Are the accretion states of AGN and XRBs analogous?

Abhijeet Borkar
Jiri Svoboda, Peter Boorman, Emily Moravec, Daniel Kynoch

Astronomical Institute
of the Czech Academy of Sciences

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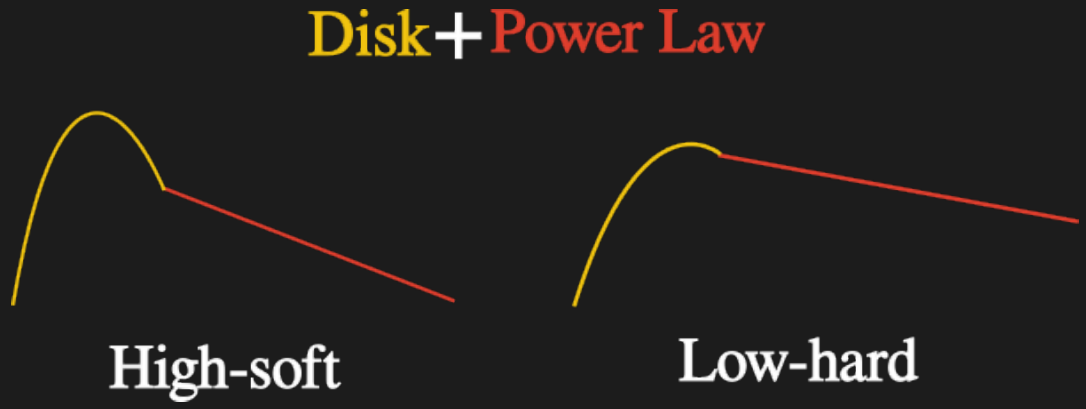
The Hardness-Intensity Diagram

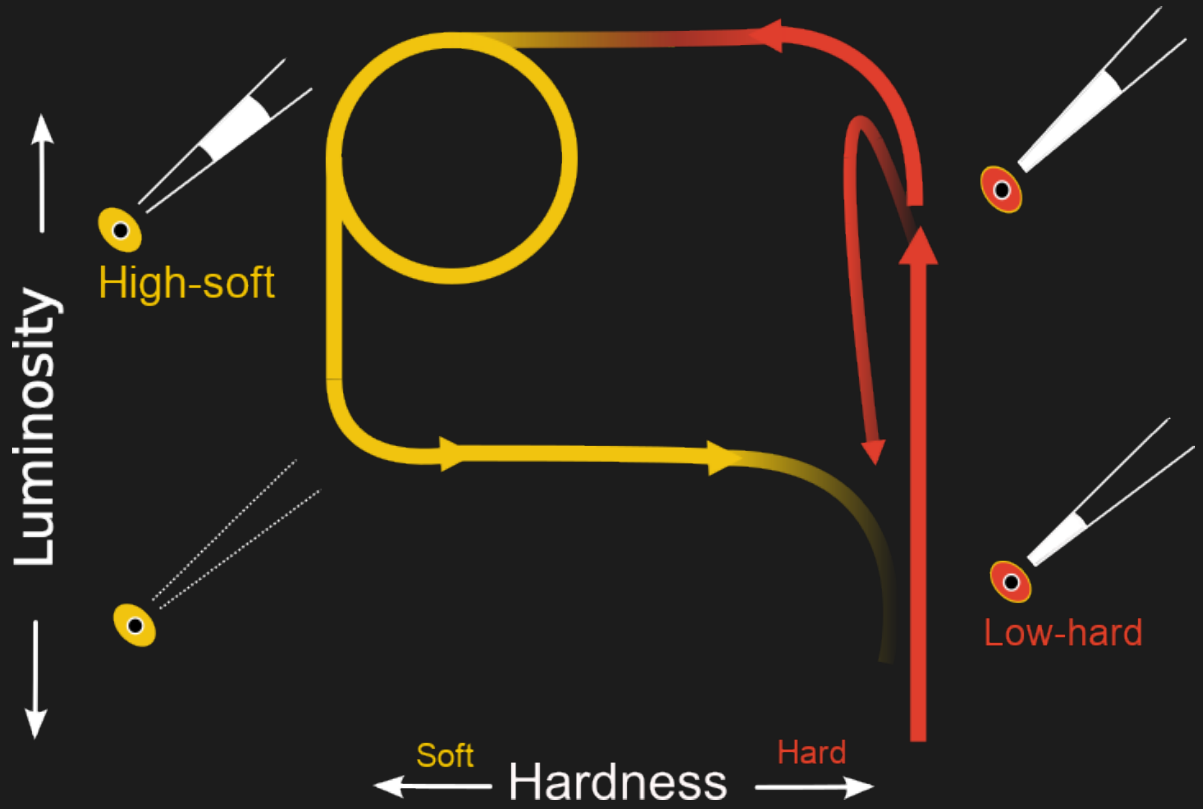
$$\text{Hardness} = \frac{L_{hard}}{L_{soft} + L_{hard}} = \frac{L_{PL}}{L_{disk} + L_{PL}}$$

High accretion mode:
0.1 – 1 L_{Edd}, dominated by thermal disk blackbody emission.

Low accretion mode:
<0.01 L_{Edd}, advection dominated emission, power-law spectrum in hard X-rays



The Hardness-Intensity Diagram



Based on Fender *et al.* (2004)

The Hardness-Intensity Diagram for AGNs

Direct comparison between XRBs and AGNs is not straightforward.

- The accretion disk is larger, lower in temperature, and located further away.
- Disk emission peaks in UV band, while the X-ray is dominated by power-law.
- Timescales ~ 10^5 years, instead of few hundred days.
- AGN masses span four orders of magnitude → Eddington ratio instead of luminosity.

Catalogue Compilation

1. Cross-match 4XMM and OMC5 with same RA-DEC and OBSID.
2. Cross-match with Veron-Cetty & Veron (2010) and SDSS DR14 AGN/quasar catalogs to get confirmed AGN.
3. Cross-match with VLA-FIRST and VLASS radio catalogs to get radio fluxes.
4. Quality cuts for: UV extension, UV detection significance, exposure, X-ray obscuration. Remove: blazars, $z < 0.001$ sources.
5. Same procedure for BAT AGN Spectroscopic Survey (BASS) sources.

Estimating Luminosity

Total luminosity:

