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THE LONGEVITY OF CIRCUMSTELLAR DISKS: THE η CHAMAELEONTIS CLUSTER

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ABSTRACT

We have analysed near-infrared *JHKL* observations of the members of the ≈9 Myr-old η Chamaeleontis cluster. Using $(J-H)/(K-L)$ and $(H-K)/(K-L)$ IR colour-colour diagrams for the brightest 15 members of the cluster, we find the fraction of stellar systems with near-IR excess emission was 0.60 ± 0.13 (2σ). For the CTT and WTT star population, we also find a strong correlation between the IR excess and Hα emission which is also known as an accretion indicator. The $(K-L)$ excess of these stars appears to indicate a wide range of star-disk activity; from a CTT star with high levels of accretion, to CTT – WTT transitional objects with evidence for some on-going accretion, and WTT stars with weak or absent IR excesses. Among the brightest 15 members, four stars (RECX 5, 9, 11 and ECHA J0843.3-7905) with IR excesses $\Delta(K-L) > 0.4$ mag and strong or variable optical emission were identified as likely experiencing on-going mass accretion from their circumstellar disks which we confirmed their accretion disks from the optical high-resolution echelle spectroscopic study. The resulting accretion fraction of 0.27 ± 0.13 (2σ) suggests that the accretion phase, in addition to the disks themselves, can endure for at least ~ 10 Myr.

Key words : accretion: accretion disks – circumstellar matter – open clusters and associations: individual: η Chamaeleontis

I. INTRODUCTION

Circumstellar disks are a natural by-product of the star formation process (e.g. Shu, Adams & Lizano 1987). Therefore, the study of pre-main sequence (PMS) circumstellar disks provides clues for understanding the star formation and evolution and the planet formation process. Especially, determination of disk longevity and the duration of the accretion phase in low-mass PMS stars are crucial inputs for understanding the mechanisms of planet formation and the growth of proto-planets to their final masses. Studies of the disk fraction in PMS clusters – the majority based on K-band surveys or limited-sensitivity L-band surveys – suggest most inner disks and star-disk interactions disappear in a few Myr (e.g. Haisch, Lada & Lada 2001). This is in apparent conflict with some planet formation theories demanding Jovian planet formation timescales >10 Myr. This issue has been difficult to resolve in the past owing to the lack of 'older' PMS samples; PMS populations with ages of 5 – 50 Myr appear free from their parent molecular clouds and generally are dispersed among the Galactic field population. The detection and study of disks of the η Chamaeleontis cluster can usefully contribute to this debate; the age of the cluster is ≈ 9 Myr and it's proximity (d = 97 pc) ensures optical and IR observations can be made at high sensitivity.

The η Cha cluster was discovered by Mamajek, Lawson & Feigelson (1999) from a deep *ROSAT* High-Resolution Imager observation aimed at a 'clump' of four RASS sources centred in Chamaeleon near $8^h42^m06^s$, $-79°01'38''$, 7.5° southwest of Cha I, that were later found to be T Tauri stars (Alcalá et al. 1997; Covino et al. 1997). The HRI observation recovered the four RASS sources and detected eight other sources; additional six of which were shown to be Weak-lined T Tauri (WTT) stars with weak optical emission line spectra, often seen only at Hα, by Mamajek et al. (1999) from spectroscopic study. Subsequent study has since revealed five other X-ray faint cluster members. The cluster is located nearby ($d \simeq 97$ pc; from *Hipparcos* parallaxes $\pi = 10.28 \pm 0.31$ mas), and is a compact (extent ~ 1 pc), coeval ($t = 9 \pm 1$ Myr; Lawson & Feigelson 2001) system of PMS stars with a small (18 known primaries) population of stars spanning a relatively large range in mass ($M = 0.15 - 3.40 M_\odot$; Mamajek et al. 1999, 2000; Lawson et al. 2001, 2002; Lyo et al. 2004a; Song et al. 2004) in a region free from the molecular material ($E(b-y) = -0.004$ for η Cha; Westin 1985). The cluster contains three early-type systems led by η Cha

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(spectral type B8) after which the cluster is named, HD 75505 (A1), the A7+A8 dual-lined eclipsing binary and δ Scuti system RS Cha, and 15 low-mass primaries (K6-M5.5) including one bona-fide classical T Tauri (CTT) star with a rich optical emission line spectrum and significant continuum veiling (Lyo et el. 2004b). Importantly, this census is known to be virtually complete in the inner region from a combination of a deep *ROSAT* exposure, optical photometry and proper motion study of the field. Unlike most other PMS populations, these membership criteria are independent of the presence or absence of circumstellar disks. We can thus use the η Cha population as an unbiased laboratory to investigate the fraction of IR excess and accretion at a critical intermediate-age phase of disk evolution.

