Planetary Systems Hosted by Evolved Stars

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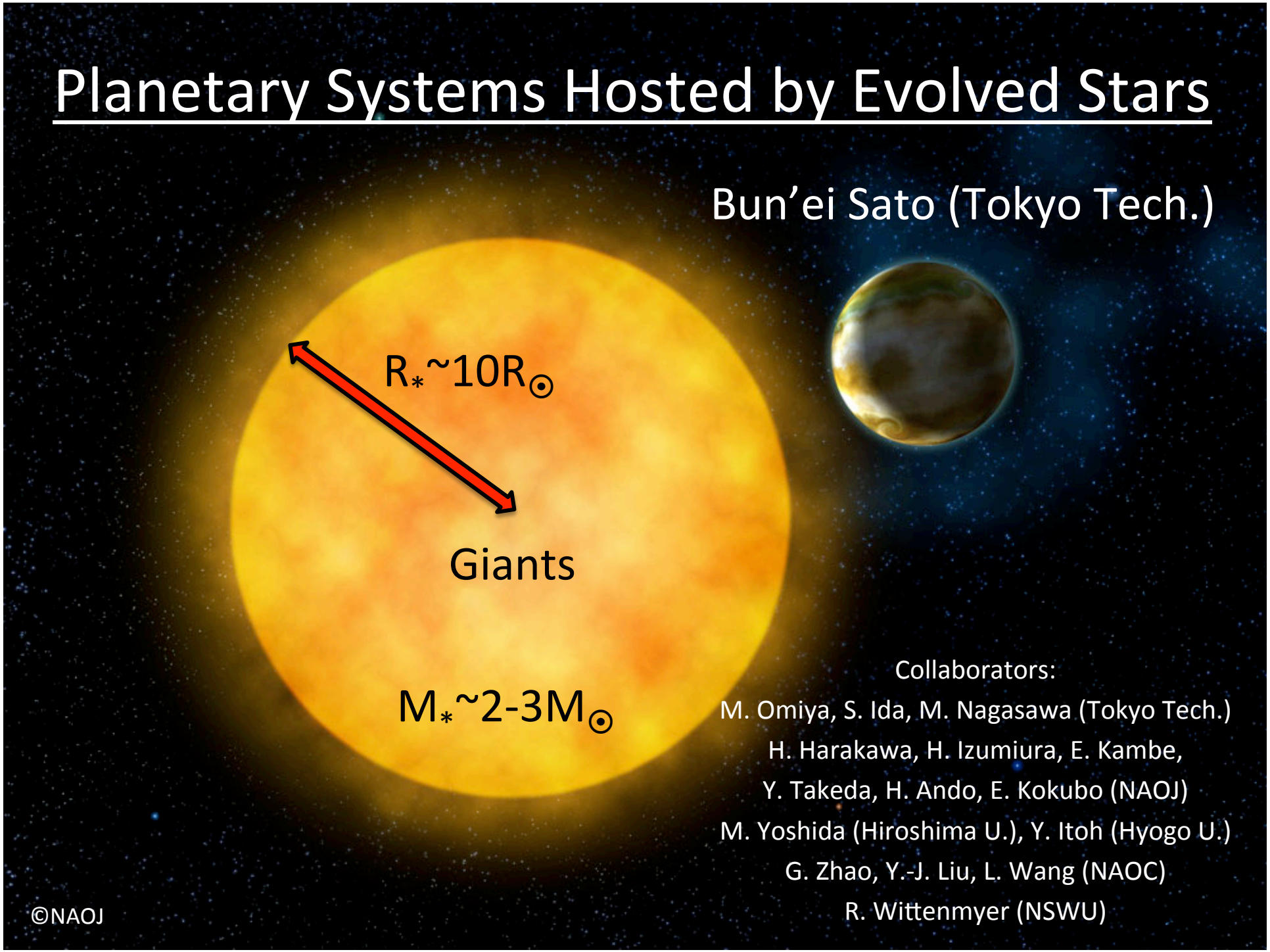

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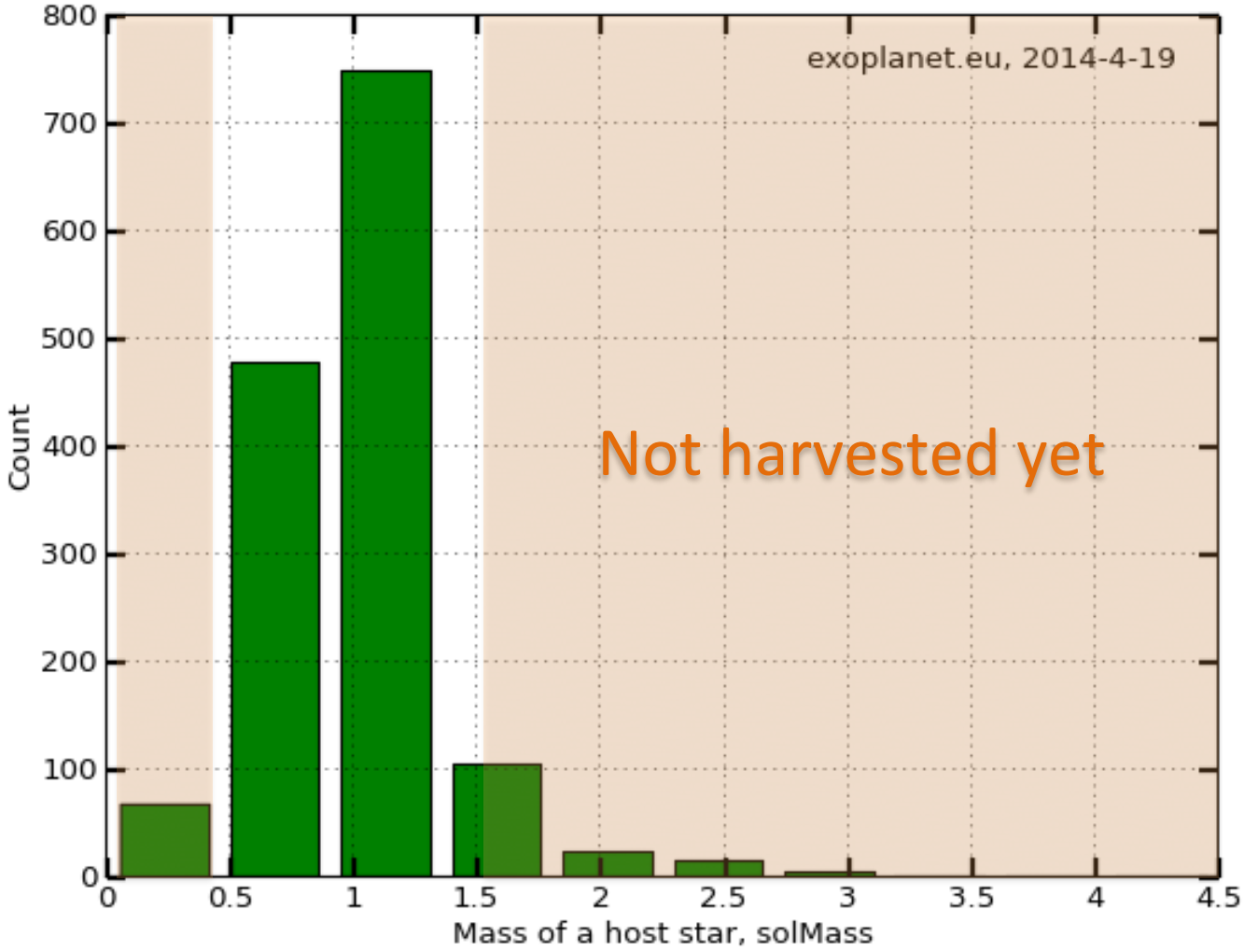
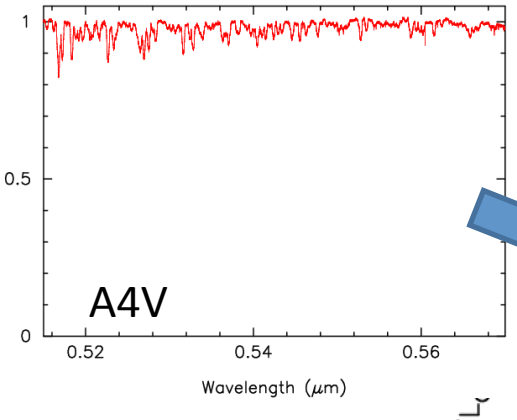
Mass of a planet-host star

