Seminar research notes

**Using Bayesian Hierarchical Modelling with Machine Learning to Determine Age Distributions in Open Clusters**

I guess I will begin by giving a short intro of the project  
then explaining why we chose to do age determinations of open clusters (**very useful for testing stellar evolution and formation models etc.**)  
Talk about Red giants importance I guess using HR diagram to explain how fast stars move along the HR diagram.

Do I mention globular clusters?  
asteroseismology

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| Open clusters   * Typical distances of one to a few kpc, largely due to observational bias * Found primarily in the Galactic plane * open clusters lose members steadily, and most eventually dissolve into the Galactic field star population. * Since open clusters dissolve readily, the oldest open clusters place only a lower limit on the age of the Galactic disk. Still, that limit is both important and reasonable, with NGC 6791 and Be 17 being ∼10 Gyr * It is possible, though not convincingly demonstrated, that some of the globular clusters (e.g., 47 Tuc) belong to the thick disk. * **How do we determine stellar ages of open clusters?**  color-magnitude diagram (CMD). The location of stars in the CMD provide a model-dependent set of correlated constraints on the cluster’s age, metallicity, distance, and reddening.   **Downside**: often times cluster CMDs are contaminated by foreground and background Galactic field stars. Such contaminants can be removed by proper motion or radial velocity cuts.   * Typical age uncertainties, even in the most carefully studied clusters, are ± 20%. * Open clusters, each containing stars with a range of masses but only a single age, abundance pattern, and distance, have provided tremendous insight into a range of astrophysical problems, from those intimately related to stellar interiors, atmospheres, and evolution, to problems of cosmology, to disk and planet formation. Figure 5, for instance, shows the lithium abundance vs. Teff for NGC 2547 members and the expectations from 30 Myr and 50 Myr models **ALLOWS US TO TEST+IMPROVE MODELS**      * Improved age precision will in turn be necessary for answering questions in new fields, such as stellar disk dissipation and planet formation timescales.       Hippel, Ted von (2005). “Galactic Open Clusters". Journal: ASP Conference Series. url: <https://arxiv.org/abs/astro-ph/0509152v1>.   * Present day open cluster formation rate within 2 Kpc projected distance from the sun: ~ 0.45 Kpc-2 Myr-1   Battinelli et al. (1991). “The age distribution of galactic open clusters”. Journal: ASP Conference Series, volume: 13, pages: 139, url: <http://www.aspbooks.org/publications/13/139.pdf>   * used to trace the structure and evolution of the Galactic disk * spatial distribution and kinematical properties of OCs provide critical constraints on the overall structure and dynamical evolution of the galactic disk * when combined with abundance data, OCs serve as excellent tracers of the abundance gradient along the Galactic disk as well as the temporal evolution of this abundance gradient, which can be used to constrain the chemical evolution history of the Galactic disk * this is because OCs have formed at all epochs and since their ages, distances, and metallicities can be derived more reliably than the same parameters of the field stars.   FIGURE OUT WHY THIS IS   * Observed disk abundance gradient and its evolution offer the opportunity to test theories of star formation and disk chemical evolution.   Chen, L. and Houage, J.L. (2009). “Galactic Open Clusters and the LOCS Project”. Journal: ASP Conference Series, volume: 404, pages: 343, url: <http://aspbooks.org/publications/404/343.pdf>   * The advantage of dating star clusters over individual stars – whose age determination relies entirely on the knowledge of individual metallicities, effective temperatures and gravities (or absolute magnitudes), which have to be fitted by the appropriate theoretical model – stems from the fact that star clusters are made of coeval objects, largely with the same initial chemical composition and located at the same distance, so that it is possible to use morphological parameters deduced from theoretical isochrones in order to derive their age. In this way one can bypass the thorny problem of determining a reliable empirical and theoretical temperature scale, and of acquiring high resolution spectroscopy for large samples of stars * OCs are expected to be disrupted easily by encounters with massive clouds in the disk (Spitzer 1958); however, the most massive OCs or those with orbits that keep them far away from the Galactic plane for most of their lifetimes are expected to survive for longer periods of time. * The determination of the age-metallicity relationship for halo and disk objects has been the subject of numerous studies, because it poses a constraint to the chemical evolution history of the Galaxy.   