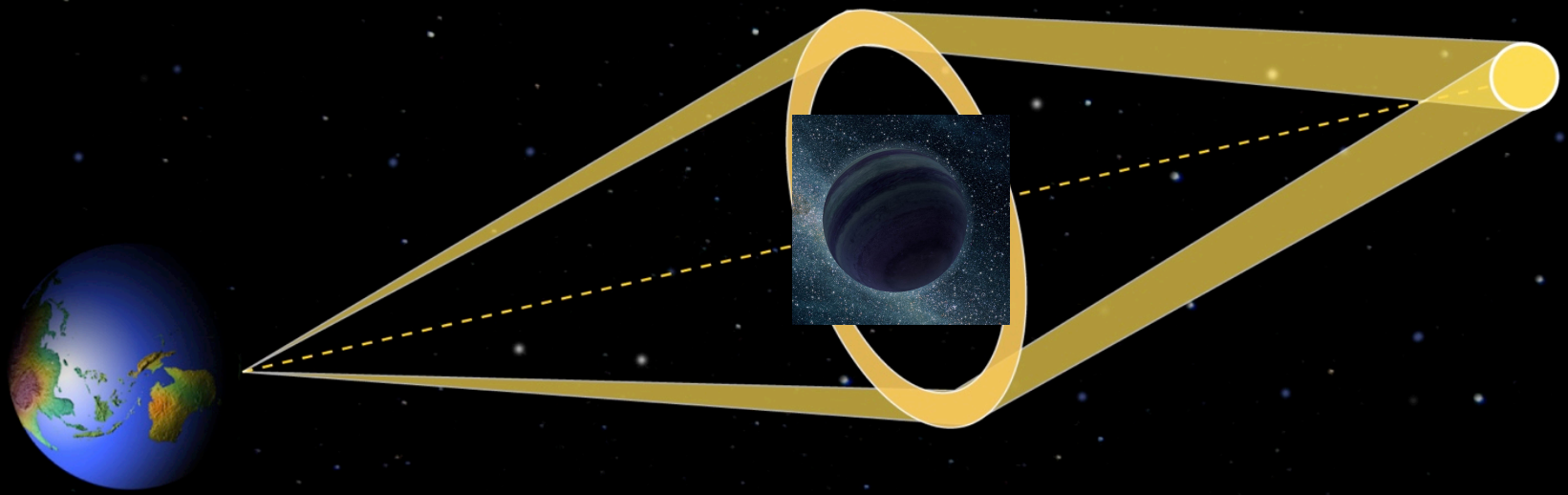
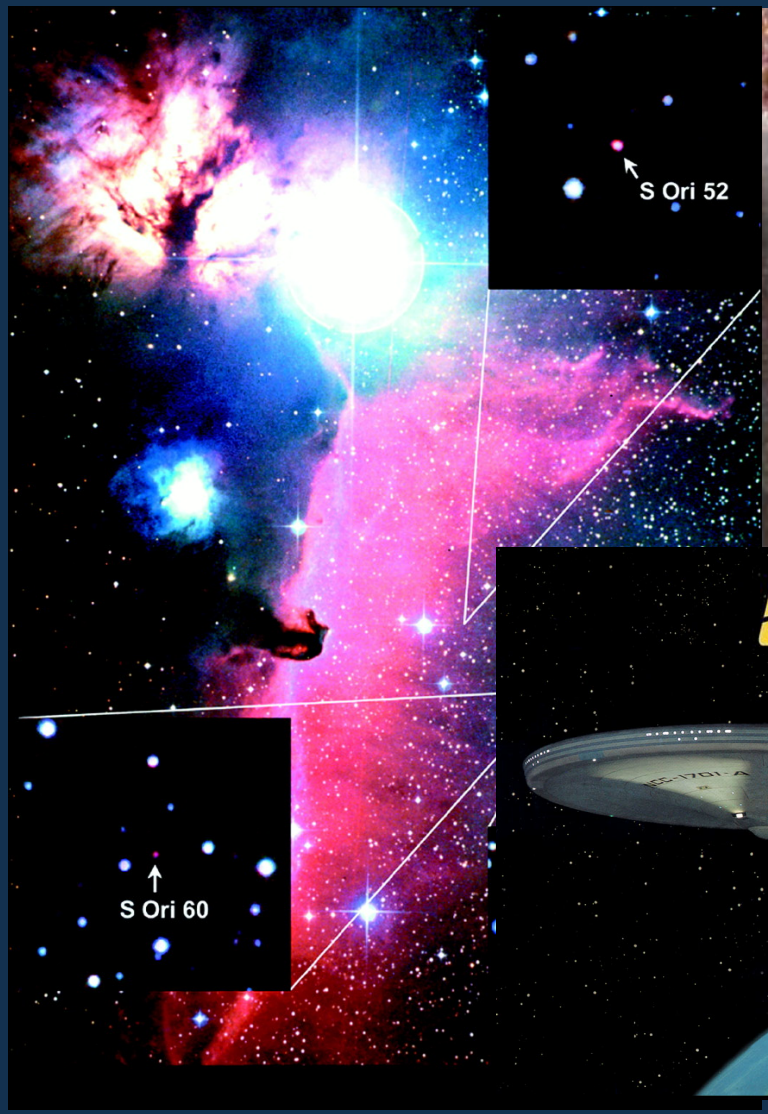
Free-floating planets from microlensing



Takahiro Sumi (Osaka University)

Free-floating planetary-mass objects in young star forming region



Zapatero Osorio, et al. 2000

Oasa et al. 1999,2006

In 2414, the USS rosenante found the rogue planet Solyon

MOA (since 1995)

(Microlensing Observation in Astrophysics)

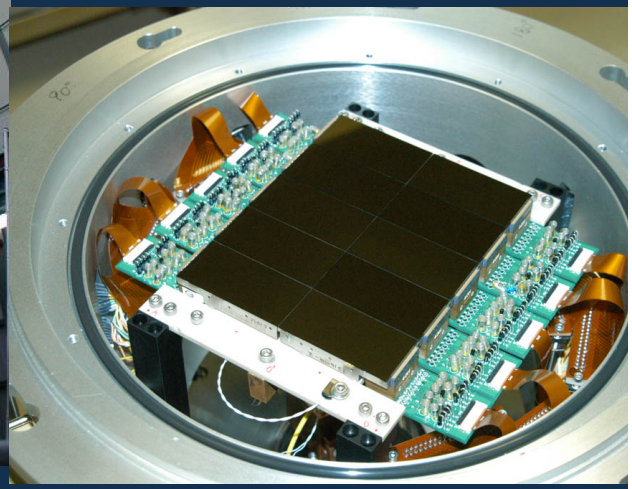
(New Zealand/Mt. John Observatory, Latitude： 44°S, Alt: 1029m)

