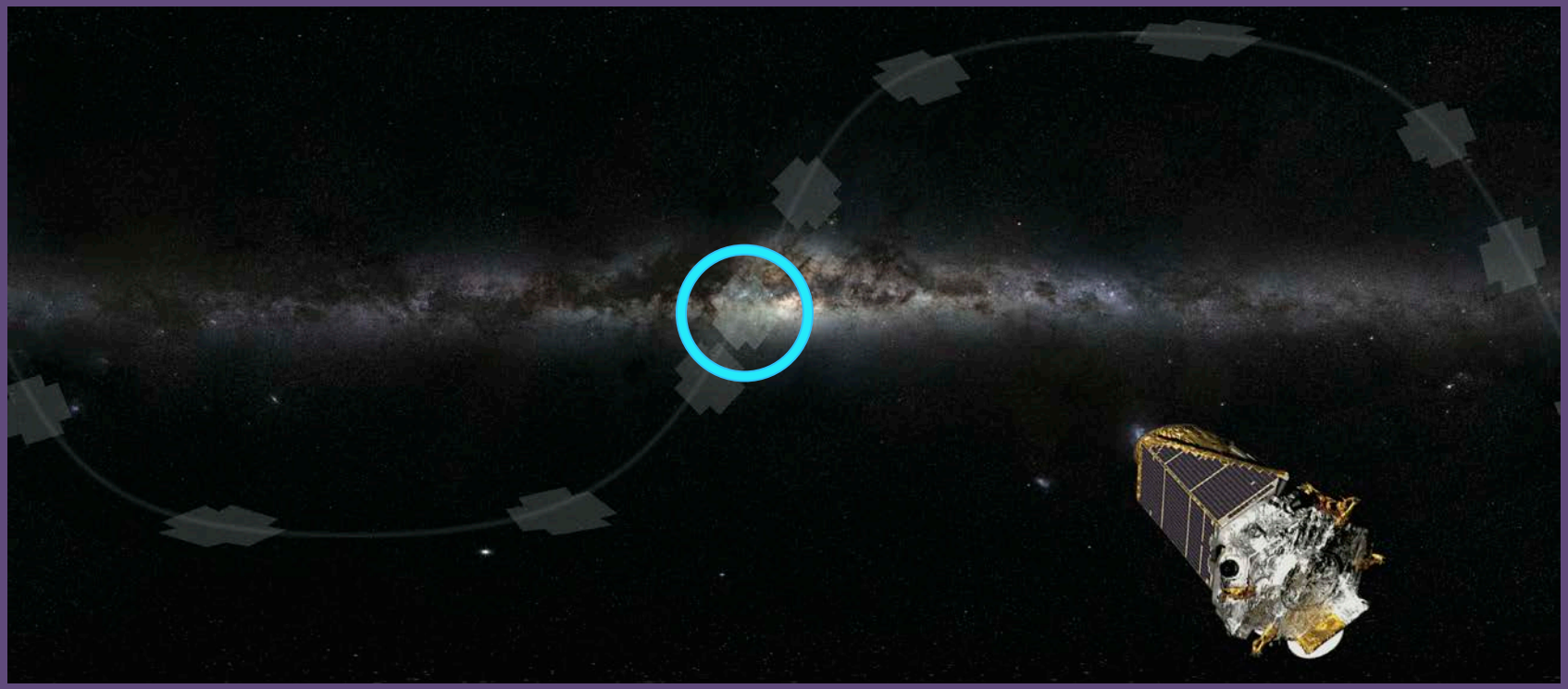
K2's Campaign 9 (*K2*C9): The First Automated Microlensing Survey from the Ground and from Space



Calen B. Henderson
JPL/Caltech (NPP Fellow)

Jet Propulsion Laboratory
California Institute of Technology

ExSoCal 2016
Thursday, 22/September

Key Contributors to *K2C9*

Microlensing Science Team

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Rachel Street
Project Scientist
Las Cumbres Observatory Global Telescope

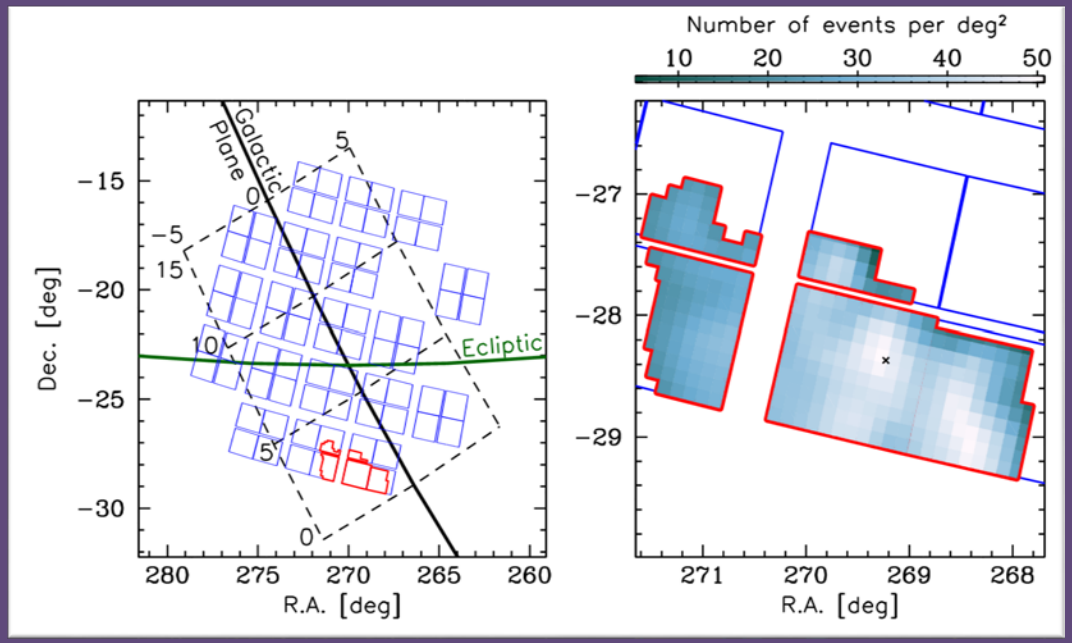
K2 Project Office

Tom Barclay
K2 Guest Observer Office Director
NASA Ames

Geert Barentsen
K2 Guest Observer Office
NASA Ames

Steve Howell
Project Scientist
NASA Ames

What is *K2C9*?

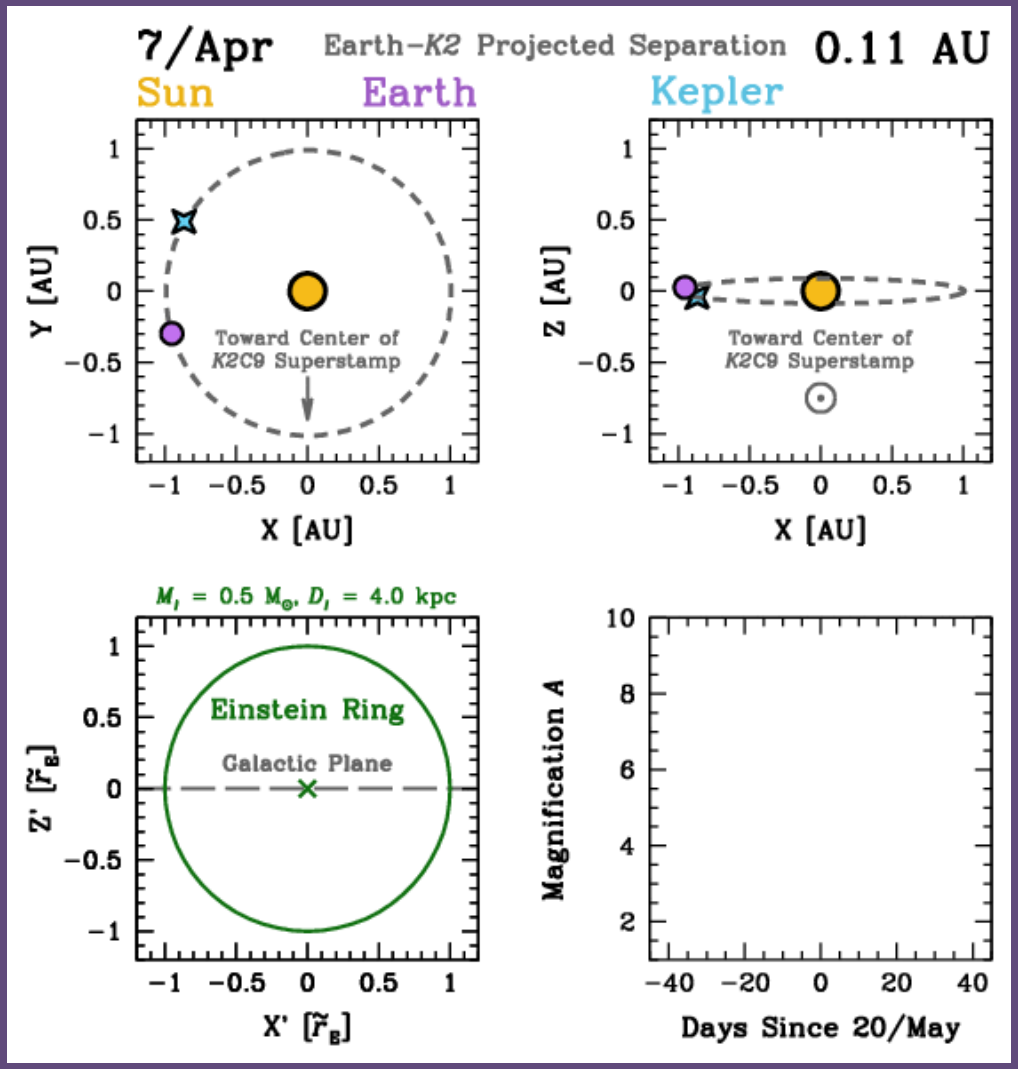


Area*	3.74 deg^2
Cadence	30 min
Events*	106 (expected)
Start	22/April, 14:04 UT
End	2/July, 22:34 UT
Duration	71.4 days

Found in Henderson+ (2015) arXiv:1512.09142
Uses methodology of Poleski (2016) MNRAS, 455, 3656

* Postage stamps added later to C9a (34) & C9b (61) target lists for ongoing events (70 unique)

But what does satellite parallax *mean*?



Henderson+ (2015) arXiv:1512.09142

Found at:
http://www.astronomy.ohio-state.edu/~henderson/k2c9_parallax_animations/

Science Goals: Quality versus Quantity

Addressing (relatively) Unexplored Demographic Questions

1. Free-floating planets
2. Galactic distribution
3. Cold and bound exoplanets

Science Goals: Quality versus Quantity

Addressing (relatively) Unexplored Demographic Questions

1. Free-floating planets
2. Galactic distribution
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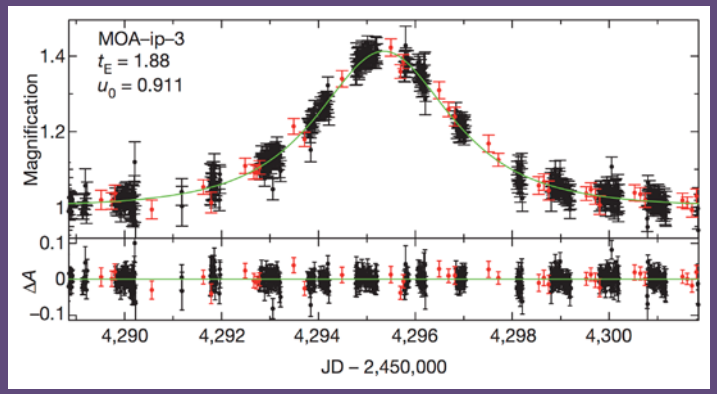
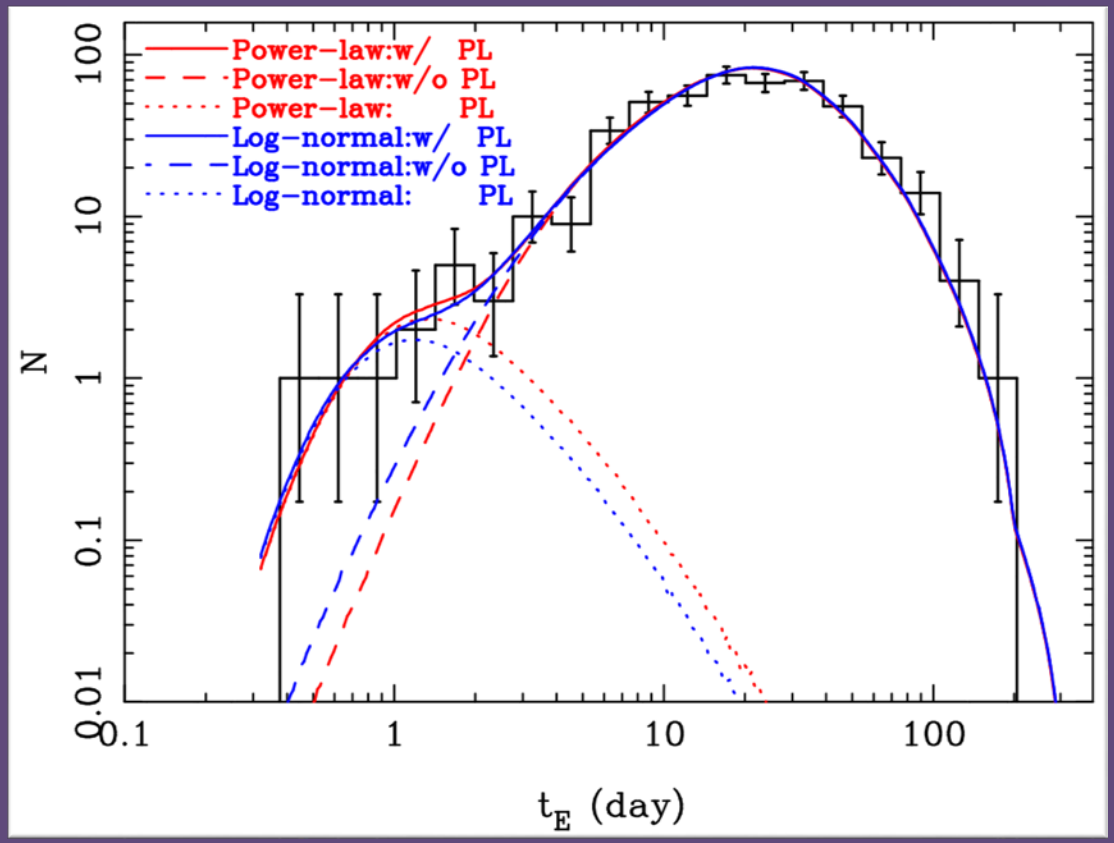
Free-floating Planets (FFPs)

