

# 2RE J0241-525: A nearby post T-Tauri visual binary system

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## ABSTRACT

We present high spatial resolution X-ray observations, photometry and spectroscopy of the two low mass, active stars proposed as optical counterparts to the extreme ultra-violet source 2RE J0241-525 (= EUVE J0241-530). It is confirmed that both stars, which are of types dK7e and dM3e and separated by 22 arcsecs, are sources of soft X-ray emission and exhibit substantial chromospheric activity. Radial velocity measurements indicate that the two components are physically associated and most probably single. The projected equatorial velocities are measured as  $(75 \pm 3) \text{ km s}^{-1}$  and  $(11.7 \pm 0.7) \text{ km s}^{-1}$  for the hotter and cooler components respectively and whilst the hotter component has a relatively high photospheric lithium abundance,  $\log N(\text{Li}) = 1.5 \pm 0.2$ , we are unable to detect any lithium in the cooler star. Isochrone fitting to this “mini-cluster” yields an age of (3-70) Myr and a distance of (19-60) pc. An empirical comparison of the lithium abundances with those for similar stars in young clusters and associations narrows this age range to (5-30) Myr and a corresponding distance of (26-50) pc. We conclude that this object is a nearby post T-Tauri system, but we cannot locate any possible birth site. It appears unlikely that the system can have been ejected from a nearby open cluster in a two or three body encounter.

**Key words:** Stars: late-type - Stars: pre-main sequence - Stars: activity - Stars: rotation - X-rays: stars

## 1 INTRODUCTION

The *ROSAT* X-ray/extreme ultra-violet (EUV) satellite completed a successful all-sky survey in 1991. The initial results from the UK-built EUV Wide Field Camera (WFC) have been published in the form of a bright-source catalogue Pounds et al. (1993) and in the more comprehensive “2RE” catalogue (Pye et al. 1995), which contains 479 EUV sources. The majority of these sources are magnetically active late-type stars which emit EUV photons from a hot corona that is confined and heated by a magnetic field, which is in turn generated in the stellar convection zone by the interaction of differential rotation and cyclonic motions – a mechanism known as the dynamo process. Empirically, rapid rotation appears to be the key to these phenomena and it has been shown that there are two main sub-classes of EUV bright, magnetically active stars; those that rotate rapidly because they are in tidally locked, short-period binary systems (Jeffries, Bertram & Spurgeon 1995) and those that are single and rotate rapidly because they are young and have not yet lost a substantial amount of angular momentum (Jeffries 1995 – hereafter J95).

Single, ultra-fast rotating ( $v \sin i > 40 \text{ km s}^{-1}$ ), low-mass stars are rare amongst the field-star population, but are common in the young Pleiades and Alpha Persei clusters (e.g. Stauffer, Hartmann & Jones 1989; Stauffer 1991). The known examples of rapidly rotating field stars include AB Dor, HK Aqr, HD 197890, BD+22° 4409 and 2RE 1816+541 and have spectral types of K0 to M2, periods from 0.3 to 0.8 days and projected equatorial velocities ( $v \sin i$ ) up to  $170 \text{ km s}^{-1}$  (see Young, Skumanich & Harlan 1984; Innis et al. 1988; Anders et al. 1993; Jeffries et al. 1994; Jeffries, James & Bromage 1994). These objects are much closer than stars of equivalent spectral type in the Pleiades and are important because detailed observations can be performed to investigate the operation of the dynamo at extreme rotation rates (e.g. Collier-Cameron & Unruh 1994; Robinson et al. 1994) and to explore how ultra-fast rotating stars in young clusters lose vast amounts of angular momentum in their early lives (e.g. Collier-Cameron & Robinson 1989; Jeffries 1993).

Less extreme examples of young, rapid rotators have been found by virtue of their photospheric lithium abun-

dances. Li is rapidly depleted in cool stellar atmospheres because mixing processes bring material from interior regions that are hot enough to burn Li in p,  $\alpha$  reactions. The equivalent width (EW) of the Li I line at 6708 Å has been used as an empirical age indicator by several authors (*e.g.* Tagliaciferri et al. 1994; Favata et al. 1995; J95) to show that the low-mass content of X-ray and EUV surveys contain many stars at least as young as the Pleiades (age  $\sim 70$  Myr). J95 has gone further than this, and shown that the ultra-fast rotators and lithium-rich low-mass stars may share a common evolutionary origin, because they have very similar space motions to the Pleiades, and also to a kinematic group of young, early-type stars in the solar vicinity, known as the Local Association.

Some of the Li-rich stars investigated by J95 are in visual binary systems, where, if the components are physically associated rather than being in the same line of sight, one can presumably be confident that the components have the same age and composition (see also Martín, Magazzù & Rebolo 1992; Pallavicini, Pasquini & Randich 1992; Martín & Brandner 1995). These are of special interest because they form “mini-clusters”, where in principle, the components could be matched to isochrones on colour-magnitude diagrams in order to obtain more reliable age and distance estimates. Furthermore, comparison could also be made between the Li abundances seen in both components and theoretical isochrones of Li depletion (*e.g.* d’Antona & Mazzitelli 1994).

Even younger late-type stars have been found in X-ray surveys of star formation regions and have been variously classified as either classical T-Tauri stars (CTTS), weak lined T-Tauri stars (WTTS) or post T-Tauri stars (PTTS) (*e.g.* Walter et al. 1988; Neuhäuser et al. 1995a, and references therein). The distinction between CTTS and WTTS is usually made upon the strength of emission lines, veiling of the optical spectrum and the strength of any infra-red (IR) excess. In WTTS the H $\alpha$  emission is thought to be mainly chromospheric and is smaller than about 5 Å, there is little veiling of the optical spectrum and a small or even absent IR excess. In CTTS much greater H $\alpha$  emission is seen along with optical veiling and a prominent IR excess. It is generally assumed that these phenomena relate to the presence or not of active accretion and circumstellar gas or dust. In recent years, some evidence has emerged that there is an evolutionary link between WTTS and CTTS, in that WTTS are simply CTTS that have dispersed their disks, spun up and become more magnetically active (Edwards et al. 1993; Bouvier et al. 1993a,b; Neuhäuser et al. 1995a), although this is confused by the fact that CTTS and WTTS are found at the same age. PTTS were postulated by Herbig (1978), as a slightly older generation of T-Tauri stars that might be more widely dispersed from their birth sites. This view is supported by X-rays surveys of Orion (Sterzik et al. 1995), where a widely distributed WTTS population is found. It seems that the distinction between PTTS and WTTS may only be their closeness to a region of star formation. Several of the rapidly rotating, lithium rich field stars referred to above, have been labelled as PTTS in the past.

In this paper, we present new spectroscopic, photometric and high spatial resolution X-ray observations of a visual binary system that is the proposed optical counterpart to the EUV source 2RE J0241-525 (Mason et al. 1995). We

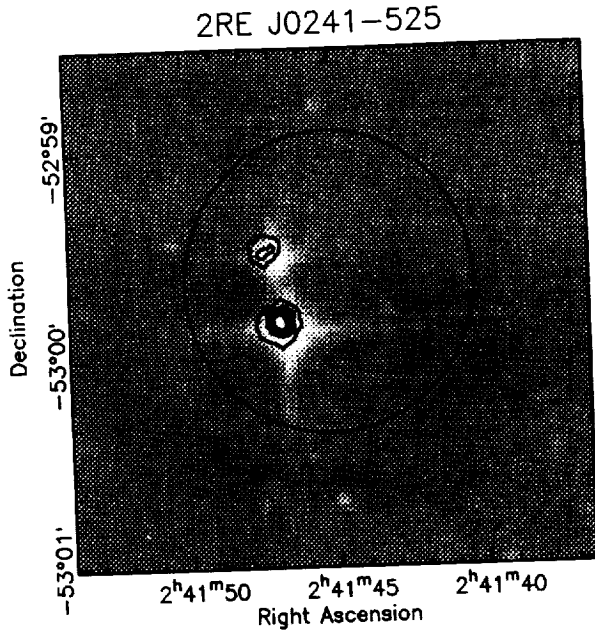


Figure 1. Contoured HRI image (0.2-2.0 keV) of the 2RE J0241-525 field overlaid on an optical image of the field. The circle represents the position of the WFC source error circle.

show that the components are physically associated and that both stars are extremely active and rapidly rotating. From isochrone fitting and a consideration of the observed Li abundances it seems likely that neither component has evolved to the zero age main sequence (ZAMS) and that the system is similar to WTTS, but is not associated with any particular star formation region.

## 2 OBSERVATIONS

### 2.1 ROSAT HRI observations

The WFC source 2RE J0241-525 was detected at the position  $02^{\text{h}}41^{\text{m}}45.2^{\text{s}}$   $-52^{\circ}59'38''$  (J2000.0) with a positional error of 44-arcsec and count-rates of  $2.5 \times 10^{-2} \text{ s}^{-1}$  and  $1.4 \times 10^{-2} \text{ s}^{-1}$  in the S1 and S2 filters (see Pye et al. 1995 for details). In the WFC optical identification programme, Mason et al. (1995) have identified the EUV source with two dMe stars, inside the WFC error circle, separated by 22 arcsec (see Figure 1). Ball & Bromage (1995) have reported that the northern dMe star exhibits considerable U-band flare activity. A corresponding source, EUVE J0241-530, was also seen in the subsequent Extreme Ultraviolet Explorer (EUVE) sky survey at a position nearly coincident with the WFC source. This also contains the two counterparts within its nominal 1 arc-minute error circle (Bowyer et al. 1994). The spatial resolution of the WFC (or EUVE) is insufficient to resolve this pair, but new observations were obtained with the ROSAT High Resolution Imager (HRI) on 10-11 December 1992.

