AN INSIGHT INTO THE SPECTRAL STATES IN RADIO LOUD AGNs THROUGH THE MODELS OF ACCRETION DISK

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Abstract

We are generating a python code-based web tool for the spectrum of the accretion disk (initially standard disc). The accretion disk spectrum is dependent on various parameters of the accreting system. Those parameters are mass of the central compact object (we assumed it to be black hole), inner and outer radius of the disk, inclination angle of the disk with respect to the observer, mass accretion rate, viscosity, accretion efficiency, Eddington ratio. Through this coding we will try to understand whether high excitation radio galaxies (HERGs) and low excitation radio galaxies (LERGs) can be explained to be analogous to the corresponding black hole X-ray binary (BHXRB) states. We further examine the parameter space region in which different AGN classes are possible counterparts of BHXRB states.

1. Introduction

The standard model of accretion disks describes the dynamics of matter swirling around a central massive object, such as a black hole or neutron star. This model is consistent with Keplerian dynamics, where inner regions rotate faster than outer regions. This is known as differential rotation. The model relies on several key assumptions: it assumes a thin disk approximation with steady-state condition with a constant mass flow rate and that the disk is in hydrostatic equilibrium, balancing gravitational forces and pressure gradients. It assumes accretion disks to be optically thick and behave like ideal gas. **We study the case where the central accretion object is a black hole**. The assumptions already mentioned lead to a particular way of conversion of gravitational energy into thermal energy, resulting in radiation emission, peaking in the X-ray or optical-ultraviolet regime of the spectrum depending upon mass of the black hole. While the standard model effectively explains various astrophysical phenomena, including the luminosity of quasars and the behaviour of X-ray binaries, it can be adapted to incorporate additional factors such as magnetic fields and relativistic effects. The relativistic effects and the effects due to magnetic fields are beyond the scope of this particular piece of work.

2.1 Our Work

We created a python web app using the mathematical relations in the standard model proposed by **Shakura and Sunyaev in 1973**. It aims to incorporate varying range of input parameters and generate a graphical representation of temperature profile and spectrum very quickly. This enables us to visualise the luminosity density in different regions of the electromagnetic spectrum, further calculating the net luminosity emitted. This will help us understand if active galactic nuclei (AGNs) have accretion states analogous to that of X-ray binaries.

The equations used are:

$$L = \xi \dot{M} c^2, \quad L = \epsilon L_{Edd} \;\; ➔ \;\; \dot{M} = \frac{\epsilon}{\xi}\frac{1.3\times10^{31}}{c^2}\frac{M_\bullet}{M_\odot}$$

Here ξ is the accretion efficiency and ϵ is the Eddington ratio.

Temperatute as a function of r ➔ $T(r) = \left(\frac{3GM_\bullet \dot{M}}{8\pi\sigma}\right)^{\frac{1}{4}} \left[\frac{1-\sqrt{\frac{r_i}{r}}}{r^3}\right]^{\frac{1}{4}} K$

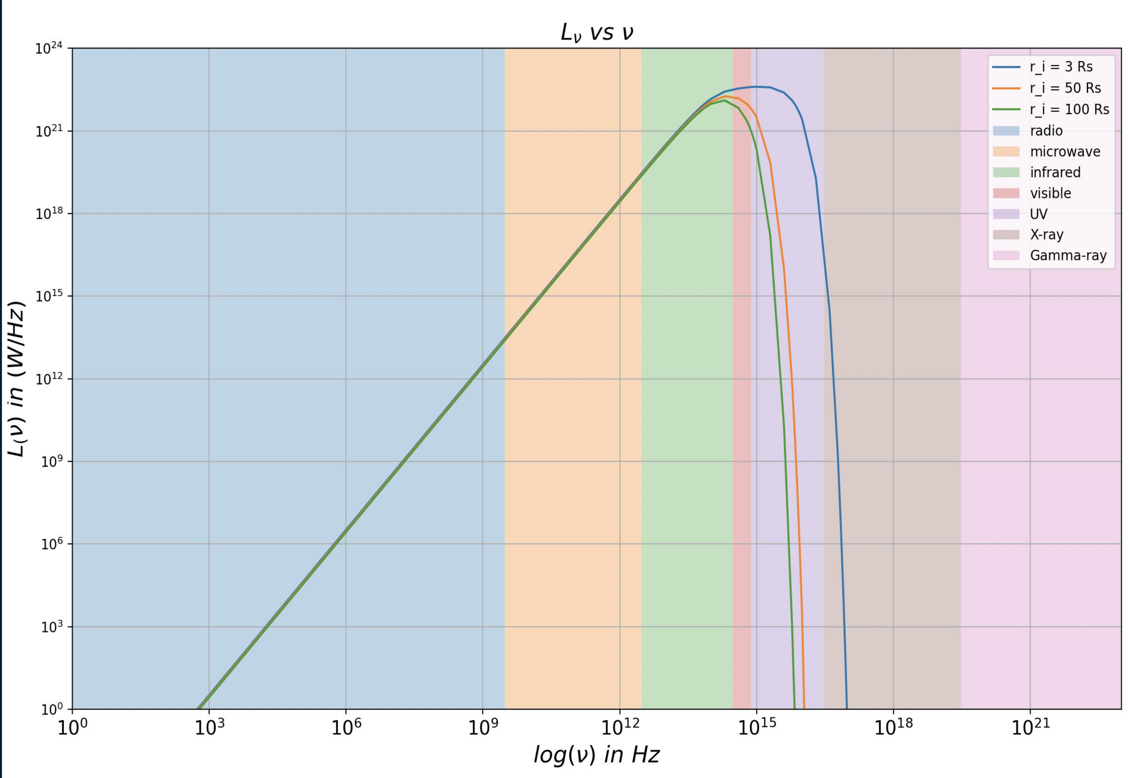
The Luminosity density ➔ $L_\nu = \frac{16\pi^2 h\nu^3}{c^2}\cos i \int_{r_i}^{r_o} \frac{r}{e^{\frac{h\nu}{KT(r)}}-1}\, dr\; WHz^{-1}$

