Thin Accretion Disks Around Black Holes

Modelling the Secondary Maximum

M.D.Aksulu[1] K.Y.Ekşi[1] E.Kalemci[2] Ü.Ertan[2]

[1]Faculty of Science and Letters
Istanbul Technical University

[2]Faculty of Engineering and Natural Sciences
Sabancı University

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Motivation

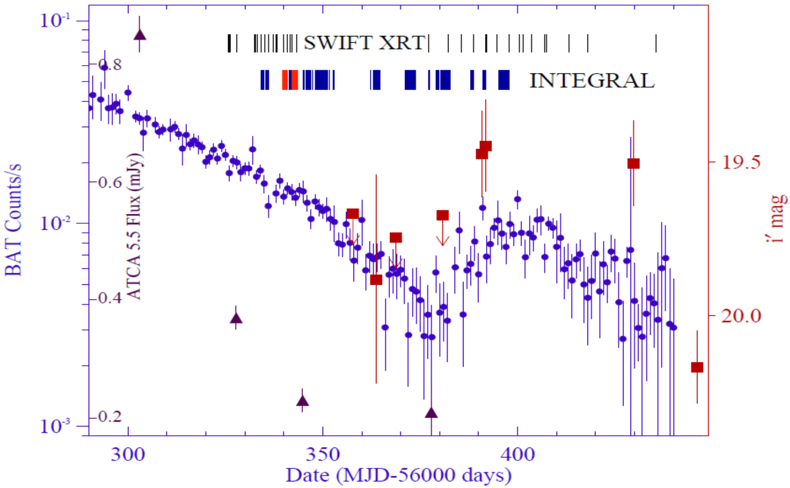

Figure: Multi-wavelength observation of J1745-26 [Chun et al., 2013]

Outline

- Disk formation around BH
- Properties of BH SXTs
- Disk equation
- Numerical Methods
- Results
- Future work

Disk formation in BH binaries

- Accretion via Roche-lobe overflow (low mass companion).
- Matter transferred inwards due to MHD instabilities.
- Heating due to viscous dissipation.

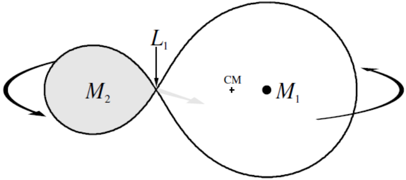

Figure: Accretion via Roche-lobe overflow [Frank et al., 2002]

State transition

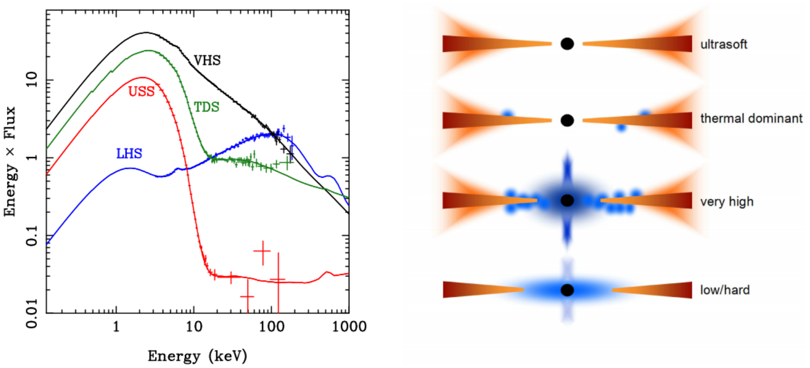

Figure: Spectrum in various states [Done et al., 2007]

