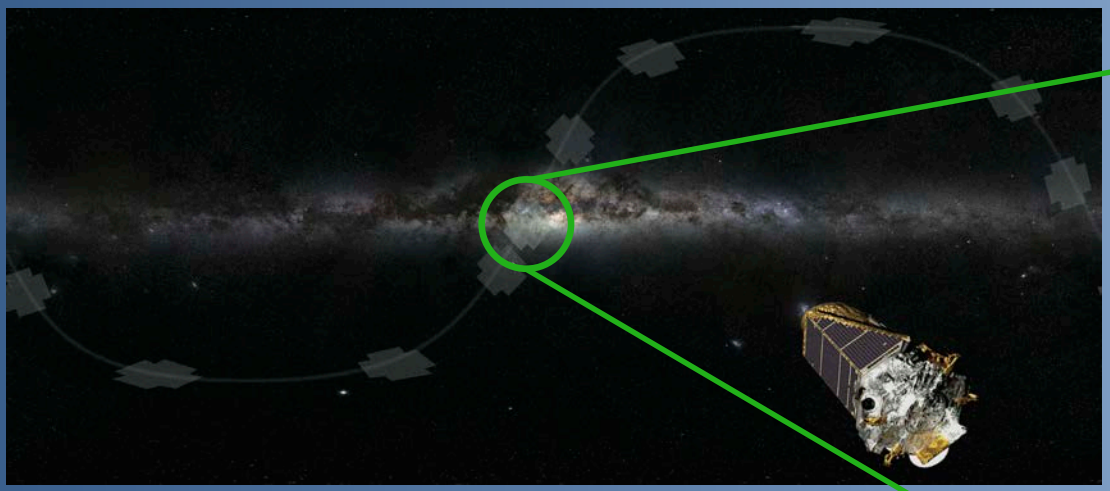
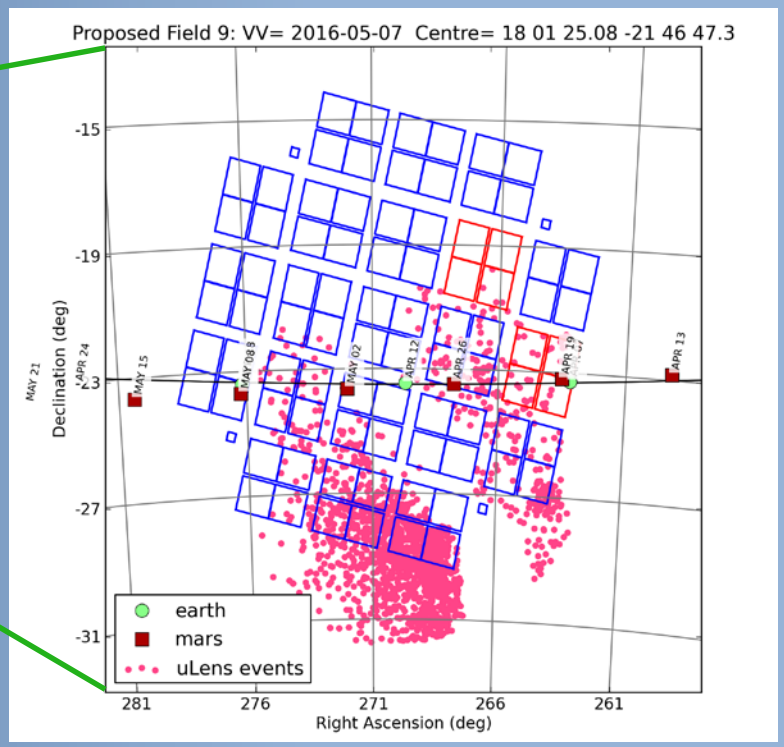
K2's Campaign 9: The First Microlensing Survey from the Ground and from Space





Calen B. Henderson (JPL/Caltech)

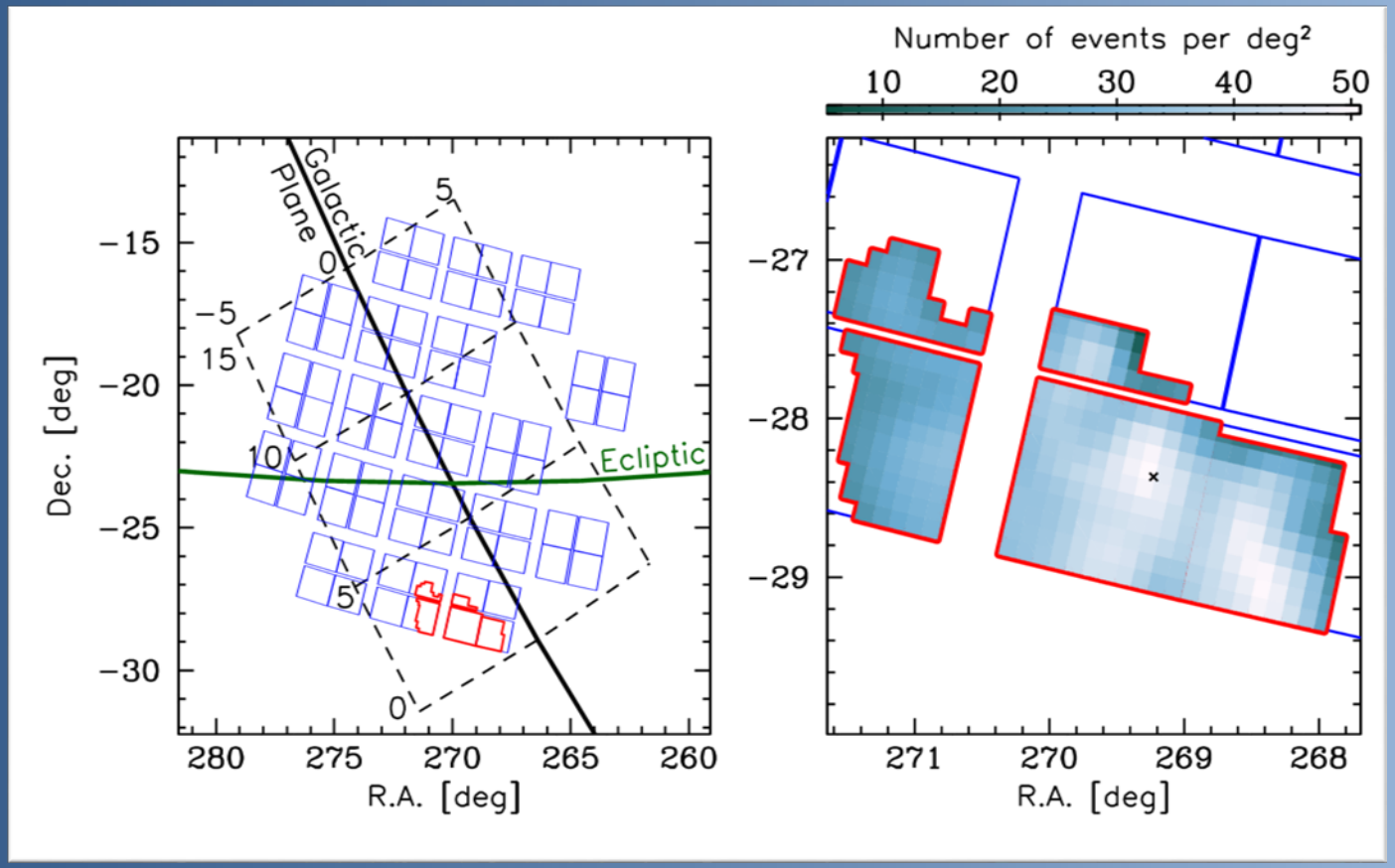
*K2*C9 Microlensing Science Team Member

Exoplanets I: Davos, Switzerland

F, 8/Jul/2016

Jet Propulsion Laboratory
California Institute of Technology

Parameters of *K2C9*



Dates

21/Apr → 1/Jul

Area*

3.7 deg^2

Cadence

30 minutes

Events*

120+

Found in: [Henderson+ (2016) arXiv:1512.09142]

Uses methodology of: [Poleski (2016) MNRAS, 455, 3656]

Why conduct microlensing from space?

Why conduct microlensing from space?

Standard Observables

Single Object Lens

Einstein Timescale: t_E

Finite Source Size: ρ

Why conduct microlensing from space?

Standard Observables

Single Object Lens

Einstein Timescale: t_E

Finite Source Size: ρ

Two-body Lens

Mass Ratio: q

Projected Separation: s

Why conduct microlensing from space?

Standard Observables

Single Object Lens

Einstein Timescale: t_E

Finite Source Size: ρ

Two-body Lens

Mass Ratio: q

Projected Separation: s

Parameters

Lens Mass: M_l

Lens System Distance: D

Why conduct microlensing from space?

Standard Observables

Single Object Lens

Einstein Timescale: t_E

Finite Source Size: ρ

Two-body Lens

Mass Ratio: q

Projected Separation: s

?

Parameters

Lens Mass: M_l

Lens System Distance: D

Why conduct microlensing from space?

Standard Observables

$$M_l = \theta_E / (\kappa \pi_E)$$

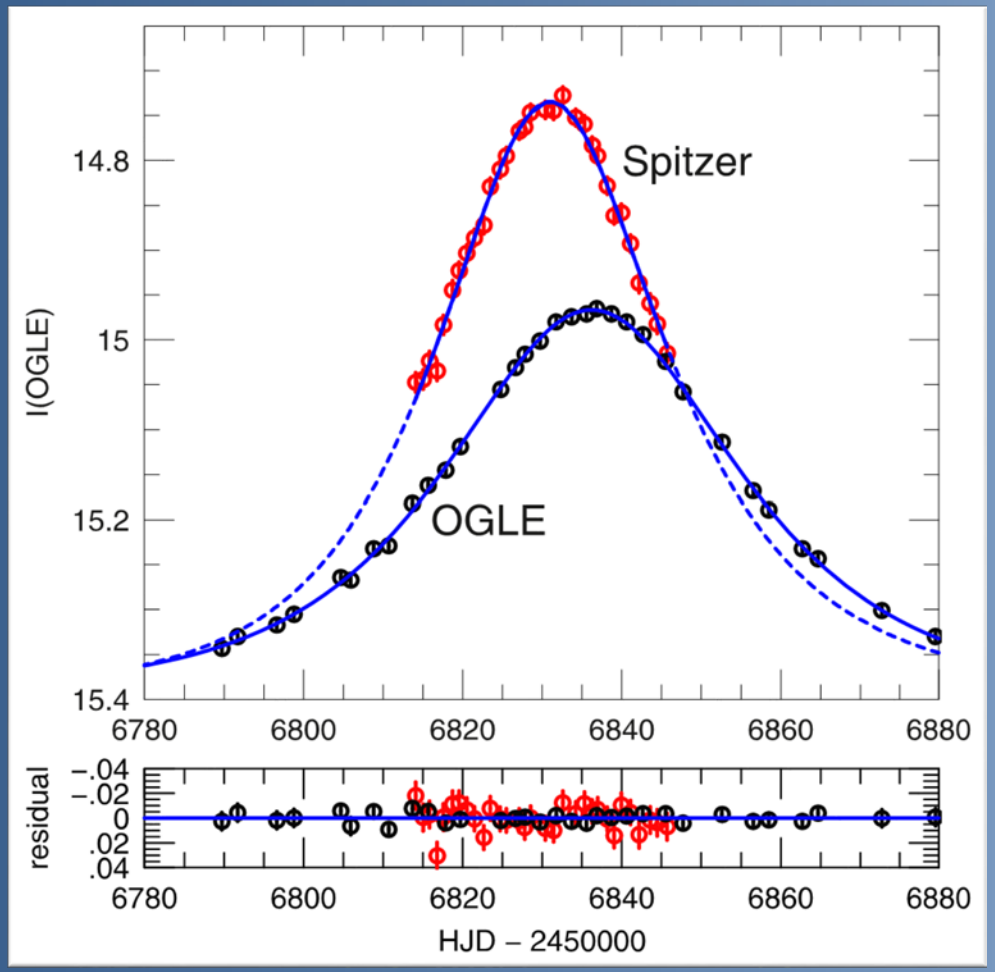
M_l: Lens Mass

θ_E: Einstein Radius

κ: Constant

π_E: Microlens Parallax (Satellite Parallax)

