Radial Velocity Method of Companion Detection

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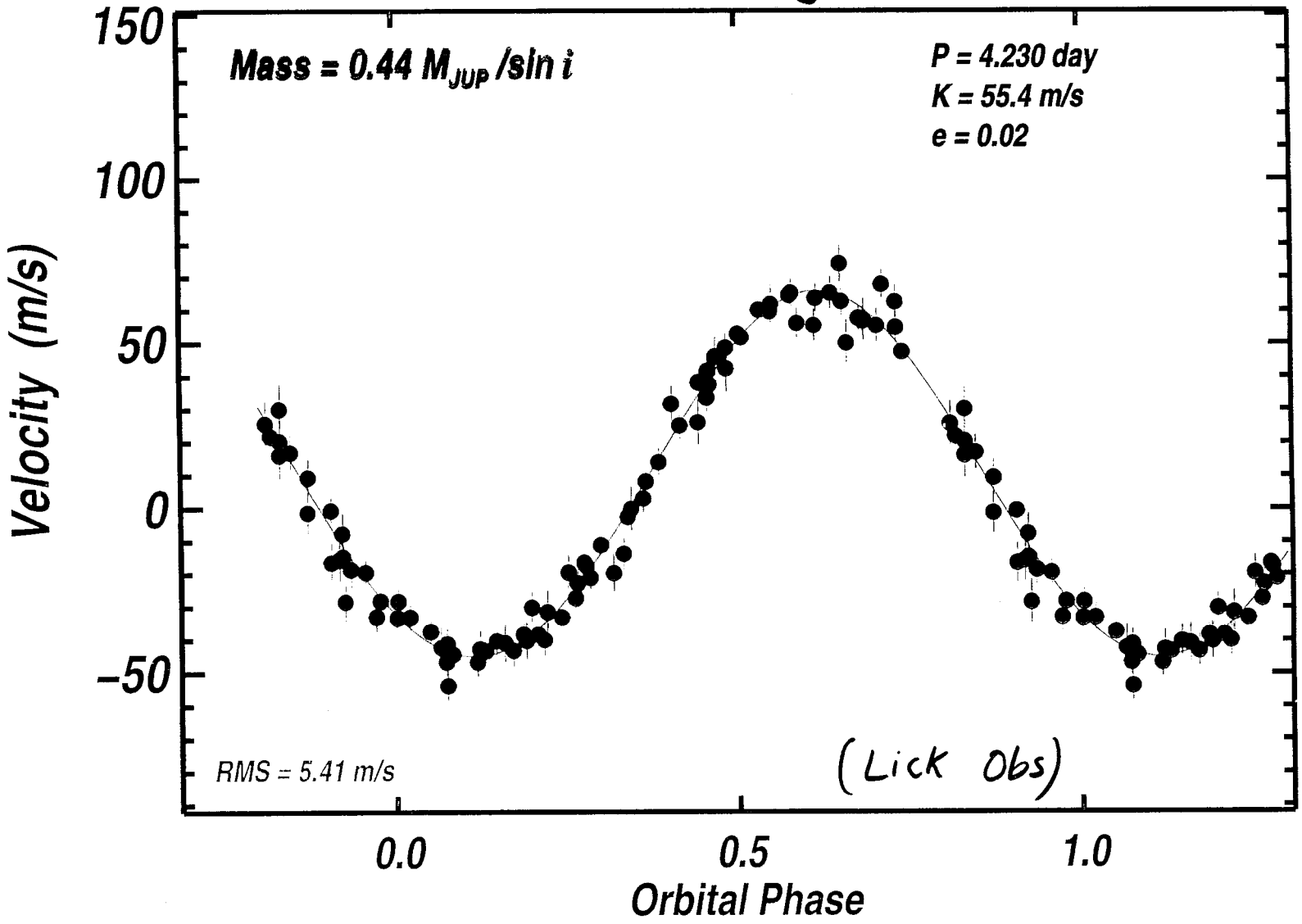
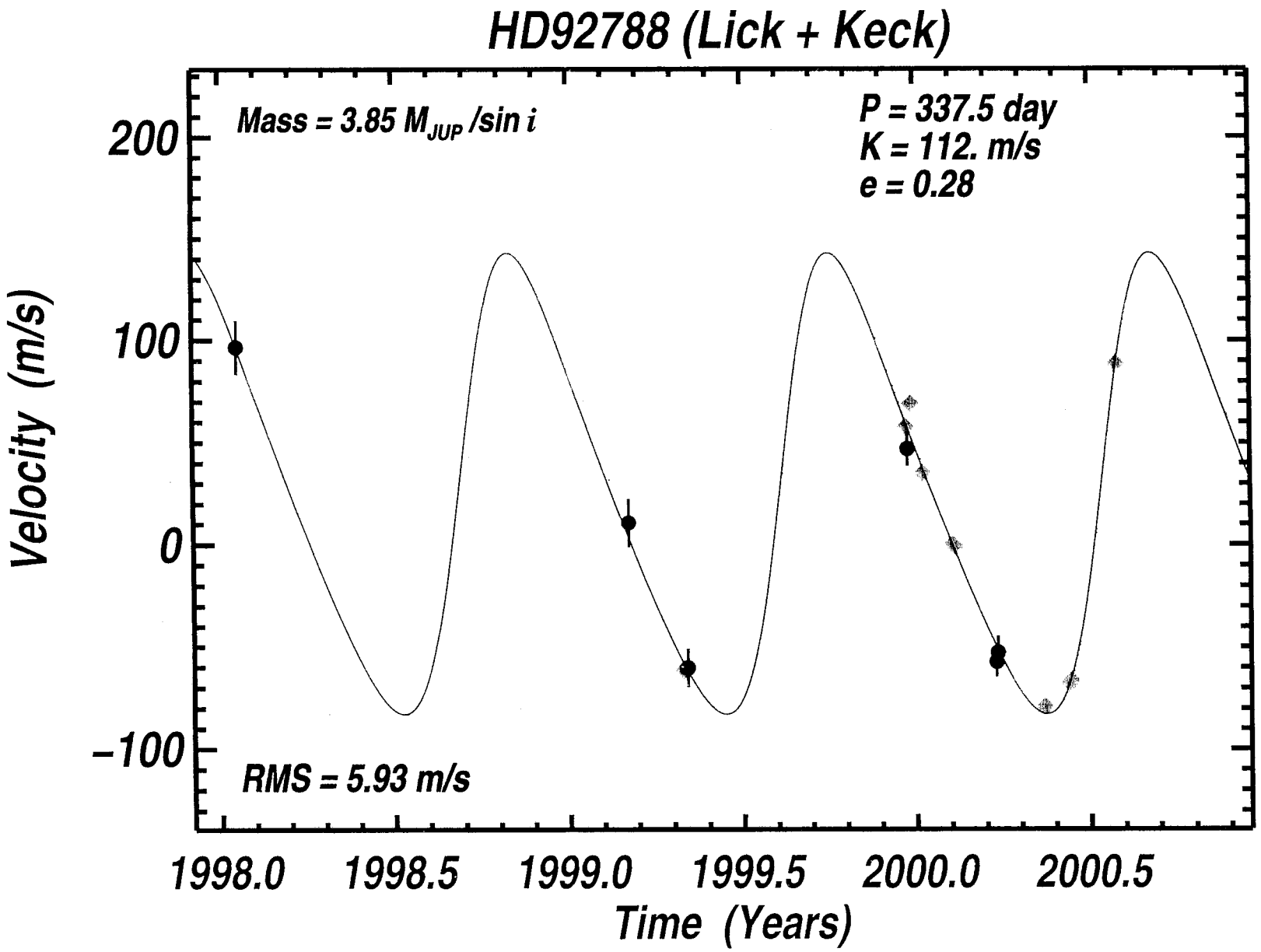
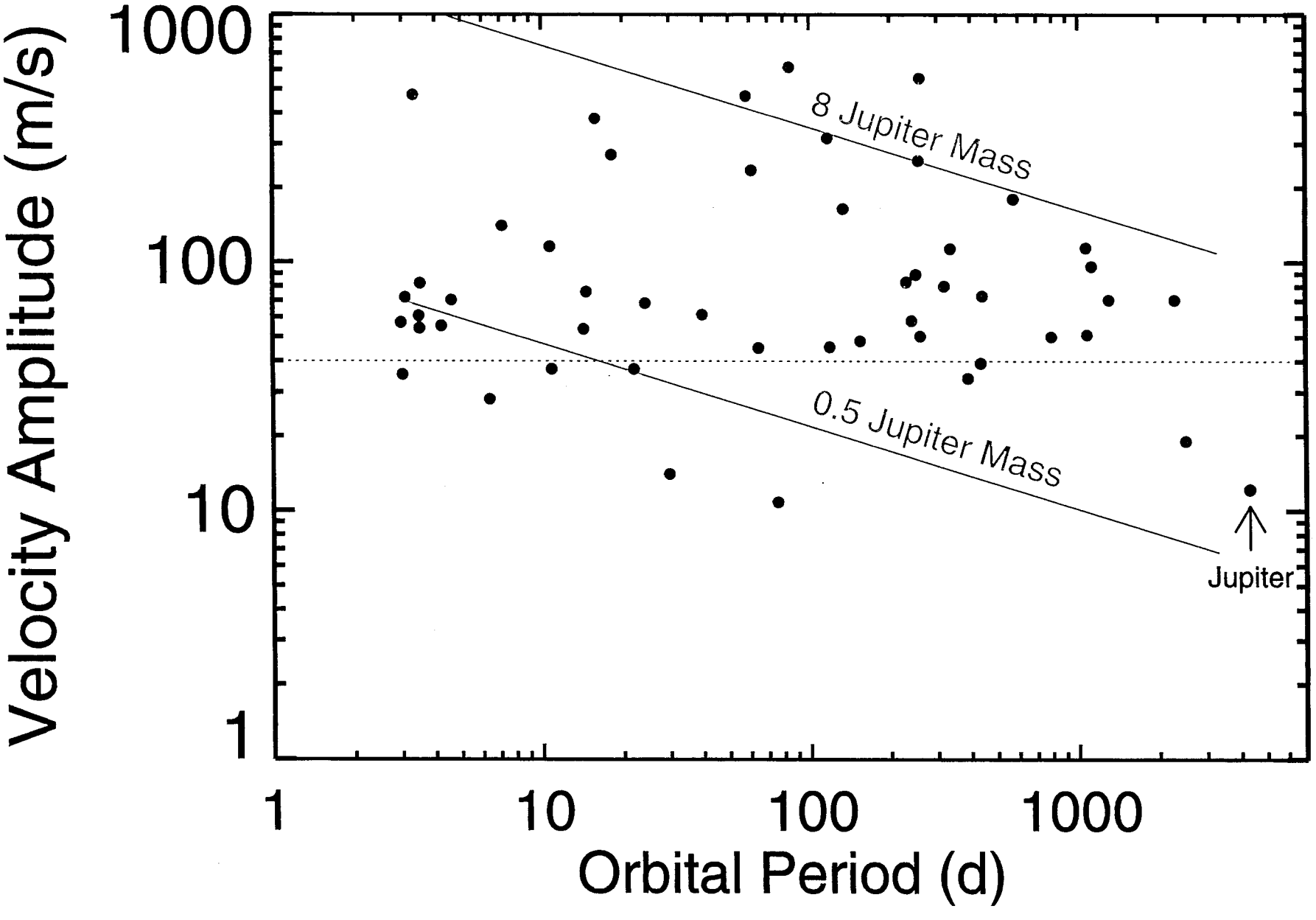
51 Peg

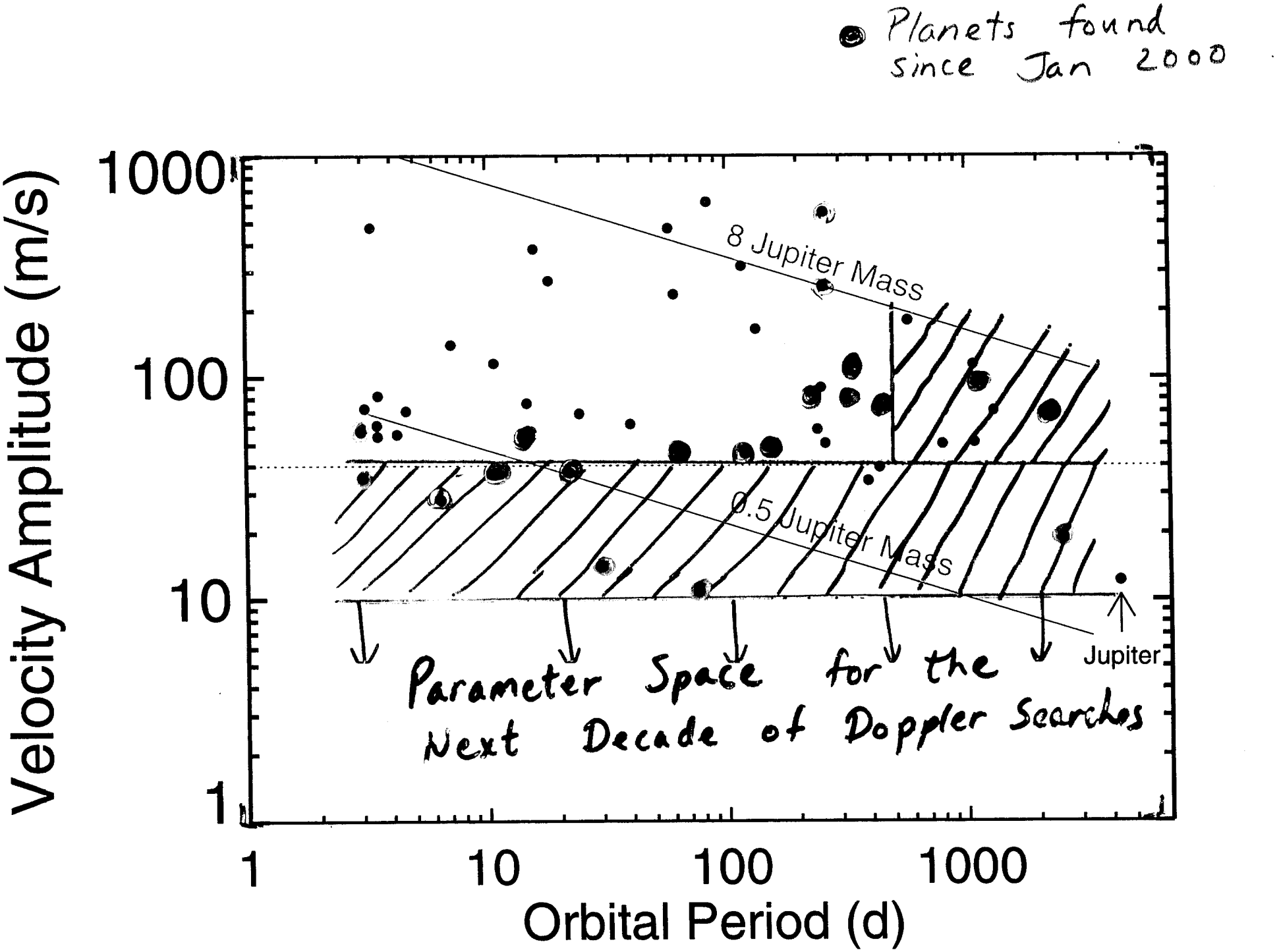

Mass = 0.44 M_{JUP} /sin i
P = 4.230 day
K = 55.4 m/s
e = 0.02
RMS = 5.41 m/s
(Lick Obs)
150
100
50
0
−50
Velocity (m/s)
0.0
0.5
1.0
Orbital Phase


HD92788 (Lick + Keck)
Mass = 3.85 M_{JUP} /sin i
P = 337.5 day
K = 112. m/s
e = 0.28
RMS = 5.93 m/s
200
100
0
−100
Velocity (m/s)
1998.0
1998.5
1999.0
1999.5
2000.0
2000.5
Time (Years)

