Resonant stars / disk interactions: implications for MBH evolution

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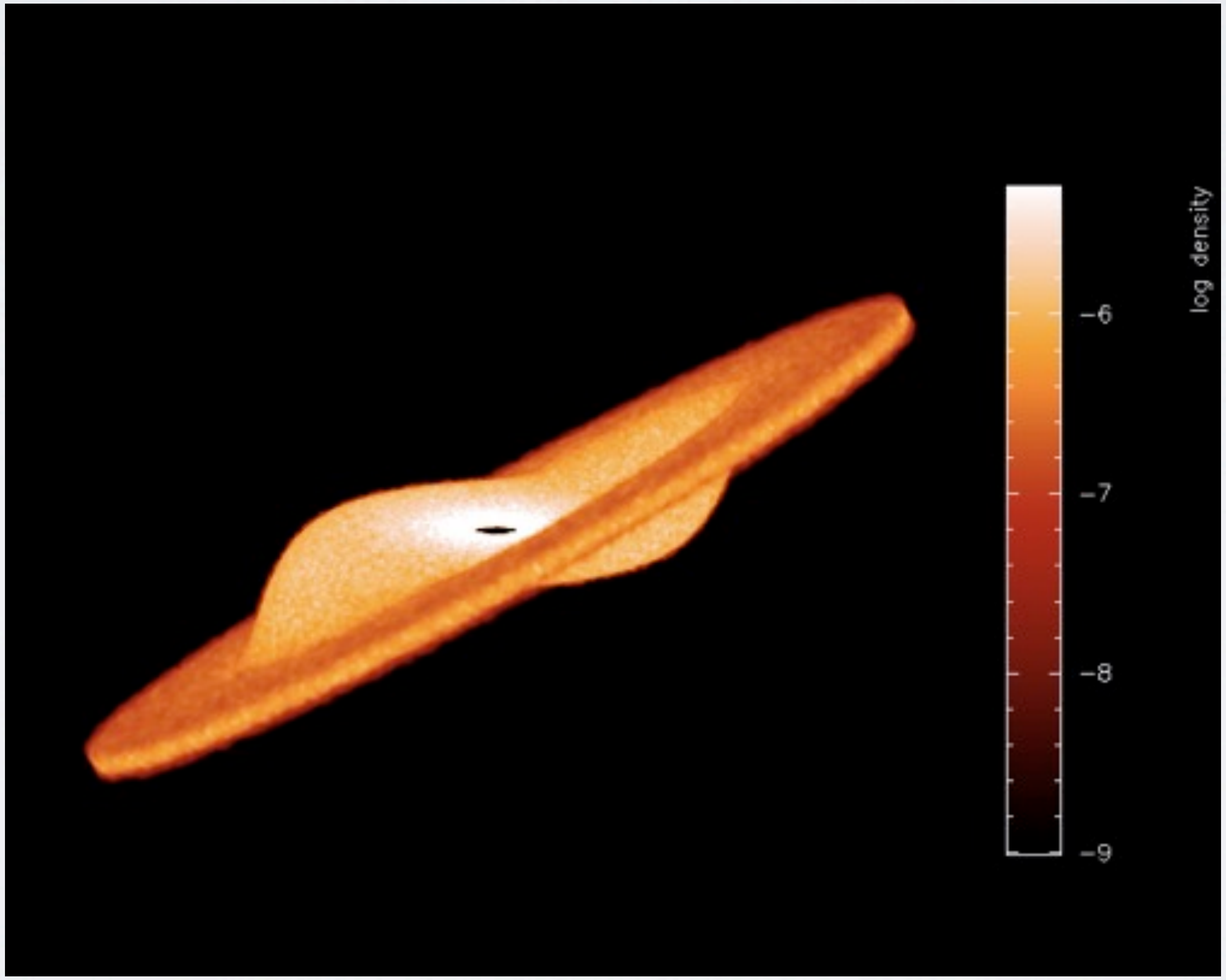


