Observational Needs for Transit Surveys

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Lehigh University

Why Are Observations Needed?

<u>Planet Detection</u>

Show me there might be a planet there

<u>Planet Confirmation</u>

Prove that the thing causing the event is a planet

<u>System Characterization</u>

Tell me everything about the planet and its host star

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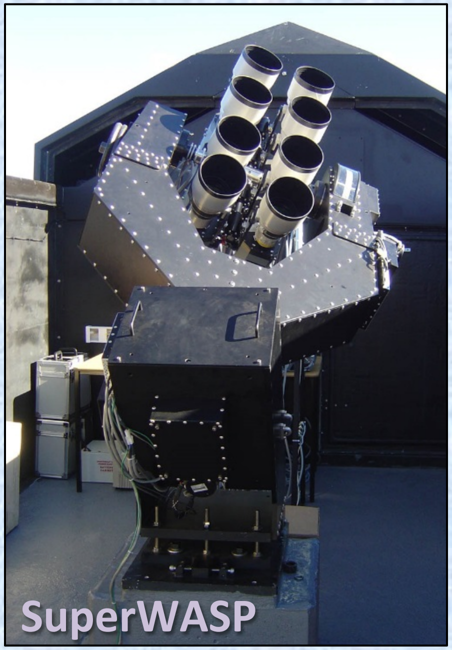
Transit Discovery

Robotic small telescope surveys

Wide fields, small apertures, hundreds of discoveries

- **OGLE**
- **XO**
- **TrES**



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Transit Discovery

Targeted transit surveys

- Narrow fields, medium apertures
- Monitor hundreds to thousands of stars
- Target high-priority stars, most M dwarfs
- Handful of high-impact discoveries

TRAPPIST

MEarth

<u>Cluster / Field surveys</u>

- SWEEPS
- STEPSS
- EXPLORE-OC
- PISCES

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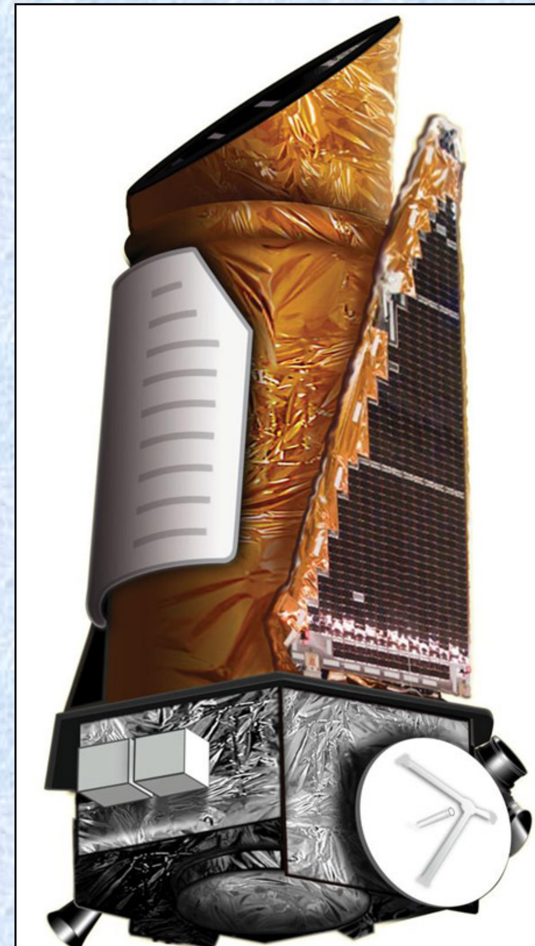
Transit Discovery

Space-based transit surveys

- 1,000s to 100,000s of candidates

Kepler



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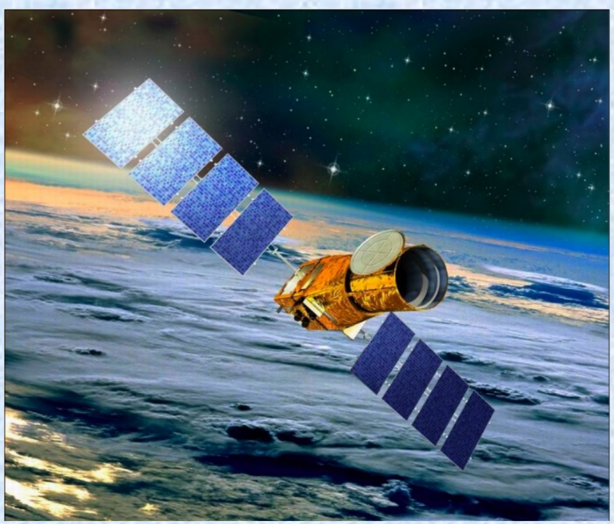
CoRoT



