Galactic distribution of Planets with Spitzer as a precursor of the WFIRST microlensing survey

Science in Our Own Backyard:

exploring the Galaxy and the Local Group with WFIRST

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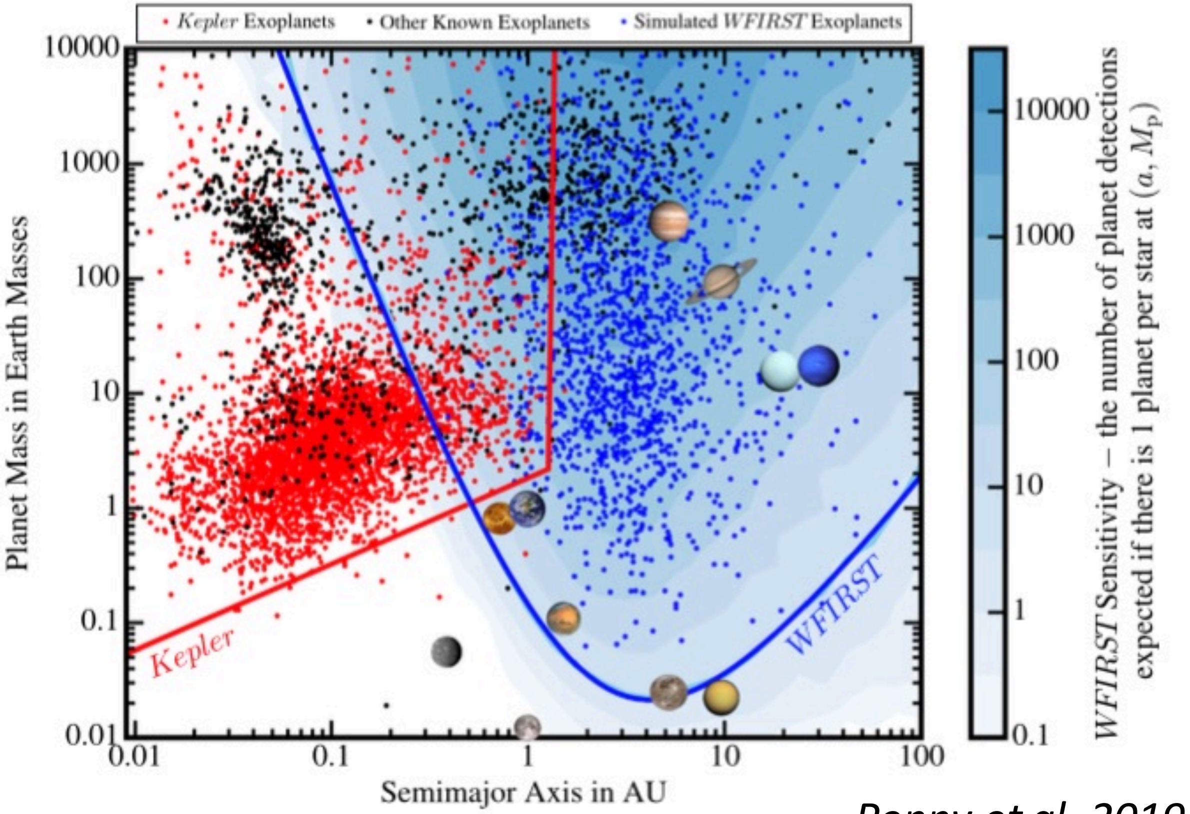
Towards the Demographics of Exoplanets

Microlensing and Exoplanets Astrophysics

The WFIRST Microlensing survey for Exoplanets



Penny et al, 2019

Peak sensitivity beyond the snow line ($\approx R_E$)

