High Precision Exoplanet Observations with Amateur Telescopes

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HAL Meeting: October 19, 2017

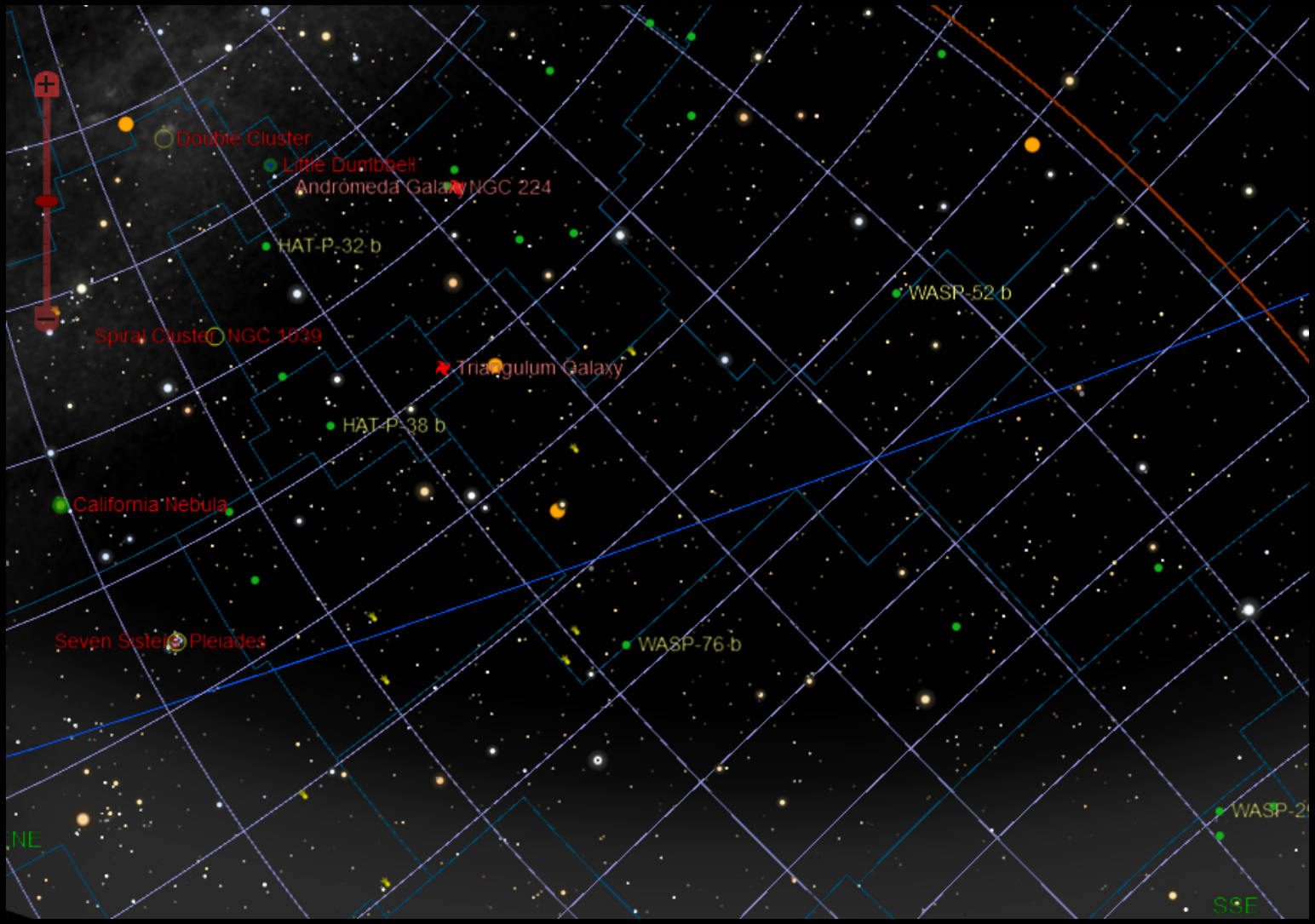
The AAVSO
(American Association of Variable Star Observers)

- Founded in 1911:
  - traditional focus: observing and archiving data on variable stars
  - users: professional astronomers and research scientists
  - foster and support pro/am collaborations

