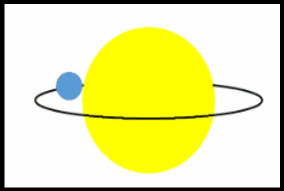


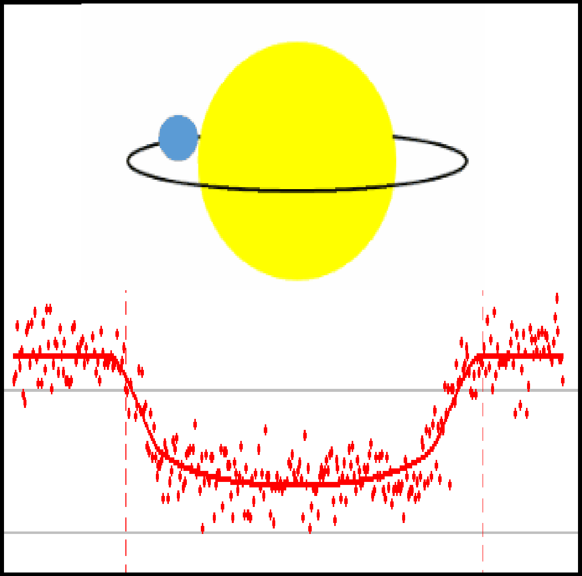
Exoplanet False Positive Detection with Sub-meter Telescopes

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

Topics

- What are typical false positives
- Why do they occur
- How do we detect them
- How you can participate in TESS

The Transit Method



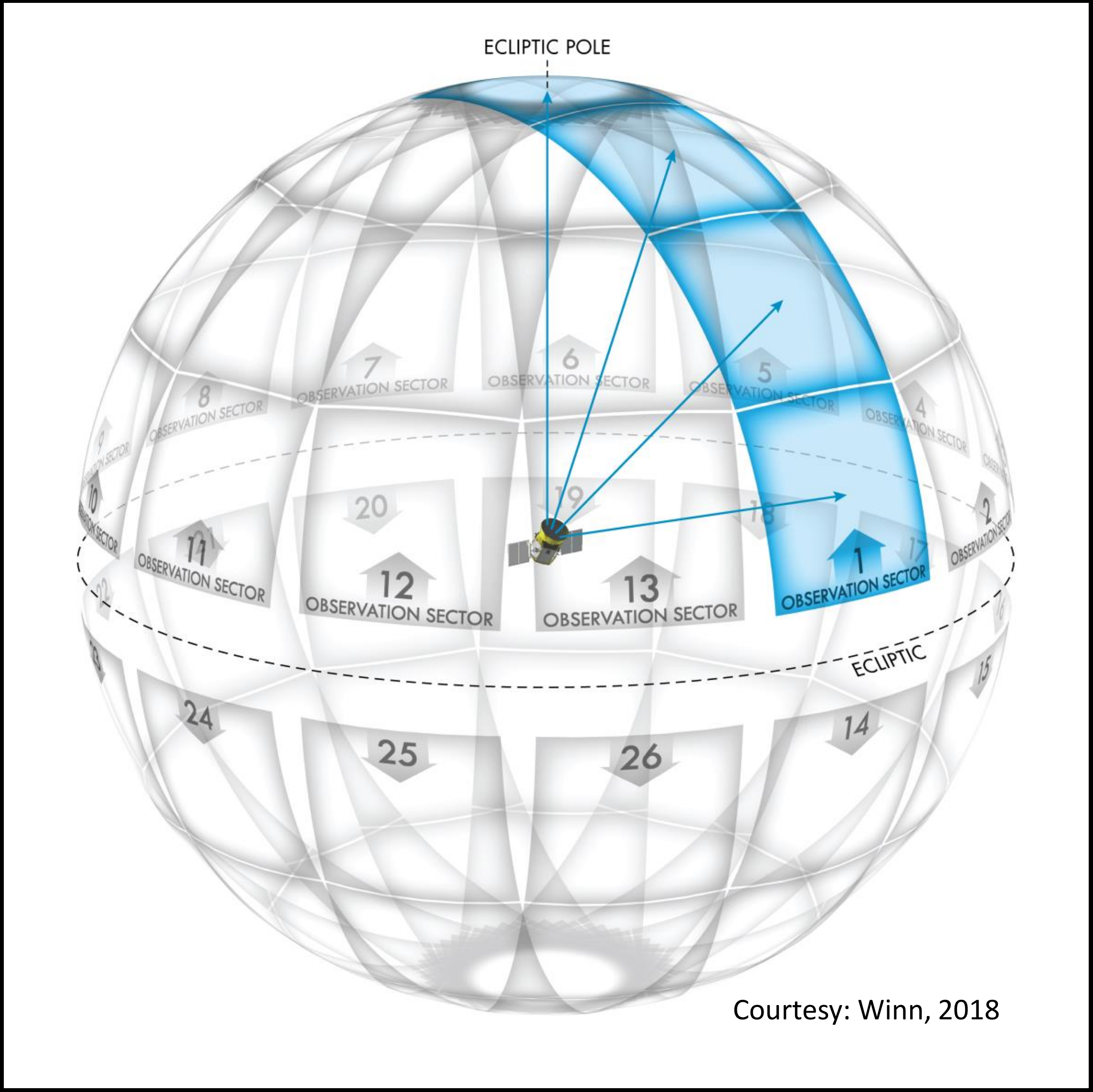
Eureka - a Planet!

...or is it a false positive???

A False Positive

- Occurs when a dip in the blended light of multiple stars mimics the light curve of an exoplanet transit
- The culprit is often an eclipsing binary or variable star near the target star

