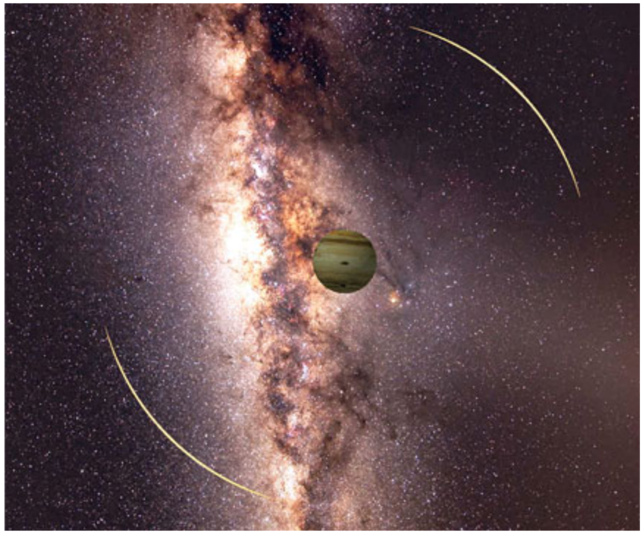
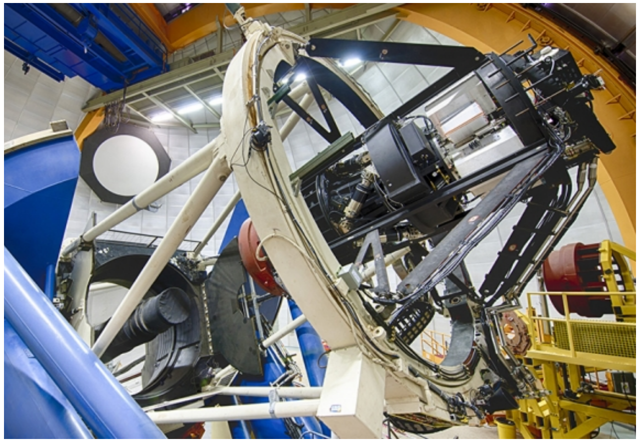
Measuring the Free-Floating Planet Mass Function with K2 & DECam





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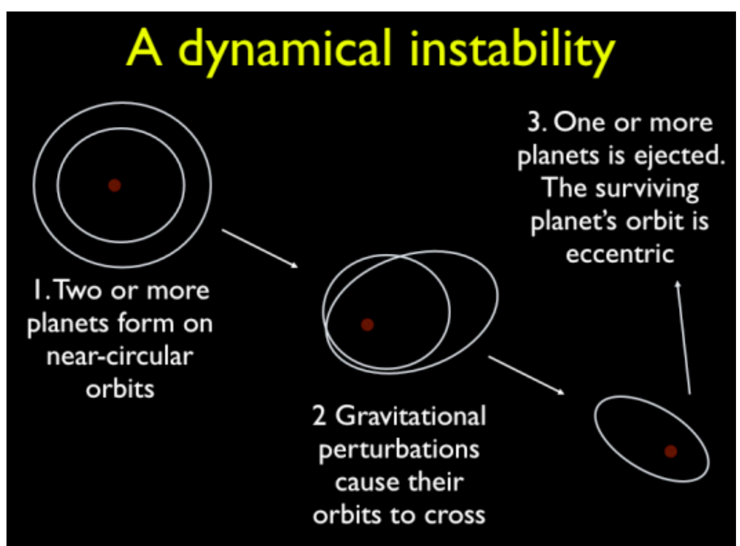
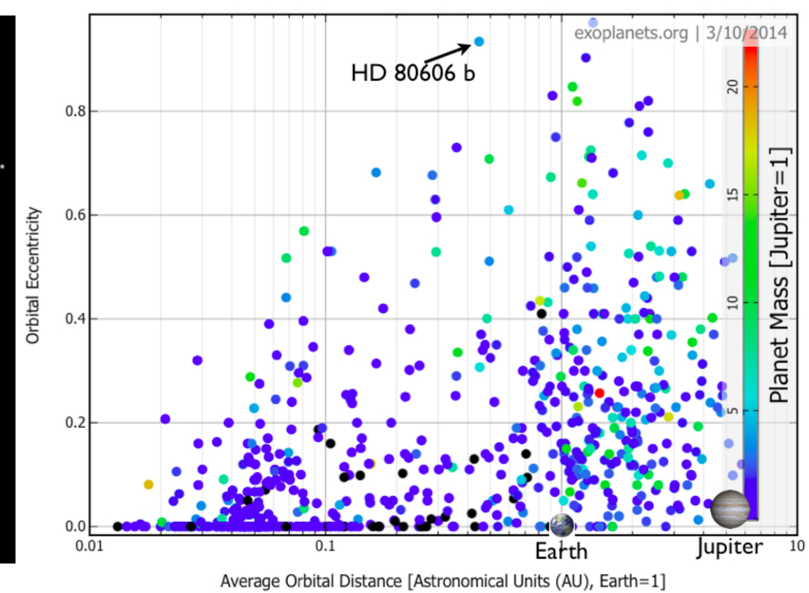
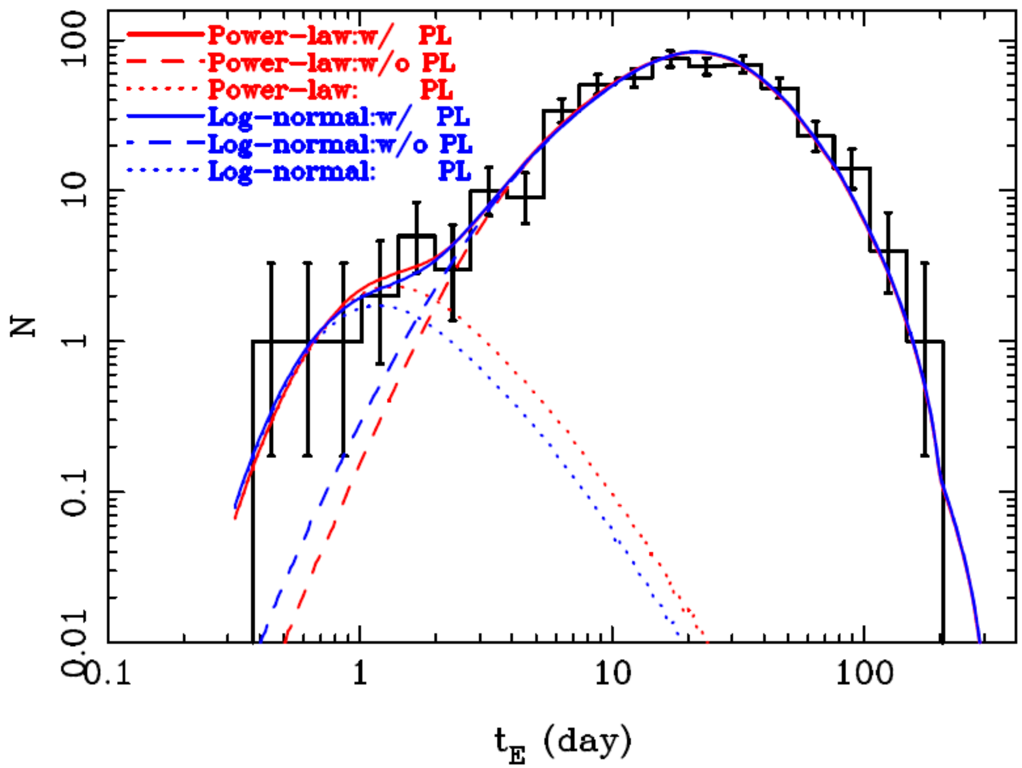
Free-Floating Planets

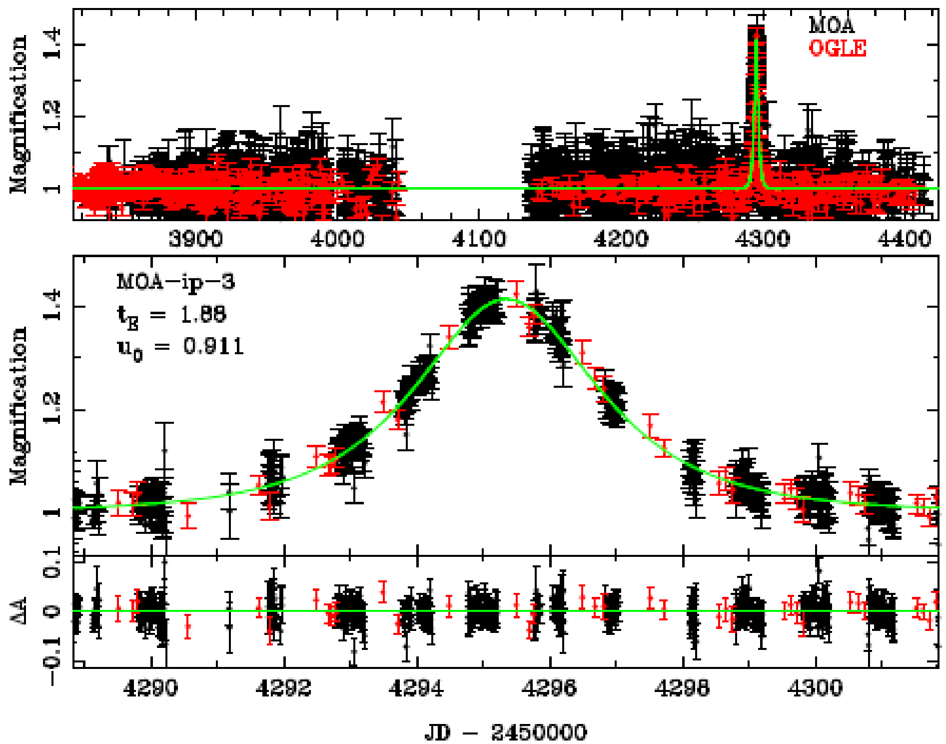
- Planets without host stars
- Probably form in low numbers as failed stars
- More probably formed through ejections of planets after protoplanetary disk dissipation
- **Their mass distribution bears the fingerprints of the formation and subsequent evolution of planetary systems**
- **K2 offers a one-time opportunity to measure their masses**





Finding Free-floating Planets with Microlensing





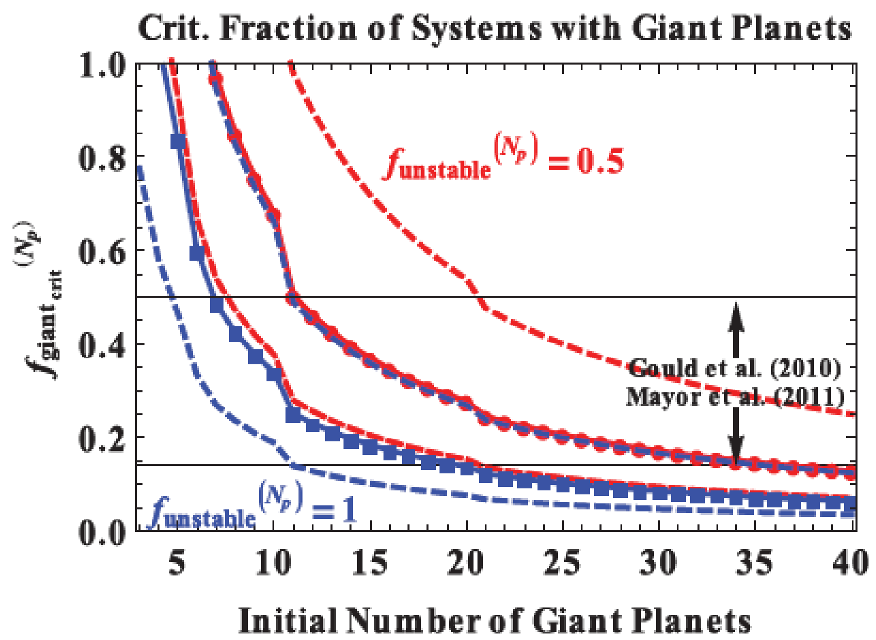
MOA microlensing survey – found 11 short duration microlensing events

Implies 1.9 Free-floating Jupiters per star!