The HRI has a field of view approximately  $38' \times 38'$ , is sensitive to photons in the 0.2-2.0 keV range and has a spatial resolution of about 3 arcseconds on-axis (see Pfeffermann et al. 1986; David et al. 1992). The central part of the 3036-s HRI exposure is shown in Figure 1 in contour

form, overlaid on an optical image of the same field, obtained from the Space Telescope Science Institute digitized sky survey. Also marked, is the WFC error circle. It is clear from Figure 1 that the two candidate stars, that we will call north (N) and south (S) are both sources of soft X-ray emission, and therefore likely to contribute to the EUV emission seen by the WFC and EUVE.

The count-rates and positions of the X-ray sources have been determined with a maximum likelihood point source searching (PSS) method (part of the Starlink ASTERIX package), which optimises both source and background strengths with respect to the Cash likelihood statistic (Allan 1992). The background was very low indeed, at approximately  $0.014 \text{ cts s}^{-1} \text{ arcmin}^{-2}$ . Raw counts were corrected for the exposure time, dead-time, quantum efficiency variations and vignetting, assuming a mean photon energy of 1 keV, to give an on-axis count-rate. These count rates were converted to an X-ray flux (0.1-2.4 keV) assuming a conversion factor of 1 count equals  $4.4 \times 10^{-11} \text{ erg cm}^{-2}$ , which is appropriate for a  $10^7 \text{ K}$  optically thin plasma and negligible interstellar absorption (David et al. 1992).

The PSS results and X-ray fluxes are given in Table 1. Comparison with coordinates in the Hubble guide star catalogue (version 1.1), gives position discrepancies for the north and south components (in the sense X-ray position minus optical position) of 1.9 and 2.4 arcseconds in RA, and 2.1 and 2.3 arcseconds in Dec. Given the uncertainties in the X-ray and optical positions we conclude that these shifts are consistent and they are not unusually large for HRI observations.

The HRI observations were split into two observing slots, separated by 4.5 hours. Time series were constructed for each component of 2RE J0241-525, using background from an annulus surrounding both sources. The background subtracted time-series were then corrected for deadtime, vignetting and variable quantum efficiency and are shown in Figure 2, where the northern component has been displayed in 200-s bins and the southern component in 100-s bins. Clear variability is seen in the southern component. The mean count rate in the first observing slot is  $(0.127 \pm 0.018) \text{ counts s}^{-1}$ , whereas in the second slot the count rate is  $(0.275 \pm 0.029) \text{ counts s}^{-1}$ . The corresponding means in the northern component are  $(0.056 \pm 0.006)$  and  $(0.061 \pm 0.007) \text{ counts s}^{-1}$ , and there is no evidence for variability. The cause for the variability in the southern component could be flaring or rotational modulation. The system would be an interesting target for a longer follow up observation.

## 2.2 Photometry

UBV(RI)<sub>C</sub> photoelectric photometry of the proposed optical counterparts was performed on the 0.75-m telescope of the South African Astronomical Observatory (SAAO) on 17 Dec 1992 with a single channel photometer. A 13 arcsec aperture was used and the seeing was approximately 1 arcsec (FWHM), so contamination between the components should be negligible. Extinction values were determined from Cousins E-region standards (Menzies et al. 1989) and standard magnitudes derived from the well determined colour equations at SAAO. UBV(RI)<sub>C</sub> magnitudes are listed in Table 2.

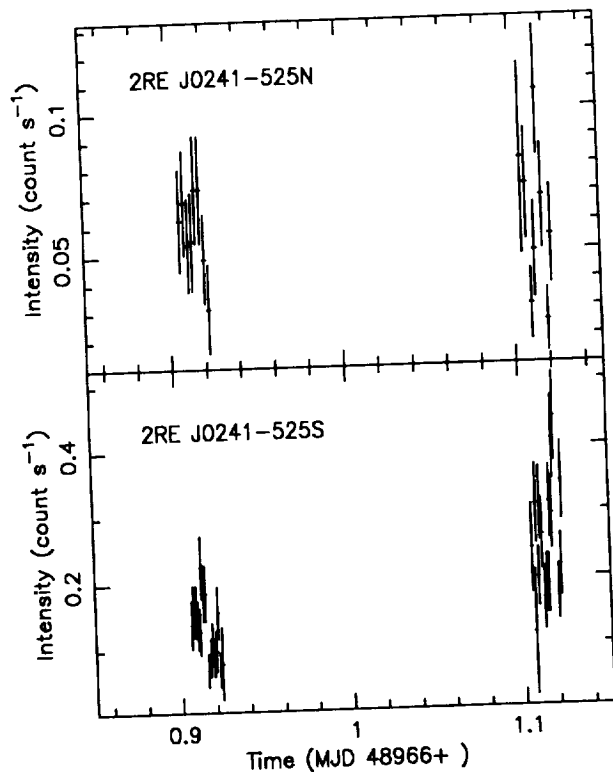


Figure 2. Time series of the HRI observations (0.2-2.0 keV) for the northern and southern components of 2RE J0241-525. The northern component is in 200-s time bins, while the southern component is in 100-s time bins.

## 2.3 Low and intermediate resolution spectroscopy

Low and intermediate resolution spectra of the optical counterparts were obtained in December 1991 with the 1.9-m telescope at SAAO, equipped with the Royal Greenwich Observatory UNIT spectrograph and the Reticon Photon Counting System. Three separate wavelength ranges were covered; (i) 3400-6800 Å at a resolution of 6 Å, (ii) 3600-4200 Å at a resolution of 1.4 Å, and (iii) 5800-6800 Å at a resolution of 2.0 Å. Spectra were flat-fielded with long quartz lamp exposures and corrected for atmospheric extinction using data from Spencer-Jones (1980). Wavelength calibration was achieved by reference to Argon arc lamp spectra. Absolute flux calibration was attempted with exposures of flux-standards from Stone & Baldwin (1983). Because the slit-width was set at about 1.6-arcsec, the observations cannot be considered spectrophotometric. Nevertheless, Doyle et al. (1990) have shown, with the same instrumentation, that this approach can yield fluxes accurate to 20 percent, although we conservatively estimate our errors to be within a factor of two.

Figure 3 shows the low-resolution spectra of the optical counterparts. Spectral types were estimated from the depression of the TiO bandheads at 4760 Å, 5167 Å, 5448 Å and the MgH bandhead at 4780 Å, relative to the local continuum. These temperature sensitive indices have been calibrated by Mathioudakis (1992). From these measurements, spectral types of dK7 and dM3 are estimated, with an uncertainty of  $\pm$  half a spectral subclass. Balmer emission lines

**Table 1.** PSS Results

	RA J2000.0	Dec	Error arcsec	Raw counts	Flux cts/ks	Flux (0.1-2.4 keV) ( $\times 10^{-13}$ erg cm $^{-2}$ s $^{-1}$ )
2RE J0241-525N	02 41 47.34	-52 59 28.0	0.5	186 $\pm$ 19	59 $\pm$ 6	13.0 $\pm$ 1.3
2RE J0241-525S	02 41 46.84	-52 59 49.3	0.2	628 $\pm$ 36	202 $\pm$ 11	44.7 $\pm$ 2.4

**Table 2.** Photoelectric photometry

	HJD 2448900+	V	B-V	U-B	V-R <sub>C</sub>	V-I <sub>C</sub>
2RE J0241-525N	74.345	12.167 $\pm$ 0.003	1.484 $\pm$ 0.006	0.984 $\pm$ 0.014	1.055 $\pm$ 0.004	2.372 $\pm$ 0.003
2RE J0241-525S	74.352	10.276 $\pm$ 0.004	1.258 $\pm$ 0.003	0.930 $\pm$ 0.007	0.808 $\pm$ 0.002	1.595 $\pm$ 0.002

