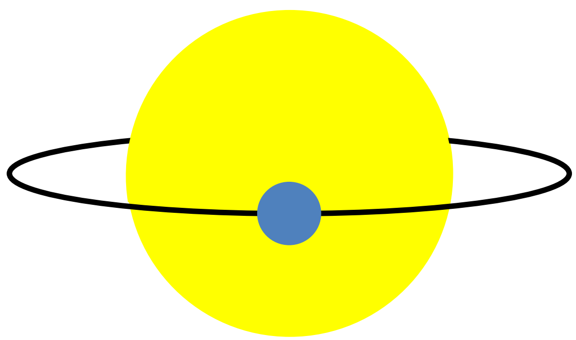
Detection of Exoplanets by Amateur Astronomers

September 17, 2015



by

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Background

- Exoplanet (Extrasolar Planet) – a planet orbiting a distant "host star"

- First exoplanet was discovered in 1992

- Confirmed exoplanets to-date: 1,889

- Detection techniques:
  - Transit Method (1,256) – measurement of a dip in the star's light curve as the planet transits its face; orbit must be edge-on to Earth's
  - Radial Velocity Method (548) – measurement of the Doppler shift in the host star's wavelength due to its movement by an orbiting planet(s)
  - Microlensing (33) – measurement of the change in magnification of a background star as a planet orbits the foreground "lensing" star
  - Direct Observation (39) – the "Holy Grail" of methods to determine habitable planets (see October 2015 *S&T* article)

- Both space-based (e.g., Kepler) and ground based observatories have detected exoplanets

Amateur astronomers can detect exoplanets:

…using the transit method to determine light curves

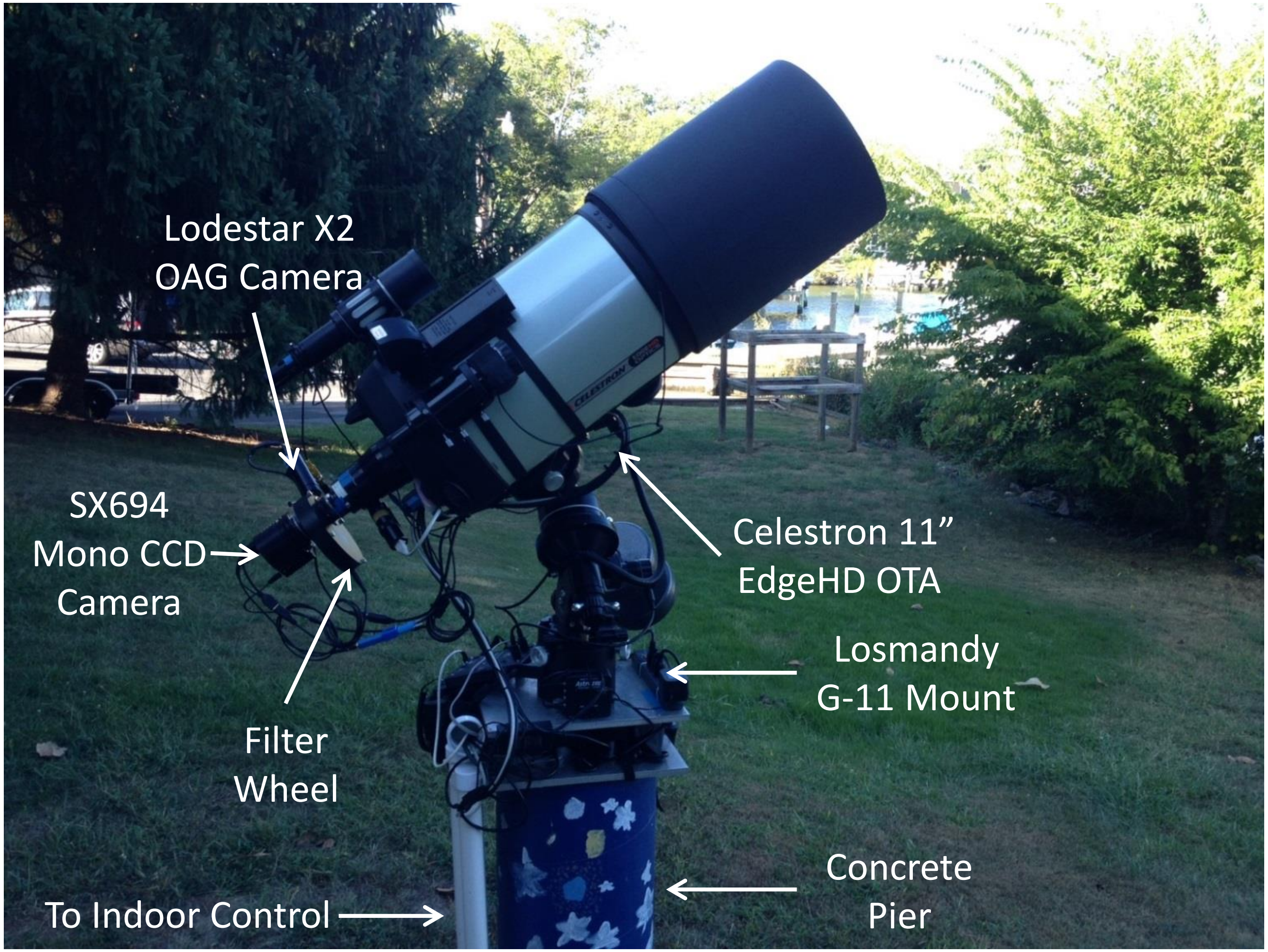
…using the same equipment used for deep sky imaging

…with surprising accuracy

…even in light polluted areas!

Case Study

Observatory Setup
Location: Suburban Annapolis, MD



Case Study: Detection of Tres-5b

Host Star: Tres-5 (aka GSC 3949:967),
V (mag.) = 13.7

Date/Time: August 16, 2015,
8:56-11:26PM (EDT)

Site: Suburban Annapolis, MD

Image scale= 0.63 arc-sec/pixel

FOV=14x11 arc-min.