TESS All-Sky Survey

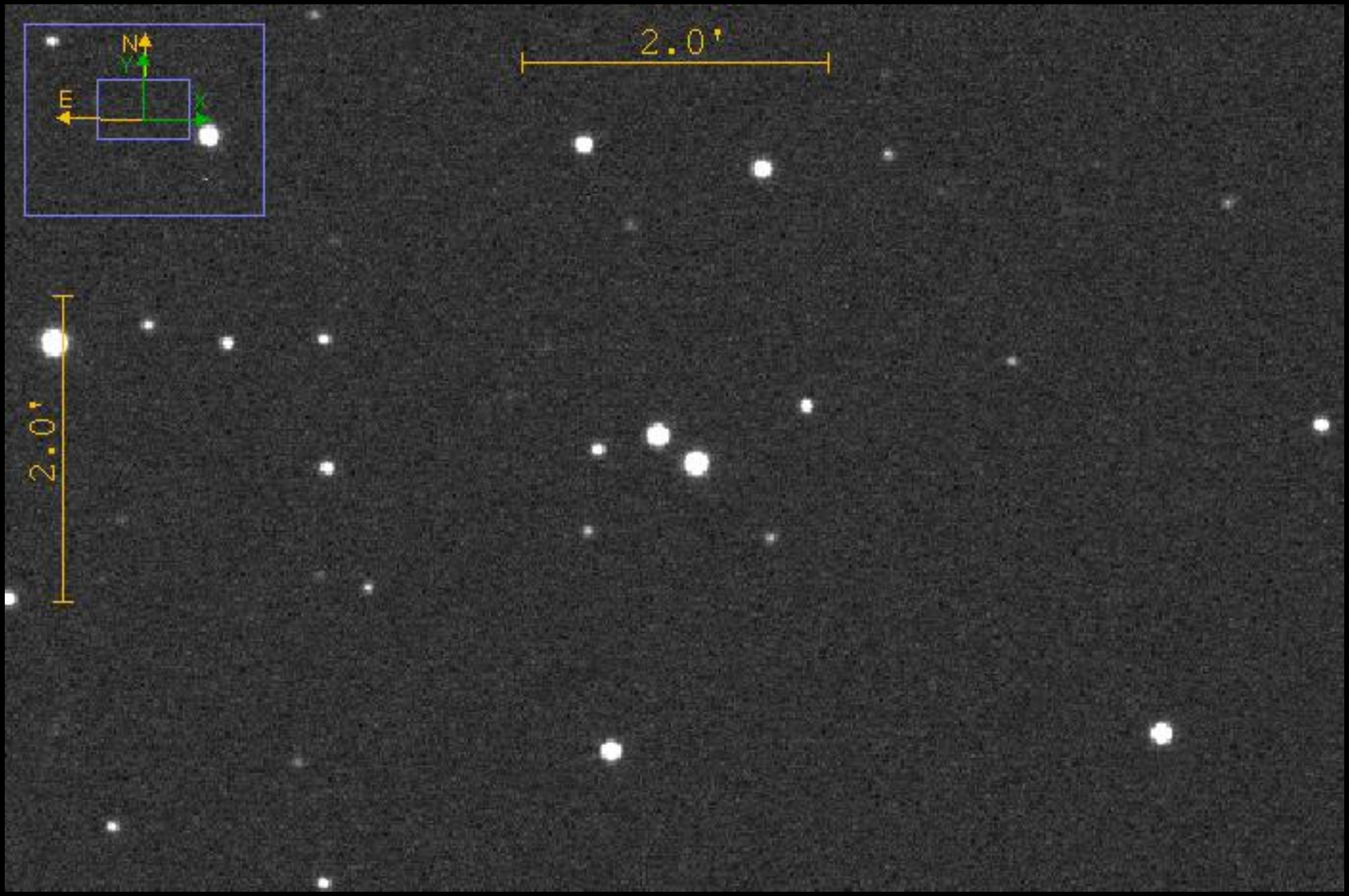


Each region gets 27 days of coverage

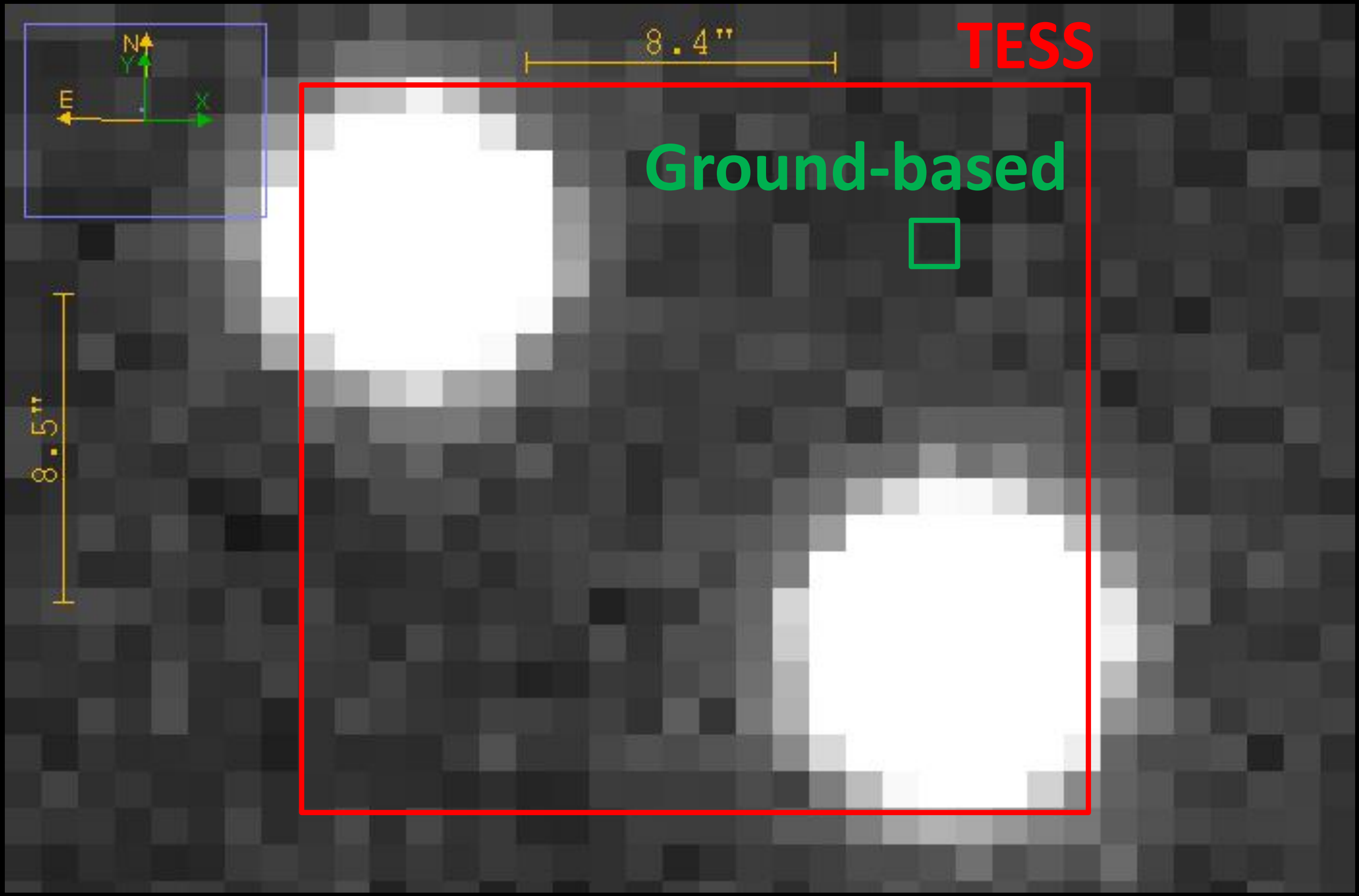
The Challenge

- All-sky surveys such as TESS use large pixels and photometric apertures
  - the light from multiple stars may thus be blended together
- Thus, periodic 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