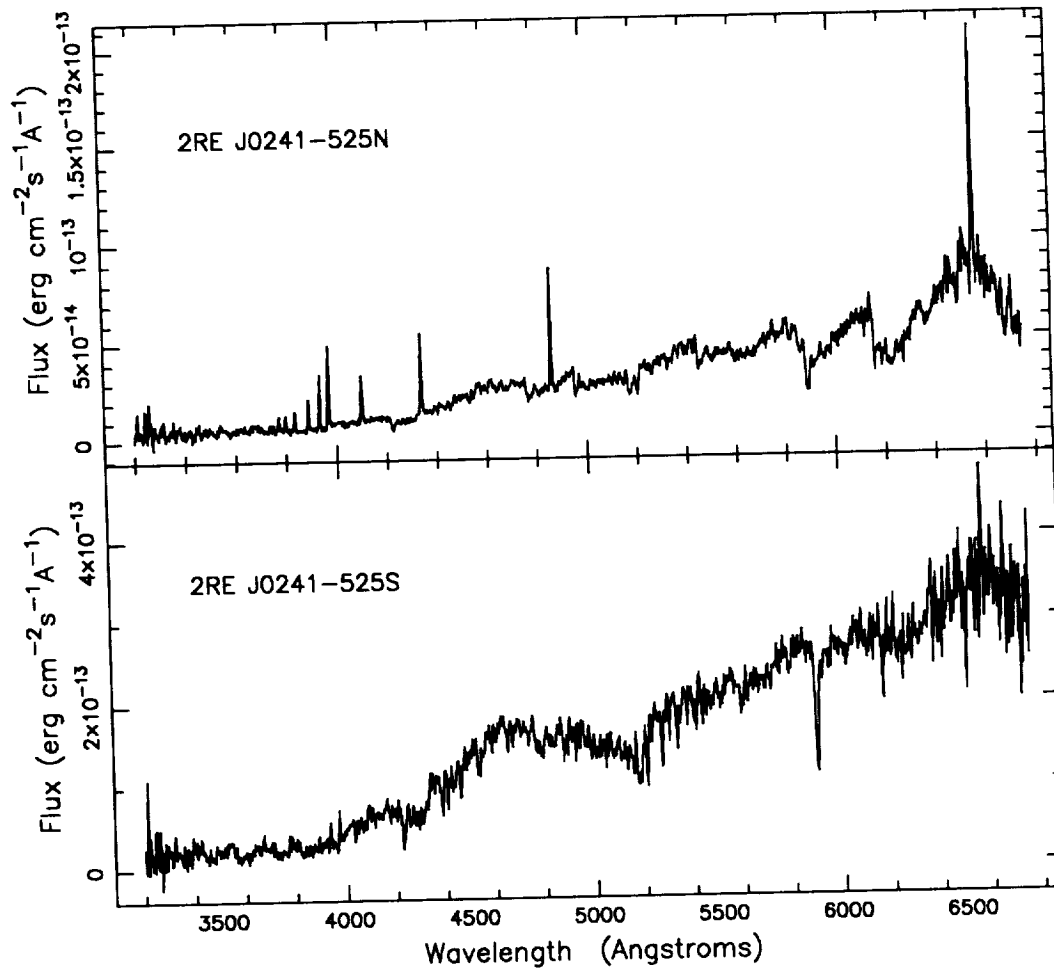
**Figure 3.** Low resolution SAAO spectra of the north and south components of 2RE J0241-525.

Table 3. Line fluxes in units of  $10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$ , from the low and intermediate resolution spectroscopy.

Component	H $\alpha$ EW ( $\text{\AA}$ )	H $\alpha$	H $\beta$	H $\gamma$	H $\delta$	Ca H/H $\epsilon$	Ca K	H8	H9	H10	H11
2RE J0241-525N Low	5.8	5.2	2.8	2.0	1.3	2.4	1.2	0.92	0.53	0.31	0.27
2RE J0241-525S Low	0.7	2.4	-	-	-	1.2	0.80	-	-	-	-
2RE J0241-525N Int	5.7	5.8	-	-	0.80	1.2	1.1	-	-	-	-
2RE J0241-525S Int	1.1	4.1	-	-	-	1.5	1.6	-	-	-	-

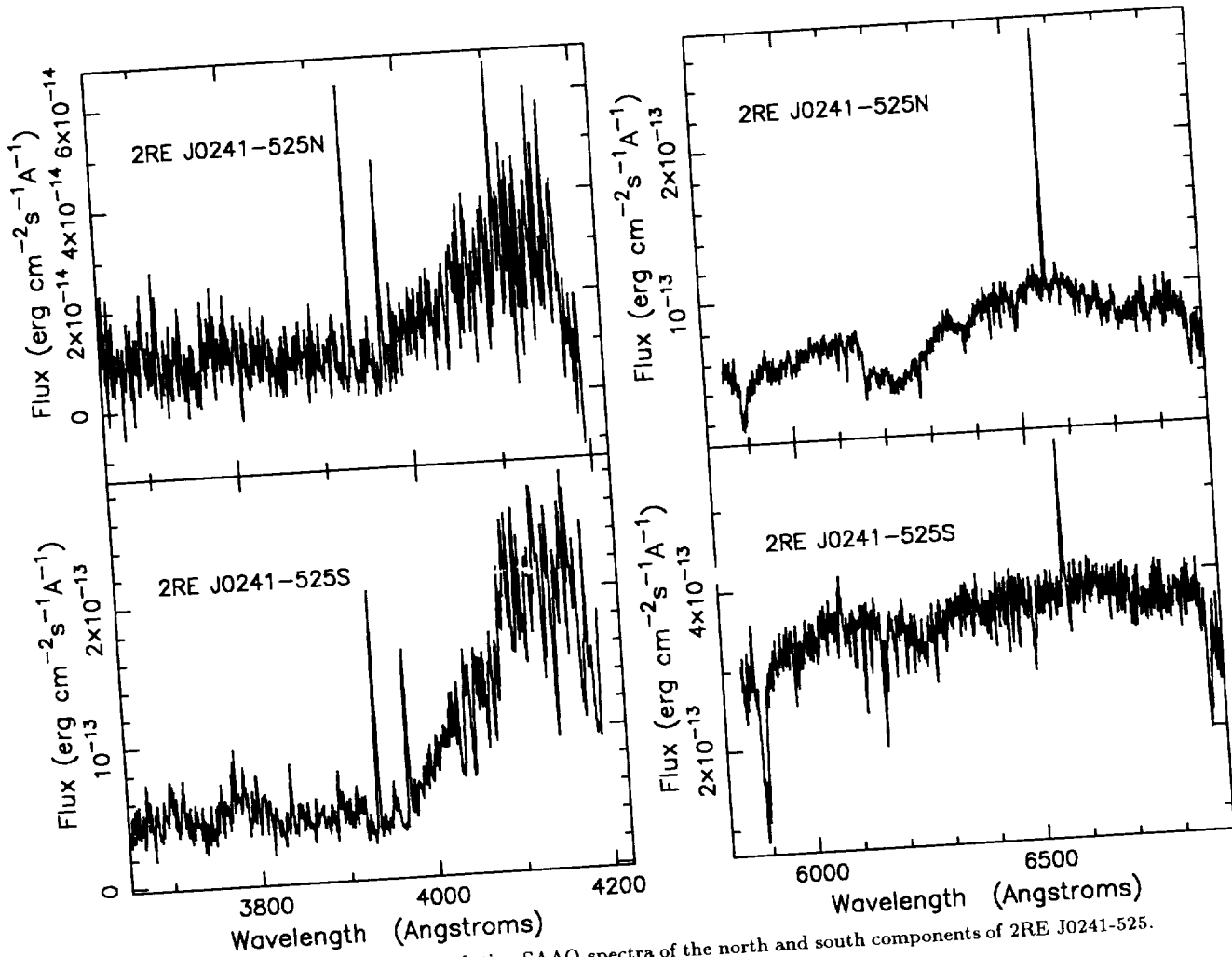


Figure 4. Intermediate resolution SAAO spectra of the north and south components of 2RE J0241-525.

are clearly evident in the spectrum of the cooler, northern component, as well as Ca II H & K emission lines. There is also evidence for H $\alpha$  and Ca II H & K emission in the southern component, but this is more obvious in the higher resolution spectra (see Figure 4). Where there is sufficient signal, chromospheric emission line fluxes have been calculated by fitting Gaussian profiles above the local continuum level. These fluxes are given in Table 3.

Intermediate resolution spectra in the blue and red wavelength ranges are shown in Figure 4. Again, chromospheric emission lines are clearly visible, this time in both the northern and southern components. Fluxes are calcu-

lated by fitting Gaussians above the local continuum, and the results given in Table 3. Also given are the EWs of the H $\alpha$  emission lines, which are of more utility in comparisons with other work. On 26/27 December 1991, 2RE J0241-525N was monitored at H $\alpha$  for approximately 3 hours, between 23:00 UT and 02:00 UT, with 60-s exposures. No evidence for any significant variability was found, either on short timescales, or over the length of the monitoring period. The mean H $\alpha$  EW was 5.57 Å from 150 spectra, with a standard deviation of 0.85 Å, compatible with the estimated EW error for each spectrum.

## 2.4 High resolution spectroscopy

High resolution spectra of 2RE J0241-525 were obtained with échelle spectrographs at the Mount Stromlo (MSO) 1.9-m telescope on 22 June 1994 (one spectrum of the southern component), at the Cerro Tololo Interamerican Observatory (CTIO) 4-m telescope on 15 January 1995 (one spectrum each of the northern and southern components) and at the Anglo Australian Observatory 3.9-m telescope (AAT) on 21 (south component) and 22 January 1995 (both components). The MSO observations were performed with a 79 lines mm<sup>-1</sup> grating, a 2048 pixel square Tektronix CCD and a 2 arcsec slit width that yielded a resolution of 0.15 Å at H $\alpha$ . The CTIO observations used a 31.6 lines mm<sup>-1</sup> grating, a 2048 pixel square Tektronix CCD and a 0.8 arcsec slit to give a 2-pixel resolution of about 0.15 Å at H $\alpha$ . The AAT observations used a 79 lines mm<sup>-1</sup> grating, a 1024 pixel square Tektronix CCD and a 1.2 arcsec slit which gave a resolution of 0.16 Å at H $\alpha$ . The CTIO spectra were debiased, flat-fielded and extracted (by JRS) using IRAF routines, while the MSO and AAT spectra were reduced using the ECHOMOP package (Mills & Webb 1994). In all cases, the slit length was long enough to allow sky subtraction of the spectra without overlapping the adjacent orders. The signal to noise ratios of the AAT and CTIO spectra were in the range 60-90 per pixel, while the MSO spectrum was poorer, with a signal to noise of 30.

