Molecular hydrogen emission from discs in the η Chamaeleontis cluster

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Accepted 2007 May 30; Received 2007 May 29; in original form 2007 April 29

ABSTRACT
Discs in the 6 Myr old cluster η Chamaeleontis were searched for emission from hot H2. Around the M3 star ECHA J0843.3−7905, we detect circumstellar gas orbiting at ∼2 au. If the gas is ultraviolet excited, the ro-vibrational line traces a hot gas layer supported by a disc of mass ∼0.03 M⊙, similar to the minimum mass solar nebula. Such a gas reservoir at 6 Myr would promote the formation and the inwards migration of gas giant planets.

Key words: circumstellar matter – planetary systems: formation – infrared: stars.

1 INTRODUCTION
Understanding the longevity of protoplanetary discs around stars, and their dust and gas content, is an important step in understanding the formation of planetary systems. The exploration of the dust content of discs has been carried out from near-infrared (IR) to millimetre wavelengths, probing from hot discs near the stellar surface out to hundreds of au. The dust mass and the temperature can be deduced from the spectral energy distribution, although shortwards of the far-IR the disc emission is optically thick and so detailed models are needed to understand the distribution of material (Wood et al. 2002). Observations of carbon monoxide (CO) in discs are used to estimate the mass of molecular gas; however, this is subject to a number of uncertainties. The CO may be photodissociated; it freezes out on grains and is only a small amount of the total gas. The H2/CO ratio is highly variable due to these effects, and CO only effectively traces layers of the disc above and below the mid-plane. Thus, a direct tracer of the bulk of the gas is to be preferred.

Molecular hydrogen is the principal gas component in discs, and so direct observations of H2 have been undertaken by several groups, using the rotational–vibrational transitions observable in the near- and mid-IR. Mid-IR observations of the pure rotational lines offer the most direct measure of the disc mass, as the lines are emitted by low-temperature gas (∼100 K). The line intensity should give a direct measure of the disc mass for an optically thin disc. To date, detection of the pure rotational lines has proved difficult. Thi and co-workers reported detections of copious quantities of H2 from a number of different types of source (debris discs, Herbig AeBe stars and T Tauris) using the Infrared Space Observatory Short Wavelength Spectrometer (ISO SWS; Thi et al. 2001a,b). However, attempts to replicate these detections in more sensitive observations with ground-based instruments (Richter et al. 2002; Sheret, Ramsay Howat & Dent 2003) have not detected the lines. The most likely explanation for this is that the H2 detected by ISO was elsewhere in the large beam of the spectrometer rather than in the circumstellar disc. Both Richter et al. and Sheret et al. explain their non-detections by pointing out that the disc is optically thick at mid-IR wavelengths and that the H2 may be therefore self-shielded. A ground-based detection of the v = 0–0 rotational lines from the disc around AB Aurigae has been reported by Bitner et al. (2007), who detected the v = 0–0 S(1), S(2) and S(4) lines from gas at T ∼ 670 K with derived mass 0.5 M⊙. Observations with Spitzer are proving effective for probing the pure rotational lines of H2 in the circumstellar environment. Lahuis et al. (2007) have detected the v = 0–0 S(2) and v = 0–0 S(3) lines of H2 towards six of a total of 76 T Tauri and Herbig AeBe sources in their sample using the Spitzer Infrared Spectrograph. These spectra show the presence of H2 gas at T ≥ 500 K.

H2 in discs may also be excited to higher vibration levels and emit in the near-IR. The principal excitation mechanisms are by collisions in warm, dense gas or due to the passage of a shock by absorption of a ultraviolet (UV) photon and subsequent radiative decay or by X-rays. All of these mechanisms may be in action in a circumstellar disc. The first detection of emission from the v = 1–0 S(1) line at 2.1218 μm was reported by Weintraub, Kastner & Bary (2000) in TW Hya. Following this, the line has been detected by Bary, Weintraub & Kastner (2003) and Bary et al. (2005) for a selection of T Tauri stars and by Itoh et al. (2003) for LkHα 264. In these sources, the authors conclude that the line emission arises from a quiescent disc. The line width of the H2 emission from LkHα 264 suggests emission from a radius of 1 au from the parent star. For the sources observed by Bary et al. (2003), the measured widths of the lines are from 9 to 14 km s−1 and the H2 molecules are orbiting from 10 to 30 au. The detection of excited H2 at these radii offers the possibility of a large reservoir of cold H2 associated with the zone of giant planet formation.

