Exoplanet Observing: From Art to Science

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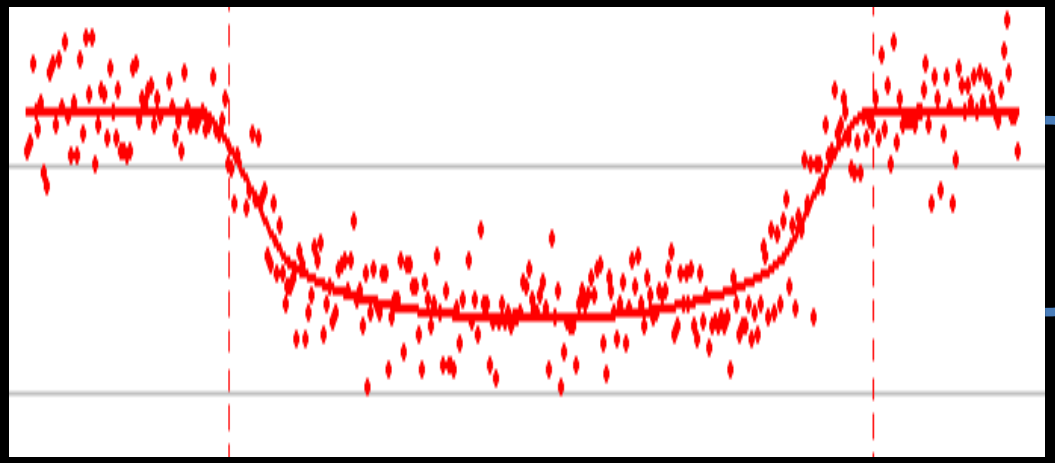
Toward Research-Grade Exoplanet Observations

…due to:

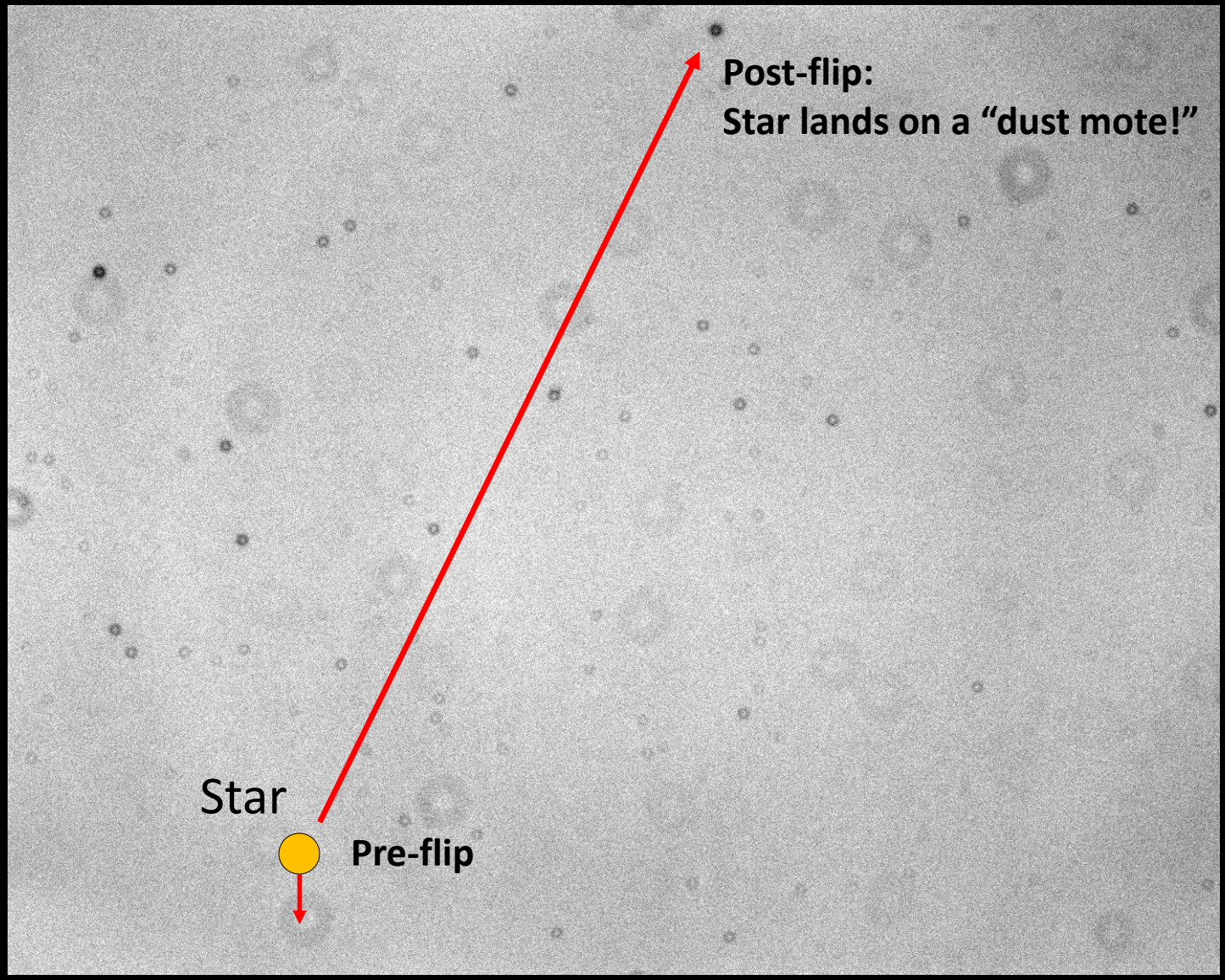
- Experience gained from recent pro/am collaborations
- Refinement of best practices (see SAS 2017 Proceedings)
- Professional software (AstroImageJ) available to amateur astronomers
- New AAVSO training course, material and supporting databases
- Technical advances leading to higher precision

