Comparison of Microlensing Planet Distribution with the Galactic Model

Naoki Koshimoto (University of Tokyo) and David Bennett (NASA Goddard)

ABSTRACT

Gravitational microlensing is almost the only technique that can study the Galactic distribution of planet as a function of distance from the Galactic center. However, the distance can be uniquely determined only when the microlens parallax, providing one of mass-distance relations, is luckily measured. Because the commonly measured event timescale t_E and lens-source relative proper motion μ_{rel} jointly give another mass-distance relation, we might extract some information of the mass or distance from them. In this study, we compare the 29 measurements of t_E and μ_{rel} from planetary sample of Suzuki et al. (2016) with a Galactic model that is commonly used in microlensing analysis. We find a statistically significant excess of the lens-source relative proper motion μ_{rel} values compared to the expectation from the Galactic model when the event timescale $t_E \gtrsim 60$ days. This excess might be interpreted as the first certain evidence that planets are less common in the bulge compared to the disk. However, uncertainty caused by the choice of Galactic model must be investigated to conclude.

1.INTRODUCTION

Gravitational microlensing

- Unique sensitivity on planets
  - beyond the H_2O snowline of mostly M-dwarf host stars
  - in the Galactic disk or bulge (Fig.1)

→ Microlensing toward Galactic bulge is almost only tool that can study the Galactic distribution of planets.

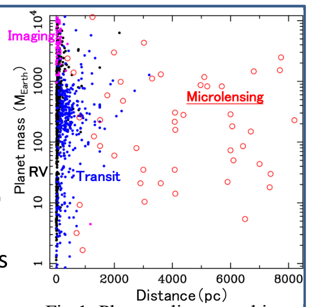
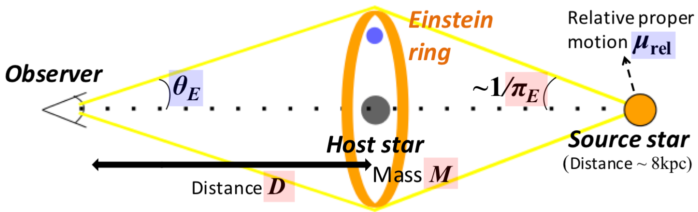


Fig.1: Planets discovered in distance vs. planet mass parameter space.

Host distance is not routinely measured



Three observables needed to measure the host distance D

Event timescale	t_E [$= \theta_E/\mu_{rel}$]	Angular Einstein radius $\theta_E(M, D)$
Lens-source relative proper motion	μ_{rel}	
Microlens parallax	$\pi_E(M, D)$	

: Always measured
: Rarely measured

→ No conclusive study on the Galactic distribution of planets so far due to the rareness of events with π_E measurement.

2.Method

Distribution of t_E and μ_{rel}

- We focus on distribution of t_E and μ_{rel} which are
  - including information of (mass and) distance distribution
  - routinely measured for planetary events so **larger and unbiased sample is available** compared to using D itself

Compared with a model of our galaxy (Galactic model)

- Microlensing is caused by a star following the structure of our galaxy that have been studied for decades.
  - Probability of events with (t_E, μ_{rel}) observed is

$$P_{obs}(\mu_{rel}, t_E) = \underbrace{P_{\mu lens}(\mu_{rel}, t_E)}_{\text{Probability of event with } (t_E, \mu_{rel}) \text{ occurs}} \times \underbrace{\epsilon(t_E)}_{\text{Detection efficiency}}$$

  - The detection efficiency term is cancelled by considering **probability of μ_{rel} observed for a given t_E**

$$P_{obs}(\mu_{rel} | t_E) = P_{\mu lens}(\mu_{rel} | t_E)$$

→ Model-calculated distribution of μ_{rel} for a given t_E can be fairly compared with observed distribution.

3. Sample and model

29 planetary events from statistical studies

- 29 measurements of t_E and μ_{rel} for planetary events of the Suzuki et al. 2016's combined sample.

→ Largest and most complete microlensing planet sample so far

Galactic model for planet host stars

- We use a Galactic model used in Bennett et al. (2014) that consists of the following three distributions.
  - Stellar mass function: Kroupa 2001's power law where slopes are taken from Sumi+11
  - Stellar density distribution: Boxy-shaped bar + Exponential thin & thick disks
  - Stellar velocity distribution:
    Bar: Solid rotation + constant velocity dispersion
    Disks: Flat rotation curve + constant velocity dispersion
- Because compared sample consists of planet host stars, we additionally consider the following uncertain probability:
  - **Probability of hosting planet**: $P_{host} \propto M^{\alpha} D^{\beta}$

4. Results (**Preliminary**)

Visual comparison of observation with model

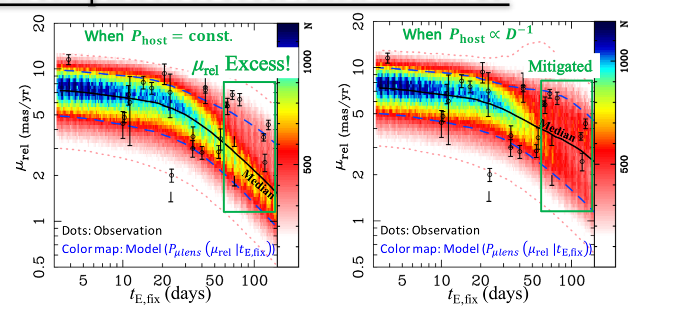


Fig.2: Comparison of μ_{rel} distribution as a function of given t_E between the observation (black dots) and the model (color map and curves). Left is when the probability of hosting planet P_{host} is constant while the right is when $P_{host} \propto D^{-1}$.

- At least 8 out of 9 events with $t_E > 60$ days have μ_{rel} above the model median when P_{host} = const. (Green box in the left panel of Fig.2)
- The excess is mitigated when $P_{host} \propto D^{-1}$ is assumed. (Right panel)

Maximum likelihood

- Fig. 3 shows relative likelihood of α and β

$$\mathcal{L}(\alpha, \beta) = \prod_i P_{\mu lens}(\mu_{rel,i} | t_{E,i}; \alpha, \beta)$$

where the product is taken over all 29 events. This shows that $\beta < 0$ (closer lens) is favored regardless of α value.

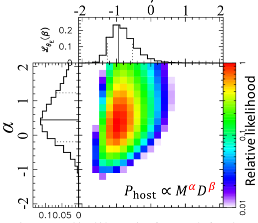


Fig.3: Likelihood of α and β when $P_{host} \propto M^{\alpha} D^{\beta}$ is assumed

Updated Galactic model is needed!!

- The excess could be also interpreted as an implication of a problem in the used Galactic model. In fact, we are aware of some simplistic features in our model that are inconsistent with the recent Gaia measurements. So an updated Galactic model is needed to conclude.