Inferring Planet Occurrence Rates in Different Galactic Populations: Connecting K2 and Roman

Matthew Lastovka[1,2], Thomas Barclay[2], Robert F. Wilson[1,2], & Emily Gilbert[3]

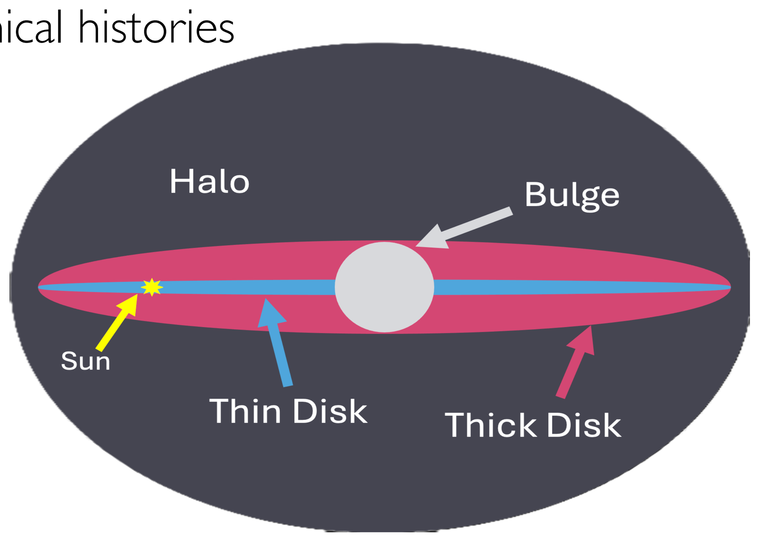
[1]University of Maryland - College Park, [2]NASA Goddard Space Flight Center, [3]Caltech/IPAC-NASA Exoplanet Science Institute

Why Study Occurrence Rates Across Galactic Populations?

Exoplanet demographics is known to depend on host star properties (e.g. metal-rich stars host more planets[e.g. 1])

The Galaxy hosts multiple different stellar populations, each characterized by different distributions of ages, chemical compositions, and dynamical histories

These galactic substructures provide a powerful laboratory to study how stellar properties influence planet formation and evolution



Correlations between Stellar Properties

When studying occurrence rates across populations, we *must* disentangle correlations between stellar properties if we want to understand what is driving occurrence rate differences

Example of one correlation:

The planet occurrence rate is lower in the thick disk than the thin disk.[2,3] Is this caused by:

1) Metallicity? (thick disk hosts generally lower metallicity stars[4]; metal-poor stars host fewer planets[e.g. 1])
2) Age? (thick disk stars tend to be older than thin disk stars[4]; occurrence rates known to change with stellar age[e.g. 5])
3) Something else unique about the thick disk? (dynamical interactions, the radiation environment, etc., could lower the occurrence rate[e.g. 6])

Comparing Thin and Thick Disk Occurrence with K2 & APOGEE

Goal: Compare the occurrence rate in the thick and thin disks while explicitly controlling for stellar metallicity.

K2 has observed a diversity of planets in the thin and thick disk. We combine a sample of planets from K2[3,7, and more] with chemical abundances from APOGEE[8] to calculate occurrence rates in the thin and thick disks.

To explore the effect of metallicity, we split the thin disk into two bins to compare the thin and thick disk occurrence rates at constant metallicity

Preliminary results:

We find that the lower occurrence rate seen in the thick disk can be explained solely by metallicity differences between the disks

The occurrence rate is consistent with the low [Fe/H] thin disk, contradicting previous results.[3]

