Testing the disk-corona interplay in broad-line AGN

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MAX-PLANCK-GESELLSCHAFT

MPE

X-RAY ASTRONOMY 2019
Current Challenges and New Frontiers in the Next Decade

12.09.2019

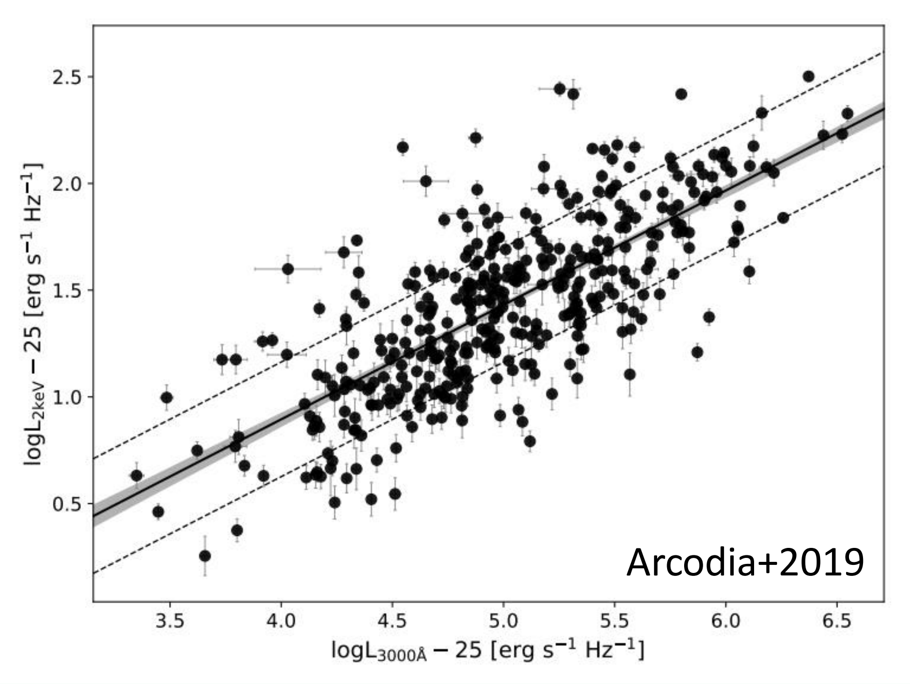
Outline

- The smoking gun: the $L_X - L_{UV}$
- The **disk-corona model**
- The methodology: an **observational test**
- Results & Conclusions

The smoking gun of the Disk-Corona interplay

Relation between the **Disk** and the **Corona**

L_X

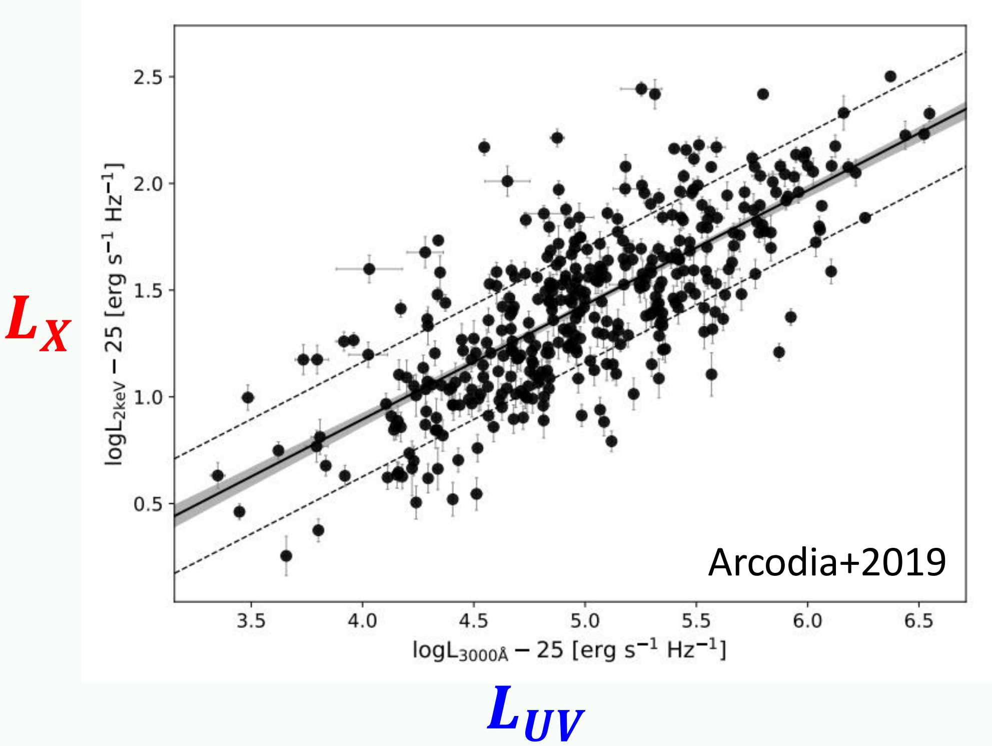


L_{UV}

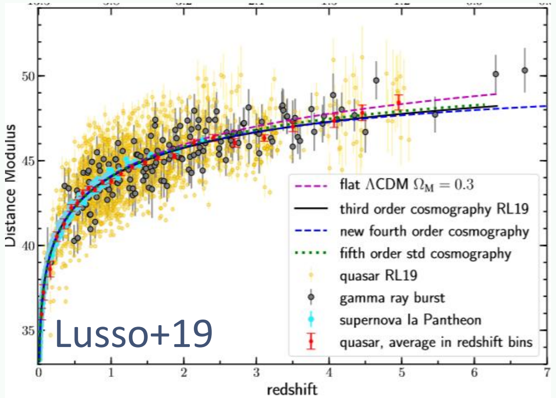
- Known for ~ 40 yrs, mostly as α_{OX} (Tananbaum+79 and many others)

The smoking gun of the Disk-Corona interplay

Relation between the **Disk** and the **Corona**

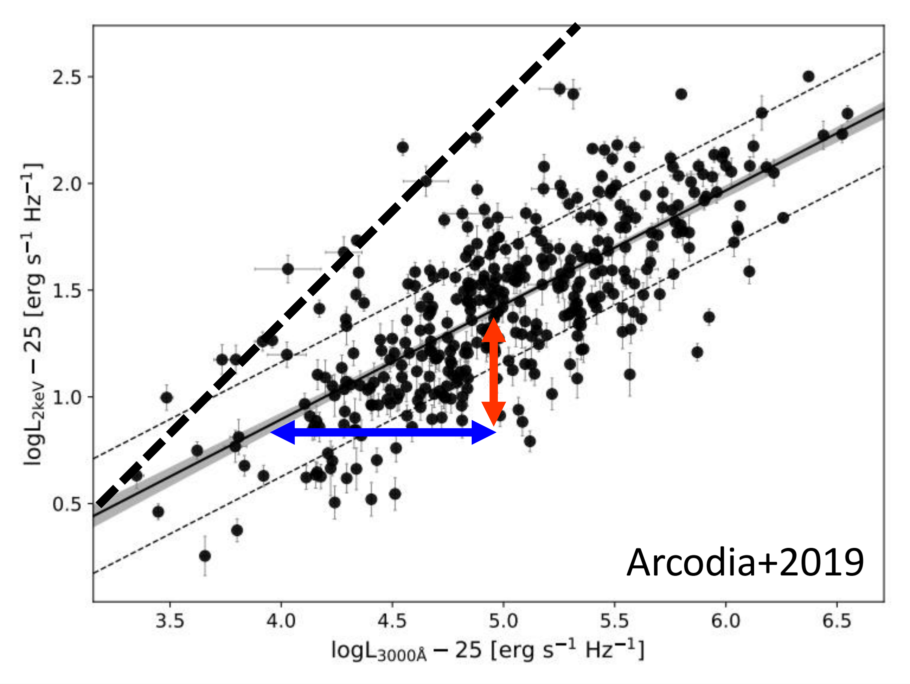


- Known for ~ 40 yrs, mostly as $\boldsymbol{\alpha_{OX}}$ (Tananbaum+79 and many others)
- Used for **many** applications: CXRB, XLF, L_{BOL}, SEDs… (e.g. Marconi+04, Hopkins+07, Lusso+10)
  even for cosmology (e.g. Risaliti & Lusso 15, 18)
- But no conclusive physical explanation yet
  (but see Lusso & Risaliti 17, Kubota & Done 18)



The smoking gun of the Disk-Corona interplay

L_X

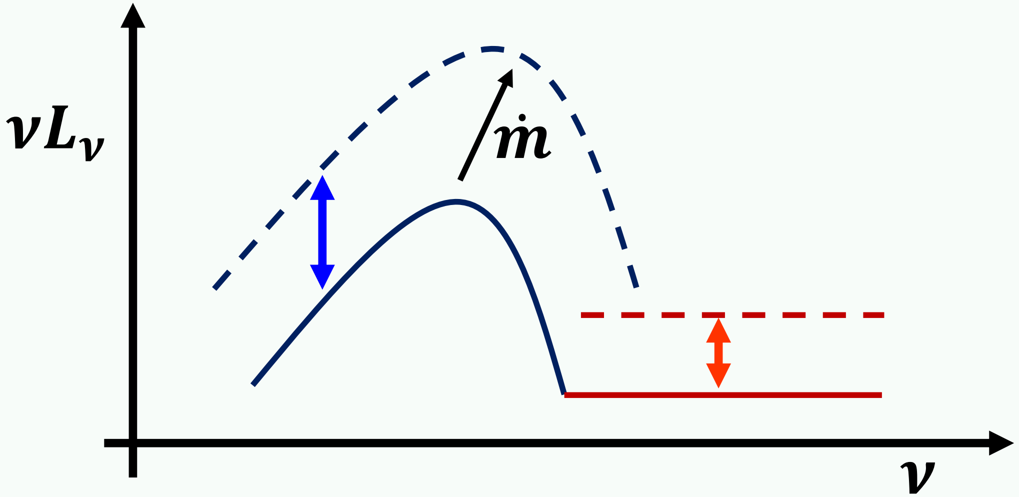


L_{UV}

Slope ≈ 0.65

$\sigma_{phys} \lesssim 0.2$ dex

Lusso & Risaliti 16
Chiaraluce+ 18



The emission from the **Corona** <u>increases less</u> than the **Disk** emission

→ Some mechanism regulates their energetic connection

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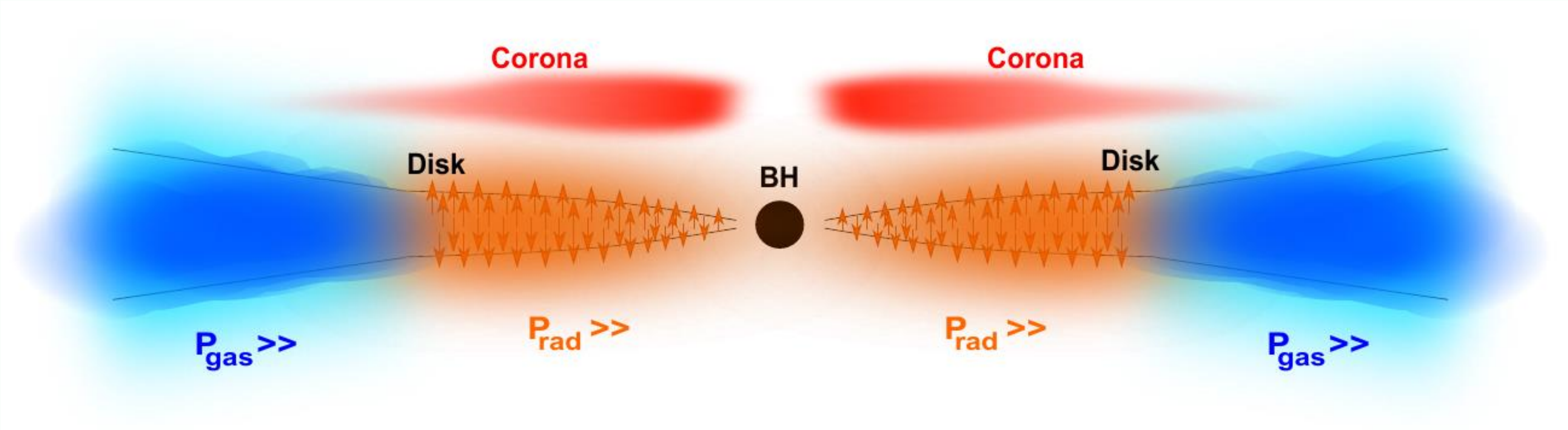
The disk-corona model



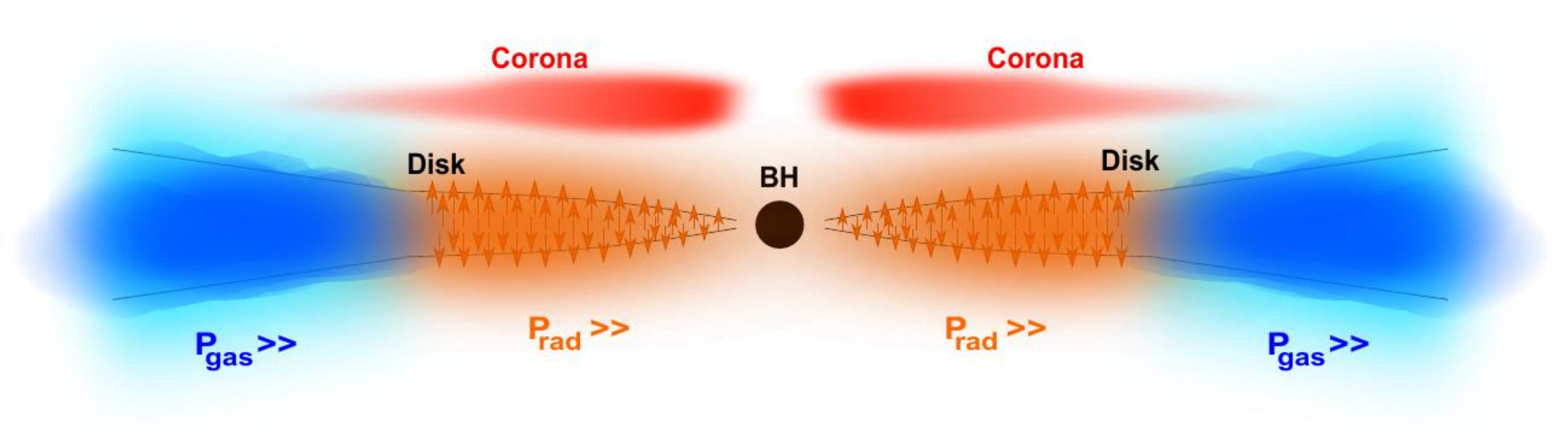
AGN in a sweet spot of accretion
$\dot{m} \approx$ **(0.0x – 1)**

- Prescriptions from the standard accretion theory (Shakura&Sunyaev73, Pringle81)
- Modified with:

→ Generalised **viscosity law:** $\tau_{r\varphi} \propto P_{gas}^{\mu} P_{tot}^{1-\mu}$

$\mu =$ **DISK ACCRETION PRESCRIPTION**

The disk-corona model



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$\mu =$ **DISK ACCRETION PRESCRIPTION**

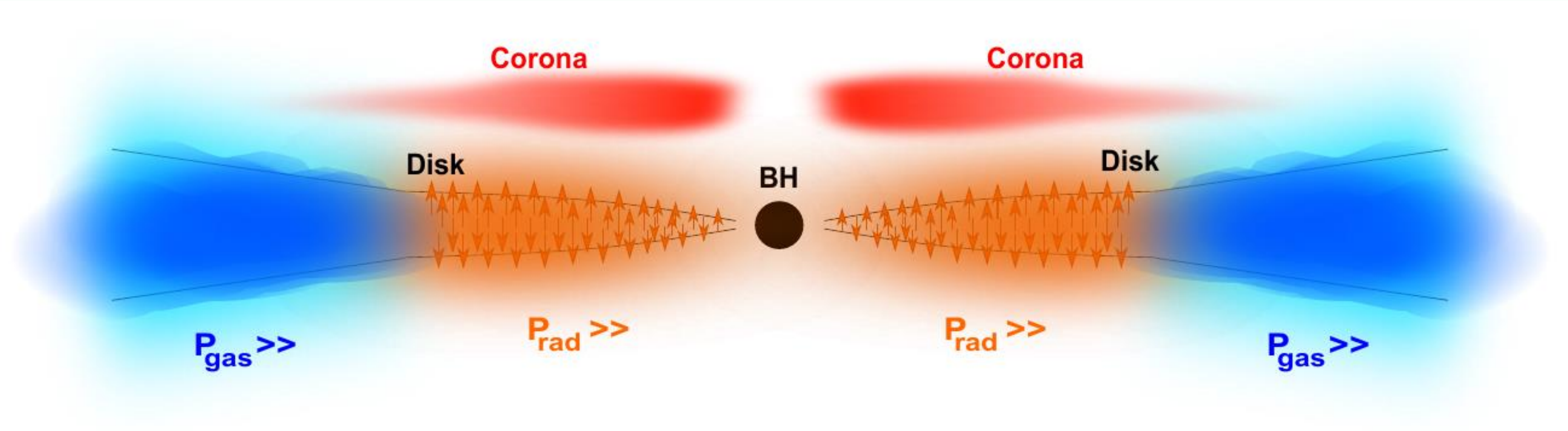
→ **X-ray corona**: $f = \frac{Q_{cor}}{Q_{accr}} = f_{max} \left(1 + \frac{P_{rad}}{P_{gas}}\right)^{-\mu/2}$

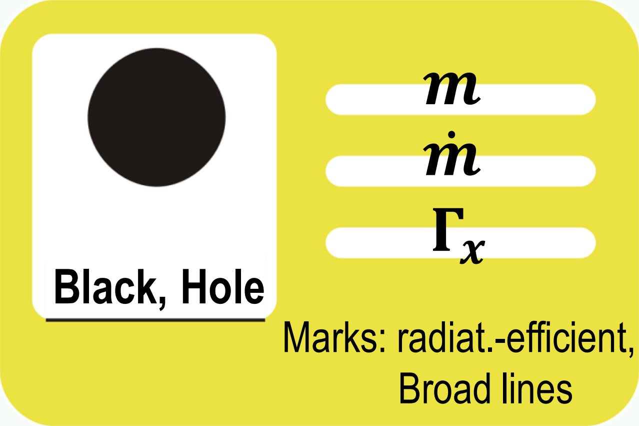
(Haardt & Maraschi 91,93)
(Svensson & Zdziarski 94)

(Merloni & Fabian 02; Merloni 03)

$f_{max} =$ **MAX CORONAL STRENGTH**

The disk-corona model





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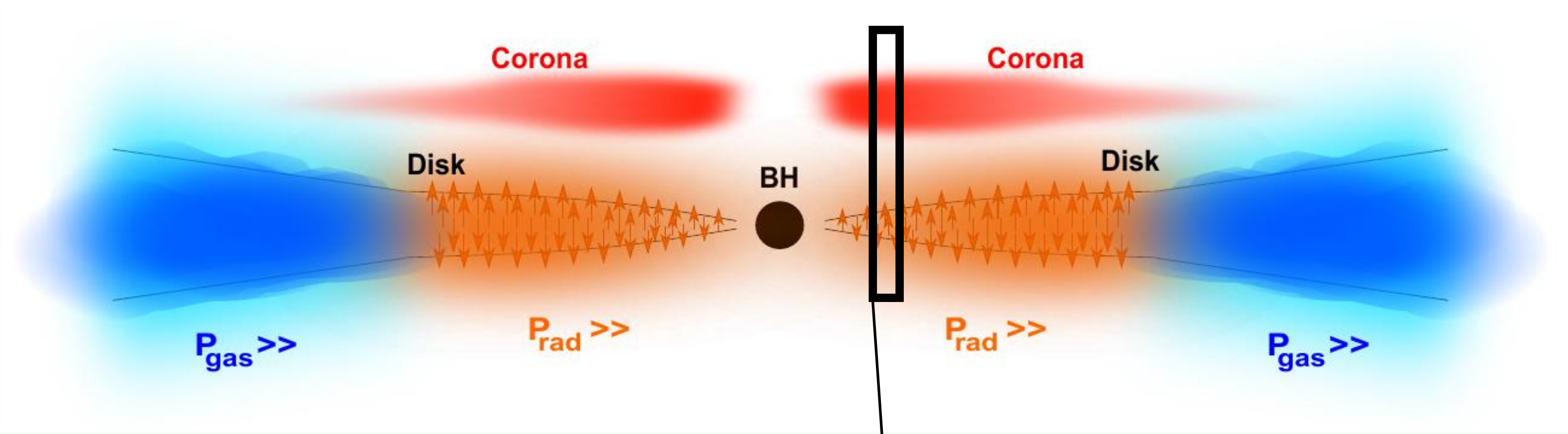

