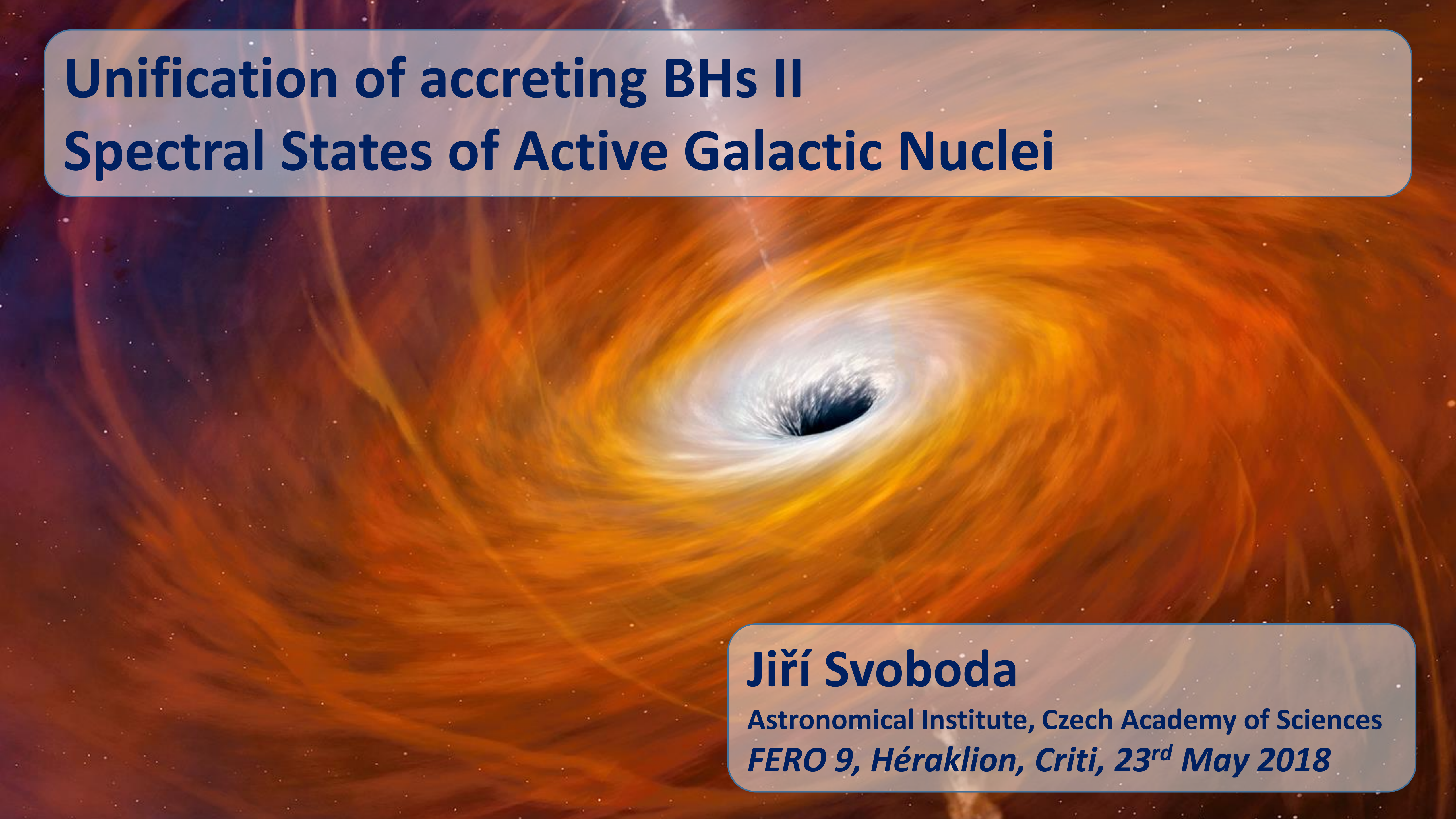

Unification of accreting BHs II
Spectral States of Active Galactic Nuclei

Jiří Svoboda

Astronomical Institute, Czech Academy of Sciences

FERO 9, Héraklion, Criti, 23rd May 2018

Before we start…

- thanks to:
  - **Matteo Guainazzi, Andrea Merloni**, Ignacio de la Calle, Giovanni Miniutti, Sara Elisa Motta, Margherita Giustini, Gabriele Ponti, Barbara de Marco, Marion Cadolle Bel, Erin Kara, Victoria Grinberg, and all FERO participants
  - organisers of FERO 9

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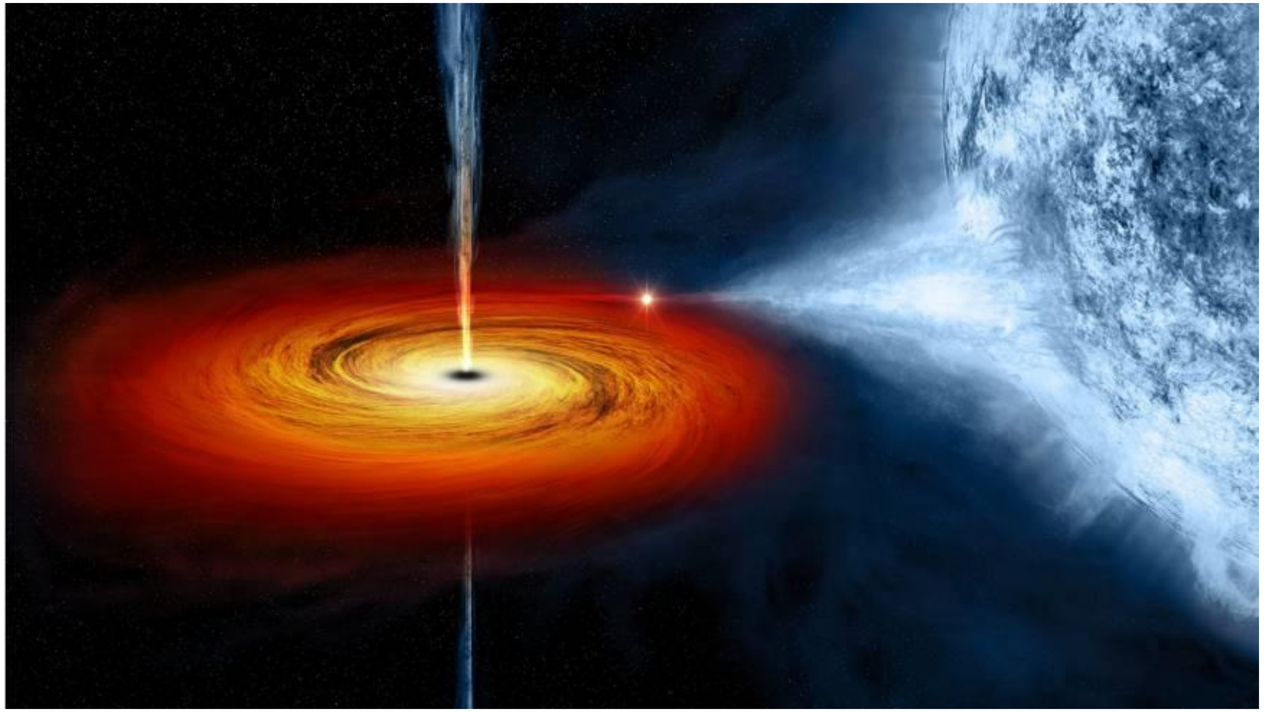
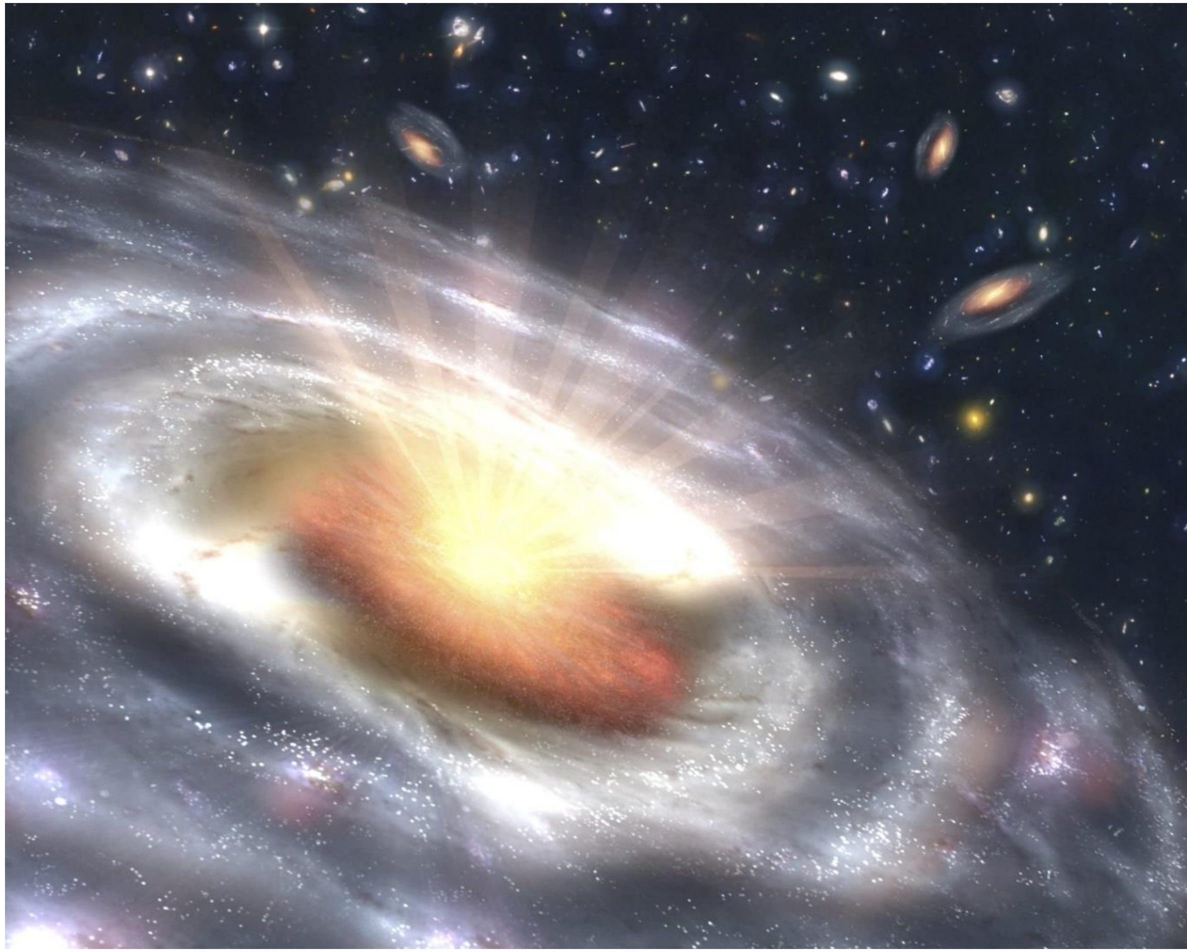
  - organisers of FERO 9
- this talk will not be a comprehensive review but rather incomplete and personal overview of open issues
- variability – talks by Gabriele and Barbara

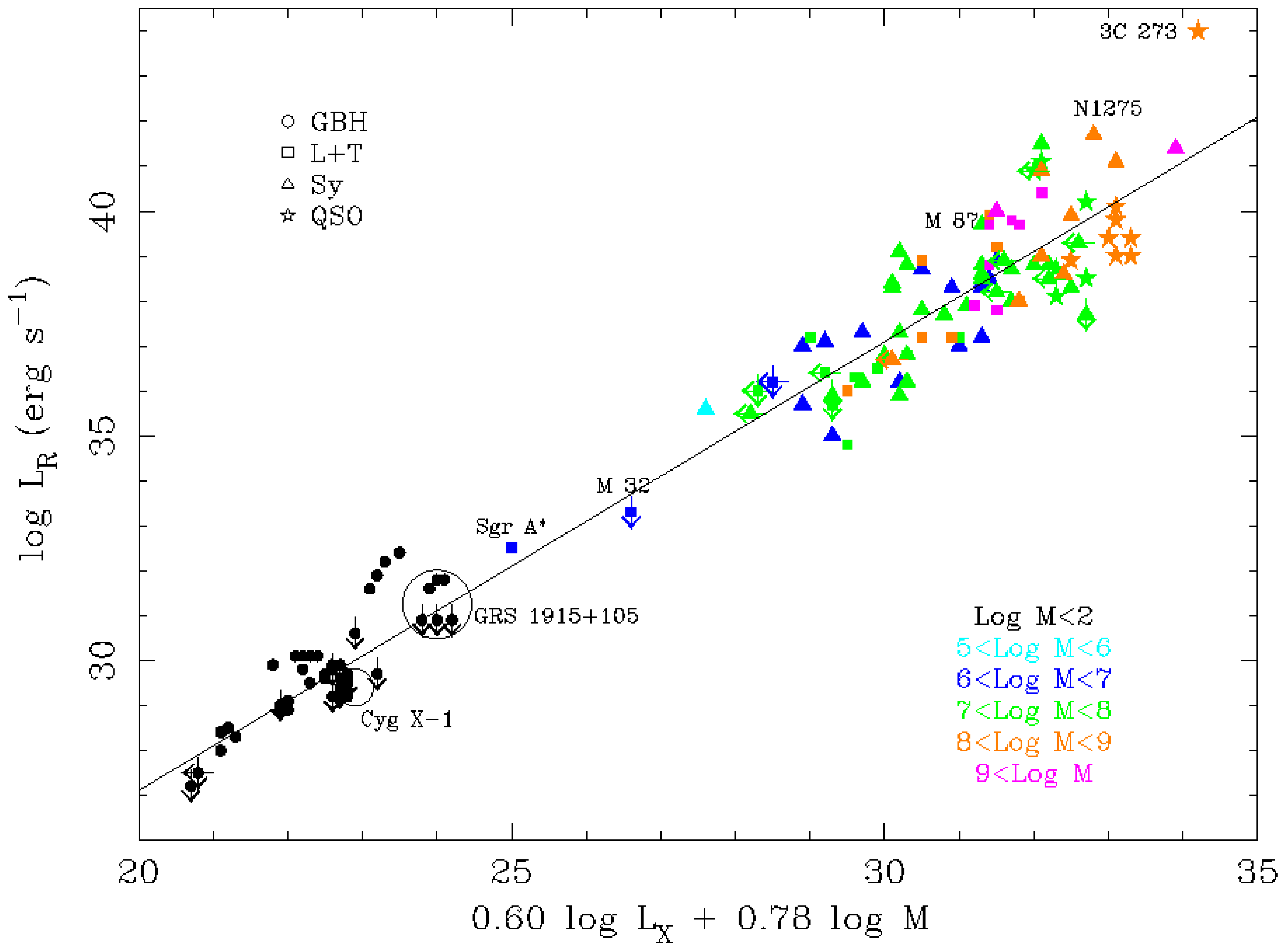
What's common for AGN and XRB?
- Accretion on Black Holes

- matter with non-zero angular momentum accretes in the form of the **accretion disk**





Fundamental plane of BH activity



- radio luminosity correlates with *both* BH mass and X-ray luminosity
- the relation shows the connection between accretion flows (x-rays) and jet activity (radio)

Merloni et al. (2003),

Falcke et al. (2004)

What's different for AGN and XRB?

	XRB (stellar-mass BH)	**AGN (super-massive BH)**
mass	$3\text{-}10^{2}\ M_{\odot}$	$10^{5}\text{-}10^{10}\ M_{\odot}$
size	$\geq$ 10 km	0.01 – 100 AU
time scale*	ms	hours - days

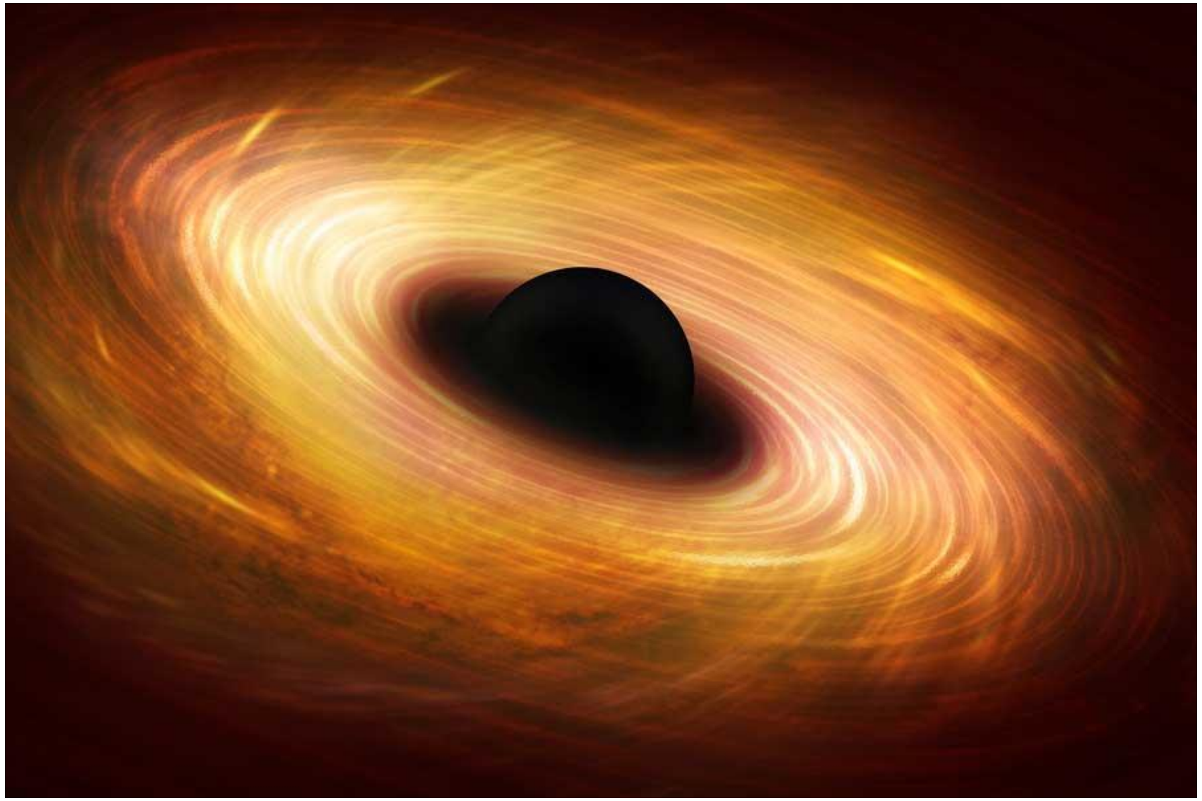
* time scale corresponding to the Keplerian orbital period at 10 GM/c^2

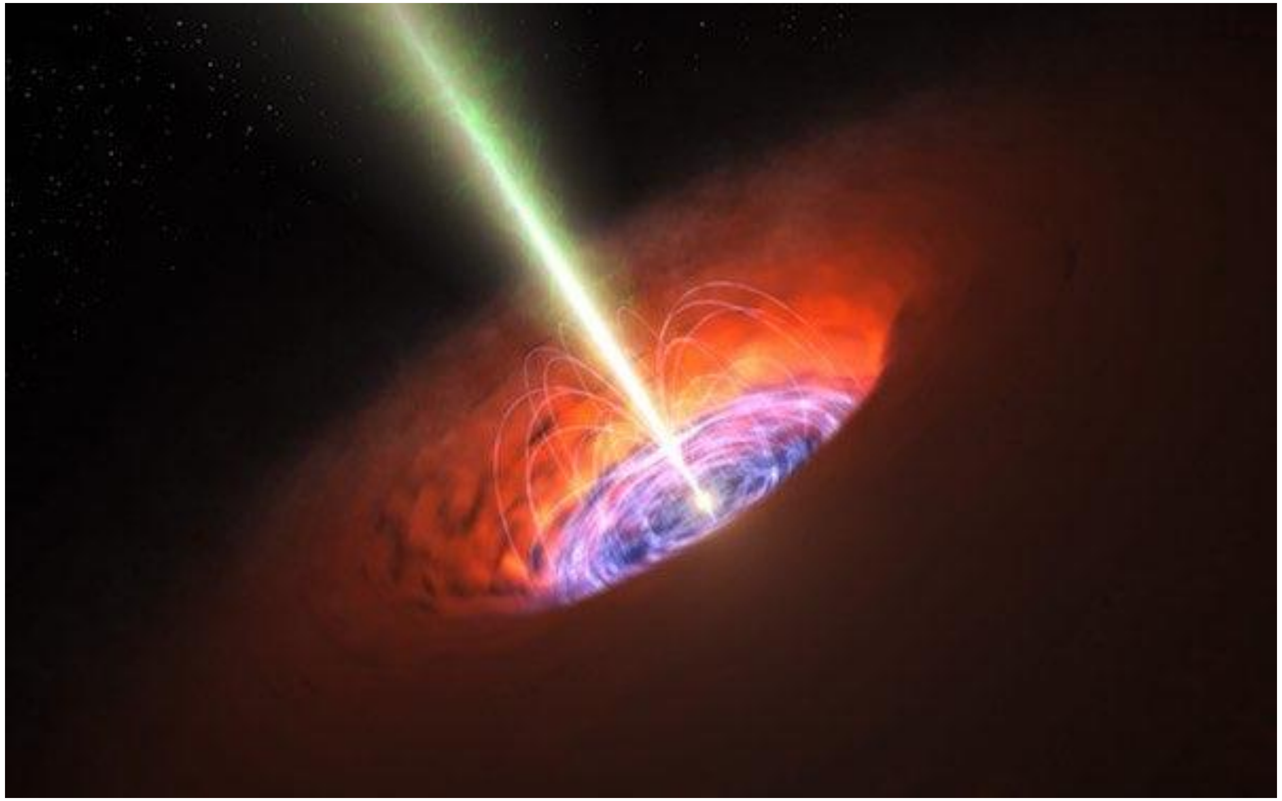
What’s different for AGN and XRB?