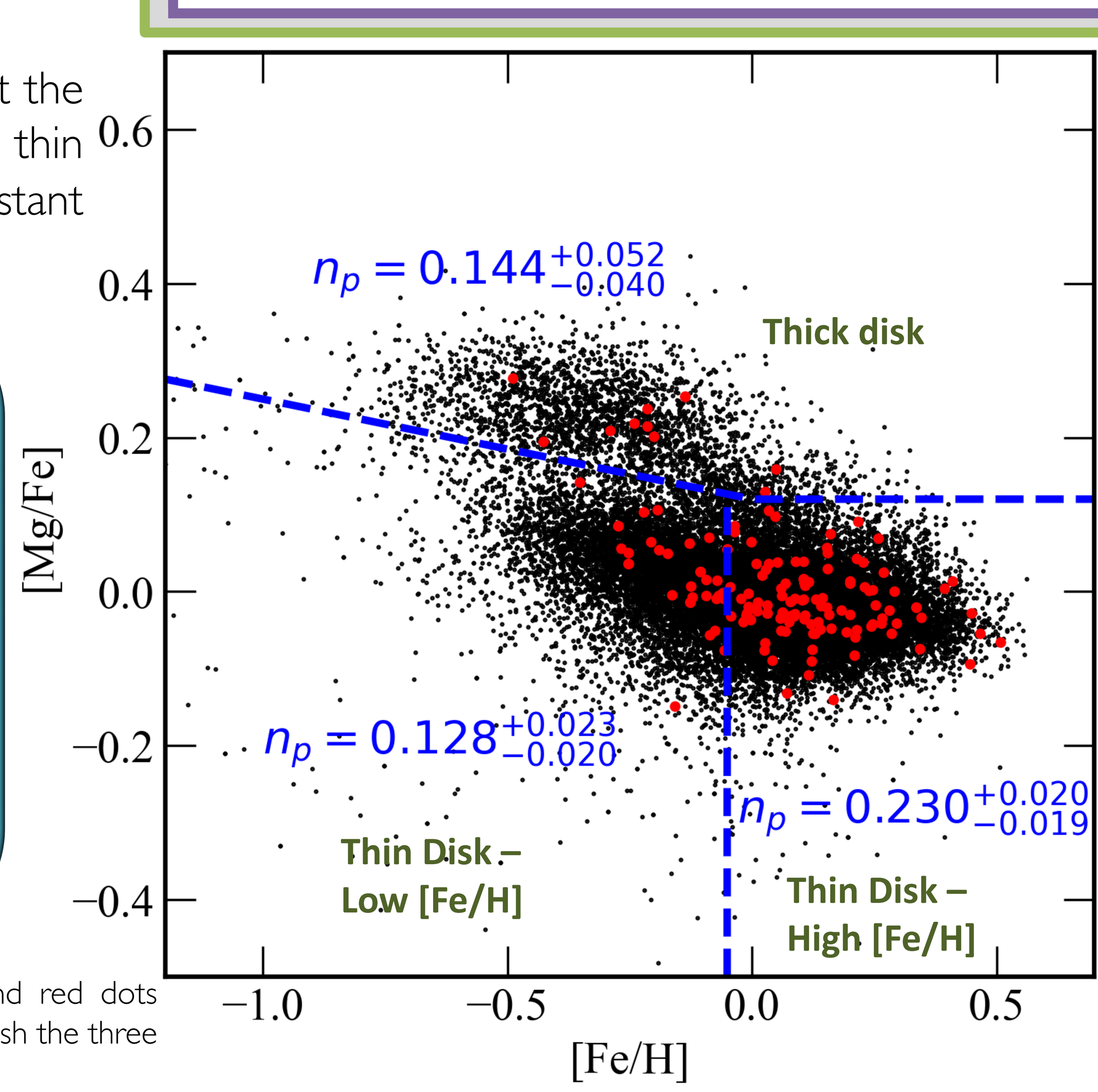
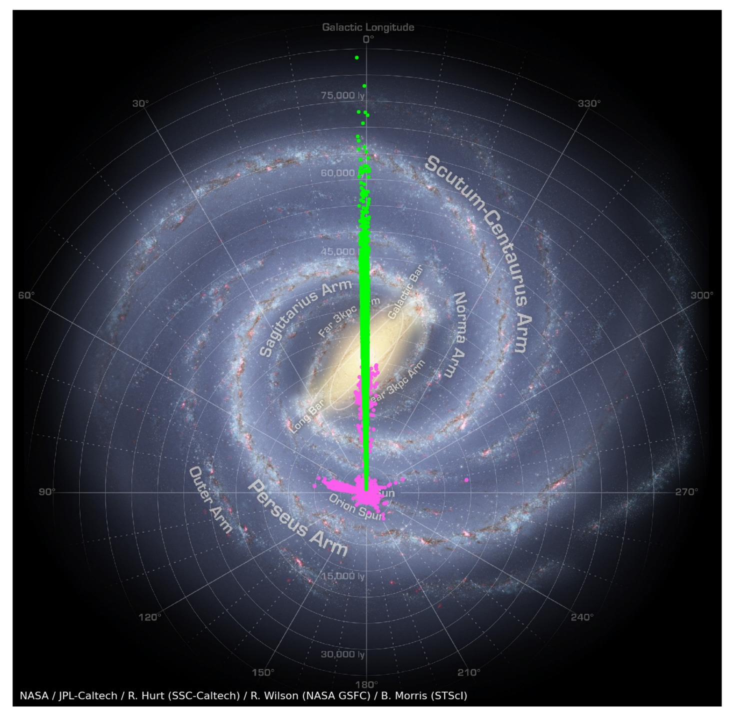


