Resonant stars/disk interactions: Application to NGC 4258

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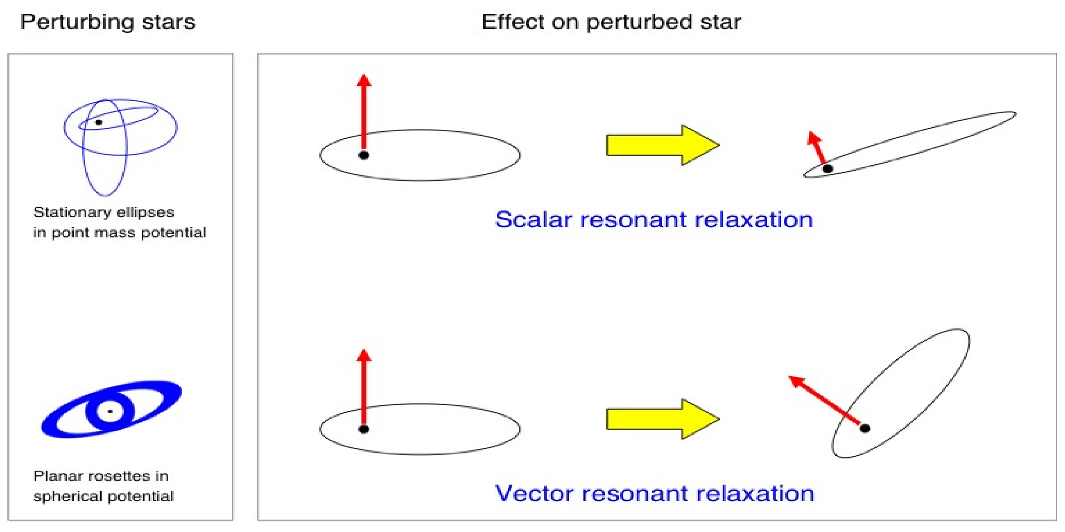
Accretion disks around massive black holes (MBH) in active galaxies can exhibit warps, as observed in the maser disk of NGC4258. The physics driving the warp are still debated. We propose a new warping mechanism: resonant torquing of the disk by stars in the dense cusp around the MBH. We show that resonant torquing can explain the warp in NGC 4258 .We are now investigating if the resonant torques, by acting on the disk, may also modify the MBH spin, and therefore its evolution. **Bregman et al. 09**

Introduction

The Resonant Relaxation (RR) Mechanism

Two-body interactions inevitably lead to non-coherent relaxation of energy and angular momentum on long enough timescales. However, when the potential has approximate symmetries that persist for a coherence time, such as near a MBH in a galactic nucleus, the perturbations on a test star are no longer random, but correlated (e.g. due to fixed ellipses in a Keplerian potential; fixed orbital planes in a spherical potential). This leads to rapid coherent RR of the angular momentum (Rauch and Tremaine 1996).

RR dominates the dynamics of processes that occur near a MBH, for example, it is expected to affect the rate of gravitational wave (GW) emission from extreme mass ratio inspiral (EMRI), and the orbits of stars observed near the Galactic MBH.



RR timescales

The residual torque on a test star $\tau = N_\star^{1/2} G M_\star / r$

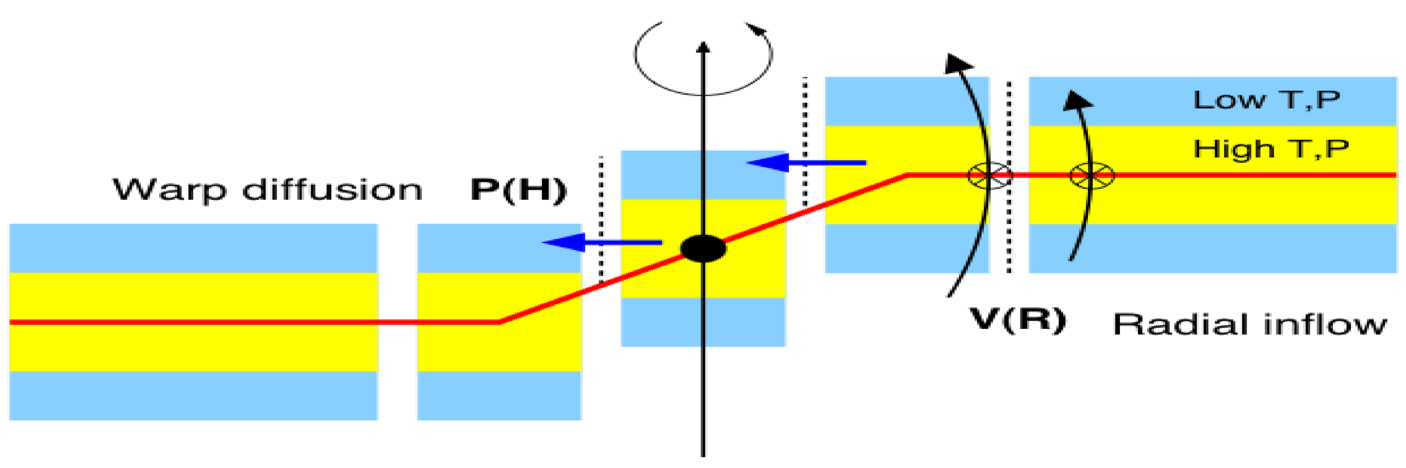
These torques are fixed until RR itself randomises the orbital planes at the coherence time $t_0 = L_c/\tau$, which is also the vector RR timescale (timescale to rotate a ring by $\pi/3$)

