Torque and Dissipation at the Inner Region of a Thin Accretion Disk

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Galactic BH X-Ray Binaries

Accretion Disk formation requires removal of angular momentum so that matter can spiral inwards. The stress responsible is thought to be magnetic in nature.

Problems with the Standard Thin Disk Theory for accretion:
\begin{itemize}
  \item Razor-thin disk: unlikely for a real disk where we would expect the disk thickness to increase with accretion rate. We look at disks for which \(H/R < 0.1\). This happens for \(L/\dot{L}_{\text{Edd}} = 0.3\). (McClintock et al. 2006)
  \item No torque at or inside the ISCO, i.e. energy dissipation ends at the ISCO. This does not need to hold if the torque is magnetic.
\end{itemize}

OUR MODEL
\begin{itemize}
  \item Non-relativistic Hydrodynamic model for a steady, axisymmetric disk that is in hydrostatic equilibrium in the vertical direction.
  \item Uses pseudo-Newtonian potentials for both non-spinning (Paczynski & Wiita 1980) and spinning (Mukhopadhyay 2000) BHs.
  \item Uses the \(a\)-prescription for stress. (Shakura & Sunyaev 1973). We use constant values of \(a = 0.01, 0.1, 0.2\) and also a variable \(a\) motivated by MHD simulations (Krolik & Hawley 2003).
  \item Numerical solutions are obtained using a relaxation method. The inner point of the grid is at the "sonic point", \(R_{\text{sonic}}\), and the outer boundary is at \(10^6 R_{\text{ISCO}}\). The equations are then integrated from \(R_{\text{ISCO}}\) to the event horizon using the solutions from the relaxation method as boundary conditions.
  \item No "No-torque" boundary condition is applied at the ISCO. Instead we require a smooth flow through the sonic radius. At the outer boundary the disk equations are assumed to have self-similar solutions (Narayan & Yi 1994).
\end{itemize}

Error in Spin Estimation

Maximum \(\Delta a\) for a non-spinning BH is 0.07
Maximum \(\Delta a\) for an \(a = 0.95\) BH is 0.008

Estimating Spin from the Observed Spectra

The standard thin disk theory assumes the accretion disk terminates at \(R_{\text{ISCO}}\) which depends on spin. Therefore knowing \(R_{\text{ISCO}}\) one can find spin:
\[ a = a_{\text{M}} \left( \frac{J}{a_{\text{M}} GM^2 c} \right) \]

Additional torque and dissipation inside the ISCO is significant in locating \(R_m\) by the standard theory. Error in spin measurement:

Estimating Errors in BH Spin Measurement Due to Dissipation Inside the ISCO

\begin{itemize}
  \item Use a numerical method to solve hydrostatic equation of conservation of mass, linear momentum, angular momentum, and energy. Parameters solved for are \(p\) (density), \(c_s\) (sound speed), \(v_r\) (radial infall velocity), \(\Omega\) (angular velocity) as functions of radius \(R\), and also the eigenvalues \(R_s\) (sonic radius) and \(J\) (specific angular momentum where stress is zero).
  \item Find viscous dissipation \(\text{d}L/\text{d}R\) and from that the temperature \(T(R)\) using local black body assumptions.
  \item Assume the disk emits like a multicolor blackbody and find the integrated spectrum using the \(T(R)\) obtained from the above expression.
  \item Fit the model spectra with standard disk model. For a non-spinning BH we used DISKPN (Gierliński et al. 1999) and find \(R_m\) from the normalization:
\[ X = \left( R_m \times 10^{-20} \text{cm}^2 \text{(19keV)}^2 \text{c} \right) \]

From \(R_m\) we calculate the spin \(a_m\).

\begin{itemize}
  \item Use a similar approach for spinning BHs. \(R_m\) can be calculated from the flux ratios of our models to the standard thin disk model. The results are shown in the figures on the left.
\end{itemize}

Conclusions

For thin disks the error in spin estimation caused by torque and dissipation inside the ISCO is less than other sources of uncertainties, for example, uncertainties in mass, distance or inclination.