# Achieving High Precision Transit Observations with Sub-meter Telescopes

Dennis M. Conti

Chair, AAVSO Exoplanet Section
Member, KELT Follow-up Team
Member, TESS TFOP Working Group

Know Thy Star – Know Thy Planet
October 12, 2017

# The AAVSO
# (American Association of Variable Star Observers)

- Founded in 1911:
  - traditional focus: observing and archiving data on variable stars
  - active participants in over 108 countries
  - 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 through:
  - promulgation of "best practices"
  - advances in observing technology and techniques

# Immediate Goal

- Increase the quality and quantity of follow-up observers in preparation for TESS

- Advantages of a large network of qualified observers: increased temporal and geographic coverage of transits

- Goal accomplished through:
  - "best practices" documentation
  - training
  - tools
  - developing and testing new observing techniques, especially to assist with false positive detection

# 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

- 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

Visible

ONAG

Alt. 1

Visible+NIR

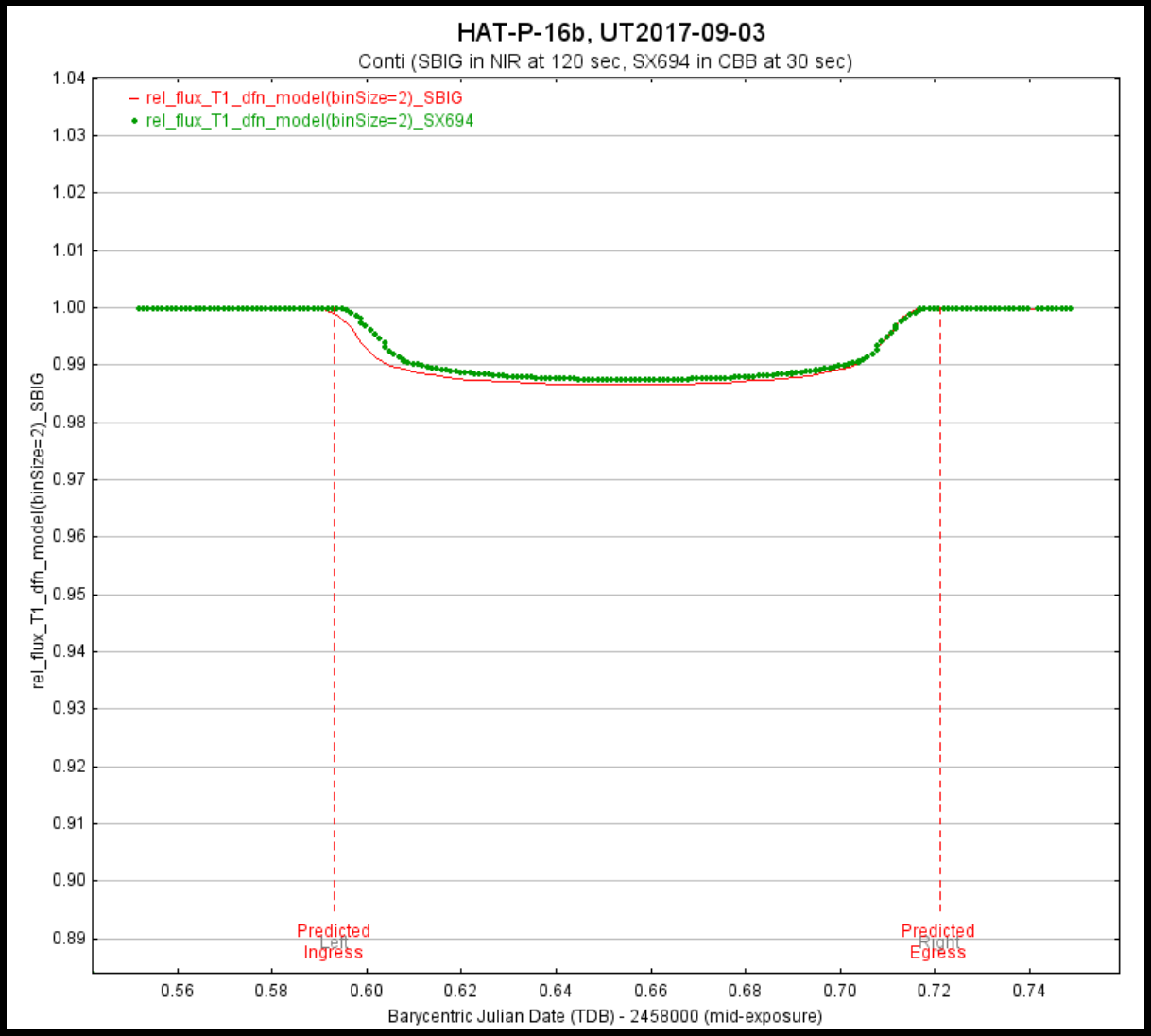
Dichroic Beam Splitter

NIR>750nm

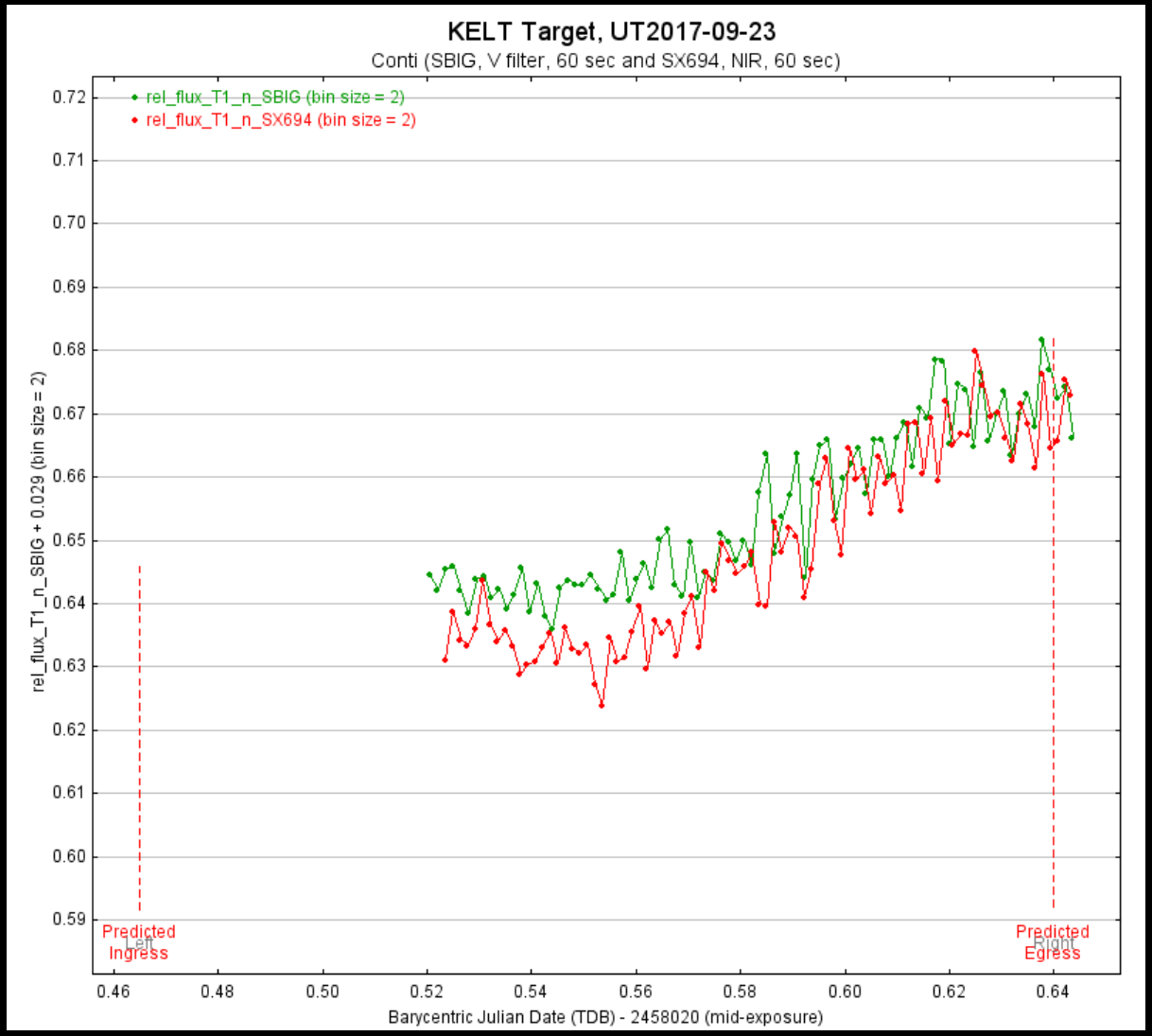
Imaging Camera-2

Innovations Foresight, LLC

# Dual Bandwidth Measurements During an Exoplanet Transit



# Dual Bandwidth Measurements During an Eclipsing Binary Transit



# Summary: Achievements To-Date

- "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:
  - Sample Datasets (Conti)
  - Observation worksheet with hot links (Conti)
  - AstroImageJ for transit modeling (Collins)
  - Speckle Toolbox (Rowe)
- Improved techniques developed for:
  - higher precision autoguiding
  - simultaneous, multi-band measurement

# Addendum

# Traditional Off-Axis Guiding

Guide Camera

Visible+NIR

G★

T★

Visible+NIR

Visible+NIR

Pickoff Mirror

Visible+NIR

Imaging 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!