The Orbital Dynamics of Small Stars and their Exoplanets

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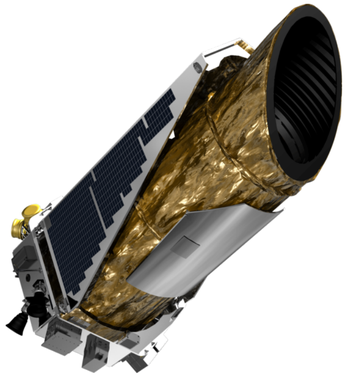
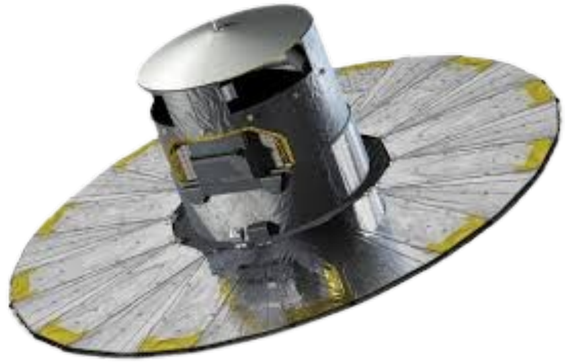
Exoplanet demographics

There is a LOT of exoplanet data.



Kepler/K2

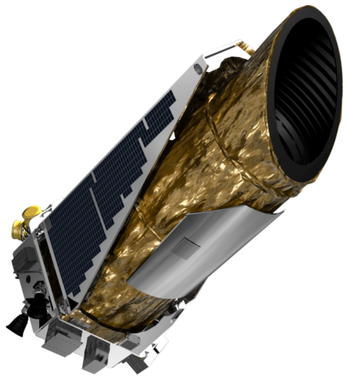
TESS



Gaia

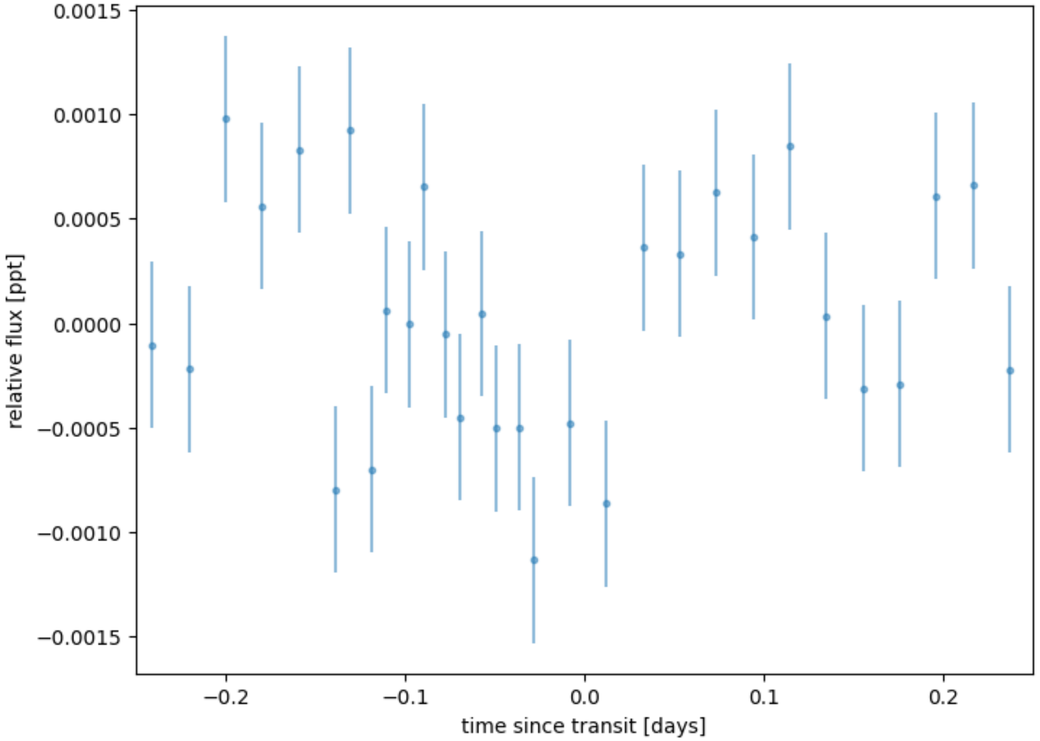
stellar parameters, kinematic measurements, and
thousands upon thousands of transit light curves