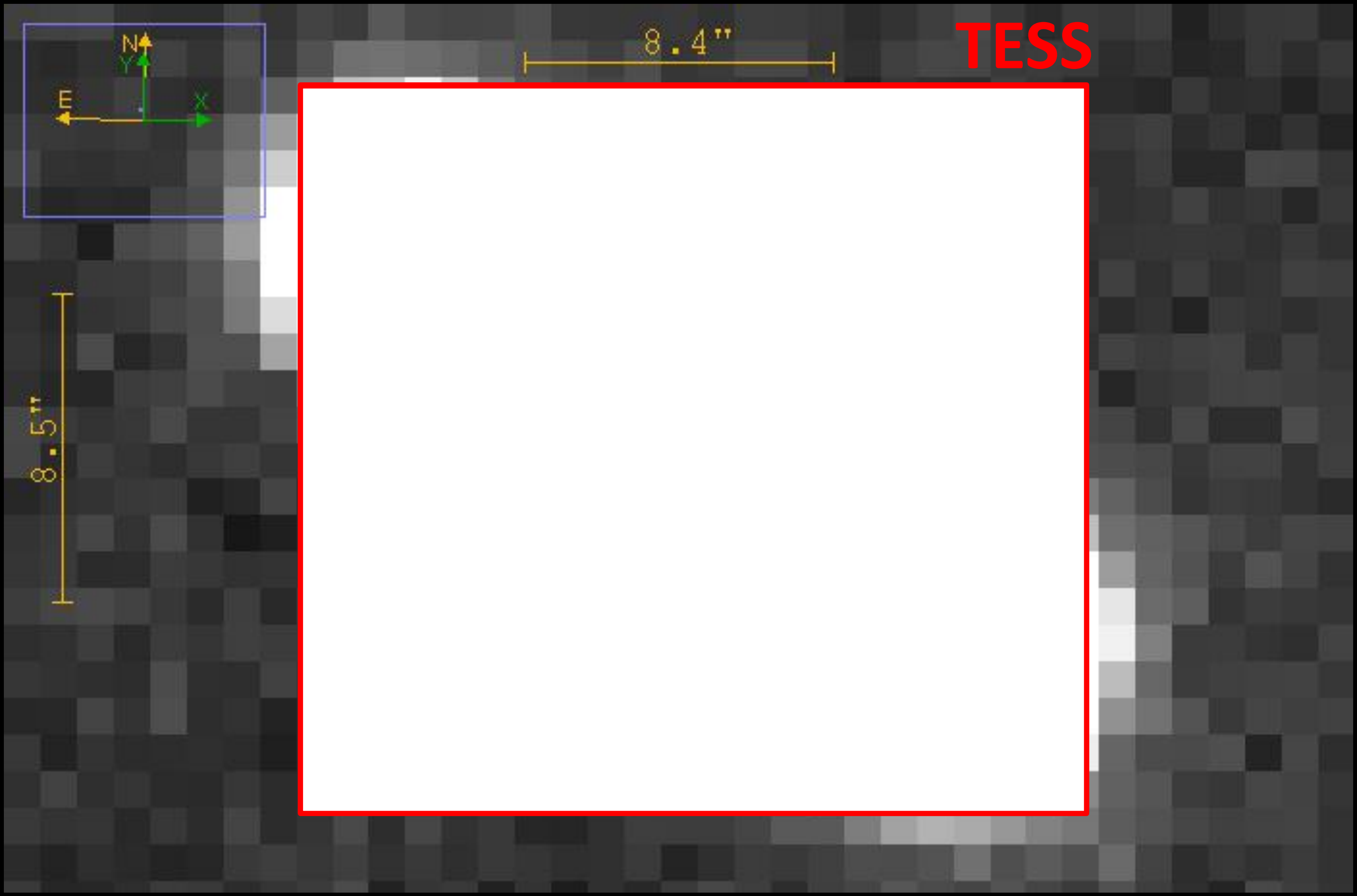
A Typical Ground-Based Image



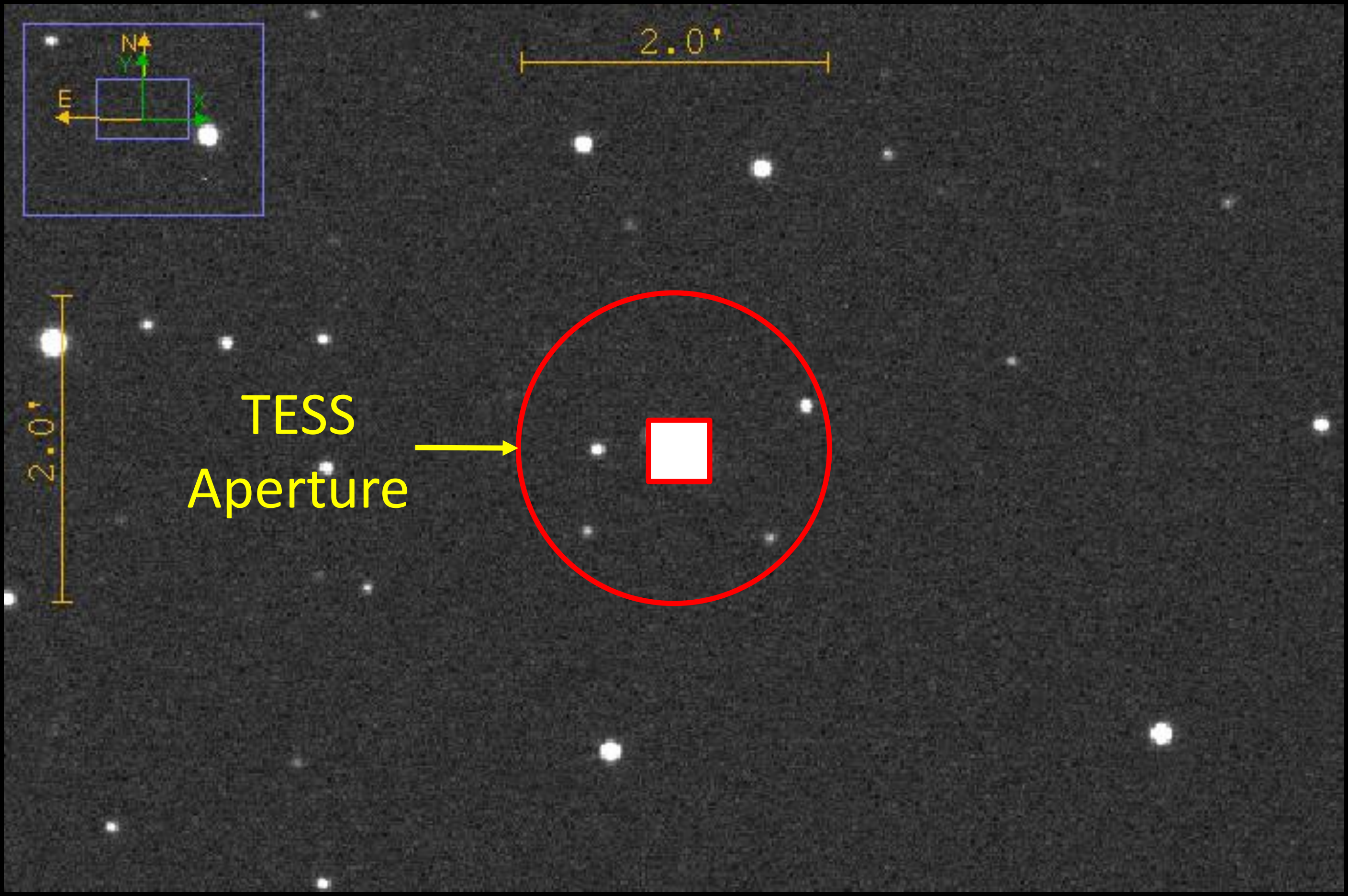
Pixel Sizes



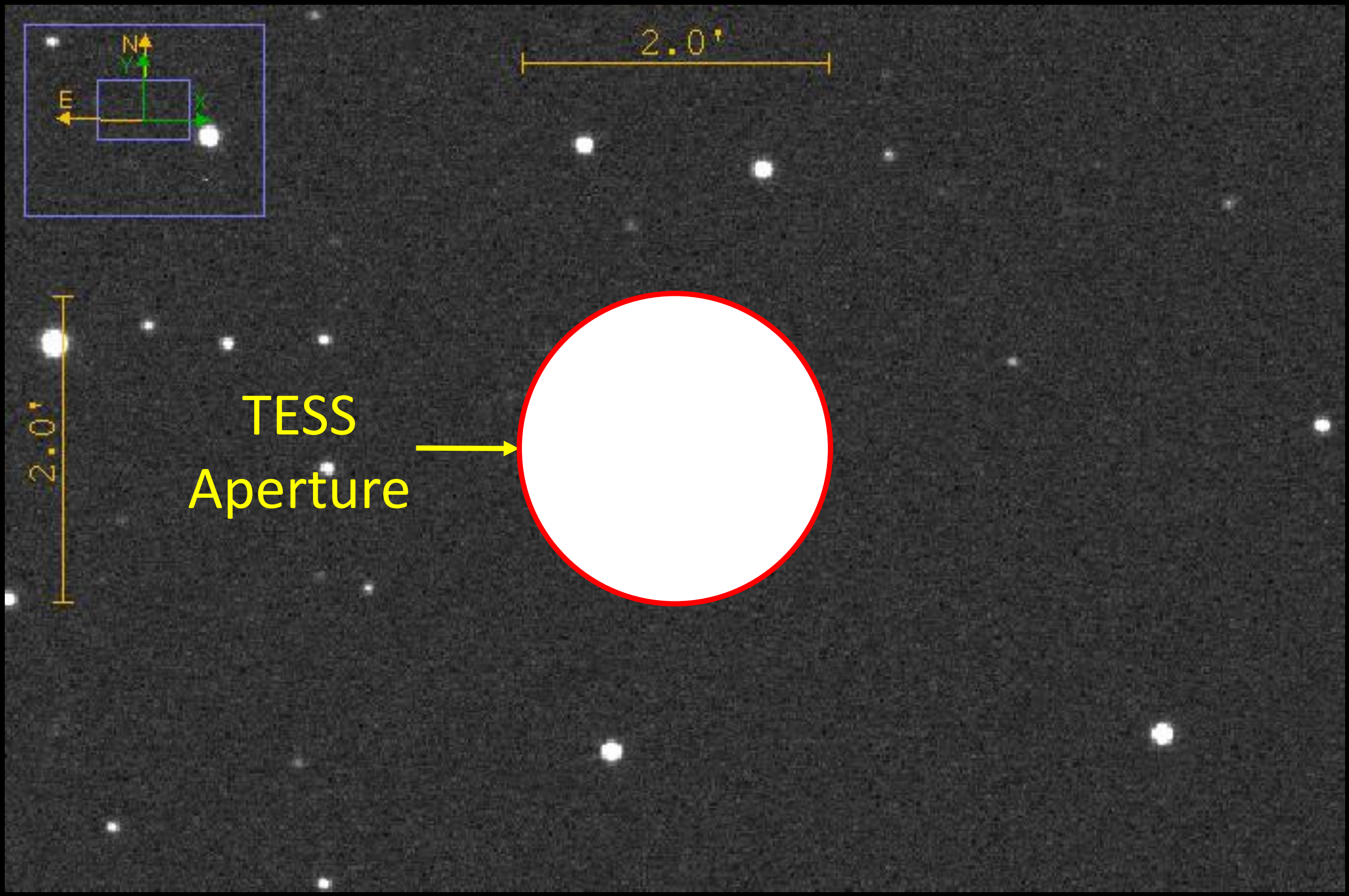
Pixel Sizes



Typical TESS Photometric Aperture

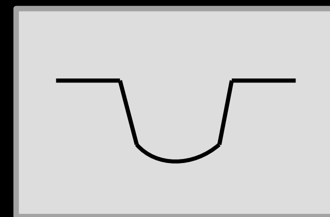


Typical TESS Photometric Aperture

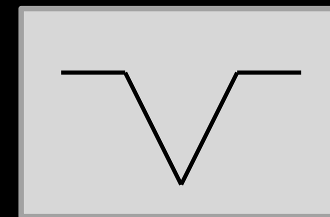


How Do We Detect False Positives?

- Shape ("morphology") of light curve

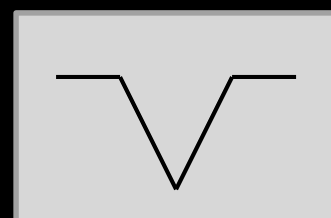


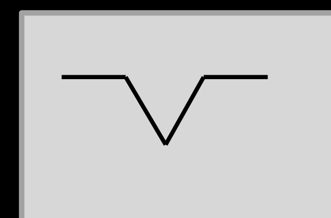
vs.



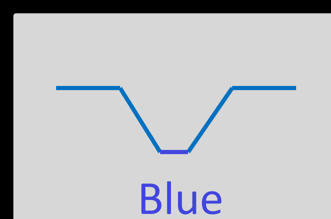
Bucket-shaped V-shaped

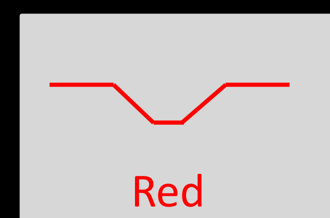
- Alternating ("odd-even") V-shapes at different depths or not evenly spaced



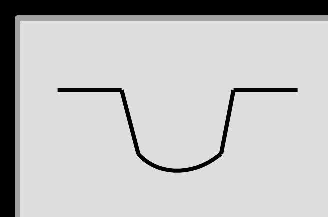


- Depth variations (> 5 mmag) in different passband





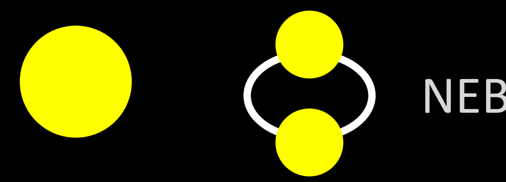
- Depths indicating a non-planetary transiting body (> 2.5 Jupiter radii)



$=(R_p/R_*)^2$

