MOA (since 1995)

(Microlensing Observation in Astrophysics)

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

MOA (until ~1500)

(the world largest bird in NZ)

- height:3.5m
- weight:250kg
- can not fly
- Extinct 500 years ago

(Maori ate them)

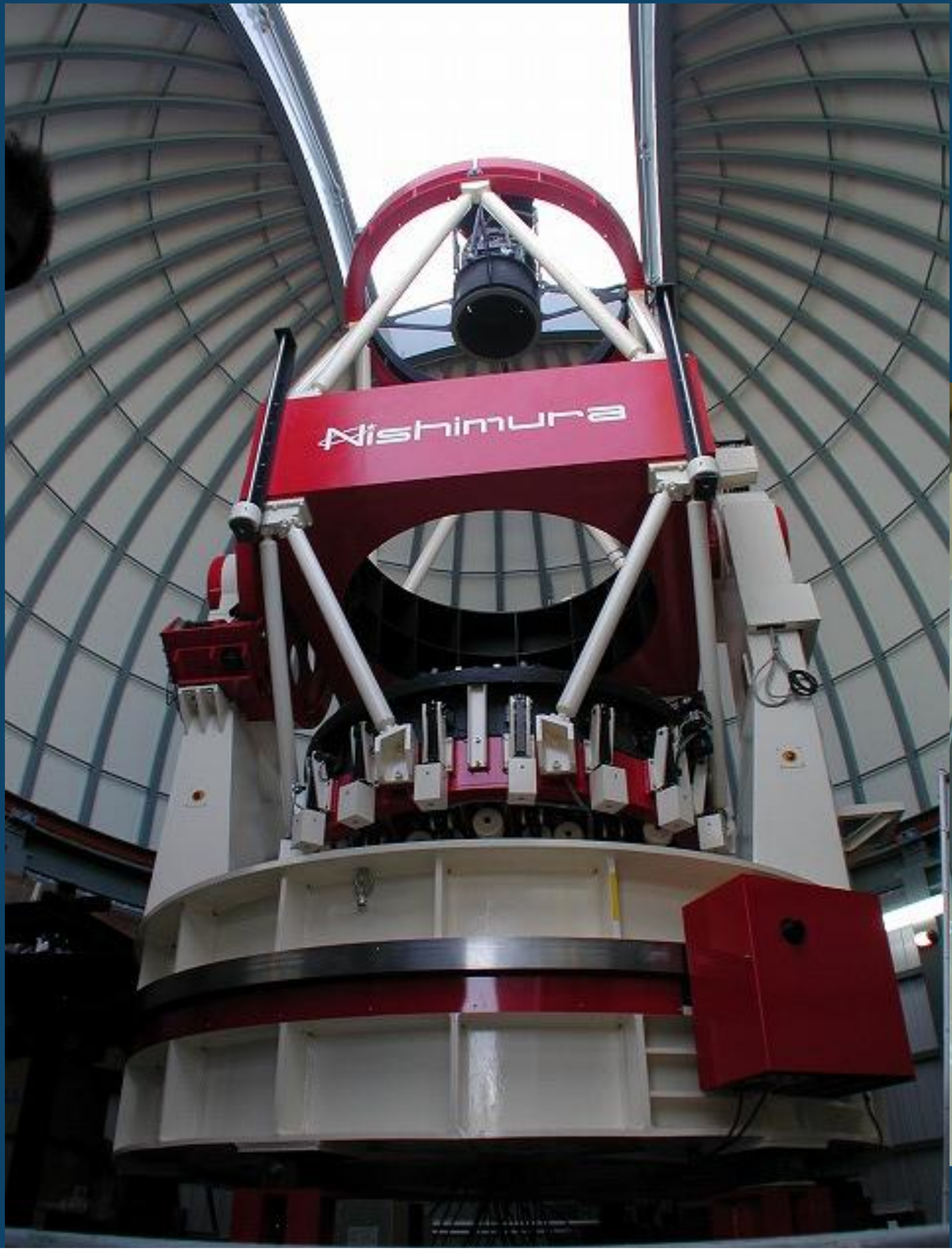
MOA-II 1.8m

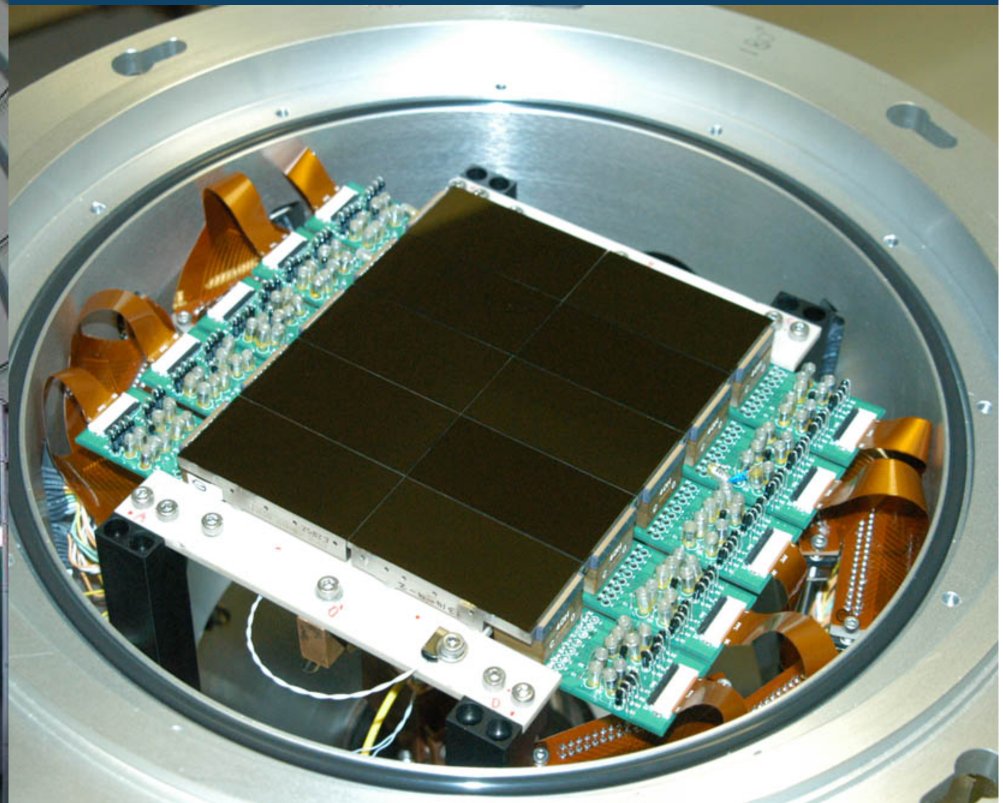
Mirror : 1.8m

CCD : 80M pix.(12x15cm)