Mirror : 1.8m

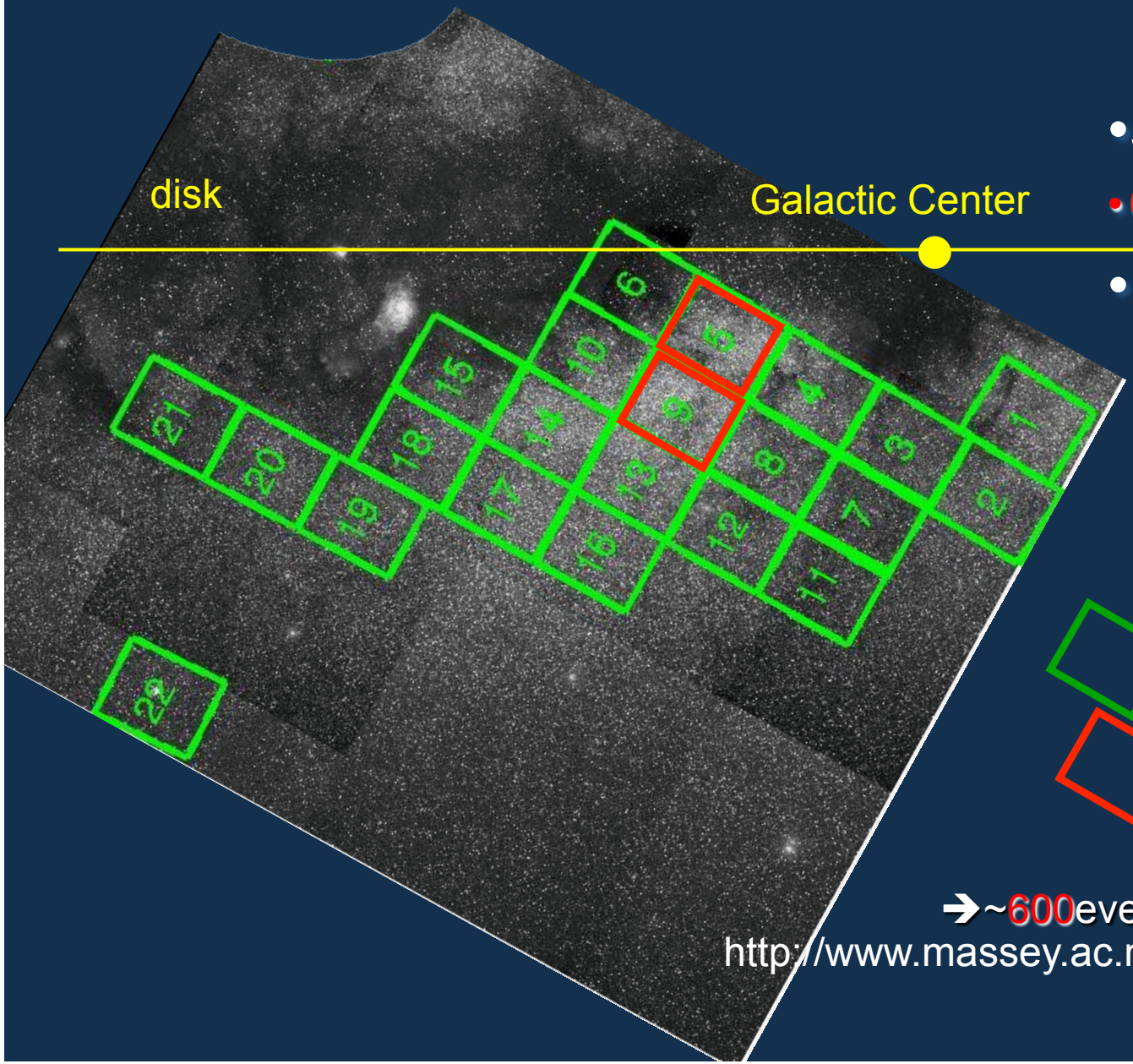
CCD : 80M pix.

FOV : 2.2 deg.^{2}

cadence: 10-50 min.



Observational fields



- 50 deg.^{2}
- (200x full moon)
- 50 M stars

1obs/1hr

1obs/10min.

➔~600events／yr

http://www.massey.ac.nz/~iabond/alert/alert.html

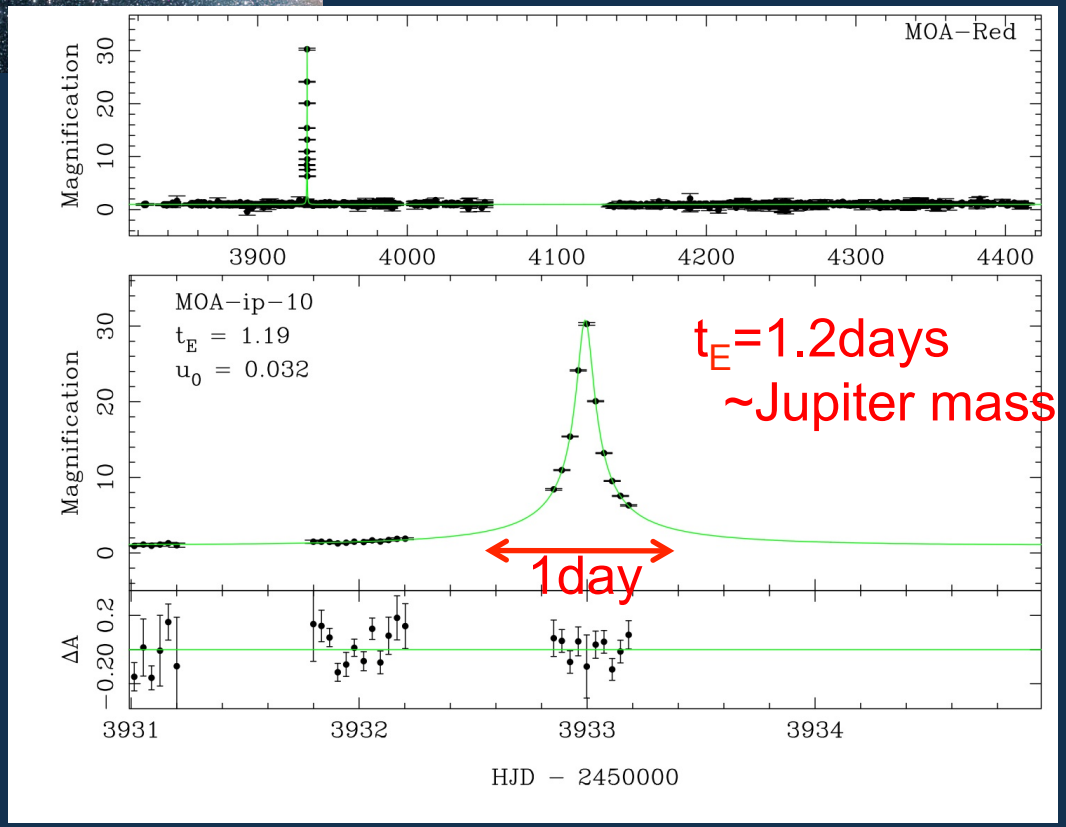
Free-Floating Planet, events with timescale t_E< 2 days

$$t_E = \frac{R_E(M,D)}{v_t} \sim \sqrt{M/M_J}\ day$$

~20days for stars

M : lens mass
M_J: Jupiter mass
D : distance
v_t: velocity

Found
10 short events
in 2 years of data.



Mass,
Distance,
Velocity
degenerate.

