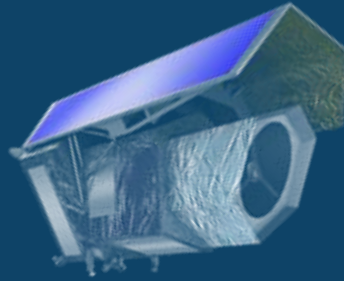


Contemporaneous Microlensing and Other Time Domain Surveys

Roman



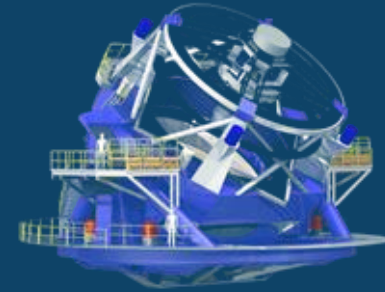
Euclid



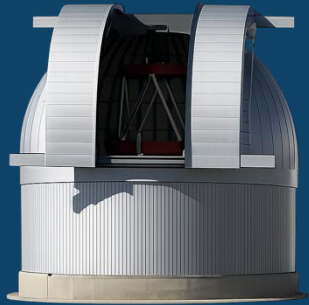
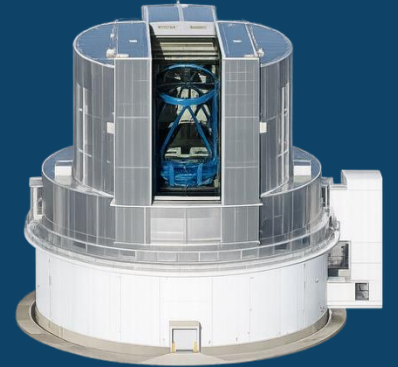
Earth 2.0



Rubin



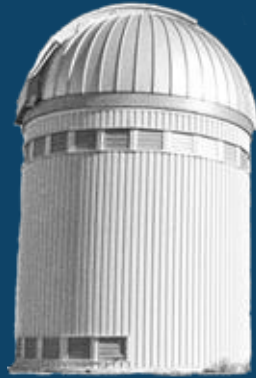
Subaru



MOA



PRIME



OGLE



KMTNet



Blanco 4m

Takahiro Sumi (U of Osaka), with inputs from Andrzej Udalski, Weicheng ZAang, Sun-Ju Chung & Rachel Street

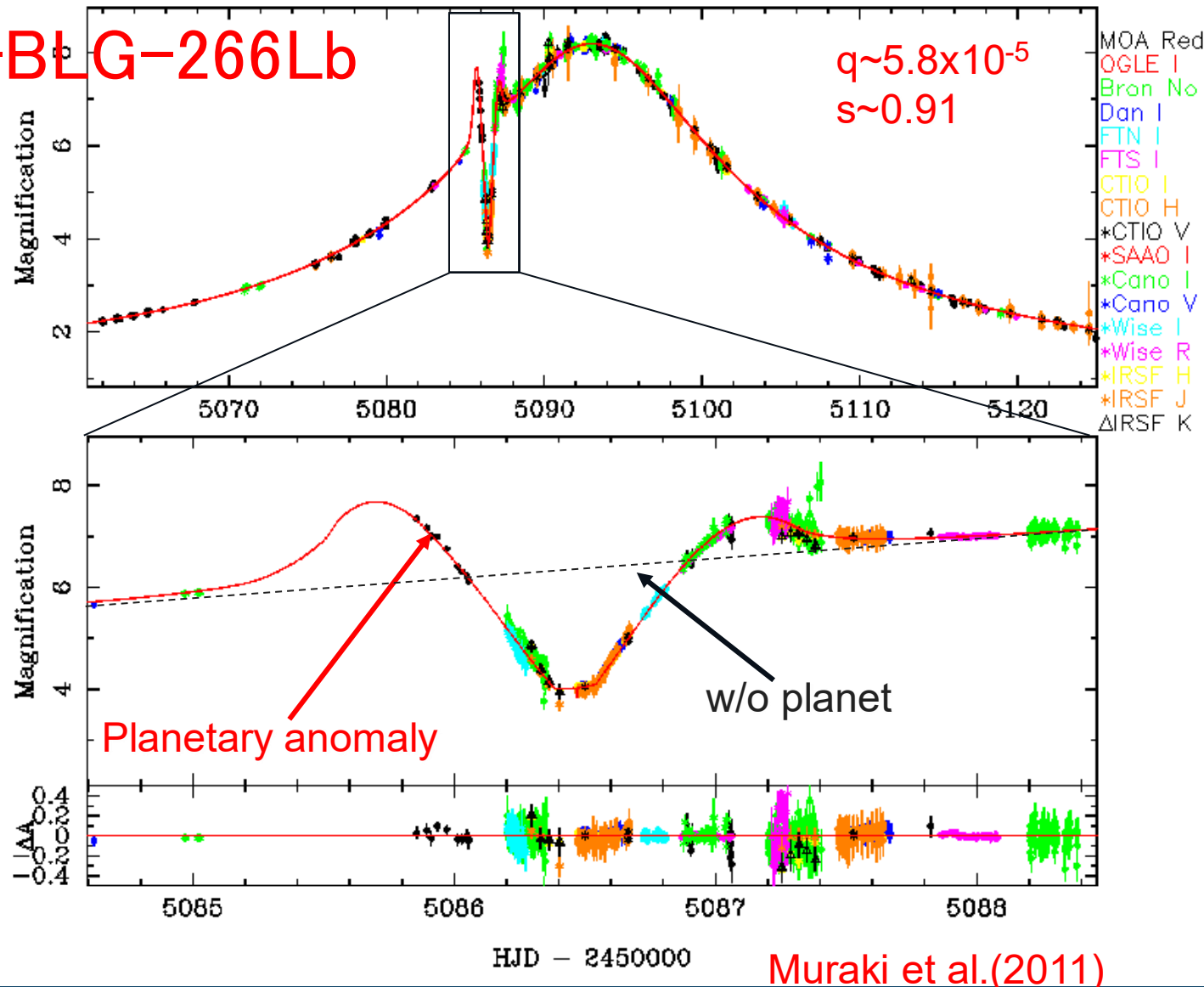
Image credits: Rubin Obs., NASA, ESA, Earth2, OGLE, MOA, PRIME, Subaru, KMTNet/SAAO

Survey telescopes issue Real-time Alerts to follow-up teams

MOA-2009-BLG-266Lb

Planetary
signal found
on 11/9/2009

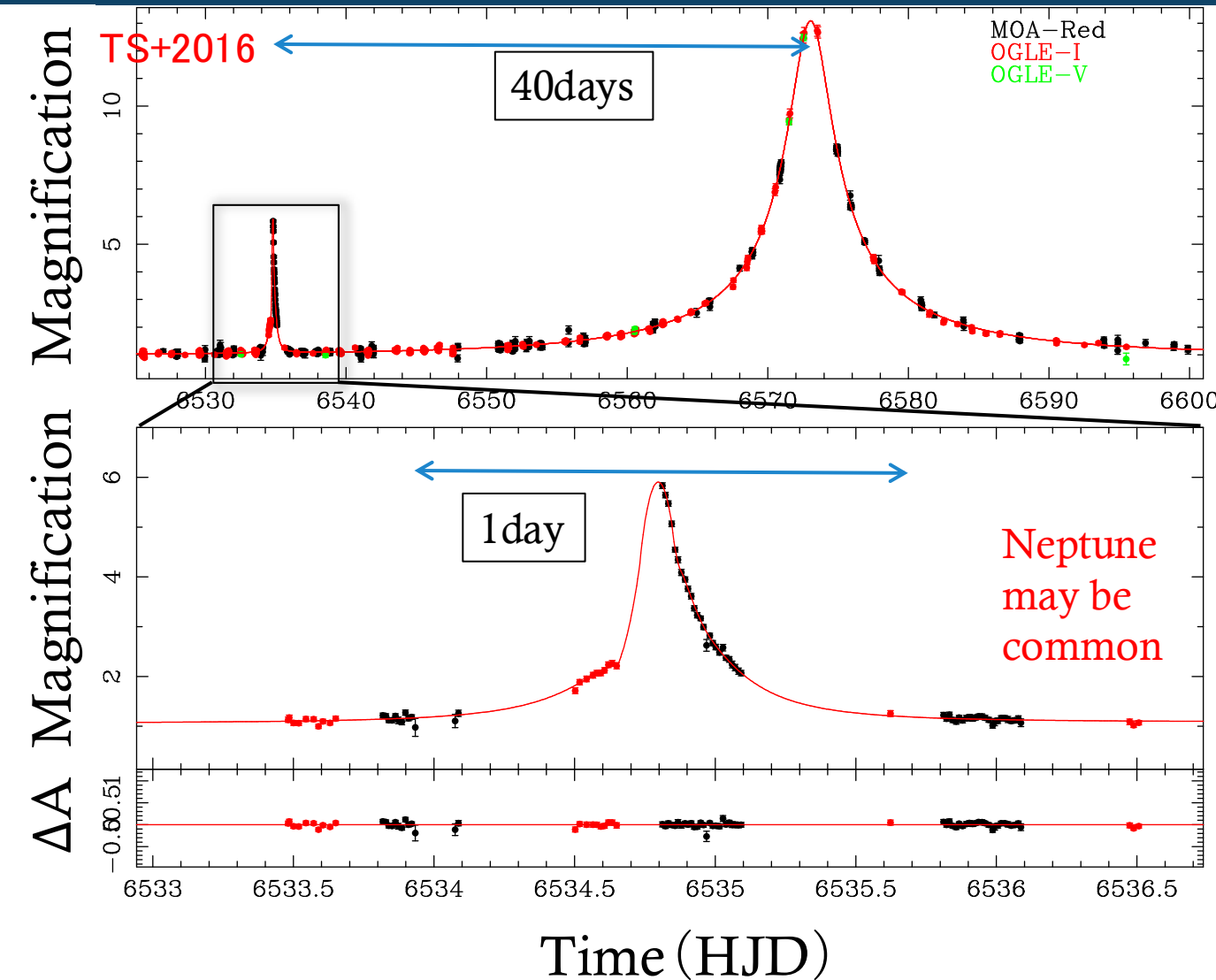
Follow-up by
telescopes
around the
world



- Fill the gap to cover short anomaly
- Confirm anomaly

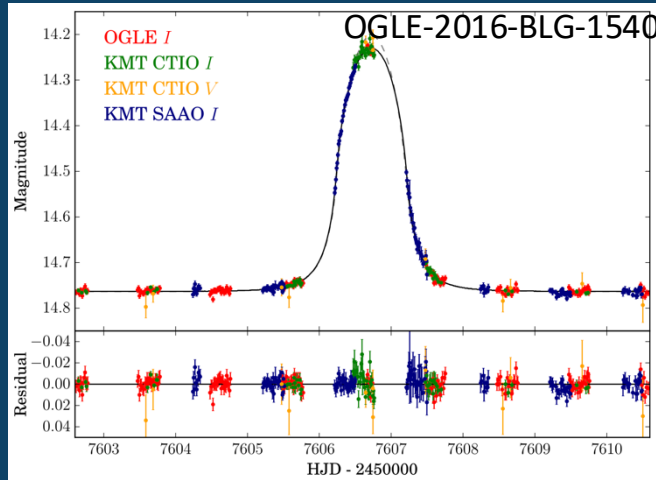
MOA-2013-BLG-605: the Neptune analog planet

$q=3 \times 10^{-4}$, $s=2.3$,
Neptune or super Earth around Brown-dwarf

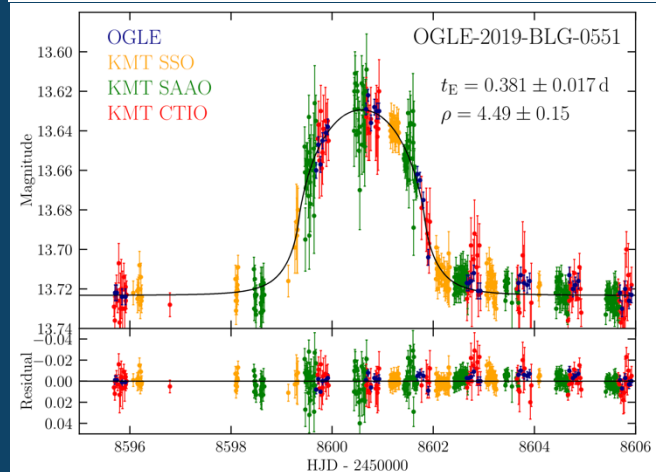


- High cadence surveys cover the short/rapid anomaly
- Ground surveys cover longer range. May detect planet or hosts missed by Roman

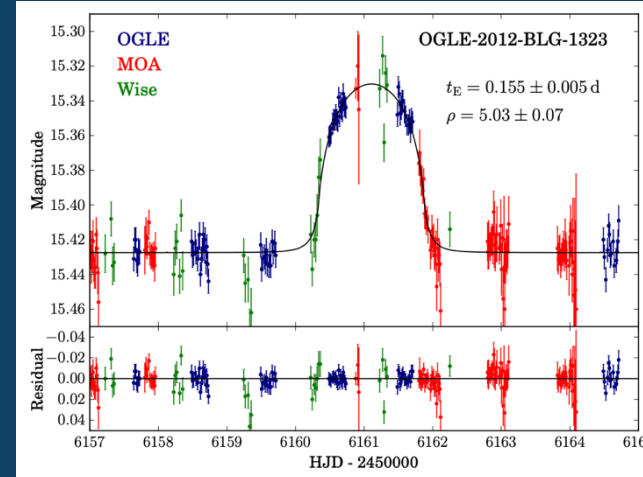
Short FFP candidates with Finite Source (FS)



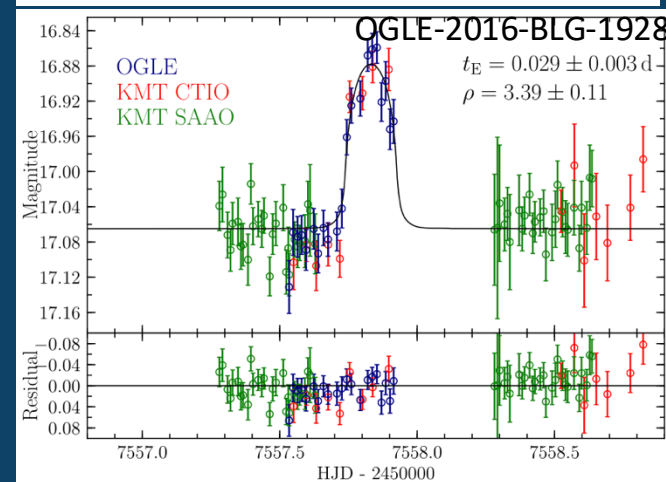
Mróz + 2018
 $\theta_E = 9.2 \pm 0.5 \mu\text{as}$



Mróz + 2020
 $\theta_E = 4.35 \pm 0.34 \mu\text{as}$



Mróz + 2019
 $\theta_E = 2.37 \pm 0.10 \mu\text{as}$

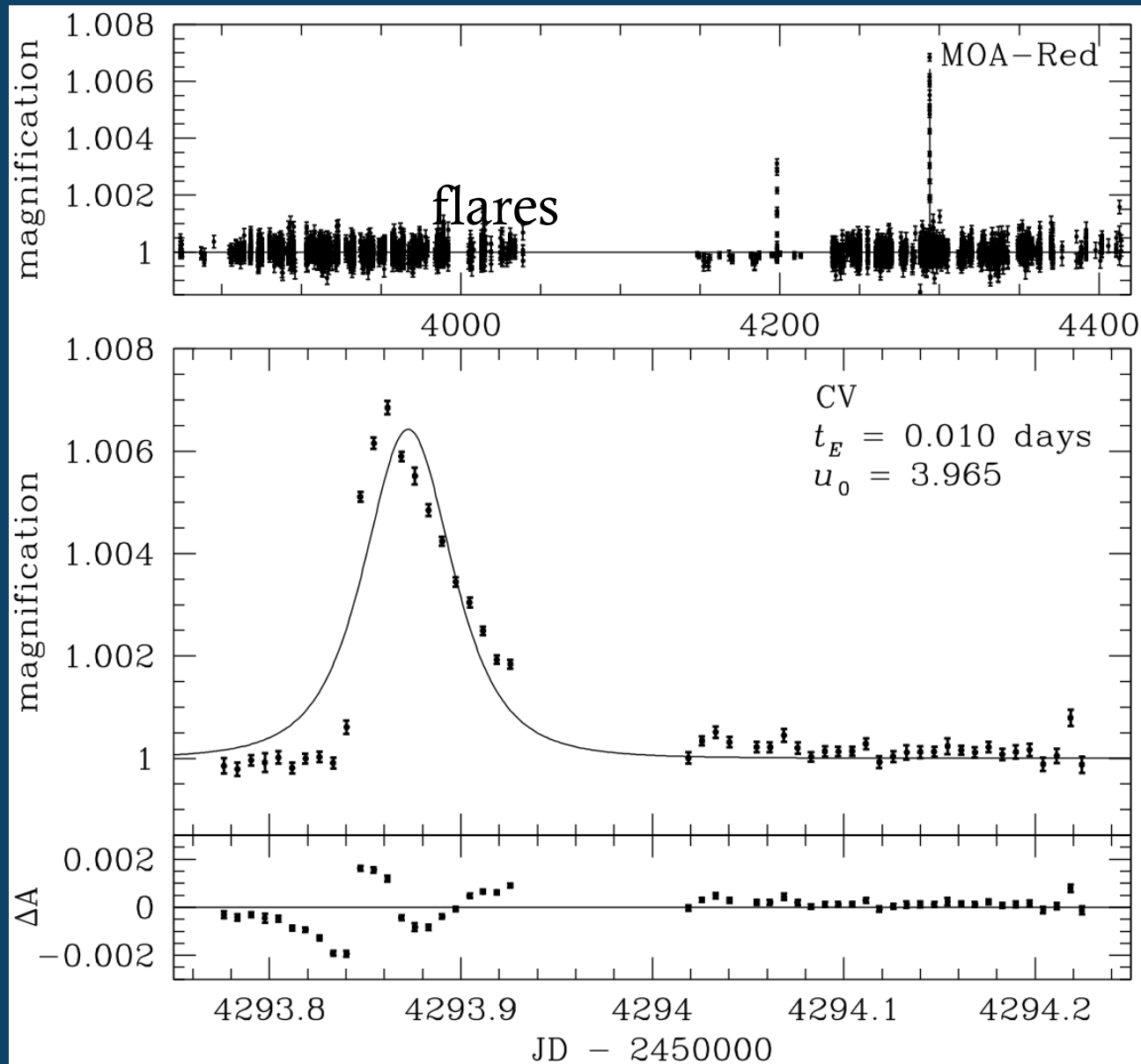


Mróz + 2020
 $\theta_E = 0.842 \pm 0.064 \mu\text{as}$

Terrestrial mass

- Characterize the short light curve shape
- Confirm the short events which cannot be followed up later

Short flares are main source of background for FFP



- High cadence light curves help to remove the false positives like flares

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

Degeneracy in parameters

Einstein crossing timescale:

Mass

$$t_E = \frac{R_E(M, D)}{v_t}$$

Distance

v_t

Transverse velocity

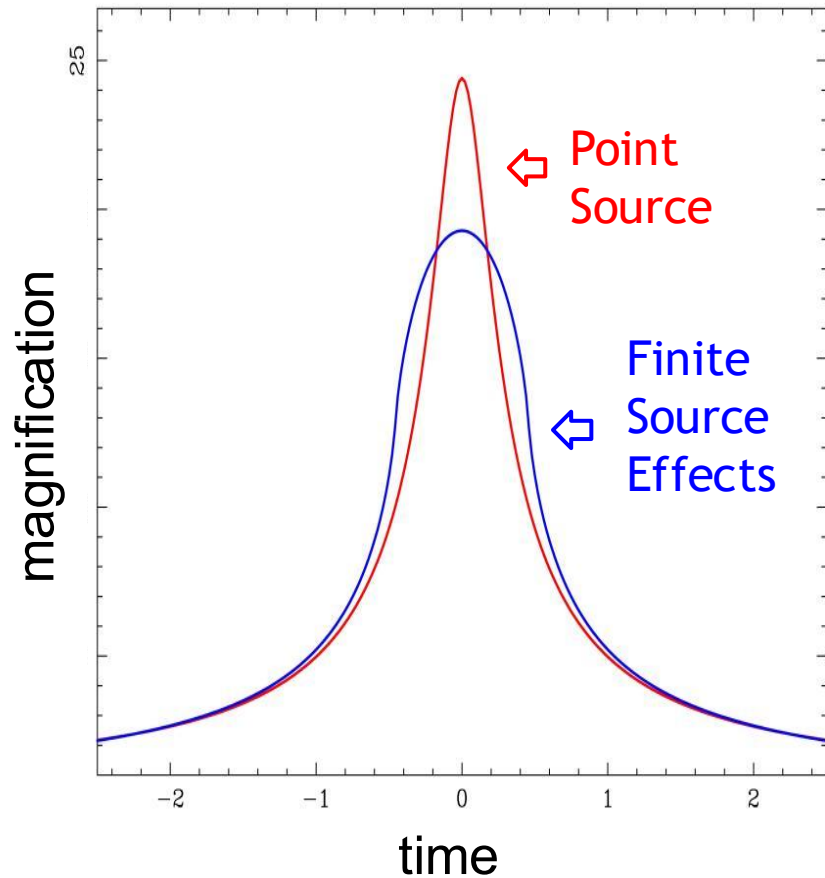
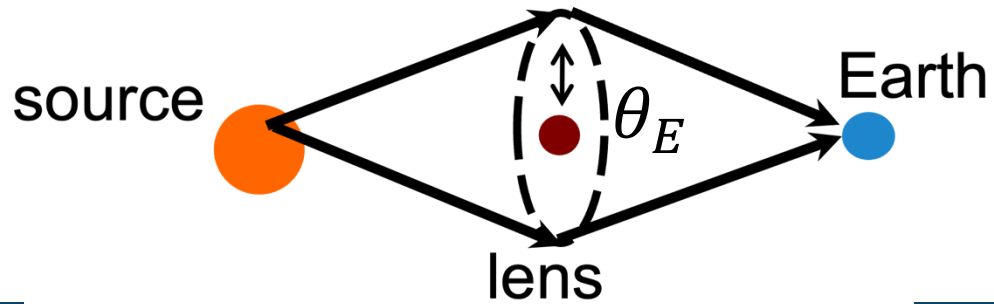
Einstein Radius:

$$R_E = \sqrt{\frac{4GM}{c^2} \frac{D_L}{D_S} (D_S - D_L)}$$

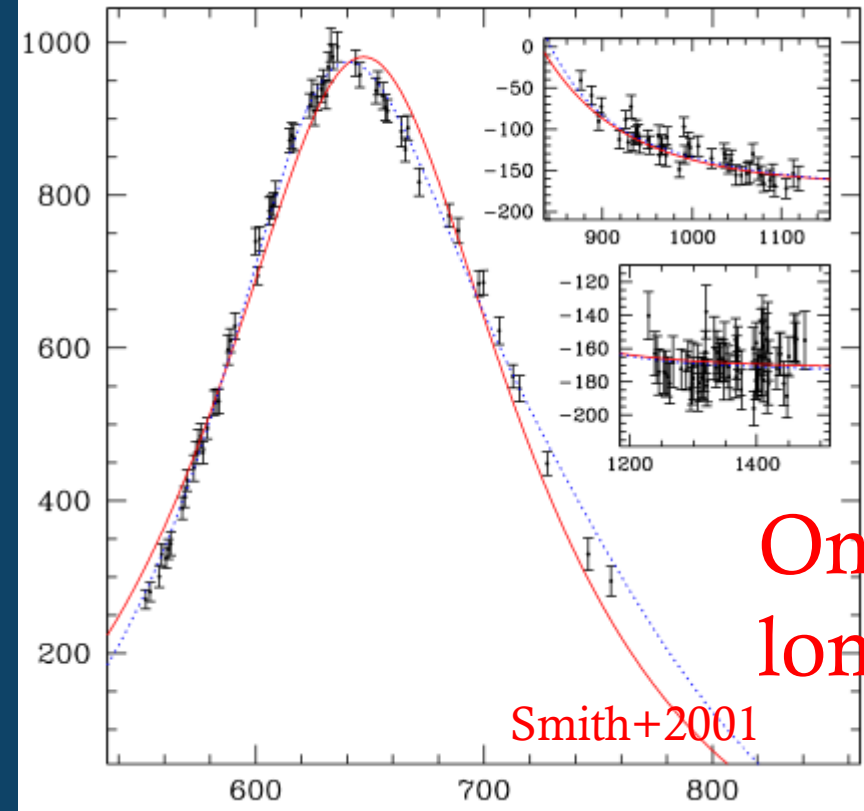
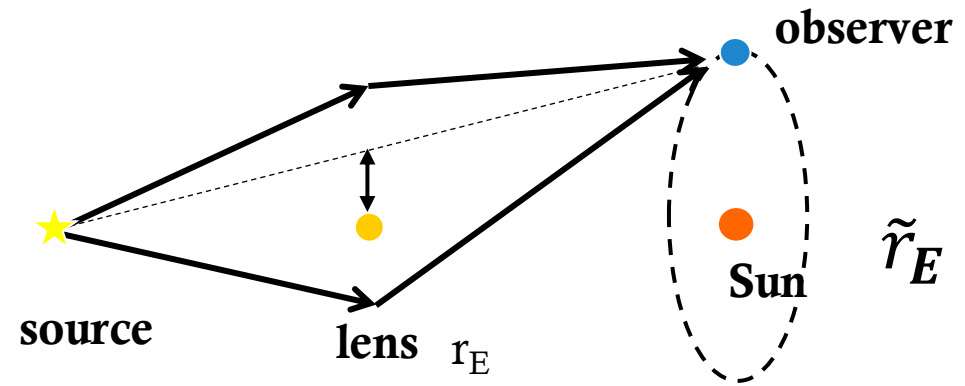
Need high order effect to break the degeneracy

Finite Source Effects & Microlensing Parallax Yield Lens Mass

■ Finite Source Effects



■ Microlensing orbital Parallax



Only for
long event

Finite Source Effects & Microlensing Parallax Yield

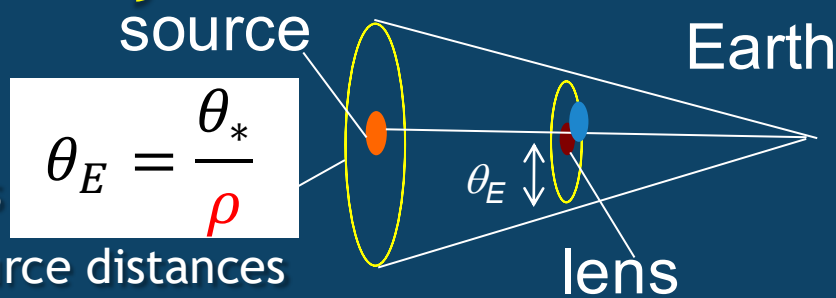
Lens System Mass

- Finite source effects

Angular Einstein radius

θ_* = source star angular radius

D_L and D_S are the lens and source distances



Angular R_E :

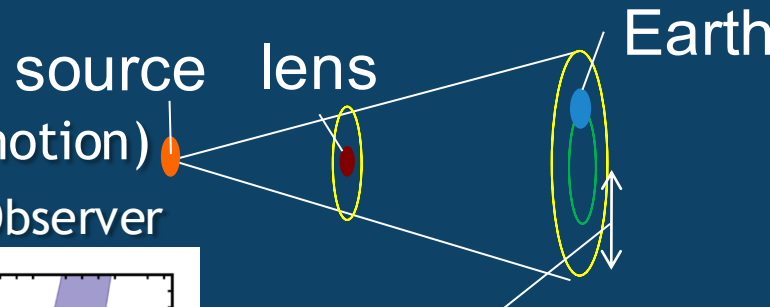
$$\theta_E = \frac{R_E}{D_L} = \sqrt{\frac{4GM}{c^2} \frac{D_S - D_L}{D_S D_L}}$$



- Parallax

(Effect of Earth's orbital motion)

Einstein radius projected to Observer



$$\tilde{r}_E = \frac{au}{\pi_E}$$

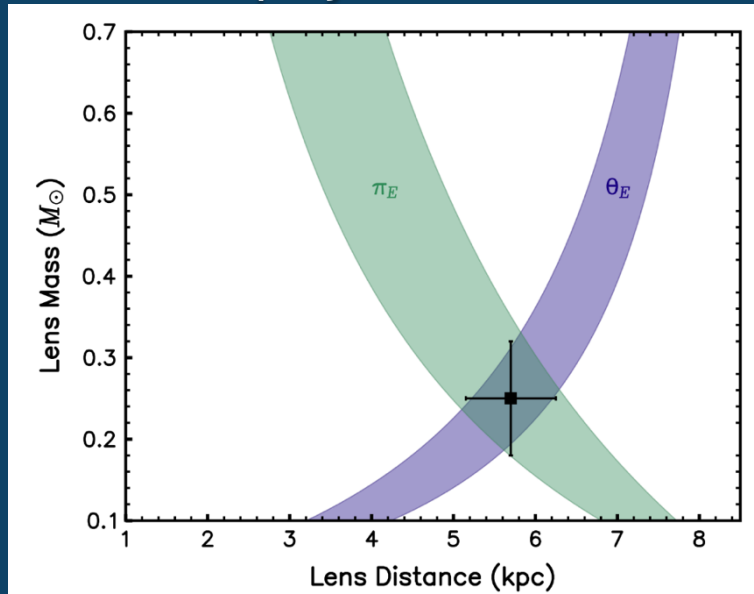
Projected R_E :

$$\tilde{r}_E = R_E \frac{D_S}{D_S - D_L} = \sqrt{\frac{4GM}{c^2} \frac{D_S D_L}{D_S - D_L}}$$



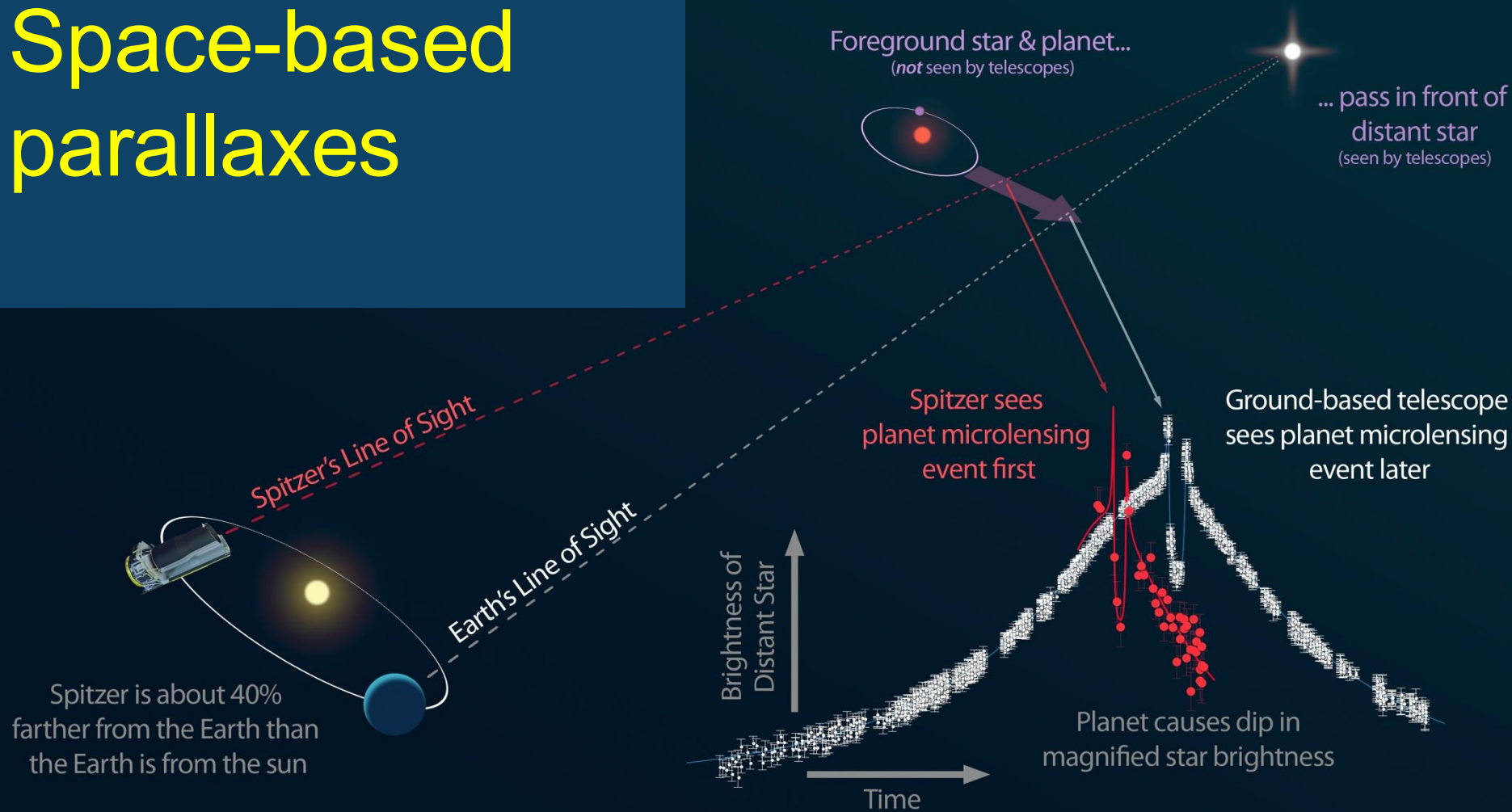
$$\text{Lens Mass: } M = \frac{c^2}{4G} \tilde{r}_E \theta_E = \frac{\theta_E}{\kappa \pi_E}$$

$$\kappa = \frac{4G}{c^2 au} = 8.144 \text{ mas}/M_\odot$$

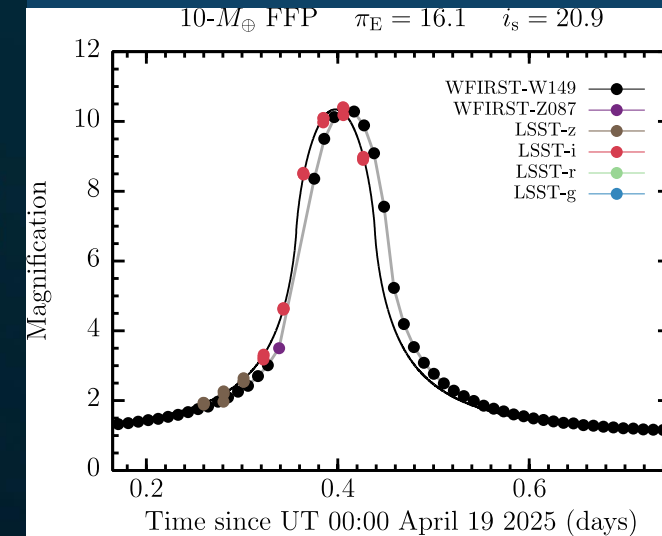


Mass Measurements via Simultaneous Roman–Ground obs.