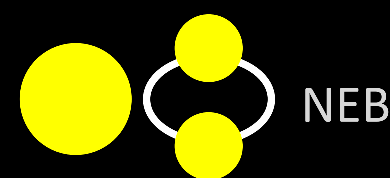
False Positive Scenarios and Detection Factors

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

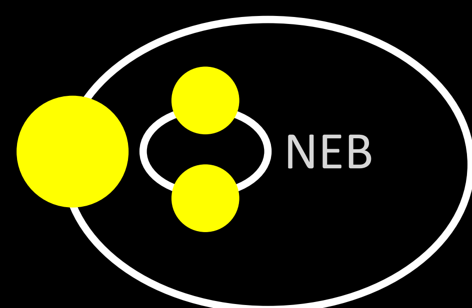


V-shape curve of a near-by star has odd-even depth changes

The NEB and target can't be spatially distinguished*



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

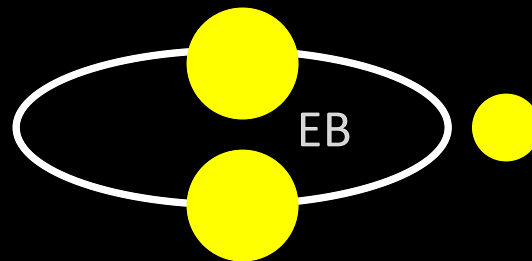


Depth varies in different bandpasses

* Note: could be chance alignments

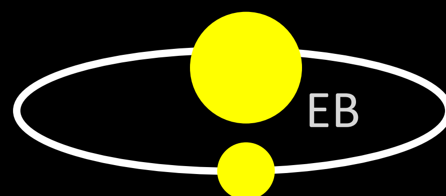
False Positive Scenarios and Detection Factors (cont'd)

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



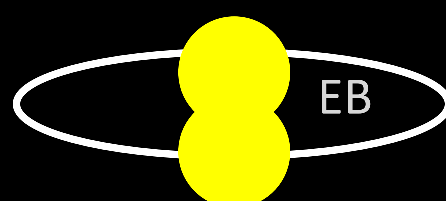
A V-shaped curve (if spatially resolvable from neighbor)

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



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

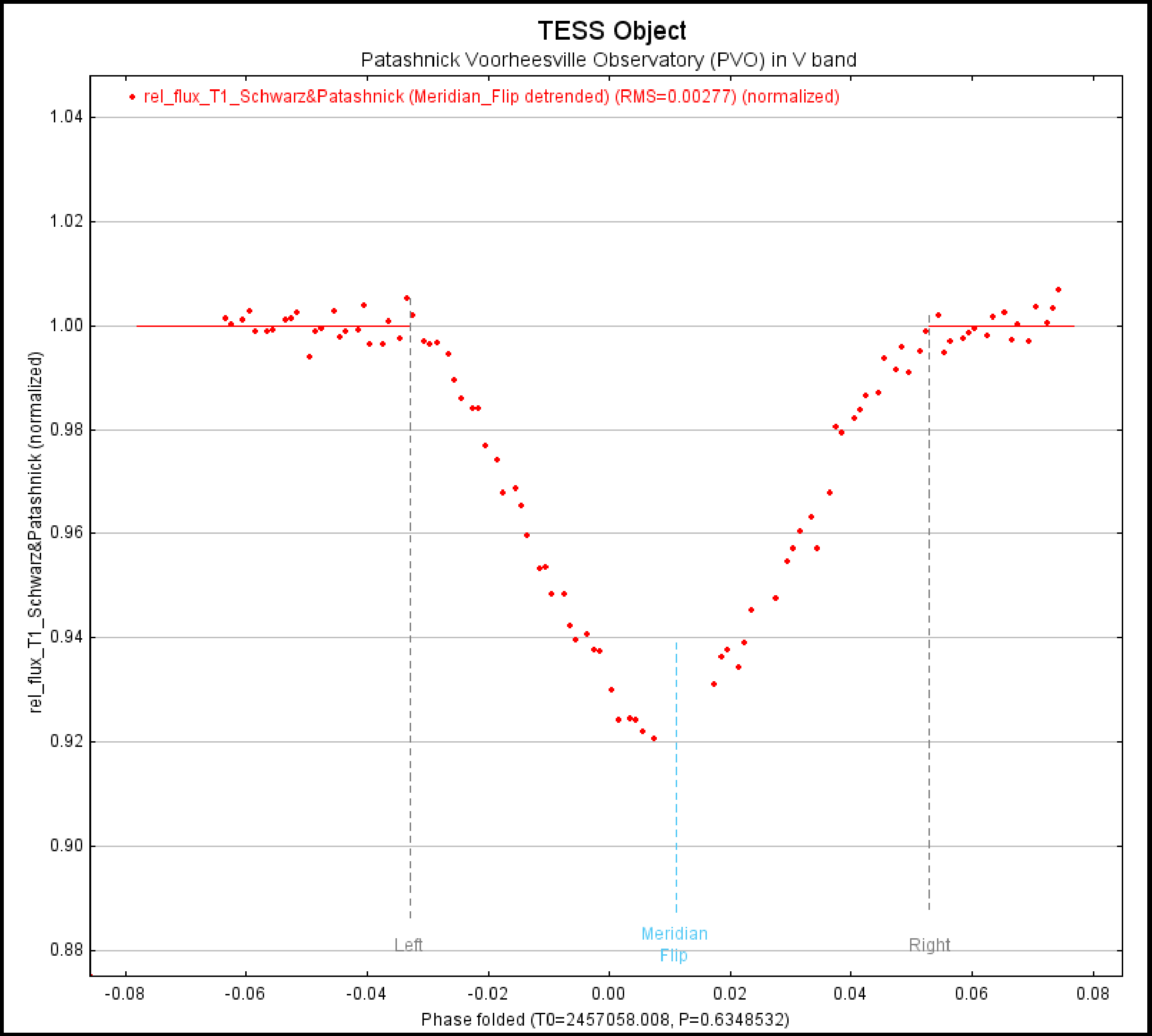
Secondary star in an EB "grazes" the primary star