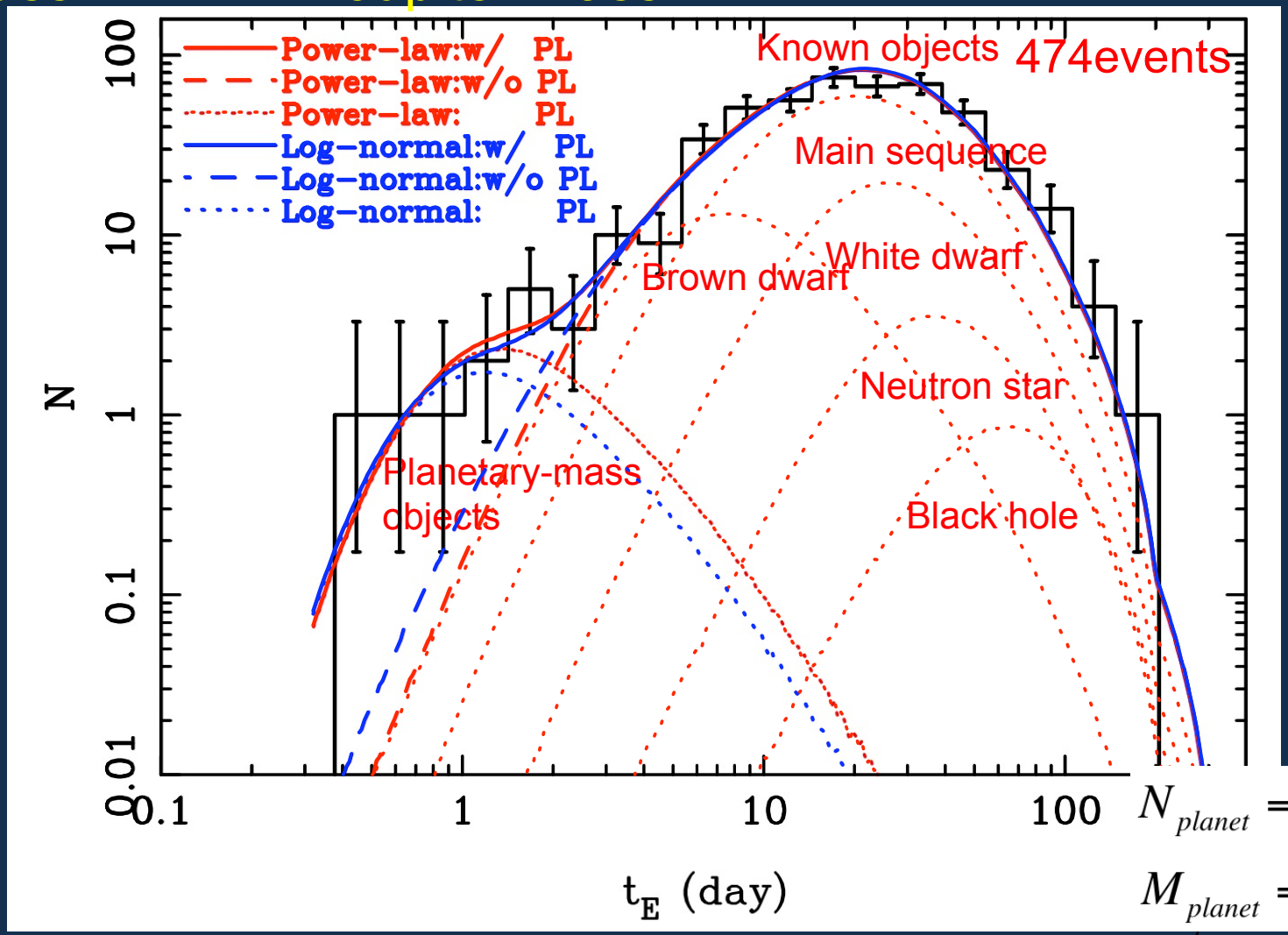
So need
statistical
analysis

WFIRST can detect Earth-mass FFP

Timescale t_E distribution

abundance :~1.8 as common as stars
Mass : ～Jupiter mass

474 events selected
from 1000 candidates in 2 yrs



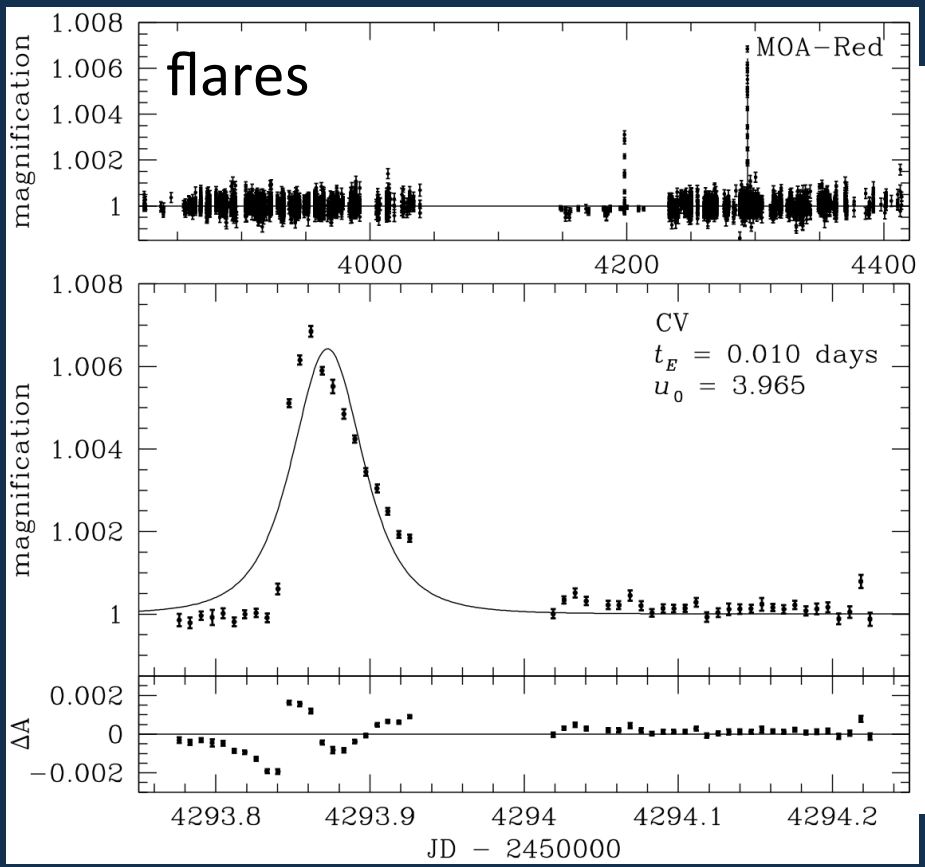
MOA
OGLE

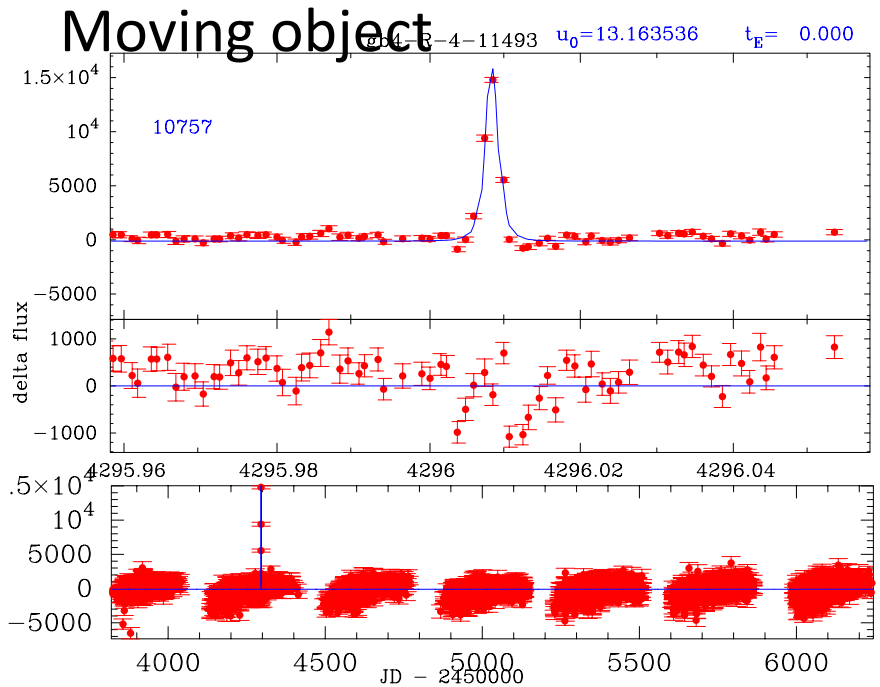
$$N_{planet} = 1.8^{+1.7}_{-0.8} N_{star}$$