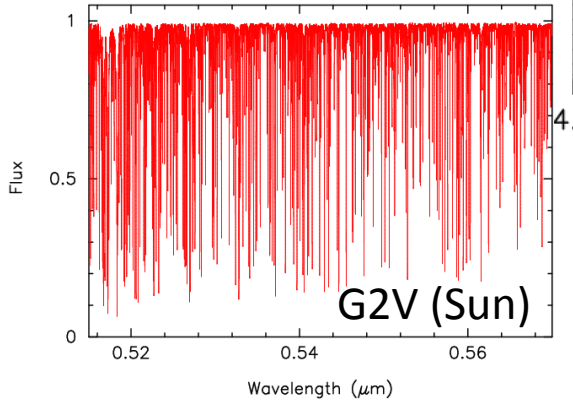


http://exoplanet.eu

Targeting Evolved Stars to Search for Planets around Intermediate-Mass Stars

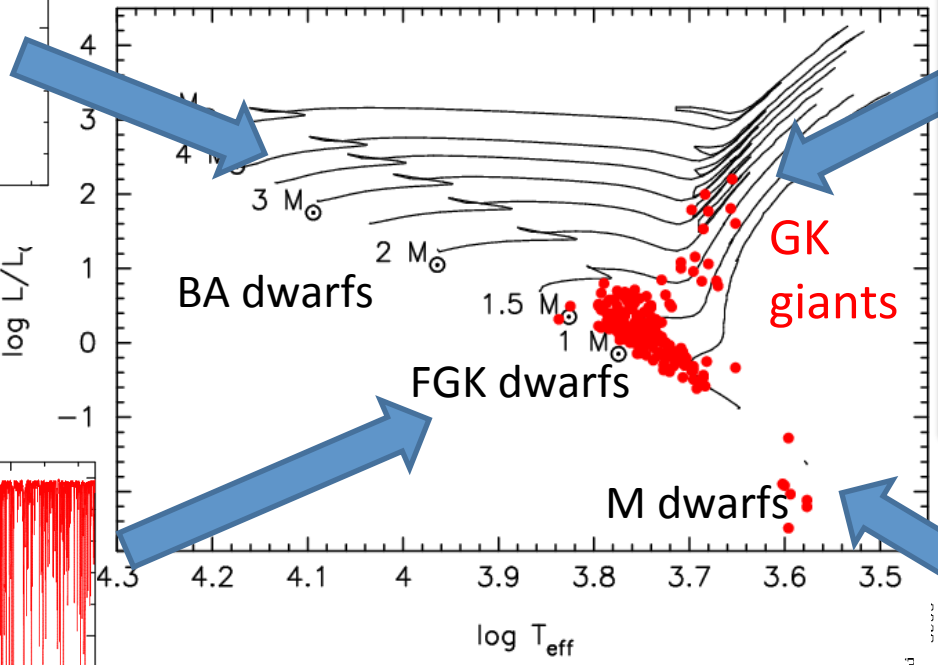


Small N_{line}
Broad lines
➔ low RV precision

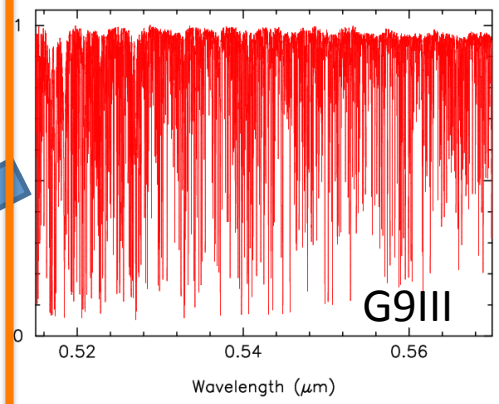


Many sharp and deep lines
➔ high RV precision

Distribution of planet-host stars

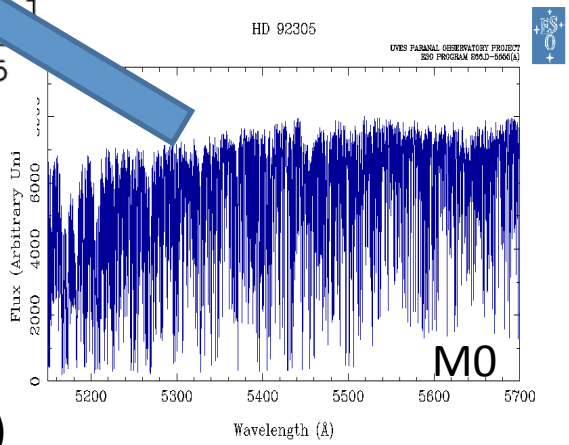


Our targets (1.5-5$M_\odot$)



