accretion

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matter falling under gravity of a mass M from a large distance to a distance R from it releases potential energy

$$\sim \frac{GM}{R}$$

per unit mass

For $$R \lesssim 12\frac{GM}{c^2}$$

this is more efficient than nuclear burning

So accreting stellar-mass black holes and neutron stars are luminous, and

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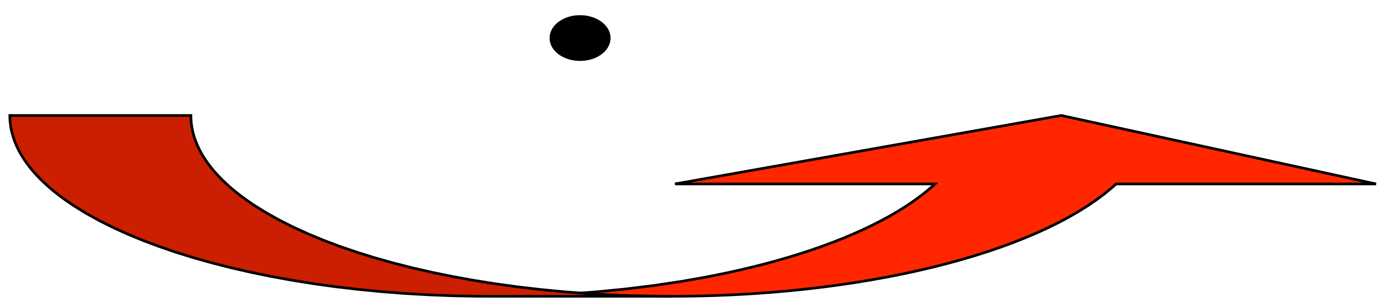
So accreting stellar-mass black holes and neutron stars are luminous, and

accretion on to a supermassive black holes must power the brightest objects in the Universe

accretion - e.g to a black hole

infalling matter does not hit black hole in general, but must *orbit* it:
— it is *never* `aimed' directly at the hole



— initial orbit is a rosette since potential is never exactly R^{-1}

infalling *gas*: self—intersections → dissipation →

energy loss, but NO angular momentum loss

accretion - e.g to a black hole

infalling matter does not hit black hole in general, but must *orbit* it

energy loss, but NO angular momentum loss

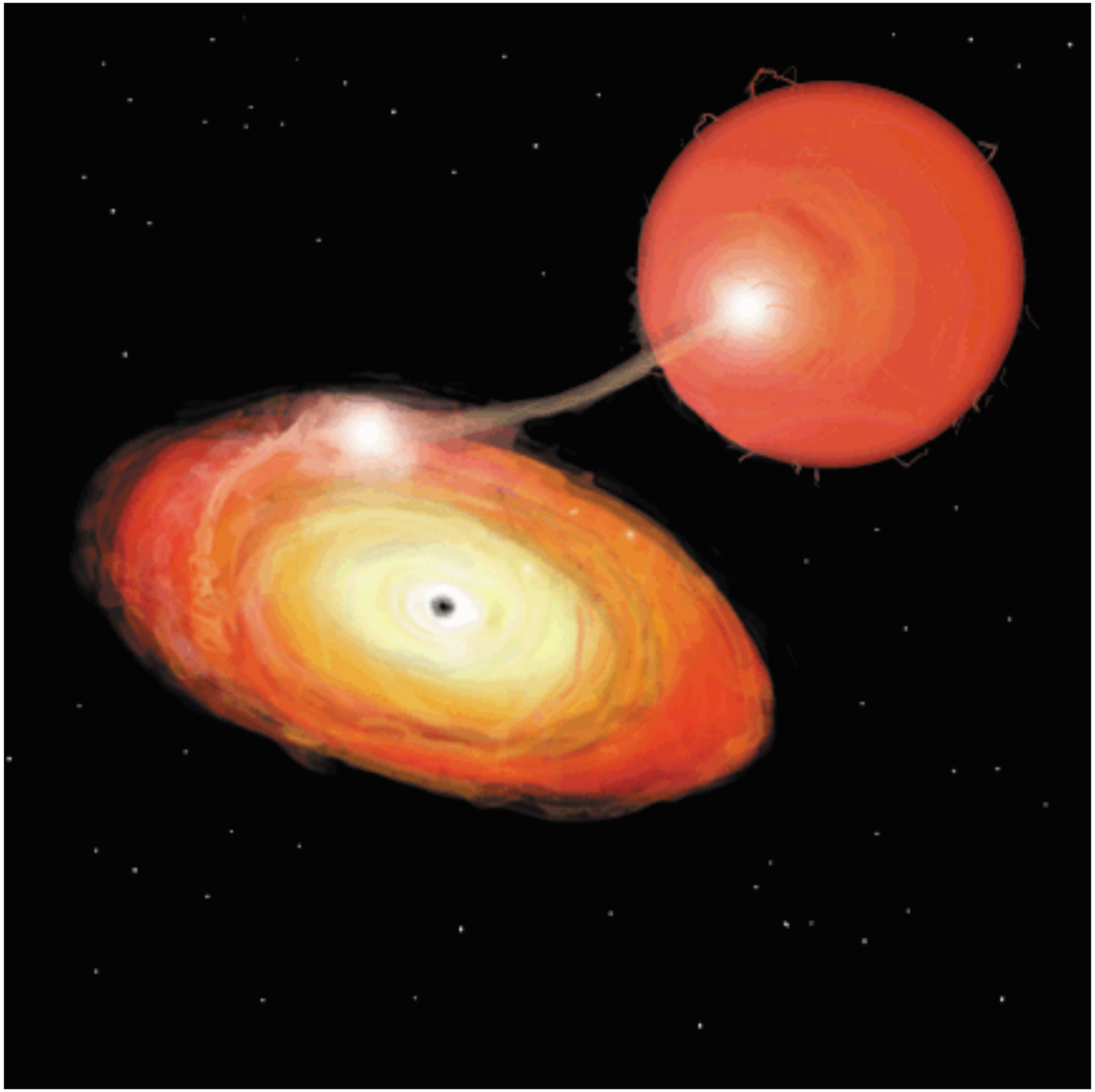
Kepler orbit with lowest energy for fixed a.m. is a *circle*

thus orbit circularizes, with radius such that it retains its orginal specific angular momentum

further energy loss only possible if angular momentum can be removed:

matter spirals inwards through a succession of circular orbits of decreasing angular momentum

accretion disc



close binary system with an accretion disc

disc formation is unavoidable

all accreting gas has enough angular momentum to orbit the accretor, so a disc always forms

