Current Status of BOAO Planet Search Program

The 4th Workshop on Extra-Solar Planet Search with Accurate Radial Velocity Measurements

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Contents

1. Scientific goals of the project

By measuring precise RV of about 50 early K giant stars, we want

- to study the nature and cause of RV variation of K giant stars
- to investigate the correlation between planet formation and stellar mass

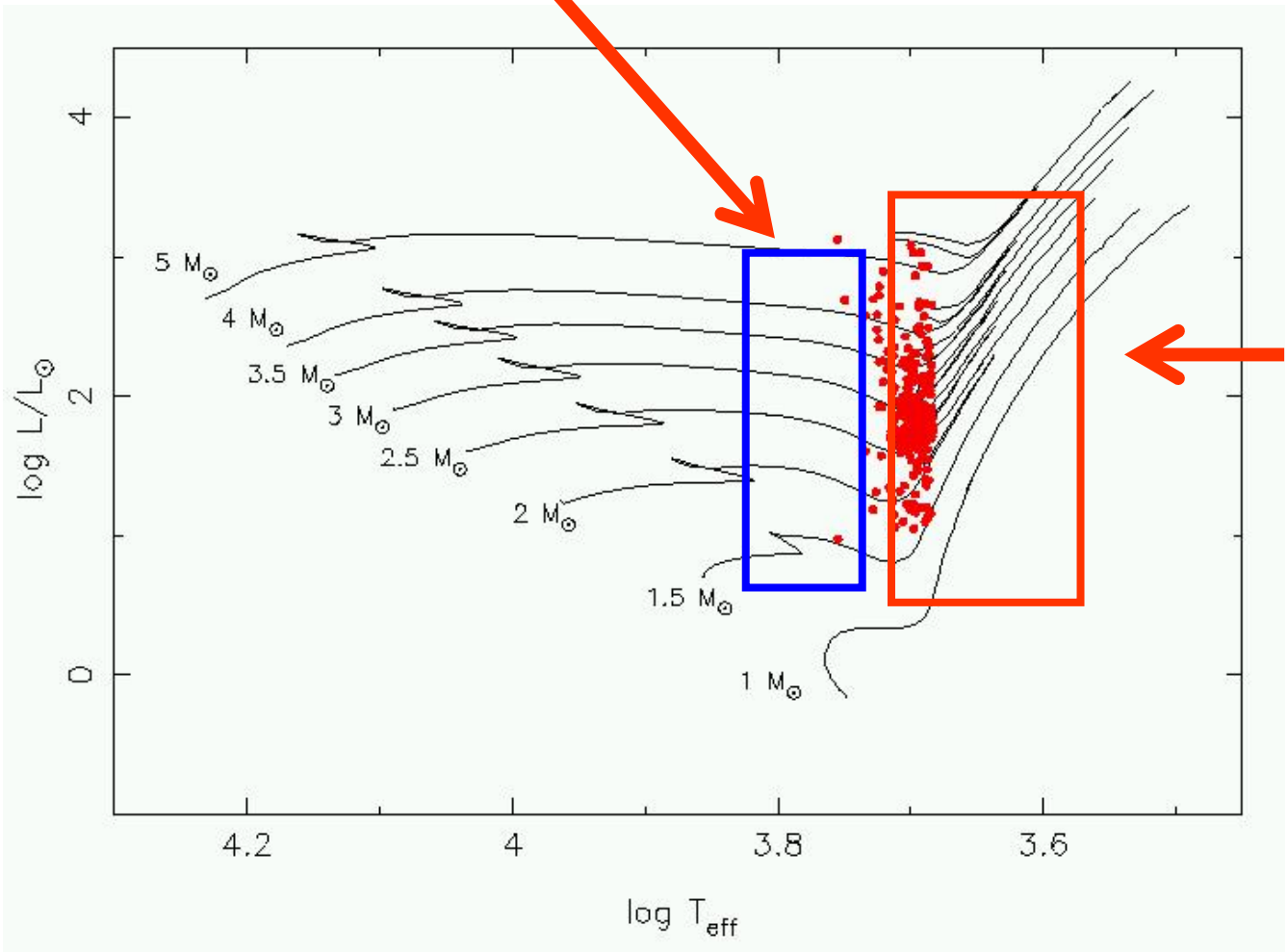
Early (K0-K4) K giant stars

- low-amplitude RV variability of K giant stars are well know since 1990s.
- we still do not know well about the nature and cause of the RV variation are not well investigated
- typical periods, to stellar oscillation/surface feature/unseen companion etc.
- to find the "blue border" between pulsating K and stable G-giants.

background of the project

- most of RV exo-planet search programs are looking for G dwarf stars.
- study planet formation around massive stars
  ➔ Ap, K, G stars
- In 2003, Okayama already started G- giants survey
- K – giants : to avoid duplication with other programs
- BOES RV accuracy were demonstrated earlier & collaborators for K giants observation were available

Okayama Observatory (Japan)
survey of 57 G-type giants



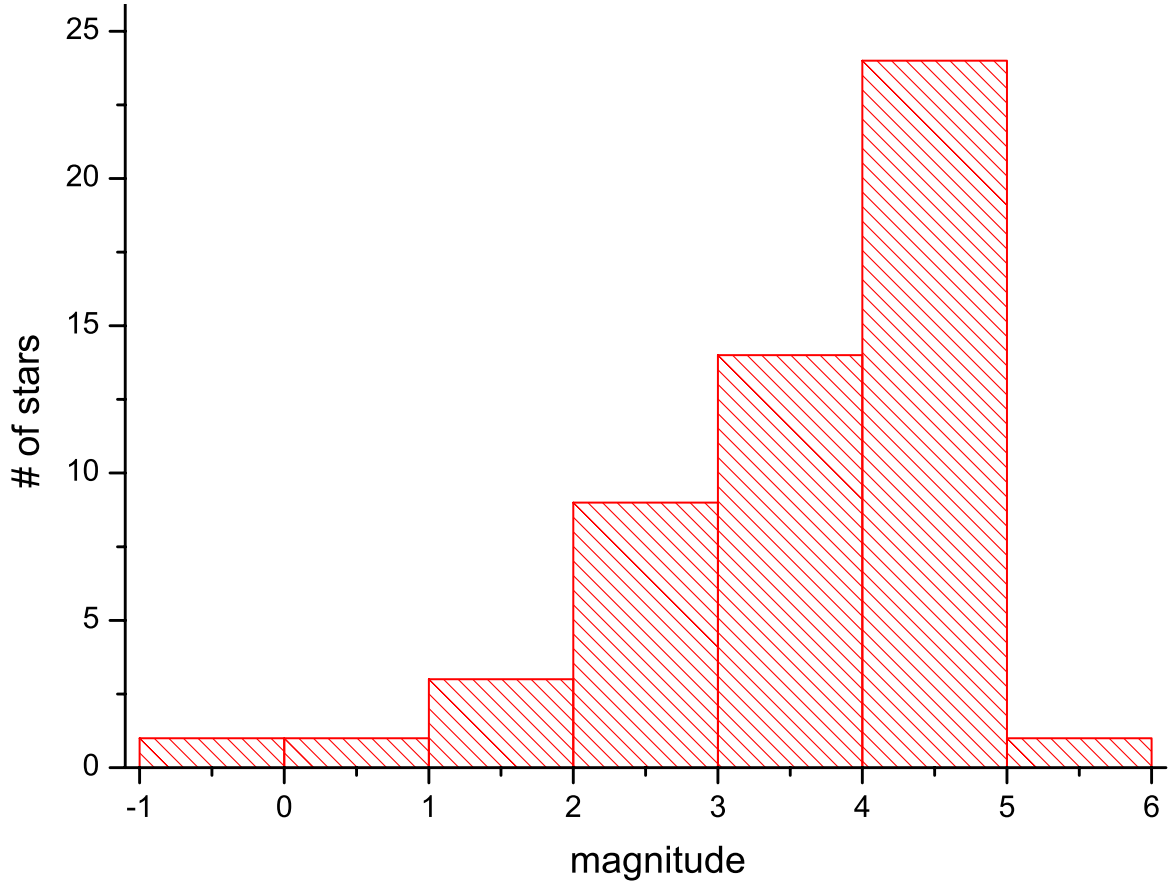
BOAO
survey is
focused on
early
K-giants

