EPSC Abstracts
Vol. 8, EPSC2013-172, 2013
European Planetary Science Congress 2013

The curious case of Kepler-36

S. Paardekooper(1), H. Rein (2), W. Kley (3)
(1) DAMTP, University of Cambridge, UK (2) IAS, Princeton, USA (3) Universität Tübingen, Germany

Abstract

The planetary system Kepler-36 consists of two planets extremely close together (semi-major axis differ by $\sim$ 10 % only) but have very different compositions: the outer planet is 8 times less dense compared to the inner planet. It is a challenge for planet formation theory to come up with a plausible scenario explaining this odd couple. We show that convergent migration of planets in a turbulent protoplanetary disc can naturally account for systems like this, a scenario in which the planets come very close together through tidal forces from the disc, while the turbulent nature of the disc allows the system to pass through all resonances along the way, all the time avoiding close encounters and instability. The result is a stable planetary system close to a 7:6 mean motion resonance, in agreement with observations.

1. Introduction

Kepler-36 [1] consists of an inner rocky planet and an outer gaseous planet, orbiting close to a 7:6 commensurability. The parameters of the system are summarised in Table 1.

	Planet b	Planet c
Mass ($10^{-5}M_*$)	1.33	2.42
Semi-Major axis (AU)	0.1153	0.1283
Eccentricity	< 0.04	< 0.04
Period (d)	13.83989	16.23855
Mean density (g cm^{-3})	7.46	0.89

Table 1: Properties of the Kepler-36 planetary system, where the stellar mass is $M_* = 1.071\ \mathrm{M}_\odot$. Data adapted from [1].

It is quite a surprise to see two planets of such different structure so close together. In the Solar system, for example, there is an obvious composition gradient, with terrestrial planets close to the Sun and gas giant planets further away. This is thought to reflect different conditions at the time of formation. In the case of Kepler-36, it is difficult to see how, in this picture, a Neptune-type planet can be that close to a Super-Earth.

A second mystery is that the system is very close to being chaotic [2], with Lyapunov time scales of only 10 years. Moreover, only a few percent of the orbits consistent with the observations is stable [2]. It therefore seems that the parameters of this system are very finely tuned.

2. Planet migration and resonances

Since the discovery of the first extrasolar planet around a Solar type star [4], we know that planets can migrate after their formation, a mechanism involving interaction with the protoplanetary disc that is usually invoked to explain gas giant planets very close to their central star. However, since the speed of migration depends on the mass of the planet, planet migration can bring planets of different mass together, a process known as convergent migration.

Planets undergoing convergent migration usually end up in mean motion resonances (MMRs). The most famous example is probably Gliese 876, a system in a 2:1 MMR [5, 6, 7]. Resonances of higher degree (e.g. 3:2, 4:3) can be obtained for low mass planets in more massive discs [8]. Getting close to the 7:6 MMR, as is necessary for Kepler-36, would require an extremely massive disc, on the brink of gravitational instability. Such a massive disc would not last very long, so that an extremely short formation time for these planets would be required. Moreover, migration time scales would also be alarmingly short, making survival of this system problematic.

3. This work

Protoplanetary discs are thought to be turbulent. This turbulence, most likely due to the magneto-rotational instability [9], drives accretion onto the central star, but it also leads to stochastic gravitational forces onto any embedded planets [10]. These stochastic forces can have dramatic impact on the formation of resonances [11]. We studied planet migration for the

Kepler-36 system in a turbulent disc, using both hydrodynamical and modified N-body simulations [12]. A typical example hydrodynamic run for different levels of stochastic forcing is shown in Fig. 1.

