Effects of Compton Cooling on Outflow in a Two Component Accretion Flow around a Black Hole: Results of a Coupled Monte Carlo TVD Simulation

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Abstract

We wish to investigate the effects of cooling of the Compton cloud on the outflow formation rate in an accretion disk around a black hole. We carry out a time dependent numerical simulation where both the hydrodynamics and the radiative transfer processes are coupled together. We consider a two-component accretion flow in which the Keplerian disk is immersed into an accreting low-angular momentum flow (halo) around a black hole. The soft photons which originate from the Keplerian disk are inverse-Comptonized by the electrons in the halo and the region between the centrifugal pressure supported shocks and the horizon. We run several cases by changing the rate of the Keplerian disk and see the effects on the shock location and properties of the outflow and the spectrum. We show that as a result of Comptonization of the Compton cloud, the cloud becomes cooler with the increase in the Keplerian disk rate. As the resultant thermal pressure is reduced, the post-shock region collapses and the outflow rate is also reduced. Since the hard radiation is produced from the post-shock region, and the spectral slope increases with the reduction of the electron temperature, the cooling produces softer spectrum. We thus find a direct correlation between the spectral states and the outflow rates of an accreting black hole.

Simulation Set Up and Procedure

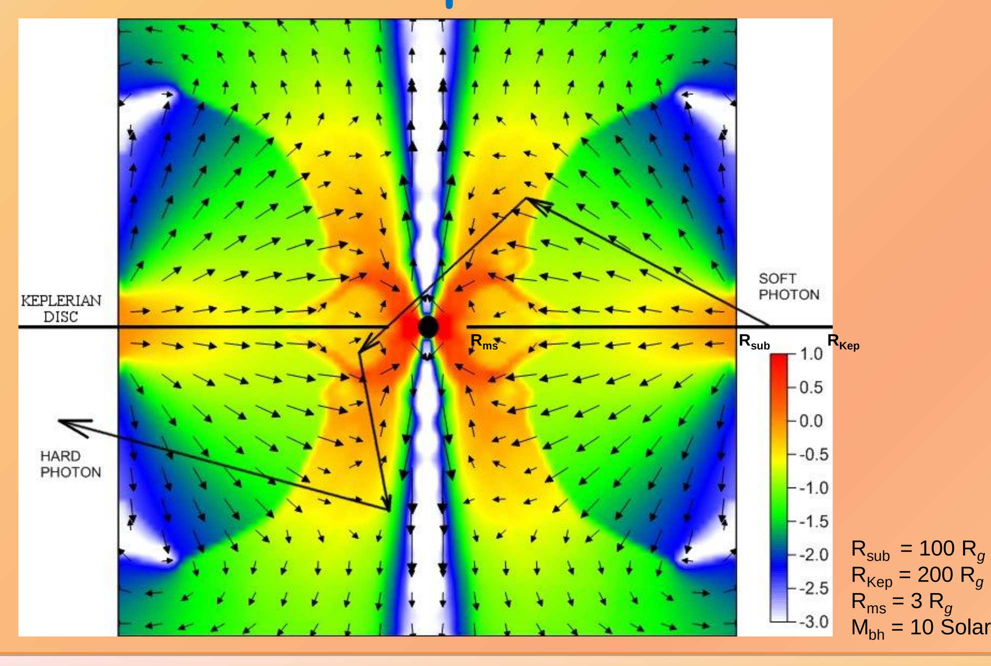
All the simulations have been performed using a time dependent radiation hydrodynamic simulation code .

TVD code
to study hydrodynamics of accretion flow (calculate velocity, density and temperature profile inside electron cloud)

Monte Carlo code
to study Comptonization of photons (find spectral and timing properties, thermal energy loss of electrons etc.)

COUPLING

1. Calculate velocity, density and temperature profile inside accretion disk using TVD code.
2. Calculate the spectrum using Monte Carlo code.
3. Compute thermal energy loss (or gain) of electrons and its new energy profile.
4. Taking new energy profile of electrons as initial condition , run TVD code again.



