Giant Planets around Giant Stars

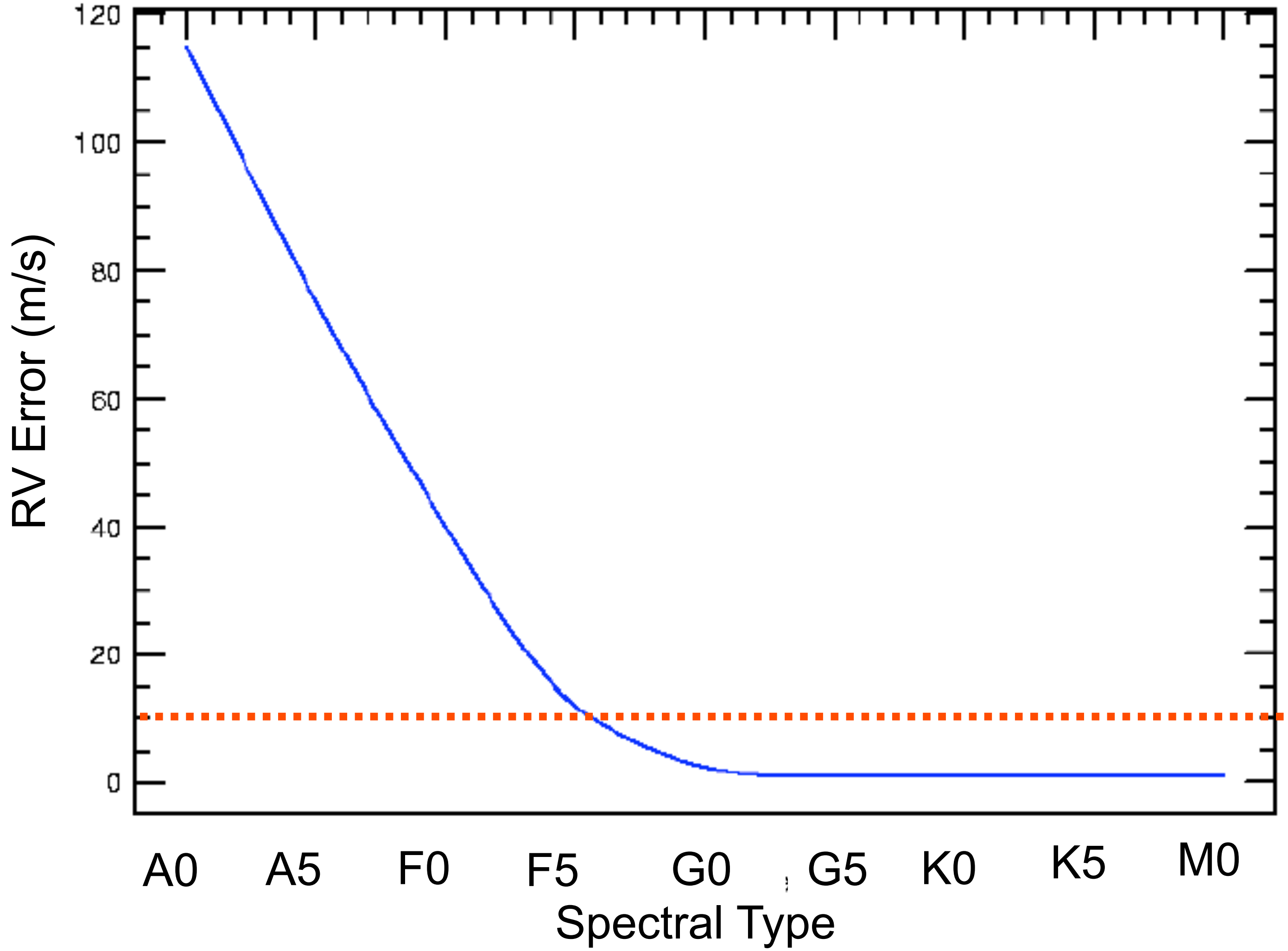
Artie P. Hatzes
Thüringer Landessternwarte Tautenburg

Why look for Planets around Giant Stars?

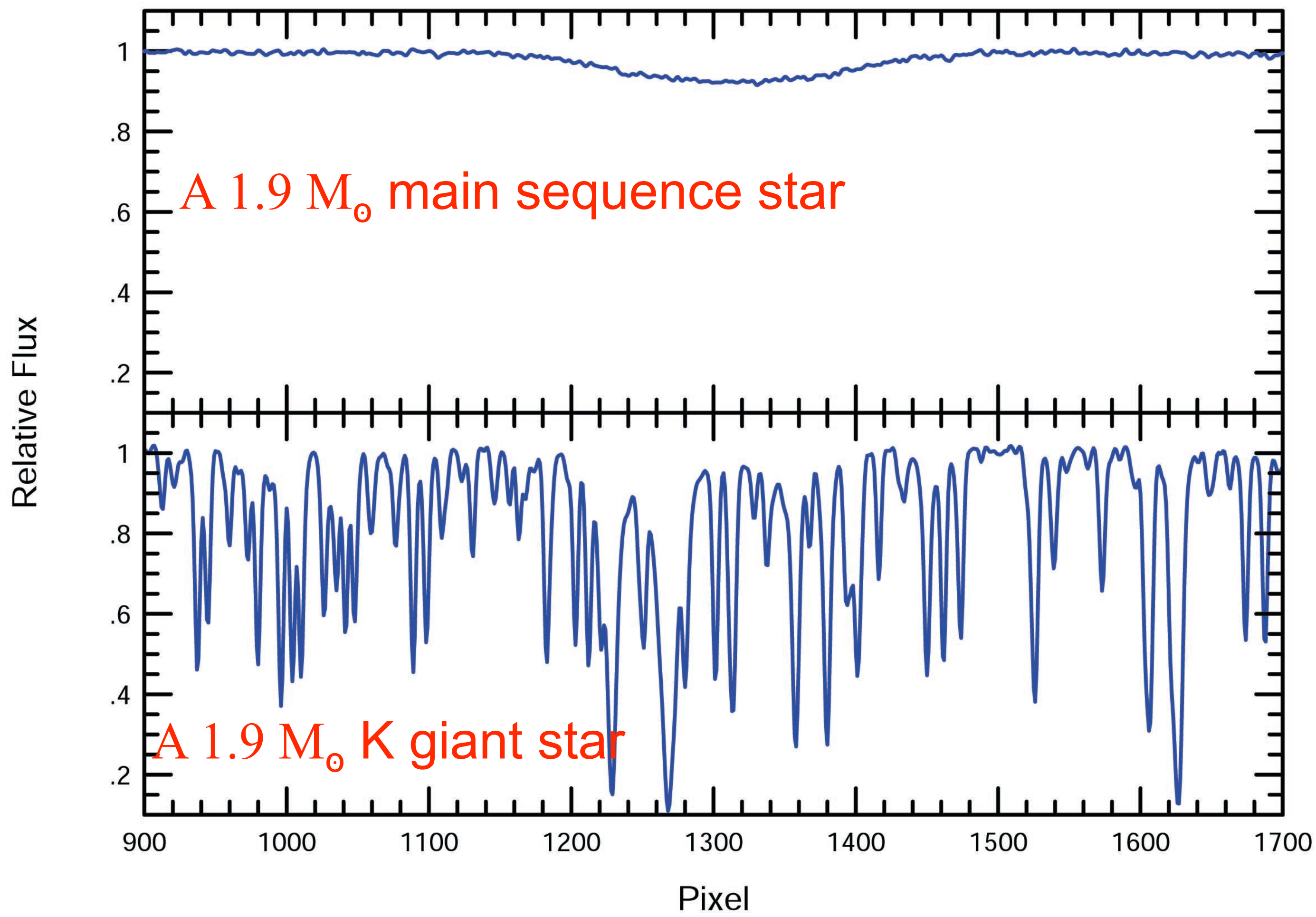
1. Probe effects of stellar evolution on planetary system evolution

2. **Probe planet formation as a function of stellar mass**

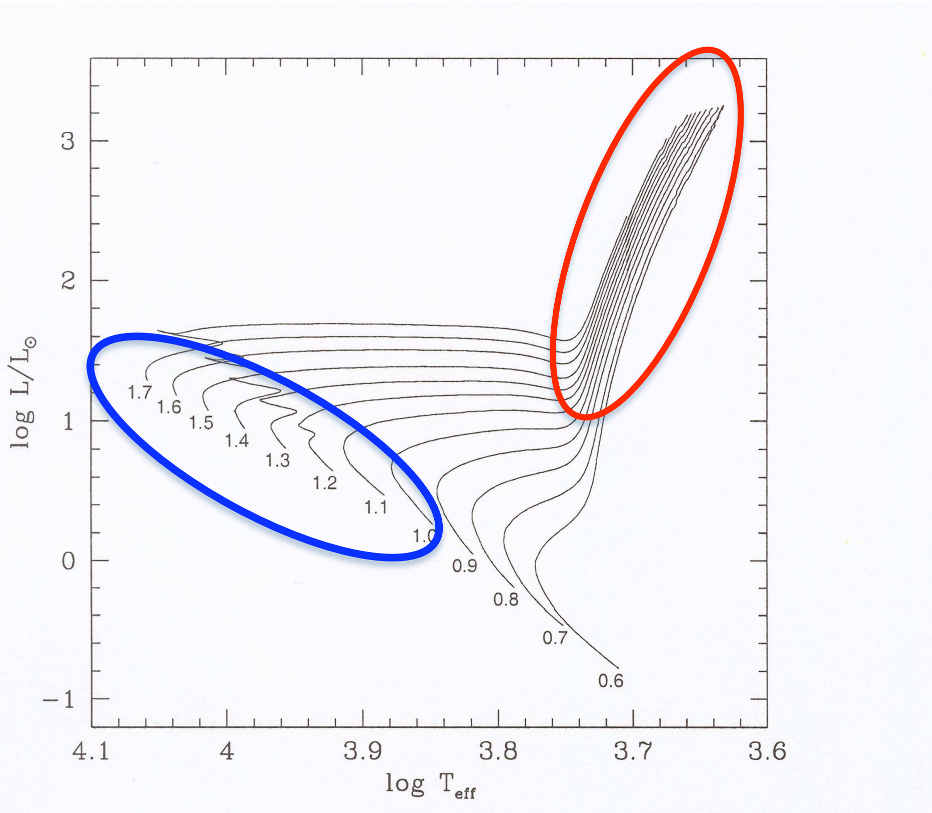
Doppler Measurement Error for Main Sequence stars

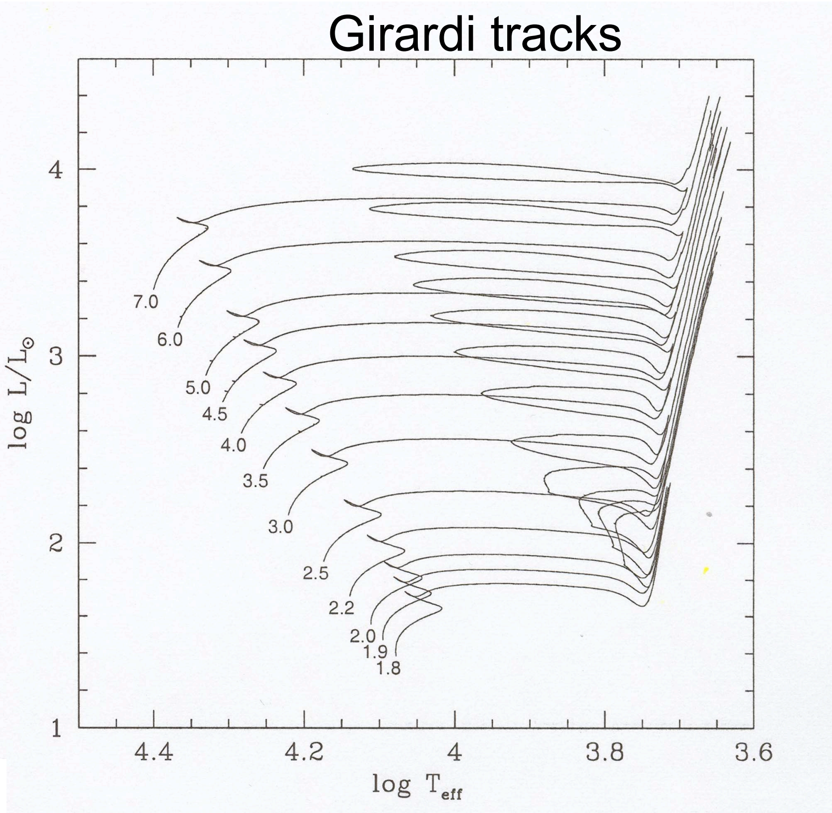


Rapid stellar rotation and high effective temperatures are bad for RV measurements:



Giant stars as Probes of Planet Formation around Intermediate-mass Stars



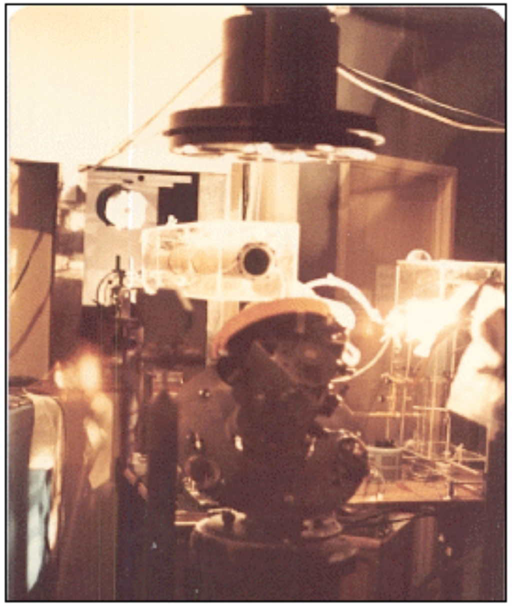


Some Forgotten History

The pioneers: Gordon Walker and Bruce Campbell

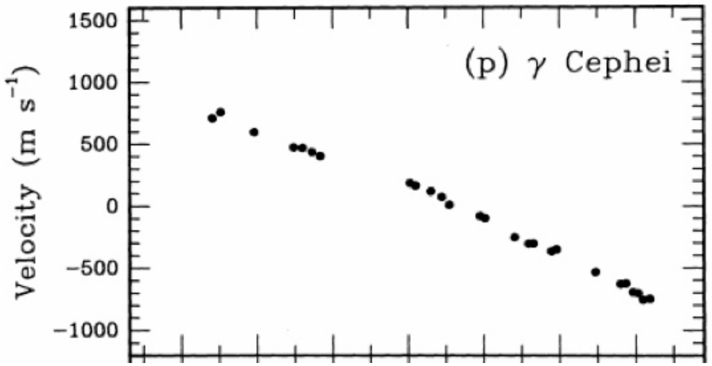
Planet search with the RV method started in 1980

Used an HF cell for calibration



Surveyed 26 stars and found evidence for the planet around γ Cep in 1988

"Probable third body variation of 25 m/s amplitude, 2.7 yr period.."

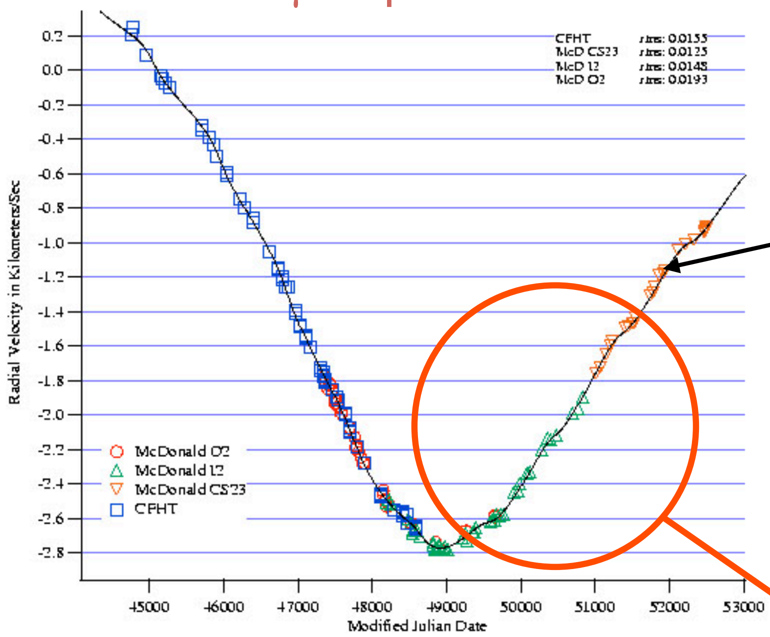


1988

"They invented the technique we all stole"