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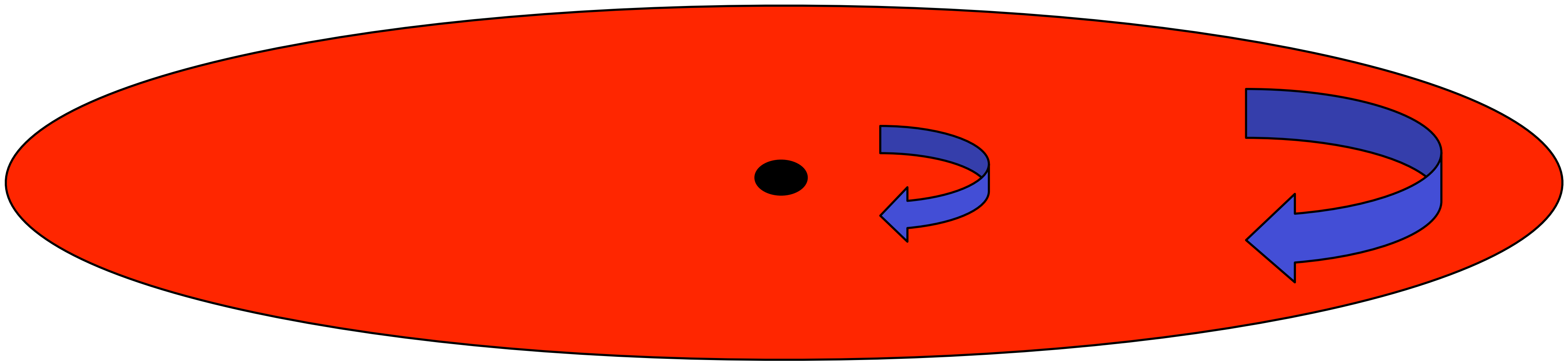
only exception — accretion on to an *extended* star — low accretion yield

accretion disc structure



flat, differentially rotating gas disc, thickness $H(R)$

surface density (mass/area) $\Sigma(R) = \rho H$

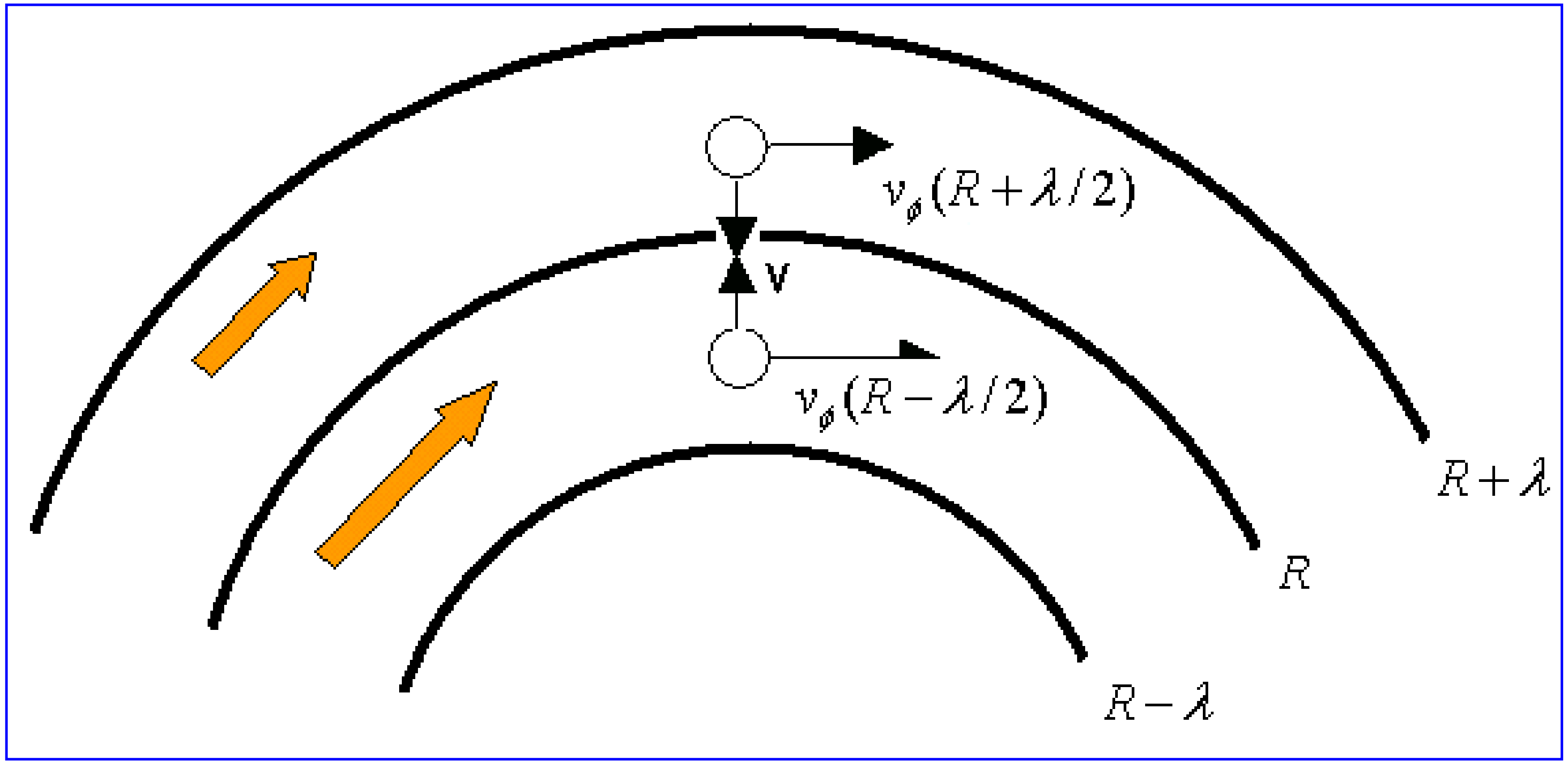
rotational angular velocity $\Omega(R)$ increases towards centre