Sensitivity to low mass planets

Sensitivity to free-floating planets

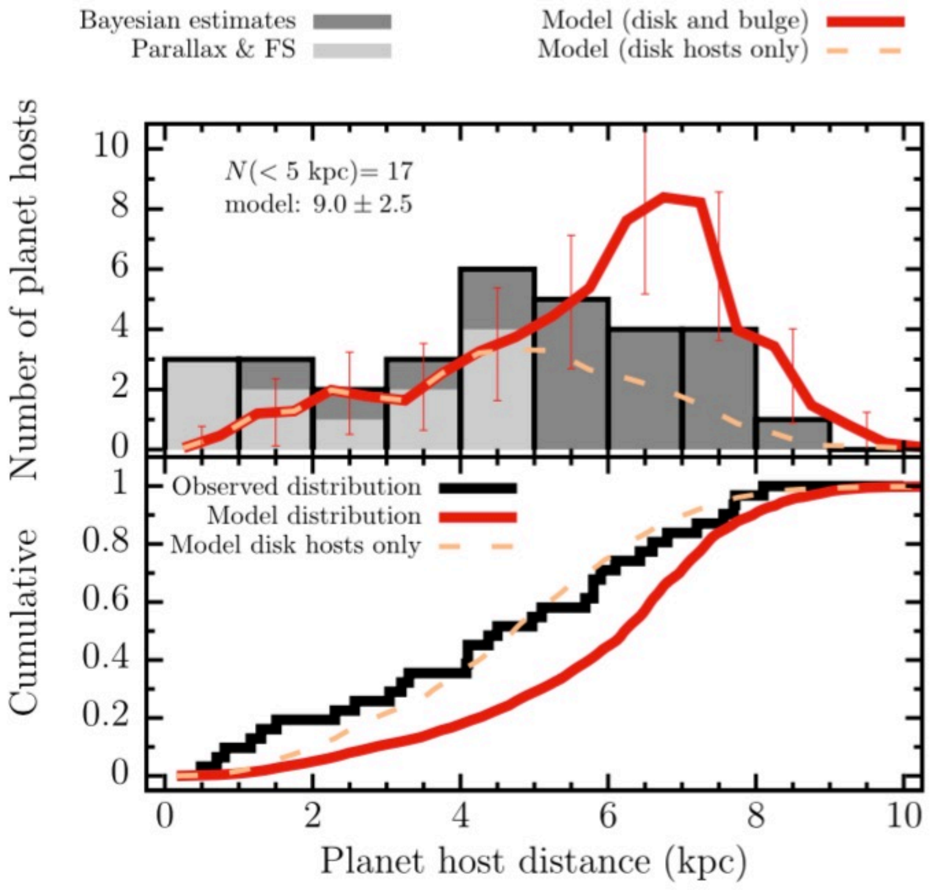
Microlensing is sensitive to planets in regions of the parameter space difficult to impossible to probe with other methods

Sensitivity to planets throughout the Galaxy

key to the Spitzer campaign

Microlensing and the Galactic Distribution of Exoplanets

Looking for exoplanets all the way to the Galactic center



Penny+, 2016

Bulge vs disk exoplanets

- Planet formation in different environments
- Impact of high radiation on protoplanetary disks
- Frequency vs age and metallicity

Microlensing Planet Distance Evaluation (before Spitzer)

- "Orbital" microlensing parallax
  - bias for nearby lenses
  - subtle signature degenerate with other second order effects
- Lens flux (AO)
  - bias for nearby lenses
- Bayesian analysis: statistical inference based on a prior model

Q: What about the underlying distribution?

A: We need the distance distribution for the underlying single-lens event population *or* a Bayes analysis

→ **enters Spitzer**

- ❑ **unbiased planet distances measured all the way to the Galactic Bulge**
- ❑ **distance distribution for the underlying single-lens event population**

Spitzer Space Telescope

….. position, position, position….