Short-timescale Microlensing Event

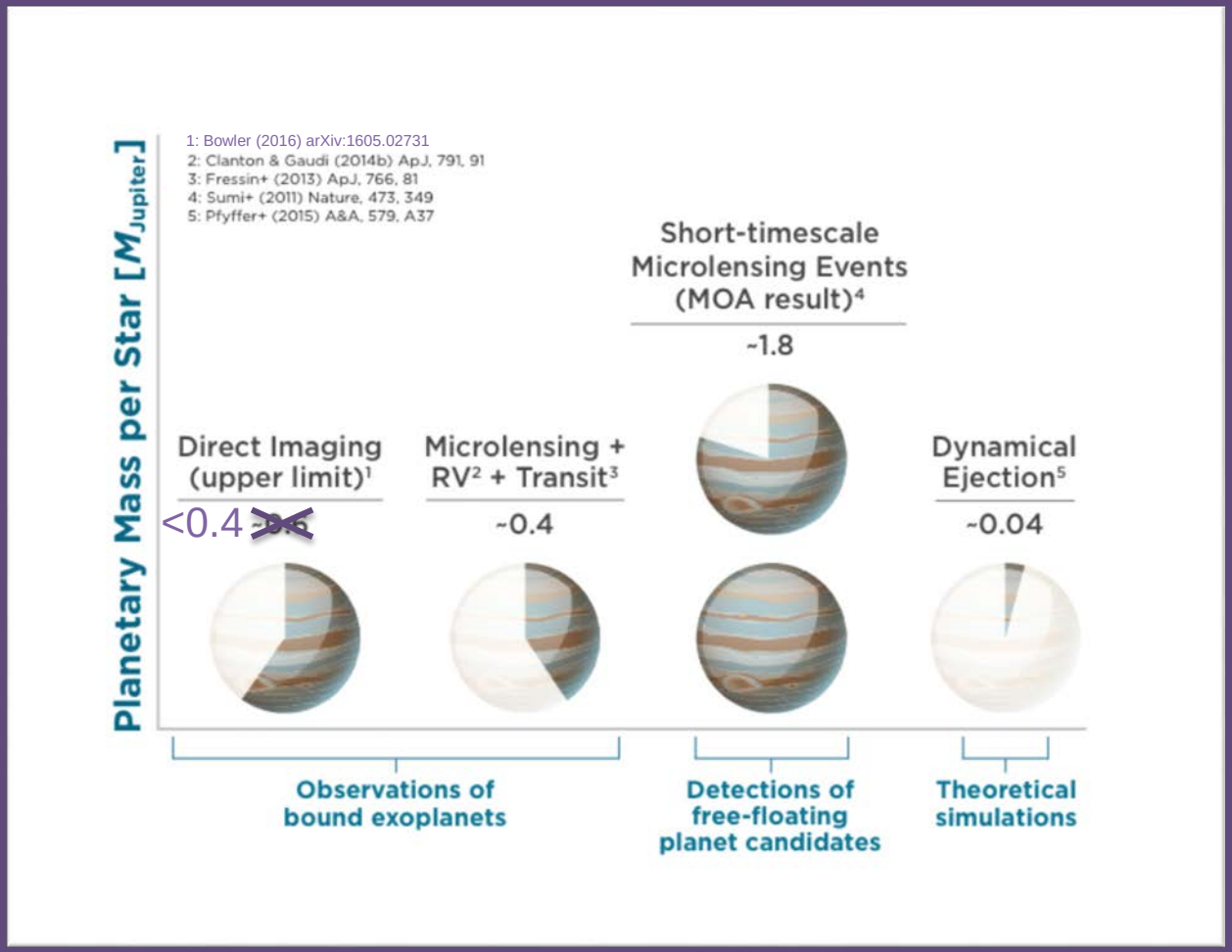


Overarching Timescale Distribution



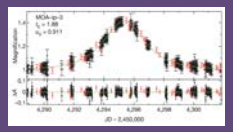
Sumi+ (2011) Nature, 473, 349

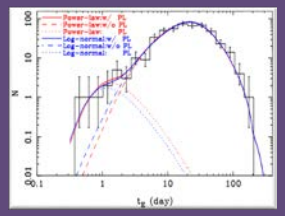
Planetary Mass Budget



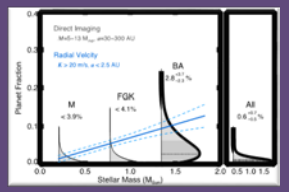
Henderson+ (2015) arXiv:1512.09142

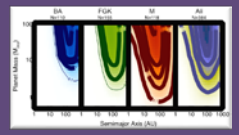
Microlensing (FFPs)



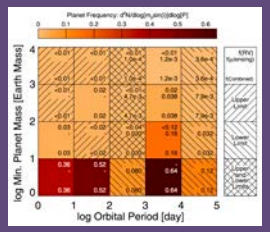


Direct Imaging

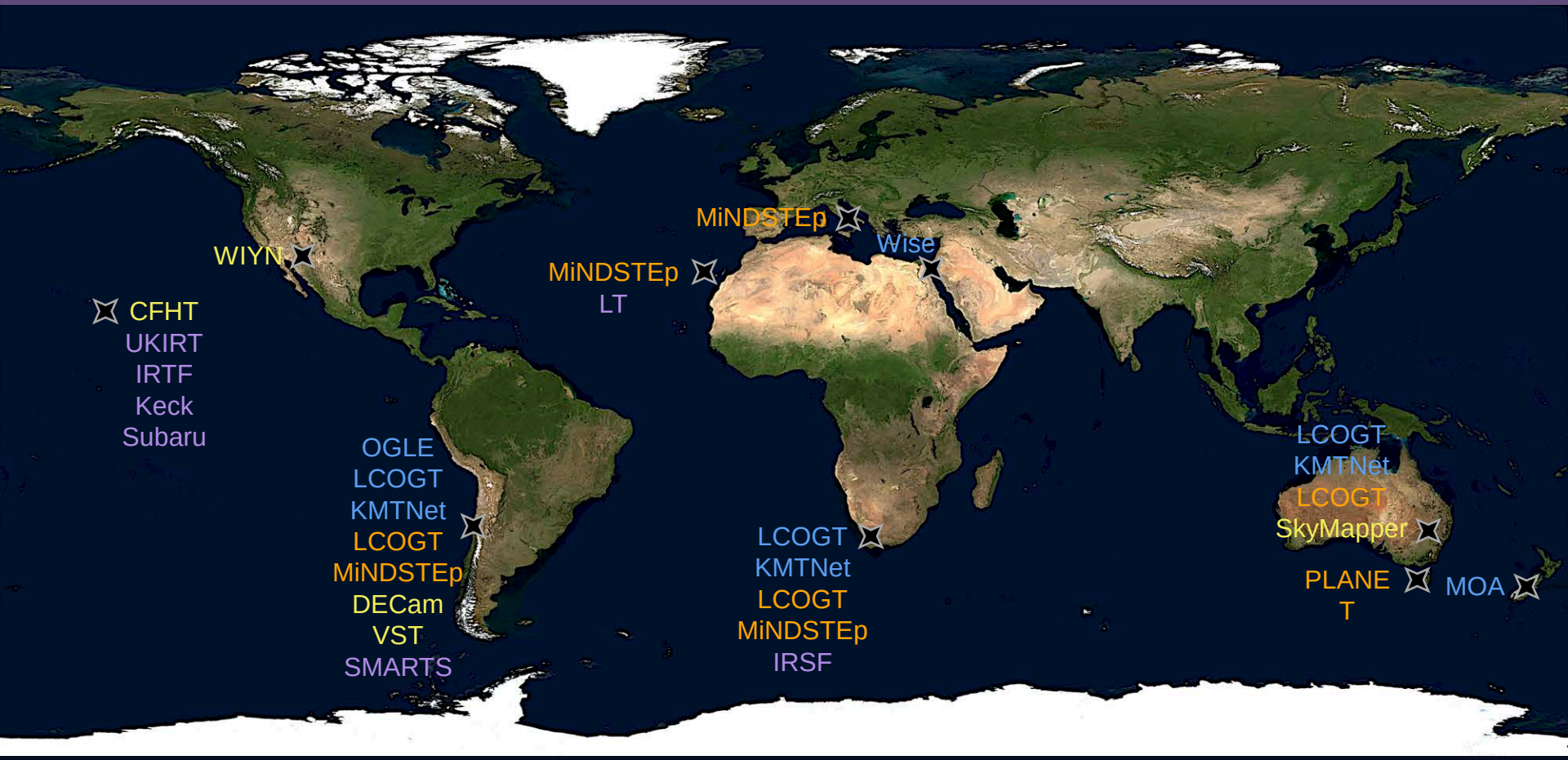




Transit + RV + Microlensing



Simultaneous Ground-based Resources



Automated Survey
Multiband Monitoring

High-cadence Follow-up
Near-infrared Source Fluxes

Henderson+ (2015) arXiv:1512.09142

Preliminary *K2C9* Parallax Inventory

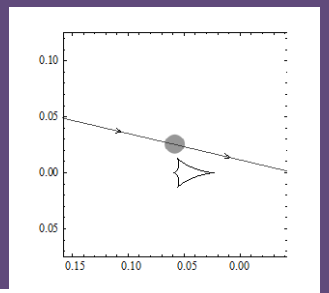
Total events	110 (180)
Bound Planets	4
FFP Candidates	7 (13)
Stellar Binaries	8
Long-timescale	13

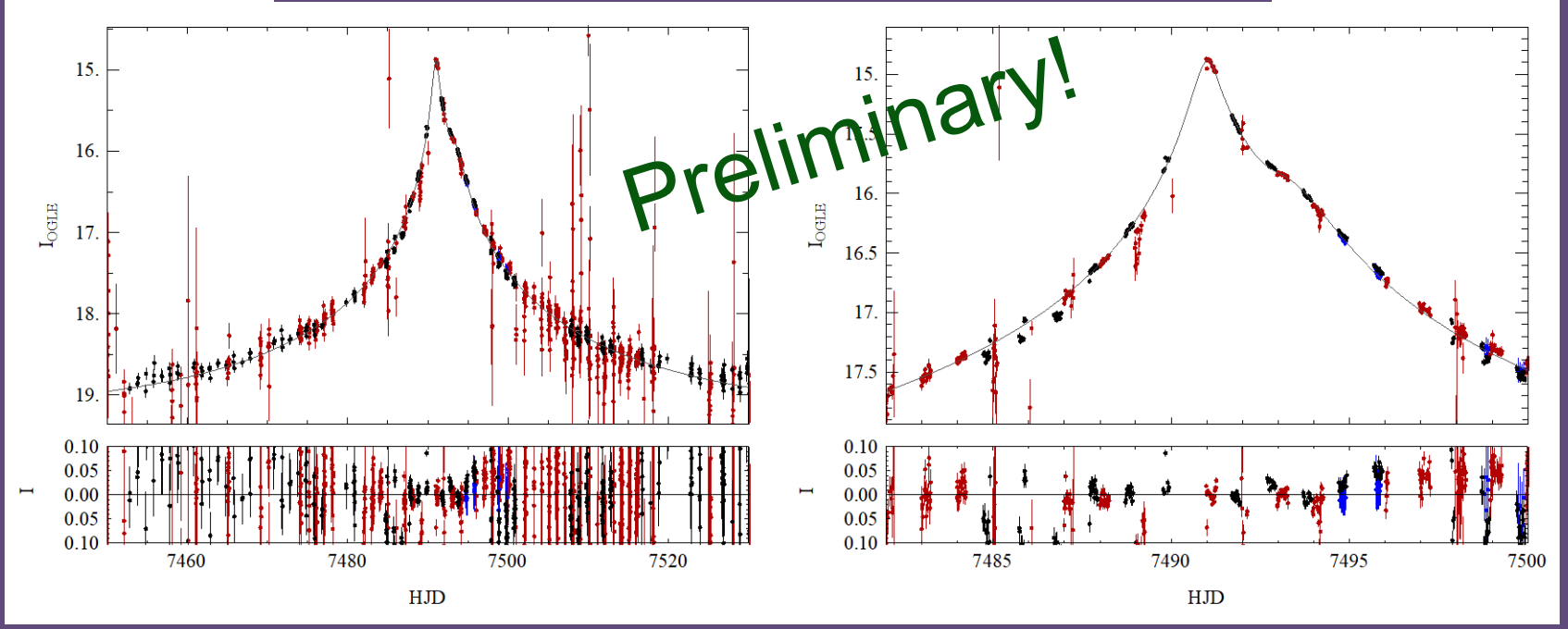
Values are, generally, lower limits!!