Space-based parallaxes



only way to measure
mass of free-floating
planets

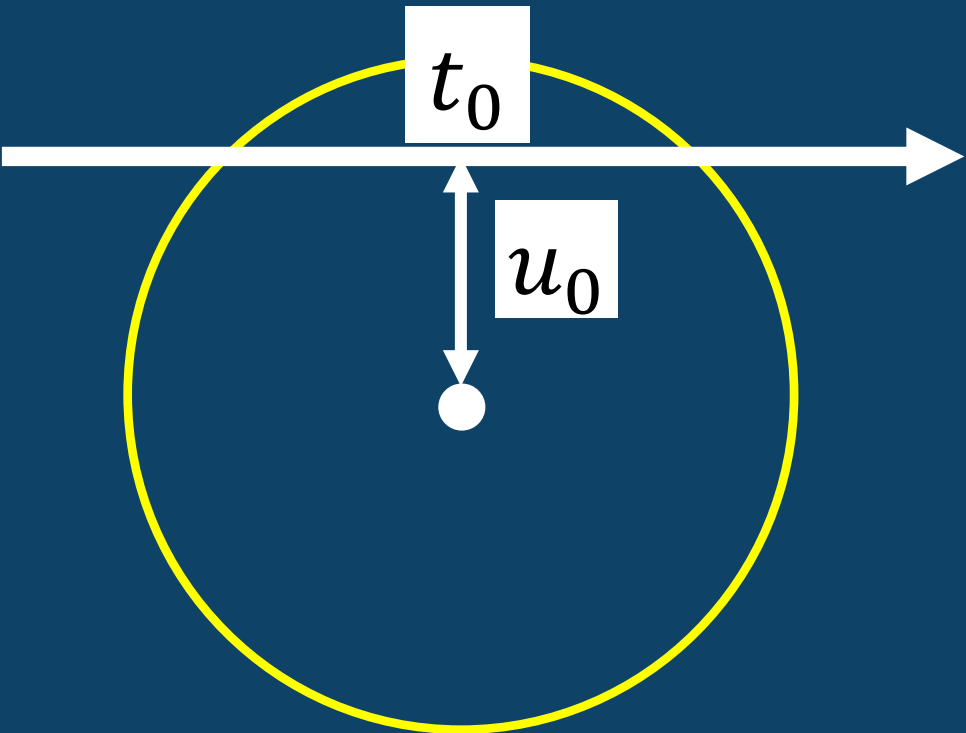


Earth-L2 is suitable for FFP

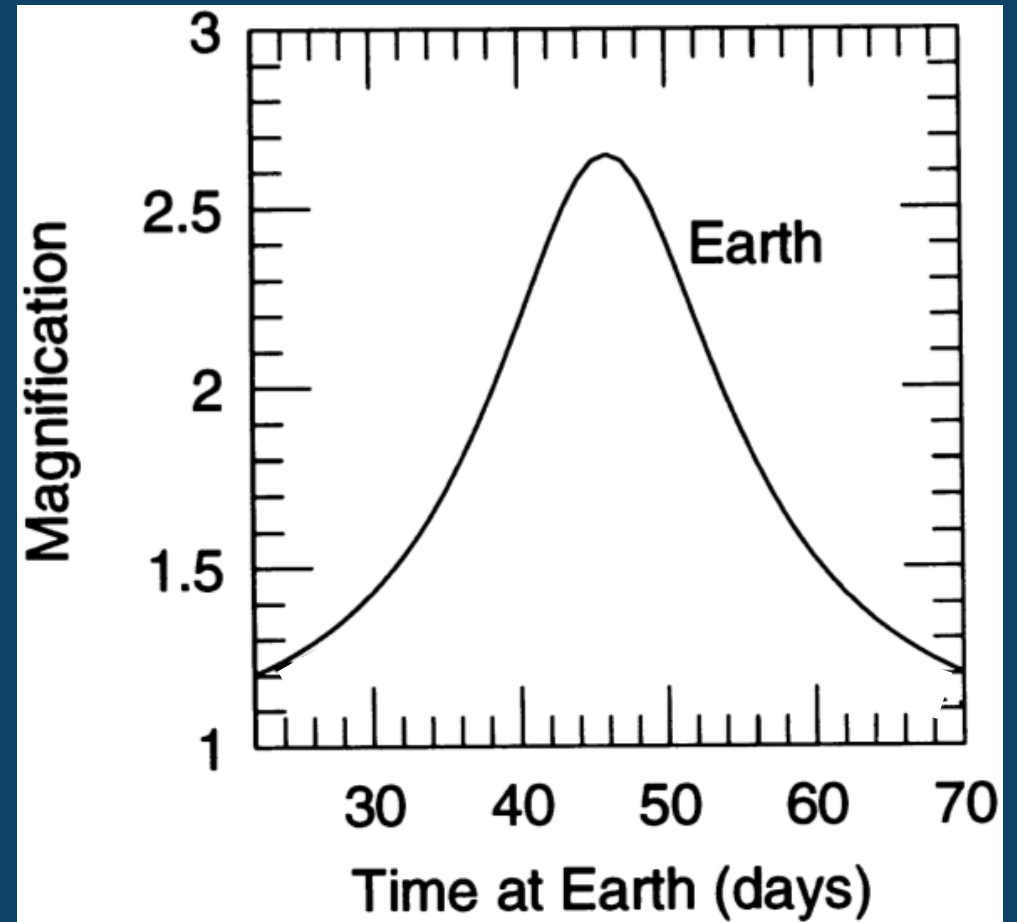
Single lens event from Earth

$$F(t) = F_s A(u(t)) + F_b$$

$$A(u(t)) = \frac{u^2 + 2}{u\sqrt{u^2 + 4}}$$



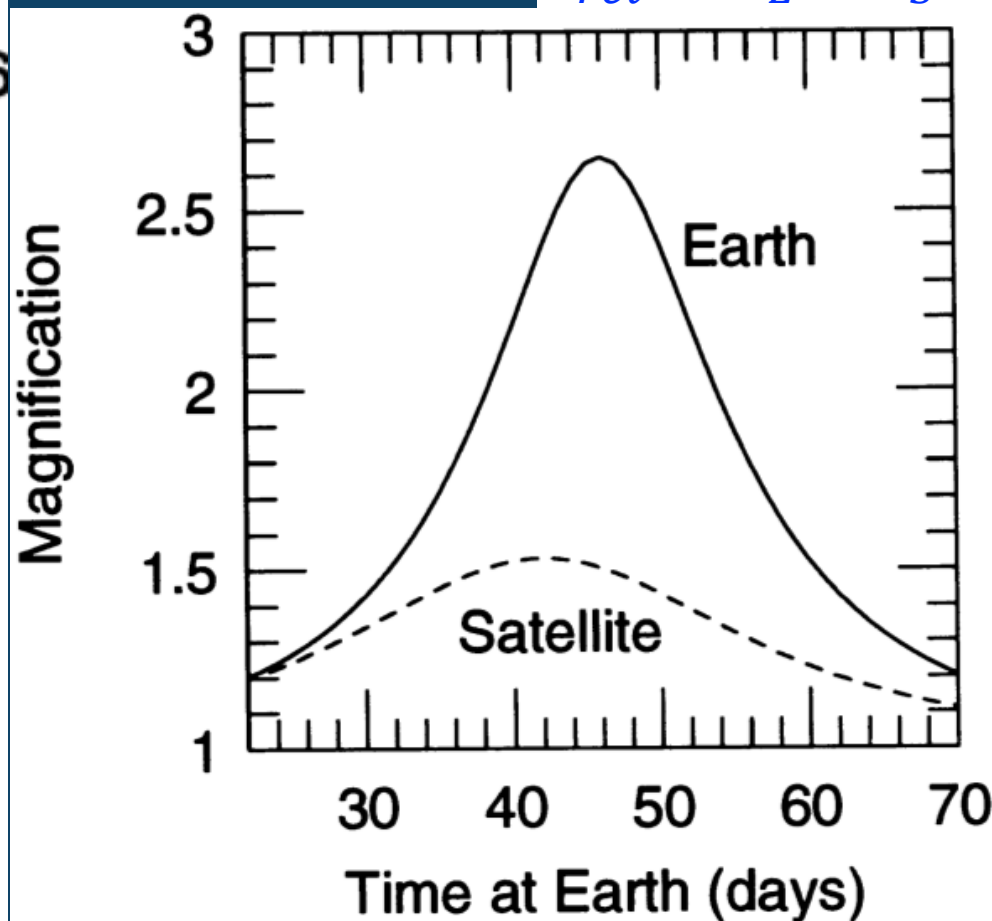
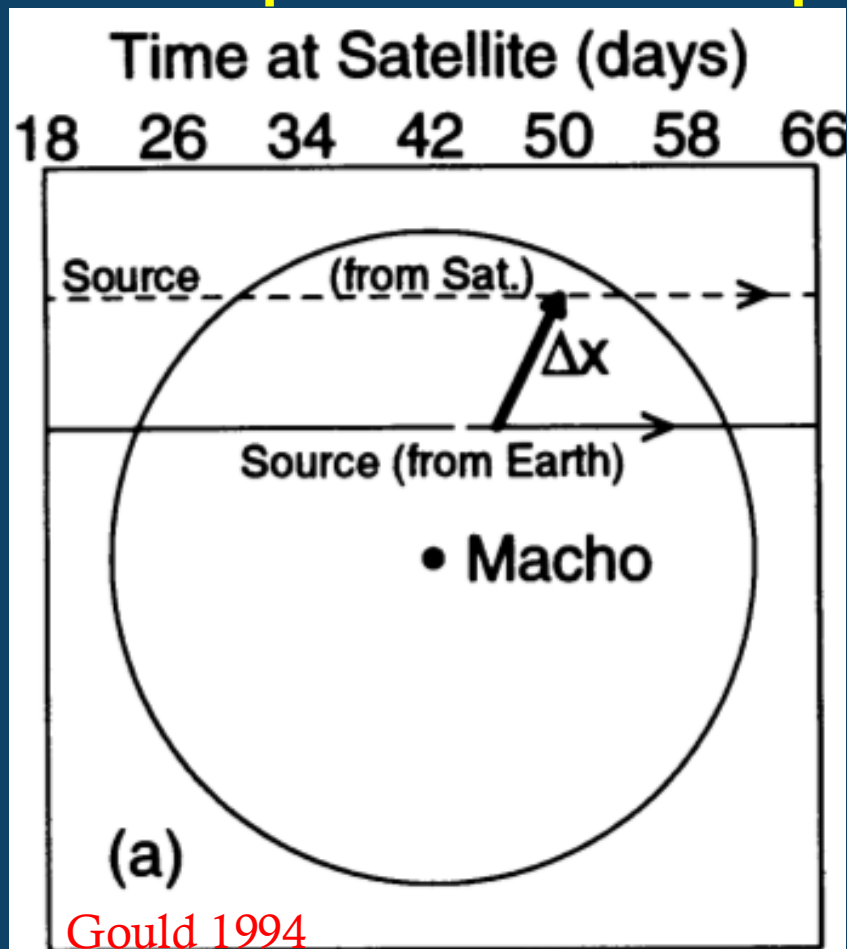
$$u(t) = \sqrt{\left(\frac{t - t_0}{t_E}\right)^2 + u_0^2}$$



Space-based parallaxes

Lens-Source relative parallax:

$$\pi_{rel} = \pi_L - \pi_S = au \left(\frac{1}{D_L} - \frac{1}{D_S} \right) = au \frac{D_S - D_L}{D_S D_L}$$



Projected R_E :

$$\begin{aligned} \tilde{r}_E &= \theta_E \frac{D_S D_L}{D_S - D_L} \\ &= \frac{au}{\pi_{rel}} \theta_E = \frac{au}{\pi_E} \end{aligned}$$

Microlensing parallax:

$$\begin{aligned} \pi_E &= \frac{\pi_{rel}}{\theta_E} = \frac{au}{\tilde{r}_E} \\ &= \frac{au}{D_\perp} \left(\frac{\Delta t_0}{t_E}, \Delta u_0 \right) \end{aligned}$$

$$\begin{aligned} \Delta t_0 &= t_{0,sat} - t_0 \\ \Delta u_0 &= u_{0,sat} - u_0 \end{aligned}$$

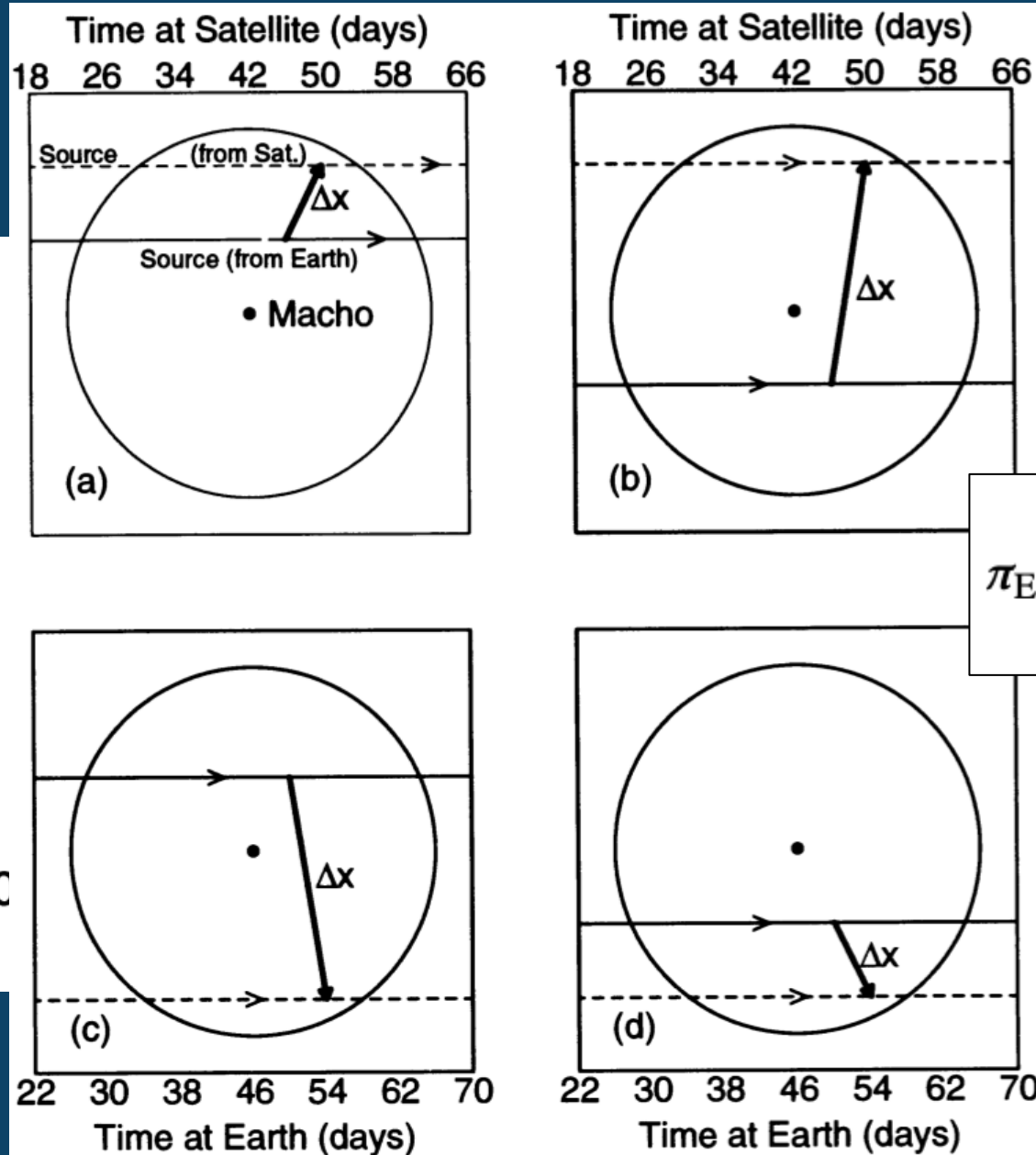
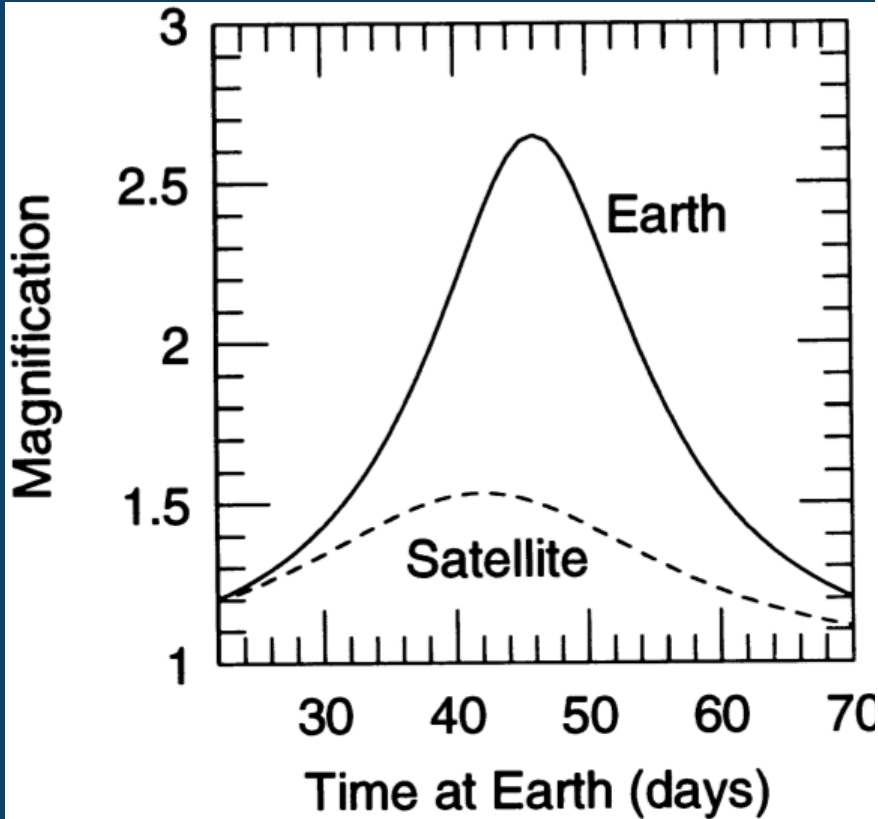
$$\Delta x = \left(\frac{\Delta t_0}{t_E}, \Delta u_0 \right) = \frac{D_\perp}{\tilde{r}_E}$$

$D_\perp$ is the projected separation between the satellite and Earth at the time of the event.

Lens Mass: $M = \frac{\theta_E}{\kappa \pi_E}$

Space-based parallaxes degeneracy

Gould 1994



+Clockwise
- Counterclockwise

$$\pi_E = \frac{\text{AU}}{D_{\perp}} \left(\frac{\Delta t_0}{t_E}, \Delta u_{0,\pm,\pm} \right)$$

OGLE-2007-BLG-224: TERRESTRIAL PARALLAX OBSERVATION OF A THICK-DISK BROWN DWARF

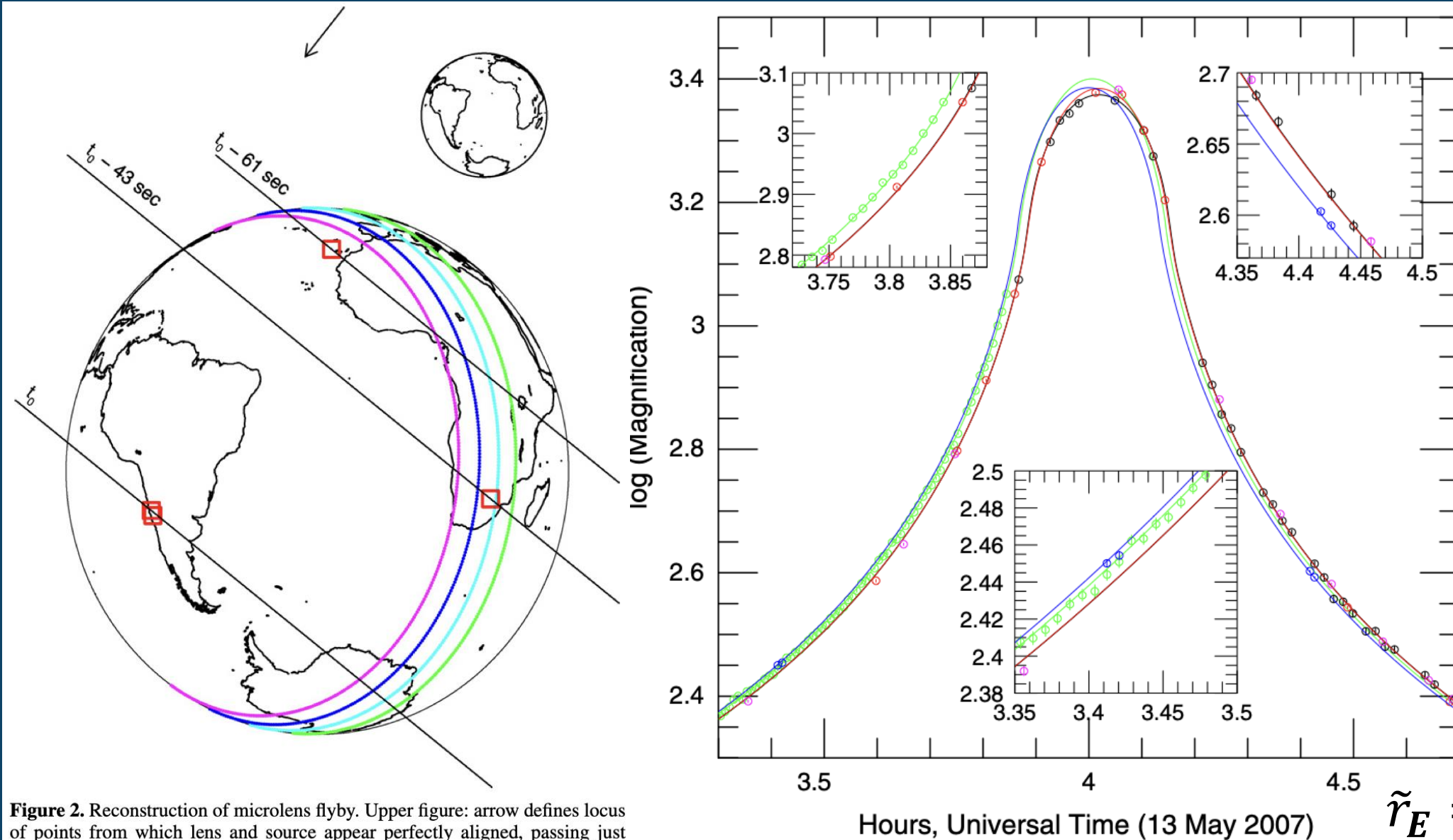
Gould+2009

$\Delta t \sim 1 \text{ min}$

Mass:
 $M = 0.056 \pm 0.004 M_{\odot}$

Distance:
 $525 \pm 40 \text{ pc}$
a transverse
velocity: $113 \pm 21 \text{ km s}^{-1}$.

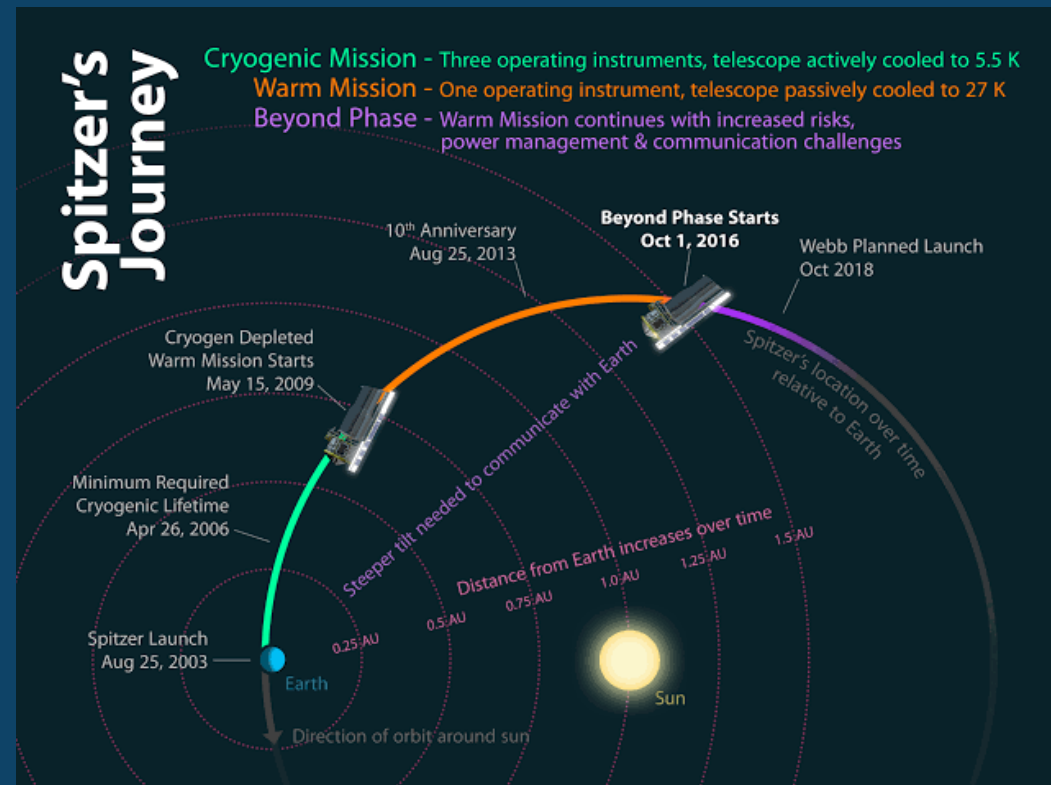
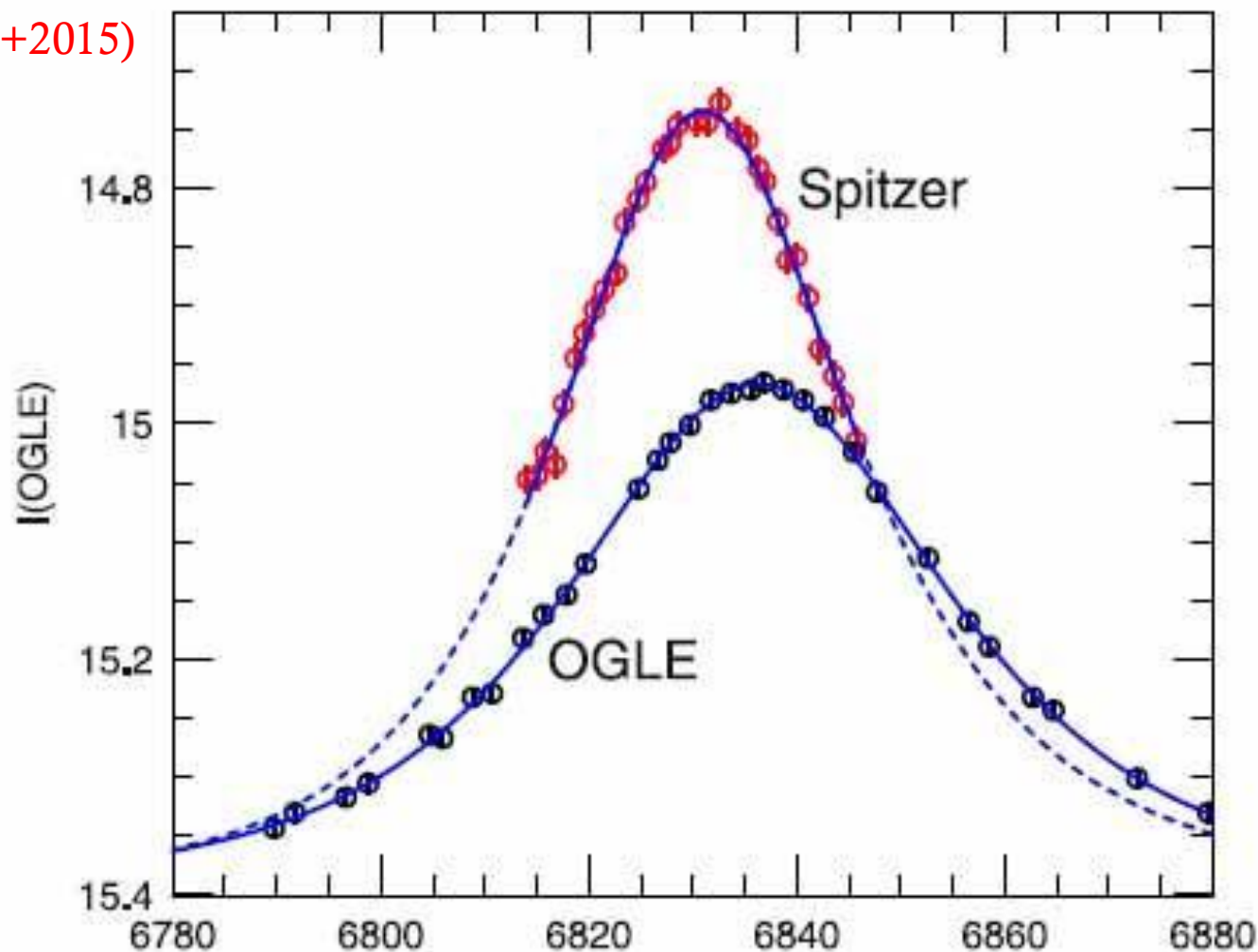
$\tilde{r}_E = 10,000 R_{Earth}$



FIRST SPACE-BASED MICROLENS PARALLAX MEASUREMENT OF AN ISOLATED STAR: SPITZER OBSERVATIONS OF OGLE-2014-BLG-0939

Earth-Spitzer Separation $D_{\perp} \sim 1.2 \text{ AU}$

(Yee+2015)



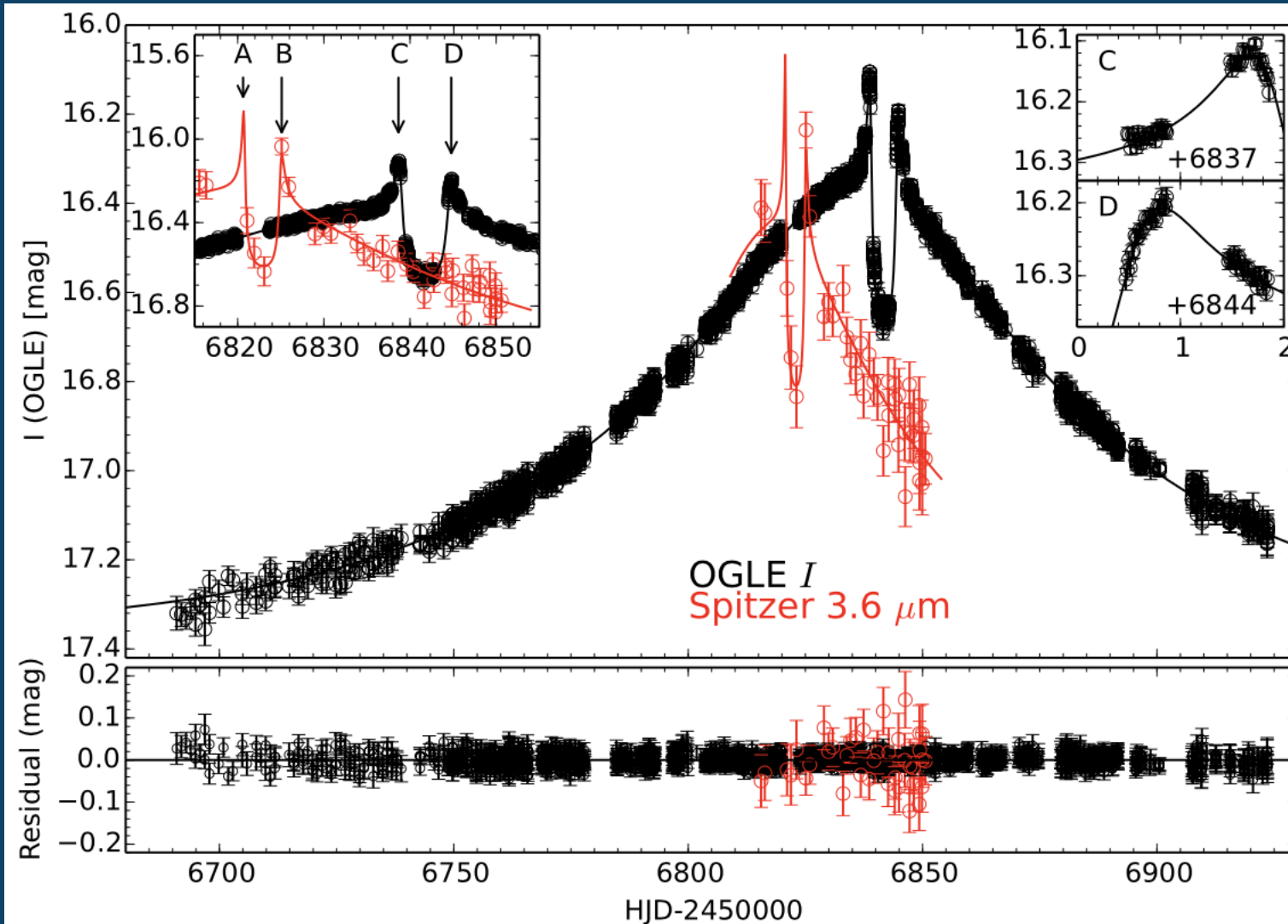
$$M = 0.23 \pm 0.007 M_{\odot}$$

$$D_L = 3.1 \pm 0.4 \text{ kpc}$$

M-dwarf at galactic disk

SPITZER AS A MICROLENS PARALLAX SATELLITE: MASS MEASUREMENT FOR THE OGLE-2014-BLG-0124L PLANET AND ITS HOST STAR

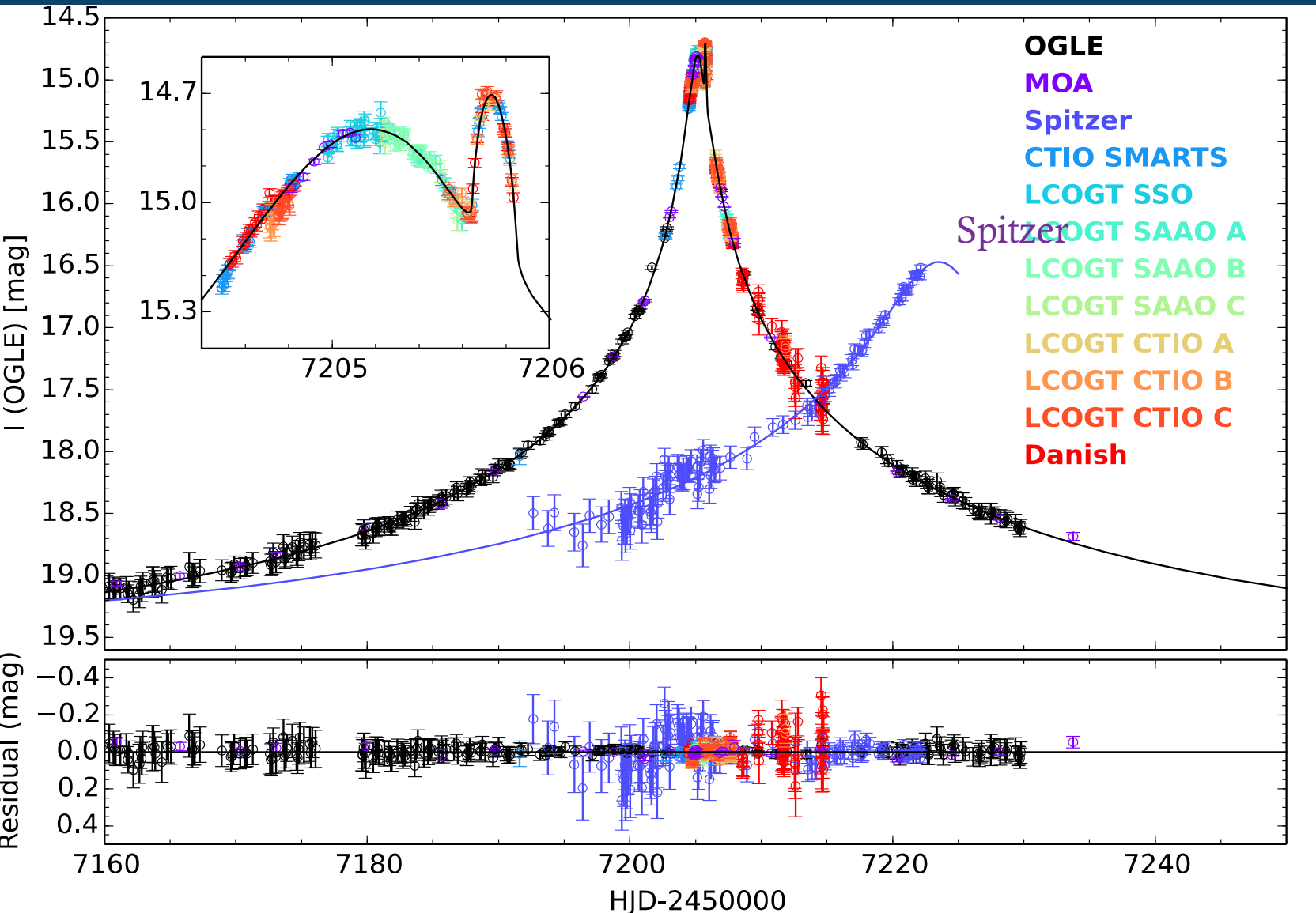
Udalski+ 2015



$$M = 0.5 M_J$$
$$M_* = 0.7 M_\odot$$
$$D_L = 4 \text{ kpc}$$

OGLE-2015-BLG-0966/MOA-2015-BLG-281

(Street et al. 2015)



$$M = 21 \pm 2 M_{\oplus}$$

$$M_* = 0.38 M_{\odot}$$

$$D_L = 2.5 - 3.3 \text{ kpc}$$

Neptune mass planet
Around M-dwarf at
galactic disk

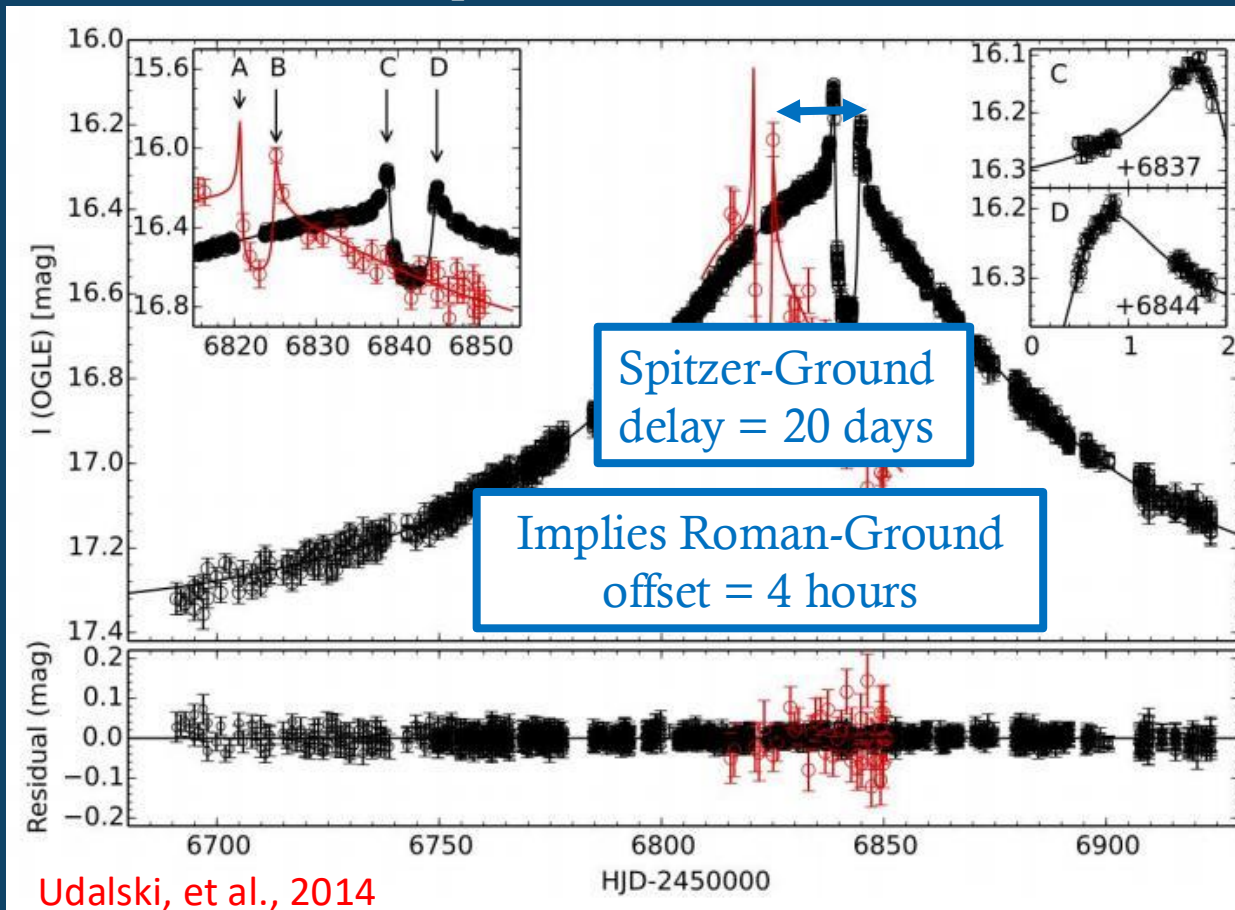
Angular Einstein Radius θ_E

$$\begin{aligned}\theta_E(M, D) &= \sqrt{\frac{4GM}{c^2} \frac{\pi_{rel}}{1au}} \\ &= 271 \mu as \left(\frac{M}{0.5 M_\odot} \right)^{\frac{1}{2}} \left(\frac{\pi_{rel}}{18 \mu as} \right)^{\frac{1}{2}}, \\ &= 1.5 \mu as \left(\frac{M}{5 M_\oplus} \right)^{\frac{1}{2}} \left(\frac{\pi_{rel}}{18 \mu as} \right)^{\frac{1}{2}}, \quad (\sim 1/180)\end{aligned}$$

$$\pi_{rel} = \pi_l - \pi_s = 1au \left(\frac{1}{D_l} - \frac{1}{D_s} \right) = 18 \mu as \quad (D_l = 7 \text{ kpc}, D_s = 8 \text{ kpc})$$

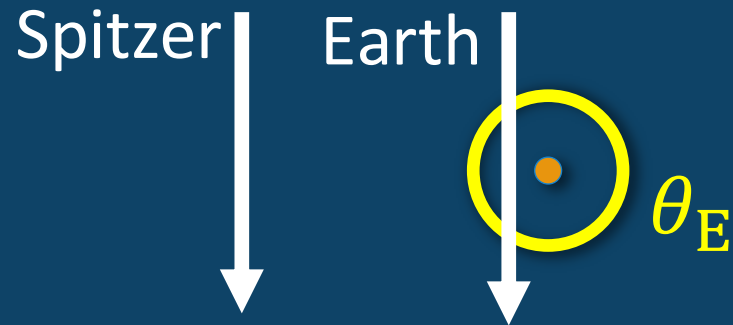
Mass Measurements via Simultaneous Roman-Ground Observation

SPITZER Microlens parallax for OGLE-2014-BLG-0124L



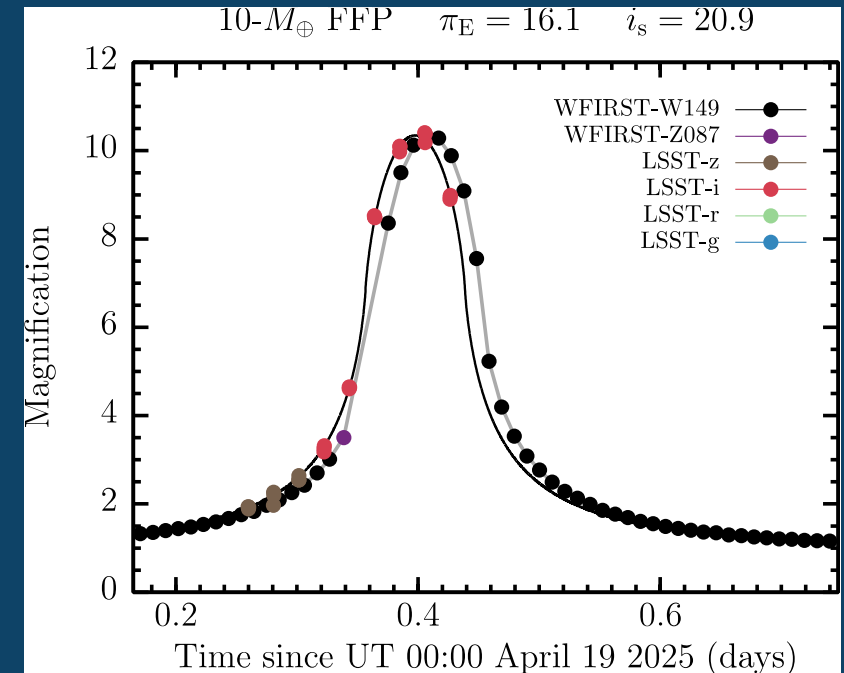
- ~20 day offset between signals w/ Spitzer at 1.2 AU from Earth
- $\Rightarrow$ 4 hour offset with Roman's 0.01 AU separation.
- Revealing microlensing parallax for **planets**, not stars!

