DISCOVERY OF GAS ACCRETION ONTO STARS IN 13 Myr OLD h AND χ PERSEI
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ABSTRACT
We report the discovery of accretion disks associated with ∼13 Myr old intermediate/low-mass stars in h and χ Persei. Optical spectroscopy of ∼5000 stars in these clusters and a surrounding halo population reveals ∼32 A–K stars with Hα emission. Matching these stars with 2MASS and optical photometry yields 25 stars with the highest probability of cluster membership and EW(Hα) ≥ 5 Å. Sixteen of these sources have EW(Hα) ≥ 10 Å. The population of accreting sources is strongly spectral type dependent: Hα emission characteristic of accretion, especially strong accretion [EW(Hα) ≥ 10 Å], is much more prevalent around stars later than G0. Strong Hα emission from accretion is typically associated with redder K, − [8] colors. The existence of accreting pre–main-sequence stars in h and χ Persei implies that circumstellar gas in some systems, especially those with primaries later than G5 spectral type, can last longer than 10–15 Myr.

Subject headings: accretion, accretion disks — open clusters and associations: individual (NGC 869, NGC 884) — planetary systems: protoplanetary disks

Online material: machine-readable table

1.INTRODUCTION

Young stars are born with massive, ~0.01–0.1 M\(\odot\) (stellar mass), disks of gas and dust. The disk viscously spreads, transporting angular momentum away from the star and mass onto the star. Accretion onto the host star is identified from strong Hα emission; typical mass accretion rates onto the star are ~10^{-5} M\(\odot\) yr\(^{-1}\) for ~1 Myr old stars (Hartmann et al. 1998). After ~5 Myr, fewer sources show strong Hα emission indicative of accretion, and accretion rates are typically much lower (~10^{-7} M\(\odot\) yr\(^{-1}\)) than at earlier ages. By ~10 Myr, few sources show signs of active accretion (Sicilia-Aguilar et al. 2005).

The timescale for accretion to cease and for nebular gas in circumstellar disks to disperse has important implications for planet formation. Massive planets may form in gas-poor/gas-free conditions (Currie & Hansen 2007; Konacki & Wolszczan 2003). However, giant planet formation requires that circumstellar disks remain massive for ~10–15 Myr, disks of gas and dust. The disk viscously spreads, transporting angular momentum away from the star and mass onto the star. Accretion onto the host star is identified from strong Hα emission; typical mass accretion rates onto the star are ~10^{-5} M\(\odot\) yr\(^{-1}\) for ~1 Myr old stars (Hartmann et al. 1998). After ~5 Myr, fewer sources show strong Hα emission indicative of accretion, and accretion rates are typically much lower (~10^{-7} M\(\odot\) yr\(^{-1}\)) than at earlier ages. By ~10 Myr, few sources show signs of active accretion (Sicilia-Aguilar et al. 2005).

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The double cluster, h and χ Persei—13 ± 1 Myr old, d = 2.34 kpc (Bragg & Kenyon 2005; Slesnick et al. 2002; Keller et al. 2001)—provides an excellent opportunity to study the properties of a statistically significant sample of the longest lived accretion disks. With ≥5000 members in the cluster and surrounding halo population (Currie et al. 2007a), robust constraints on gas accretion are possible even if the fraction of accreting sources is ~1%–2%.

In this Letter, we report the discovery of 25 sources in h and χ Persei with evidence for active gas accretion. In §2 we identify these accreting sources by measuring Hα equivalent widths and use quantitative spectral types to select actively accreting h and χ Per members from a sample of ∼5000 optical spectra. Analysis of our sample in §3 reveals that the population of accretors is almost solely comprised of stars with spectral types later than G5. We compare the strength of accretion signatures to dust emission in §4, finding a weak correlation between the Hα equivalent width and IR excess. We conclude with a brief summary and discuss future observations to investigate circumstellar gas accretion in young stars in more detail. These results show that circumstellar gas in at least stars later than ~G0 lasts ≥10–15 Myr.

