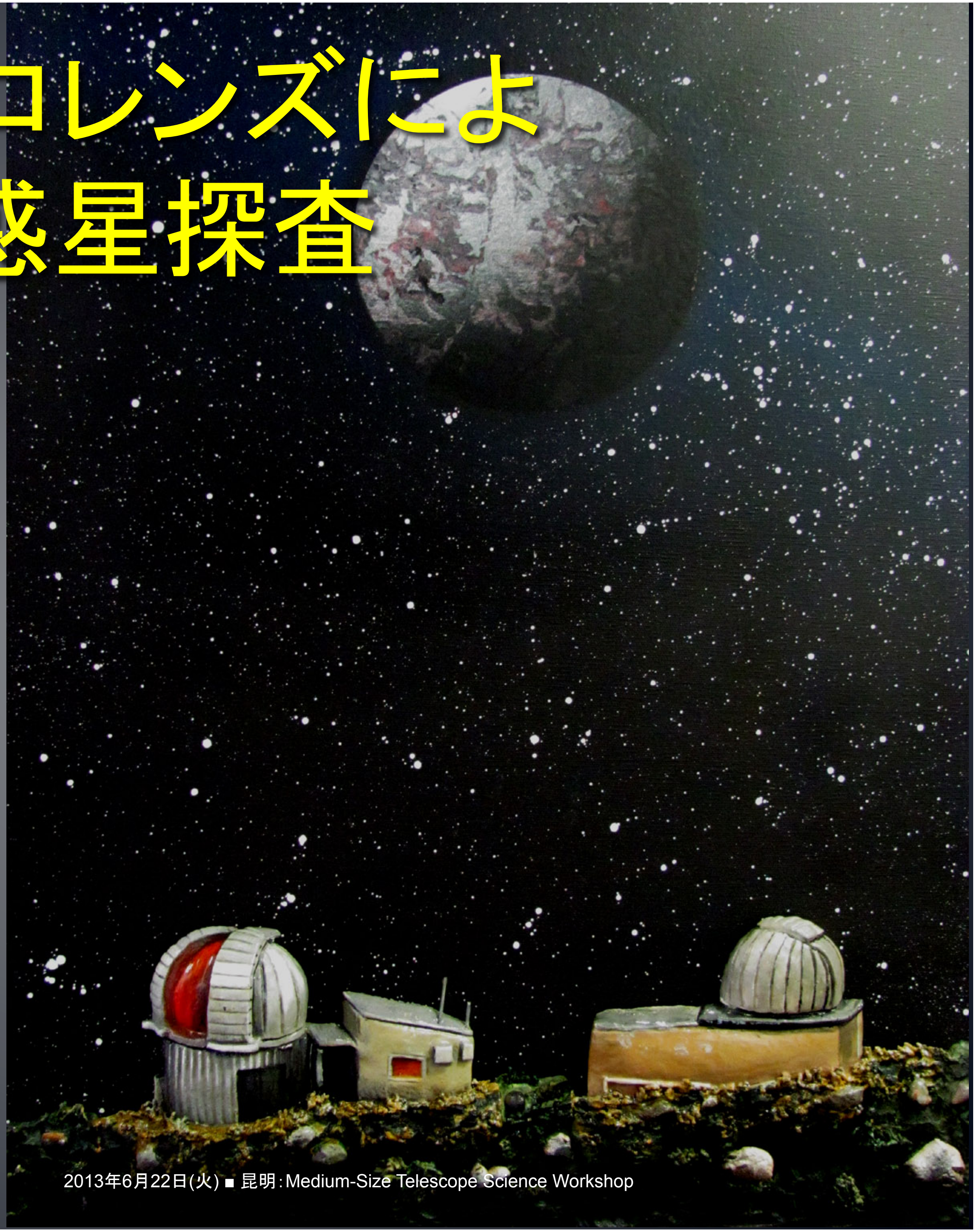
重力マイクロレンズによる系外惑星探査

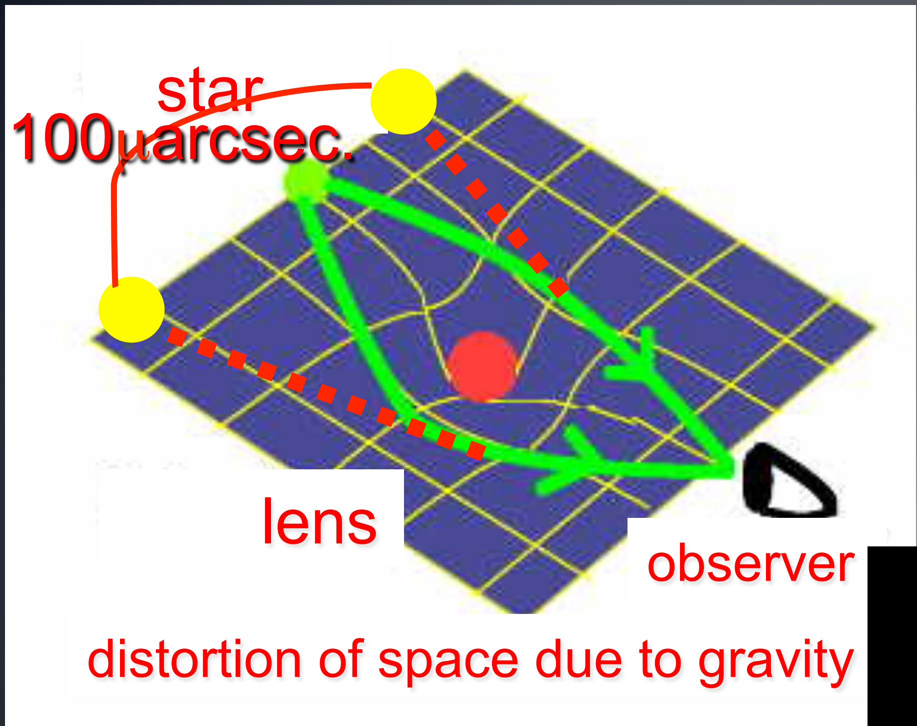


住　貴宏
（Osaka Univ.）
MOA collaboration

2013年6月22日(火) ■ 昆明:Medium-Size Telescope Science Workshop

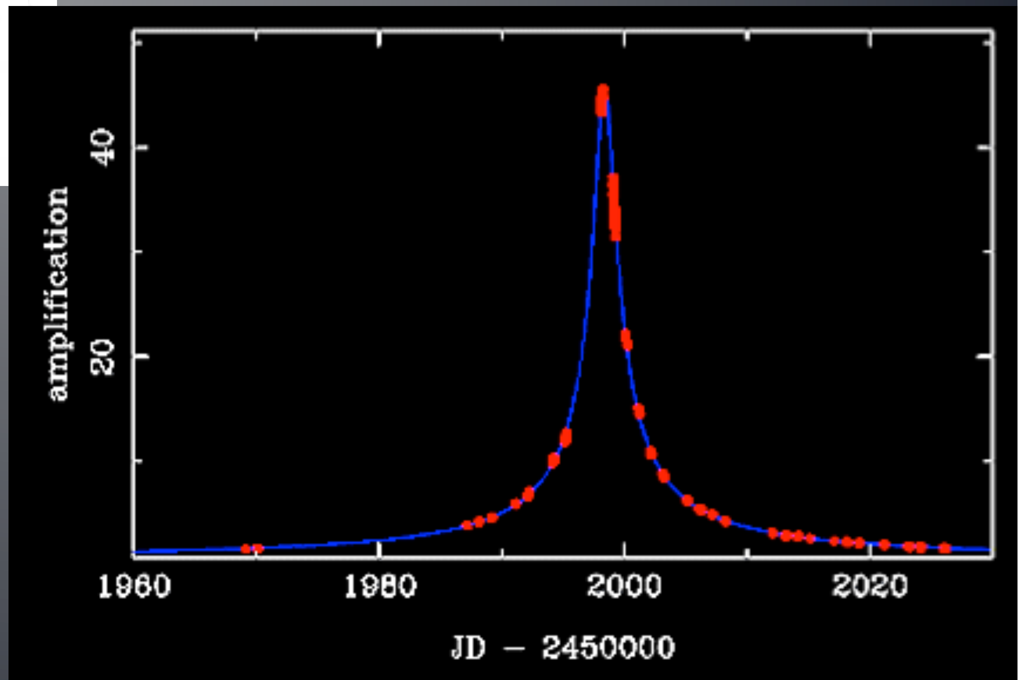
Gravitational Microlensing


Science, 1936



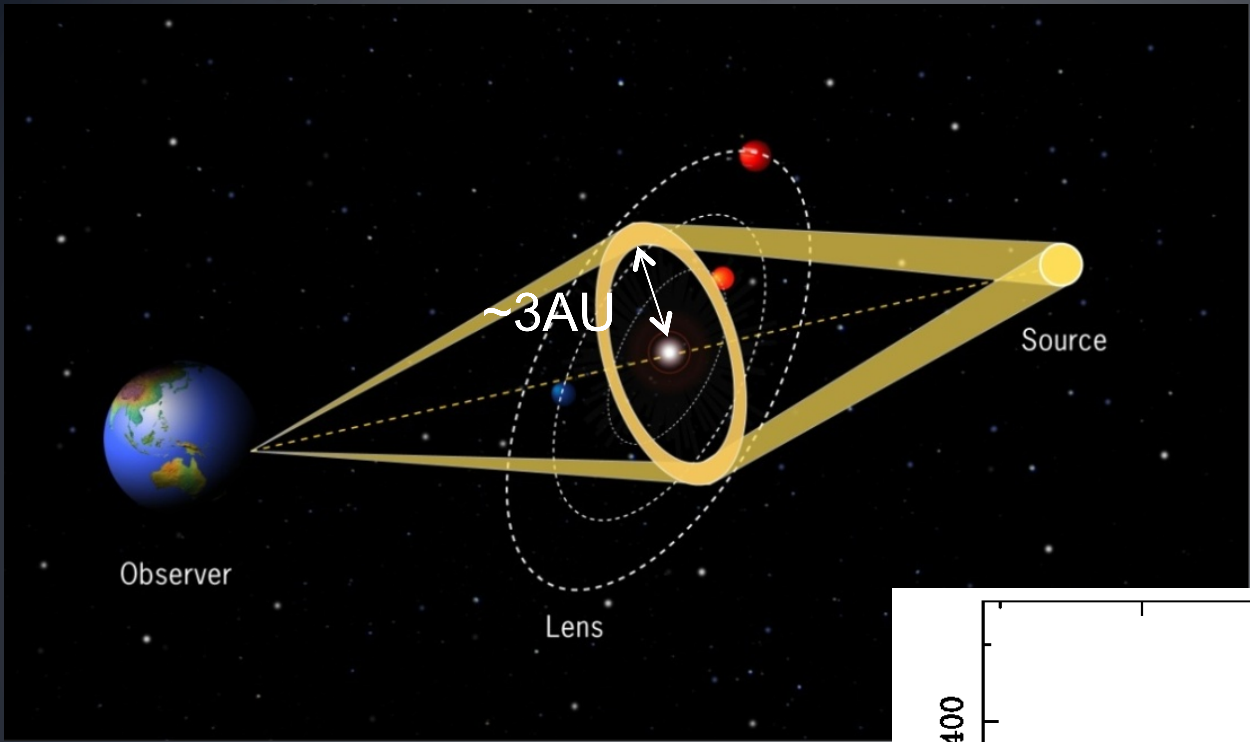
✧If a lens is a star, elongation of images is an order of 100μarcsec.