Hard and soft emissions during state transition

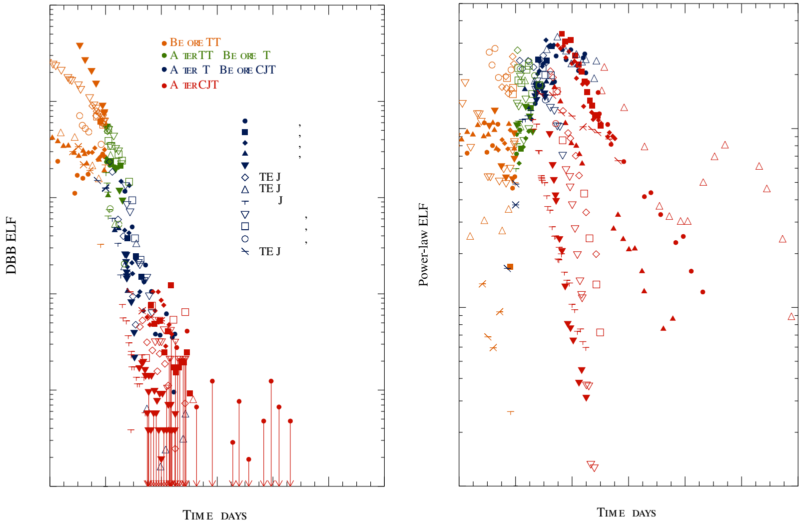

Figure: Evolution of BB and power law components of various sources [Kalemci et al., 2013]

Properties of the secondary outburst

- Happens 30-60 days after state transition.
- Luminosity increases to approx. twice its previous value.
- Sometimes an optical delay is observed.

Example lightcurves

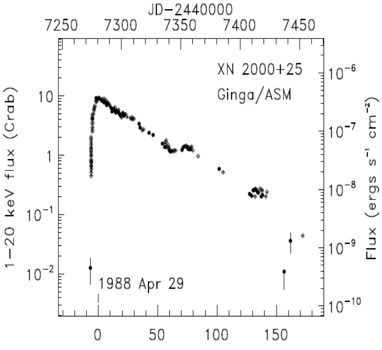

Figure: FRED-like lightcurve of XN 2000+25 [Chen et al., 1997]

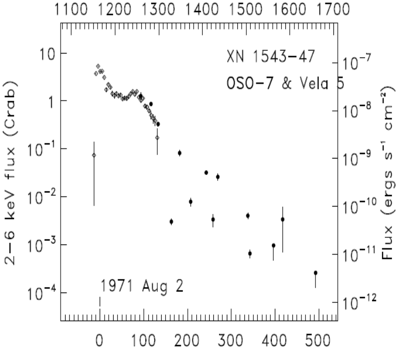

Figure: FRED-like lightcurve of XN 1543-47 [Chen et al., 1997]

Example lightcurves

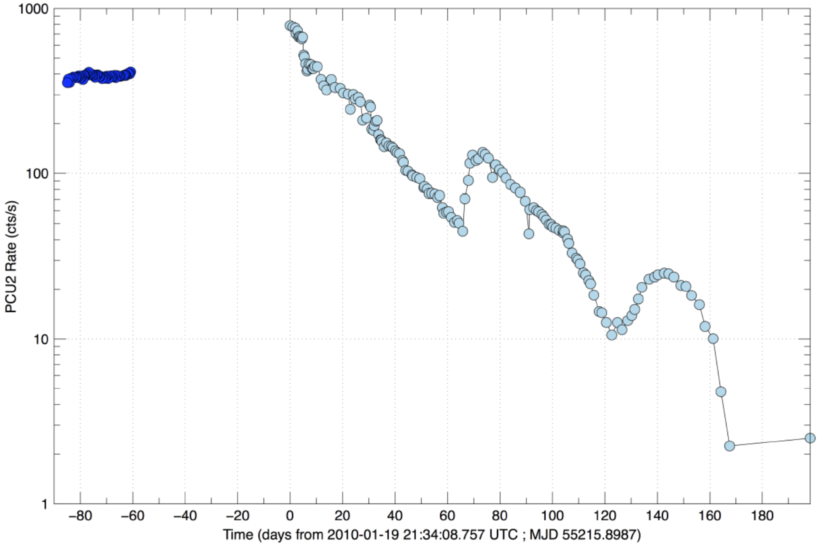

Figure: Lightcurve of XTE J1752-223 [Stiele et al., 2010]

Disk equations

- Thin disk approximation
- α viscosity prescription [Shakura & Sunyaev, 1973] (i.e. $\nu = \alpha c_s H$)
- Cylindrical symmetry

Non-linear diffusion equation:

$$\frac{\partial \Sigma}{\partial t} = \frac{3}{R} \frac{\partial}{\partial R} \left[R^{1/2} \frac{\partial}{\partial R} \left(\nu \Sigma R^{1/2} \right) \right]$$

