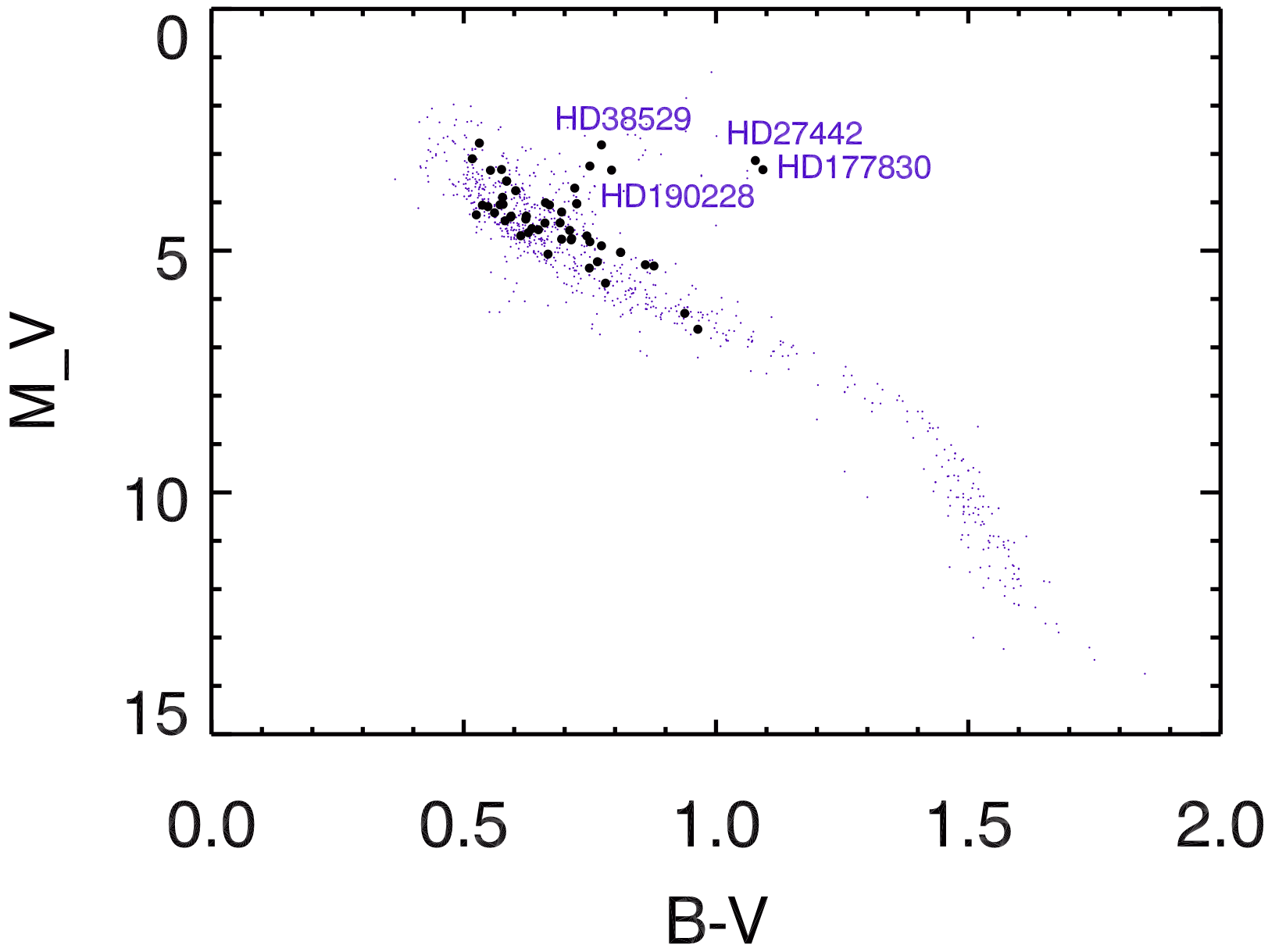
Extrasolar Planet Search

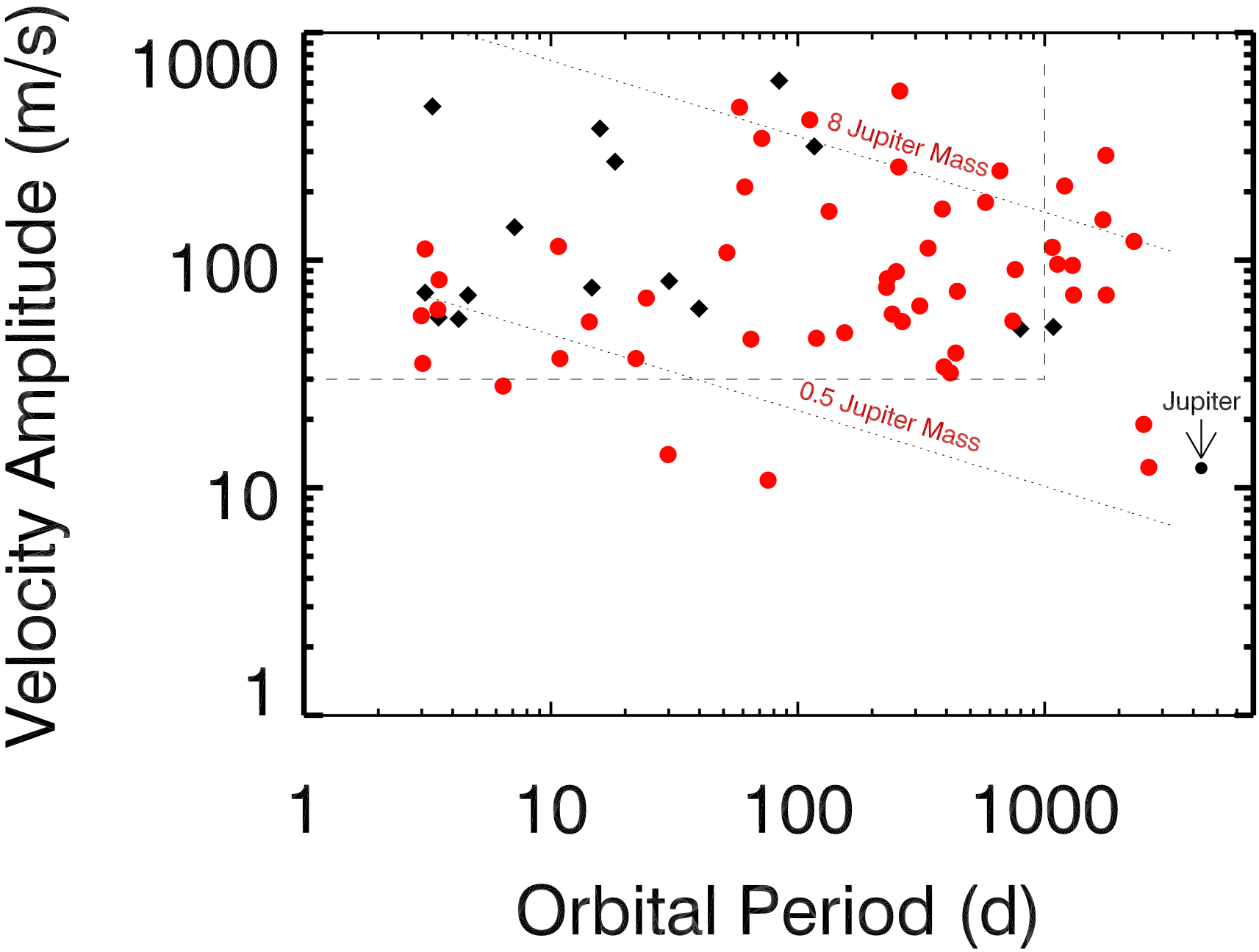
Geoff Marcy
Paul Butler
Steve Vogt
Debra Fischer

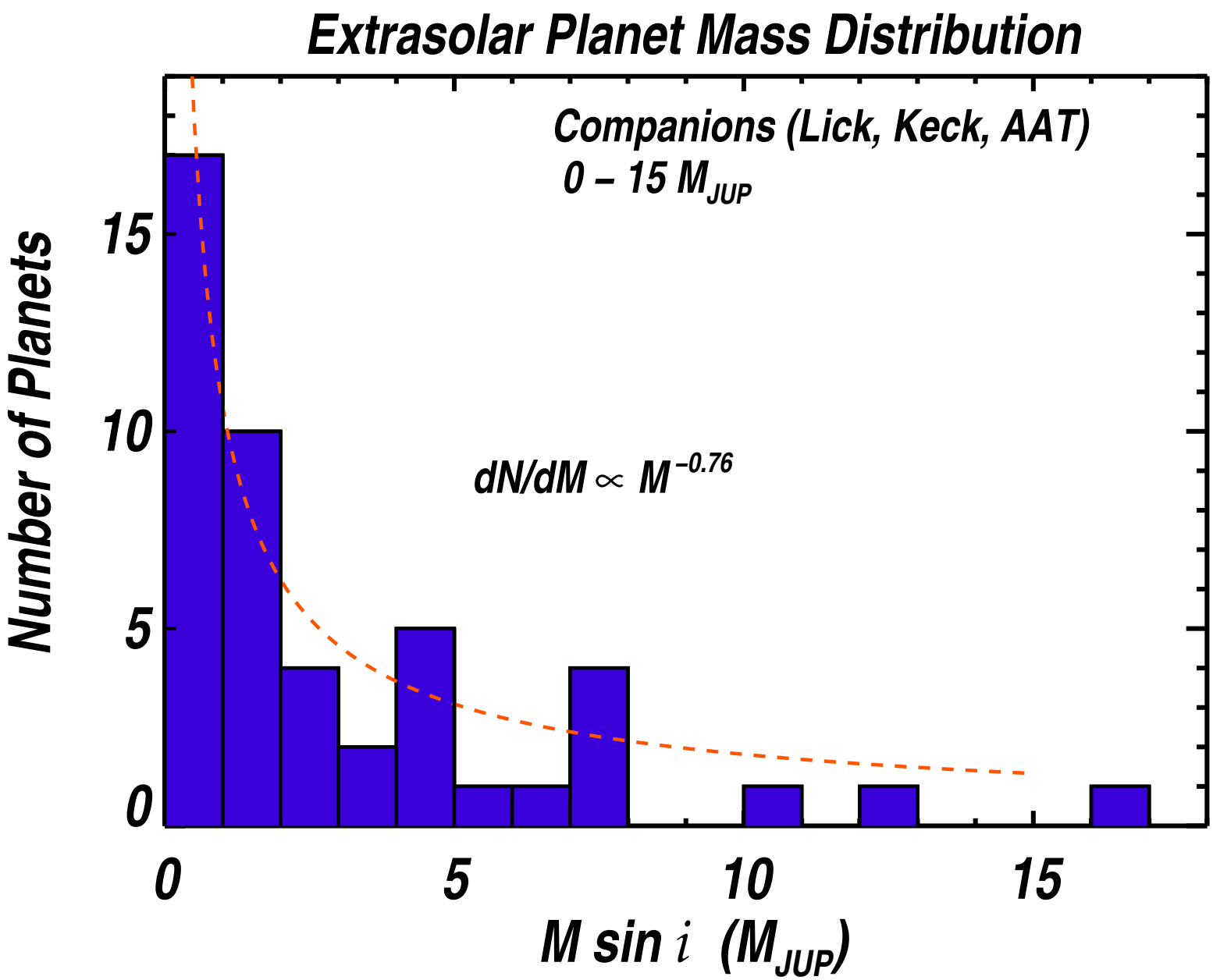
Lick Observatory: 350 stars
Keck Observatory: 550 stars
AAT Observatory: 220 stars