2. HECTOSPEC OBSERVATIONS/HYDRA ARCHIVAL DATA OF h AND χ PERSEI AND SAMPLE IDENTIFICATION

We obtained Hectospec (Fabricant et al. 2005) spectra of 4536 sources with V ~ 16–19, J ~ 14.25–16.25, and J / H ~ 0–1.5 in χ Persei and the halo population surrounding both clusters on the 6.5 m MMT telescope at Whipple Observatory during 2006 September and November. Each source was observed in three 10 minute exposures using the 270 mm\(^{-1}\) grat-
ing. This configuration yields spectra at 4000–9000 Å with 3 Å resolution. The data were processed using the standard Hectospec reduction pipeline (Fabricant et al. 2005) and typically had S/N $\geq$ 30–50 at 5000 Å.

We acquired additional spectra of 710 sources near h and χ Per with the Hydra multifiber spectrograph (Barden et al. 1993) on the WIYN 3.5 m telescope at the Kitt Peak National Observatory. Hydra spectra were obtained during two observing runs in 2000 November and 2001 October, and include stars with $V \sim 14–17$ and $J \sim 12–14.5$ (S/N $\approx$ 10–30 typically). We used the 400 g mm$^{-1}$ setting blazed at 42°, with a resolution of 7 Å and a coverage of 3600–6700 Å. The standard IRAF task dohydra was used to reduce the spectra.

To select candidate emission line stars, we measured spectral indices $[\lambda(A)]$; see Balog & Kenyon 2002] with the IRAF sbands$^5$ routine. Because classical T Tauri stars have strong Hα emission and often have strong Ca ii emission, we derived indices for Hα, Hβ, Hγ, Hδ, and several Ca ii features. For the H i features, bandpasses with widths of 30 Å (Hα) and 20 Å (Hβ, Hγ, and Hδ) yield good results. For Ca ii, we centered bandpasses at 3933 Å (20 Å width) and at 8498, 8542, and 8662 Å (20 Å) for the IR triplet lines. To identify sources with Hα emission, we compared the spectral index of Hα to Hβ, which was less likely to be in emission and typically had high signal-to-noise ratios.

The Hα and Hβ spectral indices for most stars lie in a narrow band on $I(H\beta)$ versus $I(H\alpha)$ from $\sim(0.2, 0)$ to $(0.7, 0.4)$. Accreting sources have an anomalously small Hα index for a given Hβ index (Fig. 1, left; see also Balog & Kenyon 2002; Bragg & Kenyon 2002). Candidate accreting sources are those lying outside the main distribution of sources on $I(H\beta)$ versus $I(H\alpha)$, below the line $I(H\alpha) = 0.5 \times I(H\beta) - 0.15$ (Fig. 1, left). After removing background M giants, Be stars, and low signal-to-noise ratio stars, 32 sources with clear Hα emission and moderate to high signal-to-noise spectra remain.

While each source clearly shows Hα emission, sources with weaker emission may not be accreting (White & Basri 2003). Chromospheric activity can produce very small Hα equivalent widths [EW(Hα) $\leq$ 3–5 Å]. Accreting T Tauri stars typically produce EW(Hα) $\geq$ 10–20 Å, although low rates of accretion ($\dot{M} \lesssim 10^{-9} M_\odot$ yr$^{-1}$) can produce EW(Hα) $\sim$ 3–10 Å for stars earlier than K5 (White & Basri 2003; Barrado y Navascues & Martin 2005). We consider sources with EW(Hα) $\geq$ 5 Å as potential accreting stars. To distinguish more clearly between accreting sources and chromospherically active sources, we remeasured EW(Hα) using the IRAF routine splot, smoothing any low signal-to-noise spectra and fitting the line profile to a Gaussian. Typically, splot derived only slightly smaller EW(Hα) than sbands ($\sim$ a few Å). Sources with EW(Hα) $\geq$ 10 Å are “strong” accretors. Consistent with observations of T Tauri stars in Taurus-Auriga and other clouds (e.g., Kenyon & Hartmann 1995), no sources show evidence of Ca ii emission.