Extra-Solar Planet Detections

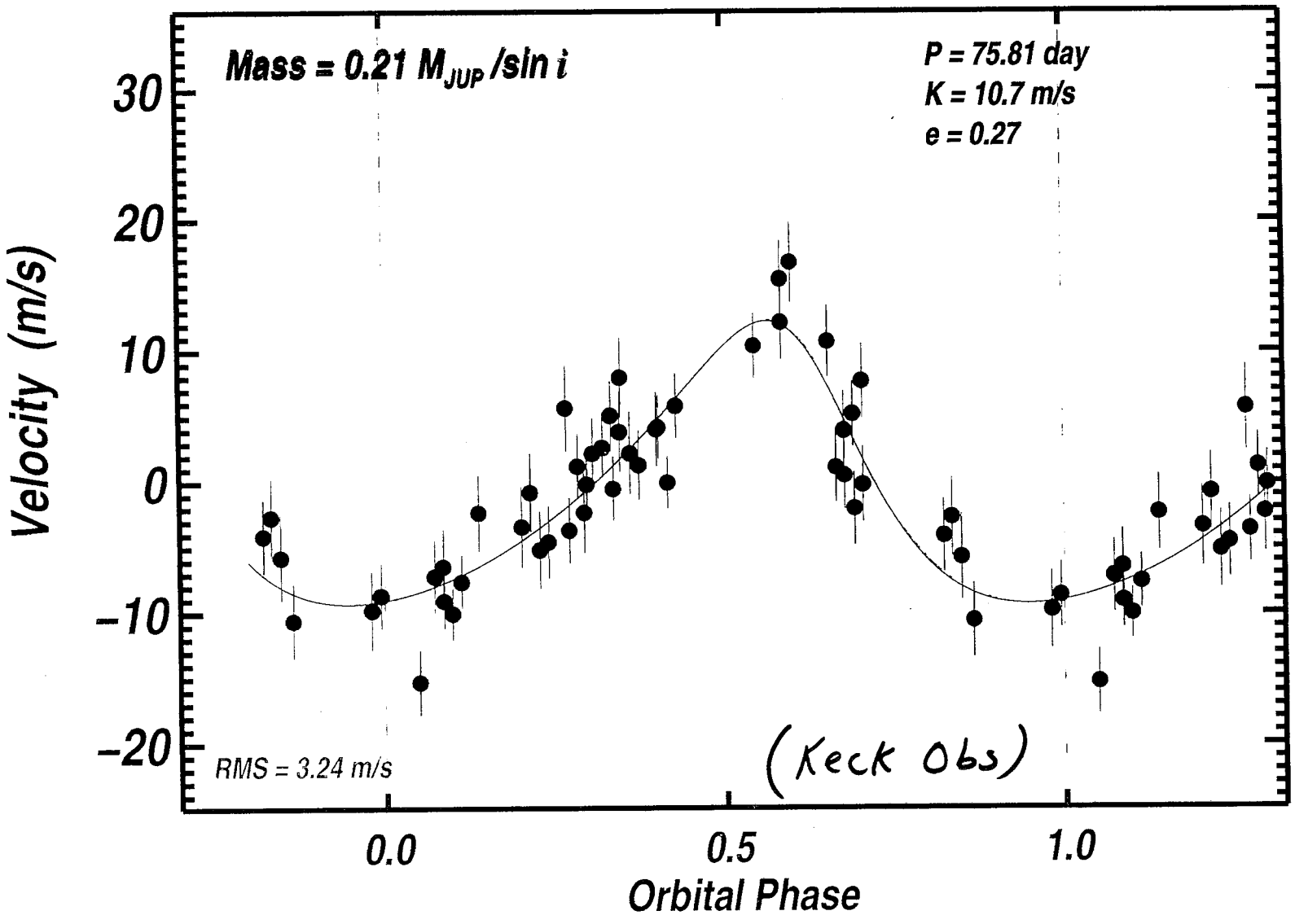


8-22-00

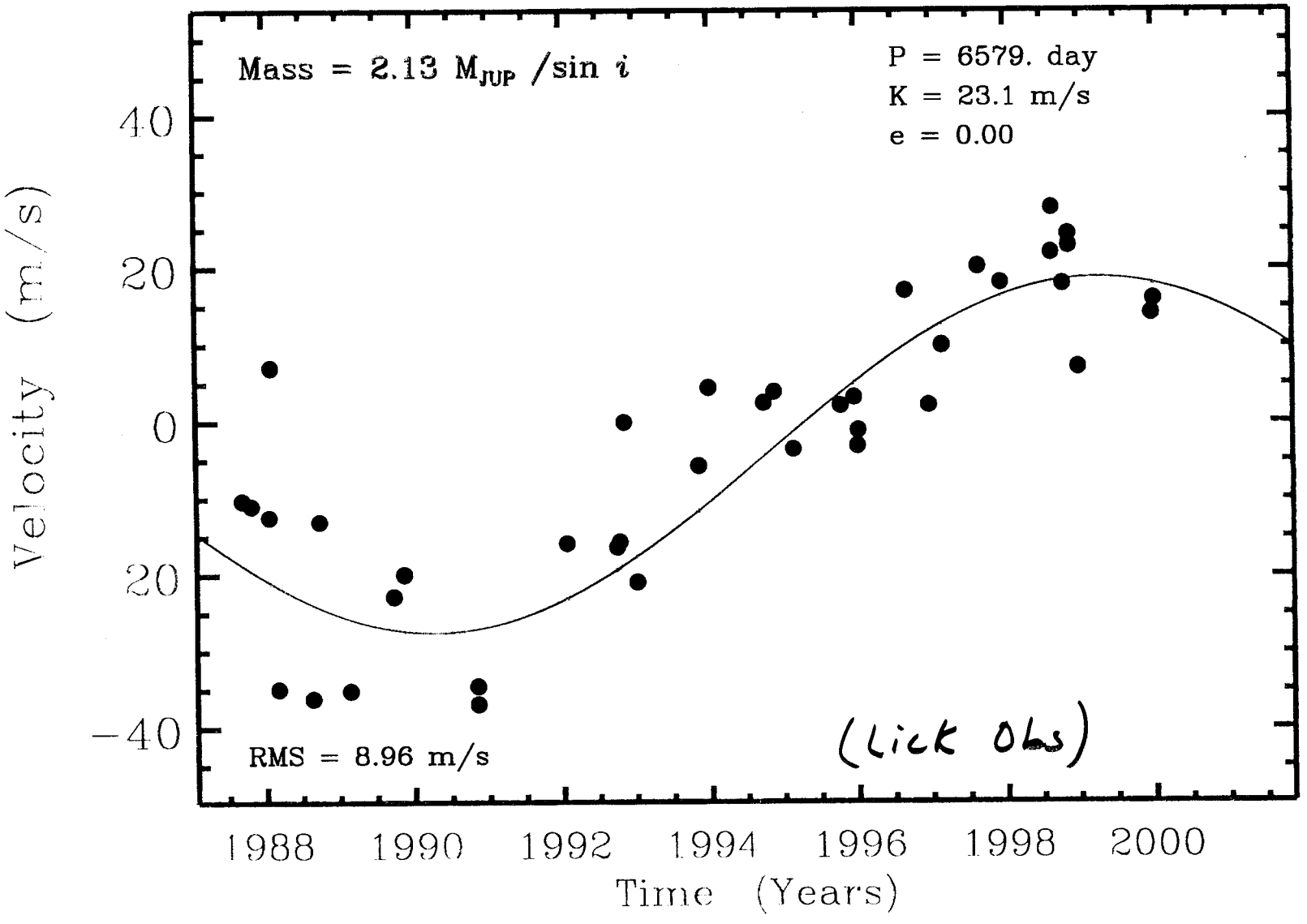

Planets found since Jan 2000
Velocity Amplitude (m/s)
1000
100
10
1
1
10
100
1000
Orbital Period (d)
8 Jupiter Mass
0.5 Jupiter Mass
Jupiter
Parameter Space for the Next Decade of Doppler Searches

8-22-00

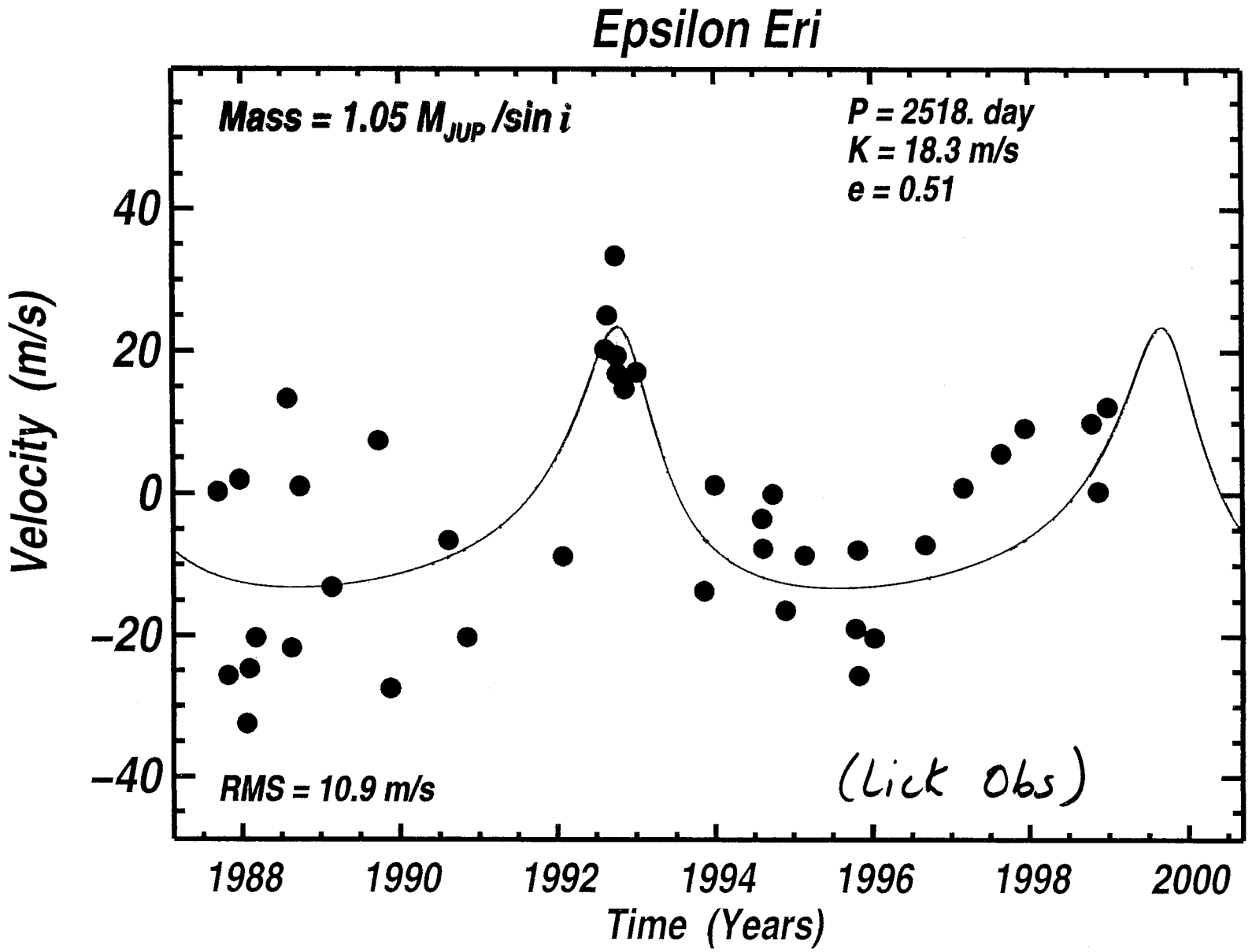
HD 16141

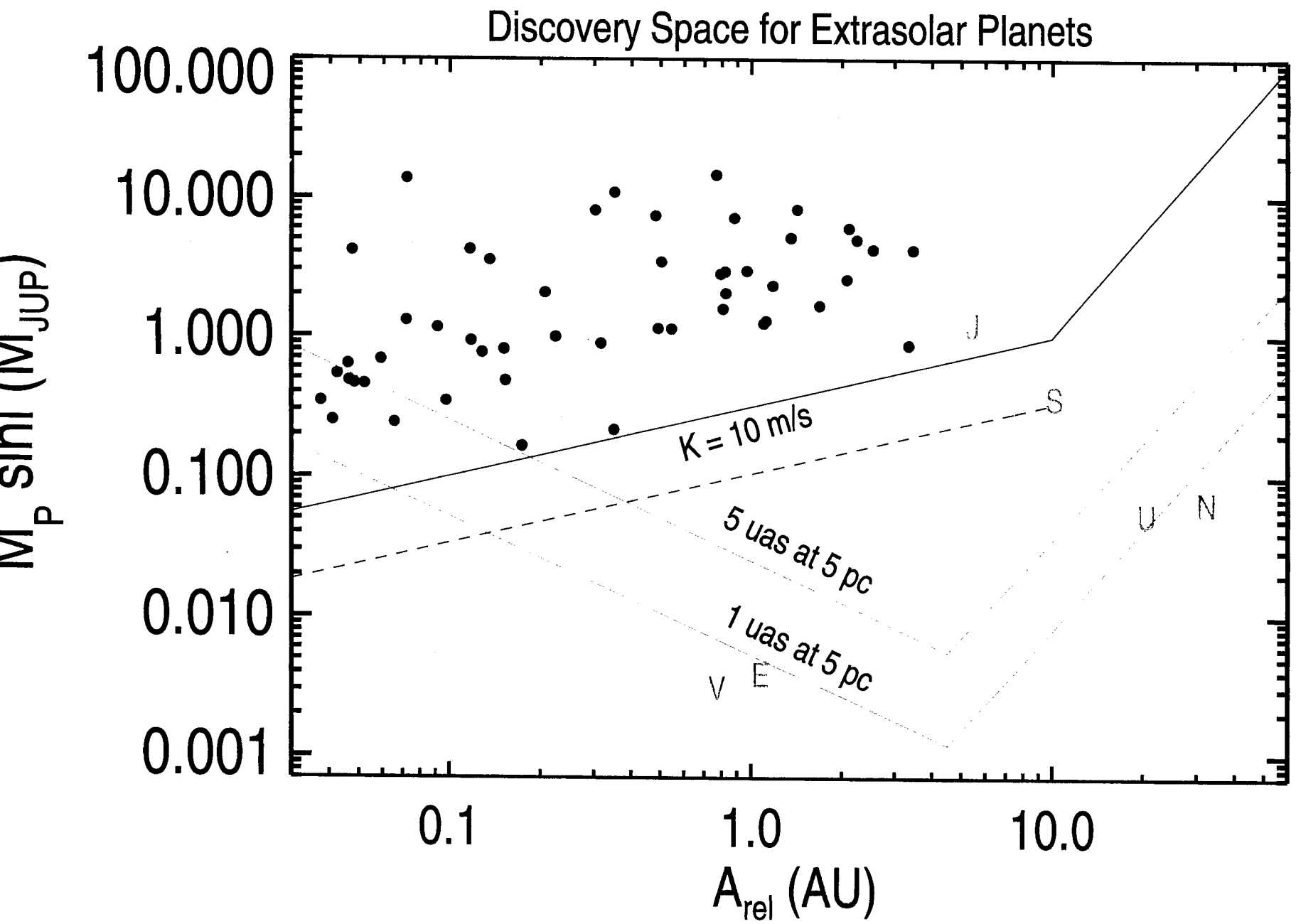

Mass = 0.21 M_{JUP} /sin i
P = 75.81 day
K = 10.7 m/s
e = 0.27
RMS = 3.24 m/s
(Keck Obs)
Velocity (m/s)
30
20
10
0
−10
−20
0.0
0.5
1.0
Orbital Phase

