

Infrared study of the η Chamaeleontis cluster and the longevity of circumstellar discs

A.-Ran Lyo,^{1*} Warrick A. Lawson,^{1*} Eric E. Mamajek,^{2*} Eric D. Feigelson,^{3*}
Eon-Chang Sung^{4,5*} and Lisa A. Crause^{6*}

¹*School of Physics, University of New South Wales, Australian Defence Force Academy, Canberra ACT 2600, Australia*

²*Steward Observatory, University of Arizona, 933 N Cherry Avenue, Tucson AZ 85721, USA*

³*Department of Astronomy and Astrophysics, Pennsylvania State University, University Park PA 16802, USA*

⁴*Research School of Astronomy & Astrophysics, Australian National University, Canberra ACT 2600, Australia*

⁵*Korea Astronomy Observatory, Taejon 305-348, Korea*

⁶*Department of Astronomy, University of Cape Town, Private Bag, Rondebosch 7700, South Africa*

Accepted 2002 September 18. Received 2002 September 17; in original form 2002 July 23

ABSTRACT

We have analysed *JHKL* observations of the stellar population of the ≈ 9 Myr-old η Chamaeleontis cluster. Using infrared (IR) colour–colour and colour–excess diagrams, we find that the fraction of stellar systems with near-IR excess emission is 0.60 ± 0.13 (2σ). This result implies considerably longer disc lifetimes than found in some recent studies of other young stellar clusters. For the classical T Tauri (CTT) and weak-lined T Tauri (WTT) star population, we also find a strong correlation between the IR excess and $H\alpha$ emission. The IR excesses of these stars indicate a wide range of star–disc activity: from a CTT star showing high levels of accretion to CTT–WTT transition objects with evidence for some on-going accretion and WTT stars with weak or absent IR excesses. Of the 15 known cluster members, four stars with IR excesses $\Delta(K - L) > 0.4$ mag are likely experiencing ongoing accretion owing to strong or variable optical emission. The resulting accretion fraction (0.27 ± 0.13 ; 2σ) shows that the accretion phase, in addition to the discs themselves, can endure for at least ~ 10 Myr.

Key words: accretion, accretion discs – circumstellar matter – stars: pre-main-sequence – open clusters and associations: individual: η Cha.

1 INTRODUCTION

Circumstellar discs are a natural by-product of the star formation process (e.g. Shu, Adams & Lizano 1987). Lada et al. (2000) found that 97 per cent of the optical protoplanetary discs in the Trapezium cluster exhibit excess in the *JHKL* colour–colour diagram, indicating that the most likely origin of the observed IR excesses are the circumstellar discs. The *disc lifetime* derived by examining the fraction of IR excess stars (the *disc fraction*) of young stellar populations as a function of age provides an empirical limit on the duration of the disc accretion phase. This is critical for understanding the evolutionary paths followed by pre-main-sequence (PMS) stars in the HR diagram, their angular momentum histories, and the time-scales available for planet building (e.g. Hartmann et al. 1998; Hillenbrand et al. 1998; Telesco et al. 2000).

Considerable debate has waged concerning the longevity of discs around low-mass PMS stars. The effort is difficult because samples

are often incomplete and biased: CTT stars are typically located by $H\alpha$ and near-IR excess surveys, while WTT stars are mostly found through X-ray surveys (Feigelson & Montmerle 1999). An influential early study on the time-scale for disc dissipation by Strom et al. (1989), based on several dozen PMS stars in the Taurus-Auriga complex, reported the CTT/WTT transition occurs around an age $t \approx 3$ Myr. This result is supported by a recent *JHKL* survey of 7 clusters with mean ages from 0.5 to 5 Myr that shows half the stars lose their discs within 3 Myr and essentially all lose their discs in 6 Myr (Haisch, Lada & Lada 2001). At a later age of $t \approx 13$ Myr, only 1/110 Sco-Cen late-type stars show spectroscopic CTT emission lines and *K*-band excesses (Mamajek, Meyer & Liebert 2002).

However, other studies suggest discs are more enduring. No evolution in disc fraction is found in the stellar populations of the Orion Nebula Cluster from $t < 0.1 - 2$ Myr (Hillenbrand et al. 1998), and in NGC 2264 from $t < 0.1 - 5$ Myr (Rebull et al. 2002). The Chamaeleon I cloud population, where the sample is enhanced through X-ray and *ISO* surveys, shows no difference in the age distribution of CTT and WTT stars from $t < 1 - 10$ Myr (Lawson, Feigelson & Huenemoerder 1996). Spectroscopic study of the

*E-mail: arl@ph.adfa.edu.au (ARL); wal@ph.adfa.edu.au (WAL); eem@as.arizona.edu (EEM); edf@astro.psu.edu (EDF); ecsung@mso.anu.edu.au (ECS); lcrause@artemis.astr.uq.edu.au (LAC)

~ 10 Myr-old TW Hydrae Association members found active accretion in two stars; TW Hya and Hen 3–600A (Muzerolle et al. 2000), albeit at mass accretion rates 1–2 mag lower than is derived for younger accreting systems.