$$M_{planet} = 1.1^{+1.2}_{-0.6} M_J$$

TS et al. 2011, Nature, 473, 7347, 349-352

Background: CV or moving objects

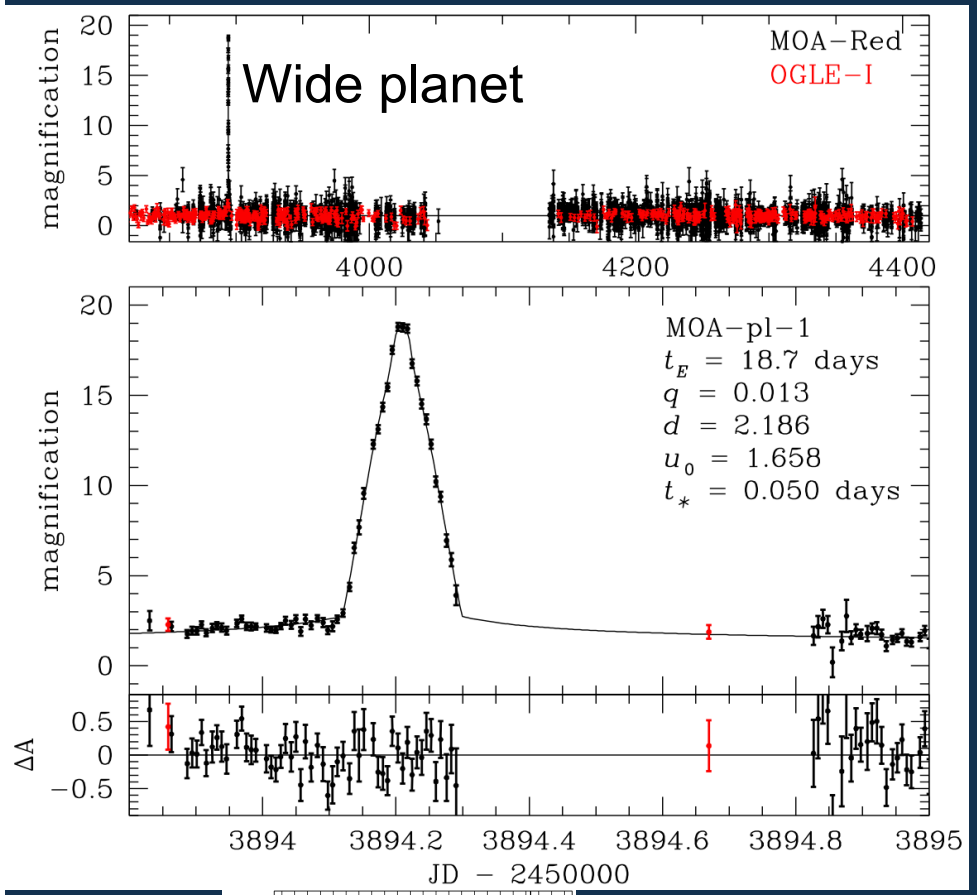


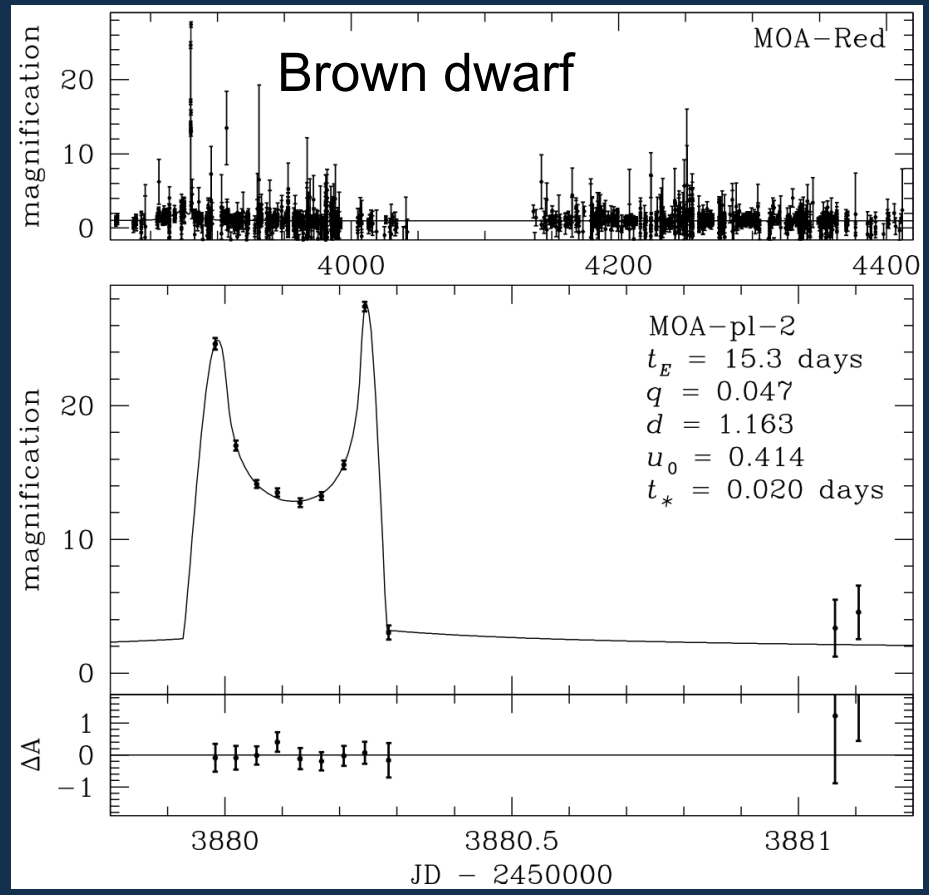


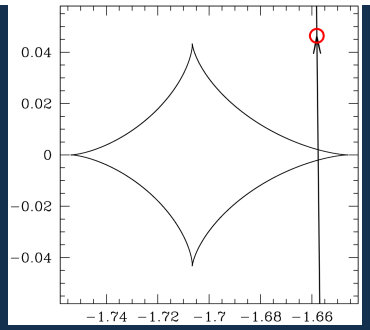
a CV gives a poor microlensing fit, often with low magnification and an unphysically bright source

