Mission Highlights

Kepler

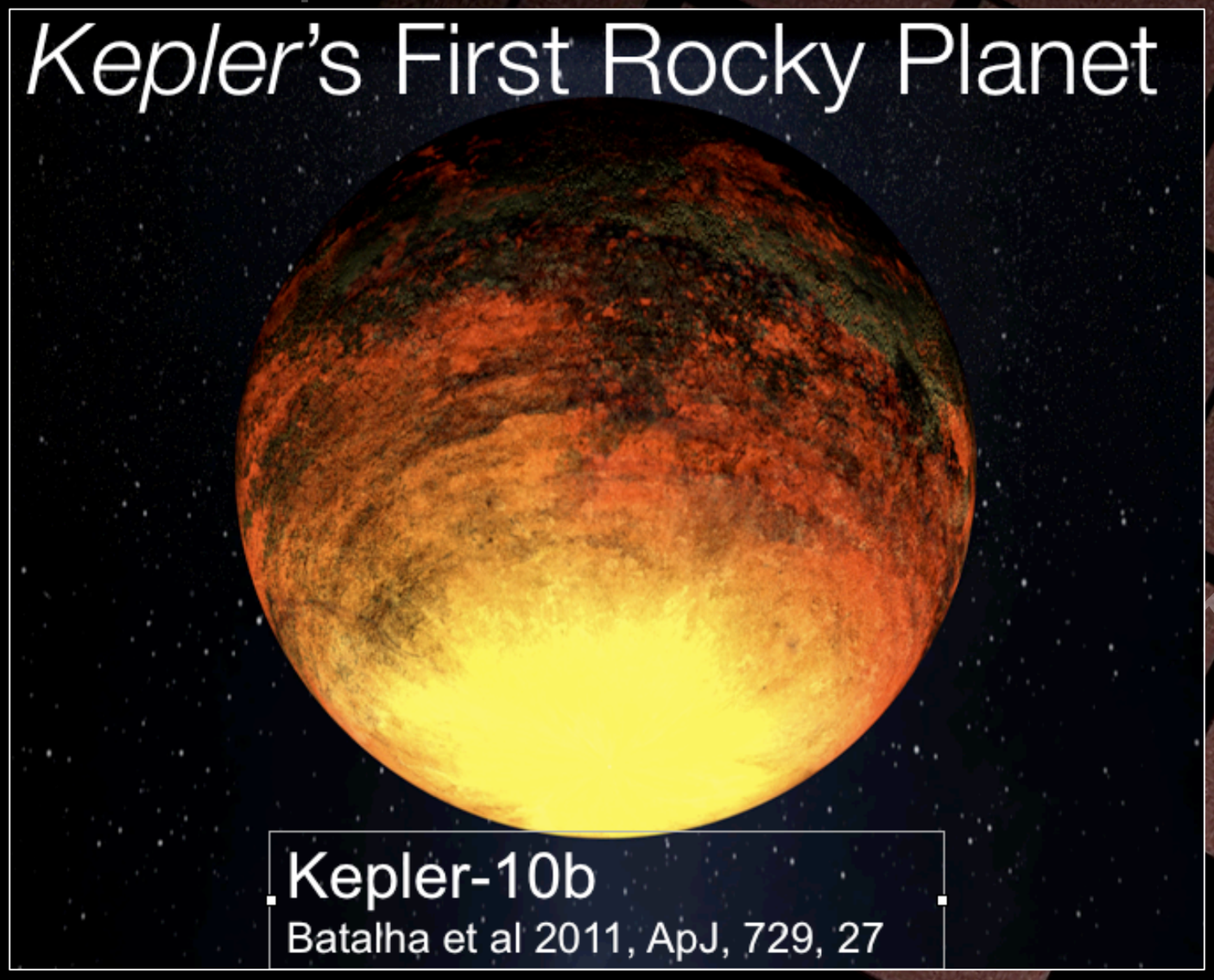
Natalie Batalha
San Jose State University

- Planet Confirmations
- KOI Catalog
- Completeness
- Stellar Noise

Kepler

Feb 2011

Kepler-10
Kepler-4
Kepler-1
Kepler-6
Kepler-3
Kepler-2
Confirmed Planet Count: 015
Kepler-8
Kepler-5
(6)
Kepler-11
Kepler-7
(3)
Kepler-9



(2) Kepler-10
Kepler-4
Kepler-1
Kepler-6
Kepler-2
Kepler-3
Kepler-8
Kepler-7
(3)
Kepler-9

(2) Kepler-10

Kepler-4

Kepler-1

Kepler-6

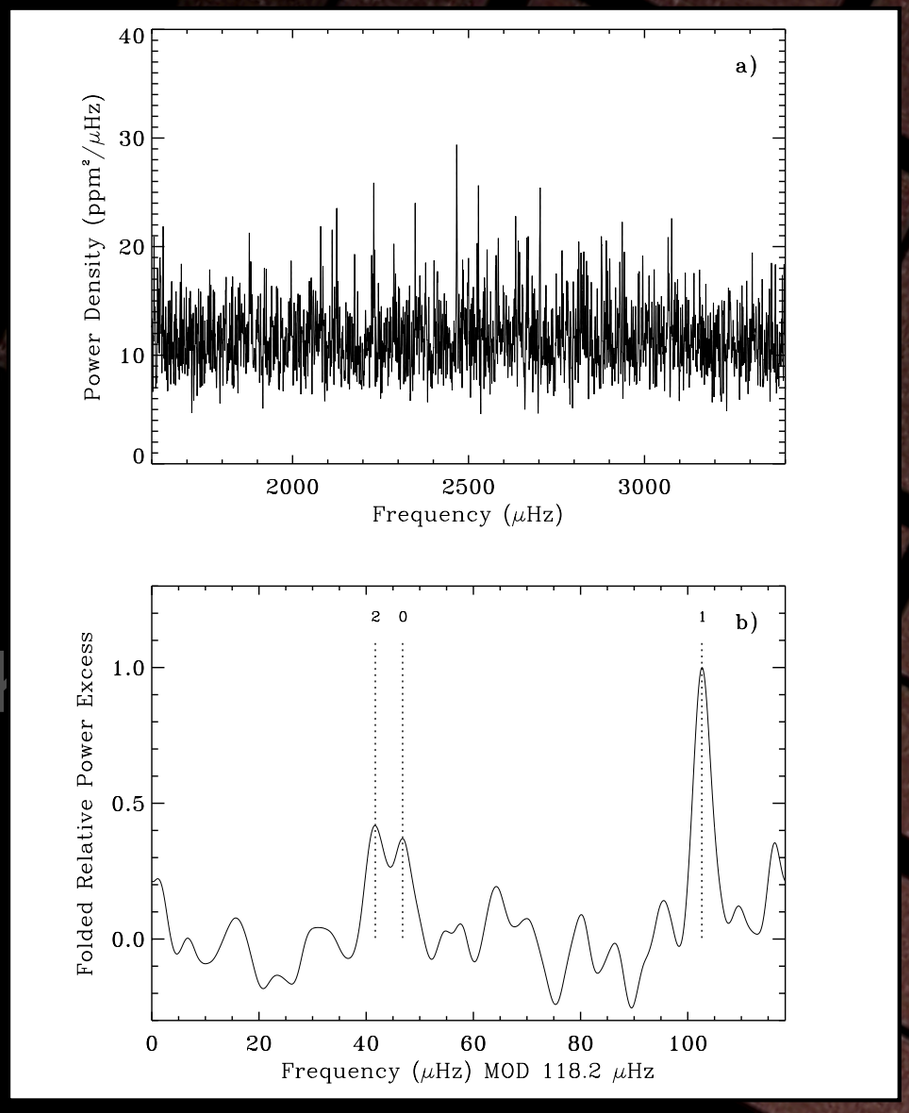
Kepler-2

Kepler-3

Kepler-8

Kepler-7

(3) Kepler-9



(2) Kepler-10

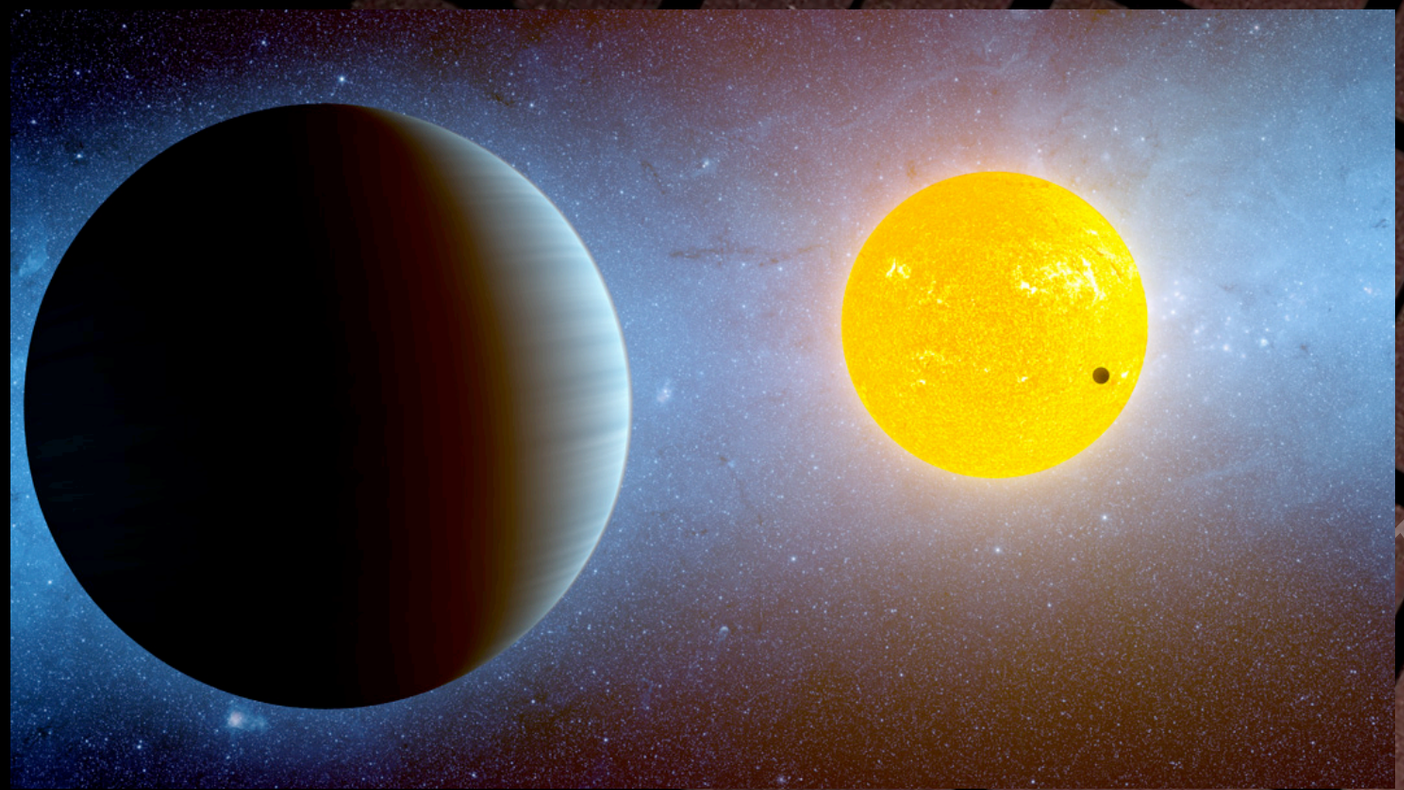
Kepler-4

Kepler-1

Kepler-6

Kepler-2

Kepler-3



Kepler-8

Kepler-7

(3) Kepler-9

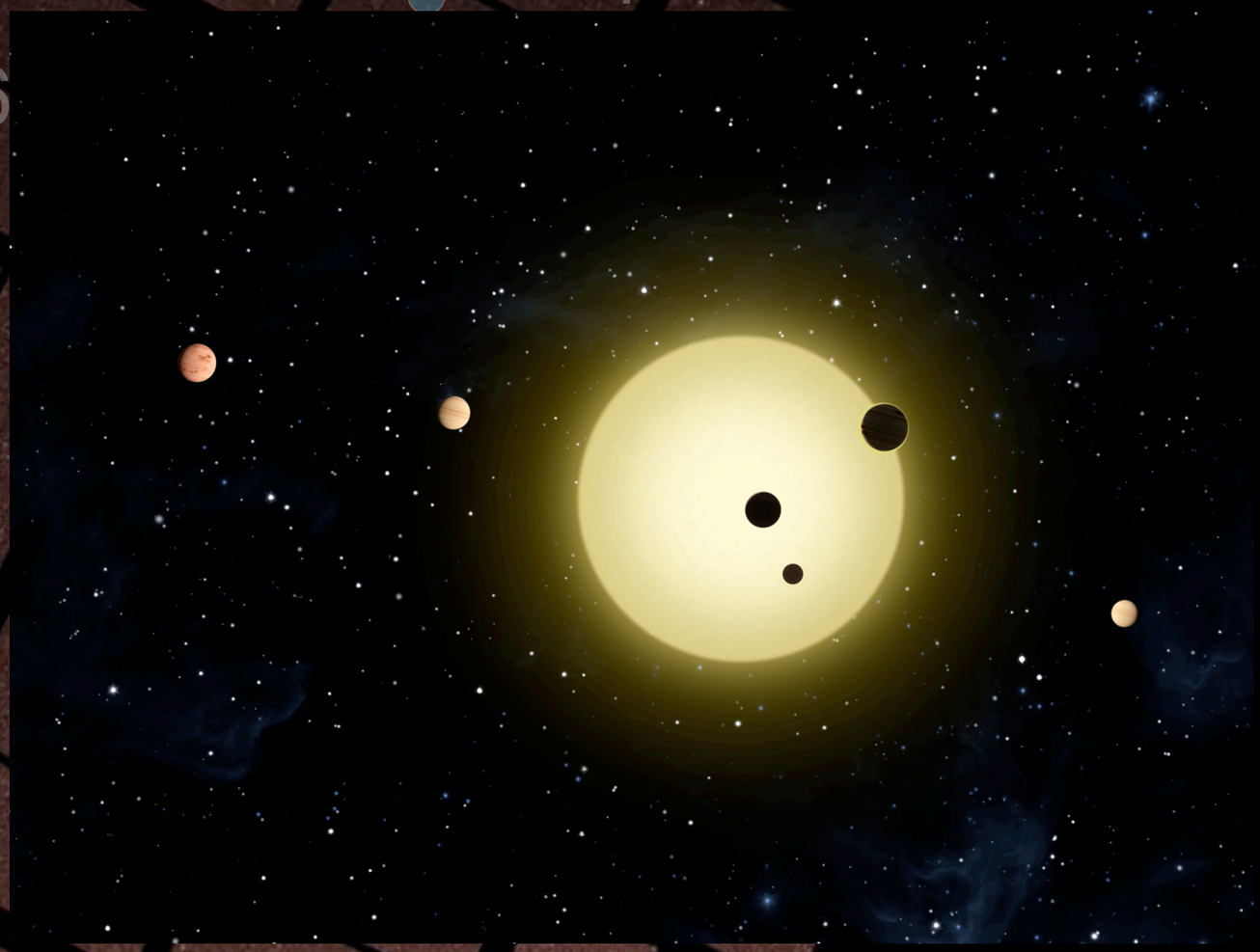
(2) Kepler-10

Kepler-12

Kepler-4

Kepler-6

Kepler-3



Kepler-5

(6)

Kepler-11

(3) Kepler-9

Lissauer et al. 2011, Nature, 470, 53

Quintana, Fri 10:45 AM

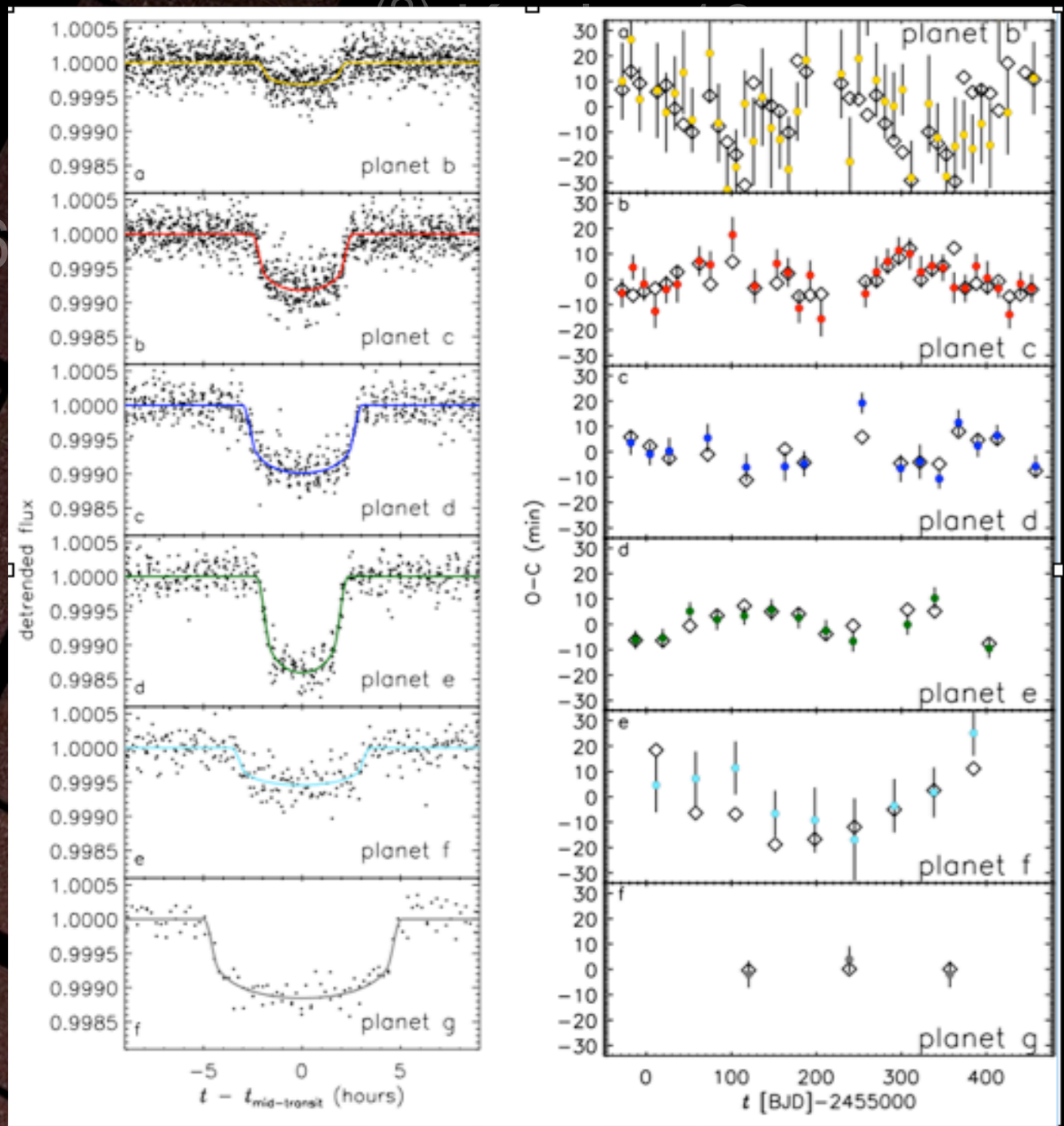
Kepler-6

Kepler-3

Kepler-5

(6)

Kepler-11



Lissauer et al. 2011, Nature, 470, 53

Quintana, Fri 10:45 AM

Sep 2011

Kepler-16

(2) Kepler-10

Kepler-12

Kepler-4

Kepler-15

Kepler-1

Kepler-6

Kepler-2

Kepler-3

Kepler-14

KOI-428

Kepler-17

Kepler-13

KOI-196

KOI-423

Kepler-8

Kepler-5

Confirmed Planet Count: 027

(6)

Kepler-11

Kepler-7

(3) Kepler-9

(2) Kepler-19

Kepler-16

(2) Kepler-10

Kepler-12

Kepler-4

Kepler-1

Kepler-6

Kepler-2

Kepler-3

KOI-428

Kepler-14

KOI-196

KOI-423

Kepler-5

(6)