Determining the Lens Mass



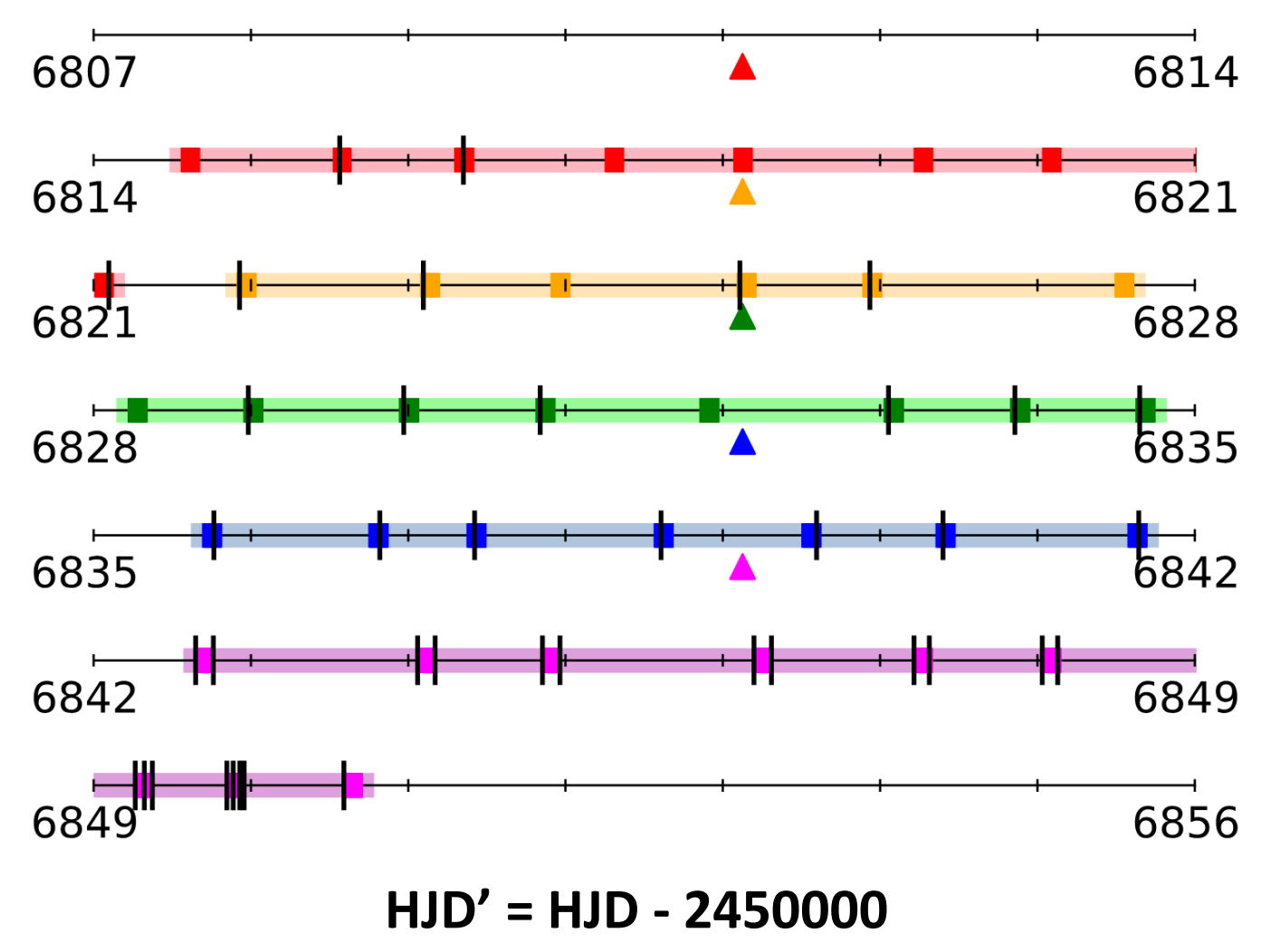
Satellite Parallax π_E

⇩

Lens Mass M_l

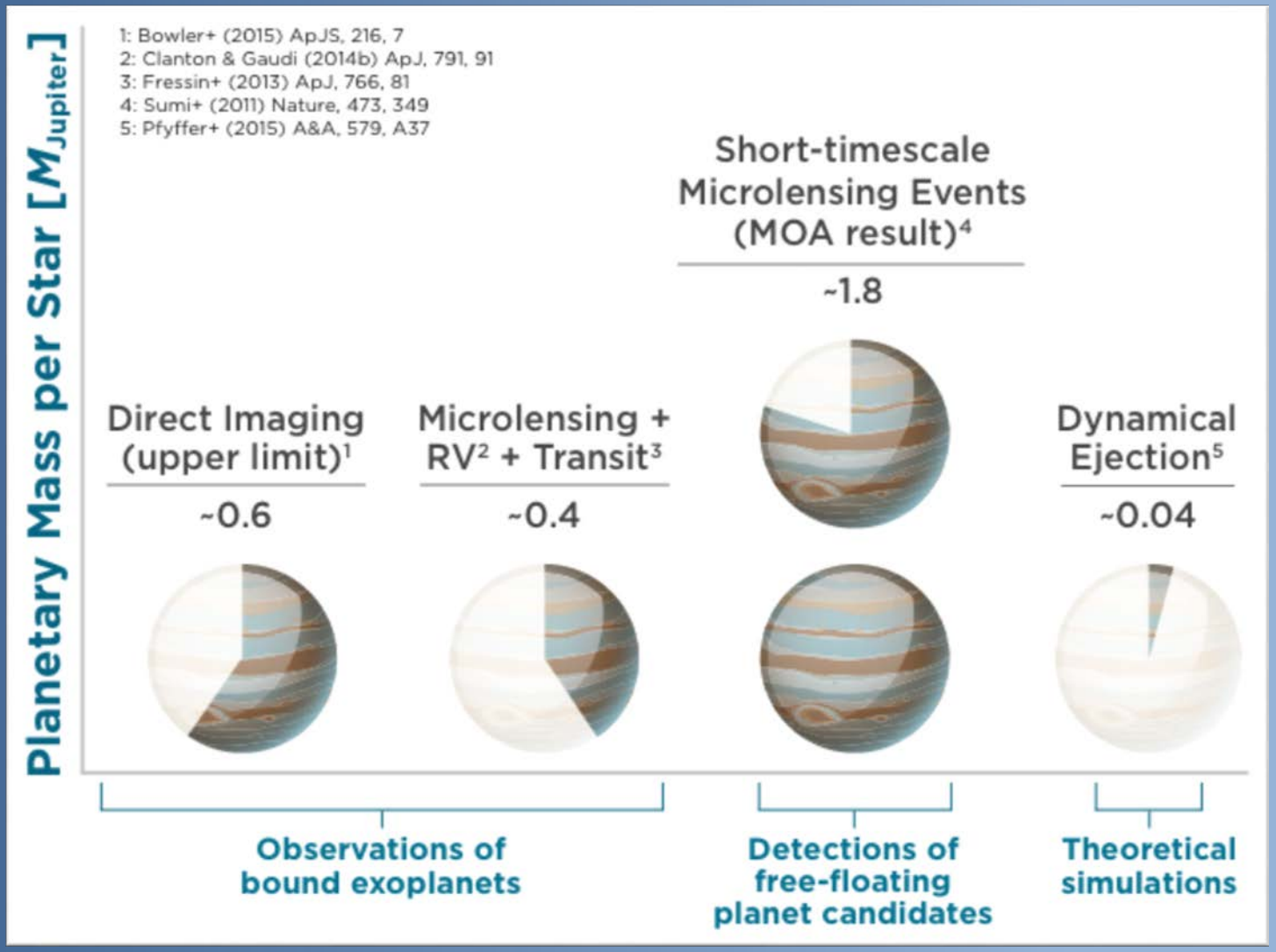
Yee+ (2015) ApJ, 802, 76

Limitation of *Spitzer* Campaigns



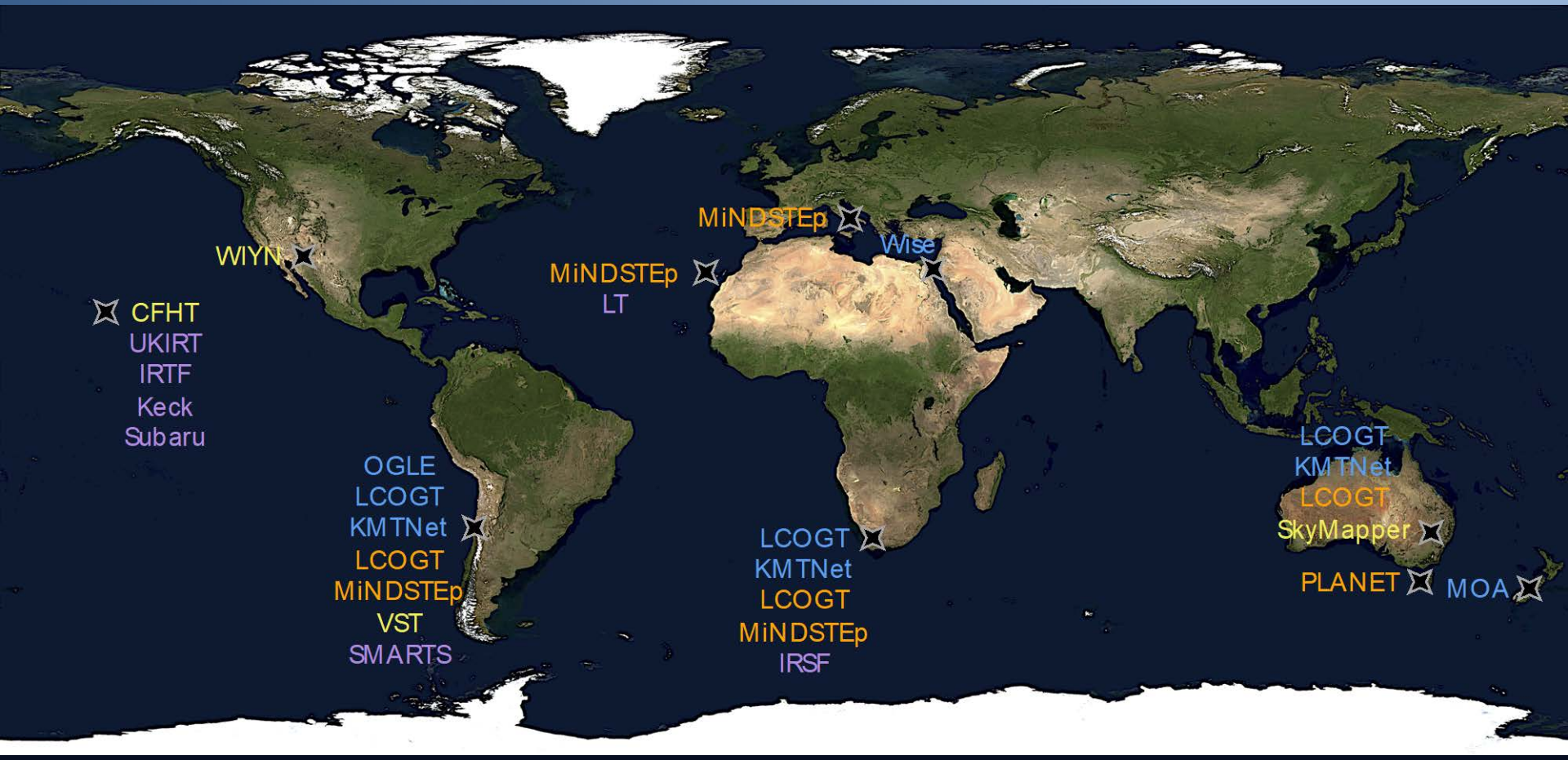
Udalski+ (2015) ApJ, 799, 237

Planetary Mass Budget



Henderson+ (2016) ArXiv:1512.09142

Concurrent Ground-based Resources



Automated Survey
Multiband Monitoring

High-cadence Follow-up
Near-infrared Source Fluxes

Henderson+ (2016) ArXiv:1512.09142

Questions to Ask:

1) Is the lens low-mass?

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1) Is the lens low-mass?