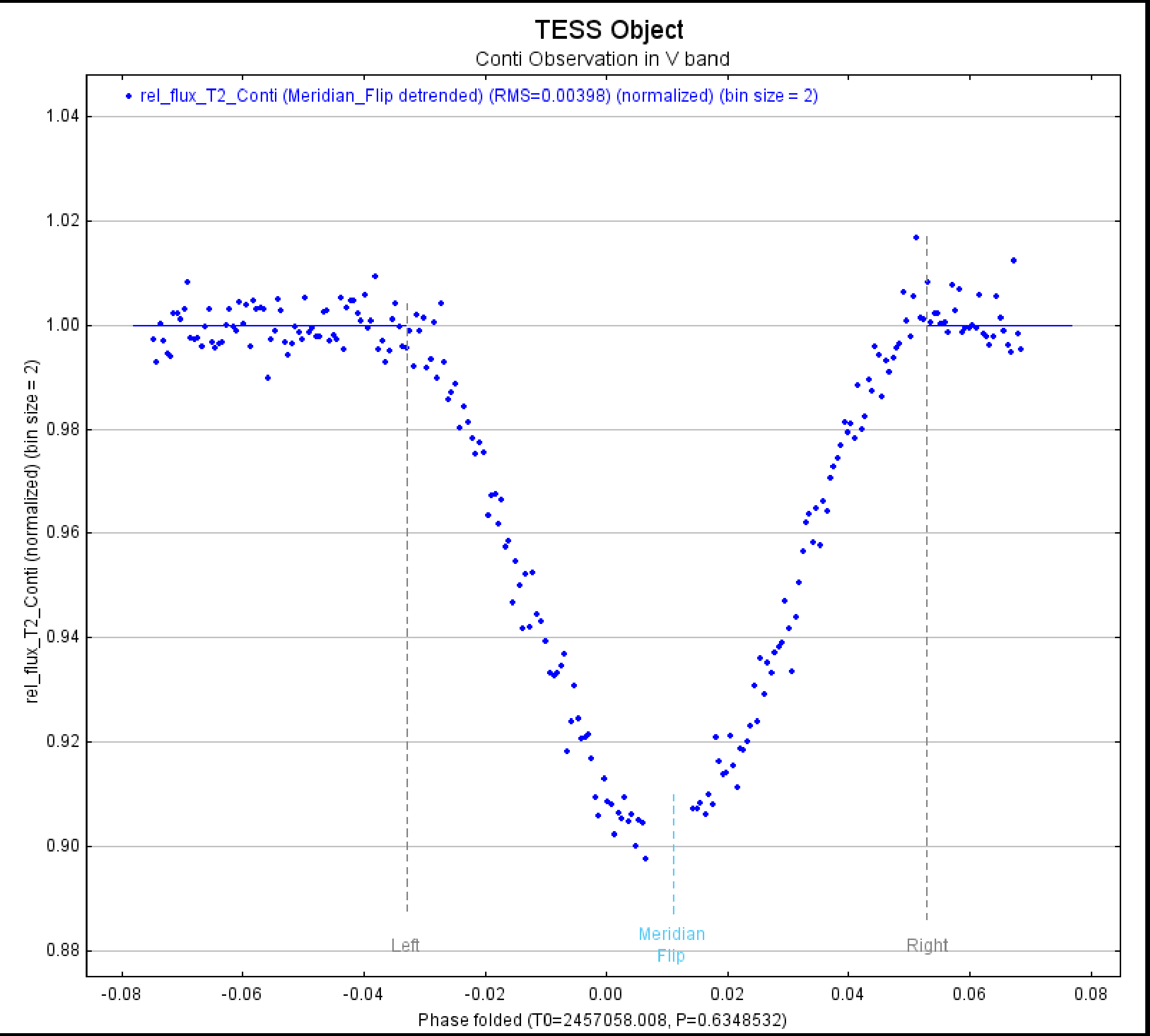
Typically a V-shaped curve

Example: Detection of a NEB

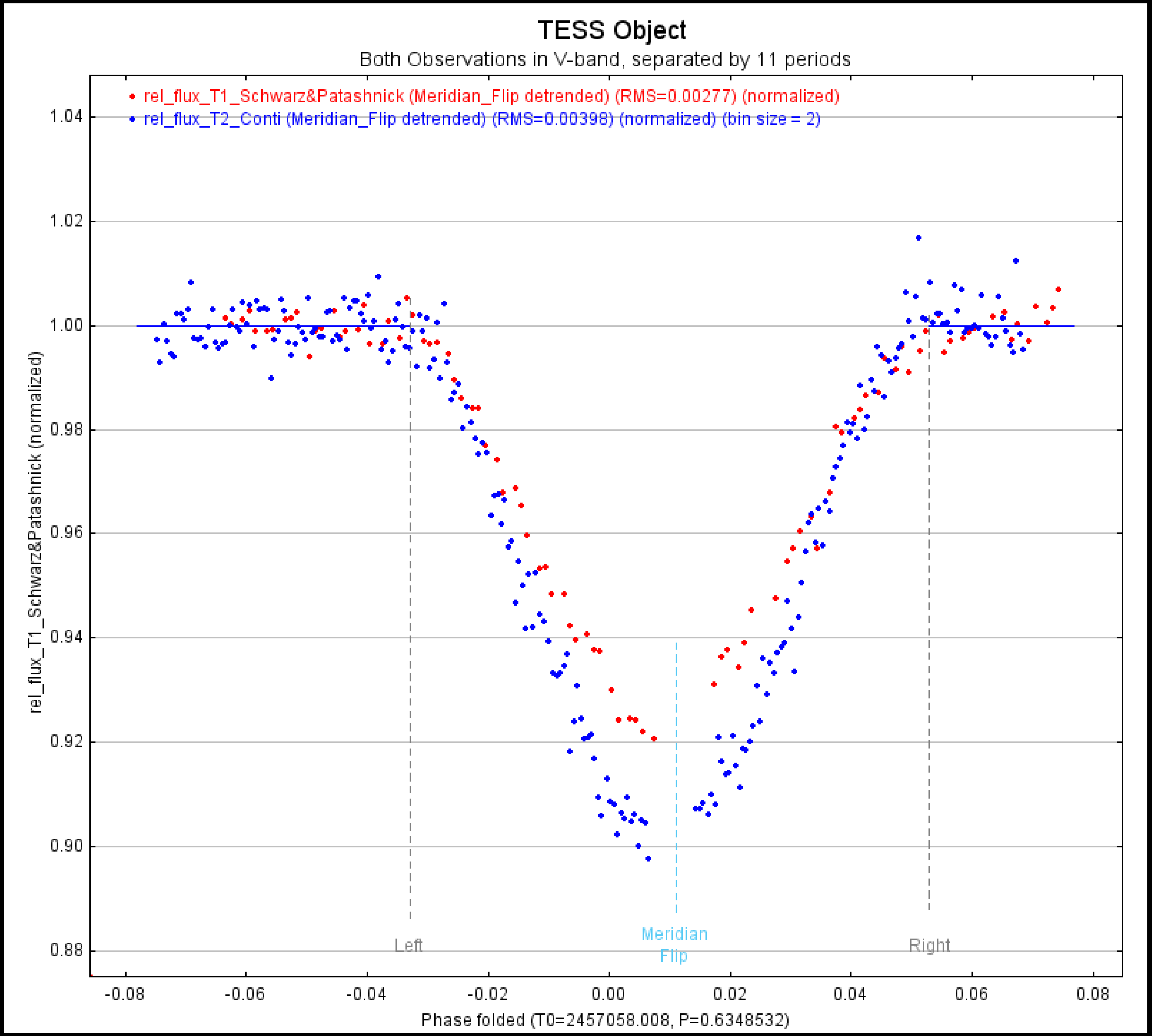
Observation 1



Observation 2
(11 eclipses later)