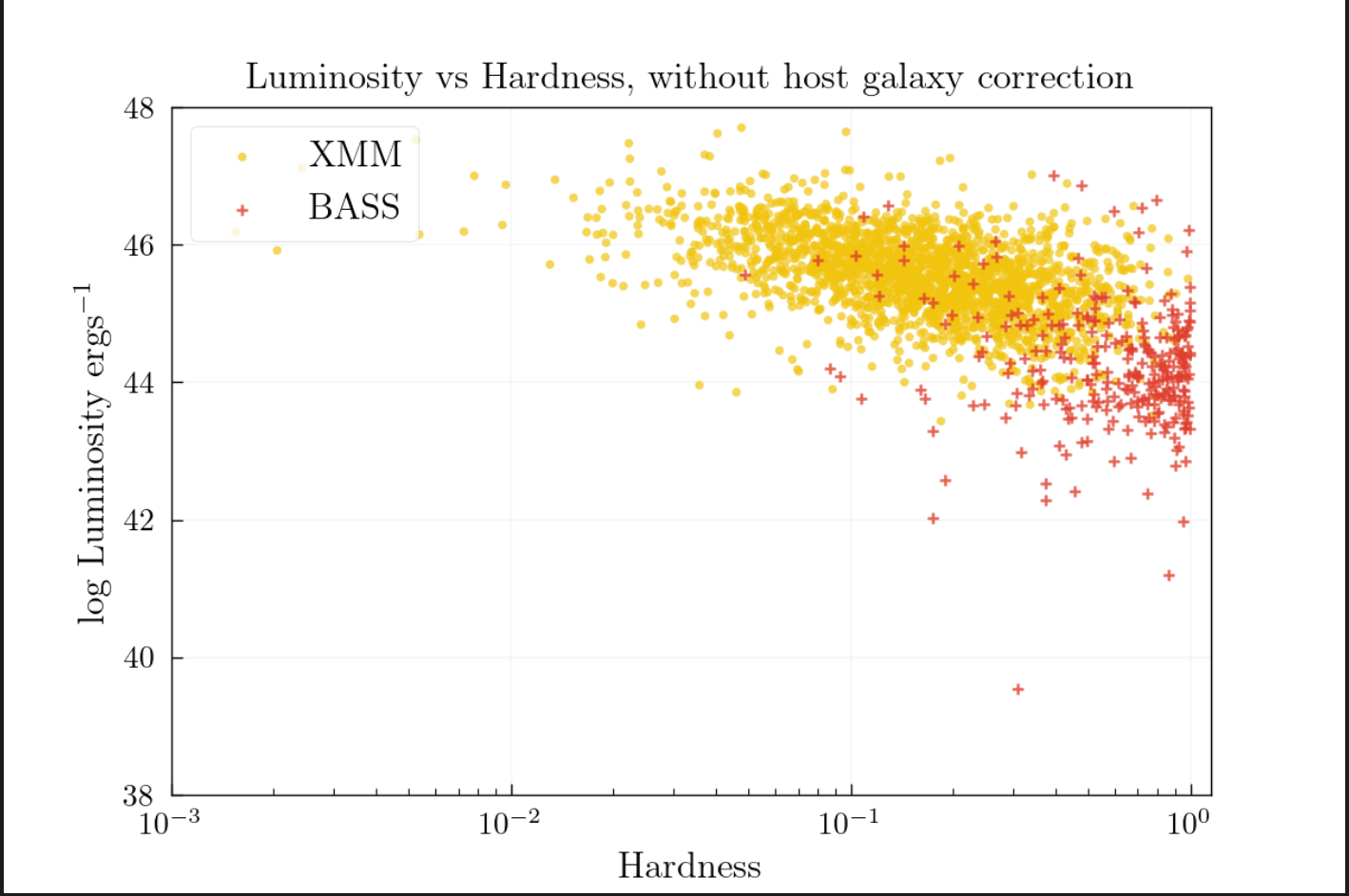
$$L_{tot} = L_X + L_{UV}$$

L_X: 0.1 – 100 keV luminosity obtained from extrapolating 2-10 keV flux.

L_{UV}: obtained from estimating the slope of UV flux in OMC fluxes.

BH mass obtained from SDSS DR 16 BH mass catalog (Rakshit et al. 2020)