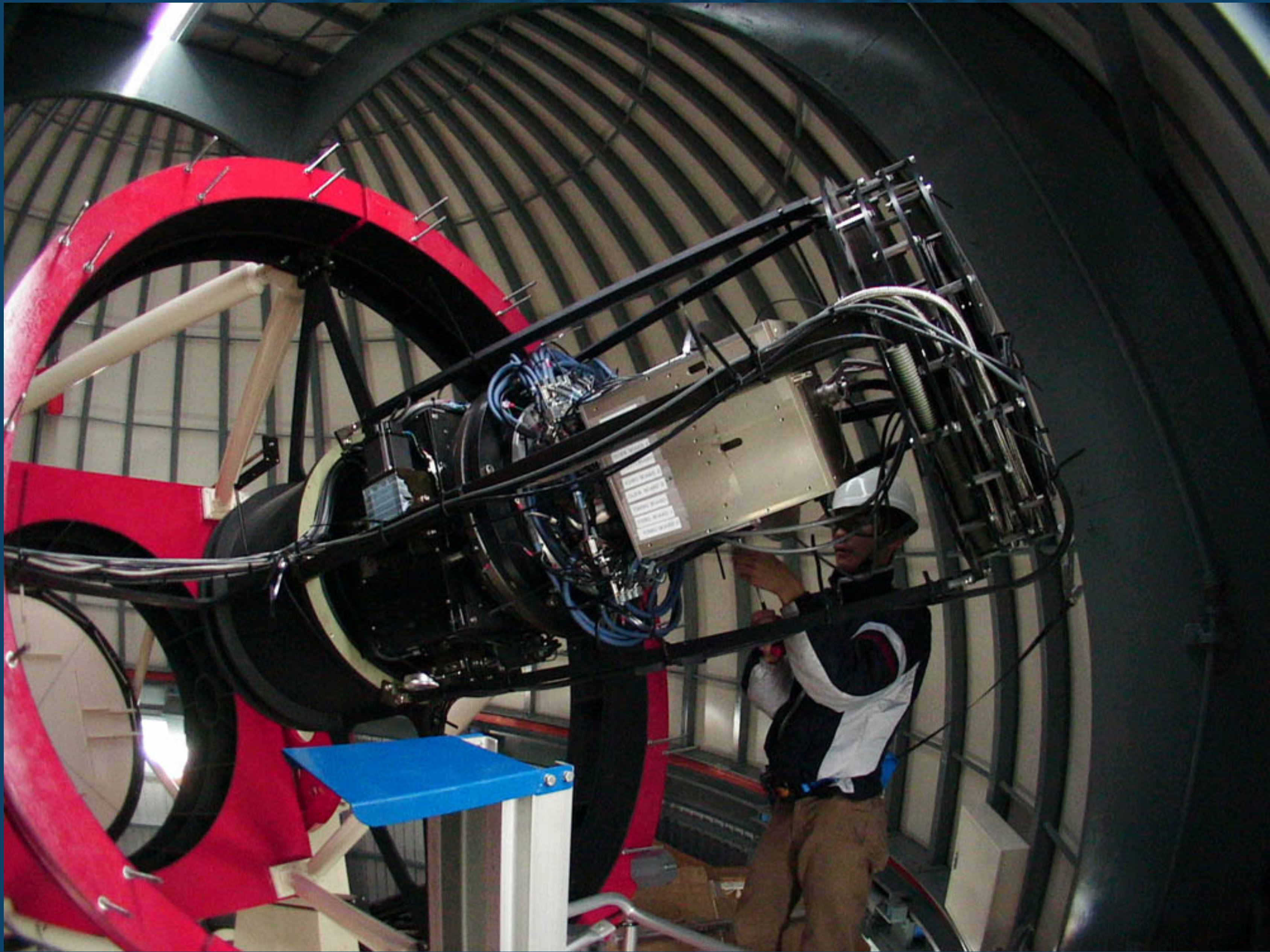
FOV : 2.2 deg.^{2}

(10 times as full moon)

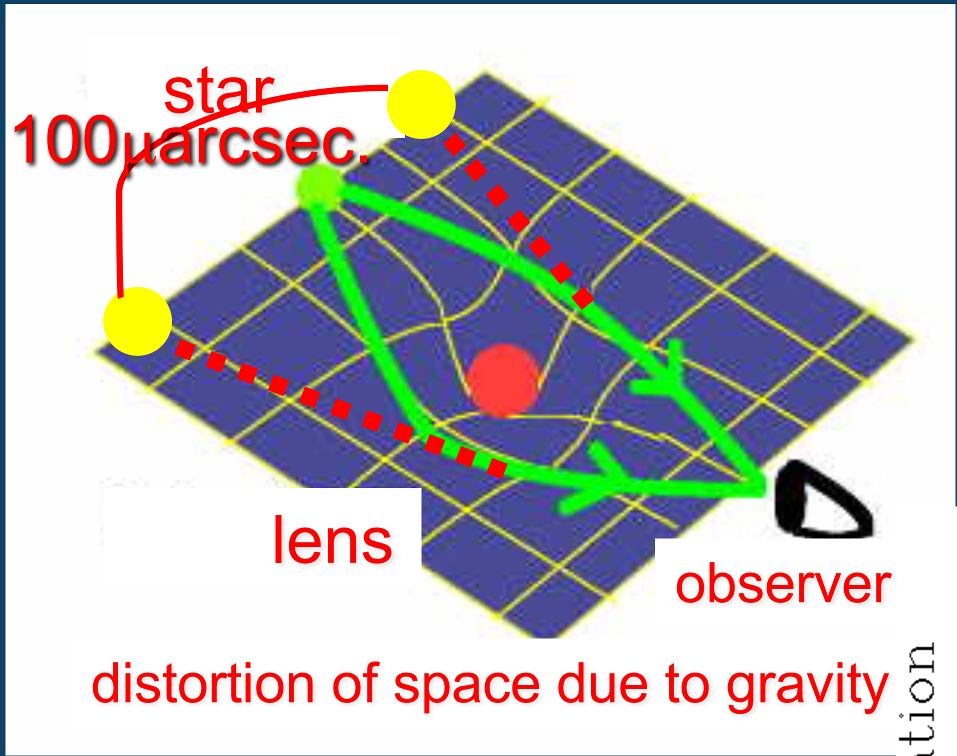




Prime focus camera



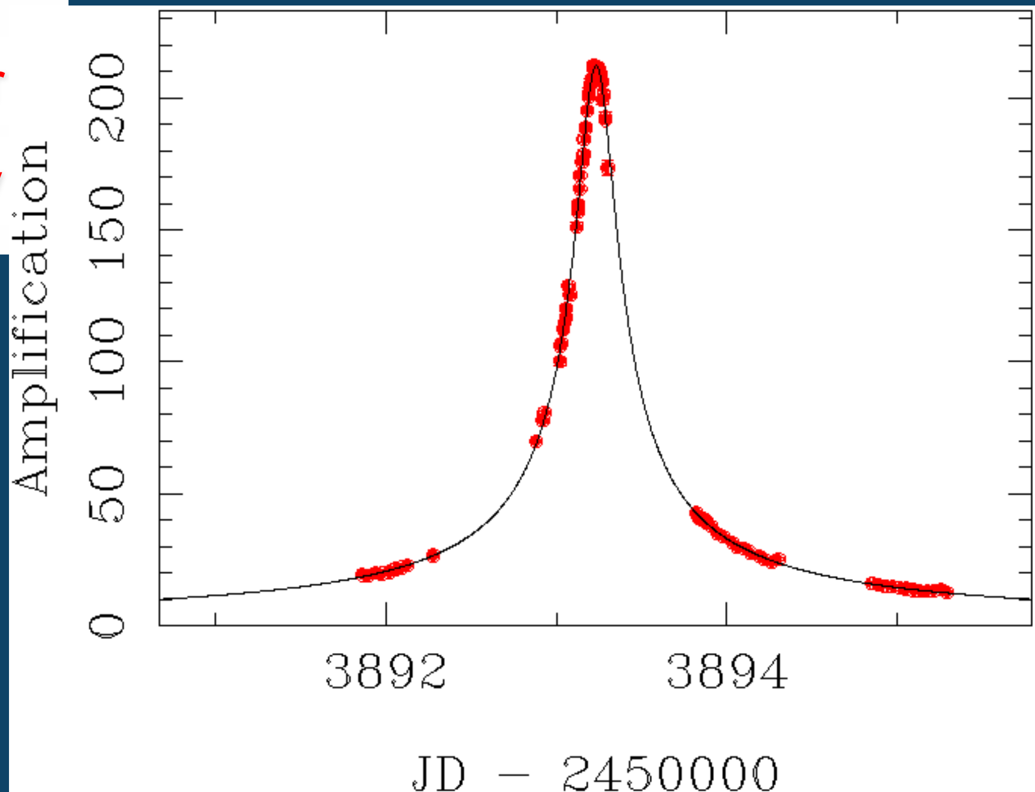
Gravitational Microlensing



✧If a lens is a star, elongation of images is an order of 100μarcsec.

