# Planets Across Space and Time (PAST)

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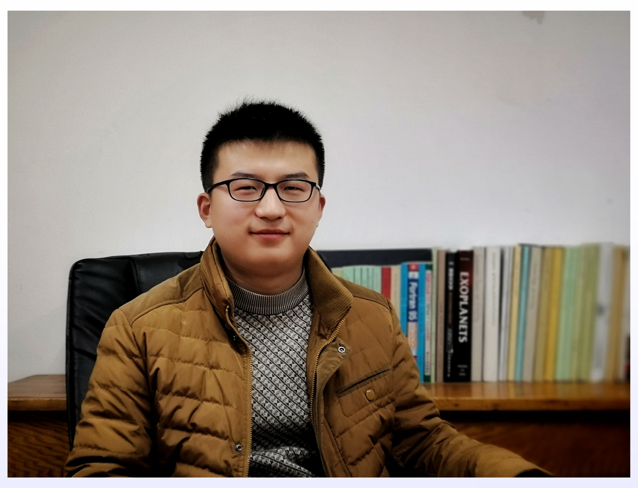

## Abstract

**Over 4,000 exoplanets have been identified and thousands of candidates are to be confirmed. What are the differences between planetary systems in different Galactic environments, and how do they evolve with time? To address these questions, we conduct a research project, dubbed Planets Across Space and Time (PAST). Here we present some first results of PAST series. We revisit the kinematic method for classification of Galactic components and extend the applicable range from $\sim 100$ pc to $\sim 1,500$ pc from the sun in order to cover most known planet hosts. Furthermore, we revisit the Age-Velocity dispersion Relation (AVR), which allows us to derive kinematic age with a typical uncertainty of 10-20% for an ensemble of stars. Applying the above revised methods, we present catalogs of kinematic properties as well as other basic stellar parameters for 2,174 planet host stars and 35,864 Kepler targets by combining data from Gaia, LAMOST, Kepler, APOGEE, RAVE, and the NASA exoplanet archive. We find that the fraction of thin (thick) disk stars increases (decreases) with the transiting planet multiplicity ($N_p$ = 0, 1, 2 and 3+) and the kinematic age decreases with $N_p$, which could be a consequence of the dynamical evolution of planetary architecture with age. The revised kinematic method and AVR as well as the stellar catalogs lay foundation for future studies on exoplanets in the Galactic context.**

## Introduction

Since the discovery of the first exoplanet in 1990s, our knowledge of exoplanets is expanding in the Galaxy. Now, the map of exoplanets is much wider with a large range of distance up to $\sim$ 10,000 pc and spread over different Galactic environments, opening up the study of exoplanets in the Galactic context.

The geometry, kinematic and chemical abundance of different components vary considerably. Thus what are the differences in the properties of planetary systems at different positions in the Galaxy with different ages? The answer will provide insights on the formation and evolution of the ubiquitous and diverse exoplanets.

