Inferring Stellar Population Ages from Integrated Light Curves

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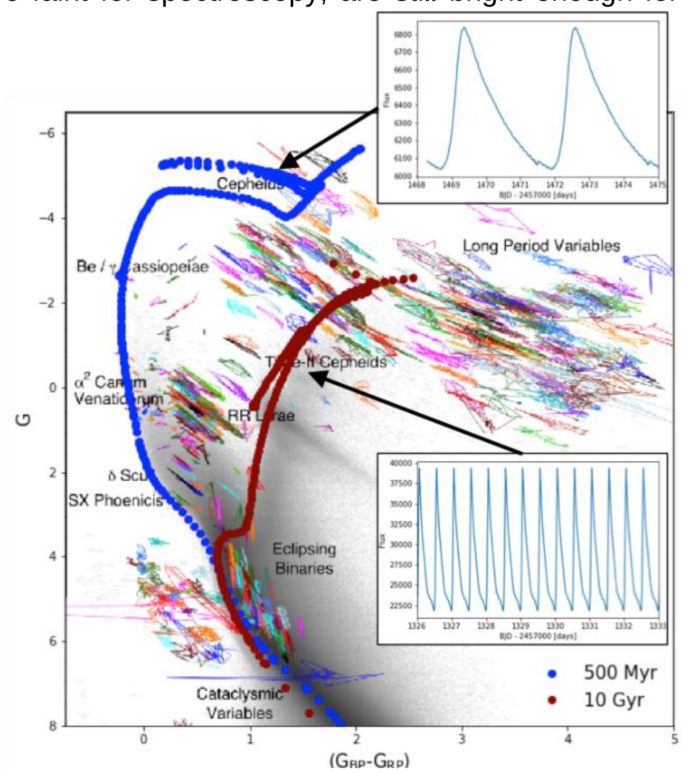
The ages of field stars and stellar clusters are fundamental to understanding the physical processes that shape galaxies. Ages of distant stellar populations – too distant for resolved-star spectroscopy – can be determined via colors, star-formation histories inferred from resolved-star CMDs, age-sensitive indices in integrated-light spectra, and stellar population templates fit to integrated-light spectra.

Just as different types of stars dominate the integrated light as a population ages, the variable stars that dominate the integrated light's *variations* change as well. Among the most well-known of these are Cepheids, which trace populations younger than 50-100 Myr, and RR Lyrae, which only appear after several Gyr, and many others (Fig 1). Each variability type displays characteristic time scales, periodicity, amplitudes, and light curve shapes. **We will use the integrated variability of stellar ensembles to differentiate young populations from old.**

Current age-determination methods require high spatial resolution (to identify individual stars, variable or not) or medium- to high-resolution spectroscopy (to measure spectroscopic characteristics of young or evolved populations), which are observationally expensive. Many star clusters and galaxies that are too distant to resolve individual stars, or too faint for spectroscopy, are still bright enough for integrated photometry. Specially-integrated time-series photometry is already being acquired by large surveys, and so will be available for "free".

Current surveys offer ideal tools to test the efficacy of this approach. The TESS survey provides high-quality photometric time-series observations for not just single stars but also open clusters, globular clusters, crowded Milky Way fields, and nearby galaxies. Since we know the ages of many of these integrated populations by other means, we can use TESS to explore the specific types of variability that correlate with age, which can then be applied to deeper surveys such as ASAS-SN, ZTF, and especially LSST that will reach lower-mass galaxies and smaller clusters at higher redshift.



The Gaia DR2 variable star CMD, showing the range of systems spanned by 500 Myr (blue) and 10 Gyr (red) populations. TESS light curves for a Cepheid star and a RRL star over the same baseline demonstrate different properties.

An ensemble stellar population contains mostly non-variable stars, alongside smaller numbers of variables of different types. The specific variable stars will change as the population ages: core-collapse supernovae appear and peter out, variable O and B stars evolve off the main sequence, Cepheids enter the instability strip and then burn out, RR Lyrae stars become dominant among the instability strip pulsators, and lower-mass stars evolve into red giants, where they undergo long-term pulsations as Miras and semi-regulars. In addition, older stellar populations will see CVs emerging. While many other types of variable sources exist, these examples will dominate the ensemble's variability both by being common and by exhibiting high-amplitude changes.

