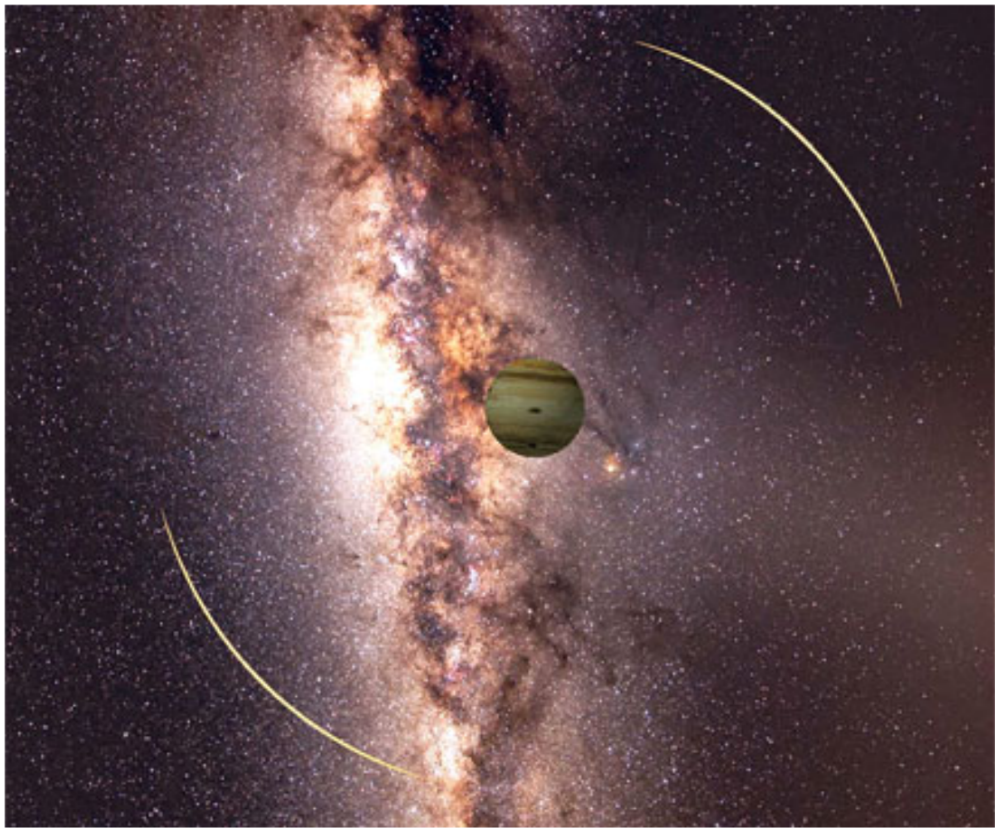
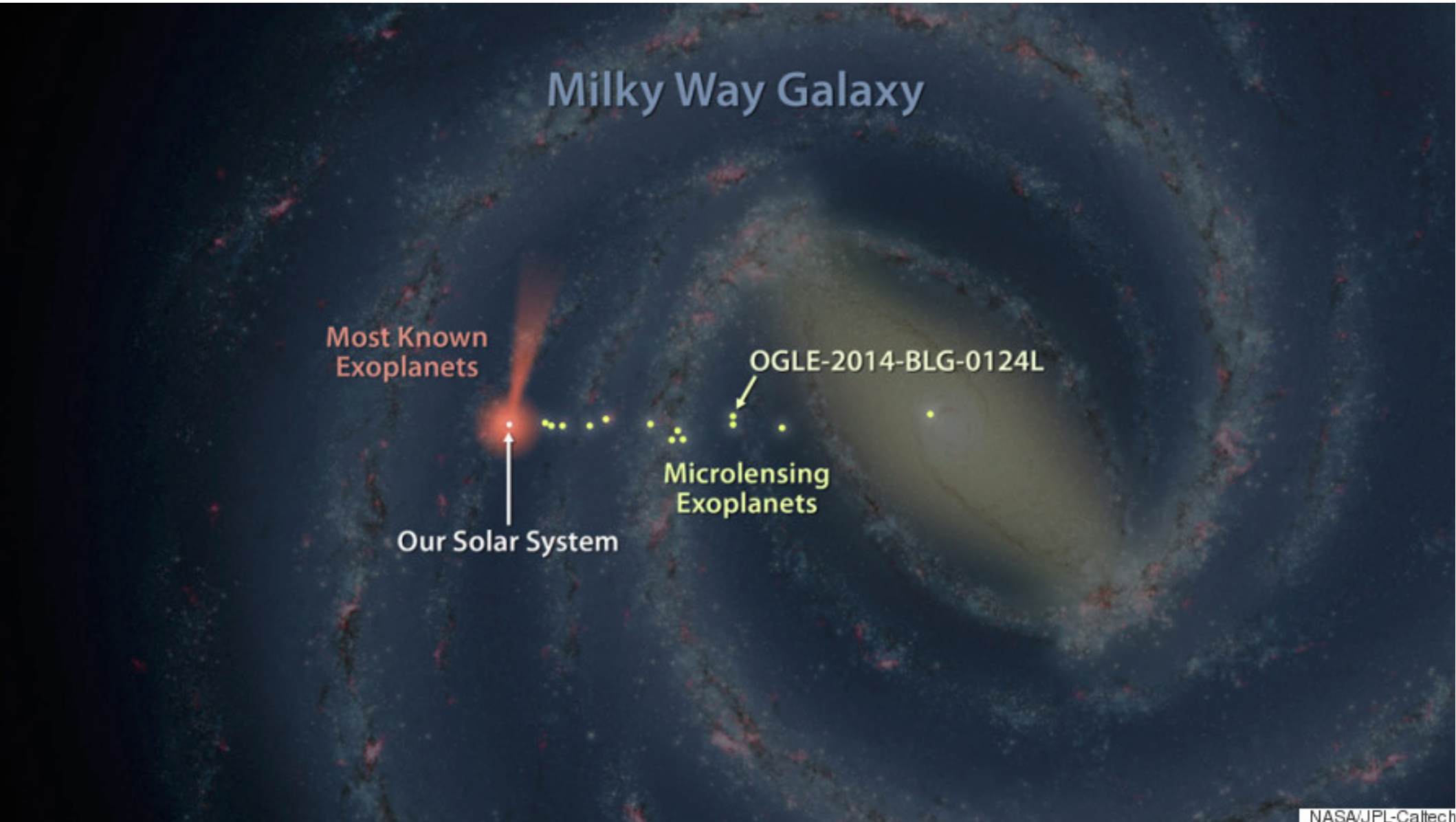
# Towards the Galactic Distribution of Planets



Matthew Penny

Sagan Fellow (2014-), Ohio State University
penny@astronomy.ohio-state.edu

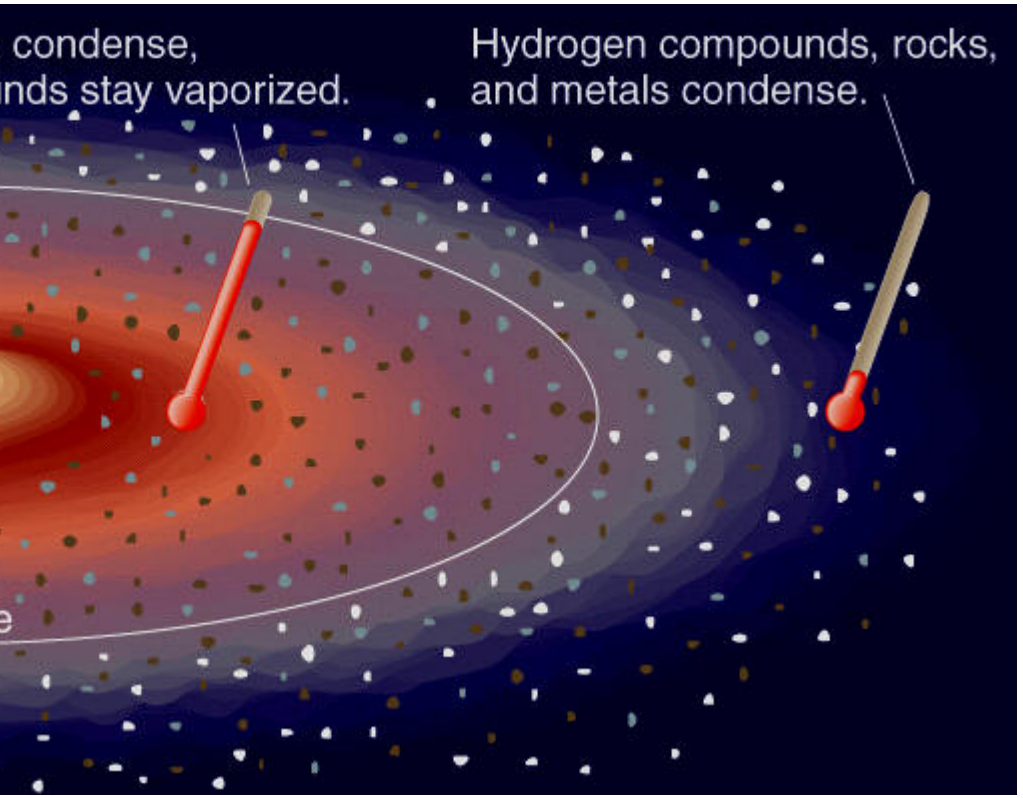
# Where are the known exoplanets?

