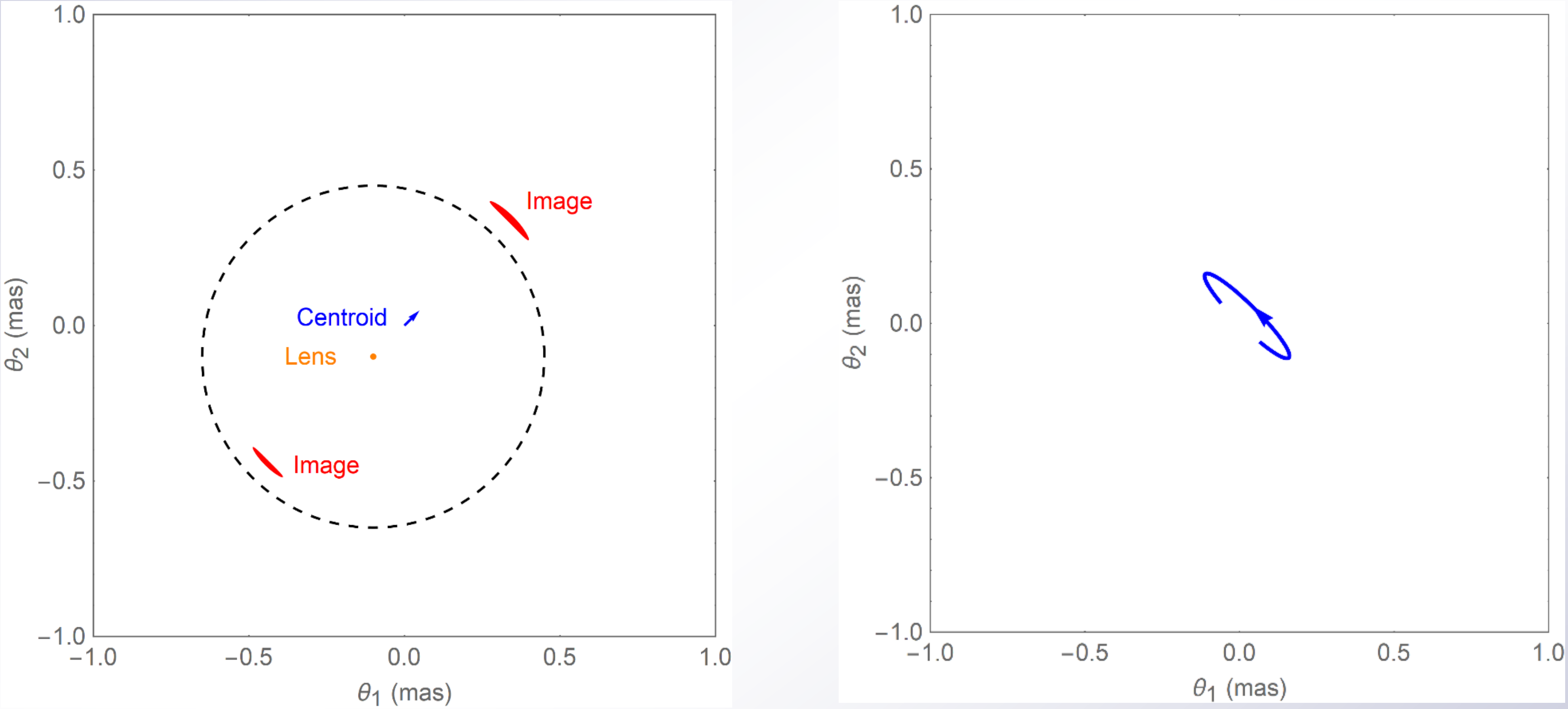
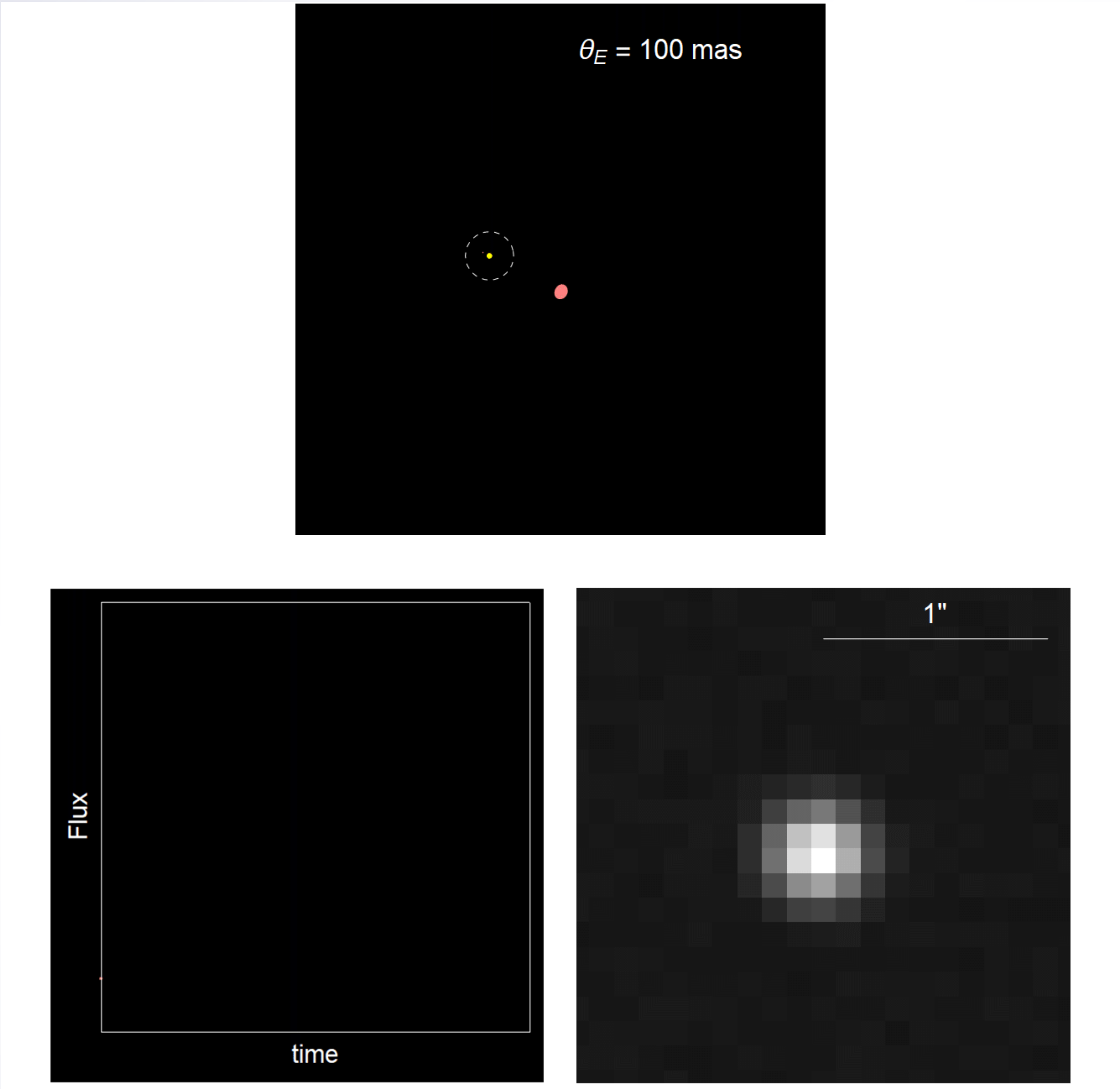
Microlensing with exquisite astrometry