Although an ensemble of variables will have a range of periods and phases (among other parameters), our initial tests with simple models suggest that even with this blending, information that reflects the variability of the underlying population persists. Fig 2 shows an integrated set of RR Lyrae and Cepheid stars with random phases and a range of periods observed at TESS cadence for a small number of days. Despite the blending and phase mixing, the Lomb-Scargle periodogram and autocorrelation analysis of combinations of 100 stars reveal clear differences between the two seemingly chaotic, composite lightcurves. That number of high-amplitude variable stars is characteristic of a 10 Gyr population, with Omega Cen, a $4 \times 10^6\ M_{\text{Sun}}$ cluster considered to be particularly RRL-rich, having ~100 RR Lyrae.

The project's initial phase will consist of constructing significantly more refined models (including the effects of background stellar density), and also studying the light curves of real systems where we know the age distribution. TESS data of open and globular clusters of the Milky Way and the LMC will be valuable testbeds of single stellar populations of known ages, well-determined by independent methods. Fields in the LMC have mixtures of stellar populations, with age ranges well-constrained by resolved-star studies. These synthetic and empirical data sets will enable us to calibrate the optimum set of variability indicators to constrain stellar age.

With these indicators, we will constrain stellar ages in clusters and galaxies that fall serendipitously within the TESS, ZTF, and LSST footprints. This method offers an independent approach to determining the ages of galaxy field populations and stellar clusters, fundamental to re-tracing the evolution of these systems across cosmic time.

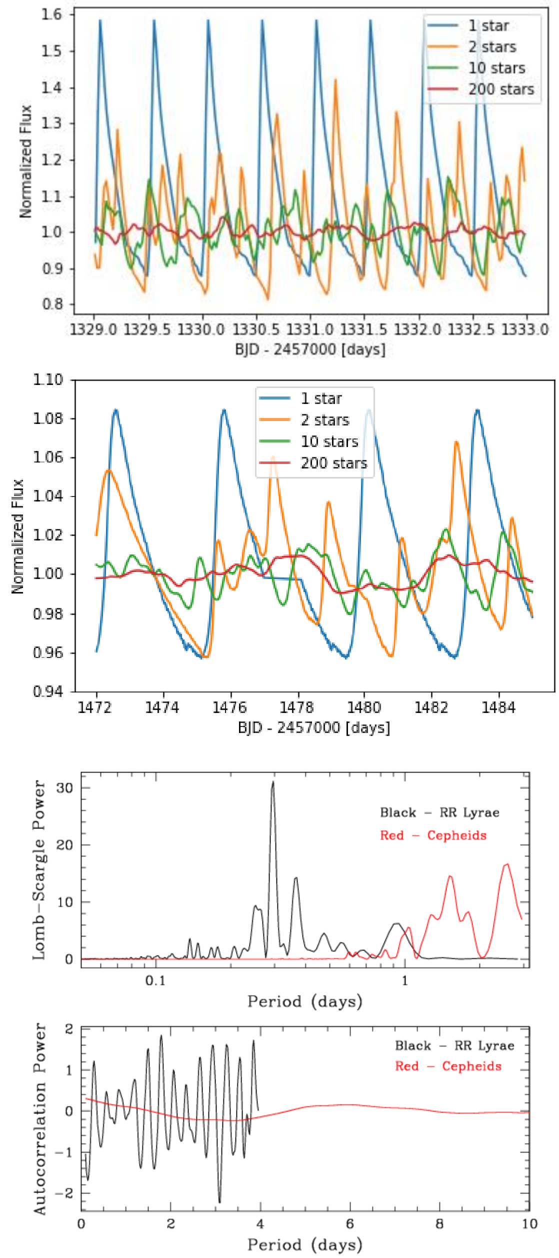


Figure 2: *Top 2 Panels*: Synthetic combinations of RR Lyrae and Cepheid stars with randomized phase and periods. *Bottom 2 Panels*: Simple time-series analysis of the synthetic composite light curves, demonstrating that the variability properties of even large numbers of composite light curves can be distinguished.

Team Members: Gail Zasowski has expertise in stellar populations and stellar clusters in both the Milky Way and extragalactic systems, using photometry and high-resolution spectroscopy. Joshua Pepper runs the KELT ground-based transit survey and is on the TESS Science team, with extensive experience with wide-field photometric surveys and the detection and characterization of variable stars.