Planned Ground-based Survey for Bright Microlensing Events

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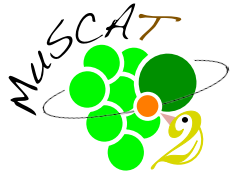
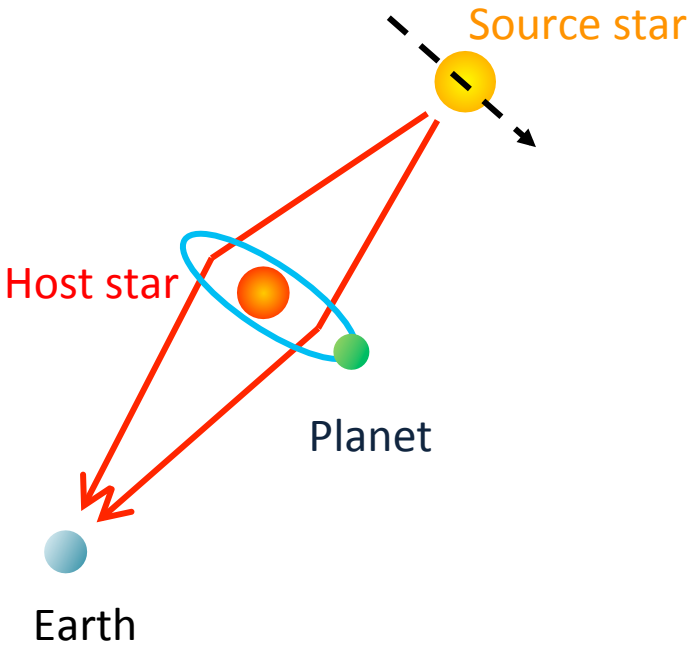
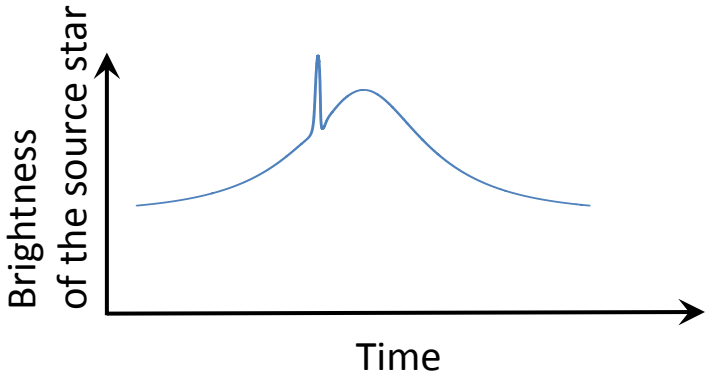
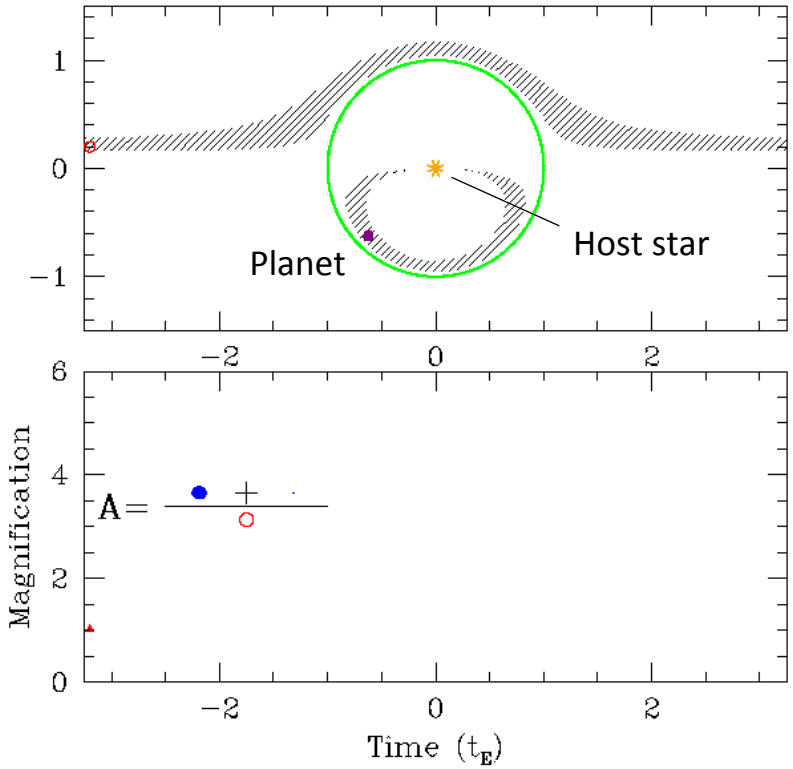


