Black Holes from Stars to Galaxies – Across the Range of Masses
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Self-gravitating warped disks around nuclear black holes

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Abstract. Many galactic nuclei contain disks of gas and possibly stars surrounding a supermassive black hole. These disks may play a key role in the evolution of galactic centers. Here we address the problem of finding stable warped equilibrium configurations for such disks, considering the attraction by the black hole and the disk self-gravity as the only acting forces. We model these disks as a collection of concentric, circular rings.

We find the equilibria of such systems of rings, and determine how they scale with the ring parameters and the mass of the central black hole. We show that in some cases these disk equilibria may be highly warped. We then analyze the stability of these disks, using both direct time integration and linear stability analysis. This shows that the warped disks are stable for a range of disk-to-black hole mass ratios, when the rings extend over a limited range of radii.

Keywords. Galaxies: nuclei, dynamics, black hole physics.

1. Introduction

Nuclear disks are known to exist in many galaxies (see for example Herrnstein *et al.* (1996); Genzel *et al.* (2003)). We address the problem of finding stable warped configurations for such disks.

2. Stable Warped Disks

The disk is modeled as a collection of concentric, self-gravitating circular rings surrounding a black hole. The mutual torque between two rings (i, j) has the following dependency (see Arnaboldi & Sparke (1994)):

$$\frac{\partial V_m(\alpha_{ij})}{\partial \alpha_{ij}} \propto \frac{m_i m_j r_i r_j \sin 2\alpha_{ij}}{\pi^2 (r_i^2 + r_j^2)^{3/2}}. \tag{2.1}$$

Here, m and r are the ring masses and radii respectively, and α denotes the inclination angle between the rings. The equilibrium is evaluated by setting all the torques around line of nodes (LONs) to zero. The solutions give the inclination angles of all rings, for a given precession rate. After some algebra, the latter reduces to:

$$\frac{\dot{\phi}}{\Omega_j} = -\frac{D_i}{2A_i}\ \frac{m_i}{M_{bh}}, \tag{2.2}$$

where D and A are constants specific to each equilibrium.

The stability of the system is studied using standard perturbational method. Figure 2 depicts the equilibrium configurations for the least and most massive disks of one stable family. One sees clearly that the higher mass disk has a more pronounced warp.

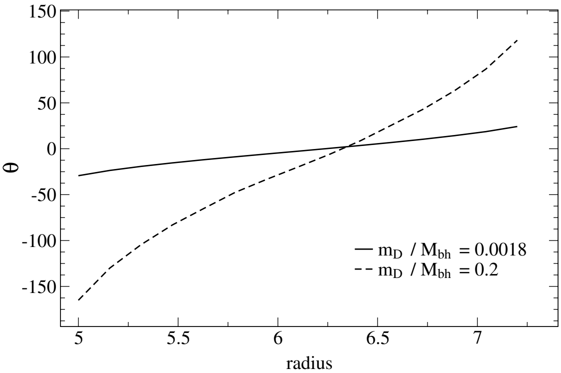

Figure 1. Stable equilibria for a disk of constant surface density.

3. Time Evolution of The Disk

Time integration of the equations of motion is carried out to cross-check the disk stability. Rings still sharing a common LONs after many orbital periods are considered to form a stable disk. Figures 2 and 3 show disks with masses $0.25M_{bh}$ and $0.05M_{bh}$ respectively. The effect of changing the disk mass on the stability is obvious. The higher mass disk dissolves after 10 orbital periods, where the lower mass disk is stable.

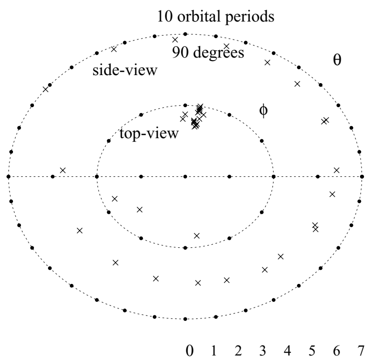

Figure 2. Time evolution of a disk with mass $M_d = 0.25M_{bh}$. After 10 orbital periods the disk dissolves into subrings, hence is unstable.

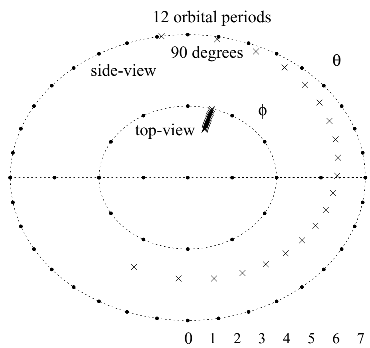

Figure 3. As in figure 2, but for a disk having $M_d = 0.05M_{bh}$. The rings still lie on the same LONs after 12 orbital periods, hence the disk is stable.

4. Conclusions

We found that more massive nuclear disks in galaxies can have more pronounced warps. These warps are stable in a mass range $0.002 \lesssim M_d/M_{bh} \lesssim 0.2$.

References

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