Filter: Clear

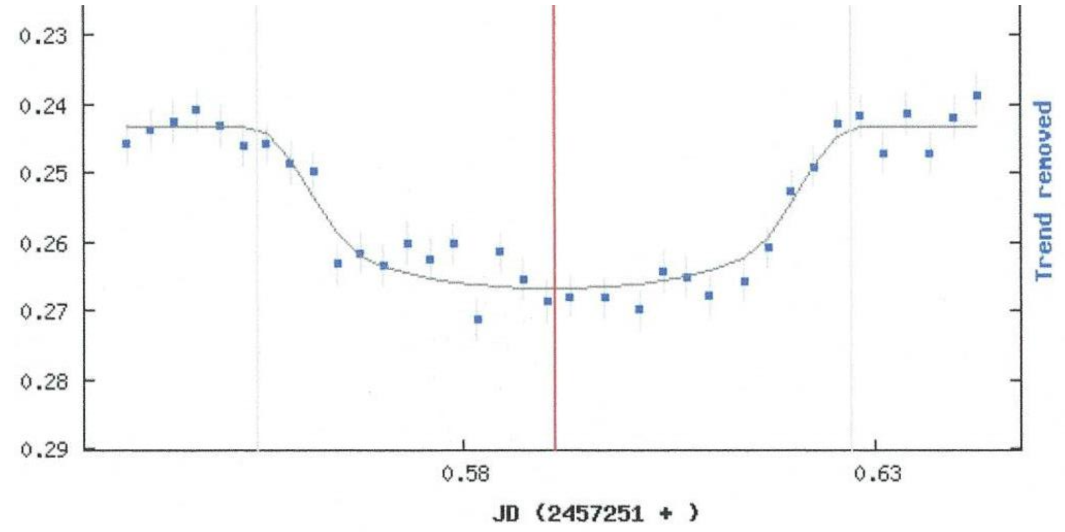
Exposures: 72@2 minutes each

Group size = 2 data points

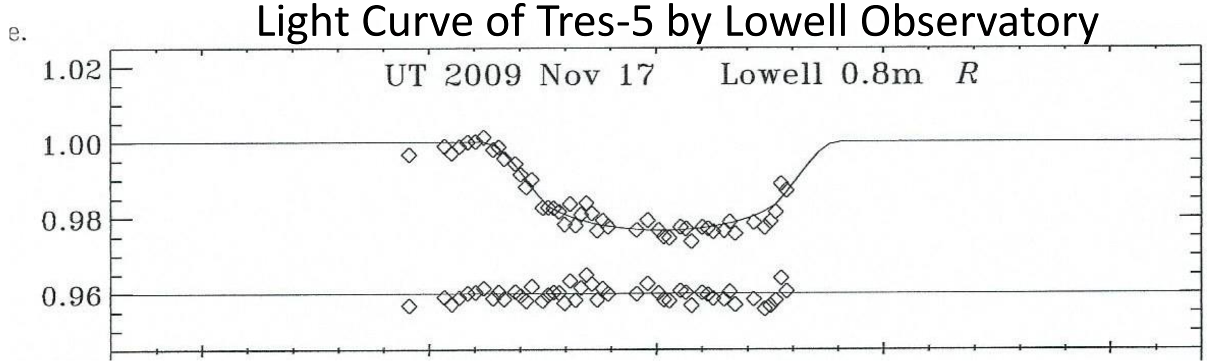
<u>Note</u>: Located in light-polluted portion of the night sky