Numerical methods

- Implicit finite differences method
- Relatively large time steps
- Parallel computing when possible
- DIM included
- Realistic opacities included using [Alexander & Ferguson, 1994] [Iglesias & Rogers, 1996]
- Irradiation from central source included
- Lamppost irradiation source included.
- Shadowing of the disk included

$$\begin{bmatrix} 1 & 0 & 0 & 0 & \cdots & 0 & 0 \\ -\alpha & 1 & \alpha & 0 & \cdots & 0 & 0 \\ 0 & -\alpha & 1 & \alpha & \cdots & 0 & 0 \\ 0 & 0 & -\alpha & 1 & \alpha & \cdots & 0 \\ \vdots & & & & & & \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_0^{n+1} \\ C_1^{n+1} \\ C_2^{n+1} \\ C_3^{n+1} \\ \vdots \\ C_{N-1}^{n+1} \end{bmatrix} = \begin{bmatrix} C_0^n \\ C_1^n \\ C_2^n \\ C_3^n \\ \vdots \\ C_{N-1}^n \end{bmatrix}$$

Figure: N unknowns and N equations for the next time step.

Comparison with analytical solutions

- Approximate solutions introduced by Pringle.
- DIM excluded, only free-free opacities used.

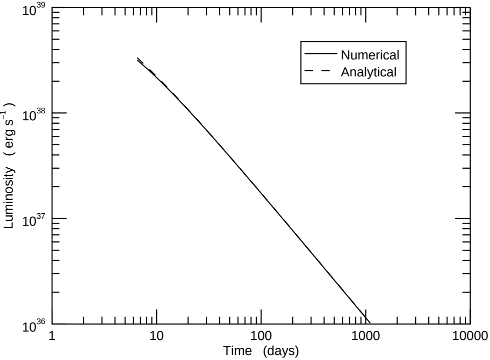

Figure: Comparison of produced lightcurve with analytical solution (no DIM, no irradation).

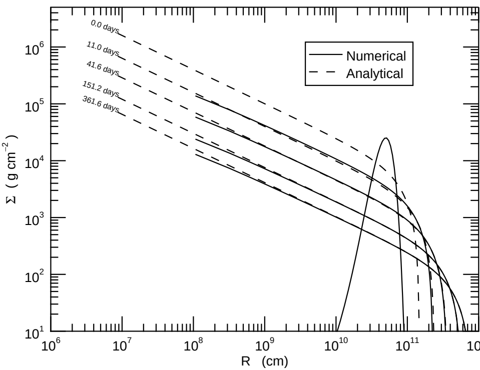

Figure: Comparison of produced surface mass density with analytical solution (no DIM, no irradation).

Disk instability model

- "Hot" and "cold" states determined by irradiation temperatures and central temperature.
- $\alpha = 0.1$ for hot state and $\alpha = 0.033$ for cold state [Ertan & Alpar, 2002]

Stability Criteria:
[Dubus et al., 2001]

$$T_{max} = 10700 \alpha_c^{-0.1} R_{10}^{-0.05\xi} \mathrm{K}$$

$$T_{min} = (29900 - 11300\xi)\, \alpha_h^{-0.22} M_1^{-0.01} R_{10}^{-0.05-0.12\xi} \mathrm{K}$$

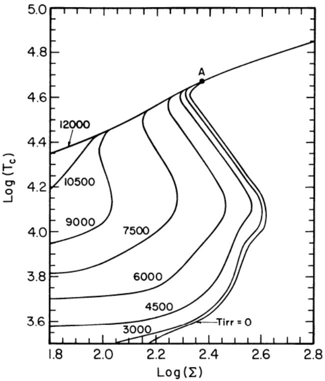

Figure: Thermal equilibrium curves at $\log R = 10.5\mathrm{cm}$. [Tuchman et al., 1990]