Kepler-11

KOI-428b

Star: F5IV

P=6.87 days

R_p=1.17 +/- 0.04 R_J

M_p=2.2 +/- 0.4 M_J

Santerne et al. 2011, A&A, 528, 63

Kepler-16

(2) Kepler-10

Kepler-12

Kepler-4

Kepler-1

Kepler-6

Kepler-2

Kepler-3

KOI-428

Kepler-14

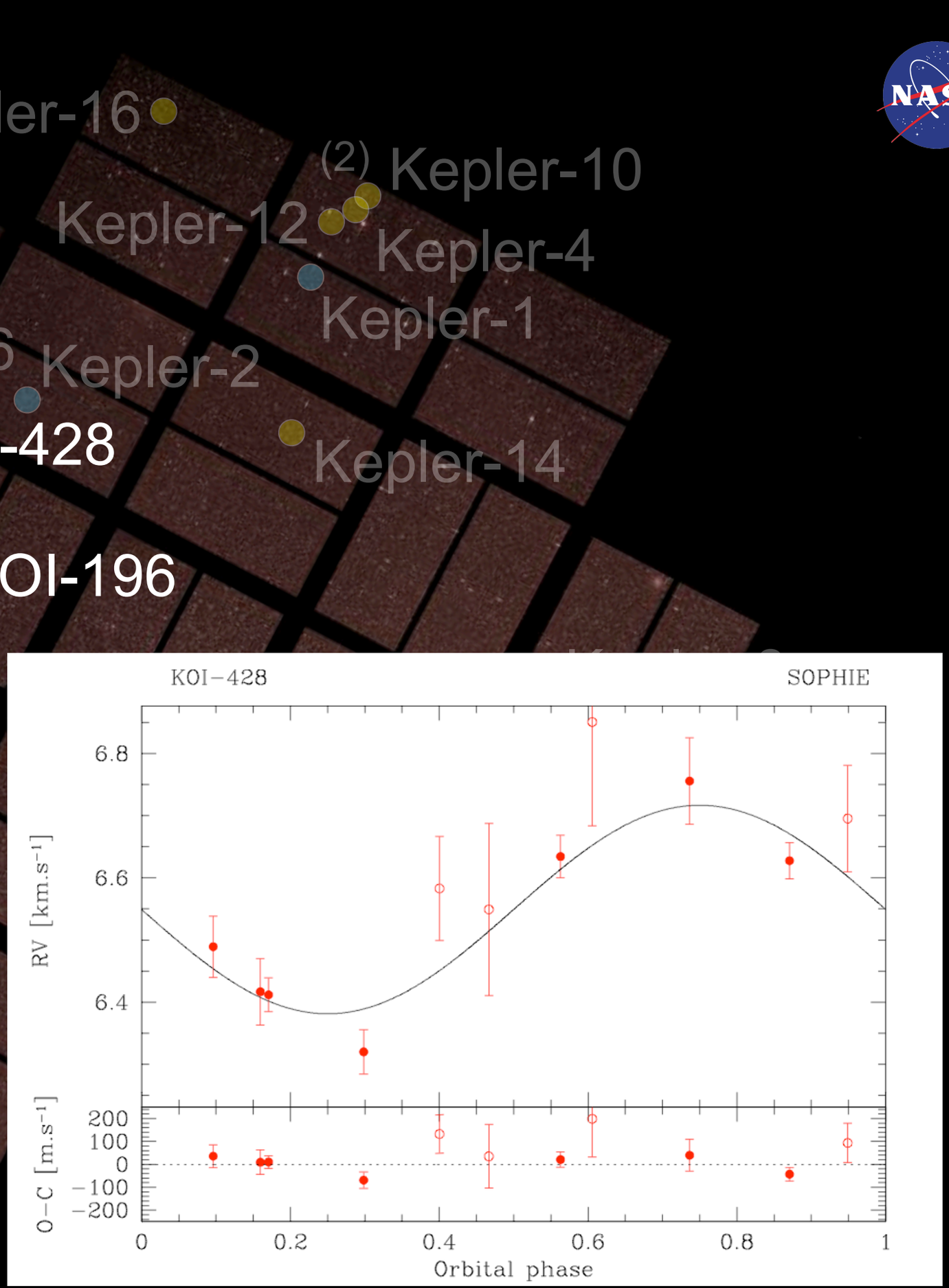
KOI-196

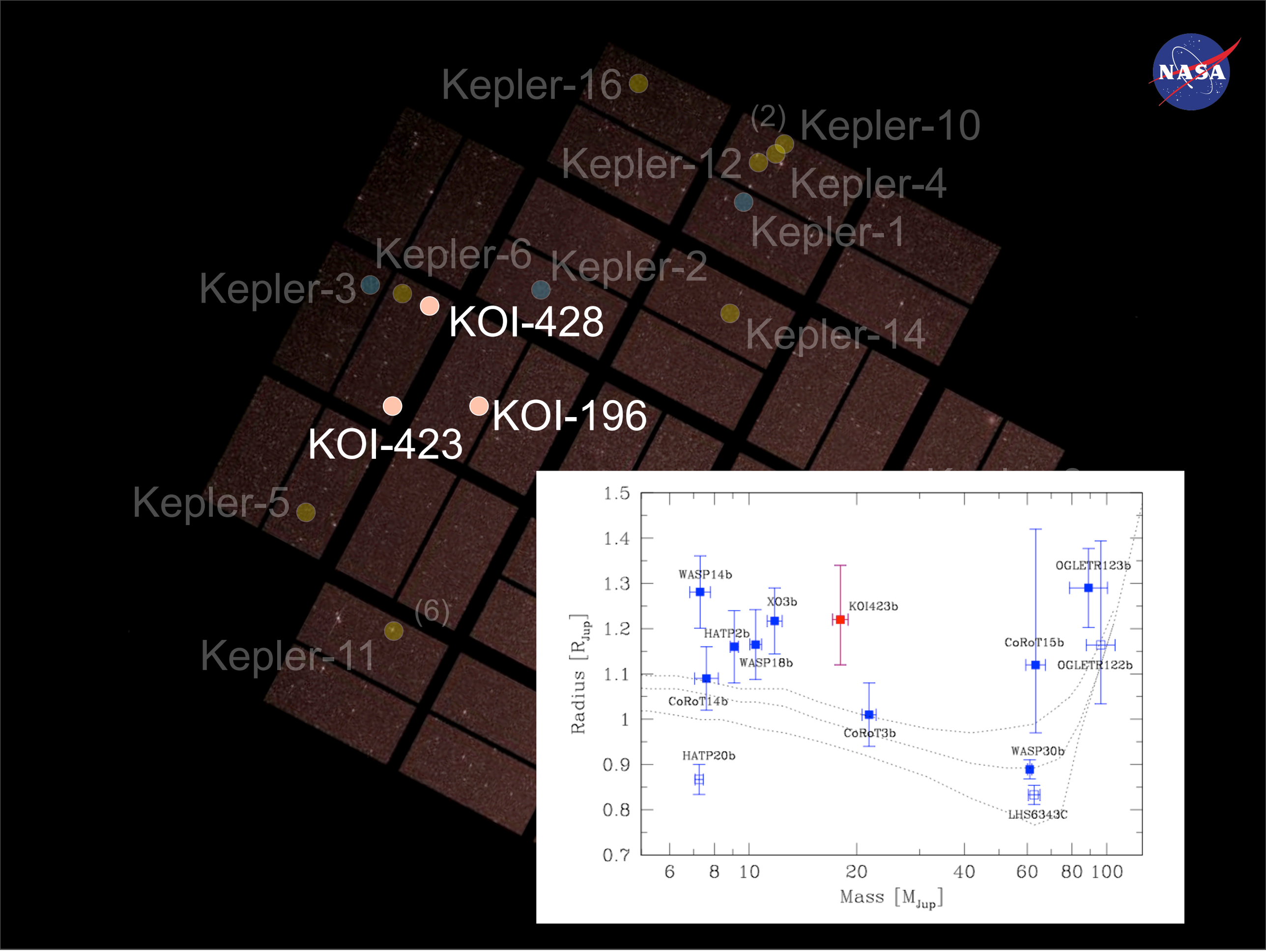
KOI-423

Kepler-5

(6)

Kepler-11




Kepler-16
(2)
Kepler-10
Kepler-12
Kepler-4
Kepler-1
Kepler-6
Kepler-2
Kepler-3
KOI-428
Kepler-14
KOI-196
KOI-423
Kepler-5
(6)
Kepler-11
Radius [R_Jup]
Mass [M_Jup]
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
6
8
10
20
40
60
80
100
WASP14b
XO3b
KOI423b
HATP2b
WASP18b
CoRoT15b
OGLETR123b
OGLETR122b
CoRoT14b
CoRoT3b
HATP20b
WASP30b
LHS6343C

Accelerated Data Release

Recognizing the high demand for data, the project has revised its Data Release Policies, providing for a significantly accelerated schedule.

- September 23, 2011: Quarter 3
- January, 2012: Q4 - ?
- 6 month cadence, pending HQ approval

http://archive.stsci.edu/kepler

http://nexsci.caltech.edu/

Kepler-16

(2) Kepler-10

Kepler-12

Kepler-4

Kepler-15

Kepler-1

Kepler-6

Kepler-2

Kepler-3

Kepler-14

KOI-428

Kepler-17

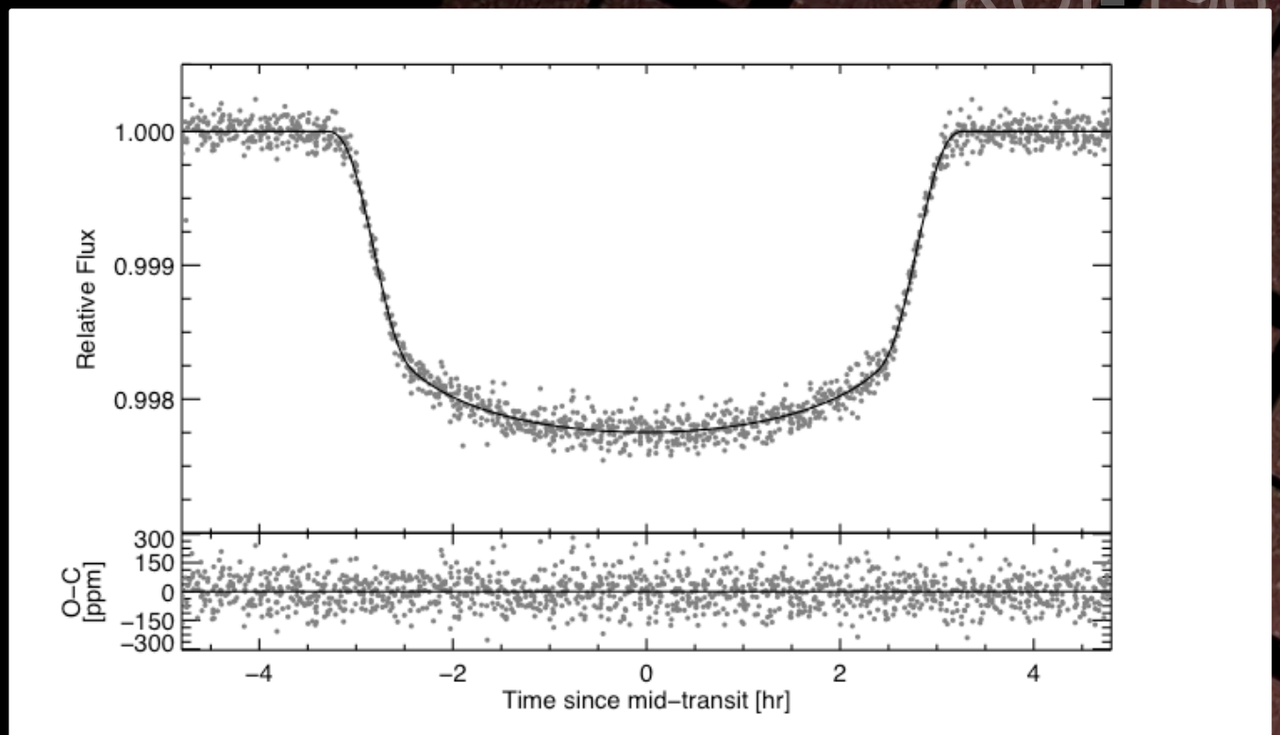
Kepler-13

KOI-196

Kepler-8

Kepler-7

(2) Kepler-19



Buchhave et al. 2011
Poster: 19.17

Buchhave et al. 2011, arXiv:1106.5510

Kepler-16

(2) Kepler-10

Kepler-12

Kepler-4

Kepler-15

Kepler-1

Kepler-6

Kepler-2

Kepler-14

Kepler-13

Kepler-8

Kepler-7

Kepler-19

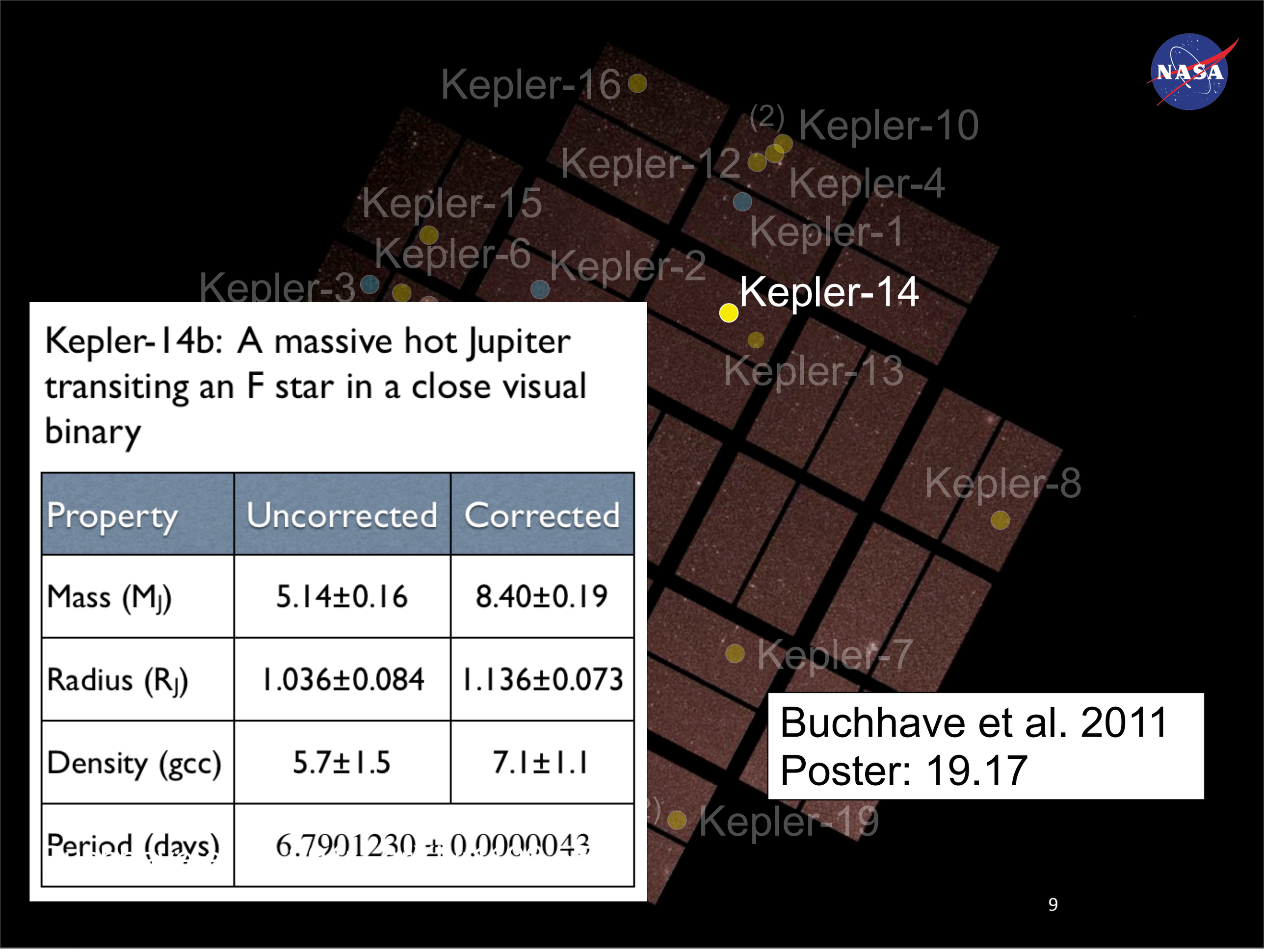
N

E

0.3”

Buchhave et al. 2011, arXiv:1106.5510

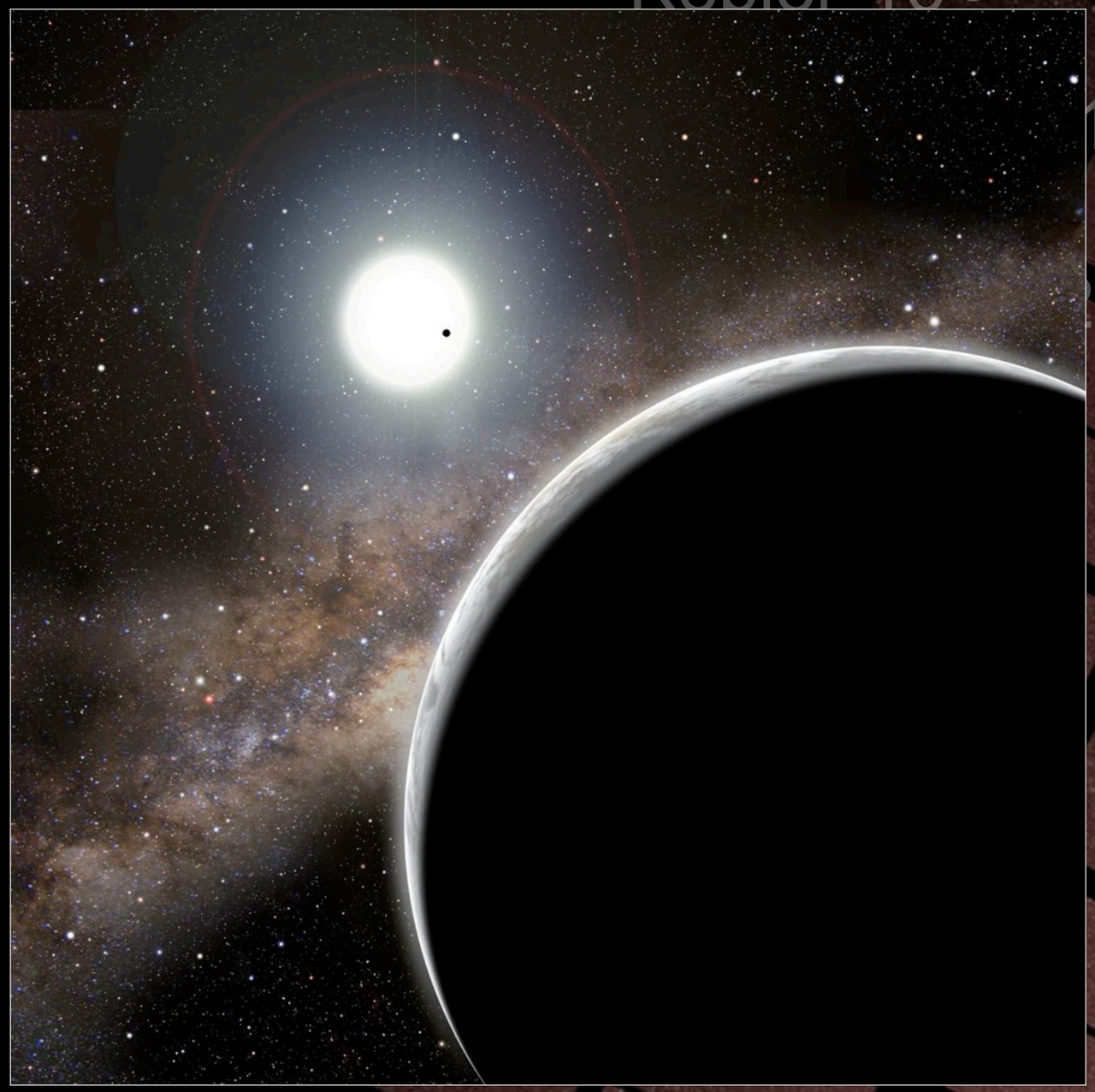
Buchhave et al. 2011
Poster: 19.17



Kepler-14b: A massive hot Jupiter transiting an F star in a close visual binary

Property	Uncorrected	Corrected
Mass (M_J)	5.14±0.16	8.40±0.19
Radius (R_J)	1.036±0.084	1.136±0.073
Density (gcc)	5.7±1.5	7.1±1.1
Period (days)	6.7901230 ± 0.0000043	

Buchhave et al. 2011
Poster: 19.17



Kepler-16

(2) Kepler-10

12

Kepler-4

Kepler-1

Kepler-14

Kepler-13

Kepler-8

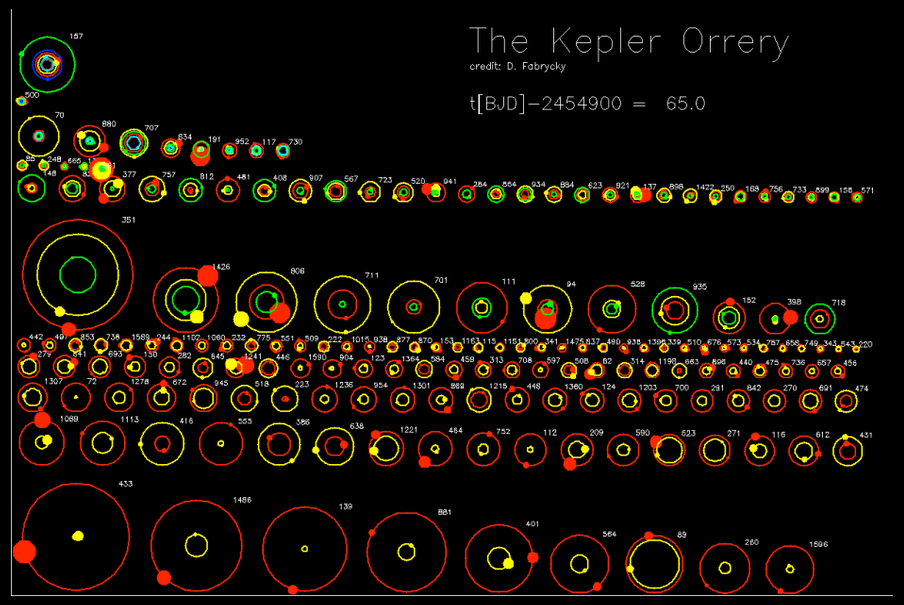
Kepler-7

(3) Kepler-9

(2) Kepler-19

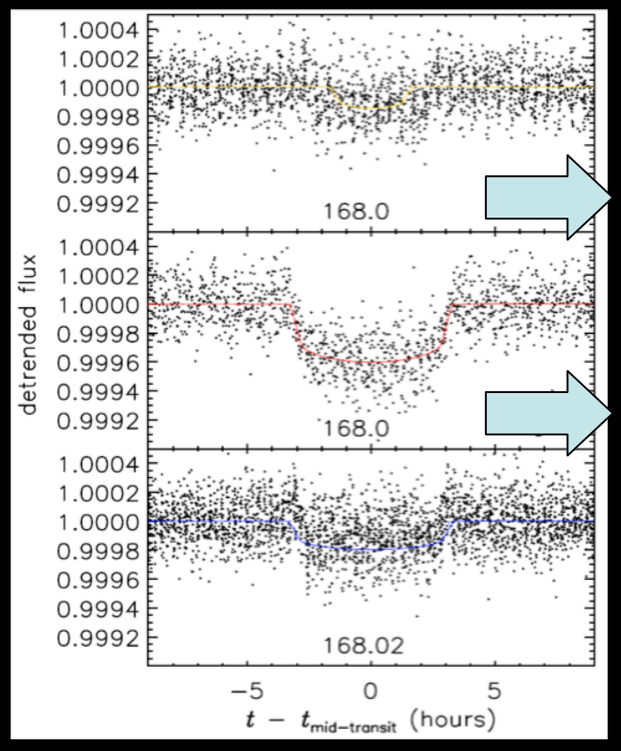
Ballard et al 2011, arXiv:1109.1561; M 2:30

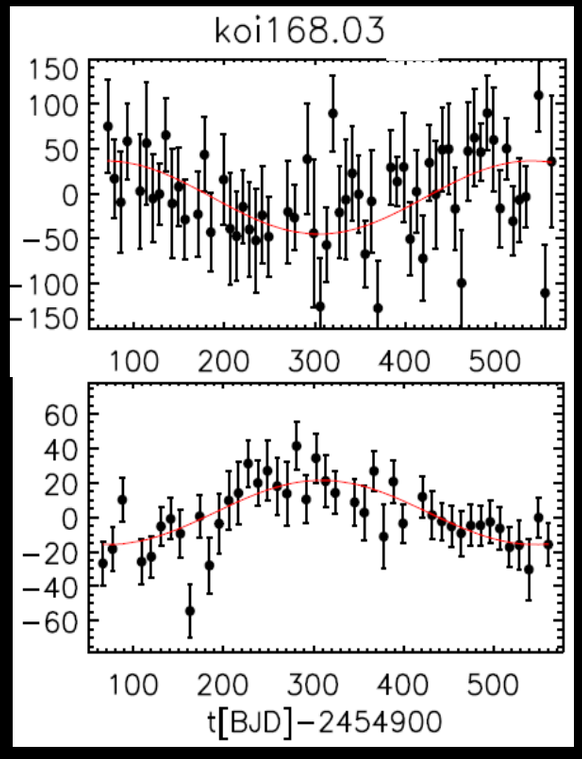
The Multiples



Identifying New Multiples
- Rowe, Mon 2:15PM, 03.02

Reliability of Kepler's multiple transiting candidate systems.
- Lissauer, Mon 5PM, 04.05