Launch: 25 August 2003

Orbit: Earth-trailing, heliocentric

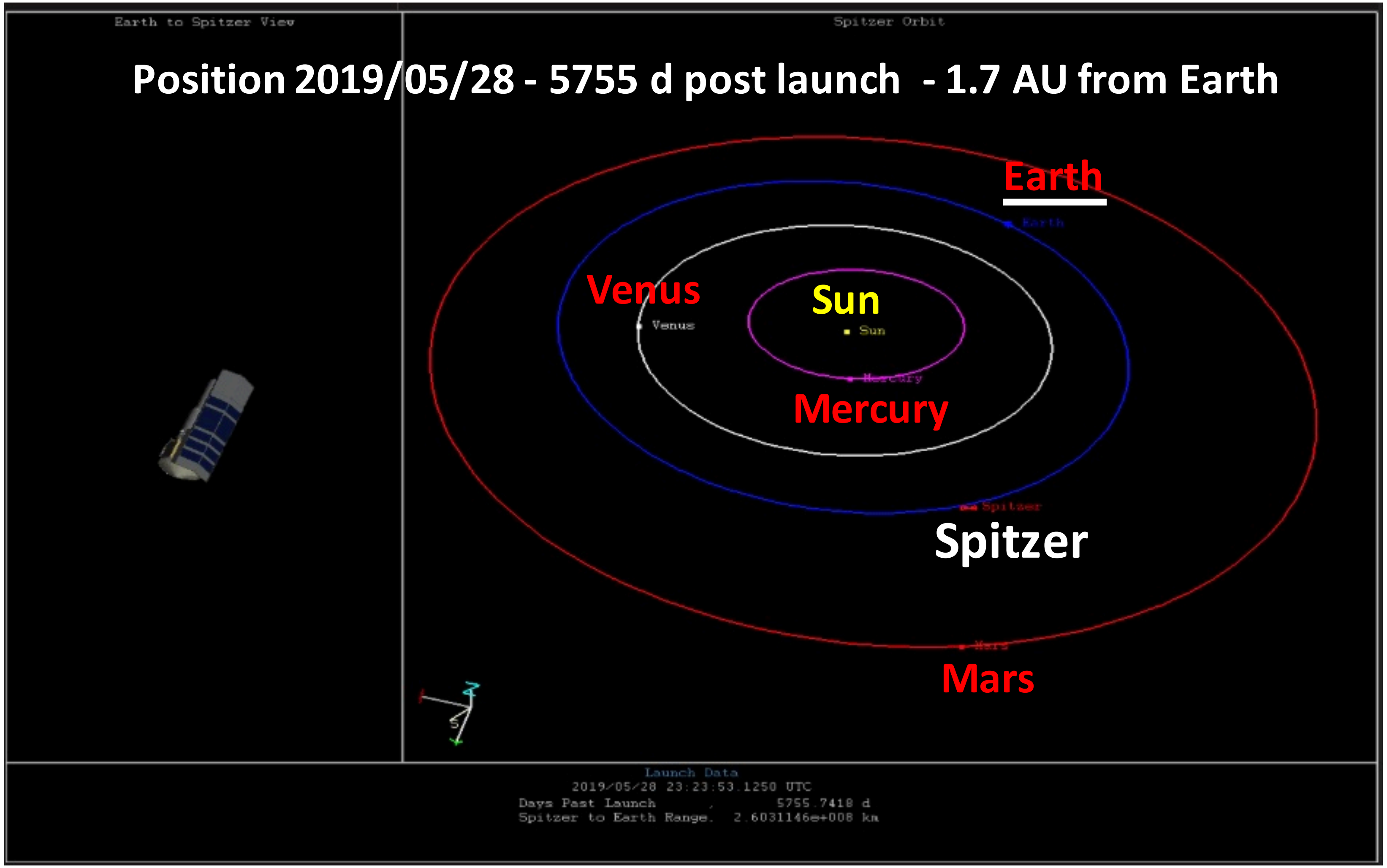
Telescope: 85 cm diameter

Camera: IRAC, $5.2' \times 5.2'$ fov, 3.6 μm channel, 1.2”/px

6 weeks visibility window toward the Bulge during the summer (2014-now)

Possibility for “almost ToO” scheduling mode

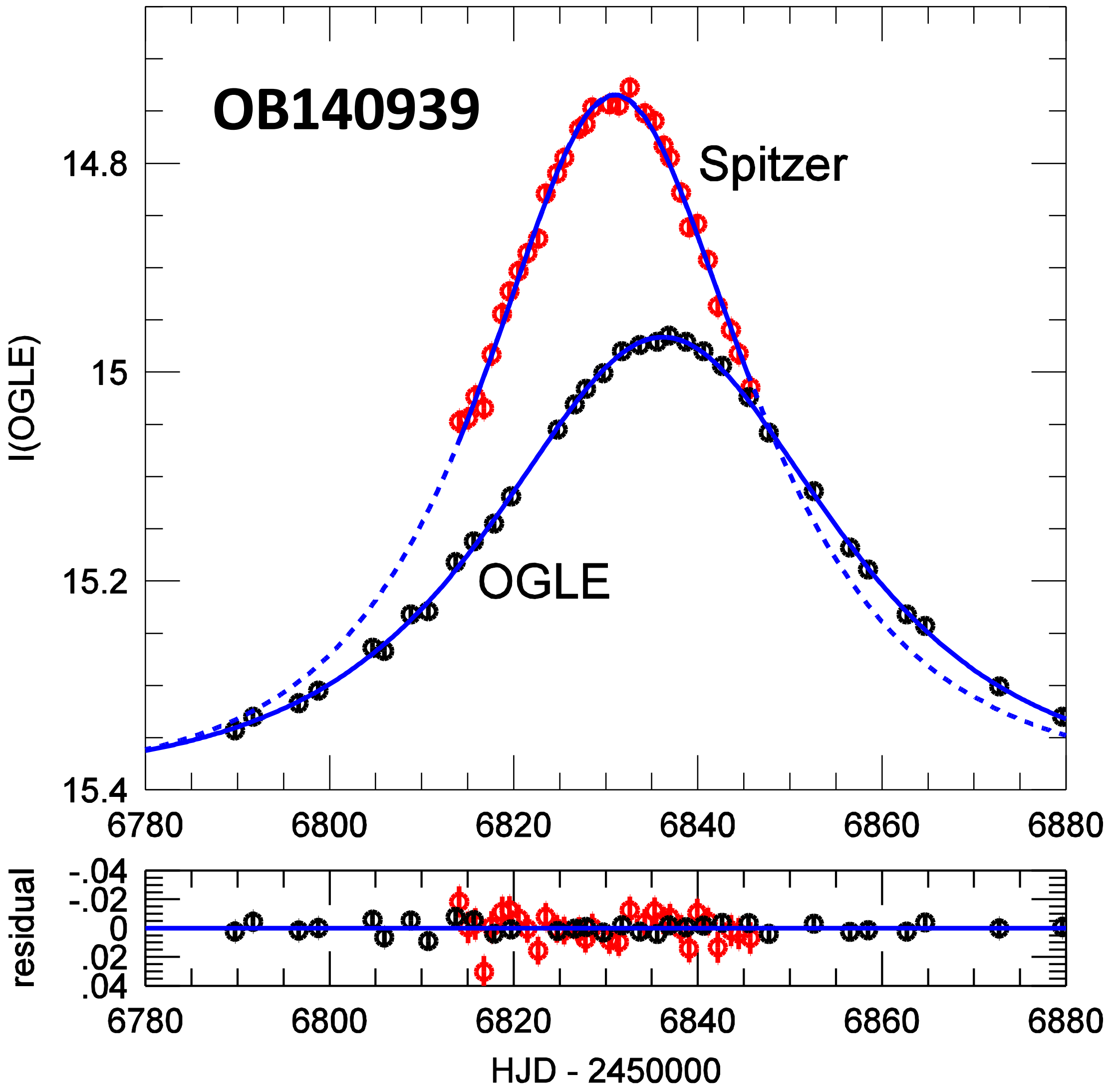
At $\mathcal{O}(1\ AU)$ Spitzer is the ideal second observer to measure the “satellite” microlensing parallax (Refsdal 1966, Gould 1994)



NASA/JPL

The microlensing parallax in the sky, π_E

It is not a small effect!



