New Evidence That Pre-Main-Sequence Stars Are Older Than We Thought

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constellation

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Introduction We present results derived using a self-consistent, semi-empirical set of pre-main-sequence (pre-MS) model isochrones. It is well known that ages derived using currently available sets of pre-MS isochrones are both model and colour dependent. Furthermore, for a given model and colour index, isochrones deviate away from the observed cluster sequence for masses $\lesssim 0.5\,M_{\odot}$. We address this issue with our new semi-empirical isochrones which give ages greater than current literature ages by up to a factor two. We use robust observational constraints, in this case the *K*-band magnitudes of eclipsing and spectroscopic binaries, as the basis for our colour-T_{eff} relation in combination with observed colours of Pleiads. We then allow for the effects of gravity using model atmospheres, which allows us to fit these models to a homogeneous dataset of young (< 20 Myr) pre-MS clusters taken in the Sloan Digital Sky Survey (SDSS) photometric system. The revised ages bring the pre-MS ages in line with the main-sequence nuclear ages of Naylor (2009) and may explain the discrepancy between formation times required by planet formation models and the estimated disc lifetimes of protoplanetary discs.

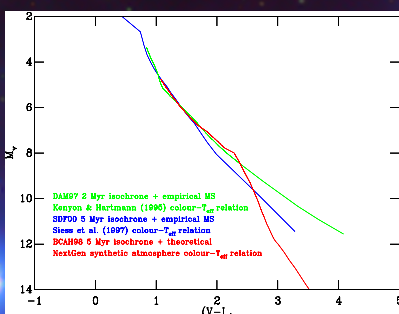

Fig. 1 – Contemporary pre-MS isochrones

Current theory Fig. 1 displays three sets of pre-MS isochrones generally used in CMD analysis (Baraffe et al., 1998 - red; D'Antona & Mazzitelli, 1997 - green and Siess et al., 2000 - blue). Although all three appear to coincide blueward of (*V-I*) ~ 1.7, the BCAH98 and SDF00 isochrones are for an age of 5 Myr, whereas the DAM97 is for 2 Myr. Furthermore, the photometric magnitudes for the BCAH98 isochrone are derived using the NextGen synthetic atmospheres convolved with filter responses, whilst the SDF00 and DAM97 magnitudes are created using empirically based colour-T_{eff} relations (Siess et al., 1997, and Kenyon & Hartmann, 1995, respectively). Redward of (*V-I*) ~ 1.7 the differences are obvious with all three diverging drastically. So how does this look when compared with an observed sequence?

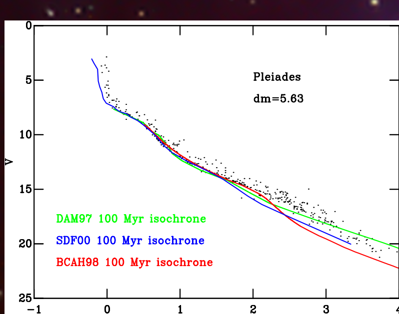

Fig. 2 – Pleiades (see Stauffer et al., 2007, and references therein) with 100 Myr isochrones.

Issues In Fig. 2 each isochrone appears to model the main-sequence regime (*V-I*) < 1.7 as accurately as the other, but the pre-MS (*V-I*) > 1.7 differences are still apparent. Can we trust *VI* photometry at the red end when the reddest Landolt standards lie at (*V-I*) ~ 3 i.e. how can we choose which model best represents the data?

Method If we use the better constrained SDSS system we overcome the calibration uncertainty. Using Stripe 82 of the SDSS, (Ivezic et al., 2007) we are confident of our photometric calibration to (*g-i*) ~ 3.5.

We first overlay isochrones on the combination of Pleiades and Praesepe data (Fig. 3) converting L_{bol} and T_{eff} to magnitudes and colours using the NextGen/GAIA atmospheric models (Brott & Hauschildt, 2005).

We see the same problem redward of (*g-i*) ~ 2, as seen in Fig. 2. We use these data to create a semi-empirical set of bolometric corrections (BCs), which fit the data (see Fig. 4 for details). We then use these to produce new isochrones, which we apply to younger clusters. We can now be certain of our red calibration as we observed the Pleiades and all target fields in a homogeneous fashion on the same observing run.

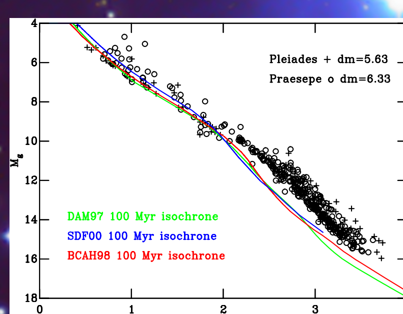

Fig. 3 – Combined CMD of Pleiades and Praesepe. Overlaid are three 100 Myr isochrones created using our theoretical NextGen/GAIA BCs.

The details of our approach

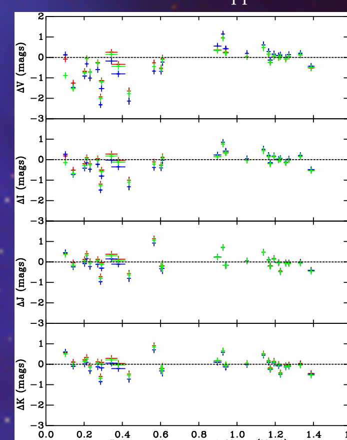

Fig. 4 – Difference in observed absolute magnitude and the isochrone predictions for a sample of binaries. The *K*-band magnitude is the one most reliably predicted by the models. Therefore, to create our semi-empirical BCs we use the *K*-band magnitude of each Pleiad in combination with the isochrones to obtain a T_{eff}. We then calculate the difference between the theoretical and observed BC which we apply to all gravities for a given T_{eff}. Compared to previous Pleiades tuning techniques, our BCs are gravity dependent and our masses tied to a reliable scale.

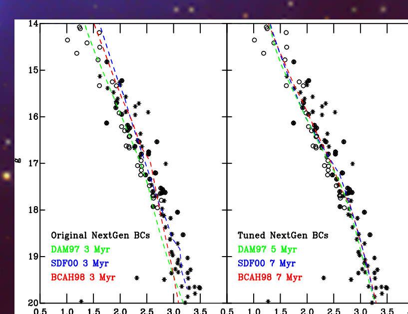

Fig. 5 – CMD of Lam Ori with member from Barrado y Navascués et al. (2007), Dolan & Mathieu (2001) and Sacco et al. (2008).

Results Isochrones created with our originally derived BCs used to create the colour-T_{eff} relation (left) and our Pleiades tuned BCs (right). Note how the isochrones follow the entire dataset and the older ages needed for this fit.