EXPANDING A BONA FIDE SAMPLE OF INTERMEDIATE-MASS BLACK HOLES IN ACTIVE GALACTIC NUCLEI:

X-RAY CONFIRMATION OF NEW CANDIDATES WITH XMM-NEWTON AND CHANDRA

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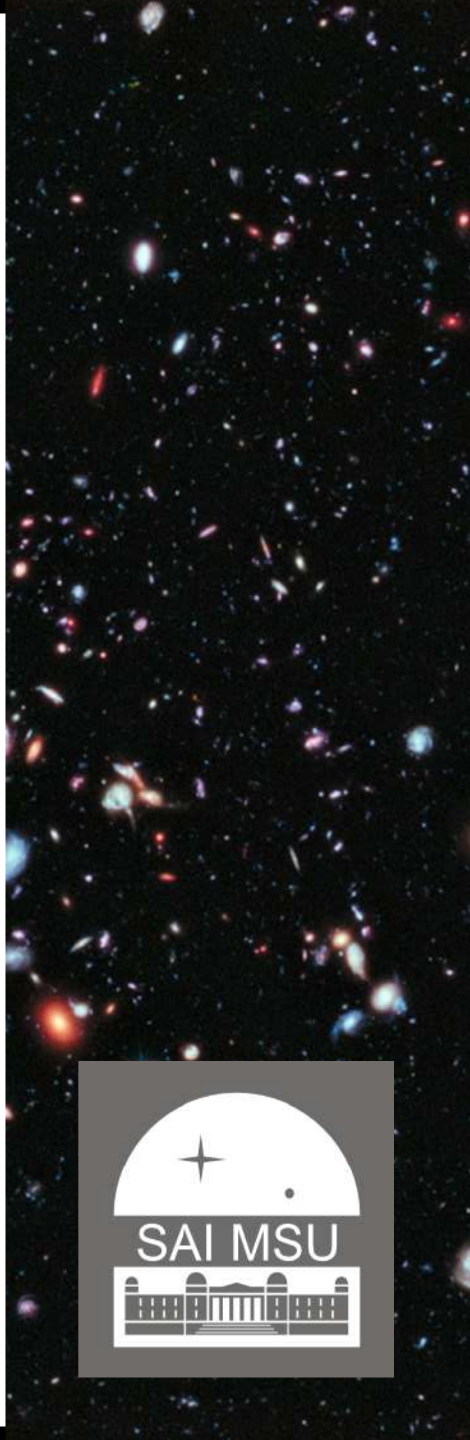
Growing black holes: accretion and mergers
2022, Kathmandu, Nepal

