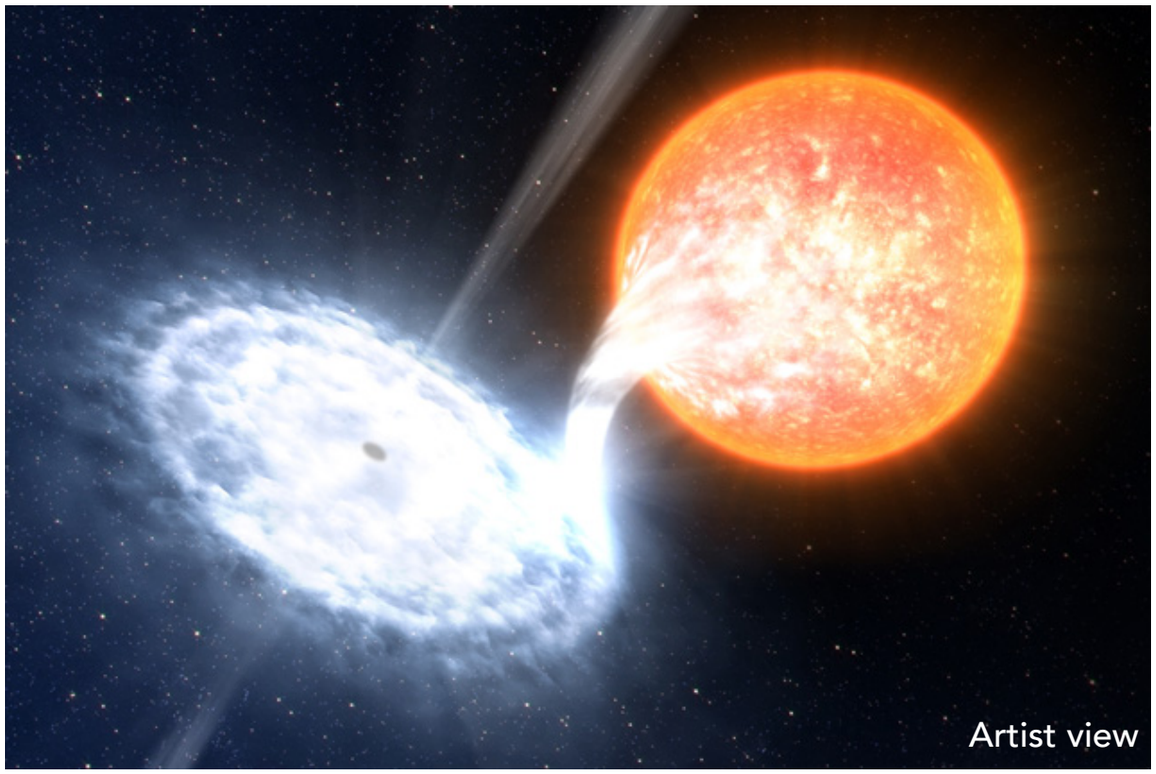
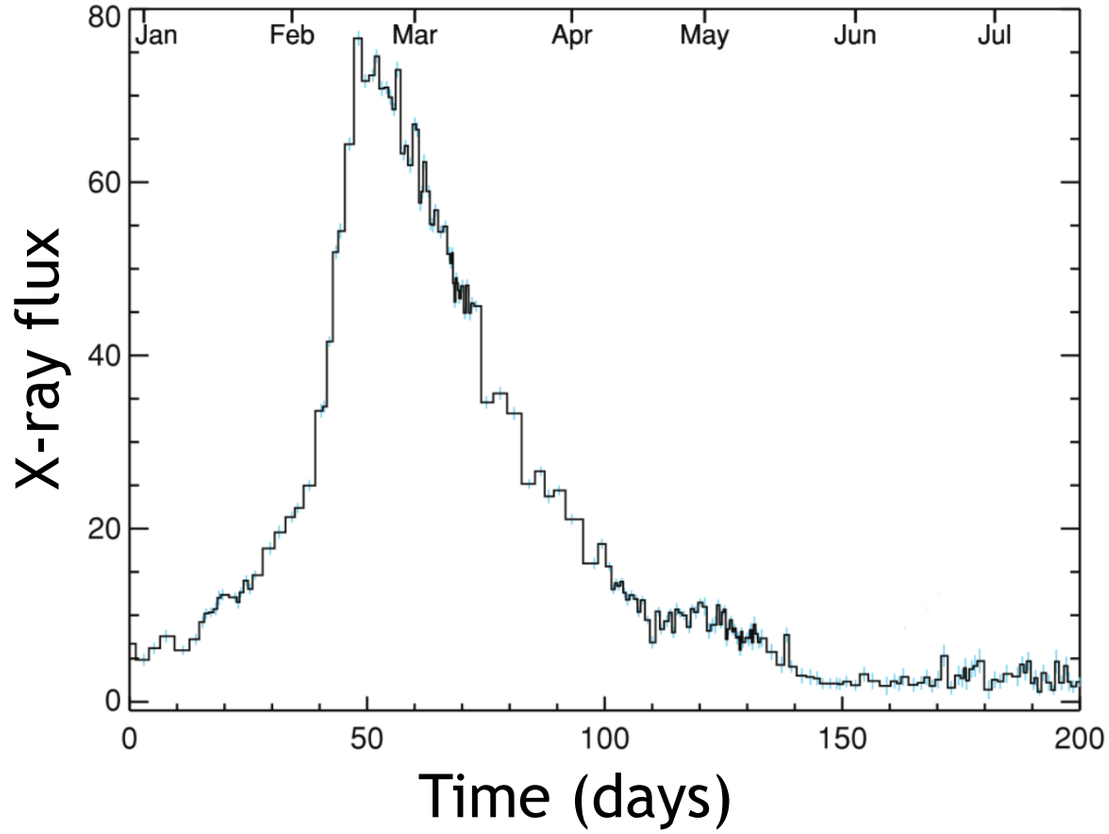
Modelling the hysteresis cycles of Black-Hole X-ray binaries

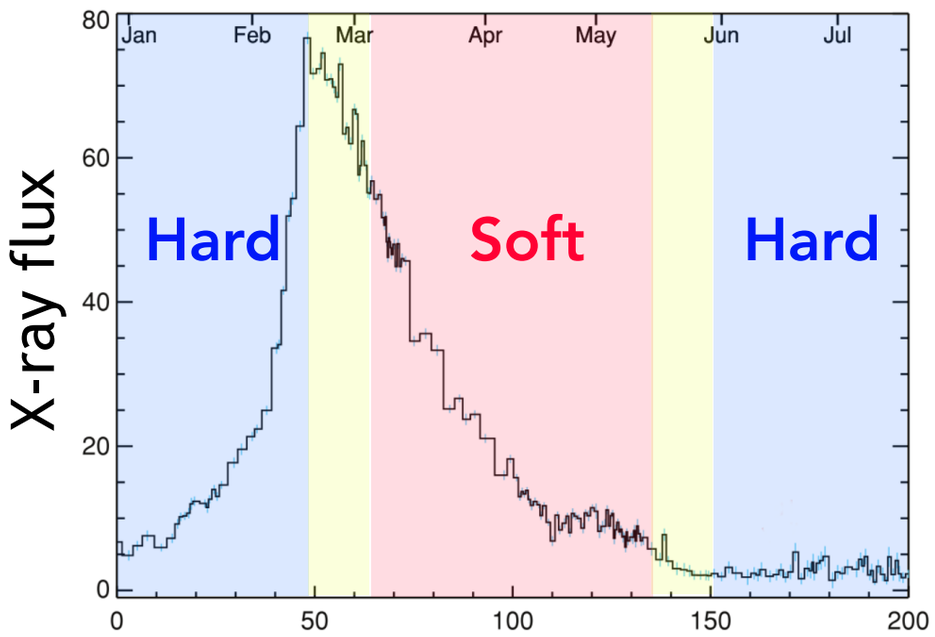
G. Marcel

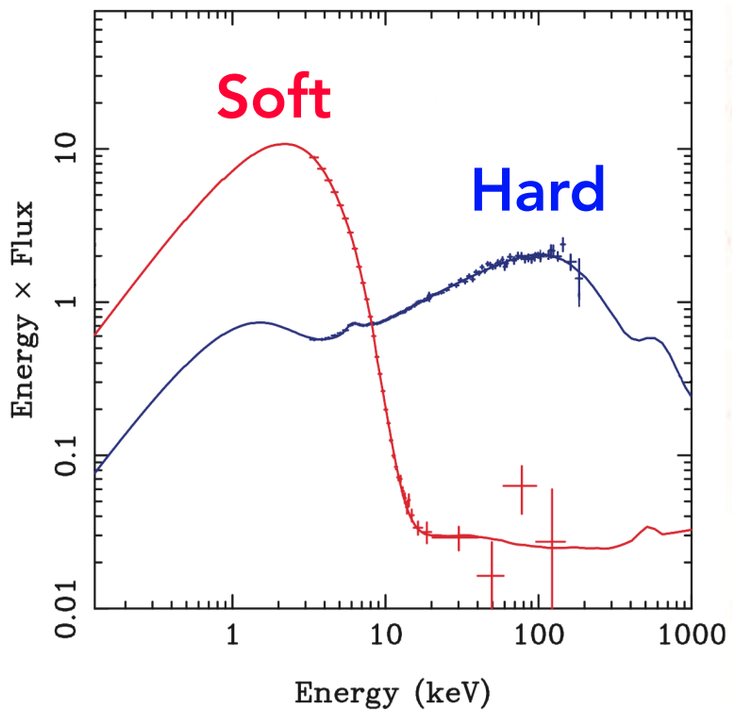




collaborators: **J. Ferreira, P-O Petrucci, M. Clavel, G. Henri**, R. Belmont, J. Malzac, S. Corbel, J. Rodriguez, M. Coriat

A spectral…





Zhang 2013

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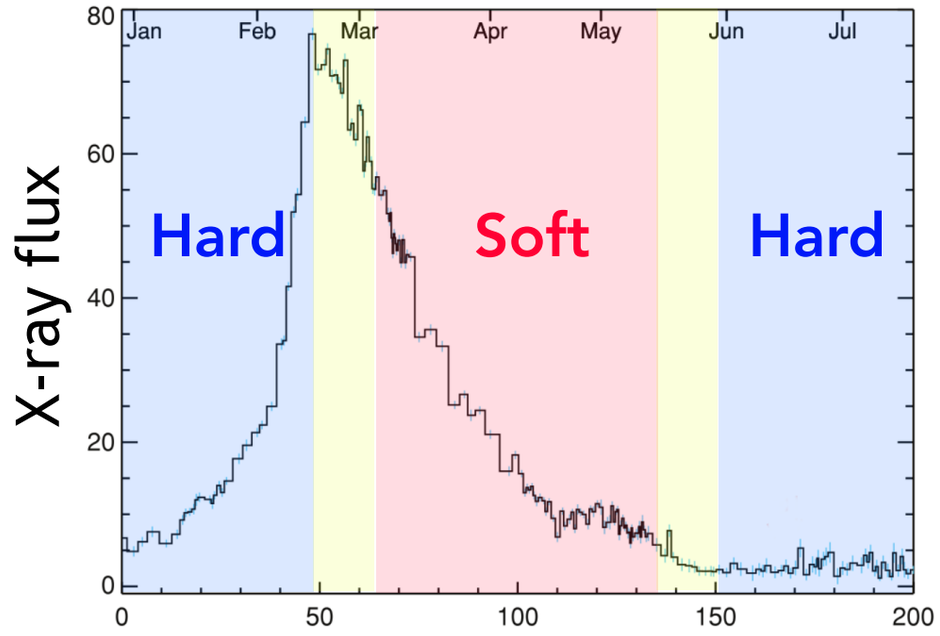

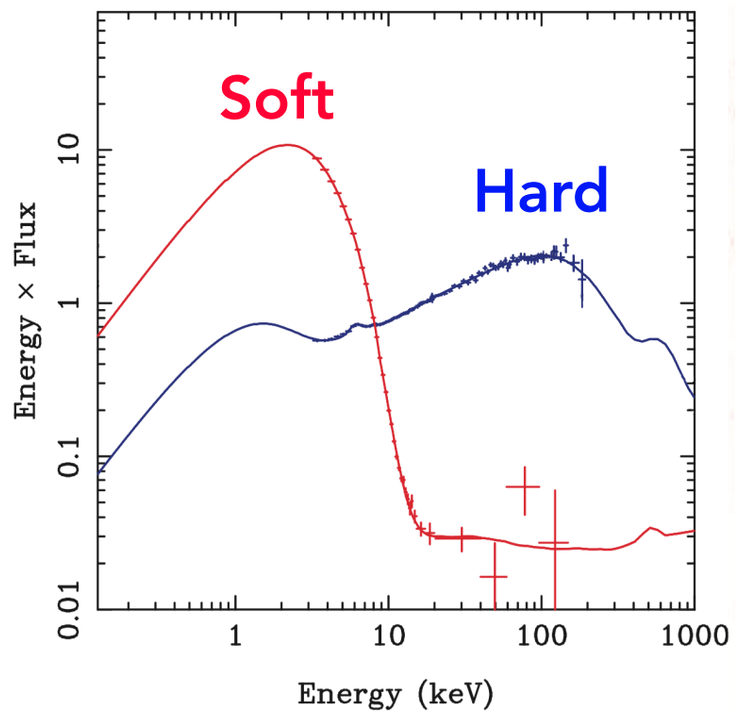

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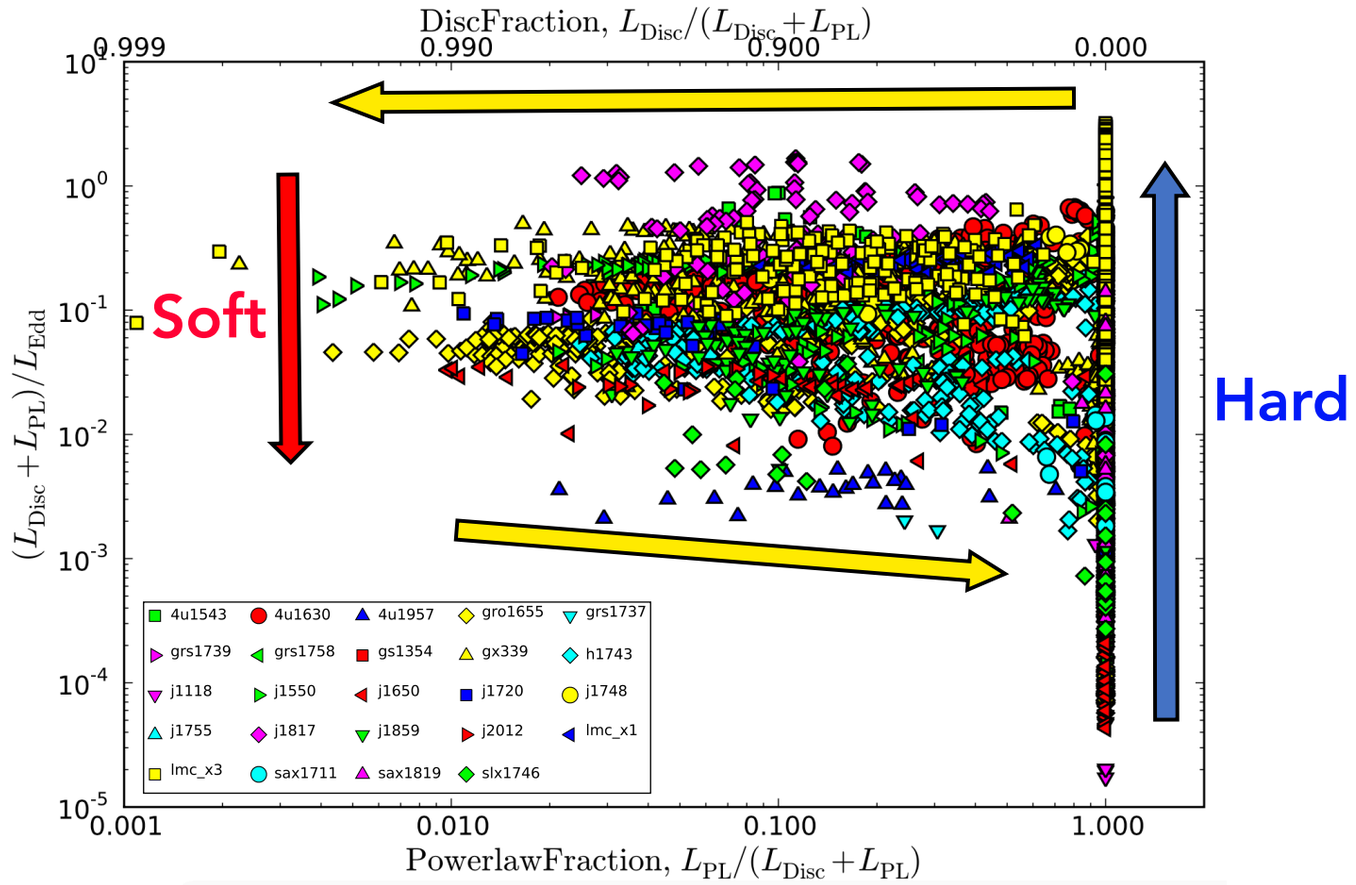
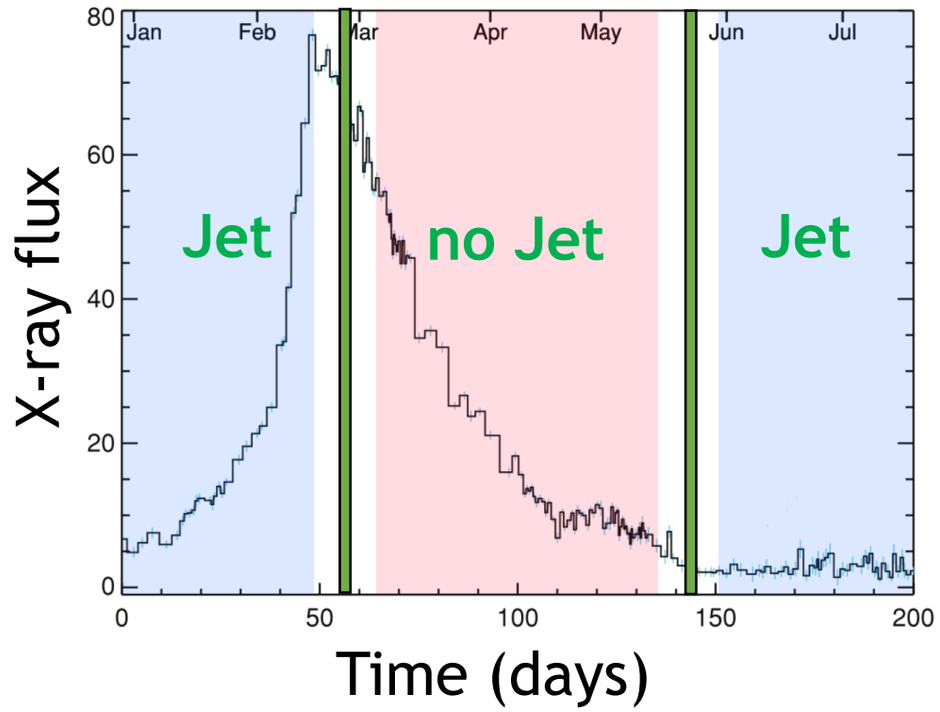
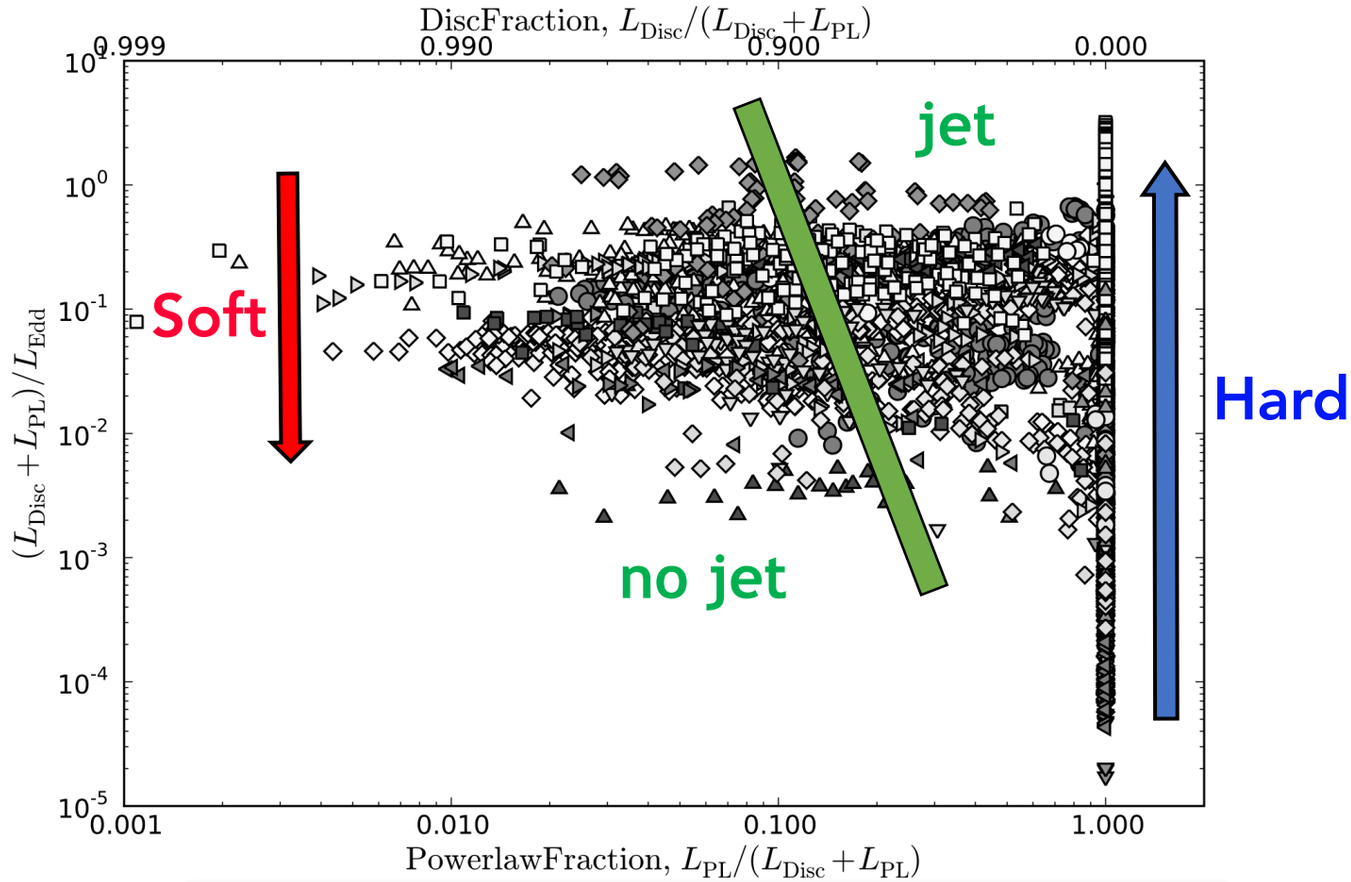