Figure 1: Black points indicate all stars in our sample and red dots indicate the planet host stars. The blue dashed lines distinguish the three bins where we calculate occurrence rates.

Using Roman to Study Galactic Populations

Previous studies of planet occurrence across galactic populations have suffered due to the small sample size of planets beyond the thin disk



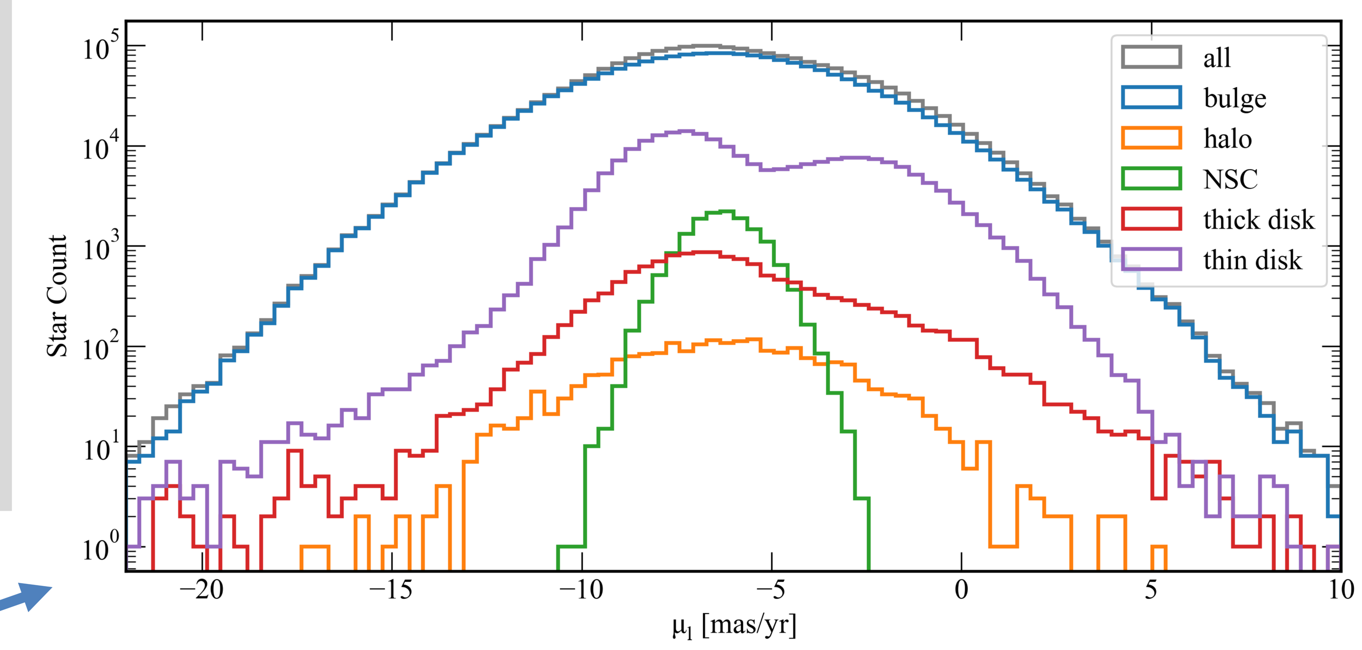
The Roman Galactic Bulge Time Domain Survey (GBTDS) will solve this by detecting ~100,000 transiting planets,[9] including more than 10,000 planets in the bulge, thin disk, and thick disk, each.

Figure 1: **Roman will probe parts of the Galaxy never before covered by exoplanet surveys.** Pink points indicate all known planets, and the green points indicate simulated detections from the Roman GBTDS.