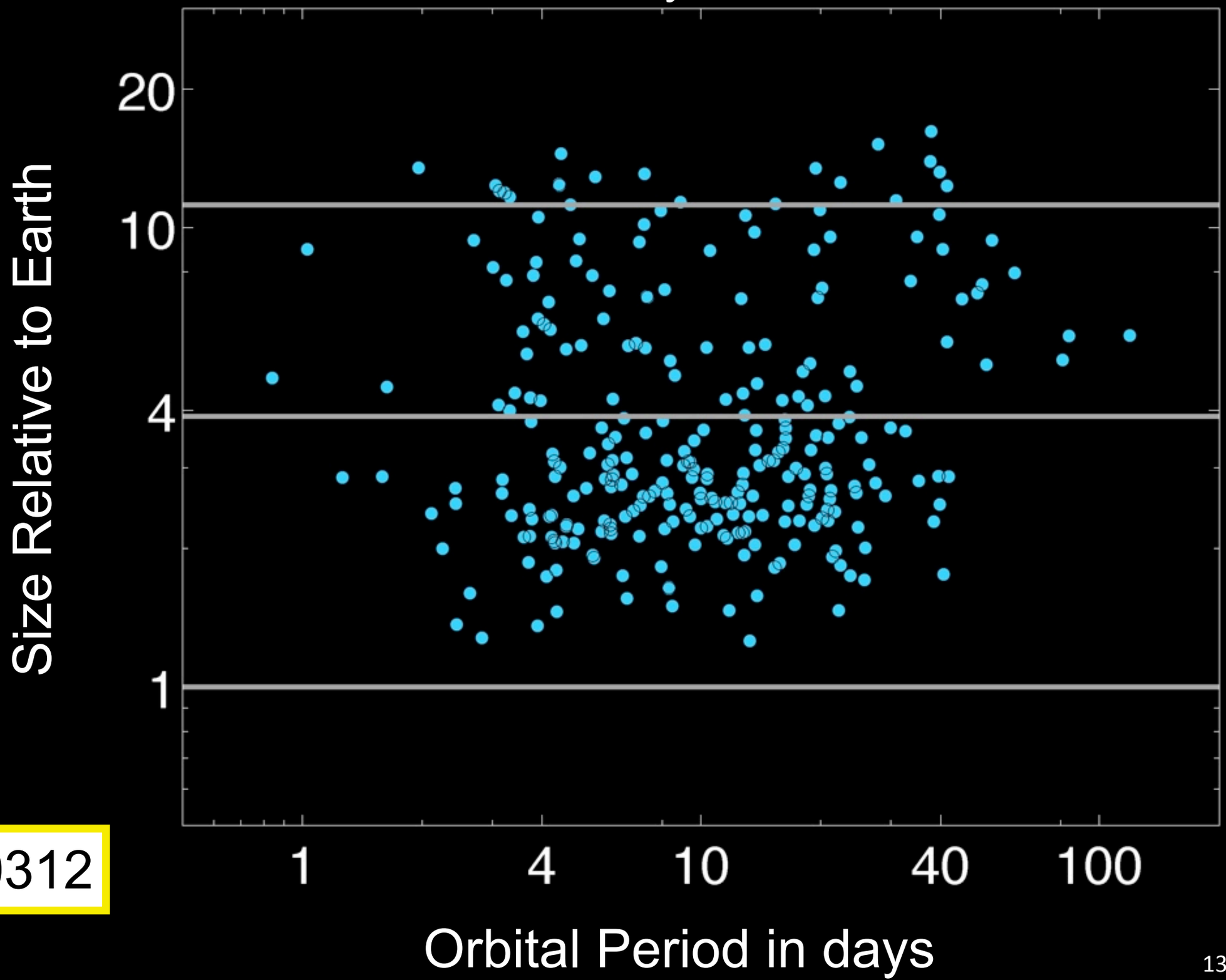


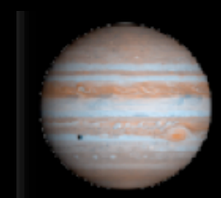
New Kepler TTV Results
- Ford, Mon 2PM, 03.01

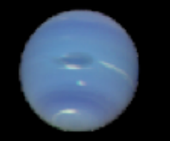
- Planet Confirmations
- **KOI Catalog**
- Completeness
- Stellar Noise