Yee, Udalski, SCN et al, 2015

Key to Measure the lens physical parameters

$$M = \frac{\theta_E}{k\,\pi_E} \qquad \pi_{rel} = \theta_E \pi_E$$

$$D_L = \frac{AU}{\pi_{rel} + \pi_S}$$

The angular Einstein radius, θ_E, is usually measured for planetary events – and occasionally for (high magnification) single-lens events - If not, the physical parameters can still be recovered at least statistically

The Spitzer Microlensing Campaign

follow up program for microlensing events selected from ground-based surveys (OGLE+MOA+KMT): ~ 2000/year

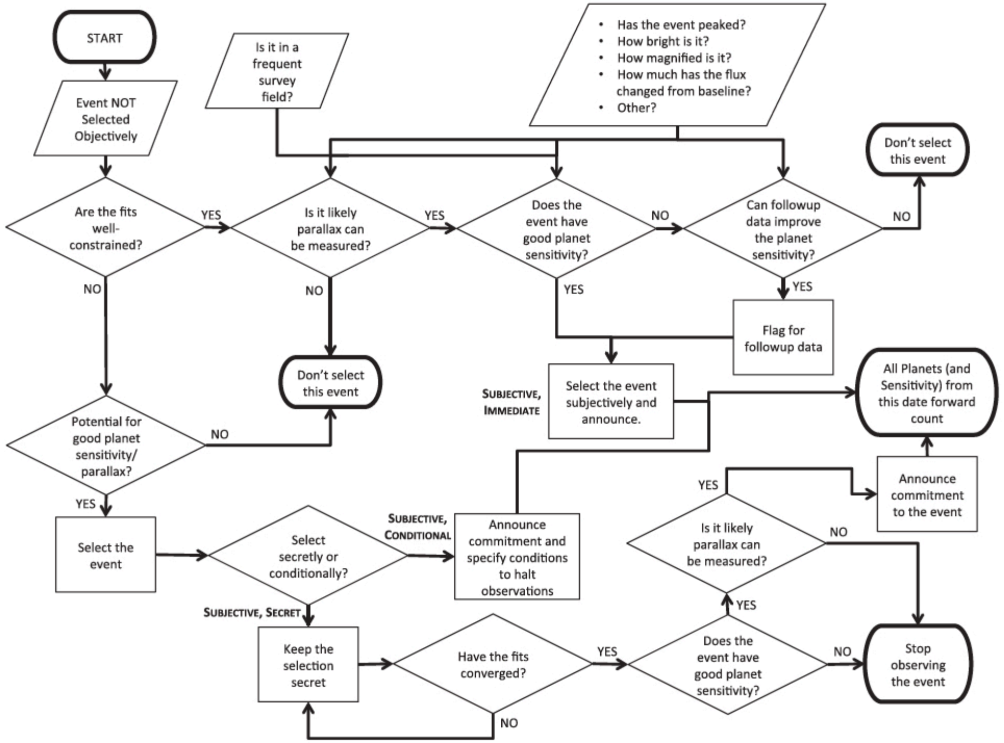
almost 800 events observed so far

✓	2014: 100 hr	62 evts	DDT program
✓	2015: 832 hr	169 evts	full Bulge visibility window
✓	2016: 350 hr	179 evts	partly overlaps with K2C9
✓	2017: 350 hr	176 evts	
✓	2018: 350 hr	177 evts	KMTNet alerts
➢	2019: 350 hr	ongoing	

