SPECTRAL PROPERTIES OF A TWO COMPONENT AND TWO TEMPERATURE ADVECTIVE FLOW

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Low angular momentum accretion flows very often have centrifugal pressure supported standing shock waves which can accelerate flow particles. The accelerated particles in turn emit synchrotron radiation in presence of magnetic fields. Efficient cooling of the electrons reduces its temperature in comparison to the protons. In this paper, we assume two temperature flows to explore this property of shocks and present an example of the emitted radiation spectrum.

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1. Introduction
Chakrabarti (1989) showed that the centrifugal barrier in a low angular momentum accretion flow can produce stable shocks. Chakrabarti and Wiita (1992) and Chakrabarti and Titarchuk (1985) showed that shocks could play a major role in determining the spectrum of the emitted radiation. Particularly important is that, the post-shock region, which is the repository of hot electrons, can easily inverse Comptonize photons from a Keplerian disk located in the pre-shock region and the power-law component of the flow may be formed easily without taking resort to any hypothetical electron cloud. However, photons can also be generated by thermal or magnetic bremsstrahlung and they can also be comptonized by the hot electrons. Just as cosmic rays may be accelerated by shocks in supernovae explosions (Bell 1978ab; 1981), the standing shocks in accretion disks, through which much of the accreting matters pass before entering into a black hole, or forming a jet, should be important to energize matter. The resulting power-law electrons would also inverse

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Comptonize along with maxwell-Bolzmann electrons. In the present paper, we are interested to identify the signatures of this energetic matter in the spectra of black holes.

2. Solution Procedure

For a given case, we fix the outer boundary at a large distance (say, $10^6 r_g$) and supply matter (both electrons and protons) with the same temperature (say, $T_p = T_e = 10^6 K$). We calculate density and temperature at any point by solving the energy equations separately for electrons and protons. We compute the radiation emitted by the flow through bremsstrahlung and synchrotron radiation. These low energy photons are then inverse Comptonized by the hot electrons in the flow. We followed the procedures presented in Chakrabarti and Titarchuk (1995) and Titarchuk and Lyubarskij (1994) for computing the Comptonized spectrum due to Maxwell-Boltzmann electrons and power-law electrons respectively. At the end, we add the contributions to get the net photon emissions from the flow. The geometry of the flow is chosen to be conical. The angle $\Theta$ subtended by the flow with the z-axis is chosen to be a parameter. For simplicity, we also choose the shock location $X_s$ and the compression ratio $R$ as free parameters. The shock of compression ratio $R$ causes the formation of power-law electrons of slope $p = (R + 2)/(R − 1)$ (Bell, 1978ab). This power-law electrons produce a power-law of the synchrotron emission with slope $q = (1 − p)/2$ (Longair 1981). The power-law electrons have energy minimum at $E_{\text{min}} = 3\theta$, where, $\theta$ is electron temperature, and energy maximum at $E_{\text{max}}$ obtained self-consistently by conserving the number of power-law electrons and by computing the number of scattering that the electrons undergo inside the disk before they escape. (Here $E$ is the bulk Lorentz factor of the electrons.) In a realistic flow, not all of the incoming matter is expected to pass through the accretion shock, and we assume that the percentage of electrons $\zeta$ having power-law index to be a free parameter.

We can vary parameters such as $\Theta$, $X_s$, $R$, $\zeta$ and $\dot{m} = \dot{M}/\dot{M}_{\text{Edd}}$, the accretion rate of the flow in units of the Eddington rate $\dot{M}_{\text{Edd}}$. We present a typical spectrum assuming a black hole of mass $10 M_\odot$. Details are in Mandal & Chakrabarti (2004).

3. Results and Interpretations

Figure 1 shows the variation of the electron and proton temperatures ($T_e$ and $T_p$ respectively) when $\dot{m} = 0.0005$, $R = 3.9$, $\Theta = 77^\circ$, $\zeta = 0.7$ and $X_s = 10$ as a function of the radial distance $X$ (measured in units of the Schwarzschild radius $r_g$). The electrons start becoming cooler closer to the black hole when the number density gets higher. Higher number density increases the cooling for $X \lesssim 300$. Very close to the black hole, especially after the shock at $X = X_s = 10$, the splitting is dramatic and electrons become very much cooler. With our parameters, below $X \sim X_s = 5.8$, the cooling is so strong that Comptonization procedure breaks down. We left the temperature to be local Keplerian temperature for $X < X_c$. 
In Figure 2, we present the corresponding spectrum with all the contributions from the accretion flow. Here, different curves are marked with a number. The curve marked ‘1’ is due to synchrotron emission from the post-shock region (which is also known as the Centrifugal pressure dominated BOundary Layer or the CENBOL region) emitted by Maxwell electrons. The curve marked ‘2’ is that due to the power-law electrons at CENBOL. The curve marked ‘3’ is the synchrotron emission
from the pre-shock part of the accretion flow. The curve marked ‘4’ gives the Comptonized spectra of the synchrotron radiation from the pre-shock accretion flow. The curve marked ‘5’ which is really made up of two pieces, one (up to the self-absorption frequency $\nu_a$) of a black-body power-law of slope $-2$, and the other of a power-law of slope same as curve ‘2’ due to power-law electrons, gives the net synchrotron emission from the CENBOL region after the self-absorption is taken care of. The curve marked ‘6’ is the Comptonization of the soft synchrotron photons emitted from Maxwell electrons. The curve marked ‘7’ is the Comptonization of the soft synchrotron photons emitted from the power-law electrons. The curve marked ‘8’ is the total Compton spectra from the pre-shock as well as the post-shock regions.

It is clear that the power-law electrons generated at the shocks in accretion can leave its signature on the emitted spectrum, as is evidenced from the power-law part of the spectrum near $\log(\nu) \sim 14 - 15$. From $\log(\nu) \sim 16 - 18$, the power-law photons are produced mainly due to Comptonization of the CENBOL photons, while the power-law around $\log(\nu) \sim 19 - 20$ is mainly due to the Comptonization of the photons from the pre-shock region. Thus separate regions of the spectrum can be identified with separate physical processes inside an accretion disk.

4. Concluding Remarks

Our conclusion is that there are several ways a shock may be identified in the spectrum. At a strong shock, the power-law electrons are produced with a very high $E_{\text{max}}$ and that produces a power-law feature in the spectrum. There is a bump in the spectrum at around $\log_{10}(\nu) \sim 14 - 15$. On the top of this, another bump at around $10^{17}\,\text{Hz}$ would have been present had the Keplerian disk been there.

In Chakrabarti and Titarchuk (1985) soft photons due to a Keplerian disk was responsible to cool down the post-shock region. There are enough evidence that this two component advective flow is correct. We used only the sub-Keplerian (or halo) component in the present paper. Here, considered soft photons to be locally generated due to thermal and magnetic bremsstrahlung processes. In future, we shall incorporate a Keplerian disk and obtain a combined spectrum. We shall compare these results with observed spectra in order to see if these theoretically predicted shocks are actually present.

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