Amateur Astronomer Participation in the TESS Exoplanet Mission

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TESS:
Transiting Exoplanet Survey Satellite

The next generation of exoplanet discovery space telescopes
TESS Predecessors

Kepler

- FOV: Small area in Cygnus
- Targets: Earth-size planets around Sun-like stars
- Status: Completed

K2

- FOV: Ecliptic plane
- Targets: Various
- Status: Near end-of-life

Courtesy: NASA
All Use the Transiting Method
The TESS Mission

• Targets: near-by, bright stars

• Key science objective:
  "Measure the masses of 50 small (less than 4 Earth radii) transiting planets"
  – mass coupled with radius measurements from photometry, can give us average density
  – density will help us identify rocky planets

• TESS has been called a “finder scope” for JWST (James Webb Space Telescope)

• Amateur participation will be an important part of the TESS pipeline
Other Mission Facts

• Image downloads will occur 2 months after checkout

• TESS will cover 85% of the sky – an area 350 times that of Kepler

• TESS will observe into the near-infrared
TESS’ Unique Orbit

Note: Orbit is stable for a century!

Courtesy: Michael Richmond
TESS Orientation

Courtesy: Winn, 2018
Each region gets 27 days of coverage

Courtesy: Winn, 2018
Simulated TESS Planet Detections

Sullivan et al. (2015)

- detectable planets around pre-selected target stars
- detectable planets around other stars in full-frame images
TESS Operation

• Data downloads occur when TESS is near Earth in its orbit, in order to reduce download times

• Two 13.7 day orbits per sector
  – so each sector is viewed for at least 27 days

• Ecliptic poles are viewed for 300 days due to overlapping sectors

• Northern ecliptic imaging to begin mid-2019 (a portion of Southern ecliptic in mid-2018)

• Targets:
  – Overall stars: 470 million
  – Pre-selected stars: approx. 200,000
Each camera has a 4” aperture and f/1.4 lens
->image scale of 21”/pixel
Every 2 Seconds

Every 2 min. = a stack of 60 2-second images

“Postage Stamp” images around pre-selected stars (nominal 10 x 10 pixels)

Full Frame Image (2048 x 2048 pixels)

Every 30 min. = a stack of 900 2-second images
Typical TESS Photometric Aperture: nominal 1 arc-minute radius
TESS Pixel:
21 arc-seconds
The Challenge

• Due to size of TESS pixels and photometric apertures, the light from multiple stars may be blended together

• Thus, periodic dips in light can be caused by either a true exoplanet transit or various types of false positives

• Initial vetting is first done by computer, then by voting of science team members

• Remaining vetting is done by ground-based, follow-up observations
Ground-based Observation Objectives

• Determine the source and cause of two or more periodic dips; could be due to:
  – False alarms (e.g., systematics or noise)
  – False positives
  – True exoplanet transits

• Obtain more accurate planet radii measurements

• Obtain transit time variation (TTV) measurements
TTV Example: WASP-39b

ExoPlanet WASP-39b - Virgo - 05-16-2017UT
MAH Observatory 16"CCT 06.7 STL11K 33sec - No Filter

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Courtesy: Rick Bria
Observed – Computed: WASP-39b

WASP-39 b

Exoplanet Transit Database: O-C vs EPOCH

M = 55342.9688 + 0.055259 * E

EPOCH (years 2010 - 2016, 18 records)

Courtesy: ETD

Rick Bria

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Photometric Factors Used in Detecting False Positives

- Shape ("morphology") of light curve

- Alternating ("odd-even") V-shapes at different depths or not evenly spaced

- Depth variations (> 5 mmag) in different passbands

- Depths indicating a non-planetary transiting body (> 2.5 Jupiter radii)

\[ \left( \frac{R_p}{R_*} \right)^2 = \delta \]
False Positive Scenarios and Detection Factors

The target star has a near-by eclipsing binary (NEB)*

The NEB and target can’t be spatially distinguished*

Hierarchical triple: the target star and NEB are orbiting each other

* Note: could be chance alignments

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Target star is an eclipsing binary (EB) with blending from a neighbor.

Secondary star in an EB is small enough to mimic a planet transit.

Secondary star in an EB "grazes" the primary star.

A V-shaped curve (if spatially resolvable from neighbor).

Depth and radius of target may imply a non-planetary transit.

Typically a V-shaped curve.
Example: Detection of a NEB
Observation 1
Observation 2
(11 eclipses later)
Phase Folded Observations

TESS Object
Both Observations in V-band, separated by 11 periods

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Overall TESS Pipeline

TESS Objects of Interest (TOIs)

False positive screening, blend & stellar characterization

Seeing-Limited Phot. (SG1)
ID nearby EBs, measure photometric blending

Recon Spectroscopy (SG2)
Stellar parameters, ID blended spectra

High-Res Imaging (SG3)
Resolve close companions, characterize multiplicity

Planetary confirmation and characterization

Precise RV Work (SG4)
Derive planetary orbits and masses

Space-Based Photometry (SG5)
Improved light curve, ephemeris, meas. TTVs

Courtesy: Collins, 2018
Amateur Astronomer Participation

• Help distinguish false positives: TESS Follow-up Observing Program (TFOP) Seeing Limited Subgroup

• Help refine the ephemerides after planets are confirmed: observation uploads to ExoFOP-TESS

• Products required from observer:
  – Sample FOV and a plate solved image
  – Comparison stars used
  – Light curve
  – Measurement and plot configuration files used
Online Tools

• TESS Transit Finder – helps observers find suitable targets for a given location during a given time period

• TESS Observations Coordinator – notifies other observers of intent to observe a particular target at a certain time and in a certain wavelength

• ExoFOP-TESS – submission of observation summaries and data products
Training Resources

• AAVSO Exoplanet Observing Course – an online, four week course:
  – exoplanet observing best practices
  – use of AstroImageJ for image calibration, differential photometry, and exoplanet transit modeling

• Documentation: “A Practical Guide to Exoplanet Observing” (http://astrodennis.com)
Best Practices

• Image for at least 30 minutes pre-ingress and post-egress

• Use autoguiding to achieve minimal image shift over a 4-6 hour observation window
  – Preferably, guide on the science image

• Use a precise timing source

• Use BJD_{TDB} as timebase

• Handle meridian flips efficiently

• Maximize SNR of target without reaching non-linearity or saturation
Future NASA Exoplanet Missions
Exoplanet Missions

- 2020
- Observations in infrared
- Begin characterization of exoplanet atmospheres

Courtesy: NASA
- Mid-2020s
- Direct imaging of exoplanet atmospheres
Starshade Technology

Courtesy: NASA

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Summary

• Amateur astronomers have already proven their value in supporting existing exoplanet surveys and missions

• The TESS mission provides amateurs with the opportunity to participate in the next frontier of exoplanet discovery

• Opportunities for co-authorship of scientific papers provide an additional benefit

• Amateurs with astro-imaging experience already have the basic complement of equipment and techniques

• Training opportunities, software and documentation are available to enhance one’s exoplanet observing skills
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