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Planet Detection

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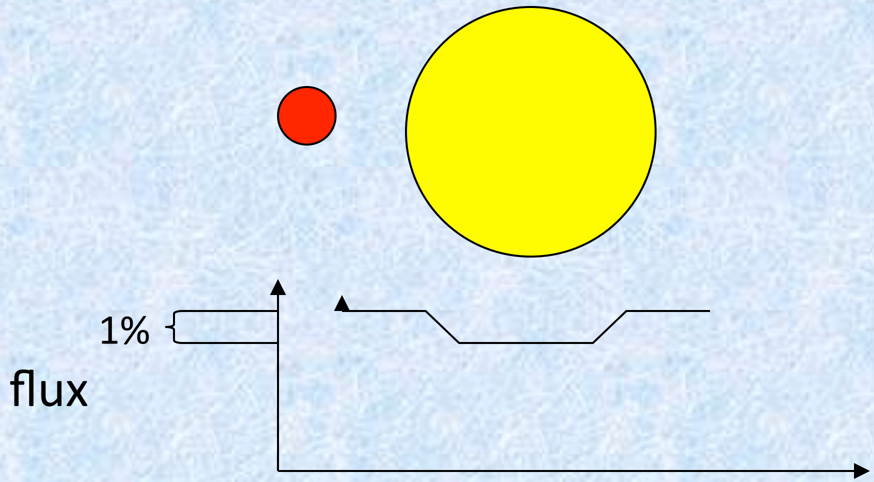
Transit Confirmation

- Real astrophysical transit/eclipse vs. false alarm
  - Photometric confirmation with original or new telescope
  - Required if pushing SNR limits
  - Verify ephemeris

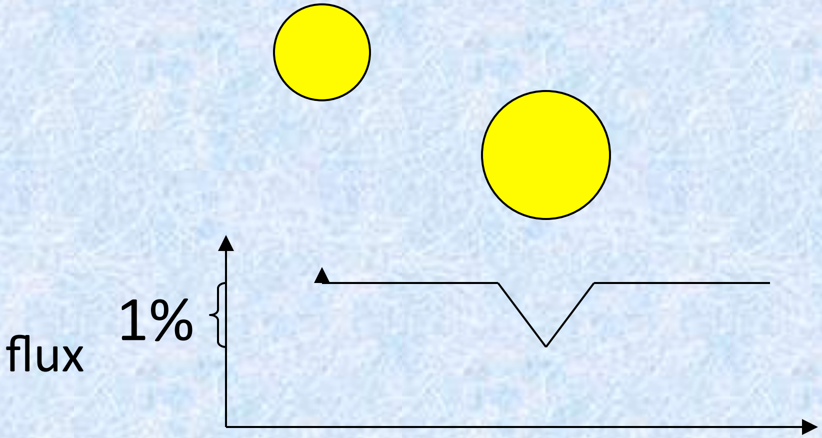
Planet Confirmation – False Positives



- Target is an EB with a large MS primary and a small MS secondary, or a giant star with a MS secondary