Candidates as of June 2010

Q0-Q1: May-June 2009



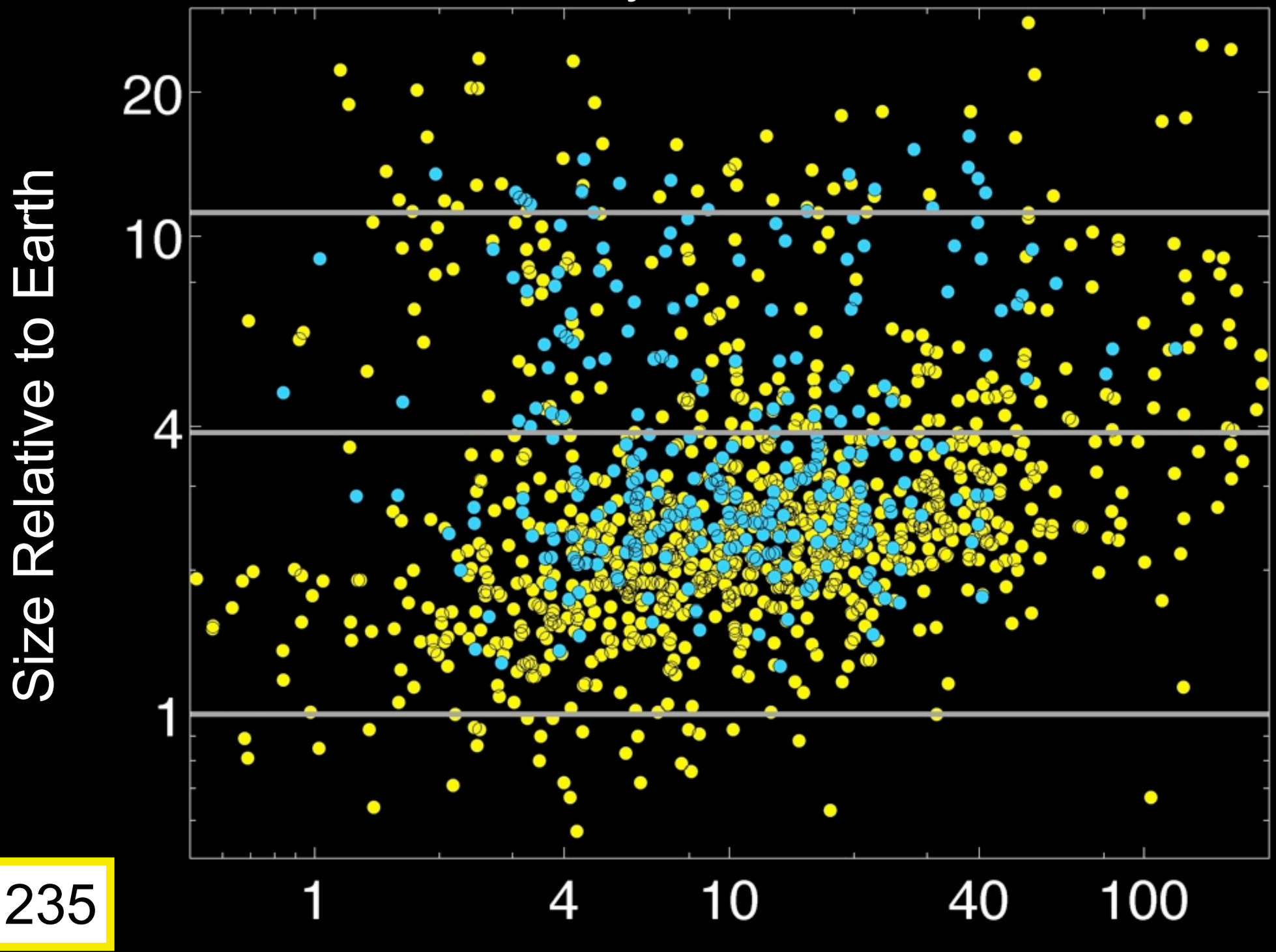


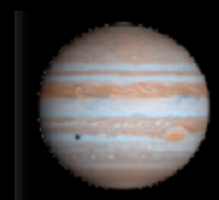


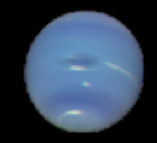
0312

Candidates as of Feb 2011

Q0-Q5: May 2009 - Jun 2010



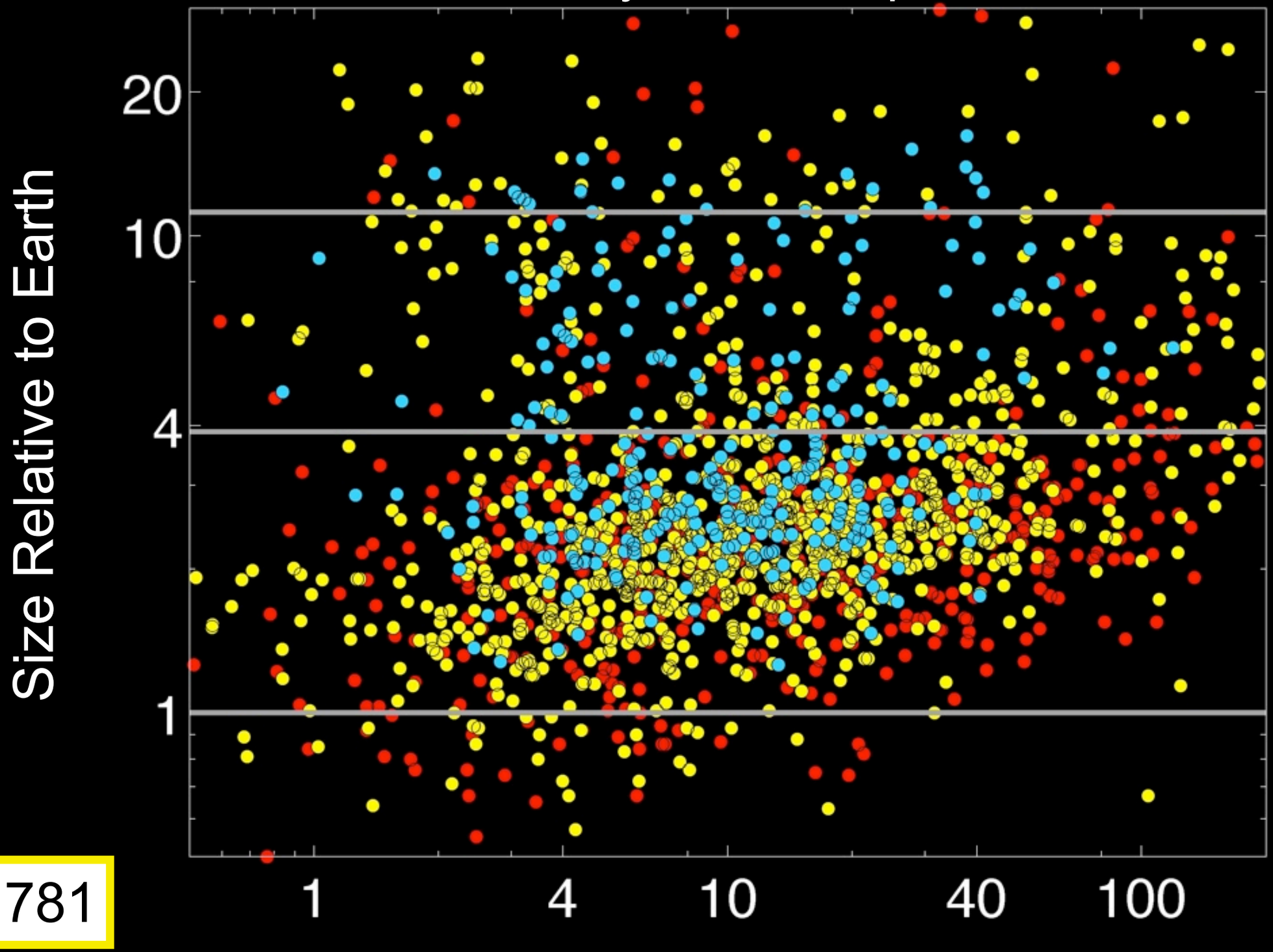




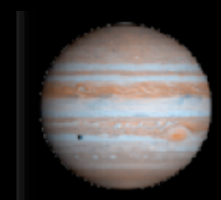
1235

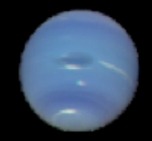
Candidates as of Sep 12, 2011

Q0-Q6: May 2009 - Sep 2010



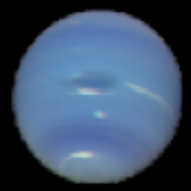
1781





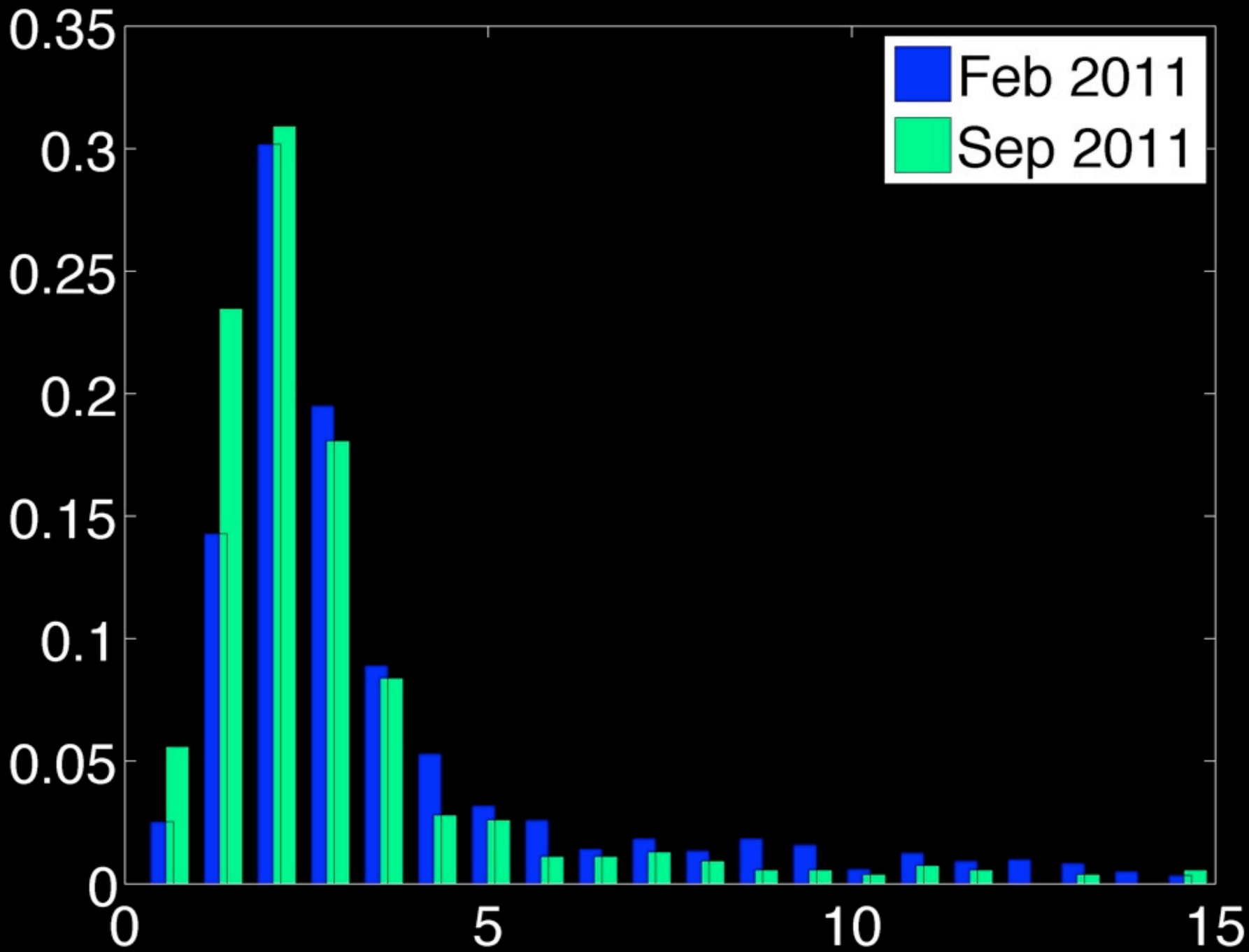
Candidates as of Sep 12, 2011

Q0-Q6: May 2009 - Sep 2010

⬆95%	⬆58%	⬆41%	⬆24%
			
<1.25 R_e	1.25 - 2 R_e	2 - 6 R_e	6 - 15 R_e
123	412	988	204

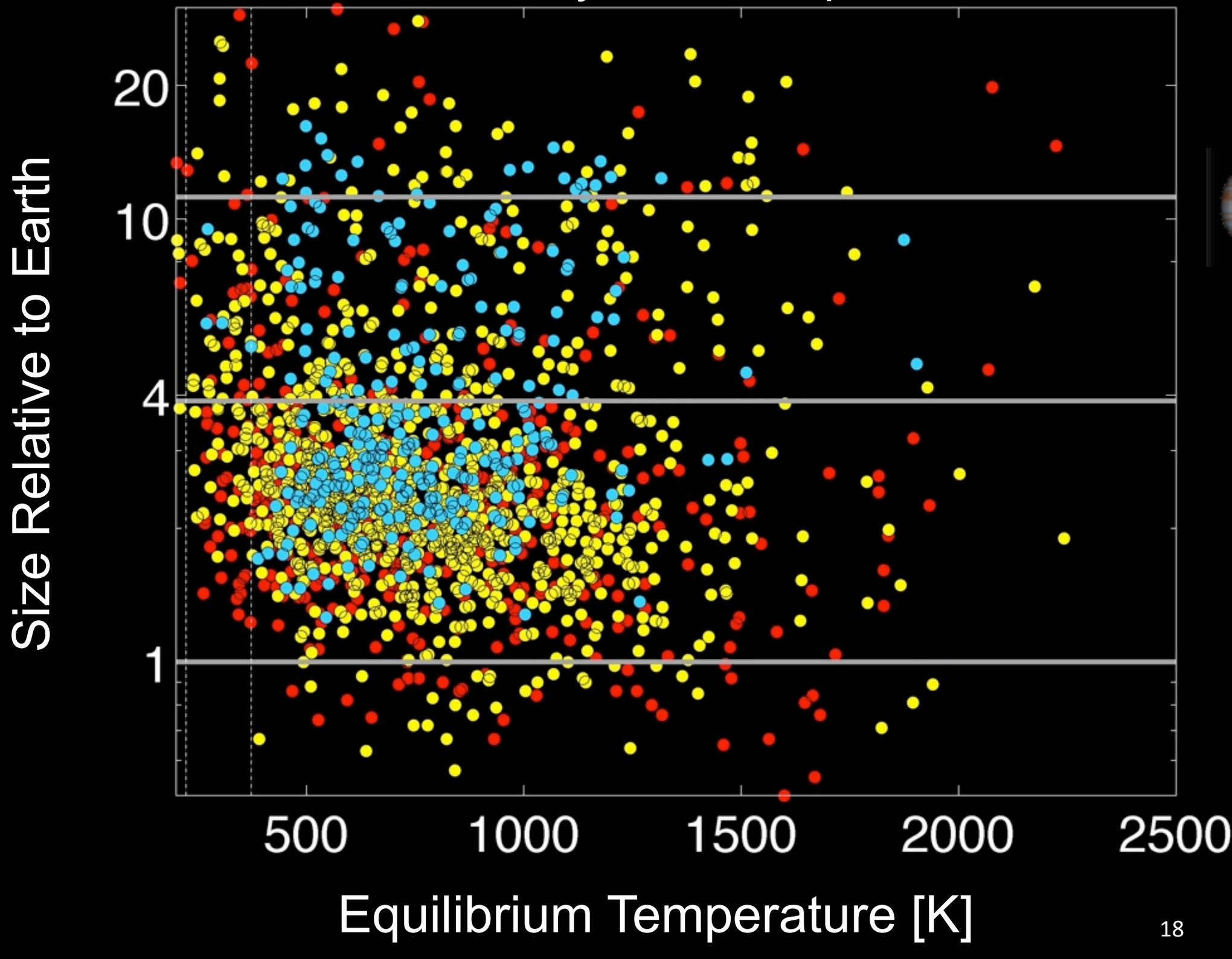
1781 45% increase since February 2011

Size Distribution: Feb vs Sep



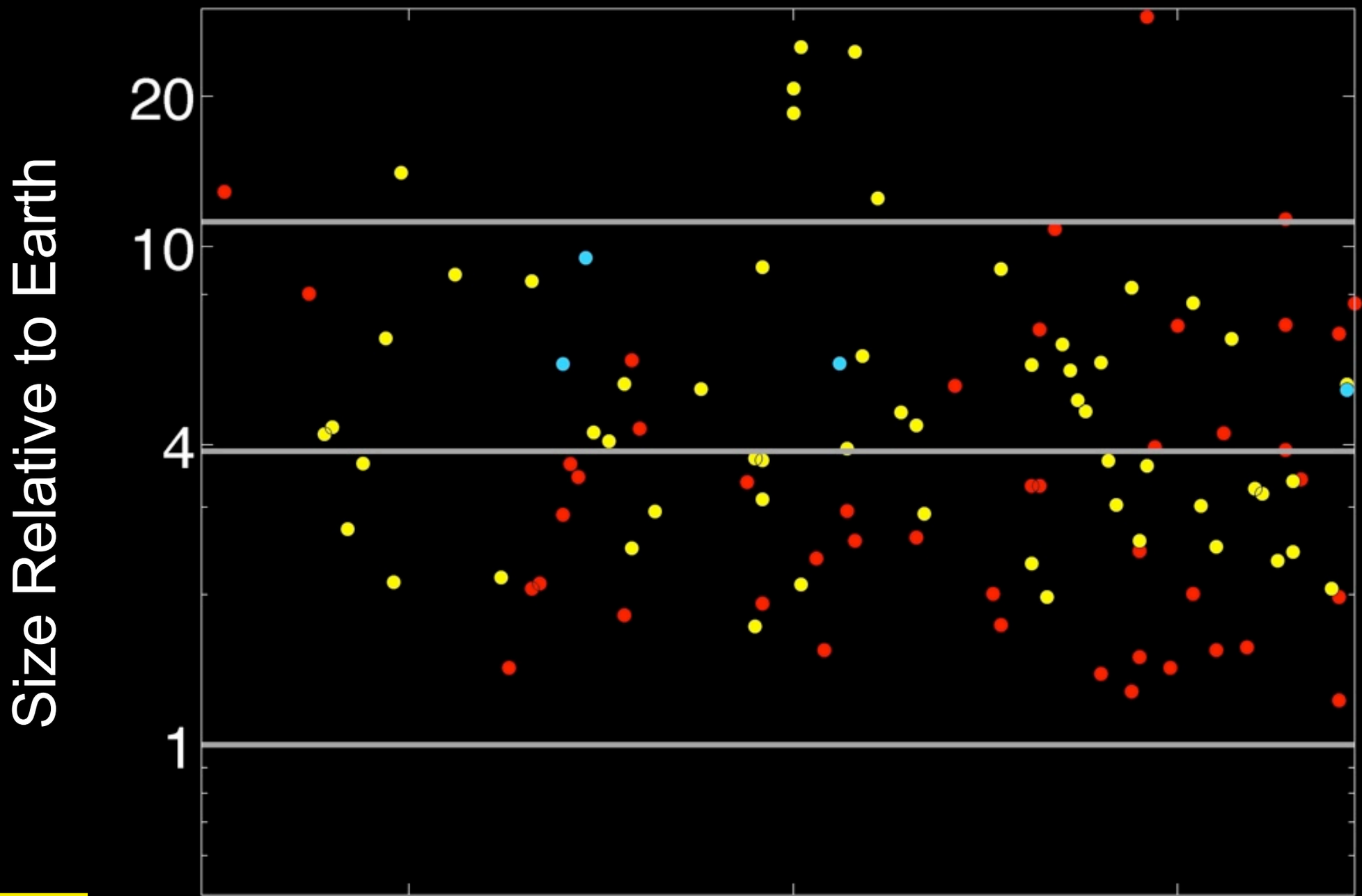
Candidates as of Sep 12, 2011

Q0-Q6: May 2009 - Sep 2010



Candidates as of Sep 12, 2011

Q0-Q6: May 2009 - Sep 2010

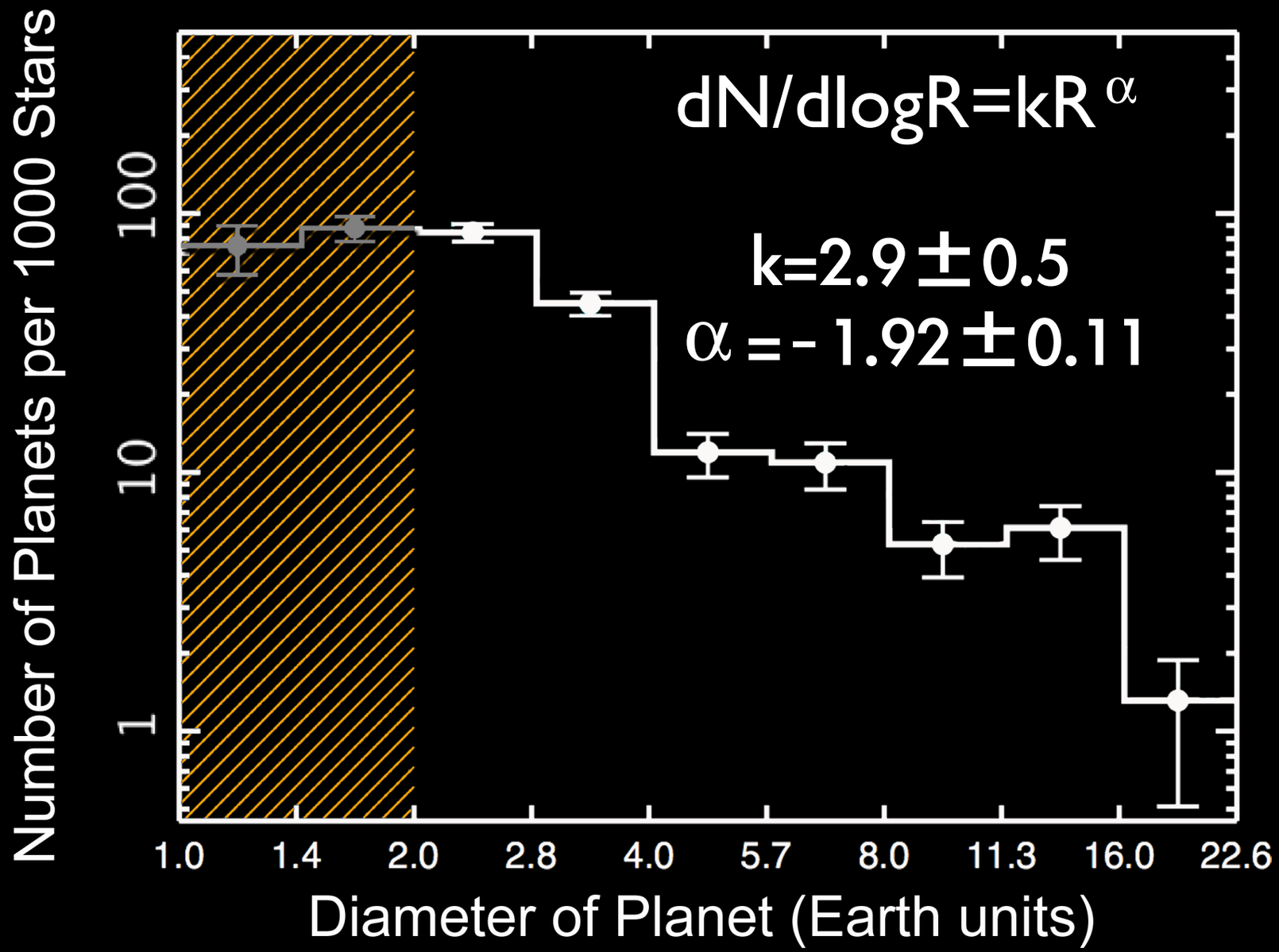


121

⬆124%

Distribution of Planet Diameters

For Orbital Periods < 50 Days



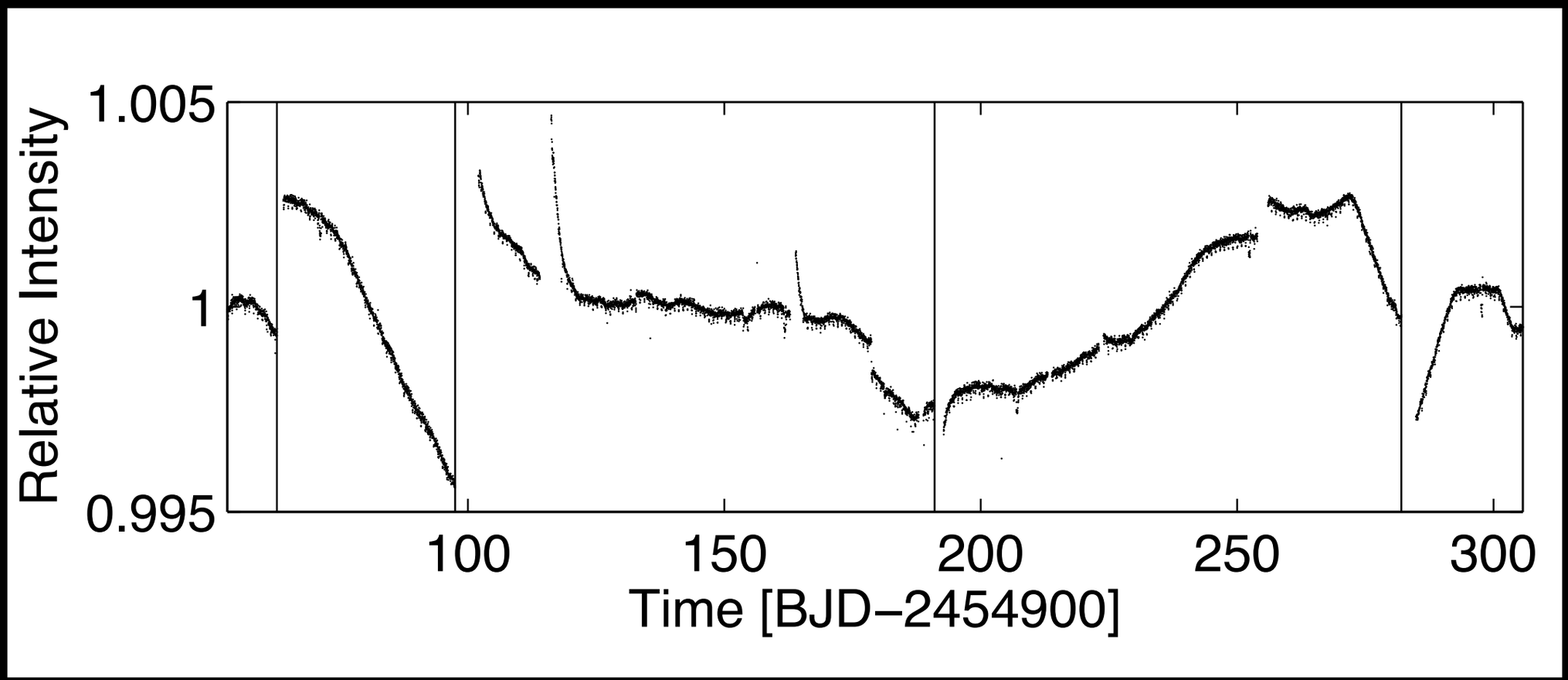
Howard et al. 2011, arXiv: 1103.2541

- Planet Confirmations
- KOI Catalog
- Completeness
- Stellar Noise

Kepler

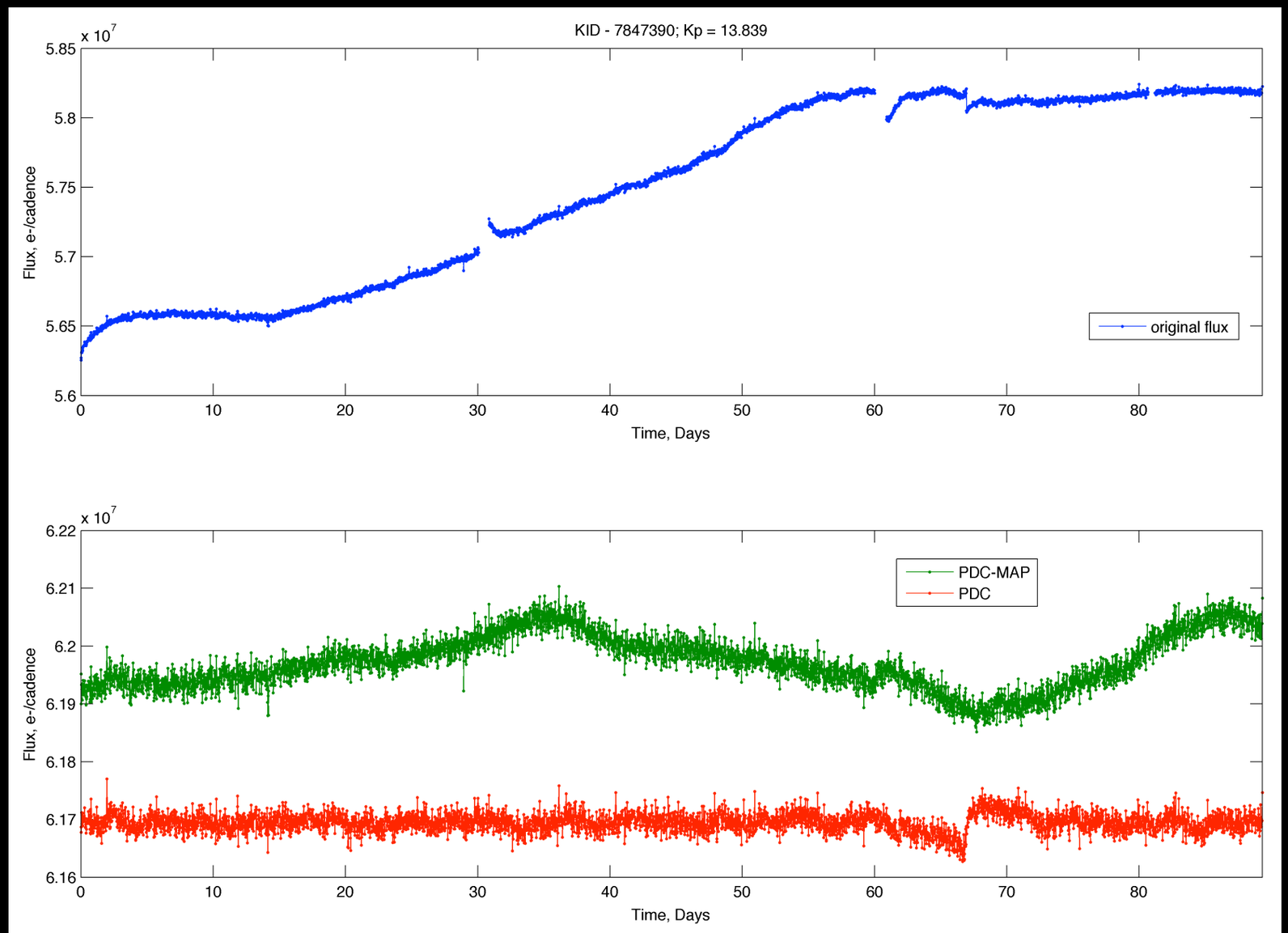
Factors Affecting Completeness

1) Multi-Quarter Transit Search:
   - Feb 2011 catalog: analysis of Q0-Q5 data based on non-pipeline tools to detect long-period events.
   - Didn't benefit from pipeline whitening filters



Factors Affecting Completeness

2) <u>Sudden Pixel Sensitivity Dropouts</u>:
Transit detection analysis keys off anomalous event instead of real transits.



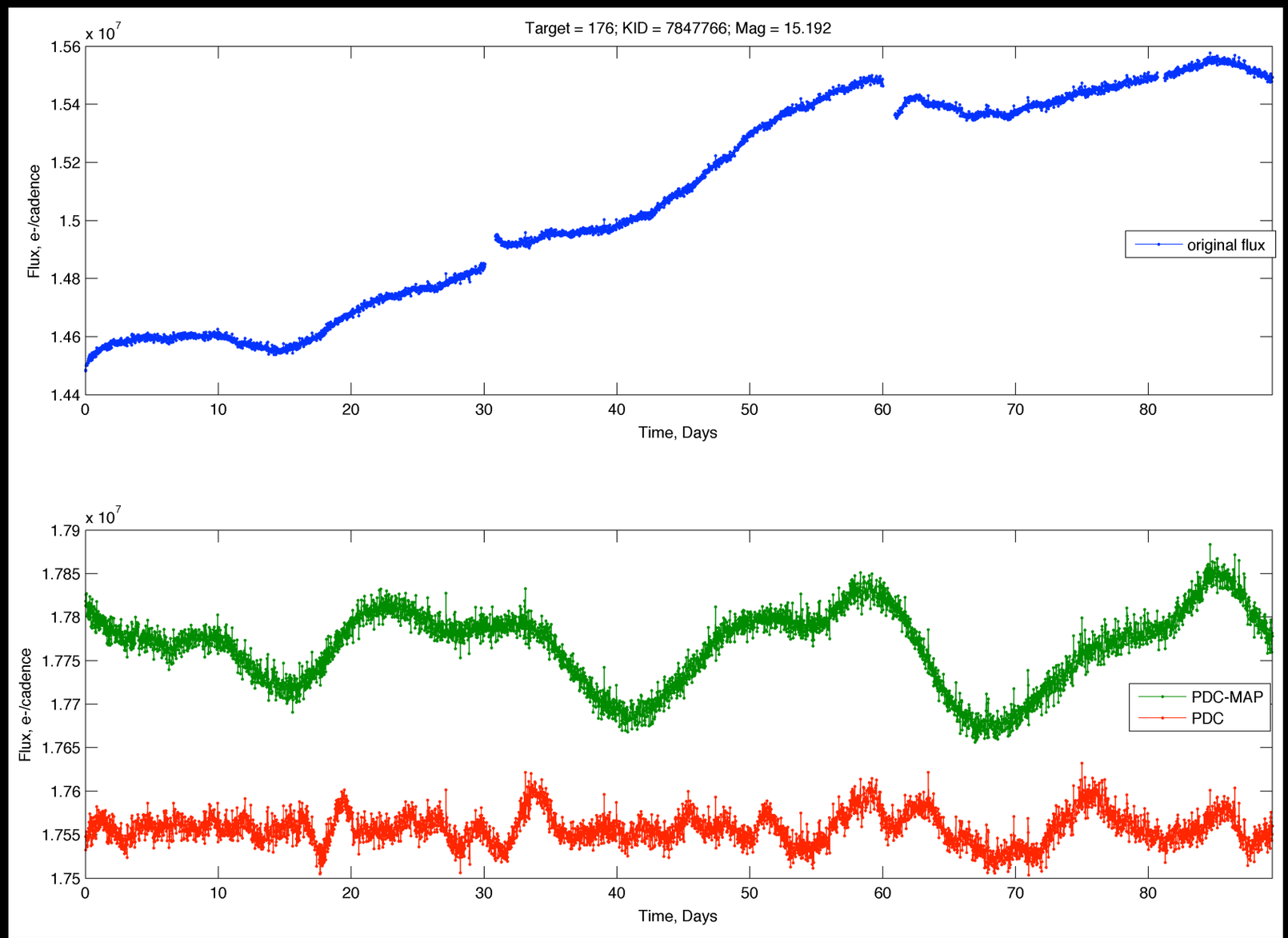
Original flux

PDC

PDC-MAP

Factors Affecting Completeness

3) <u>Pre-search Data Conditioning</u>:
First generation filters occasionally introduced high frequency noise. This has been greatly improved with PDC-MAP.



