Amateur Astronomer Participation in the TESS Exoplanet Mission

Dennis M. Conti
Chair, AAVSO Exoplanet Section
Member, TESS Follow-up Observing Program

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?

Can we directly image the planet?

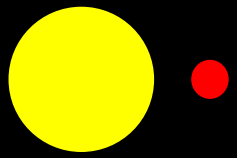
The Night Sky

Most stars host one or more planets

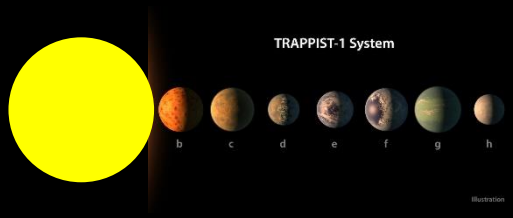
Their orbital orientations vary
from our line of sight

The Strange World of Exoplanets

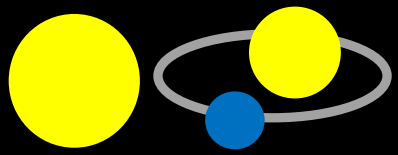
- Most exoplanets we have discovered are close-in, large planets: “Hot Jupiters”



- Some stars have multiple planets

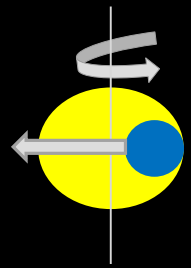


- Some planets orbit a star in a multiple star system

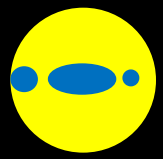


- Some “planets” are free-floating

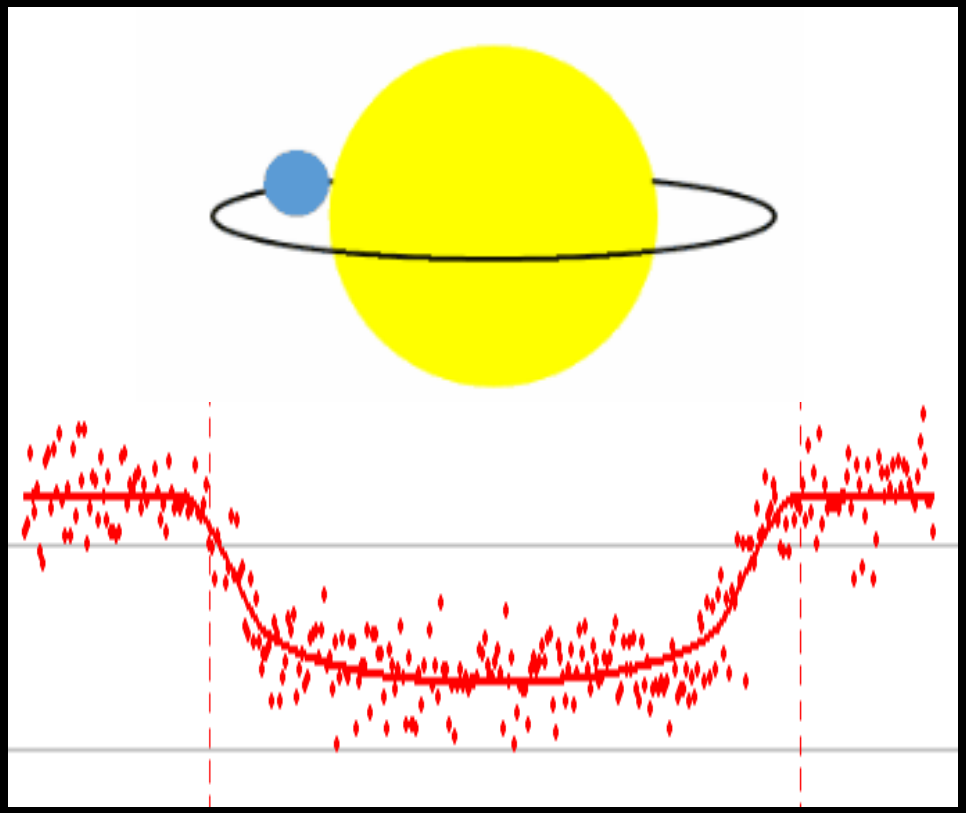
- Some planets’ orbits are opposite from their star’s rotation



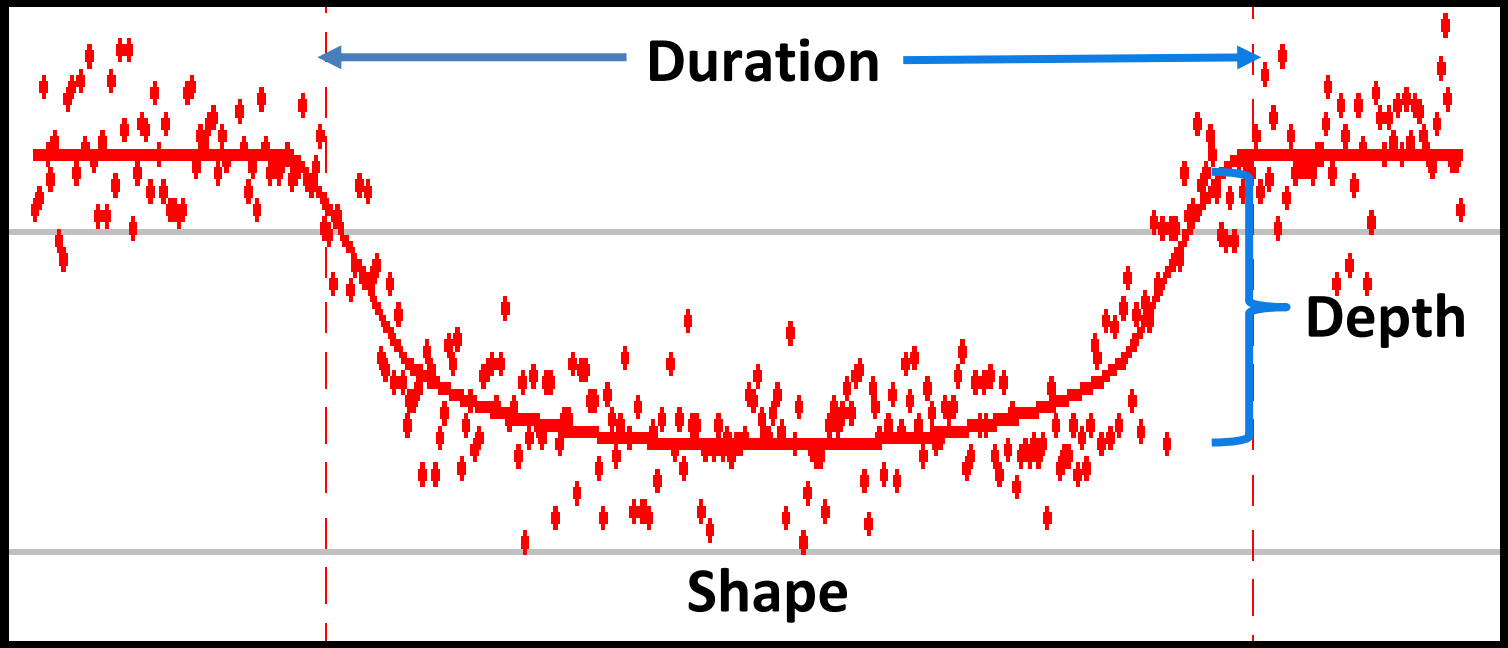
- Some planetesimals are disintegrating around their host star

