High-contrast imaging of intermediate mass giants with long-term Radial Velocity trends

(Ryu et al. 2016, ApJ, 825, 127)

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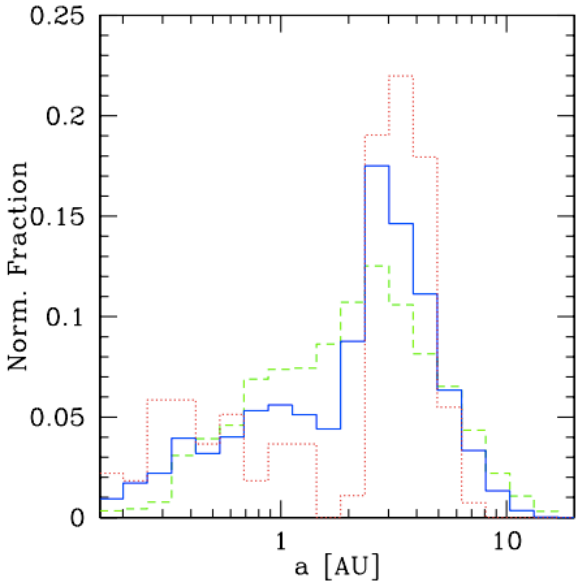
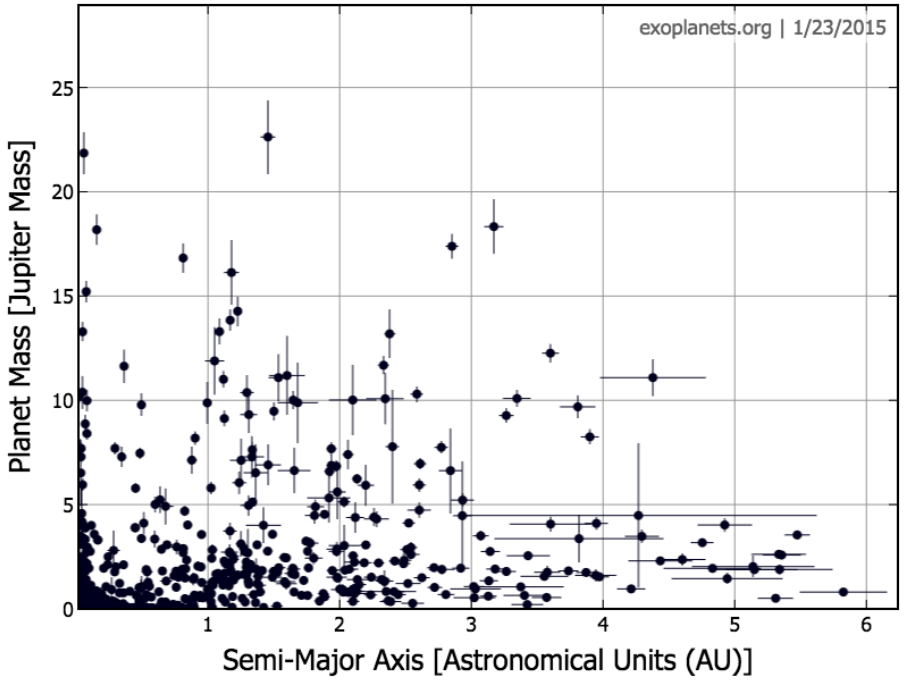
Suggestion from planet formation theory