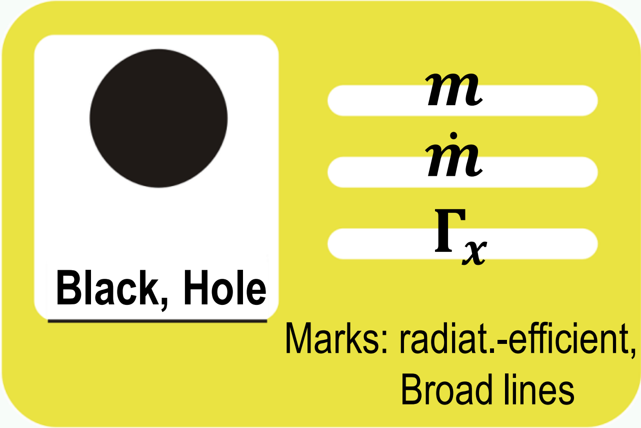

→

Radial profiles:
P, ρ, T, h, f

→

$L_X \propto f Q_{accr}$

L_{UV} multicolor BB

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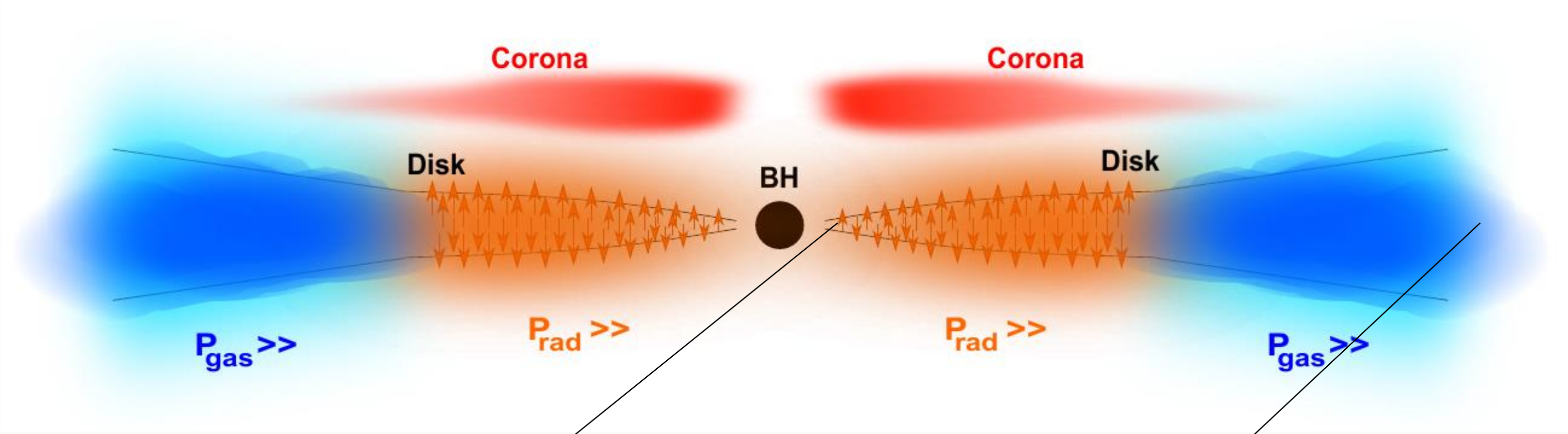
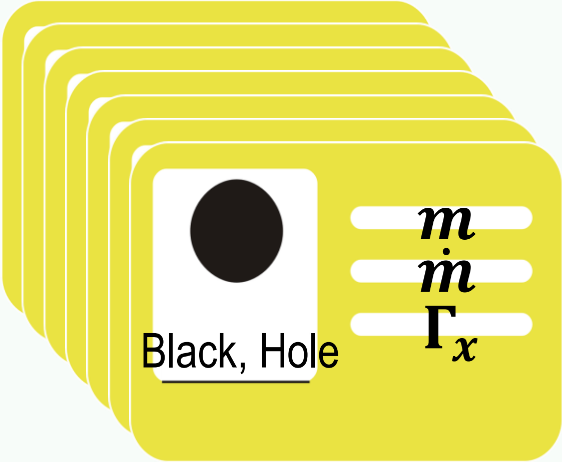
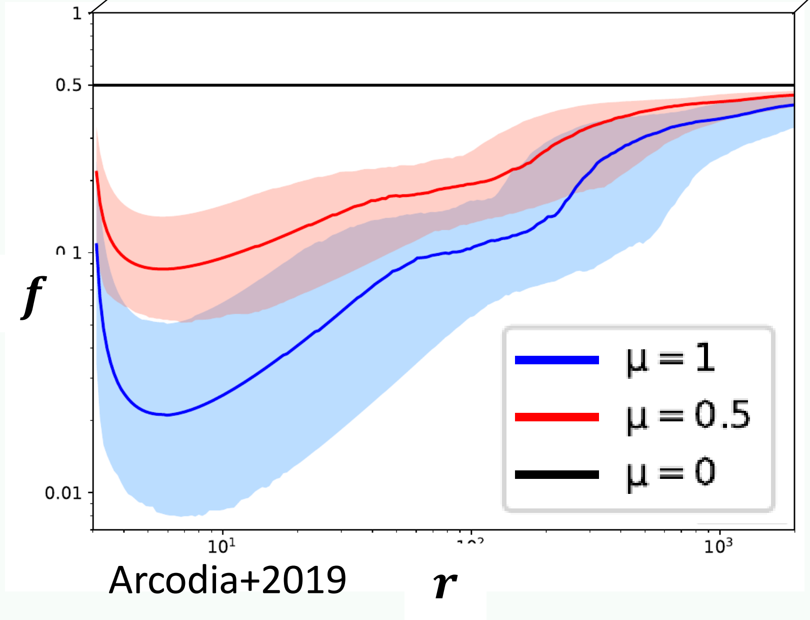
The disk-corona model







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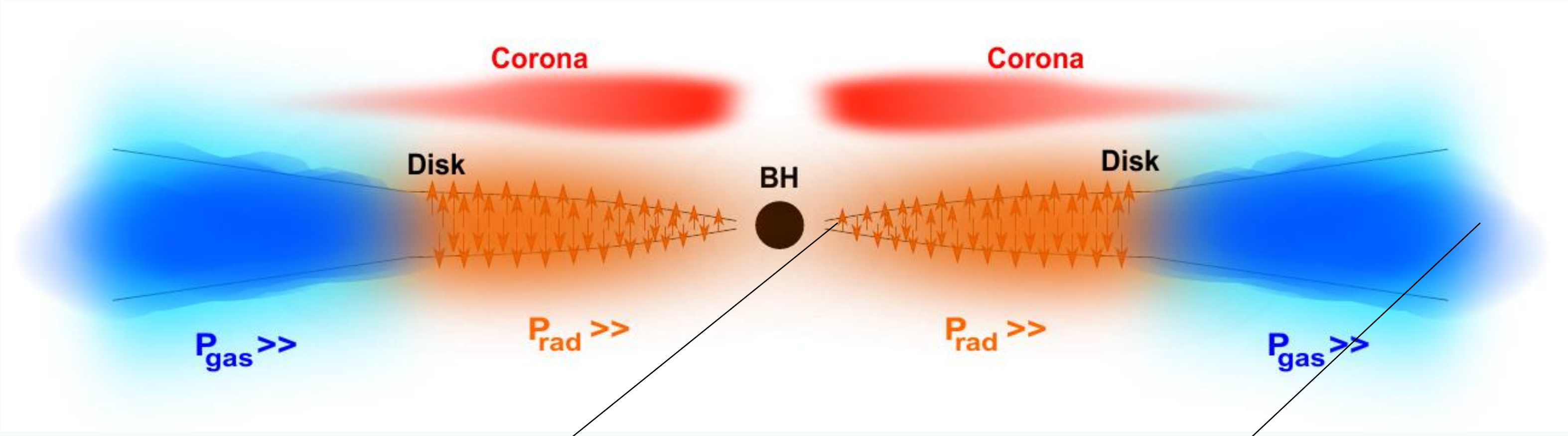

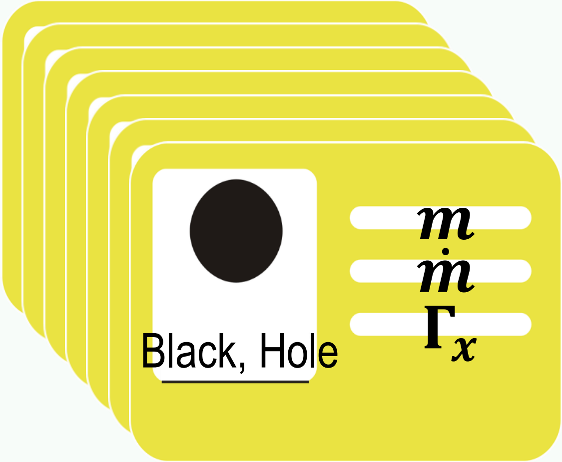

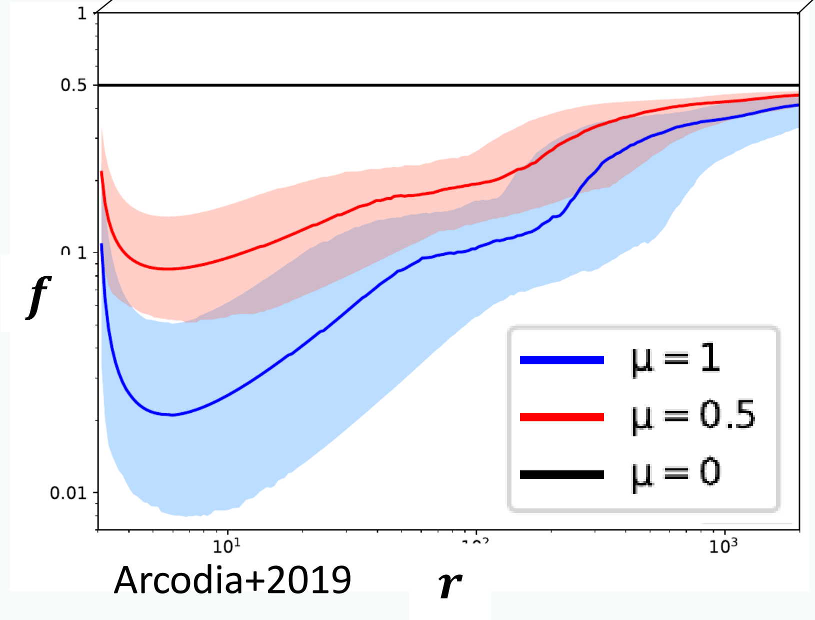

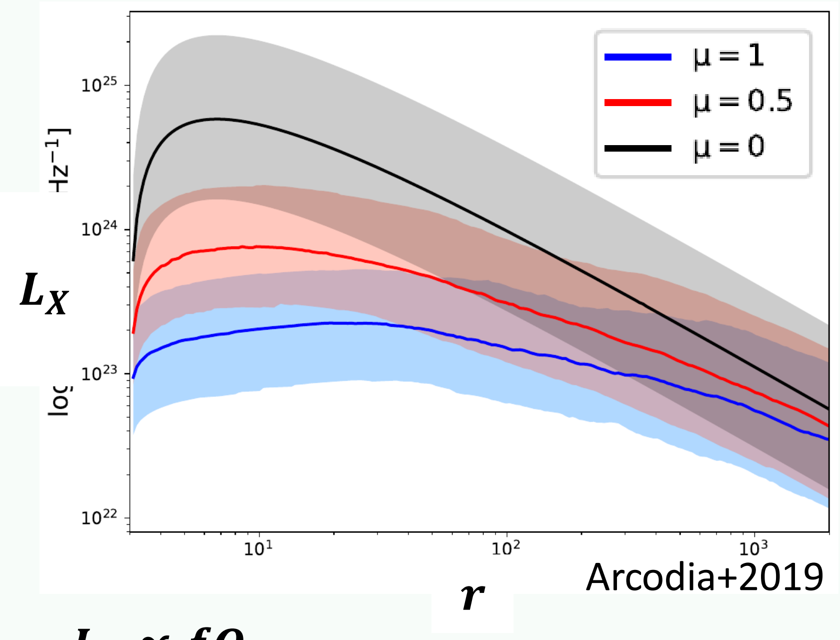

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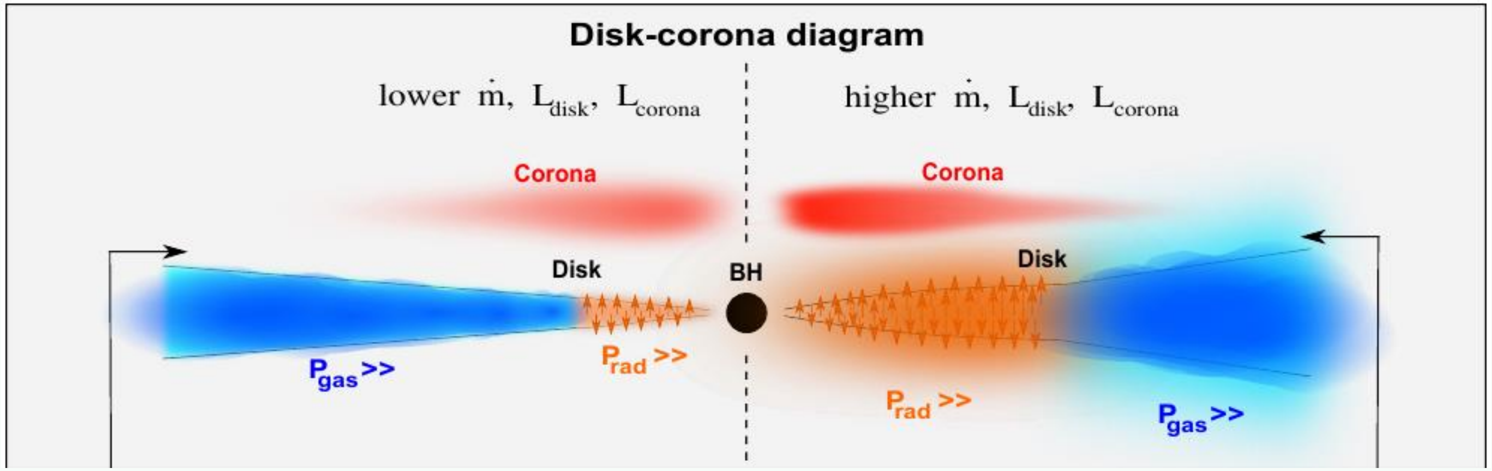
$L_X \propto f Q_{accr}$

Qualitative prediction: $L_X - L_{UV}$ slope < 1



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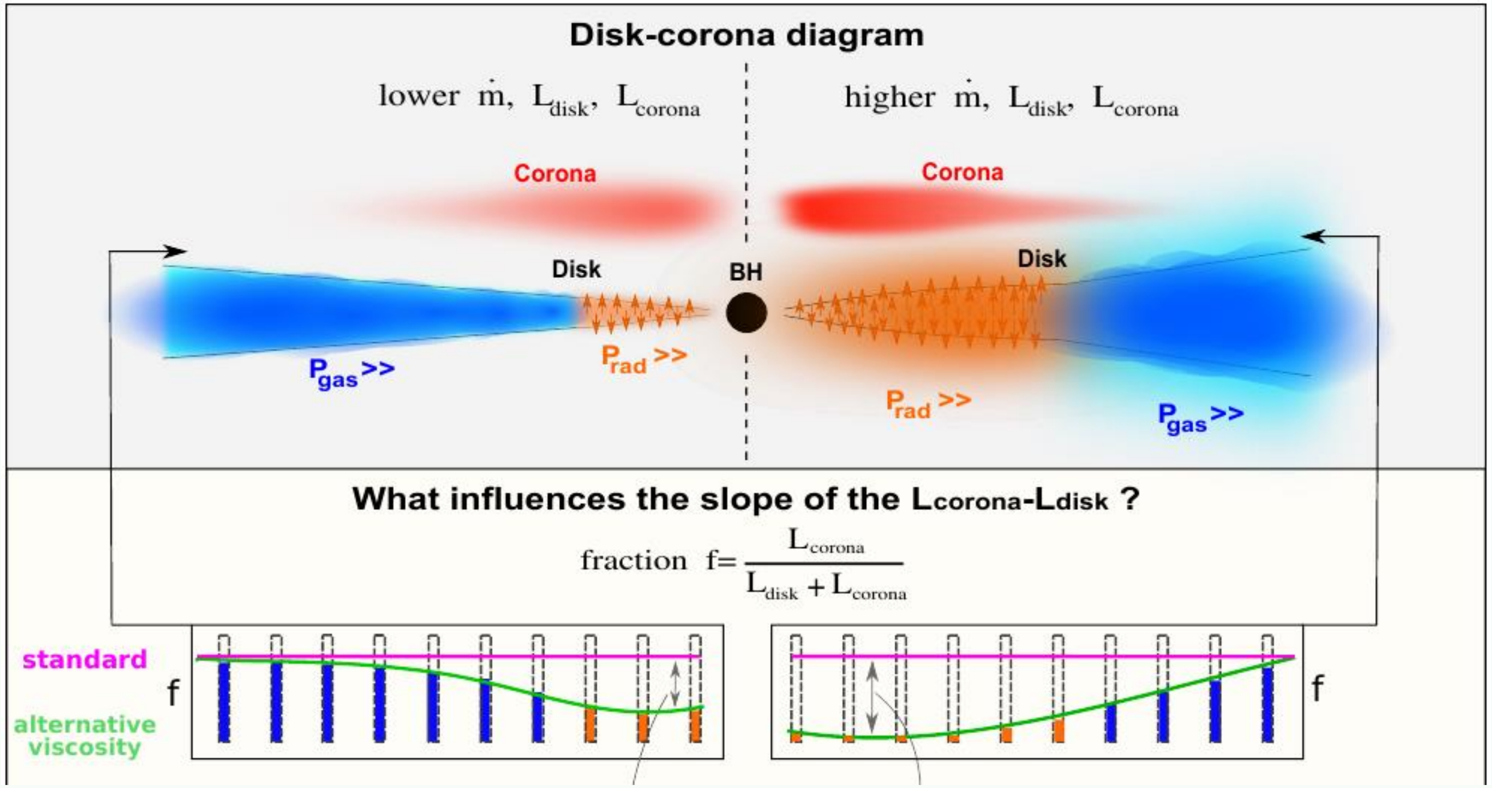
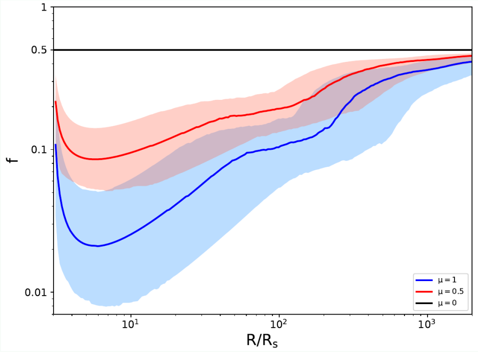
$$f = \boldsymbol{f}_{max}\left(1+\frac{P_{rad}}{P_{gas}}\right)^{-\mu/2}$$