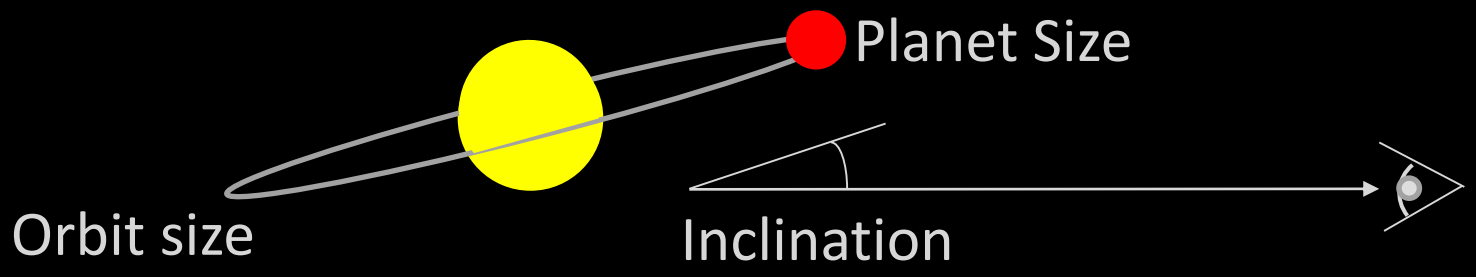


The Transit Method: The Dominant Method Used by Amateur Astronomers

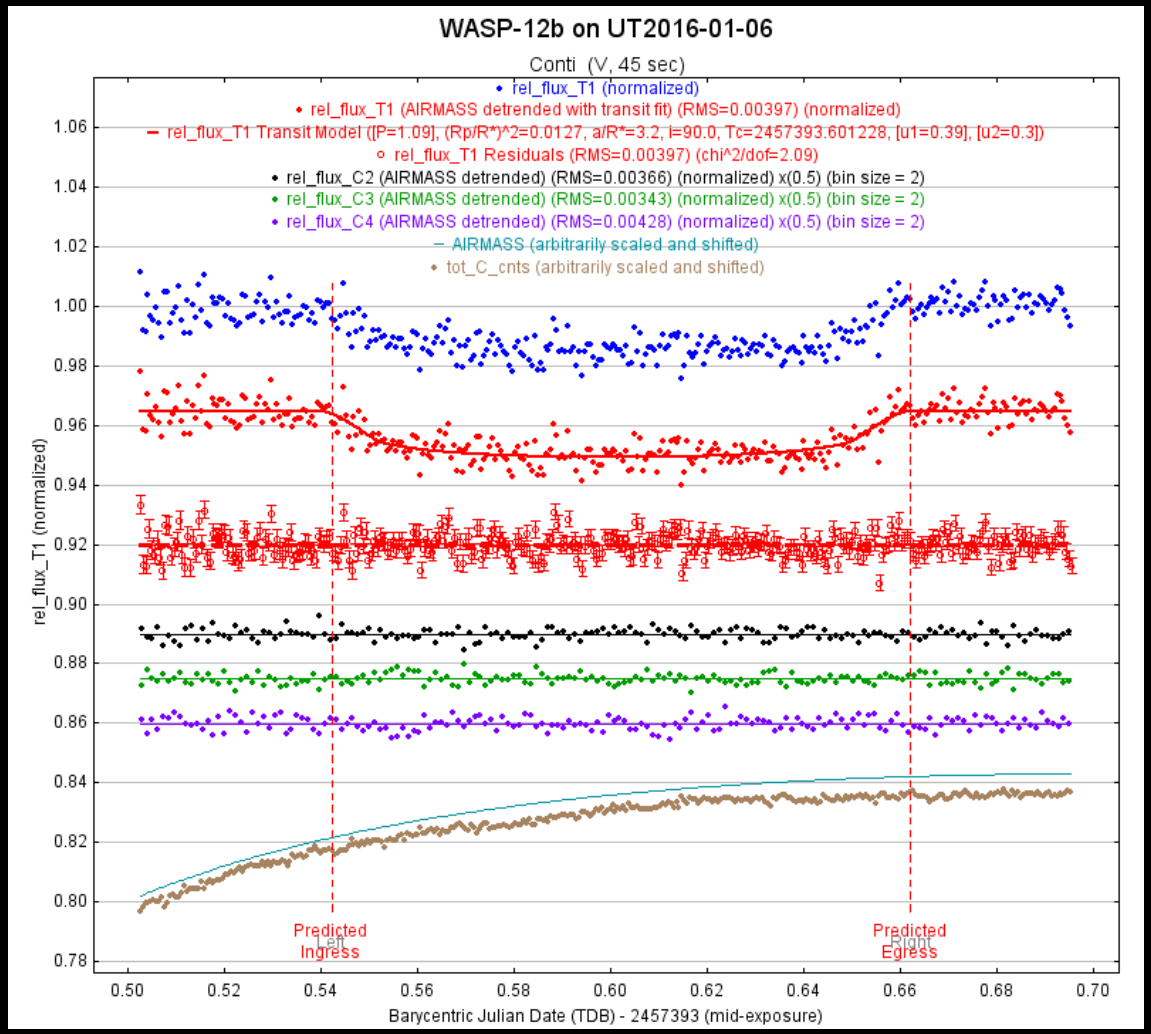


We can learn a lot from the light curve!





AstroImageJ: All-in-One Exoplanet Software (freeware)

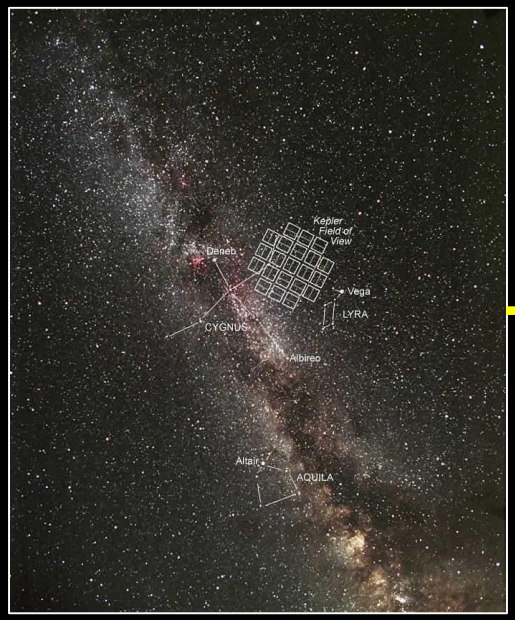


TESS:
Transiting Exoplanet Survey Satellite

The next generation of exoplanet discovery space telescopes

TESS Predecessors

Kepler

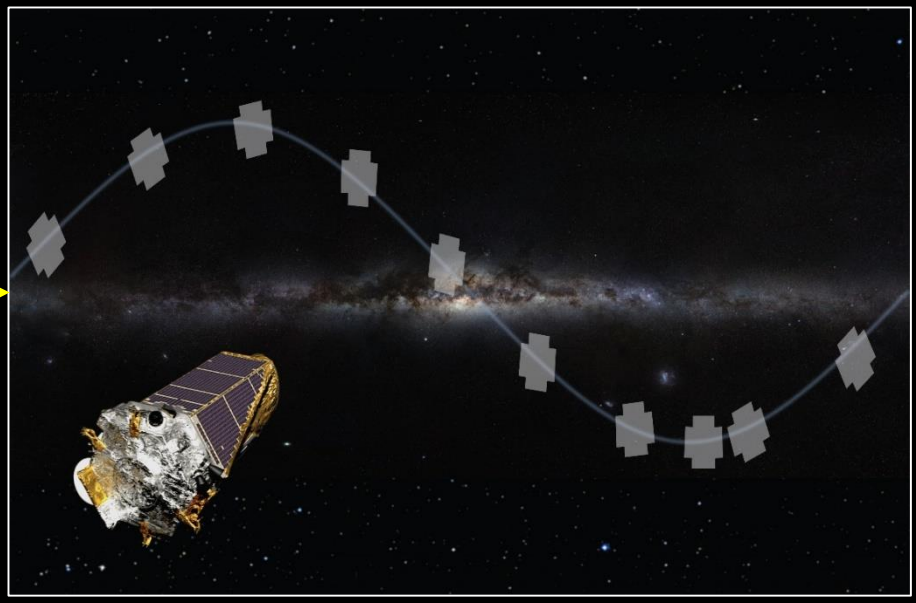


Courtesy : NASA

Targets: In small area in Cygnus, Earth-size planets around Sun-like stars

Status: Completed

K2



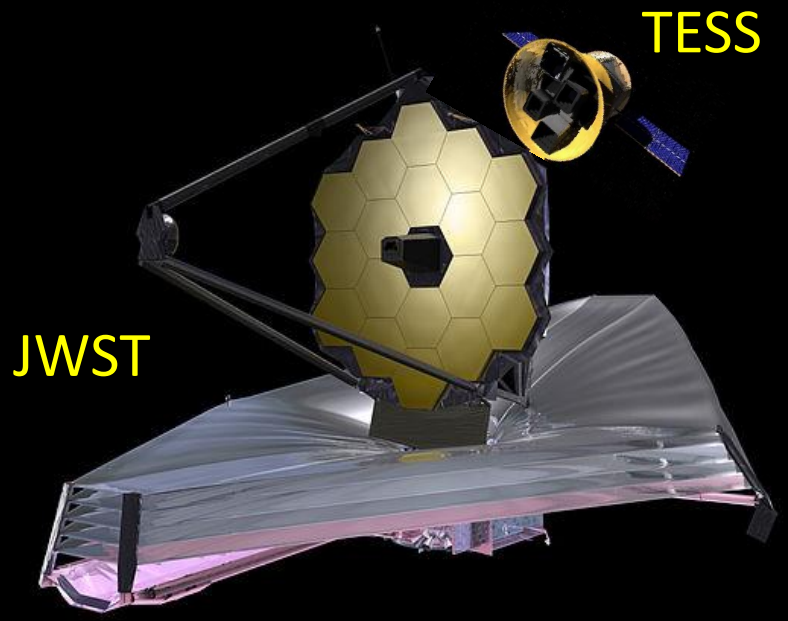
Courtesy : NASA

Targets: In ecliptic plane, of various types

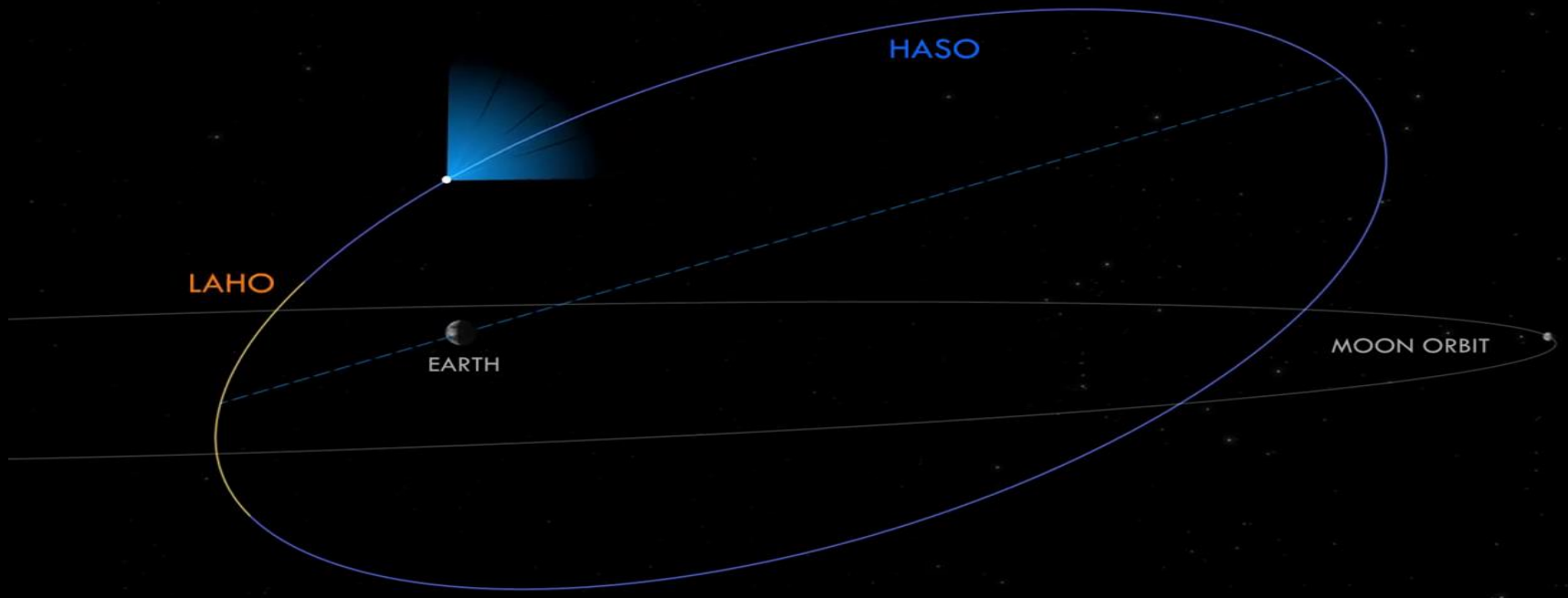
Status: Near end-of-life

TESS Mission

- All-sky survey of bright, near-by (30-300 lyrs) stars
- Science objective: measure masses of 50 planets whose size is less than 4 Earth radii
- Think of TESS as a “finder scope” for the James Webb Space Telescope (JWST)