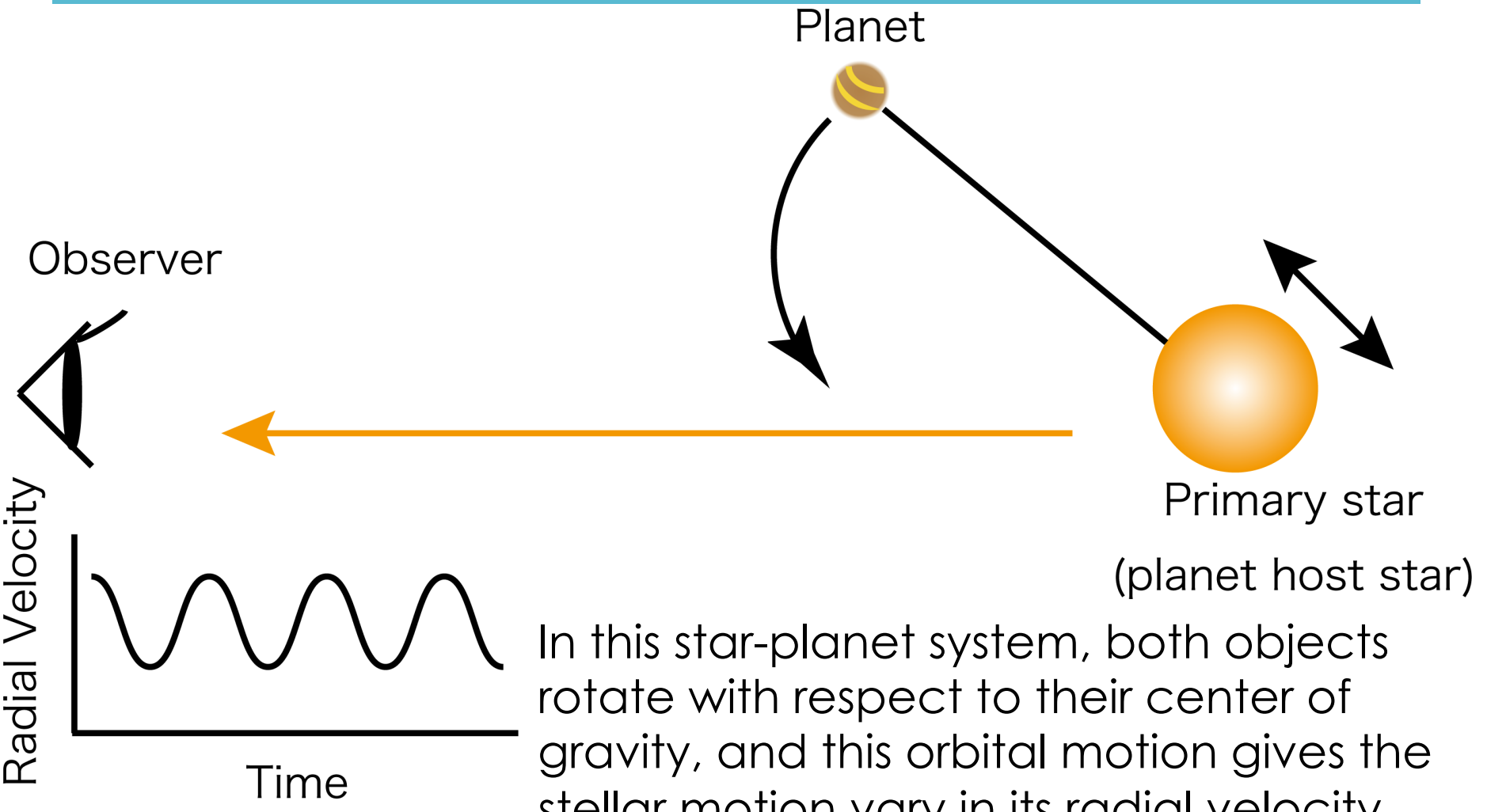
Beyond 5 AU, occurrence rate of planet decreases (Mordanisi + 2012, each line represents stellar metallicity difference)



