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On fitting planetary systems in counter-revolving configurations

Julie Gayon-Markt^{1,2★} and Eric Bois¹

¹University of Nice Sophia-Antipolis, CNRS, Observatoire de la Côte d'Azur, B.P. 4229, F-06304 Nice, Cedex 4, France

²NASA Ames Research Center, Space Science and Astrobiology Division, MS 245-3, Moffett Field, CA 94035, USA

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ABSTRACT

In Gayon & Bois and Gayon, Bois & Scholl, (i) we studied the theoretical feasibility and efficiency of retrograde mean motion resonances (i.e. two planets are both in orbital resonance and in counter-revolving configuration), (ii) we showed that retrograde resonances can generate interesting mechanisms of stability and (iii) we obtained a dynamical fit involving a counter-revolving configuration that is consistent with the observations of the HD 73526 planetary system. In the present Letter, we present and analyse data reductions assuming counter-revolving configurations for eight compact multiplanetary systems detected through the radial velocity method. In each case, we select the best fit leading to a dynamically stable solution. The resulting data reductions obtained in rms and $\sqrt{\chi^2_{\nu}}$ values for counter-revolving configurations are of the same order, and sometimes slightly better than for prograde configurations. In the end, these fits tend to show that, over the eight studied multiplanetary systems, six of them could be regulated by a mechanism involving a counter-revolving configuration.

Key words: techniques: radial velocities – planetary systems.

1 INTRODUCTION

The orbital element determination of extrasolar planets from radial velocity measurements is relatively complex. As mentioned in Beaugé et al. (2008), the equations relating observations to orbital elements (and minimal planetary masses) are highly non-linear and generate different local minima in the parameter space, and consequently, different possible observational fits. Moreover, in order to correctly determine orbital elements, the ratio between the N number of observations and the M number of free parameters must be relatively high. But generally, the duration of observations is only of the order of two or three times the orbital period of the outer planet of a system.

Owing to the necessity of observing systems over a large number of times, the outer planet period (in order to determine orbital elements with a convenient precision), the assurance of a correct determination of orbital elements is not necessarily guaranteed. The real dynamics of multiplanetary systems found until now is consequently difficult to point out. At this time, the orbital elements of only one multiplanetary system prove to be acquired: the very compact Gliese 876 system. Known since 1998 (Delfosse et al. 1998; Marcy et al. 1998, 2001; Rivera et al. 2005), a large series of observations has allowed to gather a sufficient number of radial velocity measurements to determine with a good precision the orbital elements of the Gliese 876 main planets. Such a determination has

continually been improved since 1998. While the two major planets are revolving around their host star in about 30 and 60 d, observations have been performed for 7 yr. The N/P ratio between the number of observations (N) and the orbital period (P) of planets is then particularly high and permits a good precision of the Gliese 876 system fit. Unfortunately, the whole of other detected multiplanetary systems does not present such a high N/P ratio. The orbital determination of all the other systems is not still completely acquired. In the present Letter, we propose to carry out new observational fits for specific configurations of several compact multiplanetary systems. For eight compact planetary systems (HD 37124, HD 69830, HD 73526, HD 108874, HD 128311, HD 155358, HD 160691 and HD 202206), we indeed assume that one planet of each system moves in retrograde direction on its orbit, while other planets have a prograde motion around the host star.

2 METHOD

In this Letter, we particularly focus on systems harbouring planets with large masses and close to their host star. As a consequence, the Keplerian approximation is no longer suitable. It is necessary to perform dynamical fits instead. We use a genetic algorithm (PIKAIA; see Charbonneau 1995) with a set of initial conditions randomly taken in the orbital parameter space. We refer to Beaugé, Ferraz-Mello & Michtchenco (2007) for a complete description of the radial velocity method and the use of the PIKAIA code. Owing to the current theories of planetary formation (in a disc of gas and dust) and to a large number of parameters to fit in the case of orbital motions in

★E-mail: julie.gayon@oca.eu

a three-dimensional space, dynamical fits are generally performed while considering coplanar (and prograde) configurations. Hence, the code we use was first developed for such prograde and coplanar orbits. As a consequence, we have modified the PIKAIA code in such a way that observational fits can be performed for planetary systems harbouring one planet (whatever its location within the system) in retrograde motion on its orbit (contrary to other planets of the same system).