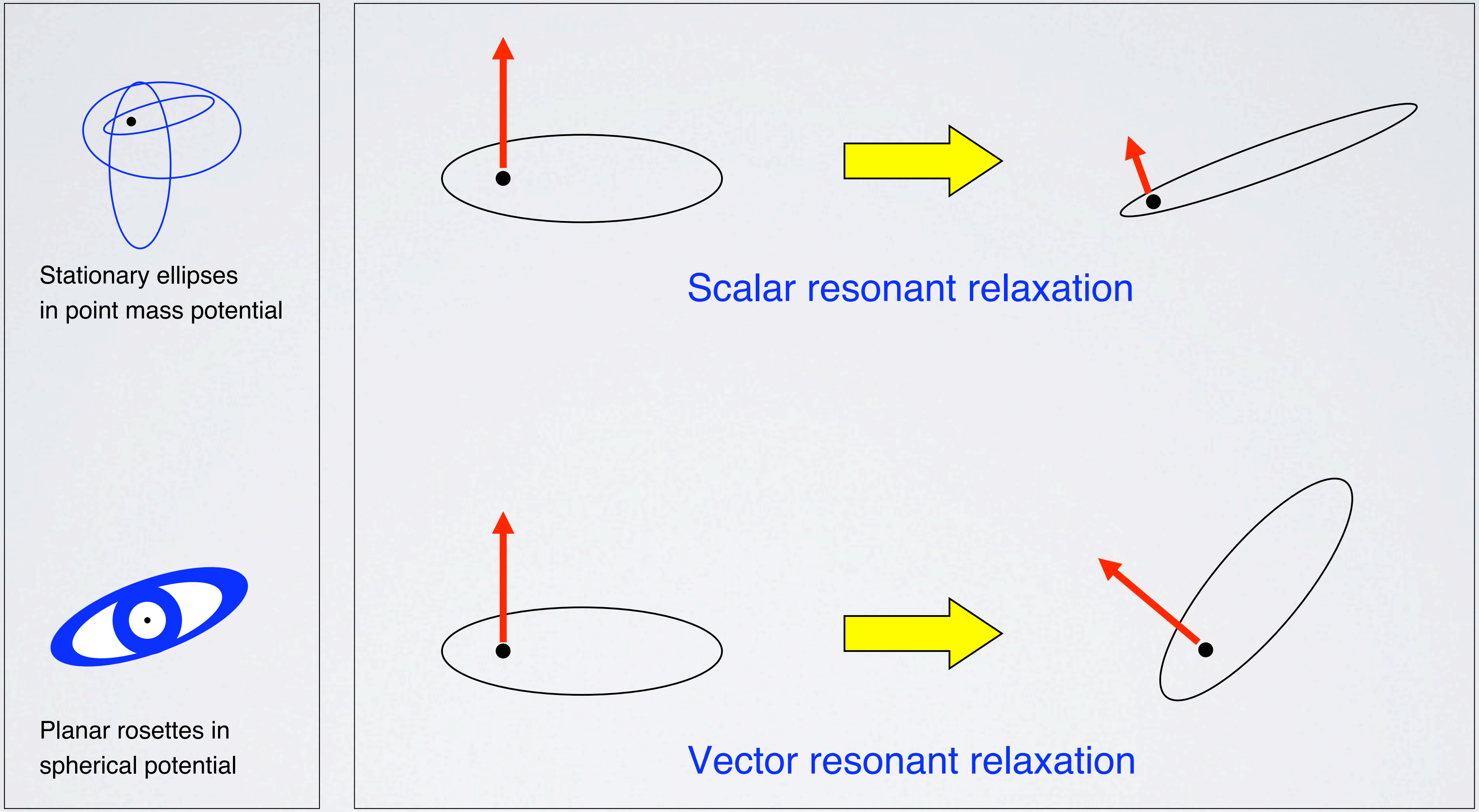
Simulation of a warped accretion disk- G.Lodato

The key question

Motivation:

- Spin affects accretion efficiency.
- The puzzle of very massive BH in the early universe.
- Evidence for MBH spin precession.
- Warped disks (NGC4258)

RR mechanism



Perturbing stars

Stationary ellipses
in point mass potential

Planar rosettes in
spherical potential

Effect on perturbed star

Scalar resonant relaxation

Vector resonant relaxation

Rauch & Tremaine 96

vector RR

The residual torque on a test mass $$\tau = N_\star^{1/2}\frac{GM_\star}{r}$$

The coherence time $$t_0 = A_0 L_c/\tau = A_0 P M_\bullet/(M_\star N_\star^{1/2})$$

$t \gg t_0$ $|\triangle L|/L_c = 1$ $\longrightarrow$ $[(\triangle L)_{t_0}/L_c](t_{vRR}/t_o)^{1/2} = 1$

$$\boxed{t_{vRR} = \frac{1}{\beta_\nu^2}\frac{M_\bullet}{M_\star}\frac{P}{N_\star^{1/2}}(\frac{r}{R})^{2\theta}}$$

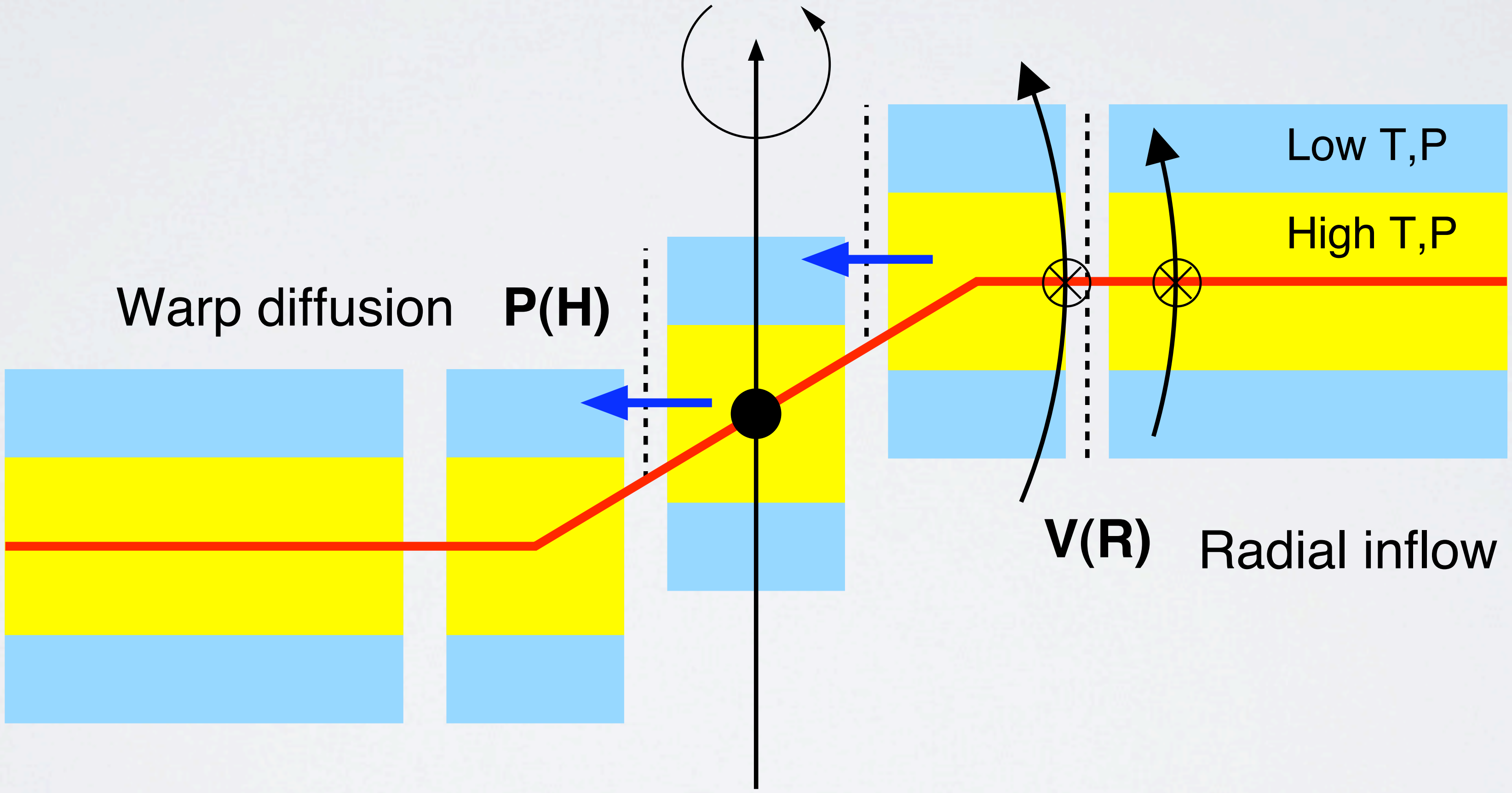
$M_\star N_\star \ll M_\bullet$
$\theta = sgn(r-R)$