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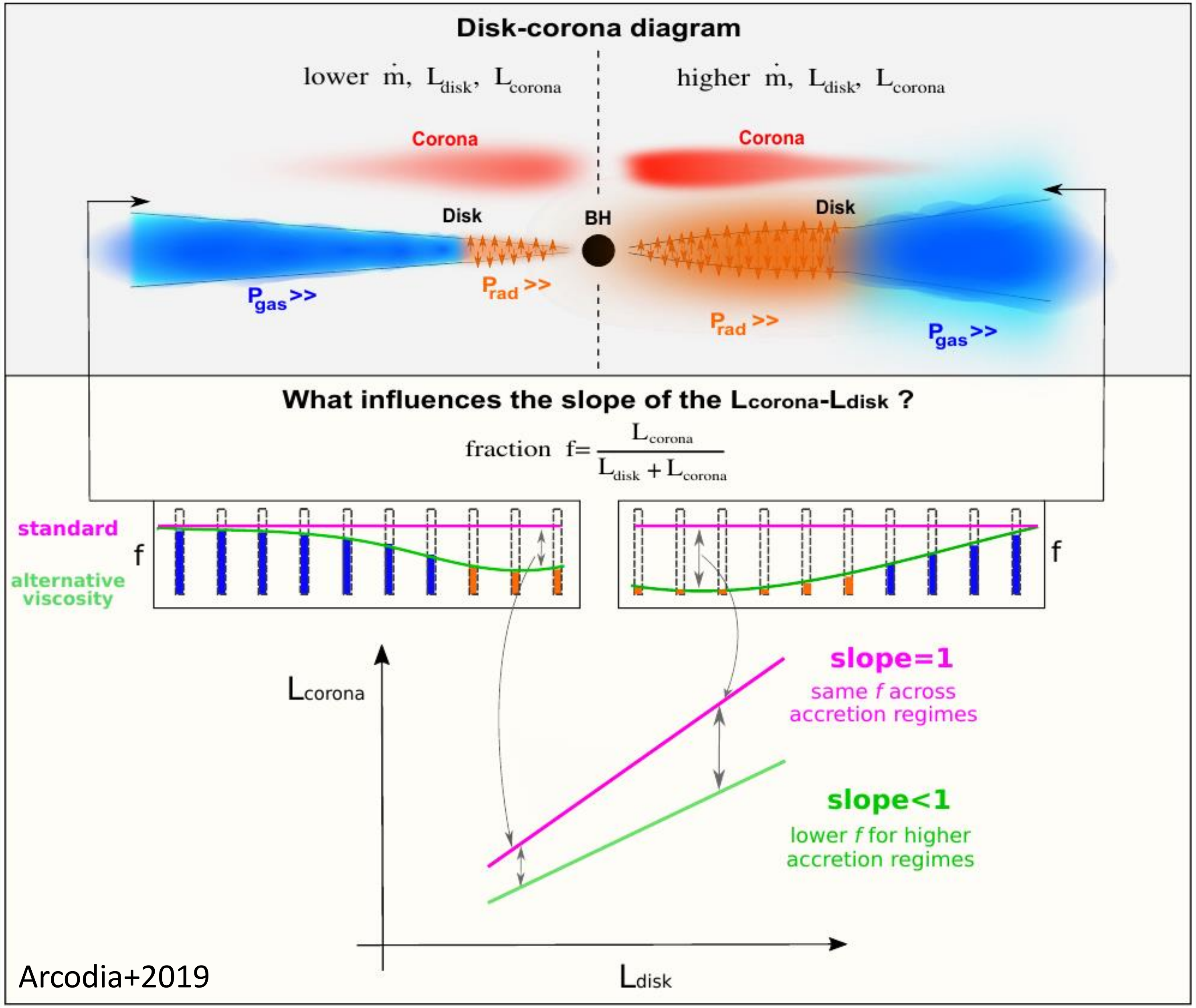

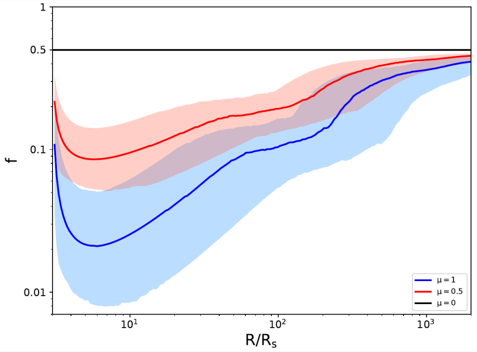

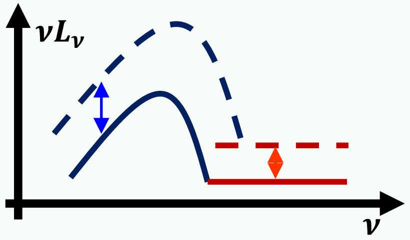

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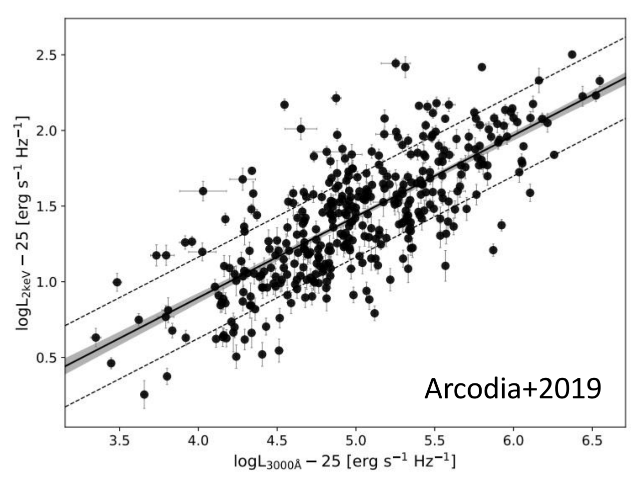
Observational test: methodology

- We built a sample of radiatively-efficient BL AGN
  - Starting from 1787 BL AGN in **XMM-XXL** (Liu+16, Menzel+16)
  - Minimizing contamination from extinction, X-ray absorption, X-ray reflection
  - $N = 379$ (referred to as XMM-XXL)



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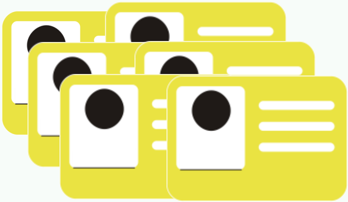

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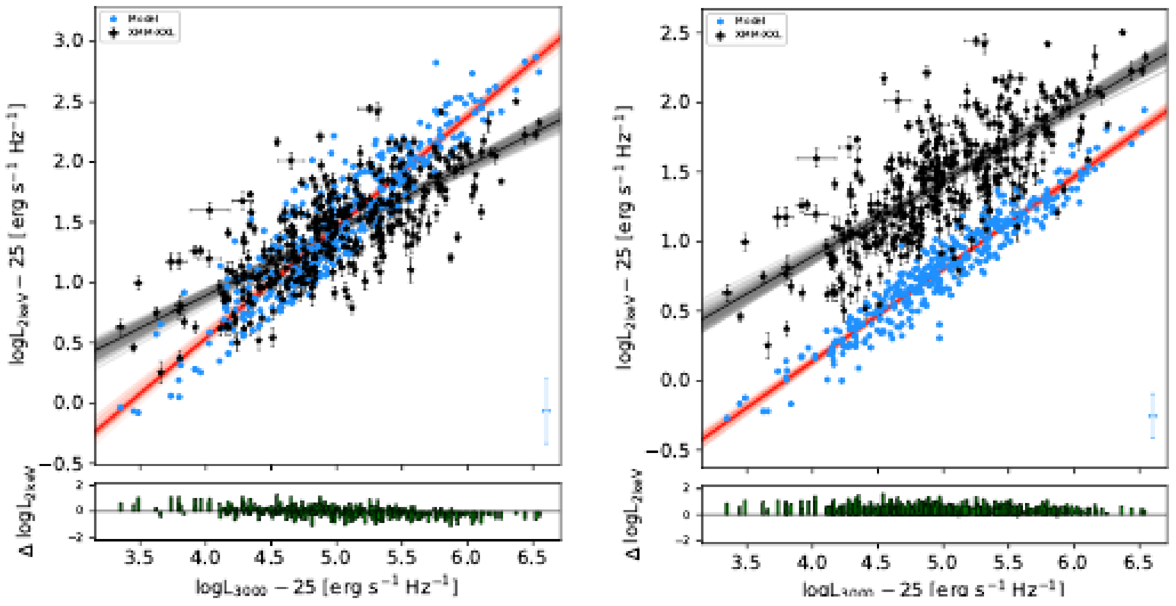
  - $N = 379$ (referred to as XMM-XXL)
- We take all the BH IDs of XMM-XXL ($m, \dot{m},$ …
- Mock $L_X - L_{UV}$ for every μ, f_{max} →



Arcodia+2019

Match in
normalization, slope
and **scatter**

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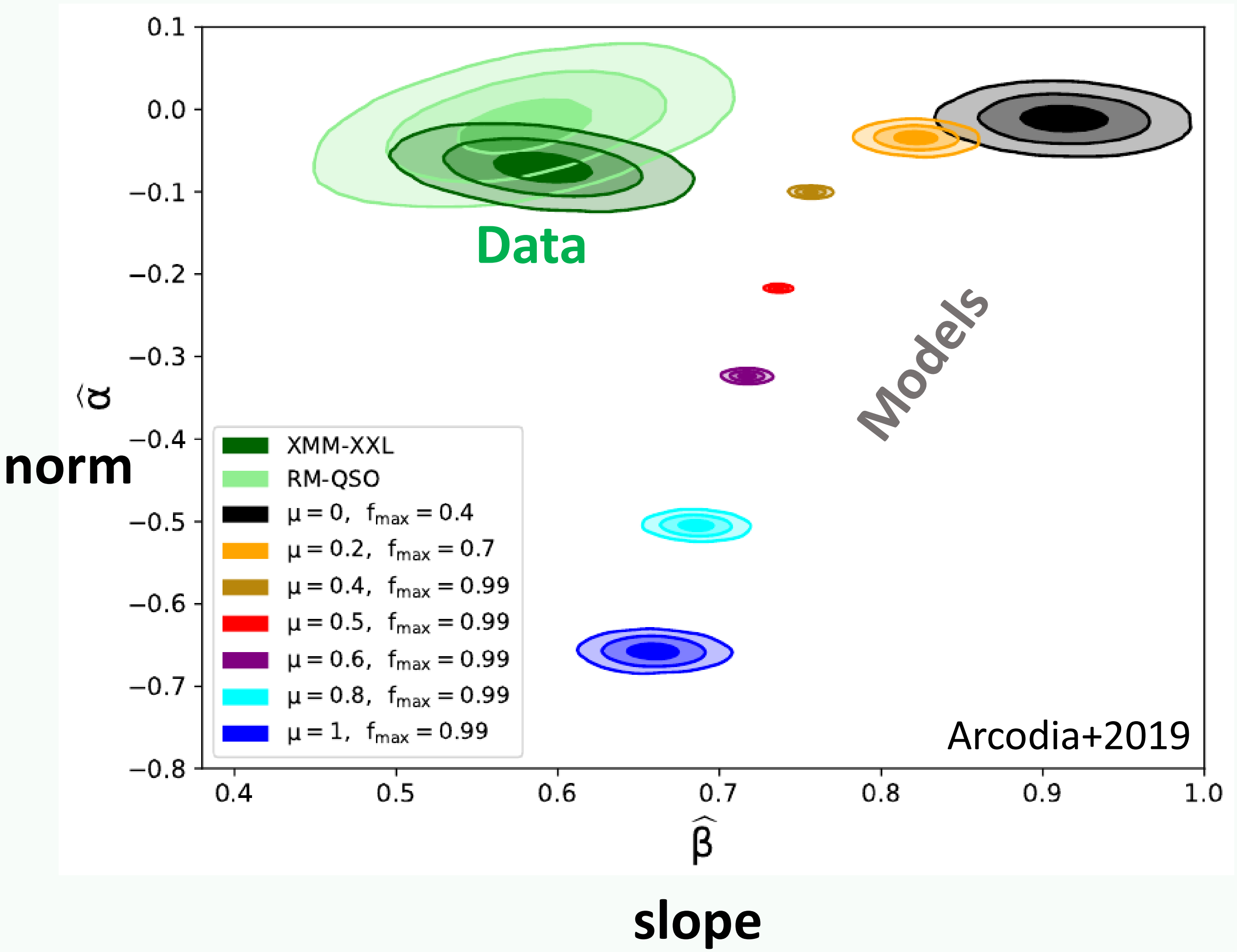
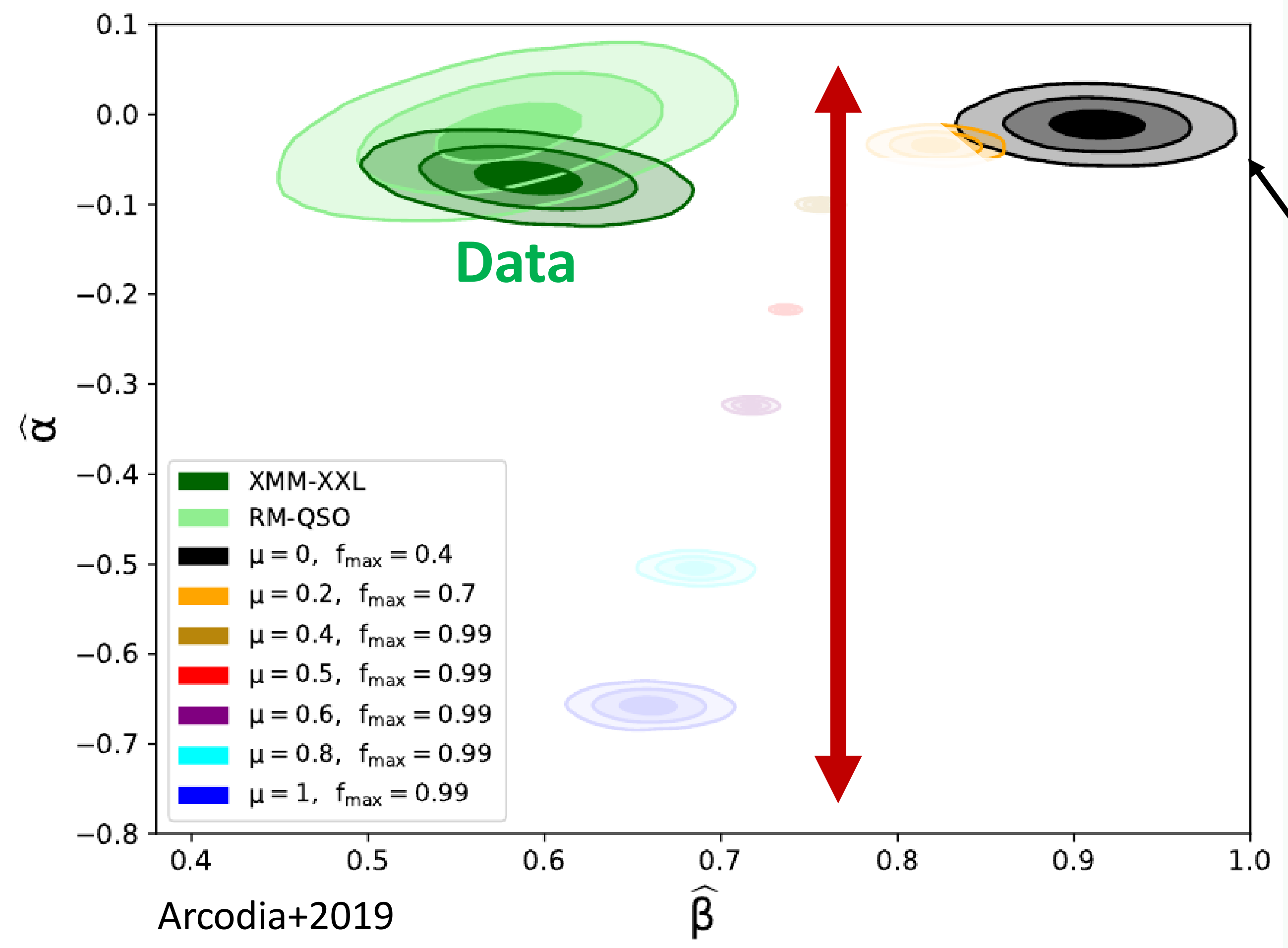
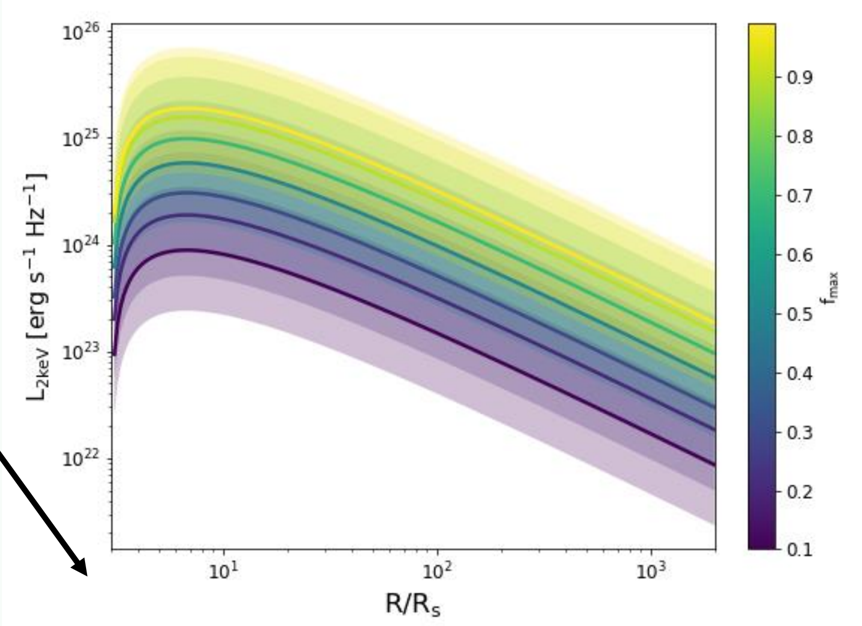
Results: a complete picture