Moving object gives symmetric but unphysical microlensing fit, often with low magnification and an unphysically bright source

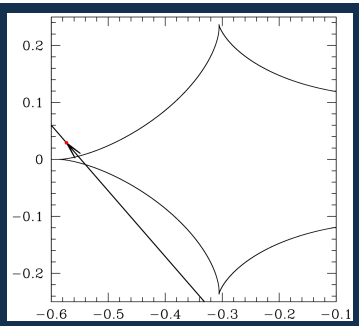
Background: Short Binary/planetary Events







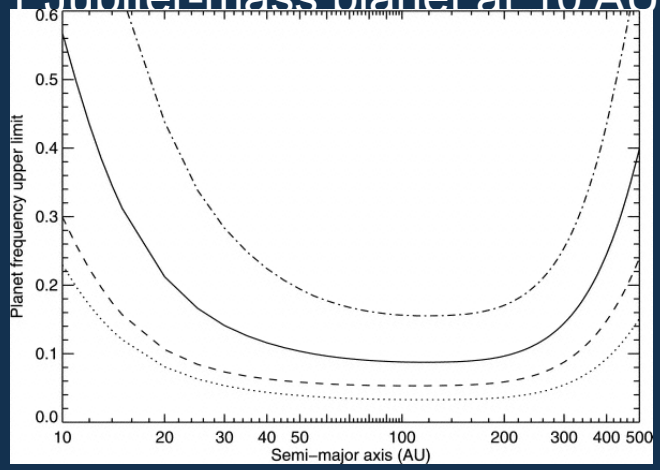
We can find or rule out the host within 10AU

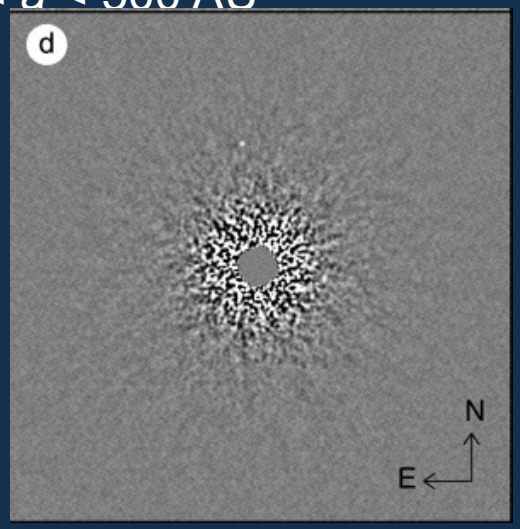


Unbound or distant planets?

- Microlensing data only sets a lower limit on the separation: no host stars within 10AU
  - HST follow-up can set tighter limits or detect host

- 8m telescope, Direct imaging limits （Lafreniere et al. 2007)
  - < 40% of stars have 1 Jupiter-mass planet at 10 AU < *a* < 500 AU





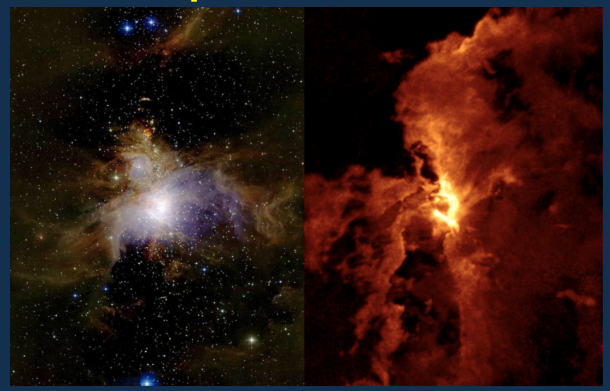
- We find 1.8 planets per star,

➔ so at least 1.4 planets per star (75%) should be free!

Formation Scenarios:

1. formed on their own through gas cloud collapse similar to star formation (sub brown dwarf)

- Hard to form Jupiter-mass objects
- Planetary-mass sub brown dwarf can explain only 1 or 2 short events.
- Abrupt change in mass function at Jupiter-mass do not support this scenario.



2. formed around a host star, and scattered out from orbit

Hot Jupiters orbiting hot stars have high obliquities (Winn et al. 2010, Triaud et al. 2010)

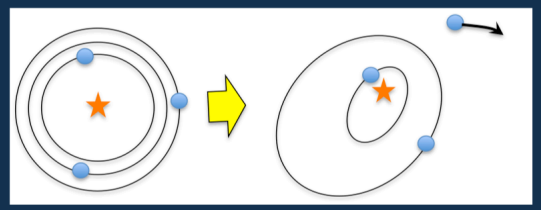
➔ evidence of gravitational interaction

Hot Jupiters are alone (Latham et al. 2011)

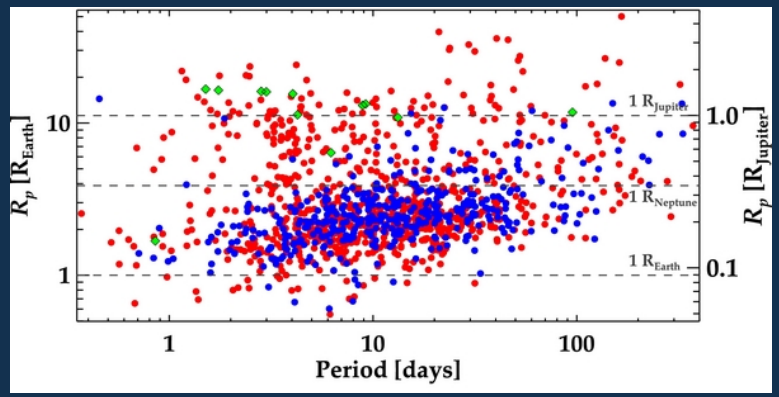
➔ evidence of gravitational interaction

No desert for short-period super-earths (Howard et al. 2010)

