Common Methods for Detecting Planets and the BLS Algorithm

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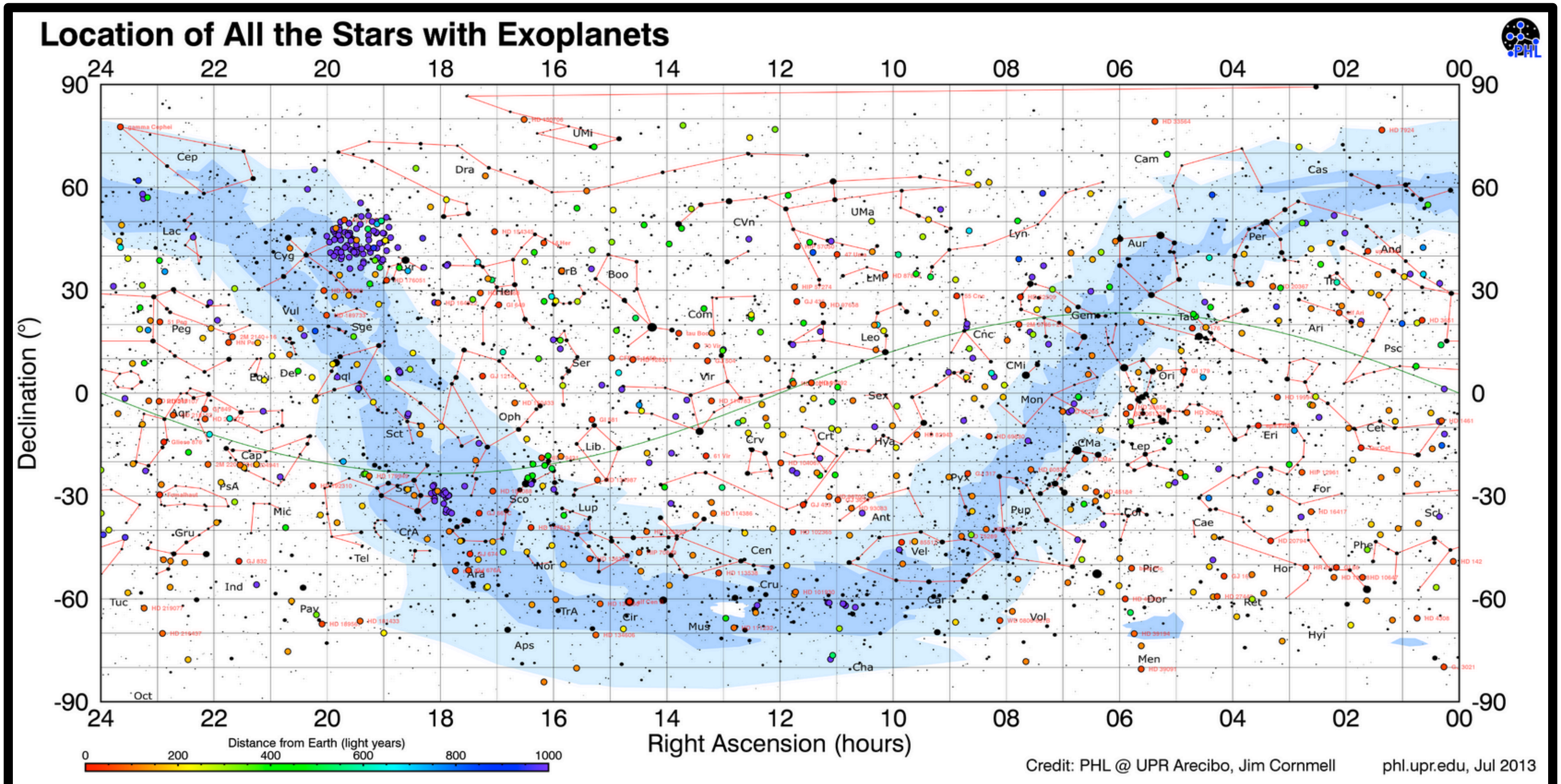
Astronomy 689

Thursday, September 16, 2015

Exoplanets

- Explosion of work in the past 15 years
- 1642 confirmed planets as of 10:18AM; 5429 candidates
- Observationally biased towards large planets with short orbits



Exoplanet Detection

- Transit Eclipse Photometry
- Radial Velocities
- Timing Variations
- Gravitational Microlensing
- Direct Imaging