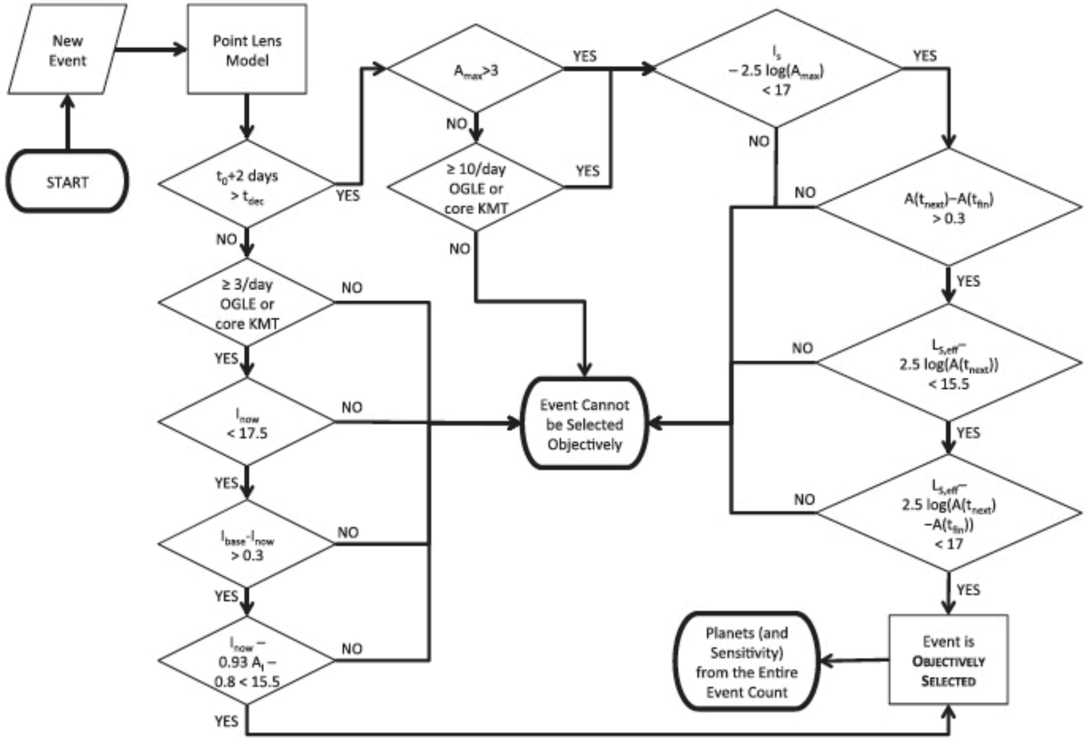
Towards the Galactic Distribution of Exoplanets

A follow-up microlensing campaign with a protocol for building a valid statistical sample

