AGN Hardness-Intensity Diagram by XMM-Newton

STRONGGRAVITY
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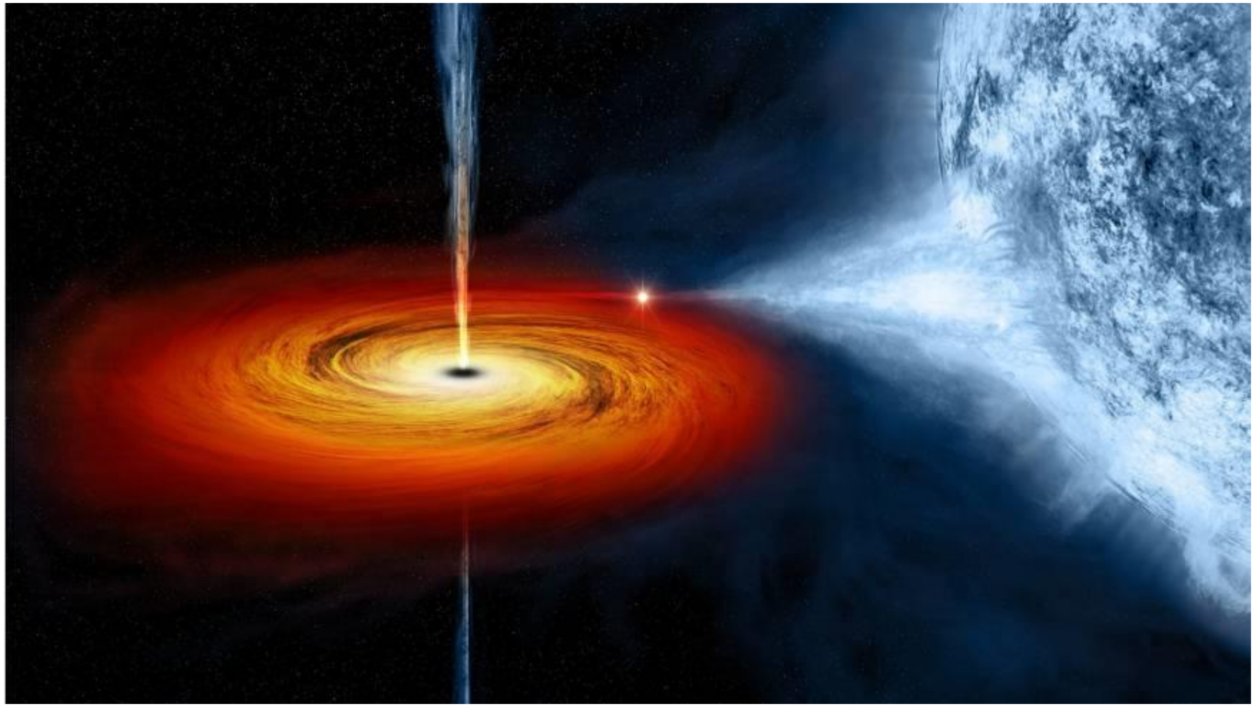
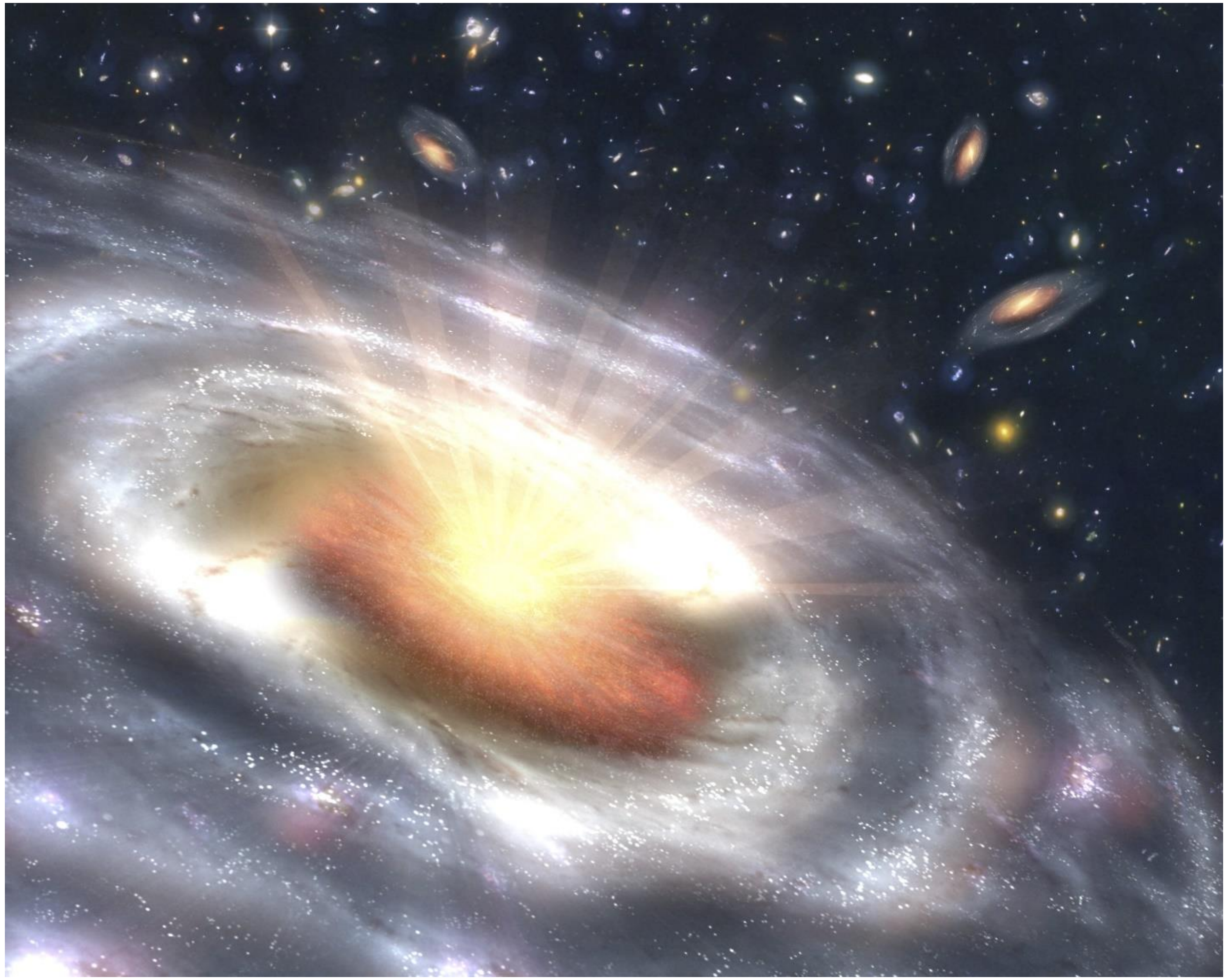
Jiří Svoboda, Czech Academy of Sciences,
Matteo Guainazzi (ESA), Andrea Merloni (MPE)
From quiescence to outburst: when microquasars go wild!, Porquerolles, France, 28th Sep 2017

Accreting Black Holes



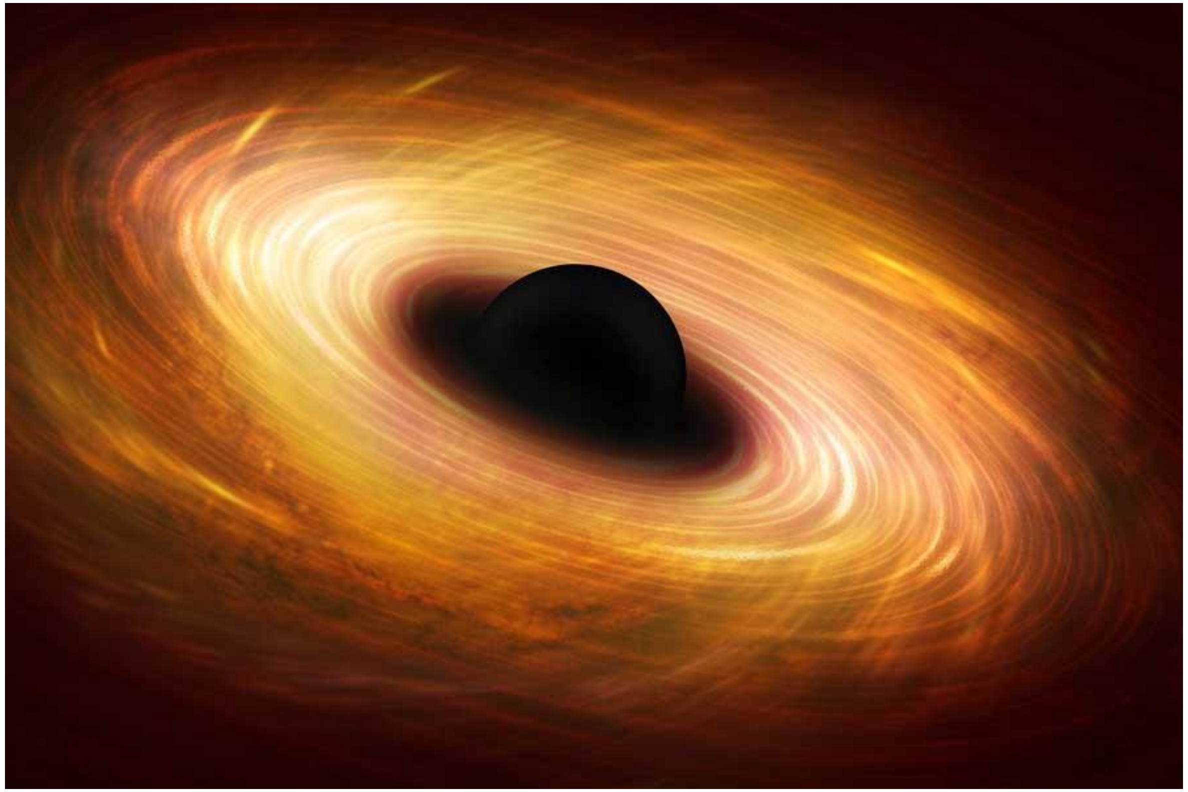
X-ray Binaries (XRB)