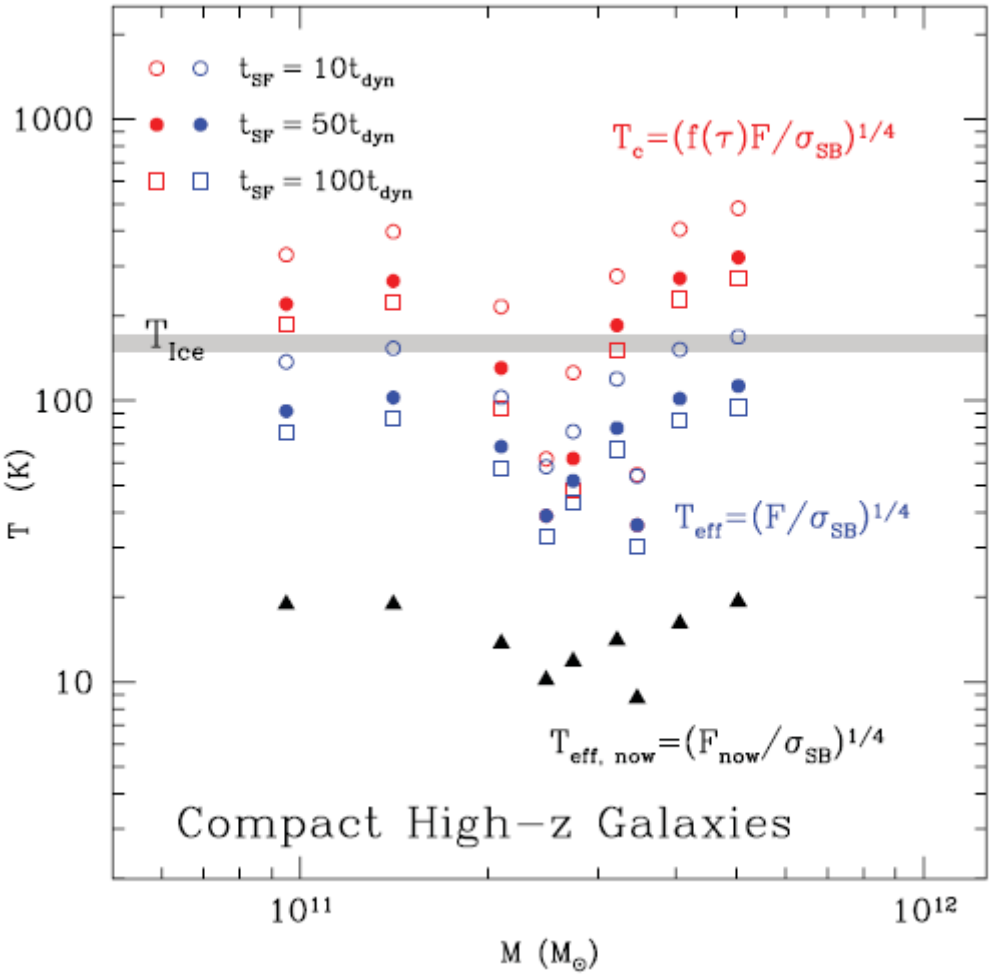


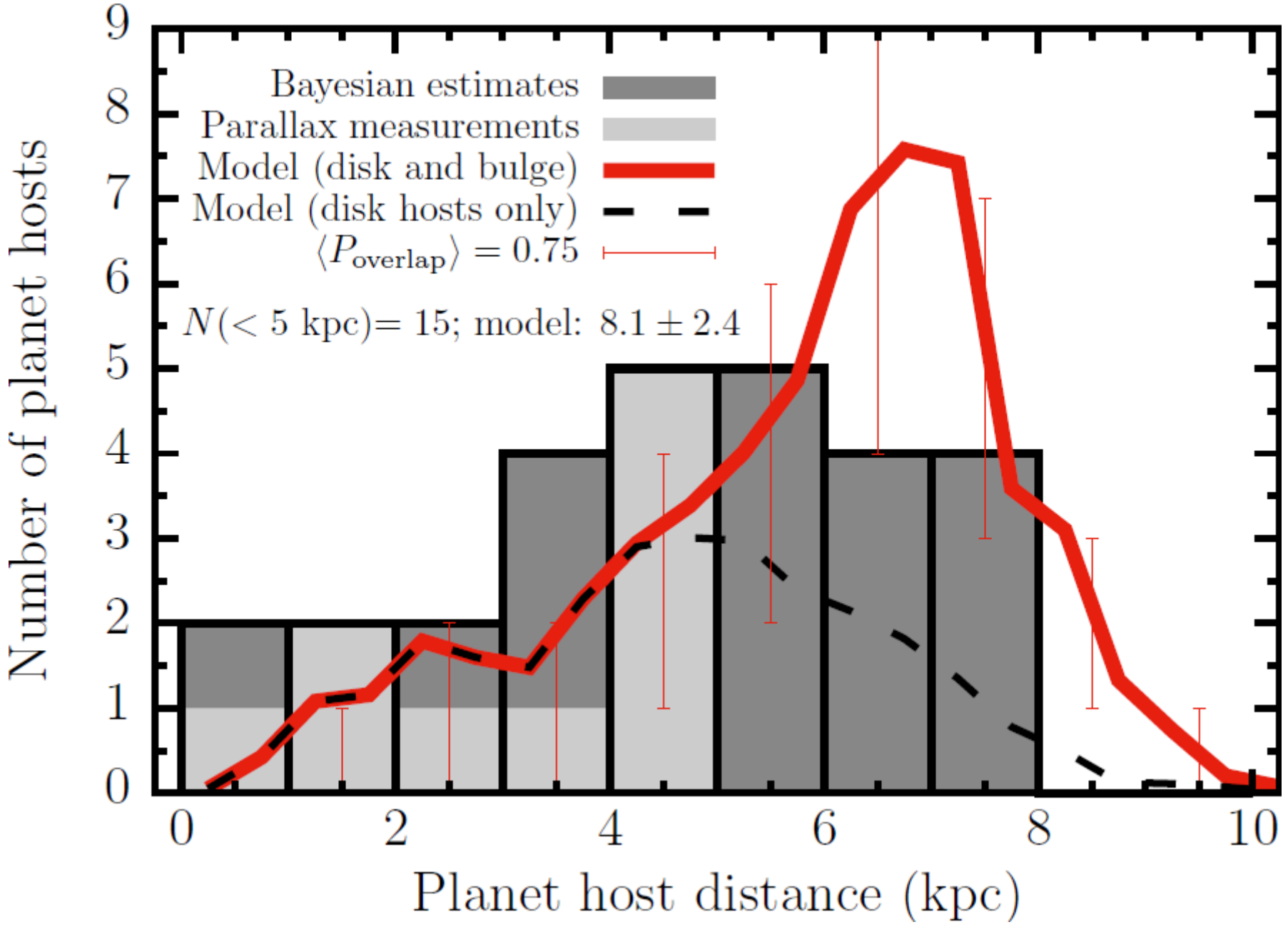
# Does planet formation in the bulge differ from the disk?

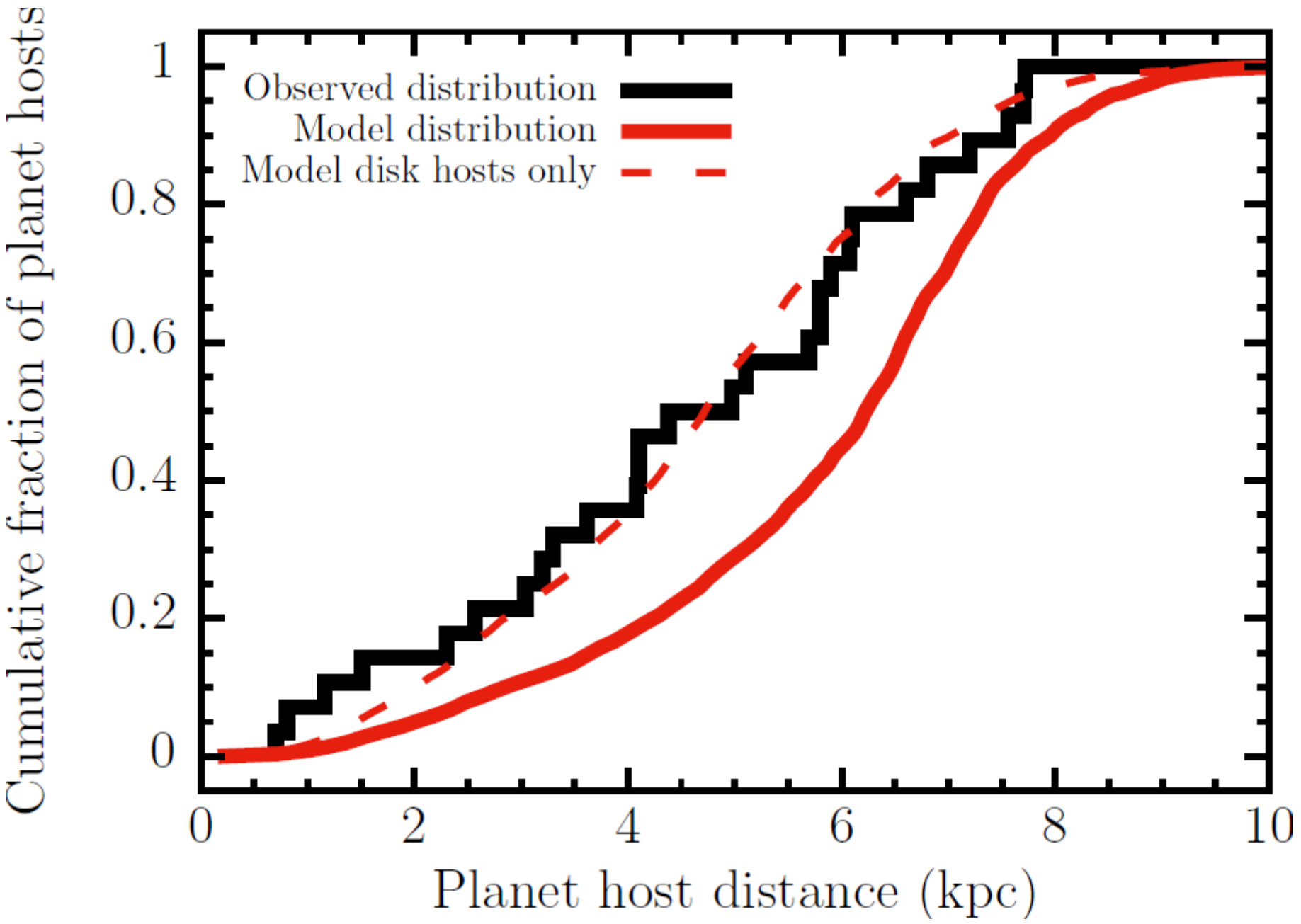
**Gas giants in hot water: inhibiting giant planet formation and planet habitability in dense star clusters through cosmic time**

