Radial-velocity search for exoplanets around metal-rich stars

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Who is he?

• Hiroki Harakawa
  • 3/2014: Got Ph.D at Tokyo Institute of Technology
  • Supervisor: Bun’ei Sato

• Major: Search for exoplanets

• Now: TMT project office
Discovered exoplanets

- different sensitivity in each method
- Radial-Velocity (RV) method is one of the promising methods in wide range parameters
Radial Velocity method

• an indirect detection method for exoplanets
• gravitationally pull each other (planet-star) ⇒ star is wobbled by the planet
• RV varies periodically ⇒ precise Doppler-shift measurement
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Giant planet formation

- Two formation processes
  - core-accretion model
    - efficient in inner region (< 10 AU)
  - disk gravitational instability
    - efficient in outer region (> 30 AU)

- RV method can detect planets in inner region (<5 AU)
  - the detected gas-giants should be formed by core-accretion process

(e.g.) Mizuno (1980); Pollack et al. (1996)
(e.g.) Boss (1997); Mayer et al. (2002)
Core-Accretion model

- pass through many physical processes
  - solid-cores grow beyond snow-line (~3AU@Solar system)
    ⇒ gas accretion
    ⇒ gas-giants form

- inward orbital migration (e.g. Lin & Papaloizou, 85)
  until disk-gas dissipates (~10Myr) (Haisch+01)

⇒ disk lifetime may control the inward migration

- Multiple planets ⇒ planet-planet scattering (e.g. Nagasawa+ 08)
  - cause of Hot-Jupiters and distant planets (>10AU)

- Planet formation should have evolutorial trends of planet formation from various conditions
  (e.g. metallicity, stellar mass)
Planet occurrence vs. [Fe/H]

- Solar-type stars (0.7-1.3M☉)
- increase exponentially

Fischer & Valenti 2005
Planet occurrence vs. stellar mass

- $a_p < 2.5$ AU

- intermediate mass stars ($1.5-2.0\,M_\odot$)
- proportional to host-stellar mass

Johnson+ 07,10
Comparison with theories

- Population Synthesis, e.g. Ida & Lin 04
  - Mordasini+09
  - Superpose Monte-Carlo simulations through many physical processes
  - Regenerate planet dist.

- Orbital migration and Disk-dissipation
  - Calculate orbital evolutions taking account of the precise disk dissipation process

Necessary to know planet dist. without any obs. biases, and its correlation with stellar properties
$m_p, a_p$ dist. for solar-type stars

- estimate empirical dist. as power-law function taking account of detection-limits

$$dN = CM^\alpha P^\beta d \ln M d \ln P$$

- integrated studies for planet dist.
  - although further investigation for the correlation to host stellar properties is needed
\( m_p, a_p \) dist. for IMS stars

\[ dN = CM^\alpha P^\beta d \ln M d \ln P \]

- IMS stars (1.5-2.0 M\( \odot \))
- 1\( \sigma \) confidence area
- solar-type stars Cumming+ 08
- Bowler+ 10

- tend to host massive and distant planets
- only one Hot-Jupiter is detected at IMS stars
Previous works

<table>
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<tr>
<th>integrated</th>
<th>stellar mass</th>
<th>metallicity</th>
</tr>
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<tbody>
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<td>(J07,10)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>(B10)</td>
<td>✓</td>
<td>X</td>
</tr>
</tbody>
</table>

planet dist. vs. [Fe/H] is still unknown
Why we should consider Metallicity?

- Age of cluster (Myr)
  - circumstellar disks in low-metallicity cluster may dissipate in a short time

- Theoretical study for disk evolution taking account of X-ray photoevaporation

- Yasui et al. 2010: Disk dissipate within almost 1 Myr?

- Elcolano & Clarke 2010: Log(Dispersion timescale) [yr] vs. Log((Z/Z\(\odot\))):
  - slope = 0.52

Metallicity may correlate with disk-lifetime \(\Rightarrow\) also with orbital migration?
Why we should consider Metallicity?

• Previous theoretical studies assumed metallicity to be a solid material amount
  ⇒ core-formation timescale is shortened
• metallicity - disk-lifetime correlation
  • may additionally enhance...
    • HJ formation
      • orbital migration
    • Jupiter analog formation
      • core formation and gas accretion (and migration?)
Goal of this work

Reveal the correlation between stellar metallicity and giant planet distribution

• Targets:
  metal-rich stars
    • RV search for giant planets

• Planet number dist. (occurrence rate):
  take account of detection-limits
    • collection for “missed planets”
the RV search

- originated from Subaru/N2K project
  - search metal-rich FGK dwarfs for HJs
- 50 Promising candidates ⇒ Intensive obs. @OAO
- Uniform samples ⇒ High efficiency obs. @Subaru
635 FGK stars in total
approx. solar-$T_{\text{eff}}$
bias toward metal-rich stars
RESULTS AND DISCUSSIONS:
5 NEW PLANETS TO 3 STARS
One of the most large mass MS-stars to host a planet

F7V, $M_* = 1.5M_\odot$, [Fe/H] = +0.37
273 d, 6.4$M_J$
intermediate mass MS stars cannot be observed precisely

- rapid rotation
- high $T_{\text{eff}}$

evolved (cooled down) stars are suitable

but unexpectedly rare HJs: stellar evolution?

\[
\begin{array}{|c|c|}
\hline
[\text{Fe/H}] & [\alpha/\text{Fe}] \\
\hline
+0.5 & 0.0 \\
0.0 & 0.3 \\
0.0 & 0.0 \\
-0.5 & 0.0 \\
\hline
\end{array}
\]

- very high [Fe/H] stars tend to have high mass

such stars are suitable targets for

- not only planets around metal-rich stars
- but also planets around IM stars
Multi-Jovian planet system

K1 IV, $M_* = 1.3 M_\odot$, $[\text{Fe/H}] = +0.25$
- $b : 550 \text{ d, } 1 M_J$
- $c : 2100 \text{ d (3.5 AU), } 3 M_J$

F7V, $M_* = 1.4 M_\odot$, $[\text{Fe/H}] = +0.25$
- $b : 352 \text{ d, } 3 M_J$
- $c : 2374 \text{ d (3.9 AU), } 3 M_J$
Multi-Jovian planet system

\[ b : e = 0.078 \]
\[ c : e = 0.098 + \text{RV trend} \]

\[ b : e = 0.17 \]
\[ c : e = 0.76^{+0.17}_{-0.24} \]
How such strange systems are formed?

- The most eccentric planet among planets in multiple systems
- Multi-circular orbit system
- Solar system analog
  - Only two systems are known to date

Kozai mechanism

- Evolution of ecc. and incl. (exchange periodically each other) due to the perturbation of outer companion
How such strange systems are formed?

RV trend (outer companion) circular orbits
Should be key samples to improve secular evolution theories

NO RV trend eccentric orbits
Summary and Future prospects

- Metallicity vs. planet dist. is a key issue to unveil planet orbital evolution

- Discovered 5 new planets to 3 stars using OAO and Subaru
  - two “strange” multiple systems and the massive host with a massive planet

Next...

- NEED MORE SAMPLES for statistical studies!
  - use archival data in other sites?

- Planet search for stars in open clusters
  - precise comparison with various metallicity clusters