Radial-velocity search for exoplanets around metal-rich stars

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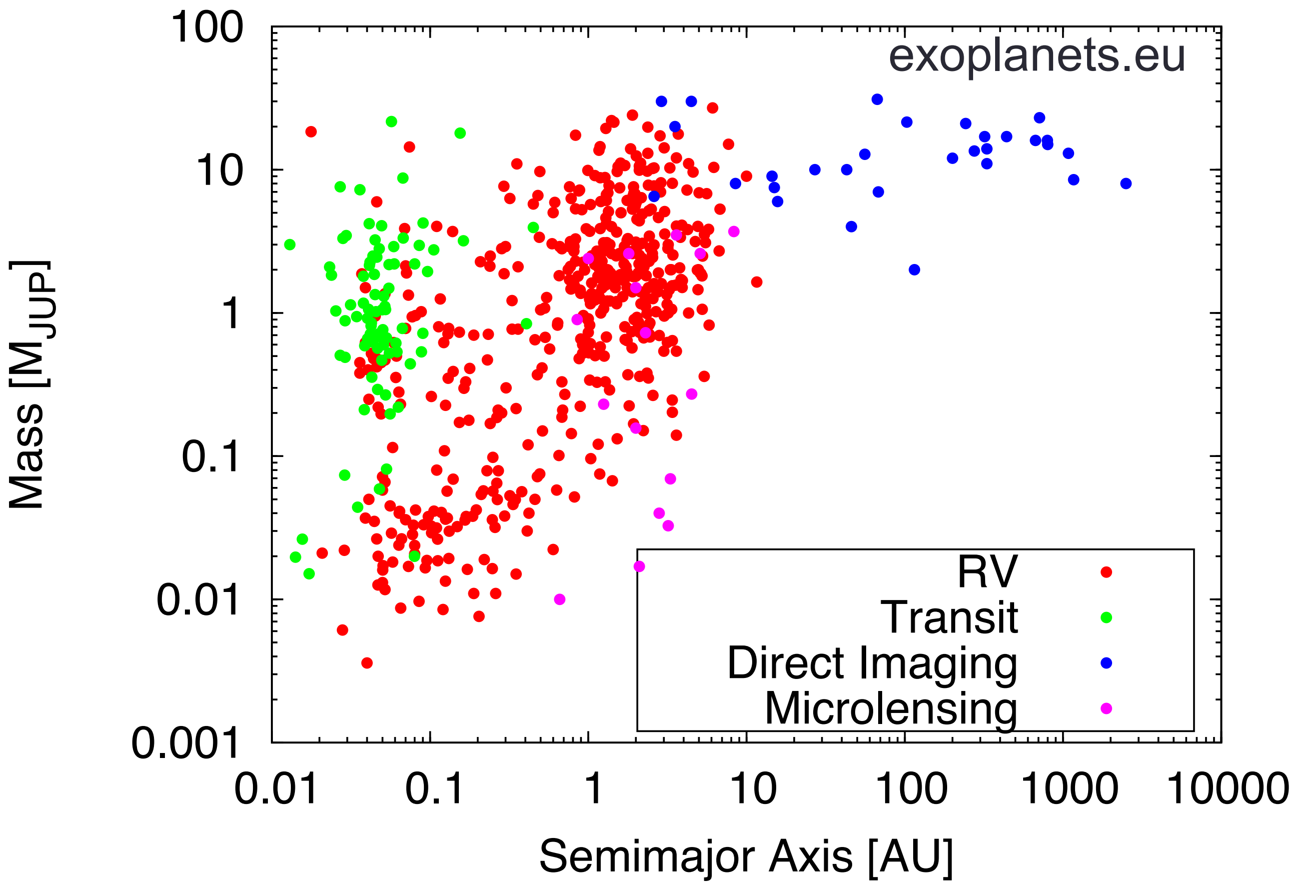
Who is he?

- Hiroki Harakawa
  - 3/2014: Got Ph.D at Tokyo Institute of Technology
  - Supervisor : Bun'ei Sato
  - Major : Search for exoplanets
  - Now: TMT project office

