On the lifetime of discs around late-type stars

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ABSTRACT

We address the question of whether protoplanetary discs around low-mass stars (e.g. M-dwarfs) may be longer lived than their solar-type counterparts. This question is particularly relevant in assessing the planet-making potential of these lower mass discs. Given the uncertainties inherent to age-dating young stars, we propose an alternative approach that is to analyse the spatial distribution of disc-bearing low-mass stars and compare it to that of disc-bearing solar-type stars in the same cluster. A significant age difference between the two populations should be reflected in their average nearest-neighbour distance (normalized to the number of sources), where the older population should appear more spread out.

To this aim, we perform a Minimum Spanning Tree (MST) analysis on the spatial distribution of disc-bearing young stellar objects (YSOs) in six nearby low-mass star-forming regions. We find no evidence for significant age differences between the disc-bearing low-mass (later than M2) and 'solar-type' (earlier than M2) stars in these regions. We model our results by constructing and analysing synthetic fractal distributions that we evolve for typical values of the velocity dispersions. A comparison of results obtained using simple models to the results from our MST analysis suggests that the lifetime of discs around M-stars is similar to that of discs around solar-type stars. Furthermore, a model-independent spatial analysis of the observations robustly shows that any age differences between the two samples must be smaller than the average age difference between disc-bearing classical T Tauri stars and discless weak-lined T Tauri stars.

Key words: accretion, accretion discs – protoplanetary discs – circumstellar matter – stars: pre-main-sequence.

1 INTRODUCTION

The lifetime of protoplanetary discs around young low-mass stars has been the subject of numerous recent observational and theoretical studies (e.g. Sicilia-Aguilar et al. 2008; Currie & Kenyon 2009; Ercolano, Clarke & Robitaille 2009b; Luhman et al. 2010; Ercolano, Clarke & Hall 2011). The interest is justified by the key role played by this circumstellar material in the formation and evolution of planetary systems, by providing the gas and dust reservoirs from which planets form and through which they migrate.

Discs around solar-type stars are rarely seen for systems of age 10 Myr or older (e.g. Mamajek 2009), implying that (giant) planet formation around such stars must occur within this time-scale. There has been considerable interest recently with regard to planetary systems around lower mass stars (e.g. Pascucci et al. 2011). The reason that studying M-dwarfs is attractive is, first of all, their larger population: assuming a Salpeter/Kroupa initial mass function

(Salpeter 1955; Kroupa 2002) there are 50/10 0.2 $M_\odot$ stars for every 1 $M_\odot$ star. Furthermore, their habitable zones (HZ) extend close to the parent star allowing for a stronger (detectable) radial velocity signal from potentially Neptune-size planets or smaller.

There are, however, a number of possible drawbacks to the search of planetary systems around M-dwarfs, namely their stronger magnetic activity and the possibility of tidal locking for planets with a small orbital separation from the star. There is at present no consensus with regard to whether either of these factors could prevent the development of life on these planets (for a recent review see Pascucci et al. 2011). With regard to the actual formation of the planets themselves there are further considerations to be made. The lower column densities of discs around late-type stars may imply longer time-scales for planet formation under the core accretion scenario, but this may be offset by the fact that the discs may be longer lived. While the absolute ages of star-forming regions (or, worse, individual objects within a region) are known to be uncertain (e.g. Mayne & Naylor 2008; Baraffe, Chabrier & Gallardo 2009), the high fraction of disc-bearing M-stars in η Chamaleontis, aged 8 Myr, has been interpreted as evidence for longer disc lifetimes

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around late-type stars (Sicilia-Aguilar et al. 2009). Furthermore, there is tentative evidence that the frequency of infrared excess emission appears to decrease less steeply with age as the mass of the central object decreases; this result, however, is not yet conclusive because only a few disc fractions have been measured for low-mass stars older than 3 Myr (Carpenter et al. 2006; Luhman 2009).

A significantly longer disc lifetime for late-type stars could have important implications for the formation and evolution of planetary systems, but compelling observational evidence is still missing. Theoretical considerations based on standard disc dispersal mechanisms do not seem to support a significantly longer disc lifetime for M-stars. Gorti, Dullemond & Hollenbach (2009) calculated models of disc dispersal driven mainly by far-ultraviolet-driven photoevaporation for stars in the range of 0.5–30 $M_\odot$, finding that disc lifetimes were only mildly dependent on stellar mass in the range of 0.5–3 $M_\odot$, with roughly only a factor of 2 difference in the time-scales at 0.5 and 3 $M_\odot$. It is unclear, however, how these results could be extrapolated down to the M-dwarf regime. The X-ray photoevaporation models of Ercolano et al. (2008, 2009a) and Owen et al. (2010) only considered the dispersal of discs around a 0.7-$M_\odot$ star. However, if a constant viscous α parameter and radial scaling (i.e. $\nu \propto R$) is assumed, the viscous scaling relations (Lynden-Bell & Pringle 1974) can be used to estimate median disc lifetimes as a function of stellar mass. By approximating the disc's lifetime as the time over which the viscous accretion rates become equal to the wind mass-loss rates, described in Owen et al. (2011) as the 'null' model (see also Ercolano & Clarke 2010), we find that

$$\tau_d \propto L_X^{-2/3} t_\nu^{1/3} M_d(0)^{2/3} \propto L_X^{-2/3} R_1^{1/3} M_*^{-1/6} M_d(0)^{2/3}, \quad (1)$$