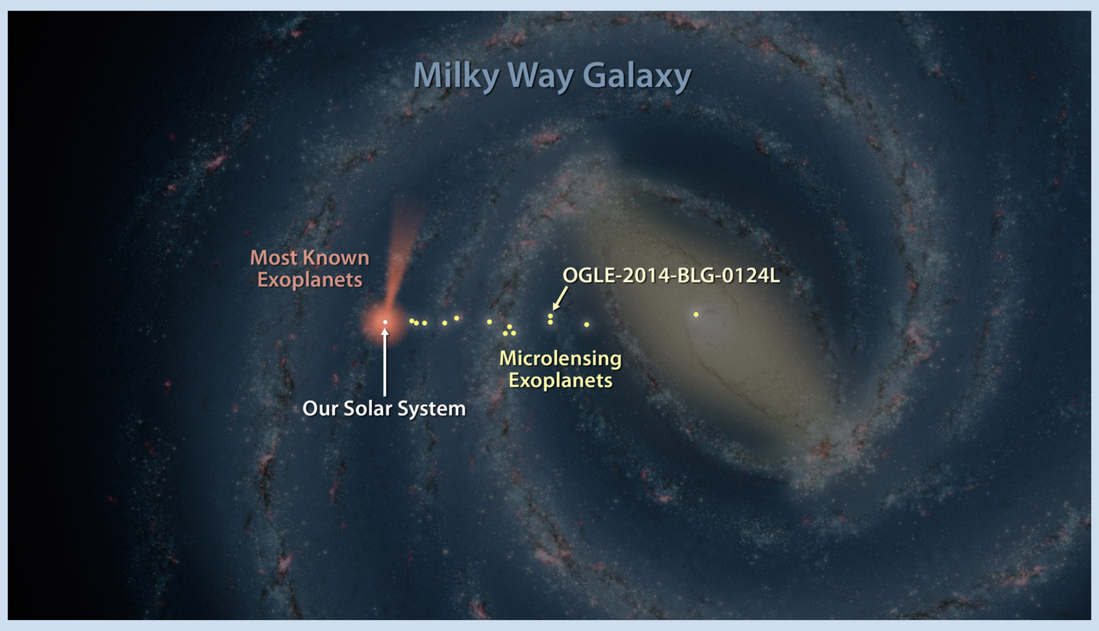


***Figure 1**: Map of exoplanets in the Milky Way.*

To this end, the first step is to figure out which Galactic components exoplanet hosts belong to. One of well-established methods to distinguish Galactic components is the kinematic approach by comparing the kinematic properties of a given star to the typical kinematic characteristics of a Galactic component (e.g., Bensby et al. 2003). However, the kinematic characteristics were limited in the Solar neighborhood within $\sim$ 100 pc (Bensby et al. 2003, 2014).

The second step is to obtain the accurate ages of exoplanet host stars, which can be estimated statistically from Age-Velocity dispersion Relation (AVR, Wielen 1977; Holmberg et al. 2009) with stellar kinematics (i.e., 3D Galactic positions and velocities). However the derived uncertainties in kinematic age is relatively large ($\sim 30\% - 60\%$) due to the large uncertainties of AVR parameters, insufficient to carry out precious age evolution studies.

Thus in order to characterize exoplanet host stars:

**1. The applicable range require to extend to beyond 1,000 pc.**

**2. Requiring more accurate AVR.**

In recent years, the kinematic method has ushered in a major opportunity, thanks to the high-quality astrometry and radial velocity data provided mainly by the Gaia and LAMOST.

## Revising kinematic methods

Based on the LAMOST DR4 (Xiang et al. 2017) and Gaia DR2 catalogs (Gaia Collaboration et al. 2018), by applying accuracy, isotropy and uniformity filter, we conduct a calibration sample of 130,403 stars with kinematics and age data.

Using the calibration sample, we calculated the kinematic characteristics within $\sim 1,500$ pc and extend the applicable range of kinematic methods to classify the Galactic components. We also refit the AVR. Thanks to the enlargement of the sample and the improvement of the accuracy of data, the error of AVR coefficient is greatly reduced, and the kinematic age error decrease to $\sim 10\% - 20\%$.

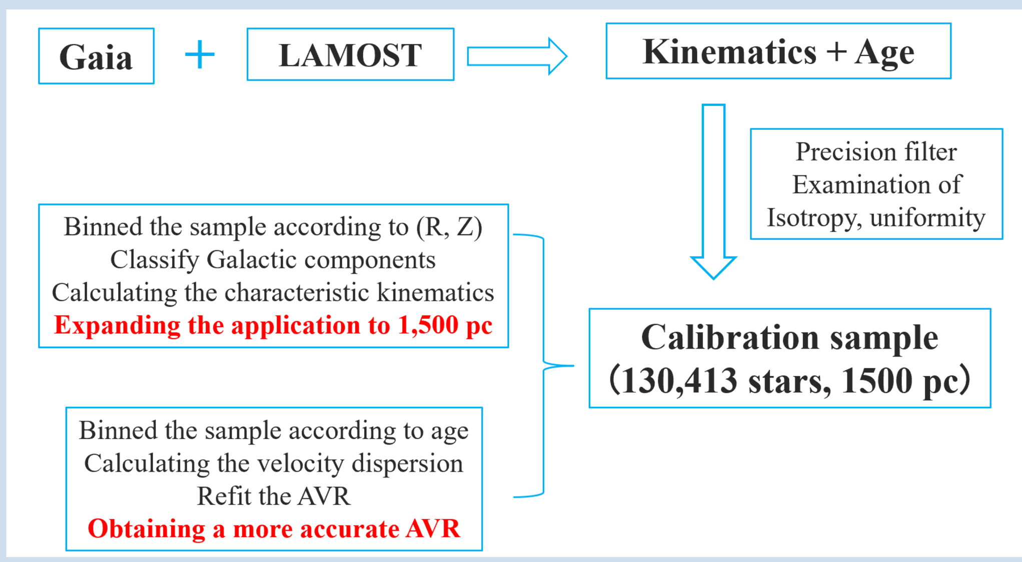


***Figure 2**: The basic procedure of revising the kinematic methods to characterize the memberships of Galactic components and stellar Age.*

## Kinematic catalogs

By combining data from Gaia, LAMOST, APOGEE, RAVE and the NASA exoplanet archive, by adopting the revised kinematic methods, we obtain the kinematics (i.e., Galactic position and velocity) and the Galactic component membership for 2,174 host stars of 2872 planets and construct a planet host stellar catalog with kinematic properties and other basic parameters.