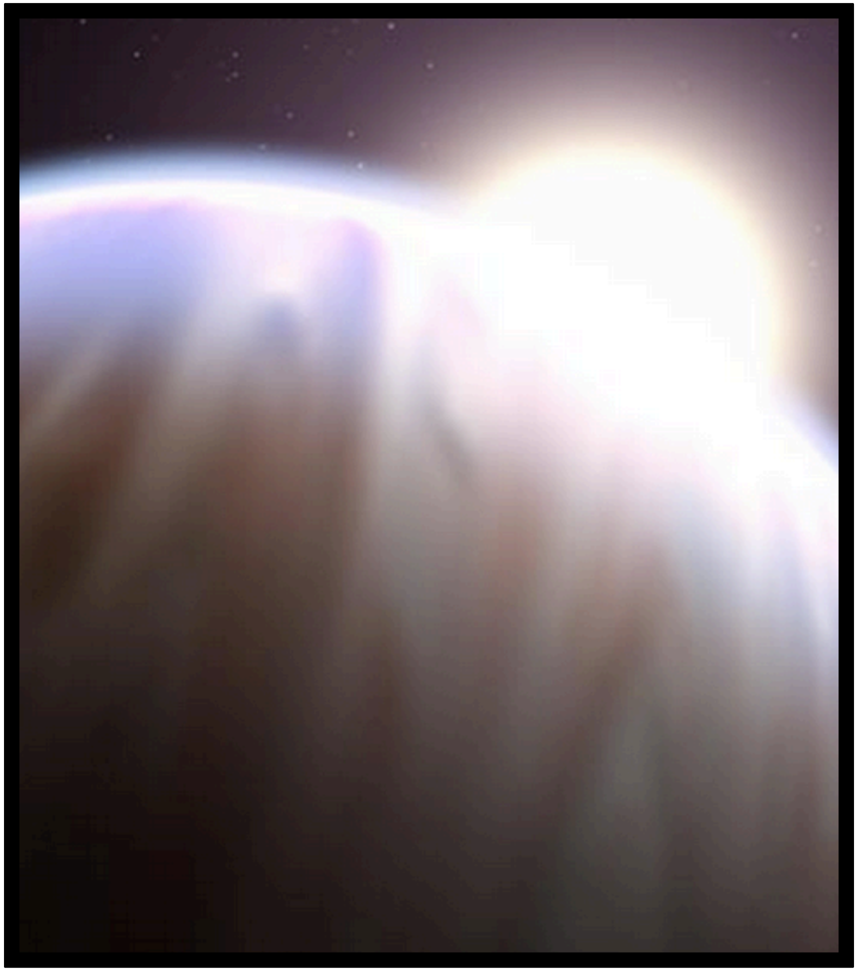


Image Courtesy of www.jpl.nasa.gov

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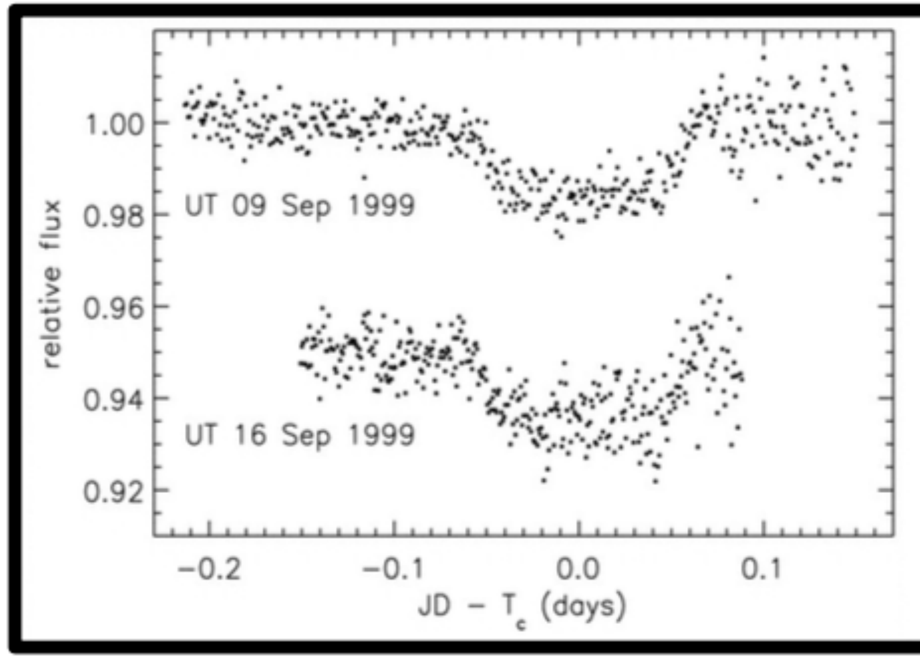

1.35 R_J radius planet on a 3.5 day orbit
Charbonneau, et al. 1999, ApJL, 529, L45

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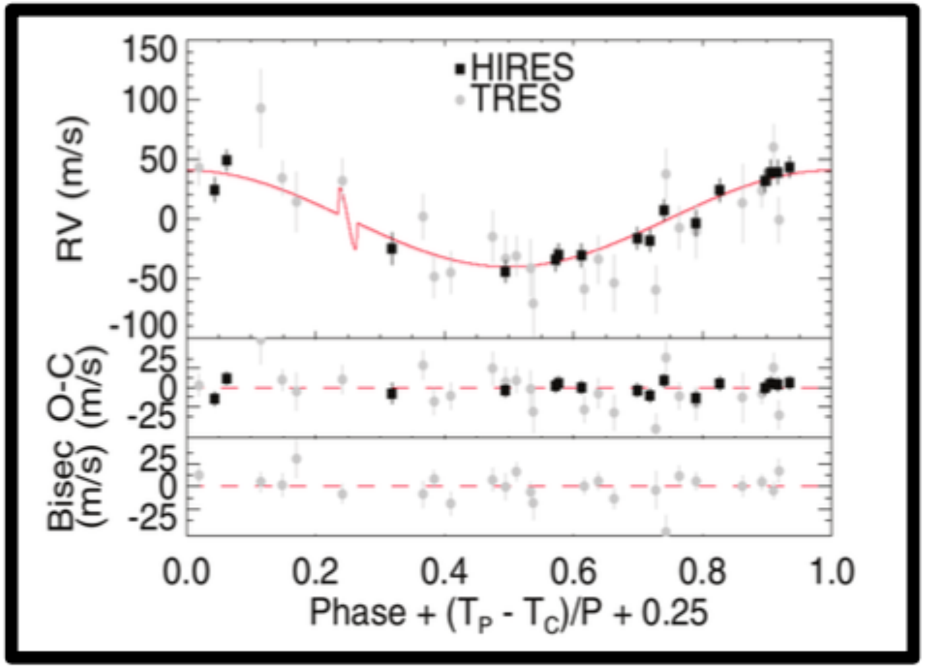

0.5 MJ mass planet on a 9.7 day orbit
Collins, et al., 2014, AJ, 147, 39

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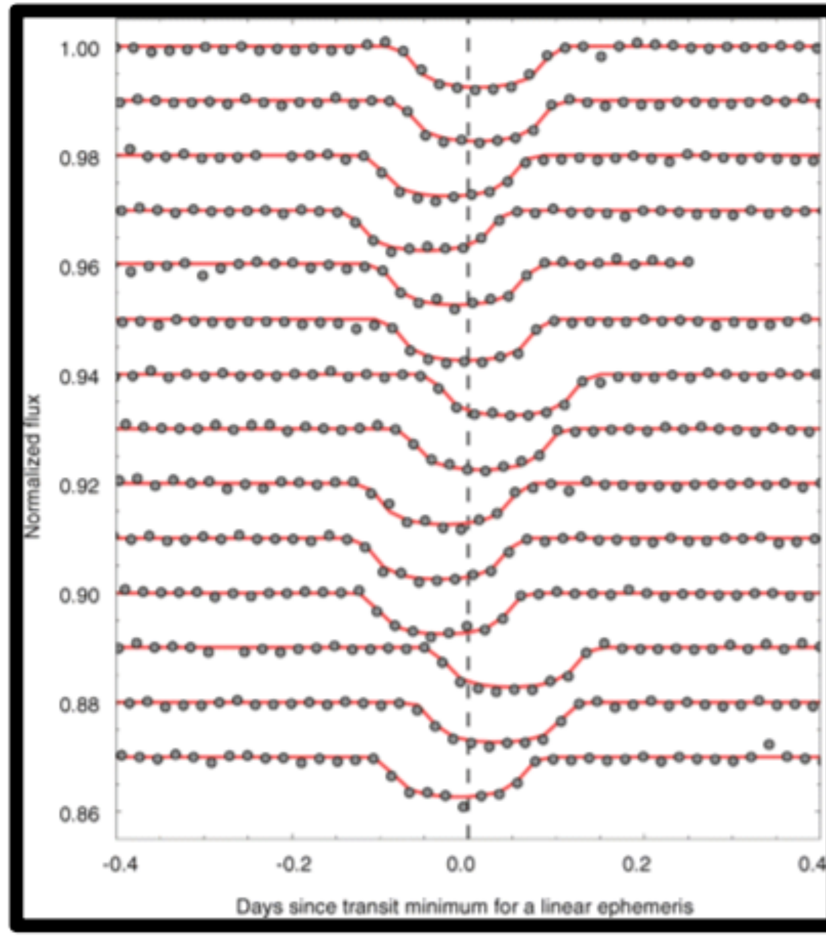