The measurement of disc lifetimes is muddled by several other issues. First, despite the broad overlap in CTT and WTT age distributions, few intermediate cases are known, suggesting that the transition between the two states is rapid (Wolk & Walter 1996). Secondly, some studies suggest that two disc lifetimes must be considered; one associated with a rapid decline in accretion on to the star and another associated with a slower dissipation of the outer disc (Clarke, Gendrin & Sotomayor 2001). Thirdly, efforts to reconcile rotational distributions of both PMS and zero-age main sequence stellar clusters assuming star–disc rotational coupling during the accretion phase have deduced relatively long 10–15 Myr disc lifetimes for slowly rotating stars (Bouvier, Forestini & Allain 1997; Tinker, Pinsonneault & Terndrup 2002), but ~ 3 Myr disc lifetimes may suffice if the stellar interiors have sufficient radial differential rotation (Barnes, Sofia & Pinsonneault 2001). Finally, the astrophysical processes leading to disc dissipation are highly uncertain. Possible mechanisms include accretion on to the star, bipolar outflow, stellar winds, photoevaporation, close gravitational encounters and incorporation of disc material into planets (see the review by Hollenbach, Yorke & Johnstone 2000).

The recently discovered η Chamaeleontis cluster has the potential of clarifying some of the observational issues. It is a nearby ($\simeq 97$ pc), compact (extent ~ 1 pc) and coeval ($t = 9 \pm 1$ Myr; Lawson & Feigelson 2001) system of PMS stars with a small (15 known primaries) population of stars spanning a relatively large range in mass ($M = 0.2\text{--}3.4 M_{\odot}$; Mamajek, Lawson & Feigelson 1999, 2000; Lawson et al. 2001, 2002). The cluster includes η Cha (spectral type B8), HD 75 505 (A5), the A7+A8 binary and δ Scuti system RS Cha, 11 WTT stars (K5–M4) and 1 CTT star (M2). 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 discs. 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 disc evolution.

2 OBSERVATIONS AND DATA REDUCTION

An L -band ($3.5 \mu\text{m}$) map of the η Cha cluster was made during 1999 July 26–28 with the 0.6-m South Pole Infrared Explorer (SPIREX) telescope, using the Abu camera which had a $1 \text{ k} \times 1 \text{ k}$ InSb detector array. The Abu camera had a plate scale of $0.6 \text{ arcsec pixel}^{-1}$, giving a field-of-view (FOV) of 100 arcmin^2 . Our observations were conducted in good conditions with below-average background levels. The raw data frames were pipeline-reduced at the Rochester Institute of Technology before being delivered to us. Using custom IRAF routines written for the SPIREX/Abu system, we then merged the multiple dithered images made of each field into single frames for further analysis.

JHK_N -band images 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 InSb detector array and we selected a FOV of 4.5 arcmin^2 giving a resolution of $0.5 \text{ arcsec pixel}^{-1}$. Our observations were obtained under photometric conditions in $< 2 \text{ arcsec}$ seeing. The CASPIR

Table 1. *JHKL* photometry for members of the η Cha cluster.

Star	<i>J</i>	<i>H</i>	<i>K</i>	<i>L</i>
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	–
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	–

images were linearized, sky-subtracted and flat-fielded using customized IRAF routines based on, e.g. CCDPROC.

The SPIREX and CASPIR images were analysed using photometric routines (such as PHOT) running within IRAF. Fluxes were extracted and calibrated by comparison with standard stars listed on the SPIREX homepage¹ and IRIS photometric standards (Carter & Meadows 1995), respectively.

Examination of the image profiles for the early-type cluster members (η Cha, RS Cha and HD 75 505) suggested the onset of saturation in the CASPIR *J* and *H* frames. For this reason we obtained *JHKL* photometry (in the SAAO system; Carter 1995) for these three stars (*JHK* only for HD 75 505) 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, which we discuss below.

Table 1 lists the *JHKL* photometry of the η Cha cluster members. We adopt 1σ uncertainties of 0.03 mag for the SAAO *JHK* and the CASPIR *JHK_N* data. For the brighter *L*-band sources ($L < 9$) we adopt a 1σ uncertainty of 0.05 mag. Fainter *L*-band magnitudes are uncertain by 0.1 mag. For several RECX stars we can compare our observations with on-line DENIS *JK* observations and with *JHKL* data published by Alcalá et al. (1995). In most cases, the magnitudes differ by < 0.1 mag, which we consider to be insignificant given differences between IR photometric systems, and the intrinsic variability of these stars (Lawson et al. 2001). A special case is the eclipsing binary RS Cha. Using the ephemeris of Clausen & Nordström (1978) we find the SPIREX *L*-band measurement was obtained during the secondary eclipse, whereas the CASPIR and SAAO magnitudes were obtained at maximum light.