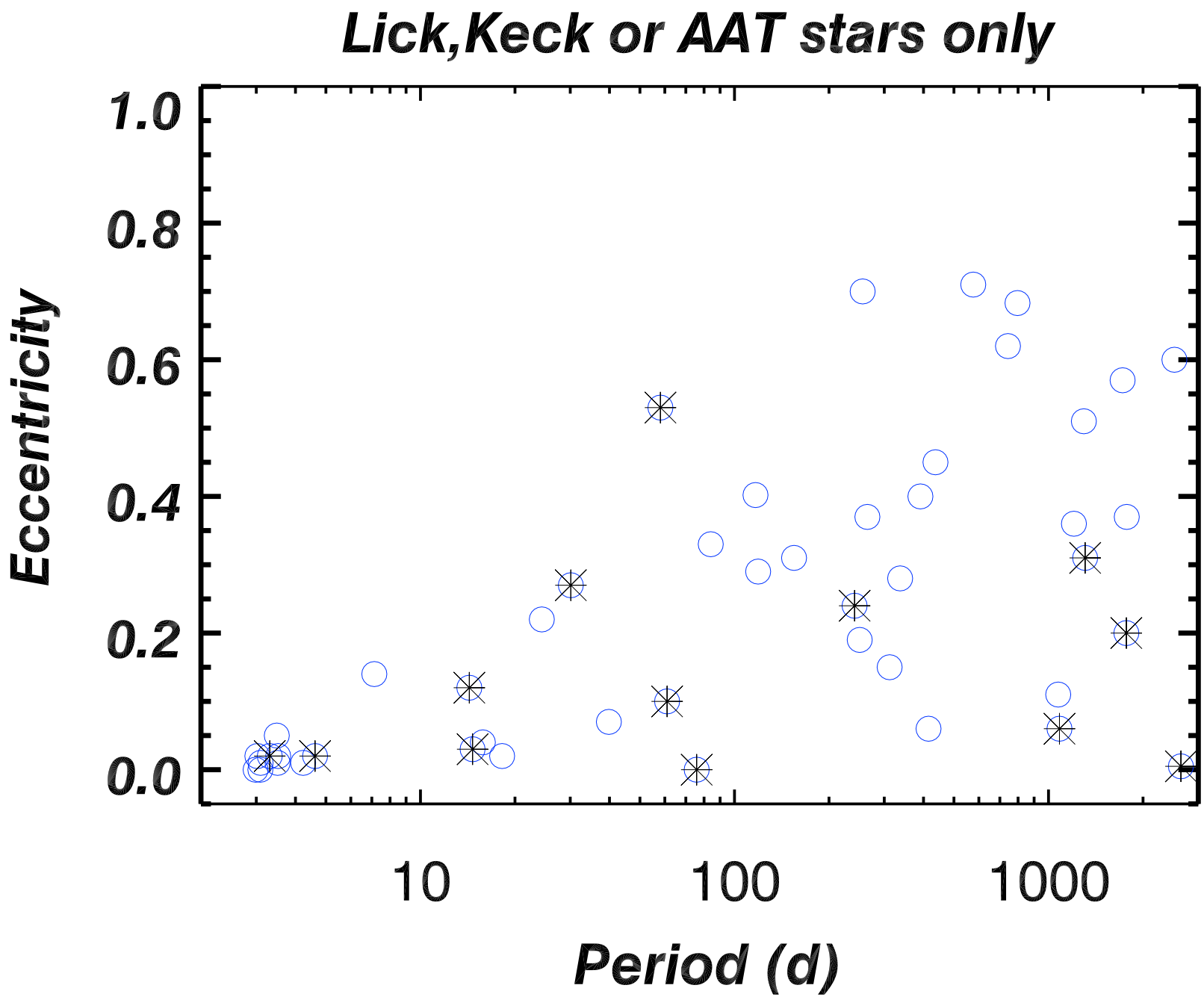
Sample Characteristics

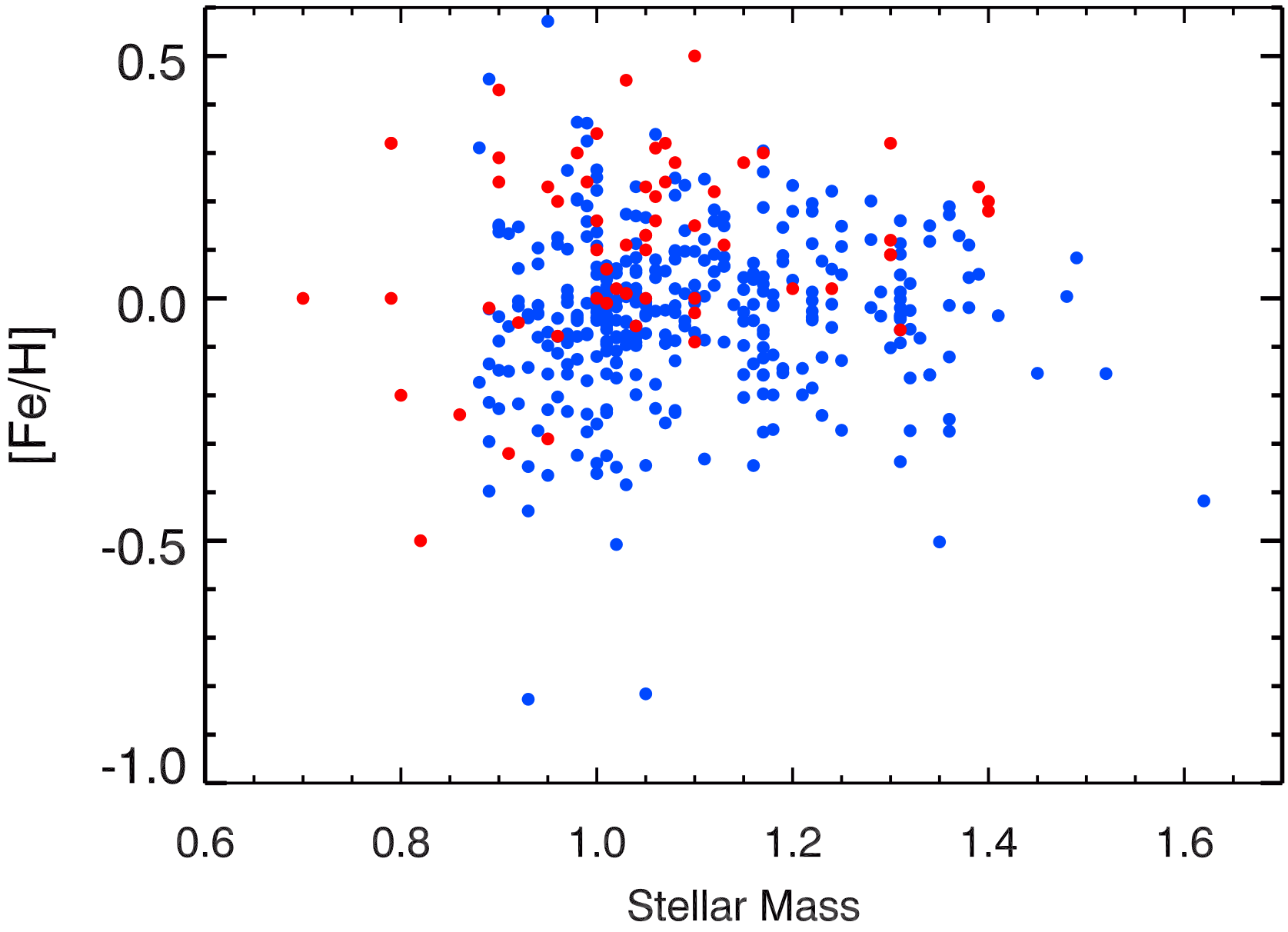
1) Spectral type
   Main Sequence, late F -> Mdwarf
2) Single Stars
   Exclude known binaries with sep < 2arcsec
3) Magnitude
   V < 8.0 at Lick
   but volume-limited at Keck
4) Chromospherically inactive

