Revising Star and Planet Formation Timescales

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Abstract

We have derived ages for 13 young (< 30 Myr) star-forming regions (SFRs) and find they are up to a factor two older than the ages typically adopted in the literature. This result has wide-ranging implications, including that circumstellar discs survive longer (~10–12 Myr) and that the average Class I lifetime is greater (~1 Myr) than currently believed.

A revised age scale for pre-main-sequence stars

For each SFR we have derived two ages from colour-magnitude diagrams (CMDs); the first from the main-sequence (MS) population and the second from the pre-MS population. Comparing these two ages we find broad agreement (see Fig. 1). As pre-MS ages are used to study the lifetime of YSO evolutionary phases, this result implies that such lifetimes are currently **underestimated by up to a factor of two**. Combining our revised ages with near-IR observations suggests that circumstellar discs **survive approximately twice as long** as previously thought (see Fig. 2). Interestingly the three youngest SFRs have MS ages which are notably older (factors of 2–3) than their pre-MS ages.

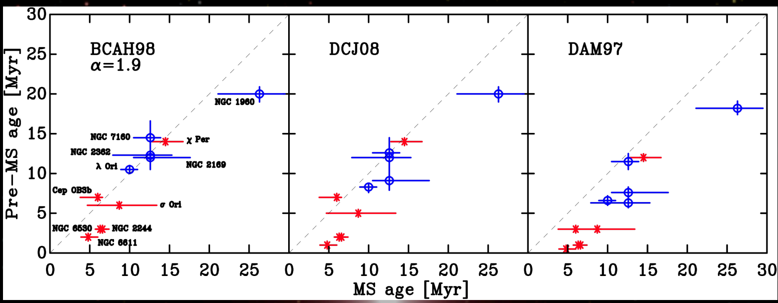

Fig. 1. The MS versus pre-MS ages for the SFRs in our sample. The blue circles and error bars represent the SFRs for which the MS and pre-MS ages were derived using the τ^2 fitting statistic. The red asterisks and error bars denote SFRs for which the MS age was derived using the τ^2 fitting statistic; however, the pre-MS age is a nominal age at a mass of 0.75 $M_{\odot}$. Note that both IC 348 and IC 5146 are not shown in this figure as no MS ages were derived due to the insufficient number of MS stars.

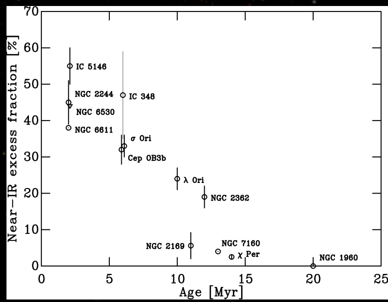

Fig. 2. Fraction of stars (typically spectral types mid-K and later) with near-IR excess disc emission as a function of our revised age. Circles represent the disc fraction based on *Spitzer* observations. The triangle denotes the disc fraction based on 2MASS JHK_s observations.

SFR	Age (Myr)
NGC 6611 (Eagle Nebula, M 16); IC 5146 (Cocoon Nebula); NGC 6530 (Lagoon Nebula, M 8); NGC 2244 (Rosette Nebula)	2
σ Ori; Cep OB3b; IC 348	6
λ Ori (Collinder 69)	10
NGC 2169	11
NGC 2362	12
NGC 7160	13
χ Per	14
NGC 1960 (M 36)	20

Main-sequence

Models of the evolution between the zero-age main-sequence and terminal-age main-sequence (Lejeune & Schaerer 2001, A&A, 366, 538) were used in conjunction with the τ^2 fitting statistic (Naylor & Jeffries 2006, MNRAS, 373, 1251) to derive a homogeneous set of MS ages, distances and reddenings.

- *U-B*, *B-V* colour-colour diagram => reddening (see Fig. 3).
- *V*, *B-V* CMD => age and distance simultaneously (see Fig. 4).

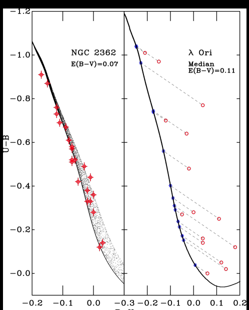

Fig. 3. Examples of photometric data fitted for reddening. Left: NGC 2362 data (Johnson & Morgan 1953, ApJ, 117, 313) fitted for a mean reddening. Right: λ Ori data (Murdin & Penston 1977, MNRAS, 181, 657) individually de-reddened.

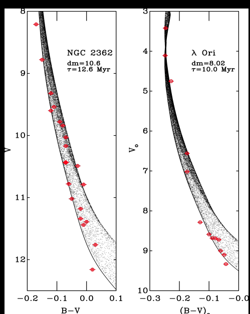

Fig. 4. Examples of photometric data fitted for age and distance simultaneously. Left: NGC 2362 data. Right: De-reddened λ Ori data.

Pre main-sequence

We created new semi-empirical pre-MS model isochrones using existing interior models, but adopted empirical colour-T_{eff} and bolometric corrections for stars cooler than 4000 K. Equally important, we transformed the isochrones to the natural photometric system of the observations (see Bell et al. 2012, MNRAS, 424, 3178).

- Observed luminosity spread commensurate with the two-dimensional model distribution => τ^2 fitting statistic (see Fig. 5).
- Luminosity spread too large => nominal ages; compare a 0.75 $M_{\odot}$ star with the approximate middle of the pre-MS locus (see Fig. 6).

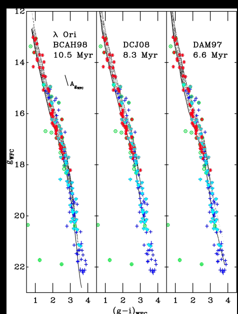

Fig. 5. Stars selected as members of the λ Ori association (spectroscopic, X-ray and IR excess diagnostics). The best-fitting model distributions are overlaid at the best-fit MS distance and reddened assuming the median value derived from the MS population.

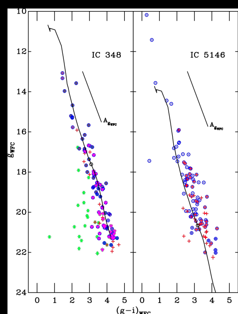

Fig. 6. Stars selected as members of IC 348 (left) and IC 5146 (right). A 6 Myr DCJ08 (Dotter et al. 2008, ApJS, 178, 89) single-star model isochrone is overlaid in each panel at the best-fit MS distance and reddened assuming the median value derived from the MS population.