To derive quantitative spectral types for these 32 sources, we used spectral indices for Hβ, Hγ, Hδ, the G band (4305 Å), and Mg i (5175 Å). We fit piecewise linear relationships between each spectral index and spectral type from the Jacoby et al. (1984) standards, derived spectral types for each index, and adopted the median as the spectral type. For the three sources with Hδ in emission, we derived a spectral type from the four other indices without signs of accretion. The resulting spectral type distribution ranged from A7 to M0 with typical uncertainties of $\sim$1–2 subclasses. We compared our results to those using the quantitative spectral typing method of Hernandez et al. (2004) and found the agreement to be excellent.

To identify stars likely associated with the clusters, we used optical photometry (Keller et al. 2001) and 2MASS/IRAC photometry from Currie et al. (2007a). We exploited the well-constrained age and reddening of the double cluster and derived the expected 2MASS J magnitude of members at each spectral type. Sources within 0.2 mag of a band defined by the 12 and 14 Myr stellar isochrones (from Siess et al. 2000) were identified as members (see Currie et al. 2007a). Figure 1 shows the 30 sources consistent with membership: the other two sources were a late K star and an M0 star that are too cool to fall within the isochrone. Although these two sources may lie at the cluster distance and have slightly different ages (e.g., 10 or 15 Myr) or extinctions, the clusters appear to have a small age spread (Meynet et al. 1993; Keller et al. 2001; Slesnick et al. 2004). The spectral type of a source was determined by fitting a function of the form $\log T$ to the $\chi^2 = \sum (J \text{mag} - J \text{mag}_\text{model})^2$. Interestingly, T Tauri stars appear to have a lower limit on the ratio of accretion rate to mass of $\dot{M} / M \approx 10^{-5}$, although this limit may be an artifact of observational biases.

Fig. 1.—Left: Hα spectral index plotted against Hδ index. Sources lying below the dotted line were selected for emission signatures; sources between the main distribution and the line typically had lower signal-to-noise ratios. Right: Spectral type vs. J magnitude for h and χ Per members with Hα emission. The dotted line indicates the faint limit of the survey. The 12 and 14 Myr isochrones (top and bottom thick lines) are overplotted with 0.2 mag errors (top and bottom gray lines). The errors in derived spectral type are overplotted as bars on the data points (triangles).
have EW(Hα) ≥ 10 Å while only 6/16 of the sources G5 and earlier have EW(Hα) ≥ 10 Å. Four of five sources with EW(Hα) ≥ 20 Å are later than K0, and the sources with the strongest Hα emission (EW ~ 47 and 59 Å) are a K7 and K4 star. The atlas of both emission-line and non-emission-line stars will appear in the full spectroscopy survey paper (T. Currie et al. 2008, in preparation).

The spectral type distribution of accreting sources is comprised almost exclusively of sources later than G0. Because we do not have a complete sample of nonaccreting sources at a given spectral type, we cannot accurately measure the frequency of accretors as a function of spectral type/mass. Nevertheless, we can estimate the fraction of accreting sources in our sample by deriving how many of the 5145 (4536 from Hectospec, 609 from Hydra) sources with near-IR photometry lie along the h and χ Per isochrone in J(J − H). We follow Currie et al. (2007a) and identify as cluster members 2040 sources within a band that extends 0.3 mag fainter and 0.75 mag brighter (the binary locus) than the 13 Myr isochrone, where the vast majority of nonmembers lie below the isochrone. We estimate the spectral types of sources from their J − H colors and divide the sample into two populations, earlier than F8 and later than F8, and compute the frequency of accreting sources in each population.