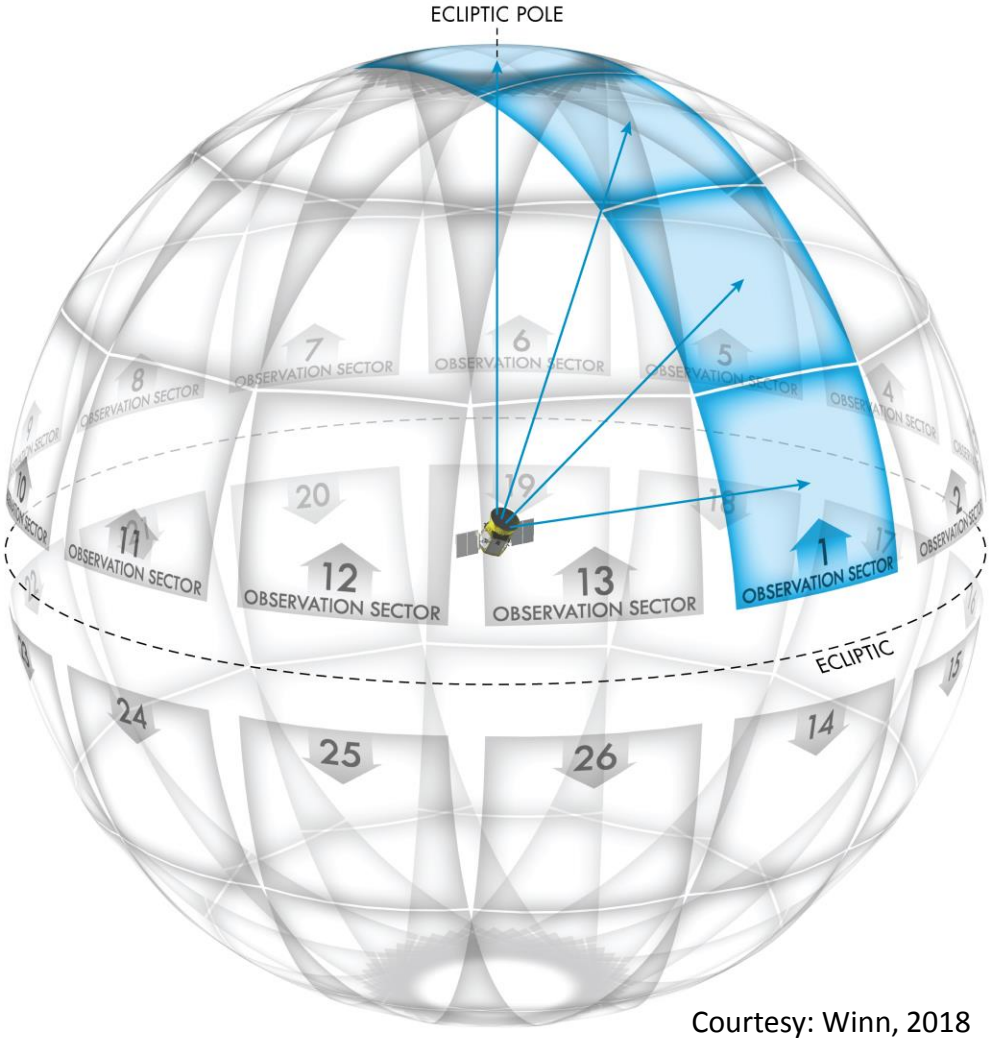
TESS' Unique Orbit



Courtesy: Michael Richmond

Orbit is stable for a century!

TESS All-Sky Survey



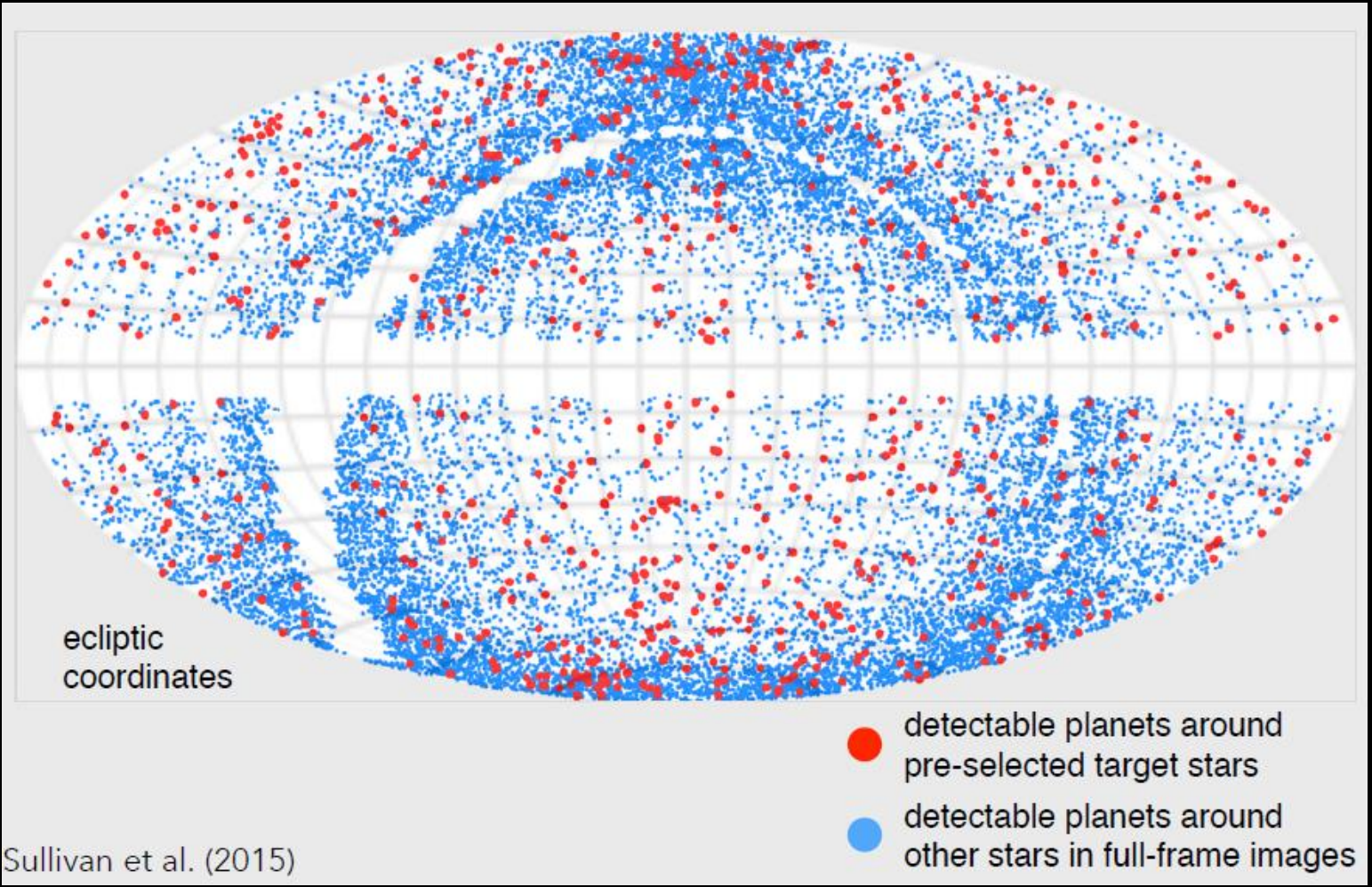
Courtesy: Winn, 2018

Each region gets 27 days of coverage

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
- Imaging of Southern Ecliptic Hemisphere HAS BEGUN - Northern ecliptic imaging to begin mid-2019
- Targets:
  - Overall stars: 470 million
  - Pre-selected stars: approx. 200,000

