The TESS Exoplanet Mission and Amateur Astronomer Participation

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TESS: Transiting Exoplanet Survey Satellite

The next generation of exoplanet discovery space telescopes
The Big Picture

Is there life on a planet outside our Solar system?

Is the planet rocky?

Can the planet support liquid water?

Does it have an atmosphere?

Does its atmosphere show signs of life?
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!
TESS Orientation

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

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A Typical Ground-Based Image
Pixel Sizes

Ground-based

TESS

8.4"

8.5"

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Typical TESS Photometric Aperture
Typical TESS Photometric Aperture
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"SCT 16.7 STL11K 33sec - No Filter

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

Exoplanet Transit Database: O-C vs EPOCH

\[ M = 55342.9688 + 4.055259 \times E \]

EPOCH (years 2010 - 2016, 18 records)

Courtesy: ETD

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Photometric Factors Used in Detecting False Positives

- Shape ("morphology") of light curve
  - Bucket-shaped
    - vs.
    - V-shaped

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

- Depth variations (> 5 mmag) in different passbands
  - Blue vs. Red
  \[ (\frac{R_p}{R_*})^2 \]

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

V-shape curve of a near-by star has odd-even depth changes

Depth varies in different bandpasses
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

- rel_flux_T1_Schwarz&Patashnick (Median_Flip detrended) (RMS=0.00277) (normalized)
- rel_flux_T2_Corti (Median_Flip detrended) (RMS=0.00399) (normalized) (bin size = 2)
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

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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
• 2020
• Observations in infrared
• Begin characterization of exoplanet atmospheres
• Mid-2020s
• Direct imaging of exoplanet atmospheres

Courtesy: NASA
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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