- **Different physical properties of the accretion discs**
  - disc densities and ionisations may be largely different
- **Structure of the X-ray corona**
  - additional Comptonisation component in AGN responsible for the soft X-ray excess *(Gierlinski & Done, 2004; Done et al., 2012)*
- **Triggering of the activity**
  - an XRB is relatively an isolated system
  - AGN activity may be triggered by galaxy mergers *(e.g. Koss et al. 2010, Ellison et al. 2011)*, but see also *Villforth et al. (2014)*
    - feeding and feedback cycle – co-evolution of active SMBH and star formation (see, e.g., *Fiore et al., 2017*)

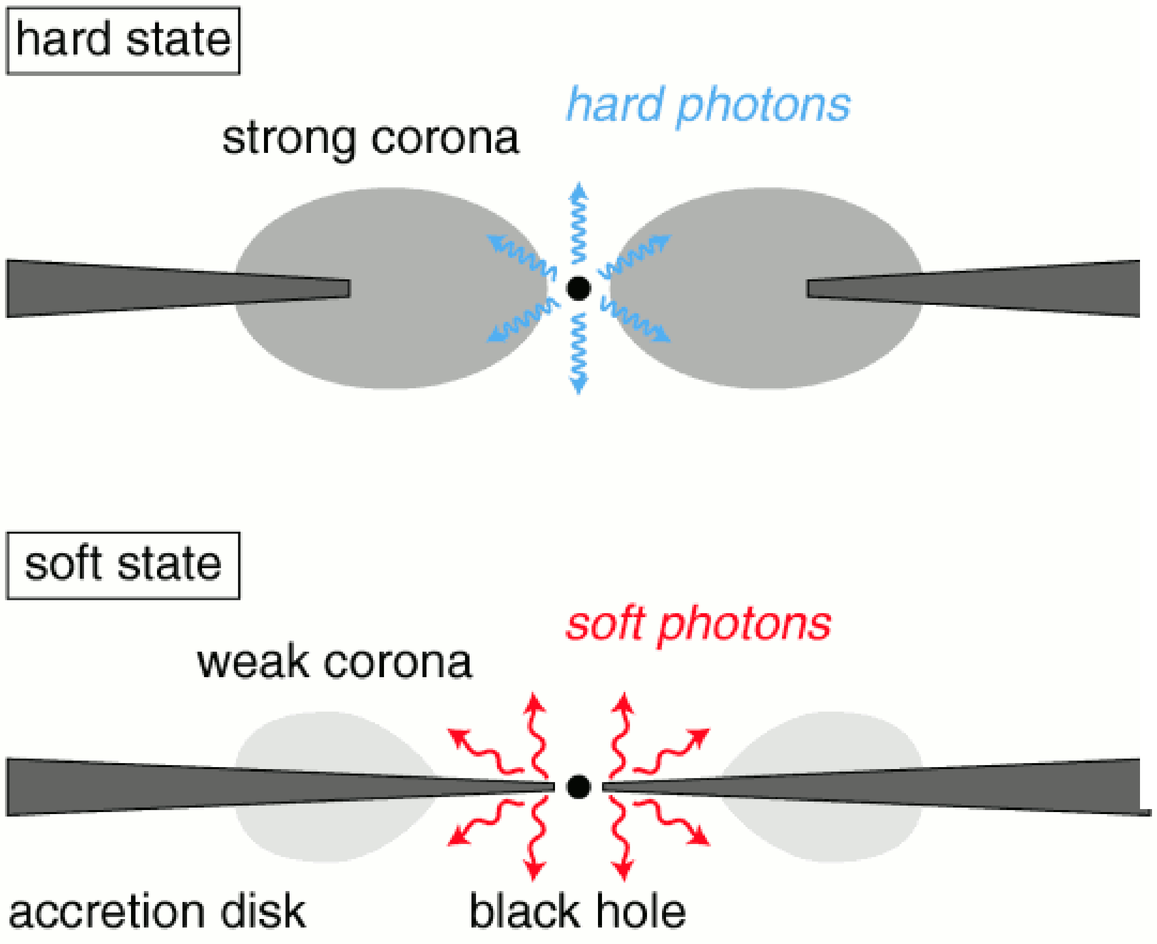
X-ray Binaries: different accretion states

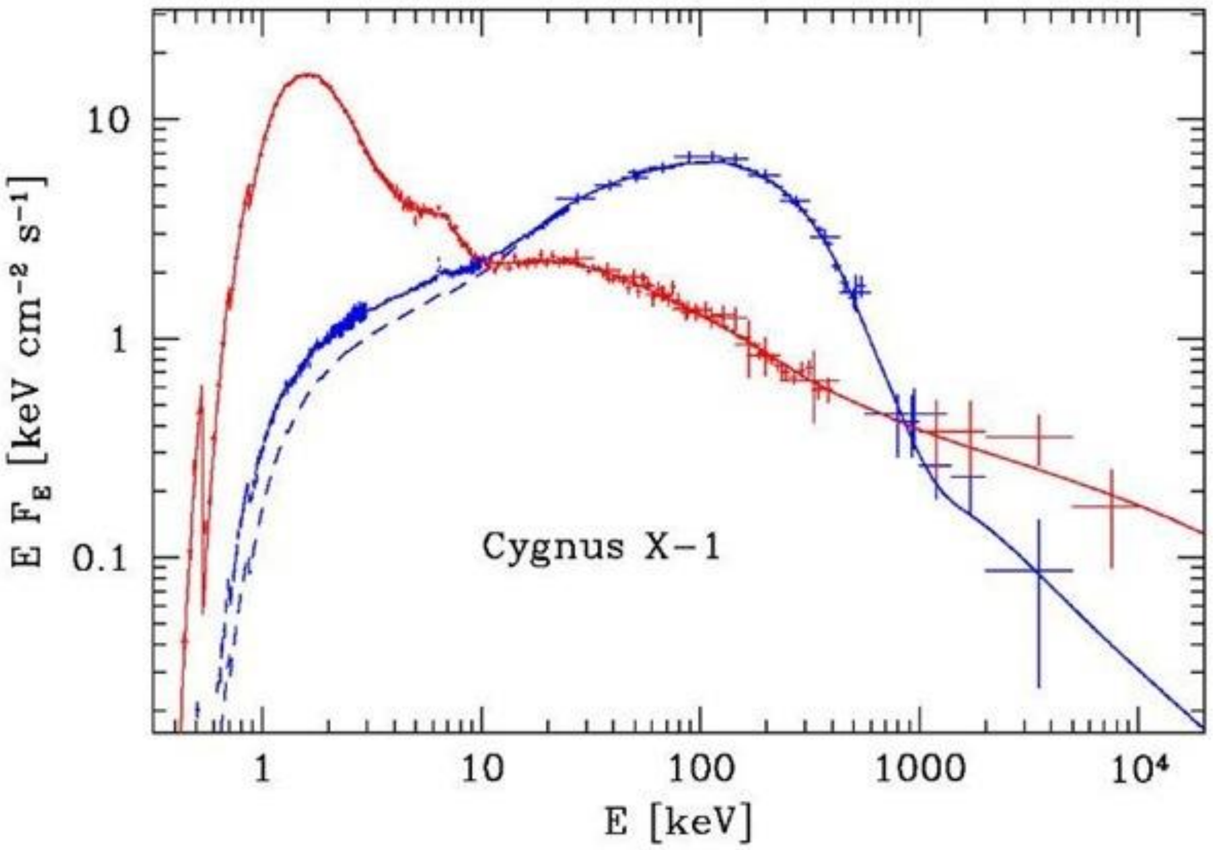
- accretion rate determines the nature of the accretion flow





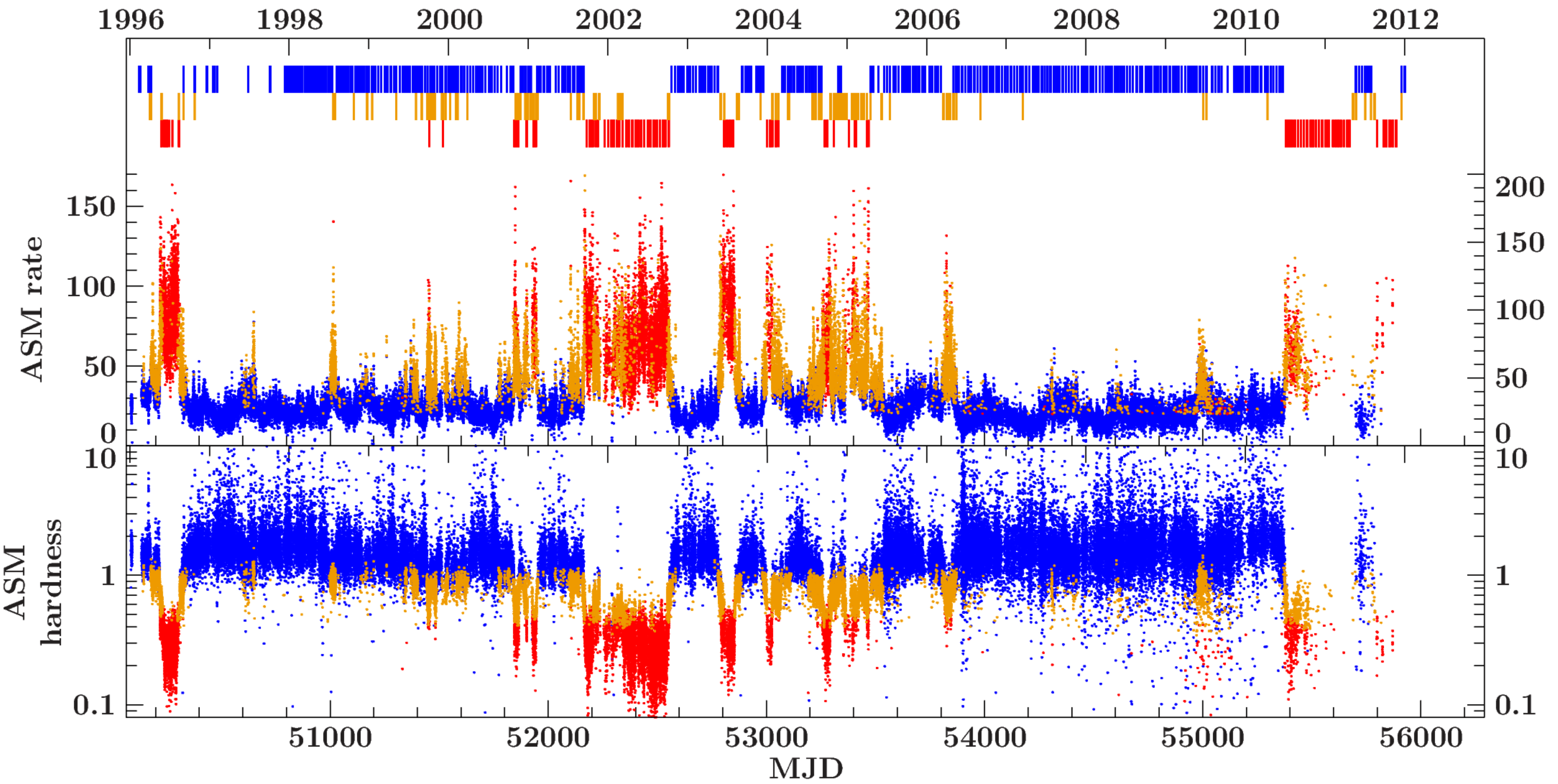
X-ray Binaries: spectral states





for more details see, e.g., Remillard & McClintock 06, Done+04, Meyer-Hofmeister+05, Zdziarski+04, Zycki+01,...

Variability – changes of XRB spectral states

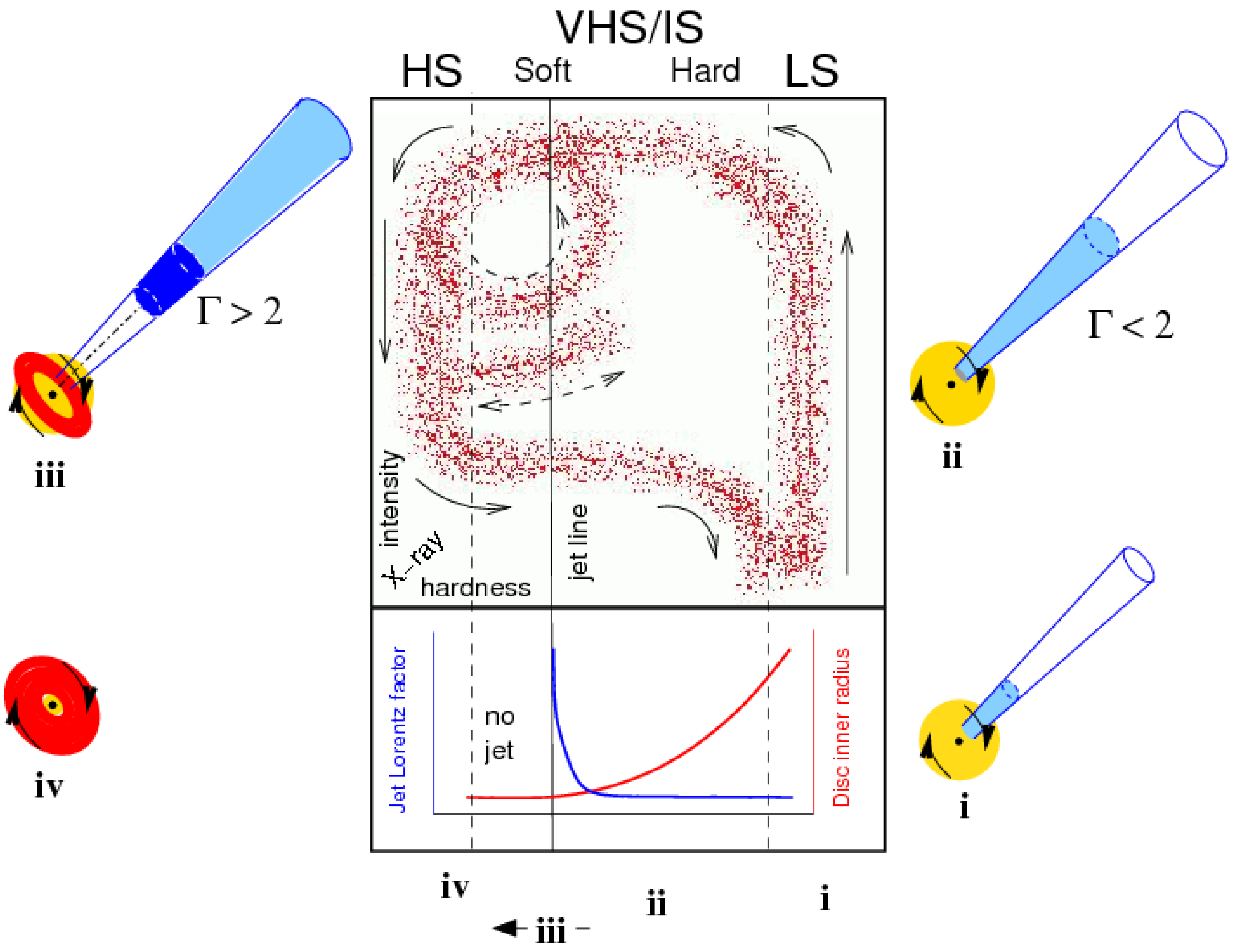


Cyg X-1

Grinberg+14

Evolution of spectral states - hysteresis

- the evolution goes always in the **same direction**
- some theoretical explanations exist (Chakrabarti & Titarchuk 95, Smith+ 02, Liu+ 05, Petrucci+ 08, Contopoulos+ 15)