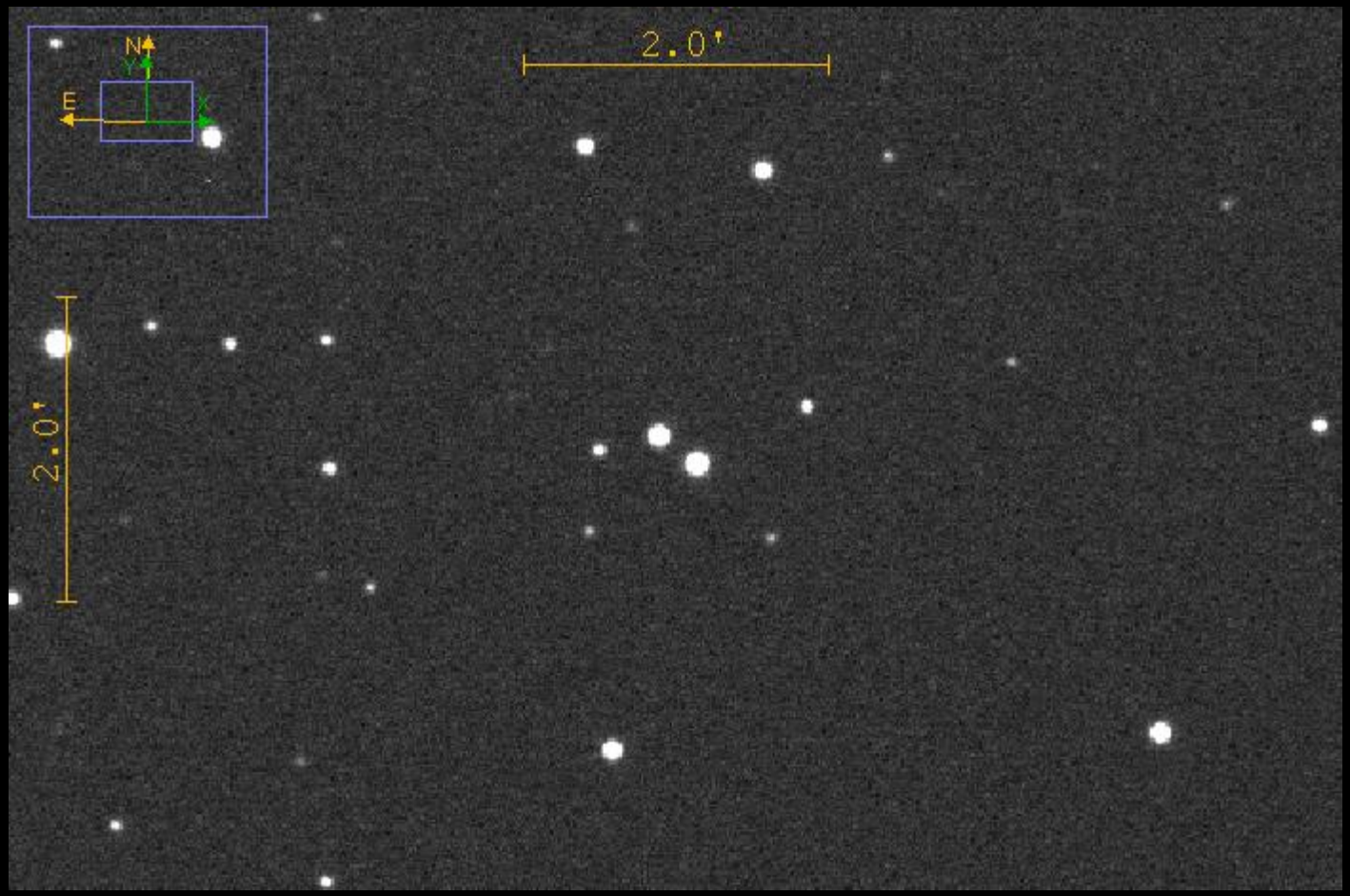
Simulated TESS Planet Detections



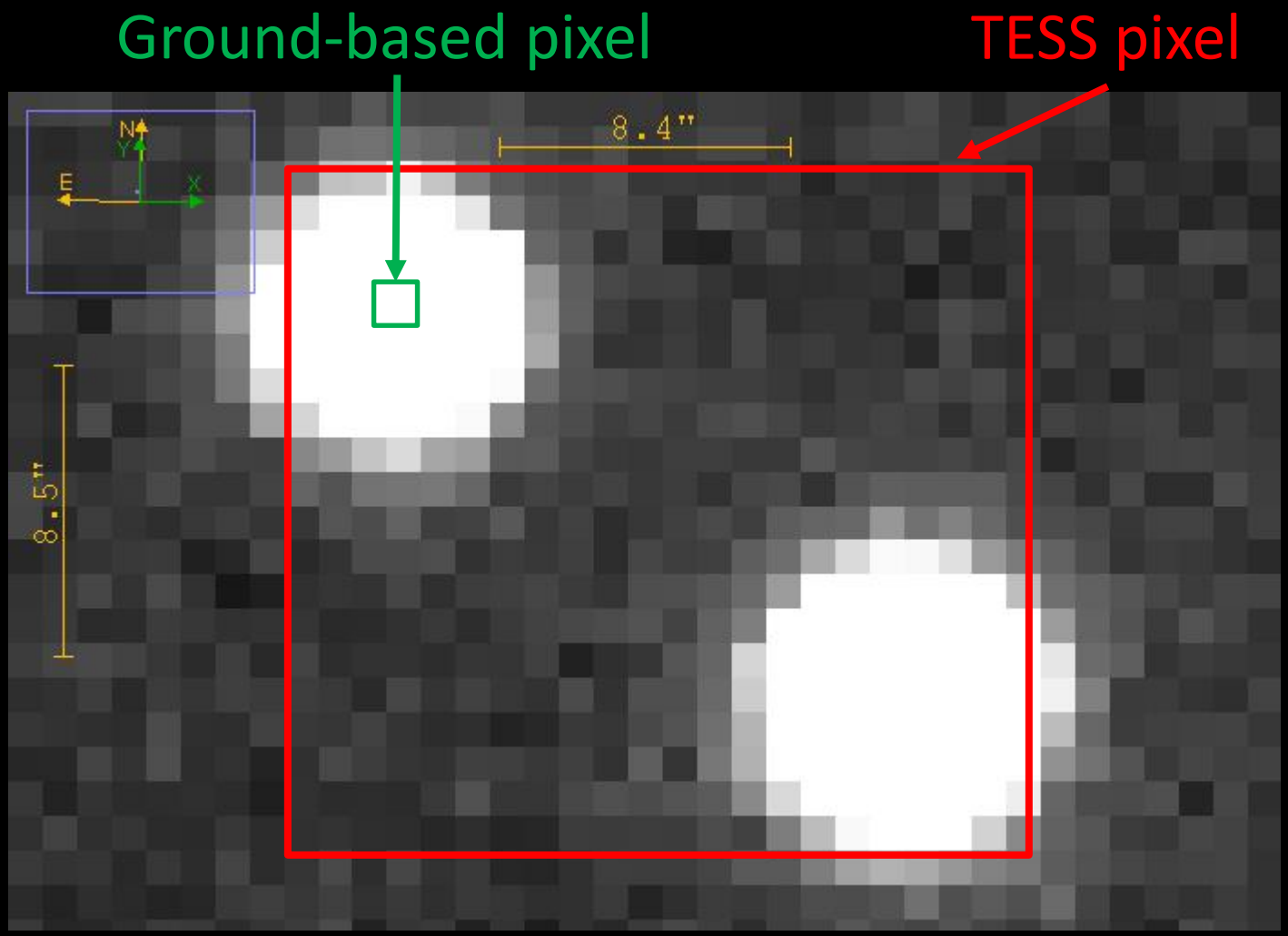
The Challenge with TESS

- The light from multiple stars may be blended together in a TESS image
- Thus dips in light can be caused by either a true exoplanet transit or various types of false positives
- Ground-based, follow-up observations are needed to make this distinction