High RV precision,
but larger stellar noise

Faint in visible
➔ infrared
spectrograph
(e.g., Subaru/IRD)



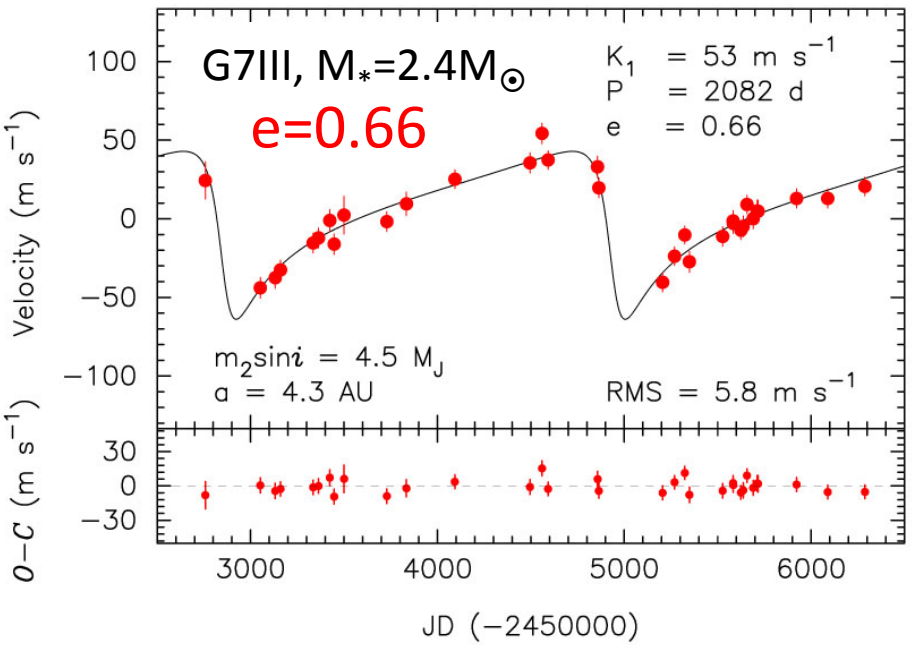
East-Asian Planet Search Network (EAPSNET)

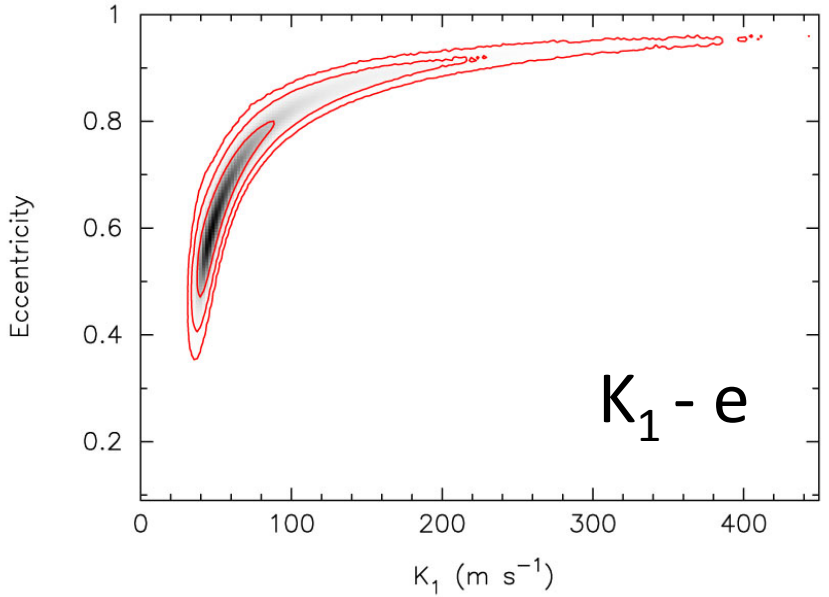
- Japan: OAO 1.88m Tel., ~50-70 nights/yr
  - 300 GK giants (V<6), since 2001
  - Fiber-fed and slit, I_2 Cell, δ_{RV}~2--4 m/s
- China: Xinglong 2.16m Tel., ~40 nights/yr
  - 100 GK giants (V~6), since 2005
  - Fiber-fed, I_2 Cell, δ_{RV}~8 m/s
- Korea: BOAO 1.8m Tel., ~2 weeks/yr
  - 190 GK giants (V<6.5), since 2005
  - Fiber-fed, I_2 Cell, δ_{RV}~7 m/s
- Japan: Subaru 8.2m Tel.
  - >200 GK giants (6.5<V<7), since 2006
  - Slit, I_2 Cell, δ_{RV}~3 m/s
- Turkey & Russia: TUBITAK 1.5m Tel.
  - 50 GK giants (V~6.5), since 2008
  - Slit, I_2 Cell, δ_{RV}~10 m/s

~30 planets and BDs have been found so far by the network

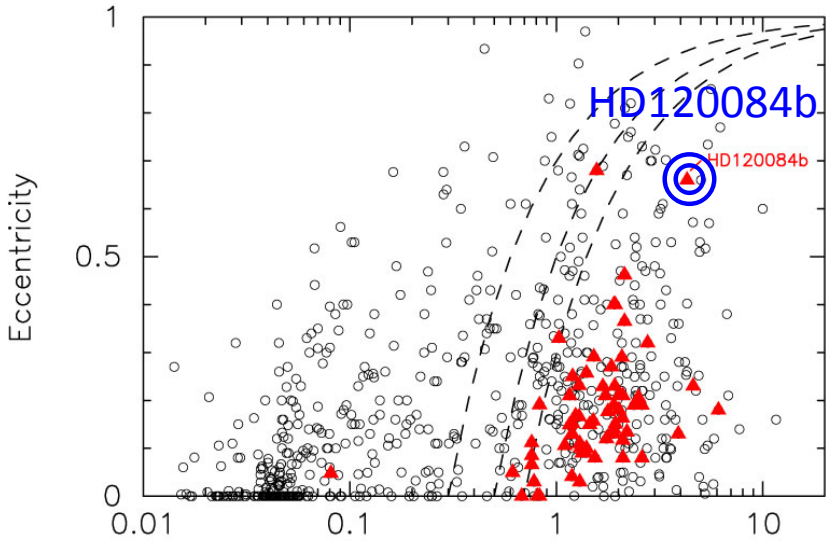
(e.g. Sato et al. 2013)