Most G-giant stars (90%) are stable in radial velocity to a level of < 30m/s in a time span of 1-2 yr (Sato et al. 2005) :

Targets

- 50 Early K1~K5 & some late G giants (limited by brightness and Declination)
- 10 M giants
- some Ap and Cepheids

Histogram of the target stars brightness

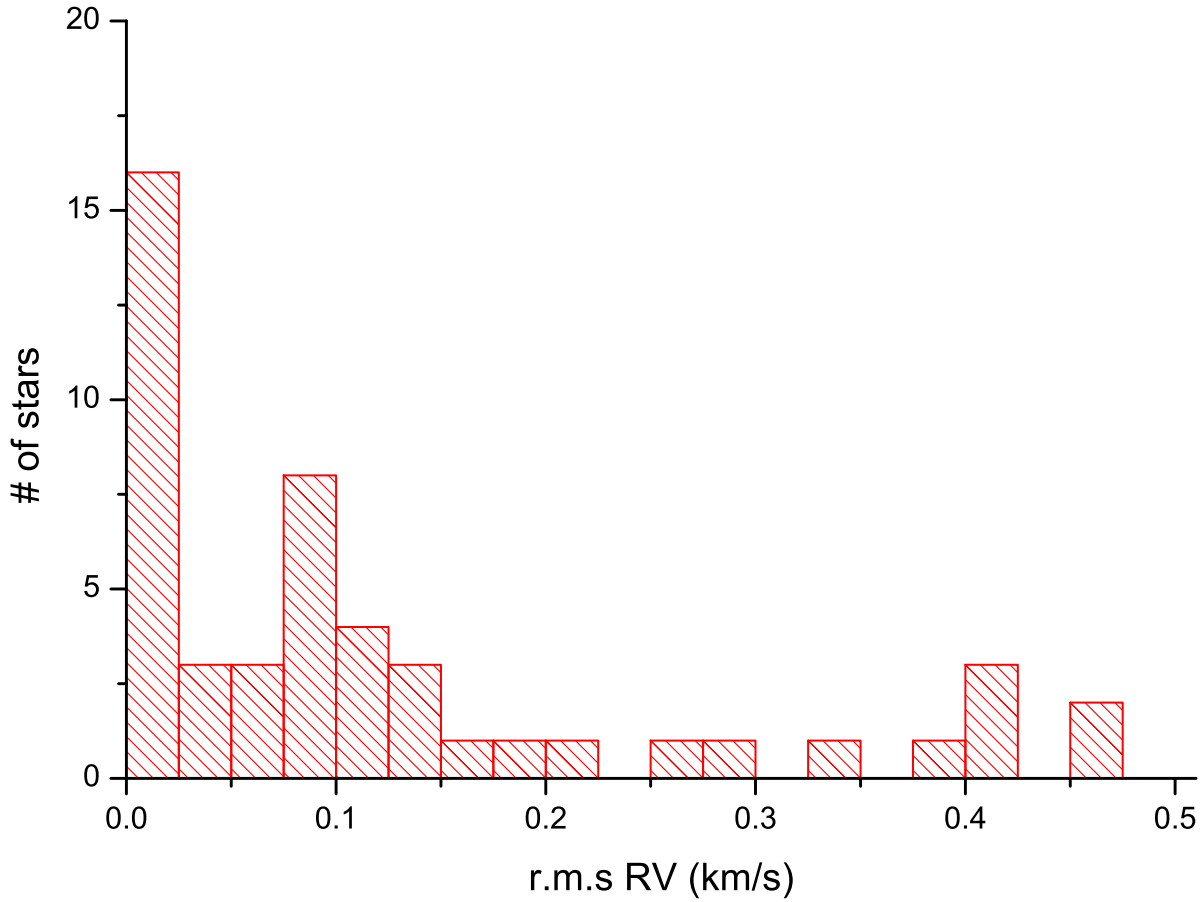


time allocation to the project

TABLE Observing time allocated to K-giant(G-giant)

2004A:	2004B: 25(0)
2005A: 26(8)	2005B: 13(6)
2006A: 10(8)	2006B: 10(6)
2007A: 12(6)	2007B: 7(6)
2008A: 12(6)	2008B: 12(6)
2009A: 13(6)	2009B: 8(6)