where the second relation is for a flared reprocessing disc (e.g. Chiang & Goldreich 1997), t_ν is the viscous time, R_1 is the initial scale size of the disc and $M_d(0)$ is the initial disc mass which is expected to scale linearly with mass (e.g. Alexander & Armitage 2006). The X-ray luminosity has been observationally shown to scale approximately as $L_X \propto M_*^{3/2}$ (e.g. Preibisch et al. 2005; Güdel et al. 2007). However, the scaling of t_ν, and hence R_1, with mass is rather more uncertain, both observationally and theoretically. Alexander & Armitage (2006) use the observed $\dot{M} \propto M_*^2$ scaling (e.g. Muzerolle et al. 2005; Natta, Testi & Randich 2006; Sicilia-Aguilar et al. 2006) to argue that $t_\nu \propto M_*^{-1}$, which yields $\tau_d \propto M_*^{-2/3}$. However, the solution for t_ν from the $M-\dot{M}$ relation is far from unique (e.g. Dullemond, Natta & Testi 2006). Furthermore, the observationally determined $M-\dot{M}$ relation has not yet been confirmed as a physical relation and the role played by observational biases in its derivation is still uncertain (e.g. Clarke & Pringle 2006; Tilling et al. 2008). By instead assuming that all the stars form from cores with identical ratios of rotational to gravitational energy (β), $R_1 \propto M_*$ and thus $\tau_d \propto M_*^{-1/6}$. By including all the known scalings in equation (1), one finds

$$\tau_d \propto M_*^{-1/2} R_1^{1/3}. \quad (2)$$

Therefore, while the actual variation in disc lifetime with mass is unclear, for all the sensible scalings of disc radius with mass, it is clear that X-ray photoevaporation predicts only a mild negative scaling between disc lifetime and mass.

There are clearly a number of, potentially important, theoretical uncertainties and these highlight the need to find alternative methods, based on observations, to understand the dependence of disc lifetimes on stellar mass, which is essential to constrain models of disc evolution and planet formation around M-dwarfs. In this paper we compare the spatial distribution of disc-bearing young late-type

stars (later than M2) to that of earlier types, which we crudely refer to as 'solar-type stars' (i.e. earlier than M2). The aim is to look for the statistical signature of a longer lived disc population amongst the lower mass stars, which should manifest itself as larger mean separations between disc-bearing low-mass stars. This is based on the simple assumption that the older stars would have had more time to move away from their birthplace at the typical velocity dispersions measured for low-mass star-forming regions (of the order of 1 km s^{-1}). Indeed, a spatial comparison of Class I and Class II sources showed that Class I sources were less distributed than the Class IIs, and were still more likely to be near the filamentary structures in the gas in which they presumably formed (e.g. Gutermuth et al. 2008; Maaskant et al. 2011).

In Section 2 we describe the hypothesis in more detail as well as the methods and observational data sets employed. In Section 3 we present the results of the analysis as well as the Monte Carlo simulations to assess the robustness of our results. Finally, a discussion of the physical implications is given in Section 4.

2 HYPOTHESIS, METHODS AND OBSERVATIONS

If it is true that discs around low-mass stars live significantly longer than discs around more massive (solar-type) stars, and that stars in a cluster are formed over an extended period (i.e. the age-spread within a cluster is comparable to the time-scale over which protoplanetary discs disperse), then the disc-bearing low-mass (later than M2) stellar population in a given cluster should be on average older than the disc-bearing solar-mass population (earlier than M2) in the same cluster. The mean age difference amongst the two stellar populations should be reflected in the relative spatial distribution of the young stars, with the disc-bearing low-mass stars being more spread out than the solar-mass stars. Indeed at a velocity of 1 km s^{-1}, which is a typical velocity dispersion measured for a nearby low-mass star forming region, a disc-bearing M-star would be able to travel approximately 10 pc during a hypothetical 10-Myr lifetime of its disc, while a disc-bearing solar-type star may only move a fraction of that distance.

Table 1. Physical properties of the star-forming region [[1a]Oliveira et al. (2009); [1b]Straižys, Černis & Bartašiūte (1996) and Dzib et al. (2010); [2]Williams (2001); [3a]Comerón (2008); [3b]Merín et al. (2008); [4]Makarov (2007); [5a]Luhman (2004), Kenyon, Gómez & Whitney (2008) and references therein; [5b]Kenyon, Dobrzycka & Hartmann (1994); [6]Kraus & Hillenbrand (2008); [7a]Muench et al. (2003); Luhman et al. (2003); [7b]Herbst (2008), Luhman et al. (2003), Scholz et al. (1999), Cernis (1993); [8]Herbig 1998; [9a]Luhman (2007, 2008); [9b]Whittet et al. (1997); [10]Dubath, Reipurth & Mayor (1996); [11]Spezzi et al. (2008); [12a]Sicilia-Aguilar et al. (2005, 2006); [12b]Contreras et al. (2002)].

Region	Age (Myr)	Distance (pc)	Size (pc)	σ_v (km s^{-1})
Serpens	2–6[1a]	260–415[1b]	0.4	0.25–0.611[2]
Lupus III	2–6[3a,3b]	200[3a]	2.4	1.3[4]
Taurus	1[5a]	140[5b]	18	0.2[6]
IC 348	2–3[7a]	261–340[7b]	0.95	0.1–0.2[8]
ChaI	2[9a]	162[9b]	2.8	0.6–1.2[10]
ChaII	4–5[11]	178[9b]	2.3	–
Tr 37	4[12a]	900[12b]	4.7	–
Tr 37 West	1[12a]	900[12b]	4.7	–

The recent compilation of catalogues of young stellar objects (YSOs) in nearby star-forming regions renders possible a preliminary investigation of the spatial distribution of disc-bearing YSOs. We have collected data for seven nearby star-forming regions, including the position of the YSOs, their spectral classification and whether an infrared excess (i.e. a disc) is detected for each individual object. In Table 1 we summarize the physical properties of the regions studied and provide references for the data we used. We note that the 'size' quoted in the table is not the size commonly given in the literature for these regions but it is an effective radius of the region occupied by the well-characterized, disc-bearing YSOs used in our analysis. This was obtained by simply plotting the disc-bearing sources, calculating the area occupied by them and deriving an effective radius from it.