A Highly Eccentric Planet : HD120084 b





- $M_2 \sin i$ is below $13 M_{JUP}$ with 99% confidence regardless of uncertainties in K_1 and e
- Analysis of long-term RV trend excludes existence of companion with $>13 M_J$ ($>80 M_J$) within ~36AU(~90AU)

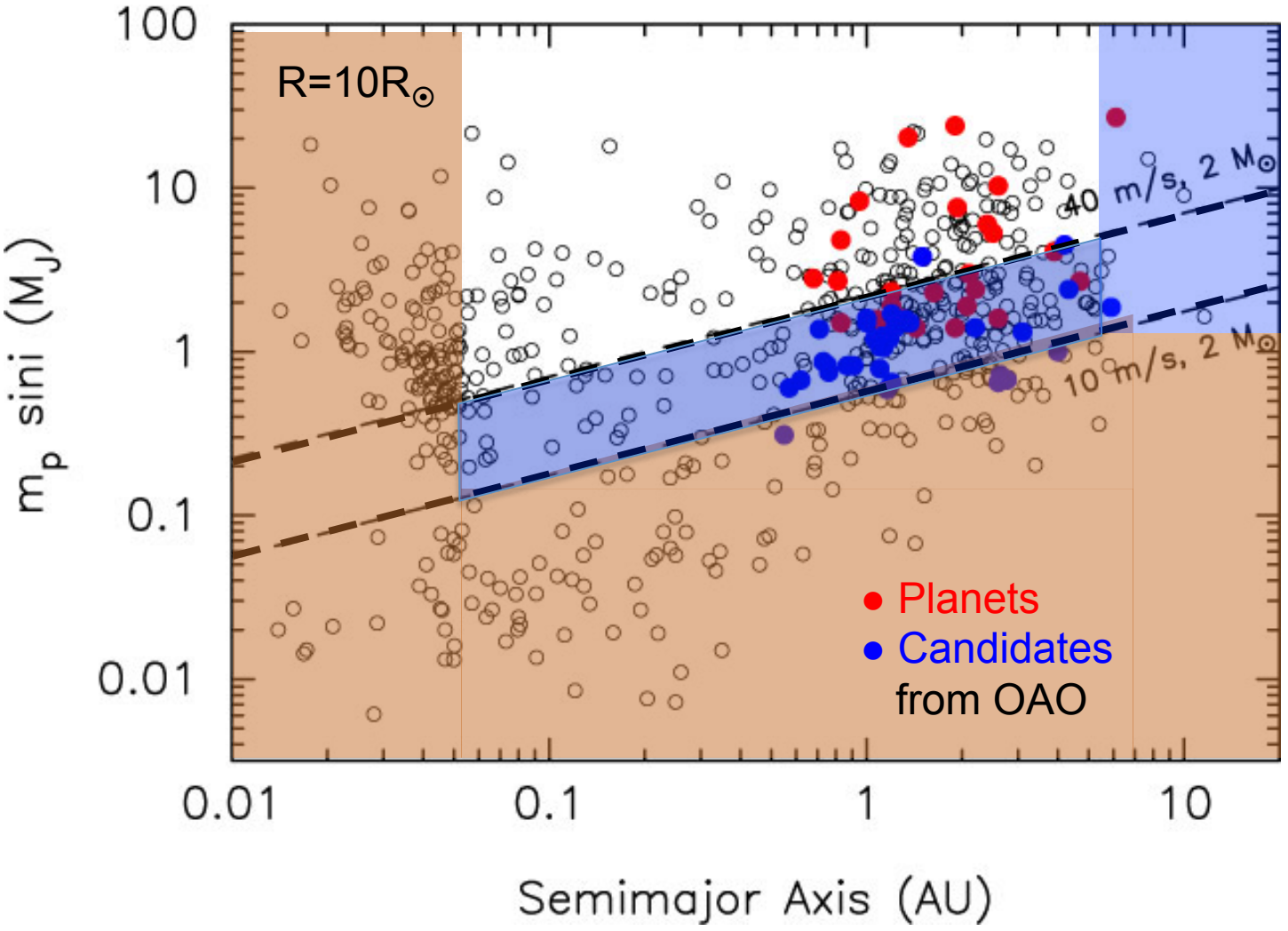


Sato et al. 2013, PASJ, 65, 85

Currently Known Properties of Planets around Intermediate-Mass Evolved Stars

- Occurrence rate of giant planets
  - increases as stellar mass at least up to ~1.9$M_\odot$ (~10–20%; e.g. Johnson+ 2007; Bowler+ 2010)
  - but decreases for >3$M_\odot$ (Sato+ in prep.)
- Planet-mass distribution
  - super-massive (>5M_J) planets are more abundant around more massive (>2$M_\odot$) giants (e.g. Lovis & Mayor 2007)
- Semimajor-axis distribution
  - almost all the planets found around IM evolved stars reside beyond a~0.6 AU (e.g. Sato+ 2008; Johnson+ 2007)
- Planet-metallicity correlation
  - unclear for evolved stars (e.g. Pasquini+ 2007; Takeda+ 2008; Mortier+ 2013)