Challenge with Using Roman

While Roman provides unprecedented opportunities, it also presents unique challenges to inferring occurrence rates across galactic populations

Namely, previously used techniques to determine a star's membership in a particular population will not be available for Roman (no chemical abundances & lack of full 3D velocity information)



Occurrence Rate Procedure

1) Use a galactic population synthesis model (e.g., SYNTHPOP[10,11]) to forward model the proper motion distributions of each galactic population in the Roman field

2) Fit a linear combination of the models to the proper motion distribution of your observed stellar sample

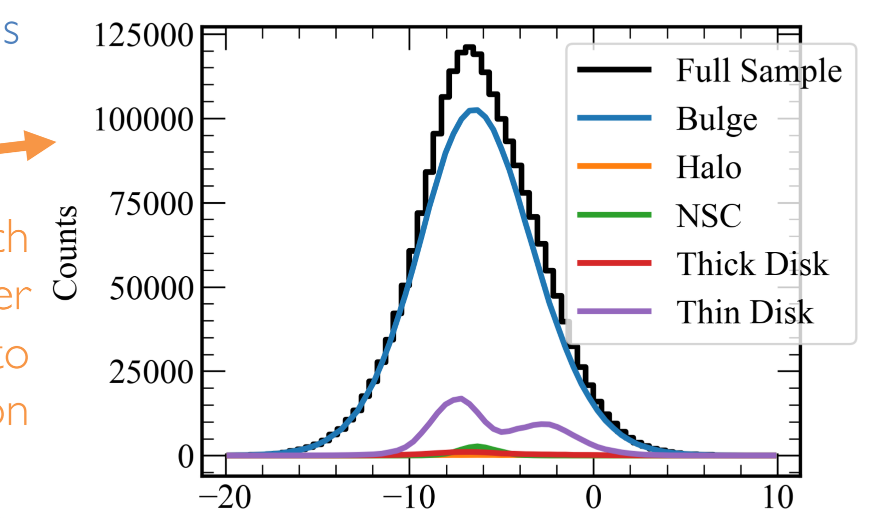
3) Repeat the model fitting, this time using just the observed planet host stars

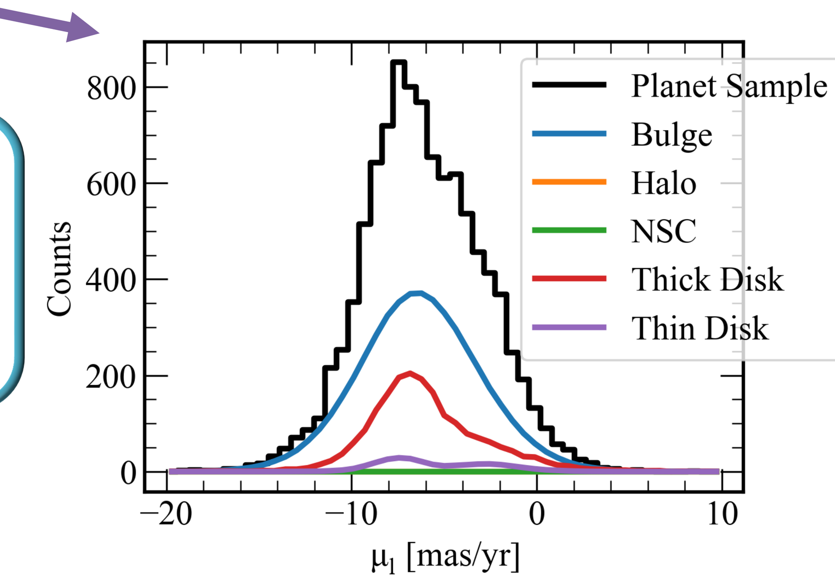
4) Calculate the occurrence rate by taking the number of planets divided by the number of stars in each population

The proper motion distributions for each population are unique

The normalization of each component tells you the number of stars in your sample belong to that population