Original flux

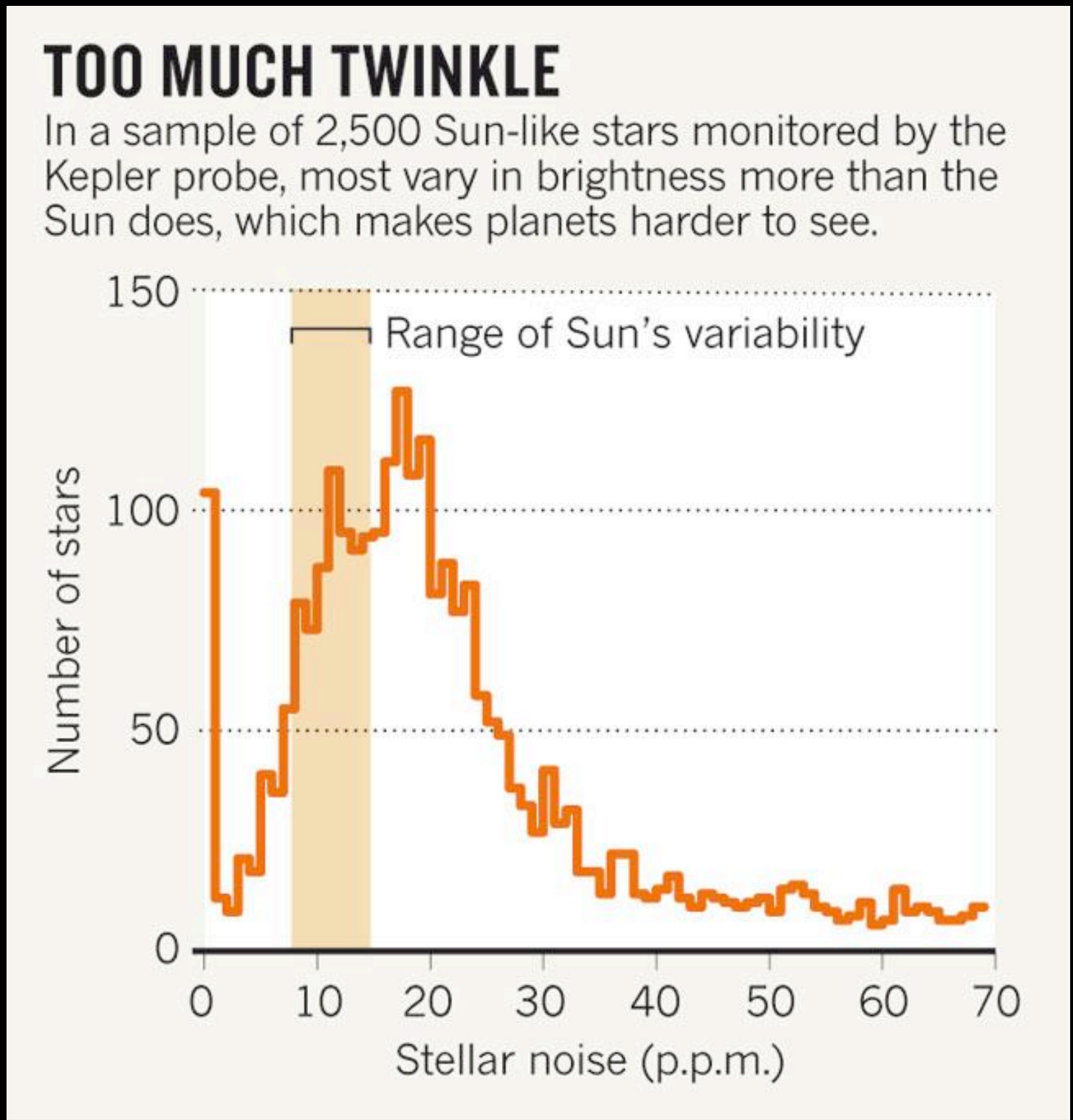
PDC

PDC-MAP

- Planet Confirmations
- KOI Catalog
- Completeness
- Stellar Noise

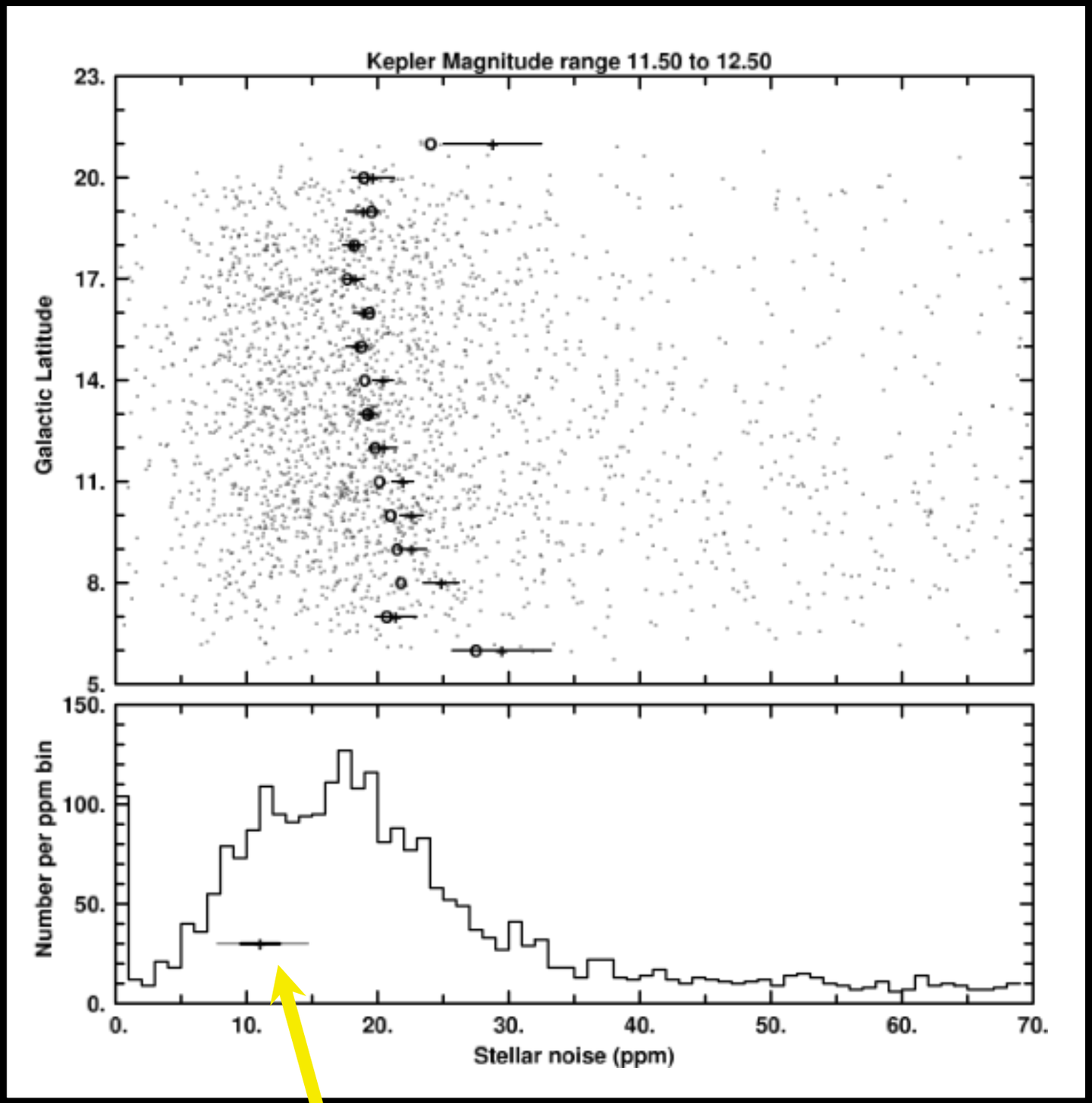
Kepler

Stellar Noise: simulation vs observation



Nature **477**, 142-143 (Sept 6, 2011)

Stellar Noise: simulation vs observation



Simulated:
- instrument: 17.3 ppm
- stars: 10 ppm
- total: 20 ppm

Observed:
- instrument: 21.4
- stars: 19.5
- total: 29 ppm

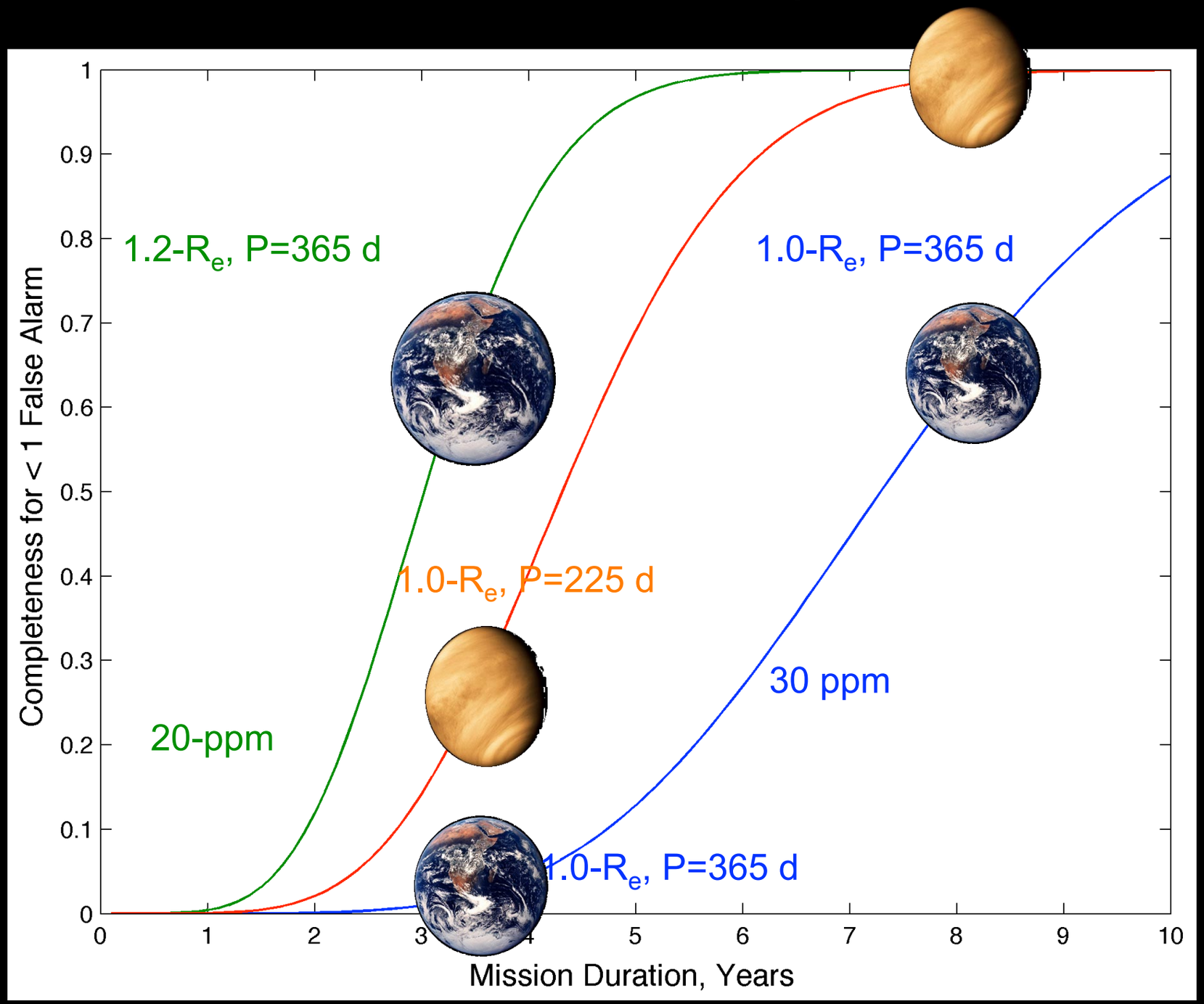
45% higher than expected

Range of solar variability.

Gilliland et al. 2011 arXiv: 1107.5207

Stellar Noise: simulation vs observation

6.5-hr variability is stochastic and will average out over multiple orbits

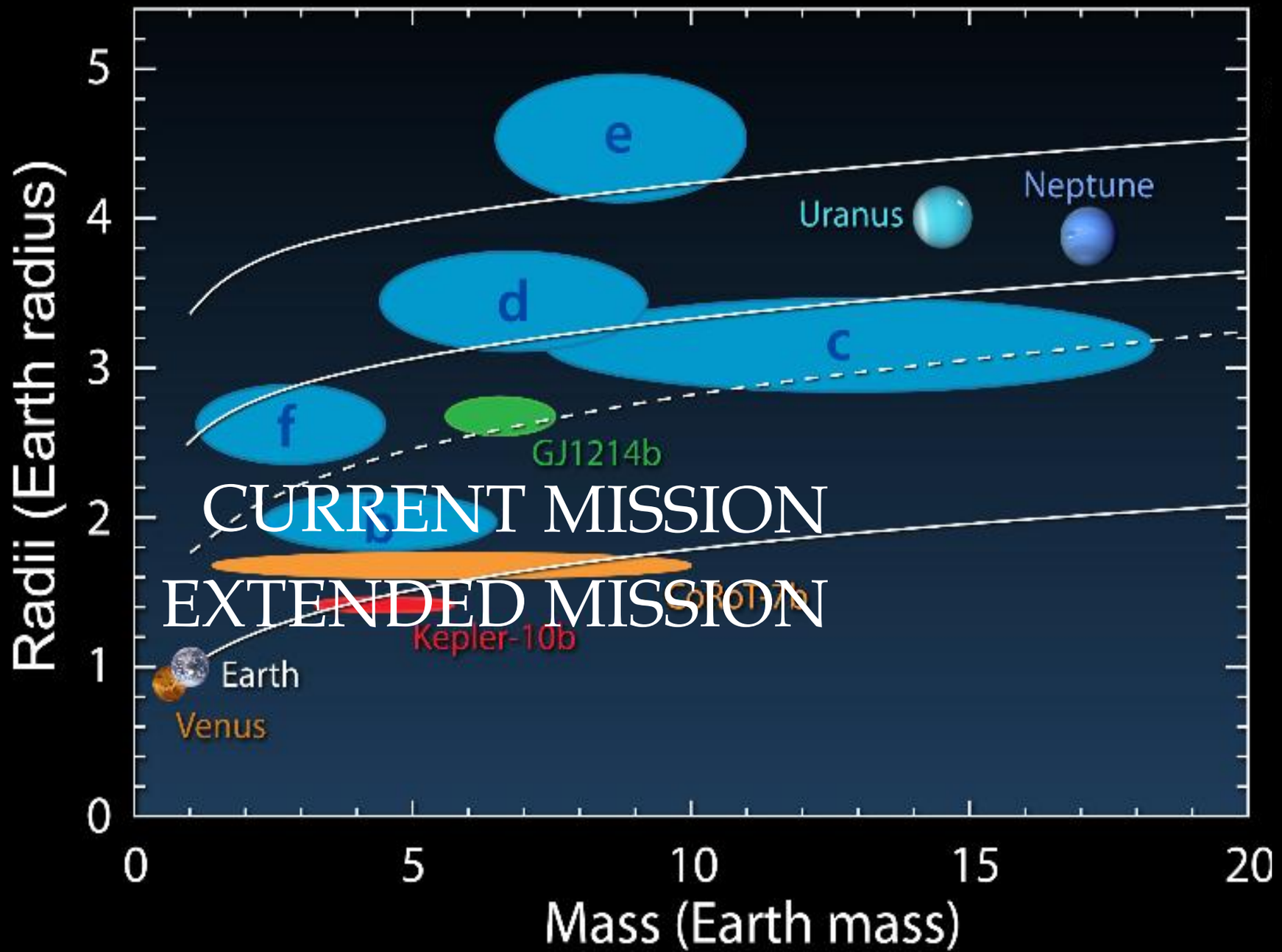


The goal of true Earth-analogs is reachable by extending the mission length

Jenkins et al.: Poster 19.14

Stellar Noise: simulation vs observation

6.5-hr variability is stochastic and will average out over multiple orbits



The goal of true Earth-analogs is reachable by extending the mission length

Jenkins et al.: Poster 19.14

Extended Mission

- <u>Communications</u>

  K_a-band data rate expected to drop from 4.3 Mbits/s to 3.9 Mbits/s in Summer 2012.

  Lengthening the monthly contacts slightly will allow us to maintain 170k targets throughout primary mission.

  Flexibility via target management, downlink duration, and downlink frequency thereafter.

- <u>Propellant</u>:

  Hydrazine is used by the thrusters which de-spin the reaction wheels used to point the telescope.

  Based on current and predicted use and adding margin for safe-modes, there is sufficient fuel to operate until Sep 2020.

"One day, from the shores of a new world, we'll gaze at the sea that took us there. And its waves will be stars."

Rui Borges, Sagan Day Essay Contest
http://kepler.nasa.gov/education/sagan

Kepler

Kepler

NASA

First Kepler Science Conference

Note: abstract deadline extended to 9/28

Highlighting Kepler's Contributions to:

- exoplanet statistics
- sub-Neptune size planets
- multi-planet systems
- giant planets & planet atmospheres
- exoplanet theory
- asteroseismology
- stellar activity, clusters, and other stellar astrophysics
- eclipsing and interacting binaries

2011 DEC 5-9

NASA Ames Research Center

Moffett Field, CA

http://kepler.nasa.gov/Science/keplerconference

Kepler's performance in Year-2

Summary:

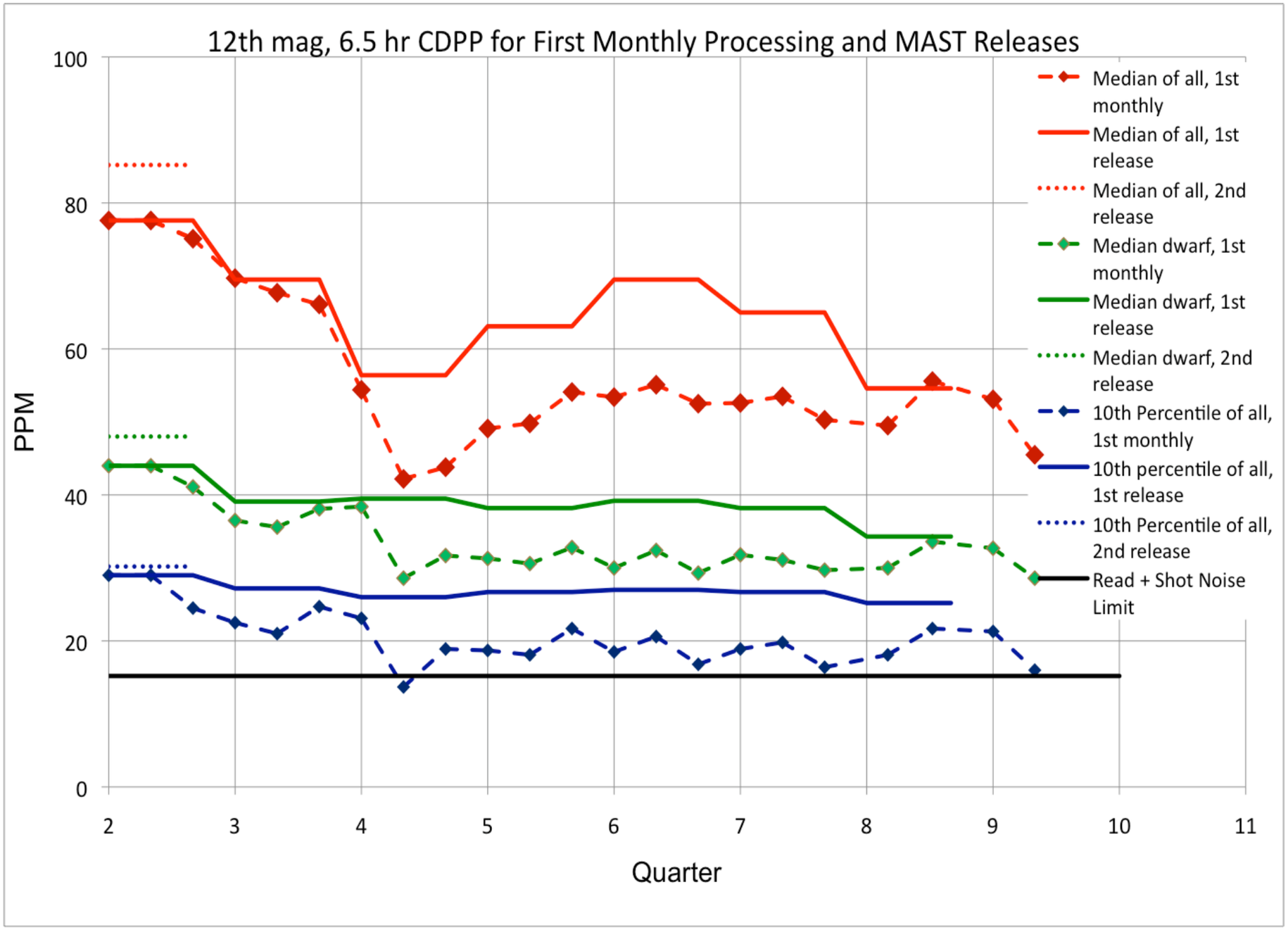
- No hardware failures since Module-3 loss (Jan 2010)
- No unplanned interruptions to Science Data Collection since March 2011
- Key performance metrics are either steady or show a repeatable seasonal trend since the start of Q3
- Evidence for linearly increasing charge transfer inefficiency from 60 ppm to 140 ppm in two years. At this rate the value will be ~400 ppm at the end of 8 years, which may be significant for calibration or aperture selection
- Reaction wheel friction and noise unchanged since year-1
- Solar panel and battery performance is nominal
- Data completeness at 92.1% since start of mission (requirement=92%)

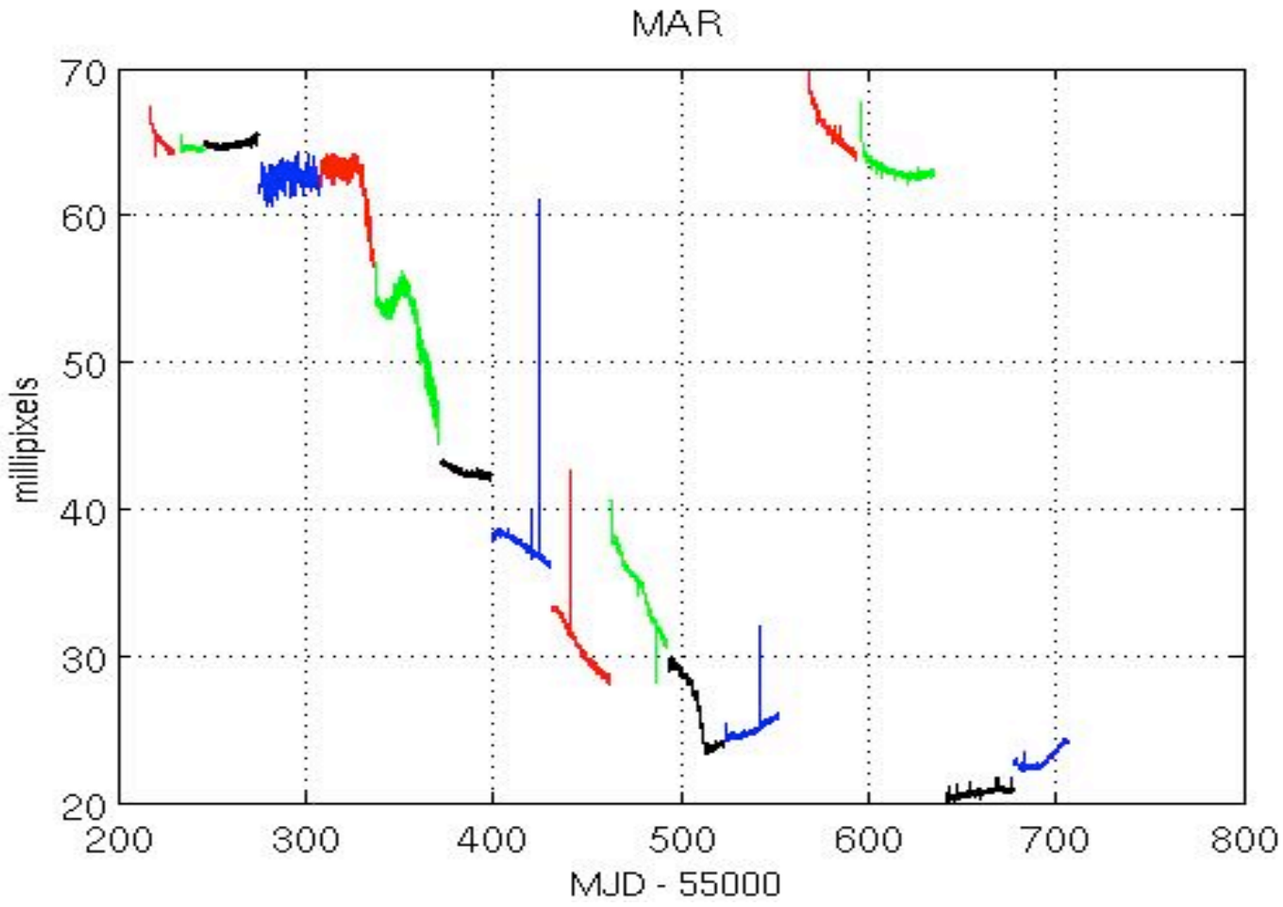
=>Good: we can count on flight system performance to give the expected improvement in Earth-size HZ planet detection as a function of mission length

=>Bad: no miracles here to obviate the need for an extended mission, given the unexpectedly large astrophysical noise of "Sunlike" stars (Gilliland, et al. 2011, ApJ accepted)

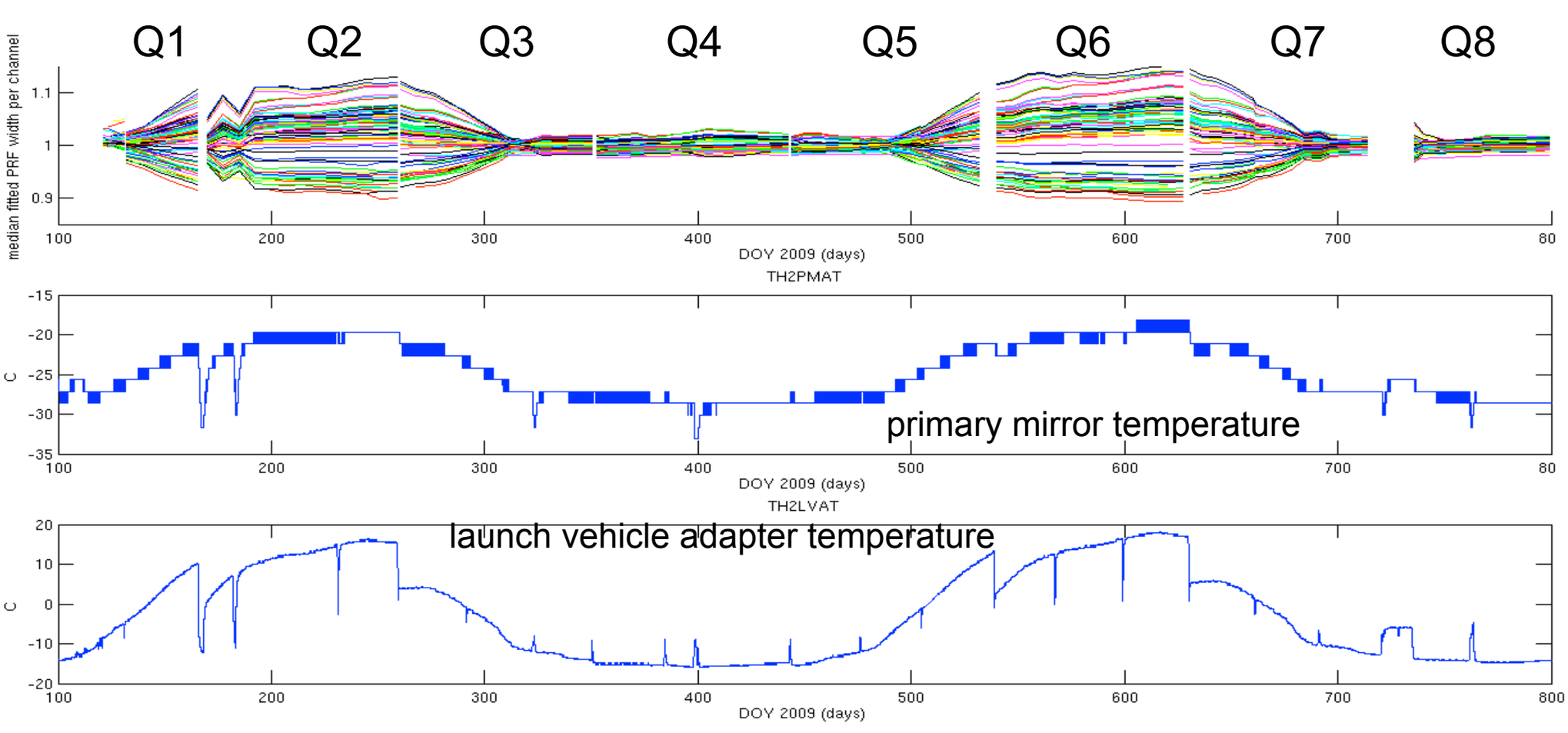
Photometer Performance in Year-2

Combined Differential Photometric Precision (CDPP) has been stable since Q3.
Median precision for Kp=12 dwarfs is ~40 ppm with somewhat lower values for monthly measurements (dashed lines) and shortened quarters due to some over-fitting in PDC.