So many free-floating planets is very hard to explain

Planet–planet scattering alone cannot explain the free-floating planet population

Dimitri Veras[1★] and Sean N. Raymond[2,3★]

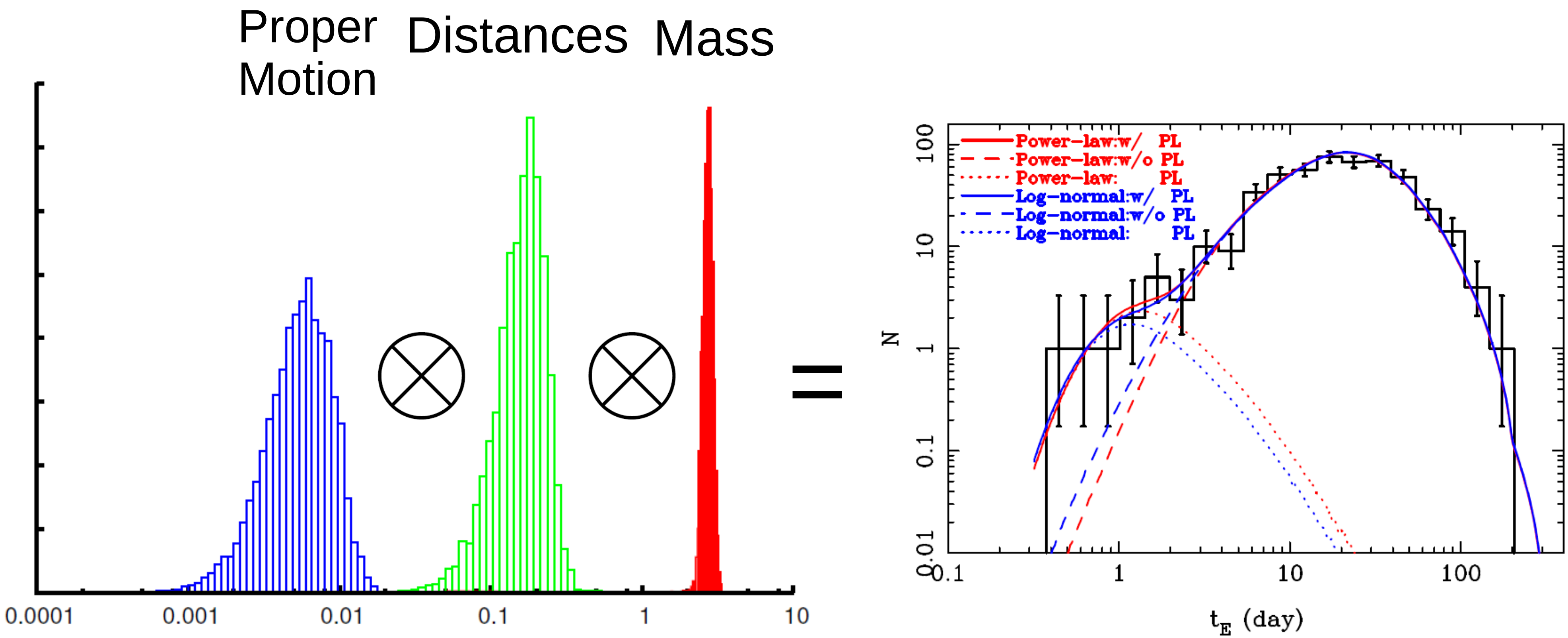


SUBSTELLAR OBJECTS IN NEARBY YOUNG CLUSTERS (SONYC). VI. THE PLANETARY-MASS DOMAIN OF NGC 1333

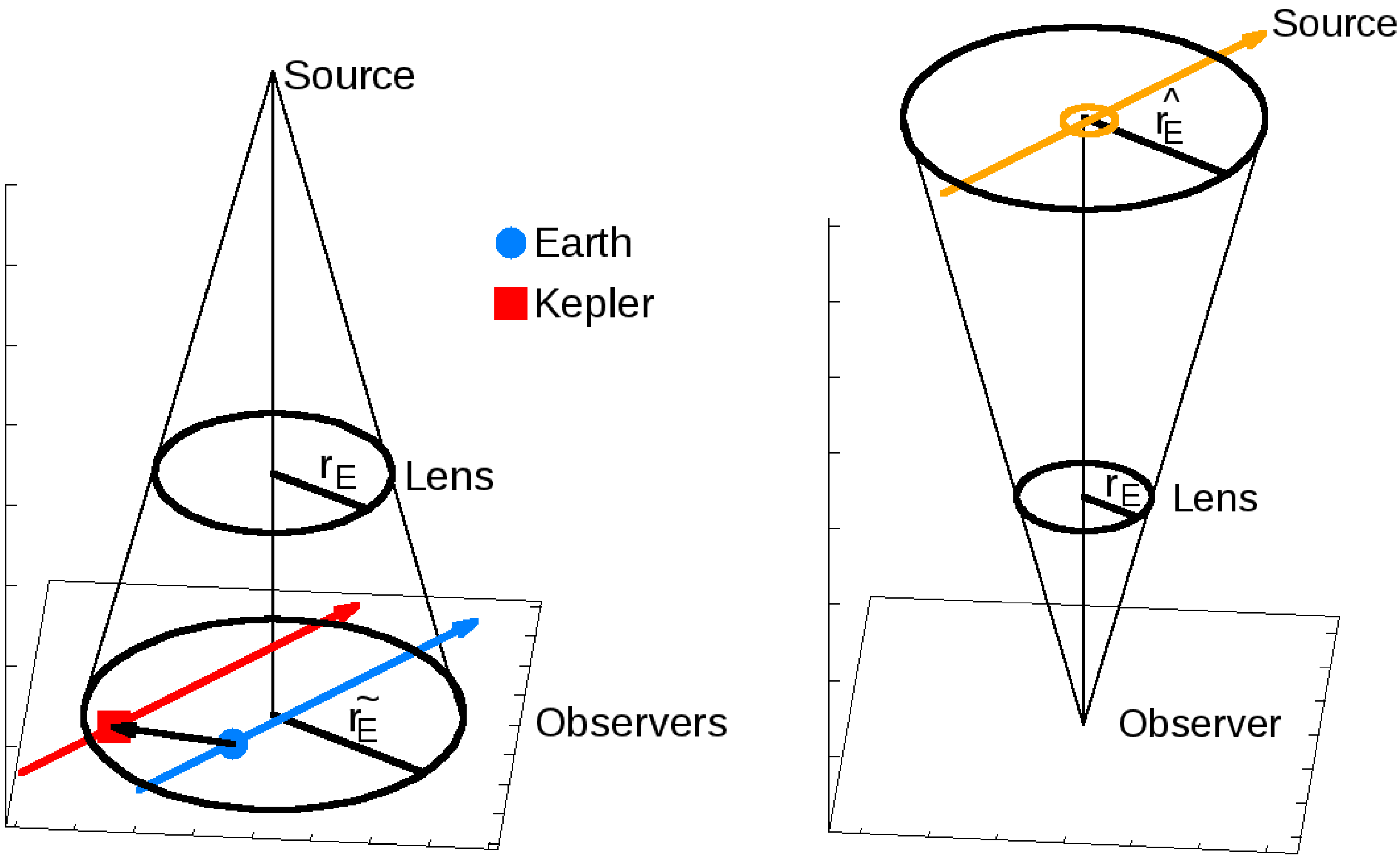
Alexander Scholz[1], Ray Jayawardhana[2,6], Koraljka Muzic[2], Vincent Geers[3], Motohide Tamura[4], and Ichi Tanaka[5]

down to 6 $M_{\rm Jup}$. However, given that planemos are 20–50 times less numerous than stars, their contribution to the object number and mass budget in young clusters is negligible. Our findings disagree strongly with the recent claim from a microlensing study that free-floating planetary-mass objects are twice as common as stars—if the

Progress Requires Mass Distribution



Deconvolving the Timescale Distribution



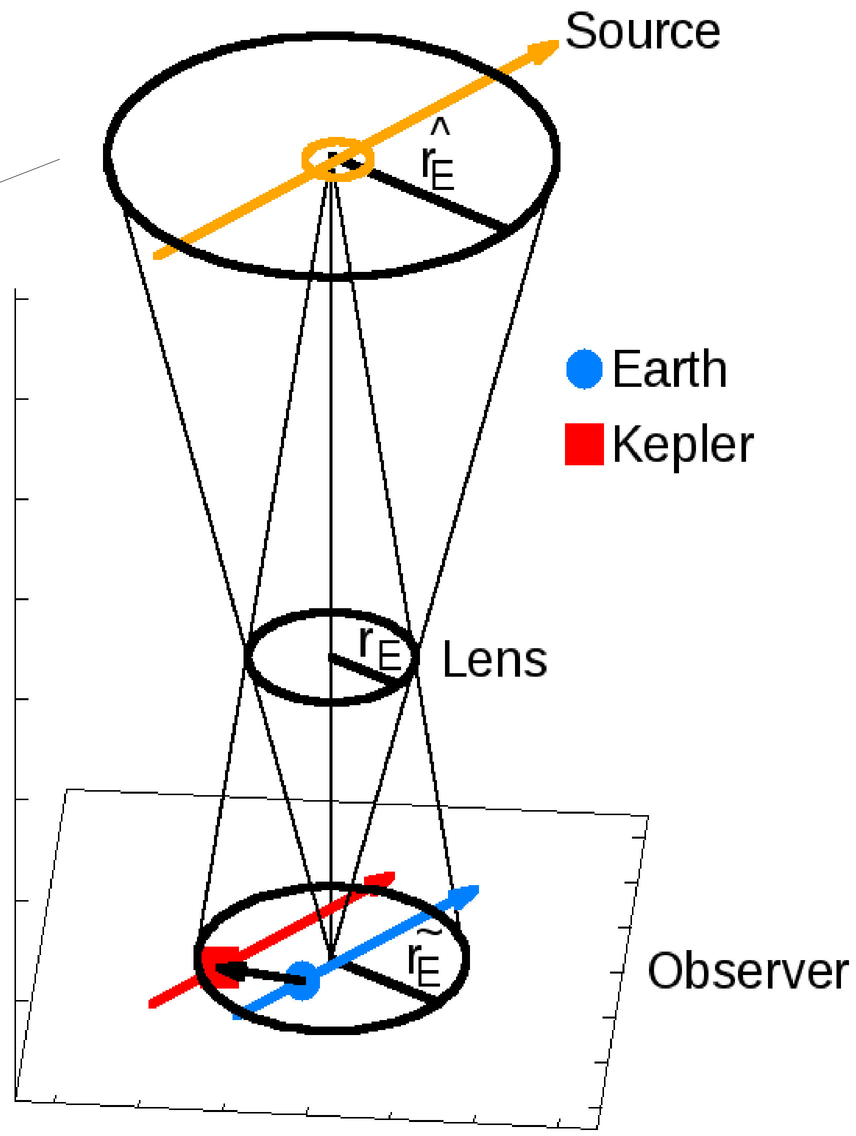
Measuring the Mass of a Free-Floating Planet