2.1 Spatial analysis

We employ the Minimum Spanning Tree (MST) method to calculate average stellar separations. An MST is formed by connecting all the points (spatial positions in this case) in order to form a unified network, such that the total length (i.e. sum) of all of the connections is minimized, and no closed loops are formed. The method is routinely employed to study large-scale star-forming regions in galaxies (e.g. Bastian et al. 2007, 2009, 2011; Gieles, Bastian & Ercolano 2008; Schmeja, Gouliermis & Klessen 2009) as well as local star-forming regions (Koenig et al. 2008; Schmeja, Kumar & Ferreira 2008; Gutermuth et al. 2009). We constructed MST diagrams for the disc-bearing low-mass and solar-type stars in each region and calculated the average nearest-neighbour distance (d_{av}) for the
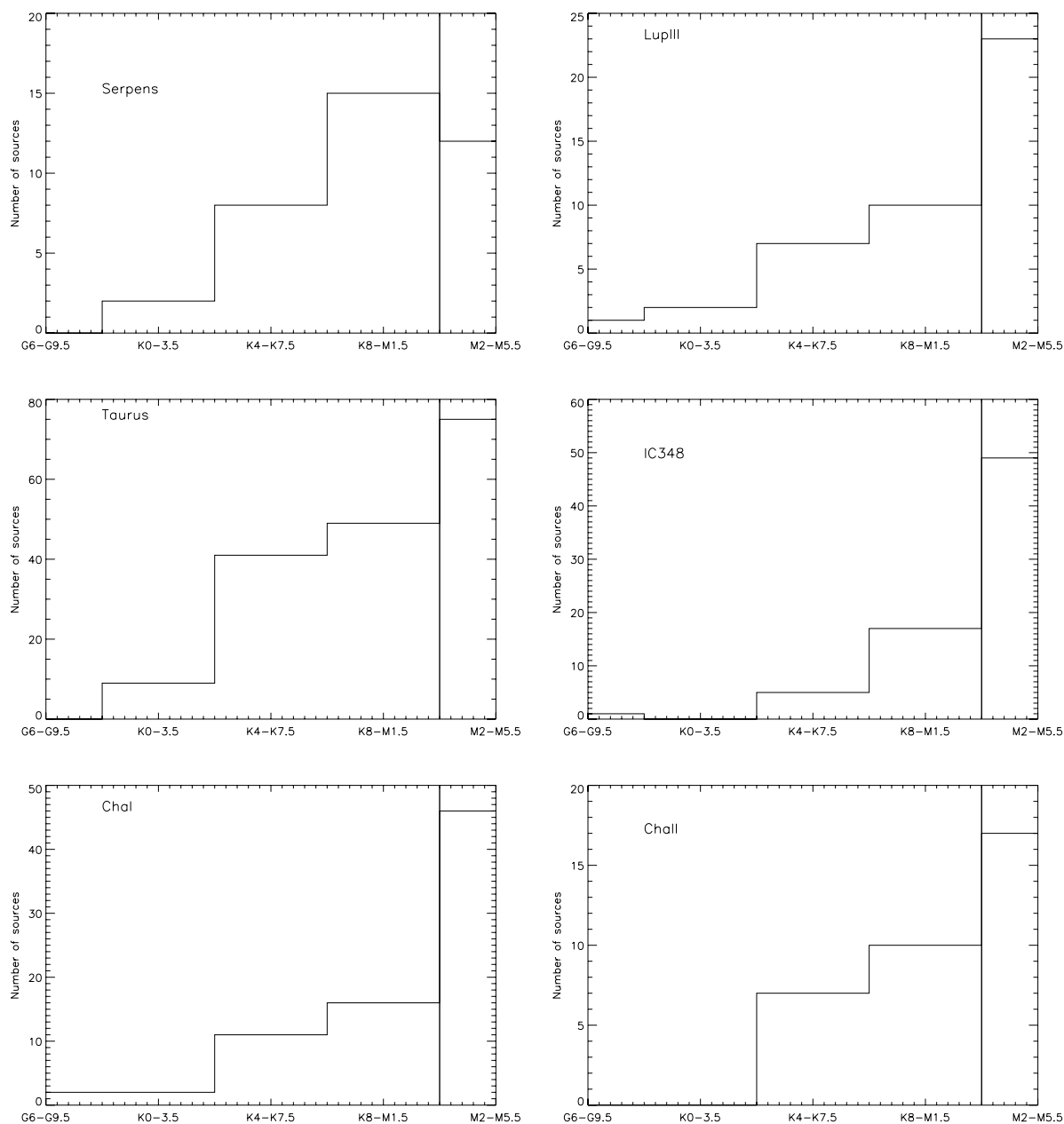

Figure 1. The distribution of spectral types of the disc-bearing sources in the region studied. The thick horizontal line shows the formal separation between 'solar types' and 'low mass' stars set at M2 in this work.