Long term variation of transit times for KOI-872b
Nesvorny, et al. 2012, Science, 336, 1133

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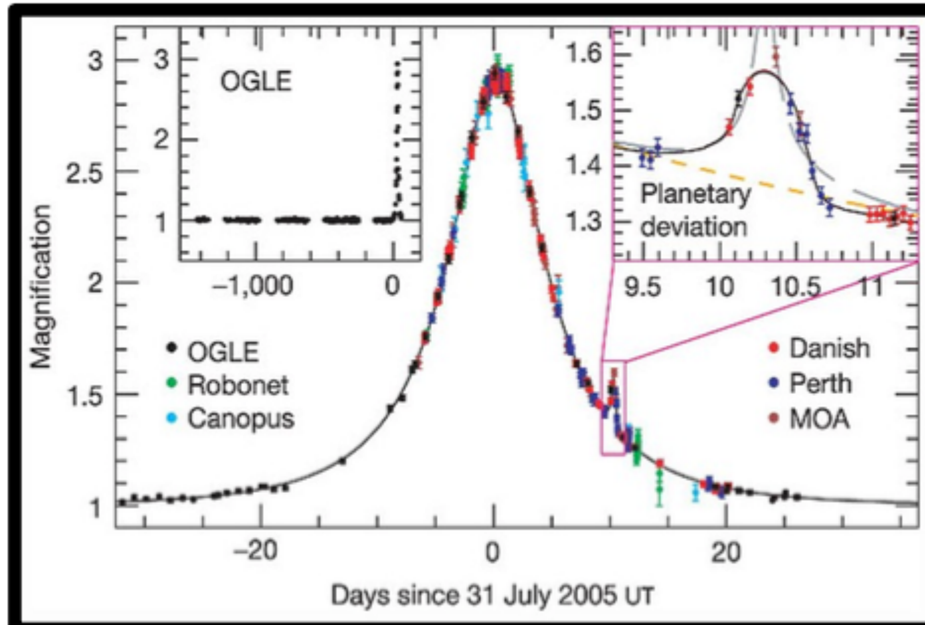

5.5 M_E mass planet
Beaulieu, et al 20016, Nature, 439, 437

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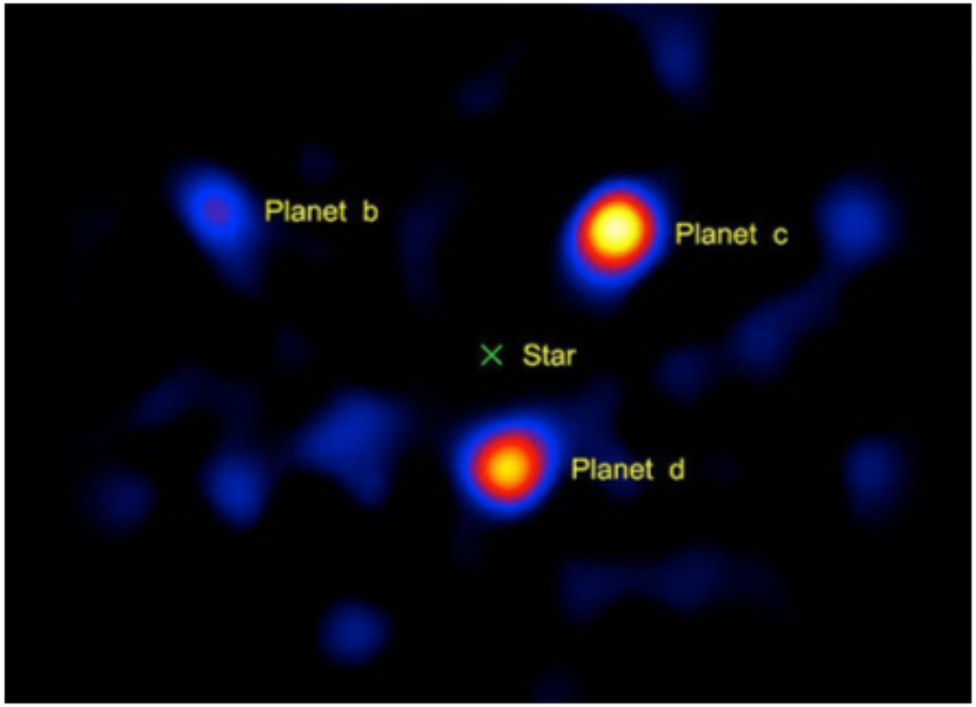

HR7899 with 3 massive exoplanets
Serabyn, et al. 2009, BAAS, 42, no 1, 377.06

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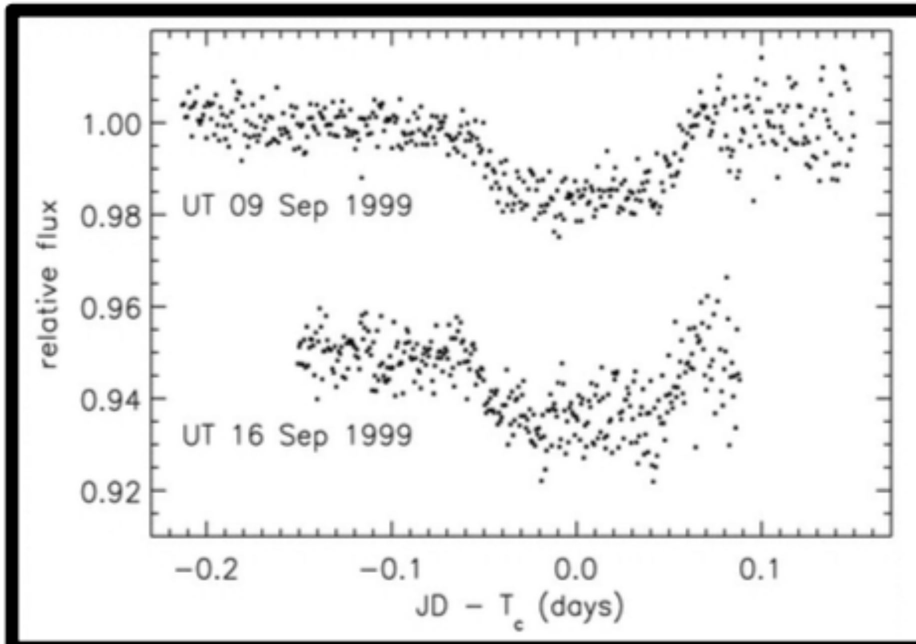
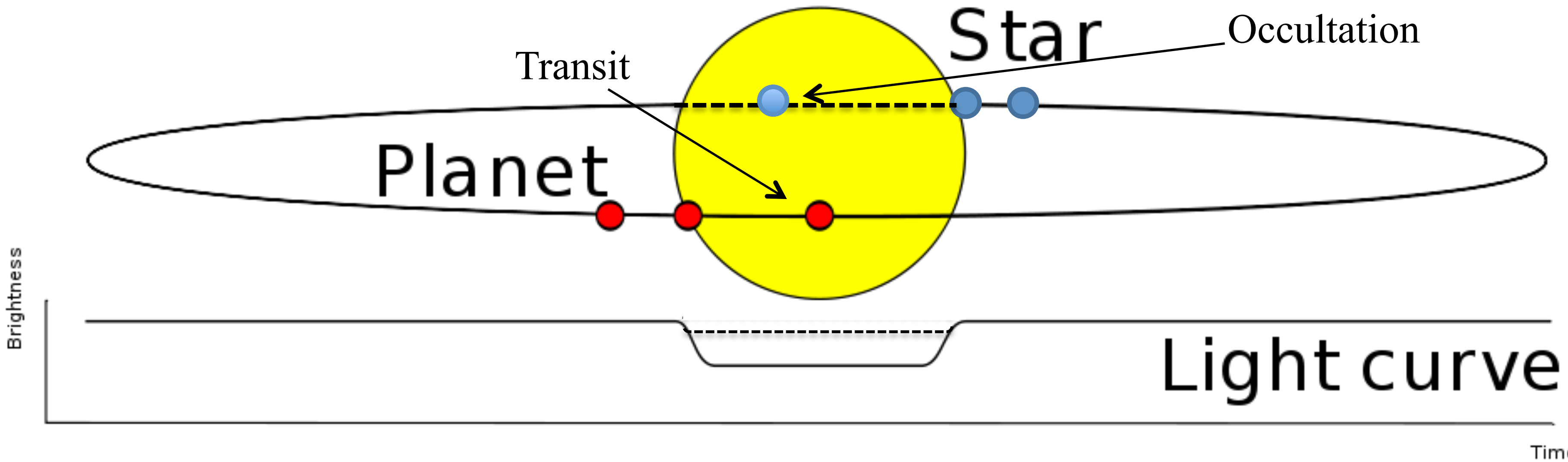


