Planetary Census Through Time and Space aided by LAMOST-Gaia-Kepler

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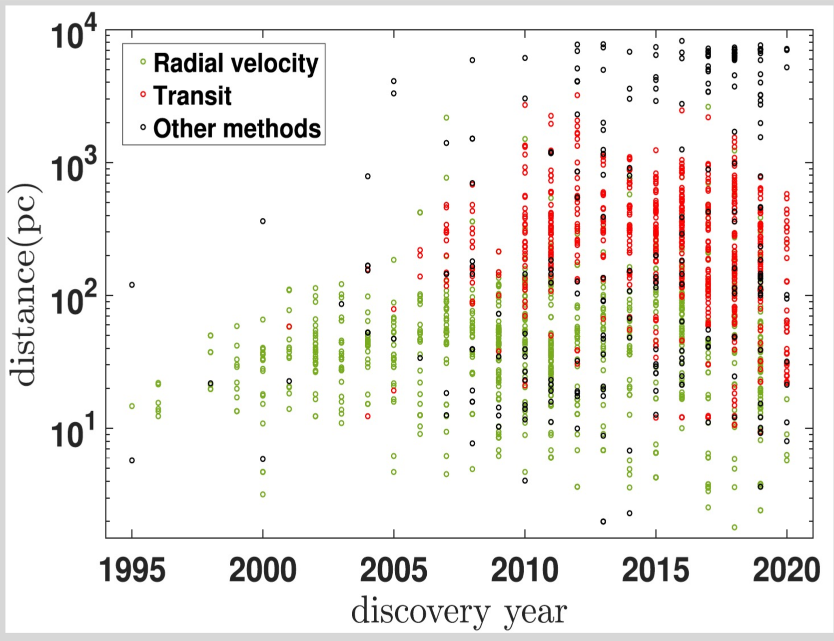
Motivation



Since the discovery of the first exoplanet (51 Peg b) orbiting a solar star in 1995, the study of exoplanets has been one of the most active frontiers. To date, over 5000 exoplanets have been discovered and thousands of candidates are yet to be confirmed. The map of known exoplanets has expanded significantly from the solar neighborhood (100-200 pc) to a much larger area (orders of 1000 pc) in the Galaxy thanks to the improvement of observational technology. We are therefore entering a new era of exoplanet census in the Milky Way Galaxy.

The PAST Projects

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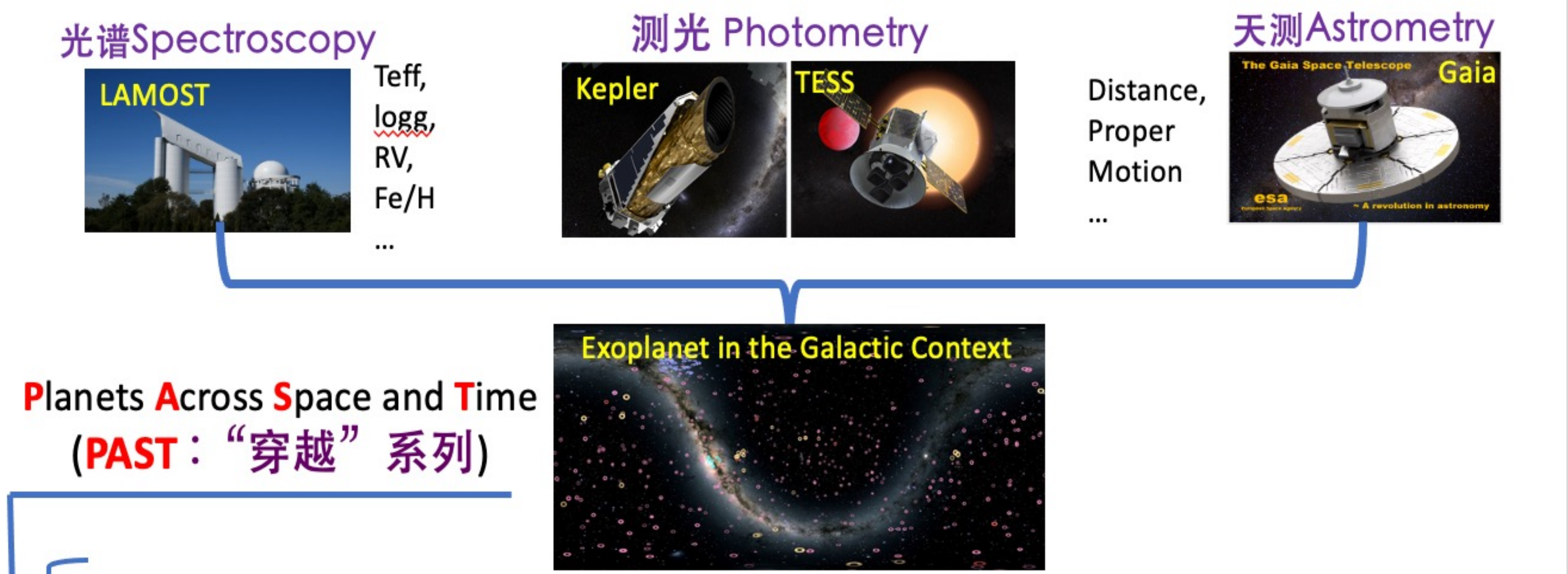
Exoplanet Census in the Milky Way