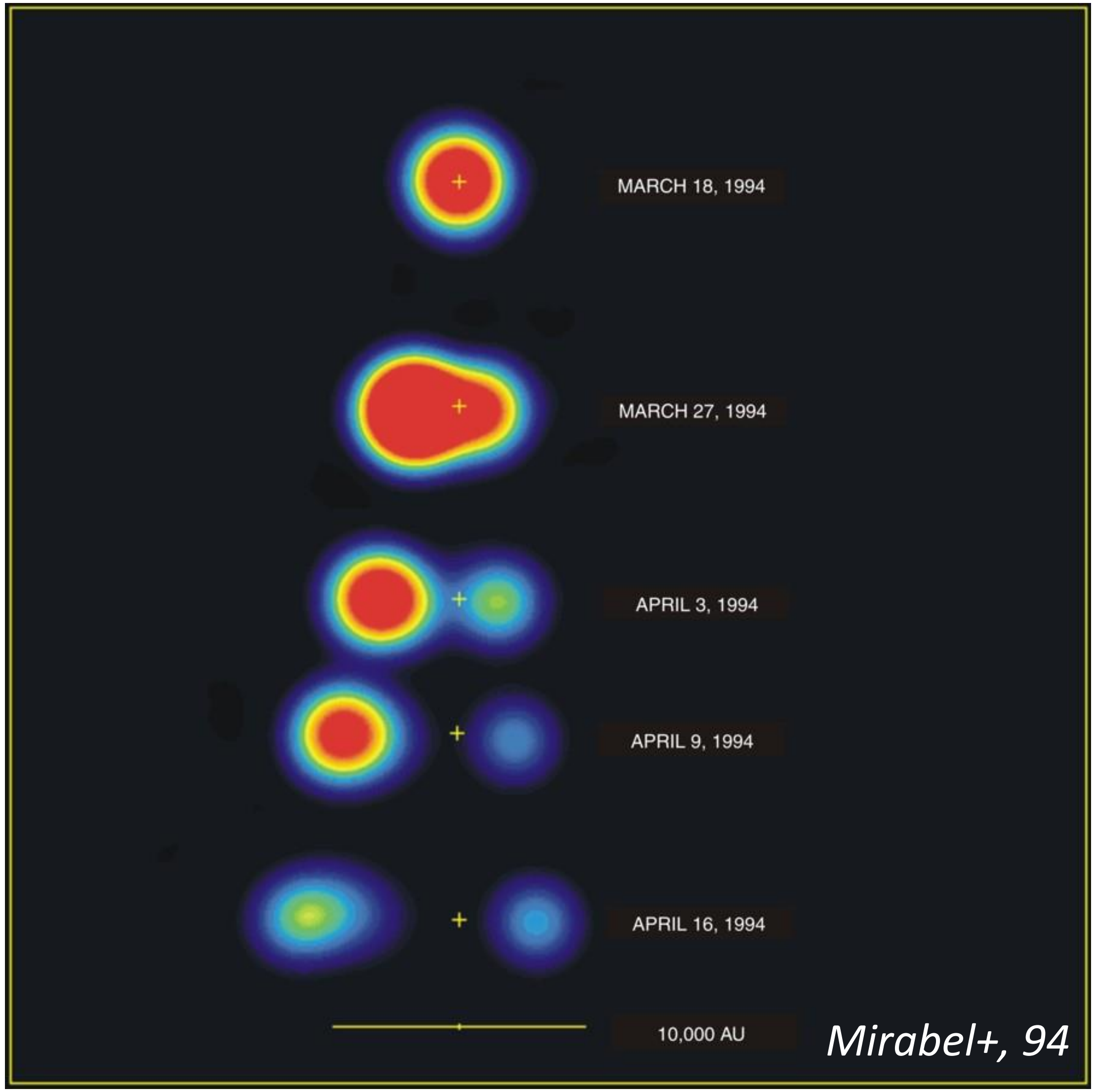


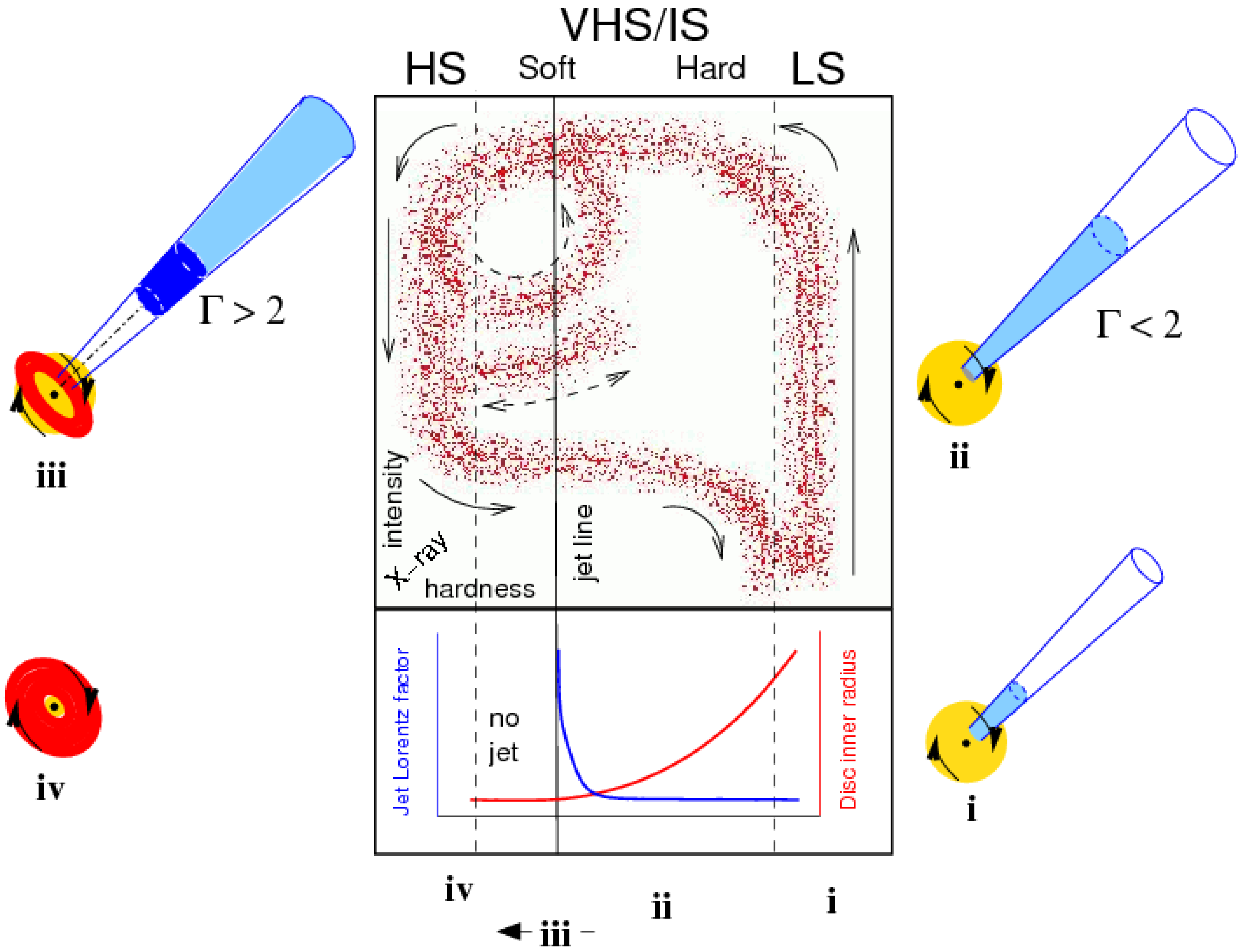
HS = high/soft, VHS = very high/soft

IS = intermediate state, LS = low/hard state

Credit: Fender+, 04

Transient jets (blobs) in the intermediate state

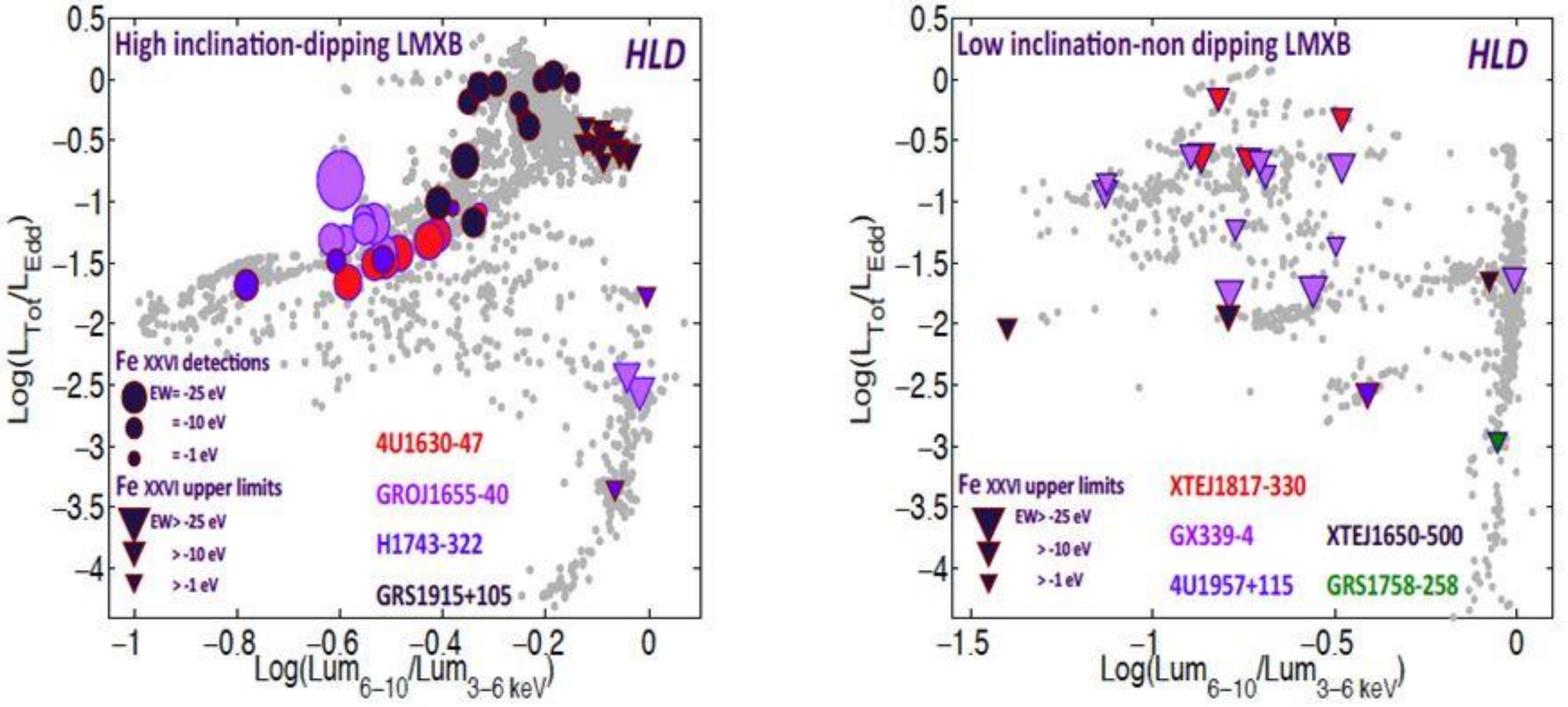




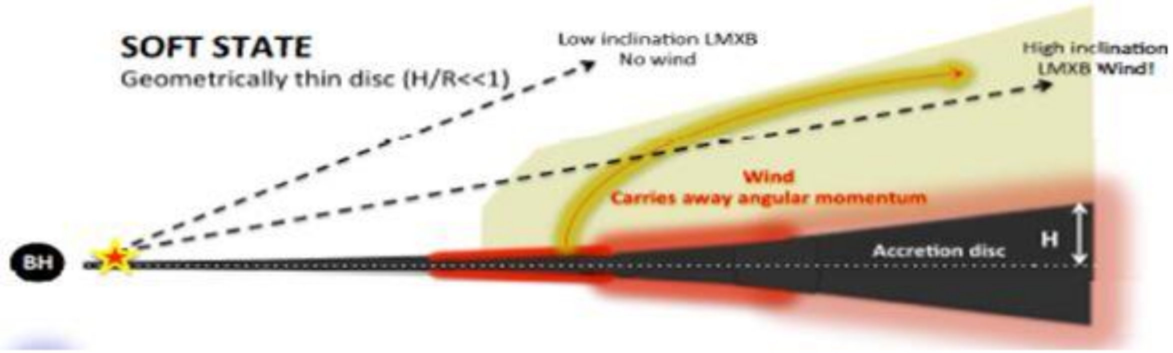
BH: absorption lines in high inc

Jets in the hard states, winds in the soft states

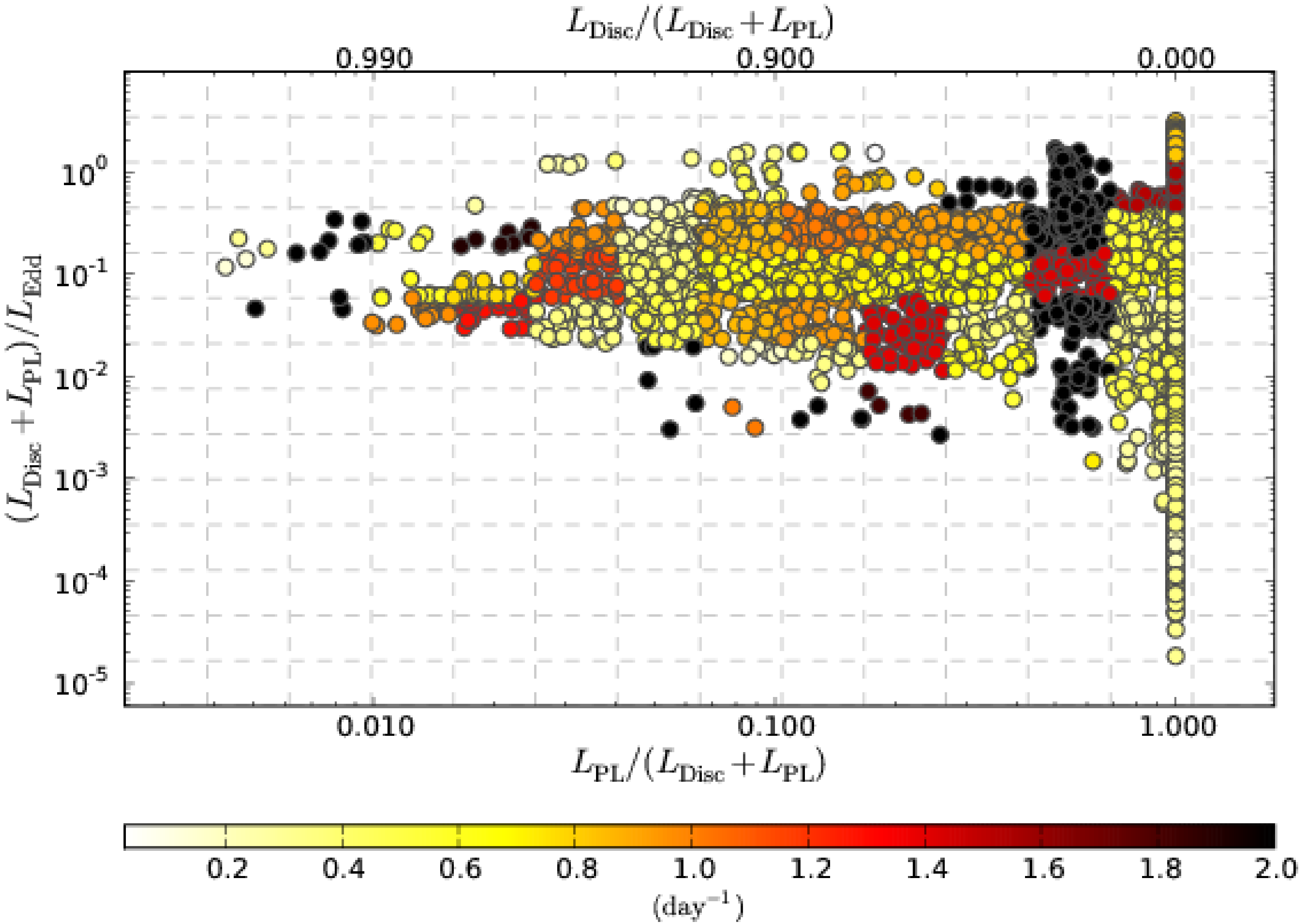
- observational evidence for the winds depends on inclination *(Ponti+2012)*



Ponti et al 2012



Rate of XRB spectral states



Dunn+, 10

Can we study spectral states in AGN?

- first, why do we care?

Can we study spectral states in AGN?

- first, why do we care?
  - understanding of the accretion evolution in AGN can help us to answer longstanding questions:

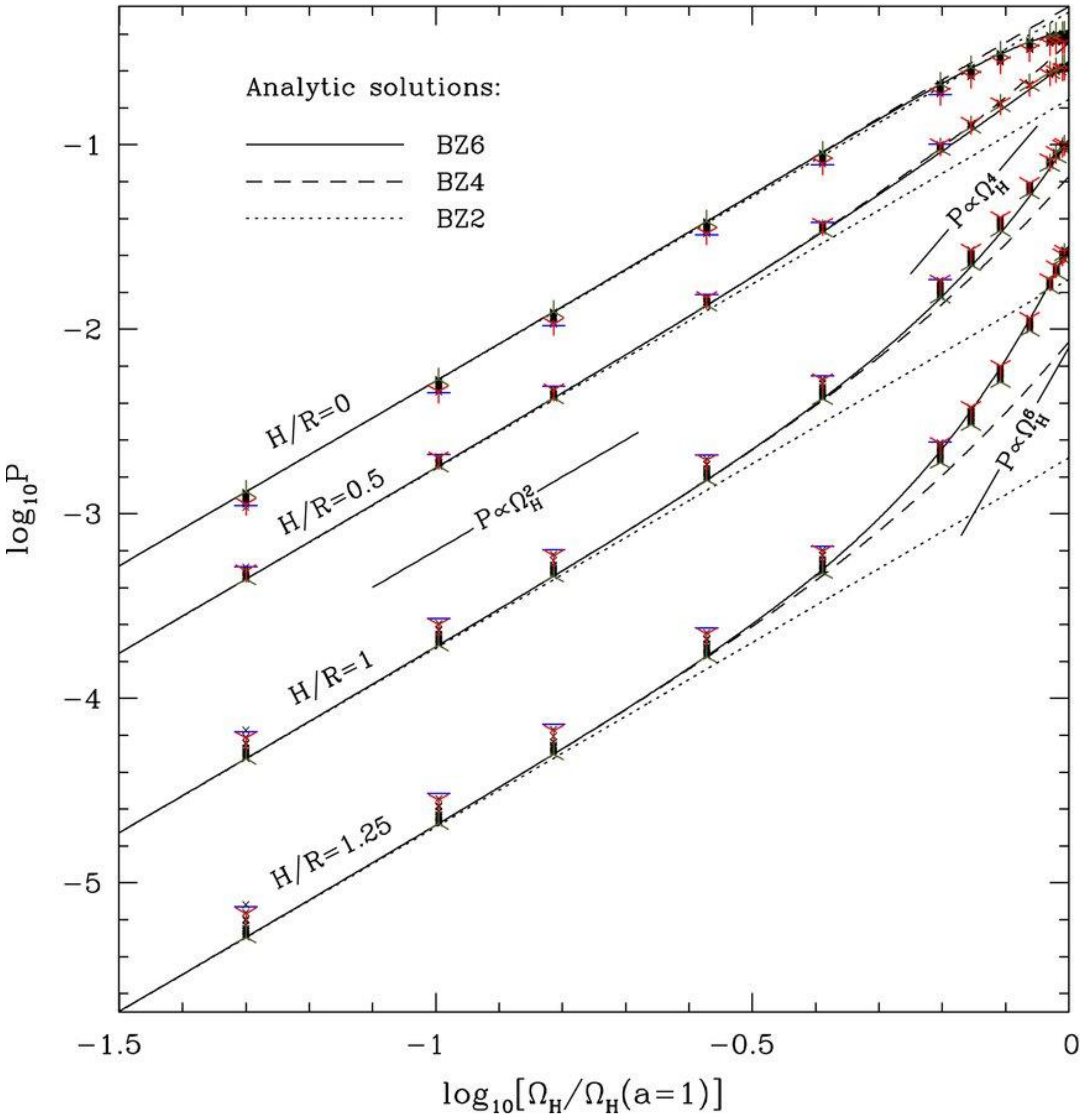
1. **Is AGN activity a temporary episode of a full accretion cycle similar to XRB?**
2. **Can we apply what we learn from XRB to AGN and vice versa?**
3. **Is AGN radio-dichotomy** (about 10% of AGN are radio-loud, the rest is quiet) **due to dichotomy of black hole spin values** (with powerful jets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