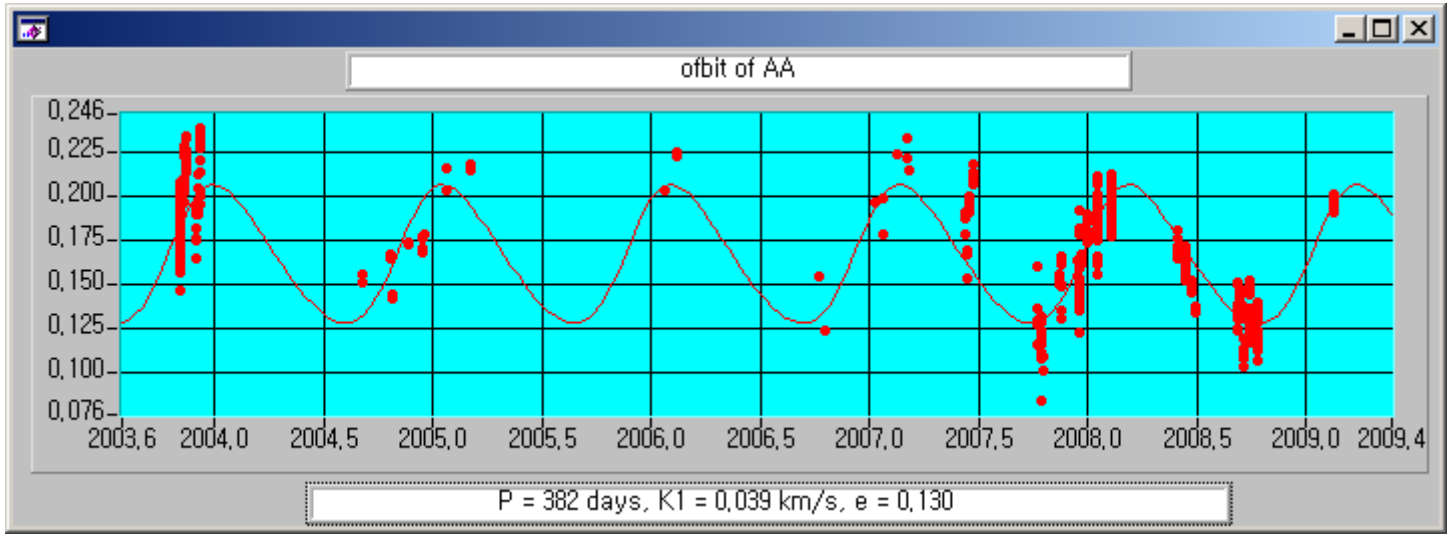
Histogram of r.m.s. RV variation

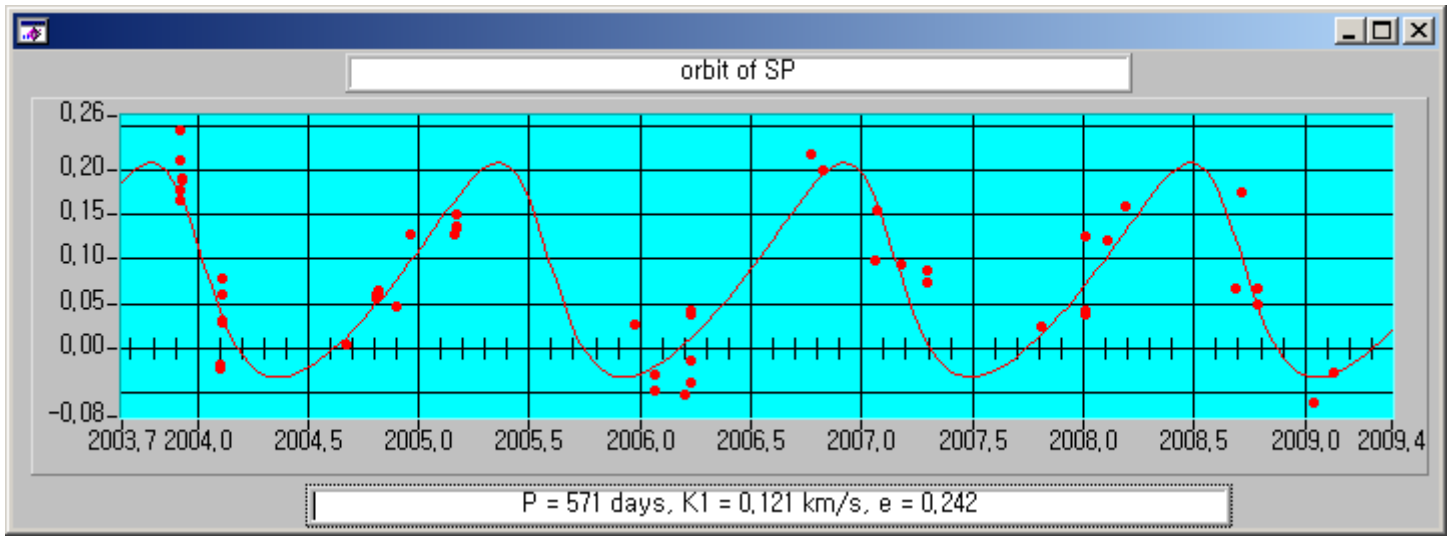


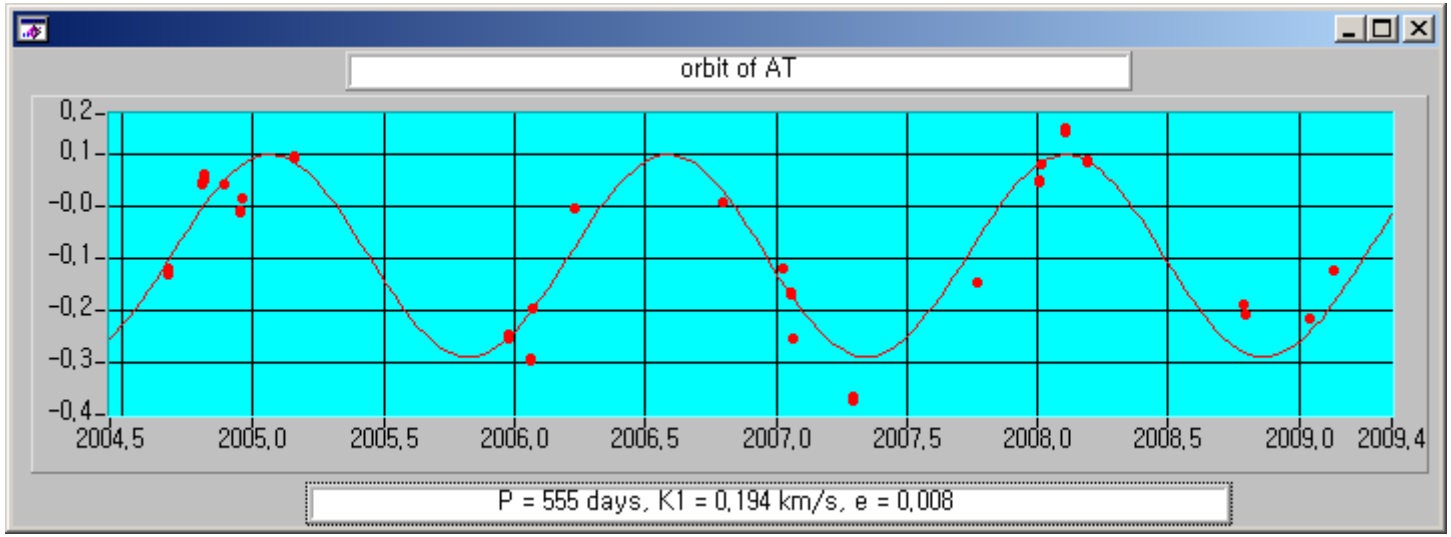
List of the exoplanet candidates detected by BOES

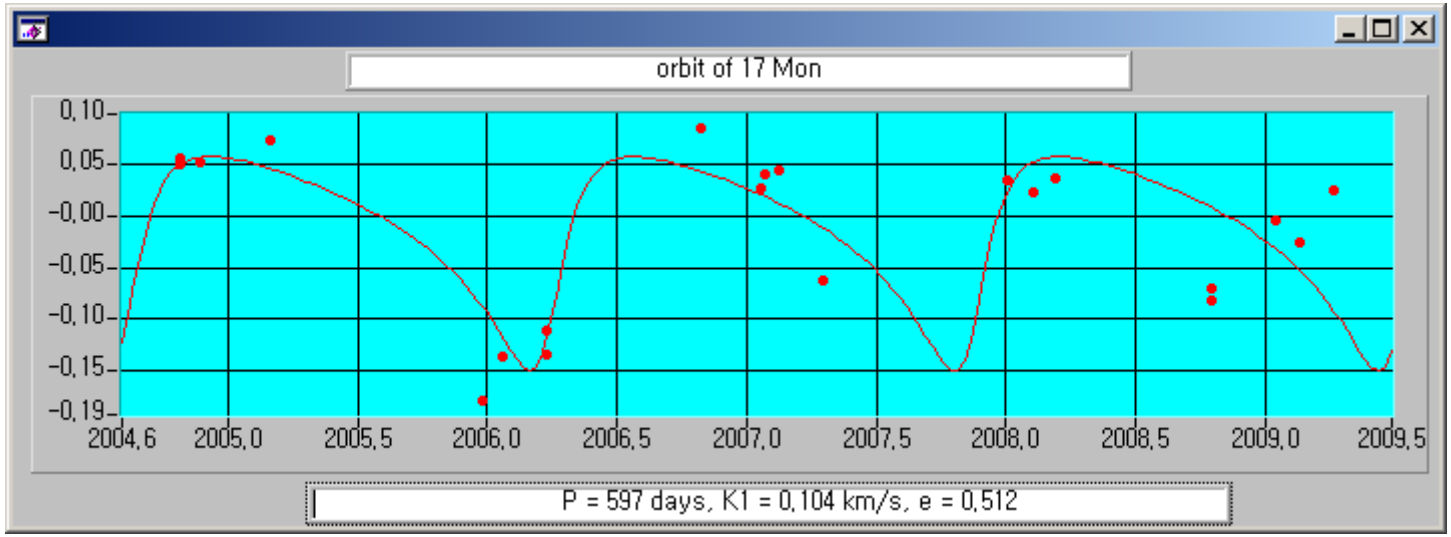
Star	period (days)	K1 (km/s) semi-amplitude	e	$m_P \sin i$ M_J	Note
AA	382	0.039	0.130		
SP	571	0.121	0.242		
AT	555	0.194	0.008		
17Mon	597	0.118	0.361		
Bet Gem	598	0.046	0.010	2.3	confirmed (2,3,4)
3751	597	0.281	0.132		
Gam1 Leo	428	0.208	0.144	9.8	Accepted visual binary
Iot Dra	510	0.303	0.704	8.9	confirmed (1)
EC	418	0.142	0.174		
PH	833	0.150	0.155		
GD	688	0.173	0.142		