Valerio Bozza
University of Salerno, Italy

Microlensing

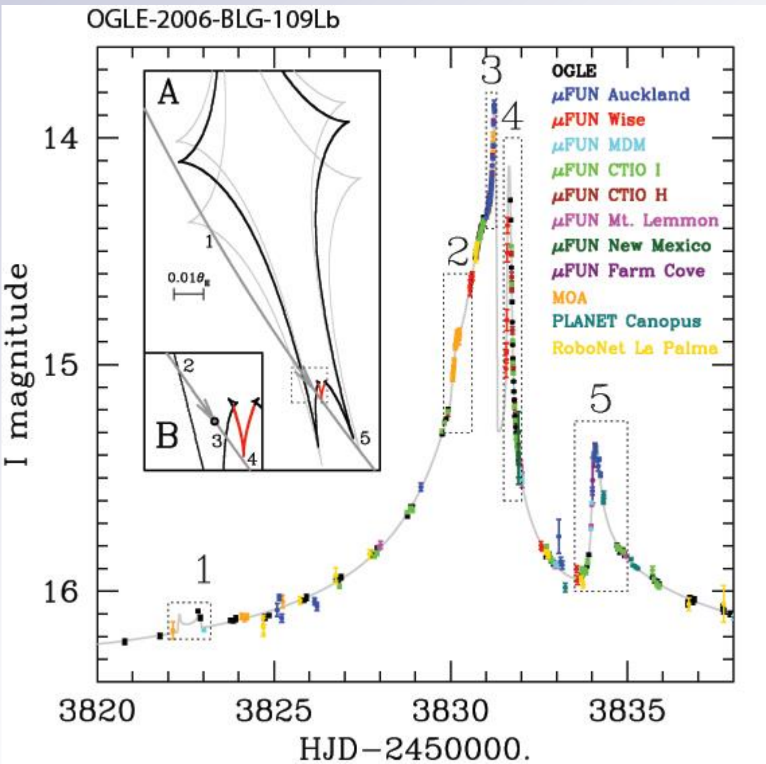
- **Microlensing** occurs when the light of a background star is deflected by the gravitational field of a foreground object.
- **Photometric** and **astrometric** signals.

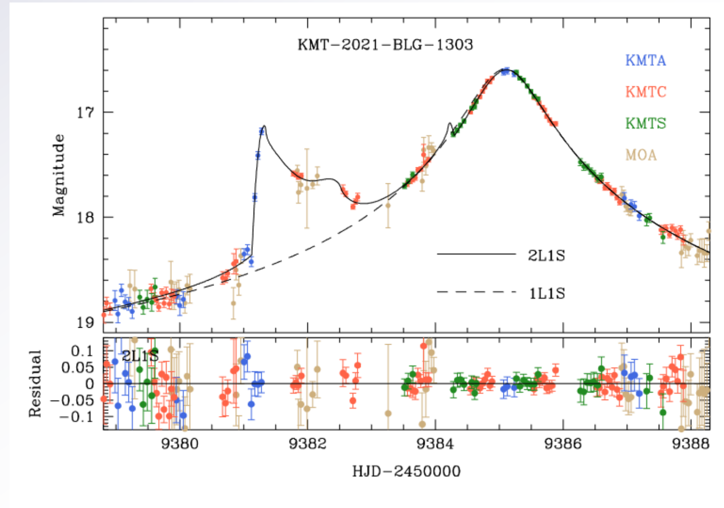


Photometry *Astrometry*

Planets with Microlensing

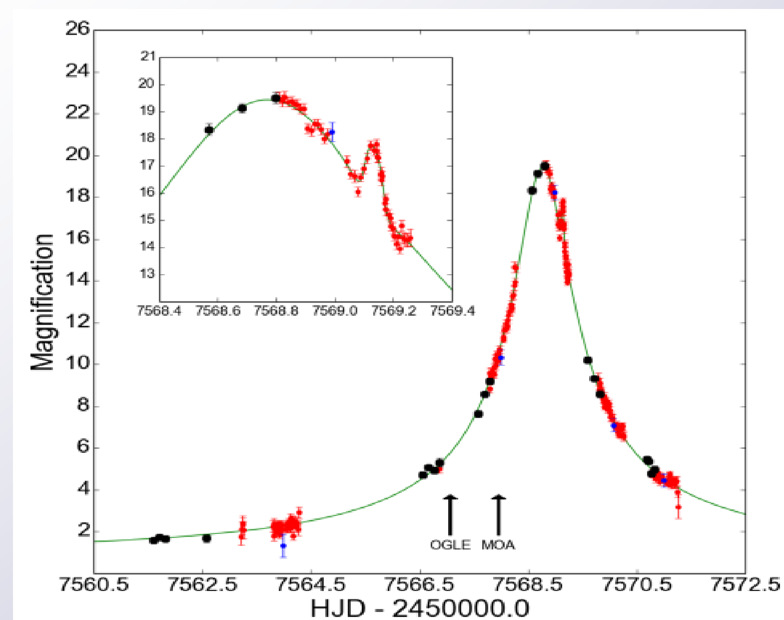
- **204 Planets** up to present
  (Han et al. 2022)





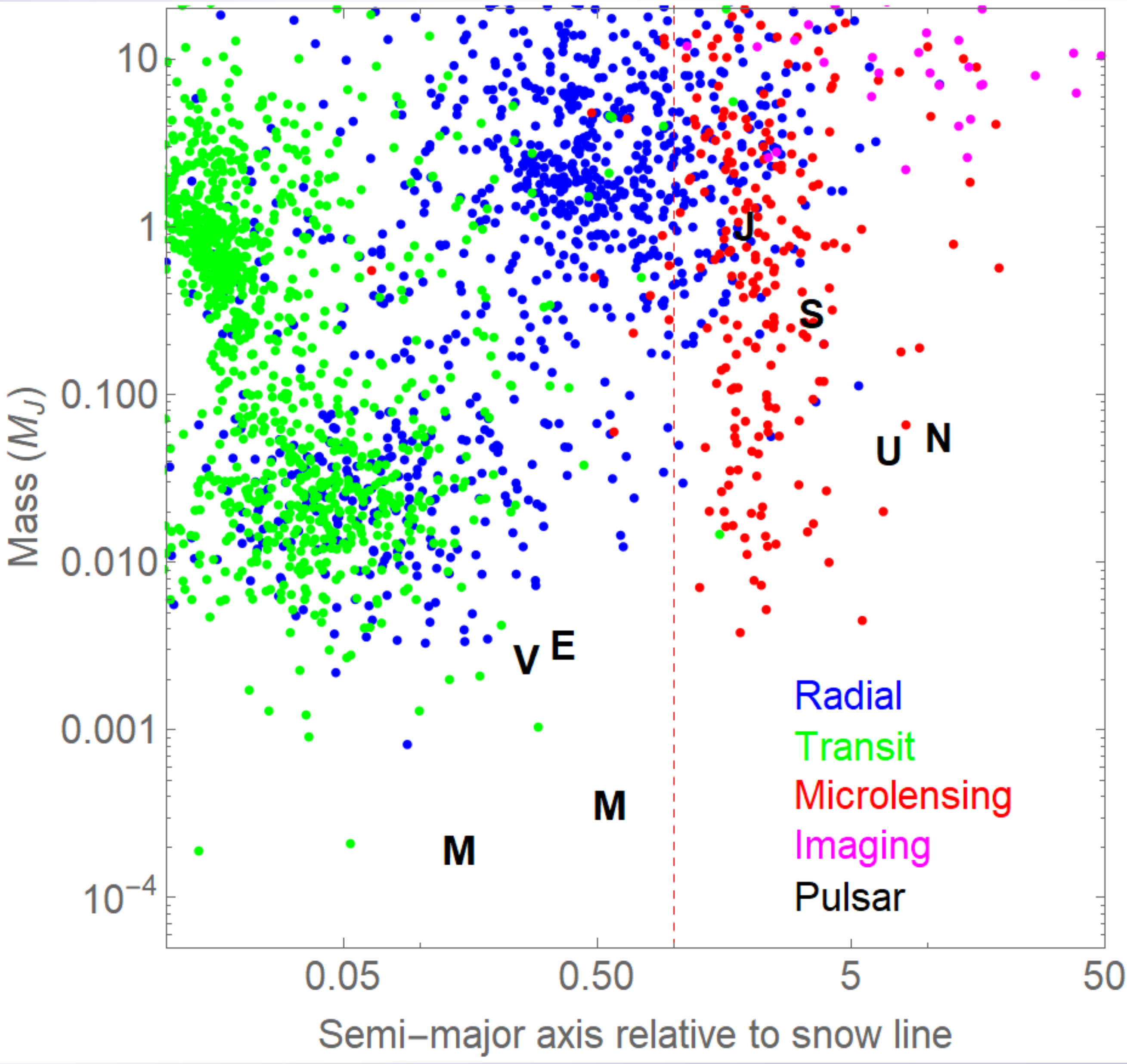
Multi-planetary systems:
Gaudi et al. (2008)