Estimating the total H2 mass is a complex task, as each of the possible excitation mechanisms may be at work in a particular disc. Work so far (Bary et al. 2003) suggests that the v = 1–0 S(1) line is
tracing only a thin hot zone at the top surfaces of the gas disc, and so is not ideal as a bulk mass tracer. However, the presence of this line is very useful as an indicator that gas is still present in a disc; as a diagnostic of the orbital radius (with high-resolution spectroscopy); and for comparison to dust excesses from the inner disc. These data may address the vital question of whether a gas supply still exists at a few Myr, when giant planet cores have grown massive enough to begin to accrete their thick atmospheres.

The discovery of a new young star cluster, η Chamaeleontis, at a distance of just 97 pc by Mamajek, Lawson & Feigelson (1999) presents an exciting opportunity for studying disc formation at close range. The discovery was made in a deep ROSAT image. Lyo et al. (2003) found that an unusually high proportion of the stars have an L-band excess indicative of the presence of a dust disc. For their derived age of the stars in the cluster (9 Myr), such a high disc fraction (60 ± 13 per cent) implied that disc lifetimes may be higher than previously thought. Haisch, Lada & Lada (2001) measured the disc fraction in clusters of different ages, finding a linear relationship between cluster age and disc fraction. From this, the disc fraction should drop below 60 per cent for an age of 2–3 Myr. Recent work on the η Chamaeleontis cluster has challenged the idea that it has an unusually high disc fraction for the age of the cluster. The age has been revised downwards slightly to 6 (±1) Myr (Luhman & Steeghs 2004), but that more dust discs are revealed as having discs by Megeath et al. (2005) cast doubt on some of the earlier disc excesses. Haisch, Lada & Lada (2005) found that an unusually high proportion of the stars have an L-band excess indicative of the presence of a dust disc; as a diagnostic of the orbital radius (with high-resolution spectroscopy); and for comparison to dust excesses from the inner disc. These data may address the vital question of whether a gas supply still exists at a few Myr, when giant planet cores have grown massive enough to begin to accrete their thick atmospheres.

Table 1. Observational log and target data.

| Name | RA (J2000) | Dec (J2000) | Magnitude | Spectral type | Total on-source observation time |
|------|------------|------------|-----------|--------------|---------------------------------|
| RECX3 | 8 43 37.2 | −79 03 31 | K = 9.61 | M3.25 | 48 min |
| RECX5 | 8 42 27.30 | −78 57 48 | K = 9.96 | M4 | 48 min |
| RECX6 | 8 42 39 | −78 54 43 | K = 9.46 | M3 | 48 min |
| RECX9 | 8 44 16.6 | −78 59 34.4 | K = 9.50 | M4.5 | 48 min |
| RECX11 | 8 47 01.64 | −78 59 34.4 | K = 7.71 | K5.5 | 32 min |
| RECX12 | 8 47 56.77 | −78 54 53.1 | K = 8.51 | M3.25 | 32 min |
| ECHA J0843.3–7905 | 8 41 30.6 | −78 53 07 | K = 9.45 | M3.25 | 48 min |

*aCoordinates from Mamajek et al. (1999). bFrom Luhman & Steeghs (2004).

2 OBSERVATIONS AND DATA REDUCTION

The observations were carried out on 2005 February 25 using the Phoenix high-resolution infrared spectrograph on the southern Gemini telescope at Cerro Pachon, Chile. The observations were carried out in conditions of thin cirrus; the seeing, as measured from the full width half-maxima of the stars, varied between 0.5 and 0.8 arcsec during the night. Phoenix is a single-order spectrograph containing a 1024 × 1024 InSb Aladdin II array (Hinkle et al. 2003). With the K4748 filter and the grating centred at the wavelength of the H2 v = 1–0 S(1) line (2.1218 μm) the wavelength coverage obtained was from 2.11787 to 2.12703 μm. The slit width selected was 0.35 arcsec, matched to four detector pixels. The spectral resolving power close to the wavelength of the H2 line was measured to be 62.400 using a telluric OH line at 2.121 774 μm. This corresponds to a wavelength range per pixel of 0.34 × 10−5 μm. Each source was acquired through the Phoenix imaging channel. Observations of the science targets were ratioed by the spectrum of the bright star Beta Car (V = 1.68, A2IV) to correct for atmospheric features. Three observations of the star were made throughout the night. Wavelength calibration was obtained using the six brightest telluric absorption features present in the spectrum. Using this calibration, the wavelengths of the two brightest OH emission lines present are obtained to better than 0.15 × 10−4 μm. We take this as a measure of the accuracy of the wavelength calibration. A flat-field frame was obtained from observations of a Quartz Halogen lamp in the Gemini Facility Calibration Unit (Ramsay Howat et al. 2000). The flux calibration for the individual observations was carried out using the known K-band magnitude of the sources themselves (see Table 1).