FFP Mass Measurements via Simultaneous Roman-Ground Observation



- Because Spitzer-Earth projected separation is $\sim 20 \mu\text{as}$ @ 7kpc,
- This is much larger than $\theta_E \sim 1 \mu\text{as}$ of a planetary mass lens
- the event will be observed from either Earth or Spitzer, but not both.

- Roman's 0.01AU separation is optimal
- only way to measure mass of free-floating planets

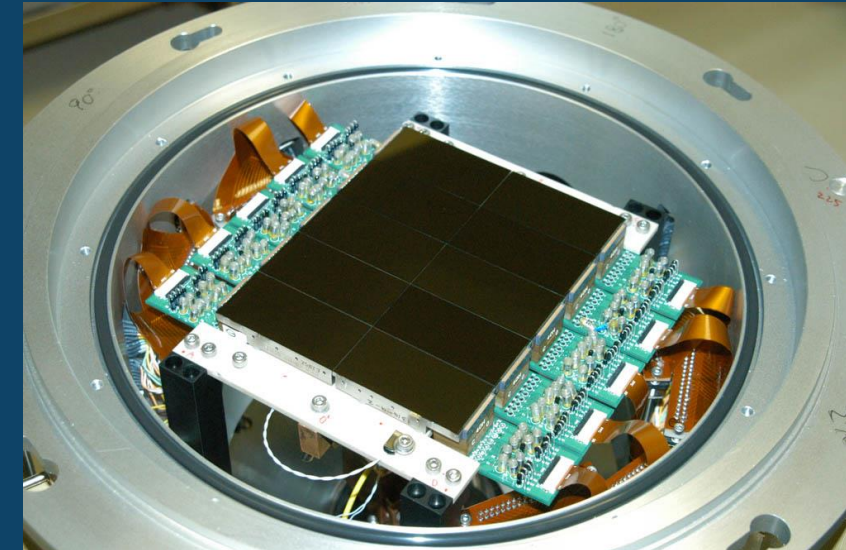
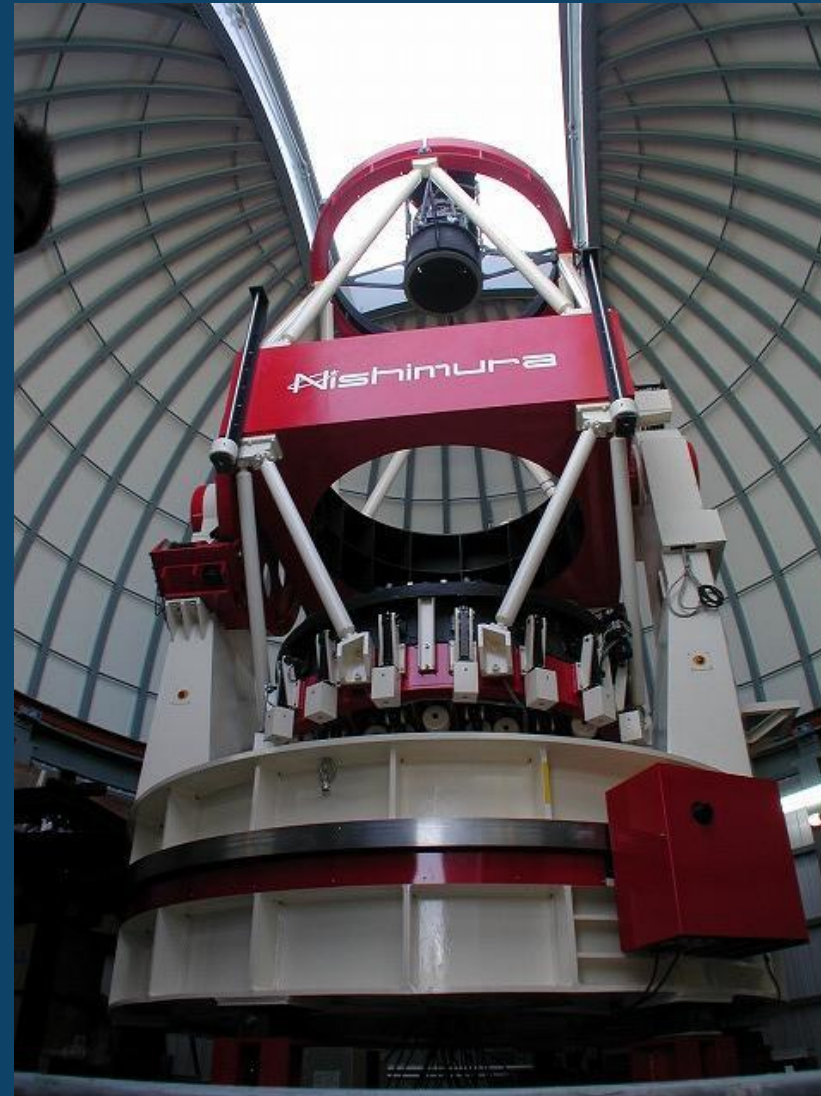


MOA (since 1995)



(Microlensing Observation in Astrophysics)

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



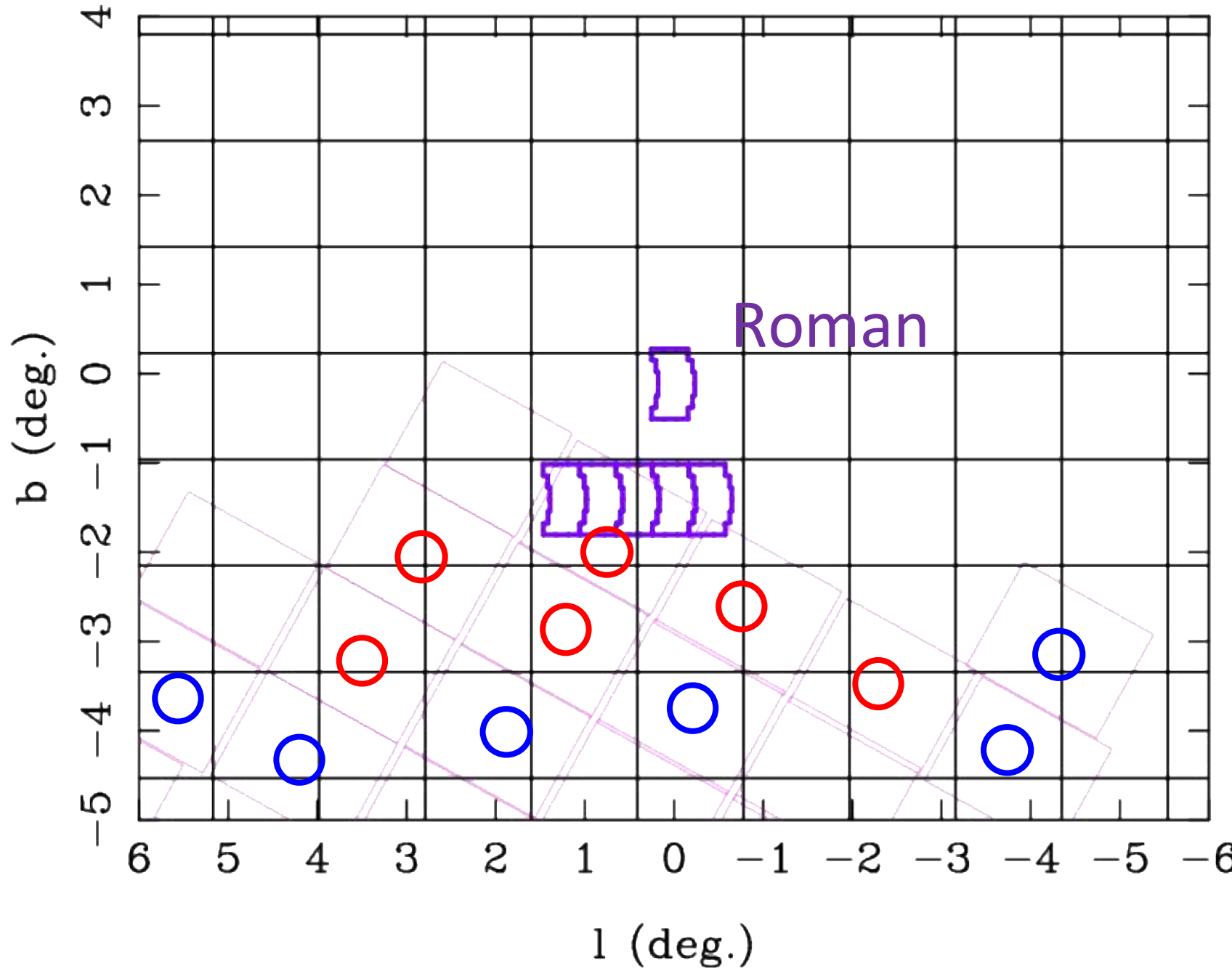
Mirror : 1.8m

CCD : 80M pix.(12x15cm)

FOV : 2.2 deg.²

(10 times as full moon)

MOA observation fields



• 50 deg.² (20Mstars)

• 1 obs./95 min. (M_{jup})

○ 1 obs./47 min. (M_{nep})

○ 1 obs./15 min. ($M_{\oplus}$)

12 (6) events with timescale $t_E < 1$ (0.5) days

3535 / 6111 events in 9 years (2006-2014)

13 FSPL events (2 FSPL with $t_E < 0.5$ day)

Einstein
timescale:

Angular Einstein Radius

$$t_E = \frac{\theta_E(M, D)}{\mu_{\text{rel}}(v_t, D)} \sim 0.05 \sqrt{\frac{M}{M_\oplus}} \text{ day}$$

Relative proper
motion

~20 days for stars

M: lens mass

M_J : Jupiter mass

D: distance

v_t : velocity

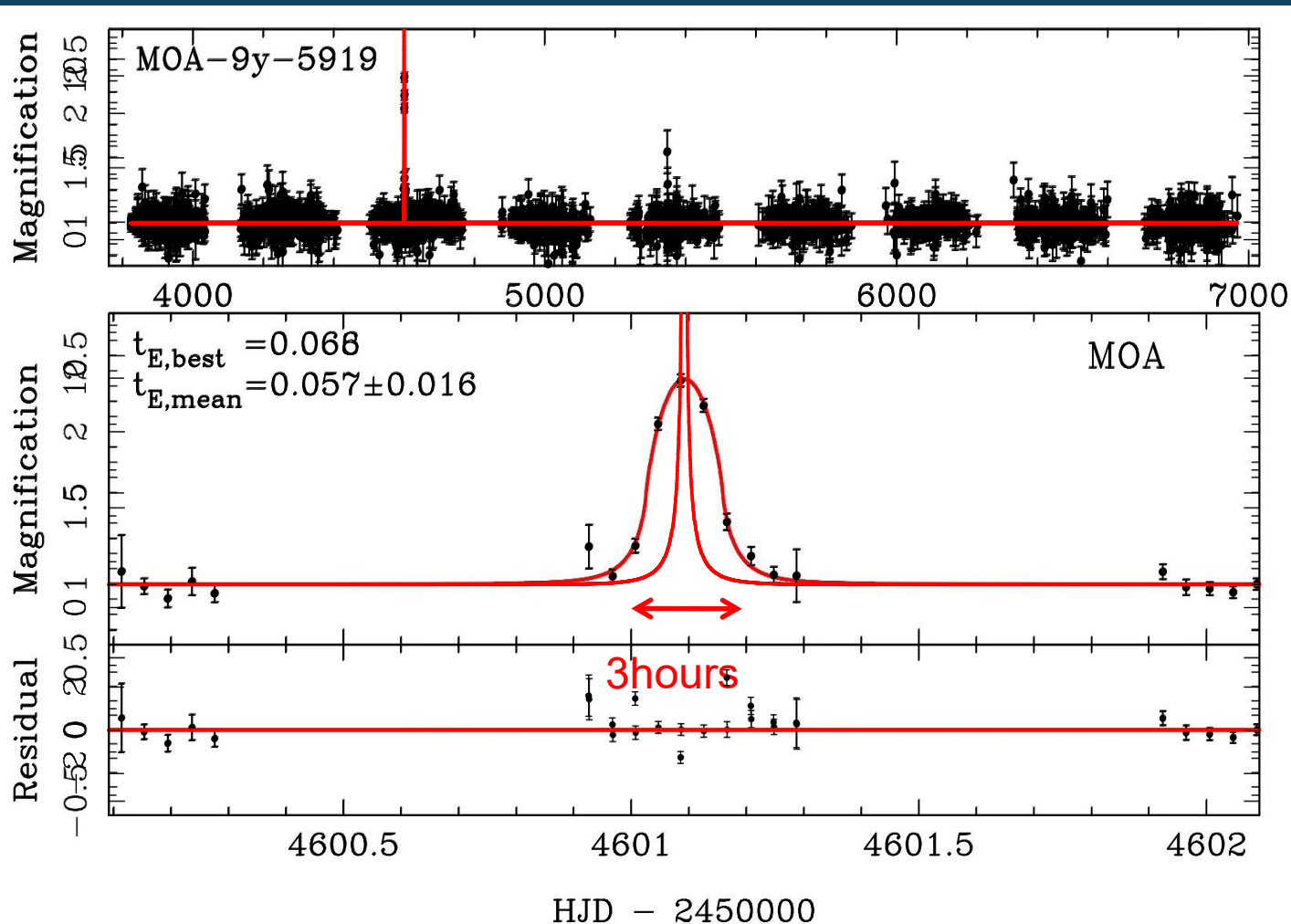
Angular source radius

$$t_* = \frac{\theta_*}{\mu_{\text{rel}}(v_t, D)} \sim 0.1 \sqrt{\frac{M}{M_\oplus}} \text{ day}$$

Finite source
parameter

$$\rho = \frac{\theta_*}{\theta_E}$$

Determined



Short isolated events with FS

FFP or wide separated planet

$$\theta_E = 4.73 \pm 0.75 \mu\text{as}$$

$$M = 22.3^{+42.2}_{-17.4} M_{\oplus}$$

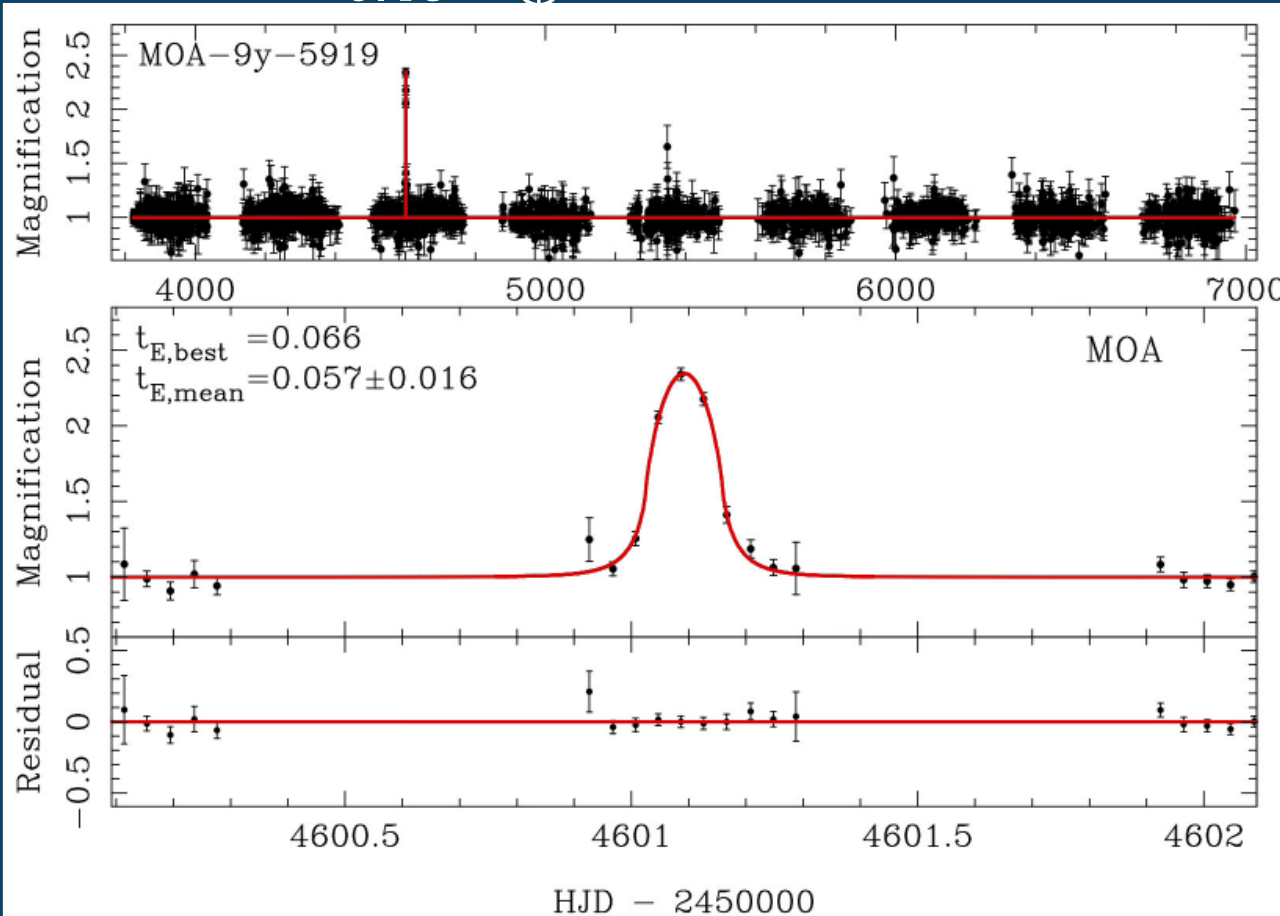
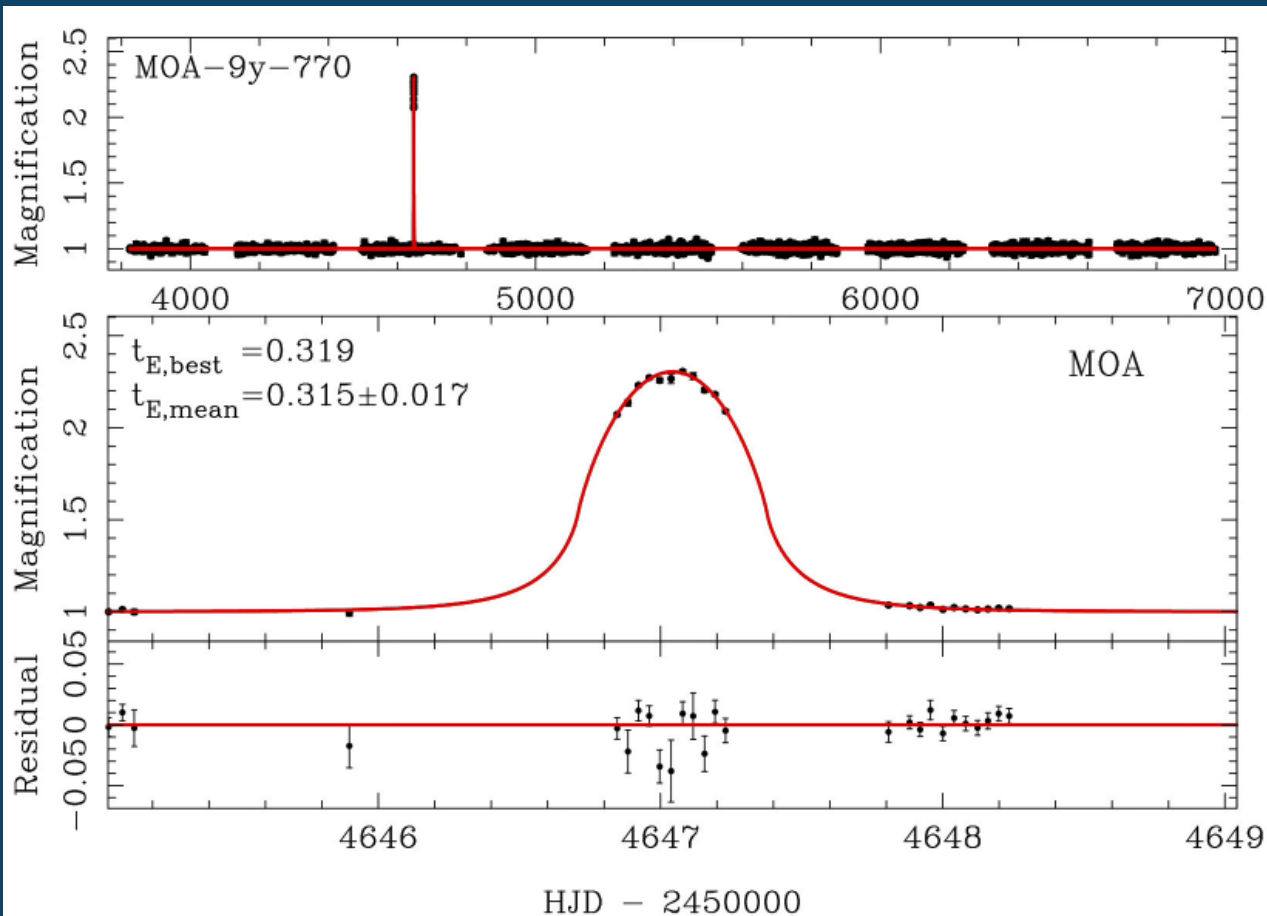
Prior: $dN/d\log M \propto M^{-0.91}$

down to $M_{\text{lo}} = 0.0033, 0.33$

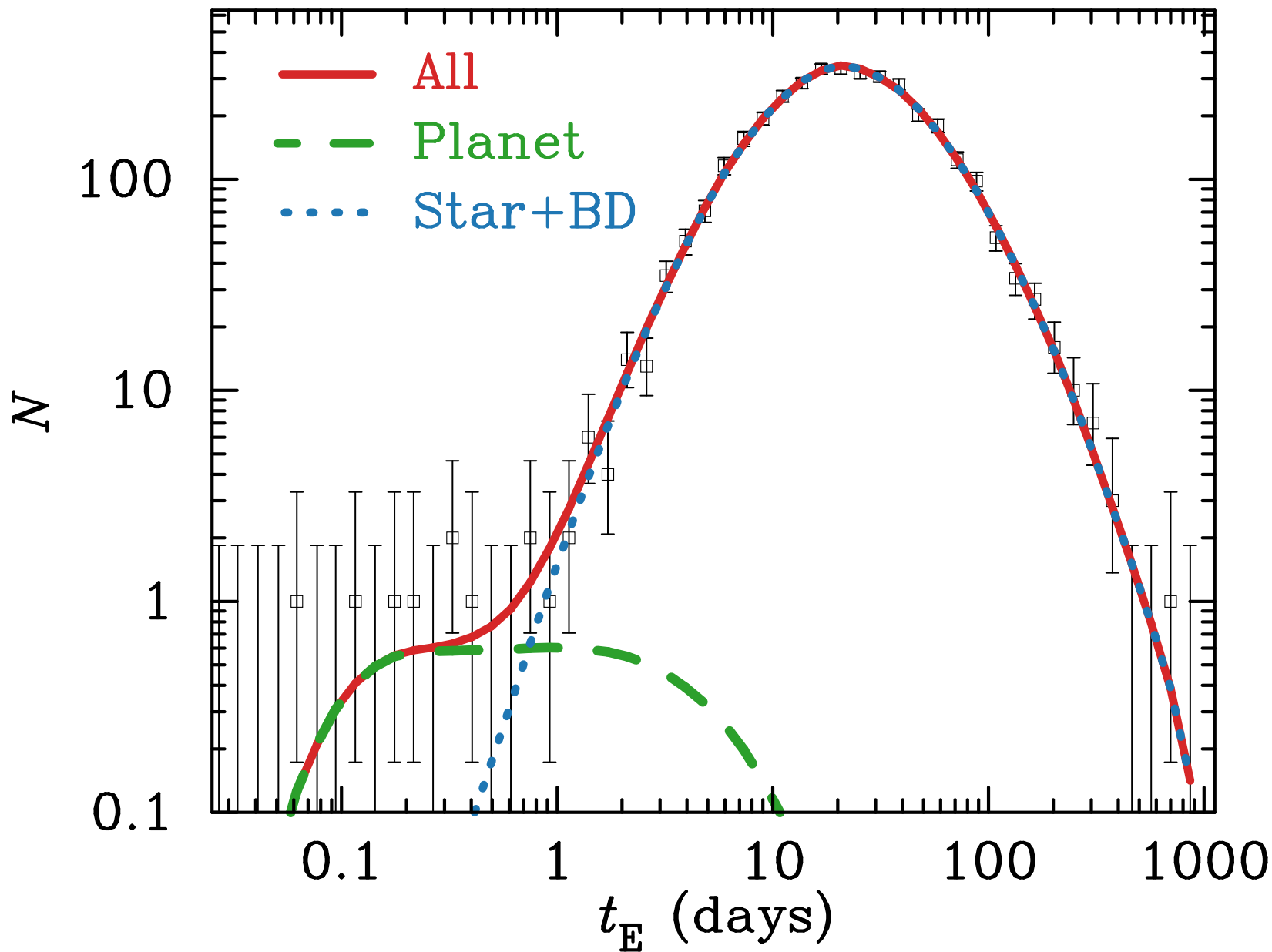
$$\theta_E = 0.90 \pm 0.14 \mu\text{as}$$

$$M = 0.37^{+1.11}_{-0.27} M_{\oplus} (M_{\text{lo}} = 0.0033)$$

$$M = 0.75^{+1.23}_{-0.46} M_{\oplus} (M_{\text{lo}} = 0.33)$$



Timescale t_E distribution

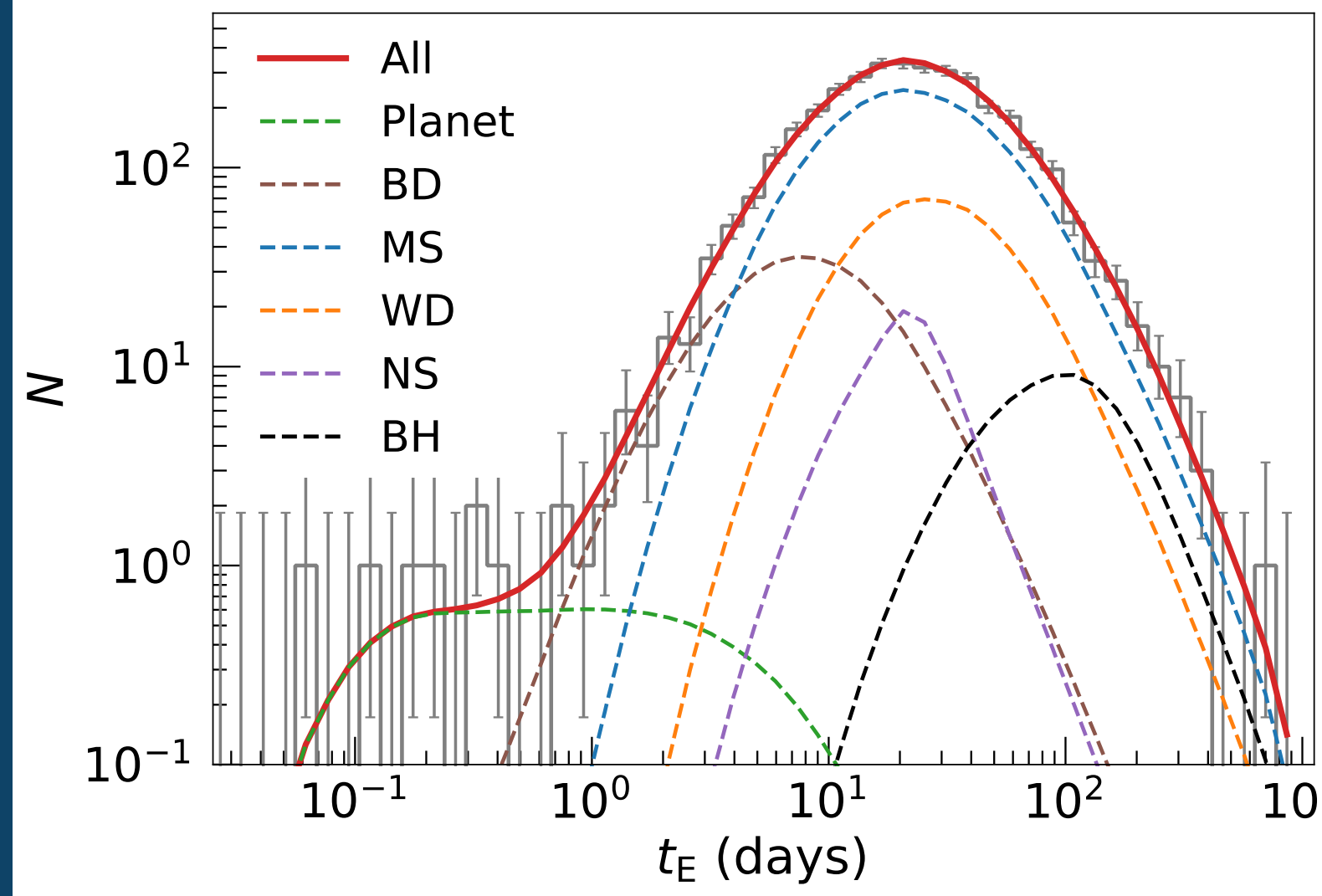


3535 / 6111 events in 9 years (2006-2014)
12 (6) events with $t_E < 1$ (0.5) days

- Well explained by Star+BD for $t_E > 1$ day
- Excess at Short t_E for $t_E < 1$ day
- Consistent to OGLE

Timescale t_E distribution

3535 events



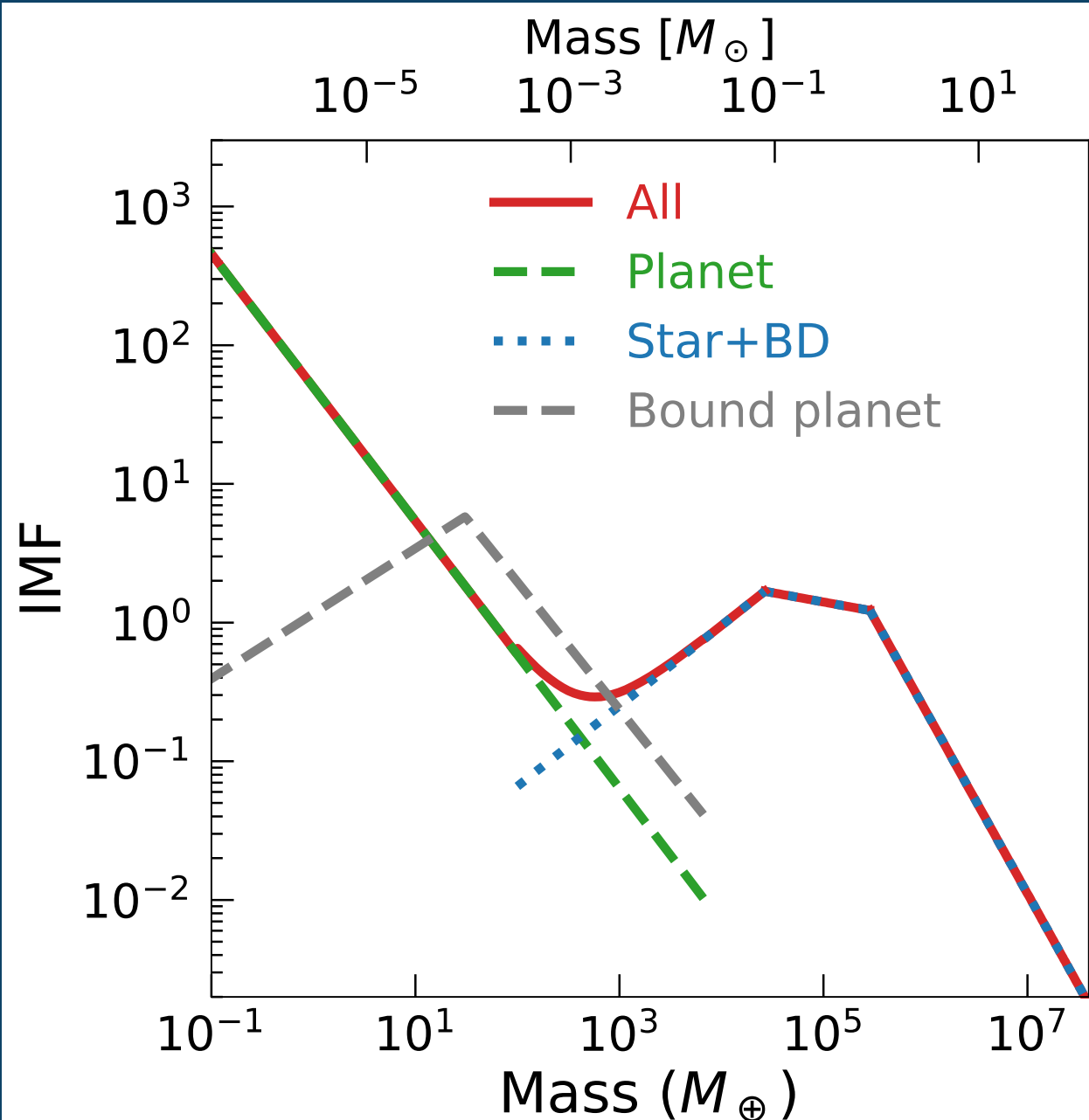
$$\frac{dN_4}{d \log M} = \frac{2.18^{+0.52}_{-1.40}}{\text{dex} \times \text{star}} \left(\frac{M}{8 M_{\oplus}} \right)^{-\alpha_4}$$

$$\frac{dN_4}{d \log M} = \frac{5.48^{+1.18}_{-3.50}}{\text{dex} \times M_{\odot}} \left(\frac{M}{8 M_{\oplus}} \right)^{-\alpha_4}$$

$$0.96^{+0.47}_{-0.27} \text{ for } M/M_{\odot} < 0.02$$

- Well explained by Star+BD for $t_E > 1 \text{ day}$
- Excess at Short t_E for $t_E < 1 \text{ day}$

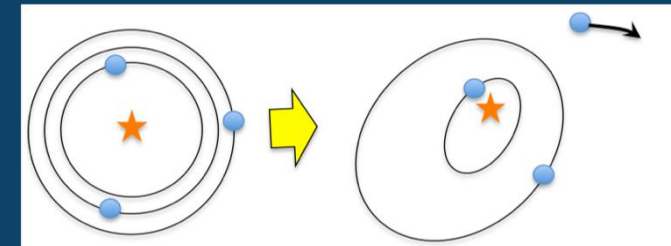
FFP Mass Function



$$\frac{dN_4}{d \log M} = \frac{2.18_{-1.40}^{+0.52}}{\text{dex} \times \text{star}} \left(\frac{M}{8 M_{\oplus}} \right)^{-\alpha_4}$$

$$\alpha_4 = 0.96_{-0.27}^{+0.47} \text{ for } M/M_{\odot} < 0.02$$

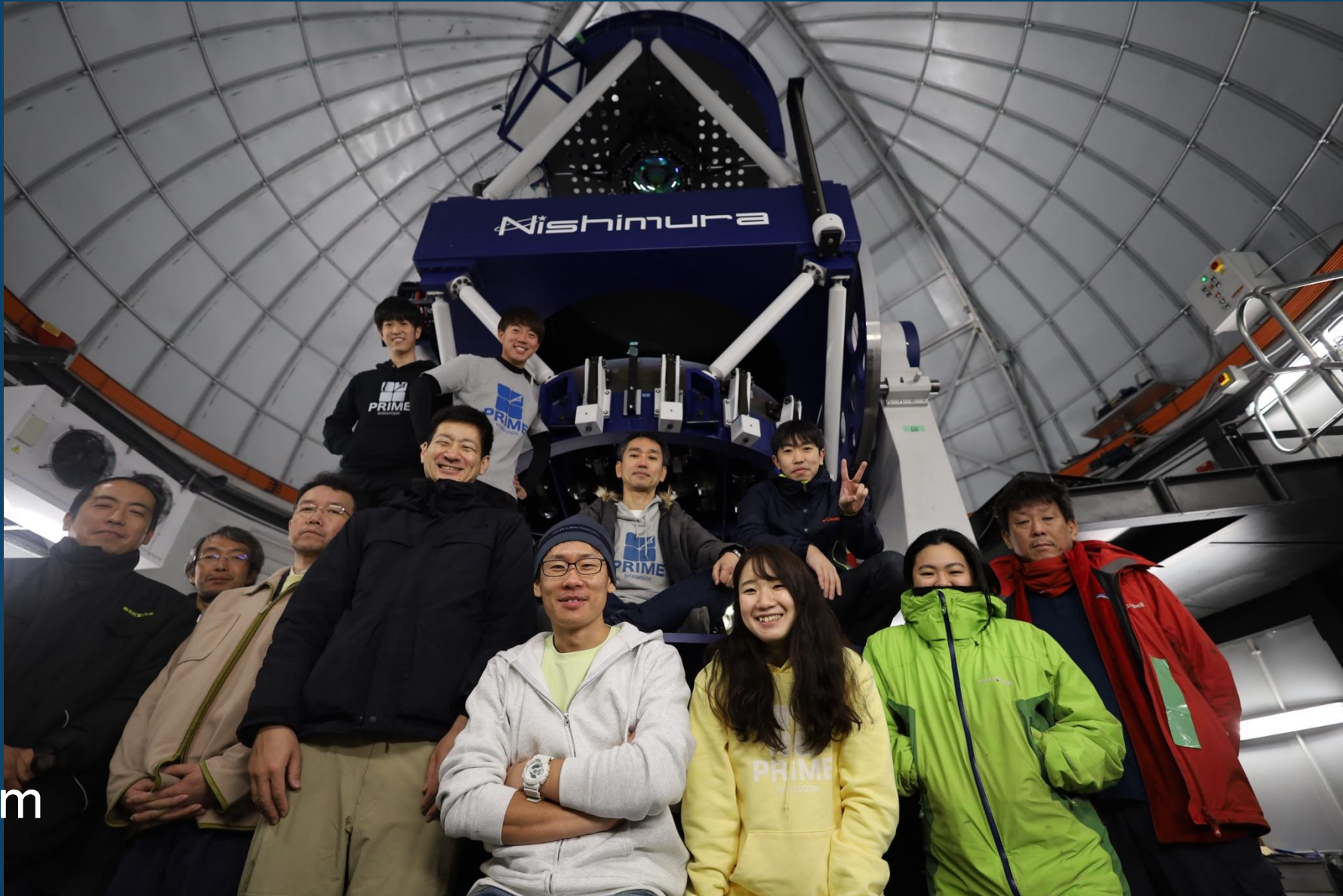
- More low-mass ($\sim M_{\oplus}$) FFP than heavier ones
- $\alpha_4 = 0.96$ is steeper than that of bound planets of $\alpha_{\text{bound}} \sim 0.6$.
- Among planets formed around a star, the less massive planets, the more frequently ejected to be FFP.