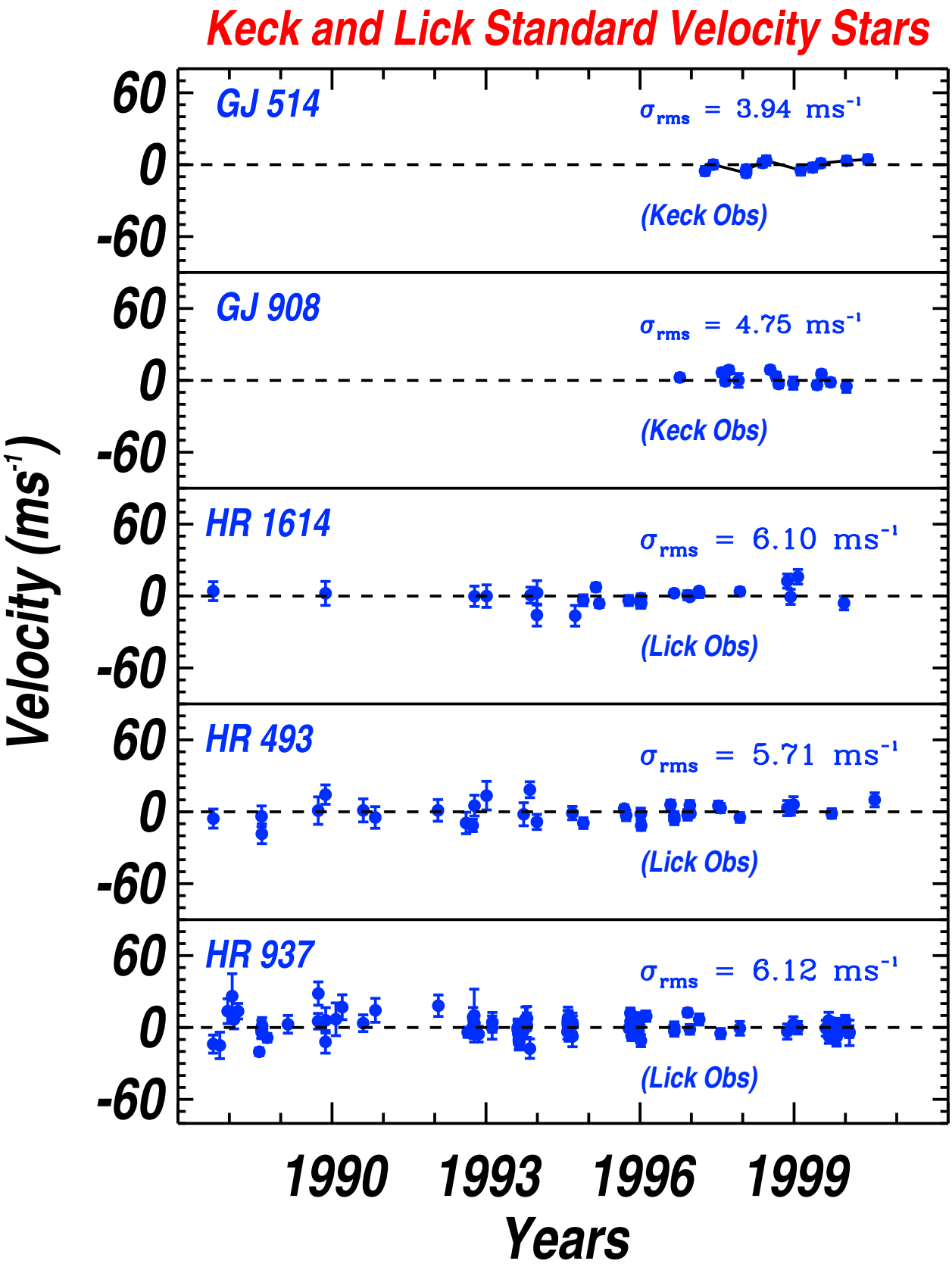

HD38529
HD27442
HD177830
HD190228
0
5
10
15
M_V
0.0
0.5
1.0
1.5
2.0
B-V

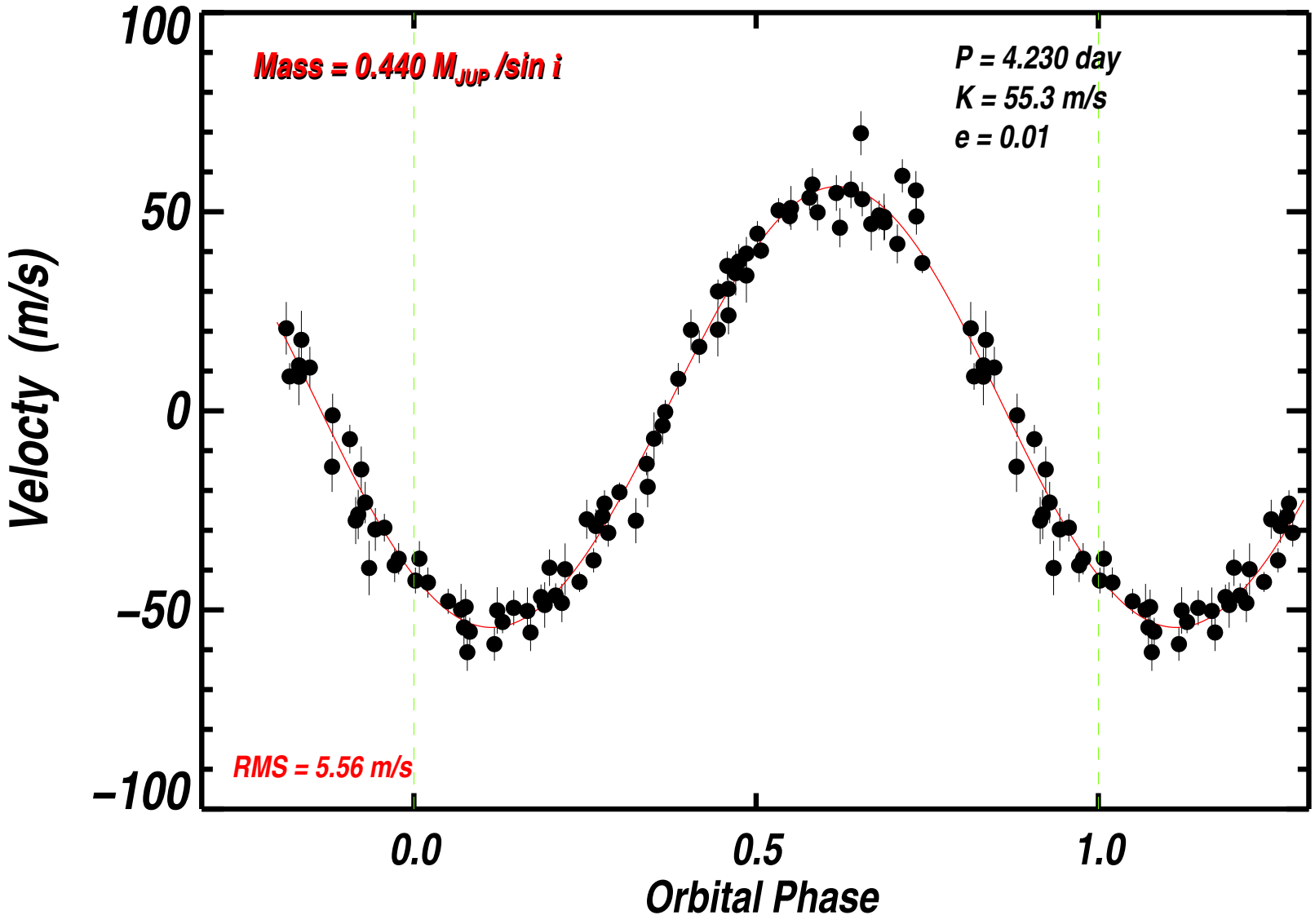

Velocity Amplitude (m/s)
1000
100
10
1
1
10
100
1000
Orbital Period (d)
8 Jupiter Mass
0.5 Jupiter Mass
Jupiter

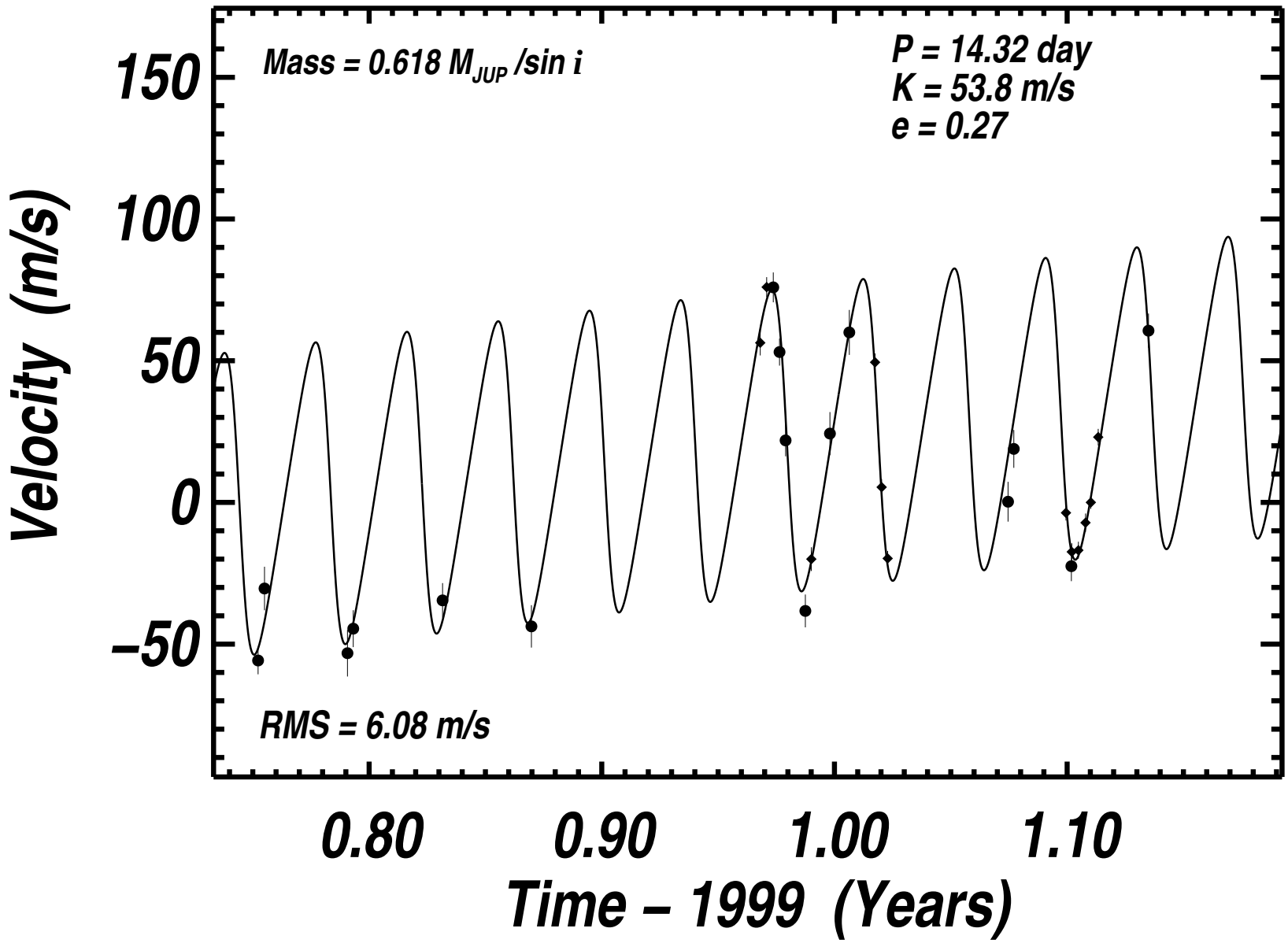

Extrasolar Planet Mass Distribution
Companions (Lick, Keck, AAT)
0 – 15 M_{JUP}
$dN/dM \propto M^{-0.76}$
Number of Planets
0
5
10
15
0
5
10
15
M sin i (M_{JUP})