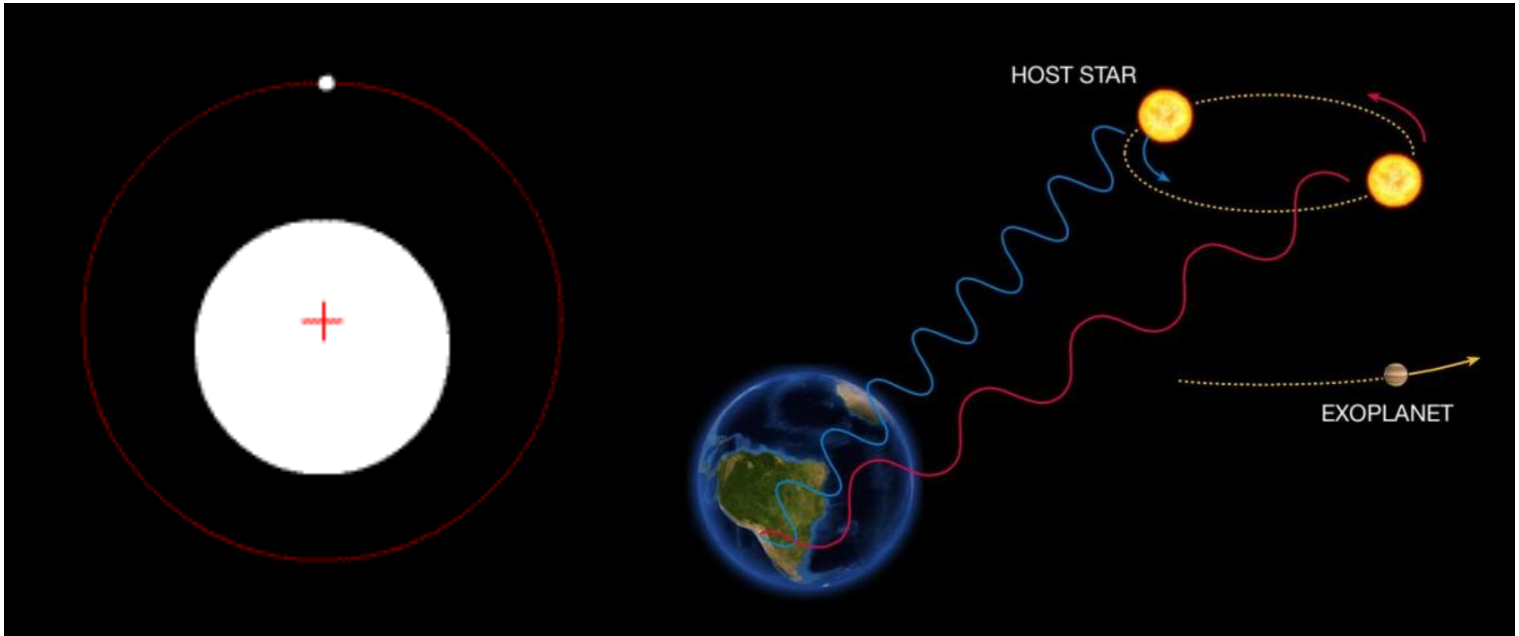
Discovered exoplanets



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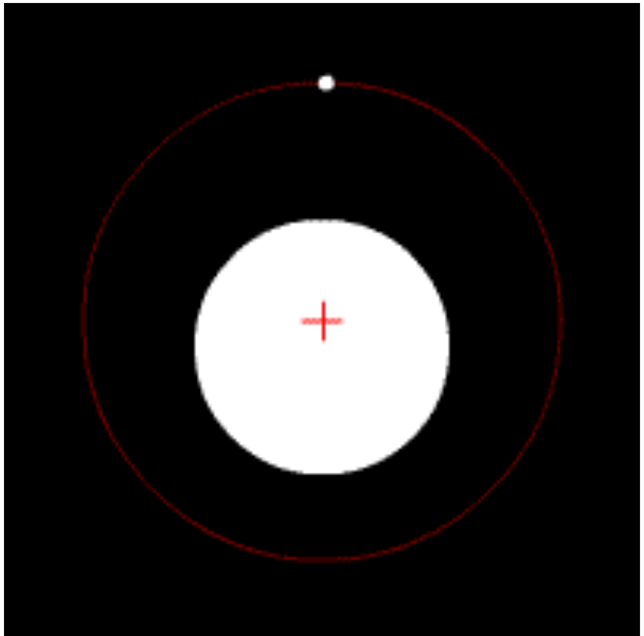
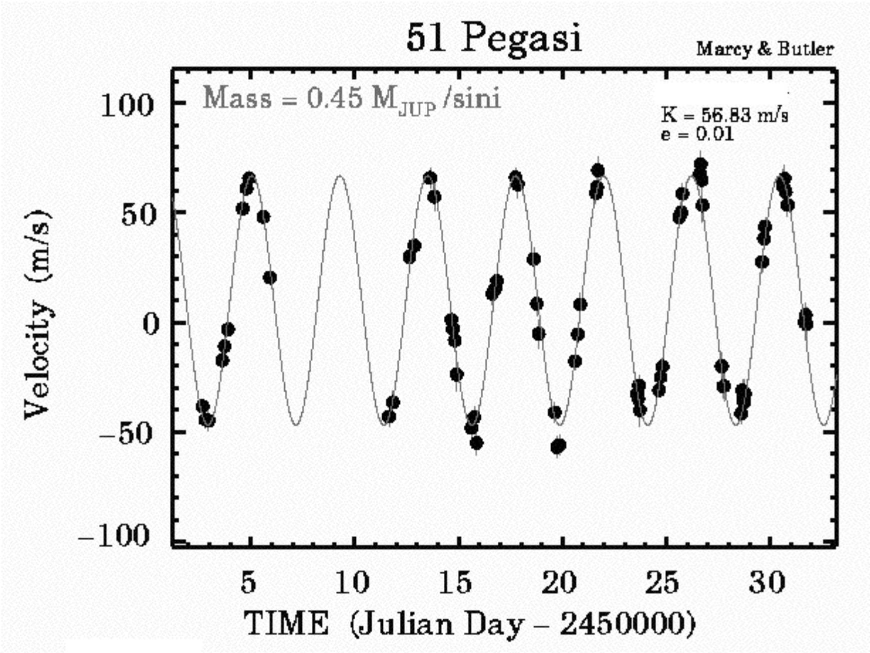




Giant planet formation

- Two formation processes
  - core-accretion model
    (e.g.) Mizuno (1980);Pollack et al.(1996)
    - efficient in inner region (< 10 AU)
  - disk gravitational instability
    (e.g.) Boss (1997);Mayer et al.(2002)
    - 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

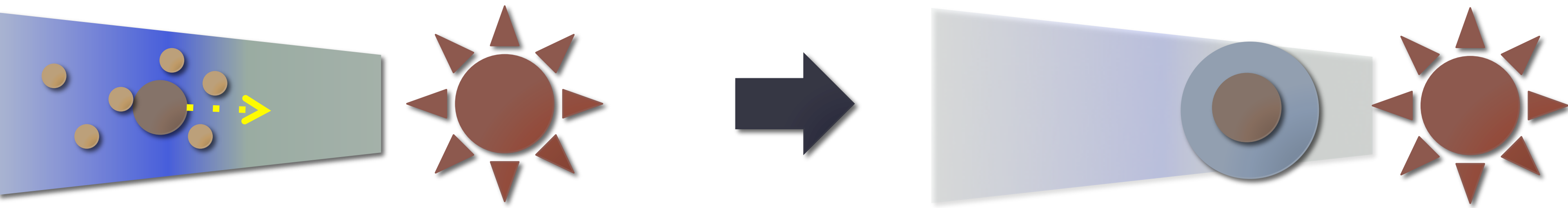
Core-Accretion model

- 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)

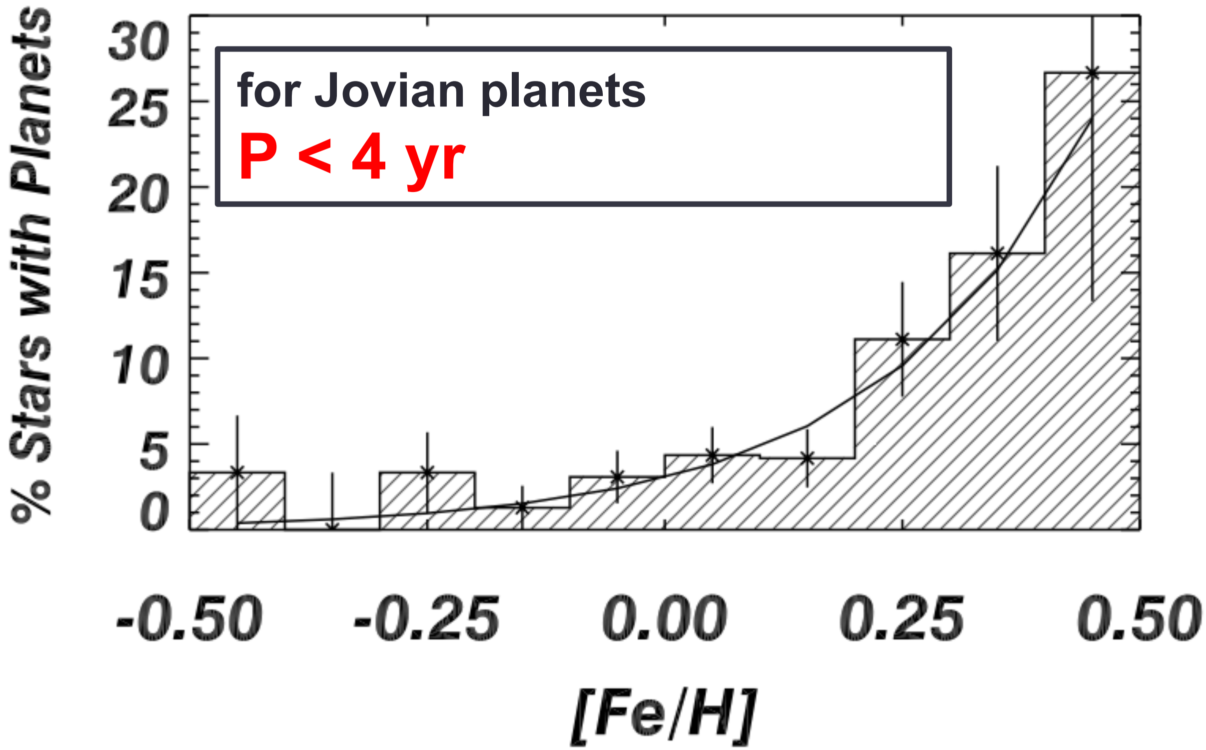
⇒ **disk lifetime may control the inward migration**

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

- Planet formation should have evolutional trends of planet formation from various conditions (e.g. metallicity, stellar mass)