✧Just see a star magnified

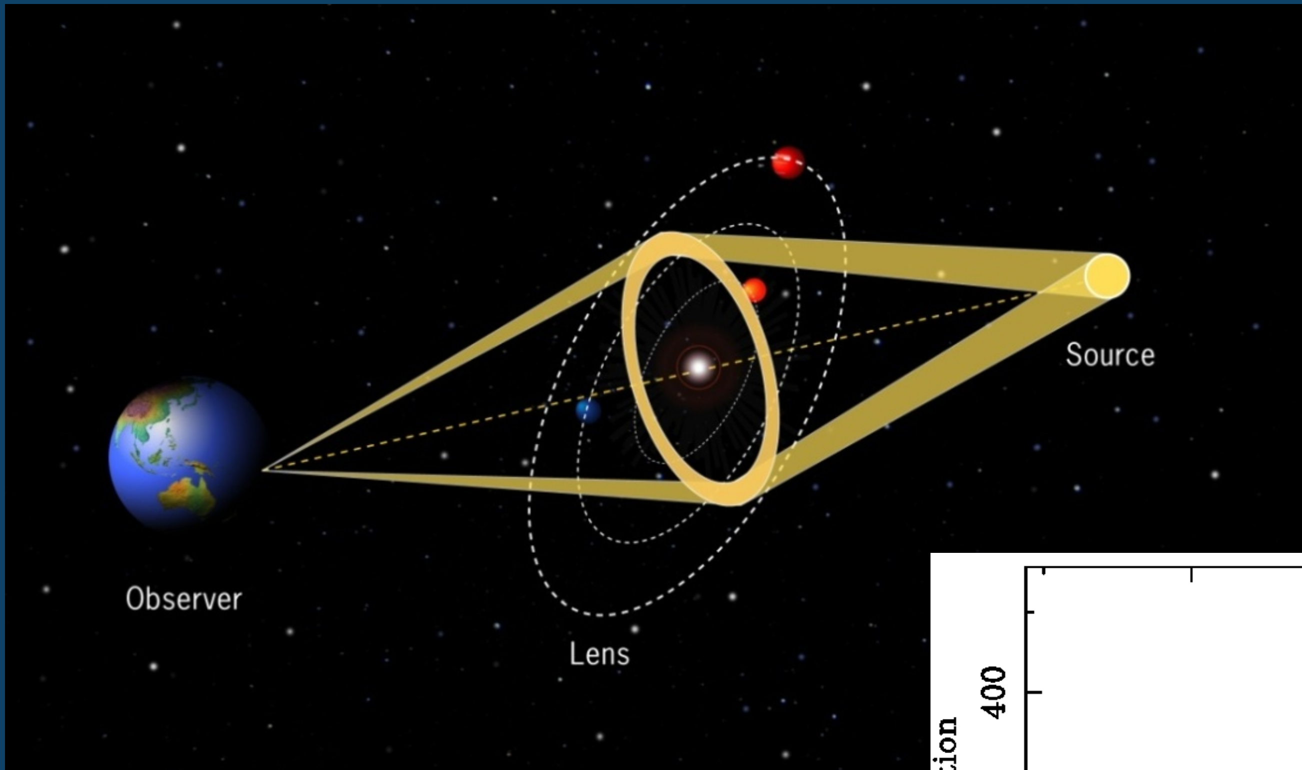
✧Einstein predicted 1936, but concluded impossible to observe. Event rate is 1/1M



- 1986

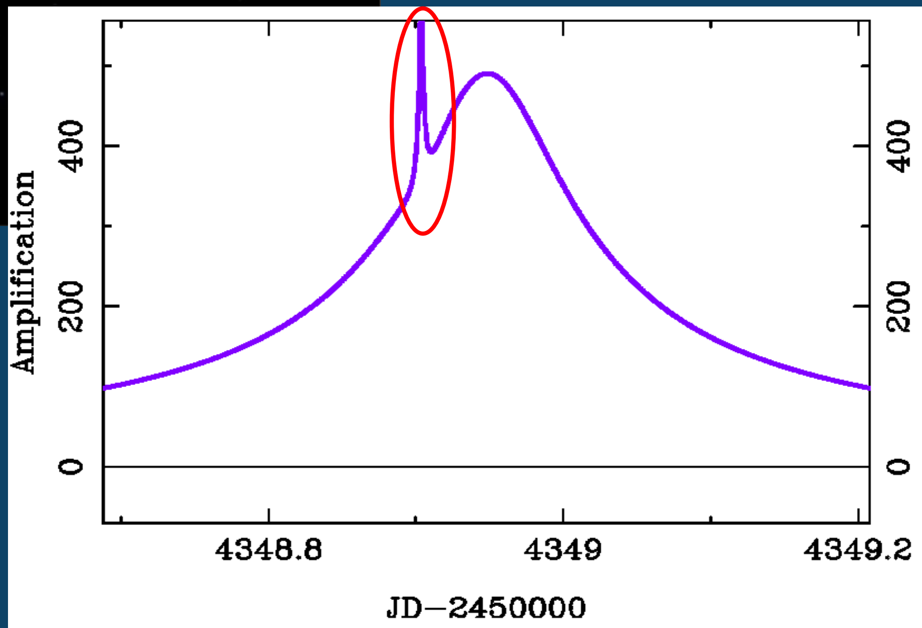
Watch Millions stars
Paczynski

planetary microlensing

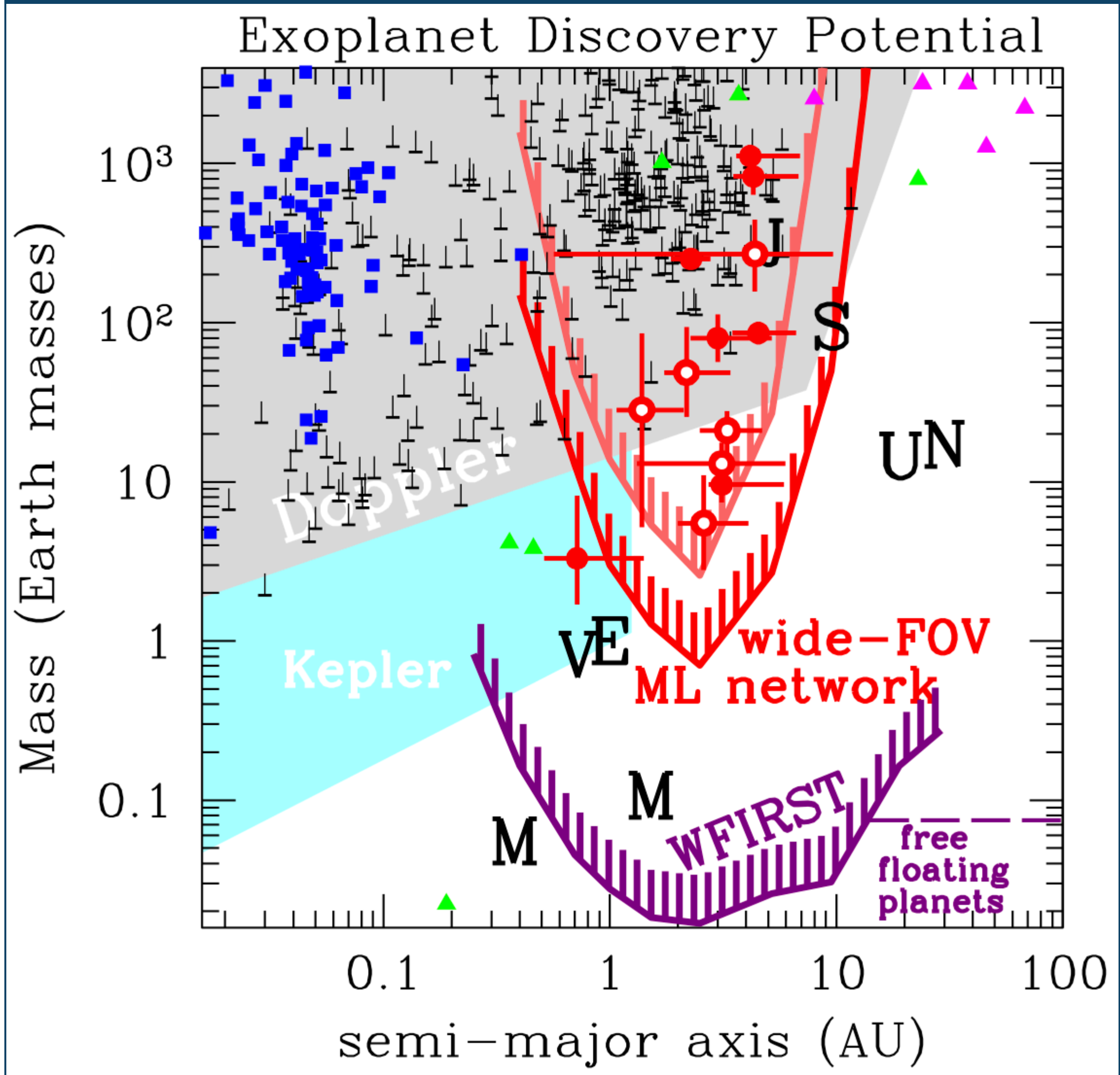


Time scale: $t_p \sim M^{1/2} \sim 1 day(M_J)$

Sensitive to Cold planets outside of snowline ($\sim 3a_{snow}$)