✧Just see a star magnified

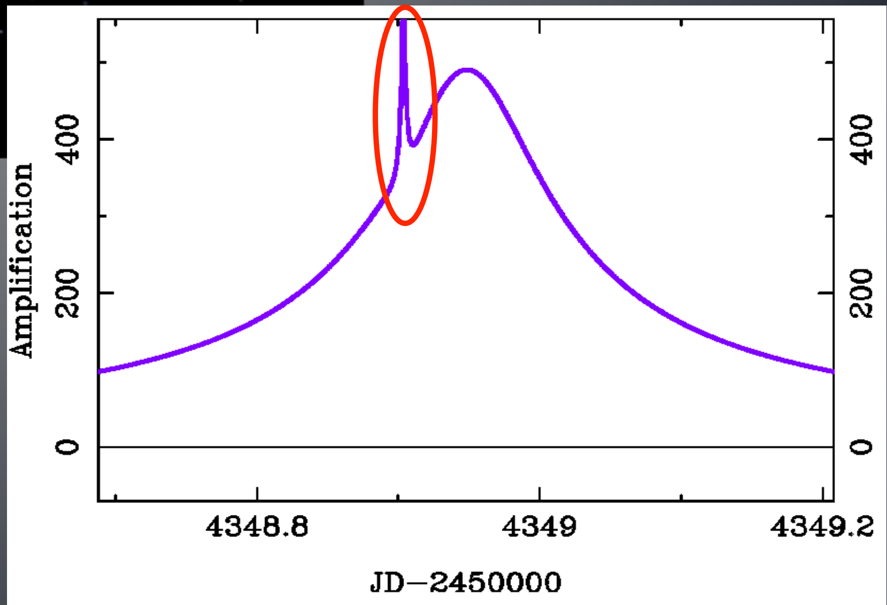


プラスティックレンズ

planetary microlensing



Mao & Paczynski 1991



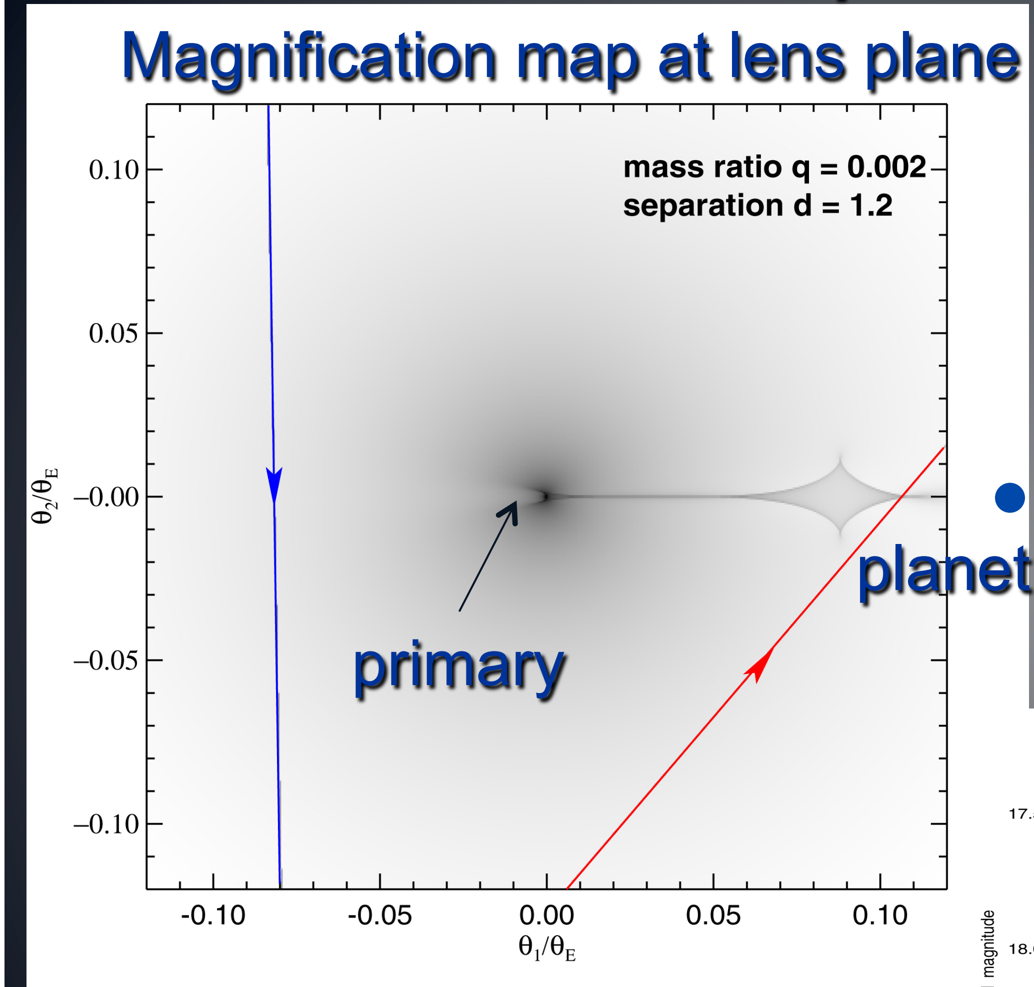
Time scale: t_p~$M^{1/2}$ ~1day(M_J)

Rare and short but not weak!

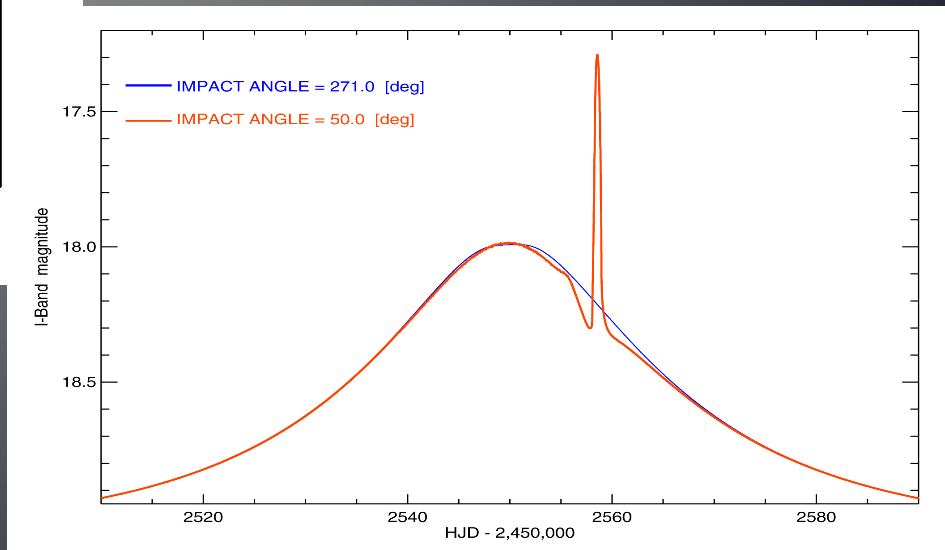
Sensitive to Cold planets outside of snowline (~3AU)

Caustics

How to detect/miss a planet orbiting a microlens star



low-mass planet signals are rare and brief, but not weak→
Need large sample with moderate precision and High cadence

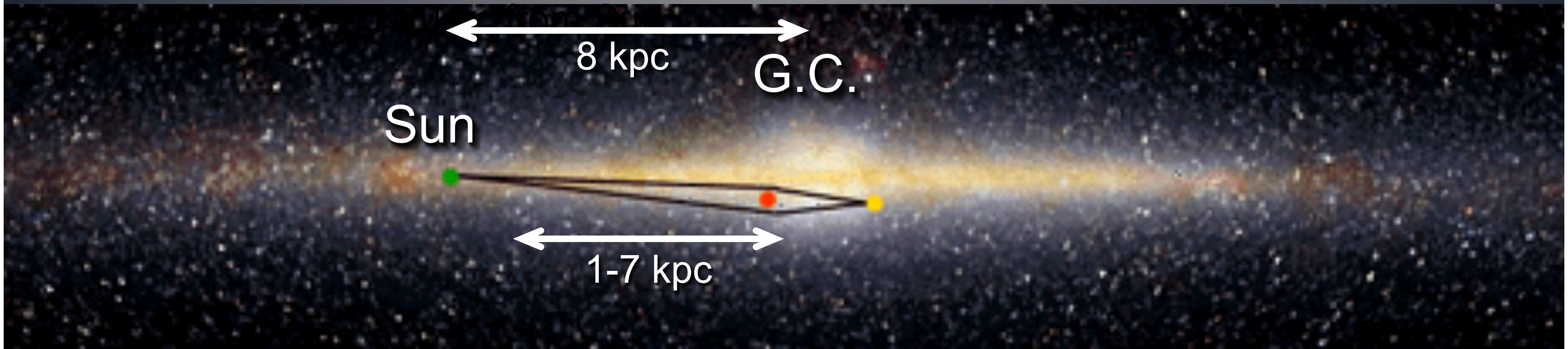


Microlensing Target Fields are in the Galactic Bulge

Microlensing event rate : ~10^{-5} events/yr/star

Planetary event : ~10^{-2}

→ need Wide Field for Many stars



Time scale ~ 30days ($M_\odot$)

~ a few days (M_{Jup})

~ hours ($M_\oplus$)

→ need high cadence

Microlensing observation global network

Survery

OGLE (Optical Gravitational Lensing Experiment)

MOA (Microlensing Observations in Astrophysics)

Micro lensing Alert

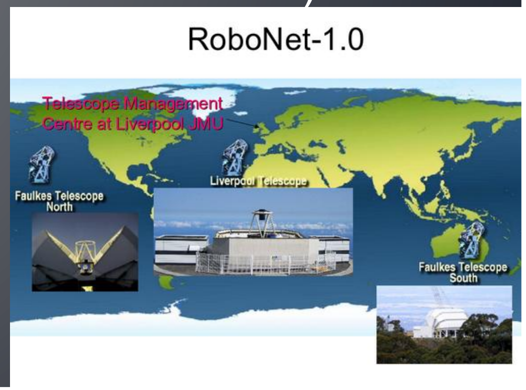
Anomaly Alert

Follow-up

MicroFUN (Microlensing Follow-Up Network)

PLANET (Probing Lensing Anomaly Network)

MiNDSTEp



1m-class including 30cm armature telescopes

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-II1.8m telescope

（New Zealand/Mt. John Observatory at NZ, 44°S ）

Mirror : 1.8m (F=2.91)

CCD　: 8k　x　10k pix. (MOA-cam3)

FOV　: 2.2 deg.^{2}

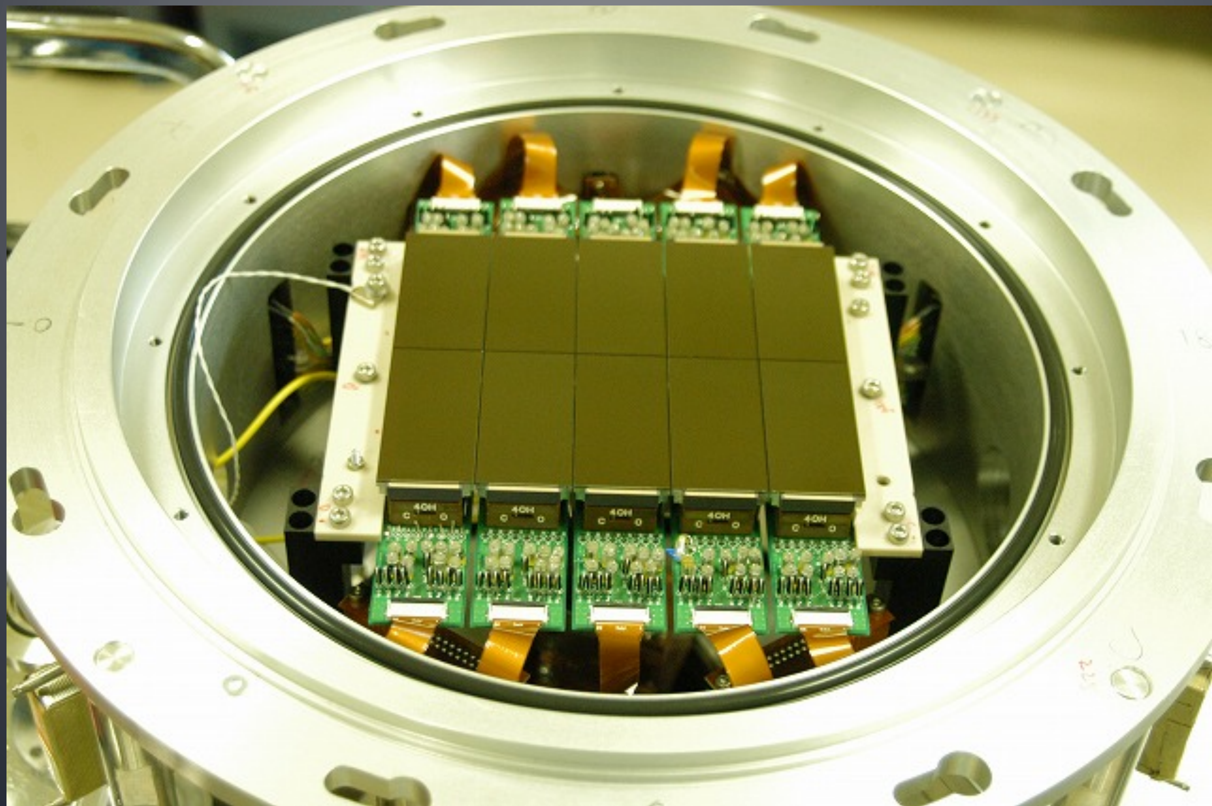
MOA-cam3

CCD : 8k x 10k pix. (10 E2V CCD4482)