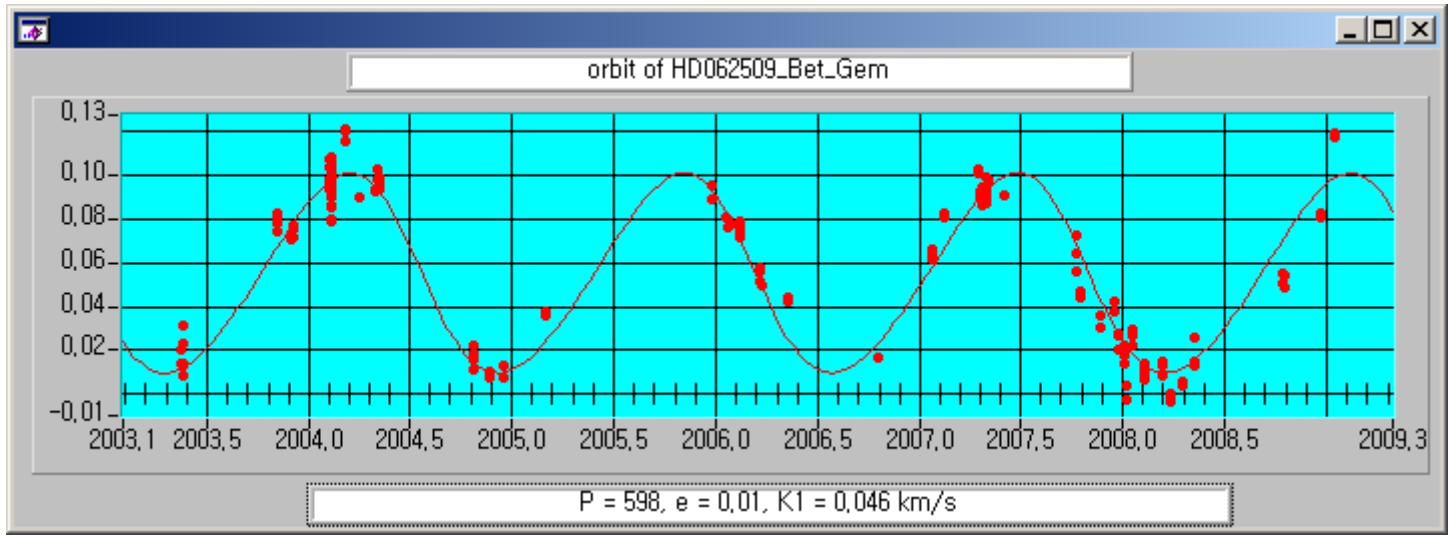
1: Frink et al. 2002, 2: Hatzes et al. 2006, 3: Reffert et al. 2006,
4: Han et al. 2008

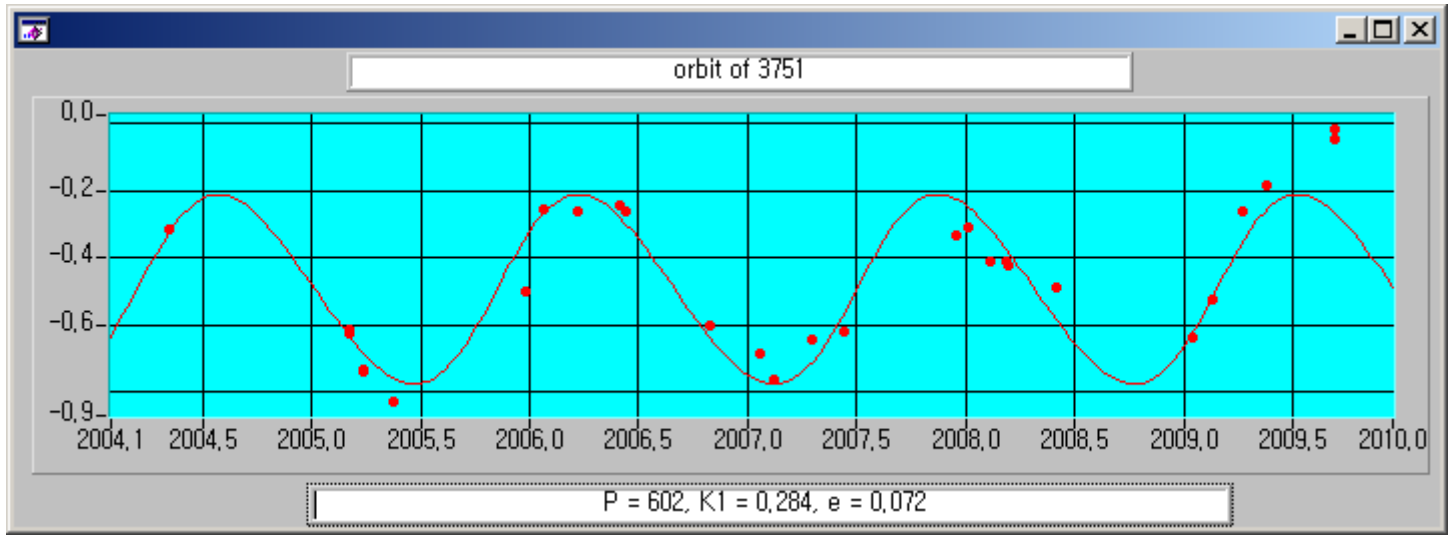

ofbit of AA
0,246
0,225
0,200
0,175
0,150
0,125
0,100
0,076
2003,6 2004,0 2004,5 2005,0 2005,5 2006,0 2006,5 2007,0 2007,5 2008,0 2008,5 2009,0 2009,4
P = 382 days, K1 = 0,039 km/s, e = 0,130

