Structure and Stability of X-Ray Irradiated Accretion Disk

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Abstract:

We present here the mathematical approach in calculating the structural changes which take place in the outer regions of the accretion disk due to X-ray irradiation.

It is shown here that an X-ray source powered by accretion, modifies the outer disc structure.

Our calculations for the transition radius and Circularization Radius in case of various low mass X-ray binaries show that the X-ray irradiation becomes dominant after transition radius only in some binary systems.

Structure of the X-ray Irradiated Accretion Disk:

The general Radiative Transport equation is given by

$$\frac{acT^4}{\tau} \approx \frac{acT^4}{\kappa\Sigma} \approx F(r), \quad \tau(r) > 1$$

where *F(r)* is the flux of the heat generated internally by viscosity,

τ represents optical depth,

κ represents opacity,

Σ is the Surface Density.

or, The above equation can be written as

$$\sigma T^4 = F_0(r)\,[\tau]$$

Now taking X-ray Irradiation into consideration, the above equation modifies to (Dubus et.al. 1999)

$$\sigma T^4 = F_0(r)\,[\tau] + F_{ir}(r,h)$$

Where Fir(r,h) measures the flux due to X-ray Irradiation and is given by (Vrtelik et.al 1989)

$$F_{ir}(r,h) = \frac{f_2 L_X}{4\pi r} \frac{\partial h/r}{\partial r}$$

Taking into account both the opacities, we can write as:

$$\sigma T^4 = F_0(r)\left[\Sigma\left(\bar{\kappa}_{ff} + \bar{\kappa}_{es}\right)\right] + F_{ir}(r,h)$$

Solving the above equation with other Standard Model Equations, we get a differential equation given as:

$$\frac{\partial y}{\partial x} = \frac{y}{x} + A_p x^{-10} y^8 - B_p x^{\frac{25}{2}} y^{-12} - C_p x^{\frac{1}{2}} y^{-2}$$

