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Global aspects of the formation of γ Cephei b

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Abstract. Discoveries of extrasolar planets in tight binaries are of great scientific value since these systems can be used to gain new insights in planetary development processes. Gamma Cephei, one of the most thoroughly investigated double star systems is hosting a Jovian planet at a distance of about 2 AU from its primary, a 1.4 solar-mass K1 III-IV star (Neuhäuser *et al.* 2007; Torres 2007). We comprise aspects of dynamical stability, disc heating processes and different giant planet (GP) formation scenarios in order to gain a better understanding of the open questions that remain in explaining the formation of gamma Cephei b.

Keywords. planetary systems: formation, binaries: general, planetary systems: protoplanetary disks

1. Introduction

A very attractive system from a dynamical point of view, gamma Cep has been a focus of scientific interest ever since the first announcement of the existence of a planet in the system (Hatzes *et al.* 2003). The topics were centered on possible additional planets (Dvorak *et al.* 2003; Haghighipour 2006) as well as different formation scenarios (Thebault *et al.* 2004; Kley & Nelson 2008; Xie & Zhou 2009). Dynamical studies show, that the binaries' highly eccentric orbit ($e \approx 0.4$) and the relatively small separation of the stellar components ($a \approx 20\ AU$) restrict the stable area around the primary gamma Cep A to about 4 AU. When constant gas drag is included in N-Body simulations, Thebault *et al.* (2004) find that a core accretion (CA) model (Pollack *et al.* 1996) is capable of producing a GP of comparable mass in required timescales, but well inside its observed orbit. Besides CA, GP formation through gravitational instability (GI) (Boss 2001) is one of the most widely accepted theories. We are interested whether GI can be considered a viable formation scenario for the GP gamma Cep b.

2. Methods

Apart from surface-density, a protoplanetary disc's temperature is one of the most important parameters in planetary formation. It is vital in all current models, preventing or facilitating GI induced collapses (Kratter *et al.* 2010), as well as granting an effective density boost outside the so called 'Snow Line' (Kennedy & Kenyon 2008). Typically two major heat sources are taken into account, the radiative influence of the star as well as viscous dissipation of gravitational potential energy within the accretion disc itself. In the case of gamma Cephei the cyclic pumping caused by the secondary constitutes another main source of disc heating. In order to gain reliable estimates on the temperature development in the heavily perturbed circumprimary disc, hydrodynamic simulations are essential. We use a modified version of the grid code described in Theis & Orlova (2004) including energy transfer and FARGO transport (Masset 2000). The disc's surface density was chosen, so that the existing GP should be able to form at a distance of 2 AU with respect to the available mass within its feeding zone (Lissauer 1987). This resulted in a density $\rho_0 = 2 \cdot 10^{-9}$ g/cm^3 equal to the value used in Thebault *et al.* (2004). We also estimated the mass requirements of a CA based planetary core (10 M_{earth}) to form from coagulated dust in the orbital plane which produced a density about three to five times as high featuring a dust to gas ratio of 10^{-2}. The simulation was started with an initial density decay law of $r^{-3/4}$, as well as standard values for viscosity and temperature profiles. In order to separate internal disc heating from stellar heating processes we did not include stellar radiation in our hydrodynamic simulations. Instead we used analytical temperature estimates on the stellar influence for passive flat (Safronov 1972) as well as flared discs (Bell 1999) without photon reprocessing, adapted to the early gamma Cep system. It is important to consider the stars' evolutionary tracks in this respect, putting the primary close to a spectral type of F1.