Tres-5 Light Curve

Light Curve of Tres-5 by Dennis Conti

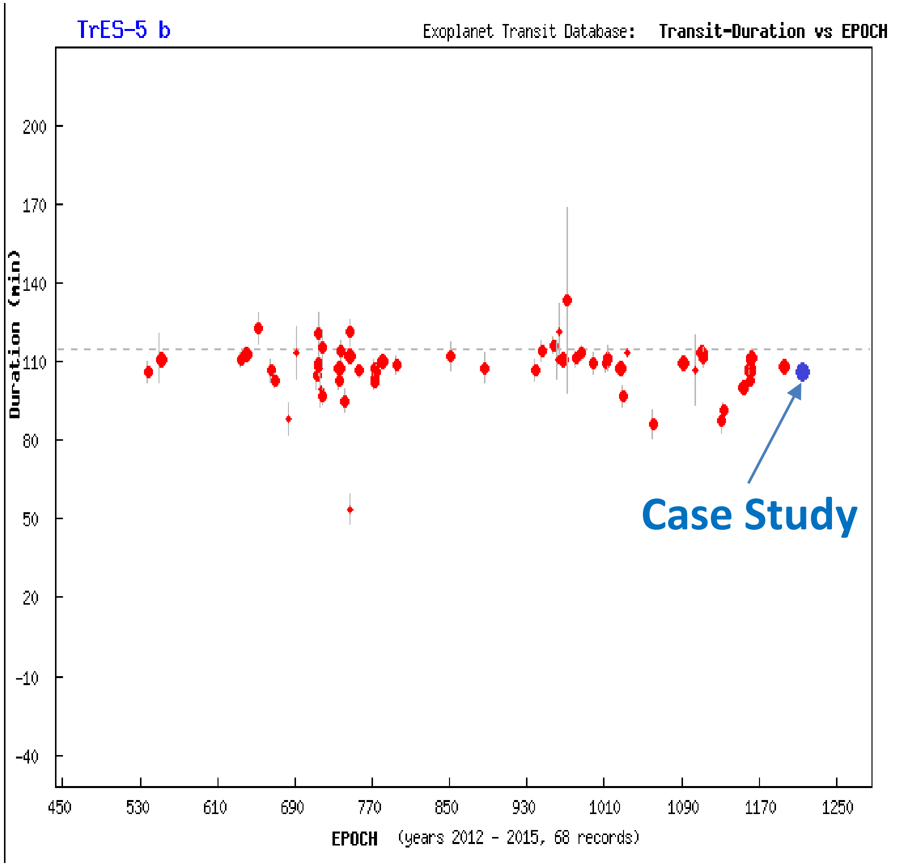


Light Curve of Tres-5 by Lowell Observatory

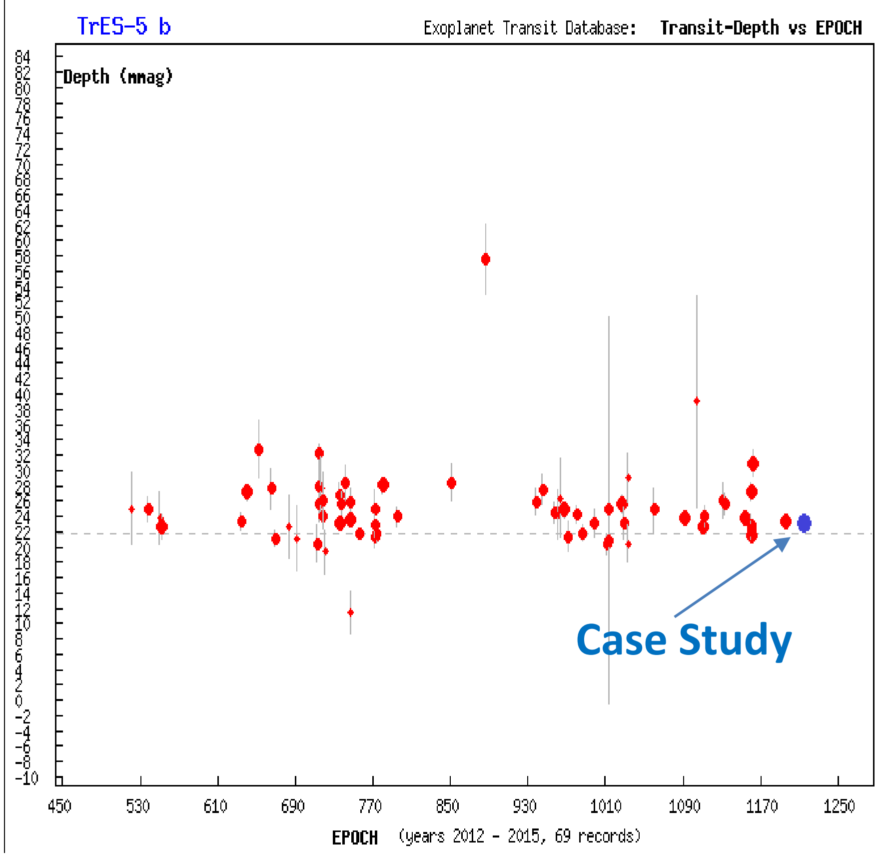


Case Study vs. Other Recorded Observations

Transit Duration

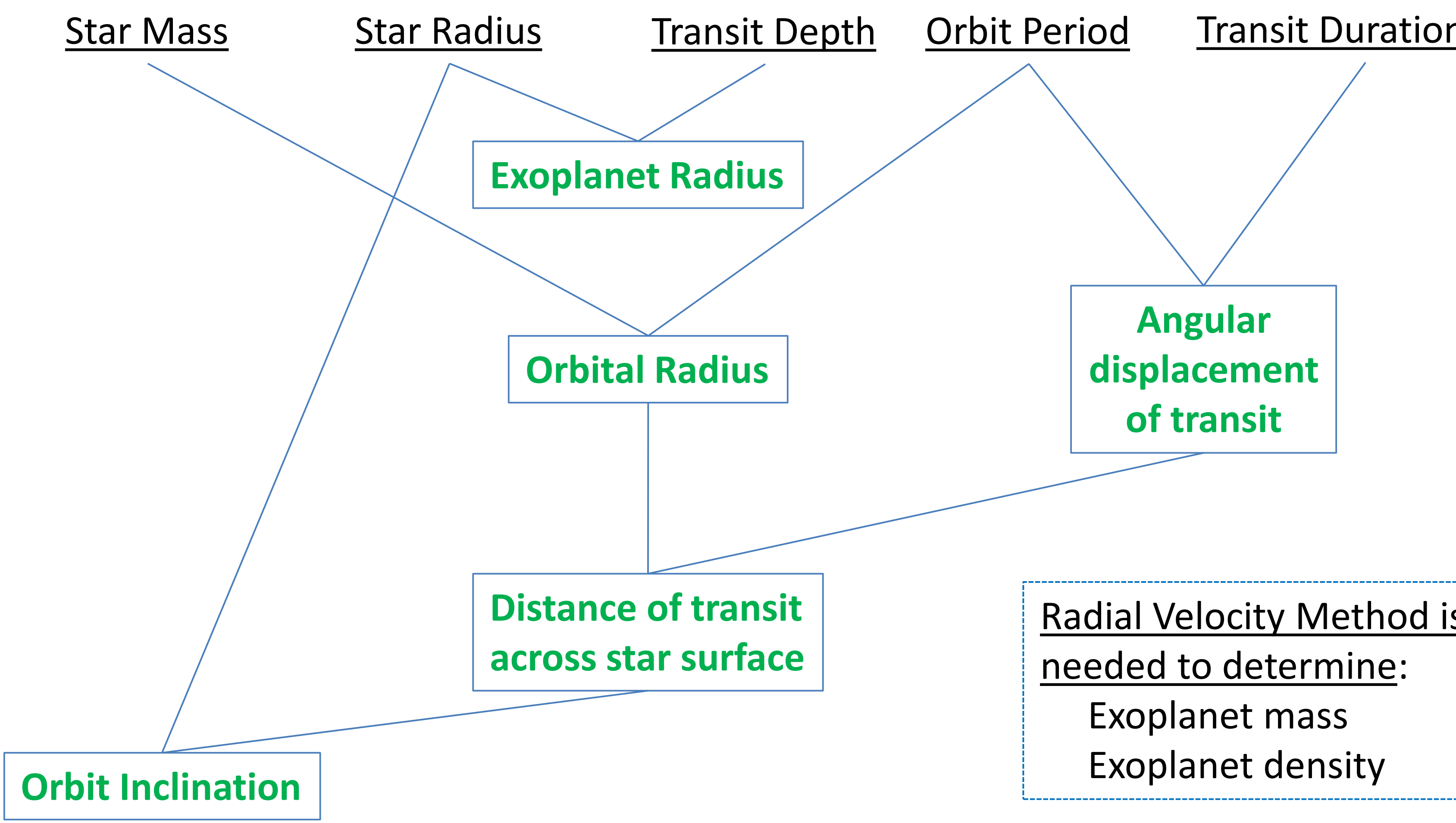


Transit Depth



Derivation of Exoplanet Properties Using the Transit Method

Given:



Radial Velocity Method is needed to determine:

Exoplanet mass

Exoplanet density

Creating the Light Curve

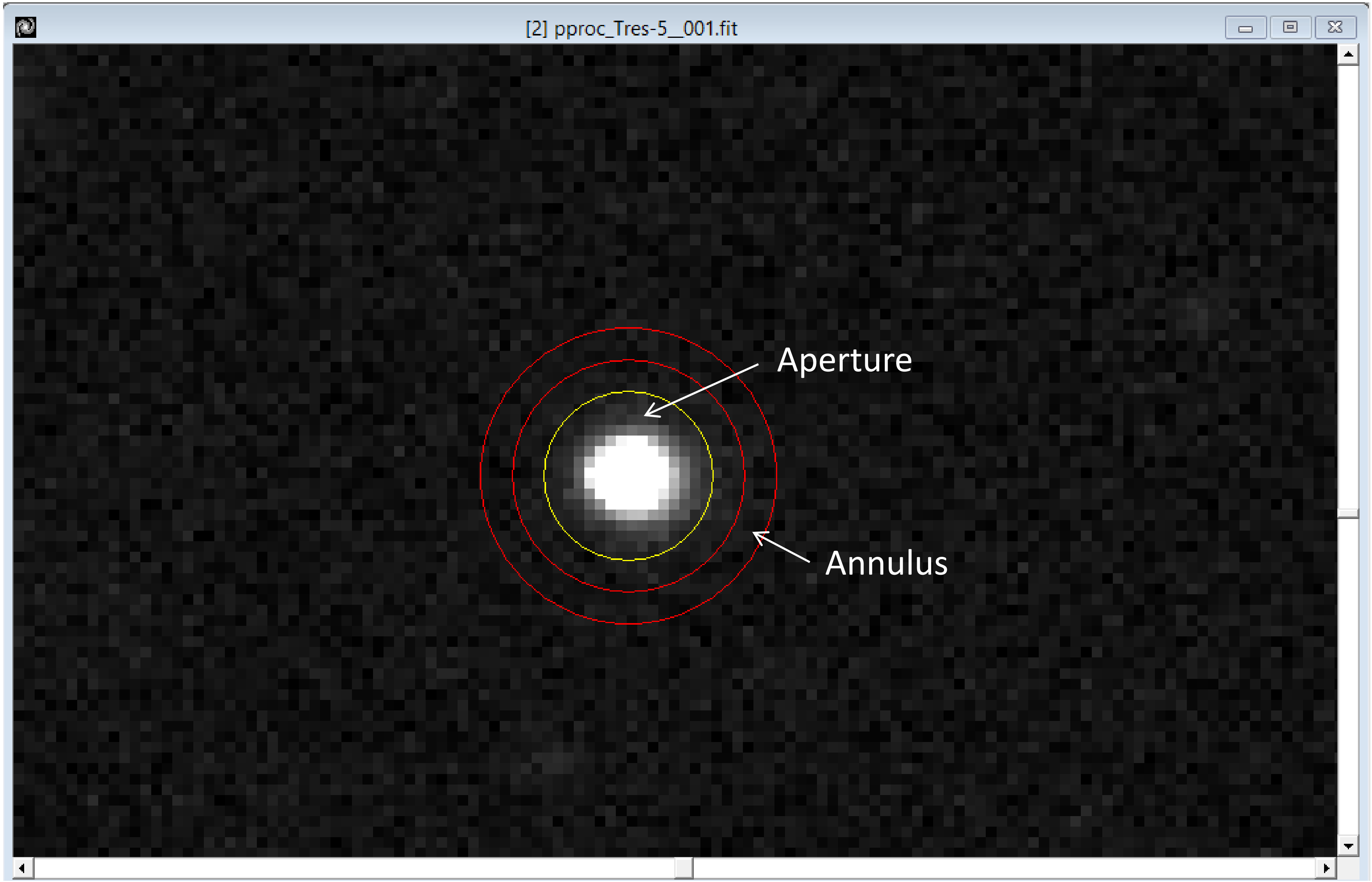
- A data point on the light curve = the magnitude difference between the Host Star and one or more comparison stars

- Star magnitude = star brightness less background sky noise (due to light pollution, sky glow, moon light, etc.)

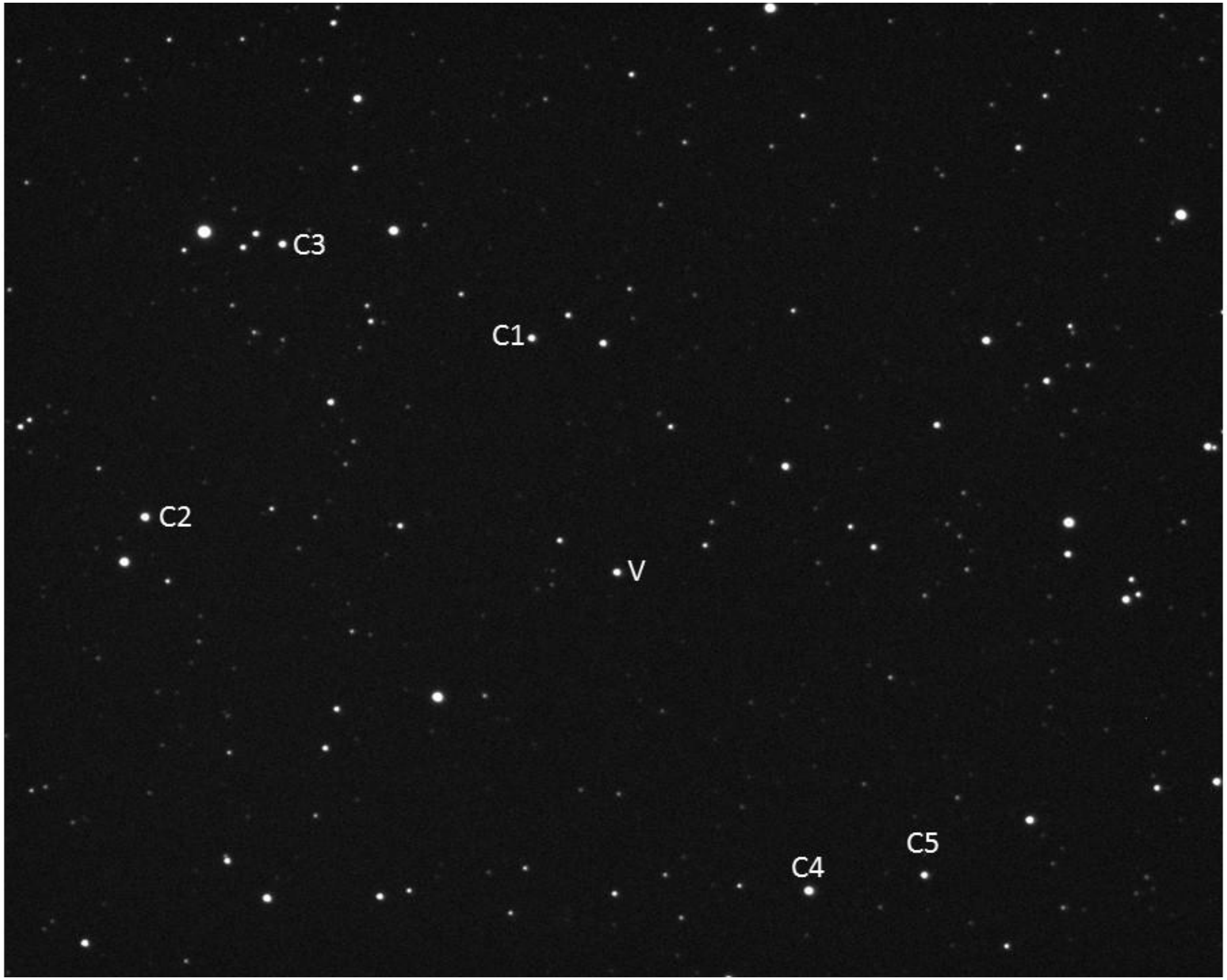
- Differential Photometry is used to calculate magnitudes and differences

- http://var2.astro.cz/ETD/protocol.php is used to perform a curve fit based on assumptions regarding limb darkening, etc.