"subjective" criteria

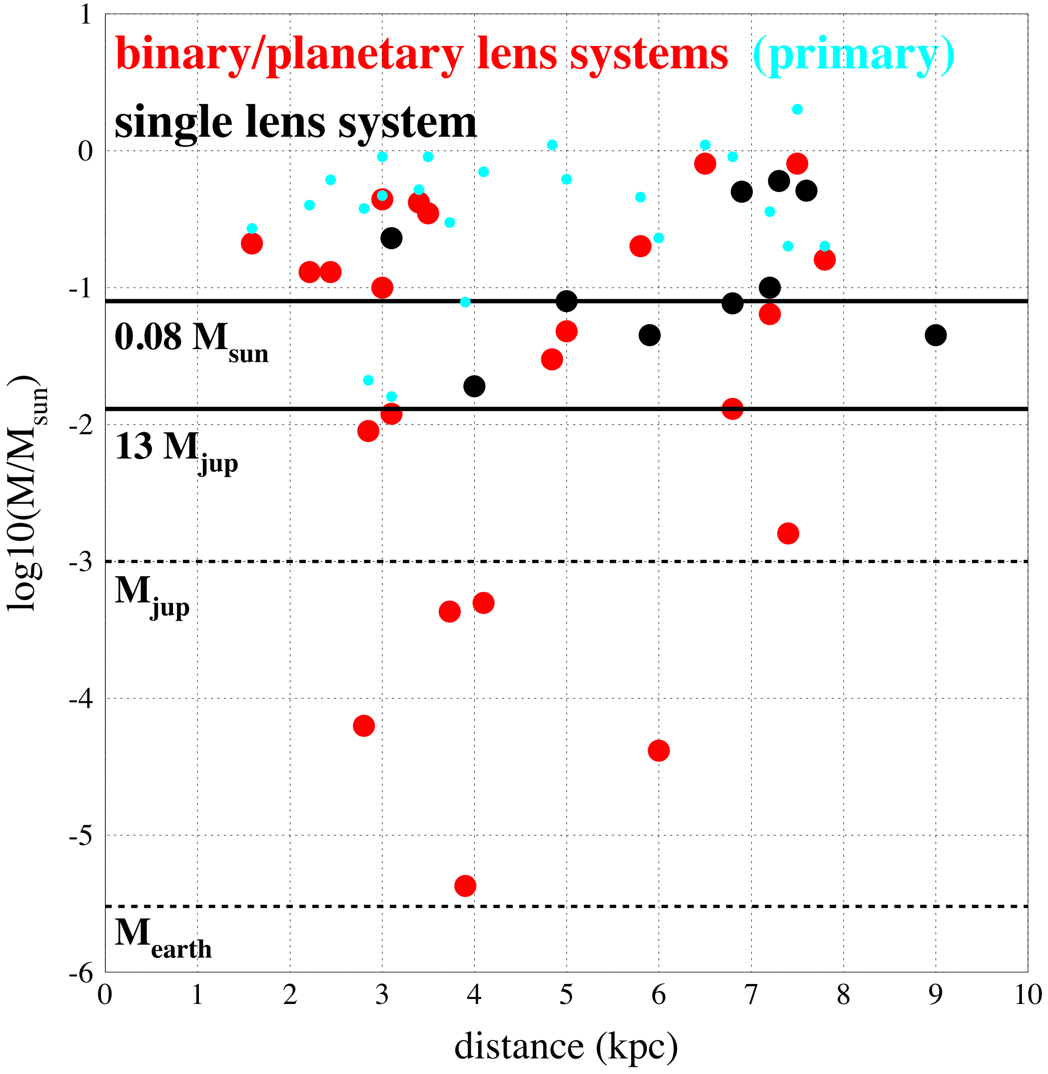


"objective" criteria



Yee+15

Spitzer Microlensing Campaign: 2014-2018



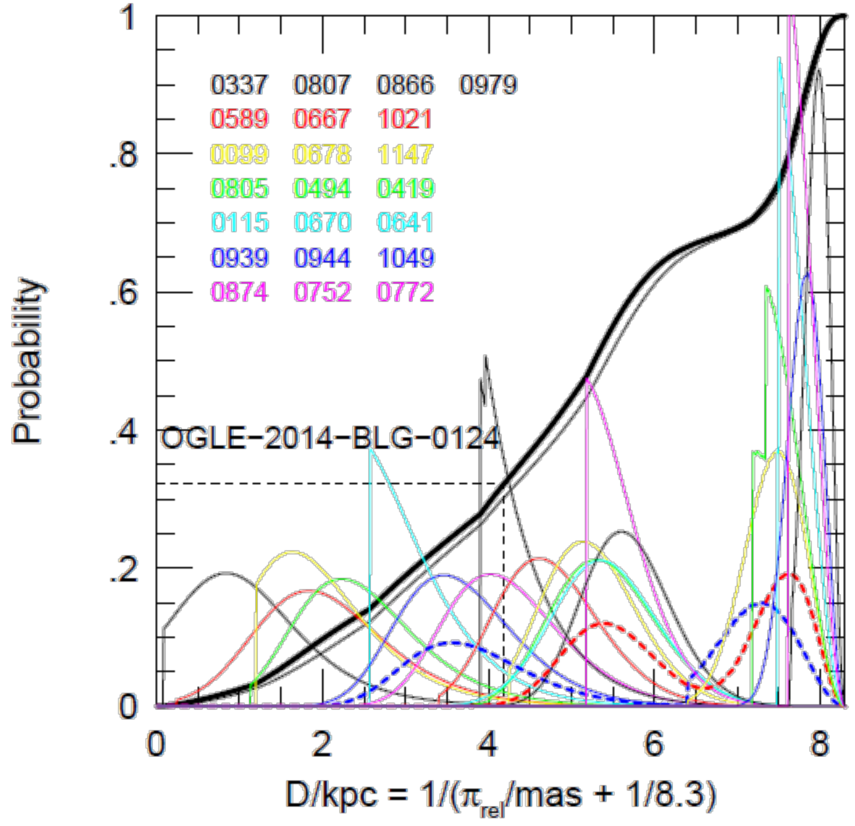
~760 microlensing events followed up so far

- ✓ **33 lens systems with well constrained physical parameters**
  - ➢ **7 planetary systems**
  - ➢ **16 binary lens systems**
    - ❑ **1 massive remnant in a well-separated binary**
    - ❑ **2 brown dwarf- brown dwarf systems**
    - ❑ **3 systems with a brown dwarf companion**
  - ➢ **10 single lens systems**
    - ❑ **2-4 brown dwarf lenses**
    - ❑ **1 Earth-Spitzer-K2C9 lens**
- ✓ **62 single lens systems with measured microlensing parallax and statistical-based evaluation of the lens physical parameters** *(not shown in the plot)*

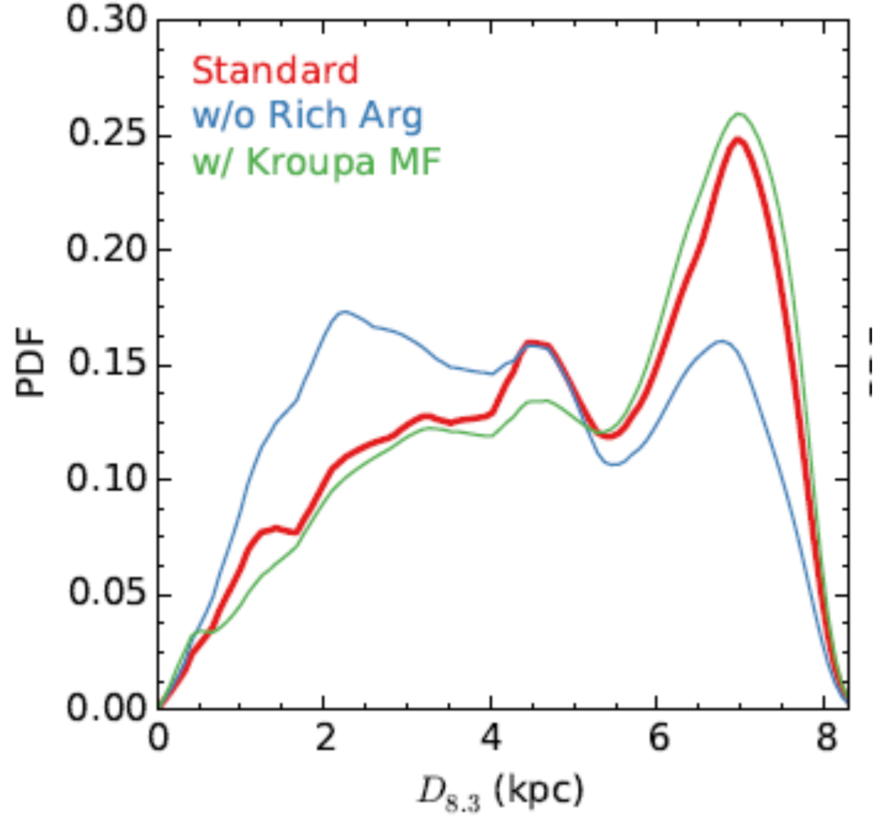
Towards the Galactic Distribution of Exoplanets

