Self-Gravitating Warped Disks Around Supermassive Black Holes

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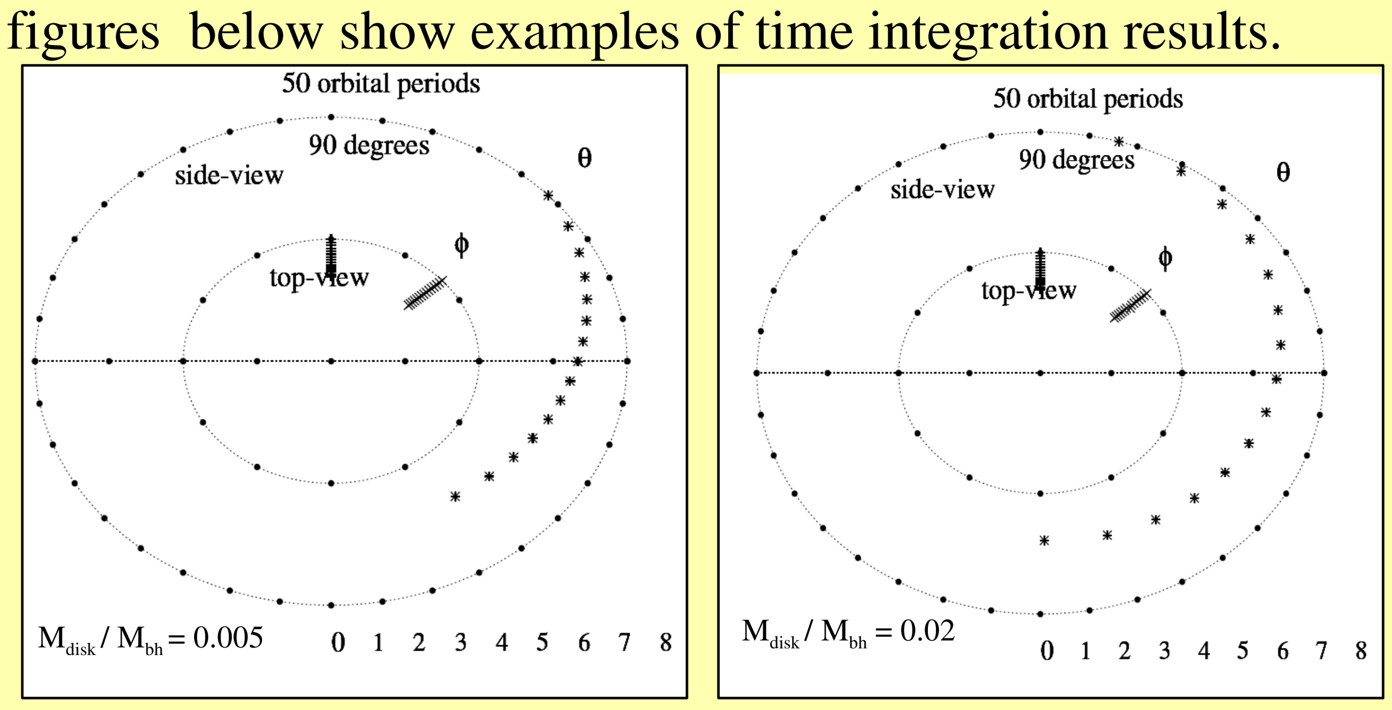
1) Introduction:

Many galaxies, including our own, contain disks of gas and probably stars surrounding their central supermassive black hole (SMBH) [1,2]. These disks might be relevant for the classification of galactic nuclei in case they obscure the central activity [3], and/or for the paradox of young stars in the vicinity of a SMBH [2]. We search for steadily precessing warped equilibrium configurations for such disks, considering the influence of the black hole and the self-gravity as the only acting forces. We investigate whether these equilibria are stable by perturbation theory and time integration. We show that stable, warped disk configurations also exist for the interesting disk masses between 10^{-3}-$10^{-1} M_{bh}$, and determine how they scale with the disk parameters and the mass of the black hole.

