Are the accretion states of AGNs and XRBs analogous?

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Brno, Czechia
20th February 2023


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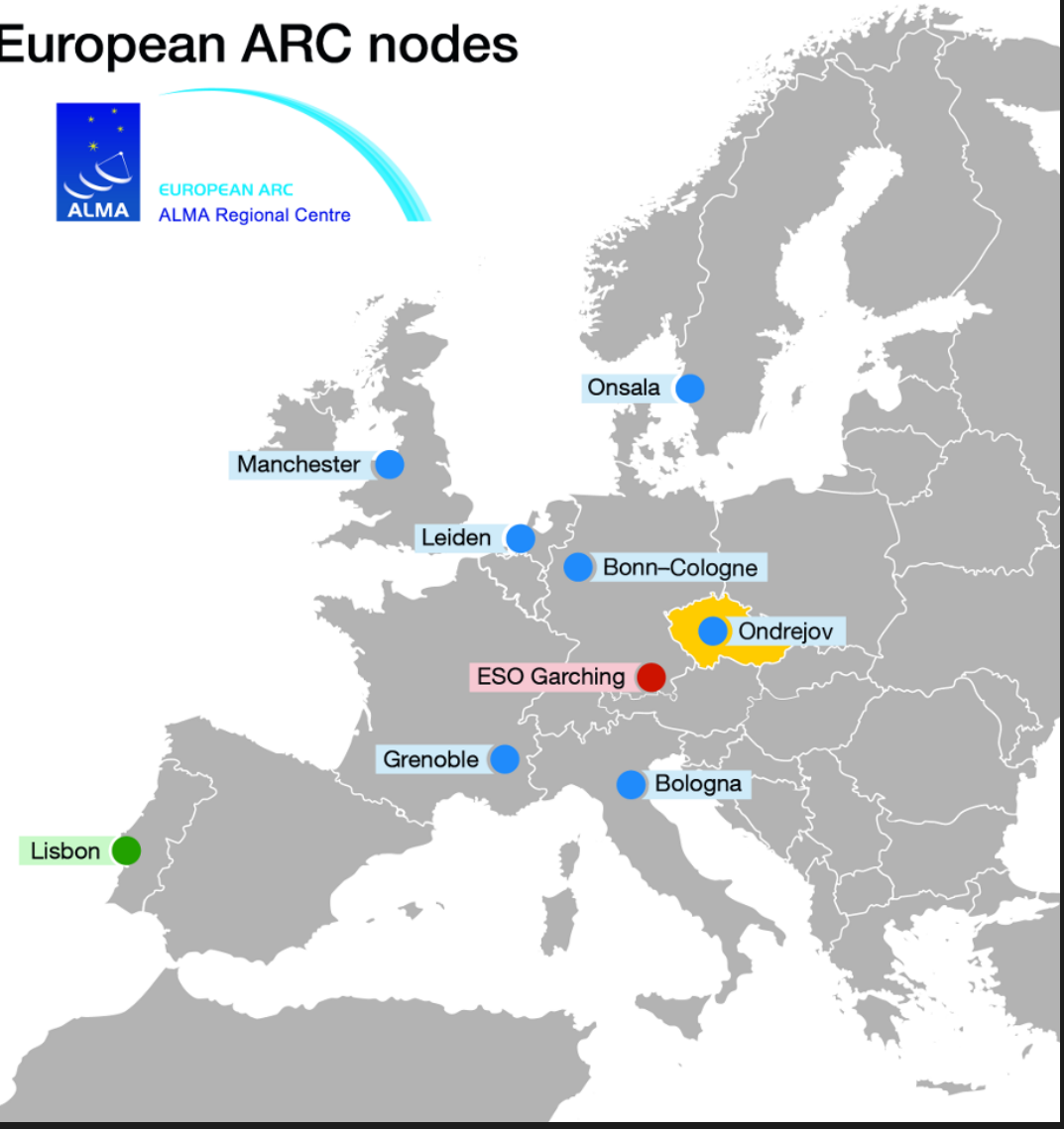


Meeting of ALMA Young Astronomers

MAYA 2023

- A conference targeted towards Early Career Astronomers.
- All astronomical subjects, ALMA observing modes, observations, simulations, technical & instrumentation are welcome.
- Fully online, interaction with ALMA staff, social events.