This Figure shows the vertical cross-section of our simulated accretion disk. The Keplerian disk resides on the equatorial plane and the colors show the density profile of the sub-Keplerian flow. The zig-zag path shows the typical photon trajectory. The computation is done in a 100R_g by 100R_g box. Keplerian disk is assumed to extend upto 200R_g from R_{ms} .

Simulation Results

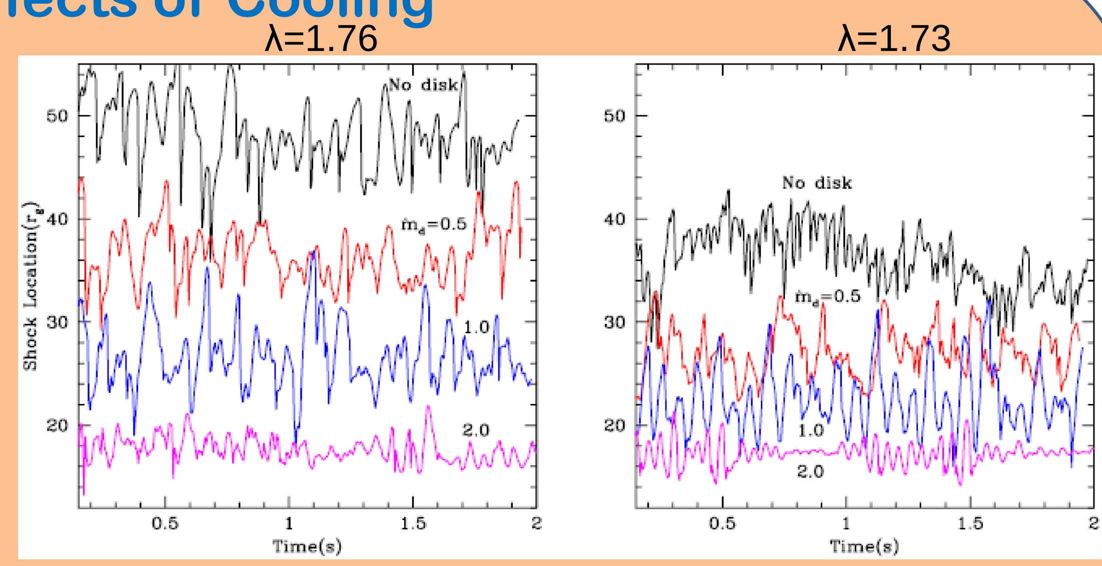
We have simulated several cases by varying the Keplerian disk rate keeping the sub-Keplerian halo rate constant for two different angular momenta . Our aim is to see the effects of the increased cooling on the flow dynamics as well as the spectral properties of the accretion disk. Below we show the results. More details can be found in Garain, Ghosh & Chakrabarti, **2012**, ApJ, **758**, 114.

Effects of Cooling

Table 1: Parameters used for the simulations.