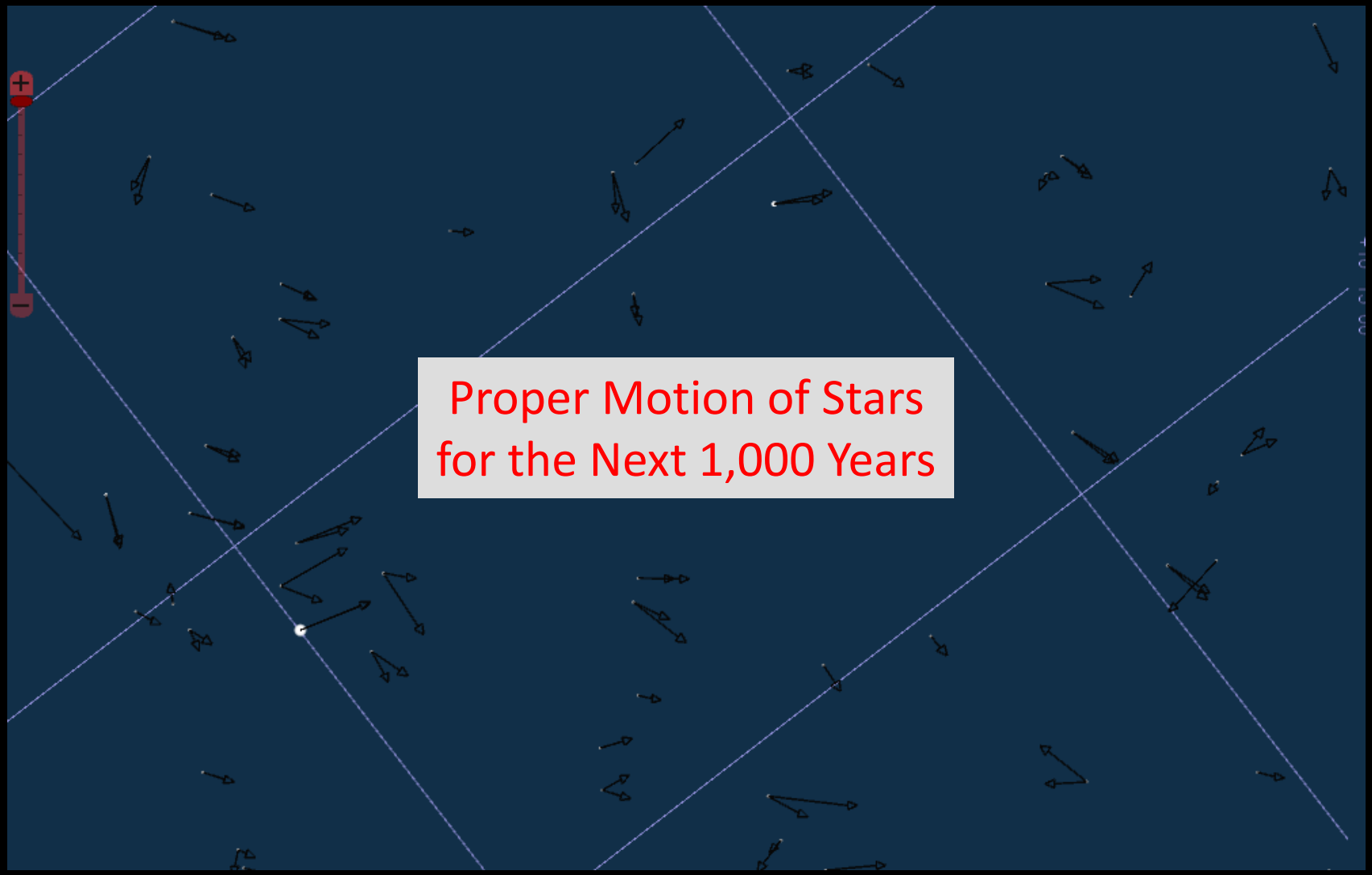
- In 2015, established an Exoplanet Section

- Section's purpose: help observers conduct research-grade, exoplanet observations

The Night Sky Tonight



The Sky is a Very Active Place!!

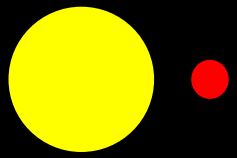


Some Interesting Facts

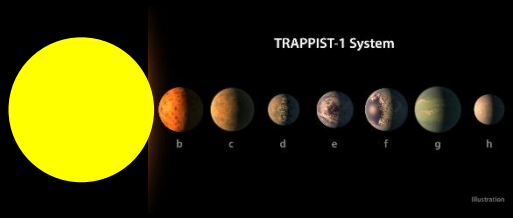
- There are as many planets as there are stars
- Planets are diverse in mass, density, and composition
- Some planets are tidally locked to their parent star
- More than 50% of stars have one or more companion star
- Planets in multi-star systems are quite common
- Some binary stars eclipsing each other can look like a planet transiting a host star

The Strange World of Exoplanets

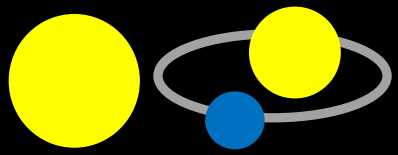
- Most exoplanets we have discovered are close-in, large planets: “Hot Jupiters”



- Some stars have multiple planets

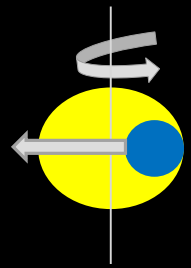


- Some planets orbit a star in a multiple star system

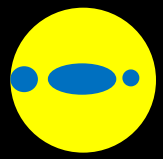


- Some “planets” are free-floating

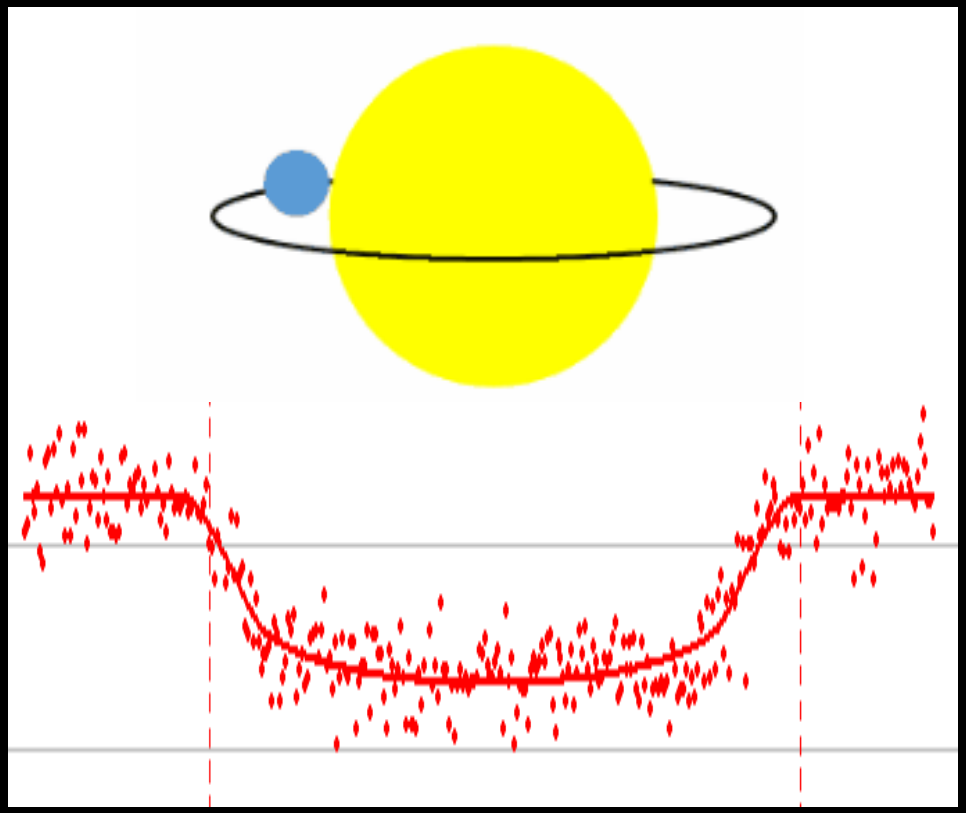
- Some planets’ orbits are opposite from their star’s rotation