Disc viscosity

In plane viscosity- $\nu_1 = \alpha_1 C_s H$

$$\longrightarrow \quad \alpha_2 = \frac{1}{2\alpha_1}$$

Perpendicular viscosity- $\nu_2 = \alpha_2 C_s H$



α disk model: stress tensor $\sigma_{ij} = \alpha P$ $(0 < \alpha < 1)$

$$t_{visc} = R^2/\nu$$

RR warping of an accretion disk

Angular momentum condition

$$\overset{L_{disk}}{\boxed{wM_d(R)L_c(R)}} \leq \overset{L_\star}{\boxed{N_\star^{1/2}M_\star L_c(r)}}$$

$$r_L \leq r$$

Timescale condition

$$wt_{vRR}(r,R) \leq t_{visc}$$

$$t_{visc} = min(t_{\nu_1}, t_{\nu_2})$$

$$r_t^{(-)} \leq r \leq r_t^{(+)}$$

The disk will warp only if $max(r_t^{(-)}, r_L) \leq r \leq r_t^{(+)}$

where: r radius in the cusp, R radius in the disk, $L_c = (GM_\bullet r)^{1/2}$ and $w^2 = 2(1 - cos\omega)$

RR disk warping and early MBH evolution

RR may affect low-mass MBHs in early universe:

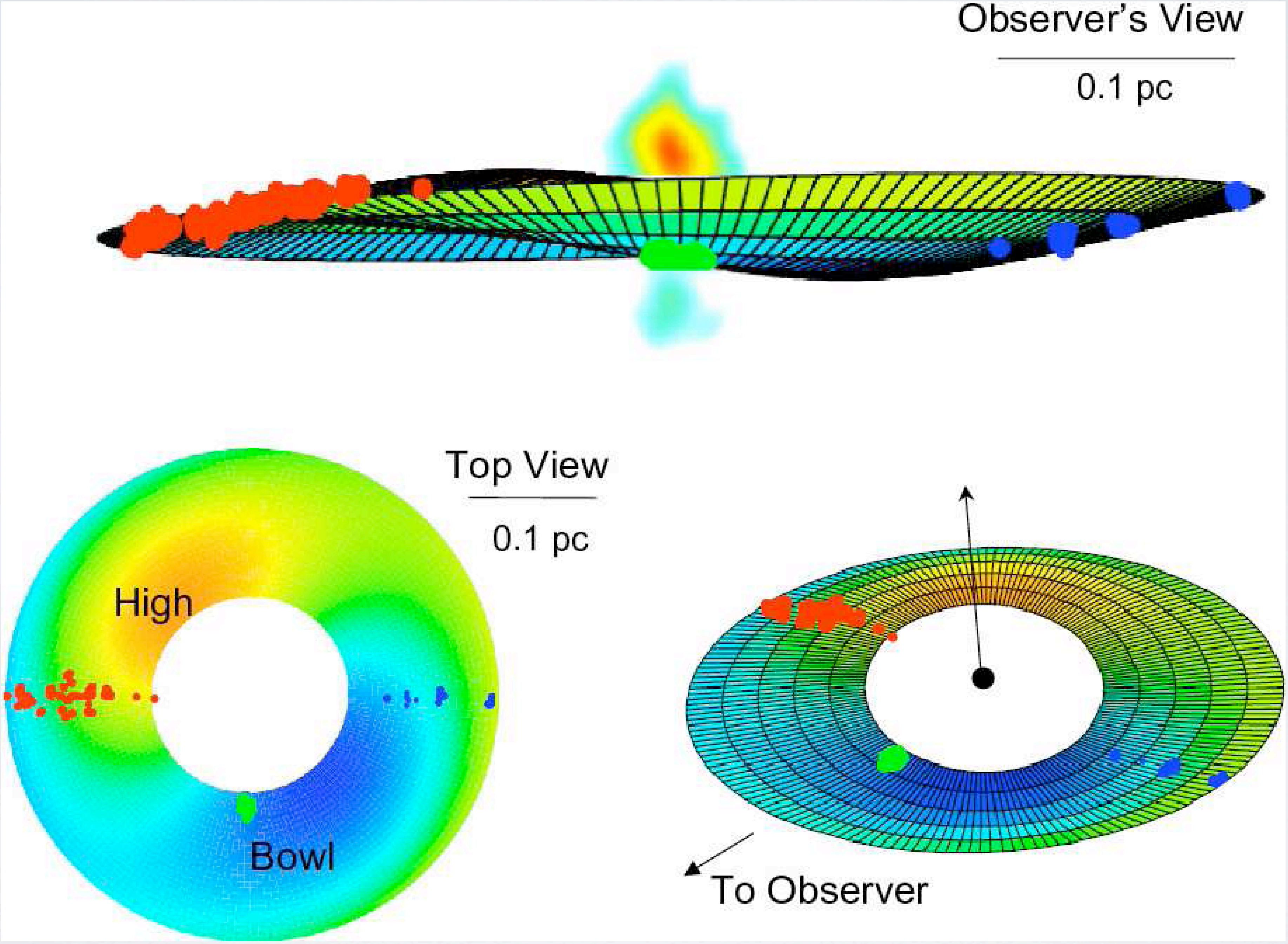
$$\frac{\sqrt{N}}{Q}P \sim T_{vRR} < t_{inflow} \sim \frac{(R/H)^2}{\alpha}P$$