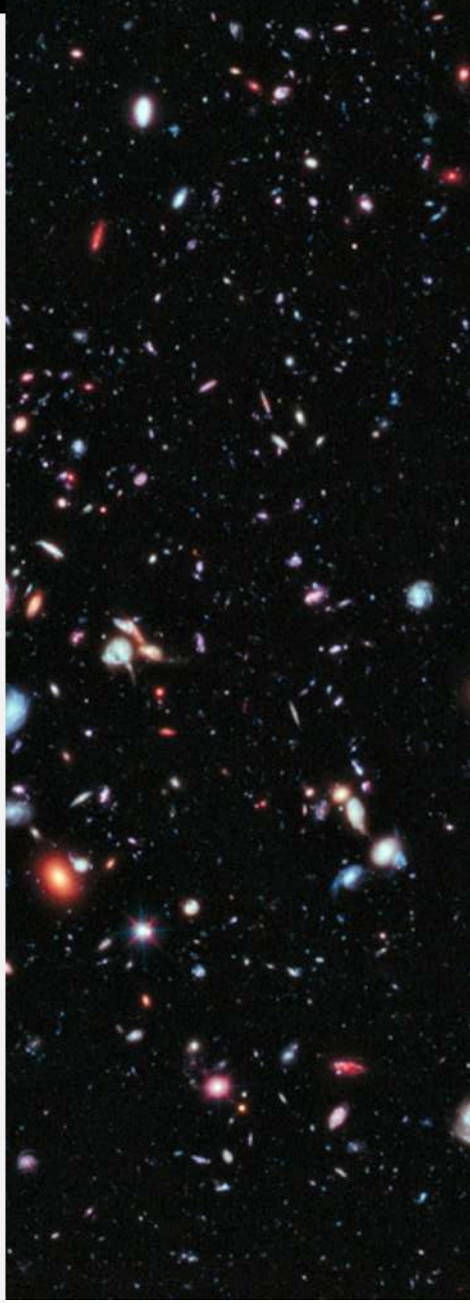


SAI MSU

INTRODUCTION

- IMBHs (100 $M_\odot$ < M_{BH} < 10^5 $M_\odot$) are important for cosmology
  - early SMBH assembly: low-mass (~100 $M_\odot$) or heavy (>10^5 $M_\odot$) “seed” black holes?

- Where we can search for IMBHs:
  - AGN: optical selection, X-ray follow-up
  - Ultra/Hyper-luminous X-ray sources: bright off-nuclear X-ray sources
  - Globular clusters