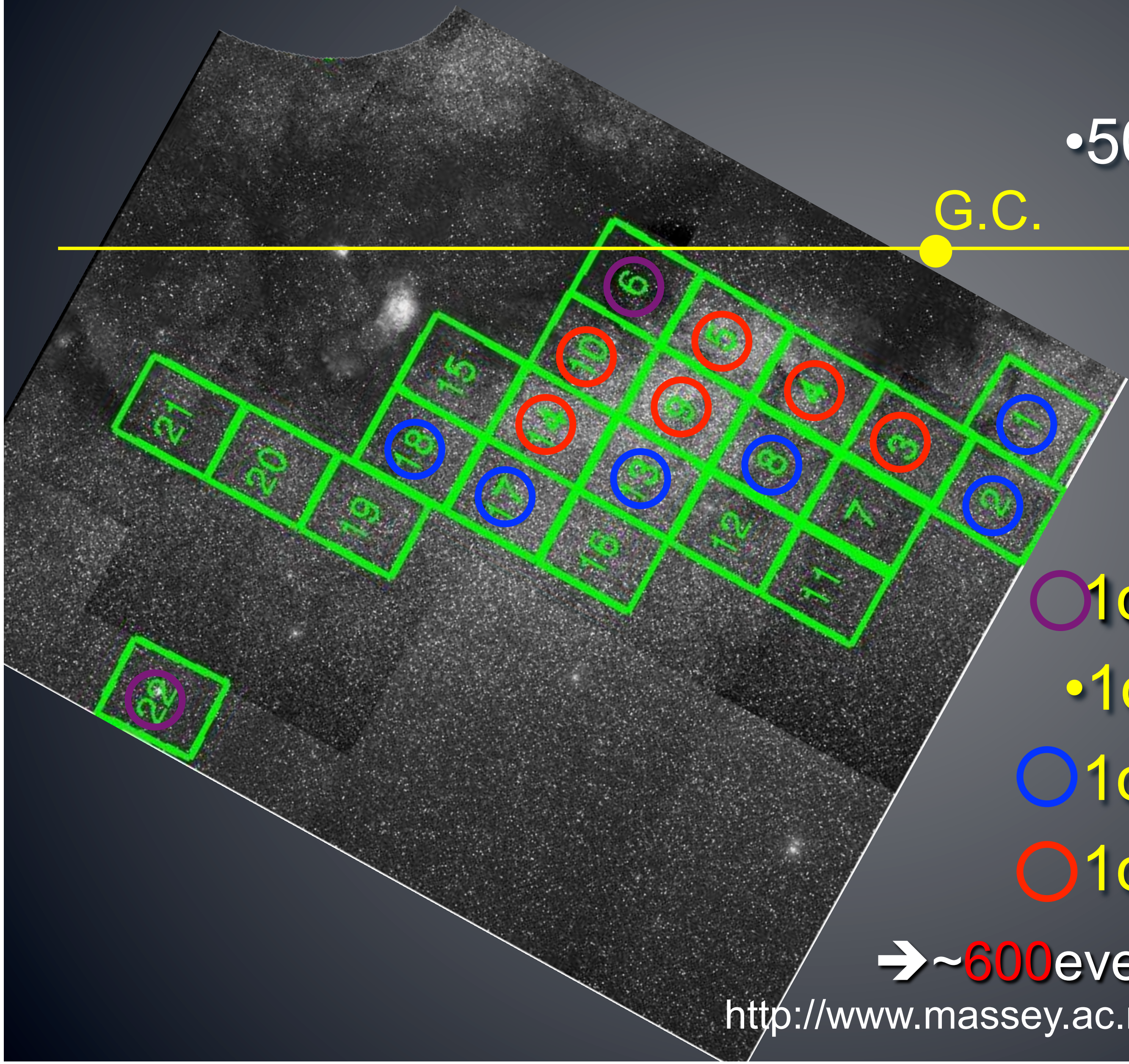
Pixel size: 0.58 arcsec/pix (15μm)

FOV : 2.2 deg.^{2}

Read out : 32 sec



Observation by MOA



- 50 deg.^{2}(20Mstars)

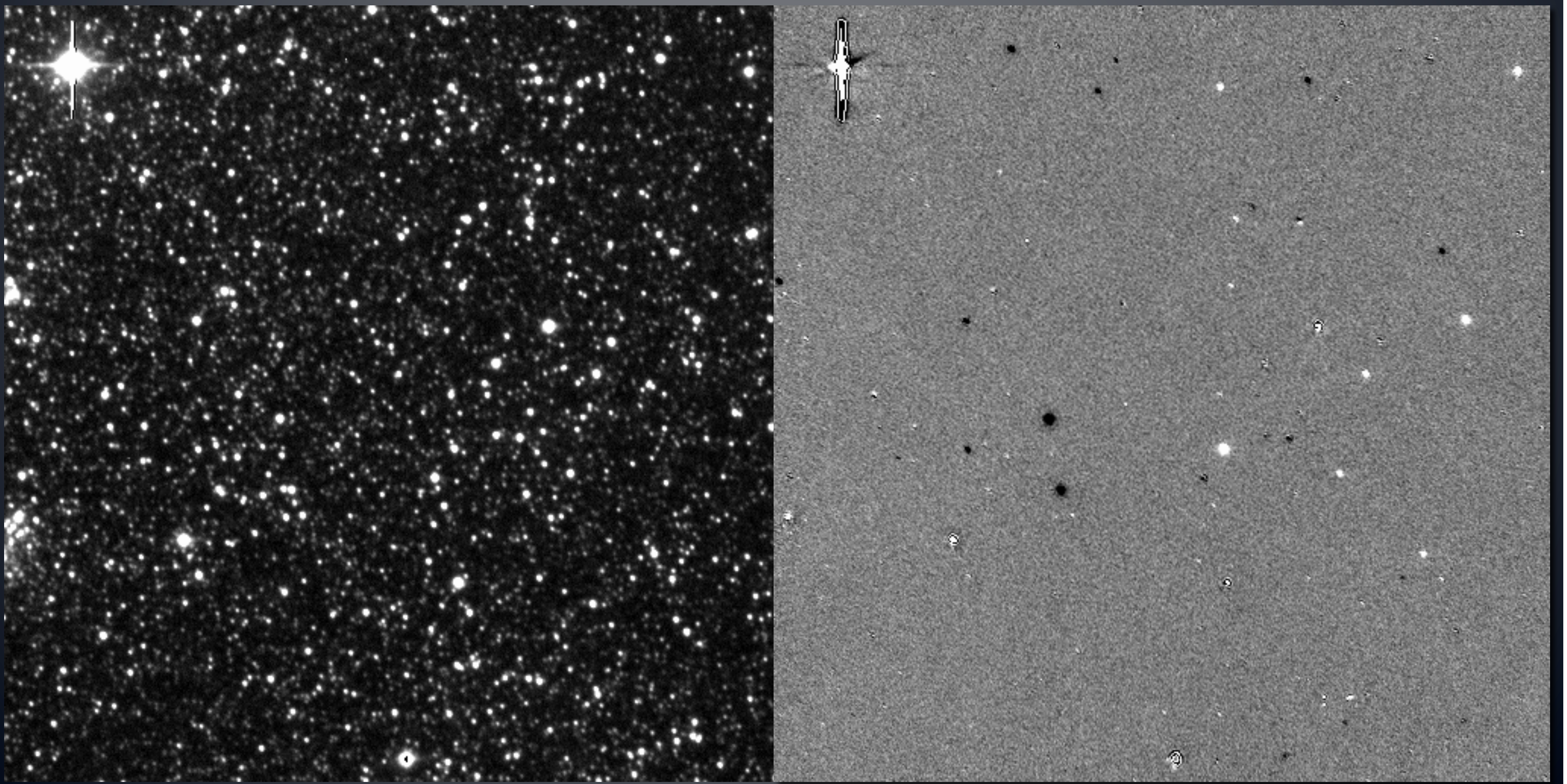
- ○ 1obs./night.(>M_{Jup})
- 1obs./95min.(M_{jup})
- ○ 1obs./47min. (M_{nep})
- ○ 1obs./15min. ($M_{\oplus}$)

➔~600events /yr

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

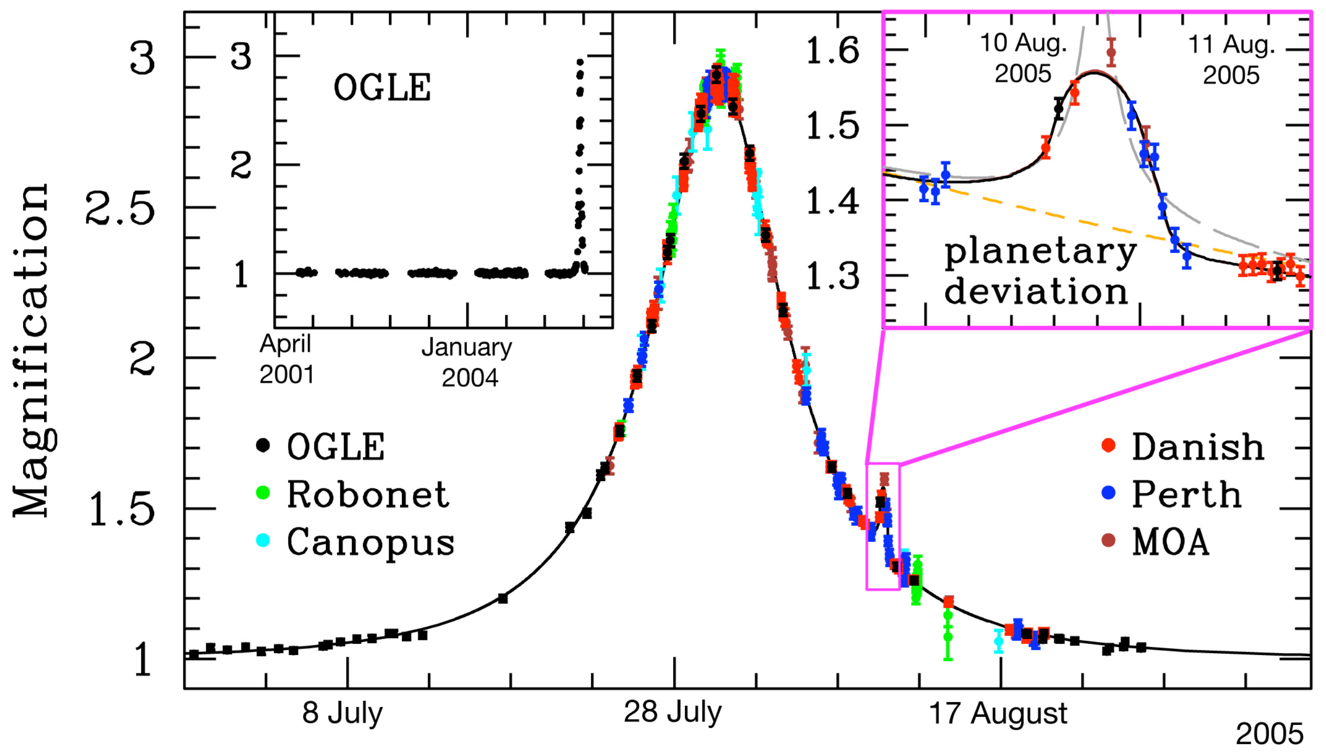
Difference Image Analysis (DIA)

Observed subtracted



5.5 Earth mass:OGLE-2005-BLG-390

Sep~3AU



Light Curve of OGLE-2005-BLG-390

The smallest Planet ! (at that time)