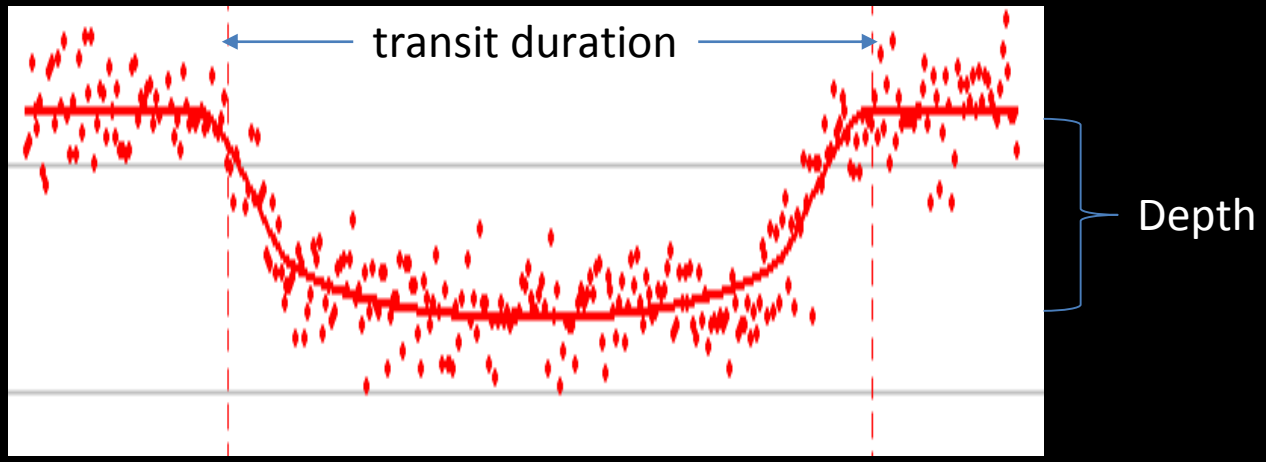
- Some planetesimals are disintegrating around their host star



The Transit Method: The Dominant Method Used by Amateur Astronomers



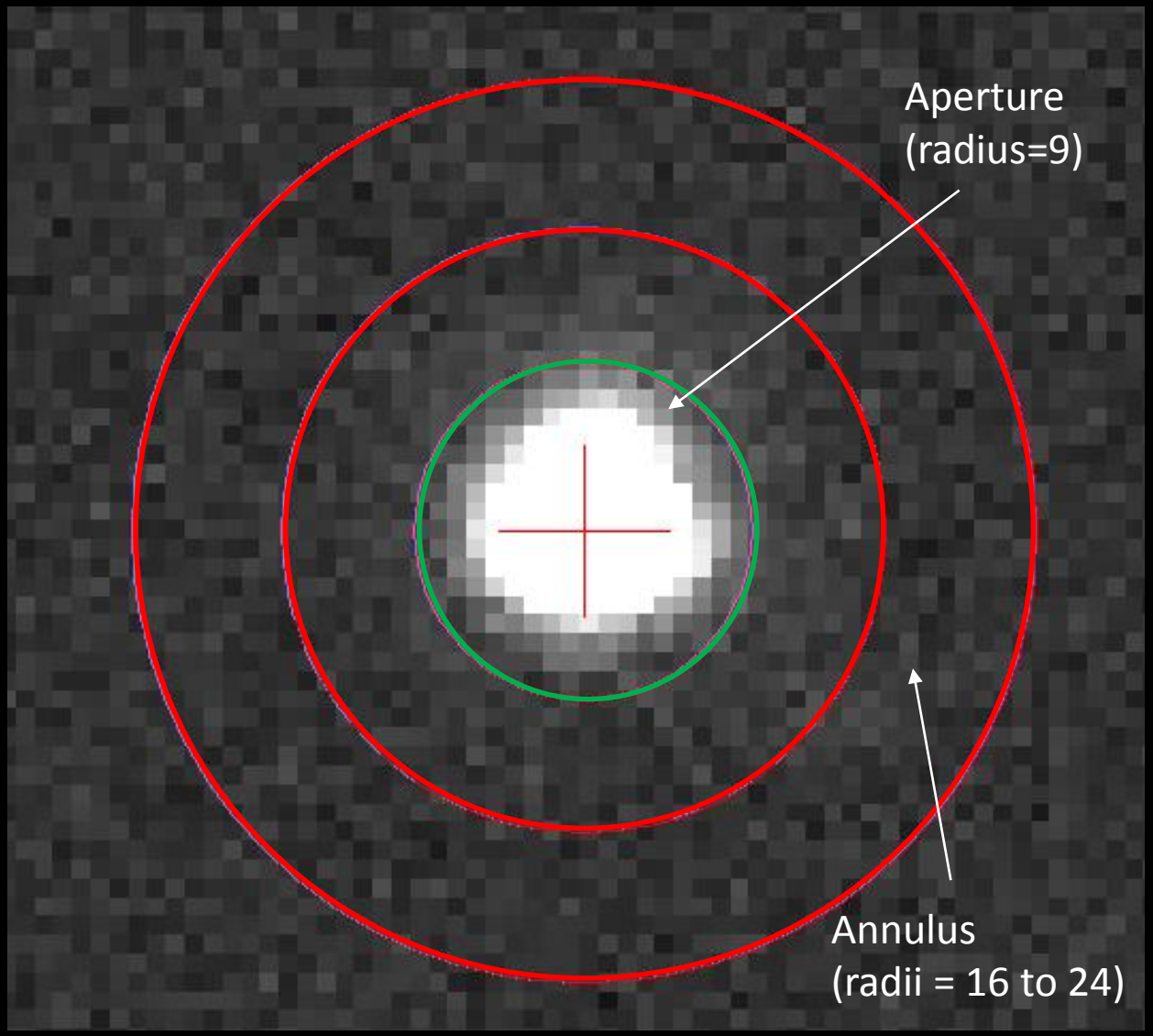
The Transit Light Curve:
A Relative Measure of the Host Star's Brightness (Flux)



