decades long quiescence of V1118 Ori and also during its 2015 outburst (Giannini *et al.* 2016). He I has a very high ionization potential and its presence in emission can be likely attributed to composite origin arising from accretion funnel flow and/or from an accretion shock (Edwards *et al.* 2003).

Ca II IRT: The emission features in Ca II IRT lines are believed to form in the magnetospeheric accretion funnels in YSOs (Muzerolle *et al.* 1998). In our spectrum of V1118 Ori, we have found the Ca II IRT lines to be in emission, thereby likely indicating of magnetospheric accretion process.

Hα: Hα in emission in YSOs likely arises because of several processes like chromospheric activity, hot spots on the stellar surface, stellar rotation, magnetic field topology, etc., apart from the accretion rate (Alcalá *et al.* 2014). In our spectrum of V1118 Ori, Hα line is found to be in emission. As V1118 Ori is currently in quiescent phase, therefore, the likely significant contribution to the emission line in Hα is from the other processes as mentioned above, apart from the accretion rate.

3.9 *V733 Cep*

V733 Cep, also known as the Persson's star is located in the L1216 = Cep F cloud in the Cepheus region at a distance of 800 pc (Reipurth *et al.* 2007). Based upon the Spectral Energy Distribution (SED) analysis and spectroscopic similarity with that of FU Ori, Reipurth *et al.* (2007) classified V733 Cep as an FUorions candidate, with it, has undergone an outburst sometime between 1953 and 1984. The spectral features that we have observed in our TANSPEC spectrum of V733 Cep are CO bandheads in K, H_2 1-0 S(10) at 1.6665 μm, 1.28 μm Paschenβ and the 1.083 μm He I. We are currently studying the evolution of the various spectral features of V733 Cep in detail and a separate paper is currently under preparation.

4. Summary and conclusion

We have presented here a single epoch spectra of nine young eruptive variables that are either classified as FUor or EXor. Our observations with TANSPEC clearly emphasize the unique wide spectral coverage of TANSPEC starting at optical wavelengths of 0.55 μm to all the way till the NIR wavelengths at 2.5 μm. The resolution and especially, the wide spectral range makes TANSPEC an ideal instrument to probe the innermost regions of the circumstellar disc of YSOs from where the accretion and the outflow process onto the young star occurs. In this paper, we have analysed the line profile shapes of the observed set of episodically accreting young stars. We have tried to explain the observed line profile shapes based on the existing models that explains the physical processes that occur in these group of sources. The episodically accreting stars are broadly classified into FUors and EXors with our current theoretical understanding is that the accretion mechanism onto the central young star is possibly different in the sub-groups (Hartmann & Kenyon 1996). Our observation of the set of FUors and EXors, points to the similar understanding, however, more spectroscopic observations with a larger set and time series spectra are needed to validate the current theoretical understanding.

The main conclusions that can be drawn from this study are summarized below:

1. The classical bi-modal spectroscopic classification of the episodically accreting young stars based on the absorption/emission profile of the CO bandheads probably needs a revision. For better categorization, we need to look at a set of common line profile shapes and compare them with the current theoretical models.
2. The changing of the spectral line profiles and the emergence of new spectroscopic features, as

observed in the cases of XZ Tau and V1118 Ori brings forth the necessity of the long term spectroscopic monitoring for better understanding of the physical processes that govern the disc evolution and the accretion dynamics. Time evolution spectroscopic studies will also help to establish link between the accretion and outflow processes.

3. We further identify V960 Mon, which is classified as FUor, to be somewhat peculiar in the sense that it displays spectroscopic features like the H_2 recombination lines in its spectrum that are generally associated with the spectrum of EXors.
4. We plan to further monitor the source V1118 Ori spectroscopically. The CO bandhead features were prominently detectable in emission in its spectrum. However, in our spectrum, the features were barely detectable. Therefore, we urge for more observations to better understand its current evolution and also to corroborate our observation.

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