Exoplanet demographics

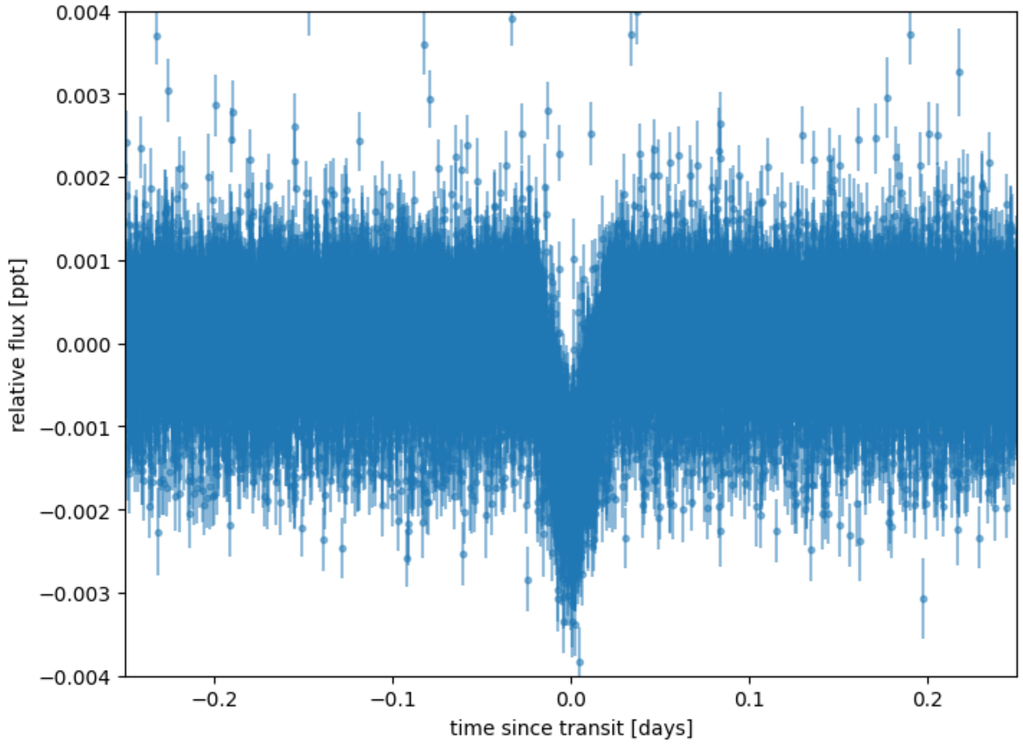


However, the precision of these data varies...