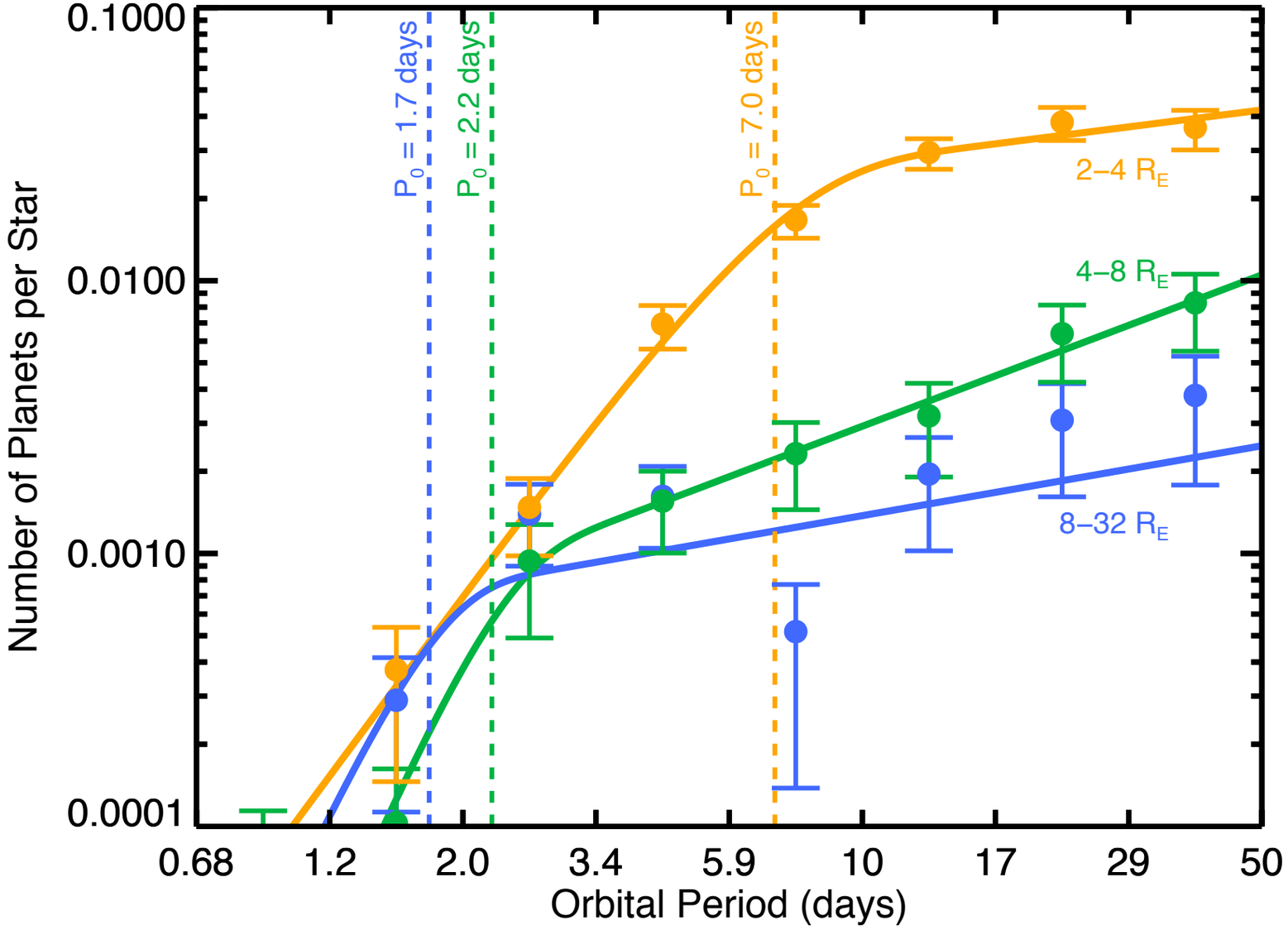
Pointing: Maximum Attitude Residual (in millipixels) is the largest distance any target on the focal plane is from its predicted location. The goal has been to keep MAR under 100 millipixels.



Focus: PRF width shows consistent seasonal change, highly correlated with spacecraft temperatures. Sun shines on back of S/C in Q1-3, Q5-7,...

Frequencies

Power law increase with period; exponential fall off below P_0



Hot-Jupiters
(P < 10 days):

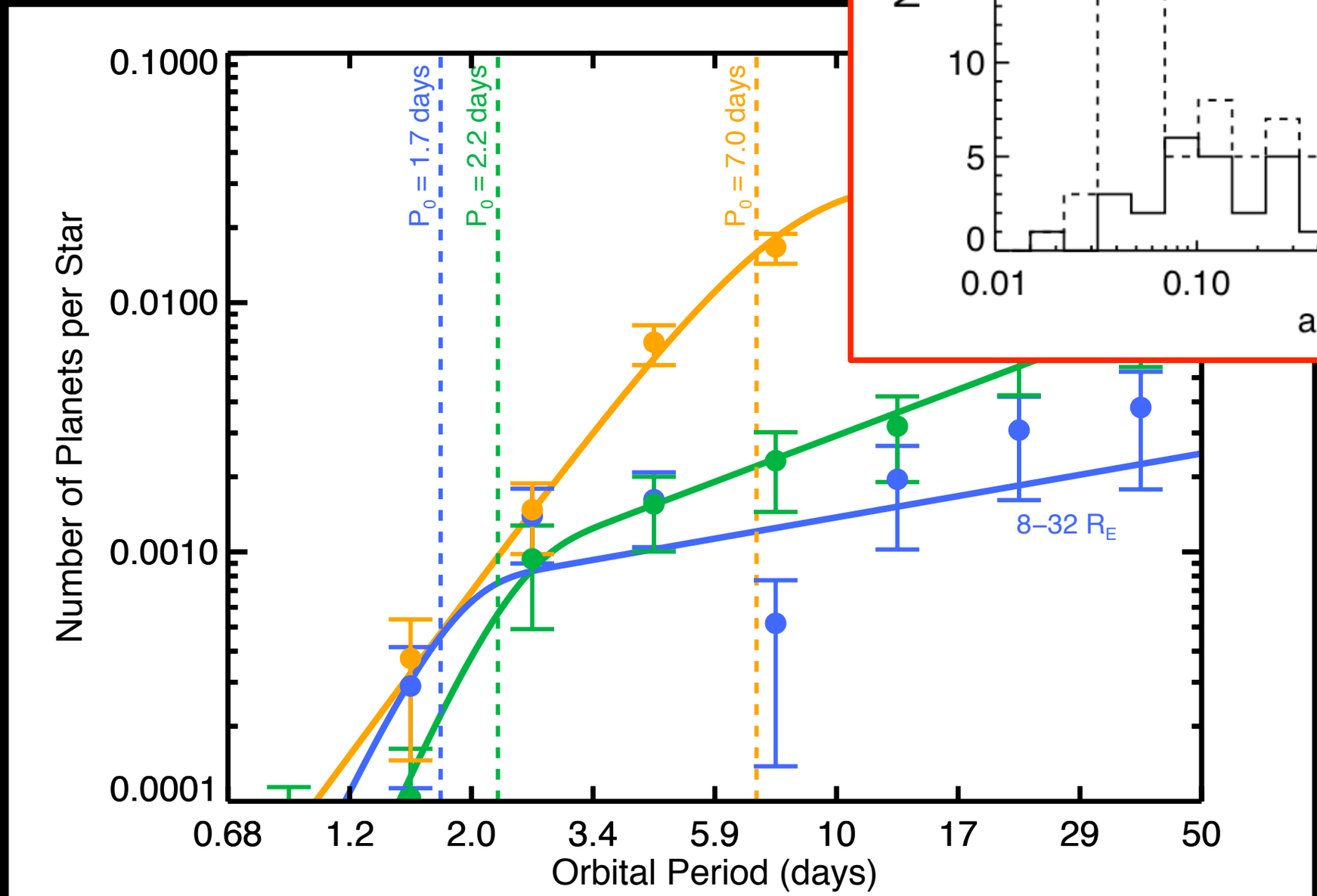
Kepler: 0.004
RV: 0.012

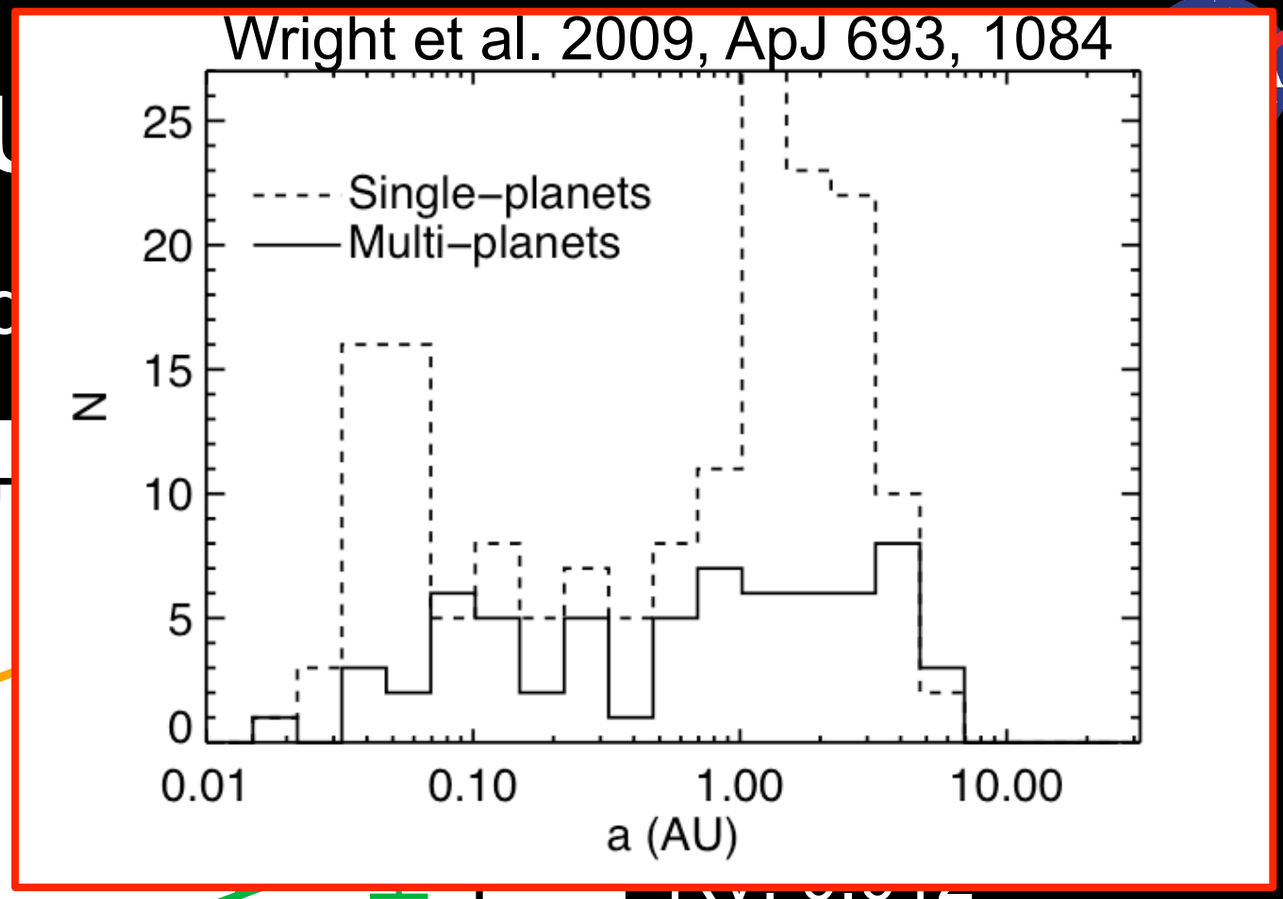
3x's lower in Kepler sample

Howard et al. 2011, arXiv: 1103.2541

Frequ

Power law increase with period



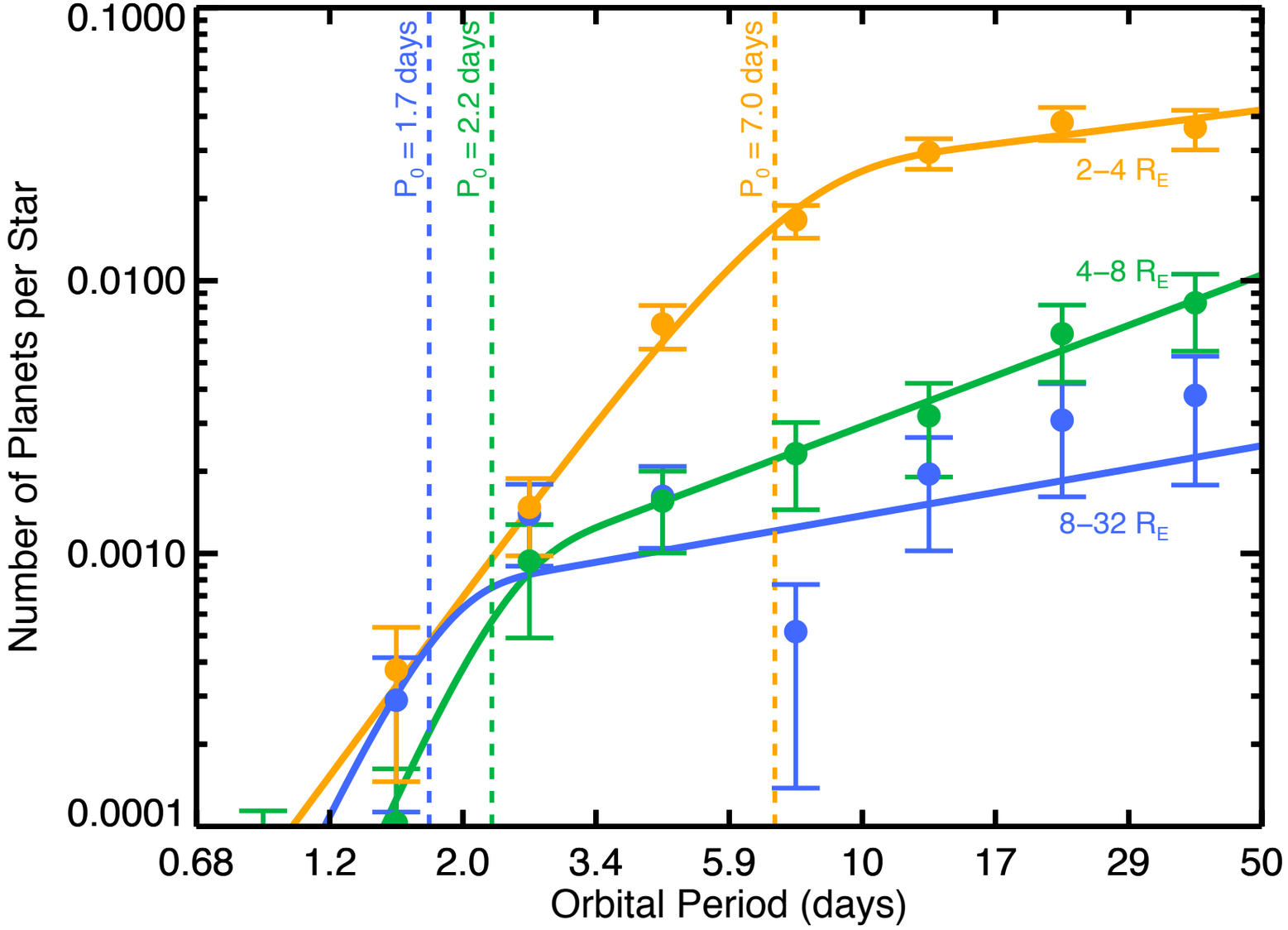


3x's lower in Kepler sample

Howard et al. 2011, arXiv: 1103.2541

Frequencies

Power law increase with period; exponential fall off below P_0

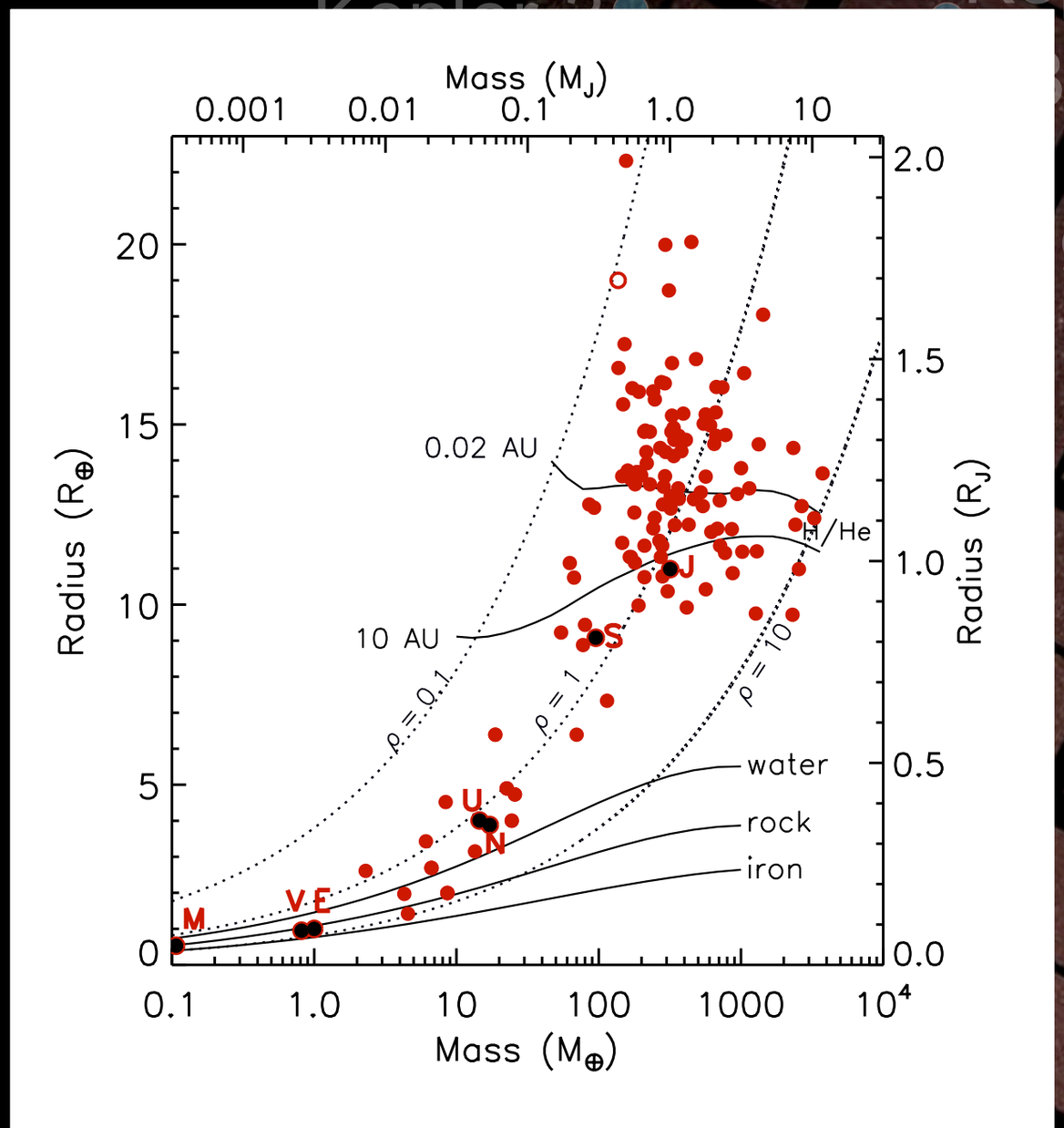


Hot-Jupiters
(P < 10 days):