1.35 R_J radius planet on a 3.5 day orbit
Charbonneau, et al. 1999, ApJL, 529, L45

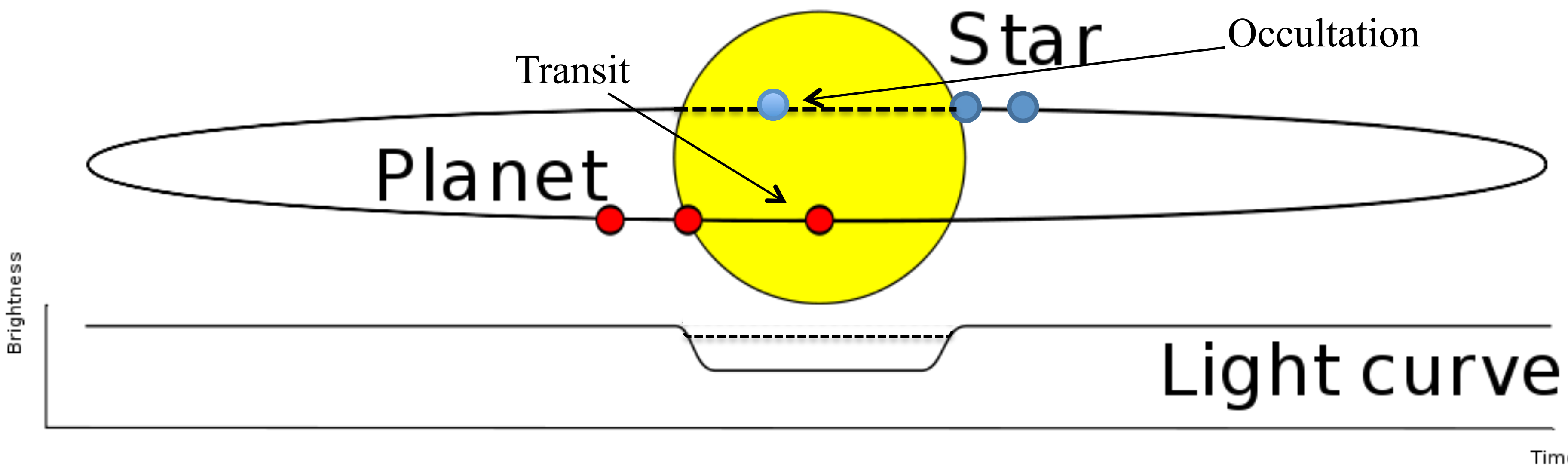
Eclipse Events



Transit – The planet is in front of the star, eclipsing the star.

Occultation – The planet is behind the star, being eclipsed by the star.

