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.

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).

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.

<table>
<thead>
<tr>
<th>Object</th>
<th>Epoch 1 (UT Date)</th>
<th>Position Angle (degrees)</th>
<th>Separation (arcsec)</th>
<th>Epoch 2 (UT Date)</th>
<th>Position Angle (degrees)</th>
<th>Separation (arcsec)</th>
<th>Rel. Δ(RA) (mas/yr)</th>
<th>Rel. Δ(dec) (mas/yr)</th>
<th>Proper Motion, RA (mas/yr)</th>
<th>Proper Motion, Dec (mas/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KOI 13</td>
<td>19 Jun 2010</td>
<td>279.7</td>
<td>1.165</td>
<td>28 May 2013</td>
<td>279.1</td>
<td>1.160</td>
<td>+1.0±1.0</td>
<td>+4.4±1.0</td>
<td>+1.0±1.3</td>
<td>-10.2±1.0</td>
</tr>
<tr>
<td>KOI 98 (Kepler 14)</td>
<td>19 Jun 2010</td>
<td>143.7</td>
<td>0.290</td>
<td>28 May 2013</td>
<td>143.8</td>
<td>0.287</td>
<td>-0.7±1.0</td>
<td>+0.7±1.0</td>
<td>+0.6±2.4</td>
<td>-17.4±2.1</td>
</tr>
<tr>
<td>KOI 258</td>
<td>19 Sep 2010</td>
<td>72.8</td>
<td>1.014</td>
<td>21 Sep 2013</td>
<td>72.6</td>
<td>1.016</td>
<td>+0.9±1.0</td>
<td>+1.5±1.0</td>
<td>-1.6±1.2</td>
<td>4.0±1.1</td>
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<tr>
<td>KOI 976</td>
<td>13 Jun 2011</td>
<td>316.5</td>
<td>0.259</td>
<td>21 Sep 2013</td>
<td>315.5</td>
<td>0.253</td>
<td>+0.4±1.3</td>
<td>-3.3±1.3</td>
<td>3.5±1.3</td>
<td>-0.6±1.3</td>
</tr>
</tbody>
</table>

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

IV. What’s Next?

- We will bring DSSI to the DCT at Lowell Observatory in summer 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