Dunn et al. 2010

A spectral… and a dynamical Hysteresis!
—> Coincidence?

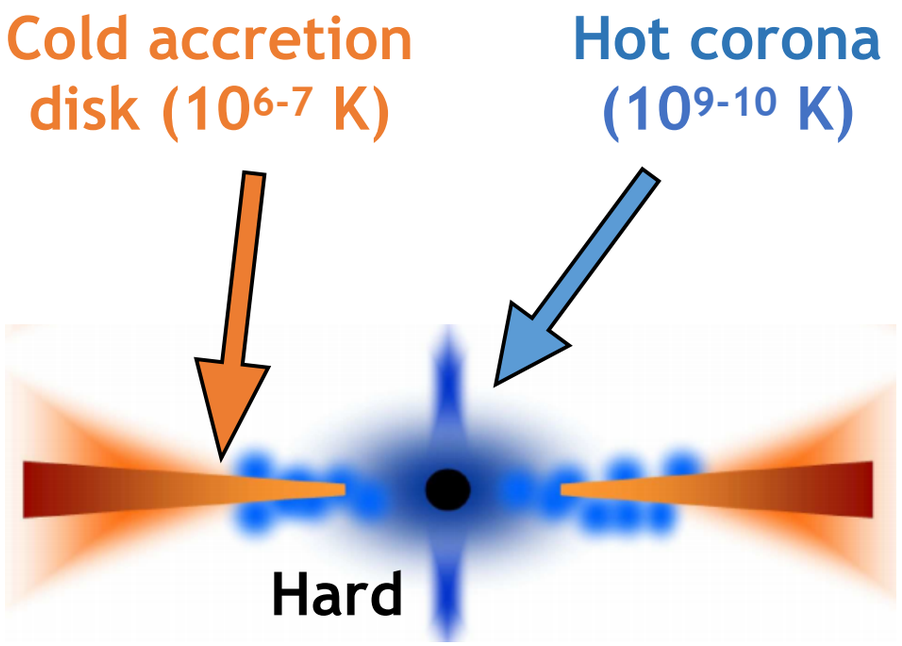


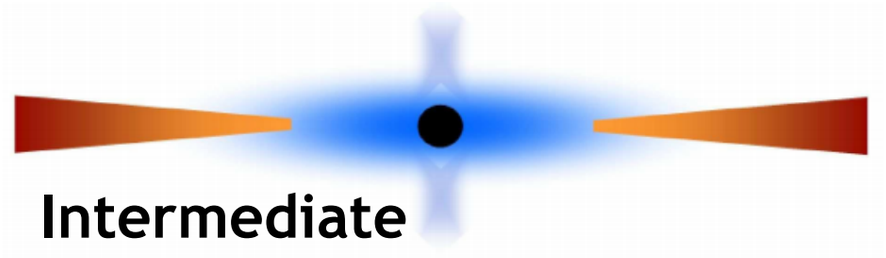


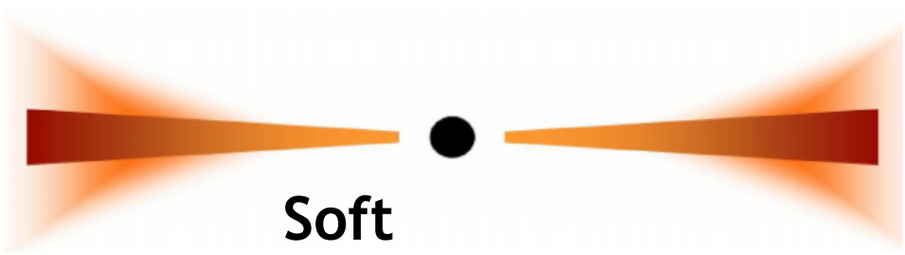
Dunn et al. 2010

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

Conventional framework







Esin et al. 1996
Done et al. 2007

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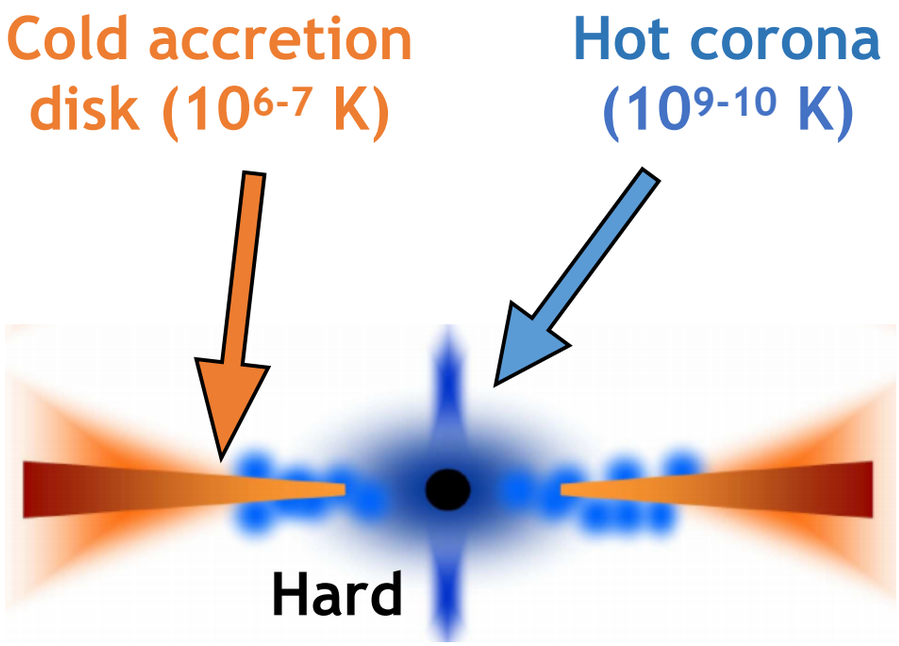
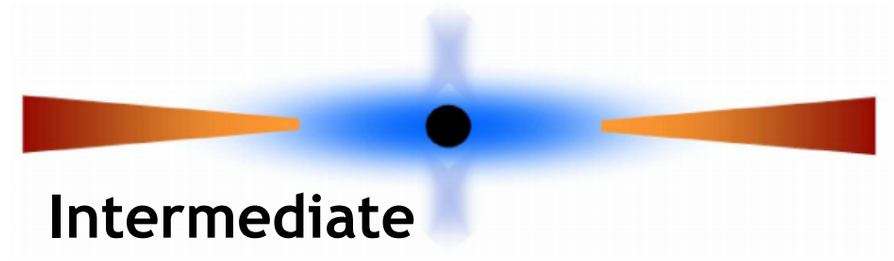
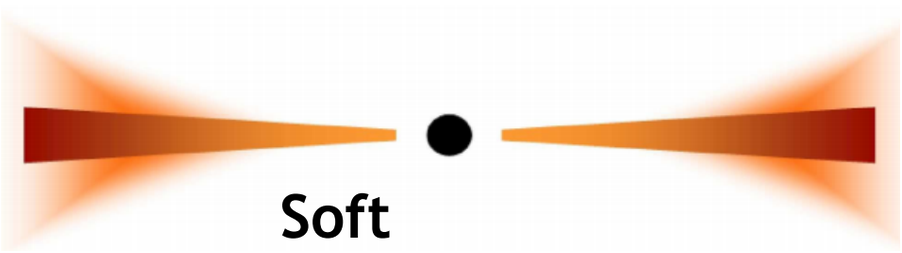






Esin et al. 1996
Done et al. 2007

Major unanswered questions:

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

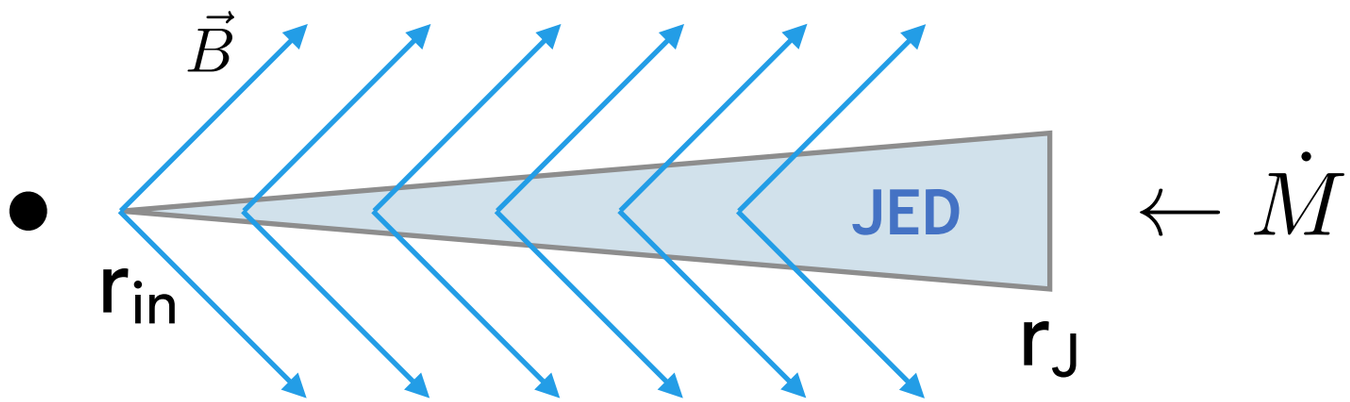
(2) Cycle?

(3) Spectral state transitions?
(4) Dynamical state transitions? Jet lines?

(5) Why should those 2 transitions be related?

Our paradigm: the JED-SAD framework

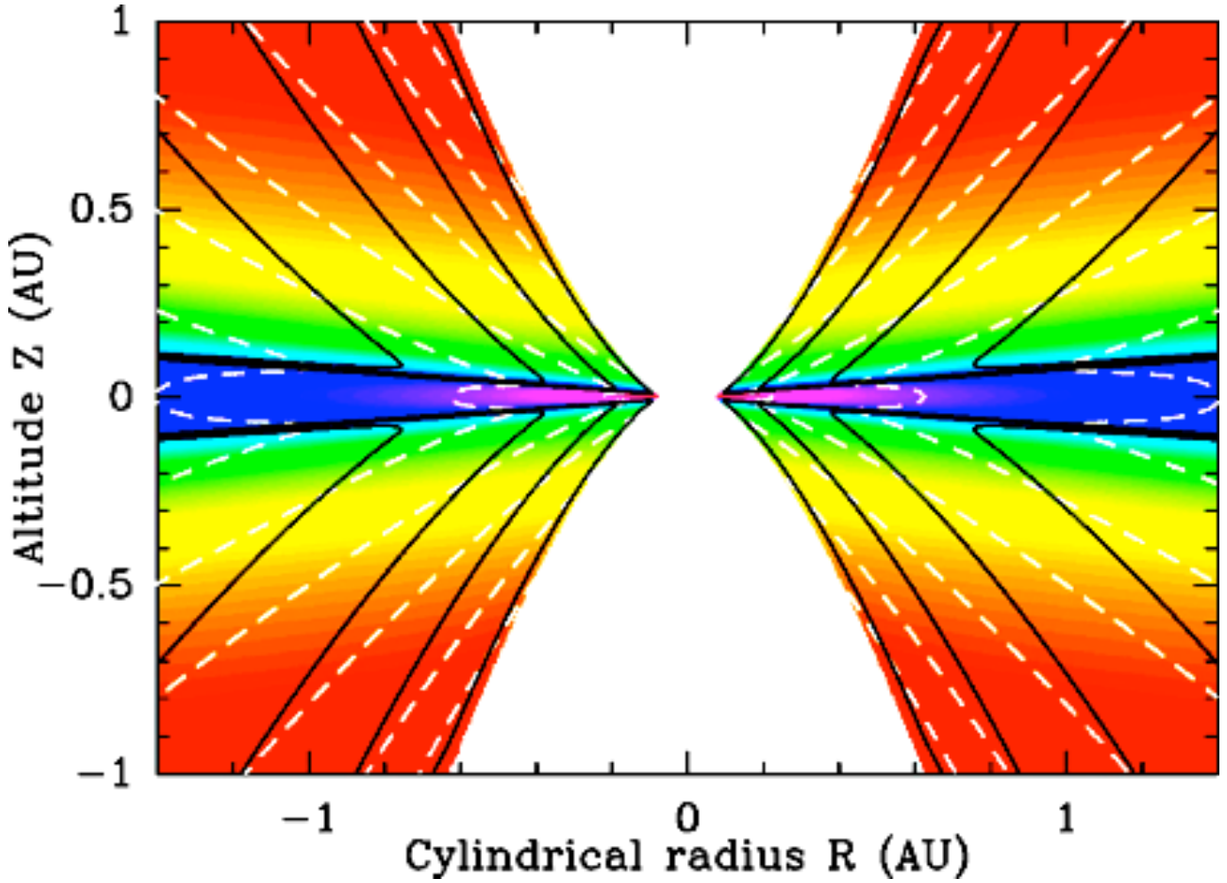
Ferreira et al. 2006
Petrucci et al. 2008



Jet Emitting Disk: Ferreira 1997

- Accretion due to magnetic torque,
- $P_{jets} = b\, P_{acc}$,
- $v_r \geq c_s$ —> Supersonic accretion flow

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



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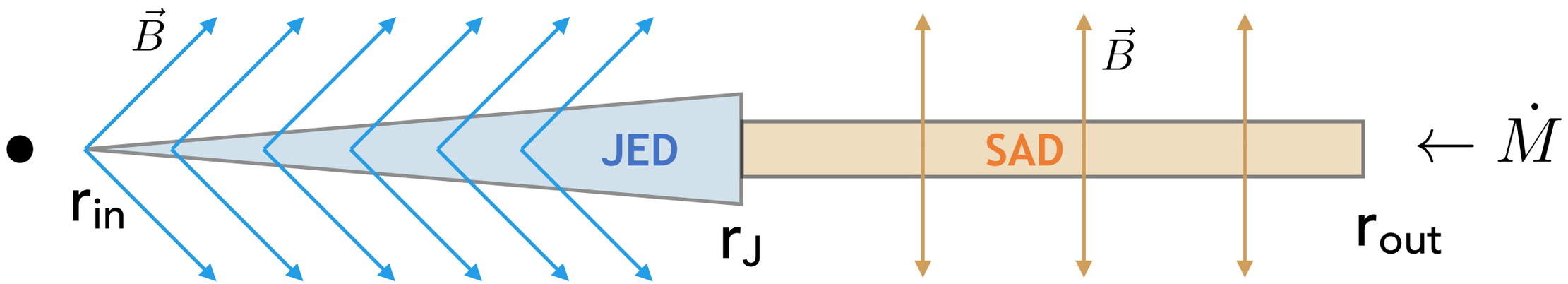

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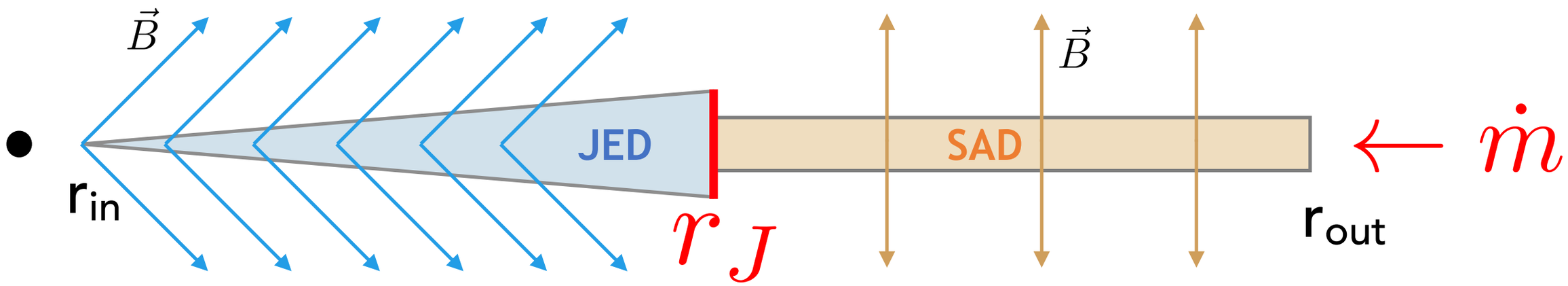