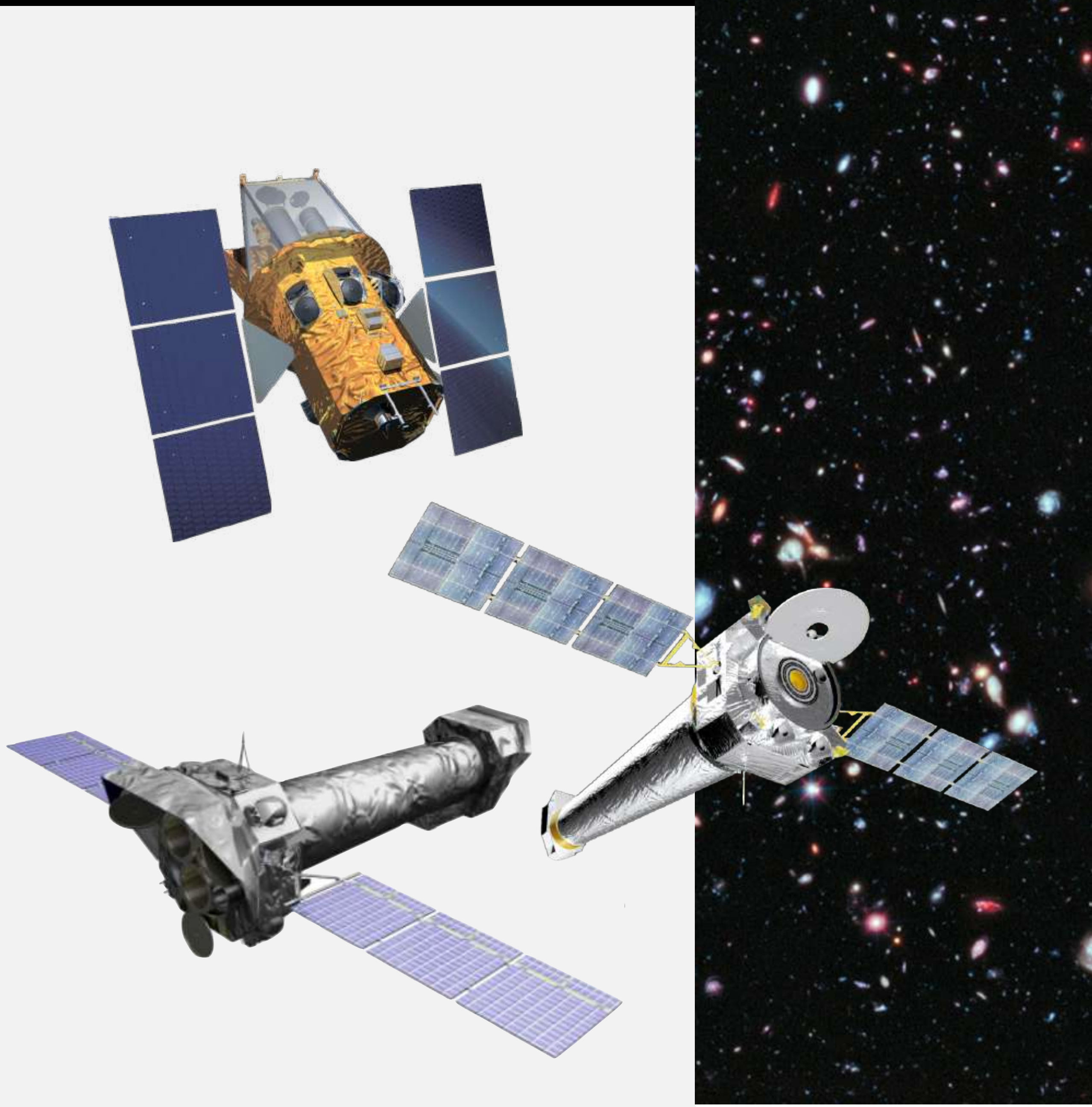


SOURCES OF X-RAY DATA

X-ray detection of corona serves as a solid confirmation of AGN nature of selected IMBH candidates.

Data sources:

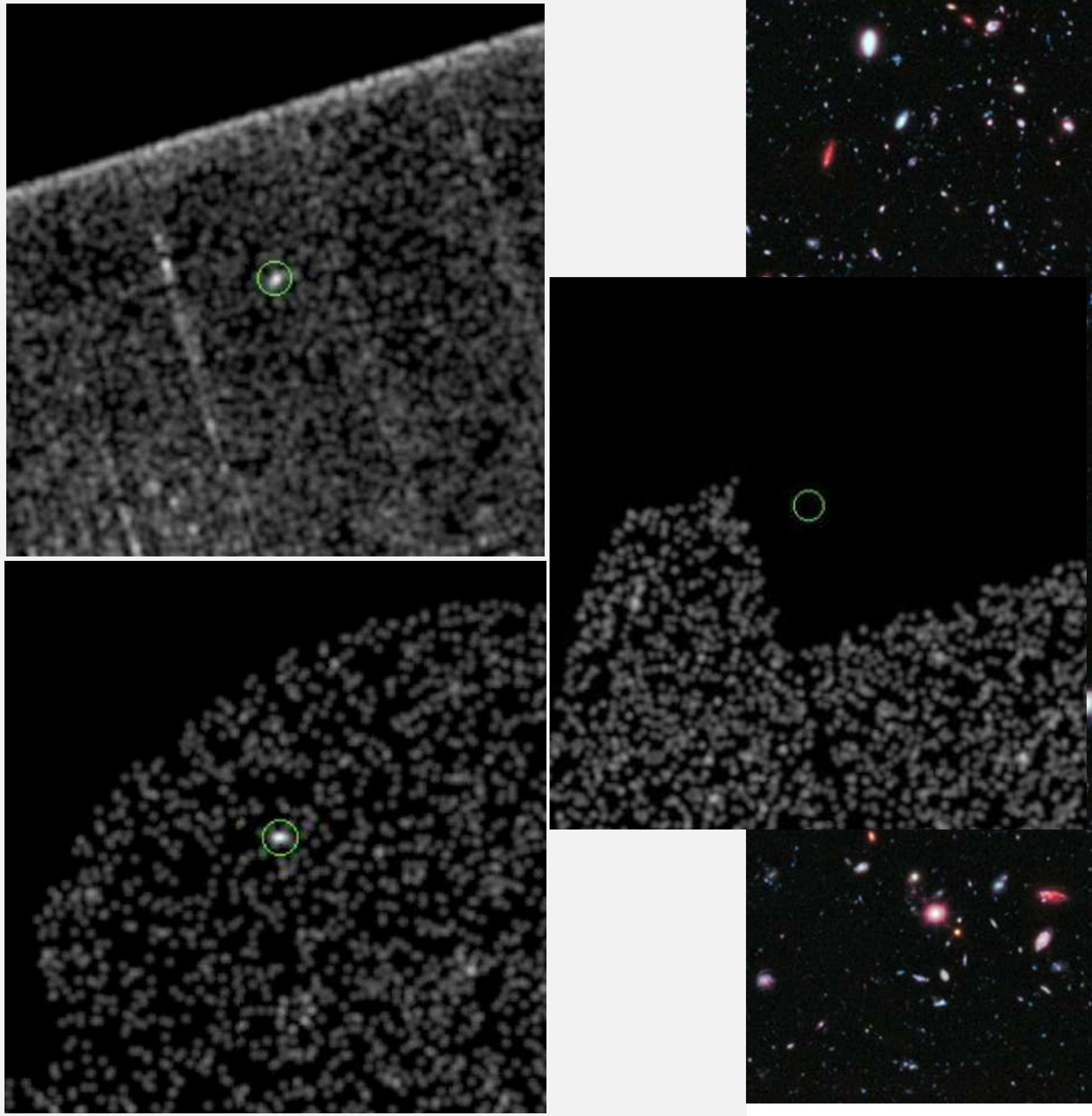
- Catalogs (Chandra Source Catalog 2, 4XMM-DR10, Second Swift XRT Point Source Catalog, Second ROSAT all-sky survey)
- Archival observations from XMM-Newton, Chandra and Swift
- Our X-ray follow-up from XMM-Newton, Chandra and Swift



