Precise Radial Velocity Survey with IRD
Search for Planets like Earth around Late-M Dwarfs:
Precise Radial Velocity Survey with IRD

PI: Bun’ei Sato (Tokyo Institute of Technology)
Co-PI: Nagayoshi Ohashi (NAOJ, Subaru)


Summary

- InfraRed Doppler instrument (IRD)
  - A high-dispersion (R=70,000) near-infrared spectrograph for Subaru telescope
  - Currently RV precision of ~2 m/s is achievable for M dwarfs

- IRD-SSP
  - Aiming at detecting earth-mass (~1-3M_{earth}) planets in habitable zone around late-M dwarfs, and unveiling planet population in wide range of mass and orbit around late-M dwarfs
  - We expect to find ~60 planets in 60 sample stars by 5-year (175 nights; 35 nights/year) survey.
  - The first-two-year survey (19A-20B; 70 nights) is now officially approved.
  - Observations have been conducted almost every month since this February.
  - The first screening observation is now ongoing.
Overview of the IRD instrument

- **Fiber injection system (AO bench)**
- **Laser frequency comb (IR Observing floor)**
- **Mode scrambler**
- **Resolution**: R=70000
- **Wavelength**: 0.97-1.75μm
- **Cryo**: 80K (detector), 180K (optics)

**Details**

- **Star light From AO**
- **Fiber (Comb)**
- **Fiber (star)**
- **Coudé Room**
- **Spectrometer system (Coudé room)**

**Graphs**

- **Frequency stability**: < 0.7 MHz/week
- **Comb spacing**: 12.5 GHz
- **Contrast**: > 20 dB
- **Wavelength range**: 970 nm to 1750 nm
- **Contrast**: 11,000 lines
GJ 436 (M3V)

July, 2018
RV precision and stability

- Long-term monitoring of Barnard’s star (GJ699; M4V)

<table>
<thead>
<tr>
<th></th>
<th>Total error</th>
<th>Internal error</th>
<th>Instrument + activity error</th>
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</thead>
<tbody>
<tr>
<td><strong>All data</strong></td>
<td>4.1 m/s</td>
<td>1.8 m/s</td>
<td>3.7 m/s</td>
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<tr>
<td><strong>Selected data</strong></td>
<td>2.7 m/s</td>
<td>1.8 m/s</td>
<td>2.0 m/s</td>
</tr>
</tbody>
</table>

※SN~170
RV monitoring of planet-host stars

### 51 Peg

<table>
<thead>
<tr>
<th>Spectral type</th>
<th>G2IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planet mass ($m_p \sin i$)</td>
<td>$0.466 , M_{\text{Jup}}$</td>
</tr>
<tr>
<td>Period</td>
<td>$4.23$</td>
</tr>
<tr>
<td>$K$ (m/s)</td>
<td>$55.4 \pm 1.4$ (IRD)</td>
</tr>
<tr>
<td></td>
<td>$54.93 \pm 0.18$ (Birkby et al. 2017)</td>
</tr>
</tbody>
</table>

### GJ436

<table>
<thead>
<tr>
<th>Spectral type</th>
<th>M3V</th>
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</thead>
<tbody>
<tr>
<td>Planet mass ($m_p \sin i$)</td>
<td>$21.36 , M_{\text{Earth}}$</td>
</tr>
<tr>
<td>Period</td>
<td>$2.644$</td>
</tr>
<tr>
<td>$K$ (m/s)</td>
<td>$16.4 \pm 1.0$ (IRD)</td>
</tr>
<tr>
<td></td>
<td>$17.38 \pm 0.17$ (Trifonov et al. 2018)</td>
</tr>
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Purposes and goals of IRD-SSP

- **Purposes**
  - Detecting earth-mass ($\sim 1-3M_{\text{Earth}}$) planets in habitable zone around nearby late-M dwarfs for future characterization
  - Understanding planet formation and evolution (e.g. orbital migration) across snow line by unveiling planet distribution in wide range of mass and orbit around late-M dwarfs

- **Goals**
  - Detecting a habitable-zone earth-mass planet around a late-M dwarf
  - Unveiling distribution of
    - earth-mass planets in $P<100$ d
    - super-earths in $P<300$ d
    - giant planets in $P<1000$ d across slow line
Sample

- D<25pc, M=0.08-0.25☉, J<11.5, no Ha emission ➔ 150 stars were selected by low-resolution spectroscopy

- Double-line spectroscopic binaries and rapid rotators will be screened out by initial observations with IRD

- Best 60 stars will be selected for IRD survey

![Sample chart](image-url)
We expect to find \(~\)60 planets in 60 stars by 175-nights observations.

The number of the expected planets depend on adopted theoretical models of planet formation and evolution.
Summary of February – July 2019

- **Allocated nights**
  - 2/18(2nd), 19(2nd), 20(2nd), 21(2nd), 22(2nd), 23(2nd), 24(2nd)
  - 3/21(2nd), 22(2nd), 23(2nd)
  - 4/17(full), 18(2nd)
  - 5/18(1), 19(2), 20(2), 22(f), 24(1), 25(1), 26(1)
  - 6/15(f), 16(1st), 17(1st), 18(2nd), 19(2nd), 20(2nd), 21(2nd), 26(2nd)
  - 7/11(1st), 14(2nd)

- **Cumulative allocated nights**
  - 16.5 nights from S19A

- **Rough success rate**
  - ~77% (12.7/16.5 nights)

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### Observed stars

| stars observed once | 28 |
| stars observed twice | 16 |
| stars observed 3 times | 16 |
| stars observe >3 times | 11 |

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### Current progress of observation

<table>
<thead>
<tr>
<th>Month</th>
<th>Feb.</th>
<th>March</th>
<th>April</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allocated</td>
<td>3.5 nights</td>
<td>1.5 nights</td>
<td>1.5 nights</td>
</tr>
<tr>
<td>Observed</td>
<td>0.5 nights</td>
<td>~1.5 nights</td>
<td>~1.5 nights</td>
</tr>
</tbody>
</table>

### Numbers of Allocated nights and results in S19A

<table>
<thead>
<tr>
<th>Month</th>
<th>May</th>
<th>June</th>
<th>July</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allocated</td>
<td>4 nights</td>
<td>4.5 nights</td>
<td>1 nights</td>
</tr>
<tr>
<td>Observed</td>
<td>3.7 nights</td>
<td>~4 nights</td>
<td>1.5 nights</td>
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</table>
IRD Screening: Planet candidates?

- Moderately large ($\sigma \sim 12$ m/s) RV variations

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**Preliminary results**

<table>
<thead>
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<th>JD - 2454833</th>
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IRD Screening: AO images

- To check existence of visual companions in the images of IRD-FIM
  - e.g. A companion with contrast ratio 1:7 = M4 : M7
  - Angular separation = 0.2", distance 17.7pc → 3.5AU (P~13.5yr)
IRD Screening: Spectral shape

From HR spectra we also check Activity indicators (line shape, Pachen, He I Metallicity)
IRD Screening: Spectroscopic binary

Median RV Error = 6.48 m s$^{-1}$
RV Standard Dev. = 8690.61 m s$^{-1}$

~20 km/s
IRD Screening: Target candidates

- NOT visual binary
- NOT spectroscopic binary
- Rotation is slow
- Small RV jitter

Long term RV monitor to search for planets

Preliminary results
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