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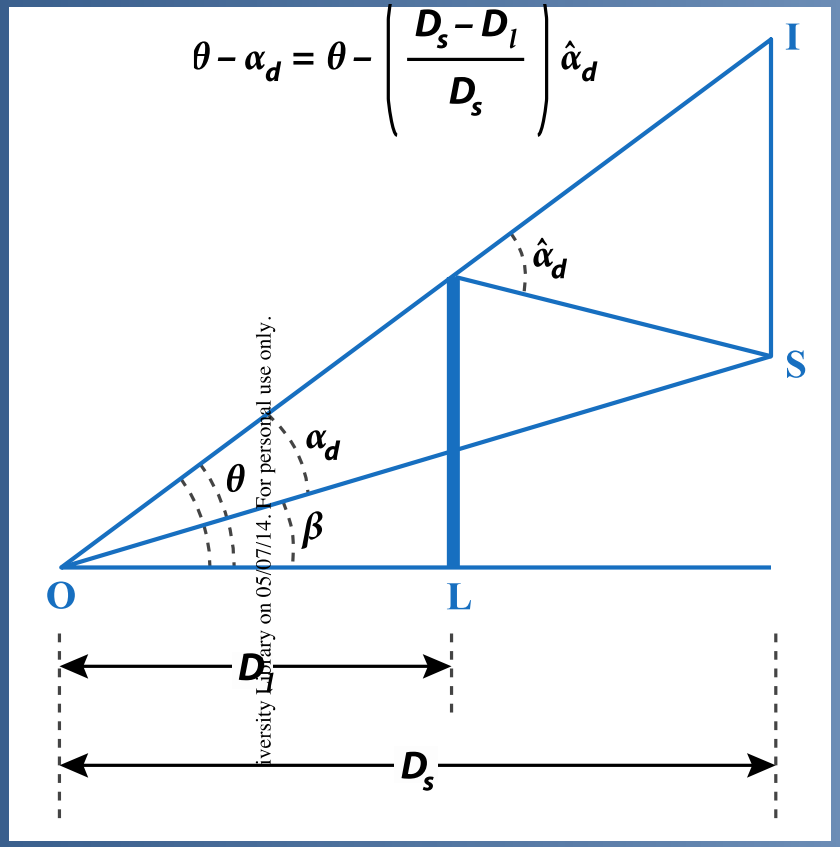
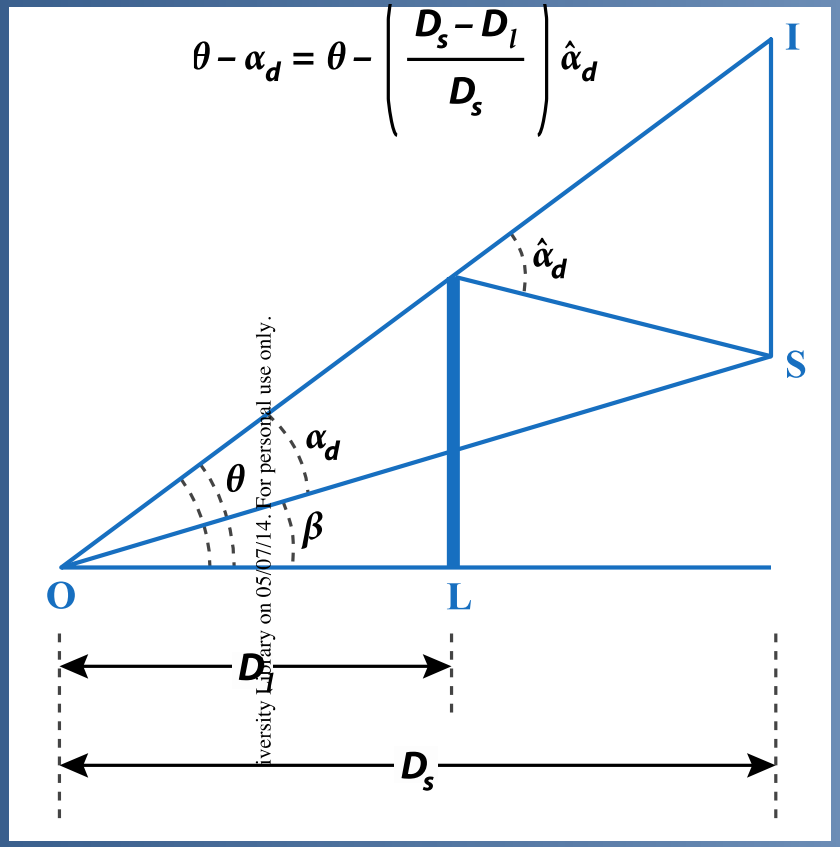
Microlensing Geometry



iversity Library on 05/07/14. For personal use only.

Gaudi (2012) ARAA, 50, 411

Microlensing Geometry



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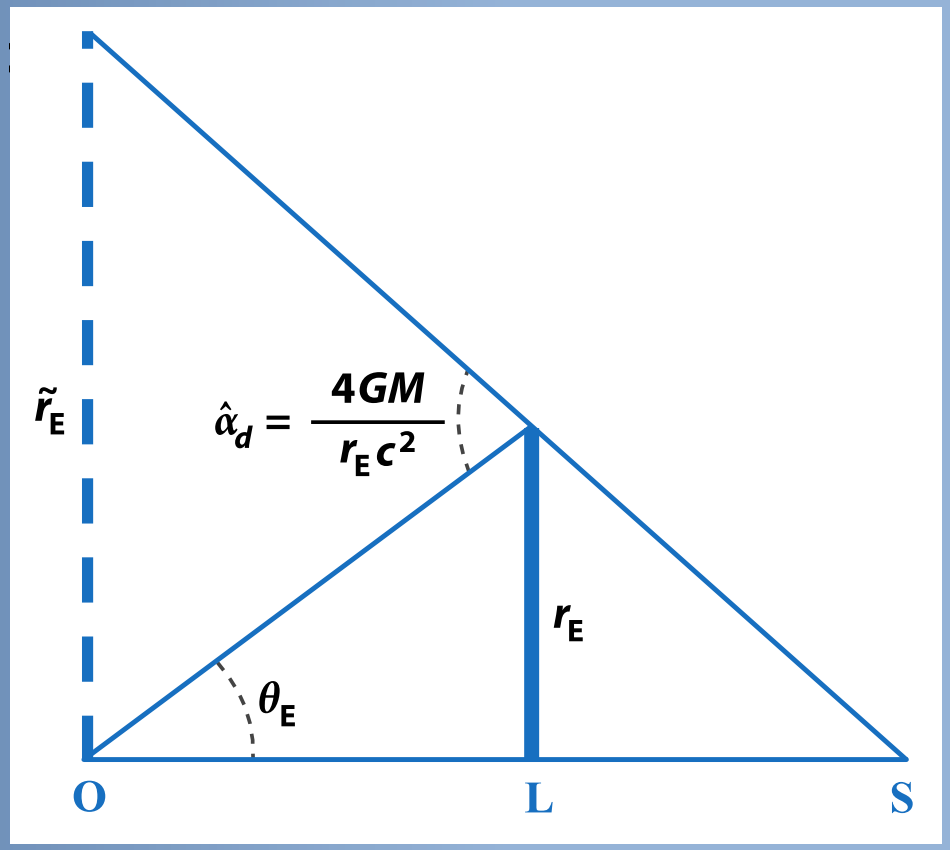
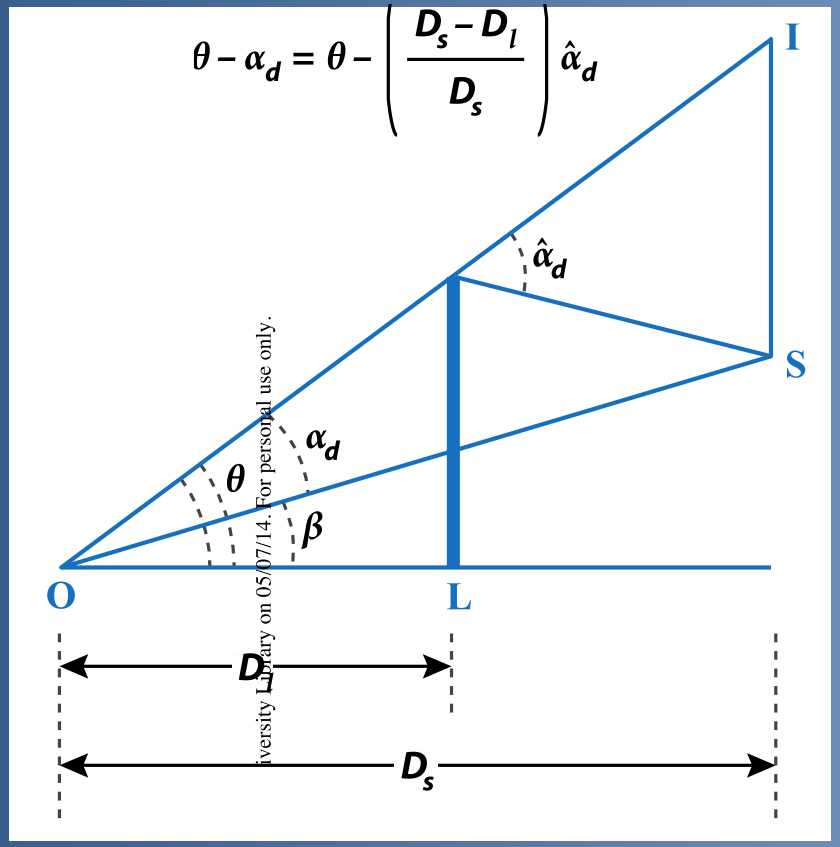
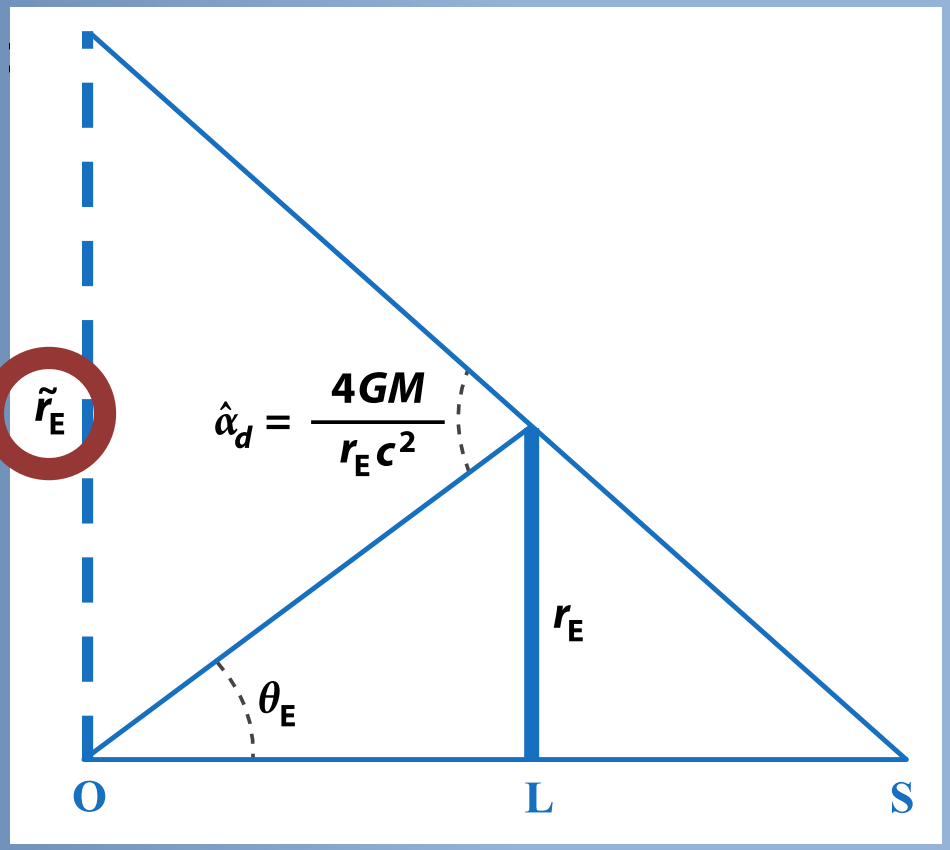