planet-disk interactions are of secondary importance to planet-planet scattering



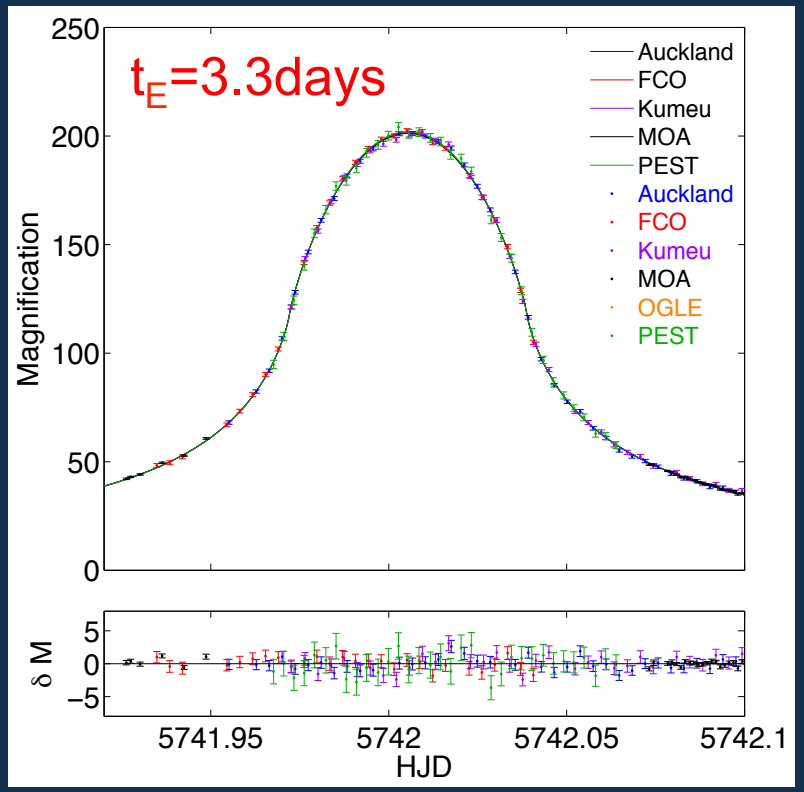
•Single-planet
•Multi-planet



keep detecting ~5 short events/yr

Short events with Strong finite source effects

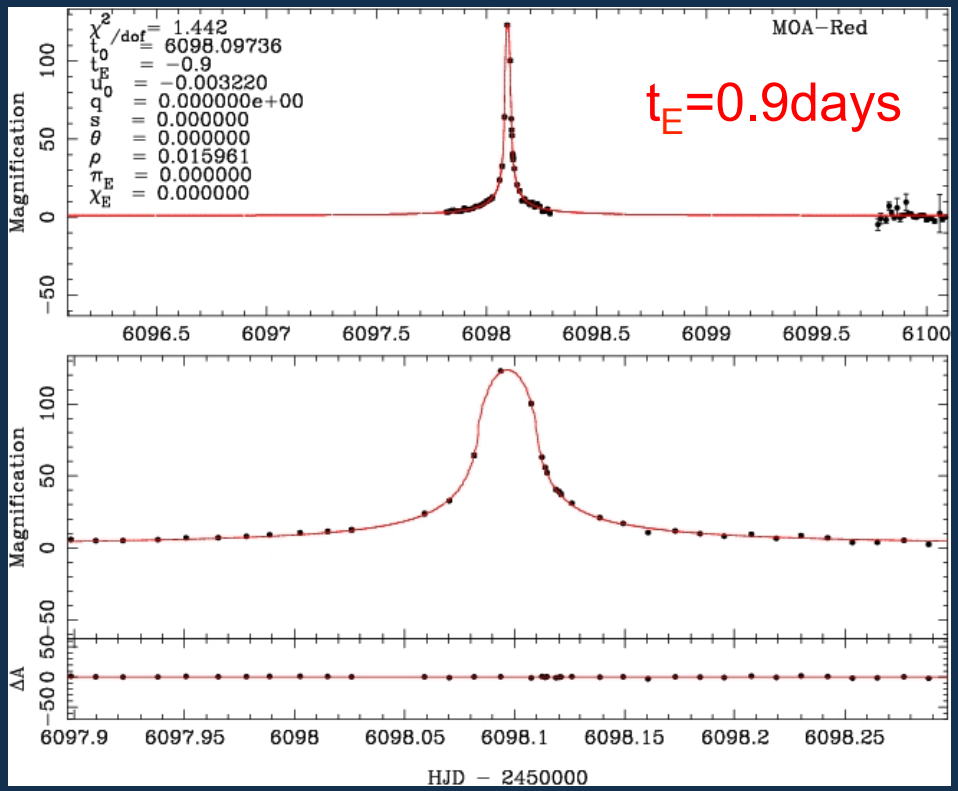
MOA-2011-BLG-274



θ_E=0.08, M~0.8M_J
if the marginal parallax is real.

Freeman+ in preparation

MOA-2012-BLG-403

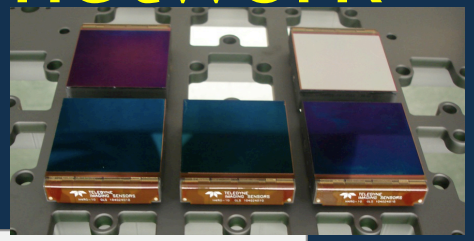


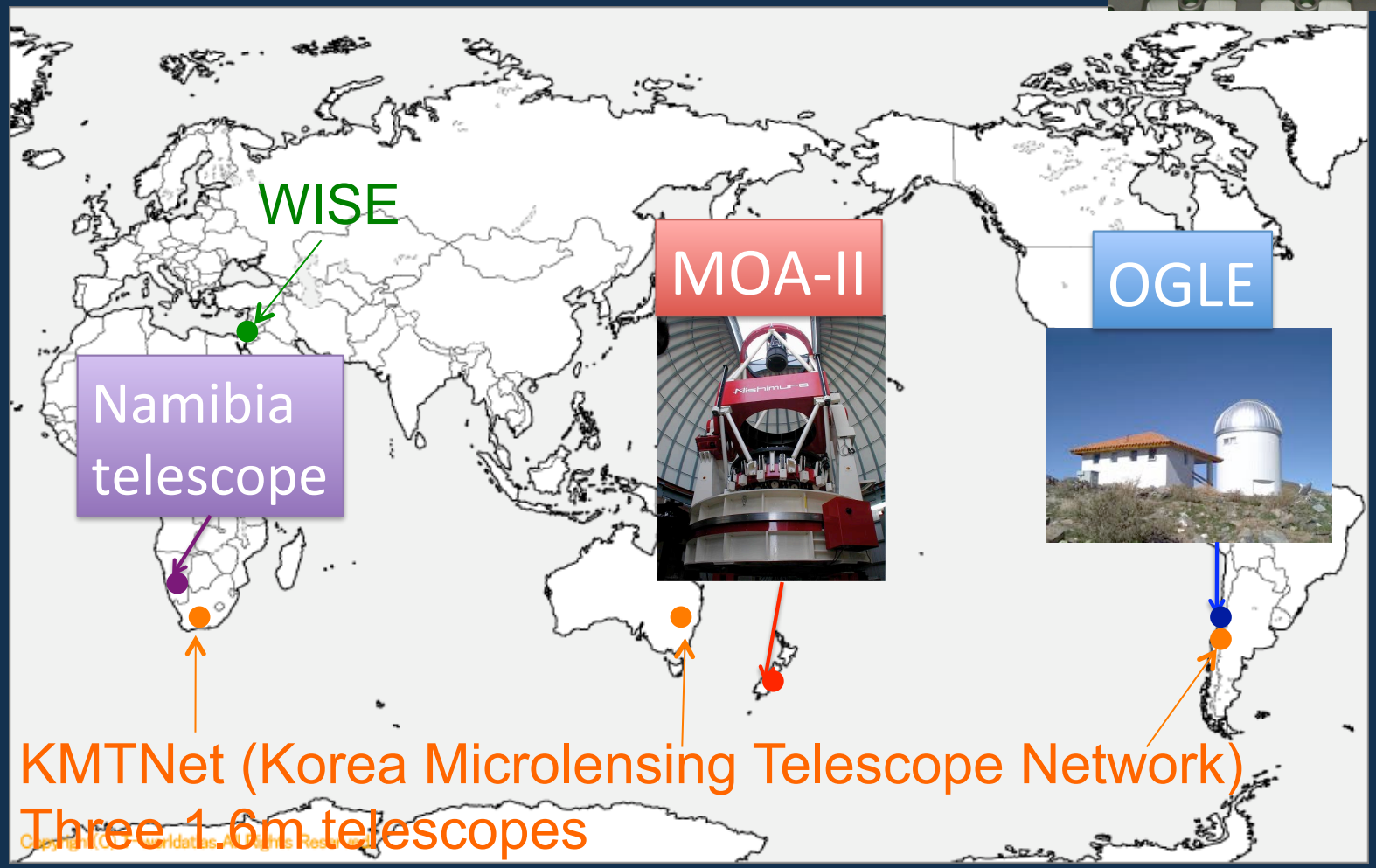
Mass can be given if Parallax is measured by K2