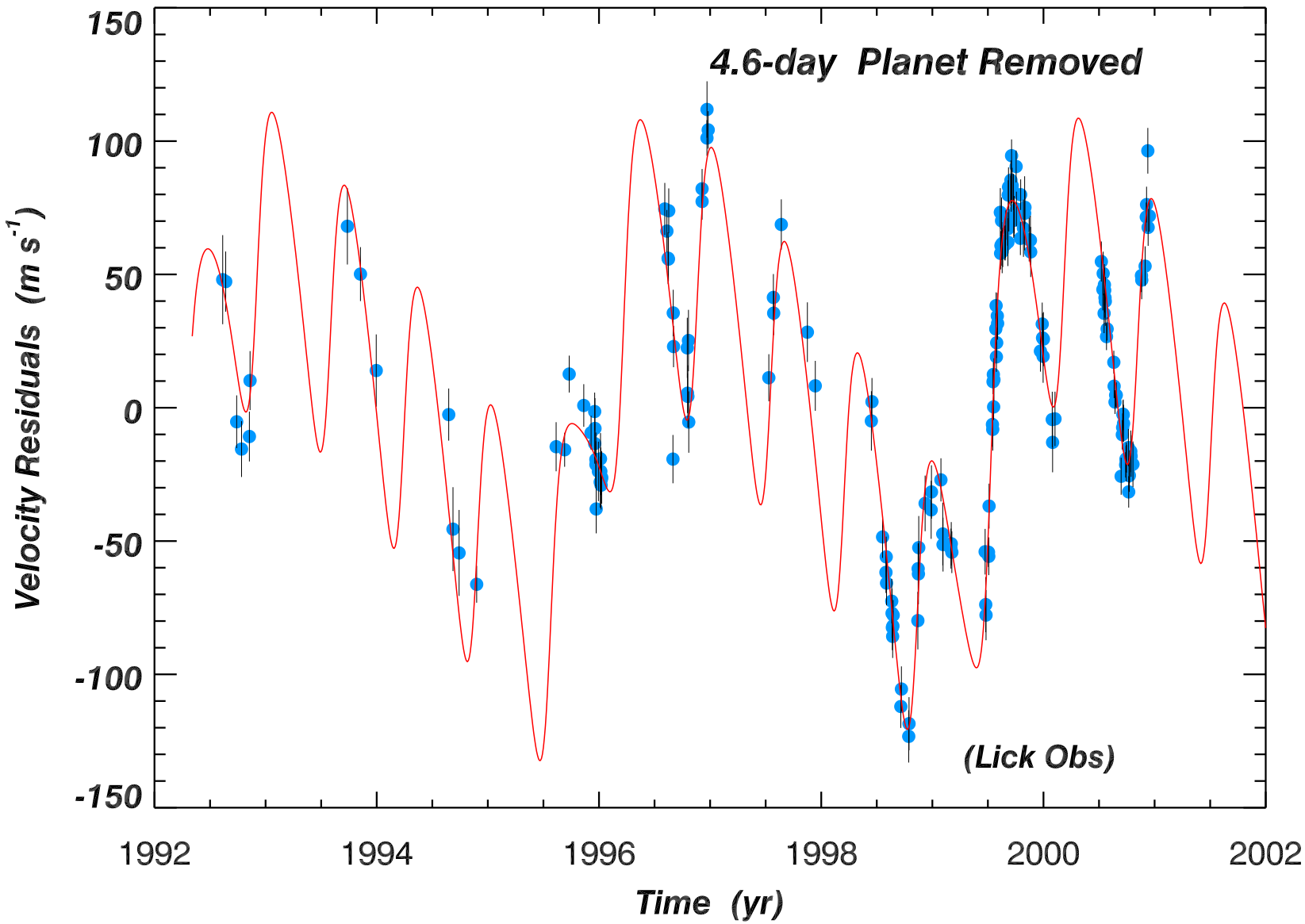

Lick,Keck or AAT stars only
Eccentricity
1.0
0.8
0.6
0.4
0.2
0.0
10
100
1000
Period (d)

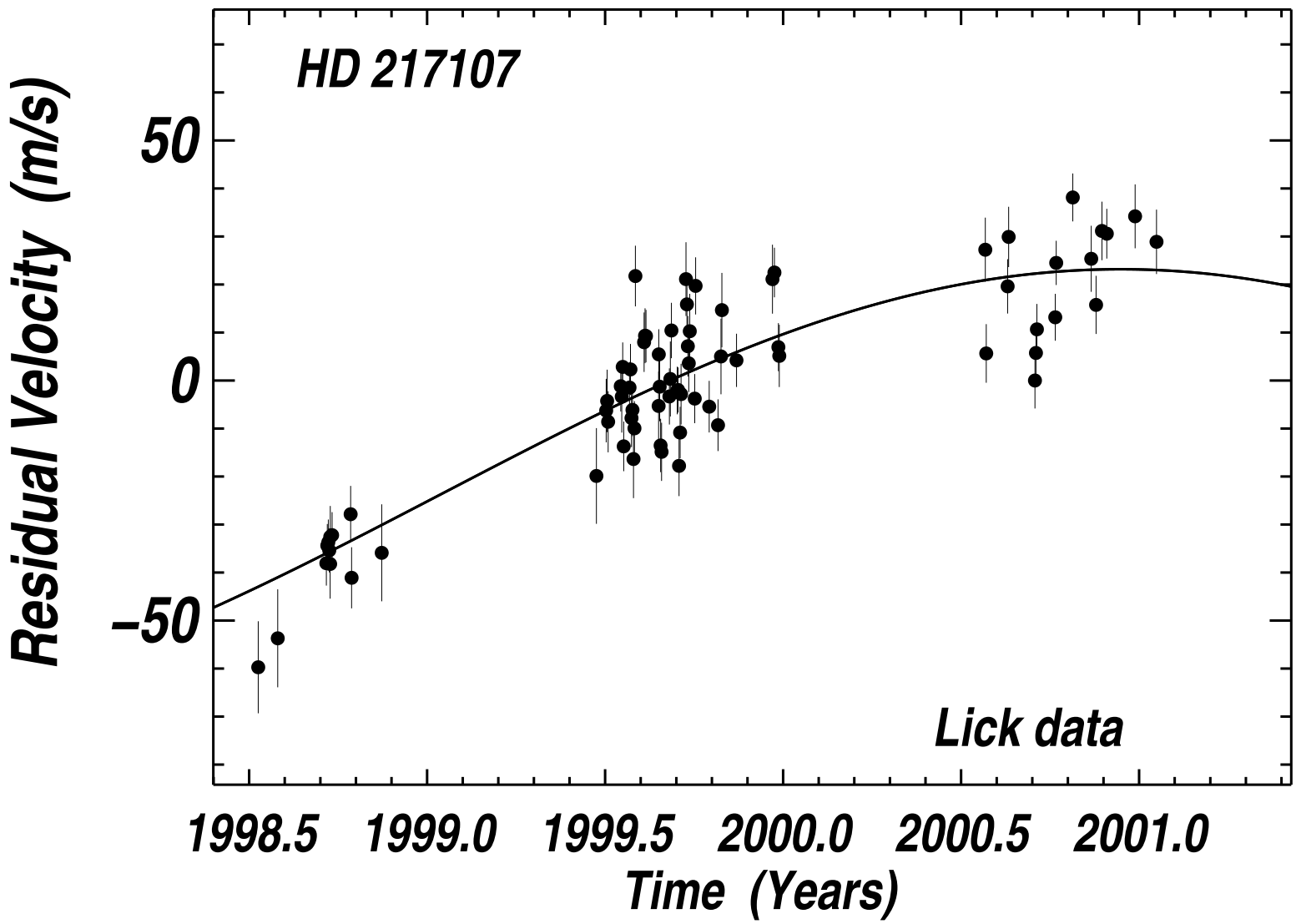

0.5
0.0
-0.5
-1.0
[Fe/H]
0.6
0.8
1.0
1.2
1.4
1.6
Stellar Mass


Keck and Lick Standard Velocity Stars
GJ 514
σrms = 3.94 ms-1
(Keck Obs)
GJ 908
σrms = 4.75 ms-1
(Keck Obs)
HR 1614
σrms = 6.10 ms-1
(Lick Obs)
HR 493
σrms = 5.71 ms-1
(Lick Obs)
HR 937
σrms = 6.12 ms-1
(Lick Obs)
60
0
-60
Velocity (ms-1)
1990
1993
1996
1999
Years


Mass = 0.440 M_JUP /sin i
P = 4.230 day
K = 55.3 m/s
e = 0.01
RMS = 5.56 m/s
100
50
0
−50
−100
Velocty (m/s)
0.0
0.5
1.0
Orbital Phase


Mass = 0.618 M_{JUP} /sin i
P = 14.32 day
K = 53.8 m/s
e = 0.27
RMS = 6.08 m/s
150
100
50
0
−50
Velocity (m/s)
0.80
0.90
1.00
1.10
Time – 1999 (Years)


4.6-day Planet Removed
(Lick Obs)
Velocity Residuals (m s-1)
Time (yr)
150
100
50
0
-50
-100
-150
1992
1994
1996
1998
2000
2002


HD 217107
Lick data
Residual Velocity (m/s)
50
0
−50
1998.5
1999.0
1999.5
2000.0
2000.5
2001.0
Time (Years)