The Key Tools of Differential Photometry



Selection of Comparison Stars around Tres-5



Accuracy of Case Study Results

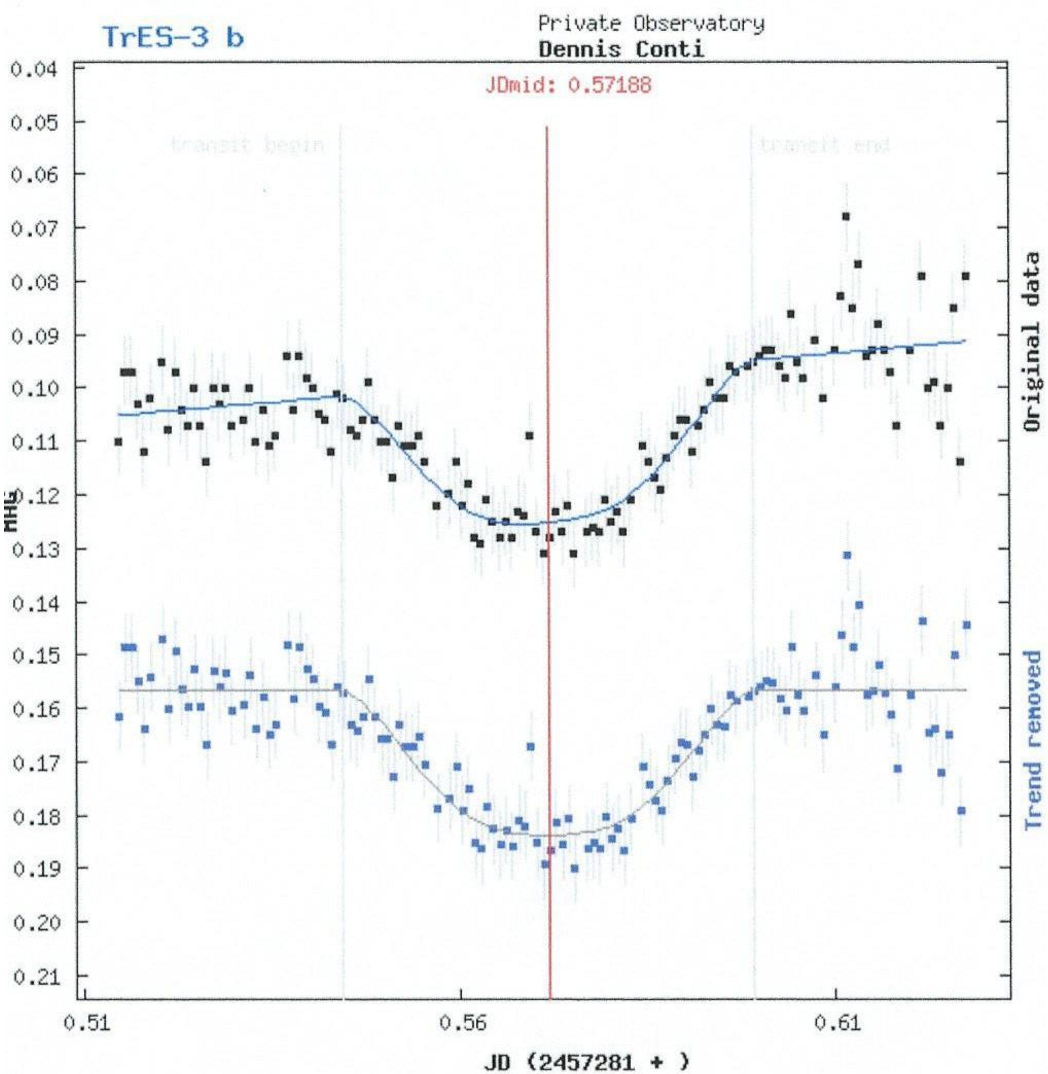
- Light Curve results:
  - Transit depth: .0235 +/- 0.0012 mag.
  - Transit duration: 103.6 +/- 2.6 minutes

- Measured vs. Published Data of Tres-5b:

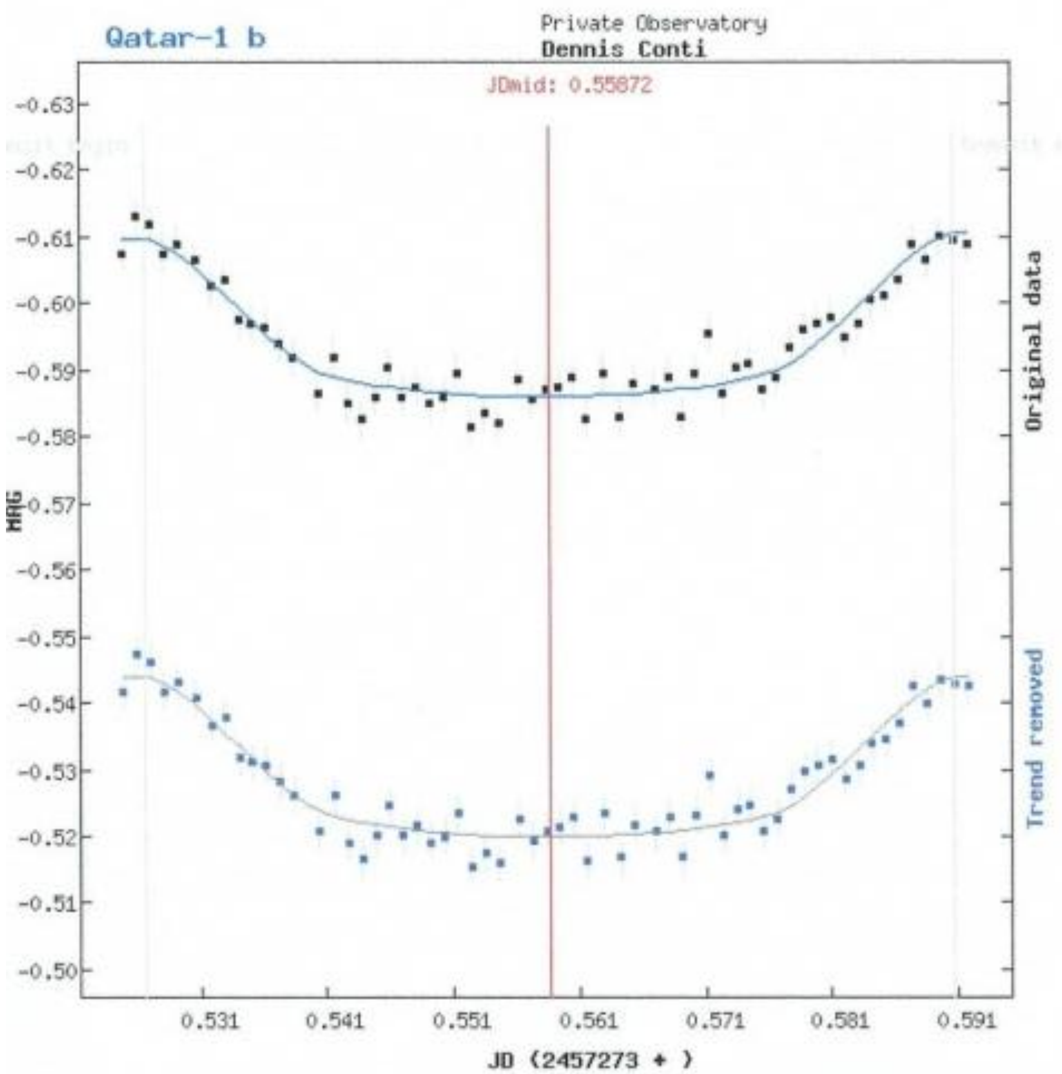
Property	Measured	Published	Accuracy
Orbit Inclination	83.53 +/-0.34 °	84.53°	1.2%
Size (planet radius)	1.237+/-.031 R_{Jup}= 53,737 miles	1.209 R_{Jup}= 52,520 miles	2.3%