$$Q \lesssim 10^5 - 10^6$$

$Q = M_{\bullet}/M_{\star}$

Maser disk NGC4258

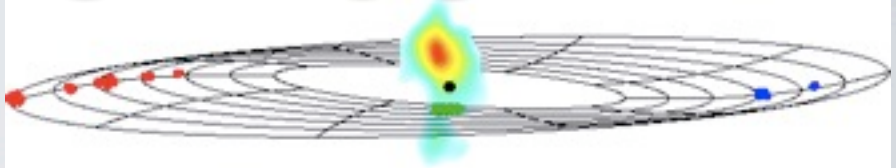
Herrnstein et al 1996

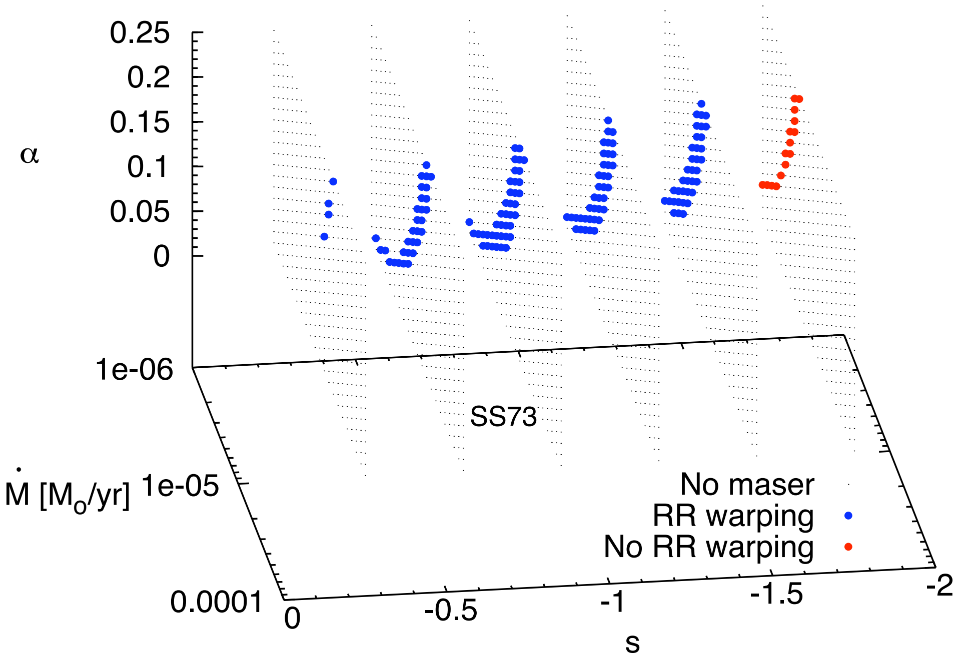


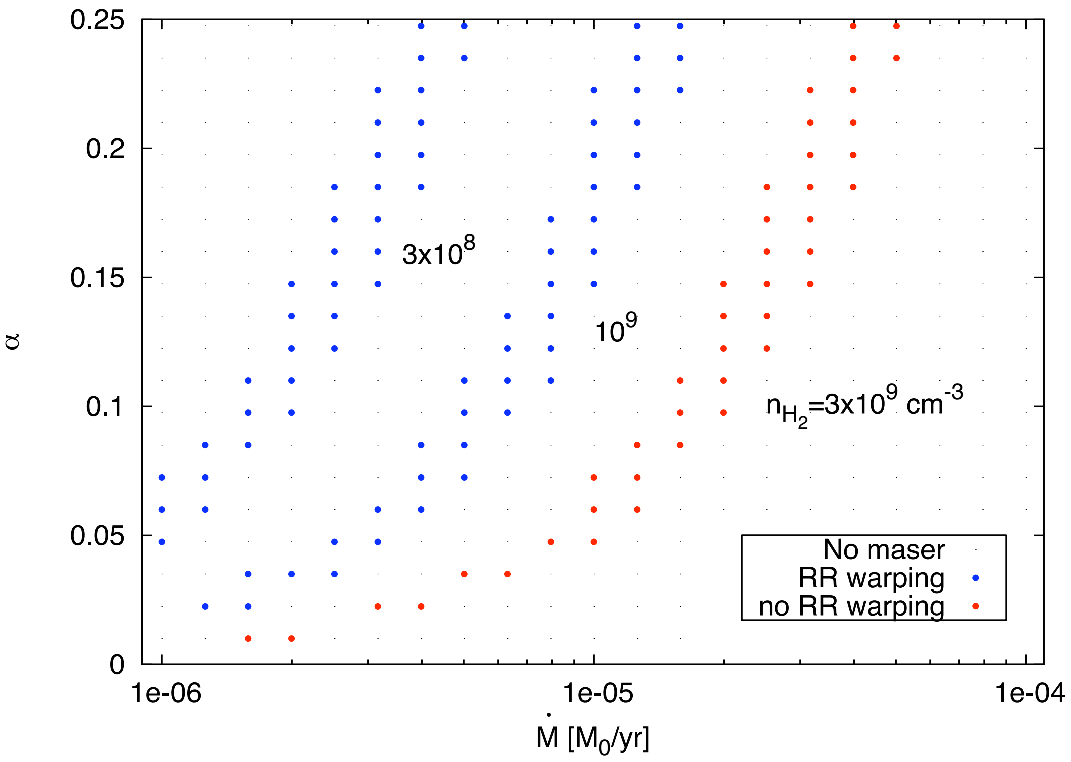
Radio measurements of x, v, $\dot{v}$

$D = 7.2 \pm 0.3\, Mpc$ $M_\bullet = 3.7 \times 10^7\, M_\odot$ $R = 0.14 - 0.28\, pc$ $\gamma = 1.5$ warp $\sim 8^\circ$

RR disk warping of NGC4258







$$s = -3/4$$

Bregman et.al 2009 ApJ

The *O*(10±) NGC4258 disk warp on the *O*(0.1pc) scale is naturally explained by RR torques of *O*(106) stars on the *O*(1pc) scale.