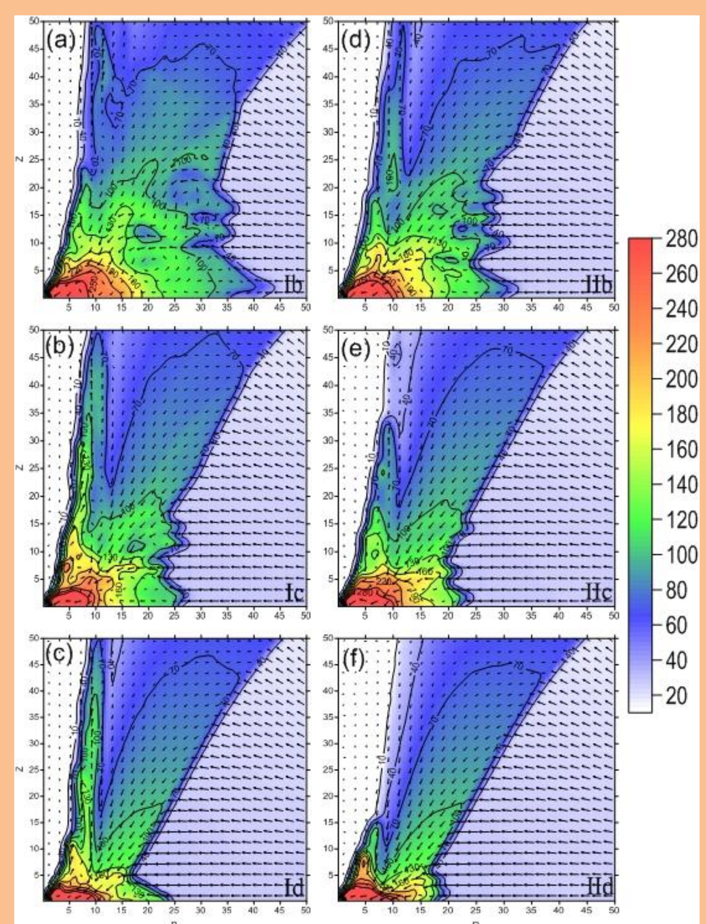
Case	ϵ, λ	$\dot m_h$	$\dot m_d$
1a	0.0021, 1.76	1.0	No Disk
1b	0.0021, 1.76	1.0	0.5
1c	0.0021, 1.76	1.0	1.0
1d	0.0021, 1.76	1.0	2.0
2a	0.0021, 1.73	1.0	No Disk
2b	0.0021, 1.73	1.0	0.5
2c	0.0021, 1.73	1.0	1.0
2d	0.0021, 1.73	1.0	2.0

In the above Table, we present the parameters for all the simulated cases. ε is the specific energy and λ is the specific angular momentum at the outer boundary. $\dot m_h$ is the halo accretion rate and $\dot m_d$ is the disk accretion rate.



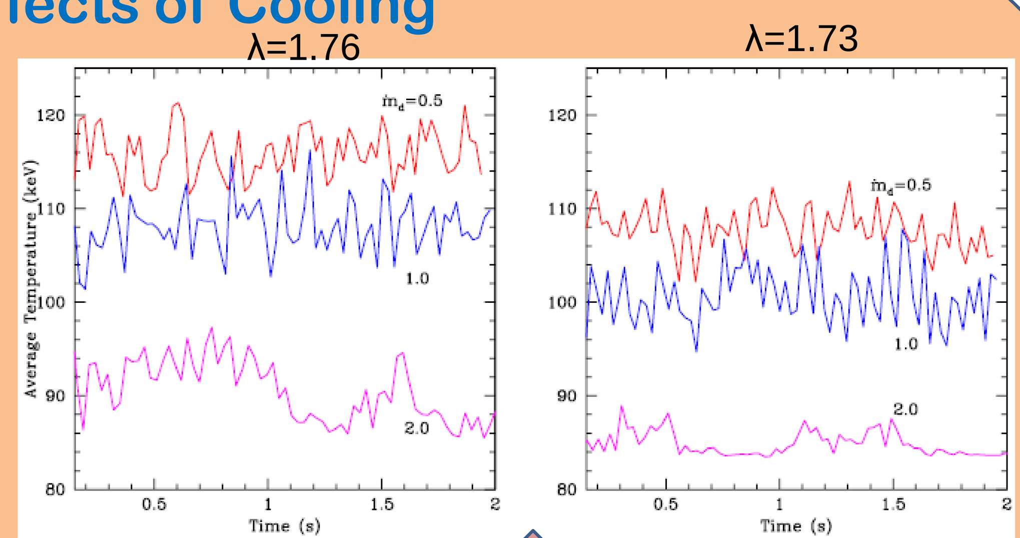
Time variation of the shock location is shown in the above Figure. Shock location moves toward black hole as disk rate $\dot m_d$ is increased. It shows that the postshock region collapses i.e. the size of the CENBOL decreases with the increase of cooling.

