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Near-infrared Accretion Diagnostics of Young Stellar Objects

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1. Introduction

Hydrogen emission lines in the Brackett series are thought to trace the accretion process in Young Stellar Objects (YSOs) (Muzerolle et al. 1998; Bary et al. 2008), arising when material from a protoplanetary disk accretes onto its star and is shock heated (Hartmann et al. 2016). Studying the characteristics of these lines, such as their equivalent width (EW) and full-width at half maximum (FWHM), may yield a better understanding of the kinematics and rates of accretion as they relate to stellar and disk properties.

2. Methods

We study the characteristics of Brackett emission lines for 165 YSOs in the Taurus star-forming region with spectra from the Immersion Grating Infrared Spectrometer (IGRINS). Each IGRINS spectrum covers the *H* and *K* bands of the near-infrared with a resolving power of $\lambda/\Delta\lambda \sim 45,000$ (Mace et al. 2016, 2018). The spectra are combined averages from 1 to 10 epochs spanning up to 3yr as part of the IGRINS YSO Survey. We focus our analysis on strong emission lines requiring continuous emission across four resolution elements (~30 km s^{-1}) at or above 3σ, determined from adjacent continuum noise. For each of the 89 sources which meet this threshold, we calculate the line peak, full-width at zero intensity, FWHM, total flux, EW, and asymmetry factor (AF). We define the AF as:

$$\mathrm{AF} = \frac{2(\lambda_{\mathrm{center}} - \lambda_{\mathrm{blue}})}{(\lambda_{\mathrm{red}} - \lambda_{\mathrm{blue}})} - 1,$$

where $\lambda_{\mathrm{center}}$ is the wavelength dividing the total line flux in half, and λ_{blue} and λ_{red} are the wavelengths where the line meets the continuum. A negative AF corresponds to a line with a flux-weighted center that is shifted toward shorter wavelengths. To determine errors on the line parameters, we run 10^4 bootstrap Monte Carlo simulations adding Gaussian noise at the level of the adjacent continuum. Finally, we use *K*-band veiling measurements, r_k (Kidder et al. 2020, in preparation), to correct the EWs for 59 stars where the veiling measurement is possible using the formula:

$$\mathrm{EW}_{\mathrm{corrected}} = \mathrm{EW}(1 + r_k).$$

We also reconstruct part of the spectral energy distribution (SED) for each star in our sample and compute its spectral slope, α. Contributions of the star and disk to the SED overlap in the region between 2 and 20μm, so the spectral slope of this region, given by

$$\alpha(\lambda) = \frac{\delta \log(\lambda F_\lambda)}{\delta \log(\lambda)},$$

roughly describes the presence and quantity of disk material. The α value determines a YSO's "Class," where a Class I source has $\alpha > 0.3$, a Class II source has $-1.6 < \alpha < -0.3$, and a Class III source has $\alpha < -1.6$. We use data from the *Wide-field Infrared Survey*

Explorer All-Sky Data Release (Wright et al. 2010) with fluxes, F_λ, at 3.35, 4.60, 11.56, and 22.09μm to calculate α.

3. Discussion

We focus our discussion on the strongest Brackett line, Brγ, presenting the line properties of our sample in Figure 1. Brγ is detected from 89 sources, including 8 Class Is (out of 9), 72 Class IIs (out of 102), and 9 Class IIIs (out of 54). We find a loose trend between spectral slope and uncorrected EW. The large scatter, however, implies that other factors affect the relationship between the two. For example, it is possible that sources with higher α values also experience higher continuum veiling, which would lower their measured EWs. We see a similar trend in the veiling-corrected EWs, although the scatter persists, indicating a large variability in accretion rates within a given class.