- FFP are 19_{-13}^{+23} times more abundant than bound planets outside of snowline (6 times of all known planets)



PRIME



PRIME team

PRIME

JAXA contribution

(PRime-focus Infrared Mirolensing Experiment)

Funded by JSPS

Primary: **1.8m** , (f/2.29)

FOV: $(1.25\text{deg})^2 = \mathbf{1.45\text{deg}^2}$ ($0.5''/\text{pix}$)
(6x full moon). H-band, @ **SAAO**

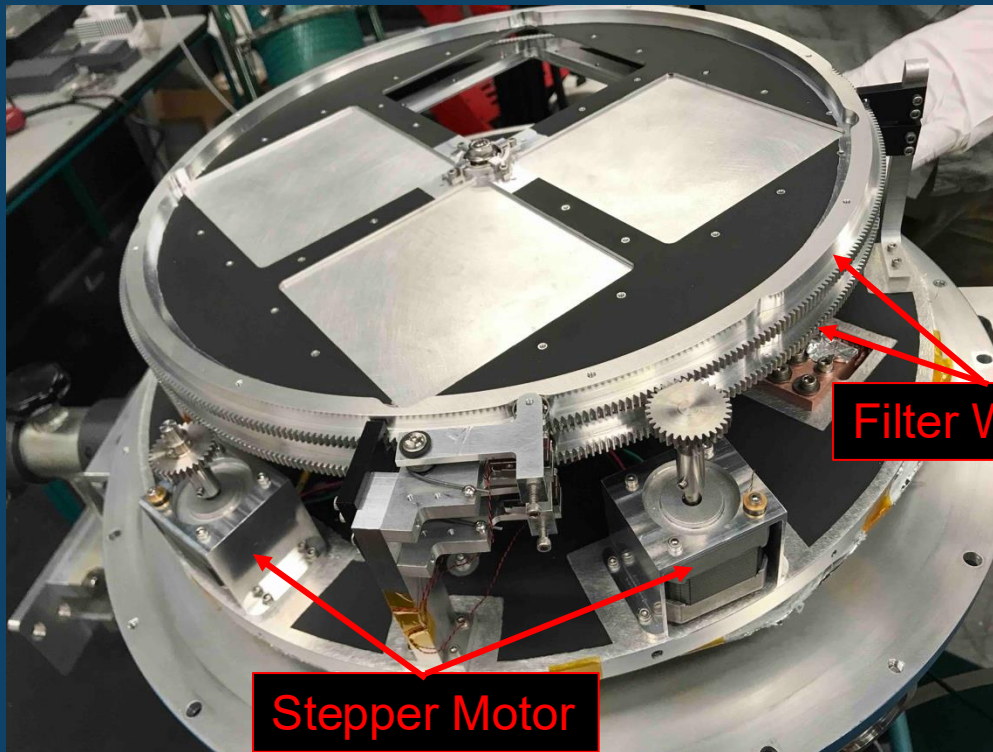
- The first dedicated NIR microlensing survey
- Support Roman
 - Precursor obs.
 - Concurrent obs.



PRIME-cam

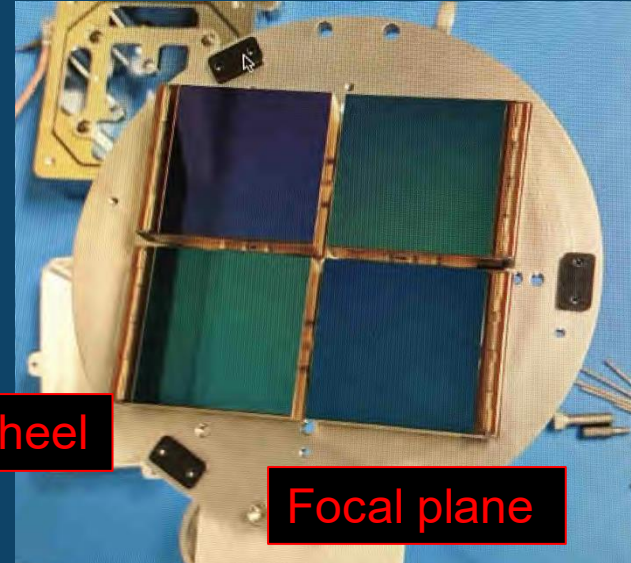
Delayed due to COVID19, but
completed Aug 2022

U. of Maryland manufacture the camera @GSFC by
Loaning 4 Teledyne 4kx4k H4RG-10 from Roman team



Stepper Motor

Filter Wheel



Focal plane

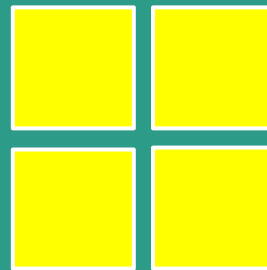
- FOV: 1.45deg^2 (0.5"/pix)
- $T \sim 114\text{K}$
- ACADIA electronics
- 2 filter wheels (6 filters)
(Y, J, H, 3 Narrow bands)

PRIME-cam

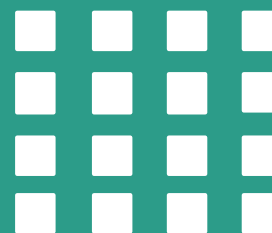
Alexander Kuttyrev (NASA/GSFC,UMD)+
Yuki Hirao (Osaka U.)

FOV comparisons

PRIME



VISTA



Roman



UKIRT



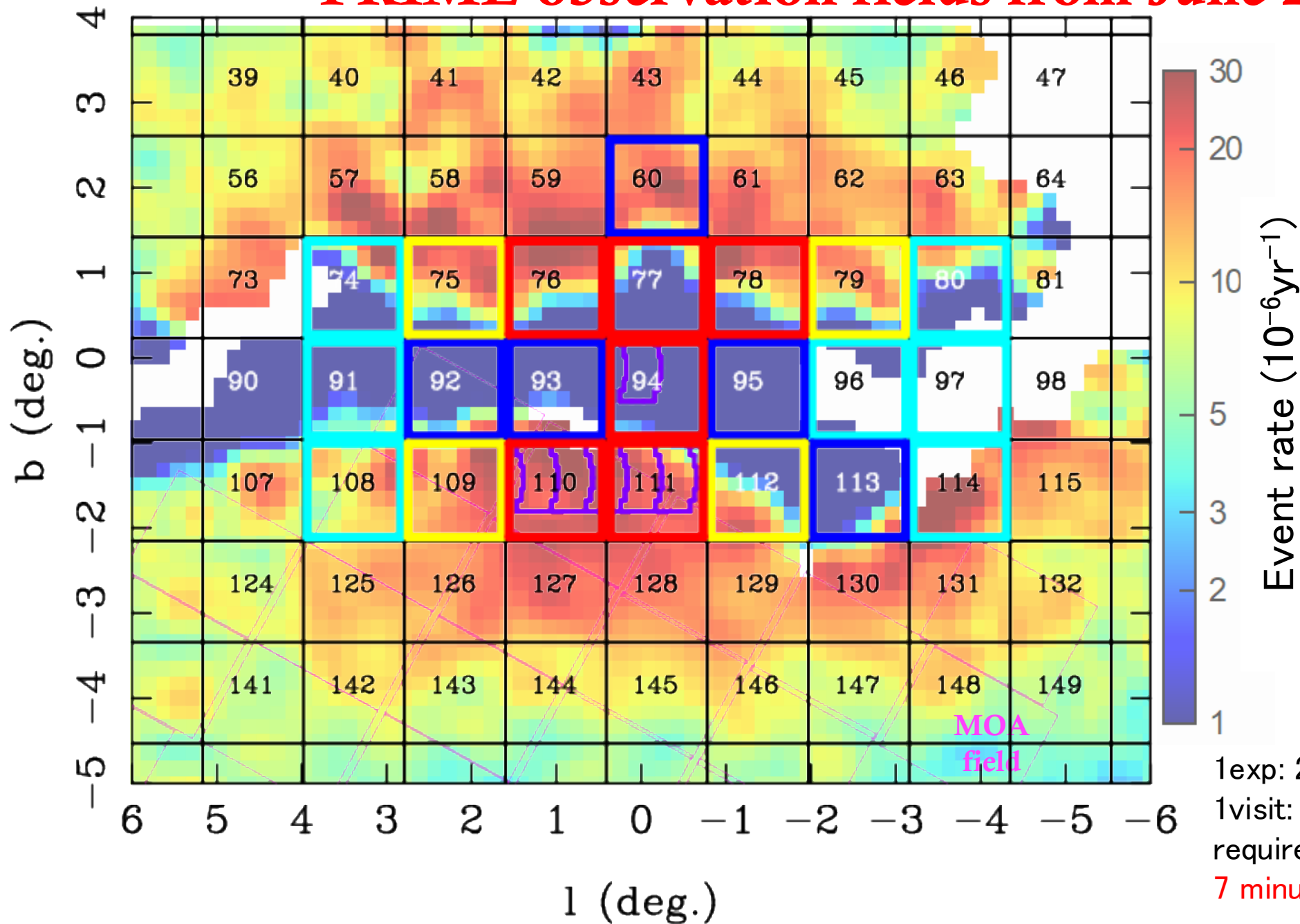
満月



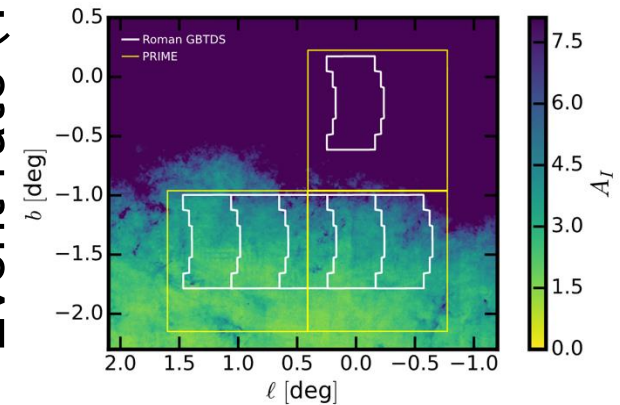
Hubble



PRIME observation fields from June 2nd 2025

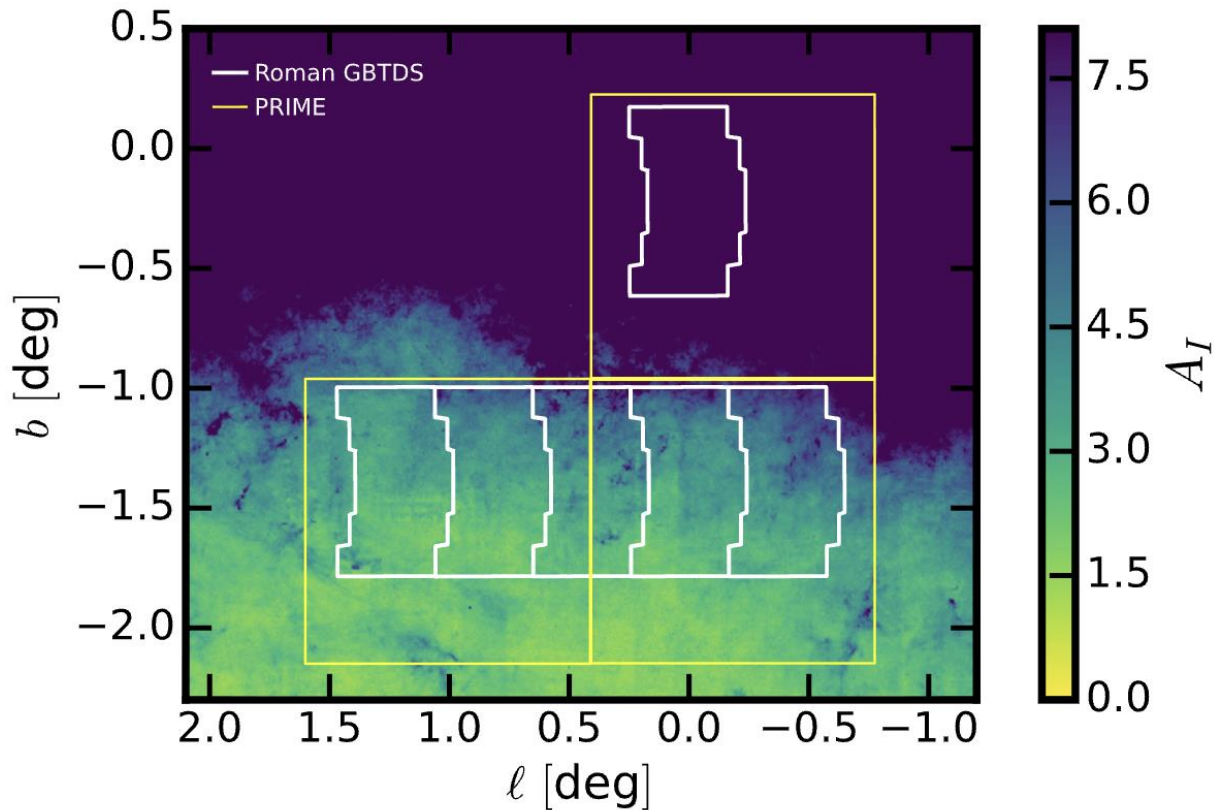


4/cycle: 21.6min: 6
2/cycle: 43.1min: 4
1/cycle: 86.2min: 5
1/night: : 7

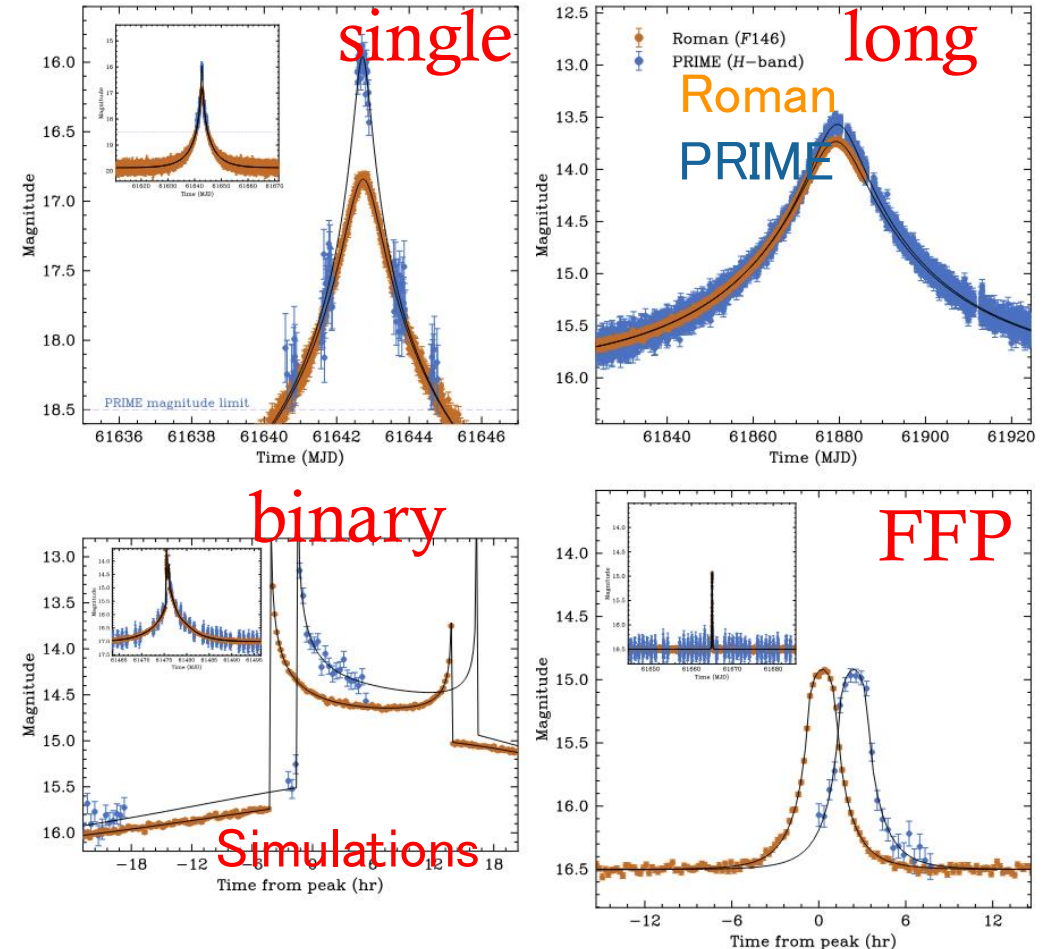


1exp: $2.86 \times 3\text{frames} = 8.58 \text{ sec.}$
 1visit: $8.58 \times 6 \text{ exp} = \mathbf{51.5 \text{ sec}}$
 requires 140 sec including overhead.
7 minutes for 3 fields

Mass Measurements via Simultaneous PRIME–Roman obs.



3 RPRIME fields cover 6 Roman
fields with 7 min. cadence

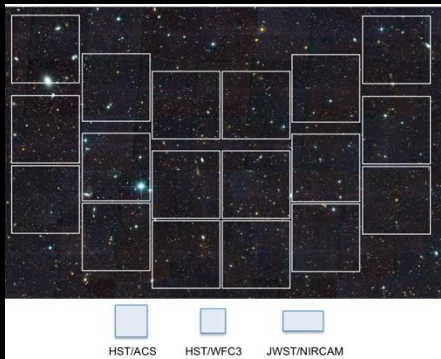


Roman-Subaru Synergistic Observations (100nights)

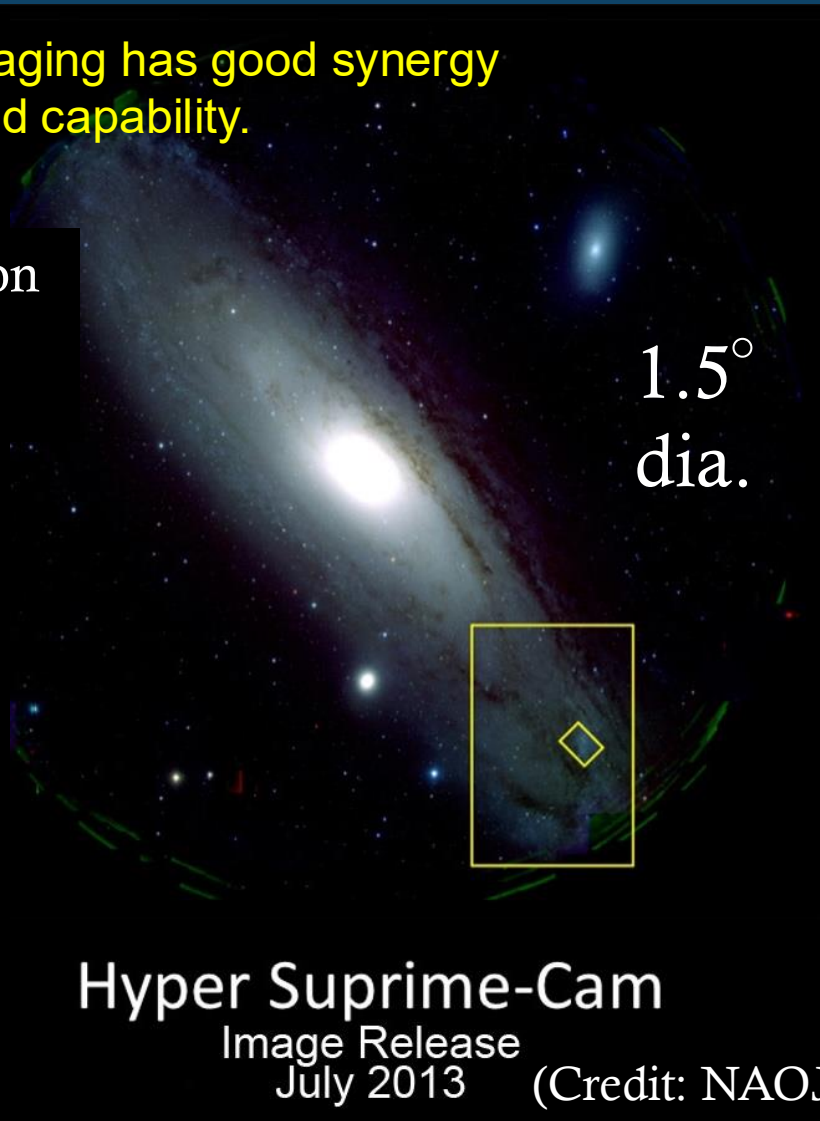
Roman's wide-band imaging has good synergy with Subaru's multi-band capability.



Moon
 0.5°
dia.



Roman WFI
 0.28deg^2



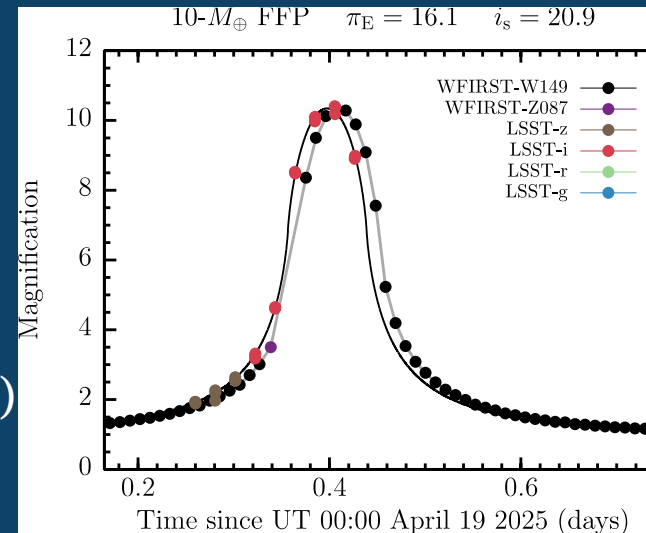
1.5°
dia.

Hyper Suprime-Cam
Image Release
July 2013 (Credit: NAOJ)

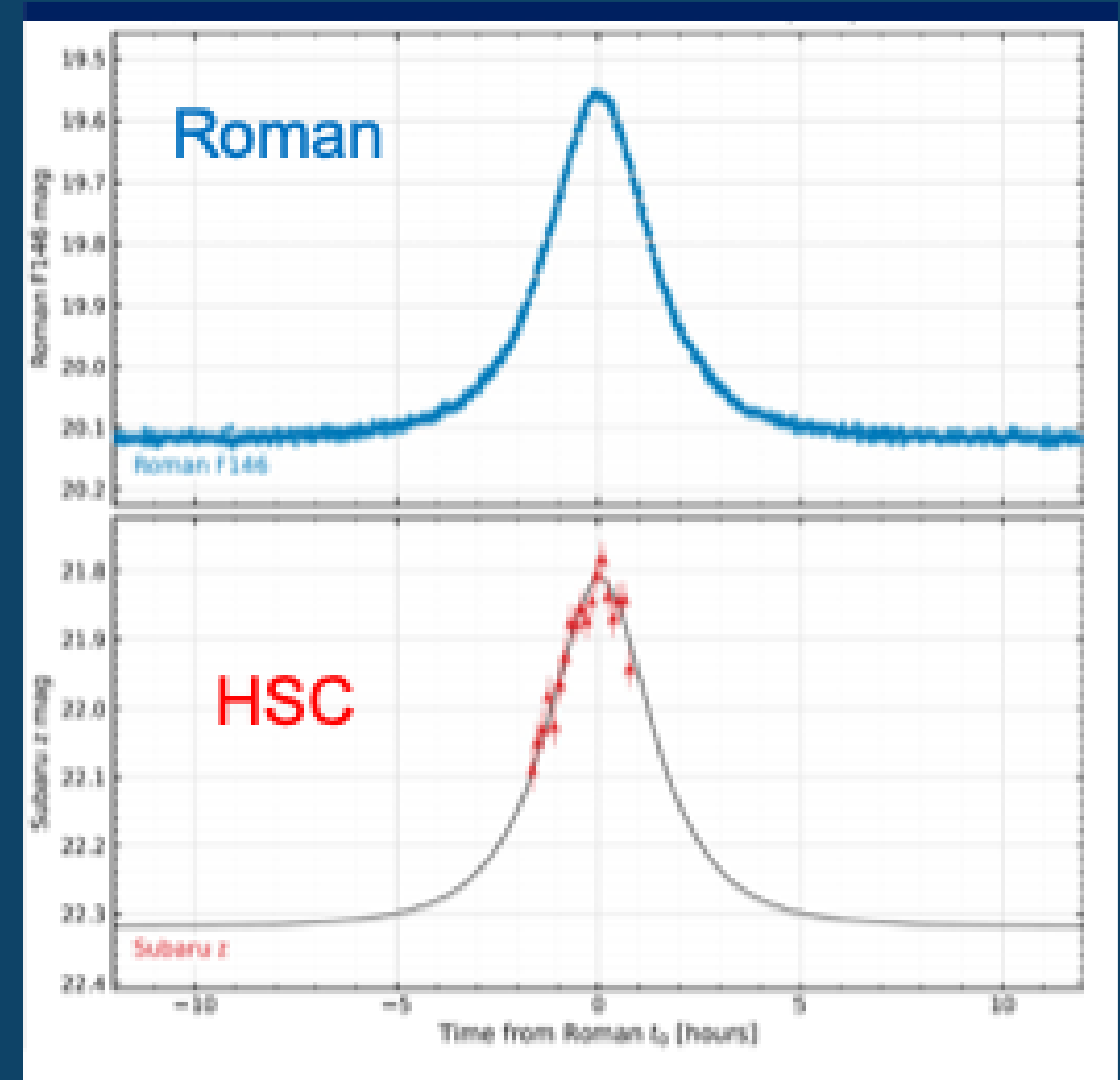
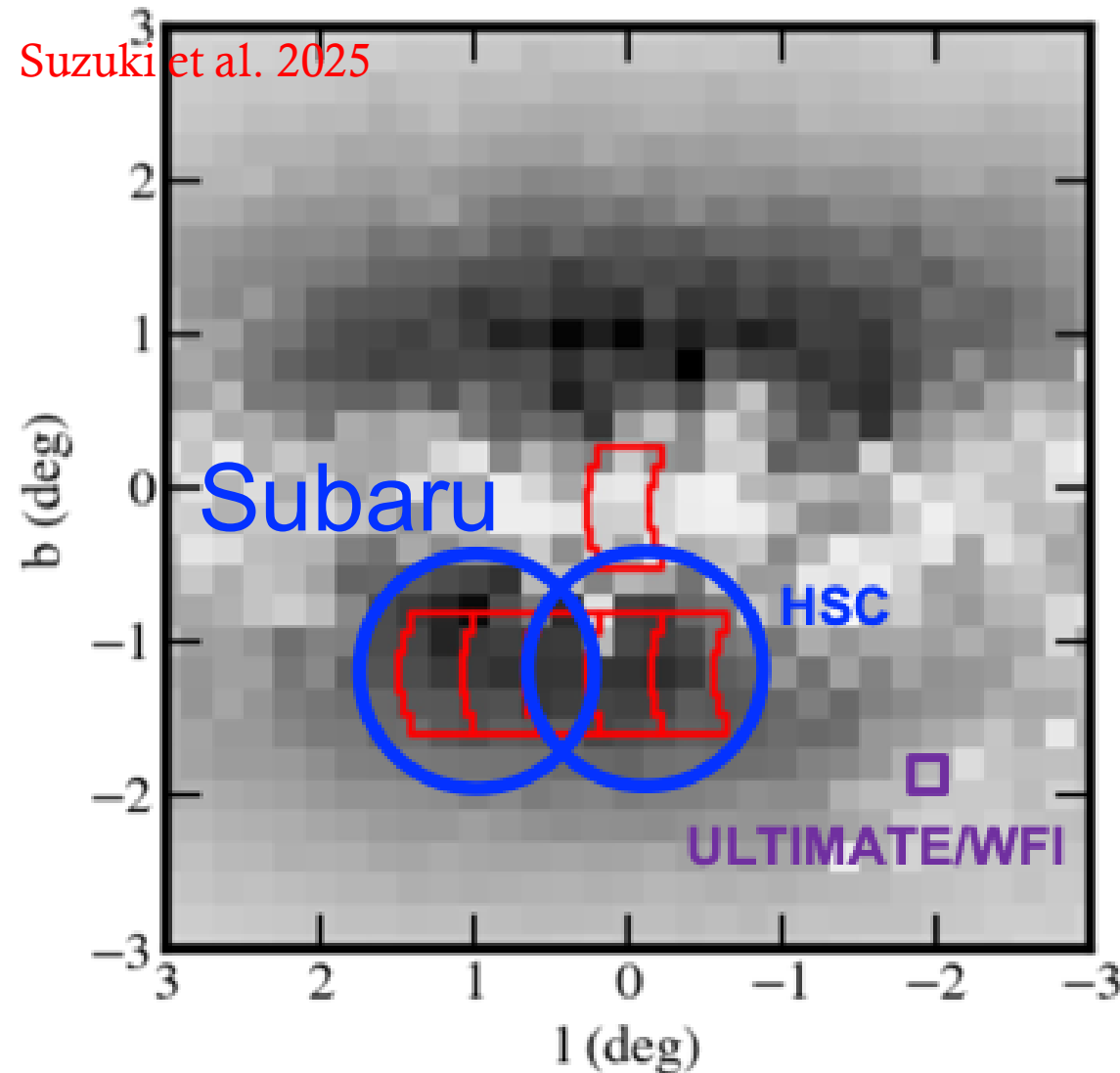
- 100 nights of Subaru reserved for synergistic Observations

Selected 3 priority themes:

- SN Ia Redshift(HSC,PFS):40nights
- Cosmology Redshift(PFS):40nights
- GBTDS (HSC) : 20 nights



Roman-Subaru/HSC Concurrent Observations for FFP Mass Measurements



Roman-Subaru/ULTIMET Concurrent Observations

Subaru strategic program (SSP) (~ 300 nights)



Towards Ultimate Subaru Telescope

<https://sites.google.com/naoj.org/ultimate-subaru>

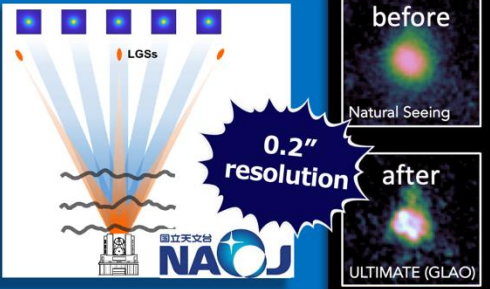
2029-

ULTIMATE
Subaru

High spatial resolution $\times$ Large field of view

Ground Layer AO (GLAO)

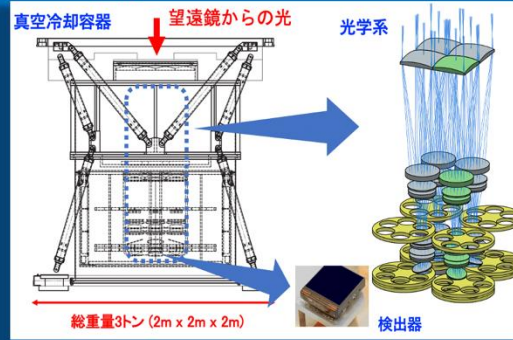
0.2" resolution across 20' field



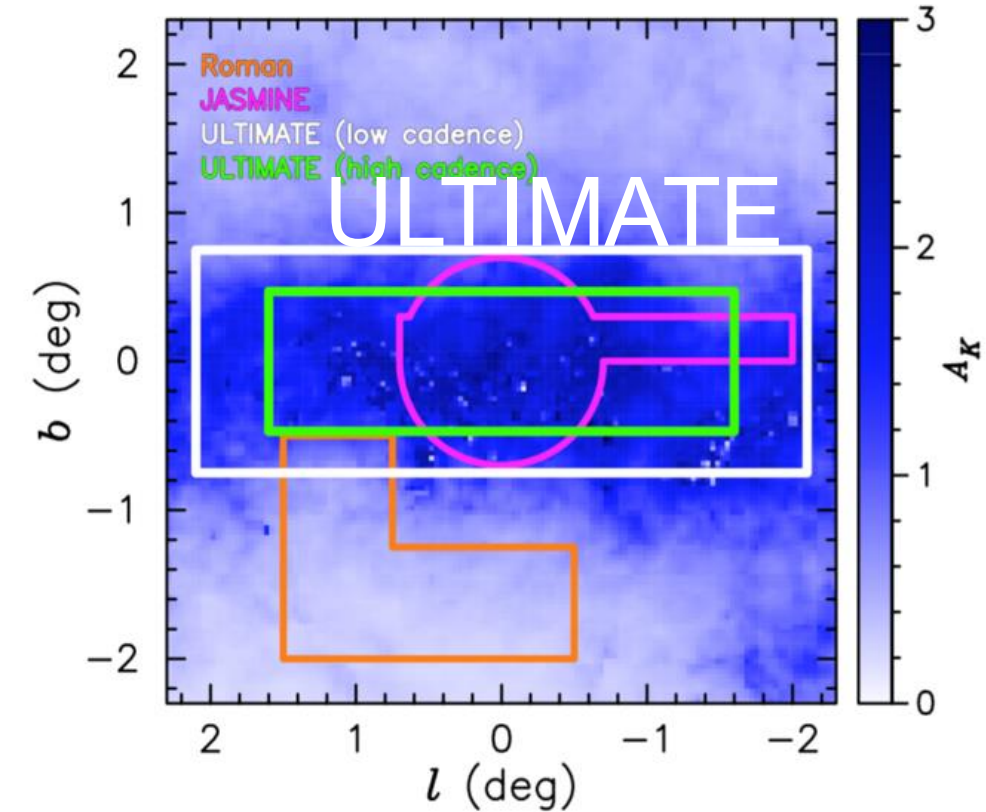
NAOJ's official project

Wide-field NIR imager (WFI)

FoV=14'x14'=200arcmin²



JSPS grant project (Kodama+, 2024-2030)



- FWHM $\sim 0.2-0.3''$
- FOV 14'x14' @K-band
- less extinction K-band
- can use Bright night!