Geoff Marcy

γ Cephei

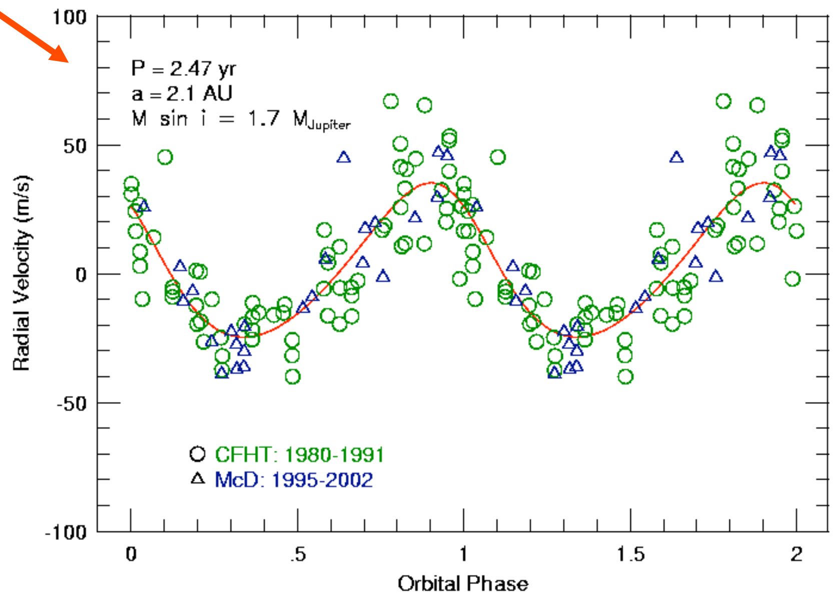


Binary

Period	56.8 ± 5 Years
Msini	~ 0.4 ± 0.1 M_{Sun}

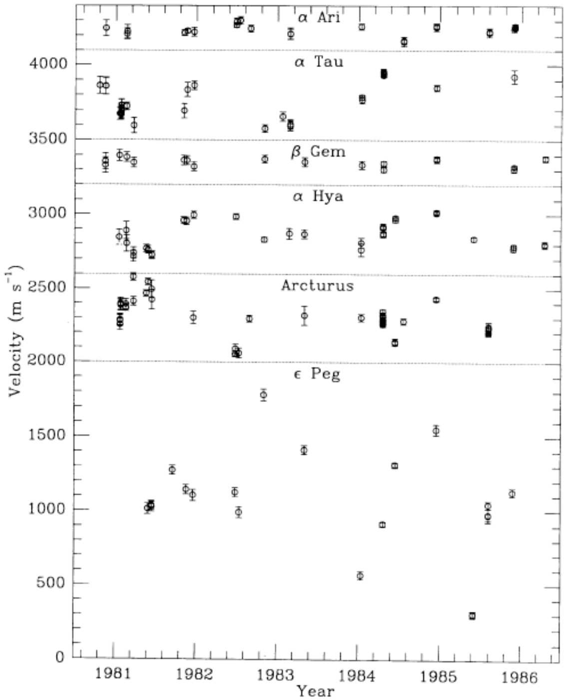
Planet

Period	2.47 Years
Msini	1.76 $M_{Jupiter}$

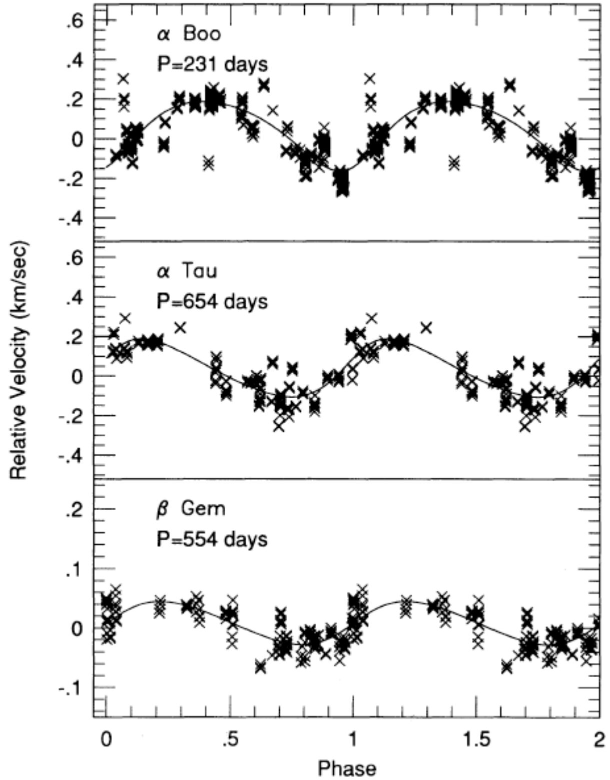


The First Hints of Planets around K Giants

Walker et al. 1989



Hatzes & Cochran 1993

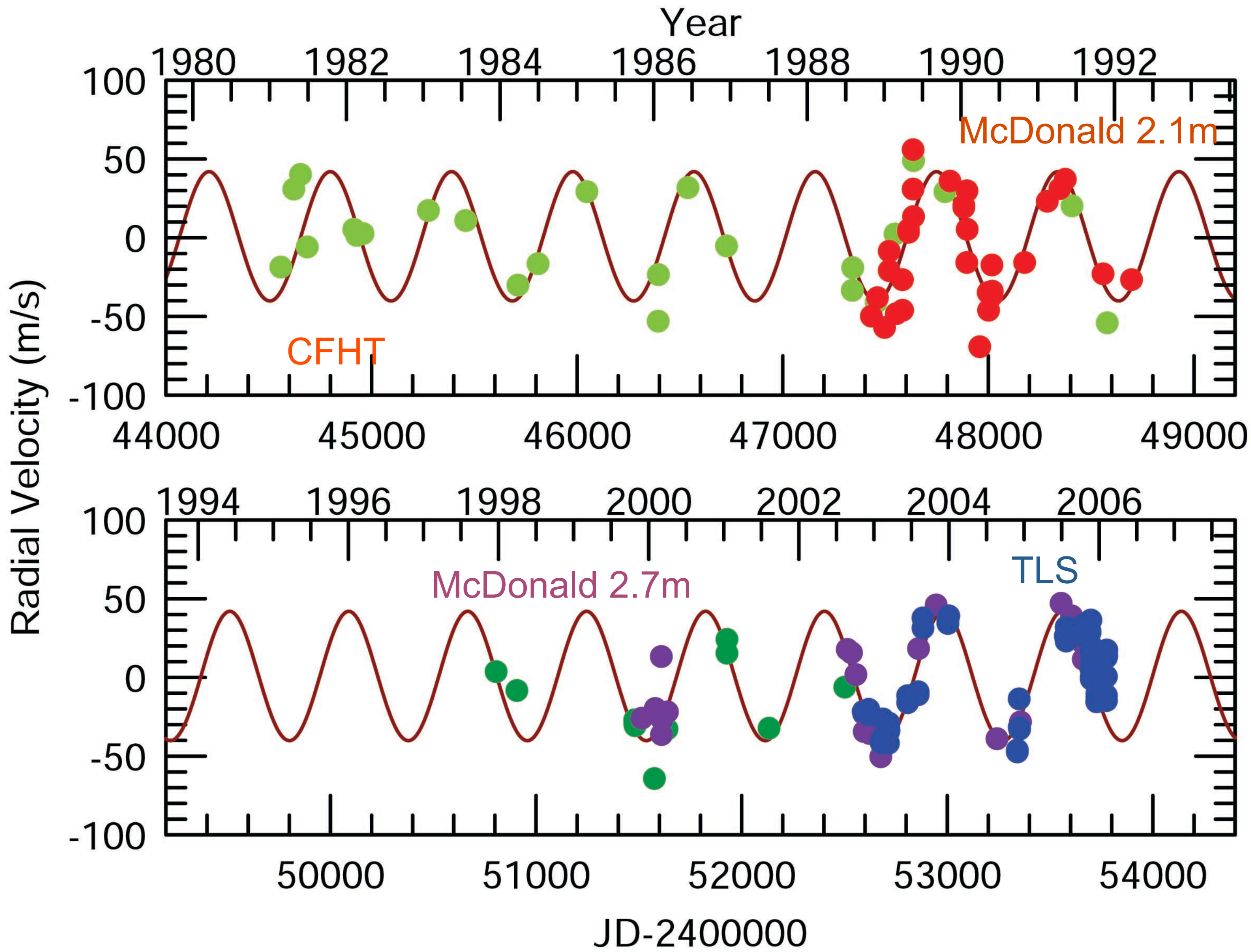


Msini = 11.7 M_J

Msini = 2.9 M_J

Hatzes & Cochran inferred a companion mass to Aldebaran of 11.4 $M_{Jupiter}$ assuming a 2.5 $M_{\odot}$ host star

The Planet around Pollux



Period = 590 days, m sin i = 2.3 M_{Jup}.

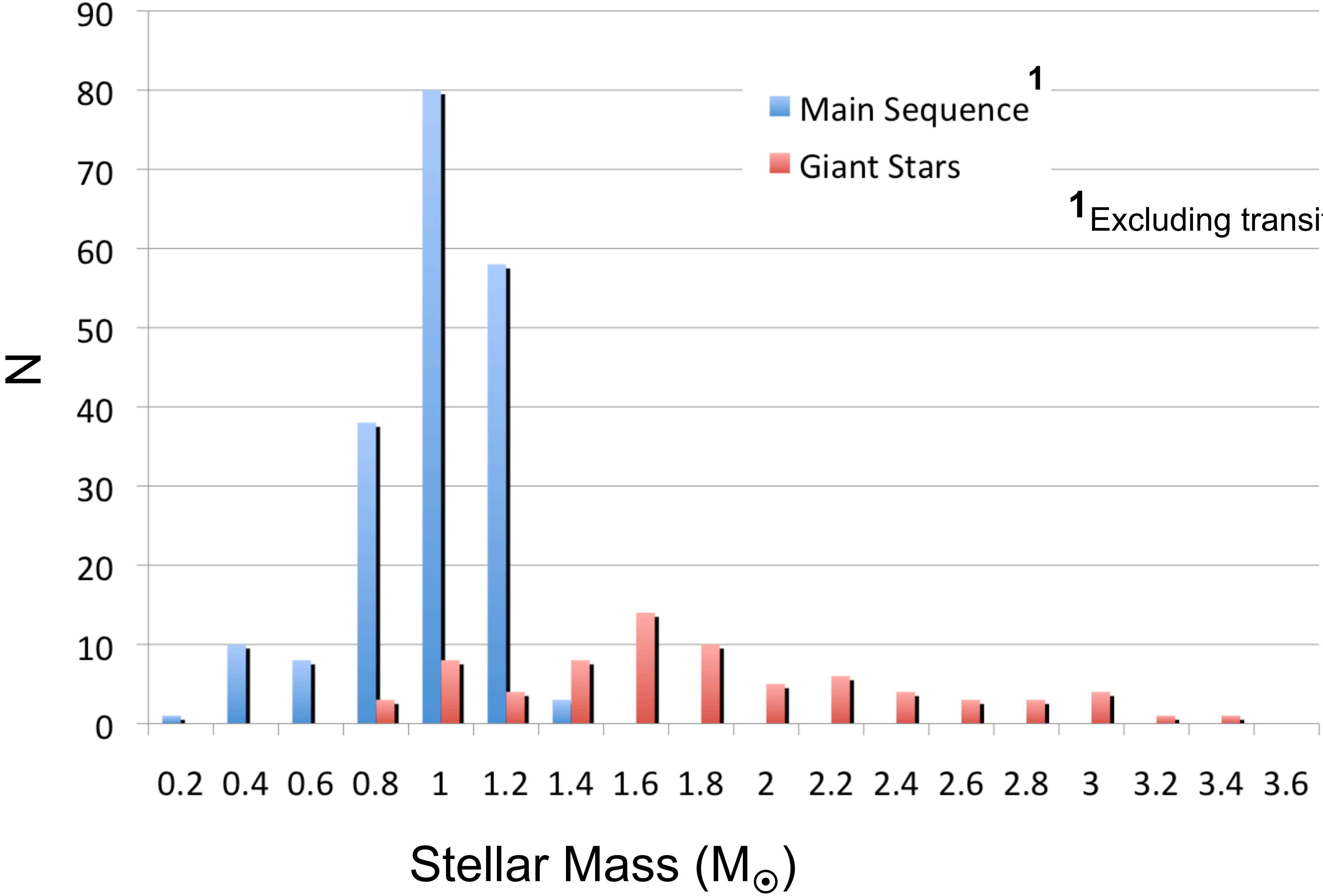
Mass of star = 1.9 solar masses

The K-Giant Planet "Factories"

Program	Investigators	Telescope
California	Johnson et al.	Keck
Japanese Planet Program	Sato et al.	Subaro, OAO
Heidelberg	Reffert, Quirrenbach et al.	LIck 2-m Shane Telescope, CAT
Korean Program	Han, Lee, et al.	BOAO
McDonald Planet Search	Cochran, Endl, (Hatzes) et al.	2.7m HJS
Tautenburg	Hatzes, Döllinger	2-m AJS
Penn State/Torun	Niedzielski et al.	HET

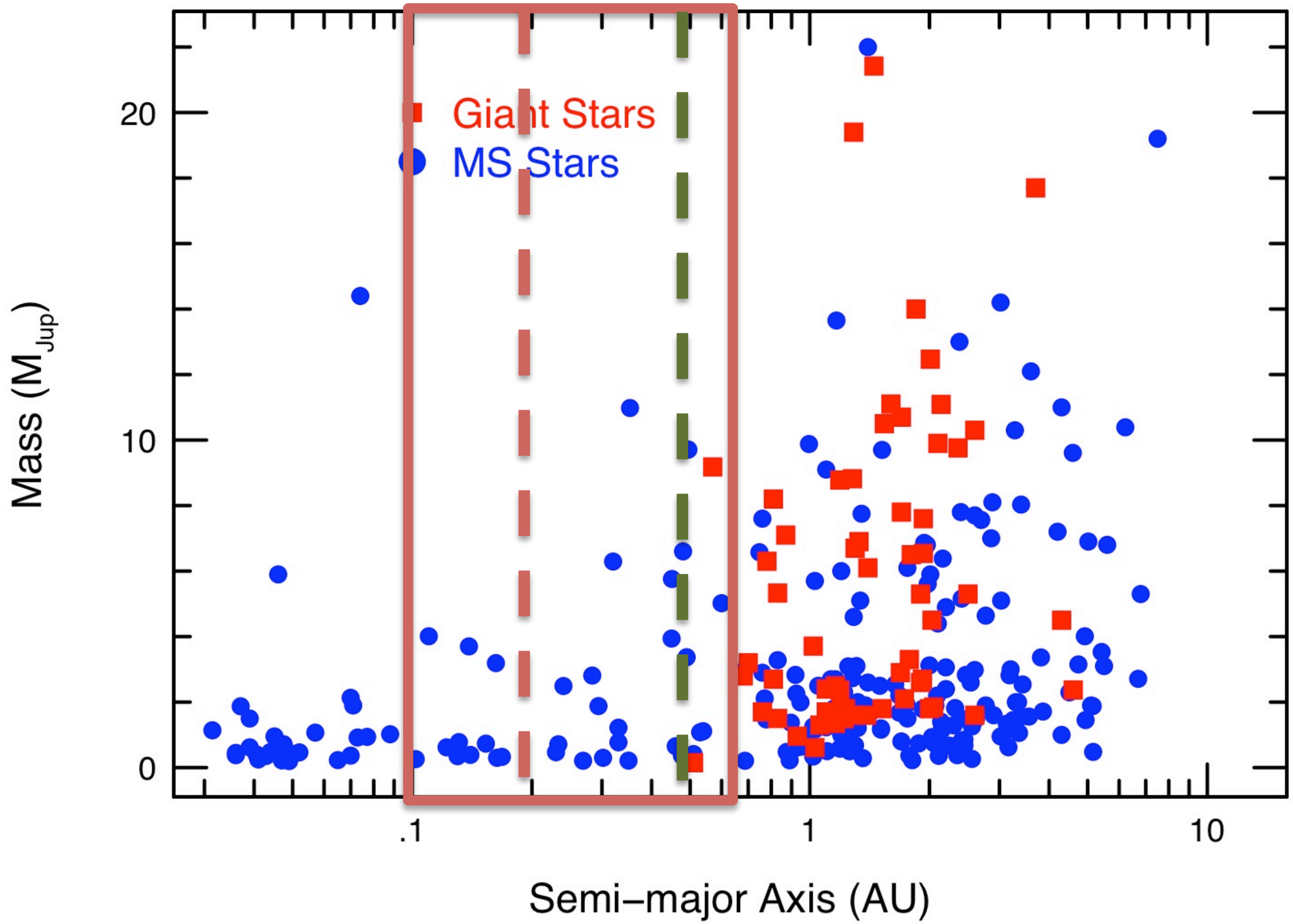
Currently about 100 giant stars host giant planets

The Distribution of Host Star Masses Detected with RV



[1] Excluding transits

Property #1 : There seems to a lack of planets with a = 0.1 – 0.7 AU

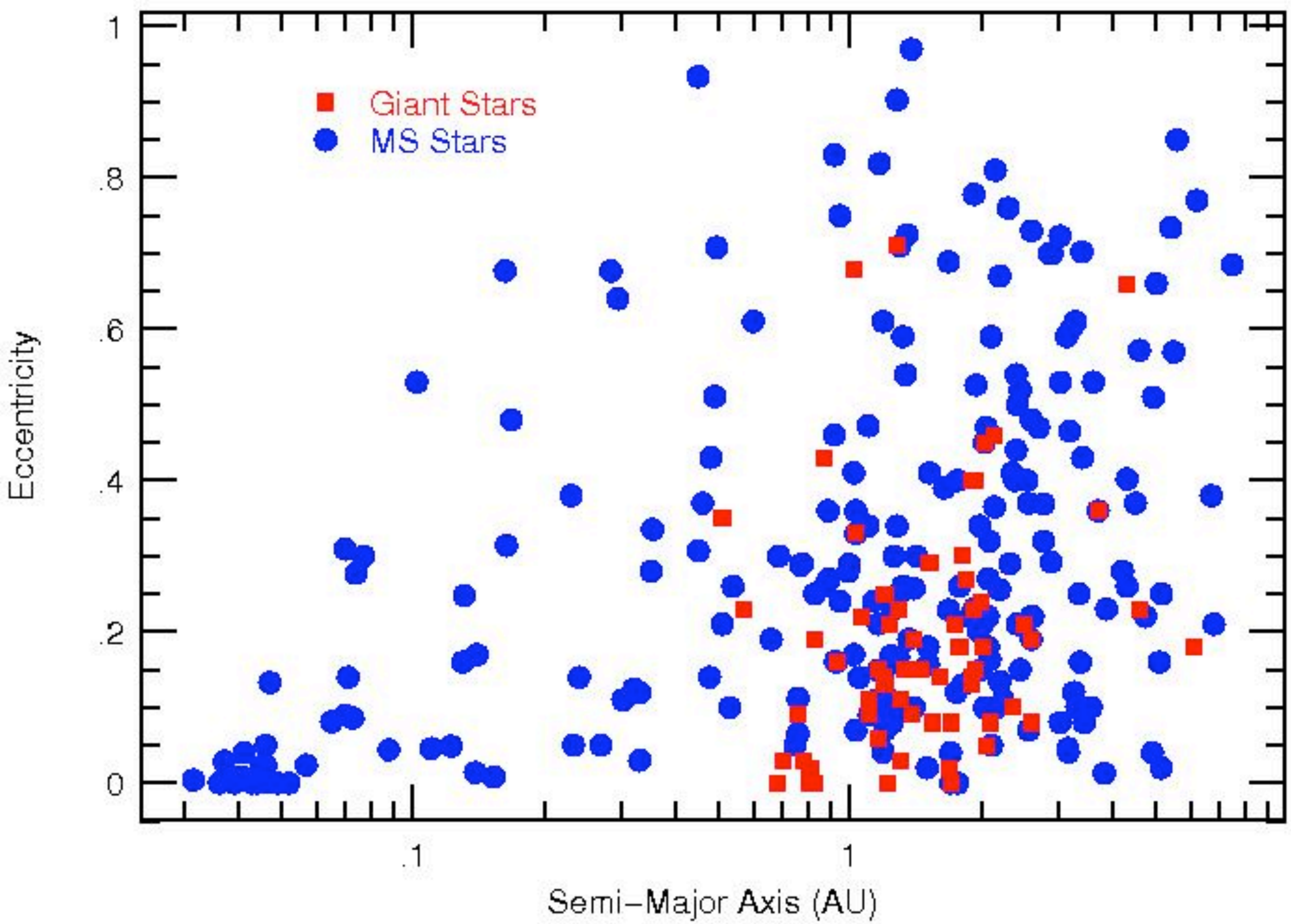


No Companions with a < 0.6 AU:

- Not a bias (Johnson et al. 2007; Bowler et al. 2010)
- Clump stars may disrupt orbits out to 0.5 AU, but not for post main sequence stars (Sato et al. 2008)
- Not likely that large radius of star has swallowed planet for stars on first ascent up giant branch