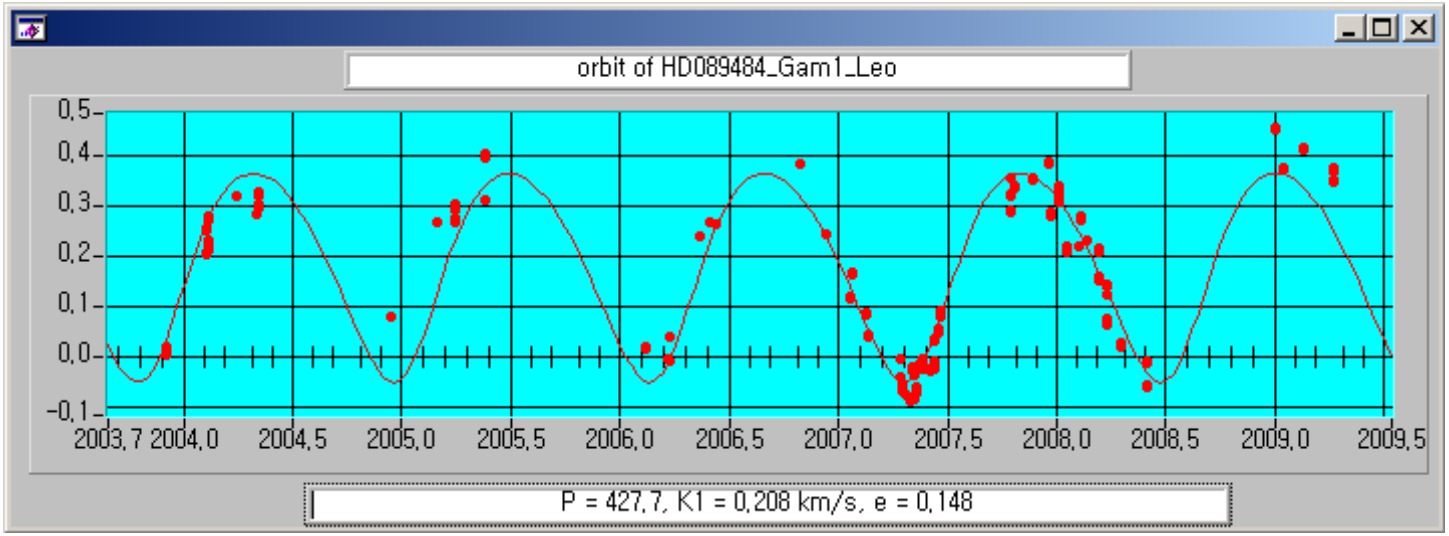

orbit of SP
0,26
0,20
0,15
0,10
0,05
0,00
-0,08
2003,7 2004,0 2004,5 2005,0 2005,5 2006,0 2006,5 2007,0 2007,5 2008,0 2008,5 2009,0 2009,4
P = 571 days, K1 = 0,121 km/s, e = 0,242

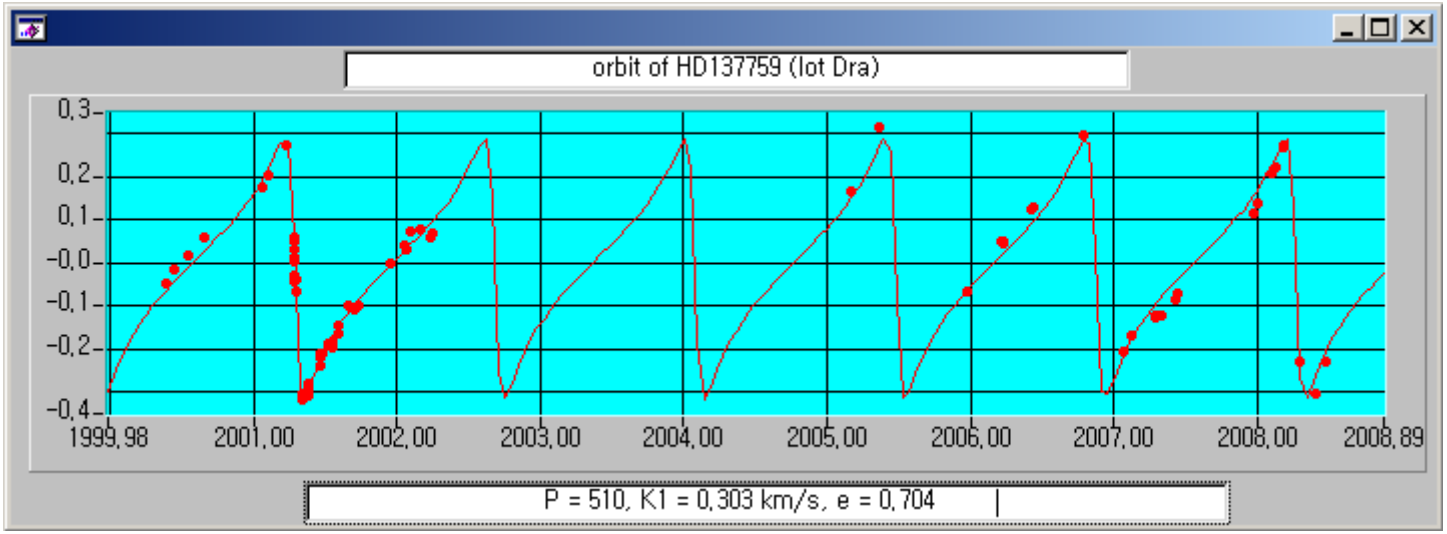

orbit of AT
0,2
0,1
-0,0
-0,1
-0,2
-0,3
-0,4
2004,5
2005,0
2005,5
2006,0
2006,5
2007,0
2007,5
2008,0
2008,5
2009,0
2009,4
P = 555 days, K1 = 0,194 km/s, e = 0,008

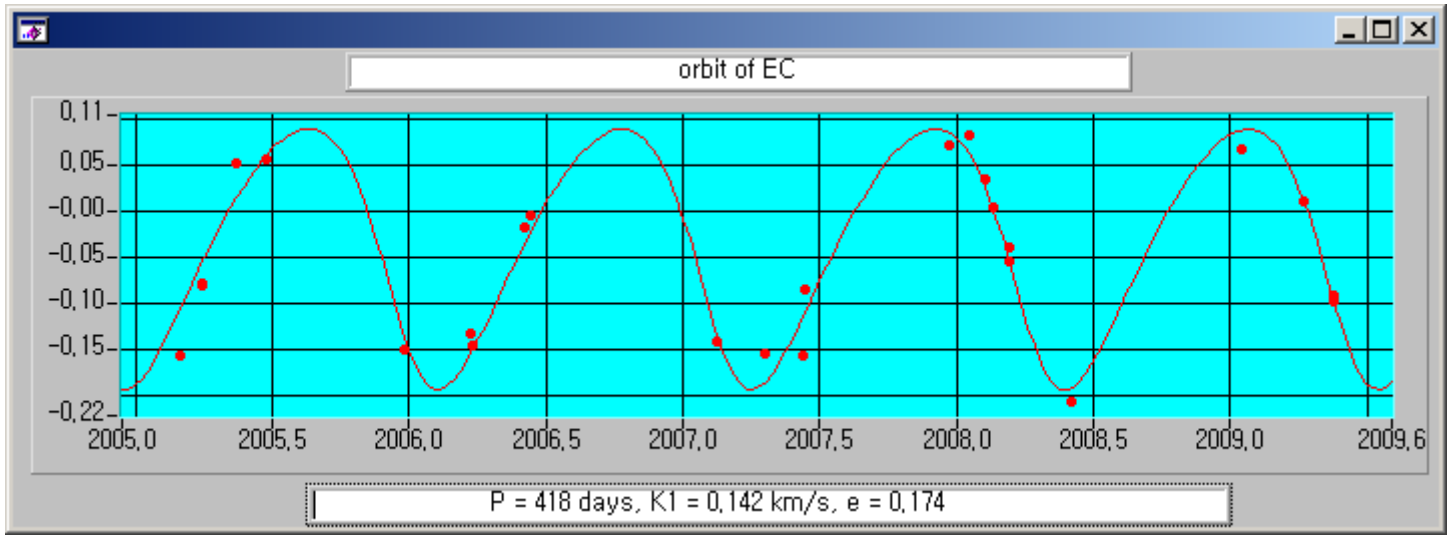

orbit of 17 Mon
0,10
0,05
-0,00
-0,05
-0,10
-0,15
-0,19
2004,6
2005,0
2005,5
2006,0
2006,5
2007,0
2007,5
2008,0
2008,5
2009,0
2009,5
P = 597 days, K1 = 0,104 km/s, e = 0,512