OGLE: Optical Gravitational Lensing Experiment

Andrzej Udalski



Warsaw 1.3-m

@ Las Campanas, Chile

- in operation since **1992**
- since 2010 as **OGLE-IV/V** (Udalski et al. 2015)
- over **2 billion** source monitored
- **1.7×10^{12}** photometric measurements by 2025
- over **25,000** microlensing detections
- over **150** exoplanets discovered

Milky Way

Magellanic System



The Optical Gravitational Lensing Experiment (1992 -)



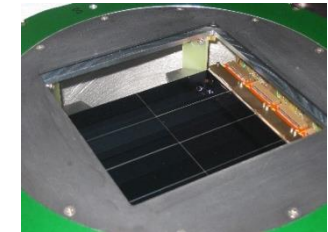
Phases of the OGLE Survey:

OGLE-I (1992 – 1995). 1 m Swope telescope at Las Campanas Observatory, Chile. ~2 million stars observed. Microlensing



OGLE-II (1997 – 2000). 1.3 m Warsaw telescope. ~40 million stars observed. Variable and non-Variable Stars in GB, MC

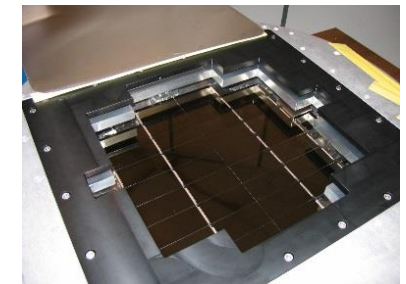
OGLE-III (2001– 2009). 8k x 8k mosaic CCD. ~200 million stars observed (GB, GD, MC). Extrasolar Planets, Microlensing



OGLE-IV (2010 – 2025). 32-chip 256 Mpixel mosaic CCD. >Two billion stars regularly monitored

(March 17, 2020 – August 12, 2022: CoViD-19 pandemic stopped observations)

OGLE-V (2025 –). 32-chip 256 Mpixel mosaic CCD. >Two billion stars regularly monitored

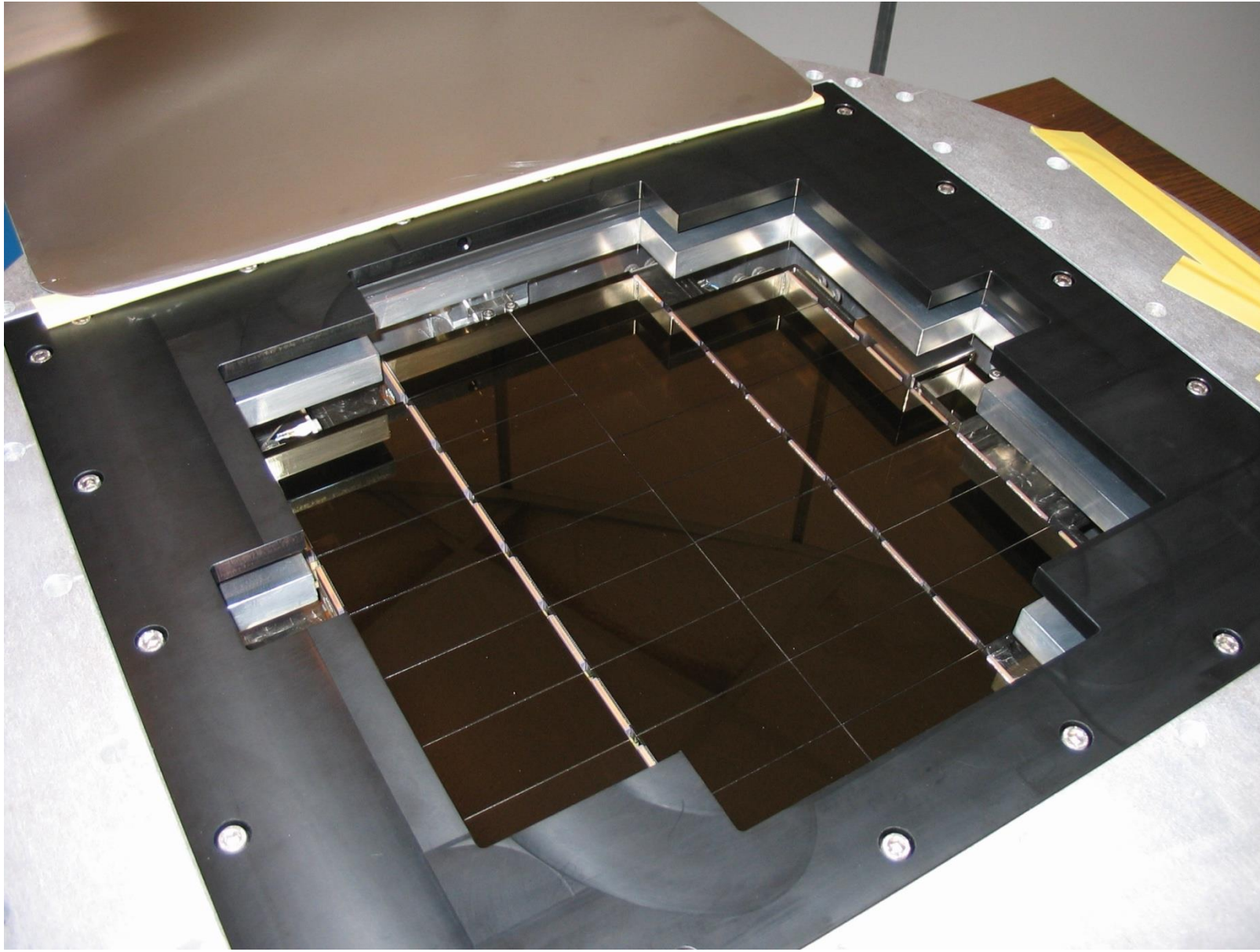


European Research Council
Established by the European Commission
AdG 2010–2014

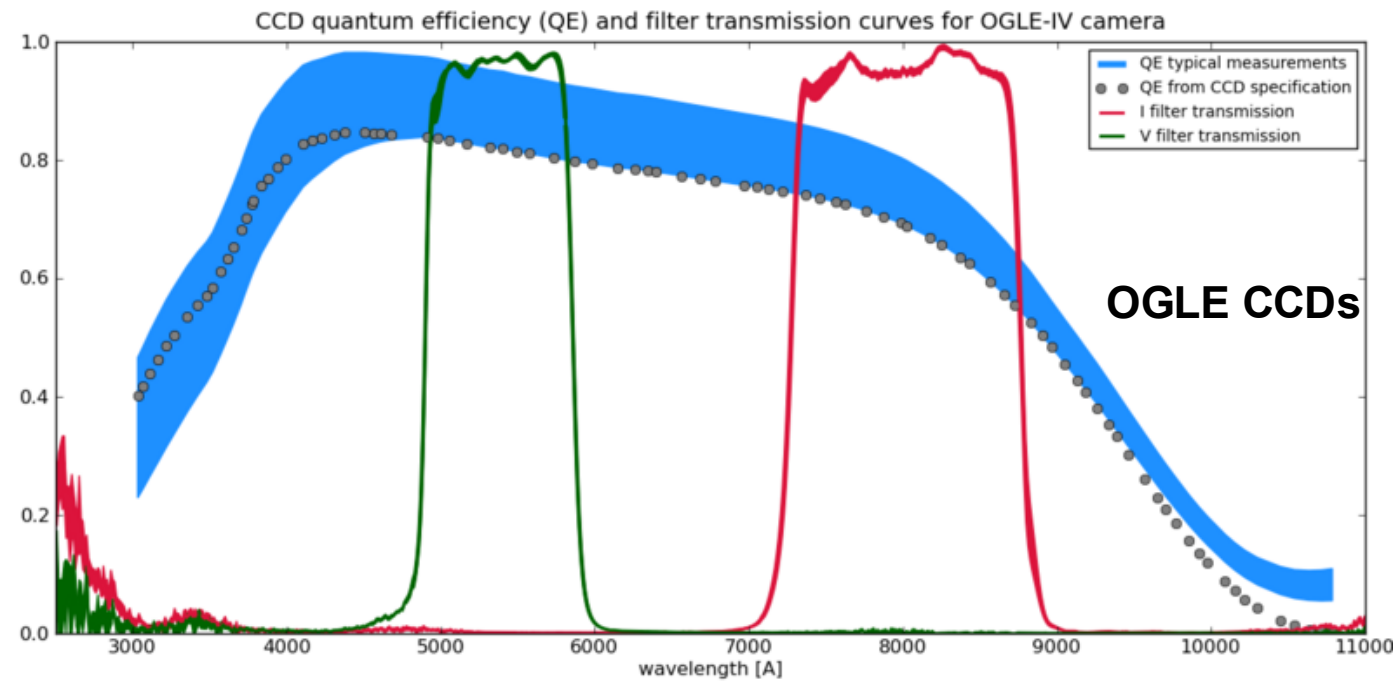
<http://ogle.astrow.edu.pl>



Mosaic Camera – 32 CCDs

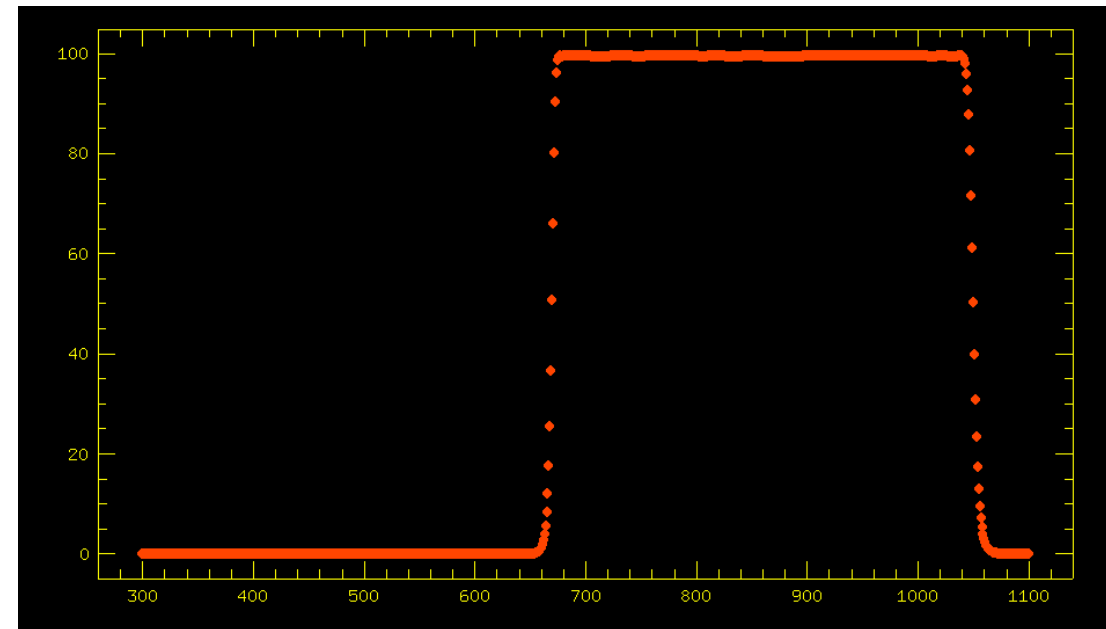


OGLE Filters



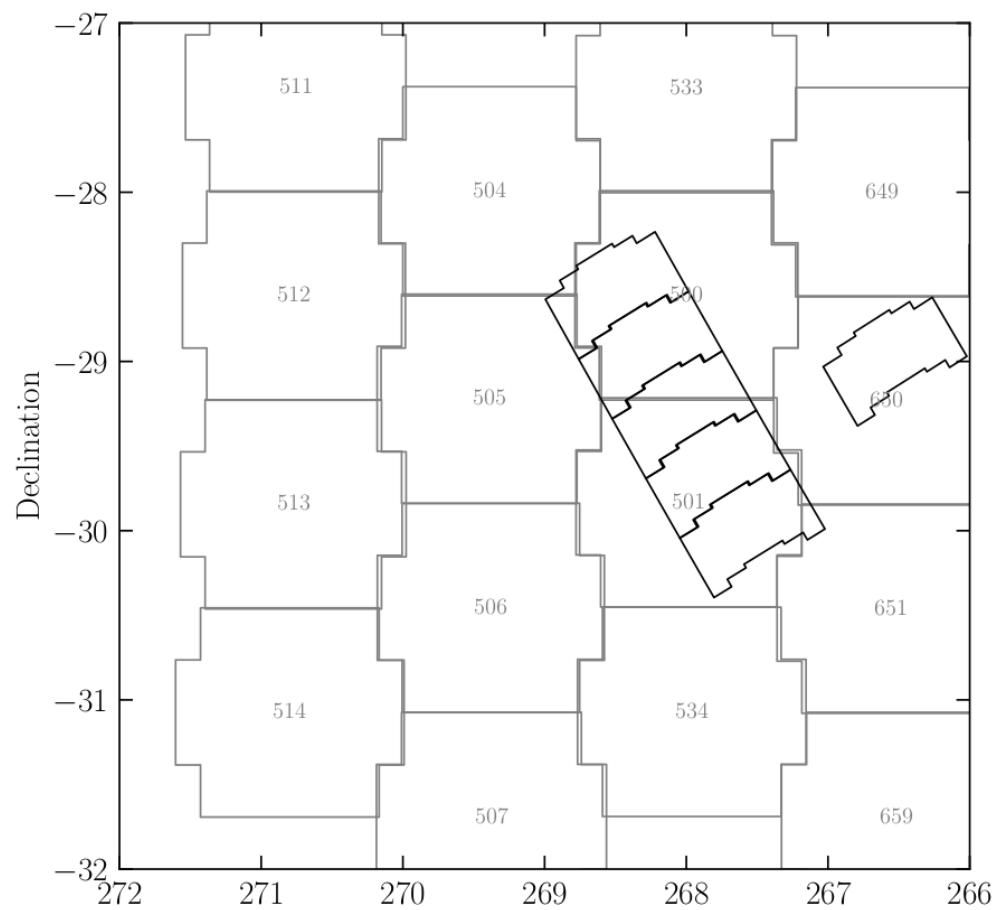
V-band

I-band

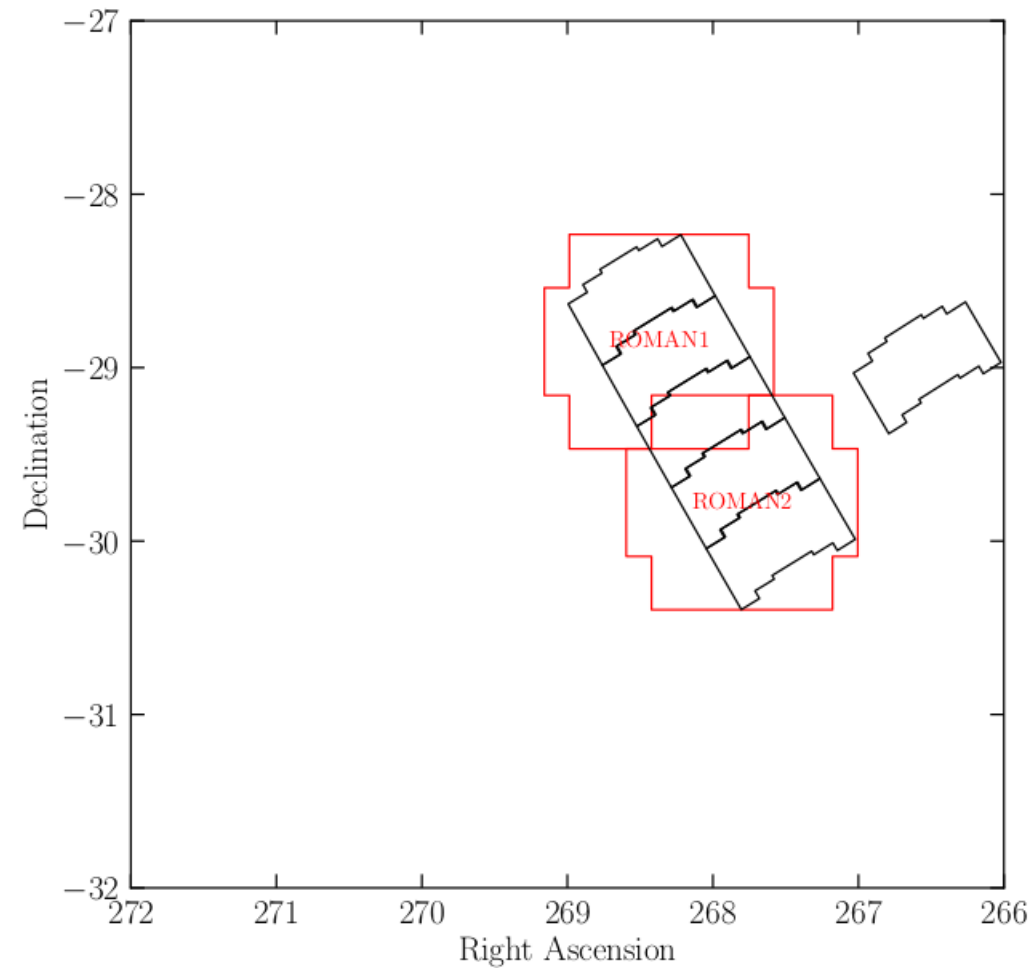


New R_{wide} filter for *ROMAN*

OGLE Fields and Roman

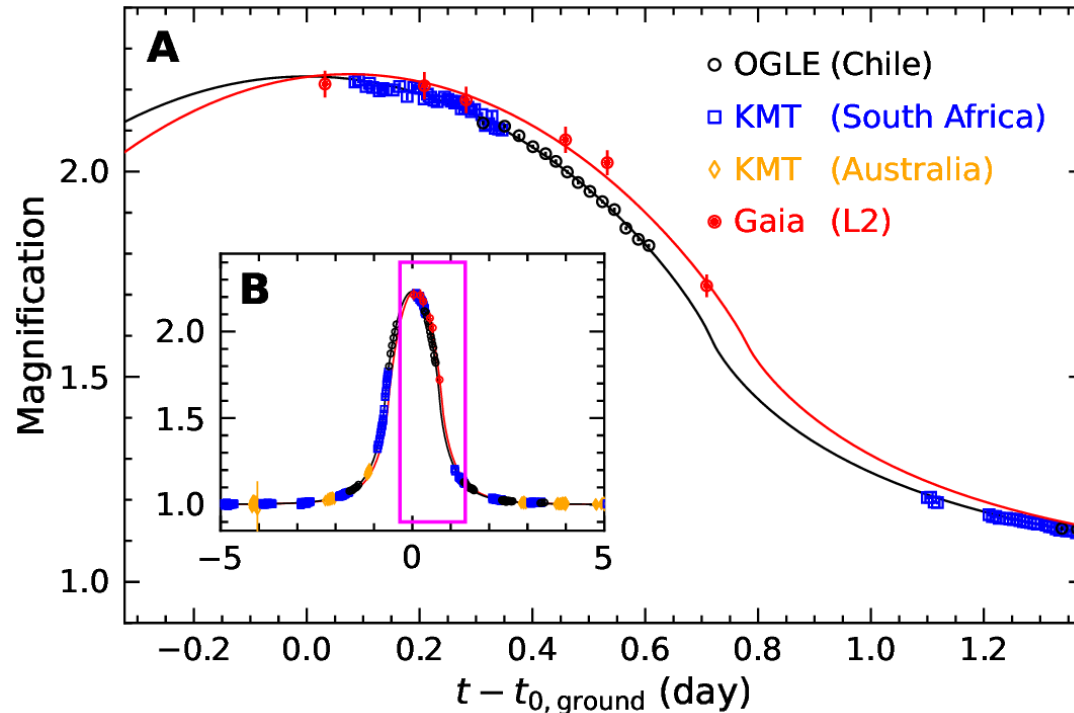


Roman fields on current OGLE fields



Two new OGLE dedicated *ROMAN* fields

Breakthrough – the First Detection of **True FFP**: Direct Mass Measurement with Microlensing



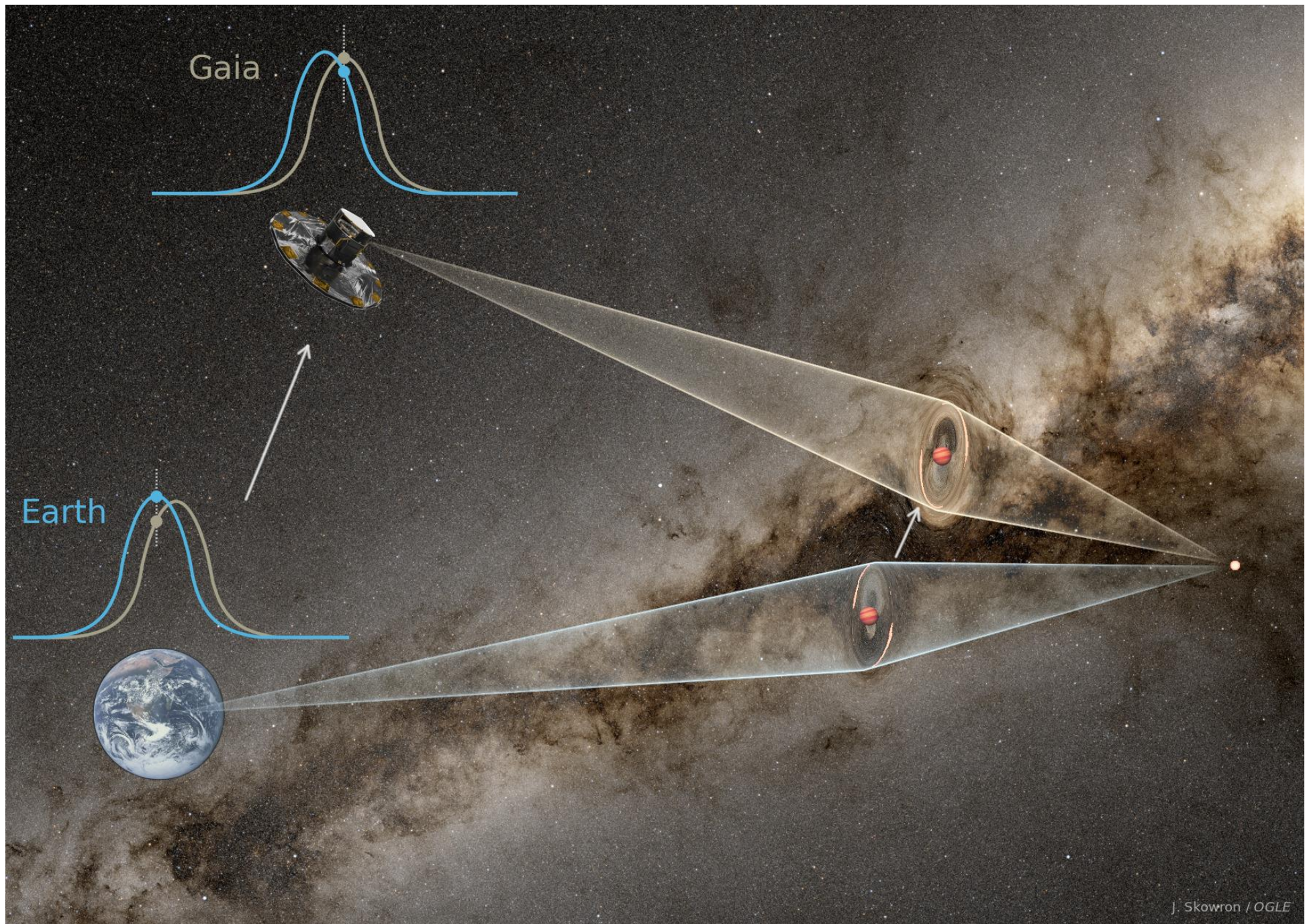
Dong, Wu, Ryu, Udalski, Mróz, *et al.* (2026), **Science** 391, 96

**KMT-2024-BLG-0792/
OGLE-2024-BLG-0516:**

**The first FFP event with
a measured mass thanks to
concurrent Gaia observations
(~70 Earth masses)**

First TRUE Free-Floating Planet

OGLE is waiting for similar events observed from the ground and by the ROMAN mission



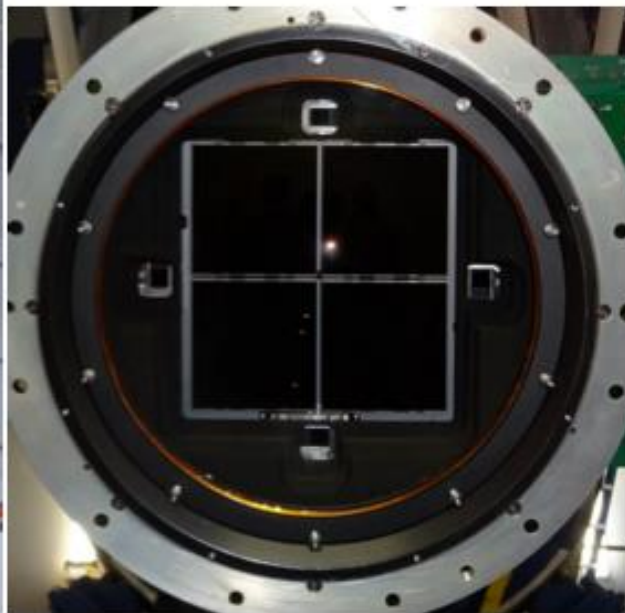
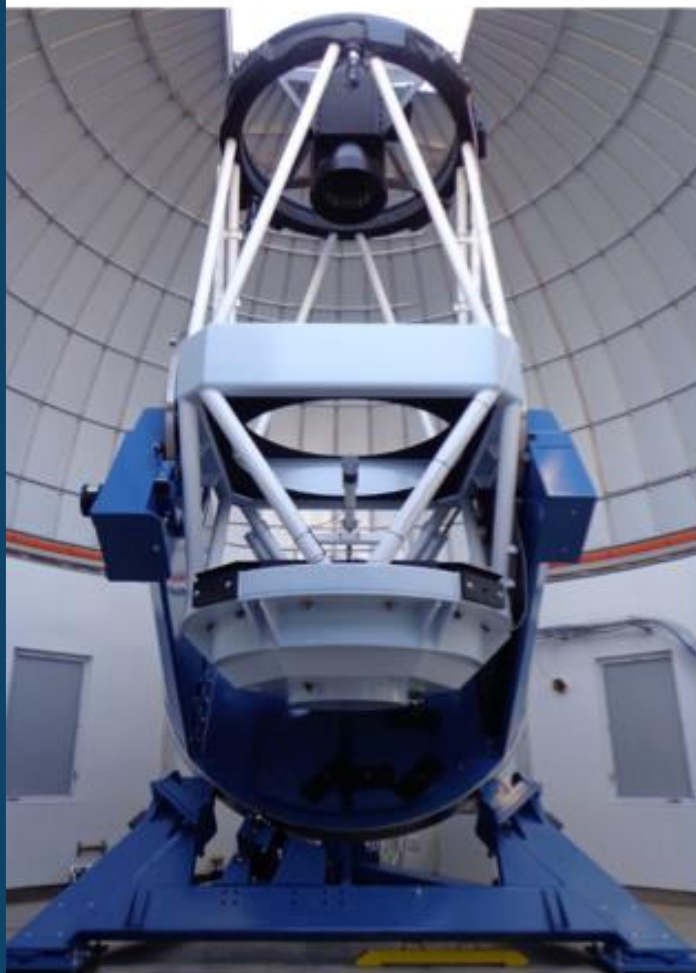
Korea Microlensing Telescope Network (KMTNet)



1.6m

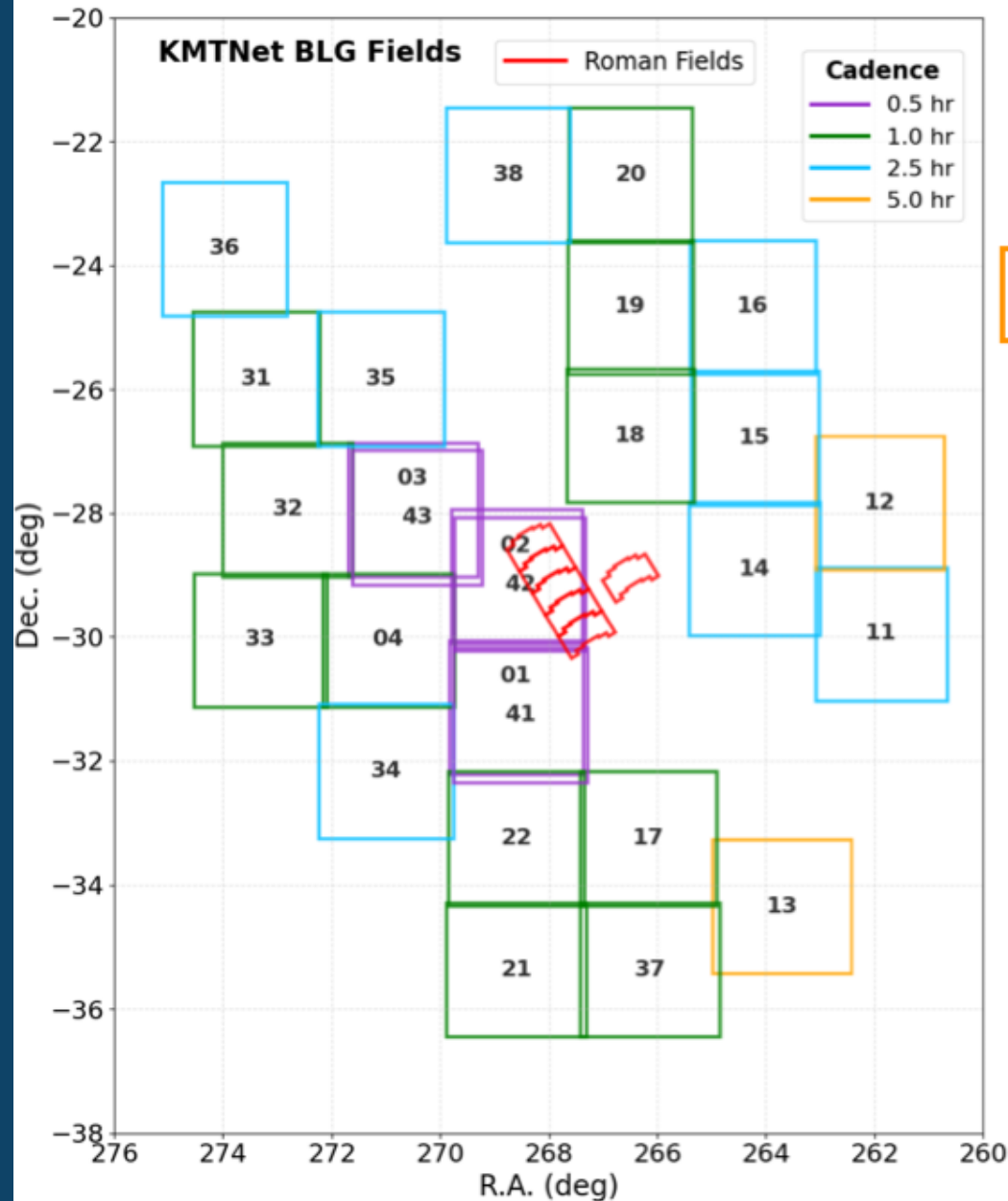


KMTNet System



Parameter	Value
Diameter	1.6m x 3
Camera	(18k x 18k) 340M pixels
Pixel size	0.4 arcsec
FoV	4 deg ²
Filter	I-/V- band (10:1)
Exposure time	60s(I)/90s(V)
Quantum efficiency	~80% in I ~85% in V

KMTNet + Roman Fields



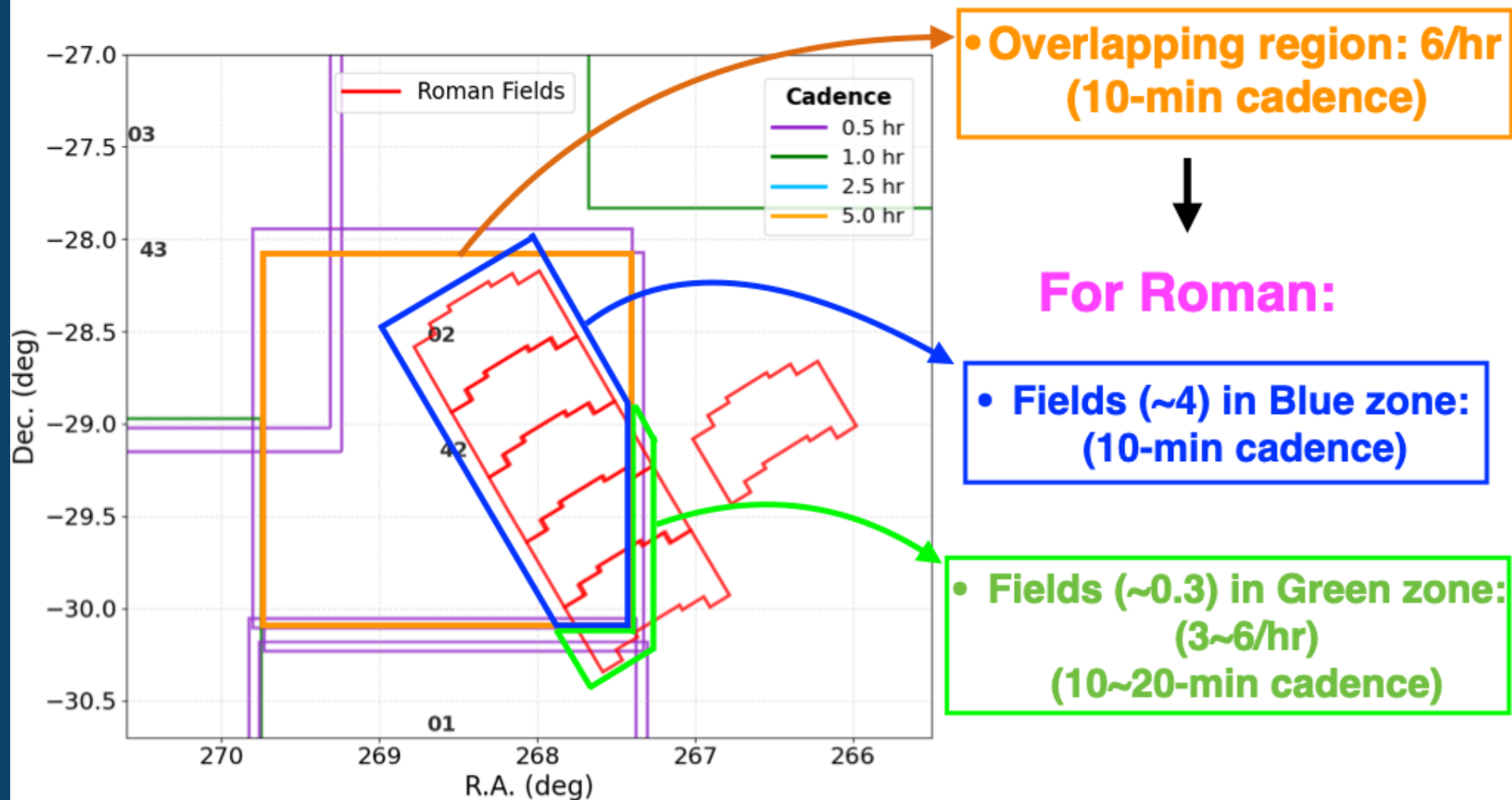
KMTNet: 27 fields (~96 deg²)

Cadence:

- Each of fields **02/42/03/43**: **3/hr**

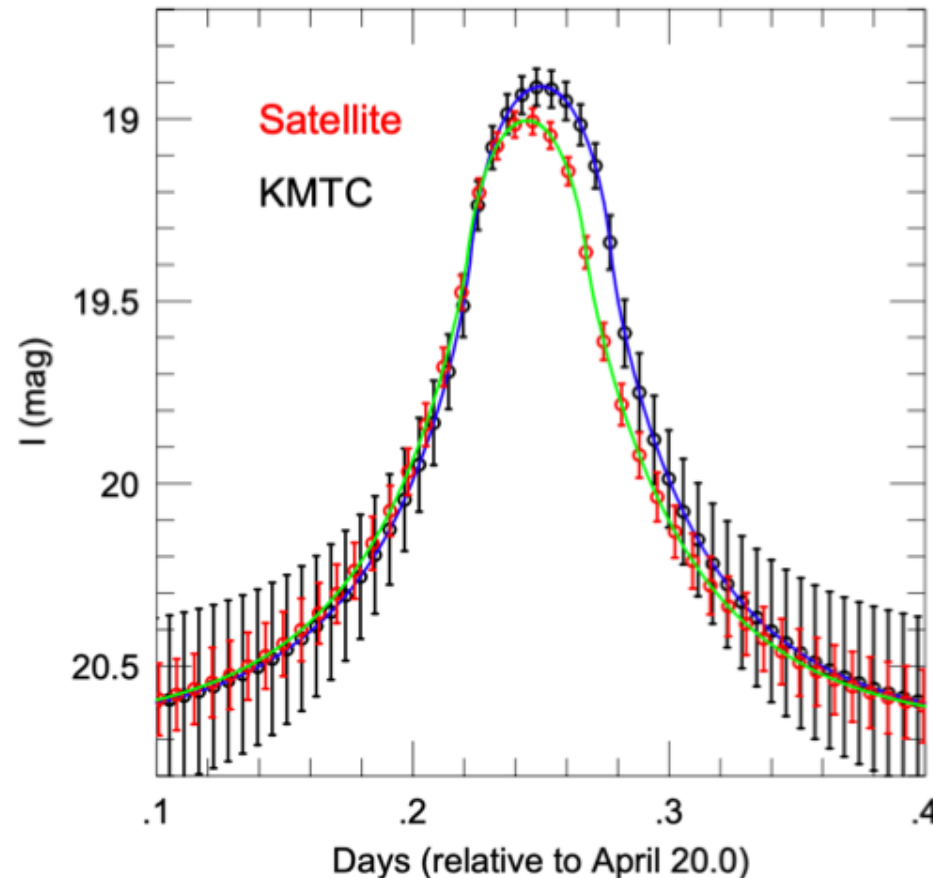
- KMT fields 02/42 cover ~4 Roman fields**

KMTNet + Roman Fields



Advantage 1

- For some bright Roman events
⇒ very helpful for **measuring their parallax** thanks to **better coverage** than other ground-based observatories



