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Calibrating gyrochronology using Galactic kinematics

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ABSTRACT

Gyrochronology, the method of inferring the age of a star from its rotation period, could provide ages for billions of stars over the coming decade of time-domain astronomy. However, the gyrochronology relations remain poorly calibrated due to a lack of precise ages for old, cool main-sequence stars. Now however, with proper motion measurements from Gaia, Galactic kinematics can be used as an age proxy, and the magnetic and rotational evolution of stars can be examined in detail. We demonstrate that kinematic ages, inferred from the velocity dispersions of groups of stars, beautifully illustrate the time and mass-dependence of the gyrochronology relations. We use kinematic ages of field stars, plus benchmark clusters and asteroseismic stars, to calibrate a new empirical, Gaussian process gyrochronology relation, that fully captures the complex rotational evolution of cool dwarfs over a range of masses and ages. We use cross validation to demonstrate that this relation accurately predicts ages for FGKM dwarfs.

Keywords: Stellar Rotation — Stellar Evolution — Stellar Activity — Stellar Magnetic Fields — Low Mass Stars — Solar Analogs — Milky Way Dynamics

1. INTRODUCTION

Stars with significant convective envelopes ($\lesssim 1.3\,\mathrm{M}_\odot$) have strong magnetic fields and slowly lose angular momentum via magnetic braking (*e.g.* Schatzman 1962; Weber & Davis 1967; Skumanich 1972; Kawaler 1988; Pinsonneault et al. 1989). Although stars are born with random rotation periods, from 1 to 10 days, observations of young open clusters reveal that their rotation periods converge onto a unique sequence by ∼500-700 million years (*e.g.* Irwin & Bouvier 2009; Gallet & Bouvier 2013). After this time, the rotation period of a star is thought to be determined, to first order, by its color and age alone. This is the principle behind gyrochronology, the method of inferring a star's age from its rotation period (*e.g.* Barnes 2003, 2007, 2010; Meibom et al. 2011, 2015).

The rotational evolution of stars is clearly a complicated process and, to fully calibrate the gyrochronology relations we need a large sample of reliable ages for stars spanning a range of ages and masses. In this paper, we use the velocity dispersions of field stars to qualitatively explore the rotational evolution of GKM dwarfs, and show that kinematics could provide a gyrochronology calibration sample.

1.1. *Using kinematics as an age proxy*

In **?** we demonstrated that kinematics can be used to explore the evolution of stellar rotation. In this paper we take the next step and use kinematics to calibrate a new gyrochronology relation. This paper is laid out as follows. In section **??** we describe the calibration of a new AVR, and how we used it to calculate ages for over 6000 stars with measured rotation periods. In this section we also compare these kinematc ages with literature age measurements. In section **??** we describe how we use these kinematic ages to calibrate a new empirical gyrochronology relation.

2. METHOD

$$p(v_{\mathbf{xyz}}, D|\mu_\alpha, \mu_\delta, \alpha, \delta, \pi) = p(\mu_\alpha, \mu_\delta, \alpha, \delta, \pi|v_{\mathbf{xyz}}, D)p(v_{\mathbf{xyz}})p(D), \tag{1}$$

where D is distance, α is Right Ascension (RA), δ is declination (dec), π is parallax, μ_α is proper motion in RA, and μ_δ is proper motion in dec.

3. RESULTS

4. DISCUSSION

5. CONCLUSION

This work was partly developed at the 2019 KITP conference 'Better stars, better planets'. Parts of this project are based on ideas explored at the Gaia sprints at the Flatiron Institute in New York City, 2016 and MPIA, Heidelberg, 2017. This work made use of the gaia-kepler.fun crossmatch database created by Megan Bedell.

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