Bound Planetary Candidate!

Telescope
MOA
Danish 1.54m
OGLE

$$q = \frac{M_p}{M_*} \sim 0.03$$

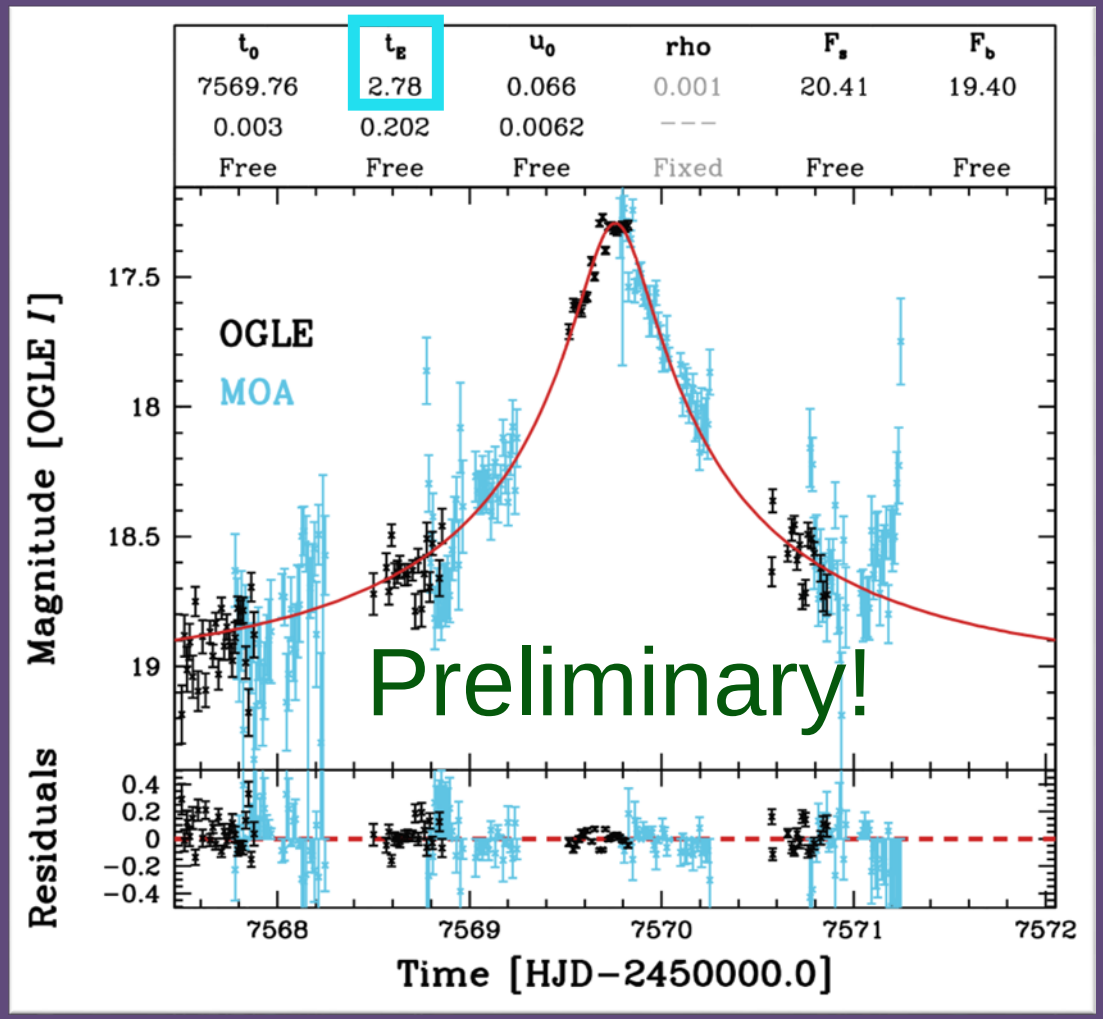




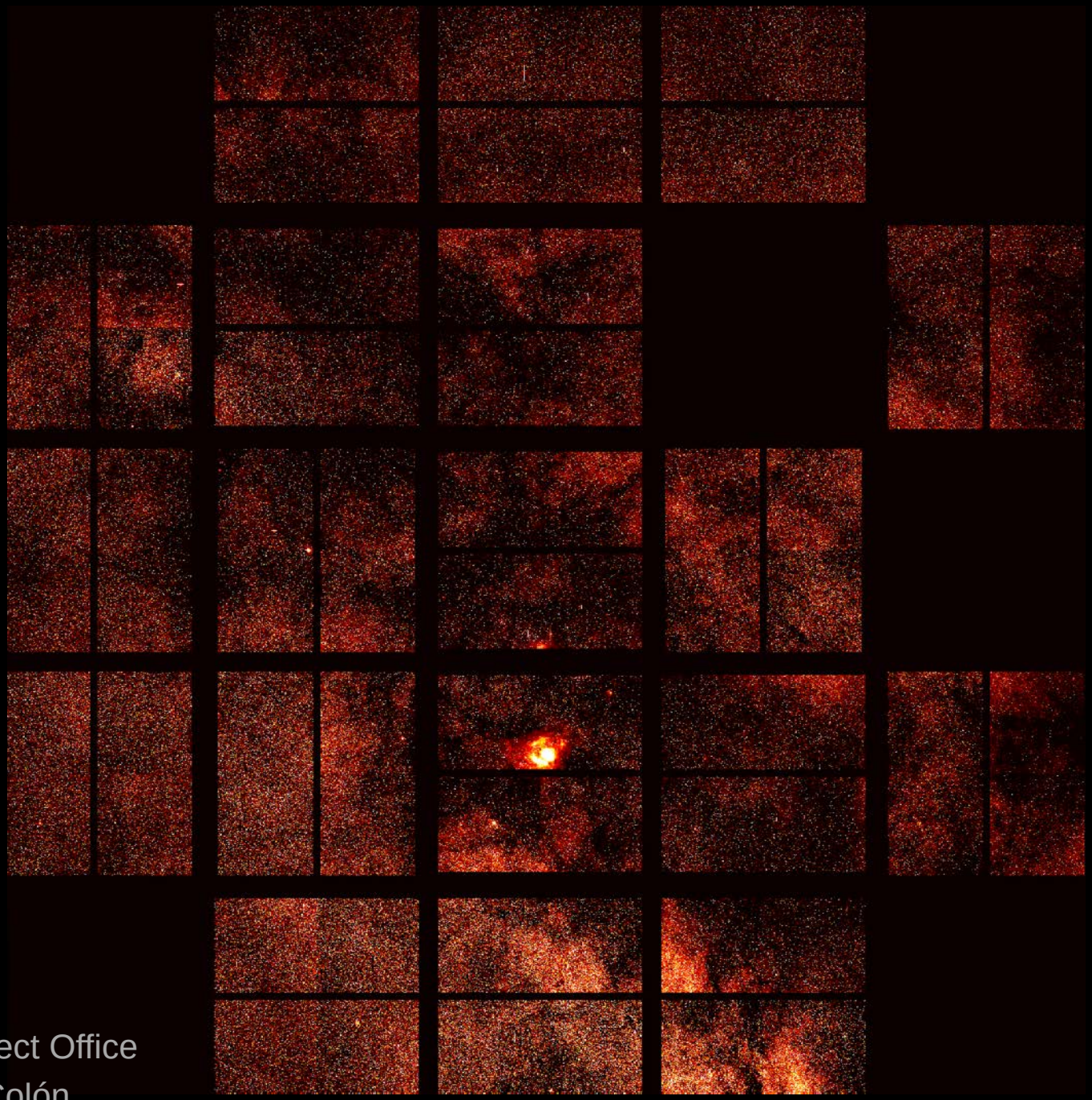
From Valerio Bozza's real-time modeling:

http://www.fisica.unisa.it/GravitationAstrophysics/RTModel.htm

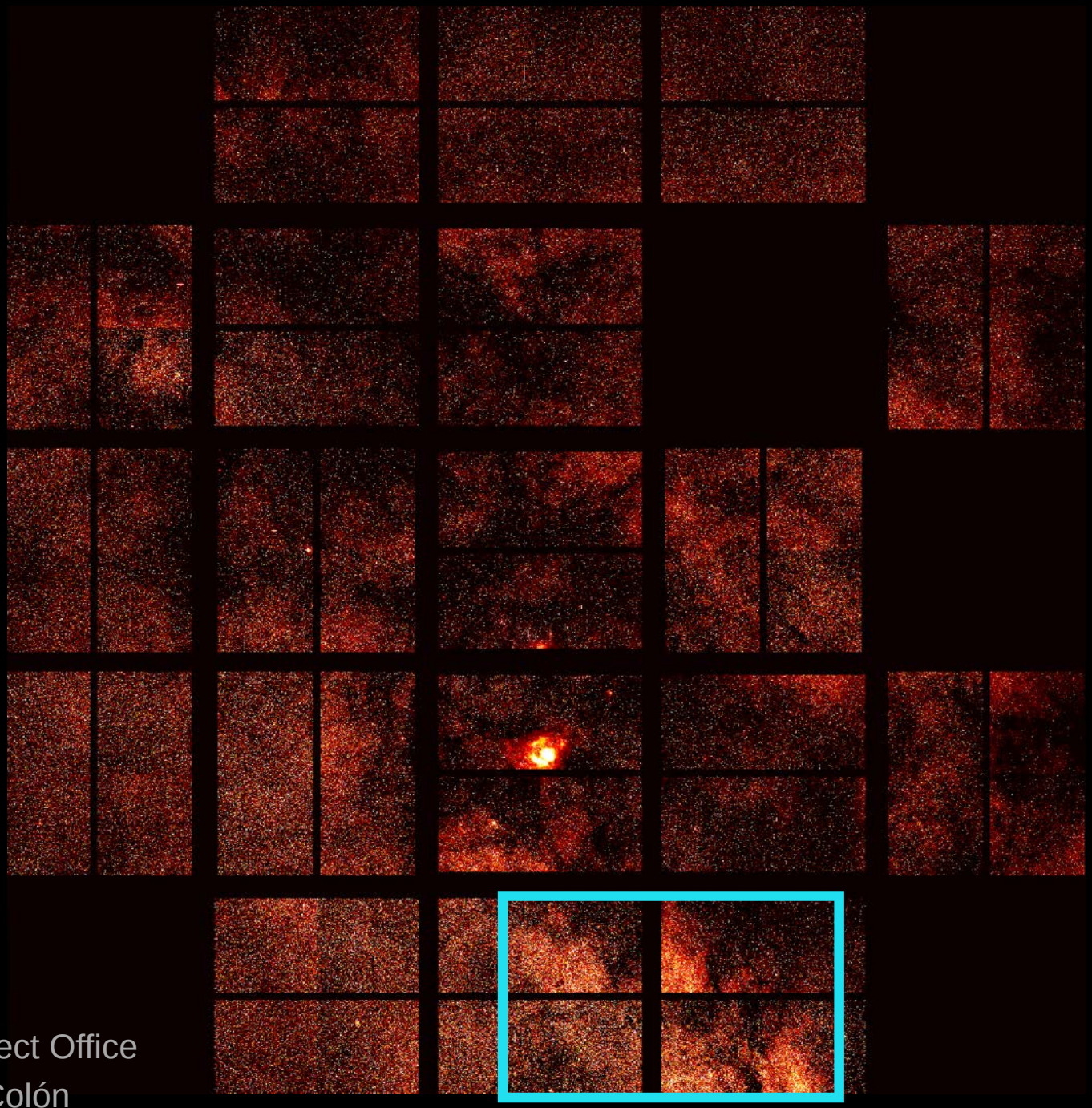
Free-floating Planet Candidate



Modeled by C. B. Henderson

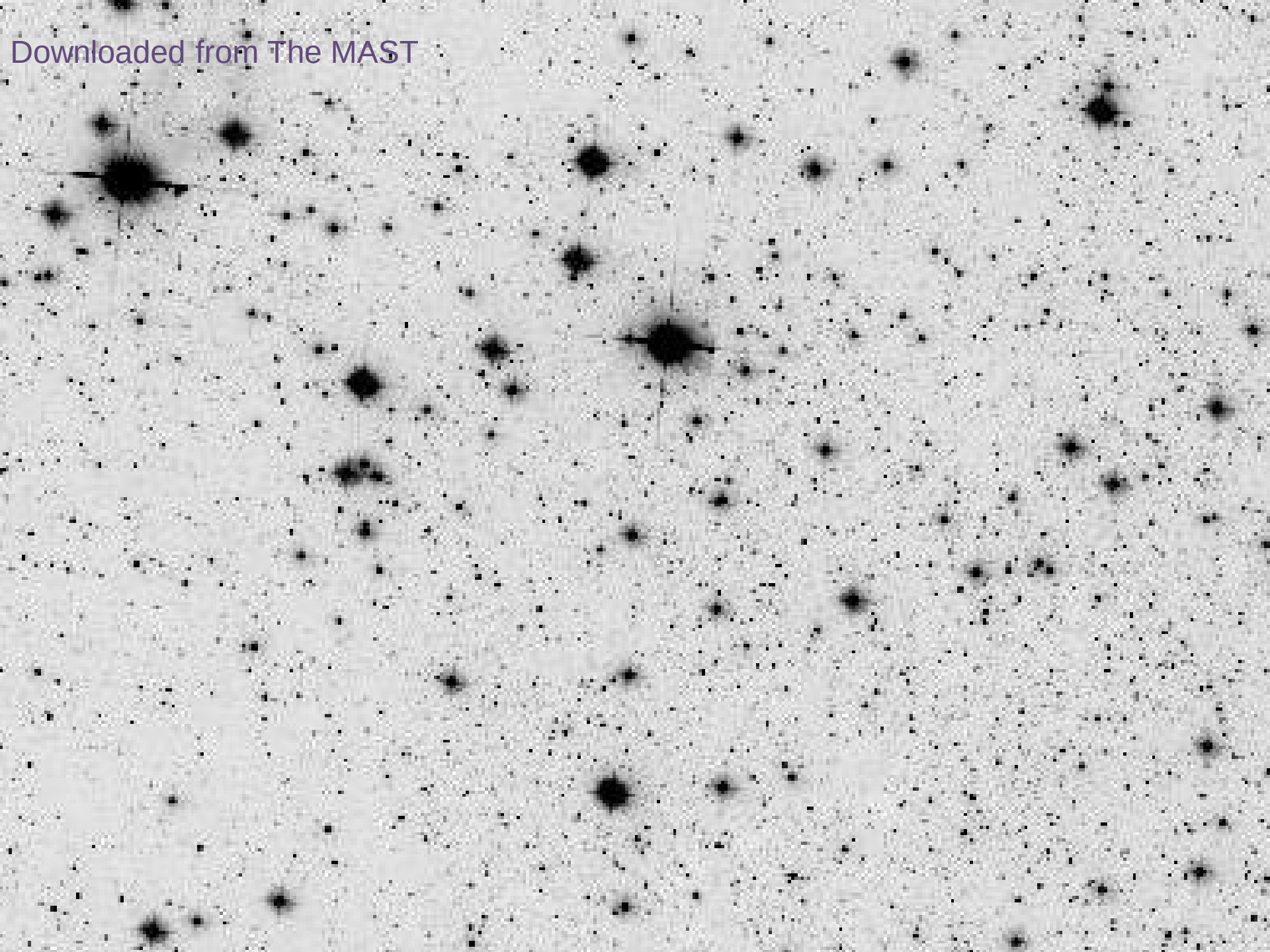


From *K2* Project Office
Courtesy K. Colón



From *K2* Project Office
Courtesy K. Colón

Downloaded from The MAST



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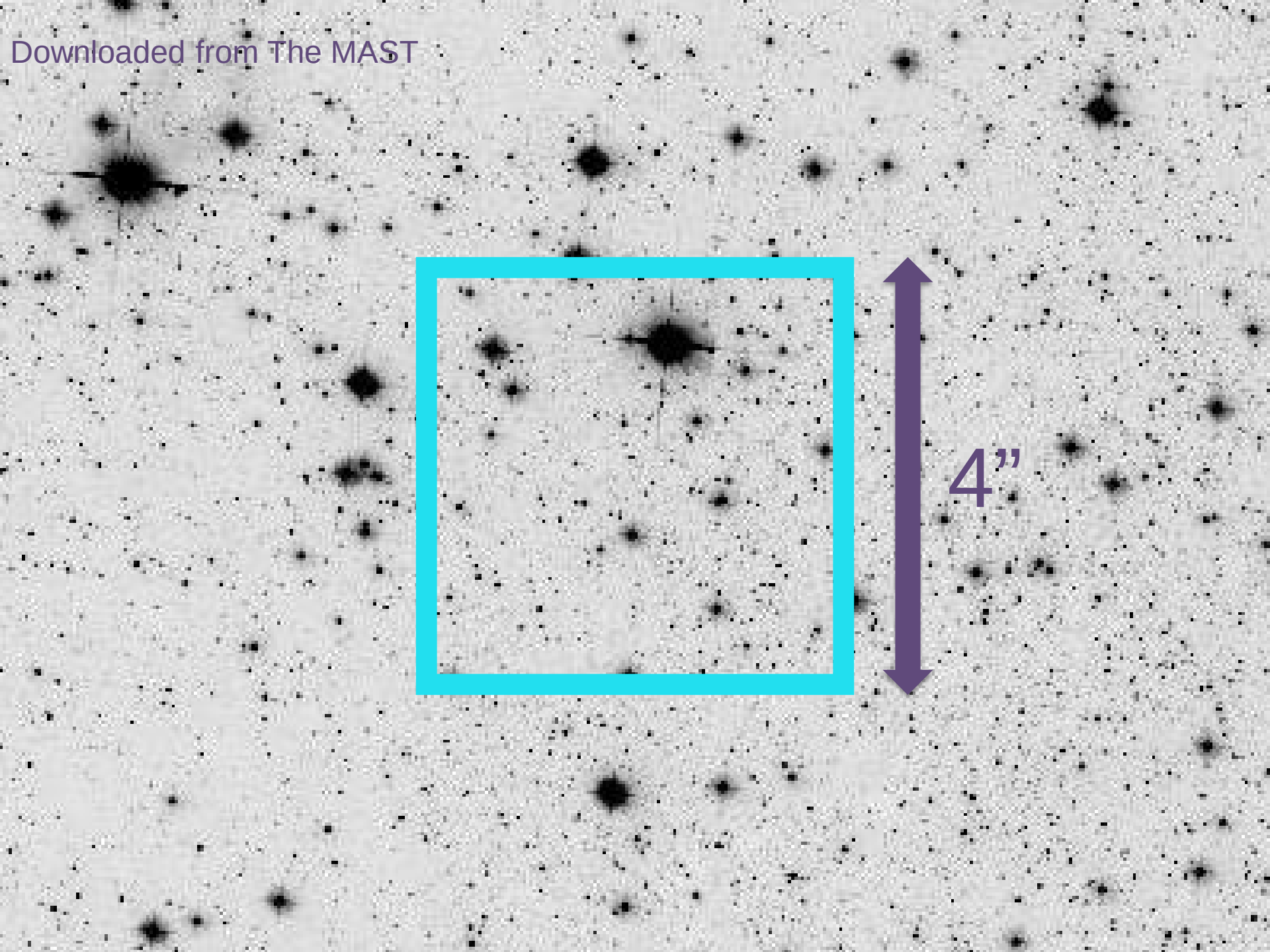
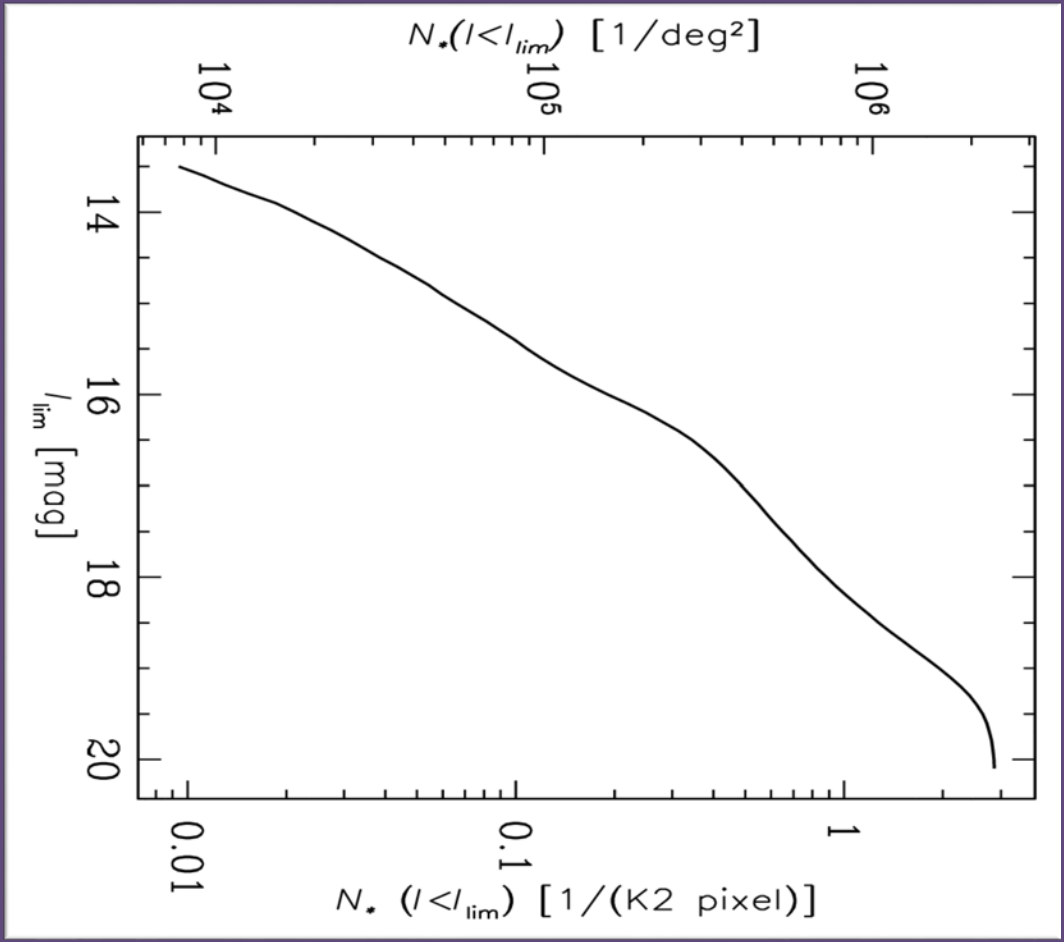
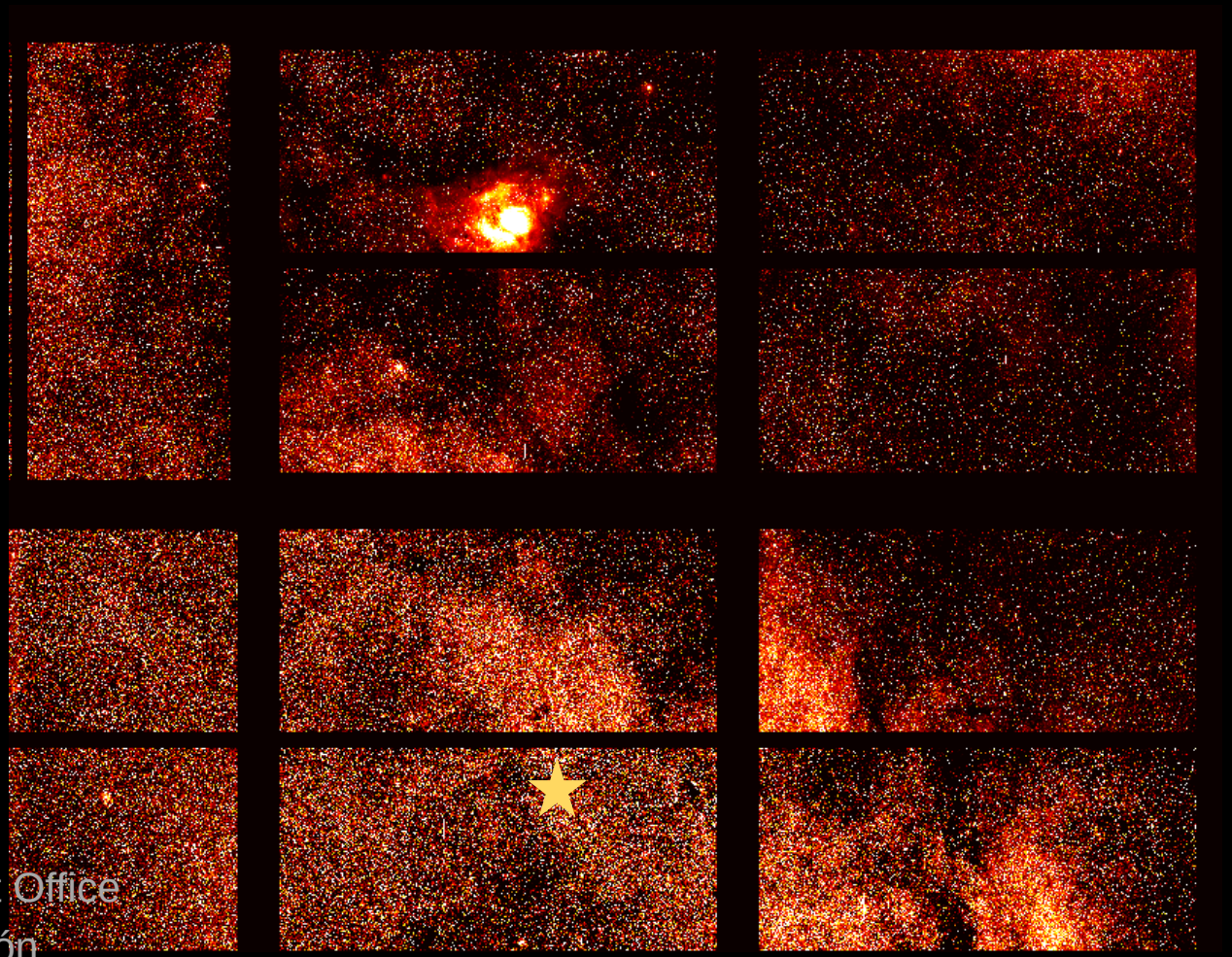