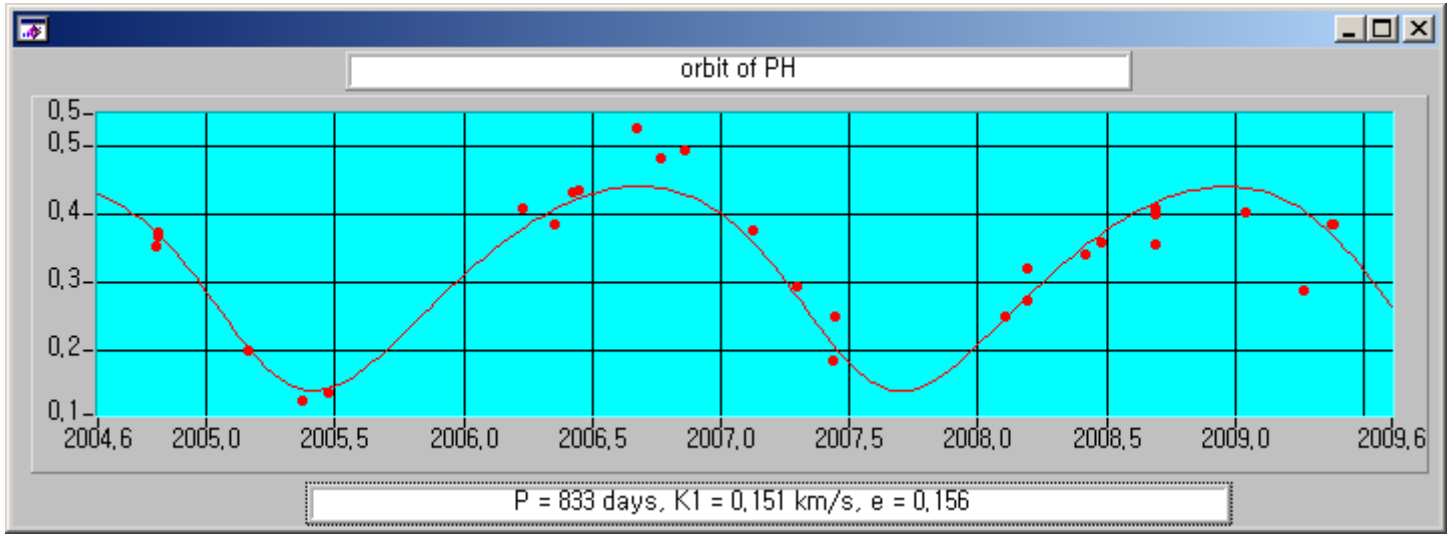

orbit of HD062509_Bet_Gem
0,13
0,10
0,08
0,06
0,04
0,02
-0,01
2003,1
2003,5
2004,0
2004,5
2005,0
2005,5
2006,0
2006,5
2007,0
2007,5
2008,0
2008,5
2009,3
P = 598, e = 0,01, K1 = 0,046 km/s

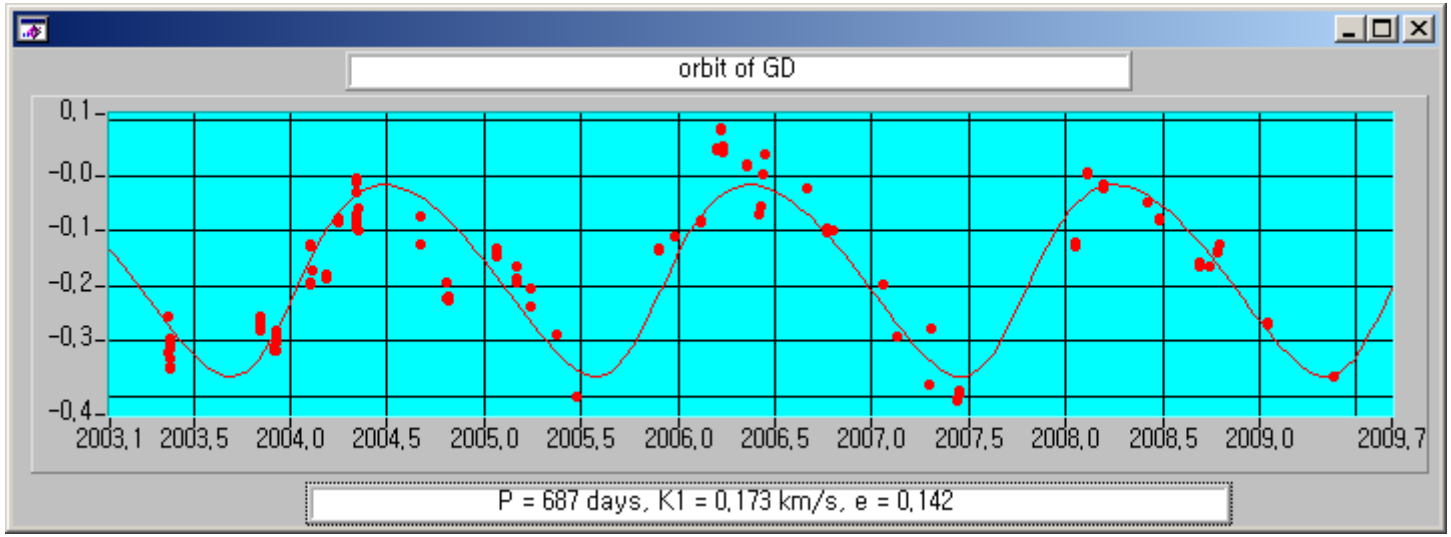

orbit of 3751
0,0
-0,2
-0,4
-0,6
-0,9
2004,1
2004,5
2005,0
2005,5
2006,0
2006,5
2007,0
2007,5
2008,0
2008,5
2009,0
2009,5
2010,0
P = 602, K1 = 0,284, e = 0,072


orbit of HD089484_Gam1_Leo
0,5
0,4
0,3
0,2
0,1
0,0
-0,1
2003,7 2004,0
2004,5
2005,0
2005,5
2006,0
2006,5
2007,0
2007,5
2008,0
2008,5
2009,0
2009,5
P = 427,7, K1 = 0,208 km/s, e = 0,148

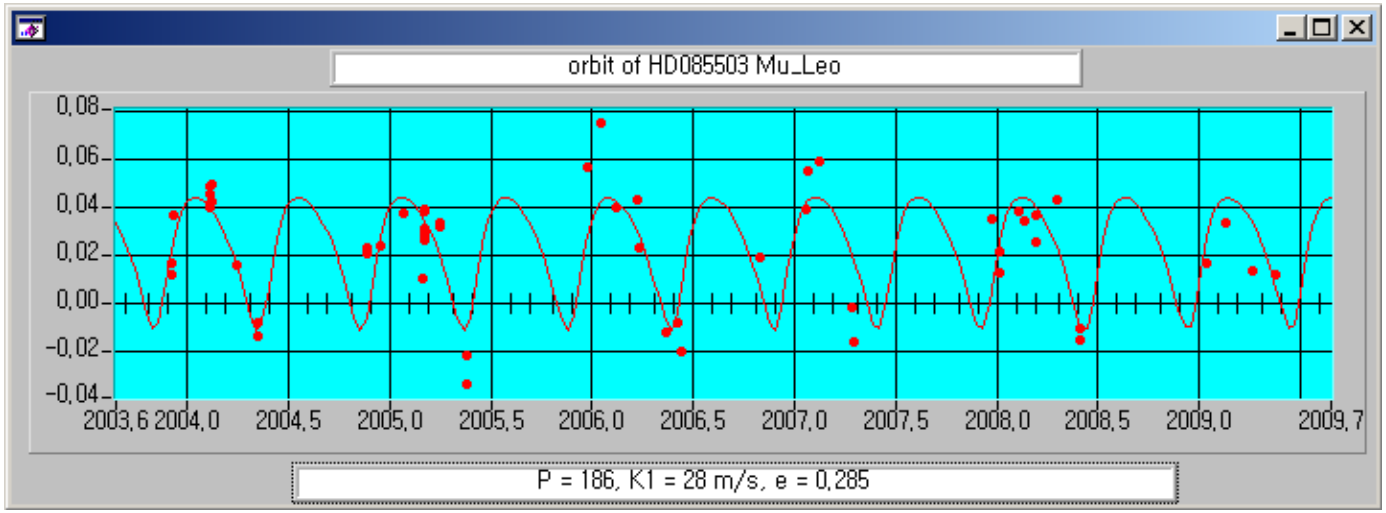

orbit of HD137759 (Iot Dra)
0,3
0,2
0,1
-0,0
-0,1
-0,2
-0,4
1999,98
2001,00
2002,00
2003,00
2004,00
2005,00
2006,00
2007,00
2008,00
2008,89
P = 510, K1 = 0,303 km/s, e = 0,704