Gaudi (2012) ARAA, 50, 411

Microlensing Geometry

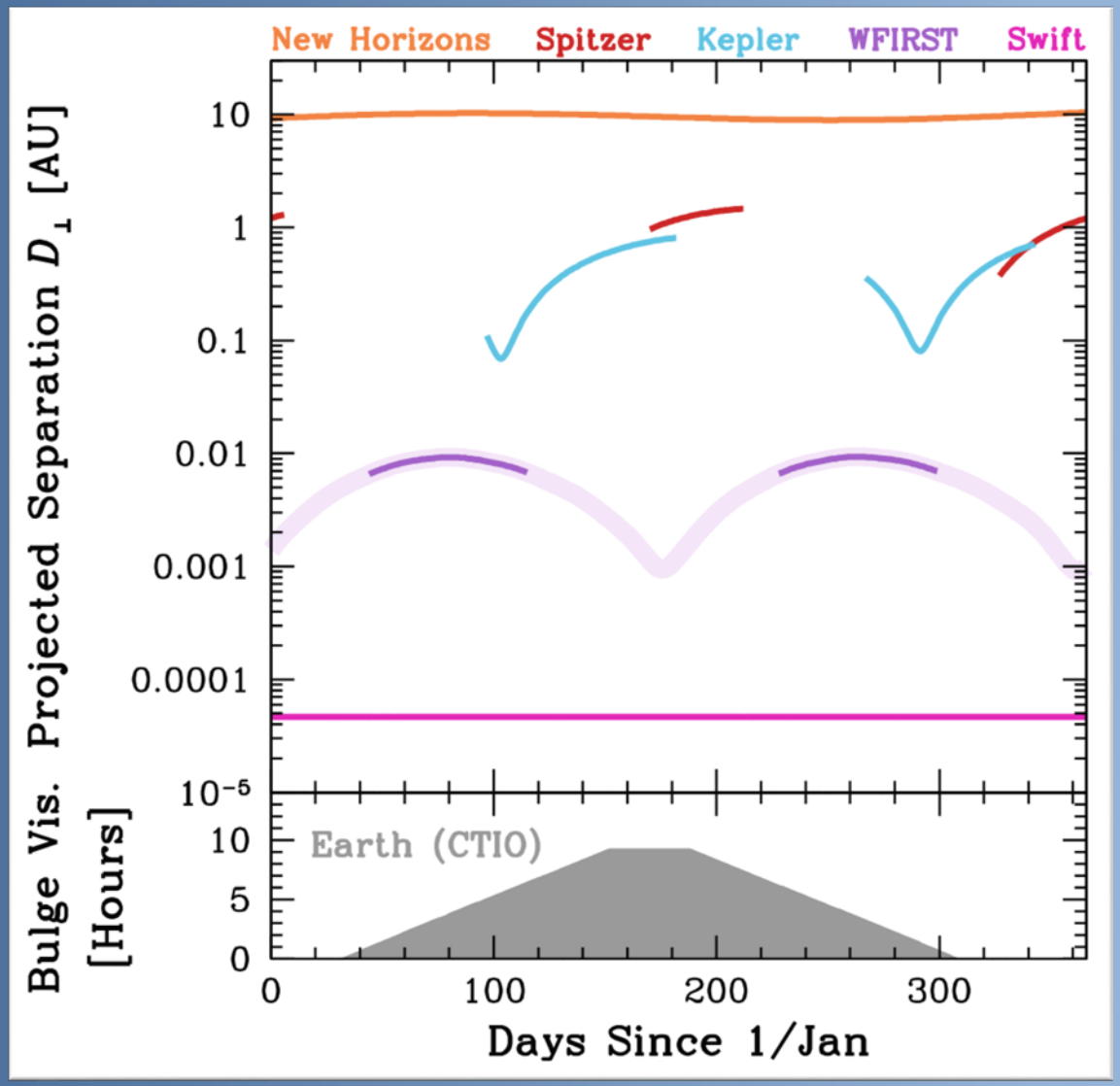


iversity Library on 05/07/14. For personal use only.



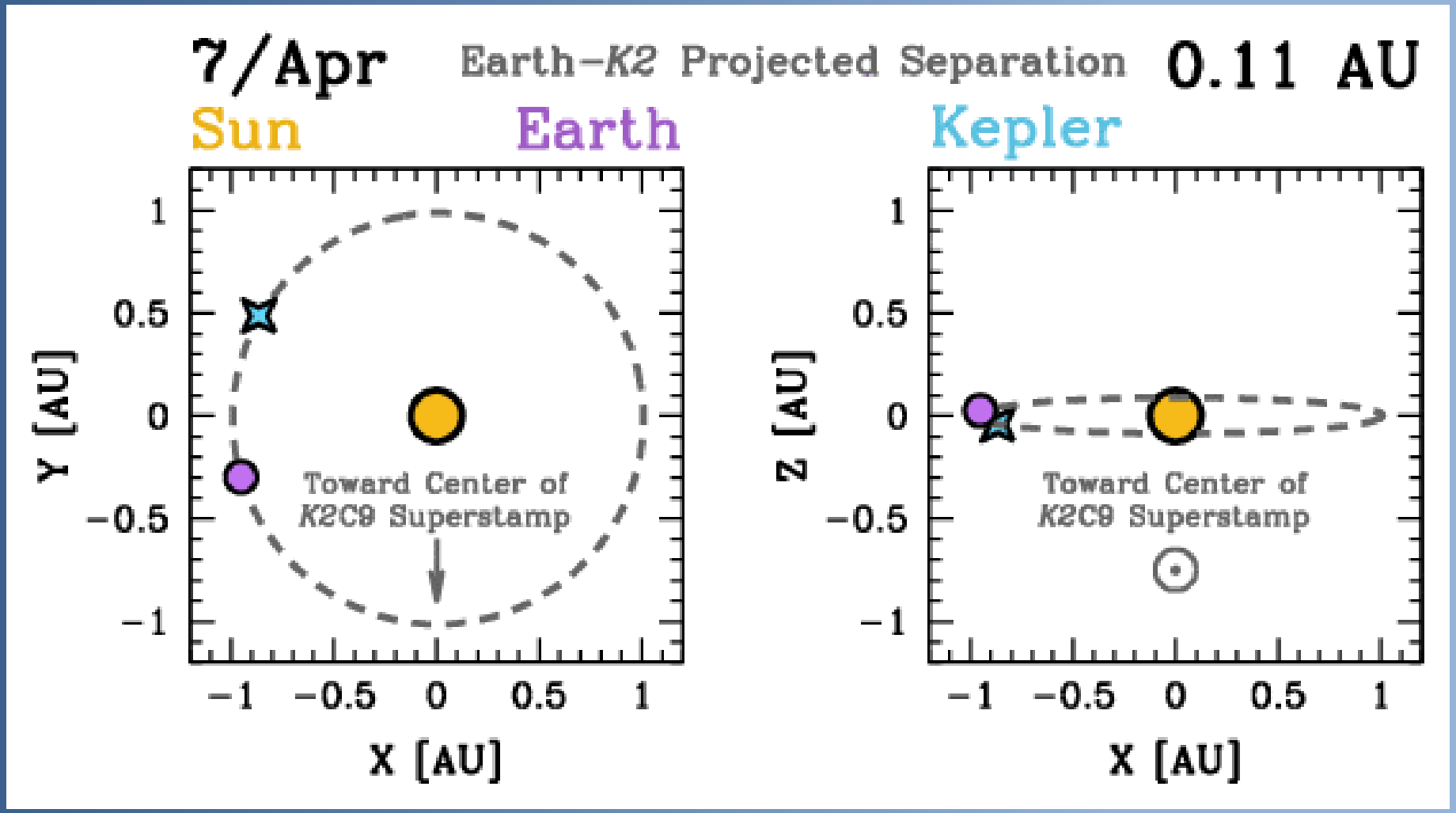
Gaudi (2012) ARAA, 50, 411

Current and Future Space Missions

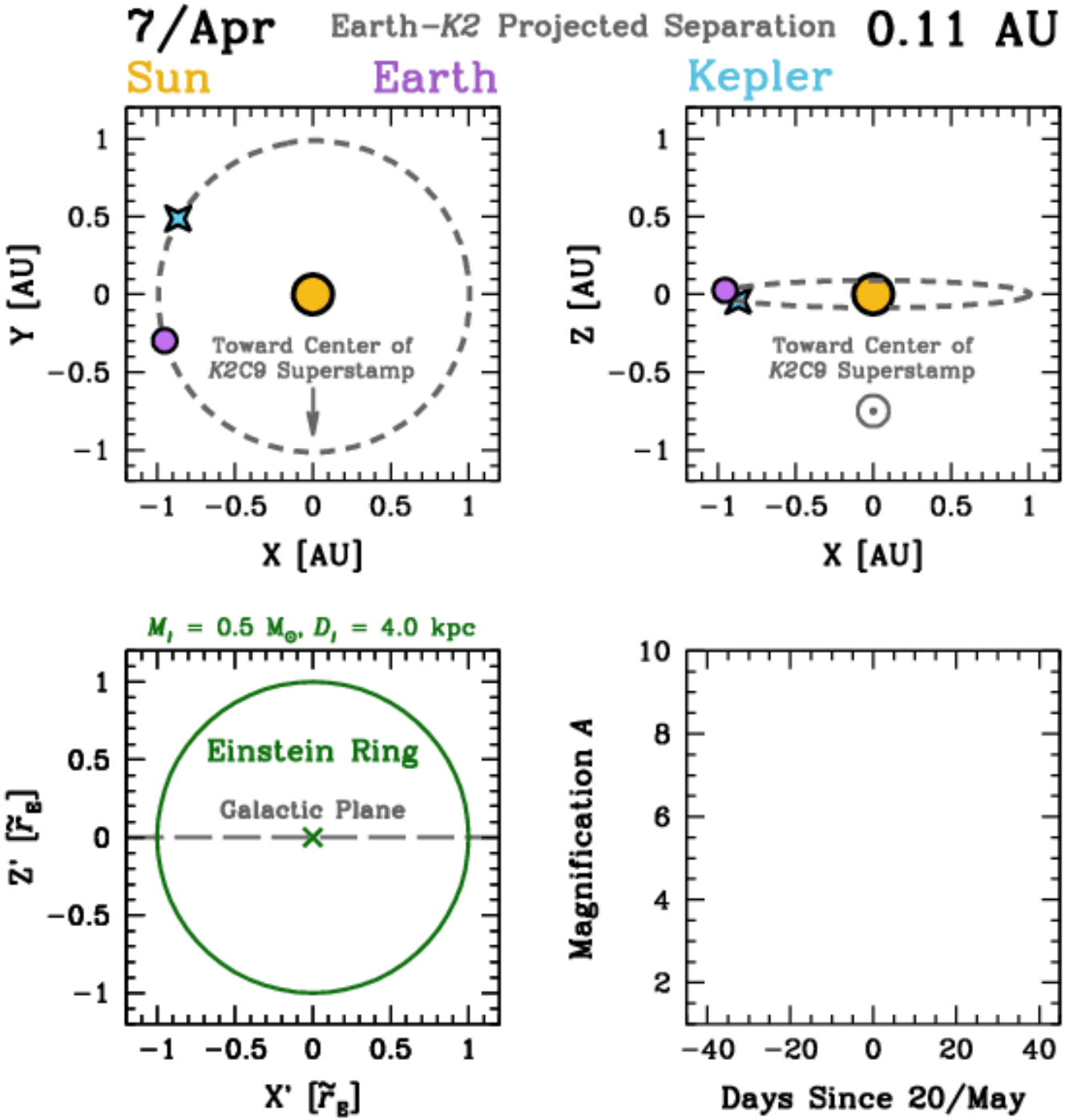


Henderson & Shvartzvald (2016) arXiv:1603.05249

Orbital Geometry

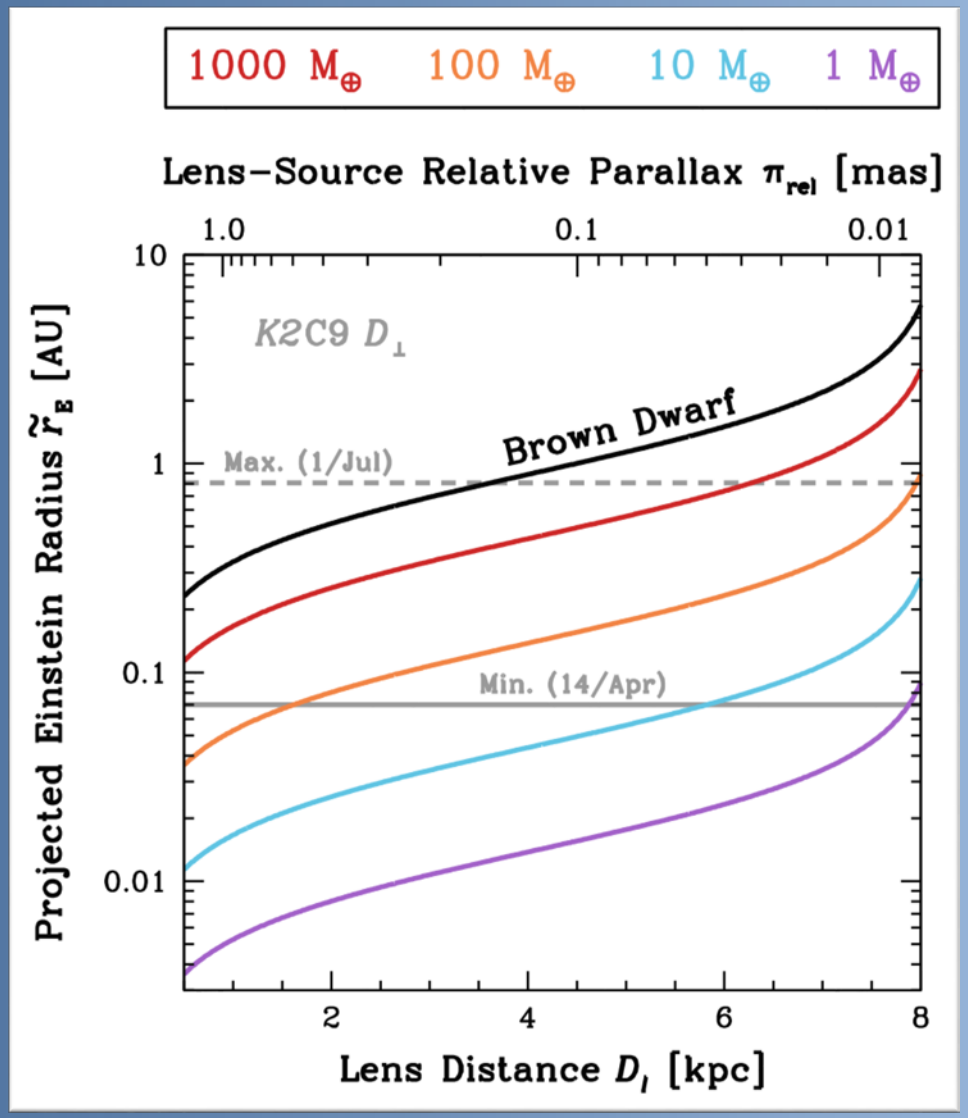


Online link to parallax animations!