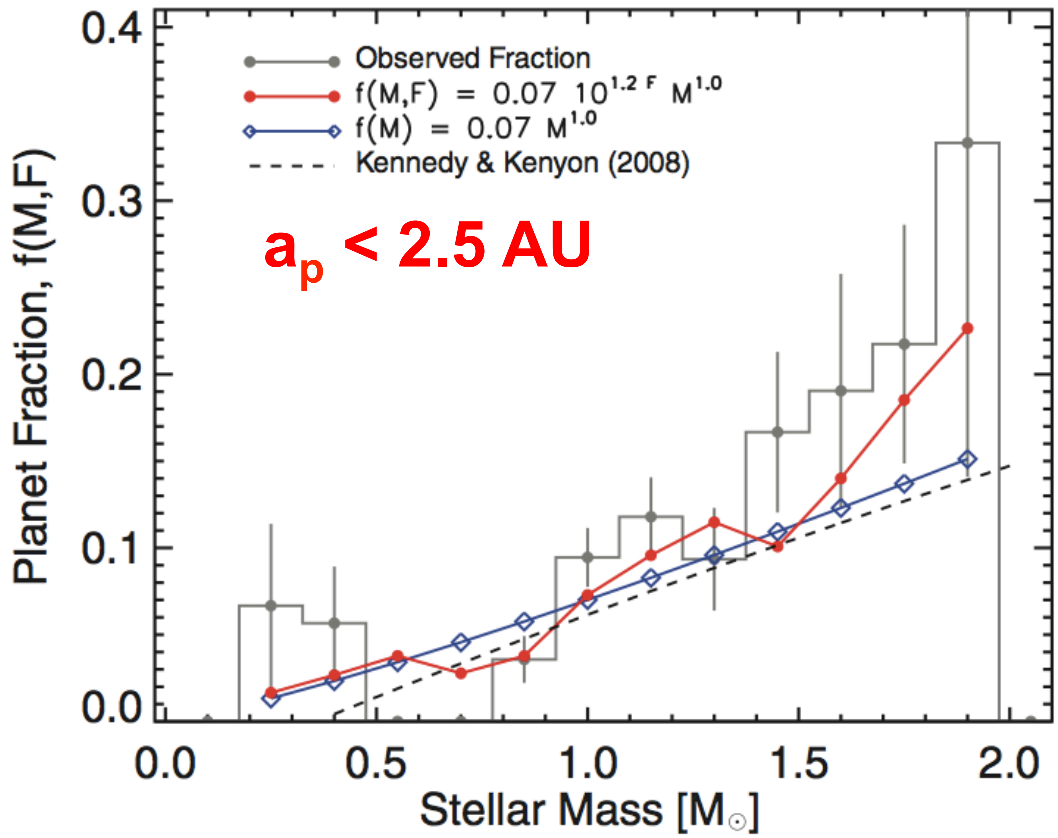
Planet occurrence vs. [Fe/H]



Fischer & Valenti 2005

- Solar-type stars(0.7-1.3$M_\odot$)
  - increase exponentially

Planet occurrence vs. stellar mass

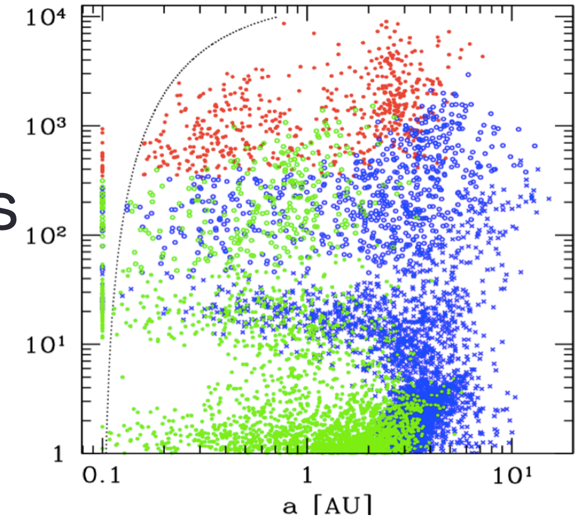


Johnson+ 07,10

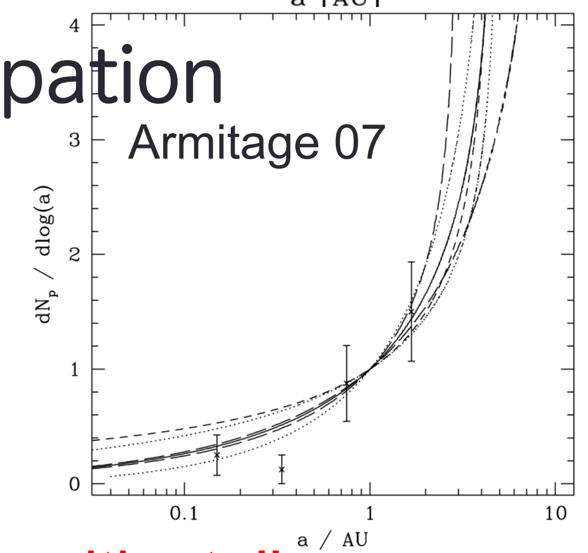
- intermediate mass stars(1.5-2.0$M_\odot$)
  - proportional to host-stellar mass

Comparison with theories

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



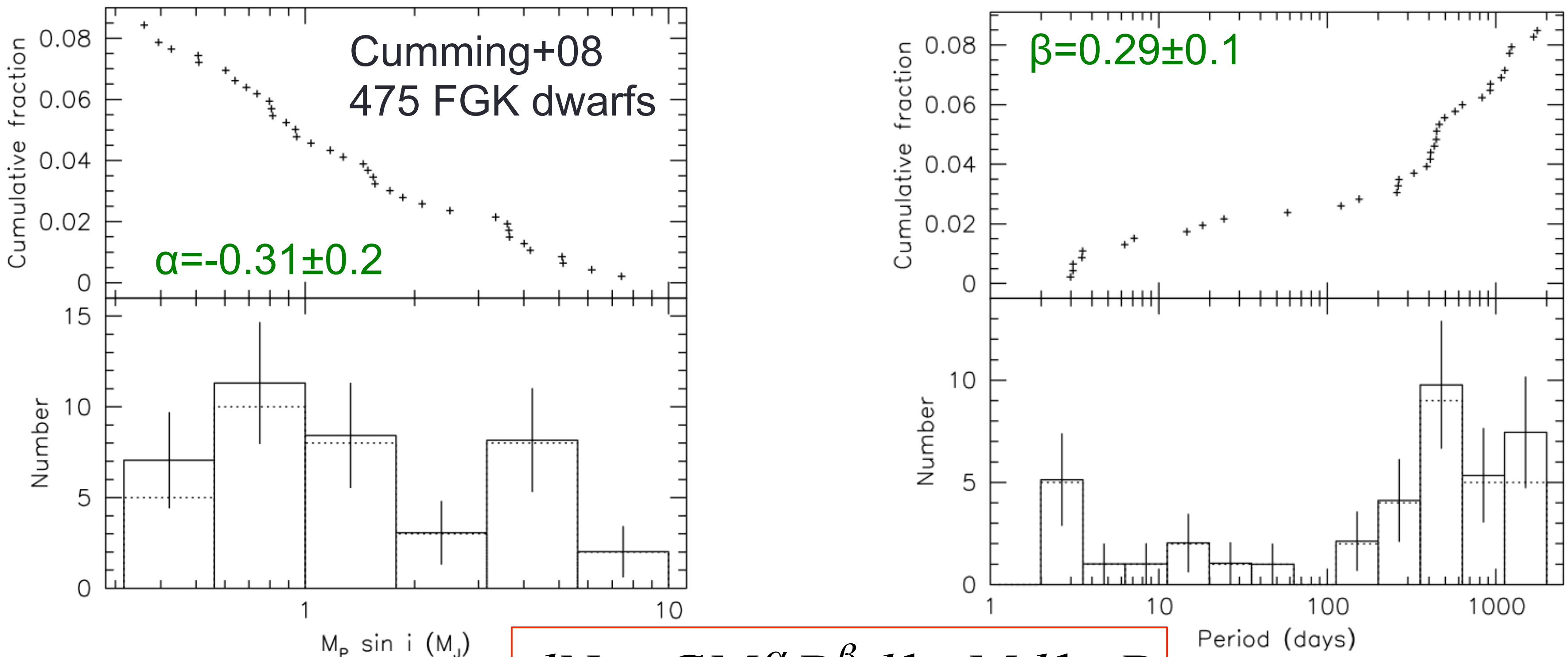
- Orbital migration and Disk-dissipation
  - Calculate orbital evolutions taking account of the precise disk dissipation process