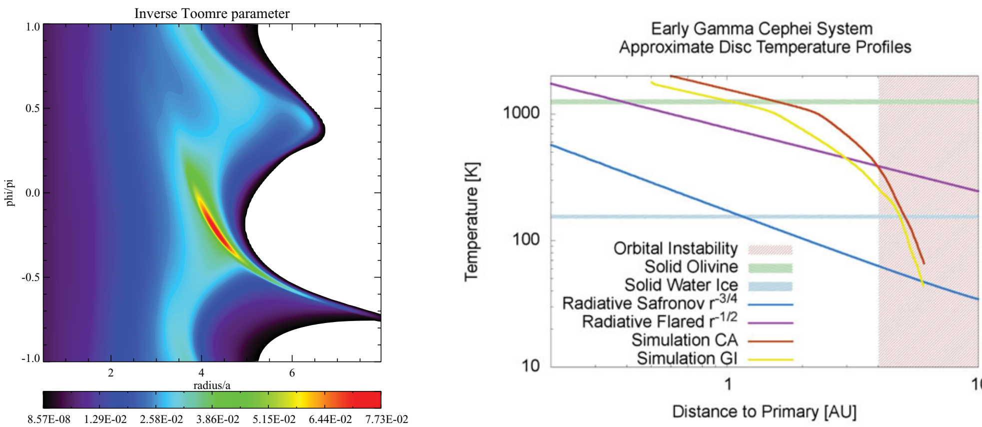

Figure 1. *left:* Snapshot of the inverse Toomre parameter after 100 binary revolutions. Values below 10^{-8} are depicted as white. *right:* Azimuthally averaged temperature profiles of the disc featuring analytical estimates on stellar radiative heating of a passive, flat, optically thick disc, a flared disc, and disc profiles resulting form hydrodynamic simulations without stellar radiative heating for different initial densities. Evaporation temperatures are taken from Pollack *et al.* (1994).

3. Results

We calculated the azimuthally averaged disc temperatures (Figure 1, *right*), the inverse Toomre parameter (Figure 1, *left*) and checked the cooling criterion (Kratter *et al.* 2010) for two non self gravitating disc models around gamma Cep A throughout 100 binary revolutions. After the initial relaxation phase the inverse Toomre parameter did not exceed unity, even-though the cooling criterion was fulfilled in vast regions of the disc, meaning that a GI induced collapse is not possible in this setup. The temperature profiles of the disc are also unfavorable for CA models since the snow line will not be reached inside the dynamically stable region. Our next steps will be inclusion of self-gravity in our calculations, as well as the study of the influence of initial parameters on these results, in order to approach answers to the open questions on the formation of gamma Cep b.

References

Bell, K. R. 1999, *ApJ*, 526, 411
Boss, A. P. 2001, *ApJ*, 563, 367
Dvorak, R., Pilat-Lohinger, E., Funk, B., & Freistetter, F. 2003, *A&AL*, 398, 1

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Haghighipour N. 2006, *ApJ*, 644, 543
Hatzes, A. P., Cochran, W. D., Endl, M., McArthur, B., Paulson, D. B., Walker, G. A. H.., Campbell, B., & Yang, S. 2003, *ApJ*, 599, 1383
Kennedy, G. M. & Kenyon, S. J. 2008, *ApJ*, 673, 502
Kley, W. & Nelson, R. P. 2008, *A&A*, 486, 617
Kratter, K. M., Murray-Clay, R. A., & Youdin, A. N. 2010, *ApJ*, 710, 1375
Lissauer, J. J. 1987, *Icarus*, 69, 249
Masset, F. 2000, *A&AS*, 141, 165
Neuhäuser, R., Mugrauer, M., Fukagawa, M., Torres, G., & Schmidt, T. 2007, *A&A*, 462, 777
Pollack, J. B., Hollenbach, D., Beckwith, S., Simonelli, D. P., Roush, T., & Fong, W. 1994, *ApJ*, 421, 615
Pollack, J. B., Hubickyj, O., Bodenheimer, P., Lissauer, J. J., Podolak, M., & Greenzweig, Y. 1996, *Icarus*, 124, 62
Safronov, V. S. 1972, *Academy of Sciences USSR, IPST*
Thebault P., Marzari, F., Scholl, H., Turrini, D., & Barbieri, M. 2004, *A&A*, 427, 1097
Theis, Ch. & Orlova, N. 2004, *A&A*, 418, 959
Torres, G. 2007, *ApJ*, 654, 1095
Xie, J. & Zhou, J. 2009, *ApJ*, 698, 2066