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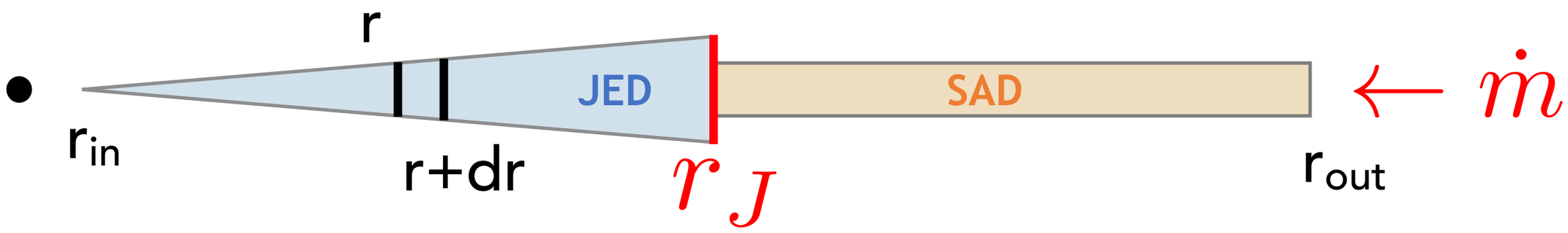
$$\Rightarrow 2 \text{ control parameters: } \dot{m} \text{ and } r_J$$

The 2T disk thermal structure

ions: 1/2 q_{acc} = q^{i}_{adv} + q_{ie}

electrons: 1/2 q_{acc} = q_{rad} + q^{e}_{adv} - q_{ie}



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Advection processes calculated outside-in

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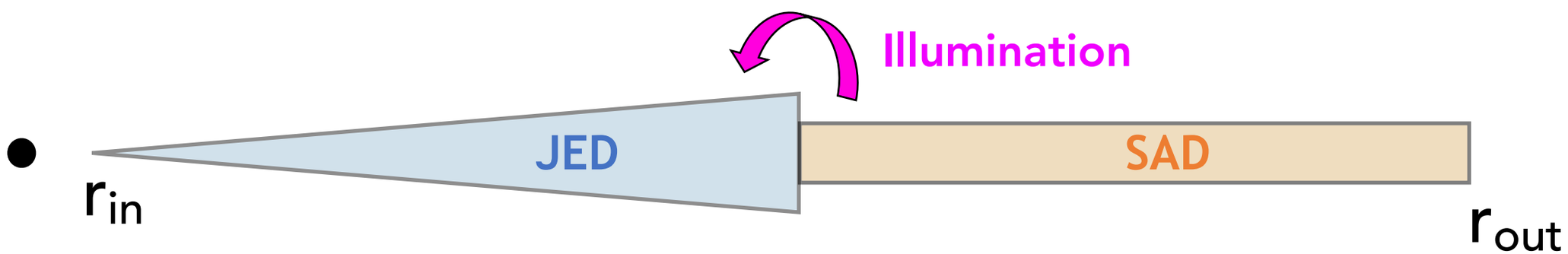
Radiative cooling as a bridge formula (Hubeny 1991) between:

- 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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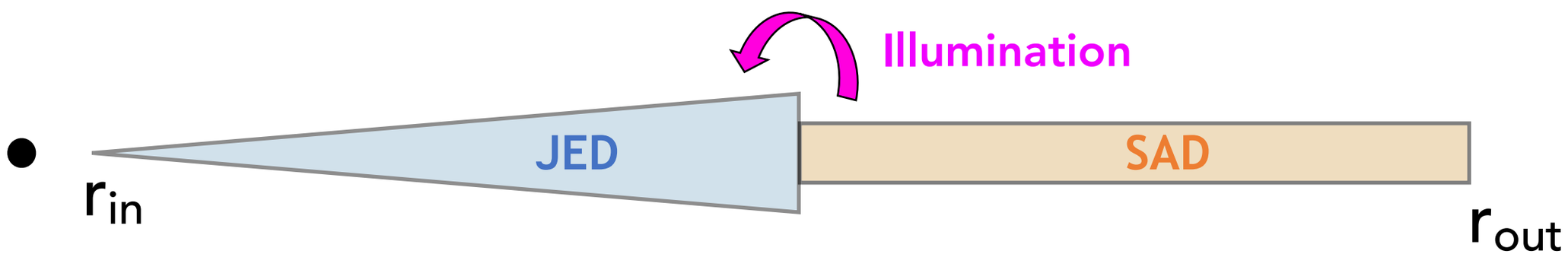

Electron temperature, optical depth, *etc… as* function of radius, giving us access to the full **Spectral Energy Distribution** with BELM!

The 2T disk thermal structure

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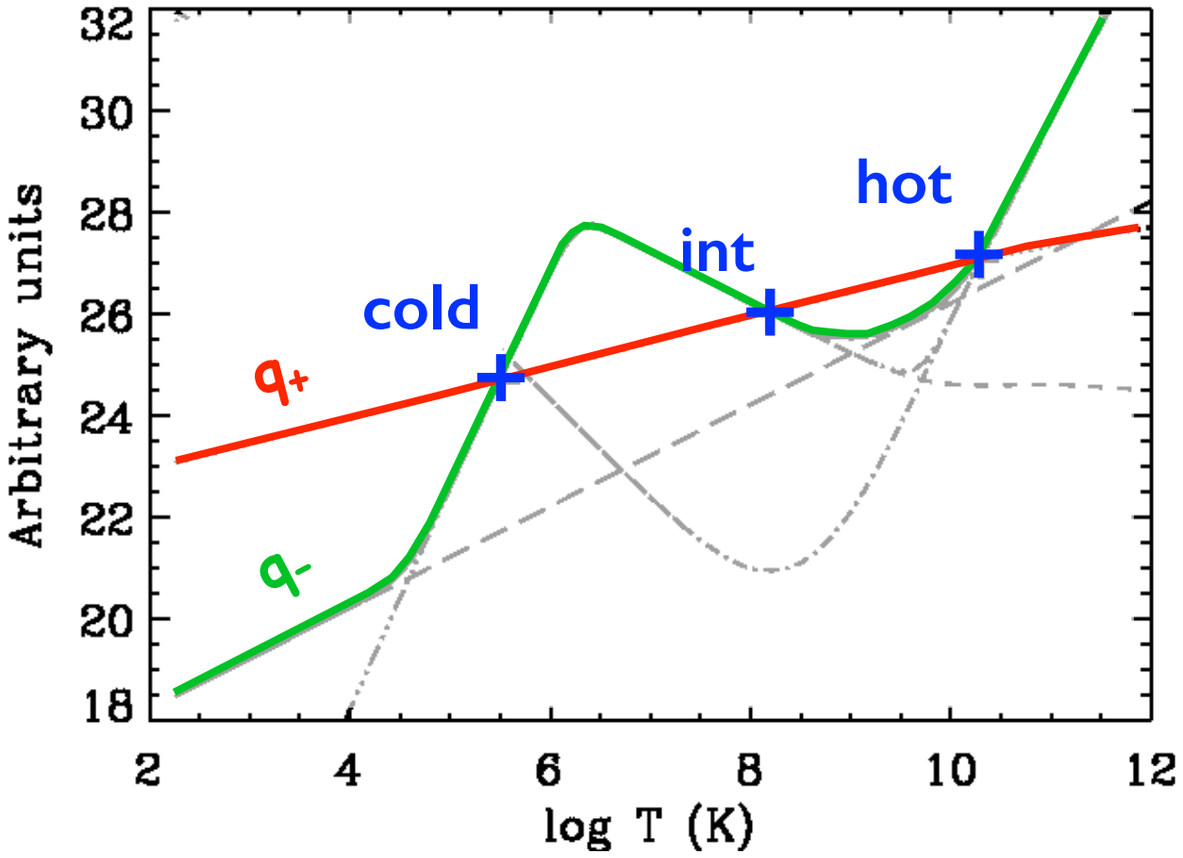
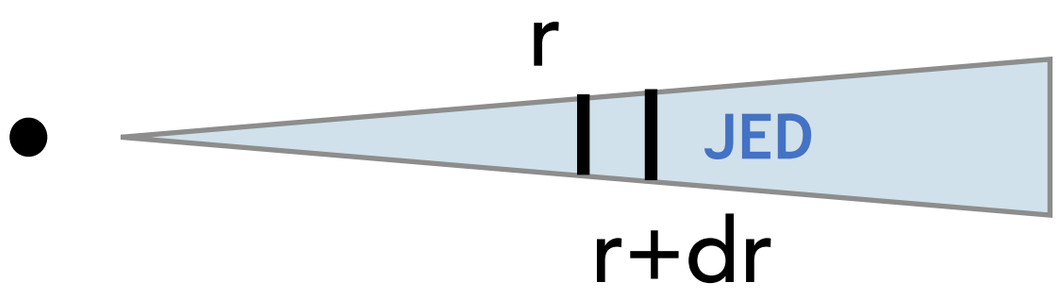
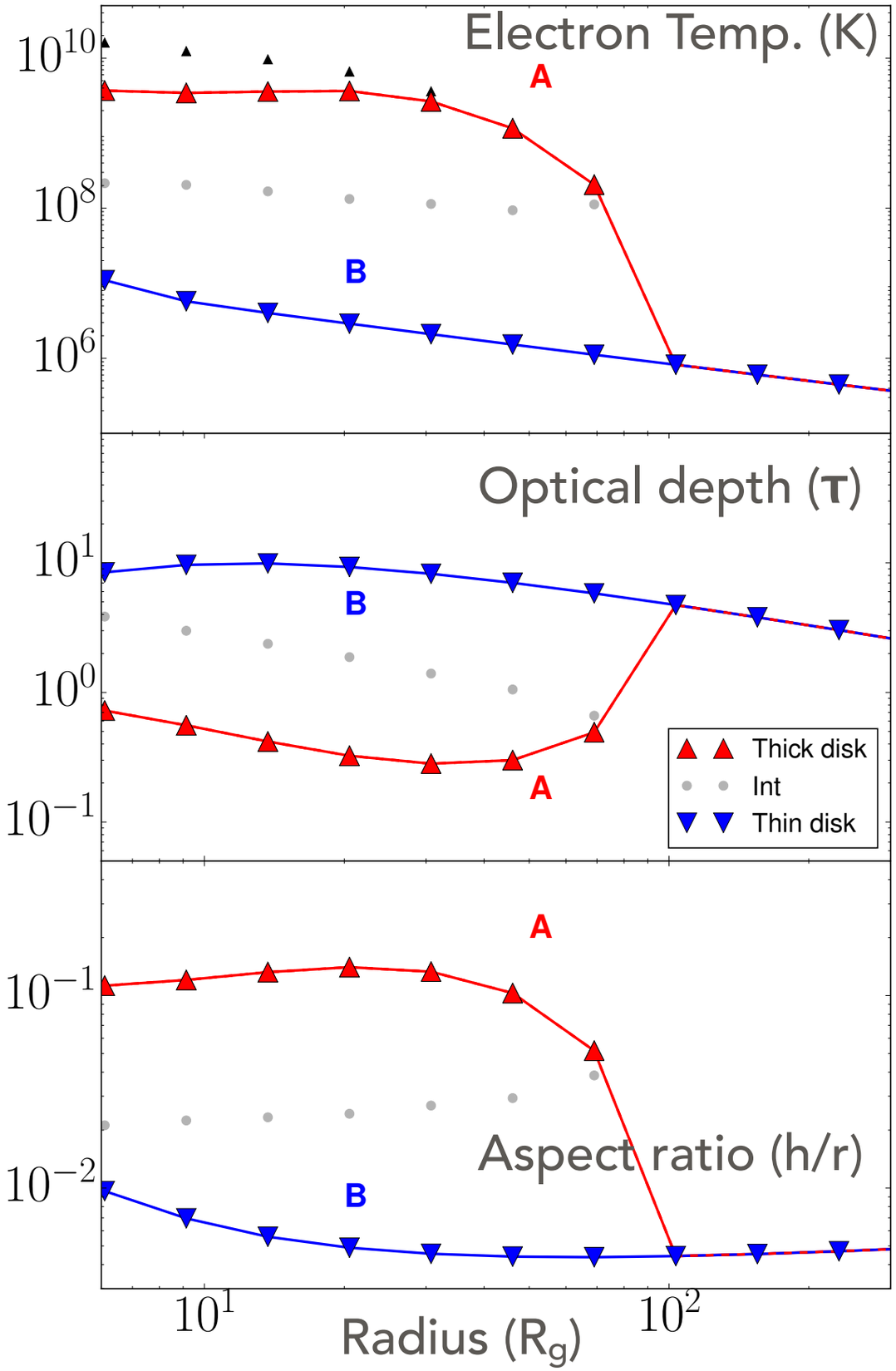
Up to 3 possible solutions at each radius
for 1T plasma Petrucci et al. 2010
—> suitable for Hard States?





At low luminosity… L = 10^{-3} L_{Edd}



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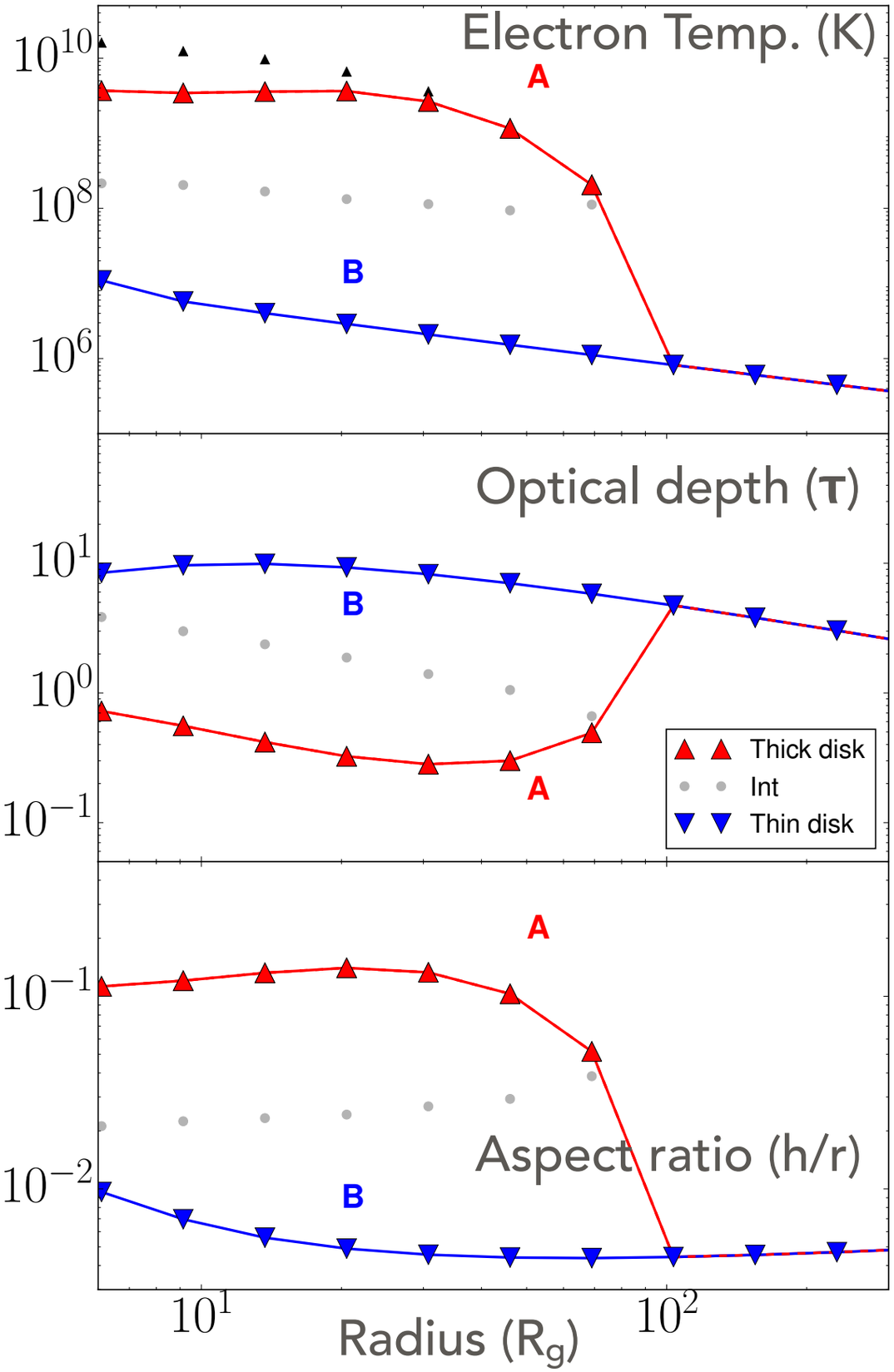
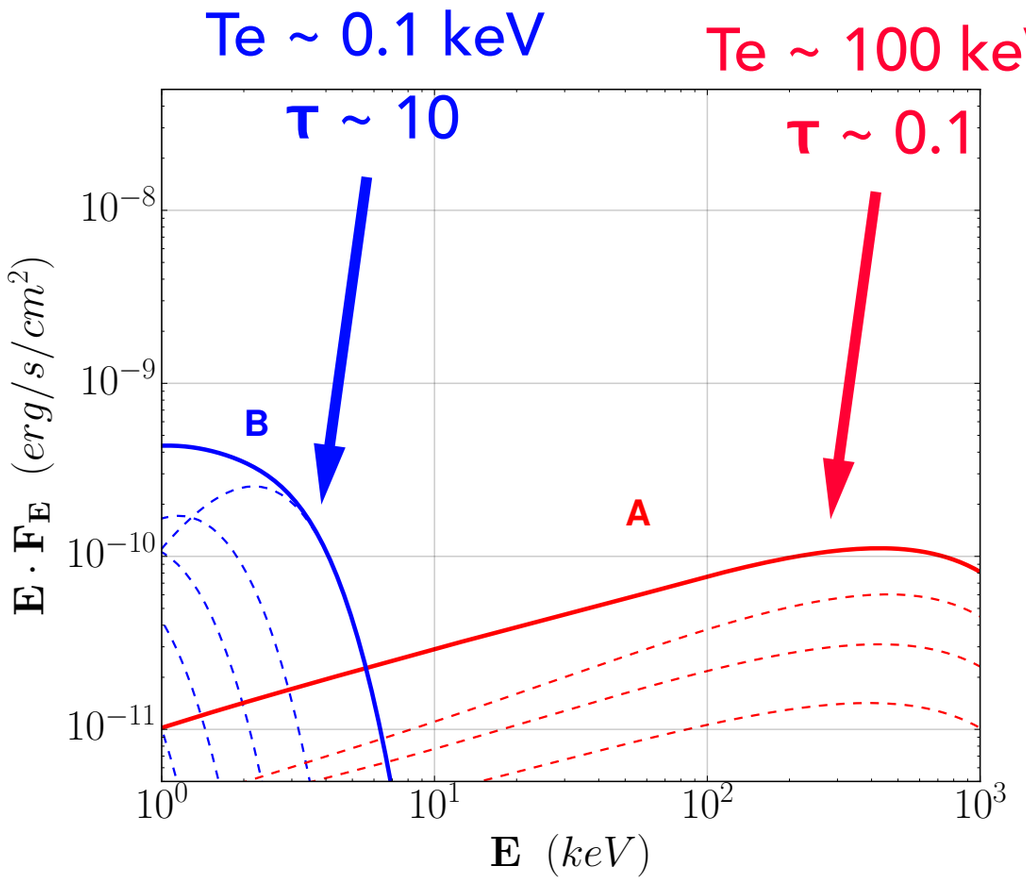
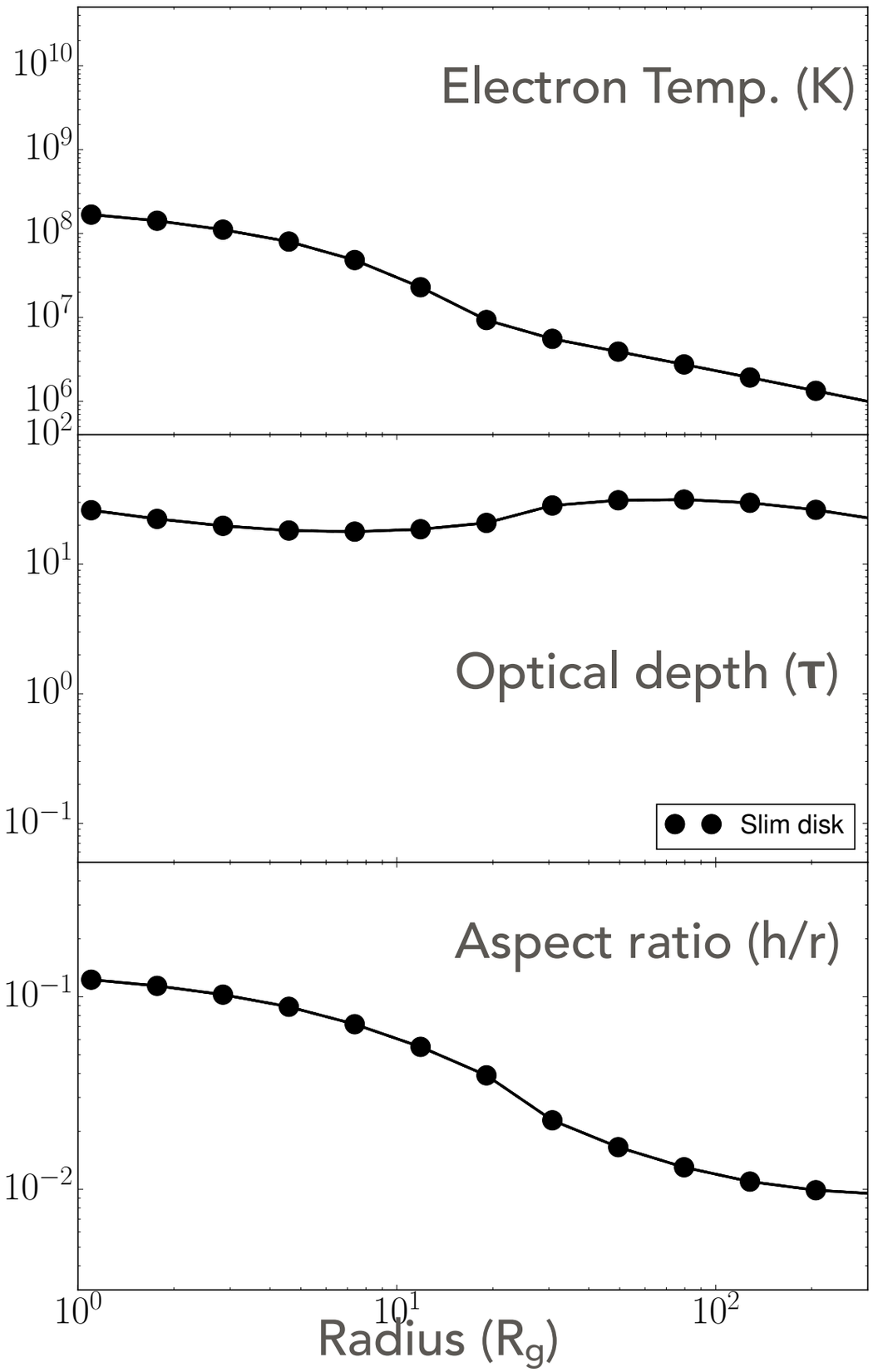