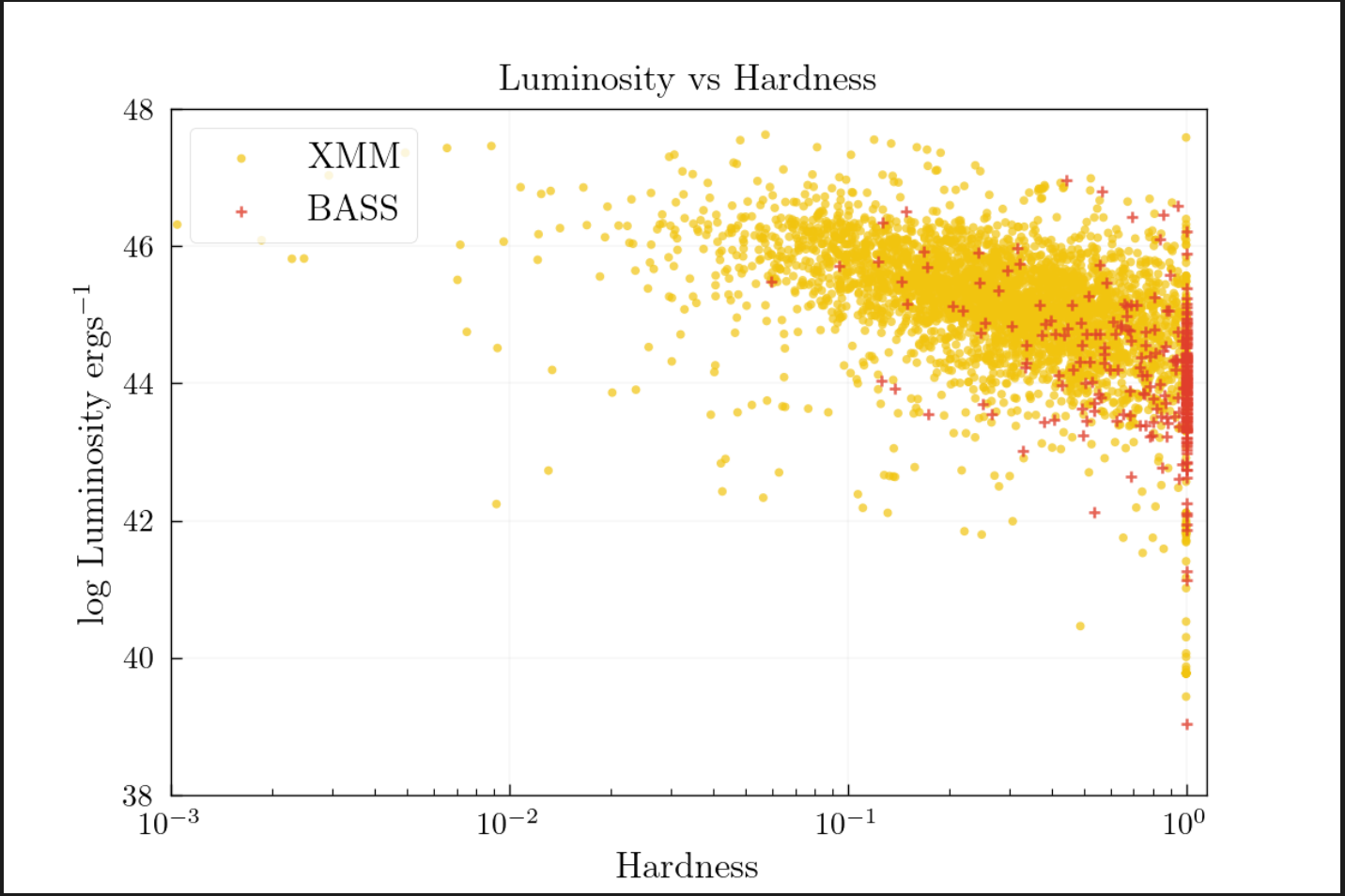
The Hardness-Intensity Diagram for AGN

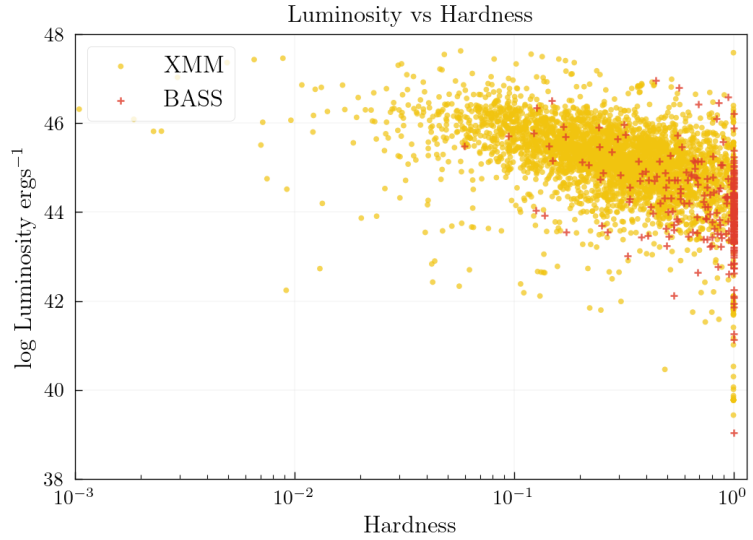


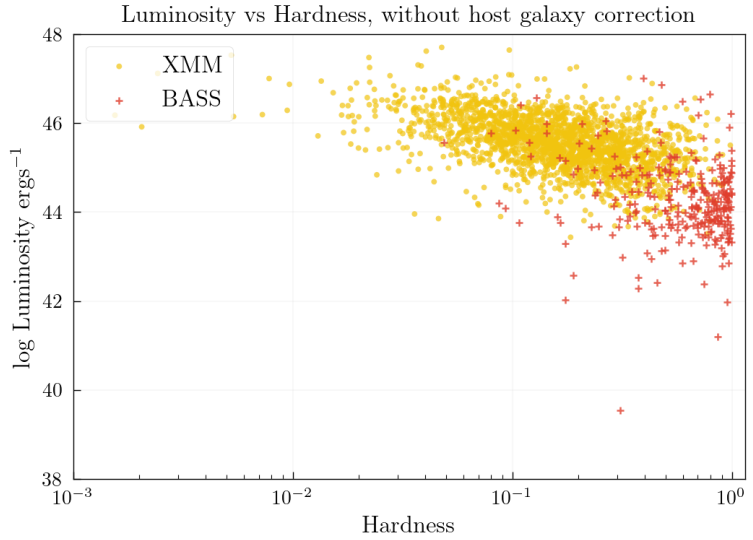
Catalogue Compilation

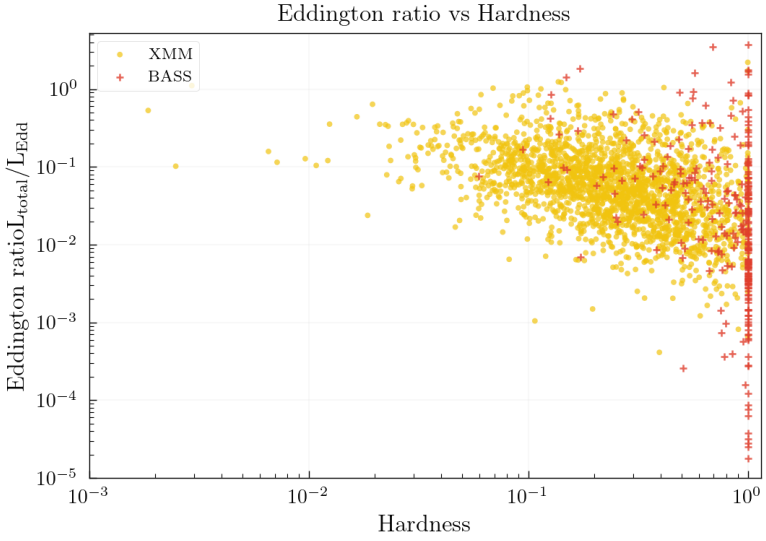
- **Host galaxy subtraction:**
  1. Estimate SFR from X-ray and UV luminosity, and remove SF contribution to total luminosity.
  2. Moves sources to right and bottom.
  3. Crude method, needs sophisticated approach (D. Kynoch+), but does not affect overall results.

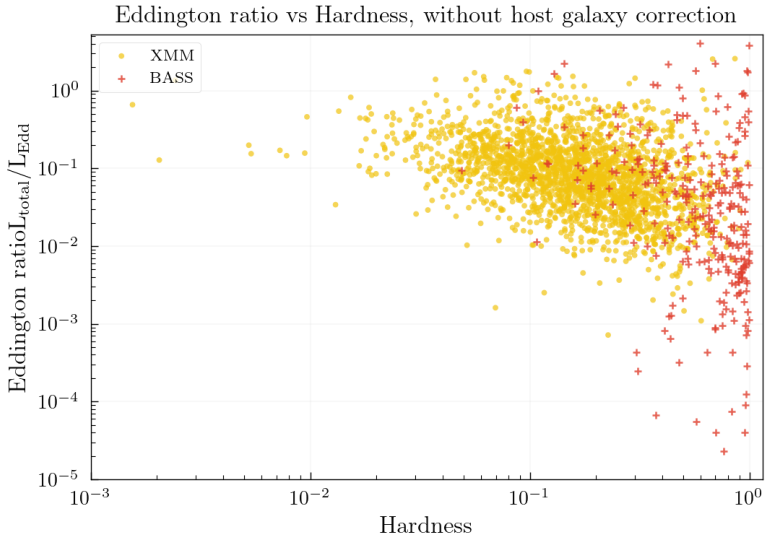
The Hardness-Intensity Diagram for AGN



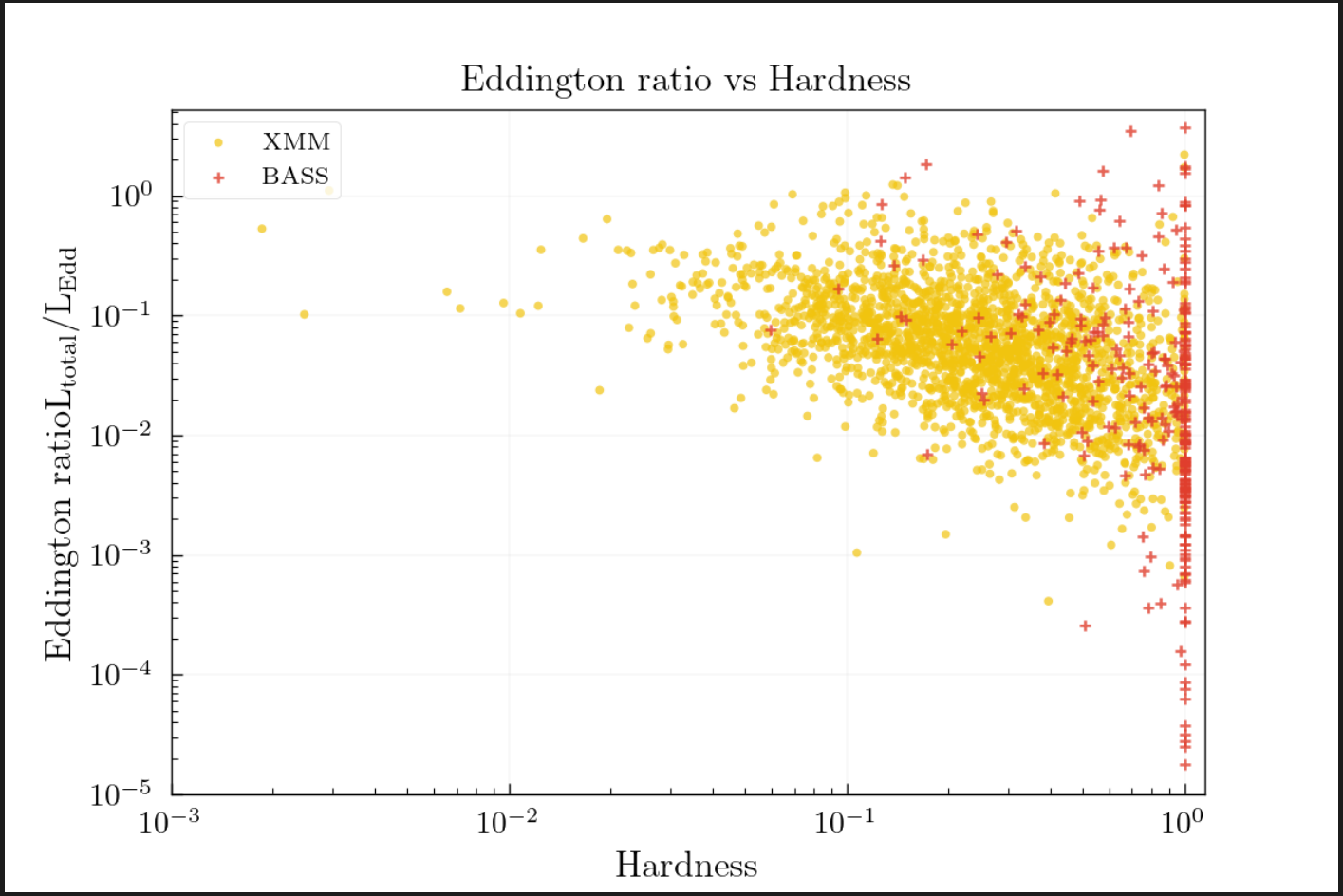

Luminosity vs Hardness
XMM
BASS
log Luminosity ergs^{-1}
Hardness
48
46
44
42
40
38
10^{-3}
10^{-2}
10^{-1}
10^{0}