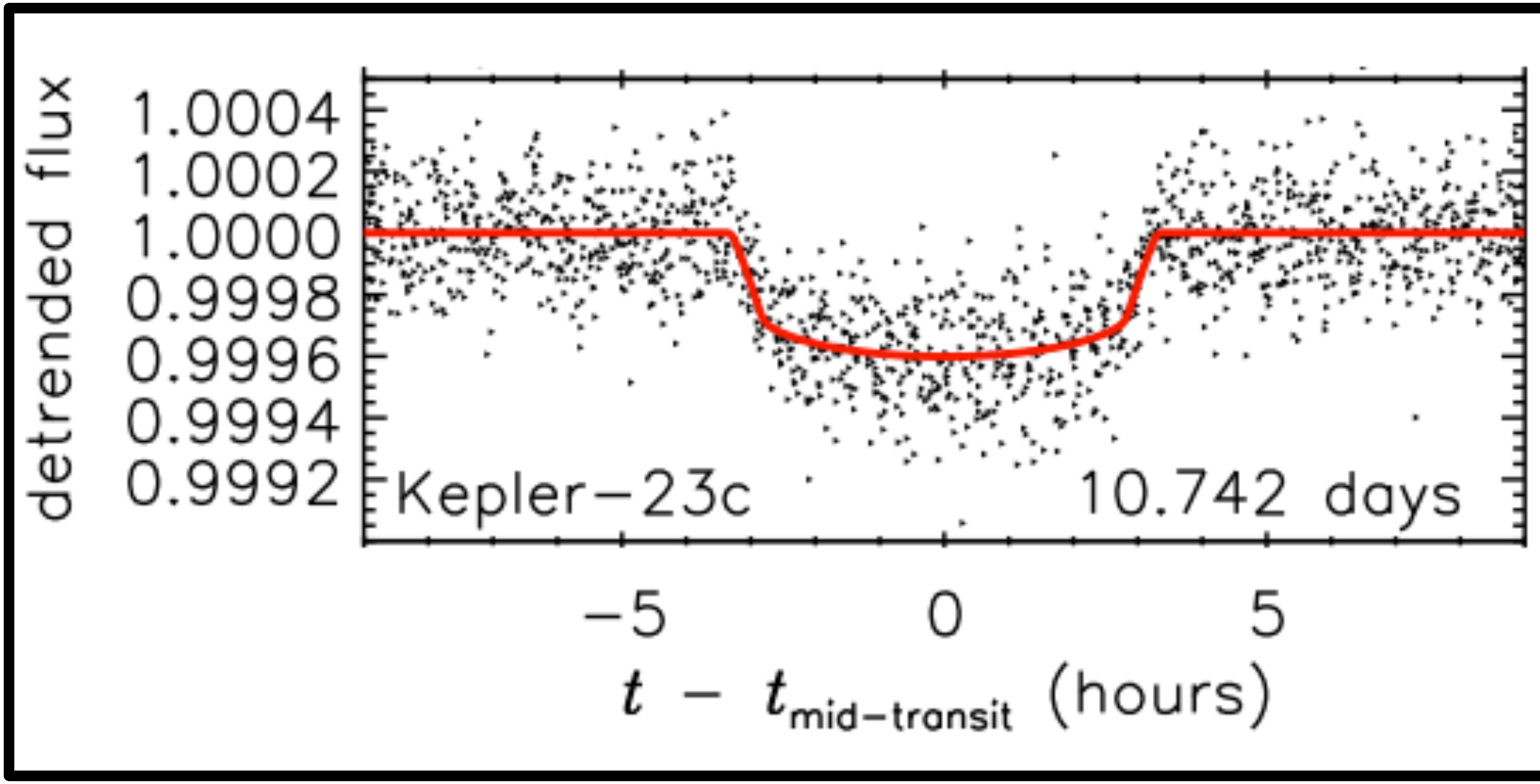
Information from Eclipses



Exoplanet transits and eclipsing binary stars allow for the ratio of the radii in the system to be determined.

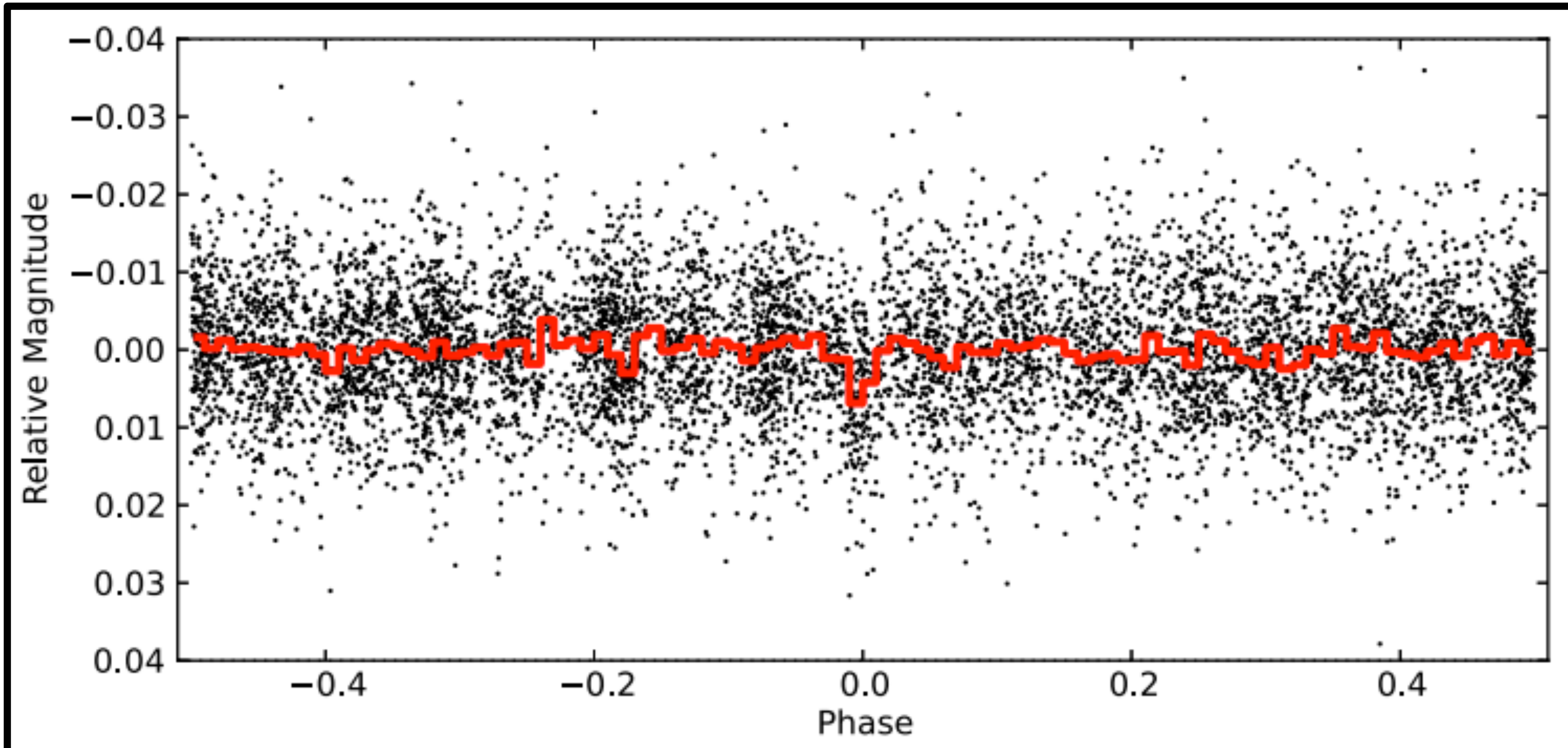
Seager & Ornelas, 2002, arXiv 0206.228

Kepler Light Curve



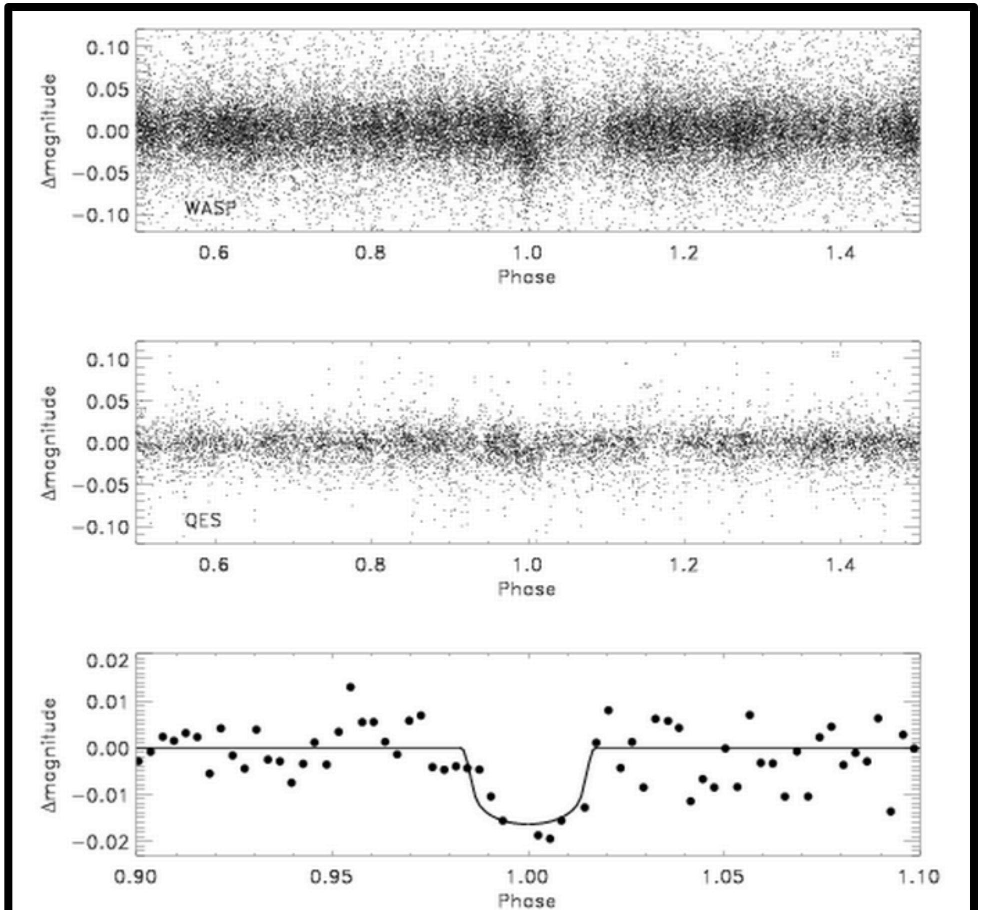
Transit of Kepler 23b
Ford, et al. 2012, ApJ, 750, 113