- Planetary Properties as functions of Galactic Environments (e.g., Thin/Thick disks)
- Planetary Properties as functions of Time (Kinematic age, Isochrone age, Rotation age)

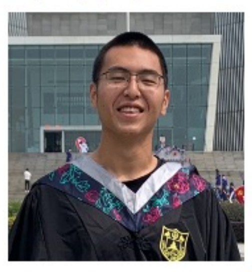
In the Galactic context, one of fundamental questions in studying exoplanets is: what are the differences in the properties of planetary systems at different positions in the Galaxy with different ages? The answer to this question will provide insights on the formation and evolution of the ubiquitous and diverse exoplanets in different Galactic environments. To address this question, we conduct a research project, dubbed Planets Across Space and Time (PAST).

The PAST Team and Papers

Di-Chang CHEN 陈迪昌

Jia-Yi YANG 杨佳祎

Pei-Wei TU 涂培玮



Rui-Sheng ZHANG 张睿晟

Methods and Catalogs

PAST-1: Characterizing the Memberships of Galactic Components and Stellar Ages: Revisiting the Kinematic **Methods** and Applying to Planet Host Stars — Chen +2021 ApJ arXiv:2102.09424

PAST-2: **Catalog** and Analyses of the LAMOST-Gaia-Kepler Stellar Kinematic Properties — arXiv:2107.10704 Chen + 2021 AJ

Applications

PAST-3: Temporal Evolution and Chemical Dependence of the Radius Gap of Small Planets — Chen +2022 AJ arXiv:2204.01940

PAST-4: Occurrence rate and Architecture of Kepler-like Planets in the Galactic Thin/Thick Disks and the Dependence on Kinematic Age — Yang + 2023 AJ arXiv:2310.20113

PAST-5: A Declining Occurrence of Hot Jupiters — Chen + 2023 PNAS arXiv:2311.00305

