Dissipation in Global Simulations of Accretion Disks

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Abstract

We use the Athena++ code to perform global magnetohydrodynamic simulations of black hole accretion disks. Our goal is to examine the spatial distribution of energy dissipation to shed light on the physical mechanisms underlying the steep power law (SPL) state, where the spectra exhibits an energetically important non-thermal tail the extents to hundreds of keVs. Our work does not assume arbitrarily imposed boundary conditions at the innermost stable circular orbit. In particular, we intend to assess the feasibility of dissipating more of the accretion power in the disk upper layers and if the disk-corona structure, which is often invoked to explain the SPL state, can physically arise in an accretion flow. Our preliminary results show significant dissipation above and below the disk mid-plane, especially near the black hole.

Introduction

The physical origin of the steep power law (SPL) state spectra in black hole X-ray binaries (BHB) is an important outstanding question in astrophysics. When in the SPL state, BHBs exhibit energetically significant power law tails to at least several hundred keVs. These photon energies are much higher tahn what one can reasonably expect from the average temperatures of the disks at the ISCO. Previous local simulations and 1-D spectral calculations suggested that dissipating a large fraction of the accretion power near the photosphere may offer a plausible explanation.

Observations

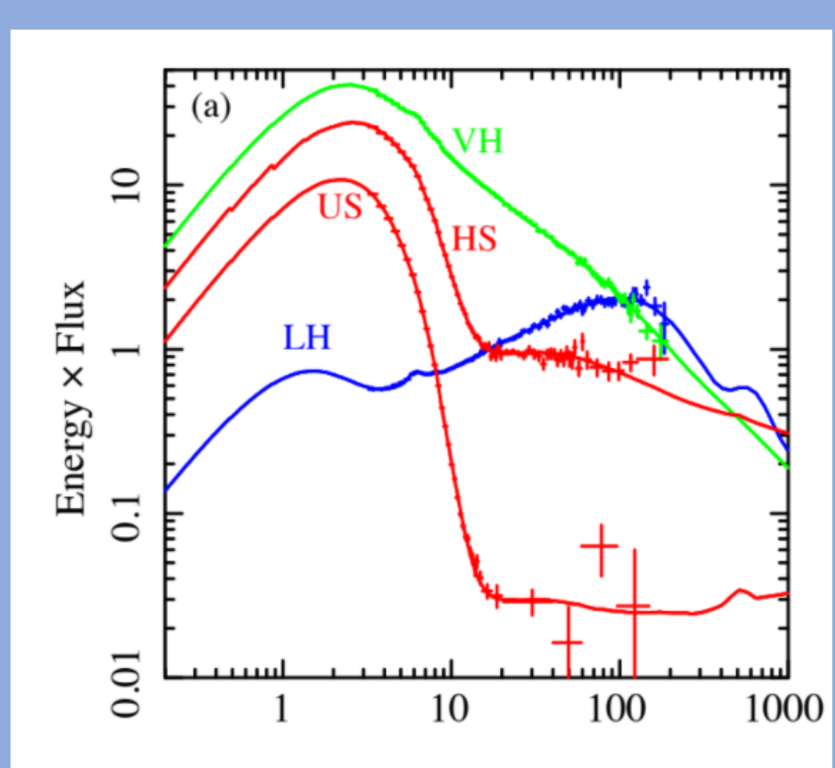

Figure 1: Spectral States from black hole X-ray binary J1655-40 (Done 2010). The green curve is the SPL (also called very high, VH) state, where the highly energetic power-law spectral tail extends to beyond several hundred keVs.