Kelt Light Curve



Transit of Kelt 6b
Collins, et al. 2014, AJ, 147, 39

Small Telescope Transit Searches



Transit of WASP-57b
Faedi, et al. 2013, A&A, 551, A73

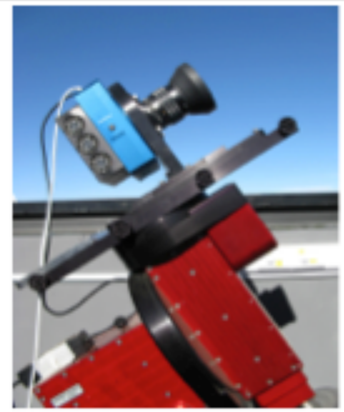
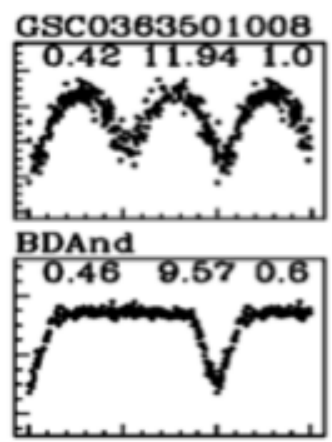


Image Courtesy of
KELT South Homepage

Image Courtesy of
SuperWASP Homepage



Bakos, et al., 2002

Image Courtesy of
cfa.harvard.edu

Box Least Squares Method

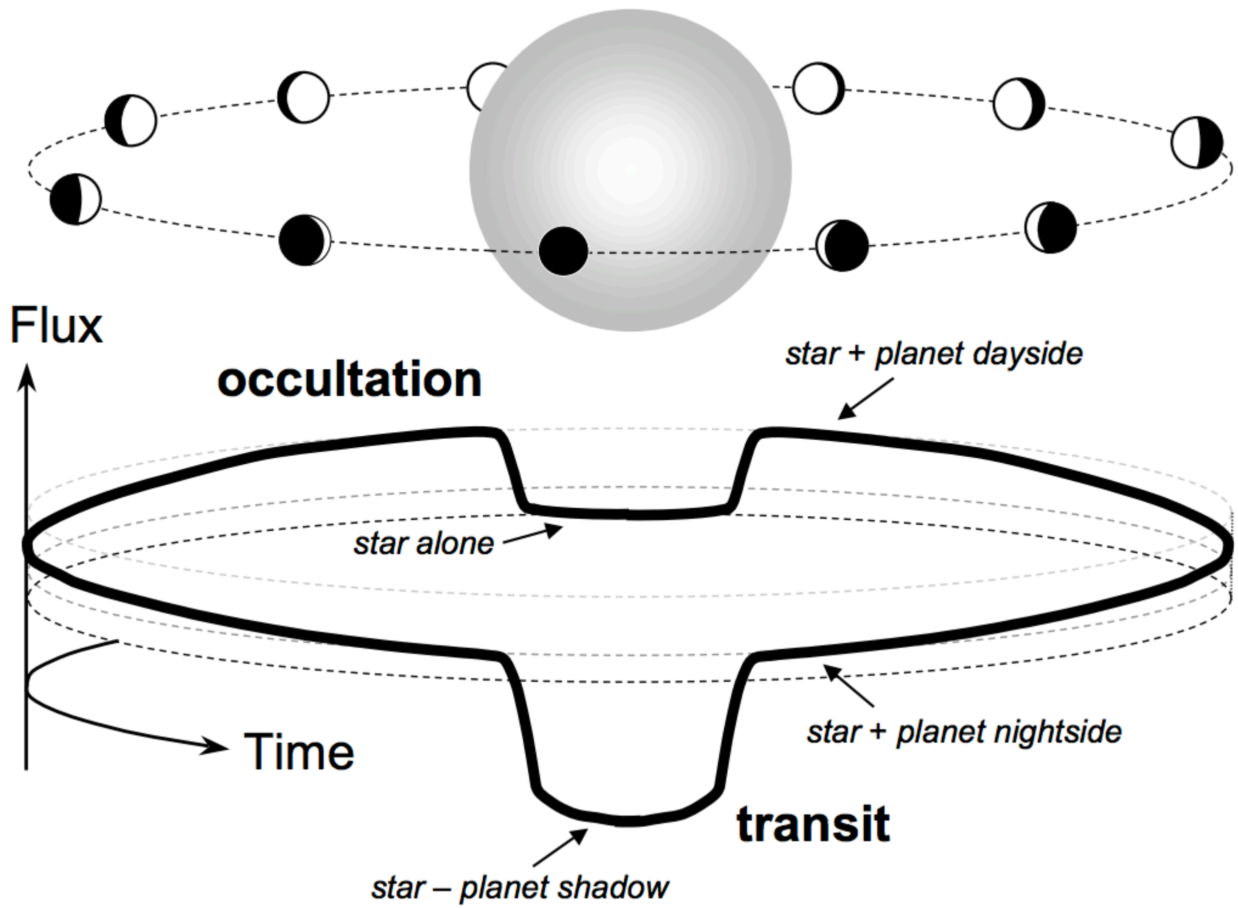


Image from Winn 2010, ArXiv 1001.2010

Box Least Squares Method

Kovacs et al. 2002, A&A, 391, 369

Minimization of D:

$$L = [i_1, i_2]; H = [1, i_1) \& (i_2, n]$$

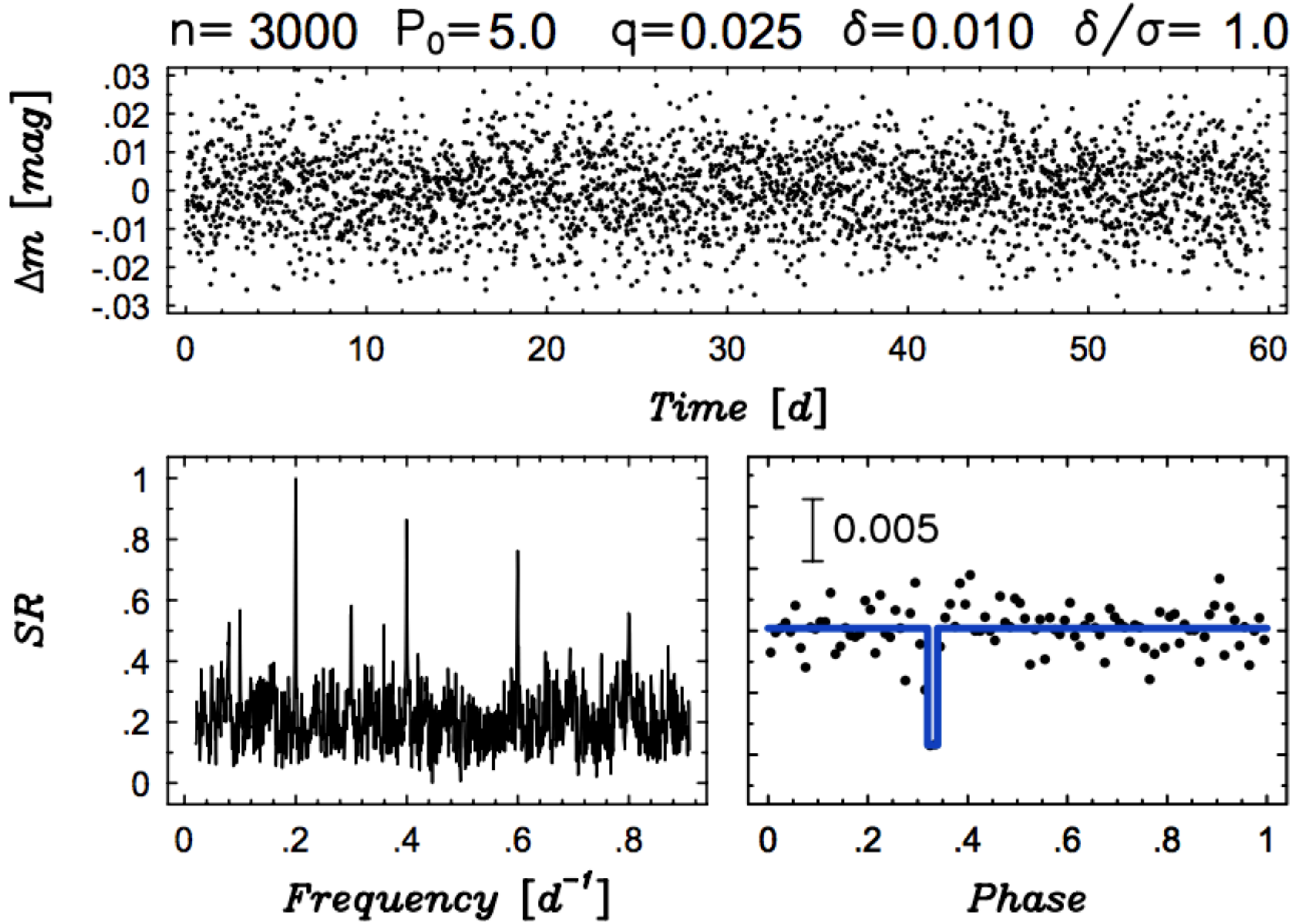
$$D = \sum_{i=1}^{i_1-1} w_i (x_i - H)^2 + \sum_{i=i_2+1}^{n} w_i (x_i - H)^2 + \sum_{i=i_1}^{i_2} w_i (x_i - L)^2 \quad L = \frac{s}{r} \quad H = -\frac{s}{1-r}$$

$$D = \sum_{i=1}^{n} w_i x_i^2 - \frac{s^2}{r(1-r)} \qquad s = \sum_{i=i_1}^{i_2} w_i x_i^2 \qquad r = \sum_{i=i_1}^{i_2} w_i \qquad w_i = \sigma_i^{-2} \left[\sum_{i=j}^{n} \sigma_j^{-2} \right]^{-1}$$

For all periods:

$$SR = MAX \left\{ \left[\frac{s^2(i_1, i_2)}{r(i_1, i_2)[1 - r(i_1, i_2)]} \right]^{\frac{1}{2}} \right\}$$