A Typical Ground-Based Image

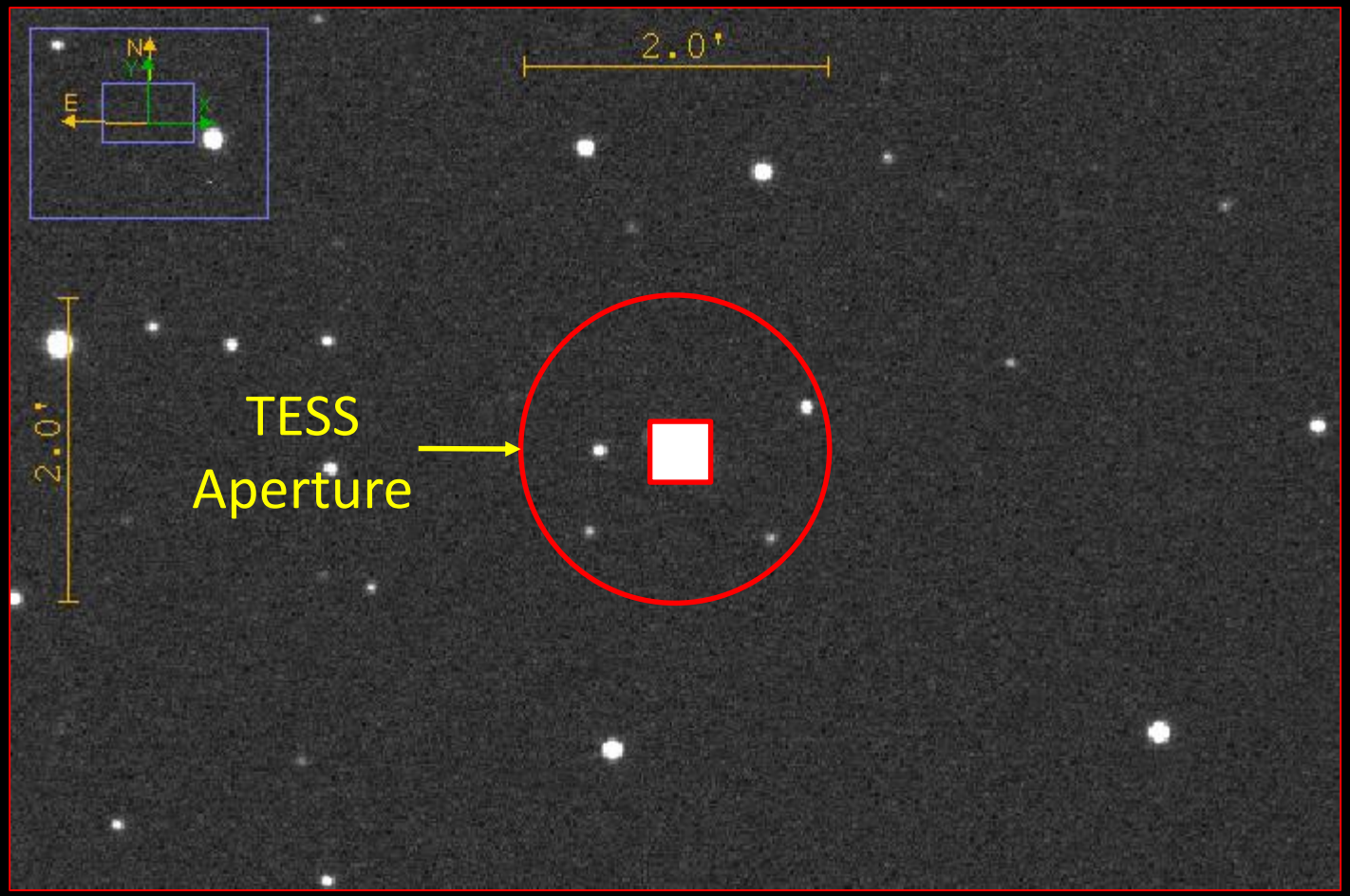


Pixel Sizes

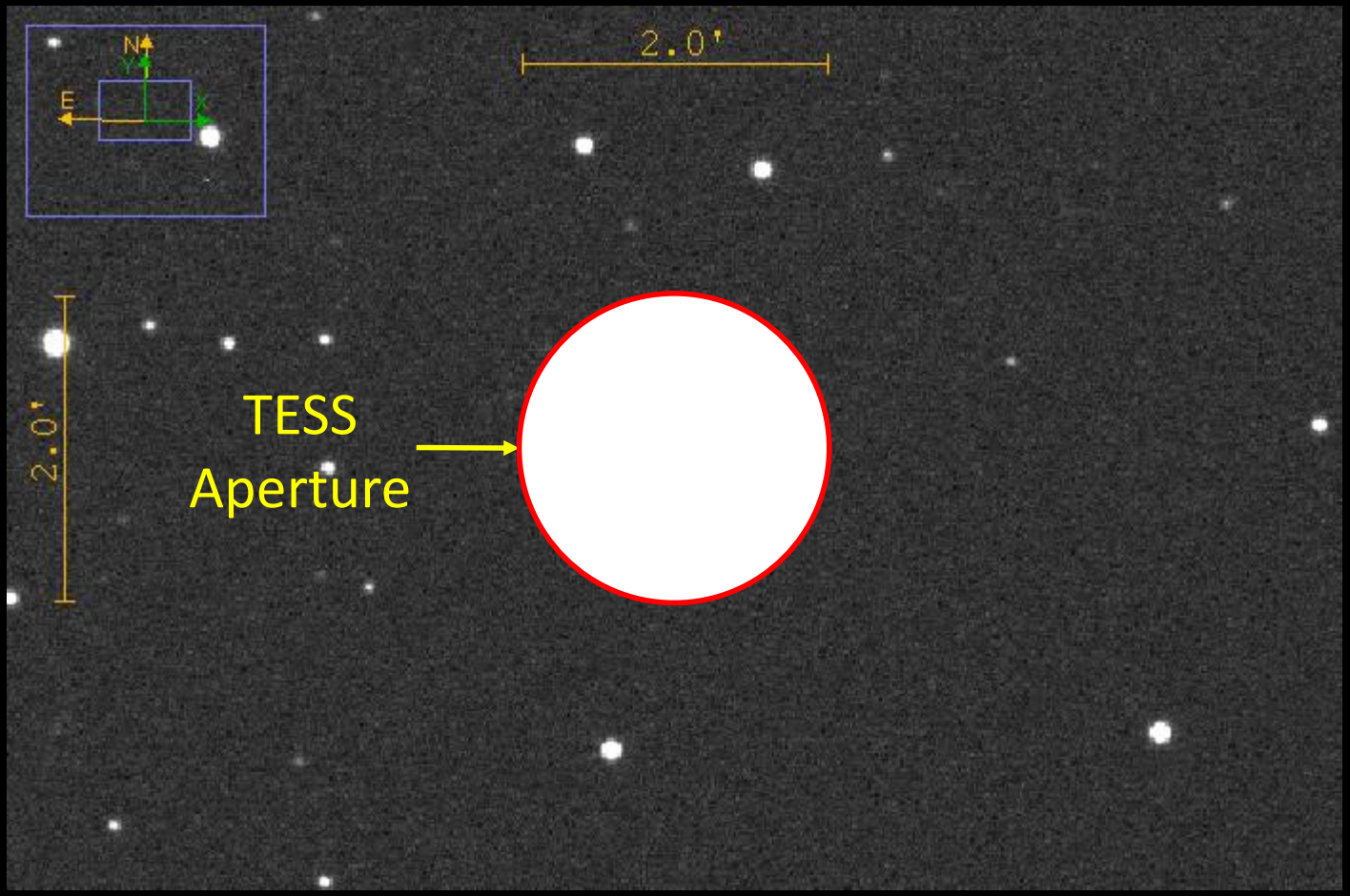


Pixel Sizes

Typical TESS Photometric Aperture

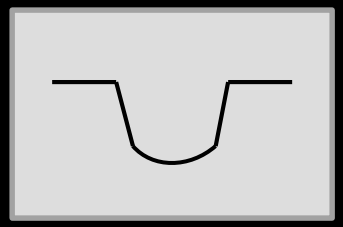


Typical TESS Photometric Aperture

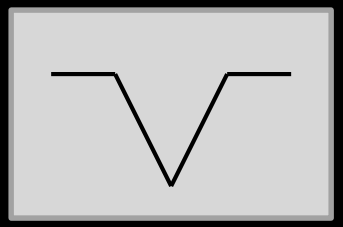


So How Do We Detect False Positives?

- Shape of the light curve

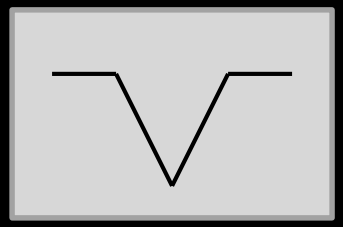


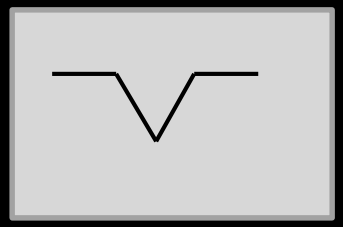
vs.



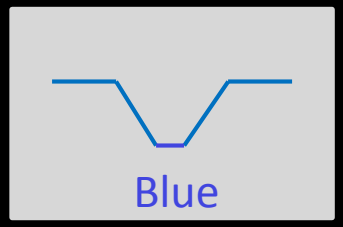
Bucket-shaped V-shaped

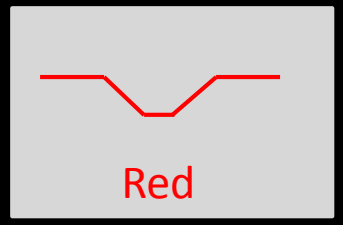
- Alternating ("odd-even") V-shapes at different depths or not evenly spaced



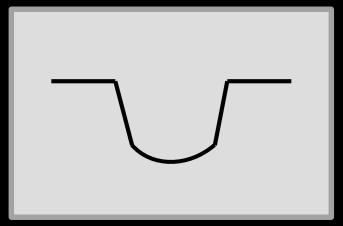


- Depth variations in using different filters





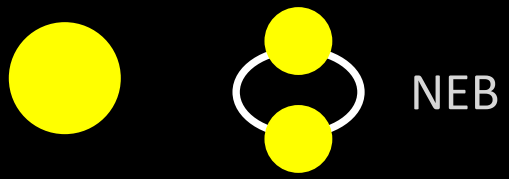
- Depths indicating a non-planetary transiting body (> 2.5 Jupiter radii)



$= (R_p/R_*)^2$

False Positive Scenarios and Detection Factors

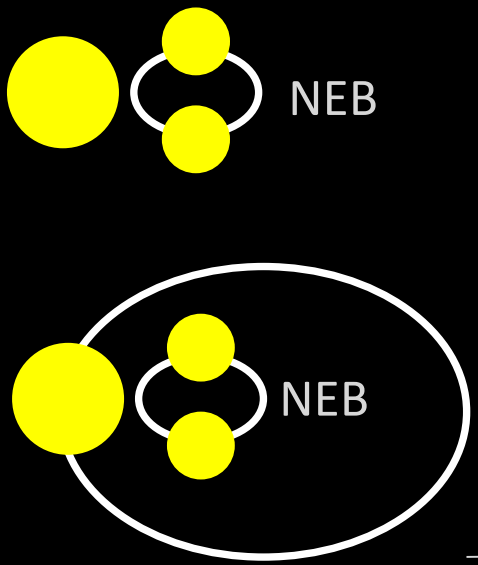
The target star has a near-by eclipsing binary (NEB)*



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

The NEB and target can't be spatially distinguished*

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

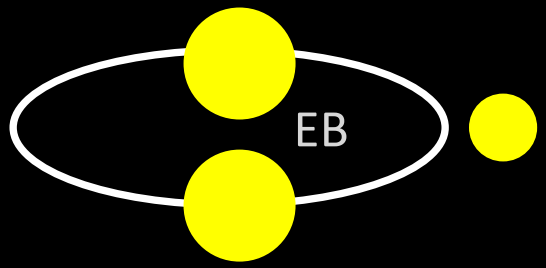


Depth varies in different bandpasses

* Note: could be chance alignments

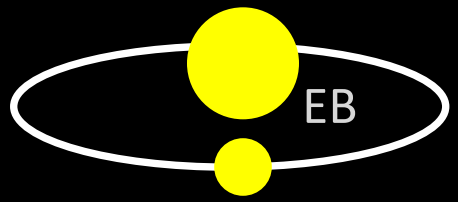
False Positive Scenarios and Detection Factors (cont'd)

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



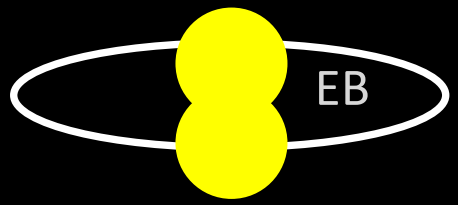
A V-shaped curve (if spatially resolvable from neighbor)

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



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

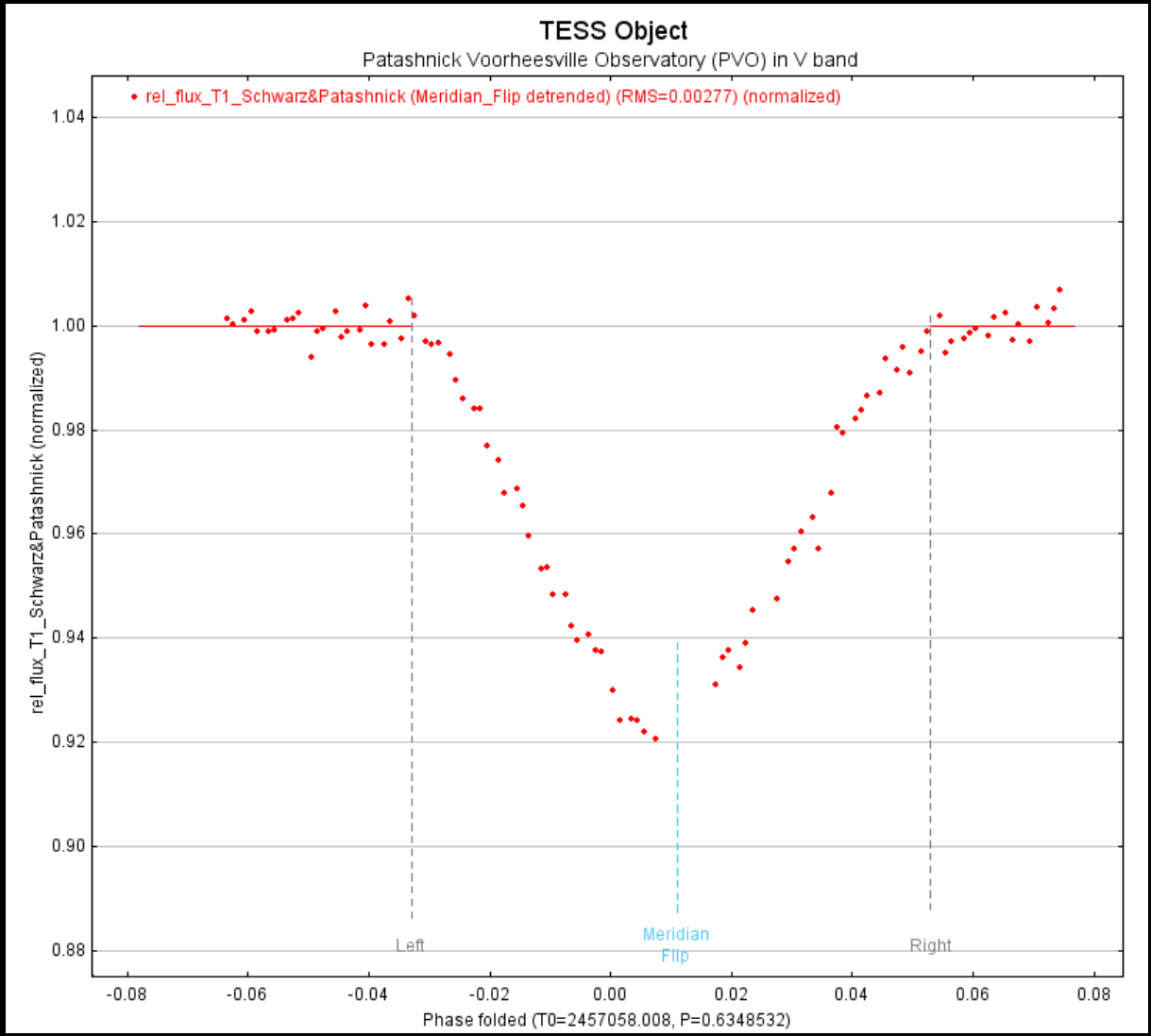
Secondary star in an EB "grazes" the primary star