Besides, in order to have a reliable Galactic census of planets (e.g., occurrence rate and difference between stars with and without planets), one also needs accurate characterizations of the homogeneous filed stars. Here we focus on the Kepler targets because the Kepler mission has provided an unprecedented legacy sample for astrophysics and exoplanet science thanks to the long-term baseline, high-precision observations (Brown et al. 2011; Mathur et al. 2017). By combining astrometry data from Gaia DR2 and radial velocity from LAMOST DR4 (with no bias to planet hosts), we present a LAMOST-Gaia-Kepler catalogue of 35,835 Kepler stars with kinematic properties and other basic parameters (e.g., [Fe/H], [$\alpha$/Fe]).

## Kinematic properties vs. $N_p$

Based on the LAMOST-Gaia-Kepler catalog, we further explore the differences between the kinematic properties of Kepler planet host stars and those of other stars without Kepler planets, which are meaningful to study the formation and evolution environment of planetary systems. For a fair comparison between the kinematic properties of stars with and without Kepler planets, we construct a control sample by selecting the nearest neighbors of planet hosts in the spacial distribution and detection ability.

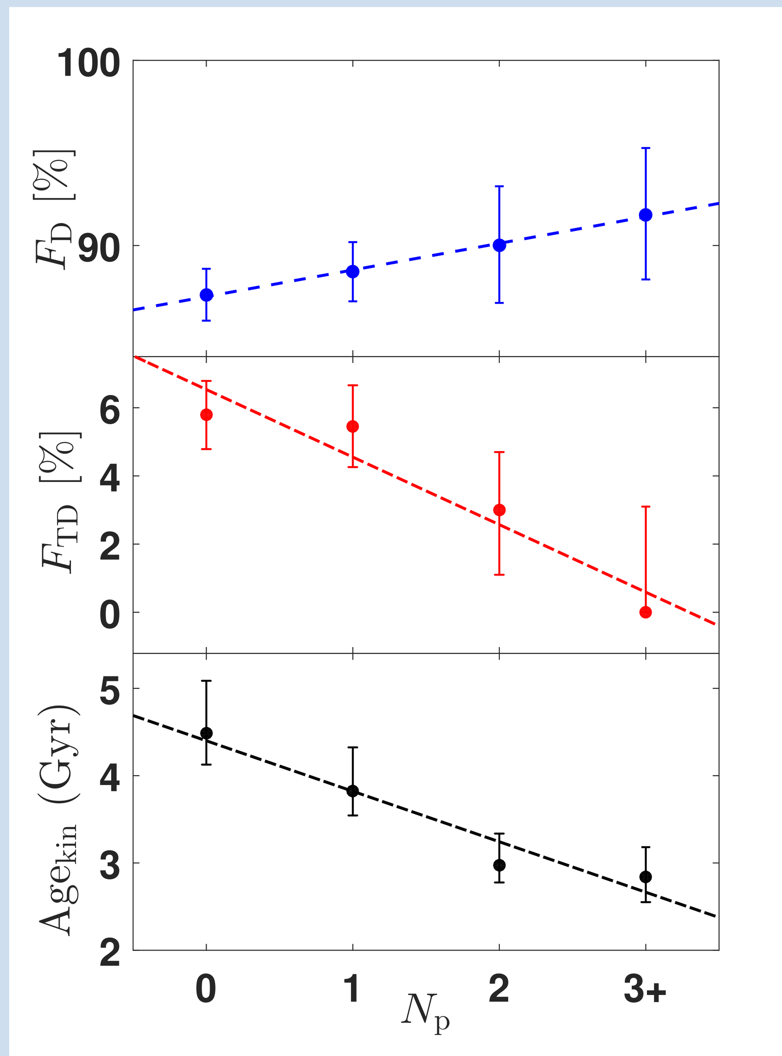


***Figure 3**: Fractions of thin disk stars ($F_D$) and thick disk stars ($F_{TD}$) and kinematic age ($Age_{kin}$) as functions of the the transiting planet multiplicity ($N_p$) detected around a star in the LAMOST-Gaia-Kepler sample.*

Comparing to stars in the control sample, we find that we find a trend that the fraction of thin (thick) disk stars increases (decreases) with transiting planet multiplicity ($N_p$) and the kinematic age decreases with $N_p$. That is to say, planetary systems, especially multiple planetary systems favors young, thin disk stars. This provides insights into the formation and evolution of planetary systems with the Galactic components and stellar age.

One possible explanation for the trend is that the long term dynamical evolution can pump up orbital eccentricity/inclination of planets (e.g. Zhou et al. 2007) or even cause planet merge/ejection (e.g. Pu & Wu 2015), which reduces the observed transiting planet multiplicity i.e., $N_p$. Specifically, in a subsequent paper of the PAST project (Yang et al. in prep), we will study whether/how planetary occurrence and architecture change with Galactic environments based on LAMOST-Gaia-Kepler catalog.