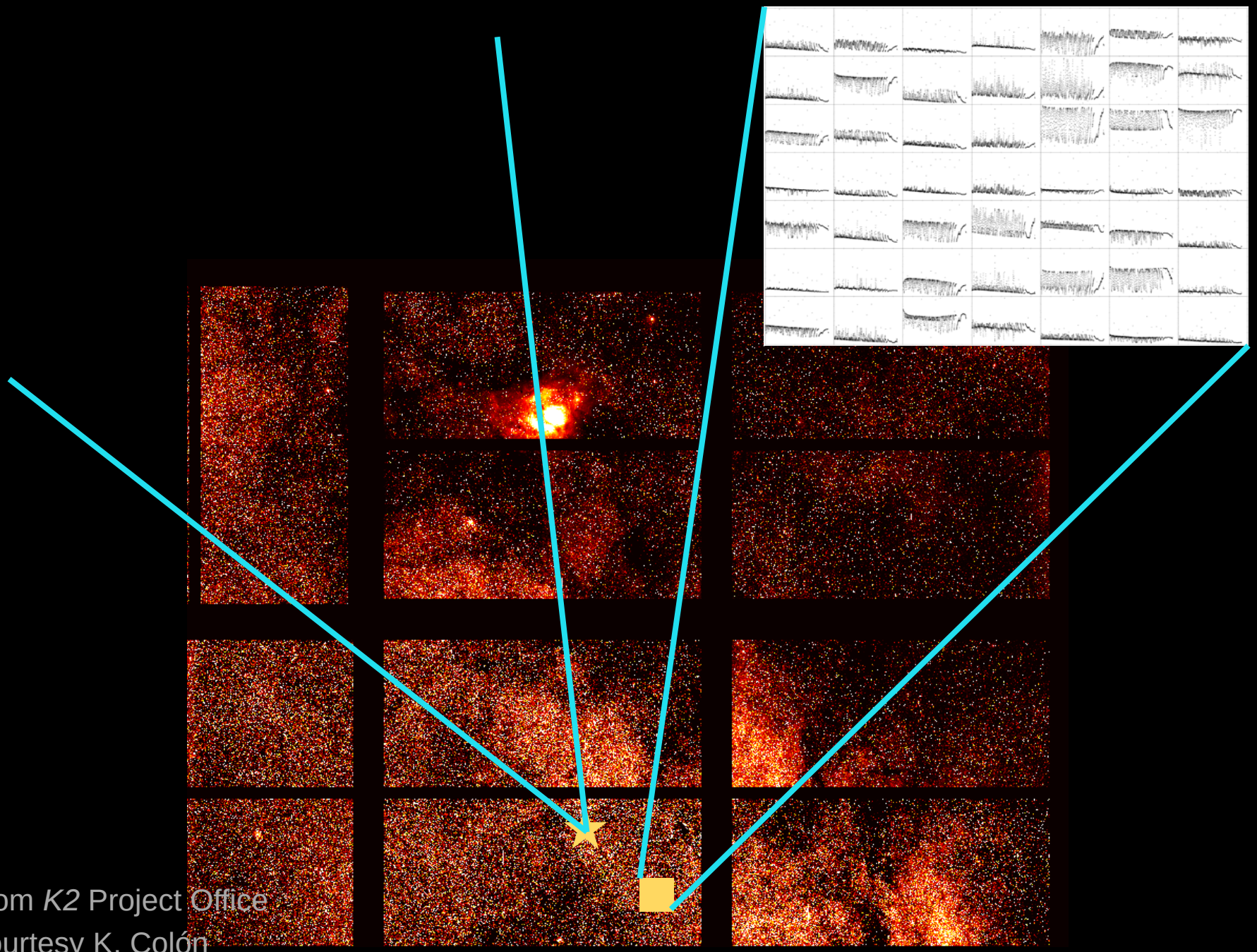
Moving Forward – Photometry Challenges: Blending in *Kepler*



Henderson+ (2015) arXiv:1512.09142



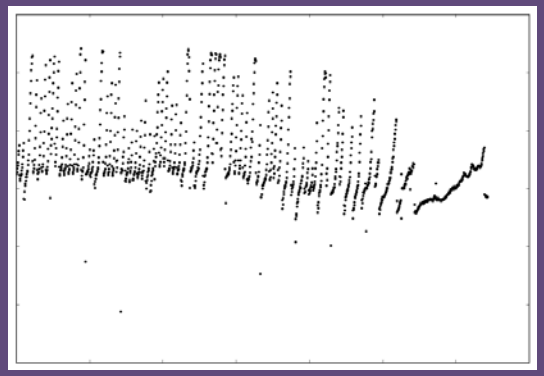
From *K2* Project Office
Courtesy K. Colón



From *K2* Project Office
Courtesy K. Colón

Moving Forward – Photometry Challenges: *Kepler* Event Recovery

Causal Pixel Model



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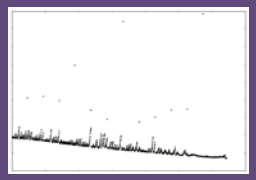
Input pixels



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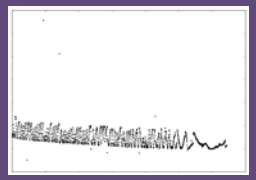

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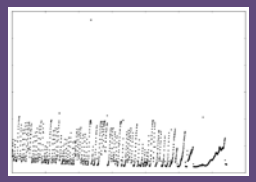

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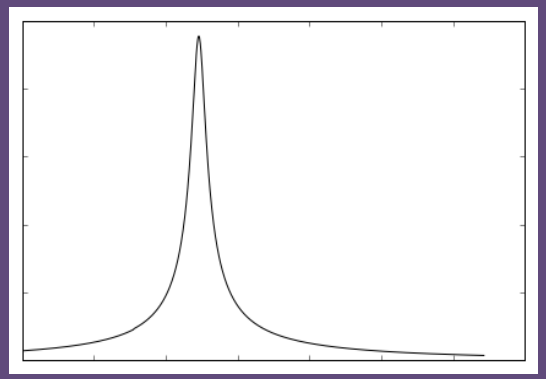
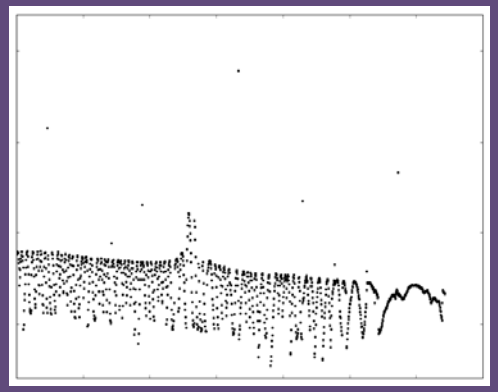
Microlensing Model

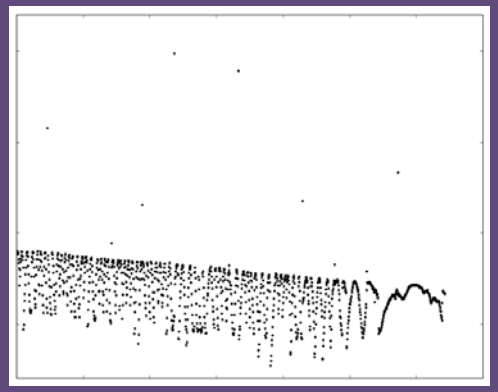


Moving Forward – Photometry Challenges: *Kepler* Event Recovery

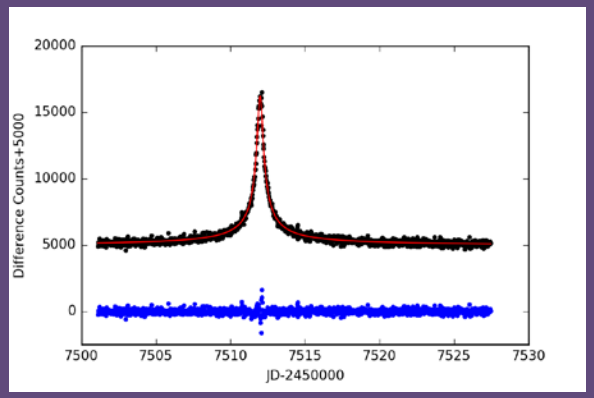
Raw Pixel Light Curve
(i.e., data!)



Causal Pixel Model



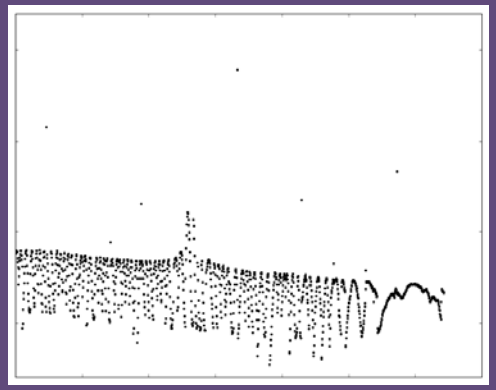
Output light curve!



Moving Forward – Photometry Challenges: *Kepler* Event Recovery

Dun Wang
Graduate Student, NYU

Raw Pixel Light Curve
(i.e., data!)



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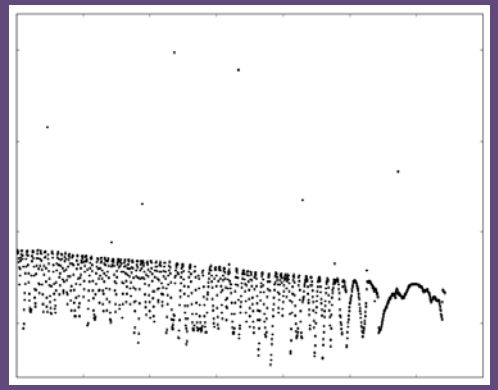
Causal Pixel Model



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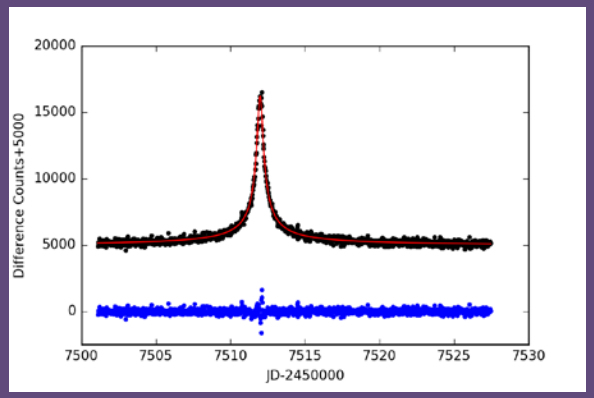
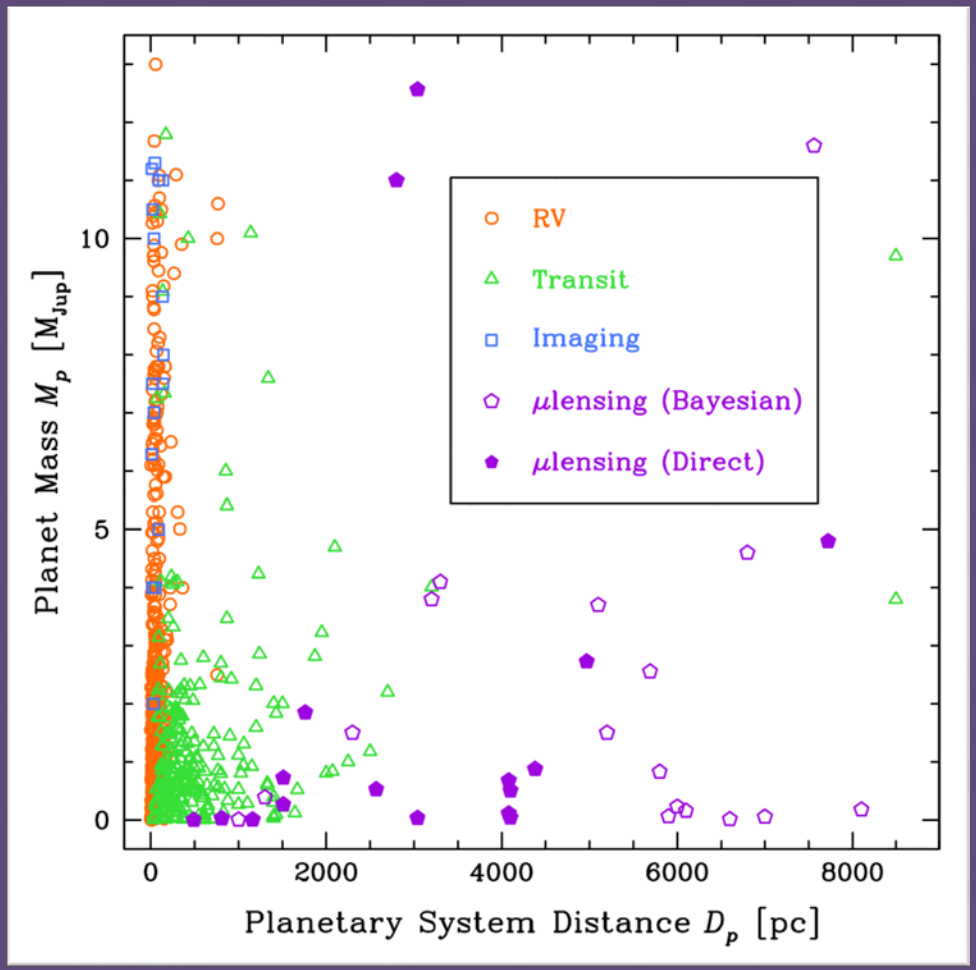
Output light curve!