Calculating irradiation temperature

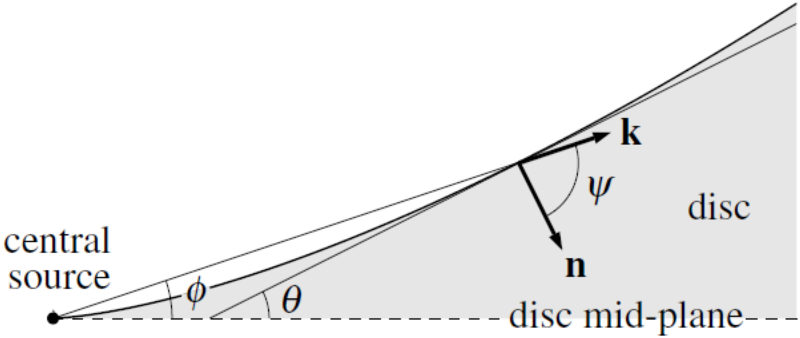

Figure: Calculating irradiation. [Frank et al., 2002]

Received flux from irradiation source:

$$F_{irr} = \frac{L_{pt}}{4\pi R^2}(1-\beta)\cos(\psi)$$

Generated irradiation temperatures

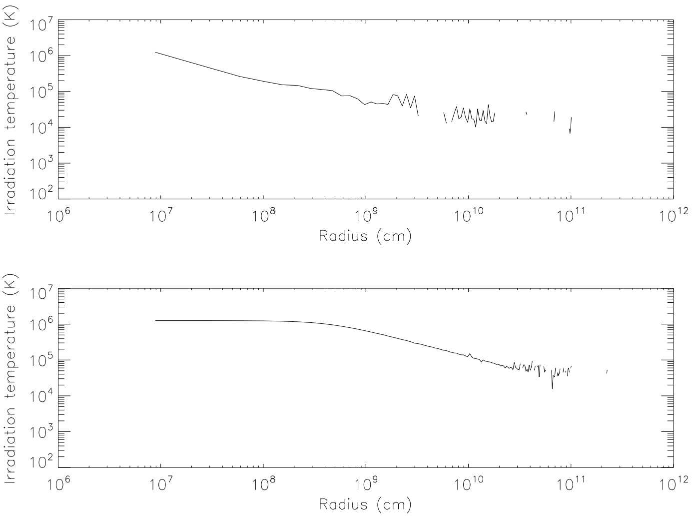

Figure: Irradiation temperatures, before and after, corona formation.

Results

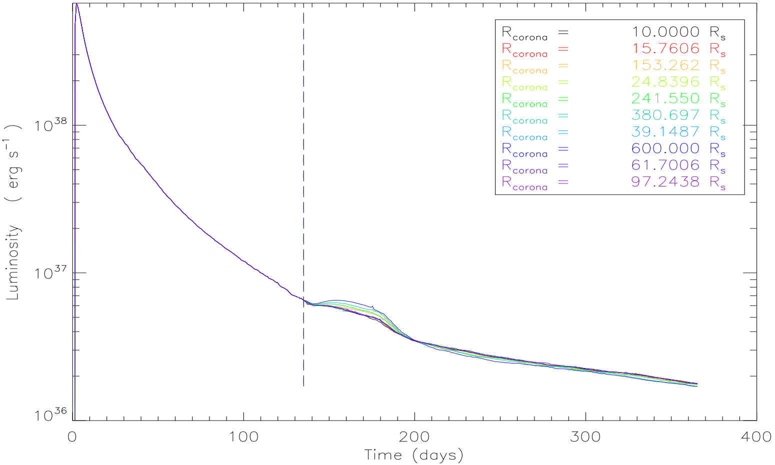

Figure: Obtained light curves for varying corona radius.

Results

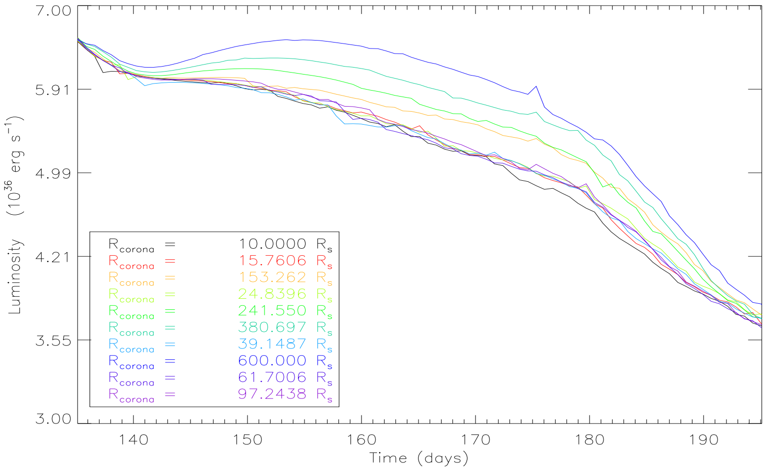

Figure: Obtained light curves for varying corona radius.

