Self-consistent X-ray Spectra from Accreting Black Hole Binaries

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Observational Motivation

- Typical spectra of accreting galactic BHs include thermal, power-law, and broad iron-line features.
- These features are caused by distinct physical processes in the system, but are closely inter-dependent.
- A single integrated model can potentially explain the complete spectrum and constrain BH parameters.

**XMM, RXTE/PCA, and HEXTE observations of GX 339–4**

*credit: J. Miller*
Ray-tracing in Kerr metric: two paradigms

Description of model
  - Steady-state thin disk
  - ISCO boundary conditions
  - Hot corona

Results
  - Degeneracy of parameters
  - Breaking degeneracy

Applications
Observer-to-Emitter

The “traditional” paradigm in KERRVIEW traces photons along geodesic paths from a distant observer to the disk.

cf. Schnittman, Krolik, & Hawley 2006
Emitter-to-Observer

To include scattering effects properly, it is necessary to trace the photon paths from the emission region to the observer

cf. Schnittman & Reynolds 2006
The two methods agree quite well for line emission.

\[ a/M = 0.9, \ R_{\text{in}} = R_{\text{ISCO}}, \ R_{\text{out}} = 15M, \ l_{\text{em}}(r) \sim r^{-2} \]
The emission model is a modified Novikov-Thorne steady-state thin disk

- **disk parameters:**
  - BH mass $M$
  - BH spin $a/M$
  - accretion rate $\dot{M}/\dot{M}_{\text{Edd}}$
  - observer inclination $i$
  - ISCO torque gives added efficiency $\Delta \eta$ (Agol & Krolik 1999)

- **corona parameters:**
  - temperature, density profile $T_c(r), \rho_c(r)$
    (ADAF: $T_c \sim r^{-1}, \rho_c \sim r^{-3/2}$)
  - optical depth to Compton scattering $\tau_{\text{es}}$
inside the ISCO, the gas follows geodesic trajectories determined by $E$, $\ell$, and $v^r$ at the ISCO

- gas expands rapidly during the plunge according to the expansion parameter $\theta \equiv v^r/\alpha$, cooling adiabatically
Electron Scattering

- at each point along photon path, probability of electron scattering is $d\tau_{es} \ll 1$
- transform to a locally flat “ZAMO” frame
- scattering is computed classically in electron frame
- up-scattered photons in turn can excite iron lines

coordinate basis  
ZAMO basis  
electron rest frame
Dependence on inclination, accretion rate

![Graphs showing the dependence of normalized intensity on inclination and accretion rate.](image)
Dependence on BH mass, coronal optical depth

Normalized Intensity vs. log E (keV) for different BH masses and optical depths.

- BH masses: 5M_☉, 7.5M_☉, 10M_☉, 12.5M_☉, 15M_☉, 20M_☉
- Optical depths: 0, 0.5, 1, 2, 4, 6
There is a degeneracy between spin and torque.
Applications/Future Work

- Integrated model will be useful to
  - probe plunging region
  - estimate coronal properties
  - predict polarization signatures
  - compute line emissivity scaling functions

- Fitting observations
  - Green’s function-type transfer (e.g. Magdziarz & Zdziarski 1995)
  - orthogonal basis of fitting functions to minimize parameter degeneracy
  - incorporate XSPEC absorption features

- 3-D numerical MHD simulations (Gammie, Hawley, Krolik, etc.)
  - develop realistic heating, cooling functions
  - measure effects of corona/jet structure
  - study plunging region
  - calculate time-dependent spectra