Online link to parallax animations!

K2's sensitivity to free-floating planets



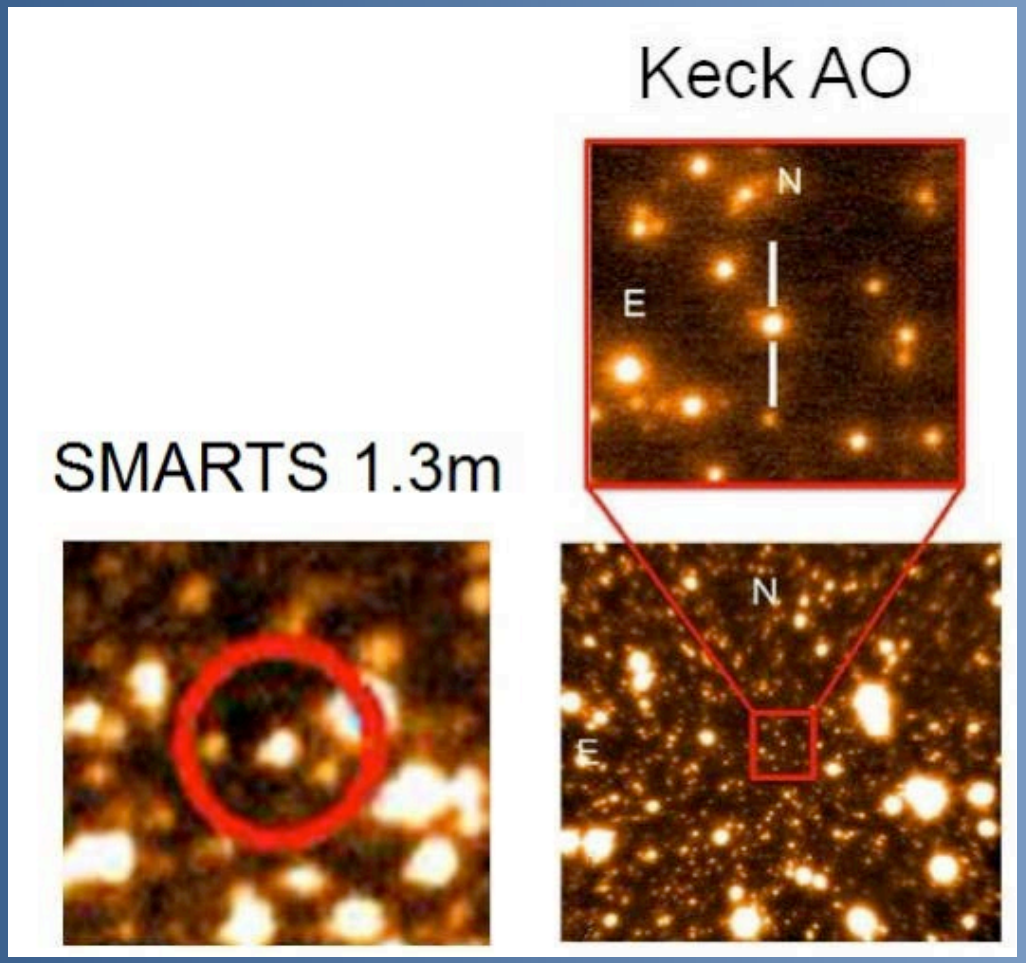
Henderson & Shvartzvald (2016) arXiv:1603.05249

Questions to Ask:

1) Is the lens low-mass?

1) Is it gravitationally bound?

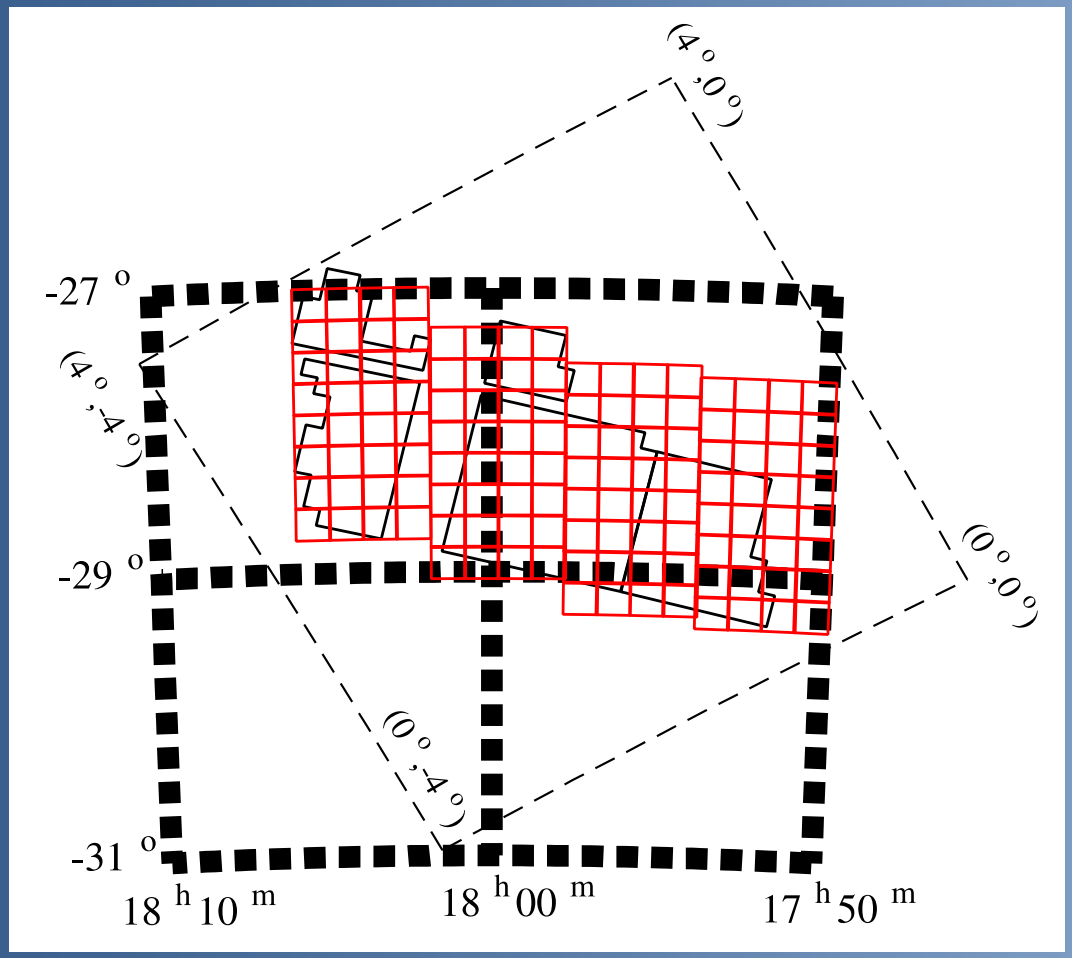
Looking for a Host Star



1. H_s from ground-based light curve data
2. H_{l+s} from high-resolution follow-up
3. Arithmetic!
4. Search for excess flux

Batista+ (2014) ApJ, 780, 54

Observing Short t_E Events in the NIR: I. Survey



UKIRT

- 32 pointings
- 2—3/night
- 6.0 deg^2
- 99.5% of *K2*C9 events

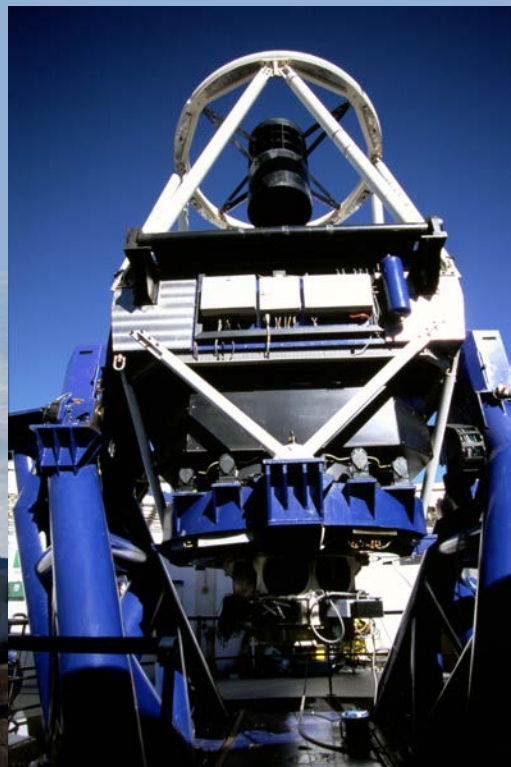
Credit: Yossi Shvartzvald

Observing Short t_E Events in the NIR: II. High-cadence Follow-up

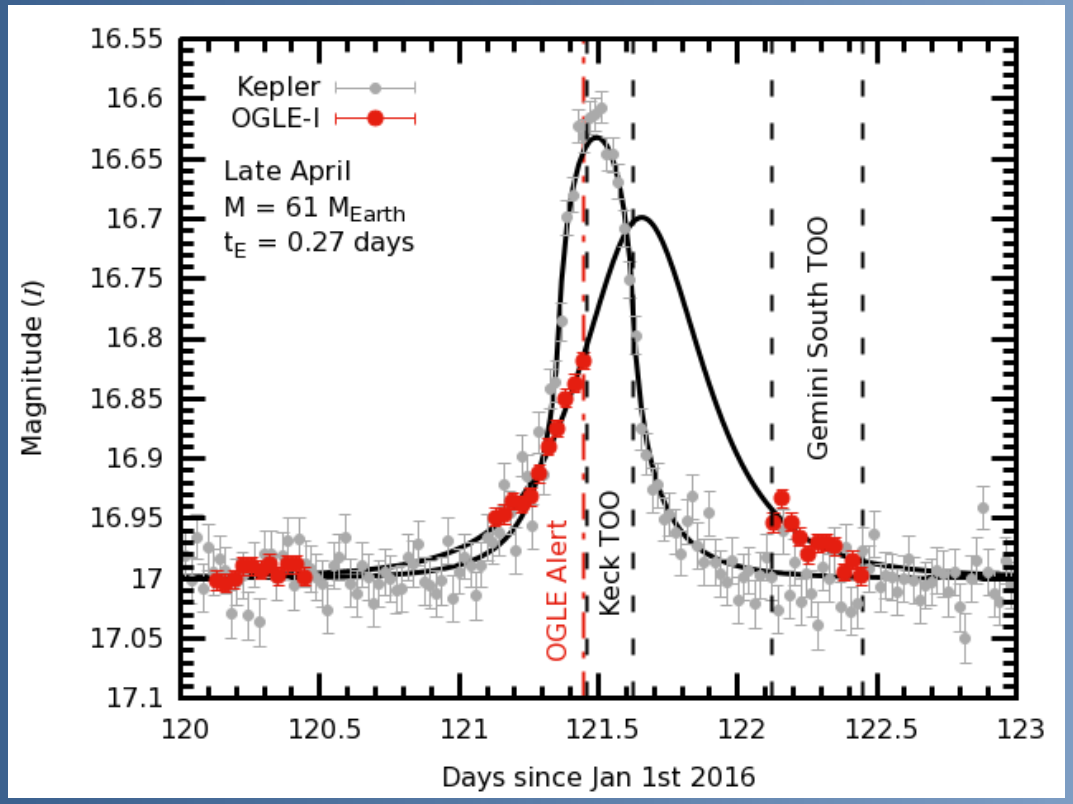
SMARTS 1.3m

NASA IRTF

Liverpool Telescope



Observing Short t_E Events in the NIR: III. Keck ToO Triggers



- ✧ 4 ToO triggers
- ✧ 20 minutes
- ✧ ~0.05—0.2”
- ✧ **Strongest lens flux constraints!**

Credit: Matthew Penny

Bonus Features!!!