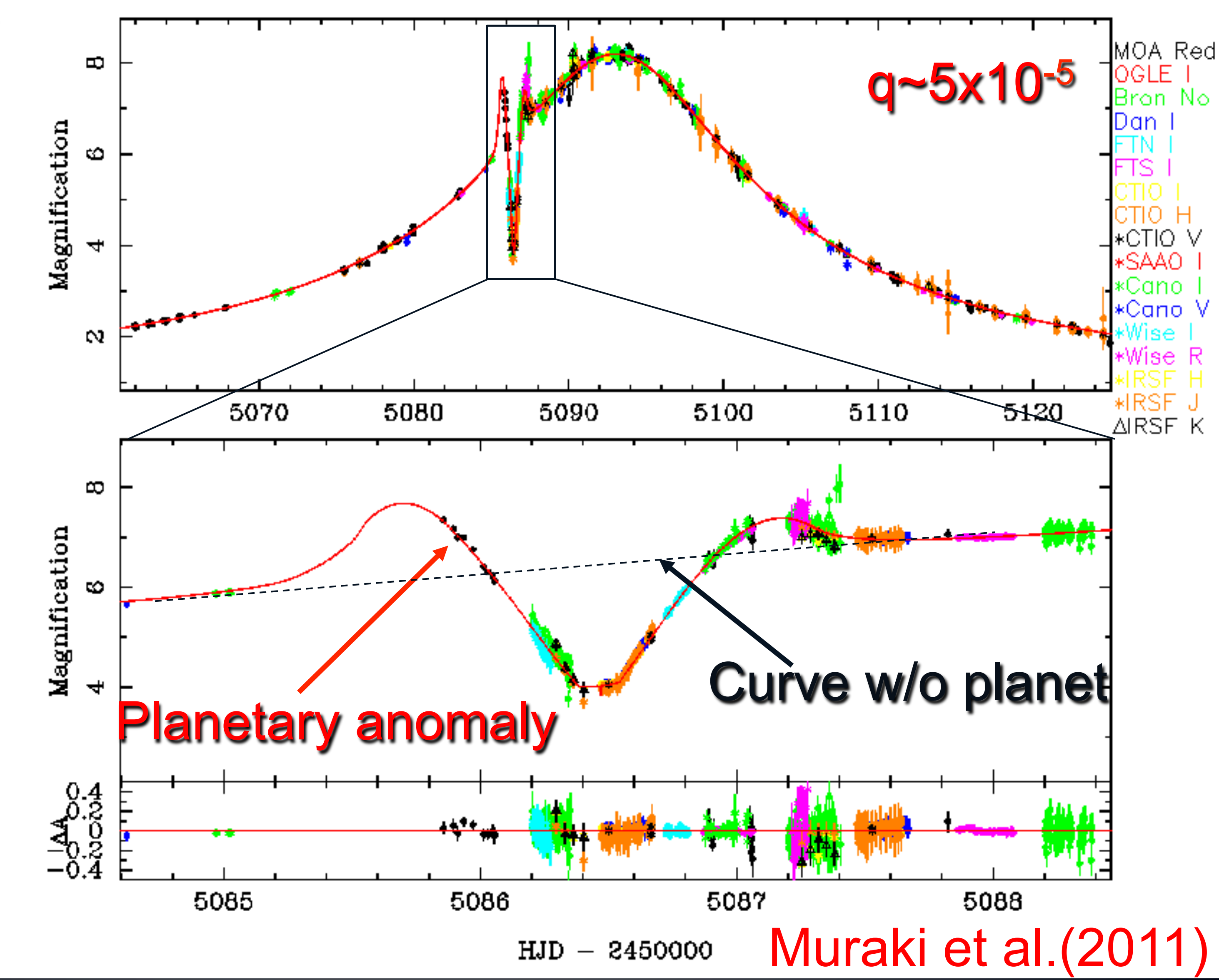
ESO PR Photo 03b/06 (January 25, 2006)

- Proved microlensing is sensitive to Super earth

(Beaulieu et al. 2006, Nature,439,437)

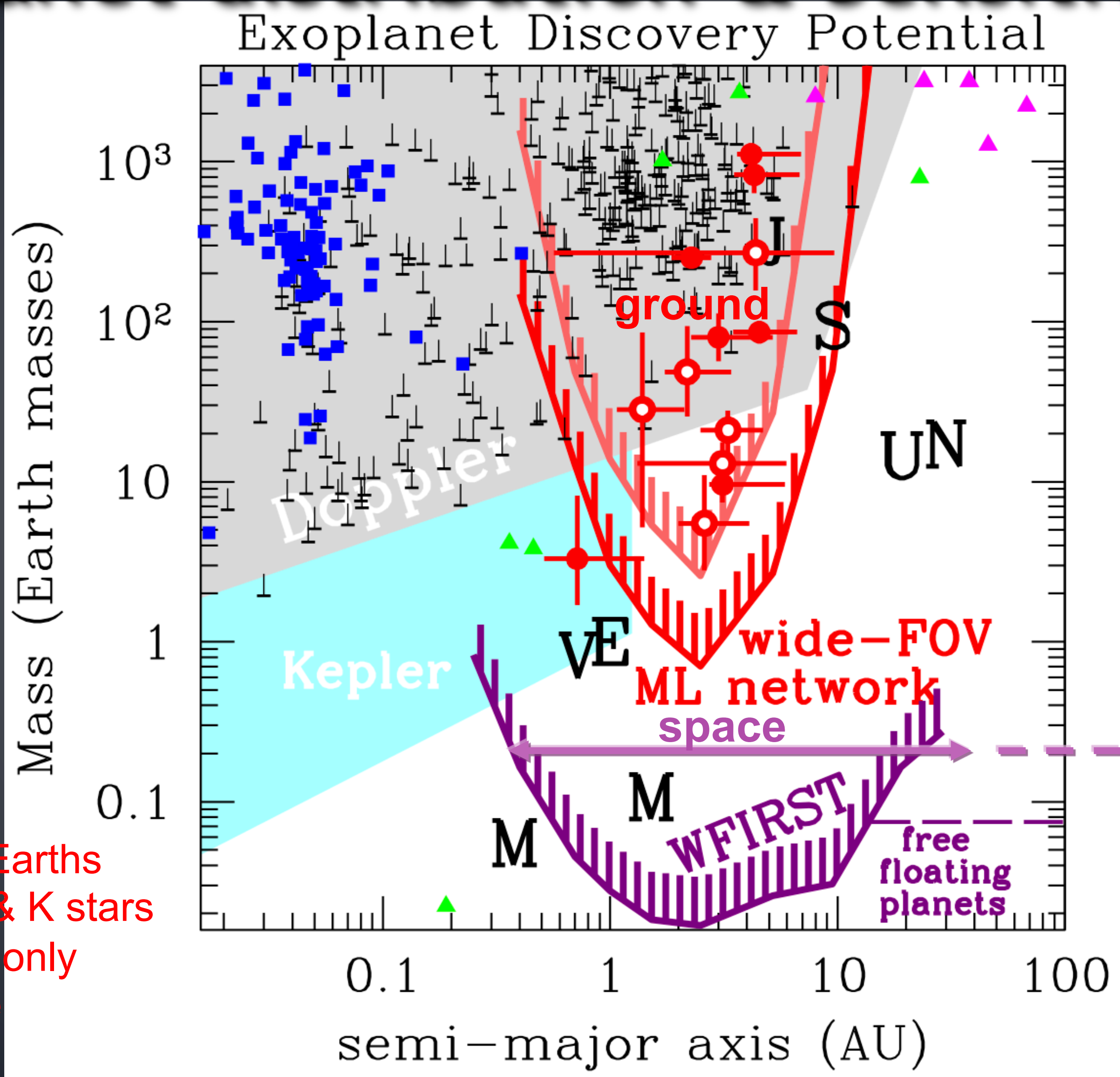
Survey & follow-up from Ground

Planetary anomaly
Is found by MOA
Survey Telescope
& followed up by
many Telescopes
Around the World



Muraki et al.(2011)