In the following sections we make use of the SAAO photometry for the three 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

¹See the SPIREX homepage at <http://pipe.cis.rit.edu/>.

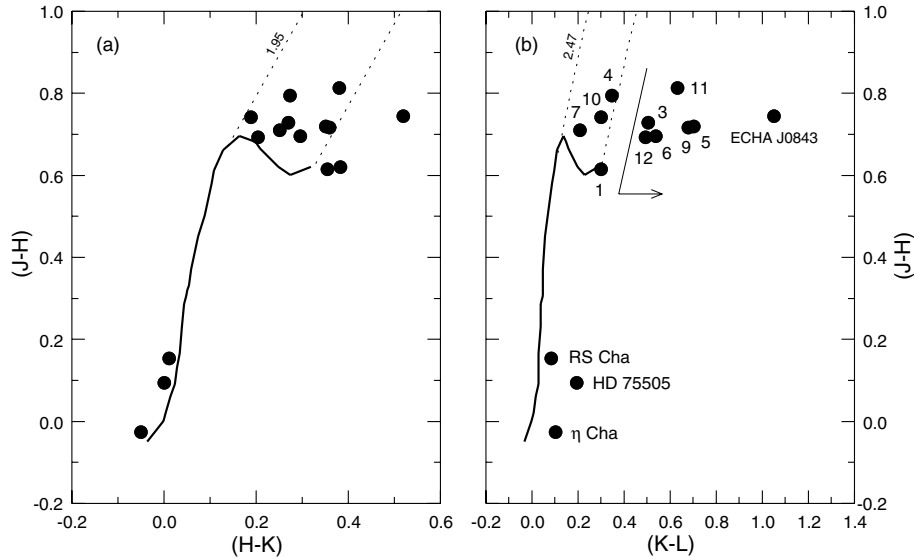


Figure 1. (a) $(J - H)/(H - K)$ and (b) $(J - H)/(K - L)$ colour–colour diagrams for the η Cha cluster. The bold lines are the locus of main-sequence stars from spectral type B8–M5, and the dashed lines represent the reddening band with gradient derived from equations given by Bessell & Brett (1988). 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; see Section 3.1.

& Brett (1988) making use of equations provided by Bessell & Brett (1988) and McGregor (1994, 1997). For $(J - H)$ and $(H - K)$ colours derived from the CASPIR photometry, the correction is small (<0.02 mag). No correction was applied to the (CASPIR $K - SPIREX L$) colour due to the mix of photometric systems, and any correction is likely swamped by the 0.05–0.1 mag uncertainty in the L -band photometry. For colours derived for the early-type stars from SAAO photometry, the effect of transforming the colours from the SAAO system to the ‘homogenized’ system is a correction of ≈ -0.02 mag.

3 ANALYSIS OF RESULTS

3.1 The infrared colour excess as a disc indicator

Colour–colour diagrams, constructed from multi-wavelength IR photometric and imaging surveys, have been shown to be a powerful tool for identifying IR excesses and circumstellar discs around stars in young clusters and star-forming regions. In particular, L -band data combined with shorter wavelength observations permit evaluation of the fraction of sources with IR excess emission from circumstellar discs – the *disc fraction* (see, e.g. Haisch, Lada & Lada 2000; Kenyon & Gómez 2001; Lada et al. 2000). As Kenyon & Gómez (2001) convincingly showed in their SPIREX L -band study of the Cha I molecular cloud, L -band photometry is nearly essential for a meaningful evaluation of the disc fraction in a young stellar population. JHK observations alone do not extend to a long enough wavelength range to enable a complete or unambiguous census of circumstellar discs in young clusters. Data obtained at $3.5 \mu\text{m}$ provide more contrast relative to photospheric emission from the central star compared with the shorter wavelength observations.

Fig. 1 shows (a) JHK and (b) $JHKL$ colour–colour diagrams of the η Cha cluster members. All 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 observed in the L band. In these diagrams the solid curves are the locus of colours 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, after due consideration of uncertainties in the reddening law and in the photometry, are IR excess objects and therefore circumstellar disc candidates. As Kenyon & Gómez (2001) found in their study of Cha I, only those stars with the largest IR excesses fall to the right of the reddening band in the JHK plane, whereas many more stars fall to the right of the reddening band once L -band data are available. If photometric errors were negligible, we could count all late-type stars with $(K - L)$ immediately to the right of the reddening band; however with 0.05–0.1 mag uncertainties in the L -band data, we count only those late-type stars with $(K - L)$ colours 0.1 mag redder than the reddening band as IR-excess objects. This criterion also largely eliminates uncertainty in the reddening law as a contributor to the disc fraction, as the reddening line is almost constant in $(K - L)$ colour over the narrow range of $(J - H)$ colours for the late-type stars.

From Fig. 1(b), the ‘gap’ in the $(K - L)$ colours between 0.34 and 0.49 allows us to count 7 stars as the most likely number of IR excess objects in the low-mass population.² To estimate the uncertainty in this number, we calculated the variation in the number of stars if the photometric uncertainties are considered at the 2σ level, i.e. twice the level of the adopted photometric errors (see Section 2). Now we find that 7 ± 2 could be counted as IR excess objects.