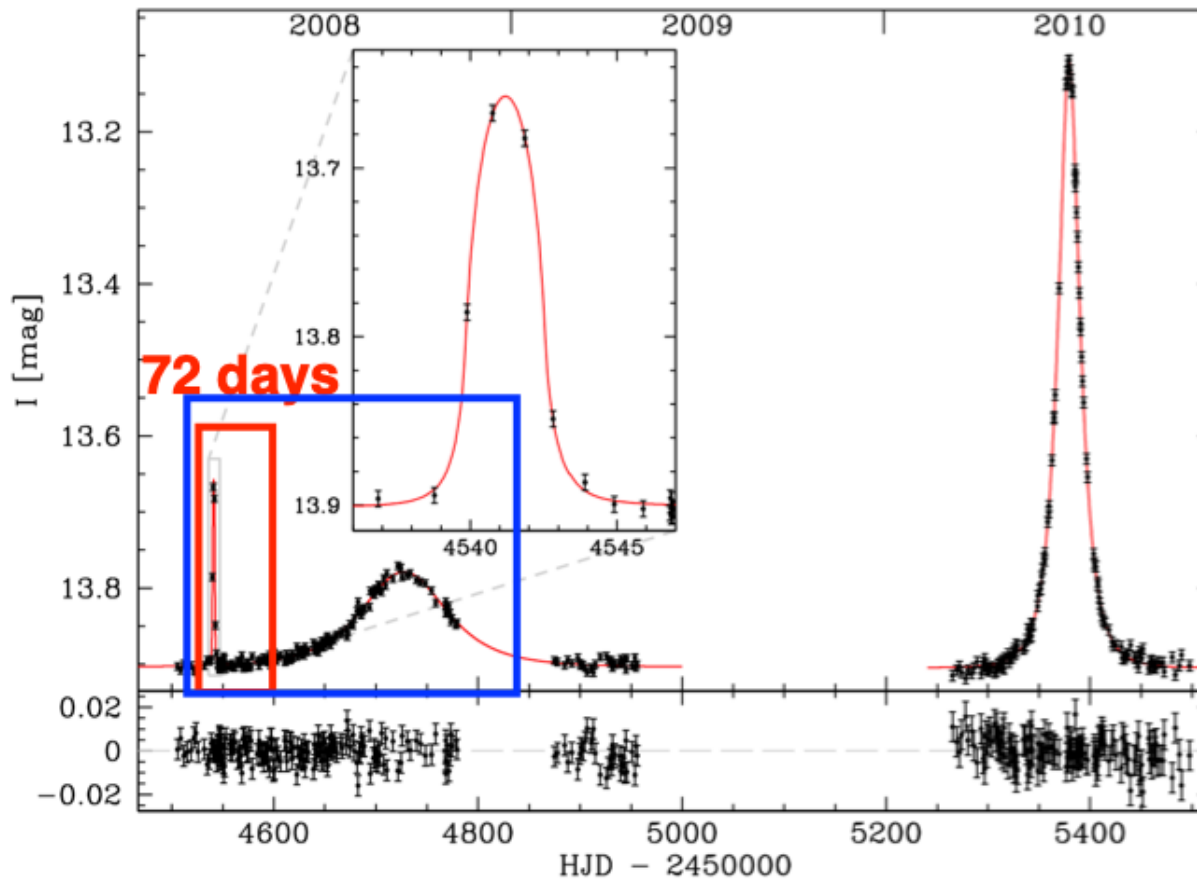
~ 4 Roman fields:
10-min cadence

Gould+(2021, RAA)

Advantage 2

KMTNet: Longer observing season than Roman

=> Can detect the host stars of FFPs



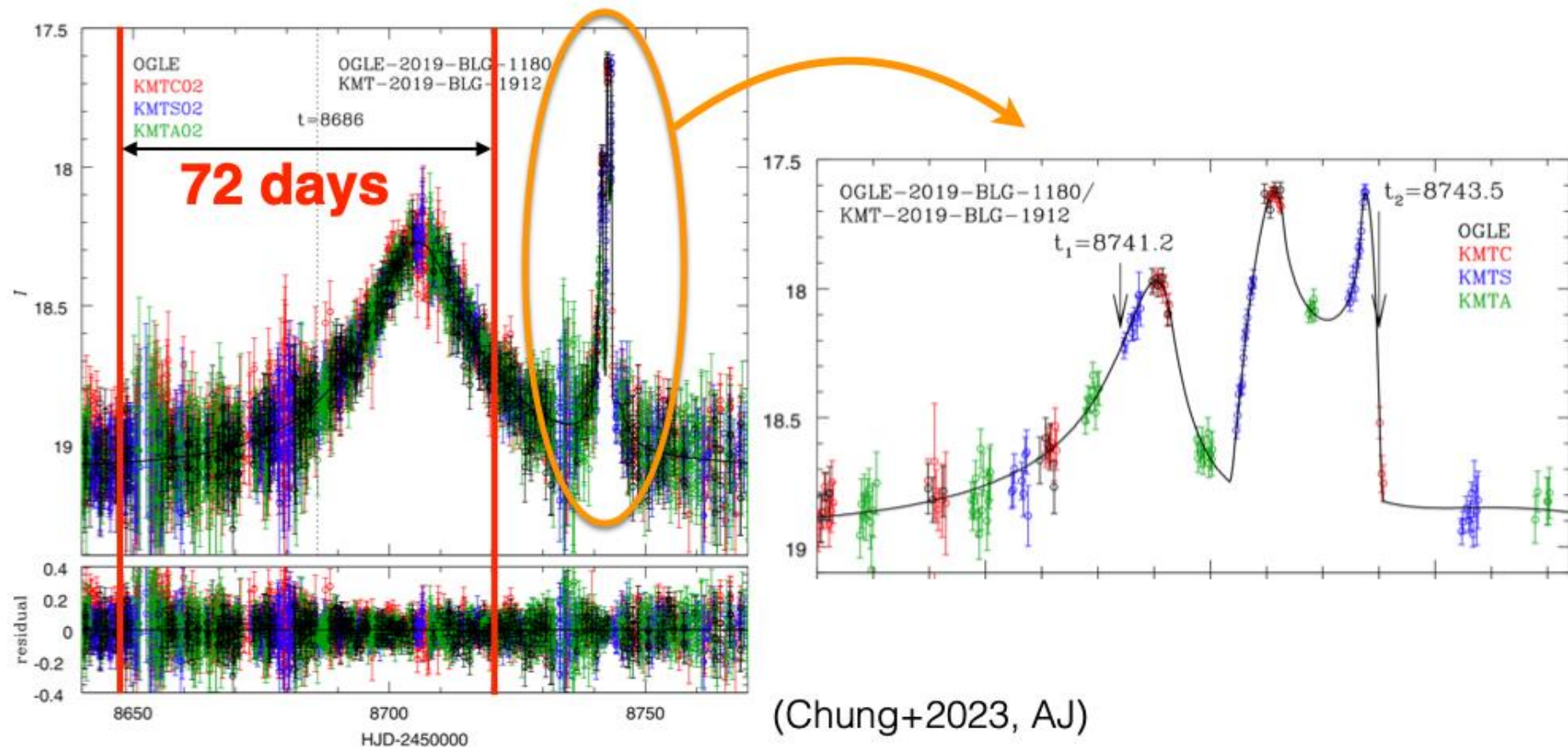
Triple Microlens OGLE-2008-BLG-092L: Binary Stellar System with a Circumprimary Uranus-type Planet

(Poleski+2014, ApJ)

Advantage 3

KMTNet: Longer observing season than Roman

=> Can detect planets in Roman-discovered events by providing coverage before or after Roman's observations



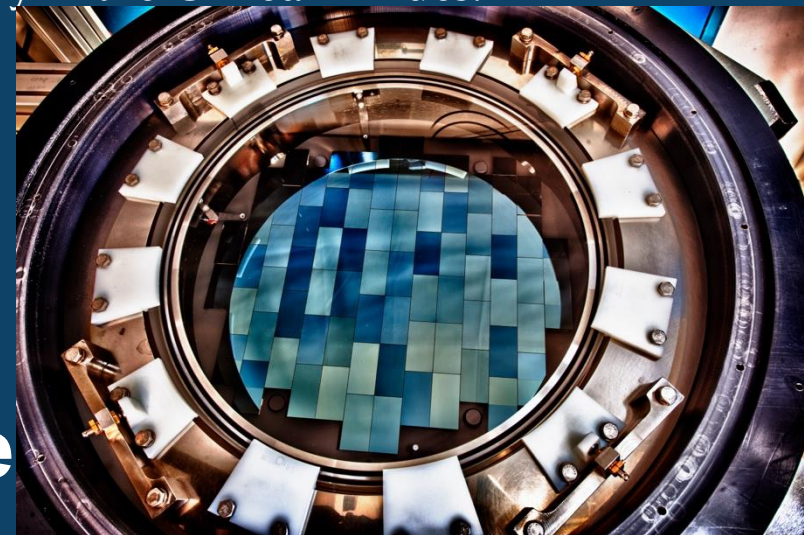
DECam Rogue Earths And Mars Survey (DREAMS)

Weicheng ZANG

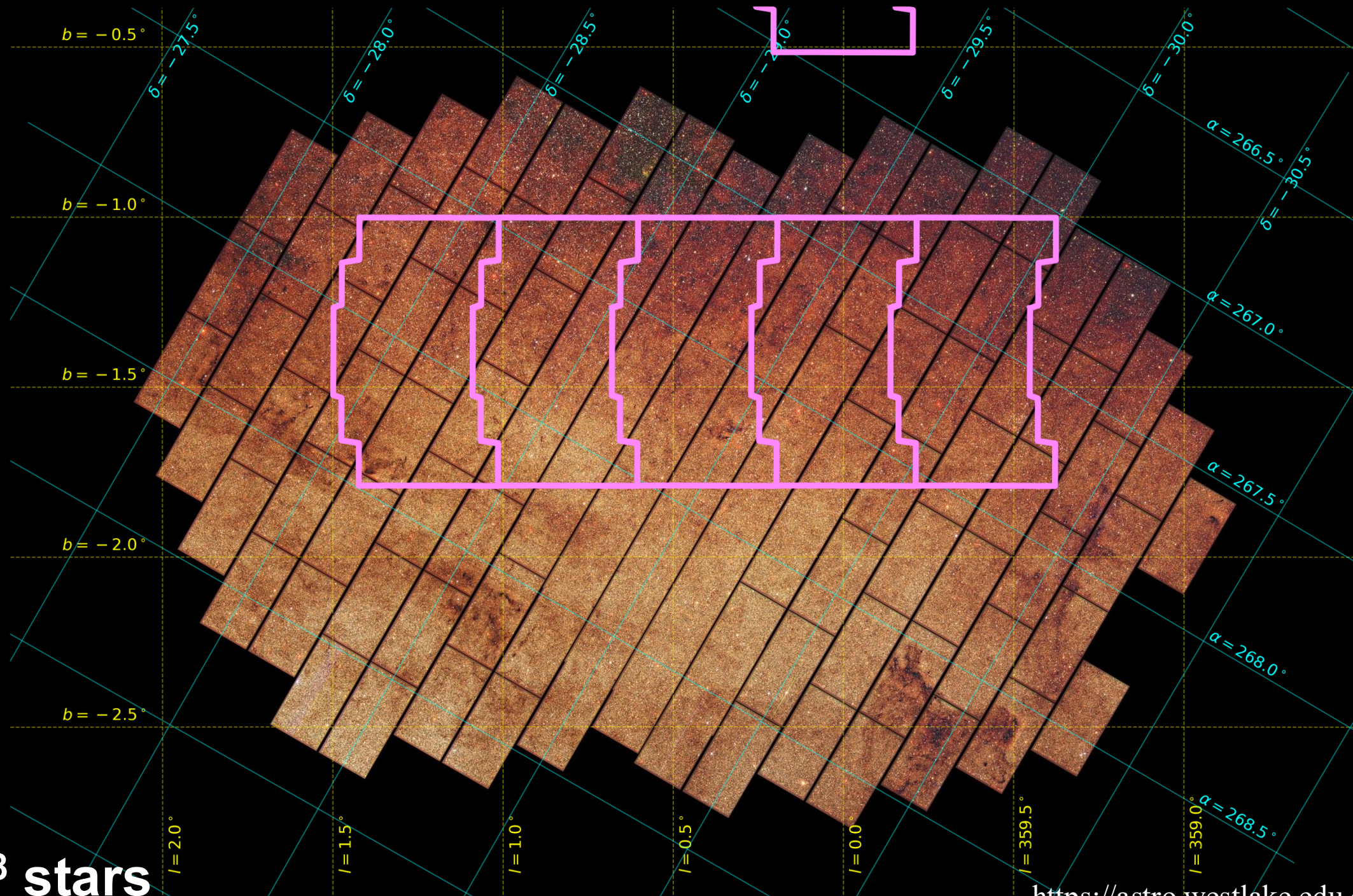
- NOIRLab Survey Program (2025-2028, ~80 nights)
- **PIs: Weicheng Zang & Hongjing Yang**
- Survey Area: 5 deg²
- **72s/frame** (90 seconds w/ overhead)
- z (80%) & r (20%) band
- Supplements from CFHT/Subaru
- **Roman precursor with 10 times cadence**
Yang, Zang et al. 2026a,b



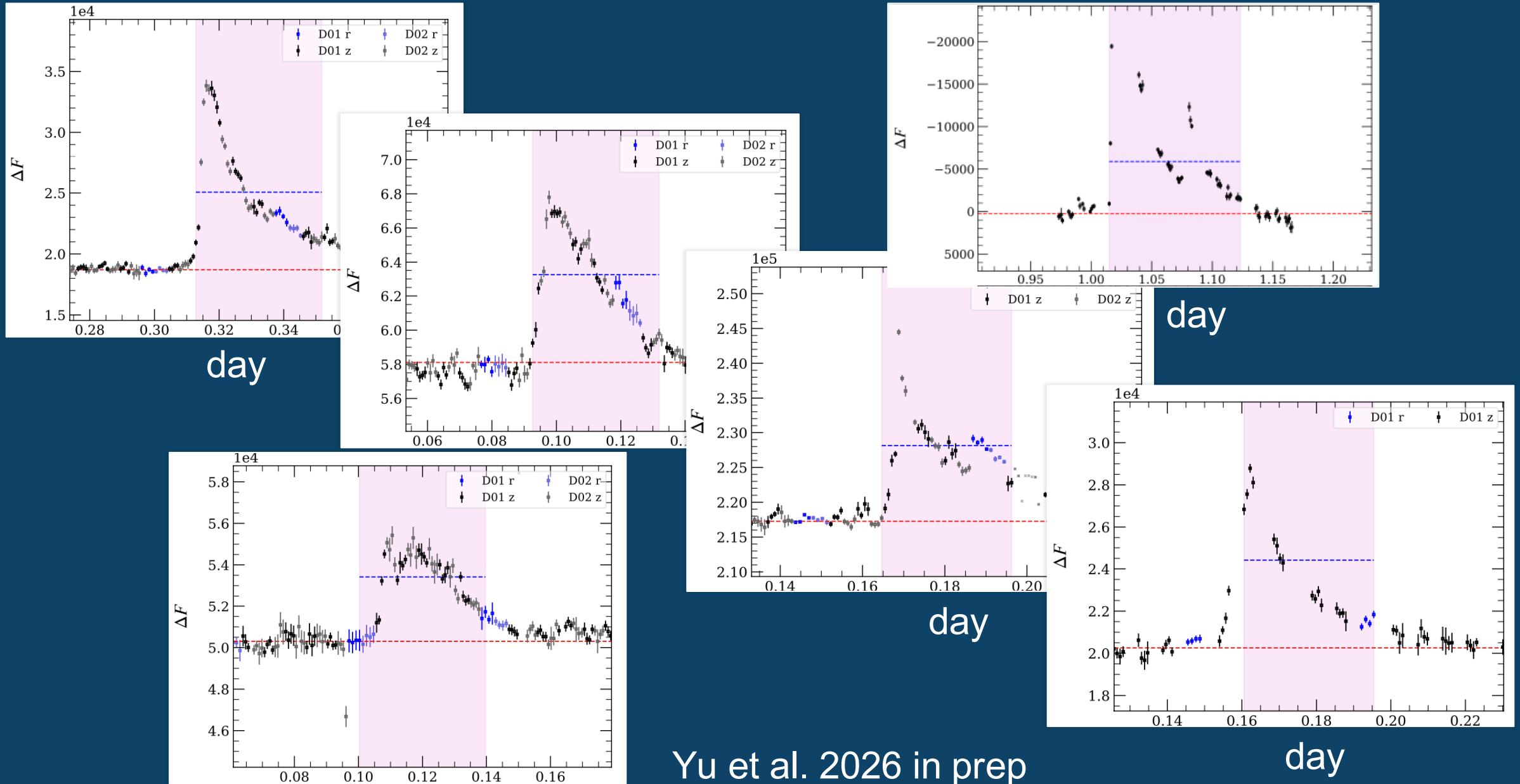
570-megapixel, high-performance digital camera mounted on the Víctor M. Blanco 4-meter Telescope at the Cerro Tololo Inter-American Observatory in the Chilean Andes.



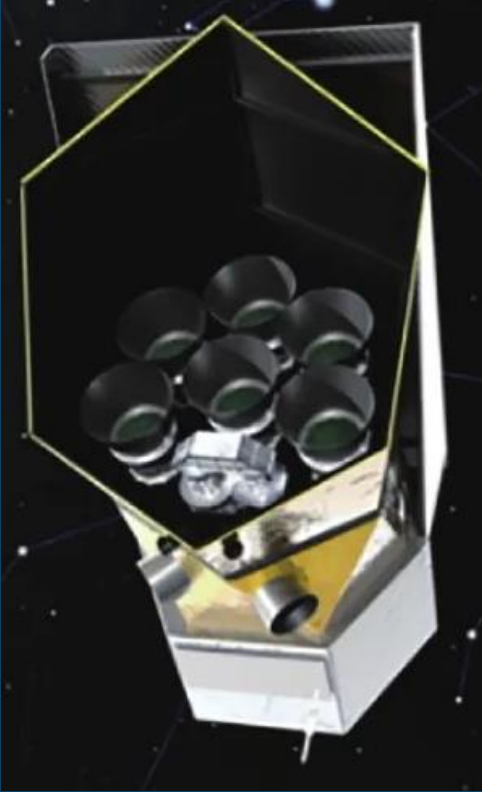
$\sim 10^8$ stars



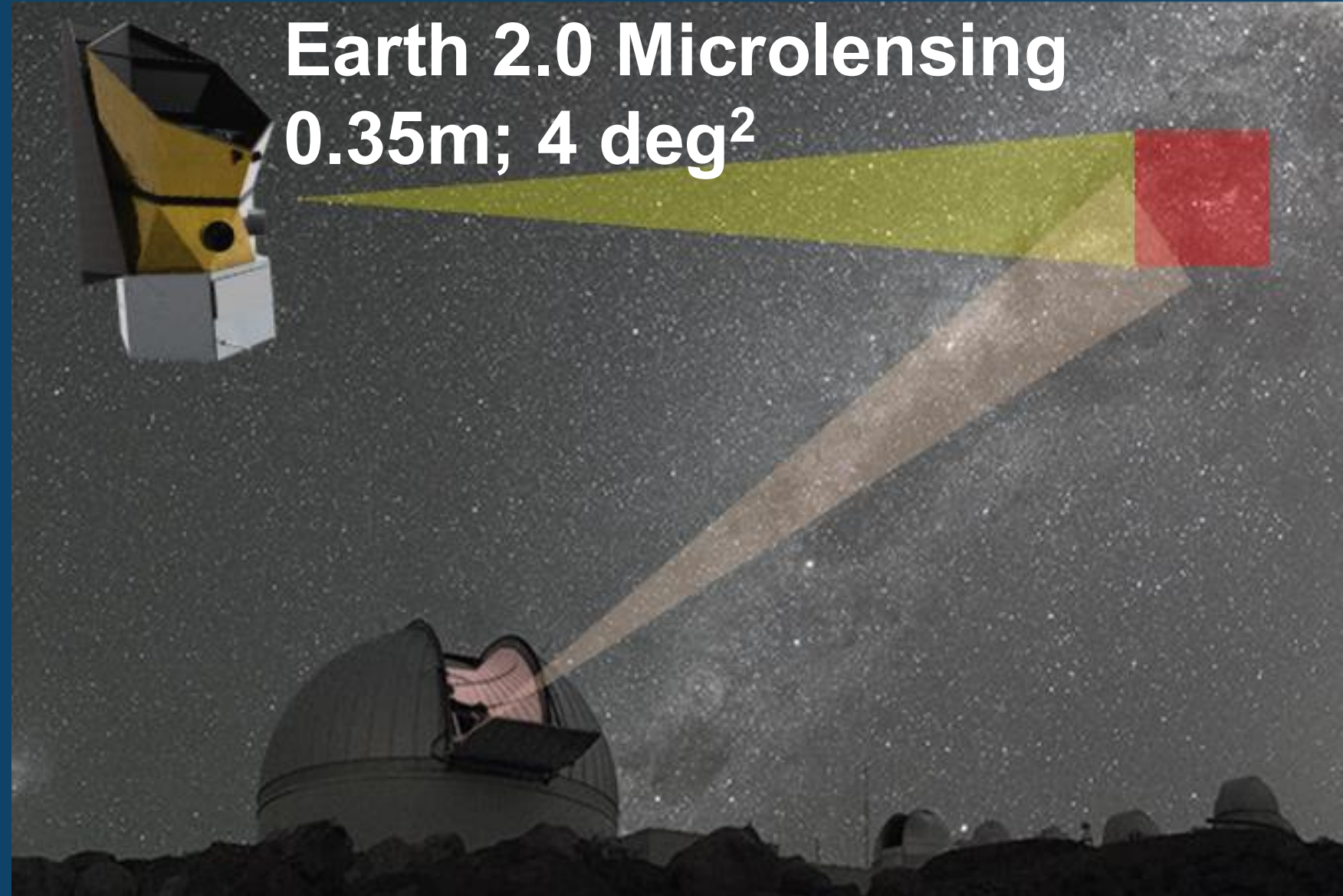
Stellar Flare is >100 times More Common than FFPs



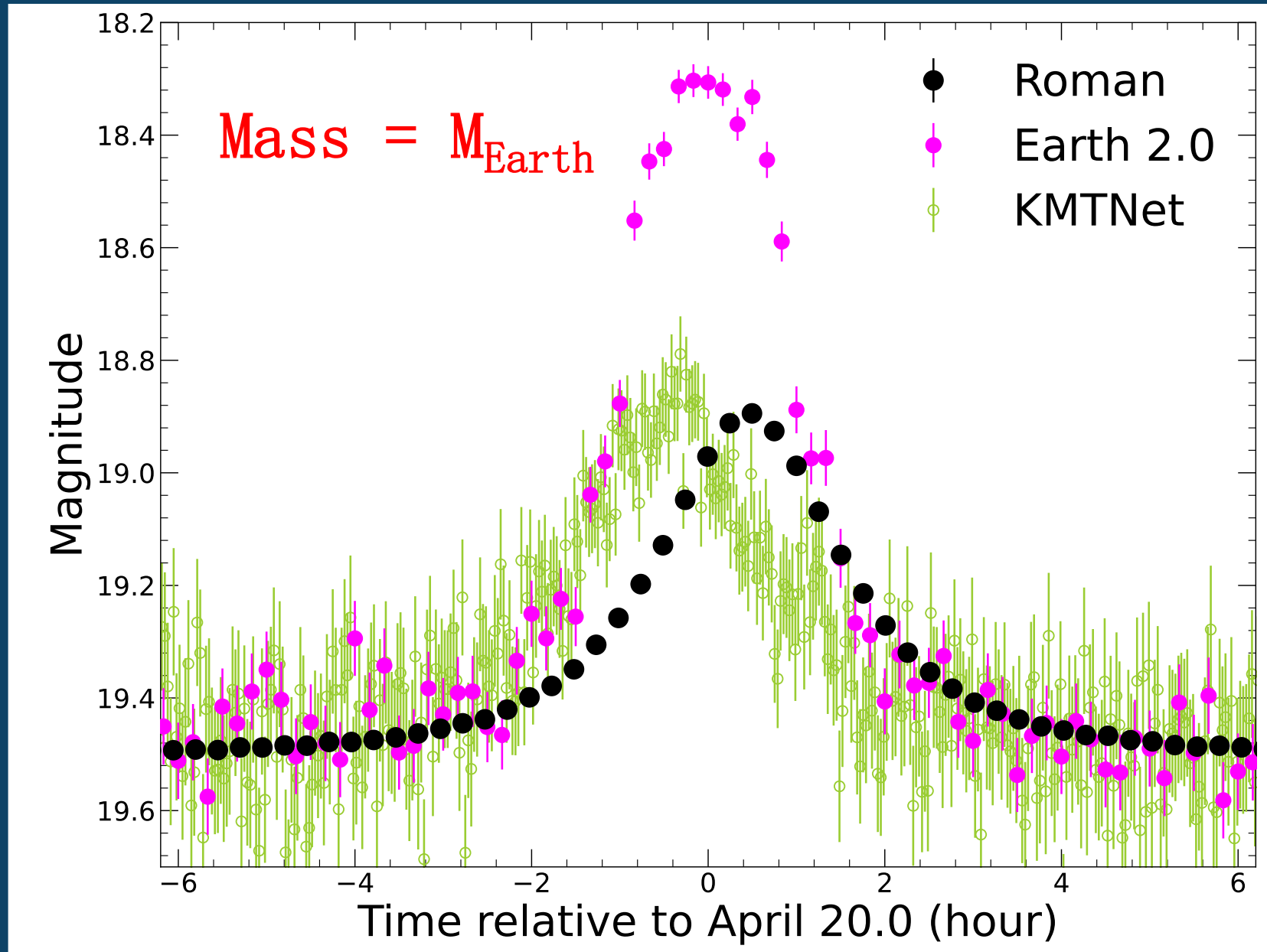
The Earth 2.0 Space Satellite (L2, 2028)



Microlensing Pls:
Weicheng Zang
Hongjing Yang



Roman + Earth 2.0 + KMTNet



Rubin's Legacy Survey of Space and Time (LSST)

Rachel Street

Timeseries ugrizy imaging of the whole Southern sky for 10yrs, starting ~fall 2025
Rapid discovery alerts

Limiting magnitudes in 30s:

u : 23.9	g : 25.0
r : 24.7	i : 24.0
z : 23.3	y : 22.1

[Ivezić, Z., et al., 2019, ApJ,
873, id.111]

8.4-meter diameter

LSSTCam: Largest digital camera

189 4k x 4k CCDs $\rightarrow$ 3200 Mpix

0.2 arcsec/pixel

SDSS-u,g,r,i,z,y filters

Field of view = 9.6 sq.deg.

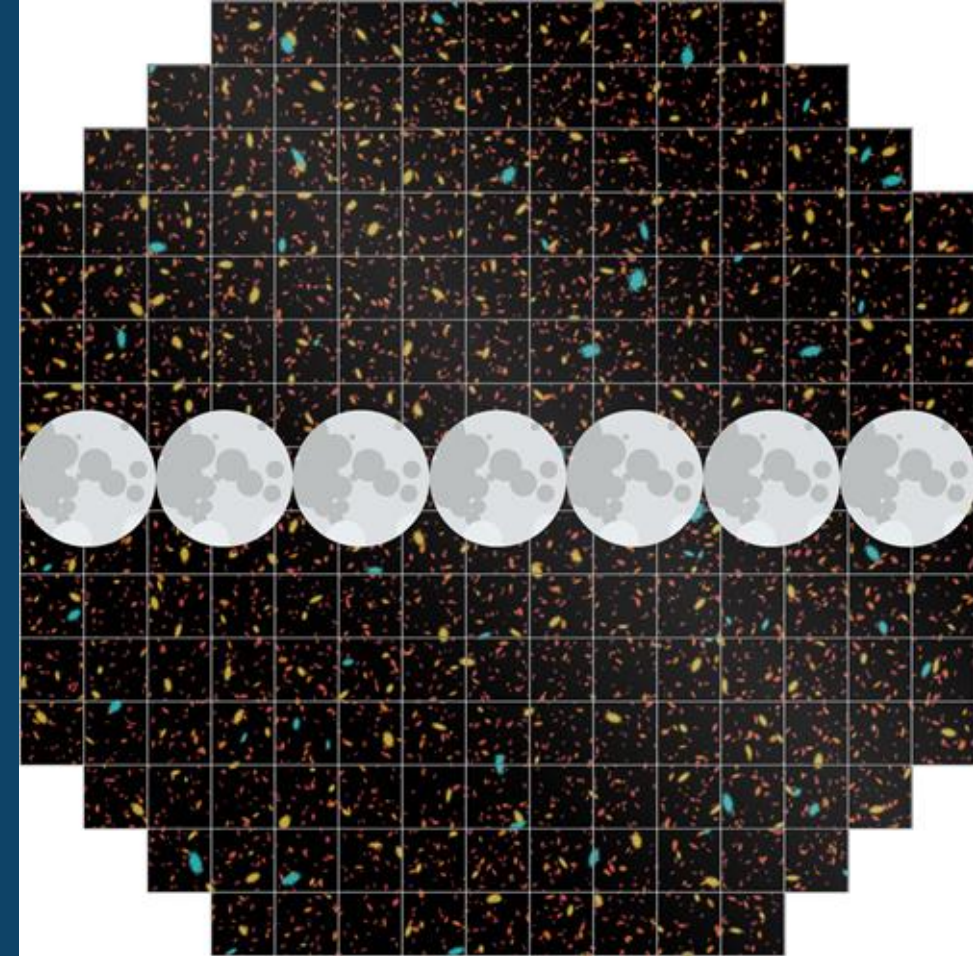
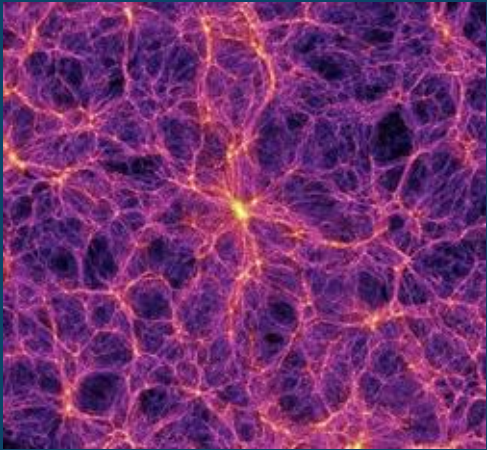


Image credits: Rubin Observatory/NSF/AURA/J. Pi, Jacqueline Ramseyer Orrell/SLAC

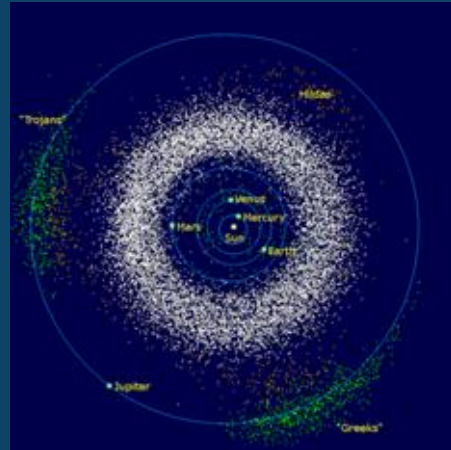
- 20 billion galaxies
- 17 billion stars
- 10 million supernovae
- 6 million Solar System objects



Rubin's Science Pillars



Dark Matter and
Dark Energy



Catalog the
Solar System



Explore the
changing sky

Transient &
variables



Milky Way
structure and
formation

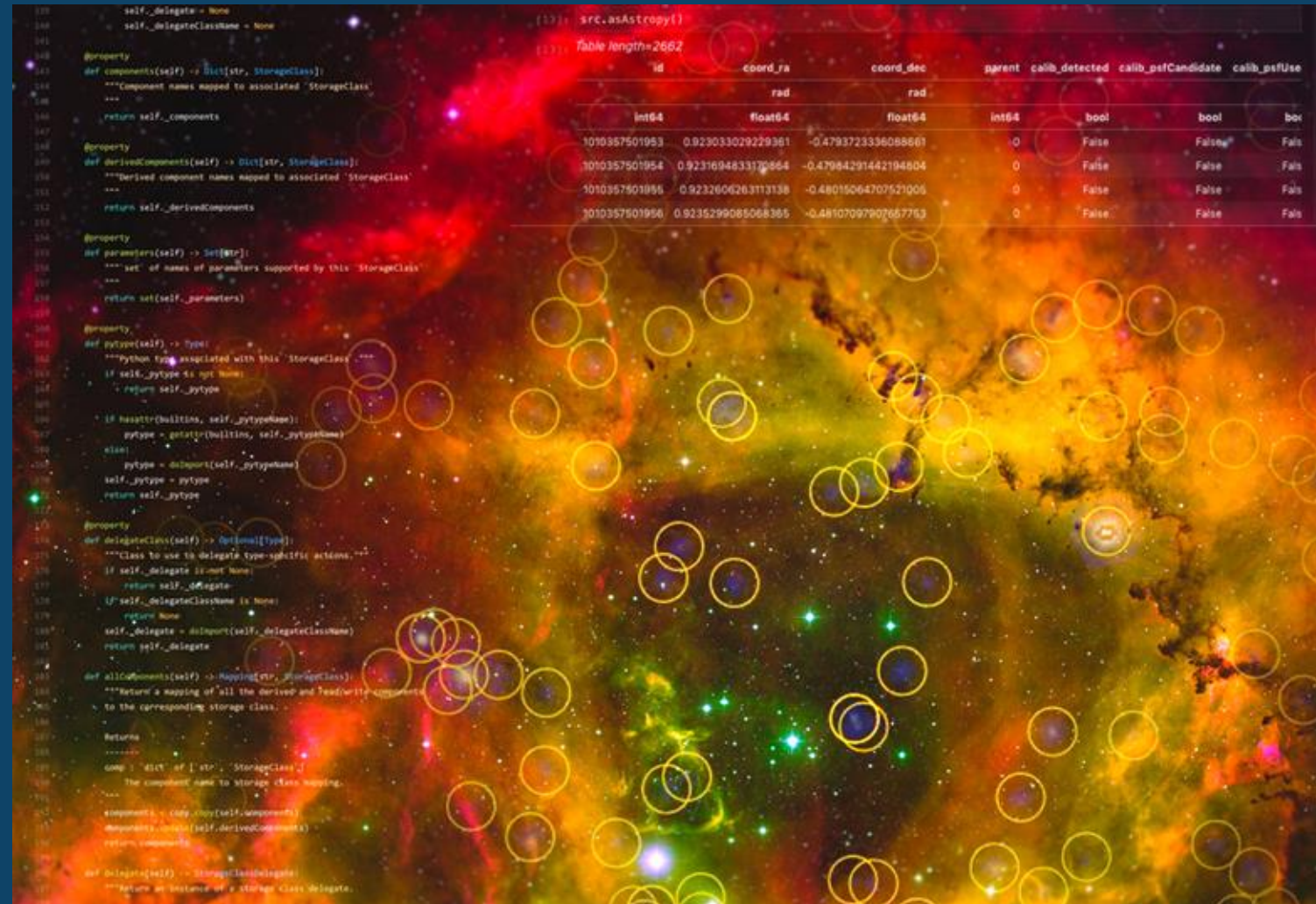
State of the art rapid data processing

Data per night 20 terabytes

Alerts per night ~10 million

Total raw image data in 10yrs 60 petabytes

- analyse every frame in real-time
- automatically issue alerts of new discoveries within 60s



Credit: RubinObs/NOIRLab/NSF/AURA/T.A. Rector (University of Alaska Anchorage)/H.