$$t_{vRR} = M_\bullet P/(M_\star N_\star^{1/2})(r/R)^{2\theta} \qquad \theta = sgn(r-R)$$

where r radius in the cusp, R radius in the disk, $M_\star$ mass of a star, $N_\star$ number of stars, P circular orbital period, $M_\bullet$ MBH mass angular momentum L and $L_c = (GM_\bullet r)^{1/2}$

Disk viscosity

There are two types of internal viscosity that act in the disk.
In-plane viscosity (ν_1), which forces matter into the MBH,
and perpendicular viscosity (ν_2), which flattens the perturbation.



The timescales corresponding to those viscosities are

$$t_{\nu_1,\nu_2} = R^2/\nu_{1,2} = R^2/(\alpha_{1,2} c_s H) \qquad \alpha_2 \sim 1/2\alpha_1$$

where α is the dimensionless viscosity parameter.

RR warping of an accretion disk

The gas in a thin accretion disk flows slowly into the MBH on nearly circular orbits. Over time, the orbit associated with a ring element of the disk shrinks and the external stellar torque on it changes. RR can significantly affect the ring only if RR is faster than the radial inflow rate and the warp diffusion rate.

$$w t_{vRR}(r,R) \le t_{visc} \qquad t_{visc} = min(t_{\nu_1}, t_{\nu_2})$$

A warp is possible in the range $r_t^{(-)} \le r_{warp} \le r_t^{(+)}$

where: $w^2 = 2(1-\cos w)$

In addition, the torquing stars must carry enough residual angular momentum to exchange it with the disk and warp it.

$$L_{disk} = w M_d(R) L_c(R) \le N_\star^{1/2} M_\star L_c(r) = L_\star$$

A warp is possible in the range $r_L \le r_{warp}$

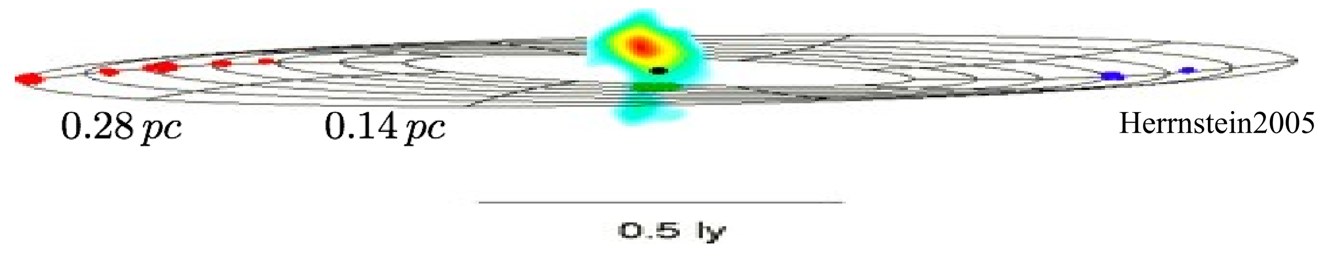
Therefore the disk will warp only if

$$max(r_t^{(-)}, r_L) \le r_{warp} \le r_t^{(+)}$$

The timescale condition implies that RR can affect only low-mass MBHs with $M_\bullet \le few \times 10^6 M_\odot$, such as expected in the early universe.

Application to NGC4258

NGC 4258 has a $w \ge 8^\circ$ warp between $R_1 = 0.14pc$ and $R_2 = 0.28pc$



We parameterize the disk by $(n_{H_2}, \dot{M}, \alpha_1, s)$ where n_{H_2} is the H_2 density at R_1 , $\dot{M}$ the mass accretion rate, α_1 is the viscosity parameter and the surface density power law slope s.
Masing can occur only in a narrow region of parameter space.