Possibility to reproduce **Hard states**!

Marcel et al. 2018a

At high luminosity… $L > 10^{-1} L_{Edd}$



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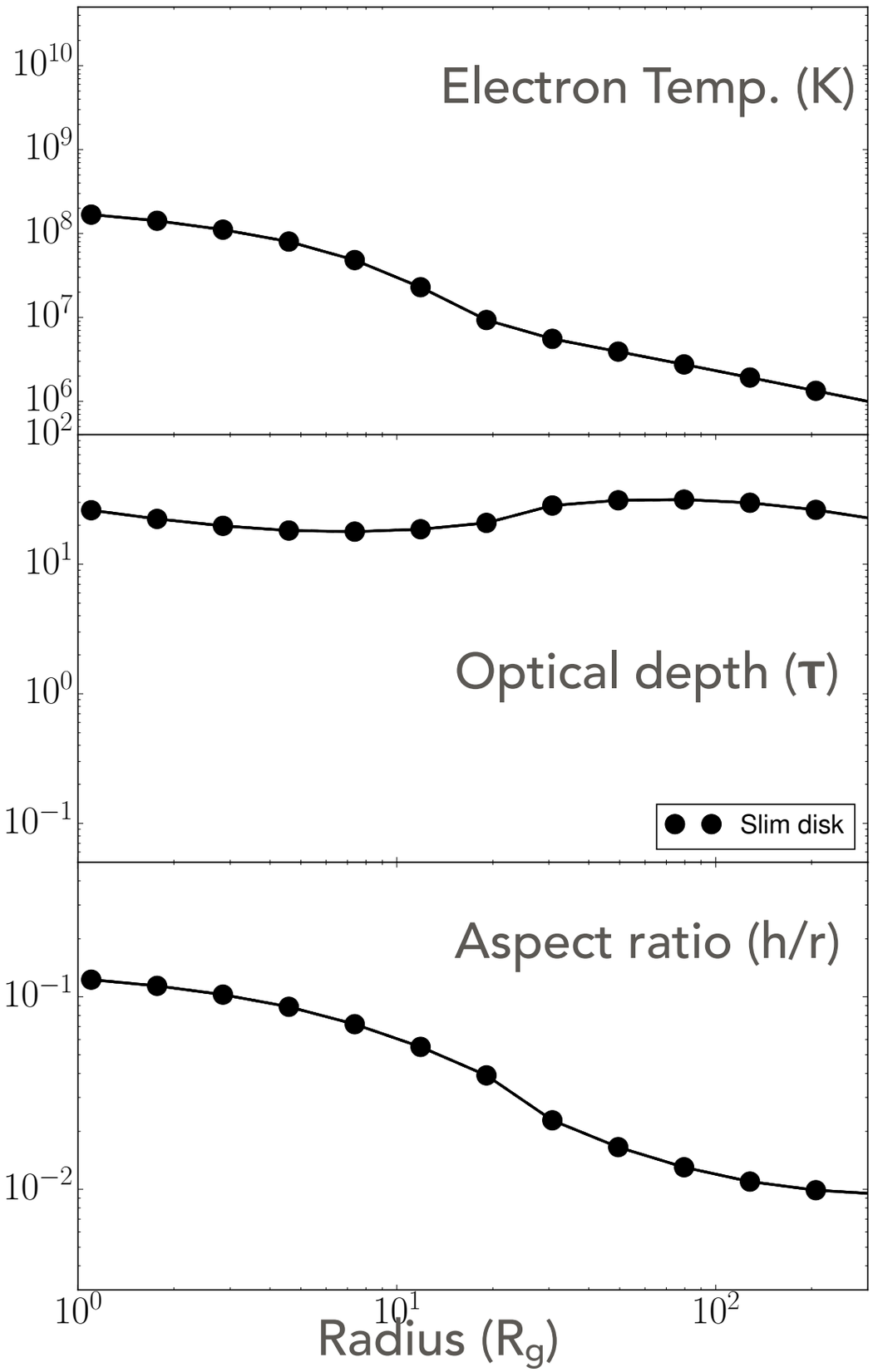
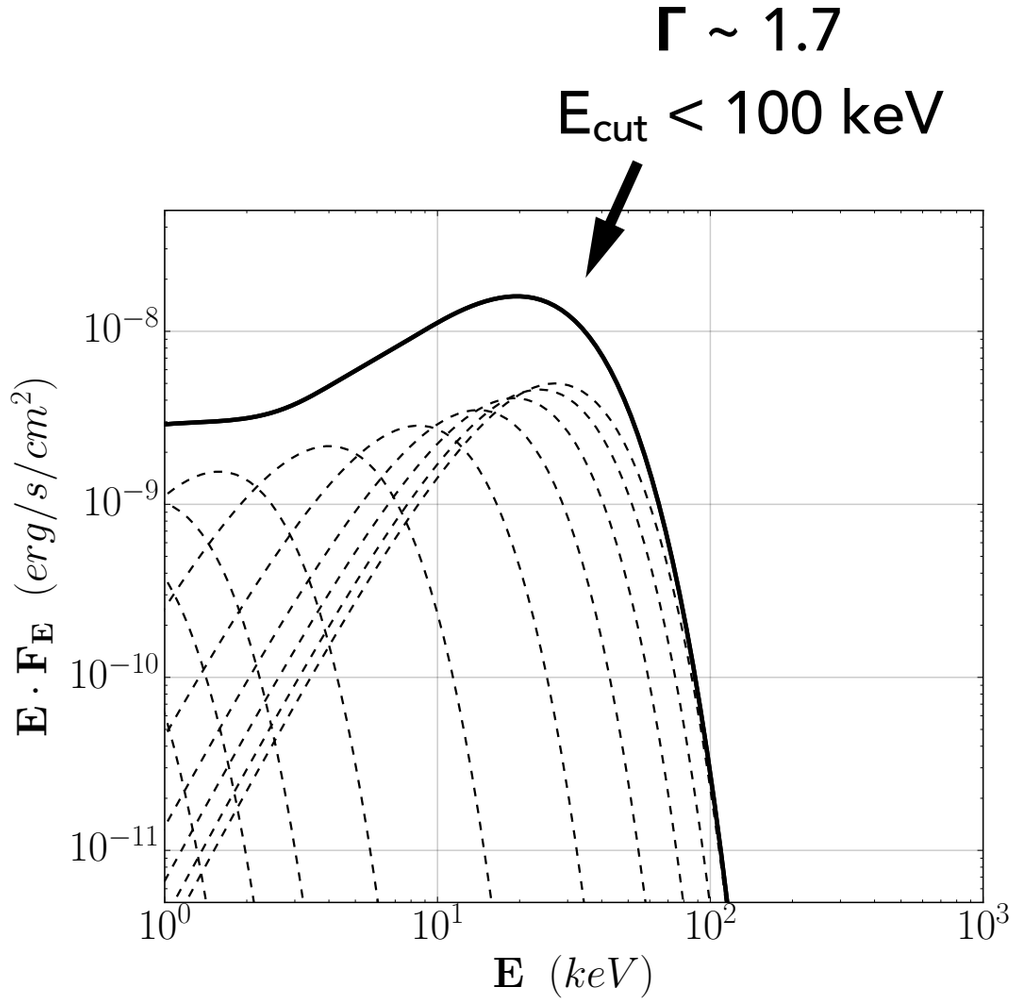




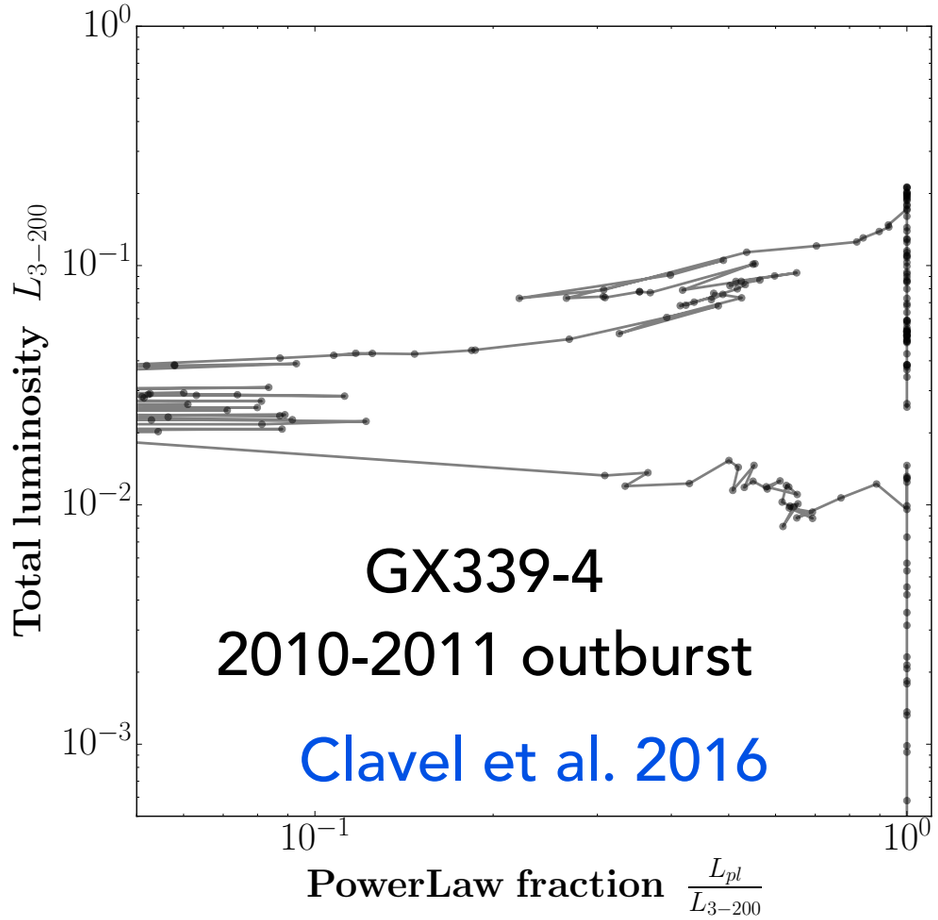
The sum of **slim JED** disk spectra reproduces a high luminosity hard state spectrum!

Marcel et al. 2018a

From theory to obs: cycle in DFLD

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

Thermal Equilibrium solutions



Global SED

Faked data (instr response+ noise+absorption)

Xspec Fits (disk+cut-off power law)

One point in the DFLD

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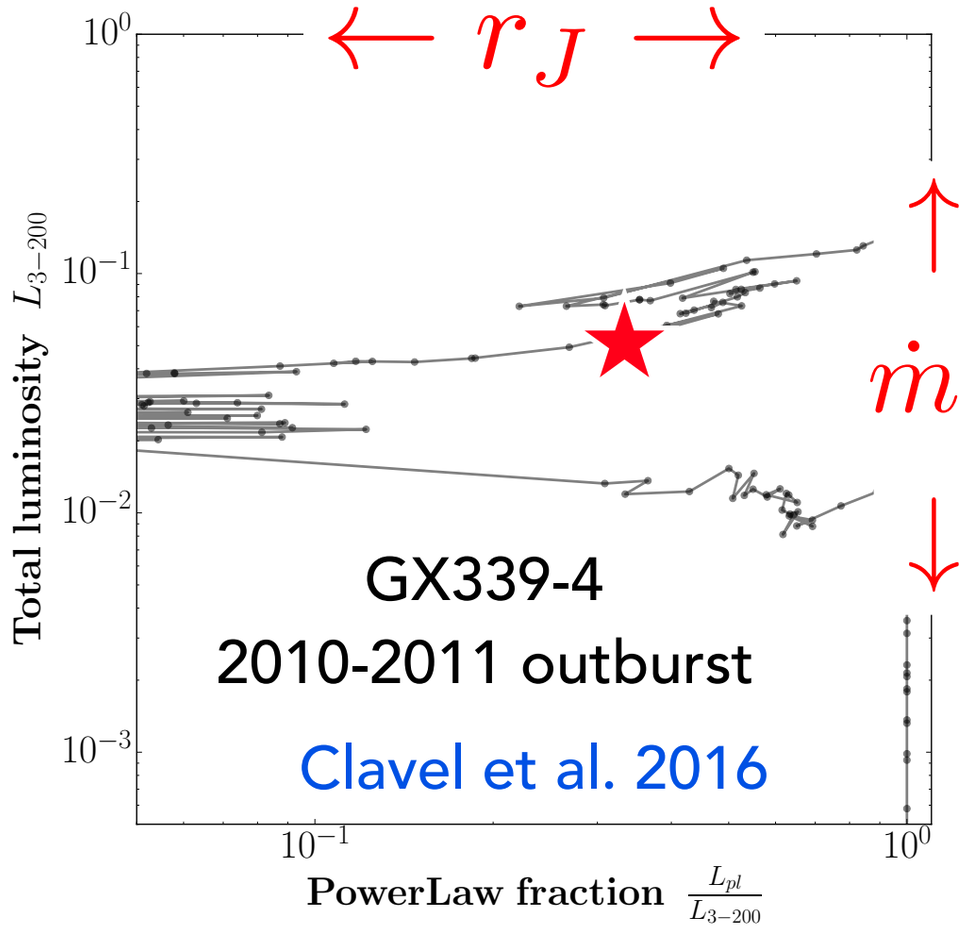

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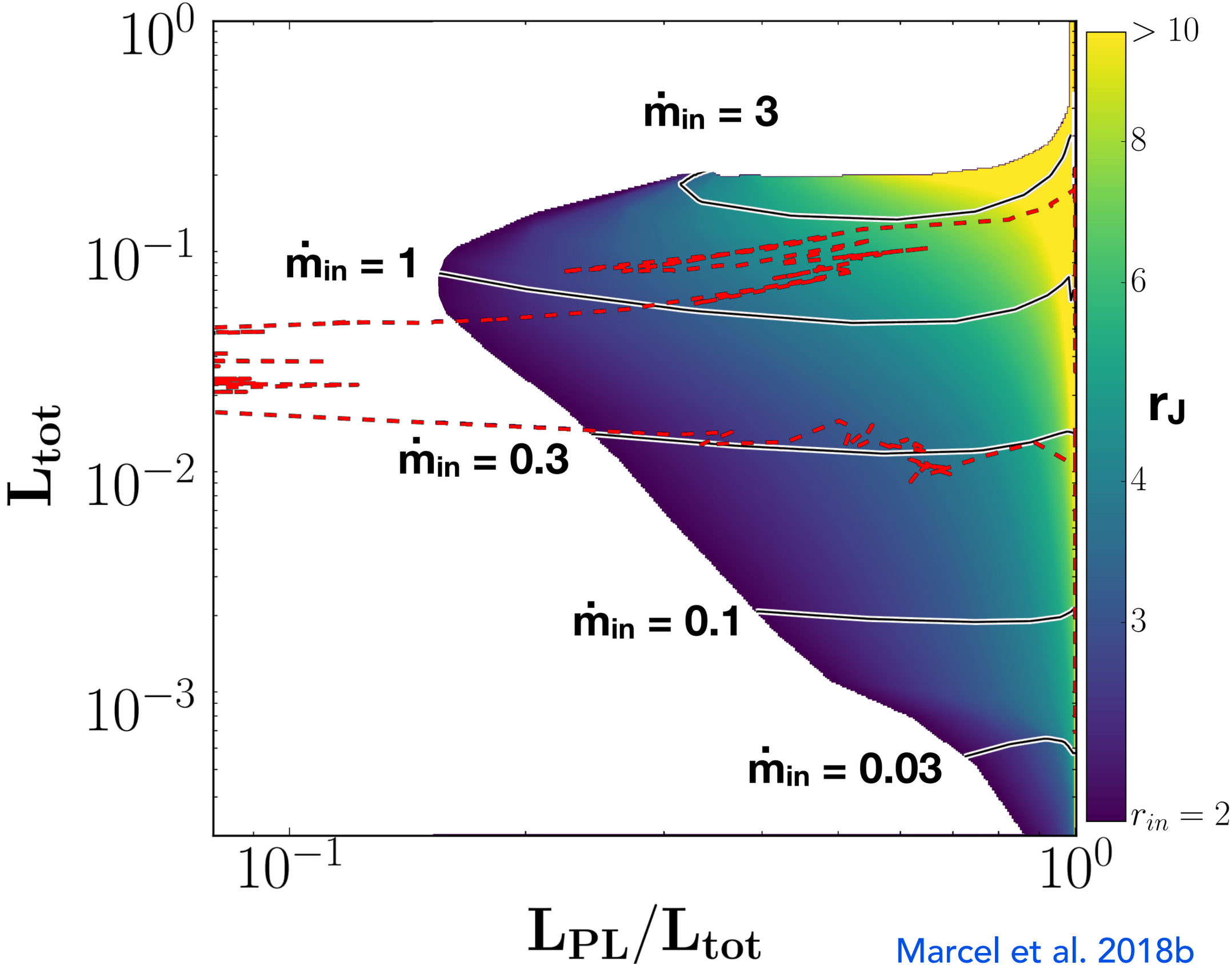