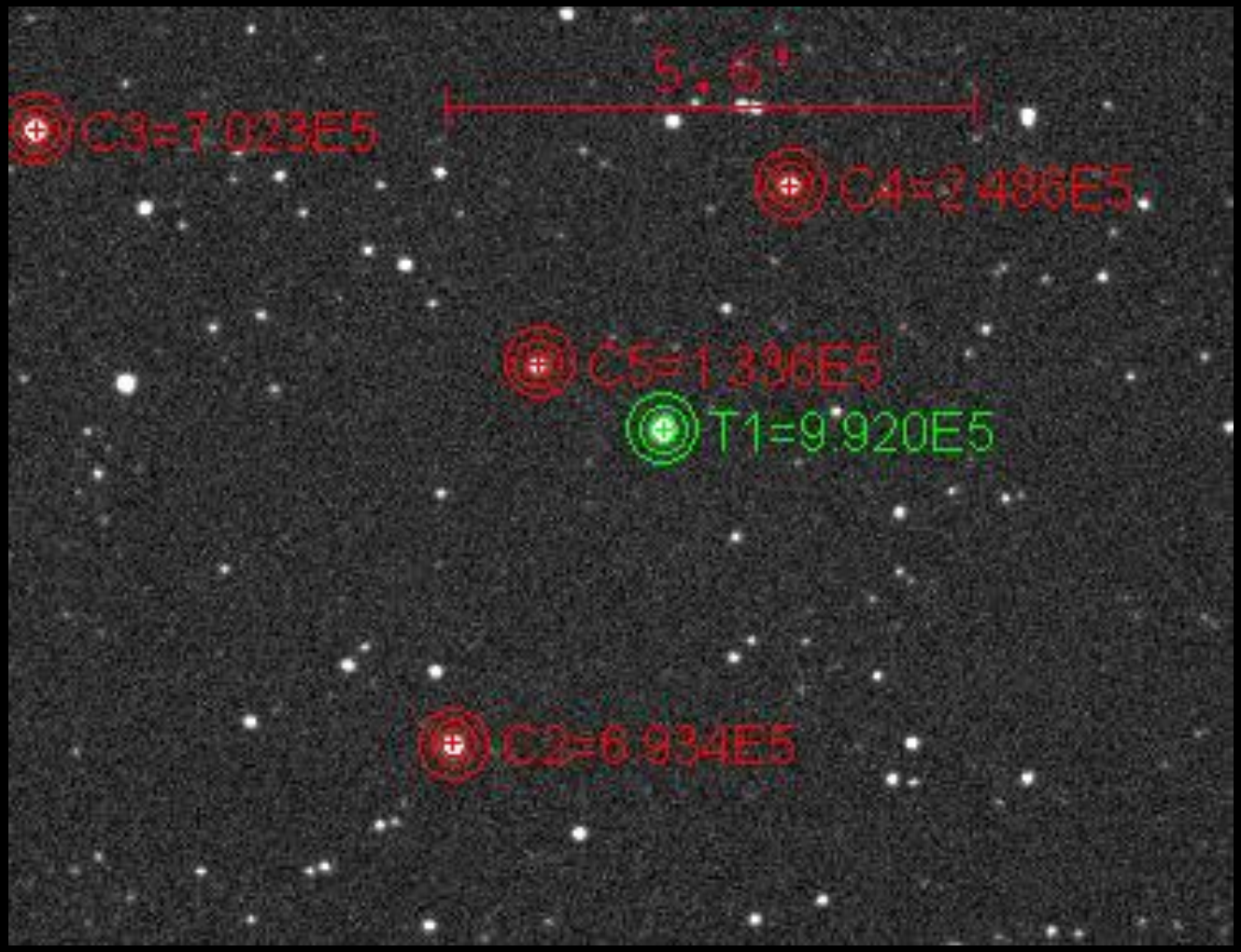
We can learn a lot just from the light curve!