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

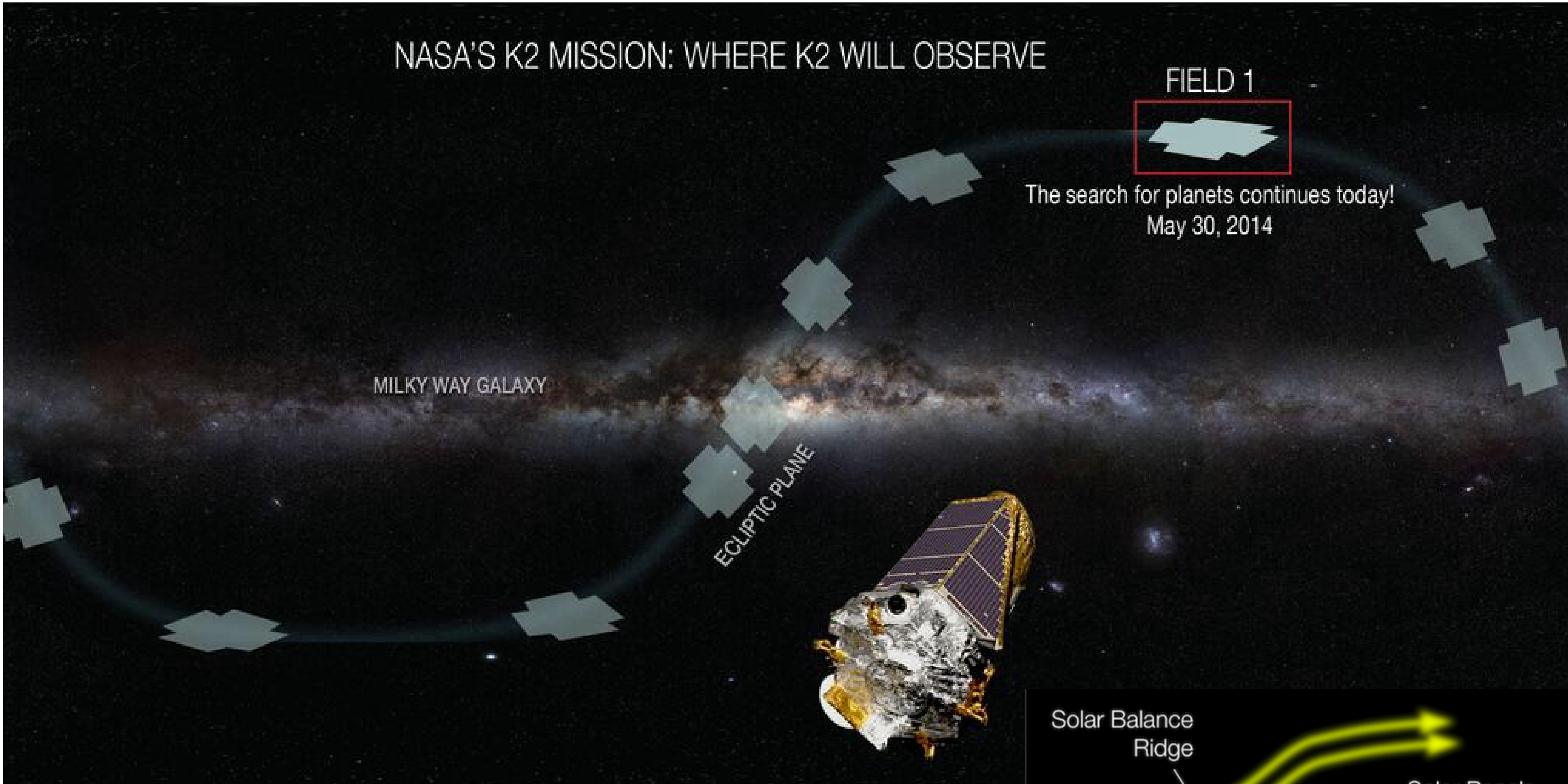
$$M = \frac{\theta_{\rm E}\pi_{\rm E}}{\kappa}$$