Sensitivity of various methods



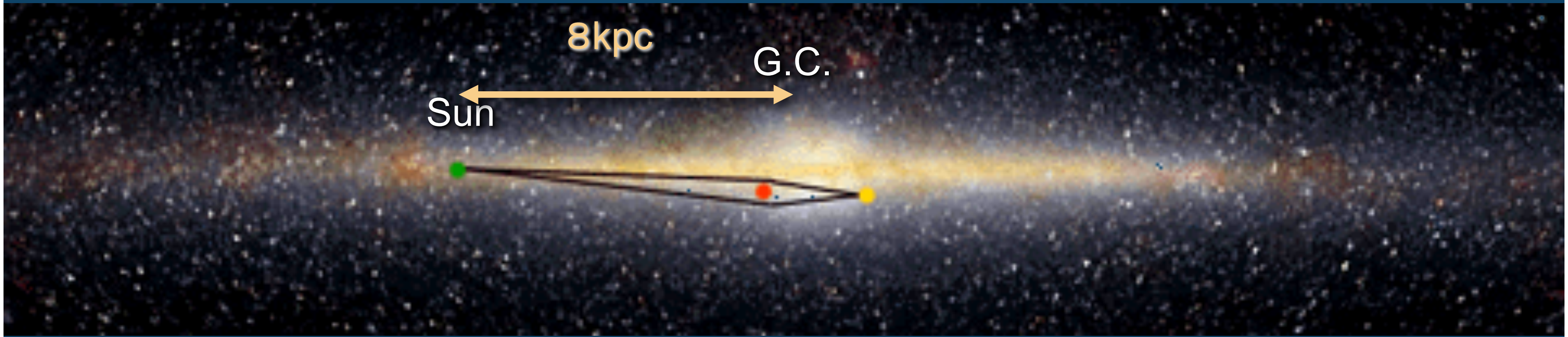
- •RV
- •transit
- •Direct image
- •Microlensing :
  not rely on flux from host

- •1-6 AU : beyond snow line
- •small planet : down to Earth
- •Faint star :M-dwarf, brown dwarf
- •No host : free floating planet
- •Far system: galactic distribution

Survey towards the Galactic Bulge

✧ why ? ➔ Probability:
Microlensing : $\sim 10^{-6}$ events/yr/star
Planetary event : $\sim 10^{-2}$

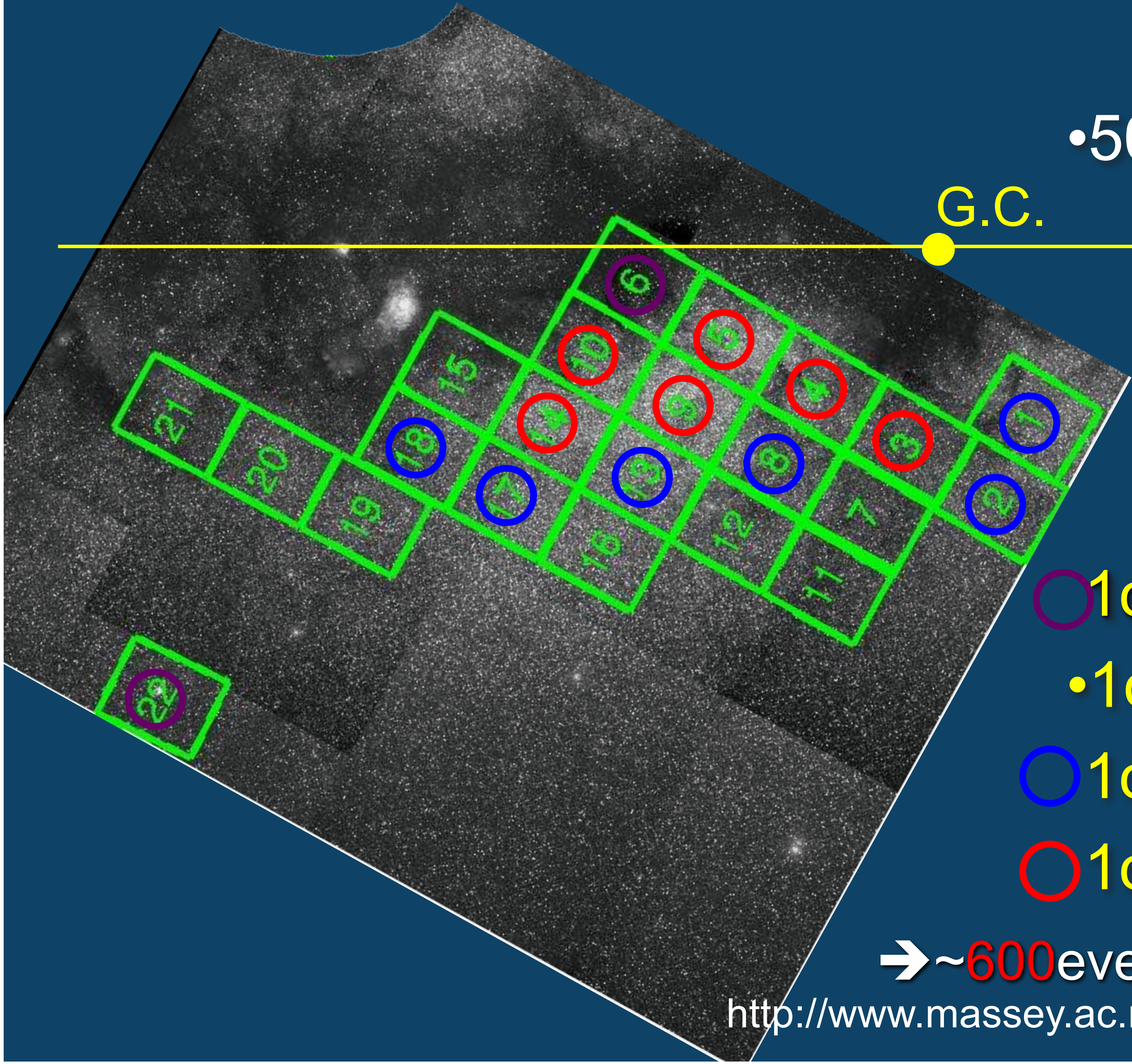
➔ need Wide Field for Many stars



Time scale ~ 30days ($M_{\odot}$)
~ a few days (M_{Jup})
~ hours ($M_{\oplus}$)

➔ need high cadence

Observational fields by MOA



•50 deg.^{2}(20Mstars)

○1obs./night.(>M_{Jup})

•1obs./95min.(M_{jup})