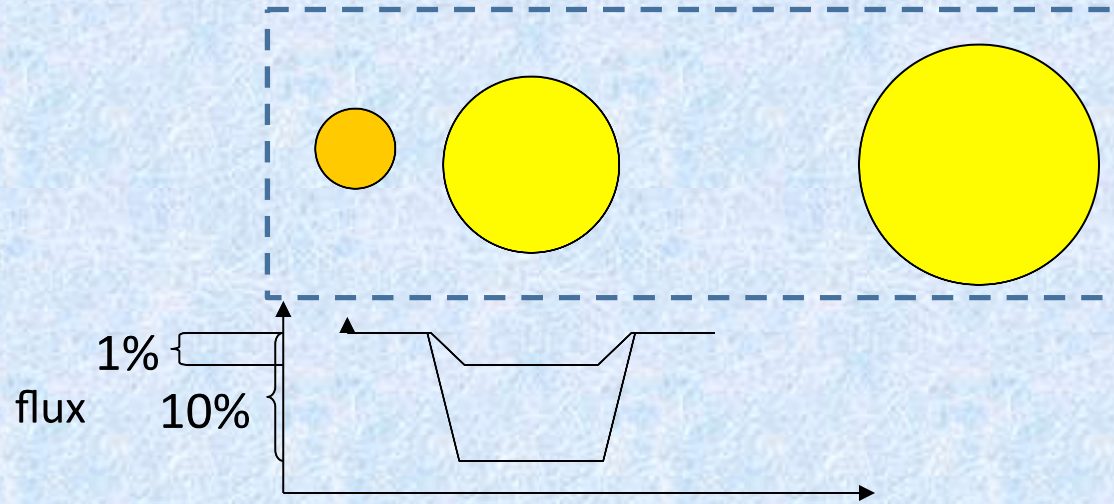
Planet Confirmation – False Positives

- Target is a grazing eclipsing binary

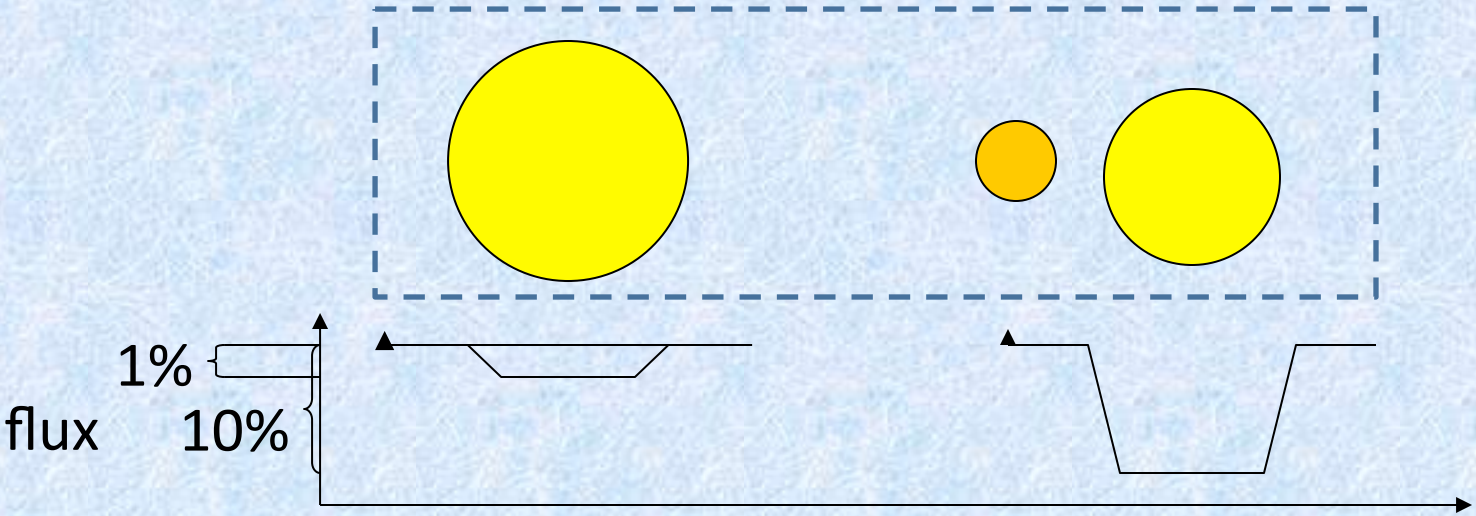


Planet Confirmation – False Positives

- Target is an EB blended with a line-of-sight or hierarchically bound star



Planet Confirmation – False Positives



- Target is a single star blended with an EB either line-of-sight or hierarchically

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Planet Confirmation – False Positives

The Pioneers

- Transit / eclipse of the expected star
  - Verify signal is not coming from a nearby (or distant) EB

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THE ASTROPHYSICAL JOURNAL, 614:979–989, 2004 October 20
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TESTING BLEND SCENARIOS FOR EXTRASOLAR TRANSITING PLANET CANDIDATES. I. OGLE-TR-33: A FALSE POSITIVE

GUILLERMO TORRES,[1] MACIEJ KONACKI,[2] DIMITAR D. SASSELOV,[1] AND SAURABH JHA[3]
Received 2004 April 23; accepted 2004 June 25

ABSTRACT

We report high-resolution spectroscopic follow-up observations of the faint transiting planet candidate OGLE-TR-33 ($V = 14.7$), located in the direction of the Galactic center. Small changes in the radial velocity of the star were detected that initially suggested the presence of a large planet or brown dwarf in orbit. However, further analysis revealed spectral line asymmetries that change in phase with the 1.95 day period, casting doubt on those measurements. These asymmetries make it more likely that the transit-like events in the light curve are the result of contamination from the light of an eclipsing binary along the same line of sight (referred to as a "blend"). We performed detailed simulations in which we generated synthetic light curves resulting from such blend scenarios and fitted them to the measured light curve. Guided by these fits and the inferred properties of the stars, we uncovered a second set of lines in our spectra that correspond to the primary of the eclipsing binary and explain the asymmetries. Using all the constraints from spectroscopy, we were then able to construct a model that satisfies all the observations and to characterize the three stars based on model isochrones. OGLE-TR-33 is fully consistent with being a hierarchical triple system composed of a slightly evolved F6 star (the brighter object) near the end of its main-sequence phase and an eclipsing binary with a K7–M0 star orbiting an F4 star. The application to OGLE-TR-33 of the formalism developed to fit light curves of transit candidates illustrates the power of such simulations for predicting additional properties of the blend and for guiding further observations that may serve to confirm that scenario, thereby ruling out a planet. Tests such as this can be very important for validating faint candidates.