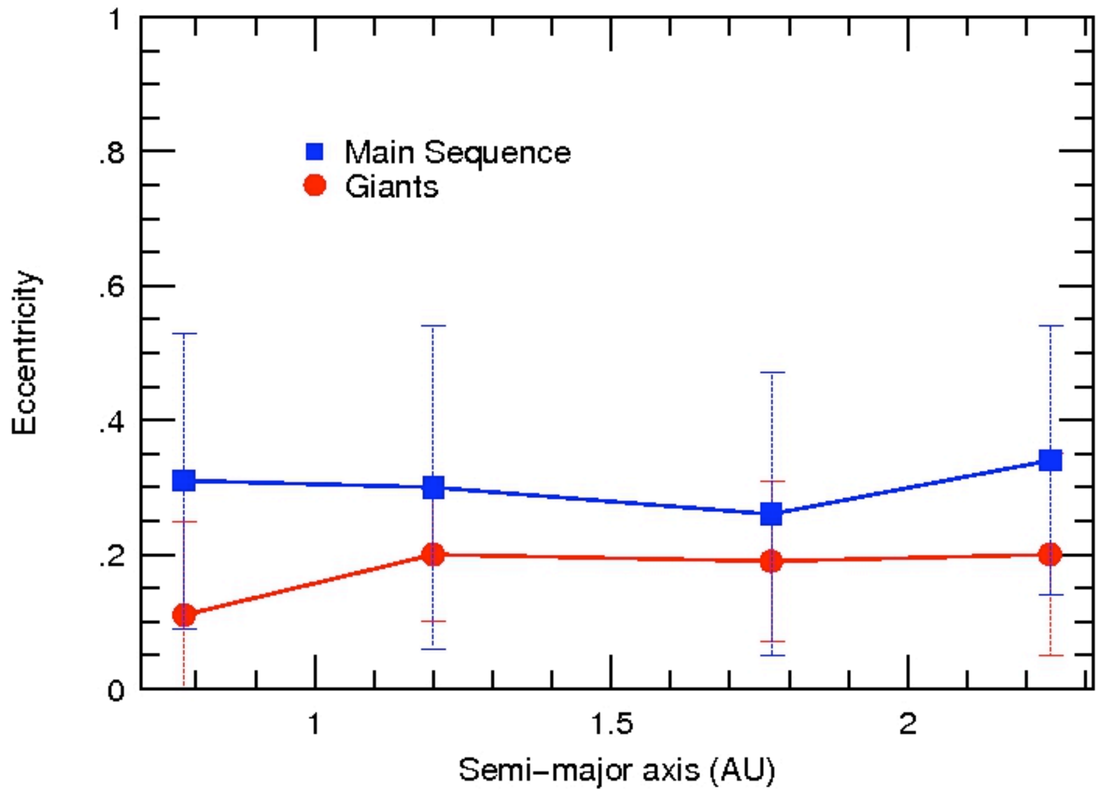
Stellar evolution may or may not explain orbital distribution of planets around intermediate mass giant stars

Property #2 : Planets around Giant stars tend to have lower eccentricities



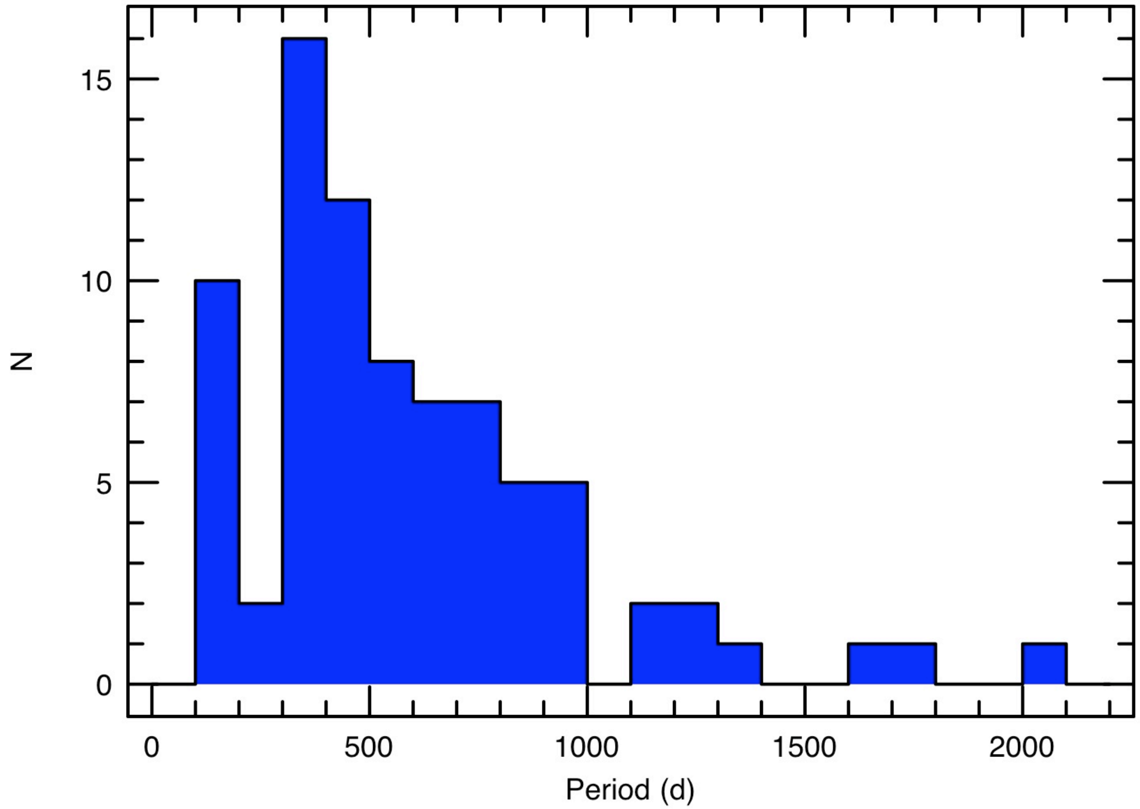
Jones et al. 2014 propose that this is real

Average eccentricity is lower, but with large scatter:



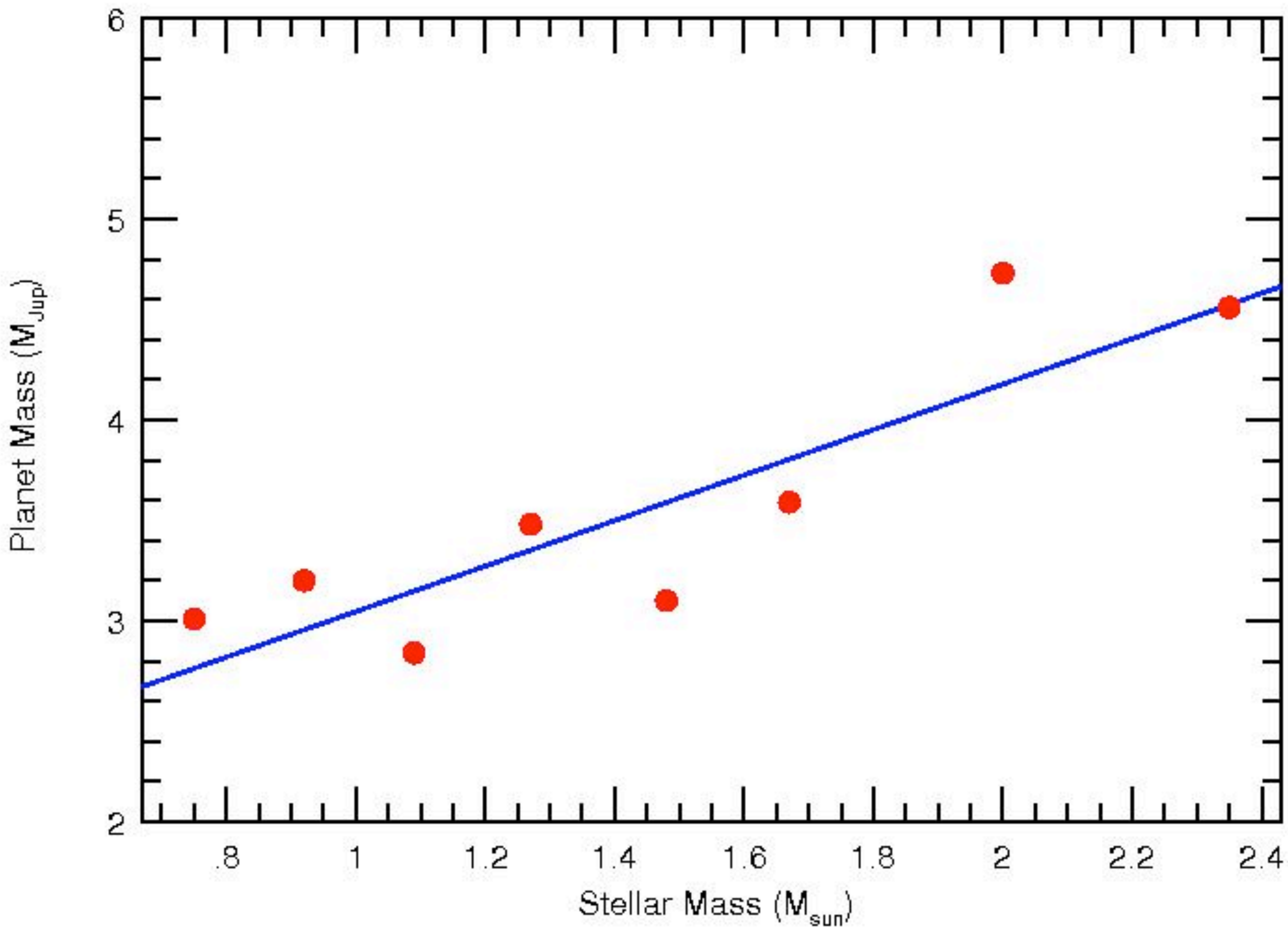
It is not clear if planets around giant stars are formed under different conditions or circularized by stellar interactions

Property #3 : 75% of planets around K giant stars have orbital periods of 400-1000 d



Worry: These are the expected rotational periods of K giant stars!

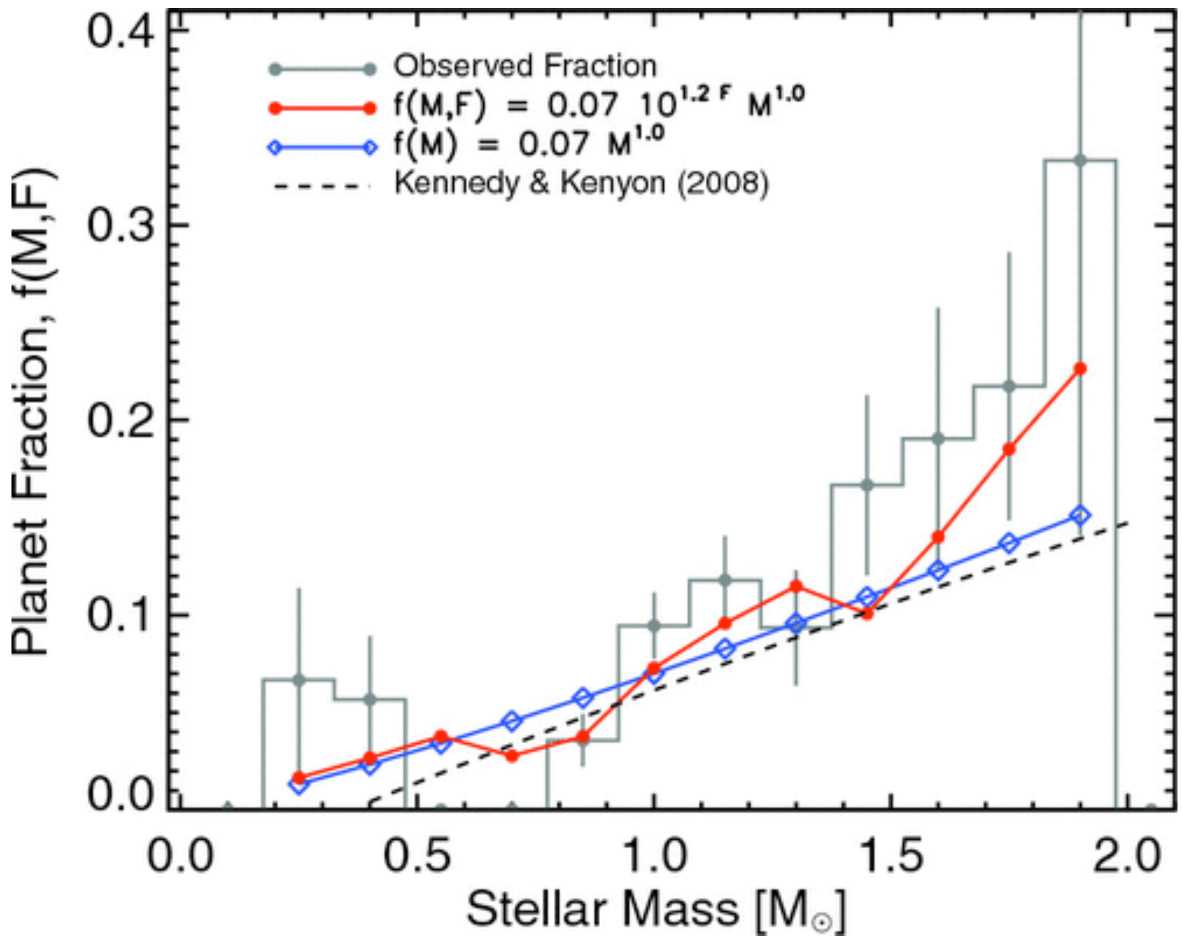
Property #4 : Planets around Giant stars tend to be more massive



Binned average show trend, but a lot of scatter in each bin. Larger masses for planets around K giant stars also proposed by Jones et al. 2014

Property #5 : More massive stars tend to have a higher frequency of planets

Johnson et al. 2010



Tautenburg sample: median mass of host star = 1.4 $M_{\odot}$, fraction of planets = 15%

The Tautenburg Sample (60 K giant stars)

P = 272 d
Msini = 6.6 M_J
e = 0.53
$M_* = 1.2\ M_\odot$

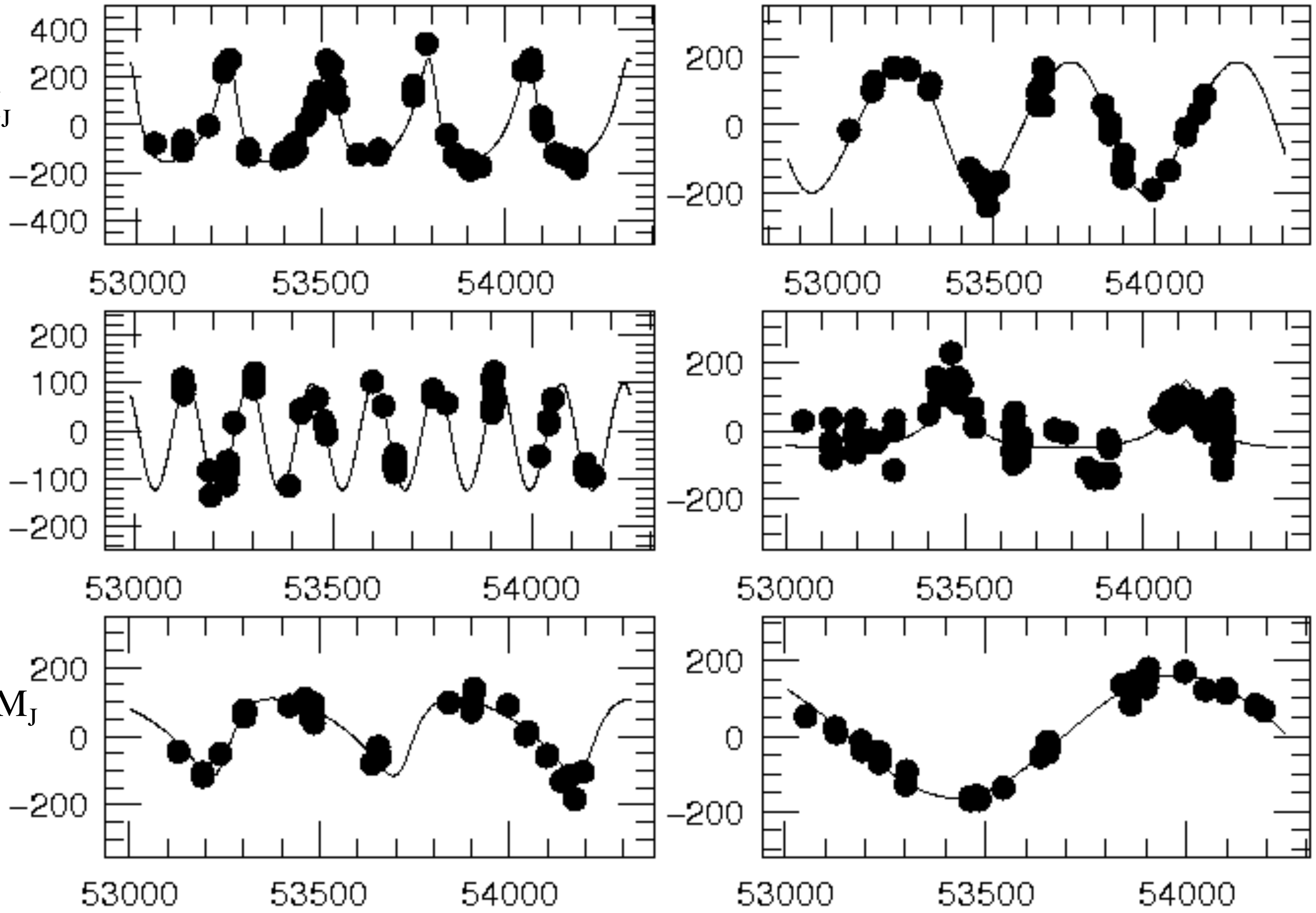
P = 517 d
Msini = 10.6 M_J
e = 0.09
$M_* = 1.84\ M_\odot$

P = 159 d
Msini = 3 M_J
e = 0.03
$M_* = 1.15\ M_\odot$

P = 657 d
Msini = 10.6 M_J
e = 0.60
$M_* = 1.2\ M_\odot$

P = 477 d
Msini = 3.8 M_J
e = 0.37
$M_* = 1.0\ M_\odot$

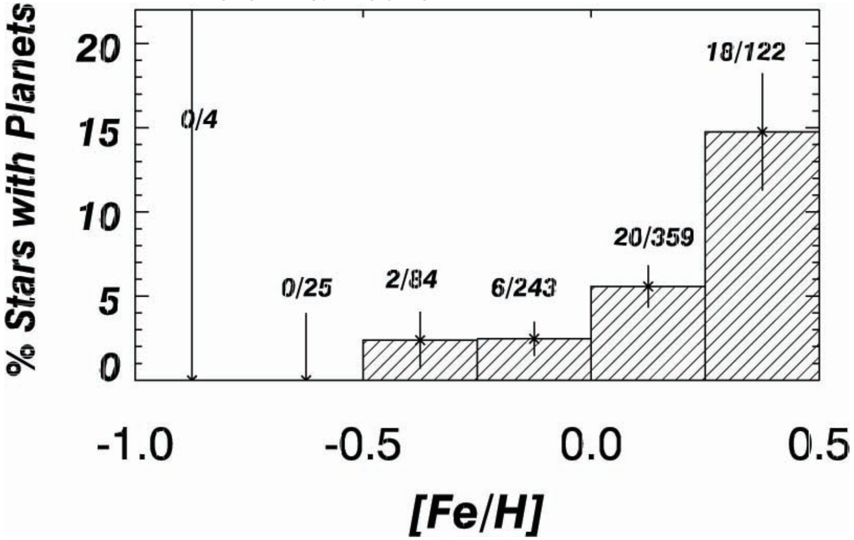
P = 1011 d
Msini = 9 M_J
e = 0.08
$M_* = 1.3\ M_\odot$