The spectra were used to obtain heliocentric radial and rotational velocities using cross-correlation techniques (*e.g.* Tonry & Davis 1979). The spectral ranges used were  $\lambda\lambda 5875$ -5955 for the MSO spectrum,  $\lambda\lambda 6640$ -6750 and  $\lambda\lambda 7770$ -7870 for the CTIO spectra and  $\lambda\lambda 5670$ -5732 for the AAT spectra. Radial velocity zero points were set by reference to spectra of several radial velocity standard stars. For the CTIO spectra these were Gliese 205, 273 and 447, while for the AAT and MSO spectra HR 1829, 3748, 4182 and 5384 were used. Projected equatorial velocities ( $v \sin i$ ) were obtained similarly, by calibrating the FWHM of the cross-correlation peaks obtained with slowly rotating, inactive standard star spectra of types similar to 2RE 0241-525N+S, that were convolved with a range of limb-darkened rotational broadening functions. The results of these analyses are given in Table 4. The weighted mean radial velocities for the north and south components are  $+11.6 \pm 0.7$  and  $+12.0 \pm 1.5$  km s<sup>-1</sup> with no evidence for significant variability. The weighted mean  $v \sin i$  values for the north and south components are  $11.7 \pm 0.7$  and  $75 \pm 3$  km s<sup>-1</sup>.

The high resolution échelle spectroscopy also includes a spectral order containing the neutral Li resonance doublet at 6708 Å. Figure 5 shows the spectral region around this line for both components. The Li I line is prominent in 2RE J0241-525S but is not clearly present in 2RE J0241-525N. The EW of the Li I lines has been estimated by comparison with inactive, slowly rotating (and therefore presumably old and entirely depleted of Li) stars of similar spectral types. The standards used are Gliese 820B (type K7V) and Gliese 687 (type dM4). The standards are broadened to the same  $v \sin i$  as the targets and then shifted to the appropriate radial velocity and subtracted from the target spectra. The resultant residual at the Li I wavelength is then integrated to give the EW, which is given in Table 5. The advantage of this technique is that it minimises the effects of blending

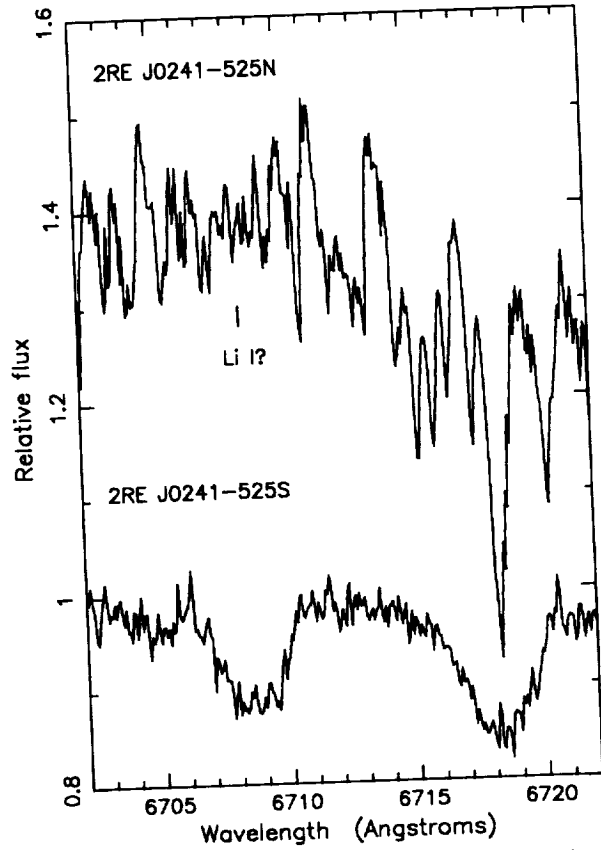


Figure 5. Normalised AAT échelle spectra in the vicinity of the Li I 6708 Å feature. The location of any possible Li I line is marked in the northern component.

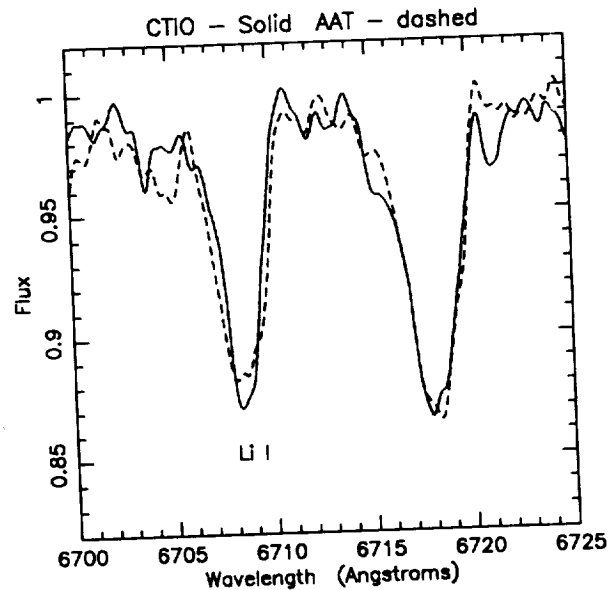
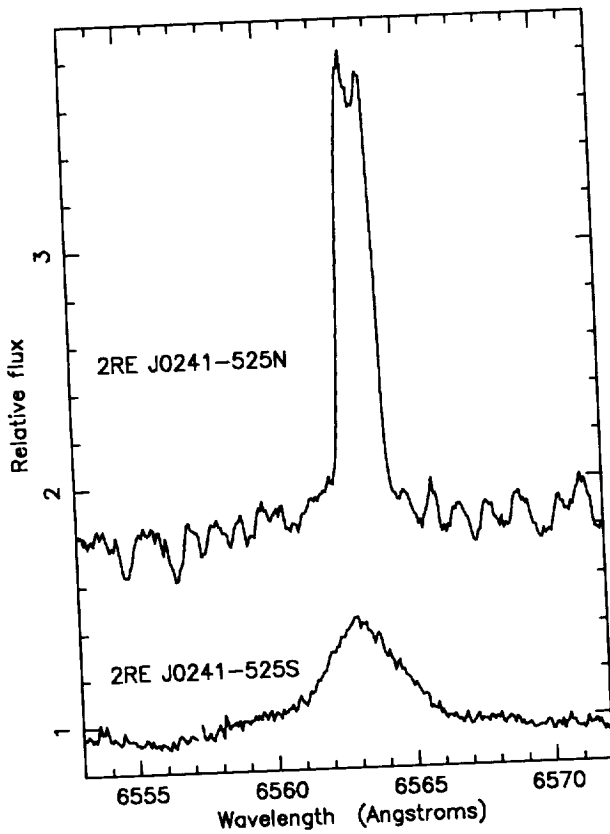


Figure 6. Normalised échelle spectra in the vicinity of the Li I 6708 Å feature. CTIO data (solid line) and AAT data (dashed line), illustrating possible profile variability. The spectra have been smoothed with a 20 km s<sup>-1</sup> FWHM Gaussian filter.

Table 4. Radial and rotational velocities

Star	HJD 2449500+	Radial Velocity $\text{km s}^{-1}$	$v \sin i$ $\text{km s}^{-1}$
2RE J0241-525N			
CTIO	233.53	$+11.6 \pm 2.0$	$12.3 \pm 1.0$
AAT	239.94	$+11.6 \pm 0.7$	$11.1 \pm 1.0$
2RE J0241-525S			
MSO	26.33	$+9.9 \pm 4.0$	$71 \pm 7$
CTIO	233.53	$+11.0 \pm 3.0$	$68 \pm 7$
AAT	238.95	$+13.3 \pm 3.1$	$80 \pm 5$
AAT	239.93	$+12.5 \pm 2.4$	$75 \pm 5$

Figure 7. Normalised AAT échelle spectra in the vicinity of the  $H\alpha$  feature.

with small surrounding lines, especially Fe I and molecular features, and allows an accurate estimate of the continuum level in the presence of rotational broadening. Of course if the metallicities of standard and target are different this might cause some systematic error, but the blended Fe I lines are small and this is a second order effect. EWs measured from each spectrum are listed in Table 5. For 2RE J0241-525S the result of this analysis is that the weighted mean Li I 6708 Å EW is  $(293 \pm 4) \text{ mÅ}$ . For 2RE J0241-525N, we are unable to identify any Li I 6708 Å line, even after the subtraction. It is conservatively estimated that the EW is less than 20 mÅ.