Effects of Cooling



Color map of temperature (keV)

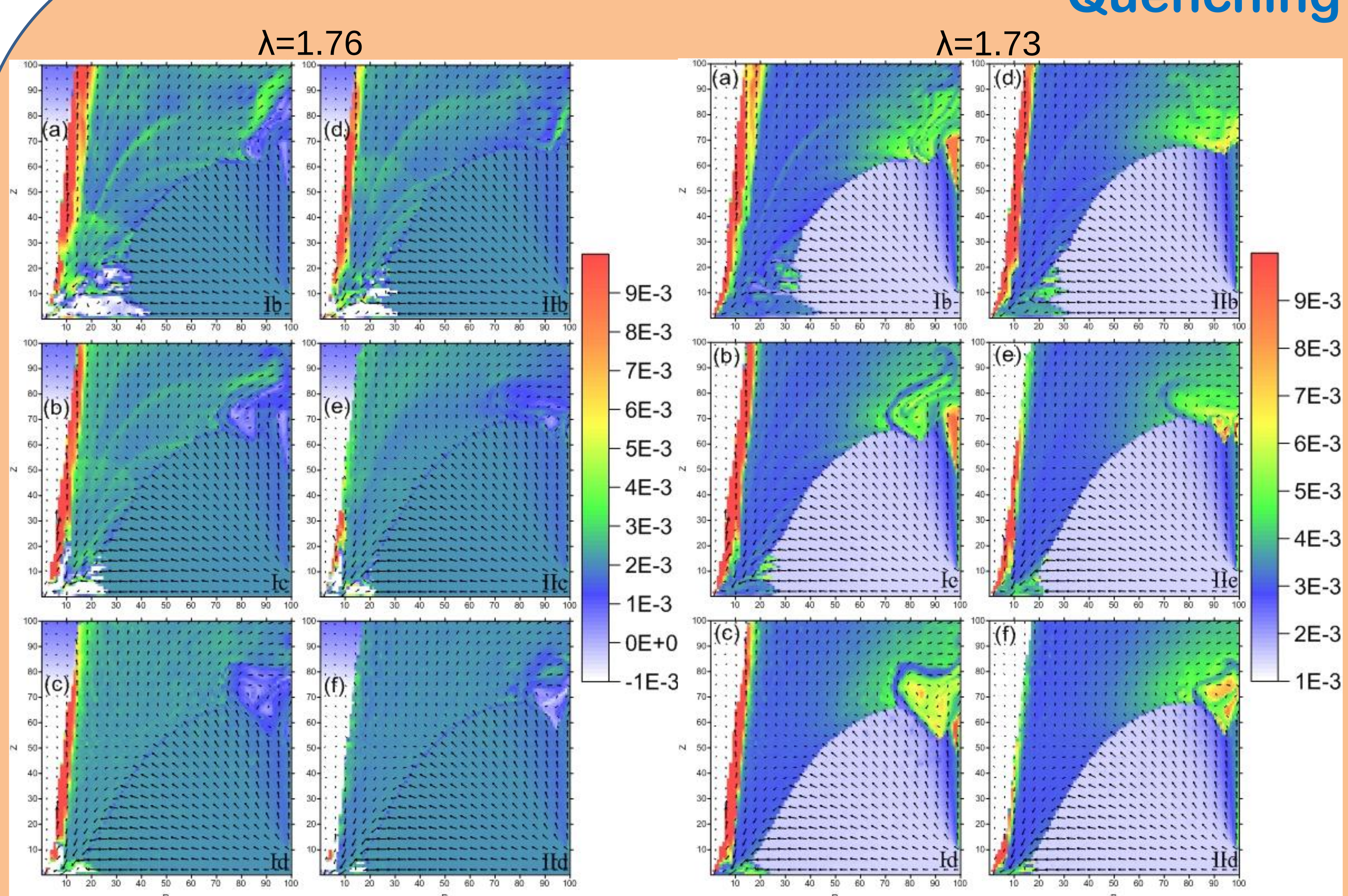
Snapshots of the temperature profile at the end of each simulations are shown on the left.