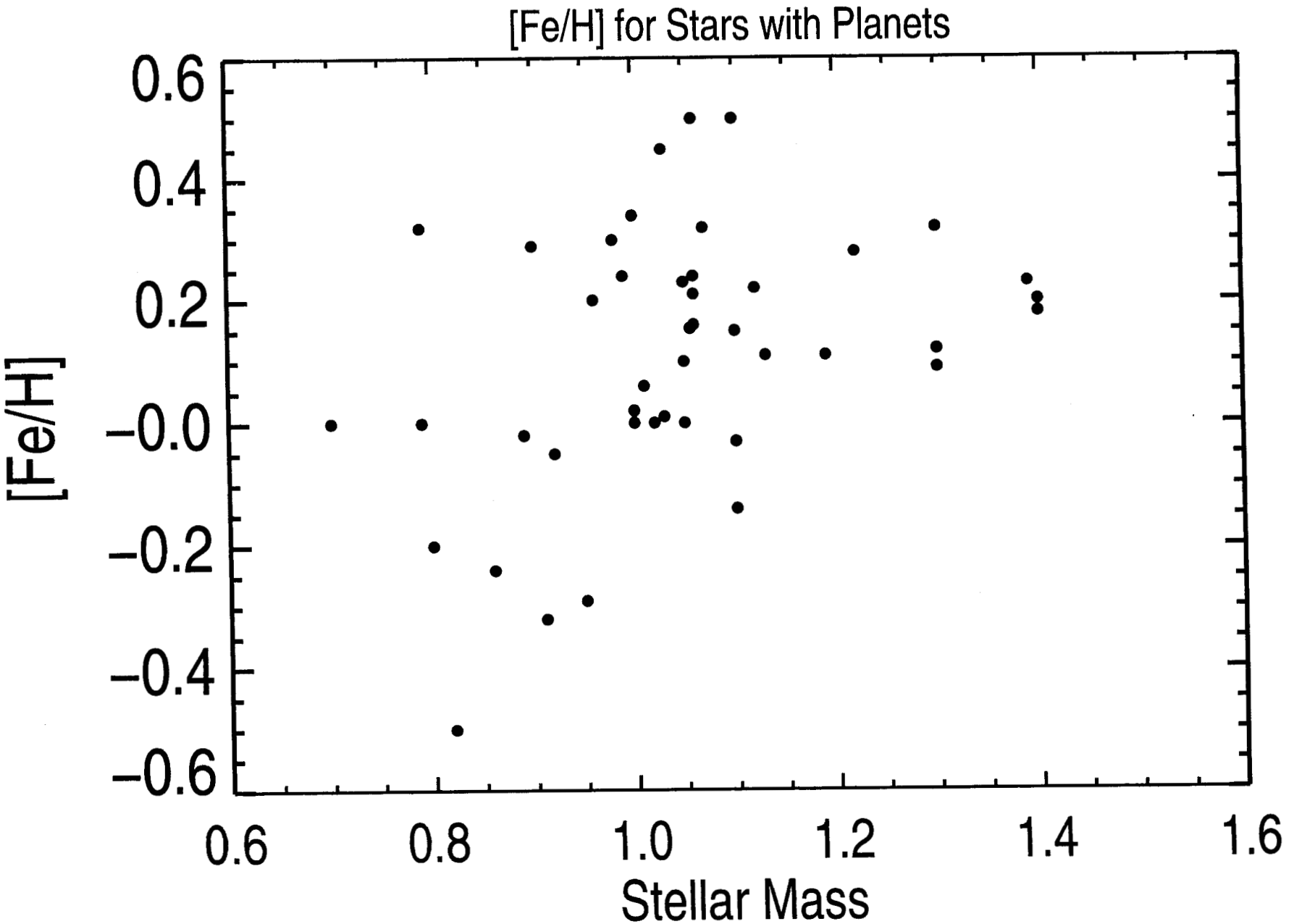
HR 1325


Mass = 2.13 M_{JUP} /sin i
P = 6579. day
K = 23.1 m/s
e = 0.00
RMS = 8.96 m/s
(Lick Obs)
Velocity (m/s)
40
20
0
20
−40
1988
1990
1992
1994
1996
1998
2000
Time (Years)

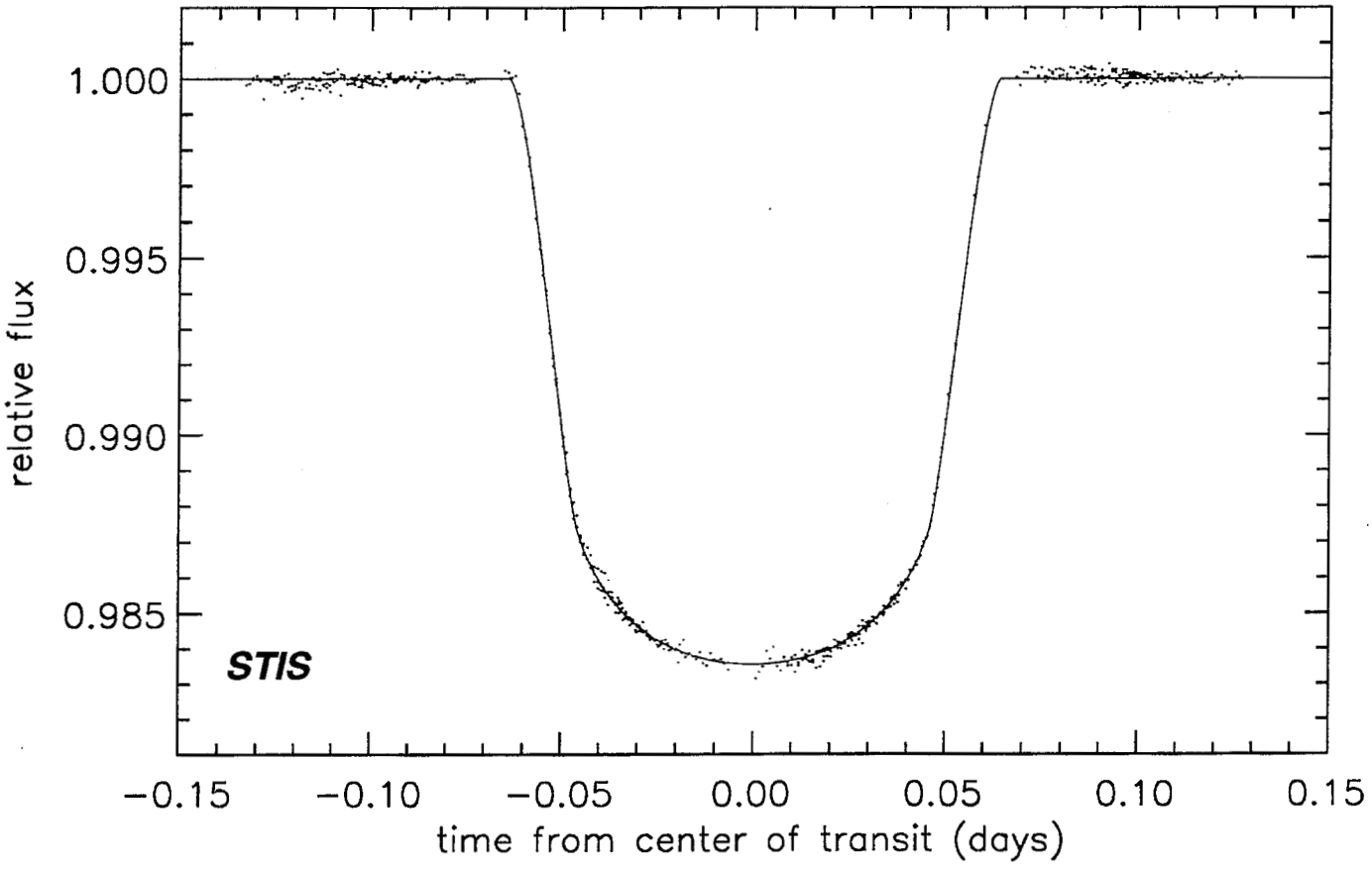
YOUNG, MAGNETIC STAR




Discovery Space for Extrasolar Planets
100.000
10.000
1.000
0.100
0.010
0.001
$M_P \sin I$ (M_{JUP})
0.1
1.0
10.0
A_{rel} (AU)
K = 10 m/s
5 uas at 5 pc
1 uas at 5 pc
J
S
U
N
V
E

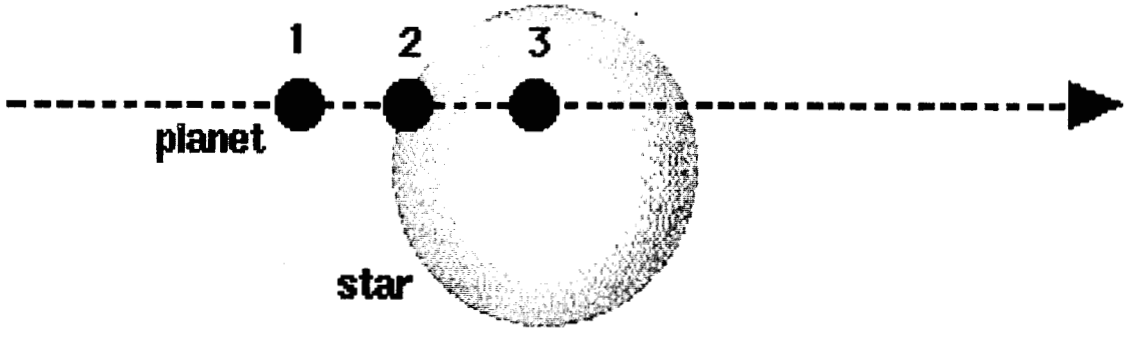

[Fe/H] for Stars with Planets
[Fe/H]
0.6
0.4
0.2
−0.0
−0.2
−0.4
−0.6
0.6
0.8
1.0
1.2
1.4
1.6
Stellar Mass

PHOTOMETRY DURING PLANET TRANSIT

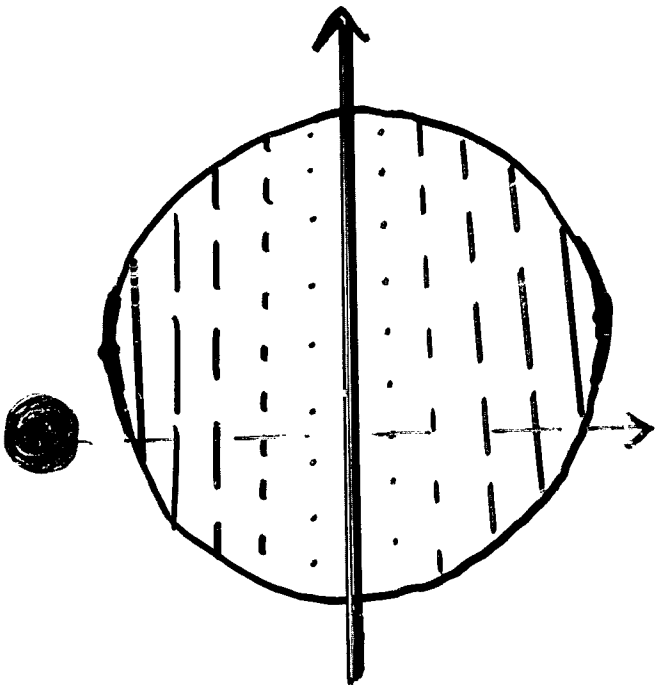


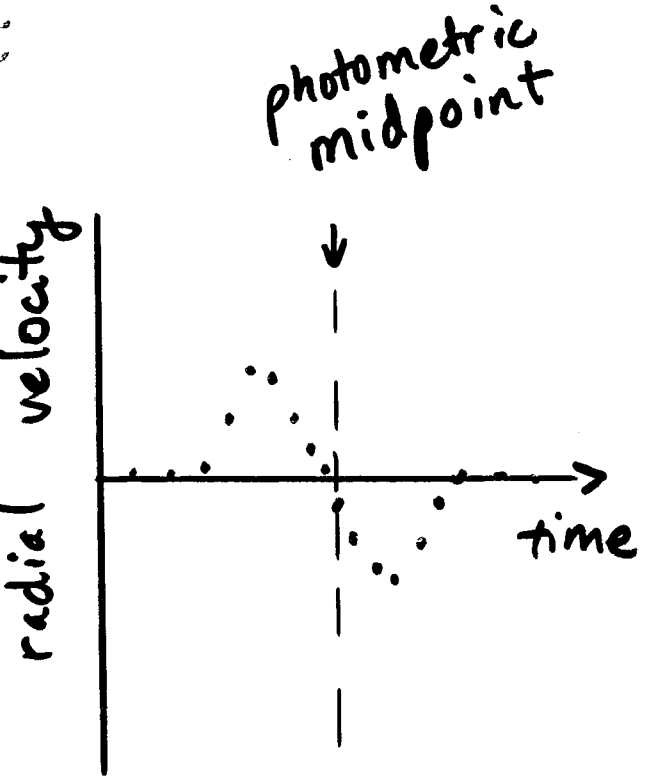
TIME (DAYS)

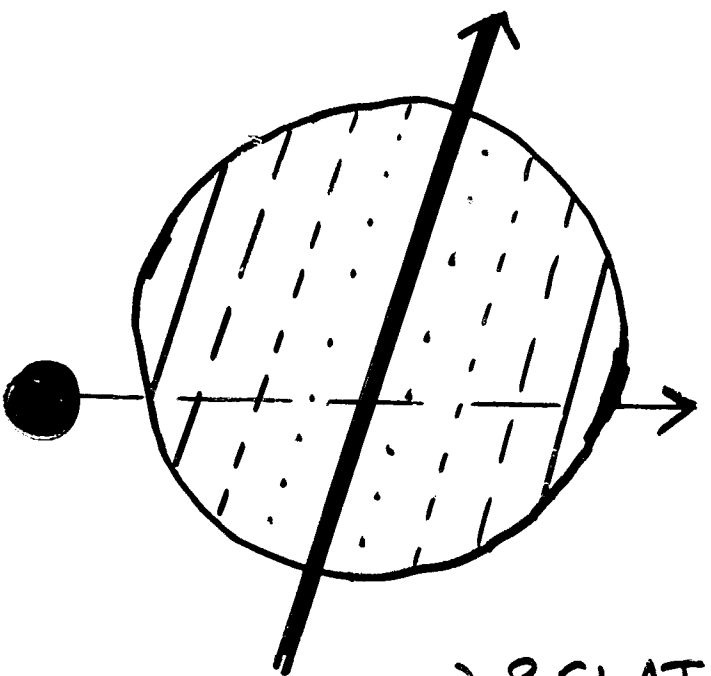
BROWN, CHARBONNEAU, GILLILAND, NOYES, BURROWS