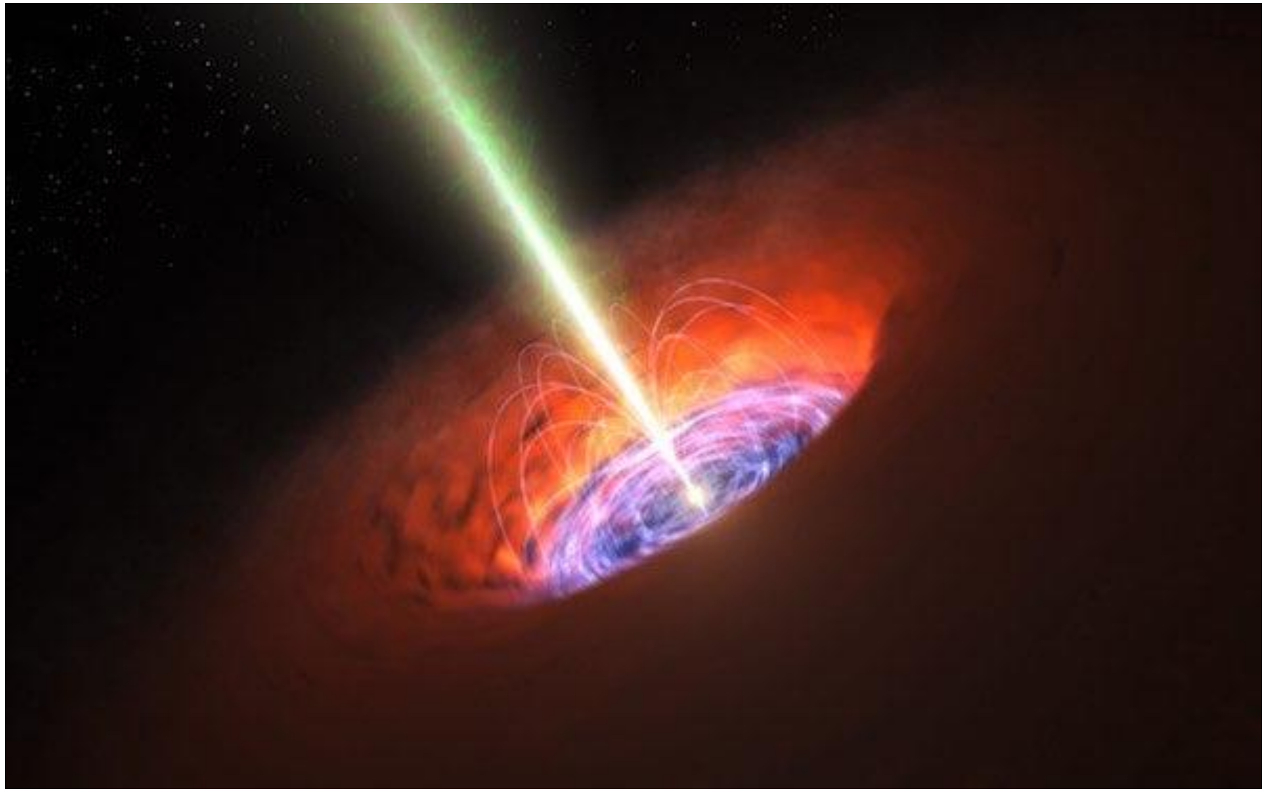


Active Galactic Nuclei (AGN)

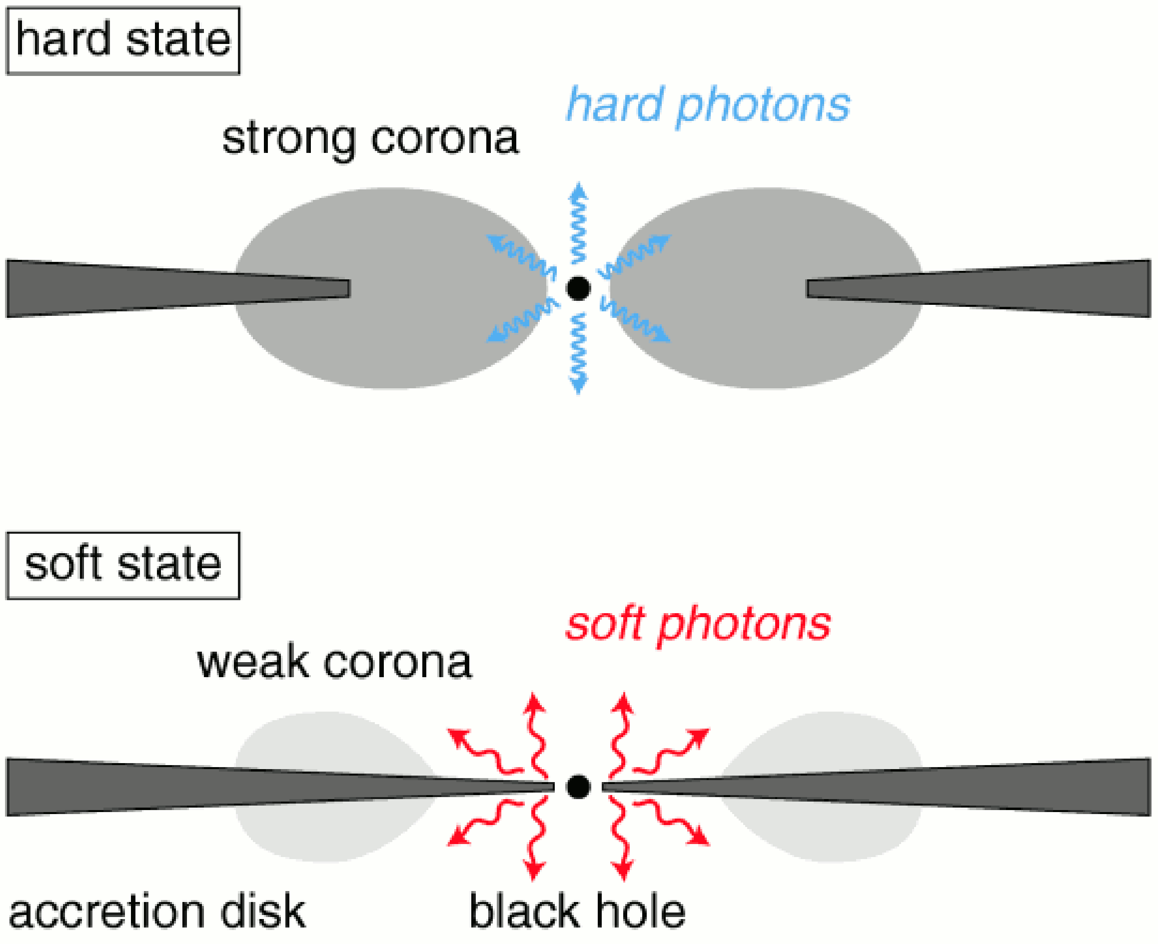
Accretion on Black Holes

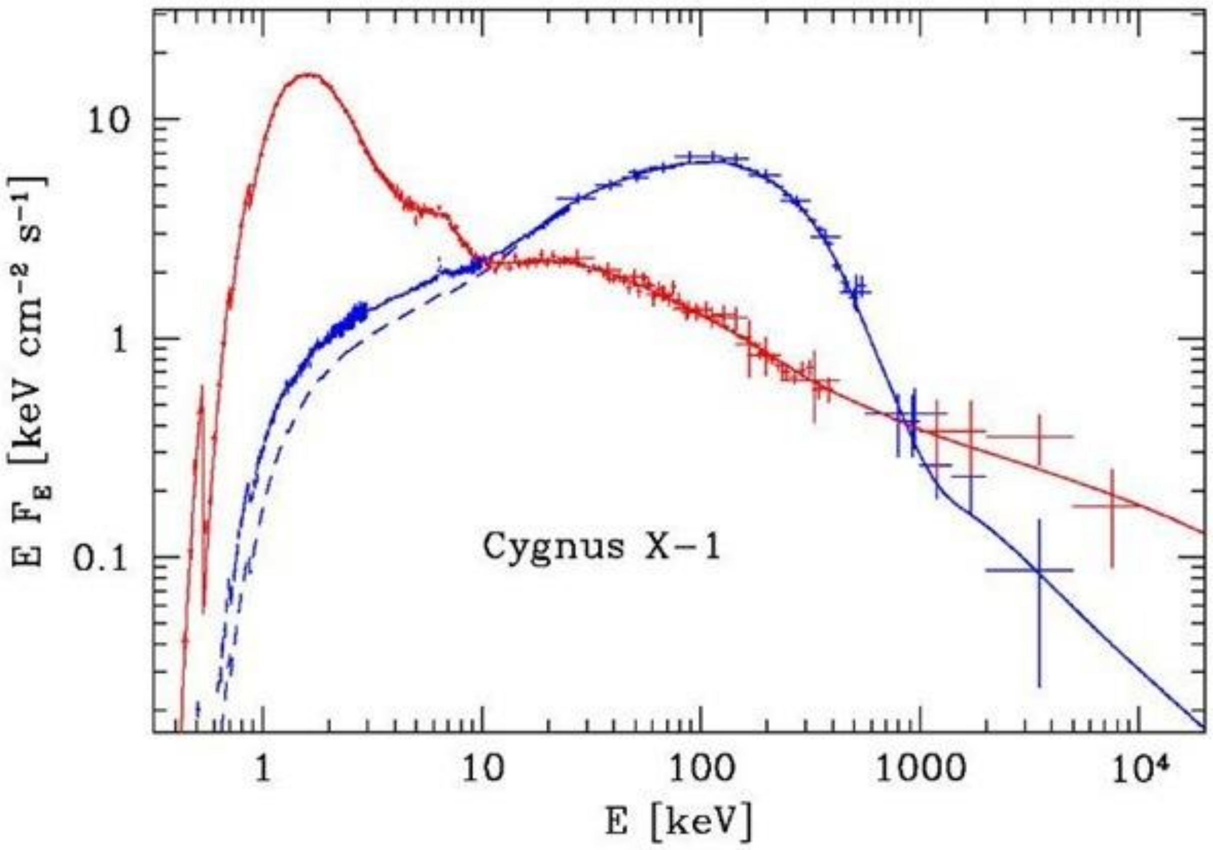
- accretion rate determines the nature of the accretion flow