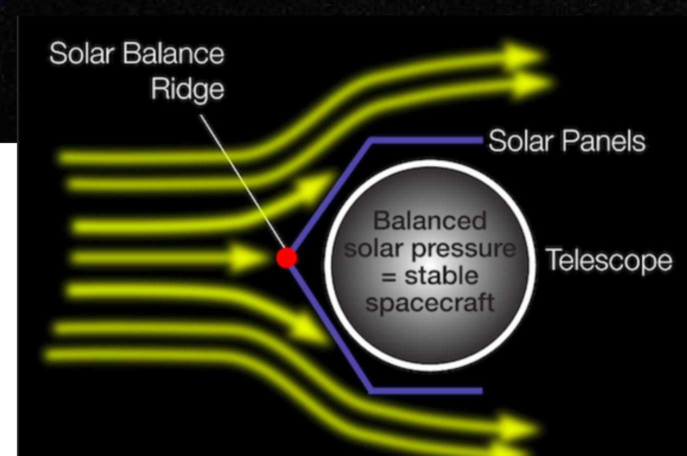
Constant

- Parallax baseline measures other projection

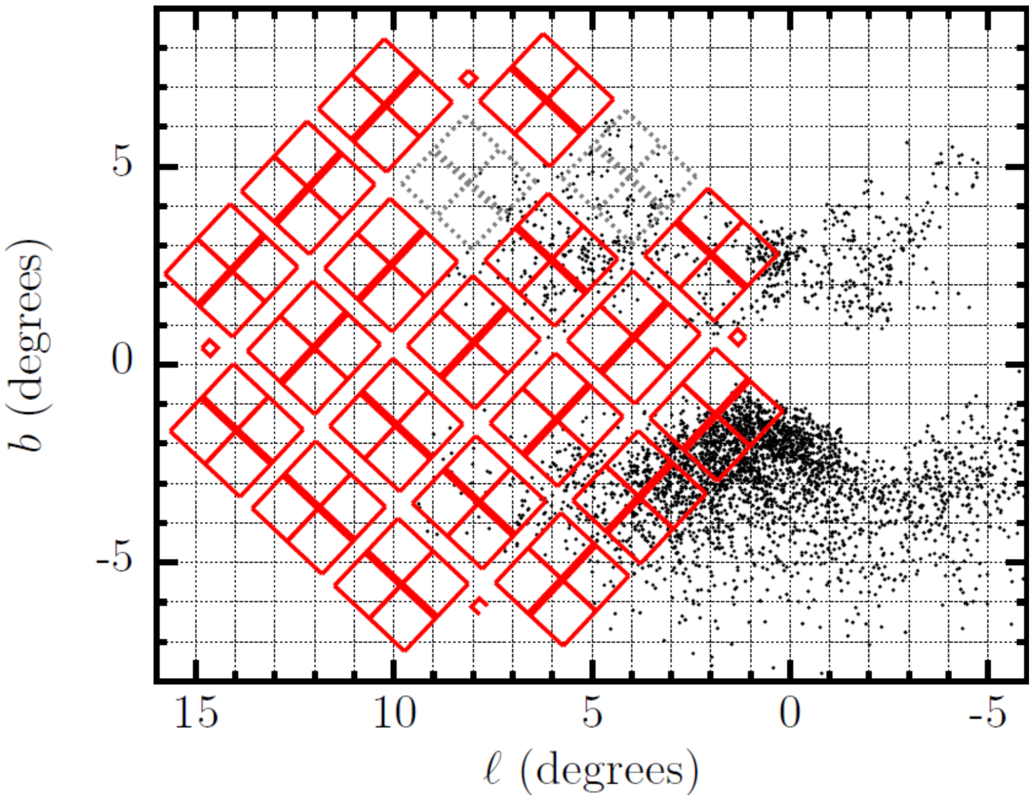


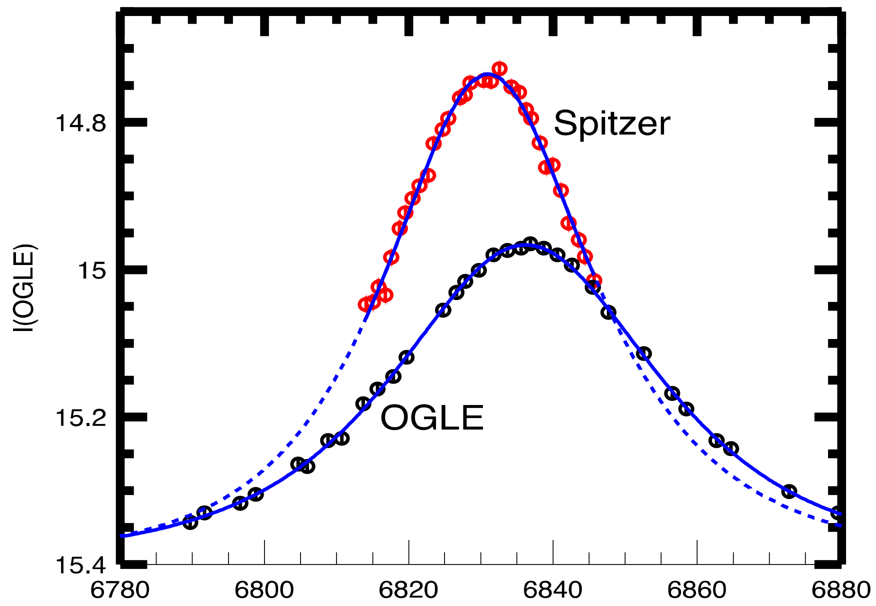
The K2 mission

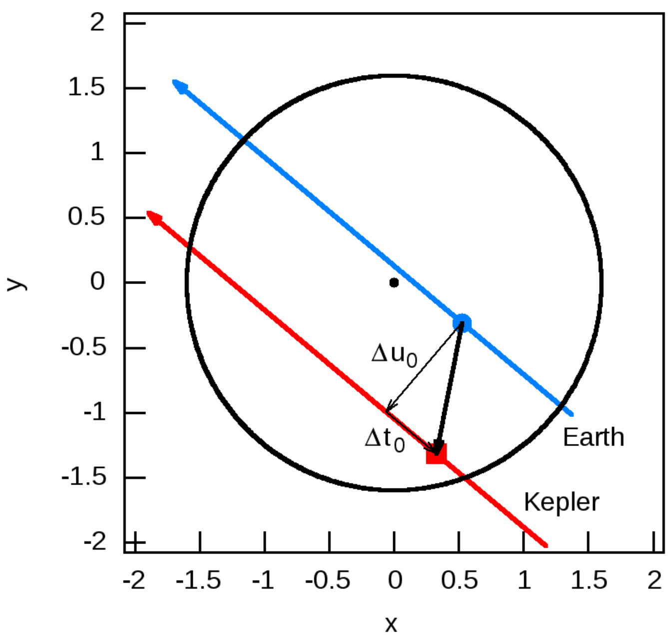




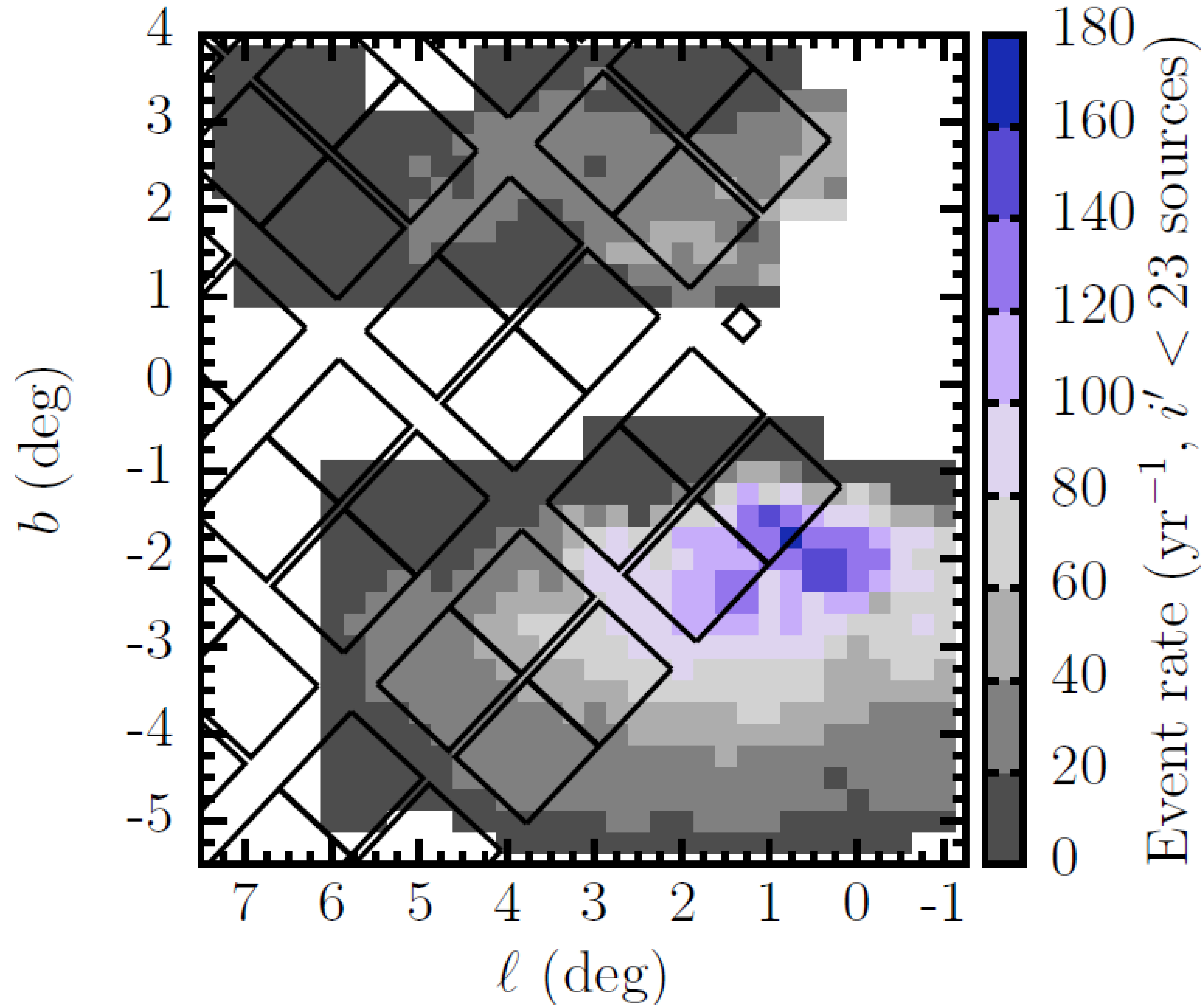
K2 Campaign 9







- 80+ day campaign Apr-Jun 2016
- Target Galactic Bulge to search for microlensing, ~5 sq deg
- Earth-K2 parallax baseline potentially enables mass and distance measurement of stars and planets



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0
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-2
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-4
-5
b (deg)
7
6
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4
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2
1
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-1
ℓ (deg)
180
160
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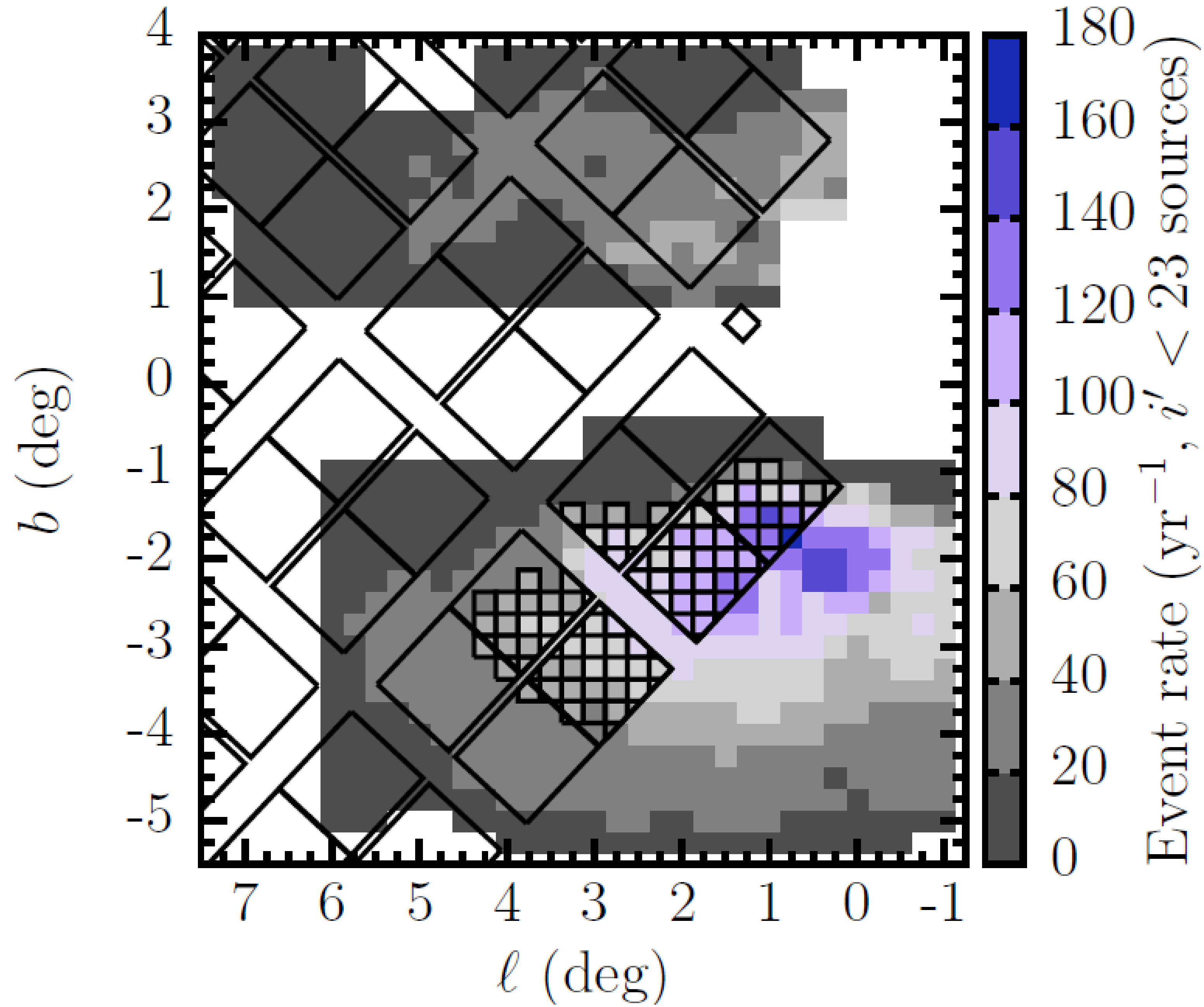
40
20
0
Event rate (yr^{-1}, $i' < 23$ sources)



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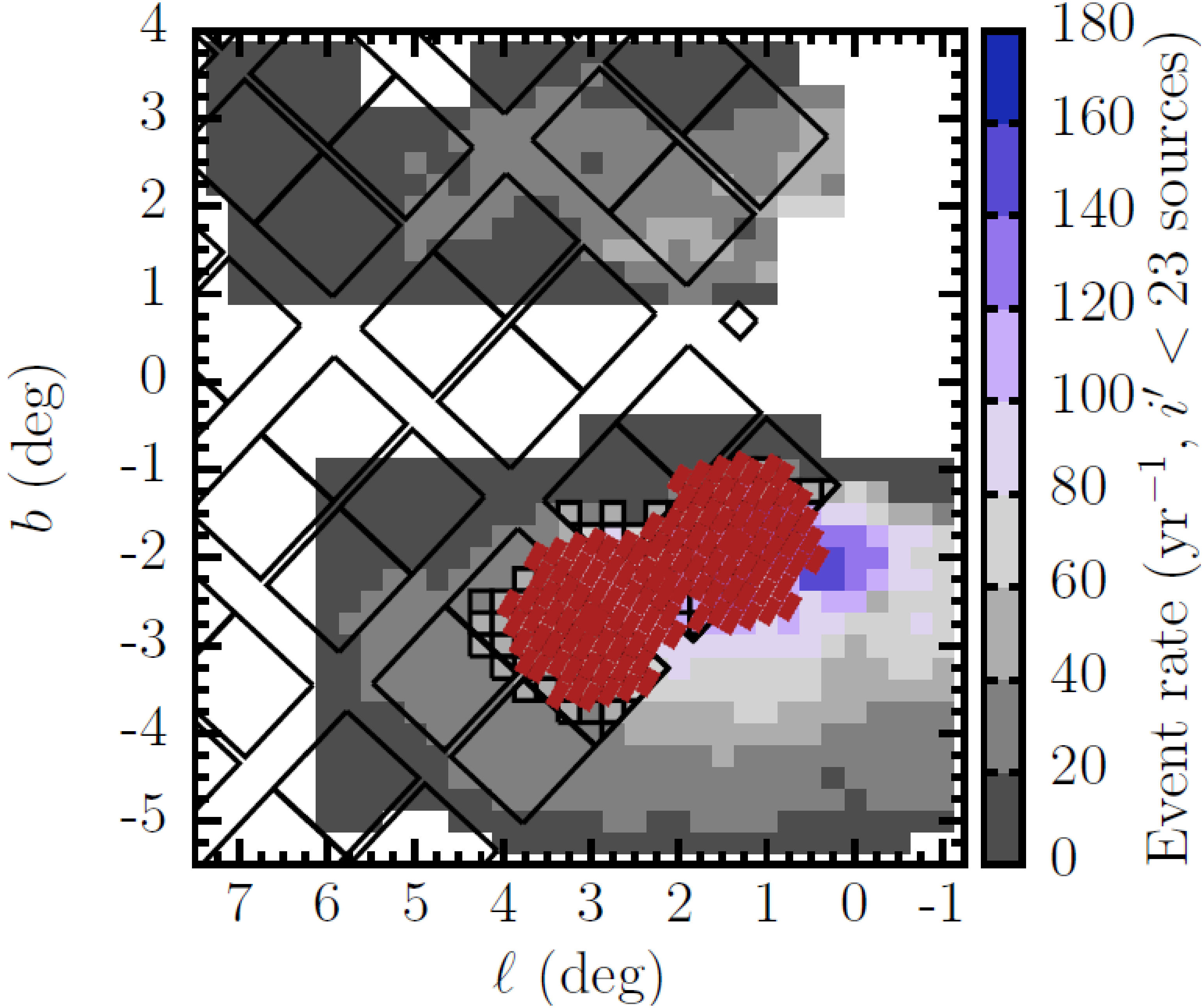