Spin paradigm

Blandford-Znajek mechanism

$$P_{jet} \approx \Phi_{mag}^2 \, \Omega_H^2 / c$$

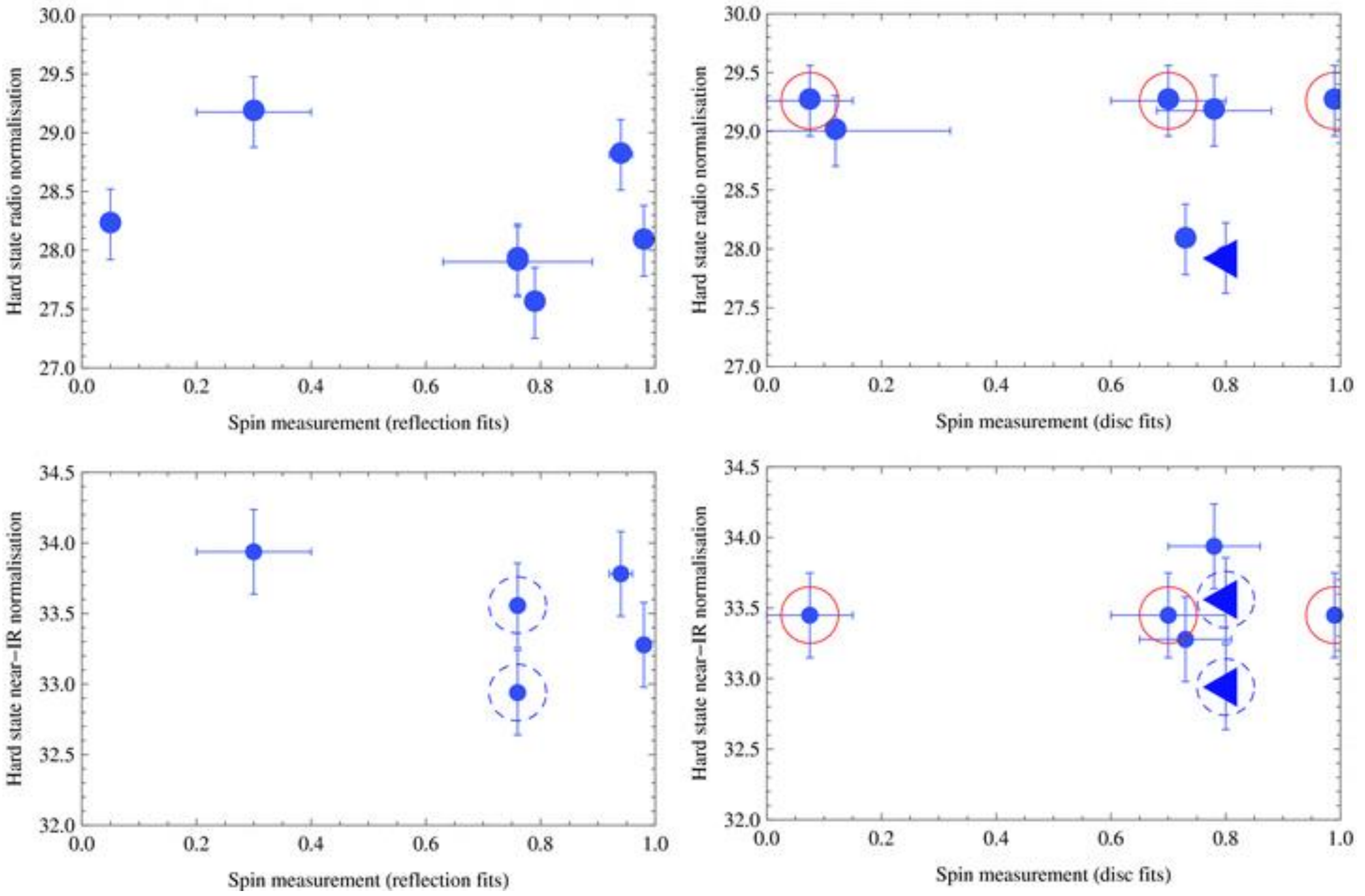
angular rotational velocity of the black hole horizon



see Moderski+98, Sikora+07 on explanation of radio dichotomy via spin paradigm

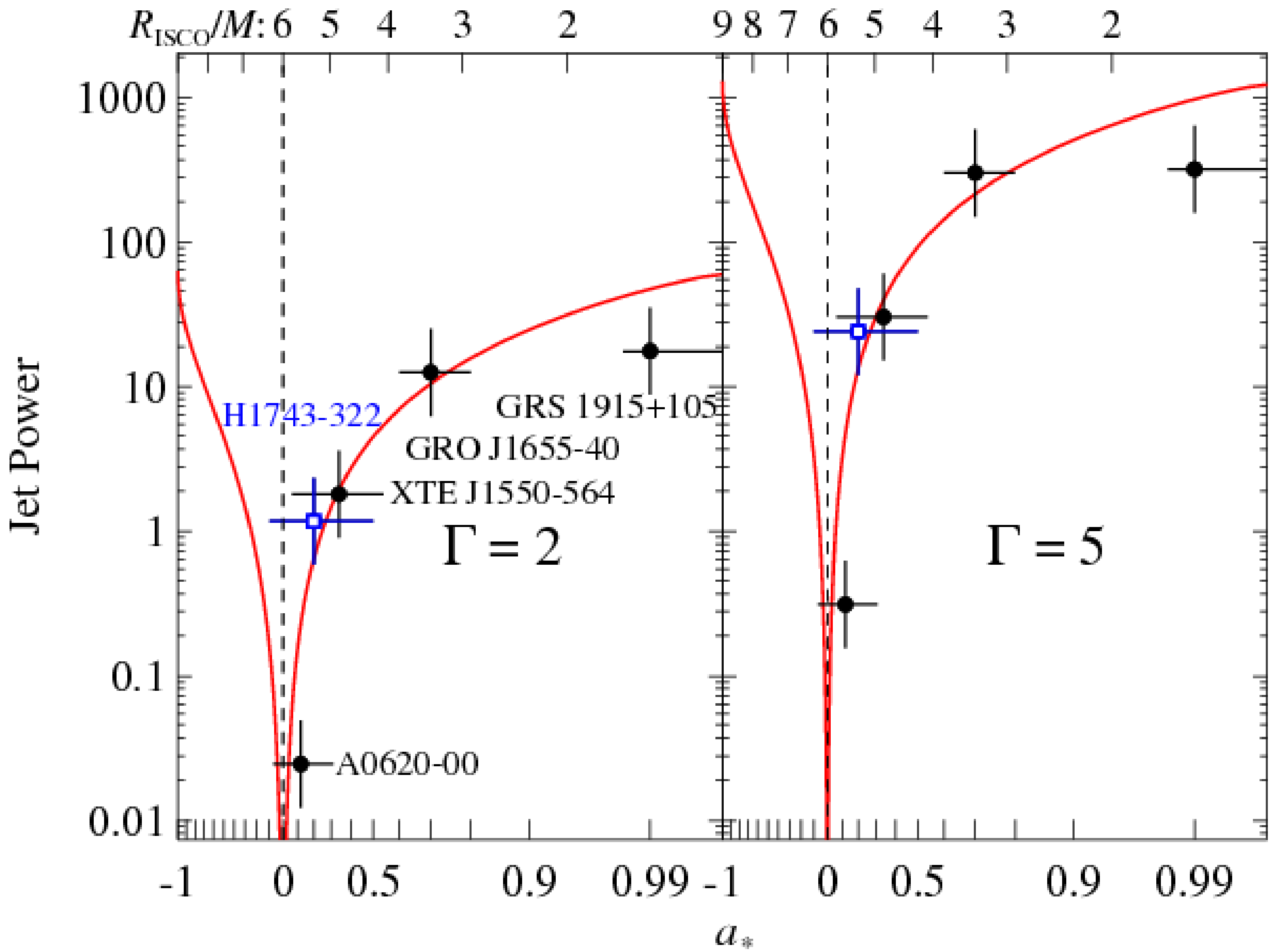
Tchekhovskoy+10

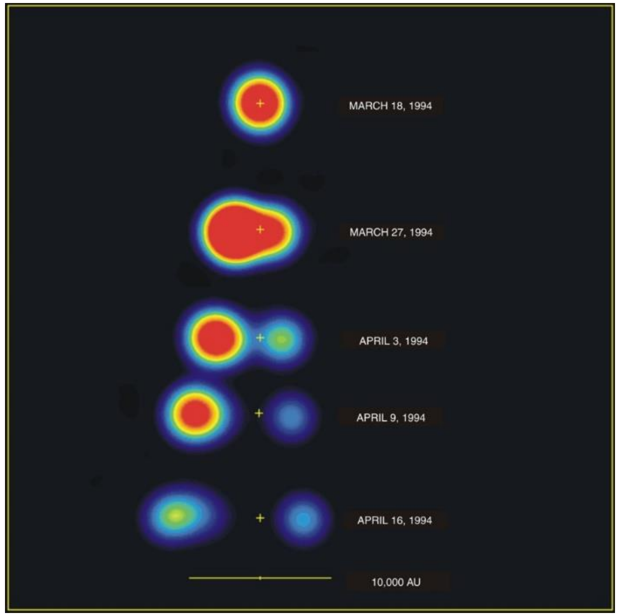
Spin – Jet Power relation from XRB observations



Fender+ 10

Spin – Jet Power relation from XRB observations

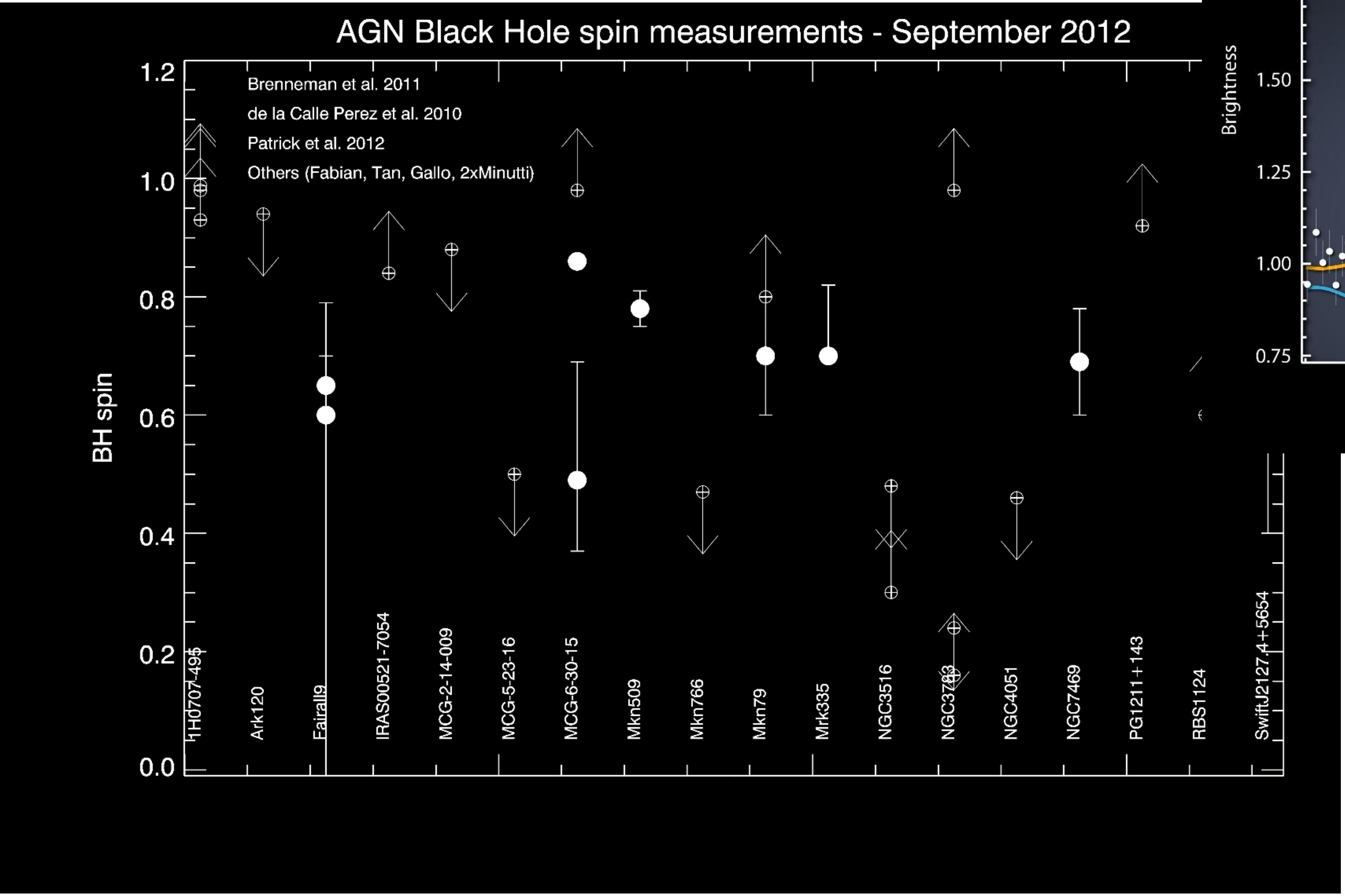


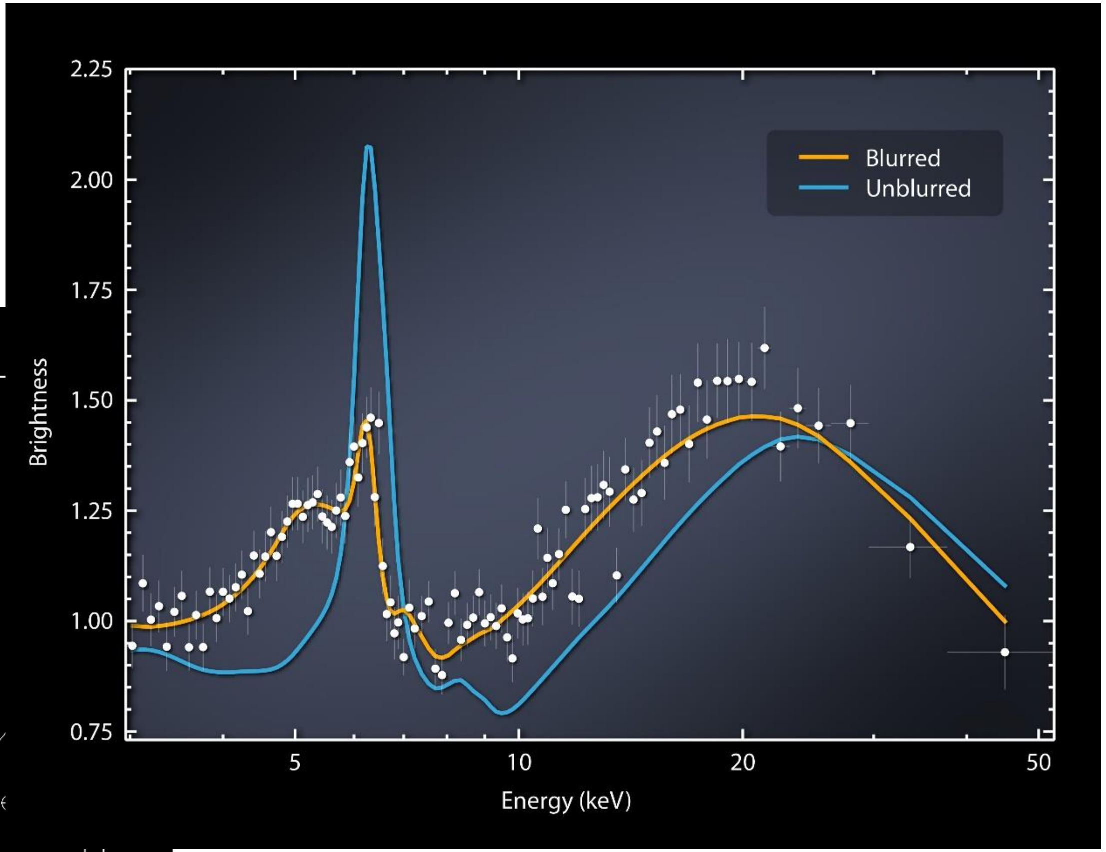


correlation works for ballistic jets

Narayan+ 12, Steiner+ 13

Spin measurements of AGN





Credit: Parker+ 14

radio-quiet AGN with high spin!

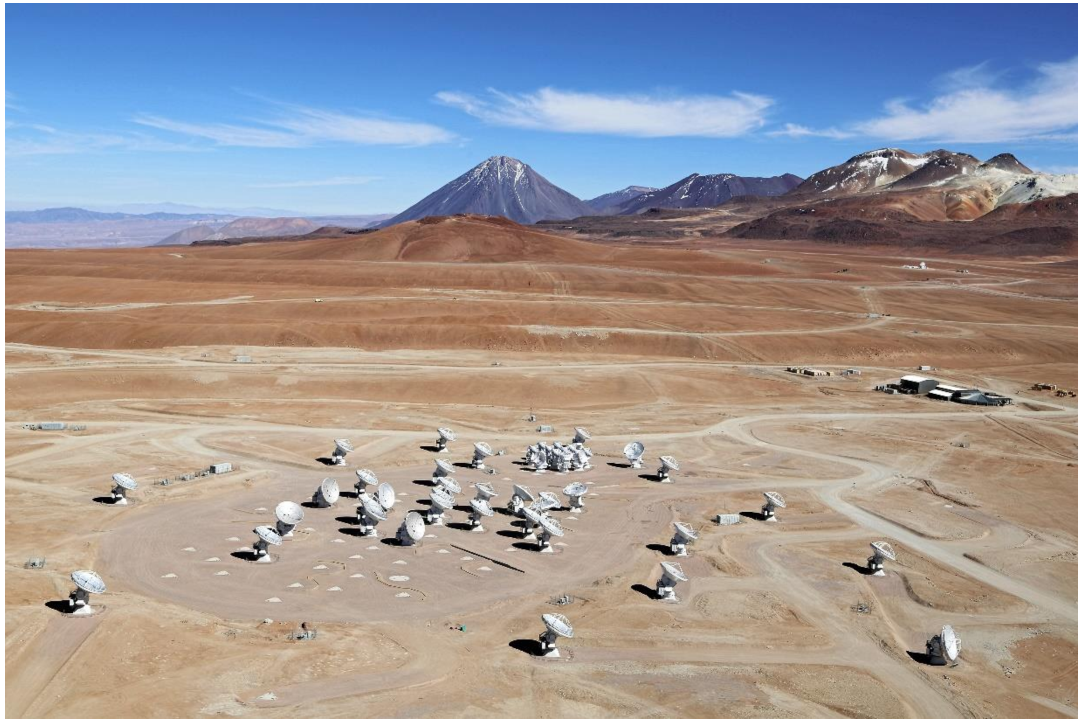
Credit: Guainazzi 12, see also Reynolds 13

Can we study spectral states in AGN?

- time scale of day-long transients translates to thousands to million years in AGN
  - cf. Schawinski et al. (2015): AGN duration ~ 10^5 years

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?