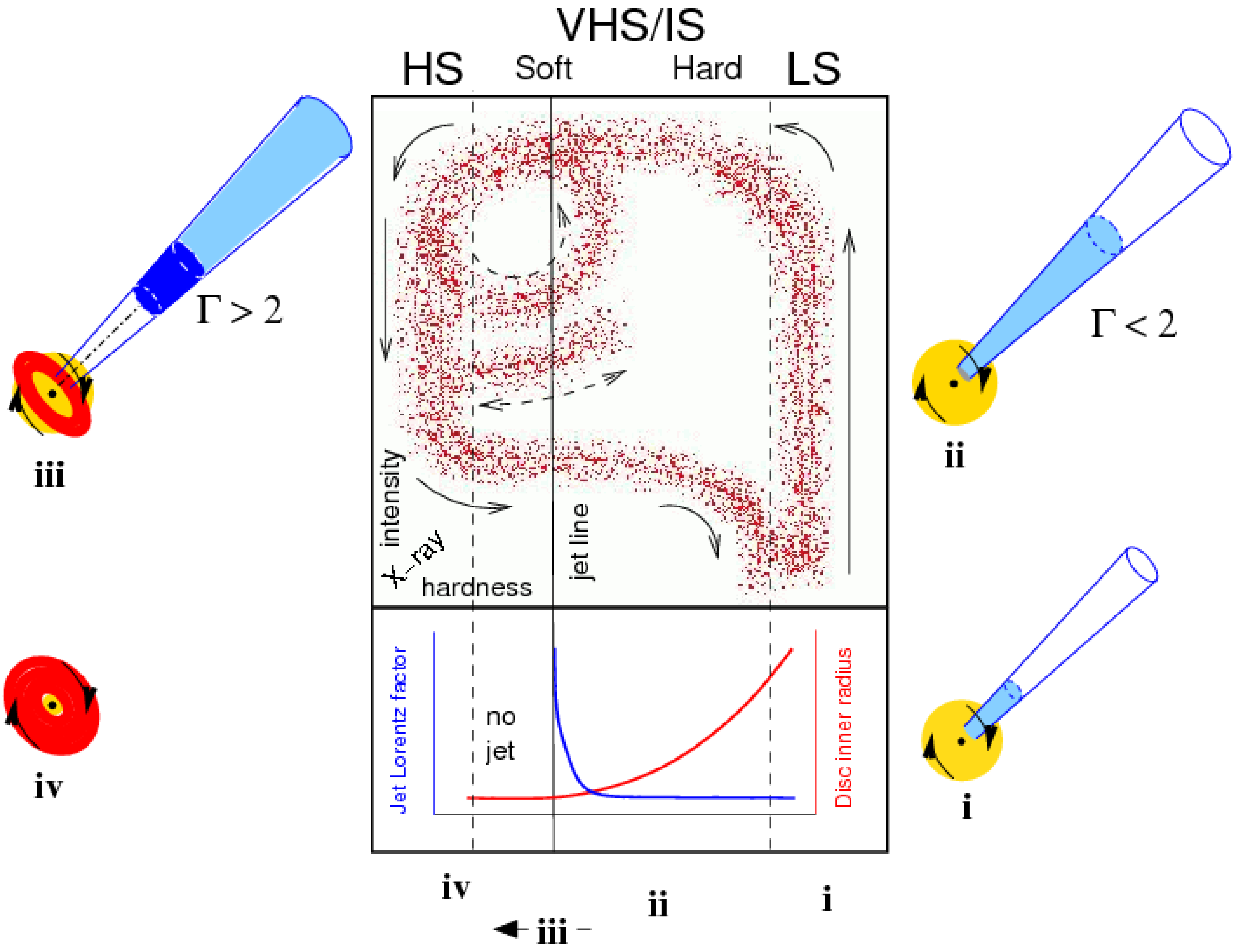


X-ray Binaries: X-ray spectral states





Evolution of XRB spectral states



HS = high/soft

VHS = very high/soft

IS = intermediate state

LS = low/hard state

Credit: Fender+, 04

Can we study spectral states in AGN?

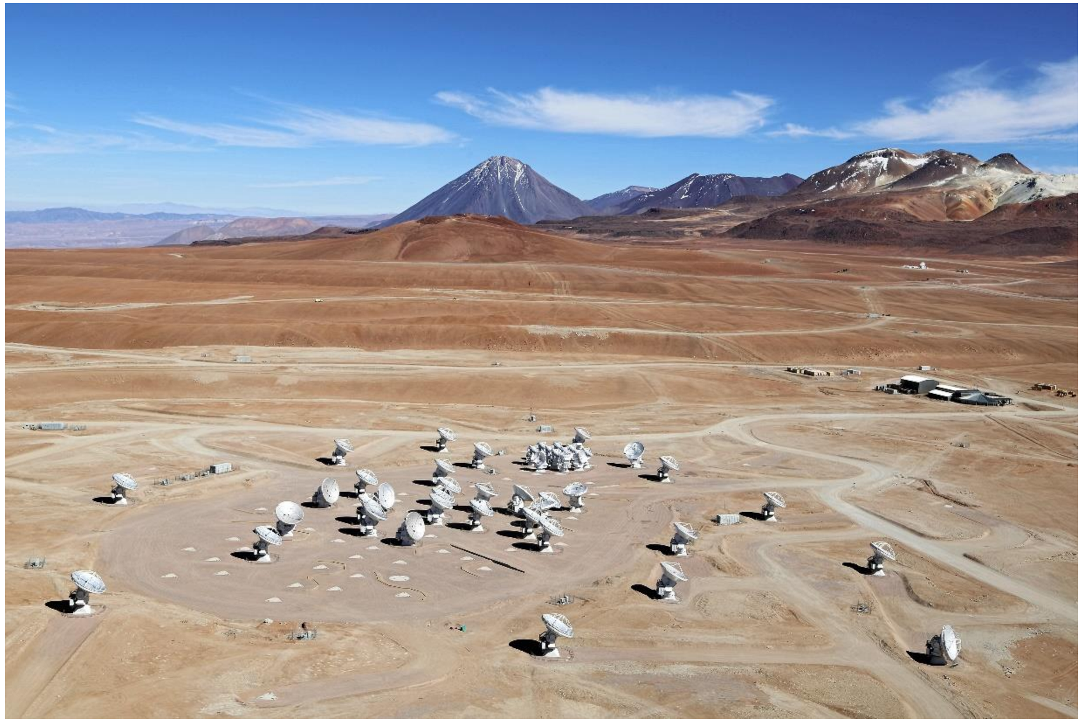
- motivation for the study:
    1. **Is AGN activity a temporary episode of a full accretion cycle similar to XRB?**
    2. **Can we apply what we learn from XRB to AGN and vice versa?**
    3. **Is AGN radio-dichotomy** (about 10% of AGN are radio-loud, the rest is quiet) **due to dichotomy of black hole spin values** (with powerful jets formed around highly spinning black holes), or is it a **temporary feature related to the accretion state?**

Can we study spectral states in AGN?

- time scale of day-long transients in XRB translates to thousands to million years in AGN

Can we study spectral states in AGN?

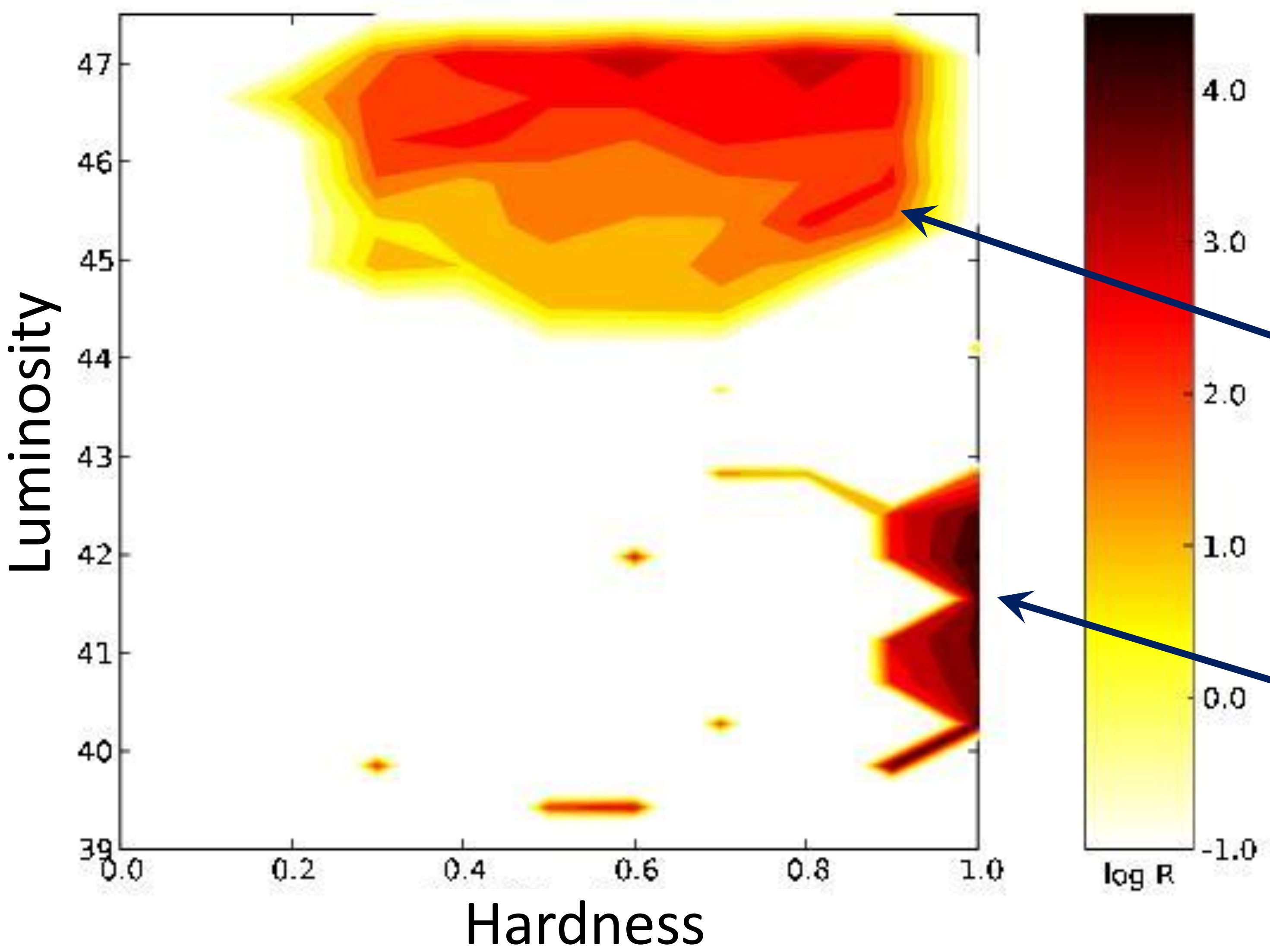
- time scale of day-long transients translates to thousands to million years in AGN, no hope to wait



Can we study spectral states in AGN?

- time scale of day-long transients in XRB translates to thousands to million years in AGN
- study of a large homogeneous sample
  - needs to be done in **X-rays (non-thermal component)** but also in **UV (AGN thermal component)**

AGN spectral states – previous works



Koerding et al. (2006a),
Koerding+ 06b, Sobolewska+ 08

sample based on SDSS (optical), ROSAT (X-rays) and FIRST (radio)

low-luminosity AGN taken from Ho et al. 97

Our project with XMM-Newton data

Main advantages:

- optical/UV and X-ray detectors on single telescope
- simultaneous measurements
  - eliminate spectral variability
- non-thermal flux estimated from 2-10 keV instead of 0.1-2.4 keV (by ROSAT)
  - eliminate X-ray absorption
- thermal emission from UV instead of the optical band
  - closer to the thermal peak

XMM-Newton catalogues

- **3XMM catalogue** (Rosen et al., 2016)
  - contains 9160 observations (2000-15) with more than 500,000 clear X-ray detections
- **OM-SUSS catalogue** (Page et al., 2012)
  - contains 7170 observations with more than 4,300,000 different UV sources
- **AGN catalogues:**
  - **Véron-Cetty & Véron (2010)**
  - **SDSS (DR12)** – quasars + AGN (Alam+, 2015)
  - **XMM-COSMOS** (Hasinger+ 07, Lusso+ 12)

→ 6188 simultaneous UV and X-ray measurements of AGN

Selection procedure of good measurements

- removing sources with extended UV emission (accretion disks have to be point sources)
- removing X-ray under-exposed sources
- removing sources with too steep ($\Gamma > 3.5$) or too flat ($\Gamma < 1.5$) X-ray slope (potentially large influence of an X-ray absorber)
- removing sources with their measured UV flux corresponding to $\lambda \leq 1240$Å in their rest frame (to be always on the same part towards the thermal peak)
- excluding sources with known nuclear HII regions
- selecting the best observation for each source