~25% of the sample have companions with M sin i = 3.5 – 10 $M_{Jupiter}$

The Planet-Metallicity Connection

Valenti & Fischer



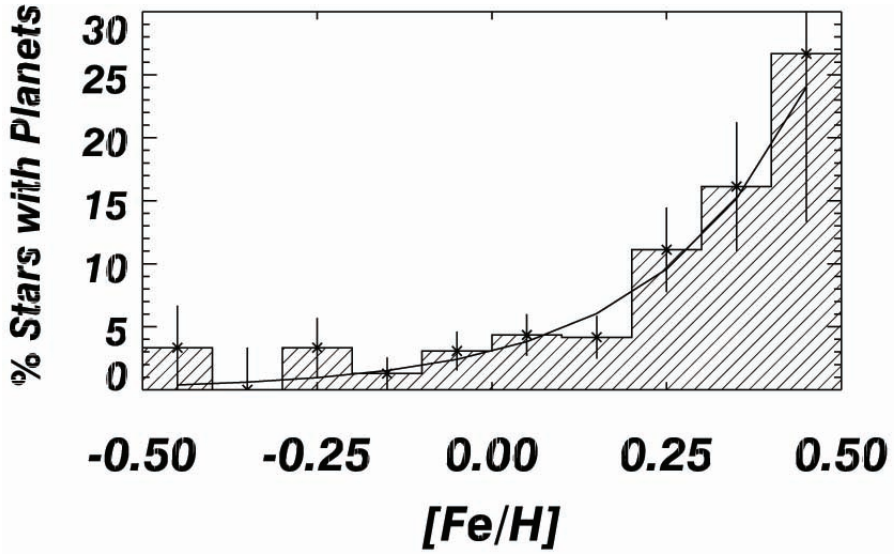
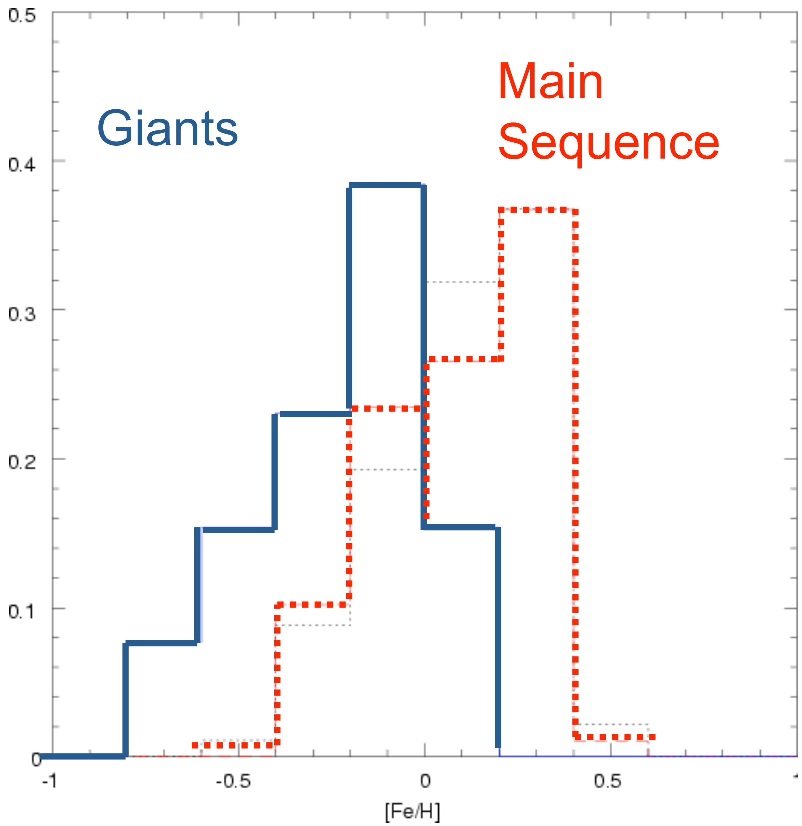
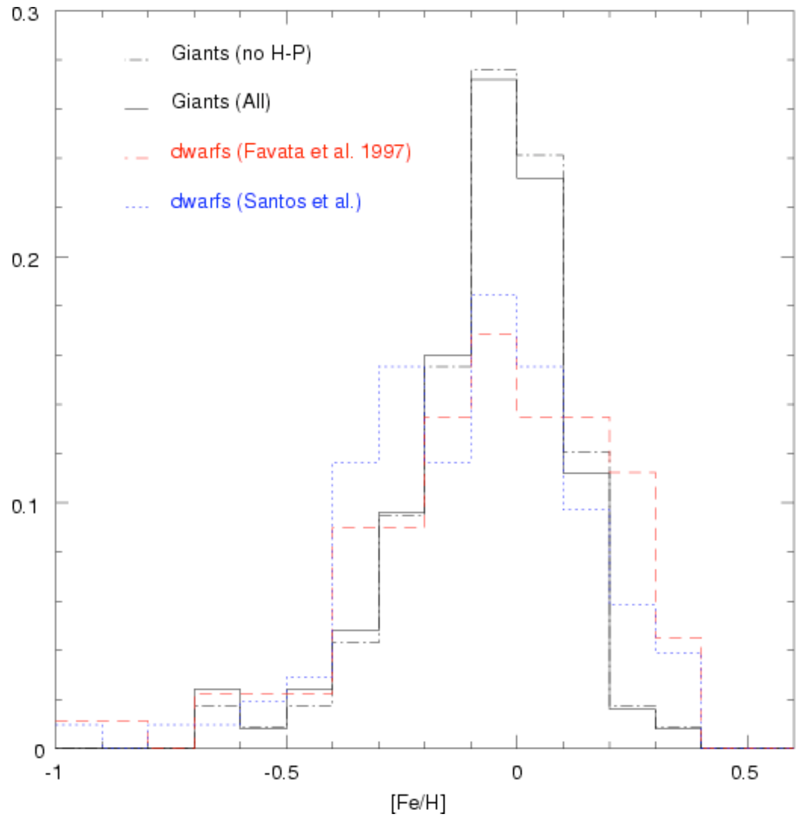


FIG. 5.—Same results as Fig. 4, but divided into 0.1 dex metallicity bins. The increasing trend in the fraction of stars with planets as a function of metallicity is well fitted with a power law, yielding the probability that an FGK-type star has a gas giant planet: $\mathcal{P}(\mathrm{planet}) = 0.03[(N_{\mathrm{Fe}}/N_{\mathrm{H}})/(N_{\mathrm{Fe}}/N_{\mathrm{H}})_{\odot}]^{2.0}$.

There is believed to be a connection between metallicity and planet formation. Stars with higher metalicity tend to have a higher frequency of planets. This is often used as evidence in favor of the core accretion theory

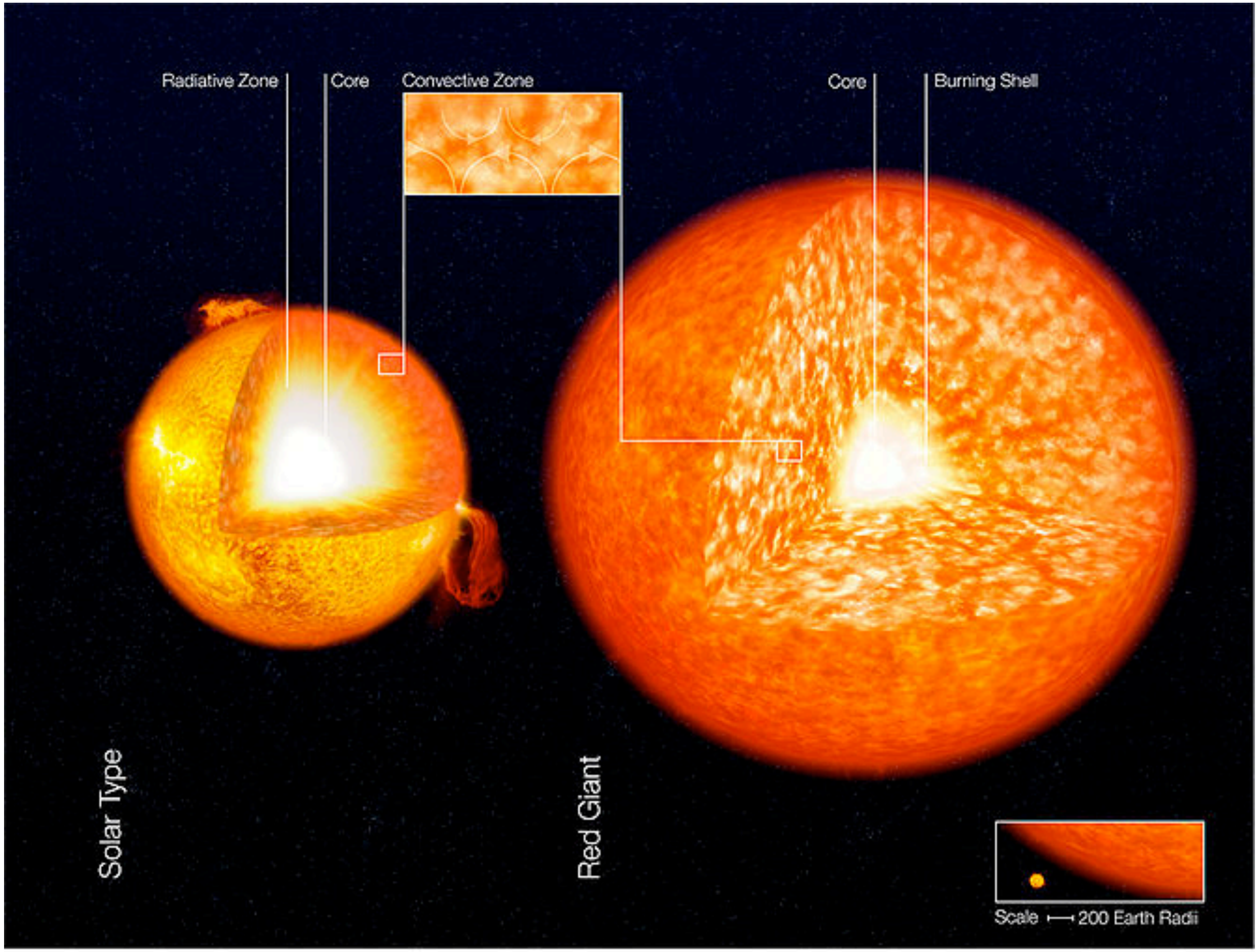
Property #6 : Planet hosting giant stars tend to not be metal rich





Pasquini et al. 2007

Schuler et al. 2005, Pasquini et al. 2007 proposed that metal-rich planet hosting stars may be due to planet engulfment

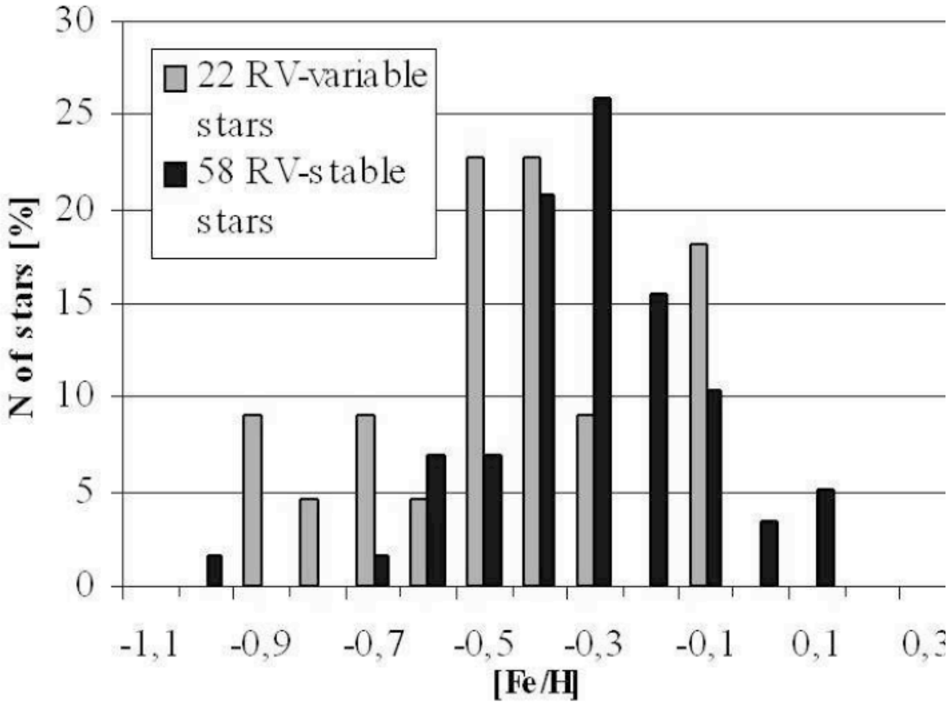


The Structure of Stars

ESO Press Photo 29/07 (6 July 2007)

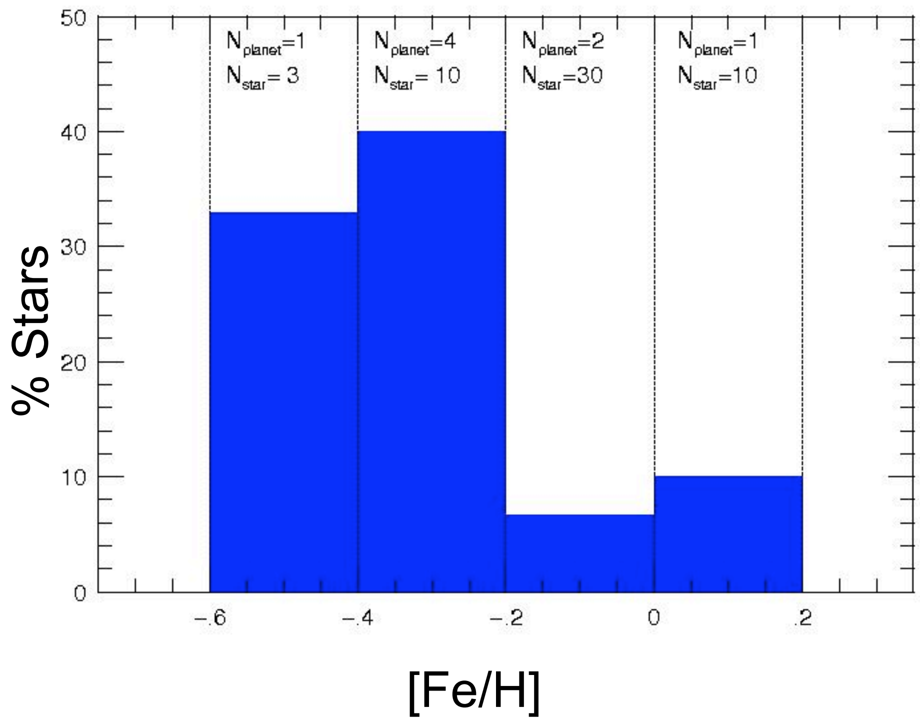
Some programs show a higher frequency of planets around the more metal poor stars:

Toruń Program



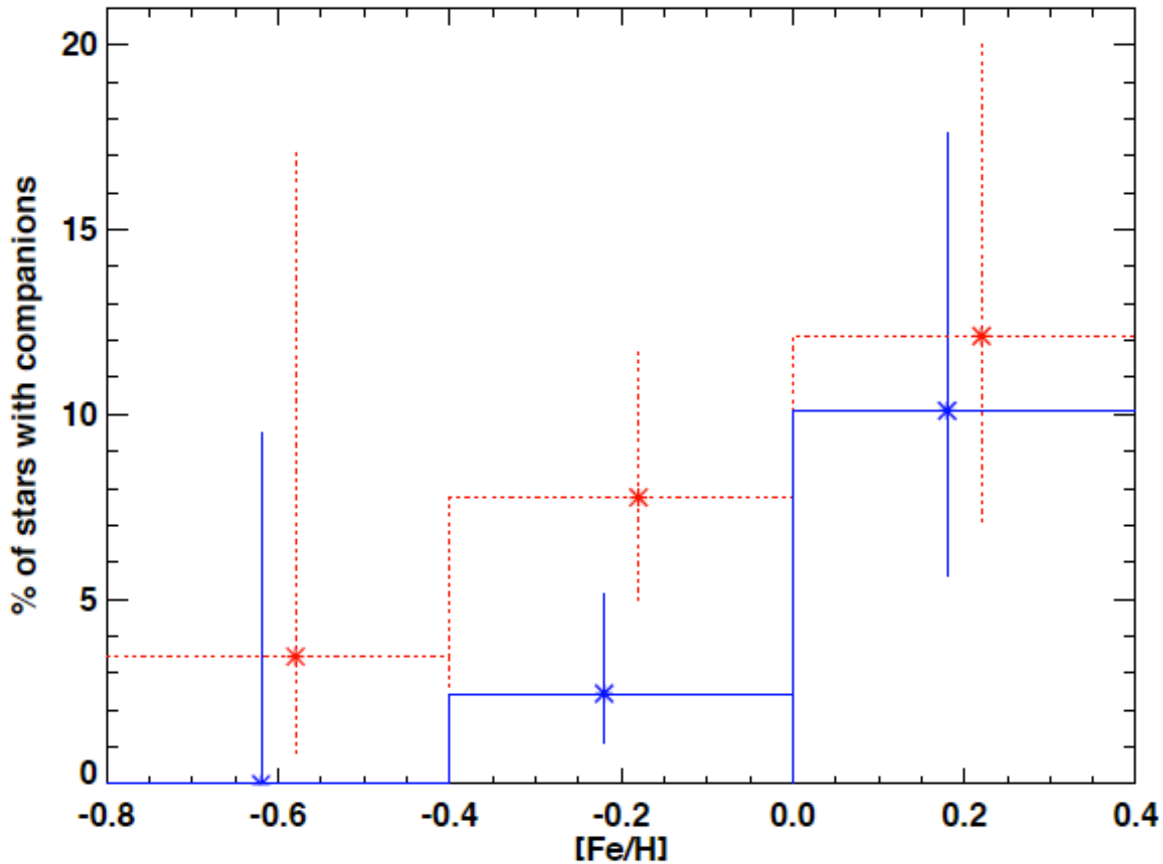
Zieliński et al. 2013

Tautenburg (60 stars)



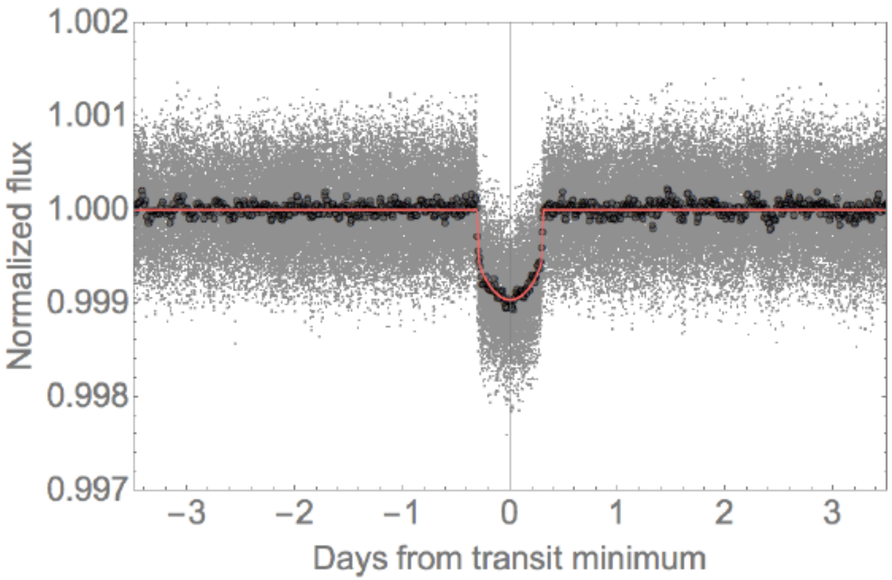
But others not:

Quirrenbach et al. 2011



Sample is still to small to make meaningful statements about metalicity effect

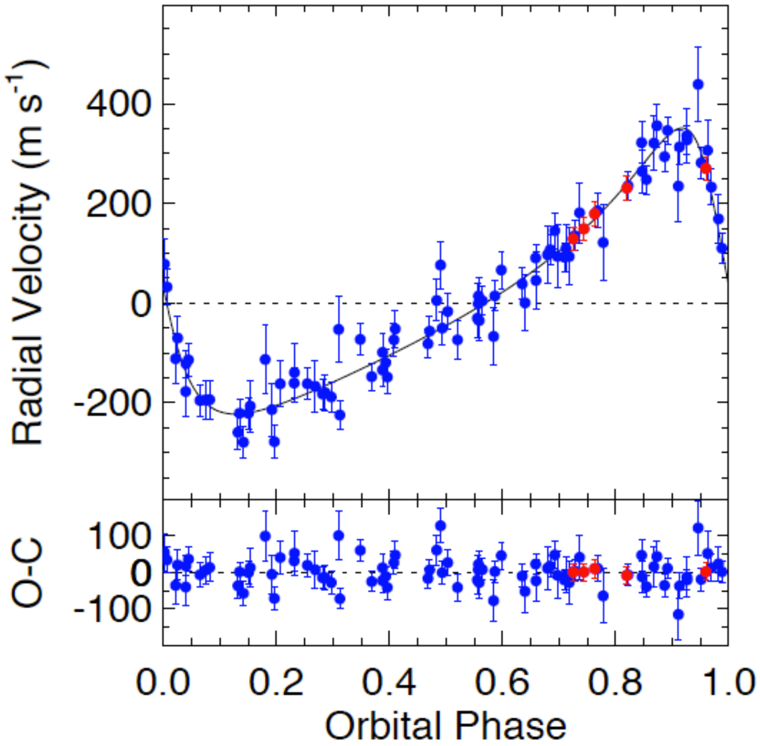
Kepler-432: A Transiting Planet around a Giant star

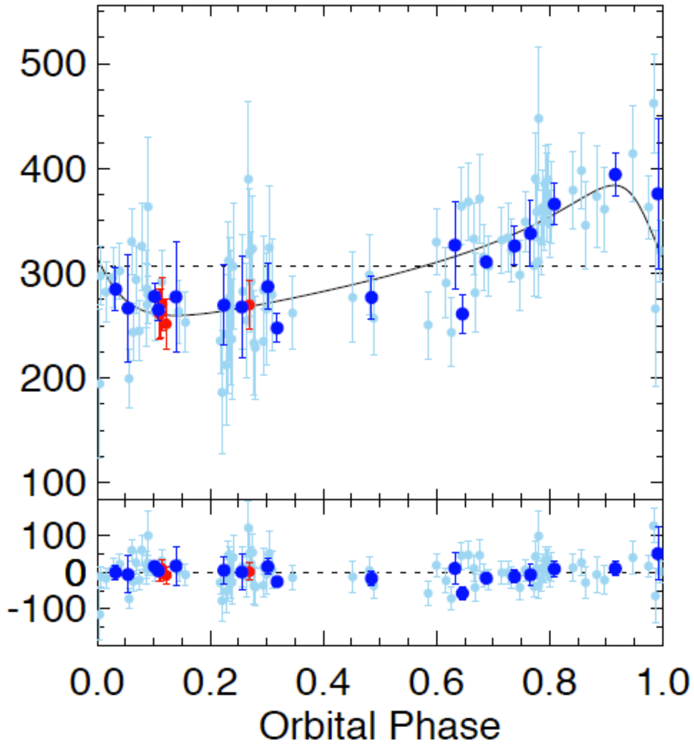


$M_{star} = 1.35\ M_{\odot}$
$R_{star} = 4.12\ R_{\odot}$

$R_p = 1.14\ M_{Jup}$
$P = 52.5$ d

Kepler-432: A Transiting Planet around a Giant star



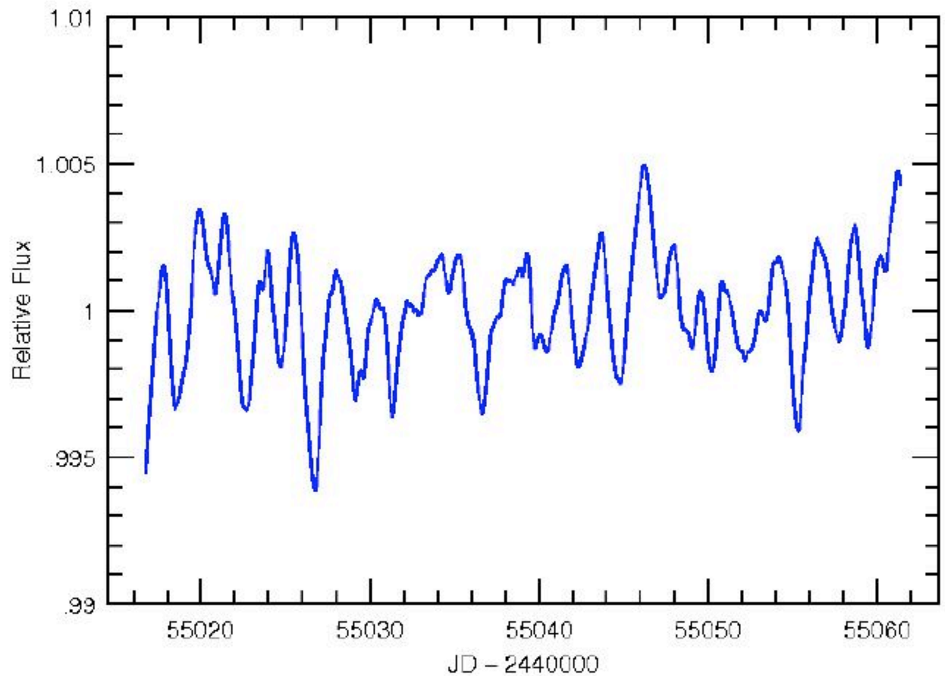


M_b = 5.4 M_{Jup}
ρ = 4.46 gm/cm^3

P_c = 411 d
M_b =2.4 M_{Jup}

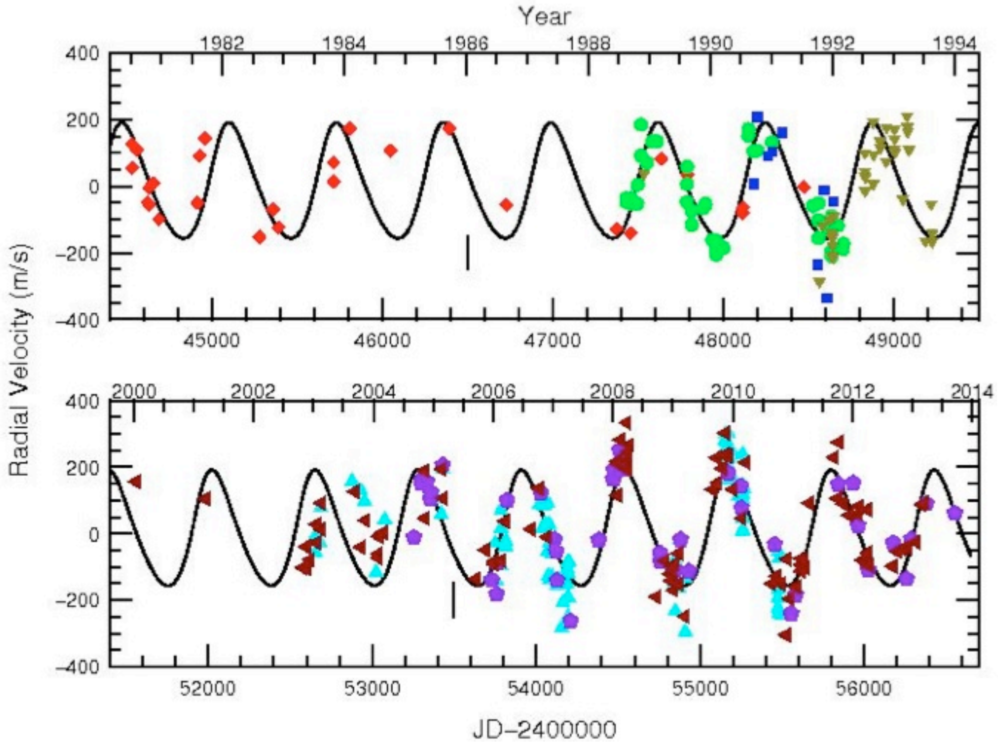
What about transits around more evolved stars?

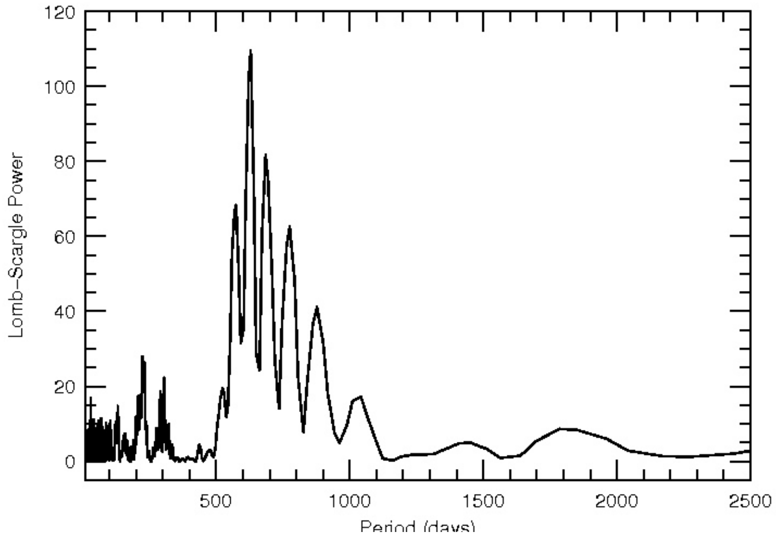
R_{star} = 10 $R_\odot$
P_p = 50 d
Transit depth (1 R_{Jup}) = 0.1 mmag
Duration = 2.5 days
P_p = 400 d, duration = 5 d

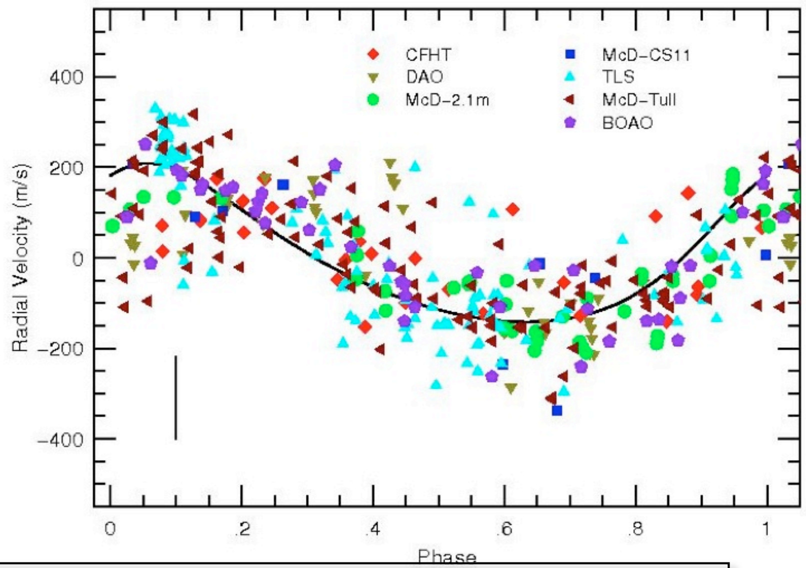


Difficult due to stellar oscillations

The Planet around Aldebaran (α Tau)



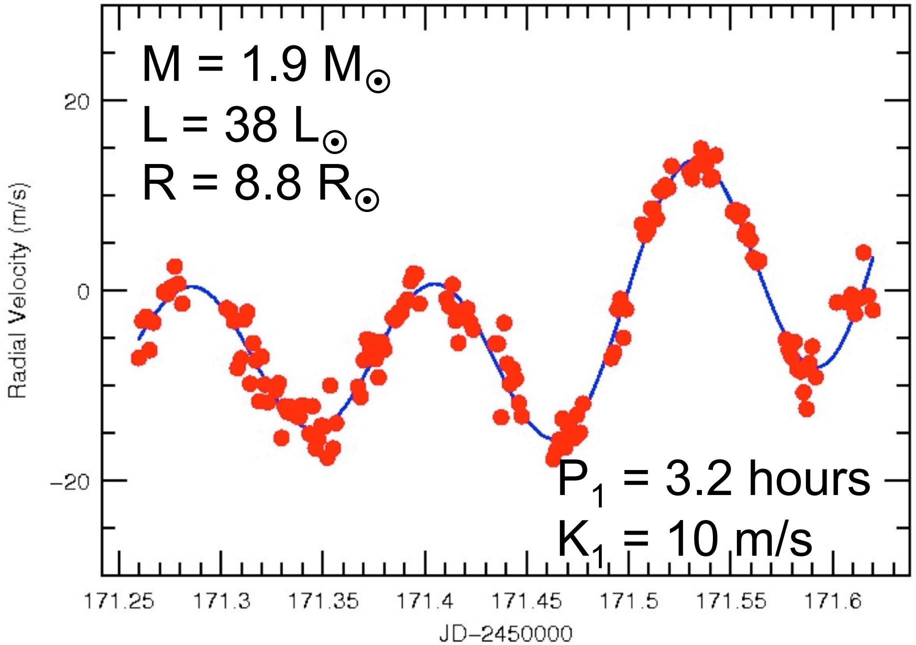


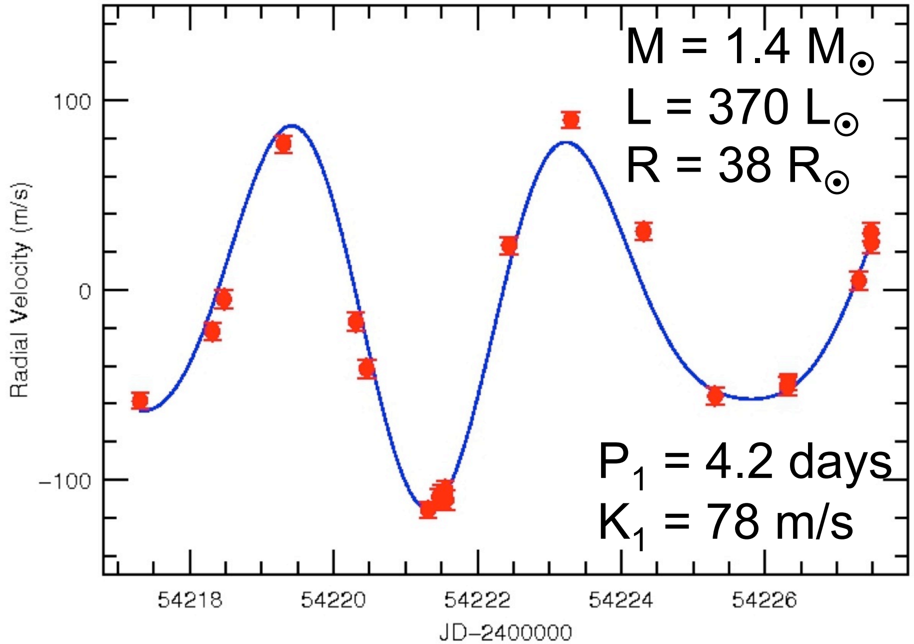


P = 630 d
m sin i = 6.9 M_{Jup}

7 Instruments, 400 measurements spanning 33 years

The Pesky Radial Velocity "Jitter"





The RV Jittter is not noise, but a signal!

Scaling relationships (Kjeldsen & Bedding 1996)

Characteristic Amplitude:

$$V_{osc}\ (\mathrm{m/s}) = (0.234 \pm 0.014)\ (L/M)$$

Giant stars: few m/s to tens m/s

Characteristic Period:

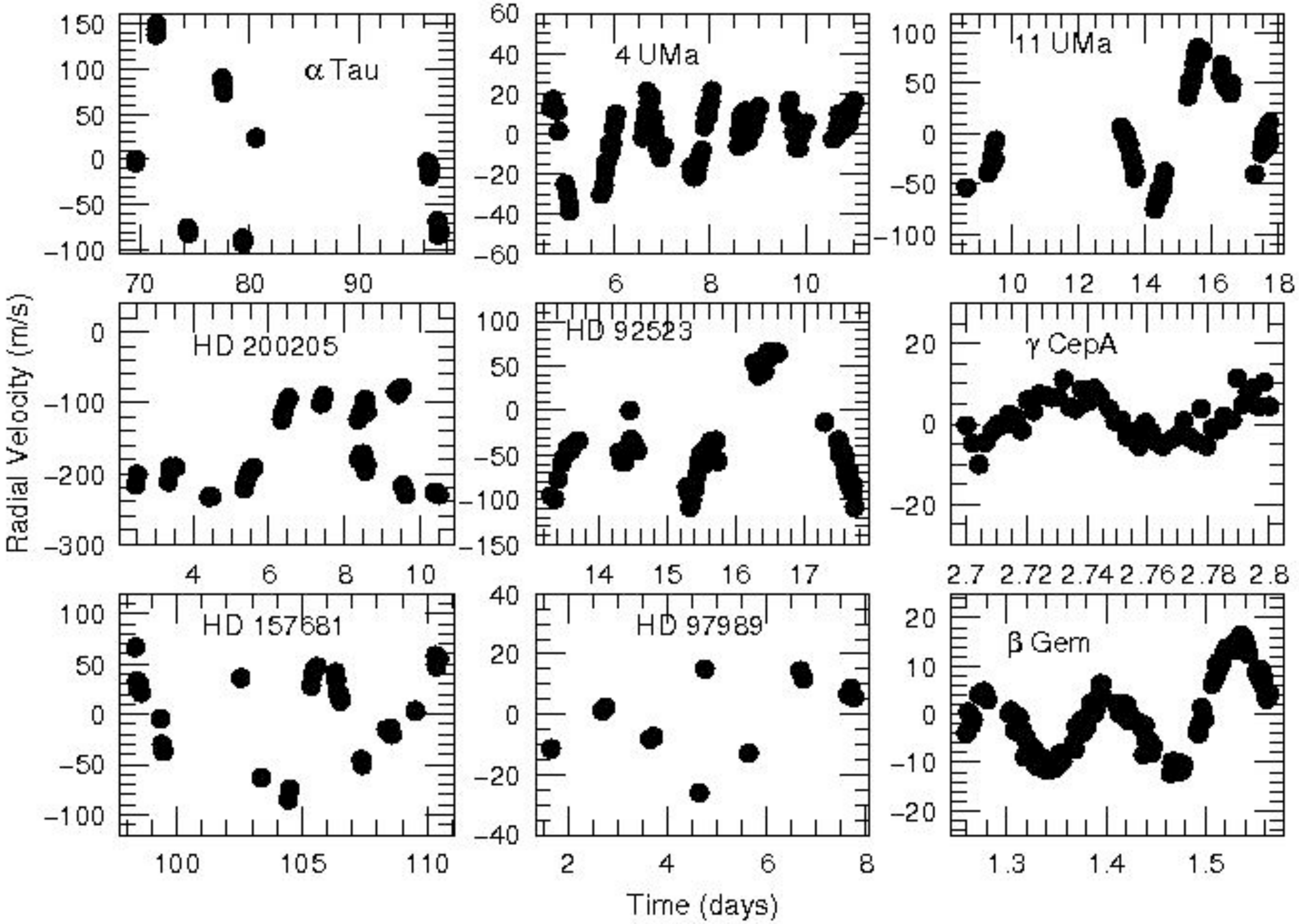
$$P\ (\mathrm{hours}) = \frac{0.09\ R^2 \sqrt{T}}{M}$$