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Government sponsorship acknowledged.

K2C9 White Paper

CAMPAIGN 9 OF THE *K2* MISSION:
OBSERVATIONAL PARAMETERS, SCIENTIFIC DRIVERS, AND COMMUNITY INVOLVEMENT
FOR A SIMULTANEOUS SPACE- AND GROUND-BASED MICROLENSING SURVEY

Henderson+ (2016) ArXiv:1512.09142

(to be submitted to PASP in February)

Microlensing Science Team

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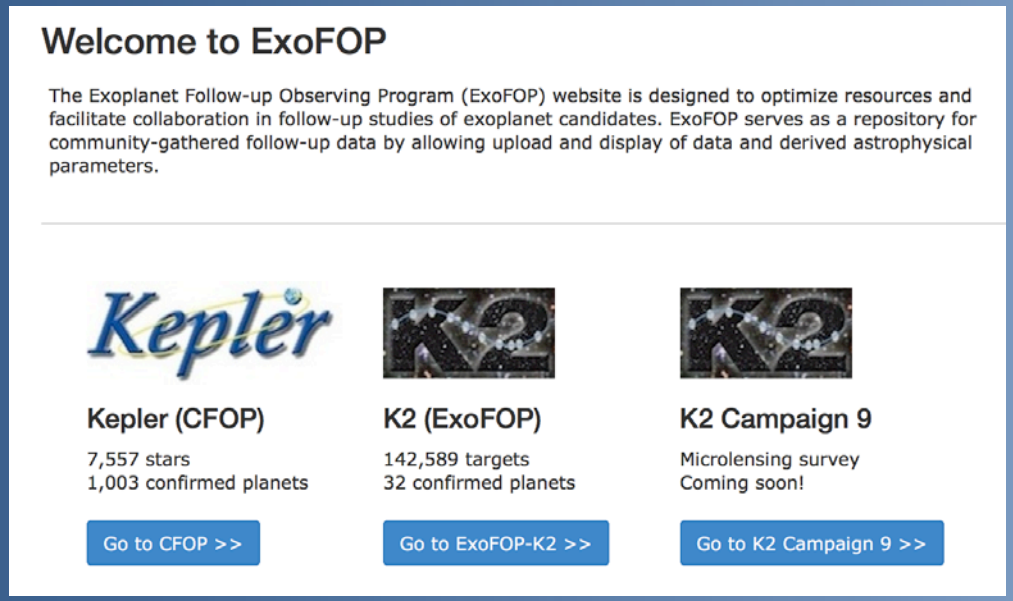
Calen B. Henderson
David W. Hogg
Matthew Penny
Radek Poleski
Rachel A. Street

Key NASA Personnel

Tom Barclay
Geert Barentsen
Steve Howell

Community Interface

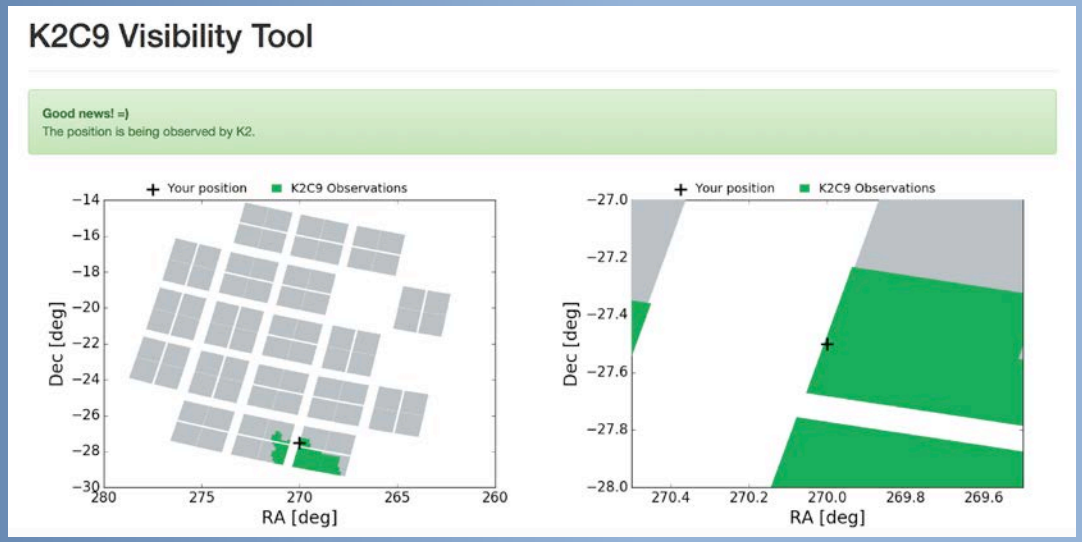


CFOP/ExoFOP

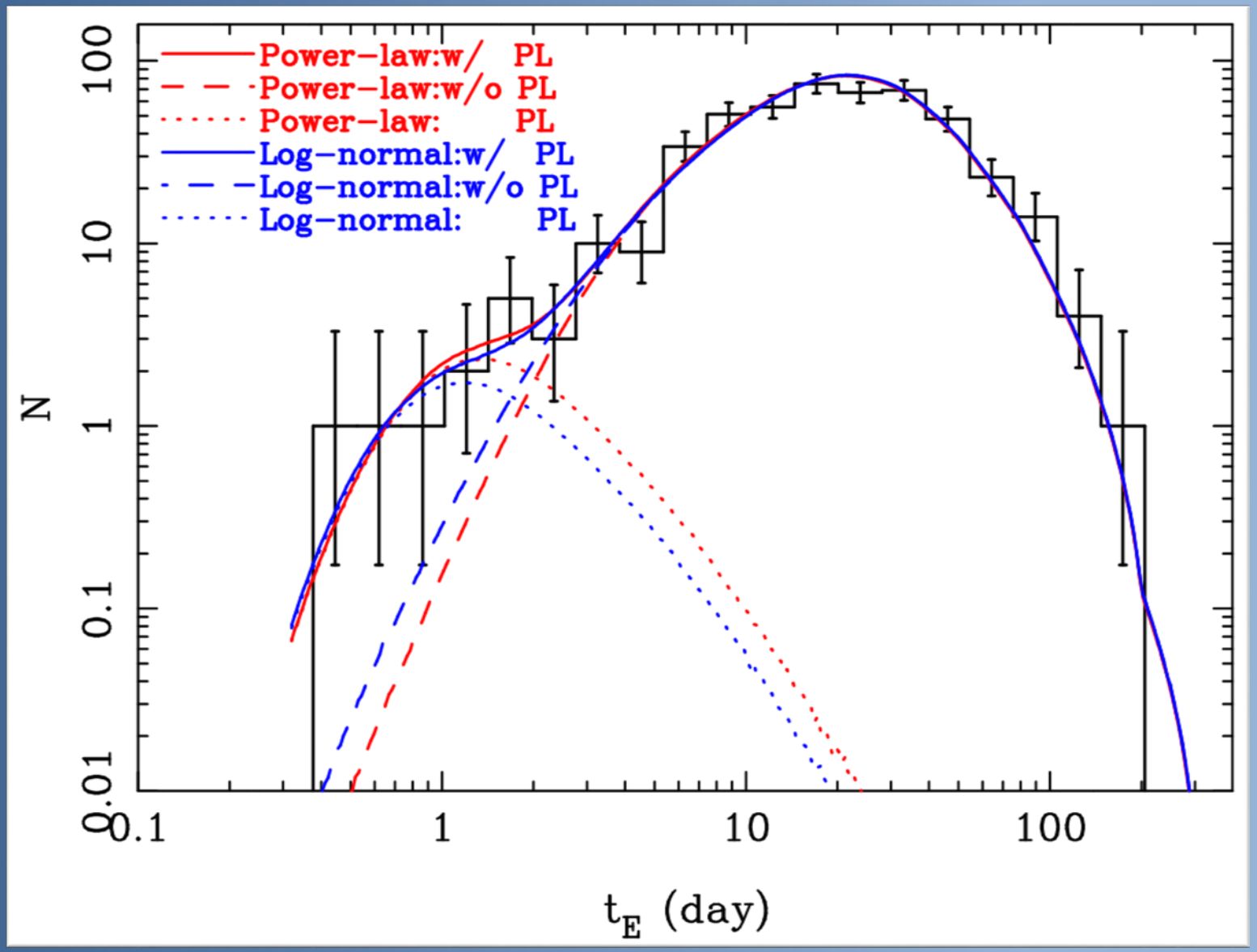
- ✧ Real-time event alerts
- ✧ Quick-look photometry
- ✧ Follow-up prioritization

K2C9 Visibility Tool

- ✧ Coordinate upload
  → Target within superstamp?