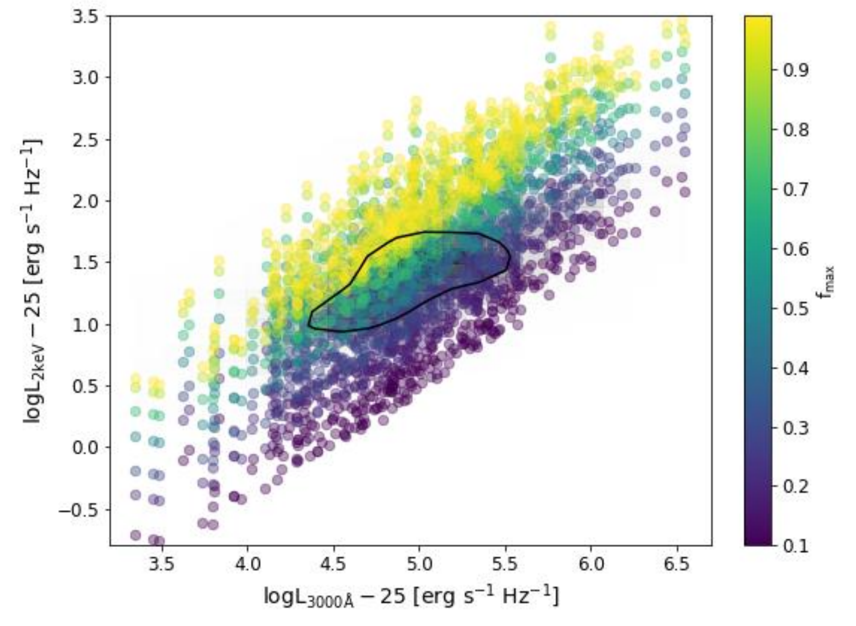


$$logL_X = \hat{\alpha} + \hat{\beta} \ logL_{UV}$$

Results: $L_X - L_{UV}$ normalization



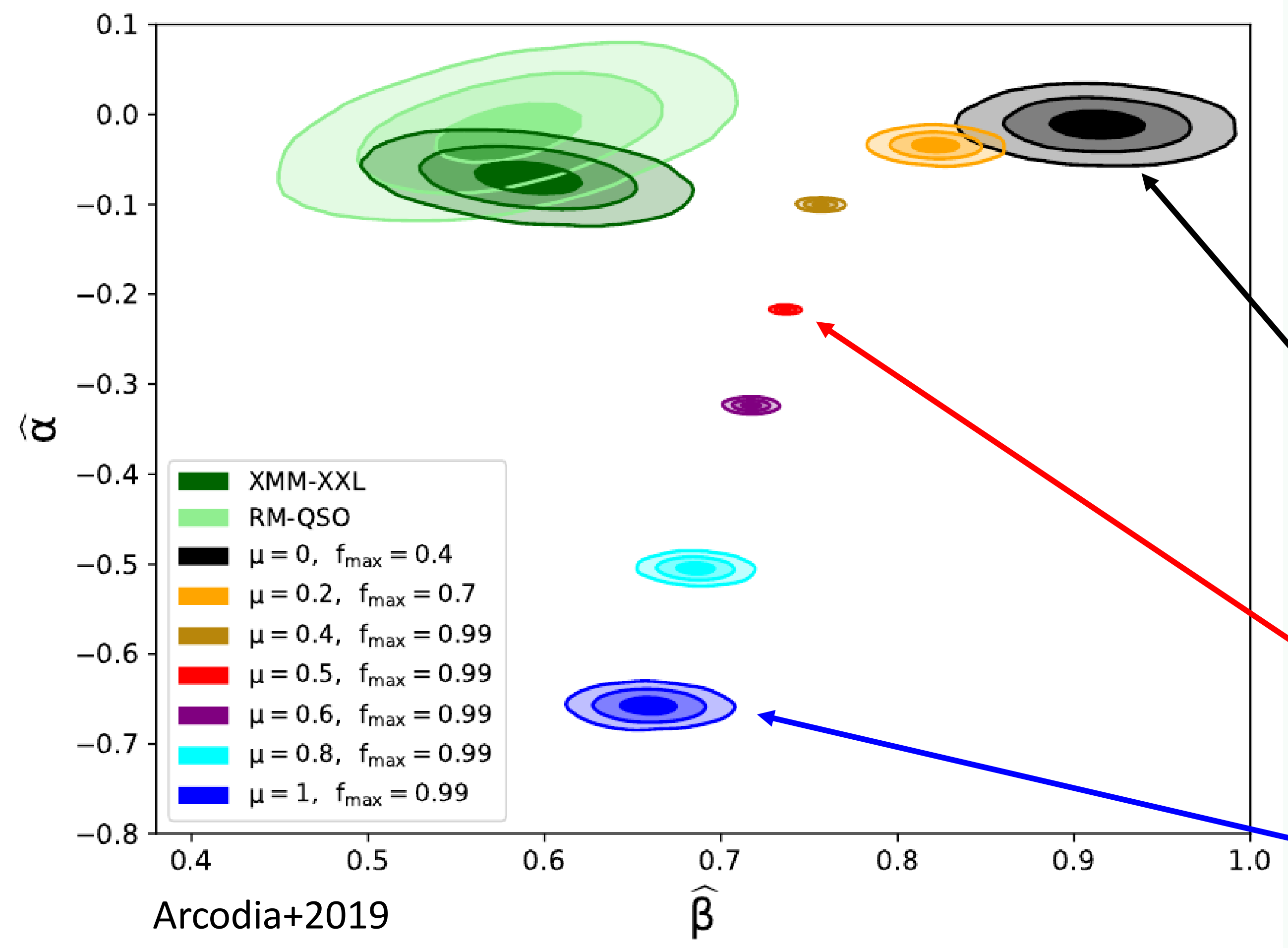


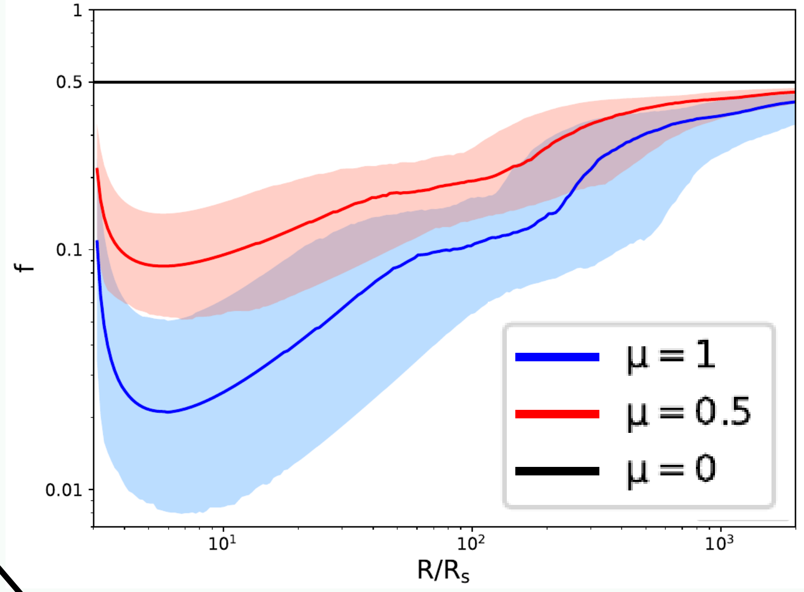


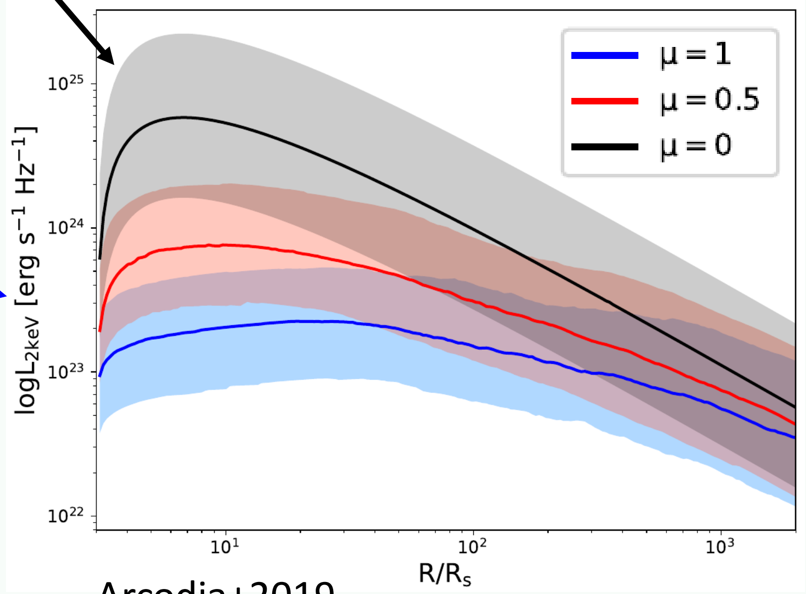
μ = DISK PRESCRIPTION

f_{max} = MAX CORONAL STRENGTH

Results: $L_X - L_{UV}$ normalization





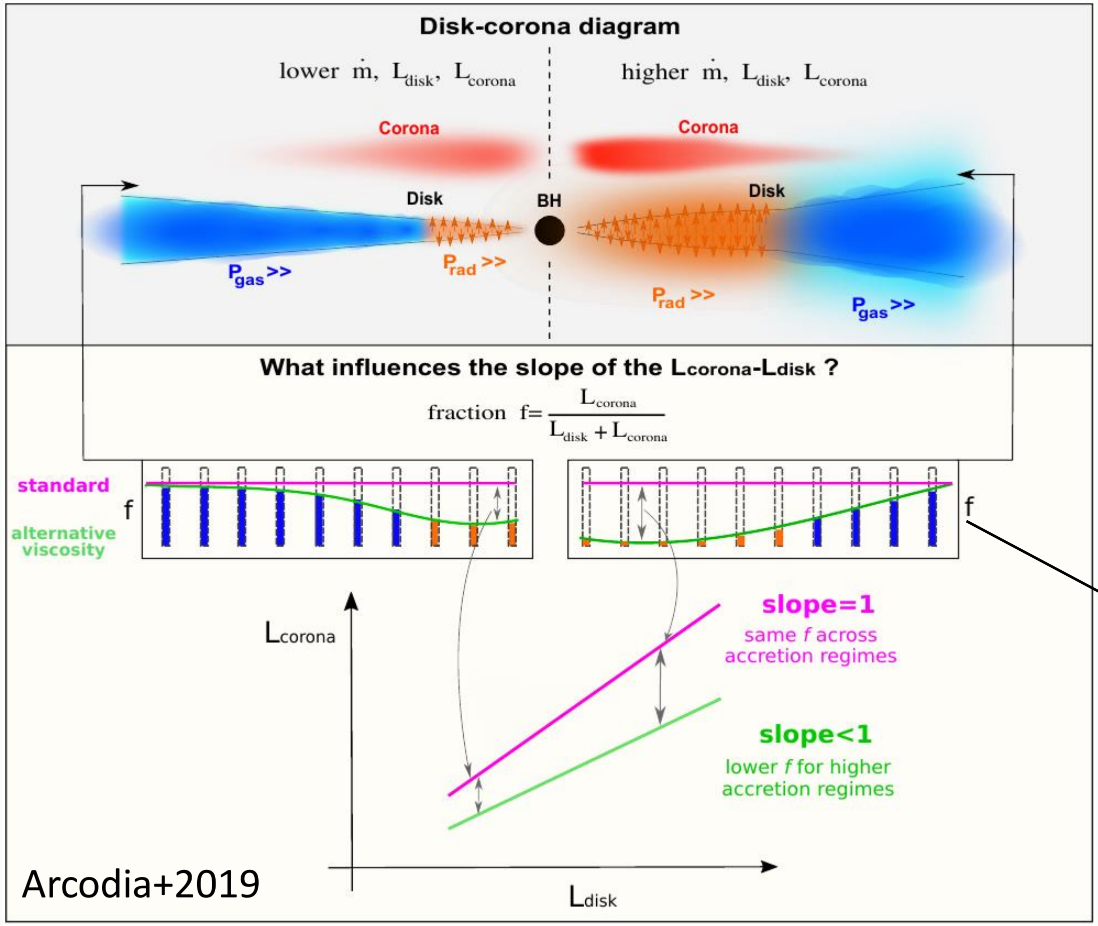


Arcodia+2019

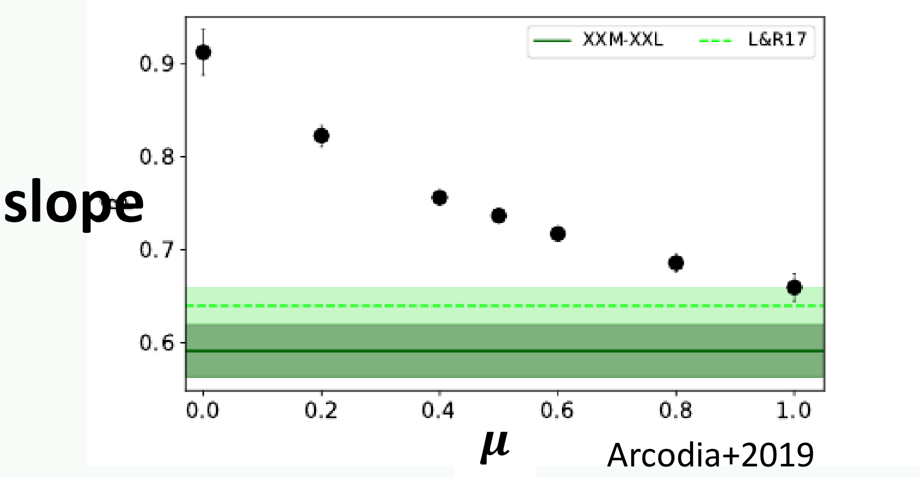
μ = **DISK PRESCRIPTION**

f_{max} = **MAX CORONAL STRENGTH**

Results: $L_X - L_{UV}$ slope



Arcodia+2019



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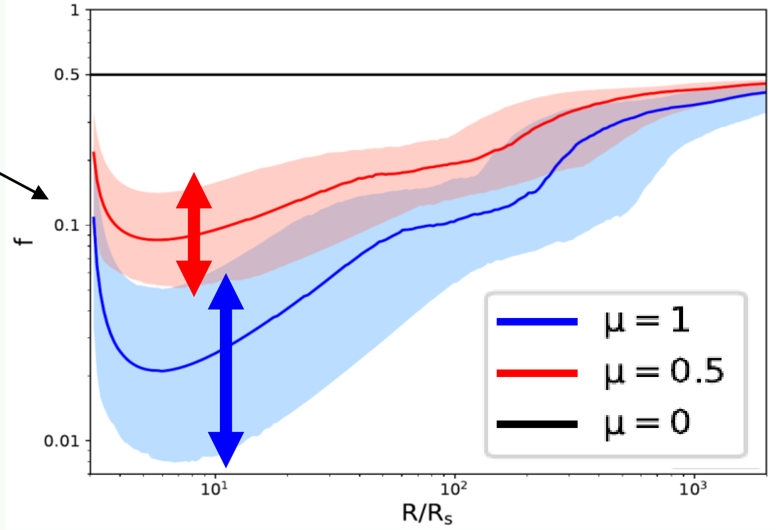
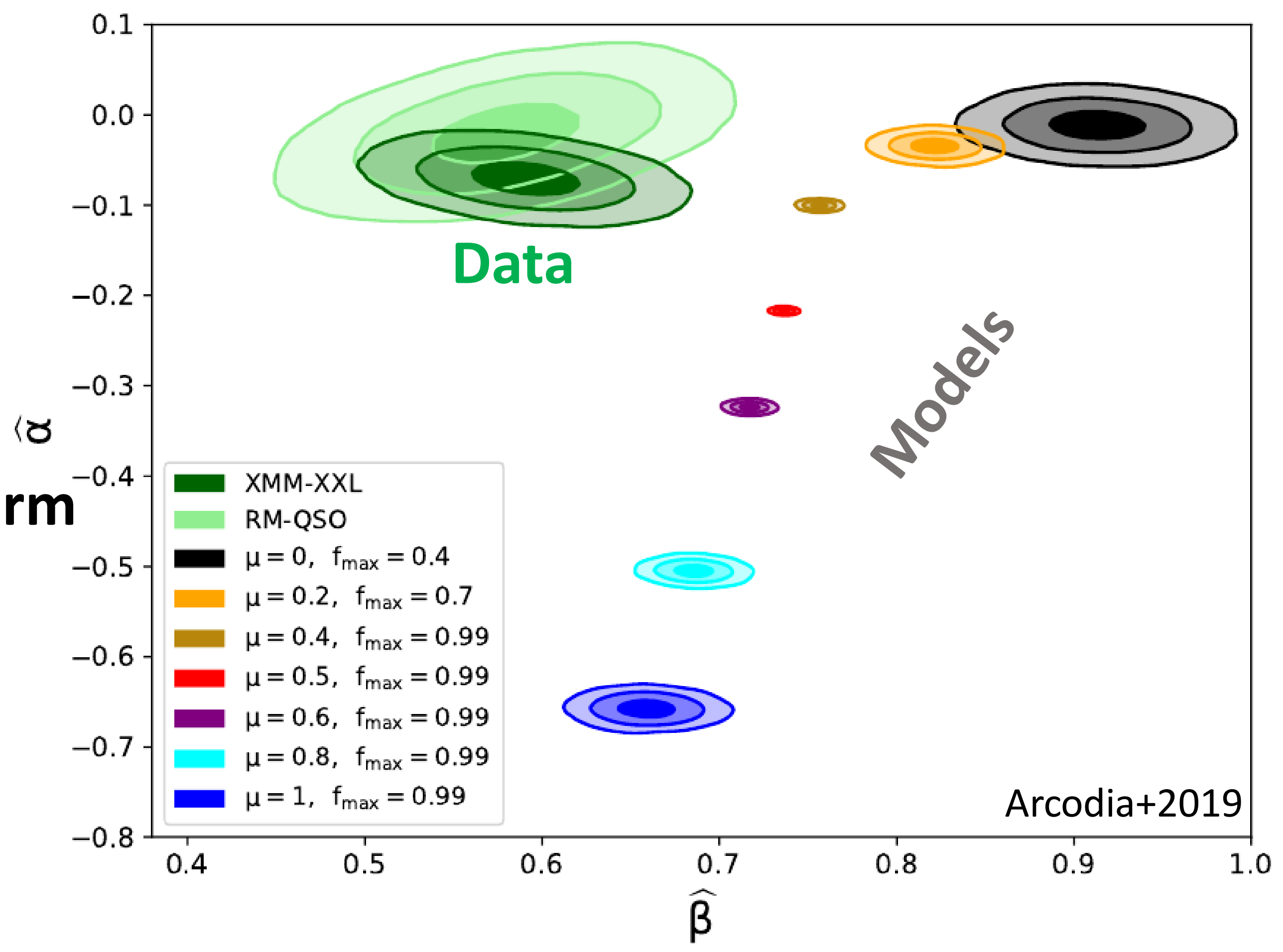


