Red giants with brown dwarfs companions

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Planets around evolved stars

1992 – Wolszczan & Frail - first planet around other star PSR B1257+12 b (c, d).

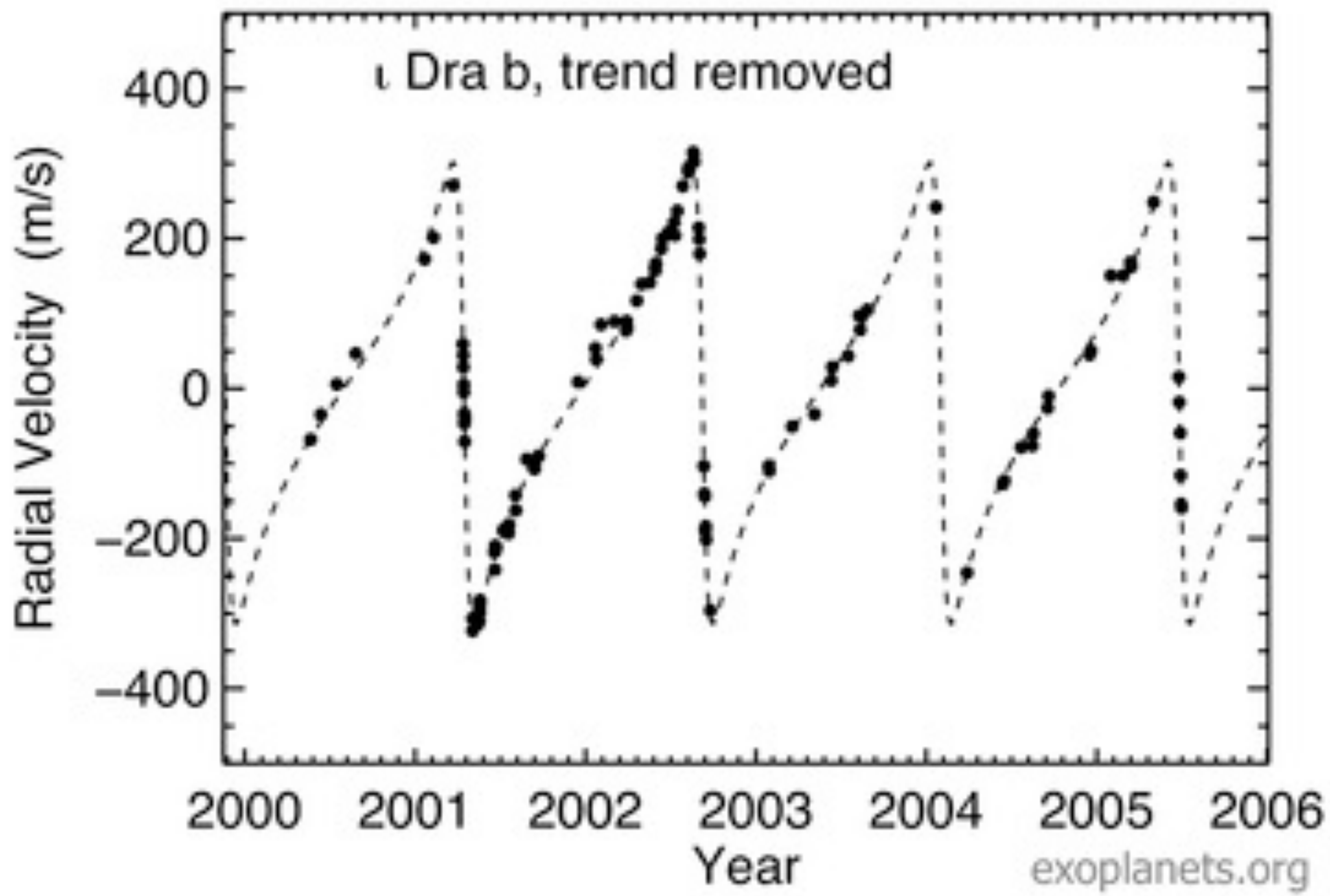
1995 – Mayor & Queloz - first planet around a solar-type star 51 Peg b.

2002 – Frink et al. - first planet around a giant – ι Dra b.

TABLE 2

SPECTROSCOPIC ORBITAL ELEMENTS FOR ι DRA

Element	Fitted Value	Estimated Uncertainty
Period P (days)	536	5
Periastron time T_0	2,452,015.8[a]	0.2[b]
Longitude of periastron ω (deg)	95.9	0.1
Eccentricity e	0.70	0.01
Mass function $f(m)$[c] ($M_\odot$)	5.1×10^{-7}	0.2×10^{-7}



Planets around evolved stars

K giants are RV **variable stars** (Walker et al. 1989 ApJ 343, 21) (30-300 m/s rms)

Short period variations are due to p-mode oscillation (Hatzes & Cochran 1998). Periods and amplitudes may be estimated from Kjeldsen & Bedding (1995) scaling relations:

amplitudes (~L/M): of up to ~200 ms^{-1}

periods ($\sim(R^2(T_{eff})^{1/2})/M$): ~hours-days

When unresolved introduce noise (jitter) to RV.

Long-period variations may be due to:

non-radial pulsations (?),

rotation-induced activity (spots),

low-mass companions.