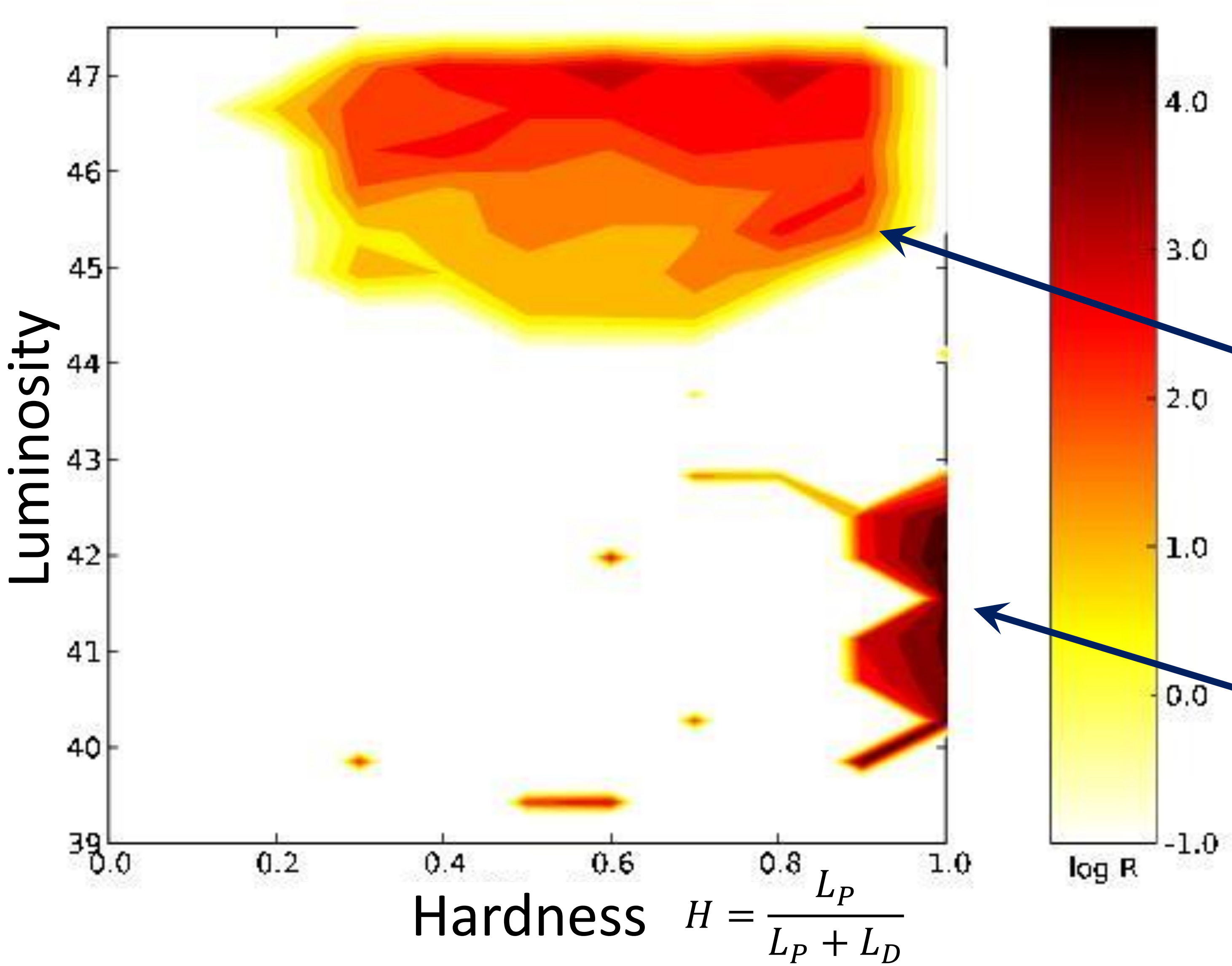
- time scale of day-long transients translates to thousands to million years in AGN
- study of a large homogeneous sample
  - needs to be done in **X-rays (non-thermal component)** but also in **UV (thermal component)**
  - accretion disk temperature:

$$T(R) = \left[\frac{3GM\dot{M}}{8\pi\sigma R^3}\right]^{1/4}, \boldsymbol{T}(R[r_g]) \sim \frac{\mathbf{1}}{\sqrt[4]{\boldsymbol{M}}} \text{ (where } r_g = \frac{GM}{c^2}\text{)}$$

$M_{BH} = 10^6\ M_{\odot}$: $kT_{peak} \sim 221\ \text{Å}\ (a = 0), 74\ \text{Å}\ (a = 1)$

$M_{BH} = 10^9\ M_{\odot}$: $kT_{peak} \sim 1240\ \text{Å}\ (a = 0), 413\ \text{Å}\ (a = 1)$

AGN spectral states – previous works

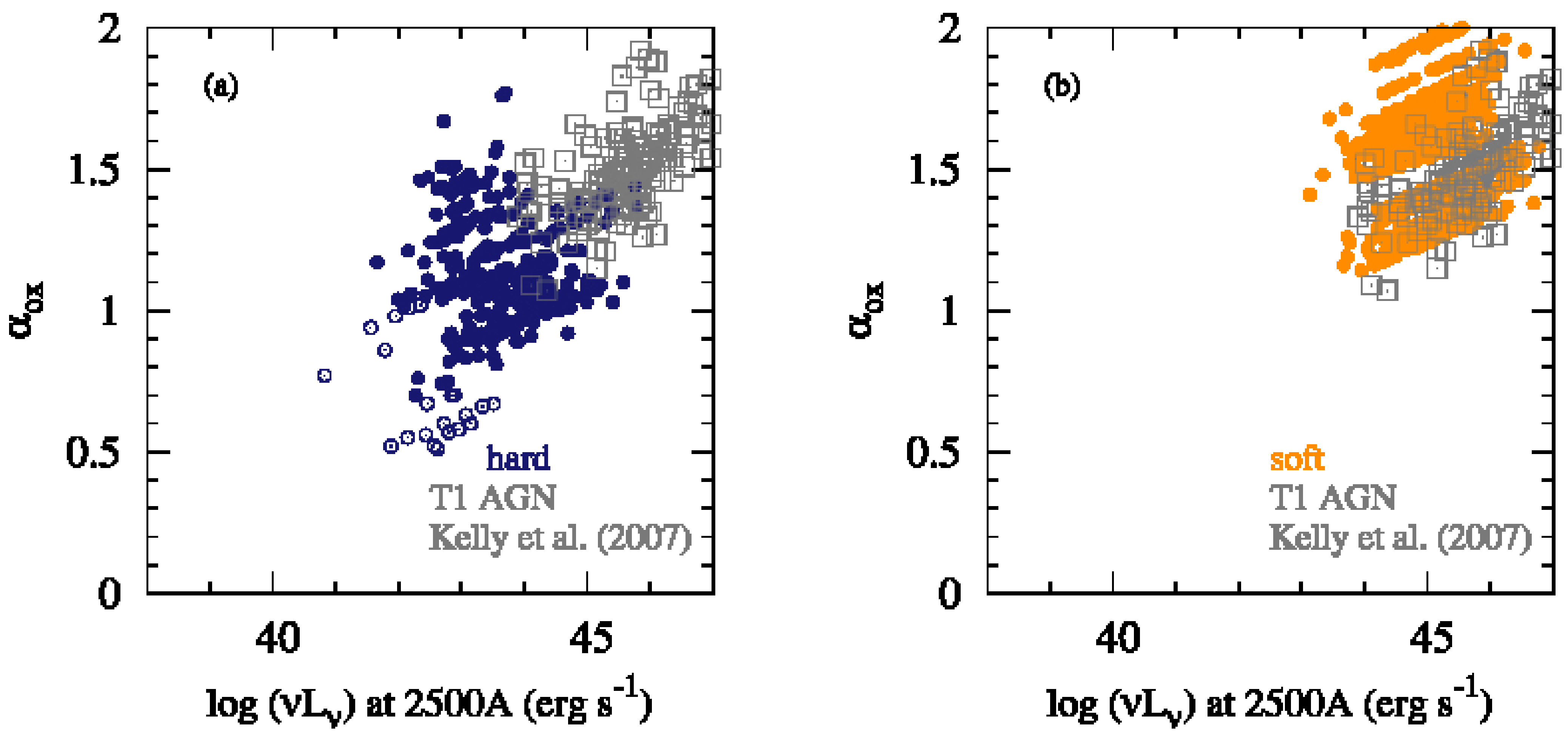


Koerding et al. (2006a)

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

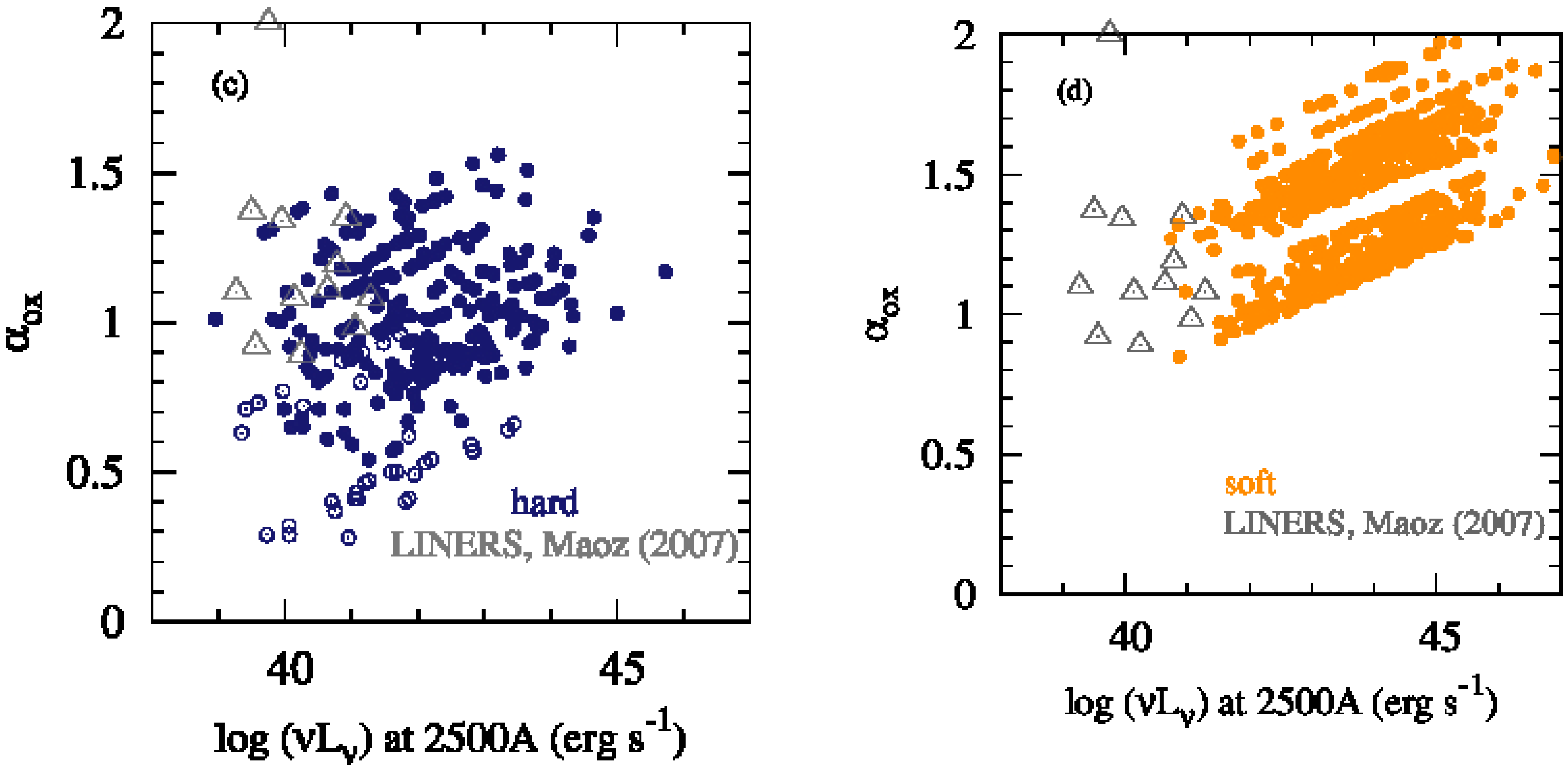
low-luminosity AGN taken from Ho et al. 97

Relation between AGN type and spectral state



Sobolewska et al. (2011)

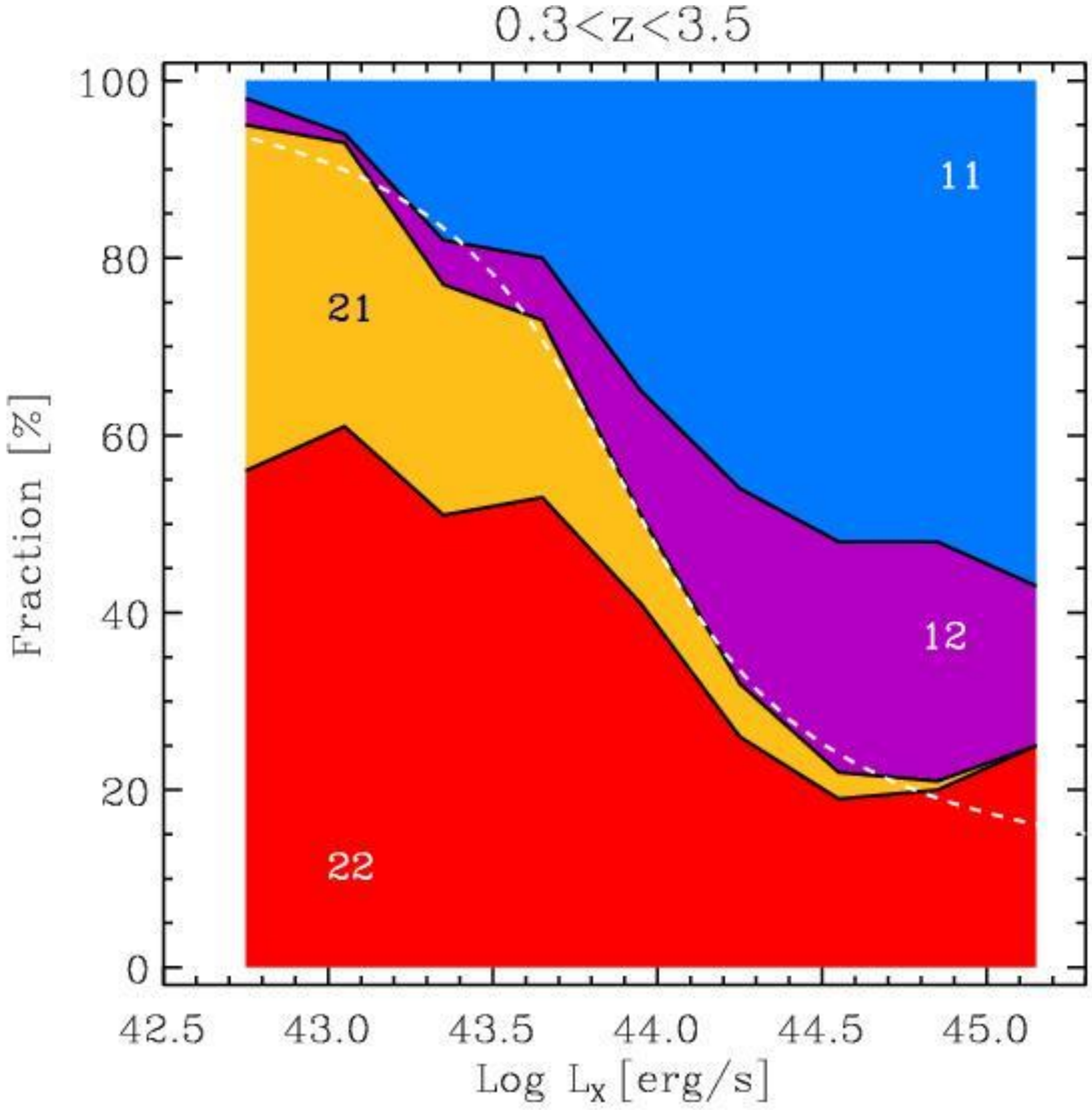
Relation between AGN type and spectral state



Sobolewska et al. (2011)

AGN types

- type optical/X-ray
  - about 30% mismatch in the XMMCOSMOS sample



Merloni et al. (2013)

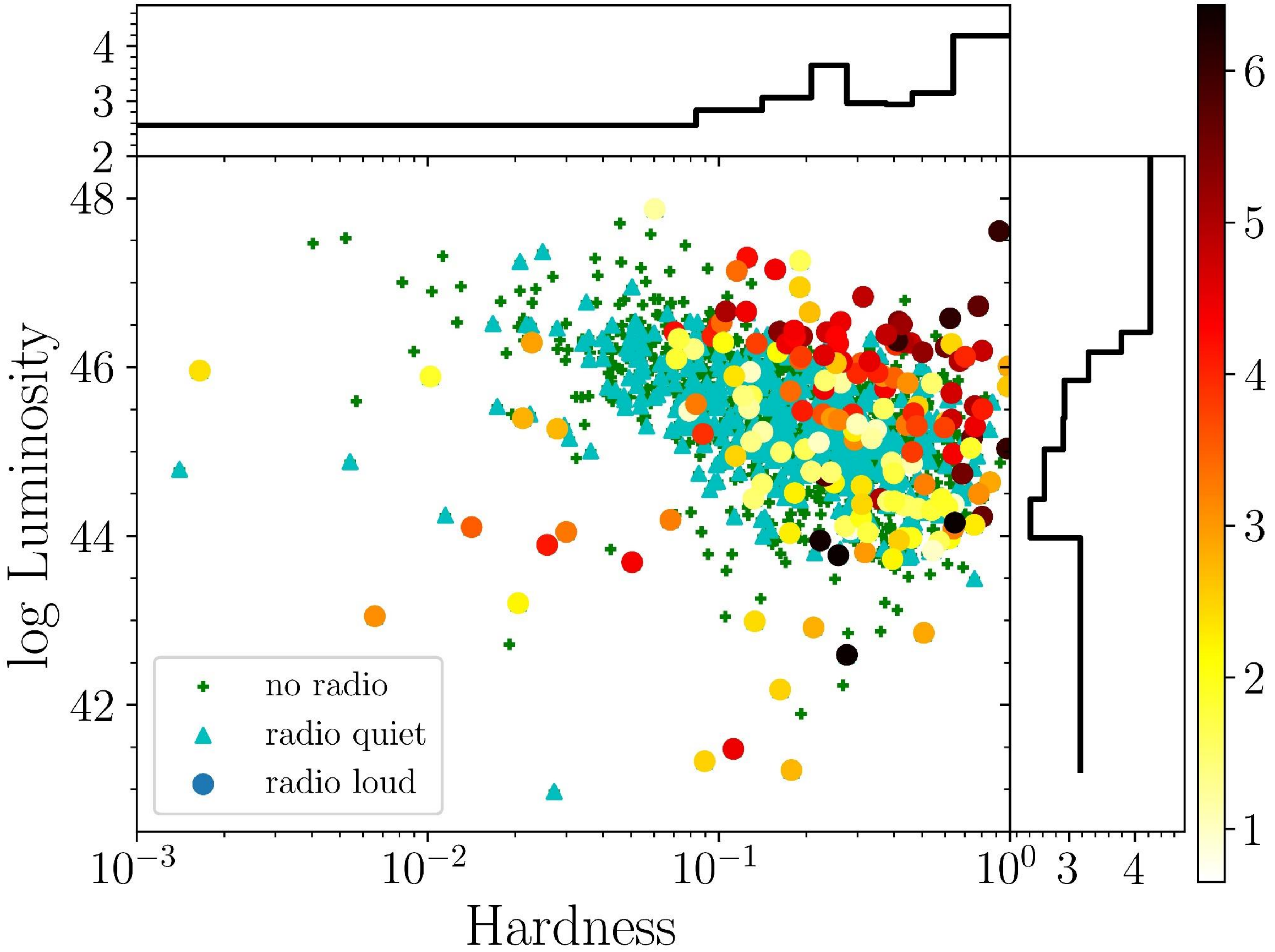
AGN spectral states with XMM-Newton

Main advantages compared to previous samples:

- 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

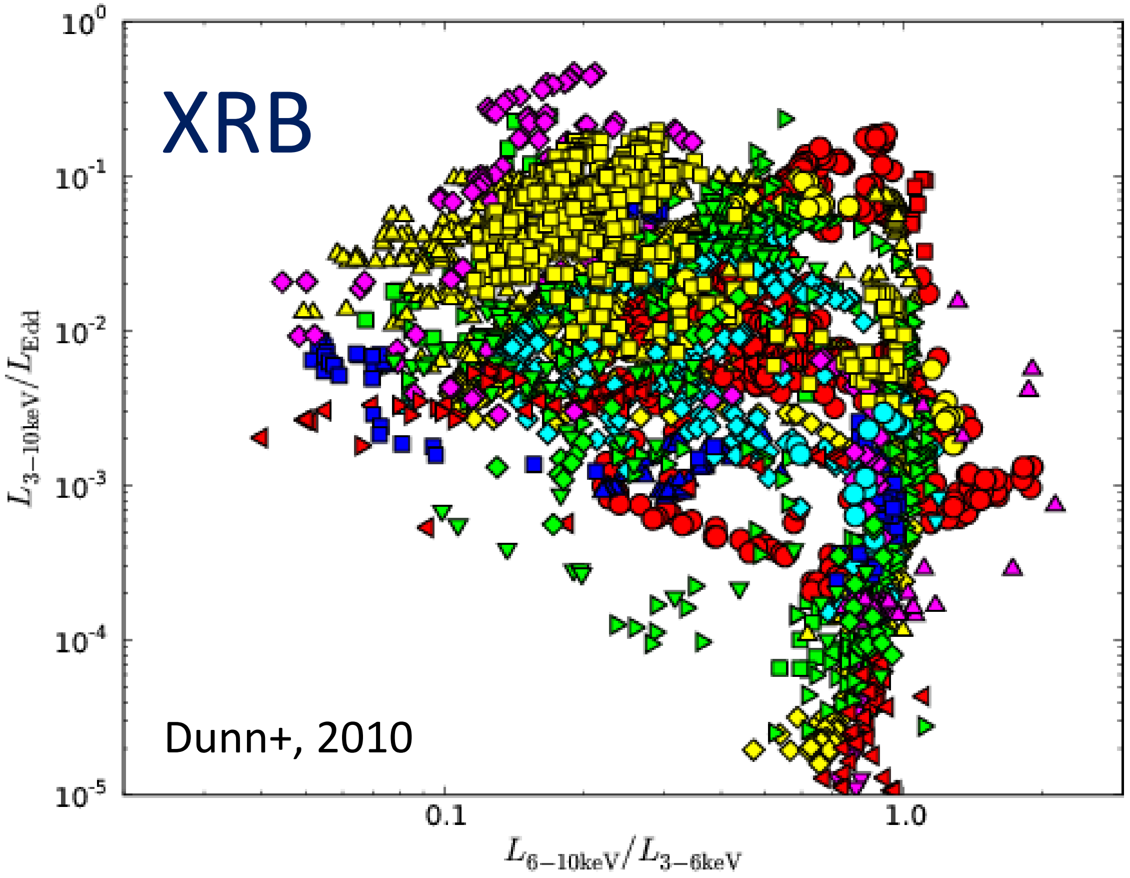
Svoboda J., Guainazzi M. and Merloni A., 2017, *A&A*, 603, A127

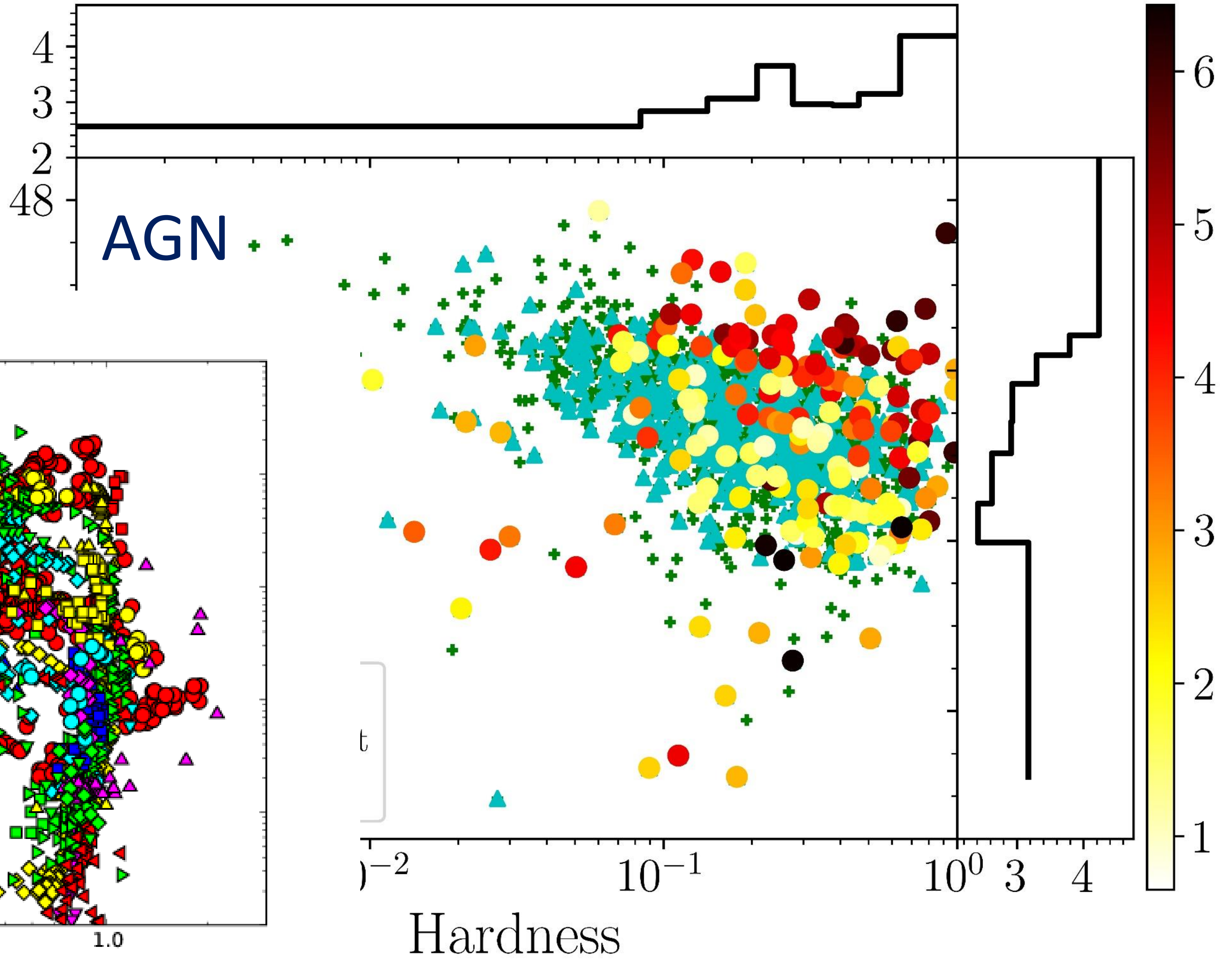
Hardness – Luminosity diagram



Svoboda et al., 2017

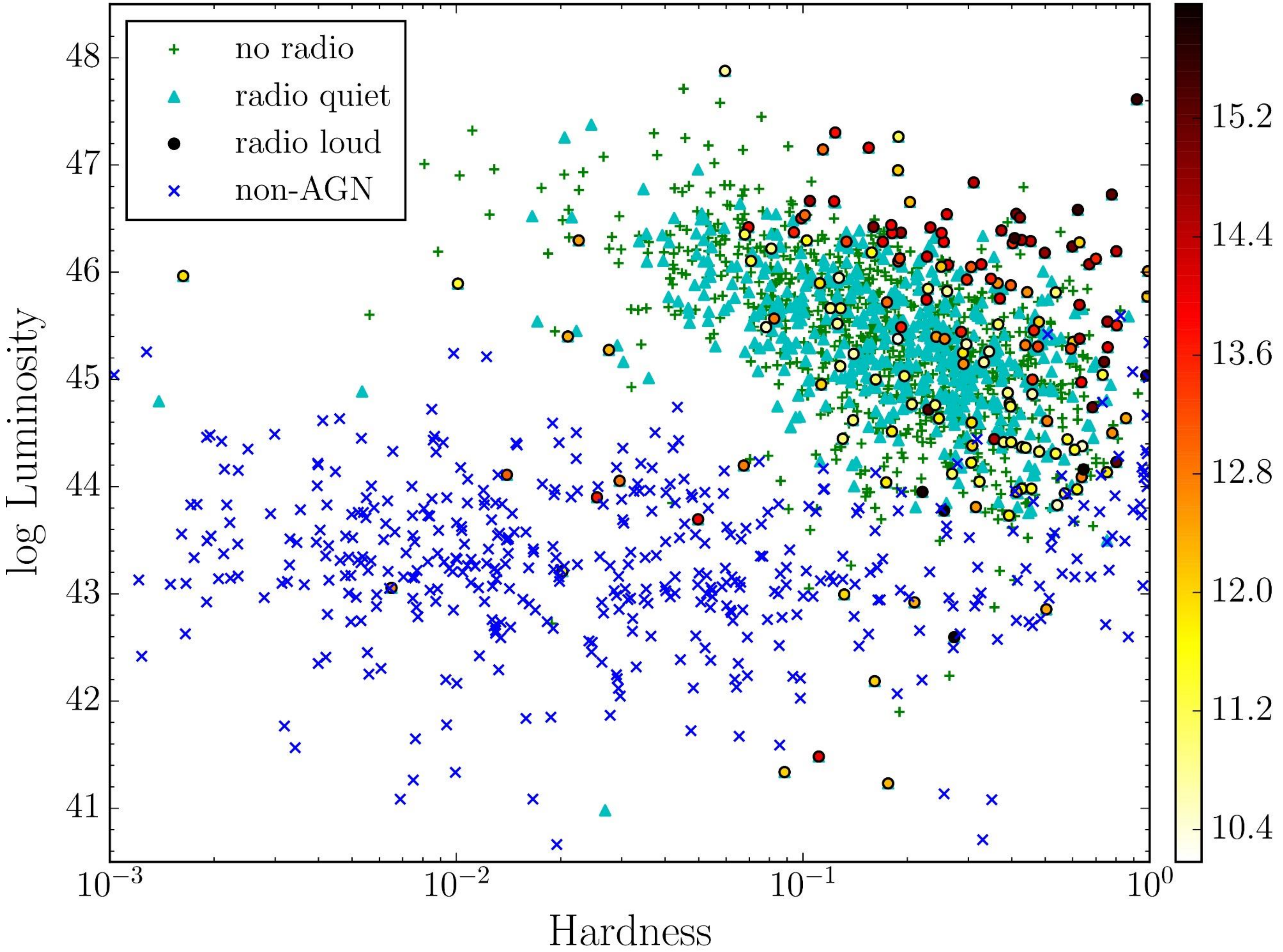
Hardness – Luminosity diagram





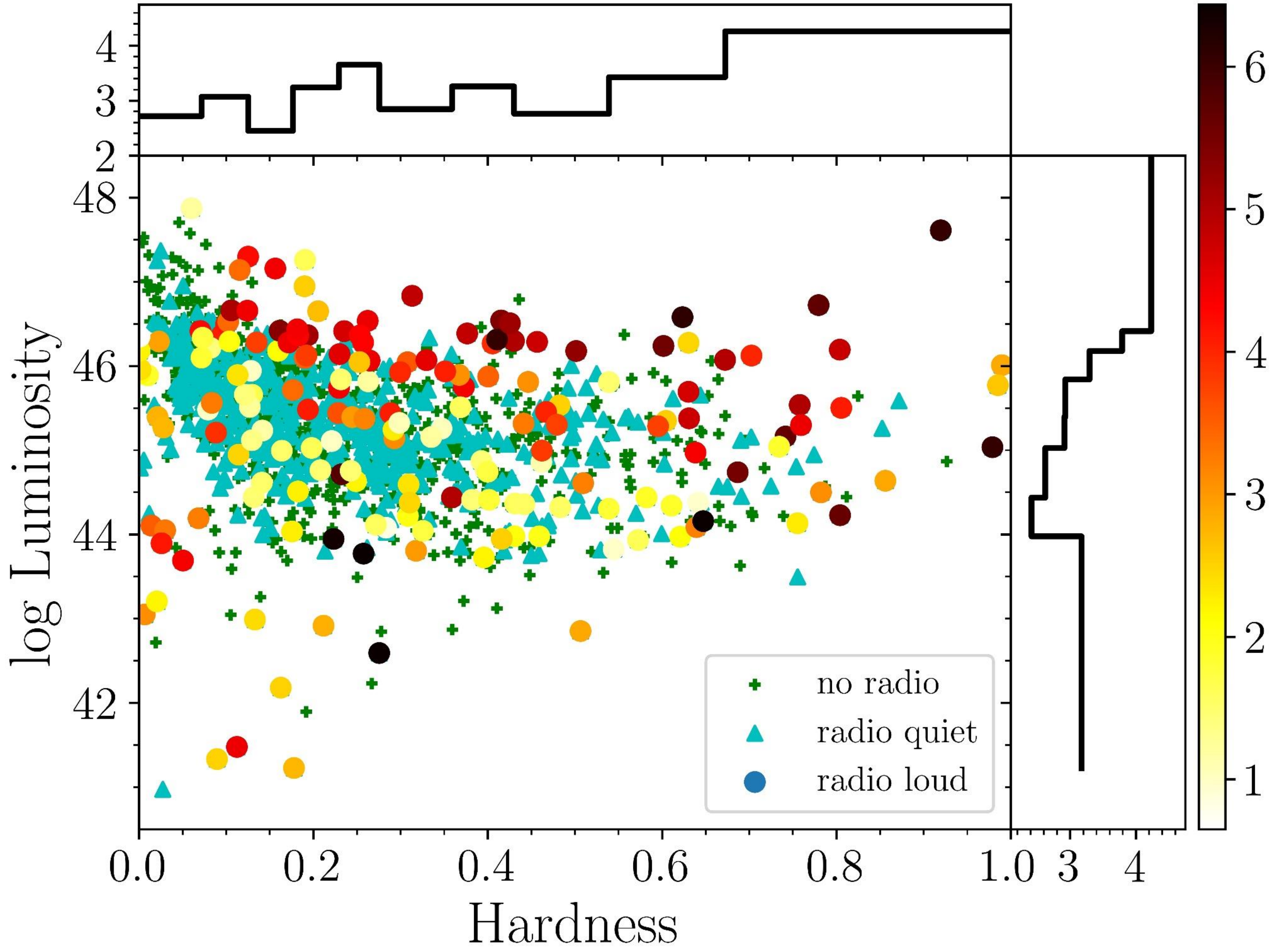
Low – luminosity sources

- 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)