Results: a complete picture

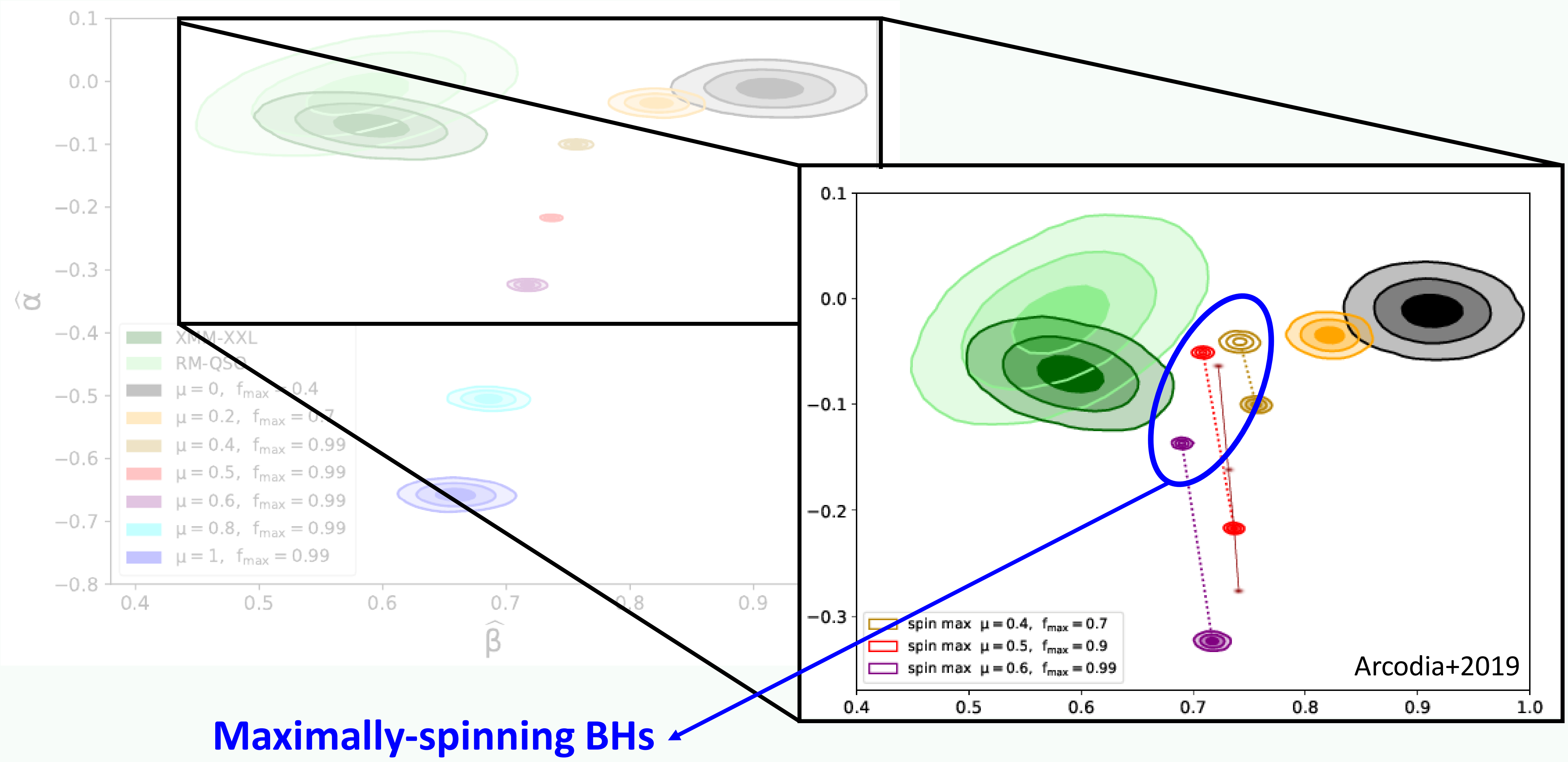


norm

slope

$$\color{red}{logL_X} = \hat{\alpha} + \hat{\beta} \; \color{blue}{logL_{UV}}$$

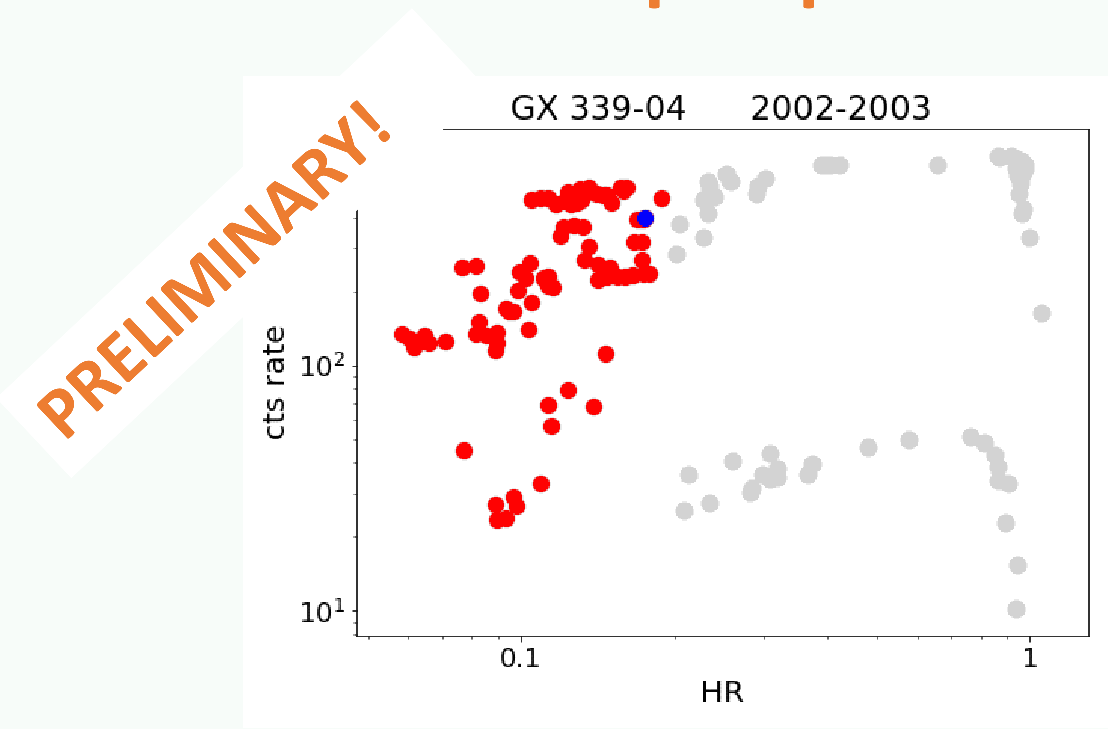
Results: the role of BH spin

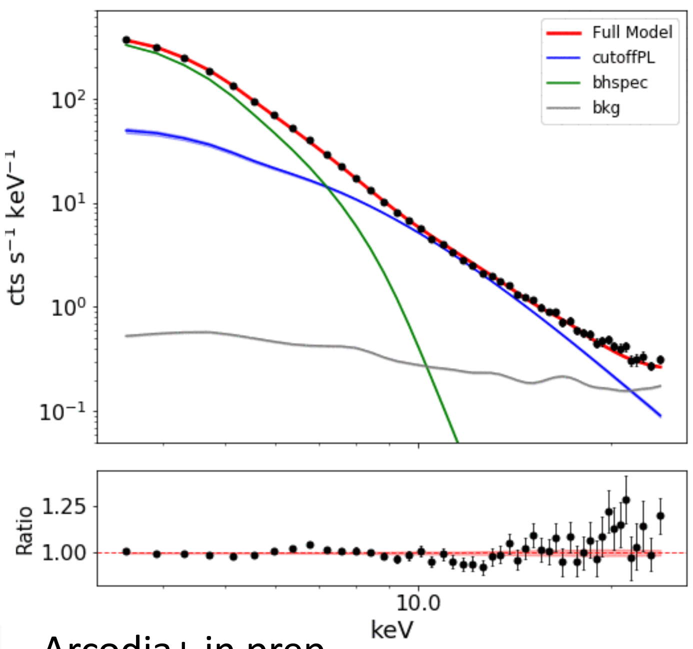


Flux-limited samples are biased in detecting high-spin sources preferentially!

(Brenneman+11; Vasudevan+16; Baronchelli+18; Reynolds19)

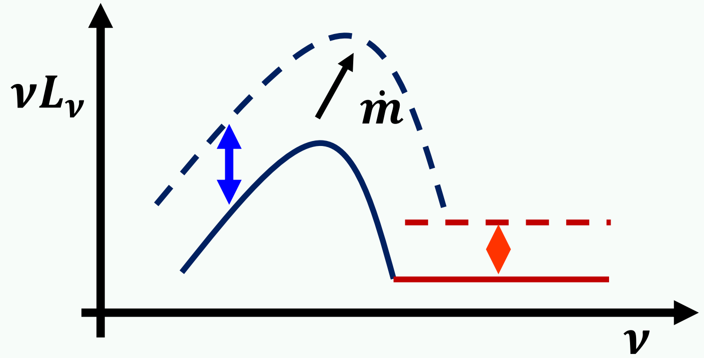
Future prospects: what about soft-states in XRBs?

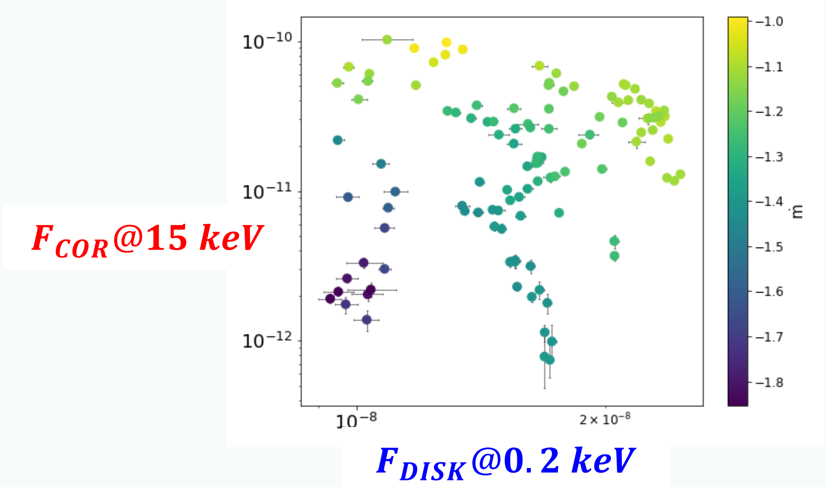




Arcodia+ in prep.

Similar behavior as in QSOs?

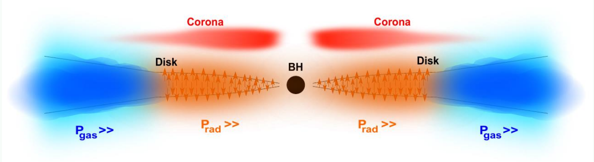




Conclusions

- The gap between simulations and observations needs to be reduced

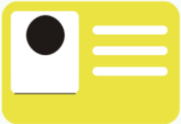
  ⟶ Simplified but motivated analytic prescriptions are still a powerful tool



- Disk-corona models should be tested against the observed $\boldsymbol{L_X - L_{UV}}$

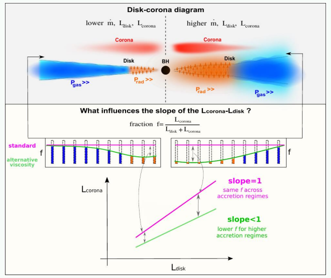
  ⟶ We modeled the observed sources $(m, \dot{m}, \Gamma_x)$ one by one

  ⟶ Match in normalization, slope and scatter of the $\boldsymbol{L_X - L_{UV}}$



- Why is the slope of the $\boldsymbol{L_X - L_{UV}} < 1$?

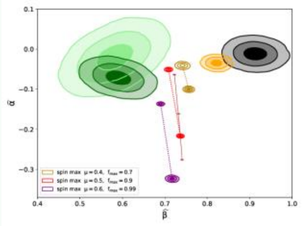
  ⟶ Our model can explain it in terms of modified accretion prescriptions



- Is the observed $\boldsymbol{L_X - L_{UV}}$ recovered?

  ⟶ In a spin=0 case, models that get the slope right show too weak coronae

  ⟶ More realistic spin distributions can relax the tension



Arcodia et al. A&A, 628, A135 (2019)

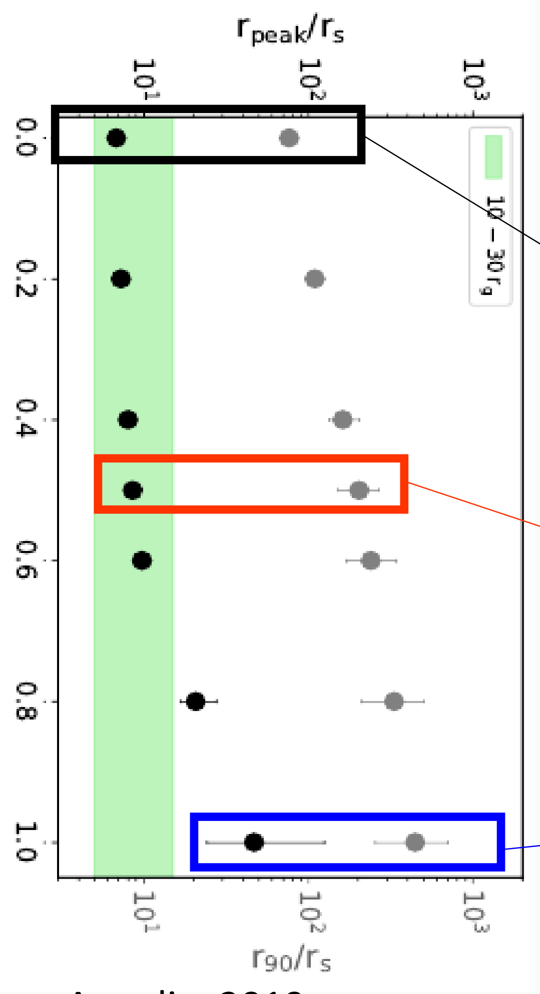
Thank you!

Results: peak of the X-ray emission

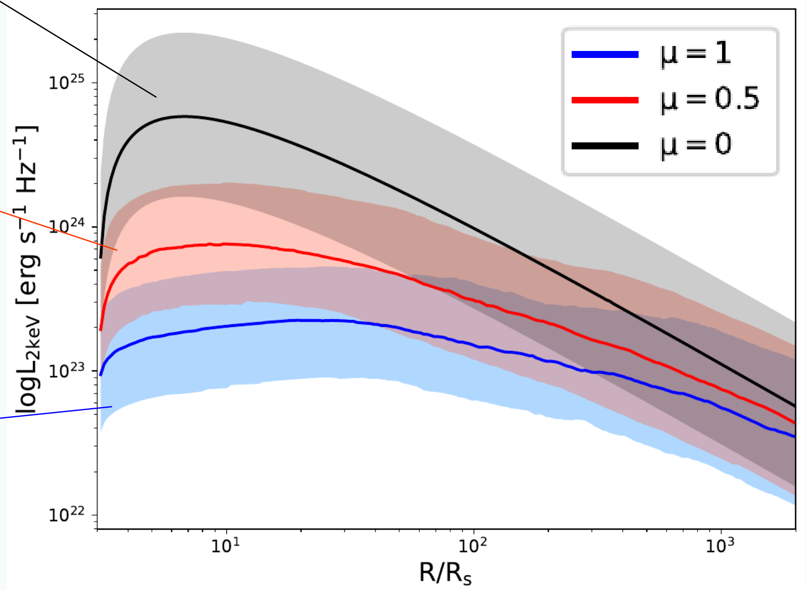
- **X-ray reverberation** and **microlensing** studies predict a corona peaking close to the BH

  (e.g. Mosquera+13, Reis & Miller 13, Wilkins +16)

μ = DISK PRESCRIPTION



Arcodia+2019



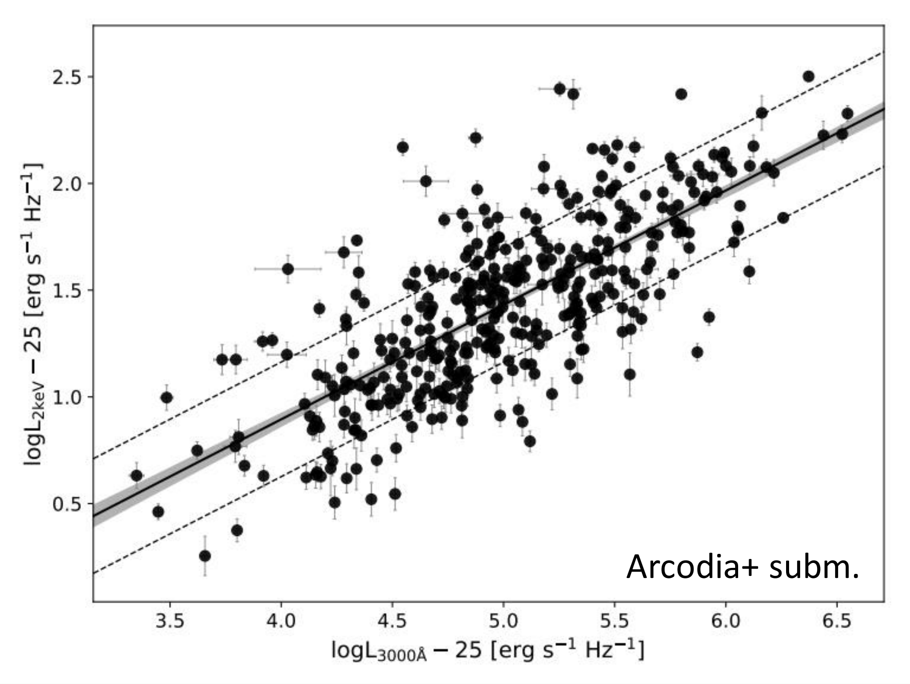
The smoking gun of the Disk-Corona interplay

AGN in a sweet spot
of accretion
$\dot{m} \approx$ **(0.0x – 1)**

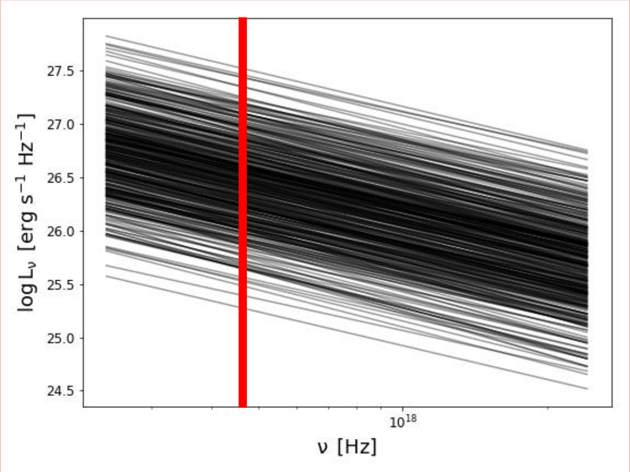
↓

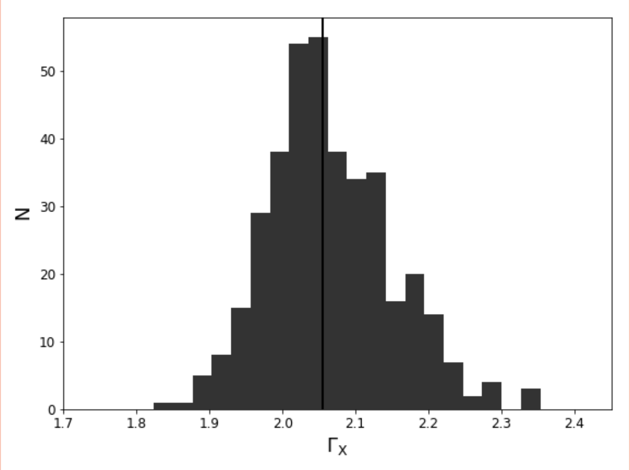
Very <u>similar properties</u>
(in X and UV separately)