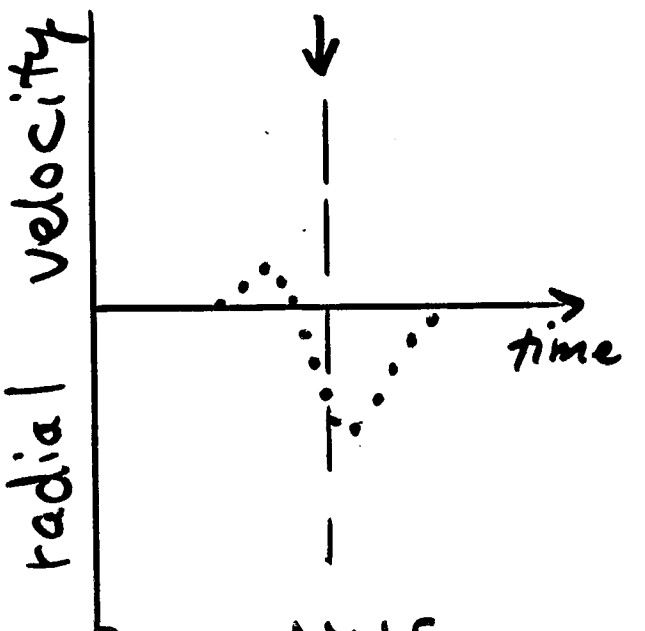


Planet Transit

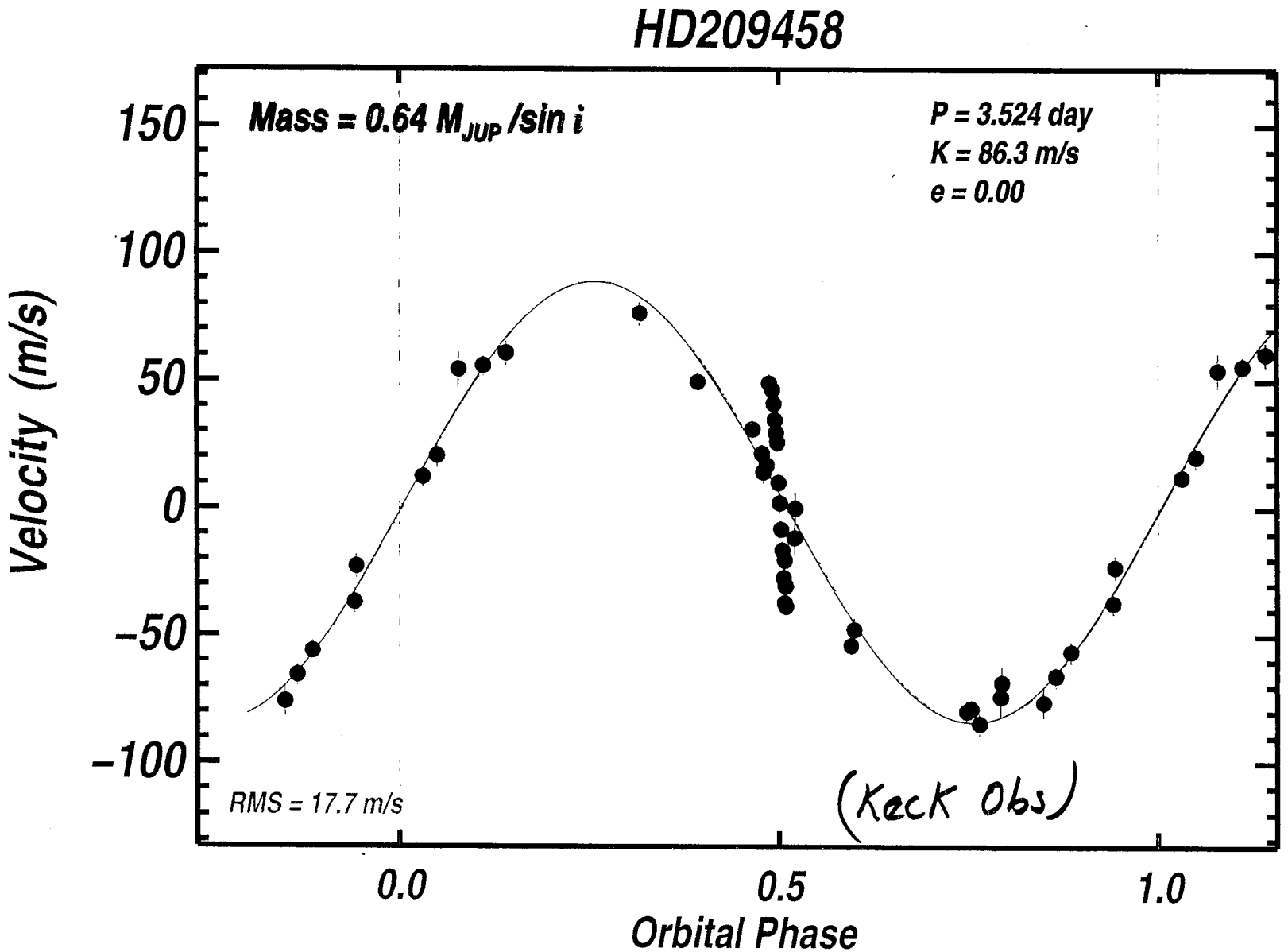


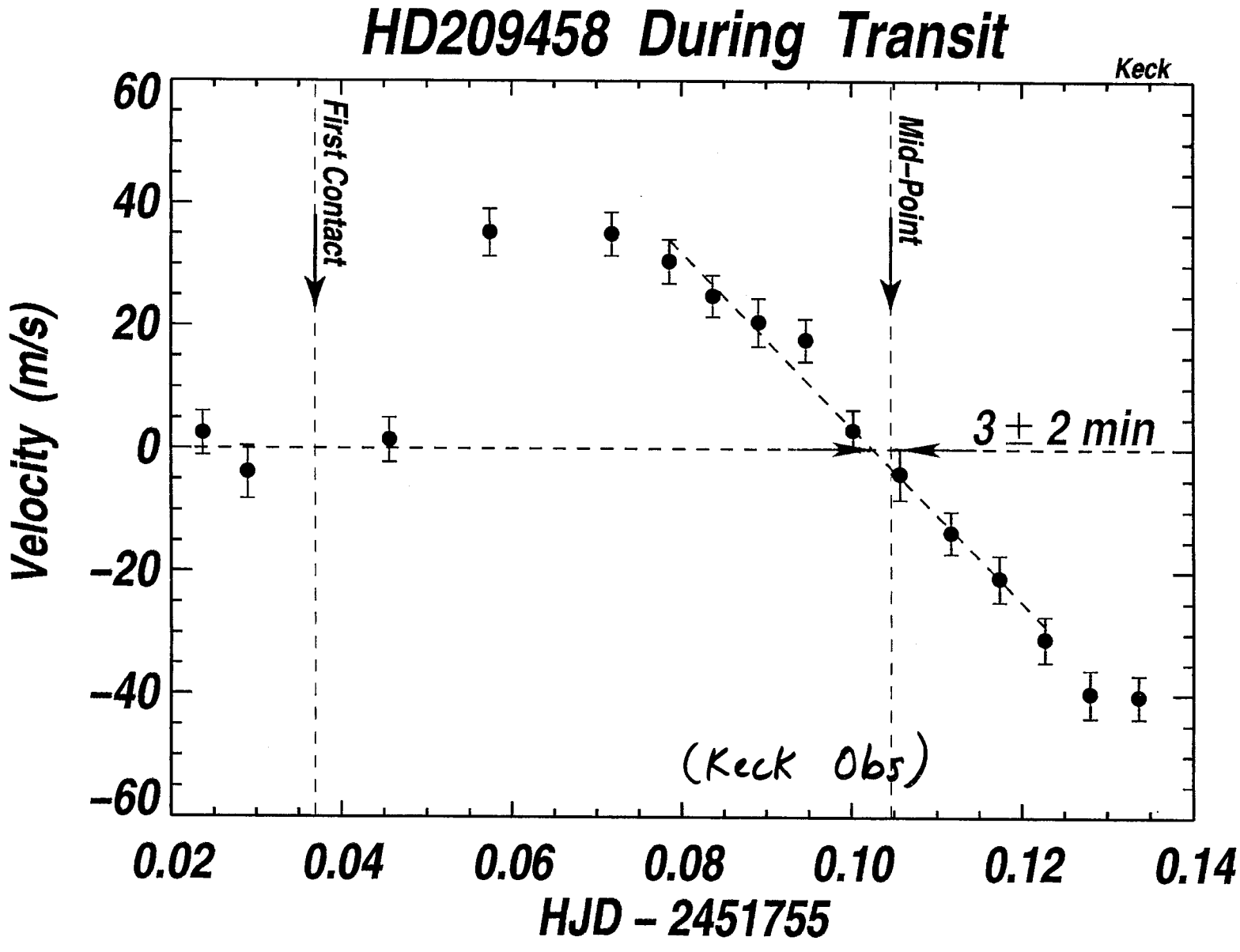


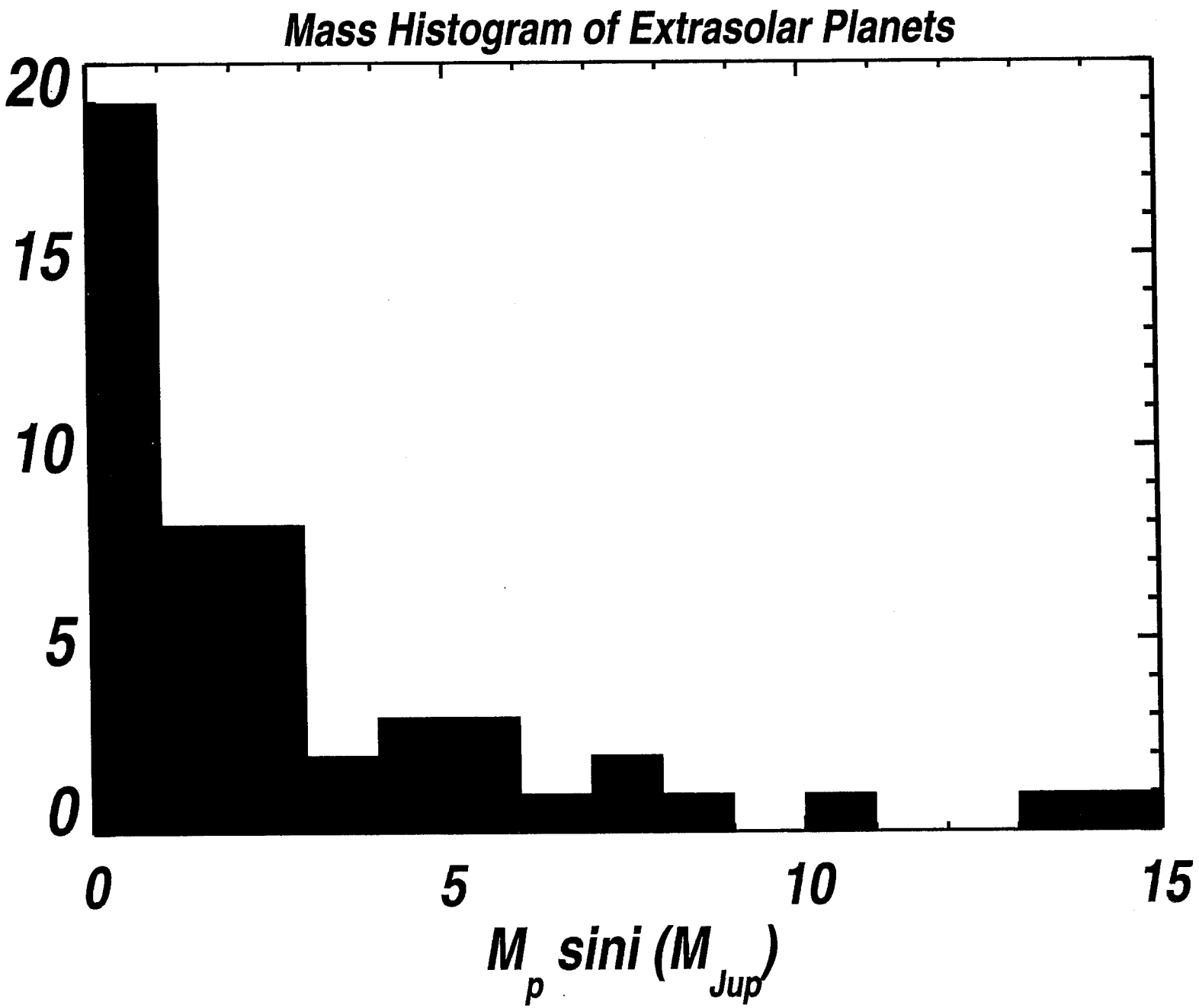




1) RELATIVE SPIN AXIS
2) LIMB- DARKENING
3) DIFFERENTIAL ROTATION


HD209458
Mass = 0.64 M_{JUP} /sin i
P = 3.524 day
K = 86.3 m/s
e = 0.00
RMS = 17.7 m/s
(Keck Obs)
Velocity (m/s)
150
100
50
0
−50
−100
0.0
0.5
1.0
Orbital Phase


HD209458 During Transit
Keck
First Contact
Mid-Point
3 ± 2 min
(Keck Obs)
Velocity (m/s)
60
40
20
0
-20
-40
-60
0.02
0.04
0.06
0.08
0.10
0.12
0.14
HJD - 2451755

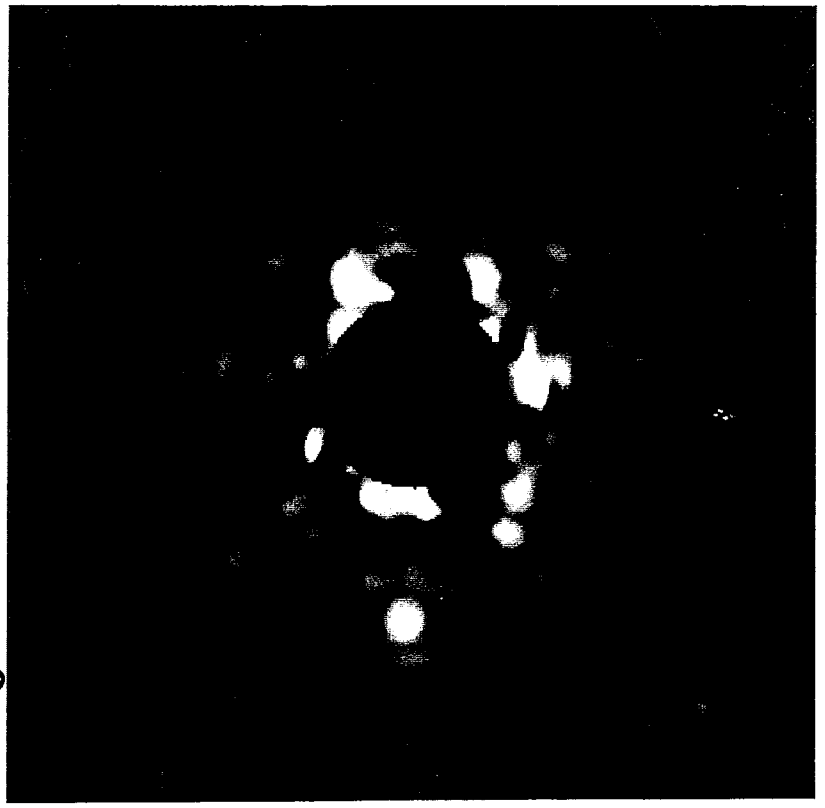

Mass Histogram of Extrasolar Planets
20
15
10
5
0
0
5
10
15
M_p sini (M_{Jup})

8-22-00

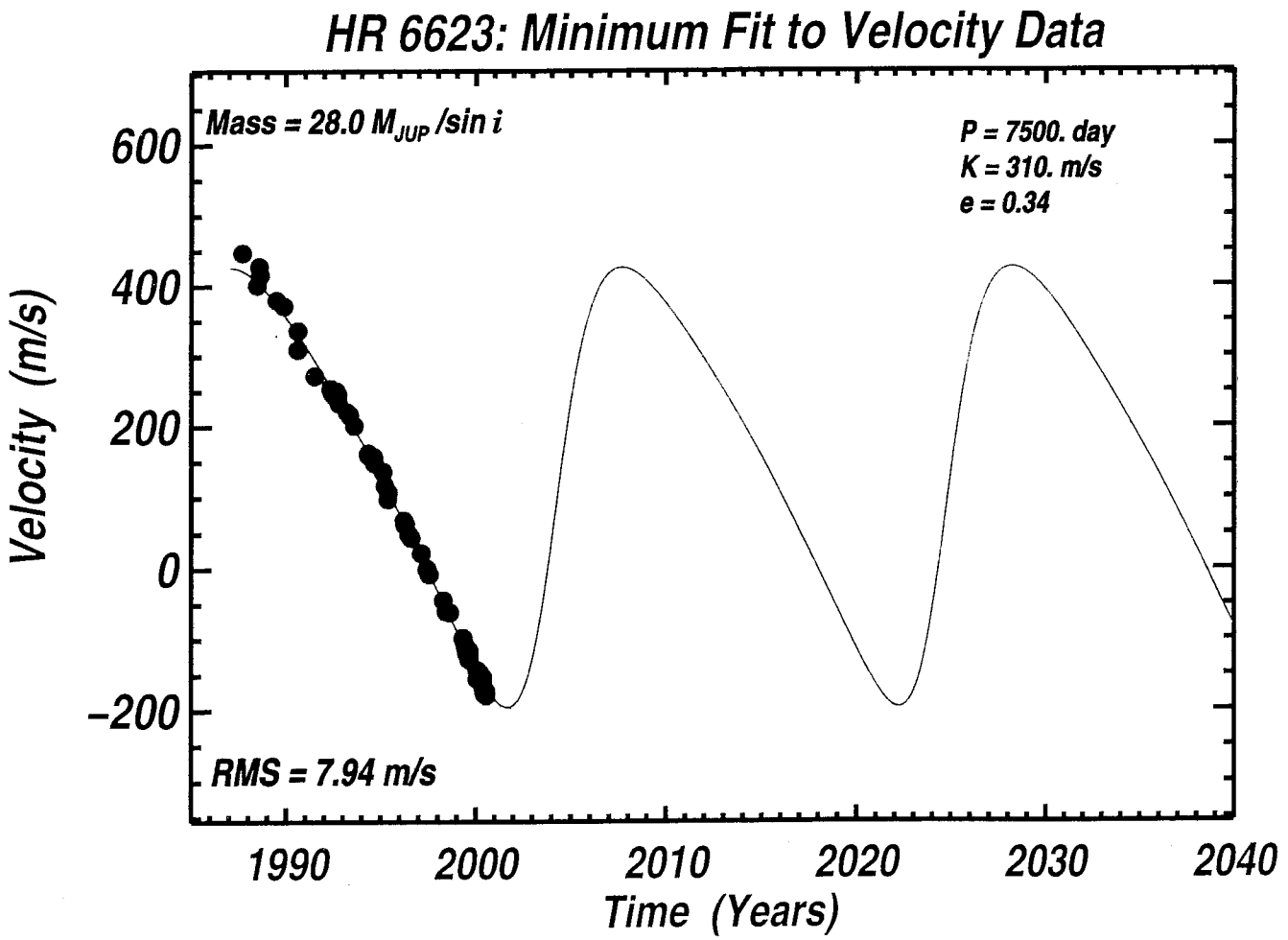
AO obs
(Lick)