two populations. We ensured that the two populations had the same number of sources by stochastically culling the number of sources in the larger population. The stochastic culling and nearest-neighbours analysis of the larger sample was performed 50 times and an average value was taken. The spread in the Monte Carlo results provided us with a measure of the error introduced by this procedure and by the low-number statistics. We only included YSOs in the sample for which spectral types were available from the literature and excluded brown dwarfs from our samples. Spectral types were measured on the basis of optical and/or near-infrared follow-up spectroscopy. For a more detailed description of the spectral type classification of the YSOs in our sample, we refer the reader to Oliveira et al. (2009) for Serpens; Hughes, Hartigan & Clampitt (1993), Krautter et al. (1997), Comerón et al. (2003) and Allen et al. (2007) for Lup III; Luhman (2004) and references therein for Taurus; Luhman et al. (2003) and Muench et al. (2003) for IC 348; Luhman (2007) and Luhman & Muench (2008) for Cha I; Spezzi et al. (2008) for Cha II; and Sicilia-Aguilar et al. (2005) for Tr 37. As will be further discussed in Section 3, we find no evidence of longer disc dispersal time-scales around the lower mass stellar population. Fig. 1 shows the distribution of the disc-bearing sources as a function of spectral types in the range of G6 to M6,[1] in all the clusters studied, apart from Tr 37 which, as described in the following section, has been excluded from our final analysis. The thick horizontal line shows the formal separation between 'solar types' and 'low mass' stars set at M2 in this work.

2.2 Method validation

As is often the case in this field, however, our analysis is plagued by small-number statistics and perhaps a signal that may be too small to be detected using the proposed technique. In order to validate our method, we performed two sets of tests that are described next.

2.2.1 Test 1: the spatial distribution of disc-bearing and discless objects

The average age difference between the disc-bearing (Class II) and discless (Class III) sources in our catalogues should be of the same order as a hypothetical age difference between disc-bearing solar-type and low-mass stars. We therefore perform a spatial analysis of the distribution of Class II and Class III objects in each of our studied clusters to verify that our method is indeed able to pick up the signal in the average separations.

The results are shown in Table 2, where it is clear that in all the cases, aside from Tr 37, the mean separation of discless stars is larger than the mean separation of disc-bearing sources. This demonstrates that the method we propose here is indeed capable of picking up age difference of the order a few Myr in these clusters. The signal is clearly present even though we included all the sources irrespective of spectral type. This latter point further suggests that the time-scales for dispersal cannot be a strong function of spectral type.

Tr 37 is the only outlier in our sample, where the disc-bearing objects appear to be more spread out than the discless stars. However, Tr 37 is known to show a distribution of ages between 1 and 8 Myr with an age gradient through the cluster from east (older) to west (younger). We have not included the so-called 'globule',

[1] Note that brown dwarf were excluded from our sample, however due to their small numbers, their inclusion does not affect the conclusions.

Table 2. The spatial distribution of the disc-bearing (Class II) versus discless (Class III) stars.

Region	Selected number		d_{av} (pc)	
	Class III	Class II	Class III	Class II
Serpens	129	38	0.10	0.065
Lupus III	64	55	0.11	0.077
Taurus	181	121	0.55	0.38
IC 348	93	206	0.18	0.16
ChaI	99	89	0.12	0.05
ChaII	40	19	0.21	0.12
Tr 37*	62	63	0.03	0.06

* Excluding the Tr 37 West sources. See Text.

Table 3. Observed average separation differences, $\Delta d_{av} = d_{av}(<M2) - d_{av}(>M2)$, between disc-bearing low-mass and solar-mass stars in young clusters.

Region	Selected number		Δd_{av}	$3 \times$ error
	<M2	>M2	(pc)	(pc)
Serpens	12	26	+0.014	0.075
Lupus III	28	22	−0.132	0.033
Taurus	104	102	−0.115	0.110
IC 348	65	26	+0.002	0.012
ChaI	61	32	−0.004	0.054
ChaII	21	18	−0.076	0.089

where evidence for a new episode of star formation was reported by Sicilia-Aguilar et al. (2006; see also Barentsen et al. 2011); however, it is likely that the complex star formation history of this region may be washing out the signal in the spatial distribution. We therefore exclude Tr 37 from further analysis.

2.2.2 Test 2: simulated clusters

In order to predict whether a detectable signal (above the 3σ error given by the Monte Carlo culling described above) is to be expected, we have performed the same MST-based spatial analysis on synthetic clusters of sizes and velocity dispersions appropriate for each of the regions listed in Table 1. We populate each cluster assuming that star formation is continuous during the evolutionary time-scale of the low-mass YSO discs and stars are 'born' in a three-dimensional fractal distribution. The simulations presented here used a 3D fractal dimension of 1.7. Cartwright & Whitworth (2004) estimated fractal dimensions in the range of 1.7 (e.g. Taurus) to 2.3 (e.g. Chamaleon). As a comparison the fractal dimension of the interstellar medium is thought to be 2.3 (Elmegreen & Falgarone 1996). In general the fractal dimension in young clusters is expected to start off low (clumpy) and increase with age (e.g. Bastian et al. 2009, 2011). We thus use a low fractal dimension to assign the birthplaces of the YSOs. A higher fractal dimension would of course weaken the expected signal, so we have also investigated models with higher (2.3) fractal dimensions and found that this only affects the results Δd_{av} by 25 per cent at most. Δd_{av} is defined as the difference between the mean d_{av} of disc-bearing low-mass and solar-type stars.