- **Small Icy planets**:
  Bond, VB et al. (2017)



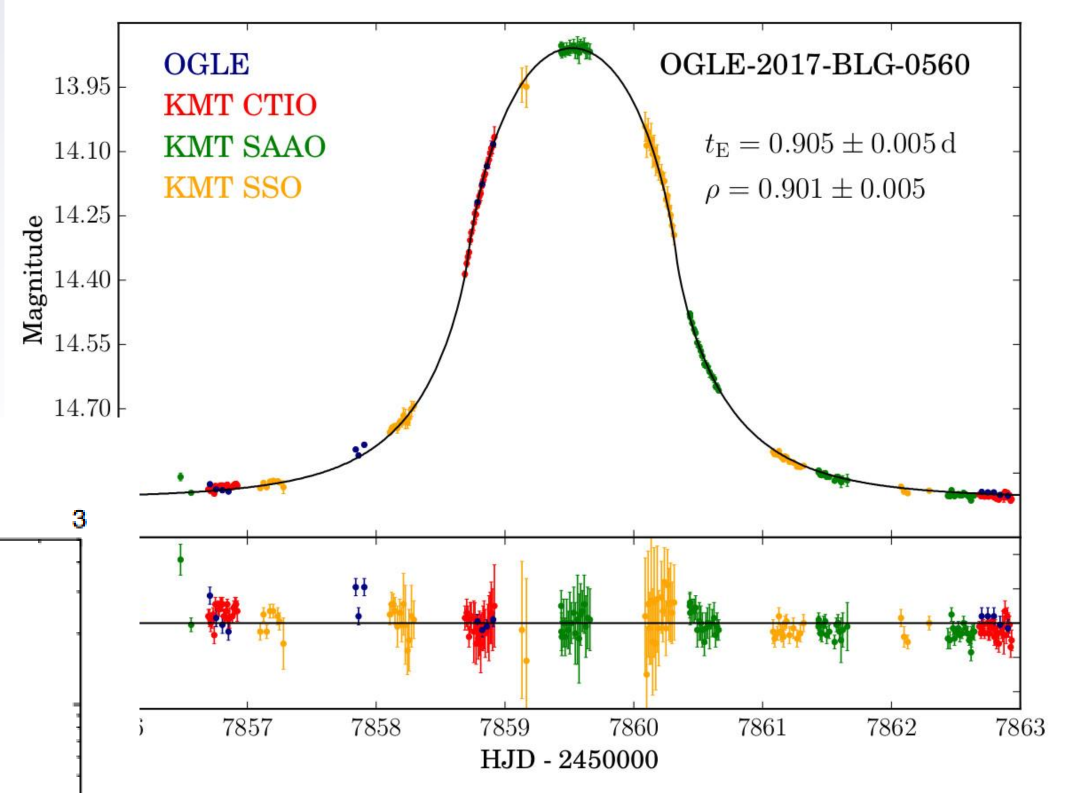
Microlensing planets

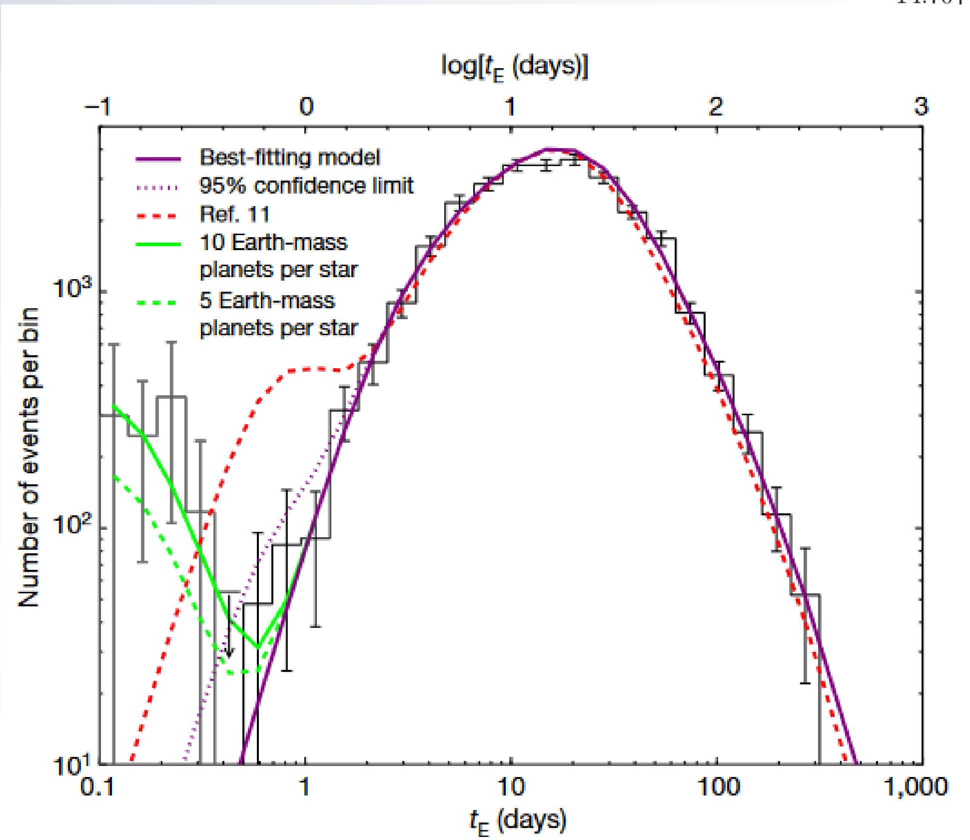
- Planets beyond the **snow line**
- Planets around **cold M-stars**



Free-floating planets

- Microlensing is able to detect **free-floating planets** down to Earth-mass.