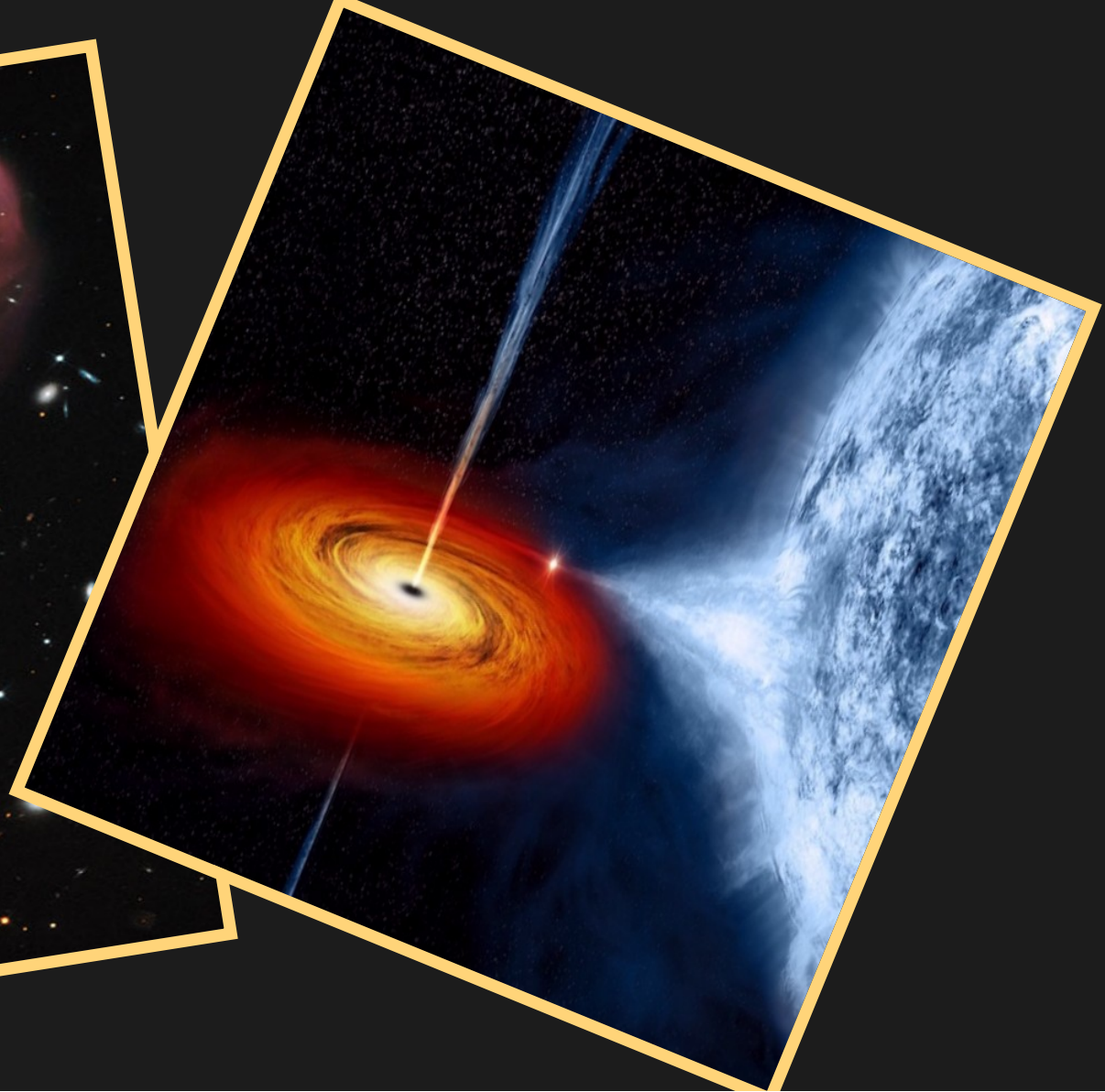
On-line event: 2023 March 6 - 10

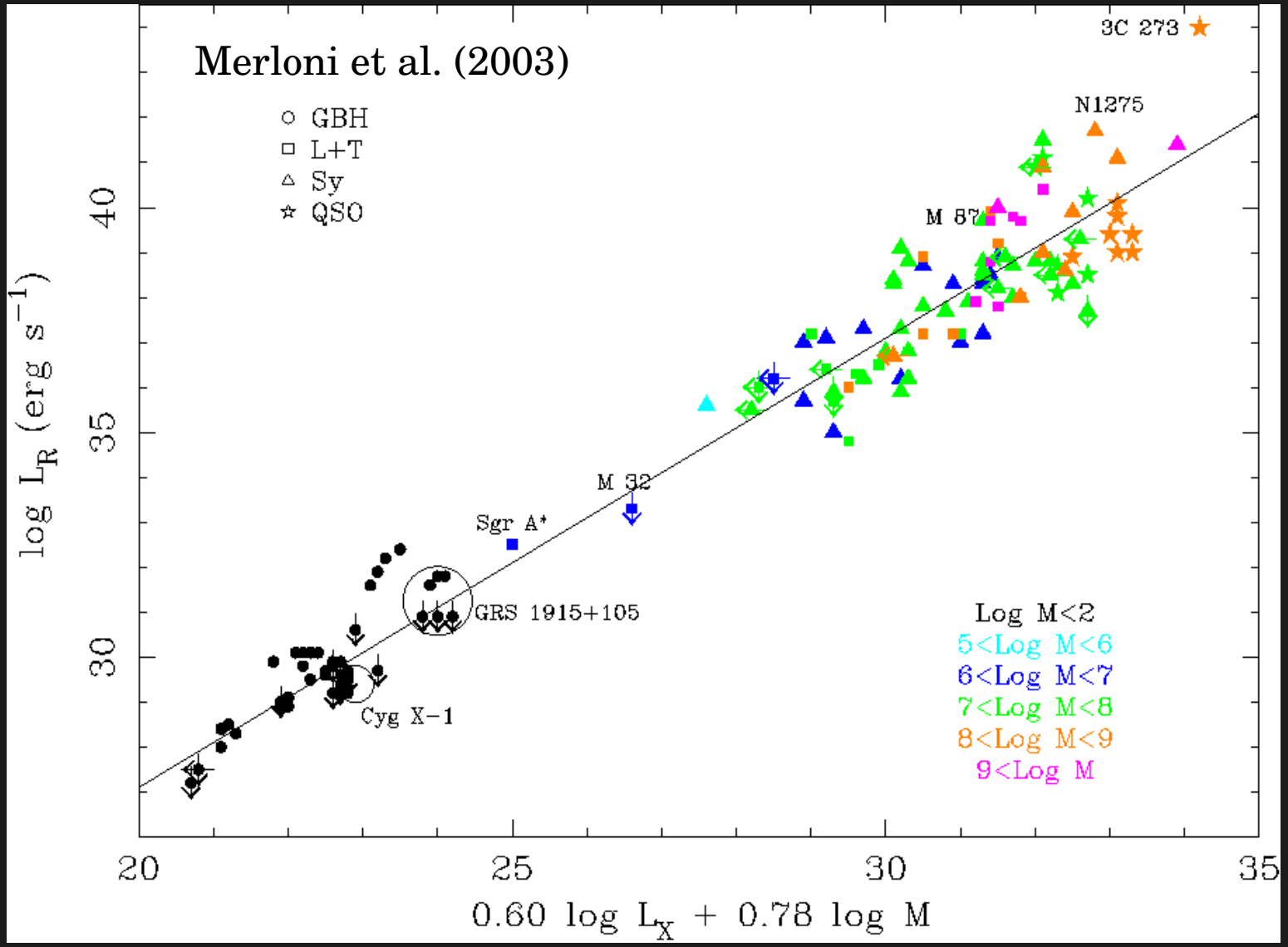
Scan QR code for details

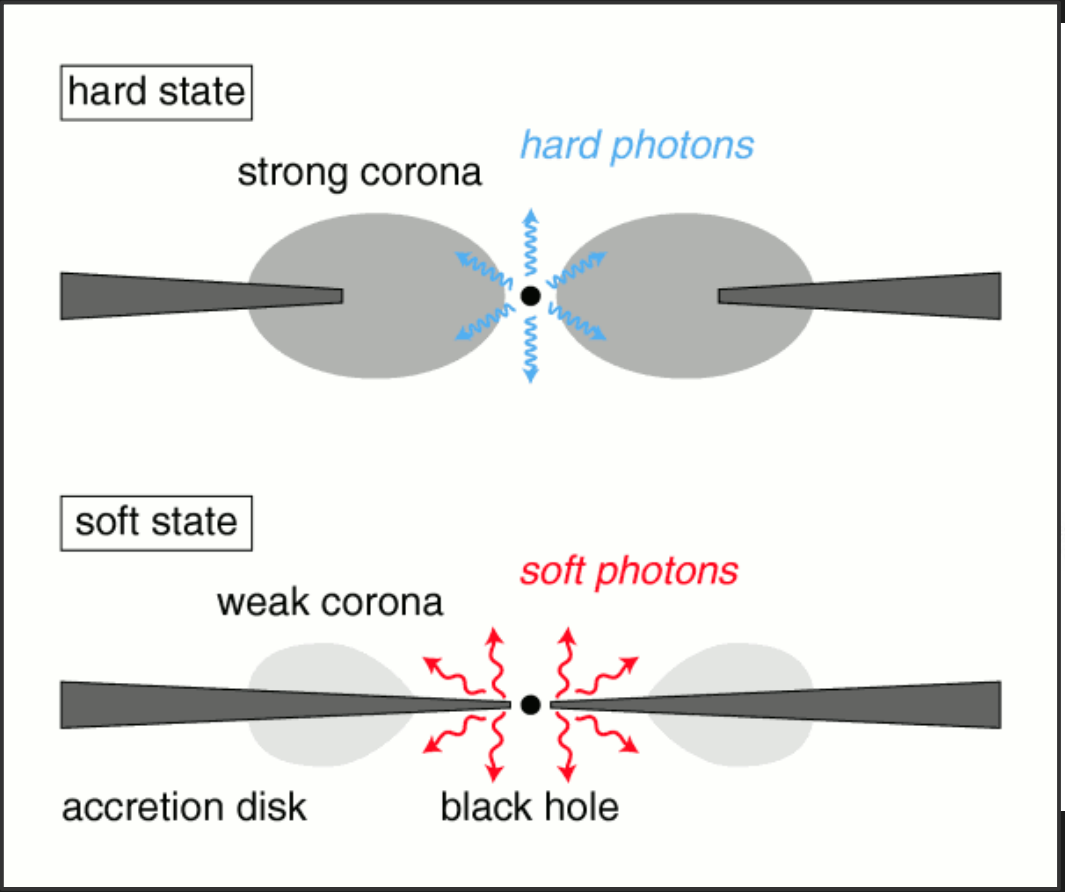
Ongoing Projects

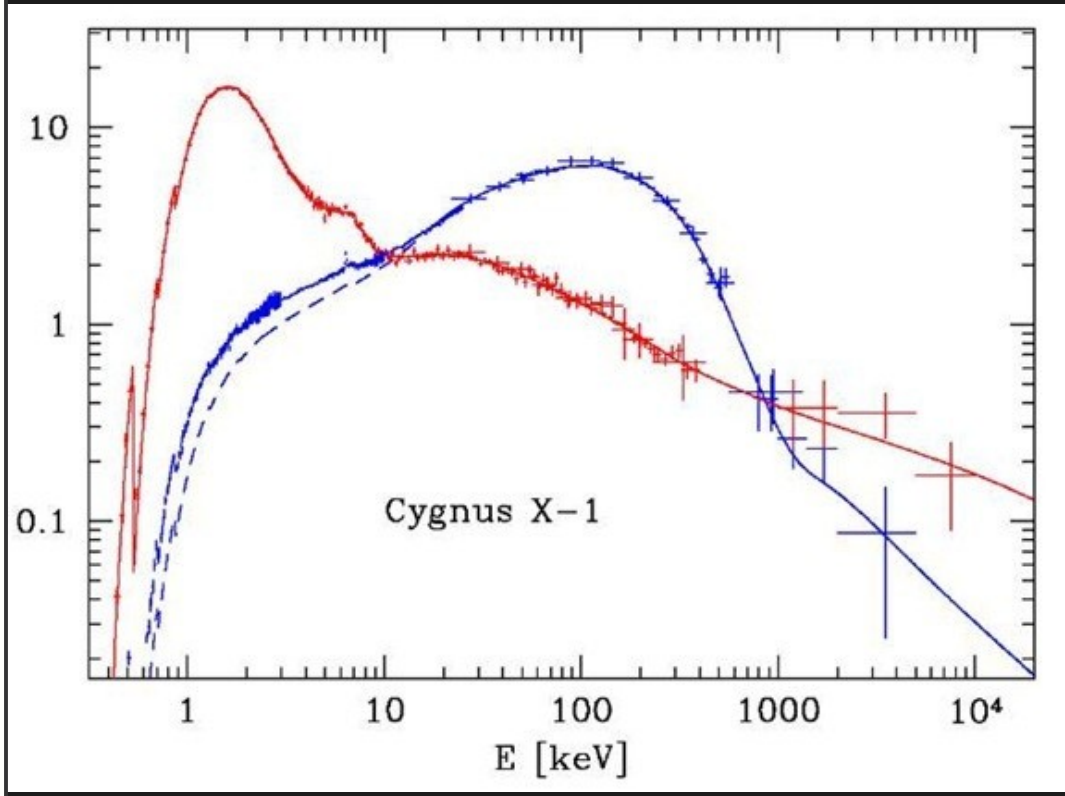
- AGN in Dwarf Galaxies
  - Multifrequency observations of Green Pea and Blueberry galaxies.
- AGN Feedback
  - Interaction between AGN emission & surrounding medium (Borkar+21; 23-in-prep.)
- Feeding AGN
  - Studying the impact of galaxy mergers on SMBH growth & AGN activity.

Are the accretion states of AGNs and XRBs analogous?




Merloni et al. (2003)
GBH
L+T
Sy
QSO
3C 273
N1275
M 87
M 32
Sgr A*
GRS 1915+105
Cyg X-1
Log M<2
5<Log M<6
6<Log M<7
7<Log M<8
8<Log M<9
9<Log M
log L_R (erg s^{-1})
0.60 log L_X + 0.78 log M
20
25
30
35
30
35
40


hard state
strong corona
hard photons
soft state
weak corona
soft photons
accretion disk
black hole

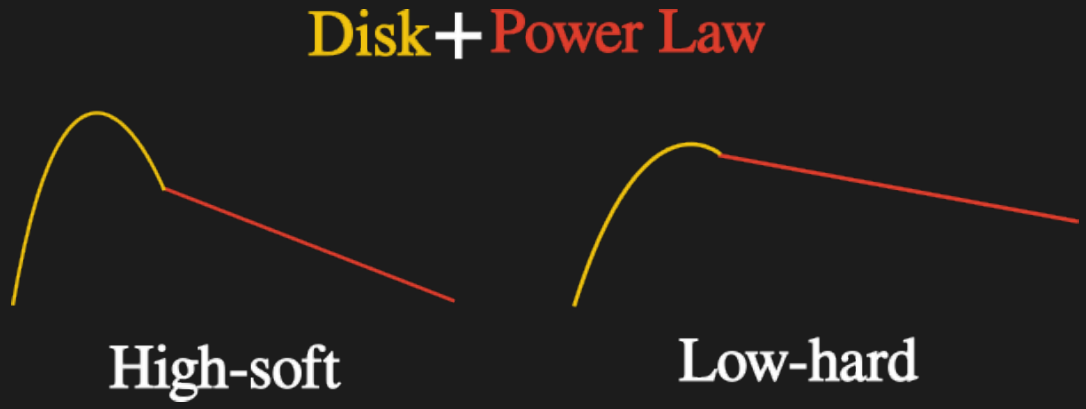

10
1
0.1
Cygnus X−1
1
10
100
1000
10⁴
E [keV]

The Hardness-Intensity Diagram

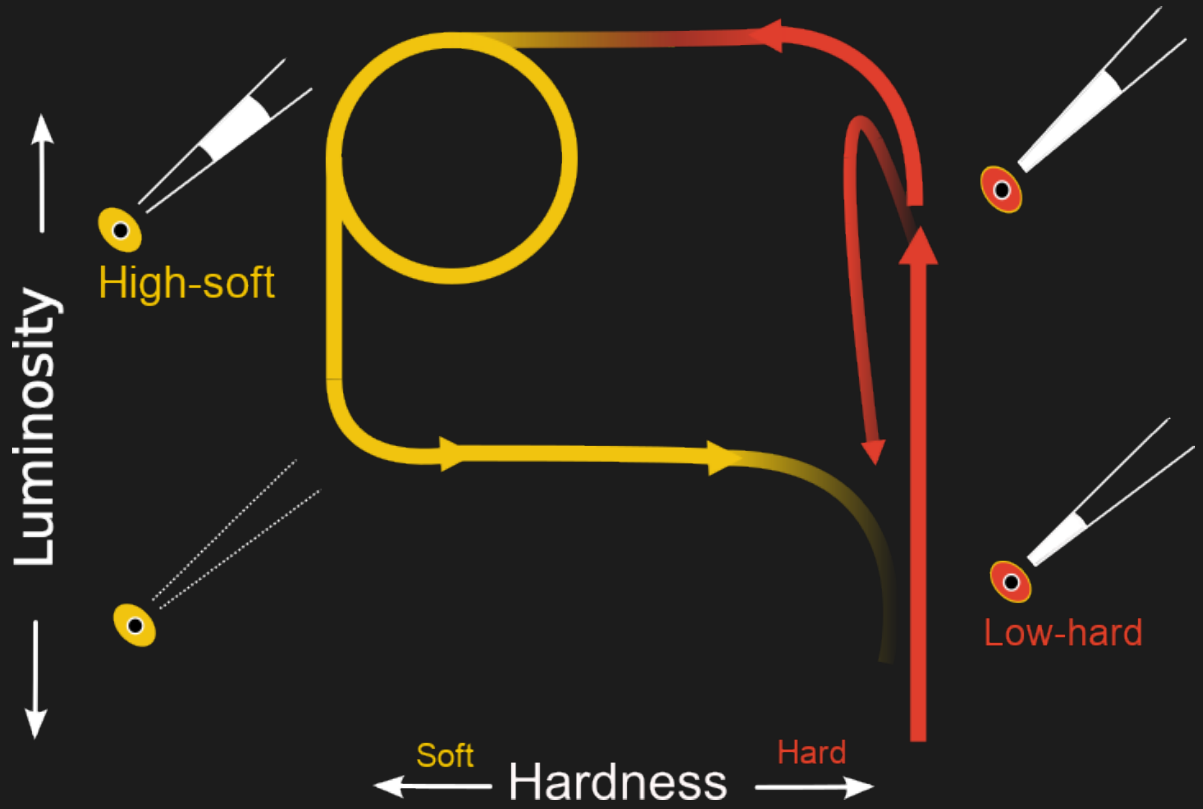
$$\text{Hardness} = \frac{L_{hard}}{L_{soft} + L_{hard}} = \frac{L_{PL}}{L_{disk} + L_{PL}}$$

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

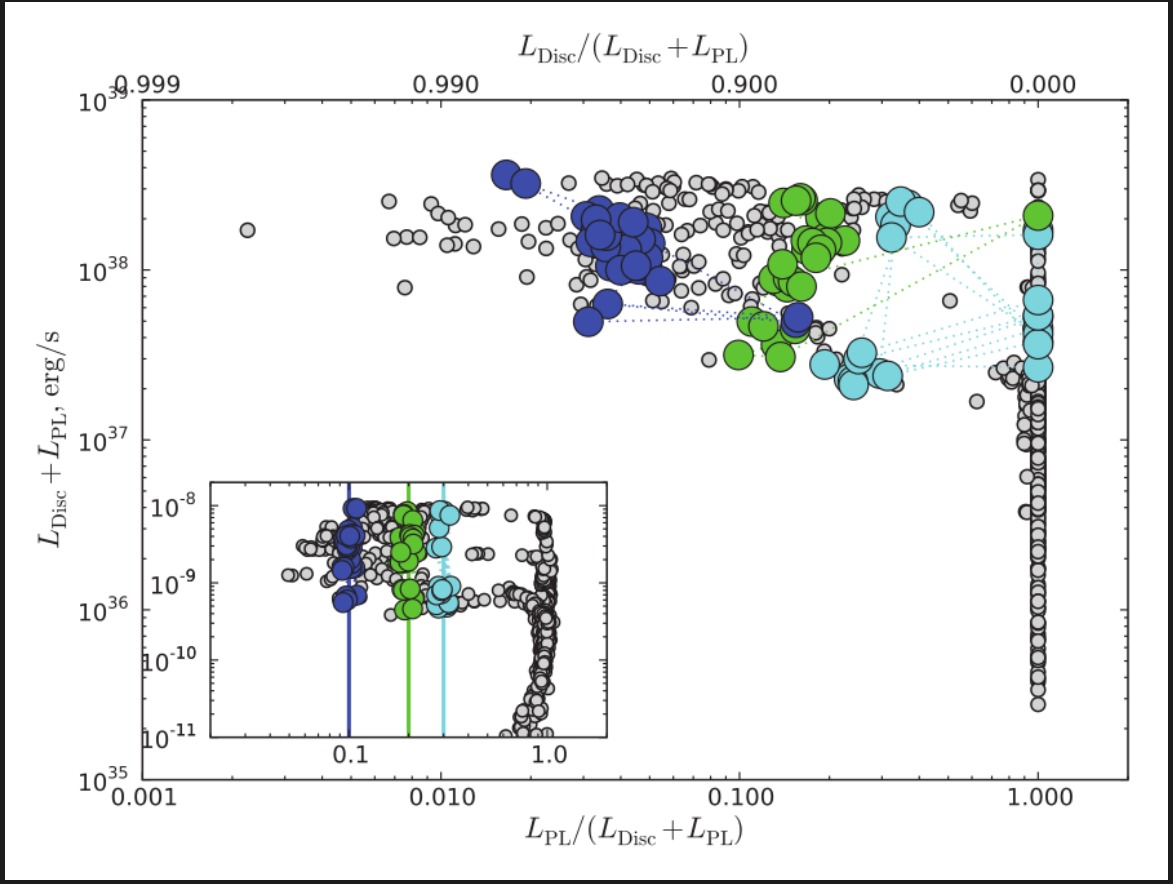


The Hardness-Intensity Diagram



Based on Fender *et al.* (2004)

The Hardness-Intensity Diagram



Dunn *et al.* (2010)

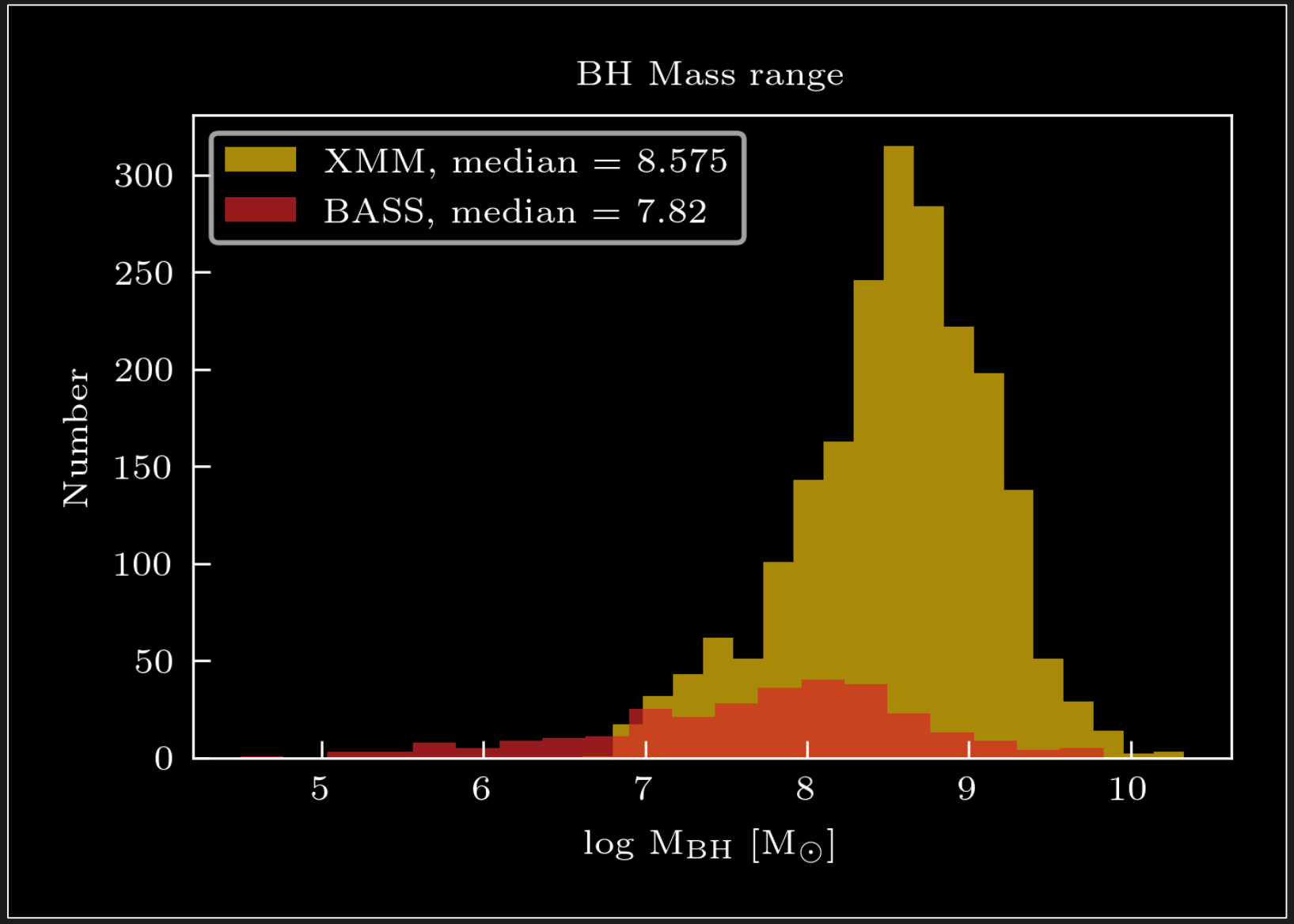
The Hardness-Intensity Diagram for AGNs

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.


