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

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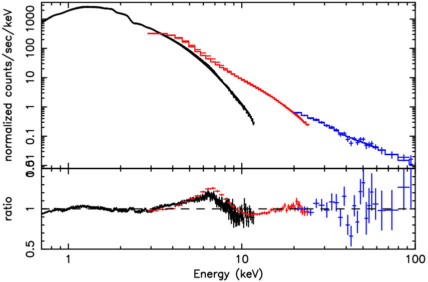
Observational Motivation

- 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

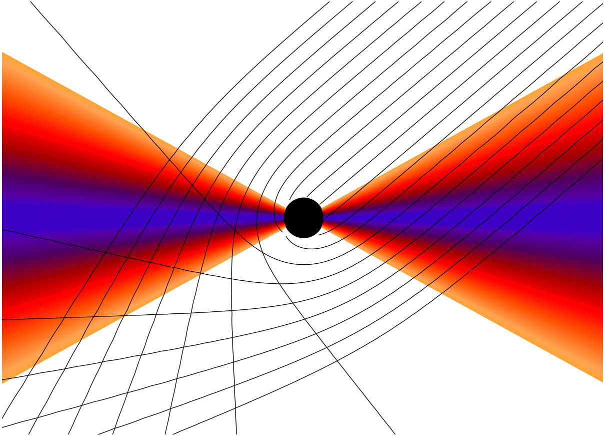
credit: J. Miller

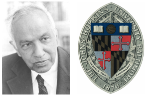
Outline

- 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

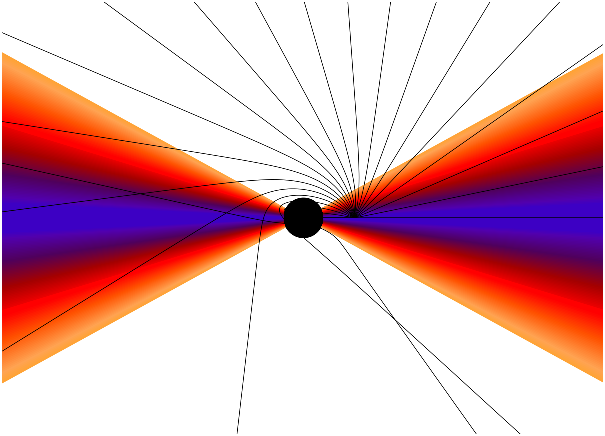




cf. Schnittman, Krolik, & Hawley 2006

Emitter-to-Observer

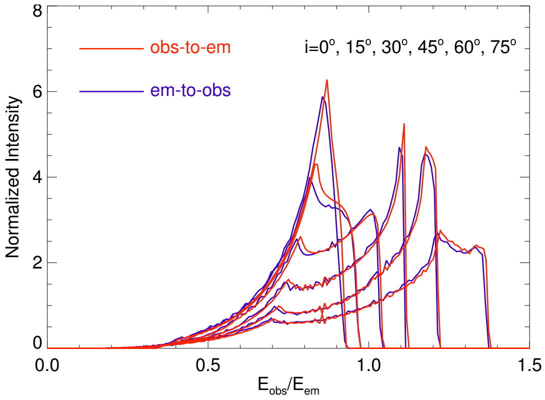
To include scattering effects properly, it is necessary to trace the photon paths from the emission region to the observer



cf. Schnittman & Reynolds 2006

The two methods agree quite well for line emission

$$a/M = 0.9,\ R_{\rm in} = R_{\rm ISCO},\ R_{\rm out} = 15M,\ I_{\rm em}(r) \sim r^{-2}$$

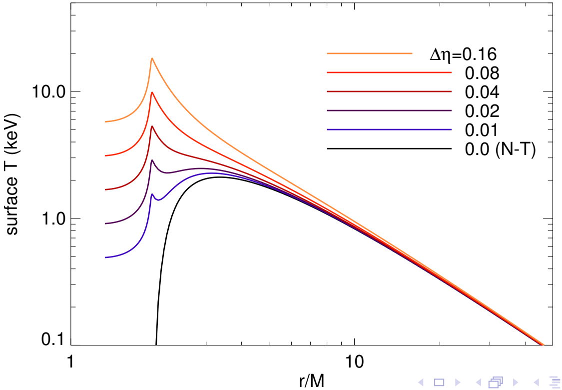


The emission model is a modified Novikov-Thorne steady-state thin disk

- disk parameters:
  - BH mass M
  - BH spin a/M
  - accretion rate $\dot{M}/\dot{M}_{\rm Edd}$
  - 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 $\tau_{\rm es}$