Here r_i and r_o are inner and outer radii of the accretion disk, and i is the disk inclination w.r.t. line of sight.

Bolometric luminosity: $L = \int L_\nu d\nu$

The Effect of Variation of r_i on Accretion Disk Spectrum

For $M_\bullet = 10^7\, M_\odot,\; \xi = 0.1, \epsilon = 1.778\times10^{-02}, r_o = 10^3\, R_s$



r_i=3 R_s	r_o=10^3 R_s
L_{bol} = 7.258 x 10^{36} Watts	
L (IR) = 2.90 x 10^{35} Watts	

r_i=50 R_s	r_o=10^3 R_s
L_{bol} = 4.05 x 10^{35} Watts	
L (IR) = 1.83 x 10^{35} Watts	

r_i=100 R_s	r_o=10^3 R_s
L_{bol}= 1.765 x 10^{35} Watts	
L (IR) = 1.23 x 10^{35} Watts	

Figure-01: Accretion disk spectrum for three values of r_i. Various other parameters are given in the text around the plot.

The spectra in Figure-01 differ at the falling part on the right-hand side, as we change the inner radius of the disk. On the left-hand side, the rising part remains same for the values of r_i equal to $3R_s$, $50R_s$ and $100R_s$. From this analysis, it is evident that the truncation affects the luminosity in the optical, UV and X-ray bands. IR band is not affected significantly.

2.2 Variation of L_{UV} with r_i

We have studied the variation of L_{UV} from the standard accretion disk for black hole masses $M_\bullet = 10^7\, M_\odot$ and 50 $M_\odot$. For this study we have use the following parameters of the accreting system.

$\epsilon = 10^{-1.75} = 1.778\times10^{-2}\;,\; \xi = 0.1$ **[From Best & Heckman, 2012]**