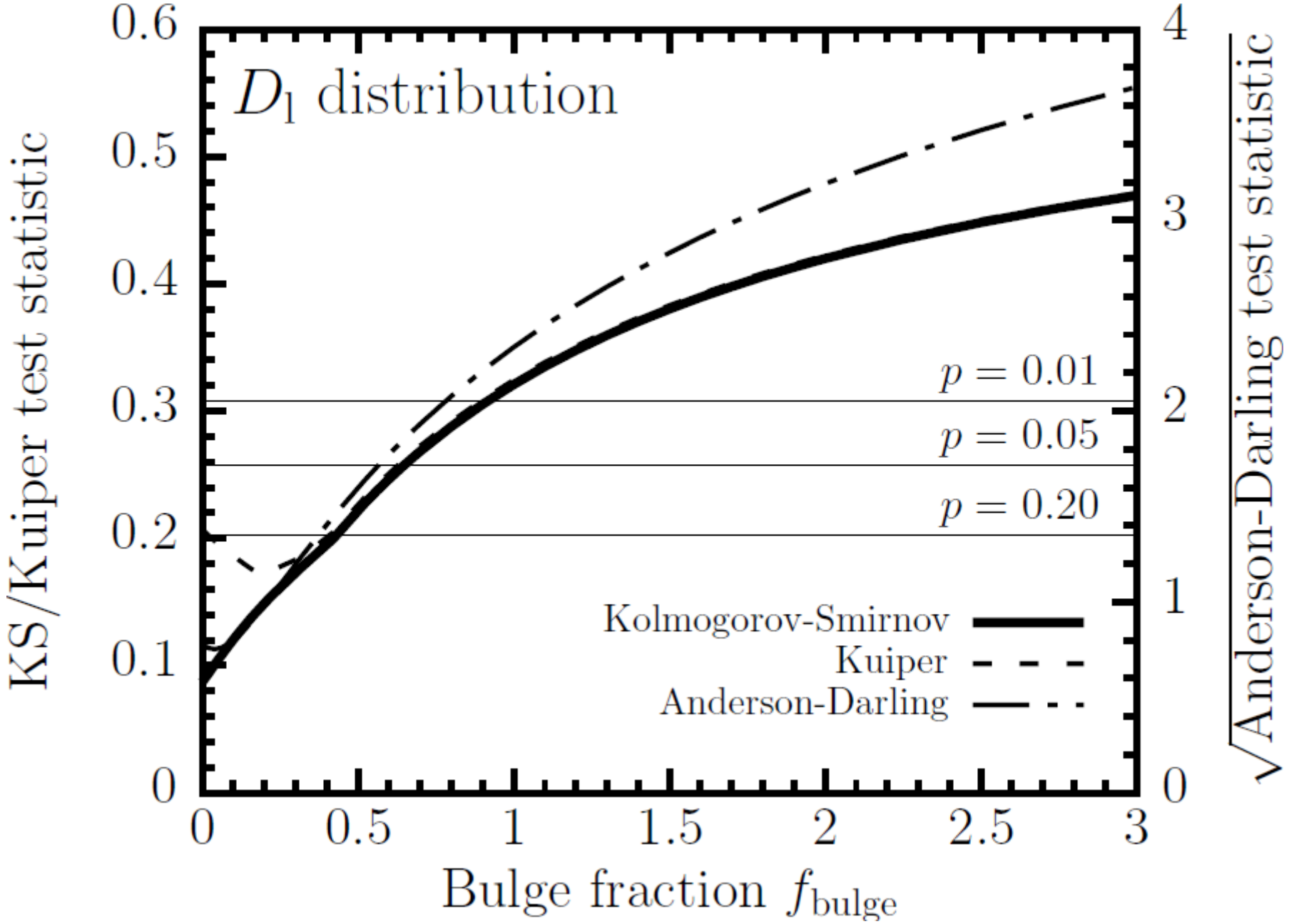
Todd A. Thompson★

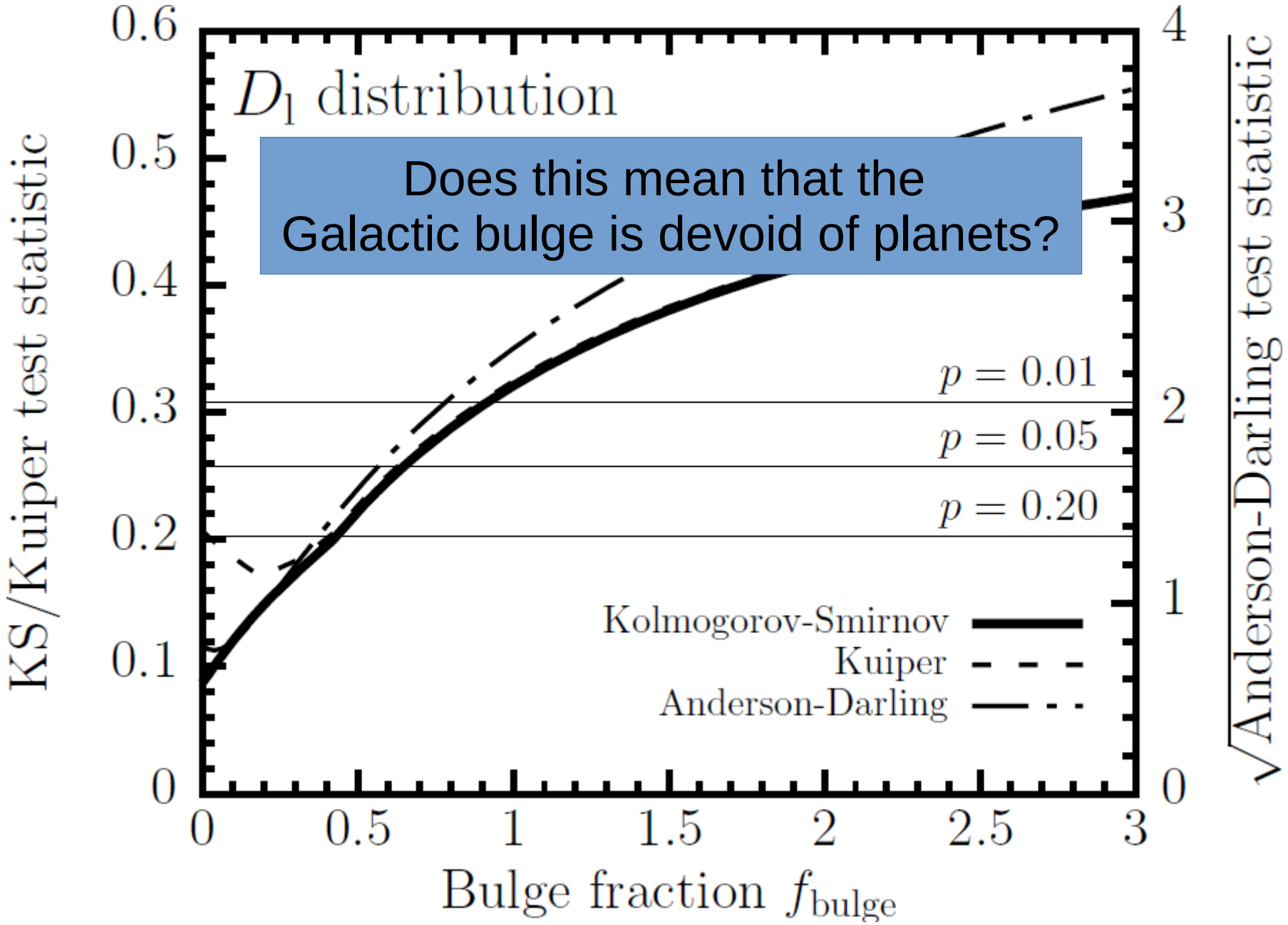



Bayesian estimates
Parallax measurements
Model (disk and bulge)
Model (disk hosts only)
$\langle P_{\rm overlap} \rangle = 0.75$
$N(< 5$ kpc$) = 15$; model: $8.1 \pm 2.4$
Number of planet hosts
Planet host distance (kpc)
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10


Cumulative fraction of planet hosts
1
0.8
0.6
0.4
0.2
0
Observed distribution
Model distribution
Model disk hosts only
0
2
4
6
8
10
Planet host distance (kpc)


$D_{\rm l}$ distribution
$p = 0.01$
$p = 0.05$
$p = 0.20$
Kolmogorov-Smirnov
Kuiper
Anderson-Darling
KS/Kuiper test statistic
$\sqrt{\text{Anderson-Darling test statistic}}$
Bulge fraction $f_{\rm bulge}$
0
0.1
0.2
0.3
0.4
0.5
0.6
0
1
2
3
4
0
0.5
1
1.5
2
2.5
3


$D_l$ distribution
Does this mean that the Galactic bulge is devoid of planets?
$p = 0.01$
$p = 0.05$
$p = 0.20$
Kolmogorov-Smirnov
Kuiper
Anderson-Darling
KS/Kuiper test statistic
$\sqrt{\text{Anderson-Darling test statistic}}$
Bulge fraction $f_{\text{bulge}}$
0
0.1
0.2
0.3
0.4
0.5
0.6
0
1
2
3
4
0
0.5
1
1.5
2
2.5
3

