Robo-AO to IRTF
Rapid near-HST resolution imaging from the ground

Christoph Baranec
Institute for Astronomy, University of Hawai‘i
PI: Robo-AO, Robo-AO-2
Alfred P. Sloan Research Fellow
Robo-AO

Fully robotic laser AO
Sub-minute overheads
Performing previously infeasible AO surveys, \( N > 1,000 \)
Diff.-limited, 0.12", on \( V < 16 \) point sources
Detects \( \Delta m \approx 5 \) at 0.5"

Baranec, et al., 2013, 2014
Robo-AO is fully automated.

- 20+ 2-min. observations per hour
- .xml observation request database
- Intelligent obs. queue, mixes science programs, incorporates ToOs/monitoring
  - Automatic satellite/laser deconfliction
- Automatic data reduction and analysis pipeline (Reduced images are ready the next day!!)
Routine Planetary Science

- Binary asteroid population studies for mV ≤ 17
- Precision astrometry of NEAs (prop. D. Duev, CIT)
- Small body nucleus characterization, exopause searches, surface mineralogy (K. Meech, et al.)
- Monitoring of ice giants in preparation of Neptune / Uranus Orbiter and Probe (next priority NASA flagship mission).
Robo-AO/Kepler survey

NASA XRP NNX15AC91G PIs: Law, Baranec & Morton.

Kepler pixels are ~4”.
Photometric apertures can be 3 by 3 pixels.
Unresolved sources contaminate transits.
We used Robo-AO to image all 3,857 KOIs.
Public access to reduced data at roboaokepler.org

Survey papers in publication:
Law et al. (2014)
Baranec et al. (2016)
Ziegler et al. (2017)
Ziegler et al. (submitted)

Below are centered cutouts from the high-resolution images of the ~3800 Kepler planetary candidates observed by Robo-AO thus far. Detected nearby stars are circled.

Click on a star to be taken to the KOI page.
KOI-1150
Confirmed planet
Kepler-786 b

Robo-AO 8-arcsec centered cutout image of KOI-1150 with any detected nearby stars circled (Law et al. 2014)

USIRFT 1-arcmin field centered on KOI-1150

Robo-AO 5-sigma detection sensitivity for KOI-1150

Nearby star properties

<table>
<thead>
<tr>
<th>Separation (')</th>
<th>Position Angle (deg)</th>
<th>LP600 Contrast (mag)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.39</td>
<td>312</td>
<td>2.41</td>
<td>Law et al. (2014)</td>
</tr>
</tbody>
</table>

Planet properties (Kepler DR23)

<table>
<thead>
<tr>
<th>Planet</th>
<th>Disposition</th>
<th>Period (days)</th>
<th>Radius (R_Earth)</th>
<th>Epoch (B/D)</th>
<th>Transit duration (hrs)</th>
<th>Transit depth (ppm)</th>
<th>Eq. Temp. (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
How get Robo-AO on the IRTF:

- Caltech/U. Hawaii provides:
  - Hardware ($600K) Software ($1M+)
  - New IR APD camera (D. Hall, NASA/NSF)
  - $200K in new optical relay, structure, misc. parts
  - $150K in contract SW and grad student support
  - 1200-1500 hours of part time IRTF FTE engineering
Robo-AO permanently mounted above the MIMS. Available anytime with mechanized fold mirror.
Mounting of laser/periscope

Mount a small periscope to bring laser near edge of primary

Need three large bolt holes for laser platform
Robo-AO to IRTF Modifications

- Instrument mounting
- Electronics rack
- Temperature control for laser projector
- Mounting laser projector (and periscope?)
- Optical relay design change
- Secondary mirror requirements / transmission of primary
- Telescope TCS interface
- Interface with Laser Traffic Control System
Baseline Performance Estimates

- Dominated by Focal Anisoplanatism

- Typical 75% cond. (1") with WFE ~200 nm (25deg)
  - \( r = 2\%, \ i = 6\%, \ H = 54\% \)

- Median conditions (0.65") WFE ~150 nm
  - \( r = 10\%, \ i = 20\%, \ H = 70\% \)
Future Robo-AO fed IR IFS

Higher SNR observations and/or increases efficiency

0.15″ spaxels (9″×9″), R~100, λ = 0.84 – 1.83 μm

Rapid Transient Surveyor
arXiv:1606.07456

 Quickly classify NEAs discovered by ATLAS, etc.

S. Wright (UCSD), S. Chen (Dunlap)
Mahalo no kou manawa!

http://robo-ao.org