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ℓ (deg)
180
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140
120
100
80
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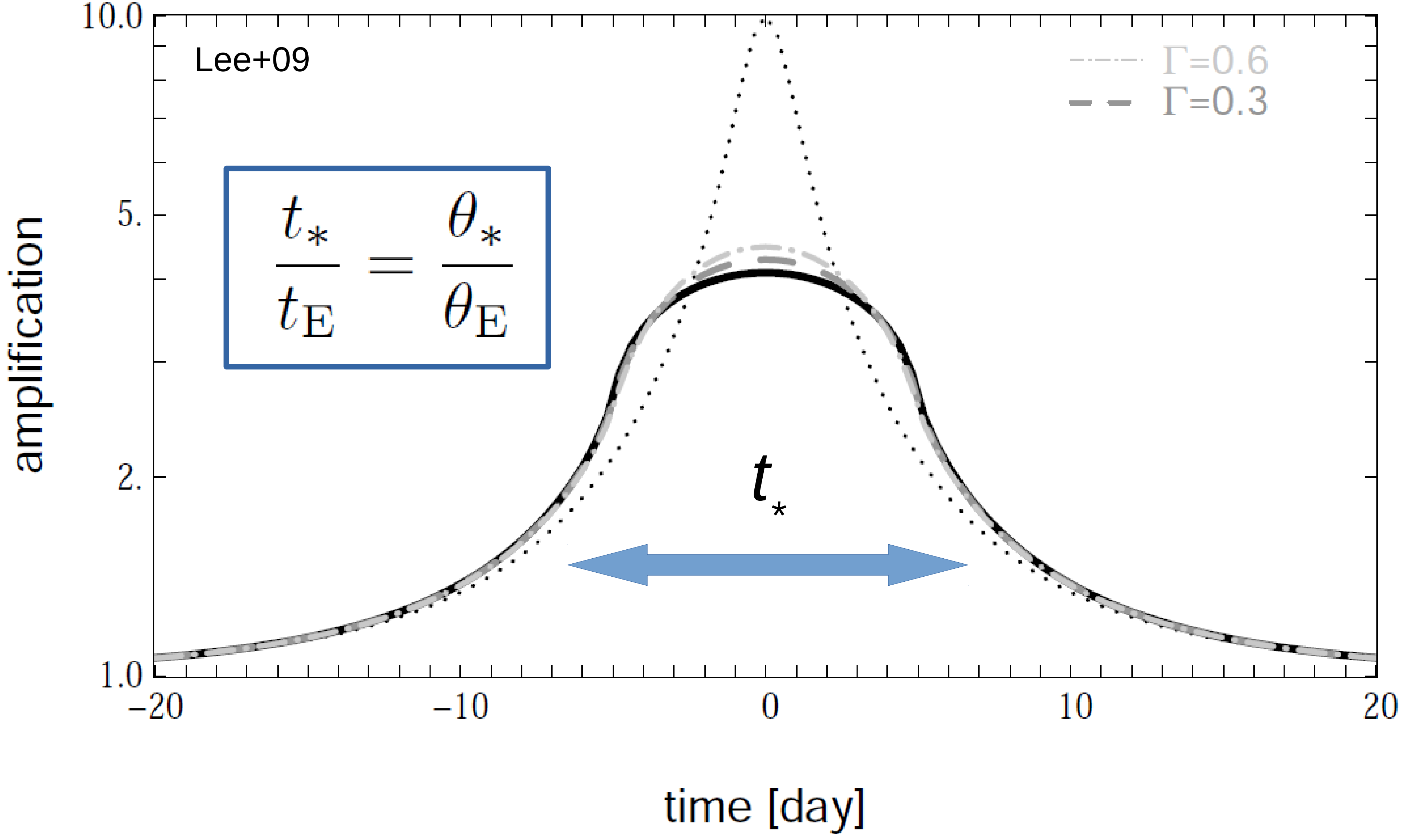
40
20
0
Event rate (yr−1, i′ < 23 sources)

Why not just use OGLE?

Need to look more closely at how the Angular Einstein Ring is measured.

Finite Source Effects



Finite Source Effects

Known

Angular Diameter
Knowable

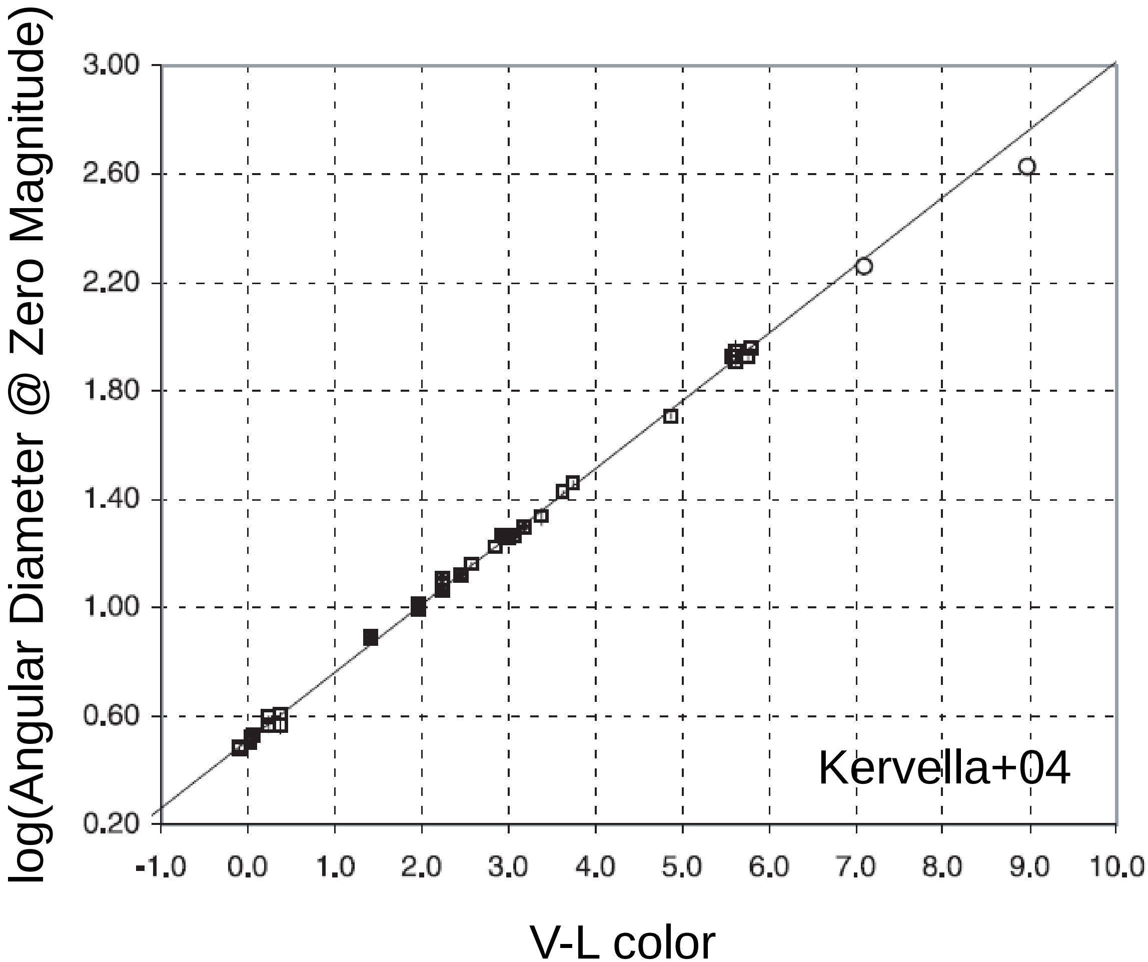
$$\frac{t_*}{t_{\mathrm{E}}} = \frac{\theta_*}{\theta_{\mathrm{E}}}$$