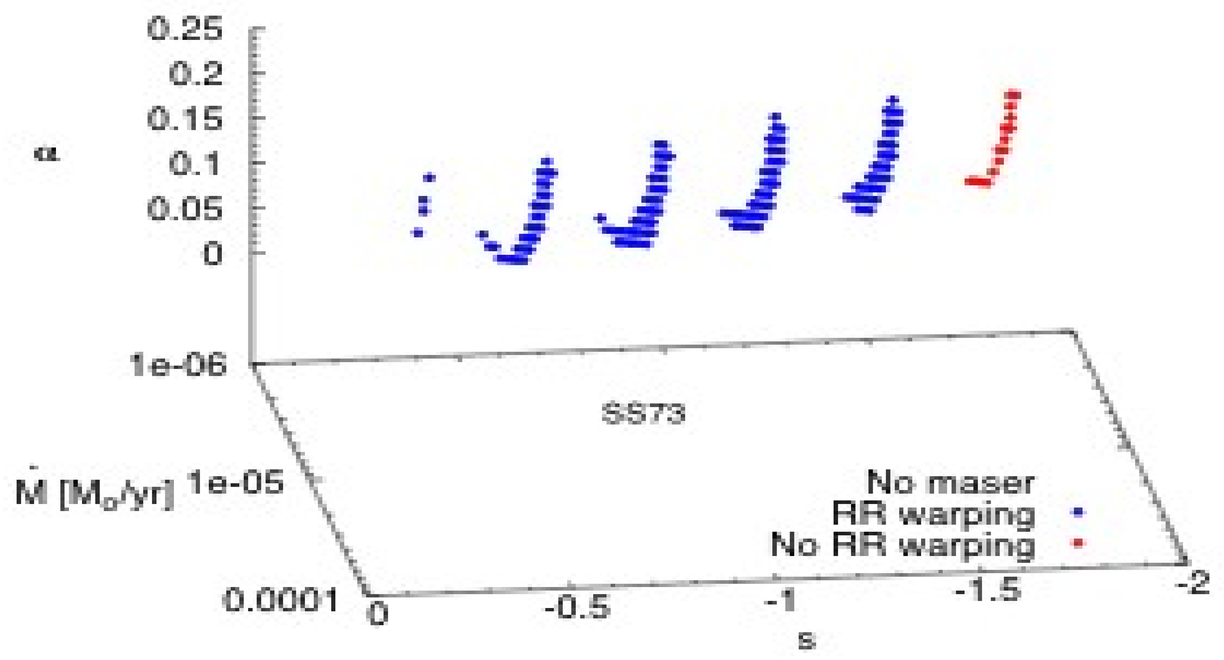
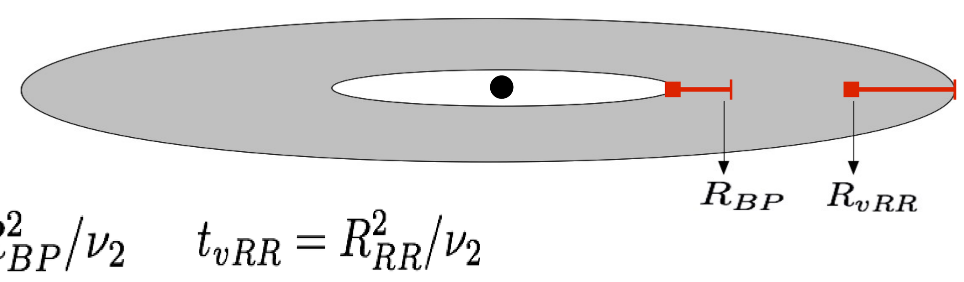


Figure
Disk parameter space. Colored dots: masing possible.
Blue dots: RR warping $(> 8^\circ)$ for $0.14pc \le r \le 0.28pc$ possible.
Red dots: RR warping too small.

RR can significantly warp the disk over almost all the disk's parameter space, without fine tuning.

The Next steps



$$t_{BP} = R_{BP}^2/\nu_2 \qquad t_{vRR} = R_{RR}^2/\nu_2$$

RR torquing and the Bardeen Petterson (BP) affect couple the stellar orbital angular momentum on large scales with the MBH spin via the long BP lever arm (R_{BP}).
Can stellar cusps affect the early evolution of MBH spin and accretion by RR?

Results

- Poisson fluctuations in the stellar distribution can transfer momentum from the stars to the maser disk and excite warps.
- RR inherent to the discreteness of the stellar system :it does not require special initial conditions.
- RR induced warps are transient , vary on timescale $t_{vRR} \sim few \times 10^7 yr$
- RR warping dominates warping dynamics. It is faster than other suggested mechanisms ($t_{BP} > few \times 10^9 yr$).

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