An improved Technique to Explore Disk Accretion Process in PMS Stars

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Abstract: The low mass PMS stars are found to be surrounded by thick flared accretion disk and the disk material is supposed to be funneled on to the stellar surface by strong and predominately dipolar magnetic field. We have developed a simple technique which uses medium resolution optical spectrum and gives reliable disk accretion rate. In this talk I will briefly describe our technique and also present the preliminary results obtained.

1 Introduction

The formation of circumstellar disks is considered to be a natural process when a molecular core collapses to form a star. There are ample evidences of the presence of circumstelar disk around intermediate and low mass pre-main sequence stars such as HAeBe and CTTS. Whereas, the recent work also reveals presence of disk in very massive stars to the objects closely resemble with floating planets. The low mass PMS stars are found to be surrounded by thick flared accretion disk and the disk material is supposed to be funneled on to the stellar surface by strong and predominately dipolar magnetic field. The knowledge of disk accretion rate in the object having different age, mass, rotation and environment is very crucial to understand not only the formation of planets but it will also shed light on stars formations as well. The disk accretion rates are primarily determined by modeling, (1) the excess blue continuum emission, (2) the optical and NIR line emission and (3) modeling of Spectral Energy Distribution (SED) in longer wavelength regime. However, the actual methods based on above mentioned modeling techniques are quite complicated, needs sophisticated instruments on the large telescope and therefore, can not be applied to very large sample (Herczeg & Hillenbrand 2008 and references therein). Furthermore, the accretion rates determined by different techniques and researcher do not agree well. Finally, the accretion rates are most likely variable on various time scale and to determine this intrinsic variability need for an easy method is realized. Keeping all these in mind we attempted to develop a simple but reliable technique which can be used on a large sample of stars. We have applied our technique to measure the accretion rates in well known Classical T Tauri Stars (CTTS) and observation and results are presented in sub sequent sections.

2 Observations and data redction

The medium resolution spectroscopic observations of CTTS and template stars were carried out using 2m HCT (Himalayan Chandra Telescope) of the Indian Astronomical Observatory equipped with the HFOSC spectrograph. Observation were made during few nights in November 2006. Two different blue and red grisms Gr14 and Gr8 were used to cover almost whole optical spectral window (3600-9200Å). The spectroscopic observations were carried out using narrow 67 micron ($\sim 0.75''$) as well as wide 1340 micron ($\sim 15.0''$) slits. The highest resolution set by the narrow slit for these two grisms are R$\sim$1000 and R$\sim$2100 respectively. The spectral shape of the stellar spectrum obtained using narrow slit at low telescope elevation is usually highly distorted by atmospheric dispersion. To avoid the atmospheric dispersion effect on our observed spectrum we rotated the instrument field de-rotator by the parallactic angle, which aligns the slit-length along the telescope elevation axis. On each night, observations of 2-3 spectrophotometric standard close to the CTTS and templates stars were also carried out with the purpose of flux calibration. The spectroscopic observations were reduced using task available in the IRAF. After bias subtraction and flat field correction, stellar spectra were optimally extracted. Arc lamps FeNe and FeAr were used for the wavelength calibration. Finally, the flux calibration was done using spectro-photometric standard stars. While doing the flux calibration usually the average spectroscopic extinction of the site is used. If the extinction of the night differ from the average extinction of the site and the spectroscopic standard stars is observed at different air-mass then there is possibility of the improper flux calibration. To avoid this problem we decided to determine the spectroscopic extinction during same observing run.

3 The modeling technique

3.1 Computation of the excess continuum emission

It is believed that any spectra of CTTS is composite of central star spectrum and the access emission coming from the disk accretion. In order to compute the excess emission in the optical spectrum due to disk accretion, we opted the magnetospheric accretion shock model proposed by Calvet & Gulbring (1998). According this model strong dipole magnetic field truncates the circumstellar disk at several stellar radii and the matter falls through magnetic fields with nearly free fall velocity. Near the stellar surface the in-falling matter forms shock and deposit it's kinetic energy into very localized region. The accretion energy quickly get thermalized and radiated away. Close to stellar surface the structure of the accretion column can be divided into three regions, according to their source of heating: the shock and post-shock regions, the photosphere below the shock, and the preshock region above it. The shocked gas is heated to extremly high temperatures and therefore initially emits mostly soft X-rays (Calvet & Gulbring 1998). Half of this radiation is sent to the photosphere below and half to the preshock region above. In turn, a fraction of the radiation from the preshock gas is emitted back toward the star, adding further nearly one forth of accretion energy to the heated photosphere. The flux of radiation incident on the photosphere deposits energy over a range of optical depths, heating the gas to temperatures higher than the undisturbed surrounding stellar photosphere.