planet distribution & Sensitivity

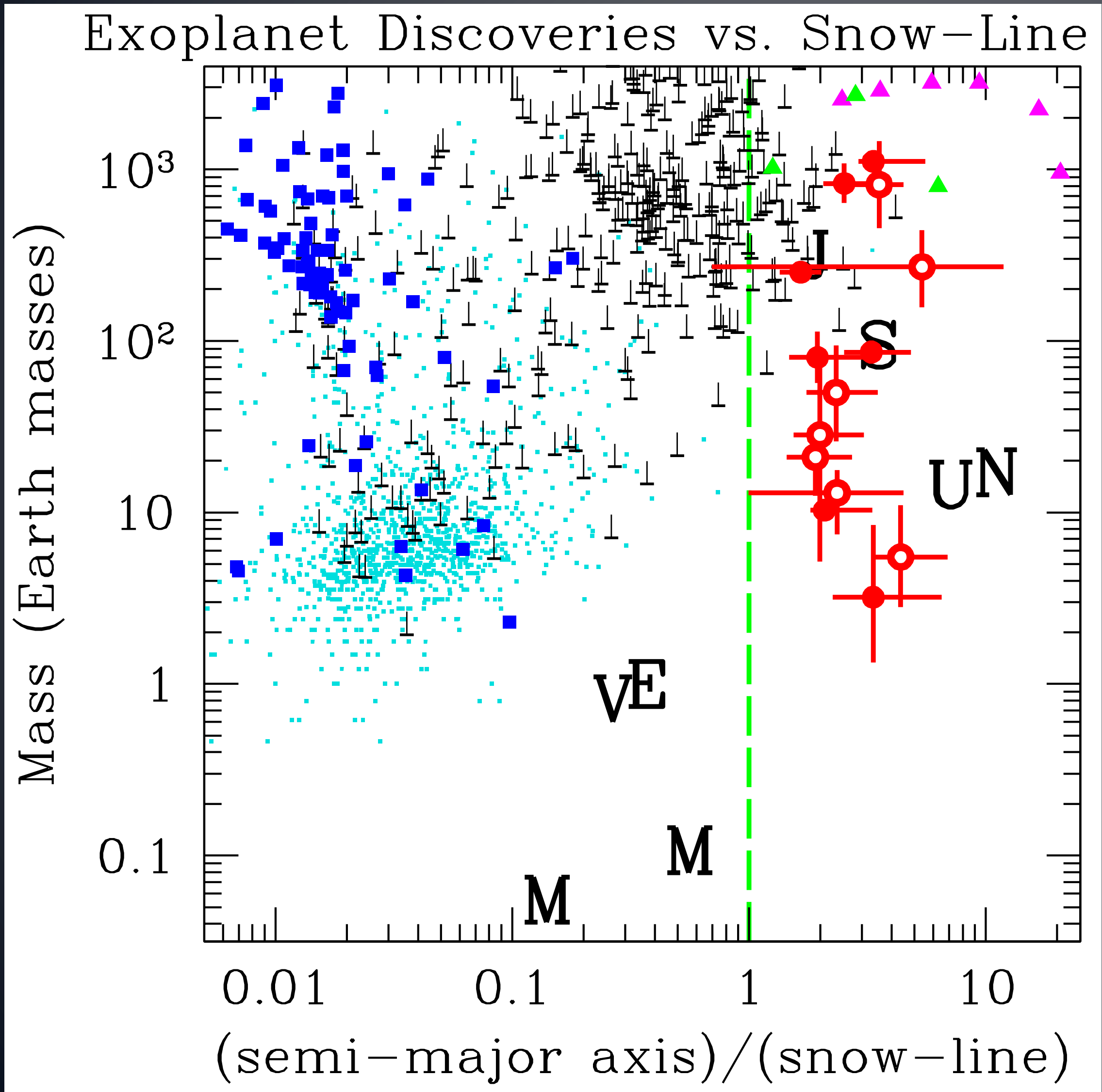


- •RV
- •transit
- •Direct image
- •Microlensing

Habitable Earths orbiting G & K stars accessible only from space

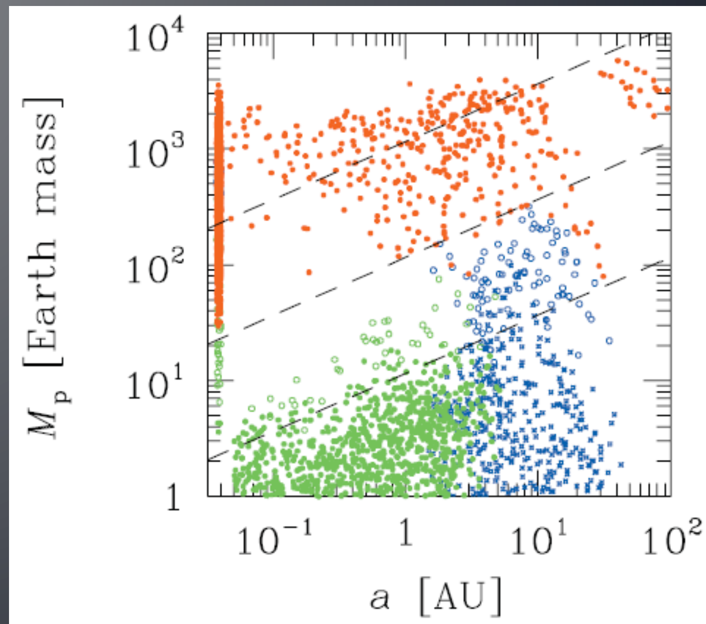
Expect ~190 free-floating Earths

Summary of Planet candidates

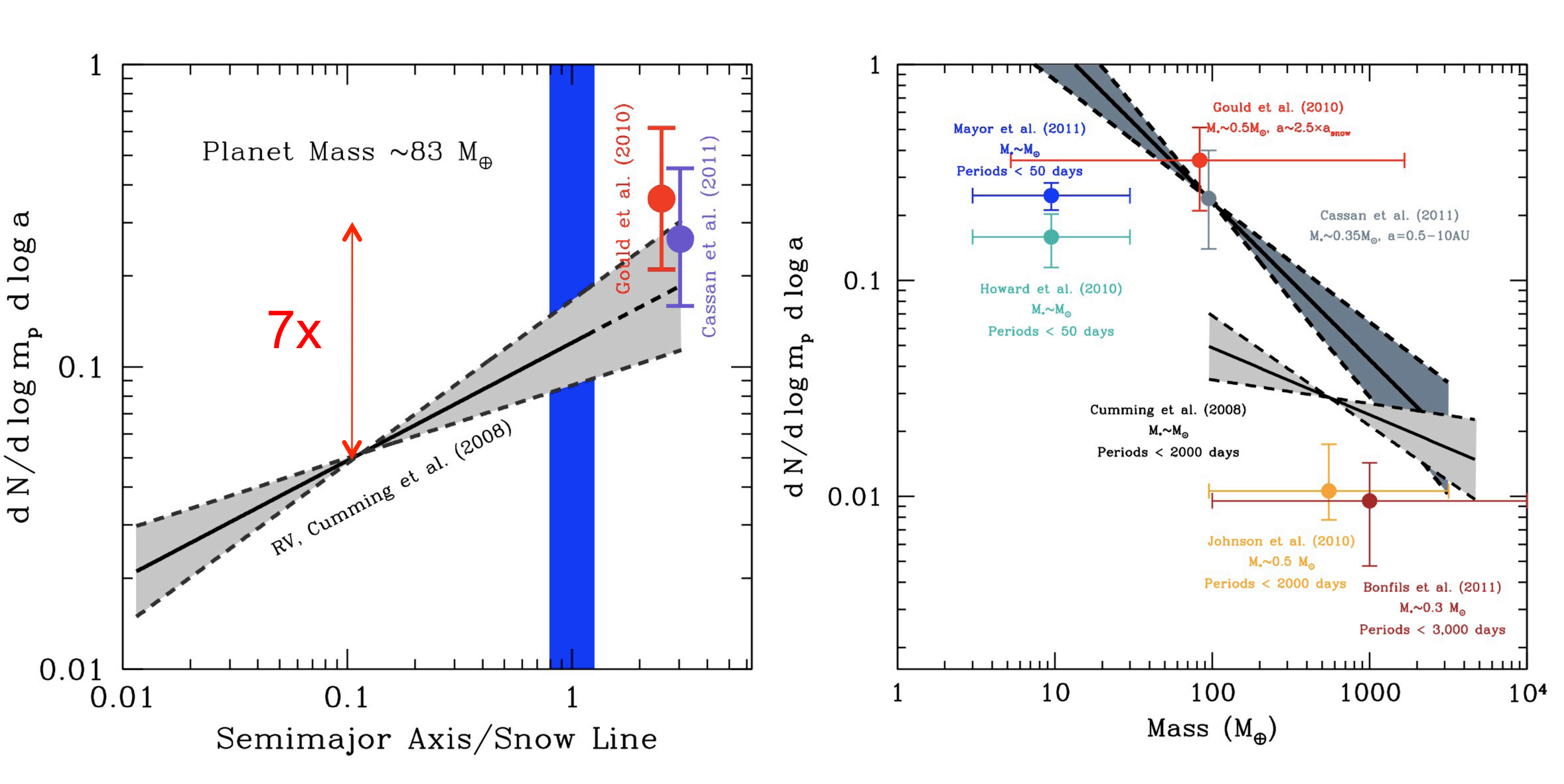


- •RV
- •transit
- •Direct image
- •Microlensing : 14planets
  - Mass measurements
  - Mass by Bayesian
- • Kepler

theory. (Ida & Lin, 2004)

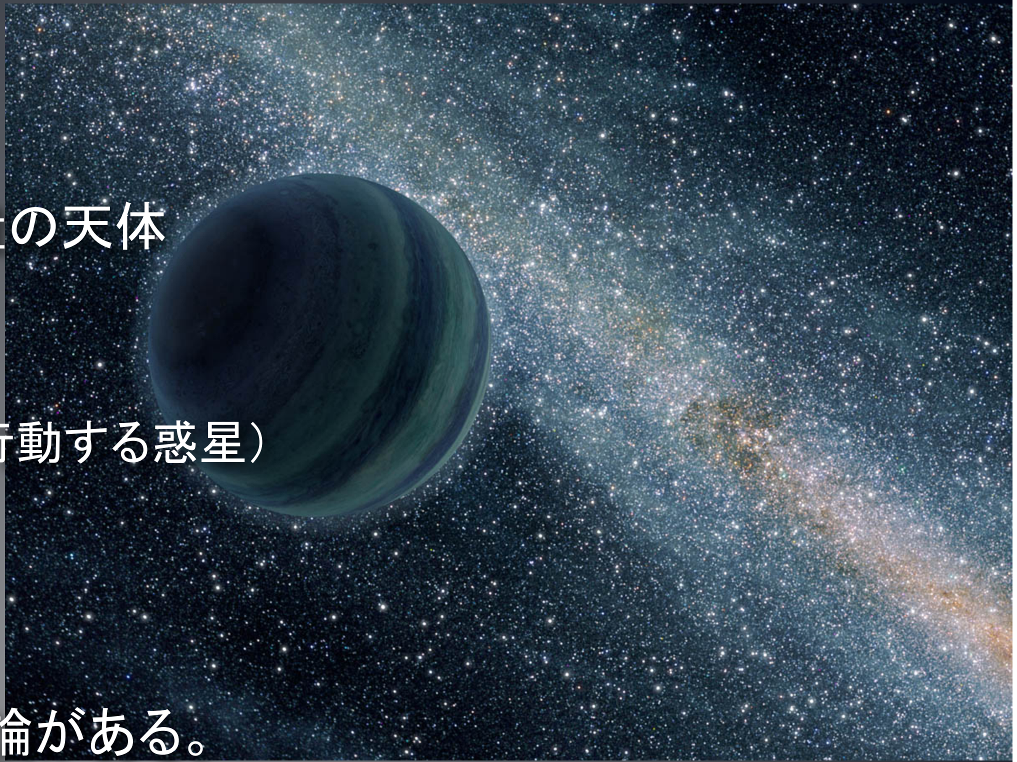


Planetary abundance by ground base observation



1.2 planet per star outside of snowline

浮遊惑星



主星の周りを回っていない惑星質量の天体

いろいろな呼ばれ方がある:

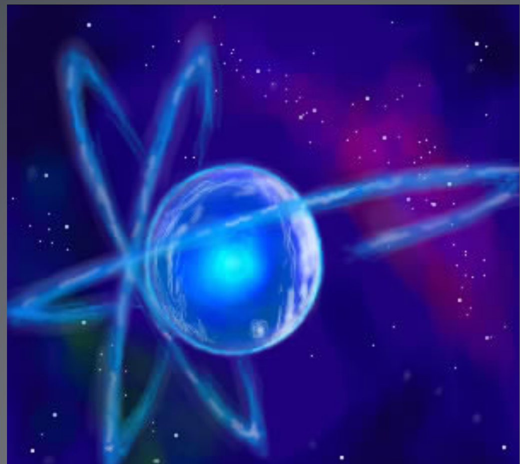
- Free-floating planet（浮遊惑星）
- Rogue planet (宿なし,自分勝手に行動する惑星）
- Interstellar planet, (星間惑星)
- Orphan planet (孤児惑星)

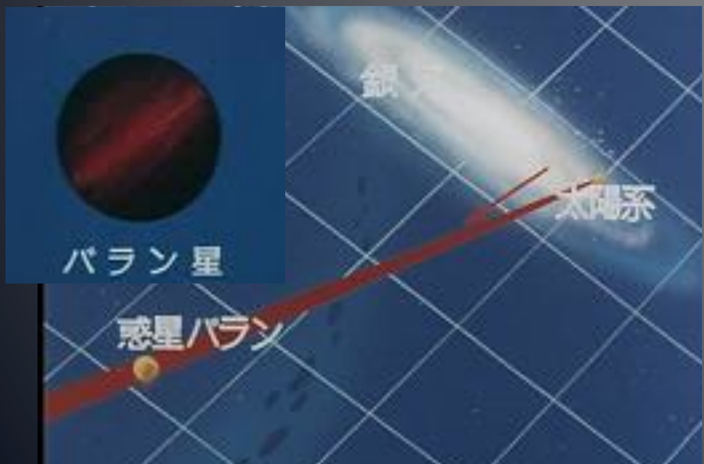
- 「惑星」と呼んで良いのかは、議論がある。
  - もともと星の周りを回っていて、それが弾き跳ばされたと思えば惑星である。
  - ガスが収縮してできたのなら、惑星ではない。ー＞「惑星質量天体」
  - 形成過程ではなく、現在の状態で決めるべき？

恒星の約1.8倍存在する。

銀河系内に～数千億個

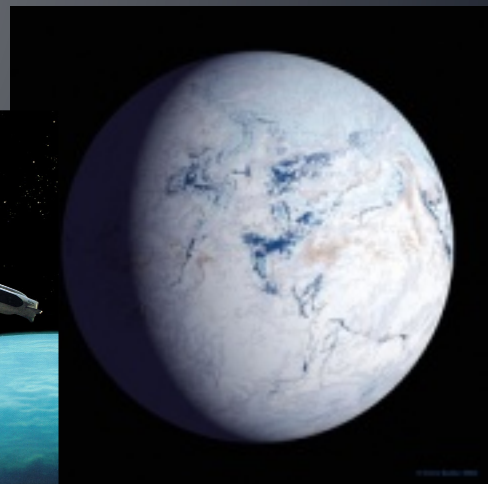
Free-floating planet


回遊惑星アクエリアス



ガミラス軍銀河方面軍前線基地

Free-floating rocky planets may have liquid water, Stevenson (1999)