L_X

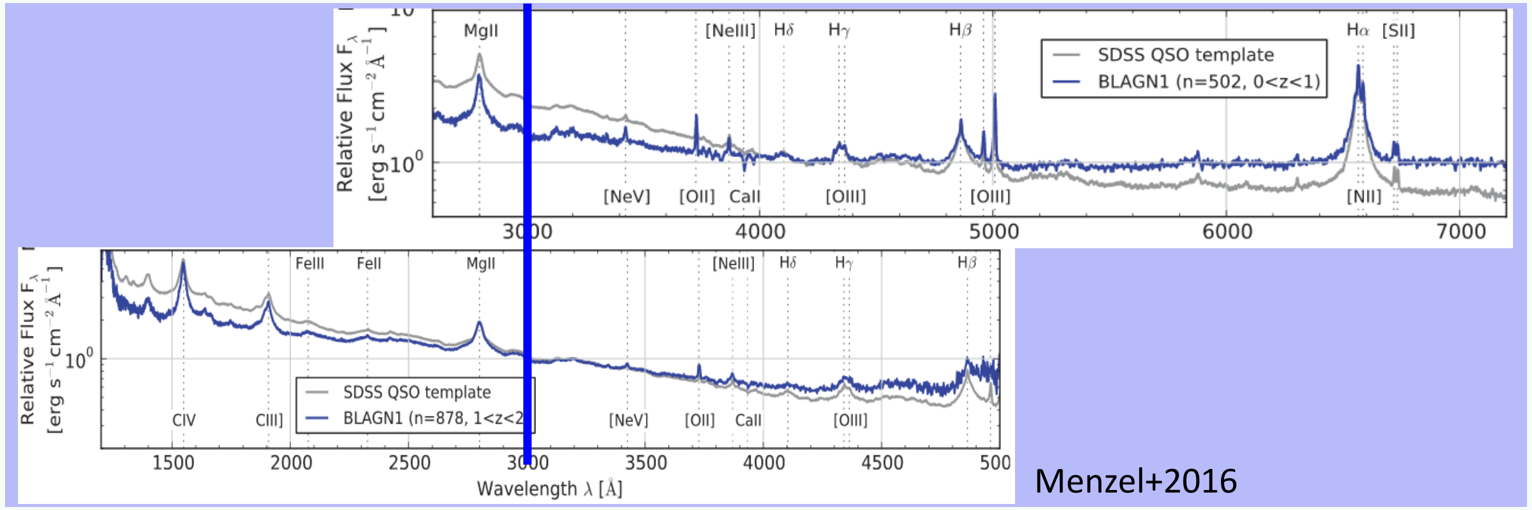


L_{UV}



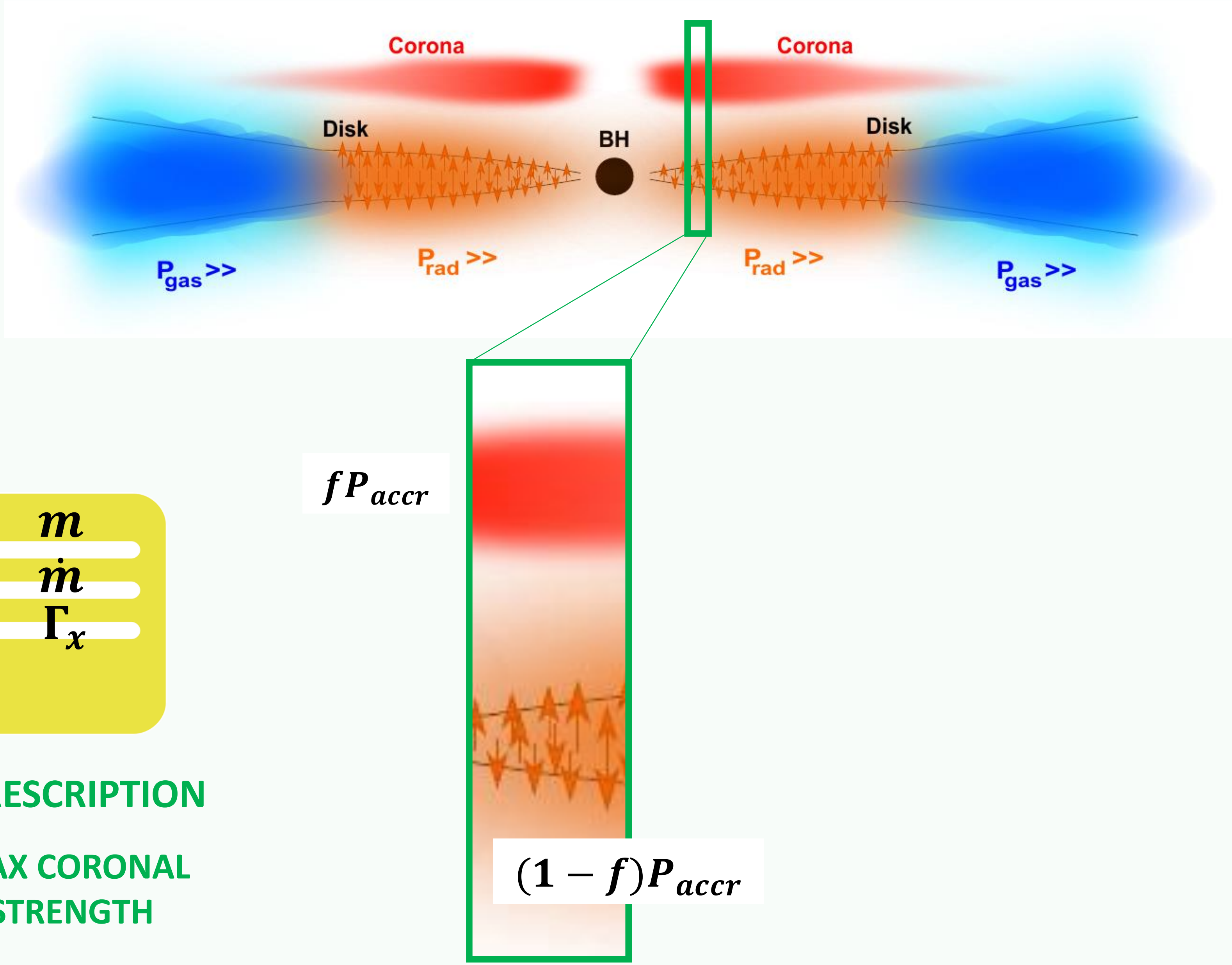


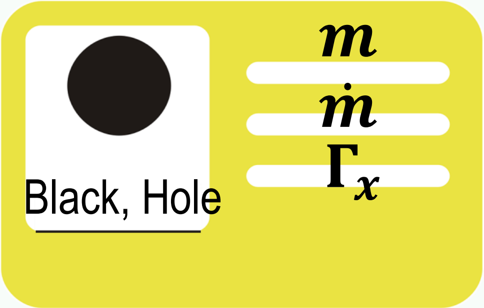
Adapted from Liu+2016



Menzel+2016

The disk-corona model





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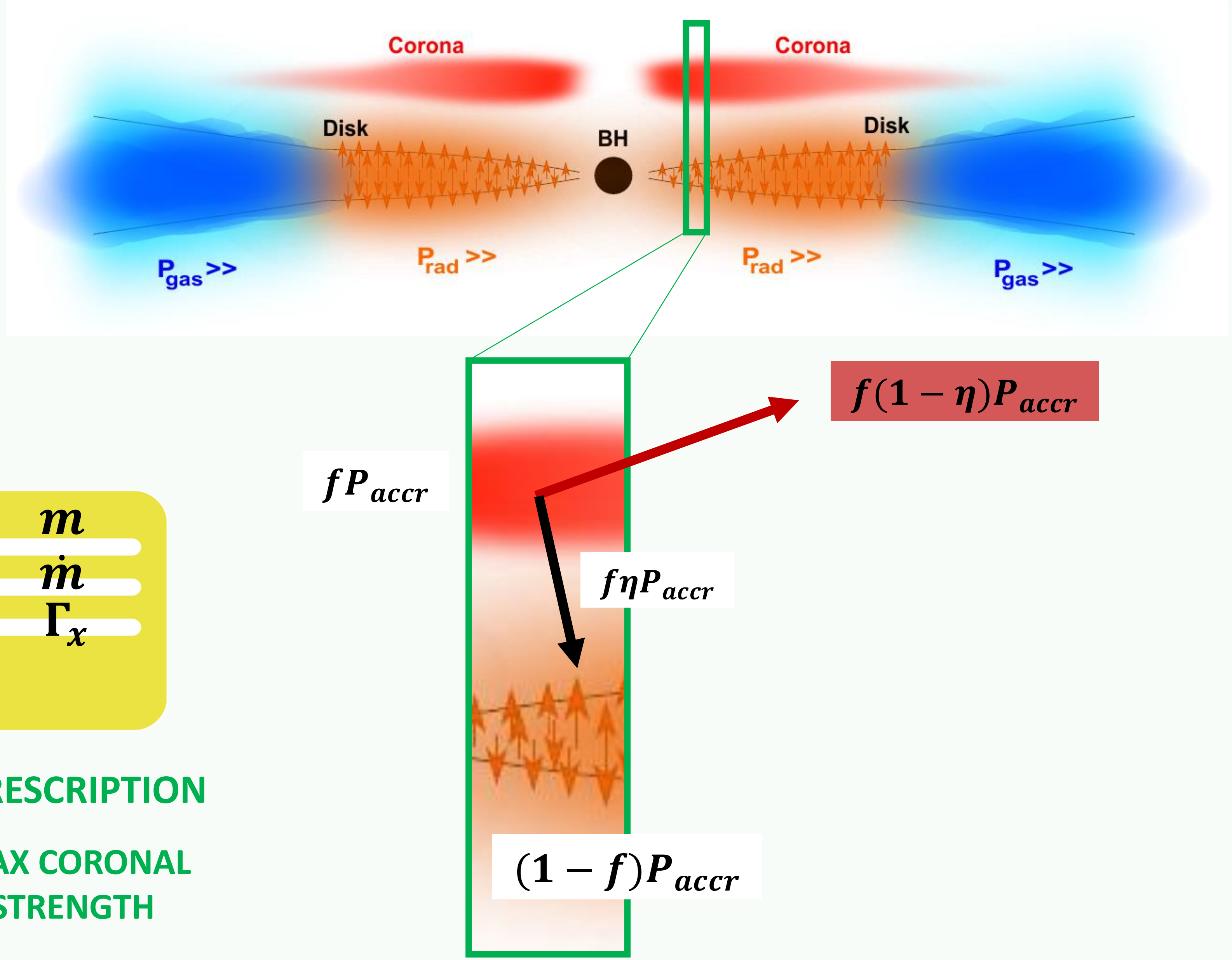
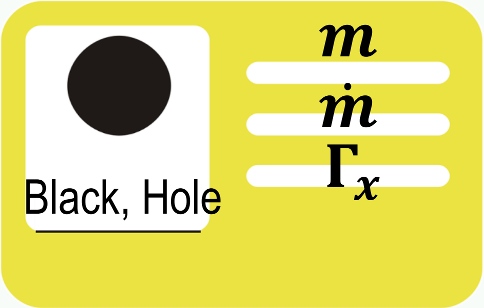
The disk-corona model





μ = DISK PRESCRIPTION

f_{max} = MAX CORONAL STRENGTH

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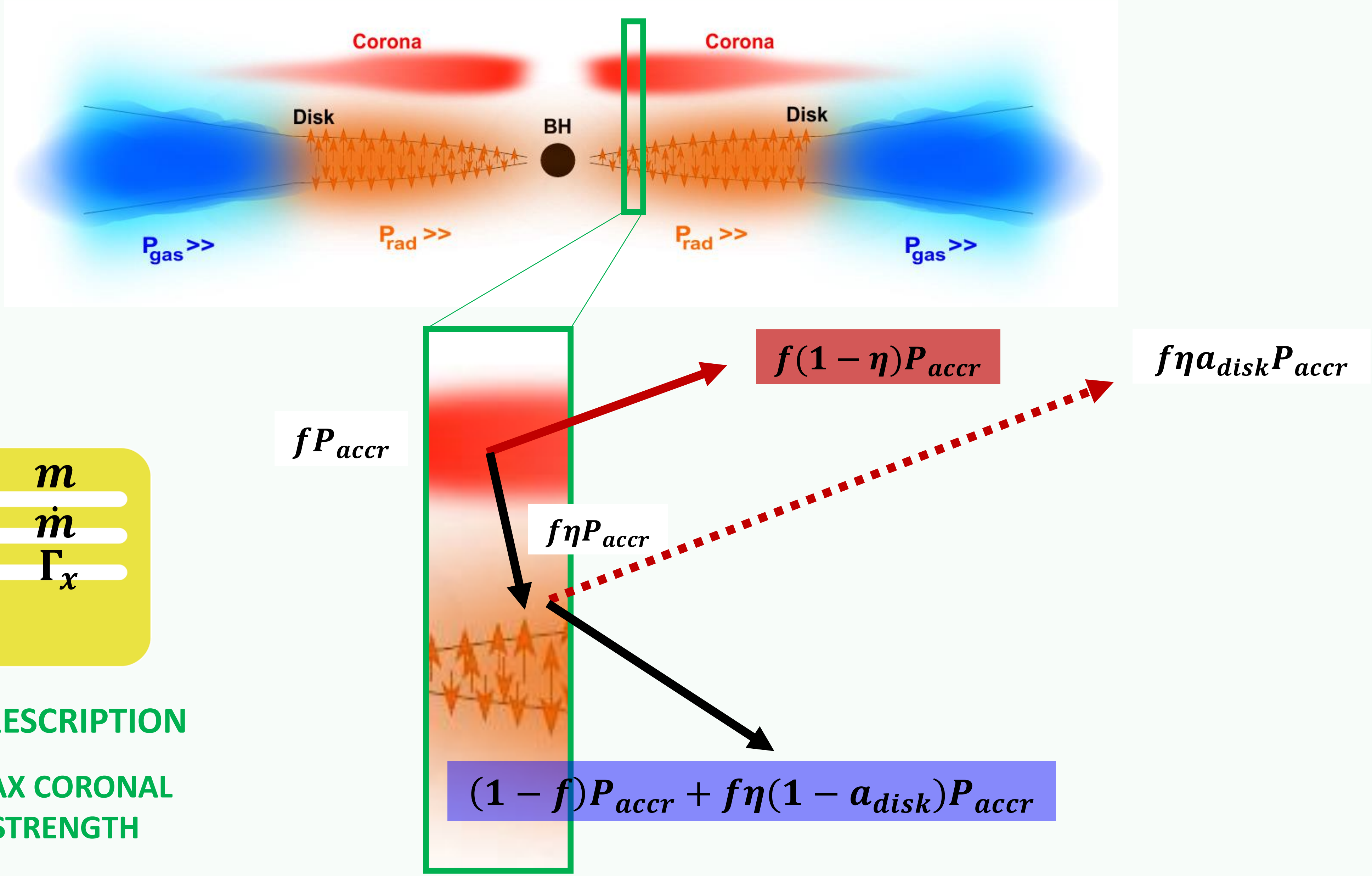

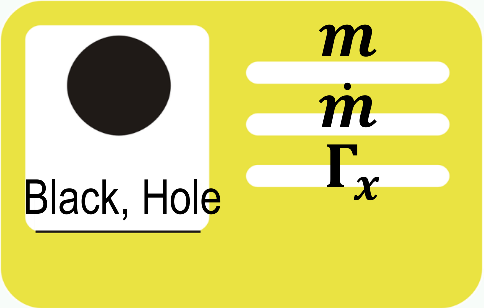

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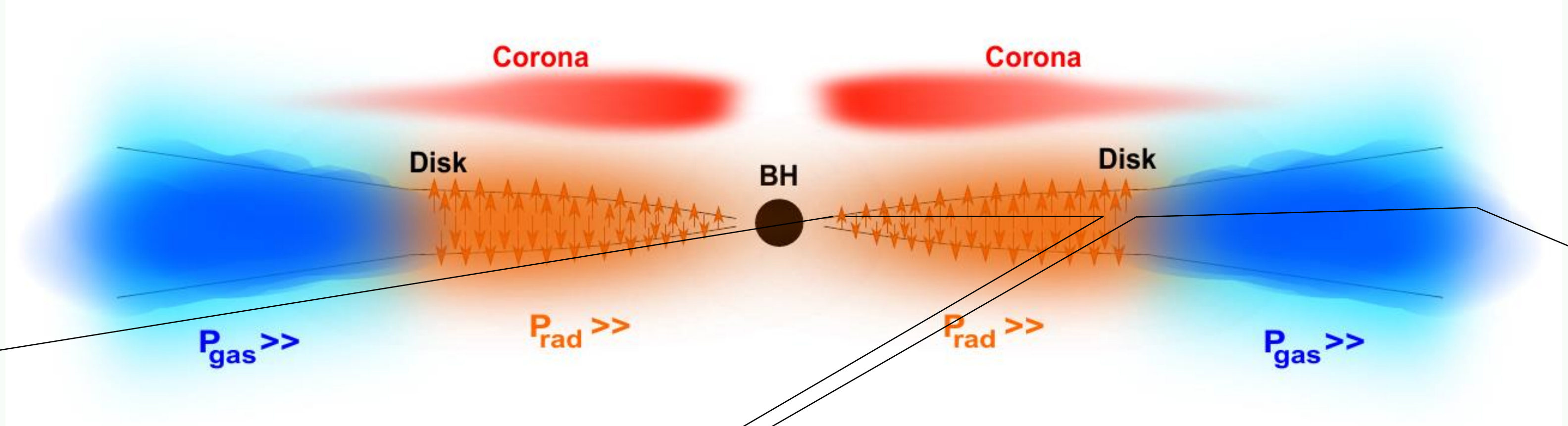


$P_{rad} \gg P_{gas}$

$$\rho \propto [\alpha_0 m]^{-\frac{4}{\mu+4}} [\dot{m}J(r)]^{\frac{2(3\mu-4)}{\mu+4}} r^{\frac{3(2-3\mu)}{\mu+4}} (1-f)^{\frac{6(\mu-2)}{\mu+4}}$$

$$T_{mid} \propto [\alpha_0 m]^{-\frac{1}{\mu+4}} [\dot{m}J(r)]^{\frac{2\mu}{\mu+4}} r^{\frac{3(2\mu^2-3\mu-2)}{2(2-\mu)(\mu+4)}} (1-f)^{\frac{2\mu-1}{\mu+4}}$$

$$h = 9.14\dot{m}J(r)(1-f)$$

$$P \propto [\alpha_0 m]^{-\frac{4}{\mu+4}} [\dot{m}J(r)]^{\frac{8\mu}{\mu+4}} r^{\frac{6(2\mu^2-3\mu-2)}{(2-\mu)(\mu+4)}} (1-f)^{\frac{4(2\mu-1)}{\mu+4}}$$

$$\frac{(2\alpha_0)^{1/\mu} - f^{2/\mu}}{f^{2/\mu}} = \frac{P_{rad}}{P_{gas}} \propto [\alpha_0 m]^{\frac{1}{\mu+4}} [\dot{m}J(r)]^{\frac{8}{\mu+4}} r^{-\frac{21}{2(\mu+4)}} (1-f)^{\frac{9}{\mu+4}}$$

$P_{gas} \gg P_{rad}$

$$\rho = 14.44\ k_0^{-3/5} \xi^{3/10} [\alpha_0 m]^{-7/10} [\dot{m}J(r)]^{2/5} r^{-33/20} (1-f)^{-3/10}$$

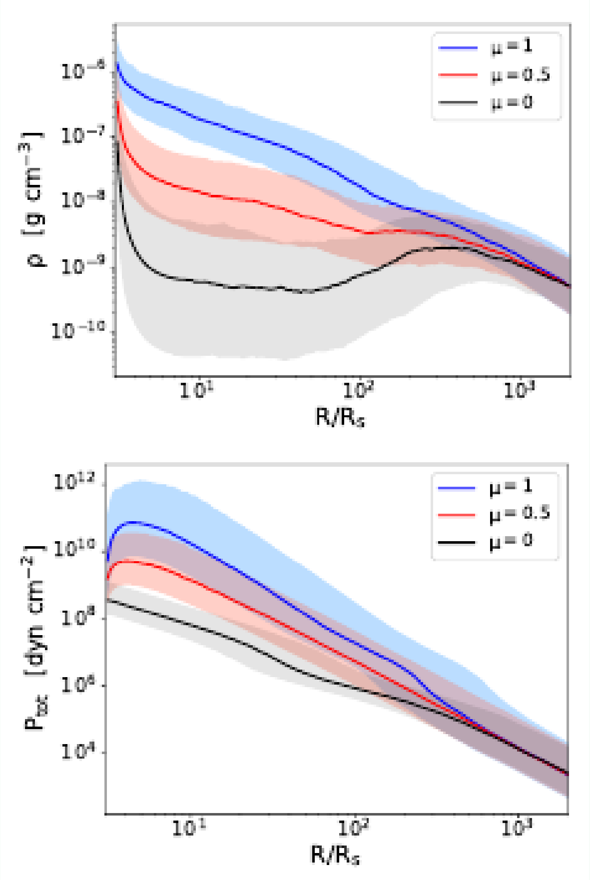
$$T = 8.01 \times 10^8\ k_0^{-4/15} \xi^{-1/5} [\alpha_0 m]^{-1/5} [\dot{m}J(r)]^{2/5} r^{-9/10} (1-f)^{1/5}$$

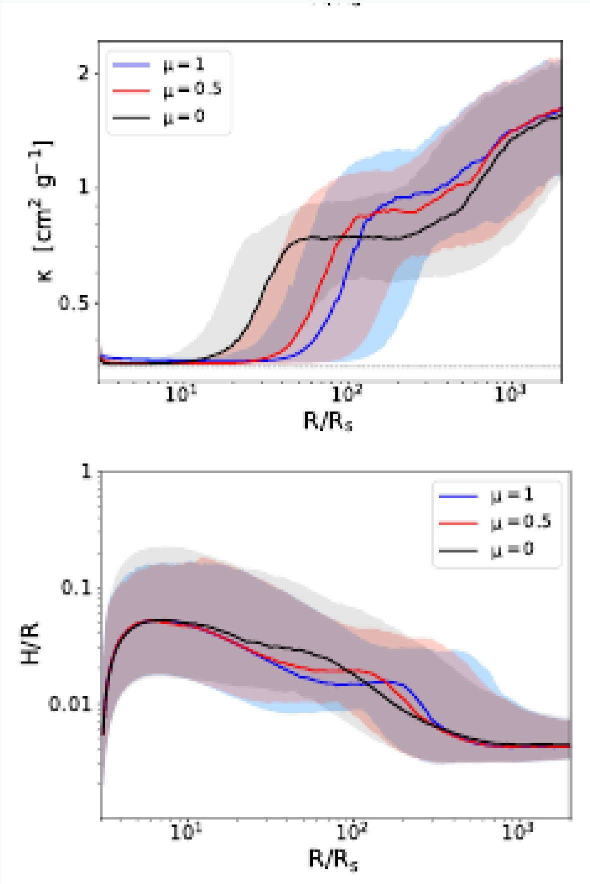
$$h = 1.72 \times 10^{-2}\ k_0^{-7/15} \xi^{-1/10} [\alpha_0 m]^{-1/10} [\dot{m}J(r)]^{1/5} r^{21/20} (1-f)^{1/10}$$

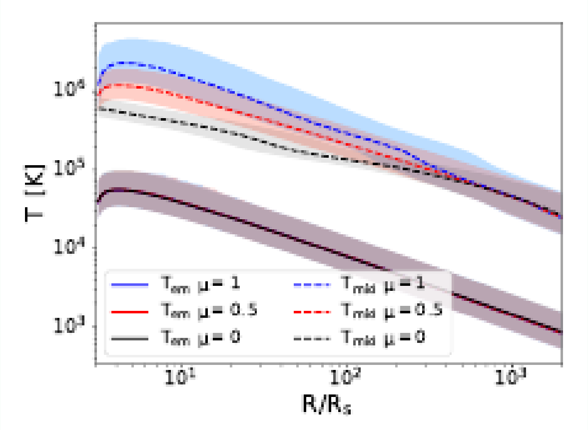
$$P = 1.91 \times 10^8\ k_0^{-13/15} \xi^{1/10} [\alpha_0 m]^{-9/10} [\dot{m}J(r)]^{4/5} r^{-51/20} (1-f)^{-1/10}$$

$$\frac{4\alpha_0^2 - f^4}{f^4} = \frac{P_{rad}}{P_{gas}} = 5.41 \times 10^2\ k_0^{-1/5} \xi^{-9/10} [\alpha_0 m]^{1/10} [\dot{m}J(r)]^{4/5} r^{-21/20} (1-f)^{9/10}$$