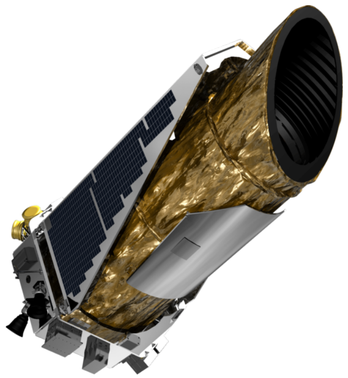
One transit of Kepler-42b



Combined transits of Kepler-42b over several years



Exoplanet demographics



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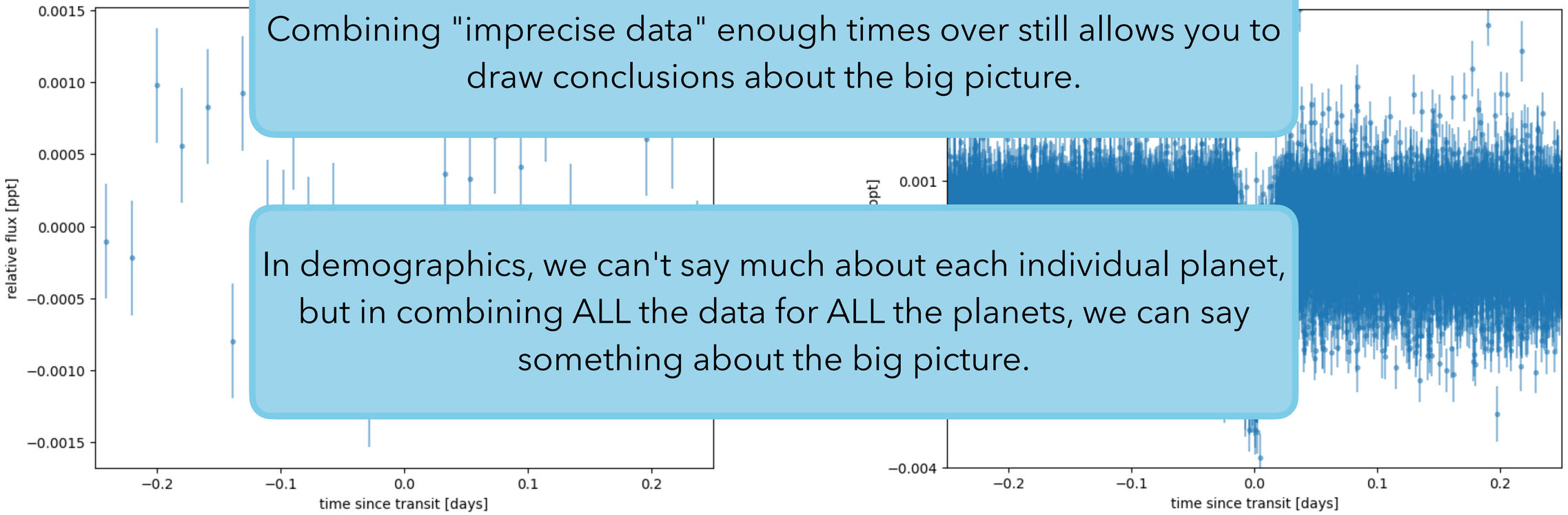
O b over several years



Combining "imprecise data" enough times over still allows you to draw conclusions about the big picture.

In demographics, we can't say much about each individual planet, but in combining ALL the data for ALL the planets, we can say something about the big picture.

What can orbits tell us?

A planet's orbital dynamical state is a signature of its formation and evolution,
and gives us clues about its climate and potential for habitability.

Likewise, a star's orbit around the center of the Galaxy provides insight into its history.

We often assume that planets form in stationary isolation—but that isn't true.
How might planetary systems be affected by their Galactic environment?

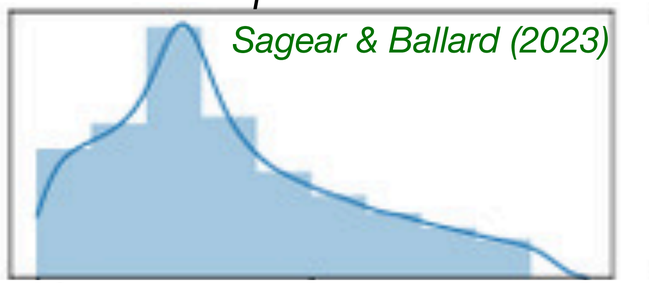
Measuring eccentricities with the *photoeccentric effect*

We can indirectly measure eccentricities from transit light curves by measuring the velocity of the transiting planet via the ***transit duration***. (Dawson & Johnson 2012)

The "photoeccentric effect" gives us wide eccentricity posteriors, but *so many* of them.

Combining eccentricity posteriors within a hierarchical Bayesian framework enables us to draw population-level conclusions about orbital dynamics.