Necessary to know planet dist.
without any obs. biases, and its correlation with stellar properties

m_p, a_p dist. for solar-type stars

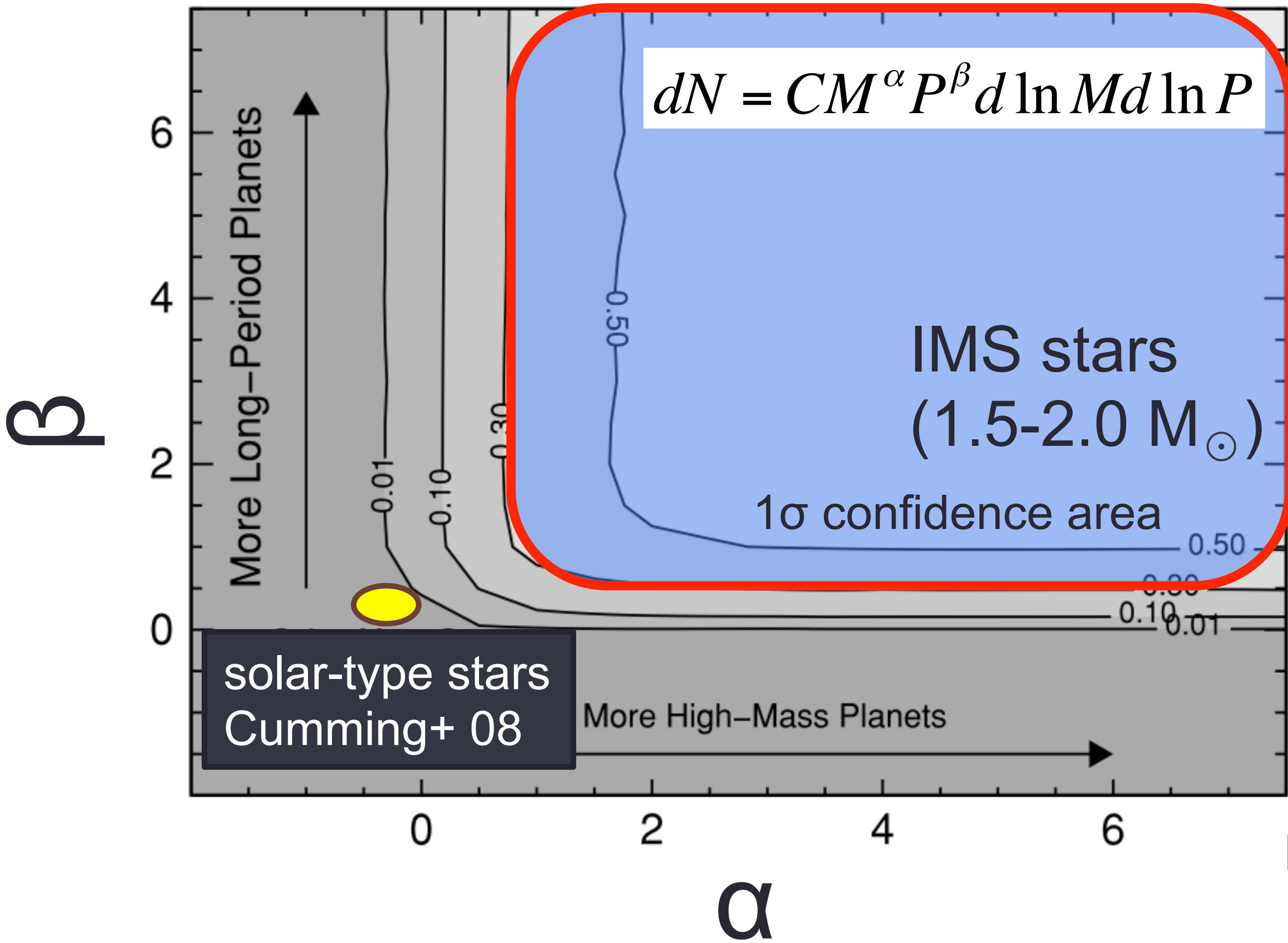
- estimate empirical dist. as power-low function taking account of detection-limits



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

- 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



Bowler+ 10

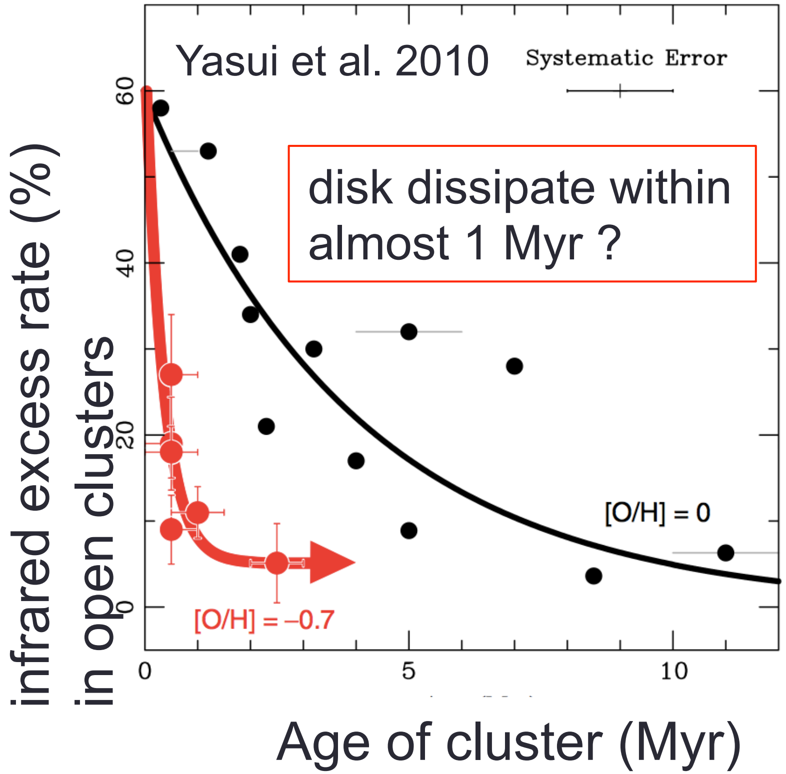
- tend to host massive and distant planets
  - only one Hot-Jupiter is detected at IMS stars

Previous works

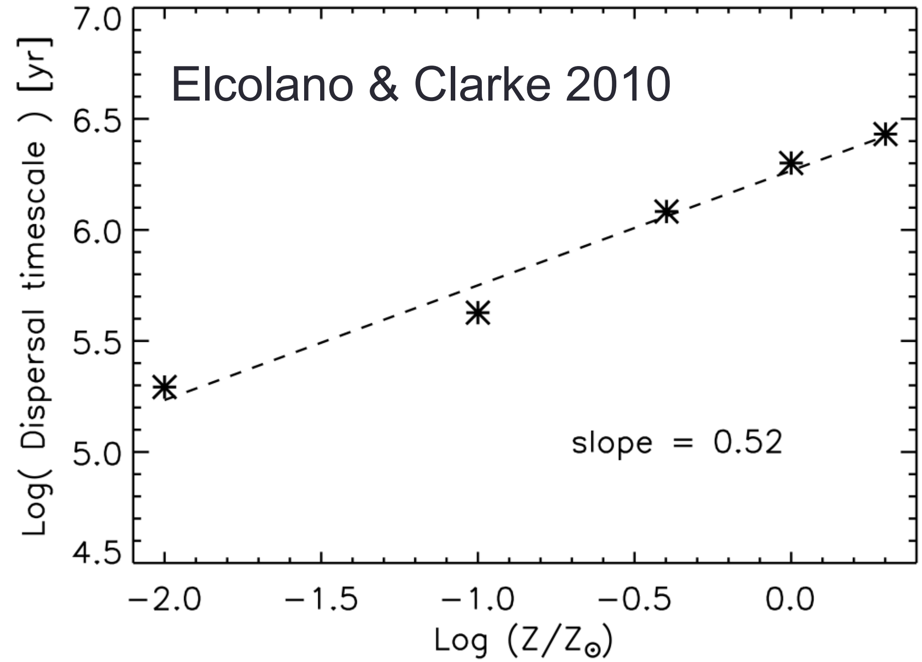
	stellar mass	metallicity
integrated	✔ (J07,10)	✔ (FV05)
m_p, a_p dist.	✔ (B10)	×

planet dist. vs. [Fe/H] is still unknown

Why we should consider Metallicity?



