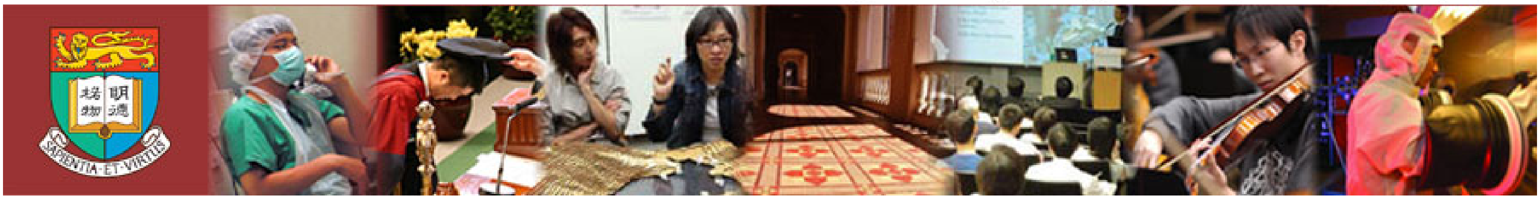

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Citation	The 2013 International Astronomical Union (IAU) Symposium 299 on Exploring the Formation and Evolution of Planetary Systems, Victoria, BC, Canada, 2-7 June 2013.
Issued Date	2013
URL	http://hdl.handle.net/10722/190779
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Discovery of a planetary system around the K giant star η Cet

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G and K Giants Survey

For more than a decade we have been studying 373 very bright (V $\leq$ 6 mag) G and K giants using high precision Doppler spectroscopy in an attempt to discover planetary companions and to understand the planet formation and evolution around intermediate-mass stars.

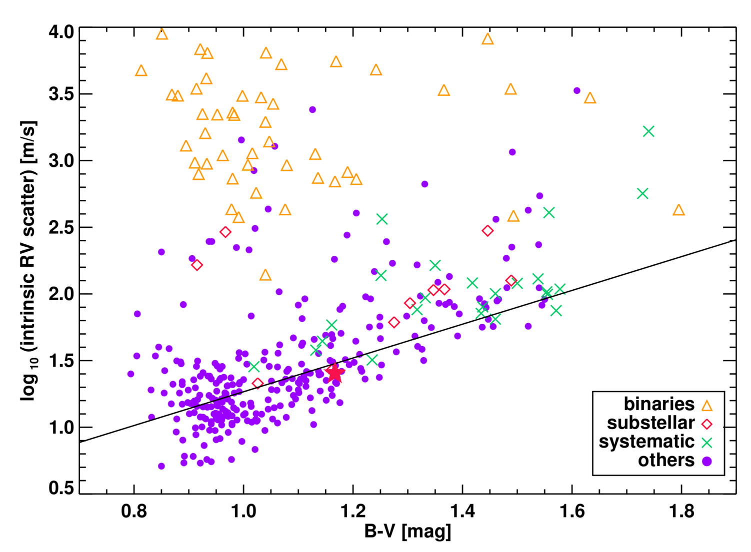
The K giant η Cet

Stellar properties of η Cet.
(HIP 5364, HD 6805, HR 334)

Spectral type	K2III$^\beta$
m_v [mag]	3.46$^\beta$
$B-V$	1.161 $\pm$ 0.005$^\beta$
Distance [pc]	38 $\pm$ 0.02$^\beta$
Mass [M$_\odot$]	1.7 $\pm$ 0.14$^\alpha$
Luminosity [L$_\odot$]	77.12 $\pm$ 1.1$^\alpha$
Radius [R$_\odot$]	14.3 $\pm$ 0.2$^\alpha$
Temperature [K]	4528 $\pm$ 19$^\alpha$
log g	2.36 $\pm$ 0.1$^\alpha$
[Fe/H]	0.07 $\pm$ 0.1$^\alpha$

α - Reffert et al. (in prep.)
β - van Leeuwen et al. (2007)

