Tracing Accretion Onto Herbig Ae/Be Stars using Near-Infrared Spectroscopy

Mario E. van den Ancker

European Southern Observatory, Karl-Schwarzschild-Str. 2, D–85748 Garching bei München, Germany

Abstract. The detection and characterization of accretion processes in the disks surrounding young stars may be directly relevant to studies of planet formation. Especially the study of systems with very low accretion rates ($<< 10^{-10}$ $M_\odot$ yr^{-1}) is important, since at those rates radial mixing becomes inefficient and disk material will have to be dissipated into larger bodies at its present location. In these proceedings, we compare the different methods of tracing accretion onto Herbig Ae/Be stars and conclude that high-resolution infrared spectroscopy is currently the only reliable method that offers the required sensitivity to shed light on this problem.

1 Accretion onto YSOs: Why Should We Care?

The mass accretion rate is thought to be a key parameter in the evolution of young stellar objects (YSOs). As a function of time, the accretion rate traces the build-up of material onto the young star and severely affects the evolution of the disk itself. Local disk structure is affected by the rate of mass flow, which in turn is determined by the rate of gravitational energy release. Several studies (e.g. Bertout et al. 1988; Hartigan et al. 1995; Hartmann et al, 1998) have shown that accretion rates around typical T Tauri stars stars are low: of the order 10^{-8}–10^{-10} $M_\odot$ yr^{-1}. Compared to typical disk-masses of < 0.1 $M_\odot$, and disk lifetimes of < 10 Myr, these low accretion rates imply that at the evolutionary stage of a typical T Tauri star, disk accretion is no longer important for building up the mass of the central star. Furthermore, at these accretion rates, the heating of the disk is dominated by reprocessing of light from the central star: the disk is passive.

However, there are several reasons why it is especially important to study accretion in YSOs with the lowest accretion rates: (1) if the accretion rate is observed to be lower than $\sim 10^{-7}$ $M_\odot$ yr^{-1} (the disk mass (typically < 0.1 $M_\odot$)/the disk dissipation timescale (< 10 Myr)), the disk cannot disappear due to accretion onto the central star(s). The conclusion that a significant mass fraction of the disk may be coagulated into larger bodies, such as comets or full-fledged planets, seems justified. (2) recent studies of infrared emission from dust in the disks surrounding Herbig Ae/Be stars (e.g. Bouwman et al. 2003) have shown that crystalline silicates are found at temperatures of a few hundred K; temperatures that are much lower than their sublimation temperature of ~ 1500 K. Therefore they cannot have formed at their present location. It is currently believed that this provides strong evidence for the importance of radial mixing in

