Two Giant Planets Orbiting the K Giant Star η Cet

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Abstract. We present evidence of a new planetary system around the K giant η Cet (HIP 5364, HD 6805, HR 334), based on 124 high-precision optical and infrared radial velocity data, taken at Lick Observatory (Hamilton) and at VLT (CRIRES). The best dynamical fit to the data is consistent with two massive planets ($m_1\sin i \approx 2.6 M_{\text{Jup}}$, $m_2\sin i \approx 3.3 M_{\text{Jup}}$) and with periods of $P_1 \approx 407$ days, $P_2 \approx 740$ days. To test the η Cet system’s stability we perform ~ 10,000 dynamical investigations with maximum time spans of $10^8$ years. We find that in case of moderate eccentricities, the planets can be effectively trapped in an anti-aligned stable 2:1 mean motion resonance (MMR), very close to the separatrix. A larger non-resonant stable region exists in low-eccentricity parameter space, although less probable than the 2:1 MMR region.

Keywords. techniques: radial velocities, methods: numerical, planetary systems

1. Introduction

More than 133 known multiple-planet systems are present in the literature up to June 2013; their number is constantly growing. Nevertheless, not many multiple planetary systems have been found around evolved giant stars so far. For more than a decade we have been studying 373 very bright ($V \leq 6$ mag) G and K giants (Frink et al. 2001) using high precision Doppler spectroscopy in an attempt to discover planetary companions around intermediate-mass stars. In this study we report the detection of two Jovian planets orbiting the K giant η Cet. This system is only the fourth known planetary system around a G and K giant stars and presents an important milestone for understanding planetary formation and evolution as a function of stellar mass, metallicity and age.

2. Observations

Between Jul. 2000 and Dec. 2011, 118 optical Doppler measurements for η Cet have been obtained with the Hamilton Échelle Spectrograph at Lick Observatory ($R \approx 60,000$, $\sigma = 3-5$ ms$^{-1}$). Starting Oct. 2011, six additional near-IR data points have been taken with CRIRES ($R \approx 100,000$, $\sigma = 40$ ms$^{-1}$). Assuming the mass of η Cet to be 1.7\textit{M}_\odot (Reffert et al. submitted) the dynamical model suggests that the η Cet system contains two strongly interacting giant planets. The orbital parameters and their estimated errors from the best dynamical fit are summarized in Table 1.

3. Dynamical tests

For the stability test we have used the \textit{Mercury} N-body simulator (Chambers 1999). We took input orbital parameters from a grid of best fits for fixed $e_1$ and $e_2$ (Fig. 1 f.g). Each grid pixel is an output orbital parameter set from the orbit fitting routine, with the stellar jitter (r.m.s. = 15.1 ms$^{-1}$) quadratically added into $\sigma_{RV}$. Using those grids as an input (~10,000 fits), we find two permitted stability regions for the η Cet planetary system: either non-resonant in near-circular orbits, or with higher probability in a moderate $e_2$ regime, where the system appears to be in an anti-aligned 2:1 MMR. In this configuration the lowest order eccentricity-type resonant angle $\theta_1$ librates around 180° and $\theta_2$ librates...
Figure 1. a) The best fit model to the data. b) Semi-major axis evolution: the planets exhibit strong perturbations, but are bound in stable orbits for at least $10^8$ yr. The mean period ratio is 2:1. d) Eccentricities are rapidly changing with the same phase. c) The resonance angles $\theta_1$ and $\theta_2$ librate with very large amplitudes of $\sim \pm 180^\circ$ — very close to the separatrix, however e) shows that the system is always in an anti-aligned planetary configuration. g) Illustrates the two stable regions in the $e_1/e_2$ plane, while f) shows the 2:1 MMR region with higher resolution.

Table 1. Best fit orbital parameters of the $\eta$ Cet planetary system.

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<tr>
<th></th>
<th>$P$ [days]</th>
<th>$m \sin i$ [$M_{Jup}$]</th>
<th>$e$</th>
<th>$\chi^2_{red}$</th>
<th>r.m.s. [$ms^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta$ Cet b</td>
<td>407.5 ± 2.7</td>
<td>2.6 ± 0.2</td>
<td>0.12 ± 0.05</td>
<td>1.013</td>
<td>15.2</td>
</tr>
<tr>
<td>$\eta$ Cet c</td>
<td>739.9 ± 4.9</td>
<td>3.3 ± 0.2</td>
<td>0.08 ± 0.04</td>
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around $0^\circ$ with very large amplitudes of $\sim \pm 180^\circ$ (Fig. 1 c,e). In fact as $\theta_1$ and $\theta_2$ are almost circulating, the system is very close to the separatrix.

4. Conclusions

We provide evidence that the $\eta$ Cet system contains two strongly interacting giant planets. The dynamical simulations show that it is very likely that the system is trapped in an anti-aligned 2:1 MMR, although a non-resonant system with near circular orbits is also possible. The $\theta_1 \approx 180^\circ$ and $\theta_2 \approx 0^\circ$ 2:1 MMR configuration is unusual, because it has not been seen so far in smooth migration capture (e.g., Lee 2004).

References