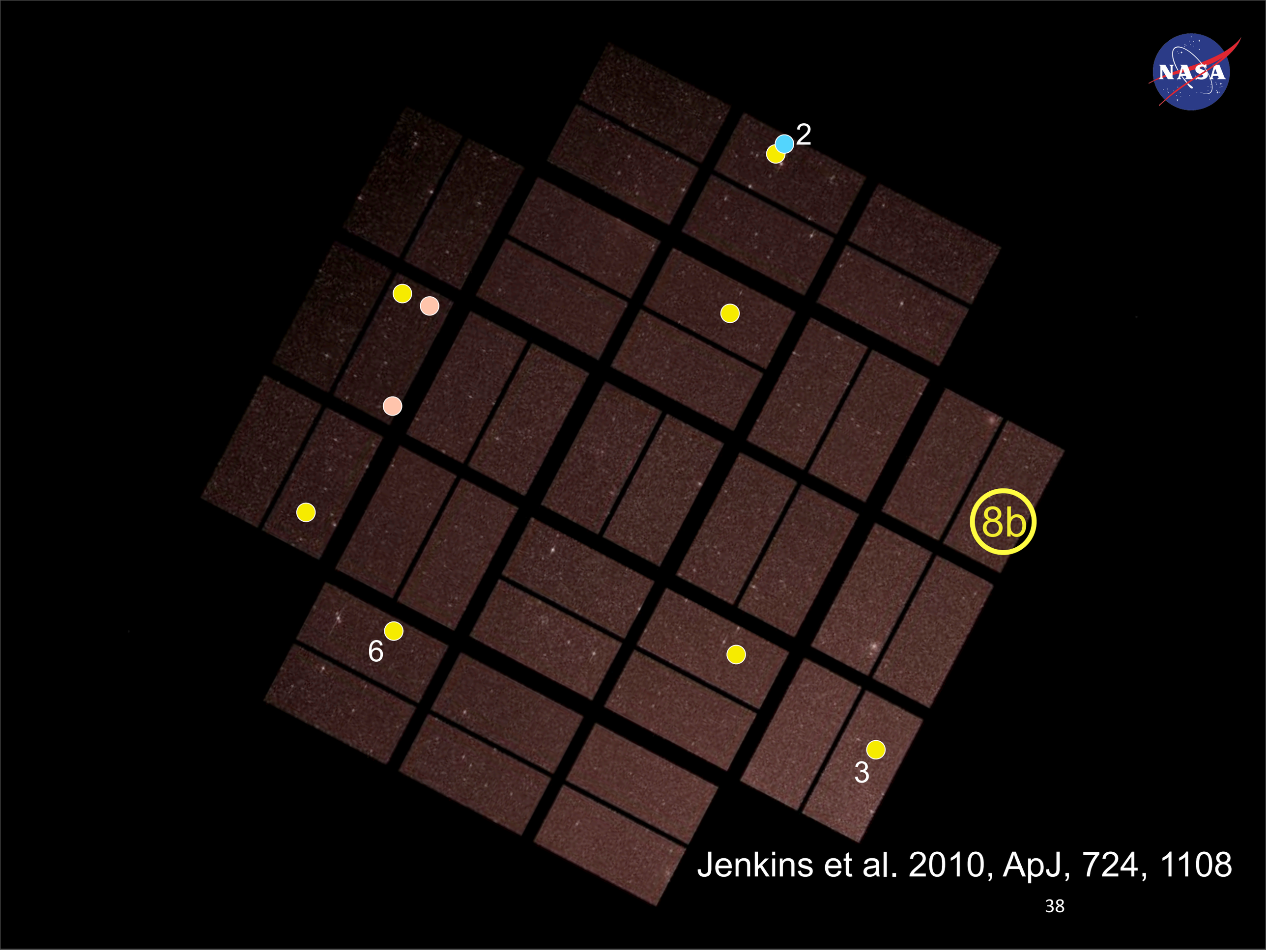
Kepler: 0.004
RV: 0.012

3x's lower in Kepler sample

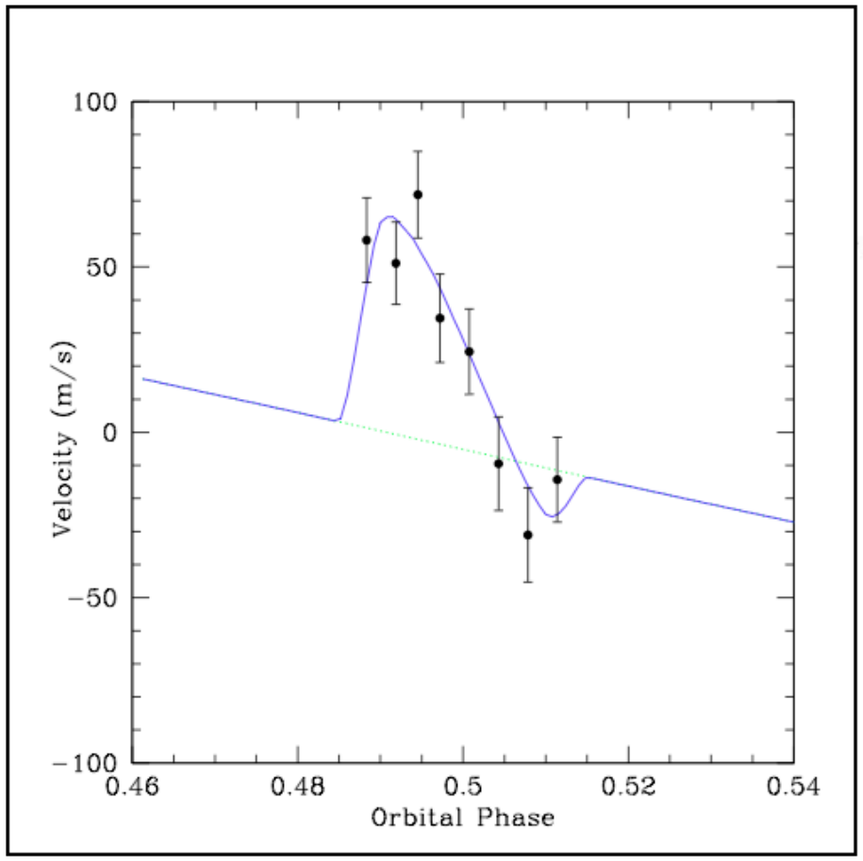
Howard et al. 2011, arXiv: 1103.2541

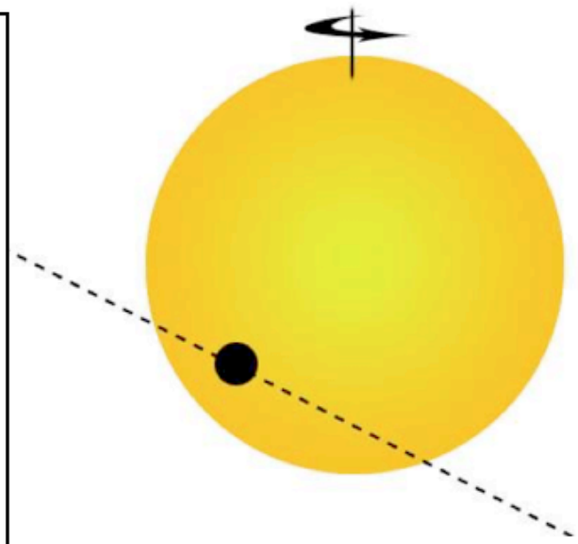


Kepler-16
(2) Kepler-10
Kepler-12
Kepler-4
Kepler-15
Kepler-1
Kepler-6
Kepler-2
Kepler-14
Kepler-13
96
Kepler-8
Kepler-7
(3) Kepler-9
(2) Kepler-19



Jenkins et al. 2010, ApJ, 724, 1108





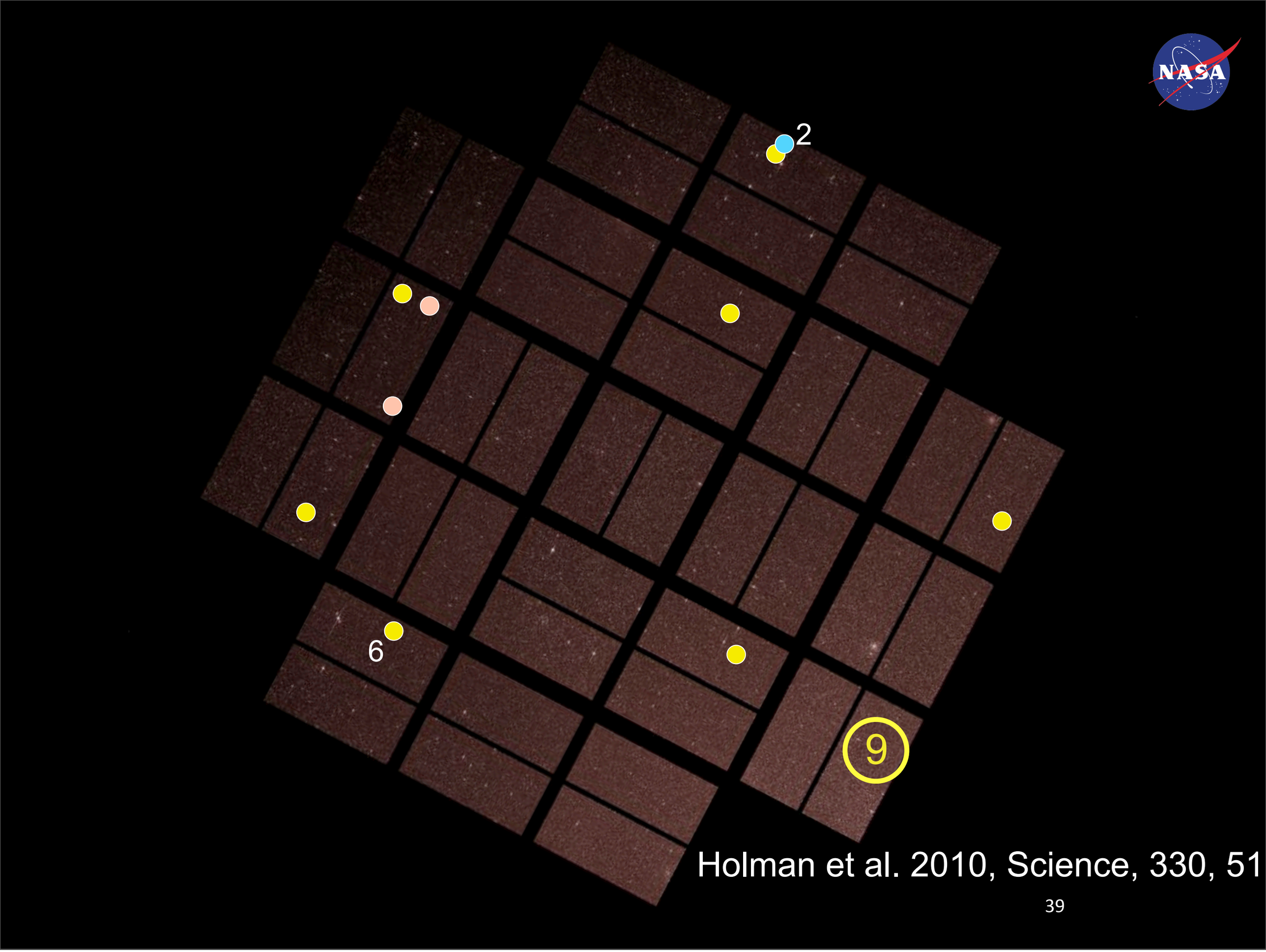
Kepler-8b:
prograde orbit
λ = -27°
b = 0.724 +/- 0.020