Liu, Lloyd,
Graham
2000

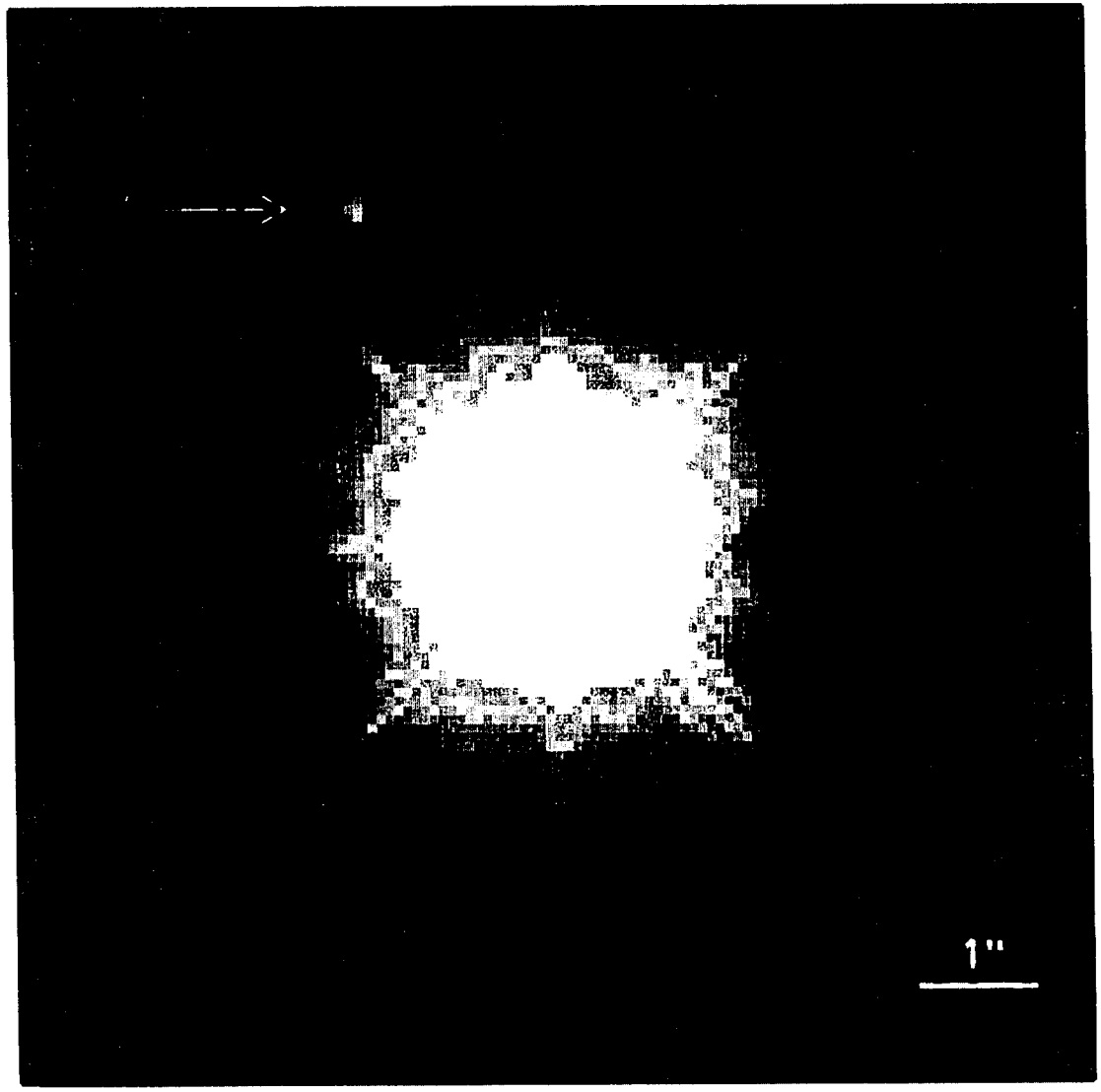
An M5 dwarf
companion to
HR 6623



1".3

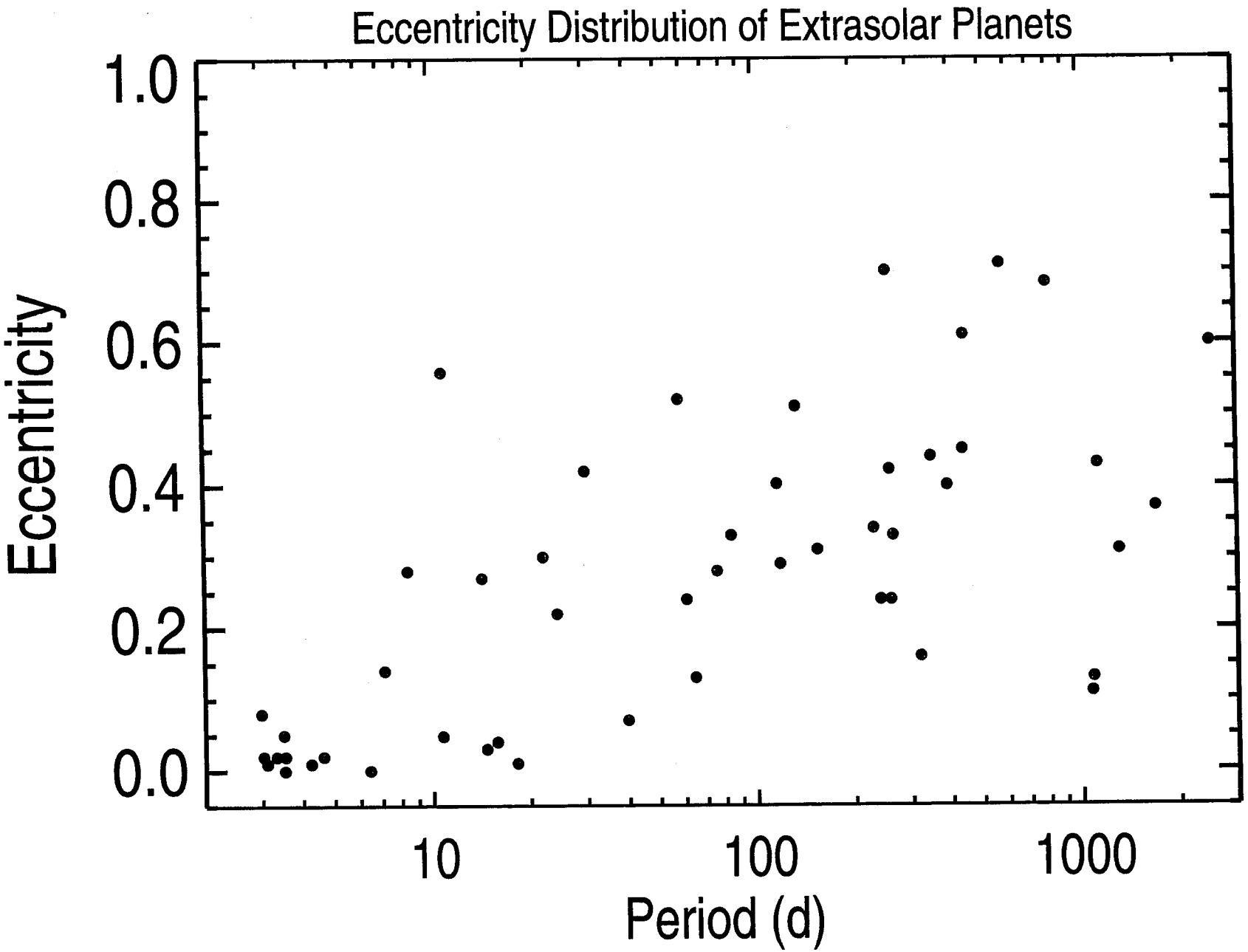


HD 114762: 2.2μm (Lick AO)

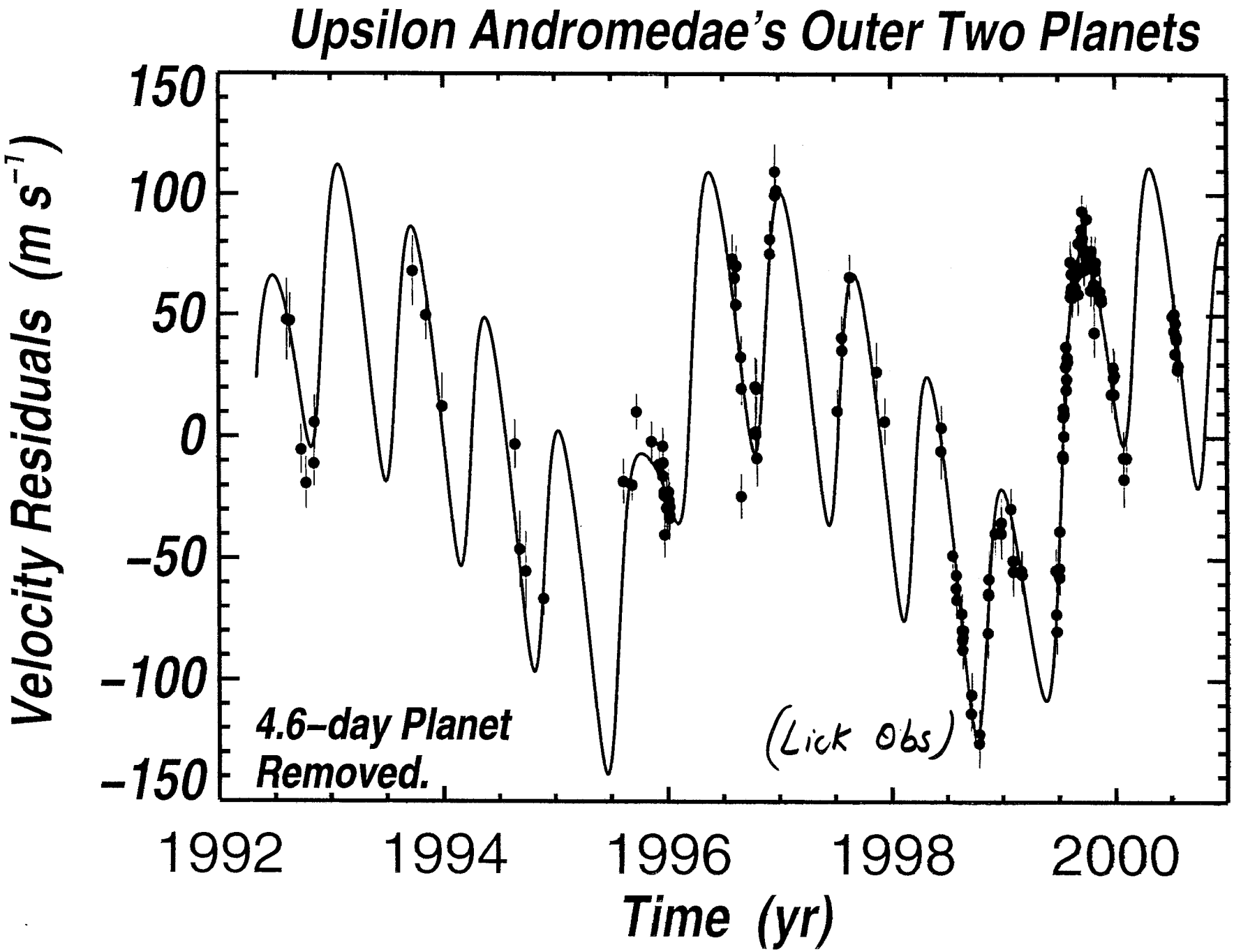


Liu, Lloyd, Graham
2000

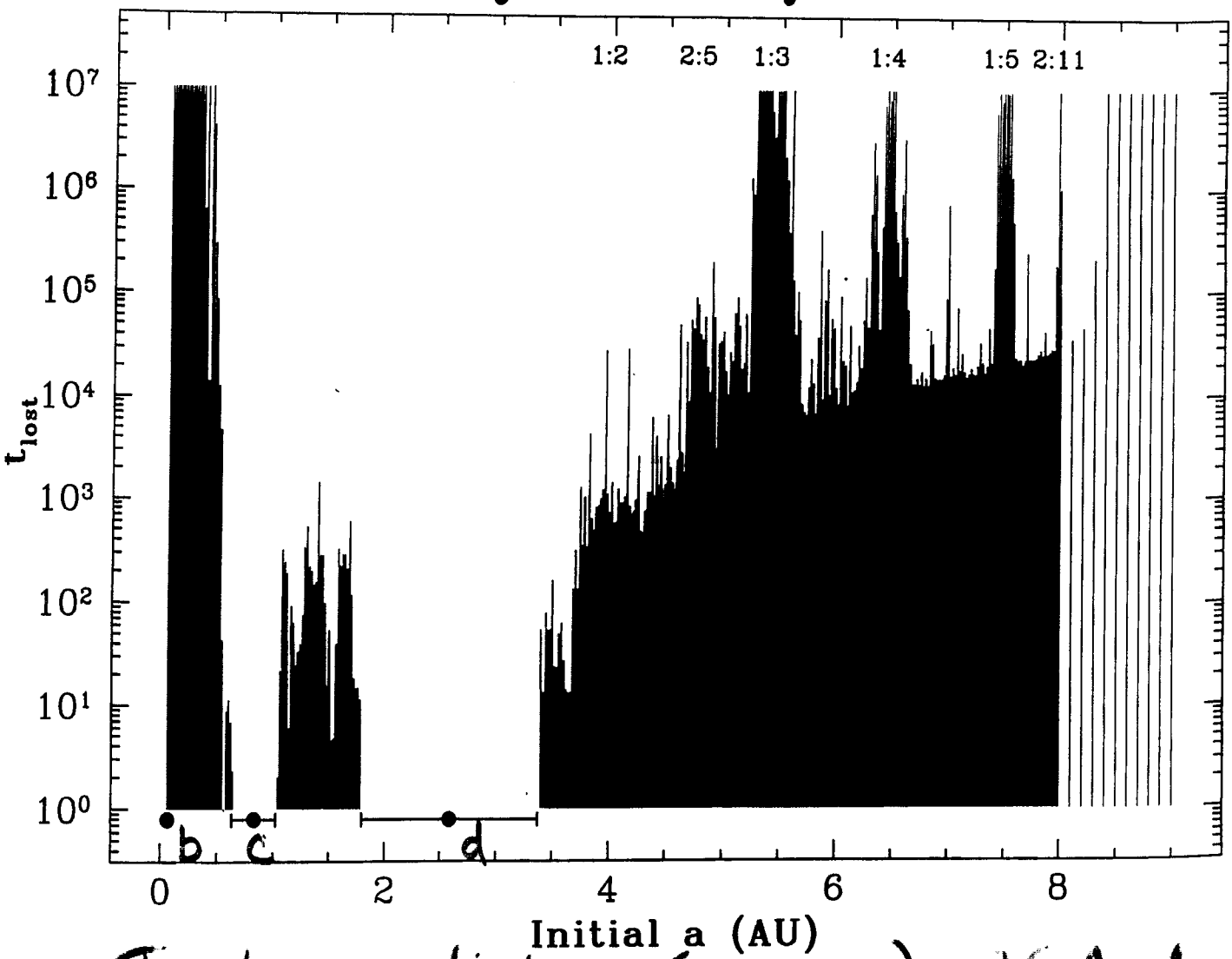
An Mdwarf
Companion


Eccentricity Distribution of Extrasolar Planets
Eccentricity
1.0
0.8
0.6
0.4
0.2
0.0
10
100
1000
Period (d)

