

Terry et al. 2022 "Adaptive Optics Imaging Can Break
the Central Caustic Cusp Approach Degeneracy in
High-magnification Microlensing Events"

MCMC-Jackknife method

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31.10.2023

- 1 Microlensing event OB110950
- 2 Jackknife method
- 3 DAOPhot, MCMC, and Jackknife

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Central caustic degeneracy

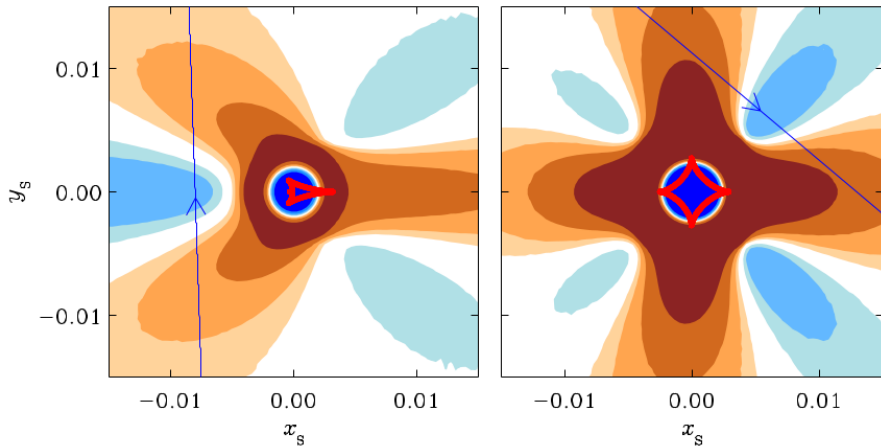
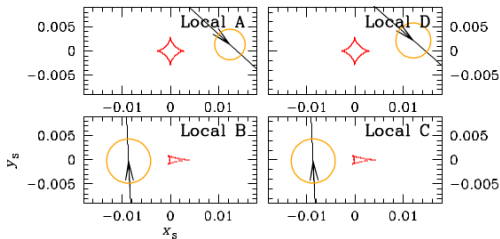
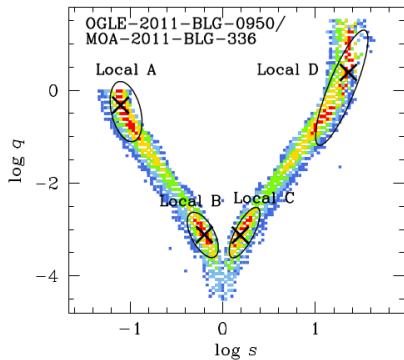


Figure 1. Central caustics induced by a planetary (left panel) and a binary companion (right panel). The regions with brownish and bluish colors represent the areas where the lensing magnification is higher and lower than the corresponding single-lensing magnification, respectively. For each tone, the color changes to darker shades when the fractional difference between the single and binary magnification is $>2\%$, 4% , 8% , and 16% , respectively.

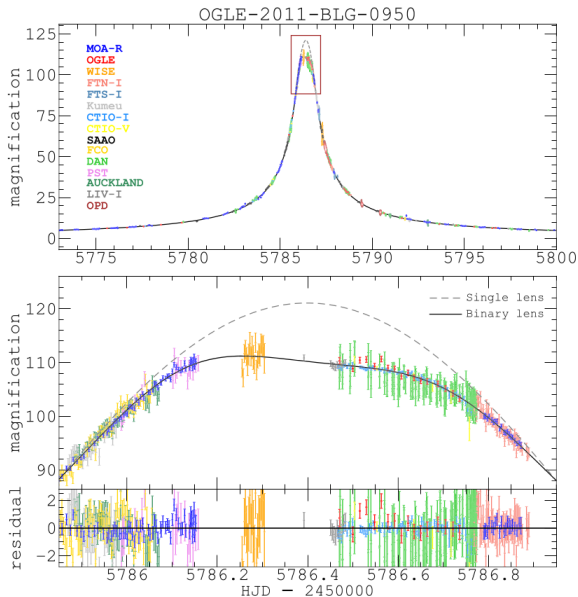
Central caustic degeneracy – the case of OB110950