angular momentum $R^2\Omega(R)$ *decreases* towards centre

disc is thin, $\dfrac{H}{R} \sim \dfrac{c_s}{v_{\rm K}} << 1$, Keplerian $R\Omega(R) = v_K = \left(\dfrac{GM}{R}\right)^{1/2}$

(pressure forces small) if and only if it can cool

accretion disc structure



torque of inner ring on outer one is $G(R) = 2\pi\nu\Sigma R^3 \dfrac{\mathrm{d}\Omega}{\mathrm{d}R}$, with $\nu \sim \lambda v$

accretion disc structure

- driver of accretion is `viscosity' - some dissipative process which transports angular momentum outwards, against a.m. gradient

- currently unknown - but may be magnetic

- characterized by a lengthscale λ and a speed v describing random motions around mean streaming (fluid) motion

- e.g. *molecular* viscosity has λ = mean free path, v = thermal speed of molecules (sound): other processes have larger λ, e.g. turbulence

- a viscosity transports fluid momentum and angular momentum within it

- gas spirals in, losing angular momentum and energy disc surface density $\Sigma(R, t)$ obeys a *diffusion equation*

$$\frac{\partial \Sigma}{\partial t} = \frac{3}{R} \frac{\partial}{\partial R} \left(R^{1/2} \frac{\partial}{\partial R} [\nu \Sigma R^{1/2}] \right)$$

where ν is 'kinematic viscosity': parametrize as $\nu = \alpha c_s H$, with $\alpha < 1$, $\dot{M}(R, t) = 3\pi\nu\Sigma$

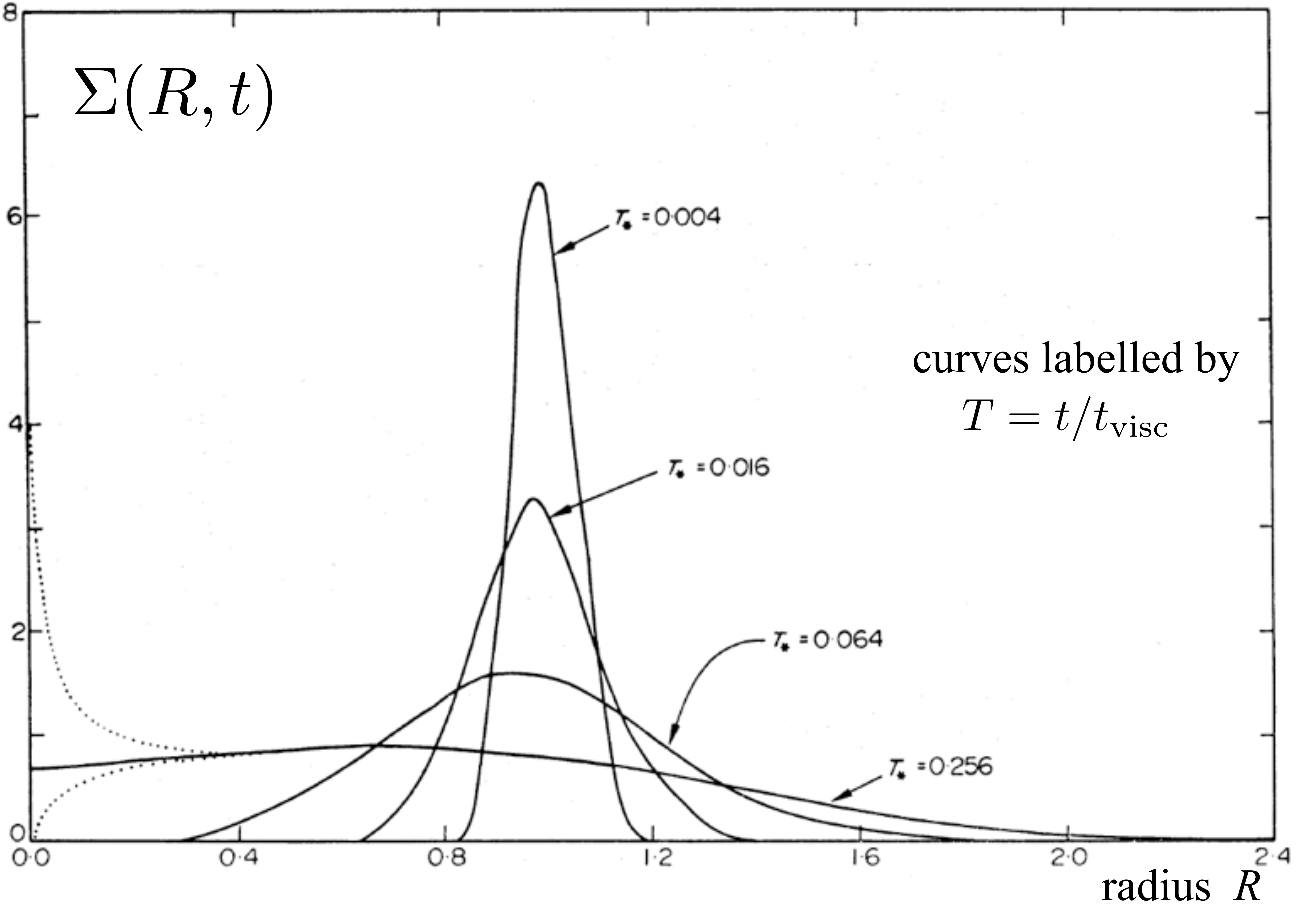
Σ spreads on *viscous timescale*

$$t_{\rm visc} = \frac{R^2}{\nu} = \frac{1}{\alpha} \left(\frac{R}{H} \right)^2 t_{\rm dyn}$$