Subject headings: binaries: eclipsing — line: profiles — planetary systems — stars: evolution — stars: individual (OGLE-TR-33)

Brown, T. 2003, ApJ, 593, 125 O'Donovan, F. T., et al. 2006, ApJ, 644, 1237 Torres, G., et al. 2006, ApJ, 644, 1237

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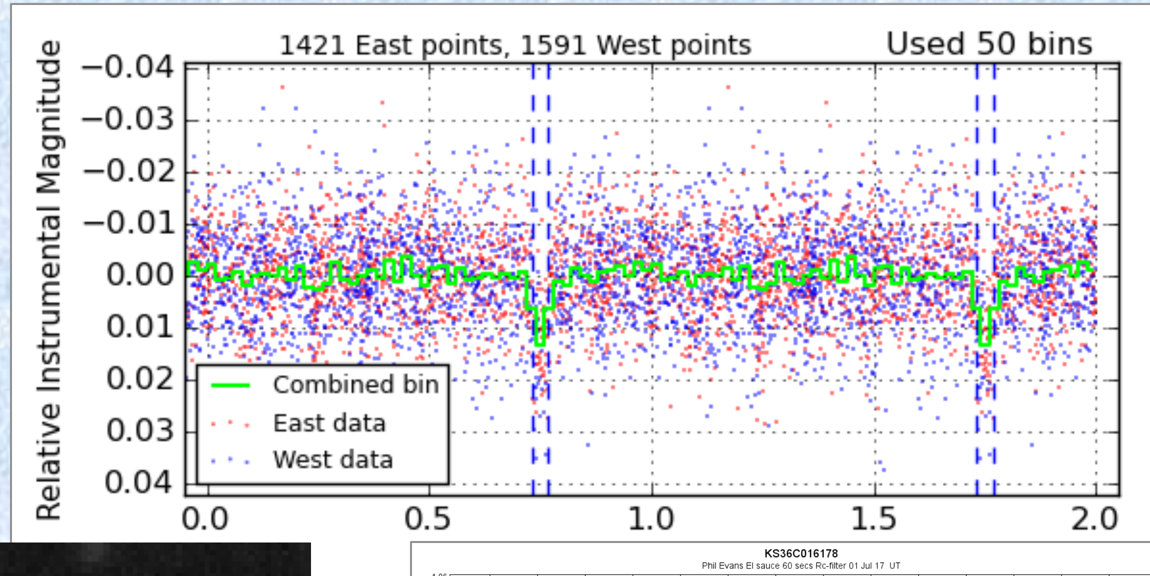
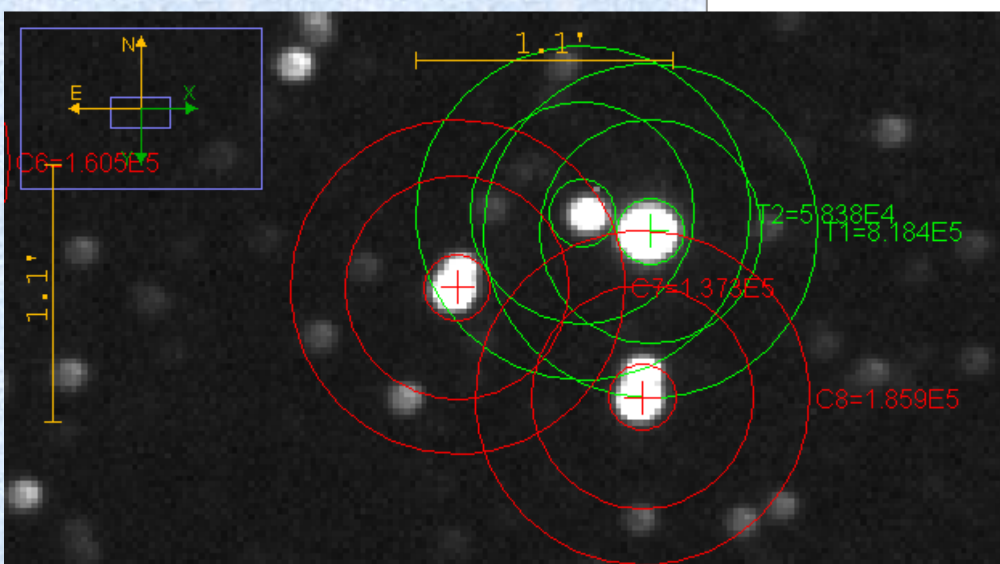
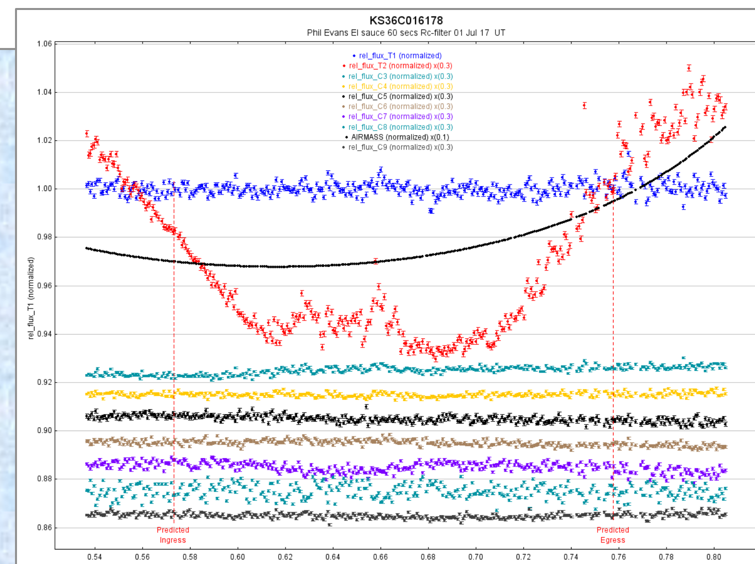
Planet Confirmation - Observations