Use of standard IR colour–colour diagrams such as Fig. 1(b) could lead to an underestimate of the disc fraction since K-type stars need to have a colour excess $\Delta(K - L) > 0.3$ to be counted, whereas late-M stars need only $\Delta(K - L) > 0.1$. An alternative IR colour–colour diagram which largely eliminates this problem is shown in

²This criterion is similar to that adopted by Kenyon & Hartmann (1995) for PMS stars in the Taurus-Auriga molecular cloud, where $(K - L) = 0.4$ delineated the disc and the discless populations.

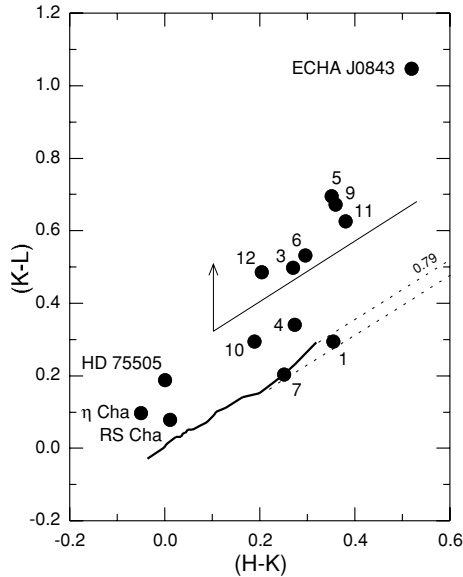


Figure 2. $(K - L)/(H - K)$ colour-colour diagram for members of the η Cha cluster surveyed at $3.5 \mu\text{m}$. See the caption to Fig. 1 for the meaning of the solid and dashed lines and other symbols.

Fig. 2. In this plane the reddening band is narrow, and the reddening vector is parallel to the main-sequence, enabling stars to be counted using the $(K - L)$ excess as the criterion. For $\Delta(K - L) > 0.25$ above the main-sequence line of Bessell & Brett (1988), we count the same 7 stars as the most-likely IR excess objects. If we adopt the same 2σ error budget as above, we again count 7 ± 2 as the range of IR excess stars. Also, as the faint cluster member ECHA J0841.5–7853 has *JHK* colours consistent with its M4 spectral type, it is unlikely to have a large IR excess, and so we conclude that 7 ± 2 out of the 12 known late-type members are IR excess objects.

For the three early-type stars, we may be justified in defining a lower colour excess as being significant. η Cha is a β Pic disc source, and with 0.05-mag uncertainty in the SAAO *L*-band flux the star has a $(K - L)$ excess that is significant at the 3σ level. For HD 75505, a 0.05-mag uncertainty in the SPIREX *L*-band magnitude gives rise to a 4σ excess. Thus with $>3\sigma$ certainty, two of the three early-type cluster members are IR excess objects.

3.2 Comparison with other accretion indicators – $H\alpha$ equivalent widths

Since an IR excess most likely indicates the presence of a circumstellar disc, we might then expect to find a correlation between the IR excess and accretion indicators such as enhanced $H\alpha$ emission, which is believed to originate in magnetospheric columns, allowing transport of disc material to the stellar surface. Two recent studies have demonstrated a correlation between the $H\alpha$ equivalent width (*EW*) and the $(K - L)$ colour in Cha I PMS stars (Kenyon & Gómez 2001), or the IR colour excess in the NGC 2264 population (Rebull et al. 2002). Comparison between the $H\alpha$ *EW* and the colour excess is desirable to eliminate redundancy caused by the spread in colour across a stellar population.

Determination of the colour excess for individual stars requires knowledge of the spectral type. For η Cha cluster members, spectral types have been determined from high-resolution studies for several RECX stars that are also *ROSAT* All-Sky Survey stars (Alcalá et al. 1995), medium resolution spectra of all cluster members (Mamajek

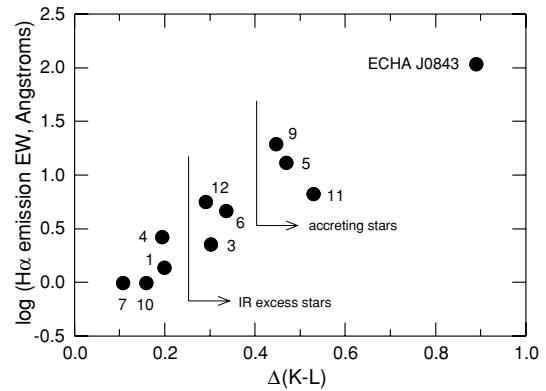


Figure 3. $H\alpha$ emission-line *EW* versus $(K - L)$ excess for the late-type stars in the η Cha cluster. The individual stars are identified by their RECX number, except for the CTT star ECHA J0843.3–7905. Stars with $\Delta(K - L) > 0.25$ are identified as IR excess objects with circumstellar discs. Those stars with $\Delta(K - L) > 0.4$ are identified as stars with accretion discs, see Section 3.3.

et al. 1999; Lawson et al. 2002) and an optical photometric study (Lawson et al. 2001, 2002). For stars common to two or three studies, comparison of the spectral types suggests a typical uncertainty of ± 1 subtype, a value comparable to the uncertainties present in the individual studies.