Kepler-42



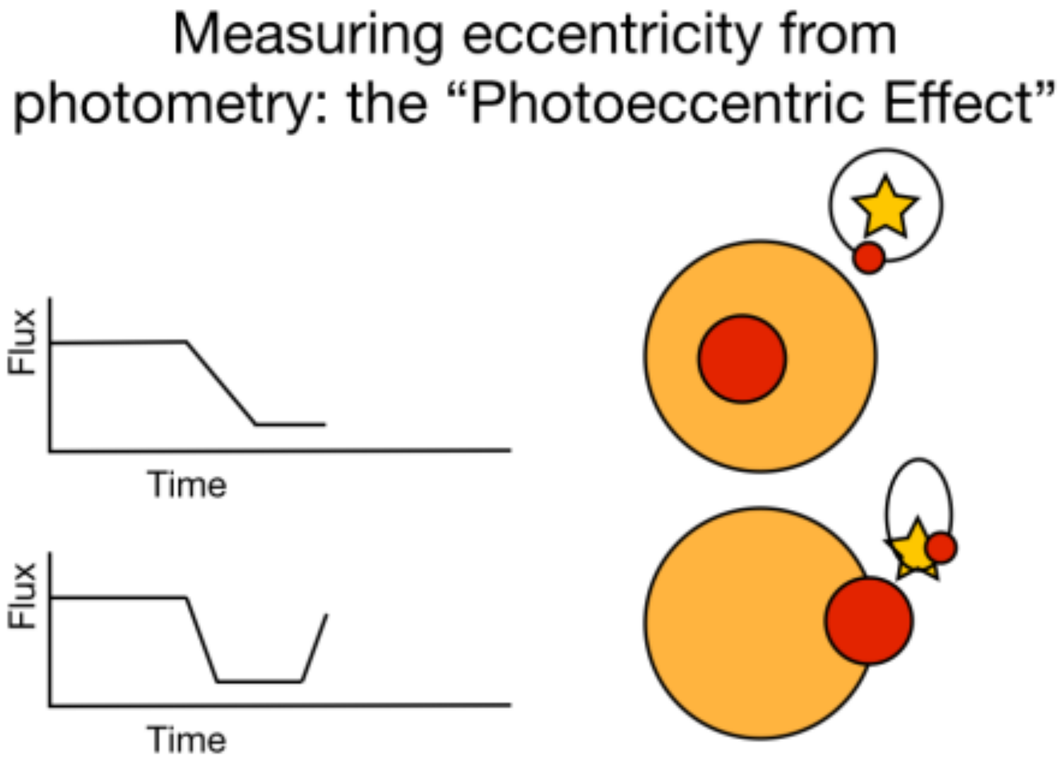


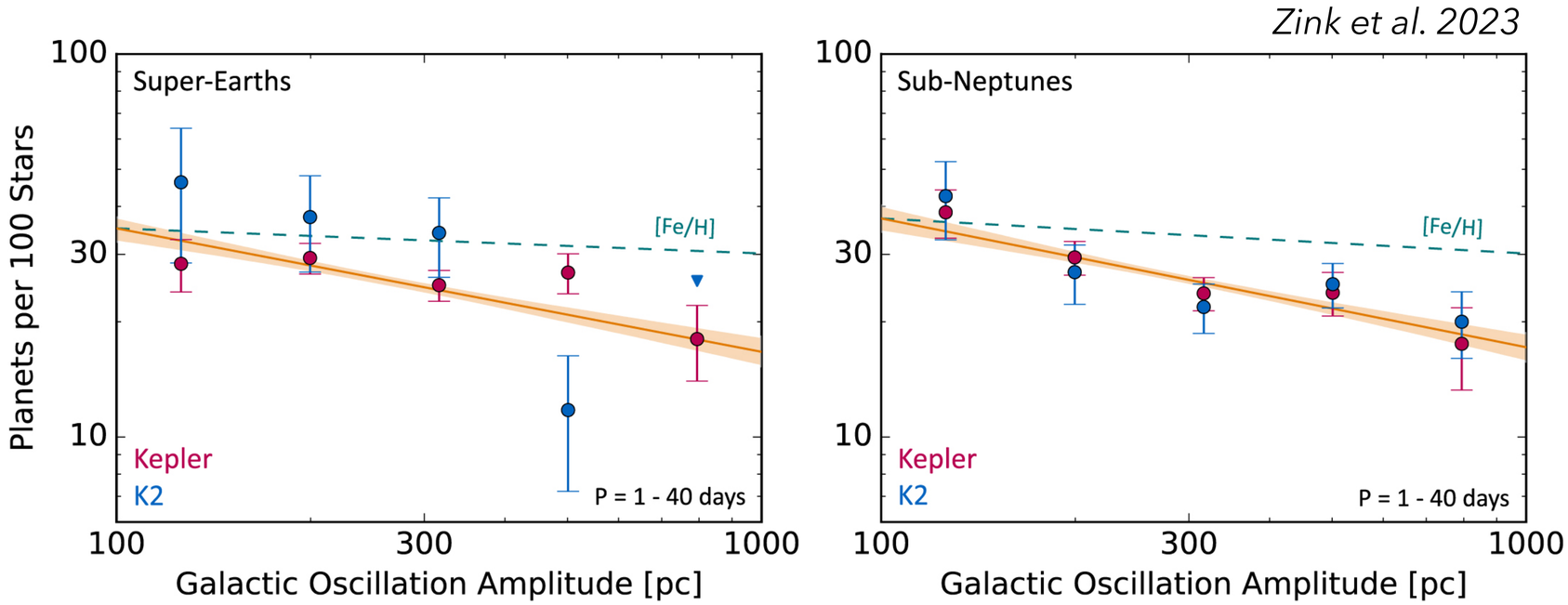
Image: Rebekah Dawson

The impact of Galactic dynamics on planetary dynamics

Planets seem to know where they are in the Galaxy.

Zink+23 (and *Lam+ in review)*: The planet occurrence rate appears to decrease with Galactic amplitude.

Zink et al. 2023



The impact of Galactic dynamics on planetary dynamics

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Zink+23 (and *Lam+ in review)*: The planet occurrence rate appears to decrease with Galactic amplitude.