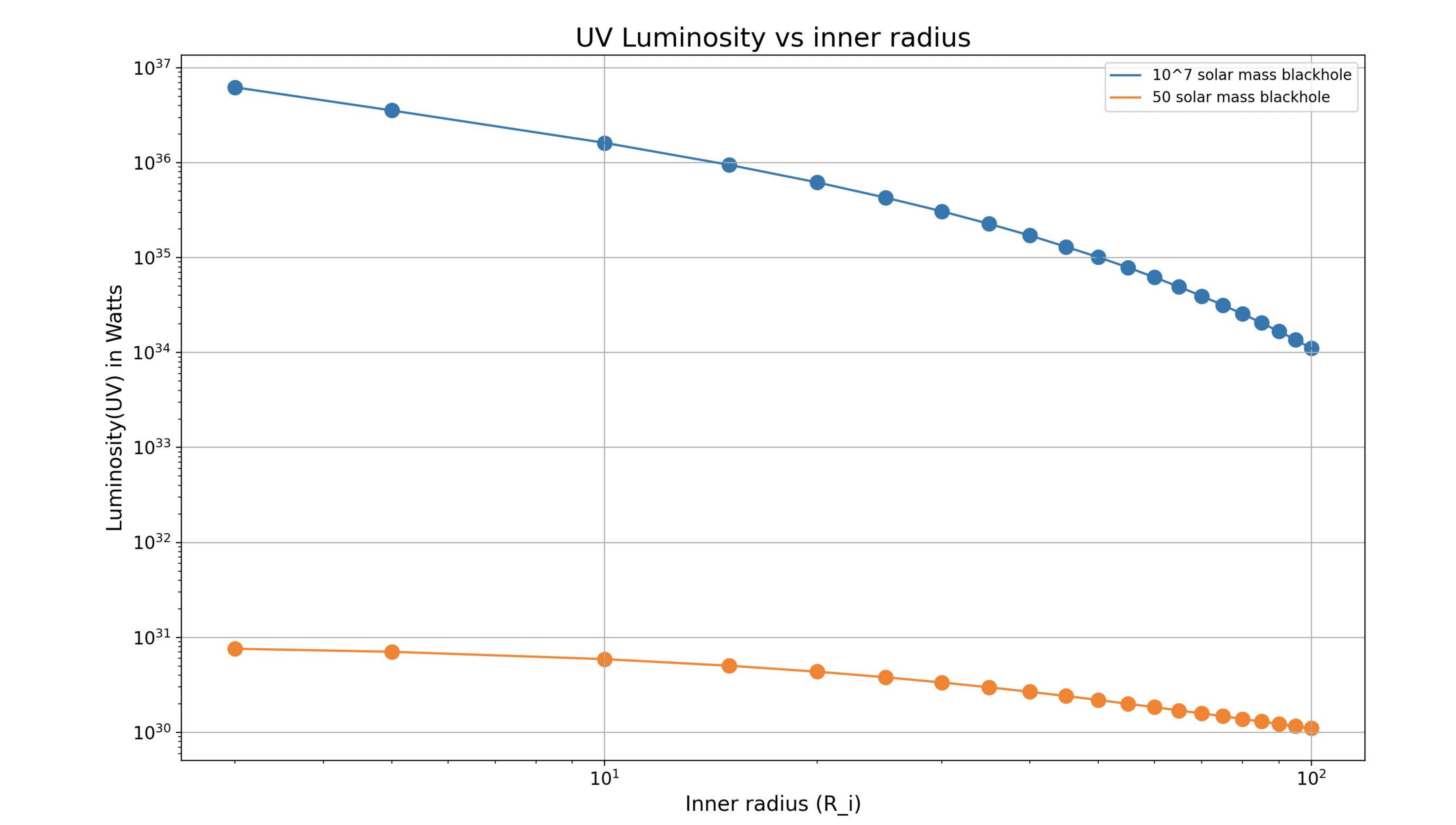


Figure-02: A plot of L_{UV} vs. r_{in}

If we truncate the inner portion of the disk at radius $r_i = 40\, R_s$, the L_{UV} falls to an oder of magnitude compared to its value for $r_i = 3\, R_s$. Even after truncation L_{UV} remains of the order of 10^{35} Watts. That seems to be enough to doubly ionize the enough number of oxygen atoms (detail calculation is underway). That means, we will be able to see the [O III] lines in the optical spectrum even if the inner portion of the standard disk is truncated at $r_i = 40\, R_s$. However, if we truncate the inner portion of the disk at $r_i = 100\, R_s$, the UV luminosity L_{UV} falls to ~ 10^{34} Watts. Even this value of UV luminosity prima facie seems to be enough to doubly ionize enough number of oxygen atoms and thus [O III] line will be visible in the optical spectrum.

3.1 The Problem We are Trying To Address

Our main objective of creating such a software is to study the accretion states of AGNs and to try to find an analogy with the states of X-ray binaries. The work of **Fender & Belloni (2004); Fender, Belloni and Gallo, (2004)** and the recent work by **Wevers et al. (2021)** have suggested the apparent scale invariance of accretion processes across seven orders of magnitude in black hole mass (from stellar mass black holes to SMBHs). For stellar mass black holes in the low-hard states, the sources have strong jets but no radiatively efficient accretion disk (i.e., standard accretion disk). However, for AGNs, if they are HERGs, they have both strong jets and strong signature of radiatively efficient accretion disk, i.e., big blue bump (see **Hardcastle, Evans & Croston 2007**). Therefore, the accretion state of HERGs in spite of having strong jets does not seem to be analogous the low-hard state of Black Hole X-ray Binaries (BHXRBs). However, if the radio galaxies are LERGs then the state of accretion in them is analogous to low-hard state of BHXRBs.

3.2 Can HERGs be in a State Analogous to Transition Phase of BHXRBs?

If we add an advective flow from the inner radius of the disk r_i between 40 R_s and 100 R_s, then jet launching is possible (Private communications to many astronomers). This rigorous calculation is under way. If so, then despite the presence of [O III] lines in the optical spectra the HERGs can be thought of as the AGNs in the Very High State or Intermediate State (VHS/IS) of accretion (Kording et al. 2006) If our rigorous calculation (underway) proves it, then this will prove Wevers et al.'s suggestion of apparent scale invariance of accretion processes across seven orders of magnitude in black hole mass (from stellar mass black holes to SMBHs). We have not considered any radiation component in the spectrum or in the UV luminosity due the advective flow from the truncated region to the black hole. The actual luminosities will be higher when we add the luminosity due to advective flow. Our conservative UV luminosity seems to be enough to cause the [O III] lines in the optical spectrum.

References

1. Best P.N., Heckman T.M., 2012, MNRAS, 421, 1569
2. Fender R. and Belloni T., 2004, ARA&A, 42, 317
3. Fender R. P., Belloni T. M., and Gallo E., 2004, MNRAS, 355, 1105
4. Hardcastle M. J., Evans D. A., Croston J. H., 2007, 376, 1849
5. Kording E.G., Jester S., Fender R., 2006, MNRAS, 372, 1366
6. Shakura, N. I., & Sunyaev, R. A. 1973, A&A, 24, 337
7. Wevers T., Pasham D.,R., van Velzen S., Miller-Jones J.C.A., Uttley P., Gendreau K.C., Remillard R., Arzoumanian Z., Lowenstein M. and A. Chiti A., 2021, arXiv:2101.04692v1