Achieving High Precision Transit Observations with Sub-meter Telescopes

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Know Thy Star – Know Thy Planet
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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
- ONAG
- Dichroic Beam Splitter
- Guide Camera
- Visible+NIR
- Visible
- NIR>750nm

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Guide Star
Target Star
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

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ONAG (Optional)

Guide Camera

Filter Wheel

Imaging Camera-1

(NIR>750nm)

Visible+NIR

Visible

ONAG

Dichroic Beam Splitter

Visible+NIR

NIR>750nm

Imaging Camera-2

Autoguiding Software

Alt. 1

Alt. 2
Dual Bandwidth Measurements During an Exoplanet Transit

![Graph showing dual bandwidth measurements during an exoplanet transit](image_url)
Dual Bandwidth Measurements During an Eclipsing Binary Transit

KELT Target, UT2017-09-23
Conti (SBIG, V filter, 60 sec and Sx694, NIR, 60 sec)

- rel_flux_T1_n_SBIG (bin size = 2)
- rel_flux_T1_n_Sx694 (bin size = 2)

Predicted Ingress
Predicted Egress

Barycentric Julian Date (TDB) - 2458029 (mid-exposure)
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

Pickoff Mirror

Visible+NIR

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:

<table>
<thead>
<tr>
<th></th>
<th>Off-Axis</th>
<th>On-Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>6/10/17</td>
<td>6/8/17</td>
</tr>
<tr>
<td>Seeing</td>
<td>2.6’’</td>
<td>3.1’’</td>
</tr>
<tr>
<td>Tracking error (in RA)</td>
<td>0.41’’</td>
<td>0.46’’</td>
</tr>
<tr>
<td>Max. deviation:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>at center of FOV</td>
<td>6.3 pixels</td>
<td>1.8 pixels</td>
</tr>
<tr>
<td>at edge of FOV</td>
<td>8.1 pixels</td>
<td>3.2 pixels</td>
</tr>
</tbody>
</table>

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