What physical mechanisms might link Galactic and planetary dynamics?

Schoettler+24, Charalambous+25: stellar flybys (on the order of 1000s of AU) could disrupt planetary orbits

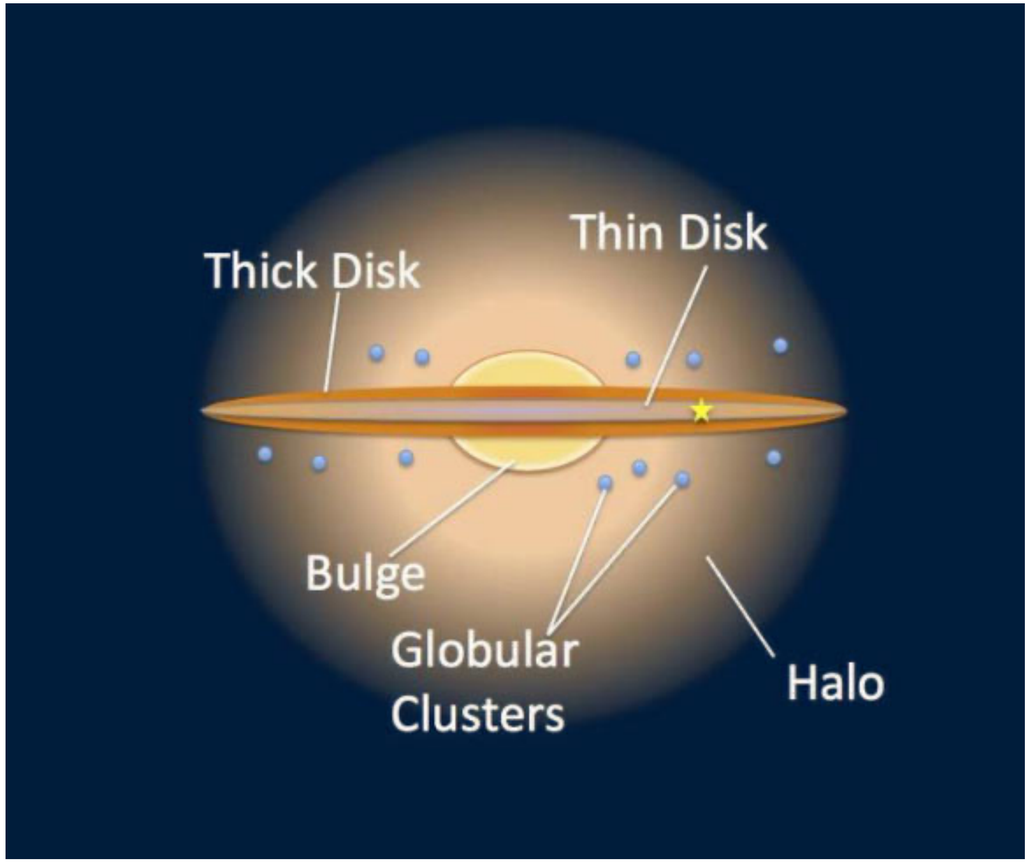
Kaib+13, Stegmann+24: Galactic tides could dynamically disrupt stellar wide binary orbits (and their planets)

The impact of Galactic dynamics on planetary dynamics

We can probe Galactic dynamical properties via kinematic disk association.