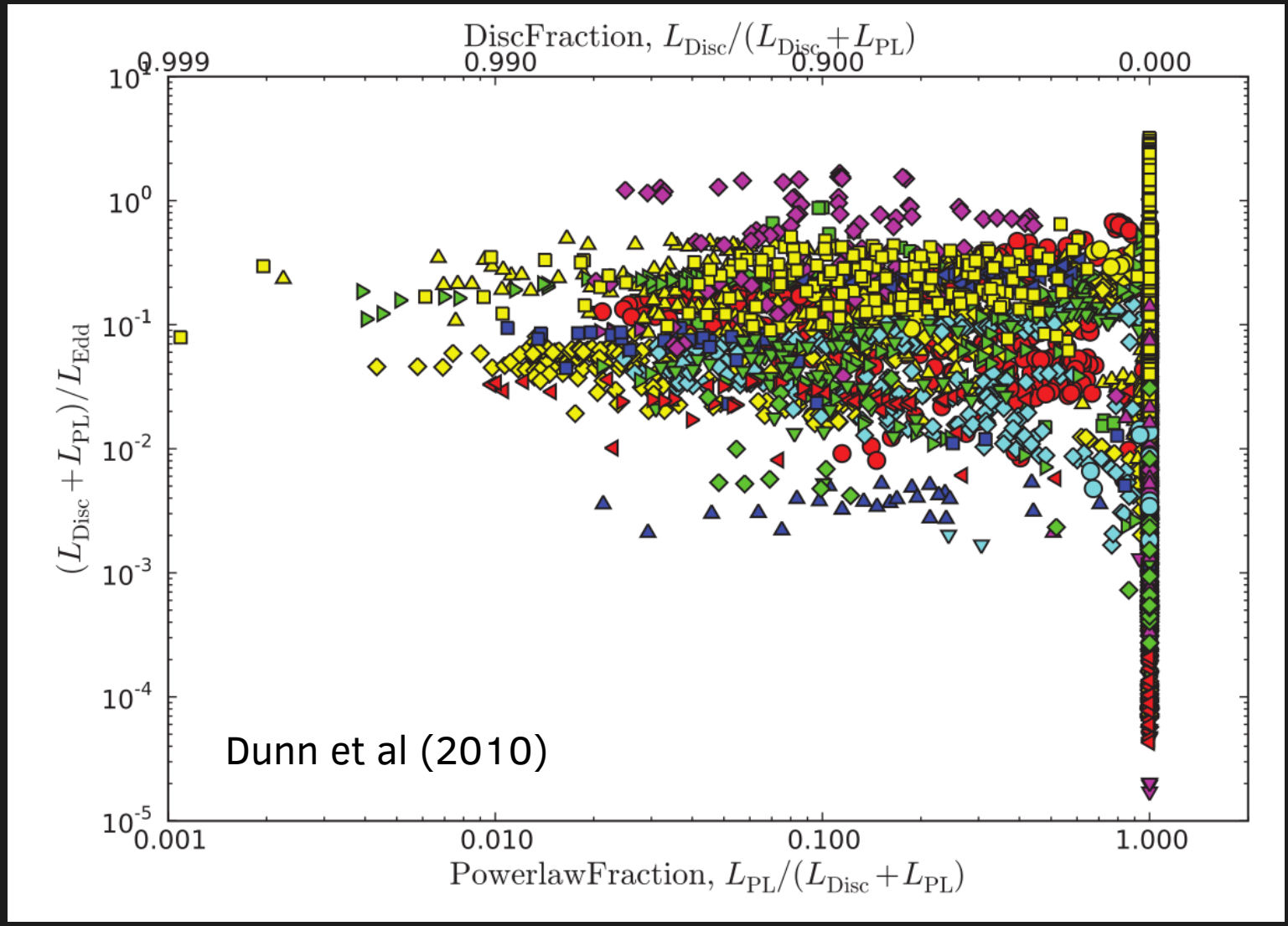

Luminosity vs Hardness, without host galaxy correction
XMM
BASS
log Luminosity ergs^{-1}
Hardness
48
46
44
42
40
38
10^{-3}
10^{-2}
10^{-1}
10^{0}


Eddington ratio vs Hardness
XMM
BASS
Eddington ratioL$_{\text{total}}$/L$_{\text{Edd}}$
Hardness
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-3}
10^{-2}
10^{-1}
10^{0}

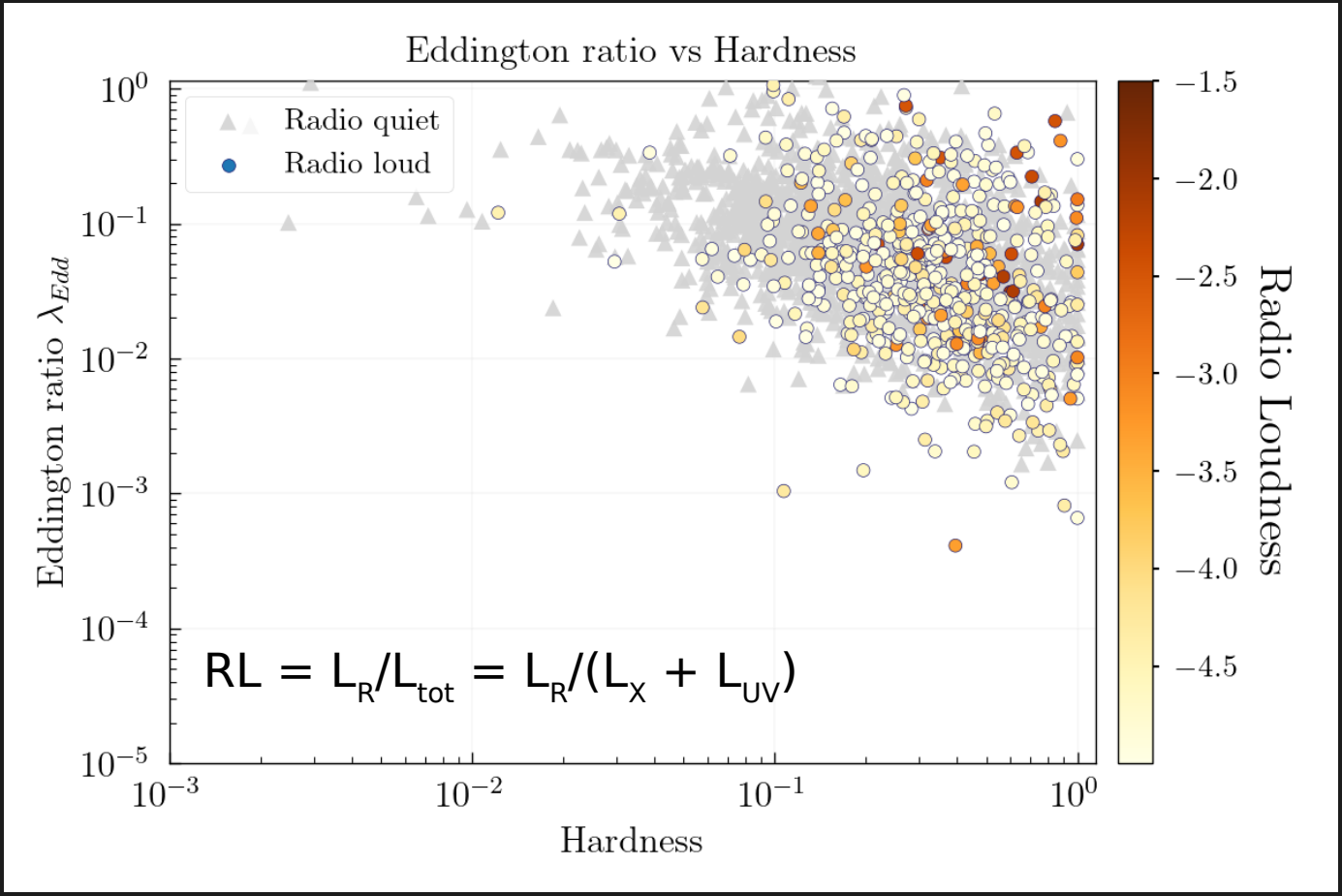

Eddington ratio vs Hardness, without host galaxy correction
XMM
BASS
Eddington ratioL$_{\text{total}}$/L$_{\text{Edd}}$
Hardness
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-3}
10^{-2}
10^{-1}
10^{0}