3 DATA REDUCTION

We have carried out dynamical fits for eight systems in counter-revolving configurations (HD 37124, HD 69830, HD 73526, HD 108874, HD 128311, HD 155358, HD 160691 and HD 202206). In each case, we have selected the best fits leading to dynamically stable solutions. While for most systems a fit involving two planets is sufficient to obtain a rather good fit (i.e. $\sqrt{\chi_v^2}$ close to 1), the assumption of three planets for the dynamical fits of the HD 37124

and HD 69830 systems is necessary. The orbital elements found for the best fit of each system are presented in Table 1, whereas the new values of $\sqrt{\chi_v^2}$ and rms are compared, in Table 2, to previous fits coming from prograde configurations (see Udry et al. 2002; Vogt et al. 2005; Butler et al. 2006; Lovis et al. 2006; Tinney et al. 2006; Cochran et al. 2007; Sándor, Kley & Klagyivik 2007). Some systems are henceforth found close to retrograde mean motion resonances (R-MMR) : HD 73526 and HD 128311 (2:1 R-MMR), HD 108874 and HD 160691 (4:1 R-MMR), HD 202206 (5:1 R-MMR), HD 155358 (8:3 R-MMR). The new radial velocities are plotted in Fig. 1 according to the new dynamical fits of each studied planetary system.

In most cases, rms and $\sqrt{\chi_v^2}$ values obtained for counter-revolving configurations are of the same order, and sometimes slightly better than for prograde configurations (see Table 2). Because the fit of the HD 160691 planetary system proves to be very bad ($\sqrt{\chi_v^2} = 2.439$) while considering two planets in counter-revolving configuration, we have tried to obtain a better result by

Table 1. New data reductions obtained for counter-revolving configurations from the following planetary systems : HD 37124 ($M_* = 0.78 M_\odot$), HD 69830 ($M_* = 0.86 M_\odot$), HD 73526 ($M_* = 1.08 M_\odot$), HD 108874 ($M_* = 0.99 M_\odot$), HD 128311 ($M_* = 0.84 M_\odot$), HD 155358 ($M_* = 0.87 M_\odot$), HD 160691 ($M_* = 1.15 M_\odot$) and HD 202206 ($M_* = 1.15 M_\odot$). Non-zero stellar jitters were used for several planetary systems : HD 37124 (3.2 m s^{-1}), HD 108874 (3.9 m s^{-1}), HD 128311 (8.9 m s^{-1}), HD 155358 (5.0 m s^{-1}).

System		m_P (M_{Jup})	P (d)	a (au)	e	i ($^\circ$)	ω ($^\circ$)	M ($^\circ$)
HD 37124	<i>b</i>	0.2059	29.377	0.1715	0.5155	0.0	250.725	64.772
	<i>c</i>	0.5894	155.332	0.5207	0.1184	180.0	266.521	334.402
	<i>d</i>	0.7575	841.881	1.6067	0.0628	0.0	49.524	325.545
HD 69830	<i>b</i>	0.0318	8.666	0.0785	0.0955	0.0	339.102	264.170
	<i>c</i>	0.0375	31.563	0.1859	0.1278	0.0	216.406	81.289
	<i>d</i>	0.0583	197.992	0.6322	0.0110	180.0	90.368	276.112
HD 73526	<i>b</i>	2.4921	187.935	0.6593	0.2401	0.0	184.569	97.297
	<i>c</i>	2.5919	379.795	1.0538	0.2048	180.0	58.545	221.361
HD 108874	<i>b</i>	1.2141	395.452	0.9953	0.0580	0.0	92.572	355.512
	<i>c</i>	0.8979	1588.626	2.5149	0.2497	180.0	17.102	27.604
HD 128311	<i>b</i>	1.5571	453.626	1.0908	0.3550	180.0	278.933	168.259
	<i>c</i>	3.2205	941.213	1.7756	0.1485	0.0	49.517	235.211
HD 155358	<i>b</i>	0.8619	194.882	0.6282	0.1262	0.0	162.492	131.054
	<i>c</i>	0.5017	528.377	1.2213	0.1732	180.0	88.737	207.200
HD 160691	<i>b</i>	1.5328	624.994	1.4684	0.3547	0.0	76.468	131.374
	<i>c</i>	1.1699	2454.668	3.6550	0.4324	180.0	174.806	178.448
HD 202206	<i>b</i>	17.4168	255.794	0.8302	0.4333	0.0	161.125	353.396
	<i>c</i>	2.7195	1235.281	2.3623	0.4012	180.0	277.846	71.407

Table 2. V_0 , rms and $\sqrt{\chi_v^2}$ values obtained for prograde and counter-revolving configurations.