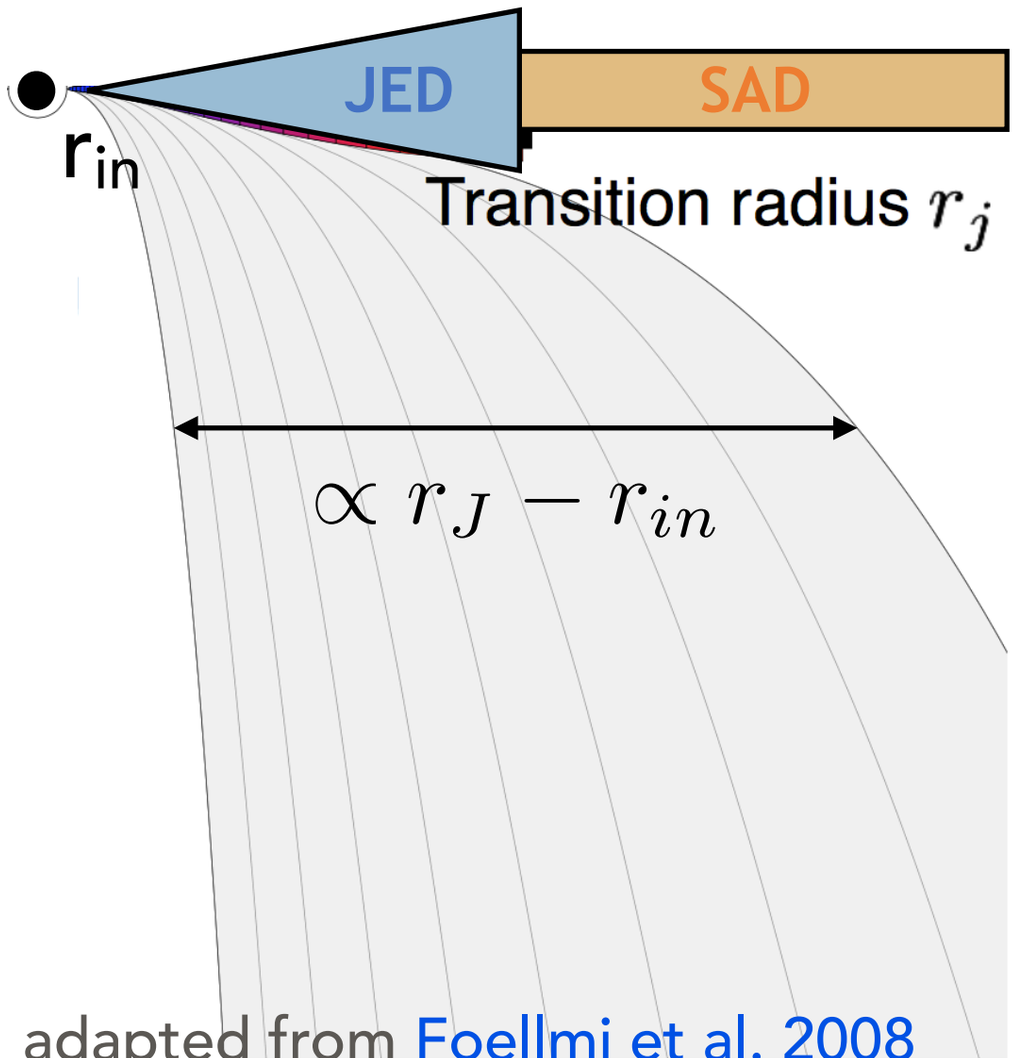
Marcel et al. 2018b

From theory to obs: cycle in DFLD

~~$L_R \propto \dot{m}^{17/12}$~~

Heinz & Sunyaev 2003

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



adapted from Foellmi et al. 2008

Marcel et al. 2018b

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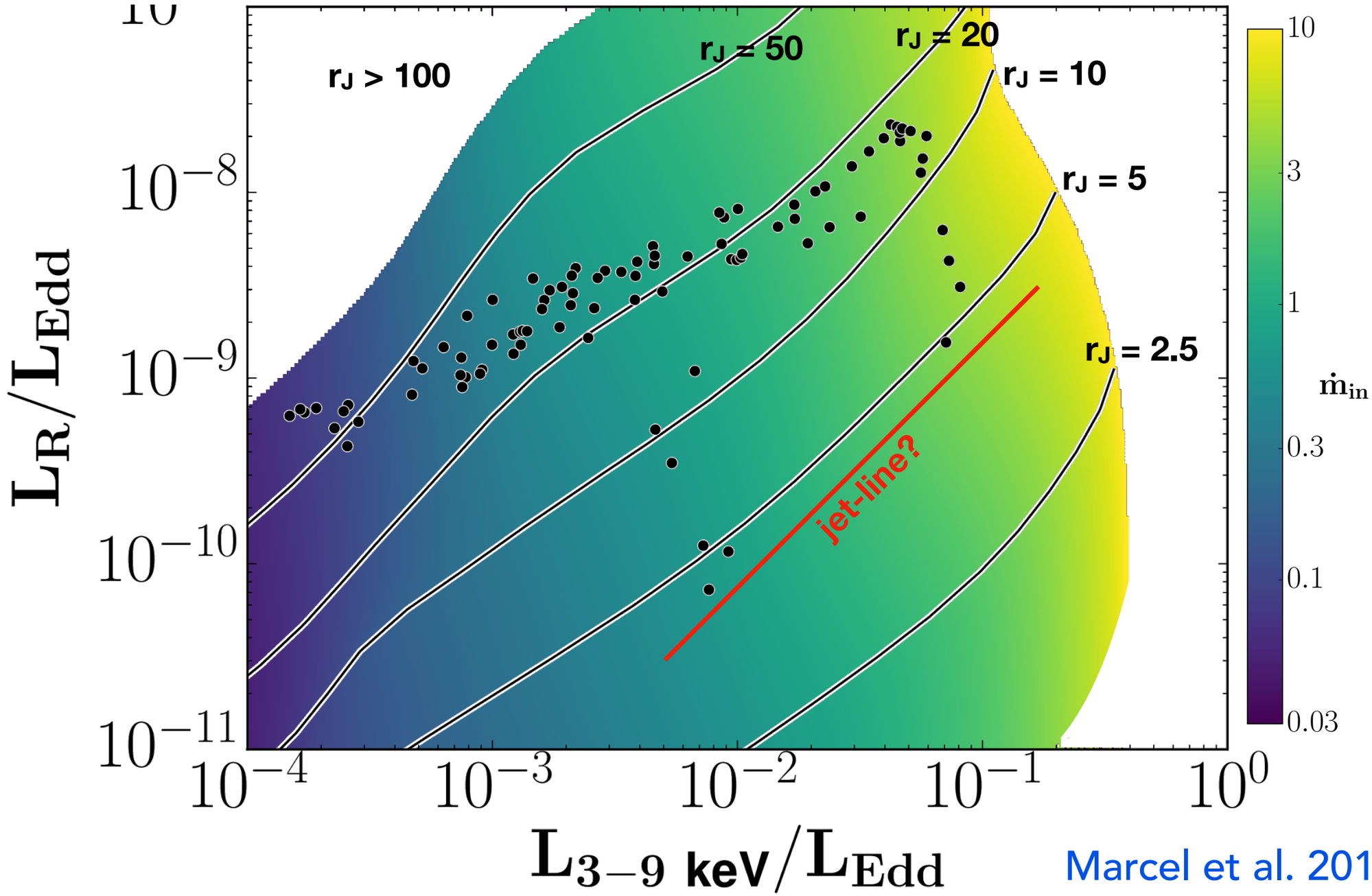