In 2414, the USS rosenante found the rogue planet Solyon

10 events with timescale t_E<2days

474events in 2 years

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

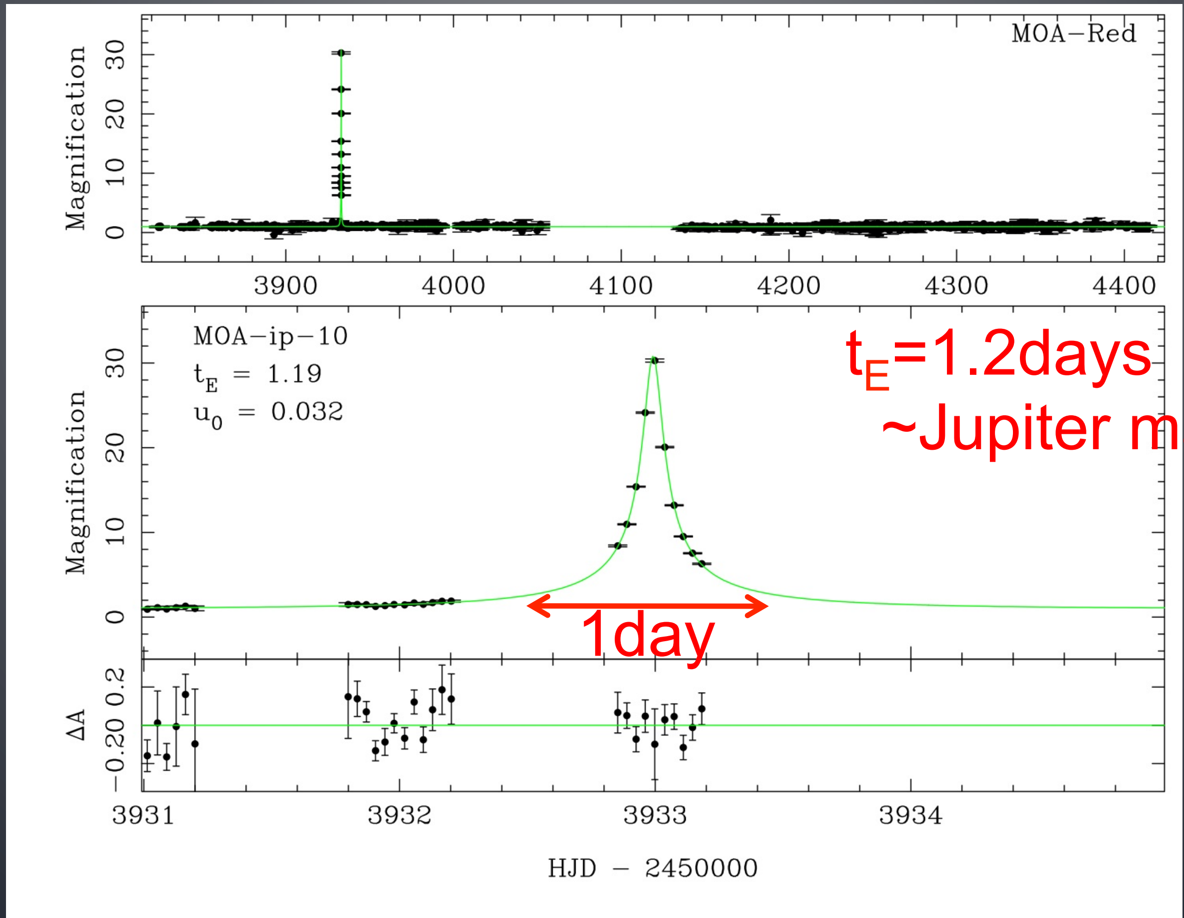
~20days for stars

M: lens mass

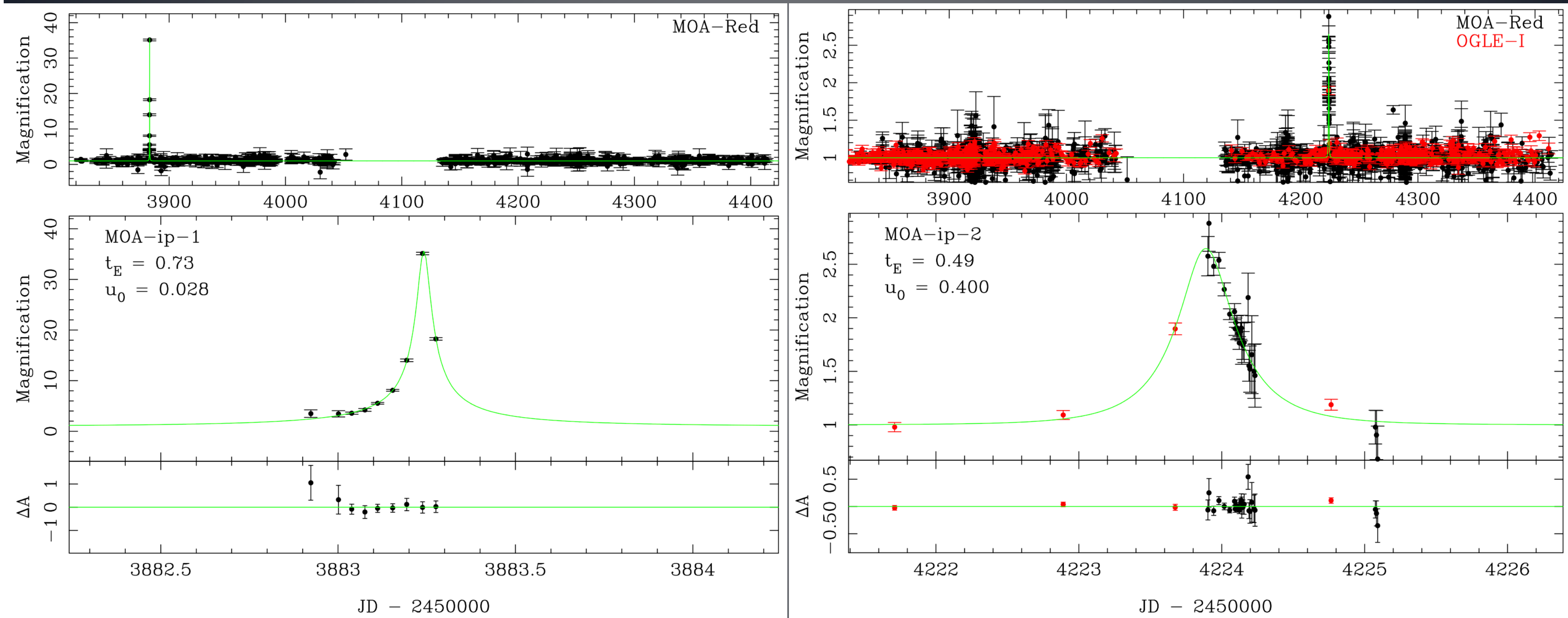
M_J: Jupiter mass

D: distance

v_t: velocity

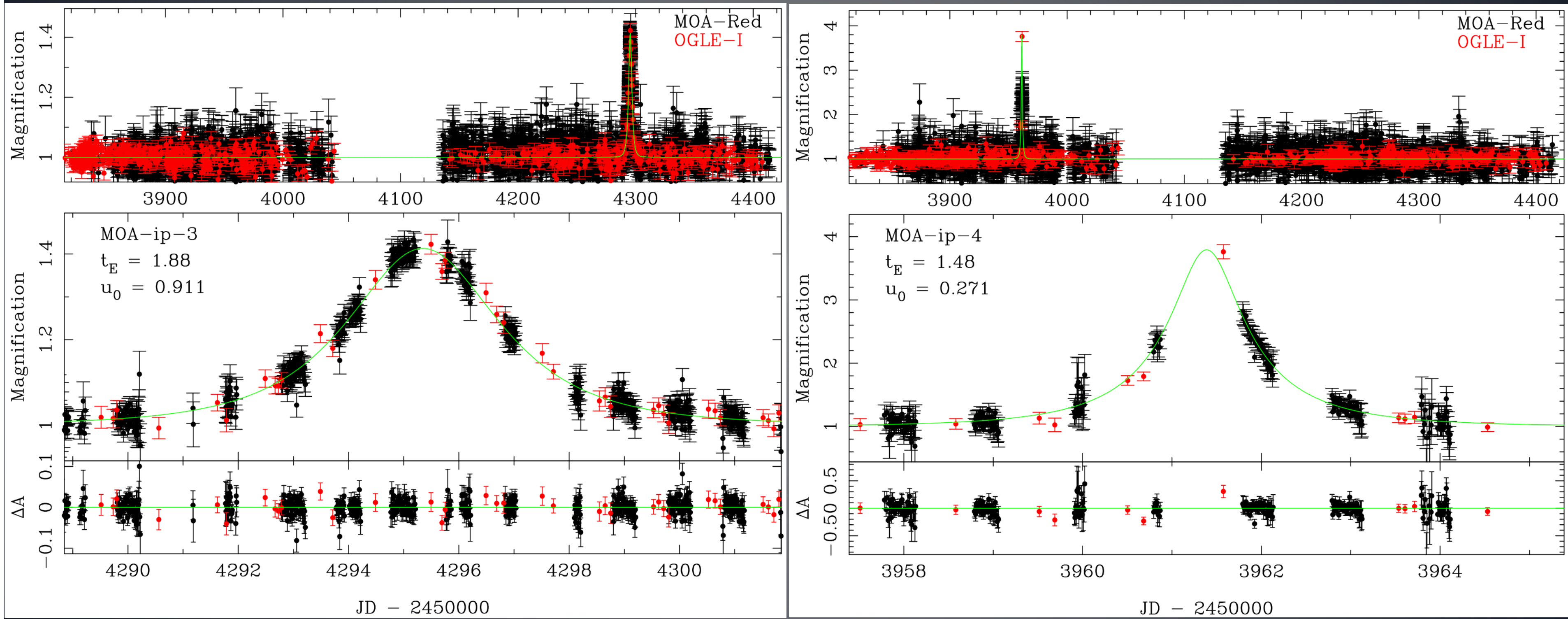


10 events with t_E< 2 days from 2006-2007
(events 1, 2)



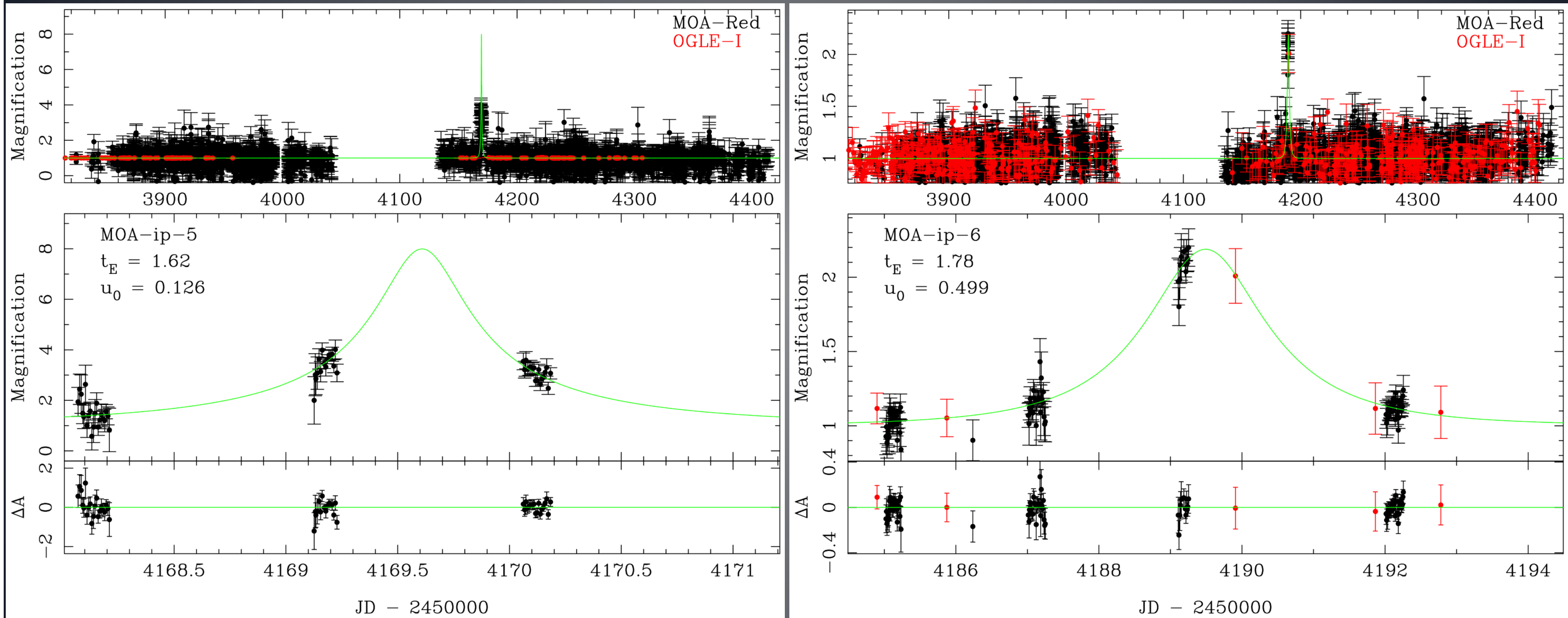
MOA data in black, confirmed by OGLE data in red

10 events with t_E< 2 days from 2006-2007
(events 3, 4)



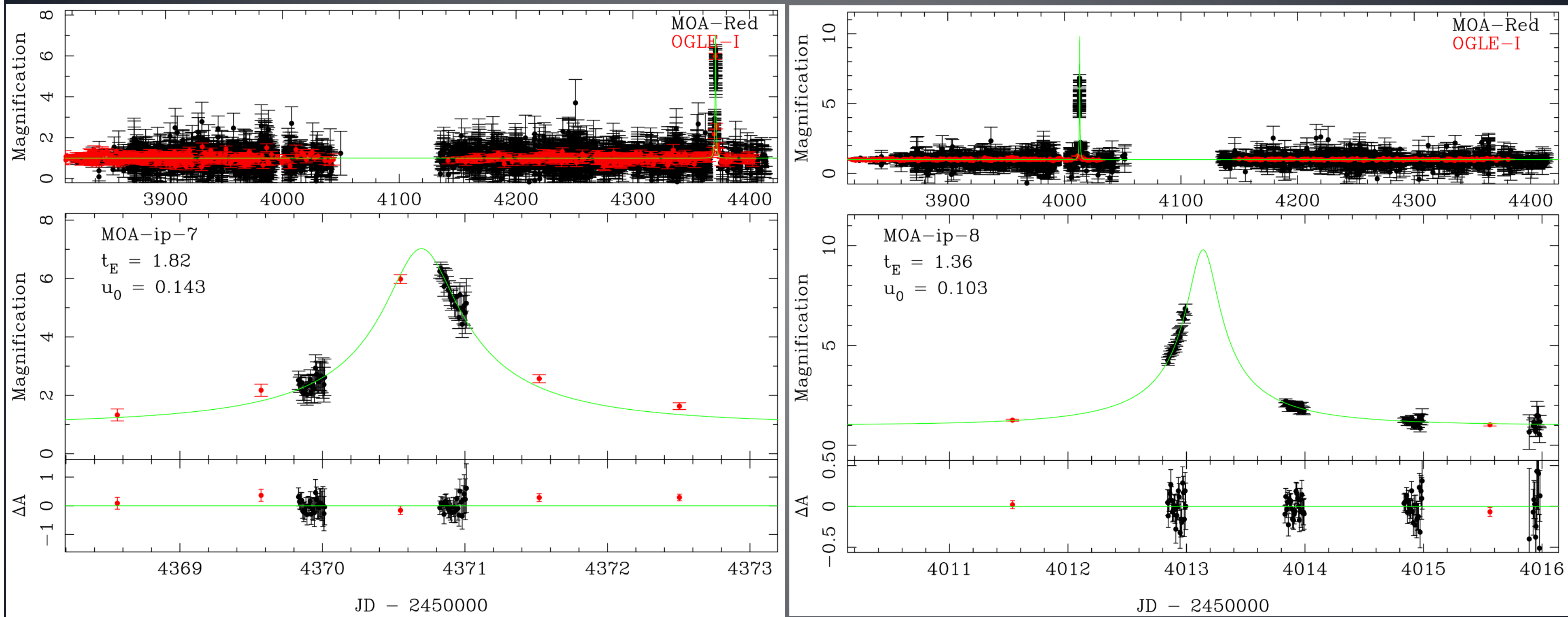
MOA data in black, confirmed by OGLE data in red