Dec. 18, 2019, 10th Gaia Science Alerts Workshop

Detecting Exoplanets by Microlensing

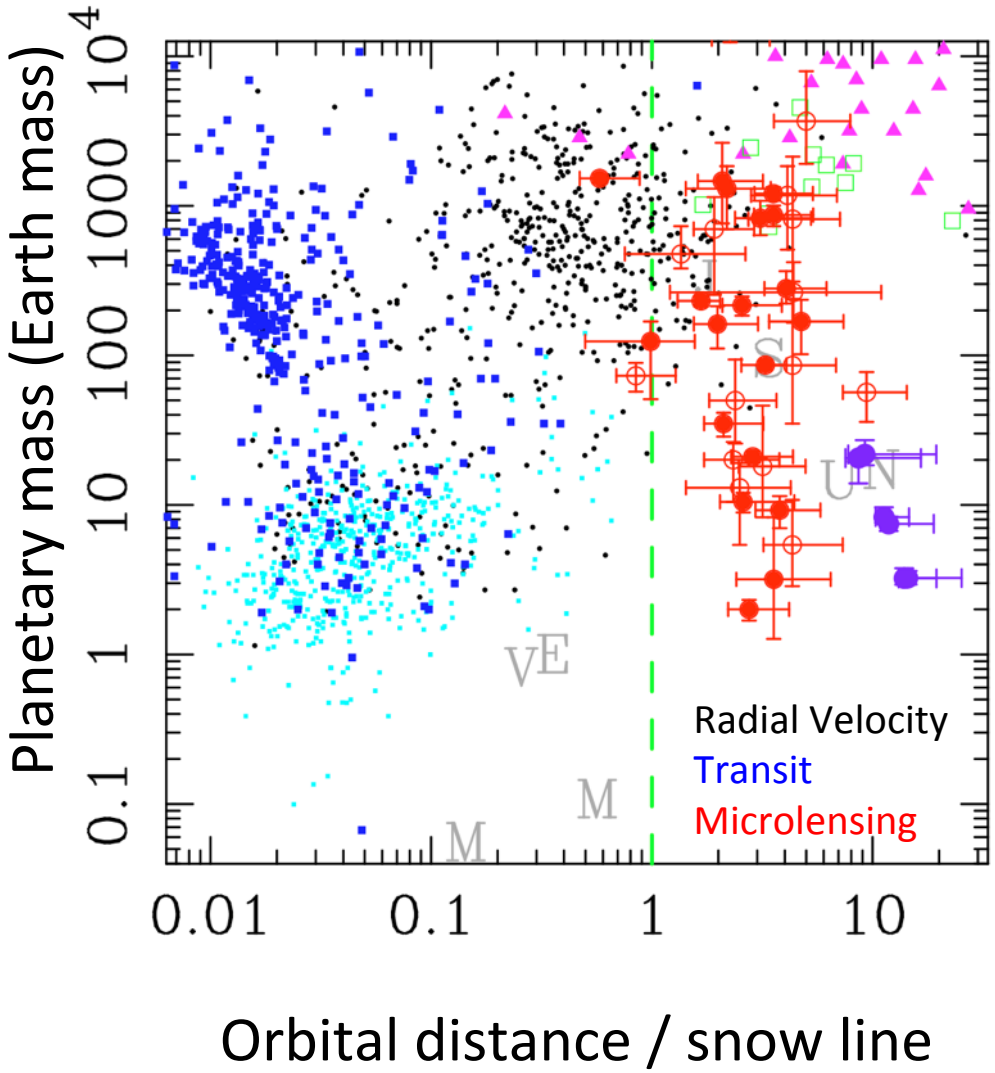






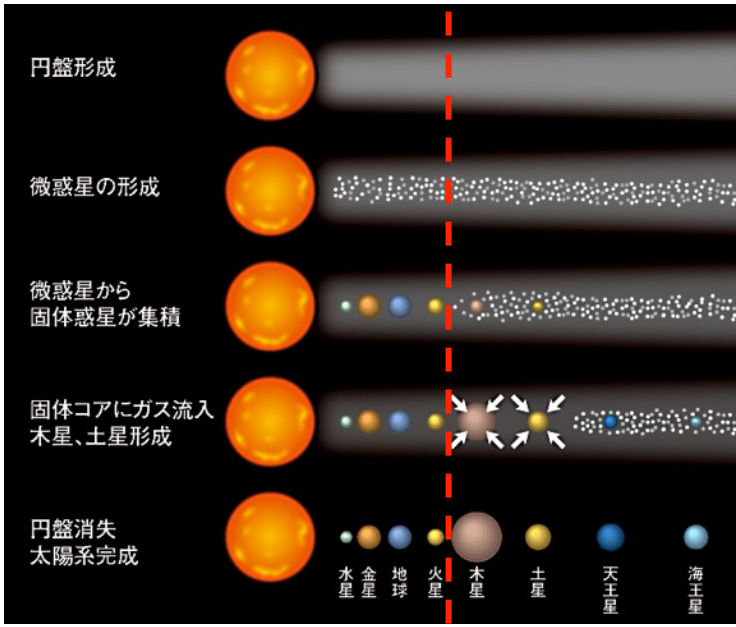
Credit: B. Scott Gaudi

Sensitivity of microlensing



Sumi et al. 2016

- Microlensing is sensitive to planets **beyond the snow line**, where gas giants efficiently form
- **>100 planets** have been found in this region



Snow line

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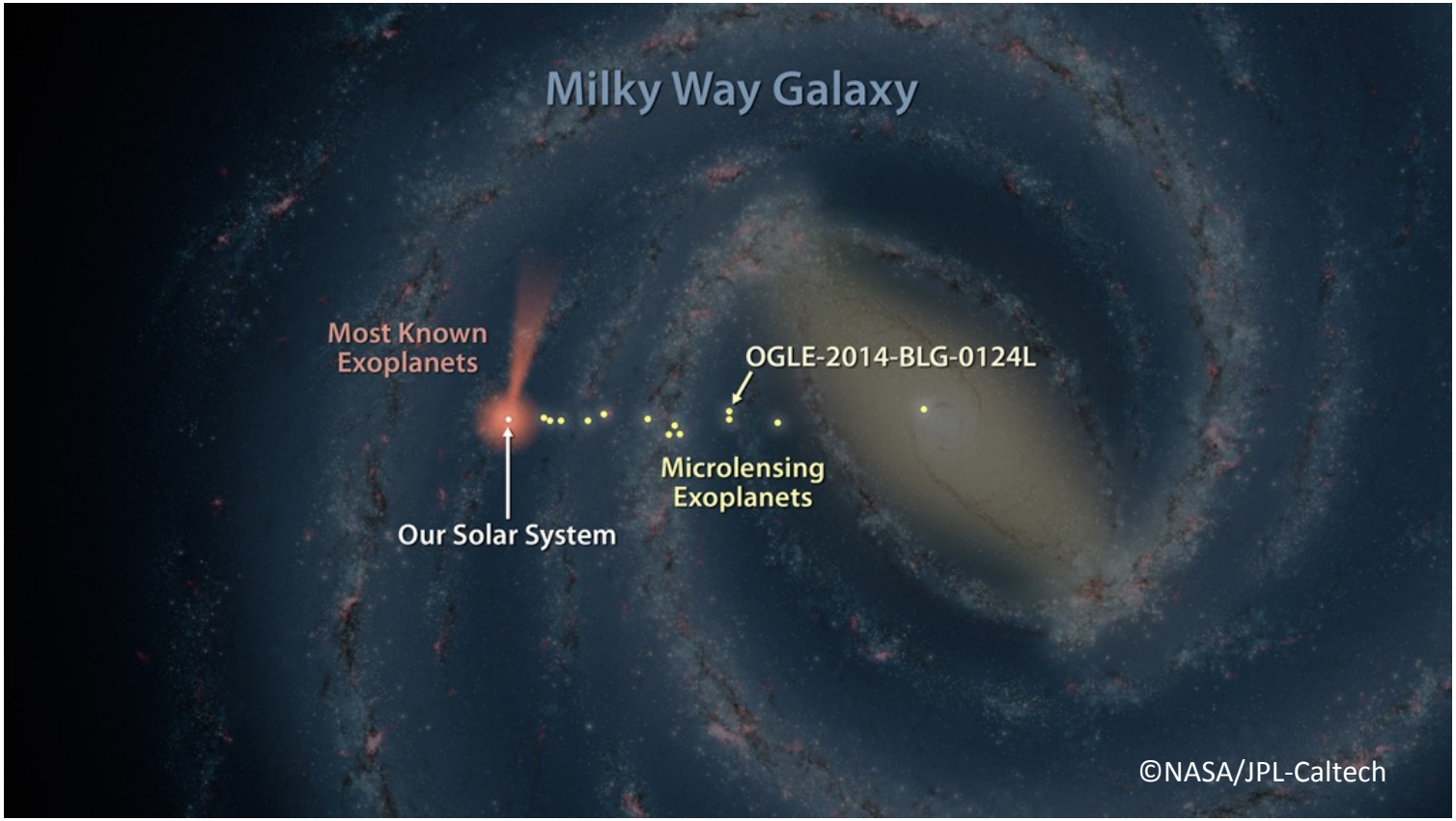
Disadvantages of microlensing