In Fig. 3, we find a strong correlation between the $H\alpha$ *EW* and the $(K - L)$ excess for the late-type members. Adopting the same colour excess as in Fig. 2, we again count the same 7 ± 2 stars as having an IR excess when photometric errors are considered.

3.3 The disc fraction – dust discs and accretion discs

Merging the above results, we conclude 9 ± 2 out of the 15 known stellar systems in the cluster, or a fraction of 0.60 ± 0.13 (2σ), have IR excesses. This number also defines the fraction of stars with *dust discs*, or the *disc fraction* of the population. However, a more important parameter in PMS star evolution is the fraction of stars possessing *accretion discs* in a young stellar population. By combining studies of populations of different ages it is possible to determine the time-scale for the end of significant star–disc activity and probably also the time-scale for Jovian planet building (e.g. Hillenbrand & Meyer 1999).

In other recent studies the number of accreting stars has been determined from the $(H - K)$ colour excess (e.g. Rebull et al. 2002). This has been a useful technique since the $(H - K)$ colour is sensitive to warm inner discs, and also since *JHK* detector arrays have allowed entire star formation regions to be surveyed. With the introduction of *L*-band imagers, sensitive to cooler dust and to lower luminosity discs owing to the increased contrast provided by the *L*-band photometry, we expect the disc fraction to increase as we demonstrate in Fig. 1. However, with the availability of *L*-band data, do we continue to detect accretion discs or are the *L*-band measurements increasingly sensitive to remnant dust discs in systems where there is no longer star–disc coupling?

The $(K - L)$ excesses measured for the η Cha cluster stars (Fig. 3) suggest a continuum of behaviour; from a CTT star (ECHA J0843.3–7905) showing strong star–disc interaction, stars that are CTT–WTT transition objects still showing evidence for on-going accretion (RECX 5, 9 and 11), WTT stars with weak IR excesses (RECX 3, 6 and 12), and WTT stars with little or no IR excess (RECX 1, 4, 7 and 10, and ECHA J0841.5–7853). Of the 15 known

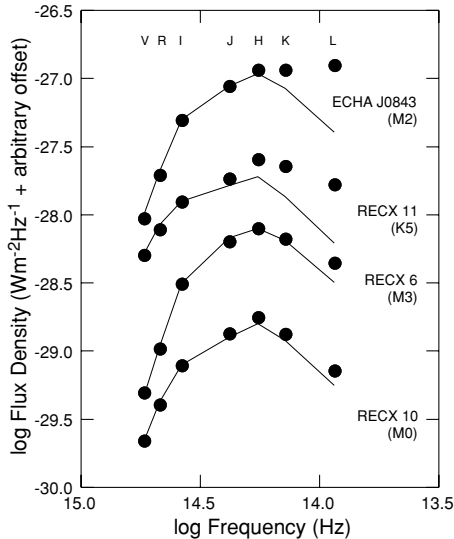


Figure 4. Spectral energy distributions for ECHA J0843.3–7905, RECX 11, RECX 6 and RECX 10. The solid lines represent spectral energy distributions for main-sequence stars of similar spectral type to the cluster stars, derived from colours given by Kenyon & Hartmann (1995), normalized to the *I*-band fluxes and assuming no reddening. The adopted spectral types are uncertain by ± 1 subtype; see Section 3.2. The worst-case photometric errors (the 5–10 per cent uncertainties in the *L*-band magnitudes) translate to roughly the plotted size of the points. The broad-band magnitudes were converted to fluxes using the conversions of Bessell (1979); Bessell & Brett (1988); Koornneef (1983).

cluster members, the 4 stars with IR excesses $\Delta(K - L) > 0.4$ are all likely to be experiencing ongoing accretion (the uncertainty in this number is ± 2 stars; 2σ). We have spectroscopically confirmed that accretion is present in two cases: ECHA J0843.3–7905 (Lawson et al. 2002) and RECX 11 (see below). For most of the late-type stars in the cluster, $\Delta(K - L) \approx 3 \Delta(H - K)$, so our accretion criterion is little different from that adopted by Rebull et al. (2002), where $\Delta(H - K) > 0.15$. These stars allow us to define an accretion fraction for the cluster of 0.27 ± 0.13 (2σ). We further consider the issue of accretion in Section 4.