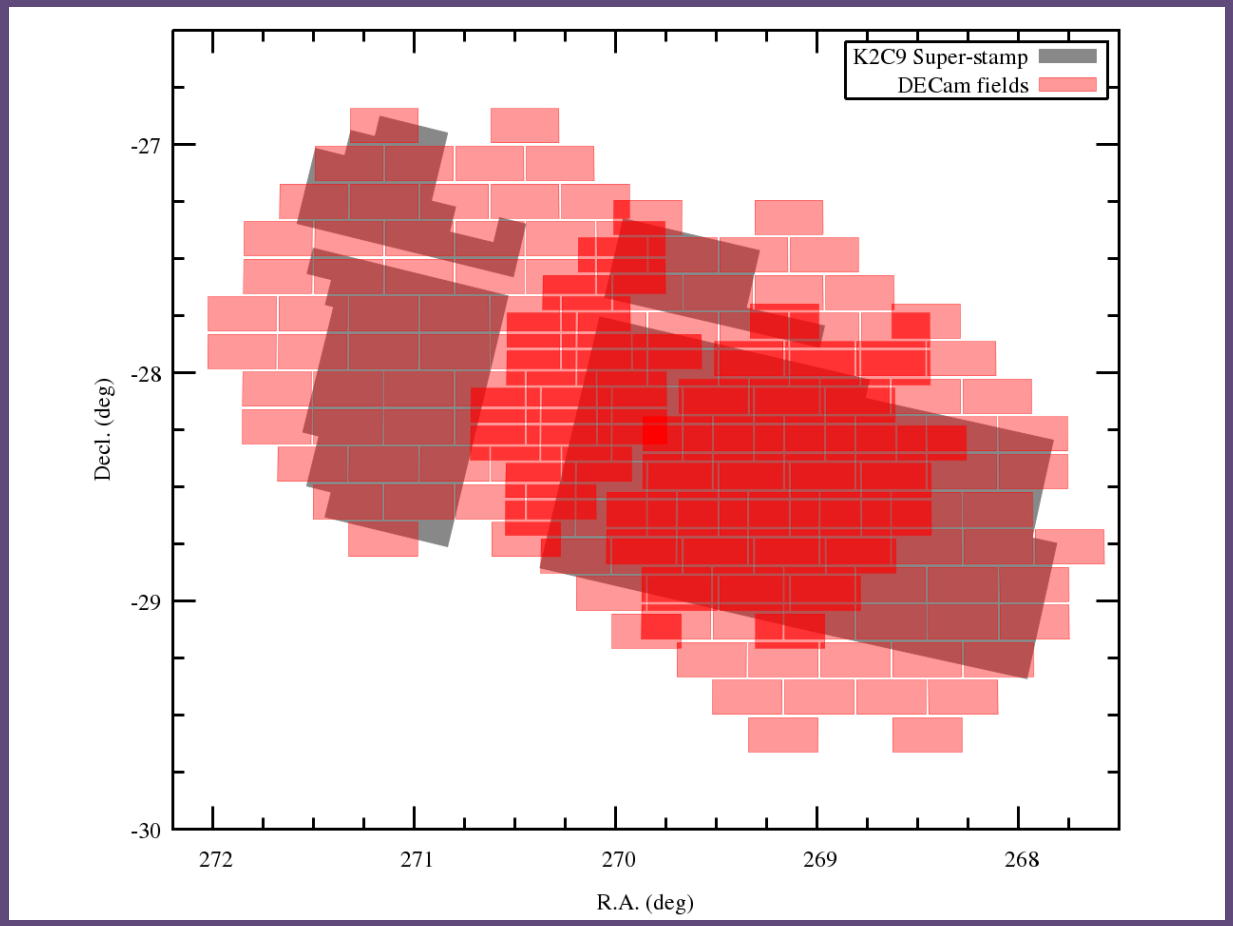


Galactic Distribution of Exoplanets



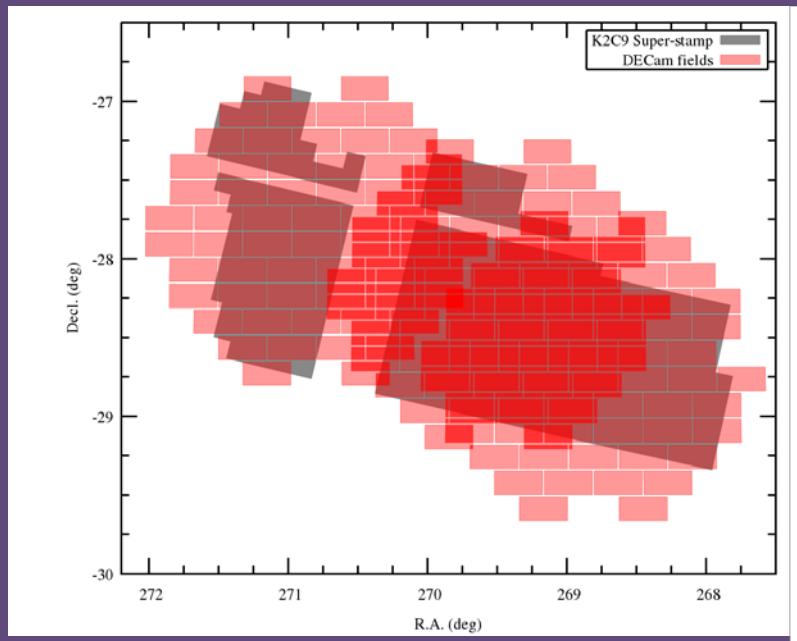
Henderson+ (2015) arXiv:1512.09142

Moving Forward – Photometry Challenges: Blending in *Kepler*

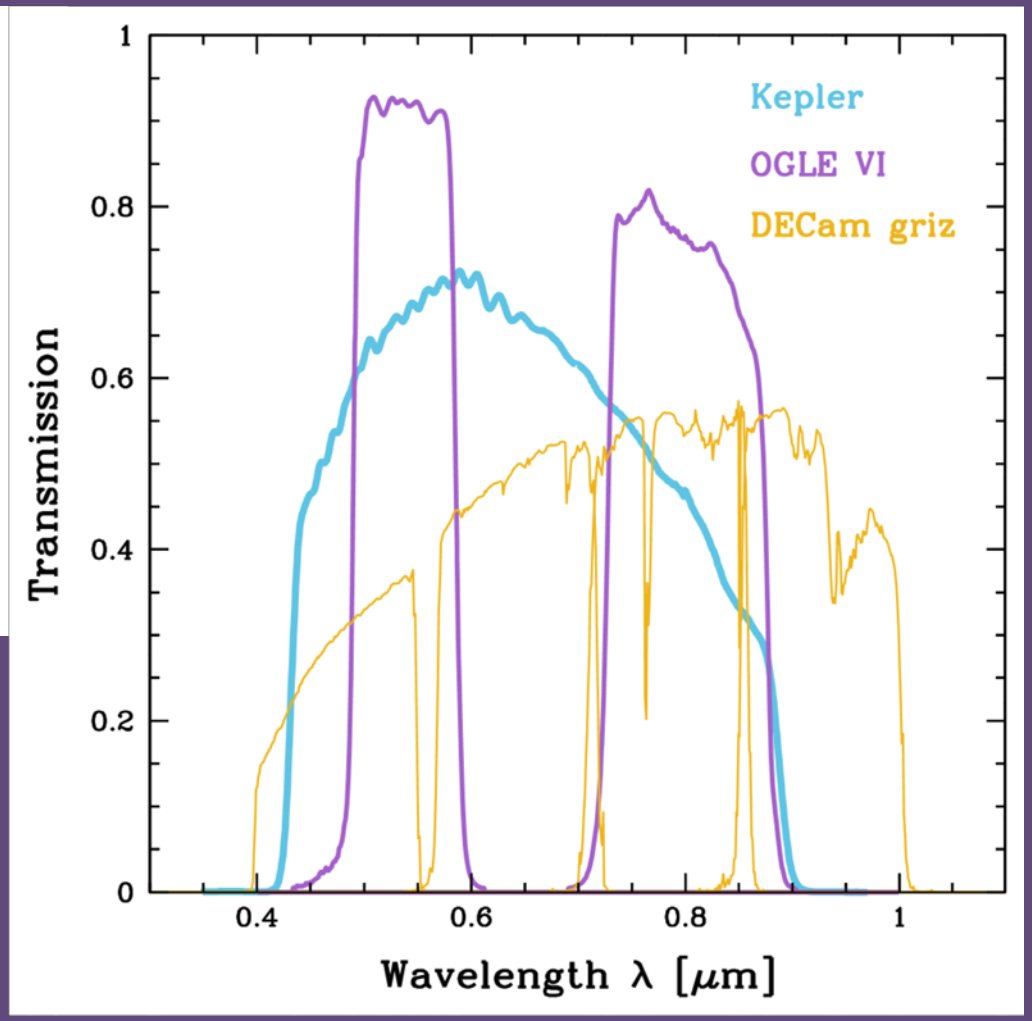


DECam effort led by M. Penny

Moving Forward – Photometry Challenges: Blending in *Kepler*

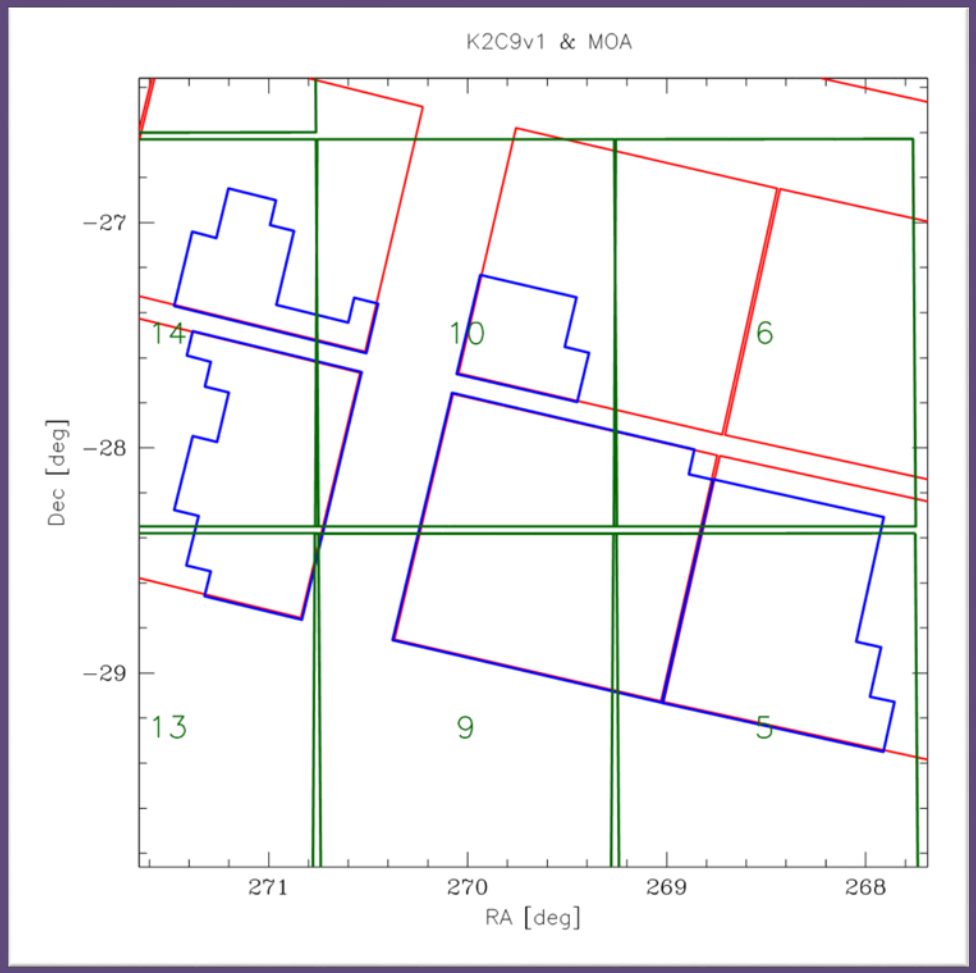


DECam effort led by M. Penny



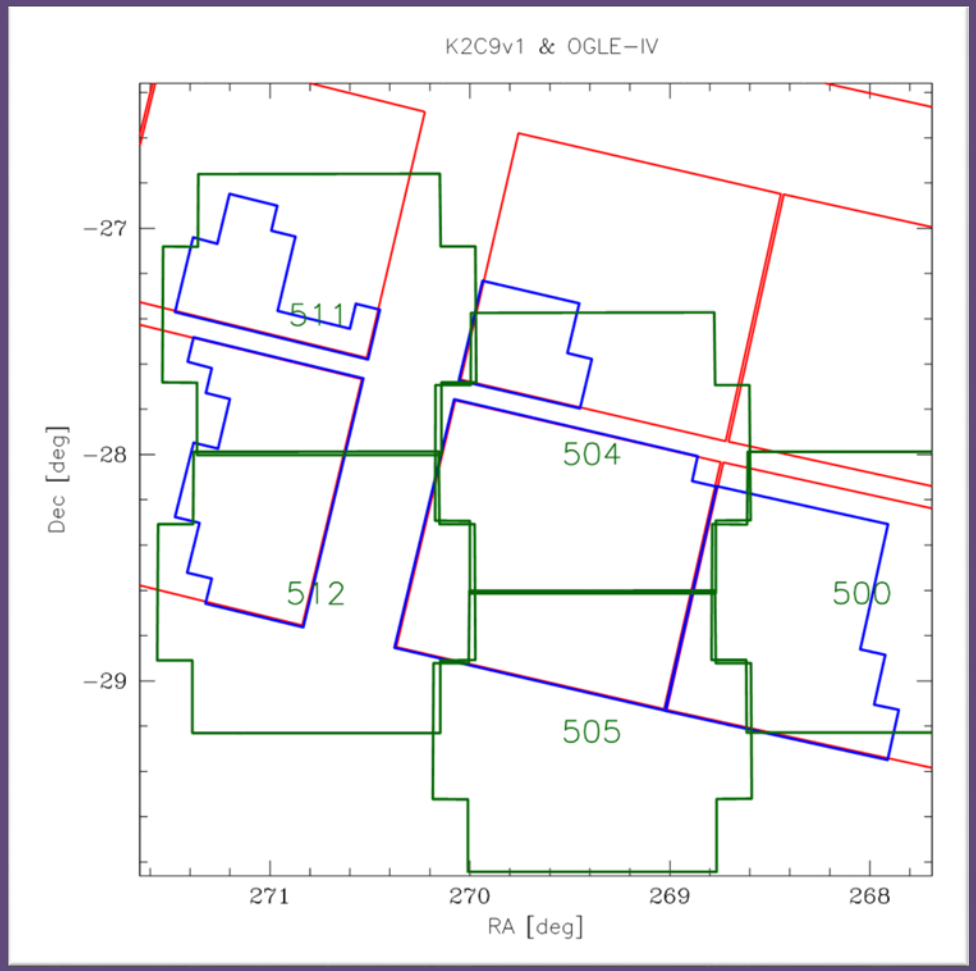
Ground-based Resources: MOA-II

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



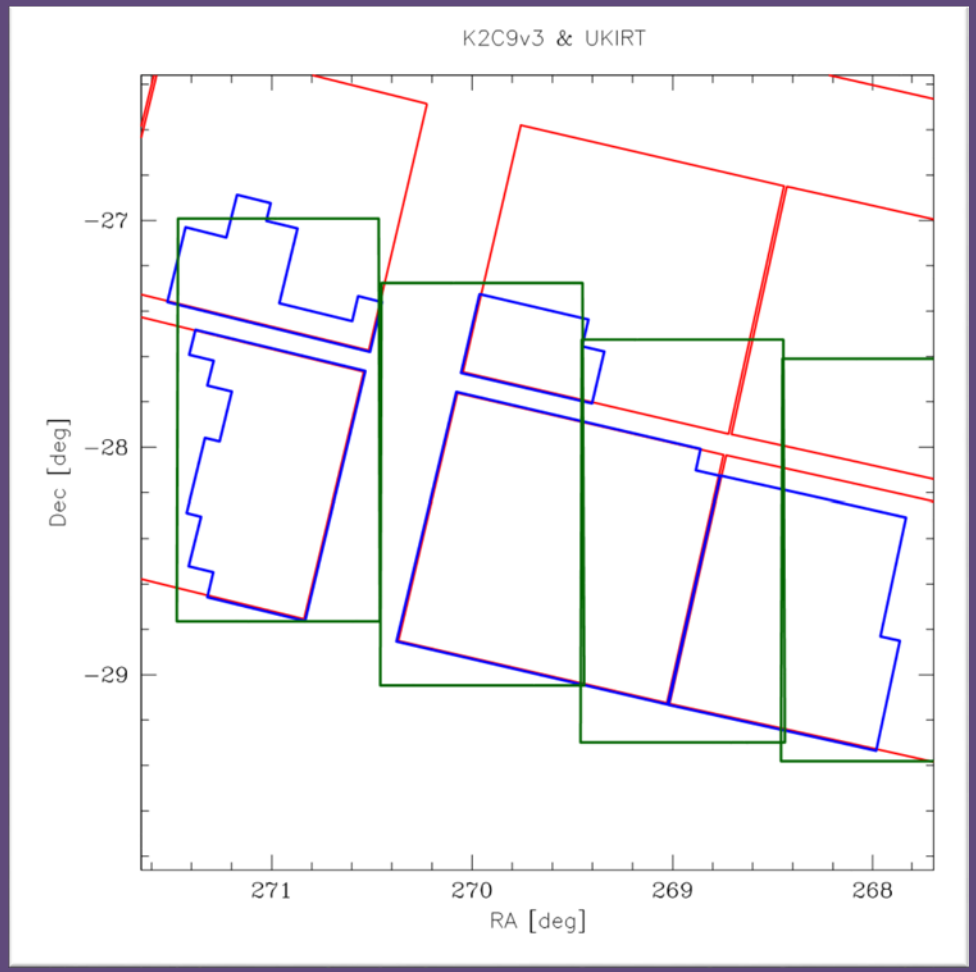
Ground-based Resources: OGLE-IV

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



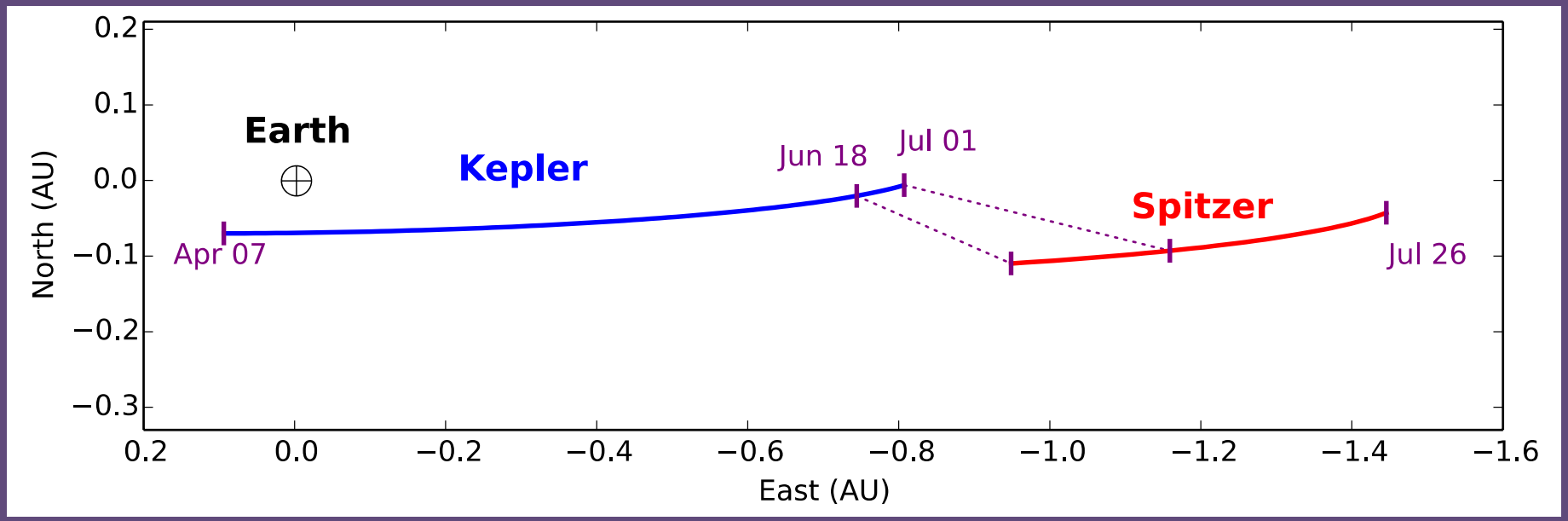
Ground-based Resources: UKIRT

- ✧ 3.8m
- ✧ 0.2 deg^2
- ✧ 2/night (C9a)
- ✧ 3/night (C9b)
- ✧ *H*-band



Moving Forward: *K2C9* Synergies

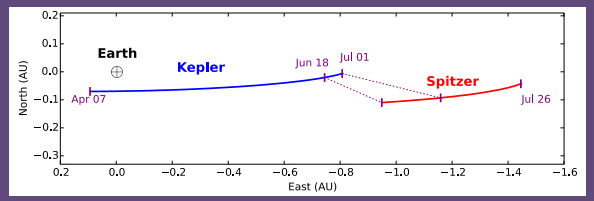
1 Spitzer



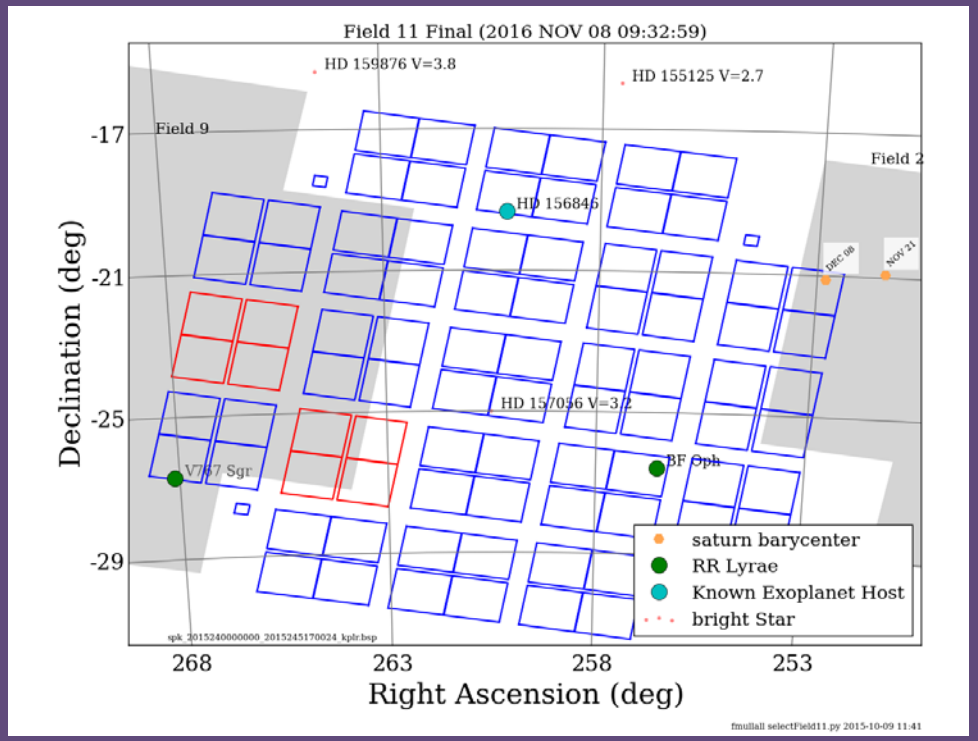
Henderson+ (2015) arXiv:1512.09142

Moving Forward: *K2C9* Synergies

1 Spitzer

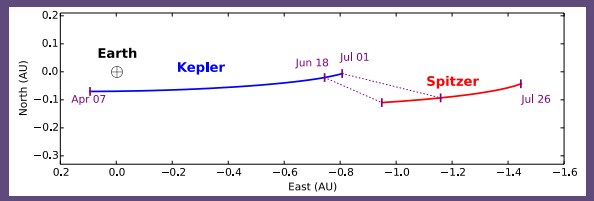


2 *K2C11*

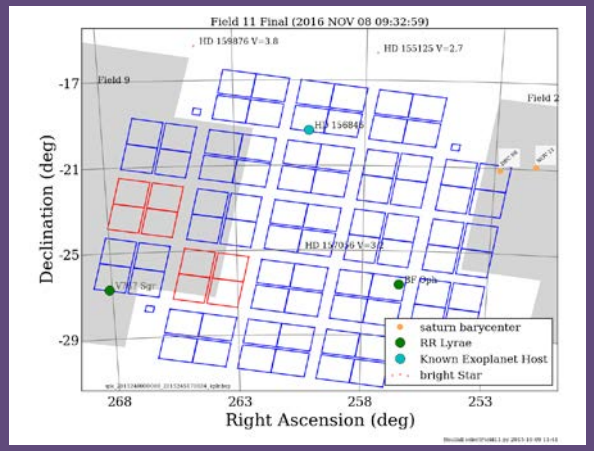