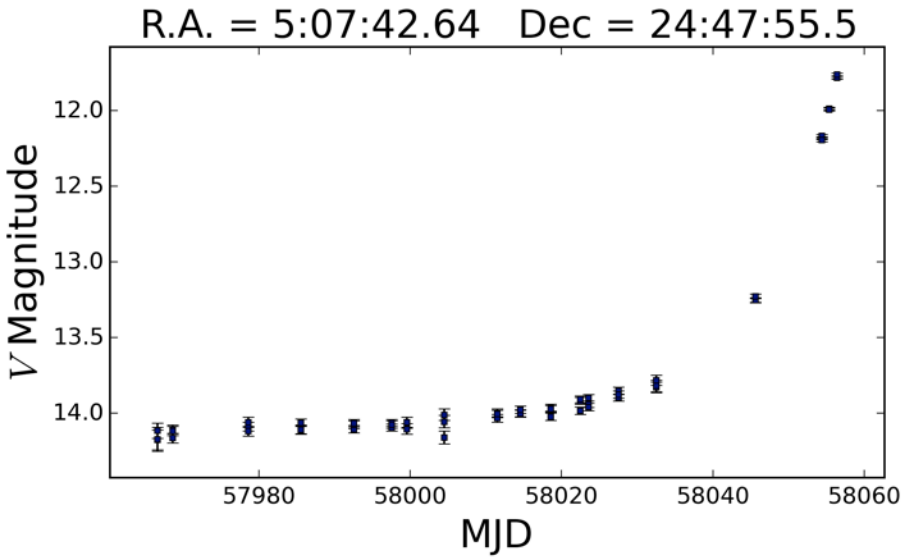
- Difficult to followup afterward
  - Current surveys are only focusing on the Galactic bulge (GB)
  - Most systems toward GB are distant and faint



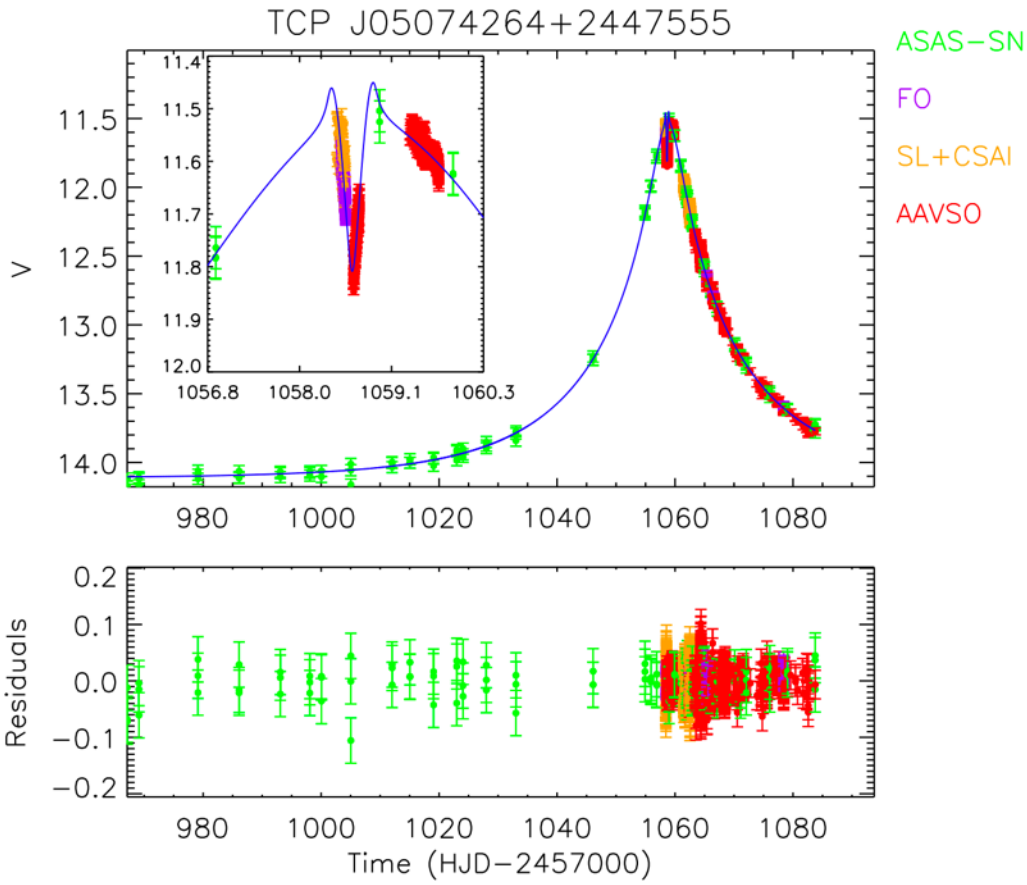
Kojima-1

- A Japanese amateur astronomer (Mr. Kojima) found a bright microlensing event by chance toward the anti-Galactic center
  - V=13.9 mag ⇒ ~11 mag
  - Instrument : Canon EOS 6D + 135mm f3.2 lens
  - Source star : a normal F dwarf at ~800 pc (closest!)