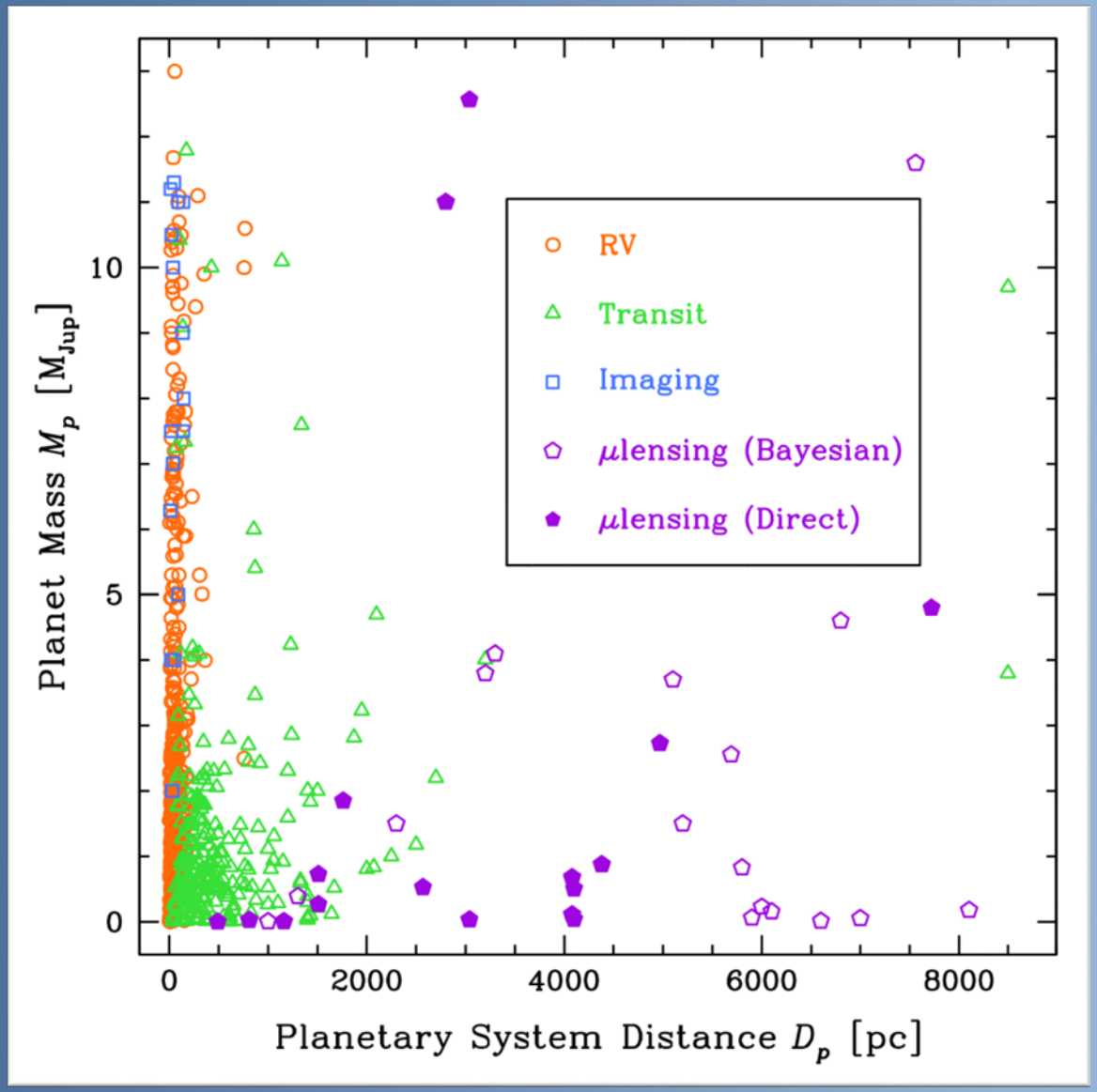


Putative FFP Population



Sumi+ (2011) Nature, 473, 349

Galactic Distribution of Exoplanets

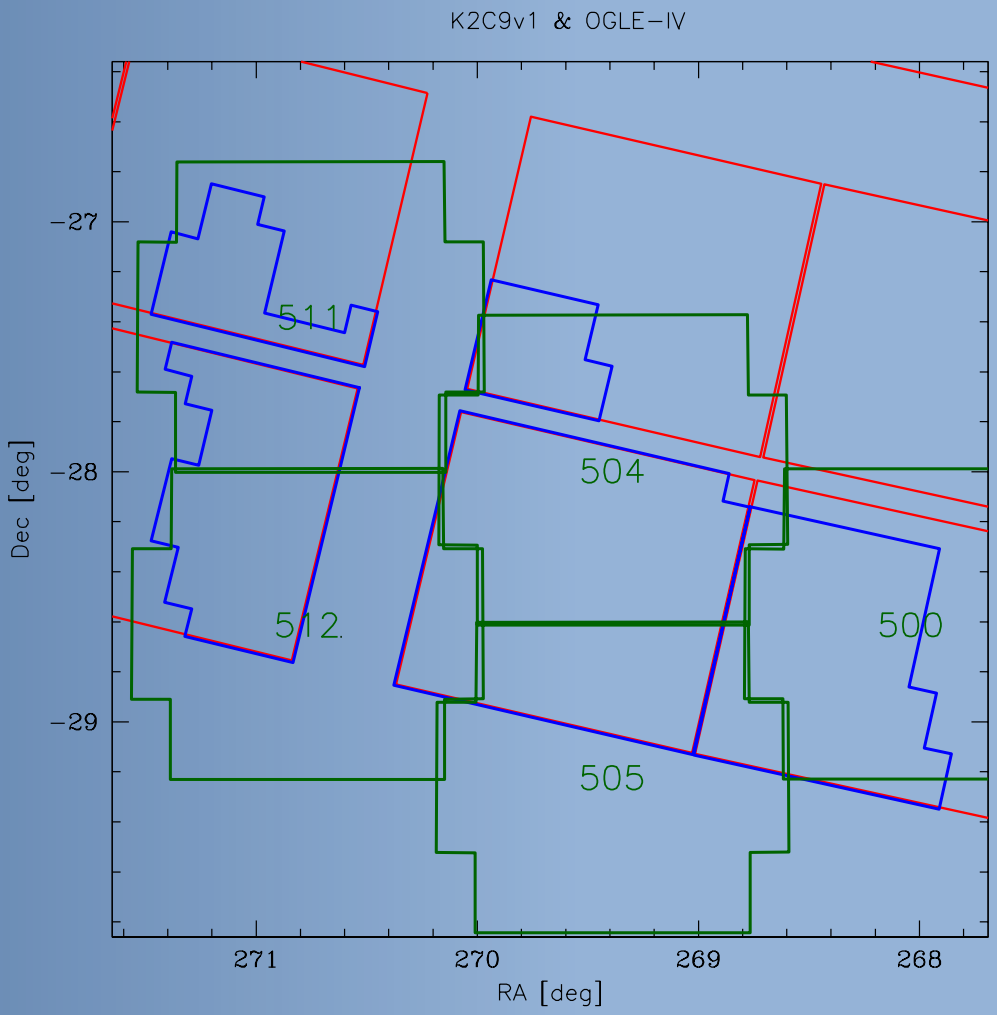


Henderson+ (2016) ArXiv:1512.09142

Concurrent Ground-based Resources

OGLE-IV

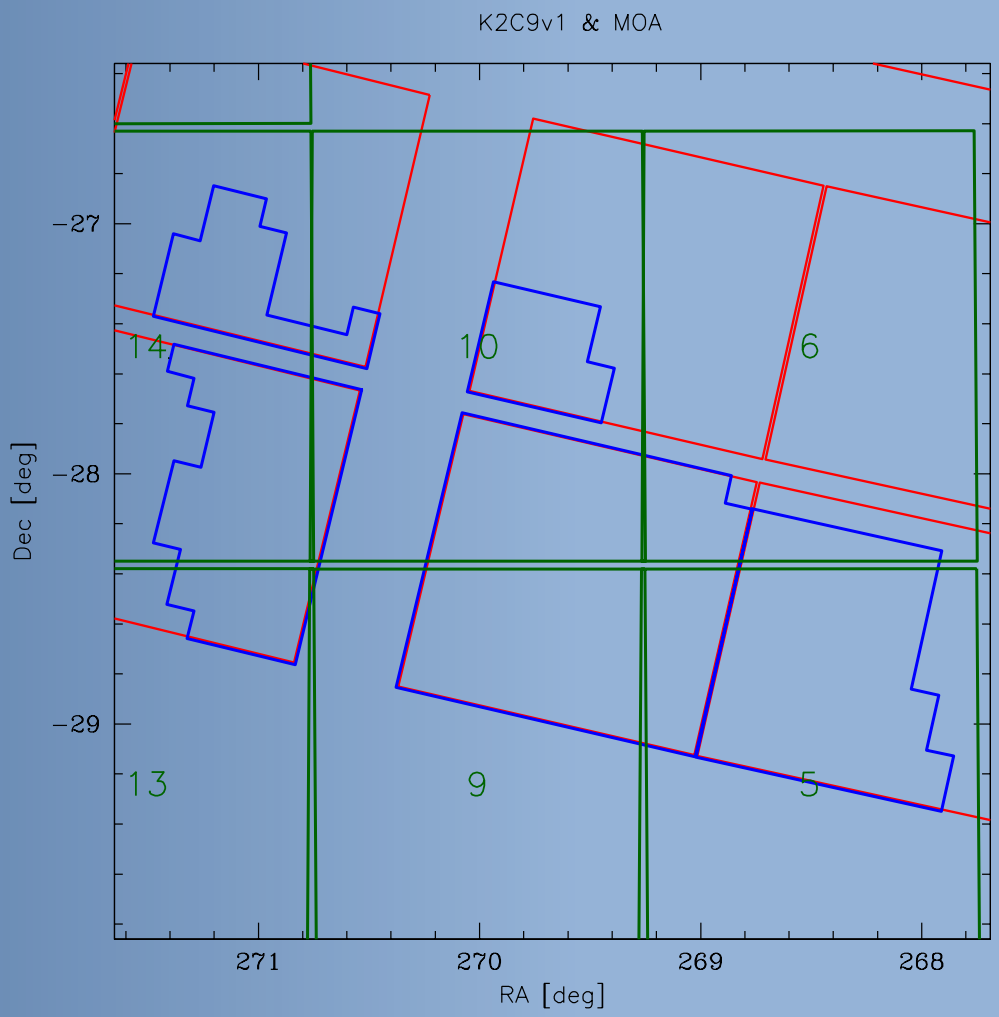
- ✧ 1.3m
- ✧ 1.4 deg^2
- ✧ 500, 504, 505, 511, 512
  - ✧ *I*-band: 20 minutes
  - ✧ *V*-band: 1—2/night



Concurrent Ground-based Resources

MOA-II

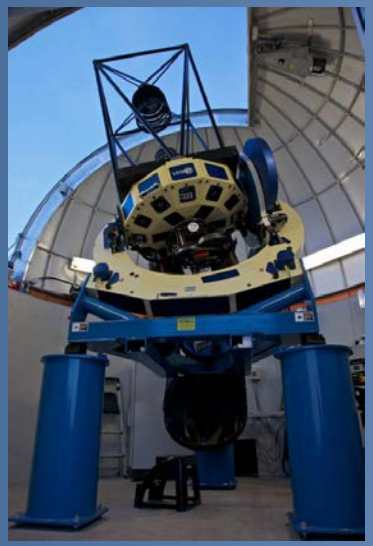
- ✧ 1.8m
- ✧ 2.2 deg^2
- ✧ 5, 9, 10, 14: 15-min
- ✧ 13: 90-min
- ✧ 6: 1/night (extinction)



Concurrent Ground-based Resources

LCOGT

- ✧ 1.0m
- ✧ 26’ x 26’
- ✧ CTIO, SAAO, SSO



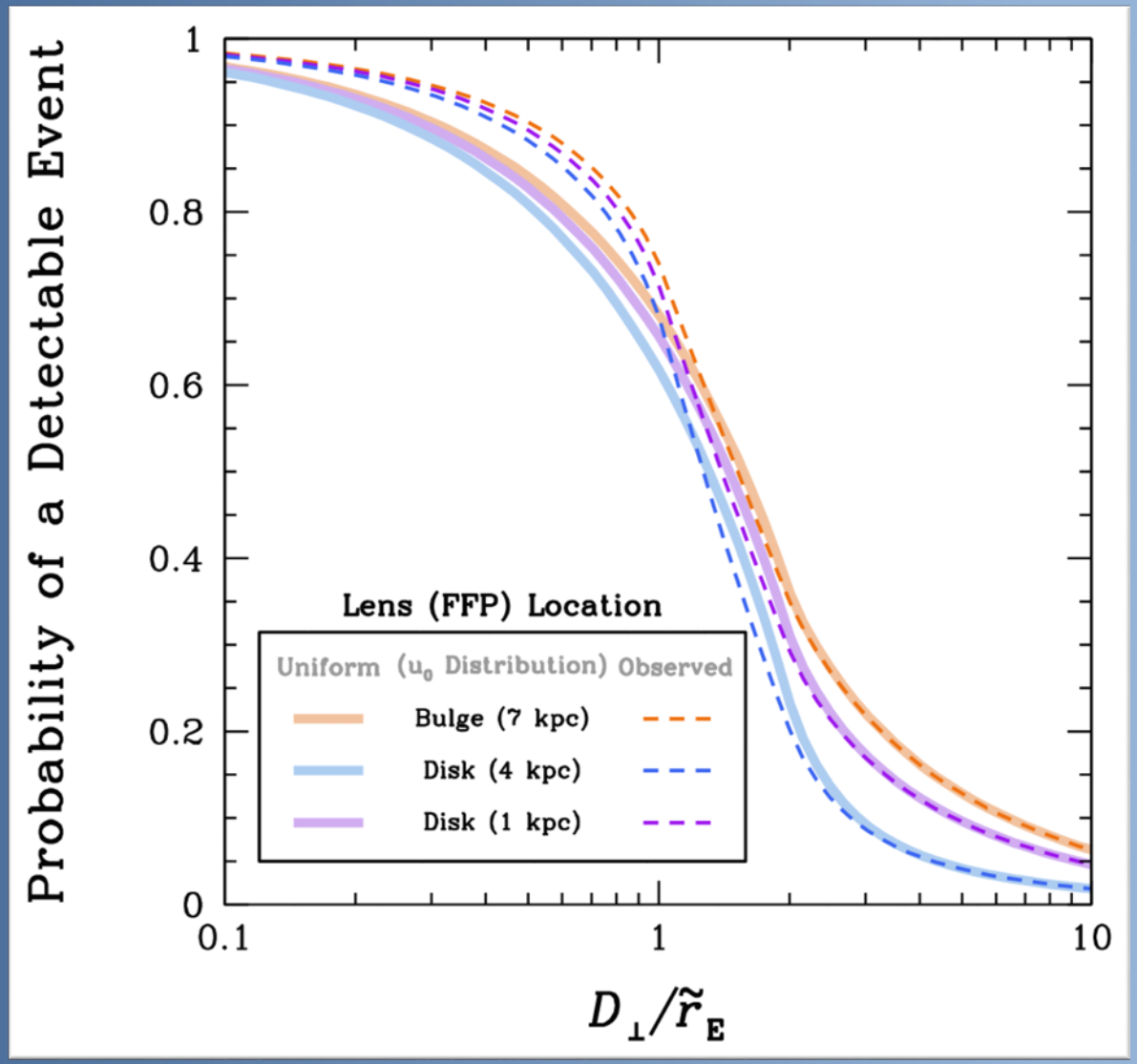
Credit: Frank Cianciolo/Mcdonald Observatory