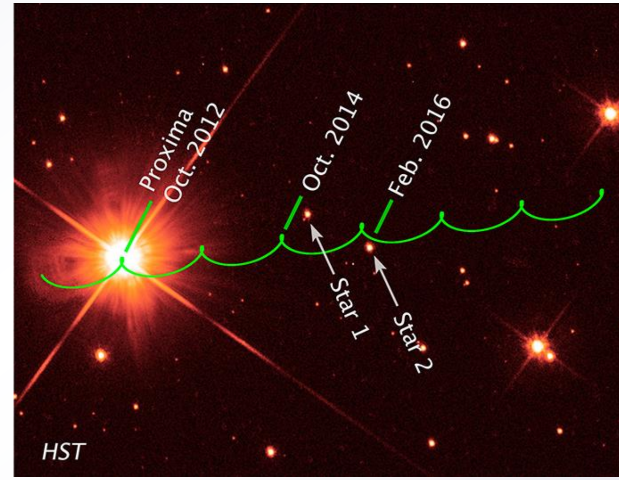


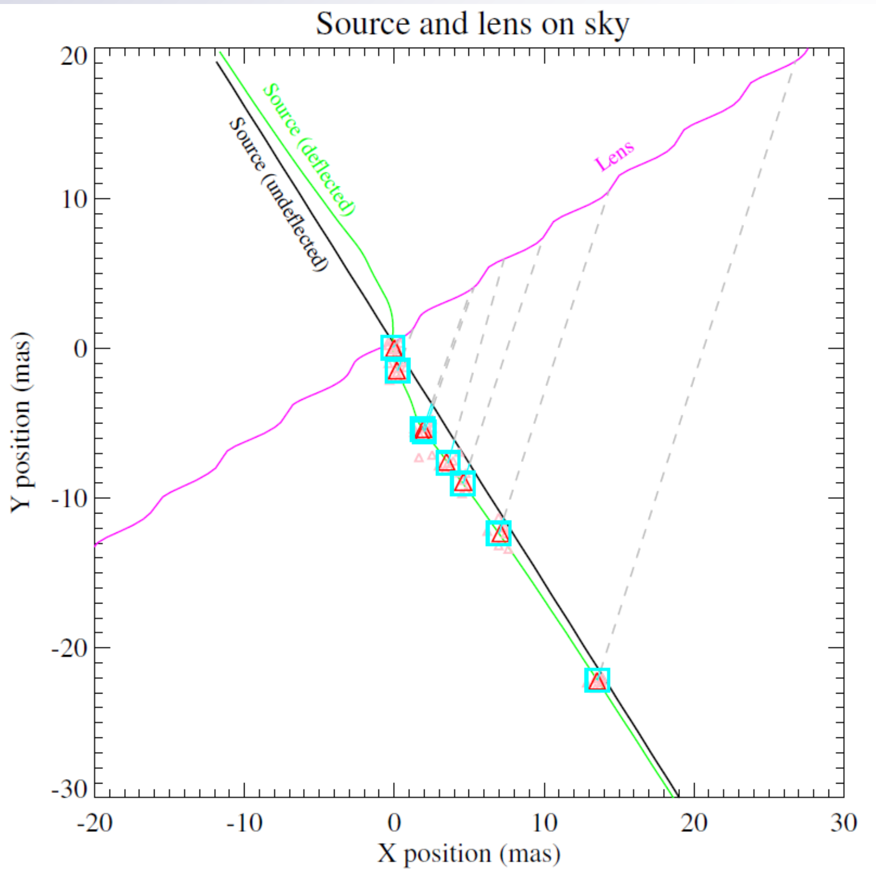


- Free-floating planets should be **as common as stars** *(Mroz et al. 2017)*

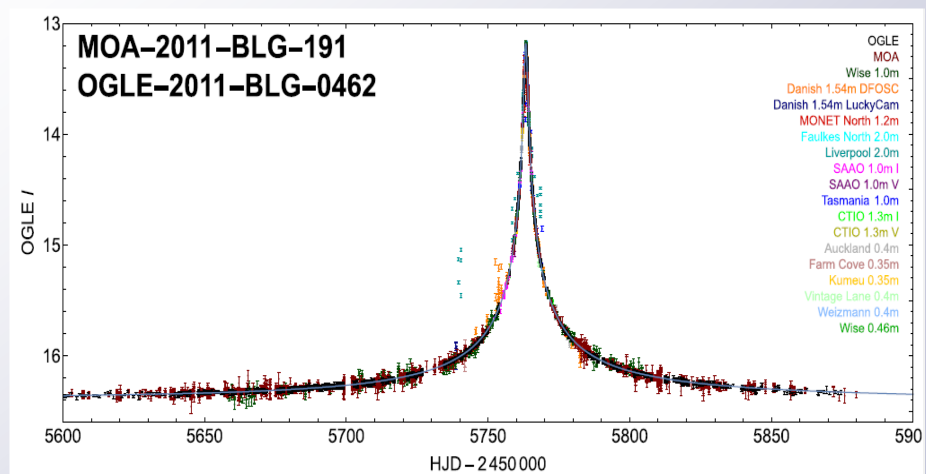
Detections of astrometric microlensing

- White dwarfs *by HST*
  (Sahu et al. 2017, Mcgill et al. 2022)
- Proxima Centauri by VLT *(Zurlo et al. 2018)*





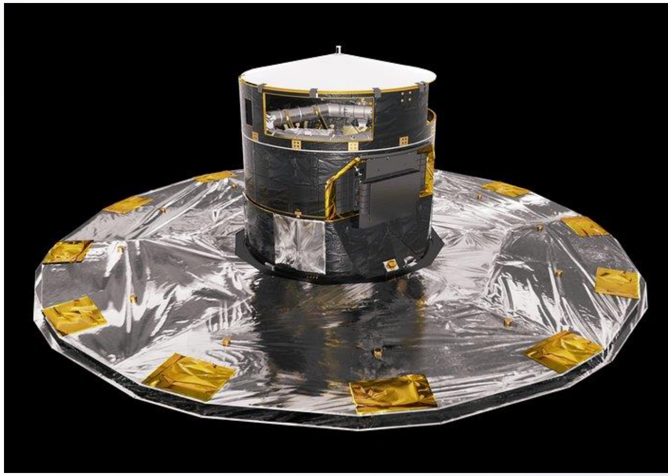
- OGLE-2011-BLG-0462:
  an isolated BH of 7 $M_\odot$ *by HST*
  Sahu, VB et al. (2022), Lam et al. (2022)