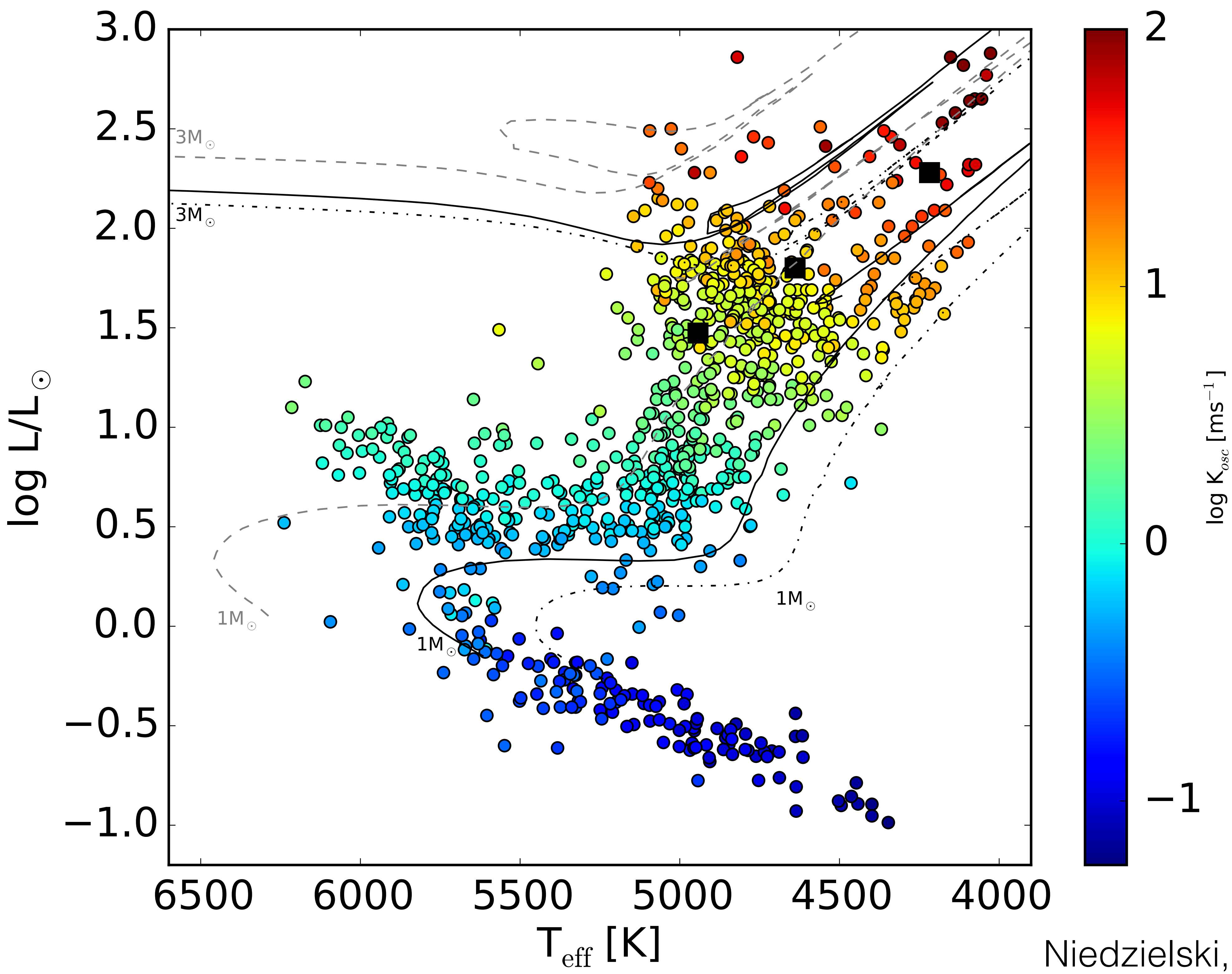
Evolutionary track overlap. Stellar parameters (mass, age) and evolutionary stage uncertain.

Planets around evolved stars

Why bother?

- Planets around $M/M_\odot > 1$ stars.
- Star-planet interactions.
- The future of the Solar System.

The PennState-Toruń Planet Search planets



Star induced jitter may be huge in giants

Niedzielski, Wolszczan et al. 2015

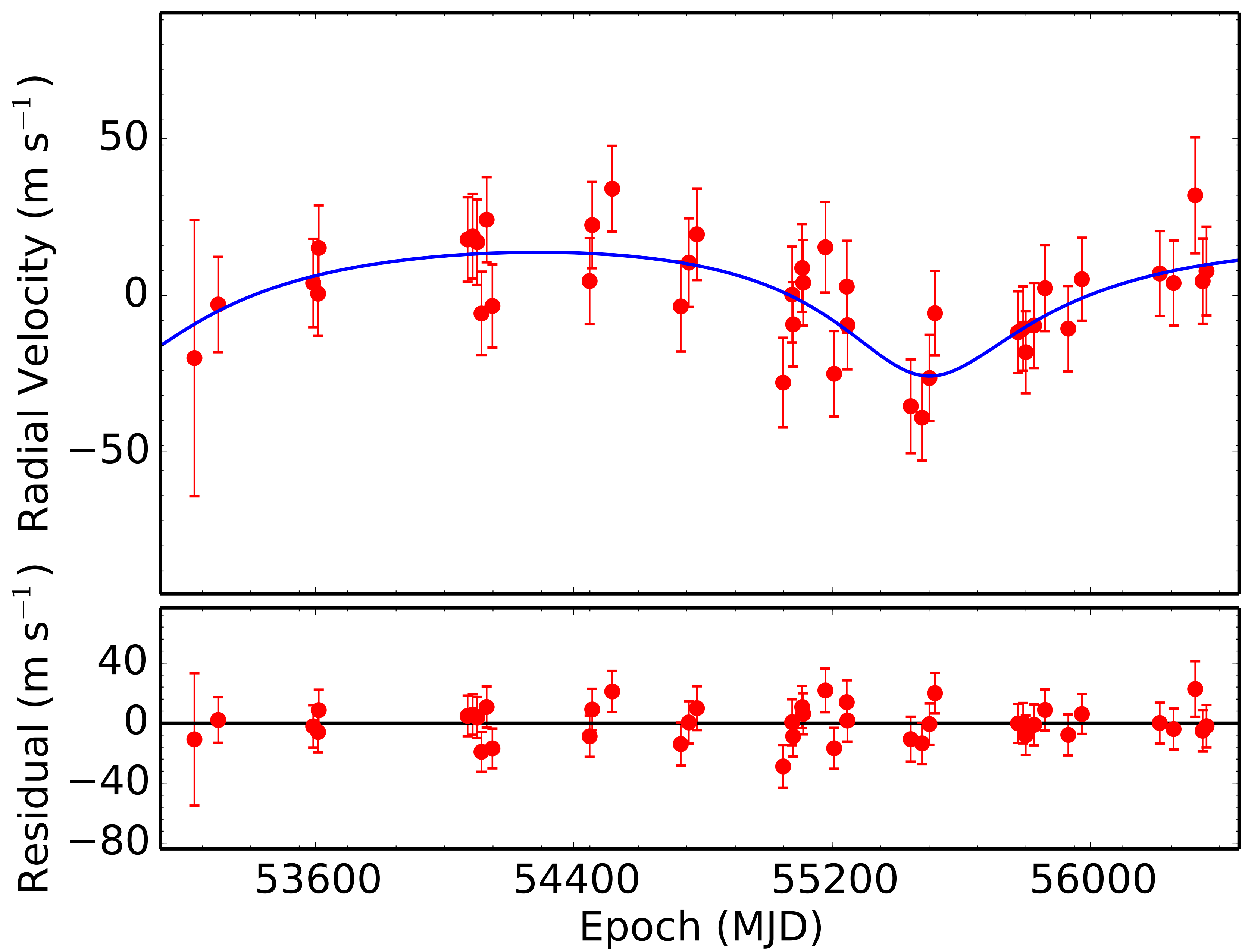
The PennState-Toruń Planet Search (PTPS) sample.