Giant stars: hours to several days

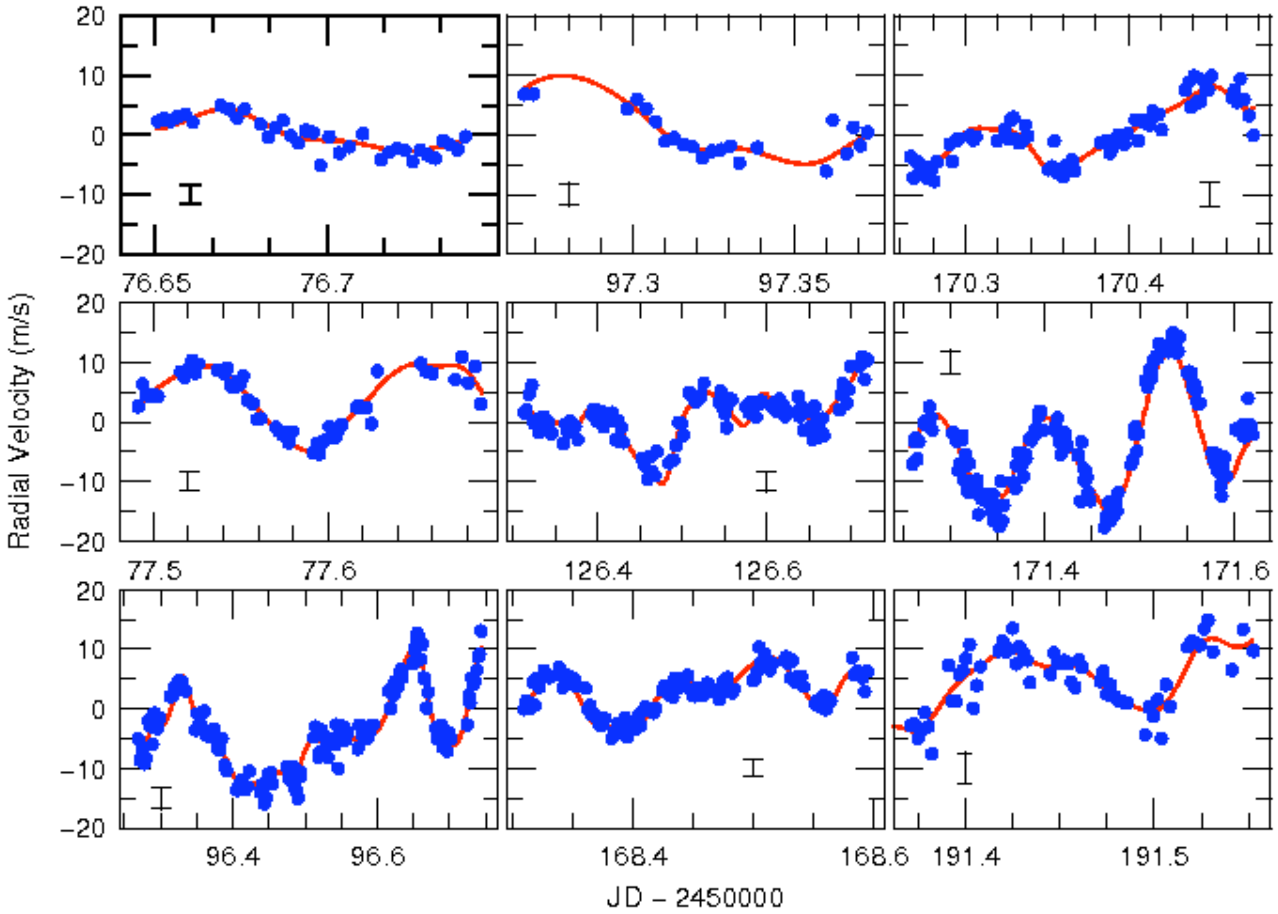
L, M, R in solar units

$T = T_{eff}/5777$ K

All giant stars oscillate!

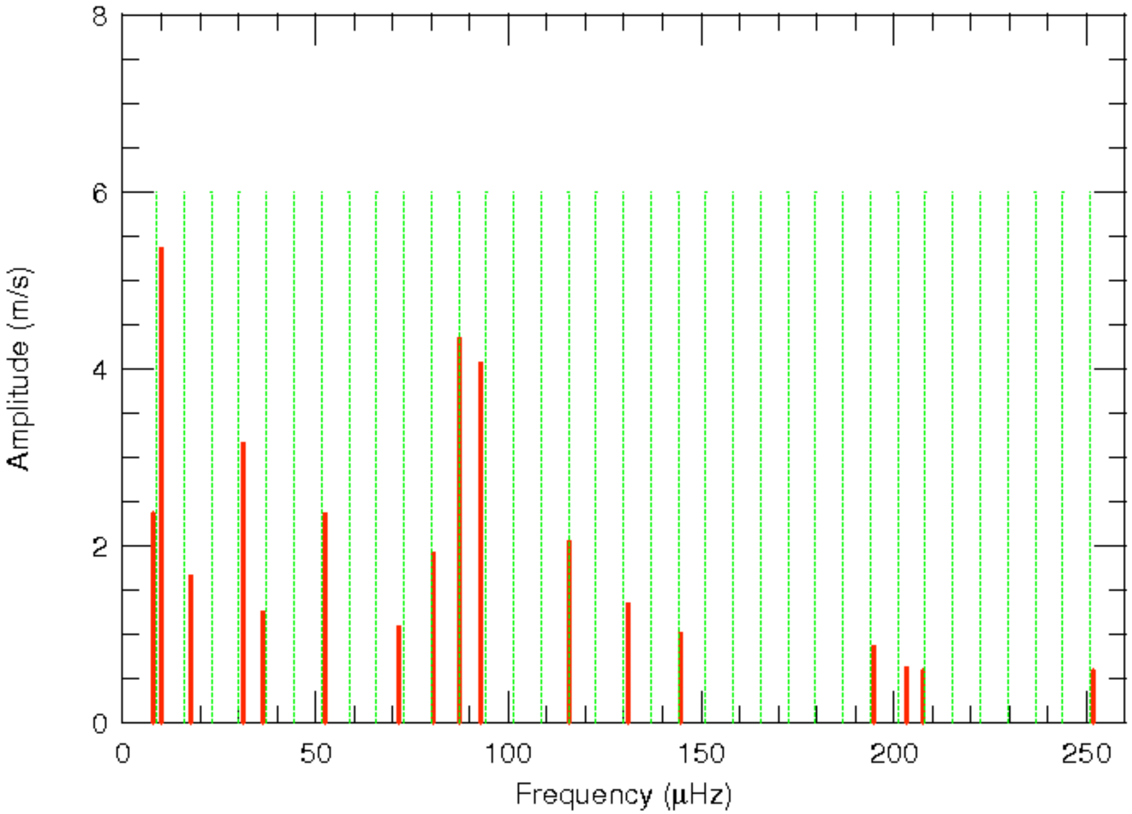


Stellar Oscillations in β Gem



Nine nights of RV measurements of β Gem. The solid line represents a 17 sine component fit. The false alarm probability of these modes is < 1% and most have FAP < 10^{-5}. The rms scatter about the final fit is 1.9 m s^{-1}

The Oscillation Spectrum of Pollux



$$\Delta\nu_o = 135\ M^{1/2}/R^{3/2}\ \ (\mu Hz)$$

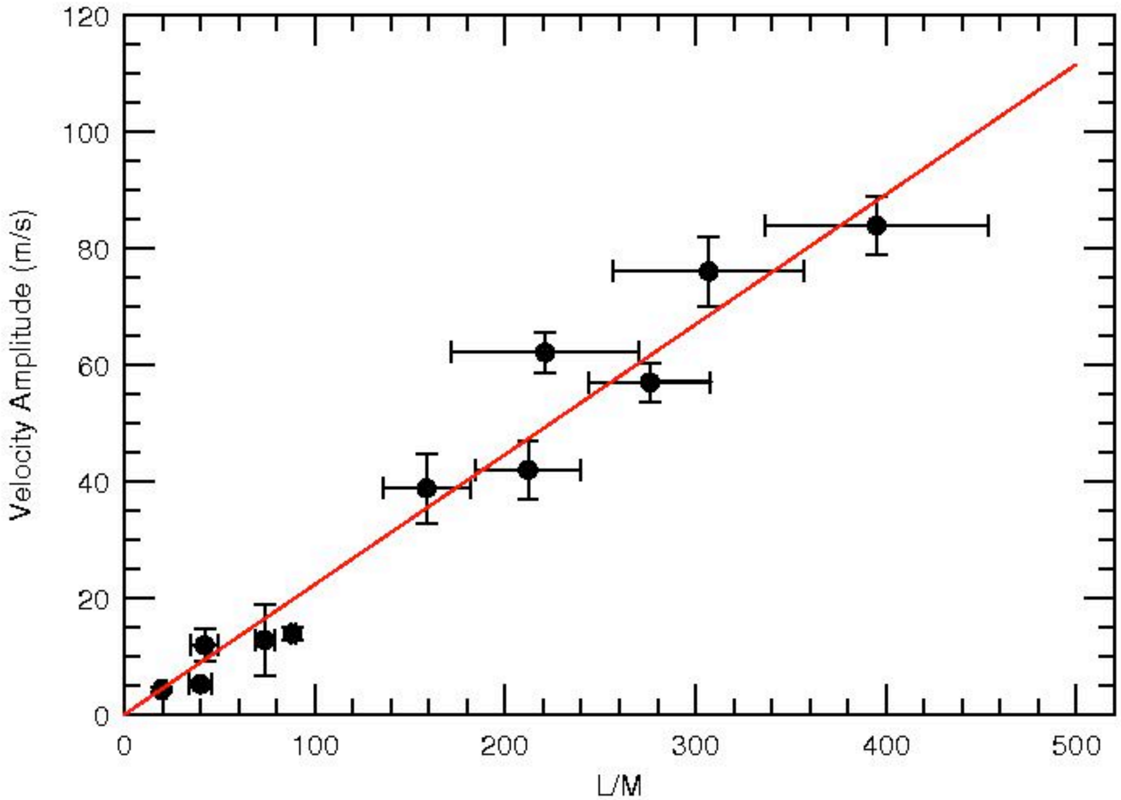
$\Delta\nu_0 = 7.12\ \mu Hz$

$R = 8.8\ R_\odot$ (interferometry)

$M = 1.91\ M_\odot$

Stellar Oscillations

Amplitude of the Dominant mode from Tautenburg sample:



$$V_{fit}\ (m/s) = (0.227 \pm 0.015)\ (L/M)$$

$$V_{osc}\ (m/s) = (0.234 \pm 0.014)\ (L/M)$$

“Amplitude” versus “Tracks” Stellar Masses

Star	Mass (Tracks)	Mass ($\Delta\nu_o$)	Mass (V_{osc})	%Error
β gem	1.91 ± 0.12	1.92 – 0.12	2.14 ± 0.23	12
α Tau	1.06 ± 0.13		1.32 ± 0.17	24
γ Cep A	1.16 ± 0.10	1.27 ± 0.11	1.36 ± 0.23	7
4 UMa	1.27 ± 0.16	1.60 ± 0.06	1.88 ± 0.30	17
HD 32518	1.17 ± 0.18		1.08 ± 0.26	8
HD 92523	1.38 ± 0.23		1.22 ± 0.30	11
HD 138265	1.53 ± 0.22		1.06 ± 0.19	30
HD 106574	1.50 ± 0.27		1.60 ± 0.25	7
HD 157681	1.80 ± 0.24		1.74 ± 0.35	3
HD 200205	1.44 ± 0.20		1.79 ± 0.31	24

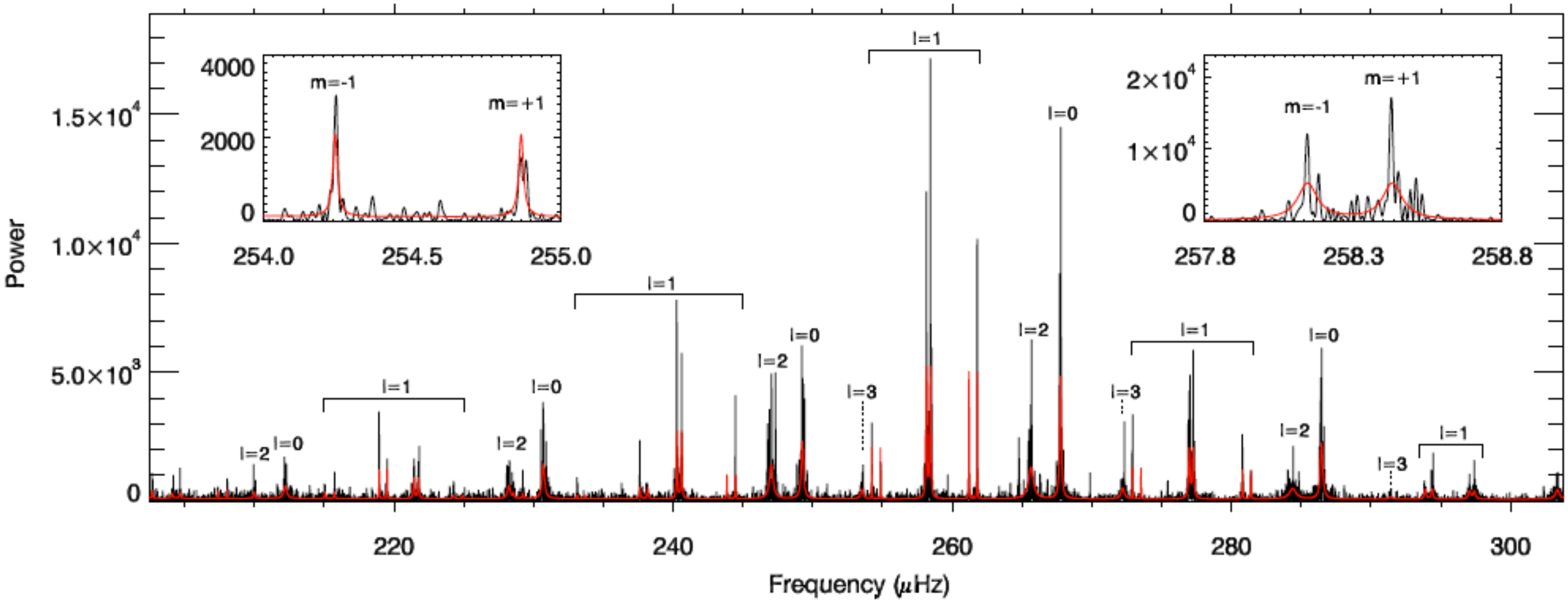
Tracks from Leo Girardi

Mean error from pulsational amplitude: 15%

Stellar Masses from tracks are generally good, but these can be checked with oscillation amplitudes

From Space it is easier to do asteroseismology of Giant stars

Power Spectrum of Kepler-432 (Quinn et al. 2014)



Trouble in K Giant (Planet) Paradise?

1. η Cet (Trifonov et al. 2014): m = 2.6 M_{Jup}, 3.3 M_{Jup}, P = 407 d, 740 d in a 2:1 resonance
   - ➢ Stable only for certain configurations

2. ν Oct (Ramm et al. 2009) : Binary system in a 1050 d orbit, "planetary companion" in a 417 d orbit, m sini = 2.4 M_{Jup}.

   - ➢ Planet orbit is dynamically unstable
   - ➢ Stable (60% chance) only if planet is in retrograde orbit (Eberle & Cuntz 2010)

Trouble in K Giant (Planet) Paradise?

