A Critical Assessment of Ages Derived Using Pre-Main-Sequence Isochrones in Colour-Magnitude Diagrams

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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Abstract

In this thesis a critical assessment of the ages derived using theoretical pre-main-sequence (pre-MS) stellar evolutionary models is presented by comparing the predictions to the low-mass pre-MS population of 14 young star-forming regions (SFRs) in colour-magnitude diagrams (CMDs).

Deriving pre-MS ages requires precise distances and estimates of the reddening. Therefore, the main-sequence (MS) members of the SFRs have been used to derive a self-consistent set of statistically robust ages, distances and reddenings with associated uncertainties using a maximum-likelihood fitting statistic and MS evolutionary models. A photometric method (known as the Q-method) for de-reddening individual stars in regions where the extinction is spatially variable has been updated and is presented. The effects of both the model dependency and the SFR composition on these derived parameters are also discussed.

The problem of calibrating photometric observations of red pre-MS stars is examined and it is shown that using observations of MS stars to transform the data into a standard photometric system can introduce significant errors in the position of the pre-MS locus in CMD space. Hence, it is crucial that precise photometric studies (especially of pre-MS objects) be carried out in the natural photometric system of the observations. This therefore requires a robust model of the system responses for the instrument used, and thus the calculated responses for the Wide-Field Camera on the *Isaac Newton* Telescope are presented. These system responses have been tested using standard star observations and have been shown to be a good representation of the photometric system.

A benchmark test for the pre-MS evolutionary models is performed by comparing them to a set of well-calibrated CMDs of the Pleiades in the wavelength regime $0.4-2.5\,\mu$m. The masses predicted by these models are also tested against dynamical masses using a sample of MS binaries by calculating the system magnitude in a given photometric band-pass. This analysis shows that for $T_{\rm eff} \lesssim 4000\,$K the models systematically overestimate the flux by a factor of 2 at $0.5\,\mu$m, though this decreases with wavelength, becoming negligible at $2.2\,\mu$m. Thus before the pre-MS models are used to derive ages, a recalibration of the models is performed by incorporating an empirical colour-$T_{\rm eff}$ relation and bolometric corrections based on the $K_{\rm s}$-band luminosity of Pleiades members, with theoretical corrections for the dependence on the surface gravity ($\log g$).

The recalibrated pre-MS model isochrones are used to derive ages from the pre-MS populations of the SFRs. These ages are then compared with the MS derivations, thus providing a powerful diagnostic tool with which to discriminate between the different pre-MS age scales that arise from a much stronger model dependency in the pre-MS regime. The revised ages assigned to each of the 14 SFRs are up to a factor two older than previous derivations, a result with wide-ranging implications, including that circumstellar discs survive longer and that the average Class II lifetime is greater than currently believed.

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Declaration

The work presented in Chapters 3 and 4 was taken from a paper published in the Monthly Notices of the Royal Astronomical Society by Cameron P. M. Bell, Tim Naylor, N. J. Mayne, R. D. Jeffries, and S. P. Littlefair entitled Pre-main-sequence isochrones – I. The Pleiades benchmark (MNRAS, 424, 3178).

Chapters 2, 5, and 6 contain work that will be published in the near future and represent the second instalment of the saga.

The photometric observations taken with the Wide-Field Camera on the *Isaac Newton* Telescope were obtained by Tim Naylor and myself. The *Isaac Newton* Telescope is operated on the island of La Palma by the *Isaac Newton* Group (ING) in the Spanish Observatorio del Roque de los Muchachos of the Institutio de Astrofisica de Canarias.

Near-IR photometric data for the sample of main-sequence binaries were obtained from the Two-Micron All-Sky Survey (2MASS), which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center, funded by the National Aeronautics and Space Administration (NASA) and the National Science Foundation.

The final reduction of the *Isaac Newton* Telescope data and the calculation of the *Isaac Newton* Telescope bandpasses were performed by Tim Naylor.

The τ^2 fitting statistic used for fitting the models to the data is the brainchild of Tim Naylor and R. D. Jeffries.

The rest of the work presented in this thesis is my own.