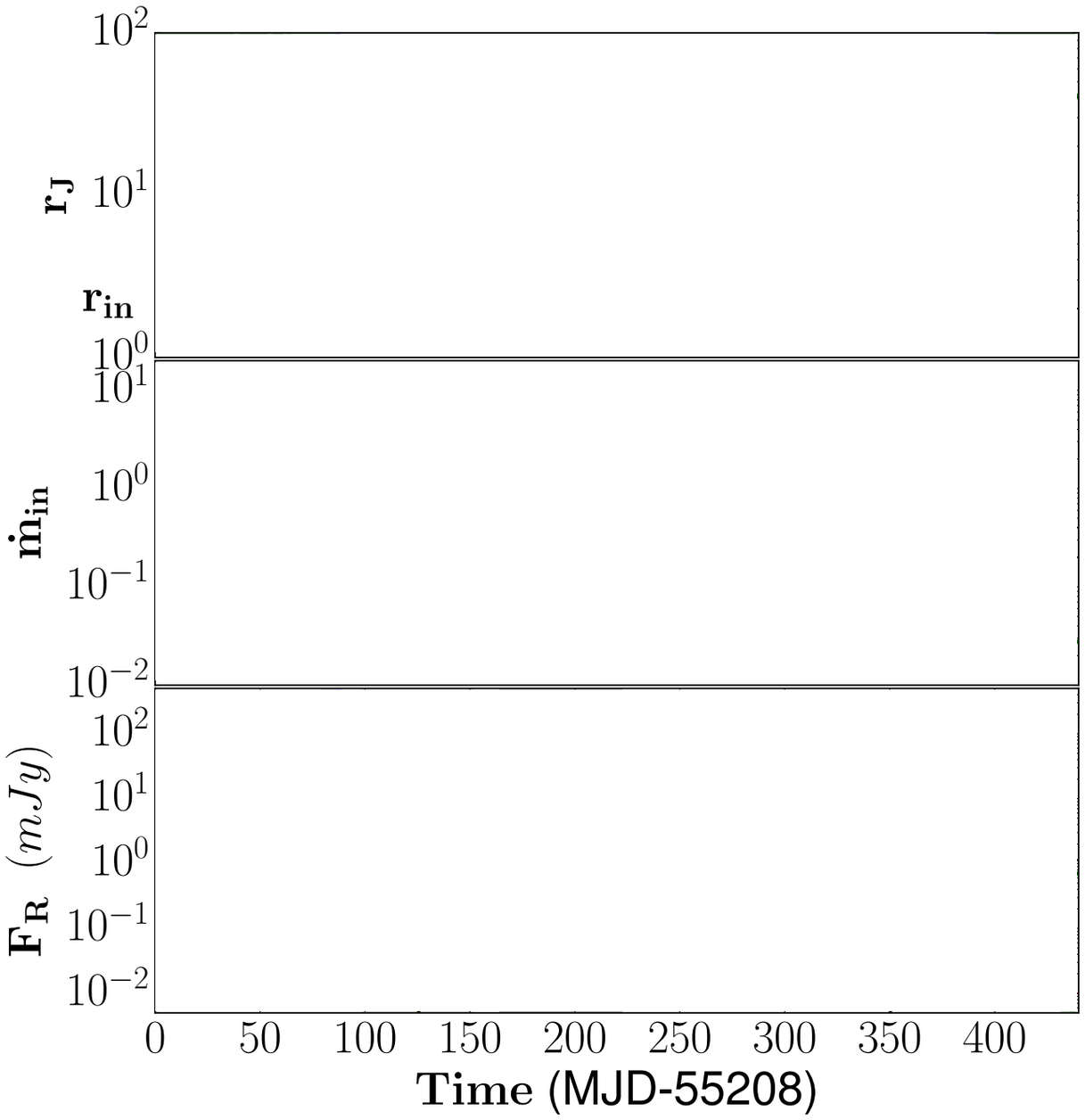
Marcel et al. 2018b

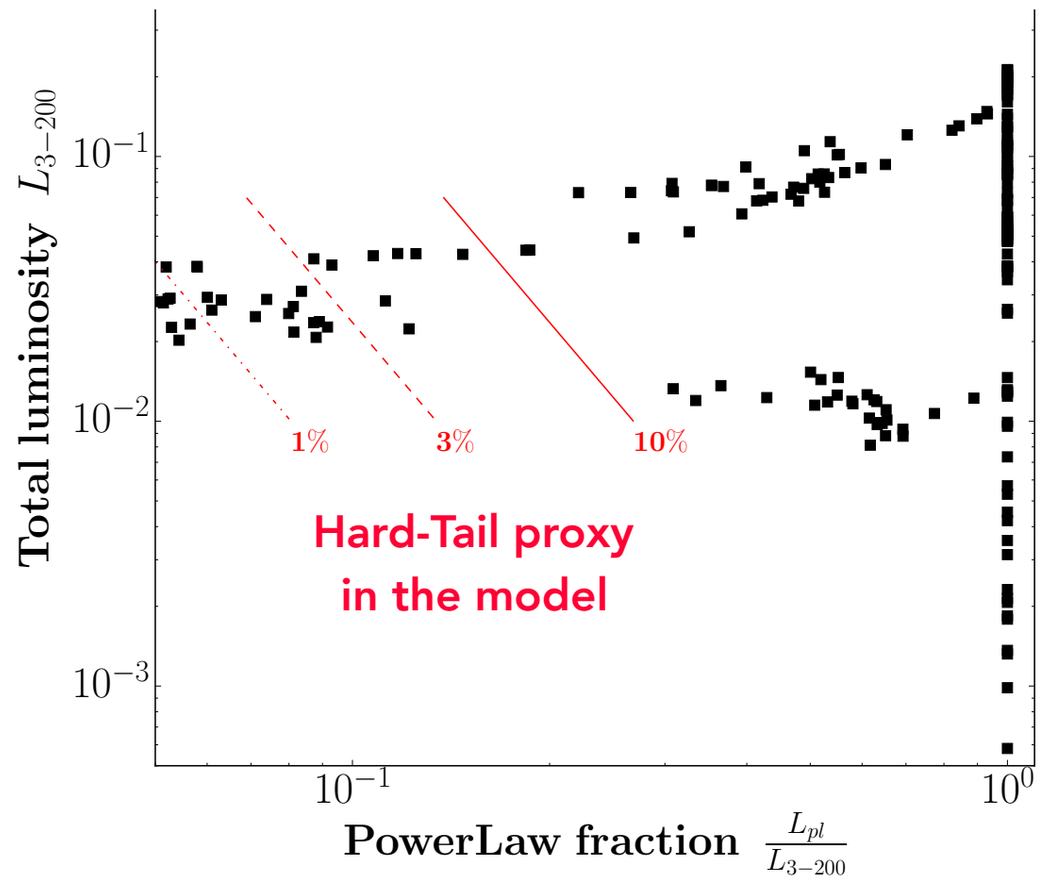
GX339-4: the 2010-2011 outburst

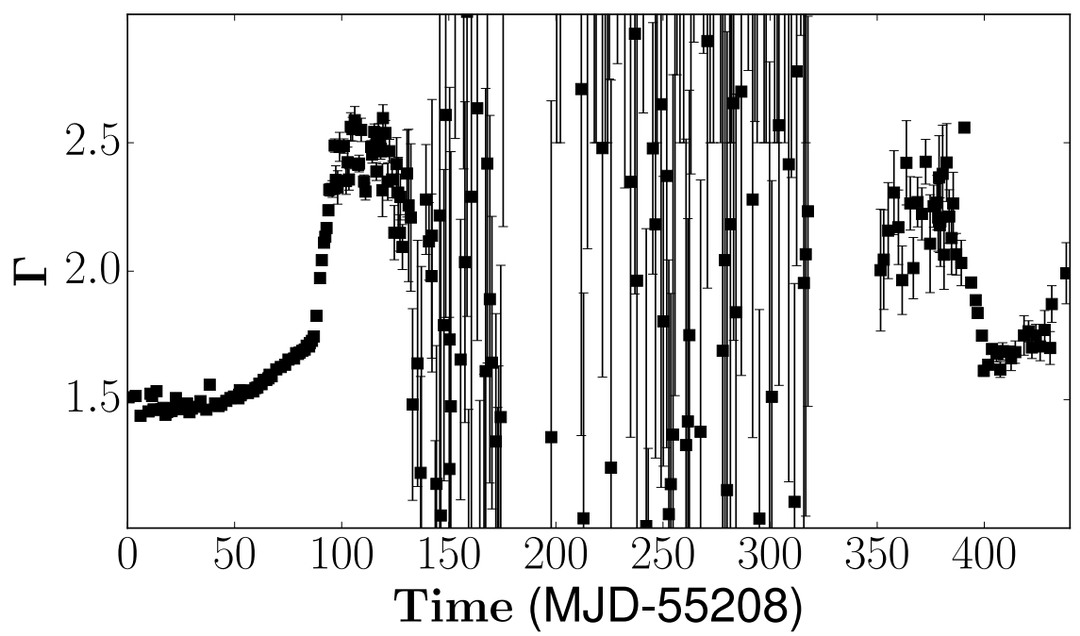
$$m = 5.8\ M_\odot$$

Miller et al. 2008 $\quad d = 8\ kpc$

$$r_{in} = 2\ R_g$$

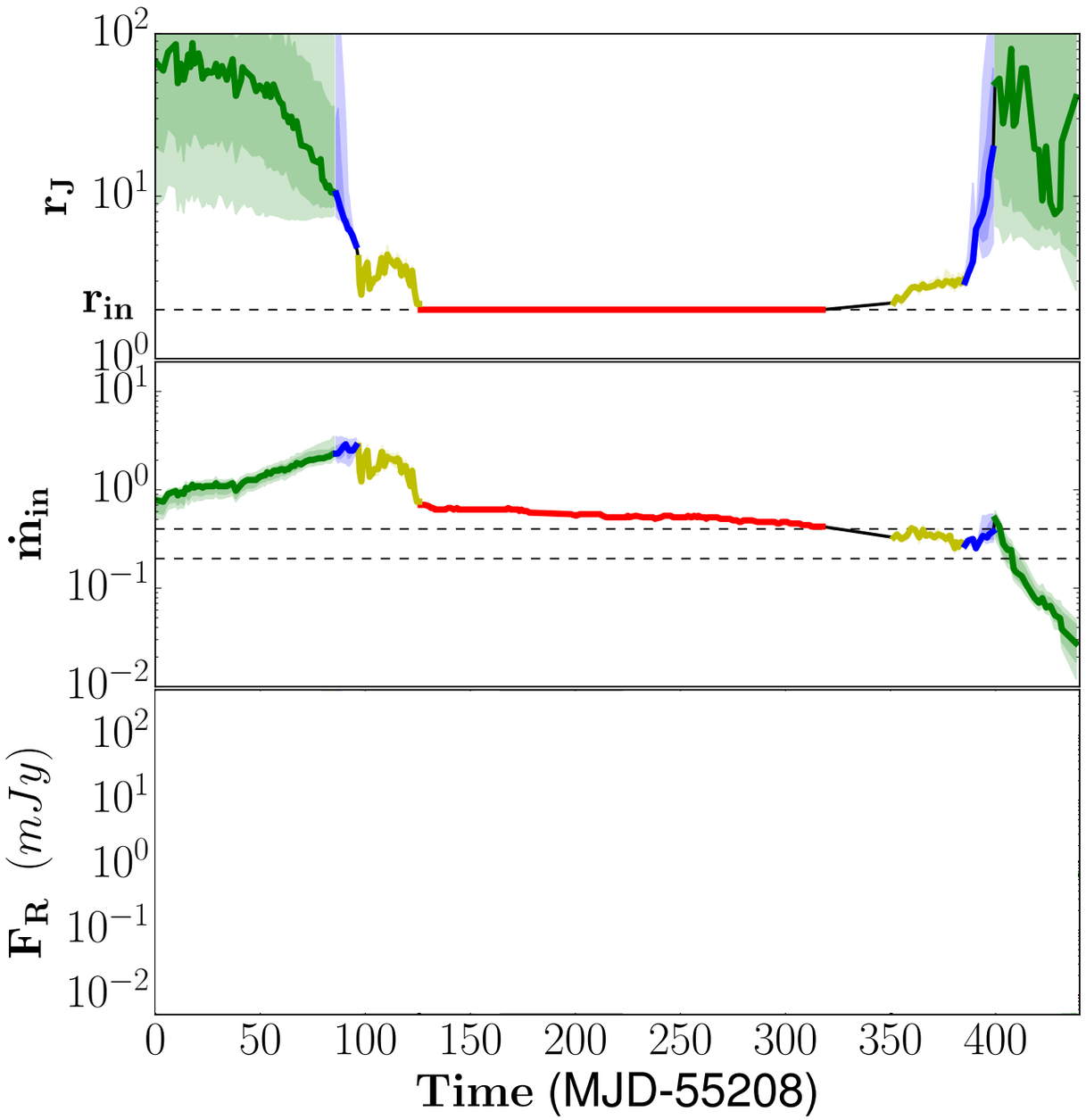


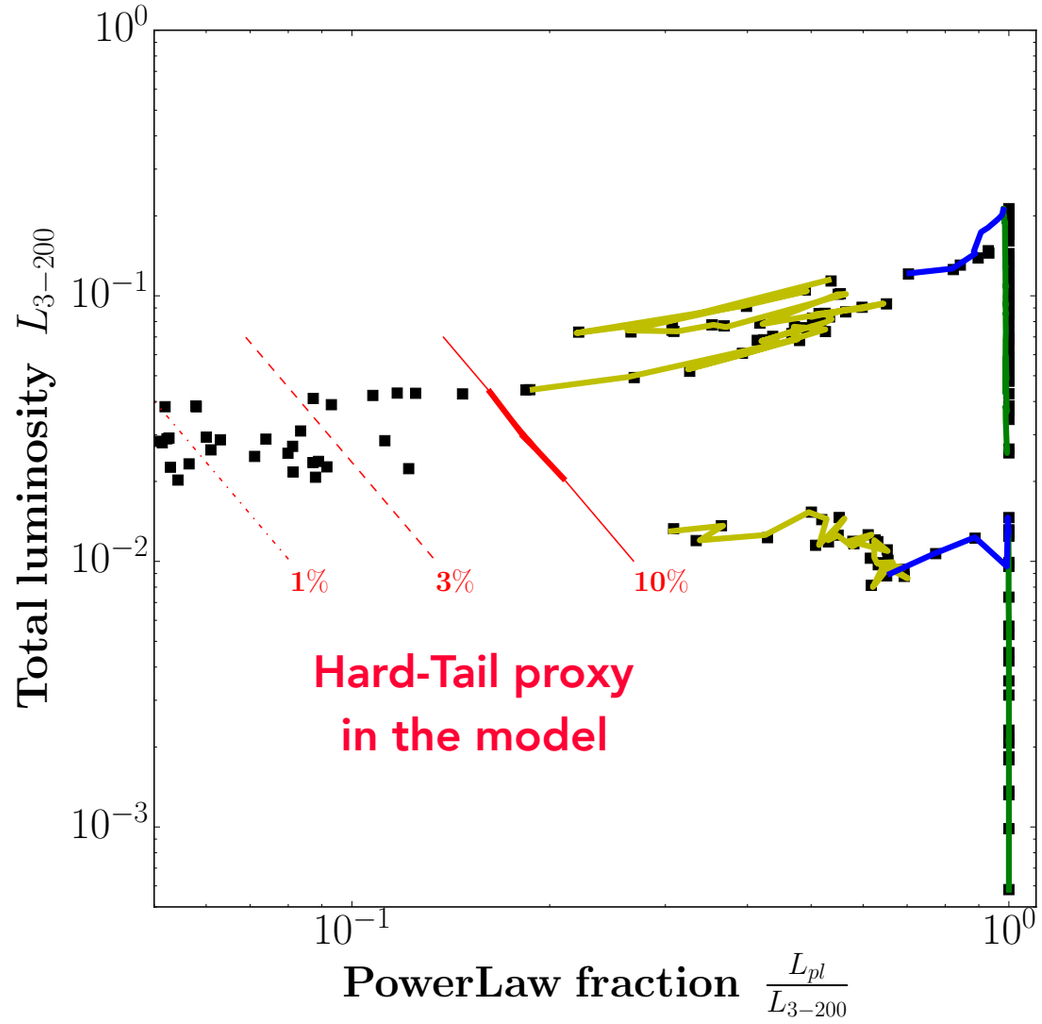


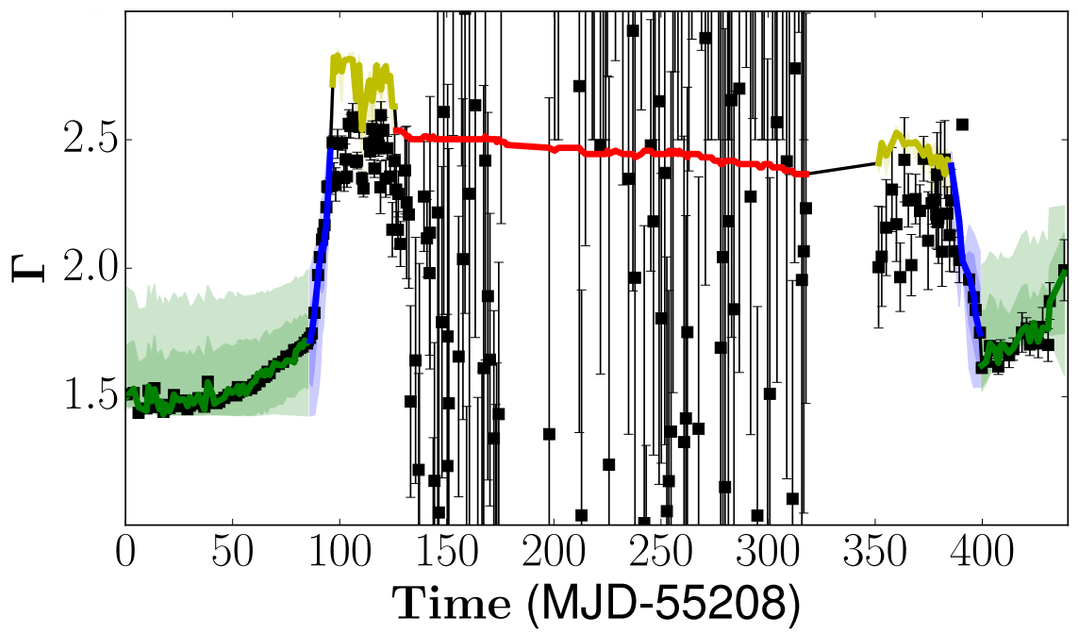


X-ray fits

Marcel et al. tbs to A&A



