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

**Hard State**
- **Strong Corona**
- **Hard Photons**

**Soft State**
- **Weak Corona**
- **Soft Photons**

![Diagram showing hard and soft states of an X-ray binary system.](image)

**Graph**

- Energy vs. Count Rate
- **Cygnus X-1**

![Graph showing energy vs. count rate for Cygnus X-1.](image)
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 $\lambda \leq 1240\text{Å}$ 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:
  \[ L_D \sim 4\pi D_L^2 \lambda F_{\lambda,2910\AA} \]

• non-thermal power-law luminosity:
  \[ L_P = 4\pi D_L^2 F_{0.1-100\text{keV}} \]
  (where \( F_{0.1-100\text{keV}} \) is an extrapolated X-ray power-law flux)

• spectral hardness:
  \[ H = \frac{L_P}{L_P + L_D} \]
Hardness – Luminosity diagram
Hardness – Luminosity diagram

AGN

XRB

Dunn+, 2010
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

consistent with thermal disc emission

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

not consistent with thermal disc emission
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 $\Gamma = 1.7$
- 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

Malzac+ 06

radio flux

log Radio flux density 15 GHz (mJ)

log (100-800)/(3-6)

XRB

Corr. coeff: 0.78148093

log HR = a + b log F_{radio}, a = -0.93563970, b = 0.46995644

harder (flatter) X-ray spectra

steep X-ray spectra

X-ray hardness

harder (flatter) X-ray spectra

Malzac+ 06
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)
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

Thank you very much for your attention!!!