→ 1522 unique high-quality simultaneous UV and X-ray measurements of AGN

Definitions

- thermal disc luminosity:

$$L_D \sim 4\pi D_L^2 \lambda F_{\lambda,2910\text{Å}}$$

- non-thermal power-law luminosity:

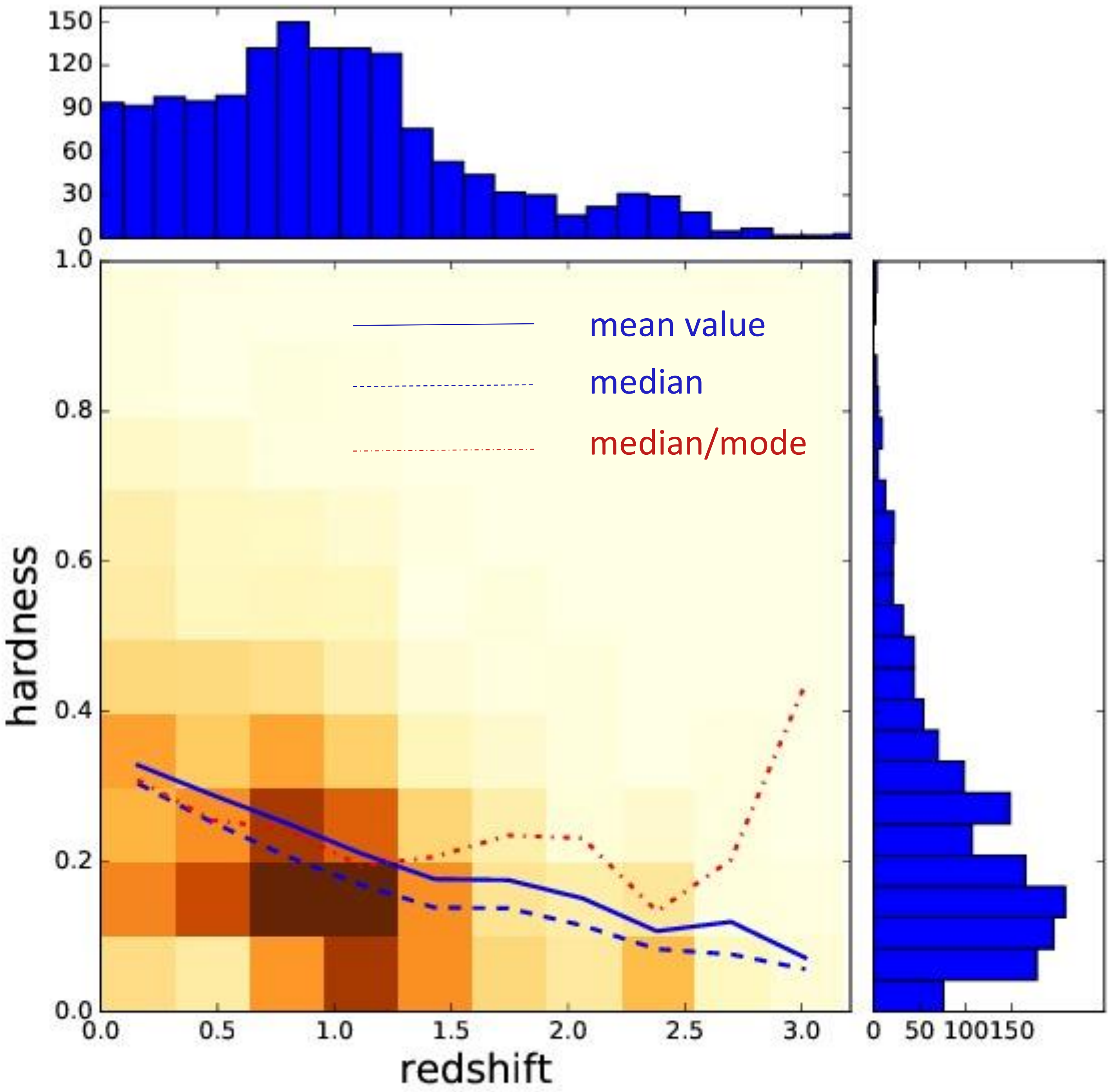
$$L_P = 4\pi D_L^2 F_{0.1-100\text{keV}}$$

(where $F_{0.1-100keV}$ is an extrapolated X-ray power-law flux)

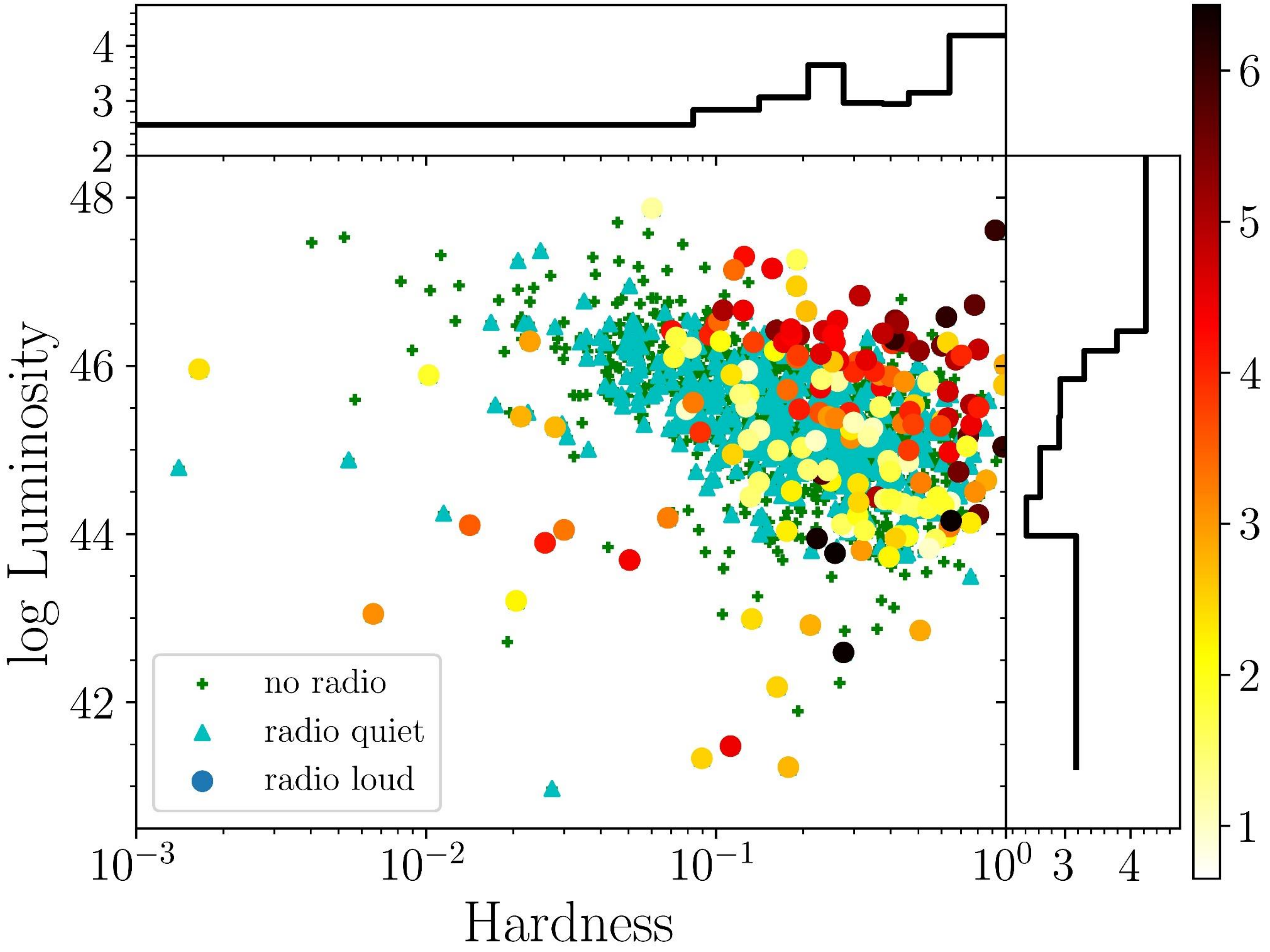
- spectral hardness: $H = \frac{L_P}{L_P + L_D}$

Redshift-hardness distribution of the sample

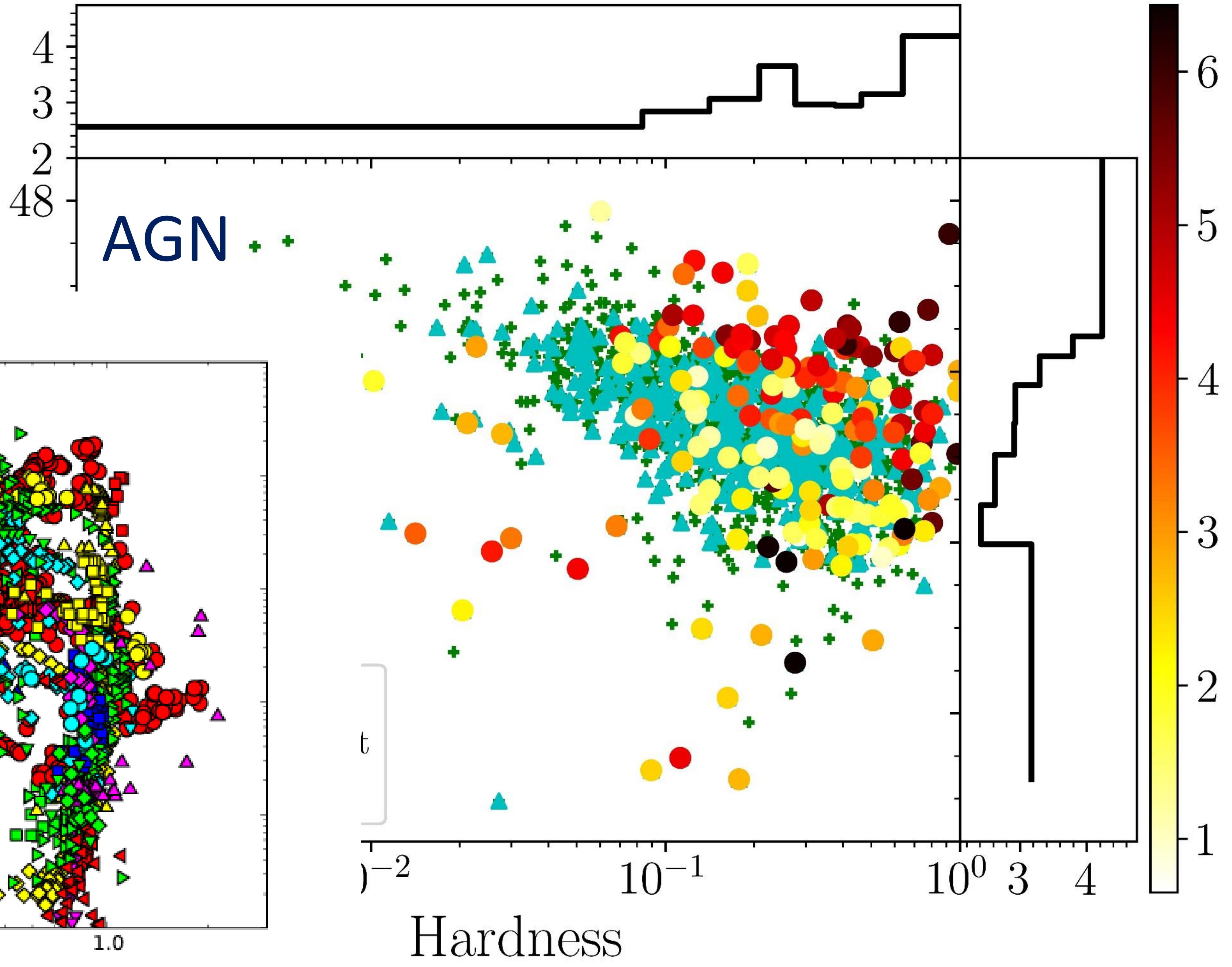
- most sources are at $z < 1.5$ (because of the $\lambda \leq 1240$Å criterion) and at low spectral hardness ($H < 0.4$)
- hardness decreases with redshift but this might be due to observational bias