II. OBSERVATIONS

A L-band (3.5 μm) map of the η Cha cluster was obtained in service mode during 1999 July 26 – 28 with the 0.6-m South Pole Infrared Explorer (SPIREX) telescope using the NOAO Abu IR camera which had a 1024 × 1024 "Aladdin" InSb 1-5 μm array. The Abu camera has a plate scale of 0.6 arcsec pixel^{-1}, giving a field-of-view (FOV) of 100 arcmin^2.

JHK_N-band images (J = 1.25μm, H = 1.65μm and K_N = 2.17μm) of the cluster members were obtained during 2002 March 2–5 with the Cryogenic Array Spectrometer/Imager (CASPIR) on the 2.3-m telescope operated by Mount Stromlo and Siding Spring Observatories (MSSSO). CASPIR uses a 256 × 256 pixel InSb detector array and we selected a FOV of 4.5 arcmin^2 giving a resolution of 0.5 arcsec pixel^{-1}.

Examination of the image profiles for the early-type cluster members (η Cha, RS Cha and HD 75505) suggested the onset of saturation in the CASPIR J and H frames. For this reason we obtained $JHKL$ photometry for these 3 stars (JHK only for HD 75505) using the 0.75-m telescope and Mark II IR photometer at the South African Astronomical Observatory (SAAO). These data, along with measurements of IR standard stars, were obtained during the week of 2002 April 30 to May 6. The SAAO KL data shows close agreement (±0.03 mag) to the CASPIR K and SPIREX L data except for the L-band measurement of RS Cha. Using the ephemeris of Clausen & Nordström (1978) we find the SPIREX L-band measurement for this eclipsing binary RS Cha was obtained during the secondary eclipse, whereas the CASPIR and SAAO magnitudes were obtained at maximum light. Table 1 lists the $JHKL$ photometry of the η Cha cluster members.

In the following sections we make use of the SAAO photometry for the 3 early-type stars; otherwise we adopt our CASPIR and SPIREX observations. Colours derived from the individual magnitudes were transformed to the 'homogenized' IR system of Bessell & Brett (1988).

Optical spectra of late-type members of the η Cha cluster were obtained in service mode using the Anglo-Australian Telescope (AAT) and University College London coudé echelle spectrograph with the 70-cm camera and 31.6 line mm^{-1} cross-disperser. The observations were obtained on the nights of 2002 June 26 (RECX 10, 11 and ECHA J0843.3–7905) and 2002 December 12 (RECX 3, 4, 5, 6, 7, 9 and 12). Utilizing a slit that subtended 1.5 arcsec on the sky, corresponding to 6-pixel resolution for the EEV2 detectors, the spectral resolution R > 30 000. The observed spectral range was from 5000 to 9200 Å.

TABLE 1.
$JHKL$ PHOTOMETRY FOR MEMBERS OF THE η CHA CLUSTER

Star	J	H	K	L
CASPIR/SPIREX observations				
RECX 1	8.20	7.60	7.27	6.97
RECX 3	10.57	9.86	9.61	9.11
RECX 4	9.69	8.92	8.66	8.32
RECX 5	10.99	10.29	9.96	9.26
RECX 6	10.42	9.74	9.46	8.93
RECX 7	8.61	7.92	7.69	7.48
RECX 9	10.53	9.83	9.50	8.82
RECX 10	9.68	8.95	8.78	8.48
RECX 11	8.85	8.06	7.71	7.08
RECX 12	9.38	8.70	8.51	8.02
η Cha	—	—	5.73	5.62
RS Cha	—	—	5.45	5.84
HD 75505	—	—	6.98	6.81
ECHA J0841.5–7853	11.90	11.30	10.94	> 10:
ECHA J0843.3–7905	10.66	9.93	9.45	8.40
SAAO observations				
η Cha	5.68	5.72	5.75	5.65
RS Cha	5.60	5.46	5.43	5.35
HD 75505	7.10	7.02	7.00	—