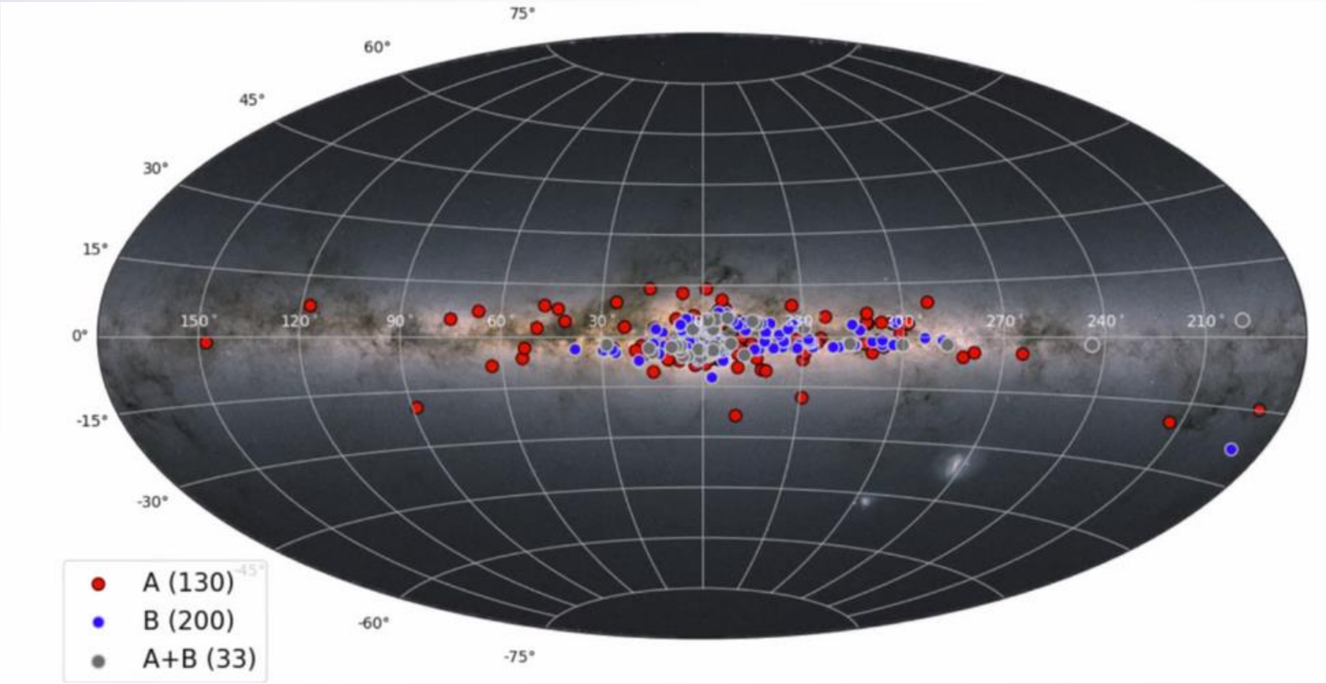


Microlensing with Gaia

- Most detailed three-dimensional map of the Milky Way

- More than **350 microlensing events** detected *(Wyrzykowski et al. 2022)*
- Over 1700 predicted using astrometric simulations *(Klüter et al. 2022)*

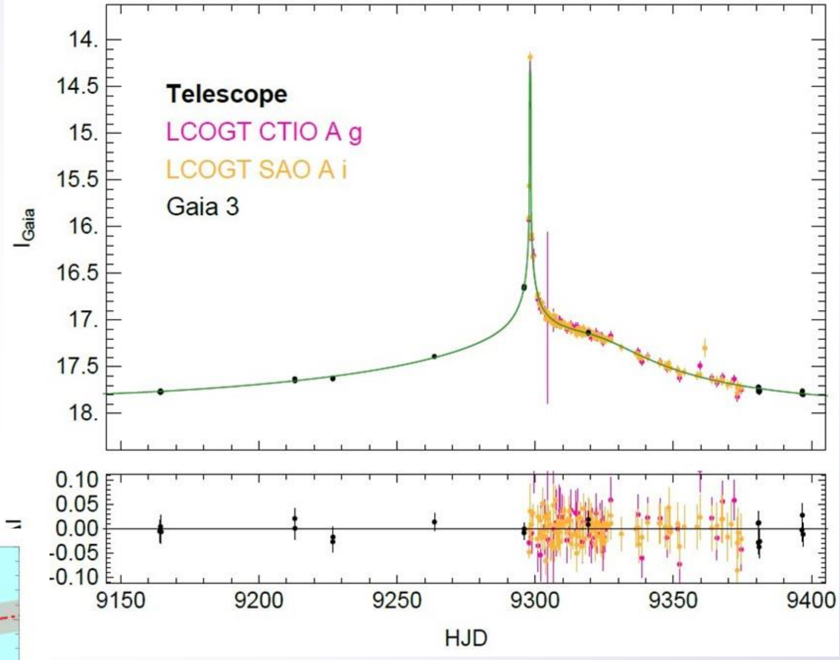


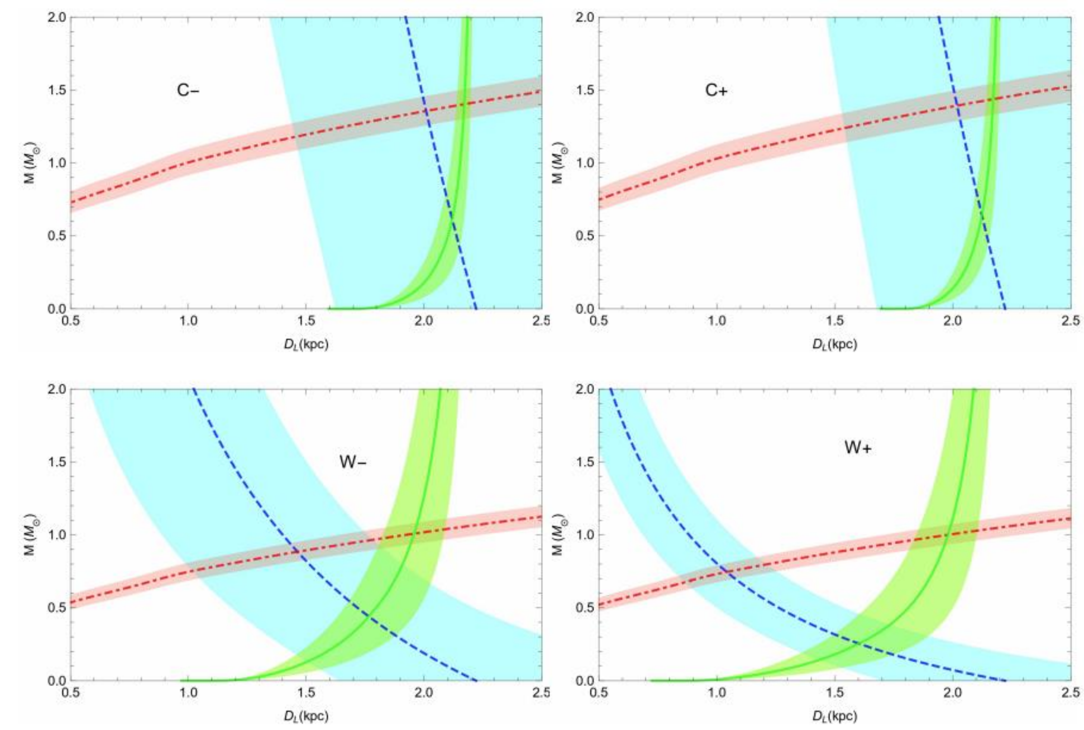


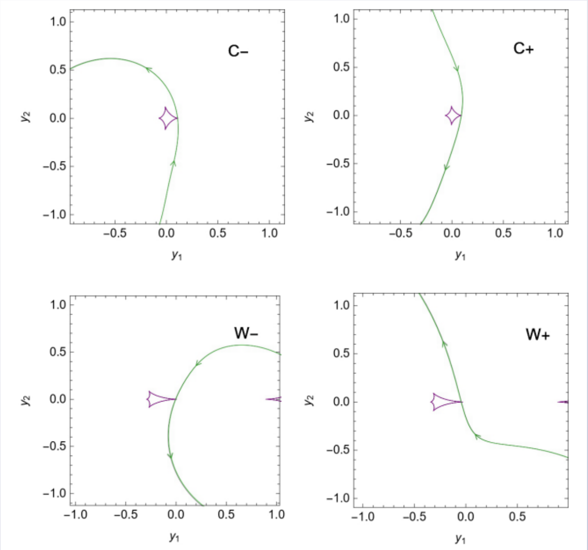
Wyrzykowski et al. 2022

Gaia21blx *(Rota, VB et al., submitted)*

- Dense **follow-up by OMEGA** key project at LCOGT.
- Four degenerate microlensing models by photometry.
- Singled-out the correct one using **Gaia parallax** and proper motion.

