Squeezing Blood from the Stone: Maximizing the Performance of Speckle Imaging for Exoplanet Validation at WIYN, Gemini North, and Beyond

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Abstract

The DSSI speckle camera has been used routinely at the WIYN 3.5-m Telescope for Kepler-related observations since 2008, and more recently, at the Gemini North 8.1-m Telescope. We discuss the detection limits of the system at these two facilities, including detection rates for companions as well as typical results for astrometric and photometric precision. In the case of Gemini observations, astrometric precision for a typical 2-minute observation is better than 1 mas. For companions discovered early on in the program, we now have more than 4 years of astrometric data and can make a preliminary assessment about whether the companions are likely to be gravitationally bound. We will also discuss techniques for improving the performance of the system beyond the current limits, and how this could impact its use for further Kepler follow-up and other exoplanet projects.

I. Kepler and Speckle

- *Kepler* follow-up observations include speckle imaging with the Differential Speckle Survey Instrument (DSSI), shown in Figure 1.

- Features of DSSI include
  - Simultaneous two-color imaging.
  - State-of-the-art EMCCD cameras.
  - Diffraction-limited imaging in the visible.

- This instrument has been used 10-15 nights per year at the WIYN Telescope, and in 2012 and 2013 at Gemini North.

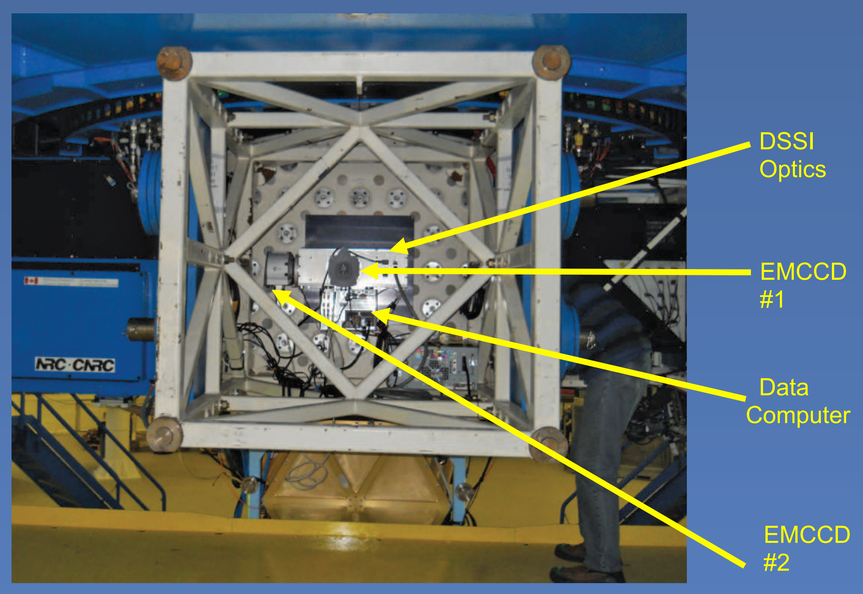

Figure 1: The Differential Speckle Survey Instrument (DSSI) mounted at Gemini.

II. Results from Gemini North

- Limiting magnitude (of primary star) 16.0-16.5 depending on observing conditions and observation time.
- Astrometric precision generally ~1 mas.
- 40 KOIs observed to date at Gemini.
- 12 close companions detected.
- Main focus at present: better analysis techniques, for example, analytic continuation in the Fourier plane: unique extrapolation of Fourier components based on the assumption of a black background on the image plane. (See Fig. 2, above right.)
- At right, detection limit curves for DSSI at Gemini (Fig. 3).
- Below, (Fig. 4) reconstructed images from WIYN and Gemini on the same target (KOI 98 = Kepler 14).

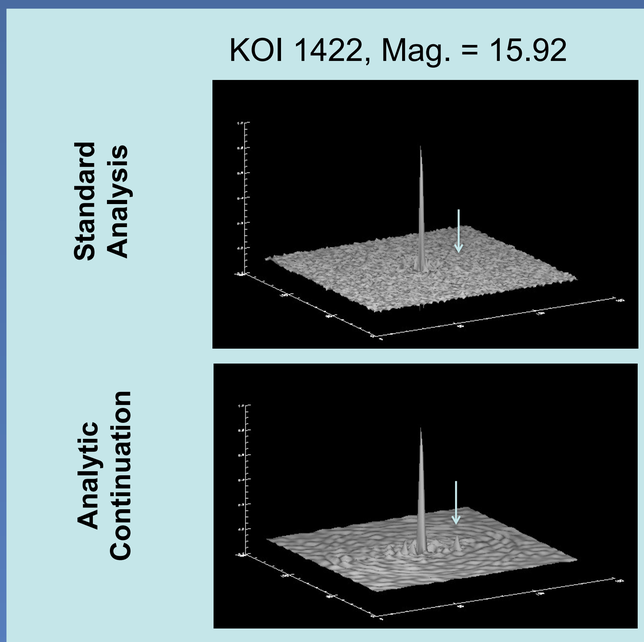

Figure 2: Example of the use of analytic continuation for faint source detection at Gemini.