LSST's Galactic Plane Survey

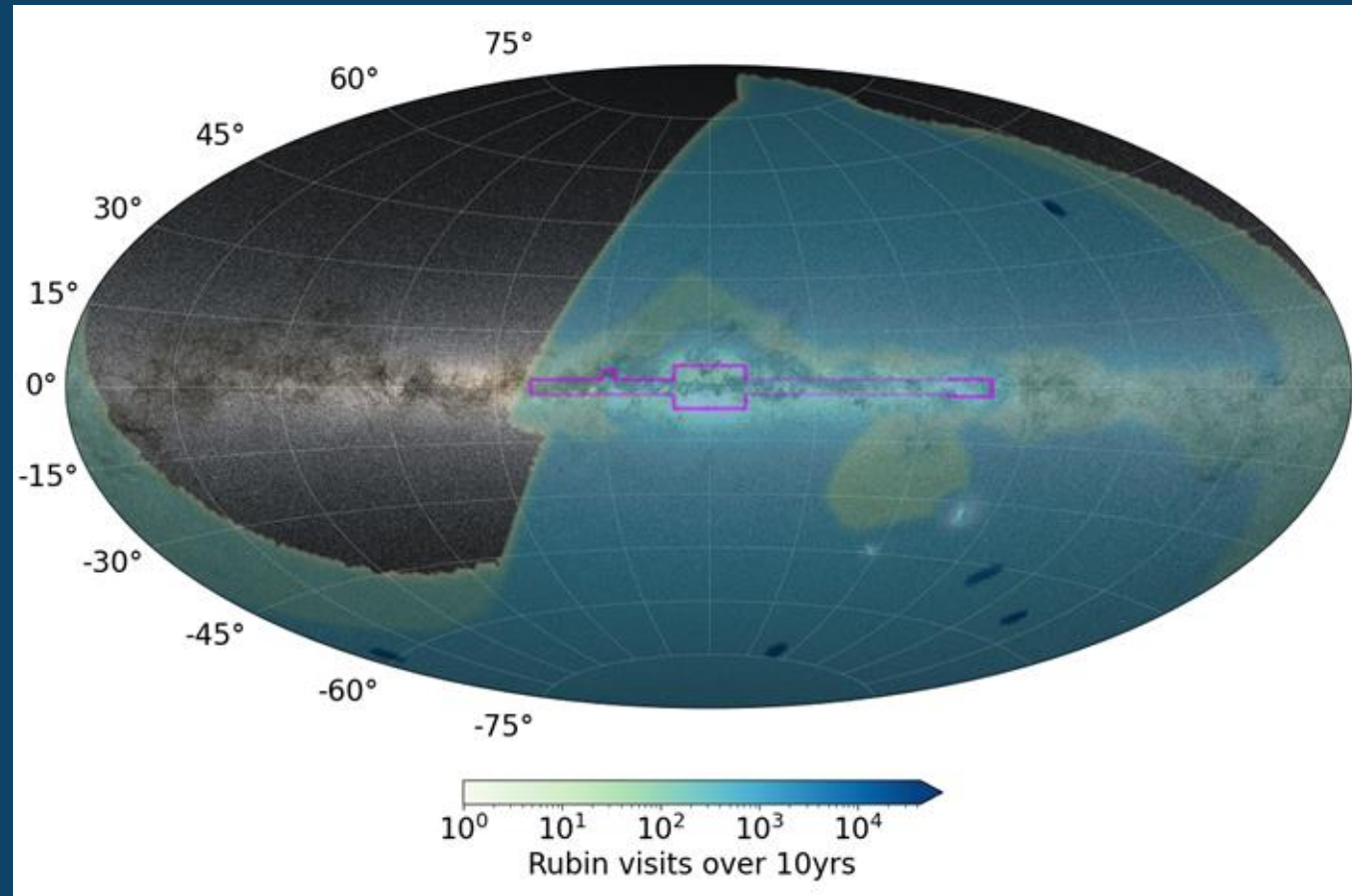
Footprint covers bulge and central plane with higher cadence

Filter balance emphasizes griz

Regular cadence (every few days) for 10yrs

[Street et al. 2023, ApJSS, 267, 15]

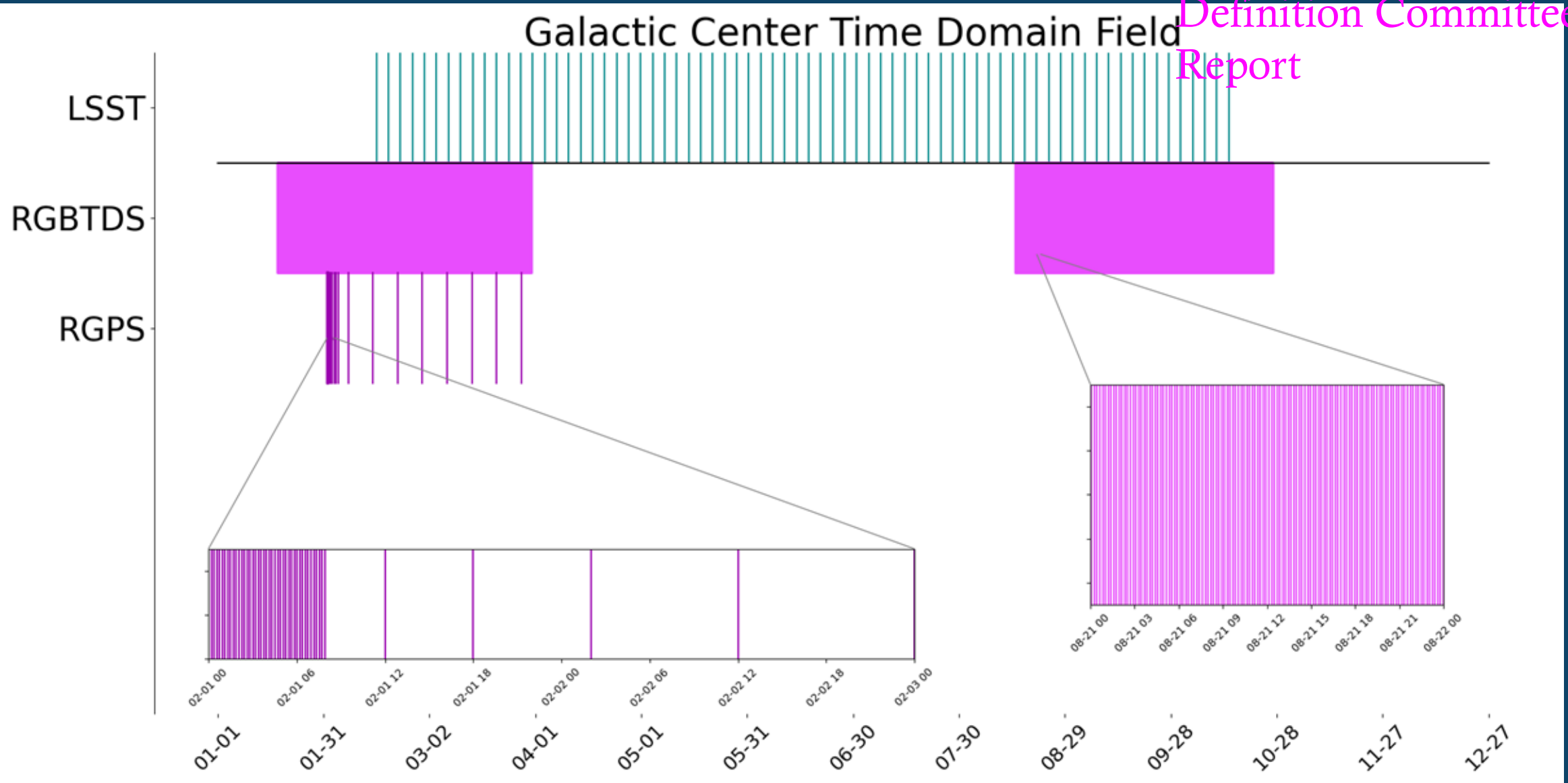
[Abrams et al. 2025, ApJS, 276, 10]



Rubin visits over 10yrs (teal shading)
Roman Galactic plane survey in purple outline

Observing seasons of Rubin and Roman

From the Roman
Galactic Plane Survey
Definition Committee
Report



Summary

- Various surveys (MOA, PRIME, Subaru, OGLE, KMTNet, DECam, EARTH2.0, LSST) are planning to conduct concurrent observation with Roman
- Space-based parallax to measure lens mass.
- Extending coverage to detect planet/hosts.
- Confirm the short signals.
- Remove the false positives

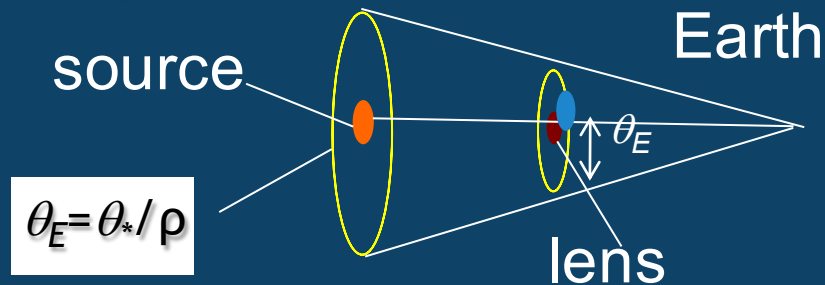
Finite Source Effects & Microlensing Parallax Yield Lens System Mass

- Finite source effects

Angular Einstein radius

θ_* = source star angular radius

D_L and D_S are the lens and source distances



$$\theta_E = \theta_* / \rho$$

Anglor R_E :

$$\theta_E = \frac{R_E}{D_L} = \sqrt{\frac{4GM}{c^2} \frac{D_S - D_L}{D_S D_L}}$$

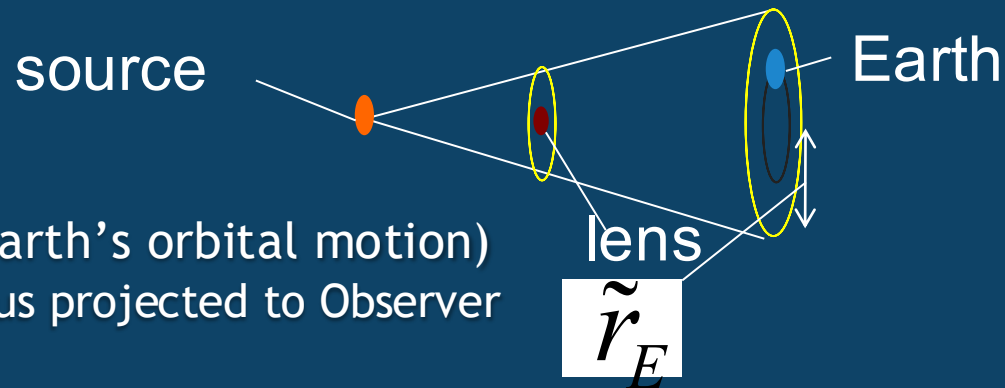


- Parallax

(Effect of Earth's orbital motion)

Einstein radius projected to Observer

OR



$$\tilde{r}_E$$

Projected R_E :

$$\tilde{r}_E = R_E \frac{D_S}{D_S - D_L} = \sqrt{\frac{4GM}{c^2} \frac{D_S D_L}{D_S - D_L}}$$

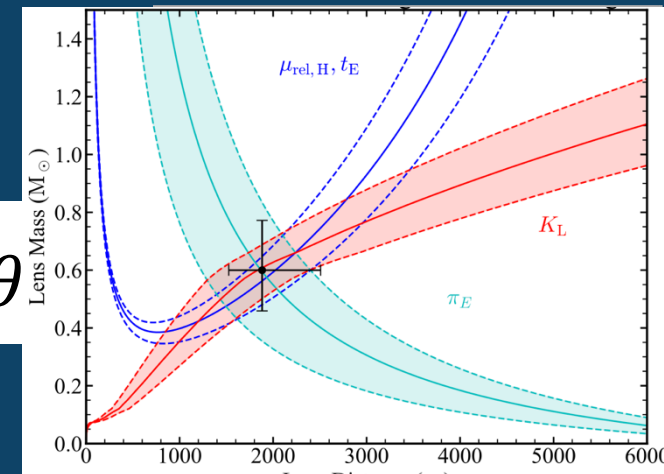
- One of above +

Lens brightness & color(AO,HST)

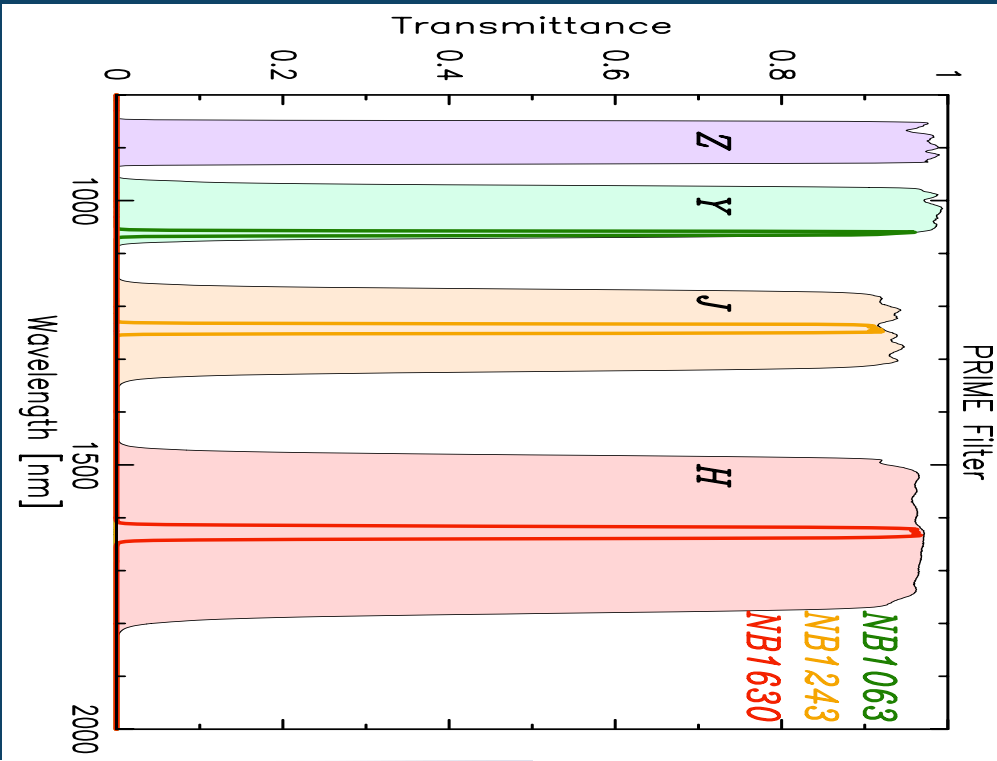
mass-luminosity relation $\rightarrow D_L$



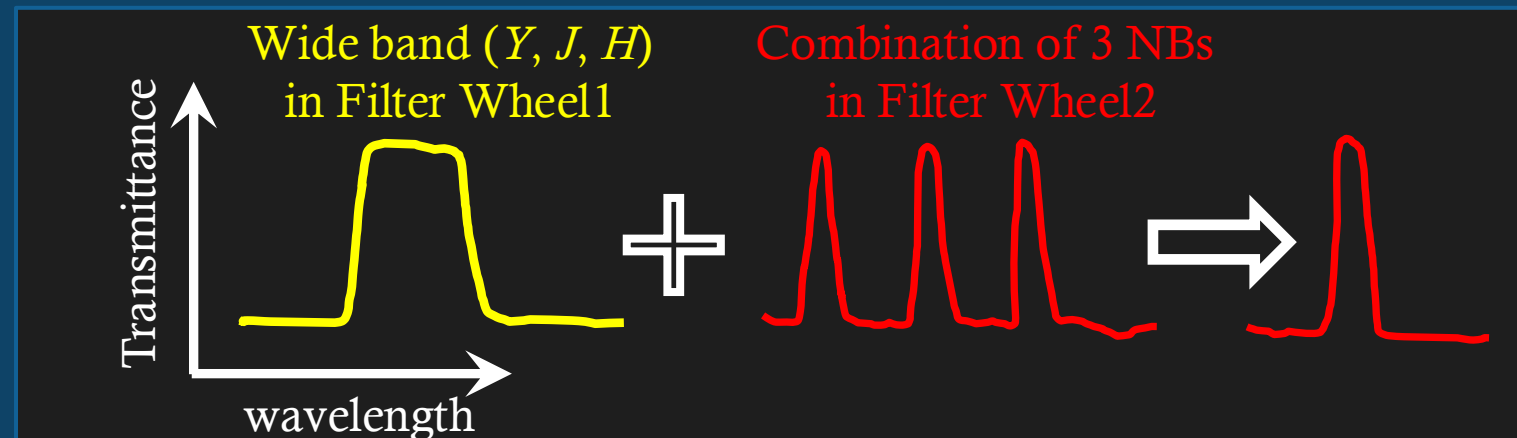
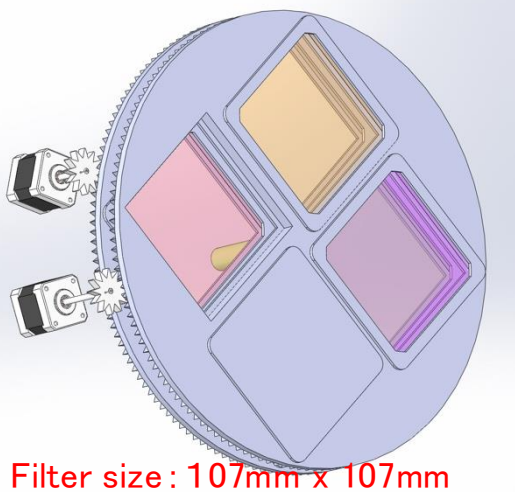
$$\text{Lens Mass: } M = \frac{c^2}{4G} \tilde{r}_E \theta$$

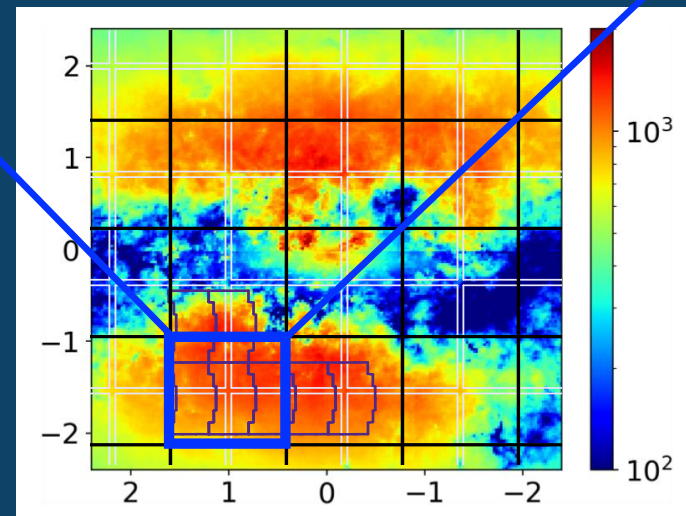
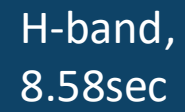


Two Cold Filter wheels

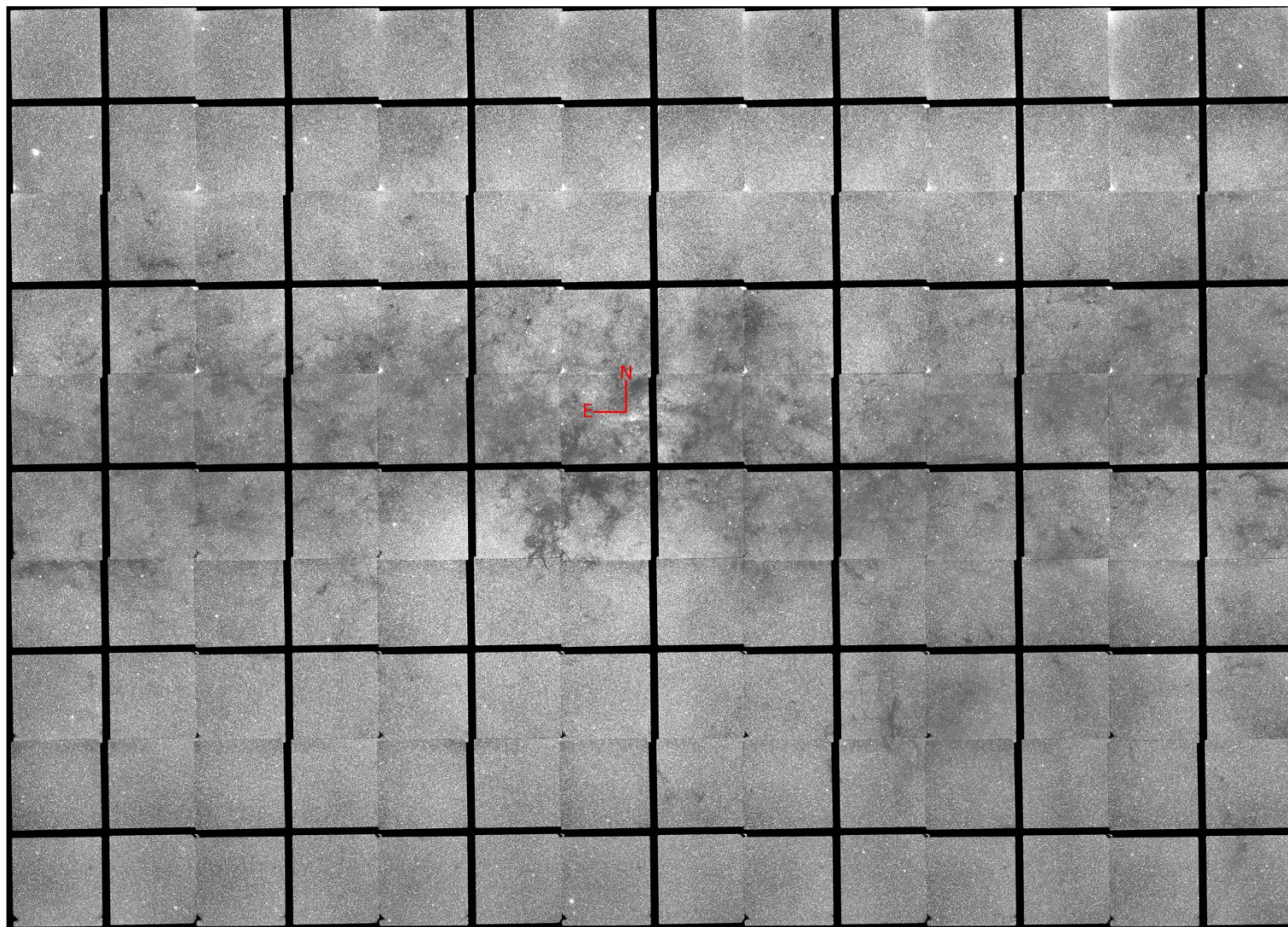


- Wheel1: blank, *Y, J, H*
 - Wheel2: blank, dark, *Z, NB*
- Limiting mag (5σ , 100sec):
Z:21.0, Y:20.1, J:19.4, H:18.5 mag
- three narrow bands in one filter:
 - 1.063 μm (Y), low OH, characterize H4RG
 - 1.243 μm (J), low OH, H_α @z=0.9, $[\text{OIII}]$ @z=1.5
 - 1.630 μm (H), low OH, H_α @z=1.5
 - Select NB by combining with a wide band filter [*Y, J, H*]

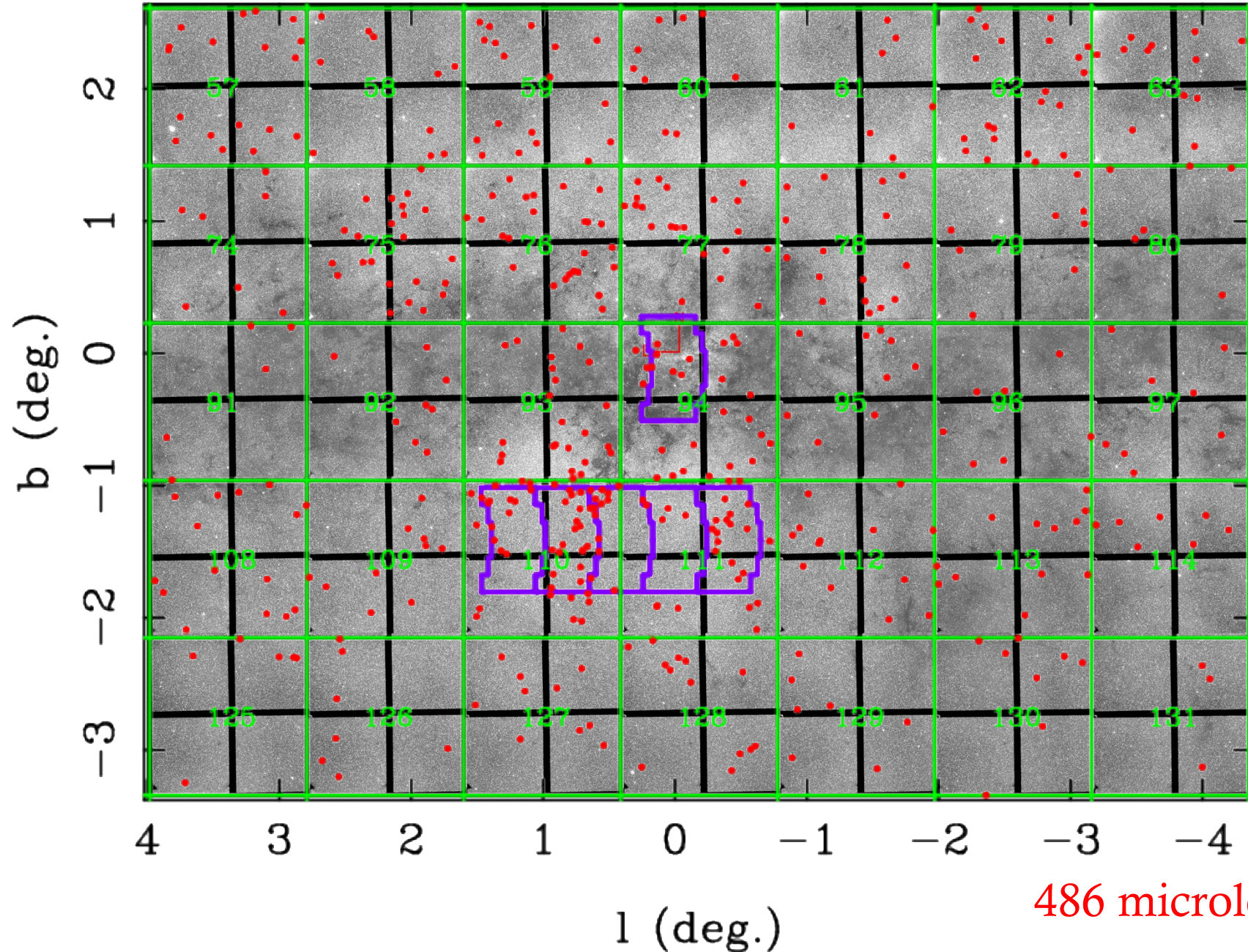




PRIME GB candidates in Feb/2024–June/2025

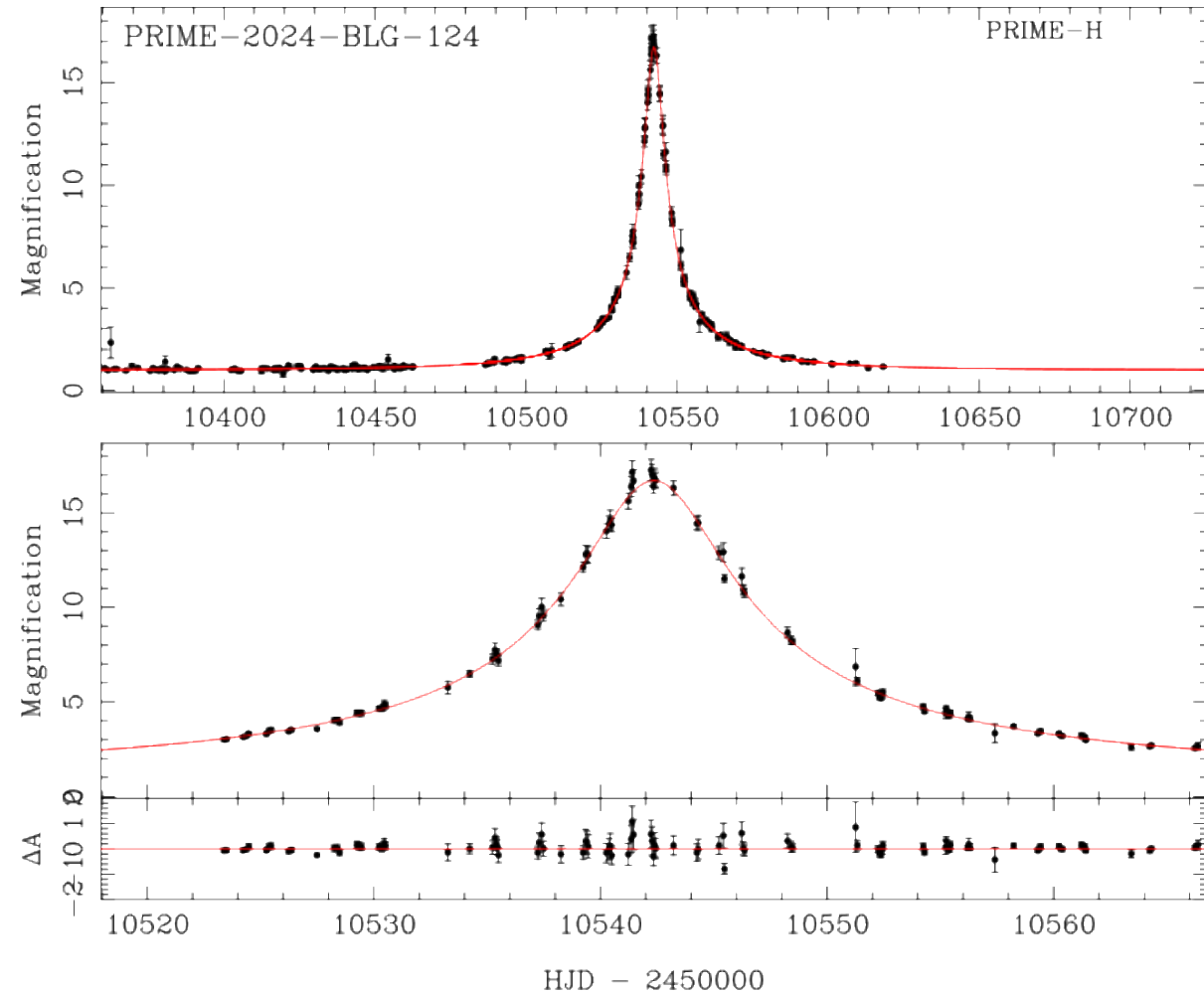
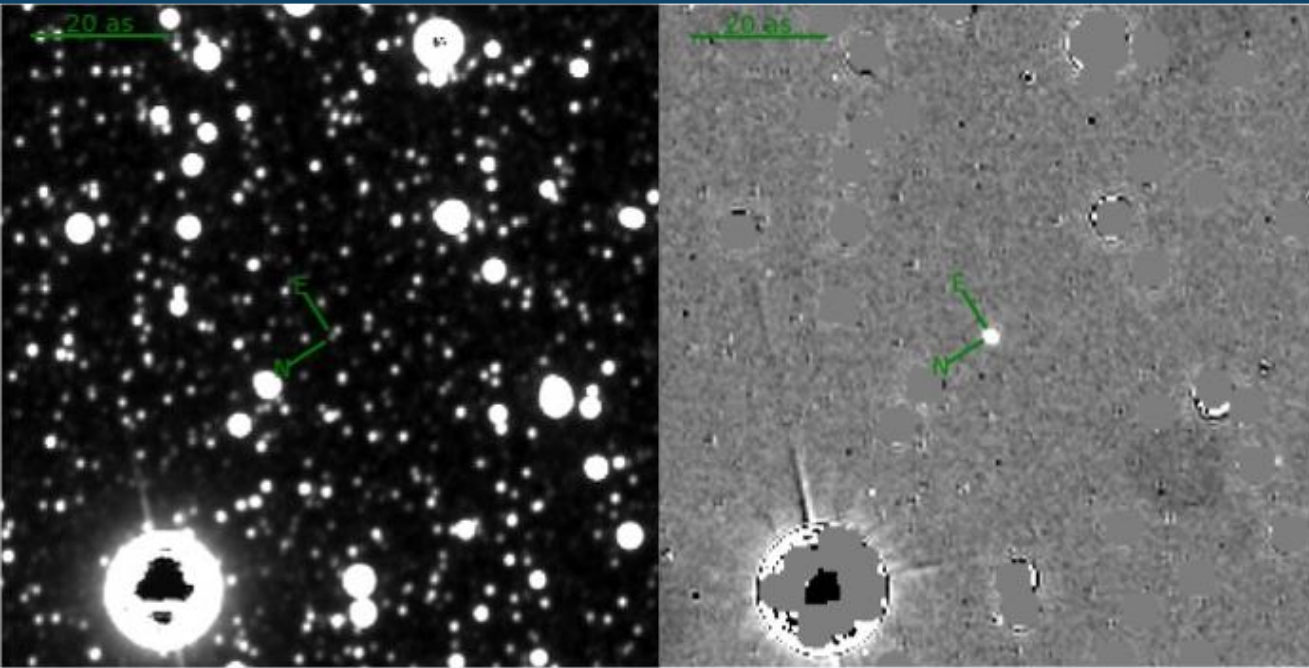


PRIME GB candidates in Feb/2024–May/2025

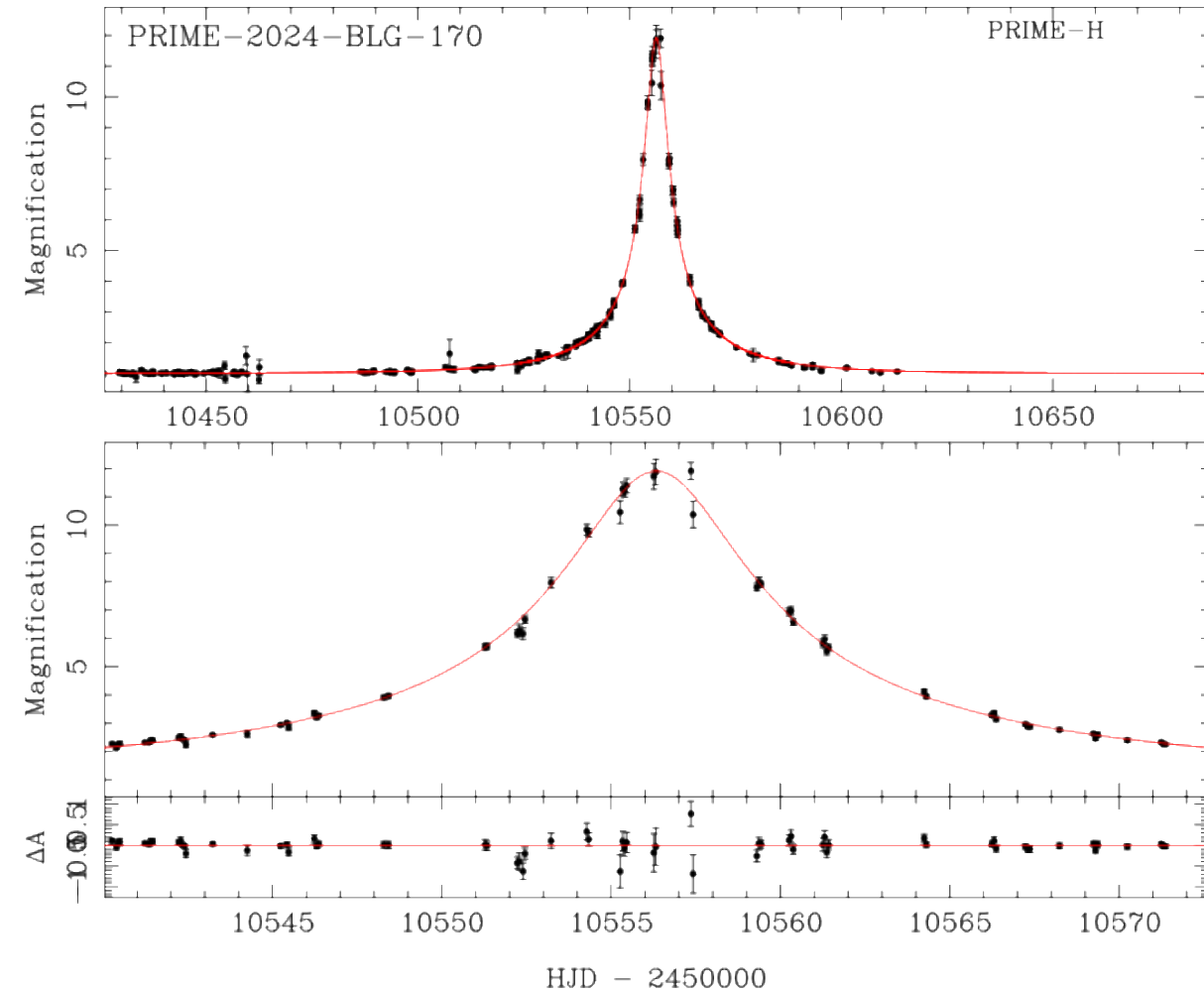
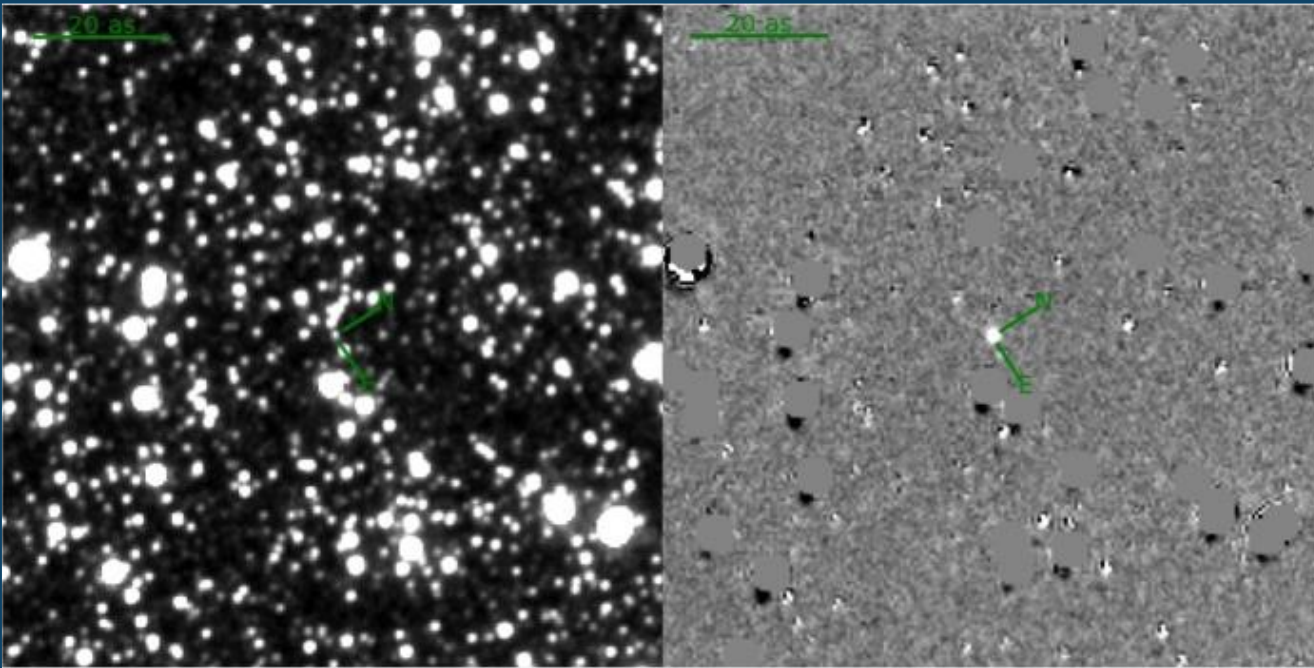