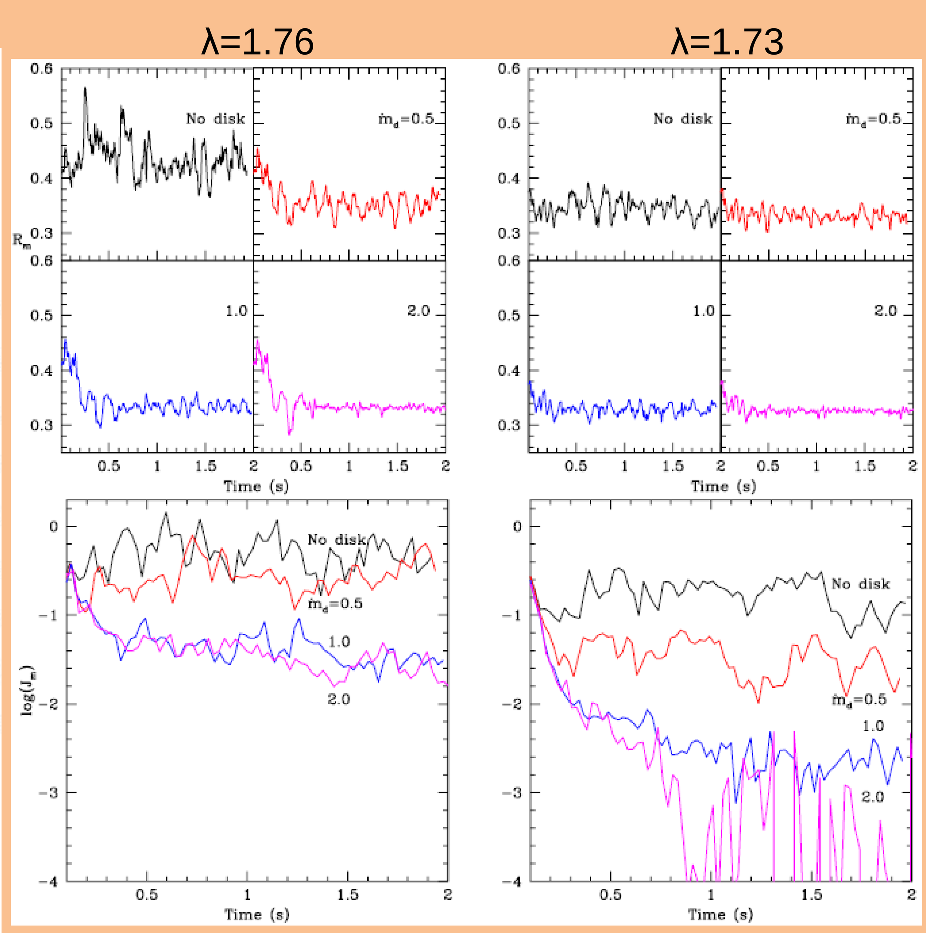
Time variation of the temperature in the post-shock region is shown in the above Figure.

Post shock regions cool down more and more as the disk rate $\dot m_d$ is increased.