Preliminary work

and future steps

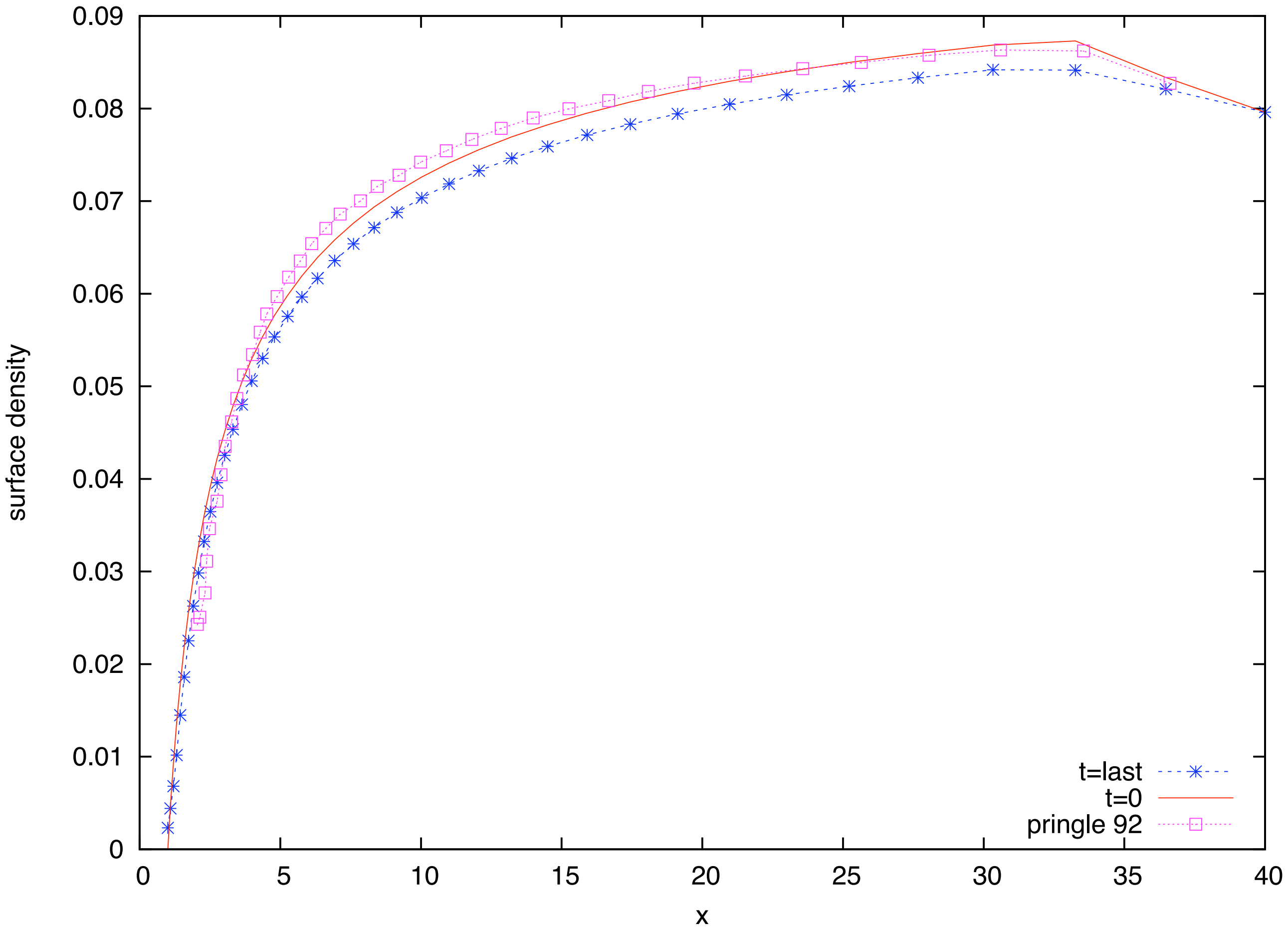
Warp diffusion in accretion discs

mass conservation + angular momentum conservation

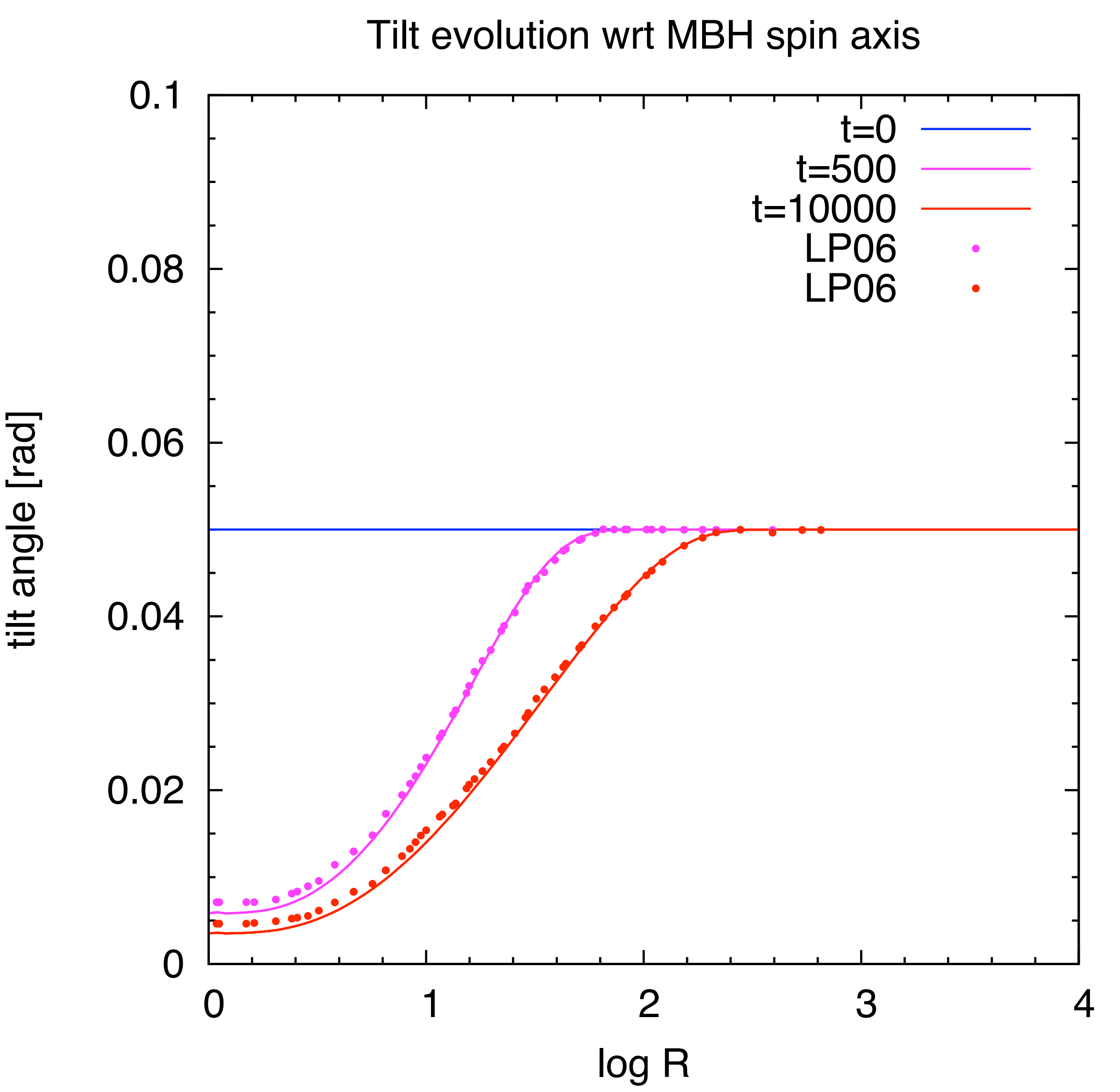
$$\frac{\partial \mathbf{L}}{\partial t} = \underbrace{\frac{3}{R}\frac{\partial}{\partial R}[\frac{R}{L}\frac{\partial}{\partial R}(\nu_1 L)\mathbf{L}] + \frac{1}{R}\frac{\partial}{\partial R}[\frac{1}{2}\nu_2 R L \frac{\partial(\mathbf{L}/L)}{\partial R}]}_{\text{diffusive part}}$$

$$\underbrace{+\frac{1}{R}\frac{\partial}{\partial R}[(\nu_2 R^2 \frac{\partial(\mathbf{L}/L)}{\partial R}^{2} - \frac{3}{2}\nu_1)\mathbf{L}]}_{\text{advective part}} + \underset{\overset{\uparrow}{\text{source term}}}{\dot{\mathbf{L}}_{(+)}} + \underset{\overset{\uparrow}{\text{sink term}}}{\dot{\mathbf{L}}_{(-)}} + \mathbf{T}_{RR}$$