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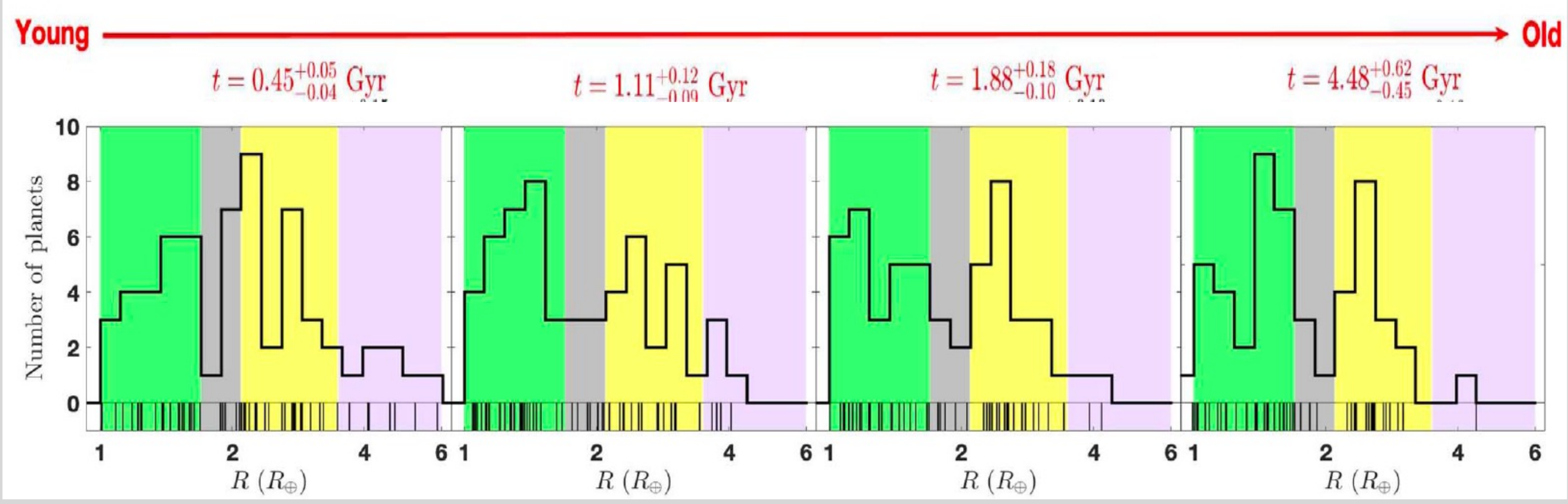
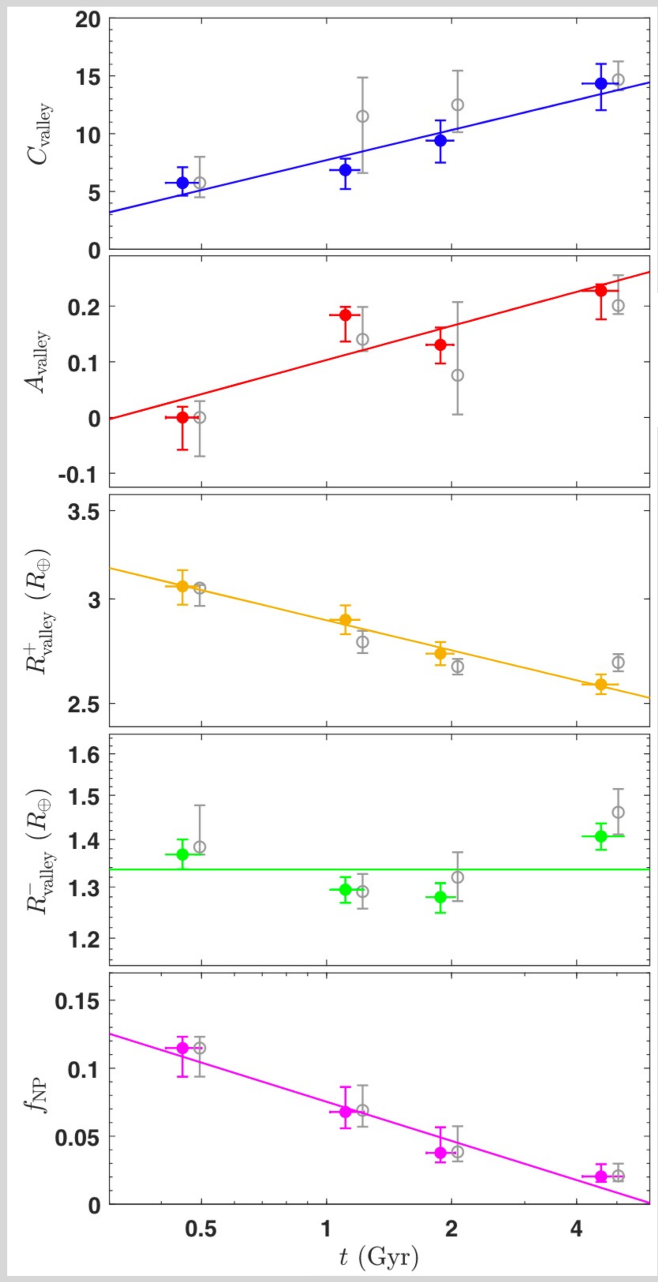
PAST-?: Zhang + 2023 in prep.

PAST-? Tu + 2023 in prep.

PAST-3: the Radius Valley is Evolving





The radius valley emerged before 1 Gyr and the contrast (C_{valley}, number ratio of super-Earths plus sub-Neptunes to the valley planets) increase with time.