The stellar jitter



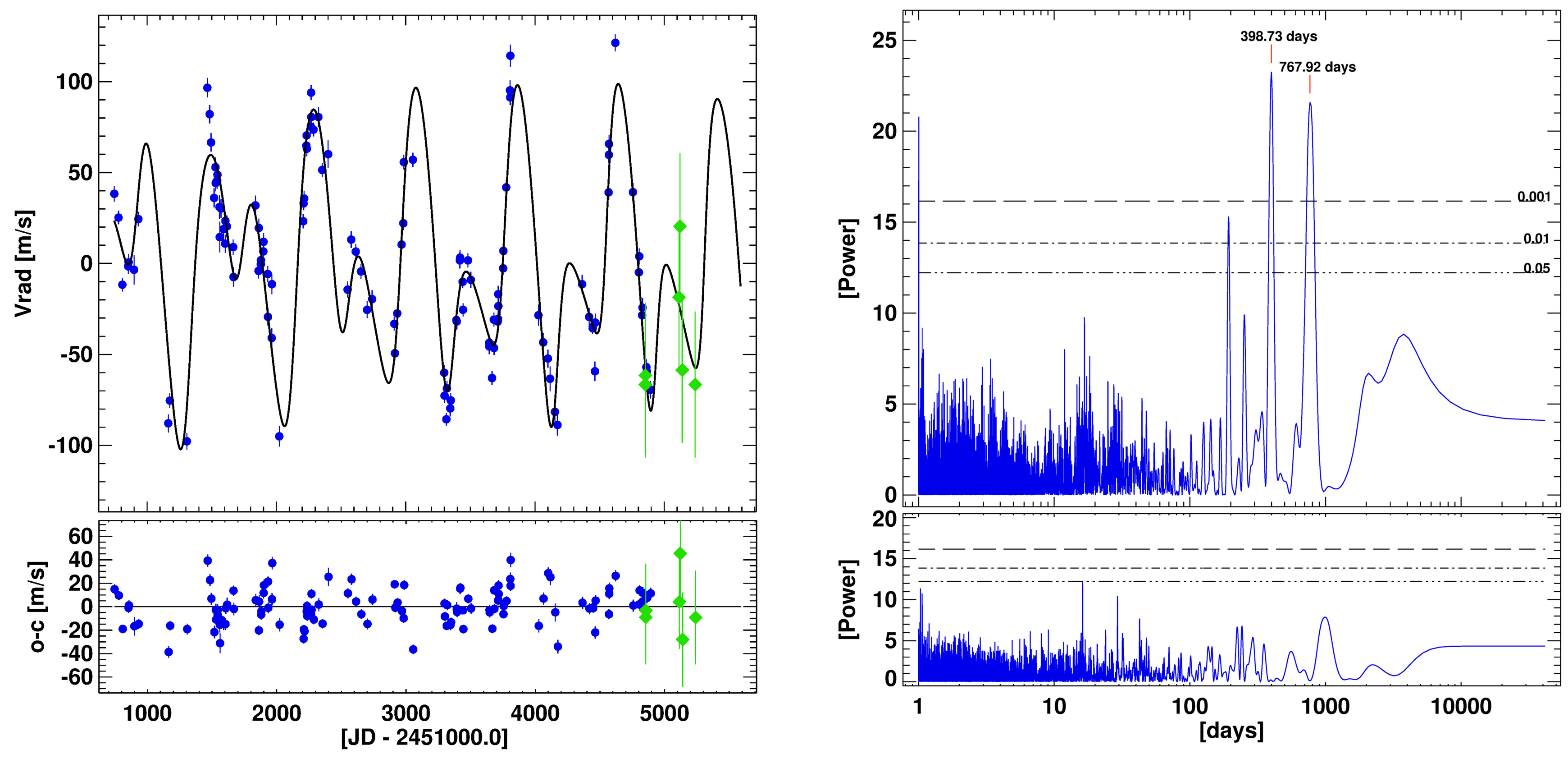
Intrinsic RV jitter observed in our sample of 373 K giants versus B–V color. A clear trend is visible in the sense that redder stars have larger intrinsic RV variations. The derived jitter for η Cet (*red star*) from the orbit fitting (15 m/s) agrees with the expected value from the trend.