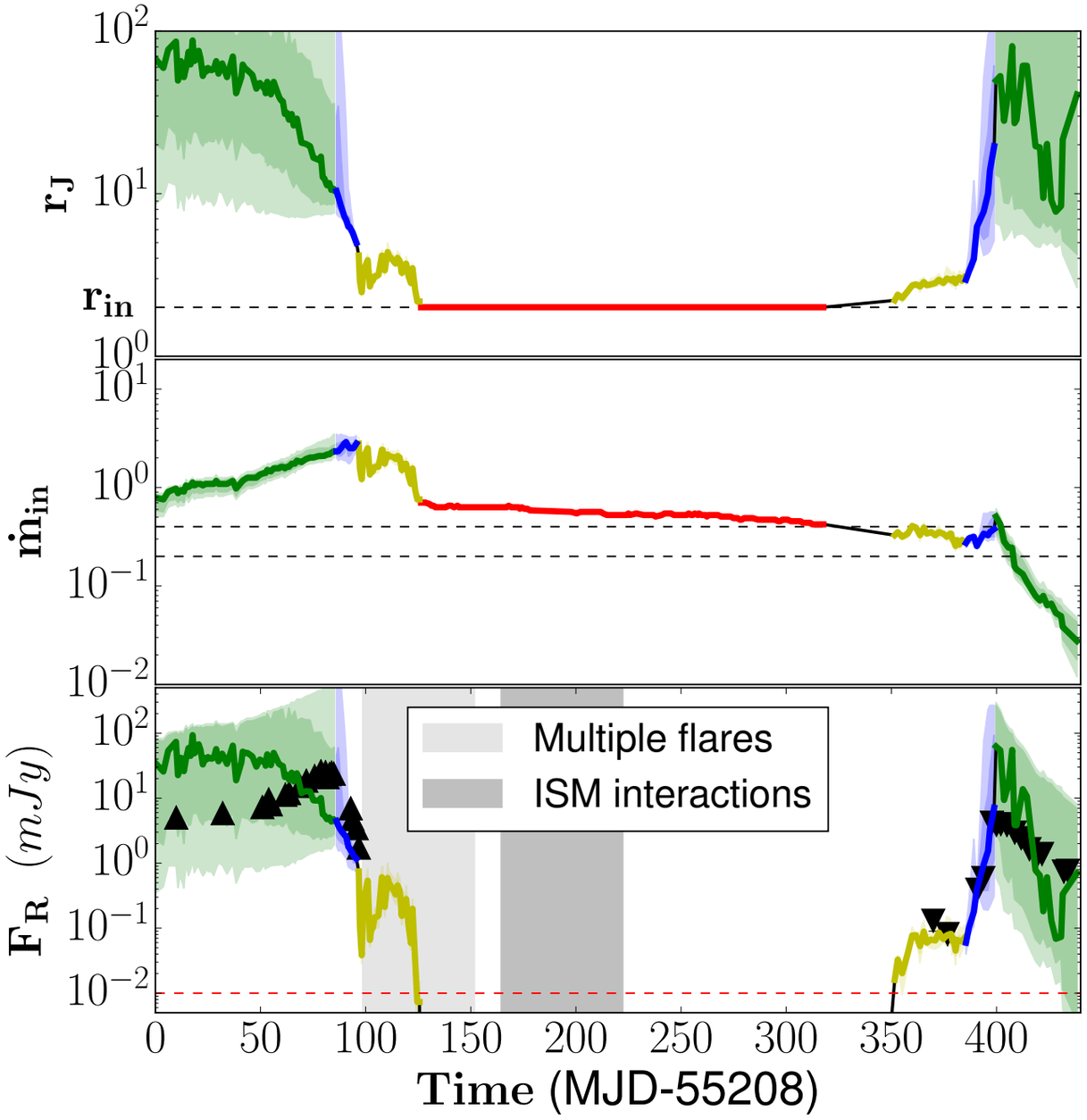


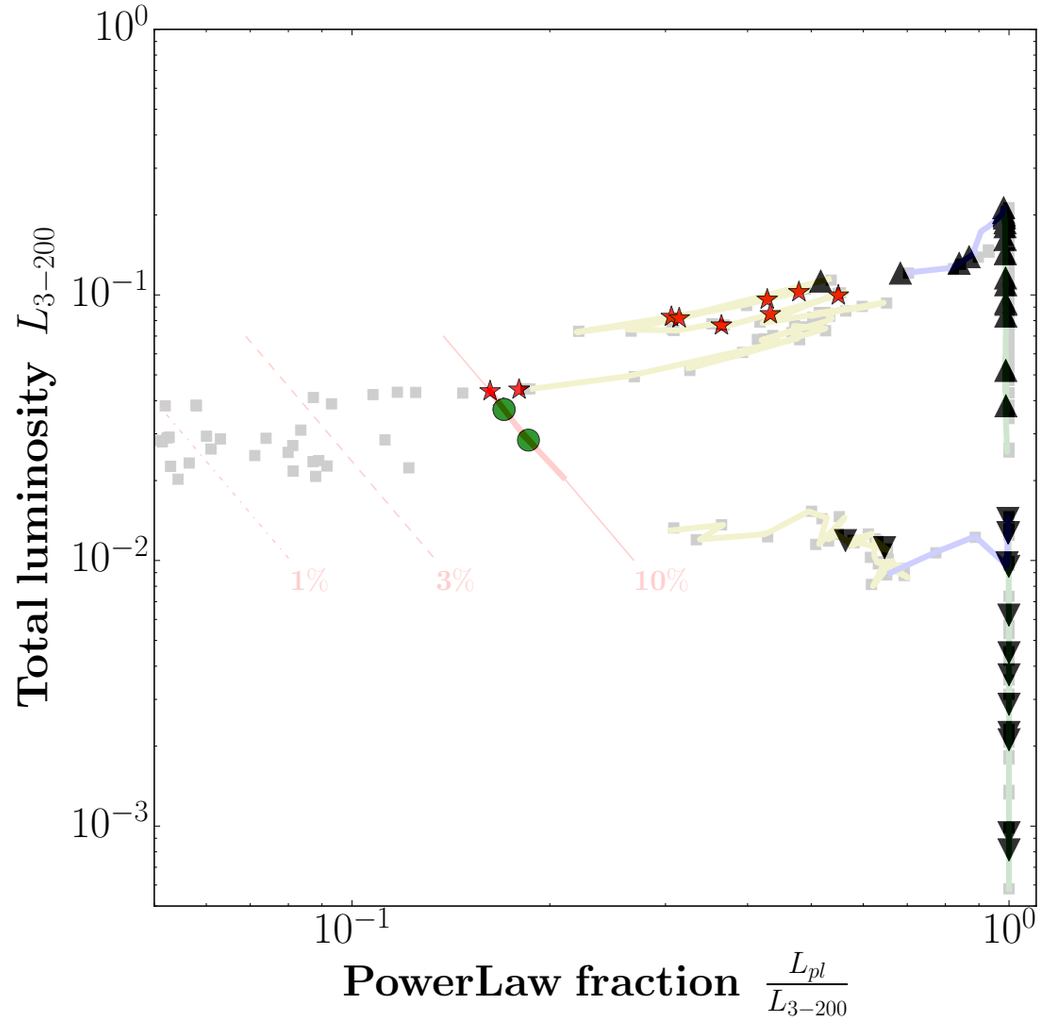


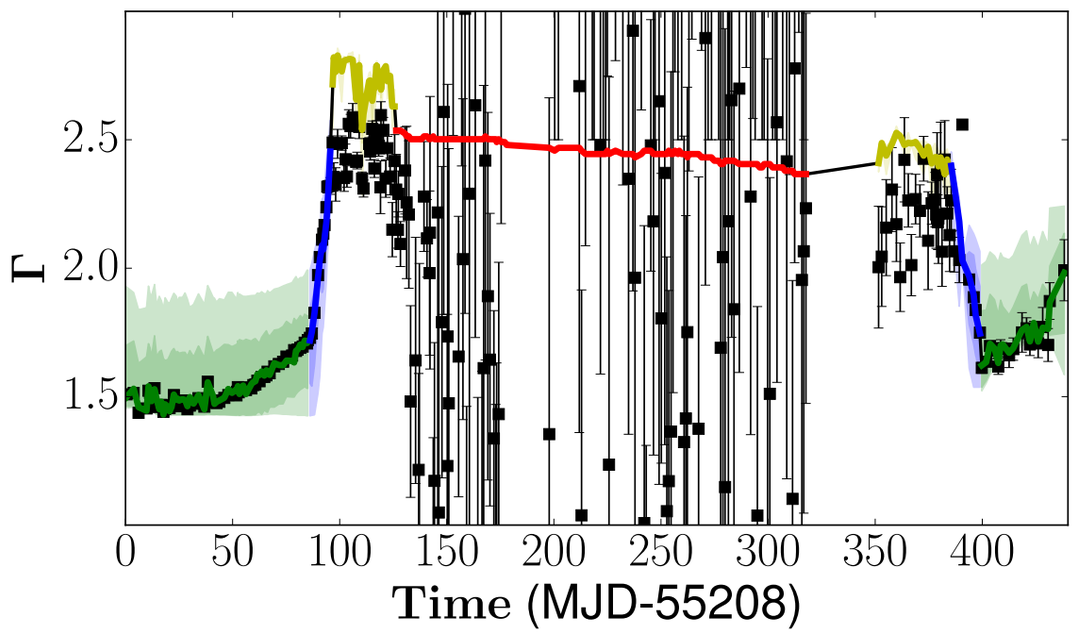
in agreement with in Esin et al. 1996

X-ray fits

Marcel et al. tbs to A&A







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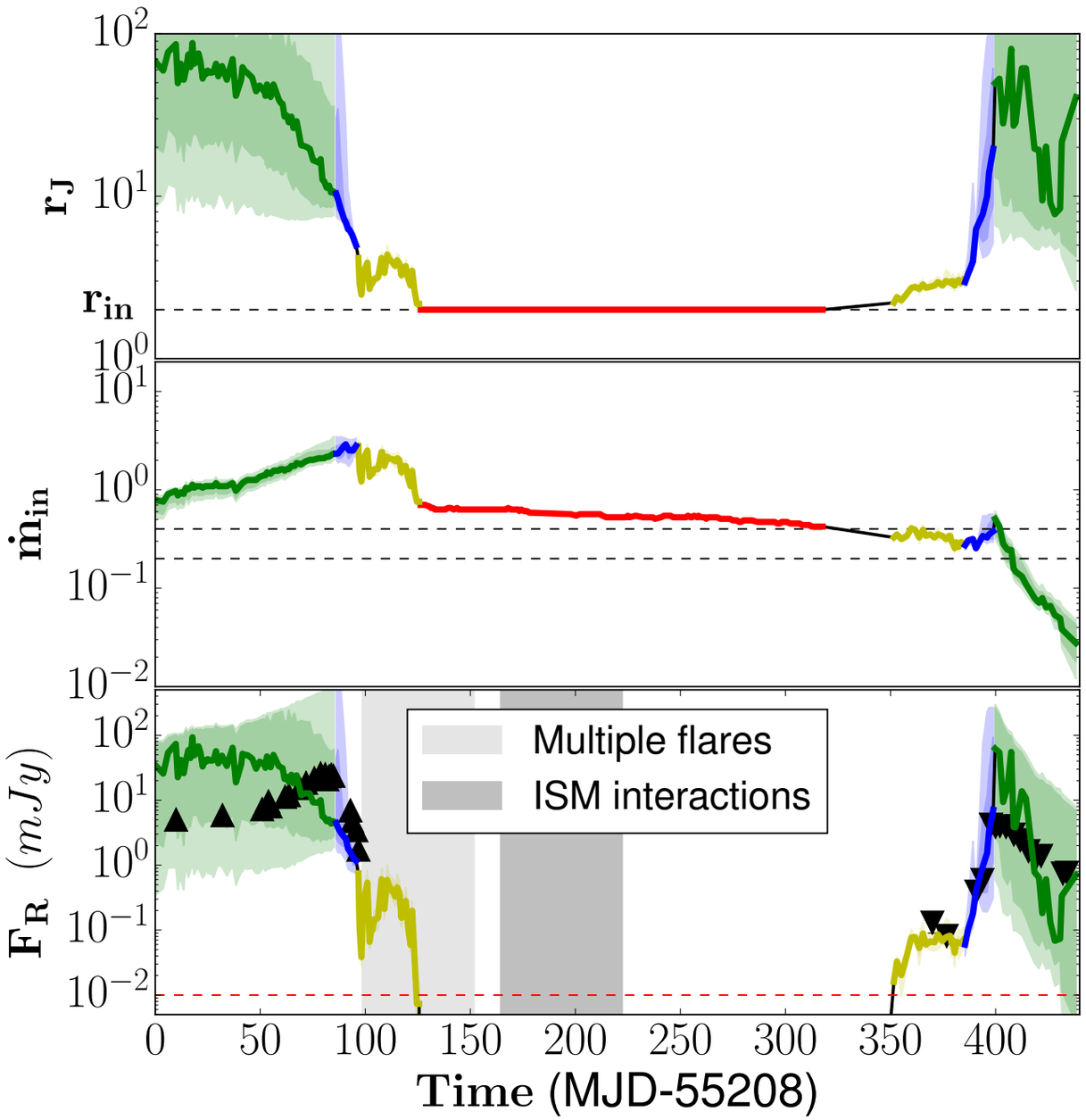
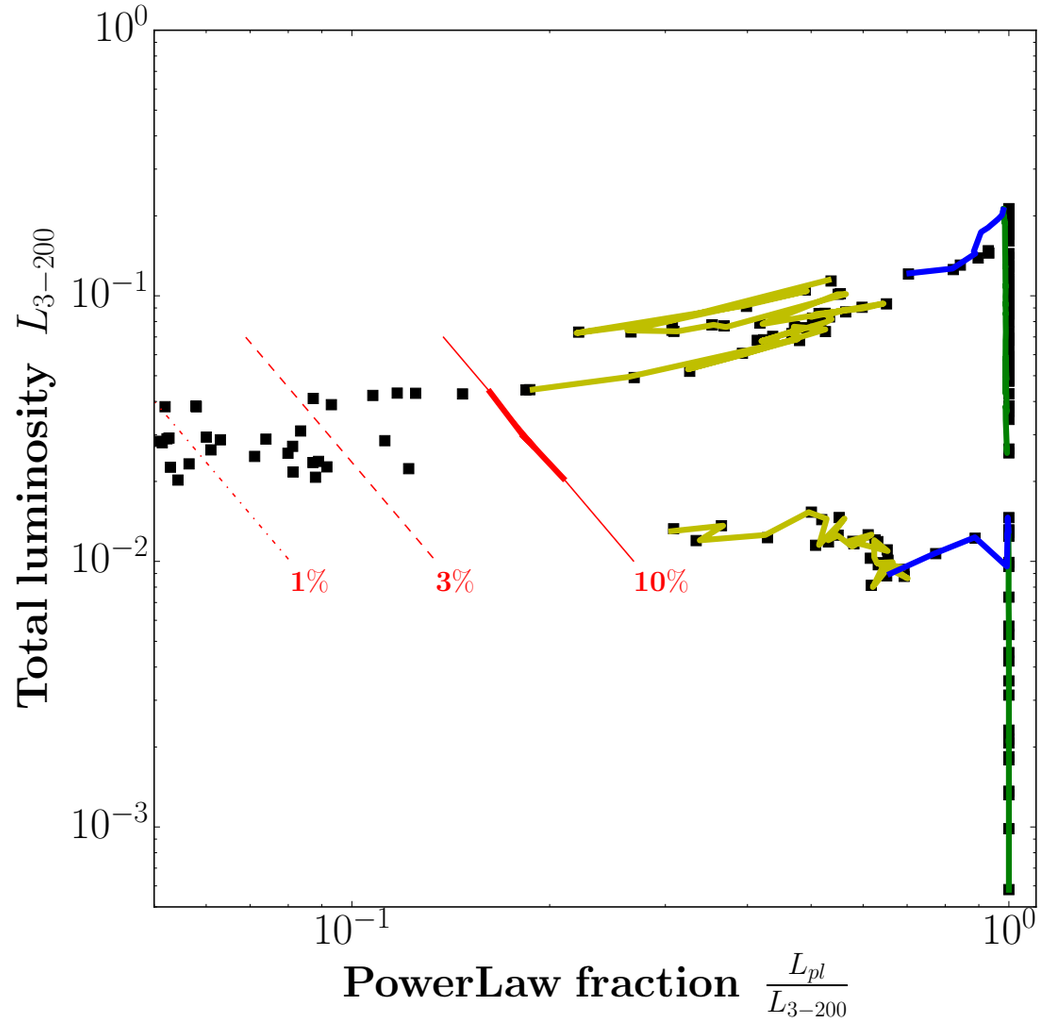
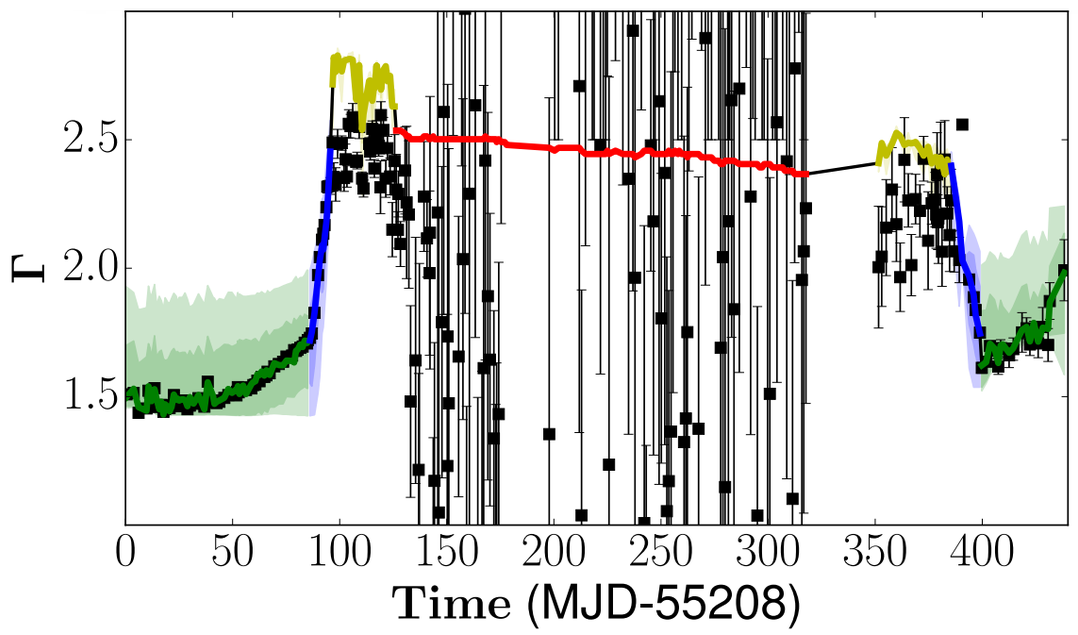
Marcel et al. tbs to A&A