Detection Limit for Planets around Giants



K_1=40m/s@2$M_\odot$
Completeness
~100%

K_1=10m/s@2$M_\odot$
Completeness
<30%

RV jitter of giants is 10-20 m/s

Unexplored or not-well explored region

Next Three-Year Program at OAO

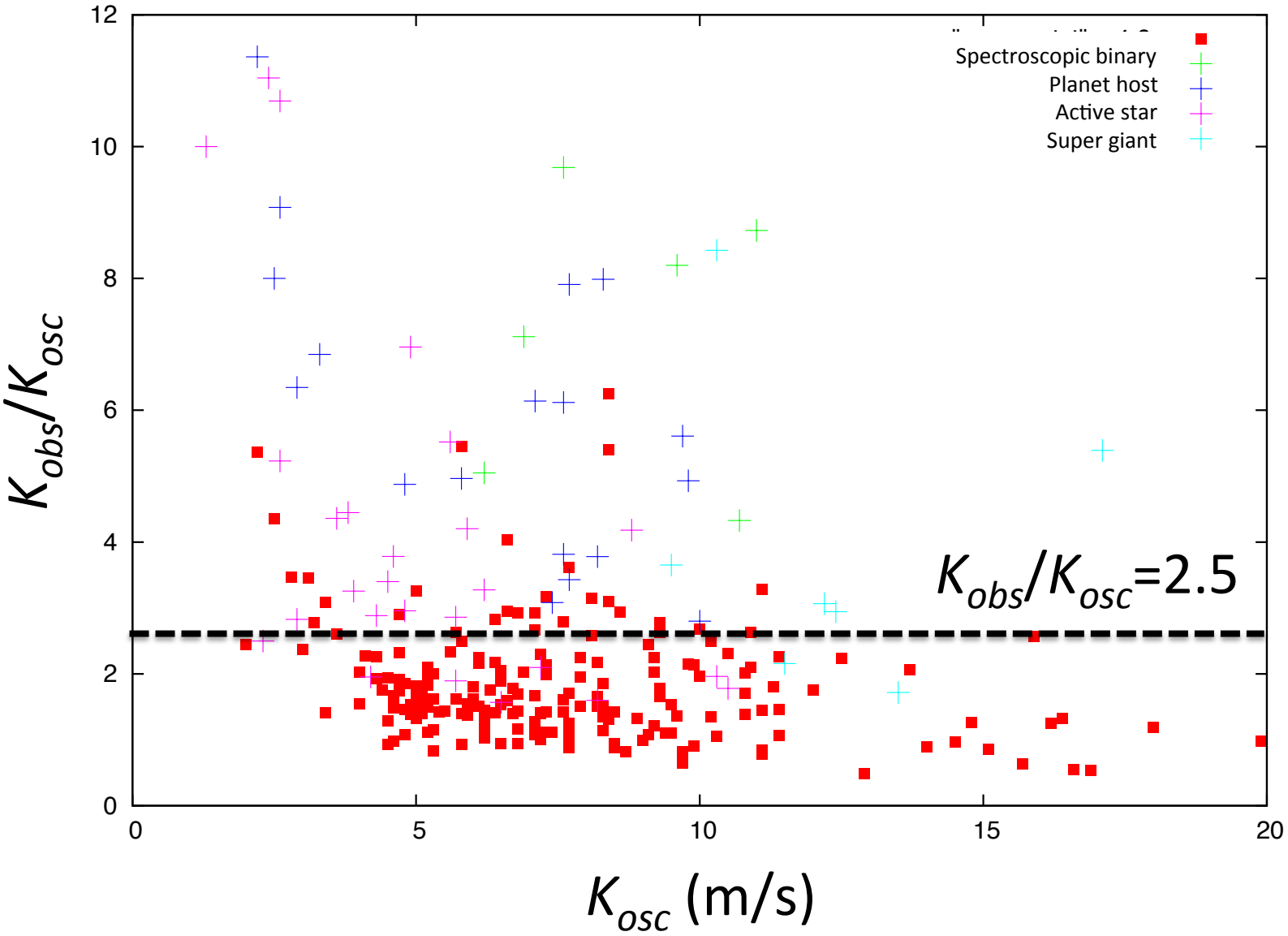
- ~50 nights/yr from 2013B to 2016A are awarded

- Targets – planets in unexplored or not-well explored region around giants
  - Lower-mass planets
    - Search for planets with $m_p \sin i$ ~1-2M_J within 5AU
  - Short-period planets
    - Intensive search for planets with $m_p \sin i$ ~40M_E-2M_J and P<40d
  - Long-period planets
    - Estimate frequency of giant planets and BDs with a>~5-10AU
  - Multi-planetary systems
    - Confirm candidates of multi-planetary systems

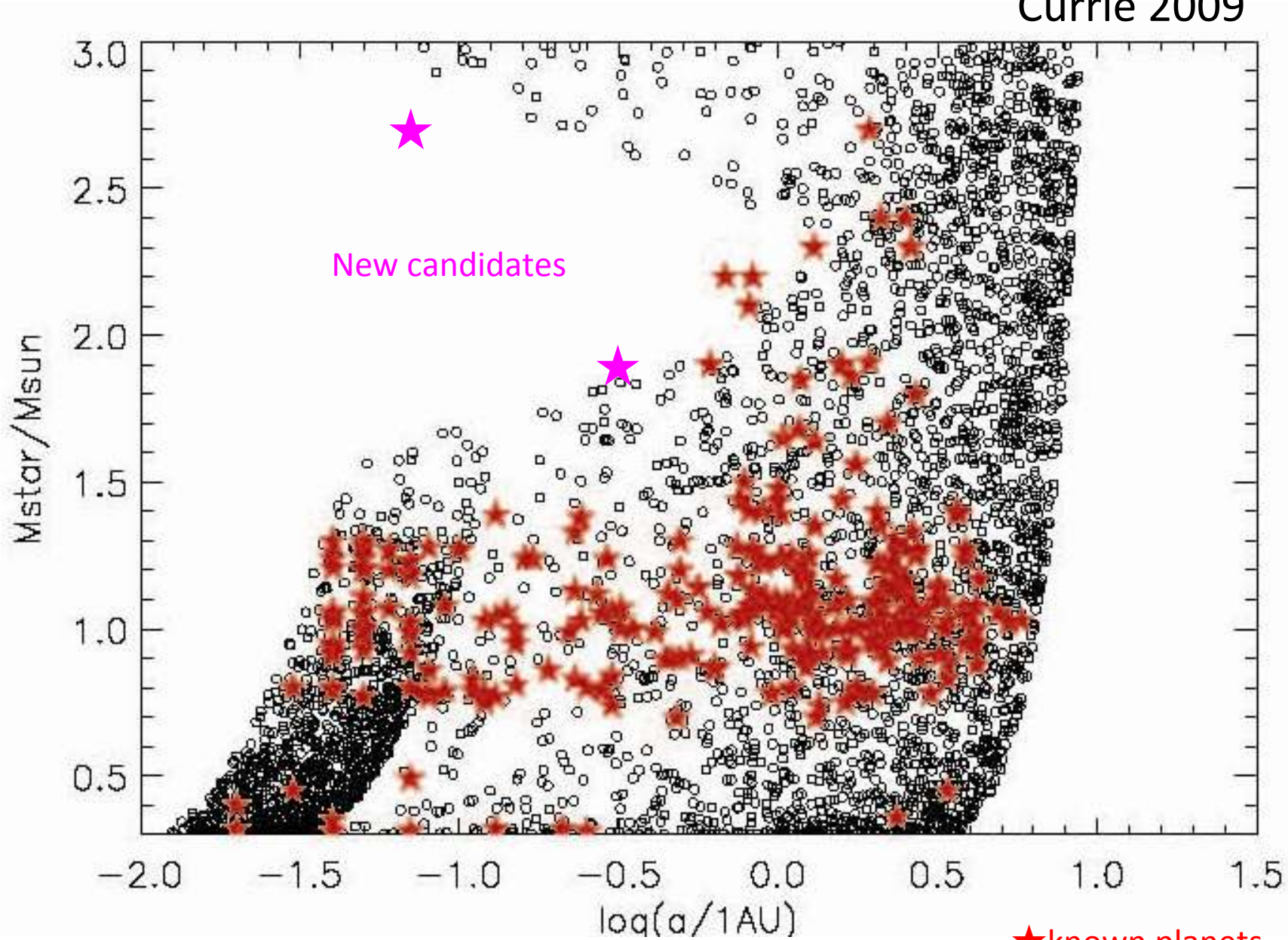
These are only detectable by Doppler technique at present