Known

Unknown

Surface Brightness-Color Relations

Measuring the color and extinction gives you the angular diameter of the source



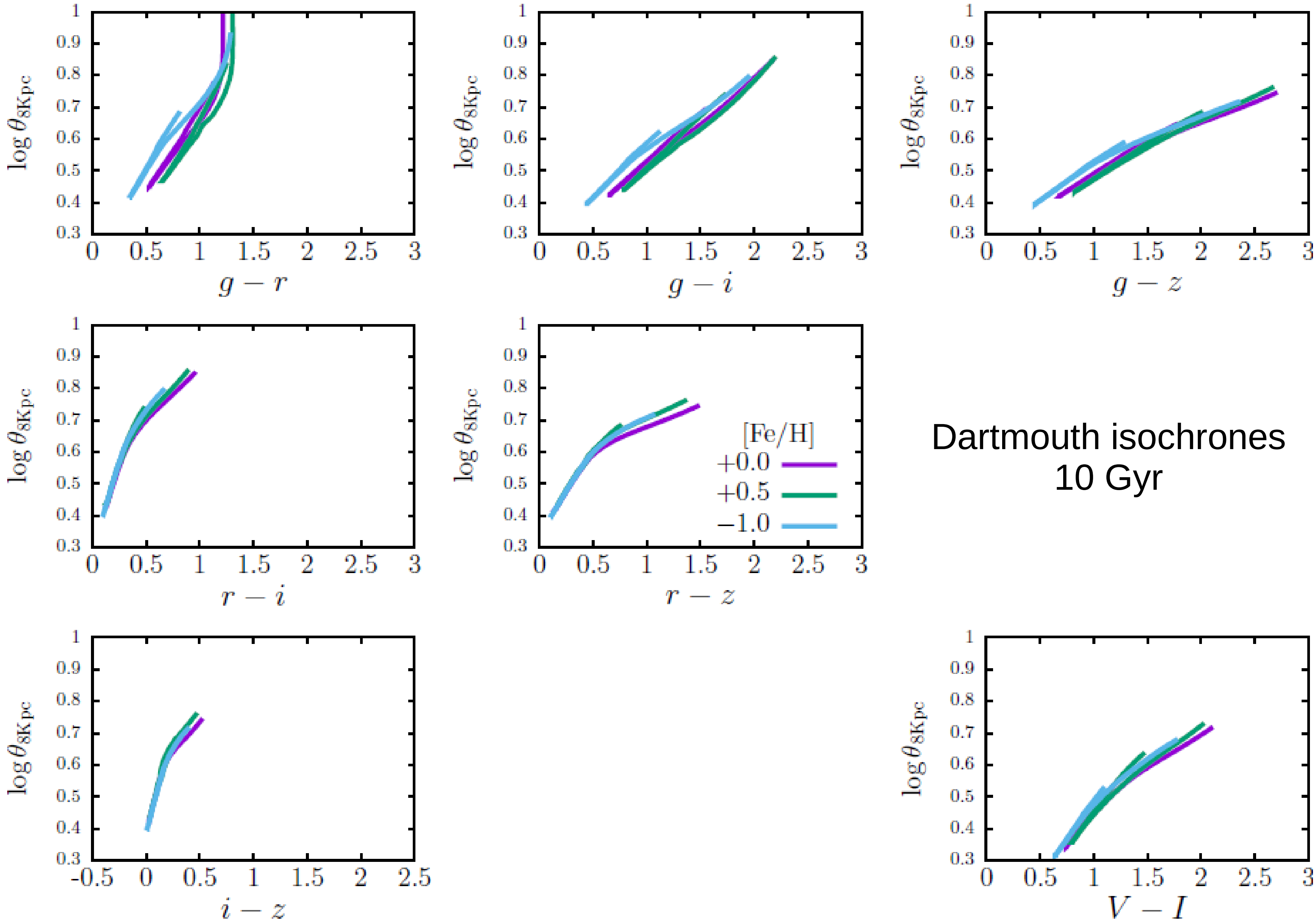
e.g.

$\log \theta_{LD}$

$= 0.0755\ (V\text{-}K) + 0.5170 - 0.2\ K$

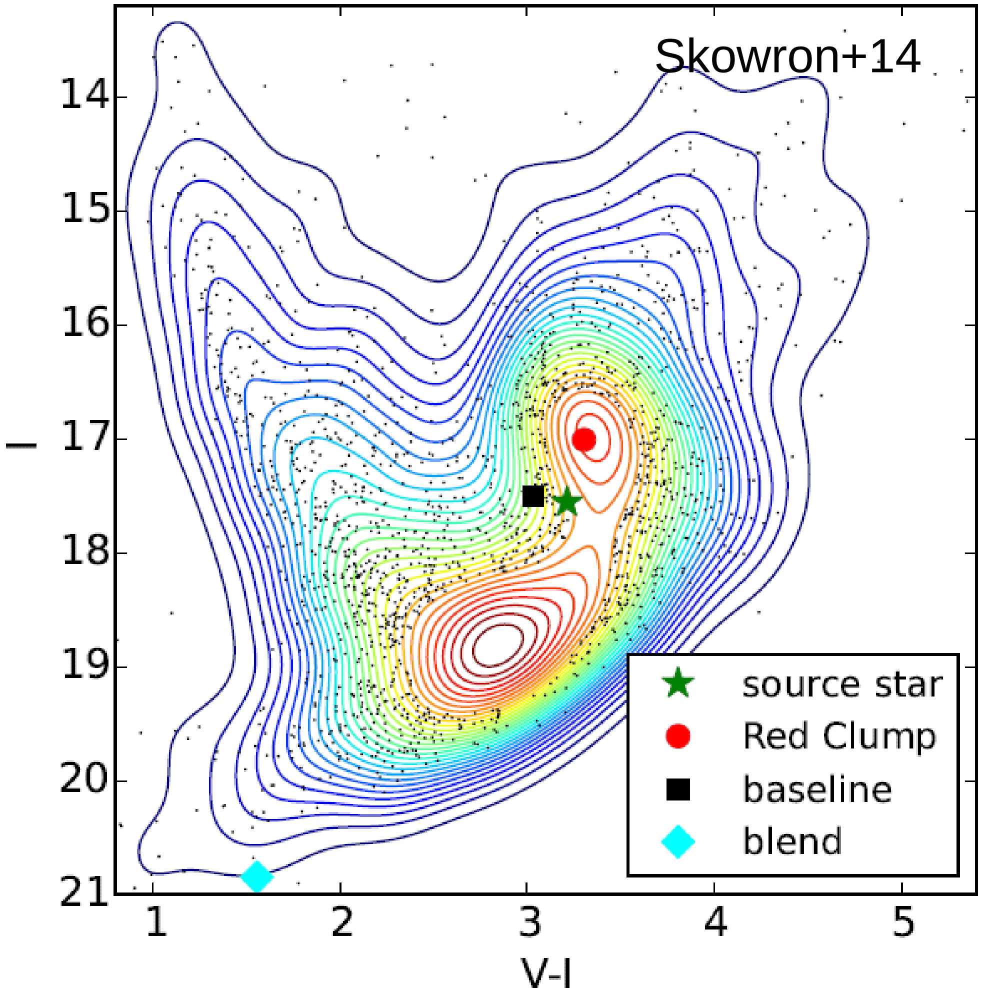
Other relations for other colors

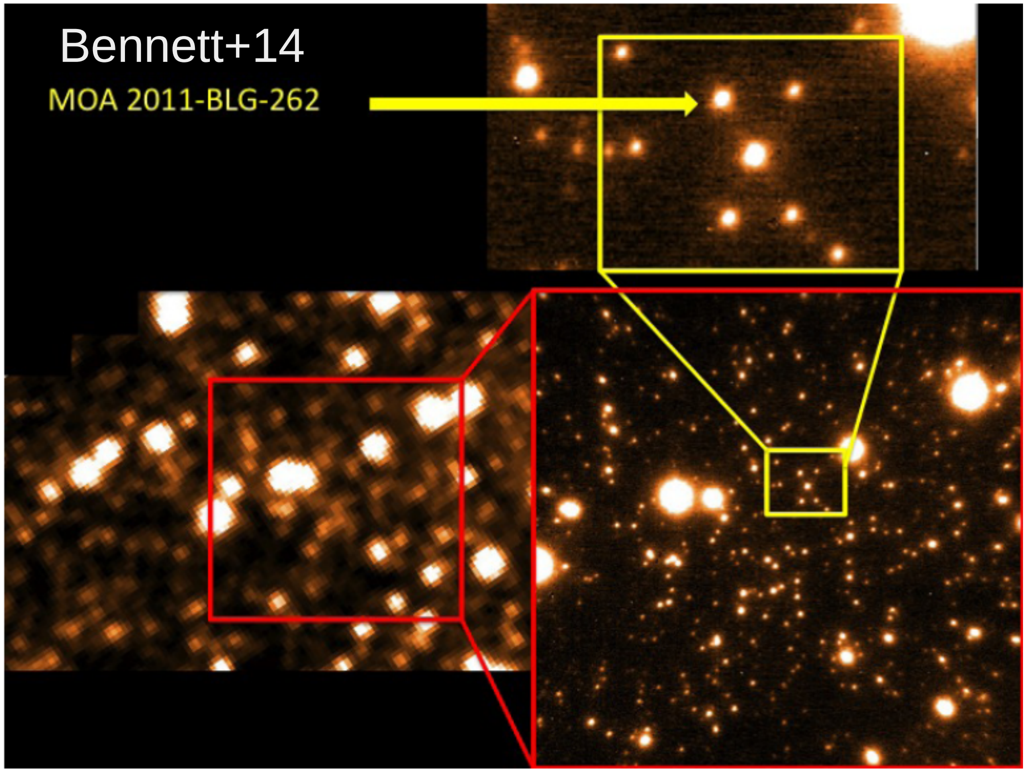
Without mid-IR, relations are more complicated