The solar-type star discs are assumed to disperse after 2 Myr and we vary the lifetime of the low-mass star discs, τ_{lm}, between 2 and 10 Myr in steps of 1 Myr. We assign the direction of motion of each star stochastically with a velocity module equal to the literature value of the velocity dispersion measured for the given region

(Table 1). For each simulation we measure Δd_{av}, after stochastically culling the synthetic clusters to the same number of sources available in the observed clusters (see Table 3). We summarize the results of our Monte Carlo simulations in Fig. 1, where each region-specific simulation is plotted in individual panels. The black, red, green, blue, magenta and cyan asterisks represent models with low-mass star disc lifetimes of 2, 3, 4, 5, 6 and 7 Myr, respectively, while the black, red and green triangles represent models with low-mass star discs dispersal time-scales of 8, 9 and 10 Myr. The solar-type disc dispersal time-scales are kept fixed at 2 Myr. We note that in our very simplified model, what matters is mainly the difference in

the assumed mean disc dispersal time-scale of solar types versus low mass, rather than the absolute ages. Here we explore parameter space by choosing to keep the solar-type discs at the same value and vary the dispersal time-scale of low-mass discs to cover a difference in age from 0 to 8 Myr. This is a very simple statistical test and it cannot be used to suggest absolute disc dispersal time-scales. This test has the only aim, in combination with the spatial analysis presented in the previous section, to provide an indication of an upper limit to the difference in disc dispersal time-scales between solar-type and low-mass stars that is compatible with the null result found in the previous section.
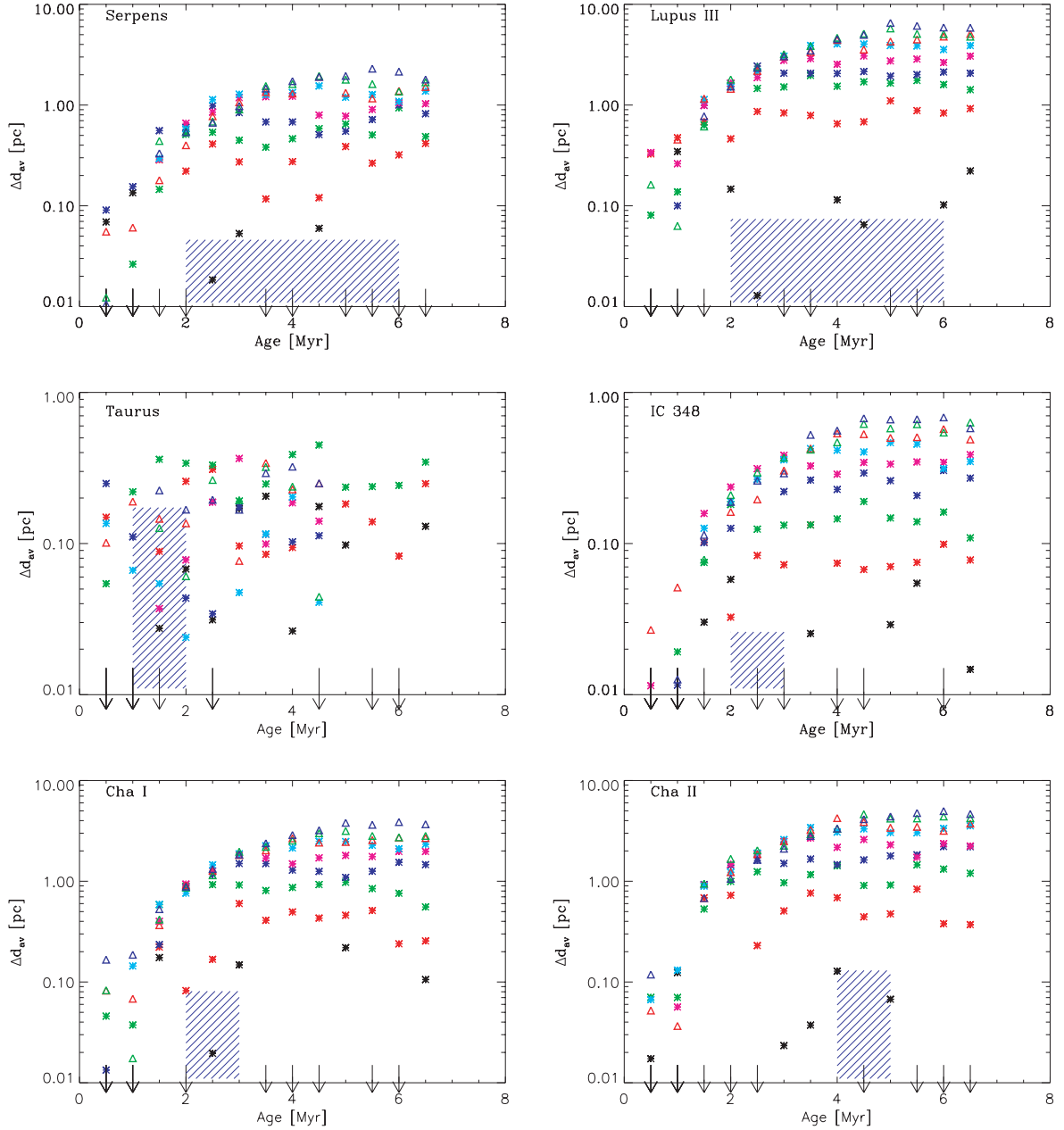

Figure 2. The difference in the nearest-neighbour distance between the low-mass and solar-mass stars as a function of age for simulated clusters with parameters as given in Table 1. The black, red, green, blue, magenta and cyan asterisks represent models with low-mass star disc lifetimes of 2, 3, 4, 5, 6 and 7 Myr, respectively, while the black, red and green triangles represent models with low-mass star discs dispersal time-scales of 8, 9 and 10 Myr. The solar-type disc dispersal time-scales are kept fixed at 2 Myr. The down-pointing arrows represent negative values, or values smaller than the lower limit on the *y*-axis, which have not been plotted on our log plot. The blue hashed box gives the three times Monte Carlo error obtained from the stochastic culling of the larger population in the spatial analysis of the observed regions (see Section 2.1).