ASAS-SN archival light curve at the time of discovery



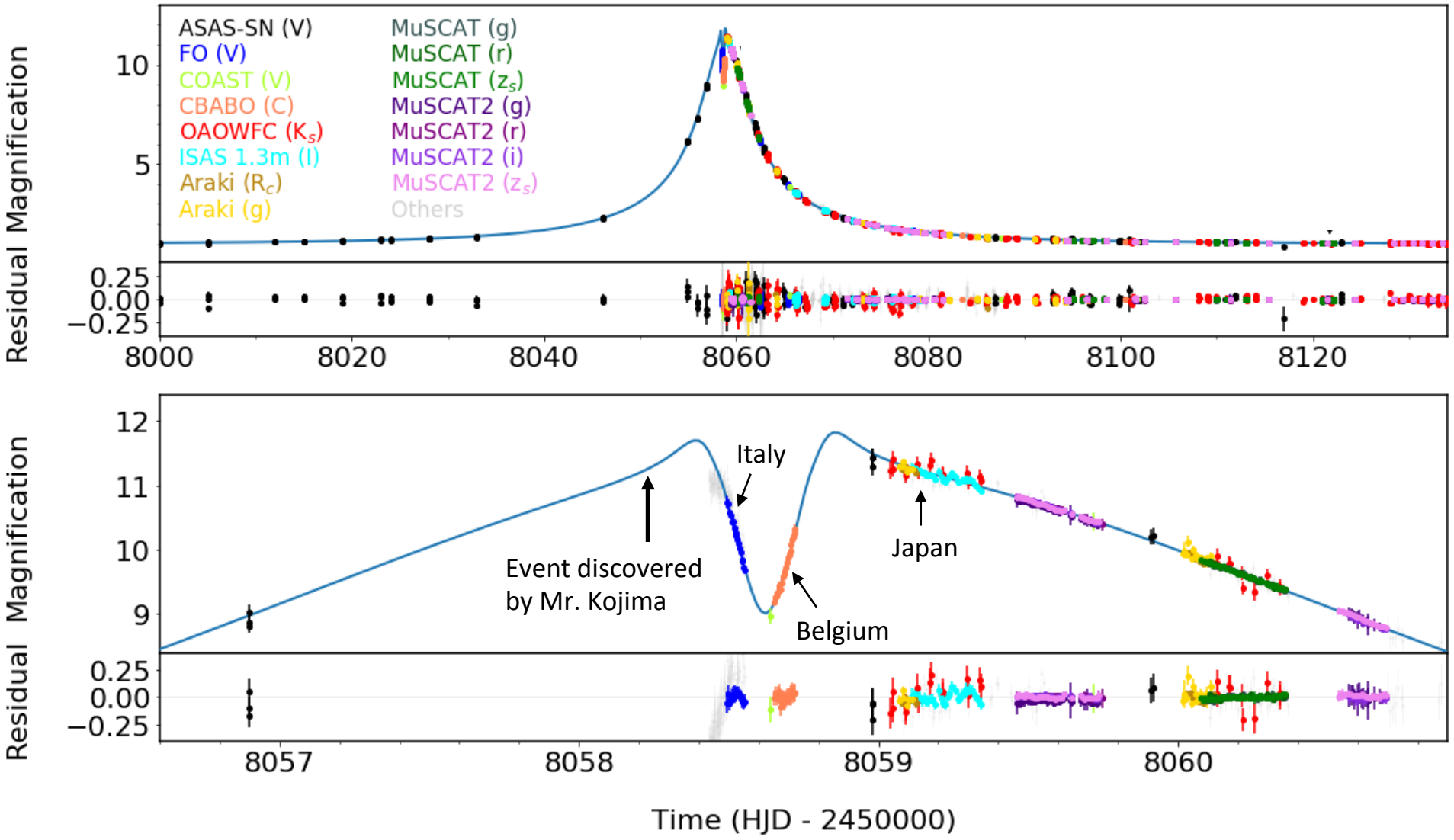
Detection of a planetary signal



Nucita et al. 2018

- Anomalous feature was detected around the peak by amateur and professional observers in Europe (Italy, Slovakia, Belgium, etc.)
- Mass ratio of the binary lens was measure to be ~10^{-4}, indicating that the companion is a planet (Nucita et al. 2018)
- The mass and distance could not directly be determined