LOWER-MASS, SHORT-PERIOD PLANETS

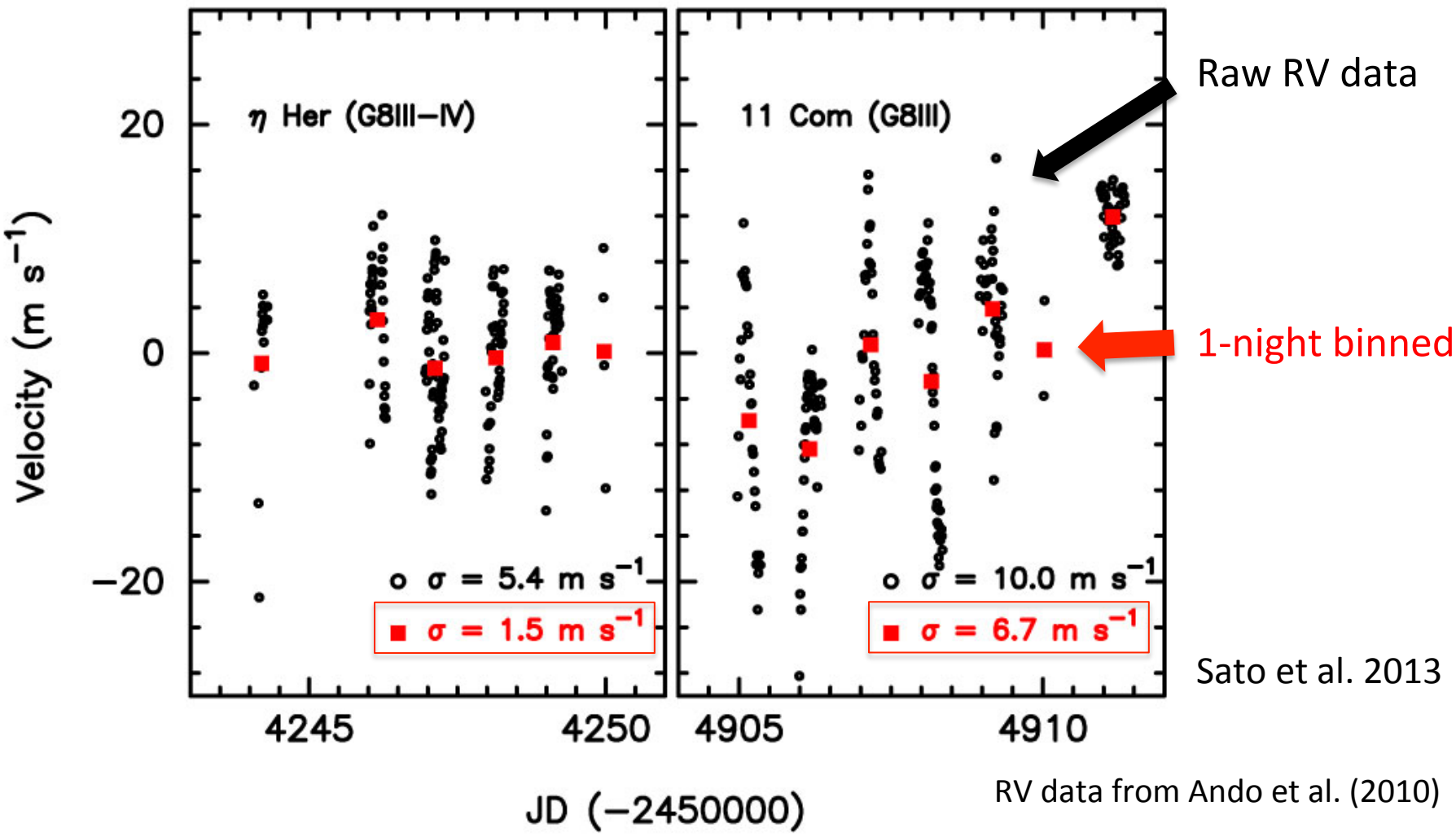
Selecting Planet-Host Candidates



Currie 2009


New candidates
Mstar/Msun
3.0
2.5
2.0
1.5
1.0
0.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
log(a/1AU)
★known planets

How are low-mass planets are detectable around GK giants ?