10 events with t_E< 2 days from 2006-2007
(events 5, 6)



MOA data in black, confirmed by OGLE data in red

10 events with t_E< 2 days from 2006-2007
(events 7, 8)



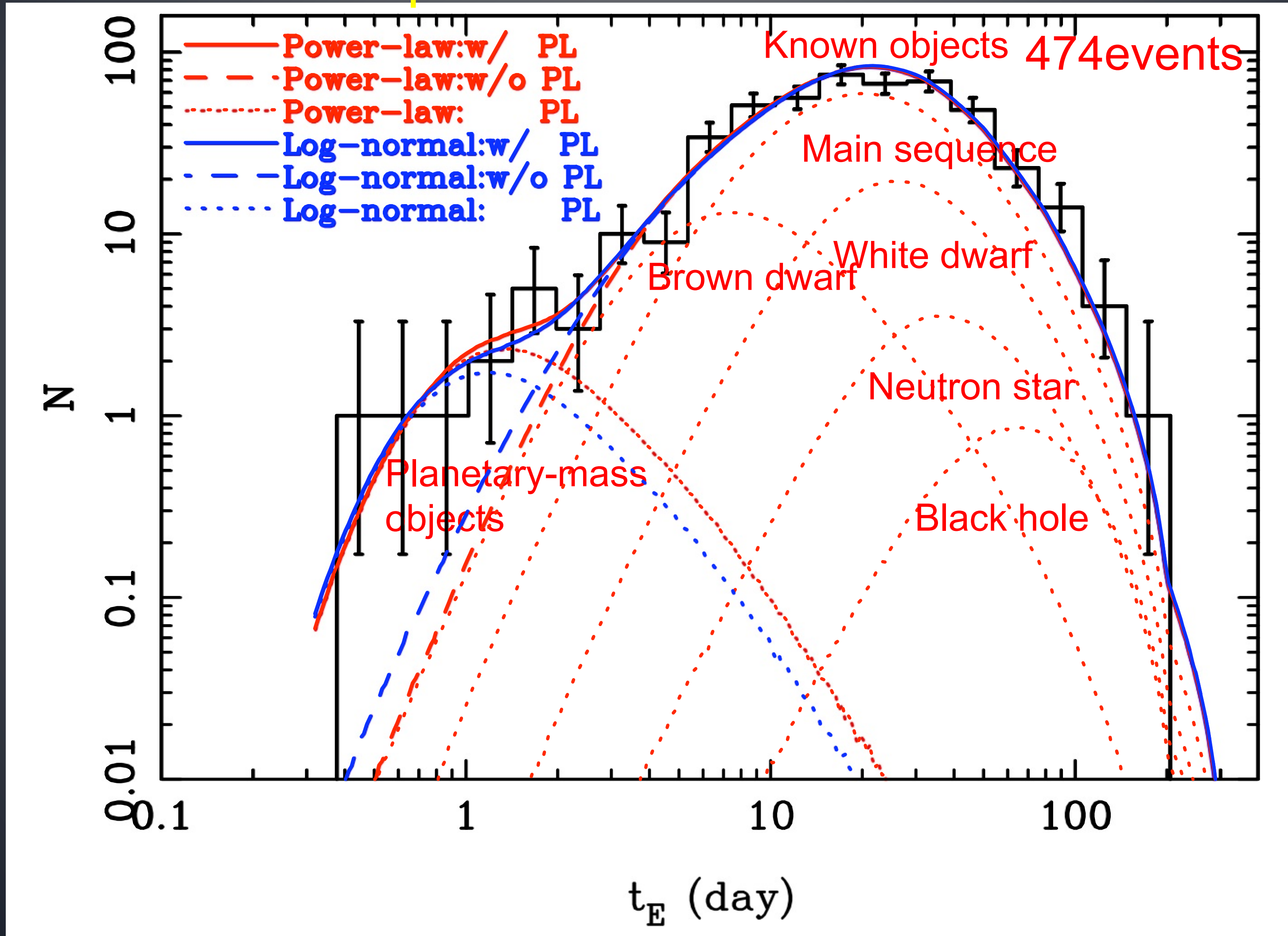
MOA data in black, confirmed by OGLE data in red

Timescale t_E distribution

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

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

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

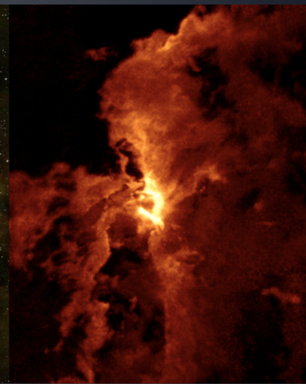


Sumi et al. 2011, Nature, 473, 7347, 349-352

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)

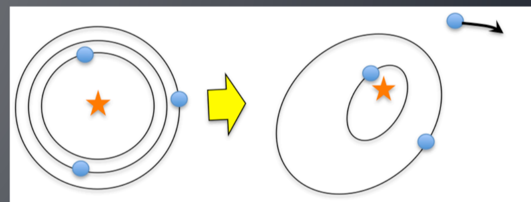
➔ evidence of gravitational interaction

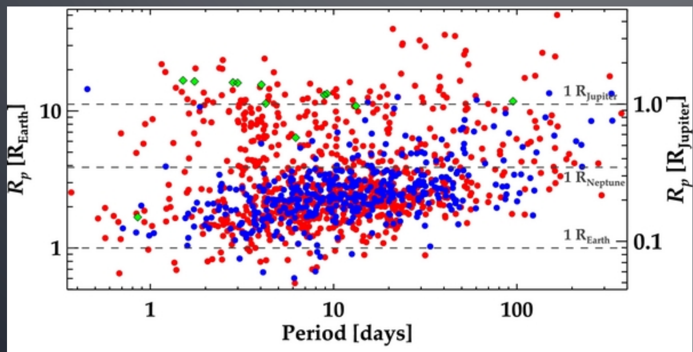
Hot Jupiters are alone (Latham et al. 2011)

➔ 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

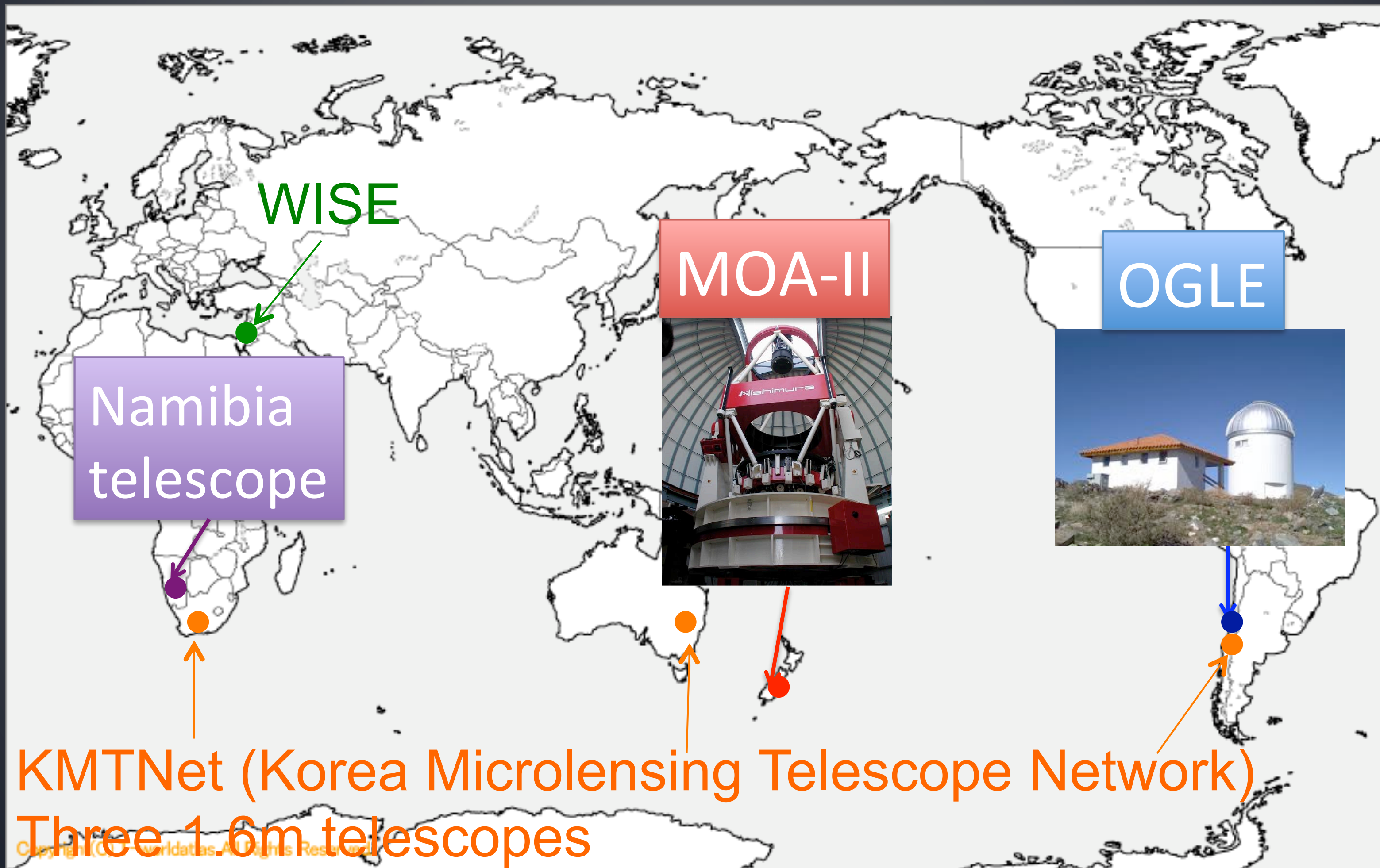




Next generation 24h survey network

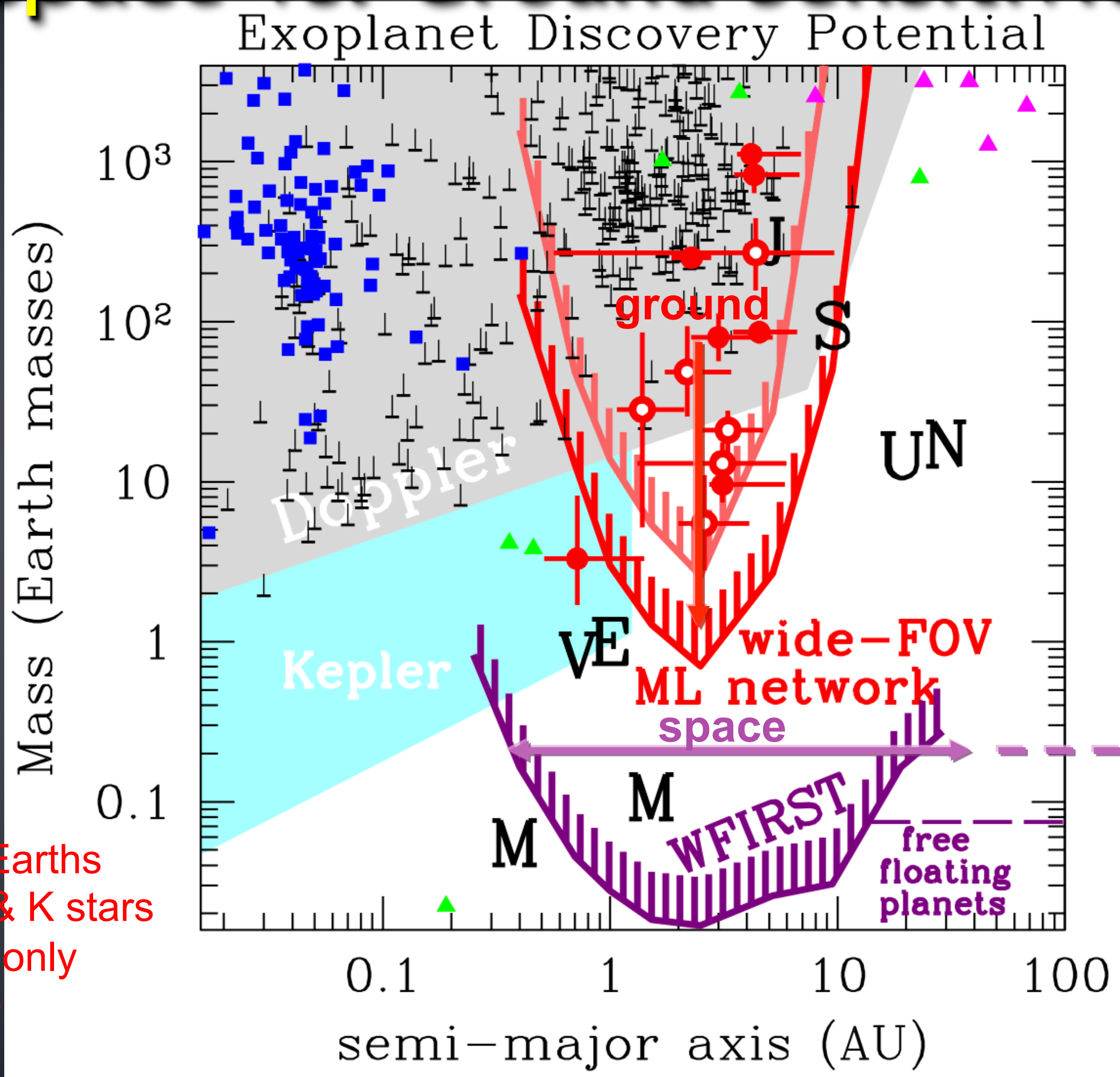
Namibia telescope (plan)
D: 1.5m
FOV: 4.8deg^2