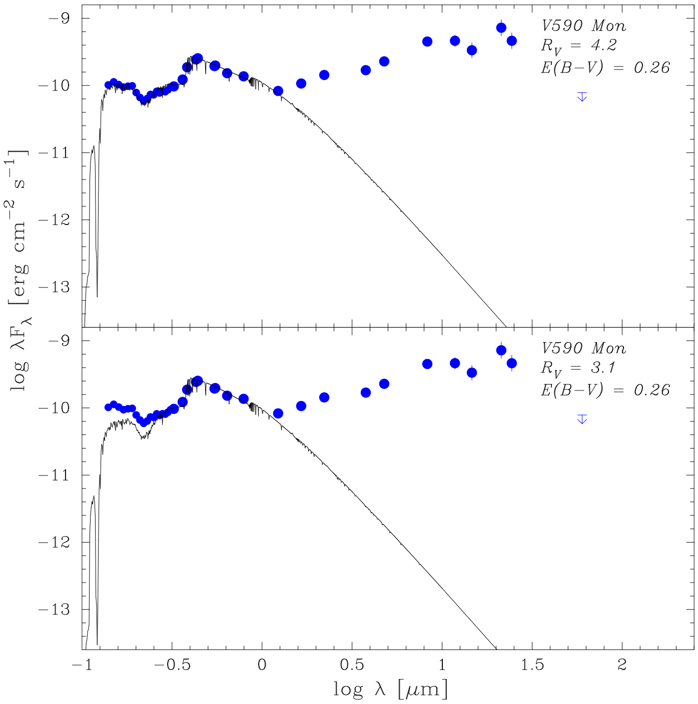

Fig. 1. Observed Spectral Energy Distribution of the Herbig Ae/Be star V590 Mon (dots) fitted to a Kurucz stellar photosphere model (solid line) appropriate for its spectral type. The top panel shows the fit adopting a foreground extinction with larger than interstellar dust grains ($R_V = A_V/E(B-V) = 4.2$), resulting in a good fit to the UV-optical SED. The bottom panel shows the appearance of an virtual UV-excess above photospheric levels when attempting to fit this SED with a normal interstellar dust composition ($R_V = 3.1$).

Herbig stars. However, radial mixing can only occur with the required efficiency in the presence of mass accretion rates larger than a few times 10^{-9} M$_\odot$ yr^{-1}. If accretion rates are proven to be lower than this limit, radial mixing becomes too inefficient to affect disk structure as a whole: not only must the mass in these disks be dissipated into larger bodies, but they also have to form from the radial distribution of material as it is observed

In these *proceedings* we will discuss the different methods of tracing accretion onto Young Stellar Objects and conclude that high-resolution infrared spectroscopy may be the most sensitive method in our current arsenal of determining accretion rates.

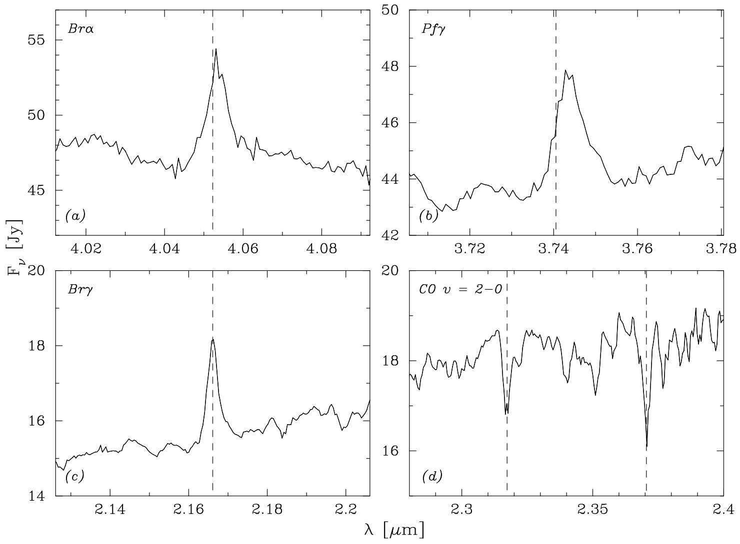

Fig. 2. Examples of detected lines in the IRTF spectra showing the lines of Brα (4.05 μm), Pfγ (3.74 μm), Brγ (2.67 μm) and the CO band-head around 2.3–2.4 μm.

2 Methods to Trace Accretion

Currently employed methods to trace accretion onto YSO can roughly be distributed into two categories: those that study the continuum emission from disk (IR) and accretion shock (UV), and those that attempt to directly study infalling gas through emission lines in the optical or infrared, or its associated free-free emission at radio wavelengths. For accretion rates at which the disk becomes passive (i.e. the majority of disk energy comes from reprocessed starlight rather than the viscous dissipation of accretion energy), the derivation of accretion rates from infrared continuum emission becomes dependent on the details of the disk structure, and hence exceedingly difficult to determine. The commonly used determination of accretion luminosities from UV excesses presumes that one has a good knowledge of stellar photospheric parameters, and of the properties of circumstellar extinction, for which one needs to correct. As the latter is often anomalous, e.g. due to differences in chemical composition or dust particle sizes, a degeneracy occurs between UV excesses commonly attributed to the accretion shock, and extinction properties (Fig. 1). Additionally, for very low mass accretion rates, typical uncertainties in stellar classification and the associated intrinsic stellar colours may prohibit the reliable determination of smaller UV excesses in commonly used photometric systems.