Few exoplanets were discovered beyond 5AU

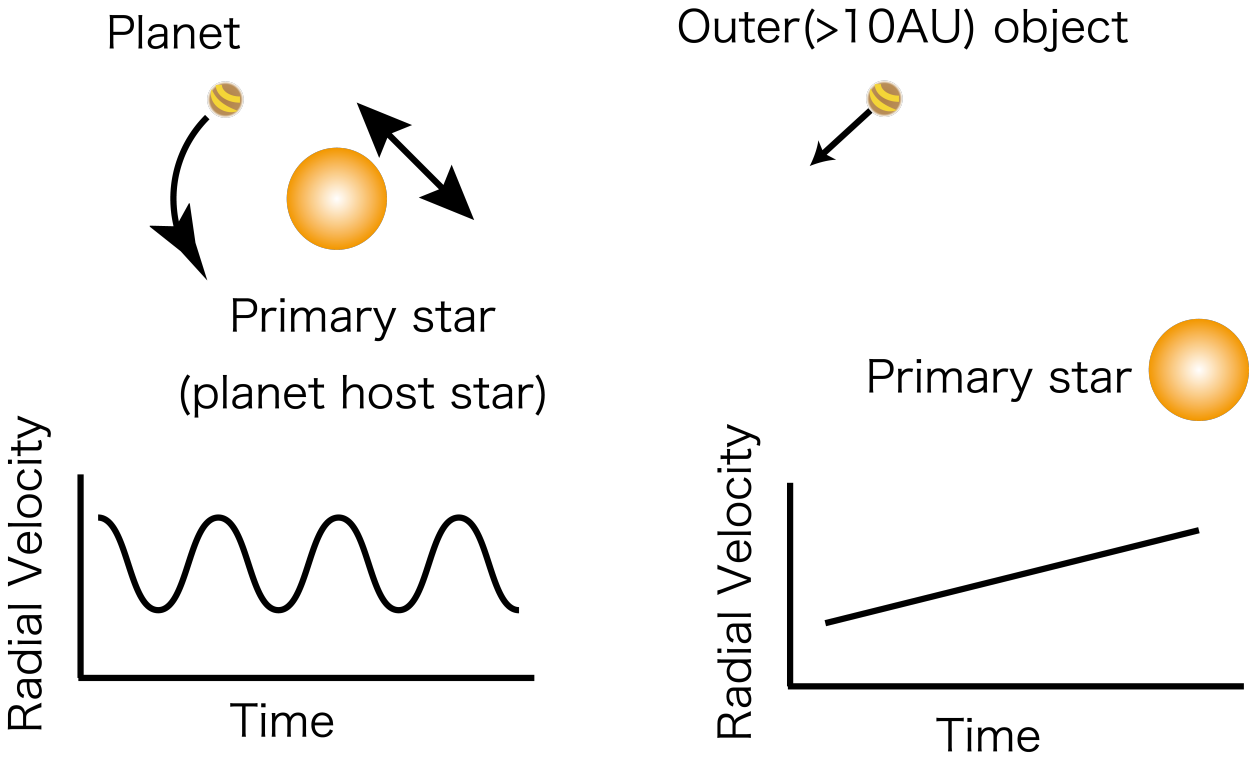
→it takes much time to discover distant planets

Extrasolar planet detection: RV (Radial Velocity) method



In this star-planet system, both objects rotate with respect to their center of gravity, and this orbital motion gives the stellar motion vary in its radial velocity.

RV trend



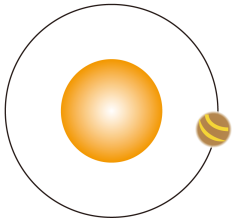
Measuring RV, we can detect objects around the star

→If an outer object rotates around the star, the RV is measured as RV trend

planet or star?