where $t_{\rm dyn}$ is the *dynamical timescale* $R/v_K = (R^3/GM)^{1/2}$

this is *long*: $t_{\rm visc} \simeq 10^{10}$ yr for $R \sim 1$ pc $(H/R \lesssim 10^{-2})$

initial ring spreads diffusively to make a disc



disc formation is unavoidable

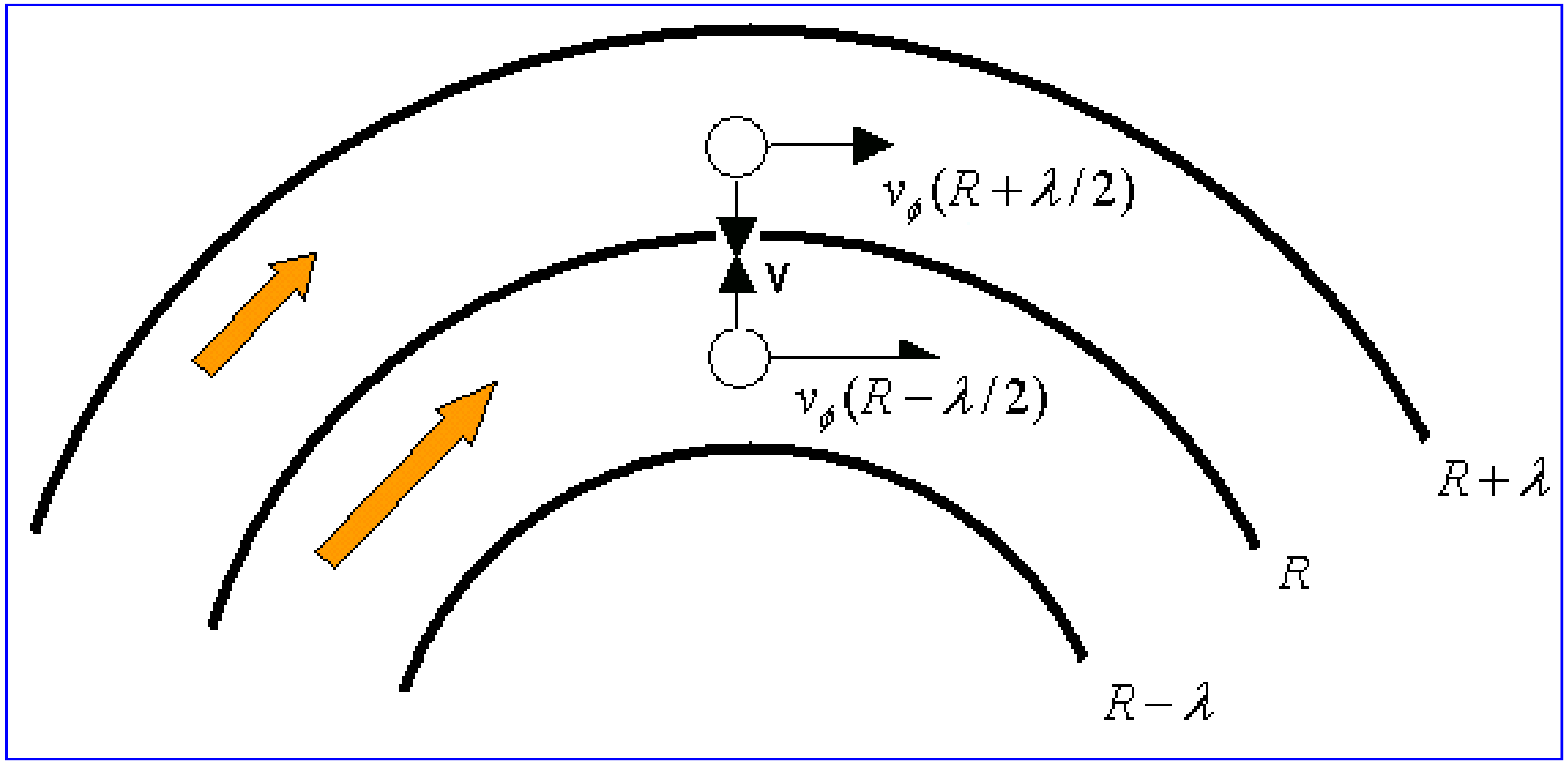
all accreting gas has enough angular momentum to orbit the hole, so a disc always forms

disc must be small enough for matter to accrete on reasonable timescales, i.e. ~ 0.1 pc for an AGN

this requires any feeding mechanism to produce an accurate `shot' towards the black hole