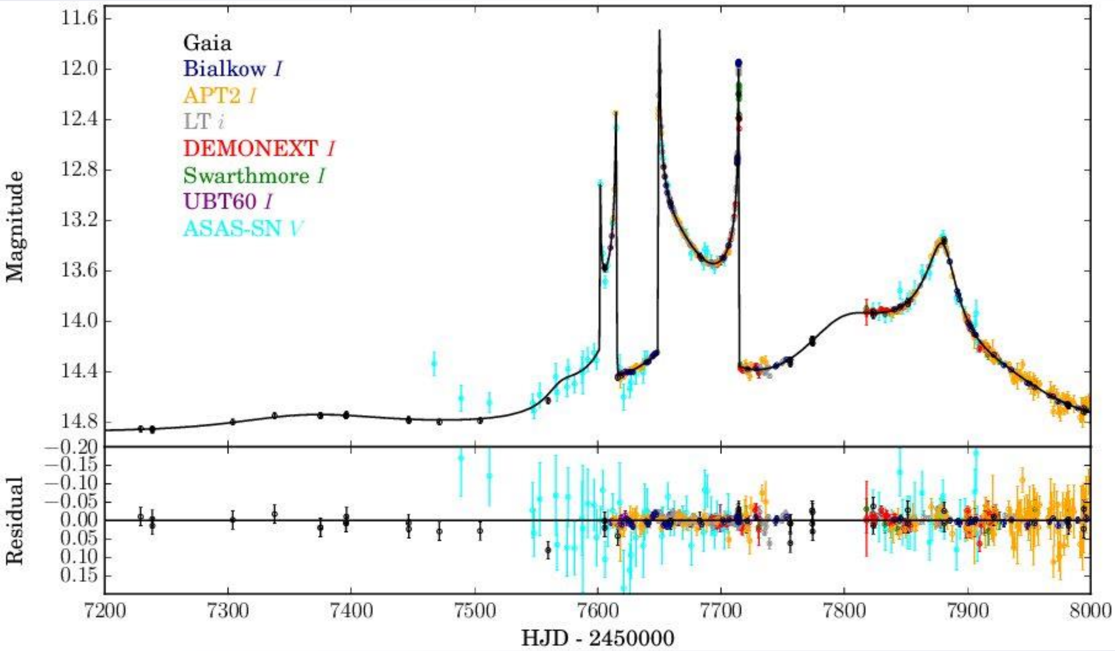


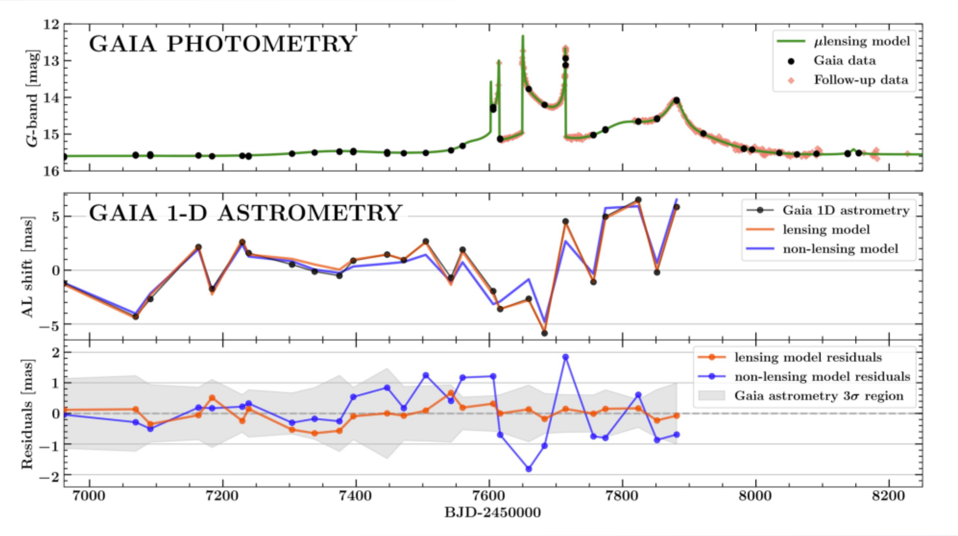




Gaia16aye *(Ribicki, …, VB et al., 2022)*

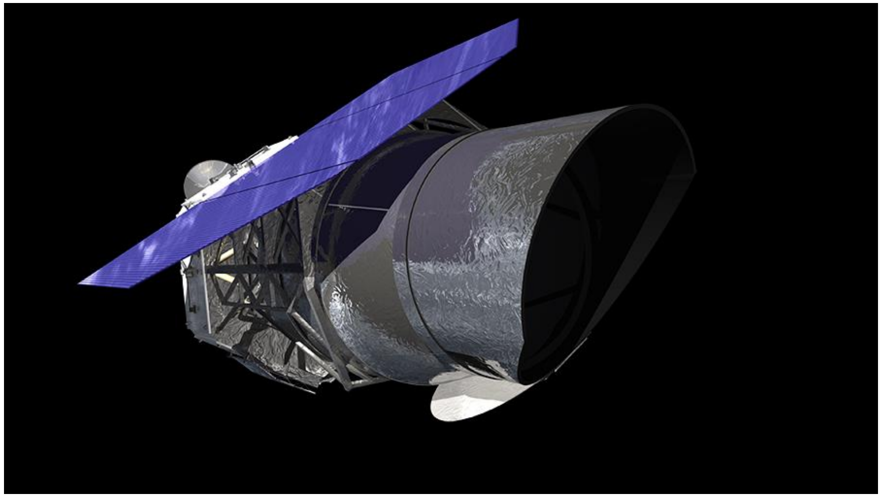
- Very long event due to binary stellar system.
- Orbital motion detected and parameterized.





- The **astrometric** time series perfectly **confirms** the **photometric** model.
- Gaia DR4 will provide **astrometric time series** for each microlensing source.

Nancy Grace Roman Telescope



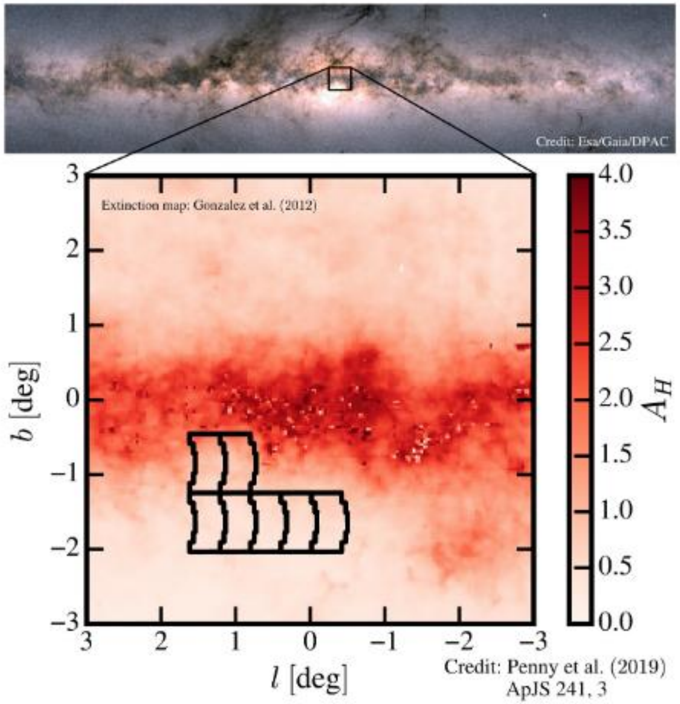
Telescope: 2.4m aperture

Wide Field Instrument

- Vis/Near IR (0.48 – 2.3 micron)
- Field of view 0.281 deg^2 (~200× HST WFC3-IR)