- Planet(at 10AU) and companion star(>100AU) make same order RV trend

outer planet



$$\frac{GM_{\mathrm{comp}}}{a^2} = \dot{v}$$

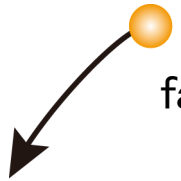
$\dot{v}$: RV trend

M_{comp} : companion or planet mass

a : distance

G : Gravitational constant

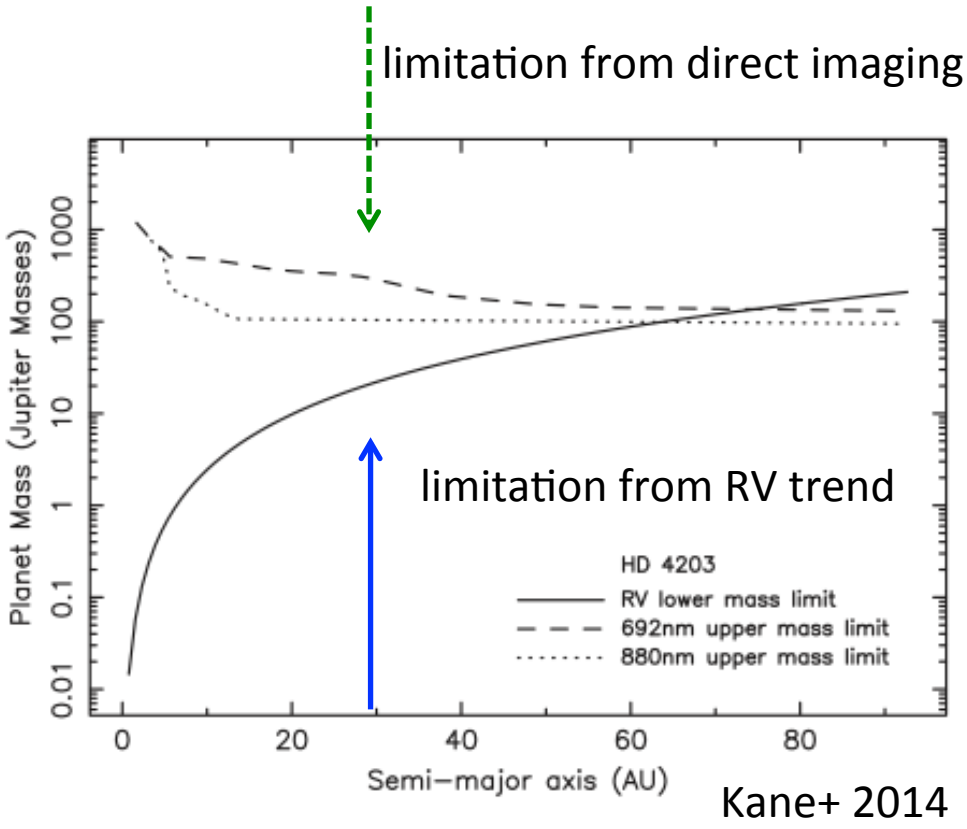
assumed circular orbit



farther companion star

- Direct imaging can detect a companion star and distinguish between planet and star

clarifying or limitation to RV trend source

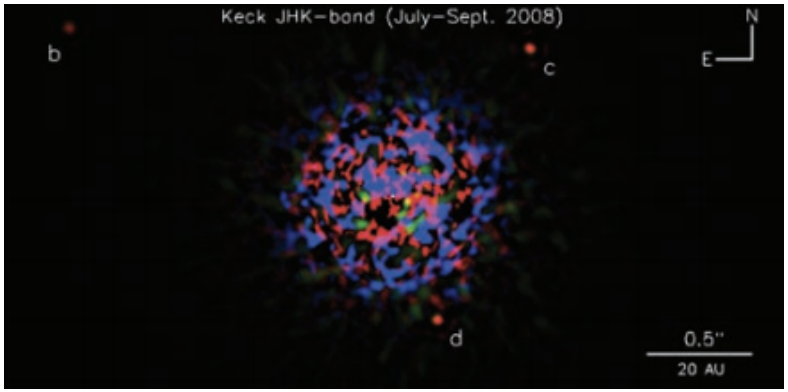


Kane+ 2014

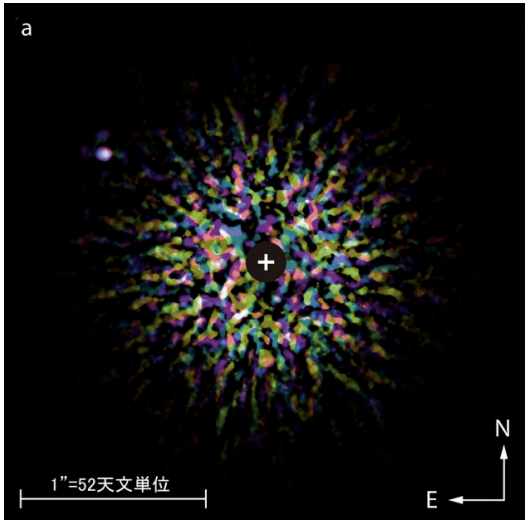
Direct imaging can detect companion stars
→it helps us to test that the detected companion star can make the observed RV trend

If there is no companion, we can limit the existence range of the RV trend source

Direct-imaging method



First direct imaged exoplanets around HR 8799 (Marois+2008)



Brown dwarf around κ Andromedae (Carson+2012)

Feature of direct-imaging method (high-contrast imaging)