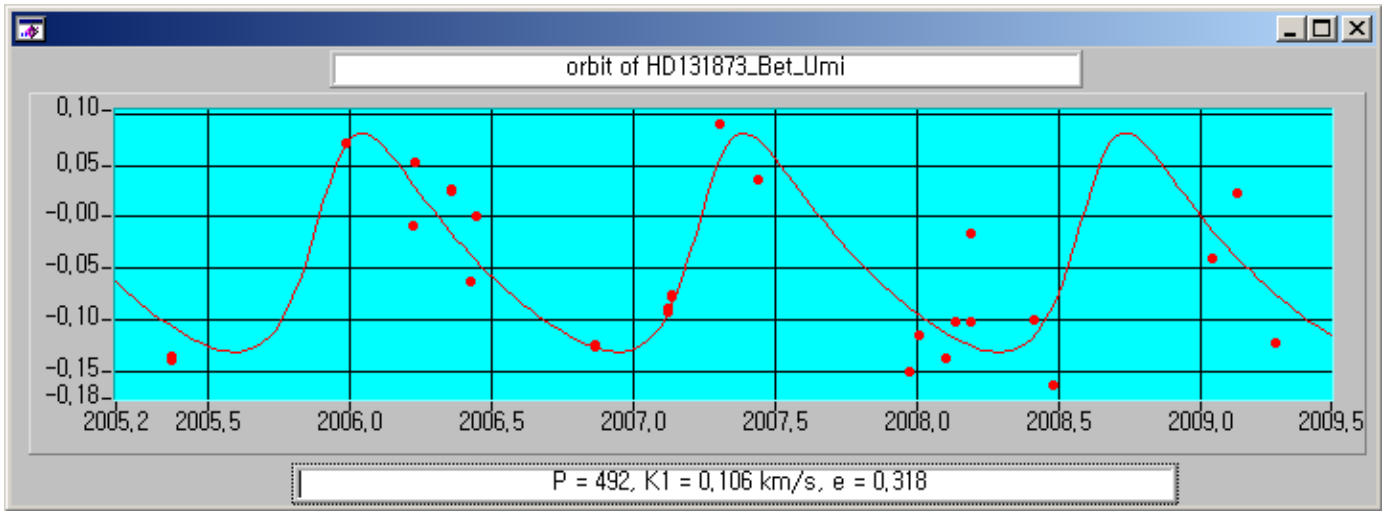

orbit of EC
0,11
0,05
-0,00
-0,05
-0,10
-0,15
-0,22
2005,0
2005,5
2006,0
2006,5
2007,0
2007,5
2008,0
2008,5
2009,0
2009,6
P = 418 days, K1 = 0,142 km/s, e = 0,174


orbit of PH
0,5
0,5
0,4
0,3
0,2
0,1
2004,6
2005,0
2005,5
2006,0
2006,5
2007,0
2007,5
2008,0
2008,5
2009,0
2009,6
P = 833 days, K1 = 0,151 km/s, e = 0,156


orbit of GD
0,1
-0,0
-0,1
-0,2
-0,3
-0,4
2003,1
2003,5
2004,0
2004,5
2005,0
2005,5
2006,0
2006,5
2007,0
2007,5
2008,0
2008,5
2009,0
2009,7
P = 687 days, K1 = 0,173 km/s, e = 0,142

Some other (dirty) examples





Gam1 Leo
– first exoplanet discovery by BOES

Table 1. some stellar parameters of γ^1 Leo

parameter	value	reference
m_V	2.01	Hipparcos
$B-V$	1.13	Hipparcos
parallax (mas)	25.96 ± 0.83	Hipparcos
M_V	−0.92 ± 0.069	derived
diameter (mas)	7.7 ± 0.3	Dyck et al. (1998)
radius($R_\odot$)	31.88 ± 1.61	derived
mass ($M_\odot$)	1.23 ± 0.21	This study
$v \sin i$ (km/s)	1.1 ± 1.3	de Medeiros & Mayor(1999)
	2.6	Gray (1982)
	3.9	Massarotti et al.(2008)
	2.7	this study
$T_{\rm eff}$	4300	Tomkin et al. (1975)
	4470	McWilliam (1990)
	4330 ± 15	This study
$\log g$	1.7	Tomkin et al. (1975)
	2.35	McWilliam (1990)
	1.59	This study
[Fe/H]	-0.49 ± 0.12	Mcwilliam (1990)
	-0.51 ± 0.05	This study
ζ(km/s)	2.4	Mcwilliam (1990)
	1.5	This study

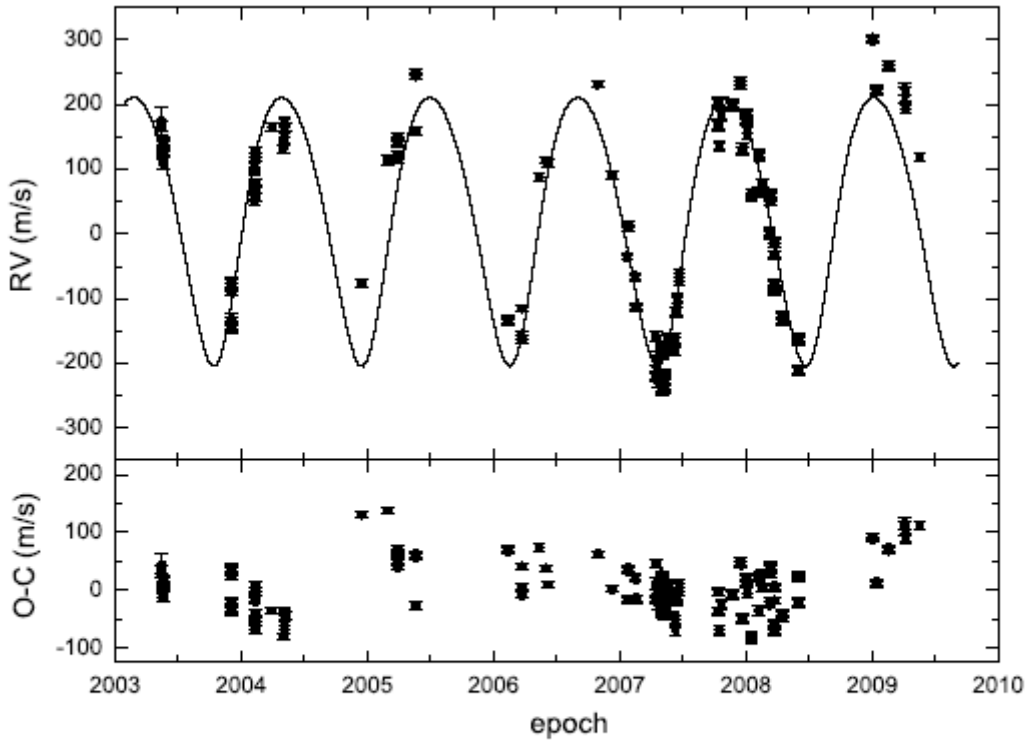


Fig. 1. Top: The observed radial velocities of γ^1 Leo . The orbital fit is shown by the solid line. Bottom: Residual RV after subtracting the orbital fit. The rms of the residuals is 40 ms^{-1}.