Orbit: Sun-Earth L2

Launch: before May 2027



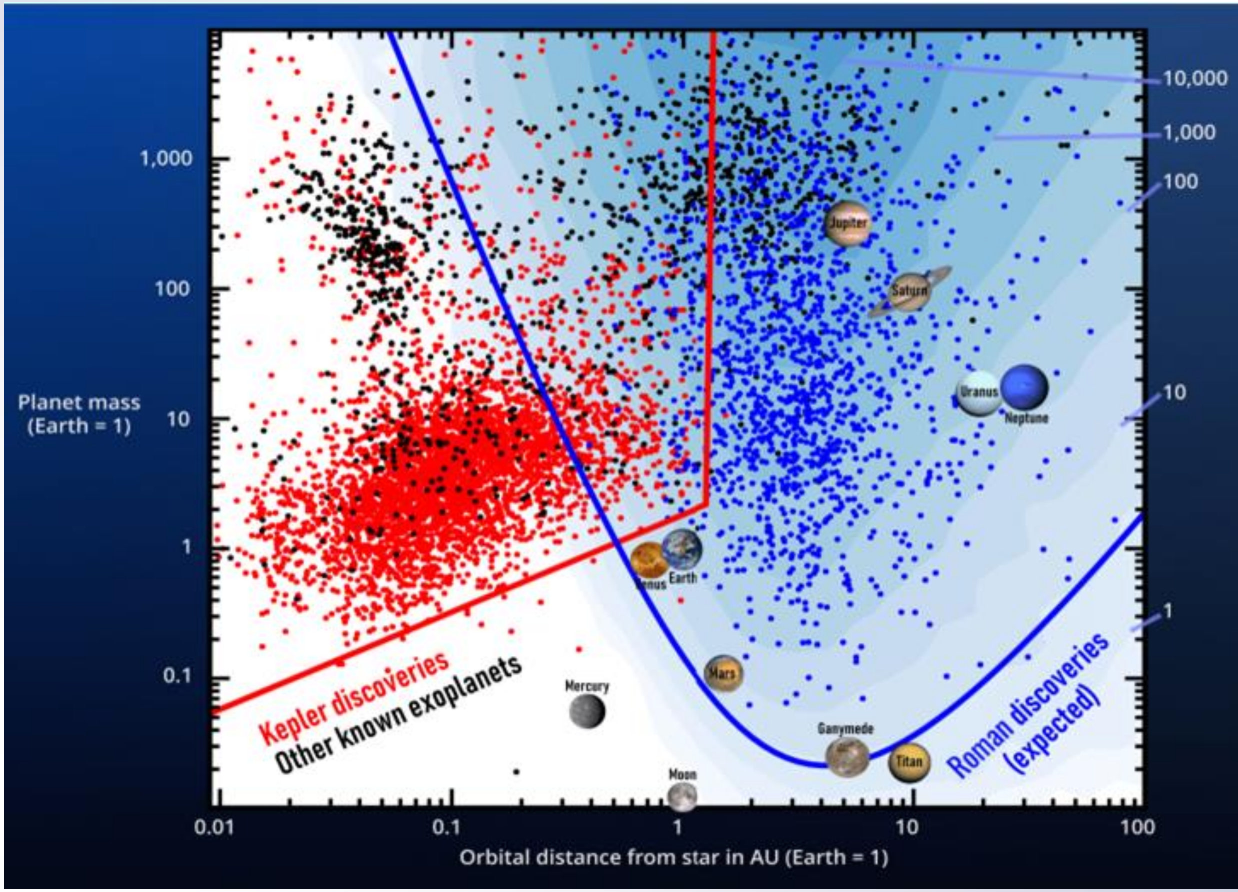
- Roman will carry 6 x 60 days **time-domain surveys** of the bulge
- Each field will be imaged every 15 minutes.
- Two-filters 0.9 – 2.4 μm
- 0.28 deg^2 FoV
- 0.16'' FWHM
- 0.11'' pixel

https://roman.gsfc.nasa.gov/

Roman Galactic Exoplanet Survey

Microlensing expectations:

- ~ **1500** bound planets.
- ~ **300** free-floating planets.
- Planets in the outer **habitable** zone.
- Analogues of **Solar System**.
- Galactic **distribution** of planets.
- Sensitivity to **exomoons**.
- **Remnant** mass function

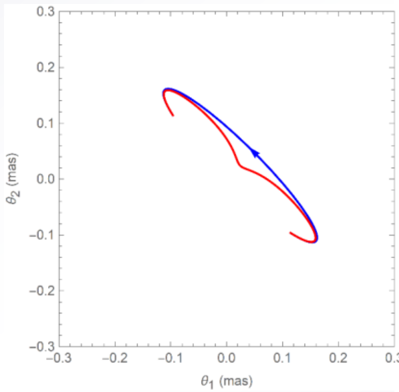


- Roman Galactic Exoplanet Survey – **Project Infrastructure Team** *(PI: S. Gaudi)*
  - Develop simulations, reduction and modeling pipelines, statistics
  - All computations based on **VBBinaryLensing** *(VB 2010; VB et al. 2018; 2021)* https://github.com/valboz/VBBinaryLensing
  - Modeling pipeline based on **RTModel** *(VB 2024).* https://github.com/valboz/RTModel