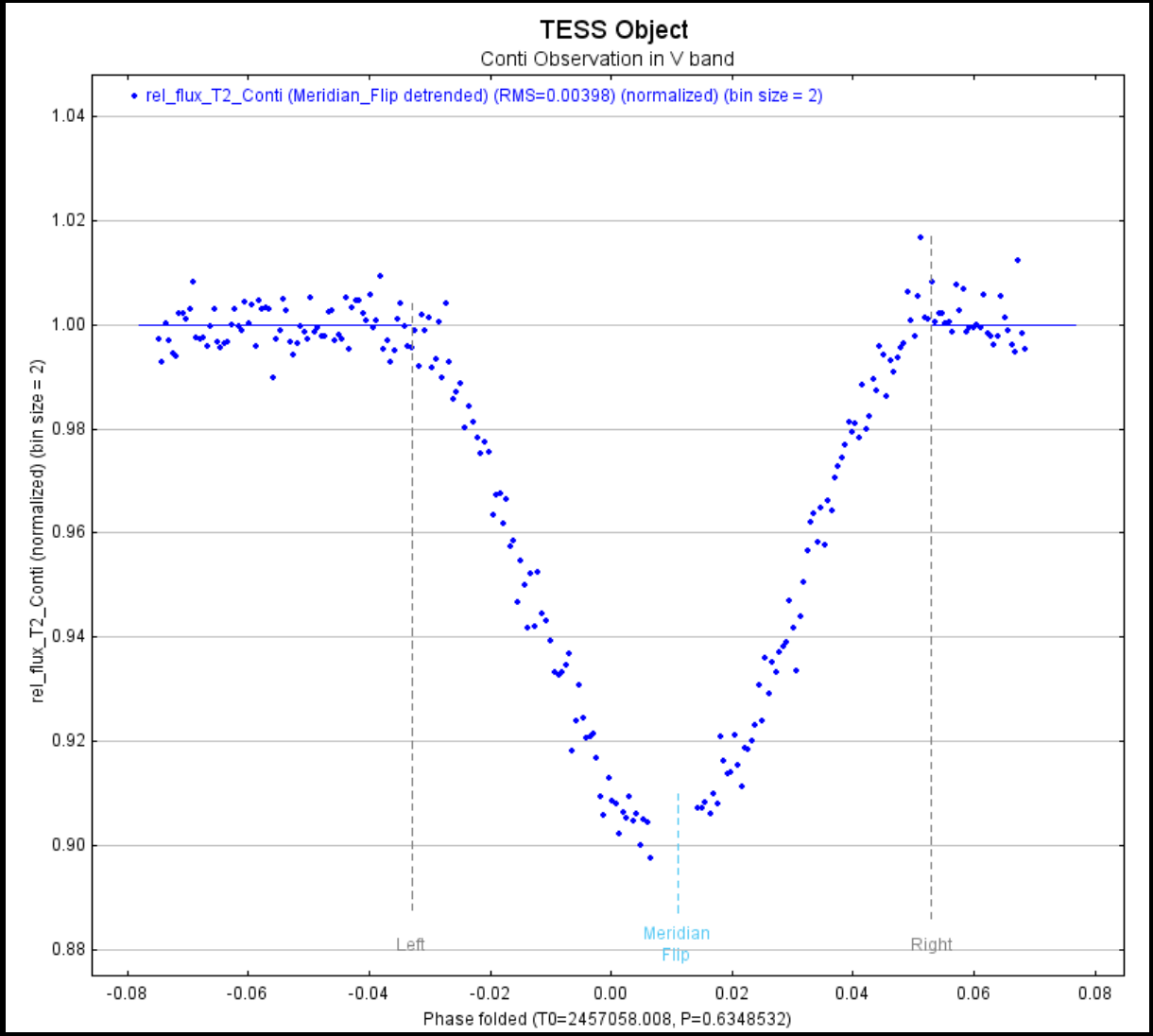
Typically a V-shaped curve

Example: Detection of a NEB

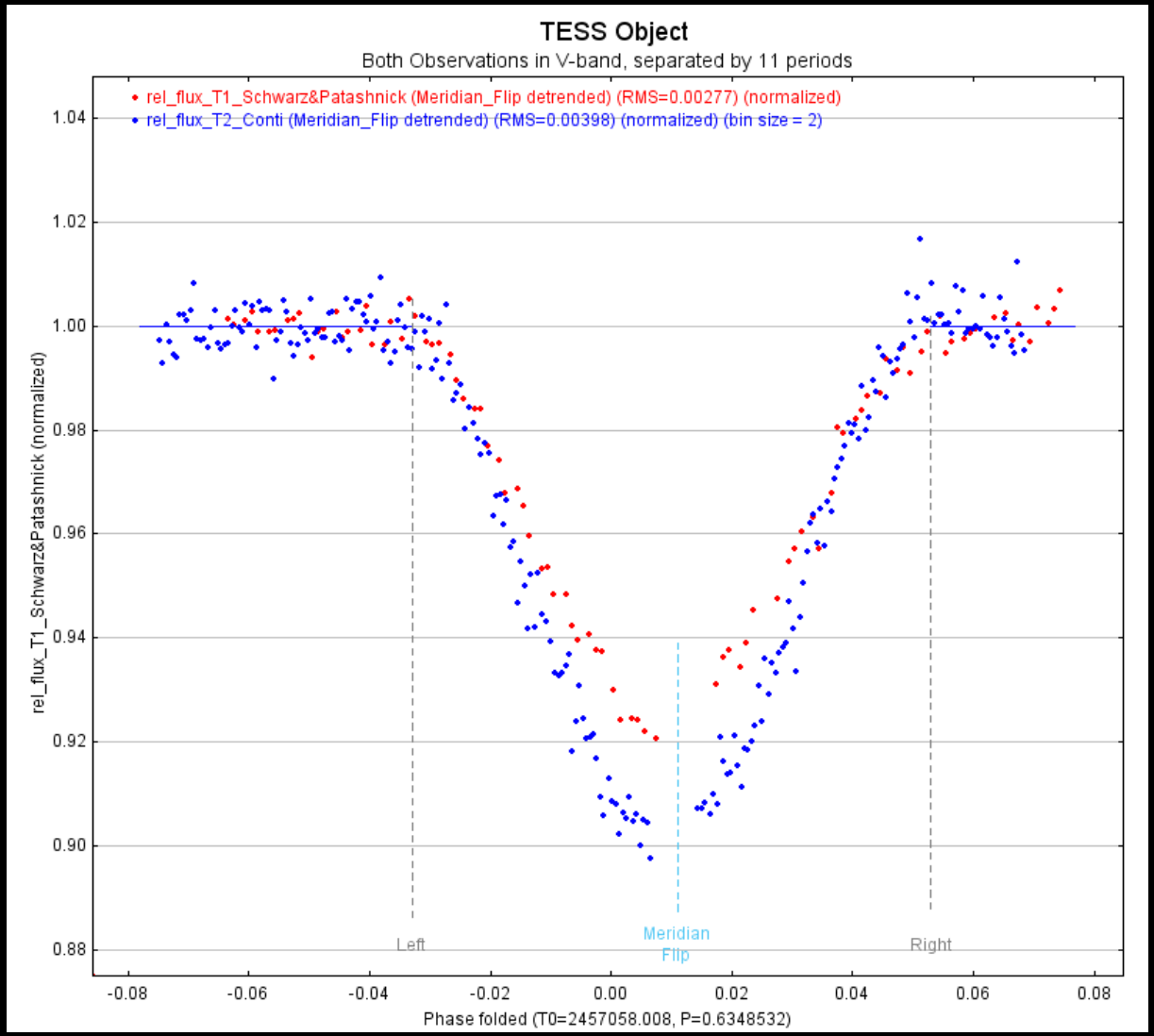
Observation 1



Observation 2
(11 eclipses later)