8b

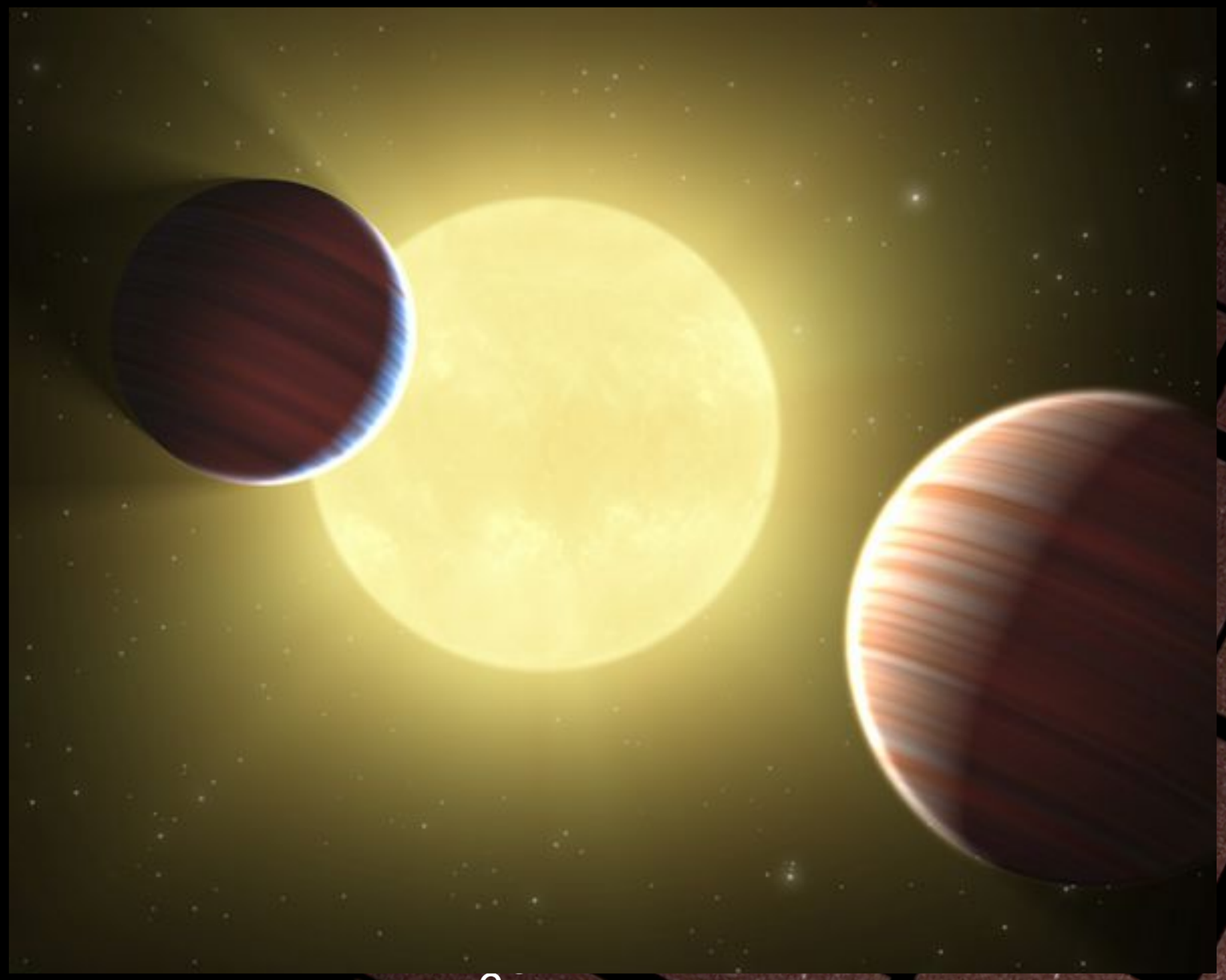
6

3

Jenkins et al. 2010, ApJ, 724, 1108



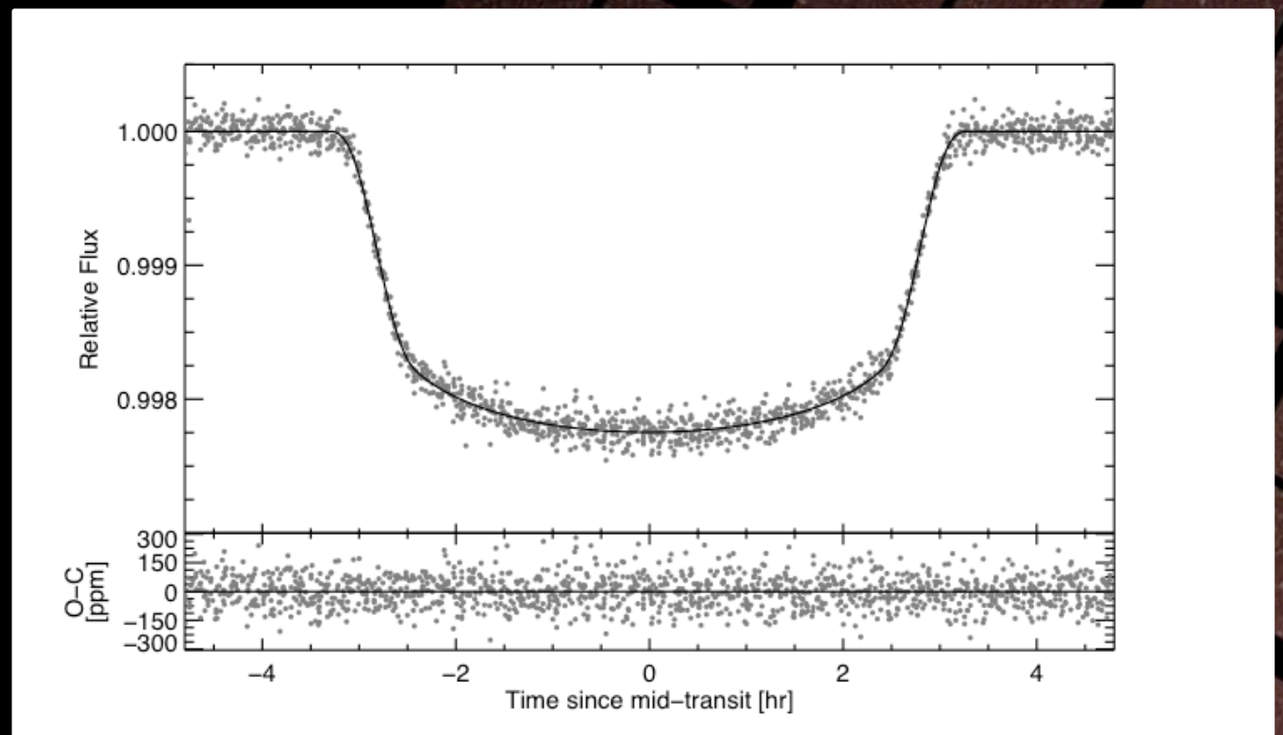
Holman et al. 2010, Science, 330, 51



6

9

Holman et al. 2010, Science, 330, 51

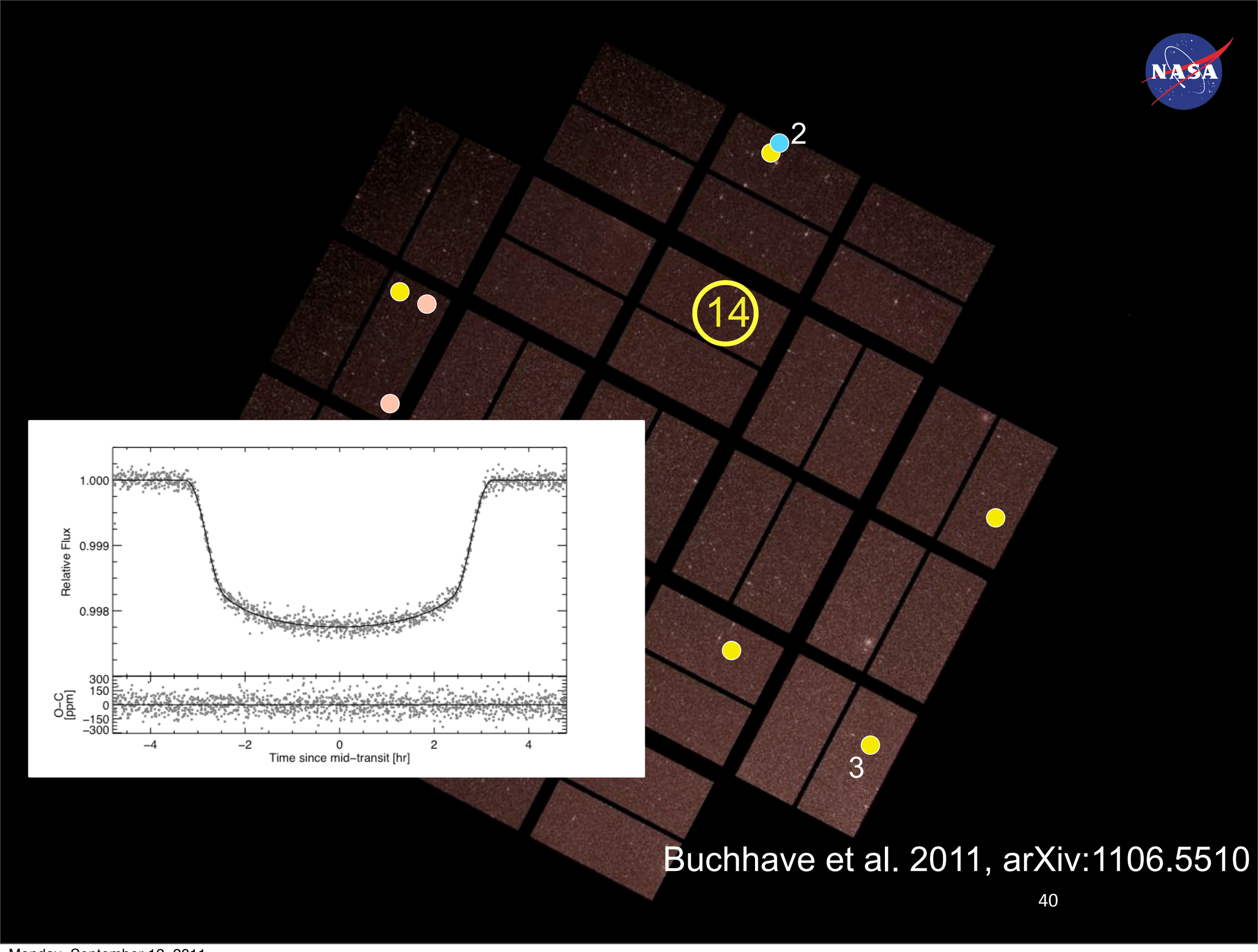


2

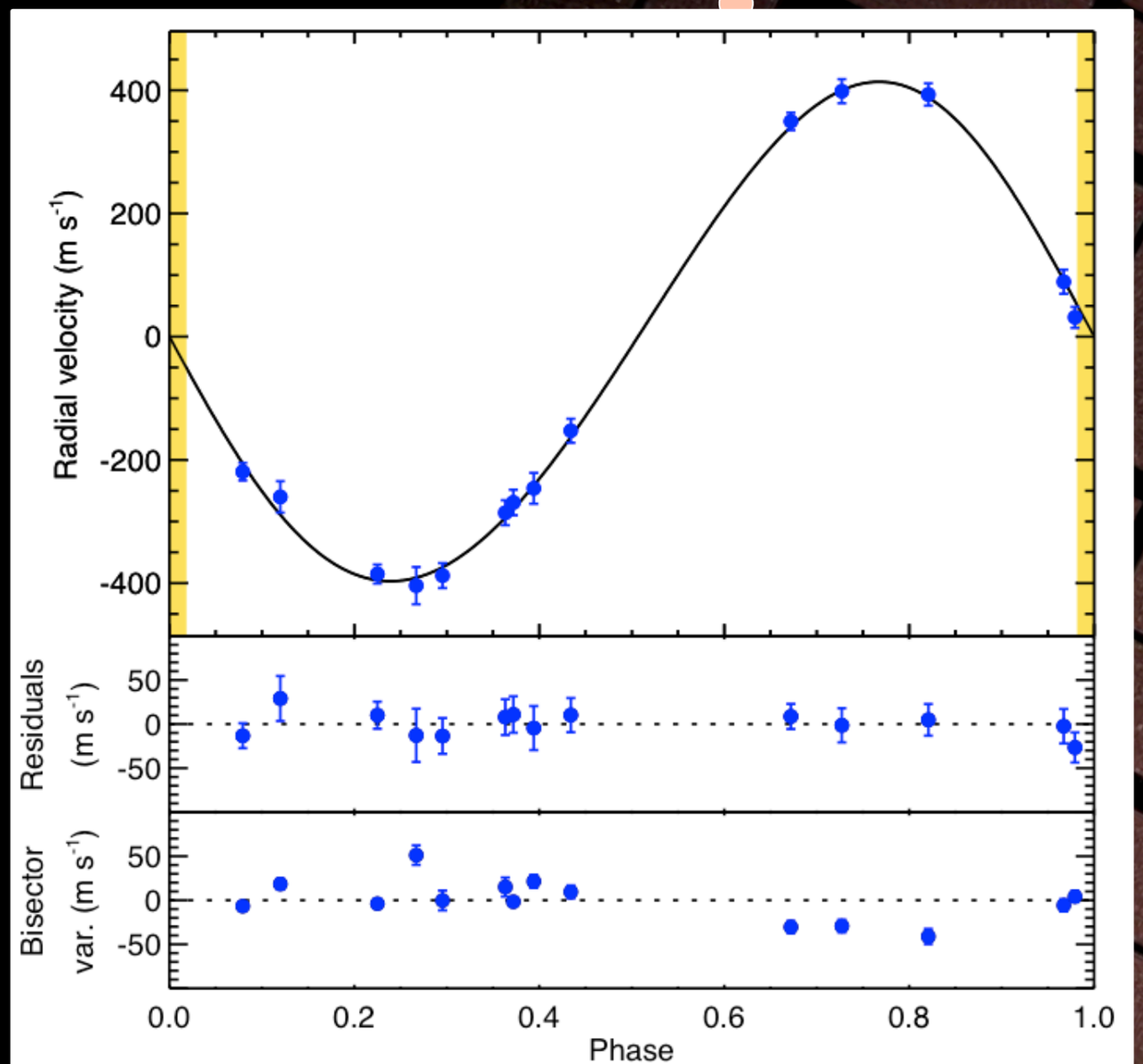
14

3

Buchhave et al. 2011, arXiv:1106.5510



Buchhave et al. 2011, arXiv:1106.5510

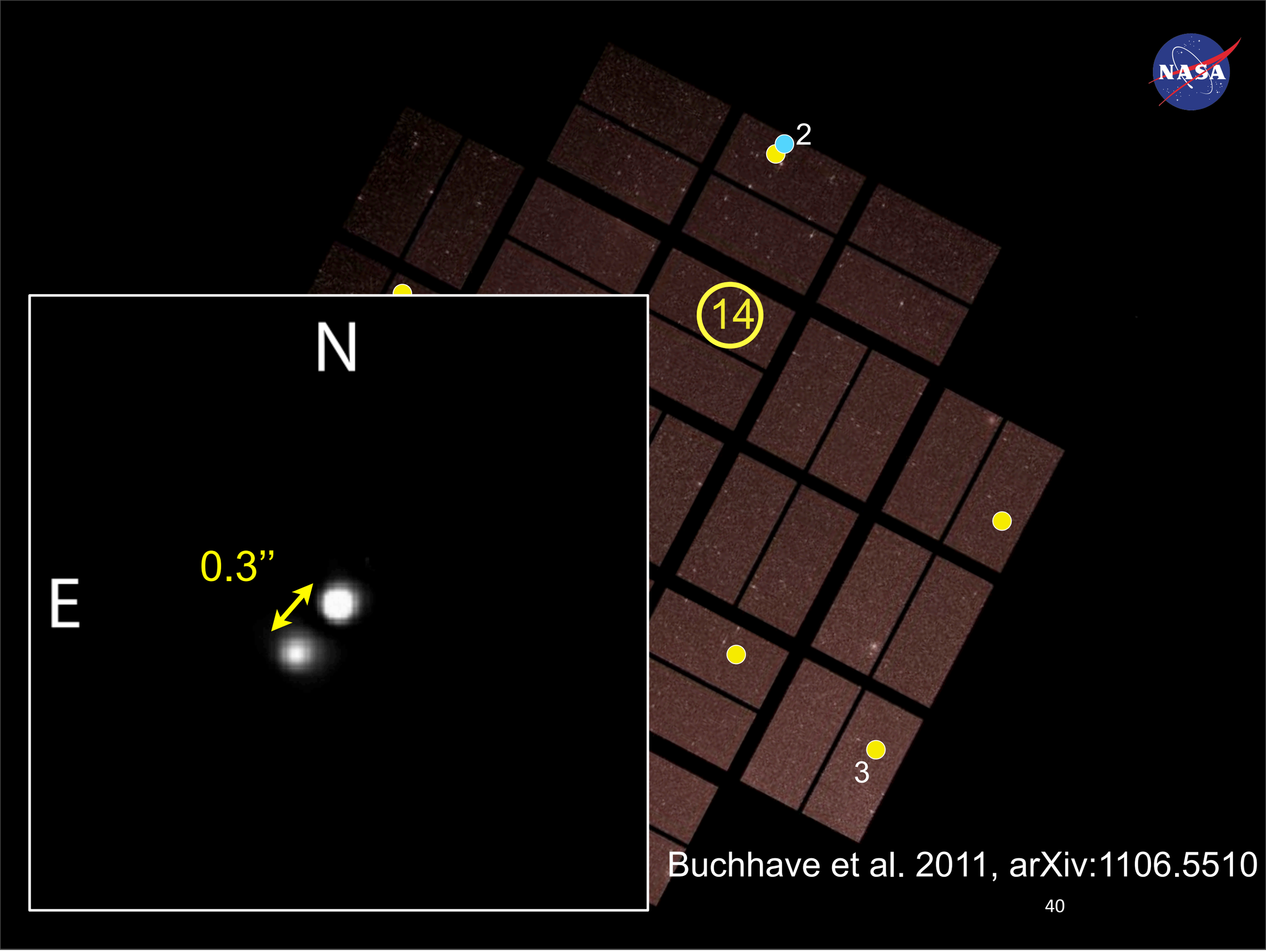


2

14

3

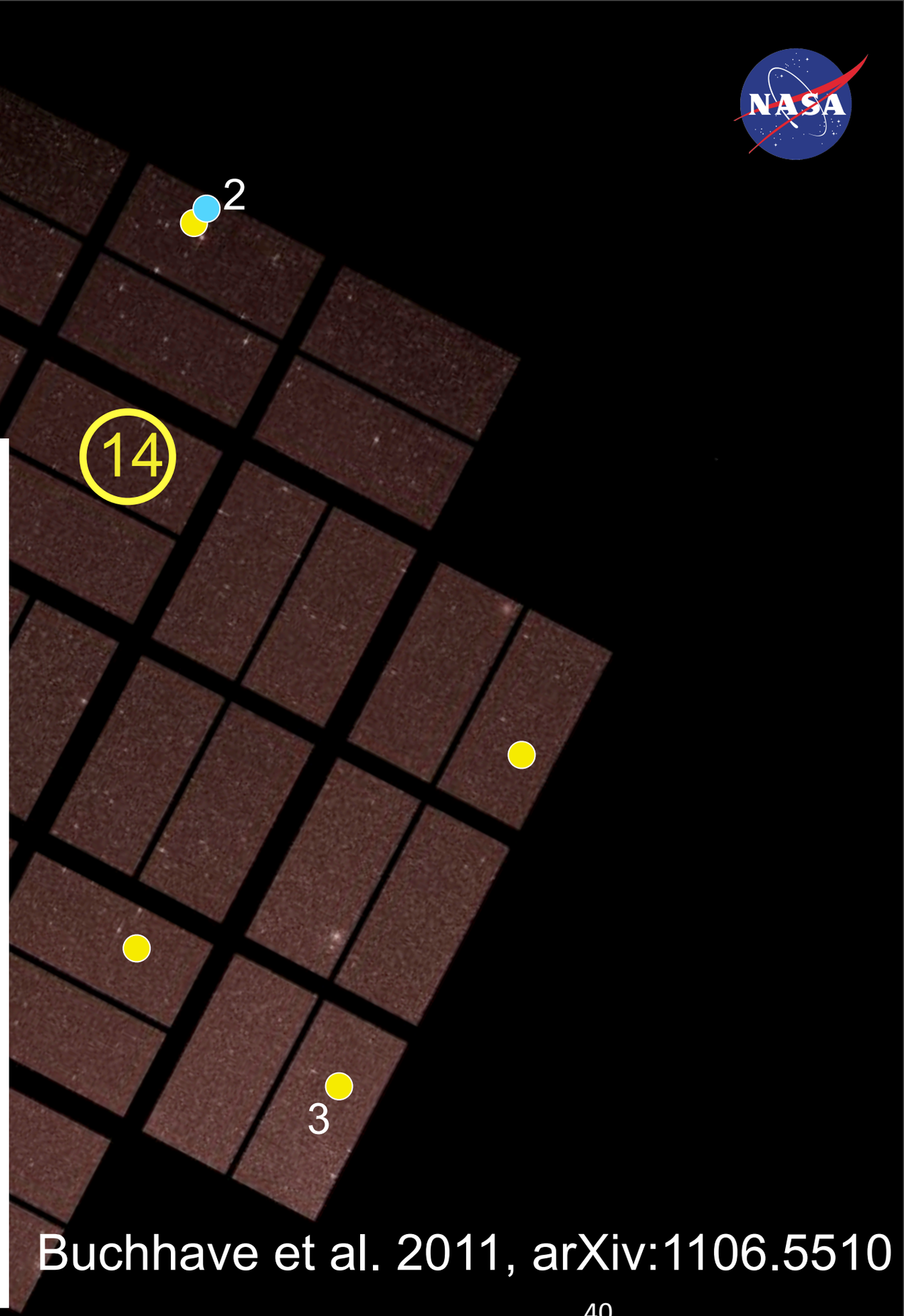
Buchhave et al. 2011, arXiv:1106.5510



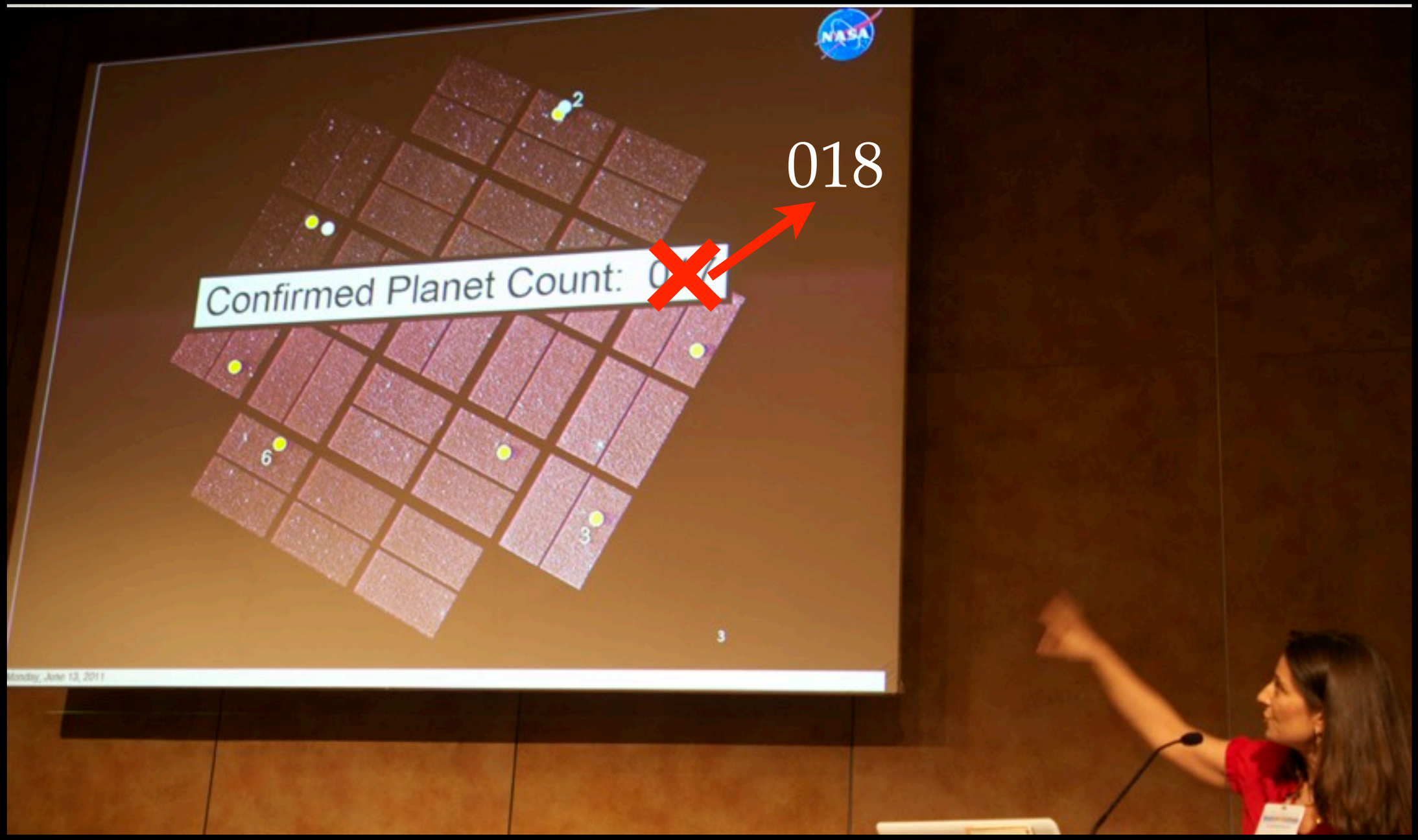
Buchhave et al. 2011, arXiv:1106.5510

Kepler-14b: A massive hot Jupiter transiting an F star in a close visual binary

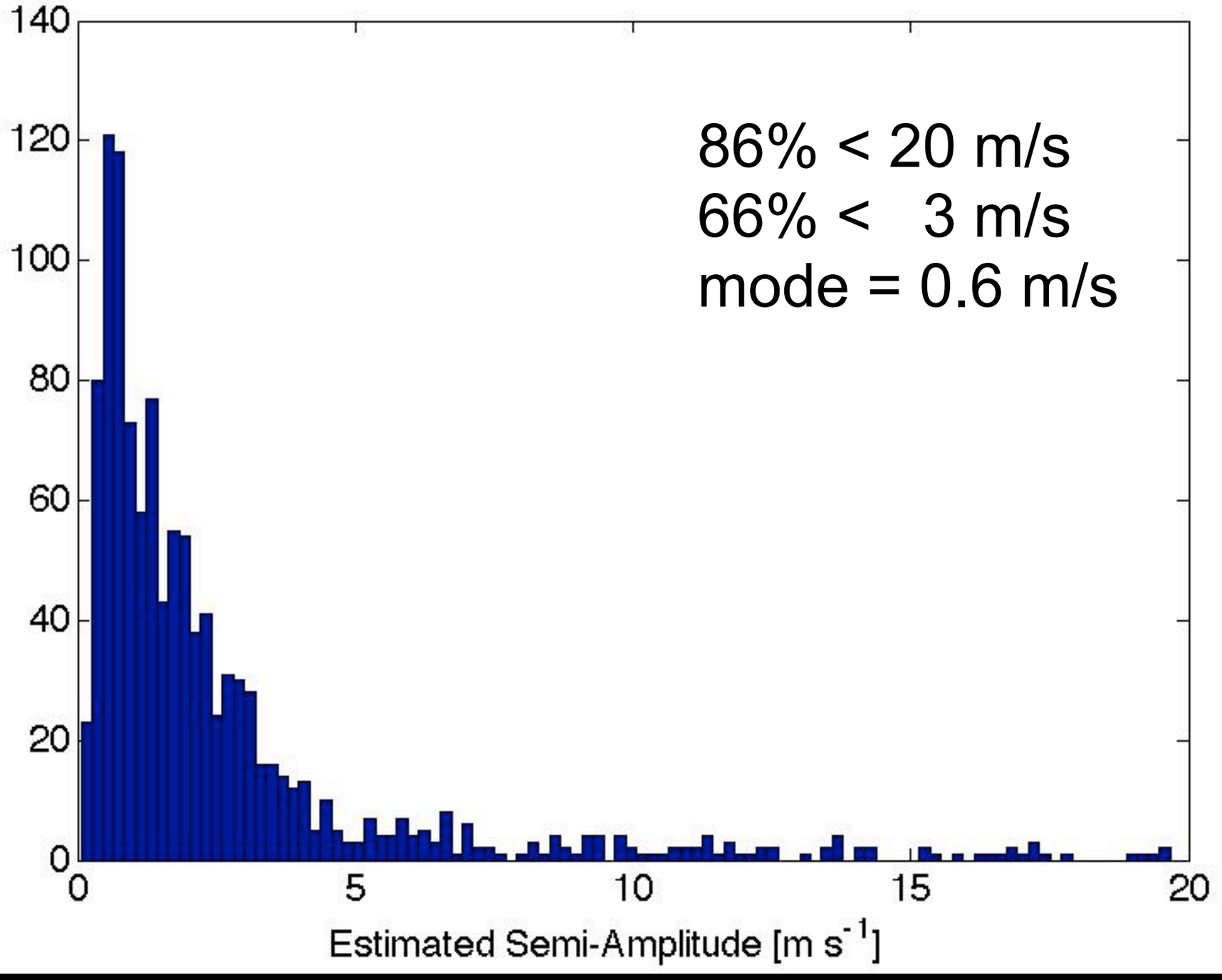
Property	Uncorrected	Corrected
Mass (M_J)	5.14±0.16	8.40±0.19
Radius (R_J)	1.036±0.084	1.136±0.073
Density (gcc)	5.7±1.5	7.1±1.1
Period (days)	6.7901230 ± 0.0000043	



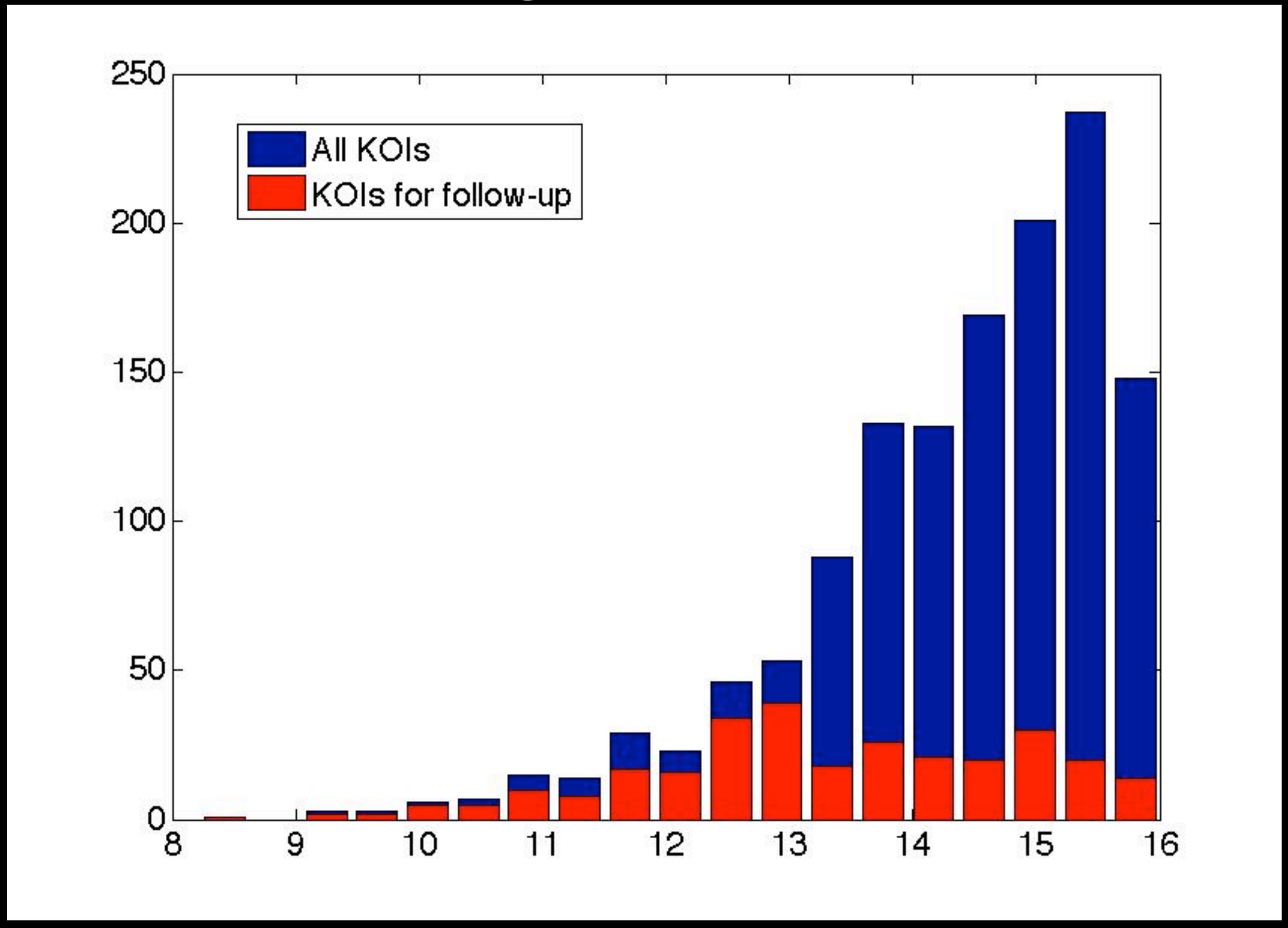
Buchhave et al. 2011, arXiv:1106.5510


018
Confirmed Planet Count:
2
6
3
3
Monday, June 13, 2011

Estimated semi-amplitude distribution



Strategies for 2011



288 Stars; 104 are multis; 144 V > 13.5; 75 high precision Doppler