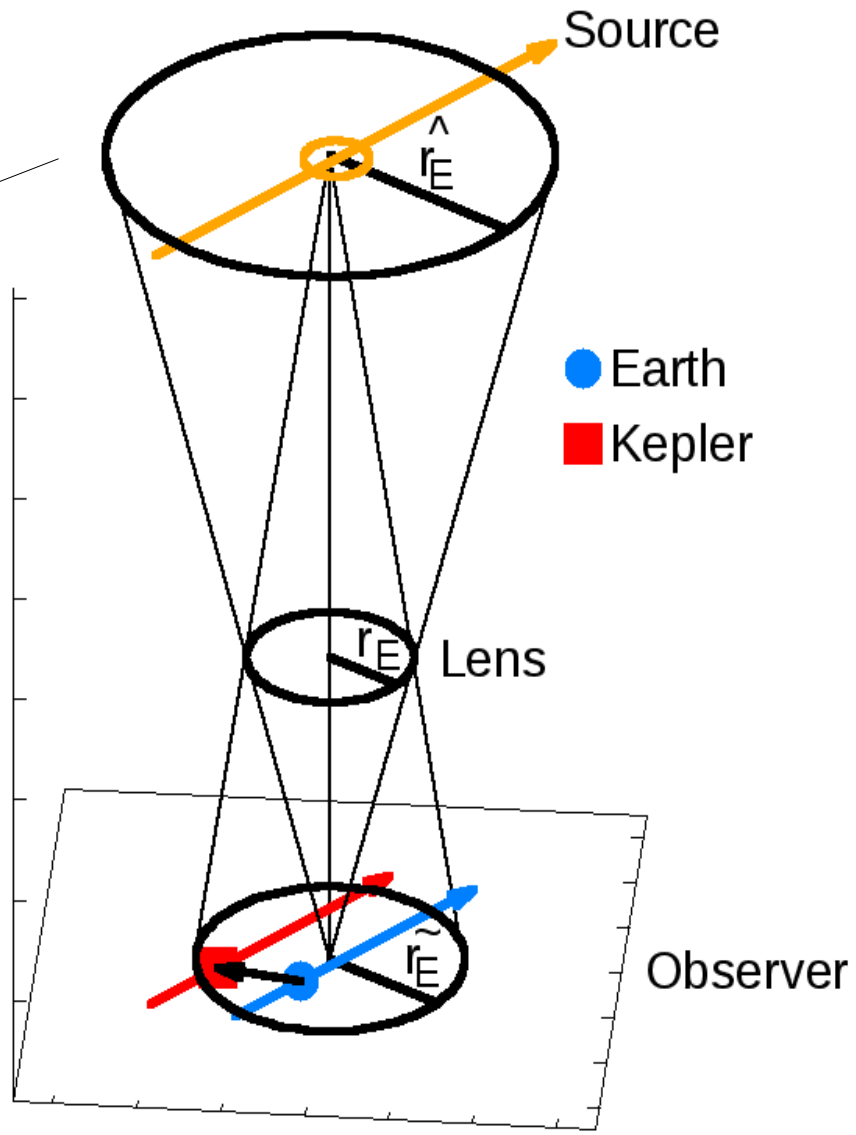
# Measuring Microlens Distances

- Finite-source effects (common for FFPs) measures one projection

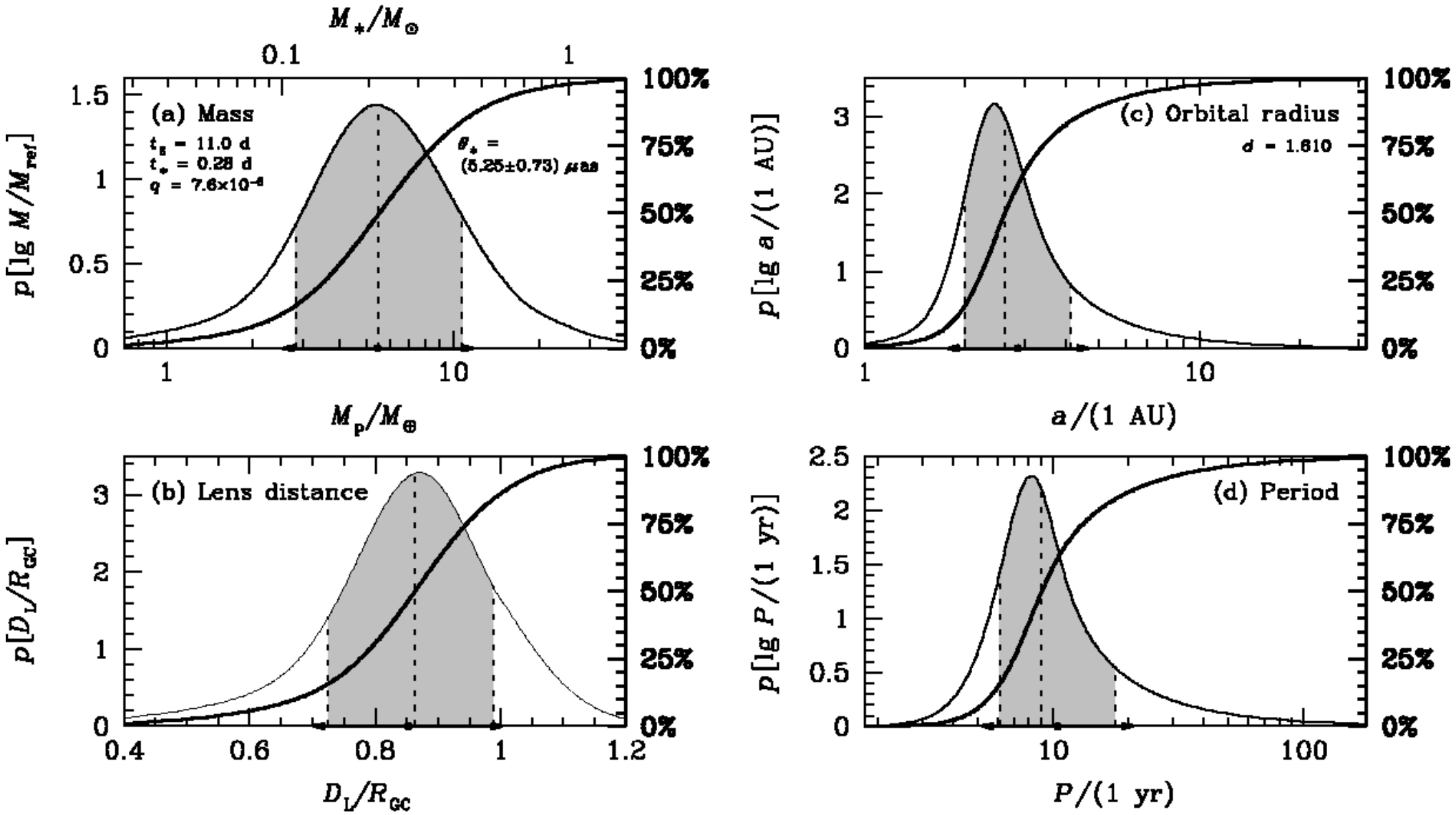
$$M = \frac{\theta_{\rm E}\pi_{\rm E}}{\kappa}$$