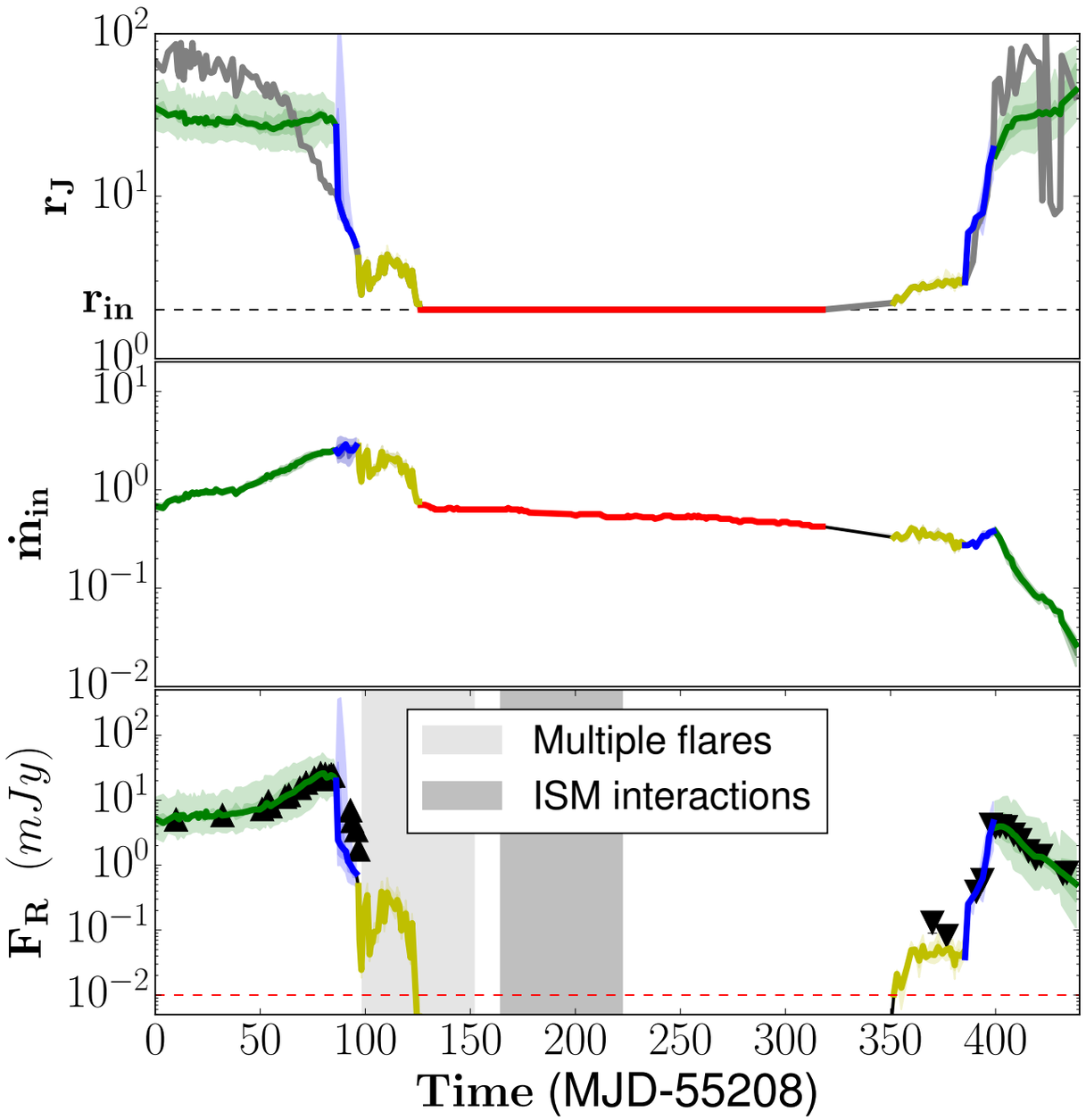


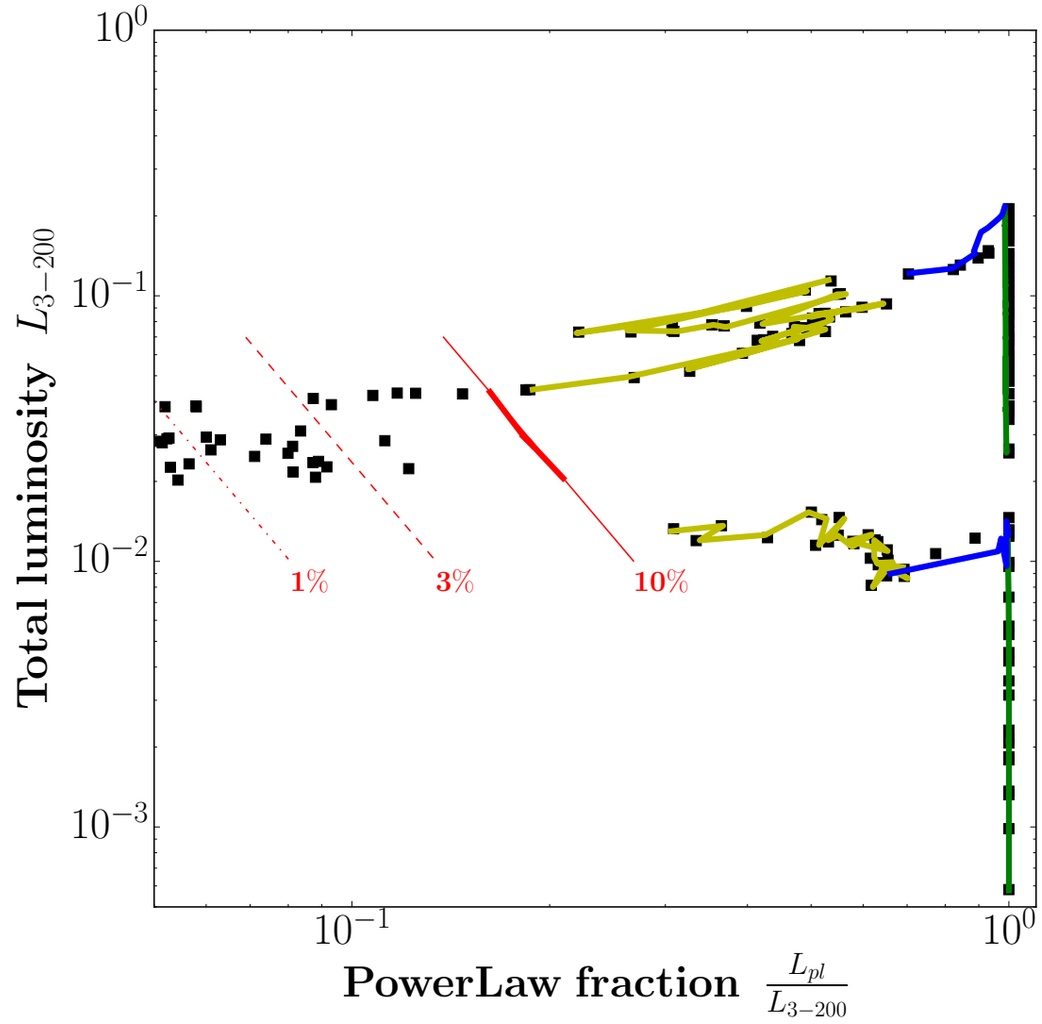


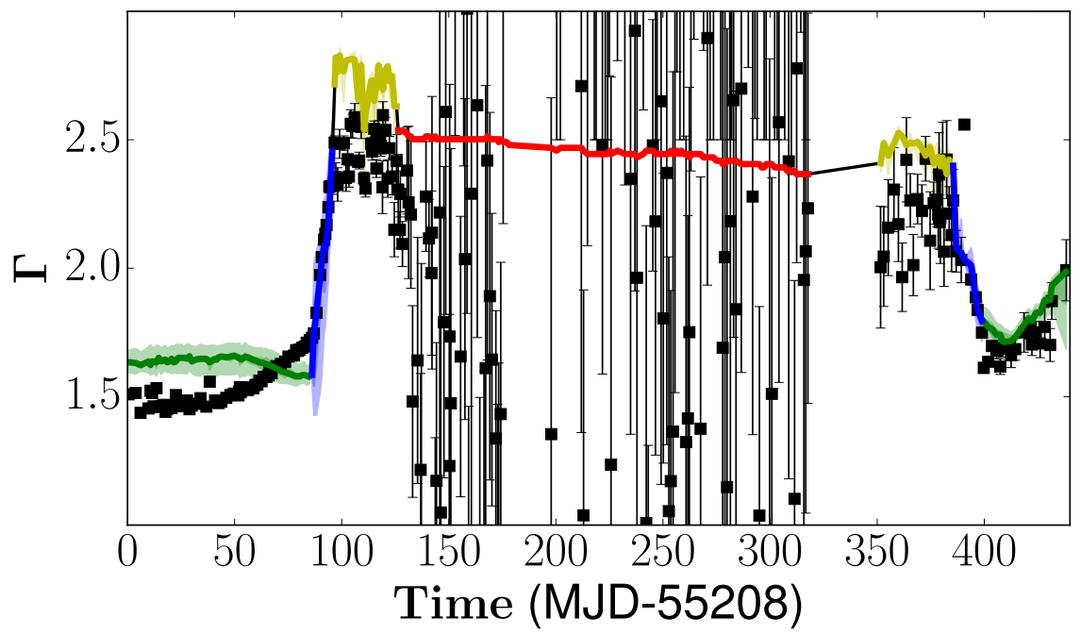


X-ray+Radio fits

Marcel et al. tbs to A&A

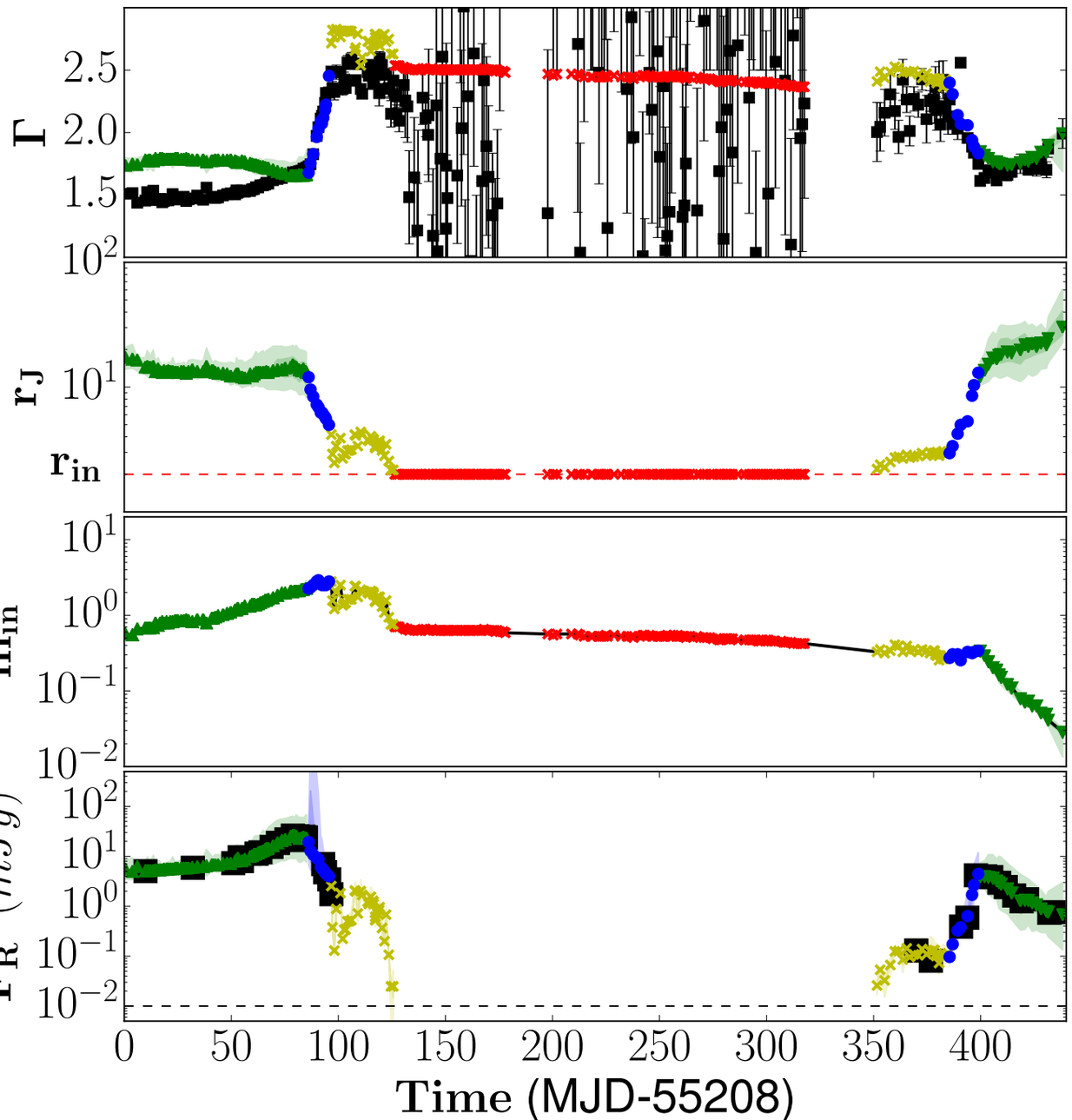


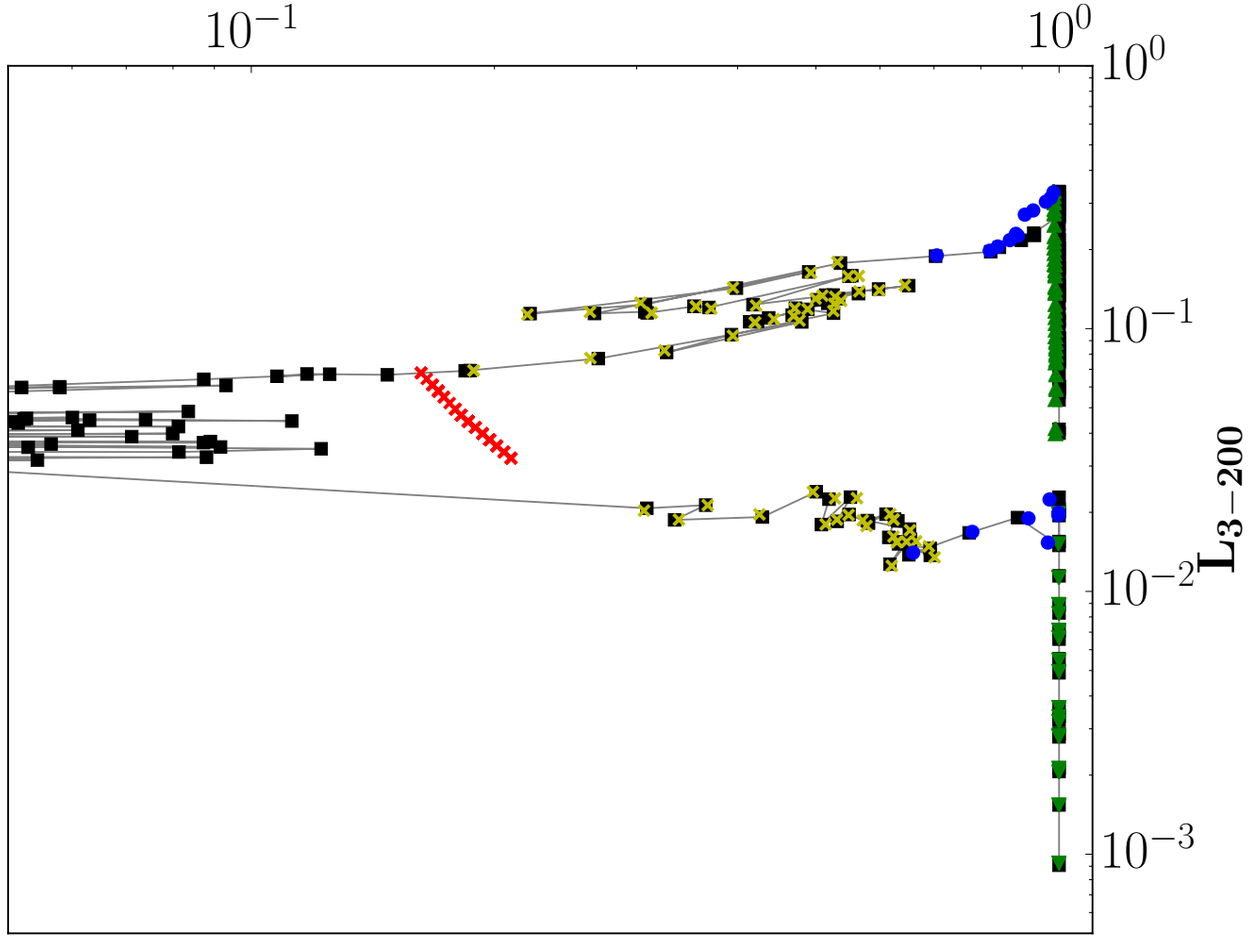




Final results

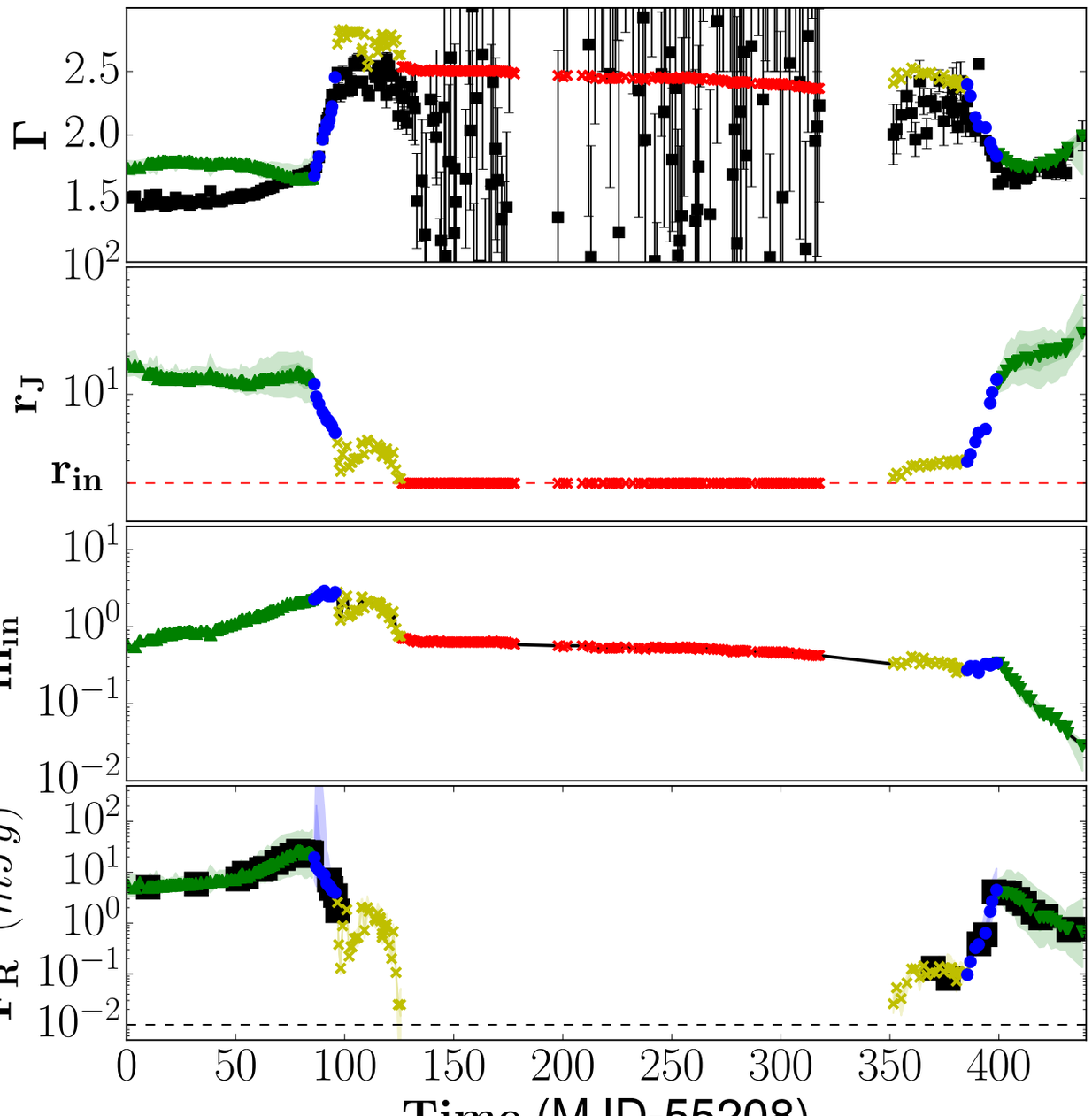
Marcel et al. tbs to A&A

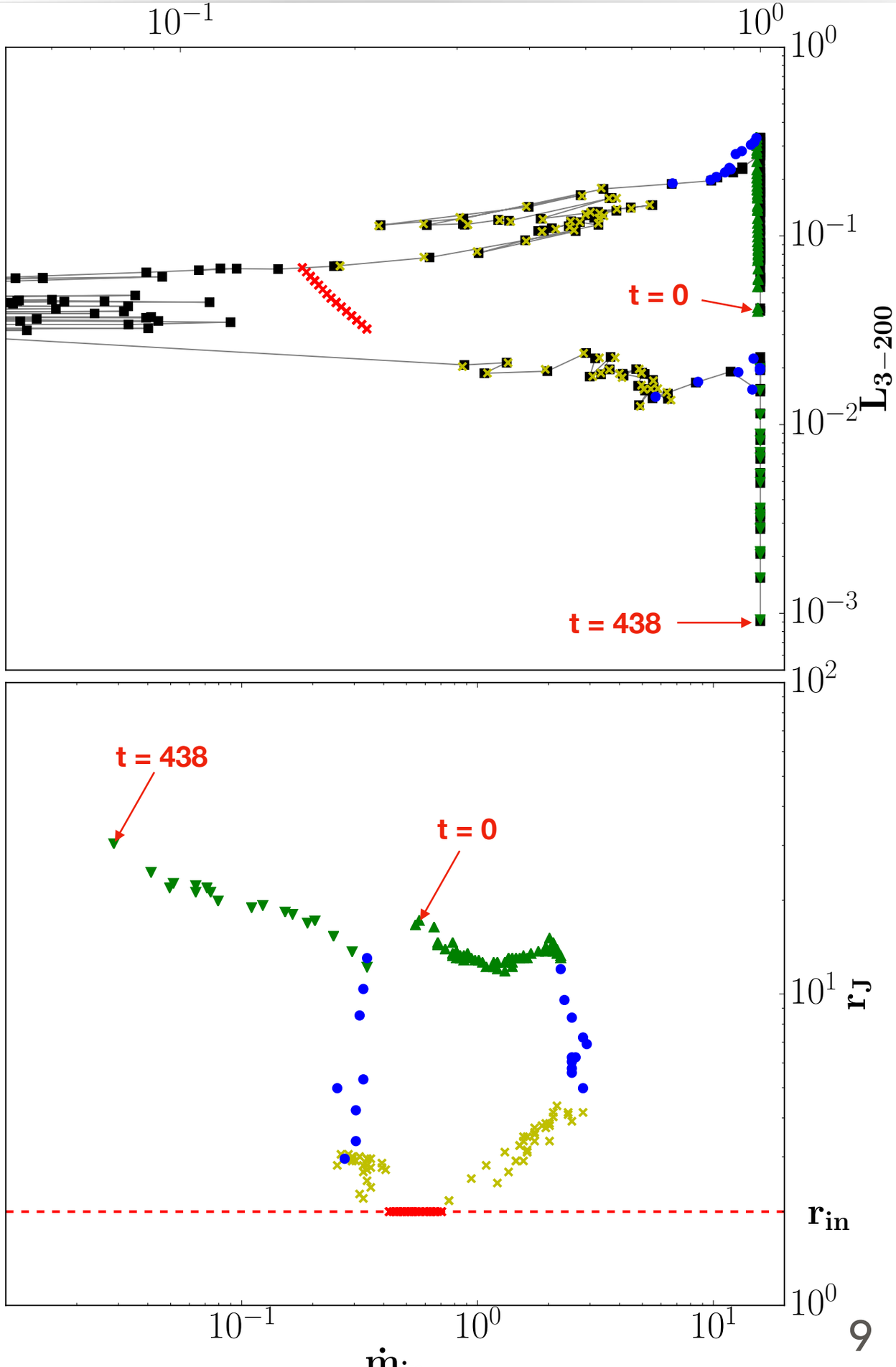




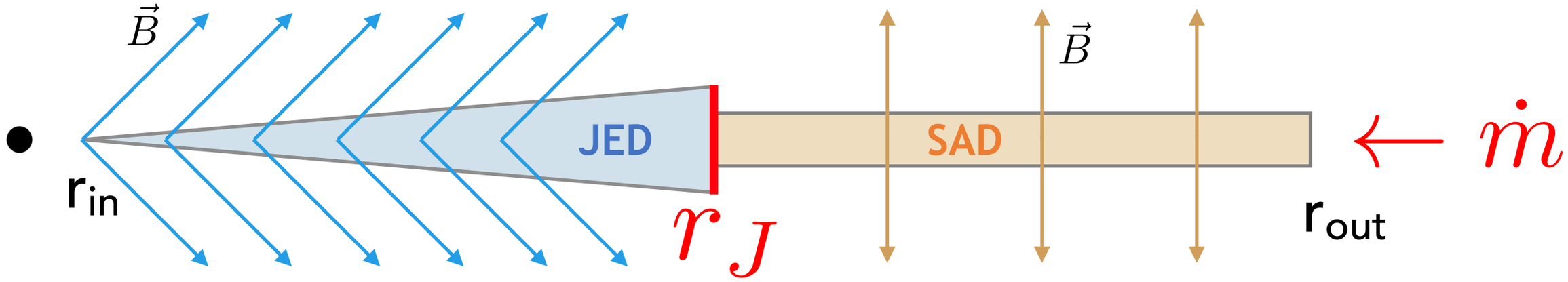
Final results

Marcel et al. tbs to A&A





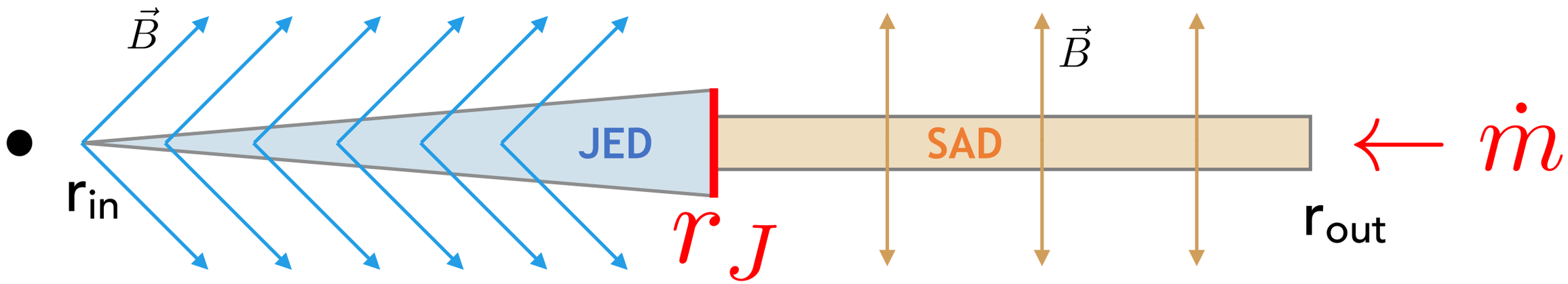
Summary and perspectives



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

(1) Reproducing hard states at high luminosities L > 0.1 L_{Edd}?
(2) Cycle?
(3) Spectral state transitions?
(4) Dynamical state transitions? Jet lines?
(5) Why should those 2 transitions be related?

Summary and perspectives



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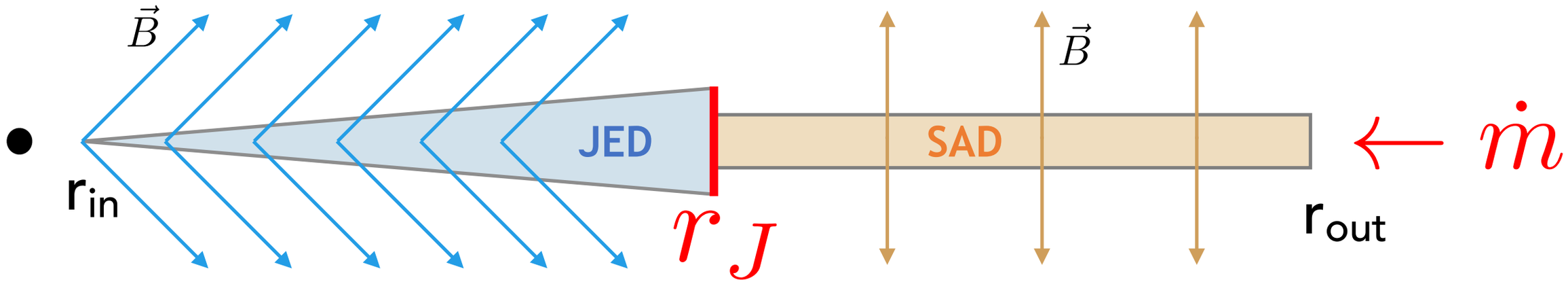
Summary and perspectives



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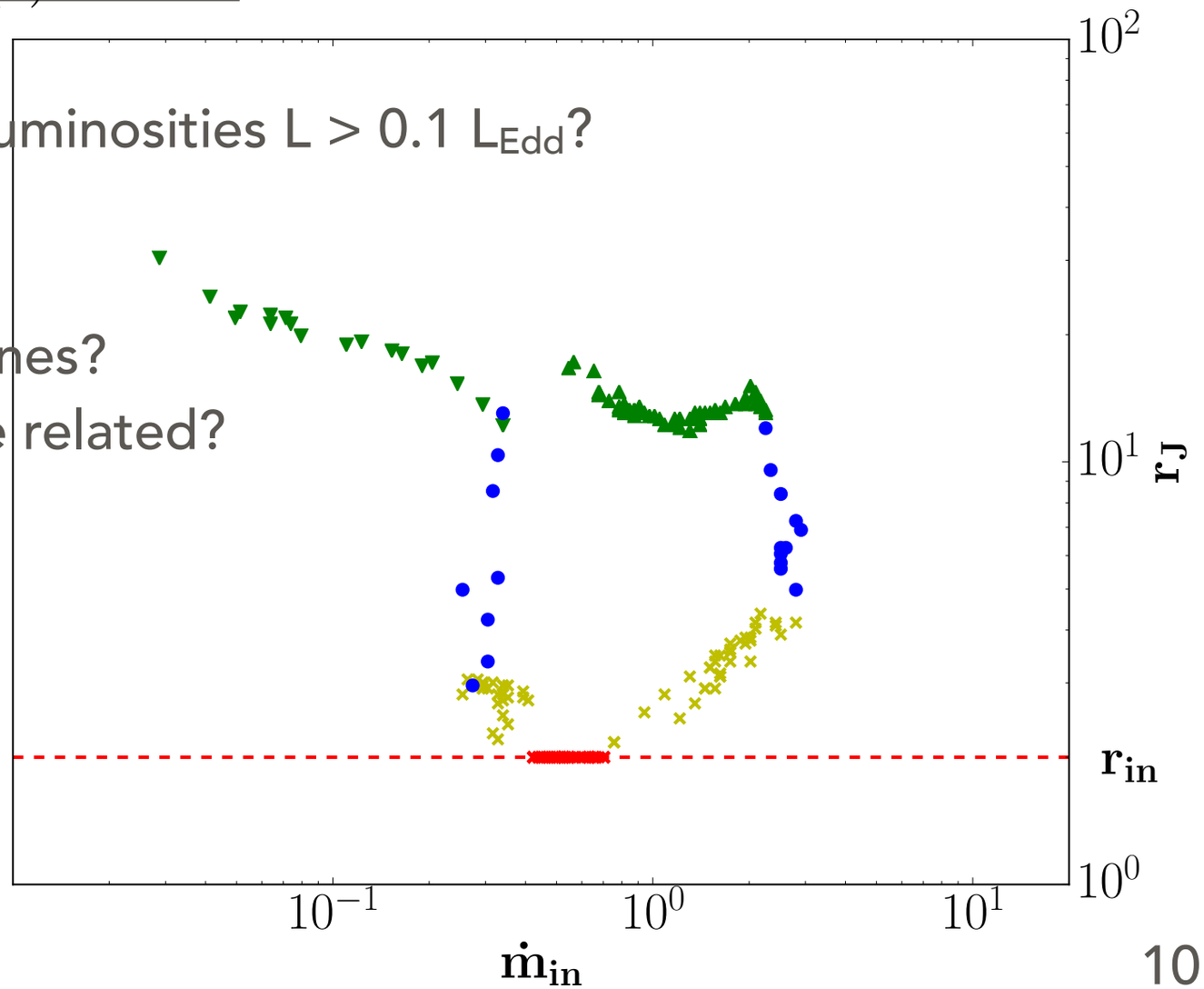
Work in progress?

- Dynamical evolution?
- Other cycles/objects?



Work in progress