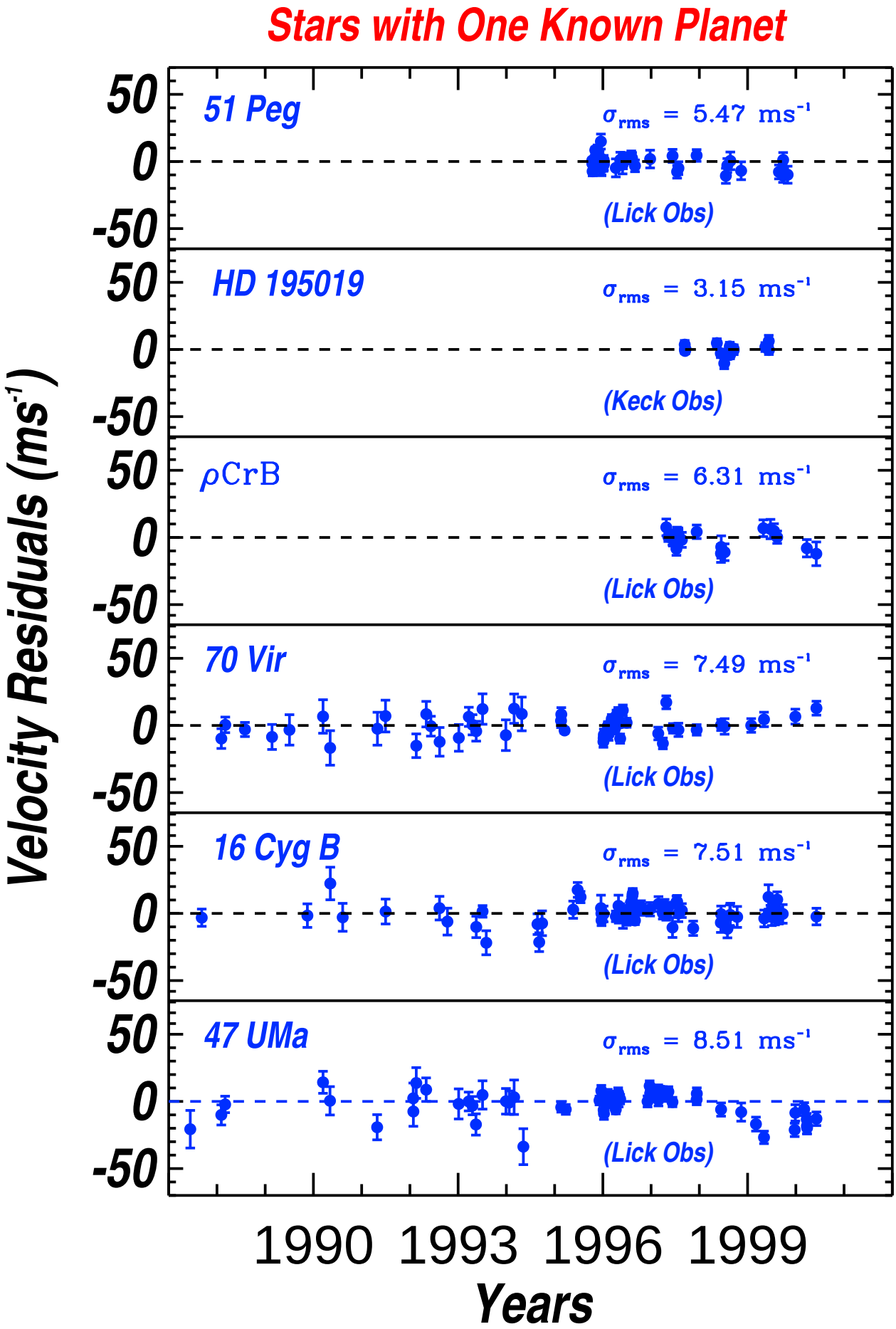
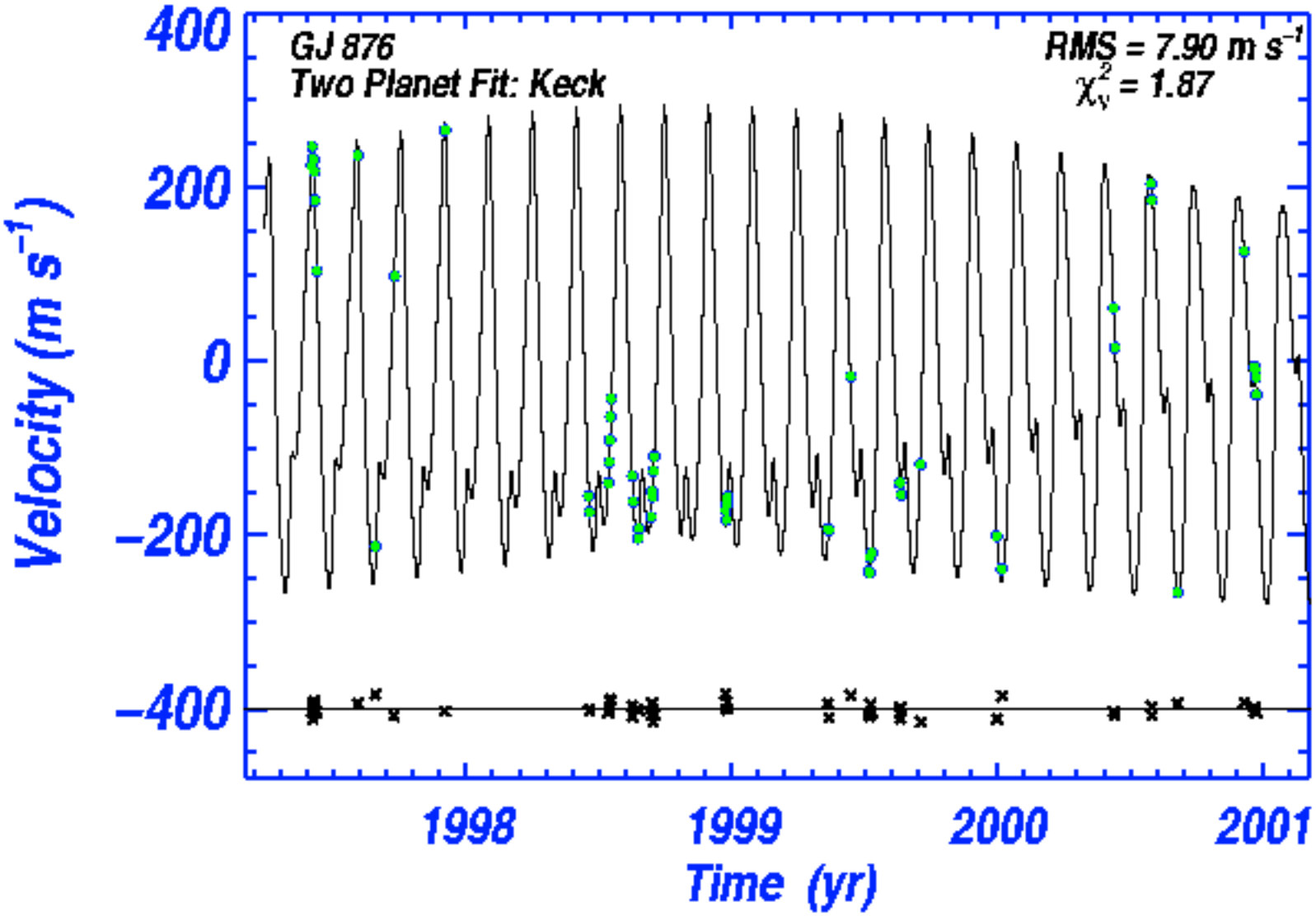
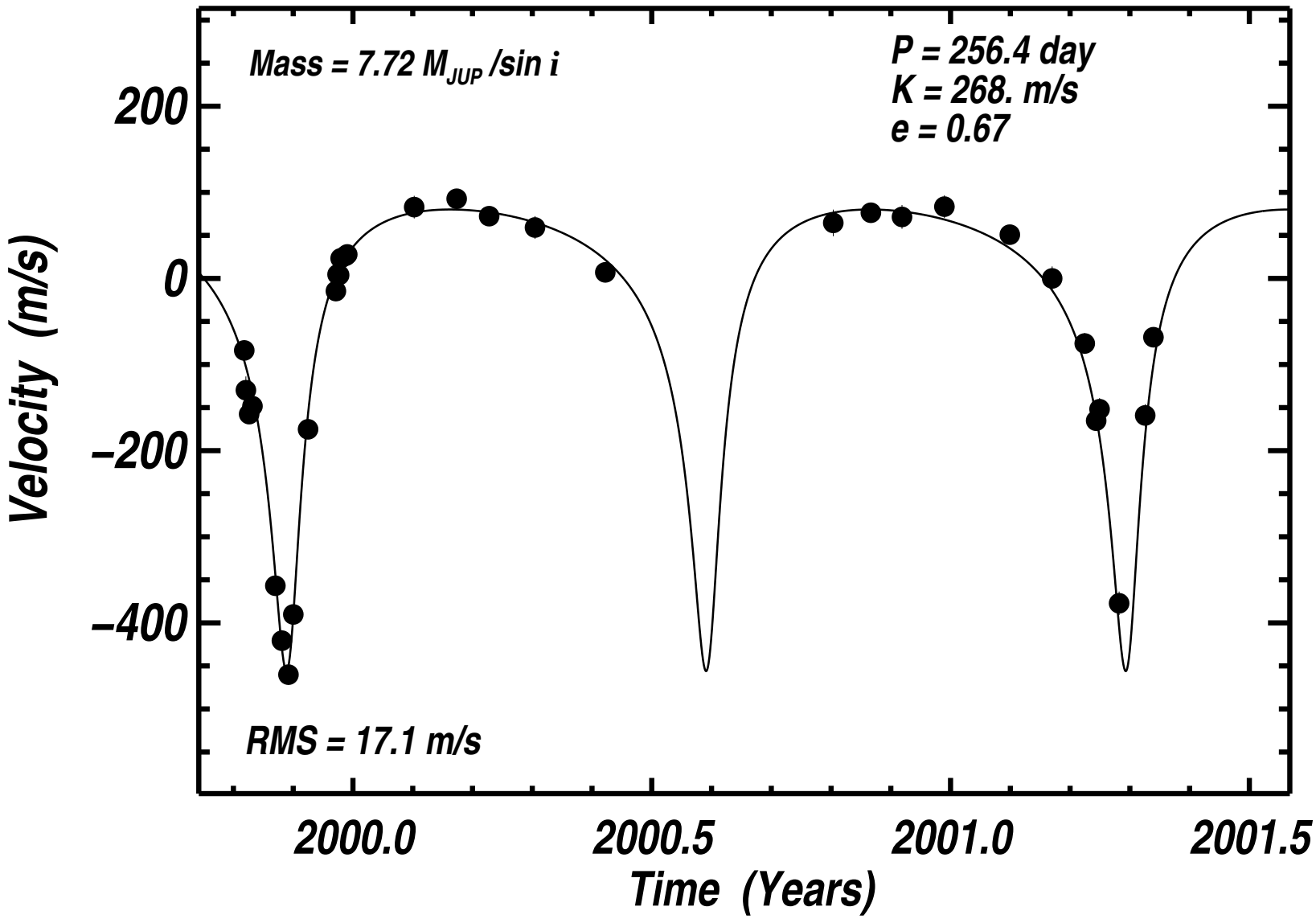

Stars with One Known Planet
51 Peg
σrms = 5.47 ms-1
(Lick Obs)
HD 195019
σrms = 3.15 ms-1
(Keck Obs)
ρCrB
σrms = 6.31 ms-1
(Lick Obs)
70 Vir
σrms = 7.49 ms-1
(Lick Obs)
16 Cyg B
σrms = 7.51 ms-1
(Lick Obs)
47 UMa
σrms = 8.51 ms-1
(Lick Obs)
50
0
-50
Velocity Residuals (ms-1)
1990
1993
1996
1999
Years