The frequency of accreting sources is low and is consistent with a spectral-type dependence. Overall, ∼1.2% (25/2040) of sources consistent with cluster membership are likely accreting. Through F8, 1/1042 (0.1%) sources with spectra show evidence of accretion. The frequency is 2.4% (24/998) for later sources. Spectral types for the nonaccreting sources will provide better constraints on the frequency of long-lived accretion disks. The low fraction of accreting stars in h and χ Per is broadly consistent with results from other studies. Sicilia-Aguilar et al. (2005, 2006) identified accretion in ~40% of stars in the 4 Myr old Tr 37 Cepheus OB2 subgroup and only one of 55 stars (~2%) in the other Cep OB2 subgroup, NGC 7160 (~1.8 Myr old). An accretion disk fraction of ~1.2% from our sample is consistent with a decline of accretion disk frequency with age.

To check these results, we consider possible selection biases. If the emission-line stars have significant optical veiling, their spectral types appear earlier than fainter (J < 16) nonaccreting stars with similar masses. We then overestimate their relative frequency. However, stars with large veiling have near-IR excesses, H − Ks ≥ 0.5 and Ks − [3.6] ≥ 0.4 (Kenyon & Hartmann 1995). With H − Ks ≤ 0.4 − 0.5 and Ks − [3.6] ≤ 0.3 − 0.4 (Currie et al. 2007a), emission-line stars in h and χ Per have little or no near-IR excess and probably have negligible veiling. If photometric errors move faint cluster stars

2002; Bragg & Kenyon 2005). Thus, the 30 sources shown in Figure 1 (right) are the most likely cluster members. Table 1 lists their properties.

Young T Tauri stars show a strong correlation between EW(Hα) and IR excess from disks (Kenyon & Hartmann 1995). Stars in ~1 Myr old Taurus-Auriga with L-band (3.8 μm) excess (K − L ≥ 0.4) typically have stronger Hα emission [EW(Hα) ≥ 10 Å] than those lacking excess. Excess sources have a range of EW(Hα), which implies a range of accretion rates. To search for a similar trend in our sample, we use the Ks − [8] color derived from the 2MASS/IRAC data (Currie et al. 2007a) as an indicator of excess emission instead of Ks − [3.6]. Eighteen of 30 sources with Hα emission are detected at [8] with errors ≤ 0.2 mag. Typically, sources without 8 μm photometry are fainter in Ks (~13.6–14.7) than those with 8 μm detections (Ks ~ 13.5–14).

3. RESULTS: EVIDENCE FOR ACCRETION AT ~13 Myr

Most of the Hα emission stars in h and χ Per have G0 or later spectral types (Fig. 2). Overall, 25/30 sources have EW ≥ 5 Å and thus are likely accreting circumstellar gas. All 14 sources later than G5 have EW ≥ 5 Å. By contrast, 5/16 sources G5 and earlier have EW(Hα) ≤ 5 Å. The distribution of sources with EW(Hα) ≥ 10 Å is even more strongly biased toward later spectral types. Seven out of eight sources later than K0 have EW(Hα) ≥ 10 Å while only 6/16 of the sources G5 and earlier have EW(Hα) ≥ 10 Å. Four of five sources with EW(Hα) ≥ 20 Å are later than K0, and the sources with the strongest Hα emission (EW ~ 47 and 59 Å) are a K7 and K4 star. The atlas of both emission-line and non-emission-line stars will appear in the full spectroscopy survey paper (T. Currie et al. 2008, in preparation).

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**TABLE 1**

| α (J2000.0) | δ (J2000.0) | ST | σ(ST, Subclasses) | EW(Hα) | Accreting? | J | K2 | K2 − [3.6] | K2 − [8] |
|-------------|-------------|----|-------------------|--------|------------|---|----|------------|---------|
| 2 22 21.62  | 57 04 00.5  | G4 | 1.0               | 13.7   | Yes        | 14.303 | 13.612 | 0.292     | ...     |
| 2 22 39.53  | 57 15 42.9  | G0 | 2.5               | 4.5    | No         | 14.315 | 13.538 | 0.271     | 0.223   |
| 2 17 36.96  | 57 01 10.6  | G0 | 3.0               | 1.8    | No         | 14.363 | 13.697 | ...       | −0.247  |
| 2 17 55.15  | 56 56 03.1  | G3 | 2.1               | 6.46   | Yes        | 14.419 | 13.613 | 0.258     | 0.096   |
| 2 21 46.44  | 57 02 44.2  | G4 | 3.0               | 5.75   | Yes        | 14.446 | 13.697 | 0.349     | 0.405   |