In Fig. 4 we show spectral energy distributions for 4 of the cluster stars. We plot the measured fluxes of the CTT star ECHA J0843.3–7905, and offset the fluxes of the other stars to illustrate the range of IR signatures that are present in these stars. ECHA J0843.3–7905 shows a flat spectrum at near-IR wavelengths with high colour excess. Ongoing accretion in this star is supported by its rich optical emission spectrum, with a $H\alpha$ $EW = -110$ Å. The star is likely associated with IRAS F08450–7854. The *IRAS* Faint Source Catalogue (*IRAS* FSC) indicates high-quality 25- and 60- μ m fluxes of 0.30 and 0.28 Jy, respectively; approximately twice the *L*-band flux. (The *IRAS* FSC indicates an upper limit 12- μ m flux of 0.27 Jy.) RECX 11 is one of three RECX stars with $\Delta(K - L) \approx 0.5$, and with a $H\alpha$ $EW \approx 7$ –20 Å, that places them near the traditional CTT-WTT star ‘boundary’ of activity. MSSSO 1.9-m/coudé spectroscopy of RECX 11 shows that the star is still accreting from its circumstellar disc, with broad (width ~ 600 km s^{-1}) and variable infall signatures at $H\alpha$ that are phased to the 3.95-d rotation period of the star (Lyo et al., in preparation). RECX 11 appears associated with IRAS F08487–7848, with 12-, 25- and 60- μ m fluxes of 0.29, 0.32 and 0.27 Jy, respectively. RECX 6 is representative of WTT stars in the cluster with IR excesses of $\Delta(K - L) \approx 0.3$, and RECX 10 is a WTT star with little or no IR excess (see Fig. 3).

3.4 Additional considerations

3.4.1 Binarity

In addition to the A7+A8 dual-lined eclipsing binary and δ Scuti system RS Cha AB, on-going study of the cluster population has found several confirmed or probable binary systems. Mamajek et al. (1999) noted that the $H\alpha$ emission profiles of RECX 7 and 9 were double, indicating that these stars may be spectroscopic binaries. Lawson et al. (2001) noted several of RECX stars had elevated *V* magnitudes compared to other cluster members of similar spectral type; RECX 9 and 12 are elevated by ≈ 0.7 mag (suggesting near-equal mass systems) and 2 of the K-type stars (RECX 1 and 7) are 0.3–0.5 mag brighter than the third K-type cluster member RECX 11.

Speckle *K*-band imaging of RECX 1 and 9 by Köhler (2001) found both stars have companions at separations of 0.1–0.2 arcsec. Observations of RECX 1 made during 1996 and 2000 showed motion that might indicate a decade-long orbit. Consideration of the stellar background density suggests these nearby stars are likely to be physically related to the primaries. If future observations confirm these systems, RECX 1AB and RECX 9AB have *K*-band brightness ratios of ≈ 0.8 and 0.5, respectively. Observations of RECX 7 made by us using the 1.9-m telescope and coudé spectrograph at MSSSO during 2002 February showed RECX 7 to be a dual-lined spectroscopic binary with a period of 2.6 d (the same as the photometric period; Lawson et al. 2001) and a mass ratio of $\approx 2.3:1$. (RECX 7 has also been observed to be a spectroscopy binary by Donati, private communication.) If RECX 7A is a near-solar mass star, then RECX 7B is a $\sim 0.4 M_{\odot}$ early-M star. RECX 12 remains a candidate binary. However, Lawson et al. (2001) found two periods (1.3 and 8.6 d) in the *V*-band light-curve of the star in observations made in 1999 and 2000. One of these periods may be the binary period.

We have considered the effect of a binary companion on the IR excesses determined from our *JHKL* photometry. For a system such as RECX 7 with a mass ratio of 2–3 : 1 we calculate, using the PMS models of Siess, Dufour & Forestini (2000), that the near-IR colours will appear redder due to the presence of the secondary by < 0.03 mag. Binaries with higher mass ratios show less distortion of the primary star colours. Owing to the luminosity ratio of such systems, any IR excess present is likely associated with the primary. For distant near-equal mass systems such as RECX 1 the available data does not allow us to determine which member of the binary contains the IR excess, or if the excess is shared. For close binaries, we would envisage a circumbinary disc if one were present; the two confirmed spectroscopic binaries in the cluster (RS Cha and RECX 7) have no IR excess (see Fig. 2). Since our criterion for the presence of an IR excess is $\Delta(K - L) > 0.25$, we conclude that binarity will not significantly distort our results.

3.4.2 Reddening

Photometry of the cluster members indicates reddening is absent or low. For the early-type stars, Westin (1985) found $E(b - y) = -0.004$ for η Cha, and the light curve of the binary RS Cha has been modelled assuming $E(B - V) = 0.0$ (e.g. Clausen & Nordström 1978). For the late-type stars, our IR photometry indicates $\Delta(J - H) \approx 0.3\Delta(K - L)$, whereas the reddening vector in this plane has a gradient of 2.47 (see Fig. 1b). We conclude that reddening is unimportant in our determination of the disc fraction.