The Hardness-Intensity Diagram for AGN

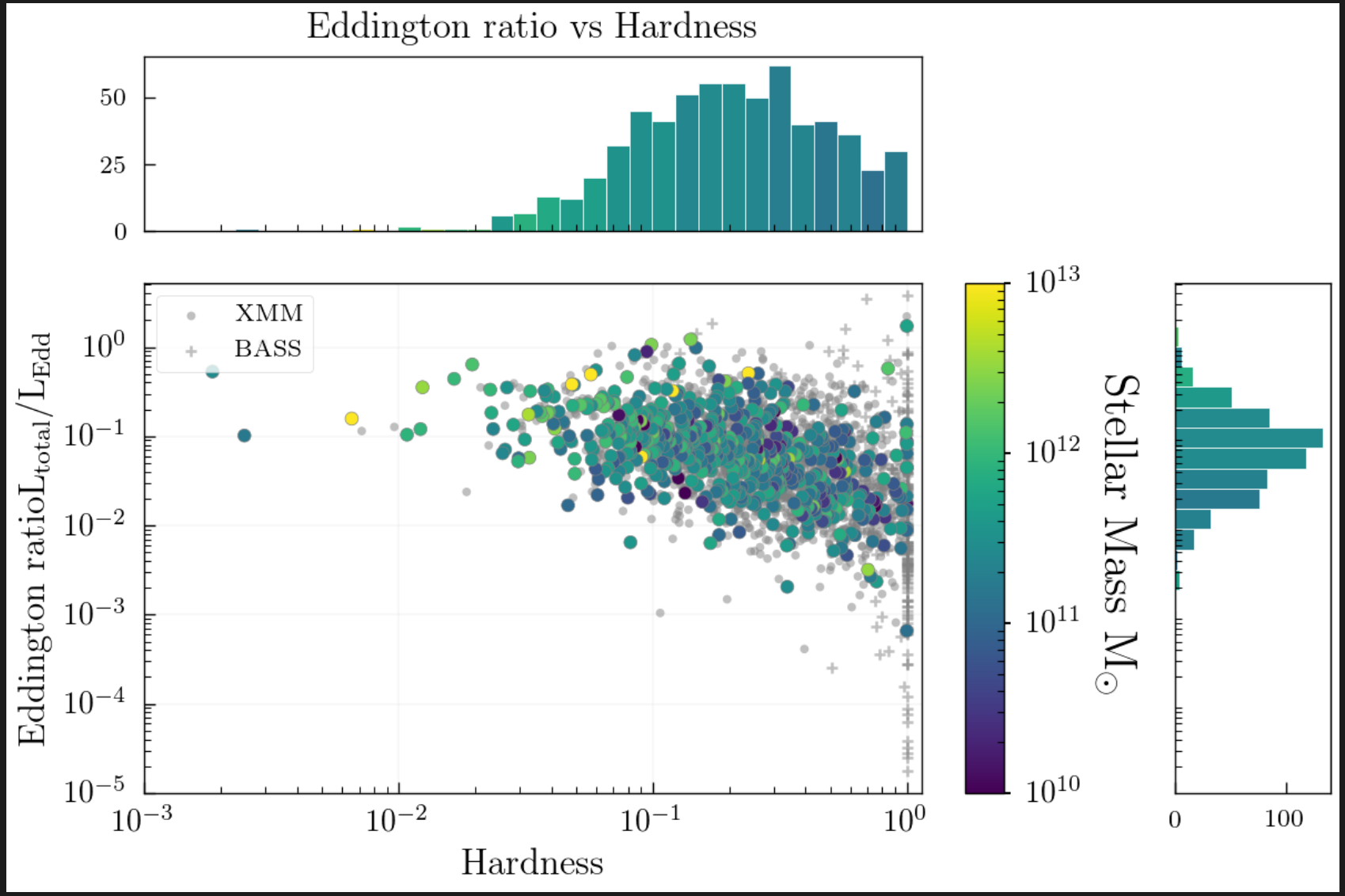


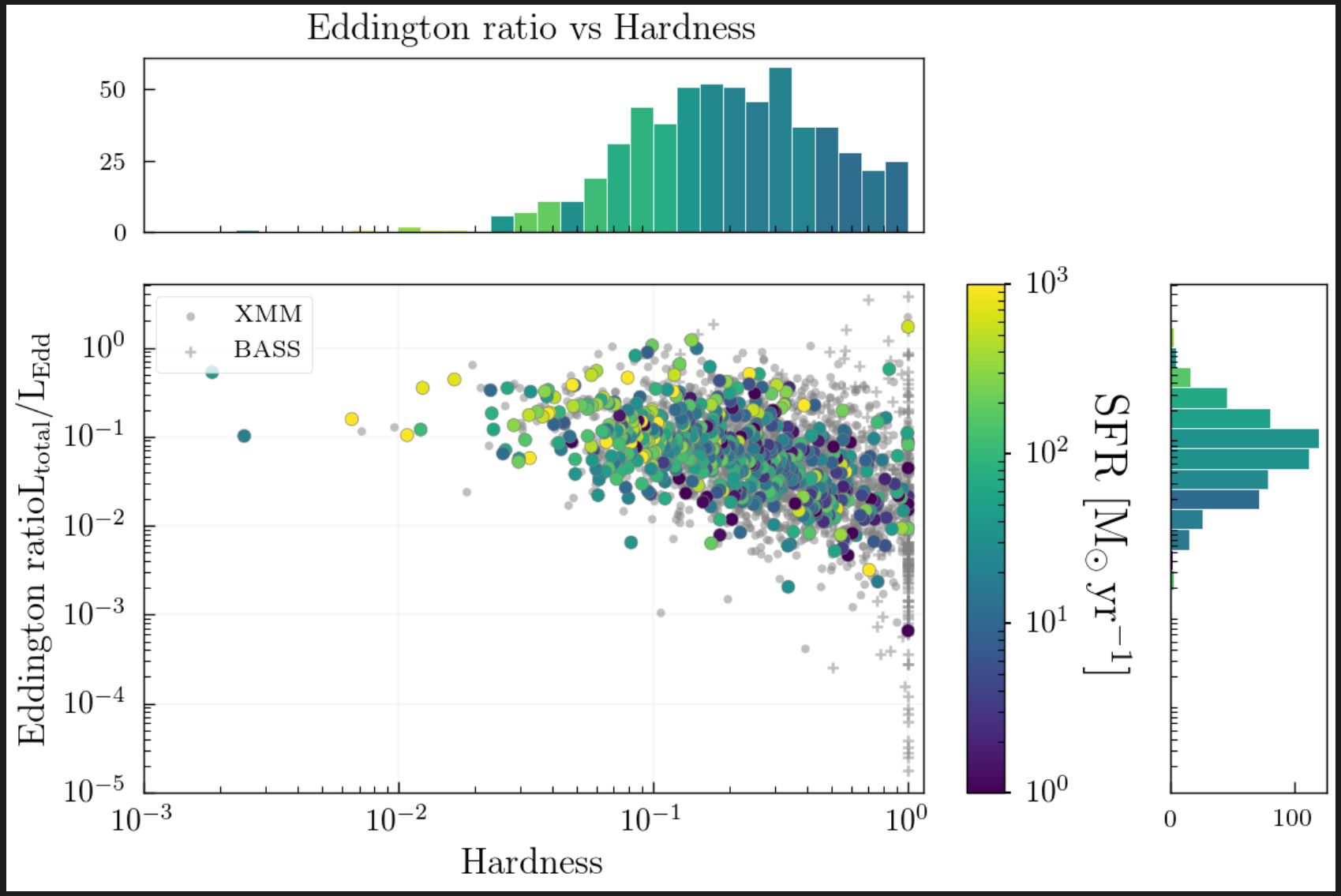

DiscFraction, $L_{\rm Disc}/(L_{\rm Disc}+L_{\rm PL})$
0.999
0.990
0.900
0.000
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$(L_{\rm Disc}+L_{\rm PL})/L_{\rm Edd}$
0.001
0.010
0.100
1.000
PowerlawFraction, $L_{\rm PL}/(L_{\rm Disc}+L_{\rm PL})$
Dunn et al (2010)