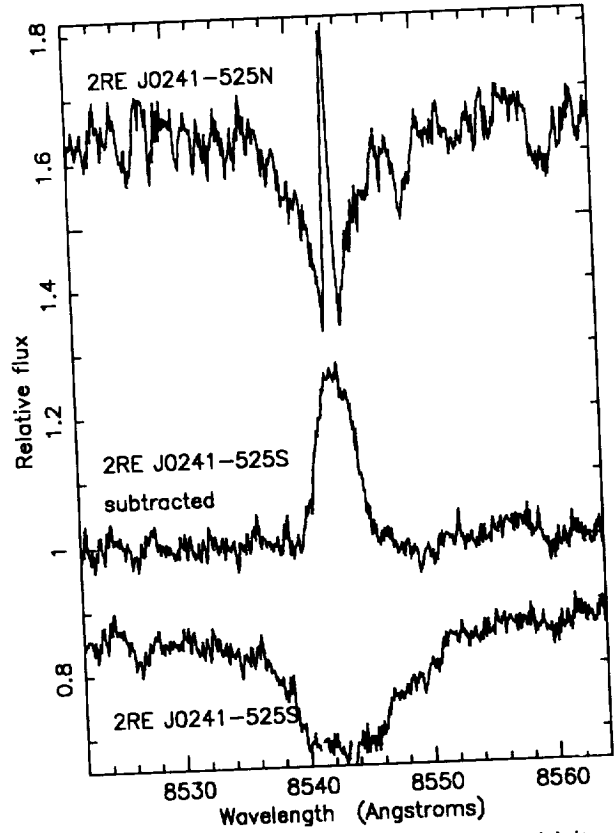


Figure 8. Normalised AAT échelle spectra in the vicinity of the Ca II 8542 Å feature. The central plot shows the spectrum of the southern component (bottom) after subtraction of a low-activity standard star (HD 4628), and illustrates the chromospheric activity present.

It was noted that the Li I 6708 Å EW measurements from MSO and CTIO for 2RE J0241-525S lower than the other two (from the AAT) by 20-30 mÅ. This is a significant difference, because all the spectra have a similar resolution and have been analysed by subtracting the same standard star spectrum. The errors quoted in Table 5, are the random statistical errors in the integral of the residual Li I line in the subtracted spectra. Changes in the EW and profiles of the Li I 6708 Å feature have been seen before in rapidly rotating cool stars like V410 Tau and BD+22° 4409 (Basri, Martín & Bertout 1991; Jeffries et al. 1994). These may be attributable to spots and plages on the stellar surface causing small changes in the profile of the temperature sensitive 6708 Å line. Figure 6 shows the mean of the two AAT spectra, with the CTIO spectrum overlaid. The data have been smoothed with a Gaussian of FWHM  $20 \text{ km s}^{-1}$ . The Li I profile seems considerably narrower in the CTIO spectrum (confirmed by Gaussian fitting), whereas the profiles of the Ca I 6718 Å feature seem comparable. This may not be surprising because the Ca I line arises from an excited level and should be less temperature sensitive.

The Li I EWs can be converted into abundances with published curves of growth. Using the Kirkpatrick et al. (1993) relationship between  $T_{\text{eff}}$  and  $(V-I)_C$ ,  $T_{\text{eff}}$  is estimated to be 3600 K and 3960 K for the northern and southern com-

ponents. The NLTE curves of growth presented by Pavlenko et al. (1995) have been used to estimate the abundances on the conventional scale relative to  $\log N(\text{H}) = 12$ . The Li abundances of the hotter and cooler components are 1.5 and  $< -0.5$  respectively. Alternatively, using the Bessell (1991) calibration of the  $(V-I)_C$ ,  $T_{\text{eff}}$  relation, values of 3500 K and 4040 K are obtained, leading to  $\log N(\text{Li})$  values of 1.6 and  $< -0.5$ . The differences between the NLTE treatment and an LTE approach are small at these temperatures, the dominant source of uncertainty will be error in the temperature scale used, and the errors in  $\log N(\text{Li})$  are estimated to be  $\pm 0.2$  in the southern component, but perhaps as much as  $\pm 0.5$  in the northern component.

Chromospheric activity can also be gauged from the high resolution spectra. The AAT, CTIO and MSO data contain the  $\text{H}\alpha$  line and the AAT data contain the  $\text{CaII}$  8542Å feature, which is also a magnetic activity indicator (Soderblom et al. 1993b). The  $\text{H}\alpha$  EWs were calculated relative to a locally fitted continuum. Telluric lines were prominent in the AAT spectra, and were removed by comparison with a rapidly rotating B-star. High resolution  $\text{H}\alpha$  spectra are shown in Figure 7 and the measured EWs listed in Table 5. The  $\text{CaII}$  8542Å chromospheric emission has been measured in the same way as the  $\text{LiI}$  EWs. The low activity standard stars were broadened, shifted and subtracted from the spectra of the two components, and the EW of the residual line at 8542Å taken as the chromospheric contribution. These EWs are also given in Table 5 and the spectra plotted in Figure 8. The  $\text{CaII}$  8542 Å EWs were converted into fluxes (for comparison purposes - see section 3.3). This was achieved by assuming Johnson  $(V-I)$  colours of 1.93 and 2.94, using the calibration against spectral type in Johnson (1966), and then using the  $I_J$  magnitude to estimate the continuum flux at 8542Å, assuming an absolute flux of  $8.32 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Å}^{-1}$  for  $I_J = 0$ .  $I_J$  actually has an effective wavelength of 9000 Å but this will not greatly influence the results for these cool stars. The derived fluxes at the earth are given in Table 5.

### 3 THE PHYSICAL AND EVOLUTIONARY STATUS OF 2RE J0241-525

#### 3.1 The age of 2RE J0241-525 from isochrone fitting

From the similarity of the measured radial velocities in Table 4, it would seem that the north and south components of 2RE J0241-525 are part of a wide binary system. Fast rotating ( $v \sin i > 10 \text{ km s}^{-1}$ ) low-mass stars are relatively rare among field stars and are usually only found in open clusters (Stauffer & Hartmann 1986), and so the chances of finding two within the same WFC error circle unless they were physically associated, seems too remote to be worth further consideration.

Low mass stars are generally found to be rapidly rotating for one of two reasons: (i) They are in tidally locked close binary systems or (ii) they are young, and have not yet lost their birth angular momenta. In this case, the second explanation is more likely. The radial velocity measurements show no variability within quite tight limits compared with the  $v \sin i$  values. However, the small number of measurements

preclude a conclusive statement at this time. Nevertheless, one would generally expect radial velocity variations comparable to or larger than the  $v \sin i$  value in tidally locked binary systems and it would therefore be quite improbable to obtain such consistent values (see Jeffries, James & Bromage 1994, for a detailed analysis of this argument), especially for 2RE J0241-525S.

Given then that the system is likely to be quite young, and that the two components are physically associated and therefore must be of similar age, then it is possible to fit isochrones to try and determine the age and distance of the "mini-cluster". For low-mass stars the most profitable colour-magnitude diagram to use is  $V$  vs  $(V-I)_C$ . The pitfalls in this process have been reviewed by Stauffer et al. (1996). They found that the critical factor was the relationship adopted between effective temperature and  $(V-I)_C$ . Following the conclusions reached in that paper, we adopt the temperature scale of Bessel (1979) for  $T_{\text{eff}} > 4500 \text{ K}$  and that of Kirkpatrick et al. (1993) for cooler atmospheres, and transform the evolutionary models of d'Antona & Mazzitelli (1994) into the observational plane. The particular models used are those which use the Canuto & Mazzitelli (1990) convection theory and the opacities of Alexander, Augason & Johnson (1989). The bolometric corrections of Bessell (1979) are used at all temperatures. Stauffer et al. (1996) find that this procedure matches the empirical Pleiades isochrone over a wide range of  $(V-I)_C$  at about 70 Myr and conclude that age estimates based upon these assumptions are robust for a number of other evolutionary models, in the sense that similar isochrones are produced if a temperature scale is used that matches the empirical Pleiades isochrone at 70 Myr.

In Figure 9 we show the results of our attempts to place both components of 2RE J0241-525 onto theoretical isochrones by varying the distance modulus. For isochrones at 3, 10, 35, and 70 Myr and the ZAMS, the distance modulus is adjusted to place 2RE J0241-525S on the isochrone. The corresponding distances are 52, 39, 28, 22 and 21 pc. In each case we can then see where 2RE J0241-525N lies relative to the same isochrone. To gain insight from this plot, one needs to consider the possible errors involved. Rapidly rotating, cool stars usually exhibit brightness variations associated with the rotation of cool, spotted regions around their surfaces. From similar objects (e.g. Jeffries et al. 1994) we can estimate an error in the  $V$  magnitude of  $\pm 0.1$  and possibly  $\pm 0.02$  in  $(V-I)_C$ , although these would tend to be correlated in the sense that if  $(V-I)_C$  increases due to coverage in cool spots,  $V$  would increase as well, and so the star would move approximately along the isochrone. Repeated measurements would assist in reducing this error. A more serious problem is systematic errors in the stellar evolution models. Comparisons with other evolutionary tracks produced by D. Vandenberg, F. Swenson (presented in Stauffer et al. 1996) and alternative opacity and convection models in d'Antona & Mazzitelli (1994), show that there can be about a 0.25 magnitude difference in the absolute magnitude of the 10 Myr isochrone, depending upon which model is used. This obviously has a corresponding effect on the distance modulus derived for 2RE J0241-525. Not only that, but there are small differences in the "gradient" of the isochrones, amounting to about 0.1 magnitudes over a range in  $(V-I)_C$  covering the two components of 2RE J0241-525. The net effects of these errors are allowed for by assuming that the



Table 5. High resolution line EWs and fluxes.