BH Mass range
XMM, median = 8.575
BASS, median = 7.82
Number
300
250
200
150
100
50
0
5
6
7
8
9
10
log M_BH [M_⊙]

Estimating Luminosity

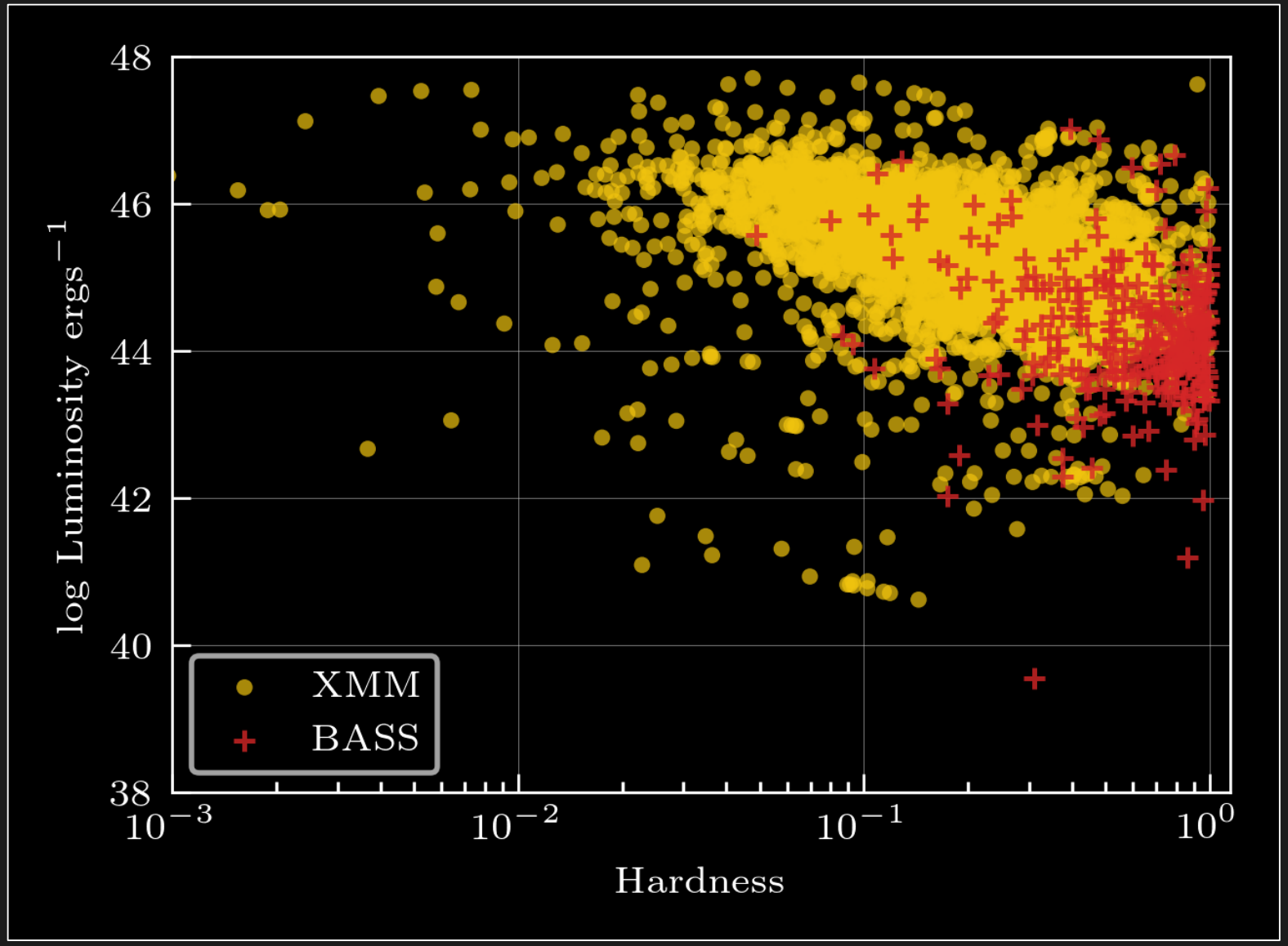
Total luminosity:

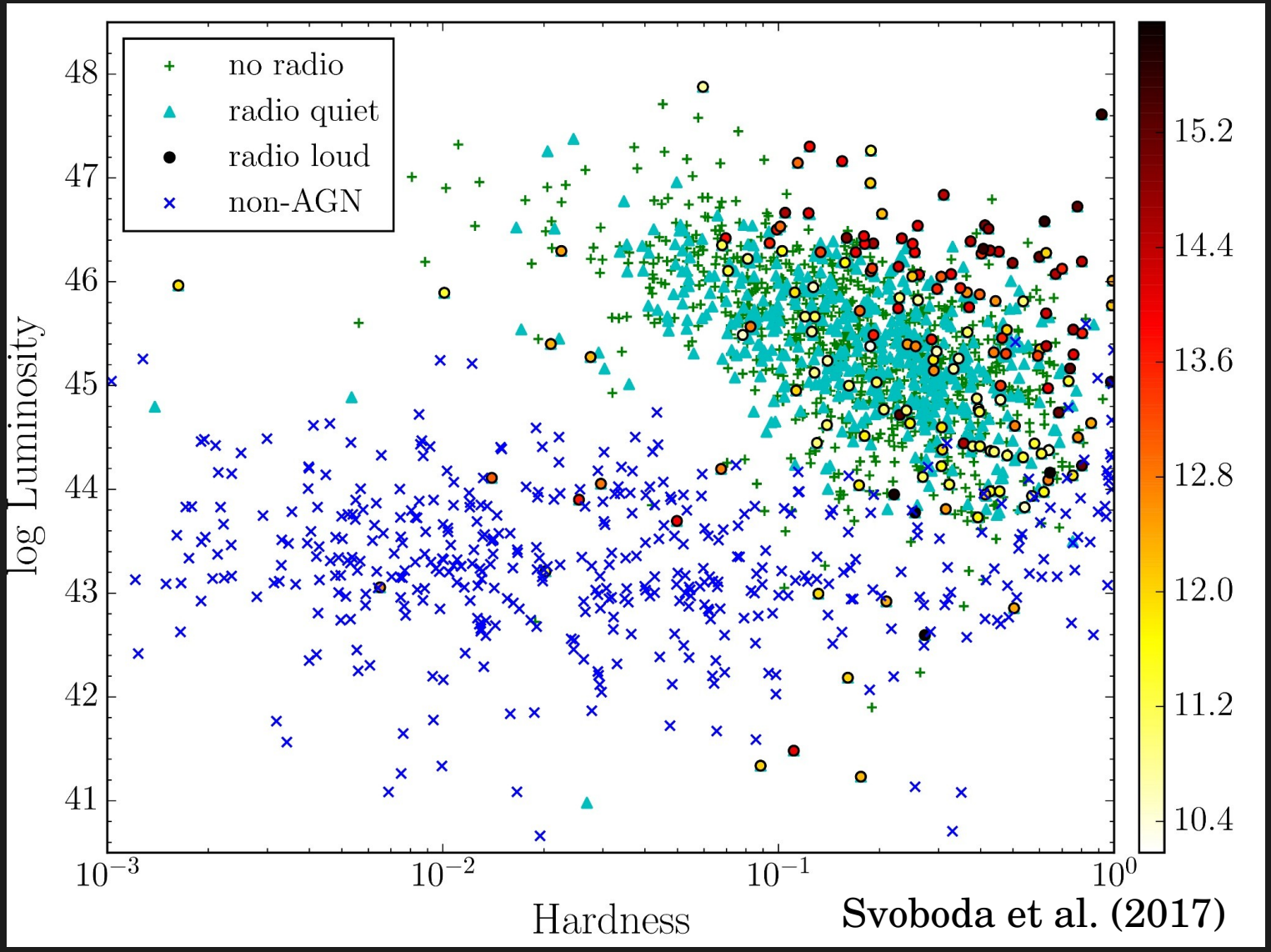
$$L_{tot} = L_X + L_{UV}$$

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.

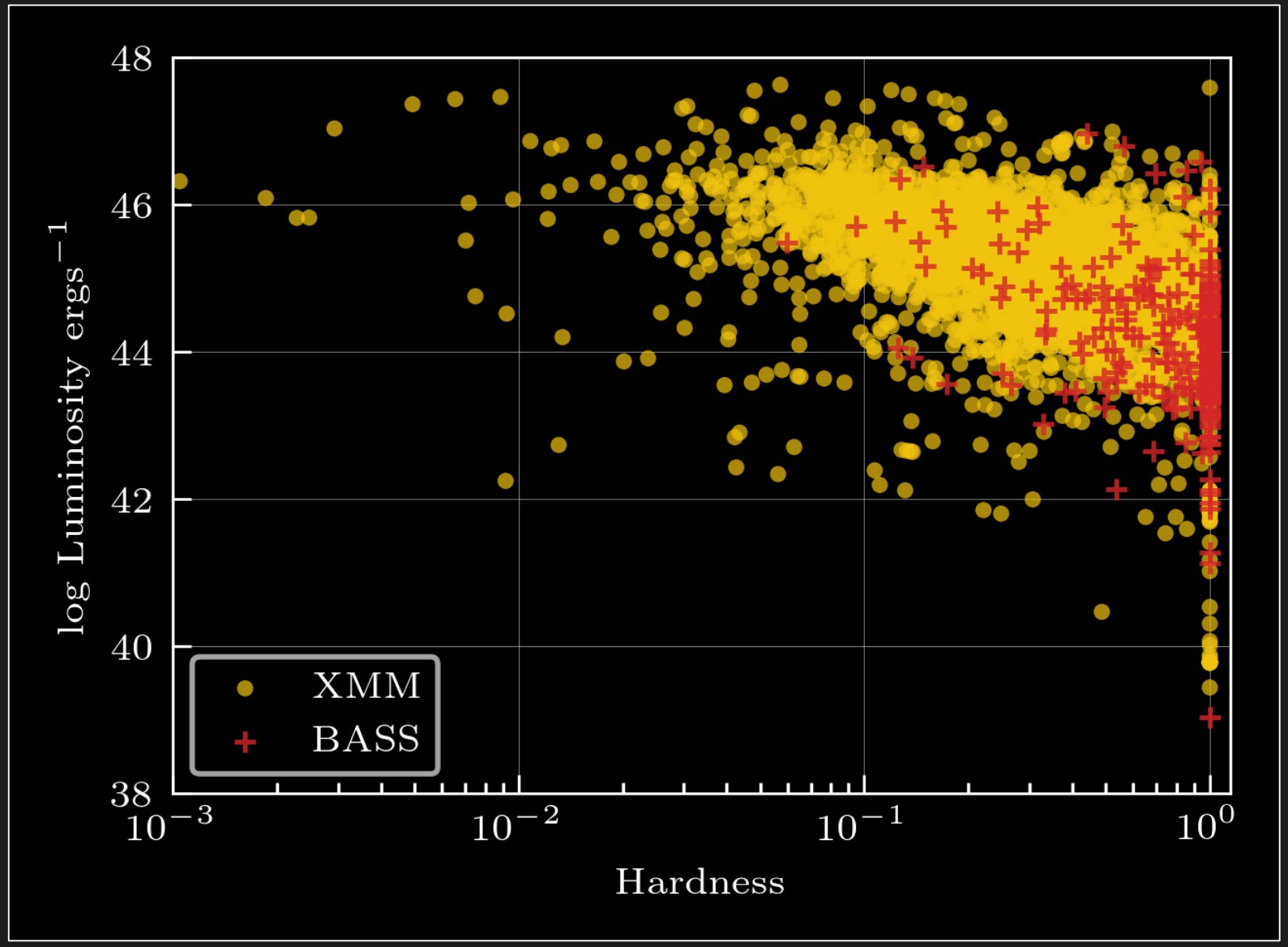
BH mass obtained from SDSS DR 16 BH mass catalog (Rakshit et al. 2020)

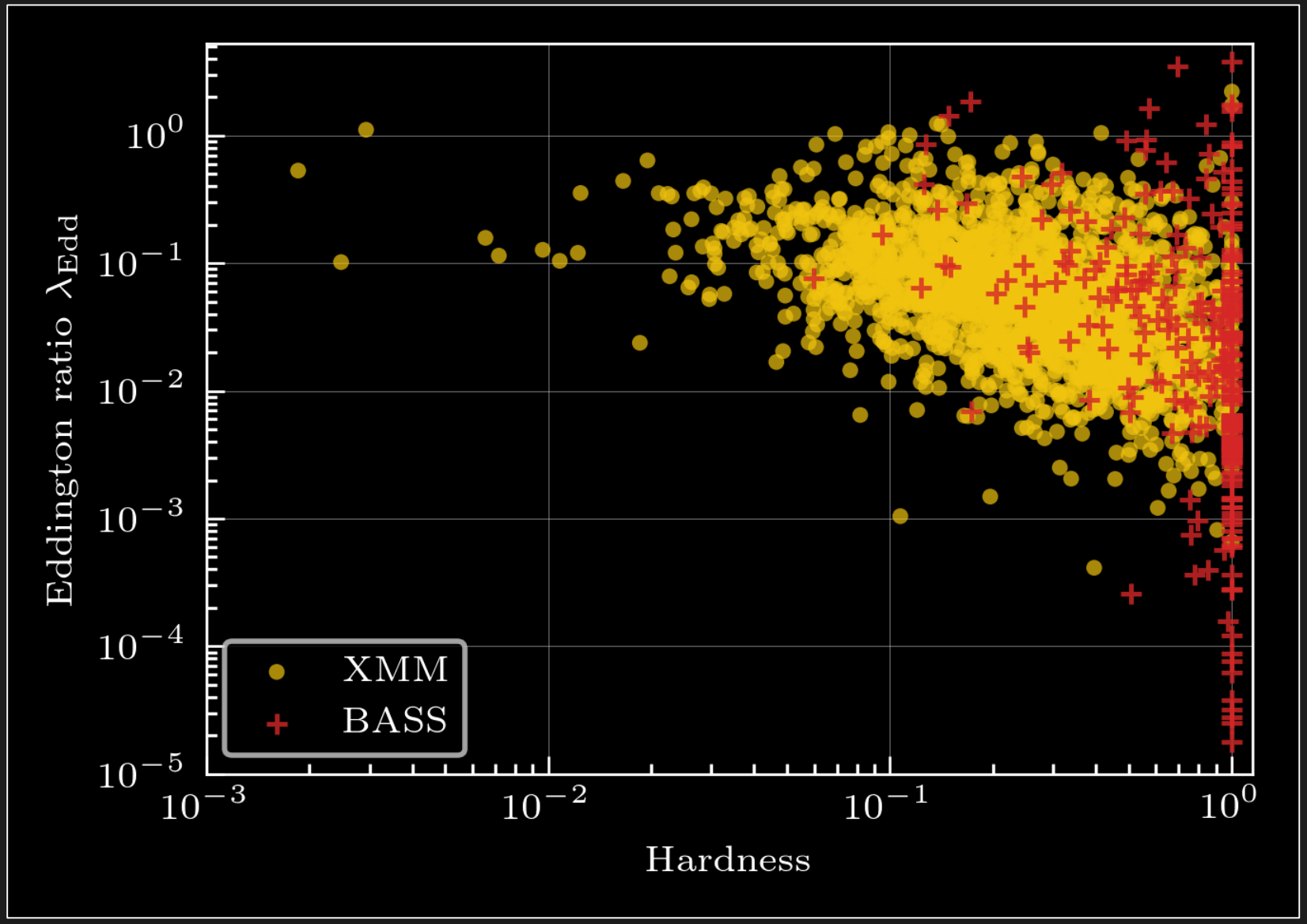

48
46
44
42
40
38
log Luminosity ergs^{-1}
XMM
BASS
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness

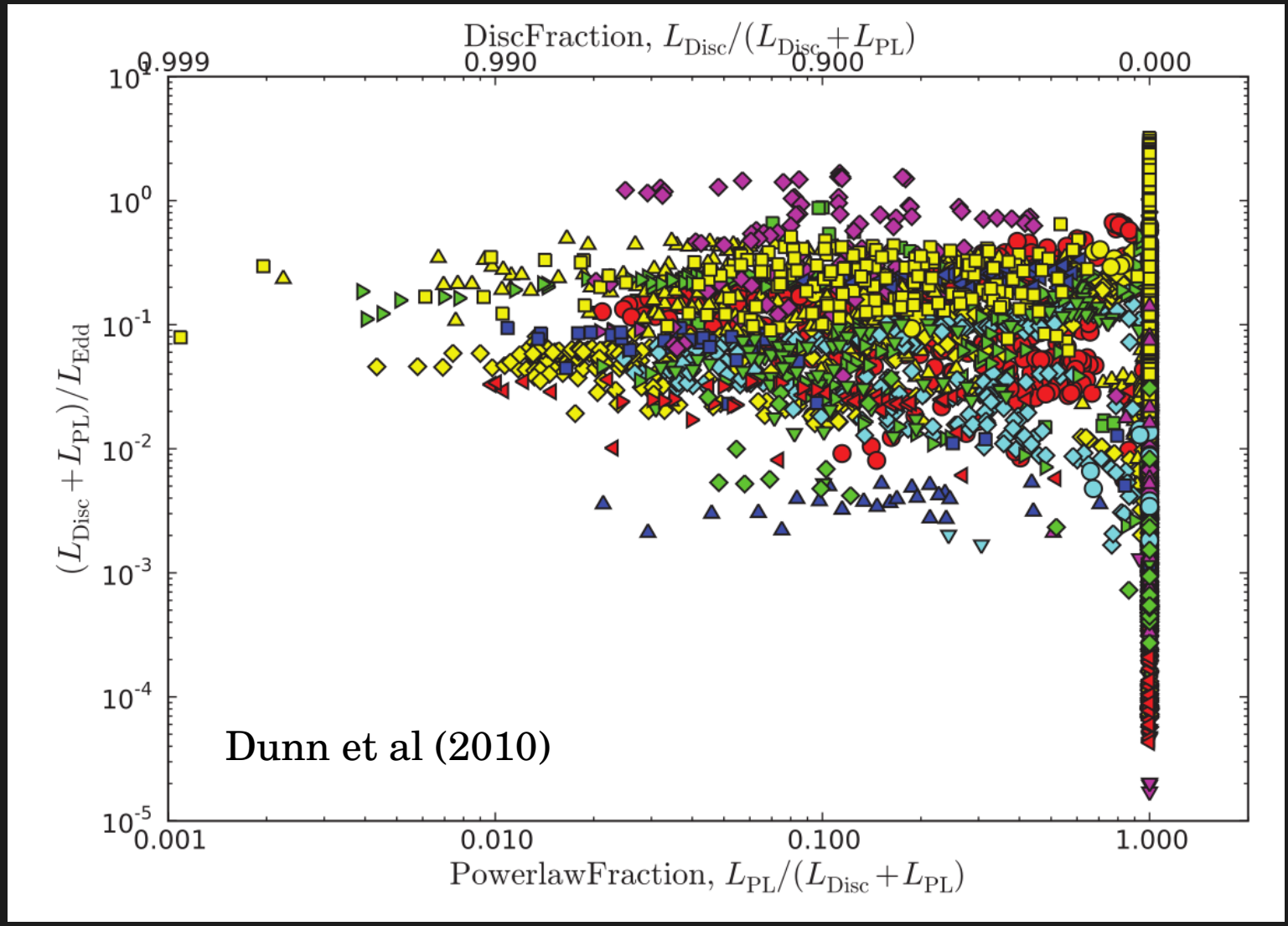

no radio
radio quiet
radio loud
non-AGN
log Luminosity
Hardness
48
47
46
45
44
43
42
41
10^{-3}
10^{-2}
10^{-1}
10^{0}
15.2
14.4
13.6
12.8
12.0
11.2
10.4
Svoboda et al. (2017)

Catalogue Compilation

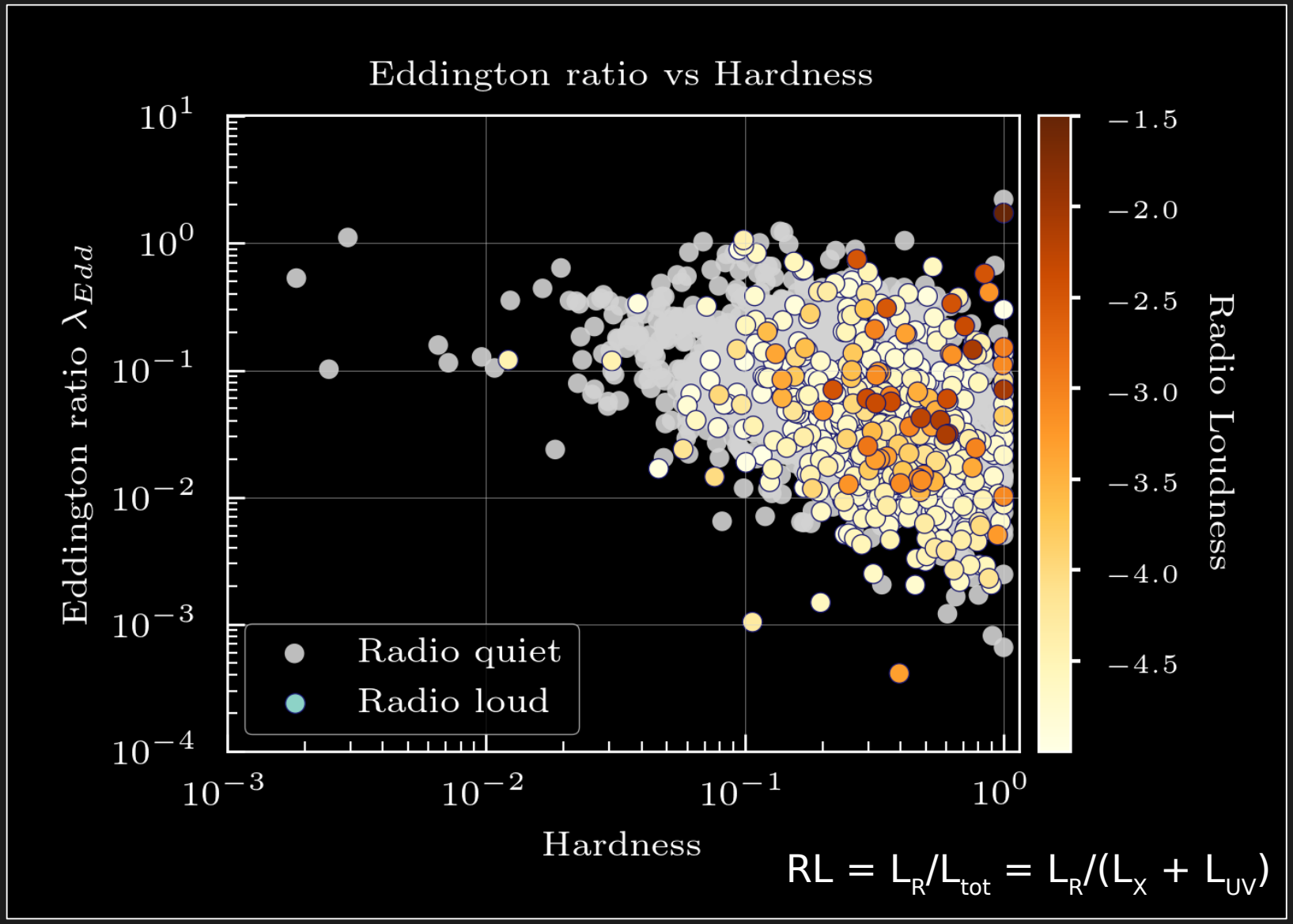
- **Host galaxy subtraction:**
  1. Estimate SFR from X-ray and UV luminosity, and remove SF contribution to total luminosity.
  2. Moves sources to right and bottom.


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

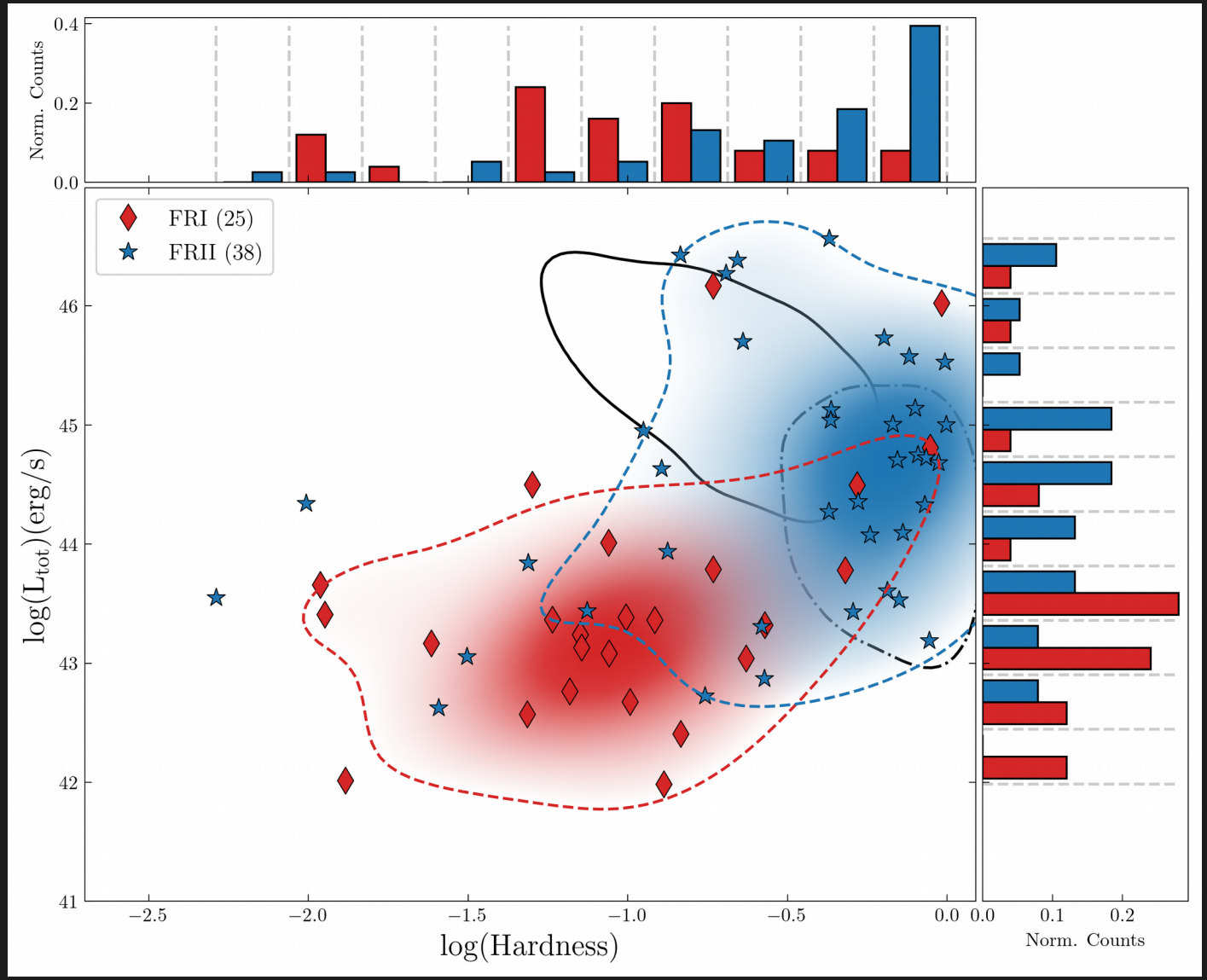

Eddington ratio $\lambda_{\rm Edd}$
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
XMM
BASS
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness


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)