Results

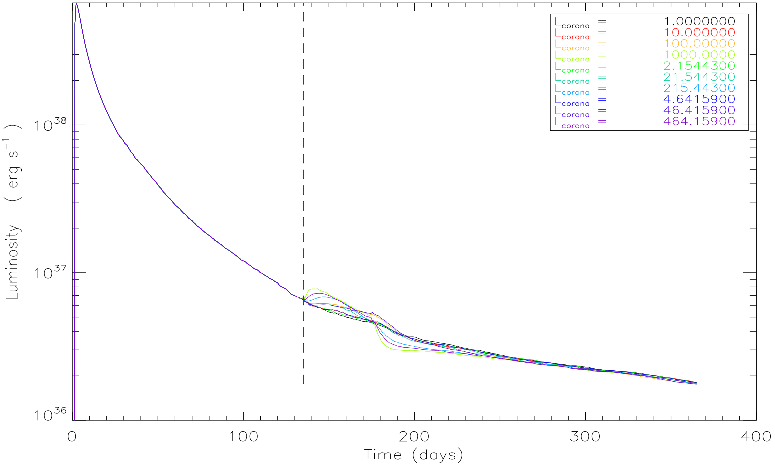

Figure: Obtained light curves for varying corona luminosity.

Results

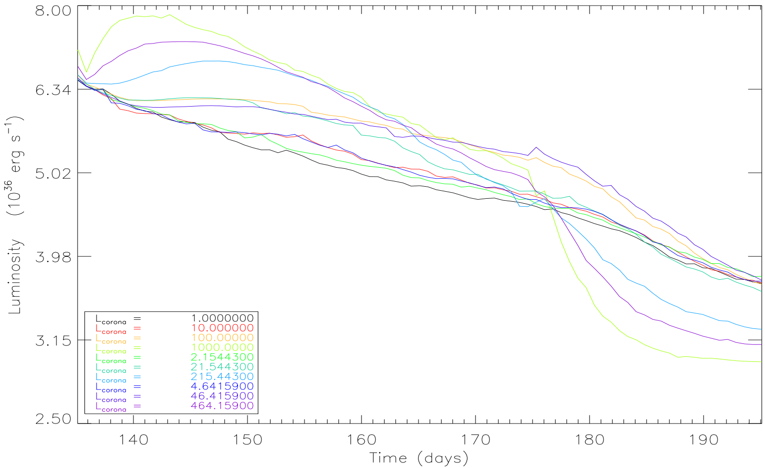

Figure: Obtained light curves for varying corona luminosity.

Results

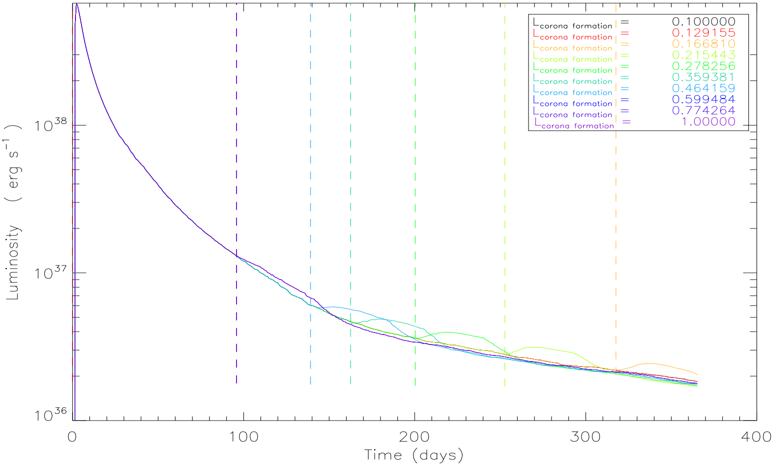

Figure: Obtained light curves for state transition luminosities.