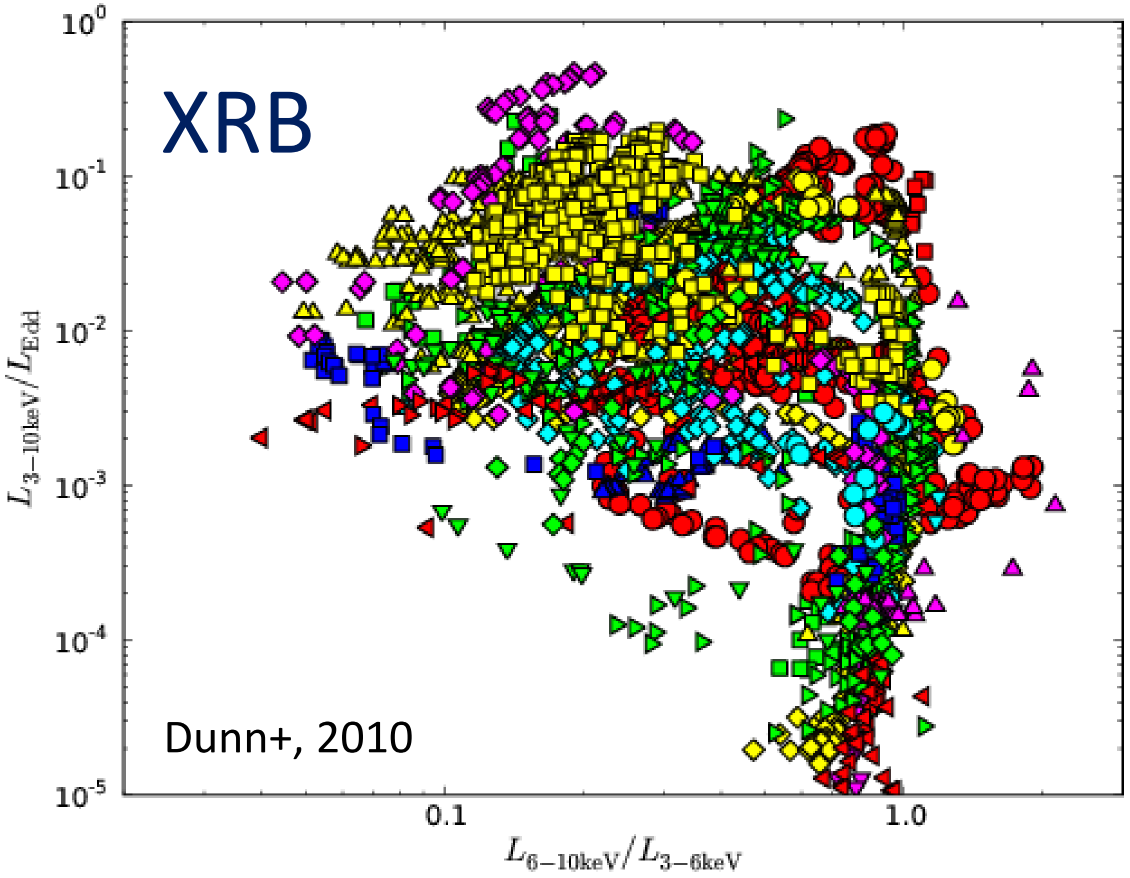


Hardness – Luminosity diagram



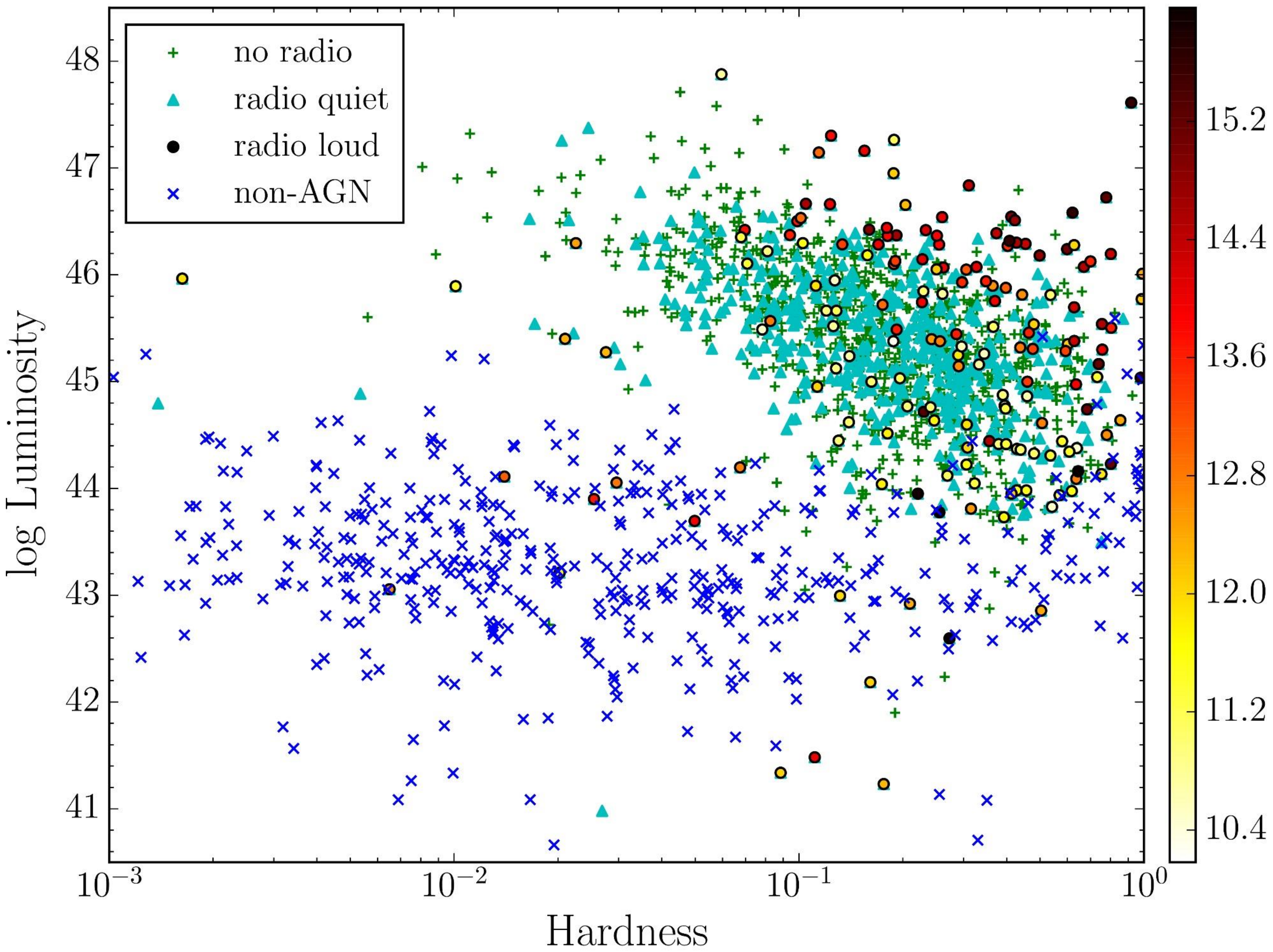
Hardness – Luminosity diagram





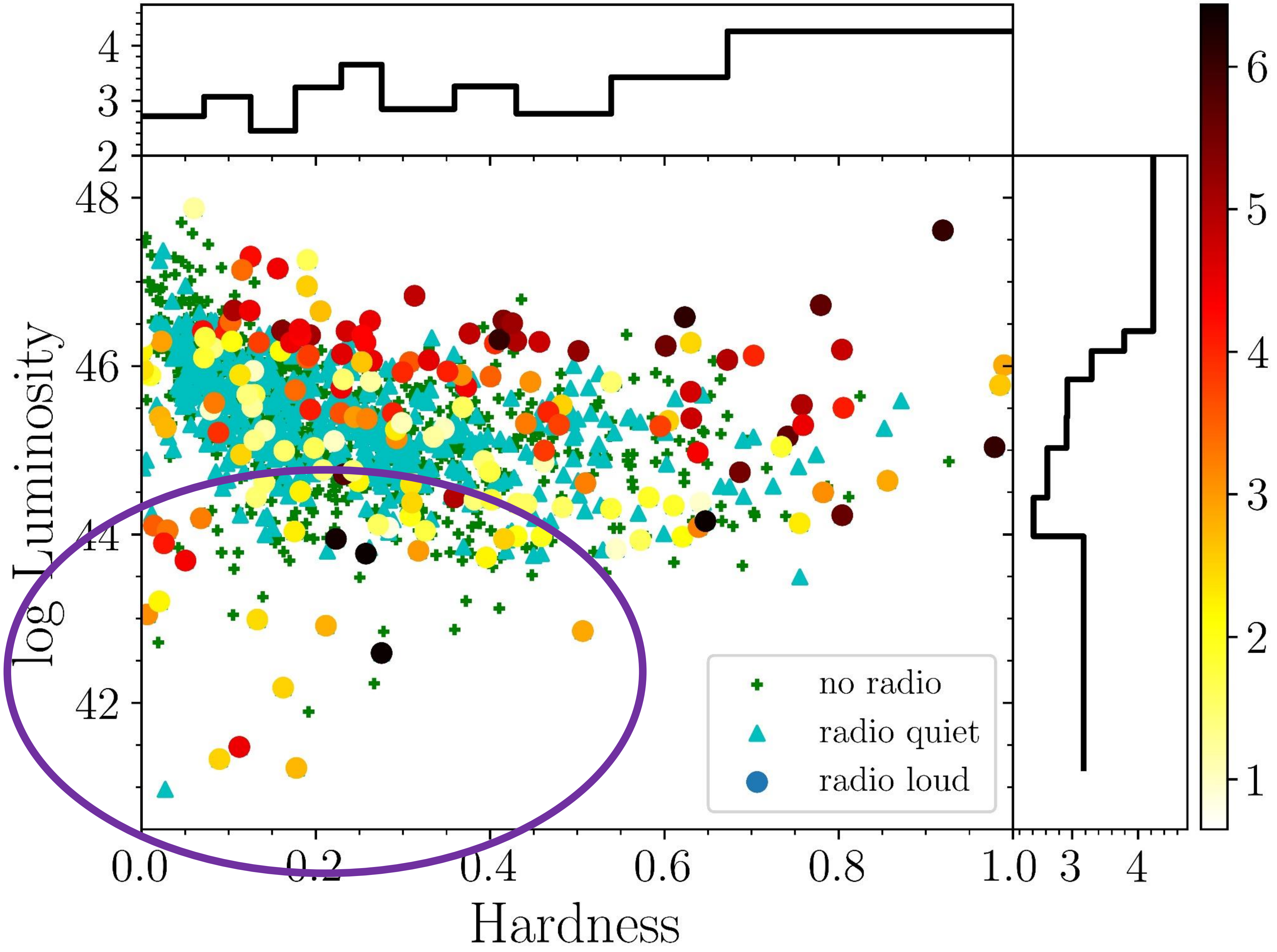
Low – luminosity sources

- problem with the **host-galaxy contamination**
- **non-AGN** show ``distribution of host galaxies'' in the Hardness-Luminosity diagram