Moving Forward: *K2C9* Synergies

1 Spitzer



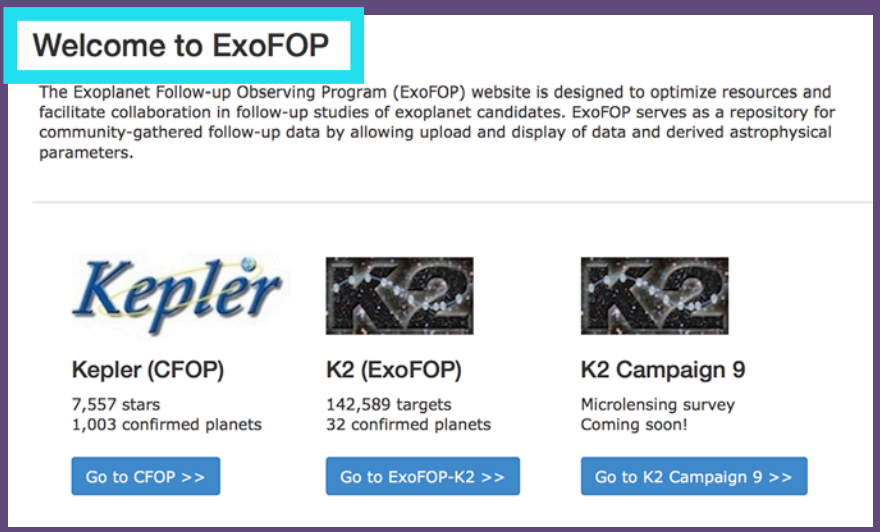
2 *K2C11*

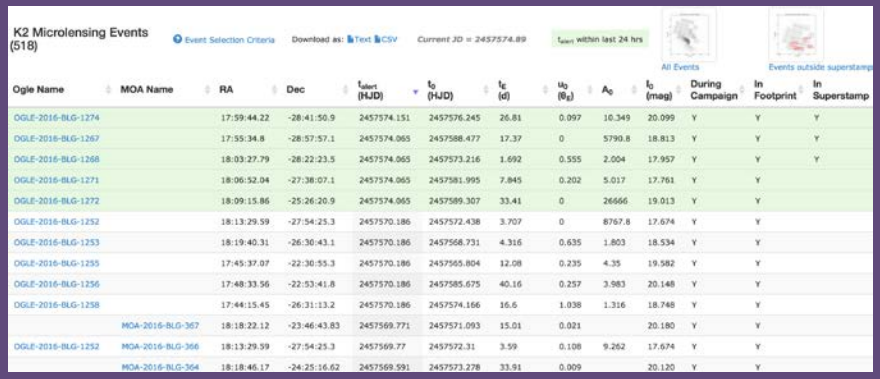


3 Non-microlensing science!

Community Interface

Your target here!!?!





K2 Microlensing Events (518) | Event Selection Criteria | Download as: Text CSV | Current JD = 2457574.89 | t_{alert} within last 24 hrs | All Events | Events outside superstamps

Ogle Name	MOA Name	RA	Dec	t_{alert} (HJD)	t_0 (HJD)	t_E (d)	u_0 (θ_E)	A_0	I_0 (mag)	During Campaign	In Footprint	In Superstamp
OGLE-2016-BLG-1274		17:59:44.22	-28:41:50.9	2457574.151	2457576.245	26.81	0.097	10.349	20.099	Y	Y	Y
OGLE-2016-BLG-1267		17:55:34.8	-28:57:57.1	2457574.065	2457588.477	17.37	0	5790.8	18.813	Y	Y	Y
OGLE-2016-BLG-1268		18:03:27.79	-28:22:23.5	2457574.065	2457573.216	1.692	0.555	2.004	17.957	Y	Y	Y
OGLE-2016-BLG-1271		18:06:52.04	-27:38:07.1	2457574.065	2457581.995	7.845	0.202	5.017	17.761	Y	Y	
OGLE-2016-BLG-1272		18:09:15.86	-25:26:20.9	2457574.065	2457589.307	33.41	0	26666	19.013	Y	Y	
OGLE-2016-BLG-1252		18:13:29.59	-27:54:25.3	2457570.186	2457572.438	3.707	0	8767.8	17.674	Y	Y	
