Towards high performance simulations of an accretion disk surrounding a supermassive black hole

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StarDisk project

AGN with Supermassive Black Hole, Accretion Disk and Nuclear Star cluster([Just et al., 2012, Kennedy et al., 2016])

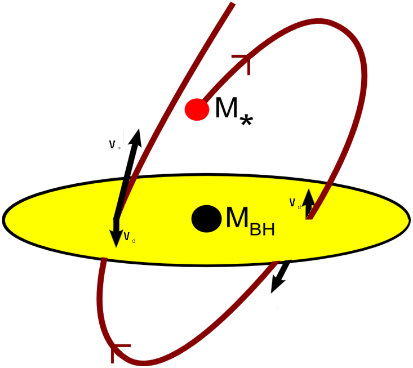


Figure: Figure illustrating the STARDISK situation, Drawing by Gareth F. Kennedy, modifications by Bekdaulet Shukirgaliyev

Governing equations and initial conditions

Euler(Navier-Stokes) equations modified by gravity:

$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \quad \frac{\partial \mathbf{m}}{\partial t} + \nabla (\mathbf{m} \cdot \mathbf{v}) + \nabla p - \nabla \sigma = \rho \mathbf{g}$

$\frac{\partial E}{\partial t} + \nabla (E \mathbf{v}) + \nabla (p \mathbf{v}) - \nabla \cdot (\sigma \mathbf{v}) = \mathbf{m} \cdot \mathbf{g}$

Ideal equation of state :$p = \rho \frac{k_{\mathrm{B}}}{\mu_{\mathrm{mol}} m_{\mathrm{H}}} T$

Cylindrical polar grid R, φ, z

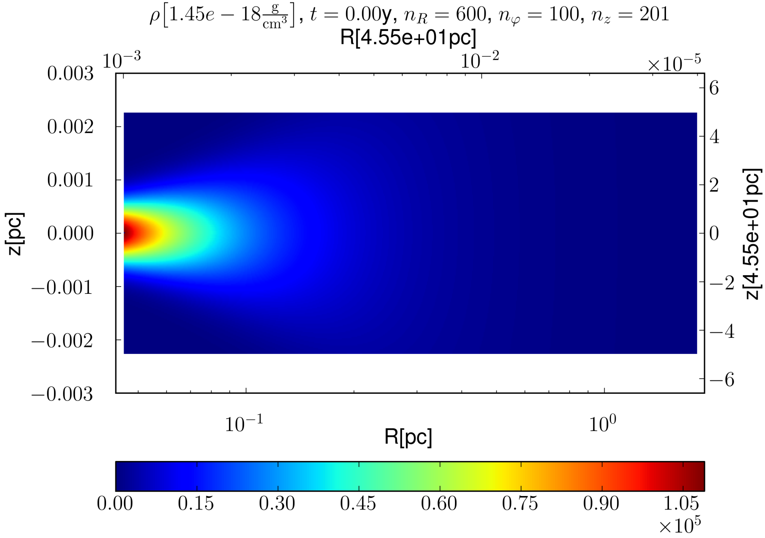
Goal: Equilibrium initial conditions, stationery

- Assume vertical isothermal profile, use momentum equation
- Use $\rho = \rho_0 \left(\frac{R}{R_0}\right)^{-\frac{3}{4}} \exp\left(-\frac{z^2}{2h(R)^2}\right)$([Kennedy et al., 2016, Shakura and Sunyaev, 1973])
- As $r \approx R$ for small z, ignore slight inconsistency in vertical isothermal structure

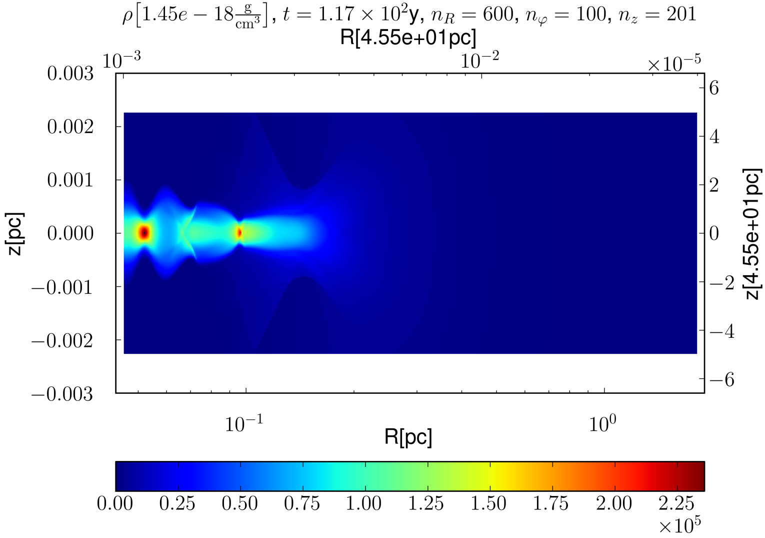
End up with

$$p = \frac{1}{3} h(R)^2 \frac{GM}{r^3} \rho \;\; v_R = 0 \quad v_\varphi = v_{\mathrm{kepler}}(R) = \sqrt{\frac{GM}{R}} \quad v_z = 0$$

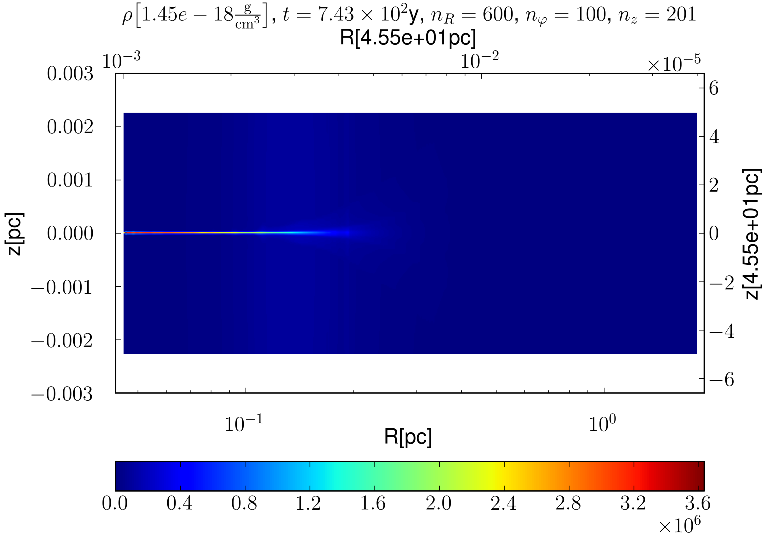
Initial conditions, ρ at $\varphi = 0$



Collapse in progress, ρ at $\varphi = 0$



Disk collapsed, ρ at $\varphi = 0$



Current problems & Further goals

- Disk collapses, much more careful treatment of initial conditions required
- Introduce heating due to star-crossing and interactions
- Far goal: Include Hydrodynamical simulation in N-Body simulation

Thank you for your attention!

[0] Just, A., Yurin, D., Makukov, M., Berczik, P., Omarov, C., Spurzem, R., and Vilkoviskij, E. Y. (2012).
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[0] Kennedy, G., Meiron, Y., Shukirgaliev, B., Panamarev, T., Berczik, P., Just, A., and Spurzem, R. (2016).
Star-disc interaction in galactic nuclei: orbits and rates of accreted stars.
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[0] Shakura, N. I. and Sunyaev, R. A. (1973).
Black holes in binary systems. Observational appearance.
Astronomy & Astrophysics, 24:337–355.