The PennState-Toruń Planet Search planets

Parameter	BD+49 828	HD 95127	HD 216536
V [mag]	9.38 ± 0.02	8.15 ± 0.01	9.23 ± 0.02
Spectral type	K0	K0	K0
π[mas]	—	3.06 ± 0.99	—
T_{eff} [K]	4943 ± 30	4218 ± 69	4639 ± 45
$\log g$	2.85 ± 0.09	1.78 ± 0.3	2.36 ± 0.21
[Fe/H]	-0.19 ± 0.06	-0.18 ± 0.05	-0.17 ± 0.09
$v_{\mathrm{rot}} \sin i_\star$ [km s^{-1}]	1.7 ± 0.8	2.6 ± 0.7	2.6 ± 0.5
$\log L_\star/L_\odot$	1.47 ± 0.13	2.28 ± 0.38	1.80 ± 0.21
$M_\star/\mathrm{M}_\odot$	1.52 ± 0.22	1.20 ± 0.22	1.36 ± 0.38
$R_\star/\mathrm{R}_\odot$	7.6 ± 1.3	20 ± 9	12.5 ± 4.0
log (Age) [yr]	9.37 ± 18	9.74 ± 0.27	9.58 ± 0.33
$P\,(\sin i_\star)^{-1}$ [days]	226 ± 114	389 ± 204	243 ± 91
K_{osc} [m s^{-1}]	$4.5^{+3.1}_{-1.8}$	37^{+79}_{-25}	11^{+15}_{-6}
P_{osc} [days]	$0.13^{+0.08}_{-0.05}$	$1.08^{+1.73}_{-0.81}$	$0.39^{+0.56}_{-0.25}$

Parameter	BD+49 828 b	HD 95127 b	HD 21653 b
p [d]	2590^{+300}_{-180}	482^{+5}_{-5}	$148.6^{+0.7}_{-0.7}$
T_0 [MJD]	55470^{+200}_{-170}	53200^{+50}_{-50}	53587^{+11}_{-11}
K [m s^{-1}]	$18.8^{+6.2}_{-2.0}$	116^{+16}_{-9}	50^{+8}_{-4}
e	$0.35^{+0.24}_{-0.10}$	$0.11^{+0.15}_{-0.06}$	$0.38^{+0.12}_{-0.10}$
ω [deg]	170^{+32}_{-30}	40^{+37}_{-40}	270^{+21}_{-20}
$m_2 \sin i$ [M$_\mathrm{J}$]	$1.6^{+0.4}_{-0.2}$	$5.01^{+0.61}_{-0.44}$	$1.47^{+0.20}_{-0.12}$
a [AU]	$4.2^{+0.32}_{-0.2}$	$1.28^{+0.01}_{-0.01}$	$0.609^{+0.002}_{-0.002}$
V_0 [m s^{-1}]	$1.1^{+1.4}_{-0.5}$	$-10.5^{+3.1}_{-2.3}$	$-4.9^{+0.7}_{-2.1}$
$\sqrt{\chi^2_\nu}$	1.35	1.14	1.29
σ_{RV} [m s^{-1}]	11.6	50.9	23.0
jitter [m s^{-1}]	$4.44^{+0.35}_{-1.00}$	47.5	17.9
N_{obs}	42	41	47

BD+ 49 828 b



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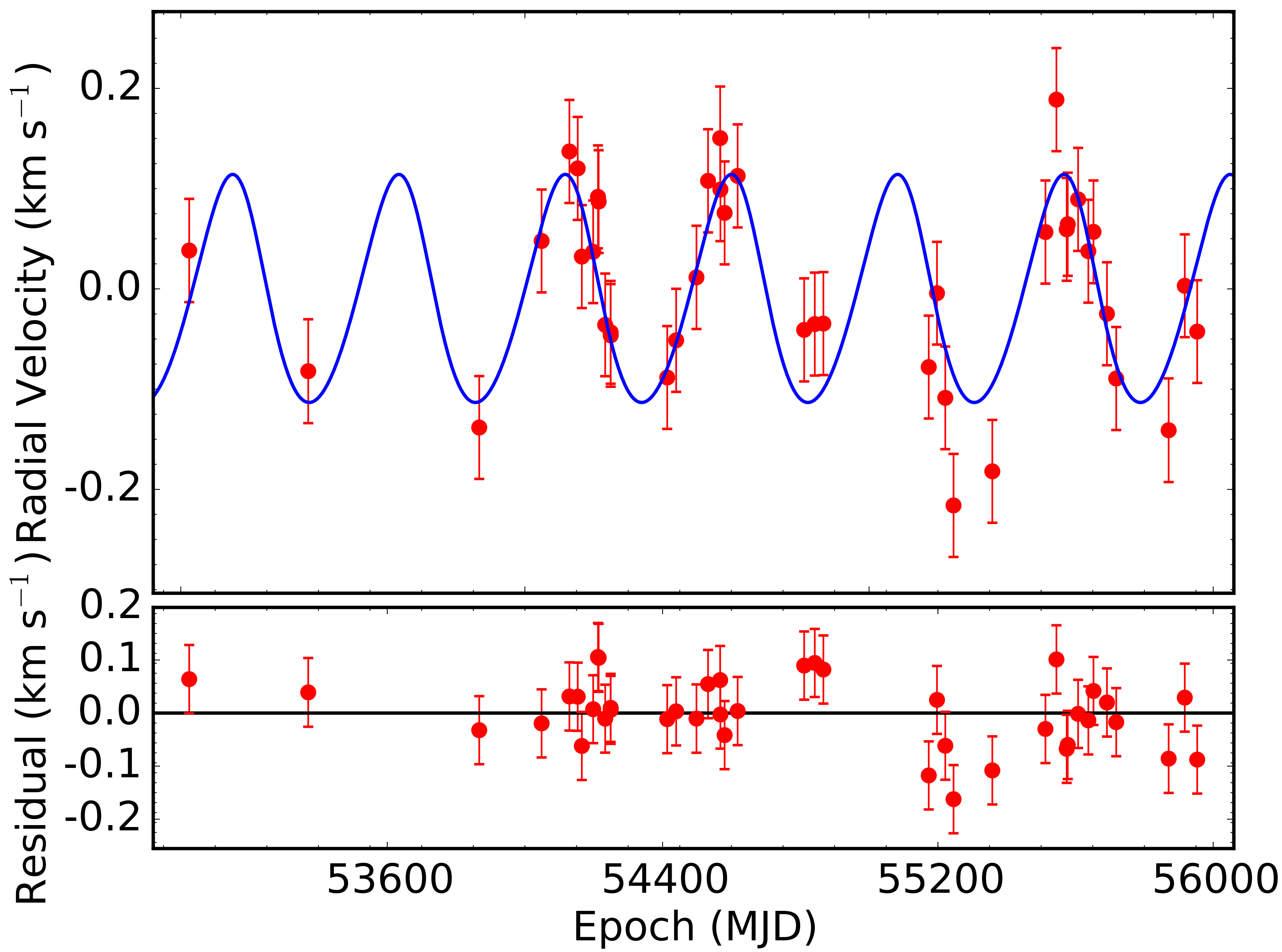
HD 95127 b