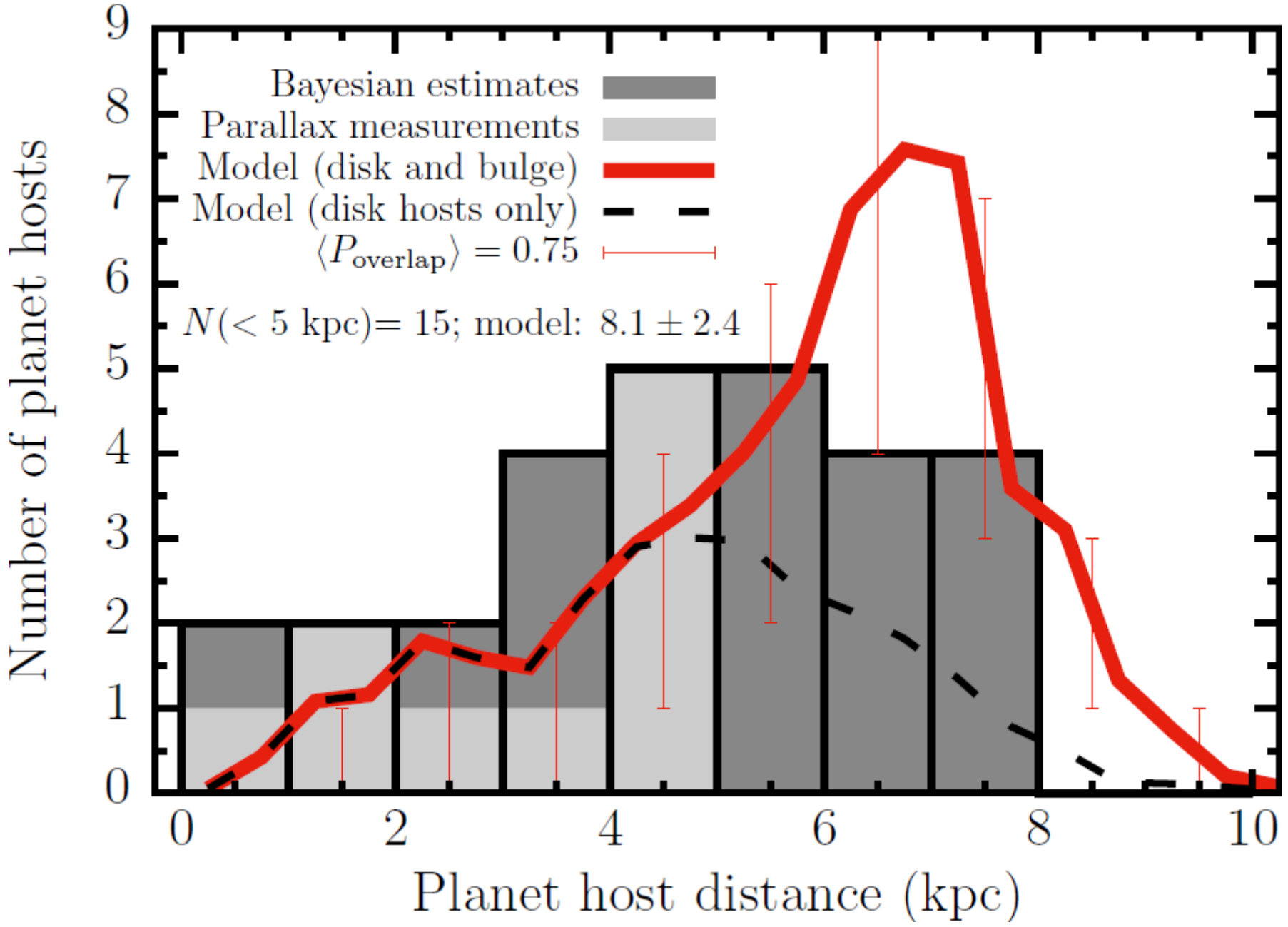
Constant

- Parallax baseline measures other projection

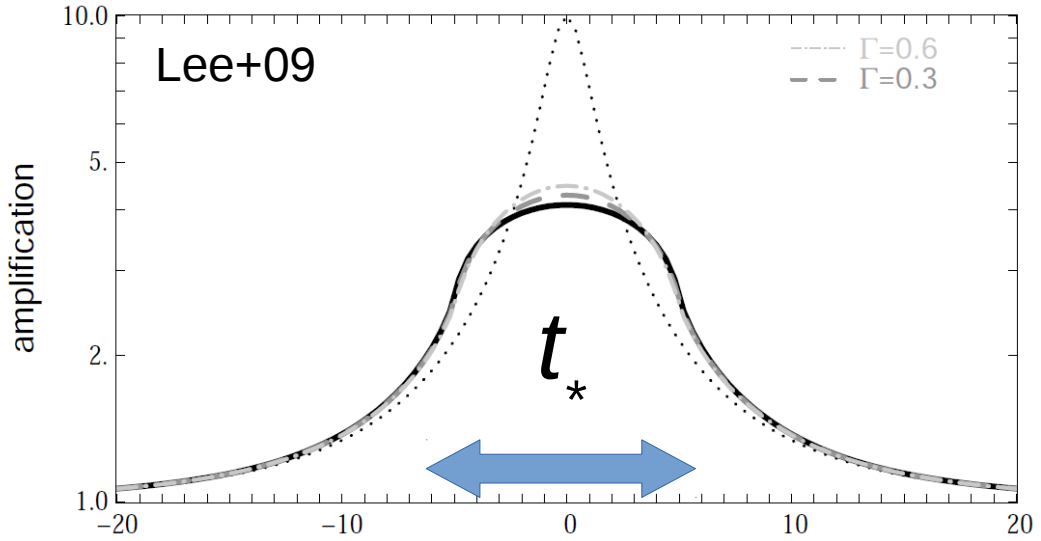


# Bayesian estimates

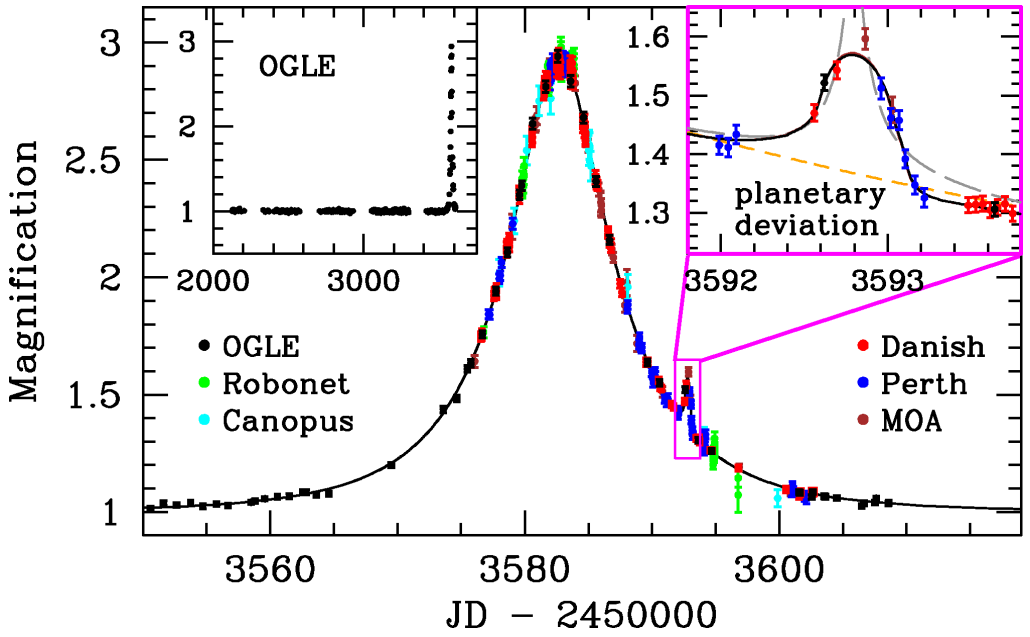



Bayesian estimates
Parallax measurements
Model (disk and bulge)
Model (disk hosts only)
$\langle P_{\rm overlap} \rangle = 0.75$
$N(< 5$ kpc$) = 15$; model: $8.1 \pm 2.4$
Number of planet hosts
Planet host distance (kpc)
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10