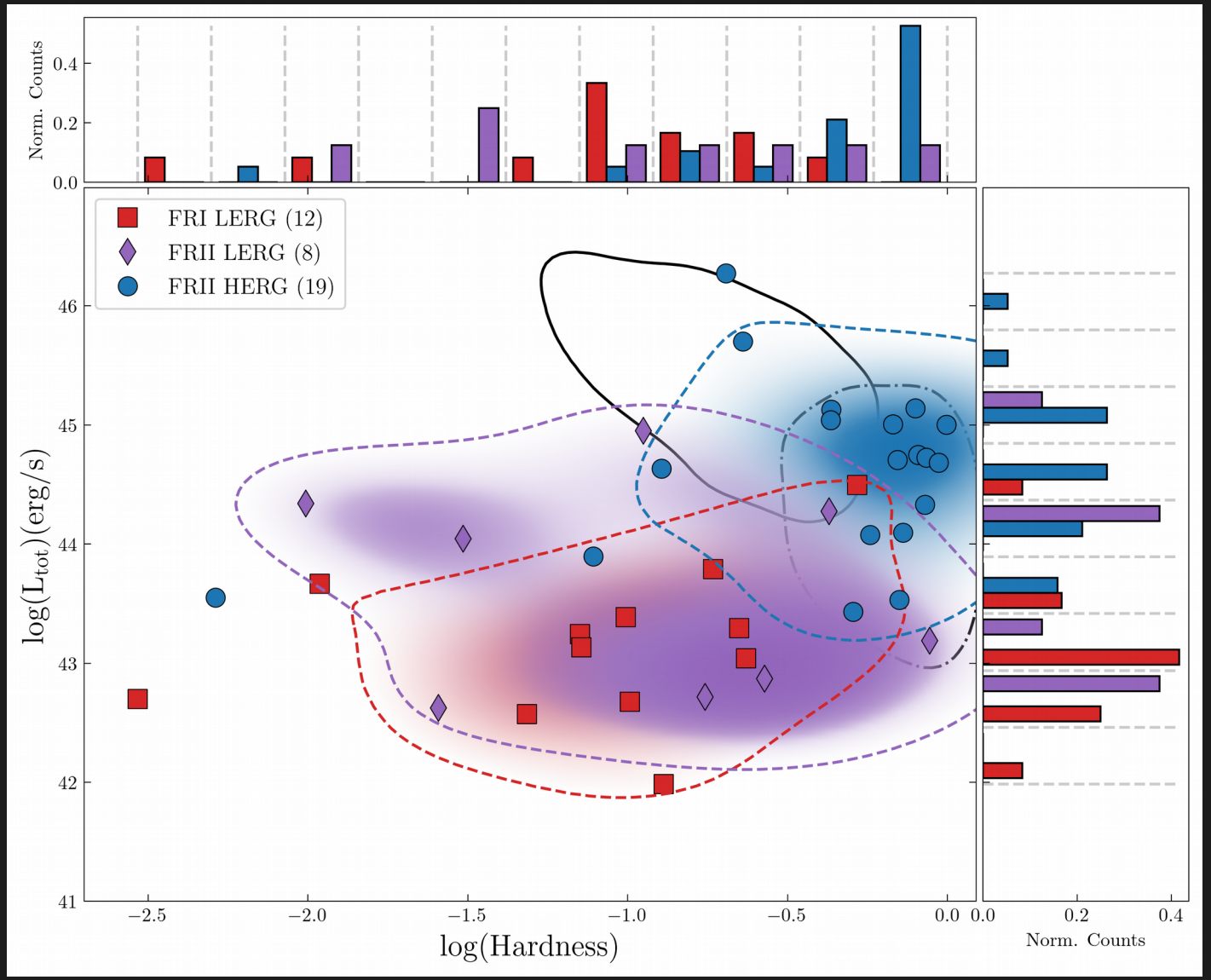
Radio Properties

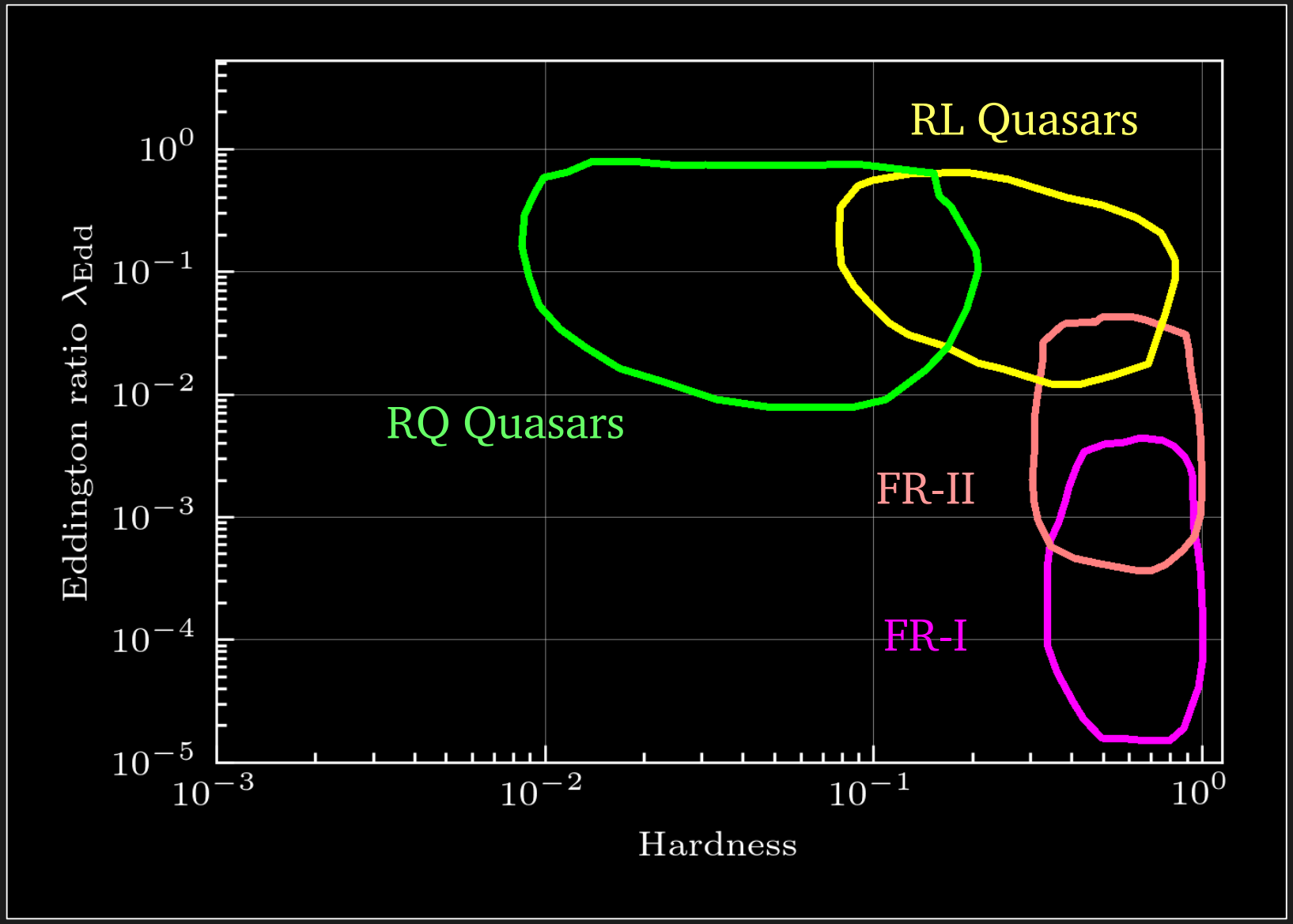

Eddington ratio vs Hardness
Eddington ratio λ_{Edd}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Radio quiet
Radio loud
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness
−1.5
−2.0
−2.5
−3.0
−3.5
−4.0
−4.5
Radio Loudness
RL = L_R/L_{tot} = $L_R/(L_X + L_{UV})$

Moravec et al. (2022)

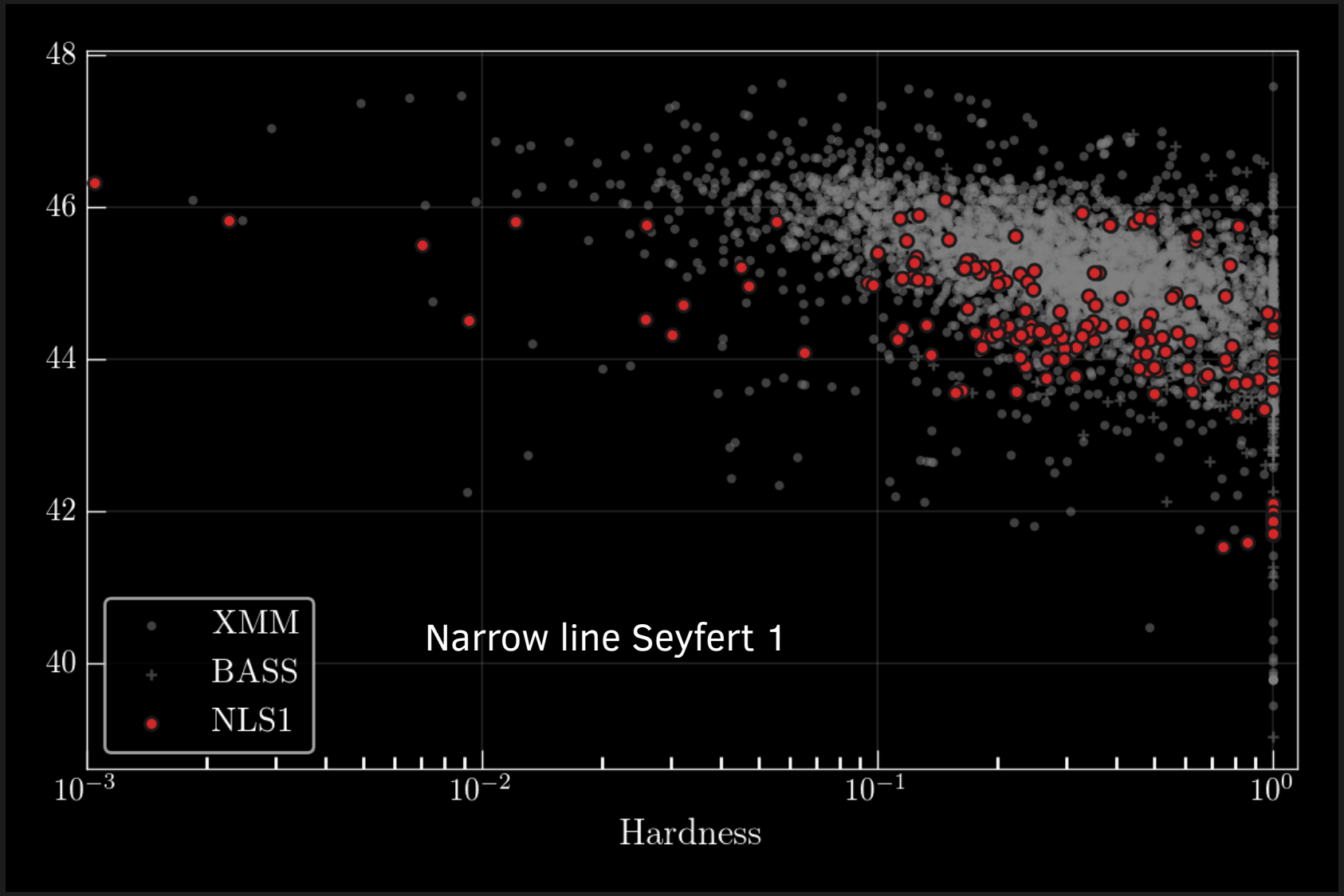


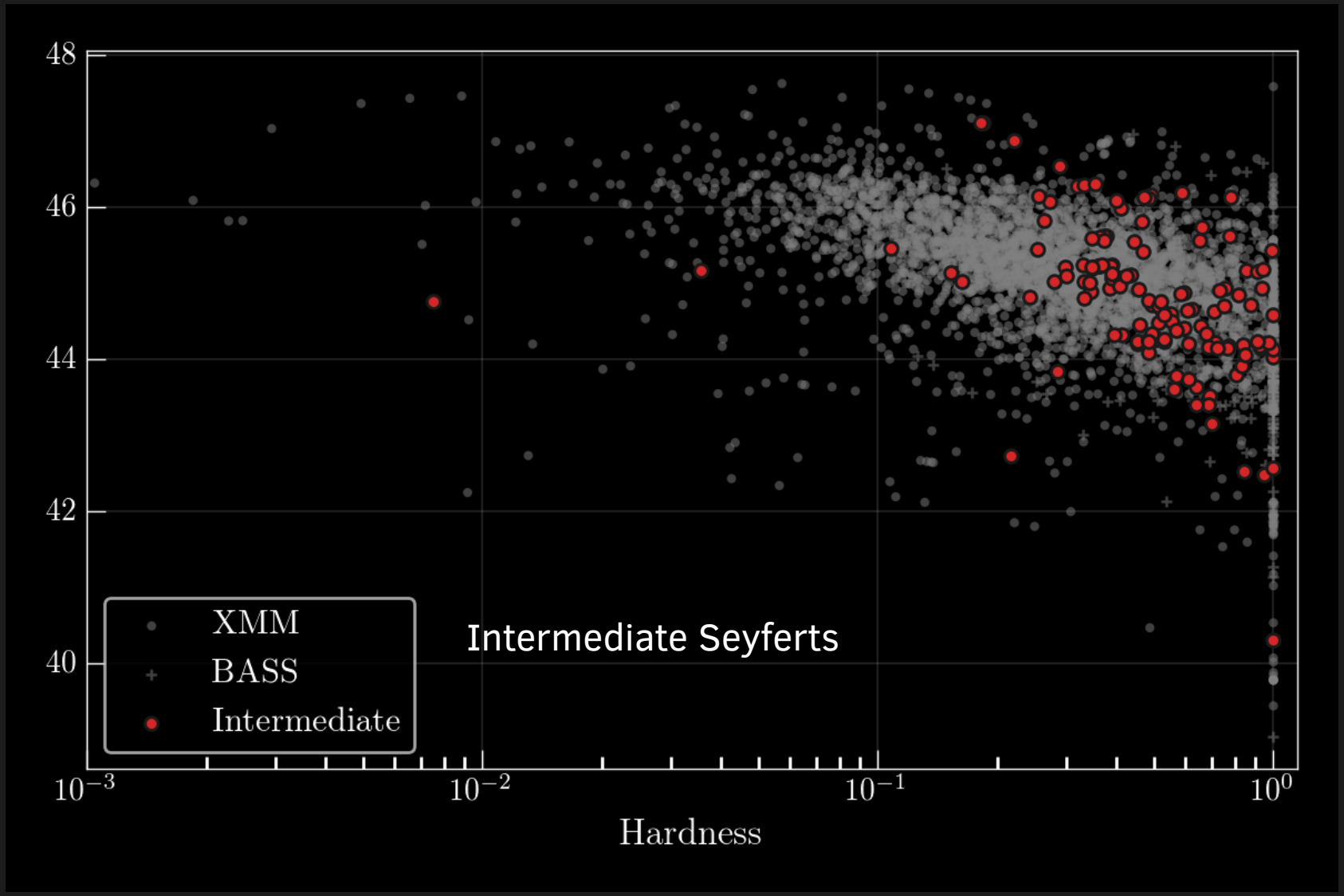
Moravec et al. (2022)

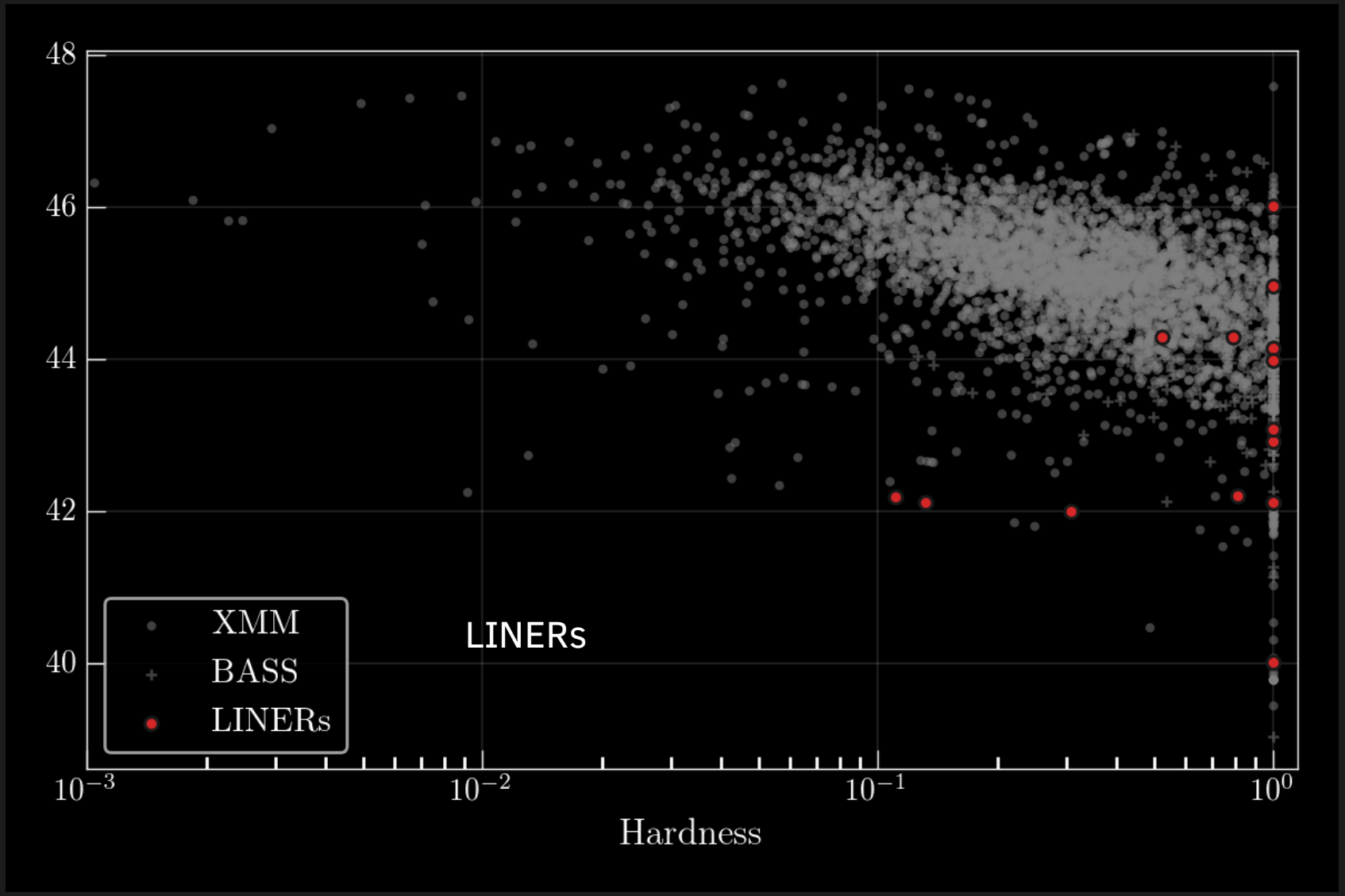



RL Quasars
RQ Quasars
FR-II
FR-I
Eddington ratio $\lambda_{\rm Edd}$
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness

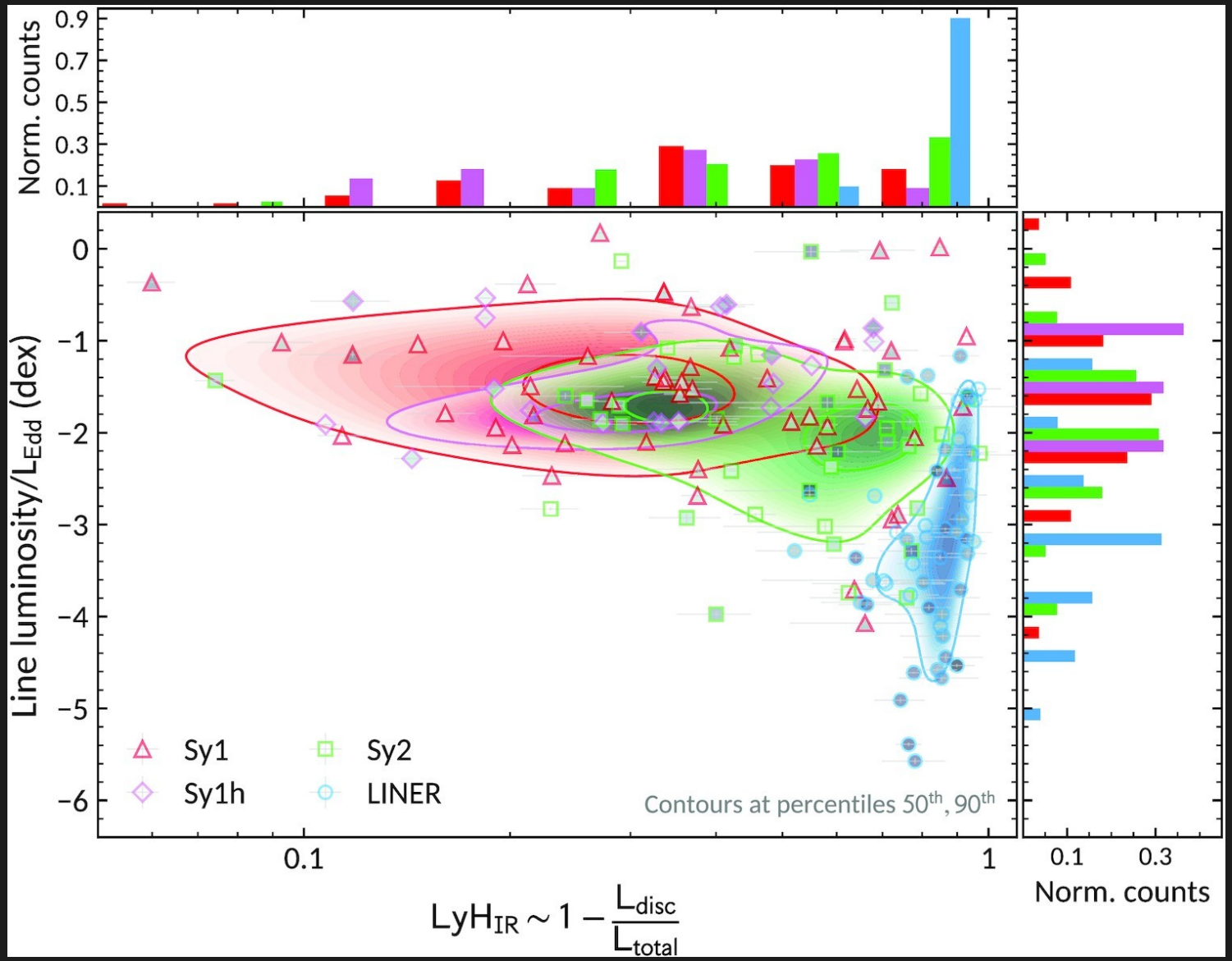
Seyfert Type


48
46
44
42
40
XMM
BASS
NLS1
Narrow line Seyfert 1
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness

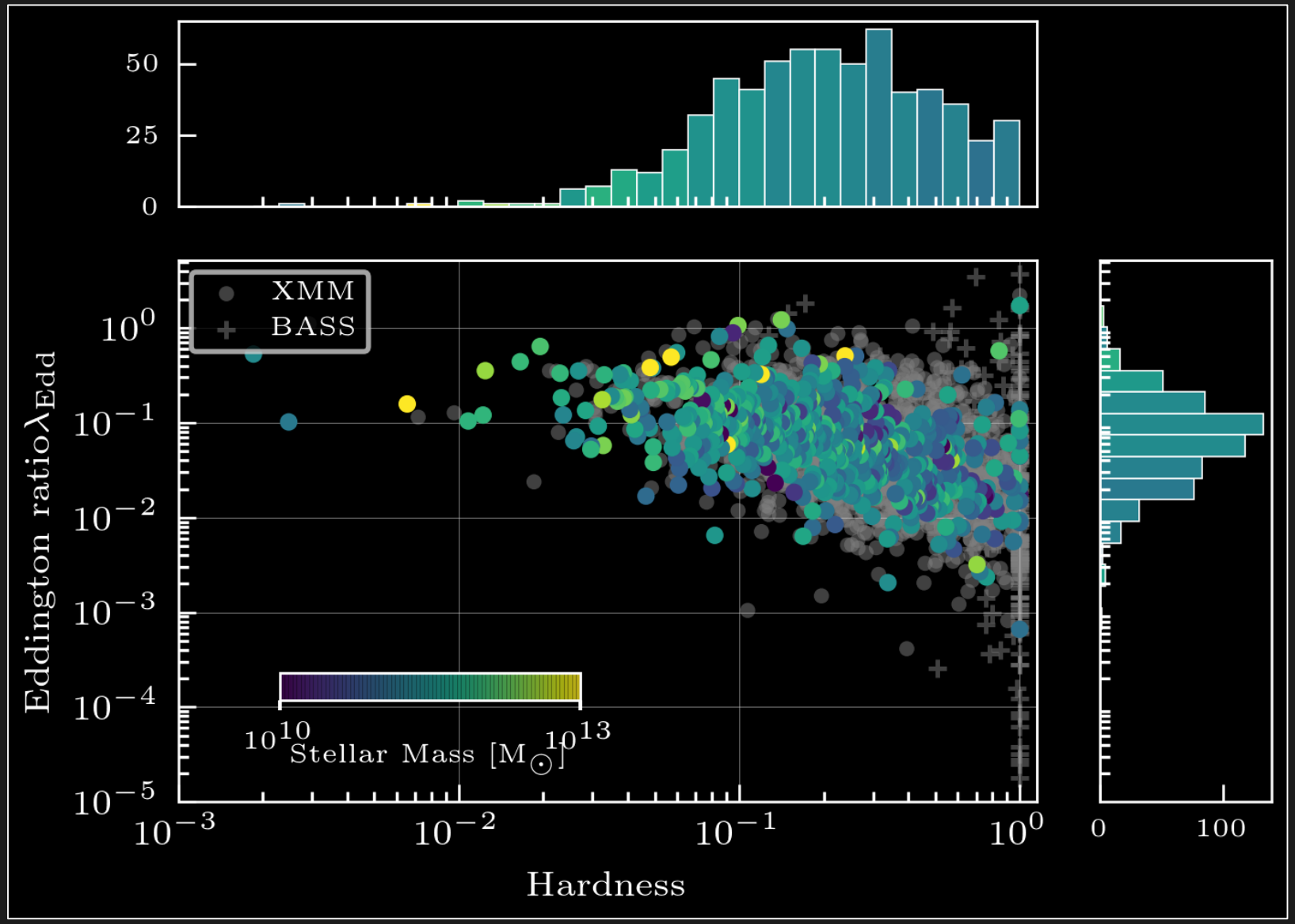

48
46
44
42
40
XMM
BASS
Intermediate
Intermediate Seyferts
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness

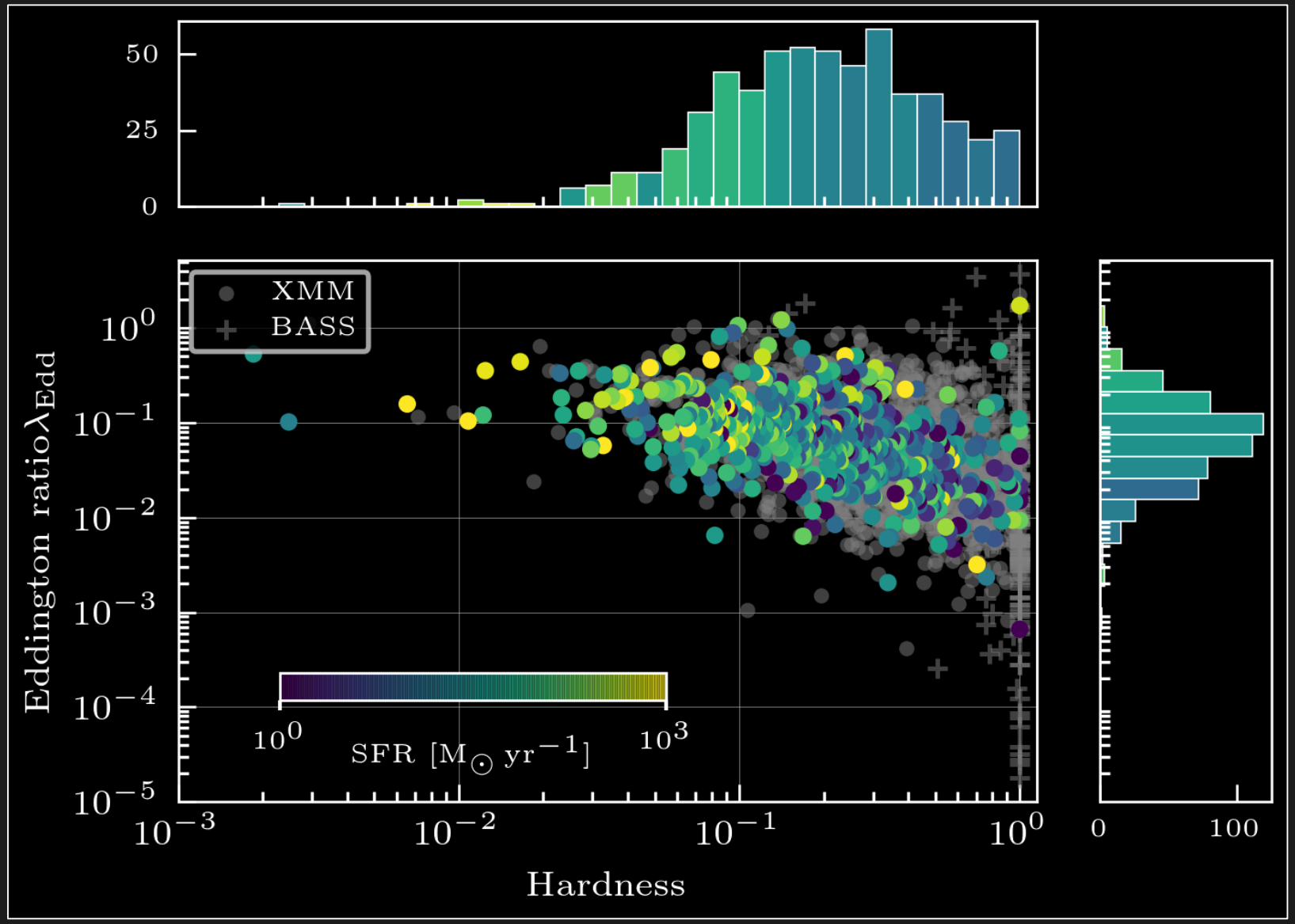

48
46
44
42
40
XMM
BASS
LINERs
LINERs
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness

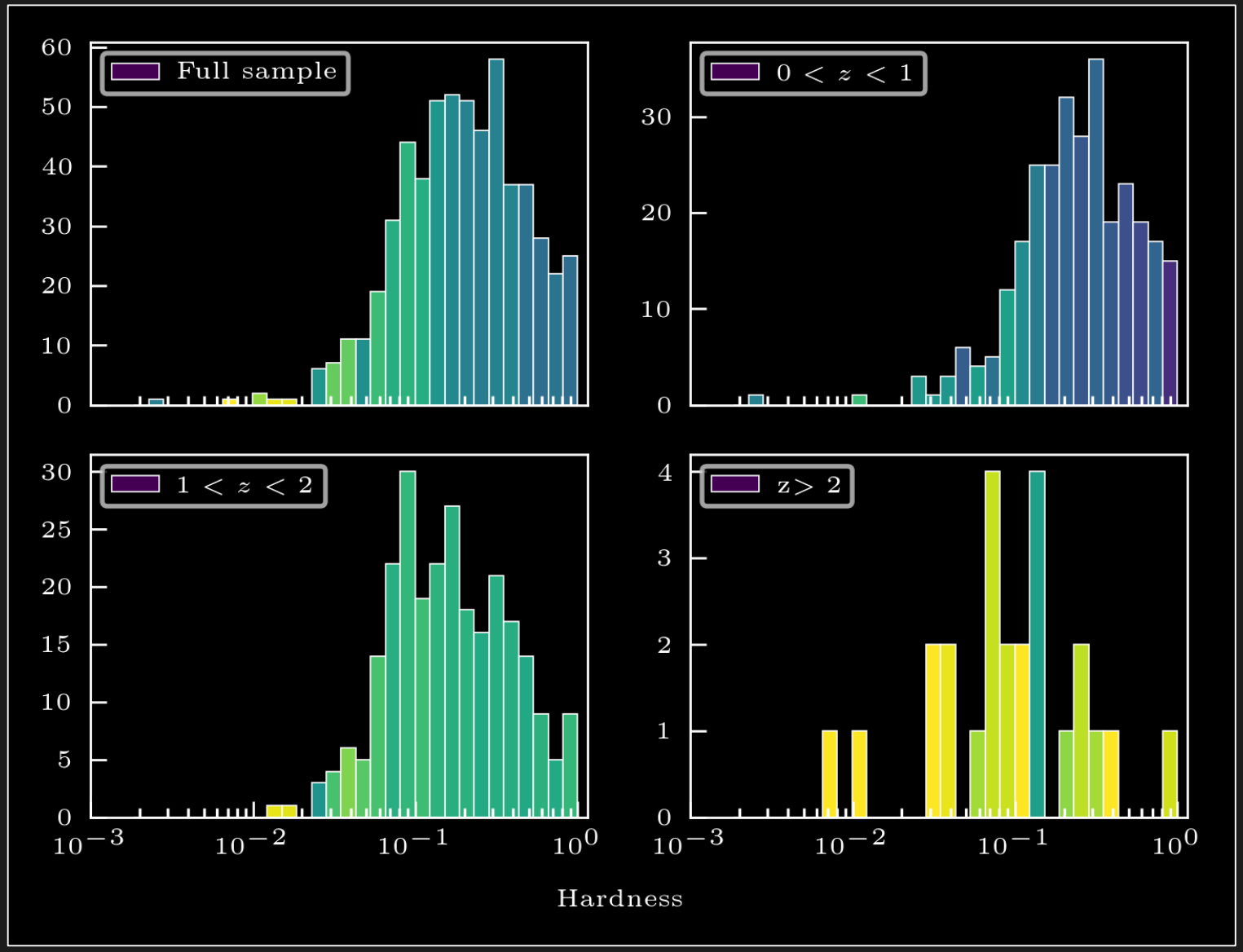
Fernandez-Ontiveros & Munoz-Darias (2021)