Thin disk: spiral arms, younger & metal-rich stars, less extreme vertical orbital excursions

Thick disk: older, metal-poor stars, more extreme vertical orbital excursions

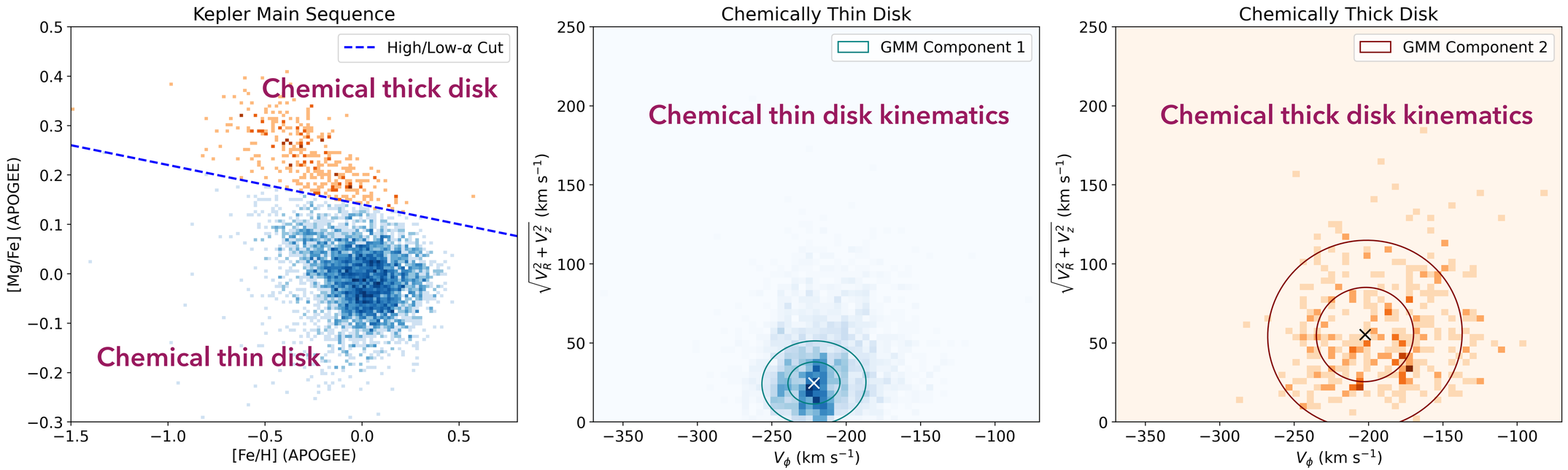


The impact of Galactic dynamics on planetary dynamics

Sagear+ (in review) PDF

Robust "thin vs. thick disk" classifications rely on both ***stellar chemistry*** and ***kinematics***, but many Kepler planet hosts don't have reliable stellar abundances.

We calibrate a kinematic disk classification method on Kepler–APOGEE stellar abundances, then apply the kinematic portion to the rest of the Kepler sample.