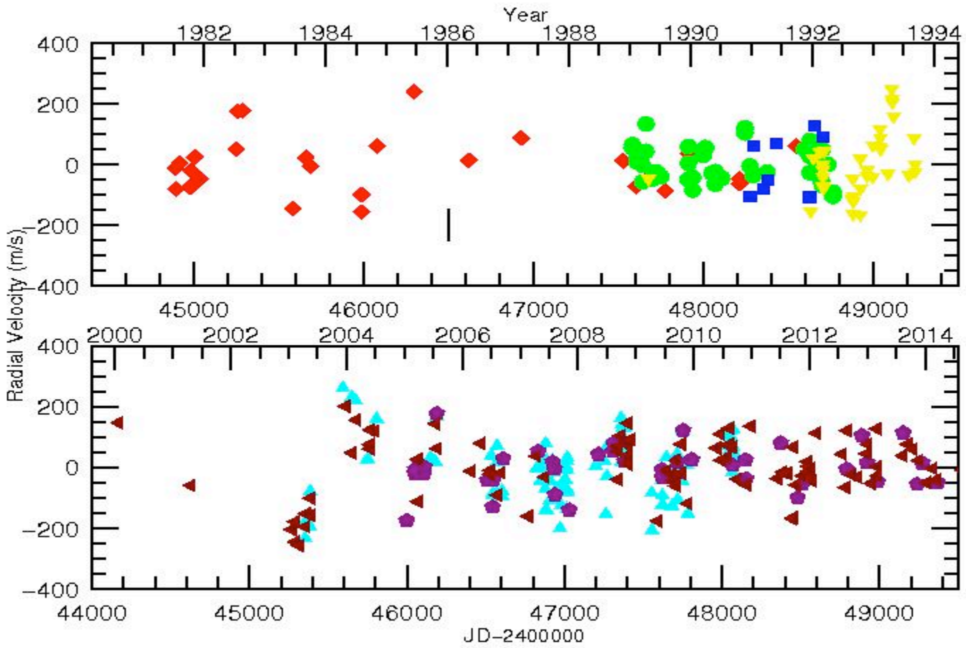
3. HD 102272 (Niedzielski et al. 2009): 5.9 M_{Jup}, 2.6 M_{Jup}, P = 127 d, 520 d (4:1 resonance)

   - Dynamical analysis shows planets will quickly collide

4. BD+20 2457 (Niedzielski et al. 2009): 21.4 M_{Jup}, 12.5 M_{Jup} with 380 d, 622 d periods.

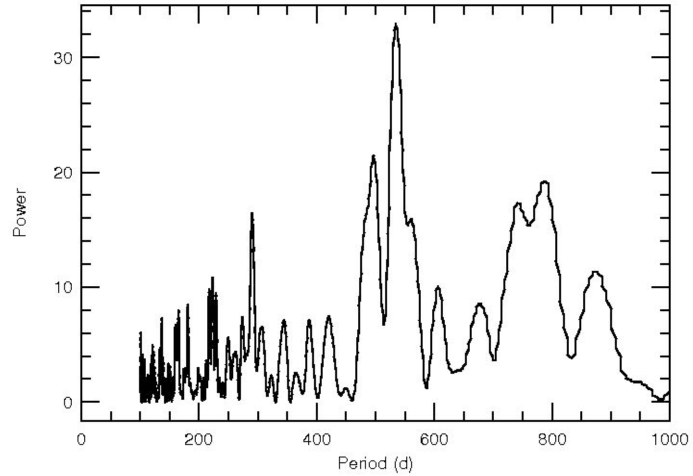
   - No stable configuration

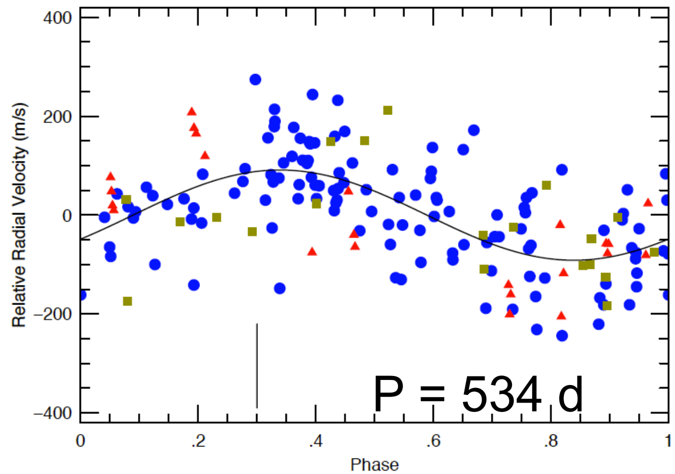
The Residual Radial Velocity Variations in α Tau



Period of 534 d
Amplitude = 90 m/s
“msini” = 3.6 M_{Jup}

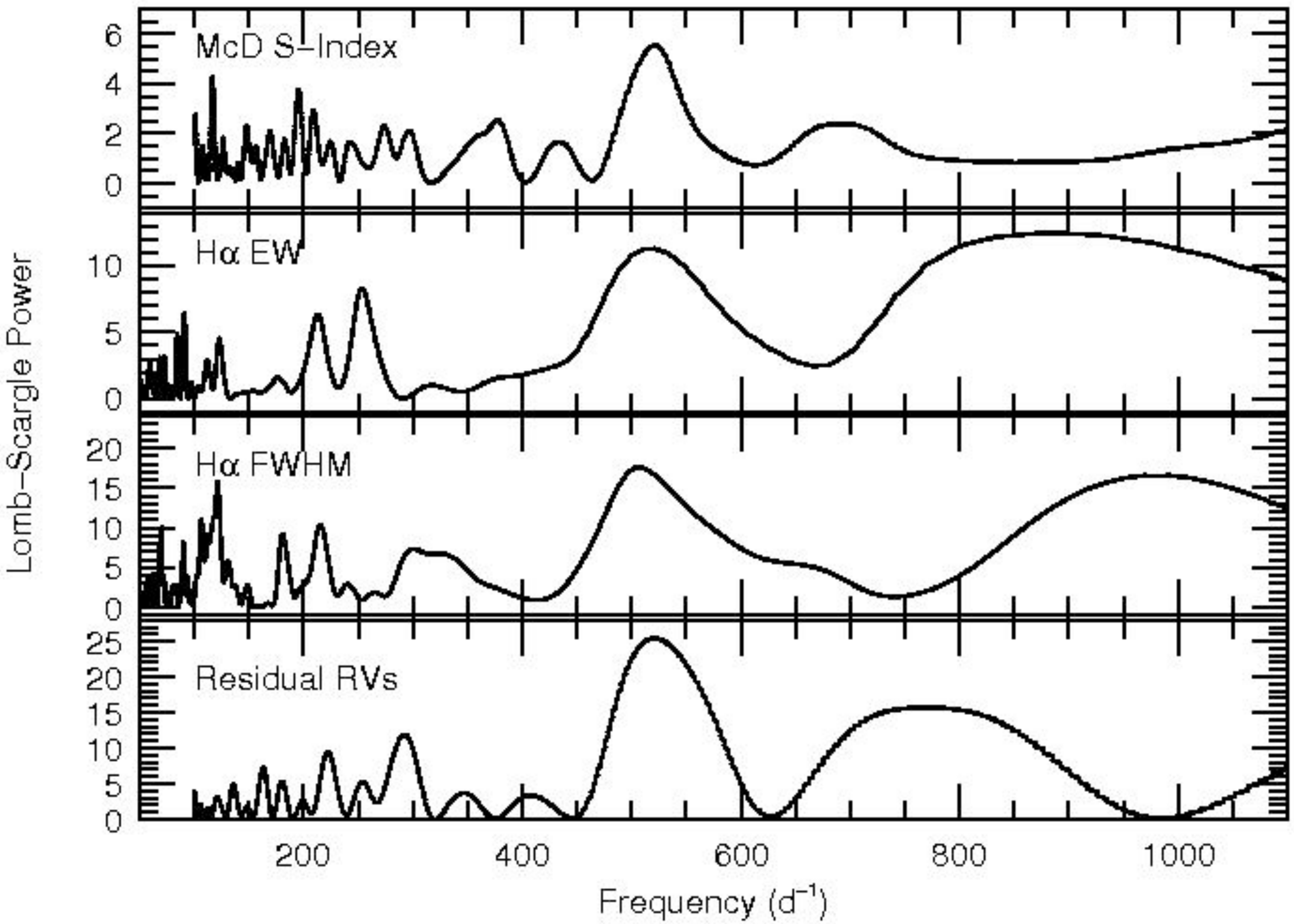
A K Giant planet that is unstable!



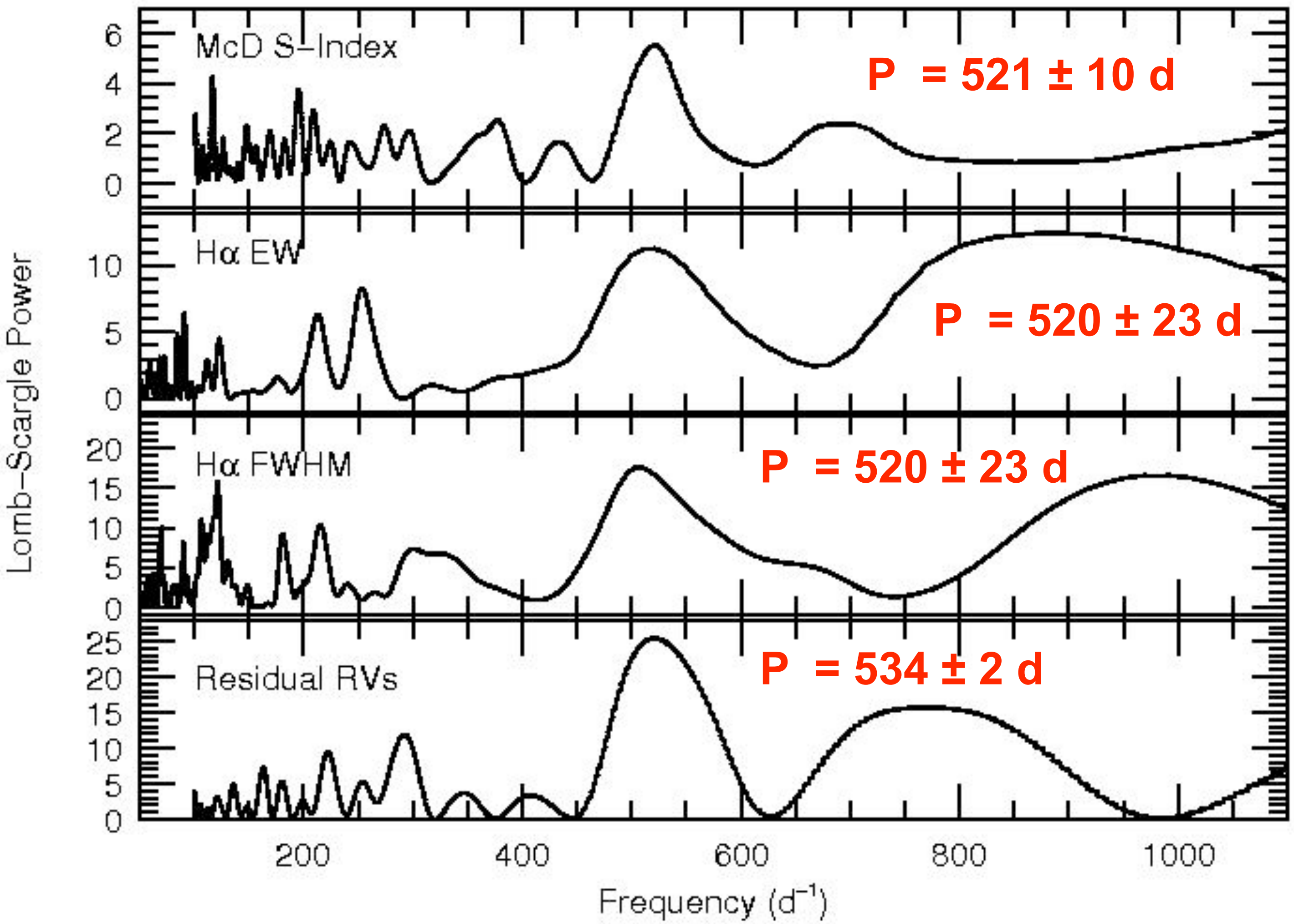


triangles: 1981-1987
squares: 1993-1994
circles: 2005-2008

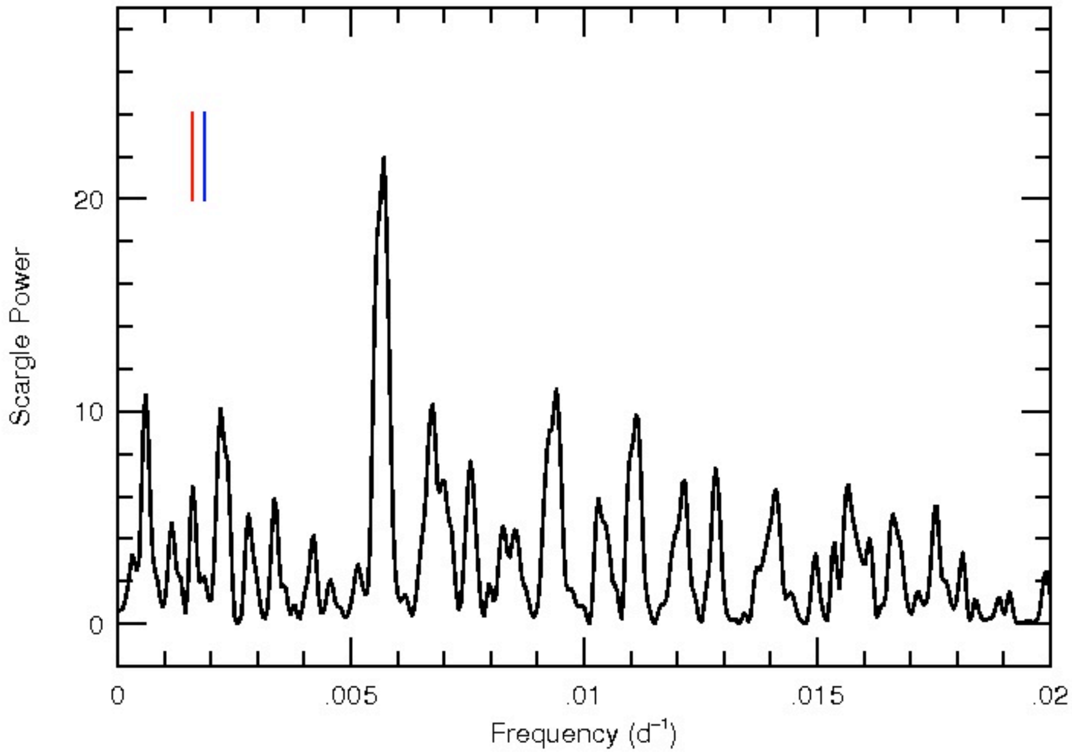
Activity Indicators



Activity Indicators



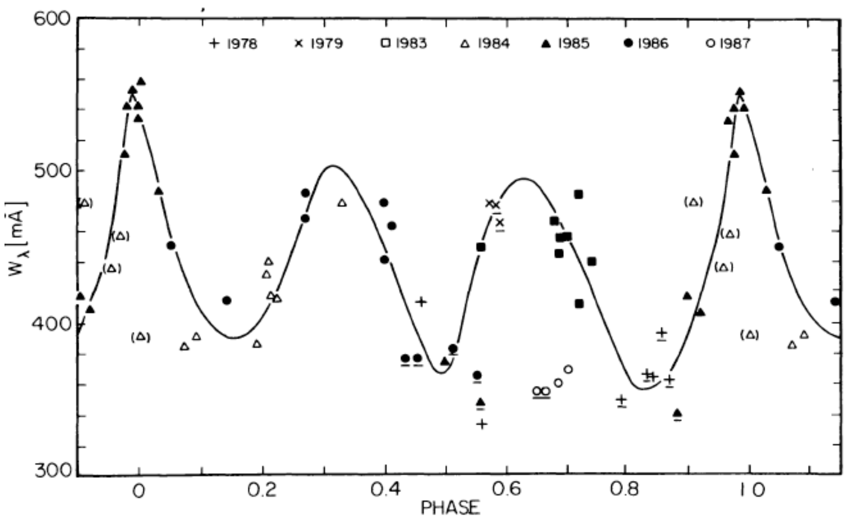
Bisectors for Aldebaran



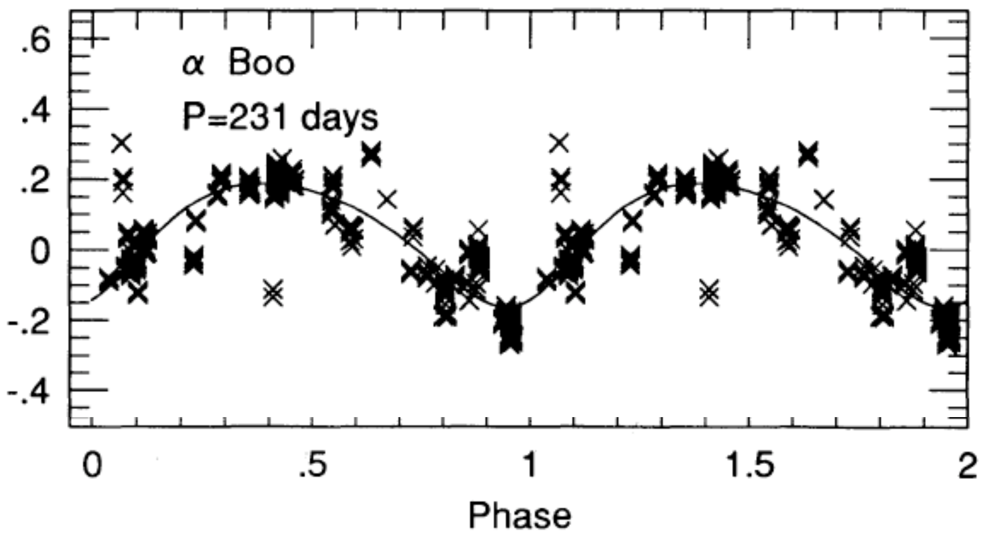
Red mark: P = 629 d
Blue mark: P = 534 d
Peak: 175 d ≈ 534/3 d

Early indications for activity in K giant stars

LAMBERT (1987)



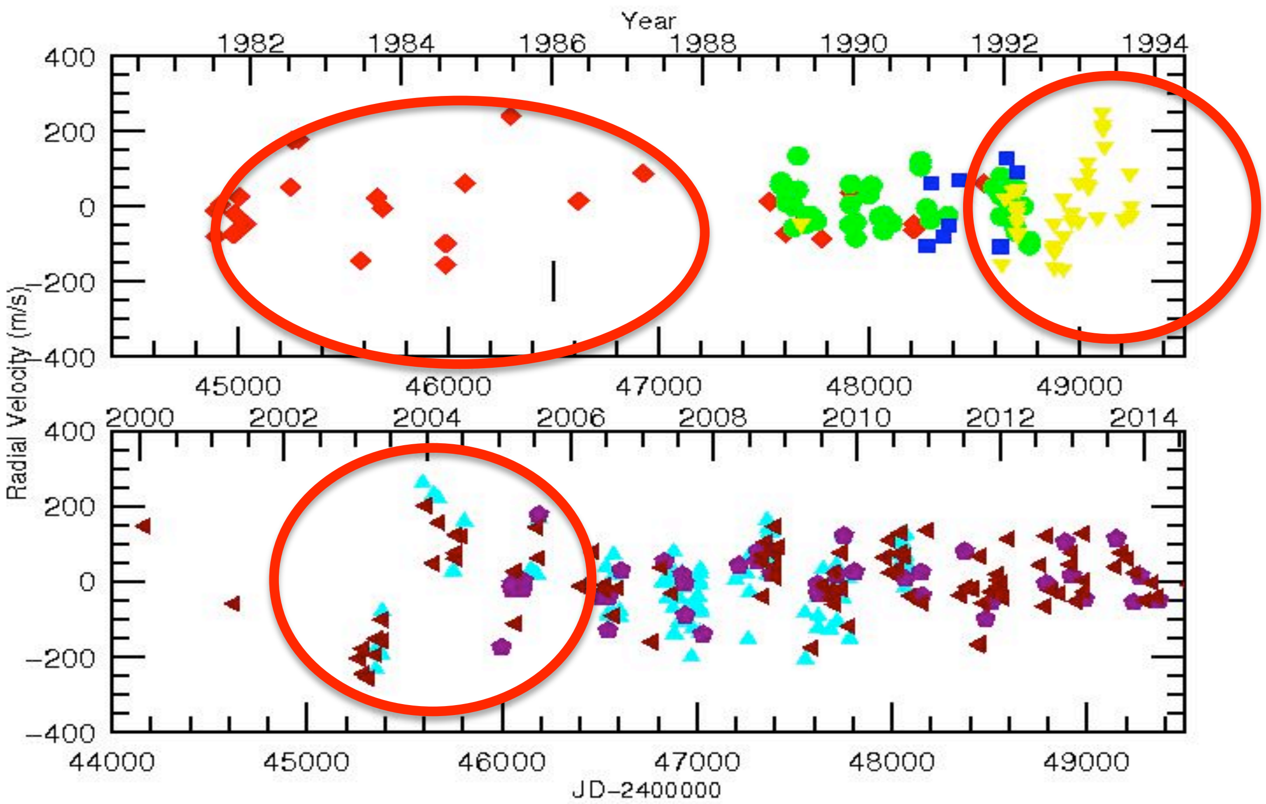
Hatzes & Cochran (1993)