The on-chip exposure time for the observations of the targets was 240 s, with exposures on the sky obtained by offsetting the source 5 arcsec along the 14 arcsec slit. Multiple 240 s exposures were taken and co-added to produce the total on-source observation time listed in Table 1.

3 RESULTS AND ANALYSIS

Molecular hydrogen has been detected here in one of the seven sources observed in the η Chamaeleontis cluster. The spectra of all the observed sources are shown in Figs 1–3. The H2 v = 1–0 S(1) line is detected in only ECHA J0843.3–7905, one of the sources known to have a circumstellar disc (Megeath et al. 2005). The spectral types for the stars range from K5.5 to M4.5 and are listed in Table 1. The error on the spectral type is ±0.25 subclasses for the M-stars and ±0.5 subclasses for the K stars (Luhman & Steeghs 2004).
After removal of the telluric features using Beta Car, the observed stellar continuum from the targets is seen to contain numerous absorption features that vary with spectral type. To obtain the best estimate of the continuum level, and hence the optimum measurement of the $\text{H}_2$ line, ECHA0843.3$-$7905 (spectral type M3.25) was ratioed by the spectrum of stars of the same spectral type (within the errors in spectral type). There are three such stars: RECX3 (M3.25), RECX6 (M3) and RECX12 (M3.25). The RECX3 spectrum has poor signal-to-noise ratio and was not used for the ongoing analysis. The RECX12 and RECX6 spectra were ratioed by Beta Car, as above, and then normalized to the flux level at 2.1218 $\mu$m to provide a template of the M3 stellar absorption features.

The ECHA J0843.3$-$7905 spectrum was ratioed by the RECX6 and the RECX12 templates separately, providing independent estimates of the $\text{H}_2$ spectrum. Excellent cancellation of the stellar absorption features is obtained in this way and comparing the two ECHA J0843.3$-$7905 spectra provides an estimate of the systematic errors. The spectrum ratioed by the RECX12 template is presented in Fig. 4.

In both spectra, the $\text{H}_2$ line is well fitted by a single Gaussian. For the spectrum ratioed by RECX6, the line width is $1.40 \pm 0.08 \times 10^{-4} \mu$m centred at $2.121894 \pm 0.03 \times 10^{-4} \mu$m, and in the spectrum divided by RECX12, $1.24 \pm 0.06 \times 10^{-4} \mu$m centred at $2.121903 \pm 0.02 \times 10^{-4} \mu$m. Deconvolving the line widths with that measured for the unresolved telluric OH lines ($0.35 \times 10^{-4} \mu$m), we obtain a
$H_2$ emission from discs in $\eta$ Cham

Figure 3. Spectra of RECX3 (lowest), RECX5 (middle) and RECX9 (lower). RECX3 flux is reduced by four to offset it from RECX9. Spectral types are M3.25, M4 and M4.5, respectively.

Figure 4. The spectrum of ECHA J0843.3−7905 divided by that of RECX12 with the fit to the $H_2\, v = 1$–$0$ S(1) line and residuals in the lower panel.

line width in the range $1.35–1.18 \times 10^{-4}$ $\mu$m corresponding to a velocity of $18 \pm 1.2$ km s$^{-1}$. The measured flux in the line is $(2.5 \pm 0.1) \times 10^{-18}$ W m$^{-2}$.