Hardness – Luminosity diagram

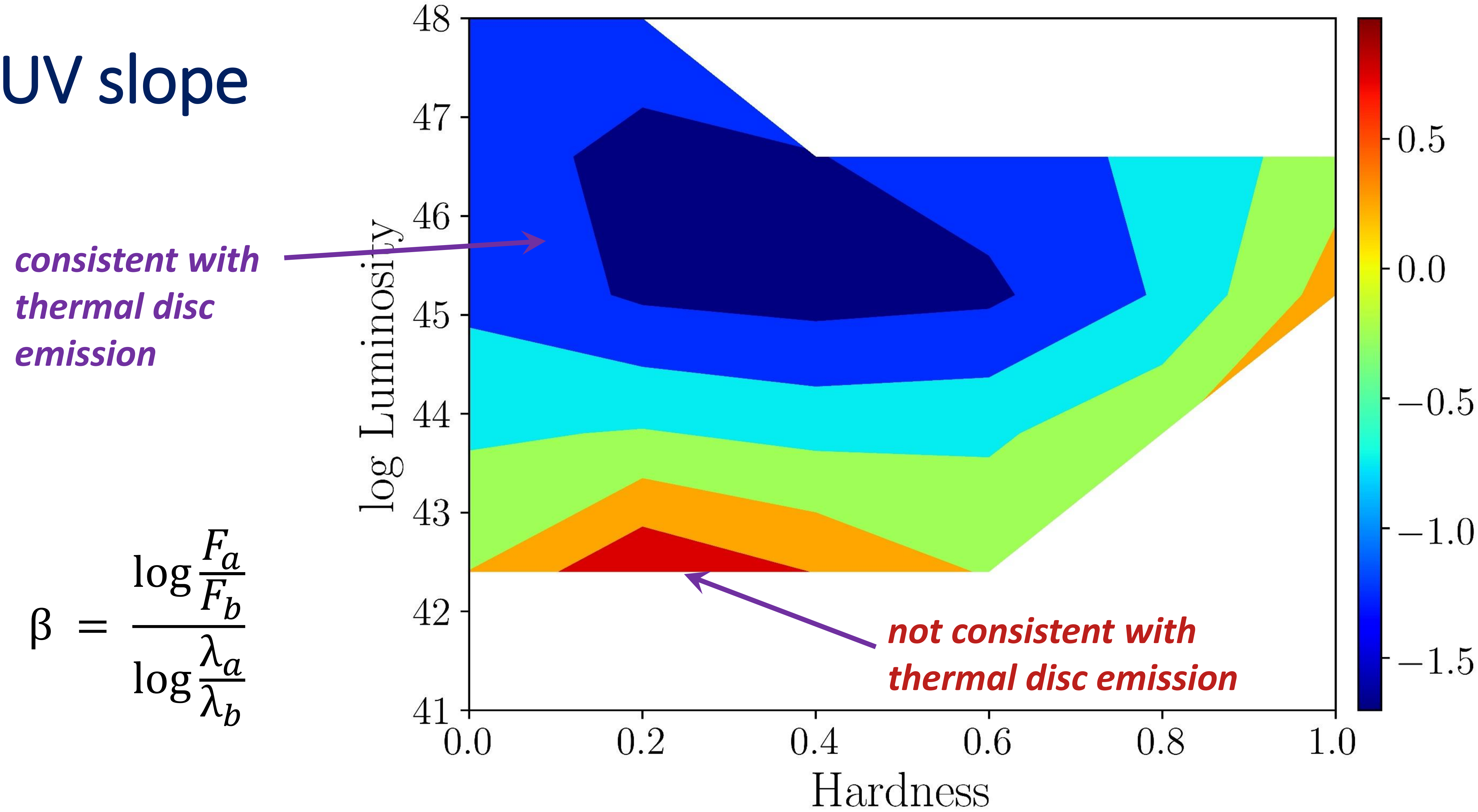
(in linear scale of the hardness)



are these sources intrinsically soft or hard?

UV slope

$$\beta = \frac{\log \frac{F_a}{F_b}}{\log \frac{\lambda_a}{\lambda_b}}$$



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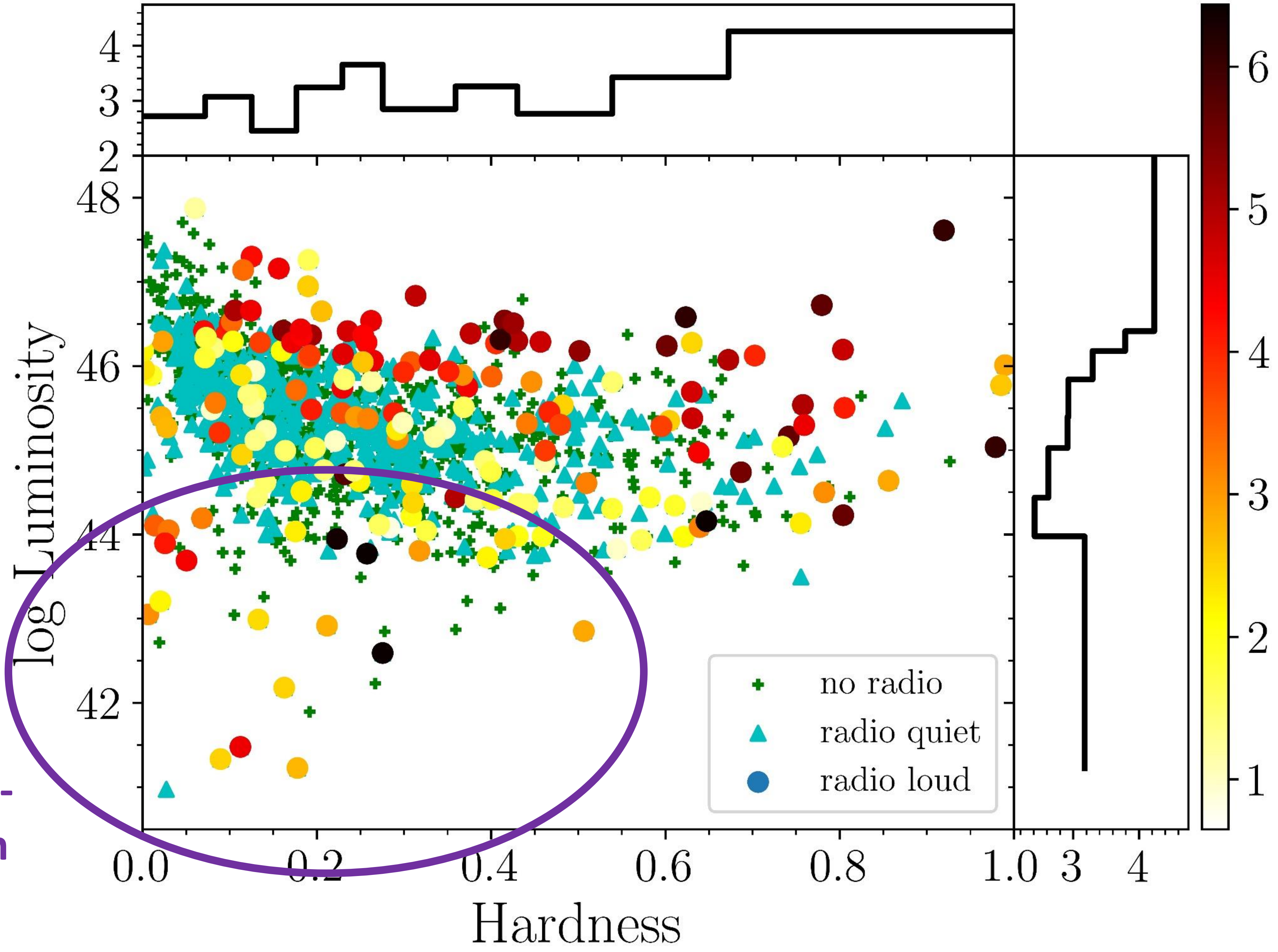
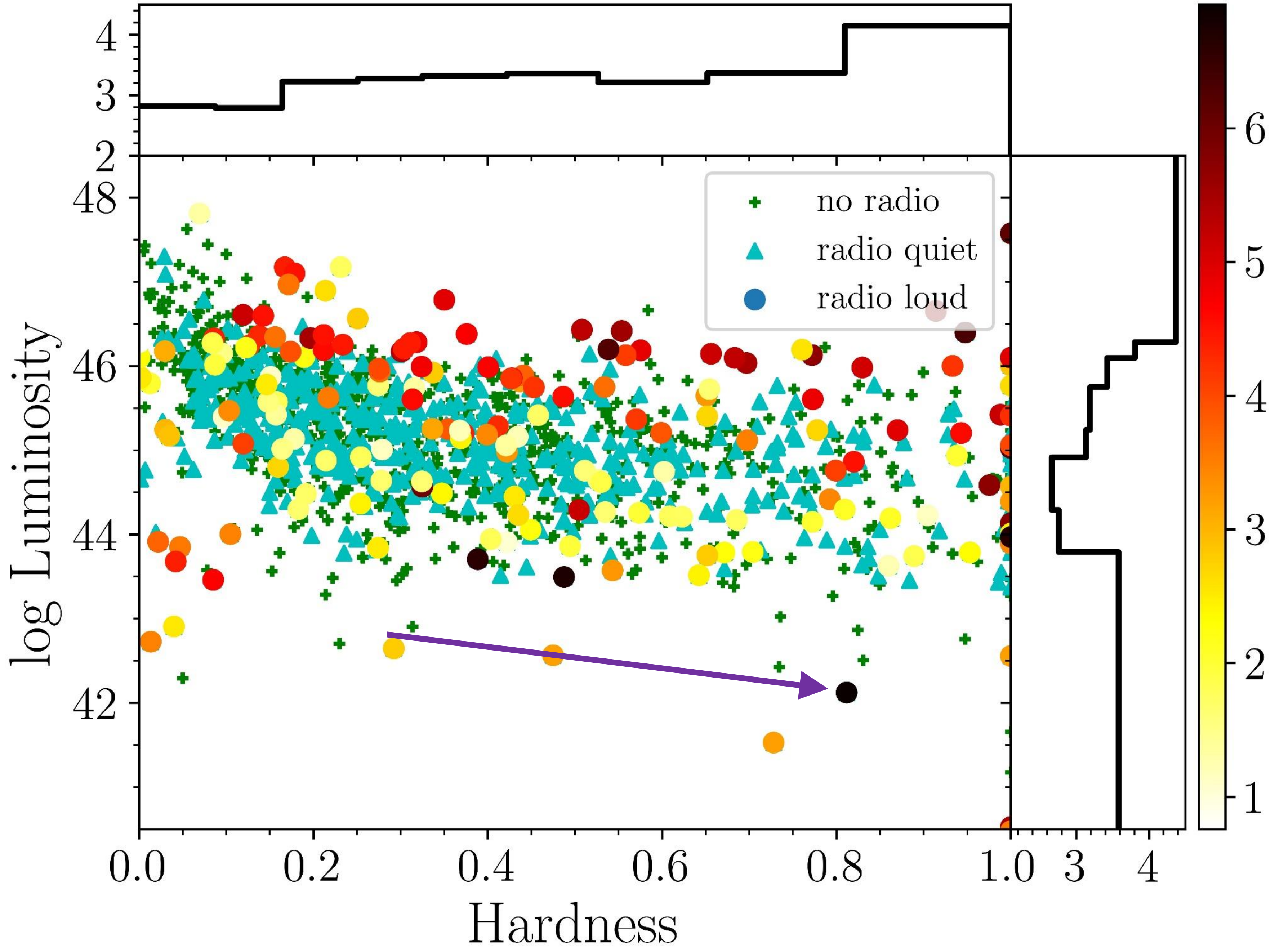