feeding SMBH efficiently is difficult

accretion disc structure

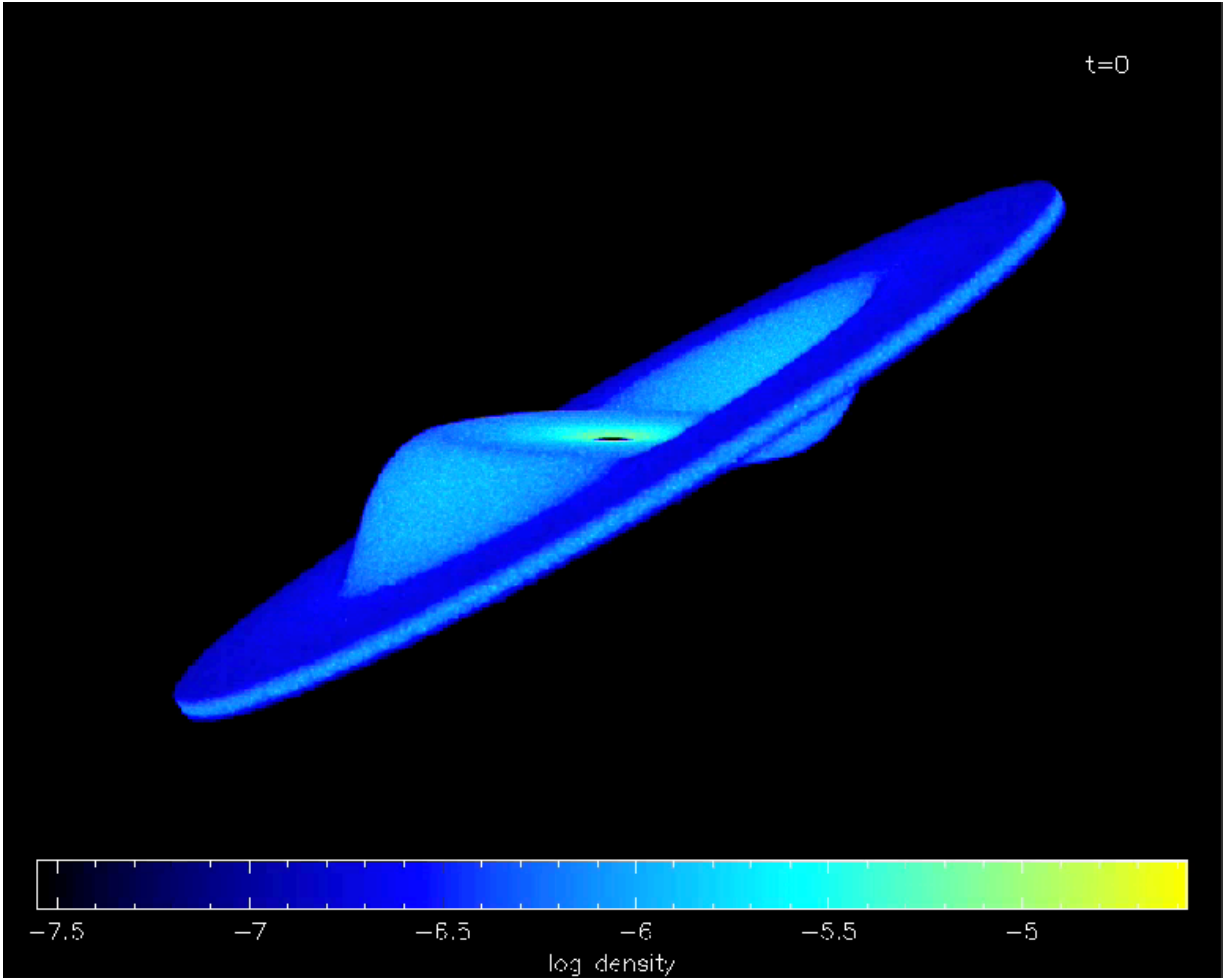


torque of inner ring on outer one is $G(R) = 2\pi\nu\Sigma R^3 \dfrac{\mathrm{d}\Omega}{\mathrm{d}R}$, with $\nu \sim \lambda v$

dissipation per unit disc face area of a steady thin disc is

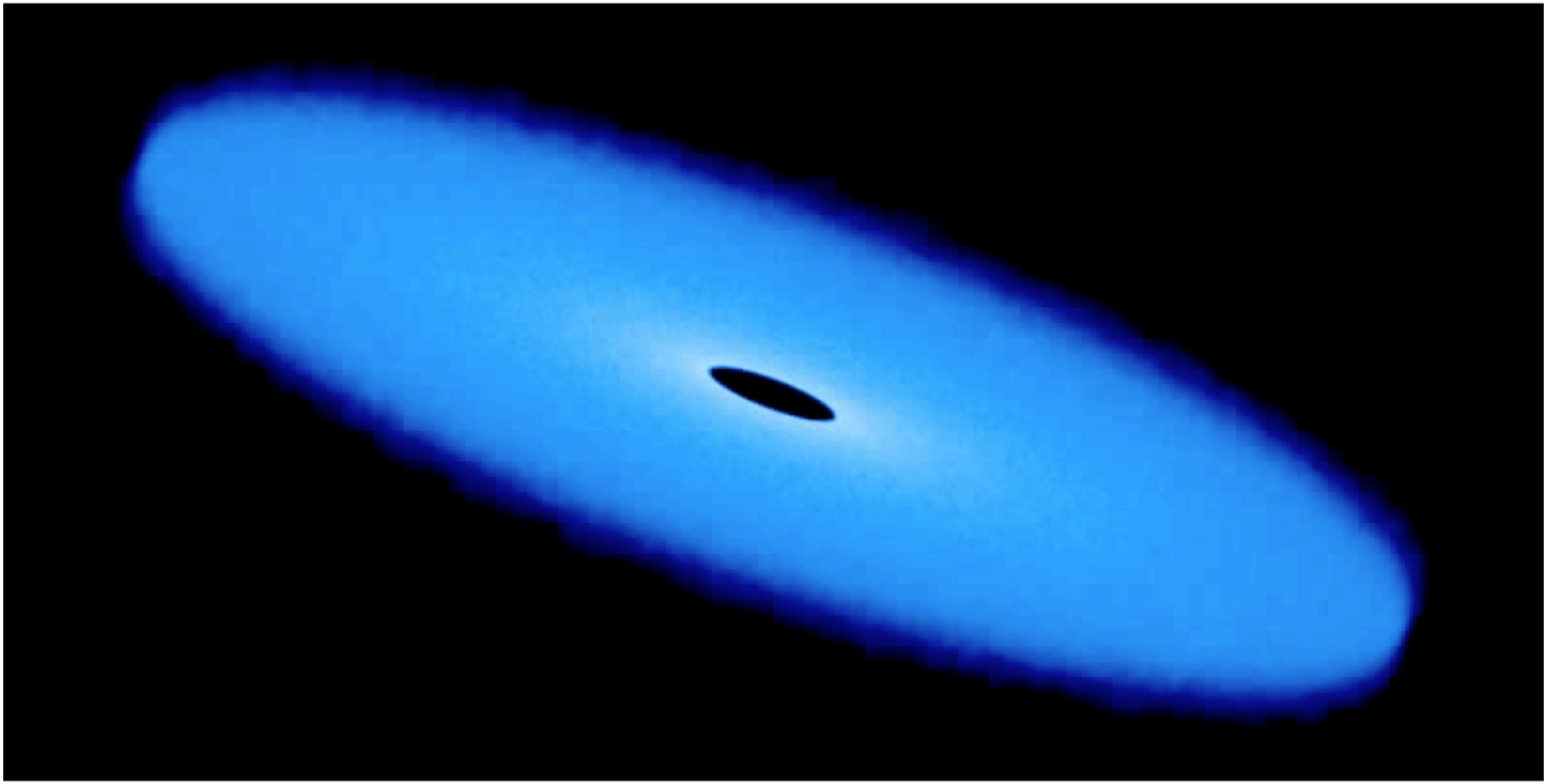
$$D(R) = \frac{3GM\dot{M}}{8\pi R^3}\left[1 - \left(\frac{R_{\rm in}}{R}\right)^{1/2}\right]$$