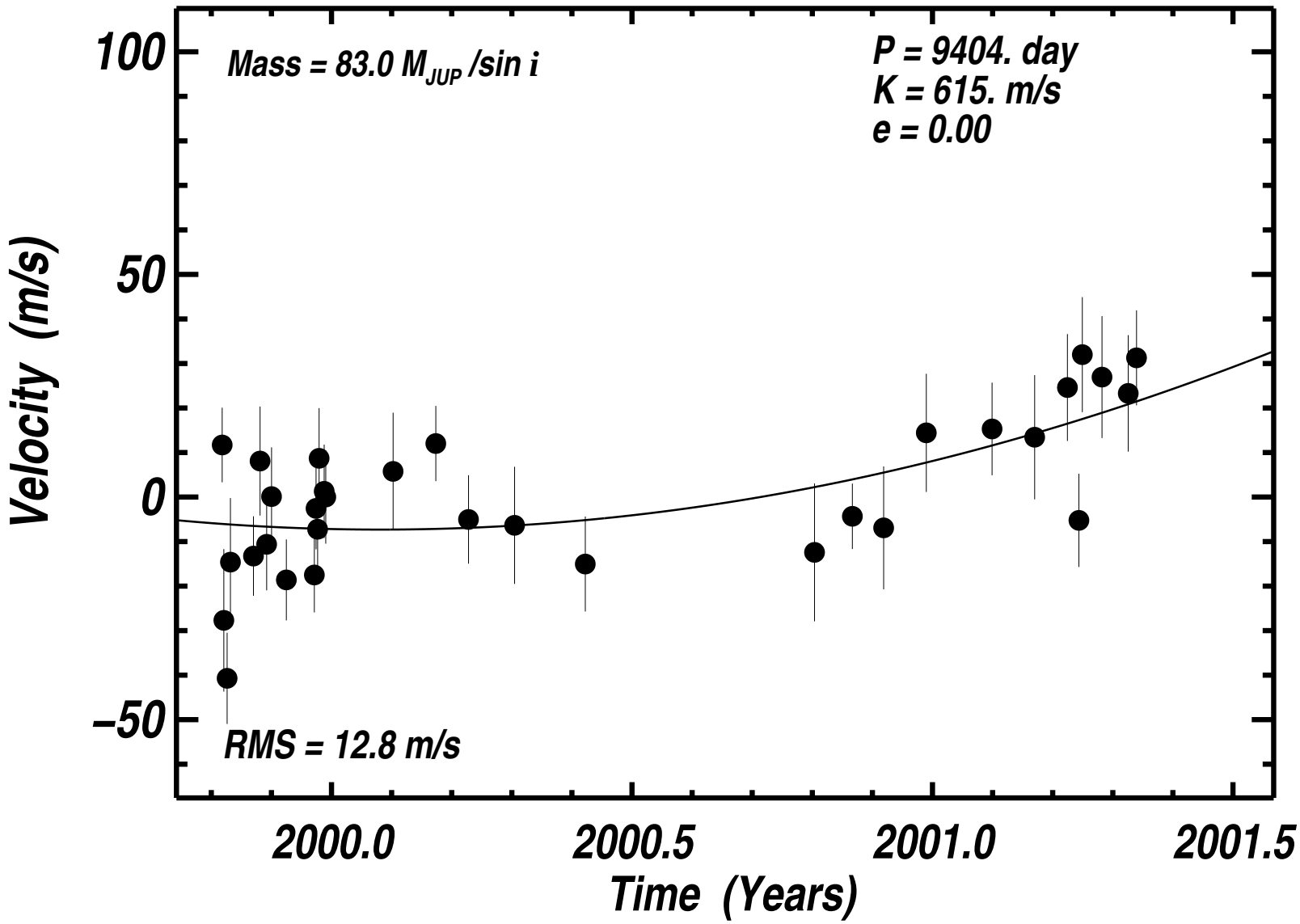
Table 5: Stellar Characteristics

star	M_* ($M_\odot$)	P (d)	$M \sin i$ (M_{JUP})	ecc	[Fe/H]	$\log R'_{HK}$	residual trend?
Tau Boo	1.3	3.3126	4.14	0.02	0.32	-4.75	yes
51 Peg	1.06	4.231	0.46	0.01	0.21	-5.03	no
Ups And b	1.3	4.617	0.68	0.02	0.12	-4.84	yes
HD 217107	0.98	7.128	1.29	0.14	0.30	-5.09	yes
55 Cnc	1.03	14.656	0.93	0.03	0.45	-4.91	yes
HD 38529	1.4	14.31	0.76	0.27	0.29	-4.89	yes
HD 195019	1.02	18.21	3.55	0.01	0.00	-4.90	no
Rho Cr B	0.95	39.81	0.99	0.07	-0.29	-5.02	no
GJ 876	0.32	60.0	2.18	0.25	N/A	N/A	yes
70 Vir	1.10	116.7	7.42	0.402	-0.03	-5.06	no
HD 12661	1.07	250.2	2.83	0.20	0.29	-5.12	yes
HD 92788	1.06	337.7	3.86	0.28	0.22	-5.04	no
16 CygB	1.02	796.7	1.68	0.68	0.09	-4.98	no
47 UMa	1.03	1097.0	2.63	0.115	-0.08	-4.99	yes

Table taken (and updated) from Fischer et al., 2001 ApJ 551, 1107. These are stars on the Lick Observatory planet search project with one planet detected and more than 2 years of data. Here we consider whether the residual velocities show trends consistent with an additional Keplerian velocity variation.


GJ 876
Two Planet Fit: Keck
RMS = 7.90 m s^{-1}
χ^2_ν = 1.87
400
200
0
−200
−400
Velocity (m s^{-1})
1998
1999
2000
2001
Time (yr)


Mass = 7.72 M_{JUP} /sin i
P = 256.4 day
K = 268. m/s
e = 0.67
RMS = 17.1 m/s
200
0
−200
−400
Velocity (m/s)
2000.0
2000.5
2001.0
2001.5
Time (Years)


Mass = 83.0 M_JUP /sin i
P = 9404. day
K = 615. m/s
e = 0.00
RMS = 12.8 m/s
100
50
0
−50
Velocity (m/s)
2000.0
2000.5
2001.0
2001.5
Time (Years)

Velocity Precision

Astrophysical Limitations

1) spectral Type

- F5V: 50 m/s
  few spectral lines
  rapid rotation
- F7V: 10 m/s
- G2V: 3 m/s

2) Chromospheric Activity

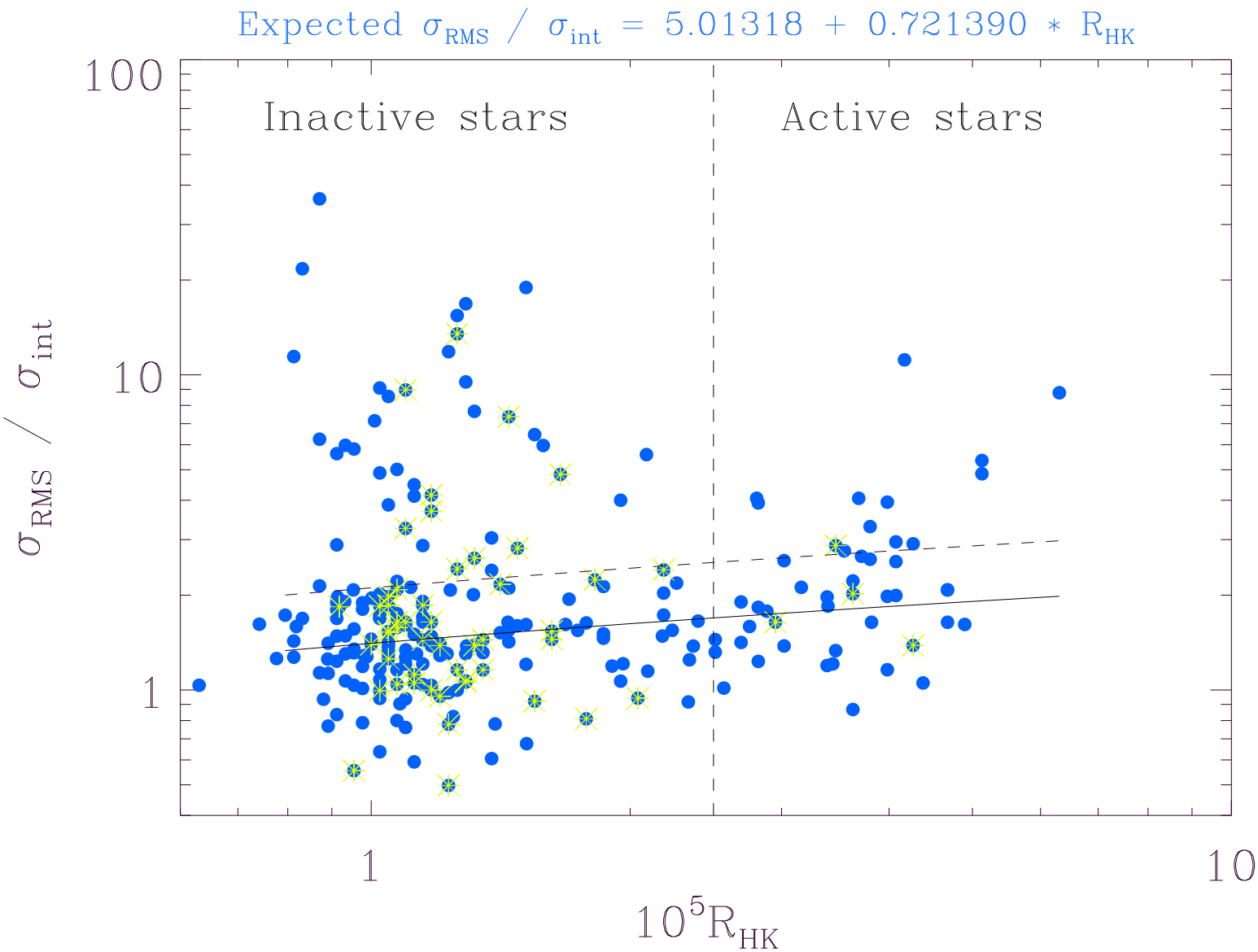
- magnetic cycles/spots
  -> photospheric noise
- lower impact on velocities
  for late K and Mdwarfs