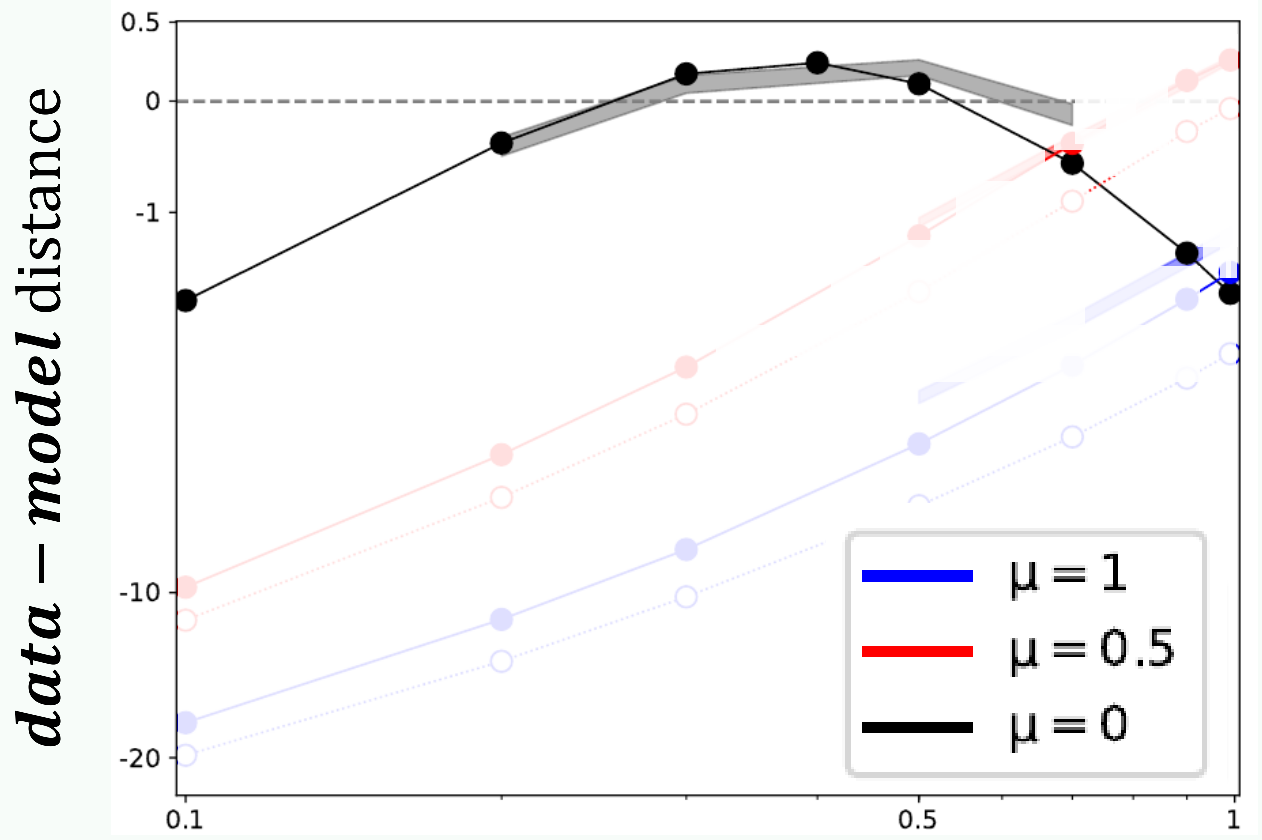
The disk-corona model



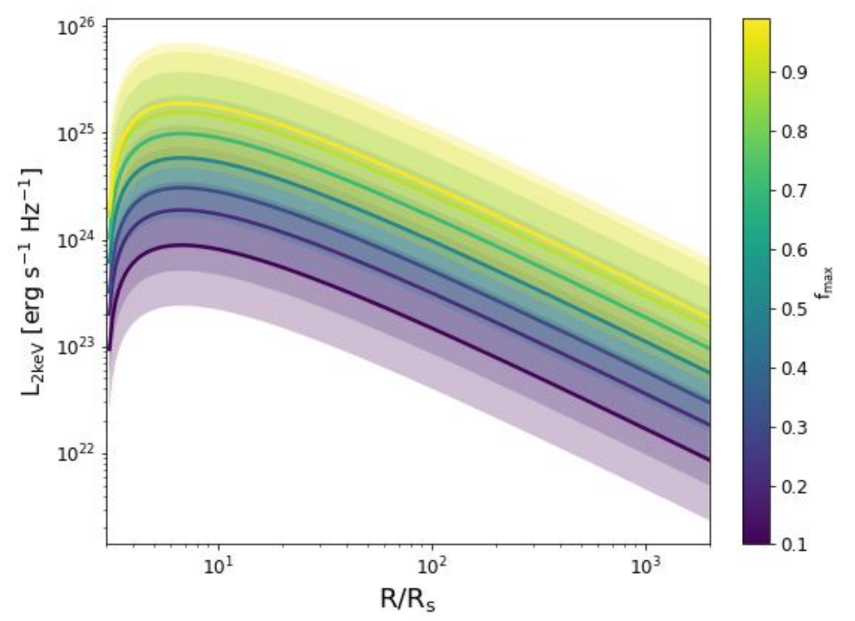


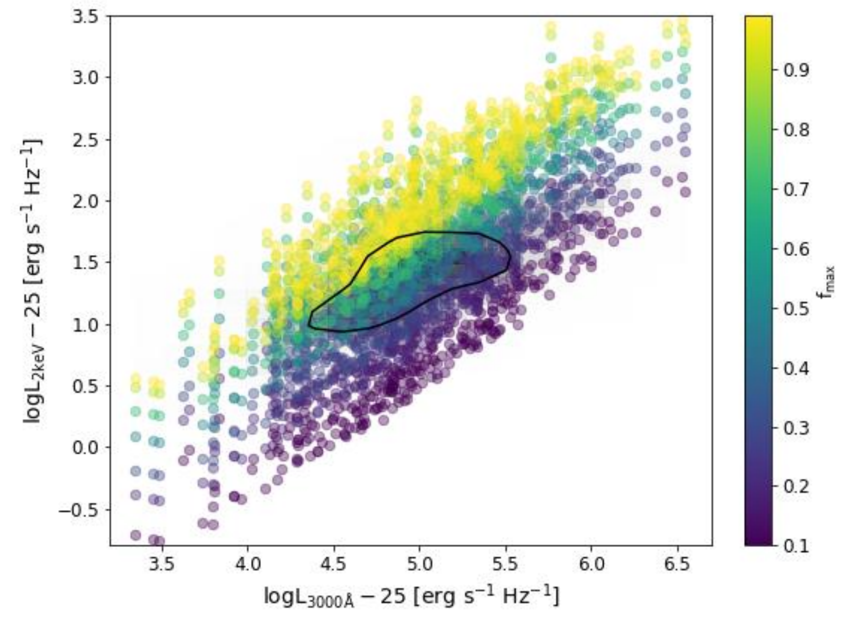


Results: $L_X - L_{UV}$ normalization



$f_{max} =$ MAX CORONAL STRENGTH





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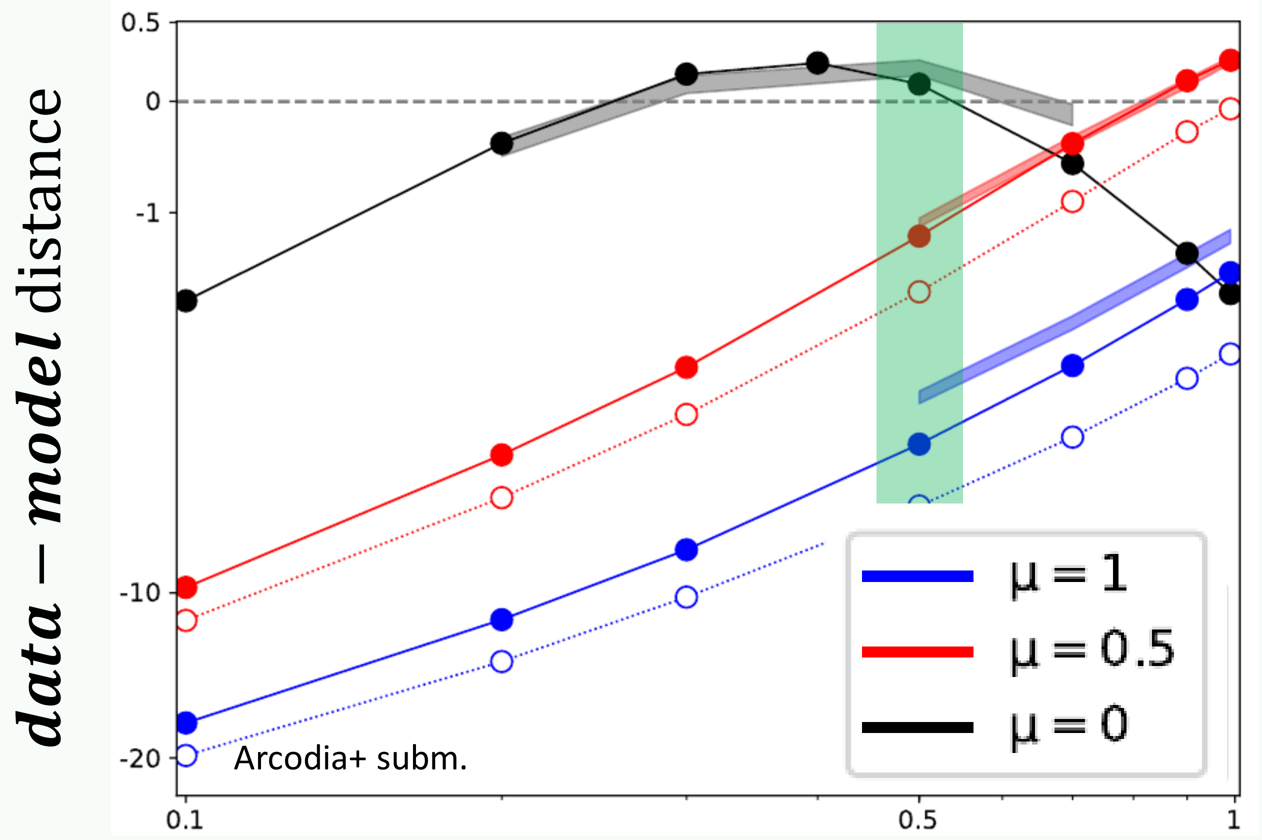

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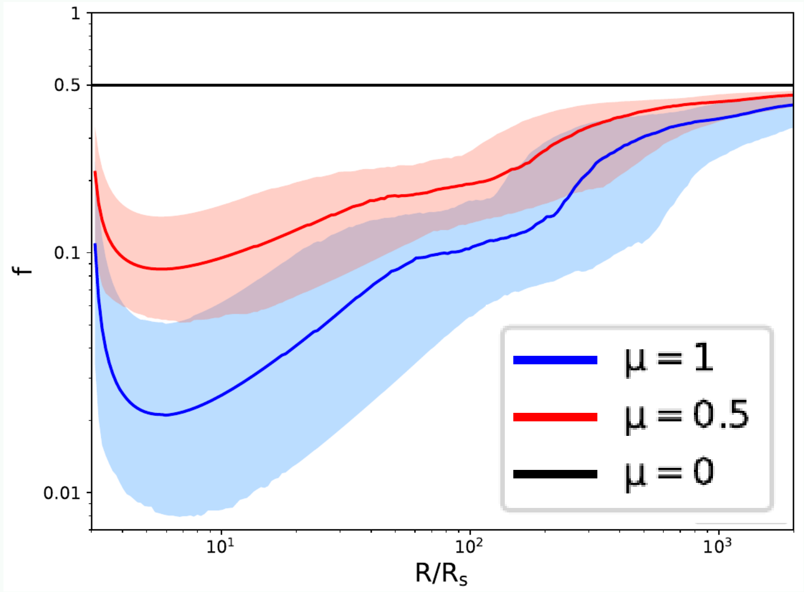
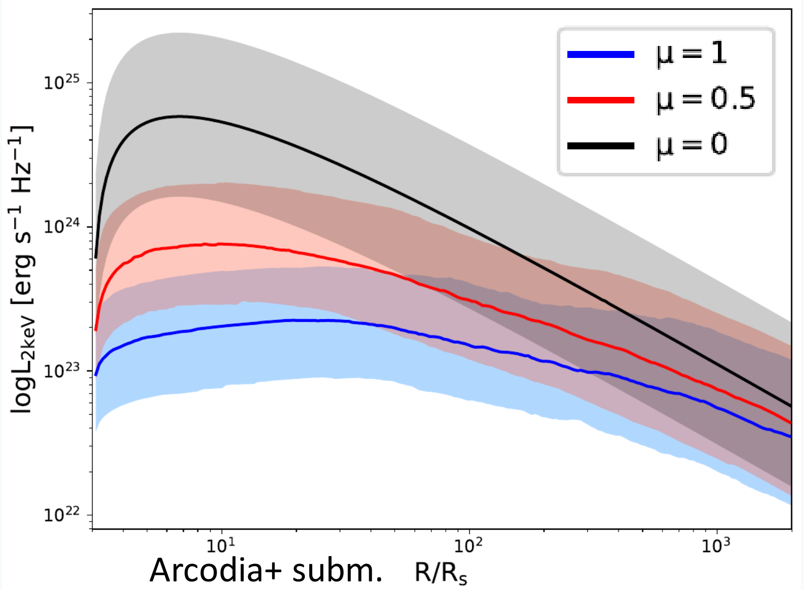
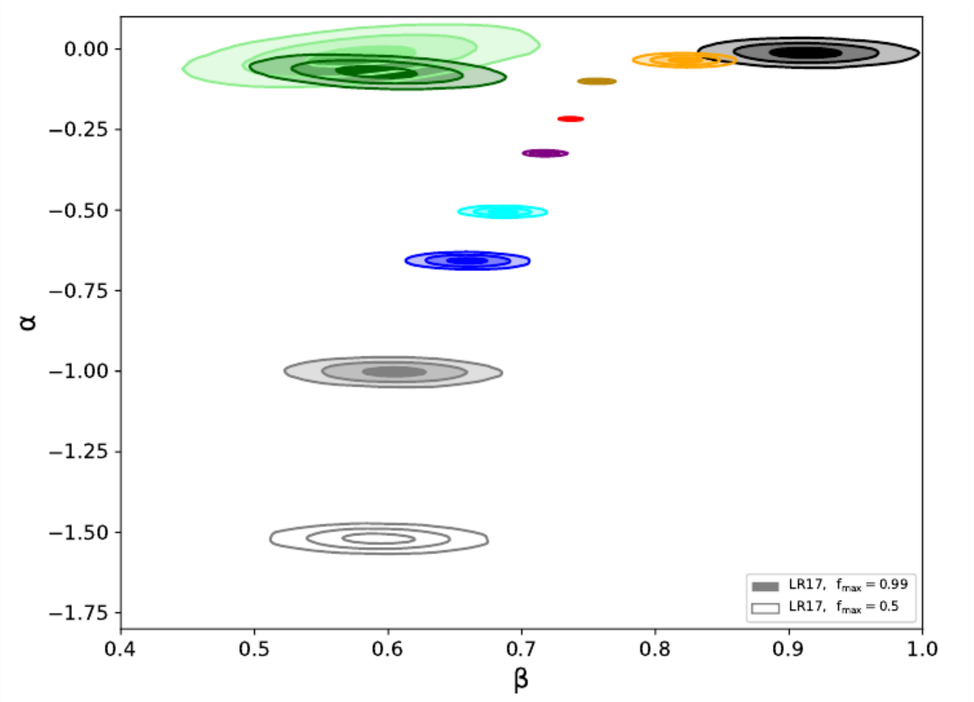
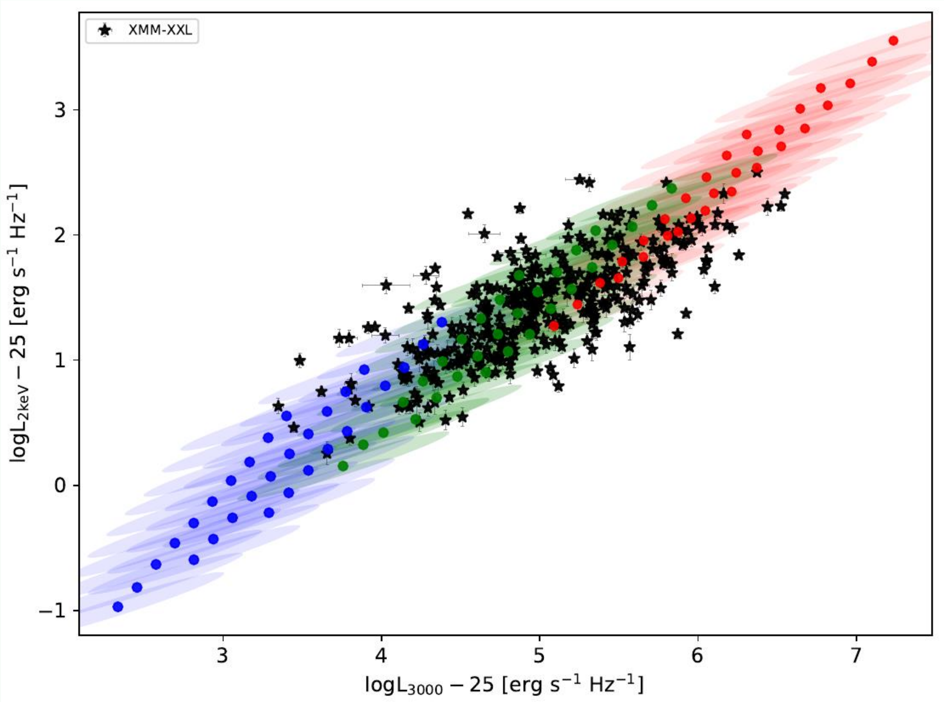