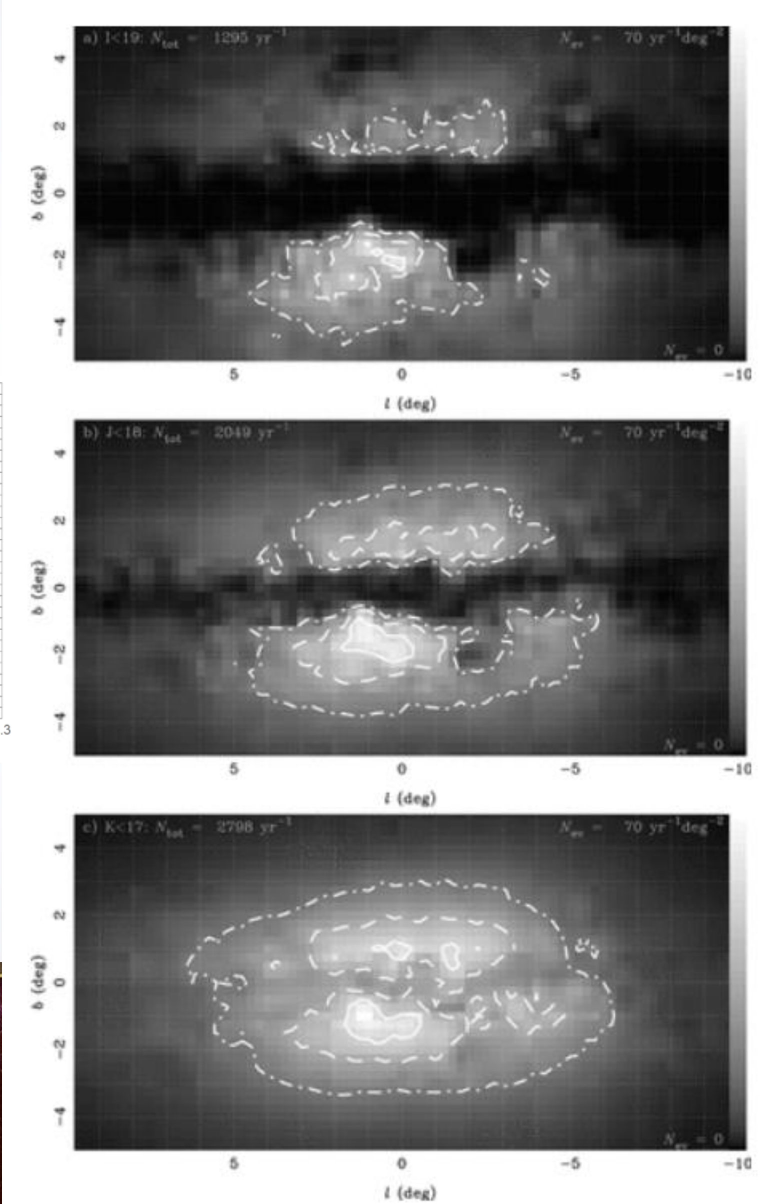
Gaia-NIR

- K-band observations allow to study **heavily extincted** regions of the bulge and the disk.
- Stellar, planetary and remnant distributions in the denser regions!

- Astrometric information crucial to break degeneracies and **measure masses**!



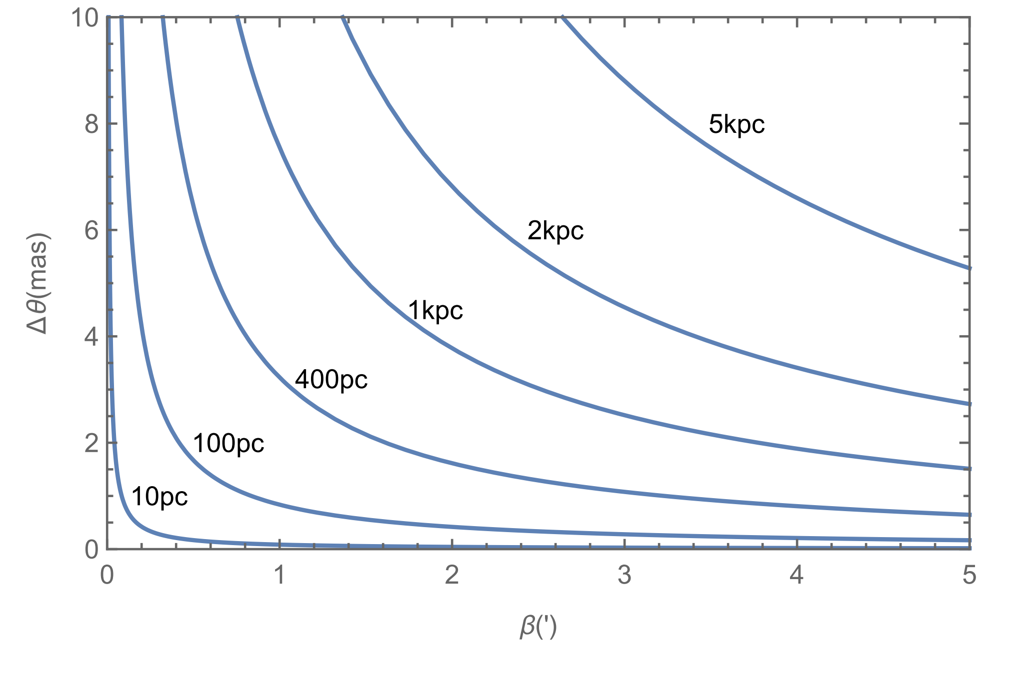
- Sparse sampling is insufficient for microlensing characterization.
- Need to design **follow-up** resources in NIR bands.

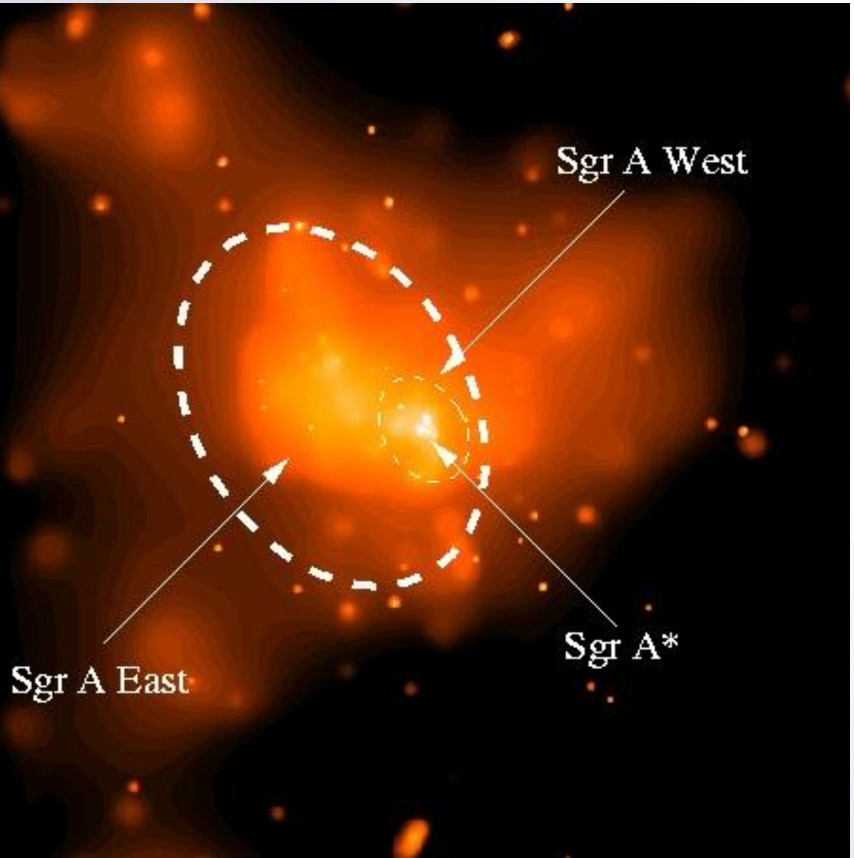


(Kerins, Robin, Marshall 2009)

Lensing by Sgr A*

- Sgr A* is a black hole with
  $$M = 4.3 \times 10^6 M_\odot$$
- Lensing shifts are of several mas for sources several arcminutes away *(Wardle & Yusef-Zadeh 1992).*





- Detailed lensing depends on the mass distribution.
- Possibility of weak lensing reconstruction!

Chandra image of Galactic center in X-rays

Conclusions

- **Microlensing** has been **very effective** within Gaia mission.
- Study of stellar binaries and planets with accurate parameters.
- **Astrometry** is the key to break degeneracies and determine the masses of the lenses.
- **Black holes** particularly benefit!
- Future microlensing mission **Roman** will observe in NIR and discover **thousands events**.
- **Gaia-NIR** may extend previous microlensing studies to **heavily extincted regions**.
- Need for follow-up.
- **Lensing by the Sgr A*** region may allow a detailed mass reconstruction.

BHTOM workshop in Vietri sul Mare (SA)

- 15 April 2024
- Hands-on sessions to learn BHTOM, an invaluable tool for follow-up telescopes.
- https://gsawg.wiki.ast.cam.ac.uk/index.php?title=BHTOM-IT-2024:main

- Organizing committee
  - Lukasz Wyrzykowski (Warsaw)
  - Pawel Zielinski (Torun)
  - Valerio Bozza (Salerno)
  - Paolo Rota (Salerno)