- circumstellar disks in low-metallicity cluster may dissipate in a short time



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

metallicity may correlate with disk-lifetime ⇒ 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

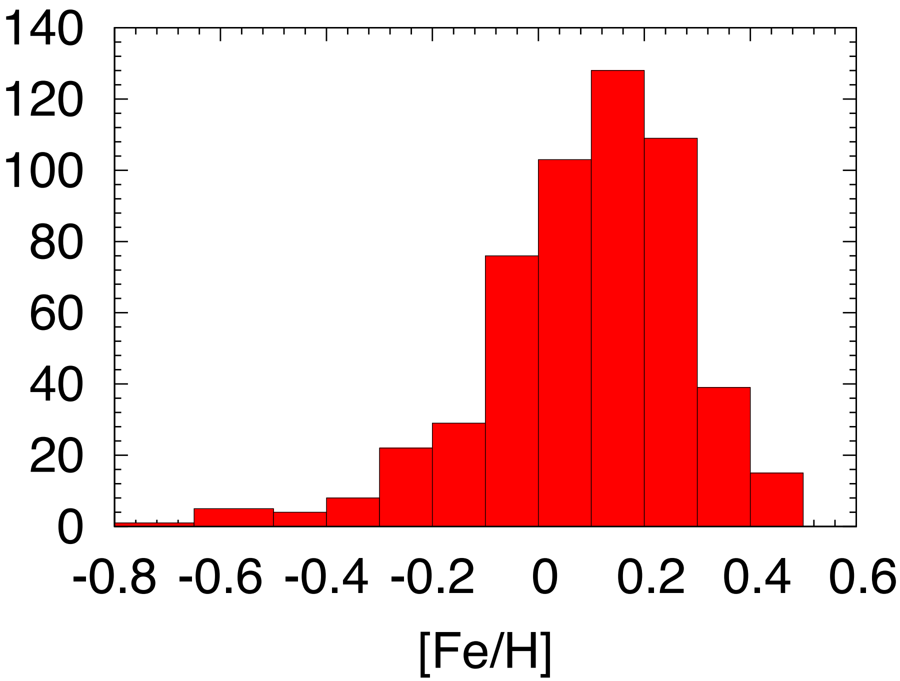
- Planet number dist. (occurrence rate)：
  take account of detection-limits
  - collection for “missed planets”

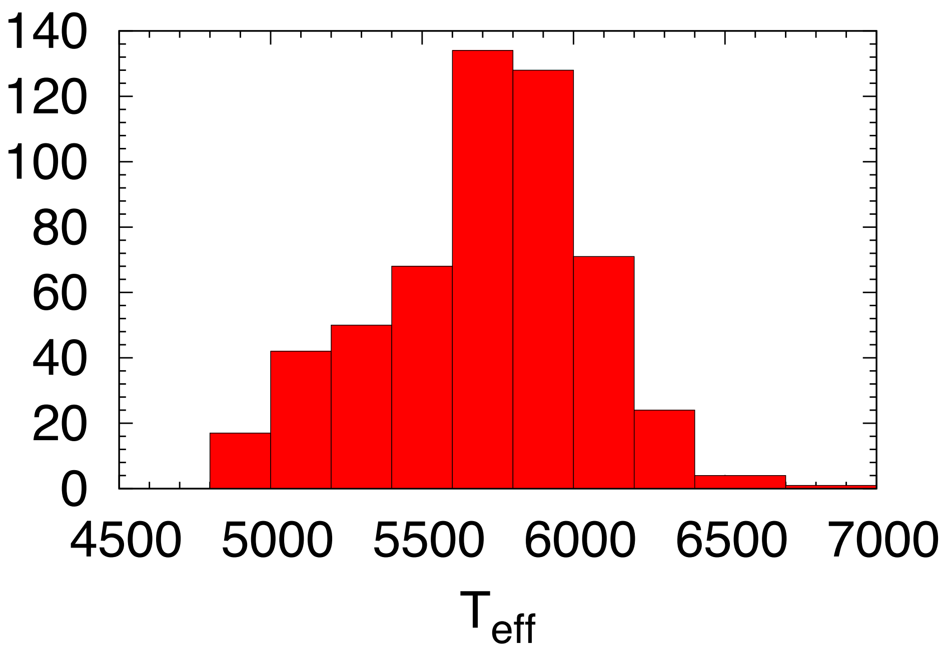
the RV search

2009.08~

- originated from Subaru/N2K project
  - search metal-rich FGK dwarfs for HJs
- 50 Promising candidates ⇒ Intensive obs. @OAO
- Uniform samples ⇒ High efficiency obs. @Subaru

Targets

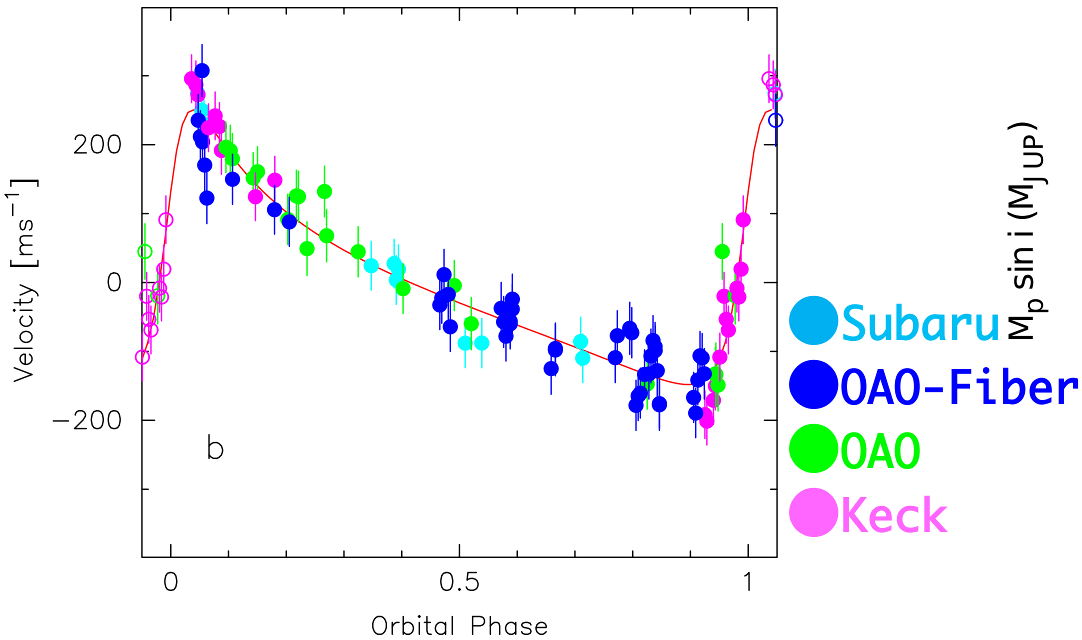


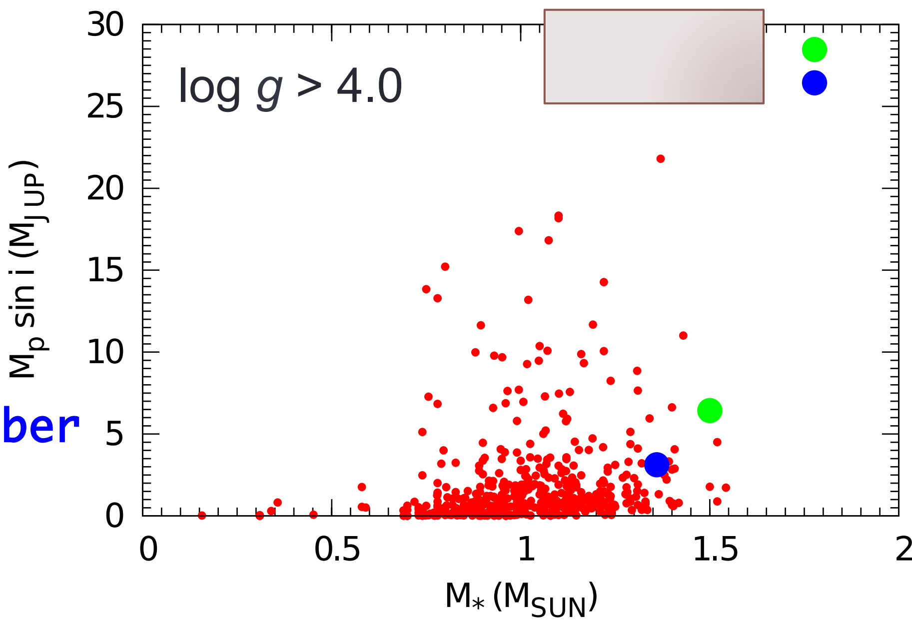


- 635 FGK stars in total
- approx. solar-T_{eff}
- biased toward metal-rich stars