486 microensing candidates

Microlensing candidates

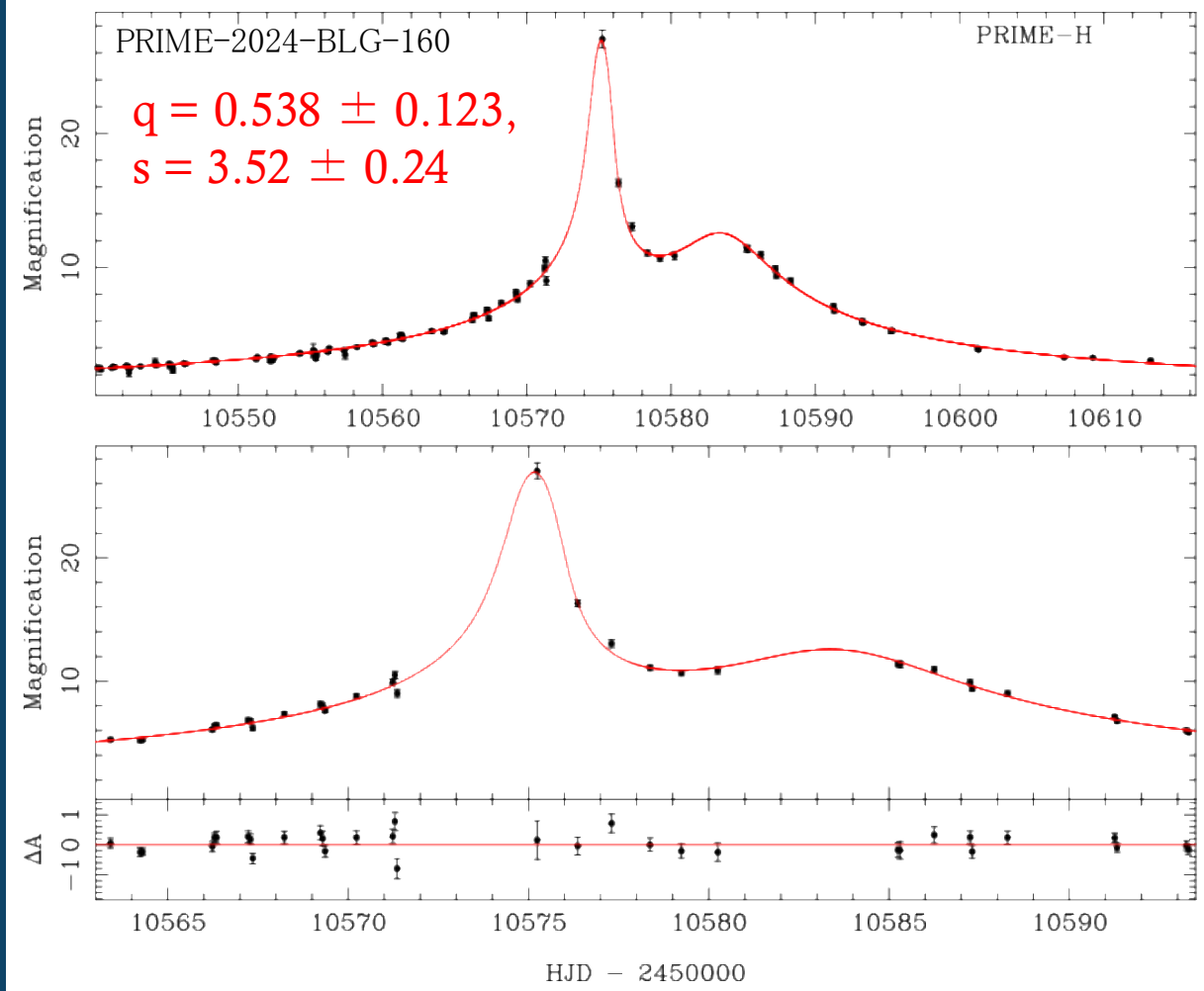
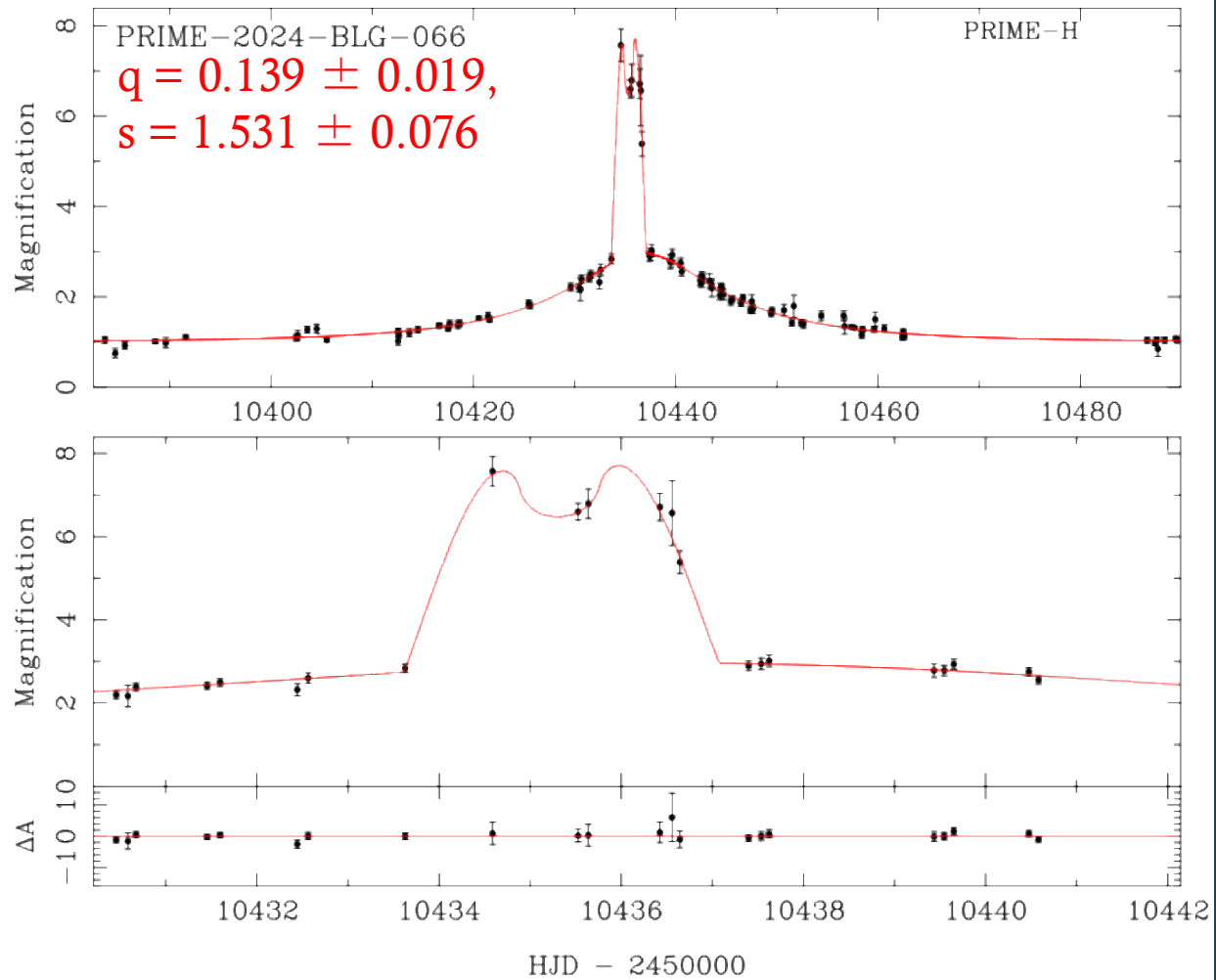


Microlensing candidates

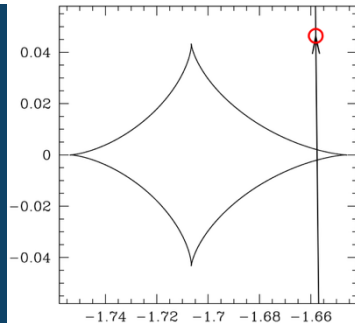
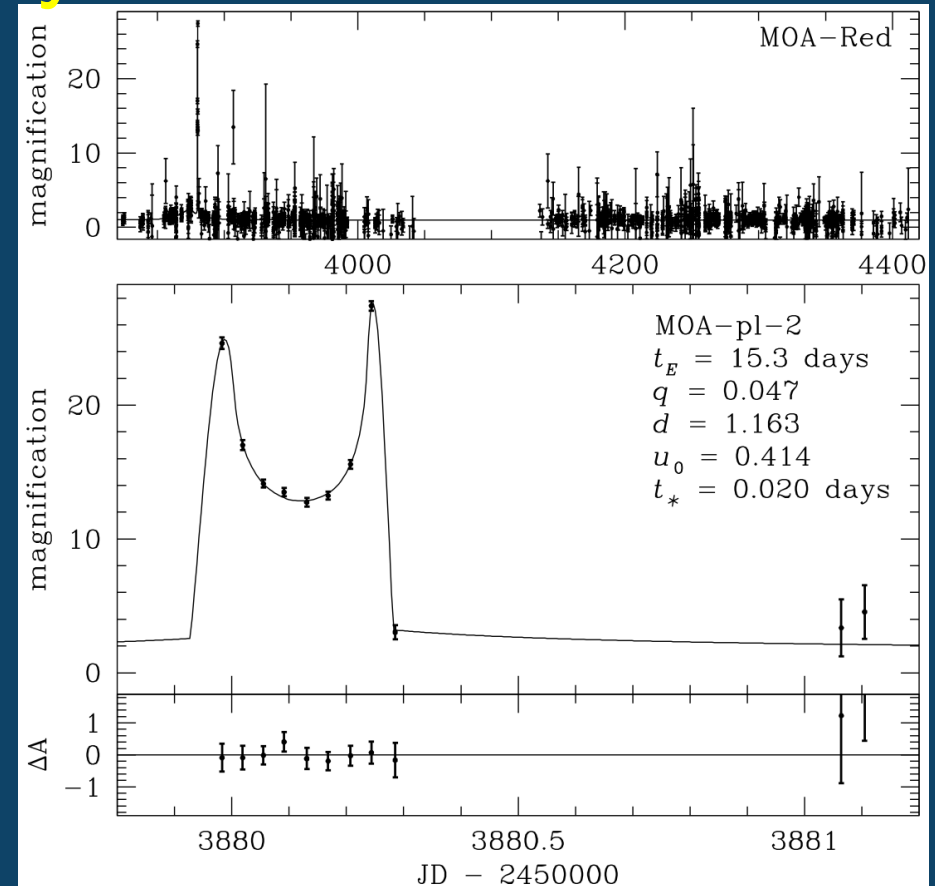
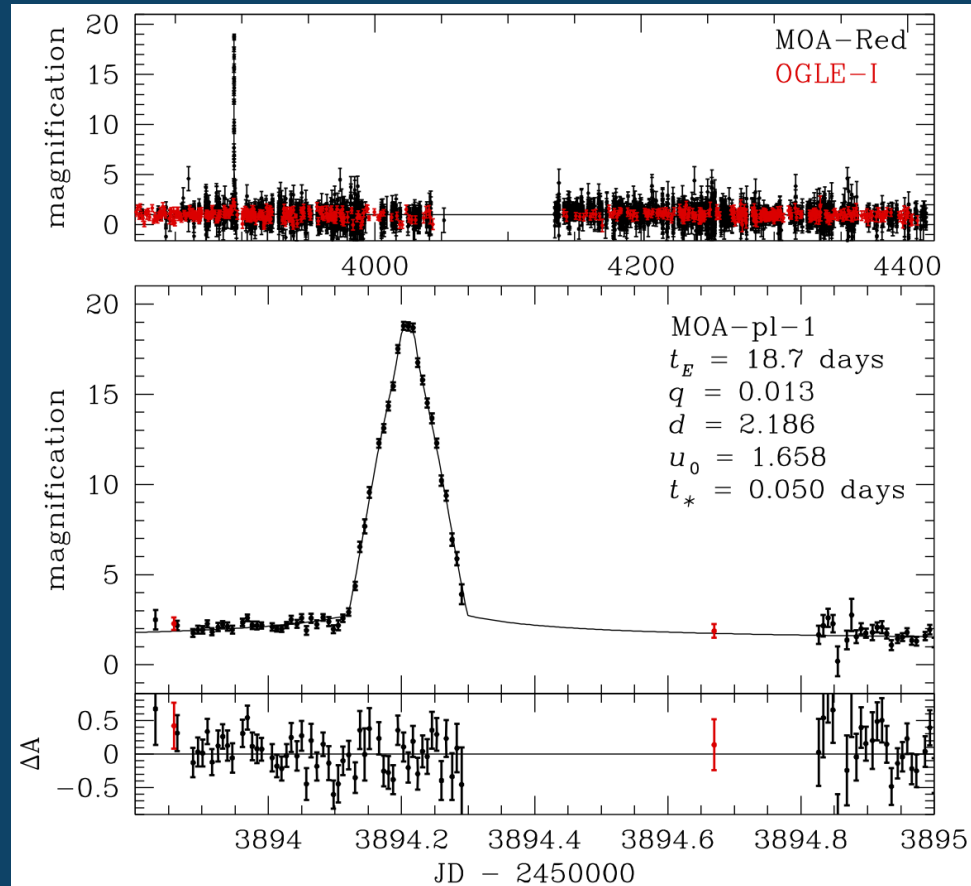


Binary Microlensing candidates

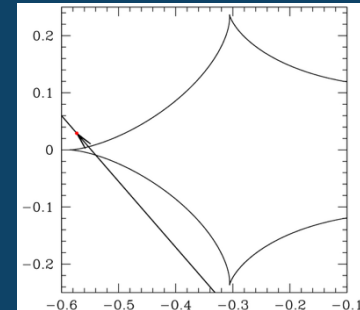
41 binary events



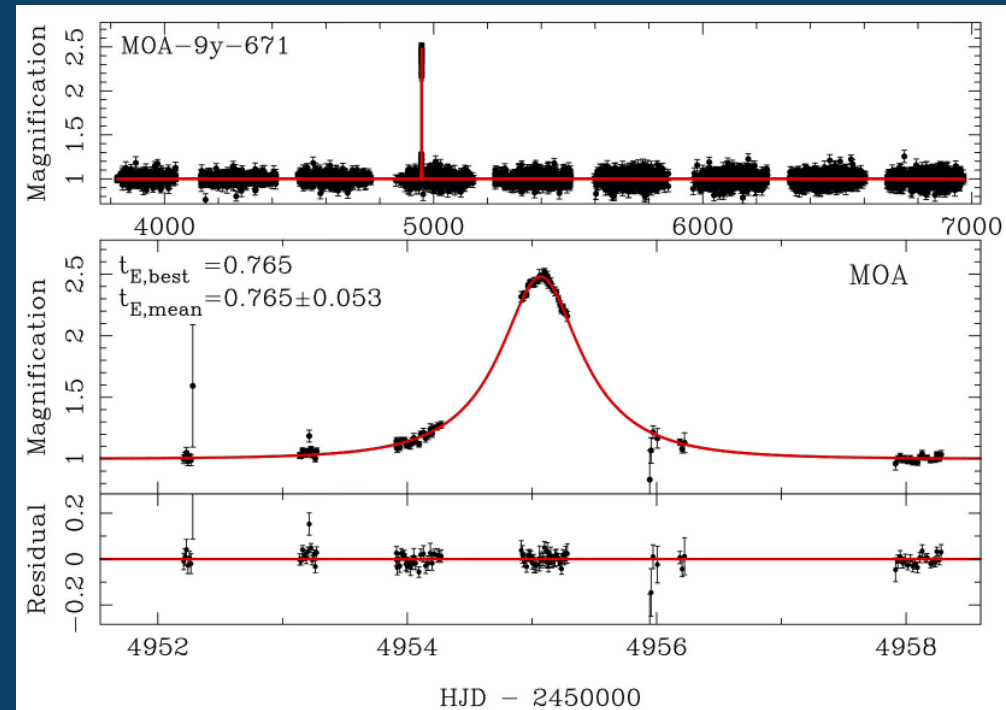
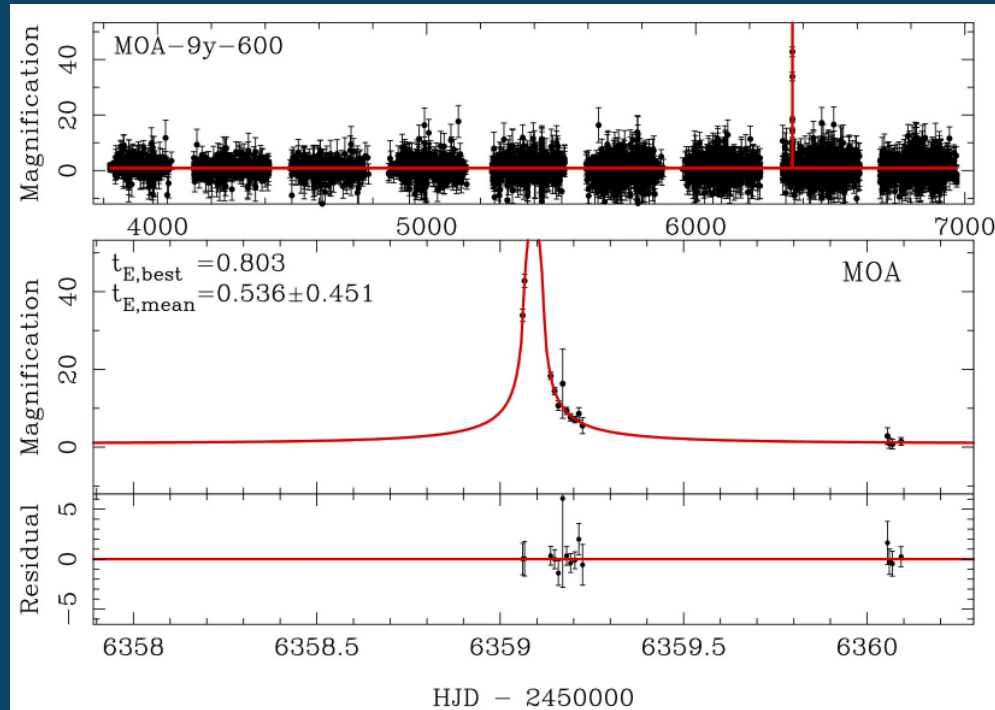
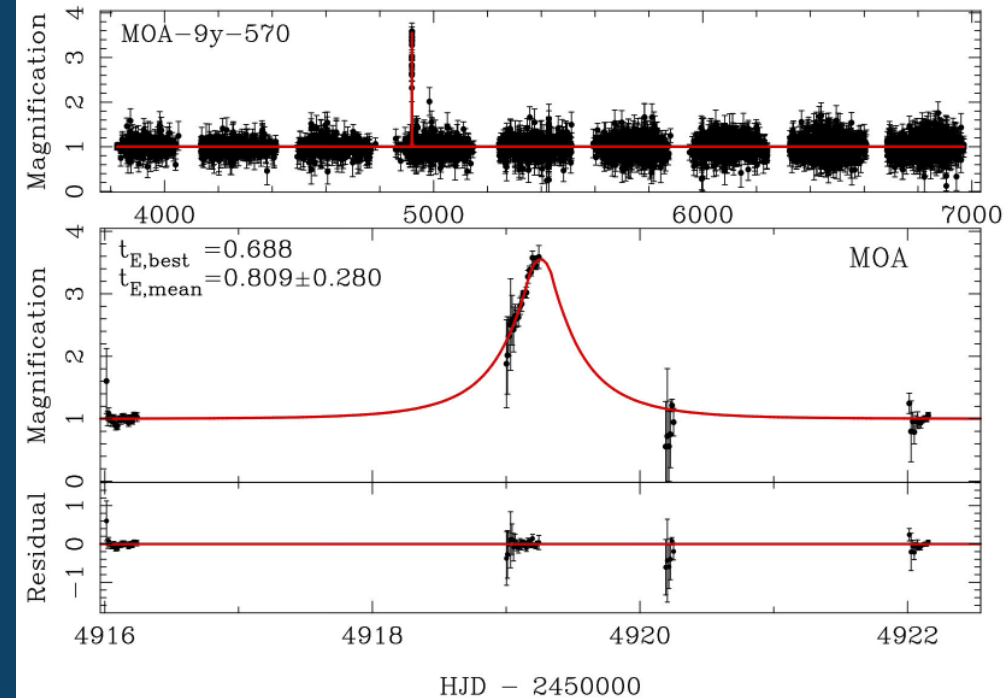
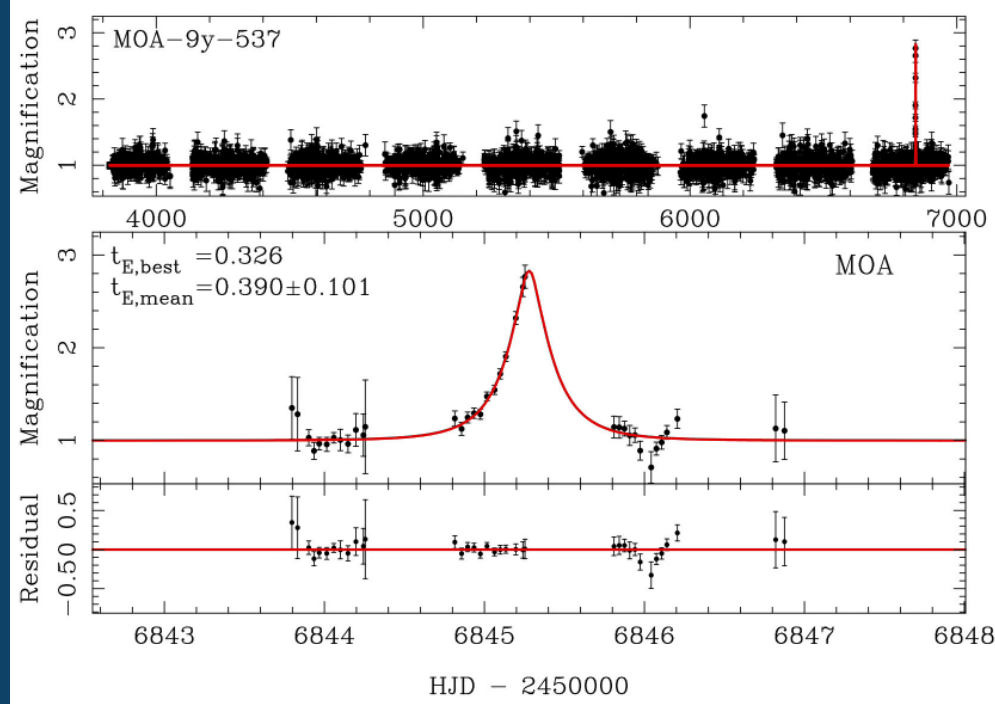
Background of short isolated events: Short Binary Events



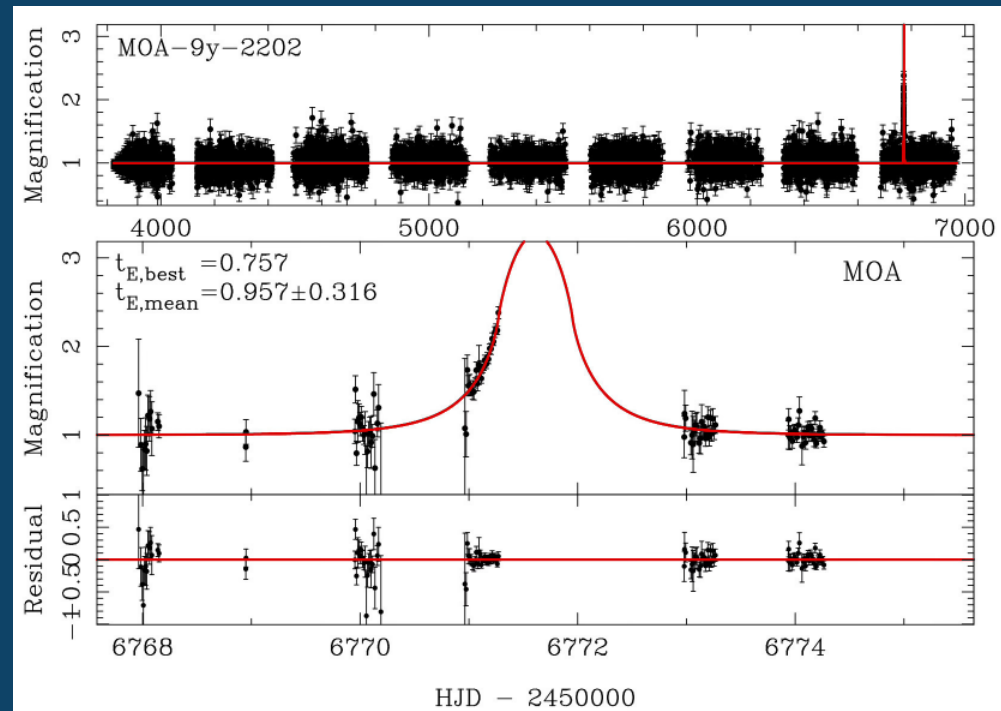
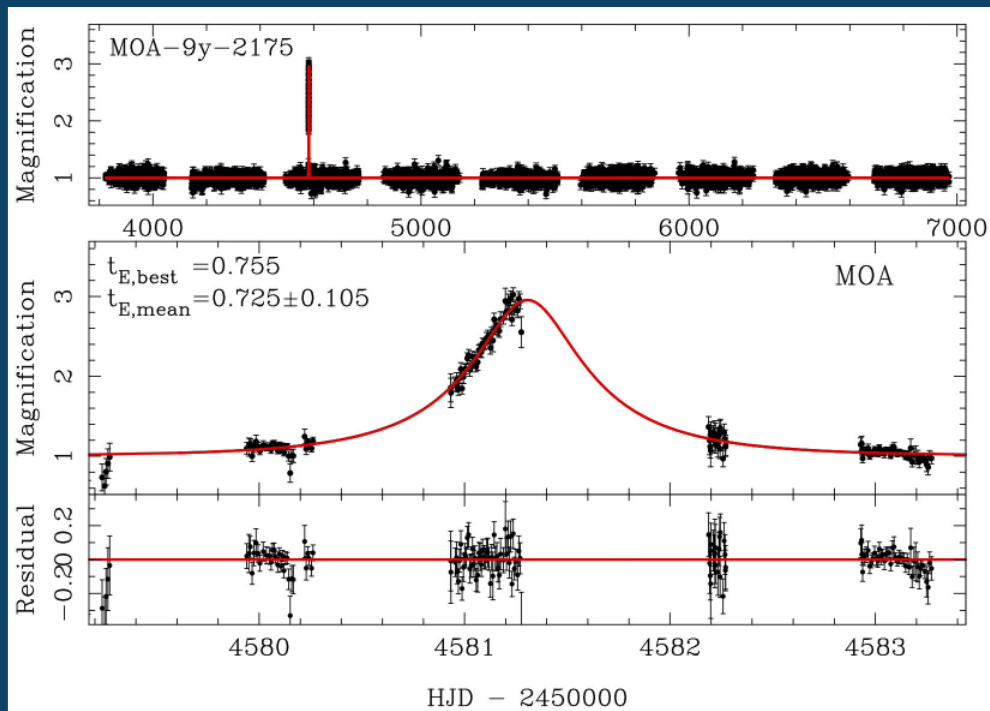
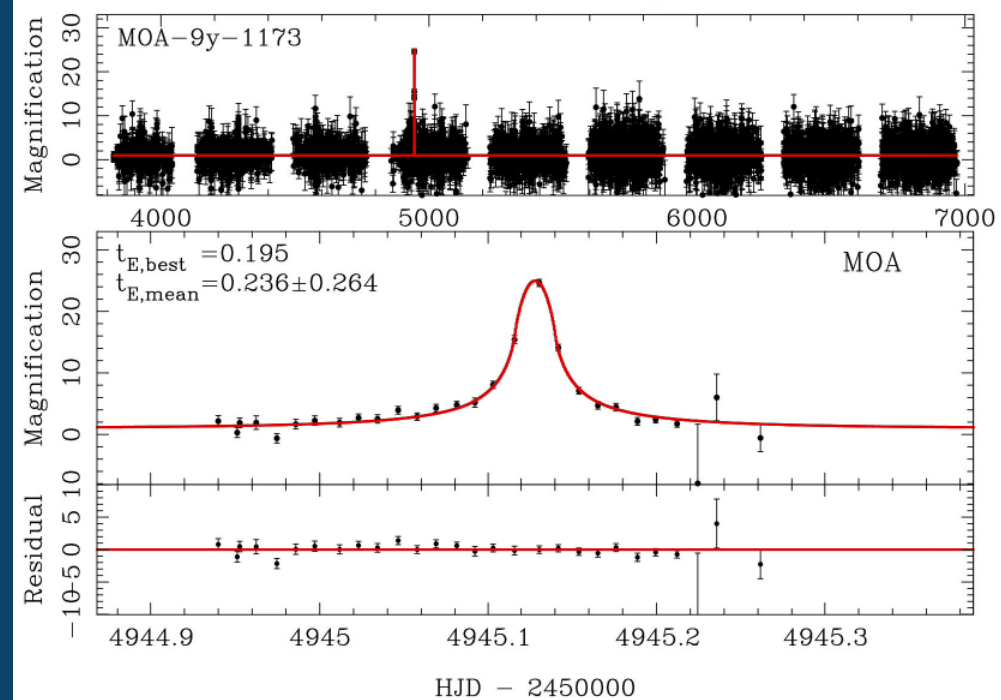
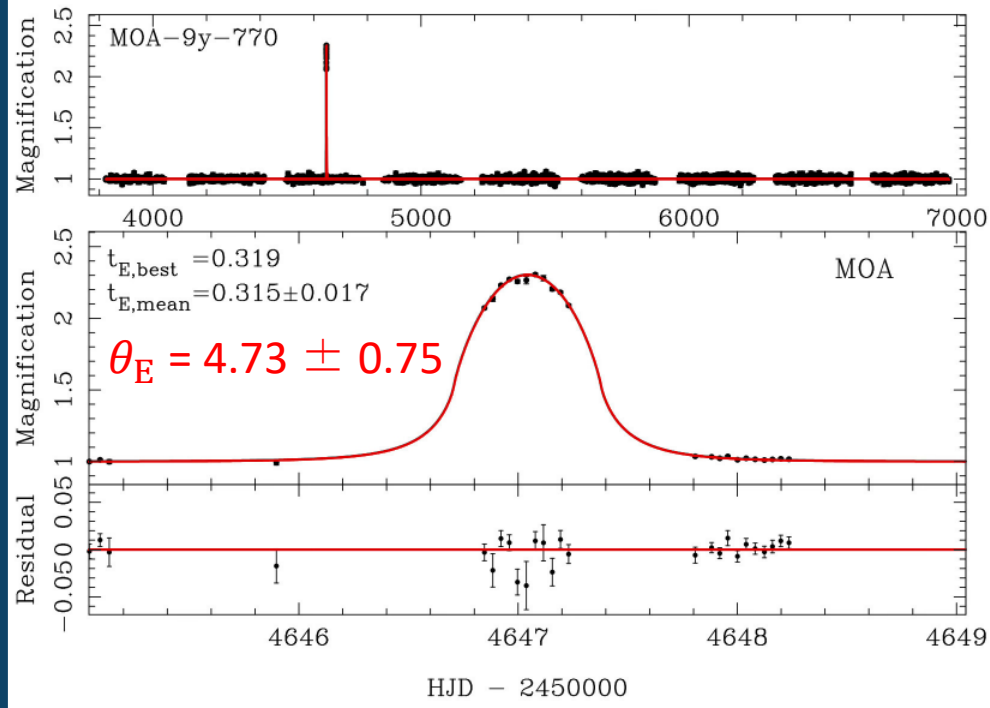
Wide-binaries ($d = 2.2, 1.2$) with planetary and brown dwarf mass ratios of $q = 0.013$ and 0.047



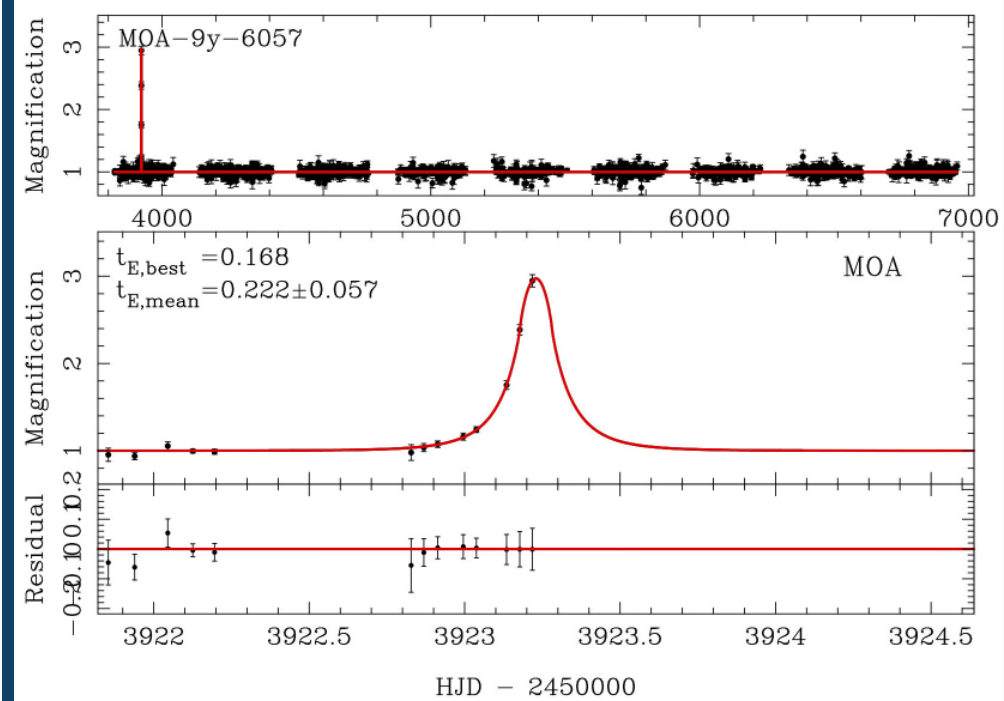
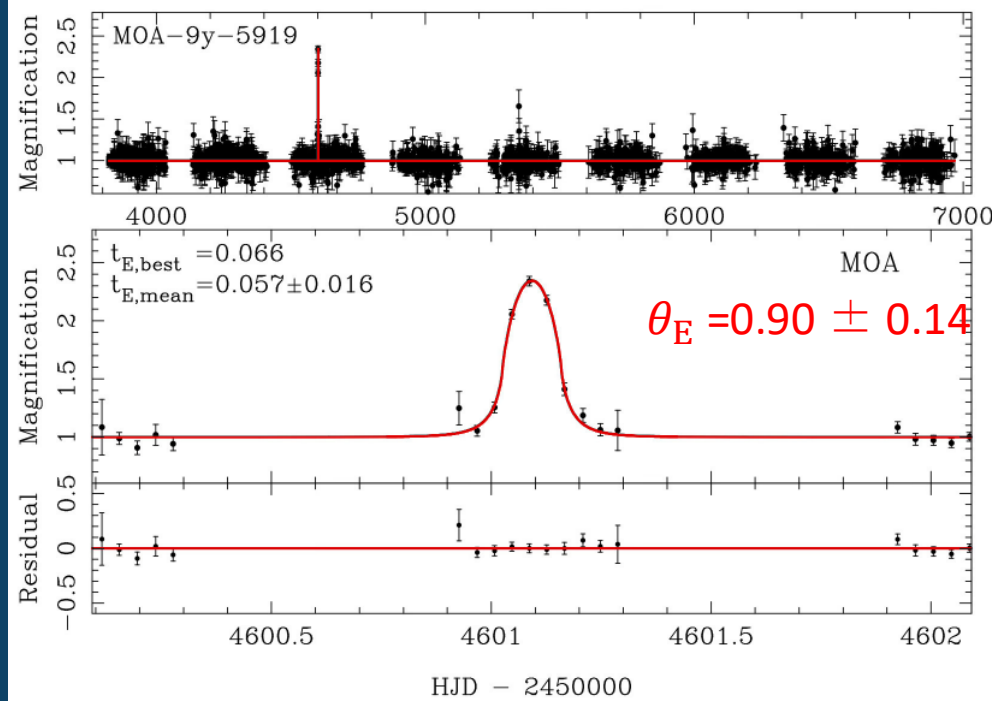
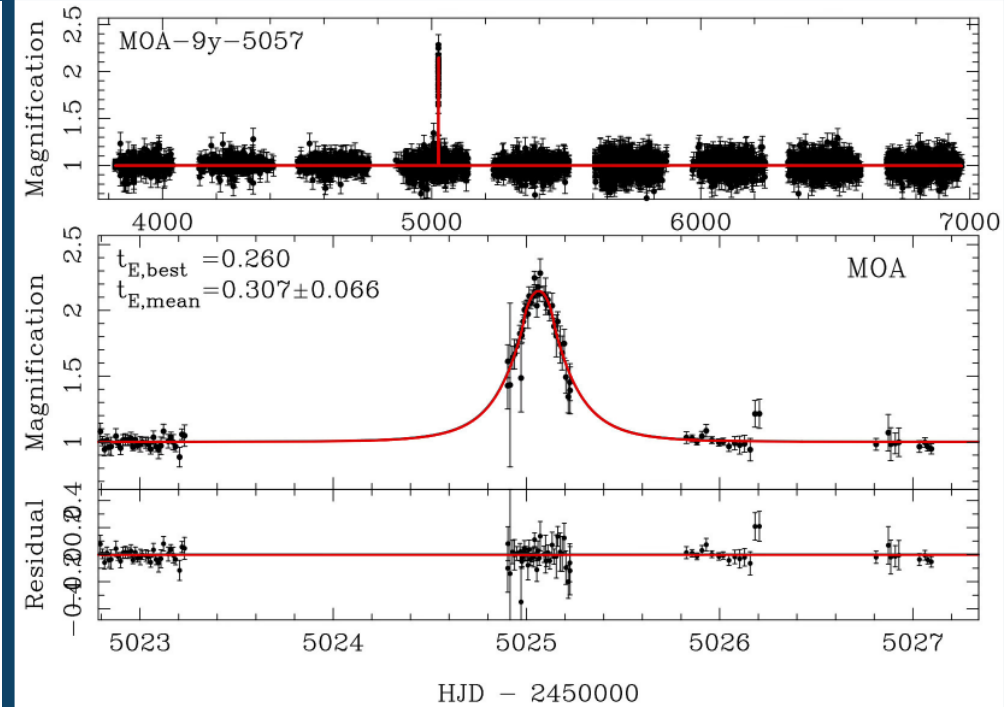
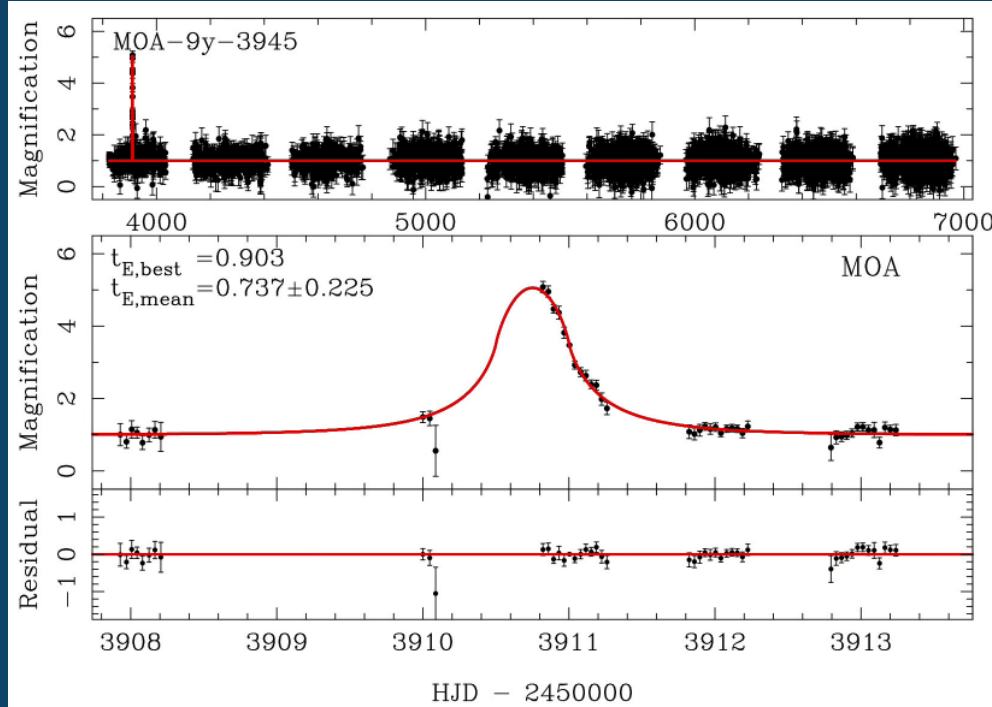
Short events with $t_E < 1$ day



Short events with $t_E < 1$ day



Short events with $t_E < 1$ day



adp

2dp

01dp

21dp

4dp

edp