RV data and the dynamical fit

- 118 optical RVs from Lick since July 2000 ($R \approx 60000$, typical error 3-5 m/s)
- Six absolute RVs in the near IR taken with CRIRES between Oct. 2011 and Dec. 2012 ($R \approx 100000$, typical error 40 m/s)
- Dynamical fit to the optical data significantly better than Keplerian fit – an evidence for interacting massive planets
- CRIRES agrees with the prediction of the dynamical model – another critical test supporting the planetary hypothesis
- Uncertainties estimated using Markov Chain Monte Carlo (MCMC) approach

2:1 MMR stable dynamical fit

Orb. Param.	η Cet b	η Cet c
P [days]	407.5 $\pm$ 2.67	744.5 $\pm$ 3.71
m sin$i$ [M_{Jup}]	2.54 $\pm$ 0.16	3.28 $\pm$ 0.19
e	0.155 $\pm$ 0.048	0.025 $\pm$ 0.046
M [deg]	211.1 $\pm$ 45.33	268.0 $\pm$ 21.33
ϖ [deg]	244.7 $\pm$ 31.64	32.5 $\pm$ 32.72
K_l [ms^{-1}]	49.6	51.7
a [AU]	1.28	1.92
$r.m.s.$ [ms^{-1}]	15.2	
χ^2_{red}	11.65 (1.013	- with jitter)