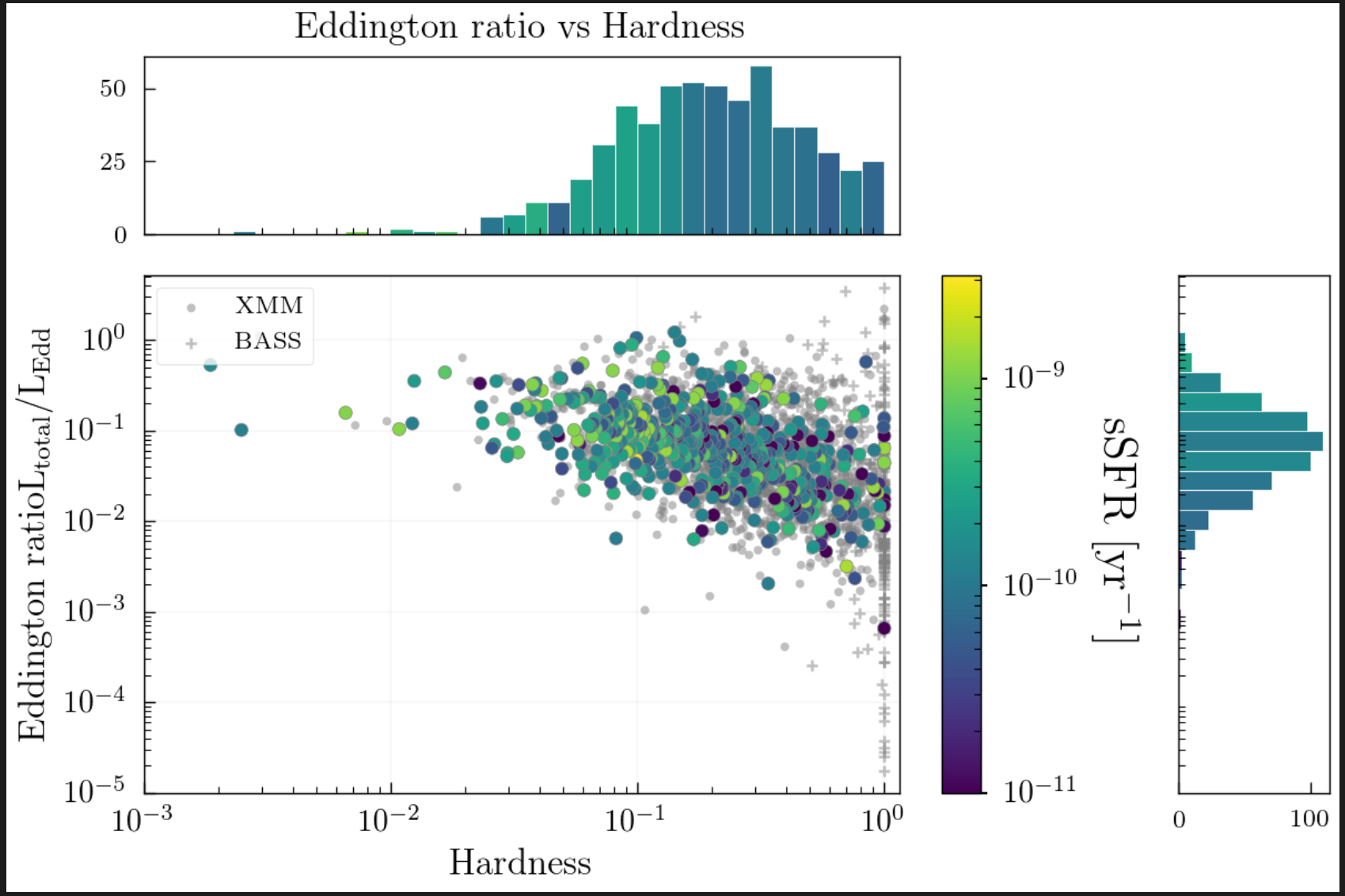
Radio Luminosity

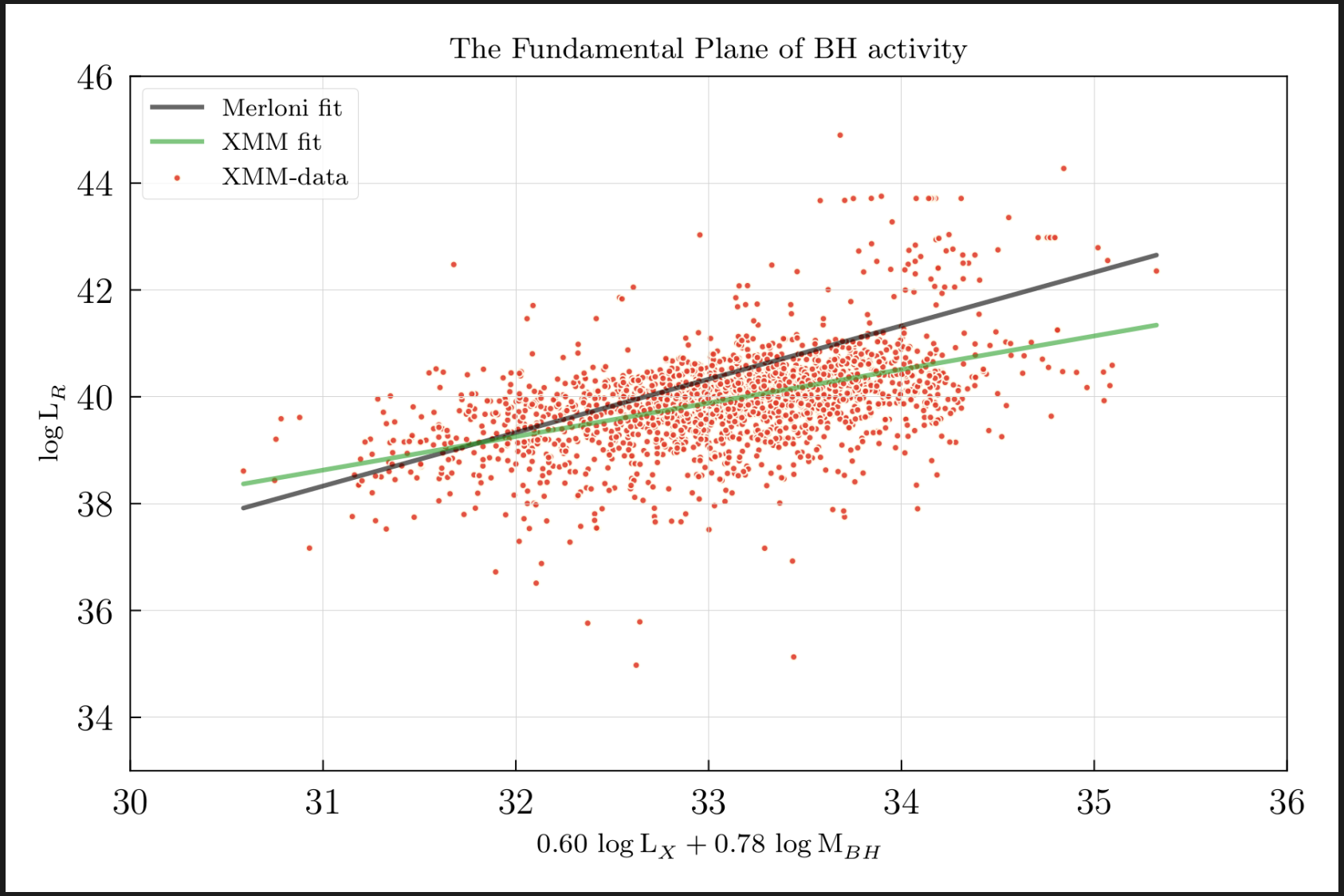


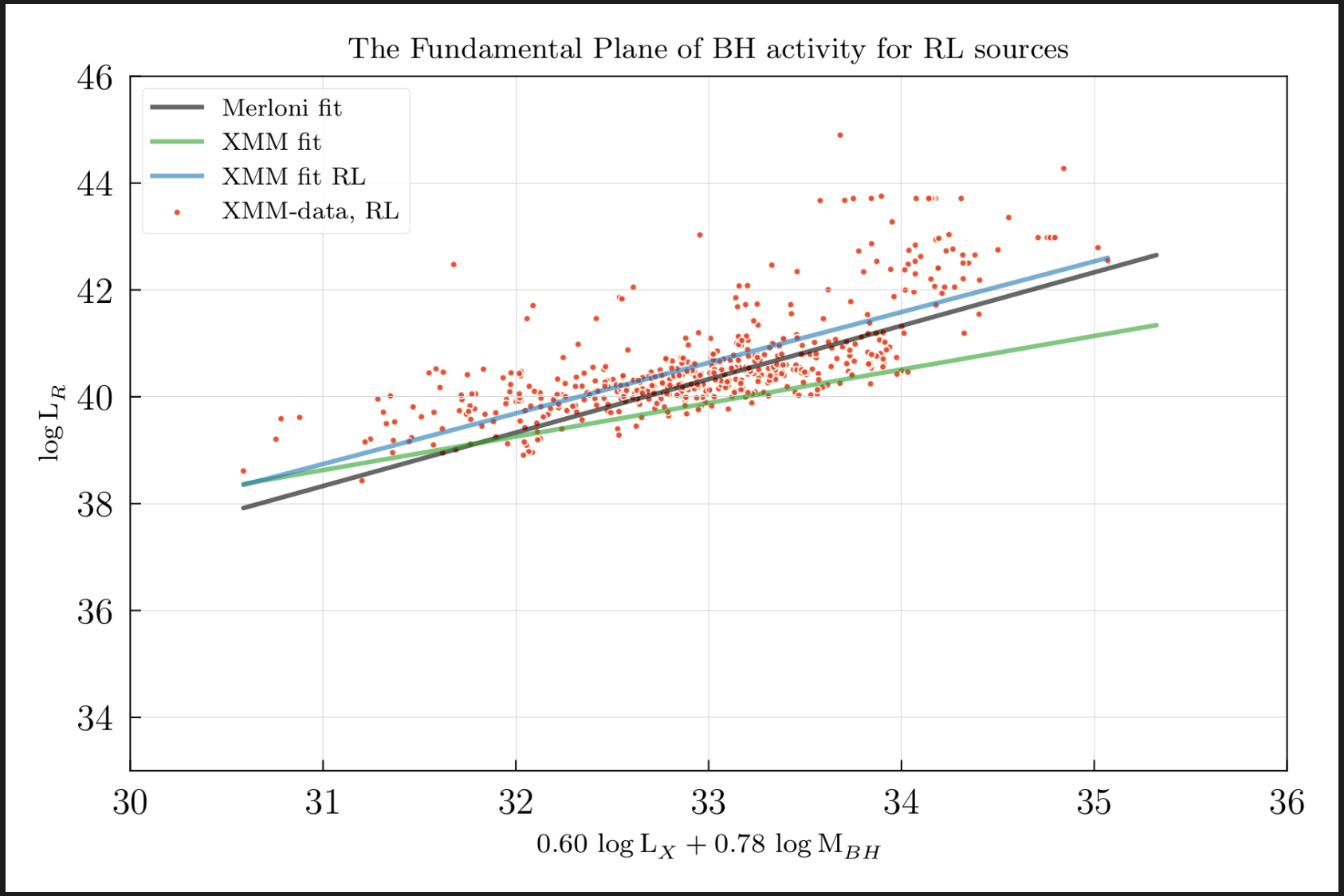
Host Galaxy Properties


Eddington ratio vs Hardness
50
25
0
XMM
BASS
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Eddington ratioL$_{\text{total}}$/L$_{\text{Edd}}$
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness
10^{13}
10^{12}
10^{11}
10^{10}
Stellar Mass M$_{\odot}$
0
100


Eddington ratio vs Hardness
50
25
0
XMM
BASS
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Eddington ratioL$_{\rm total}$/L$_{\rm Edd}$
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness
10^{3}
10^{2}
10^{1}
10^{0}
SFR [M$_\odot$ yr^{-1}]
0
100


Eddington ratio vs Hardness
50
25
0
XMM
BASS
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Eddington ratioL_{total}/L_{Edd}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness
10^{-9}
10^{-10}