The down-pointing arrows represent negative values, which have not been plotted on our log plot. The blue hashed boxes show the 3σ Monte Carlo error obtained from the stochastic sampling of the observed clusters. Fig. 2 shows that for all clusters, apart from Taurus the observations are not consistent for differences in the disc lifetimes between low-mass and solar-type stars in excess of 1 Myr, and are instead consistent with the two populations having basically indistinguishable lifetimes. This result will be further discussed in the context of the observations in the next section.

As mentioned above, the scope of this very simplified test is only to quantify the age differences to which the spatial distribution analysis presented in the previous section is sensitive, and to this aim the age difference between the two populations, rather than the absolute dispersal age of each, is the important parameter. However, it should also be noted that the 'base age', i.e. the dispersal time-scale of the shortest lived population, plays a role for those regions with ages comparable to it. To address the concern that the assumption of an older dispersal age for solar-type stars may weaken the expected signal in the younger regions, we have repeated the experiment for the synthetic IC348 and ChaI models, setting the dispersal time-scales for solar-type discs to 3 and 4 Myr. We show the results in Fig. 3, where it is clear that our conclusions are unaffected by the choice of the longer time-scales even for these young regions. Fig. 3 indicates that still the null signal is only consistent with differences smaller than 1 Myr in the mean disc dispersal time-scale of discs around the two populations.
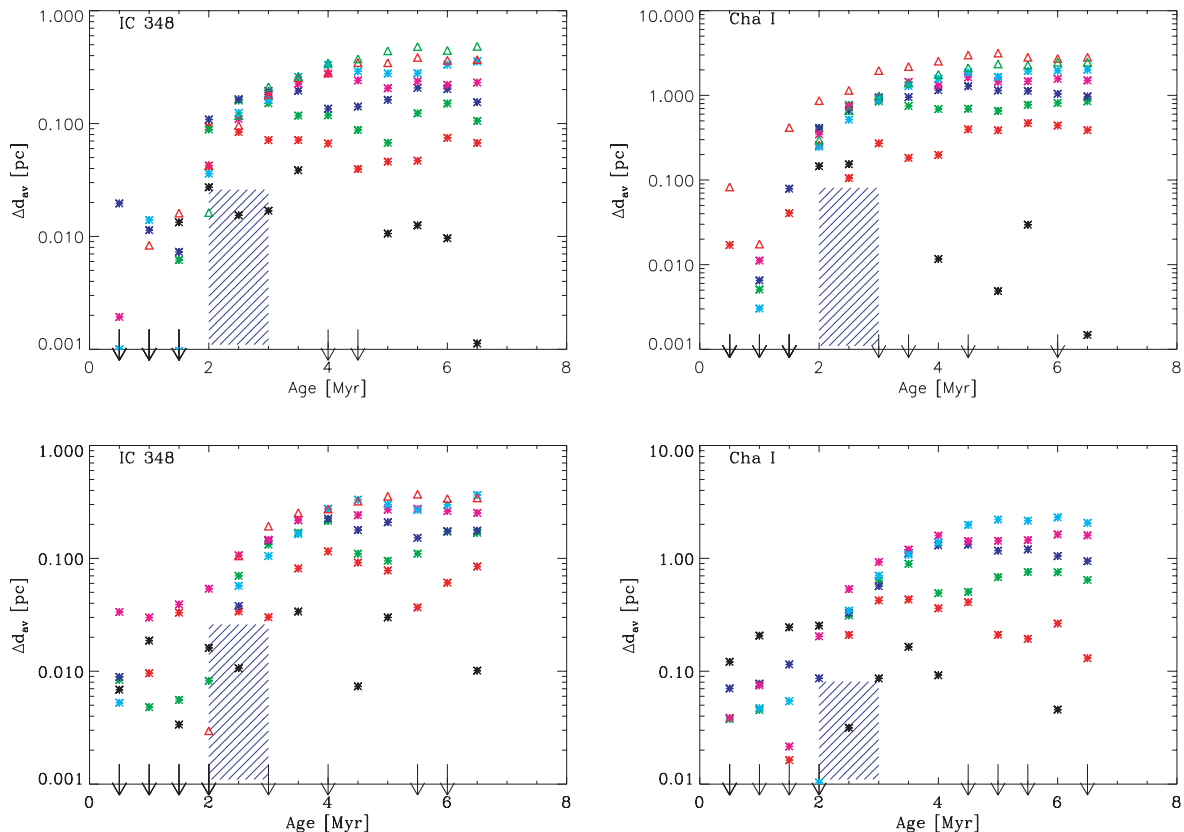
We note that, in theory, mass segregation could also result in lower average nearest-neighbour distances for the higher mass stars. This effect could easily be corrected by comparing the distribution of all YSOs (disc-bearing and discless). However, mass segregation is not expected to be a dominant effect in the low-mass low-number regions considered here, and, in any case, as will be further discussed in the next session, we do not find any difference in the distribution of YSOs as a function of mass (in the mass range considered here), regardless of whether they have an infrared excess. Dynamical expulsion of low-mass members from clusters could also be a problem that decreases the average nearest-neighbour distance of the low-mass members. Again, this effect is only expected to be relevant in a 'classical' cluster, i.e. a centrally concentrated dense object where dynamical interactions between members are common. The star-forming regions considered here are all relatively low surface density objects (cf. Bressert et al. 2010). Finally, bound clusters would also evolve differently, of course, from the simple description of expansion in our toy models, N-body simulations are required to model these effects in detail, which will be explored in a future work; this is, however, not relevant for the young low-density regions studied here.