Transit / eclipse of the expected star

- Verify signal is not coming from a nearby (or distant) EB







Planet Confirmation

Transit / eclipse of the expected star

- Verify signal is not coming from a nearby (or distant) EB
- Warnings and Caveats from RV Surveys

"MARVELS-1: A Face-on Double-lined Binary Star Masquerading as a Resonant Planetary System and Consideration of Rare False Positives in Radial Velocity Planet Searches"

Wright, et al. 2013, ApJ, 770, 119

AstroWright Blog: MARVELS-1: A Case Study in Healthy Paranoia in Science

"A Cautionary Tale: MARVELS Brown Dwarf Candidate Reveals Itself to be a Very Long Period, Highly Eccentric Spectroscopic Stellar Binary"

- Mack, C. E., 2013, AJ, 145, 139

"Don't underestimate the ability of Nature to screw with you!"
- David Ciardi

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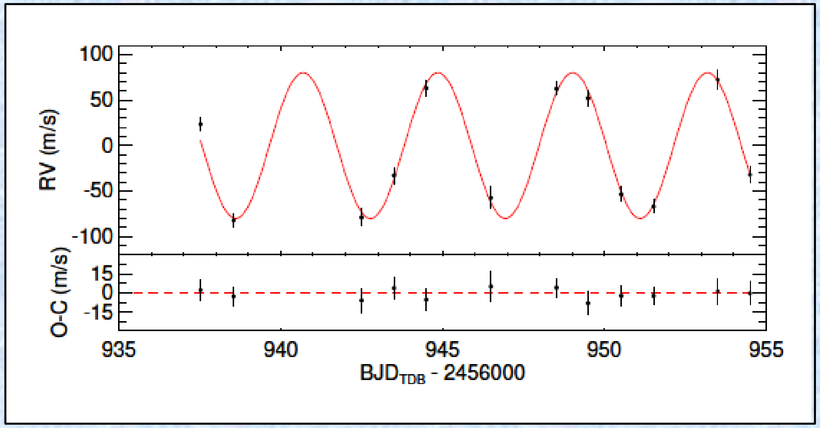
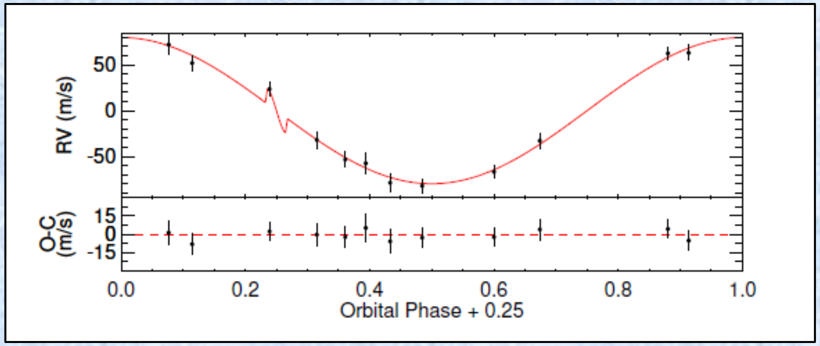
Planet Confirmation