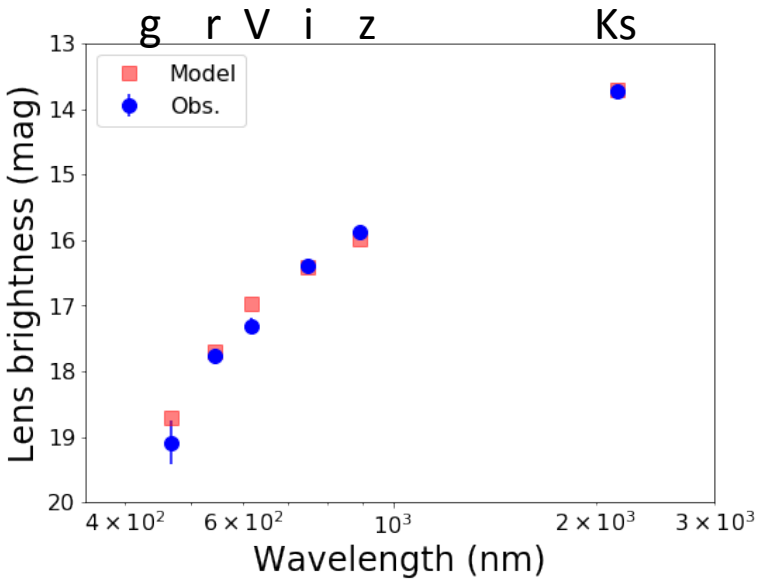
Multiband follow-ups



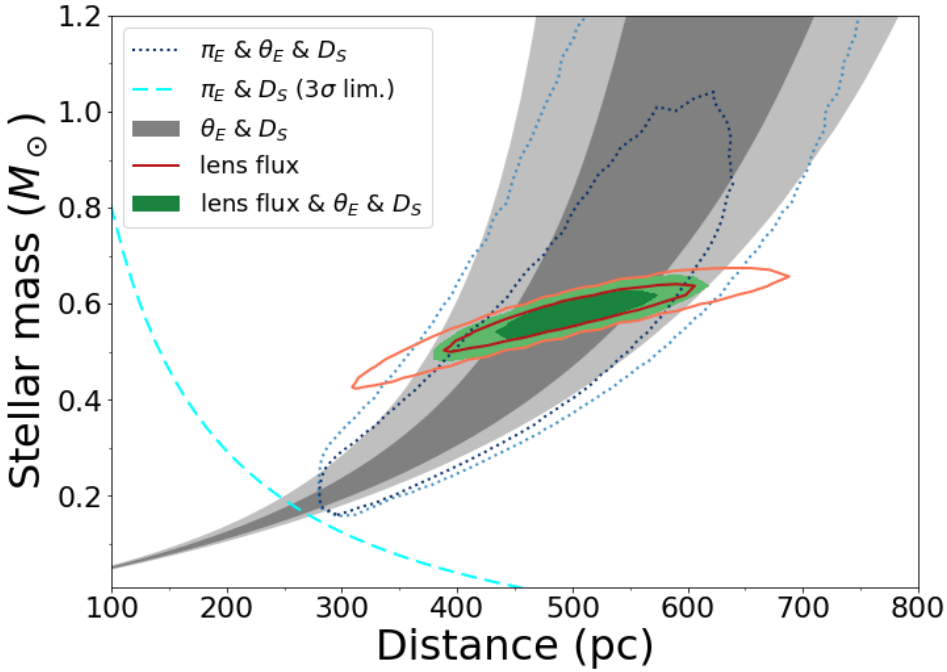
Fukui et al. 2019

Mass and distance of the planetary system

Measured brightness of the host star

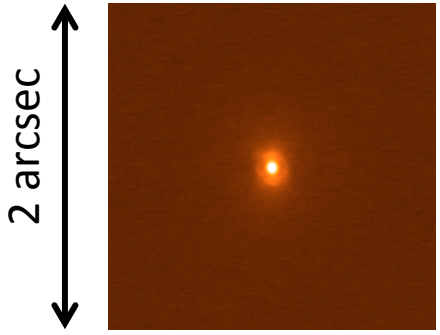


Constraints on the lens' mass and distance



Fukui et al. 2019

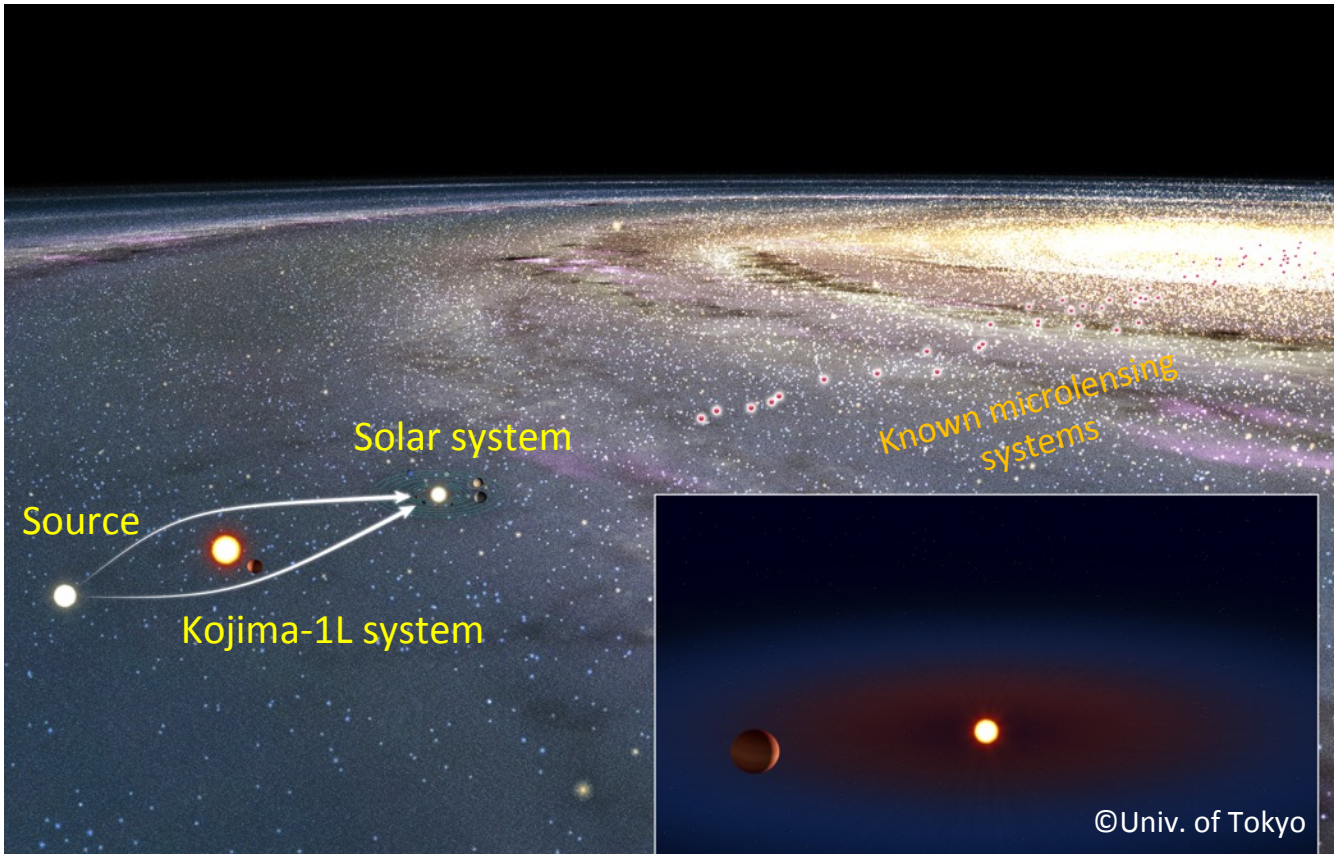
Keck+AO/Ks band



No contamination

- Host star: an M/K dwarf ($0.6M_{Sun}$)
- Planet: a Neptune ($20M_{Earth}$)
- Distance: ~500pc (nearest!)

Kojima-1L: valuable microlensing system to follow-up



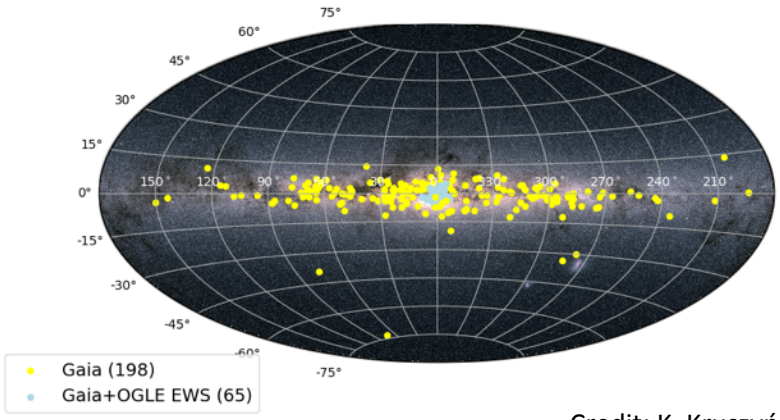
Direct spectroscopy of the host star will be feasible in a few years