Conclusion

- Temporal and spatial behavior of the accretion disk has been modeled including: DIM, realistic opacities, irradiation
- Self–shadowing of the disk is important
- An elevated irradiation source may cause secondary outbursts
- However, timescales do not match!

Future work

- Time dependent location for irradiation source to model corona growth
- Time dependent corona luminosity
- Investigate how much of the radiation is actually absorbed in the disk
- **Add truncation**

Thank you!
Any questions?

State transition

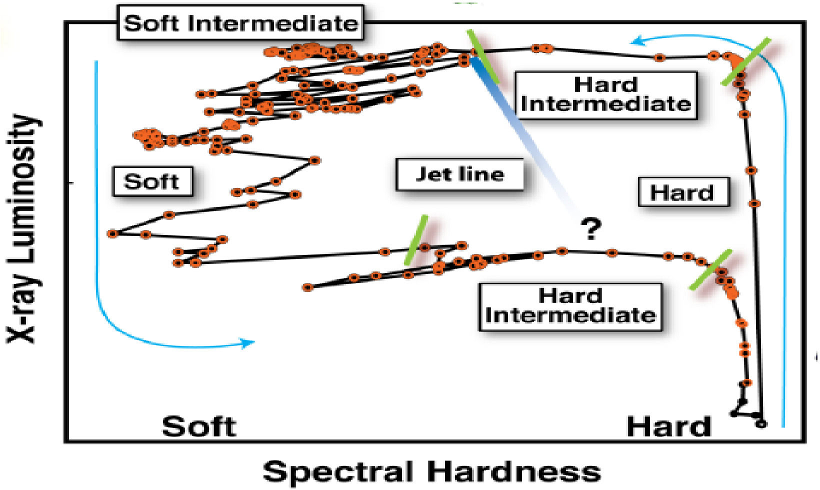

Figure: Hardness intensity diagram.

References I

Alexander, D. & Ferguson, J. (1994).
Low-temperature rosseland opacities.
The Astrophysical Journal, 437, 879–891.

Chen, W., Shrader, C., & Livio, M. (1997).
The properties of x-ray and optical light curves of x-ray novae.
The Astrophysical Journal, 491(1), 312.

Chun, Y. Y., Dinçer, T., Kalemci, E., Güver, T., Tomsick, J. A., Buxton, M. M., Brocksopp, C., Corbel, S., & Cabrera-Lavers, A. (2013).
Multiwavelength observations of the black hole transient xte j1752–223 during its 2010 outburst decay.
The Astrophysical Journal, 770(1), 10.

Done, C., Gierliński, M., & Kubota, A. (2007).
Modelling the behaviour of accretion flows in x-ray binaries.
The Astronomy and Astrophysics Review, 15(1), 1–66.

References II

Dubus, G., Hameury, J.-M., & Lasota, J.-P. (2001).
The disc instability model for x-ray transients: Evidence for truncation and irradiation.
Astronomy & Astrophysics, 373(1), 251–271.

Ertan, Ü. & Alpar, M. A. (2002).
On the outbursts of black hole soft x-ray transients.
Astronomy & Astrophysics, 393(1), 205–214.

Frank, J., King, A., & Raine, D. (2002).
Accretion power in astrophysics.
Cambridge University Press.

Iglesias, C. A. & Rogers, F. J. (1996).
Updated opal opacities.
The Astrophysical Journal, 464, 943.

References III

Kalemci, E., Dinçer, T., Tomsick, J. A., Buxton, M. M., Bailyn, C. D., & Chun, Y. Y. (2013).
Complete multiwavelength evolution of galactic black hole transients during outburst decay. i. conditions for compact jet formation.
The Astrophysical Journal, 779(2), 95.

Shakura, N. I. & Sunyaev, R. A. (1973).
Black holes in binary systems. observational appearance.
Astronomy and Astrophysics, 24, 337–355.

Stiele, H., Muñoz-Darias, T., Motta, S., & Belloni, T. (2010).
X-ray spectral and timing investigations of xte j1752-223.
Proceedings of Science (Texas 2010), 32.

References IV

Tuchman, Y., Mineshige, S., & Wheeler, J. (1990).
Structure and evolution of irradiated accretion disks. i-static thermal equilibrium structure. ii-dynamical evolution of a thermally unstable torus.
The Astrophysical Journal, 359, 164–185.