8-22-00


Upsilon Andromedae's Outer Two Planets
Velocity Residuals (m s^{-1})
150
100
50
0
-50
-100
-150
4.6-day Planet
Removed.
(Lick Obs)
1992
1994
1996
1998
2000
Time (yr)

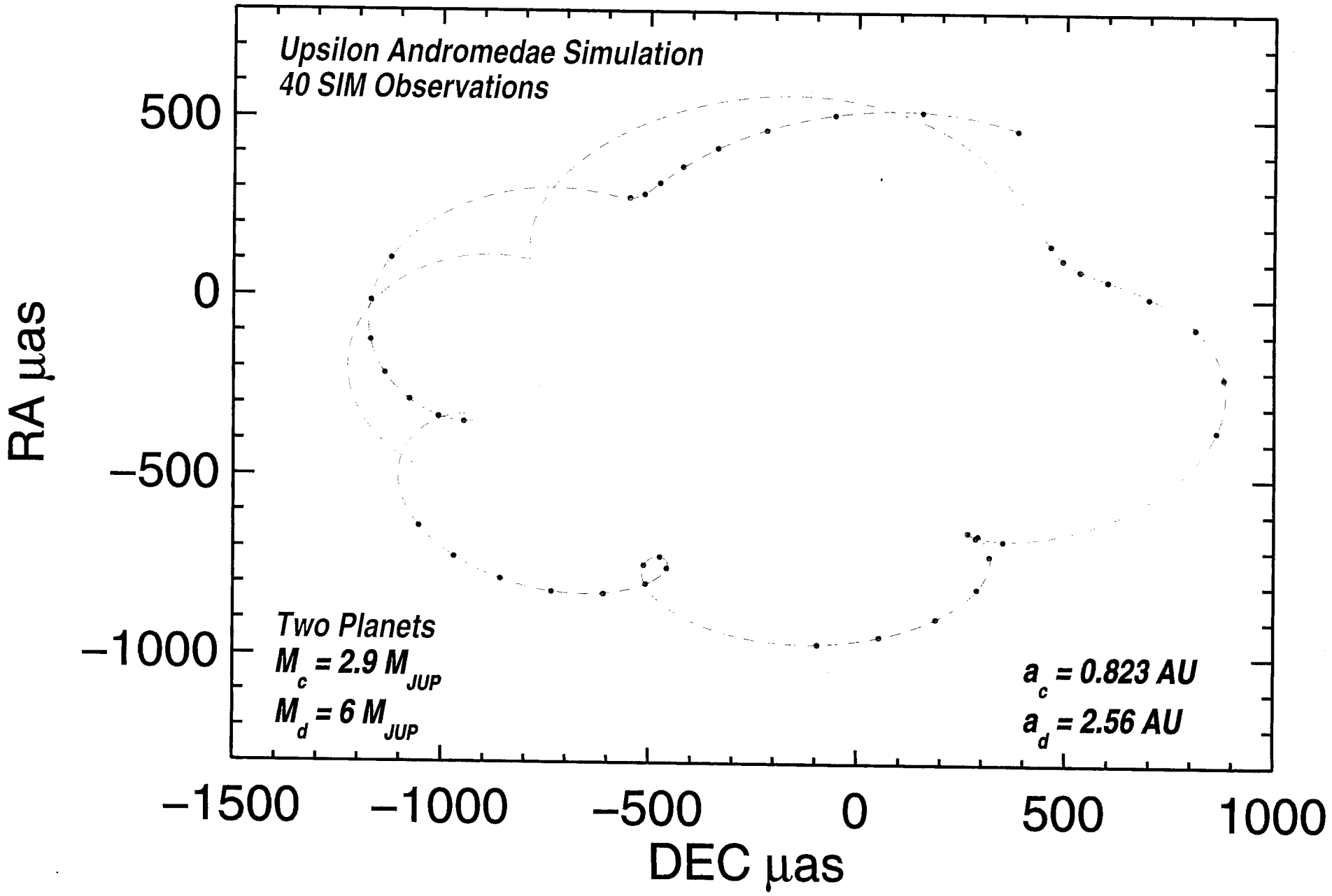
Lissauer + Rivera
Stability Analysis of υ And



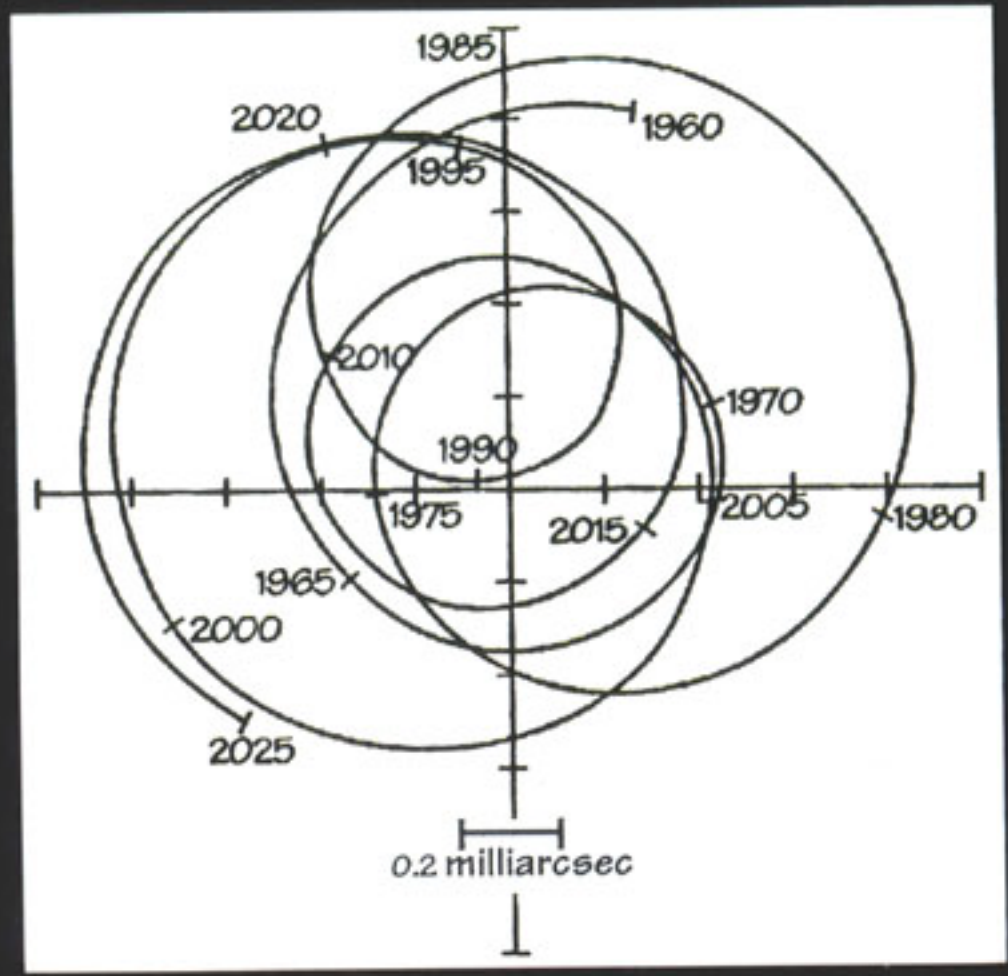
Test particles (0-8 AU) υ And

mass factor = 1 (sin i = 1)

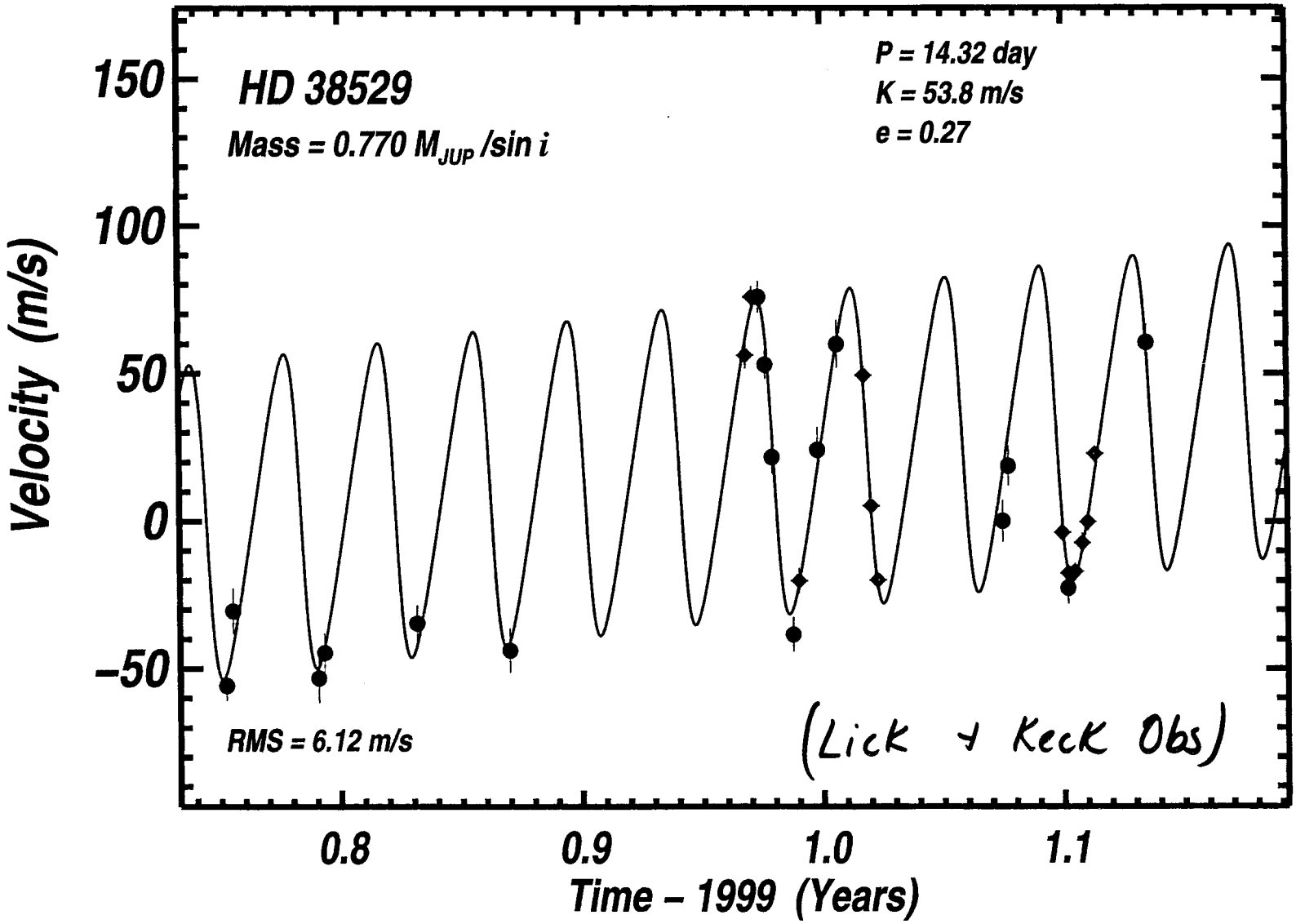
As mass factor ↑ to 4, resonance stabilities are lost and window of stability between 0-1 AU shrin.

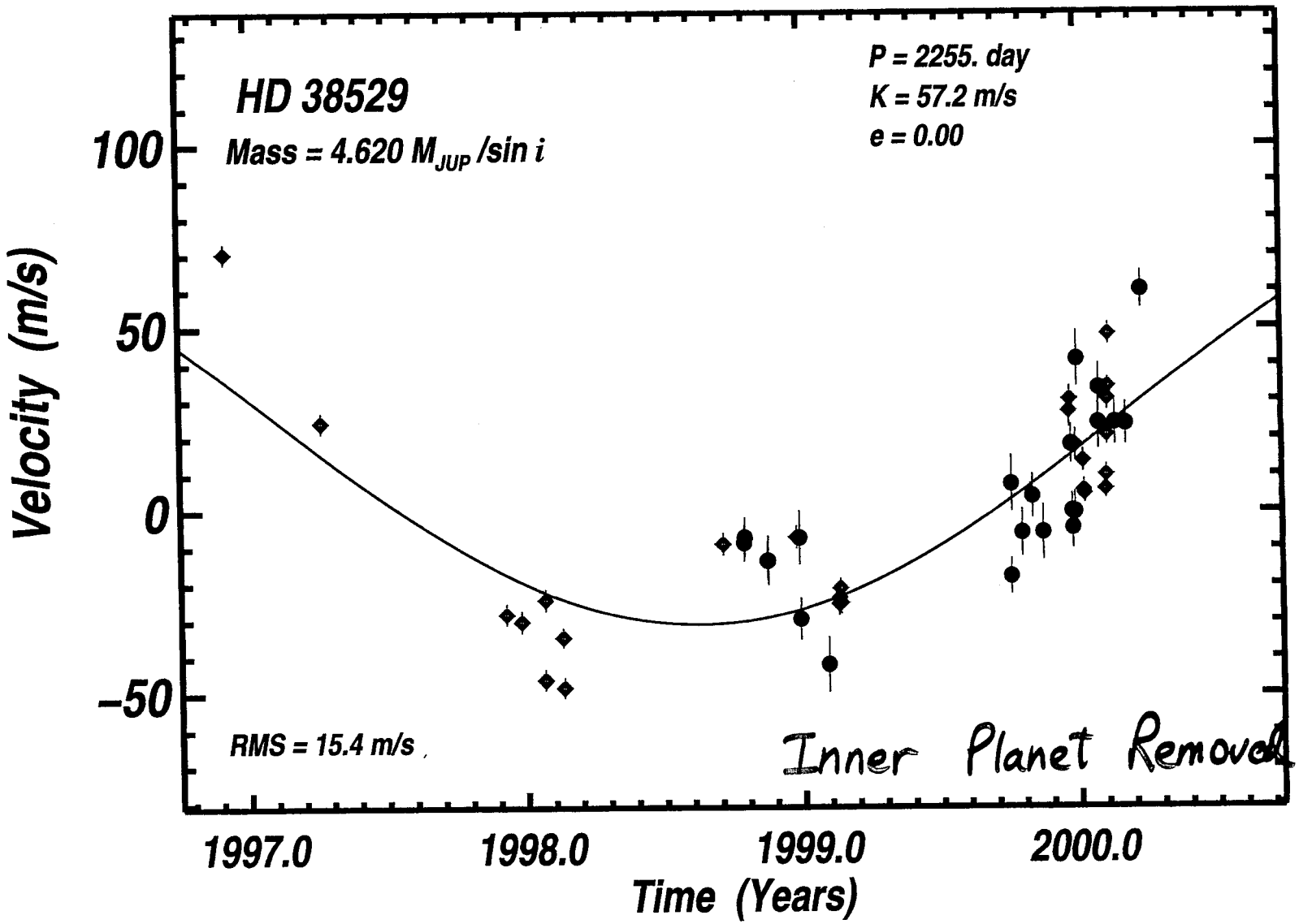

Upsilon Andromedae Simulation
40 SIM Observations
Two Planets
$M_c = 2.9\ M_{JUP}$
$M_d = 6\ M_{JUP}$
$a_c = 0.823$ AU
$a_d = 2.56$ AU
500
0
−500
−1000
RA μas
−1500
−1000
−500
0
500
1000
DEC μas