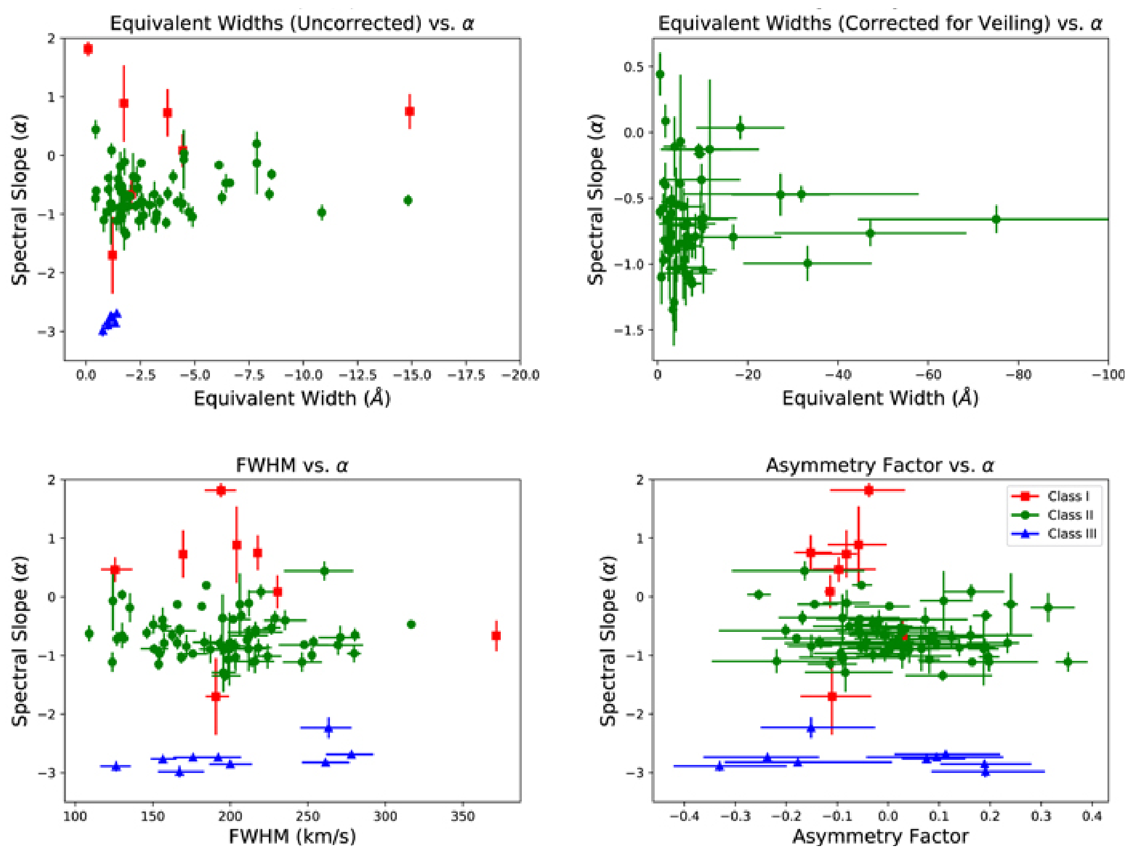

Figure 1. Brγ parameters as a function of spectral slope (*α*). Top panels present the uncorrected EWs on the left and the veiling-corrected EW for Class II sources on the right. Bottom panels present the FWHM and Asymmetry Factor on the left and right, respectively. The colors of the points indicate the accepted class of the stars as defined in Luhman et al. (2010, 2017), and Rebull et al. (2010).

Across our sample, we find an average AF value of 0.0 ± 0.1 with no significant differences between classes, so on a population level, Brγ lines are roughly symmetric. This would suggest that Brγ emission is relatively unaffected by absorption from out/in-flowing material and is a useful diagnostic for characterizing accretion in YSOs.

We find an average FWHM value of 197 ± 46 km s^{-1}, which shows no significant difference between the classes and is consistent with the findings of Folha & Emerson (2001). We do not find a correlation between the FWHM and spectral slope, implying that the characteristics of emission regions are similar despite differences in accretion rates and disk properties.

As noted above, we find Brγ emission from 9 Class III sources, which are typically assumed to be disk-less and non-accreting. The broad emission profiles, however, are consistent with the characteristics of the Class I and II sources and accretion generally (e.g., Muzerolle et al. 2001), rather than chromospheric emission. These weakly accreting sources may be tracing a small gas reservoir that has survived beyond that of the bulk dust population.

Comparing these line properties with other known characteristics of the systems (such as their mass, luminosity, or accretion rate) and observing if they are time variable will further our understanding of the accretion process in YSOs.

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