“The variations [for He I] appar to be periodic for α Boo, with a basic interval of about 78 days. It is suggested that the rotational period is about 233 days (i.e. about 78 x 3 days)”

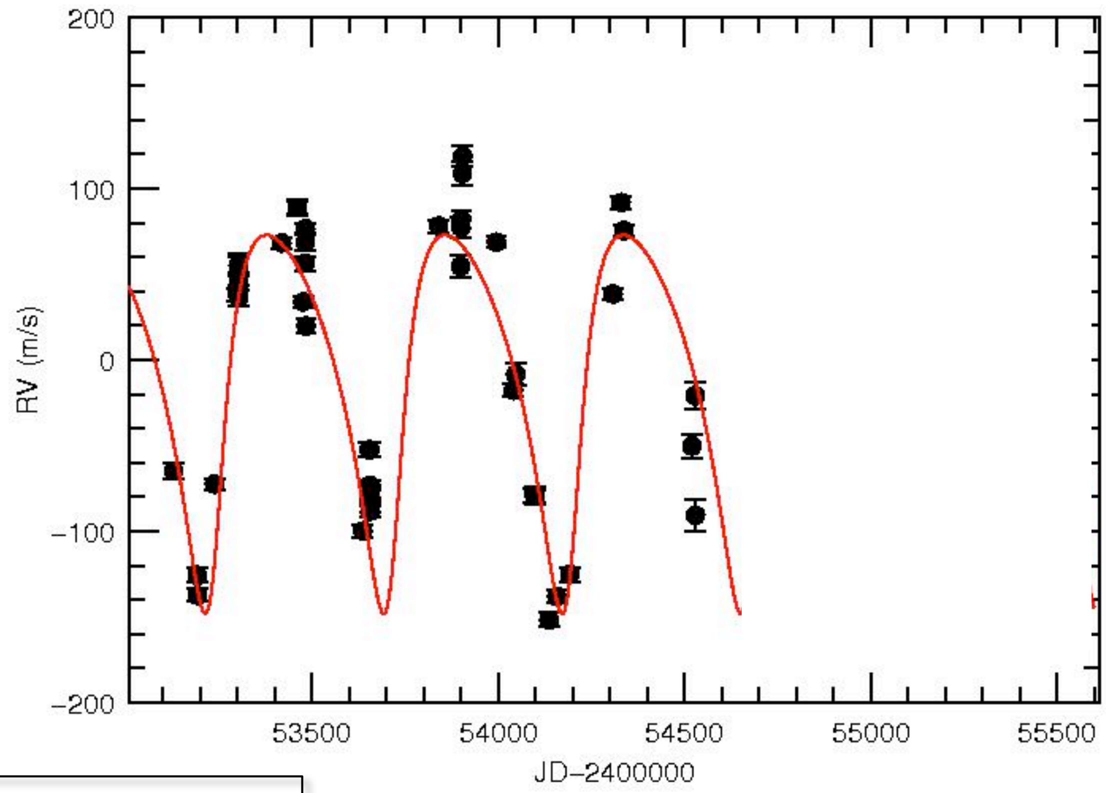
Giant stars show activity with periods and velocity amplitude comparable to “planets”

An activity cycle?



A possible activity cycle of ≈ 10 years

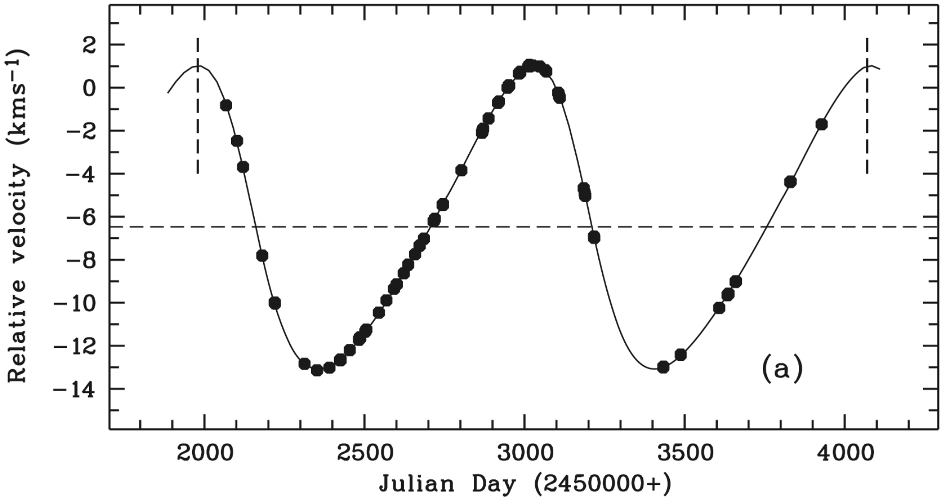
The Planet around 42 Dra?

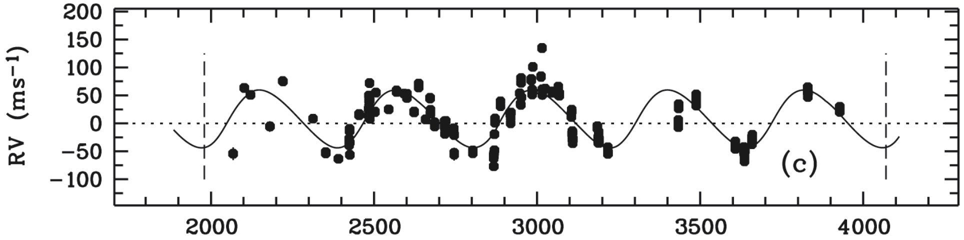


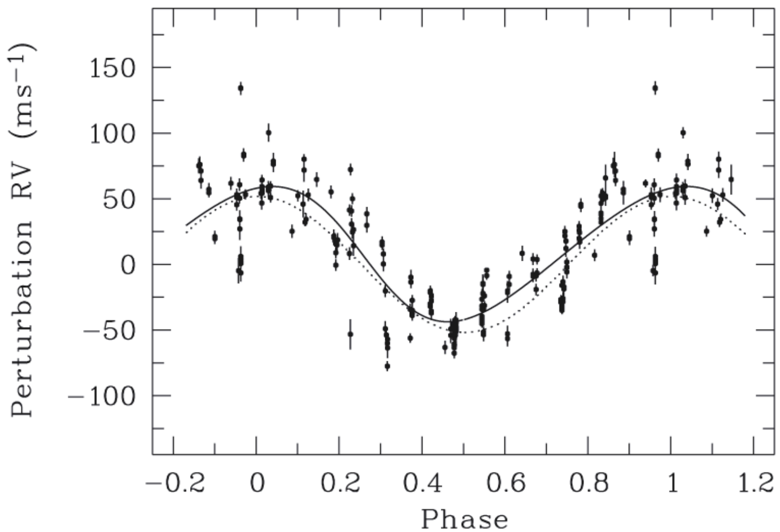
P =471 d
m sin i = 3.9 M_{Jup}

The Fascinating Case of ν Oct Ab

Ramm et al. 2014





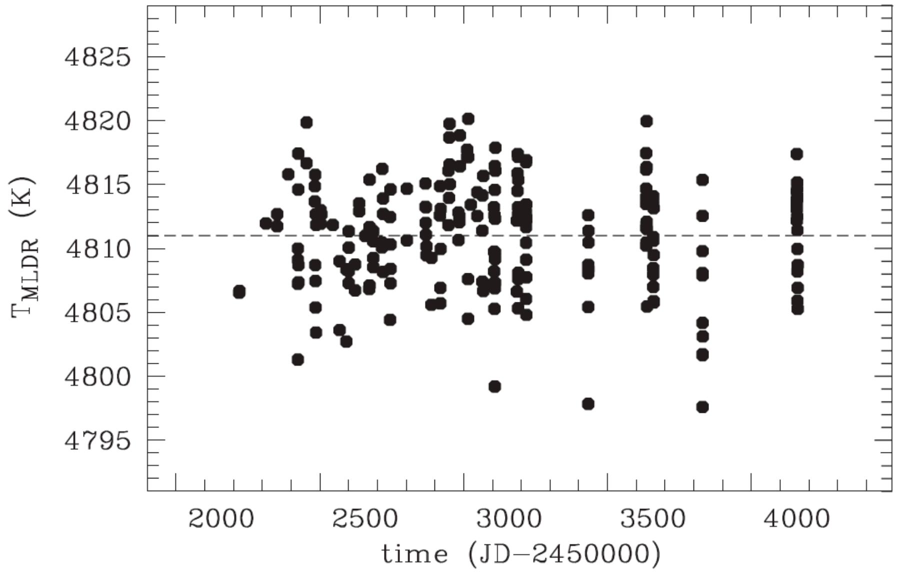


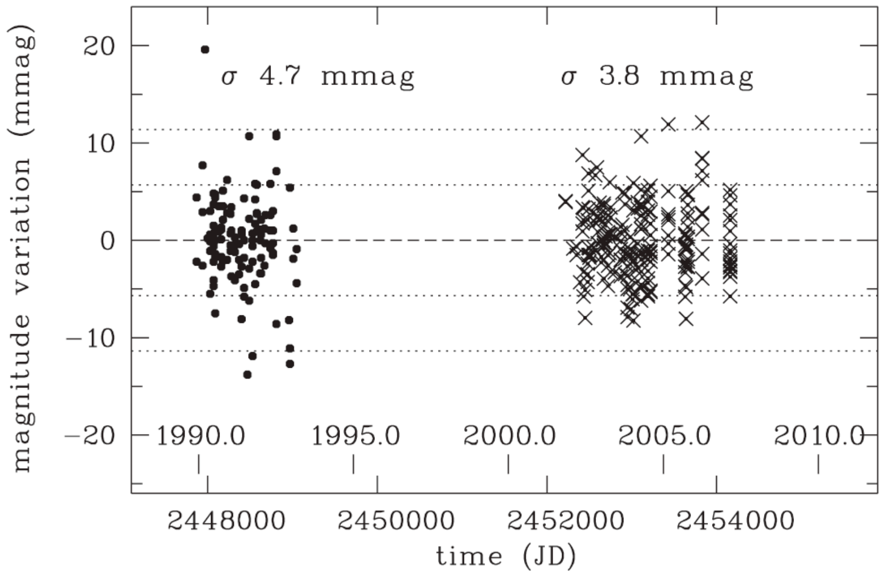
$M_A = 1.4\ M_\odot$
$M_B = 0.5\ M_\odot$
$P_{AB} = 1050$ d

$M_b = 2.4\ M_{Jup}$
$P_b = 417.4$ d

- Planet orbit dynamically unstable
- Only stable (60%) if planet orbits retrograde to binary orbit

Line Depth Ratios





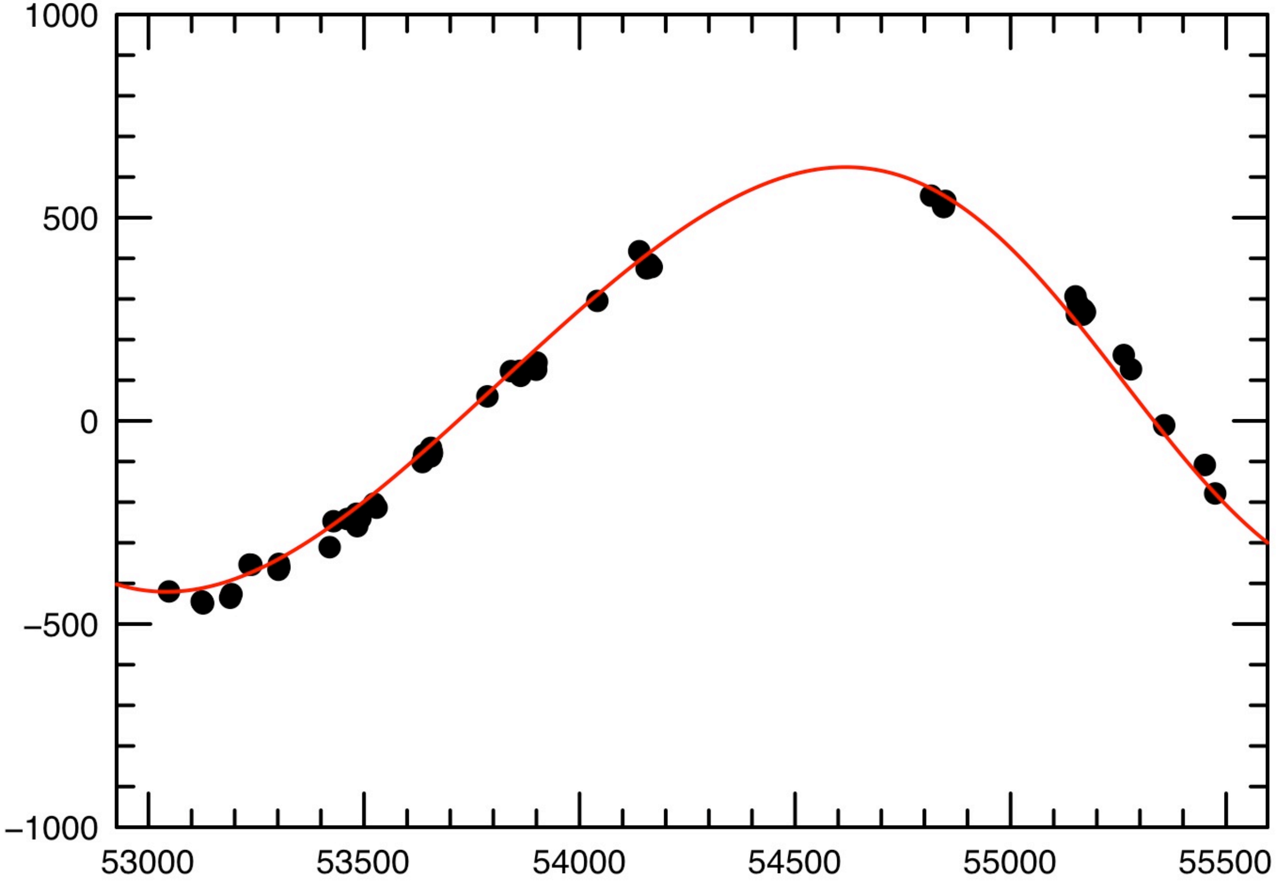
- Ramm (2015) examined the line depth ratios of temperature sensetive lines. The temperature variations of ν Oct A have a σ = 4.2 K

- Comparing to Hipparcos photometry star has been photometrically stable for 15 years

GAIA should be able to get true planet masses as well as confirm "suspicious" planets around K giant stars

Star	V	M_* ($M_\odot$)	D (pcs)	M_p (M_{Jup})	P (d)	Δa (μas)
ι Dra	3.3	1.82	20.2	12.6	511	520
β Gem	1.1	1.91	10.3	2.3	590	187
α Tau	0.9	1.13	20.4	6.5	639	420
11 UMi	5.0	1.80	119	10.5	516	75
HD 32518	6.4	1.13	117	3.0	157	14
42 Dra	4.8	1.00	96	3.8	479	46
HD 139357	6.0	1.35	118	9.6	142	142
ν Oct	3.8	1.30	21.2	2.1	471	94
4 UMa	5.7	1.23	13	7.1	386	386

$m \sin i = 42\ M_{Jup}$



Brown dwarf or star?

Summary

• Evolved giant stars are an effective way to probe planet formation around stars more massive than the sun

• Compared to solar-mass stars (small statistics) giant planets around intermediate mass stars are

1. More massive
2. More frequent
3. Less eccentric
4. Not dependent on stellar metalicity (?)

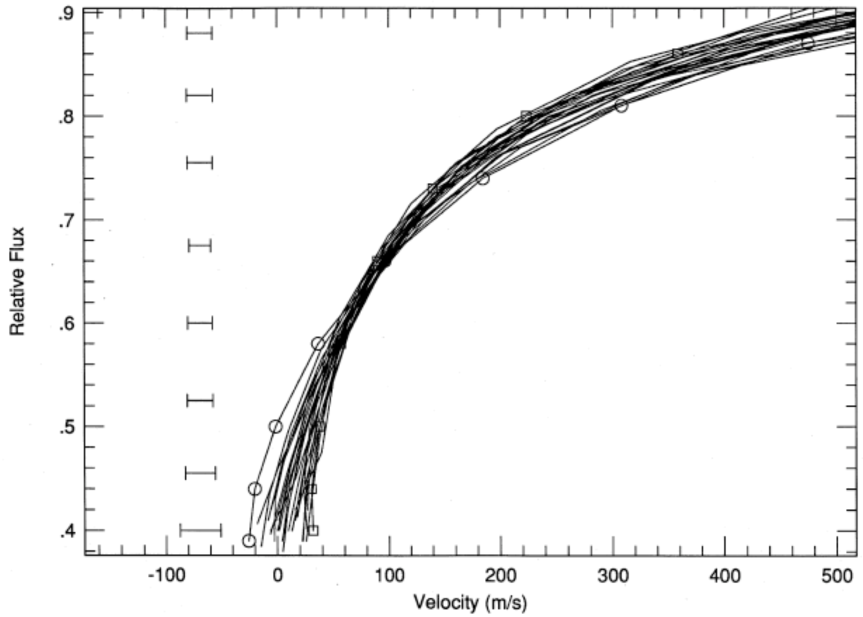
• Activity in Giant stars may masquerade as planets

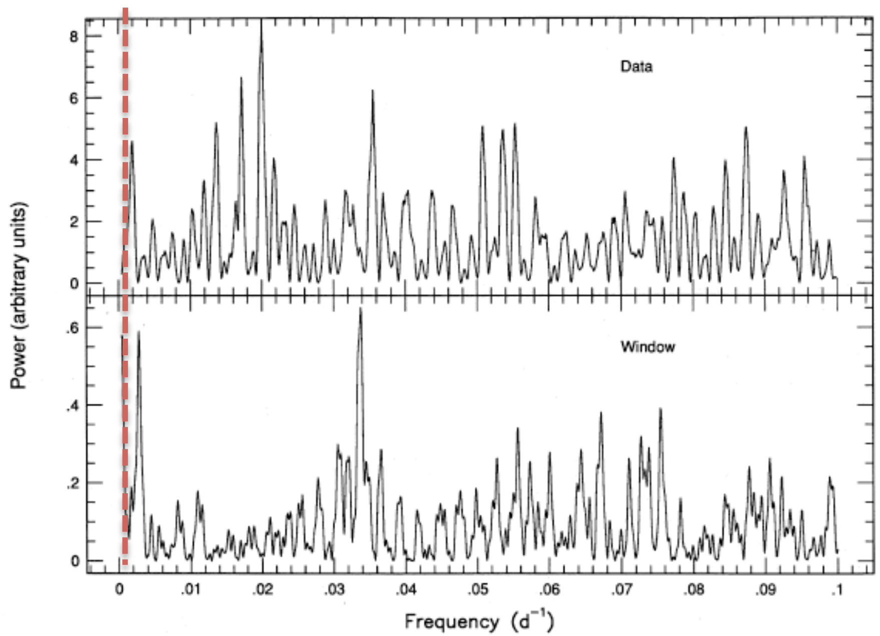
• The Radial Velocity “jitter” (oscillations) can be used to determine the stellar mass

• GAIA will determine true masses and help eliminate “false” planets

No variations in spectral line shapes

Hatzes & Cochran 1998





"You have to be careful before you claim to find a planet around an evolved star!" - Bill Borucki