- ✓ Metallicity of the host star
- ✓ Searching for additional planets by RV
- ✓ RV confirmation of Kojima-1Lb

Microlensing in the Galactic plane

- Gaia
  - Observing the whole sky once per month
  - detected ~200 events in the Galactic plane (~50 events/yr)
  - Observing cadence is too low to catch events early enough

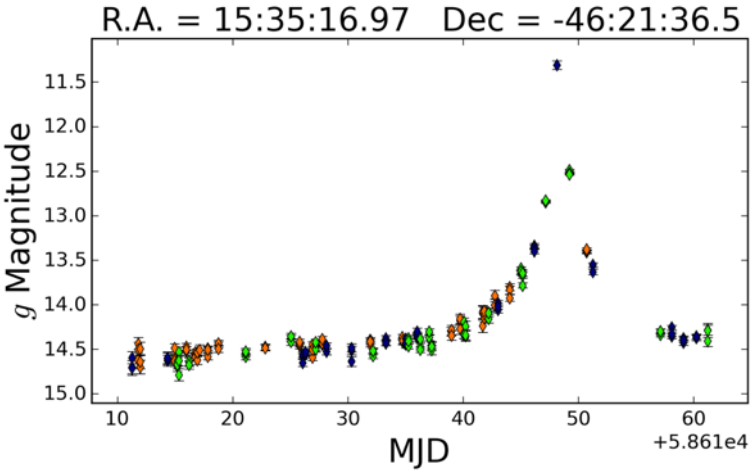
Microlensing events detected by Gaia



Credit: K. Kruszyńska

- ASAS-SN
  - All sky is observed ~once per night
  - Occasionally discovered bright events
  - Telescope aperture is too small (14cm) to detect faint (<16 mag) events

ASASSN-19pq

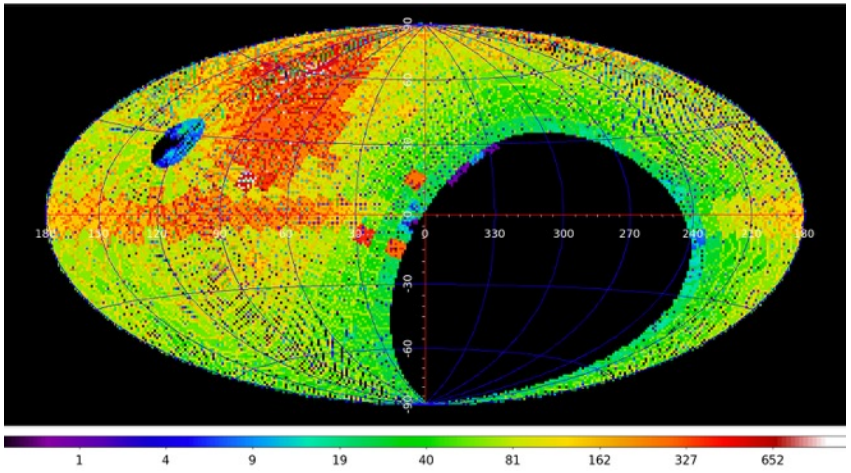


Zwicky Transient Facility (ZTF)

- ZTF
  - All visible-sky survey with the Palomar 48 inch (1.2m) telescope
  - FOV: 47 deg^2
  - Galactic plane is observed ~once per night in g and r
  - Lim. mag down to ~20 mag in r (30 sec exp.)
  - “Filters” to detect microlensing events are under development (by Lukasz and the LCO microlensing team)

Zwicky Transient Facility (ZTF) instrument installed on the 1.2m diameter Samuel Oschin Telescope at Palomar Observatory in California. Courtesy Caltech Optical Observatories

ZTF sky coverage (DR2)

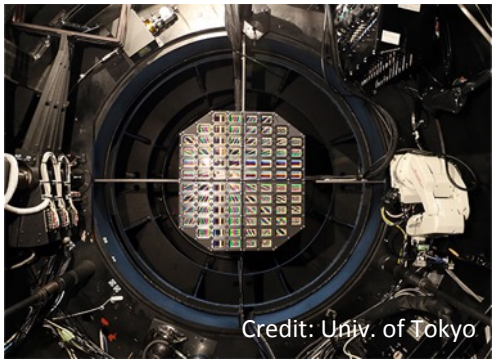


Tomo-e Gozen

- Tomo-e Gozen
  - Wide-field **CMOS** camera
  - Mounted on a 1.05m telescope at Kiso observatory, Japan
  - FOV: 20 deg^2
  - Can read images very fast (2 Hz)
  - All visible-sky is surveyed up to three times per night
  - Lim. mag ~18 mag (6 sec exp.)
  - Main sciences: super novae and near-earth asteroids
  - Regular survey started in Oct. 2019
  - Microlensing events are to be searched

TOMO·E GOZEN

1.05m Schmidt telescope



Tomo-e Gozen camera

ZTF v.s. Tomo-e Gozen

	ZTF	Tomo-e
Diameter (m)	1.2	1.05
FOV (deg^2)	47	20
Filter	g, r, i	no filter (g+r)
Median seeing (arcsec)	~2	~4.2
Exp. time per visit (sec)	30	6
Limiting mag.	~20	~18
Cadence (visit / night)	2	3
Latitude (deg)	+33.4	+35.8
Longitude (deg)	**-116.9**	**+137.6**
Operation	2018.4~	2019.10~

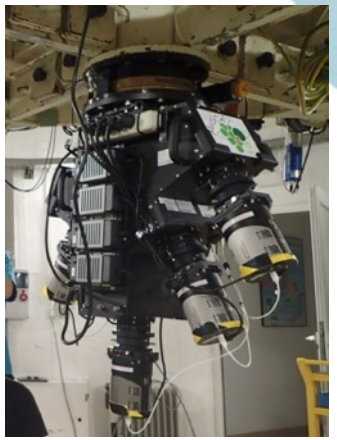
- Tomo-e is complemental to ZTF in terms of longitude.
- They, with the aid of Gaia, can quickly identify GP microlensing

Necessary follow-up observations

- (Low cadence) multiband photometry
  - To identify true microlensing events
  - To measure the color of the lens and source stars
- High or low resolution spectroscopy
  - To identify false positives due to other types of variable stars
  - To better constrain the properties of the source star (distance and angular size)
- High cadence photometry
  - To catch planetary anomalies
- High resolution imaging
  - To check contaminating stars