RESULTS AND DISCUSSIONS : 5 NEW PLANETS TO 3 STARS

Massive star hosts
Massive giant in an eccentric orbit



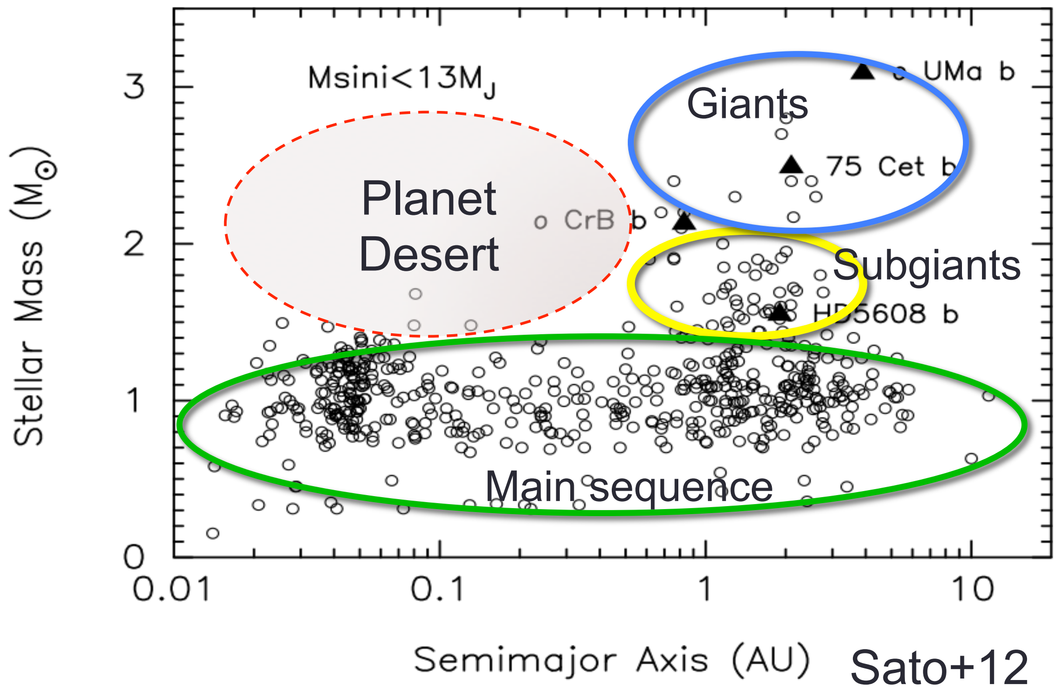


F7V, $M_*=1.5M_\odot$
[Fe/H]=+0.37
273 d, $6.4M_J$

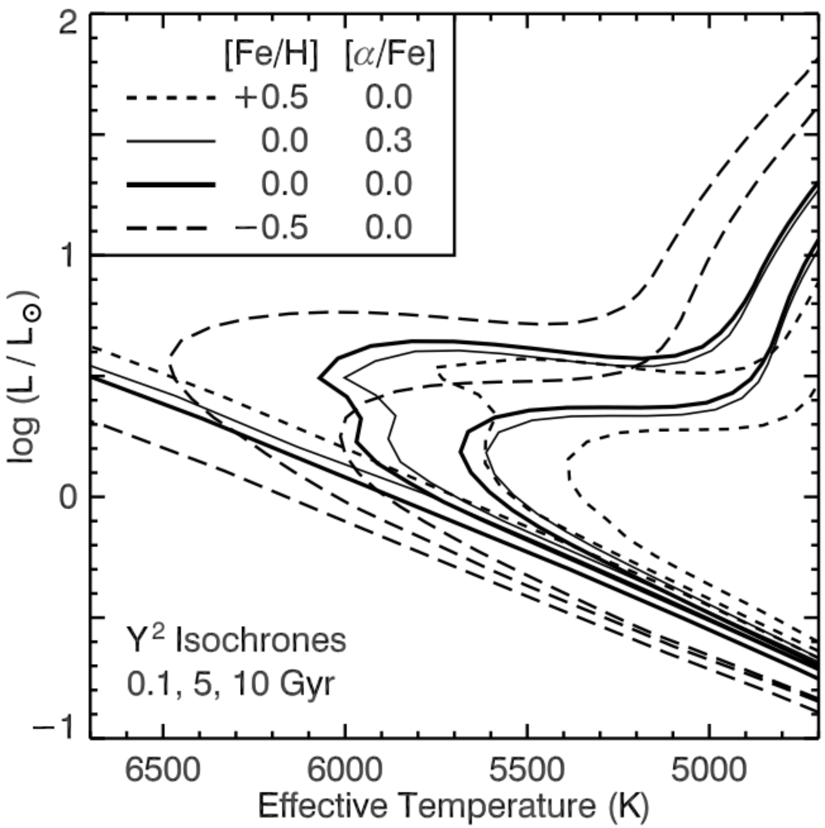
One of the most large mass MS-stars to host a planet intermediate mass MS stars cannot be observed precisely

- rapid rotaion
- high T_{eff}

evolved (cooled down) stars are suitable
but unexpectedly rare HJs : stellar evolution?



Sato+12



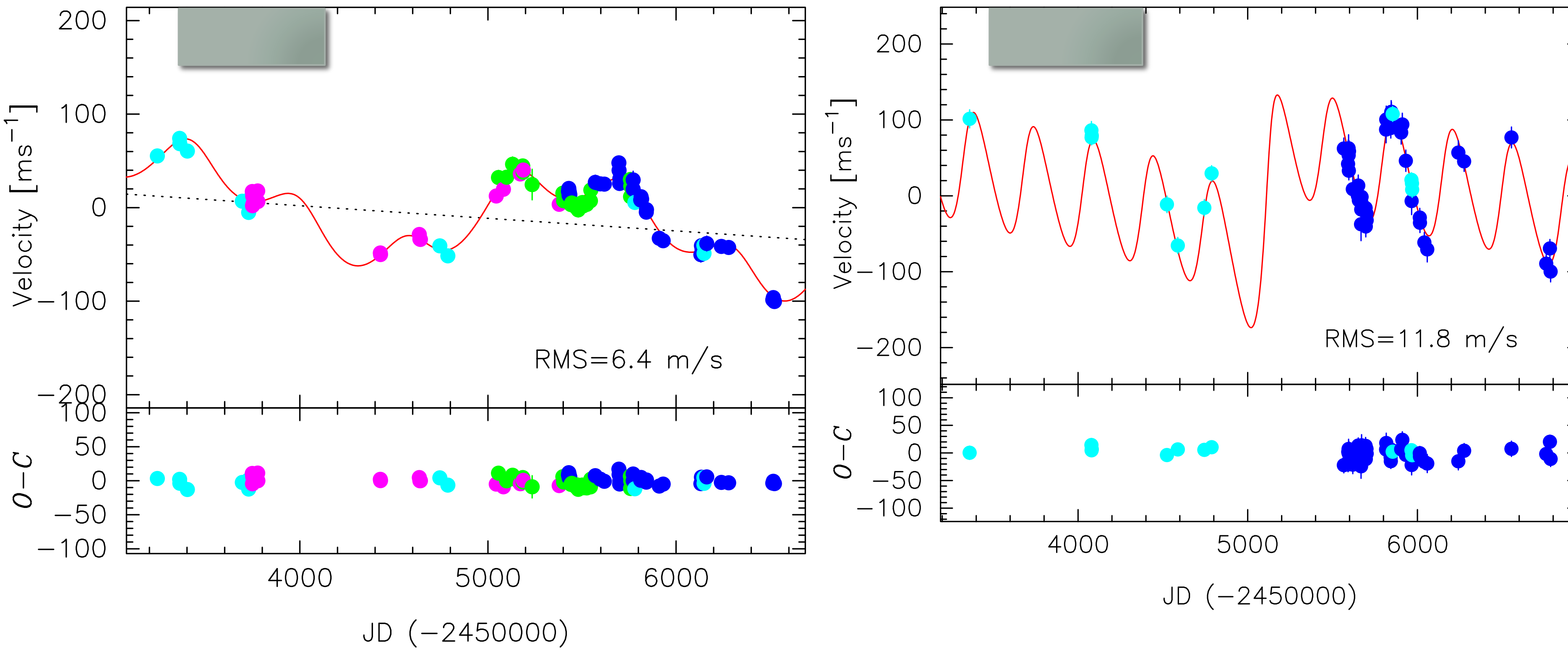
- very high [Fe/H] stars tend to have high mass