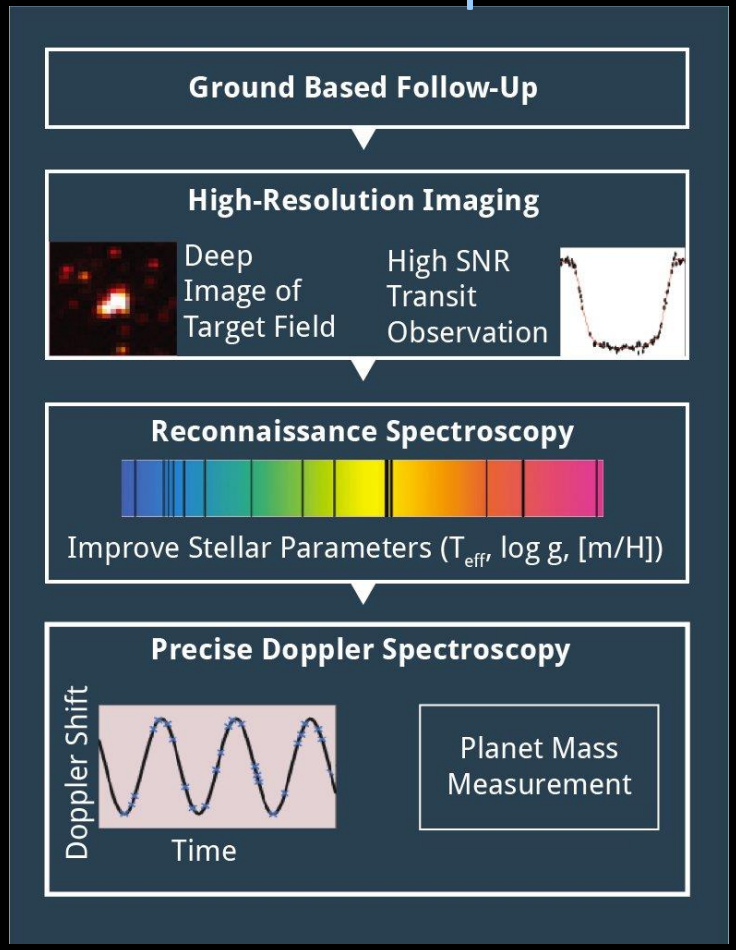


Phase Folded Observations



Amateur Astronomer Participation in TESS

The TESS Pipeline



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

Participation in the TESS Mission

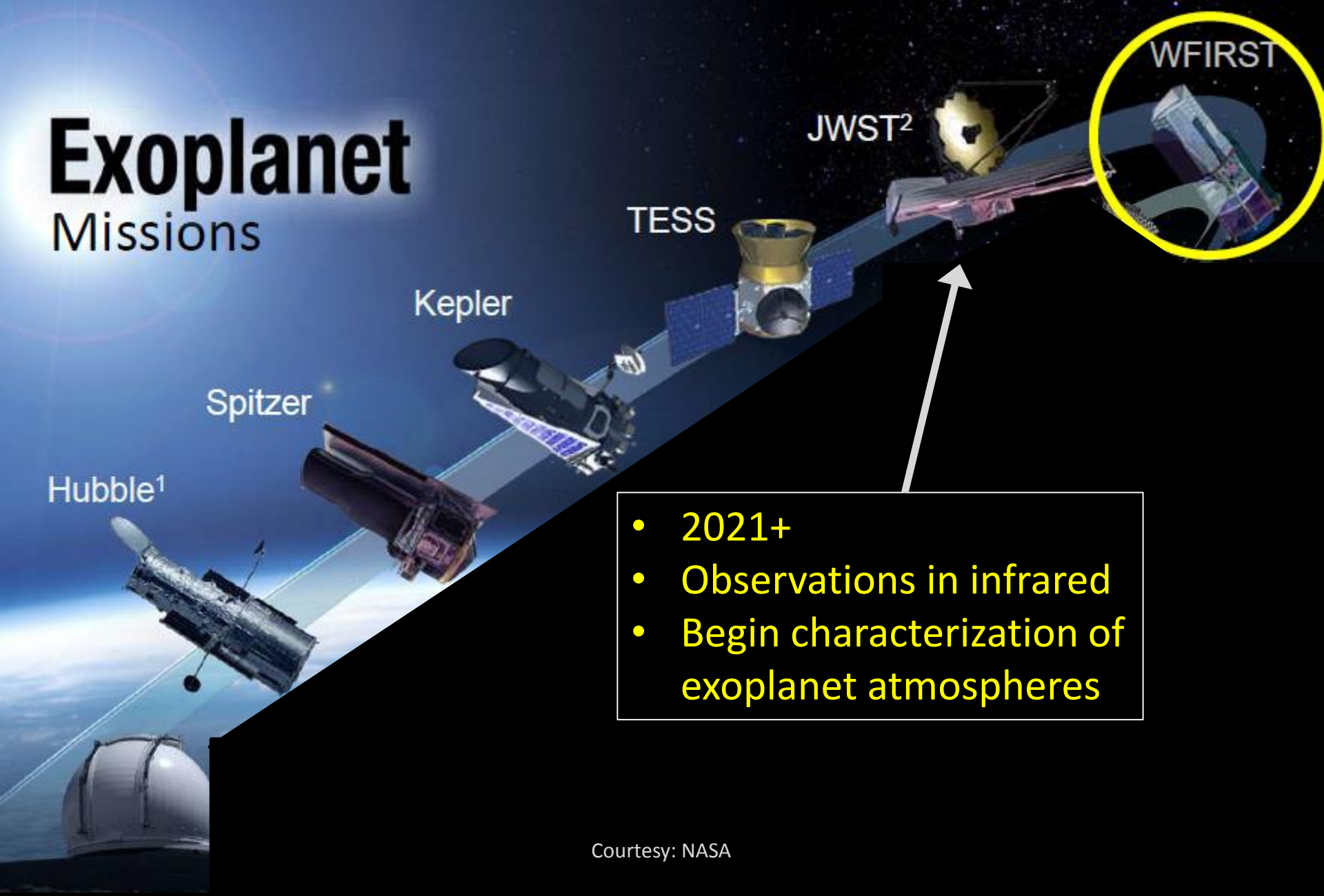
- Qualified amateur astronomers can participate in the TESS exoplanet confirmation pipeline
- Their role:
  - Help identify false positives
  - Help refine the ephemerides of candidate exoplanets
- The AAVSO has a program to facilitate participation in TESS for its members

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
  - next course will be in Feb. 2019; go to aavso.org and select CHOICE Courses tab

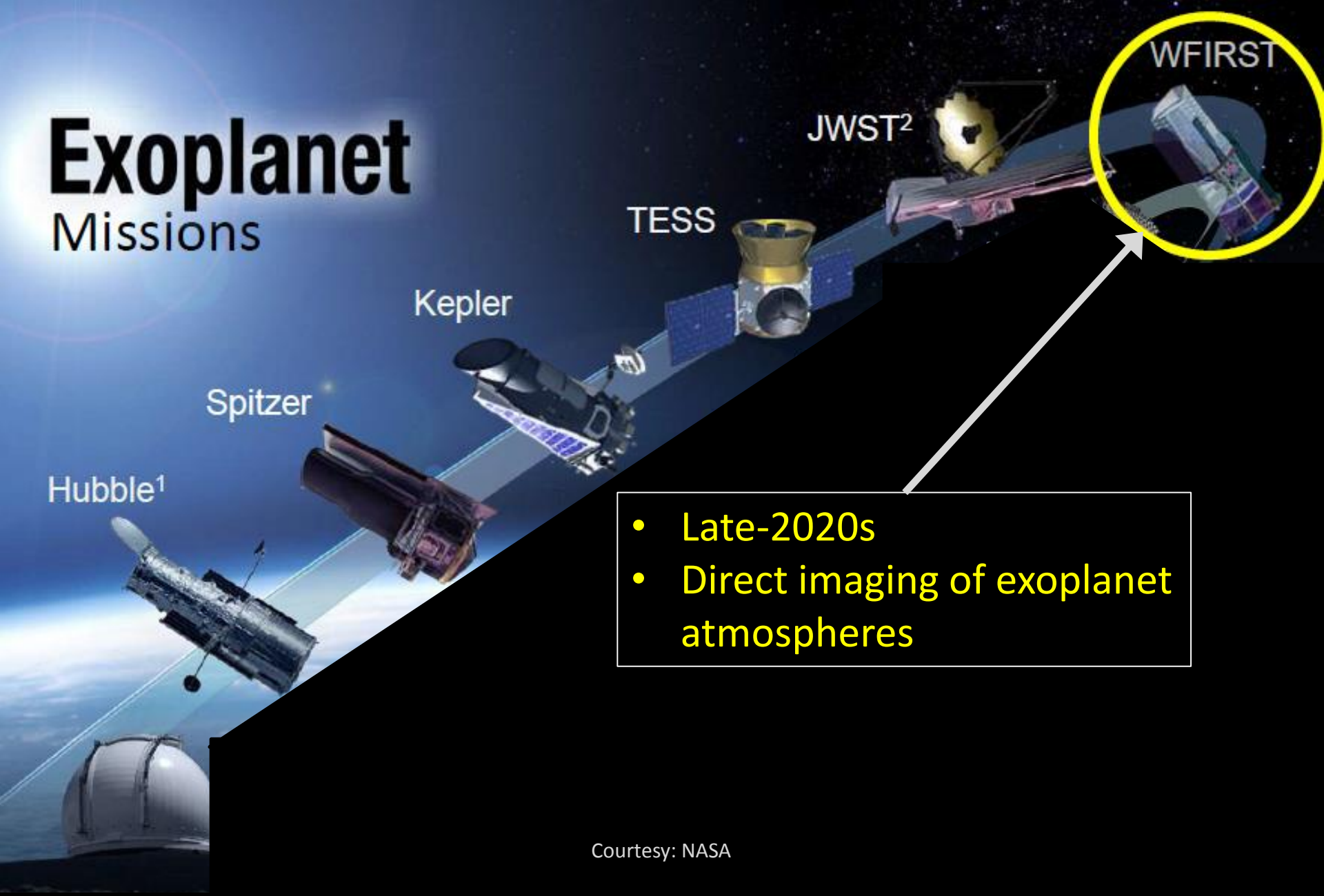
- "A Practical Guide to Exoplanet Observing" (go to astrodennis.com)

Future NASA Exoplanet Missions



- 2021+
- Observations in infrared
- Begin characterization of exoplanet atmospheres