Methods that rely on the emission of infalling gas that gets heated directly by viscous dissipation of energy appear to be more reliable tracers of accretion. The most commonly used of these may be radio continuum emission due to

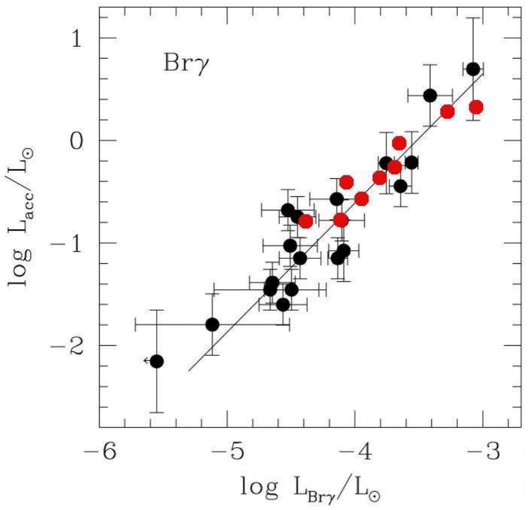

Fig. 3. Correlation between accretion luminosity as derived from UV excesses versus Brγ luminosity for T Tauri stars (black dots; from Muzerolle et al. 1998), and Herbig Ae/Be stars (grey dots; this study).

free-free transitions in H-ions (e.g. Panagia 1991; Nisini et al. 1995). However, current radio telescope sensitivities limit this method to accretion rates larger then $\sim 10^{-8}$ $M_\odot$ yr^{-1}. Therefore we conclude that the study of emission lines, and in particular infrared hydrogen recombination lines, may be the only reliable method currently available to trace the low accretion rates directly relevant to planet formation.

3 Near-IR Spectroscopy of Herbig Ae/Be stars

We obtained new 1.9–4.1 μm spectra of 26 Herbig Ae/Be stars – young massive (2–10 $M_\odot$) stars surrounded by disks – using SpeX, a medium-resolution (R = 1000–2000) cross-dispersed spectrograph mounted on NASA's *Infrared Telescope Facility* (Rayner et al. 2003). Commonly detected lines in these data include IR hydrogen recombination lines such as Brα, Pfγ and Brγ, as well as the CO band-heads around 2.3–2.4 μm (Fig. 2). All detected emission lines appear unresolved at our moderate (a few hundred km s^{-1}) spectral resolution.

The strength of these lines is expected to be a good tracer of the emission measure of infalling hydrogen gas, and hence be directly correlated to accretion. For example Muzerolle et al. (1998) and Nisini et al. (these proceedings) found a strong correlation between Brγ line strength and accretion luminosity in samples of low-mass exposed and embedded YSOs, respectively. Using ultraviolet excesses derived from archive *International Ultraviolet Explorer* data, we find that the higher-mass Herbig Ae/Be stars with strong Brγ line emission exhibit the same tight correlation between UV excess and hydrogen recombination line