Star	HJD 2449500+	Li I 6708Å EW (mÅ)	H $\alpha$ EW (Å)	Ca II 8542Å EW (Å)	$f_{\text{Ca II}}$ ( $\times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$ )
2RE J0241-525N					
CTIO	233.53	< 25	$3.30 \pm 0.02$	-	-
AAT	239.94	< 20	$2.35 \pm 0.02$	$0.63 \pm 0.01$	$1.06 \pm 0.02$
2RE J0241-525S					
MSO	26.33	$271 \pm 15$	$0.81 \pm 0.05$	-	-
CTIO	233.53	$277 \pm 7$	$1.30 \pm 0.04$	-	-
AAT	238.95	$308 \pm 7$	$1.30 \pm 0.04$	$1.07 \pm 0.03$	$4.06 \pm 0.11$
AAT	239.93	$298 \pm 7$	$1.27 \pm 0.04$	$1.07 \pm 0.03$	$4.06 \pm 0.11$

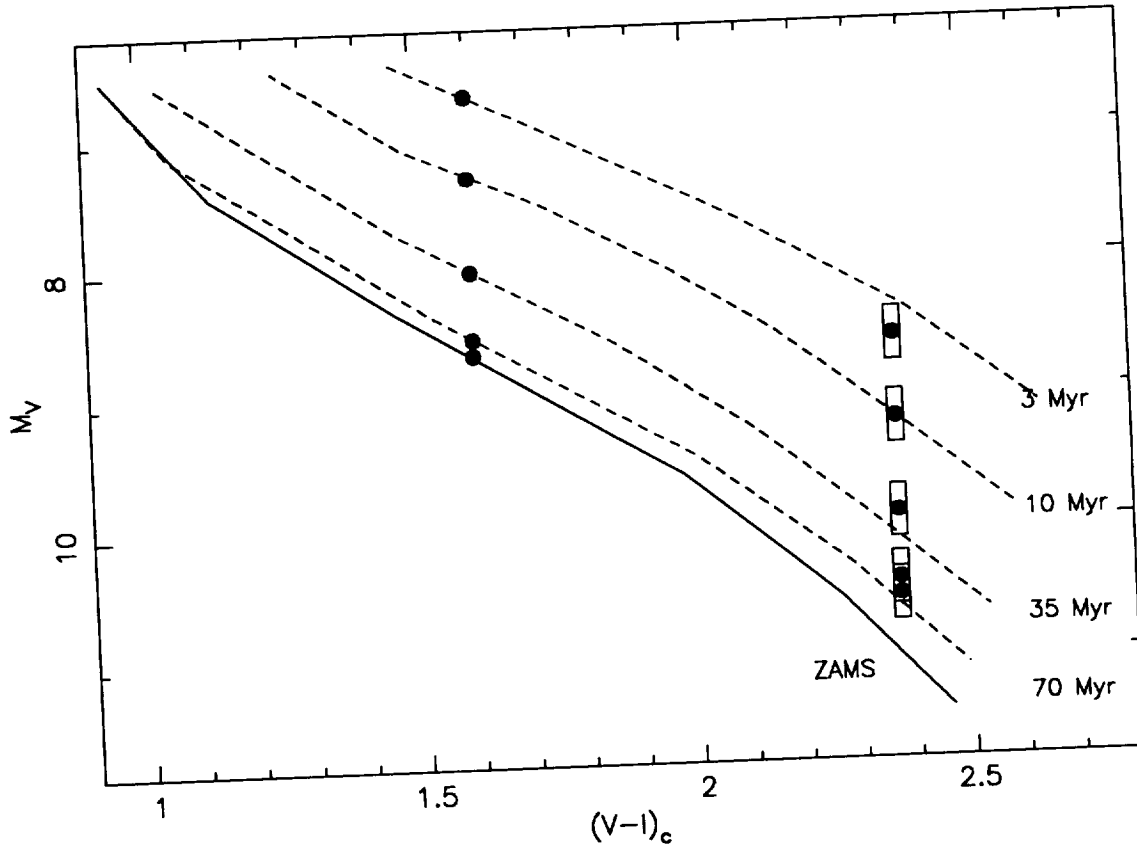


Figure 9. Isochrones in the observational  $V$  vs  $(V-I)_C$  plane. Points corresponding 2RE J0241-525N and S are overlaid, using distances (from top to bottom) of 52, 39, 28, 22 and 21 pc. Evolutionary models are from d'Antona & Mazzitelli (1994), conversion to the observational plane is via the  $T_{\text{eff}}$ ,  $(V-I)_C$  relationships proposed by Bessel (1979) and Kirkpatrick et al. (1993). The boxes around the cooler component represent possible error bounds due to systematic errors in the stellar evolution codes and brightness variations due to starspot modulation.

distance modulus is uncertain by about 0.3 magnitudes and that for the purposes of deriving an age, the cooler component can be assumed to have a net error bar of  $\pm 0.2$  in  $V$  and  $\pm 0.03$  in  $(V-I)_C$ , which, allows for starspot modulation in both components and the uncertain isochrone slope.

From Figure 9 we can conclude that the most favoured age for the 2RE J0241-525 system is  $\sim 10$  Myr. The ZAMS isochrone is excluded by our analysis. When 2RE J0241-525S is placed upon the ZAMS isochrone, 2RE J0241-525N

is 0.5 magnitudes above it. Similarly, ages less than 3 Myr seem unlikely because 2RE J0241-525N would be too faint relative to 2RE J0241-525S. It would be premature to rule out any age between about 3 and 70 Myr on the basis of the photometry alone. The corresponding distances (allowing for a further  $\pm 0.3$  error in the distance modulus) are from 60 pc to 19 pc. A weak case for excluding ages as large as 70 Myr, would be that at the implied distance of  $(22 \pm 2)$  pc, the system would have been included in the third

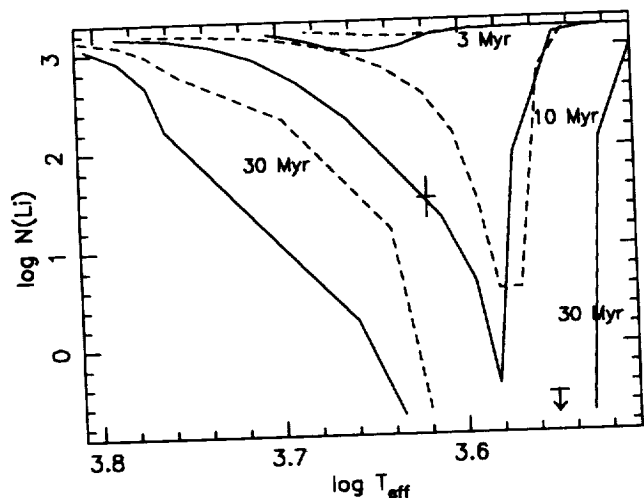


Figure 10. Isochrones of  $\log N(\text{Li})$  versus effective temperature from the models of d'Antona & Mazzitelli (1994), normalised to a cosmic abundance of  $\log N(\text{Li})=3.2$ . Isochrones at 3, 10 and 30 Myr are plotted using their set 1 and set 3 models which both use Alexander et al. (1989) opacities together with the Canuto & Mazzitelli (1990) convection model (solid lines) or standard mixing length theory (dashed lines). Points corresponding to 2RE J0241-525N and S are marked.

edition of the catalogue of nearby stars (Gliese & Jahreiss 1992), which appears to be statistically complete for K-stars within 25 pc (Hodgkin & Pye 1994). A trigonometric parallax for the system would clearly be an extremely valuable measurement.

### 3.2 The lithium abundance of the two components

The age of 2RE J0241-525 can be constrained by the measurements of Li abundance in two ways. First, by empirical comparison of the Li I EW with measurements from groups of stars of known age, it can be roughly deduced whether the system is younger or older. This is confused by any scatter present in Li I EW at a given age. Also the absolute age is still dependent on particular evolutionary models chosen to describe cluster isochrones. Second, the absolute Li abundances can be compared with theoretical models of how the photospheric depletion proceeds with time, for stars of a given mass. Note that Fekel (1996) and Soderblom et al. (1996) have urged caution in using the Li abundance-age relationship, warning of instances where it can breakdown, especially in some cases where post main-sequence objects, metal-poor population II stars or close binary systems have been found to have high Li abundance. In this case though, where both stars are very cool, appear to be single and there is supporting evidence from the isochrones and rotation rates (see later) for a pre main sequence origin, we feel reasonably secure in performing age estimates based upon Li abundance.

The data for an empirical comparison come mainly from measurements of Li depletion among the low-mass stars in the Pleiades (age 70 Myr – Soderblom et al. 1993a; García-López, Rebolo & Martín 1994), Alpha Persei cluster (age 50 Myr, Balachandran, Lambert & Stauffer 1988),

IC2391/IC2602 (age 35 Myr, Stauffer et al. 1989; S. Randich – private communication) and T-Tauri stars in the Taurus-Auriga complex (age <1-20 Myr) (Magazzù, Rebolo & Pavlenko 1992; Martín et al. 1994).