- easy to detect distant objects

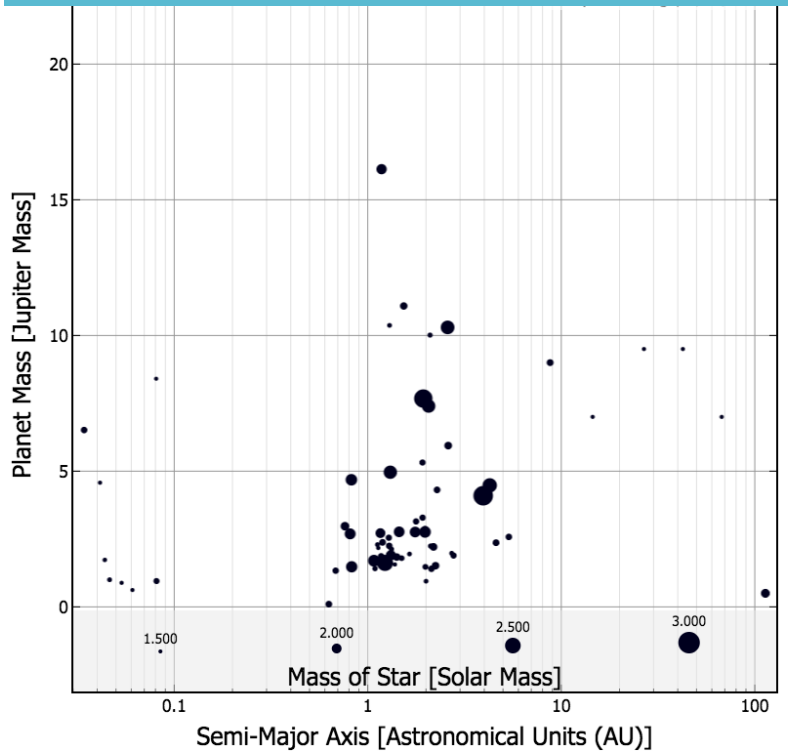
→its mass is derived via stellar evolutional model

- Young system age is required to detect planetary mass object

Okayama RV survey

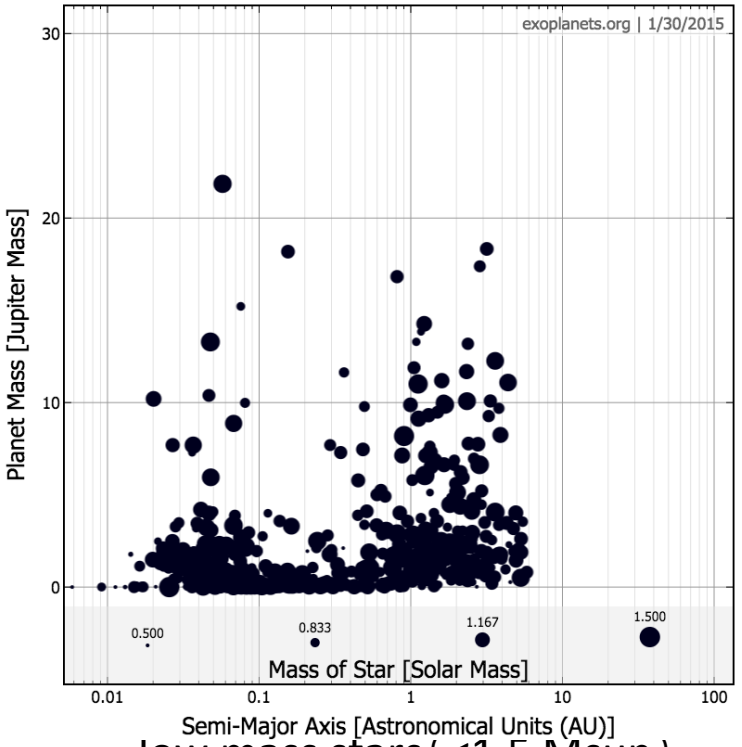
- RV survey at Okayama Astrophysical Observatory by Prof. Sato(TiTech,Tokyo Institute of Technology)
- Targets are intermediate-mass giants.
- Already about 30 planets were discovered (e.g. Sato+ 2008)

Why intermediate-mass giant ?