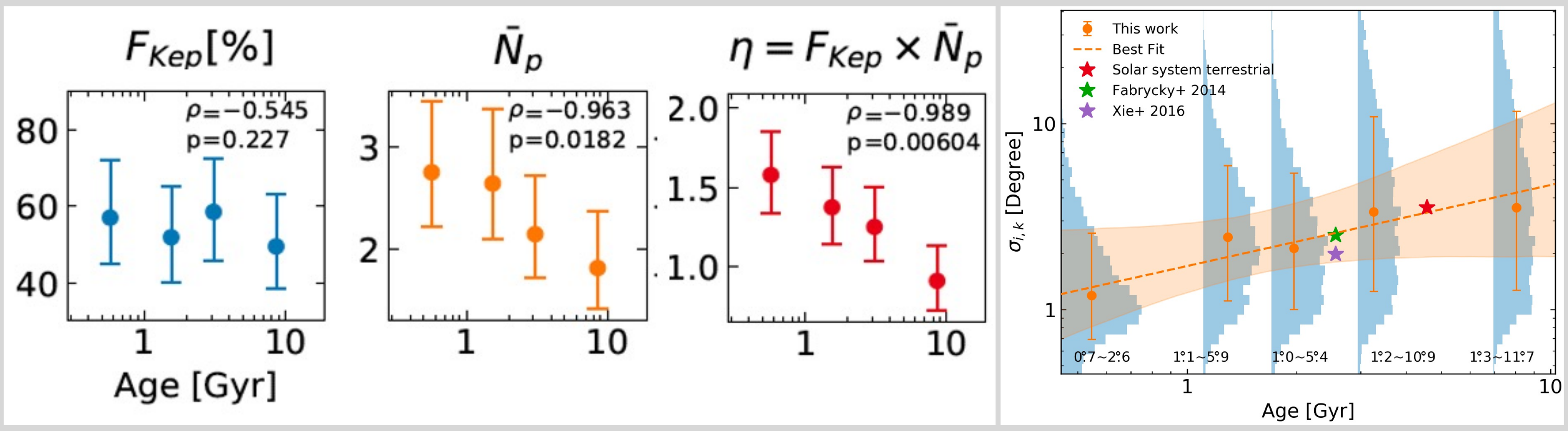
The asymmetry (A_{valley}, the number ratio in logarithm of super-Earths to sub-Neptunes) increase with time.

The R^+_{valley} (average radius of planets with size larger than Valley planets) Decrease with time. (sub-Neptunes are shrinking! Due to cooling?)

The R^-_{valley} (average radius of planets with size smaller than Valley planets. i.e., super-Earths) does not change significantly.

Fraction of Neptune sized planets (f_{NP}) decreases with time.

PAST-4: Planetary Architecture is Evolving



Fraction of stars with Kepler-like planets (F_{kep}) is relatively stable around 50%.

Average planet multiplicity (Np) decreases (~2σ significance) with age.