Quenching of Jet

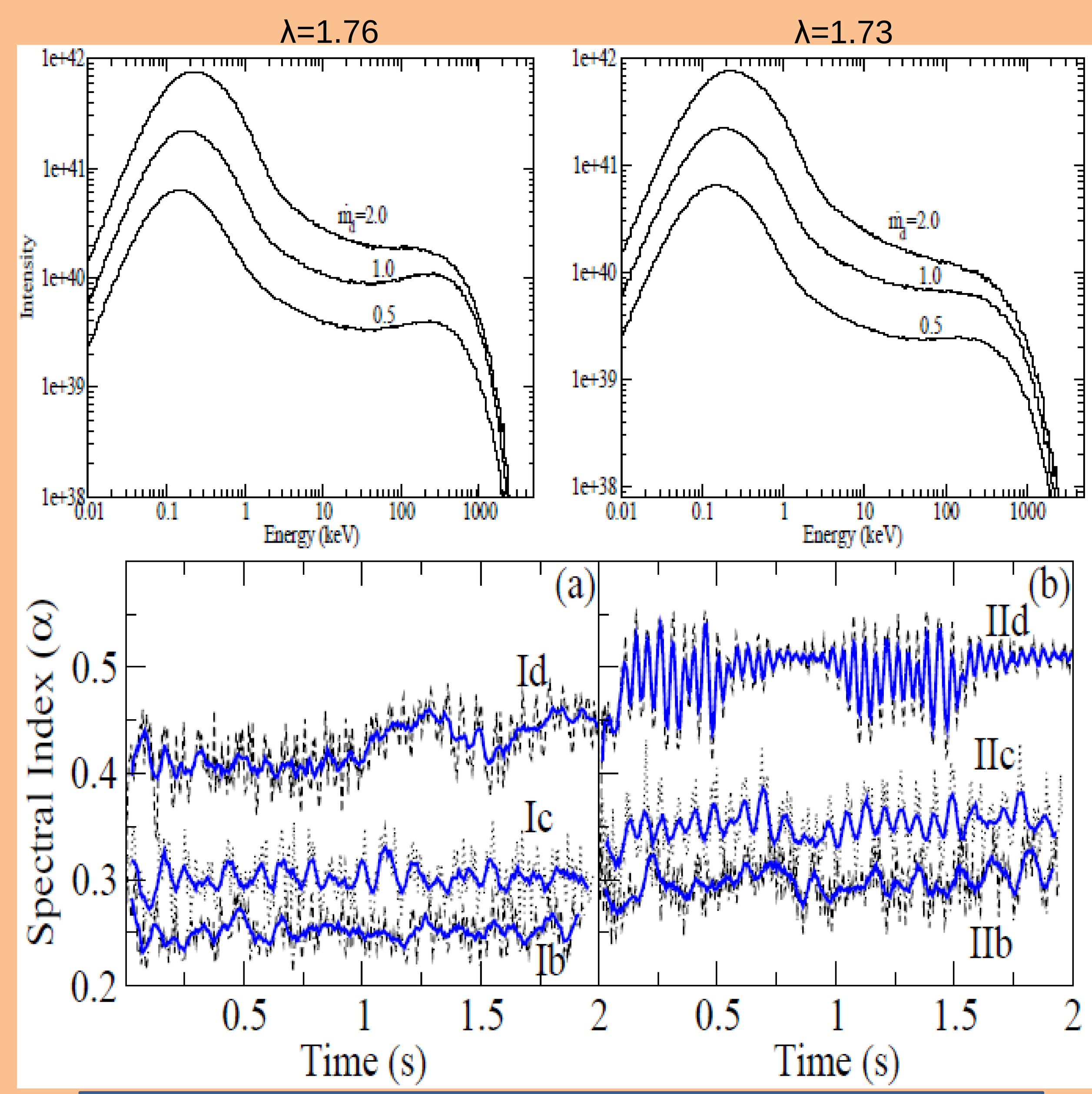


In this Figure, we present the specific energy (left) and the entropy (right) distribution for both the angular momenta for all the cooling cases at the end of the simulations. Outflowing matter should have positive energy and higher enrtropy. We see less and less amounts of matter have higher energy as cooling is increased. Also, the region, containing jet matter having higher enrtropy, shrinks with the increase of $\dot m_d$.



Top Panel: Time variation of $R_{\dot m} (= \dot M_{\rm out}/\dot M_{\rm in})$ shown here. $\dot M_{\rm out}$ is the rate at which outward pointing flow leaves the computational grid.
Bottom Panel: Time variation of $J_{\dot m} (= \dot M_{\rm jet}/\dot M_{\rm in})$ shown here. $\dot M_{\rm jet}$ is the rate of those matter which have high positive energy and high entropy.

Spectral Properties



Top Panel: Final spectra for all the cooling cases shown.
Bottom panel: Time variation of the spectral slope in the 1-10 keV range is shown. Spectrum softens as cooling is increased.

Conclusions

- **The hydrodynamics as well as the spectral properties of the accretion disk in presence of Compton cooling has been studied in a self-consistent way**
- **Increase in disk rate results in the increase of soft photons and hence, post shock region cools down more and more with increased disk rate**
- **As a result of this cooling, the thermal pressure goes down and shock forms closer to the black hole**
- **Outflow rate reduces and spectrum becomes softer as a result of this cooling**
- **This shows a direct correlation between the spectral states and the outflow rates of an accreting black hole**

References

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