The Single Lens System Control Sample

Calchi Novati+ (2015)



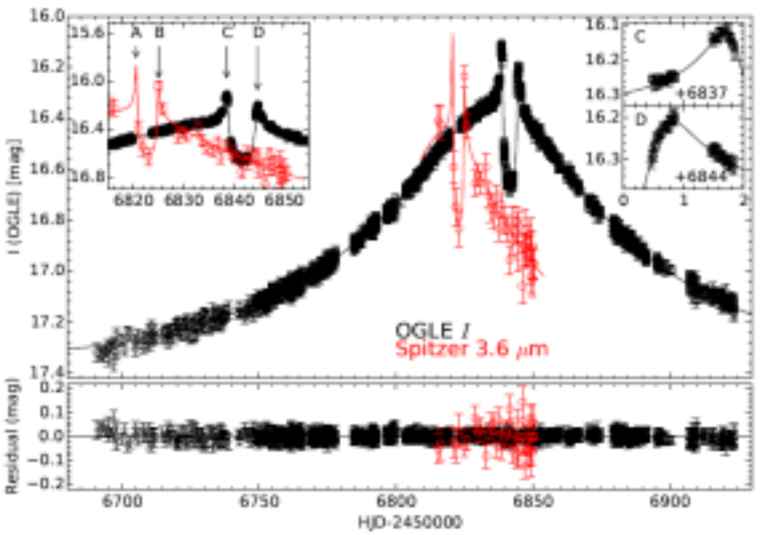
Zhu+ (2017)



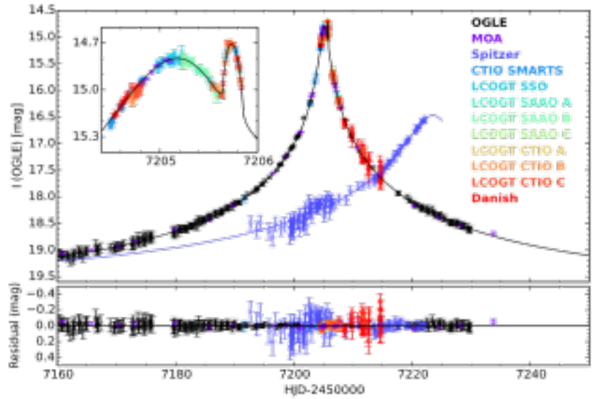
Disk planet sensitivity ≈ 2x Bulge planet sensitivity

Zhu+ (2017)

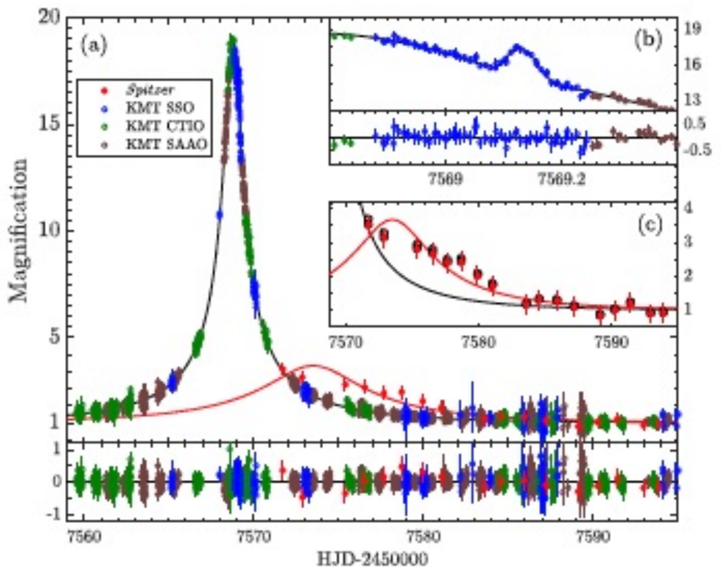
Spitzer Microlensing Campaign Exoplanets



