Alex Dunhill &
Richard Alexander
email: alex.dunhill@leicester.ac.uk

The Curiously Circular Orbit of Kepler-16b

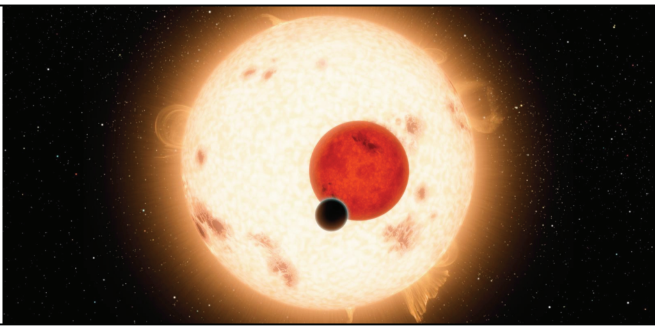
University of Leicester
Theoretical Astrophysics Group

Kepler's circumbinary planets

To date, *Kepler* has discovered 6 circumbinary planetary systems. Despite low number statistics, indications are that ~1-10% of close binary systems may host such planets (Welsh et al. 2012).

Notably, these planets are co-planar and lie on the edge of dynamical stability, indicating that they arrived at their current orbits through gentle disc migration rather than through catastrophic interactions such as scattering.

The trend is towards low eccentricity planets orbiting moderately eccentric binaries. Kepler-16b is particularly noteworthy as it has e_p = 0.0069 (Doyle et al. 2011). Previous simulations (e.g. Pierens & Nelson 2008) have shown that a planet migrating through a circumbinary disc will grow its eccentricity on short timescales, making these almost circular planetary orbits something of a mystery.



Credit: NASA / JPL-Caltech / R. Hurt

Simulations

We have performed a series of high resolution (10^7 particle) SPH simulations of an analogue to the Kepler-16 system embedded in a circumbinary disc, using a modified version of the code GADGET-2 (Dunhill et al. 2013). Our implementation carefully follows the dynamics of the planetary and stellar bodies. We have also included a time-dependent artificial viscosity prescription, in addition to a Navier-Stokes viscosity. This is parameterised as a Shakura-Sunyaev alpha-disc with α = 0.01. A representative snapshot of the inner region of one of our simulations is shown in Figure 1.

We ran three primary models, changing the planet mass and eccentricity. We find that a planet of Kepler-16b's mass does not open a full gap in the disc and so its eccentricity is strongly damped by positive torques from co-orbital material. Comparing runs with an initially eccentric planet (e_0 = 0.05) we find that there are no significant changes in how the planet's orbit evolves beyond the difference in total angular momentum of the system (see Figure 2).

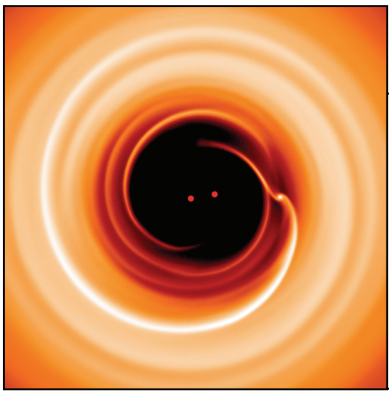


Figure 1: A representative surface density rendering of the central region of one of our SPH disc simulations, using a logarithmic colour scale.

The hydrodynamic behaviour in all of our models follows this pattern, with the gas interior to the planet driven by the binary and exterior dominated by a single spiral mode.

Abstract

Using SPH simulations of a Kepler-16 analogue embedded in a circumbinary disc, we find eccentricity damping due to disc torques. This can explain the observed low eccentricity of the planet Kepler-16b. We use the surface density scaling of these torques to place a limit on the surface density of the disc in which Kepler-16b formed and migrated.

Disc torques and surface density

Orbit-averaged disc torques on the planet Γ_d are presented in Figure 2 for our three models, showing that a trend towards positive torques emerges. Assuming that the planet never had a significantly eccentric orbit, an effect of these torques must be to damp its eccentricity.

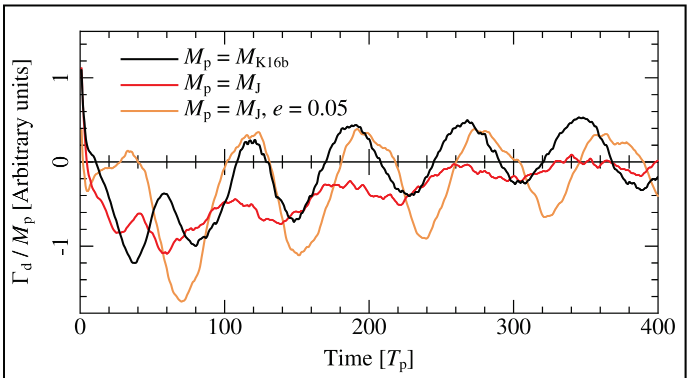


Figure 2: Orbit-averaged disc torques on the planet for our Kepler-16 analogues embedded in a 'canonical' circumbinary disc. The trend in all three cases is towards positive torques, which act to damp the planet's eccentricity. This mechanism is a possible explanation for how *Kepler*'s circumbinary planets managed to maintain their low eccentricities.

The level of the torques measured from these simulations can be used to set a real limit on the gas surface density Σ_p of the disc it migrated through, as the one scales linearly with the other. Assuming that its eccentricity was always low (e_p < 0.1), this gives the angular momentum that the disc torques must act to damp. If the eccentricity damping timescale τ_e is similar to the planet's migration time (Pierens & Nelson 2008), we have

$$\Sigma_p \lesssim 120 \left(\frac{\tau_e}{10^4\,\Omega_p} \right)^{-1} \text{g cm}^{-2}$$

Assuming an order of magnitude uncertainty in τ_e, this gives a lower limit on the surface density of Σ_{min} ~ 10 - 100 g cm^{-2}.

Given the current lack of observational constraints on disc surface densities at small radii this lower limit may provide an important constraint on theories of planet formation.

References

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A pdf of this poster and movies of our simulations can be found at http://www.astro.le.ac.uk/~acd23/K16.html