Notes.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Properties of sources with Hα emission. Sources with EW(Hα) ≥ 5 Å are identified as accreting sources. All but the final entry are from Hectospec. Uncertainties in EW(Hα) are typically ±1 Å. All photometric measurements listed are ±1σ detections. Sources were typically brighter than the 10σ limit in J (15.7) and K (14.8) (see Currie et al. 2007a). Table 1 is published in its entirety in the electronic edition of the *Astrophysical Journal*. A portion is shown here for guidance regarding its form and content.

![Fig. 2.—Spectral-type distribution of Hα emission sources (gray line), those with EW ≥ 5 Å (dash-dotted line), and those with EW ≥ 10 Å (thick dotted line). Source with Hα ∼ 5–10 Å are probably marginally accreting; those with Hα ∼ 10 Å are consistent with the strength of Hα emission from classical T Tauri stars.](image-url)
outside the isochrone, we underestimate the number of non-accreting stars. Including all stars with $J - H \approx 0.48$ (F8; 2303 total) in the cluster sample yields a stricter lower limit to the accretion frequency, $1.1\% \pm 0.2\%$, which is still much larger than the frequency for earlier type stars. Finally, we consider the possibility that the H$\alpha$ emission flux associated with late-type stars is undetectable around 1 mag brighter cluster stars with earlier spectral types. With EW(H$\alpha$) $\sim$ 5–10 Å for the late-type stars, early-type stars with similar H$\alpha$ fluxes should have EW(H$\alpha$) $\geq$ 2–5 Å, easily detectable on our spectra. Thus, we conclude that possible selection effects do not produce a false trend of increasing accretion frequency among lower mass stars.

Our sample shows a $\sim$2–3 $\sigma$ correlation between accretion and infrared excess. The majority of stars have negligible $K_s - \hbox{[8]}$ excess (Fig. 3), but some sources have $K_s - \hbox{[8]} \sim 0.4$, the nominal cutoff for IR excess in Currie et al. (2007a) and Kenyon & Hartmann (1995). One source, the K7 star, has $K_s - \hbox{[8]} \sim 1$ and is clearly redder than a stellar photosphere. Sources with larger H$\alpha$ ($\geq20$ Å) have redder $K_s - \hbox{[8]}$ colors than those with small/marginal H$\alpha$ emission. The Spearman rank correlation coefficient between $K_s - \hbox{[8]}$ and H$\alpha$ emission is $r_s = 0.60$; this distribution has a low probability of being drawn from a random sample ($p_s = 0.9\%$). The distribution is less correlated for sources with chromospheric H$\alpha$ emission ($r_s = 0.35$, $p_s \sim 22\%$). We thus find a $\sim$2–3 $\sigma$ correlation between IR excess and EW(H$\alpha$) for sources with H$\alpha$ emission. However, some debris disks in h and $\chi$ Per (Currie et al. 2007b, 2007c) have strong excesses at [8] and/or [24] without accretion. Therefore, while accretion may imply IR excess, IR excess need not imply accretion.

4. SUMMARY AND DISCUSSION

We have discovered a population of stars with accretion disks in h and $\chi$ Persei. Of the 30 H$\alpha$ emitters that are likely h and $\chi$ Per cluster/halo members, 25 have EW(H$\alpha$) consistent with circumstellar gas accretion. The spectral types of accreting sources are almost all later than G0. About $\sim$1.2% of our sample shows evidence for accretion, consistent with the low fraction of accretors at $\sim$10 Myr found by Sicilia-Aguilar et al. (2005).

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