such stars are suitable targets for

- not only planets around metal-rich stars
- but also planets around IM stars

Multi-Jovian planet system

Subaru
OAO-F
OAO
Keck

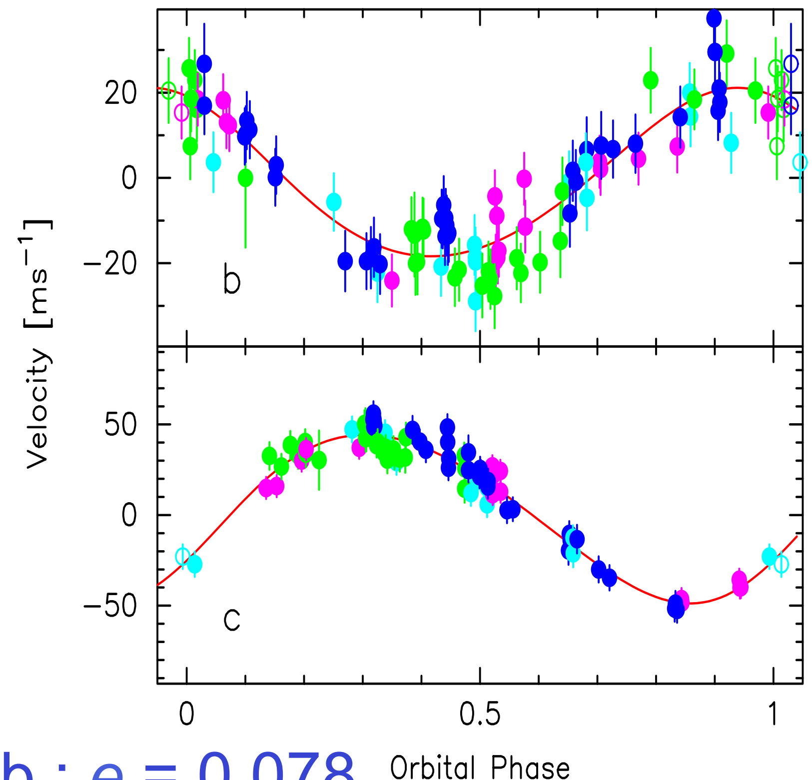


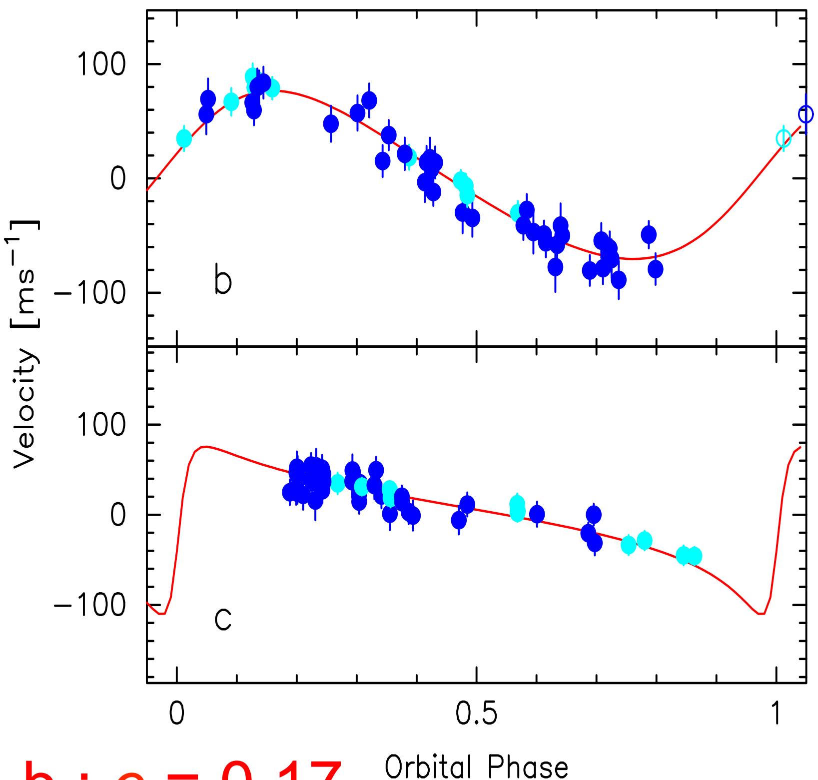
K1 IV, $M_*=1.3M_\odot$, [Fe/H]=+0.25
b : 550 d, $1M_J$
c : **2100 d (3.5 AU)**, $3M_J$

F7V, $M_*=1.4M_\odot$, [Fe/H]=+0.25
b : 352 d, $3M_J$
c : **2374 d (3.9 AU)**, $3M_J$

Multi-Jovian planet system

Subaru
OAO-F
OAO
Keck





b : e = 0.078

c : e = 0.098 + RV trend

b : e = 0.17

c : $e = 0.76(^{+0.17}_{-0.24})$

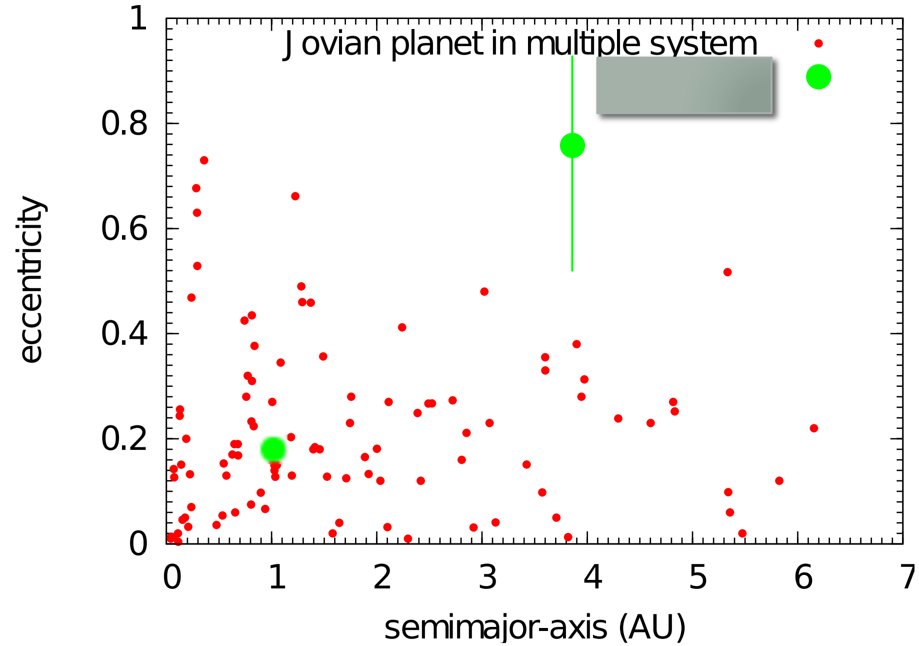
How such strange systems are formed?