Niedzielski, Wolszczan et al. 2015

The PennState-Toruń Planet Search planets

HD 216536 b

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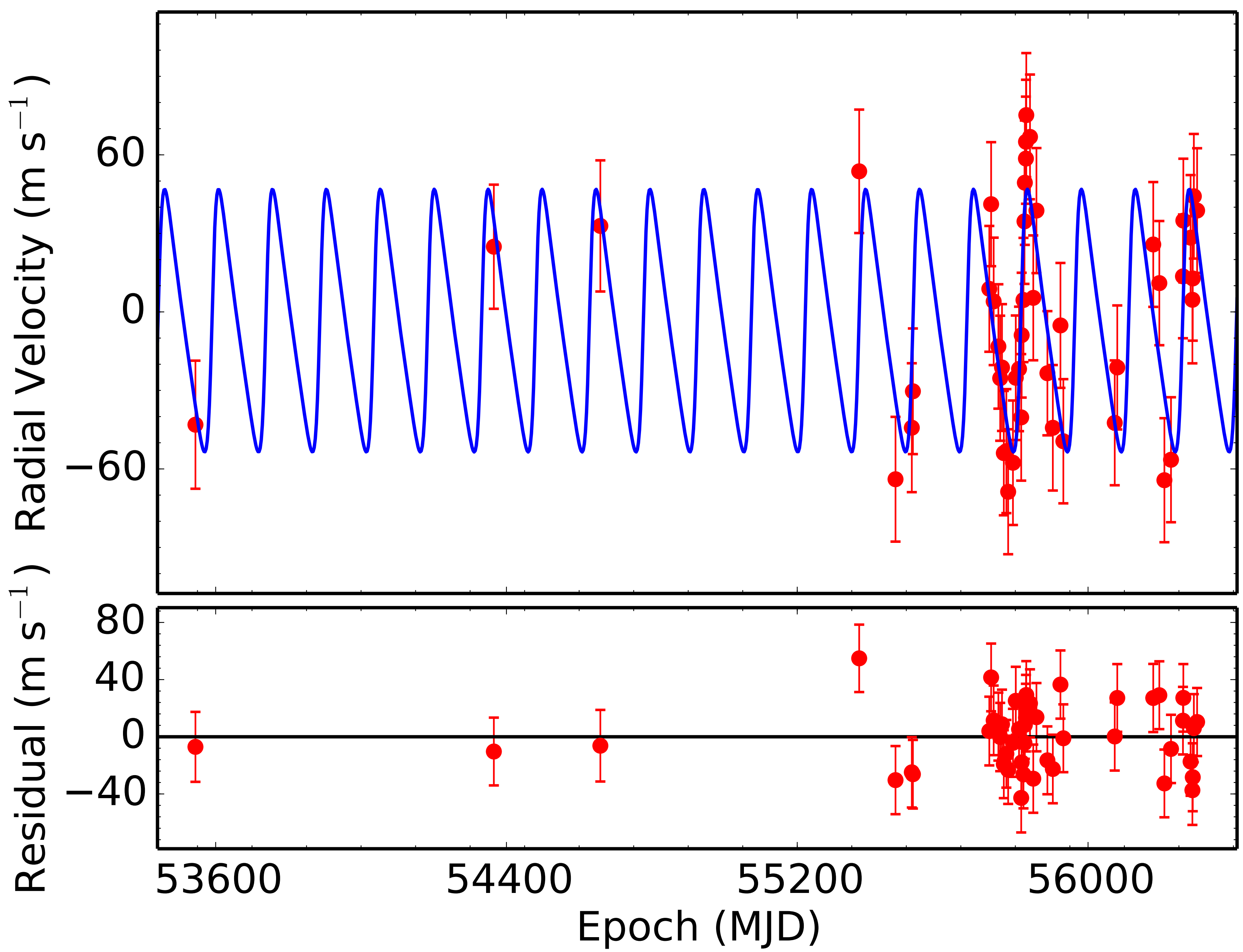
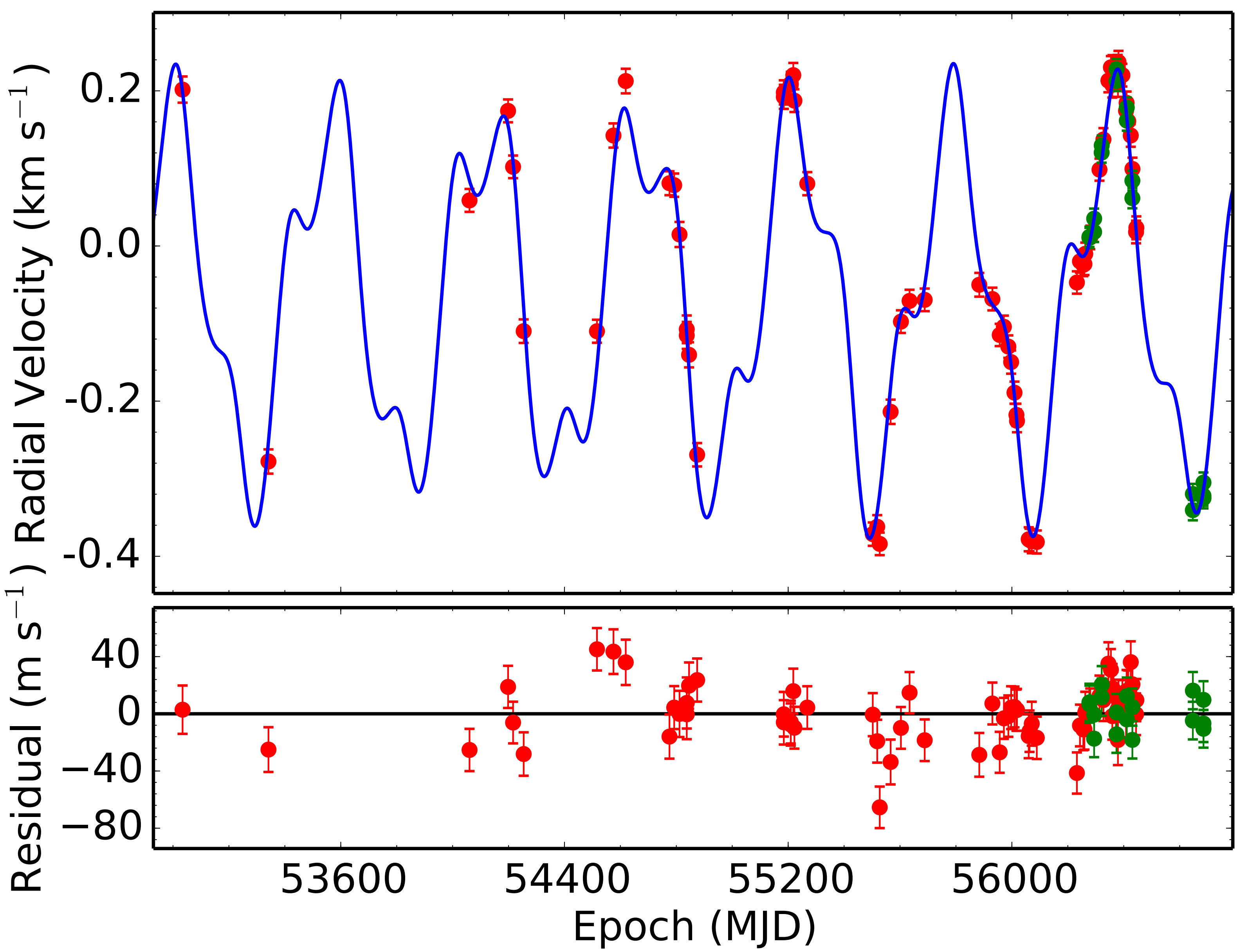