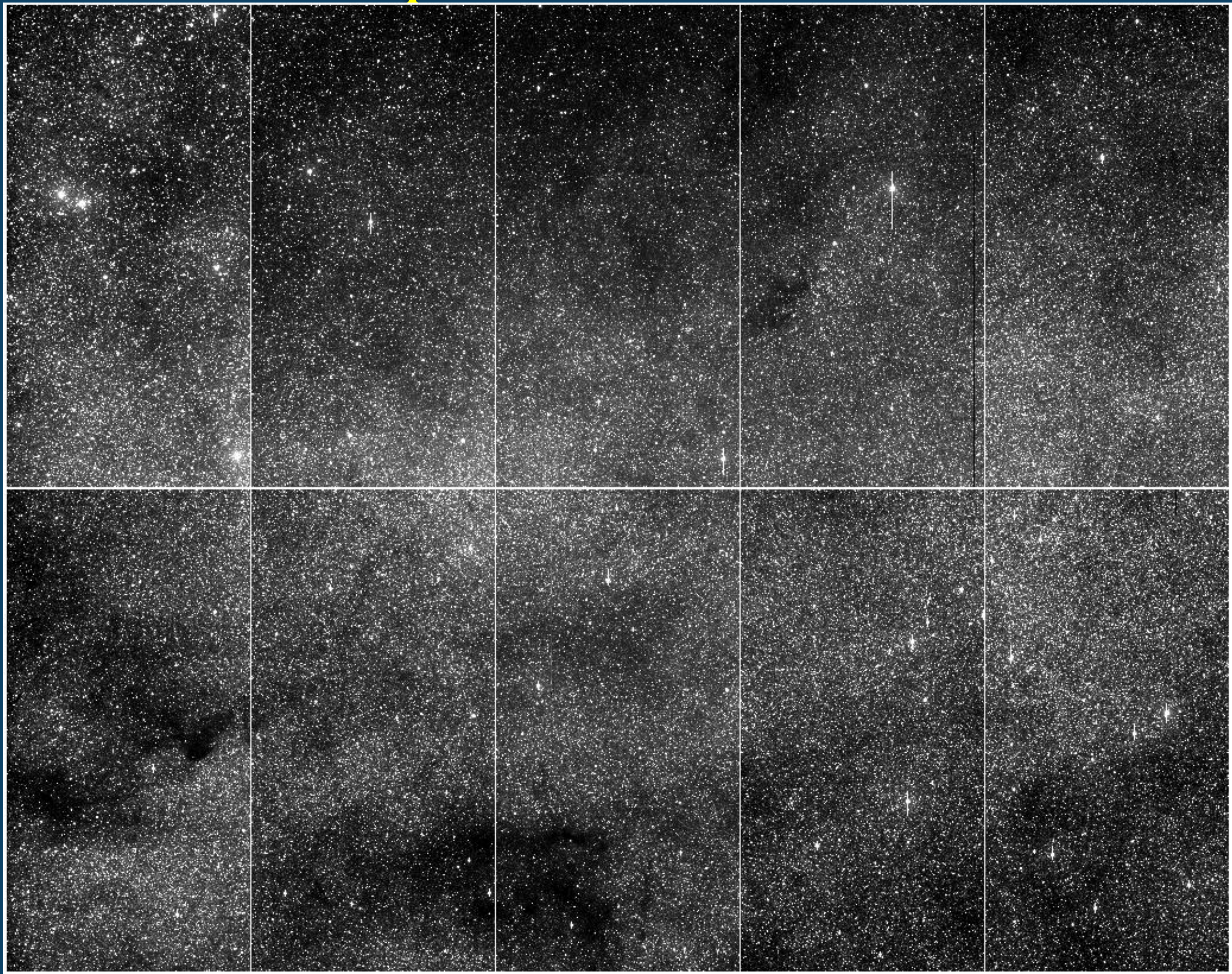
○1obs./47min. (M_{nep})

○1obs./15min. ($M_{\oplus}$)

➔~600events /yr

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

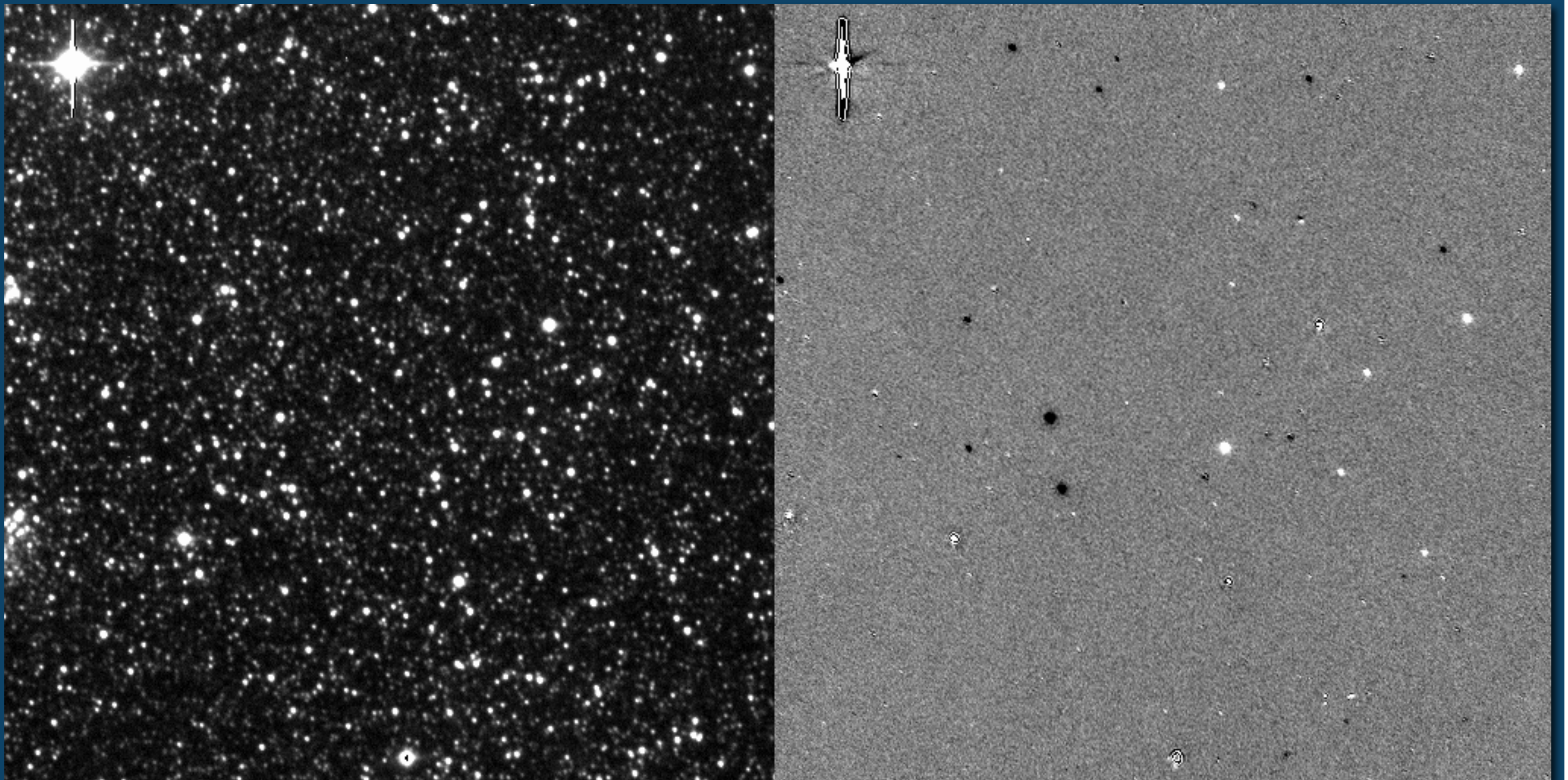
An Exposure toward GB



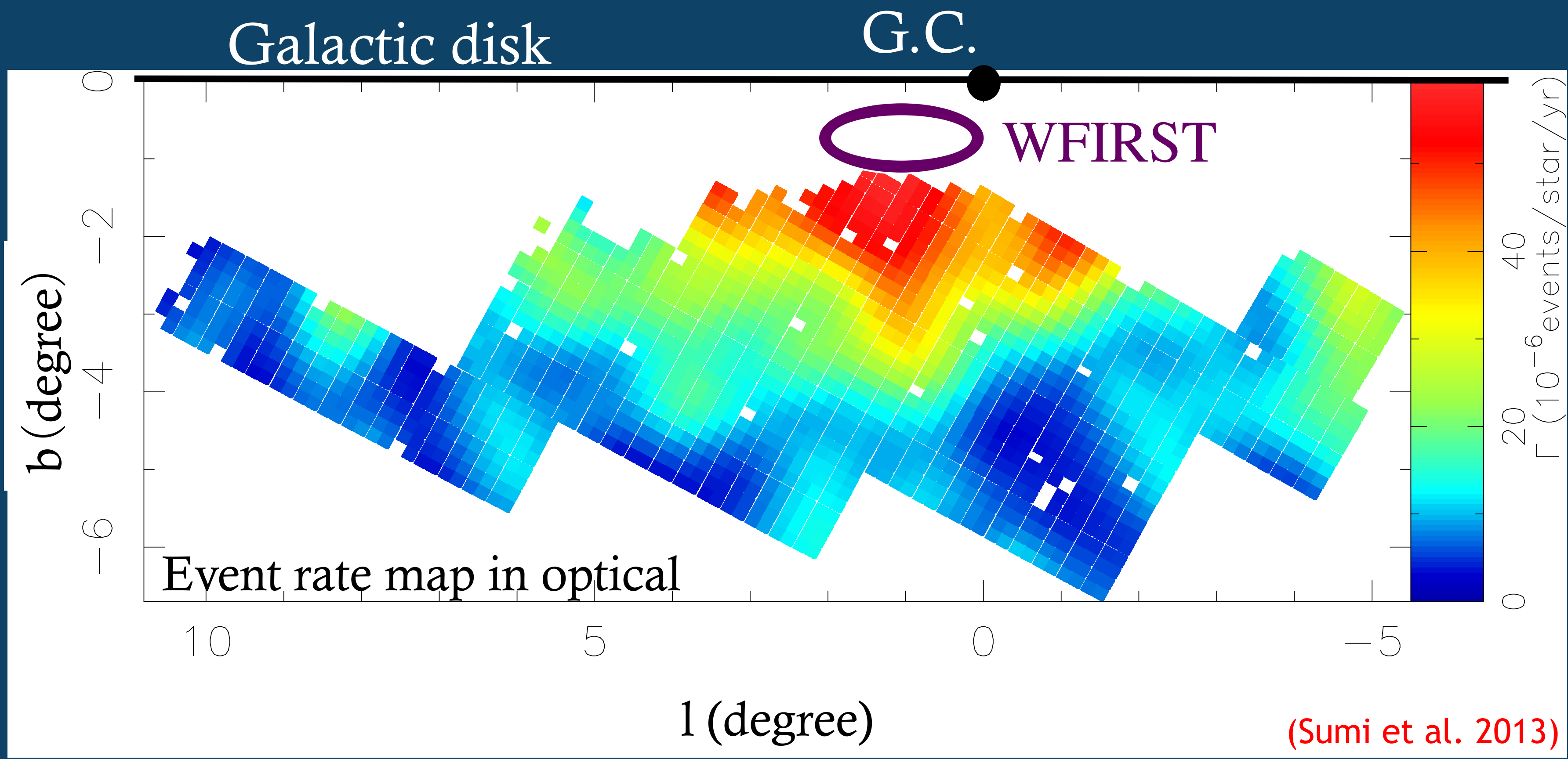
Difference Image Analysis (DIA)