The first conclusion that can be arrived at from these comparisons, is that 2RE J0241-525S has a considerably higher Li I 6708Å EW than stars of a similar colour in either the Pleiades, Alpha Persei cluster, IC2391 or IC2602. Dr S. Randich (private communication) has new measurements of stars in IC 2391/2602 and finds that, for about a dozen stars between  $(V-I)_C$  values of 1.3 and 1.9, the Li I 6708Å EW varies from < 50mÅ to about 150mÅ. From this it seems likely that 2RE J0241-525 is younger than IC2391/2602. No Li I 6708Å line has been detected in stars as cool as 2RE J0241-525N in either the Pleiades, Alpha Per or IC2391/2602 clusters. Therefore our non-detection of the line does not give an upper limit to the age in this case. Li 6708Å lines with EWs of several hundred milliangstroms have been found in WTTS and CTTS, with temperatures of  $\sim 3500$  K and ages of < 2 Myr, along with others at an age of 2 Myr with no detectable Li (Martín et al. 1994). The available evidence seems to suggest that Li depletion is not significant prior to this for very cool stars, presumably because their cores are not hot enough to burn Li. Martín et al. also present some data for WTTS at around 4000 K, similar to 2RE J0241-525S. These seem to show that these may remain undepleted of Li for somewhat longer, perhaps 3-5 Myr. This can be understood, because although in more massive stars, Li-burning central temperatures are reached more swiftly, a radiative core also develops which inhibits mixing of the depleted material. 2RE J0241-525S has clearly suffered some depletion. Its Li abundance is  $\log N(\text{Li}) = 1.5 \pm 0.2$  compared with the generally accepted cosmic abundance of  $3.2 \pm 0.2$ . Taken together, the empirical conclusion that can be reached, is that 2RE J0241-525 is younger than 35 Myr, but at least 5 Myr old, in agreement with the conclusions from the isochrone fitting.

The Li abundances can also be compared with theoretical models of depletion. Figure 10 shows the abundances of 2RE J0241-525 compared with two sets of Li depletion isochrones from the models of d'Antona & Mazzitelli (1994). These are the set 1 and set 3 models from that paper, which use opacities from Alexander, Augason & Johnson (1989) together with the Canuto & Mazzitelli (1990) convection model (solid lines) or the standard mixing length convection model (dashed lines). These two are presented to give an idea of the systematic differences between various models.

From Figure 10, it does not seem that 2RE J0241-525 can be fitted by any single isochrone. Either the cooler component has suffered too much depletion, or the hotter component not enough. Martín et al. (1994) noted a similar trend in their observations of WTTS. They concluded that this could best be explained if the cores of low mass stars reached Li-burning temperatures more quickly than currently predicted by models. This would result in the sharp dip in  $\log N(\text{Li})$  for  $\log T_{\text{eff}} > 3.55$ , moving to the right in Figure 10, perhaps allowing the 10 Myr isochrones to fit both the hot and cool components of 2RE J0241-525. An alternative interpretation would be that 2RE J0241-525S is under depleted with respect to 2RE J0241-525N, and that perhaps the system is as old as 30 Myr. This idea finds support from the observation that among the Pleiades and WTTS

it seems that rapid rotation can inhibit depletion of lithium relative to the predictions of standard stellar evolution models (Soderblom et al. 1993a; García-López et al. 1994; Martín et al. 1994). There is in any case a scatter in the Li abundances among K-type Pleiads of a given mass, which cannot be attributed to an age spread. Taken together, these properties preclude a more detailed comparison with theoretical isochrones, although the empirical comparisons should still be valid as long as we can assume that observations of one cluster or association are representative for stars at that age.

### 3.3 Rotation and magnetic activity

A further opportunity to empirically place 2RE J0241-525 in an evolutionary sequence is offered by the measurements of rotation and magnetic activity, because both show a general decline with age. The rotation rate of 2RE J0241-525S is higher than anything of a similar colour in the Hyades (age 600 Myr) but is comparable with some late K-type stars in the Pleiades and Alpha Persei clusters (Stauffer 1991) and some WTTS with ages of a few Myr (Magazzù et al. 1992). The rotation rate of 2RE J0241-525N offers even less constraint, although most Hyads of a similar colour have  $v \sin i < 10 \text{ km s}^{-1}$ .

Similarly, only weak constraints can be placed on the age from the observed coronal and chromospheric activity. This is to be expected, as it is now believed that activity depends upon age implicitly because of the more fundamental rotation-activity and rotation-age relationships. The H $\alpha$  EW is variable (see Tables 3 and 5), but at its highest, is larger than the upper envelope of the Hyades distribution with colour for both components. However, the EWs of both components are compatible with stars of equivalent colour in both the Pleiades and IC2391/IC2602 (Prosser, Stauffer & Kraft 1991; Stauffer et al. 1996).

Magnetic activity is often expressed as a ratio of the flux in a particular waveband or spectral line, to the bolometric flux. Bolometric corrections are taken from the calibration against (V-I)<sub>C</sub> of Monet et al. (1992), and bolometric fluxes of  $1.91 \times 10^{-9}$  and  $5.20 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$  are calculated for the north and south components of 2RE J0241-525 respectively. From these, we calculate the activity indices  $\log L_X/L_{\text{bol}}$ , from the 0.1-2.4 keV X-ray fluxes in Table 1, and  $\log L_{\text{CaII}8542}/L_{\text{bol}}$ , from the fluxes in Table 5.

We find  $\log L_X/L_{\text{bol}}$  values of -3.16 and -3.06 for the north and south components respectively. Comparison with stars in the Hyades (Pye et al. 1994), Pleiades (Stauffer et al. 1994) and IC2602 (Randich et al. 1995) shows that there are stars at these colours and activity levels in all of these clusters, but that they are the most active stars in each cluster. This can be understood in terms of the rotation-activity paradigm, because although there are more rapidly rotating stars in both the Pleiades and IC2602 compared with the Hyades, it seems that coronal activity saturates for  $v \sin i > 15 \text{ km s}^{-1}$ , at a value of  $\log L_X/L_{\text{bol}} \sim -3$ . Thus the X-ray activity of 2RE J0241-525 is simply consistent with the rotation rates we have measured and gives no further insight as to the evolutionary status of the system. This may not be the case for  $\log L_{\text{CaII}8542}/L_{\text{bol}}$ , which appears to increase with little evidence for any saturation, as the rotation rate increases in low-mass stars (Soderblom et al. 1993b). Unfortunately data has only been published for the

Table 6. Predicted rotation periods.

Age (Myr)	Distance (pc)	$R_N$ ( $R_\odot$ )	$R_S$ ( $R_\odot$ )	$\left(\frac{P}{\sin i}\right)_N$ (hrs)	$\left(\frac{P}{\sin i}\right)_S$ (hrs)
3	52	1.10	1.57	114.2	25.4
10	39	0.82	1.18	85.1	19.1
35	28	0.59	0.85	61.2	13.7
70	22	0.47	0.66	48.8	10.7

Pleiades. Our values for this activity index, of -4.25 and -4.11 for the north and south components, lie near the upper envelope of the Pleiades observations, but seem consistent with the correlation with Rossby number (the ratio of rotation period to convective turnover time) presented by Soderblom et al. (1993b), so offer no further age constraint beyond that supplied by the rotation rates.

It is interesting to predict the true rotation period of the two component stars, which of course will depend on their inclination angles and radii. Using the isochrones shown in Figure 9 to estimate the distance,  $d$ , in parsecs at a given age, we use a Barnes-Evans relationship of the form

$$\log \frac{R}{R_\odot} = -0.191 - 0.2V + 0.9(V - R)_C + \log d$$

to calculate the radius. Then, because  $P v \sin i = 2\pi R \sin i$ , where  $P$  is the rotation period, we can calculate  $P/\sin i$  for both components and these are given in Table 6 for a range of ages from 3 to 70 Myr. Theoretically, one might expect aligned rotation axes if the binary condensed from a cloud with uniform rotation, but probably random alignments in cases where the stars form from fragmented clouds and then pair up some time later. Observationally, Hale (1994) has found random rotation axis orientation for binary separations greater than a few tens of AU. The separation of the 2RE J0241-525 components is substantially larger than this (see section 3.4), so we cannot assume alignment of the rotation axes.

From Table 6, it is apparent that even in the absence of a parallax measurement, it may be possible to make further refinements in the age and distance estimates for 2RE J0241-525 by obtaining rotation periods for the two components. It is almost certainly feasible to do this by monitoring photometric modulation due to cool starspots on the stellar surface. Columns 5 and 6 of Table 6 are the *maximum* periods that the components can have at that particular age. Thus, for example, measuring a period of say 20 hrs for 2RE J0241-525S would indicate that the system was younger than 10 Myr, and at a distance of at least 39 pc. On the other hand, measuring a period of 10 hrs would allow any of the ages considered here, with a decreasing inclination angle for decreasing age. It should be noted that due to our discussion of uncertainty in the theoretical isochrones (see section 3.1) of about  $\pm 0.3$  magnitudes, it would be prudent to assume errors of about  $\pm 15$  percent in the predicted radii and  $P/\sin i$  values.