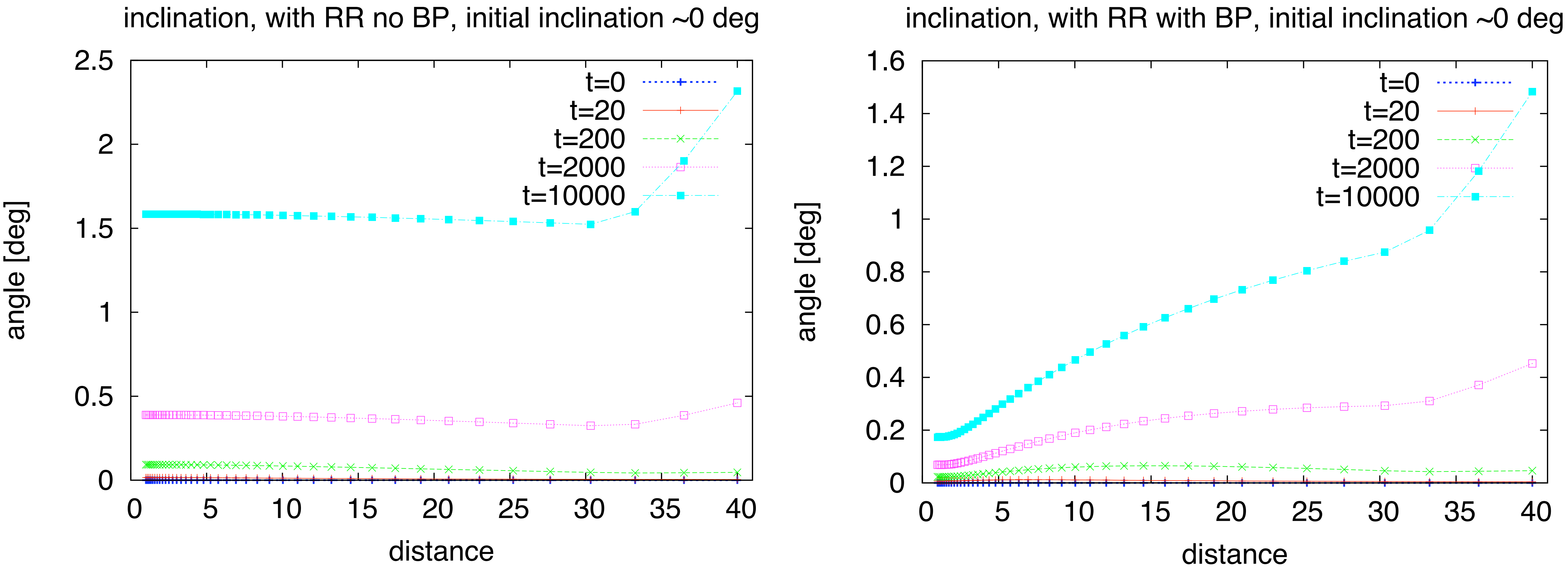
Surface density distribution for steady state disk