ARCHIVAL DATA

We performed calibration of the raw observational data and spectra extraction using the following software:

1. XMM-Newton - Science Analysis System (SAS)
2. Chandra - Chandra Interactive Analysis of Observations
3. Swift - XSelect



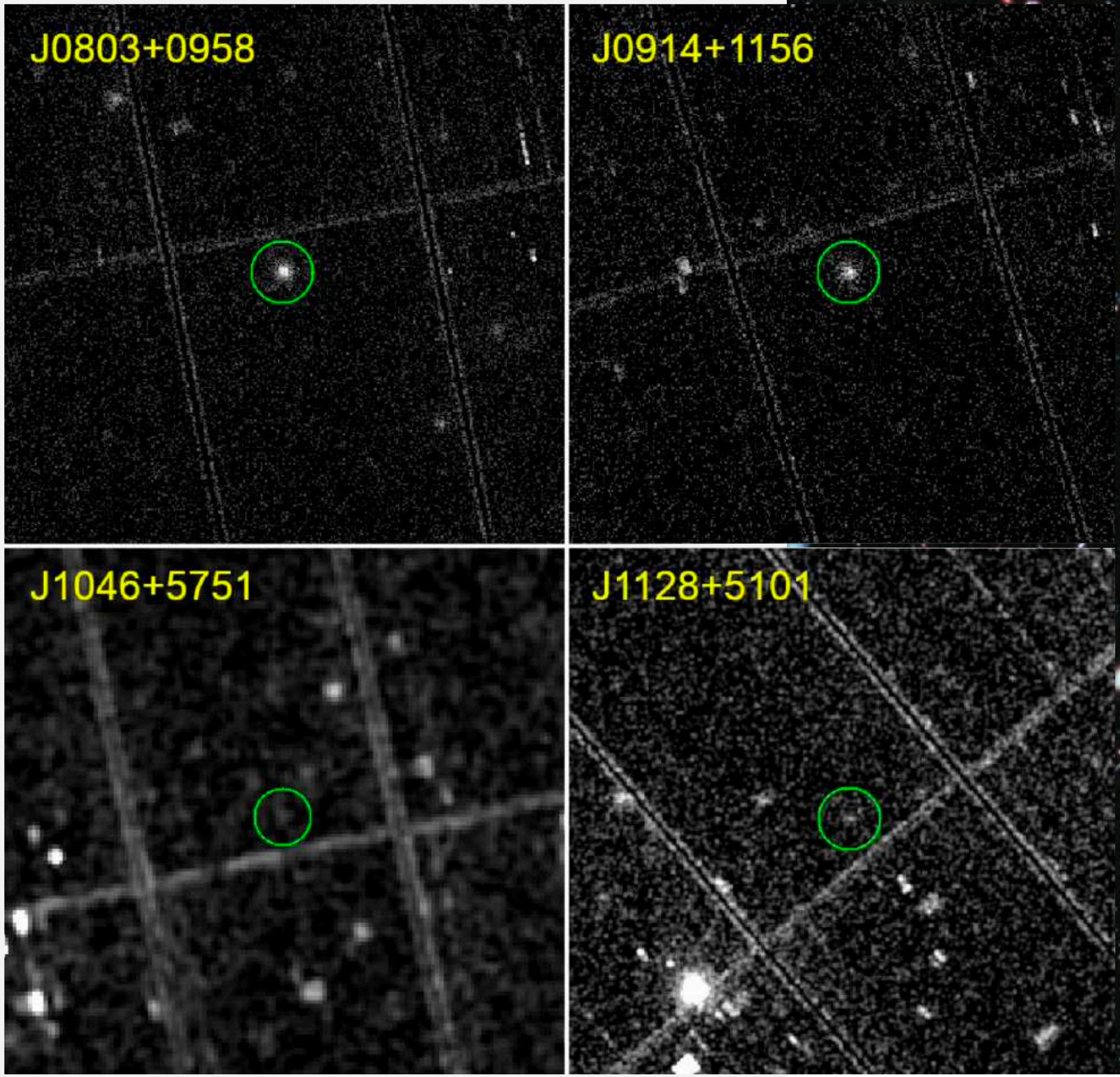
Example of XMM archival data

X-RAY FOLLOW-UP

7 observations using XMM-Newton

2 observations using Chandra