Goal: Achieving Millimagnitude Precision



= 2-9 mmag
(<1% drop)

The Importance of Minimizing Field Movement



Achieving Millimagnitude Precision

- Objective:
  "Hold the field position within a few pixels throughout the (multi-hour) observation"

- Why important?
  Systematics of 10 mmag or larger could be produced due to an (always) imperfect flat field correction

- Factors contributing to field movement:
  - Polar misalignment
  - Mount's periodic error, DEC backlash, tracking errors, etc.
  - Atmospheric seeing conditions

- Solutions:
  - Buy an expensive, high precision mount
  - Move to the Atacama desert
  - Implement advanced autoguiding techniques

Factors Affecting Autoguiding Effectiveness

- Declination of the observation
- Amount of polar misalignment
- Distance from target and comp stars to guide star
- Autoguiding method used

Autoguiding Methods

Effectiveness Reducing Field Rotation

- Use of a separate guide scope: -
  - flexure effects
  - field rotation effects
- Off-axis guiding: +
  - field rotation effects still possible
  - finding guide star could be problematic, especially for GEMs after meridian flips
- On-axis guiding (ONAG): ++
  - guide star is in the same FOV as the target star
  - field rotation is minimal
- Image guiding (future): +++
  - employs ONAG
  - uses entire image for correction vs. a single guide star
- An active optics (AO) unit can be used in conjunction with each of the above to minimize effects of rapid gear errors

Off-Axis Guiding

Guide Camera

Visible+NIR

G★

T★

Visible+NIR

Visible+NIR

Pickoff Mirror

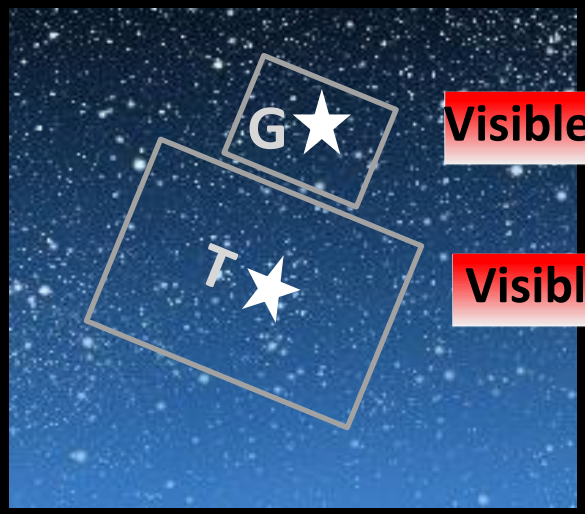
Visible+NIR

Imaging Camera

Off-Axis Guiding

Guide Camera

Visible+NIR



Visible+NIR

Visible+NIR

Pickoff Mirror

Visible+NIR

Imaging Camera

On-Axis Guiding

Imaging Camera

Visible

Visible+NIR

Dichroic Beam Splitter

NIR>750nm

Guide Camera

Innovations Foresight, LLC

On-Axis Guiding

Imaging Camera

Visible

Visible+NIR

Dichroic Beam Splitter

NIR>750nm

Guide Camera

Innovations Foresight, LLC

Benefits of On-Axis Guiding

- Distance between the Guide Star and other stars in the FOV are minimized, and so then is field movement of these stars
- For GEMs after a meridian flip, the Guide Star stays the same
- The Guide Star can = the Target Star, therefore both are affected in the same way by atmospheric turbulence
- Since the effects of seeing are less in the NIR, Guide Star wandering is less than in the visible range

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!

Looking Ahead to TESS
(Transiting Exoplanet Survey Satellite)

- All-sky survey of transiting exoplanets around bright stars
- Planned launch: March, 2018
- TESS will require ground-based observations to eliminate false positives (e.g., nearby eclipsing binaries)
- D. Conti and S. Kafka represent AAVSO on TESS Subgroup-1 (Ground-based Follow-up)
- AAVSO will be establishing a “qualified observer” program for members to upload observations to the ExoFOP-TESS database

Summary

- Best practices are now well-established for amateur astronomers to conduct research-grade exoplanet observing
- New autoguiding techniques are available to minimize star movement, and more are on the way
- TESS provides an opportunity for amateur astronomers to contribute to new exoplanet discoveries
- The AAVSO is preparing to support high quality, follow-up observations for TESS

Resources

1. A Practical Guide to Exoplanet Observing, Dennis M. Conti, http://astrodennis.com
2. Exoplanet Observing for Amateurs, Second Edition (Plus), Bruce L. Gary
3. The Exoplanet Handbook, Michael Perryman
4. The Handbook of Astronomical Image Processing, Richard Berry and James Burnell (comes with AIP4WIN photometry software)
5. The AAVSO Guide to CCD Photometry
6. The AAVSO CCD Observing Manual