Niedzielski, Wolszczan et al. 2015

The PennState-Toruń Planet Search planets

TYC 1422 614 1 b, c



Parameter	value	reference
V [mag]	10.21	Perryman & ESA (1997)
B-V [mag]	0.95±0.085	Perryman & ESA (1997)
$(B-V)_0$ [mag]	0.997	Zieliński et al. (2012)
M_V [mag]	0.81	Zieliński et al. (2012)
T_{eff} [K]	4806±45	Zieliński et al. (2012)
logg	2.85±0.18	Zieliński et al. (2012)
$[Fe/H]$	-0.20±0.08	Zieliński et al. (2012)
RV [kms^{-1}]	37.368±0.027	Zieliński et al. (2012)
$v_{rot}^{CCF} \sin i_\star$ [kms^{-1}]	1.4±0.7	Nowak (2012)
A(Li)	< 1.1	Adamów et al. (2014)
$M/M_\odot$	1.15±0.18	this work
$\log(L/L_\odot)$	1.35±0.16	this work
$R/R_\odot$	6.85±1.38	this work
log age [yr]	9.77±0.22	this work
d [pc]	759 ± 181	calculated from M_V
V_{osc} [ms^{-1}]	$4.555^{+3.718}_{-1.993}$	this work
P_{osc} [d]	$0.141^{+0.102}_{-0.064}$	this work

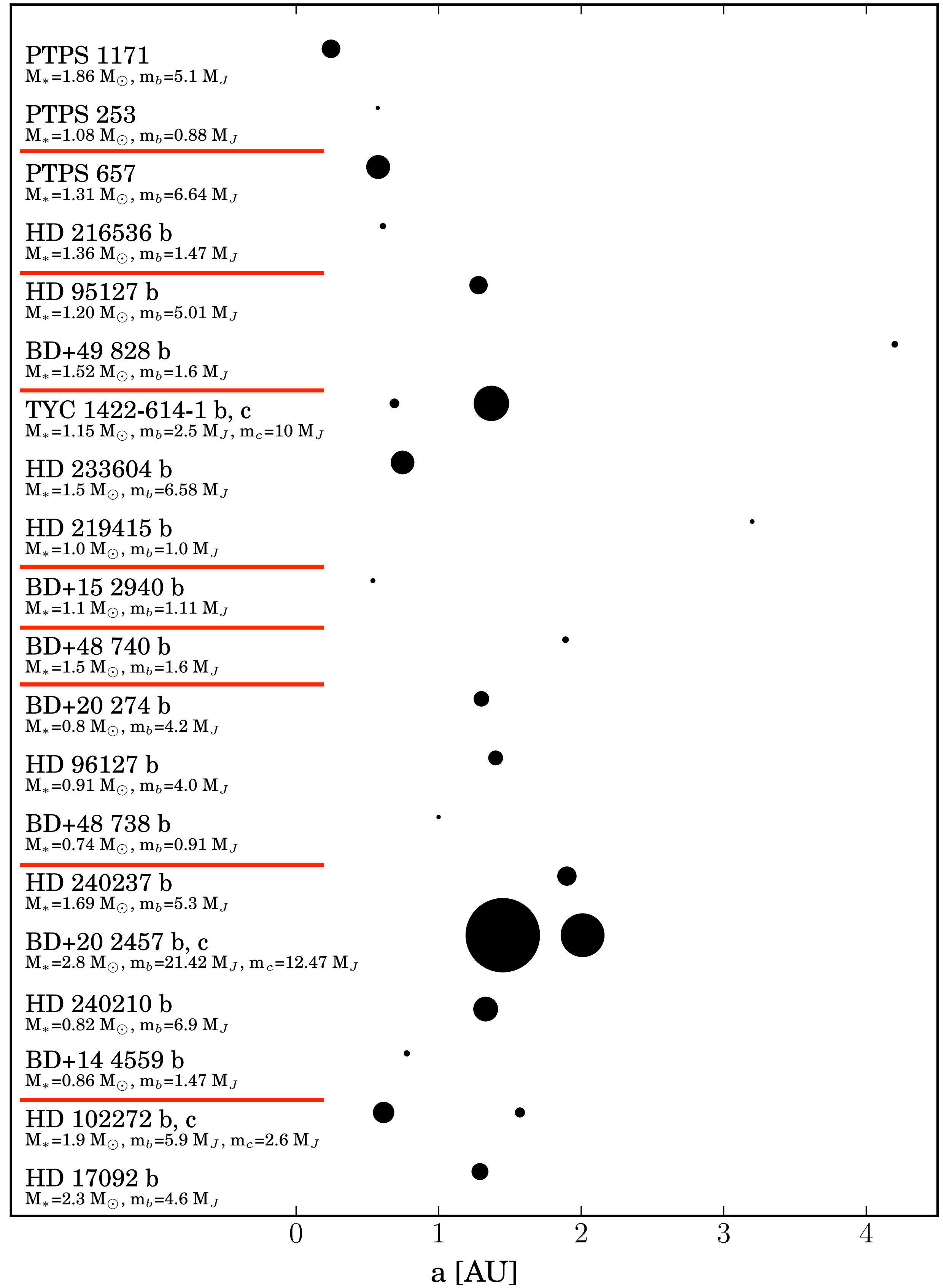
Parameter	TYC 1422-614-1 b	TYC 1422-614-1 c
P (days)	$198.40^{+0.42}_{-0.42}$	$559.3^{+1.2}_{-1.2}$
T_0 (MJD)	53236^{+25}_{-22}	53190^{+30}_{-30}
K (m s^{-1})	$82.0^{+7.0}_{-5.1}$	$233.0^{+4.5}_{-4.0}$
e	$0.06^{+0.06}_{-0.02}$	$0.048^{+0.020}_{-0.014}$
ω (deg)	50.0^{+50}_{-43}	130^{+20}_{-20}
$m_2 \sin i$ (M_J)	2.5 ± 0.4	10 ± 1
a (AU)	0.69 ± 0.03	1.37 ± 0.06
V_0 (m s^{-1})	$-68.2^{+2.0}_{-2.2}$	
offset (m s^{-1})	$37758^{+6.0}_{-6.0}$	
σ_{jitter} (m s^{-1})	$12.9^{+1.4}_{-1.2}$	
$\sqrt{\chi^2_\nu}$	1.64	
σ_{RV} (m s^{-1})	18.94	
N_{obs}	86	