Choi et al. (2012)

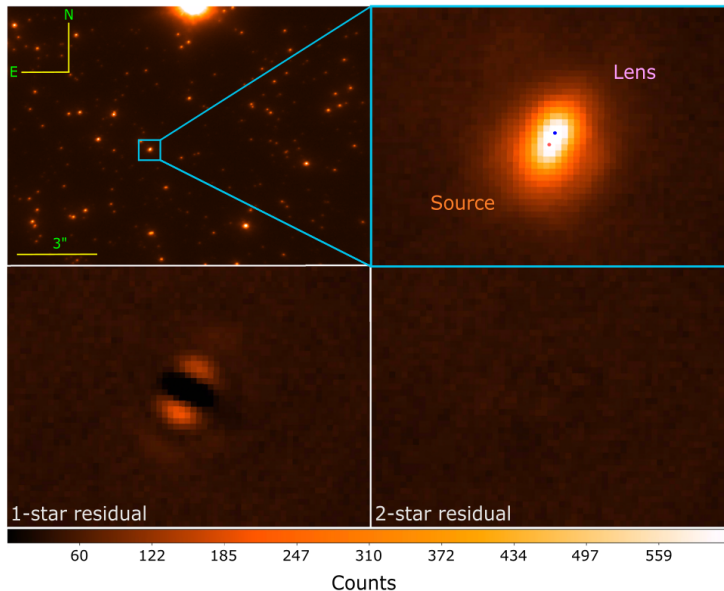
Seems to be the most problematic degeneracy for analysis of microlensing data from Roman Space Telescope.

OB110950 light curve – Terry et al. 2022

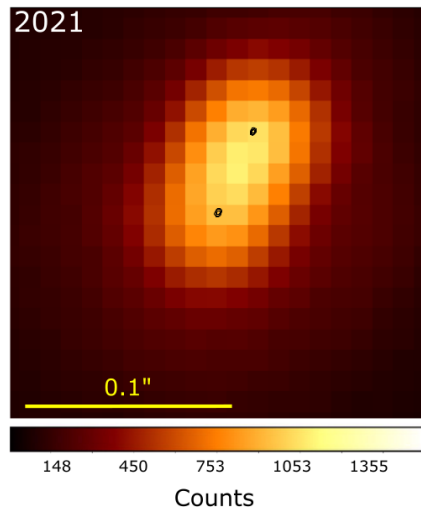
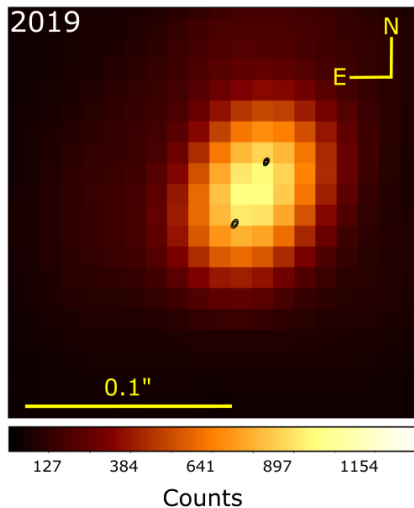


$\Delta\chi^2$ of
105 (Choi et al. 2012),
20 (Suzuki et al. 2016), or
27 (Terry et al. 2022)