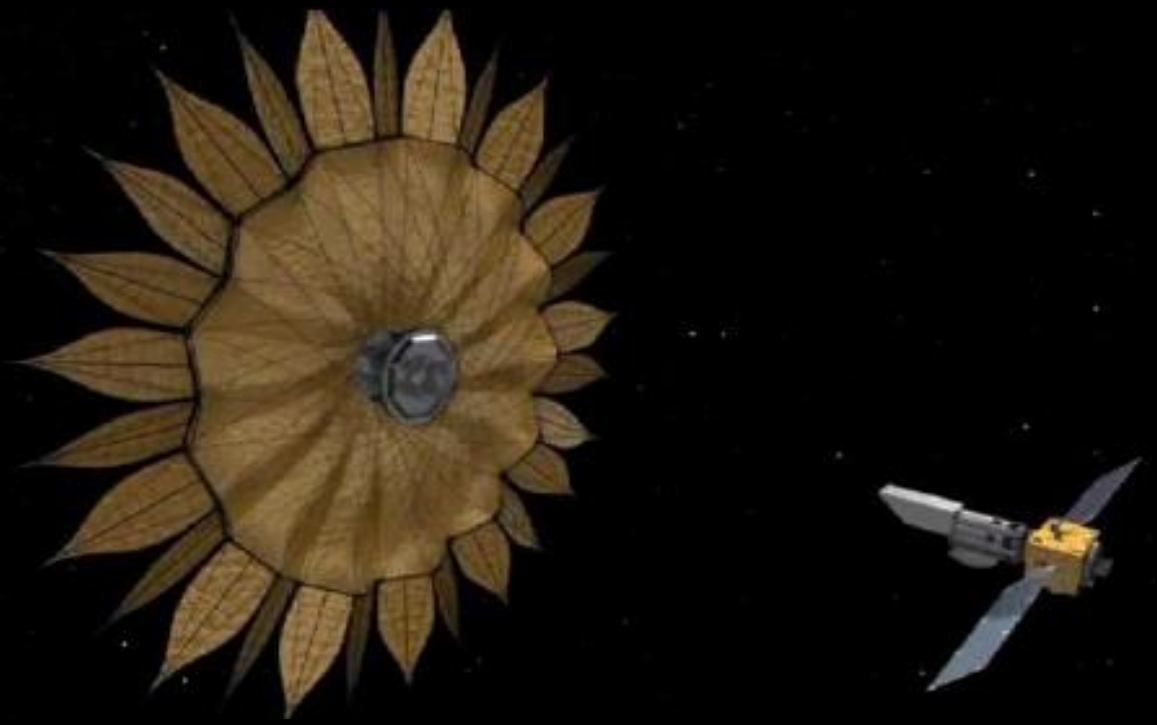
Courtesy: NASA



- Late-2020s
- Direct imaging of exoplanet atmospheres

Courtesy: NASA

Starshade Technology



Courtesy: NASA

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

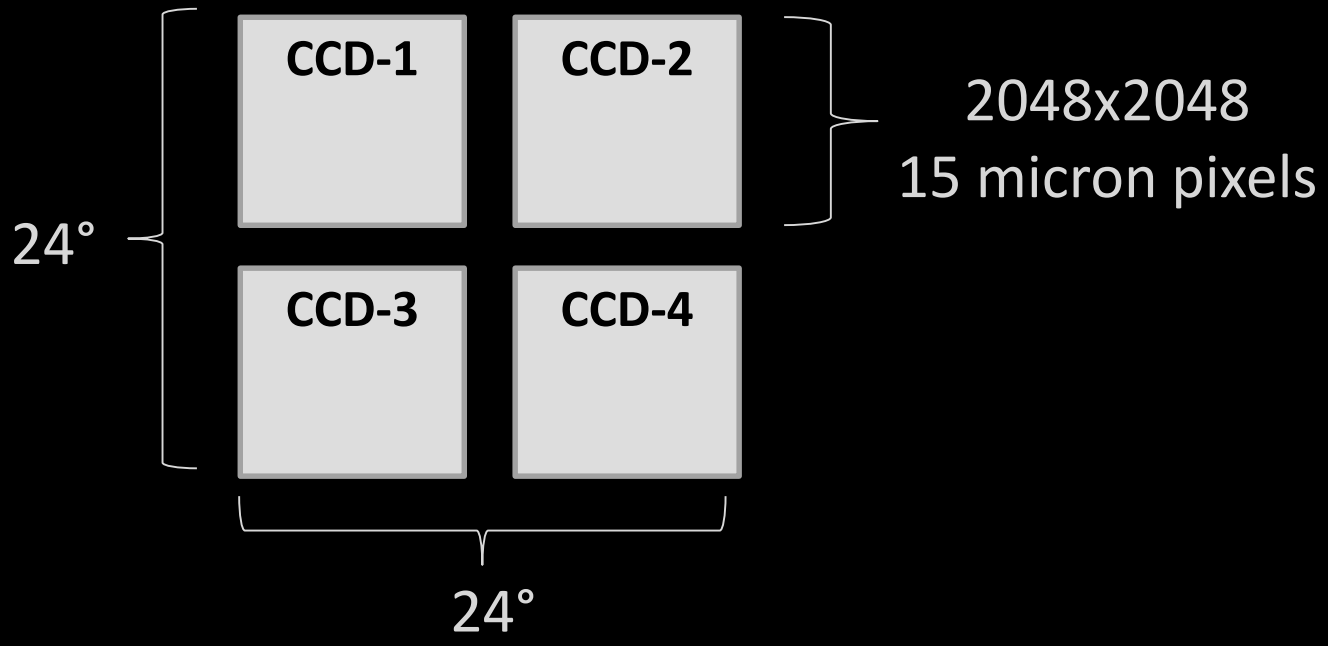
Contact Information

Email: dennis@astrodennis.com

Website: http://astrodennis.com

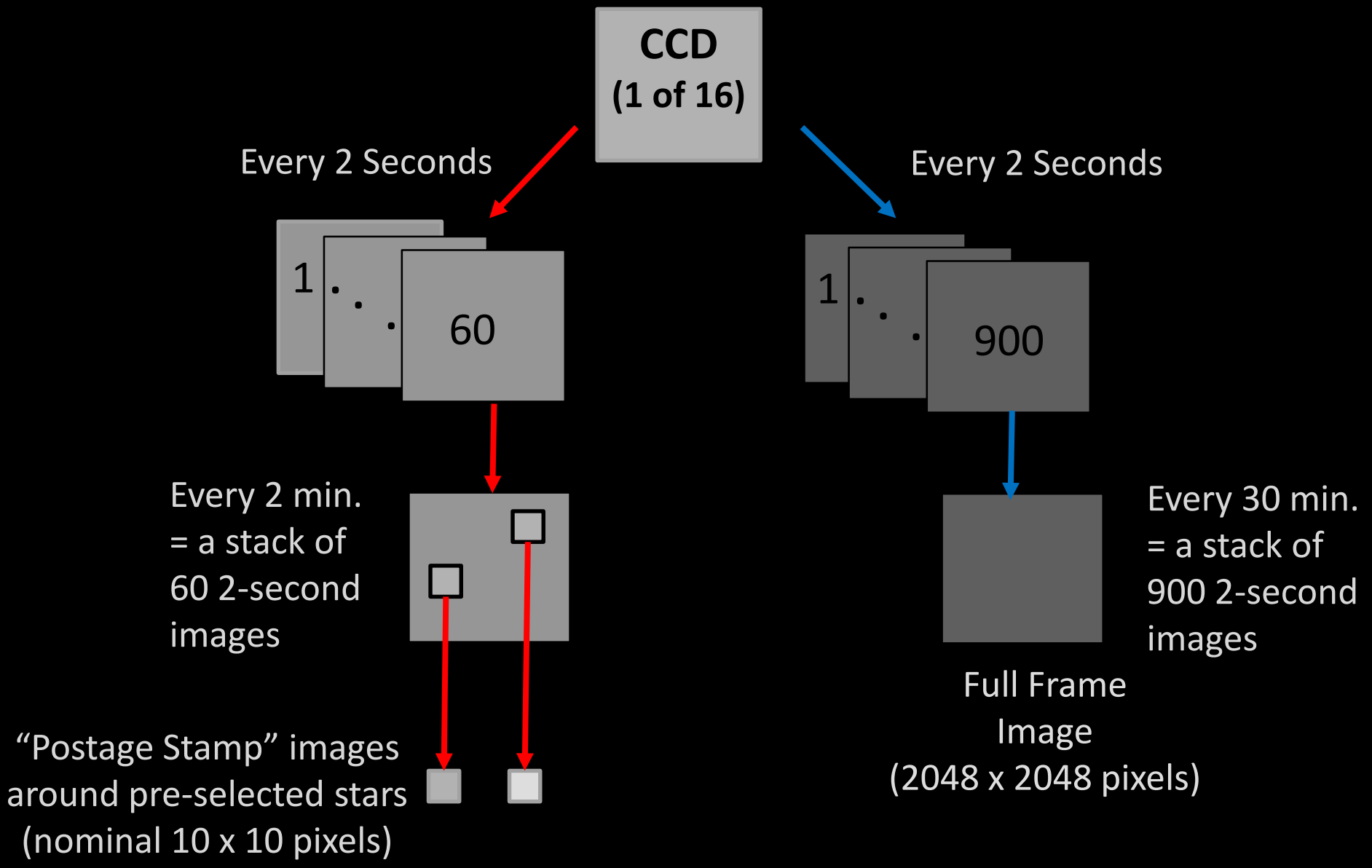
Addendum

TESS Camera
(1 of 4)



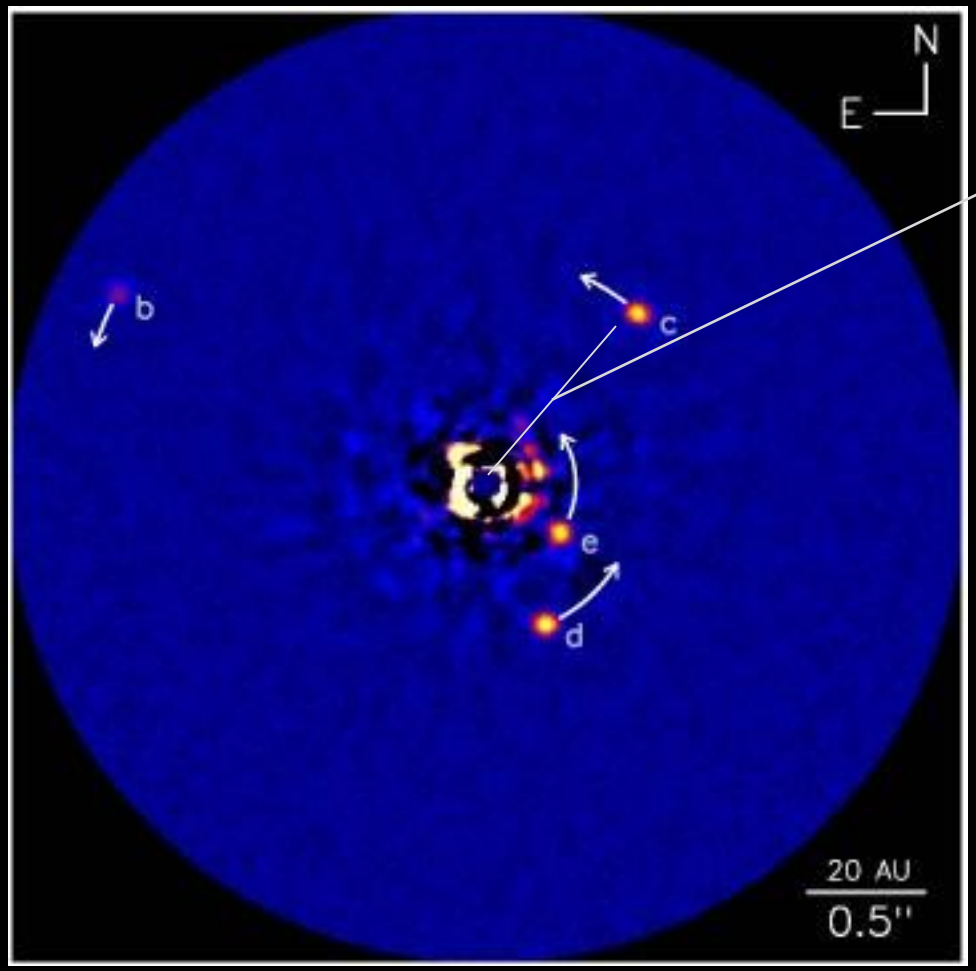
Each camera has a 4” aperture and f/1.4 lens
->image scale of 21”/pixel

TESS Images



The Challenge

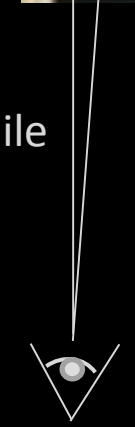
HR 8799



Courtesy: Keck Observatory

Equivalent to seeing the reflected light of a baseball that is ¼" from a lighthouse 1 mile away:

1 mile



AAVSO Qualification Program

- Facilitates participation of AAVSO members in Seeing Limited Sub-group 1(SG1)

- Steps:
  - Submission of a high quality exoplanet observation
  - Certification that four key documents have been read
  - Successful analysis of a TESS test dataset
  - Qualified participants recommended for admission to SG1

- Participants are given access to the TESS Transit Finder (TTF)

- TESS observations submitted per “SG1 Submission Guidelines” and uploaded to ExoFOP-TESS