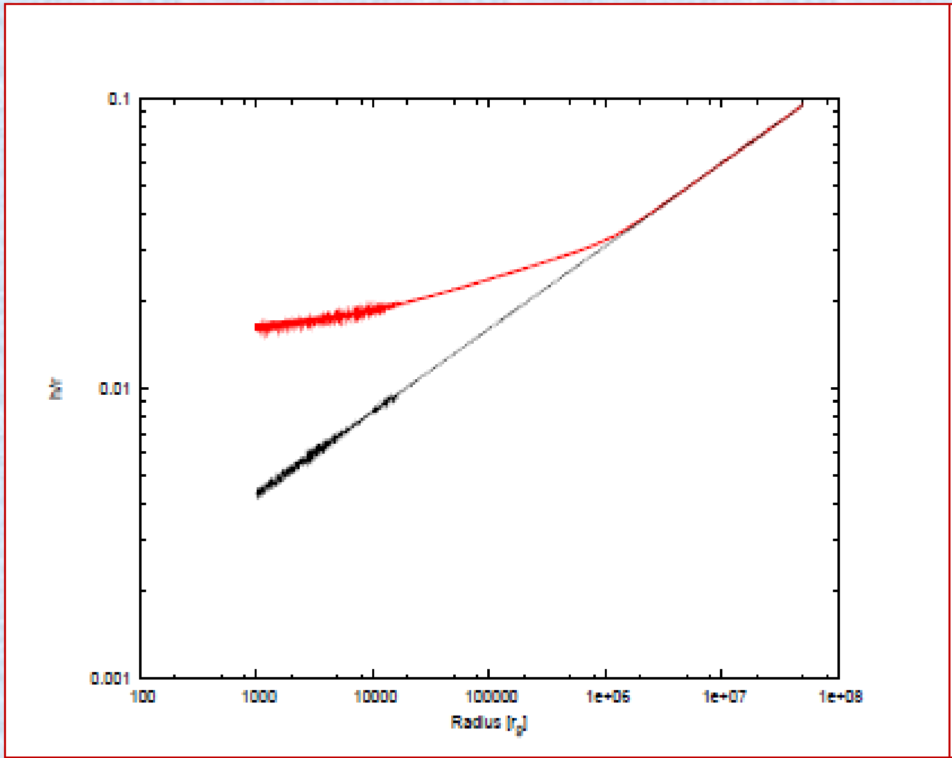
where

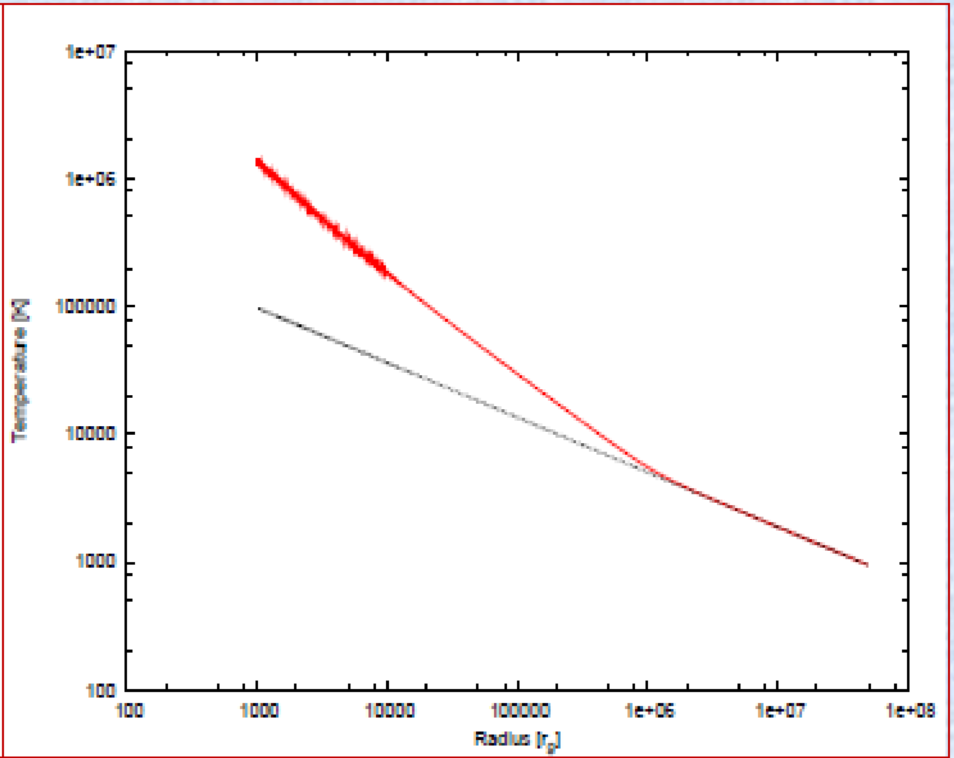
$$x = \frac{r}{r_g} \qquad y = \frac{h}{r_g}$$

$$A_p = \frac{4\pi\sigma r_g^2 c^6}{f_2 \eta \dot{M}_{in}} \left(\frac{\mu m_H}{k f_1}\right)^4 \qquad B_p = \frac{12 \times 0.64 \times 10^{23}}{128} \left(\frac{\dot{M}_{out}^3}{\dot{M}_{in}\, r_g^3 c^9}\right) \left(\frac{1}{\pi^2 \alpha^2 f_2 \eta}\right) \left(\frac{k f_1}{\mu m_H}\right)^{\frac{7}{2}}$$

$$C_p = \frac{12}{32} \left(\frac{\dot{M}_{ou}^2}{\dot{M}_{in} r_g\, c}\right) \left(\frac{\bar{\kappa}_{es}}{\pi \alpha f_2 \eta}\right)$$

Solving equation (6) for fixed values of M, $\dot{M}$, α, and η, We get the plots as shown





Circularization Radius and Transition Radius

As is clear from the figure 2, that there is a sharp transition as, we go from the X-ray Irradiated region to the region where X-Ray Irradiation is not important. We have developed an expression for calculating this transition point, called as ‘*Transition Radius*, given by

$$r_{tr} = \left[\frac{(4\alpha)^{26/45}}{\pi^{2/45}}\right]\left(\frac{12 \times 0.64 \times 10^{23}}{128\alpha^2}\right)^{14/45}\left(\frac{7}{2f_2\eta}\right)^{8/9}(\dot{M})^{2/45}\left(\frac{m_H}{k}\right)^{11/9} c^{2/3}\, r_g^{11/9}\left(\frac{\mu}{f_1}\right)^{104/45}$$

$$r_{tr} = 1.4815 \times 10^{11} \times \left(\frac{\dot{M}}{10^{17}}\right)^{2/45}\left(\frac{r_g}{1.5 \times 10^5}\right)^{11/9}\left(\frac{\alpha}{0.1}\right)^{-28/45}$$

Table 1. Comparison between the Circularization radius, Tidal Radius and Transition Radius in case of Low Mass X Ray Binaries.