10^{-11}
sSFR [yr^{-1}]
0
100


The Fundamental Plane of BH activity
Merloni fit
XMM fit
XMM-data
46
44
42
40
38
36
34
log L$_R$
30
31
32
33
34
35
36
0.60 log L$_X$ + 0.78 log M$_{BH}$


The Fundamental Plane of BH activity for RL sources
Merloni fit
XMM fit
XMM fit RL
XMM-data, RL
46
44
42
40
38
36
34
log L_R
30
31
32
33
34
35
36
0.60 log L_X + 0.78 log M_BH

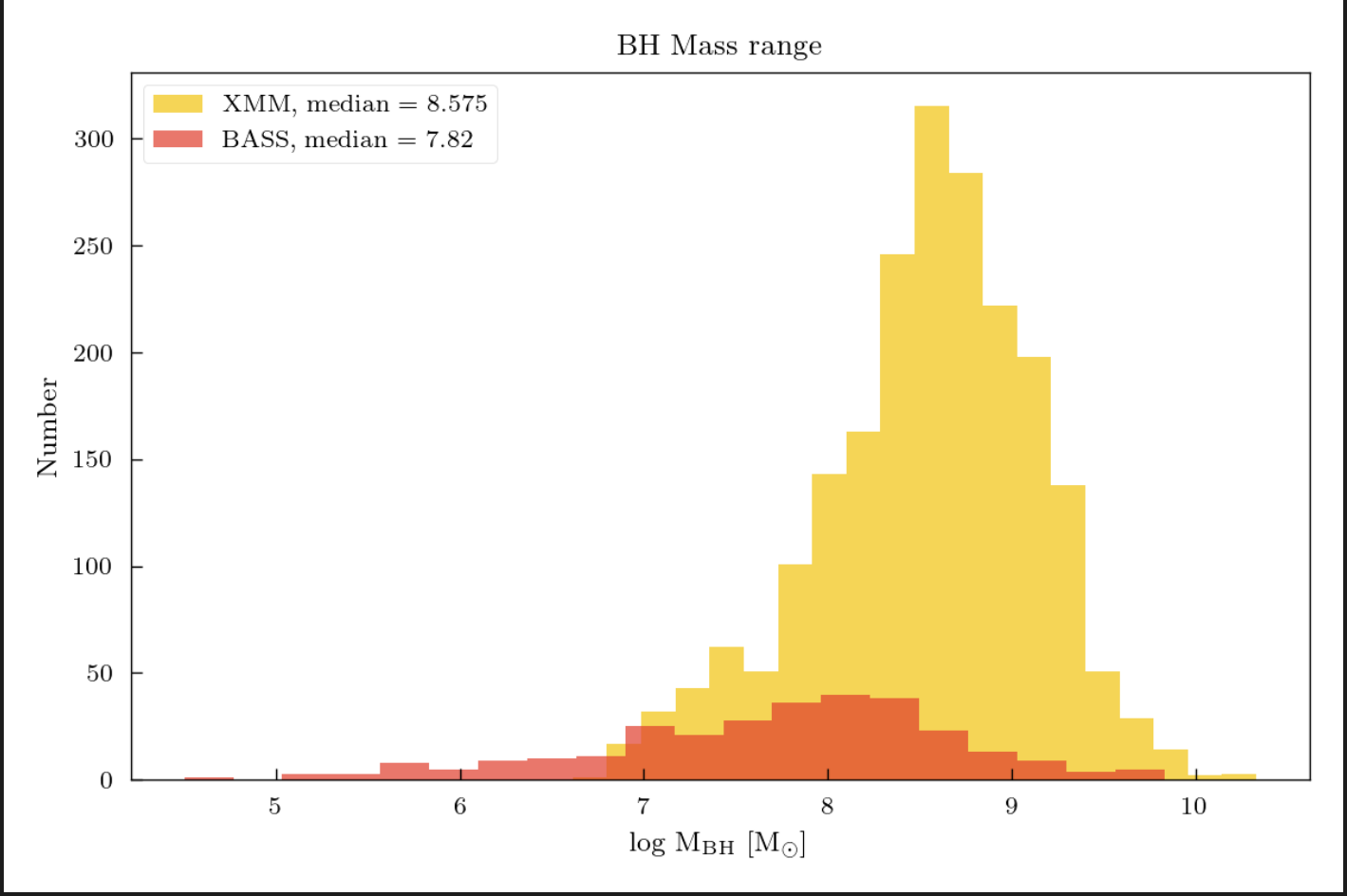
Conclusions:

- Stellar mass BHs in XRBs and SMBHs in AGNs have similar accretion states.
- Numerous quasars in the XMM-Newton sample are in the high-soft state.
- Many low-luminosity AGN from the BASS sample are in the low-hard state.
- Radio-loud sources are predominantly in the hard part of the HID. (see Jiri Svoboda's talk for more on radio AGN accretion states).
- The position within HID and host galaxy properties are somewhat correlated, suggesting a possible coevolution of AGN and host galaxy.