- How big the planet is (its radius)
- How far it is from its host star (the size of its orbit)
- How inclined is its orbit from our line-of-sight
- Whether it is truly a planet or another star

Aperture Photometry



Differential Photometry



Getting a Measure of a Star's Flux

Source Counts from aperture

Sky Background Counts from annulus

Source Counts - Sky Background

$$\text{Relative flux of Target} = \frac{\text{Target's Source Counts - Sky Background}}{\text{Sum of Comp Stars' Source Counts - Sky Background}}$$

Goals: Reduce Systematics and Identify False Positives

- Minimize movement of stars on the CCD detector during a multi-hour observing session:
  - Traditional approach: use off-axis guiding
- Distinguish false positives (example, eclipsing binaries) from true exoplanet transits:
  - An eclipsing binary star may result in different transit depths in different wavelengths
  - Traditional approach: use alternating filters

Traditional Off-Axis Guiding

Guide Camera

Visible+NIR

G★

T★

Visible+NIR

Visible+NIR

Pickoff Mirror

Visible+NIR

Imaging Camera

High Precision Autoguiding Techniques

- Goal: minimize movement of target and comp stars during a multi-hour observing session
- Active optics correct for rapid gear errors
- Traditional auto-guiding uses an off-axis guider - field rotation still an issue
- On-axis guiding techniques:
  - use science image as source of guide star (useful when guide corrections times can be = or > science image exposure times)
  - use an on-axis guider (ONAG)

On-Axis Guiding

Imaging Camera

Filter Wheel

Autoguiding Software

Guide Star

Target Star

Visible

ONAG

Visible+NIR

Dichroic Beam Splitter

NIR>750nm

Guide Camera

Innovations Foresight, LLC

Simultaneous, Multi-band Measurements

- Useful in detecting false positives (example, an eclipsing binary vs. a true exoplanet transit)

- Traditional approach: use a single camera with alternating filters
  - Disadvantages: reduces cadence in each band, potential introduction of systematics

- A new approach: repurpose the ONAG to allow for simultaneous measurements in NIR and in one or more visible bands
  - Advantages: maximizes cadence in each band, reduces systematics
  - Supports autoguiding as well!