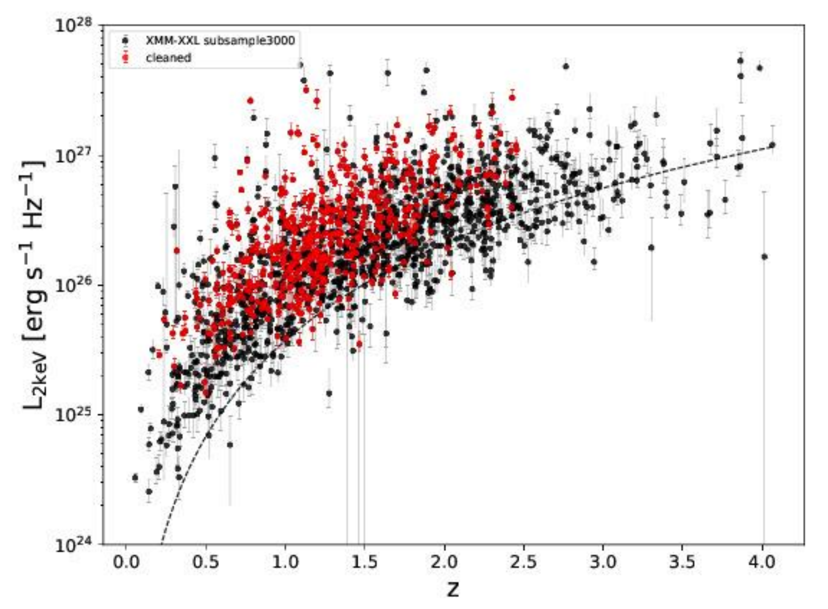


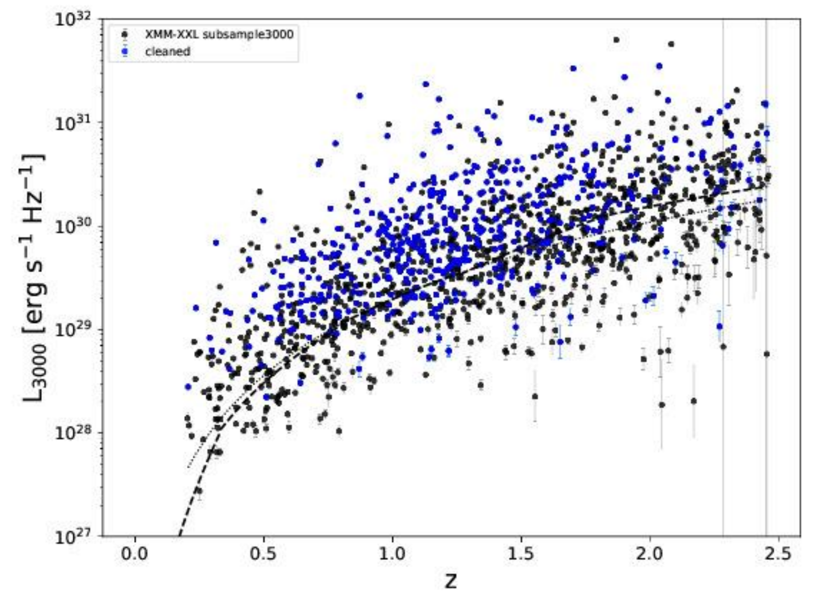
Comparison with other models

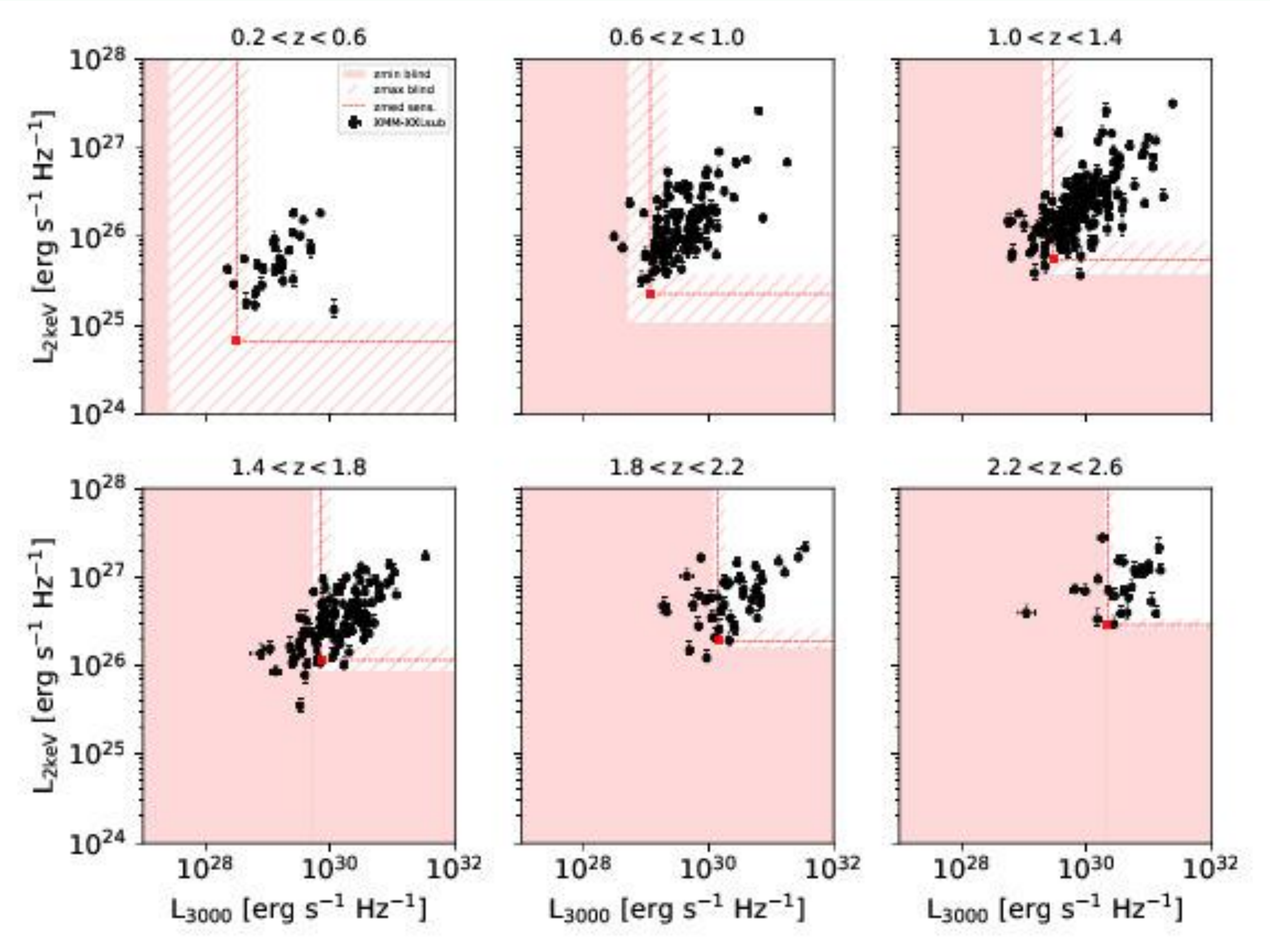




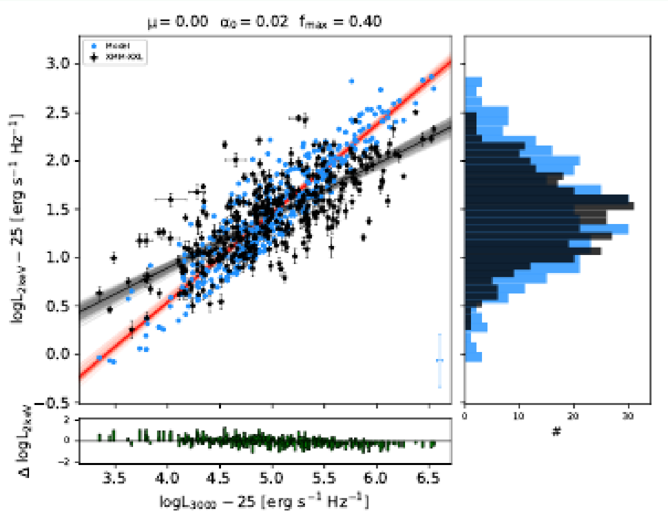
The cleaned sample

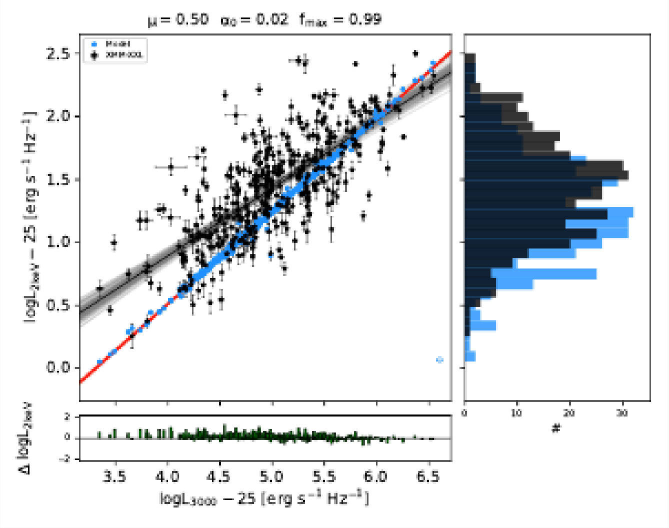


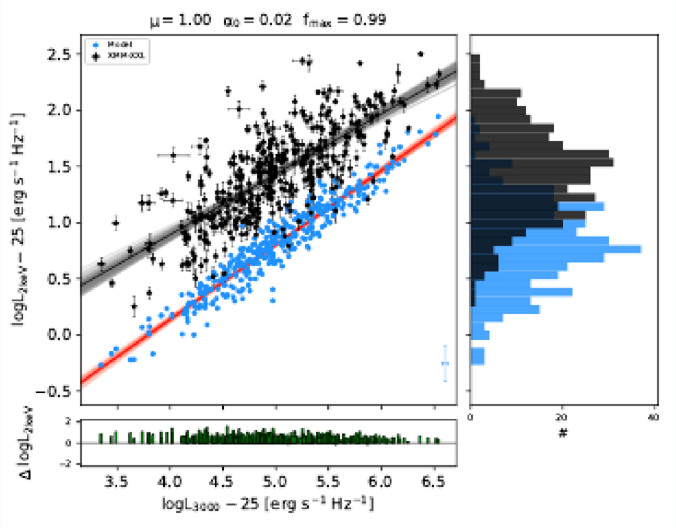


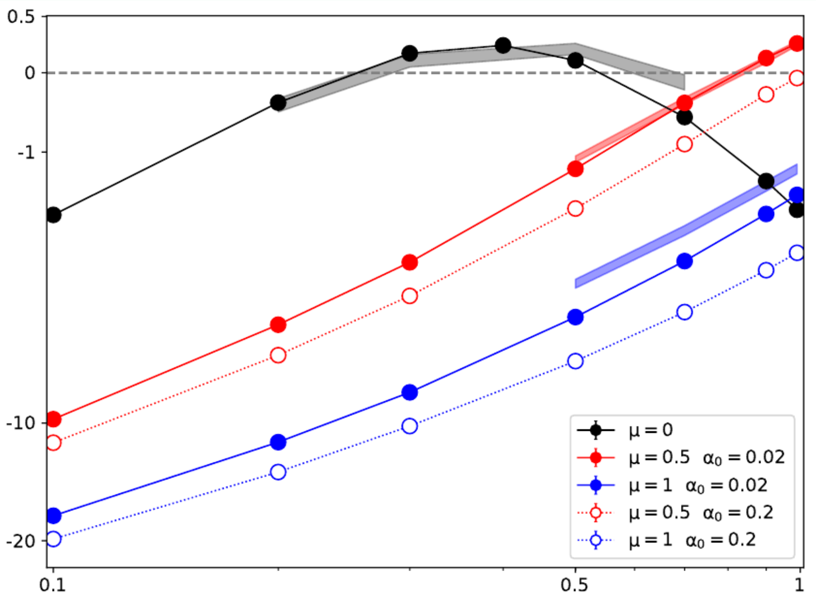


The model-mock comparison

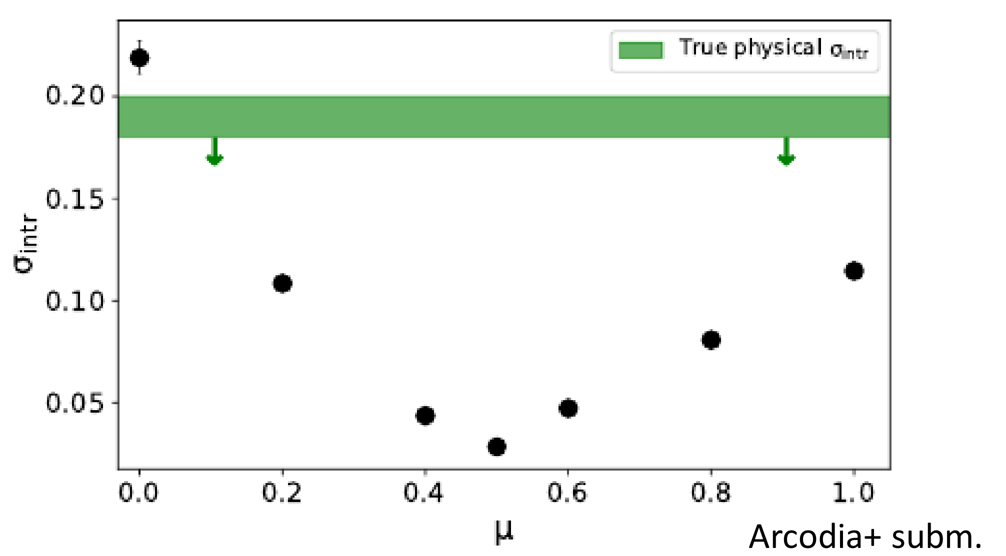








Results: $L_X - L_{UV}$ scatter



Arcodia+ subm.

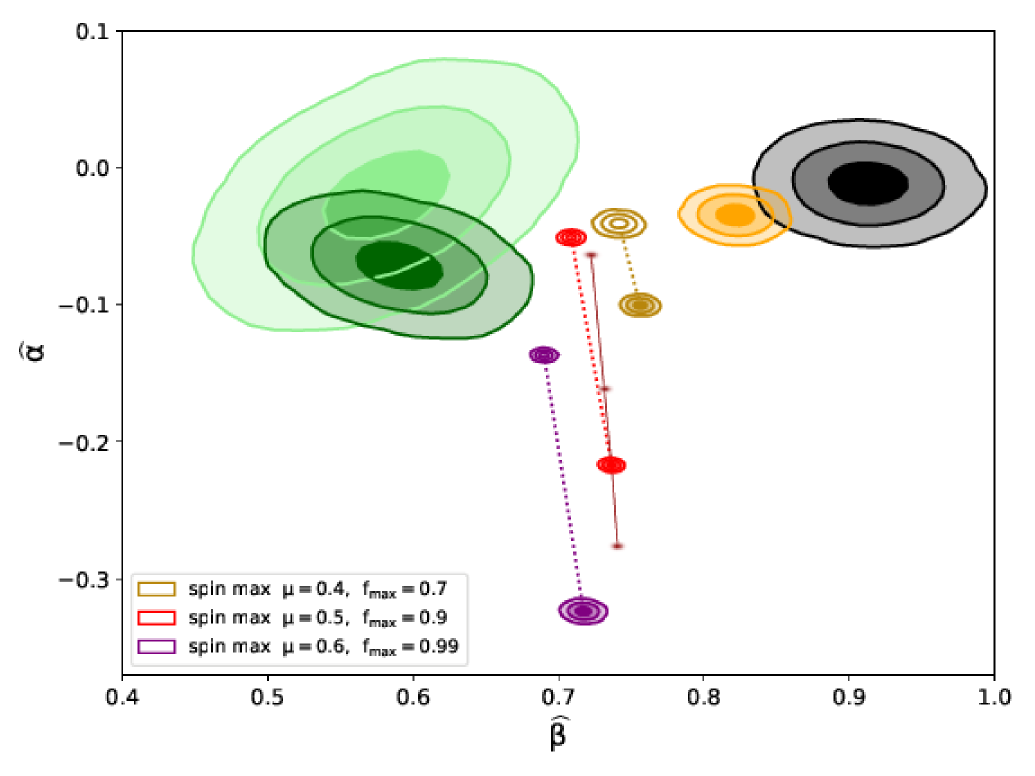
$\sigma_{phys} \lesssim 0.2$ dex

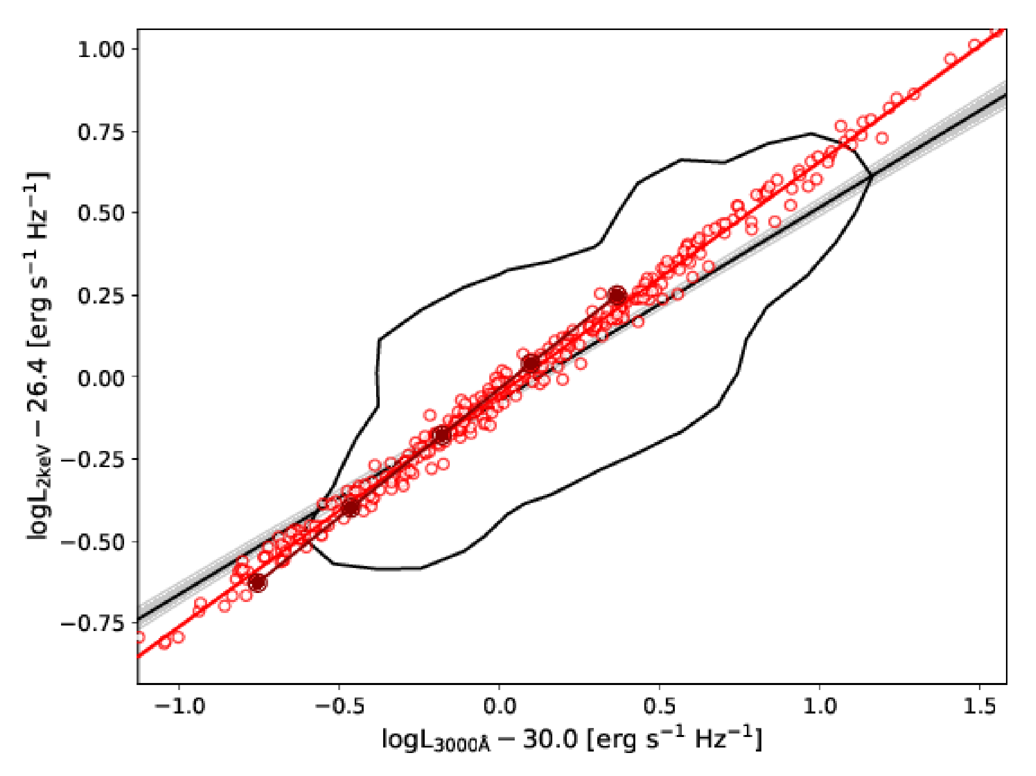
Controlling for calibration issues, variability, non-simultaneity..

(Lusso & Risaliti 16; Chiaraluce+ 18)

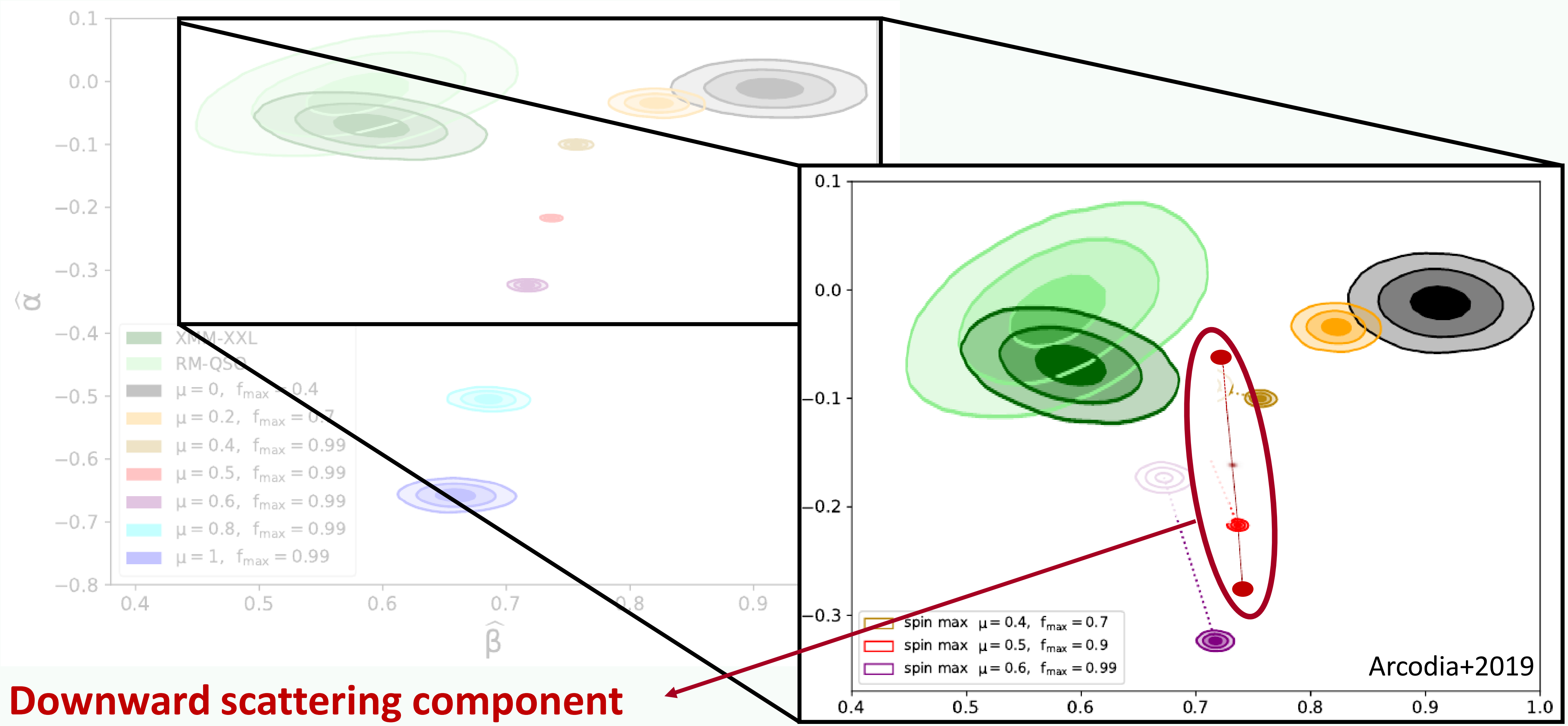
- The intrinsic scatter is given by the diversity in $\boldsymbol{m}, \boldsymbol{\Gamma_x}$ at a given $\dot{\boldsymbol{m}}$ ($\boldsymbol{L_{3000}}$)

Results: high-spin case





Results: the role of a dynamic corona



Downward scattering component

$L_{2keV} \propto f(1-\eta)P_{accr}$

$\eta = 0.55$ was adopted, we then tested different η (also mimicking outflowing coronae)

(Haardt&Maraschi93)

(Beloborodov 99; Janiuk 00)