:

- The most eccentric planet among planets in multiple systems

:

- Multi-circular orbit system
- solar system analog
  - only two systems are known to date

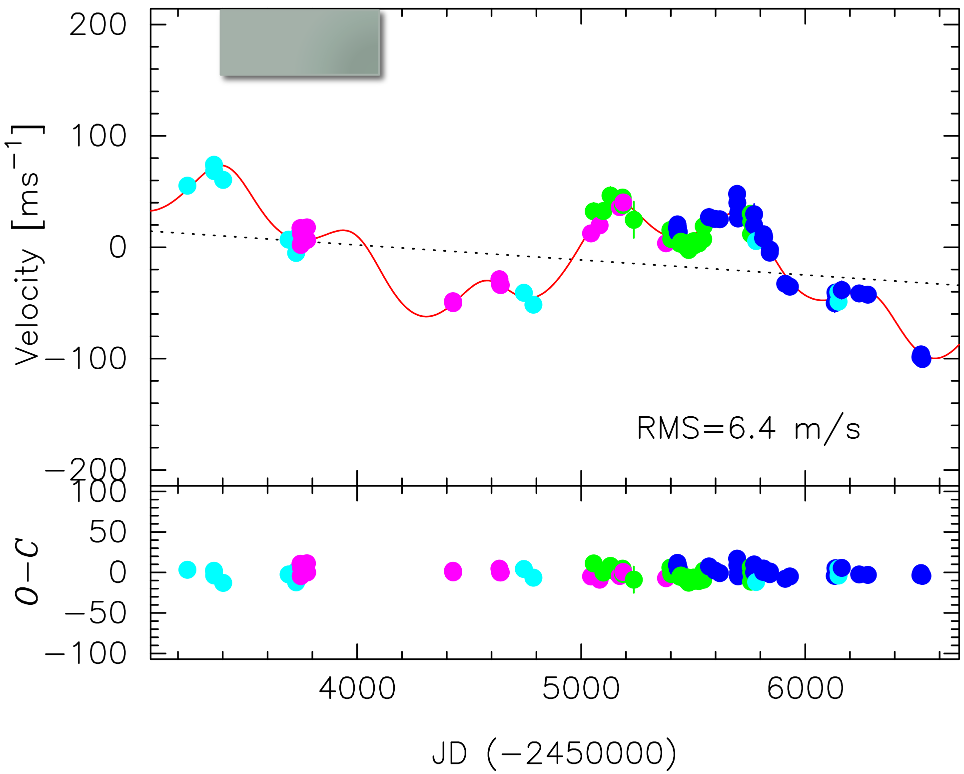


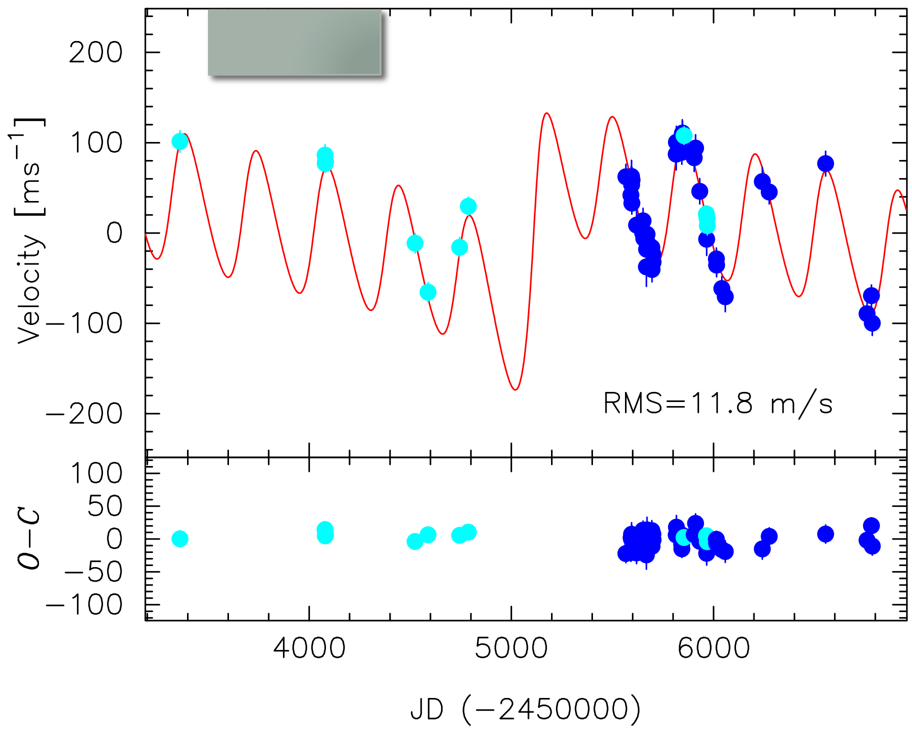
Kozai mechanism

- evolution of ecc. and incl. (exchange periodically each other) due to the perturbation of outer companion

How such strange systems are formed?

Subaru
OAO-F
OAO
Keck



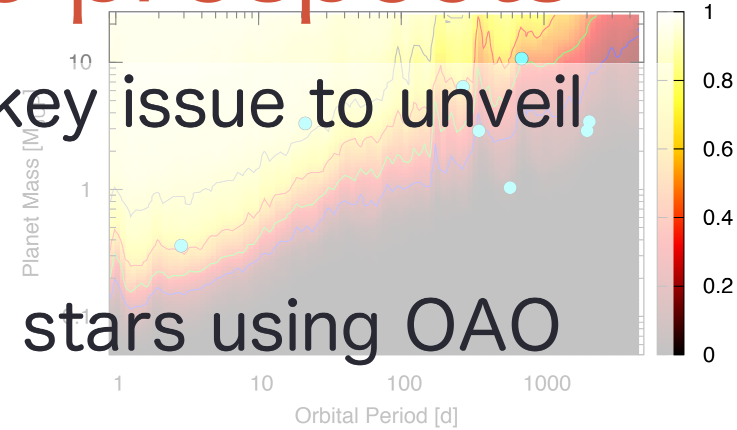


RV trend (outer companion)
circular orbits

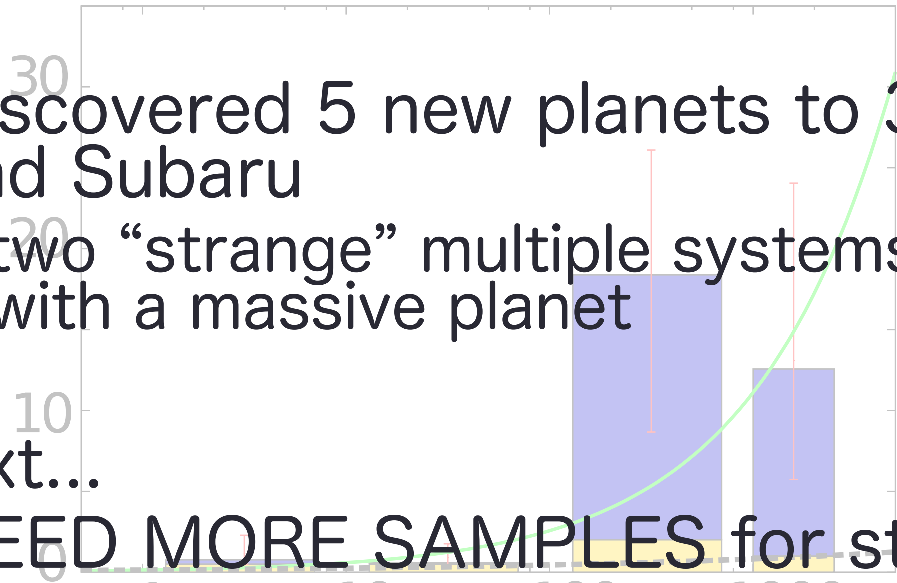
NO RV trend
eccentric orbits

Should be key samples to improve secular evolution theories

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