UV emission of these sources dominated by host-galaxy contribution

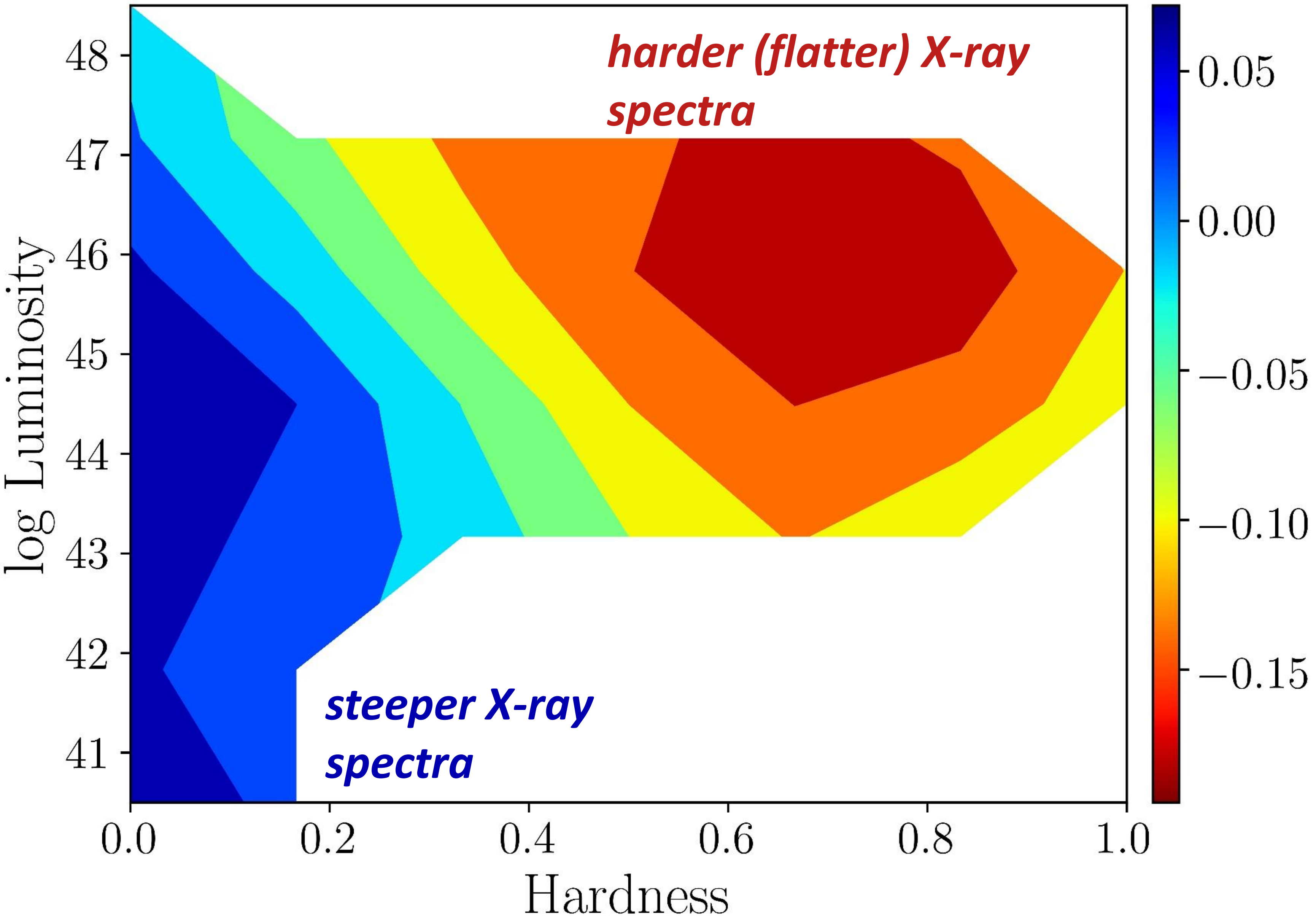
Hardness – Luminosity diagram

(after attempt to correct for host-galaxy)