Phase Folded Observations



Participation in the TESS Mission

- TESS Seeing Limited Subgroup (SG1) is part of the initial exoplanet confirmation pipeline

- SG1 participants:
  - Help identify false positives
  - Help refine the ephemerides of candidate exoplanets

- Participation requires approval of SG1 Chair (Karen Collins)
  - Approval is generally granted for those completing AAVSO's qualification program

AAVSO Qualification Program

- Facilitates participation of AAVSO members in 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

TESS Transit Finder

Local evening date	Name	V mag	Start—Mid—End	Duration	BJD_{TDB} start-mid-end	Elev. at start, mid, end	Az. at start, mid, end	HA at start, mid, end	RA & Dec (J2000)	Period (days)	Depth (ppt)	Priority	R_{planet} ($R_\oplus$)	Comments
Thu. 06-14-2018 Nautical twilight 21:45 - 04:27 (America/New_York)	TIC 414663958 Add to TOC Finding charts: Annotated, SkyMap; Info: ExoFOP TESS page, Simbad, 2MASS, VSX; Airmass plot, ACP plan	10.71 Moon 3% @150°	00:22—01:24—02:26 ± 0:07	2:04	8284.682 8284.725 8284.768	54°, 58°, 56°	148°, 175°, 203°	-1.2, -0.2, +0.9	18:02:03.00 +06:57:38.0	1.76	14.9	4		Not observed yet.
Thu. 06-14-2018 Nautical twilight 21:45 - 04:27 (America/New_York)	TIC 182183753 Add to TOC Finding charts: Annotated, SkyMap; Info: ExoFOP TESS page, Simbad, 2MASS, VSX; Airmass plot, ACP plan	11.50 Moon 3% @158°	23:43—01:49—03:55 ± 0:36	4:12	8284.655 8284.743 8284.830	34°, 51°, 50°	120°, 157°, 208°	-3.1, -0.9, +1.2	19:13:35.00 +01:58:40.0	1.17	5.9	4		Not observed yet.
Thu. 06-14-2018 Nautical twilight 21:45 - 04:27 (America/New_York)	TIC 31822871 Add to TOC Finding charts: Annotated, SkyMap; Info: ExoFOP TESS page, Simbad, 2MASS, VSX; Airmass plot, ACP plan	11.78 Moon 3% @166°	23:43—01:50—03:57 ± 0:59	4:14	8284.655 8284.744 8284.832	31°, 44°, 40°	131°, 168°, 211°	-2.7, -0.6, +1.6	18:51:44.00 -06:09:42.0	2.43	11.2	4		Not observed yet.

Other Resources

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

- 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 offering begins October 1

Summary

- Ground-based observations with small telescopes are critical in helping to confirm exoplanet candidates
- Opportunities for co-authorship of scientific papers provide an additional benefit
- Training opportunities, software and documentation are available for interested participants
- The TESS mission provides an opportunity to participate in the next frontier of exoplanet discovery!