OGLE-2016-BLG-1253		18:19:40.31	-26:30:43.1	2457570.186	2457568.731	4.316	0.635	1.803	18.534	Y	Y	
OGLE-2016-BLG-1255		17:45:37.07	-22:30:55.3	2457570.186	2457565.804	12.08	0.235	4.35	19.582	Y	Y	
OGLE-2016-BLG-1256		17:48:33.56	-22:53:41.8	2457570.186	2457585.675	40.16	0.257	3.983	20.148	Y	Y	
OGLE-2016-BLG-1258		17:44:15.45	-26:31:13.2	2457570.186	2457574.166	16.6	1.038	1.316	18.748	Y	Y	
	MOA-2016-BLG-367	18:18:22.12	-23:46:43.83	2457569.771	2457571.093	15.01	0.021		20.180	Y	Y	
OGLE-2016-BLG-1252	MOA-2016-BLG-366	18:13:29.59	-27:54:25.3	2457569.77	2457572.31	3.59	0.108	9.262	17.674	Y	Y	
	MOA-2016-BLG-364	18:18:46.17	-24:25:16.62	2457569.591	2457573.278	33.91	0.009		20.120	Y	Y	

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Come Learn and Discuss Microlensing!

Topics Include:

- *K2C9!*
- Spitzer!
- WFIRST!

Don't worry: Conference preceded by (free!) half-day microlensing workshop!

mlens2017@pac.caltech.edu

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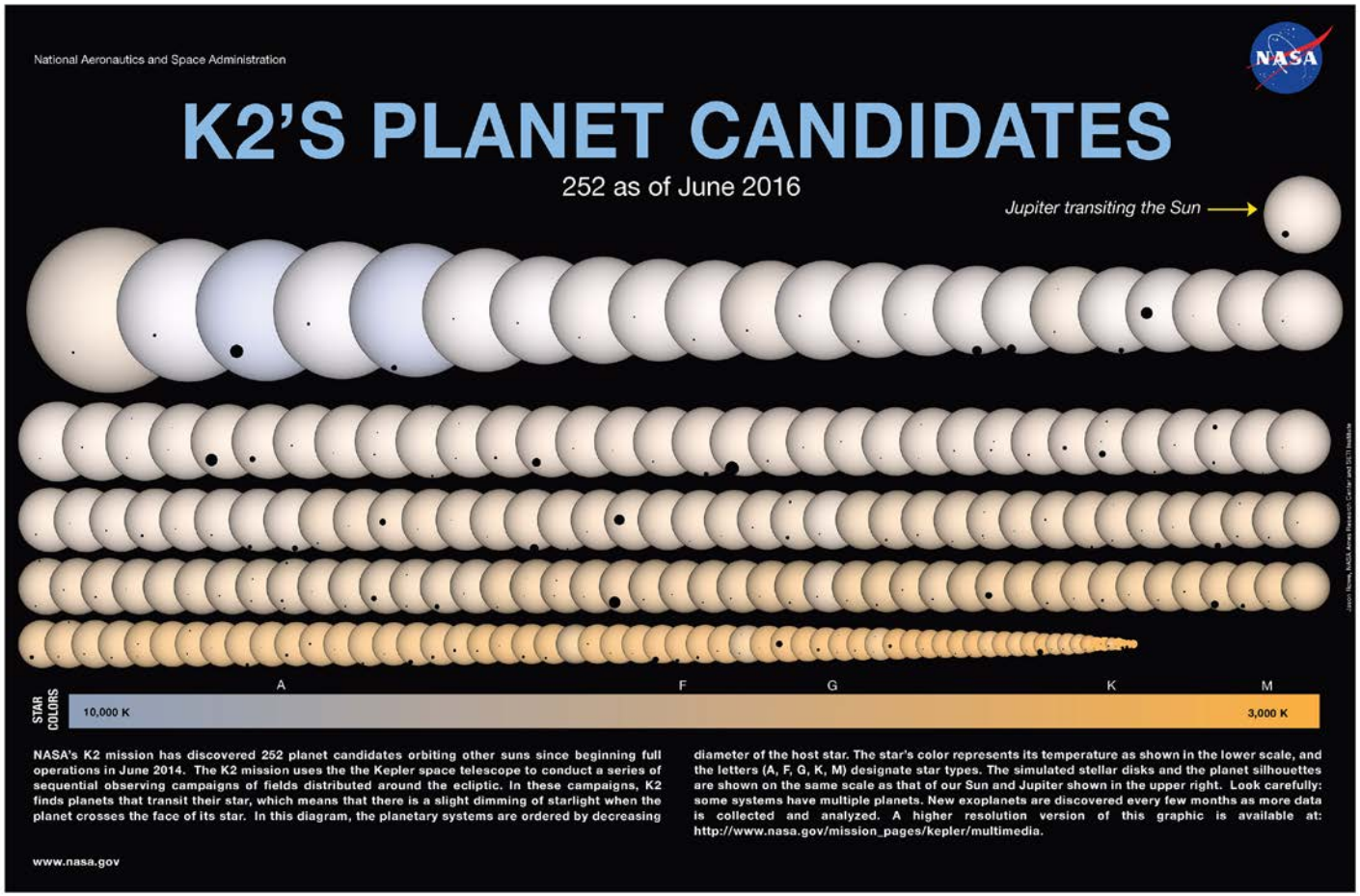
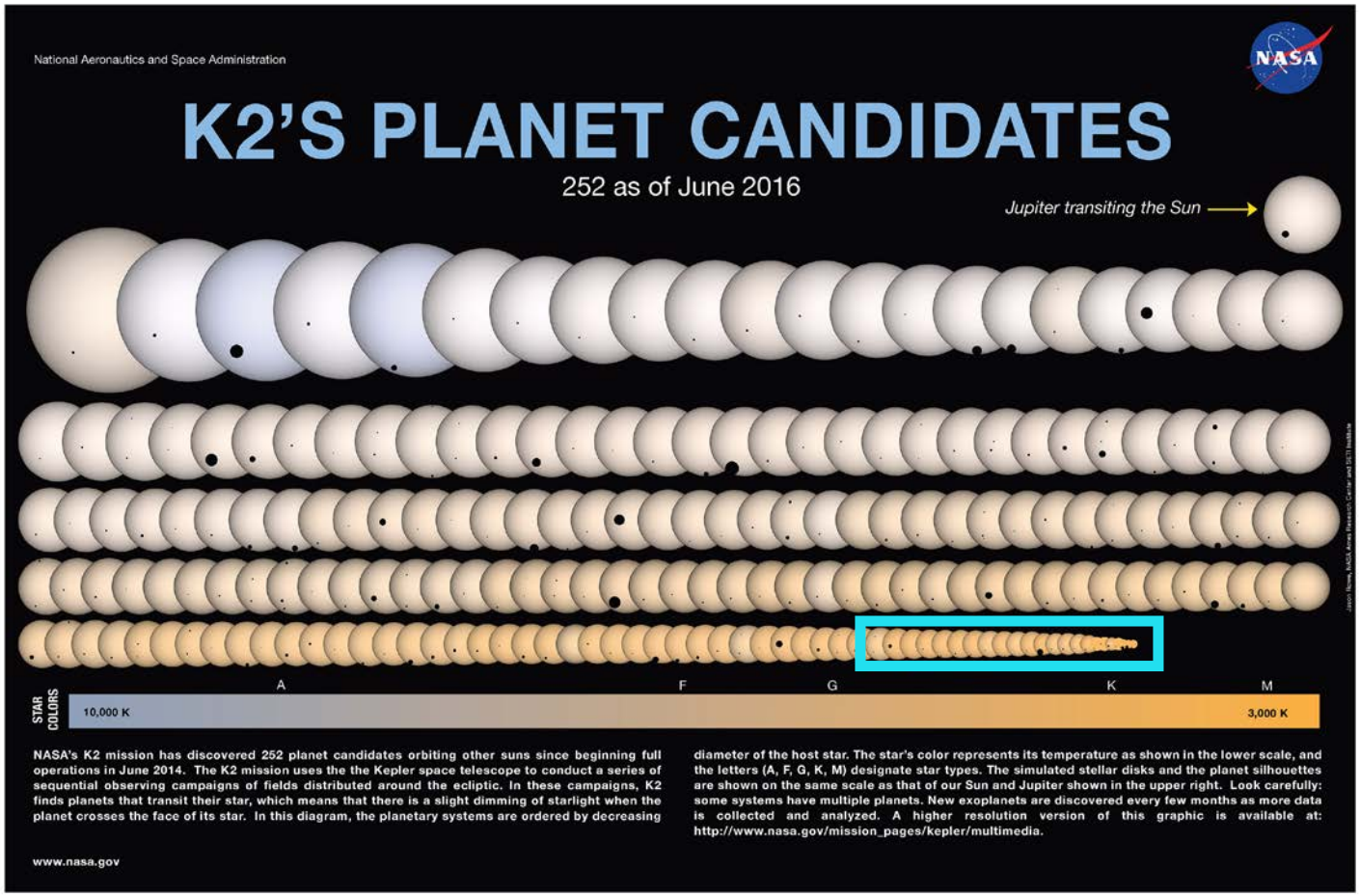
Host Stars for *K2*C9 (and microlensing!)



Host Stars for *K2*C9 (and microlensing!)