Other Exoplanet Light Curves

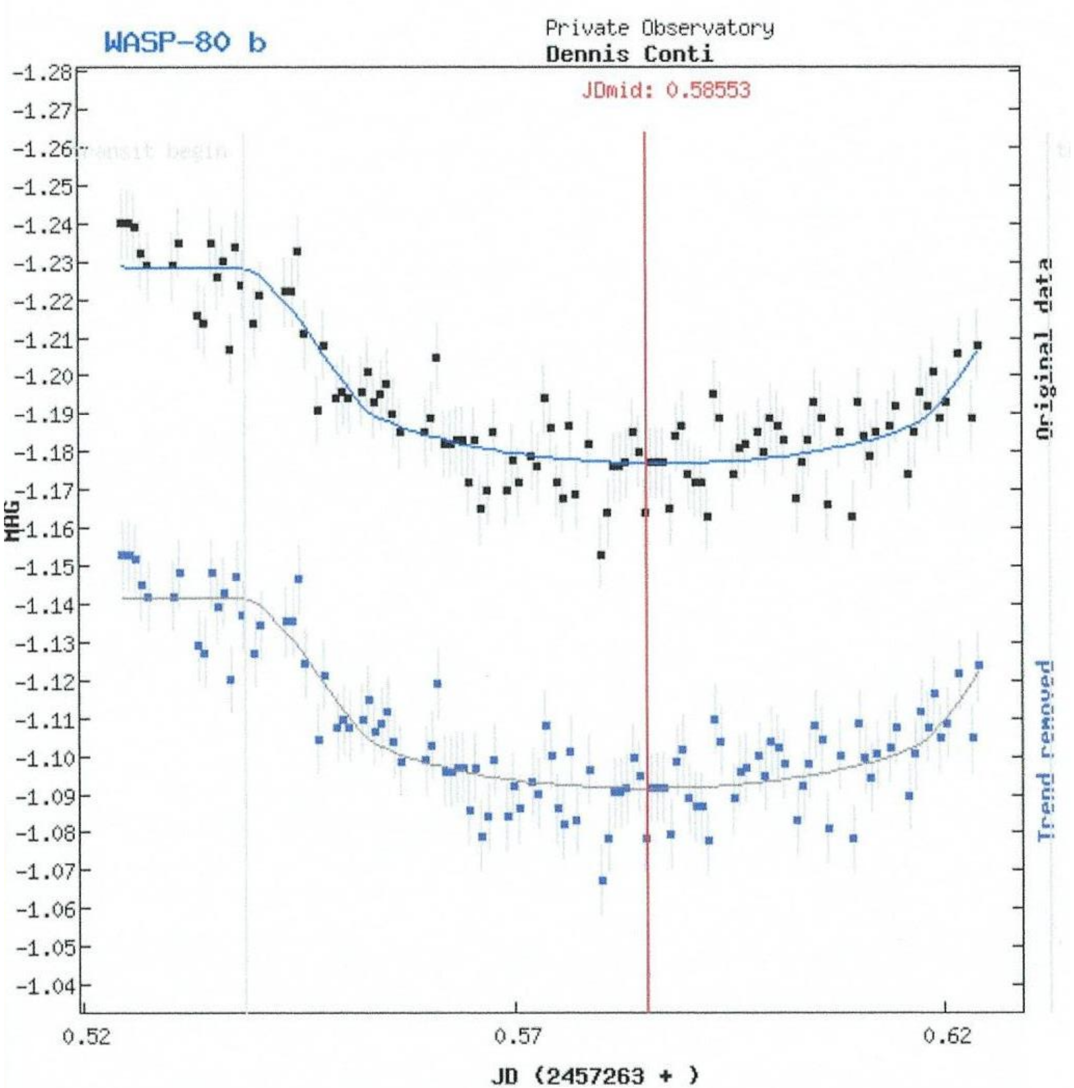
Tres-3b Light Curve



Qatar-1b Light Curve



Wasp-80b Light Curve



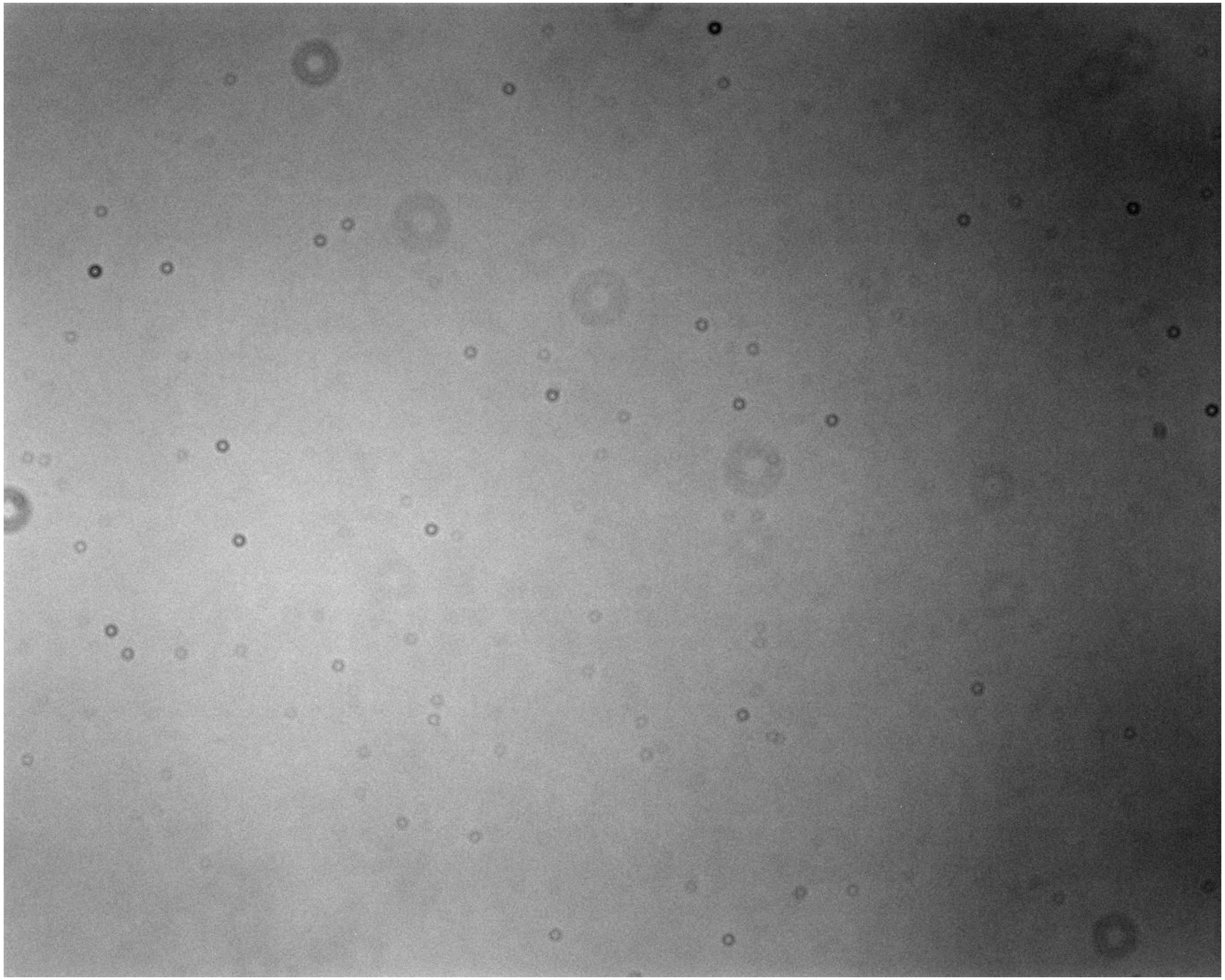
Note:
Images were taken within 25° of a full moon!