The presence of $H_2$ in the circumstellar environment may be attributed to molecular gas excited in a disc or in an outflow. For example, Takami et al. (2004) concluded that excited $H_2$ detected in the vicinity of DG Tauri arises from an outflow within 100 au of the star. This conclusion is based on a significant blueshift of the line relative to the systemic velocity of the star and to a spatial offset of the emission from the star. Moreover, DG Tau is known to have an energetic outflow. Similarly, Deming, Charbonneau & Harrington (2004) detected $H_2\, v = 1$–$0$ S(1) emission from a bipolar outflow associated with KH 15D.

We have considered the possibility that the $H_2$ emission is from an outflow associated with ECHA J0843.3−7905. We fit Gaussian functions to the spatial profile of the star along the spectrograph slit at the wavelength of the $H_2$ line and the adjacent continuum. Subtracting the continuum from the line emission and fitting a Gaussian to the results, we find that the peak of the line is centred on the same pixel as the peak of the continuum (to within 0.5 pixel or 0.04 arcsec) and there is no evidence for residual $H_2$ emission in the wings of the line. At the distance of the $\eta$ Chamaeleontis cluster (97 pc), 0.04 arcsec corresponds to a scale of ~4 au. The seeing during the observations of ECHA J0843.3−7905 was 0.7 arcsec (70 au). Since emission from outflows is observed at these radii, this is consistent with either an outflow or disc origin of the $H_2$ emission. Adopting
the radial velocity of the cluster from Mamajek et al. (1999) for ECHA J0843.3−7905 (+16 km s\(^{-1}\)) and correcting for the relative motion of the Earth on the night in question, there is no evidence for relative motion of the \(H_2\) and the star (to +1 km s\(^{-1}\)). In addition, the luminosity of the \(H_2\) line (7.2 × 10\(^{-7}\) L\(_\odot\)) is 20–1000 times fainter than the \(H_2\) luminosity seen in a range of outflows from Class I and Class II sources (Davis et al. 2001) or from DG Tau, though we note that there are many factors, including age of the source, that will affect the luminosity.

We take these diagnostics to mean that it is more likely that the \(H_2\) emission from ECHA J0843.4−7905 arises in a disc and pursue this interpretation in the following section.

### 4 Discussion

Assuming Keplerian rotation around a star of the mass of ECHA J0843.3−7905 (taken as 0.4 M\(_\odot\)), the observed \(v = 1–0\) S(1) line width implies that the gas is emitted from a region around a few au (e.g. 2 au for a disc inclination of 45°). The ECHA J0843.3−7905 line profile and width are similar to those observed in the other four disc detections, with the exception of LkCa 15 in which a clear double peaked signature is seen (Bary et al. 2003). For comparison, the \(L\)-band excesses arise at smaller radii of ≲0.1 au (Haisch et al. 2005). The correlation suggests that both trace properties of the inner disc. The prevalence of single-peaked line profiles in \(H_2\) is perhaps surprising, given that a Keplerian rotation pattern tends to produce a double-peaked line profile (if the disc is moderately edge-on and optically thin in the gas line). A line broadening mechanism may be at work in which case, a narrower Keplerian velocity would imply that the hot gas is at >2 au. The broader line width may also be due to the contribution of emission from slower moving gas at larger radii from the star. Nomura & Millar (2005) show the \(H_2\) emission in the \(v = 1–0\) S(1) line can extend over 10 au with flux greater than 0.1 of the peak flux. Thus, a contribution for an extended disc is consistent with this model and with a single peaked line.

The \(v = 1–0\) S(1) traces regions of hot gas, comprising a small fraction of the total \(H_2\) reservoir of the disc. Estimating this bulk mass by extrapolation from the \(H_2\) line strength is difficult, and would require detailed modelling of the line excitation mechanism(s) to obtain a robust estimate. We follow previous authors in using the empirical scaling mechanism derived by Bary et al. (2003) to estimate the disc mass. Calculating the mass of hot \(H_2\) from the line strength, we get 0.5 ± 0.1 M\(_\odot\) for ECHA J0843.3−7905. This calculation assumes that the excited gas is optically thin, that ro-vibrational levels of \(H_2\) are populated as for a gas in thermal equilibrium at 1500 K and that the hot \(H_2\) is located at 10–30 au. Using the scaling factors given in Bary et al. (2003) gives a mass in the range 0.05 to 5 M\(_\odot\) for the ECHA J0843.3−7905 disc. The estimated disc masses for our objects are listed along with those of the other systems with \(H_2\) detections in Table 2. A disc of the mass implied by the upper range of this scale would be very surprising for the end of the planet formation time-scale and we consider it to be unfeasible. Indications of the likely disc masses may be judged from observations by, for example, Rodriguez et al. (2005) who measure a disc of 0.3–0.4 M\(_\odot\) for the 0.8 M\(_\odot\) Class 0 star IRAS 16293–2422B and Andrews & Williams (2005) who obtain a mass of 0.5 M\(_\odot\) for the Class I source L1551-IRS5, the latter being the largest disc observed to date. The assumptions inherent in our calculation will tend to produce an overestimate of the disc mass. At radii closer to the star, the gas will be hotter, the mass fraction in the excited state relatively higher and so the total mass reduced.