3) Stability of Equilibrium:

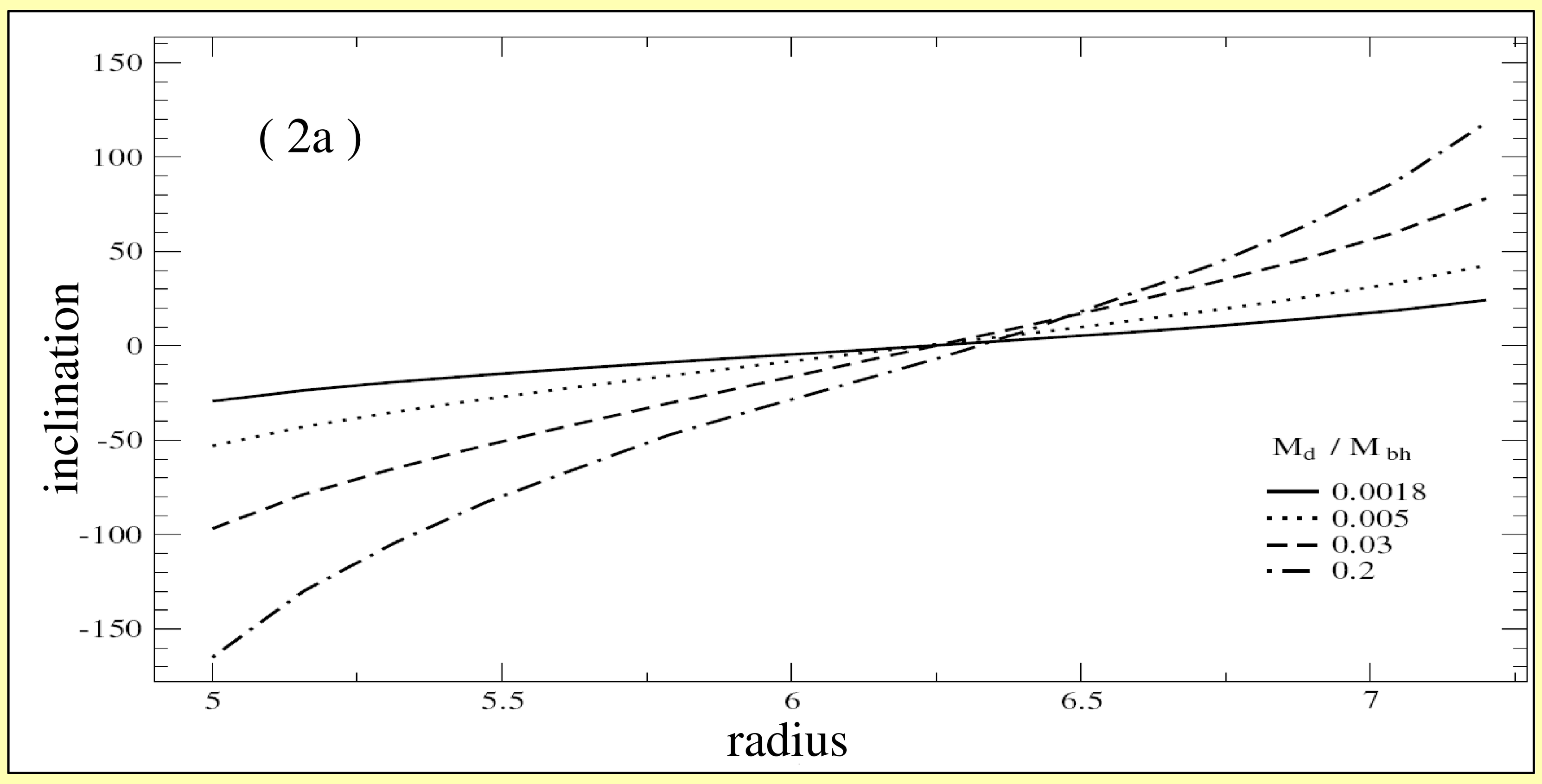
Figure (2a) in the right panel shows the disk configurations for the minimum and maximum stable mass, as obtained from perturbation analysis. The figures below show examples of time integration results.



Time evolution of warped disks: (+)'s show the initial configurations, (x)'s after 50 orbital periods. Symbols between the outermost and the innermost circles depict the disk inclination versus radius as shown on the horizontal scale, while the inner region shows azimuthal angle versus radius/2. All rings share the same LONs after 50 orbital periods, hence these disks are stable.