Systems	Counter-revolution configurations			Prograde configurations		Ref.
	V_0 (m s^{-1})	rms (m s^{-1})	$\sqrt{\chi_v^2}$	rms (m s^{-1})	$\sqrt{\chi_v^2}$	
HD 37124	3.397	5.008	1.351	4.14–5.12	0.96–1.14	(1)
HD 69830	30 289.729	0.808	1.100	0.81	1.095	(2)
HD 73526	−25.201	6.3398	1.257	8.04–8.36	1.58–1.87	(3),(4)
HD 108874	16.923	3.274	0.386	3.7	0.74	(1)
HD 128311	−0.066	15.785	1.785	18	1.9	(1)
HD 155358	10.751	5.904	1.074	6.0	1.15	(5)
HD 160691	0.550	3.469	2.439	4.7	1.1	(6)
HD 202206	14 706.445	8.517	1.418	9.6	1.5	(7)

Note. The values indicated for the prograde configurations come from: (1) Vogt et al. (2005), (2) Lovis et al. (2006), (3) Tinney et al. (2006), (4) Sándor et al. (2007), (5) Cochran et al. (2007), (6) Butler et al. (2006), (7) Udry et al. (2002).

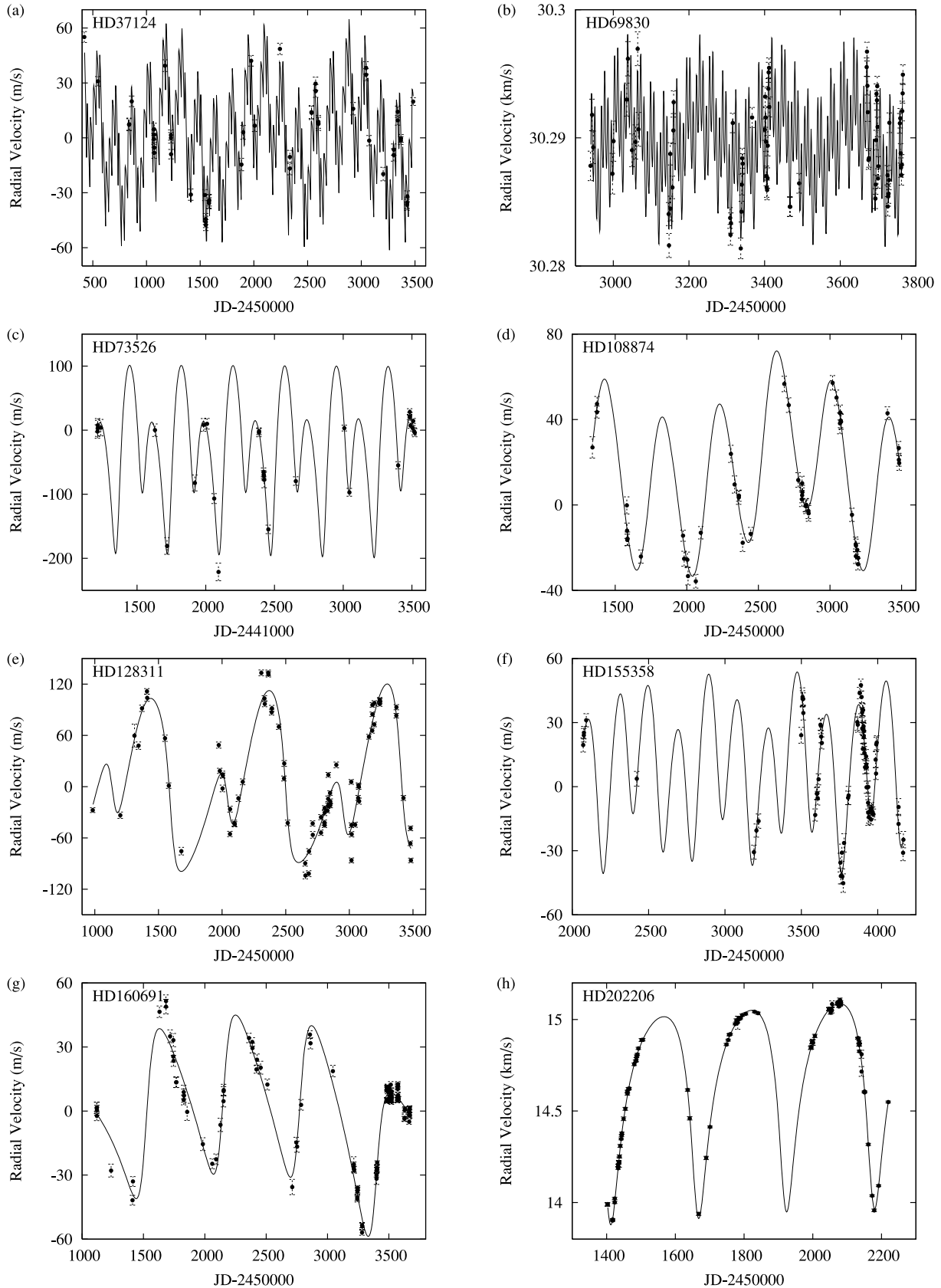


Figure 1. Dynamical fits with measured radial velocities of the following planetary systems : (a) HD 37124, (b) HD 69830, (c) HD 73526, (d) HD 108874, (e) HD 128311, (f) HD 155358, (g) HD 160691 and (h) HD 202206. Orbital elements are presented in Table 1. Radial velocity measurements are given in the references noted in Table 2.

performing a new fit with three planets, one of them revolving in retrograde motion (not shown here). However, we also find a high value of $\sqrt{\chi_r^2}$. The prograde fit for this system proves to be definitely better. In the end, for the other systems (except for the HD 37124 system), the counter-revolving configurations are consistent with the current observational data.

4 DISCUSSION

The dynamical fits presented in the present Letter tend to show that, over the eight studied multiplanetary systems, the six of them are liable to be regulated by a mechanism involving a counter-revolving configuration with a retrograde MMR. Except for the HD 37214 and HD 160691 systems for which the retrograde fits are undeniably bad, the whole of other fits are slightly better than fits in prograde configurations. Nevertheless, it remains necessary to perform new series of observations in order to enlarge the observational data samples and, as a consequence, to obtain more precise results.