Contact Information

Email: dennis@astrodennis.com

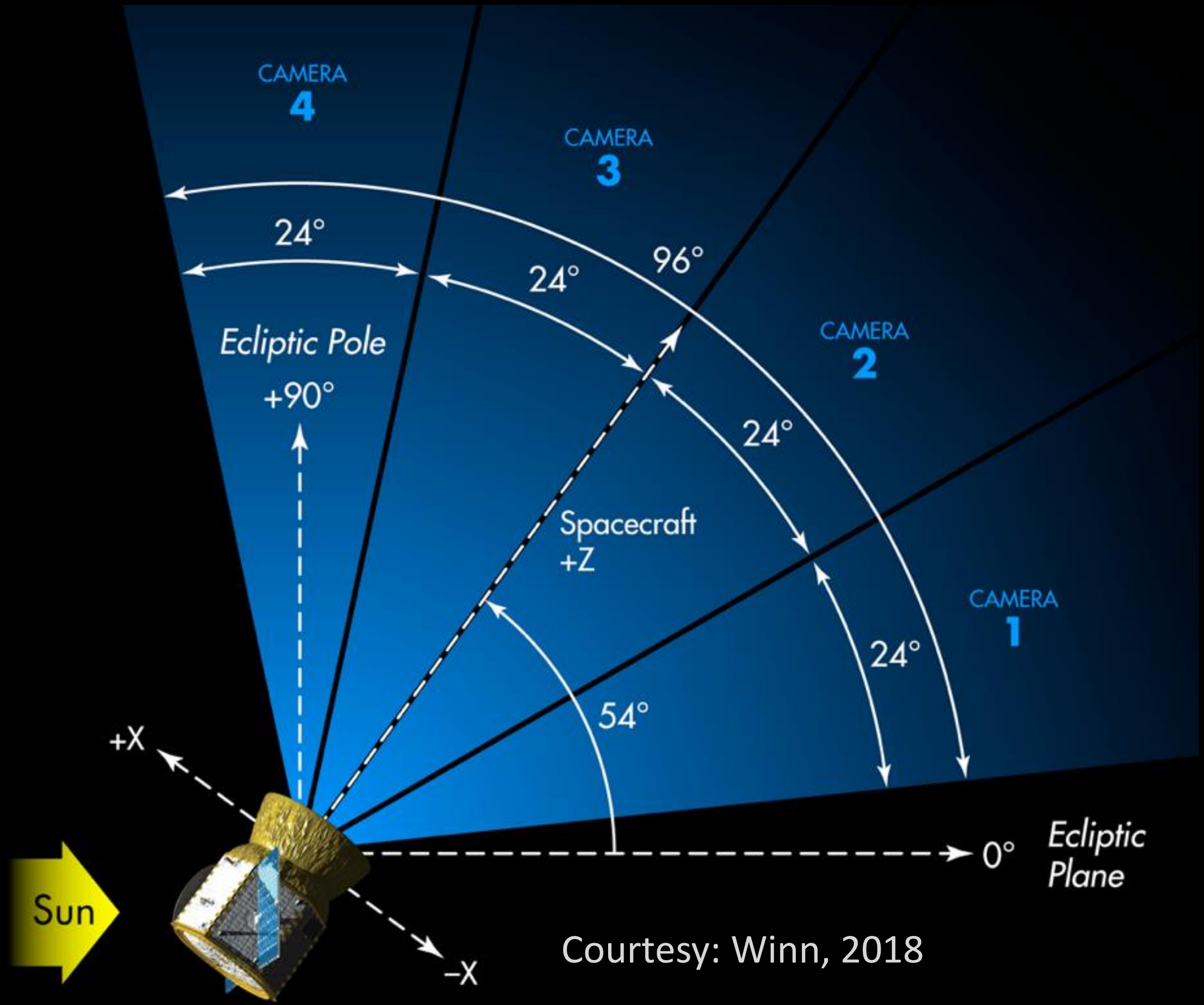
Website: http://astrodennis.com

Addenda

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

TESS Orientation

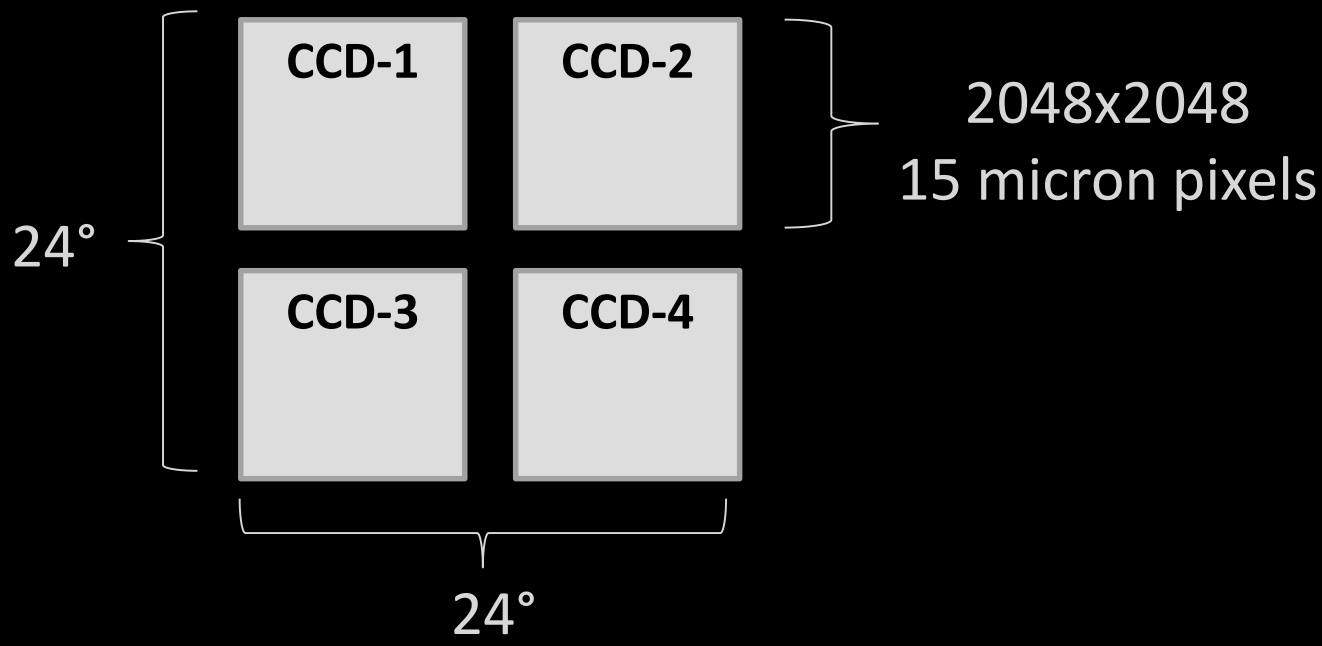


Courtesy: Winn, 2018

TESS Operation

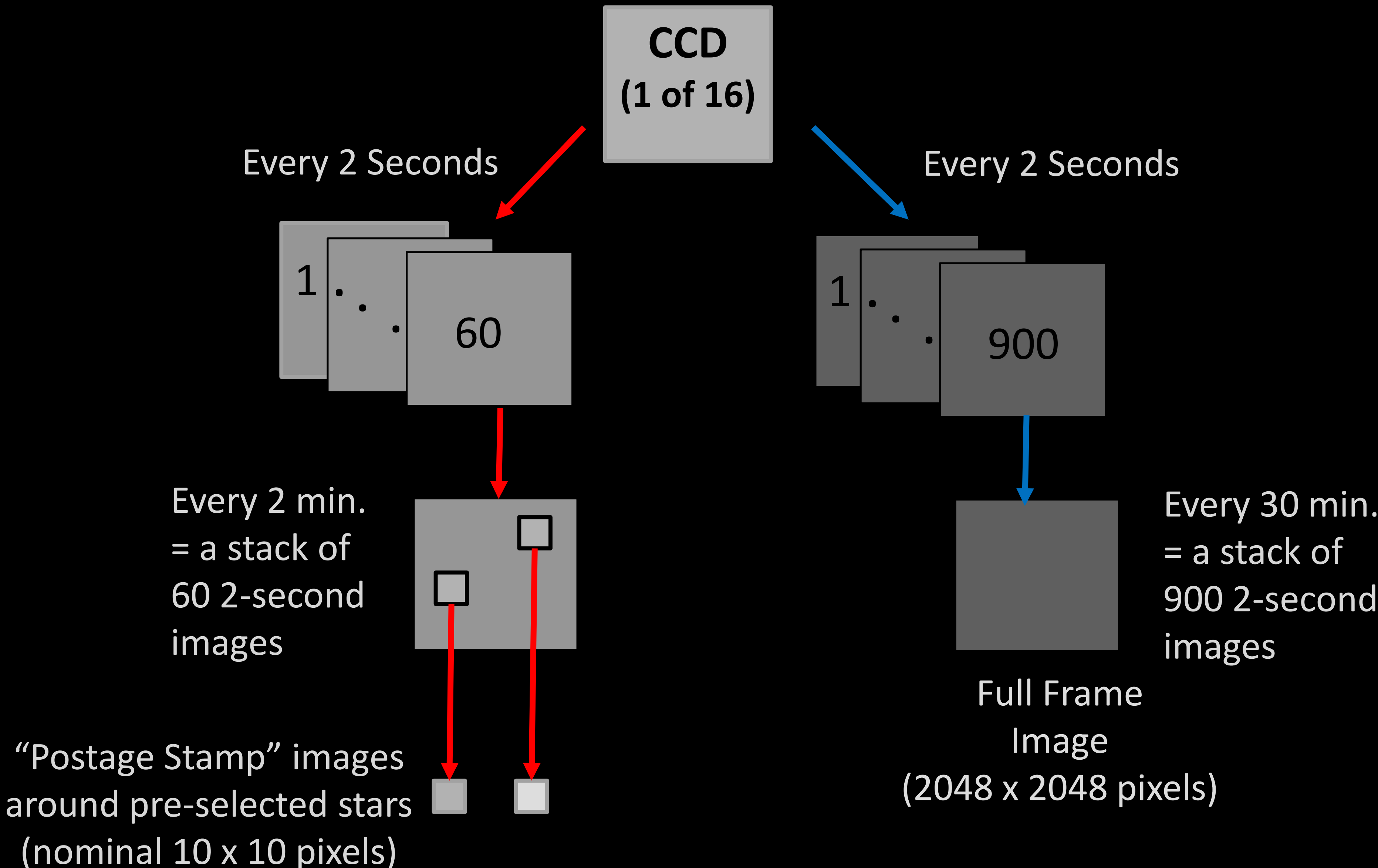
- Data downloads occur when TESS is near Earth in its orbit, in order to reduce download times
- Two 13.7 day orbits per sector
  - so each sector is viewed for at least 27 days
- Ecliptic poles are viewed for 300 days due to overlapping sectors
- Northern ecliptic imaging to begin mid-2019 (a portion of Southern ecliptic in mid-2018)
- Targets:
  - Overall stars: 470 million
  - Pre-selected stars: approx. 200,000

TESS Camera
(1 of 4)



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

TESS Images


CCD
(1 of 16)
Every 2 Seconds
1
. . .
60
Every 2 Seconds
1
. . .
900
Every 2 min.
= a stack of
60 2-second
images
Every 30 min.
= a stack of
900 2-second
images
Full Frame
Image
(2048 x 2048 pixels)
"Postage Stamp" images
around pre-selected stars
(nominal 10 x 10 pixels)

Overall TESS Pipeline

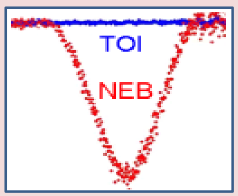
TESS Objects of Interest (TOIs)

False positive screening, blend & stellar characterization

Seeing-Limited Phot.