RV data from Ando et al. (2010)

Short-period super-earths are detectable

MULTI-PLANET SYSTEMS

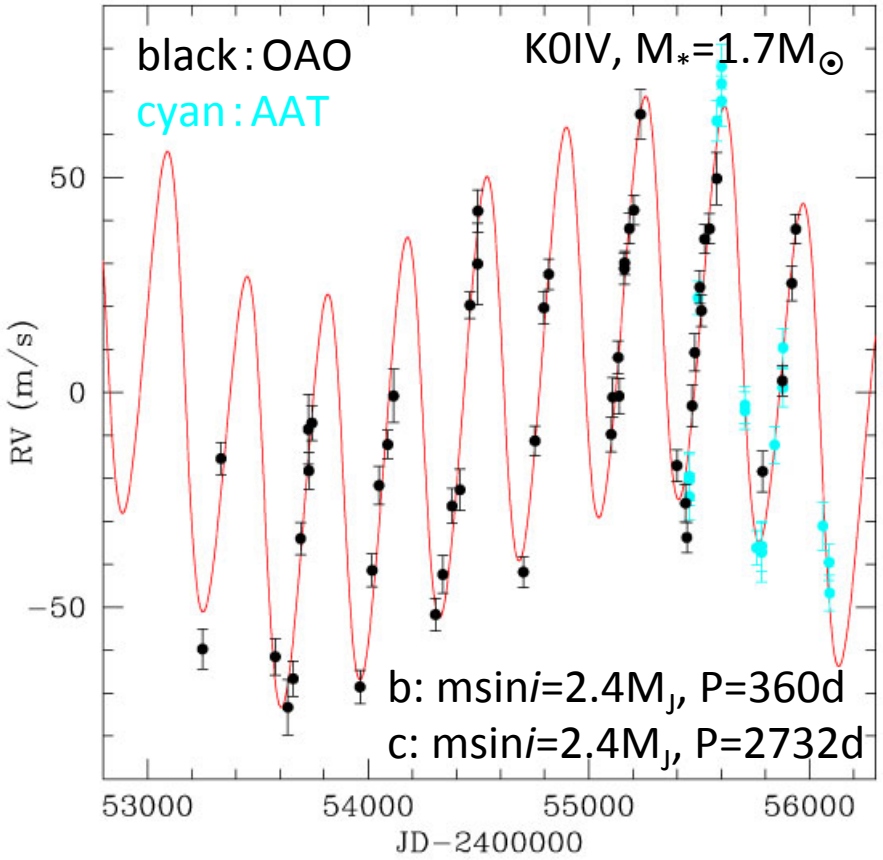
Multi-Planet Systems around Evolved Stars

- Importance of multi-planet systems (e.g. Ford 2006)
  - Evidence of orbital migration (disk-planet interaction, planet-planet scattering)
  - Setting constraint on planetary mass (orbital inclination) by taking account of orbital stability
- Several multi-giant-planet systems have been found so far
  - 24 Sextantis (2:1; Johnson et al. 2011)
  - HD 102272 (4:1?; Niedzielski et al. 2009)
  - ν Ophiuchi (6:1?; Sato et al. 2012, Quirrenbach et al. 2011)
  - BD+20 2457 (3:2?; Niedzielski et al. 2009)
  - HD 4732 (Sato et al. 2013)
  - etc.

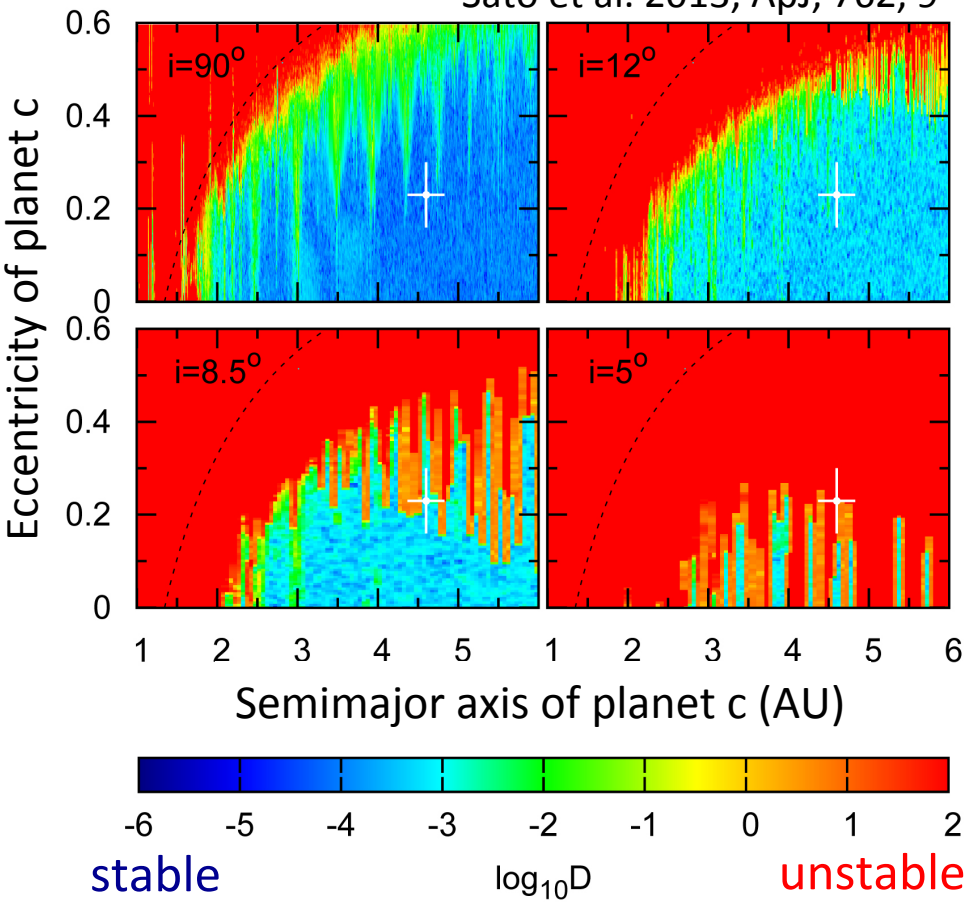
  ⇔~30-50% of giant planets around solar-type stars are in multi-planetary systems (Fischer et al. 2001; Wright et al. 2007, 2009)

A Double Planetary System: HD4732

- Observable period from OAO is limited due to low δ (~-25°) ➔collaboration with AAT
- Set upper limit on planetary mass by orbital stability analysis ➔$m_{b,c}<28M_J$ (i>5°)