Using ONAG for Dual-band Measurements

Imaging Camera-1

(Optional)
Guide Camera

Filter Wheel

Alt. 2

Autoguiding Software

Alt. 1

Visible

ONAG

Visible+NIR

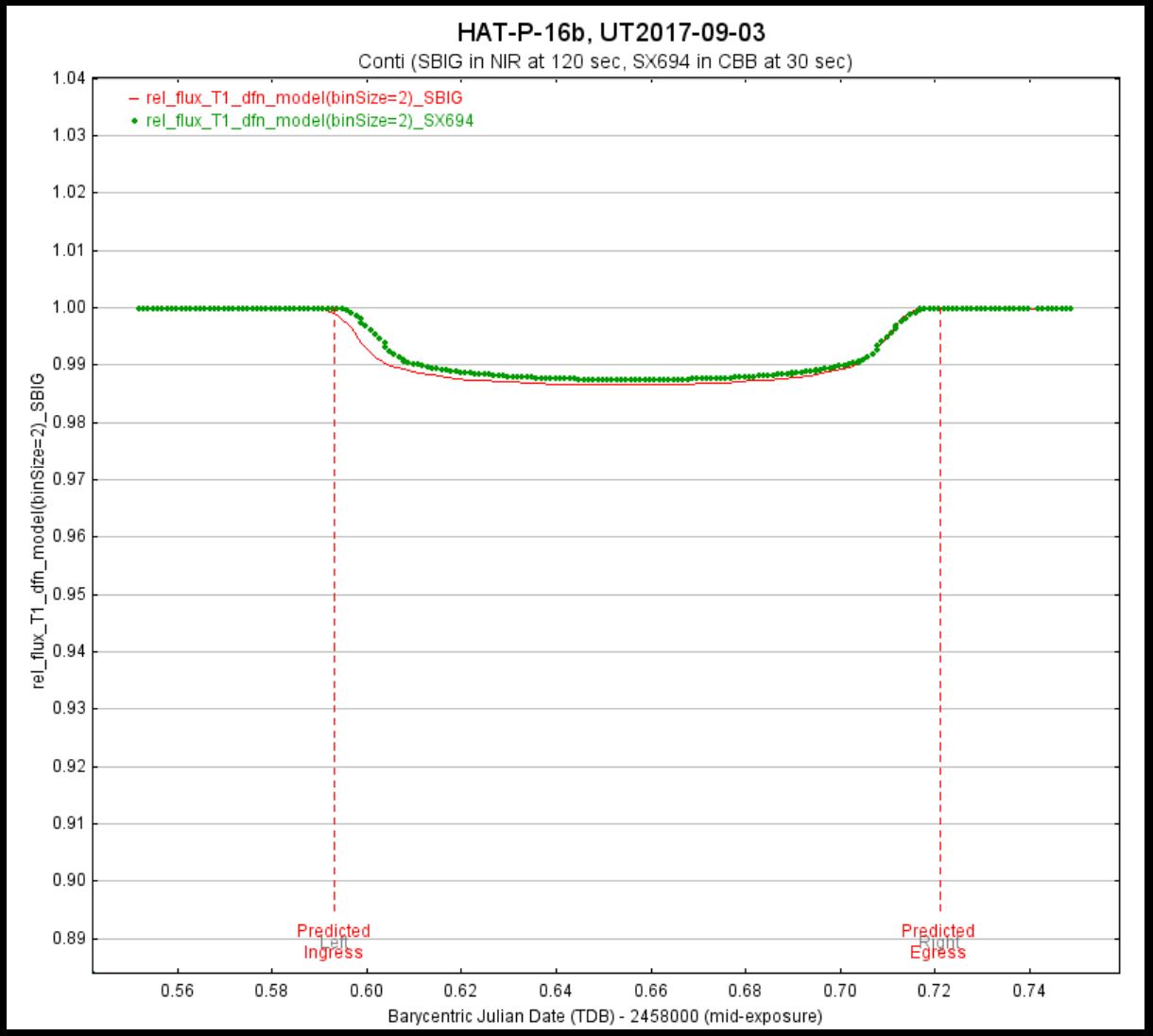
Dichroic Beam Splitter

NIR>750nm

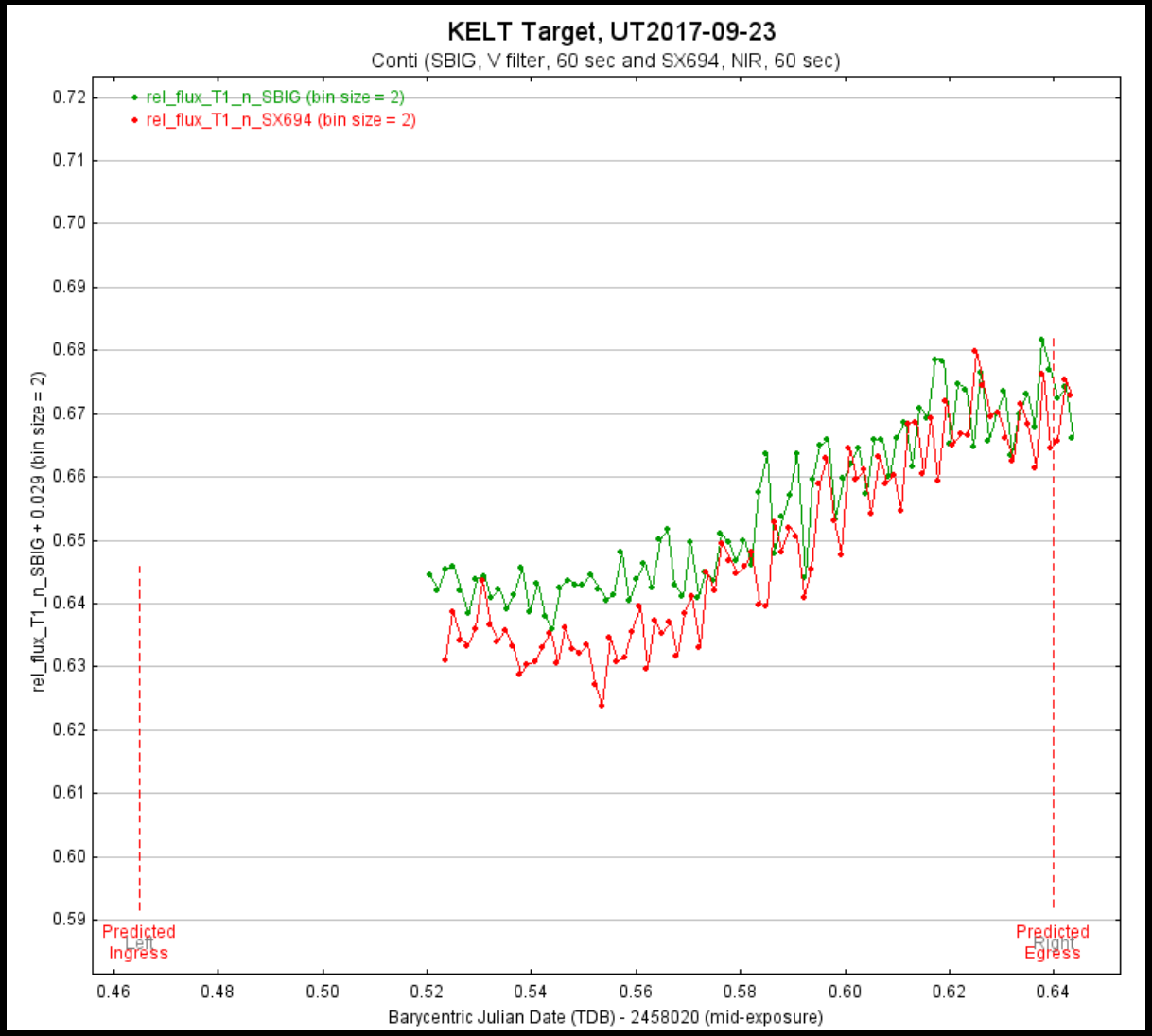
Imaging Camera-2

Innovations Foresight, LLC

Dual Bandwidth Measurements During an Exoplanet Transit