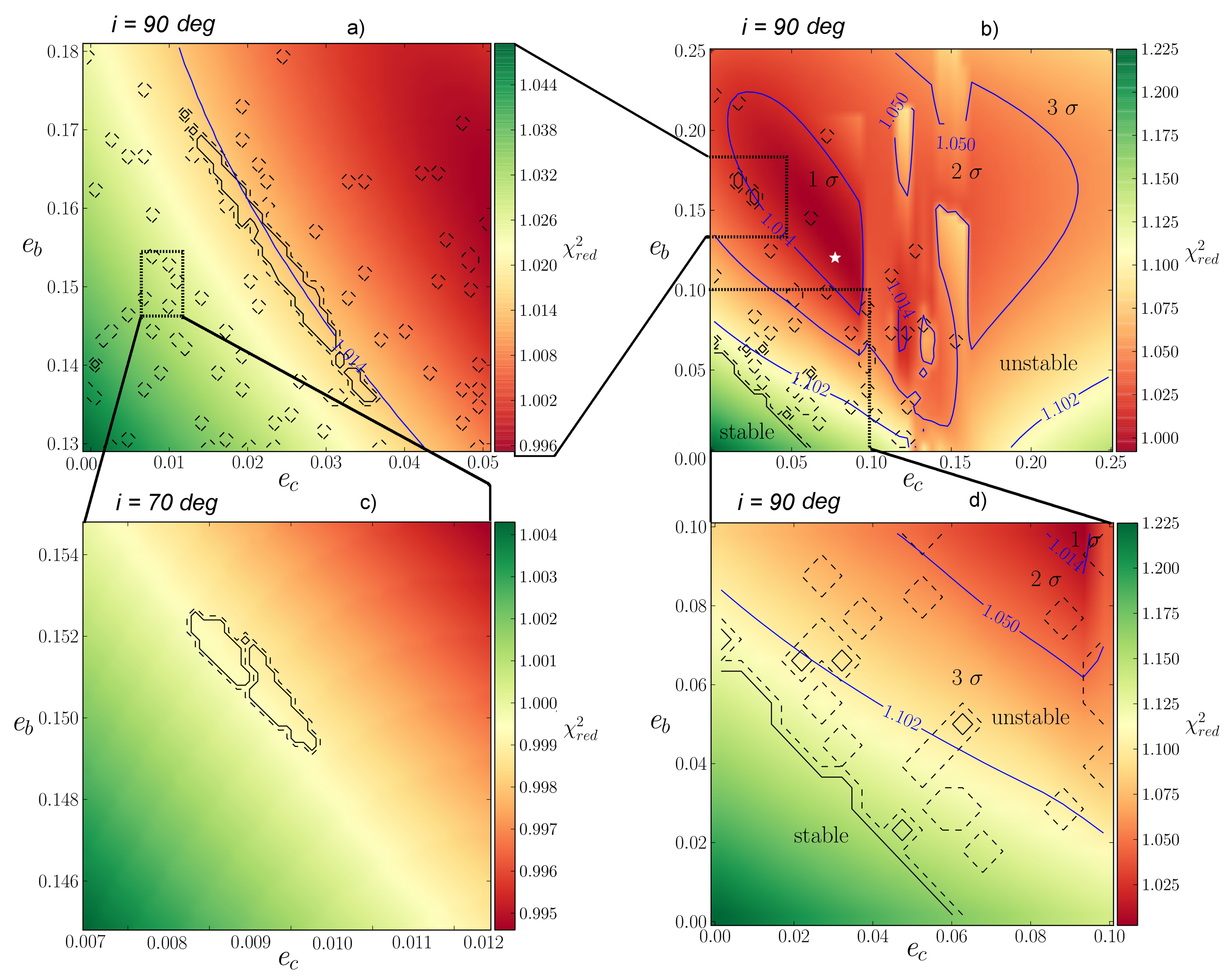


Left: Lick and CRIRES velocities are in good agreement with the best stable dynamical model (*solid line*). *Right*: Periodogram of the measured radial velocities shows two highly significant peaks around 399 and 768 days, close to the derived 407 and 740 days from the best fit. No systematics are visible in the residuals. The remaining radial velocity scatter has a standard deviation of $\approx$ 15 m/s, most likely caused by rapid solar–like p–mode oscillations.

Another possible 2:1 MMR system !

Long-term dynamical stability tests show that a narrow stable island exists with moderate eccentricities, where the mean planetary periods are in a ratio of 2:1