Although counter-revolving configurations seem possible both from an observational point of view (i.e. with observational consistency) and from a theoretical one,¹ the formation of such systems does not seem obvious. Indeed, the assumption that two giant planets are in a MMR and revolving in opposite directions around their hosting star is apparently contradicting to the most accepted formation theory of planetary systems, notably to the formation and evolution of the resonant planetary systems (core accretion mechanism combined by a planetary migration scenario). However, as mentioned in Gayon & Bois (2008), two feasible processes leading to planets revolving in opposite directions have been found. The first scenario has been introduced by Nagasawa, Ida & Bessho (2008). Starting from a hierarchical three-planet system and considering a migration mechanism including a process of planet–planet scattering as well as a tidal circularization, the authors show that close-in planets may be formed. In a few cases, due to the Kozai mechanism, one planet may enter a retrograde motion. On the other hand, with Varvoglis, we have imagined a second feasible process that is related to the capture of free-floating planets (private discussions).

¹ See Gayon & Bois (2008) and Gayon et al. (2009) for a theoretical study on the feasibility and efficiency of two planets to be in R-MMR.

By integrating the trajectories of planet-sized bodies that encounter a coplanar two-body system (a Sun-like star and a Jupiter mass), Varvoglis has found that the probability of capture is significant. Moreover, the percentage of free-floating planets forever captured is higher for retrograde motions than for prograde motions. As a consequence, it seems possible to find one day some planetary systems stabilized in counter-revolving configurations.

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