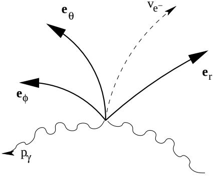
Plunging region

- inside the ISCO, the gas follows geodesic trajectories determined by E, ℓ, and v^r at the ISCO
- gas expands rapidly during the plunge according to the expansion parameter $\theta \equiv v^{\alpha}_{;\alpha}$, cooling adiabatically

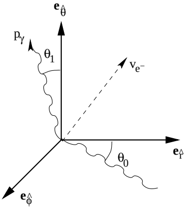


Electron Scattering

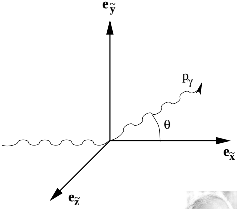
- at each point along photon path, probability of electron scattering is $d\tau_{\rm es} \ll 1$
- transform to a locally flat "ZAMO" frame
- scattering is computed classically in electron frame
- up-scattered photons in turn can excite iron lines



coordinate basis

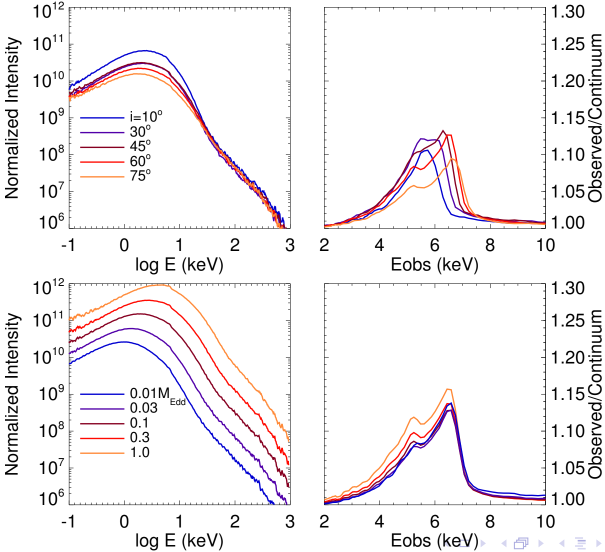


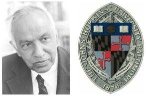
ZAMO basis



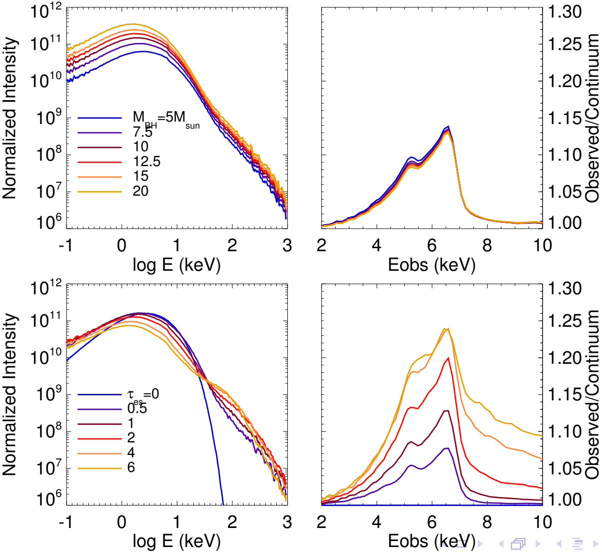
electron rest frame

Dependence on inclination, accretion rate

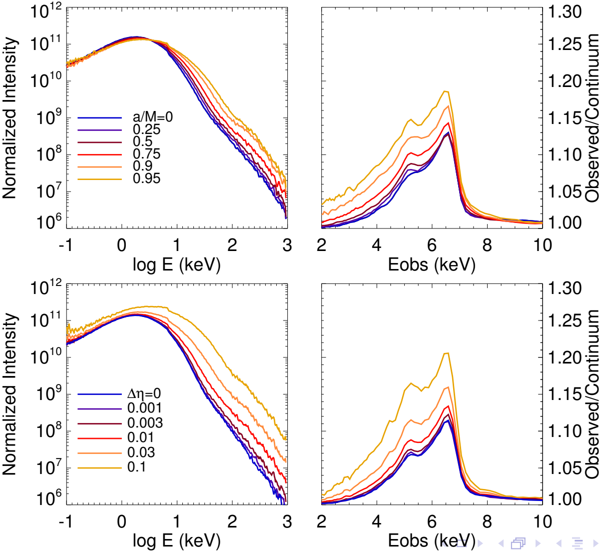




Dependence on BH mass, coronal optical depth



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

Chandra Heritage Project: pha.jhu.edu/~schnittm/chp.pdf