intermediate mass stars（>1.5 Msun）

●: 1.5, 2.0, 2.5, 3.0Msun



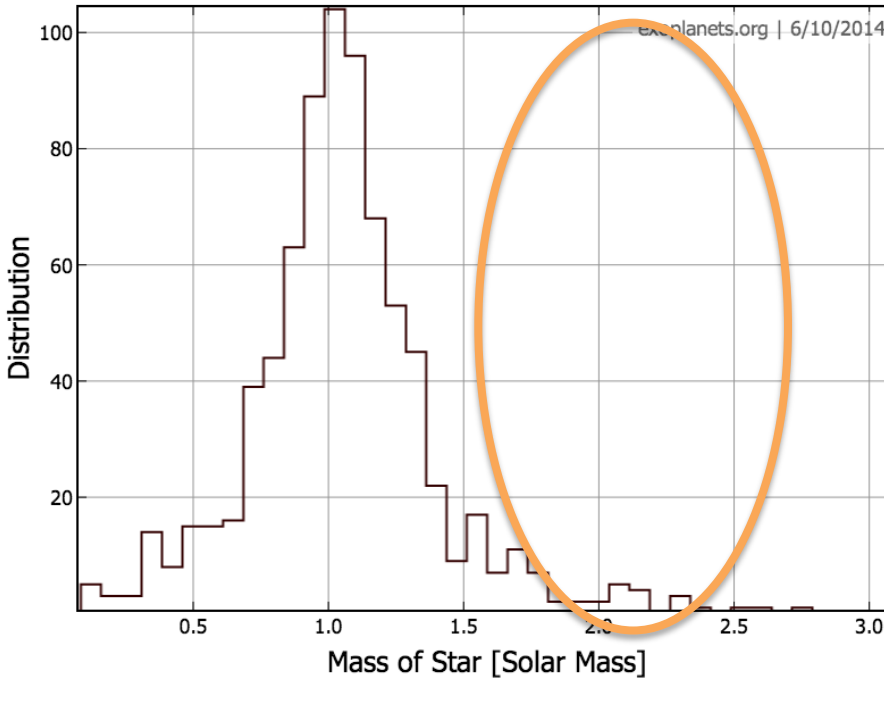
low mass stars（<1.5 Msun）

●:0.5, 0.833, 1.167, 1.5 Msun

Planet distribution around intermediate mass stars might be different from low-mass stars

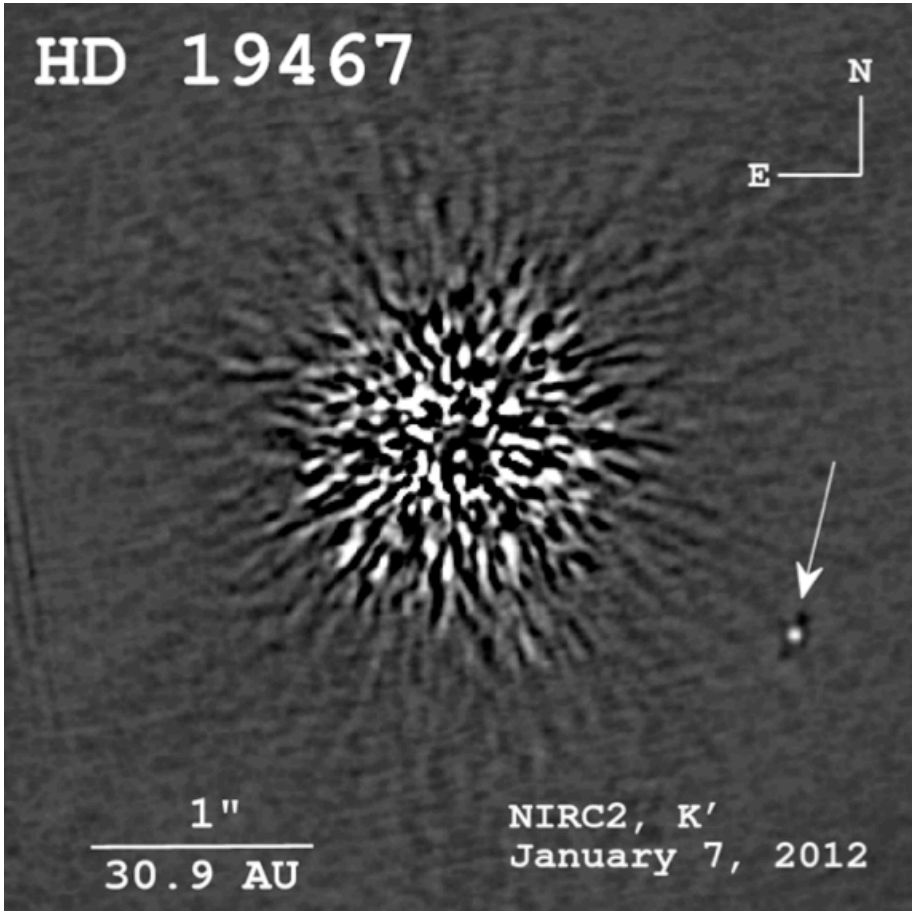
Why intermediate-mass giant ?