Salaris, M. et al. (2004). “The age of the oldest Open Clusters”. Journal: Astron.Astrophys, volume: 414, pages: 163-174, url: <https://arxiv.org/pdf/astro-ph/0310363.pdf>   * Parameters can be determined more accurately for open clusters on a statistical basis by means of numerous cluster members. Since most kinds of variable stars are present also in open clusters, they offer the unique possibility to study all the various star groups and their dependency with age or environmental properties in much more detail. * Open clusters are physically related groups of stars held together by mutual gravitational attraction, populating a limited region of space. Therefore, for all cluster stars more or less the same distance can be allocated. The process of formation takes only a considerably short time (a few Myrs) compared to the lifetime of the cluster (up to some billion years), so that all member stars are of similar age. As all the stars in a cluster are formed from the same diffuse nebula, they are all also of similar initial chemical composition (metallicity).   Netopil, M., Paunzen, E. (2011). “Variable Star Survey in Galactic Open Clusters”. Journal: ASP Conference Series, volume: 435, pages: 145, url: <http://www.aspbooks.org/publications/435/145.pdf>    Marcionni, N. et al. (2014). “Determination of Fundamental Astrophysical Properties of Poorly Known Galactic Open Clusters from Washington Photometry”. Journal: ASP Conference Series, volume: 491, pages: 193, url: <http://www.aspbooks.org/publications/491/193.pdf>   * OCs are seen over a large fraction of the disk, cover a large range in both age and metallicity. Also one of the only disk populations whose distances and ages can be accurately determined at large distances. * There is low risk in considering an OCs current location in a galaxy as being the same as its birthplace.   Bragaglia, A. et al. (2002). “Old Open Clusters as tracers of Galactic Evolution”. Journal: ASP Conference Series, volume: 274, pages: 385, url: <http://aspbooks.org/publications/274/385.pdf>   * Currently there are two main techniques for independently determining the ages of stellar populations: main sequence evolution theory (via cluster isochrones) and white dwarf cooling theory. * Understanding the formation sequence of the Galaxy is largely dependent upon accurately knowing the ages of its constituents. * WD cooling ages provide the most reliable age of the Galactic disk   Jeffery, E.J. (2007). “New Techniques to Determine Ages of Open Clusters Using White Dwarfs”. Journal: ASP Conference Series, volume: 372, pages: 92, url: <http://aspbooks.org/publications/372/097.pdf>    Bragaglia, A.; Tosi, M. (2007). “Old Open Clusters as Probes of the Galactic Disk: The BOCCE Sample”. Journal: ASP Conference Series, volume: 374, pages: 175, url: <http://aspbooks.org/publications/374/175.pdf>   * Most, and likely all, stars are formed in a clustered environment out of molecular clouds (Lada & Lada 2003). Those surviving cloud dispersal and remaining gravitationally bound are seen as open clusters, with tens to thousands of member stars.   Bhattacharya, S. et al. (2017). “Disintegration of the Aged Open Cluster Berkeley 17". Journal: The Astrophysical Journal, volume: 847, pages: 138, url: <https://iopscience.iop.org/article/10.3847/1538-4357/aa89e2/pdf> |
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| From Young and Hot to Old and Cold: Comparing White Dwarf Cooling Theory to Main‐Sequence Stellar Evolution in Open Clusters  T von Hippel, 2005 |
| White dwarfs and the ages of Open clusters  E Jeffery, S DeGennaro, T Hippel, D Dyk, W Jefferys, N Stein, 2009 |
| A BAYESIAN ANALYSIS OF THE AGES OF FOUR OPEN CLUSTERS  E Jeffery, T Hippel, D Dyk, D Stenning, E Robinson, N Stein, W Jefferys, 2016 |
| From Young and Hot to Old and Cold: Comparing White Dwarf Cooling Theory to Main‐Sequence Stellar Evolution in Open Clusters  T von Hippel, 2005 |
| WIYN Open Cluster Study. I. Deep Photometry of NGC 188  T von Hippel, A Sarajedini, 1998 |
| Intergalactic Globular Clusters  M West, P Côté, H Ferguson, M Gregg, A Jordán, R Marzke, N Tanvir, T Hippel, 2005 |
| Carraro et al. 1998, Chen et al. 2003 |
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| (see  VandenBerg, this volume). For example, the detailed studies of the old (∼4  and ∼6 Gyr, respectively) open clusters M67 and NGC 188 by VandenBerg & |
| WIKIPEDIA  An open cluster is a group of up to a few thousand stars that were formed from the same giant molecular cloud and have roughly the same age. More than 1,100 open clusters have been discovered within the Milky Way Galaxy, and many more are thought to exist.[2] They are loosely bound by mutual gravitational attraction and become disrupted by close encounters with other clusters and clouds of gas as they orbit the galactic center. This can result in a migration to the main body of the galaxy and a loss of cluster members through internal close encounters.[3] Open clusters generally survive for a few hundred million years, with the most massive ones surviving for a few billion years. In contrast, the more massive globular clusters of stars exert a stronger gravitational attraction on their members, and can survive for longer. Open clusters have been found only in spiral and irregular galaxies, in which active star formation is occurring. |

Seminar

* Harry - You will give your talk on 23rd Jan.
* The students give a presentation (25 minutes) followed by a discussion (10 minutes)
* Guidance notes: <https://canvas.bham.ac.uk/courses/36081/pages/project-seminar>
* all presentations should be in **PDF format**.
* Guy will set up a **repository where the student can upload their talks** \*before\* the seminar.