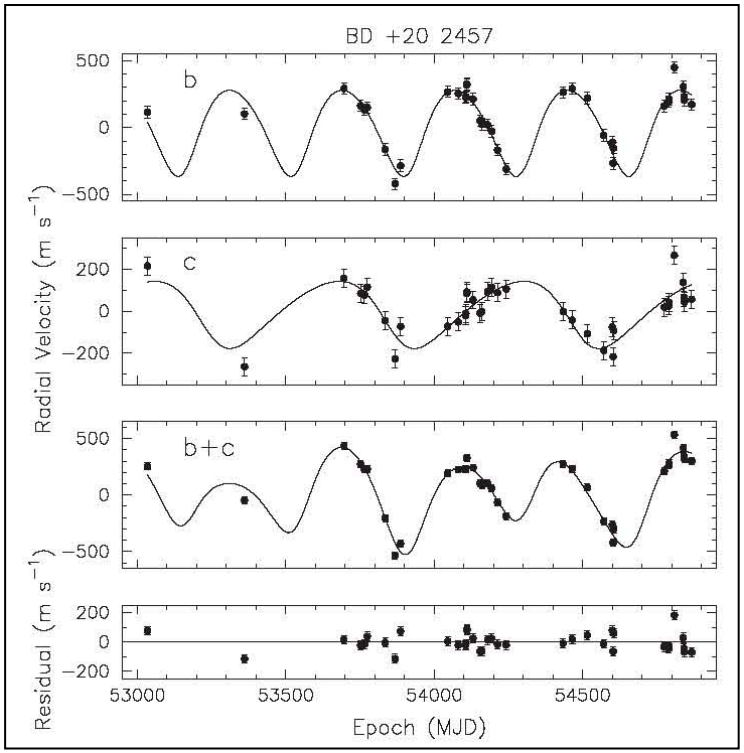
Sato et al. 2013, ApJ, 762, 9



BD+20 2457

(K2III, $M_* = 2.8 M_\odot$)

Best-fit orbits of 2-Keplerian model (b:1.45AU, $21 M_{JUP}$, c:2.01AU, $12 M_{JUP}$; Niedzielski+ 2009) are unstable (Horner+ 2014) unless they are retrograde



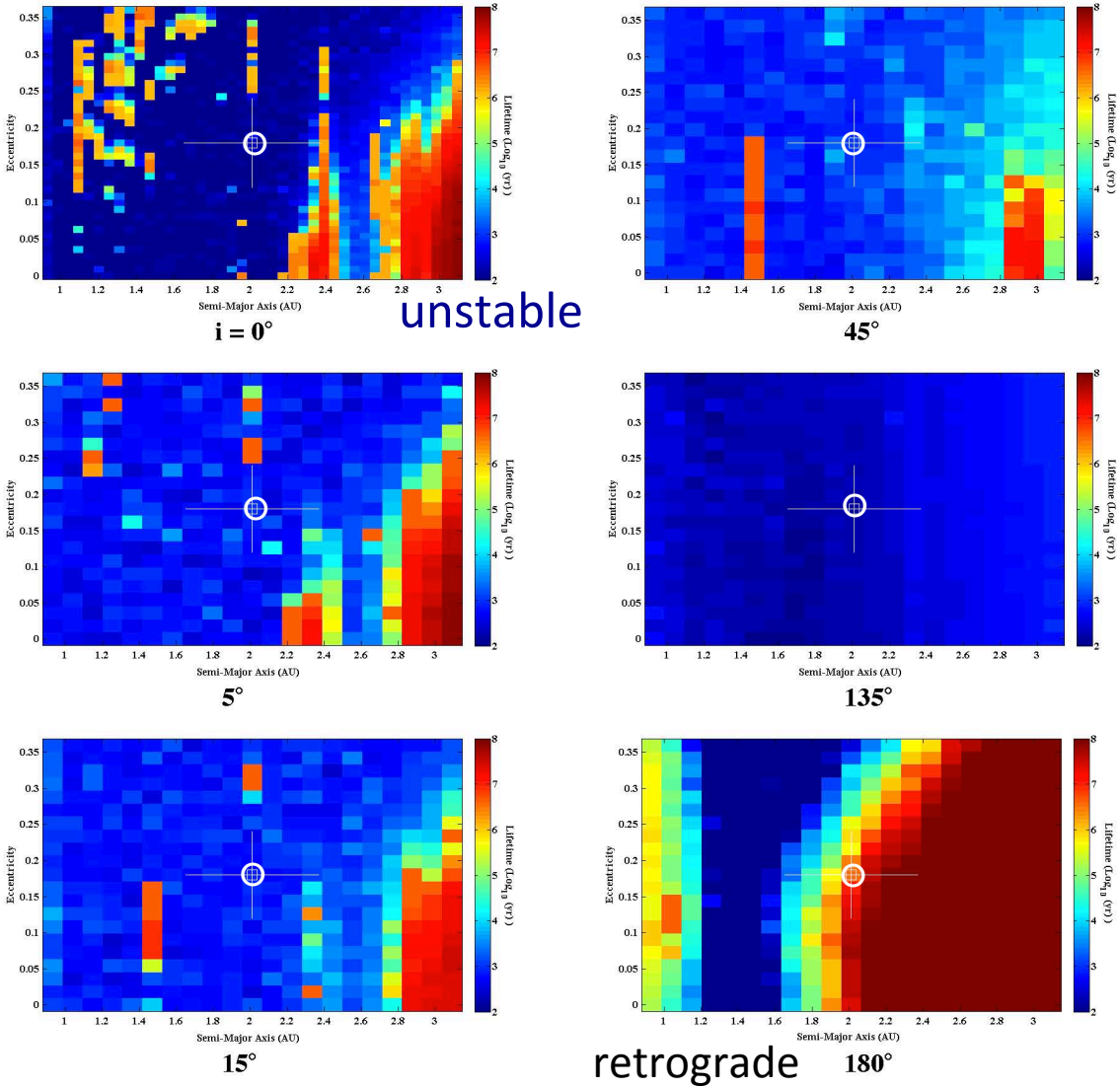
Niedzielski+ 2009

prograde

stable

unstable

Horner+ 2014



retrograde

Summary

- OAO Planet Search Program
  - ~30 planets/BDs have been found around IM giants so far
- Targets of the next 3yr program at OAO
  - Lower-mass planets, short-period planets, distant planets, multi-planet systems, which have not been well explored yet