The impact of Galactic dynamics on planetary dynamics

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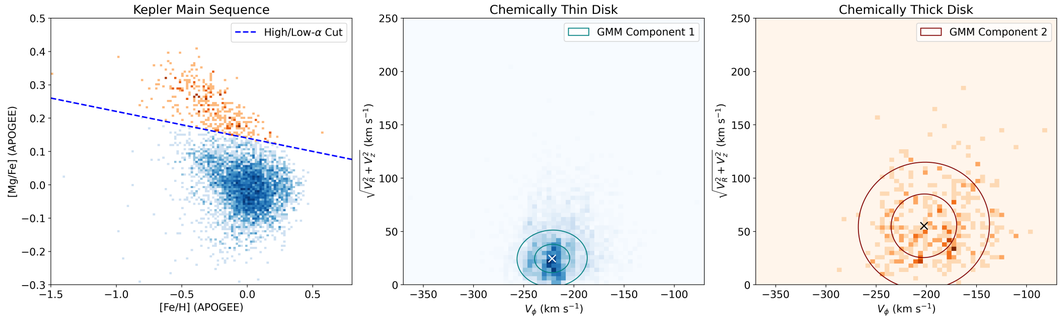
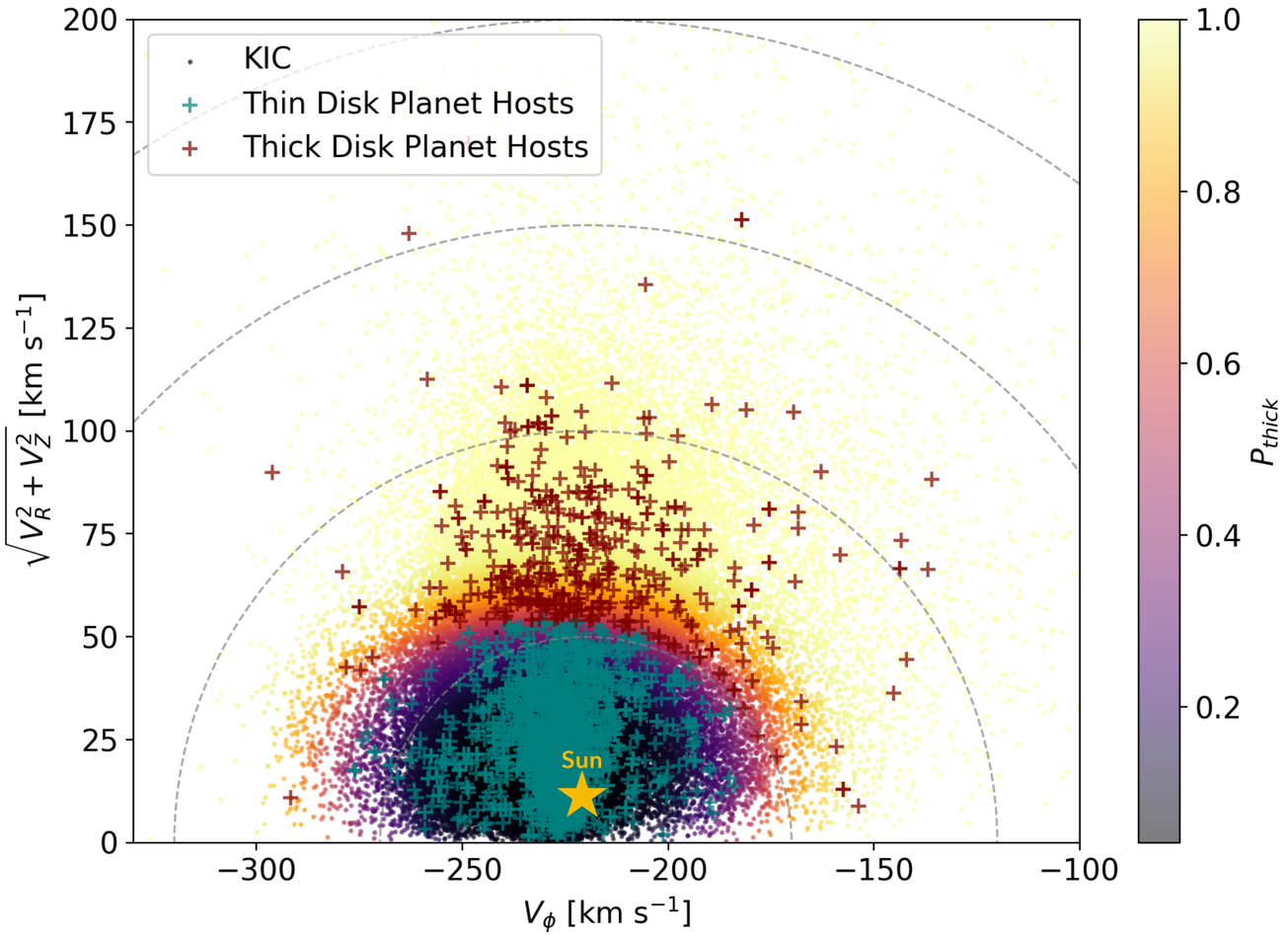


Toomre diagram (representation of relative Galactic kinematics) for our stellar sample