Motivation: Dissipation and Spectra

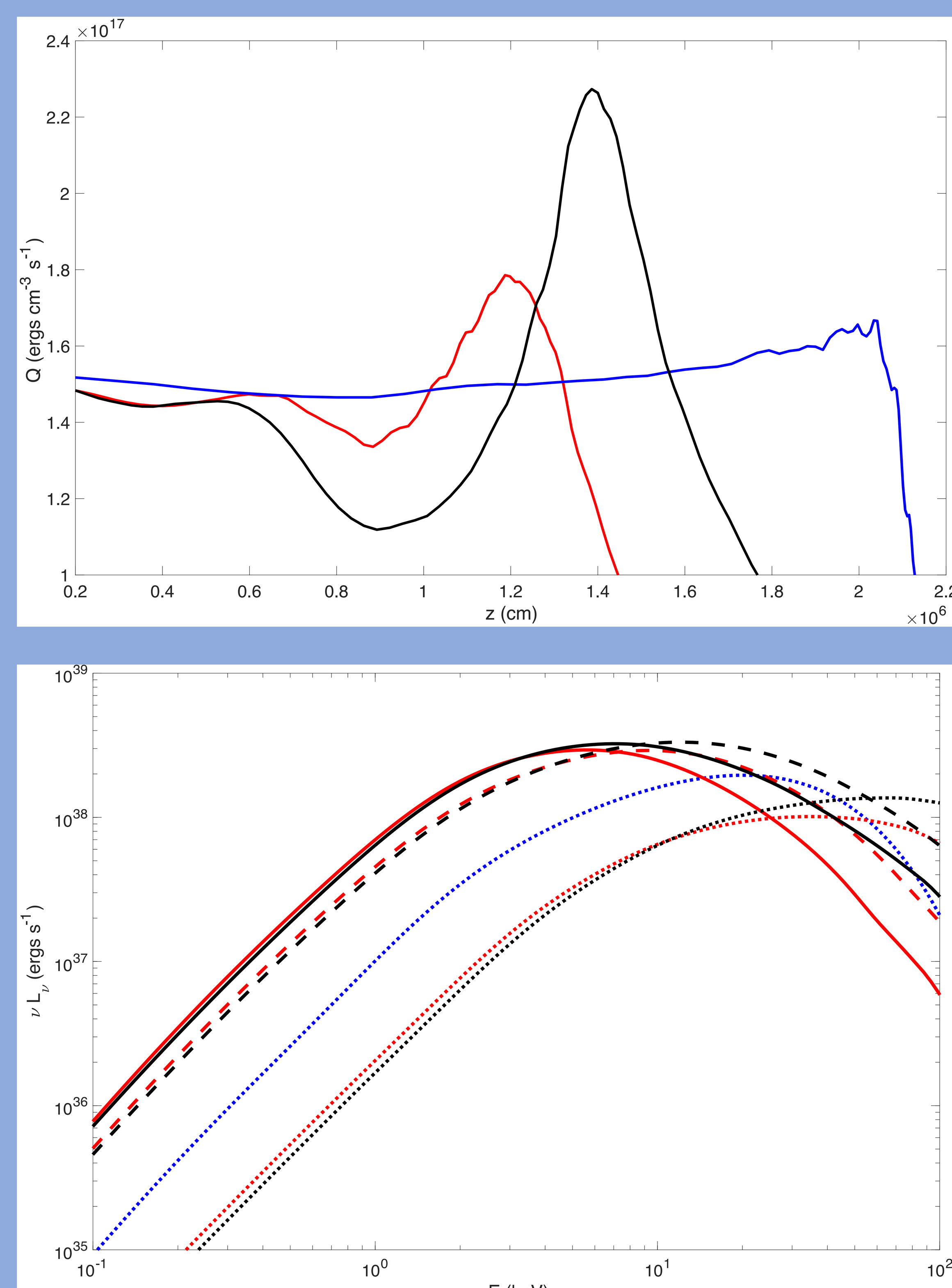

Figure 2: (Upper panel) Dissipation rate per unit volume from the one-dimensional static disk models of Dezen et al. (2019) at about $4r_g$ from the black hole as a function of height above the mid-plane. (Lower panel) Numerical full disk spectra as seen by distant observers from the same calculation, where the colors correspond to spectra from disks with the dissipation profiles from the upper panel. All curves correspond to accretion onto a 7 solar mass, a/M = 0.8 black hole. The dotted, dashed, and solid lines correspond to viewing the disk nearly edge-on, at inclination angle π/4 (measured with respect to the line of sight of the observer) and face-on, respectively.

Methodology

We conduct three-dimensional global magneto-hydrodynamic simulations of an accretion disk around a black hole with spin a/M = 0.94. Our initial condition is a hydrostatic torus with pressure maximum at 12 gravitational radii, where Keplerian orbital period is about 260 time steps. After approximately 1000 time steps, the on set of magneto-rotational instability disrupts the torus and results in accretion onto the central black hole. We set M = 1, G = 1 and c = 1, and measure distances in units of M.