# Is there other information?

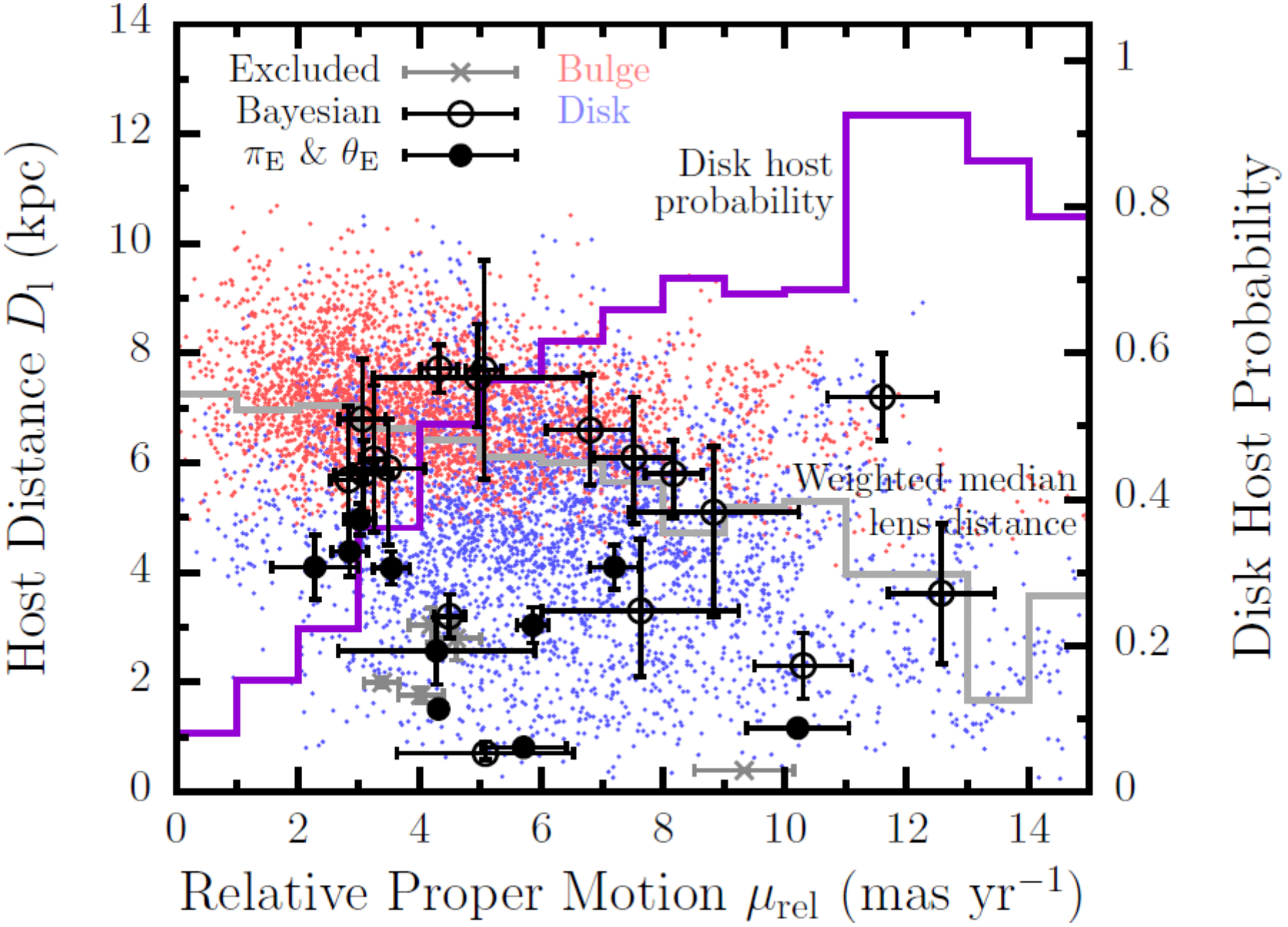


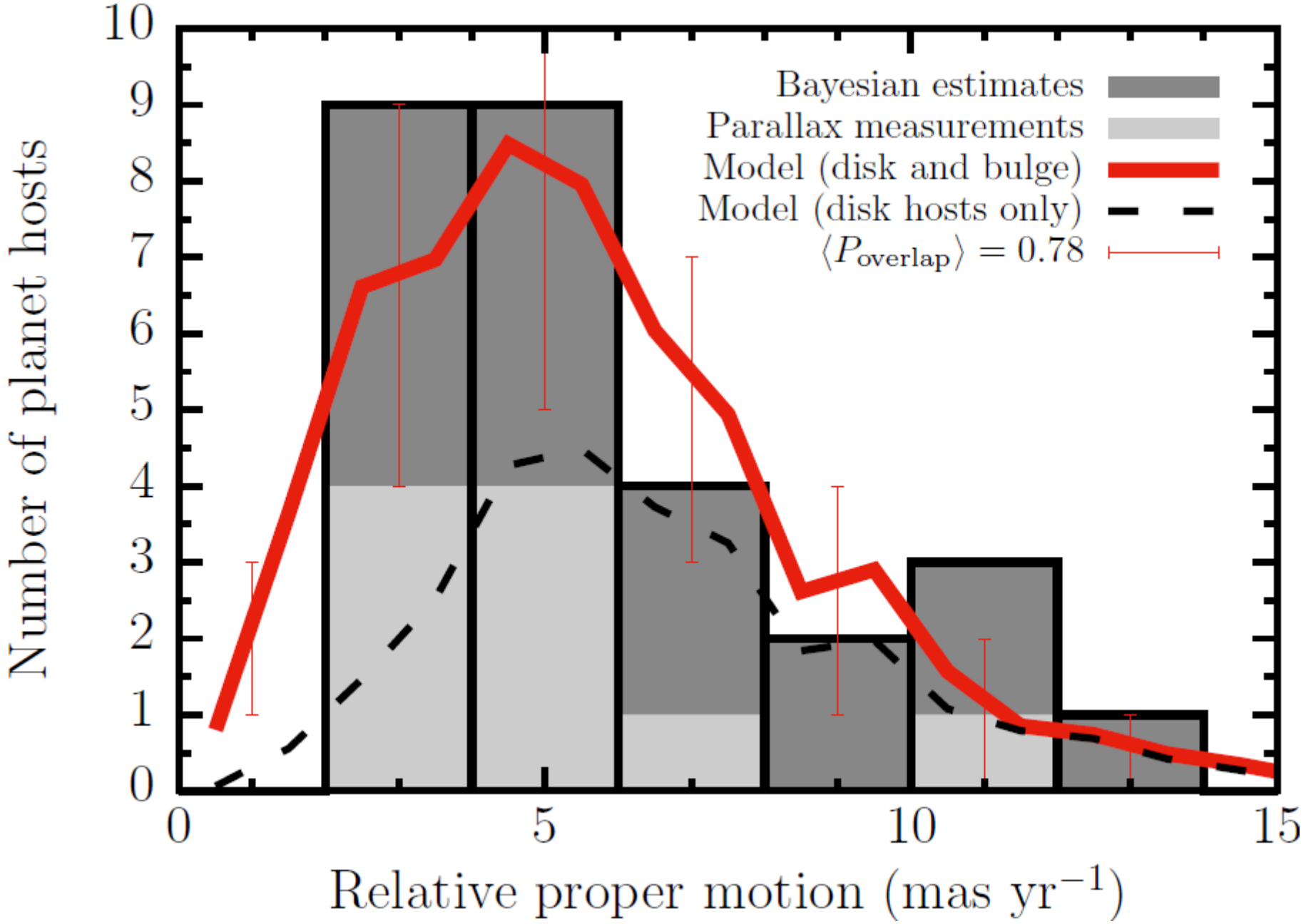

$$\frac{t_*}{t_{\rm E}} = \frac{\theta_*}{\theta_{\rm E}}$$

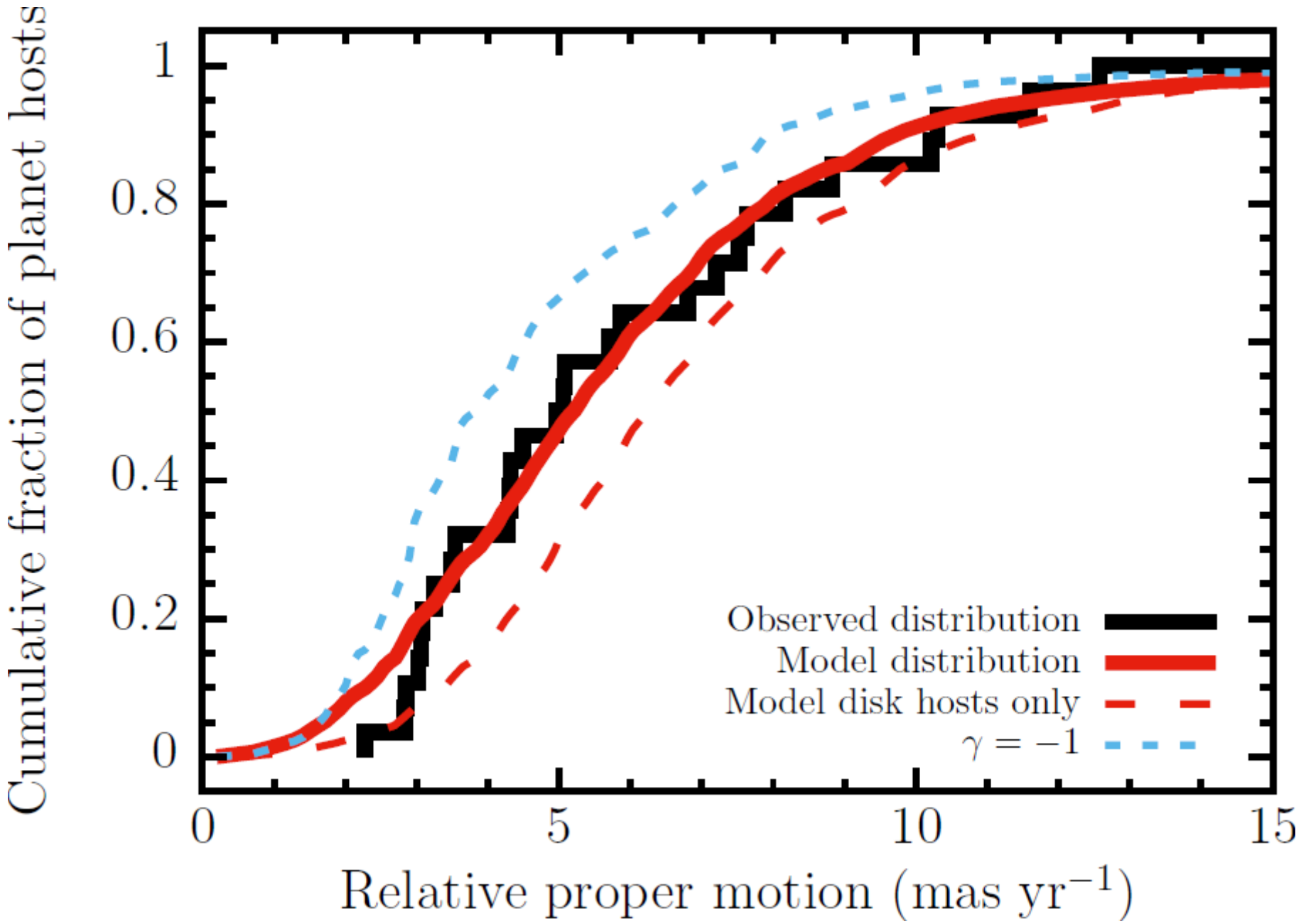


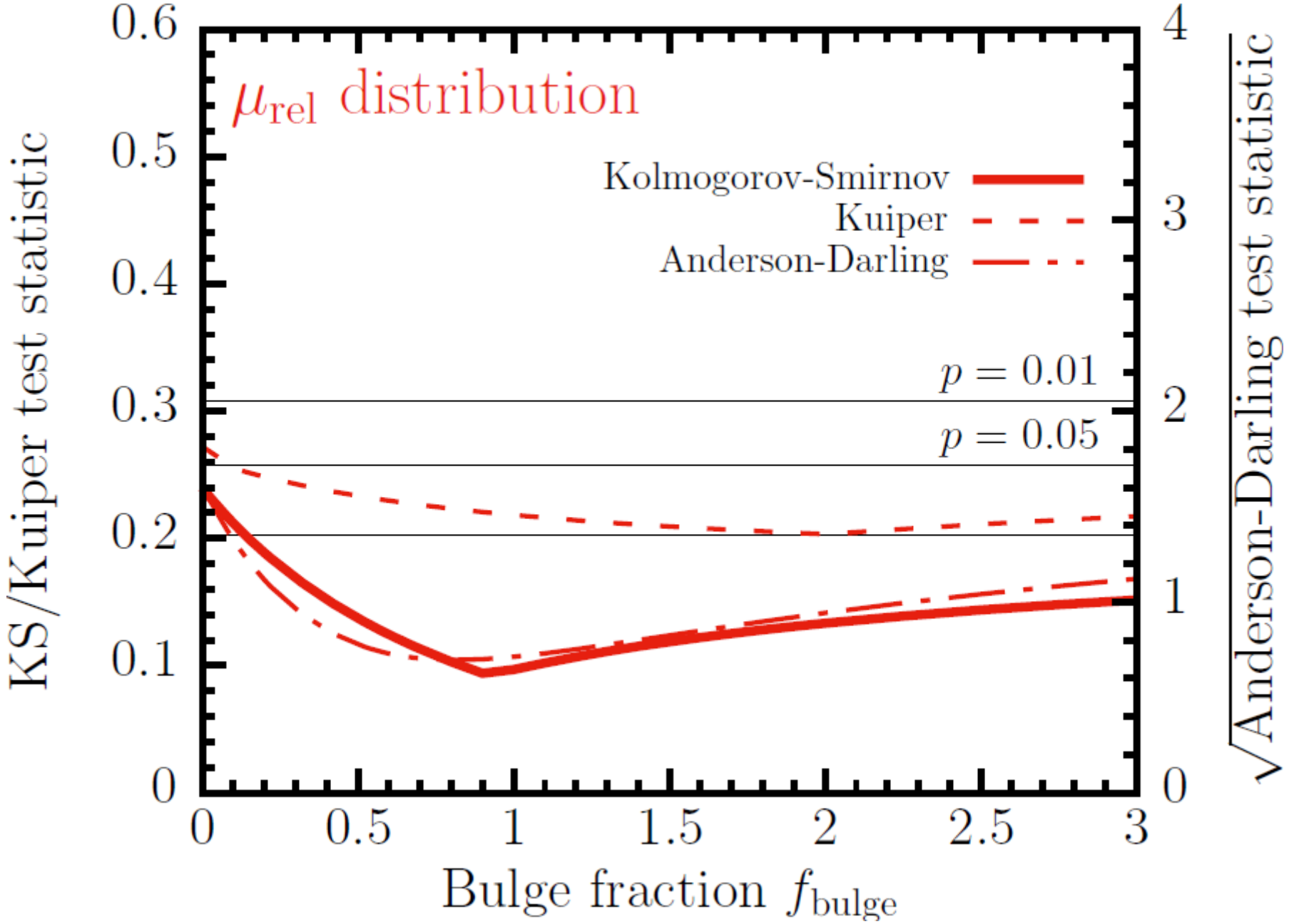

$$\mu_{\rm rel} = \frac{\theta_{\rm E}}{t_{\rm E}}$$

# Is there other information?




Bayesian estimates
Parallax measurements
Model (disk and bulge)
Model (disk hosts only)
$\langle P_{\rm overlap} \rangle = 0.78$
Number of planet hosts
Relative proper motion (mas yr$^{-1}$)
0
1
2
3
4
5
6
7
8
9
10
0
5
10
15

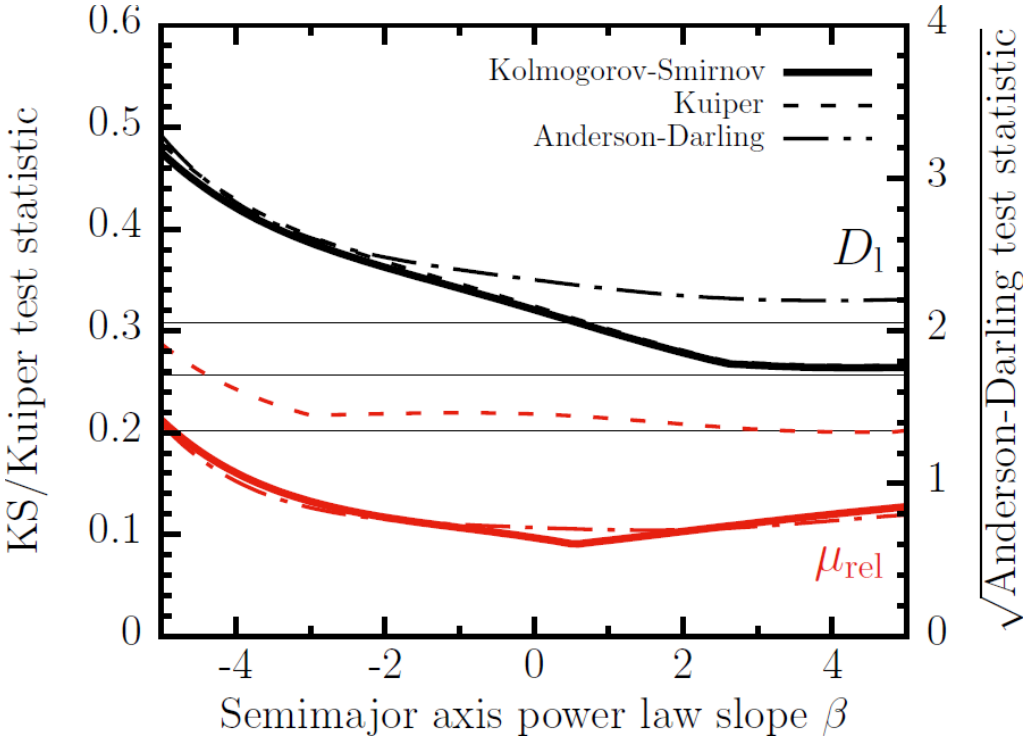

Cumulative fraction of planet hosts
1
0.8
0.6
0.4
0.2
0
0
5
10
15
Relative proper motion (mas yr$^{-1}$)
Observed distribution
Model distribution
Model disk hosts only
$\gamma = -1$