Observed

subtracted



Study the galactic structure & Optimize WFIRST microlensing survey fields by mapping the event rate



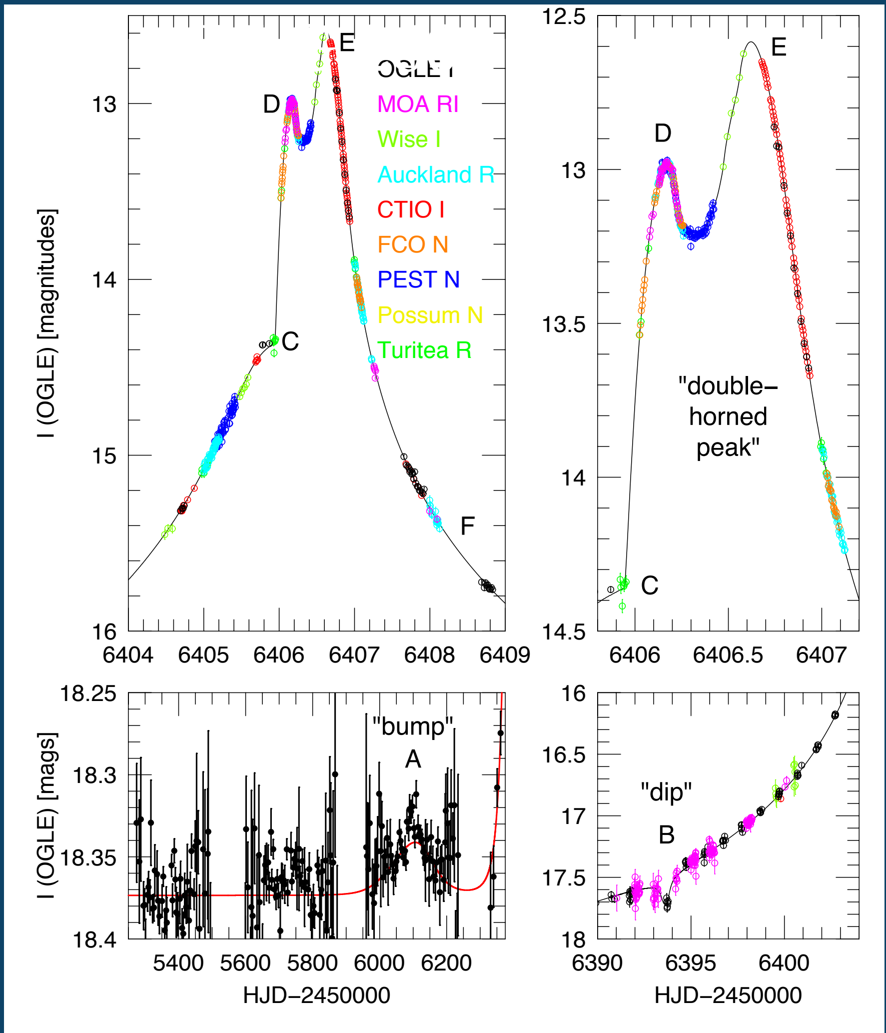
Event rate vary by a factor of 2（peak is at l=1°）

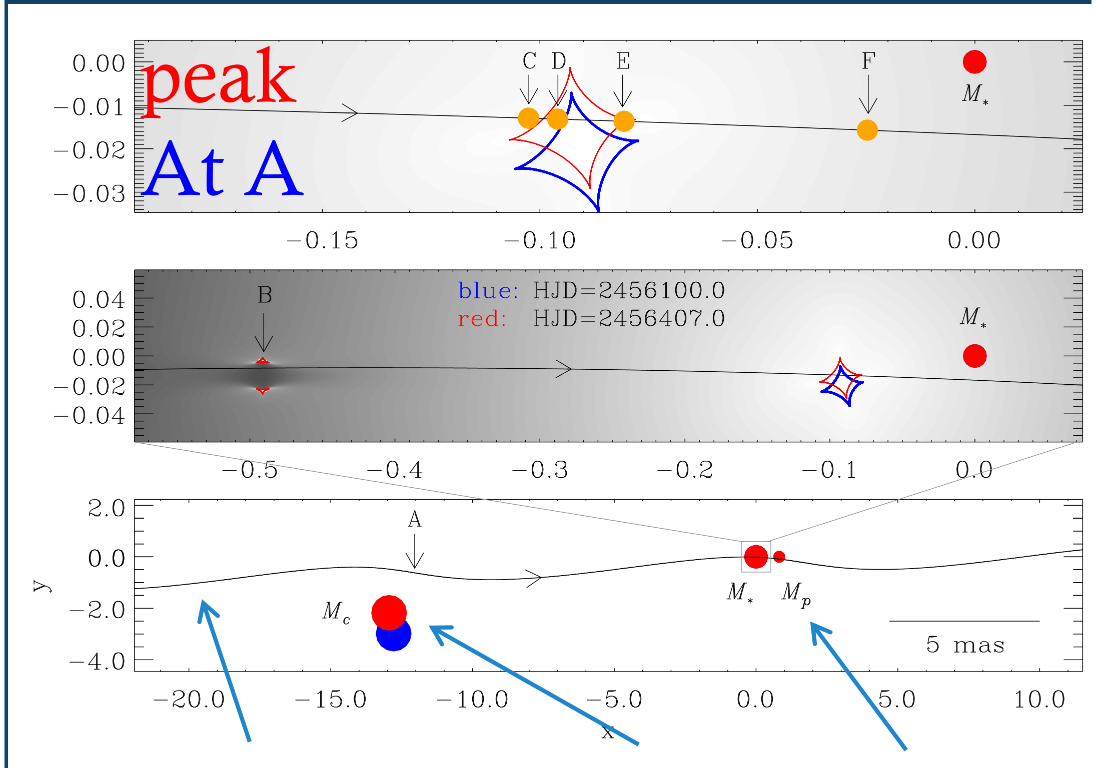
1.7 Earth-mass planet in a binary system

OGLE-2013-BLG-0341/MOA-2013-

Gould+2014

$D_l = 911.00 \pm 0.07$ kpc
$M_c = 0.121 \pm 0.009 M_\odot$
$M_h = 0.113 \pm 0.009 M_\odot$
$M_p = 1.66 \pm 0.18 \quad M_E$
$a = 0.70 \pm 0.02$ AU