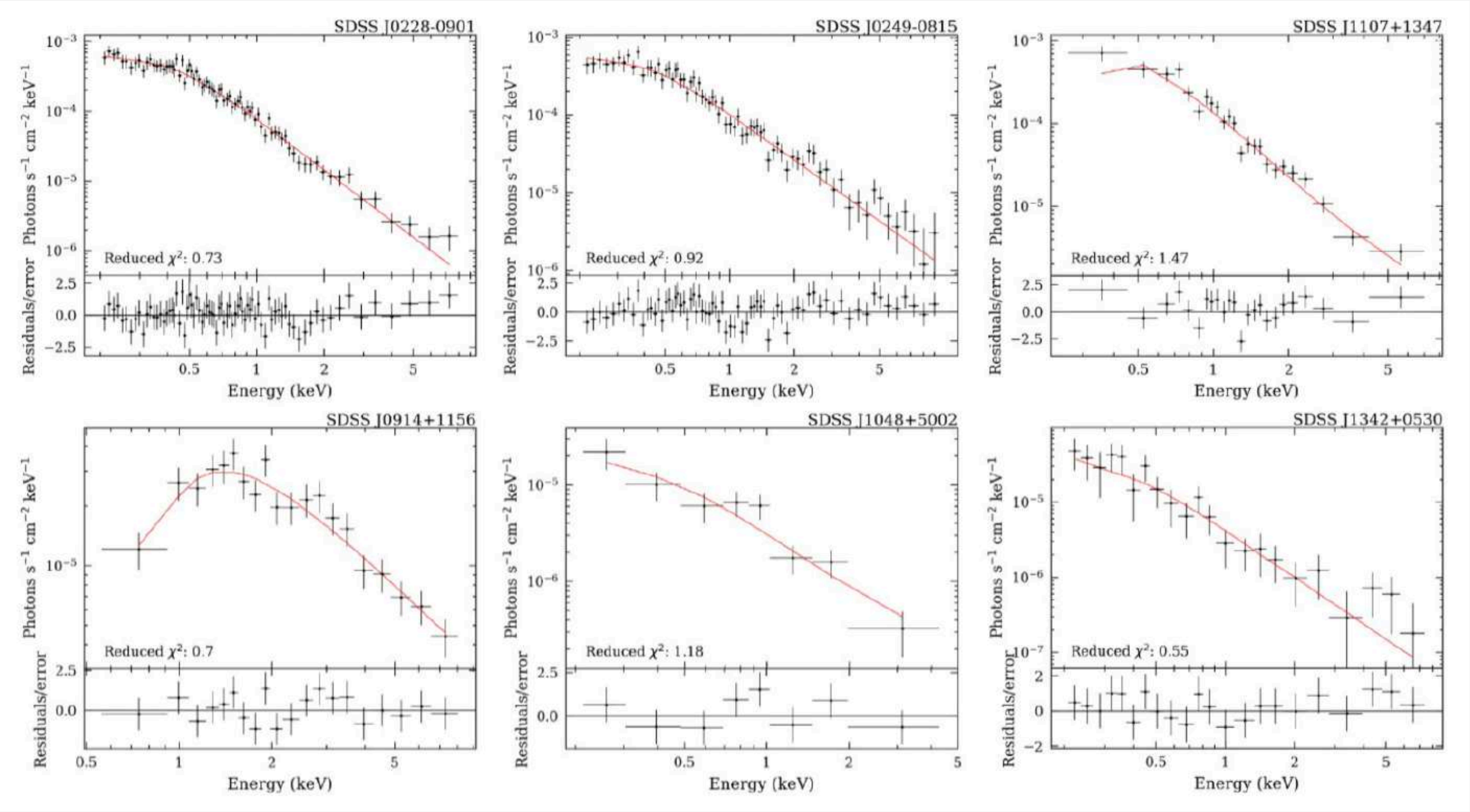
2 observations using Swift

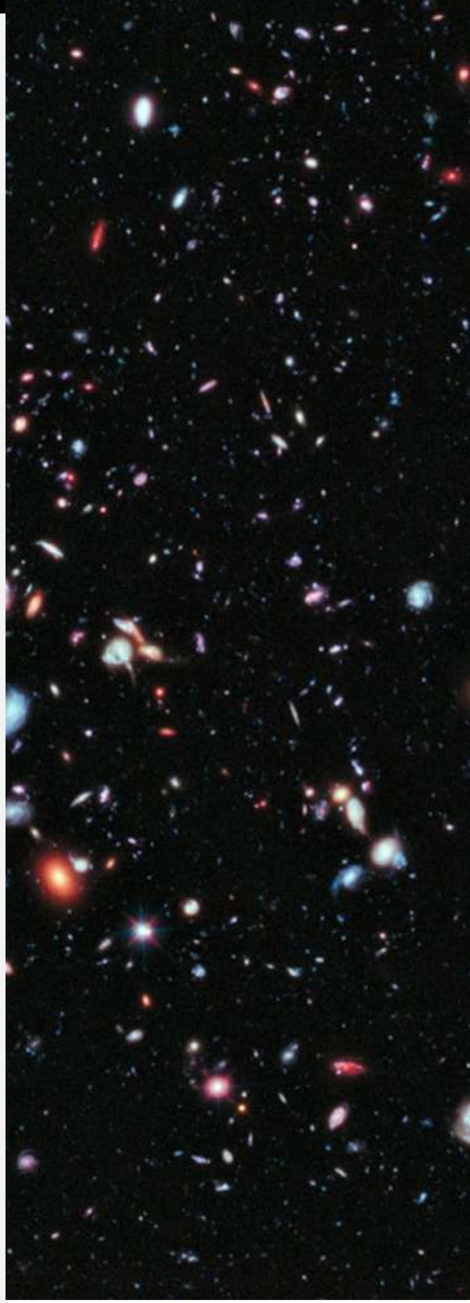


Example of our XMM observations

X-RAY SPECTRUM ANALYSIS

Fitting spectral data with power law and photoelectric absorption models





X-RAY LUMINOSITY EXPECTED FROM STELLAR POPULATION

We select only objects with X-ray luminosity higher than expected from the stellar population