And you must isolate the source

This requires measuring the color of the source ***while it is magnified***





DECam vs OGLE

- 2 fields

g: 60s
r: 30s
g: 60s
i: 30s
g: 60s
z: 30s

Cadence:
4 min g-band
13 min r,i,z-band

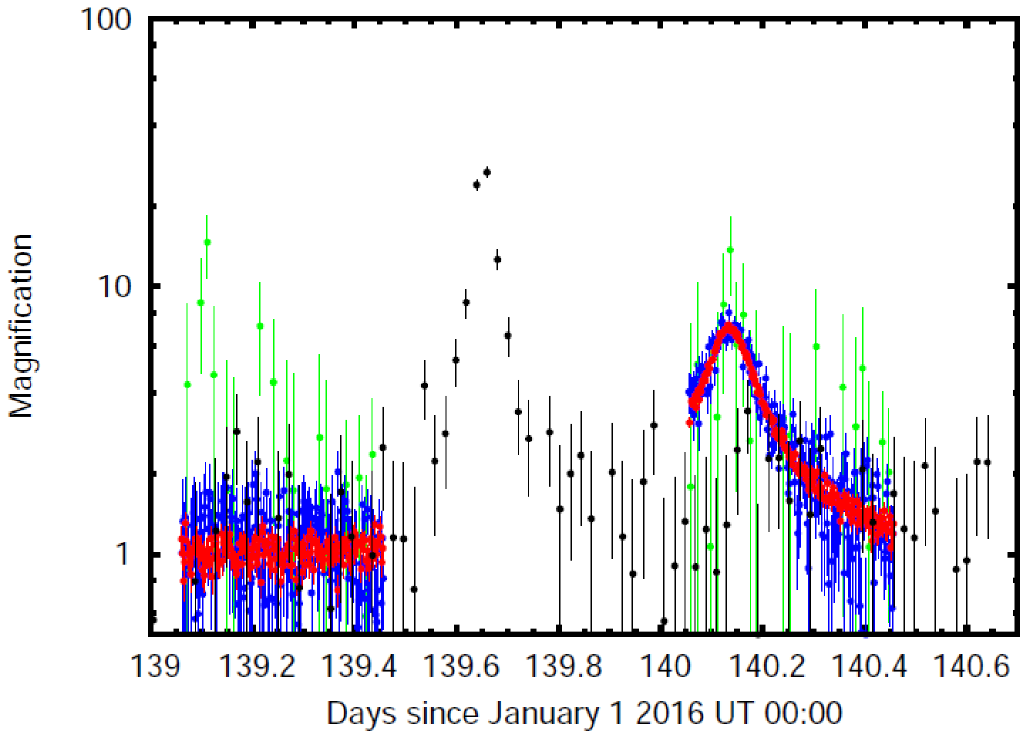
- 5 fields + others

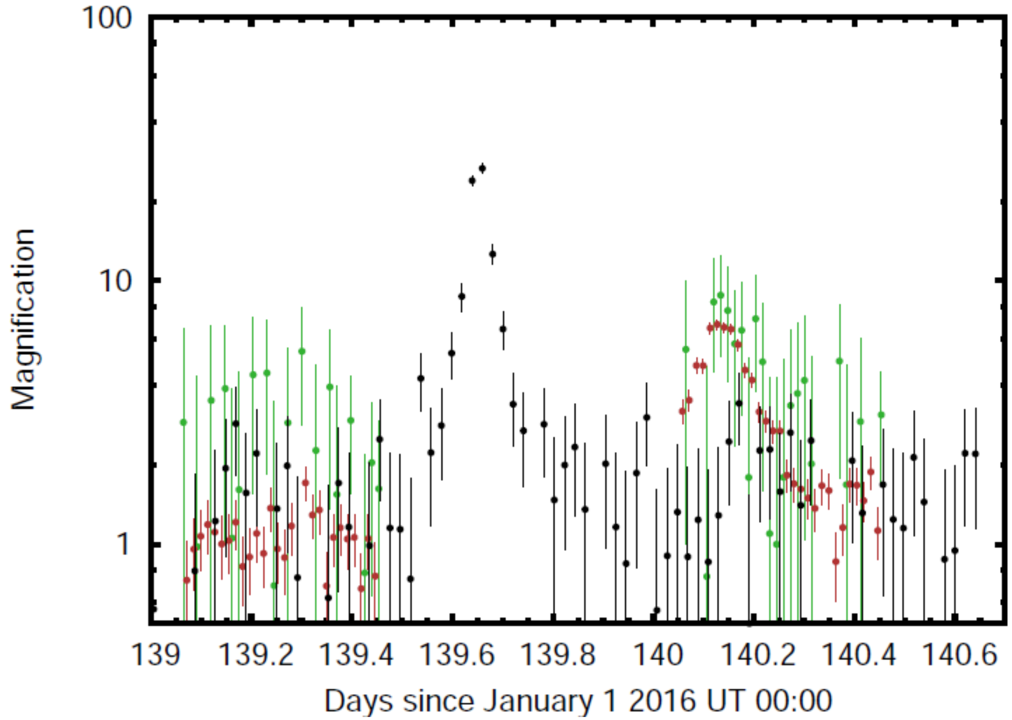
V: 150s
I: 100s

Cadence (max):
27 min V-band
27 min I-band

DECam vs OGLE

Saturn Mass (100 Earth) Free Floating Planet 6.9 Kpc away





Kp = 23.2 g' = 25.6 r' = 22.9 z' = 20.6

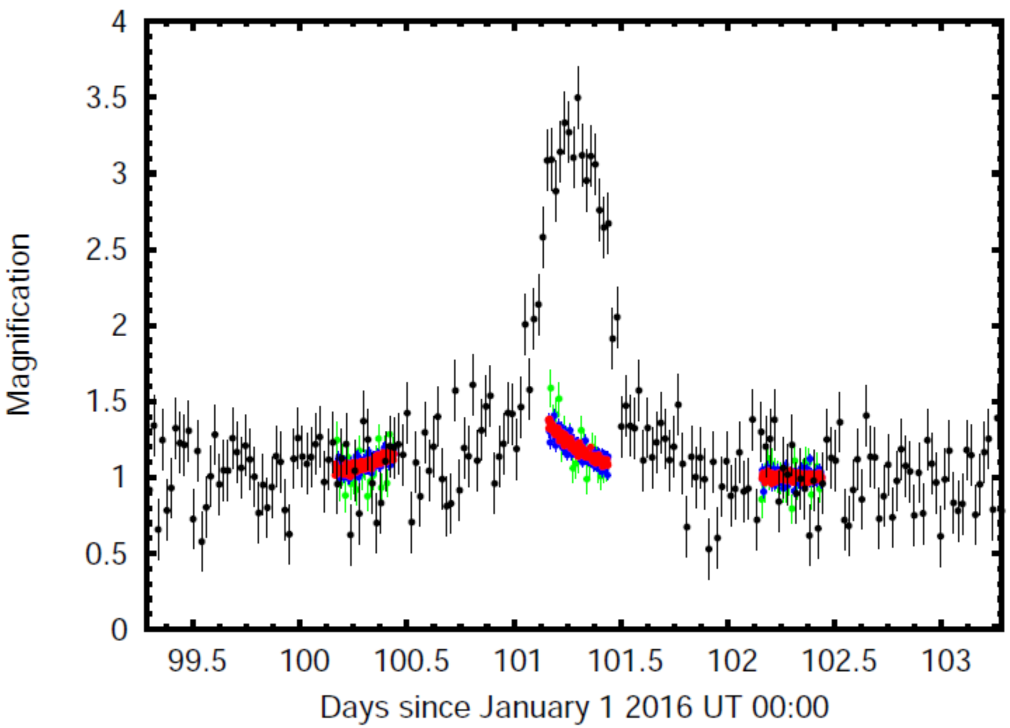
V = 24.1 I = 20.9

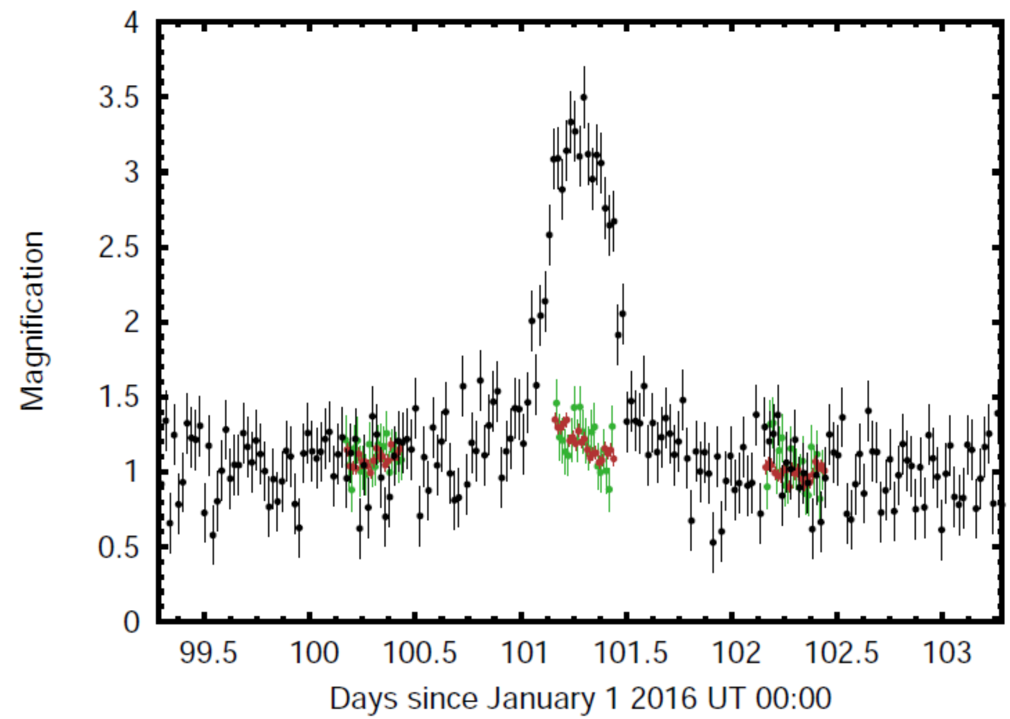
DECam errors:
piE 4%
ThetaE (g-z) 1% (0.3 mag)
ThetaE (r-z) 2% (0.07 mag)

OGLE errors:
piE 23%
ThetaE (V-I) 10% (0.45 mag)

DECam vs OGLE (radical)

10 Earth-mass Free Floating Planet 8 Kpc away





Kp = 20.7 g' = 22.7 r' = 20.4 z' = 18.7

V = 20.4 I = 18.8

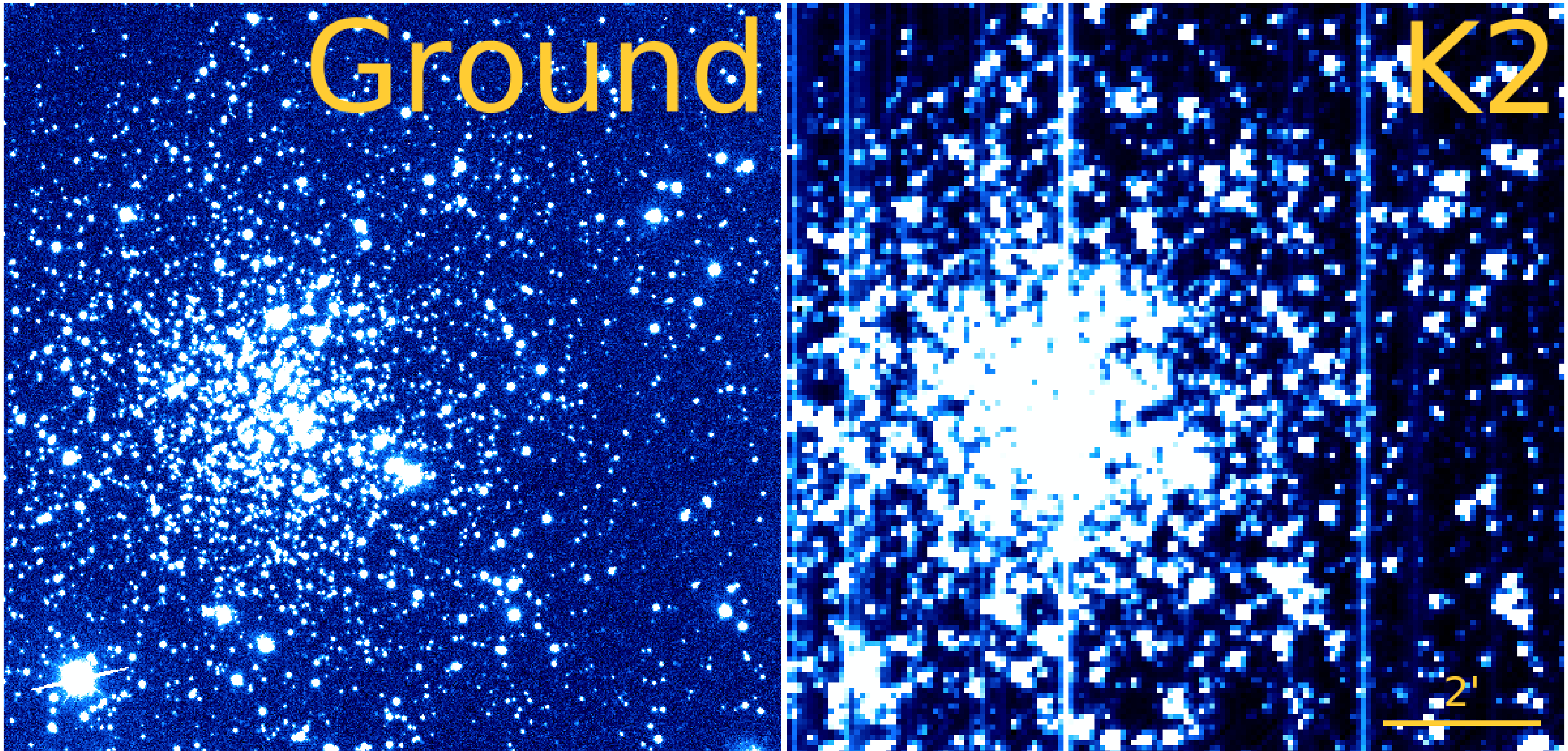
DECam errors:

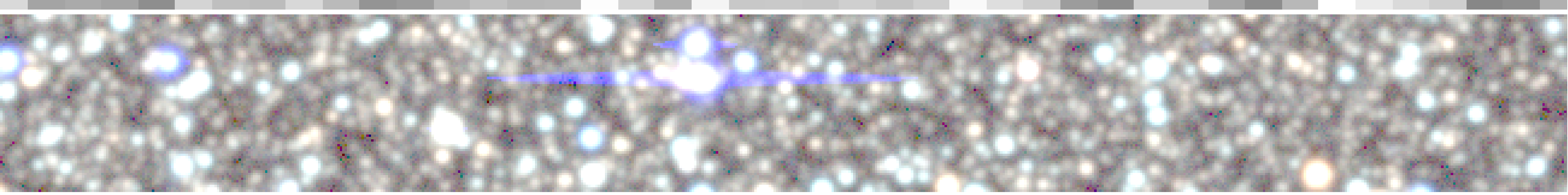
piE	27%	
ThetaE (g-z)	14%	(0.53 mag)
ThetaE (r-z)	24%	(0.52 mag)

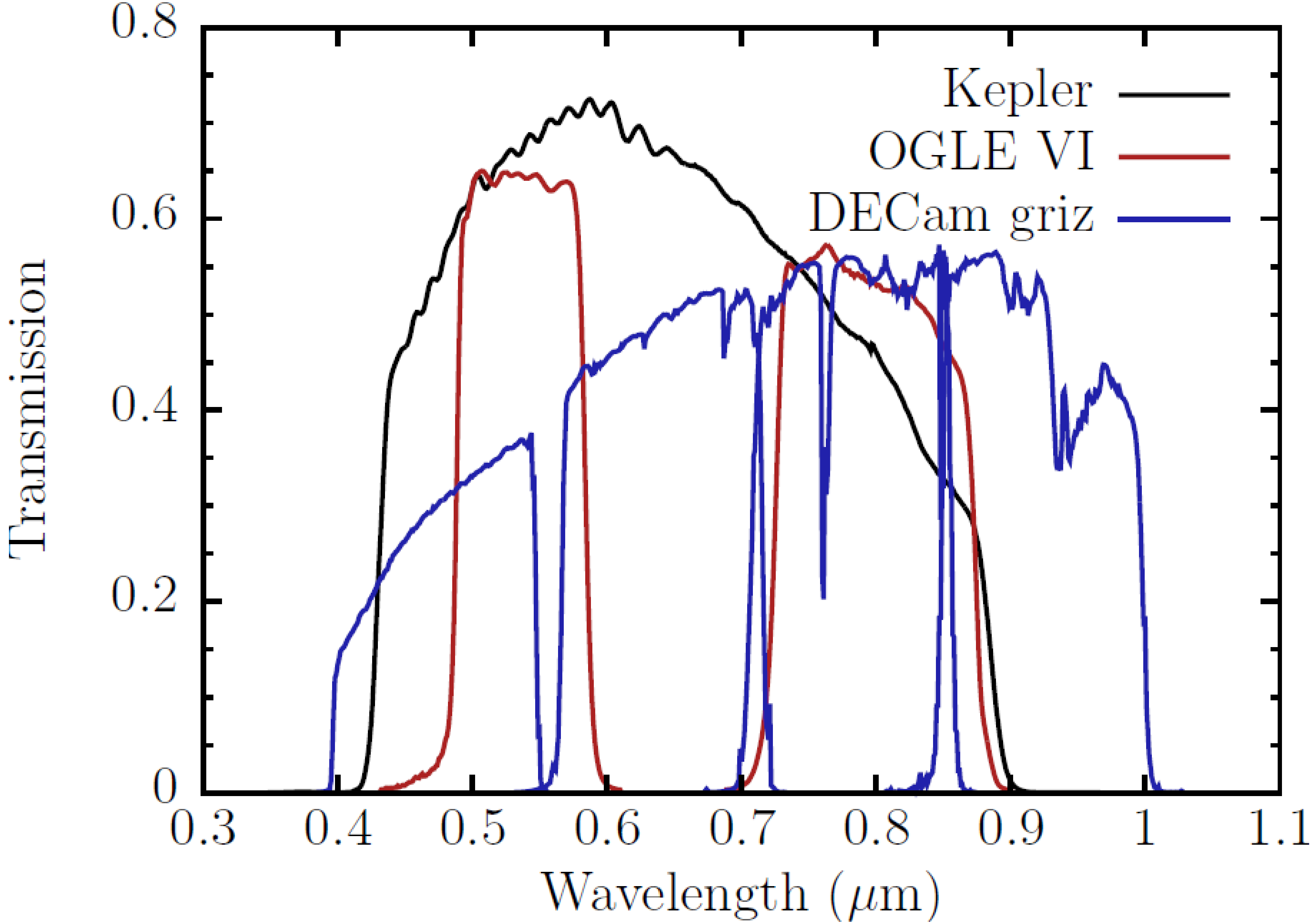
OGLE errors:

piE	75%	
ThetaE (V-I)	133%	(1.47 mag)

K2 photometry will be challenging







Kepler
OGLE VI
DECam griz
Transmission
0
0.2
0.4
0.6
0.8
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
Wavelength (μm)

K2-DECam-MOA Predicted Survey Yields

~40 Free-floating planet detections
~30 with parallaxes
~5 with full mass measurements

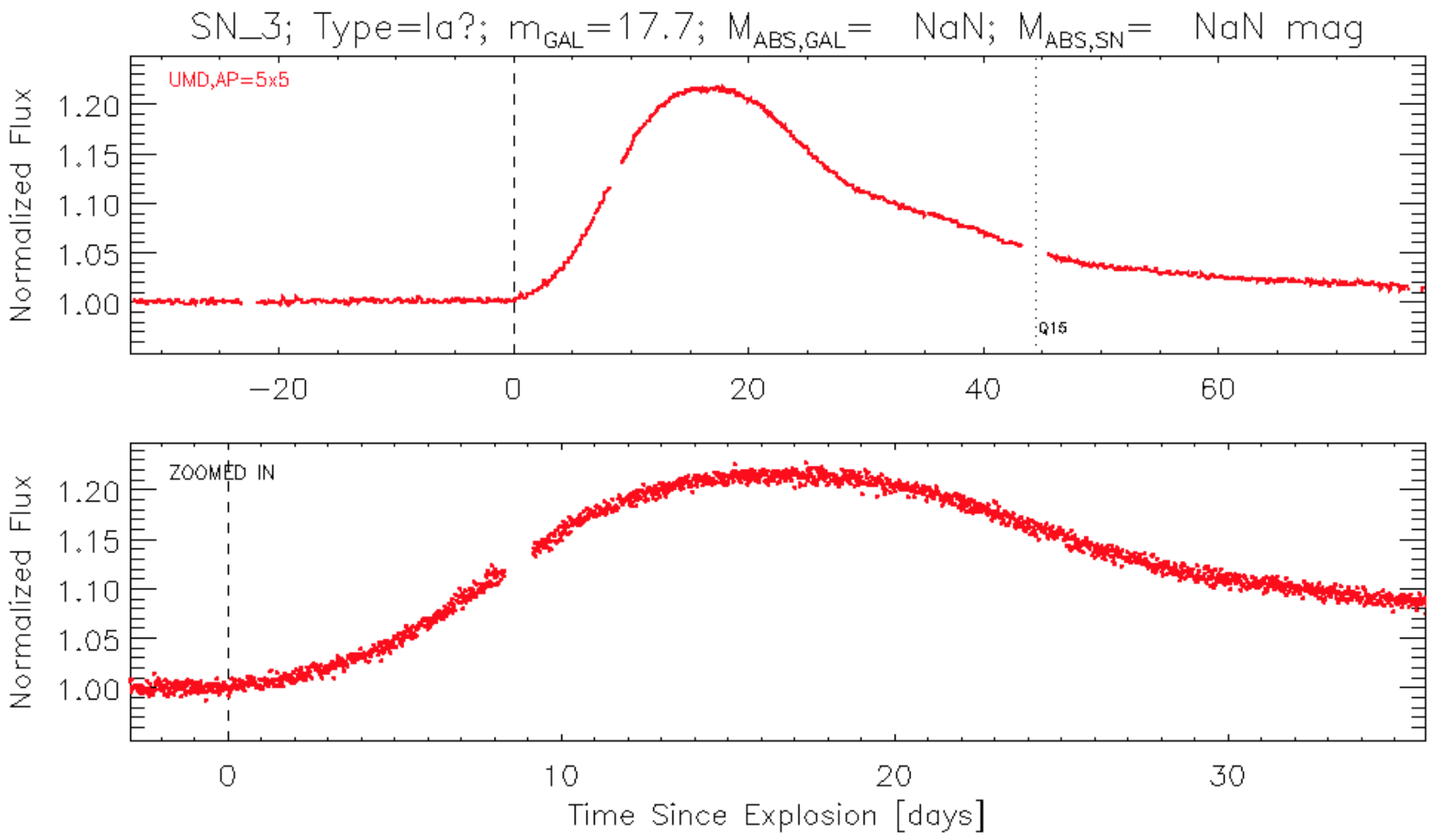
DECam – Public Data

- **Data will be made public on a timescale similar to the Kepler K2 date release**. Enabling:
  - The development of a larger US microlensing community
  - Deep KBO/solar system object searches (gets colors + orbits + rotation)
  - Bolometric survey of large M-dwarf flares
  - Asteroseismology of a host of interesting stars: bulge giants (w/Kepler+DECam), white dwarfs, blue stragglers... test stellar models
  - Transiting planets (maybe, colors)
  - Color limb-darkening coefficients in binaries
  - What else can you think of...?

Conclusions

- K2 campaign 9, in combination with ground-based observations, will enable ***for the first (and probably only) time*** definitive measurements of free-floating planet masses
- However, these mass measurements require high-cadence color measurements, which are difficult to achieve using the dedicated microlensing survey telescopes
- DECam on the Blanco is the best microlensing machine in the world – ***we must use it for this never to be repeated oppotunity***

SN-Ia in a 17th Magnitude Galaxy



Olling White Paper