### 3.4 The origins of 2RE J0241-525

2RE J0241-525 appears to have an evolutionary status similar to several other wide binary systems in which the primary (hotter star) is lithium-rich, such as AB Dor, HD 155555, HD 21845 and BD+17° 4799, and is accompanied by a lower mass active component (Martín & Brandner 1995; J95). These themselves may also be similar to the lithium-rich late-type stars in visual binary systems with young early-type stars, which are investigated by Martín et al. (1992) and Pallavicini et al. (1992). If 2RE J0241-525 is aged between 5 and 30 Myr, as suggested by the empirical evidence of the Li I 6708 Å EWs, then other indicators of youth might be present, such as an associated star formation region or T-Tauri-like behaviour.

2RE J0241-525 appears to have no spatial association with any star formation region. The chromospheric emission lines are as strong as might be expected on the basis of their interpretation as magnetic activity related phenomena, but the H $\alpha$  emission would be weak for a CTTS. There is no veiling apparent in any of our spectra, compared with stars of similar spectral type and there is no coincident source in the Infra-red astronomical satellite (IRAS) point source catalogue that would suggest the presence of dust or a disk around either star. On the basis of this evidence we would not classify either component of 2RE J0241-525 as a CTTS. The Li abundances, rotation and magnetic activity of 2RE J0241-525S seem similar to many of the WTTS found in the Taurus-Auriga and Orion molecular cloud complexes (Walter et al. 1988; Bertout 1989). In addition, the  $v \sin i$  value would be exceptionally fast for a CTTS, but is reasonably common among WTTS (Bouvier et al. 1993a). This fits in with the currently favoured paradigm (e.g. see Bouvier et al. 1993b), that the rotation rates of CTTS are regulated by magnetic coupling between the star and a disk. When the disk is dissipated the star can spin up, therefore young stars without disks (WTTS) tend to rotate faster.

Sterzik et al. (1995) and Neuhauser et al. (1995b) have found evidence for "halos" of WTTS around both the Orion and Taurus-Auriga star formation regions. They suggest that either these WTTS are older than most stars in the region (> 10 Myr), have unusually large velocity dispersions or, in some cases, may have been ejected from the star formation region in a three body encounter. It is tempting to speculate that 2RE J0241-525, and perhaps many of the lithium-rich, rapidly rotating field stars are simply more extreme examples of these runaway WTTS, in the sense that they are somewhat older and/or have slightly larger peculiar velocities with respect to their progenitor molecular clouds. J95 have suggested that many, if not the large majority of young, lithium rich stars in the solar vicinity are part of a kinematic group known as the Local Association. The group is apparent in the space-motions of young early-type stars and also includes the Pleiades and  $\alpha$  Persei clusters (Eggen 1983a,b). The hypothesis is that these stars were either ejected from young clusters, or more probably that the Local Association is the kinematic remnant of one or perhaps several star-formation regions that emerged from molecular clouds in a gravitationally unbound state (Lada & Lada 1991; Battinelli & Capuzzo-Dolcetta 1991), and have a kinematic dispersion similar to that of molecular clouds in the solar vicinity.

Although we do not have proper motion information for 2RE J0241-525, the hypothesis that it is a member of the Local Association can be tested with its radial velocity. Using the group convergent point and speed ( $\alpha = 89^\circ.7$ ,  $\delta = -35^\circ.2$ ,  $V_a = 26.5 \text{ km s}^{-1}$  – Eggen 1992), we can predict that a Local Association member at the position of 2RE J0241-525 should have a radial velocity of  $+20.7 \text{ km s}^{-1}$ , compared with weighted means for the northern and southern components, of  $+11.6 \pm 0.7$  and  $+12.0 \pm 1.5 \text{ km s}^{-1}$ . This discrepancy is not sufficient evidence to rule out Local Association membership as the 1-dimensional radial velocity dispersion could be as high as  $6 \text{ km s}^{-1}$  (J95), but neither does it particularly suggest Local Association membership. Perhaps this is not surprising as it is probable that 2RE J0241-525 is younger than the Pleiades or the  $\alpha$  Per clusters. Three younger kinematic associations that have been investigated in the past are the IC 2391 *supercluster*, that contains IC 2391 and many other young B-stars in the solar vicinity, the Sco-Cen association and the Cas-Tau association. For the IC 2391 supercluster, which we presume has a similar age to the IC 2391 cluster itself, of about 35 Myr, Eggen (1991) gives a convergent point of  $\alpha = 87^\circ.3$ ,  $\delta = -12^\circ.4$ , and a total group speed of  $27.4 \text{ km s}^{-1}$ . With these parameters, a radial velocity of  $+15.7 \text{ km s}^{-1}$  is predicted for a member at the position of 2RE J0241-525. Similarly, Jones (1971) gives a convergent point of  $\alpha = 90^\circ.3$ ,  $\delta = -30^\circ.4$  and a group speed of  $22.6 \text{ km s}^{-1}$  for the Sco-Cen association, which has a spread of ages between 5 and 15 Myr (de Geus, de Zeeuw & Lub 1989). This yields a predicted radial velocity for a kinematic group member at the position of 2RE J0241-525 of  $+16.9 \text{ km s}^{-1}$ . Blaauw (1956) has investigated the Cas-Tau association (see also Walter & Boyd 1991), which has a nuclear age of 20-30 Myr (de Zeeuw & Brand 1985), and gives a convergent point of  $\alpha = 86^\circ.0$ ,  $\delta = +4.9$  and a group speed of  $24.1 \text{ km s}^{-1}$ . For this association we would predict a radial velocity of  $+8.5 \text{ km s}^{-1}$  at the position of 2RE J0241-525. The latter three predicted radial velocities are quite close to the observed values for 2RE J0241-525 and we could speculate that it is an outlier of one of these loose associations. However, firmer conclusions must await the determination of both a trigonometric parallax and proper motion.

The angular separation of the components of 2RE J0241-525 is 22 arcsecs. The physical separation depends on orbital inclination and assumed distance, which in turn is dependent on the age of the system. Taking the empirical constraints offered by the Li abundance, an age of 5 to 30 Myr and a distance of between 26 and 50 pc is probable (allowing for the possible 0.3 error in distance modulus). The separation of the components is thus greater than between 570 AU and 1100 AU. If the system has been ejected from a cluster or star formation region, then the gravitational binding energy is equivalent to a change in the system kinetic energy corresponding to a velocity change of less than  $1 \text{ km s}^{-1}$ . If one were to postulate that the system had been ejected from, say the IC 2602 or IC 2391 clusters or from the Sco-Cen and Cas-Tau associations, which are at distances of 140-180 pc from 2RE J0241-525, then ejection velocities of at least  $5 \text{ km s}^{-1}$  (for a 30 Myr age) are required. It seems unlikely that the system could emerge intact and with its current binding energy if the system kinetic energy had been increased by more than 20 times that binding energy in a

two or three body interaction. A similar argument applies to ejection from any nearby cluster, because typical ejection velocities will range between 30 and 200 km s<sup>-1</sup> (de la Fuente 1995 and private communication). Evaporation from a cluster as a result of many interactions is more feasible, but as escape velocities for clusters like IC 2391 and IC 2602 are about 1 km s<sup>-1</sup> then the system could not reach its present position in its short lifetime. It is much more likely that 2RE J0241-525 originated in a gravitationally unbound system, perhaps similar to that now emerging from the Orion nebula, which has an internal dispersion of 3-4 km s<sup>-1</sup> (e.g. Jones & Walker 1988). In that case, 2RE J0241-525 could be up to 100 pc from its original birth molecular cloud, which may in any case have dissipated, because Leisawitz, Bash & Thaddeus (1989) have shown that clusters older than about 10 Myr do not have associated molecular clouds.

#### 4 SUMMARY

The optical counterpart to the EUV source 2RE J0241-525 has been identified as a pair of chromospherically active, low mass stars, of spectral types dK7e and dM3e. Both stars are soft X-ray sources and both show signs of rapid rotation. The spatial association of two such active stars, combined with their similar radial velocities lead us to conclude that they form a wide binary system. We have attempted to find the age of the system by isochrone fitting and using the measured lithium abundances. The isochrone fitting indicates a pre-main sequence status, although the age can only be constrained to between 3 and 70 Myr, and the distance to between 19 and 60 pc. An *empirical* comparison of the Li 6708 Å EWs with those of similar stars in young clusters and associations, lead us to believe that the age of the system is between 5 and 30 Myr, with a corresponding distance of 26 to 50 pc. We stress that caution is required in interpreting the Li abundance, because there is evidence that it does not obey a simple one to one relationship with age. The age estimates could be considerably refined if a trigonometric parallax were available, although it is possible that rotation period measurements for the two components may also place further constraints on the system distance.

Although the H $\alpha$  emission is as strong as one would expect for two such rapidly rotating stars, it is too weak for us to classify 2RE J0241-525 as a pair of classical T-Tauri stars. Neither is there any infra-red detection in the IRAS point source catalogue that might indicate that the stars still possess circumstellar material. There is no evidence that the system is linked to any particular star formation region, and only tenuous evidence of a link to any kinematic associations of young stars in the solar vicinity. It seems reasonable therefore to classify 2RE J0241-525 as a pair of post T-Tauri stars, rather than weak lined T-Tauri stars which are usually associated with a star formation region. The weak gravitational attraction between the components suggest that they have not been ejected from an open cluster after two or three body interactions. It is speculated that the system was born in a gravitationally unbound association and may have drifted by perhaps as much as 100 pc from its original birth site.

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