- Verifying that the transiting / eclipsing body is planetary mass ($M_p < 13\ M_J$)

<u>RV measurement of planetary orbit</u>

- *M* sin(*i*), and then *M*





Kuhn, et al., MNRAS, 459, 4281

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Planet Confirmation

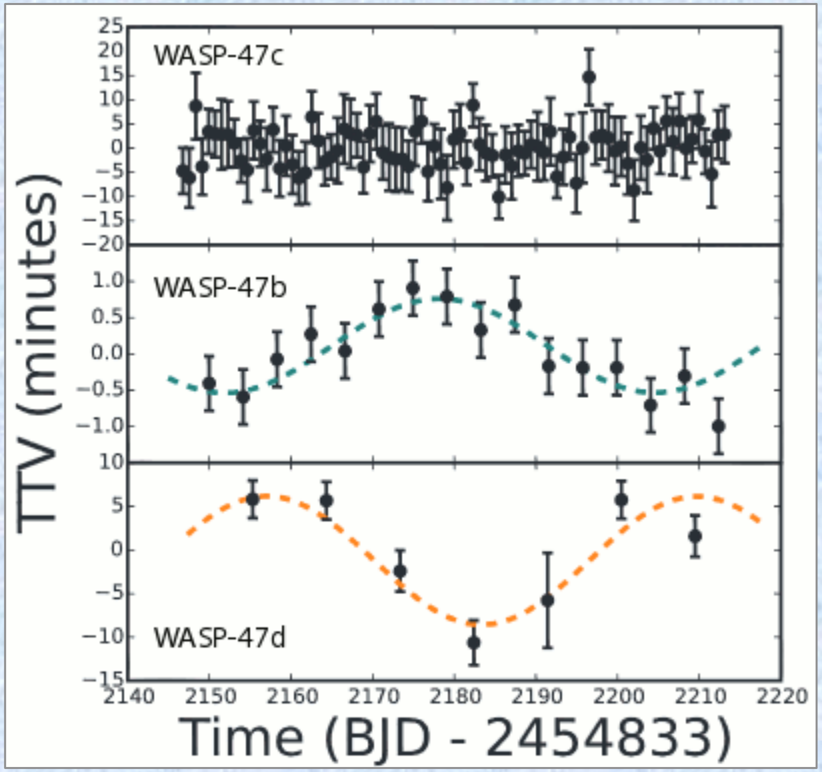
- Verifying that the transiting / eclipsing body is planetary mass ($M_p < 13$ M_J)

RV measurement of planetary orbit

- M_p sin(*i*), and then M_p

Transit Time Variations

- (TTVs) → M_p



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Planet Confirmation

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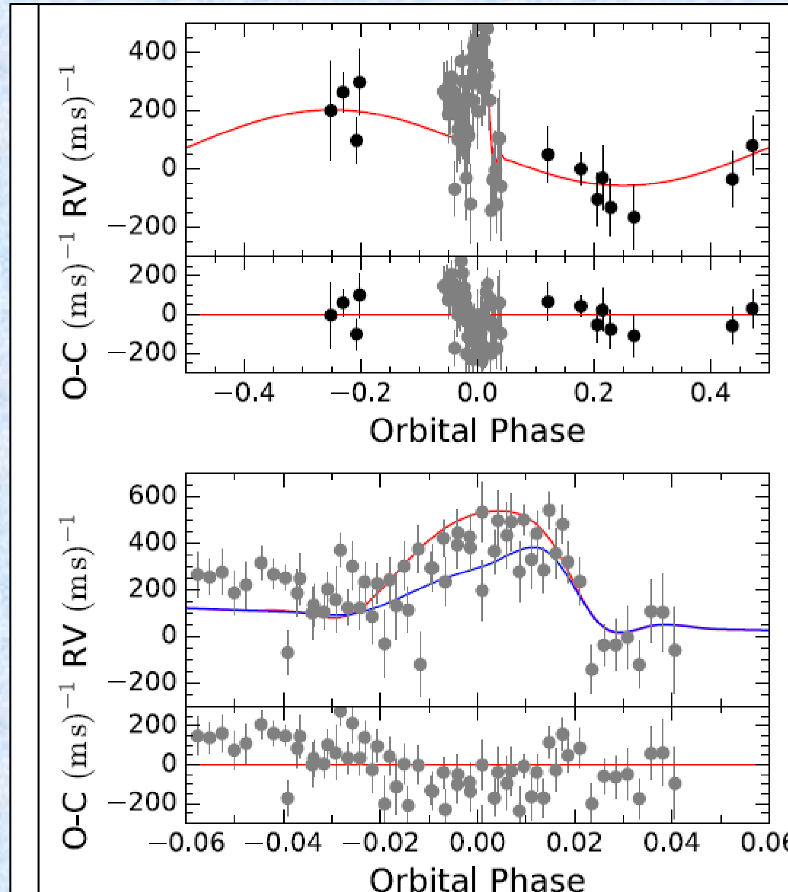