Hardness – Luminosity diagram

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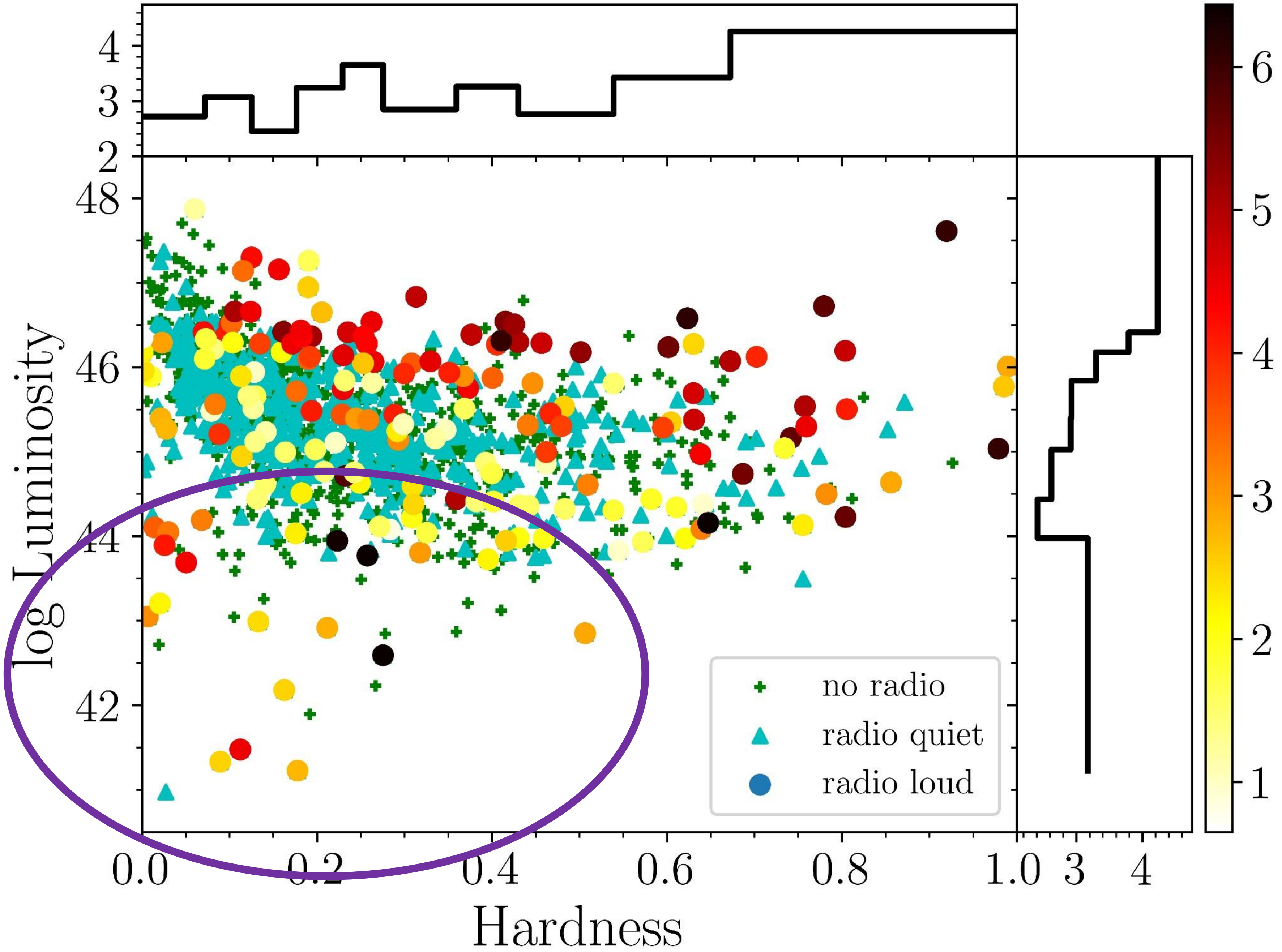
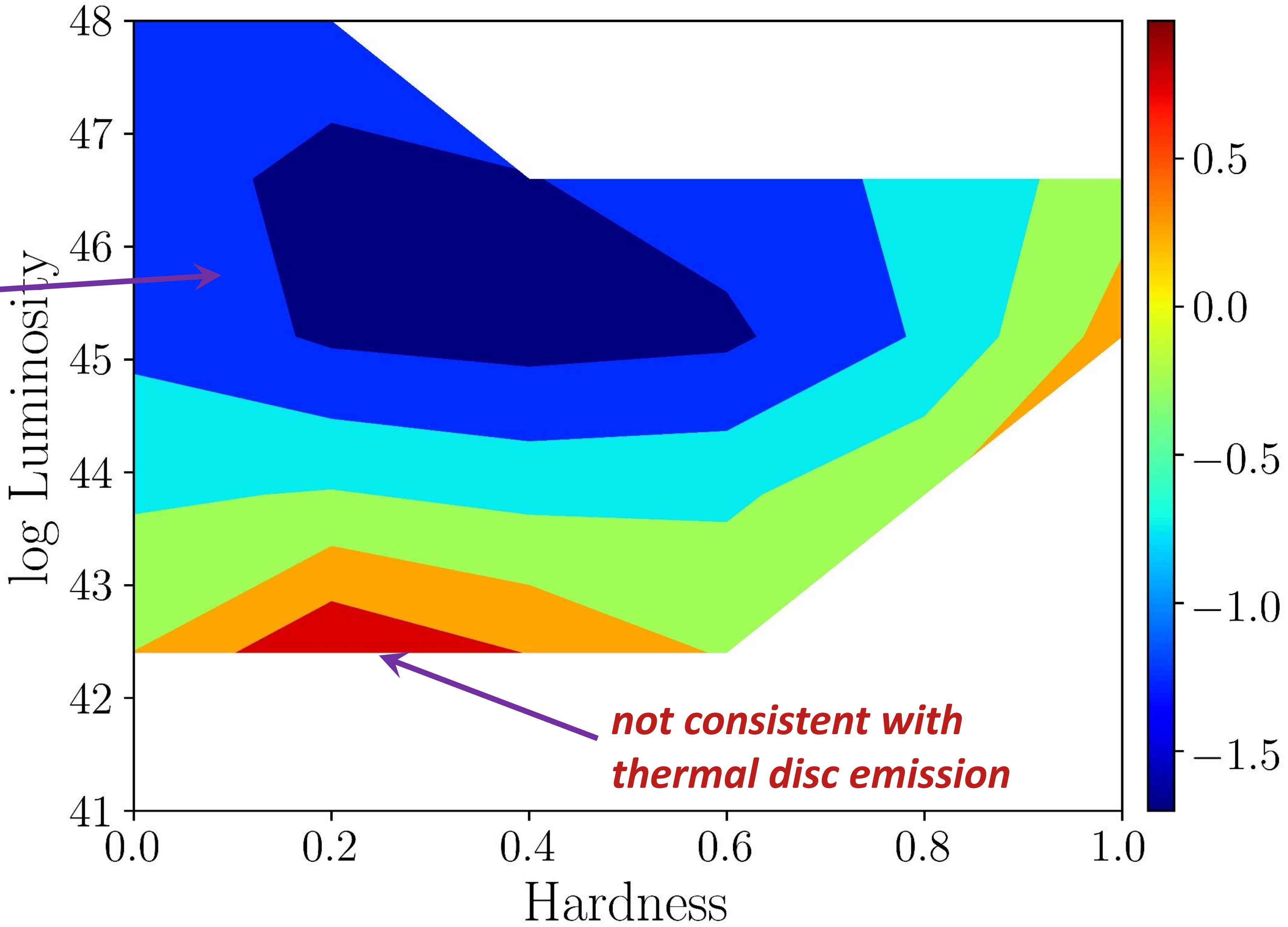


are these sources intrinsically soft or hard?

UV slope

consistent with thermal disc emission

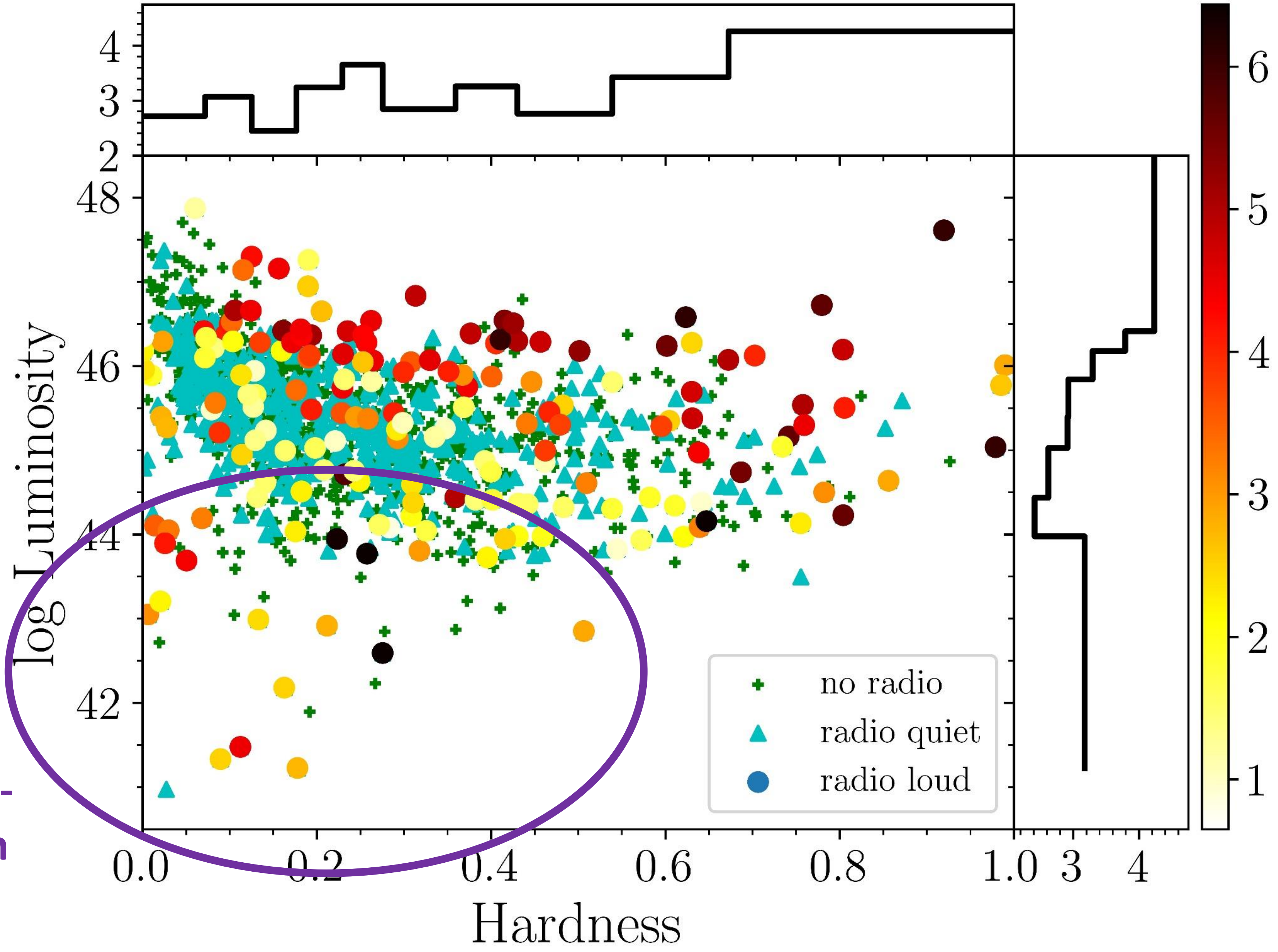


not consistent with thermal disc emission

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

Hardness – Luminosity diagram

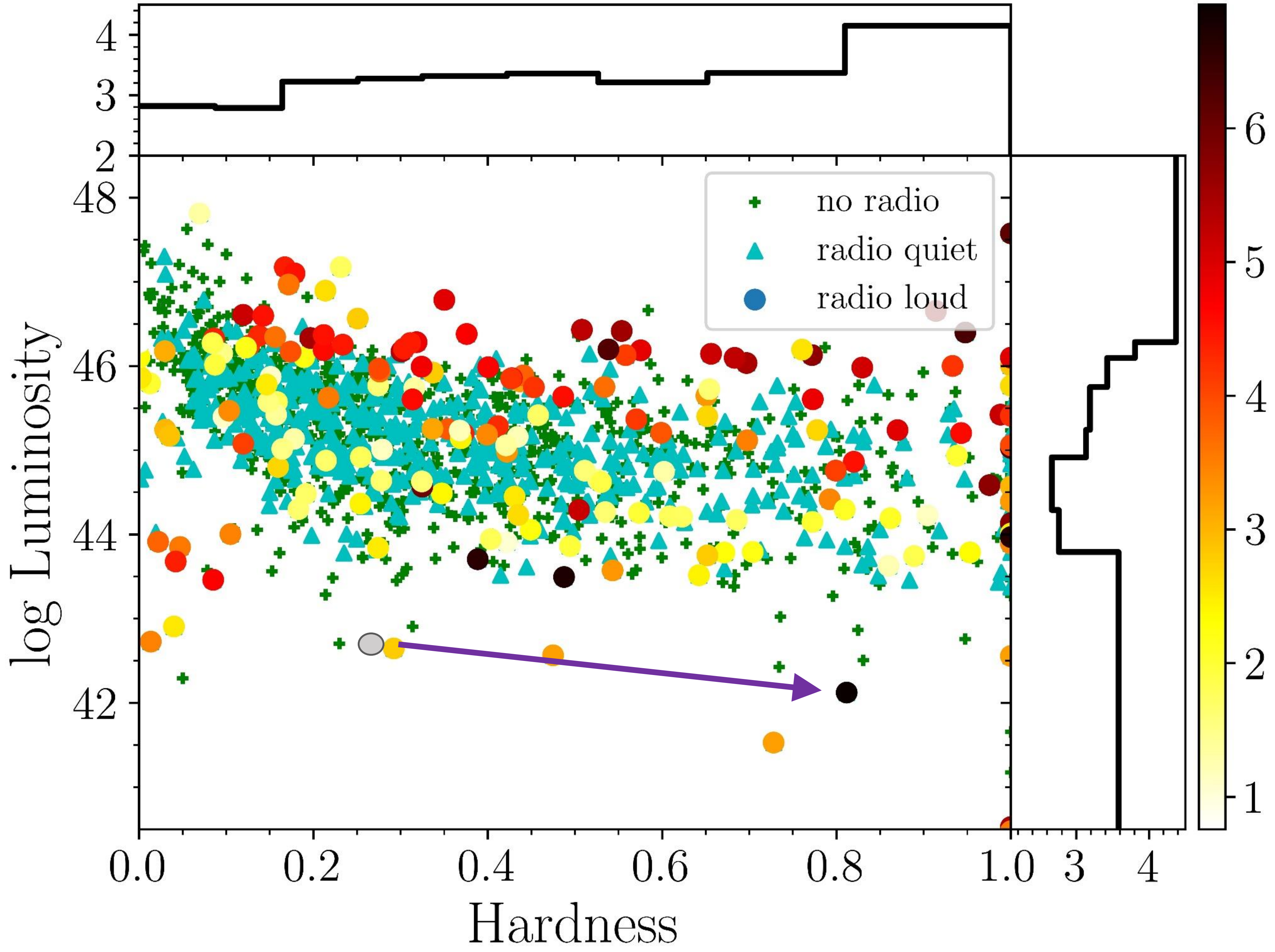
(in linear scale of the hardness)



UV emission of these sources dominated by host-galaxy contribution

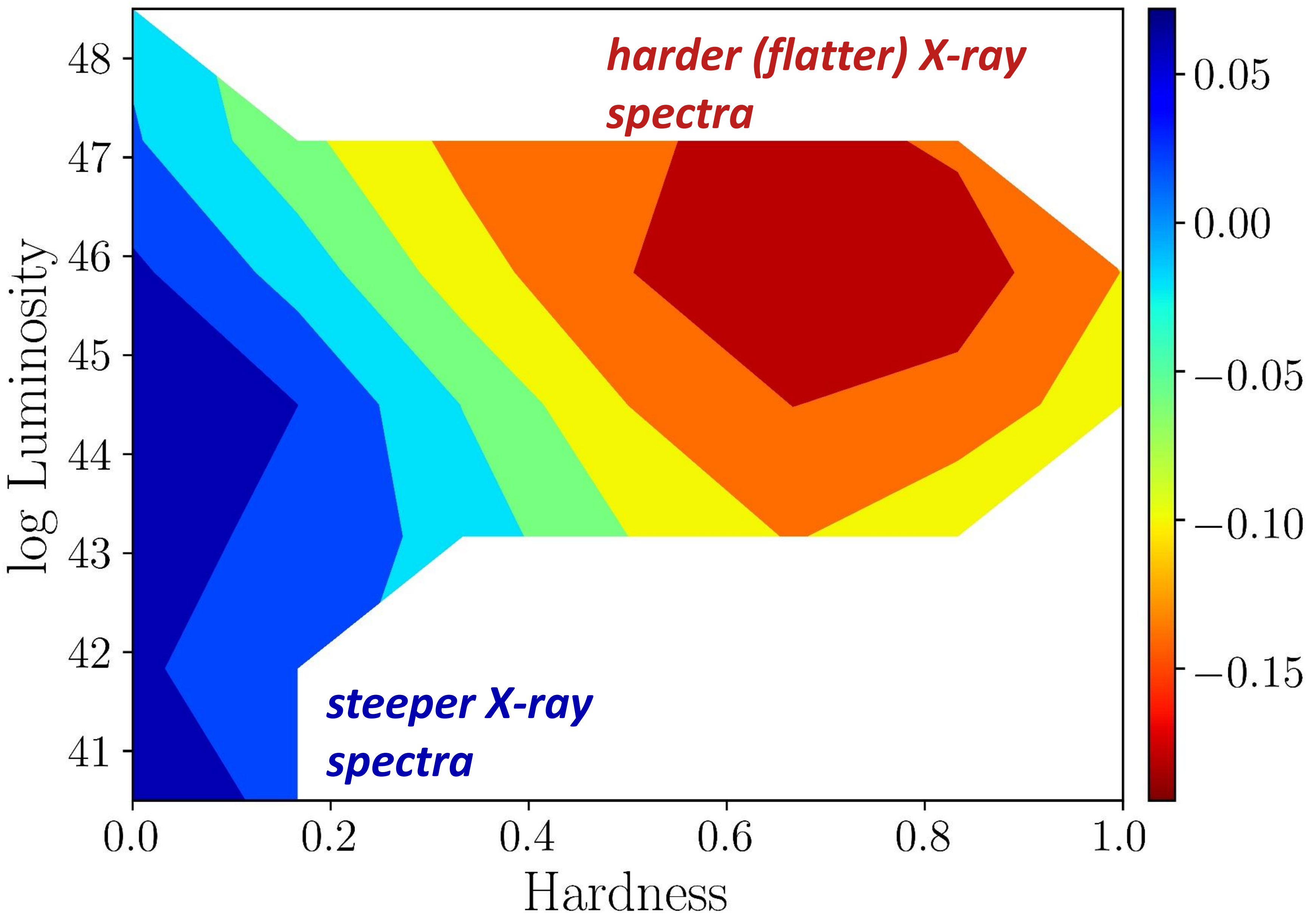
Hardness – Luminosity diagram

(after attempt to correct for host-galaxy)