Host Galaxy Properties


50
25
0
XMM
BASS
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Eddington ratio λ_{Edd}
10^{10}
Stellar Mass [$M_\odot$]
10^{13}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness
0
100

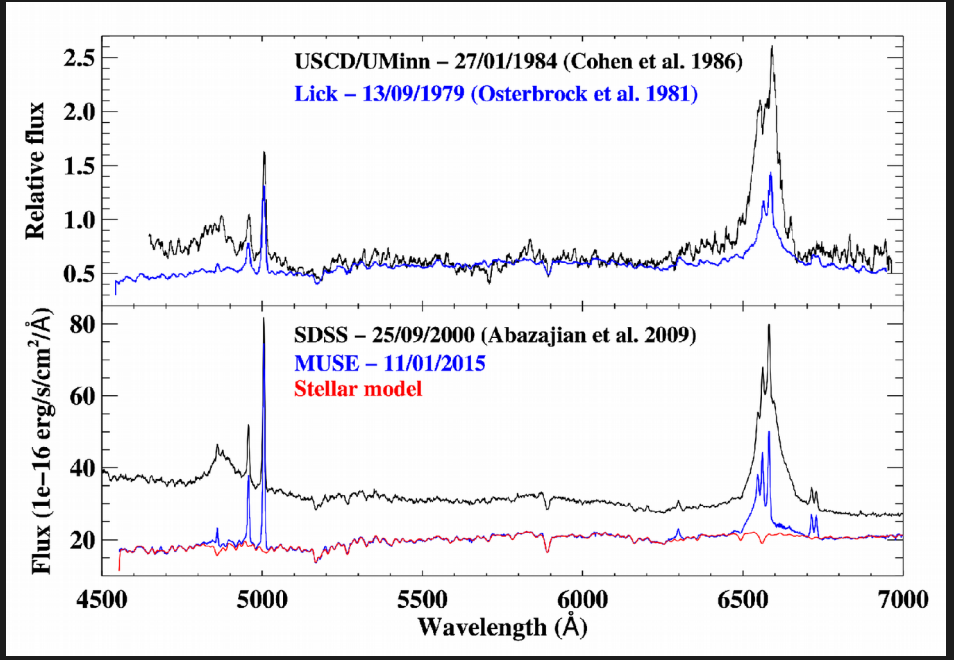

50
25
0
XMM
BASS
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Eddington ratio $\lambda_{\rm Edd}$
10^{0}
SFR [$M_\odot$ yr^{-1}]
10^{3}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness
0
100

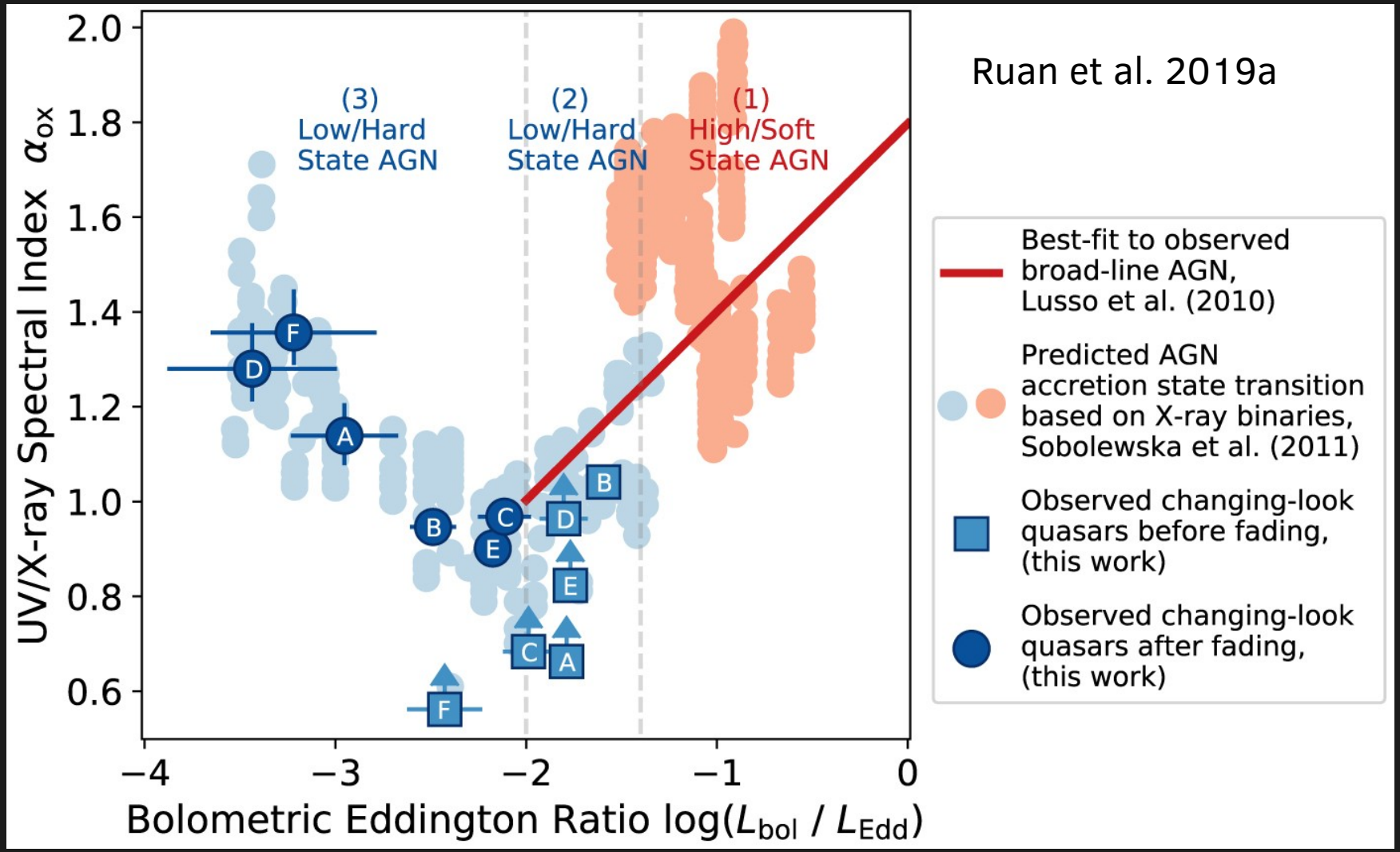

Full sample
0 < z < 1
1 < z < 2
z> 2
Hardness

Changing Look AGN

Changing Look AGN

- AGN which have been caught changing from one Seyfert type to another.
- Or changing from Compton thick to Compton thin (or the other way round).
- Change timescales of months to decades.
- Long timescales cannot be explained by simple change in obscuration.
- Require changes in the accretion process to explain the behaviour.




Ruan et al. 2019a
(3) Low/Hard State AGN
(2) Low/Hard State AGN
(1) High/Soft State AGN
UV/X-ray Spectral Index α_{ox}
Bolometric Eddington Ratio $\log(L_{bol} / L_{Edd})$
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
−4
−3
−2
−1
0
A
B
C
D
E
F
Best-fit to observed broad-line AGN, Lusso et al. (2010)
Predicted AGN accretion state transition based on X-ray binaries, Sobolewska et al. (2011)
Observed changing-look quasars before fading, (this work)
Observed changing-look quasars after fading, (this work)

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.
- The radio morphology and excitation classes occupy different places in the HID.
- The position within HID and host galaxy properties are correlated, suggesting a possible coevolution of AGN and host galaxy.

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Working Group(s):

ALMA Czech node: asu.cas.cz/alma

Relativistic Astrophysics: astro.cas.cz

Prague AGN: pragueagn.wordpress.com

IAU-International Visegrad Fund Mobility Award

- Applications open NOW!
- Deadline: April 23rd 2023, 23:59 CET
- 1 page motivation letter & CV.
- All details at https://www.iau.org/science/grants_prizes/iau-visegrad/
  Or scan the QR code

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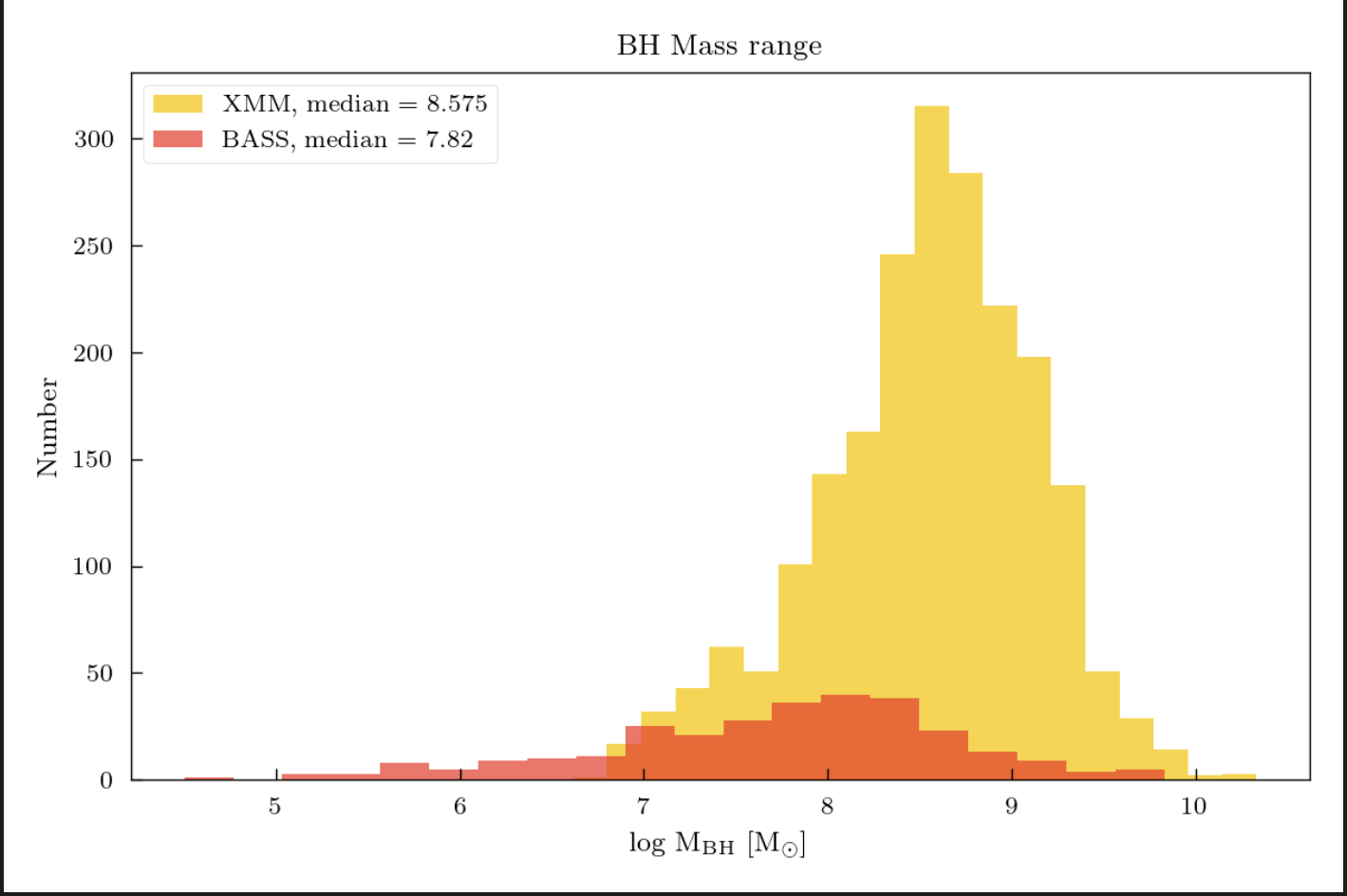
UNIWERSYTET MIKOŁAJA KOPERNIKA W TORUNIU