Zhou, et al., 2016, AJ, 152, 136

RV measurement of planetary orbit

- M_p sin(i), and then M_p

Transit Time Variations

- (TTVs) → M_p

Doppler Tomography + RV orbit

- Minimum M_p from orbit
- Projected spin-orbit alignment

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Planet Confirmation

Typical Set of Observations:

Photometric Confirmation of Transit

Spectroscopic Analysis of Host Star

RV, TTV, or DT Planet Confirmation

- Reconnaissance
- Precision / Orbit

The order and choice of observations depends on the nature of the survey and availability of follow-up resources.

Why Are Observations Needed?

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Prove that the thing causing the event is a planet

<u>**System Characterization**</u>
Tell me everything about the planet and its host star

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System Characterization

Star

- Mass
- Radius
- T_{eff}
- Age
- Luminosity
- Distance
- Metallicity
- Rotational velocity
- Rotational inclination
- Radial Velocity / 3-D motion

Planet

- Mass
- Radius
- Orbital period
- Semimajor axis
- Eccentricity
- Orbital inclination
- TTVs / other planets in the system
- Equilibrium Temperature

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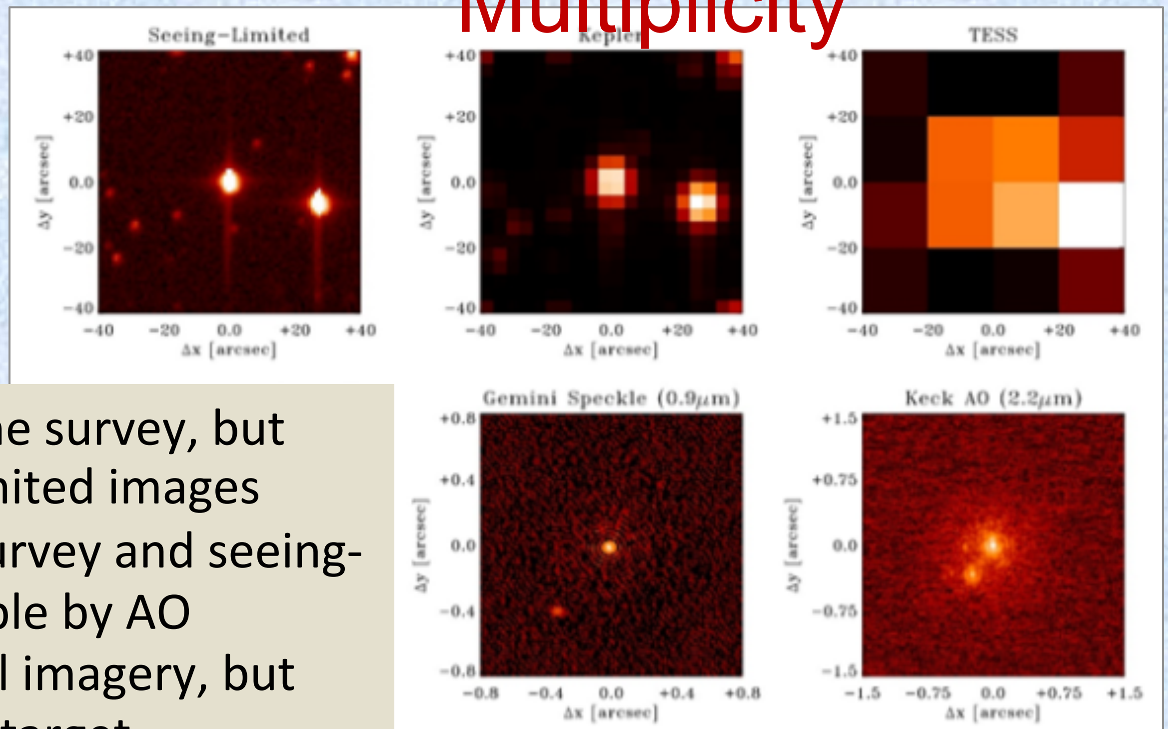
System Characterization

Know thy neighborhood, or *On the Varieties of ~~Binarity~~ Experience*

Multiplicity



- Neighbor not in the aperture, but with flux bleeding in
- Neighbor in the aperture, but distinguishable by PSF modeling in the survey
- Neighbor fully blended in the survey, but distinguishable in seeing-limited images
- Neighbor fully blended in survey and seeing-limited images, but resolvable by AO
- Neighbor fully blended in all imagery, but detectable as an SB2 of the target
- Neighbor fully blended in all imagery, but detectable if the target is an SB1

You need to know all stars within 1000 arcsec to 1 μas of your target!