Next generation 24h survey network

Namibia IR telescope (plan)
D: 1.8m
FOV: 1deg^2 w/ 4 H4RGs

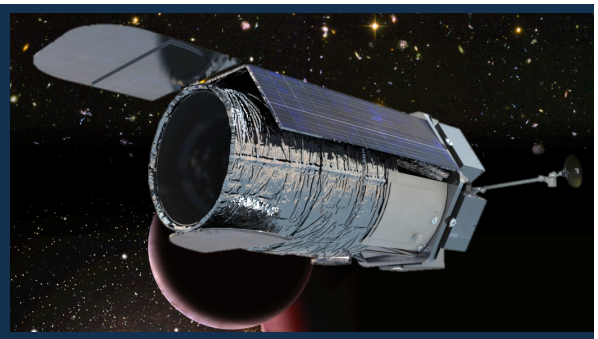
Namibia（H.E.S.S. site）
Altitude 1800m
April-October clear night：86%



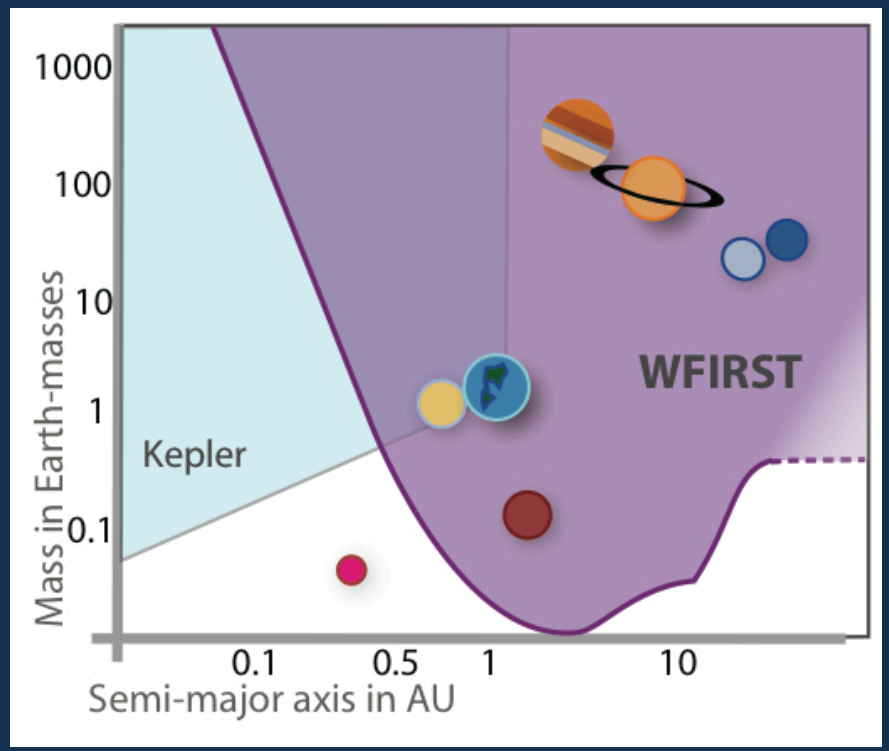


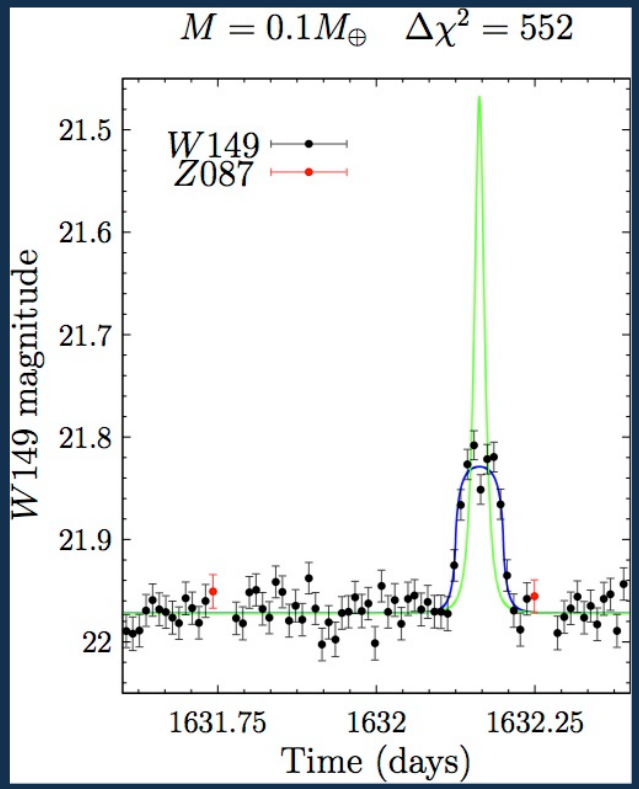
Increase the planet detection to >20planet/yr without follow-up