- few planets around mid-mass star
- B,A main sequence star is difficult to use Doppler method (fast rotation, lack absorption lines)
- GK giant is good target (slow rotation, more absorption lines)



Similar studies: TRENDS & MILO

- TaRgetting bENchmark objects with Doppler Spectroscopy (e.g. Crepp+2012) using Keck/NIRC2
- MagAO Imaging of Long-period Objects (e.g. Rodigas+16) using Magellan/MagAO
- These targets are sun-like stars and low-mass stars



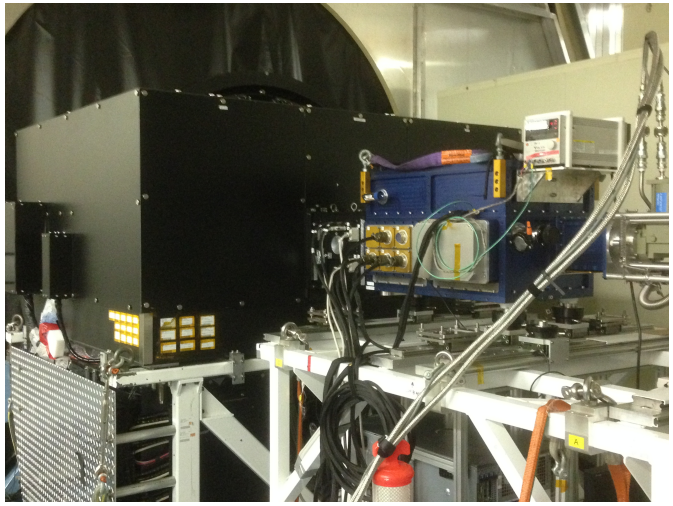
Crepp+2014

Our motivation

- Planet around intermediate mass stars are still small sample and its distribution might different from around sun-like and low-mass star
- Okayama RV planet survey detect intermediate mass giants with long-term RV trend
  →suggesting a distant object
- Our samples are different from other similar studies such like TRENDS and MILO

Observations and targets

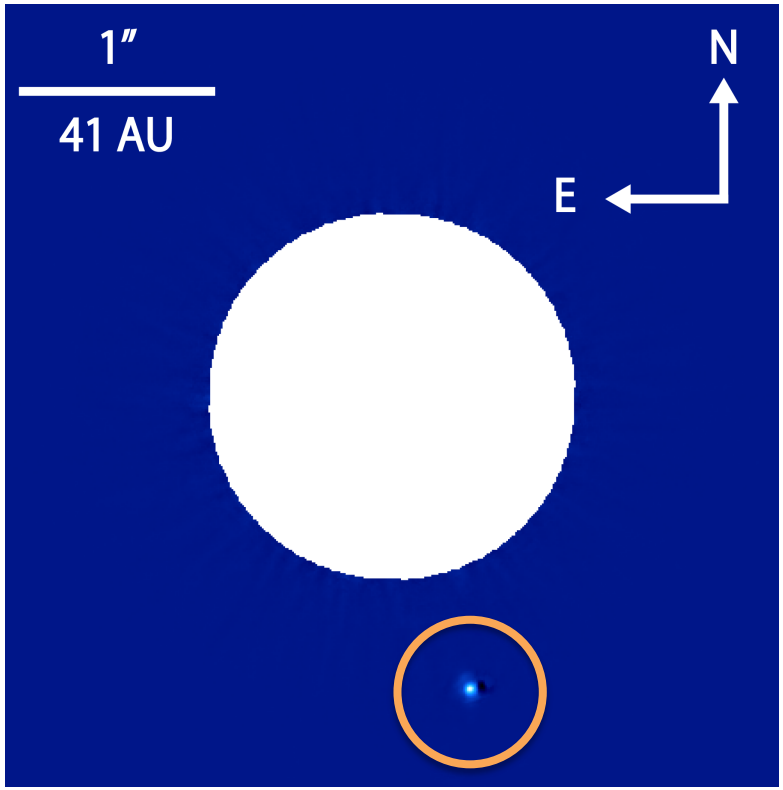
- In SEEDS project, observations were conducted
- 6 objects having RV trend
  - mass:1.39-2.95 Msun Age: 0.37-3.1Gyr
- HiCIAO+AO188 at Subaru Telescope
  2010-2013 in H band(1.6 μ m)
- Data analysis is conducted using LOCI algorithm (Lafreniére+ 2007)
- To estimate companion mass, COND model (Baraffe+ 1998) or NextGen model(Hauschidt+ 1999) was used.