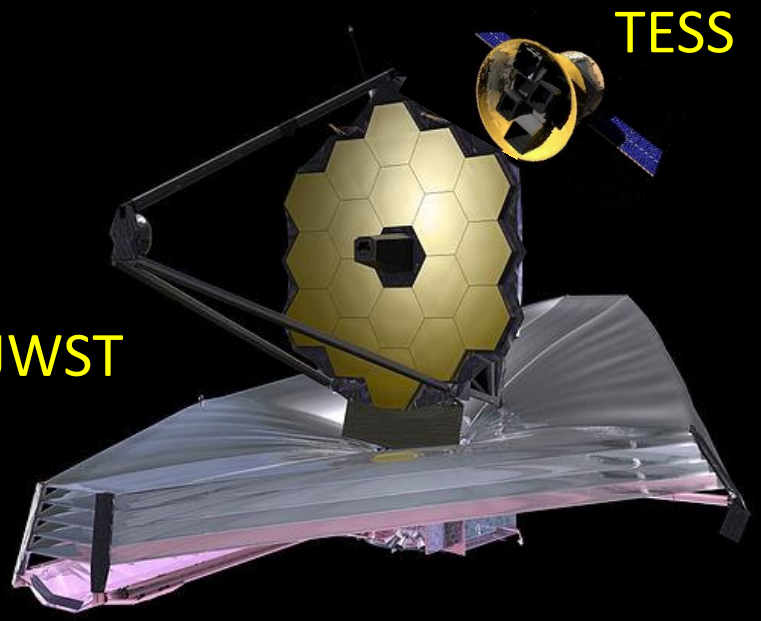


Dual Bandwidth Measurements During an Eclipsing Binary Transit

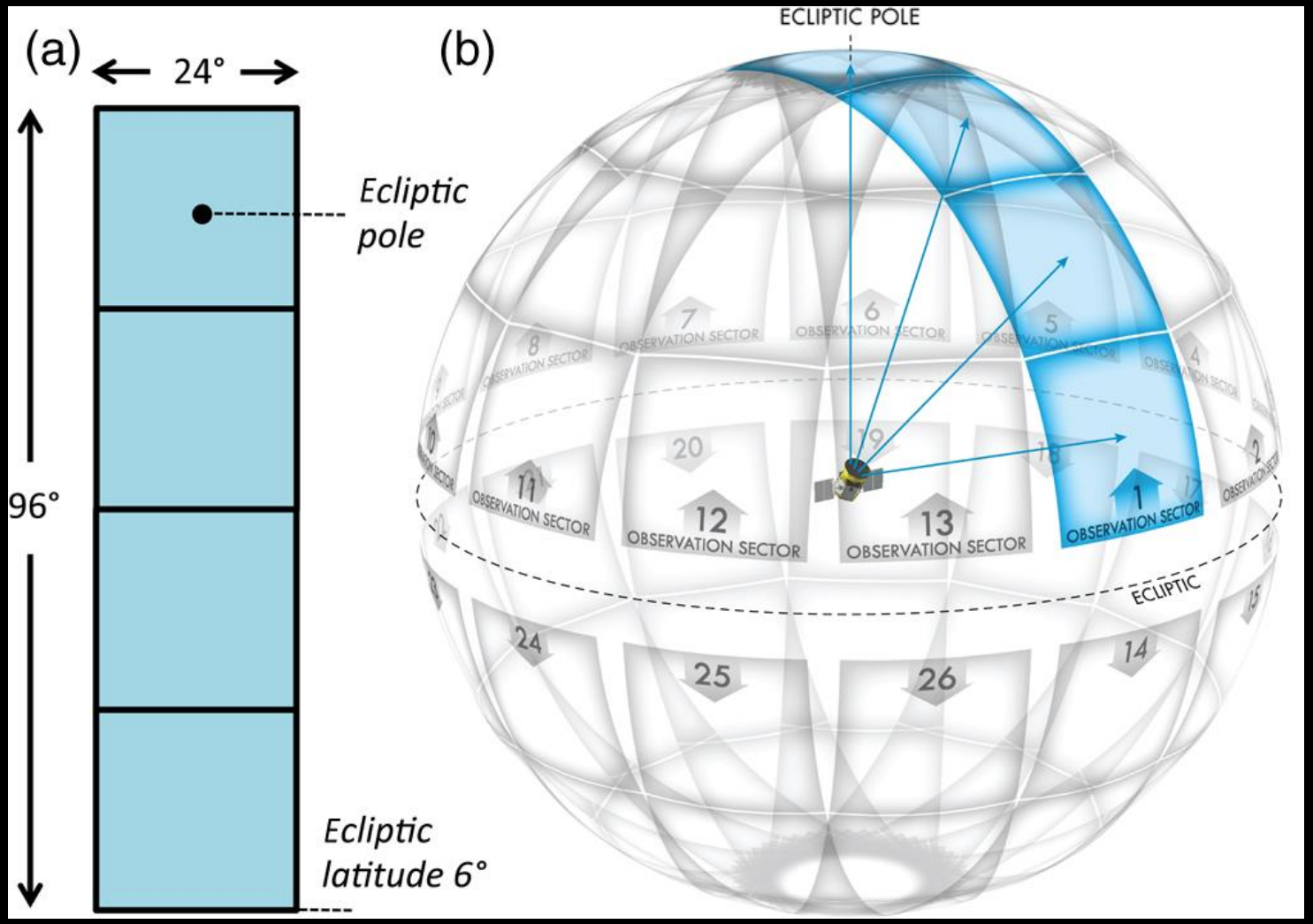


TESS: Transiting Exoplanet Survey Satellite

- All-sky survey of near-by, bright 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):



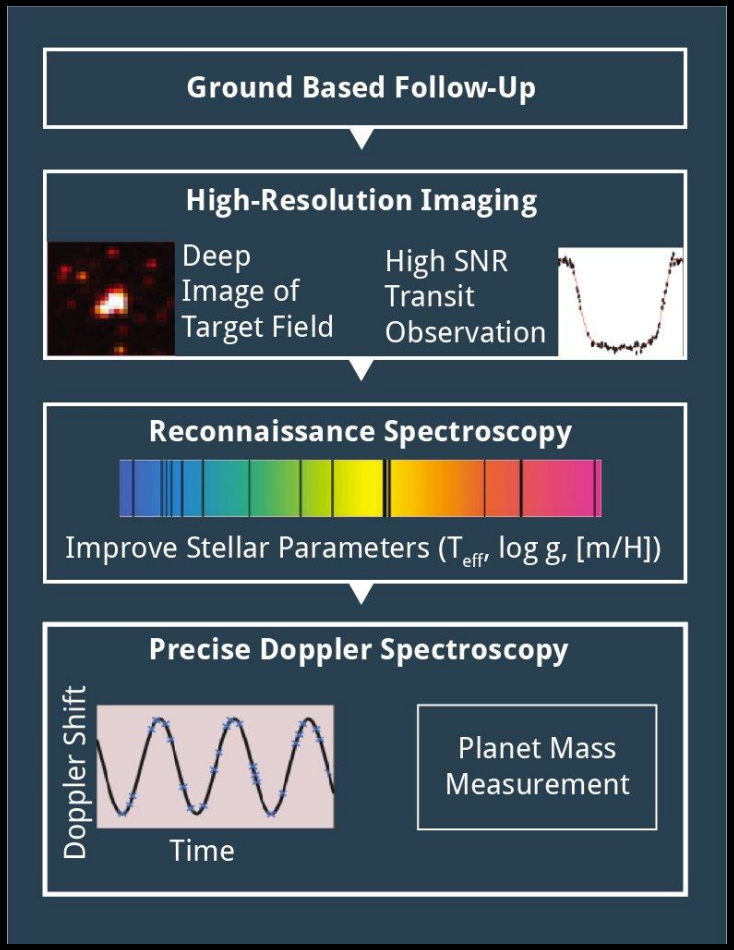
TESS: Transiting Exoplanet Survey Satellite