assumed warp (Lodato & Price 2010)

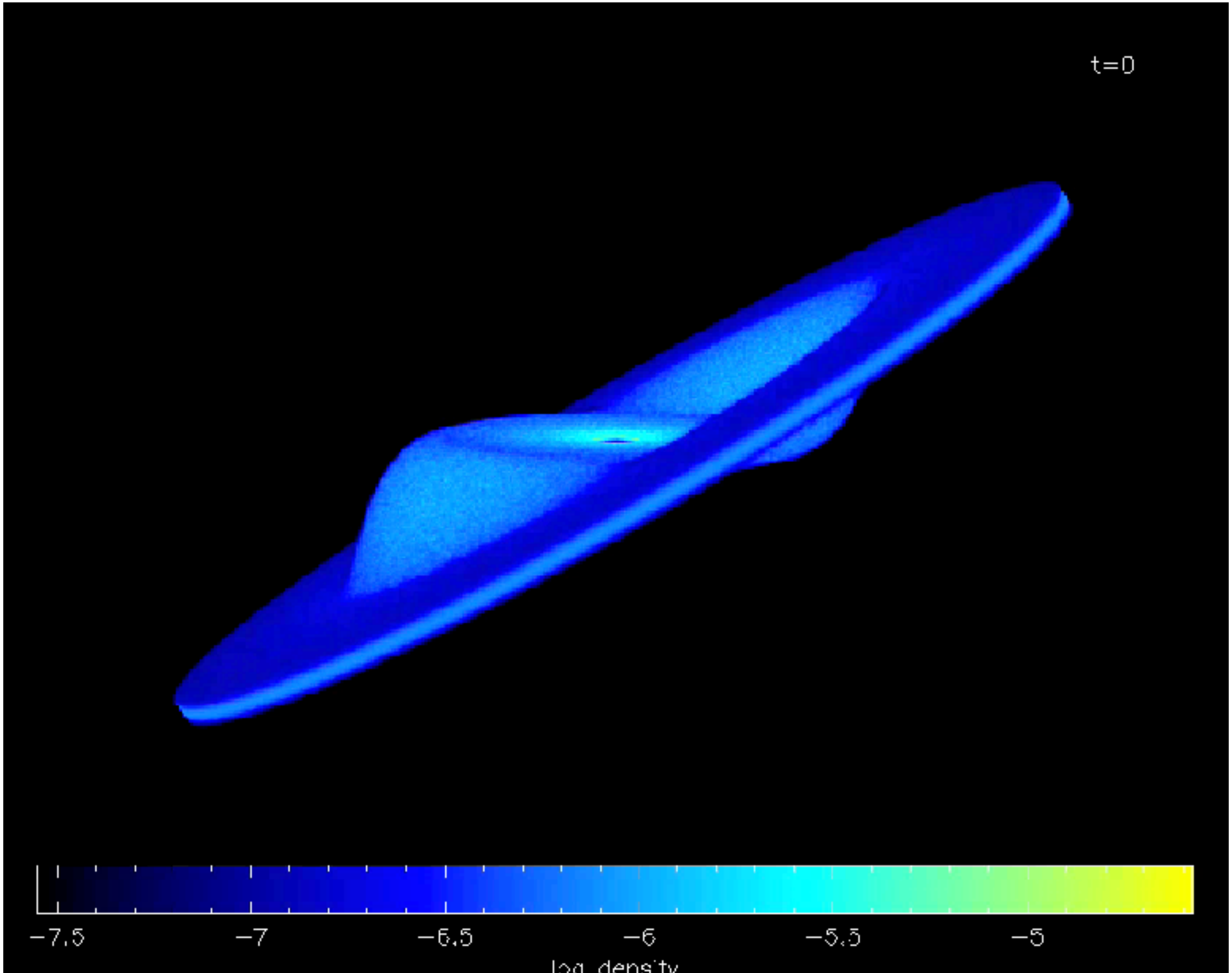


strong warp, significant viscosity

induced warp: Lense-Thirring with small tilt (Nixon & King, 2011)