HiCIAO+AO188

Results

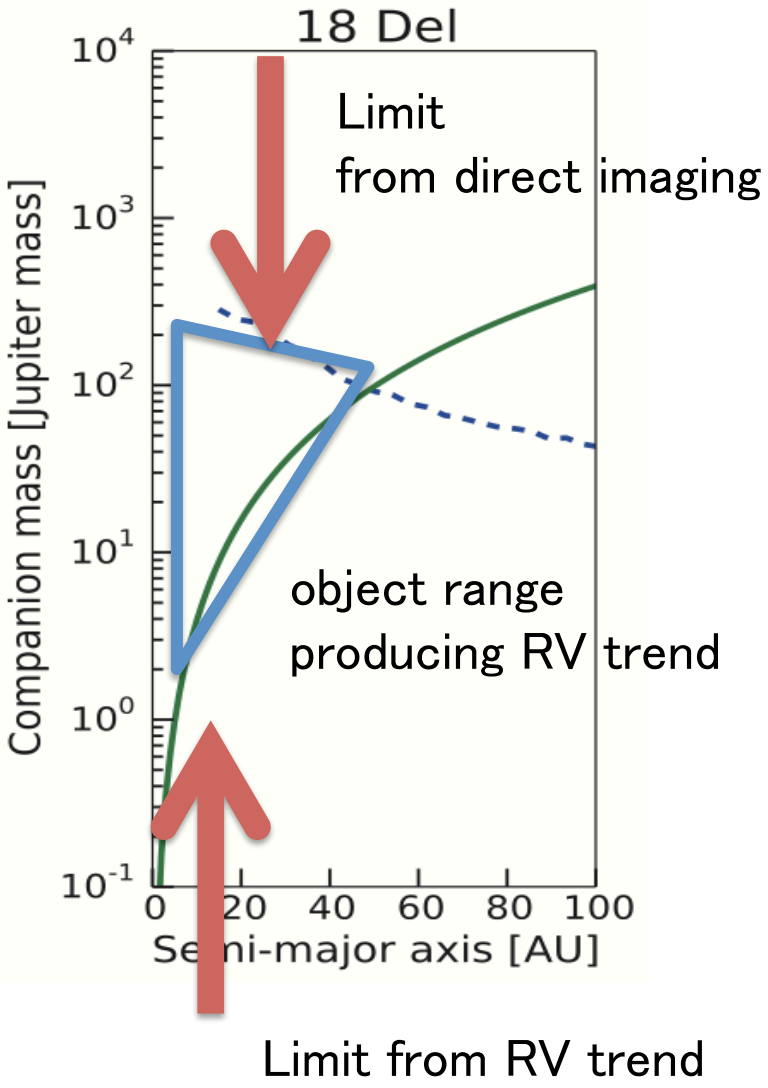
- 3 companions (stellar mass) are detected around 3 targets(γ Hya, HD5608, HD 109272) →confirmed by common proper motion test
- no companion around other 3 targets (ι Dra, 18 Del, HD 14067)



detected companion example:
γ Hya B

Discussion

- We calculate the RV mass limit from the observed RV trend
- We compare with detection limit from direct-imaging results and minimum RV trend mass
- All RV trend generator mass and semi-major axis are clarified (companion detected case) and limited (no companion case)
- Some RV trend generators can make gravitational influence to inner planets (Kozai-Lidov mechanism)



Future work

- Other RV trend targets are observed in open-use time
  (S15B-022, Dec. 2015, PI. T. Ryu)
  →HiCIAO reduction done(9 companion candidates are detected in 14 targets)
  →follow-up observations are needed
- Remain samples(~10) are required to check companion
  →however, the proposal(S16A,B,S17A) is rejected…
- After clarifying RV trend source, occurrence rate of distant planet around intermediate mass giants will be revealed

Summary

- direct-imaging observation for 6 objects and 3 have companion candidate
  - confirmed by common proper motion test
- without companion candidate object
  - combined analysis limits planet existing range
- Confirming RV trend source
  - we will discuss planet frequency around mid-mass star
- Through this strategy, we would derive occurrence rate of distant planets around intermediate-mass giants