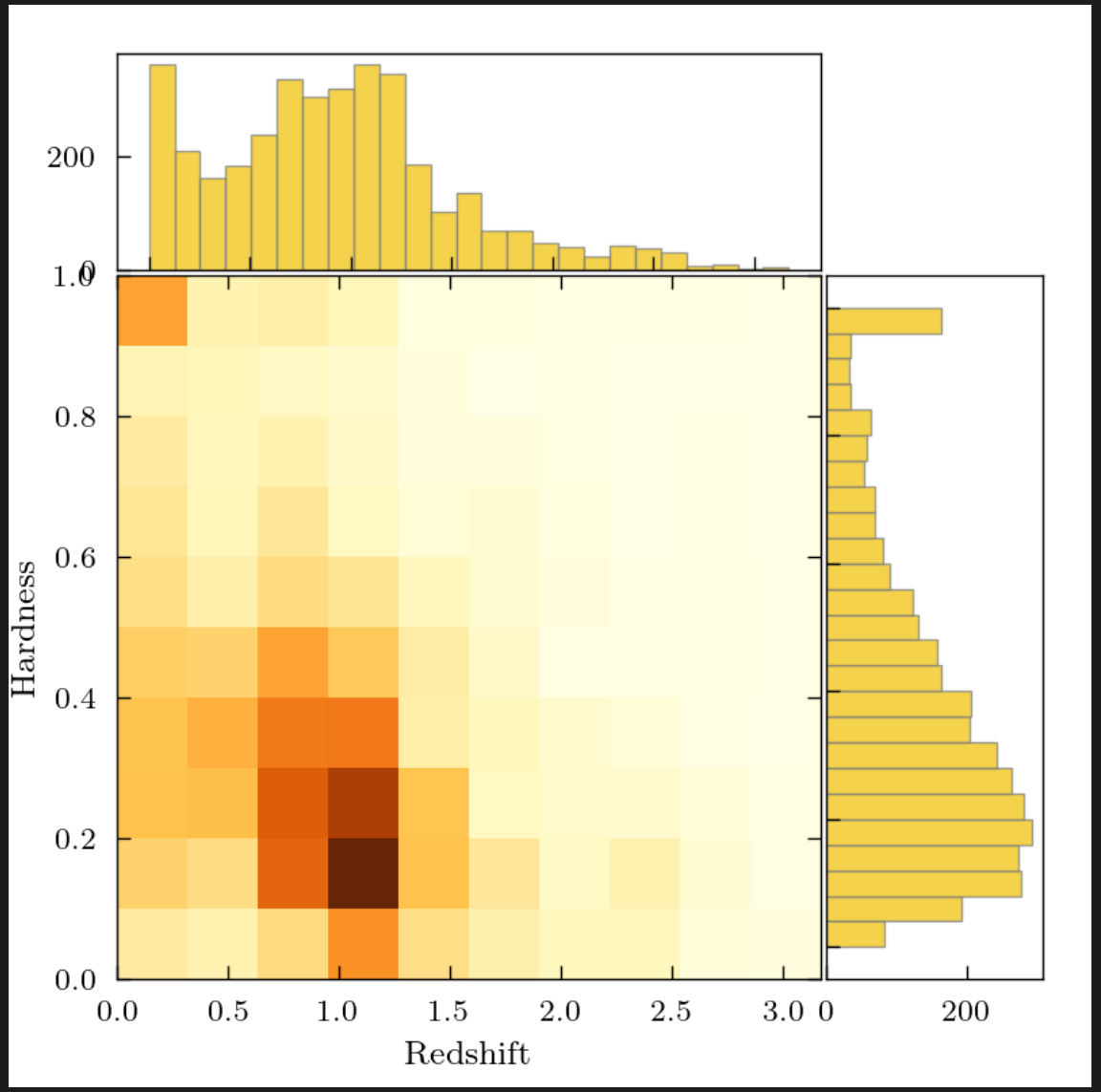
Work in Progress:

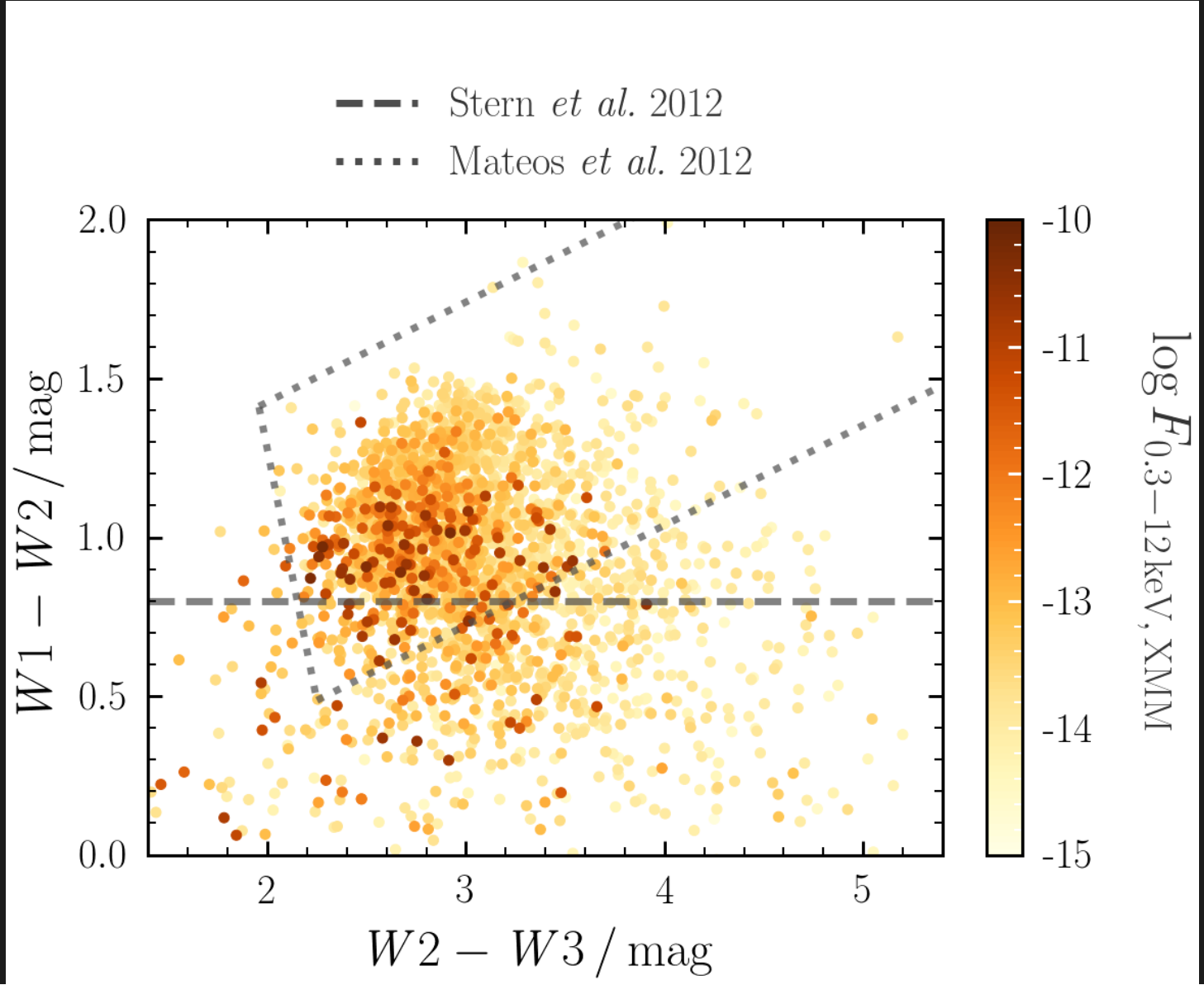
- Positioning sources in the HID with respect to
  - Seyfert type,
  - BPT classification,
  - nuclear obscuration.
- Evolution of HID and AGN properties with redshift.
- Changing-look AGN: are they AGN in accretion state transition?

Extra Slides



Extra Slides




Stern et al. 2012
Mateos et al. 2012
2.0
1.5
1.0
0.5
0.0
W1 − W2 / mag
2
3
4
5
W2 − W3 / mag
-10
-11
-12
-13
-14
-15
log F0.3−12keV, XMM