3 RESULTS

In Table 3 we summarize the results for the relative average separations of low-mass and solar-mass disc-bearing stars in the

Figure 3. The difference in the nearest-neighbour distance between the low-mass and solar-mass stars as a function of age for simulated clusters with parameters as given in Table 1 for IC348 and ChaI. The black, red, green, blue, magenta and cyan asterisks represent models with low-mass star disc lifetimes of 2, 3, 4, 5, 6 and 7 Myr, respectively, while the black, red and green triangles represent models with low-mass star discs dispersal time-scales of 8, 9 and 10 Myr. The solar-type disc dispersal time-scales are kept fixed at 3 Myr (top panels) and 4 Myr (bottom panels). The down-pointing arrows represent negative values, or values smaller than the y-axis limit, which have not been plotted on our log plot. The blue hashed box gives the three times Monte Carlo error obtained from the stochastic culling of the larger population in the spatial analysis of the observed regions (see Section 2.1).

seven regions studied. The difference between the average nearest-neighbour distancesfor these two populations (Δd_{av}) is indicated. The errors refer to the uncertainties introduced by our stochastic culling of the more numerous population, described in the previous section, and it represents the Monte Carlo error intrinsic to this procedure. In five out of the six regions studied in this work (we exclude Tr 37 from the discussion, see Section 2.2.1), the difference in d_{av} between the low- and solar-mass stars is always smaller than the 3σ error that resulted from the Monte Carlo culling. The only exception is the Lupus III region where we find a signal at the 7σ level, but with a negative sign (i.e. indicating smaller average distances for M-stars) We note however that the average distances were computed using only 15 stars in each population and are distributed over an extended non-spherical region. The same analysis performed on only the central higher density region shows a much weaker but still detectable negative signal (roughly at the 4σ level), but the low-number statistics weaken any conclusions from this one cluster alone.

This null result can be interpreted in the contexts of the statistical tests performed in Section 2. Our comparison of the spatial distributions of disc-bearing (Class II) against discless (Class III) objects, described in Section 2.2.1, showed that our method is able to recognize an age difference between these two classes of objects. This suggests in the first instance that if a similar age difference existed between disc-bearing low-mass objects and disc-bearing solar-type objects, it should also be picked up by the same method. Our Monte Carlo simulations of synthetic clusters, discussed in Section 2.2.2, allows us to determine limits on the maximum average age difference between low-mass and solar-type discs in each of the clusters. Fig. 1 shows that for all the regions, except for the young Taurus region, our results are consistent with no age difference between the two populations.

The simulated cluster analysis presented in the previous sections predicts that for an age difference between the low-mass and solar-type disc population greater or equal to 1 Myr, the Δd_{av} should be much larger than the 3σ upper limits given by the Monte Carlo errors (blue hashed boxes in Fig. 1), thus arguing for similar dispersal time-scales (black asterisks in Fig. 1) for both populations. Taurus is the only exception, where the non-detection of a signal cannot be interpreted as the two populations being co-eval. This result is largely driven by the extremely young age of the region, its large physical extension and low velocity dispersion which conspire to give an undetectable signal.

On the basis of these considerations we conclude that there is no evidence of a significant difference in the lifetimes of discs around low-mass and solar-type stars on the basis of their relative spatial distributions. Indeed, the statistically indistinguishable spatial distribution of the low-mass and solar-mass stars in Serpens, Lupus III, ChaI, ChaII and IC 348 argues against the hypothesis that discs around low-mass stars live significantly longer than discs around solar-mass stars, although we cannot rule out differences of less than 1 Myr (see Section 2).

To summarize, our simple spatial analysis using MSTs provides evidence against significantly longer disc dispersal time-scales around late-type stars (e.g. M-dwarf) compared to their solar-mass counterparts. Low-number statistics prevents us from providing tight constraints on the allowed difference in disc survival time-scales in these two populations, but our analysis, based on simple models, indicates that it is consistent with similar disc dispersal time-scales, with differences that are certainly smaller than the average age difference between CTTs and WTTs.