2) The Model & Equilibria:

We adopt a model developed for polar ring galaxies as in [4]. The disk is treated as a collection of concentric circular rings, which are under the influence of the central SMBH and their mutual gravitational attraction. Equilibrium is obtained by setting the torque around line of nodes(LONs) to zero for each of the rings, in which case the disk precesses as a rigid body.



2a) Disk inclination as a function of radius for different disk-to-black hole mass ratios. The degree of warping increases with increasing mass ratio.

Scaling Relations

The mutual torque between two rings *(i,j)* has the following dependency:

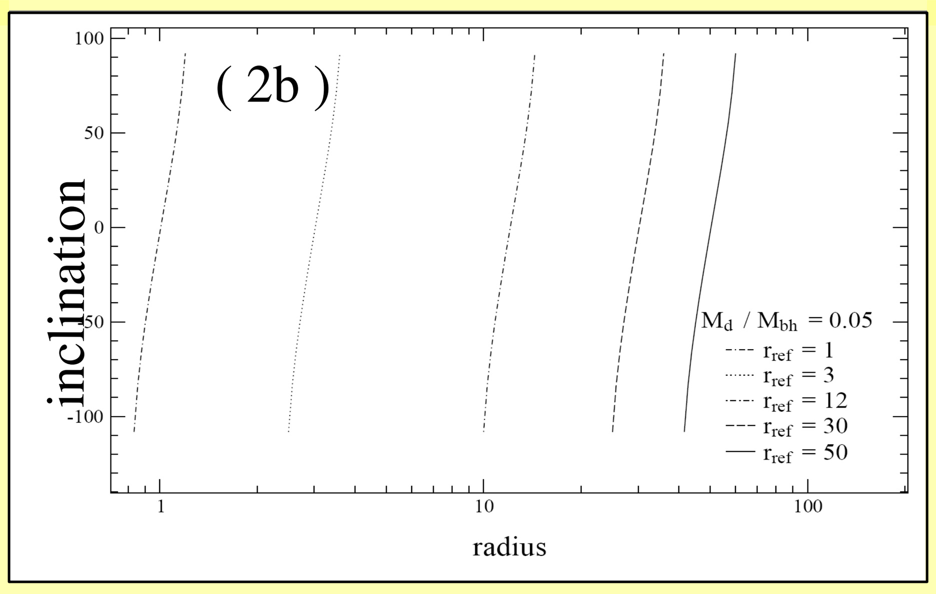
$$\frac{\partial V_m(\alpha_{ij})}{\partial \alpha_{ij}} \propto \frac{m_i m_j r_i r_j \sin 2\alpha_{ij}}{(r_i^2+r_j^2)^{3/2}}$$

This can be rewritten in terms of the parameters of a reference ring where $m_i/m_j=\gamma_i$, $r_i/r_j=\beta_i$, and α_{ij} is the relative inclination:

$$\frac{\partial V_{m_{ij}}}{\partial \alpha_i} = \frac{G}{\pi^2}\left[\sum_j \frac{\gamma_i \gamma_j \beta_i \beta_j \sin \alpha_{ij}}{(\beta_i^2+\beta_j^2)^{3/2}} I_{ij}\right] \frac{m_{ref}^2}{r_{ref}}$$

Inserting this form of the mutual torque into the equation of torque around LONs, a simple scaling relation can be written relating parameters of the rings to the black hole mass.