Stability analysis

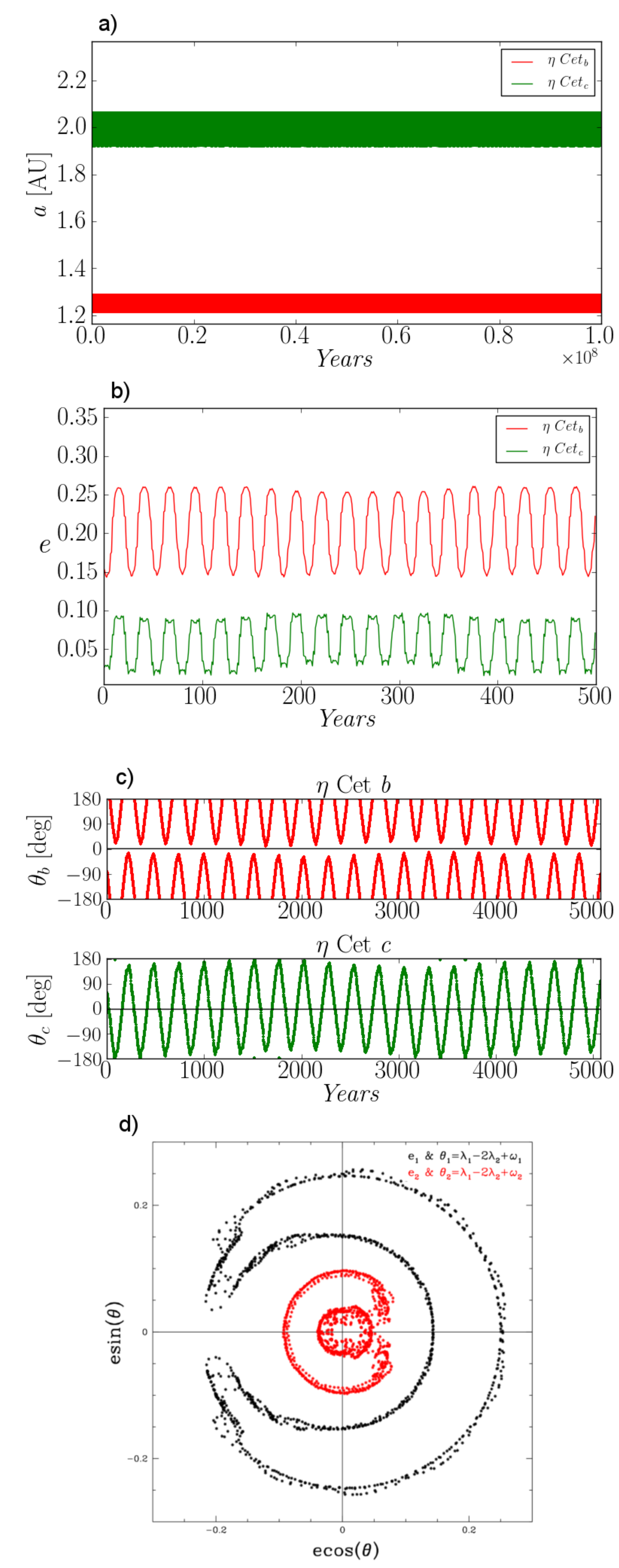


Edge-on coplanar χ^2_{red} grid with jitter included. The solid black contours indicate the stable fits, while the dashed contours indicate fits where the system survives the dynamical tests, but with chaotic scattering behavior. **b)** In the edge-on case the best dynamical fit is unstable (*white star*), however a long-term (10^8 yrs) stable 2:1 MMR region exists at the 1σ border (*blue contours*). **a)** illustrates the 2:1 MMR stable island with higher resolution. **c)** Assuming a coplanar inclined configuration the 2:1 MMR region shrinks and moves in e_b/e_c parameter space when $sin\ i\ \approx 0.94$ ($i \approx 70^\circ$). It completely vanishes when $sin\ i\ \leq 0.93$. **d)** At lower eccentricities a broad stability region exists 3σ away from the best fit, where the solutions are stable for 10^8 yrs, without being involved in any low order MMR.

Conclusions

- **The dynamical fits suggest that the η Cet system contains two strongly interacting giant planets, with $P_b\ \approx$ 407 days, $P_c\ \approx$ 740 days and minimum masses 2.6M_J, and 3.3M_J.**
- **CRIRES data confirm the radial velocity phase and amplitude from the optical and reveal another strong argument in favor of the planetary hypothesis.**
- **There is a high probability the η Cet system is nearly edge-on and involved in an anti-aligned 2:1 MMR.**
- **The stable island at near circular orbits preserves stability up to $sin\ i\ \lesssim$ 0.75 (i $\sim$ 49 deg) – this excludes the brown dwarf possibility !**

The 2:1 resonant system



a) Evolution of the planetary semi-major axis for the best 2:1 MMR fit stable for $\leq 10^8$ yrs.

b) Eccentricities are moderate and they change with large amplitudes and with the same phase.

c) The resonant angle θ_b librates around 180° and θ_c librates around 0°, practically with very large amplitude of $\sim\ \pm$180°.

d) Both resonant angles θ_c and θ_b are librating with large amplitudes, however the system is always in anti-aligned planetary configuration where the secular resonance angle $\Delta\omega$ librates around 180°.

This large-eccentricity but anti-aligned 2:1 MMR configuration is unusual because it cannot be explained so far by smooth migration capture (e.g. Lee et al. 2004).

Contact Information

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