Data from **HET** and **Harps-N**

Niedzielski, Villaver et al. 2015

The PennState-Toruń Planet Search planets

Jupiter-mass planets may be easly detected



Planets around evolved stars

Inventory of known systems around evolved stars

Parameter	$M_\star$ range	dwarfs	subgiants	giants	bright giants
N_{planet}	1-2 $M_\odot$	267	73	23	9
	all	458	77	41	14
	1-2 $M_\odot$(RV)	138	60	22	9
	all(RV)	236	64	40	14

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Niedzielski, Wolszczan et al. 2015

Properties of planets around evolved stars

No Hot Jupiters, no Earth-like planets (yet?)

Planets around massive stars are more frequent.
(Lovis & Mayor 2007, Johnson et al. 2007, Kennedy & Kenyon 2008, Johnson et al. 2010)

No planets within a<0.6 AU (primordial or due to engulfment?).
(Villaver & Livio 2007, 2009, Johnson et al. 2007, Burkert & Ida 2007, Sato 2008, Currie 2009, Kunitomo et al. 2011)

Stellar mass – planetary system mass relation.
(Lovis & Mayor 2007, Bowler et. 2010)

No planet occurrence – metallicity relation (?).
(Pasquini et al. 2008, Zieliński et al. 2009, Ghezzi et al. 2010, Mortier et al. 2013)

Brown dwarfs more common than around MS stars
(Mitchell et al. 2013; Niedzielski et al. 2013)

Red giants with brown dwarfs companions

Brown dwarfs around evolved stars more common than around MS stars:

about a dozen out of ~60 companions in BD mass range

BD occurence ratio around giants >1%. No desert?

significant increase of average companion mass for evolved stars

Red giants with brown dwarfs companions

Parameter	$M_\star$ range	dwarfs mean / median	σ	subgiants mean / median	σ	giants mean / median	σ	bright giants mean / median	σ
$m_P \sin i/m_J$	all	2.046	0.147	2.702	0.399	6.391	0.987	7.798	1.186
		0.955		1.800		4.500		6.300	
	1-2 $M_\odot$	2.459	0.212	2.705	0.416	4.557	0.592	7.688	0.854
		1.308		1.800		3.200		7.800	
	all(RV)	2.250	0.200	2.956	0.467	6.533	1.001	7.798	1.186
		1.135		1.850		4.900		6.300	
	1-2 $M_\odot$(RV)	2.532	0.256	2.977	0.492	4.731	0.592	7.688	0.854
		1.658		1.850		3.260		7.800	

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Red giants with brown dwarfs companions

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$m_P \sin i \simeq 8\ M_J \rightarrow m_P \simeq 13\ M_J$

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Red giants with brown dwarfs companions

Why the planetary mass increases?

Jean Schneider's exoplanet encyclopedia too kind for us?

RV precision good enough?

Stellar jitter prevents low-mass planet detection?

Stellar masses overestimated (Lloyd 2011)?
… or is it a selection effect?

Stellar mass overestimated or selection effect?

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		1.658		1.850		3.260		7.800	
$M_\star/M_\odot$	all	1.039	0.011	1.428	0.027	1.870	0.090	1.464	0.120
		1.031		1.450		1.900		1.395	
	1-2 $M_\odot$	1.179	0.009	1.453	0.025	1.499	0.060	1.457	0.084
		1.140		1.470		1.500		1.400	
	all(RV)	0.997	0.015	1.446	0.031	1.885	0.091	1.464	0.120
		1.030		1.475		1.900		1.395	
	1-2 $M_\odot$(RV)	1.140	0.010	1.478	0.028	1.507	0.062	1.457	0.084
		1.100		1.480		1.500		1.400	

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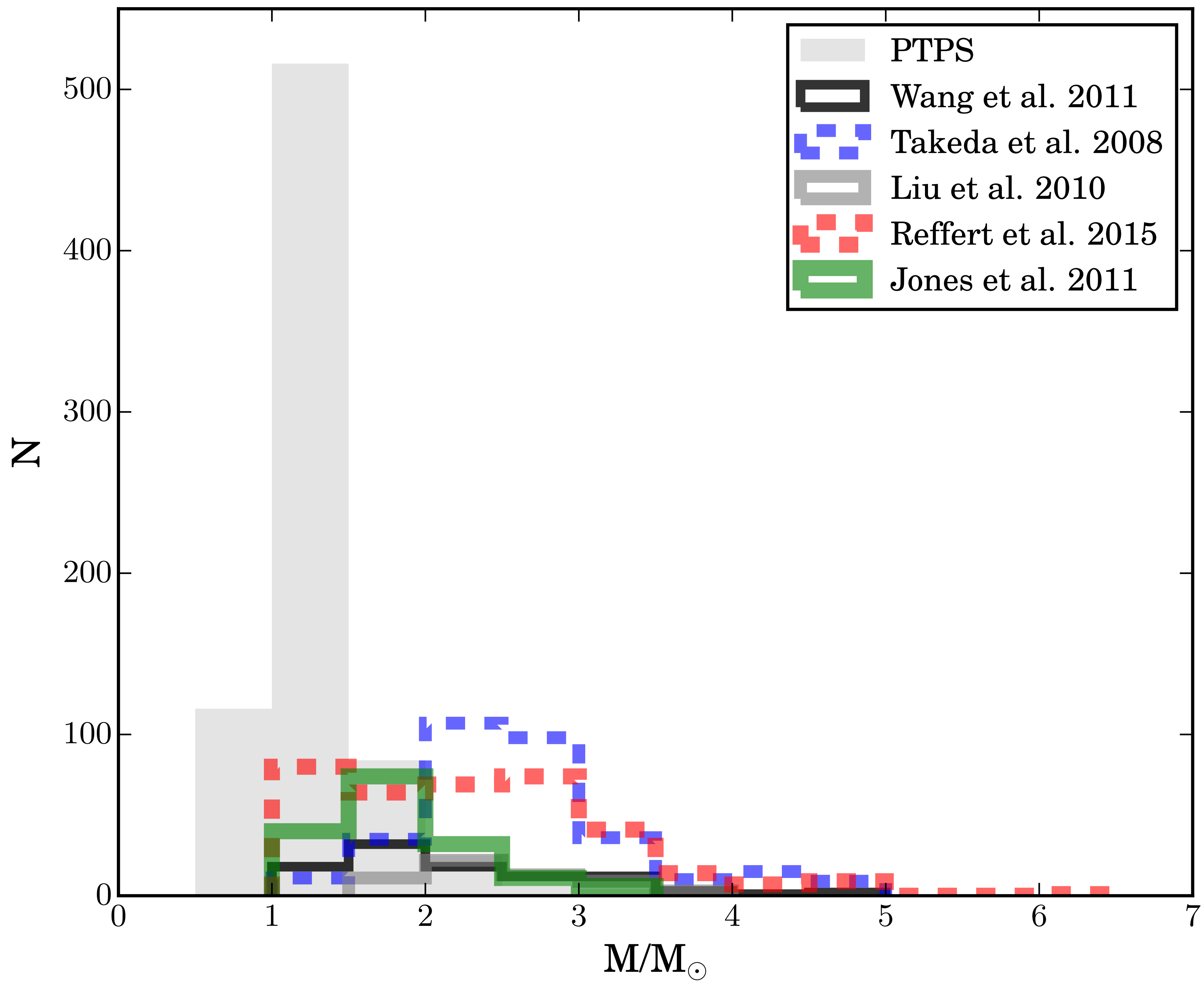
Stellar mass overestimated or selection effect?