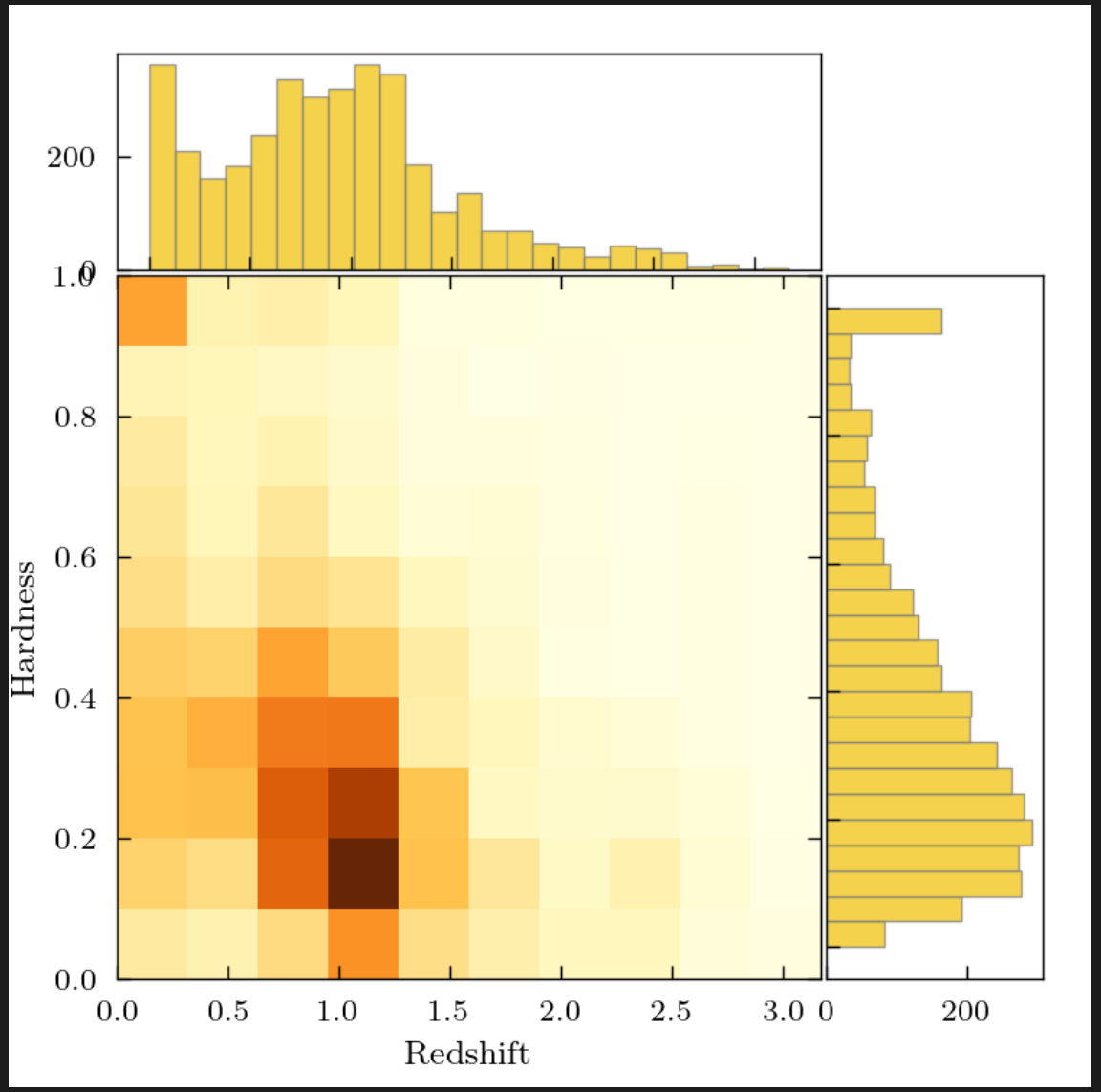
UNIVERZITA KOMENSKÉHO V BRATISLAVE

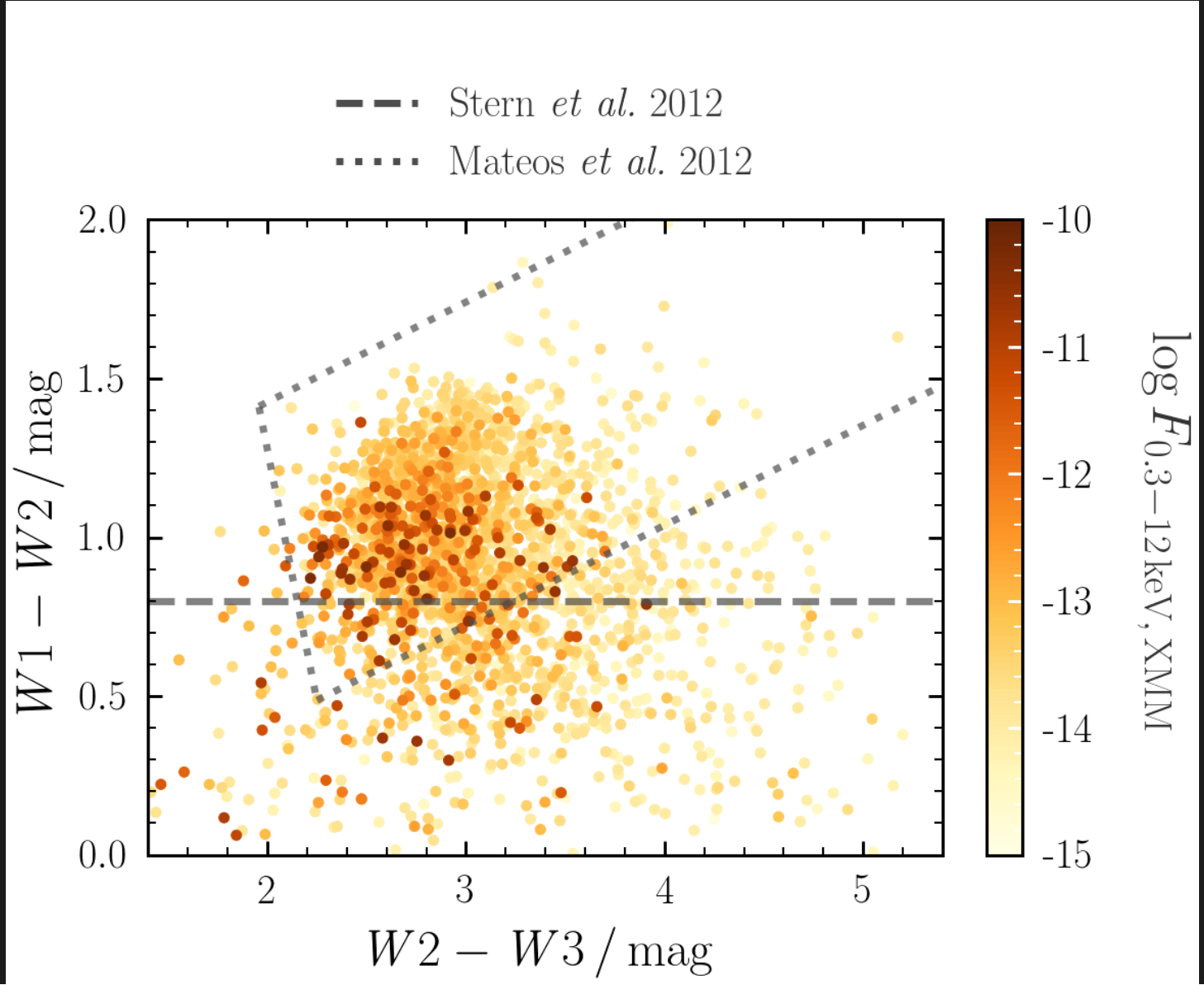
asu Astronomický ústav AV ČR

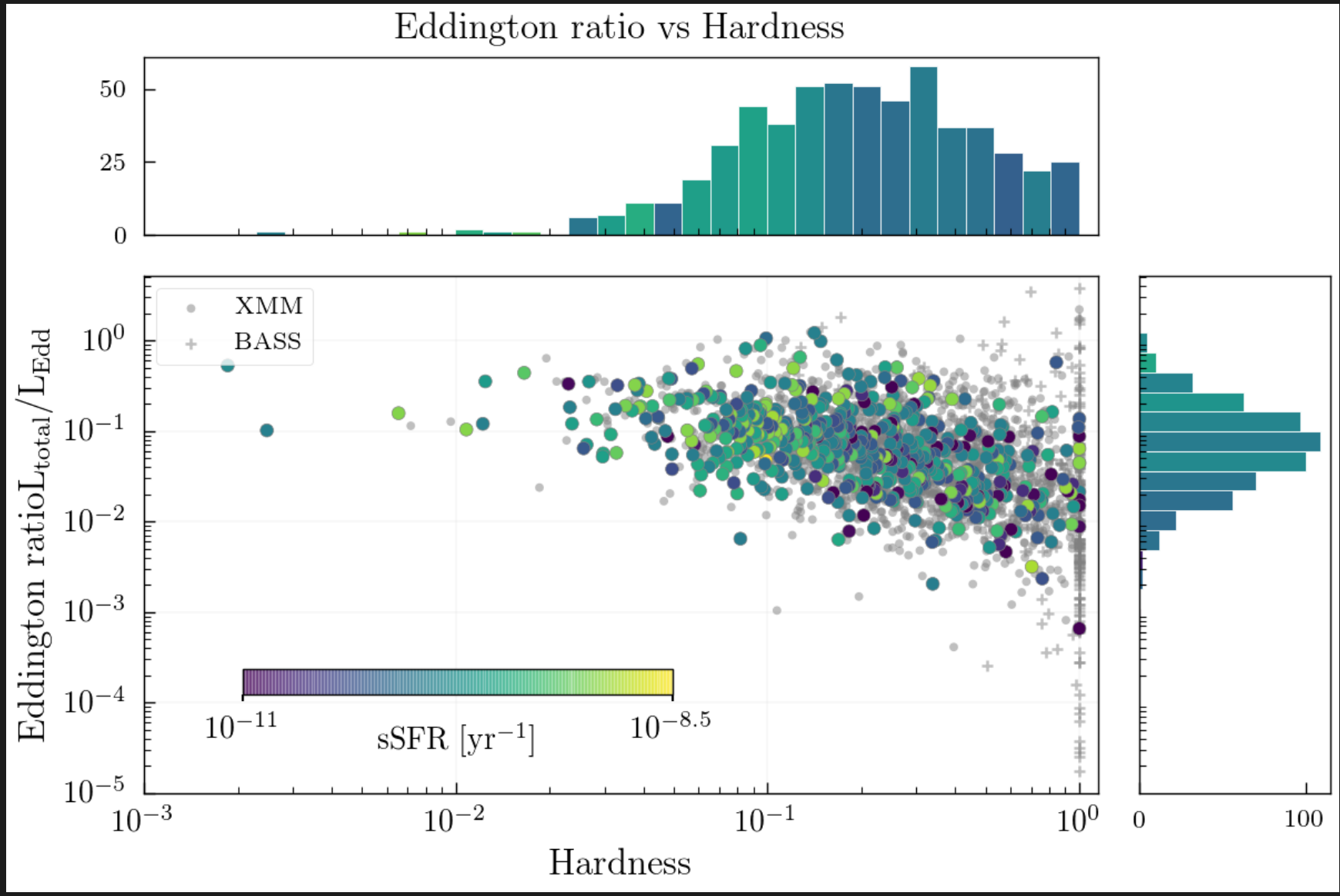
Extra Slides

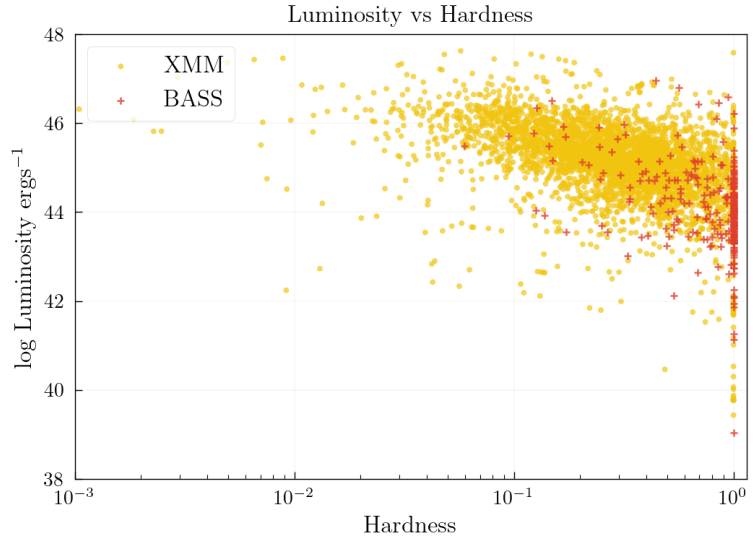


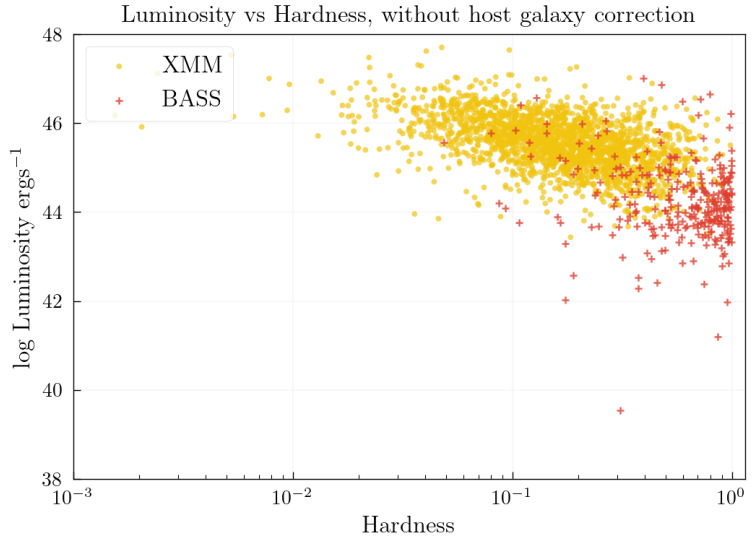
Extra Slides

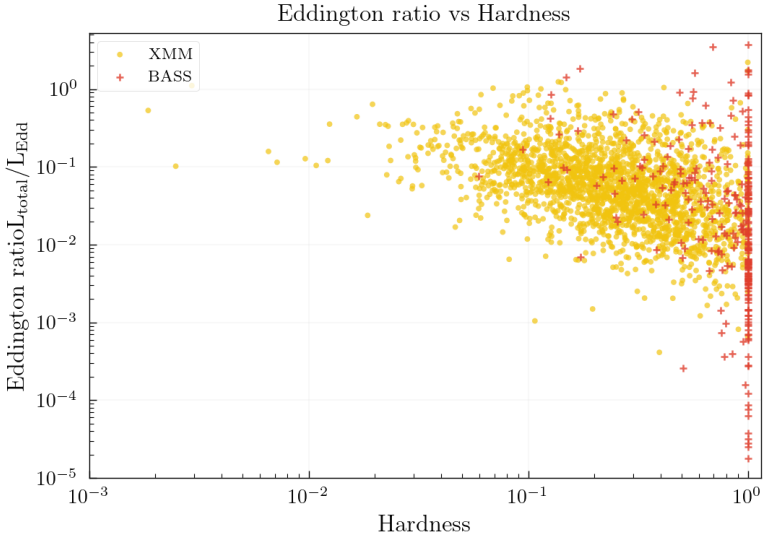


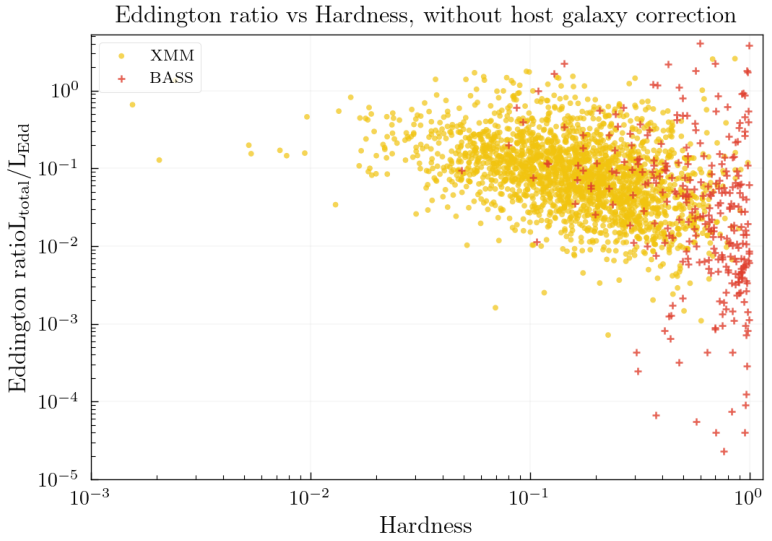

Stern et al. 2012
Mateos et al. 2012
2.0
1.5
1.0
0.5
0.0
W1 − W2 / mag
2
3
4
5
W2 − W3 / mag
-10
-11
-12
-13
-14
-15
log F0.3−12keV, XMM


Eddington ratio vs Hardness
50
25
0
XMM
BASS
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Eddington ratio L_{total}/L_{Edd}
10^{-11}
sSFR [yr^{-1}]
$10^{-8.5}$
10^{-3}
10^{-2}
10^{-1}
10^{0}
Hardness
0
100


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}