$$\frac{\dot{\phi}_i}{\Omega_{ref}} = -\frac{D_i}{2A_i}\frac{m_{ref}}{M_{bh}}$$

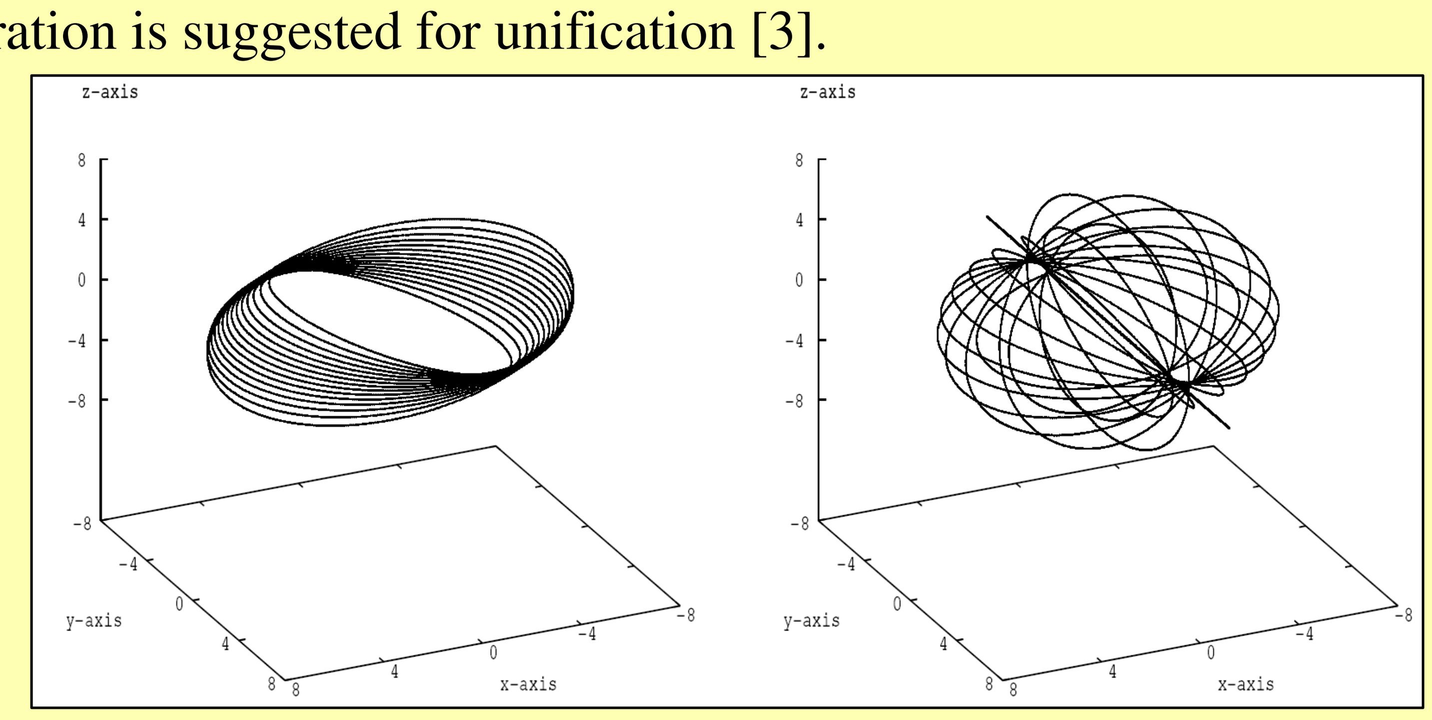


2b) Keeping $\dot{\phi}/\Omega_{ref}$ fixed when shifting the position of the reference ring results in same warped equilibrium configuration.

4) Possible Application & Implications

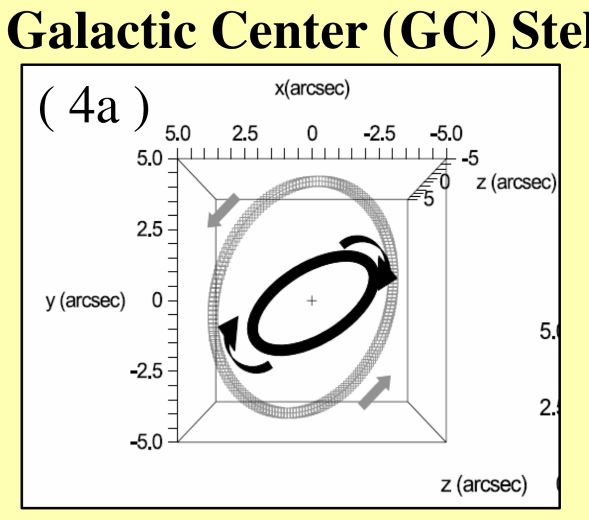
Unification of AGN

AGN unification scenario relies on the obscuration of central activity by some toroidal matter for particular viewing angles. Warped disks as a source of obscuration is suggested for unification [3].