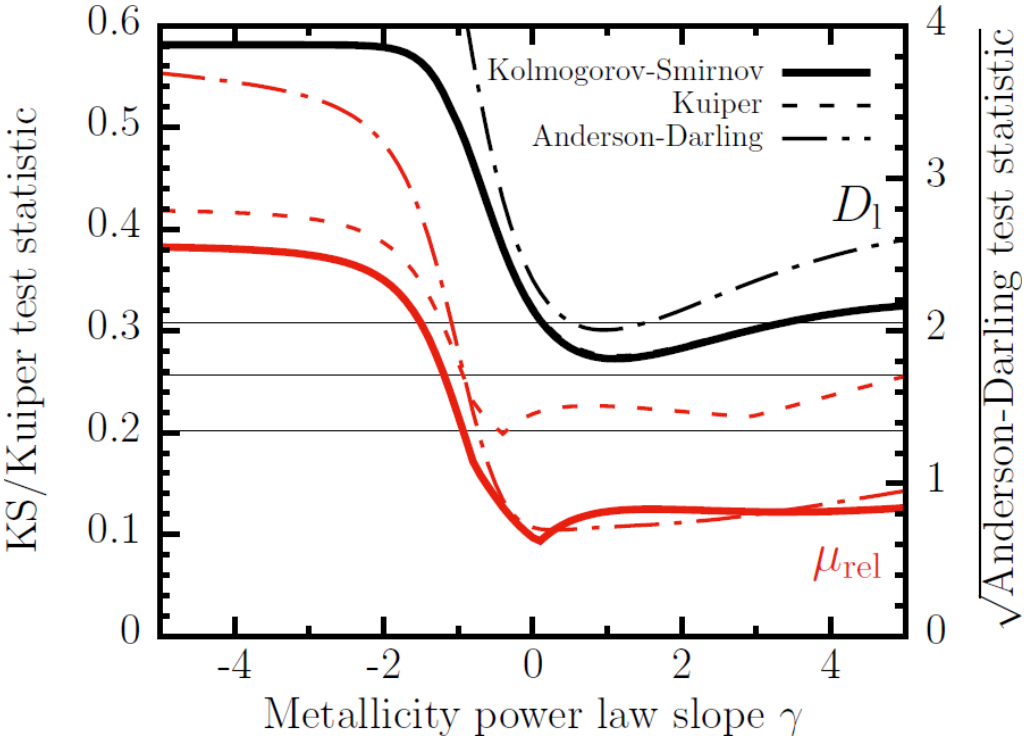

$\mu_{\rm rel}$ distribution
Kolmogorov-Smirnov
Kuiper
Anderson-Darling
$p = 0.01$
$p = 0.05$
KS/Kuiper test statistic
$\sqrt{\text{Anderson-Darling test statistic}}$
Bulge fraction $f_{\rm bulge}$
0
0.1
0.2
0.3
0.4
0.5
0.6
0
1
2
3
4
0
0.5
1
1.5
2
2.5
3

# Same events, different probe, different answers. What's going wrong?

- Model could be wrong?
- Bayesian distance estimates are flawed?
- Source distance assumptions are flawed?
- Parallax measurements affected by systematics?
- Something else?

# If real, are there other possible causes?

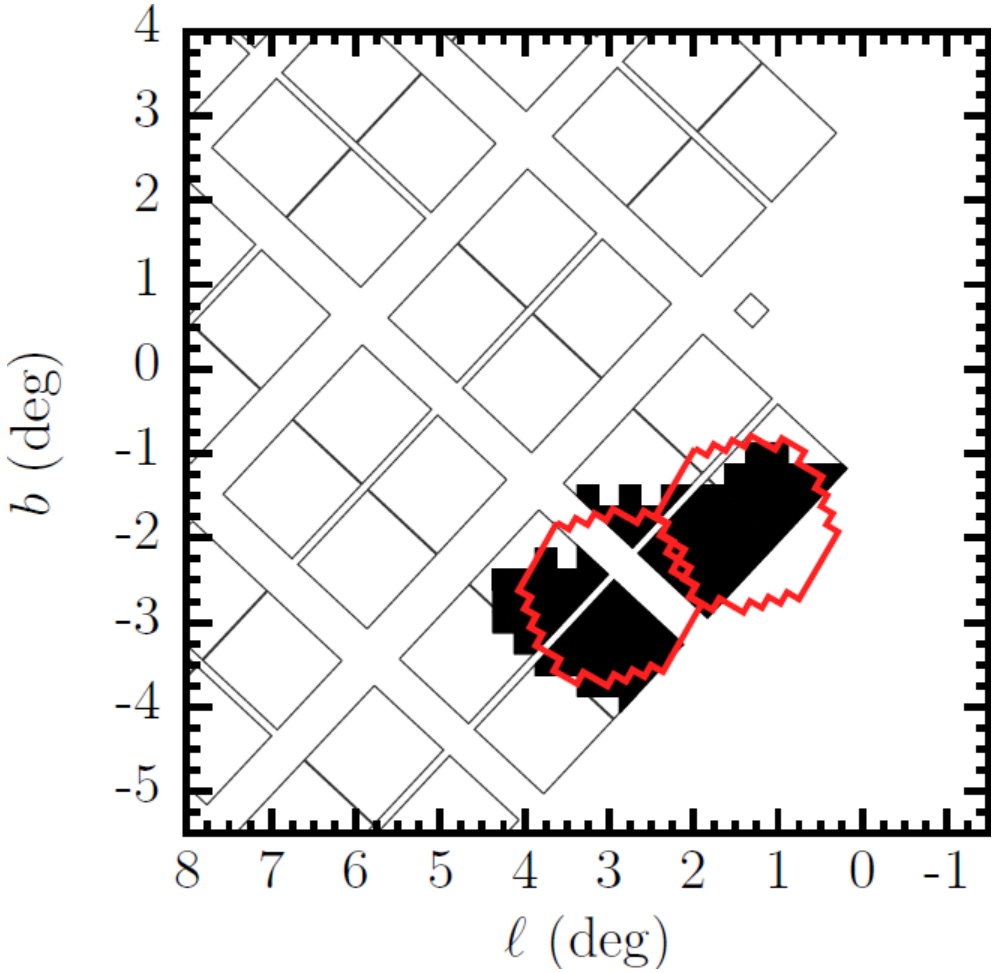


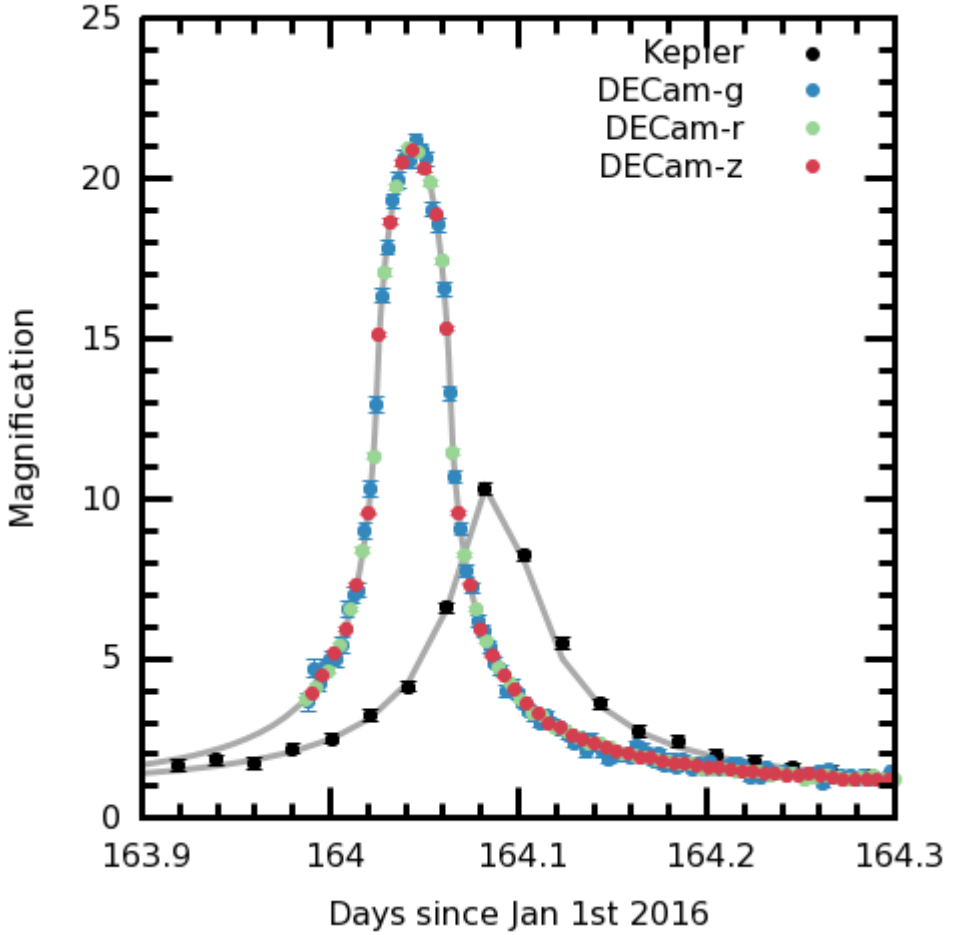



# OK, what's next?

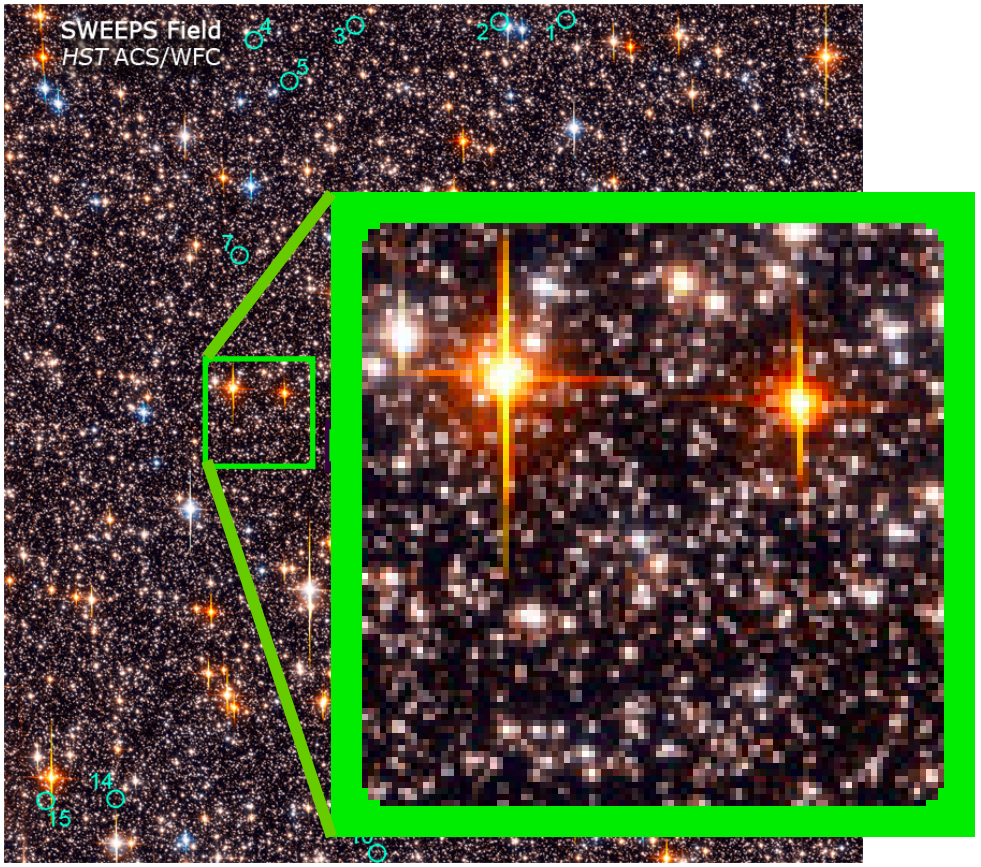
- This sample was very inhomogeneous
- Microlensing has entered the survey era
  - Wide-field, high-cadence surveys (MOA, OGLE-IV, KMTNet) can find planets without follow up
  - Controlled experiments without human decisions are much more easily modeled
- Spitzer and K2 campaign 9 will get high-quality parallaxes for many planets