Gives you the number of planets in each population

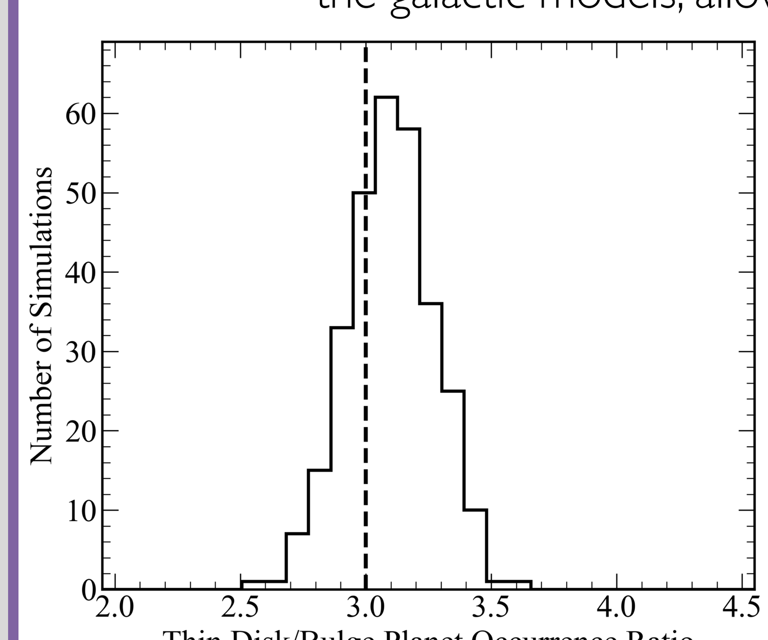




Crucially, this method does not determine whether an individual star is a member of a specific population.

It leverages the large sample size from Roman to determine statistically the fraction of your sample belonging to each population.

We can also introduce correlations between planet occurrence and stellar age and metallicity into the galactic models, allowing us to account for both correlations simultaneously



Testing the Framework:

We generated a simulated stellar population with SYNTHPOP and designated 10,000 random stars as "planet hosts"

We set the probability of a star being drawn from the thin disk as 3 times larger than the bulge (sets the relative occurrence rate between the thin disk and bulge)

We calculated the occurrence rates in the thin disk and bulge for 300 random samples of planets, finding that we were able to recover the correct relative occurrence rate

What's Next:

We won a Roman Cycle 1 proposal to improve and validate this method.

We will run tests by creating simulated Roman stellar and planet sample and test (1) how well this method can constrain the occurrence rate in each population, and (2) how well we can decorrelate planet occurrence, metallicity, and age

Takeaways

By studying planet occurrence in different galactic populations, we can learn how planet formation and evolution is affected by stellar properties.

When analyzing the occurrence rates, you must account for the correlations between stellar properties to understand the cause of the occurrence rate differences.

We find that the lower occurrence rate in the thick disk can be explained by metallicity, in contrast to previous studies.

We present a framework that will allow us to calculate occurrence rates in different galactic populations using Roman's transiting planet survey.

References

1. Petigura, E. A., et al. (2018). The California-*Kepler* Survey. IV. Metal-rich Stars Host a Greater Diversity of Planets. AJ, 155, 89.
2. Bashi, D., & Zucker, S. (2022). Exoplanets in the Galactic context: planet occurrence rates in the thin disc, thick disc, and stellar halo of *Kepler* stars. MNRAS, 510, 3449.
3. Zink, J. K., et al. (2023). Scaling K2. VI. Reduced Small-planet Occurrence in High-galactic-amplitude Stars. AJ, 165, 262.
4. Matteucci, F. (2021). Modelling the chemical evolution of the Milky Way. A&A Rev., 29, 5.
5. Sayeed, M., et al. (2025). Exoplanet Occurrence Rate with Age for FGK Stars in *Kepler*. AJ, 169, 112.
6. Hallatt, T., & Lee, E. J. (2025). On The Formation of Planets in the Milky Way's Thick Disk. ApJ, 979, 120.
7. Zink, J. K., et al. (2020b). Scaling K2. III. Comparable Planet Occurrence in the FGK Samples of Campaign and Kepler. AJ, 160, 94.
8. Beaton, R. L., et al. (2021). Final Targeting Strategy for the Sloan Digital Sky Survey IV Apache Point Observatory Galactic Evolution Experiment 2 North Survey. AJ, 162, 302.
9. Wilson, R. F., et al. (2023). Transiting Exoplanet Yields for the Roman Galactic Bulge Time Domain Survey Predicted from Pixel-level Simulations. ApJS, 269, 5.
10. Koshimoto, N., et al. (2021a). A Parametric Galactic Model toward the Galactic Bulge Based on Gaia and Microlensing Data. ApJ, 917, 78.
11. Klüter, J., et al. (2025). SYNTHPOP: A New Framework for Synthetic Milky Way Population Generation. AJ, 169, 317.

The material is based upon work supported by NASA under award number 80GSFC21M0002

matthewlastovka.weebly.com

Email: mlastovk@umd.edu