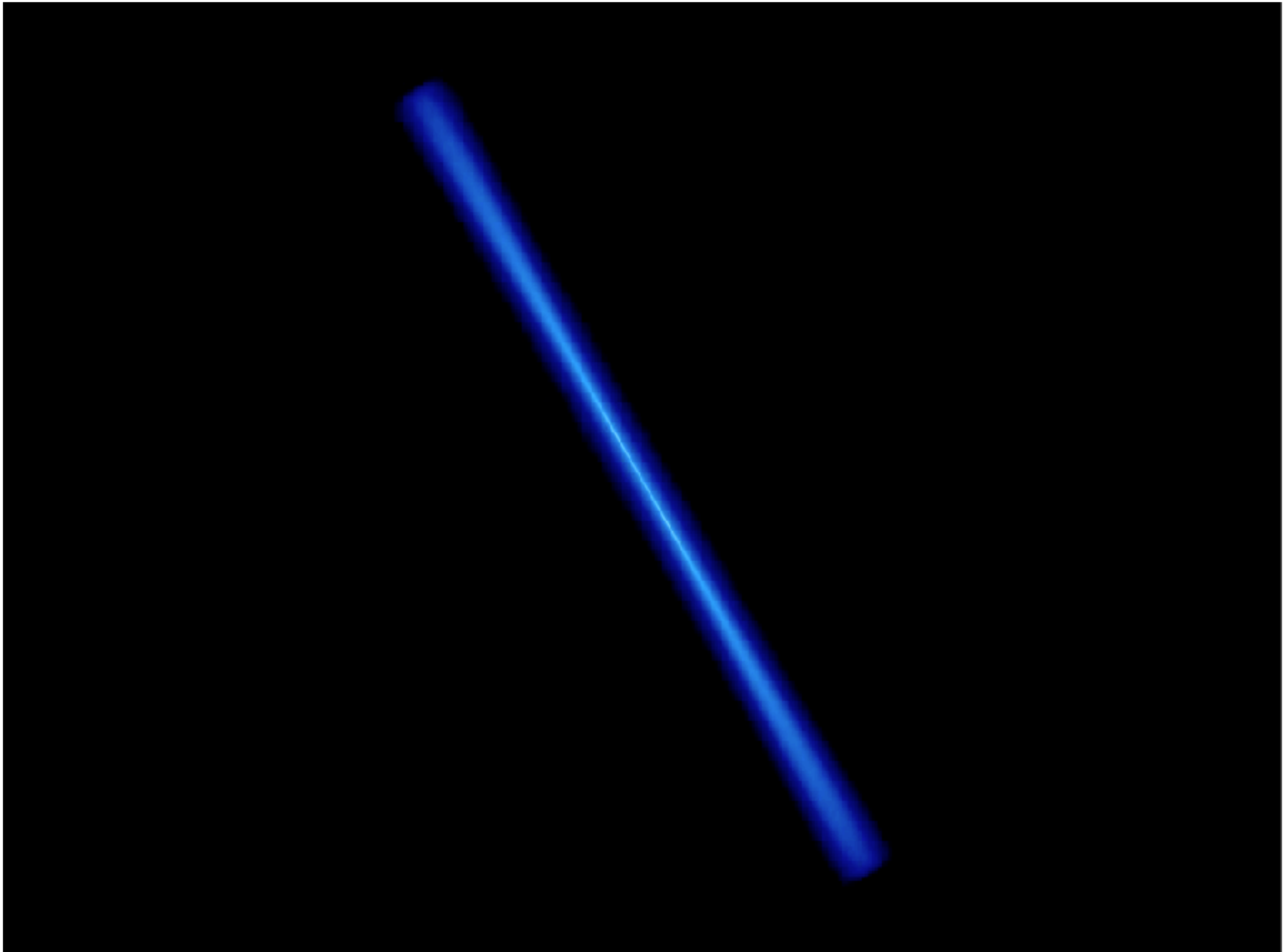


larger assumed warp (Lodato & Price, 2010)