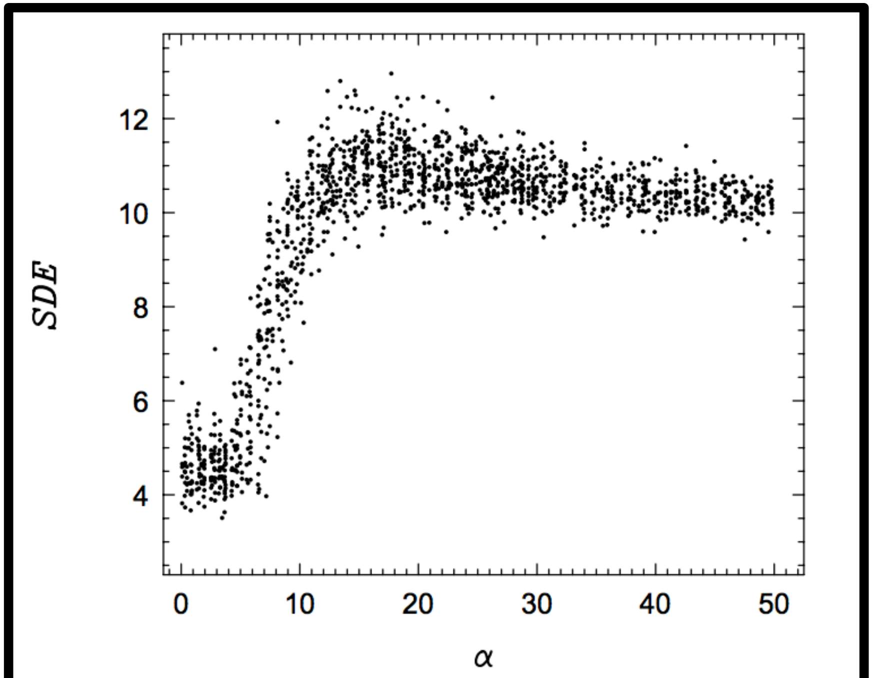
Box Least Squares Method

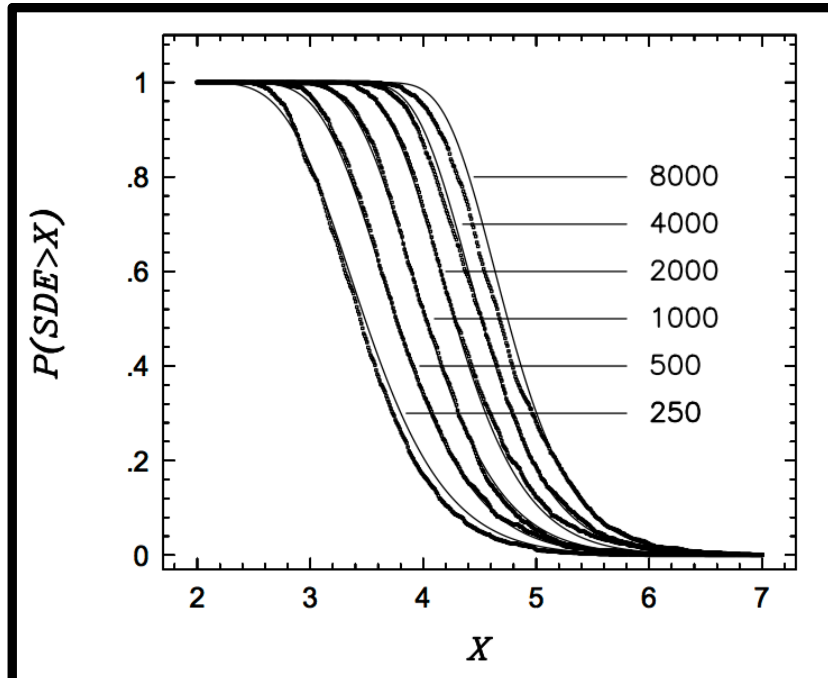


Box Least Squares Method

Signal Detection Efficiency:

$$SDE = \frac{SR_{peak} - \langle SR \rangle}{\sigma(SR)} \qquad \alpha = \frac{\delta}{\sigma}\sqrt{nq}$$

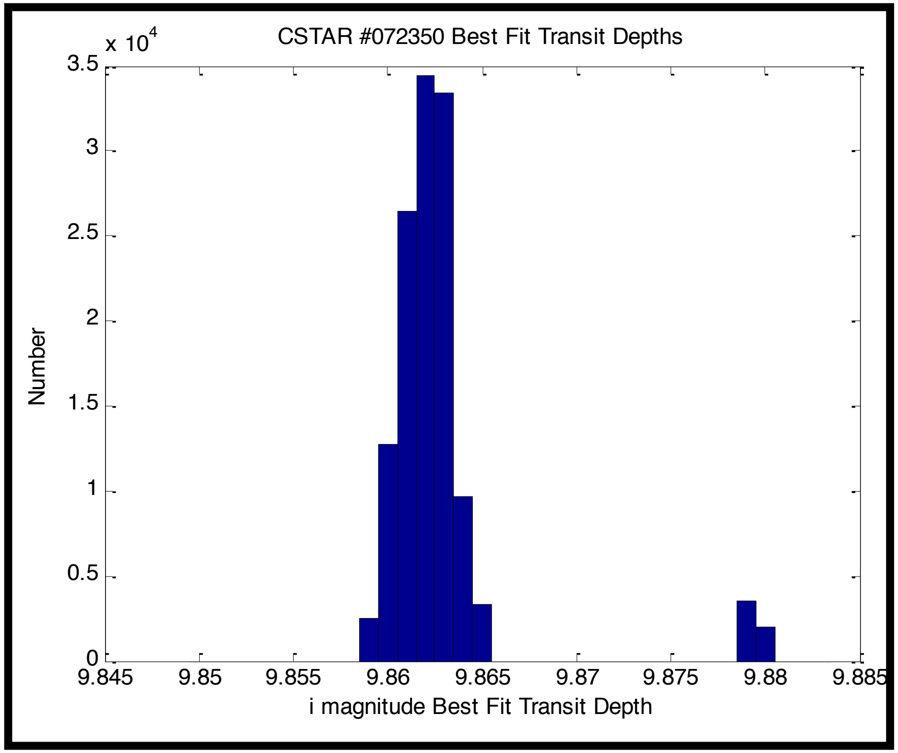


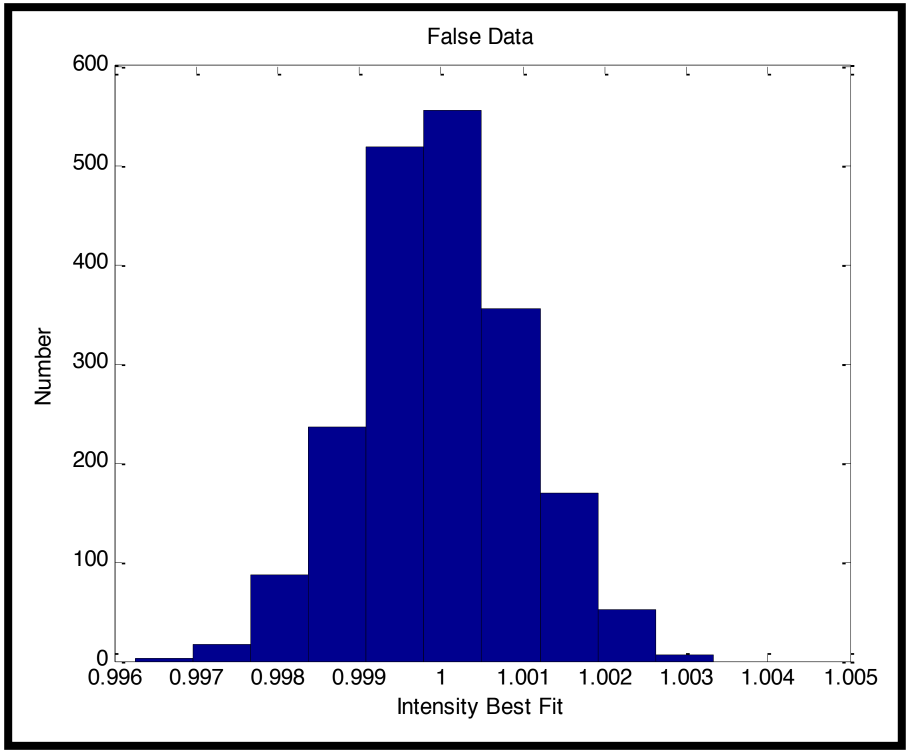


Other Requirements for Significant Detections

- Minimum of 3 eclipses
  - 2 for the period determination
  - 3 to rule out odd/even transits
- Checking the best-fit transit vs. the best-fit anti-transit
- Period aliasing checks
- SNR of candidate vs. SNR of all stars
  - False-Alarm Probability

Light Curve Statistics





Fit for Best-Fit Transit/Occultation
Depth and Time

Summary

- The transit technique is a common detection method.
- Understanding noise is a key to detections.
- Many signals can cause transit-like signals
- BLS algorithm is a powerful tool to detect planets in high noise situations