Free-floating planet search by WFIRST-AFTA



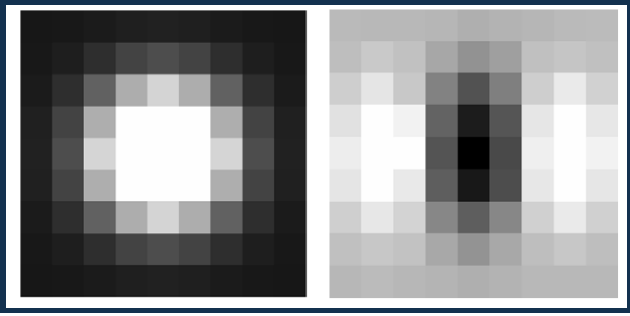
D: 2.4m
FOV : 0.281deg.^{2}
λ＜2μm
15min cadence





a simulated detection of Mars-mass FFP

M. Penny, Spergel et al.2013 **WFIRST-AFTA** SDT Final Report

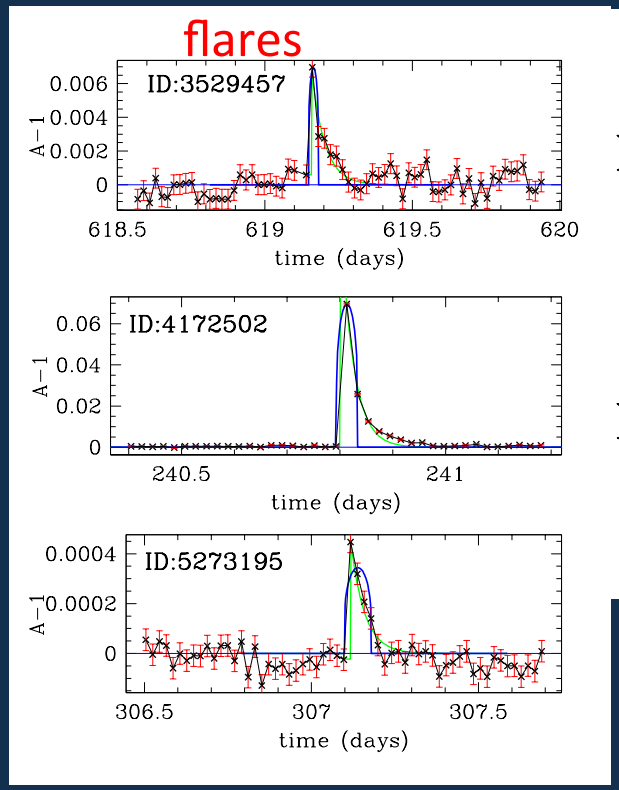


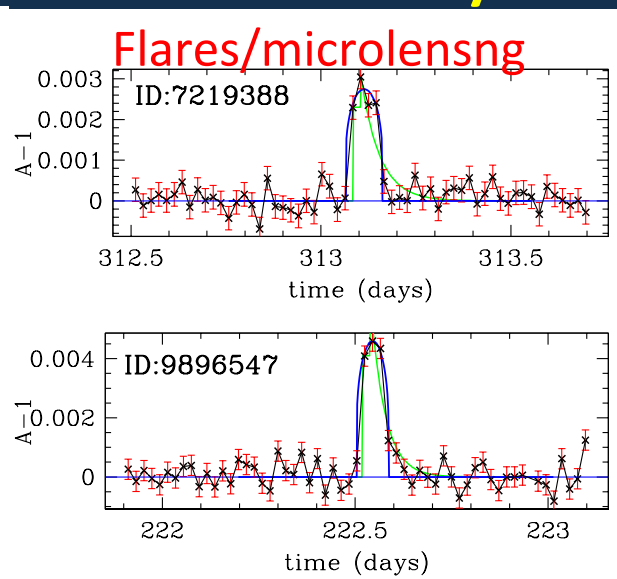
WFIRST can detect or rule out the host

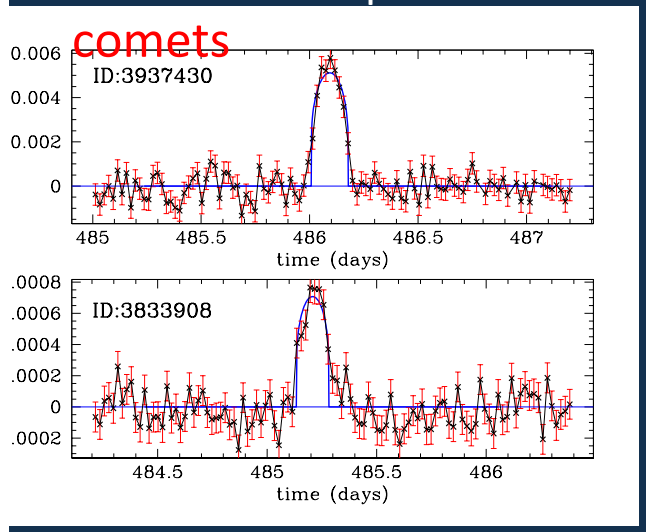
- ~3000 bound planets(~300 w/ $M < 1\ M_\oplus$)
- ~100s F-F planets (~40 w/ $M < 1\ M_\oplus$)

Limits on Primordial Black Hole Dark Matter by Kepler

Griest & Cieplak 2013

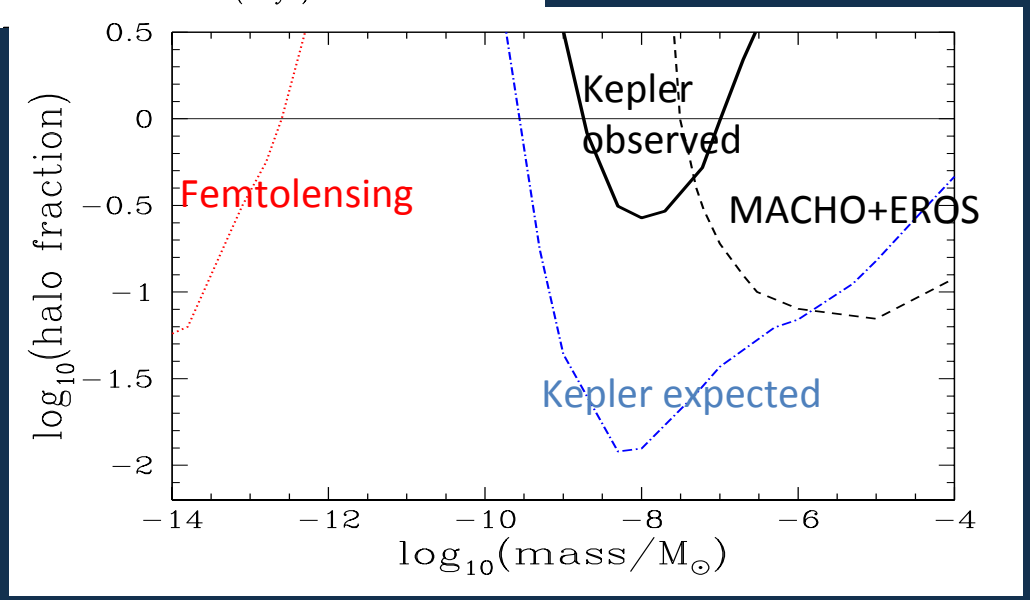






Null detection set upper limit of DM fraction of low mass object with $2 \times 10^{-9} M_\odot$ and $3 \times 10^{-8} M_\odot$

$\rho_{DMhalo} = 0.0079 M_\odot pc^{-3}$



Summary

- Free-floating planets are as common as main sequence stars and bound planets。
- They inform us not only the number of planets that survived in orbit, but also planets that formed earlier and scattered.

  important for planetary formation theory
- HST follow-up is important to detect or rule out the host.
- WFIRST will detect hundreds of FFP and ~40 Earth-mass FFP and measure the mass spectrum.