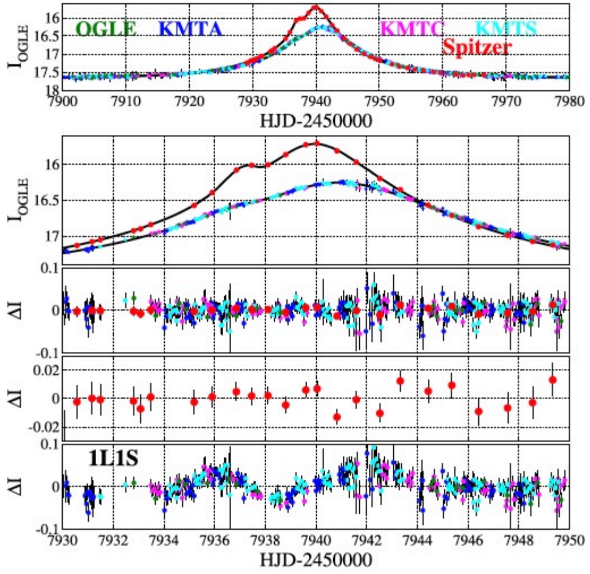
OGLE-2014-BLG-0124



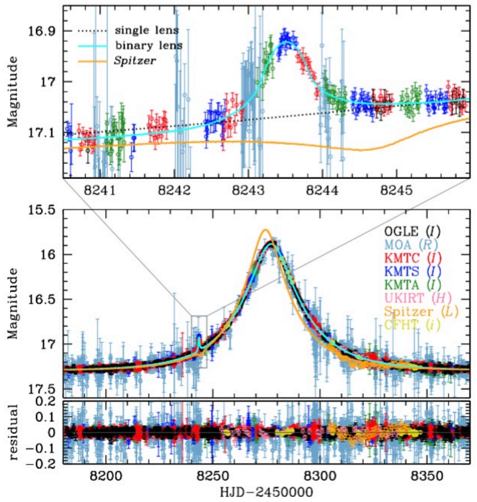
OGLE-2015-BLG-0966



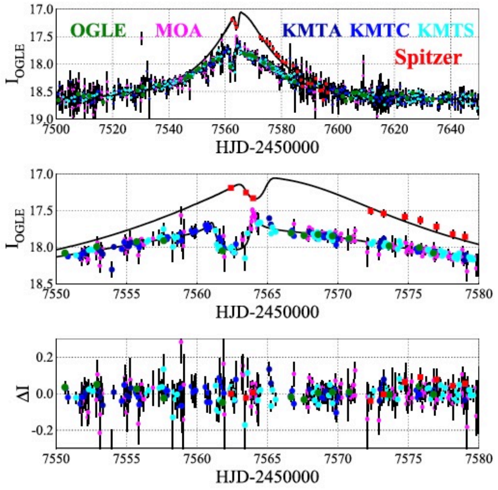
OGLE-2016-BLG-1195



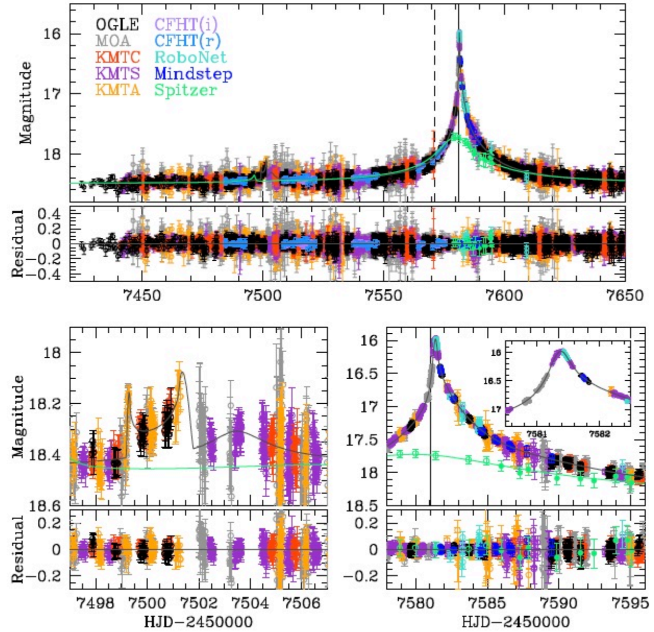
OGLE-2017-BLG-1140



OGLE-2018-BLG-0596



OGLE-2016-BLG-1067



OGLE-2016-BLG-1190

Galactic Distributions of Exoplanets

OGLE-2014-BLG-0124	$0.5\ M_J$	4.1 kpc	Udalski+ (2015)
OGLE-2015-BLG-0966	$21\ M_\oplus$	3.1 kpc	Street+ (2016)
OGLE-2016-BLG-1195	$1.4\ M_\oplus$	3.9 kpc	Shvartzvald+ (2017)
OGLE-2016-BLG-1190	$13\ M_J$	6.7 kpc	Ryu+ (2018)
OGLE-2017-BLG-1140	$1.6\ M_J$	7.3 kpc	Calchi Novati+ (2018)
OGLE-2016-BLG-1067	$0.4\ M_J$	3.7 kpc	Calchi Novati+ (2019)
OGLE-2018-BLG-0596	$13.9\ M_\oplus$	6. kpc	Jung+ (2019, *submitted*)

Disk-Bulge 3-2 (4-1?)

and OB170406, OB180799, OB180932, KB180029, ….