3) Brightness

- S/N of Observation

4) Metallicity

- higher precision with
  metal rich stars

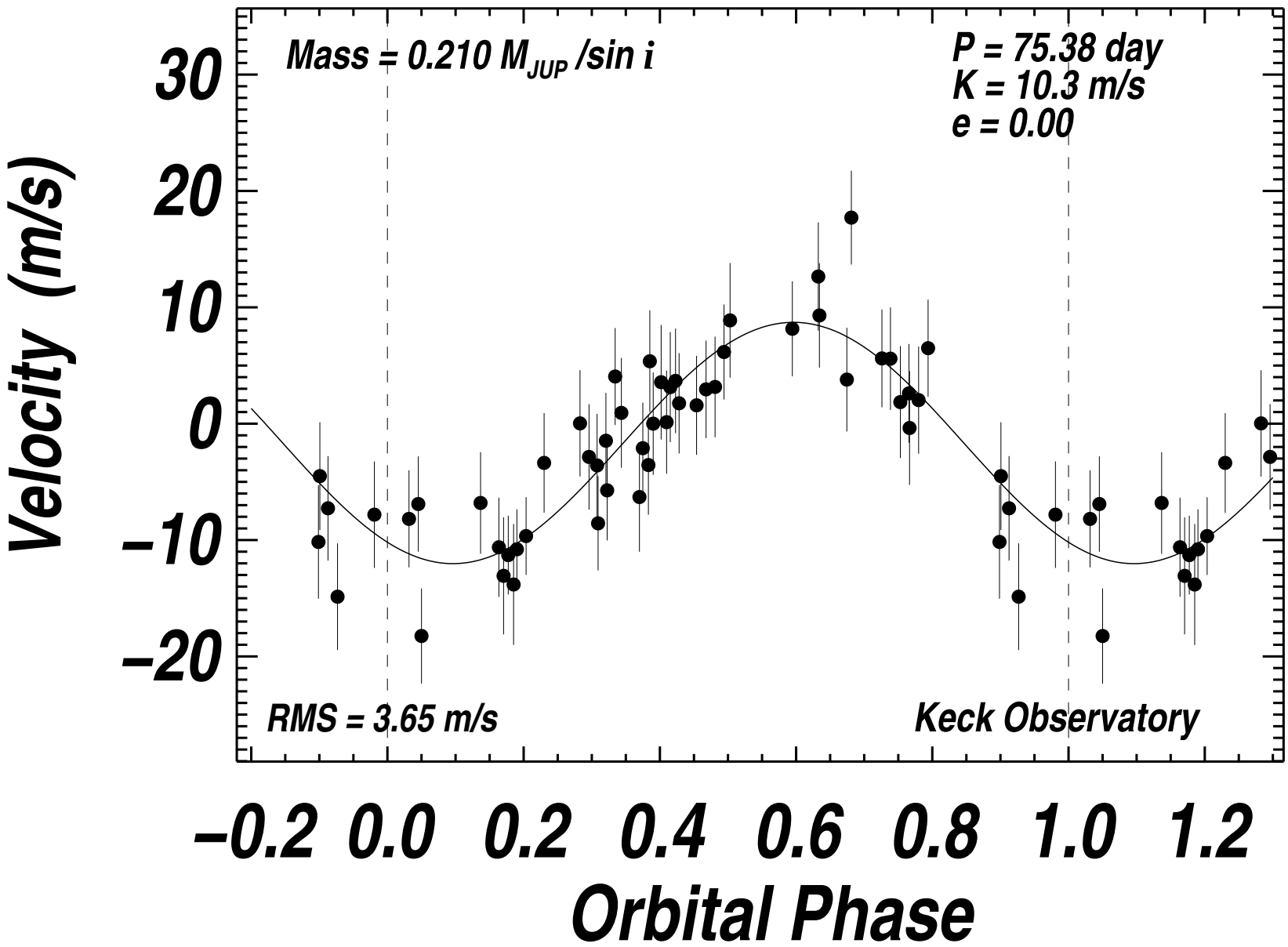

Expected σ_{RMS} / σ_{int} = 5.01318 + 0.721390 * R_{HK}
Inactive stars
Active stars
100
10
1
1
10
σ_{RMS} / σ_{int}
$10^5 R_{HK}$

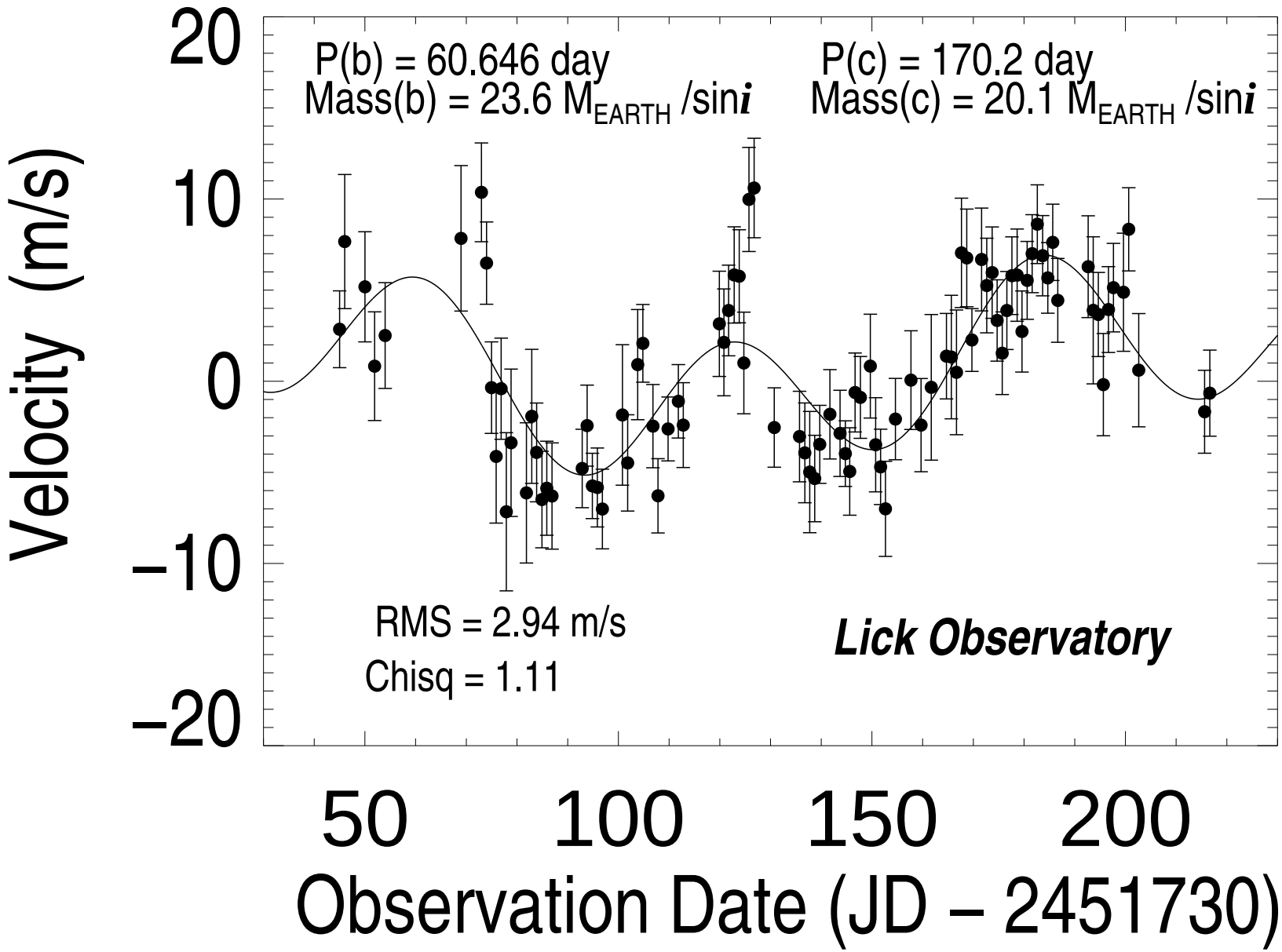
Instrumental Limitations

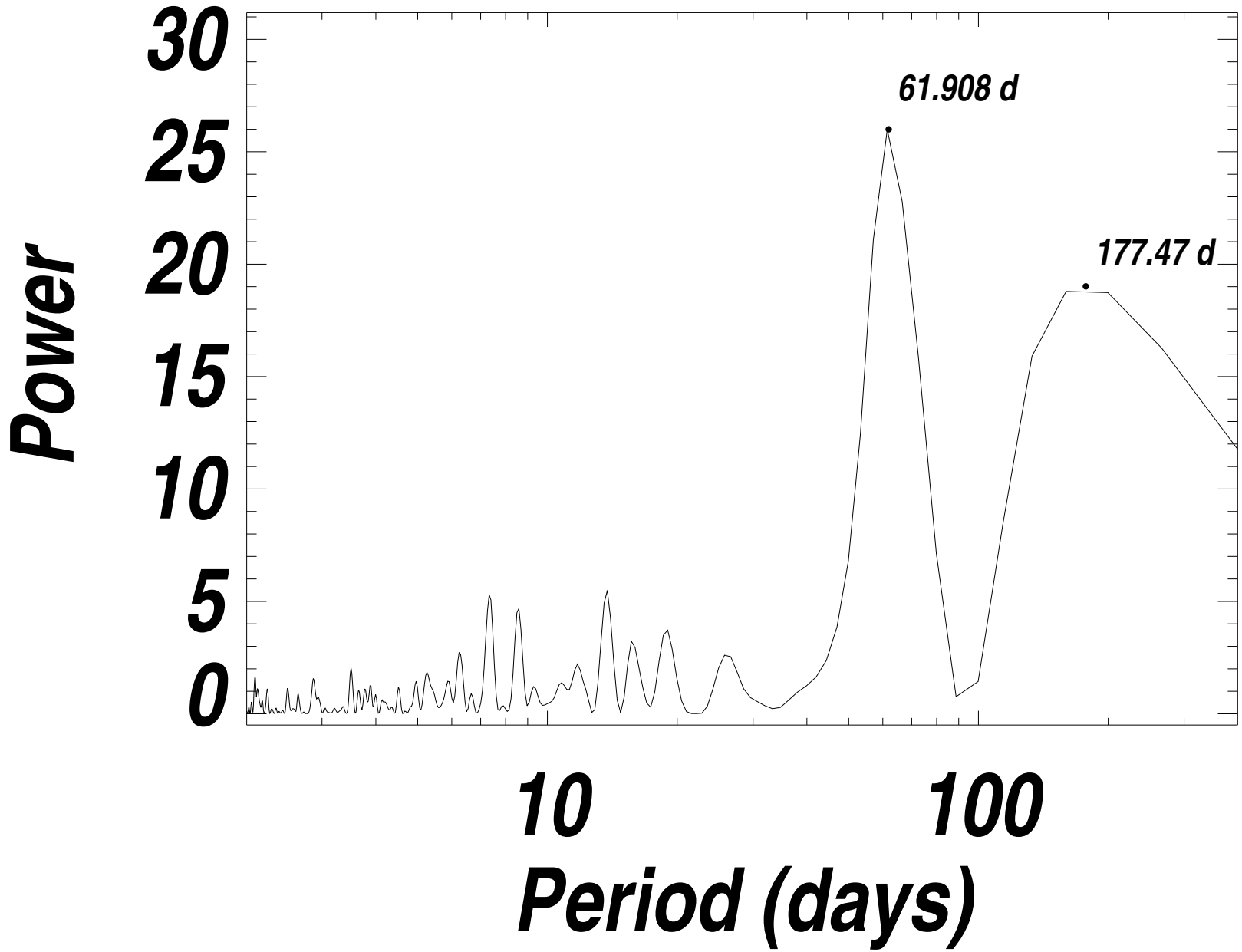
1) CCD
   thinned CCD -> charge diffusion
2) Optics
3) PSF Modeling
4) Resolution, S/N
5) Barycentric Correction