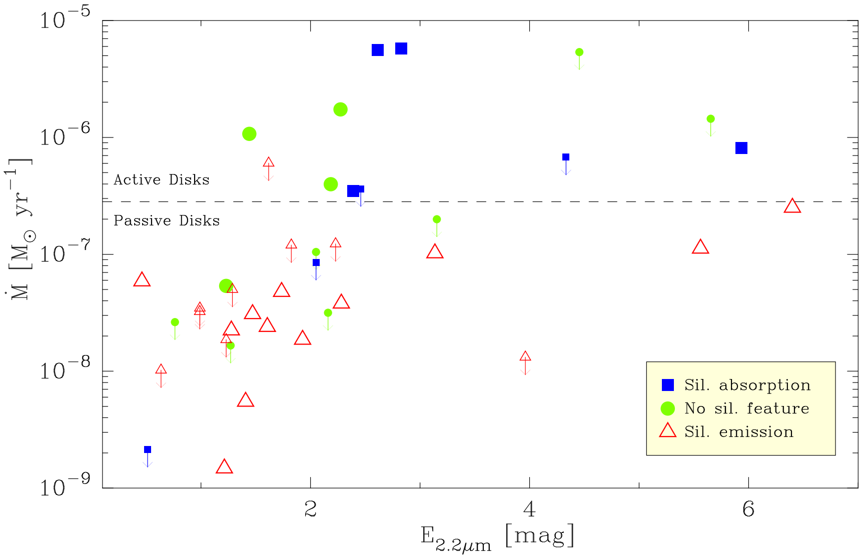

Fig. 4. Plot of derived accretion rates from Brγ line fluxes versus the continuum excess in the K-band (2.2 μm). We also plot an empirical division between disks which are dominated by viscous dissipation of energy due to accretion (active disks), and systems in which the dust is mainly heated by re-processing of light from the central star (passive disks).

strength found for their lower-mass counterparts (Fig. 3). A comparison between radio continuum data and infrared recombination line fluxes (not shown here) shown a similar tight correlation.

The accretion luminosities derived from the relation seen in Fig. 3 can easily be transferred to accretion rates using some simple assumptions about the accretion radius ($\dot{M} = L_{\rm acc} R_{\rm acc} / M_\star$). Note that, whereas we were unable to conclusively detect UV excesses in sources with $\dot{M} < 10^{-7}$ M$_\odot$ yr^{-1}, we detected Brγ line fluxes as small as a few times 10^{-16} W m^{-2}, corresponding to accretion rates as low as 10^{-9} M$_\odot$ yr^{-1}.

As an interesting side-note to this, we note that Herbig stars with high accretion rates invariably have mid-infrared spectra which show the well-known 10 μm silicate feature in absorption (Acke & van den Ancker 2004). We interpret this difference in 10 μm silicate appearance as a reflection of the different temperature structure of active disks – heated by viscous dissipation of accretion energy in the mid-plane – versus that of passive disks – heated by absorption of light from the central star hitting the disk surface. The Brγ probe of accretion rates suggests that in Herbig Ae/Be stars the transition between passive and active disks occurs at accretion rates of $\sim 2 \times 10^{-7}$ M$_\odot$ yr^{-1} (Fig. 4).

4 The Need for Higher Spectral Resolution

In the preceeding sections, we have shown that, in analogy to what is found for their lower-mass counterparts, infrared hydrogen recombination lines appear to be sensitive probes of mass accretion in Herbig Ae/Be stars. Since we did not resolve the detected lines, the only information available to us were line strengths. It is conceivable that other processes occurring in these Herbig stars (e.g. outflows, compact H II regions) can also contribute to the total hydrogen recombination line flux of the system. The tight correlation between UV excesses and Brγ luminosity illustrated in Fig. 3 demonstrates that this pollution by other processes is apparently not important for systems with high accretion rates. However, at present we are unable to fully assess whether this will also be the case when studying the systems with lower accretion rates. Therefore our derived accretion rates below 10^{-7} $M_\odot$ yr^{-1} should at this moment be regarded upper limits to the true accretion rate.

New observations with higher resolution are needed to remedy this unsatisfactory situation. Those observations should be able to distinguish the characteristic P Cygni profiles of infalling matter, and to separate those broad lines from narrow lines that may be produced by a compact H II region, and hence clarify whether we can truly attribute all the flux in the infrared hydrogen recombination lines to accretion processes.

At ESO, two interesting new instruments will soon become available with which we may seek the answer to these questions: CRIRES, an $R > 100{,}000$ spectrograph at the VLT through which these questions may be addressed through spatially unresolved high-spectral resolution observations, and AMBER at the VLTI (R = 10,000), whose unique combination of high spatial and spectral resolution may allow us to probe the accretion regions of young stars in unprecedented detail. Both instruments will have the ability to push back our detection limits for accretion rates to well below 10^{-10} $M_\odot$ yr^{-1}, the realm directly relevant for planet formation theories.

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