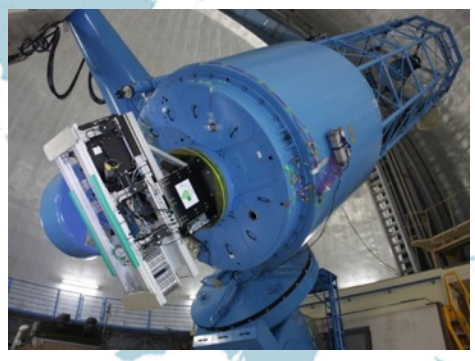
MuSCATs

MuSCAT: Multicolor **S**imultaneous **C**amera for studying **A**tmospheres of **T**ransiting exoplanets
PI: Norio Narita (Astrobiology Center; ABC)



MuSCAT2

- 1.52 m telescope in Tenerife, Spain
- 4 ch (g, r, i, z_s)
- Since 2018
- Operated by ABC and IAC
- >250 nights / year

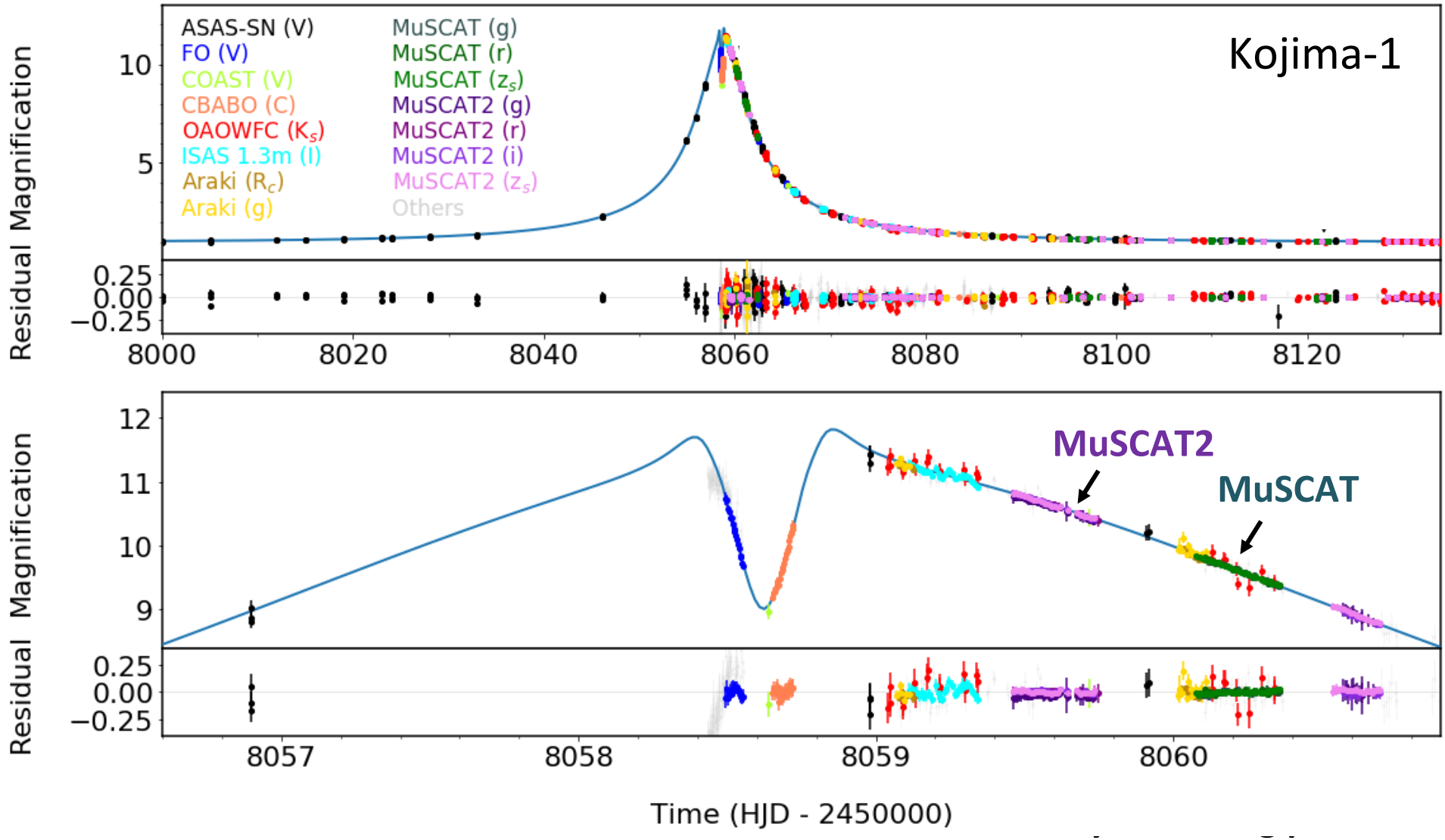


MuSCAT

- 1.88 m telescope in Okayama, Japan
- 3 ch (g, r, z_s)
- Since 2015
- operated by ABC
- ~100 nights / year