III. ANALYSIS OF RESULTS

(a) Disk Indicator; Infrared Color Excess

How can we detect circumstellar disks in young clusters? Direct imaging might be the most elegant approach but is effective only in optimal cases, e.g. extended structures such as the β Pic disk or the large face-on disk surrounding TW Hya, and usually requires the use of coronographs to mask the light from the central star. A simpler and quantifyable approach is to detect IR excess emission resulting from the reprocessing of starlight by circumstellar material. Lada et al. (2000) already showed in the $JHKL$ color-color diagram that the observed IR excesses in Trapezium PMS stars are due to proto-planetary disks. L-band data is nearly essential for a meaningful evaluation of the disk fraction in a young stellar population. JHK observations alone – the common suite of filters used to detect circumstellar disks around young stars – do not extend to a long enough wavelength range to enable a complete or unambiguous census of circumstellar disks in young clusters because K-band results might be affected by disk inclination, the disk-star mass accretion

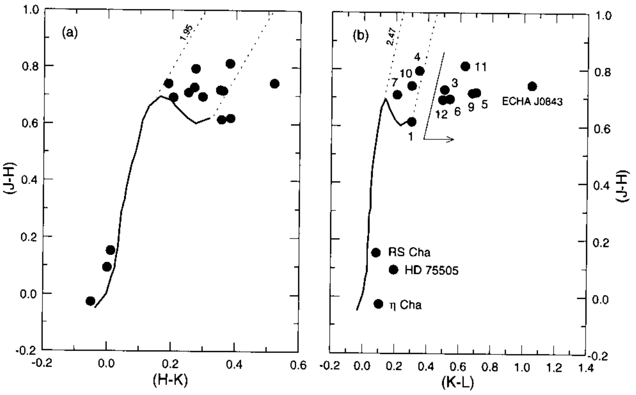

Fig. 1.— (a) $(J-H)/(H-K)$ and (b) $(J-H)/(K-L)$ color-color diagrams for the η Cha cluster. The bold lines are the locus of main-sequence stars from spectral type B8 – M5, and the dashed lines represent the reddening band with gradient derived from equations given by Bessell & Brett (1988). In (b) the late-type stars are identified by their RECX number (Mamajek et al. 1999), except for the CTT star ECHA J0843.3–7905 (Lawson et al. 2002). The vector delineates late-type stars likely to have an IR excess.

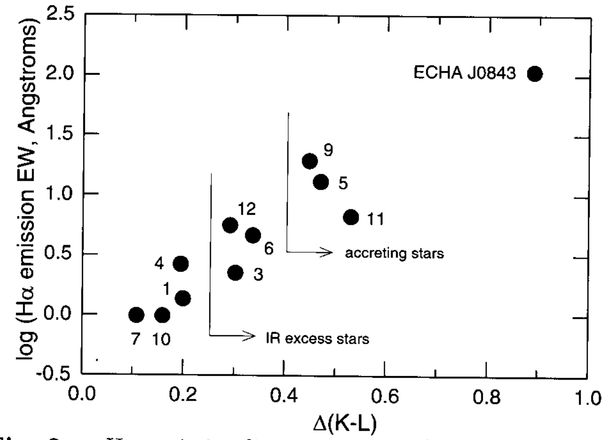

Fig. 2.— Hα emission-line EW versus $(K-L)$ excess for the late-type stars in the η Cha cluster. The individual stars are identified by their RECX number, except for the CTT star ECHA J0843.3–7905. Stars with $\Delta(K-L) > 0.25$ are identified as IR excess objects with circumstellar disks. Those stars with $\Delta(K-L) > 0.4$ are identified as stars with accretion disks.

rate, the presence and size of inner disk holes, and the presence of reflection nebula or H II regions (Haisch, Lada & Lada 2000; Kenyon & Gómez 2001). For example, spectroscopic studies of the Taurus-Auriga cloud indicate that only 2/3 of CTT stars show a clear excess in a $(J-H)/(H-K)$ color-color diagram; about 1/3 of the CTTs lie within the reddening band for main-sequence stars (Meyer, Calvet & Hillenbrand 1997). It is also likely that older, evolved disks might have weak K-band excesses but still retain an L-band excess.

Fig. 1 (a) and (b) show *JHK* and *JHKL* color-color diagrams of the η Cha cluster members. The brighest 15 cluster members are shown in Fig. 1(a). Only 14 are shown in Fig. 1(b); the M4 cluster member ECHA J0841.5-7853 was not detected at L band. In these diagrams the solid curves are the locus of colors corresponding to main-sequence stars of spectral types B8 – M5 (Bessell & Brett 1988), which encompasses the range of spectral types of the cluster members. In each figure, the dashed parallel lines define the reddening bands derived from relationships given by Bessell & Brett (1988), where $E(J-H)/E(H-K) = 1.95$ and $E(J-H)/E(K-L) = 2.47$, respectively. Stars which lie in the right of the reddening band are IR excess objects and therefore circumstellar disk candidates.

