Modelling the hysteresis cycles of Black-Hole X-ray binaries

G. Marcel

A spectral...

Zhang 2013
A spectral...
A spectral... and a dynamical Hysteresis! 
—> Coincidence?

**note:** Loss of radio signals could also be explained by inefficient spectral emission in the jet (Drappeau et al. 2017)

Dunn et al. 2009
Conventional framework

Cold accretion disk (10^6-7 K)

Hot corona (10^9-10 K)

Esin et al. 1996
Done et al. 2007
Conventional framework

Major unanswered questions:

1. Reproducing hard states at high luminosities $L > 0.1 \ L_{\text{Edd}}$? (Yuan & Narayan 2014 ARAA)

2. Cycle?

3. Spectral state transitions?
4. Dynamical state transitions? Jet lines?

5. Why should those 2 transitions be related?

Cold accretion disk ($10^6-7 \ \text{K}$)  
Hot corona ($10^9-10 \ \text{K}$)

Esin et al. 1996
Done et al. 2007
Our paradigm: the JED-SAD framework

Jet Emitting Disk:
- Accretion due to magnetic torque,
- \( P_{\text{jets}} = b P_{\text{acc}} \),
- \( v_r \geq c_s \rightarrow \) Supersonic accretion flow

\[
P_{\text{jets}} = b \frac{GM\dot{M}}{2r_{\text{in}}} \left( 1 - \frac{r_{\text{in}}}{r_J} \right)
\]

Ferreira et al. 2006
Petrucci et al. 2008

Ferreira 1997
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Standard Accretion Disk:
- Accretion due to turbulent torque,
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Ferreira 1997
Shakura & Sunyaev 1973
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$\Rightarrow$ 2 control parameters: $\dot{m}$ and $r_J$
The 2T disk thermal structure

ions: \( \frac{1}{2} q_{\text{acc}} = q_{\text{i adv}} + q_{\text{ie}} \)
electrons: \( \frac{1}{2} q_{\text{acc}} = q_{\text{rad}} + q_{\text{e adv}} - q_{\text{ie}} \)
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Part of *accretion power* not lost in the jets
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Coulomb interactions

Advection processes calculated outside-in
The 2T disk thermal structure

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Part of accretion power not lost in the jets

Radiative cooling as a bridge formula (Hubeny 1991) between:
- Thick: Blackbody radiation,
- Thin: Synchrotron, Bremsstrahlung and Compton processes as well as inverse-Compton illumination from SAD photons on the JED, using BELM code (Belmont et al. 2008).

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Part of accretion power not lost in the jets

JED

SAD

\( r_{\text{in}} \)

\( r_{\text{out}} \)
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Part of **accretion power** not lost in the jets

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Electron temperature, optical depth, etc… as function of radius, giving us access to the full **Spectral Energy Distribution** with BELM!
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Up to 3 possible solutions at each radius for 1T plasma Petrucci et al. 2010

—> suitable for Hard States?
At low luminosity... \( L = 10^{-3} L_{\text{Edd}} \)
At low luminosity… \( L = 10^{-3} \, L_{\text{Edd}} \)

Possible to reproduce **Hard states!**

Marcel et al. 2017, to be submitted
At high luminosity... $L > 10^{-1} L_{\text{Edd}}$
At high luminosity... $L > 10^{-1} L_{\text{Edd}}$

The sum of **slim JED** disk spectra reproduces a high luminosity hard state spectrum!

Γ ≈ 1.7

$E_{\text{cut}} < 100$ keV

Marcel et al. 2017, to be submitted
From theory to obs: cycle in DFLD

Model parameters \((r_J, \dot{m})\)

One point in the DFLD

Thermal Equilibrium solutions

Global SED

Faked data (instr response+ noise+absorption)

Xspec Fits (disk+cut-off power law)

GX339-4 2010-2011 outburst

Clavel et al. 2016
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GX339-4: the 2010-2011 outburst

\[ m = 5.8 \, M_\odot \]
\[ d = 8 \, kpc \]
\[ r_{in} = 2 \, R_g \]

*Miller et al. 2008*

\[ \dot{m} \]
\[ \dot{m}_{in} \]

\[ r_J \]

\[ \text{Hard-Tail proxy in the model} \]

*Clavel et al. 2016*
GX339-4: the 2010-2011 outburst

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in agreement with in Esin et al. 1996

Marcel et al. 2017, to be submitted
**GX339-4: the 2010-2011 outburst**

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\[ r_{in} = 2 \, R_g \]

Corbel et al. 2013
GX339-4: the 2010-2011 outburst

\[ L_R \propto \dot{m}^{17/12} \]

Jet synchrotron emission
Heinz & Sunyaev 2003
GX339-4: the 2010-2011 outburst

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\[ L_R \propto \dot{m}^{17/12} \times r_J (r_J - r_{in})^{5/6} \]

adapted from Foellmi et al. 2008
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$\dot{r}J$

$r_{in}$

$\dot{m}_{in}$

$\Gamma$

$F_{Radio}$

Total luminosity $L_{3-200}$

PowerLaw fraction $\frac{L_{pl}}{L_{3-200}}$

Marcel et al. 2017, to be submitted
Summary and perspectives

Results of the parametric $\dot{m}(t)$ and $r_J(t)$ model:

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Work in progress:

1. Dynamical evolution of $r_J$? Magnetic field redistribution in accretion disks ...forthcoming work...
2. Adding radio flares to the study? ...work in progress...
3. Other cycles? Other objects (Cyg X-1, V404)? ...work in progress...
Iron line?

Fig. 7: Simulated transition radius in colors and rescaled iron line radius (1/28) in black squares.

Marcel et al. 2017, to be submitted
Fig. 6: Rescaled equivalent radius (1/40) from the observed QPOs, from Gao et al. (2014) (bottom panel) and REF? (top panel) in comparison to transition radius during the evolution in the same color form as Fig. 2.

Marcel et al. 2017, to be submitted
Jet power

![Graph showing jet power over time (MJD-55208) with two data sets: one represented by circles and another by squares. The upper graph shows a logarithmic scale for the jet power (P_{jets}) ranging from $10^{-3}$ to $10^0$, while the lower graph shows a logarithmic scale for the flux density (F_R) in mJy ranging from $10^{-2}$ to $10^2$. Time (MJD-55208) ranges from 0 to 450.]