REFERENCES

Alexander R. D., Armitage P. J., 2006, ApJ, 639, L83
Allen P. R., Luhman K. L., Myers P. C., Megeath S. T., Allen L. E., Hartmann L., Fazio G. G., 2007, ApJ, 655, 1095
Baraffe I., Chabrier G., Gallardo J., 2009, ApJ, 702, L27
Barentsen G. et al., 2011, preprint (arXiv:1103.1646)
Bastian N., Ercolano B., Gieles M., Rosolowsky E., Scheepmaker R. A., Gutermuth R., Efremov Y., 2007, MNRAS, 379, 1302
Bastian N., Gieles M., Ercolano B., Gutermuth R., 2009, MNRAS, 392, 868
Bastian N. et al., 2011, MNRAS, 412, 1539
Bressert E. et al., 2010, MNRAS, 409, L54
Carpenter J. M., Mamajek E. E., Hillenbrand L. A., Meyer M. R., 2006, ApJ, 651, L49
Cartwright A., Whitworth A. P., 2004, MNRAS, 348, 589
Cernis K., 1993, Baltic Astron., 2, 214
Chiang E. I., Goldreich P., 1997, ApJ, 490, 368
Clarke C. J., Pringle J. E., 2006, MNRAS, 370, L10
Comerón F., 2008, Handbook of Star Forming Regions, Vol. II, 295
Comerón F., Fernández M., Baraffe I., Neuhäuser R., Kaas A. A., 2003, A&A, 406, 1001
Contreras M. E., Sicilia-Aguilar A., Muzerolle J., Calvet N., Berlind P., Hartmann L., 2002, AJ, 124, 1585
Currie T., Kenyon S. J., 2009, AJ, 138, 703
Dubath P., Reipurth B., Mayor M., 1996, A&A, 308, 107
Dullemond C. P., Natta A., Testi L., 2006, ApJ, 645, L69
Dzib S., Loinard L., Mioduszewski A. J., Boden A. F., Rodríguez L. F., Torres R. M., 2010, ApJ, 718, 610
Elmegreen B. G., Falgarone E., 1996, ApJ, 471, 816
Ercolano B., Clarke C. J., 2010, MNRAS, 402, 2735
Ercolano B., Drake J. J., Raymond J. C., Clarke C. C., 2008, ApJ, 688, 398
Ercolano B., Clarke C. J., Drake J. J., 2009a, ApJ, 699, 1639
Ercolano B., Clarke C. J., Robitaille T. P., 2009b, MNRAS, 394, L141
Ercolano B., Clarke C. J., Hall A. C., 2011, MNRAS, 410, 671
Gieles M., Bastian N., Ercolano B., 2008, MNRAS, 391, L93
Gorti U., Dullemond C. P., Hollenbach D., 2009, ApJ, 705, 1237
Güdel M. et al., 2007, A&A, 468, 353
Gutermuth R. A. et al., 2008, ApJ, 674, 336
Gutermuth R. A., Megeath S. T., Myers P. C., Allen L. E., Pipher J. L., Fazio G. G., 2009, ApJS, 184, 18
Herbig G. H., 1998, ApJ, 497, 736
Herbst W., 2008, Handbook of Star Forming Regions, Vol. I, 372
Hughes J., Hartigan P., Clampitt L., 1993, AJ, 105, 571
Kenyon S. J., Dobrzycka D., Hartmann L., 1994, AJ, 108, 1872
Kenyon S. J., Gómez M., Whitney B. A., 2008, Handbook of Star Forming Regions, Vol. I, 405
Koenig X. P., Allen L. E., Gutermuth R. A., Hora J. L., Brunt C. M., Muzerolle J., 2008, ApJ, 688, 1142
Kraus A. L., Hillenbrand L. A., 2008, ApJ, 686, L111
Krautter J., Wichmann R., Schmitt J. H. M. M., Alcala J. M., Neuhauser R., Terranegra L., 1997, A&AS, 123, 329
Kroupa P., 2002, Sci, 295, 82
Luhman K. L., 2004, ApJ, 617, 1216
Luhman K. L., 2007, ApJS, 173, 104
Luhman K., 2008, Handbook of Star Forming Regions, Vol. II, 169
Luhman K. L., 2009, AIP Con. Ser., 1094, 55
Luhman K. L., Muench A. A., 2008, ApJ, 684, 654

Luhman K. L., Stauffer J. R., Muench A. A., Rieke G. H., Lada E. A., Bouvier J., Lada C. J., 2003, ApJ, 593, 1093
Luhman K. et al., 2010, APJS, 186, 111
Lynden Bell D., Pringle J. E., 1974, MNRAS, 168, 603
Maaskant K. M., Bik A., Waters L. B. F. M., Kaper L., Henning T., Puga E., Horrobin M., Kainulainen J., 2011, preprint (arXiv:1104.5618)
Makarov V. V., 2007, ApJ, 670, 1225
Mamajek E. E., 2009, AIP Conf. Ser., 1158, 3
Mayne N. J., Naylor T., 2008, MNRAS, 386, 261
Merin B. et al., 2008, ApJS, 177, 551
Muench A. A. et al., 2003, AJ, 125, 2029
Muzerolle J., Luhman K., Briceõ C., Hartmann L., Calvet N., 2005, ApJ, 625, 906
Natta A., Testi L., Randich S., 2006, A&A, 452, 245
Oliveira I. et al., 2009, ApJ, 691, 672
Owen J. E., Ercolano B., Clarke C. J., Alexander R. D., 2010, MNRAS, 401, 1415
Owen J. E., Ercolano B., Clarke C. J., 2011, MNRAS, 412, 13
Pascucci I. et al., 2011, in press
Preibisch T. et al., 2005, ApJS, 160, 401

Salpeter E. E., 1955, ApJ, 121, 161
Schmeja S., Kumar M. S. N., Ferreira B., 2008, MNRAS, 389, 1209
Schmeja S., Gouliermis D. A., Klessen R. S., 2009, ApJ, 694, 367
Scholz R.-D. et al., 1999, A&AS, 137, 305
Sicilia-Aguilar A., Hartmann L. W., Hernández J., Briceño C., Calvet N., 2005, AJ, 130, 188
Sicilia-Aguilar A. et al., 2006, AJ, 132, 2135
Sicilia-Aguilar A., Henning T., Juhász A., Bouwman J., Garmire G., Garmire A., 2008, ApJ, 687, 1145
Sicilia-Aguilar A. et al., 2009, ApJ, 701, 1188
Spezzi L. et al., 2008, ApJ, 680, 1295
Straižys V., Černis K., Bartašiūt e S., 1996, Baltic Astron., 5, 125
Tilling I., Clarke C. J., Pringle J. E., Tout C. A., 2008, MNRAS, 385, 1530
Whittet D. C. B., Prusti T., Ranco G. A. P., Gerakines P. A., Kilkenny D., Larson K. A., Wesselius P. R., 1997, A&A, 327, 1194
Williams J., 2001, in Wootten A., ed., ASP Conf. 235, Science with the Atacama Large Millimeter Array. Astron. Soc. Pac., San Francisco, p. 171

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