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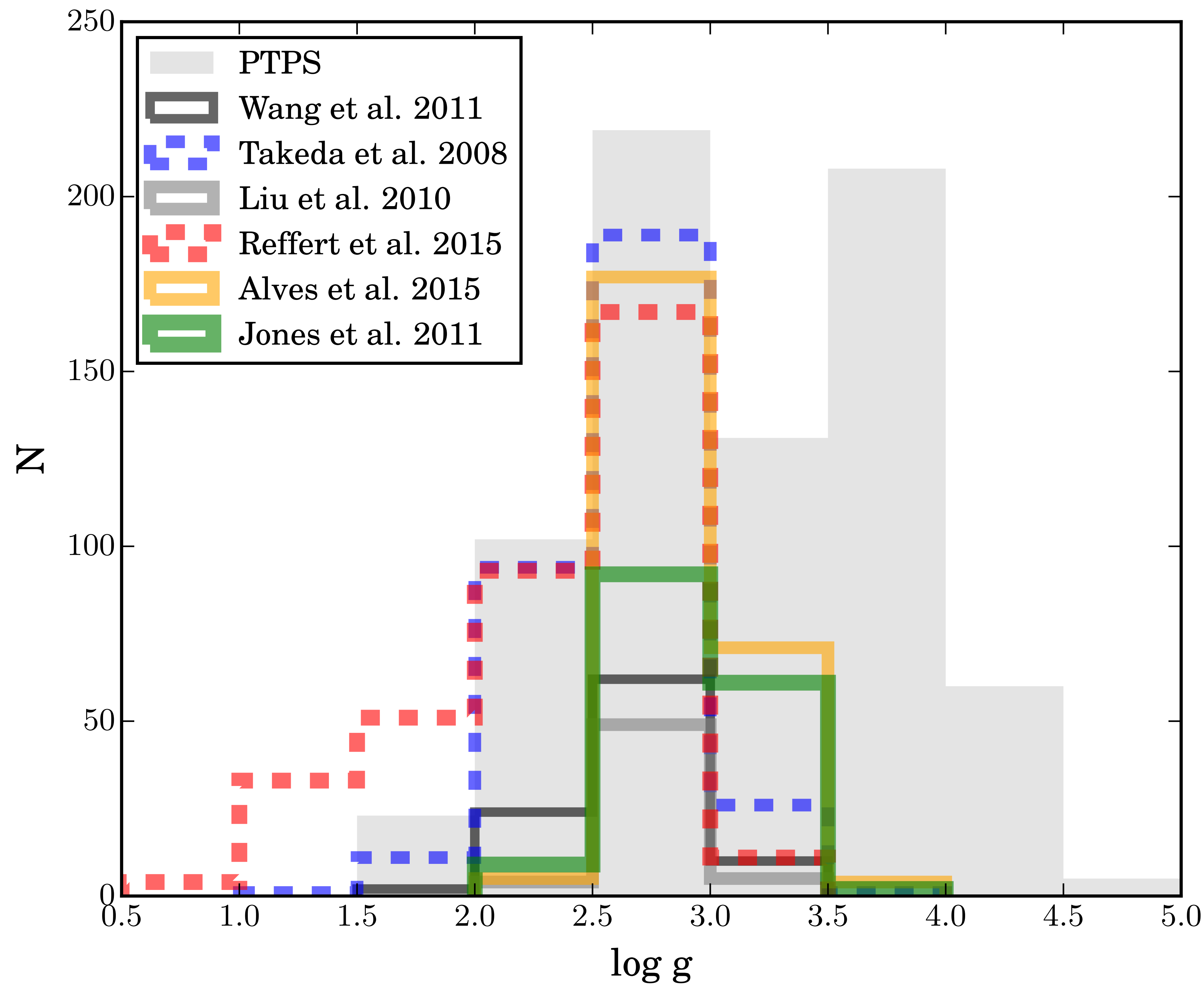