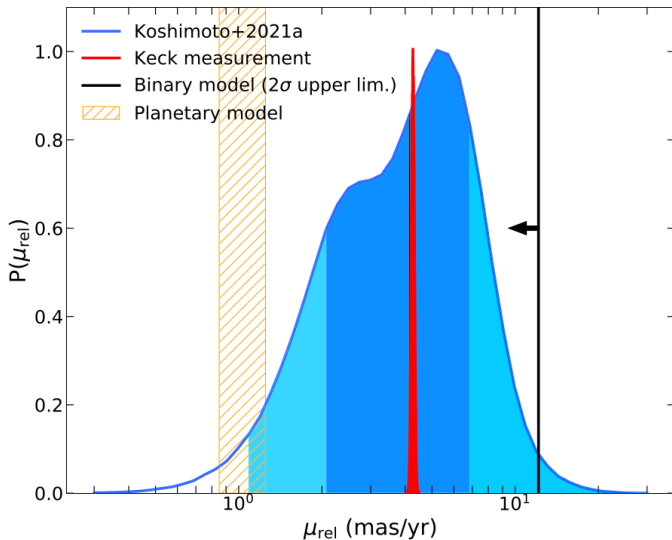
Keck AO follow-up in 2021 (Terry et al. 2022)



Keck AO follow-up in 2021 – derived centroids



Relative proper motion comparison

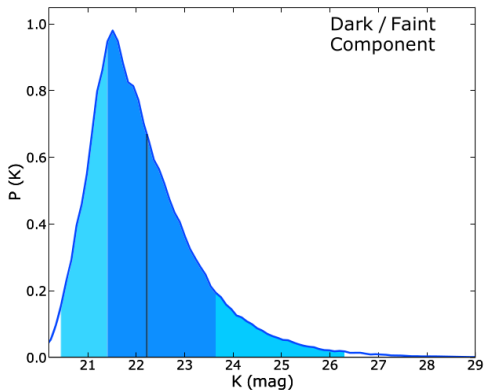
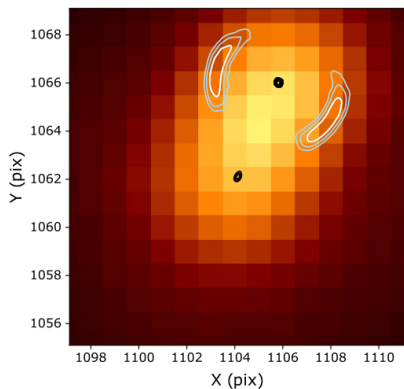


close binary:
 3.95 ± 4.10
 mas yr^{-1}

wide planet:
 1.05 ± 0.20
 mas yr^{-1}

Terry et al. (2022)

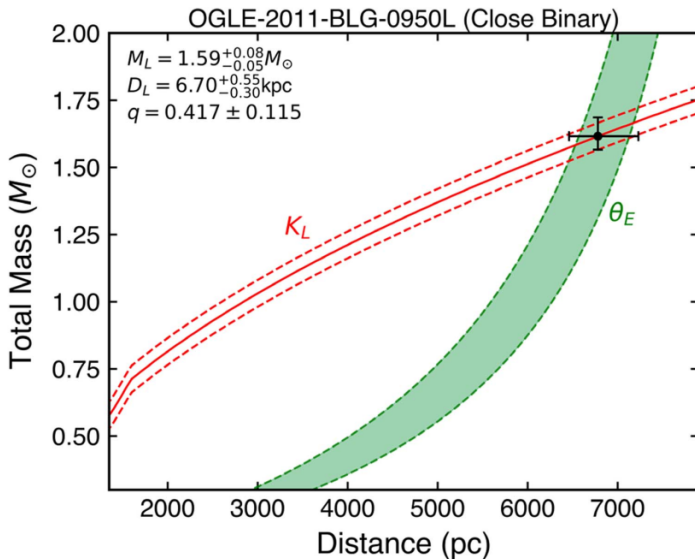
Search for wide-orbit companion to the lens



Terry et al. (2022)

Flux ratios from DAOPhot_MCMC are inconsistent with predictions from microlensing model.