Source trajectory

companion

Planetary system

Linear approximation of orbit

$\alpha(t)=\alpha_0+d\alpha/dt(t-t_{fix})$

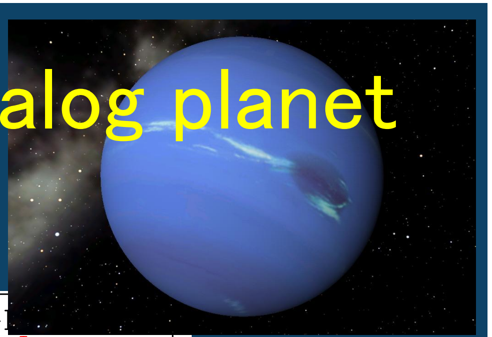
$s(t)=s_0 \ +ds/dt(t-t_{fix})$

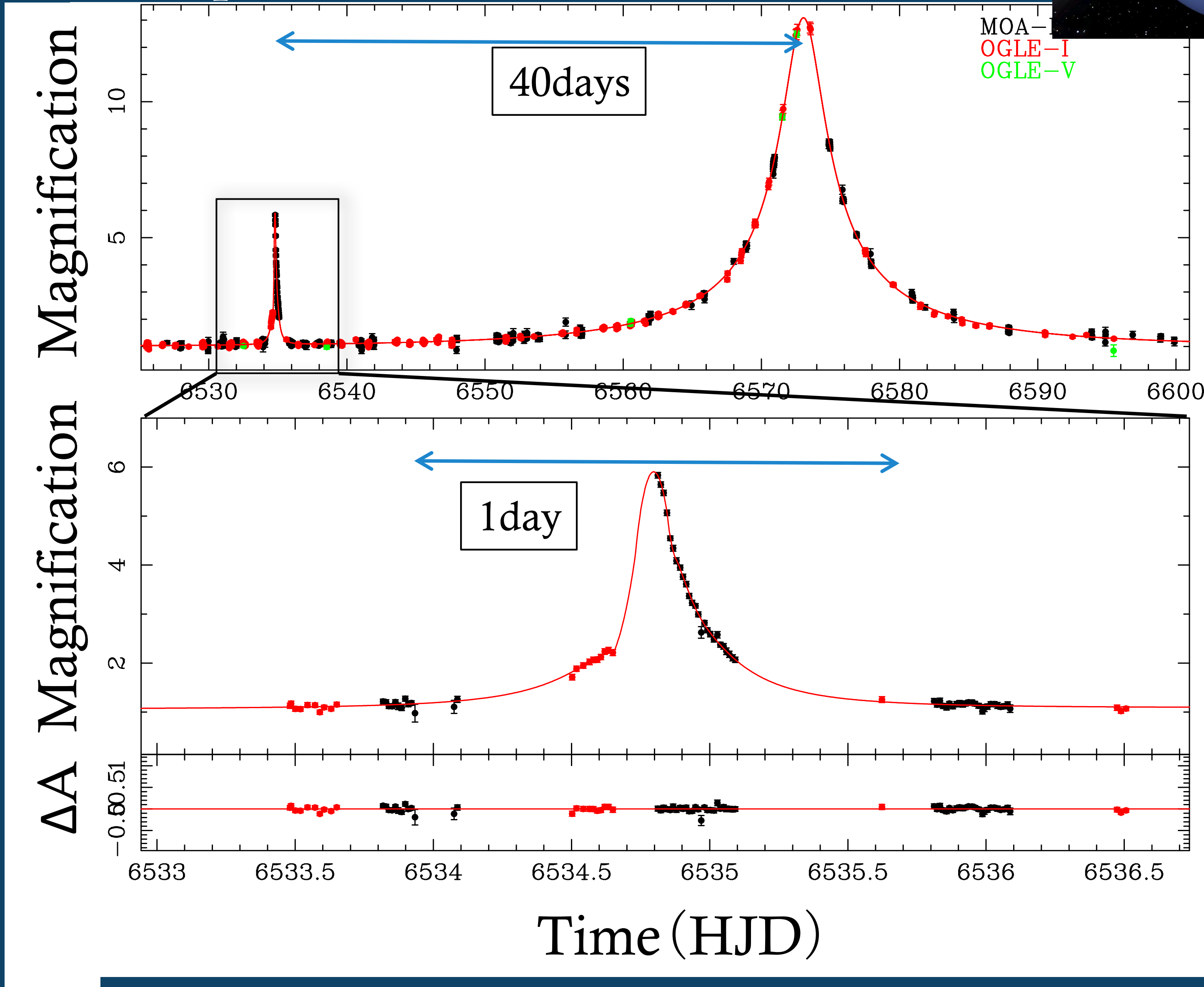
$$\left(\frac{KE}{PE}\right)_\perp = \frac{(r_\perp/AU)^3}{8\pi^2(M/M_\odot)}\left[\left(\frac{1}{s}\frac{ds}{dt}\right)^2+\left(\frac{d\alpha}{dt}\right)^2\right]$$ <1 to be bound

MOA−2013−BLG−605: the Neptune analog planet

$q=3 \times 10^{-4}$, $s=2.3$,

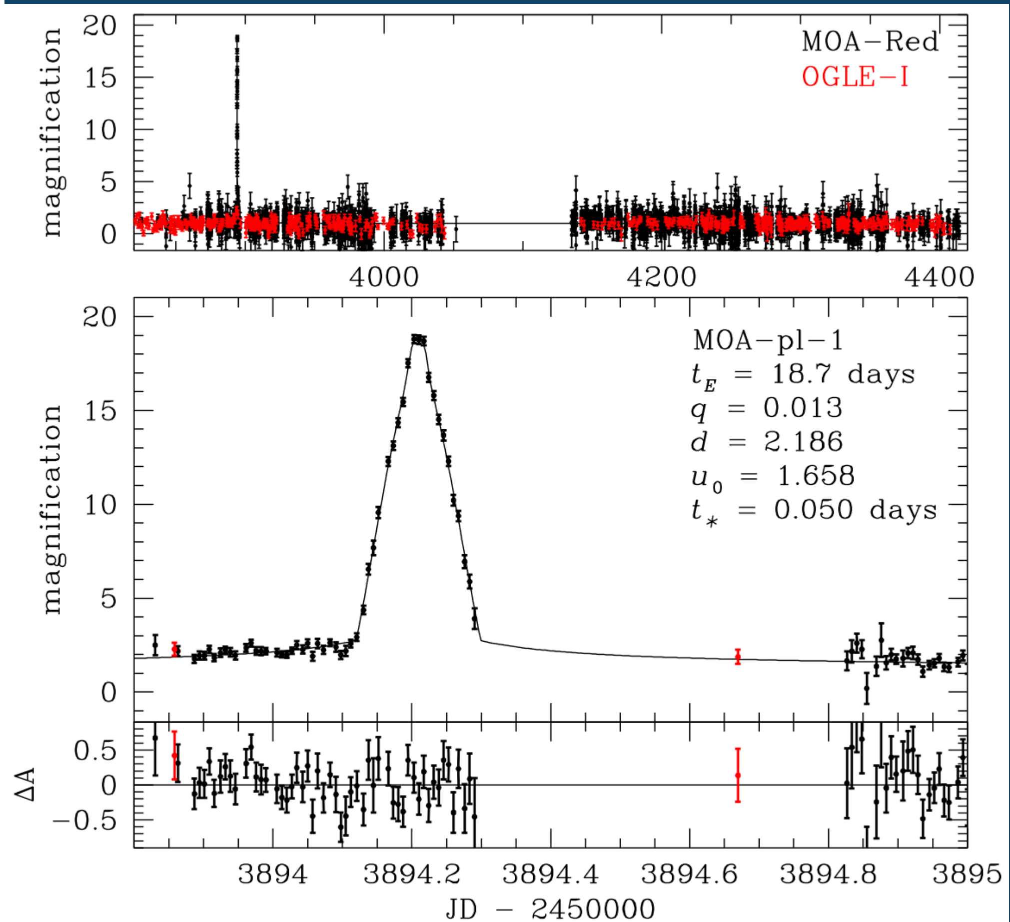
Neptune or super Earth around Brown-dwarf