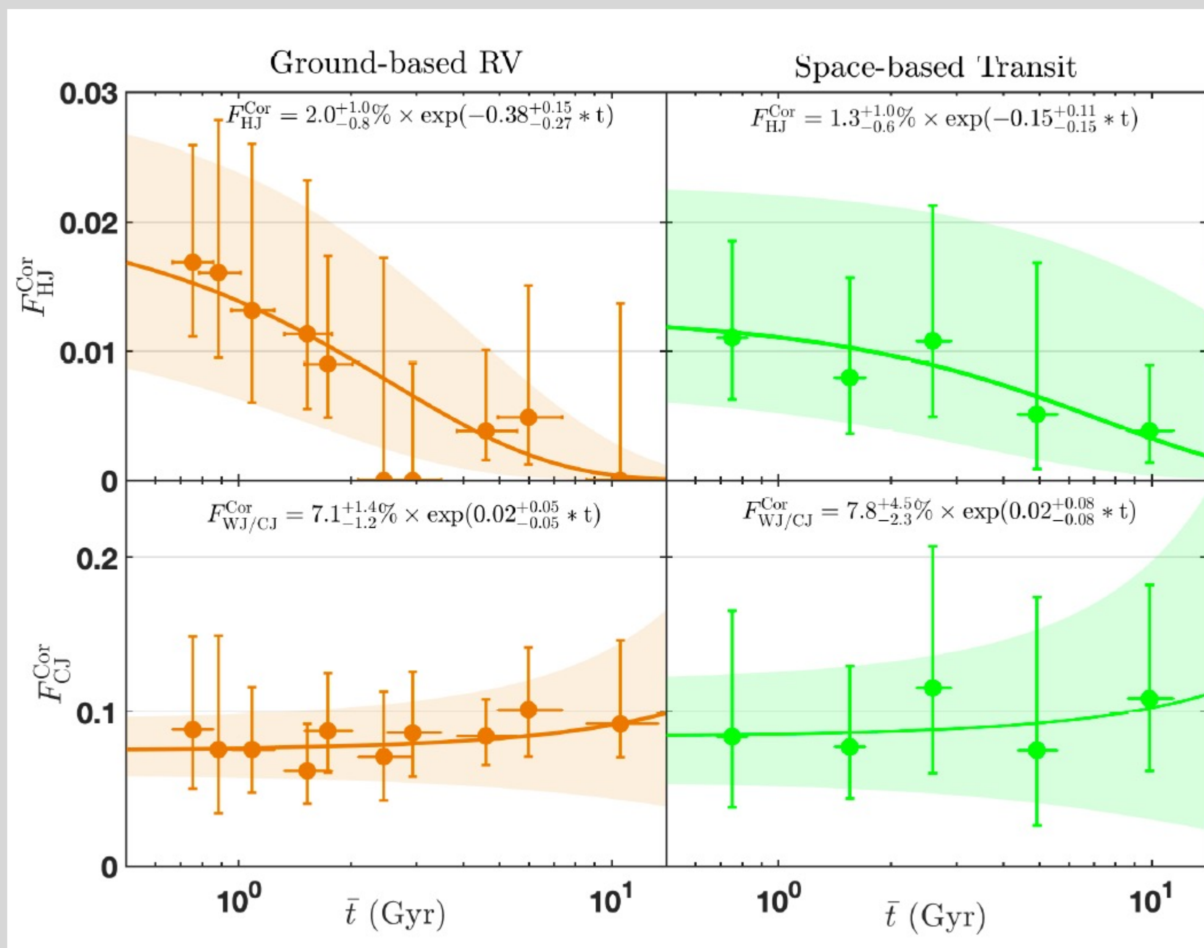
Number of planets per star (η) decreases (~3σ significance) with age.

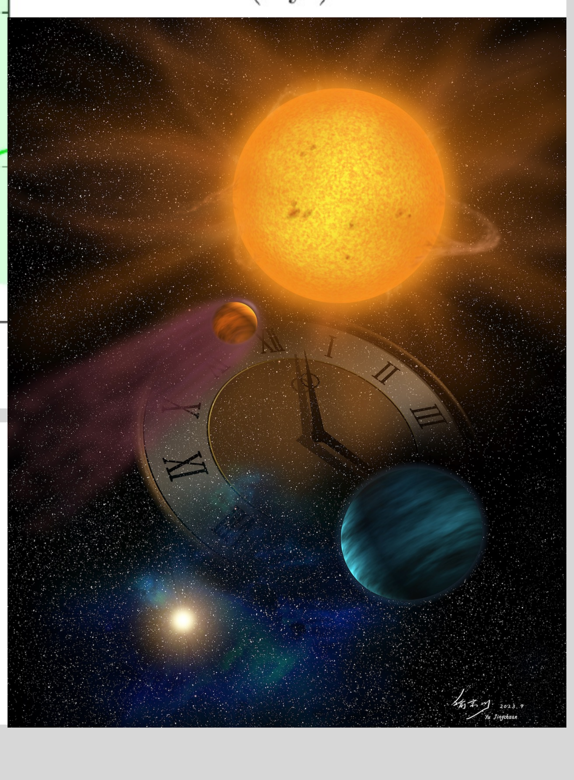
Orbital inclination dispersion ($\sigma_{i,k}$) generally increases with age.

Planet formation is robust and stable across the Galaxy history.

Planetary architecture is evolving, becoming dynamically hotter with fewer planets.

PAST-5: Hot Jupiter is Decreasing





Frequency of hot Jupiters *decreases* with star age (top 3 panels).

Frequency of cold Jupiters is *not correlated* to star age (bottom 2 panels).