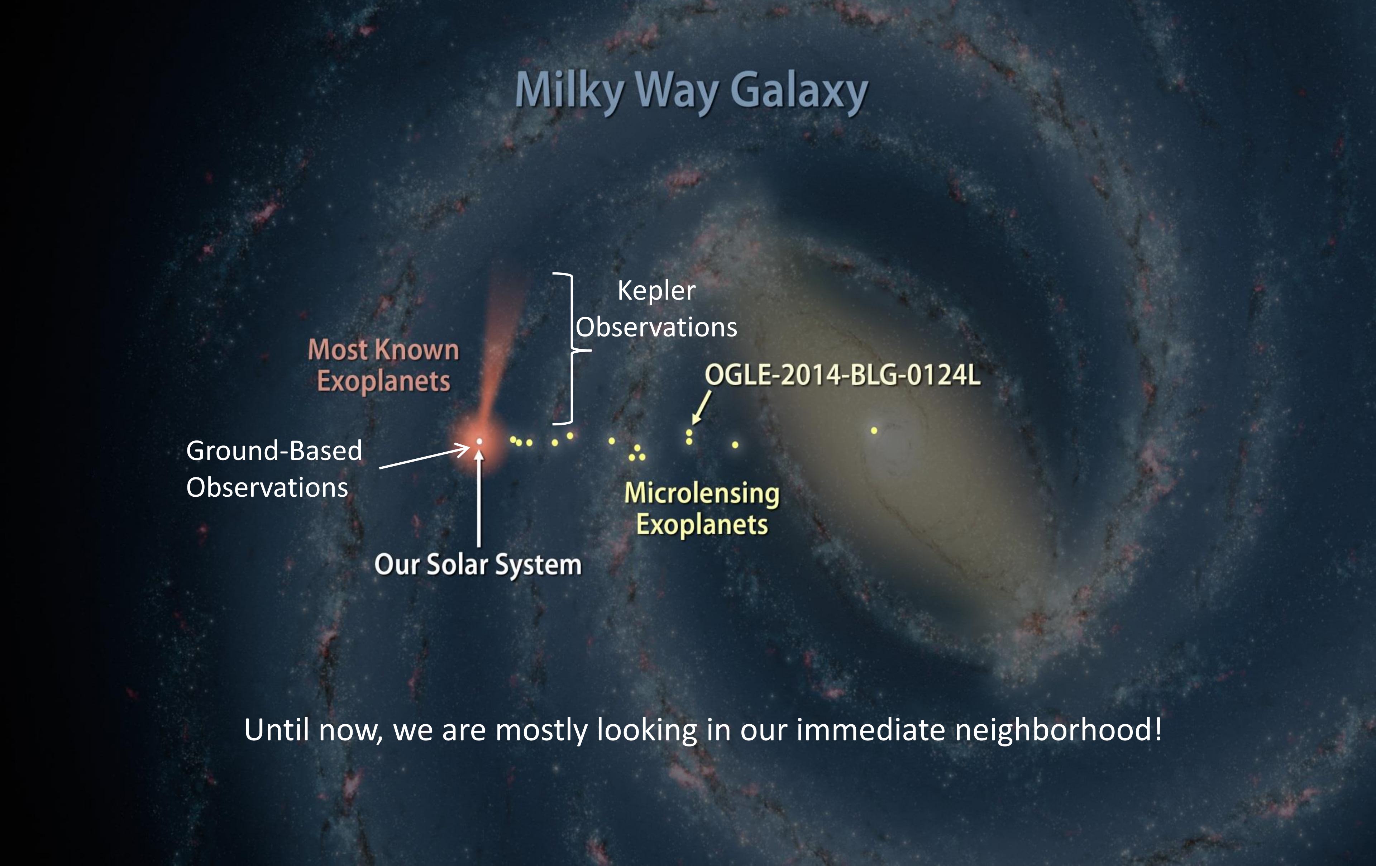
Exoplanet Detection vs. Deep Sky Imaging

- Where Exoplanet Detection is more stringent:
  - Calibration (with darks, flats) a necessity
  - Consideration for atmospheric extinction
  - Accurate polar alignment and guiding
  - Appropriate image scale (i.e., arc-seconds/pixel)
  - Choice of filter
  - Necessity to stay within CCD linearity (to avoid saturation of Host Star)
  - Choice of aperture and annulus radii

- Where Exoplanet Detection is less stringent:
  - Less sensitive to light pollution, moon light, and scintillation
  - In some cases, out-of-focus stars may be desirable

Calibration is Important!
Consider a Sample Flat Frame





Courtesy NASA/JPL-Caltech

Possible Science Contributions of Amateur Exoplanet Detection

- Confirm candidate planets (e.g., there are currently 3,704 unconfirmed Kepler candidates)
- Discover new planetary systems
- Refine transit times and depths of confirmed planets
- Help determine Transit Time Variations that could indicate multi-planetary systems
- Detect occurrences of host star events (e.g., “sun spots”)

Summary

- Detection by amateur astronomers of exoplanets <u>is</u> possible, even in light-polluted areas

- If properly coordinated, amateur astronomers could provide valuable information to professional exoplanet investigators

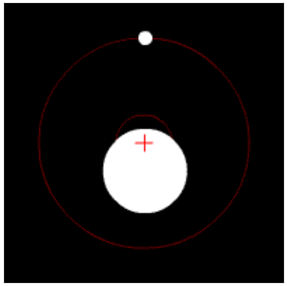
- Exoplanet detection is challenging, but extremely rewarding

The thrill of seeing a light curve develop of a transiting distant planet can be as satisfying as seeing the result of a pretty deep-sky picture!