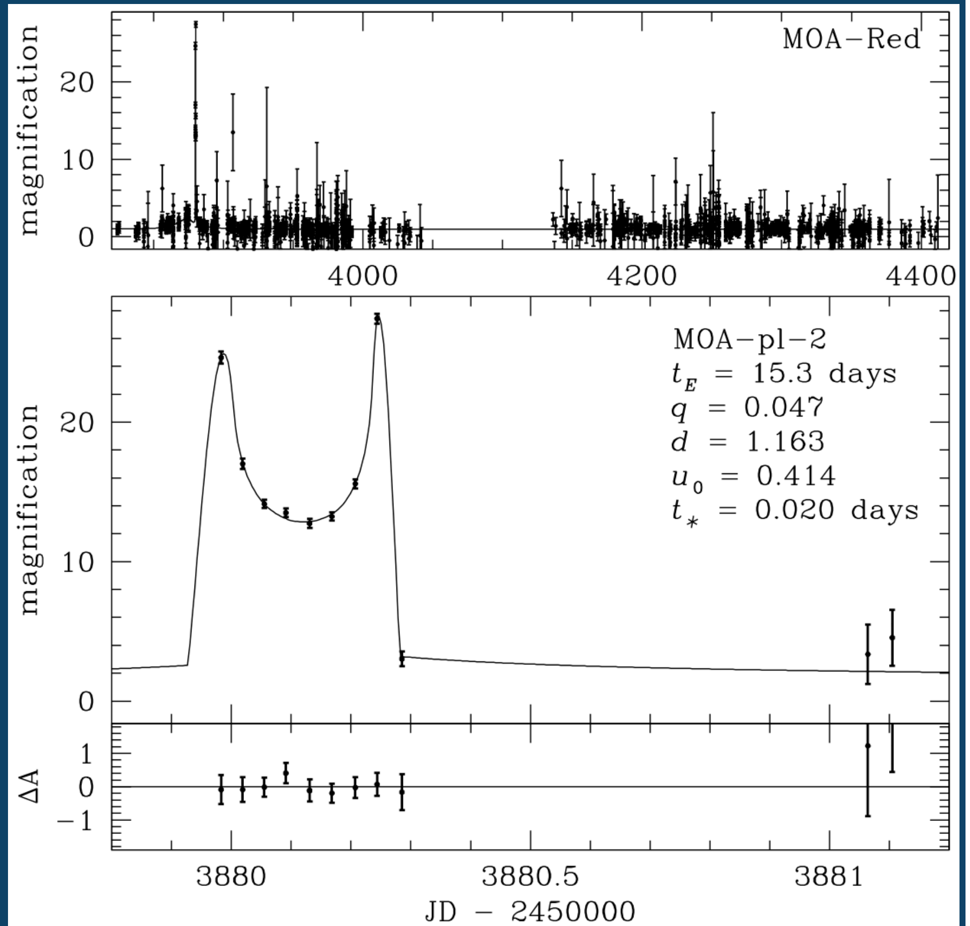


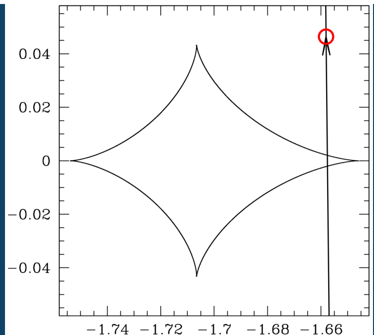


TS+2016

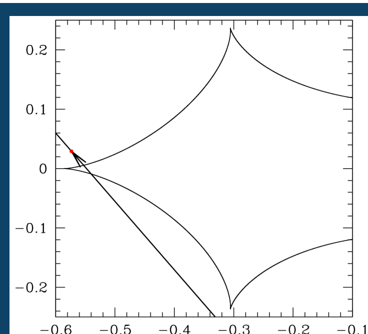
Short Binary Events



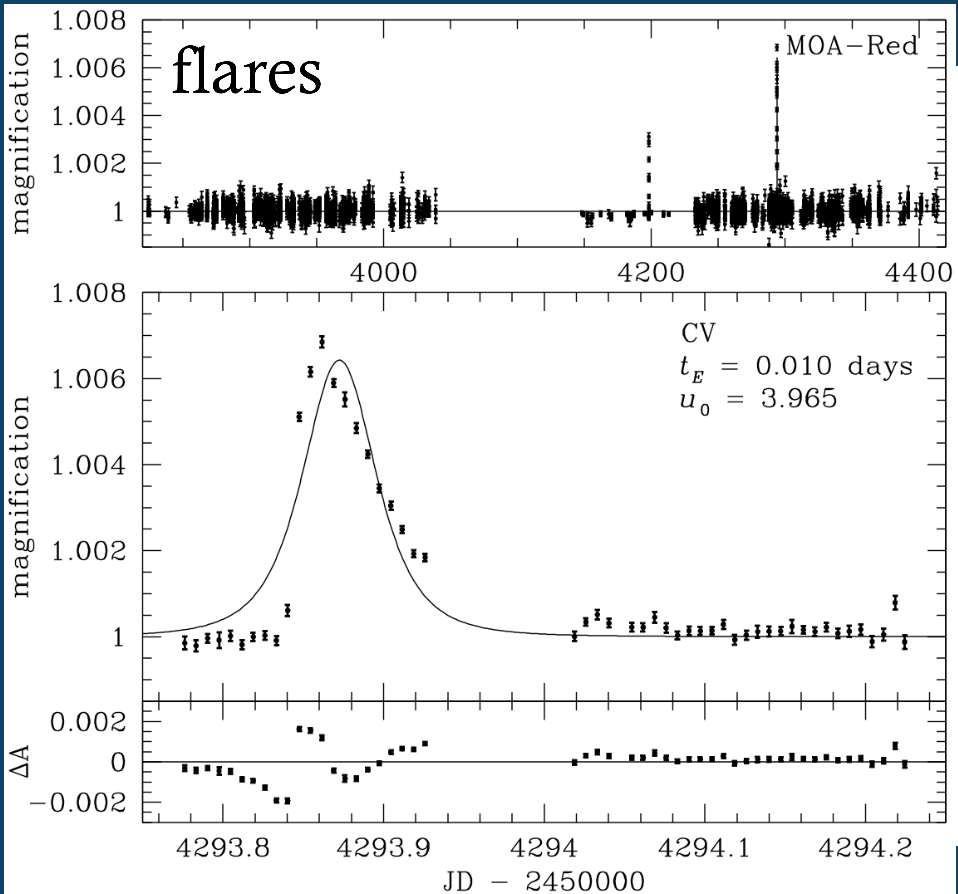


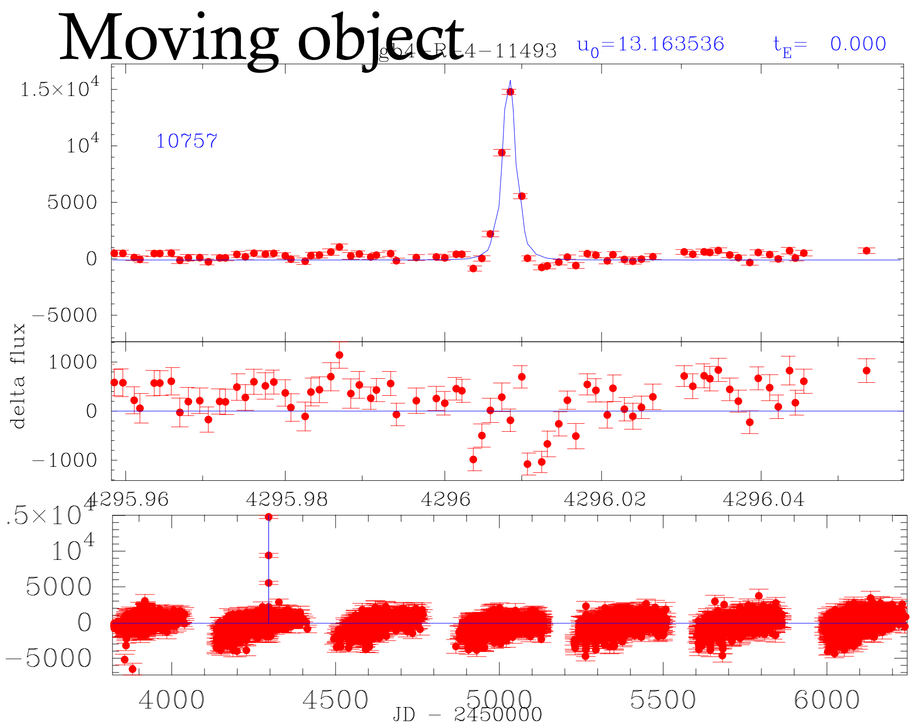


Wide-binaries (d = 2.2, 1.2) with planetary and brown dwarf mass ratios of q = 0.013 and 0.047



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