### Table 2. Upper limits and measurements of the \(H_2\) line. The calculation of the mass of hot \(H_2\) and the total disc mass is discussed in Section 4.

| Name       | Line flux (×10\(^{-18}\) W m\(^{-2}\)) | Hot \(H_2\) mass (10\(^{-6}\) M\(_\odot\)) | Total disc mass (M\(_\odot\)) |
|------------|--------------------------------------|------------------------------------------|-----------------------------|
| RECX3      | 1.8                                  | 0.36                                     | 0.04–4                      |
| RECX5      | 1.2                                  | 0.24                                     | 0.024–2.4                   |
| RECX6      | 1.3                                  | 0.26                                     | 0.03–3                      |
| RECX9      | 1.5                                  | 0.30                                     | 0.03–3                      |
| RECX11     | 2.4                                  | 0.48                                     | 0.05–5                      |
| RECX12     | 2.1                                  | 0.42                                     | 0.04–4                      |
| ECHA J0843.3−7905 | 2.5 ± 0.1 | 0.5                                     | 0.05–5                      |
| GG Tau     | 6.9 ± 0.5                            | 2.8                                      | 0.28–28                     |
| DoAr21     | 15 ± 9                               | 8.1                                      | 0.81–81                     |
| LkCa15     | 1.7 ± 0.2                            | 0.7                                      | 0.07–7                      |
| TW Hy a    | 1.0 ± 0.1                            | 0.06                                     | 6.4 × 10\(^{-3}\)–0.64     |

Although the mass estimate is very uncertain, important conclusions can be reached from the detection of gas in this and other systems. A moderate mass of \(H_2\) must still persist around ECHA J0843.3−7905 at an age of 6 Myr. It seems very unlikely that a hot component could exist unsupported by a large reservoir of cool gas in the bulk of the disc volume. The result for ECHA J0843.3−7905, in conjunction with \(H_2\) \(v = 1–0\) S(1) detections towards LkCa 15 (8 Myr) and TW Hy a (10 Myr), indicates that a gas reservoir does persist to the ages when gas giant planets are presumed to form. For example, in the models of Hubickij, Bodenheim & Lissauer (2005), Jupiter and Saturn accreted their envelopes after 2–5 Myr. The mass of hot \(H_2\) against age for all the published \(H_2\) detections is shown in Fig. 5. With the small number of objects so far studied in \(H_2\), and the wide range of parameters that affects the observability of excited \(H_2\), we can say only that there is a tendency for the older objects to contain a reduced mass of hot gas. Considering the sources cited, we also sought correlations between the detection of \(H_2\) line emission and the various other star or disc parameters (listed in Table 3). In particular, ECHA J0843.3−7905 is the star in \(\eta\) Cham with the largest excess at both near- and mid-IR wavelengths, indicating a possible correlation with the mass of hot gas. However, we find no correlation between the mass of hot \(H_2\) and the \(L\)-band excess. Since excitation of the \(H_2\) may be by UV radiation or X-radiation, we also considered these but again found no

Figure 5. Hot \(H_2\) mass versus age of the source for detections of \(H_2\). The \(H_2\) mass for all the sources is calculated following Bary et al. (2003).
**Table 3.** Properties of sample stars and their discs with disc mass calculated as discussed in Section 4.