Addendum

Radial Velocity Method (aka Doppler Spectroscopy)

- Relies on the fact that a very large planet would cause its host star to wobble slightly around their common center of mass
  - Example: The Earth's effect on the Sun is only 0.1 m/s over a 1 year period and Jupiter's is 12.4 m/s over 12 years

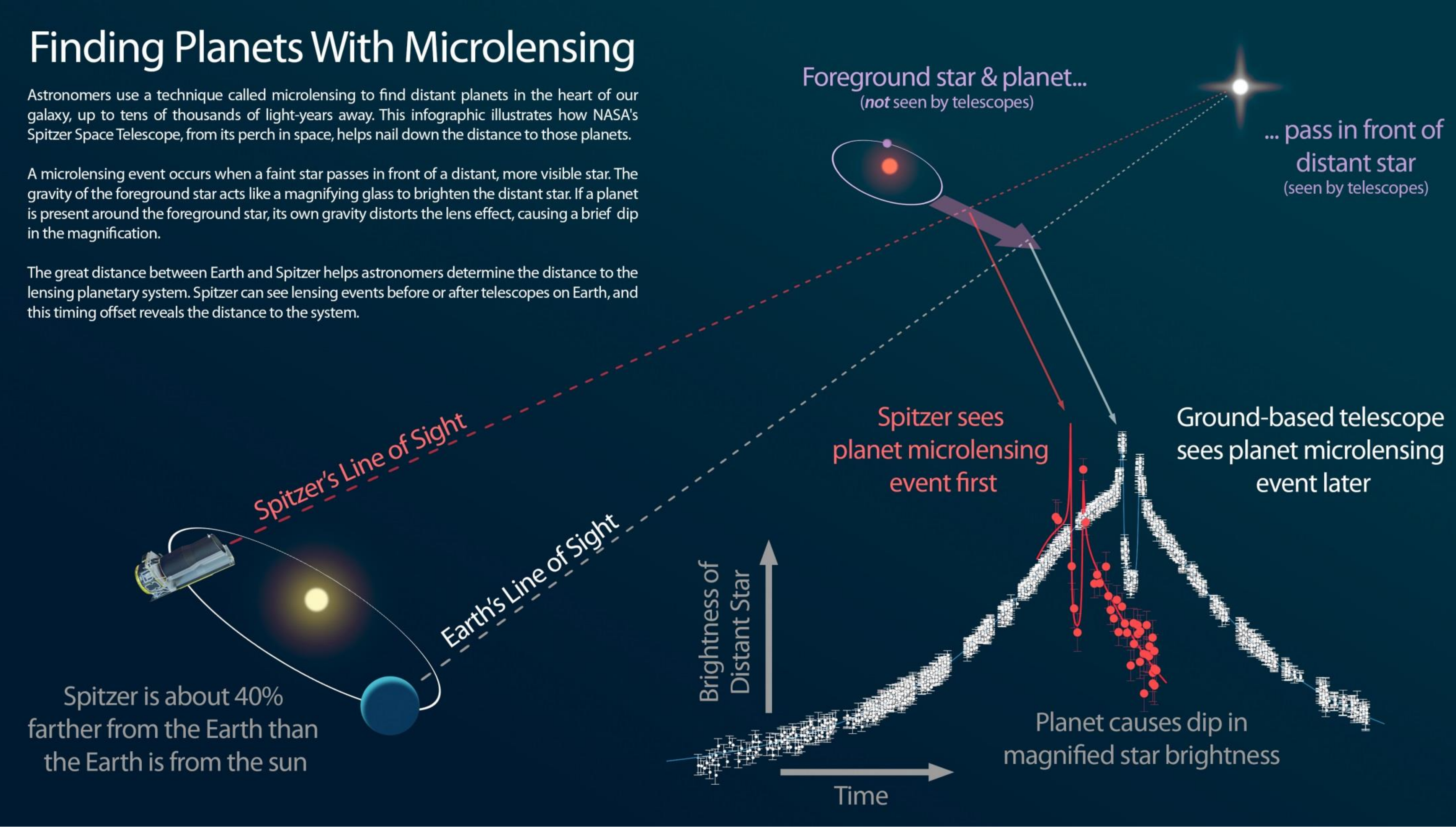


- Uses the Doppler shift of the host star's spectrum to detect this movement and compute the host star's radial velocity

- The minimum mass of the planet can be determined – the planet's orbital inclination is needed to determine more accurately the planet's mass

- Long-term observations with very sensitive spectrographs are required

- Current spectrographs can detect radial velocities down to 0.3 m/s



Courtesy NASA/JPL-Caltech

Fun Facts

- Distance:
  - 1 au = Earth's mean distance from the Sun (9.2956×10^7 miles)
  - Mercury is 0.4 au's from the Sun
  - Jupiter is 5.2 au's from the Sun

- Size:
  - Radius of Sun = 432,450 miles
  - Radius of Jupiter = 43,441 miles
  - R_{sun} = 10 R_{jup}

- Mass:
  - Mass of Sun = 1.989×10^{30} kg
  - Mass of Jupiter = 1.89813×10^{27}
  - M_{sun} = 1048 M_{jup}

Workflow and Software Used

- Start with an accurately polar aligned scope
- Choose Host Star of the planetary system:
  - consider begin time and duration of transit, magnitude of star, expected magnitude of transit depth, time to meridian crossing, etc.
  - use *http://var2.astro.cz/ETD/predictions.php*
- Update computer clock to standard time
- Create flats frames prior to each session (*Nebulosity*)
- Align (*SkyX*) and focus (*FocusMax*) on Host Star for at least 30 minutes before expected Transit Begin
- Choose an exposure time that won't cause saturation of the Host Star during the transit duration
- Begin imaging session and continue for at least 30 minutes after expected Transit End (*Nebulosity*); auto-guide during the imaging session (*PHD2*)

Post Processing

- At end of imaging session, create dark frames (*Nebulosity*)
- Eliminate "bad frames" (*CCD Inspector*)
- Select appropriate aperture and annulus radii, select comparison stars, perform differential photometry (*AIP4WIN*)
- Create light curve and submit to Exoplanet Transit Database using: *http://var2.astro.cz/ETD/prrotocol.php*

Resources

1. Exoplanet Observing for Amateurs, Second Edition (Plus), Bruce L. Gary

2. The Handbook of Astronomical Image Processing, Richard Berry and James Burnell (comes with AIP4WIN photometry software)

3. Presentation to the Texas Astronomical Society by George Hall http://georgeastro.weebly.com/exoplanet-briefing.html

4. The AAVSO Guide to CCD Photometry, Version 1.1, 2014

5. The AAVSO CCD Observing Manual, 2011