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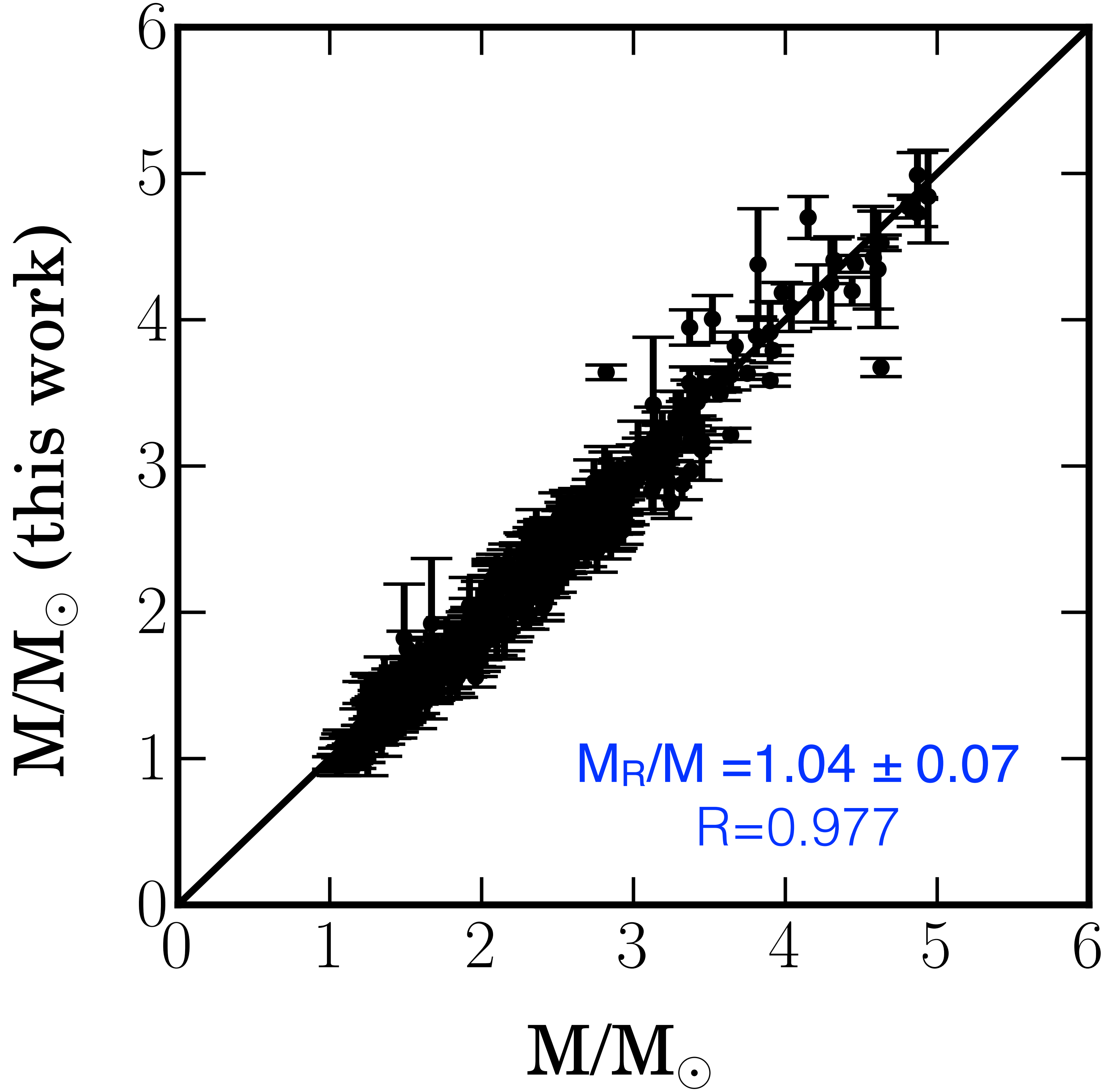
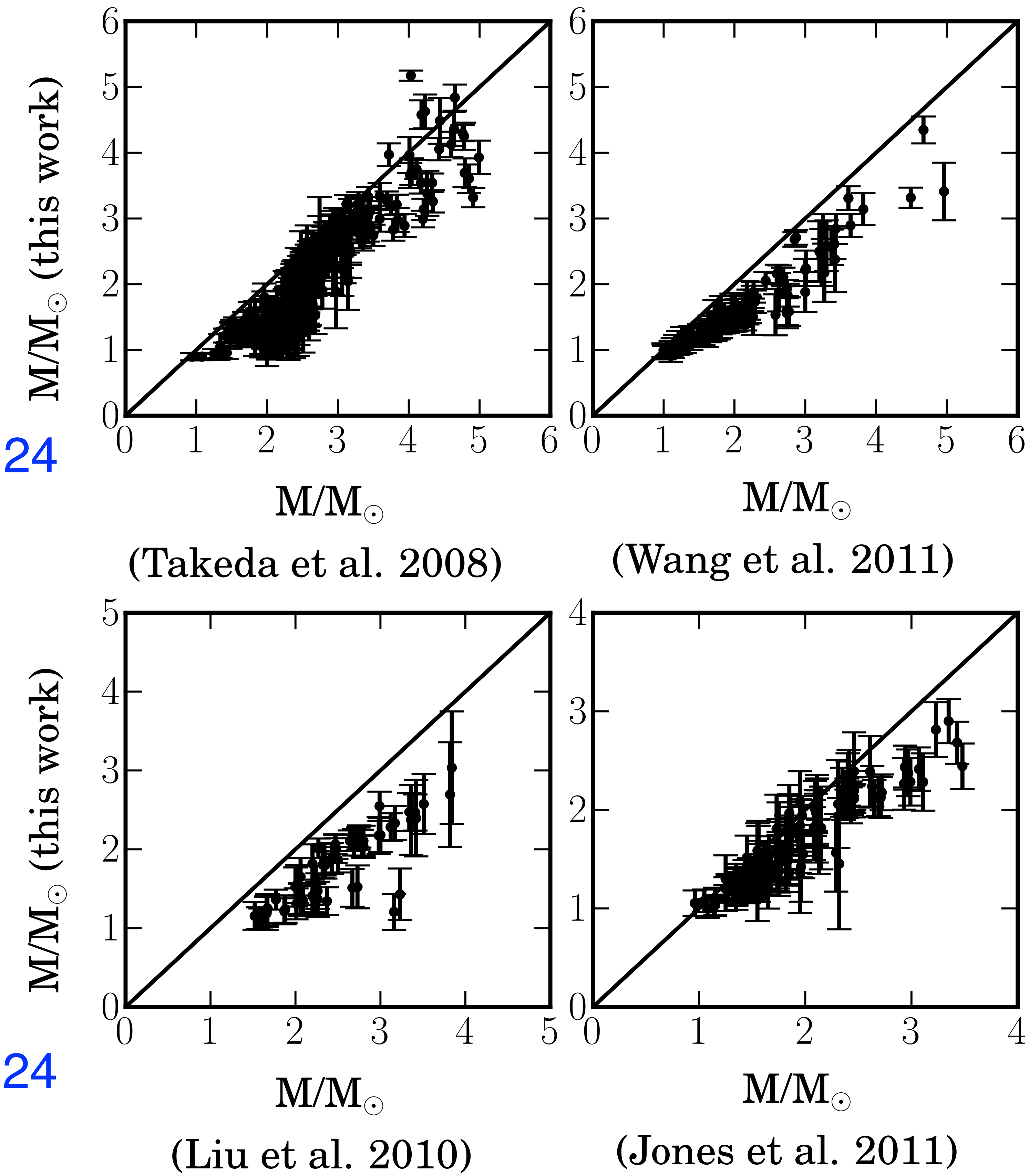


(Reffert et al. 2015)

Stellar mass overestimated or selection effect?



$M_T/M = 1.29 \pm 0.24$
R=0.911

$M_W/M = 1.28 \pm 0.15$
R=0.948

$M_L/M = 1.43 \pm 0.24$
R=0.851

$M_J/M = 1.15 \pm 0.10$
R=0.941

Conclusions:

YES - masses for some giants may be overestimated.

NO - it will not lower companion masses much.

Evolved stars indeed host more massive planets or BDs.

BUT

what is the role of stellar mass-loss?
what is actuall precision of various RV planet searches?