In our observable optical wavelength range, the access emission is dominated by the heated photosphere and which can be approximated by a black-body of effective temperature:

$$T_{eff} = \frac{1}{\sigma}(\sigma T_\star^4 + \left(\frac{3}{4}\frac{\mathcal{F}}{}\right))^{\frac{1}{4}} \tag{1}$$

where $\mathcal{F}$ is energy flux density of the accreting matter, $T_\star$ is effective temperature of the unheated photosphere and σ Stephen Boltzmann constant.

Following Calvet & Gulbring (1998) we can determine $\mathcal{F}$ as function of $\dot{M}$ and hot-spot filling factor f as:

$$\mathcal{F} = 9.8 \times 10^{10} \left(\frac{\dot{M}}{10^{-8} M_\odot yr^{-1}}\right) \times \left(\frac{M}{0.5 M_\odot}\right) \times \left(\frac{R}{0.5 R_\odot}\right)^{-3} \times \left(\frac{f}{0.01}\right)^{-1} \tag{2}$$

Where M and R are stellar mass and radius in solar unit and $\dot{M}$ is the mass accretion rate. Once the effective temperature of heated photosphere is known then the excess flux at each wavelength coming from per unit stellar surface area can be computed as.

$$E(\lambda) = B_\lambda(Teff) \tag{3}$$

3.2 Determination of the accretion and extinction parameters

Once we have computed the excess emission coming from heated photosphere then we can use the method proposed by Chelli (1999), which is nothing but slightly modified form of the method used by Gullbring et al. (1998) into discrete veiling data. According this method the CTTS spectrum can be

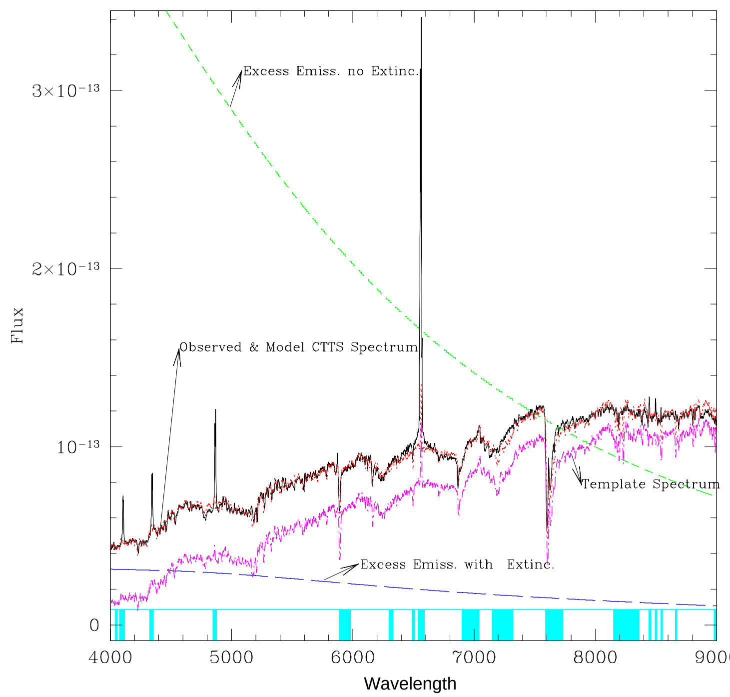

Fig. 1. Modeling observed spectrum of BP Tau a CTTS star with the template having similar MK type.

considered as a composite spectrum of the central PMS object and the excess emission predominately coming from heated photosphere. Therefore, once we have suitable template spectrum representing central PMS object then the CTTS spectrum can be synthesizes as:

$$O_c(\lambda) = p_o 10^{-0.4 f(\lambda) A_v} \left[(1-f) S(\lambda) + f E(\lambda) \right] w(\lambda)) \qquad (4)$$

where $S(\lambda)$ is observed template spectrum, p_o is scale factor which primarily depends on distances of CTTS and template stars, A_v is CTTS extinction due to circum stellar and interstellar matter, and f is filling factor of hot spots. The $w(\lambda)$ is window function used to mask the emission line such as Balmer lines and also telluric lines (see the Fig.**??**). Here we assume that the template spectrum has already been corrected for inter stellar extinction. If the $O(\lambda)$ is flux calibrated observed spectrum of CTTS star then the χ^2 merit function can be written as

$$\chi^2(p_o, A_v, f, \dot{M}) = \sum_{i=1}^{N} \left(\frac{(O_{c,i}(p_o, A_v, f, \dot{M}) - O_i)^2}{(\sigma_{o,i}^2 + \dot{\sigma}_{s,i}^2)} \right) \tag{5}$$

where the scaled varaince of the tempelate spectrum is given as:

$$\dot{\sigma}_{s,i}^2 = \left(p_o 10^{-0.4 f(\lambda) A_v} \sigma_{s,i} \right)^2 \tag{6}$$

The χ^2 is non linear function of four parameters p_o, a_v,f and $\dot{M}$, therefore, the Levenberg-Marquardt technique was used to obtain optimized values of the parameters from observation. An example of such fitting to observed spectrum of the BP Tau is shown in the Figure **??**. Where, we have shown observed and fitted BP Tau spectrum, template spectrum and excess emission with and without extinction corrections.

