MAGNETOSPHERES AND DISK ACCRETION IN HERBIG Ae/Be STARS

JAMES MUZEROLLE,1,2 PAOLA D’ALESSIO,3 NURIA CALVET,4 AND LEE HARTMANN4

Received 2003 May 16; accepted 2004 August 11

ABSTRACT

We present evidence of magnetically mediated disk accretion in Herbig Ae/Be stars. Magnetospheric accretion models of Balmer and sodium profiles calculated with appropriate stellar and rotational parameters are in qualitative agreement with the observed profiles of the Herbig Ae star UX Ori and yield a mass accretion rate of \( \sim 10^{-8} M_\odot \) year\(^{-1} \). If more recent indications of an extremely large rotation rate for this object are correct, the magnetic field geometry must deviate from that of a standard dipole in order to produce line emission consistent with observed flux levels. Models of the associated accretion shock qualitatively explain the observed distribution of excess fluxes in the Balmer discontinuity for a large ensemble of Herbig Ae/Be stars and imply typically small mass accretion rates, \( \lesssim 10^{-7} M_\odot \) year\(^{-1} \). In order for accretion to proceed onto the star, significant amounts of gas must exist inside the dust destruction radius, which is potentially problematic for recently advocated scenarios of “puffed” inner disk wall geometries. However, our models of the inner gas disk show that for the typical accretion rates we have derived, the gas should generally be optically thin, thus allowing direct stellar irradiation of the inner dust edge of the disk.

Subject headings: accretion, accretion disks — circumstellar matter — stars: emission-line, Be — stars: pre–main-sequence

1. INTRODUCTION

The class of Herbig Ae/Be (HAe/Be) stars was identified by Herbig (1960) in an attempt to find the analogs of T Tauri stars among objects of higher mass. This identification has been supported by many studies over the last several years. Observations of millimeter-wave emission suggest the presence of circumstellar disks similar to those of the low-mass classical T Tauri stars (CTTSs; Mannings et al. 1997; Mannings & Sargent 1997; Testi et al. 2001). Dusty disk models can in principle explain the infrared excess emission of many HAe/Be stars (Hillenbrand et al. 1992, hereafter HSVK92; Chiang et al. 2001; Natta et al. 2001; Dullemond et al. 2001, hereafter DDN01). In addition, imaging observations in scattered light (e.g., Grady et al. 1999b) also provide evidence for flattened or disklke large-scale dusty structures around a few HAe/Be stars.

These studies naturally raise the question: Are HAe/Be stars accreting from their disks? And if so, are the accretion rates high enough to modify stellar evolution or to imply substantial migration of potential planet-forming material? The first attempt to derive HAe/Be accretion rates was made by HSVK92, who attempted to fit the observed infrared excess emission using steady accretion disk models and estimated much higher mass accretion rates (\( 10^{-6} – 10^{-5} M_\odot \) year\(^{-1} \)) than typical of CTTSs. However, HSVK92 also needed to invoke an inner disk hole, of the order of 0.1 AU in radius, to explain the decline in near-infrared excess emission shortward of \( \lambda \sim 2 – 3 \) \( \mu \)m. Hartmann et al. (1993, hereafter HKC93) argued that the accretion could not stop indefinitely at this inner radius, and they showed that accretion at the rates inferred by HSVK92 would render any inner disk optically thick, eliminating the decline in infrared excess at short wavelengths.

Natta et al. (2001) and DDN01 revisited this problem, this time developing models that explain the infrared excess emission of HAe/Be stars as the result of heating by irradiation from the central star, rather than local accretion energy release. These authors again assumed an inner disk hole, of size \( \sim 0.3 – 0.5 \) AU, to explain the decrease in near-infrared disk emission at short wavelengths. The inner edge of the disk receives radiation from the star at near-normal incidence, and it therefore becomes much hotter at a given radius than would a geometrically thin, optically thick disk irradiated obliquely. The increased heating thus causes the disk material at the inner edge to “puff up.” DDN01 suggested that this expanded inner disk edge can quantitatively explain the magnitude of the near-infrared emission in HAe/Be spectral energy distributions (SEDs) without any accretion energy release. The location of the inner disk edge and its emission in this model is roughly consistent with recent interferometric observations (Millan-Gabet et al. 2001), which indicate near-infrared \( H \)- and \( K \)-band emission at radial distances well beyond that predicted by standard geometrically thin, optically thick irradiated disks.

While this model is attractive, the possibility of accreting material interior to the dust destruction radius must be addressed. All the low-mass T Tauri stars with near-infrared excesses exhibit accretion onto the central star, and it would be surprising if HAe/Be disks with similar properties were completely inert. Indeed, heating of the inner disk edge by stellar radiation alone is likely to raise temperatures to the point that the fractional ionization is high enough that the magnetorotational instability (MRI) thought to drive disk accretion can operate (e.g., Balbus & Hawley 1998; Gammie 1996). In CTTSs, stellar magnetospheres truncate the inner disk; but, as pointed out by HKC93, the inner disk edge in the DDN01 model lies at such large radii that magnetospheric truncation is implausible and, in any event, falls well outside of the corotation radius.