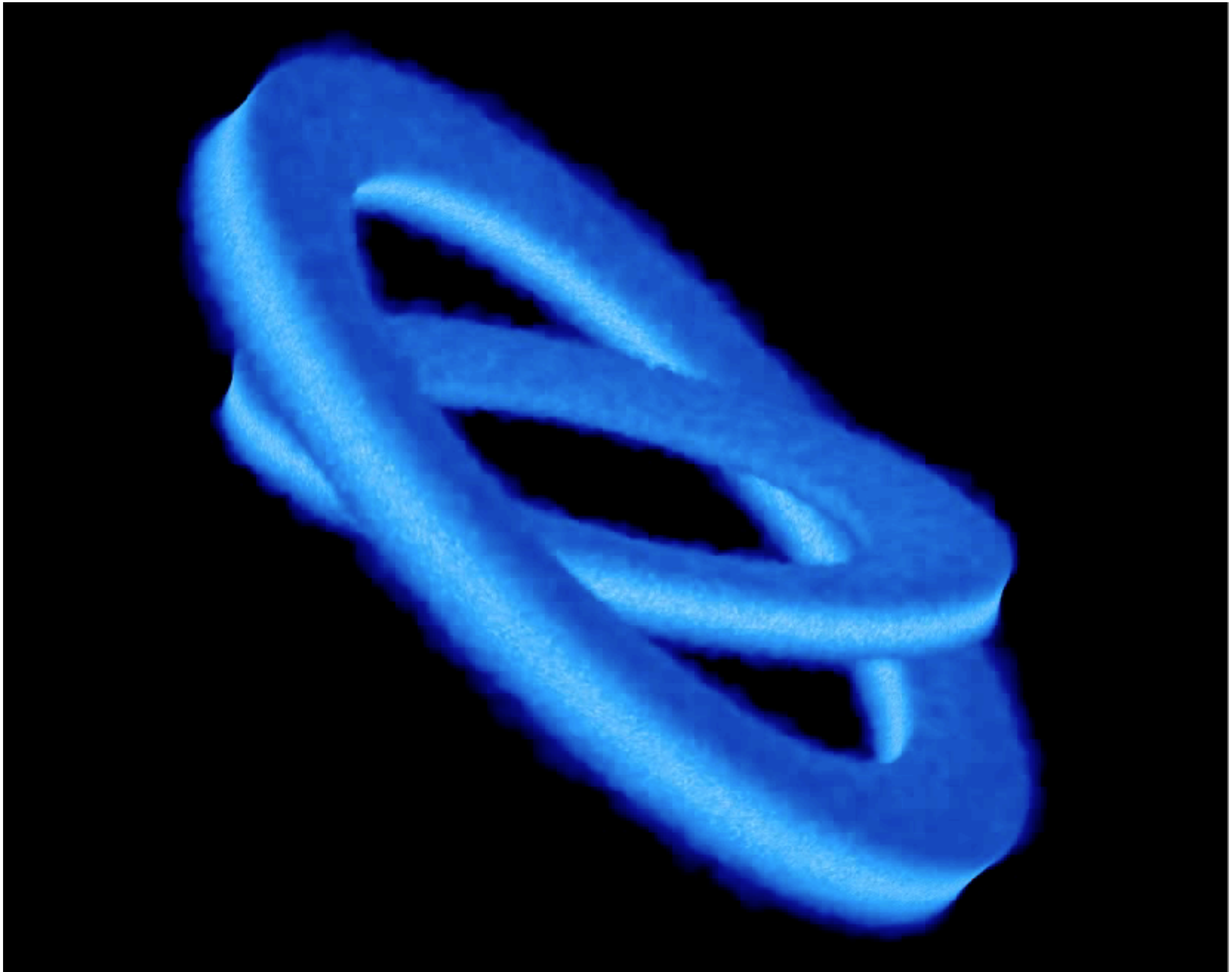


strong warp, viscosity relatively weaker: disc breaks!

Lense-Thirring: big tilt ==> rapid accretion (King & Nixon 2012

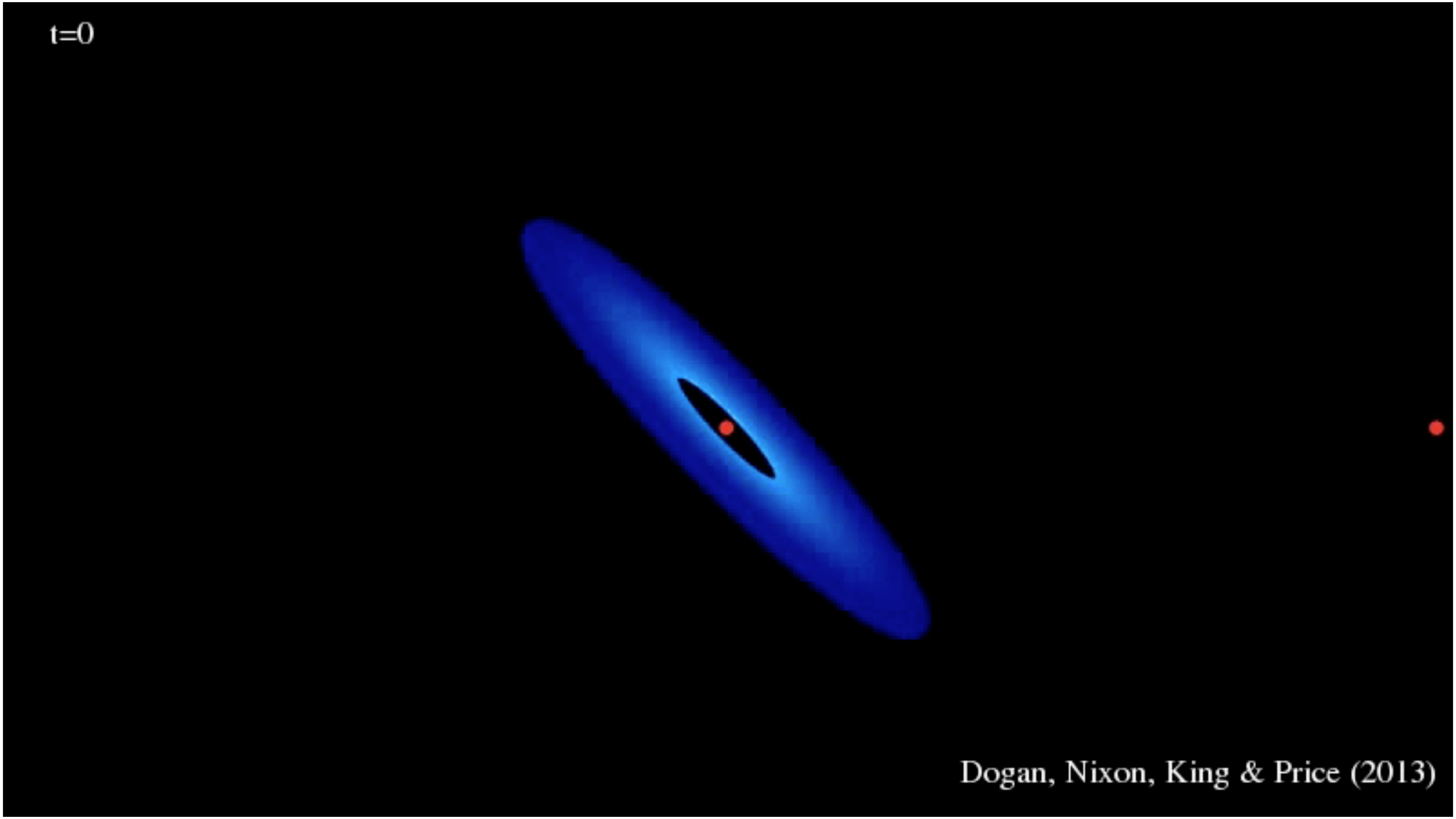


rapid accretion: counterrotating discs (Nixon & King, 2012)



circumprimary tearing:

Dogan et al. (2015)



work problem: accretion disc spectrum

$$D(R) = \frac{3GM\dot{M}}{8\pi R^3}\left[1 - \left(\frac{R_{\rm in}}{R}\right)^{1/2}\right]$$

we can take

$$D(R) = \sigma T_{\rm eff}^4$$

as defining the disc surface temperature

simplest case: disc radiates locally as a blackbody:

$$I_\nu(R) = \frac{2h\nu^3}{e^{h\nu/kT_{\rm eff}} - 1}$$

plot the continuum spectrum of a blackbody disc