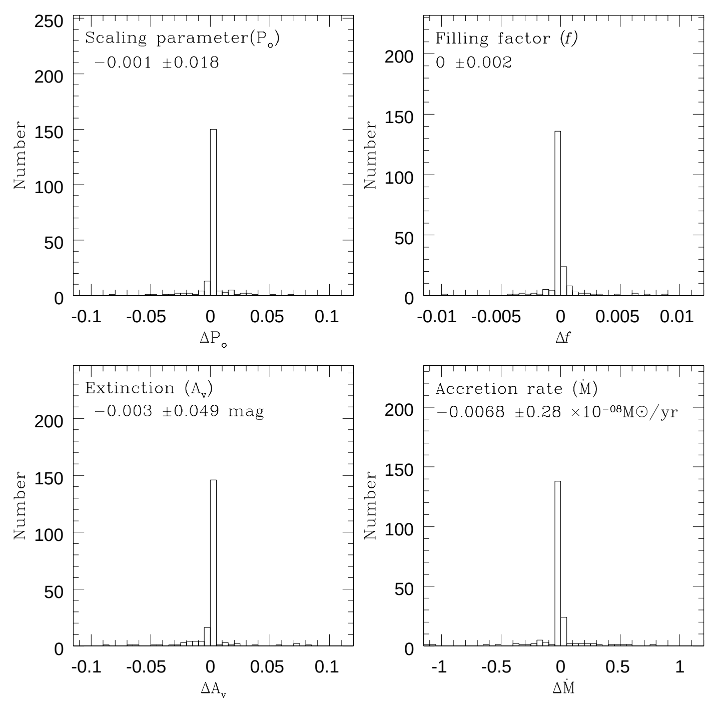

Fig. 2. Testing the reliability of the modeling technique using synthetic spectra of accreting CTTS stars.

4 Testing the modeling technique

In order to test reliability of the optimized parameters obtained from modeling of the observed data as described in previous section, we decided to first test our technique with synthesized CTTS spectrum. For this purpose we generated synthetic CTTS spectrum by adding excess emission expected from certain f and $\dot{M}$ parameters to observed template spectrum. The error associated with the excess emission is photon shot noise and that's why the Poisson noise was added to the excess emission. Then after, the spectrum was modulated with CTTS extinction (see eq 1.). Finally, the synthesized CTTS data was treated as observed CTTS and modeled using the technique described in the previous sections. The recovered parameters are compared with the actual value of parameters. This test was repeated with two hundreds randomly selected parameters having all possible values and the result are shown in the Figure **??**. It is clear from the Figure **??** that when same template was used to synthesize CTTS spectrum as well later on to model it, the recovered parameters are almost close to true values. Whereas, slightly different values of the parameters are obtained in case when different templates were used to synthesize CTTS spectrum and to model the same spectrum. From above test it appears that the model parameters can be uniquely determined provide the template has well determined extinction and its MK spectral type closely matches with CTTS one.

Table 1. CTTS modeling results

	Present Work				Previous Work			
CTTS	Temp	A_v	f	$\dot{M}$	A_v	f	$\dot{M}^a$	$\dot{M}^b$
BP Tau	V819Tau	0.43	0.011	8.3	0.51	0.007	2.3	2.9
DN Tau	V819Tau	0.68	0.016	8.4	0.25	0.005	0.2	0.3
DF Tau	LkCa7	1.42	0.003	14.5	0.45	0.023	2.3	17.7
GM Aur	V819Tau	0.47	0.037	5.6	0.31	0.001	1.0	1.0
UY Aur	V819Tau	0.77	0.008	1.6	1.26	0.010	3.2	6.5

a: disk accretion rate from Calvet & Gullbirng (1998)
b: disk accretion rate from Gullbirng et al. (1998)

5 Modeling well known CTTS spectra

After going through the rigorous testing of our modeling technique we used it on few well studied CTTS spectroscopic observation obtained from HCT. We tried to use the same template star as used by previous researchers. The optimum values of three parameters A_v, f and $\dot{M}$ of four stars are given in the Table 1. In the same table we also provide the values of these parameters obtained by Calvet & Gullbring (1998) and Gullbring et al. (1998). From the comparison of accretion rate and other parameters it appears that more are less our values closely resembles with previous finding. In few cases where we find substantial differences in some of the parameters may be interpreted either due to time variation or our/previous estimates are incorrect.

References

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