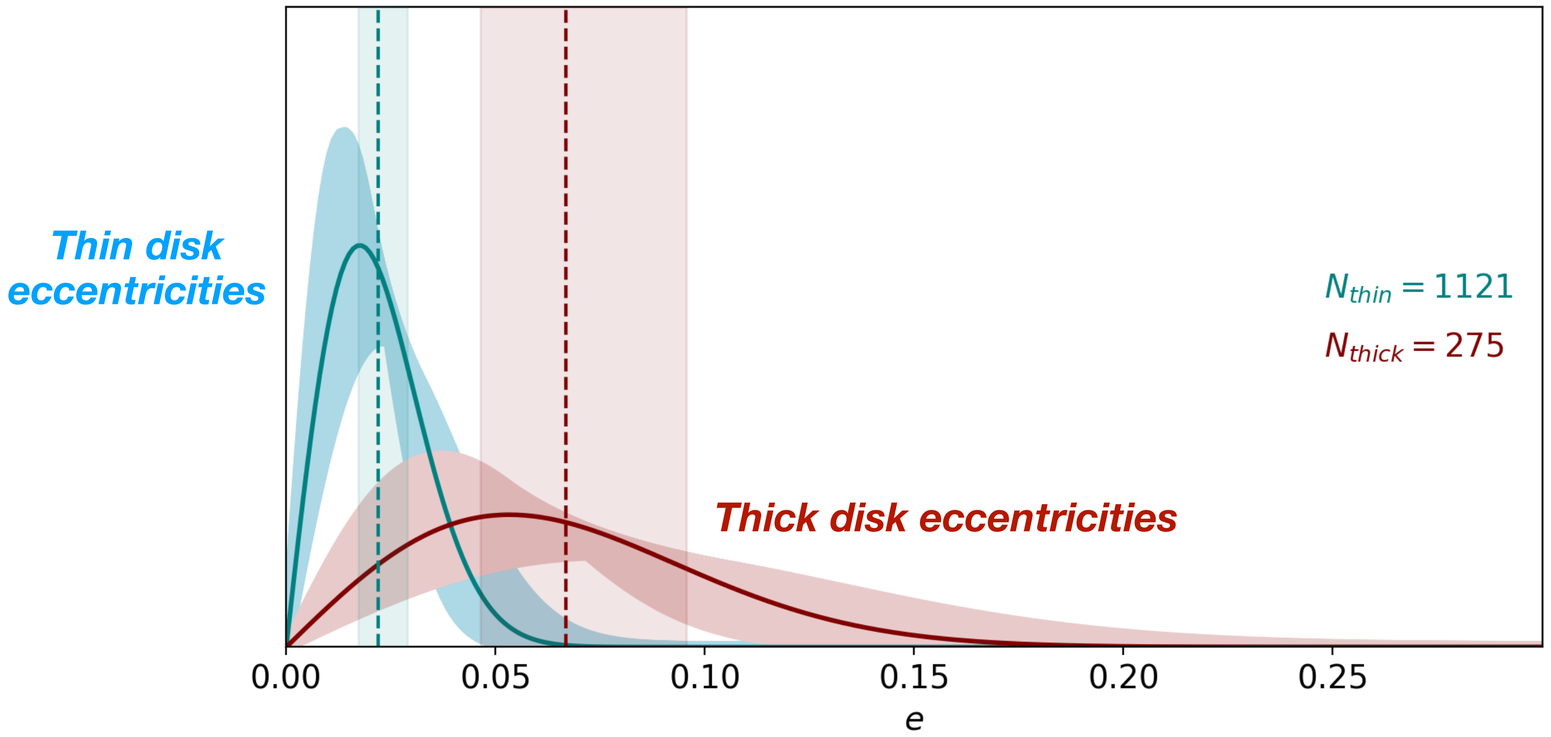
We categorize Kepler planet hosts (based on kinematic information from *Gaia)* into kinematically "thick" and "thin" disk groups.

The impact of Galactic dynamics on planetary dynamics

Sagear+ (in review) PDF

Comparing the underlying orbital eccentricities of the thin vs. thick disk groups…

Planets in the thick disk are, on average, more eccentric than planets in the thin disk.



What physical mechanisms could cause this?

- Stellar flybys?
- Wide binary membership?
- Covariance with stellar age?

We are in a great place to answer this question with ***the power of demographics!***