| Name    | Total disc mass (M̅)      | (K-L) [3.6]–[4.5]  | [5.8]–[8.0]  | log Lv (erg s)⁻¹ | Cluster or star age (Myr) |
|---------|--------------------------|------------------|-----------|-----------------|--------------------------|
| RECX3   | <0.04–4                  | 0.14⁷               | 0.06⁶     | -0.06⁶           | 29.1⁶          |
| RECX5   | <0.024–2.4               | 0.32⁷               | 0.09⁶     | 0.48³           | 29.0⁶          |
| RECX6   | <0.03–3                  | 0.19⁷               | 0.06⁶     | 0.0⁵¹           | 29.5⁶          |
| RECX9   | <0.06–6                  | 0.39⁷               | 0.19⁶     | 0.6⁶⁵           | 28.4⁶          |
| RECX11  | <0.1–10                  | 0.66⁷               | 0.23⁹     | 0.6⁶³           | 30.1⁶          |
| RECX12  | <0.04–4                  | 0.39⁷               | 0.04⁶     | 0.0³⁵           | 30.1⁶          |
| ECHA0843.3–7905 | 0.05–5               | 1.32⁷               | 0.47⁹     | 0.91⁵           | <28.5⁴       |
| GG Tau  | 0.28–28                  | 0.87⁷               | 0.8⁶⁴     | 29.4⁸          |
| DoAr21  | 0.81–81                  | 0.4³⁷               |           | 31.2⁹          |
| LkCa15  | 0.07–7                   | 0.57⁷               |           | 8³⁸            |
| TW Hya  | 6.4 × 10⁻³–0.64          | 0.1⁴                |           | 30.3⁸          |

⁷Haisch et al. (2005). ⁸Megeath et al. (2005). ⁹Mamajek et al. (1999). ⁴Lawson et al. (2002). ⁵White & Ghez (2001).
⁶Bary et al. (2003). ⁷Siess, Forestini & Bertout (1999). ⁸Simon et al. (1995). ⁹Calvet et al. (2002).

correlation. In the following section, we discuss these two excitation mechanisms.

### 4.1 Comparison to models

Detailed models of H₂ excitation in protoplanetary discs have been published by Nomura & Millar (2005) and Nomura et al. (2007). They calculate the gas and dust temperature and the density profiles self-consistently and predict line fluxes for H₂ in a UV-excited scenario, for comparison with the TW Hydra disc. Their model disc contains 0.006 M⊙ of gas and dust and has an outer radius of 100 au. It may not directly apply to ECHA J0843.3−7905 but some interesting comparisons may be made.

Nomura & Millar (2005) model the UV and the IR emission from H₂ assuming either that the UV-radiation field is described by the blackbody temperature of the star or, as with many T Tauri stars, that there is an excess of UV emission characterized by bremsstrahlung emission at higher temperature than the effective temperature of the star and by emission from Lyα. The latter model is appropriate for TW Hydrae. The ‘UV excess’ model predicts line strengths of ~10⁻⁴ of those of the model without a UV excess. Scaling the predicted $v = 1$–0 S(1) flux for TW Hydrae (at 56 pc) to the distance of ECHA J0843.3–7905 (97 pc), the ‘UV excess’ model gives 1.14 × 10⁻¹⁸ W m⁻², around five times lower than observed from ECHA J0843.3–7905. Making the simplifying assumption that the H₂ flux would scale with disc mass, a disc of 0.03 M⊙ would produce the observed ECHA J0843.3–7905 flux, approximately consistent with the lowest mass derived for the ECHA J0843.3–7905 disc by empirical methods. We therefore consider that the observed flux is consistent with UV excitation of the 0.03–0.05 M⊙ disc by a star with significant UV excess radiation. The authors were unable to obtain any information on the UV spectrum of ECHA J0843.3–7905. One anomaly, compared with the model, is that the 1–0 S(1) emission is expected to peak at around 20 au, rather than around ~2 au. Since the radial dependence of the observable flux in the line depends on the disc geometry, we expect the difference to be attributable to the differences in disc mass.