Using these IR color-color diagrams, we found that 7 ± 2 out of the 12 late-type members and two of the three early-type members are IR excess objects.

(b) Accretion Indicator; Hα Emission Line

The enhanced Hα emission above normal chromospheric levels in PMS stars is believed to originate in magnetospheric columns, which allow transport of disk material to the stellar surface. Therefore we expect to find a correlation between the IR excess and Hα emission. Comparison between the Hα equivalent width (EW) and the $(K-L)$ *color excess* is desirable to eliminate redundancy caused by the spread in *color* across a stellar population. Determination of the color excess for individual stars requires knowledge of the spectral type, which we have determined in Lyo et al. (2004b).

In Fig. 2, we find a strong correlation between the Hα EW and the $(K-L)$ excess for the late-type members. The $(K-L)$ excess of these stars appears to indicate a wide range of star-disk activity; from a CTT star with high levels of accretion, to CTT – WTT transitional objects with evidence for some on-going accretion, and WTT stars with weak or absent IR excesses.

To confirm this unexpected presence of stars with strong IR excess emission suggesting on-going mass accretion, we studied the cluster stars in more detail using high-resolution echelle spectra ($R > 30\,000$) (Fig. 3).

Our high-resolution spectroscopic study confirms that the four stars with strong IR excess emission identified in Fig. 2 (RECX 5, 9, 11 and ECHA J0843.3–7905) have broad Hα profiles indicative of ballistic accretion of material from circumstellar disks. Quantitative analysis of the Hα profiles finds accretion in these stars at rates of $10^{-9.0}$ to $10^{-10.4} M_{\odot}$/yr (see Lawson et al. 2004 in detail), comparable to that derived by Muzerolle et al. (2000) for two members (TW Hya and Hen 3-600A) of the similarly-aged TW Hydrae Association. These rates are 1 – 3 orders of magnitude lower than in younger CTT stars (e.g. Taurus CTT stars; Hartmann et al. 1998).

IV. SUMMARY

There are considerable debates in circumstellar disk lifetime. The η Cha cluster provides a good opportunity to study disk properties of PMS stars with intermediate ages whose selection is unbiased with respect

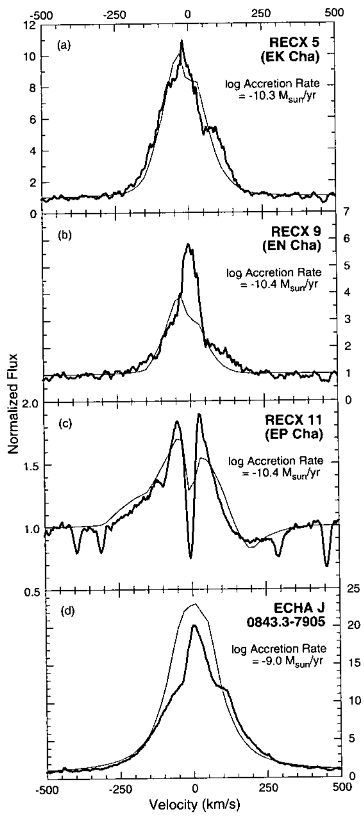

Fig. 3.— This figure is from Lawson et al. 2004 (Figure 1). Hα profiles (bold lines) for (a) RECX 5, (b) RECX 9, (c) RECX 11, and (d) ECHA J0843.3-7905. The velocity scale is anchoured to the cluster rest frame, with the corresponding wavelength range being $\approx \lambda\lambda 6552 - 6574$ Å. Magnetospheric accretion models (thin lines) are overplotted (see details in Lawson et al. 2004).

to disk existence.

We find that 9/15 or 60 percent of η Cha primaries show IR excesses in the $(J-H)/(K-L)$ diagram. One of these stars, ECHA J0843.3-7905, is a CTT star with active accretion (Lawson et al. 2002), and the Hα $-$ $\Delta(K-L)$ correlation seen in the late-type population suggests three other stars are accreting at a less rate. High-resolution spectroscopic study of Hα emission line (Fig. 3) confirms these accretion disks and it gives the accretion fraction 0.27 ± 0.13 (2σ) for this $\approx$9 Myr-old η Cha cluster.

Together infrared photometric and optical high resolution spectroscopic studies of the η Cha cluster suggest that the circumstellar disks can maintain at least $\sim$10 Myr.

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