Scheduled launch: March, 2018

Amateur Astronomer Participation in TESS

- Ground-based observations will be part of the pipeline to help identify false positives

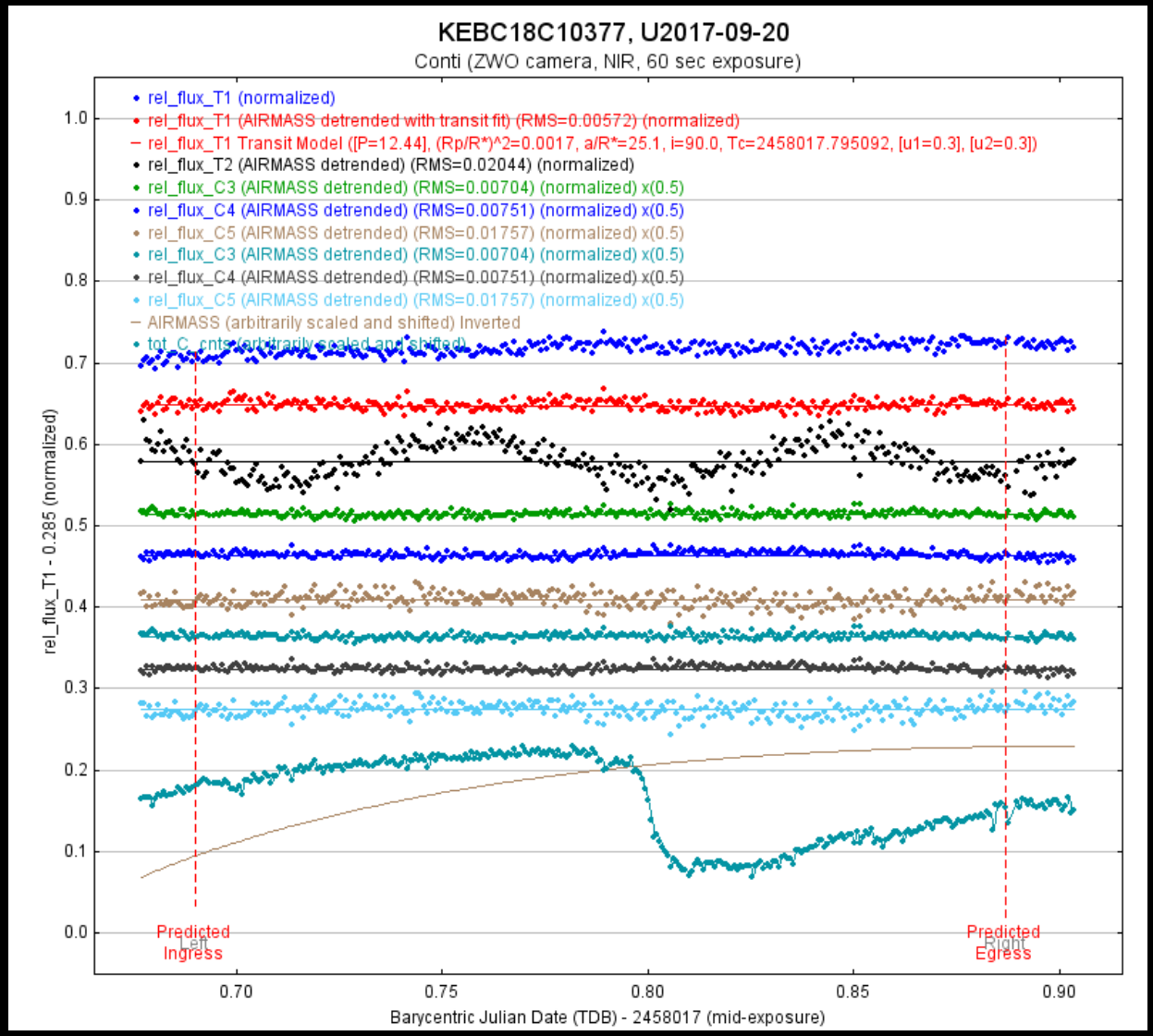


Aids to Help Amateur Astronomers Achieve Higher Precision Exoplanet Observations

- "A Practical Guide to Exoplanet Observing" (www.astrodennis.com)
  - 1,916 unique visiting users from 68 countries
- Training: AAVSO online course on Exoplanet Observing
  - 80 participants to-date
- Tools available:
  - Sample Images
  - Observation worksheet with hot links
  - AstroImageJ for exoplanet processing
- Improved techniques developed for:
  - higher precision autoguiding
  - simultaneous, multi-band measurement

Addendum

Observation with a CMOS Camera



Precision Comparison: Off-Axis vs. On-Axis Guiding

- Conditions:
  - target: HIP 94083
  - location: +76.8° declination, 41° altitude
  - exposures: 548 at 5 seconds for 1 hour
  - polar alignment: excellent
- Results:

	Off-Axis	On-Axis
– Date	6/10/17	6/8/17
– Seeing	2.6”	3.1”
– Tracking error (in RA)	0.41”	0.46”
– Max. deviation:		
at center of FOV	6.3 pixels	1.8 pixels
at edge of FOV	8.1 pixels	3.2 pixels

Under worse seeing conditions, On-Axis Guiding provided a 71% improvement over traditional Off-Axis Guiding!