Sun's Wobble

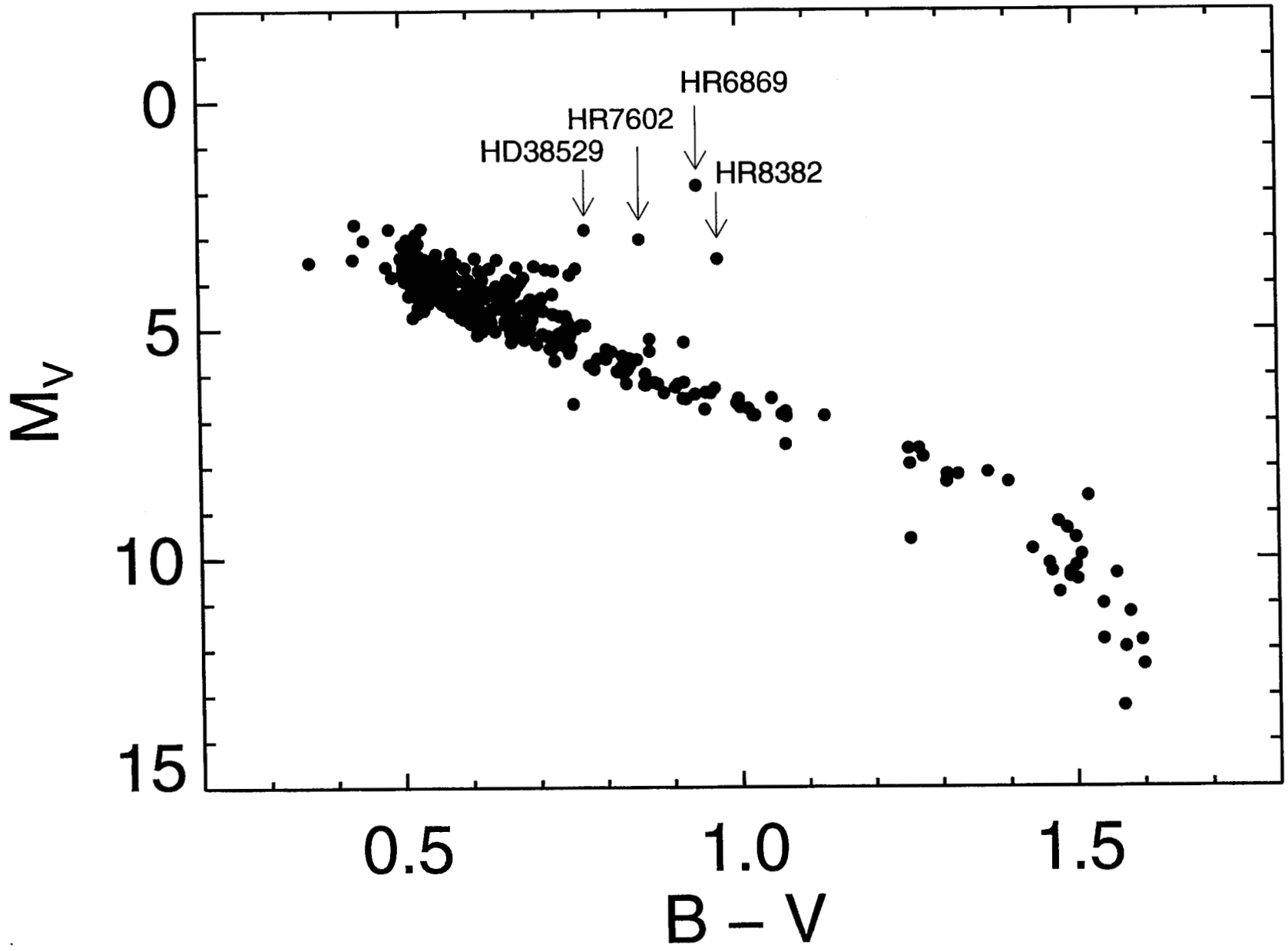


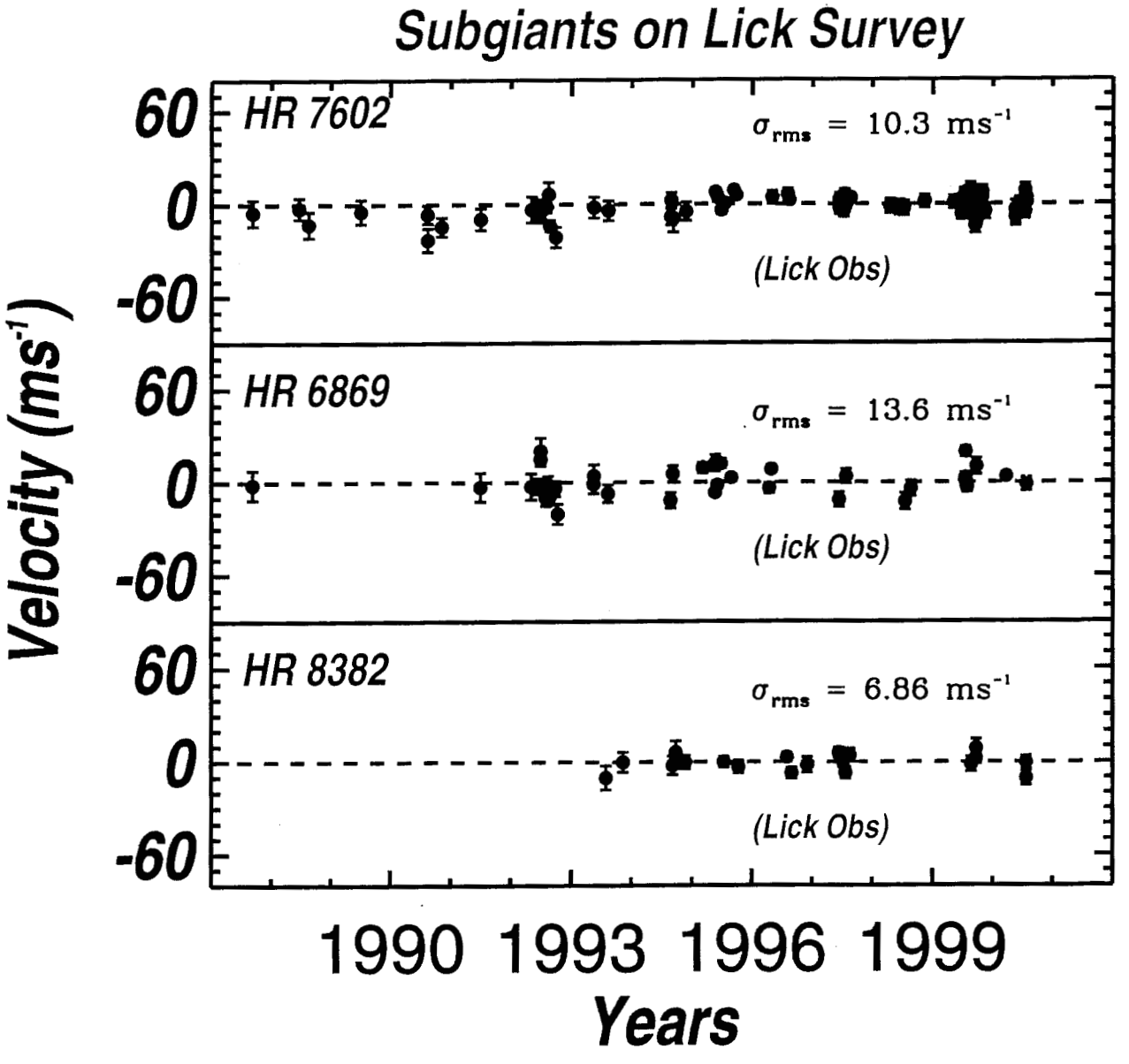
- The motion of the Sun around the center of mass of the Solar System, seen from a distance of 10 parsecs.

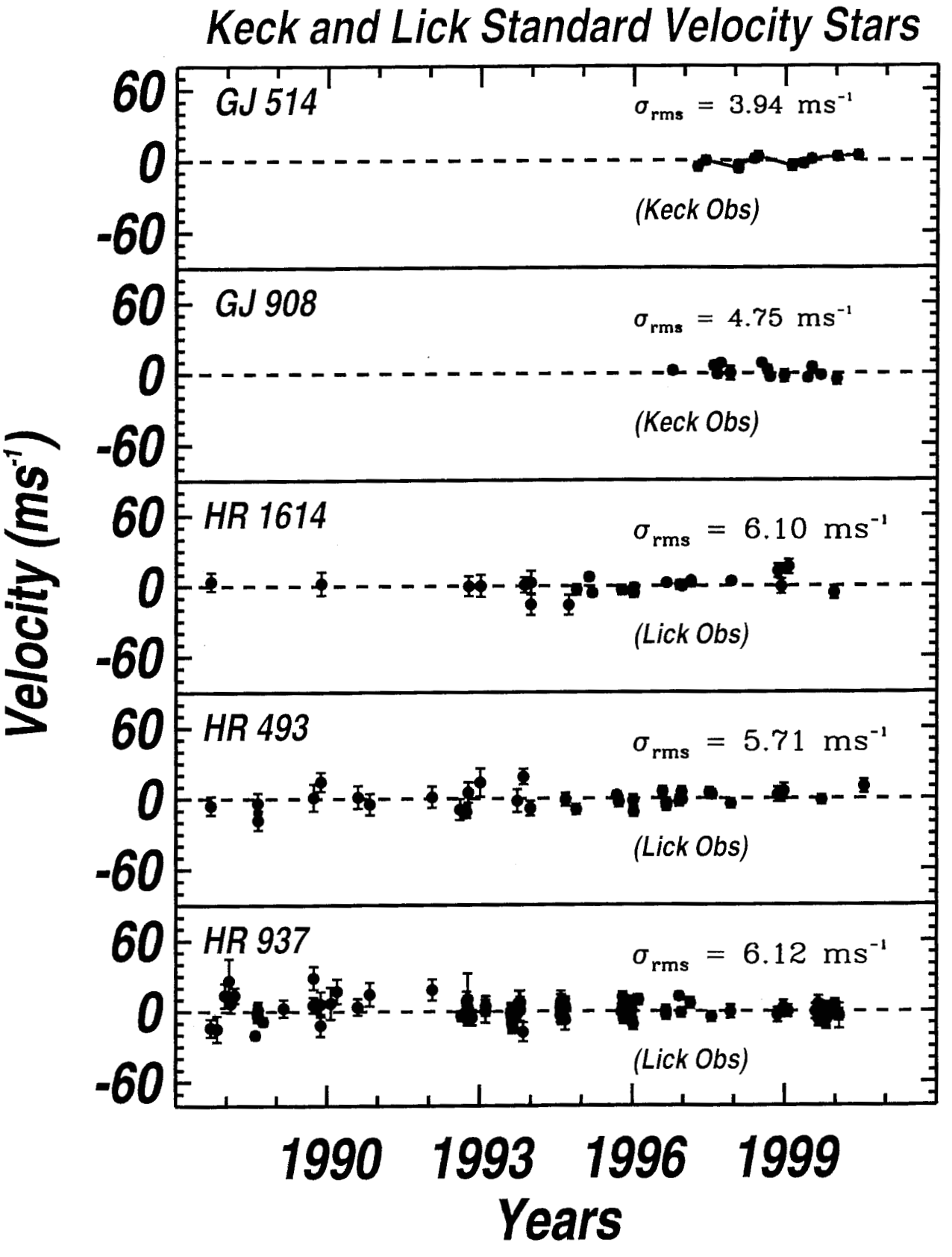

HD 38529
Mass = 0.770 M_{JUP} /sin i
P = 14.32 day
K = 53.8 m/s
e = 0.27
RMS = 6.12 m/s
(Lick + Keck Obs)
Velocity (m/s)
150
100
50
0
−50
0.8
0.9
1.0
1.1
Time – 1999 (Years)

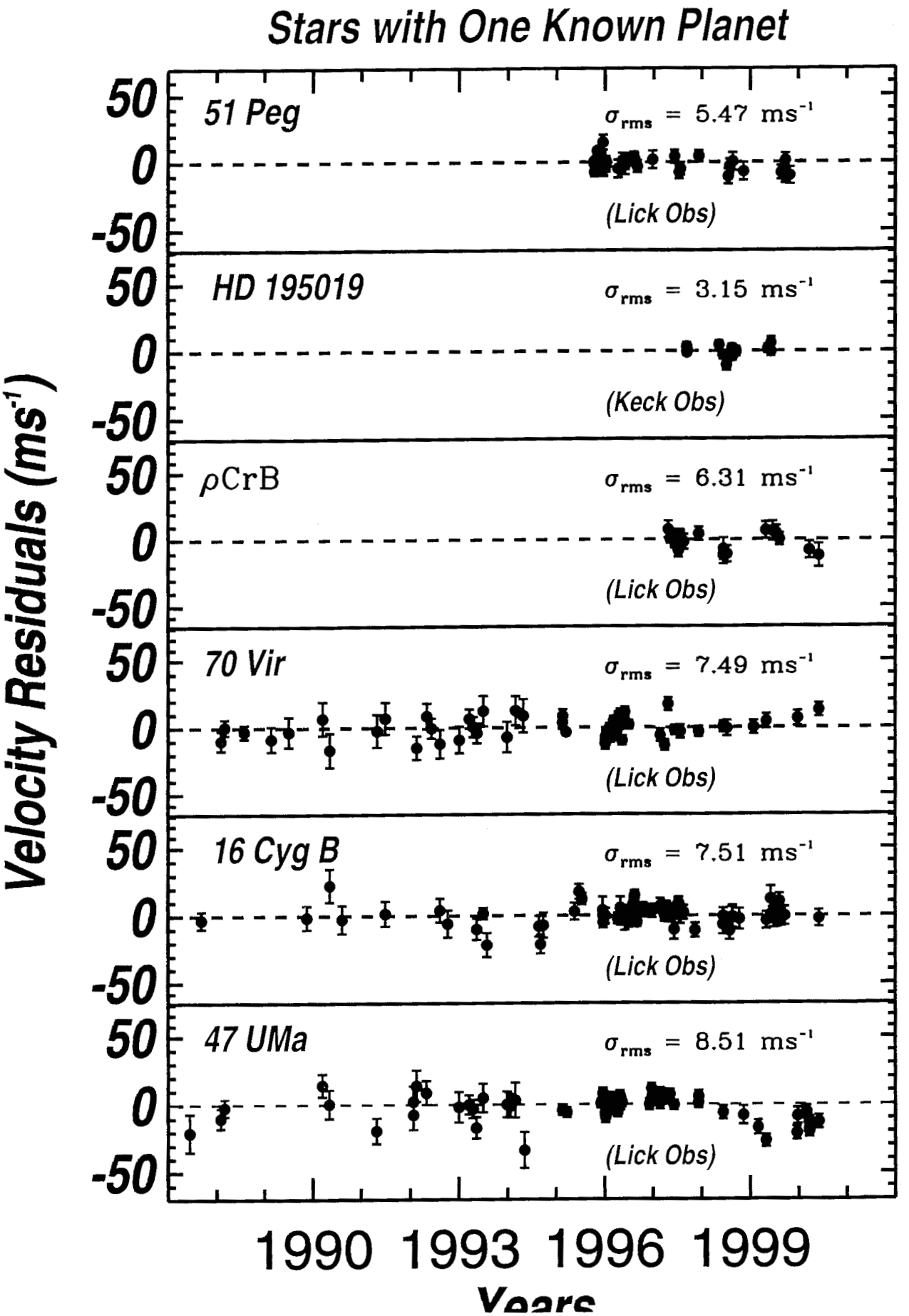

HD 38529
Mass = 4.620 M_{JUP} /sin i
P = 2255. day
K = 57.2 m/s
e = 0.00
RMS = 15.4 m/s
Inner Planet Removed
100
50
0
-50
Velocity (m/s)
1997.0
1998.0
1999.0
2000.0
Time (Years)