Maloney, Hollenbach & Tielens (1996) treat the excitation of H₂ due to irradiation by X-rays. ECHA J0843.3–7905 is not detected by ROSAT in the survey of the η Chamaeleontis cluster by Mamajek et al. (1999) giving an upper limit of log (Lv) = 28.5 erg s⁻¹ (Mamajek, Lawson & Feigelson 2000). Therefore, we can predict an upper limit for the $v = 1$–0 S(1) emission due to X-ray excitation. Based on the upper limit for log (Lv), the rate of X-ray energy deposition at the radius of the emitting gas (~2 au) is $2.5 × 10^{-21}$ erg s⁻¹, assuming an H₂ column density of 10²² cm⁻³. Given a distance to the source of 97 pc, assuming a gas density of 10³ cm⁻³ and an emitting region stretching from 2 to 22 au, we expect the emission in the $v = 1$–0 S(1) to be $2 × 10^{-19}$ W m⁻² (Maloney et al. 1996). Given the large emitting annulus that we have taken and the X-ray upper limit, this will most likely be an overestimate and yet is significantly smaller than the observed flux. Thus, we conclude that X-ray excitation is not an important mechanism in this source.

### 5 CONCLUSIONS

We have presented a survey of the η Chamaeleontis cluster in the $v = 1$–0 S(1) line of H₂. Of four stars surveyed that are currently believed to have circumstellar discs, H₂ was detected in a single source (ECHA J0843.3–7905). The line kinematics and flux have been interpreted as arising in a disc, illuminated by UV radiation from the central star. The result, combined with those in other clusters, shows that a significant amount of molecular gas is available for the formation of giant planets on time-scales of 6–10 Myr. The gas around ECHA J0843.3–7905 is located at ~2 au or beyond if the line width is not all Keplerian. The total mass of gas is estimated at 0.03–0.05 M⊙, which is slightly greater than the minimum mass solar nebula (MMSN) of 0.02 M⊙.

This gas disc meets many of the conditions thought to be necessary for the formation of giant planets, including long duration, high surface density and suitable size. For example, the gas reservoir is still substantial at 6 Myr, so a thick gas atmosphere could be added to a Jupiter-analogue core that has taken ~2 Myr to form (Hubickyj et al. 2005). Further, the surface density is comparable to the conditions in which Jupiter formed: for a standard MMSN gas–plus-dust profile of $\Sigma = 1700 r_{au}^{-3/2}$ g cm⁻² (Davis 2005). $\Sigma$ (5 au) is 150 g cm⁻², while for ECHA J0843.3–7905, a gas disc of 0.03–0.05 M⊙ exceeds an average $\Sigma = 200$ g cm⁻² even if spread over 20 au radius. The gas also lies at suitable distances where giant planets should start to form, in particular, in relation to the ‘snowline’ outside which $\Sigma$ of solid particles is favourably enhanced because volatiles freeze out into icy mantles on grains. Lecar et al. (2006) show that the snowline in a MMSN disc lies at around 2 au, and further, in for a low stellar accretion rate such as the 10⁻⁹ M⊙ per year...
of ECHA J0843.3−7905 (Lawson, Lyo & Muzerolle 2004). The
Keplerian estimate shows that the ECHA J0843.3−7905 disc ex-
tends to at least 2 au, and so beyond the snowline. Finally, in
these conditions the Type I migration rate for an Earth-mass proto-
planet core is long: the model of Menou & Goodman (2004) sug-
gests a migration time-scale $>2 \times 10^7$ yr, so a planet in the ECHA
J0843.3−7905 disc is unlikely to fall into the star. Thus, this star
is a likely site for giant planet formation, but the three other stars
surveyed without gas detections are less promising; this result is
roughly in line with observations of main-sequence Sun-like stars,
where in long-term monitoring programs $\sim 15$ per cent host gas
giants (Fischer et al. 2003).

ACKNOWLEDGMENTS

This paper is based on observations obtained at the Gemini Ob-
servatory for proposal GS-2005B-C-15. The Gemini Observatory
is operated by the Association of Universities for Research in As-
tronomy, Inc., under a cooperative agreement with the NSF on be-
half of the Gemini partnership: the National Science Foundation
(United States), the Particle Physics and Astronomy Research Coun-
cil (United Kingdom), the National Research Council (Canada),
CONICYT (Chile), the Australian Research Council (Australia),
CNPq (Brazil) and CONICET (Argentina). Phoenix was designed
and built at the National Optical Astronomical Observatories and is
made available to Gemini as a visiting instrument. The authors are
pleased to acknowledge the excellent support provided during the
observing run by Verne Smith (NOAO), Claudia Winge (Gemini)
and Sybil Adams (Gemini). We are also grateful to the anonymous
referee and to David Weintraub for their helpful comments.

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