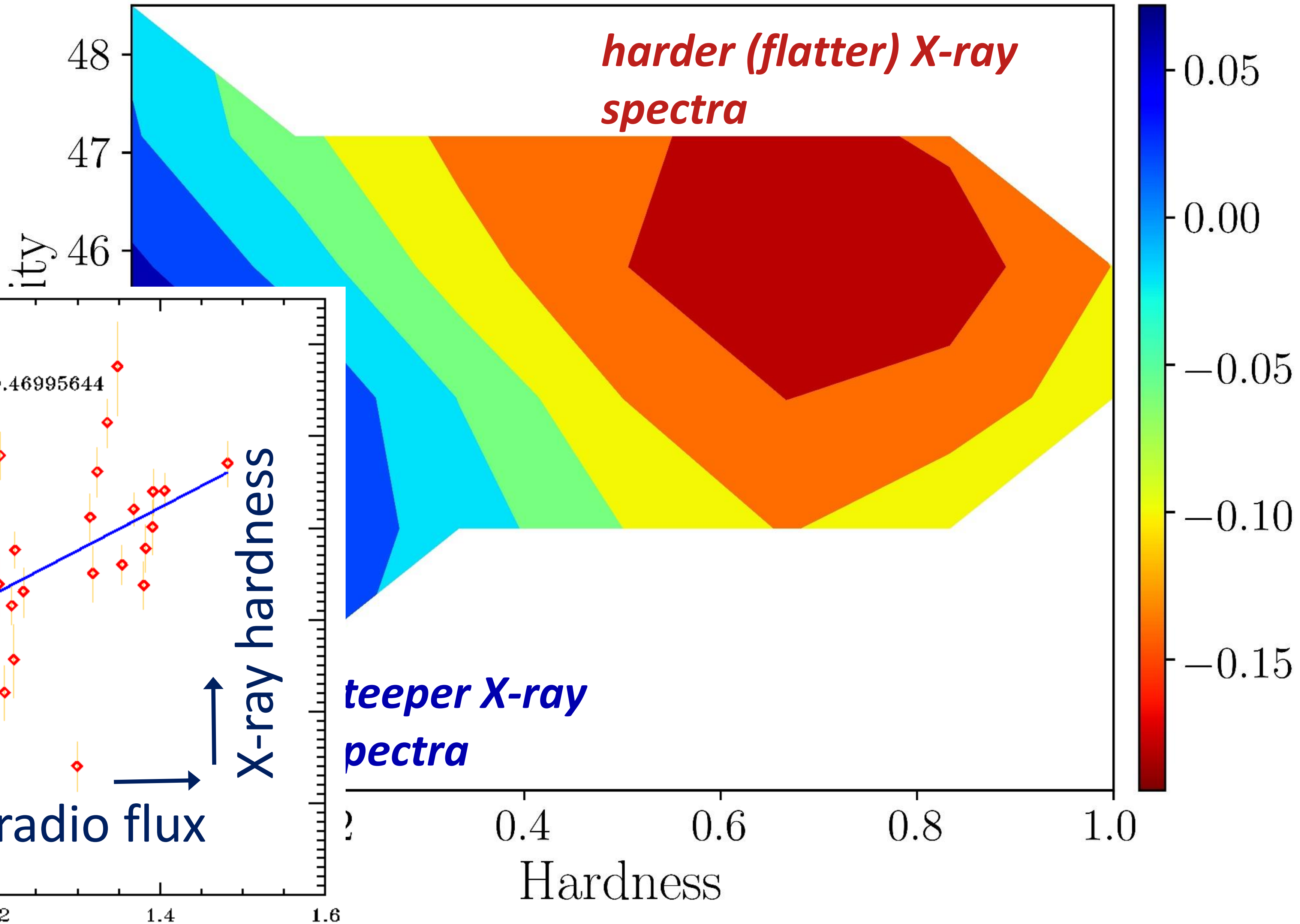
X-ray slope

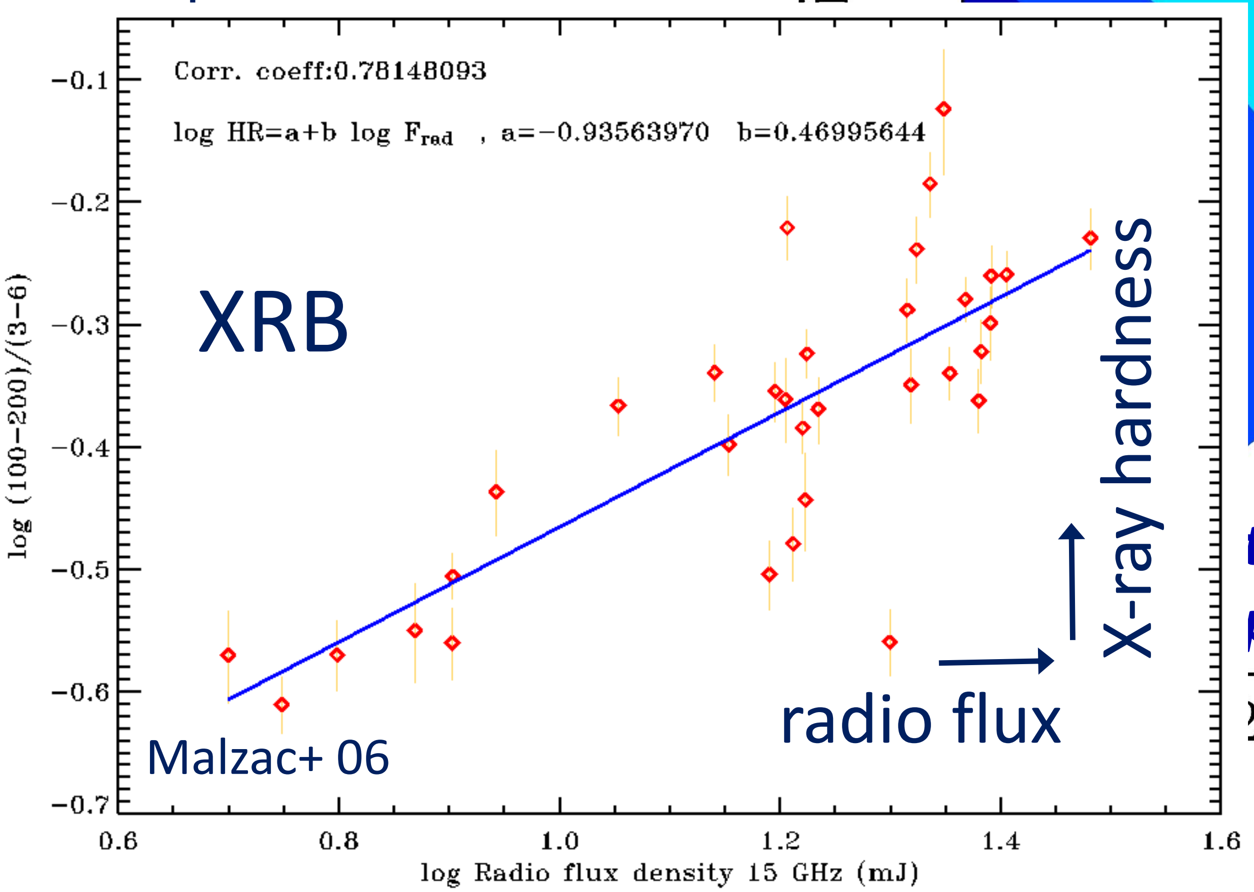
- distribution of the photon index deviation from the mean value Γ = 1.7
- harder (flatter) X-ray spectra are consistent with the higher radio loudness of sources with the larger fraction of X-ray vs. optical/UV flux



X-ray slope

- distribution of the photon index



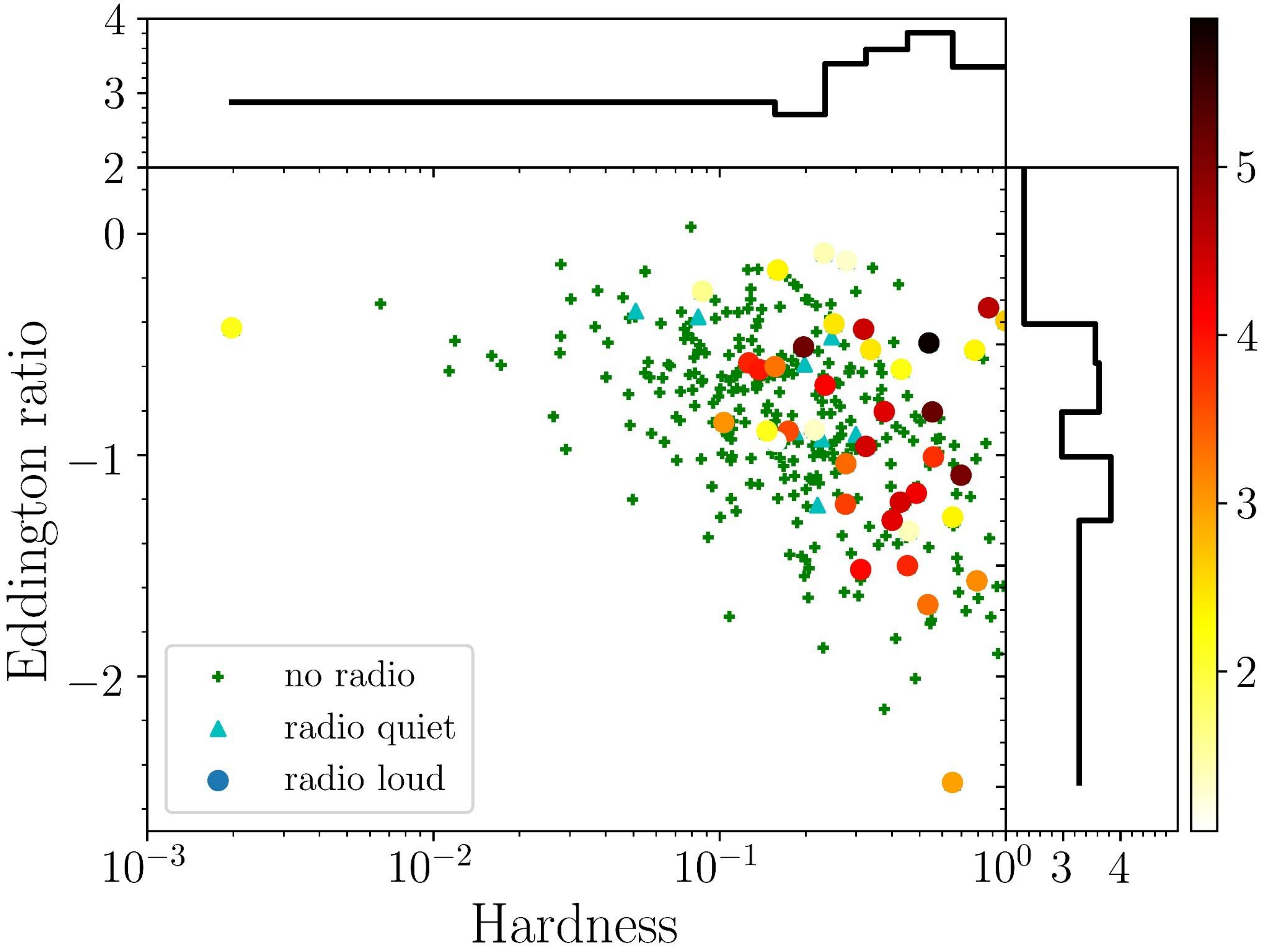


Eddington ratio

- AGN span quite large range of masses (10^5-10^{10} $M_{\odot}$)
  - **Eddington ratio** is better quantity to determine the accretion state
  - however, we do not have reliable mass measurements of such a large AGN sample
    - the most reliable methods (e.g. reverberation) were applied to about a few tens of nearby AGN
    - we used virial mass measurements from the width of optical lines
      - see Shen et al. (2011) for the SDSS sample

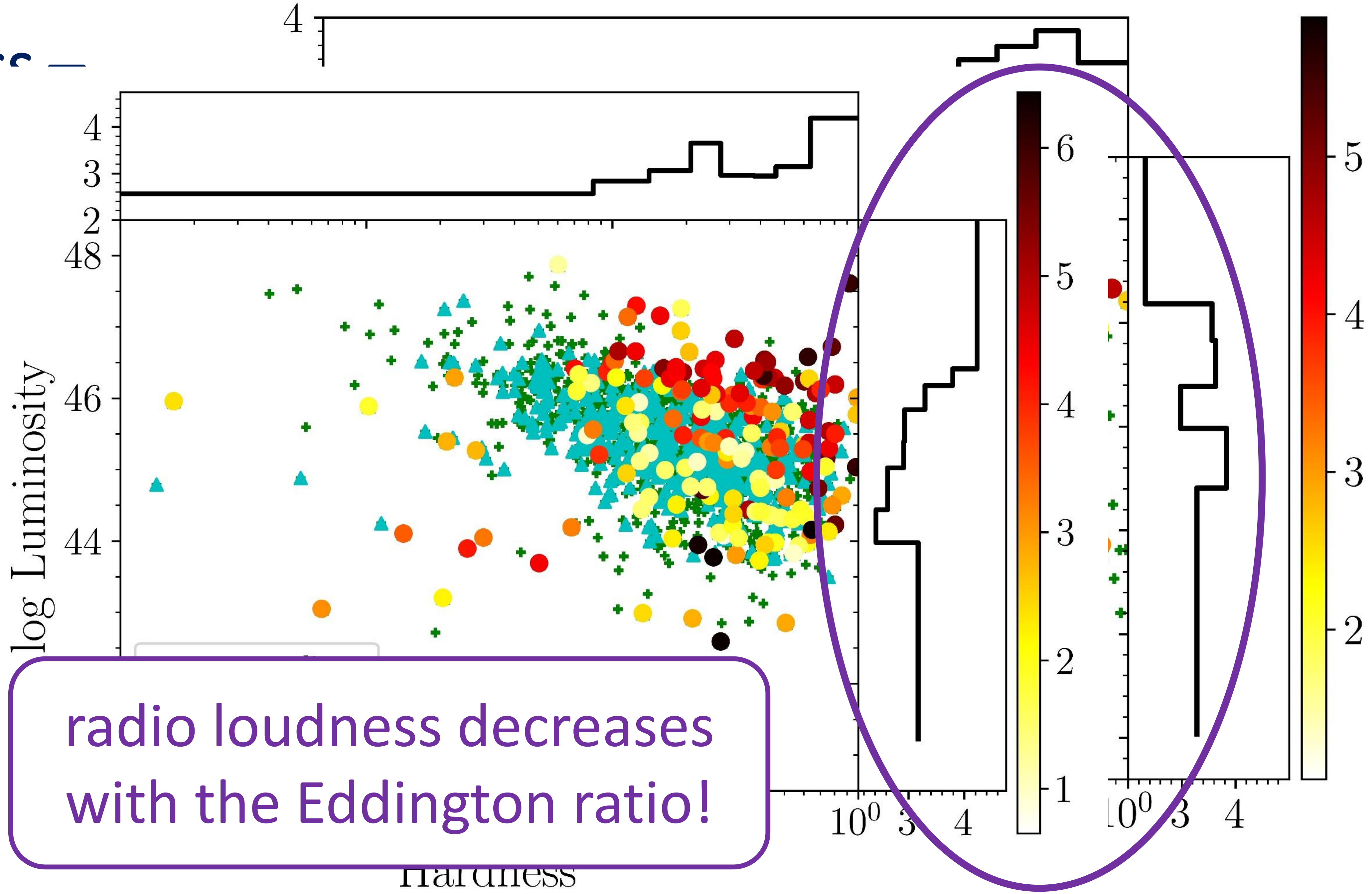
Hardness – Eddington Ratio diagram

(for SDSS sub-sample only)



Hardness – Eddingt Ratio d

(for SDSS su sample only



radio loudness decreases with the Eddington ratio!

Conclusions

- we have studied spectral states of AGN with **simultaneous optical/UV and X-ray measurements with XMM-Newton**
  - we used all available high-quality observations in the archives
- we found several **similarities to XRB spectral states:**
  - radio-loud sources have larger fraction of X-ray flux, their X-ray spectra are flatter, and they lack thermal disk emission in UV
  - radio loudness decreases with the Eddington ratio
- **AGN activity as well as the AGN radio dichotomy can be explained by the spectral state evolution similar to XRB**

(for more details see **Svoboda et al., 2017**, A&A, 603A, 127S)

Thank you very much for your attention!!!