3.4.3 *K*-band excesses in the *K*-type stars

Comparison of the IR colour excesses indicates the three *K*-type stars (RECX 1, 7 and 11) have *K*-band excesses of ~ 0.1 mag, which has the effect of increasing the ($H - K$) colours and decreasing the ($K - L$) colours. This effect is not seen in the *M*-type stars, and cannot be attributed to reddening. Without 2- μm spectroscopy we cannot confirm if the excess is caused by *K*-band activity, e.g. Greene & Lada (1996) detected Br γ emission in half the CTT stars in a sample of ρ Oph PMS stars, although in none of the WTT stars. For RECX 1, an increase in the ($K - L$) colour of ~ 0.1 mag would make the IR excess significant. However, the star is already included in our estimate of IR excess objects once we account for observational uncertainties.

4 SUMMARY AND CONCLUSIONS

Considerable uncertainty reigns concerning the longevity, or more likely, the distribution of longevities, of circumstellar discs (Section 1). Despite its modest population, the η Cha cluster provides a rare opportunity to examine – at high sensitivity – disc properties of PMS stars with intermediate ages whose selection is unbiased with respect to disc existence.³ If discs decay rapidly as indicated by some past studies, then no discs at all are expected in this cluster.

We find, however, that 9/15 or 60 per cent of η Cha primaries show IR excesses in the ($H - K$)/($K - L$) diagram (the late-type stars identified in Fig. 2, plus η Cha and HD 75505). The excess cannot be attributed to errors in photometry (Section 2), binarity (Section 3.4.1) or reddening (Section 3.4.2). Long-lived circumstellar discs are the only plausible explanation. One of these stars, ECHA J0843.3–7905, is a CTT star with active accretion (Lawson et al. 2002), and the $H\alpha - \Delta(K - L)$ correlation seen in the late-type population suggests that up to 3 other stars may be accreting (see Fig. 3). High-resolution spectroscopic study now underway will address this issue.

Why do we find a high disc fraction at $t \simeq 9$ Myr when some other studies find discs largely disappear by $t = 3$ – 6 Myr? We first recognize that, except for ECHA J0843.3–7905, the η Cha discs would have been mostly missed from *JHK* colours alone (see Fig. 1a). Sensitive *L*-band surveys are essential for the detection of aging PMS discs. The principal discrepancy among *L*-band studies lies between our high disc fraction (9/15 or 0.60) in η Cha and the low disc fraction (9/75 or 0.12) for the 5-Myr-old cluster NGC 2362 found by Haisch et al. (2001). We suggest several explanations for this difference. First, the assigned age of NGC 2362 PMS stars relies solely on the turn-off age of the O9Ib supergiant τ CMa (Balona & Laney 1996) and the assumption that all stars in the cluster are coeval. Secondly, NGC 2362 is 1480 pc distant compared with 97 pc for η Cha. The distance ratio alone degrades the *L*-band sensitivity by a factor of 200. Because of this, faint discs in NGC 2362 may not have been detected. Also, the limiting mass of the Haisch et al. (2001) study of NGC 2362 is $M \approx 1 M_{\odot}$ (spectral type mid-K) compared with $M \approx 0.2 M_{\odot}$ (spectral type M4) in our study of η Cha. As we discuss in Section 3.1, it is easier to detect an IR excess in a late-M star, compared with a *K*-type star, using standard IR colour–colour plane analysis. Also, it is possible that disc lifetimes are shorter in higher mass stars. Thirdly, there might be variance in the disc destruction rate amongst clusters owing to different rates of

close encounters or photoevaporation due to massive stars, e.g. the discs in NGC 2362 might have been stripped by the UV/wind of τ CMa (see Hollenbach et al. 2000, for theory).

A combination of the above factors can explain why there is a 2–4 dispersion in the observed disc fraction for PMS star clusters of a similar age (Hillenbrand & Meyer 1999). While noting these differences, our results seen together with studies of other older nearby PMS stars (e.g. study of the TW Hydrae Association members by Muzerolle et al. 2000) indicate that IR-detected discs can be present in ~ 60 per cent, and accretion discs can be present in ~ 30 per cent, of ~ 10 Myr old PMS stars.

ACKNOWLEDGMENTS

We thank C. Kaminski for obtaining our SPIREX/Abu observations, and J. Kastner and colleagues at the Rochester Institute of Technology for performing the pipeline analysis of the raw observations. We also thank M. Burton (UNSW) for coordinating the Australian allocation of SPIREX observing time, S. James for installing the SPIREX/Abu reduction package at ADFA, and N. Zarate (NOAO) at the IRAF help desk for on-line assistance. SPIREX was a facility operated by the Centre for Astrophysical Research in Antarctica. We thank the MSSSO and SAAO time allocation committees for telescope time during 2002, which enabled us to complete this project. MSSSO is operated by the Research School of Astronomy and Astrophysics, Australian National University. SAAO is a national facility operated by the National Research Foundation of South Africa. ARL acknowledges the support of a UNSW/ADFA International Postgraduate Research Scholarship. WAL acknowledges support from the UNSW Research Support Programme and UNSW/ADFA Special Research Grants. EEM thanks the SIRTf Legacy Science Program for support. EDF's research is supported in part by NASA contracts NAS8-38252 and NAG5-8422. LAC is supported by a National Research Foundation Post-graduate Scholarship.