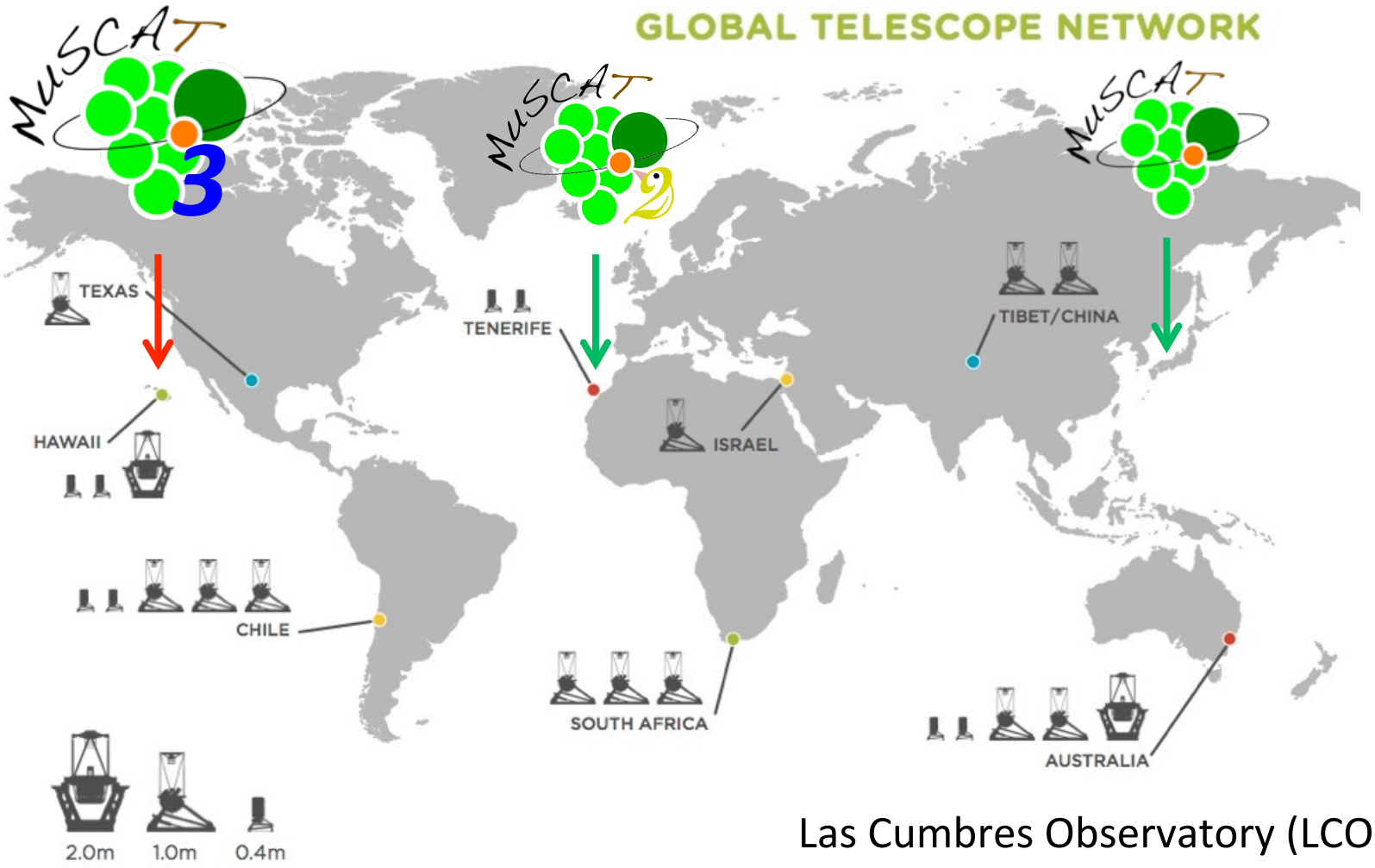
- Main Sciences: validations and characterizations of **nearby transiting planets**
- **"Filler" observations** are also possible

MuSCATs



- **"Filler" observations** are also possible

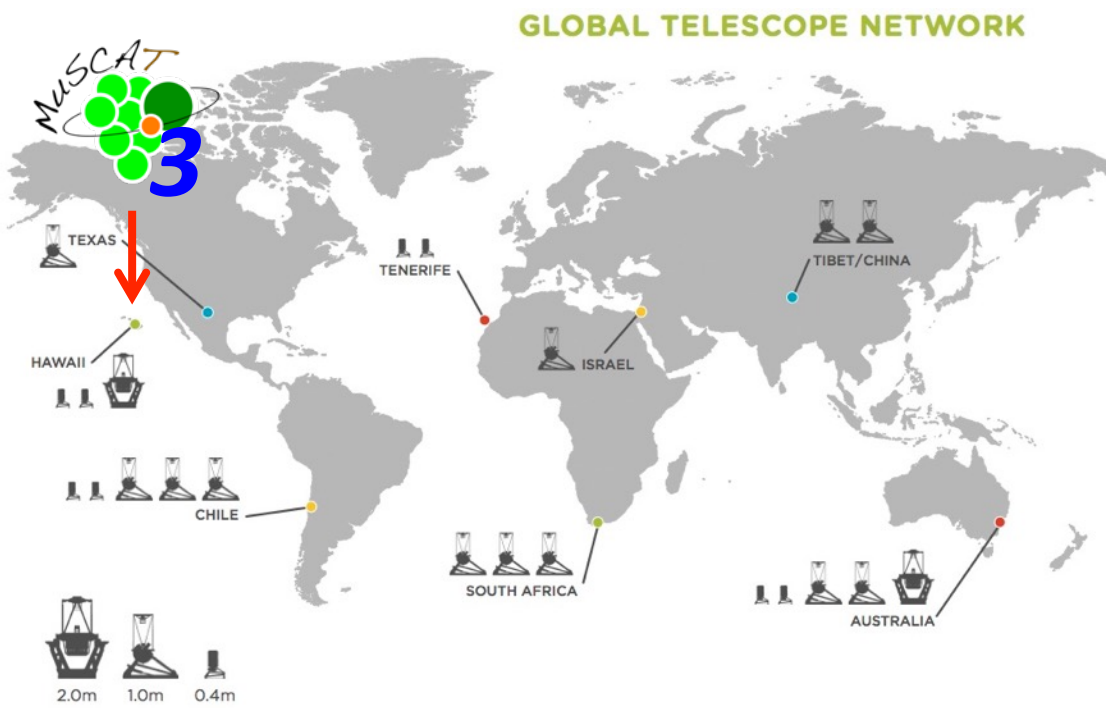
MuSCAT3



Las Cumbres Observatory (LCO)

- ✓ MuSCAT3 will be installed on the 2m FTN of LCO @Hawaii (Haleakala)
  - Will be a facility instrument, available for open use from around June 2020

LCO Key Project for Galactic-plane microlensing



- 2-m tel. x 2
  - (Multiband) imager
  - Low-res. spec
- 1-m tel. x 11 (+2)
  - Imager
  - High-res spec
- 0.4-m tel. x 10
  - Imager

- Key Projects 2020B
  - Up to 70% of all the telescope times will be dedicated to the selected Key Projects
  - Each Key Project will be awarded significant telescope times for up to 3 years
- Proposal for Galactic-plane microlensing is to be submitted
  - Members: E. Bachelet (PI), C. Briceno, M. Dominik, **A. Fukui**, M. Hundertmark, R. Street, Y. Tsapras, **L. Wyrzykowski**

Summary

- Microlensing is a unique tool to probe exoplanets **beyond the snowline**, but the planetary systems discovered toward the Galactic bulge are **difficult to be studied in detail** afterward

- **Kojima-1L** is the first example of nearby microlensing system, demonstrating that it is **feasible to survey nearby planetary events in the Galactic plane**

- We plan to search for microlensing events from the **ZTF** and **Tomo-e Gozen** surveys, which will be followed up by the **LCO network** and **MuSCATs**

- Coordination/cooperation between our planetary-event searches and Gaia/OPTICON network can maximize the scientific outcomes