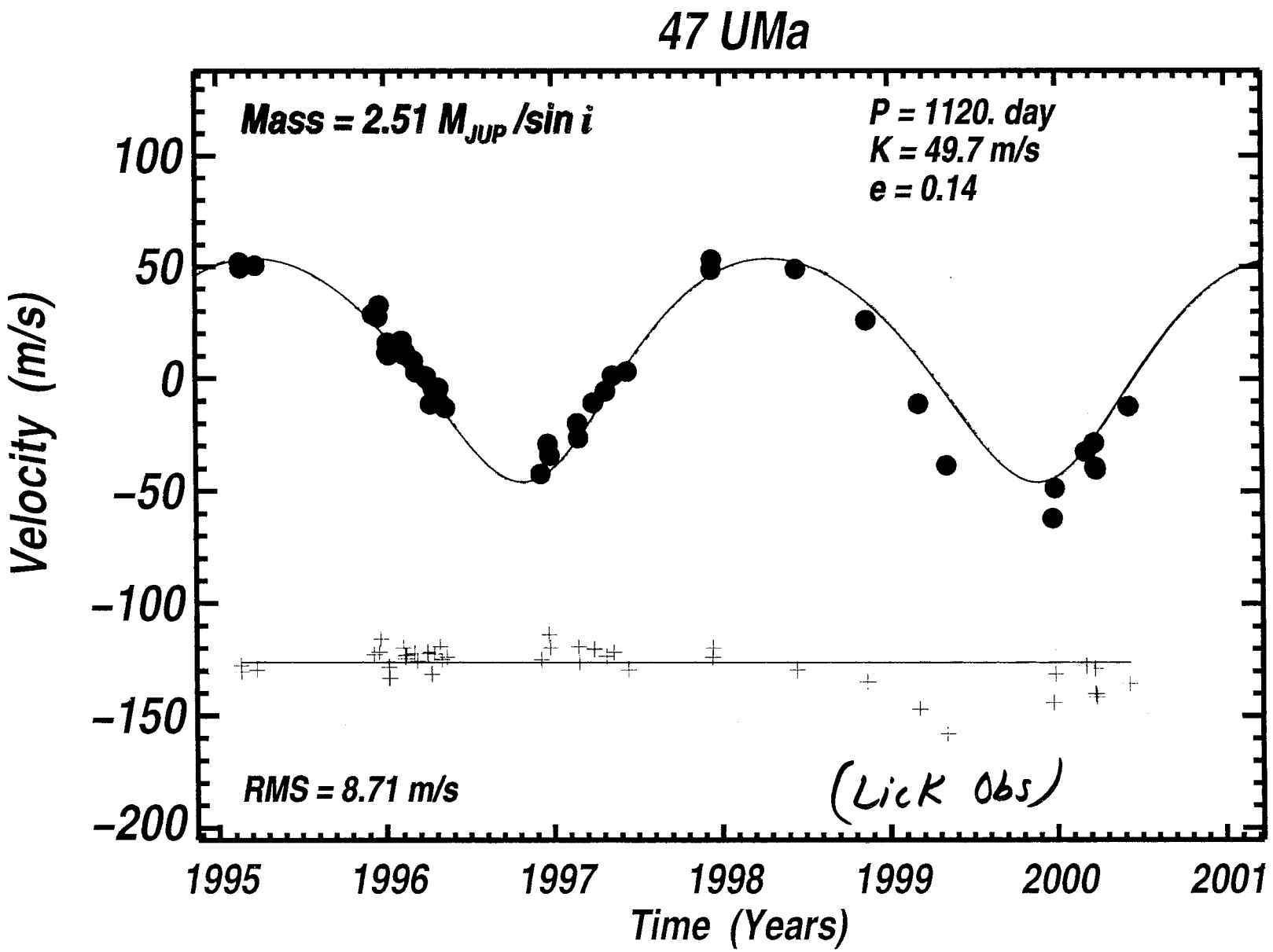
Color-magnitude Diagram - Lick Sample




Subgiants on Lick Survey
HR 7602
σ_{rms} = 10.3 ms^{-1}
(Lick Obs)
HR 6869
σ_{rms} = 13.6 ms^{-1}
(Lick Obs)
HR 8382
σ_{rms} = 6.86 ms^{-1}
(Lick Obs)
60
0
-60
Velocity (ms^{-1})
1990 1993 1996 1999
Years

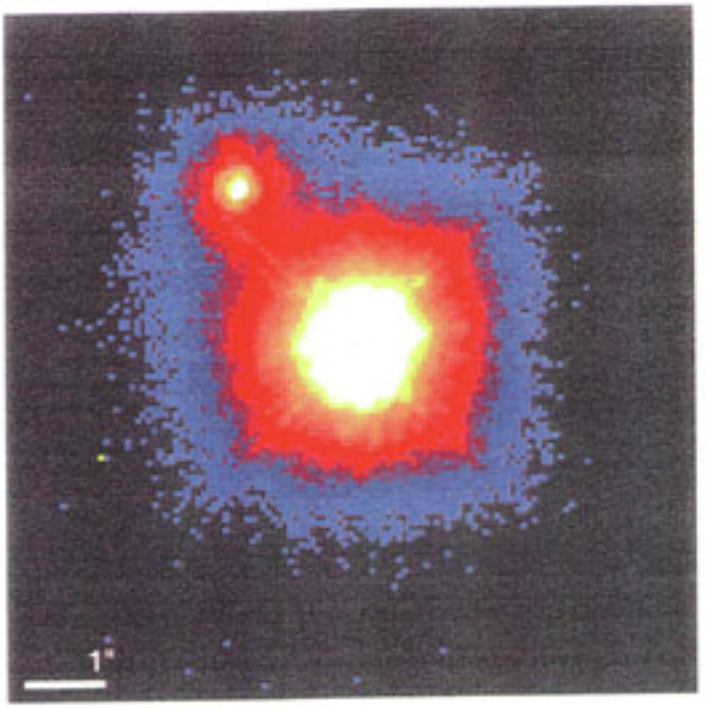

Keck and Lick Standard Velocity Stars
GJ 514
σ_{rms} = 3.94 ms^{-1}
(Keck Obs)
GJ 908
σ_{rms} = 4.75 ms^{-1}
(Keck Obs)
HR 1614
σ_{rms} = 6.10 ms^{-1}
(Lick Obs)
HR 493
σ_{rms} = 5.71 ms^{-1}
(Lick Obs)
HR 937
σ_{rms} = 6.12 ms^{-1}
(Lick Obs)
60
0
-60
Velocity (ms^{-1})
1990
1993
1996
1999
Years

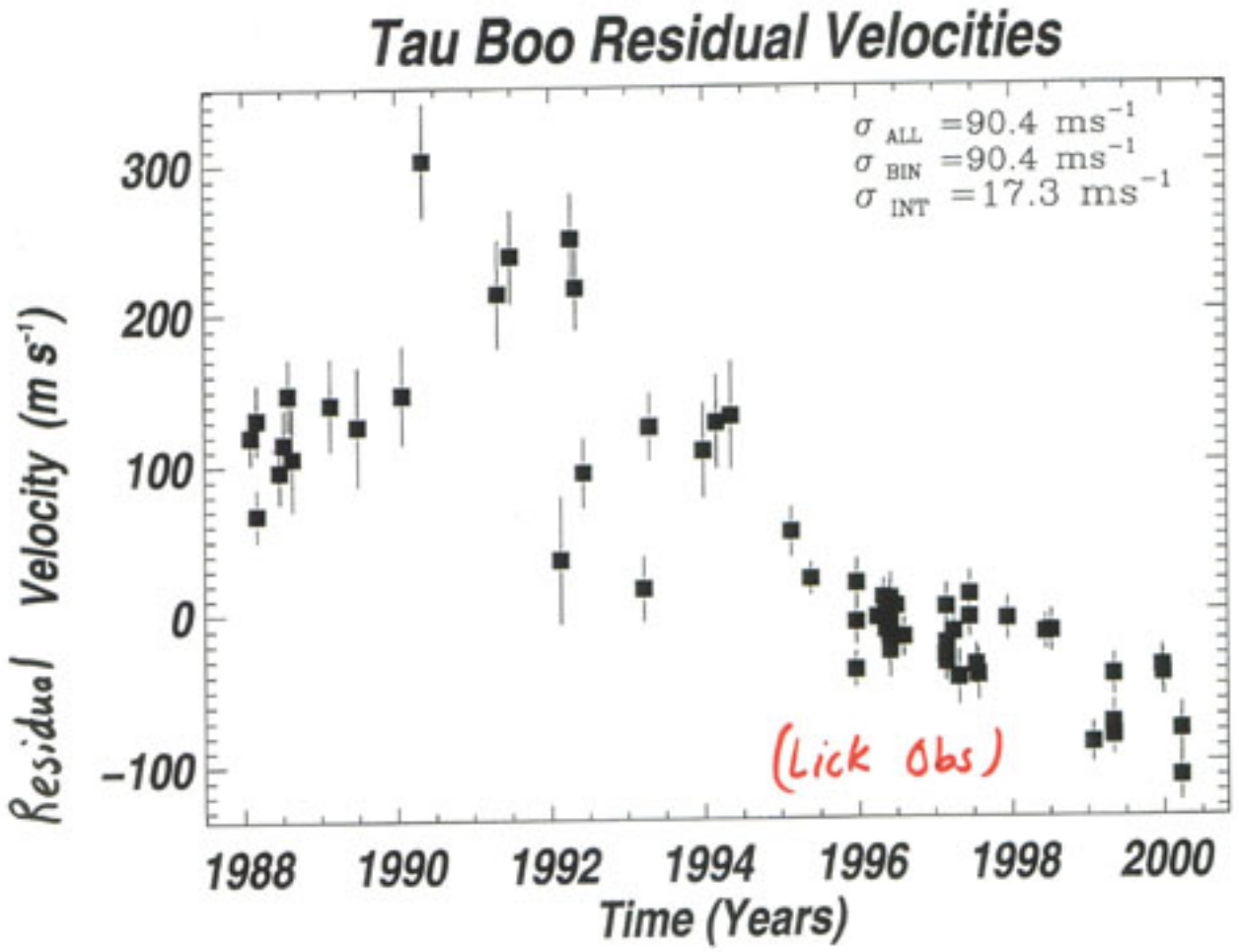

Stars with One Known Planet
51 Peg
σrms = 5.47 ms-1
(Lick Obs)
HD 195019
σrms = 3.15 ms-1
(Keck Obs)
ρCrB
σrms = 6.31 ms-1
(Lick Obs)
70 Vir
σrms = 7.49 ms-1
(Lick Obs)
16 Cyg B
σrms = 7.51 ms-1
(Lick Obs)
47 UMa
σrms = 8.51 ms-1
(Lick Obs)
50
0
-50
Velocity Residuals (ms-1)
1990 1993 1996 1999
Years

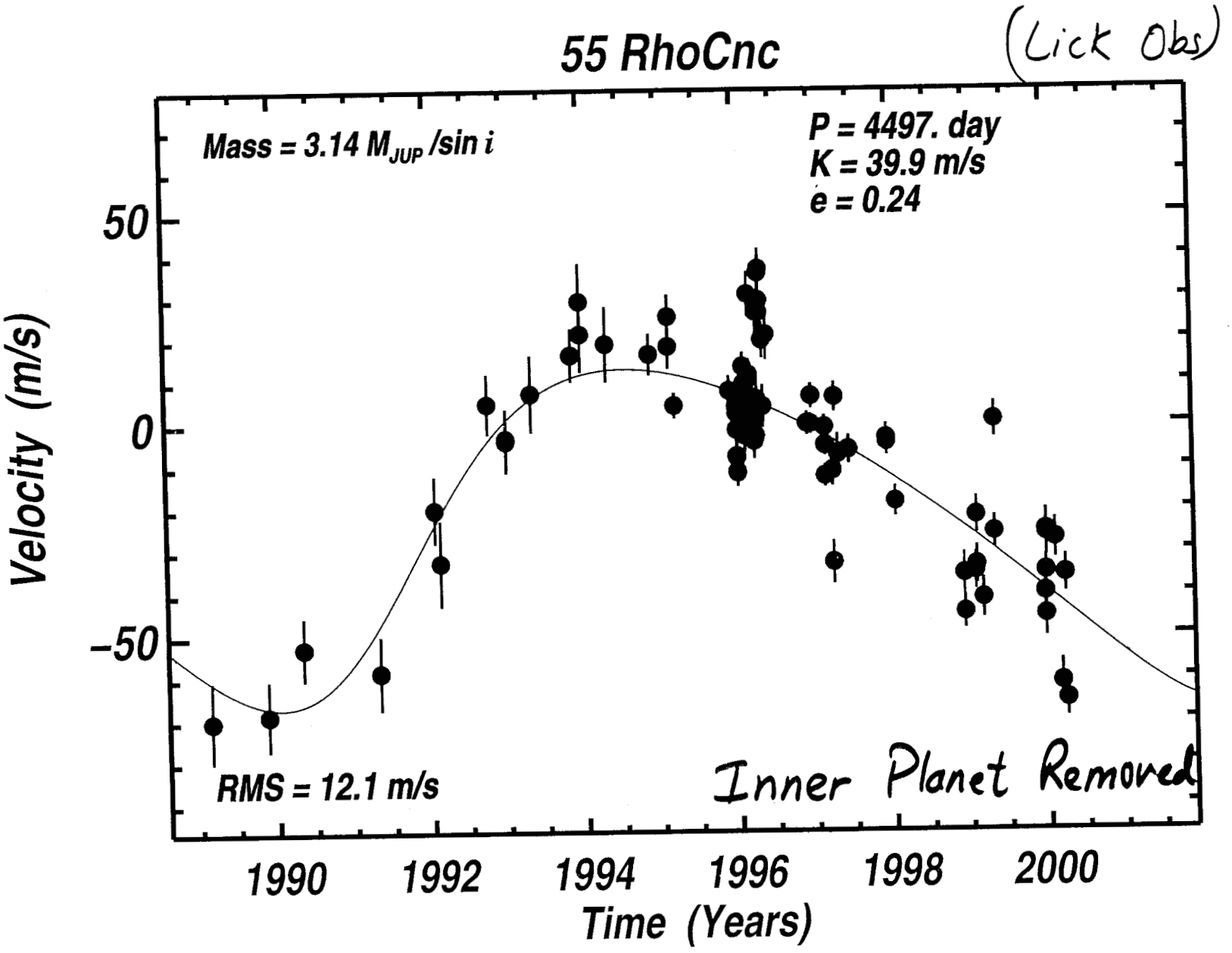

47 UMa
Mass = 2.51 M_JUP /sin i
P = 1120. day
K = 49.7 m/s
e = 0.14
RMS = 8.71 m/s
(Lick Obs)
Velocity (m/s)
100
50
0
-50
-100
-150
-200
1995
1996
1997
1998
1999
2000
2001
Time (Years)

Lick AO

Liu, Lloyd, Graham 2000






55 RhoCnc
(Lick Obs)
Mass = 3.14 M_JUP /sin i
P = 4497. day
K = 39.9 m/s
e = 0.24
50
0
−50
Velocity (m/s)
RMS = 12.1 m/s
Inner Planet Removed
1990
1992
1994
1996
1998
2000
Time (Years)

14 Planet-Bearing Stars
5 HAVE AN ADDITIONAL COMPANION

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	0.23	-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	no – Maybe
70 Vir	1.10	116.7	7.42	0.402	-0.03	-5.06	no
HD 12661	1.07	265.5	2.80	0.32	0.32	-5.12	no
HD 92788	1.06	348.1	2.11	0.44	0.24	-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	no – maybe

BIAS AGAINST MULTIPLE LONG PERIODS.

Lick Obs. Planets with > 2 yr of data.