KMTNet

- ✧ 1.6m
- ✧ 4 deg^2
- ✧ CTIO, SAAO, SSO

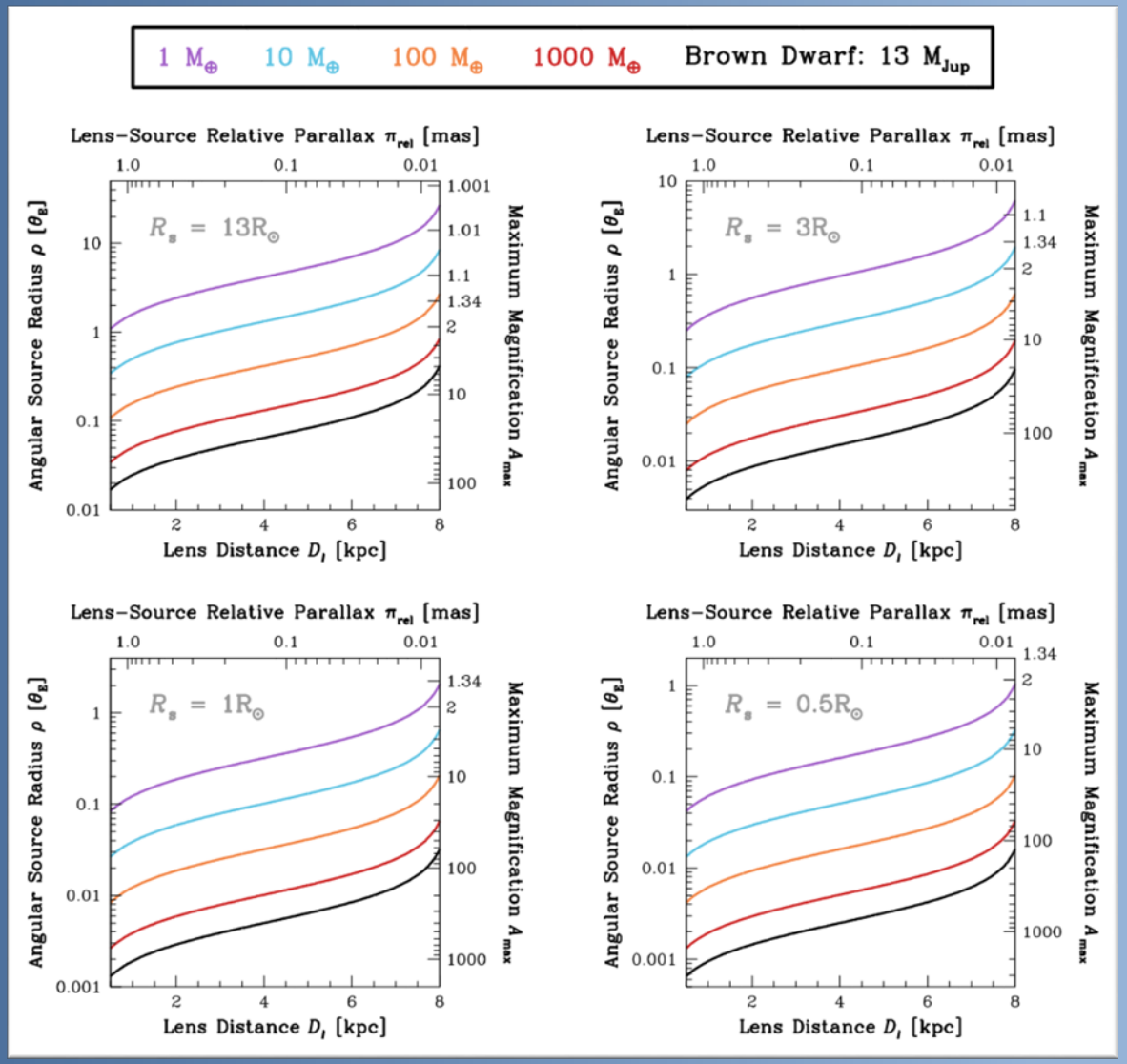
Credit: Dan Pappalardo

Detecting Events from Earth *and* space



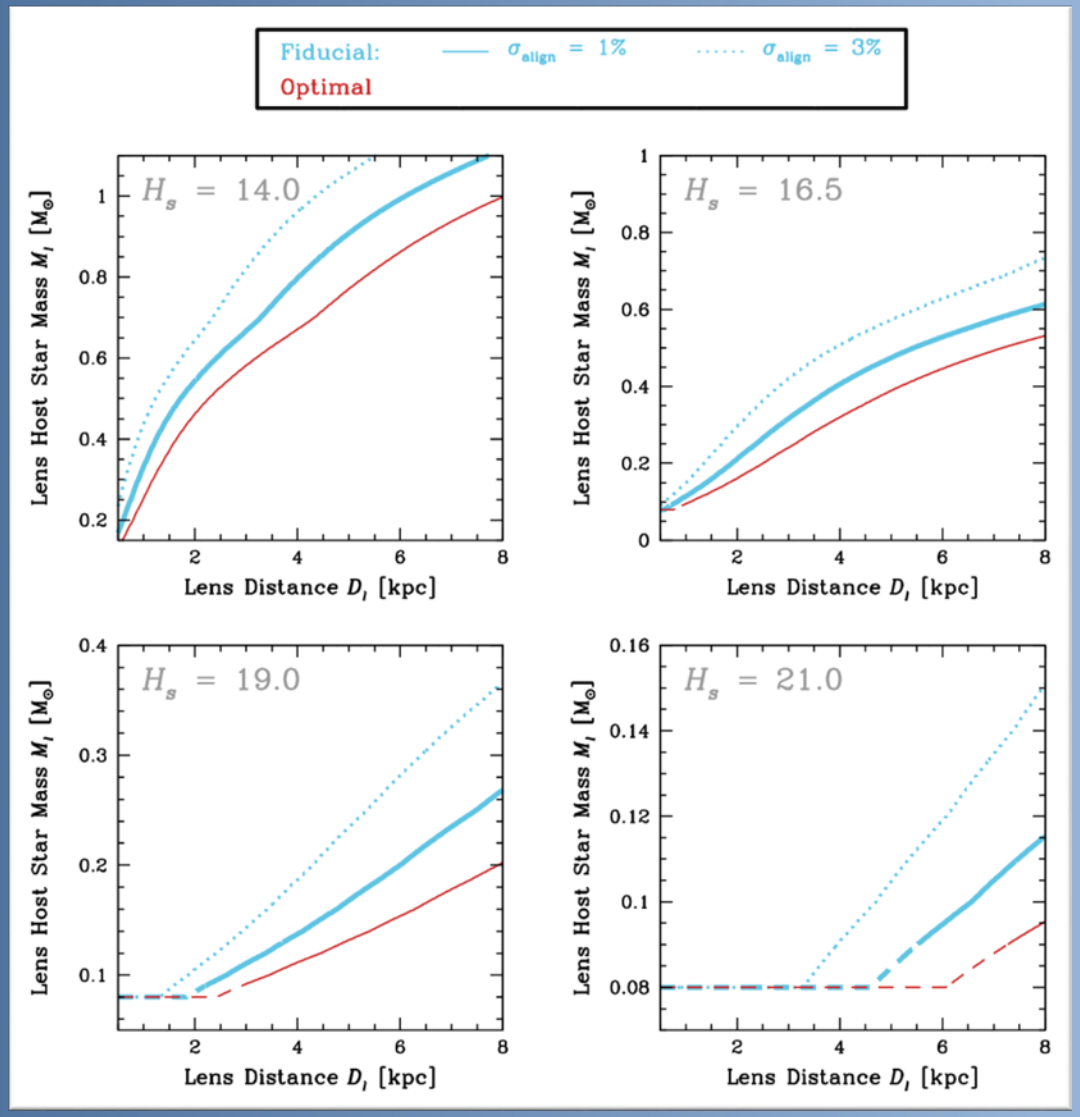
Henderson & Shvartzvald (2016) arXiv:1603.05249

Finite-source Effect Detectability



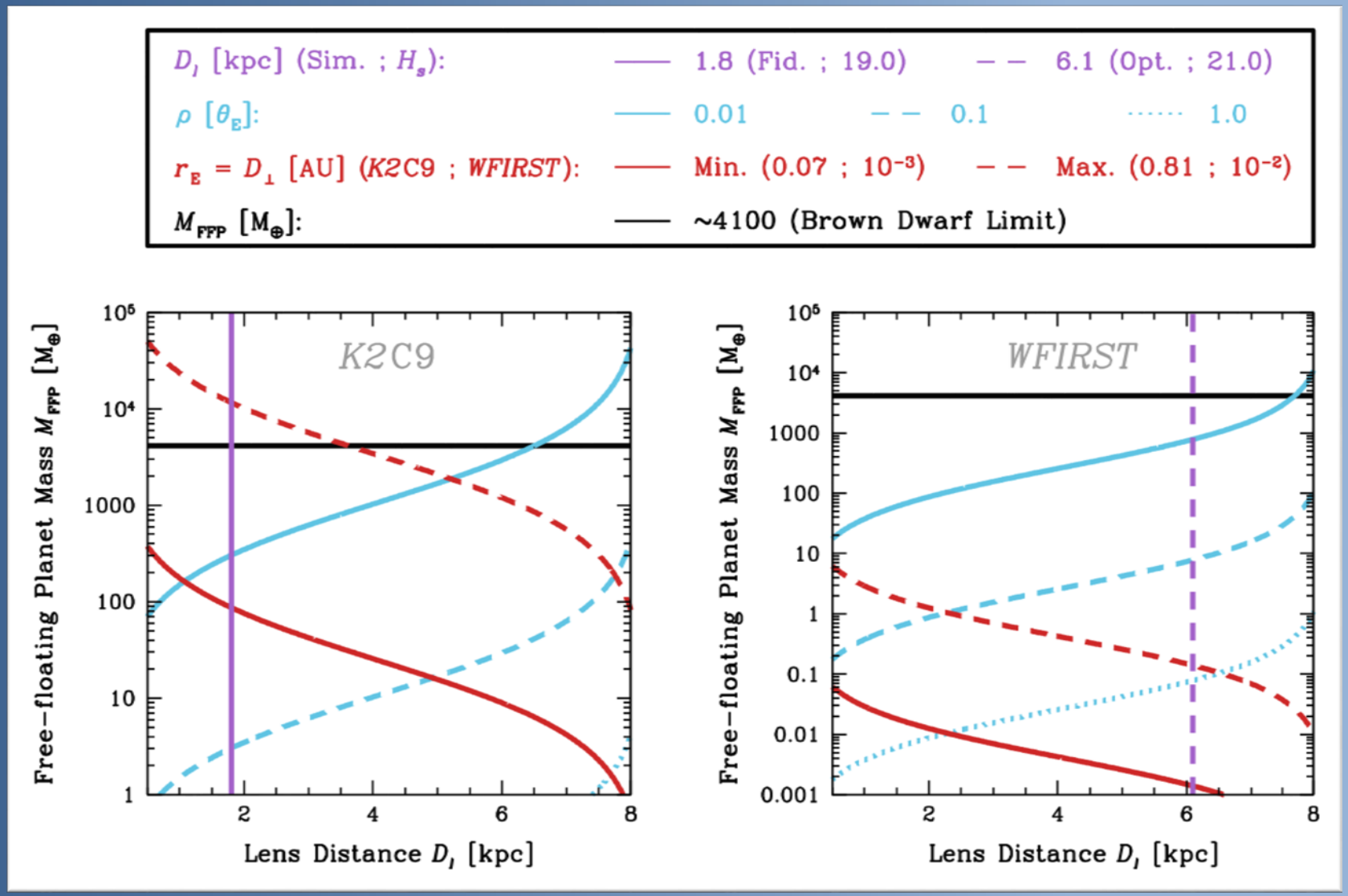
Henderson & Shvartzvald (2016) arXiv:1603.05249

Host Star Exclusion Limits



Henderson & Shvartzvald (2016) arXiv:1603.05249

Components for Full Characterization



Henderson & Shvartzvald (2016) arXiv:1603.05249