Period (days)	428.5 ± 1.25
K ($m\,s^{-1}$)	208.3 ± 4.3
e	0.144 ± 0.046
$T_{periastron}$	2451236 ± 13.5
ω (deg)	206.7 ± 9.2
rms ($m\,s^{-1}$)	43
reduced χ^2	48
m sin i ($M_{Jupiter}$)	8.78 ± 1.0
a (AU)	1.19 ± 0.02

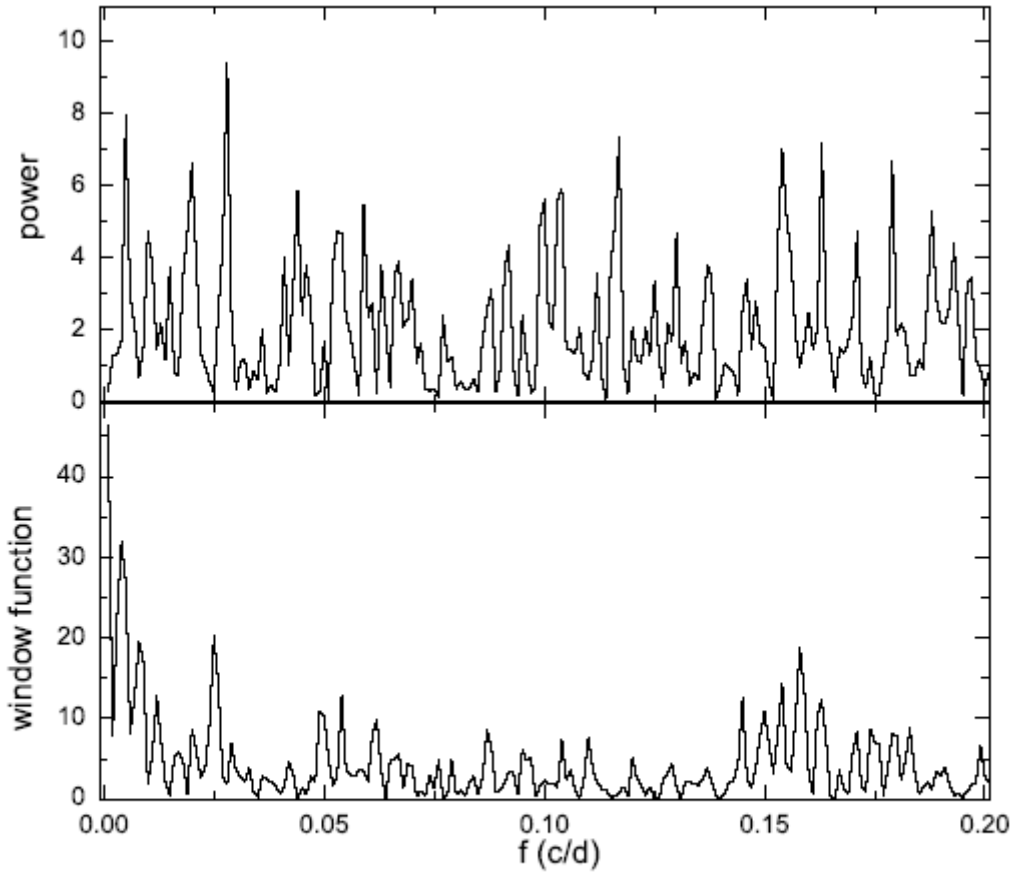


Fig. 6. The Lomb-Scargle periodogram (top) and window function (bottom) of Ca II λ 8662 line EW variation.

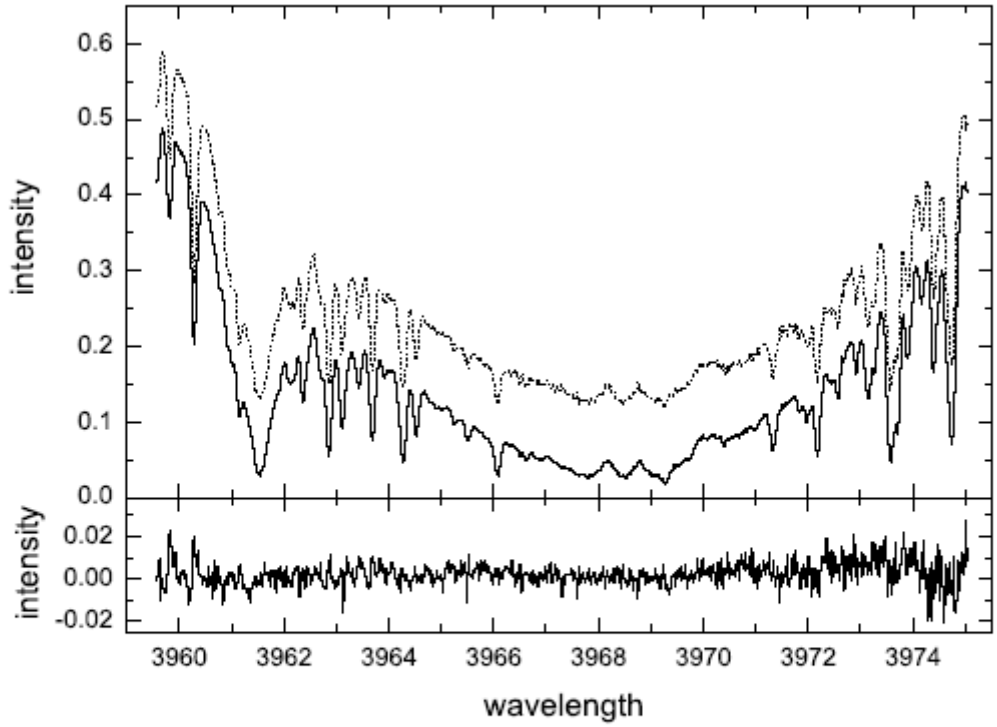


Fig. 9. Top: plot of Ca II H line profile at negative RV phase (dotted line) and positive phase (solid line). For the purpose of display, the dotted line is shifted upward by 0.1. Bottom: The difference between the two line profiles.

Gam1 Leo : main conclusions

- 428 days periodicity with more than 5 cycles
  ➔best explained by 8.8 M_Jup companion
  : expected astrometric perturbation of several tenths of milli arcseconds
- 1340-d periodicity: may imply second companion
- 8.5-d periodicity: close the expected fundamental radial pulsation frequency of the star
- one more example of low metallicity star with exoplanet

Main conclusions from the K giant survey

- about 60% of the target stars are RV variable
- about 20% of the targets shows well defined periodicic variation compatible with orbital motion
- metallicity
  Iot Dra: +0.1?, Bet Gem:+0.19, Gam1 Leo:−0.51

Future work

- to continue the RV survey and detailed study of the exoplanet stars' characteristics
- astrometric observation
- to develop more rigorous and sensitive diagnostic tools for the cause of RV variation
- to survey Ap stars to confirm the results from the K giants observation