Tilt evolution

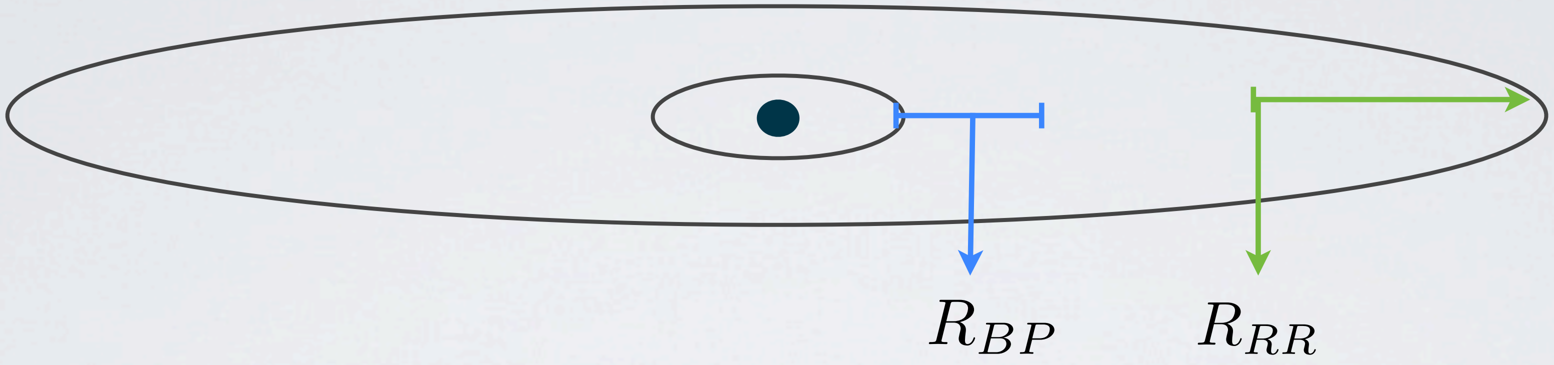


RR toy model



$M_\bullet / M_\star = 1e6 \qquad \nu_1 = \nu_2 = 1 \qquad \gamma = 1.5$

torques field



Precession angular velocity

$$\Omega_{LT} = \frac{2G}{c^2}\frac{J_\bullet}{r^3}$$

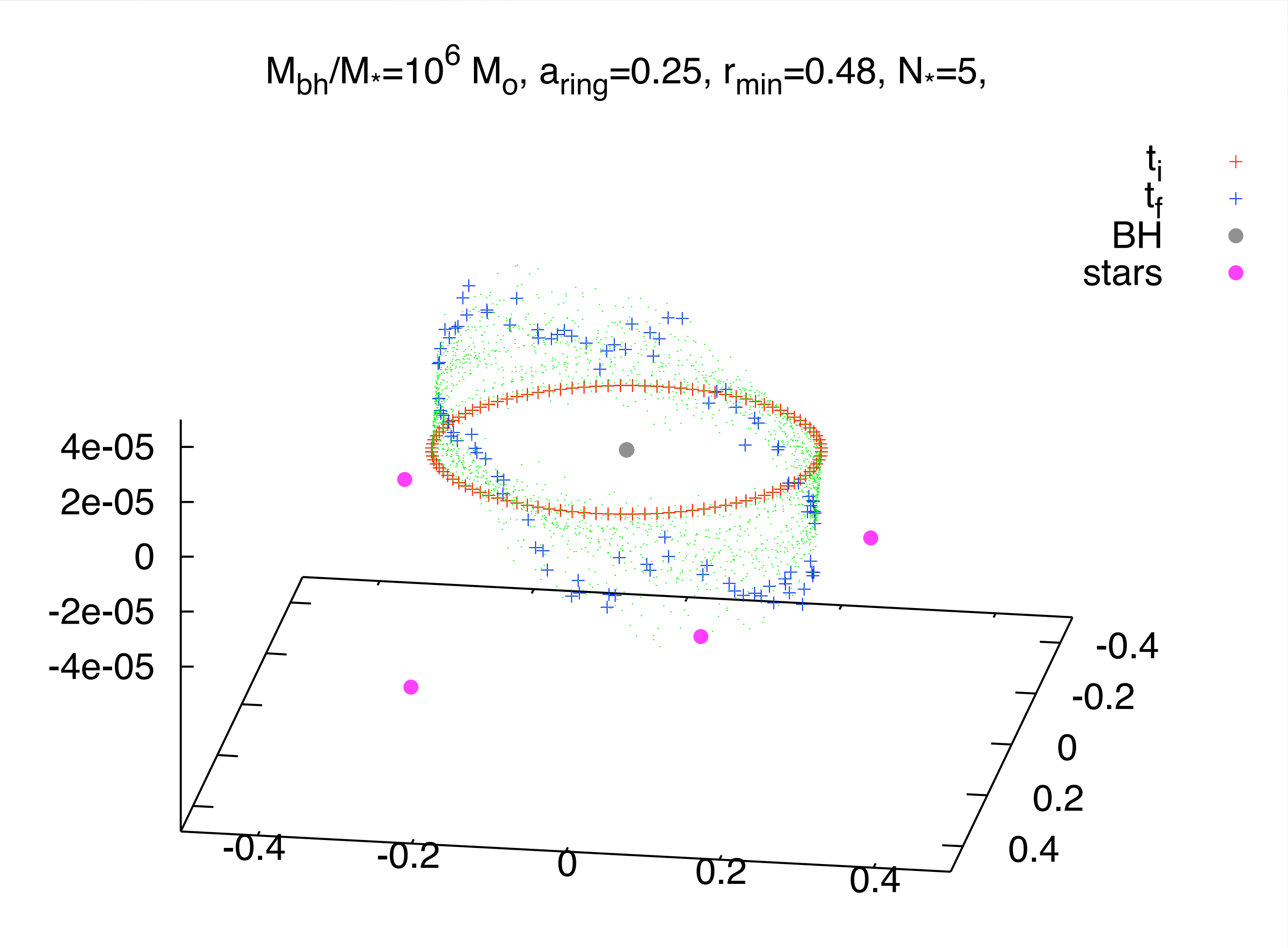
$$J_\bullet = a_* G M_\bullet^2 / c$$

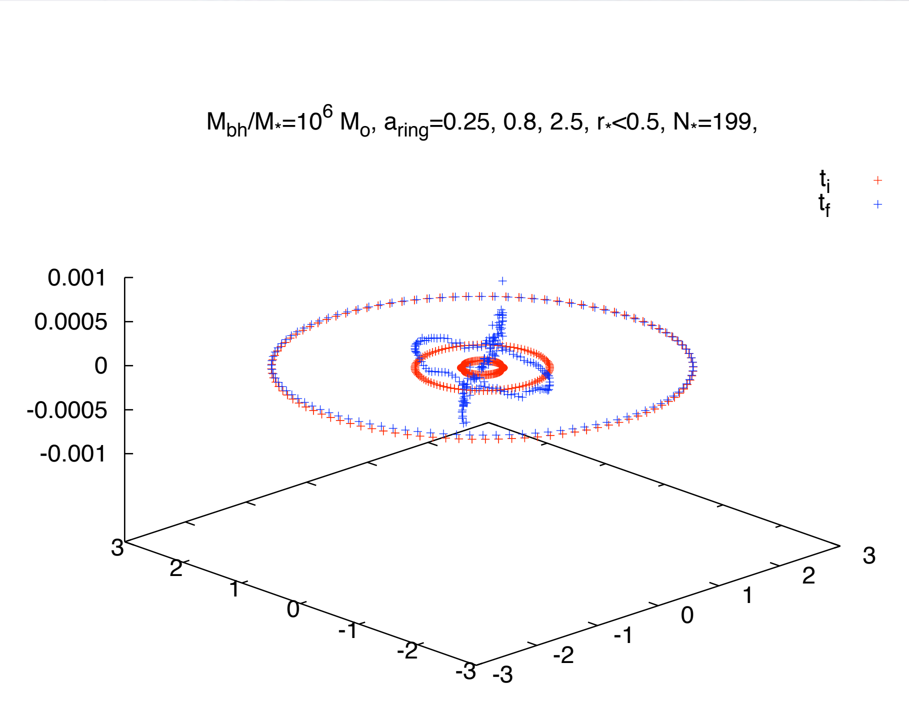
$$t_{BP} = R_{BP}^2/\nu_2$$

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

RR torquing redefine the inclination angle of the disc for the BP alignment on t_RR time scale

Results - simulations





N-body simulations, using the code developed by G. Kupi (2007)

Open questions

- Are there enough stellar black holes so close to the MBH to affect the disk?
- Will RR completely disrupt the disk?

Summary

- Poisson fluctuations in stellar distribution transfer momentum from stars to maser disk and excite torque.
- RR inherent to discreteness to stellar system: does not require special disk initial conditions.
- RR induced warps are transient, vary on a timescale $t_{vRR} \sim few \times 10^7\, yr$
- RR warping mechanism dominants warping dynamics faster than other suggested mechanisms. $t_{BP} > few \times 10^9\, yr$
- RR may rotate MBH spin vector by the Bardeen - Petterson coupling of the disk's orientation at large radii with the MBH spin direction.