REFERENCES

- Alcalá J. M., Krautter J., Schmitt J. H. M. M., Covino E., Wichmann R., Mundt R., 1995, *A&AS*, 114, 109
 Balona L. A., Laney C. D., 1996, *MNRAS*, 281, 1341
 Barnes S., Sofia S., Pinsonneault M., 2001, *ApJ*, 548, 1071
 Bessell M. S., 1979, *PASP*, 91, 589
 Bessell M. S., Brett J. M., 1988, *PASP*, 100, 1134
 Bouvier J., Forestini M., Allain S., 1997, *A&A*, 326, 1023
 Carter B. S., 1995, *Ap&SS*, 230, 163
 Carter B. S., Meadows V. S., 1995, *MNRAS*, 276, 734
 Clarke C. J., Gendrin A., Sotomayor M., 2001, *MNRAS*, 328, 485
 Clausen J. V., Nordström B., 1978, *A&AS*, 33, 87
 Feigelson E. D., Montmerle T., 1999, *ARA&A*, 37, 363
 Greene T. P., Lada C. J., 1996, *AJ*, 112, 2184
 Haisch K. E., Jr, Lada E. A., Lada C. J., 2000, *AJ*, 120, 1396
 Haisch K. E., Jr, Lada E. A., Lada C. J., 2001, *ApJ*, 553, L153
 Hartmann L., Calvet N., Gullbring E., D'Alessio P., 1998, *ApJ*, 495, 385
 Hillenbrand L. A., Meyer M. R., 1999, *BAAS*, 195, 209
 Hillenbrand L. A., Strom S. E., Calvet N., Merrill K. M., Gatley I., Makidon R. B., Meyer M. R., Skrutskie M. F., 1998, *AJ*, 116, 1816
 Hollenbach D. J., Yorke H. W., Johnstone D., 2000, in Mannings V., Boss A. P., Russell S. S., eds, *Protostars and Planets IV*. University of Arizona, Tucson, p. 401
 Kenyon S. J., Gómez M., 2001, *AJ*, 121, 2673
 Kenyon S. J., Hartmann L., 1995, *ApJS*, 101, 117
 Köhler R., 2001, in Jayawardhana R., Greene T. P., eds, *ASP Conf. Ser. Vol. 244, Young Stars Near Earth*. Astron. Soc. Pac., San Francisco, p. 277

³The importance of the η Cha cluster in this respect is recognized by its inclusion in the first year guaranteed time programme of the *Space Infrared Telescope Facility*.

- Koornneef J., 1983, *A&A*, 128, 84
- Lada C. J., Muench A. A., Haisch K. E. Jr, Lada E. A., Alves J. F., Tollestrup E. V., Willner S. P., 2000, *AJ*, 120, 3162
- Lawson W. A., Feigelson E. D., 2001, in Montmerle T., André P, eds, *ASP Conf. Ser. Vol. 243, From Darkness To Light*. Astron. Soc. Pac., San Francisco, p. 591
- Lawson W. A., Feigelson E. D., Huenemoerder D. P., 1996, *MNRAS*, 280, 1071
- Lawson W. A., Crause L. A., Mamajek E. E., Feigelson E. D., 2001, *MNRAS*, 321, 57
- Lawson W. A., Crause L. A., Mamajek E. E., Feigelson E. D., 2002, *MNRAS*, 329, L29
- Mamajek E. E., Lawson W. A., Feigelson E. D., 1999, *ApJ*, 516, L77
- Mamajek E. E., Lawson W. A., Feigelson E. D., 2000, *ApJ*, 544, 356
- Mamajek E. E., Meyer M. R., Liebert J. W., 2002, *AJ*, 124, 1670
- McGregor P. J., 1994, *PASP*, 106, 508
- McGregor P. J., 1997, *CASPIR manual*, <http://www.mso.anu.edu>
- Muzerolle J., Calvet N., Briceño C., Hartmann L., Hillenbrand L., 2000, *ApJ*, 535, L47
- Rebull L. M. et al., 2002, *AJ*, 123, 1528
- Shu F. H., Adams F. C., Lizano S., 1987, *ARA&A*, 25, 23
- Siess L., Dufour E., Forestini M., 2000, *A&A*, 358, 593
- Strom K. M., Strom S. E., Edwards S., Cabrit S., Skrutskie M. F., 1989, *AJ*, 97, 1451
- Telesco C. M. et al., 2000, *ApJ*, 530, 329
- Tinker J., Pinsonneault M., Terndrup D., 2002, *ApJ*, 564, 877
- Westin T. N. G., 1985, *A&AS*, 60, 99
- Wolk S. J., Walter F. M., 1996, *AJ*, 111, 2066

This paper has been typeset from a $\text{\TeX}/\text{\LaTeX}$ file prepared by the author.