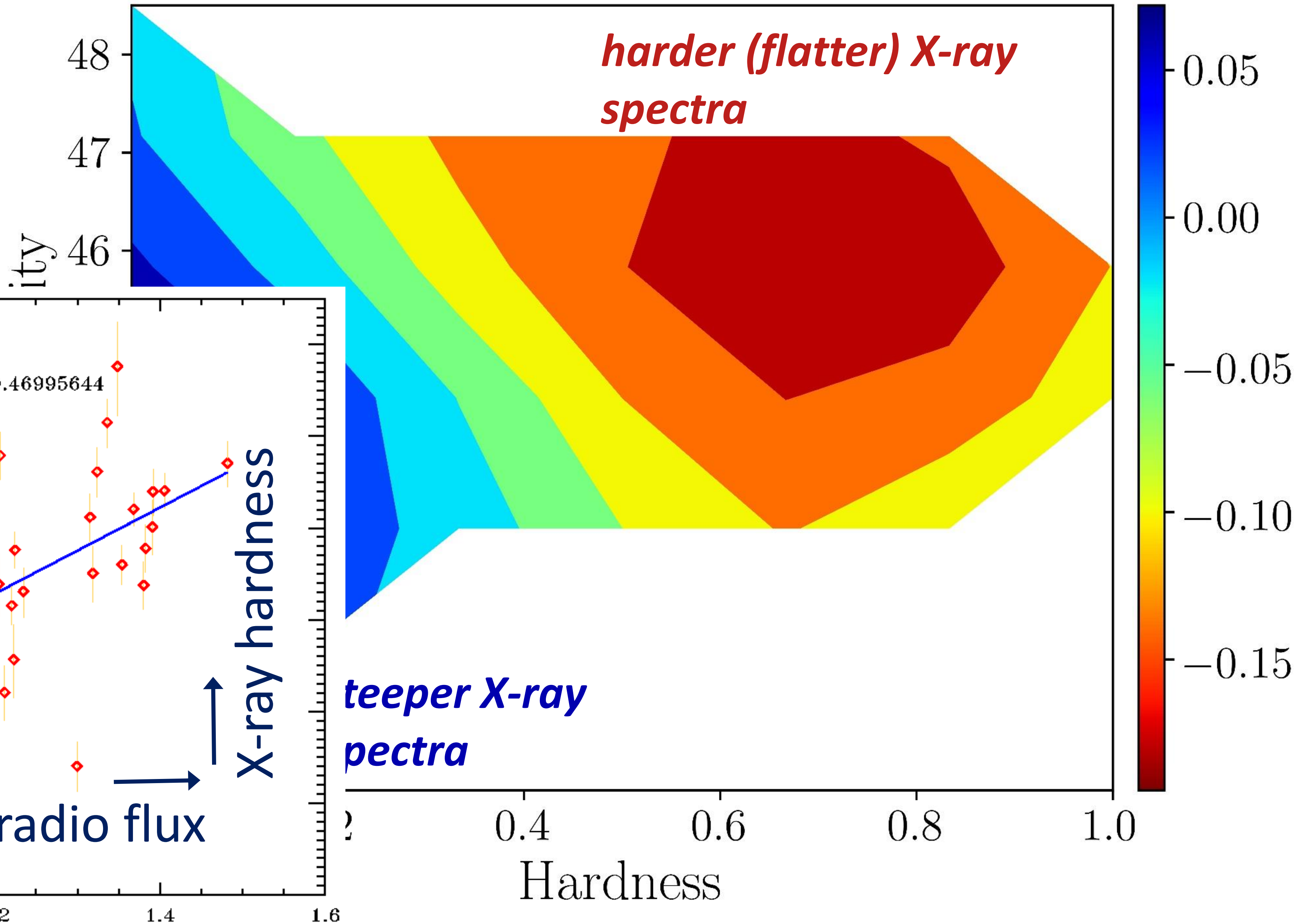
X-ray slope

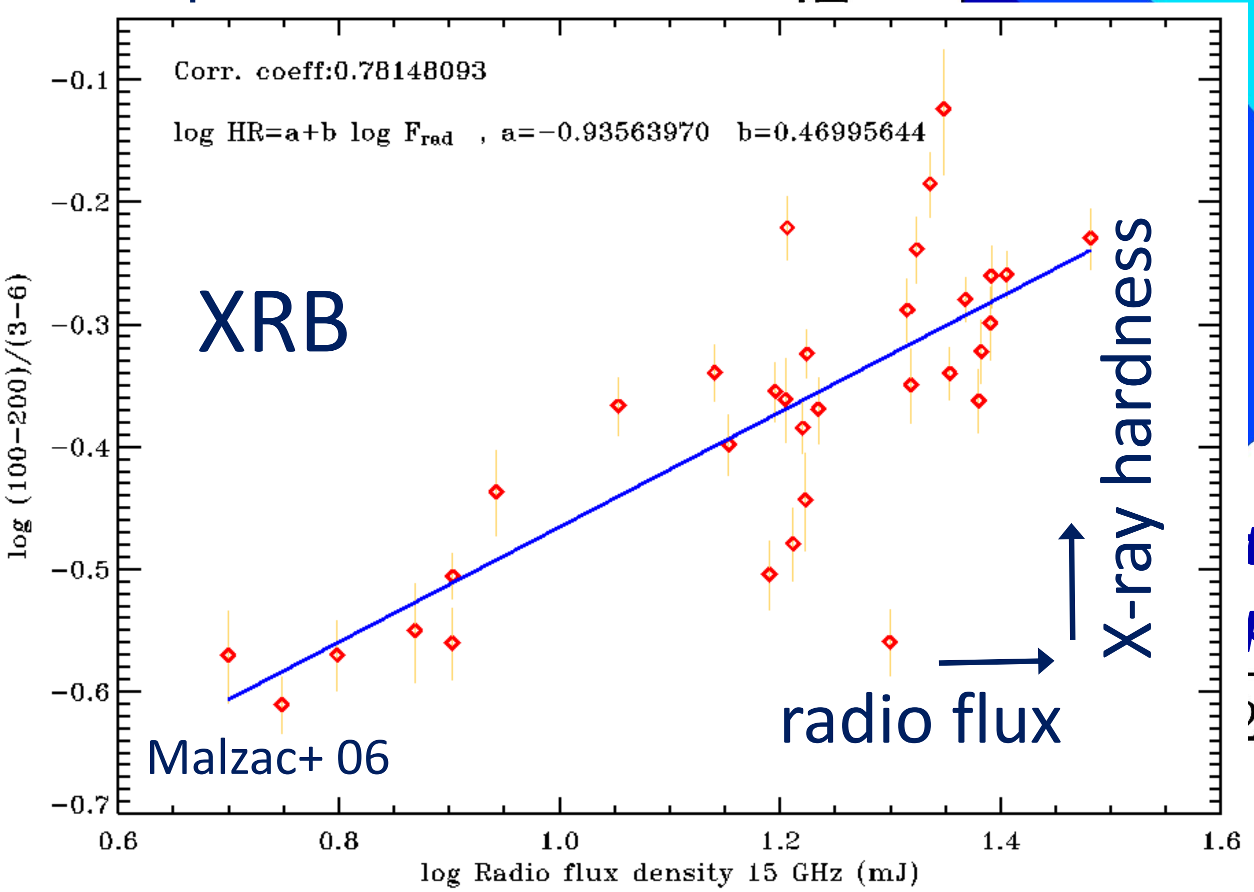
- distribution of the photon index deviation from the mean value Γ = 1.7
- harder (flatter) X-ray spectra are consistent with the higher radio loudness of sources with the larger fraction of X-ray vs. optical/UV flux



X-ray slope

- distribution of the photon index



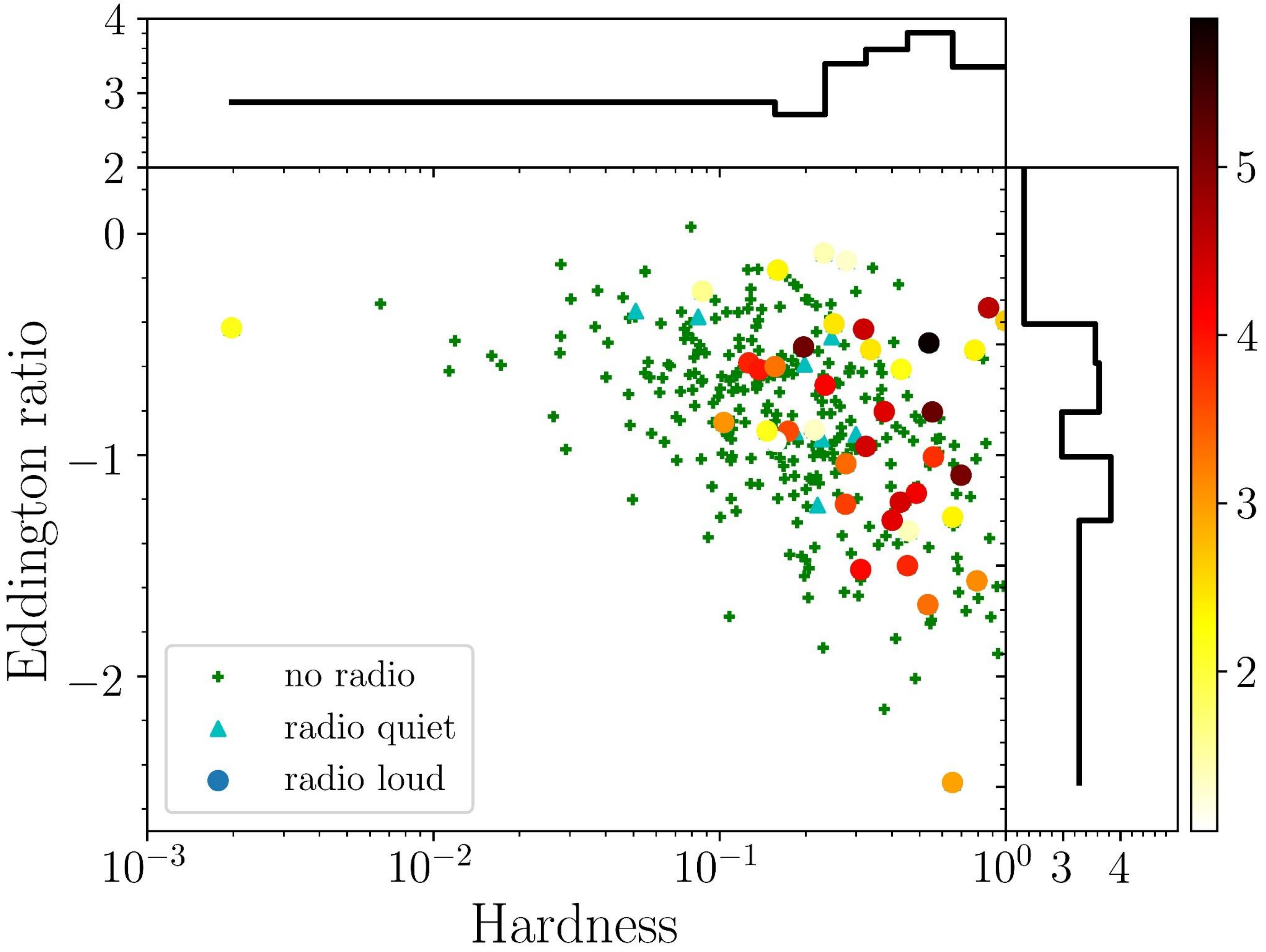


Eddington ratio

- 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

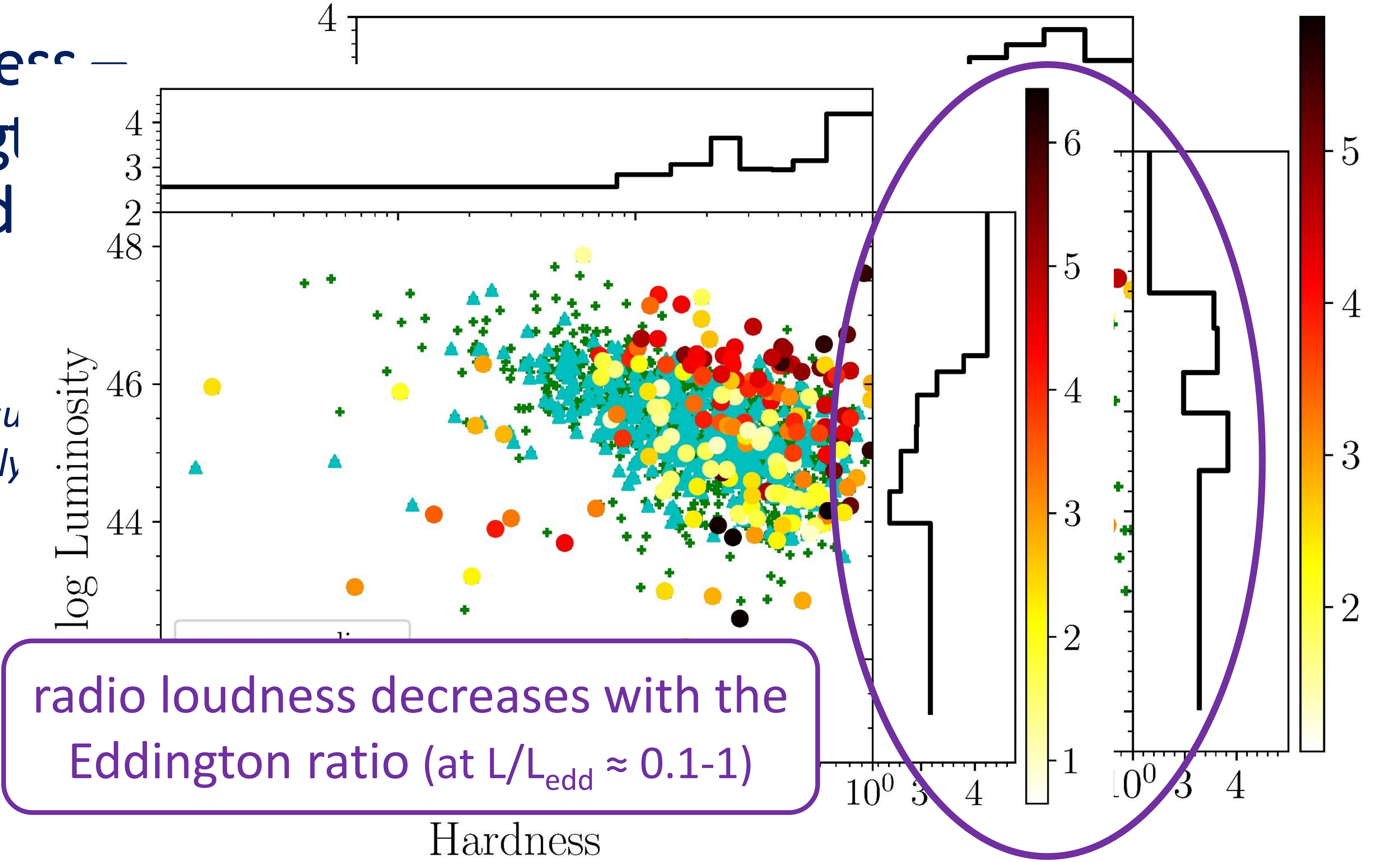
Hardness – Eddington Ratio diagram

(for SDSS sub-sample only)



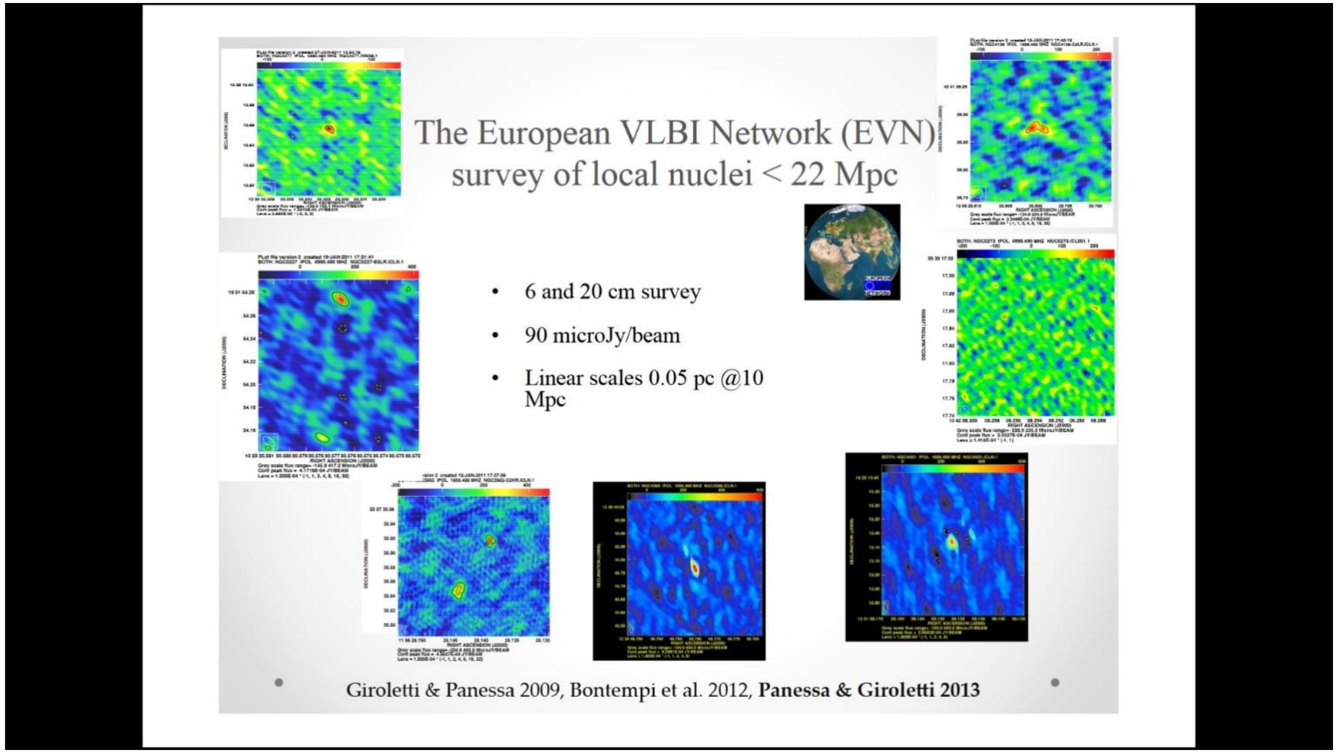
Hardne... – Edding... Ratio d...

(for SDSS su... sample only...

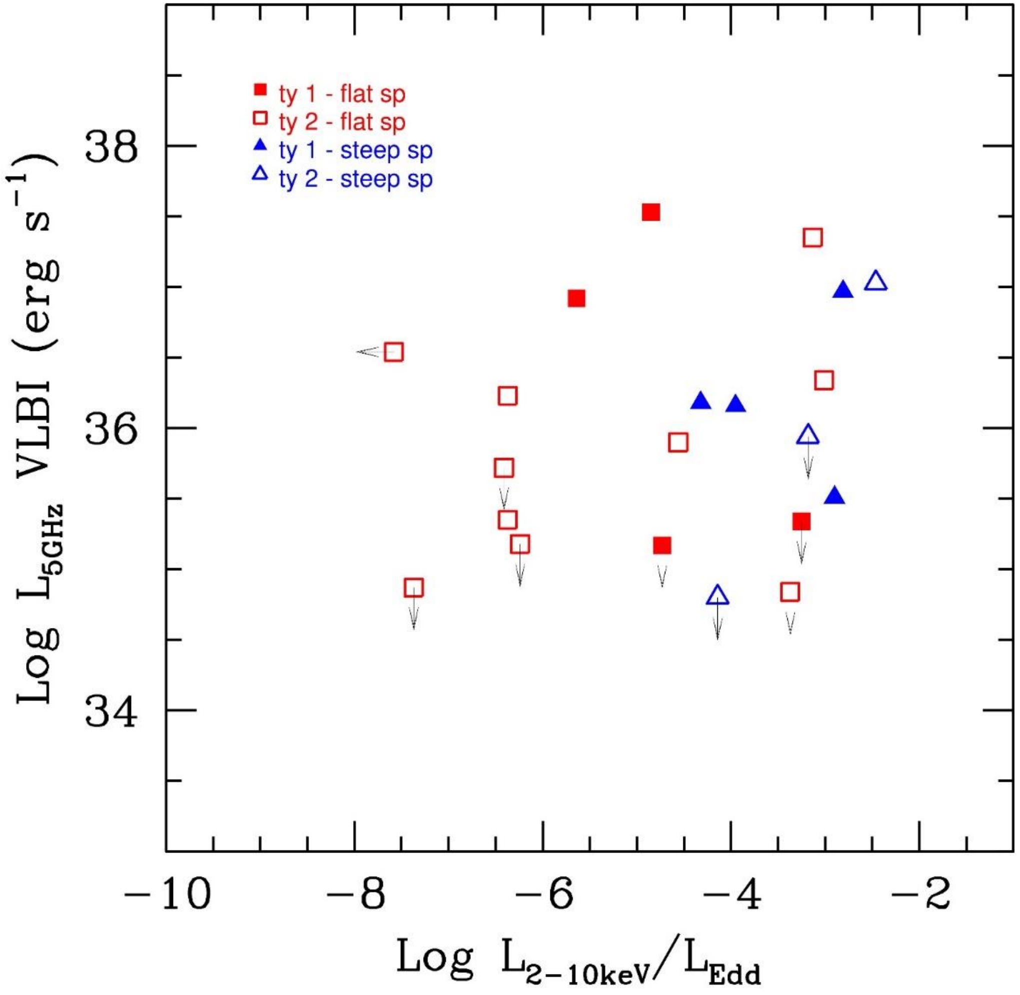


Radio properties of local Seyfert galaxies

- probing sub-pc scales with VLBI
  - no evidence for L_R vs L/L_{Edd} correlation @5 GHz (but only for L/L_{edd} <-2)



from presentation by F. Panessa, Porquerolles 2017



Panessa & Giroletti (2013)

Conclusions I – AGN-XRB similarities

- there are qualitative similarities between **AGN and 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 (for $L \sim 0.1\text{-}1\ L_{edd}$)
- AGN activity as well as the AGN radio dichotomy can be explained by the spectral state evolution similar to XRB

Conclusions II – AGN-XRB differences

- Open questions:
  - what is the influence of galaxy mergers on triggering AGN activity?
  - is AGN life-time similar to active phase of XRB, simply proportional to the BH mass?
  - are AGN accretion states influenced by different densities/ionisations of the discs or by the presence of warm corona responsible for the soft X-ray excess in AGN spectra (not present in XRB spectra),…?

Future prospects on AGN spectral states

- key ingredients for the study:
  - mass (reverberation techniques, virial masses)
  - X-ray luminosity, X-ray spectral slope
  - UV luminosity (not contaminated by host galaxy), UV spectral slope
  - radio luminosity
  - radio morphology or radio spectral shape
    - new **more-sensitive radio surveys** (VLASS, SKA)
- **large homogeneous sample**
  - **eROSITA, ATHENA/WFI** surveys with complementary surveys by instruments at other wavelengths

Thank you for your attention!!!