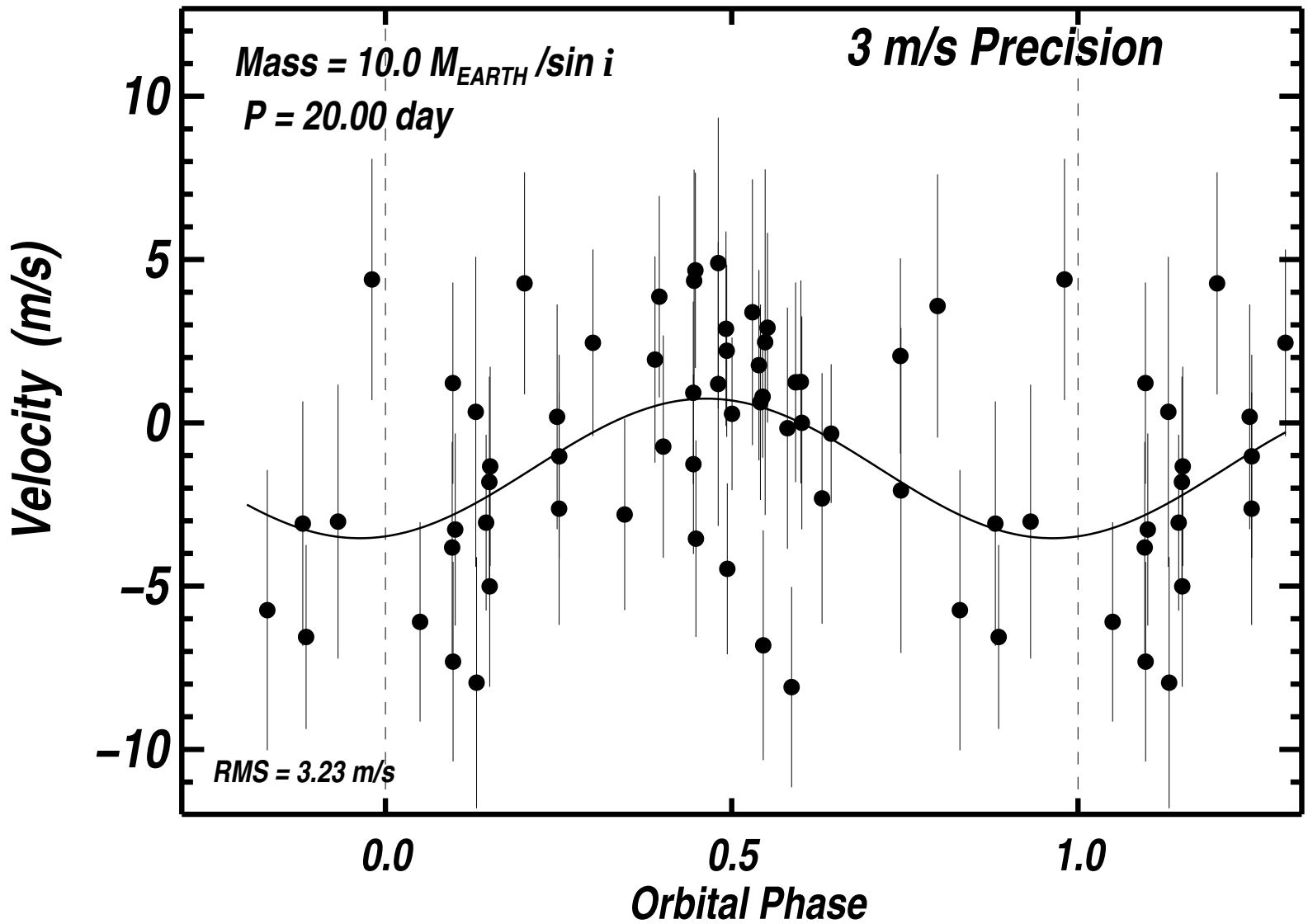
3 – 5 m/s precision for chromospherically inactive, solar (and later) type bright stars

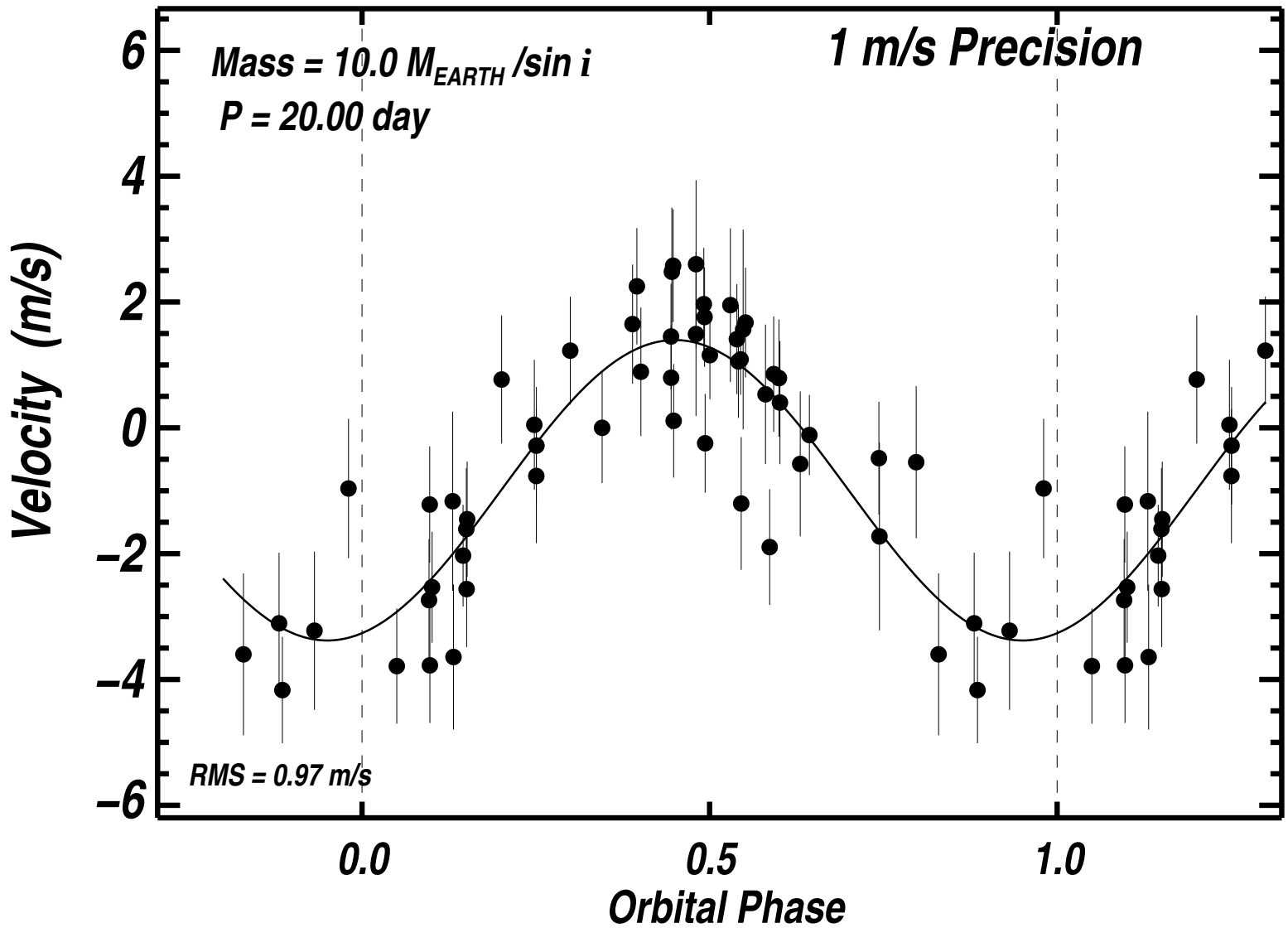
next challenge:
1m/s precision


Mass = 0.210 M_JUP /sin i
P = 75.38 day
K = 10.3 m/s
e = 0.00
RMS = 3.65 m/s
Keck Observatory
Velocity (m/s)
30
20
10
0
−10
−20
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Orbital Phase


P(b) = 60.646 day
Mass(b) = 23.6 M_EARTH /sin i
P(c) = 170.2 day
Mass(c) = 20.1 M_EARTH /sin i
RMS = 2.94 m/s
Chisq = 1.11
Lick Observatory
Velocity (m/s)
20
10
0
−10
−20
50
100
150
200
Observation Date (JD – 2451730)


Power
30
25
20
15
10
5
0
61.908 d
177.47 d
10
100
Period (days)


Mass = 10.0 M_{EARTH} /sin i
P = 20.00 day
3 m/s Precision
RMS = 3.23 m/s
Velocity (m/s)
10
5
0
−5
−10
0.0
0.5
1.0
Orbital Phase


Mass = 10.0 M_{EARTH} /sin i
P = 20.00 day
1 m/s Precision
RMS = 0.97 m/s
Velocity (m/s)
6
4
2
0
−2
−4
−6
0.0
0.5
1.0
Orbital Phase

Summary

1) ~70 Extrasolar Planets
   - 1% of stars have 51Peg type
   - 6–8% of stars have detected planets
2) Host stars are F7 – M4
   - Class IV and V
   - Single stars and Binaries
3) Mass Function
   - rises toward low mass end
4) Range of eccentricities
5) Multiple Systems Common

   Dynamical fullness may be characteristic

Future

- lower m2sini detections
- solar system analogs
- more multiple systems