System	Type	P_{orb} (d)	$M_{1\odot}$	R_c $(10^{11} cm)$	R_T $(10^{11} cm)$	R_{tr} $(10^{11} cm)$	T (K)
3A1516-569*	NS	16.60	1.4	6.5	13.0	2.2	4900
1E1740-7-2942*	BHC	12.73	10	10	20	27.38	1400
GRS-1758-258*	BHC	18.45	10	14	28	27.38	1400
401811-17*	NS	24.0667	1.4	8.3	16.6	2.2	4900
GRS 1915 +105*	BHC	33.500	14	59	118	41.3	1100
GS2023 + 338*	BHC	6.4750	12	7.1	14.2	34.2	1200
CygX-2**	NS	9.84	1.780	3.2	6.4	3.0	4200
V395 CAR**	NS	9.02	1.44	3.1	6.2	2.3	4900
XTE J2123-058**	NS	0.25	1.415	.25	0.5	2.3	4900
2A 1822-371**	NS	0.23	0.97	0.2	0.4	1.47	6300

Viscous Time scale

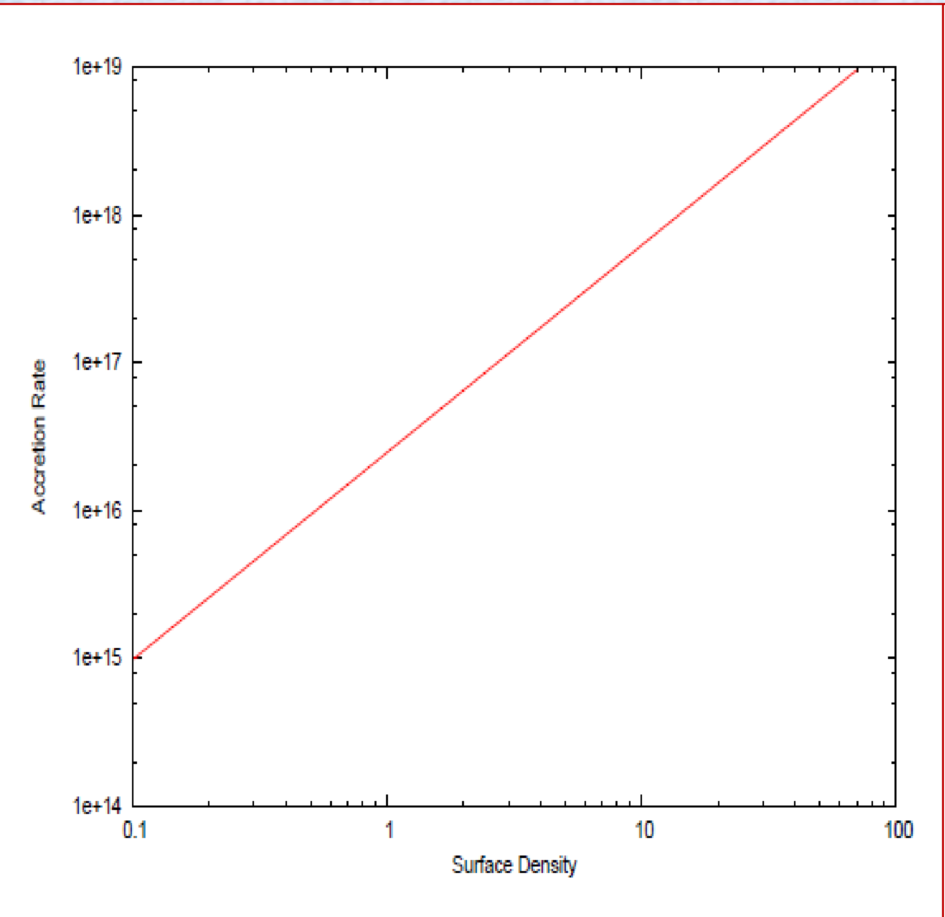
- It is the timescale on which matter diffuses through the disk under the effect of viscous torques and is given by:

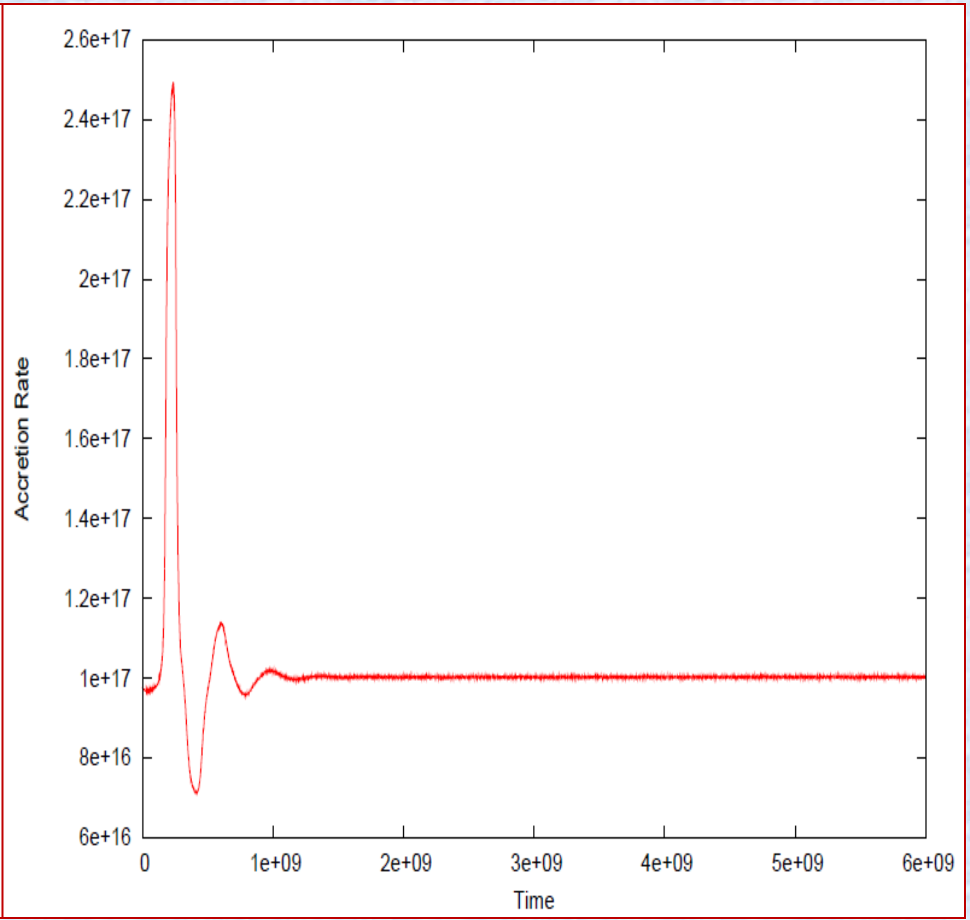
$$t_{visc} = \frac{1}{2}\left(\frac{12\times 0.64\times 10^{23}}{128}\right)^{13/45}\left(\frac{7}{2\eta f_2}\right)^{10/9}\left[\frac{(4\sigma)^{37/45}}{(\alpha)^{71/45}}\right]\left(\frac{\dot{M}_{out}^{13/15}}{\dot{M}_{in}^{10/9}}\right) r_g^{16/9}\, c^{4/3}\left(\frac{\mu m_H}{k f_1}\right)^{41/18}$$

- For a Neutron star of mass 1.4 solar *masses* and uniform accretion rate of 10^{17}, the viscous timescale comes out to be 3.82×10^{7} secs.

Stability:

For studying the stability of the such a disk, we plot a graph between the Accretion rate and Surface density, Σ for a given value of radius and also considering That the inner accretion rate is same as the outer accretion rate. However , if the inner Accretion rate changes, the effect of the same on the outer Accretion rate on viscous timescale is depicted in the fig below.





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