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



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

Space vs. Ground Sensitivity



- RV
- transit
- Direct image
- Microlensing

Expect ~190 free-floating Earths

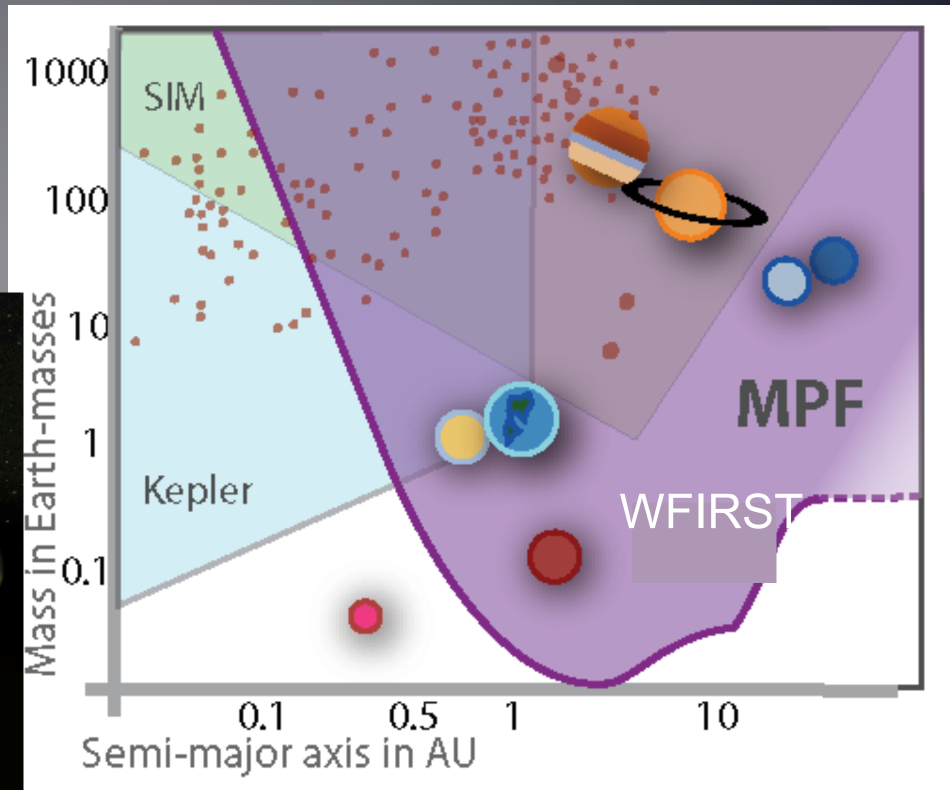
Habitable Earths orbiting G & K stars accessible only from space

マイクロレンズ系外惑星探査衛星 by WFIRST：

口径2.4m
視野:0.281平方度
λ＜2μm

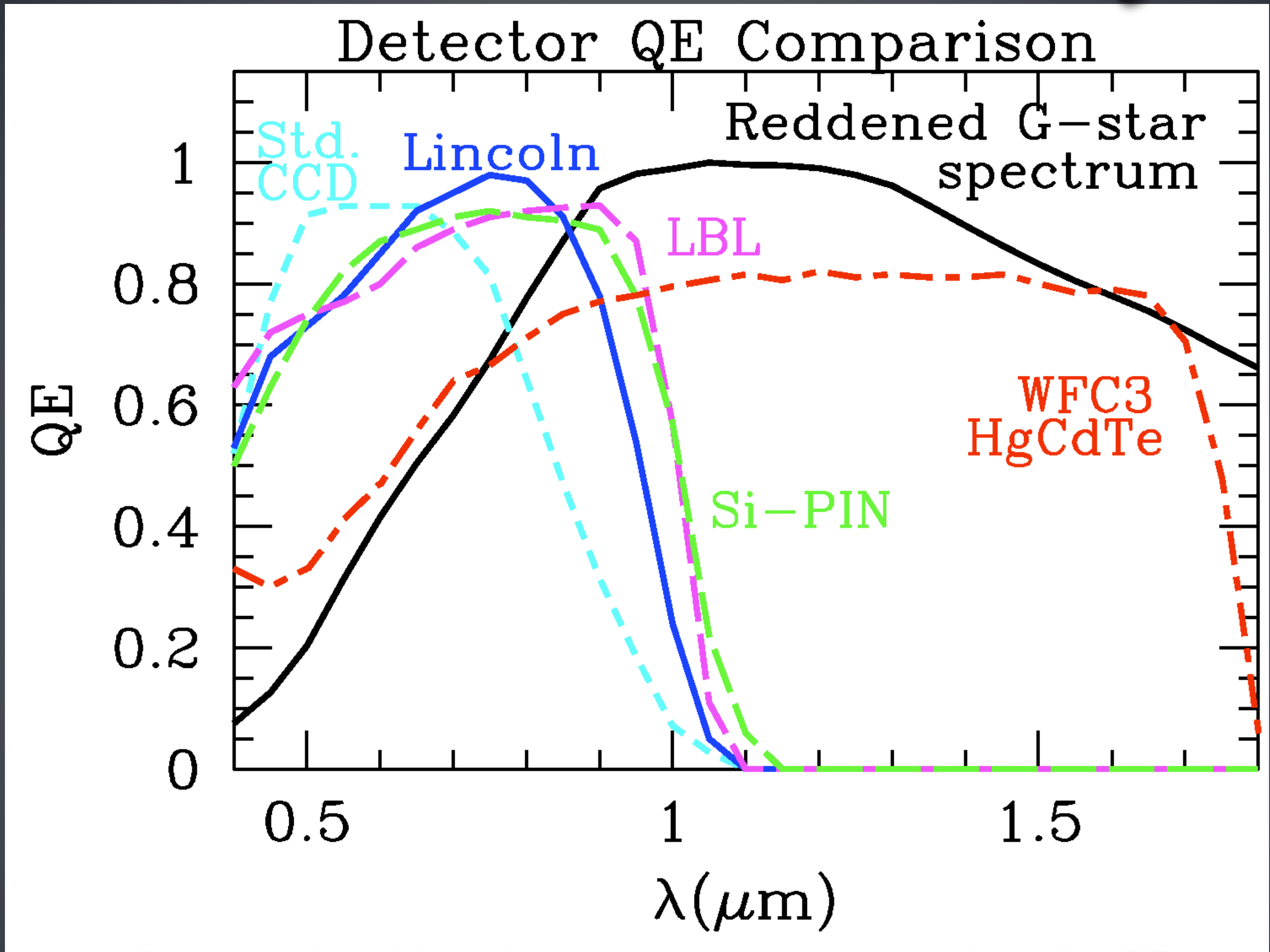
Recommended by ASTRO 2010 Decadal report

WFIRST
Wide-Field Infra-Red Survey Telescope



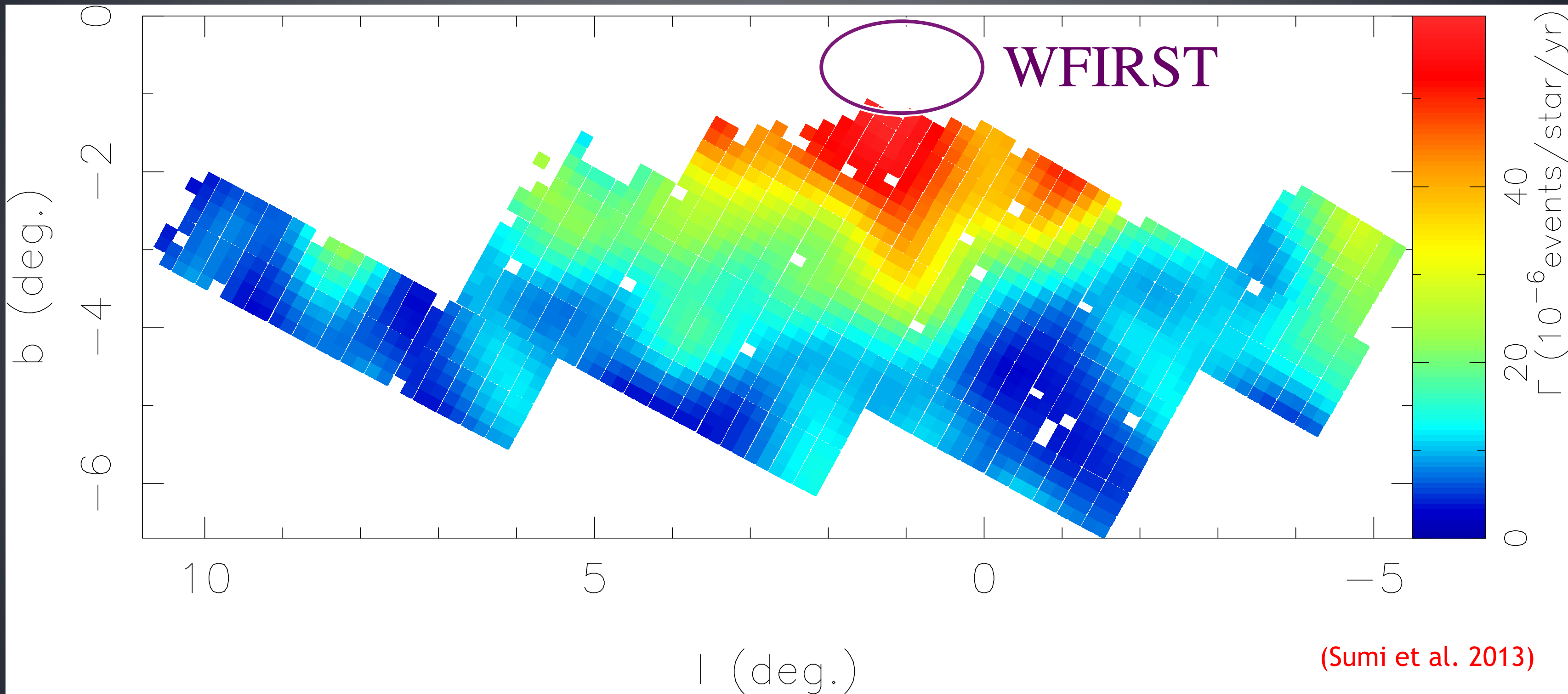
- ~3000 bound exoplanets with ~200 w/ $M < 1\ M_{\oplus}$,
- ~2000 Free-floating planets with ~100 w/ $M < 1\ M_{\oplus}$

Detector Sensitivity



The spectrum of a typical reddened source star is compared to the QE curves of CCDs and Si-PIN detector arrays. The HgCdTe detectors developed for HST's WFC3 instrument can detect twice as many photons as the most IR sensitive Si detectors (CCDs or CMOS). MPF will employ 35 HgCdTe detectors. 3 filters: "clear" 600-1700nm, "visible" 600-900nm, and "IR" 1300-1700nm.

Optimize observation fields by mapping the microlensing event rate



- ✧Peak at l=1°
- ✧1.6X higher rate than SDT report.
- ✧地上IR観測で、外挿なしでWFIRST観測領域を最適化したい。

Summary

✧ 1.2 planet per star outside of snow line.

(more than two bound planet per star with kepler.)

✧ Free-floating planets are 1.8 times as common as main sequence stars (at least same order). 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

- WFIRST will detect, (in a 500 day survey)
  - ~3000 bound exoplanets with ~200 w/ $M < 1\ M_{\oplus}$,
  - ~2000 Free-floating planets with ~100 w/ $M < 1\ M_{\oplus}$

  complete statistical census of exoplanet which Kepler started

南極望遠鏡で２４時間観測ができれば理想的