Preliminary Results

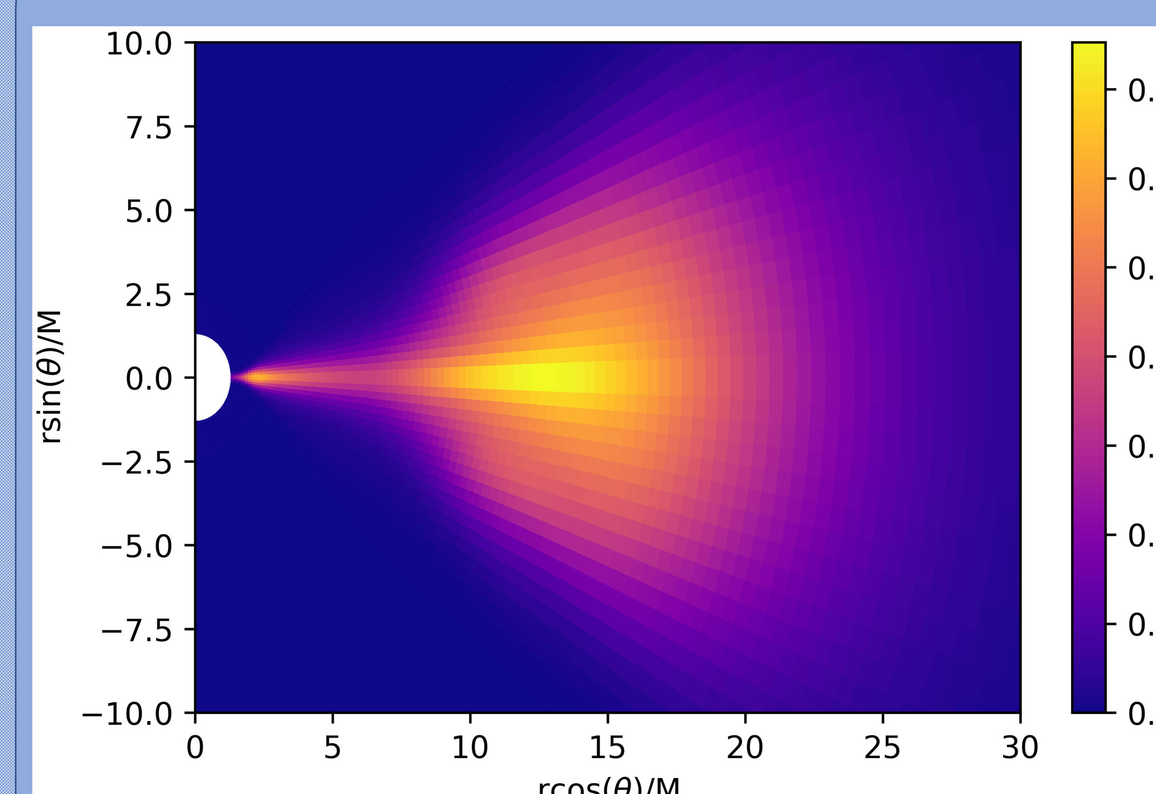

Figure 4: Side view snapshot of dimensionless disk density in the vertical plane at time step t = 1600

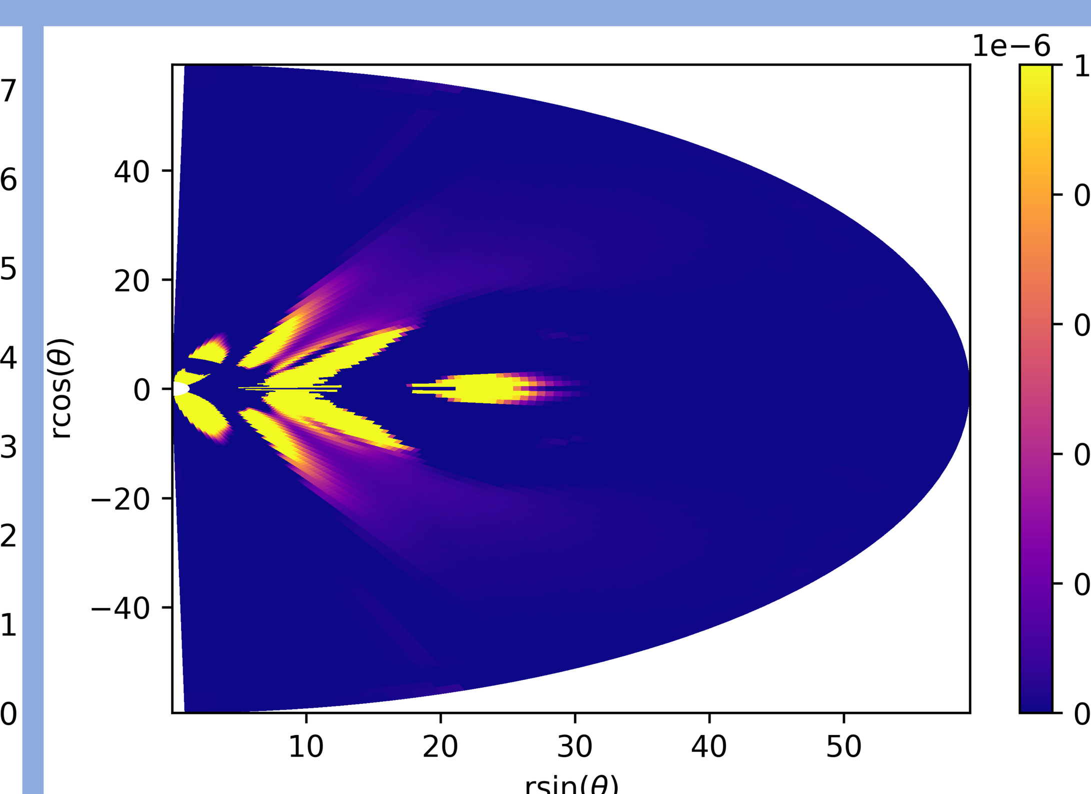

Figure 5: Dimensionless spatial distribution of dissipation for unit volume in a vertical slice of the disk at time step t = 1200.

Calculating Dissipation

The dissipation rate per unit volume Q is the rate of change of gas internal (thermal) energy density corrected by the rate of change of advected internal energy density and pressure work. The general relativistic formulation is more complicated and essentially replaces time and spatial derivatives with covariant derivatives.

$$Q = \frac{\partial e_T}{\partial t} + \vec{\nabla} \cdot (e_T \vec{v}) + p \vec{\nabla} \cdot \vec{v}$$

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