Disks around Kicked Black Holes

Joshua Faber
Center for Computational Relativity and Gravitation & School of Mathematical Sciences, RIT

12th Eastern Gravity Meeting
June 16, 2009
Disks in Astrophysics

- Disks are a ubiquitous phenomena in astrophysics since angular momentum is conserved
- Food for AGNs when accreted onto SMBH
- Milky Way: 3-4 million $M_\odot$ SMBH
- No AGN
- Stars, Gas, Dust, etc. - Nature of the disk somewhat uncertain
Disks in relativity

- Near a BH, the ISCO acts as a sink for mass

- Shakura and Sunyaev - assume shear stress proportional to pressure, find complete solution in terms of alpha

- Close Binary BHs: Much more complicated...

- Disk-Disk interactions

- Spiral waves in circumbinary disks

Colpi et al. 2009
Timescales for merging BHs

- Once the radiation reaction timescale $\ll$ disk inflow timescale, BHs decouple from the disk - $R \approx 10^3 M_{\text{BH}}$ (Schnittman & Krolik 2008)

- This leaves the remaining circumbinary disk in a (post-)Newtonian regime

- After a merger/kick, the inner regions of the disk remain bound, and the outer parts unbound
A digression on Newtonian units

- \( G = 1 \). \( G \) always equals 1.
- The natural velocity scale is the kick velocity, not \( c \).

\[ \hat{R} \equiv \frac{G M_{\text{BH}}}{v_k^2} \approx 5.3 \times 10^{11} \left( \frac{M_{\text{BH}}}{4 \times 10^6 M_\odot} \right) \left( \frac{v_k}{1000 \text{km/s}} \right)^{-2} \text{ km} \approx 3500 \text{AU} \approx 0.02 \text{ pc} \]

- There is no inherent relation between the disk mass and the BH mass
A kicked BH disk model

* Disk initially in the x-y plane, L in the +z direction
* Kick in the x-z plane, at an angle of $\theta$ from the vertical
* Assume Keplerian or quasi-Keplerian rotation

\[
\begin{align*}
    v_b(\phi) &= \sin \theta \sin \phi + \sqrt{1.0 + \sin^2 \theta \sin^2 \phi} \\
    r_b(\phi) &= v_b(\phi)^{-2}
\end{align*}
\]
The kick angle

- The kick angle $\theta$ determines the bound portion of a Keplerian disk, in units of $\hat{R}$.

- Disk masses can be determined if we assume $\sigma(r) \propto r^\alpha$. 

\[ \sigma(r) \propto r^\alpha \]

\[ \hat{R} \]

\[ \theta \]

\[ \alpha \]

\[ r \]

\[ \propto \]

\[ \sigma \]

\[ r \]

\[ ^\alpha \]

\[ \hat{R} \]

\[ \theta \]

\[ \alpha \]
Collisionless disks

* Shields, Bonning et al. (2008) considered quasi-collisionless disks around kicked BHs

* All particle orbits are independent 2-body problems

Eccentricity vs radius

“Crossing radius” vs initial radius
Global features of the disk

* Disk inclination angle differs from kick angle - reversal of direction for $\theta \gtrsim 60^\circ$

* Significant kinetic energy in vertical direction will be dissipated
Collisional disks

- Newtonian SPH can track the disk evolution without recourse to moving grids
- Heating via artificial viscosity-induced shocking
- Self-gravity of the disk is ignored
Evolution of a Kicked BH disk
Hydrodynamic properties

Top Left: $\log_{10} \rho$
Top Right: $\log_{10}\left(\frac{P}{\rho \Gamma}\right)$
Bottom: $\log_{10} P$
Future Work

* Nearly everything...