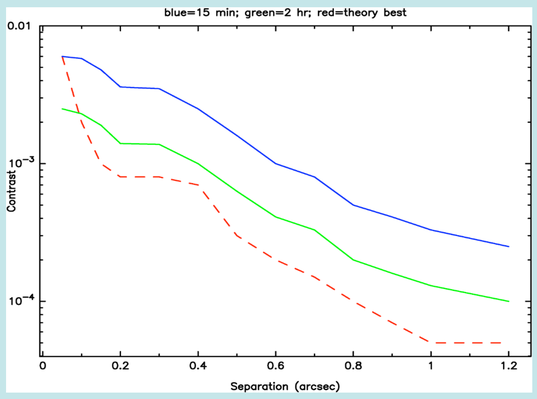

Figure 3: 3-sigma contrast curves for 15 minute (on-source, blue) and 2-hour (on-source, green) speckle observations of a star observed with DSSI on Gemini, and the theoretical best visible light results for an 8-m telescope in space (red).

III. Results from WIYN

- Limiting magnitude (of primary star) for diffraction-limited imaging = 14.0 to 14.5, depending on observing conditions and observation time.
- Astrometric precision generally ~2 mas per observation.
- Over 550 KOIs observed to date.
- ~40 close companions have been discovered.
- Below: Table of astrometric data for four systems discovered at WIYN. ***Given the lack of relative motion and the large proper motion in declination for KOI 98 = Kepler 14, this is clearly a common proper motion pair, highly likely to be gravitationally bound but with a long orbital period.***

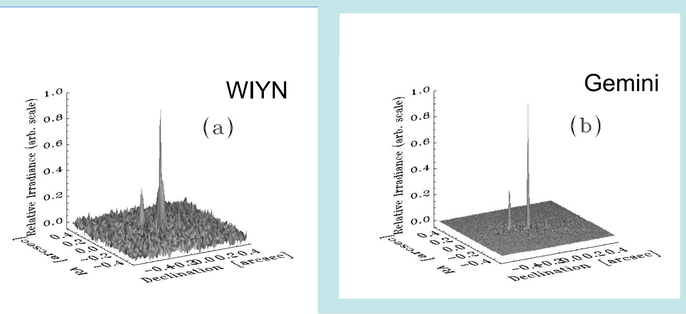

Figure 4: Comparison of WIYN and Gemini data quality. (The source is KOI 98AB, a 12th magnitude object.)

Object	Epoch 1 (UT Date)	Position Angle (degrees)	Separation (arcsec)	Epoch 2 (UT Date)	Position Angle (degrees)	Separation (arcsec)	Rel. Δ(RA) (mas/yr)	Rel. Δ(dec) (mas/yr)	Proper Motion, RA (mas/yr)	Proper Motion, Dec (mas/yr)
KOI 13	19 Jun 2010	279.7	1.165	28 May 2013	279.1	1.160	+1.0±1.0	-4.4±1.0	+1.0±1.3	-10.2±1.0
KOI 98 (Kepler 14)	19 Jun 2010	143.7	0.290	28 May 2013	143.8	0.287	-0.7±1.0	+0.7±1.0	+0.6±2.4	-17.4±2.1
KOI 258	19 Sep 2010	72.8	1.014	21 Sep 2013	72.6	1.018	+0.9±1.0	+1.5±1.0	-1.6±1.2	4.0±1.1
KOI 976	13 Jun 2011	316.5	0.259	21 Sep 2013	315.5	0.253	+0.4±1.3	-3.3±1.3	3.5±1.3	-6.0±1.3

(Proper motions from UCAC3, Tycho, and Tycho-2 Catalogs.)

IV. What's Next?

- **We will bring DSSI to the DCT at Lowell Observatory in spring of 2014, and to Gemini North in the summer of 2014. See the poster in this session by van Belle et al. for more information on speckle at DCT.**
- **Based on collection area, we should be able to go ~0.5 magnitudes fainter at DCT relative to WIYN while achieving slightly higher resolution (40 mas at λ=692 nm versus 50 mas at WIYN).**
- **Diffraction-limited imaging at DCT will be sufficient for confirmation of all Neptune- and larger-sized planets.**

References

Horch, E. P. et al. 2012, AJ, 144,165
Howell, S. B. et al. 2010, AJ, 142, 19