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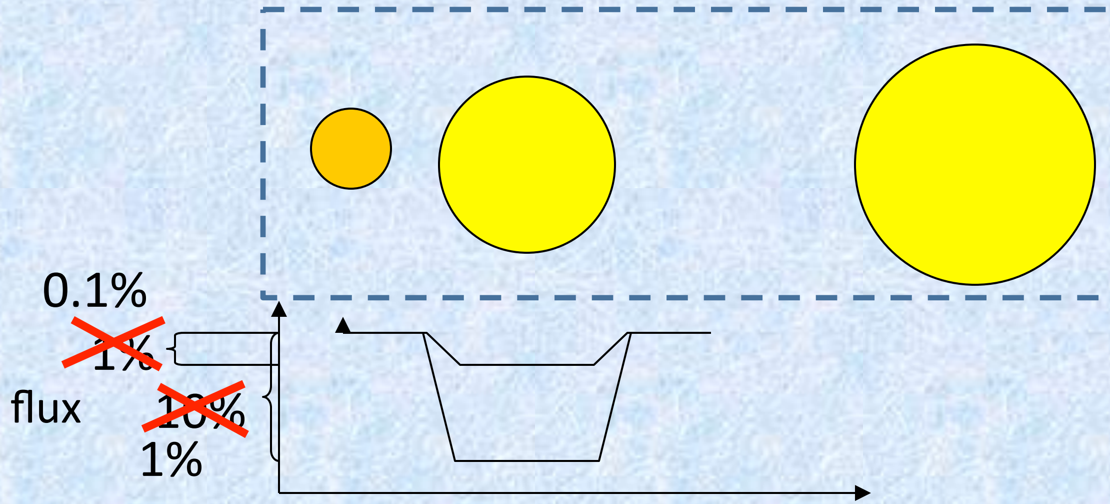
~~Transit Confirmation: False~~ Positives Characterization Fibbing

- Target is ~~an EB~~ ~~planet~~ a giant planet blended with a line-of-sight or hierarchically bound star



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System Characterization

Observables

- Time-series photometry
- Single-epoch spectrum
- Multiple spectra across orbit
- Single-epoch photometry
- Parallax

Star

- Mass
- Radius
- T_{eff}
- Age
- Luminosity
- Distance
- Metallicity
- Rotational velocity
- Rotational inclination
- Radial Velocity / 3-D motion

Planet

- Mass
- Radius
- Orbital period
- Semimajor axis
- Eccentricity
- Orbital inclination
- TTVs / other planets in the system
- Equilibrium Temperature

Doppler Tomography
Asteroseismology
Stellar Population Analysis

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Related Considerations

- Expense in time and money
- Prioritizing candidates for confirmation
  - Is it being done based on scientific value or ease?
- Rapidity of confirmation
  - Loss of ephemeris (especially for TESS)
  - Make available for particular facilities (HST, Spitzer, Swift, JWST), especially in eras of potentially declining budgets (KPNO, UKIRT)

Watch for SAG #17 Report – January 2018 AAS
David Ciardi, Joshua Pepper, Knicole Colon, Stephen Kane

Related Considerations

What have we (mostly) not observed with transits?

High cadence, high-precision, decent baseline to the point of demographic analysis

- Fast rotators
- Young stars
- Stars with IR excess and disks
- Subgiants
- Red giant stars
- Supergiants
- Hot (OBA) stars
- White dwarfs
- Neutron stars

- Flare stars
- Late M dwarfs
- LTY dwarfs
- Globular cluster members
- Halo stars
- Extragalactic stars
- Binary secondaries
- Medium binaries (not tight, not wide)

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Final thoughts, questions

- Terminological agreement
  - confirmation/characterization, reconnaissance/precision
- Do we need to confirm all candidates?
  - Either yes, or we need a representative observational survey of the candidate hosts ~**600,000 candidates from TESS FFIs**
- What is the responsibility of discovery groups to the theorists and those who calculate demographics?
  - Is information being irretrievably lost?
    - If so, is that so bad?
- Confirmation and characterization for large surveys is not being conducted exclusively by single teams. How much coordination is needed?

Thank You!