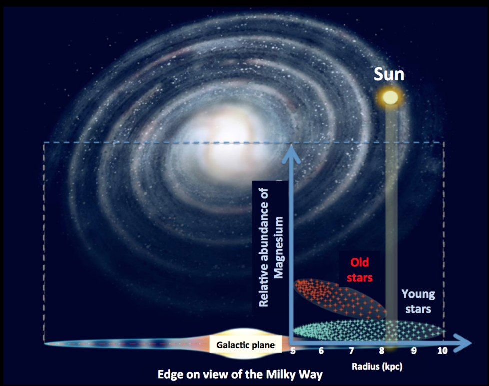
# How to successfully date a star?

## Stellar age determination for understanding Milky Way formation

*SUMMARY*




Stellar age determinations have only recently started having good accuracy for enough stars in order to constrain Milky Way formation and evolution. Indeed, not only they are difficult to obtain but also they are the key parameter in order to put on a timeframe the accretion events and star formation histories that have taken place in our very own Galaxy. This module proposes to understand how the stellar ages can be determined for large surveys, and to apply these techniques on state-of-the-art data collected by either space missions or from large international telescopes.

### OBJECTIVES

- Understanding the physics allowing to determine the stellar ages and exploring the limitations of the existent techniques.
- Obtaining a critical view on the required data to obtain the age for different stellar types, and how to obtain this data.
- Develop and apply codes of stellar age determination on state-of-the art data of galactic archaeology and derive fundamental age-related properties of the Milky Way.

### PREREQUISITES

Stellar Physics (in particular: stellar atmospheres and stellar evolution) and General astrophysics (Milky Way structure, stellar objects).

Note, however, that the first part of the METEOR will be focusing on reviewing these prerequisites as they constitute the fundamental basics for the optimal understanding of the stellar age determination methods.

### THEORY

by Georges Kordopatis & Mathias Schultheis

During the lifetime of a star, its luminosity and colour change, as do the oscillating modes of its atmosphere. At a given set of these parameters, will therefore correspond an actual age that can statistically be evaluated based on observations.

When linked with the kinematic and chemical properties of the studied star, this age allows to rewind the history of our Galaxy and understand how the Milky Way was formed. For example we can probe the amount of stars that have been accreted during the past 12 Gyr, understand when did fresh gas refill the gas reservoirs of the galactic disc, and how fast stars are radially redistributed in the disc due to the presence of the spiral arms.

The theoretical part of this module will review three main aspects of stellar physics and Galactic archaeology:

1) Stellar evolution: why and how do some observational stellar properties change over time.

2) Which are the different age estimators of single stars and stellar populations (isochrone fitting, asteroseismology, white dwarf cooling age, relative chemical abundance), and how to derive them.

3) To which extent stellar ages, when accurately known, allow us to have in hands a movie-like dataset that depicts the Milky Way history.

### APPLICATIONS

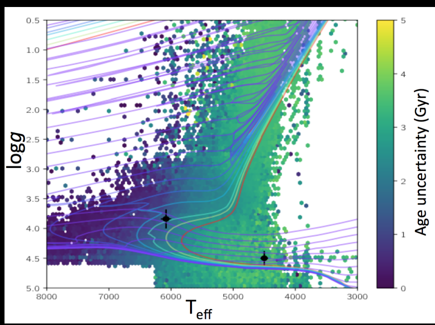
by G. Kordopatis

One or several of the above-mentioned techniques will be applied on state-of-the art data, coming from the Gaia and Kepler space missions in combination with ground-based surveys. First, the stellar ages and their uncertainties will be derived and then, fundamental relations in the Galaxy such as age-velocity dispersion and age-mean metallicity will be measured. Interpretation of these relations will be discussed in the context of Galactic archeology and more broadly in the context of galaxy formation in the Universe.

In order to achieve the goal of this module, skills that are required from nowadays astronomers will be developed: critical view on the quality and the limitations of the data, basic programming skills, data mining and statistical knowledge.

### MAIN PROGRESSION STEPS

- First quarter of the period: Review of the fundamentals of stellar evolution and stellar atmospheres.
- Second quarter of the period: Isochrone fitting method, asteroseismology. Presentation of the projects.
- Third and fourth quarters of the period: Project, chromospheric activity, gyrochronology, chemical ages. Other methods (white dwarfs) if time permitted. (Exam at end term)
- Last week : preparation of the final oral presentation.




Exemple of derived ages-uncertainties obtained for half a million stars with a 2kpc radius from the Sun combining RAVE and Gaia data (Wojno et al. 2018).

### EVALUATION

- Type of examinations: written, oral presentation, project.
- Each chapter contains numerical exercises (plotting data and interpreting them) that will be evaluated in order to obtain the mid-term grade.
- Final exam will consist of a summary dissertation of the different methods presented.
- Mid-term and final exam will have equal weights.

### BIBLIOGRAPHY & RESSOURCES


–*An introduction to stellar astrophysics*, F. LeBlanc (2010), Wiley, ISBN: 978-0-470-69956-0
–*The Ages of Stars*, D. Soderblom (2010), AR&A, 48, 581
–*The Galaxy in Context: Structural, Kinematic, and Integrated Properties*, J. Bland-Hawthorn & O. Gerhard (2016) AR&A, 54, 529
–*The Gaia-ESO Survey: radial metallicity gradients and age-metallicity relation of stars in the Milky Way disk*, Bergemann et al. (2014), A&A, 565, 89
–*Improved distances and ages for stars common to TGAS and RAVE* , McMillan et al. (2018), MNRAS, 477, 5279
–*The Gaia mission*, Gaia collaboration et al. (2016), A&A, 595, 1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