Final result – lens distance and mass



1 Microlensing event OB110950

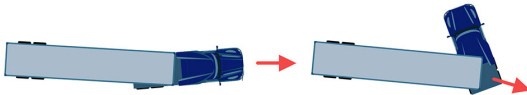
2 Jackknife method

3 DAOPhot, MCMC, and Jackknife

Jackknife



Jackknifing



Trailer Swing



- 1 From the data set of N elements, remove an element i .
- 2 Conduct your analysis – the result is x_i .
- 3 Repeat steps 1. and 2. for all i from 1 to N , resulting in $x_1, x_2 \dots x_N$.
- 4 Calculate mean value \bar{x} .
- 5 Calculate uncertainty:

$$\sqrt{\frac{N-1}{N} \sum (x_i - \bar{x})^2}$$

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Standard DAOPhot procedure

Package for crowded-field photometry by Peter Stetson (almost 6,000 citations).

- 1 estimate background level,
- 2 find stars,
- 3 construct PSF using brightest stars,
- 4 fit all stars using maximum-likelihood method,
- 5 subtract stars, search for new ones, re-fit everything.

```
-----  
COMPUTER TYPES:                                YOU ENTER:  
Command:                                       DU  
                                             Box size:    9  
Coordinates of central pixel:    201,378  
-----  
COMPUTER TYPES:  
      197  198  199  200  201  202  203  204  205  
-----  
383 | 543  556  600  633  643  630  589  538  514  
382 | 581  644  760  884  930  865  732  623  570  
381 | 651  864 1248 1823 2062 1657 1116  800  626  
380 | 775 1303 2791 5995 7442 4802 2166 1096  732  
379 | 916 1955 5933 16430 22029 11974 4104 1526  846  
378 | 977 2259 6364 16623 23622 13658 4751 1762  933  
377 | 936 1836 3878 7751 10436 7269 3380 1611  949  
376 | 798 1217 1963 3179 3815 3109 2006 1273  861  
375 | 656  847 1138 1563 1778 1621 1300 1003  790  
374 | 602  682  798  962 1090 1073  959  824  698  
373 | 550  587  653  729  801  807  782  705  638  
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Minimum, median, maximum:    570  1248 23622  
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DAOPhot and images of lenses and sources

No need to search for stars – manually provided number (1, 2, or 3).

MCMC used instead of maximum-likelihood.

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$$\chi^2 = \sum_{ij} w_{ij} [P_{ij} - s_* - f_1 \psi_E(i - x_1, j - y_1) + (1 - f_1) \psi_E(i - x_2, j - y_2)]^2.$$

Bhattacharya et al. (2017)

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MCMC used instead of maximum-likelihood.

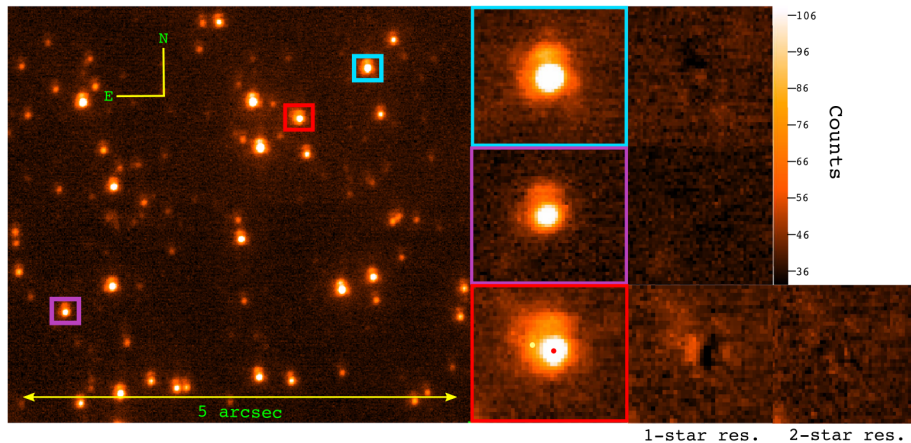
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Bhattacharya et al. (2017)

Jackknife method used to account for uncertainties due to PSF variations in individual images.

Other example – MB09319 by Terry et al. 2021



- The correct model of OB110950 is disfavoured by the photometry – good test case for Bayesian methods.
- MCMC combined with DAOPhot is used to measure stellar positions and fluxes.
- Jackknife analysis was used to account for uncertainties in PSF.

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