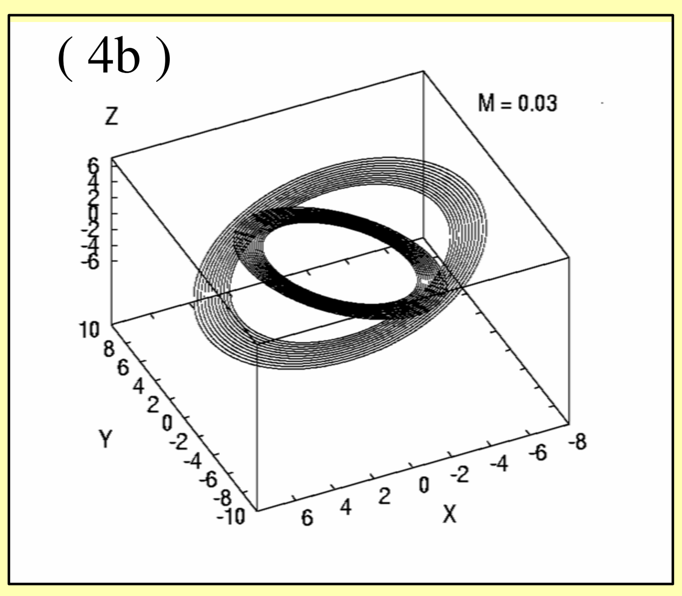


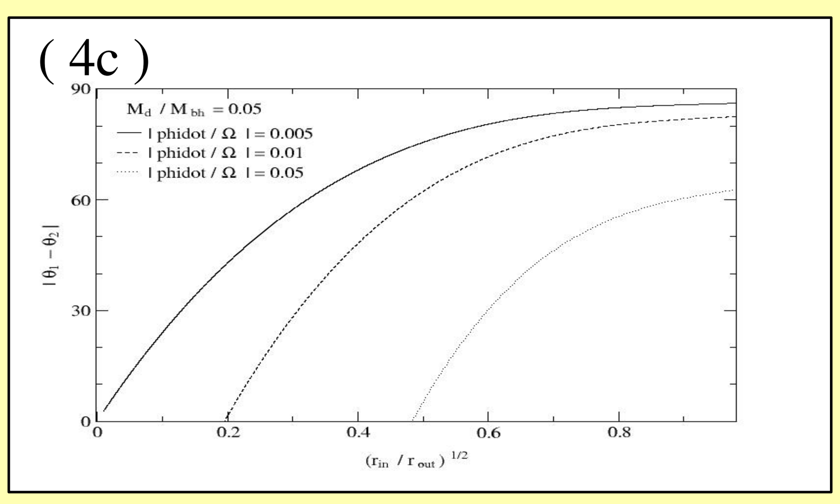
3D views of the disks with M_{disk}= 0.0018 M_{bh}(left), and M_{disk}=0.2 M_{bh}(right). As the mass ratio increases, the central region becomes obscured from most lines-of sight.

Galactic Center (GC) Stellar Disks



At a distance of 0.1-0.2 pc to the center of our galaxy, lie two mutually inclined disks of young stars [2].





***4a)** Observation of the inclined disks at the Galactic Center[2].*
***4b)** Model equilibria for two inclined disks where parameters are relevant to the GC disks*
***4c)** Mutual inclination of two rings as a function of their radius ratio for M_d = 0.05 Mbh. Different curves show the precession frequencies assumed.*

Summary & Conclusions

- High inclination warps are possible for disks surrounding supermassive black holes.
- Equilibrium properties of a disk obeys scaling rules, dependent on the mass, radius and precession rate of the disk, and mass of the BH.
- Self gravitating warped disks are stable also in the interesting mass range $10^{-3} \lesssim M_d / M_{bh} \lesssim 10^{-1}$

References:

[1] Herrnstein et.al., ApJ, **629**,719 (2005)
[2] Genzel et.al., ApJ, **594**, 812 (2003)
[3] Nayakshin, S., MNRAS, **359**, 545 (2005)
[4] Arnaboldi, M., Sparke, L., AJ, **107**, 958 (1994)