(SG1)

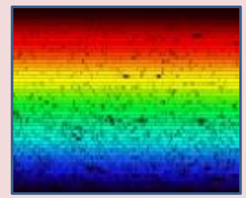
ID nearby EBs, measure photometric blending



Recon Spectroscopy

(SG2)

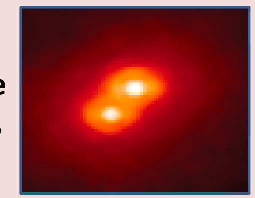
Stellar parameters, ID blended spectra



High-Res Imaging

(SG3)

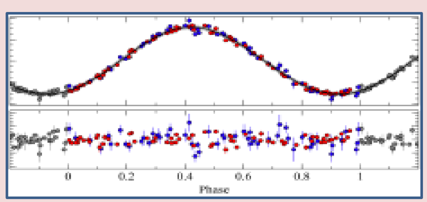
Resolve close companions, characterize multiplicity



Planetary confirmation and characterization

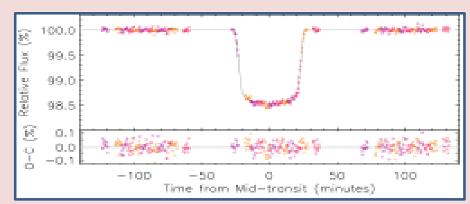
Precise RV Work (SG4)

Derive planetary orbits and masses



Space-Based Photometry (SG5)

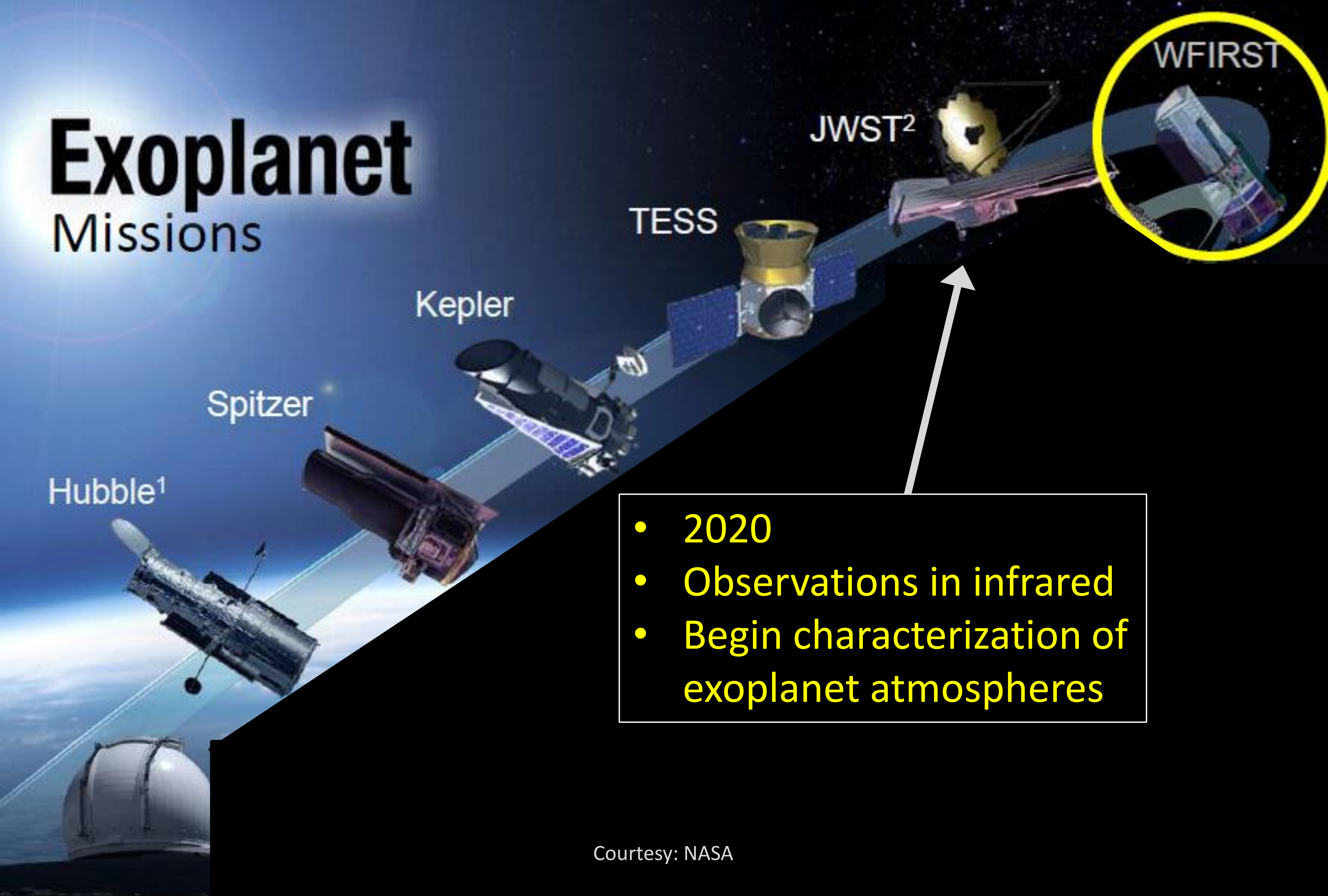
Improved light curve, ephemeris, meas. TTVs



Courtesy: Collins, 2018

Best Practices

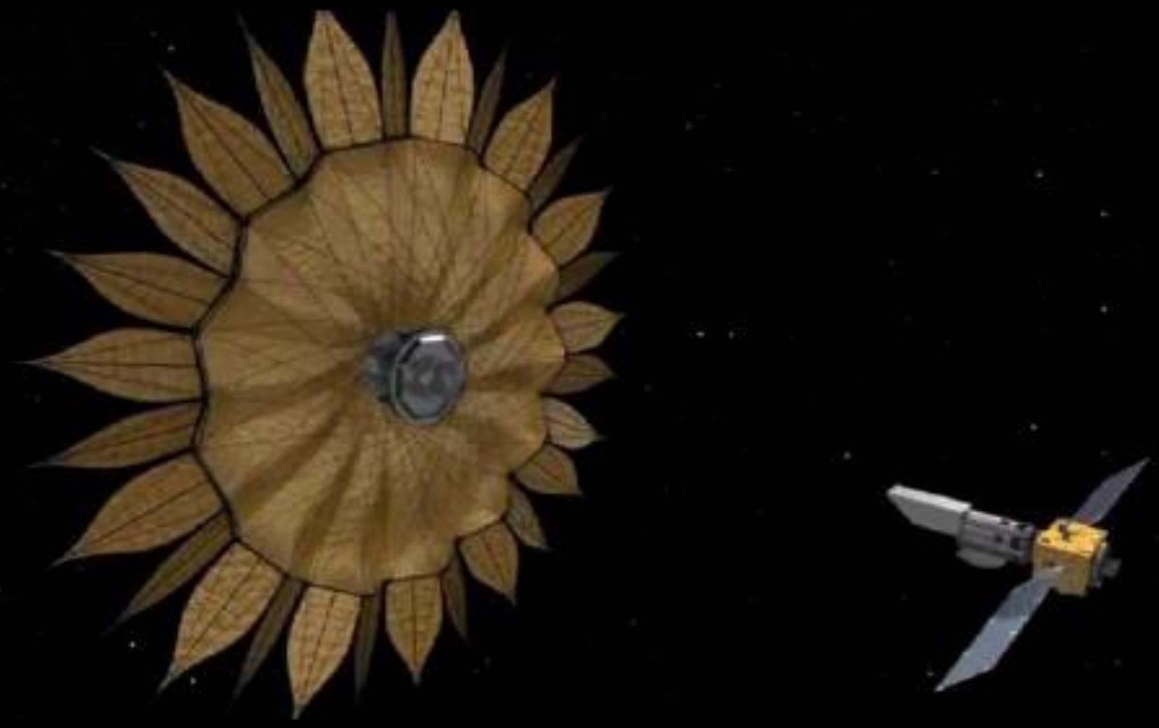
- Image for at least 30 minutes pre-ingress and post-egress
- Use autoguiding to achieve minimal image shift over a 4-6 hour observation window
  - Preferably, guide on the science image
- Use a precise timing source
- Use BJD_{TDB} as timebase
- Handle meridian flips efficiently
- Maximize SNR of target without reaching non-linearity or saturation



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

Courtesy: NASA

Starshade Technology



Courtesy: NASA