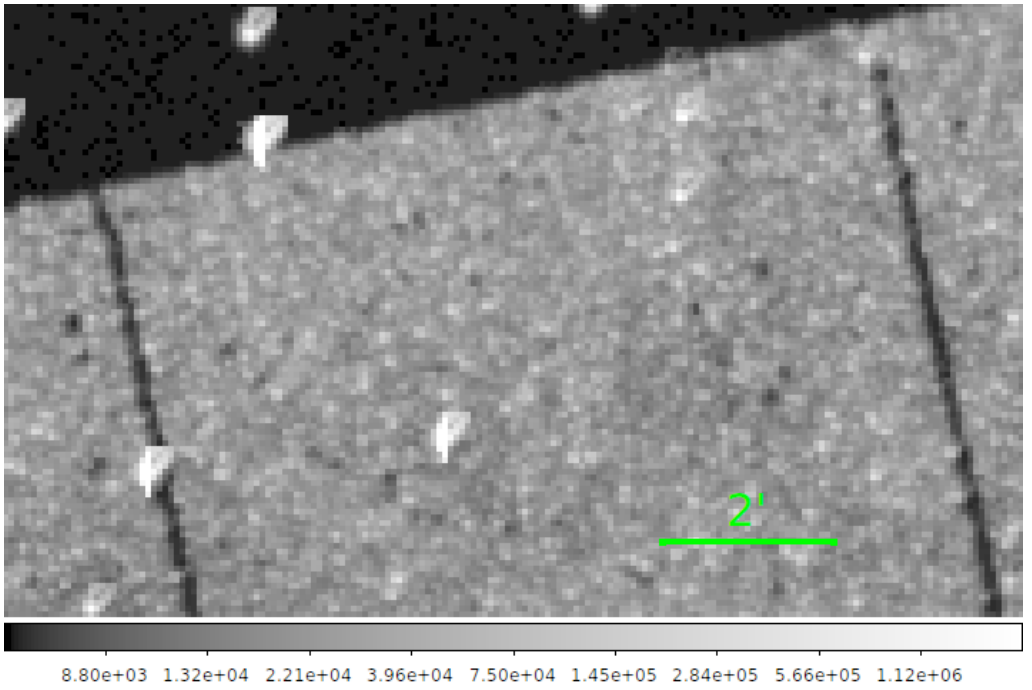
# K2 Campaign 9



# K2 Campaign 9



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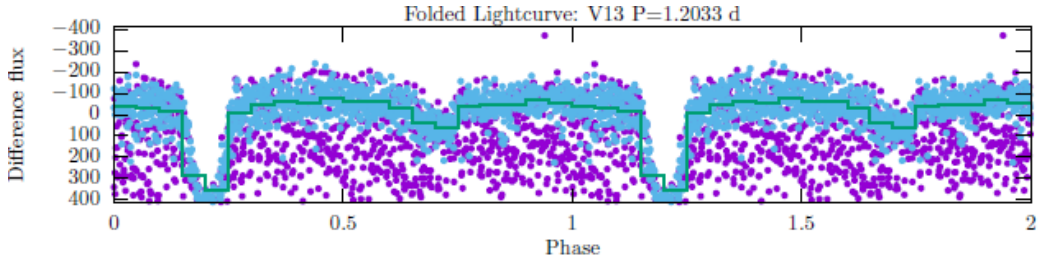


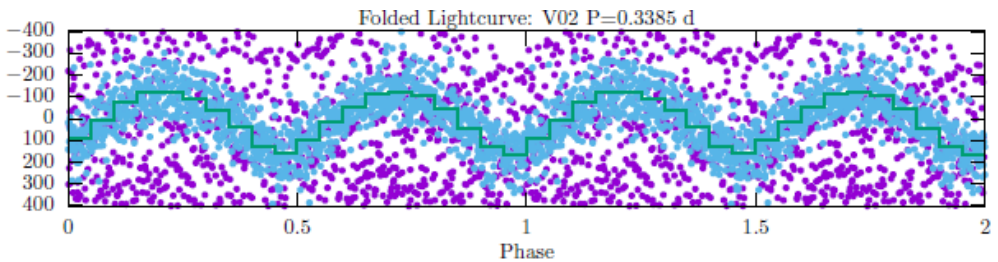


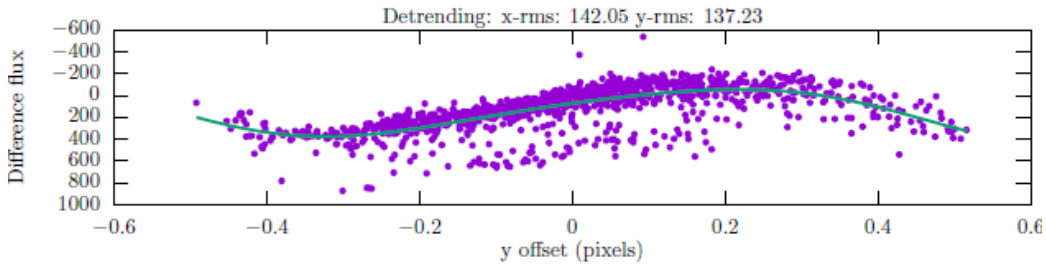


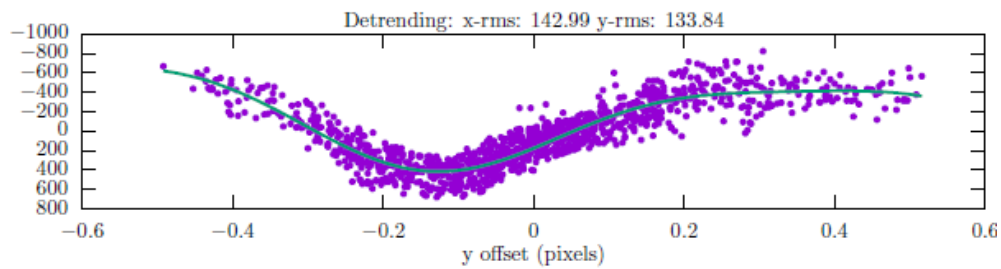


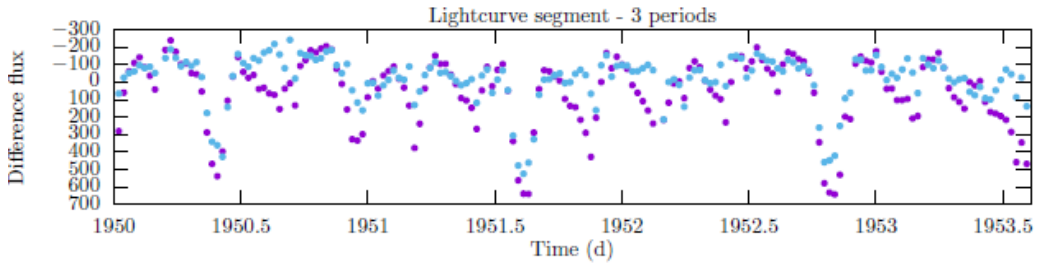


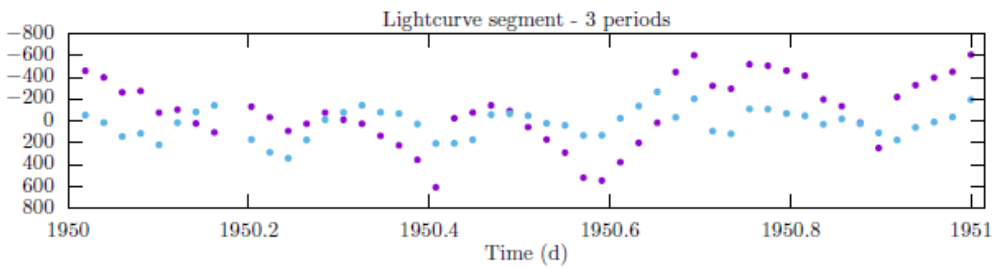


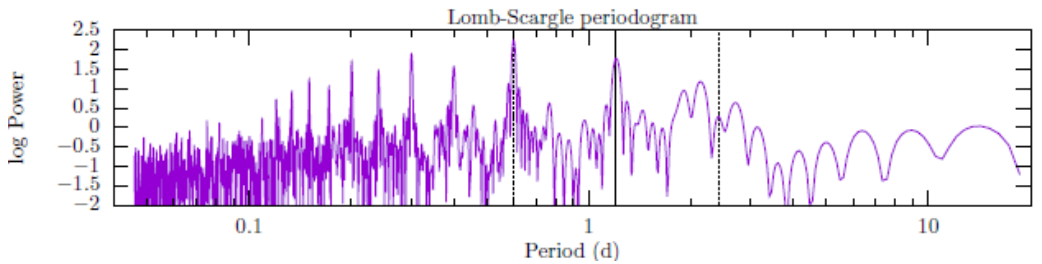


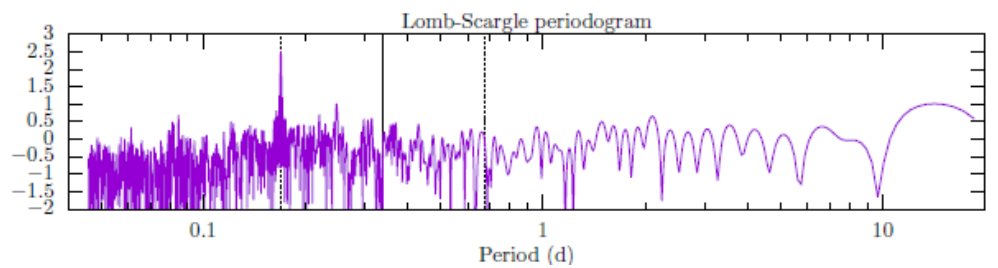

# K2 Campaign 9