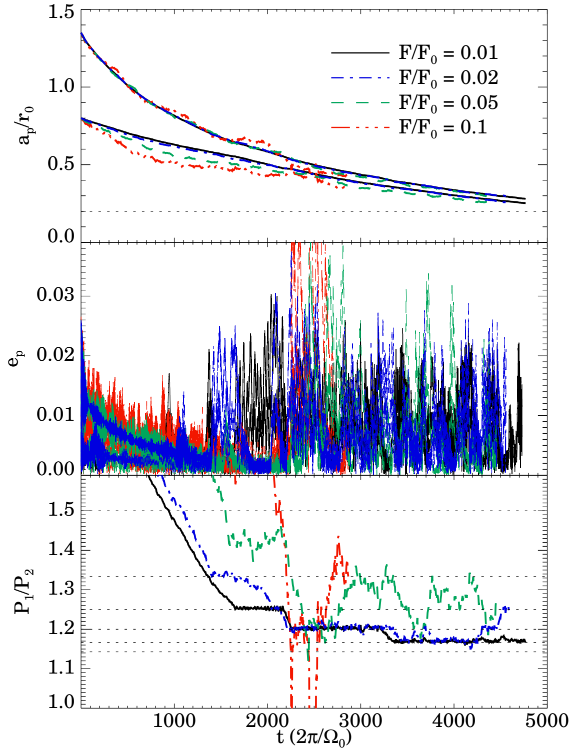

Figure 1: Evolution of a planetary system with masses similar to the Kepler-36 system in a hydrodynamic simulation with a surface density profile $\Sigma = 1.6 \cdot 10^{-3}(r/r_0)^{-1/2}\ M_*/r_0^2$ with different levels of stochastic forcing F in terms of $F_0 = \pi G \Sigma/2$. Here, r_0 is a reference radius, and for $r_0 = 1$ AU, time is in units of years. Top panel: semi-major axis; the horizontal dotted line shows the inner edge of the computational domain. Middle panel: eccentricity, where the largest value of e always belongs to the inner, lower mass planet. Bottom panel: period ratio; the horizontal dotted lines show first order commensurabilities, from 3:2 (top) to 8:7 (bottom).

This particular disc would in the absence of stochastic forcing, lead to a 4:3 MMR. However, even a very mild level of stochastic forcing completely changes the picture. The system moves through the earlier, weaker resonances, and ends up close to the 7:6 MMR (black and blue lines) for a significant amount of time. Of course, no resonance is stable in the presence of stochastic forcing, and the system can hover between resonances. This way, planets can come very close together even in low-mass discs comparable to the Minimum Mass Solar Nebula, showing that this mechanism can indeed account for planetary systems like Kepler-36.

Acknowledgements

We would like to thank Katherine Deck, Josh Carter, Yanqin Wu, James Owen and Clément Baruteau for stimulating discussions. SJP is supported by a Royal Society University Research Fellowship. Hanno Rein was supported by the Institute for Advanced Study and the NFS grant AST-0807444. Some of the simulations using FARGO were performed using the Darwin Supercomputer of the University of Cambridge High Performance Computing Service (http://www.hpc.cam.ac.uk), provided by Dell Inc. using Strategic Research Infrastructure Funding from the Higher Education Funding Council for England.

References

[1] Carter J. A., Agol E., Chaplin W. J. e. a., 2012, Science, 337, 556

[2] Deck K. M., Holman M. J., Agol E., Carter J. A., Lissauer J. J., Ragozzine D., Winn J. N., 2012, ApJ, 755, L21

[3] Author, A., Author, B., and Author, C.: First example of a cited article title, First Example Journal, Vol. 1, pp. 1-100, 1999.

[4] Mayor M., Queloz D., 1995, Nature, 378, 355

[5] Marcy G. W., Butler R. P., Fischer D., Vogt S. S., Lissauer J. J., Rivera E. J., 2001, ApJ, 556, 296

[6] Snellgrove M. D., Papaloizou J. C. B., Nelson R. P., 2001, A&A, 374, 1092

[7] Lee M. H., Peale S. J., 2002, ApJ, 567, 596

[8] Papaloizou J. C. B., Szuszkiewicz E., 2005, MNRAS, 363, 153

[9] Balbus S. A., Hawley J. F., 1991, ApJ, 376, 214

[10] Nelson R. P., Papaloizou J. C. B., 2004, MNRAS, 350, 849

[11] Rein H., Papaloizou J. C. B., 2009, A&A, 497, 595

[12] Paardekooper S.-J., Rein H., Kley, W., 2013, submitted