$$L_{\mathrm{HX}}^{\mathrm{gal}} = \alpha M_{\star} + \beta \mathrm{SFR}$$

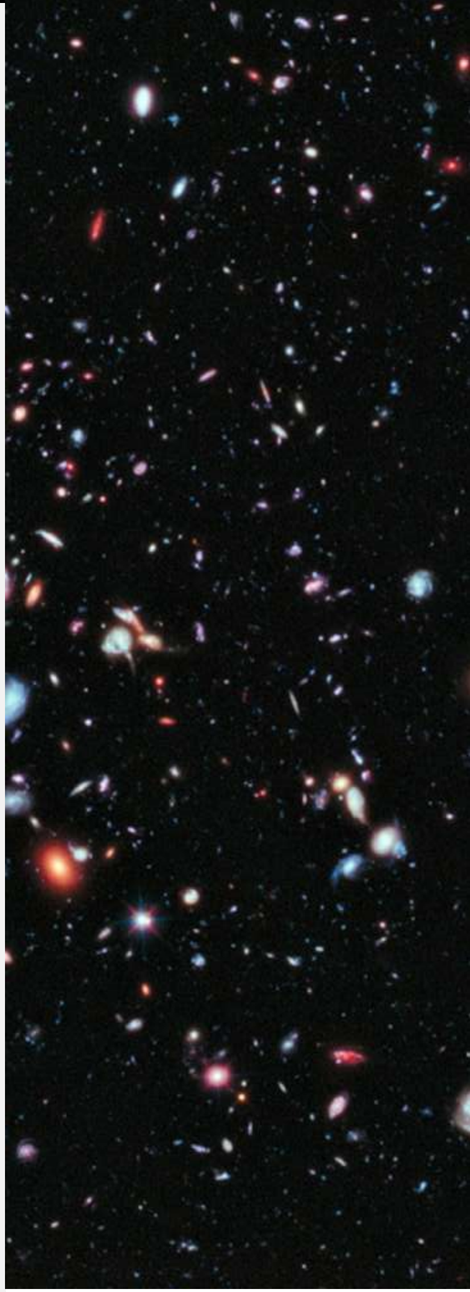
$$\alpha = (9.05 \pm 0.37) \times 10^{28} \text{ ergs s}^{-1} M_{\odot}^{-1}$$

$$\beta = (1.62 \pm 0.22) \times 10^{39} \text{ ergs s}^{-1} (M_{\odot} \text{ yr}^{-1})^{-1}$$

Lehmer et al. 2010

Data from GALEX-SDSS-WISE Legacy Catalog (GSWLC)
of stellar masses and star formation rates (Salim et al. 2016)

<u>LMXB</u> - contribution to stellar mass
<u>HMXB</u> - contribution to star formation rate



EDDINGTON ACCRETION

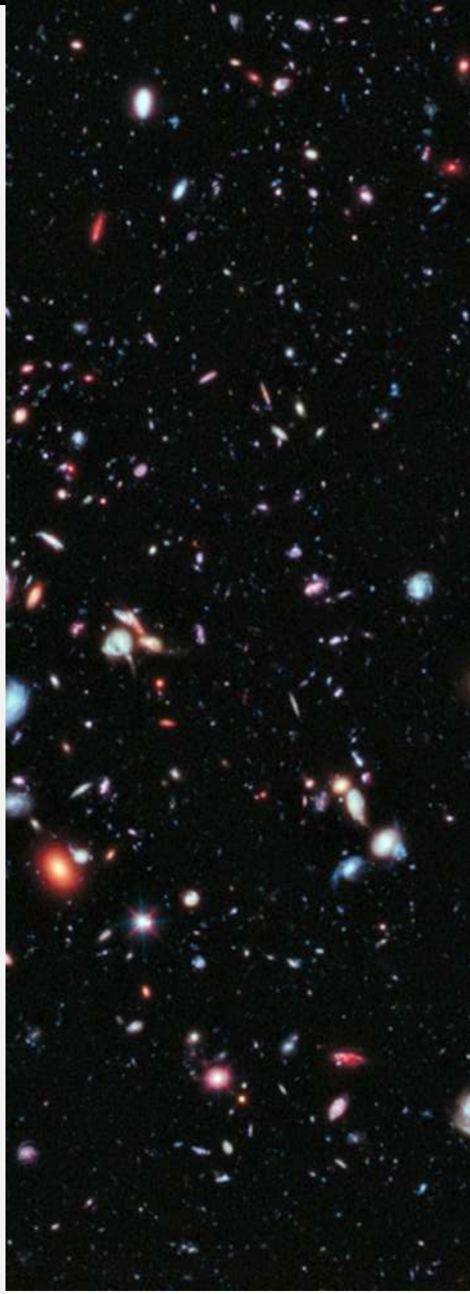
Bolometric to X-ray luminosity ratio:

$$K(L_X) = \frac{L_{bol}}{L_X} = 15.33\left[1 + \left(\frac{\log(L_X/L_\odot)}{11.48}\right)^{16.20}\right]$$

Duras et al. 2020

Eddington luminosity:

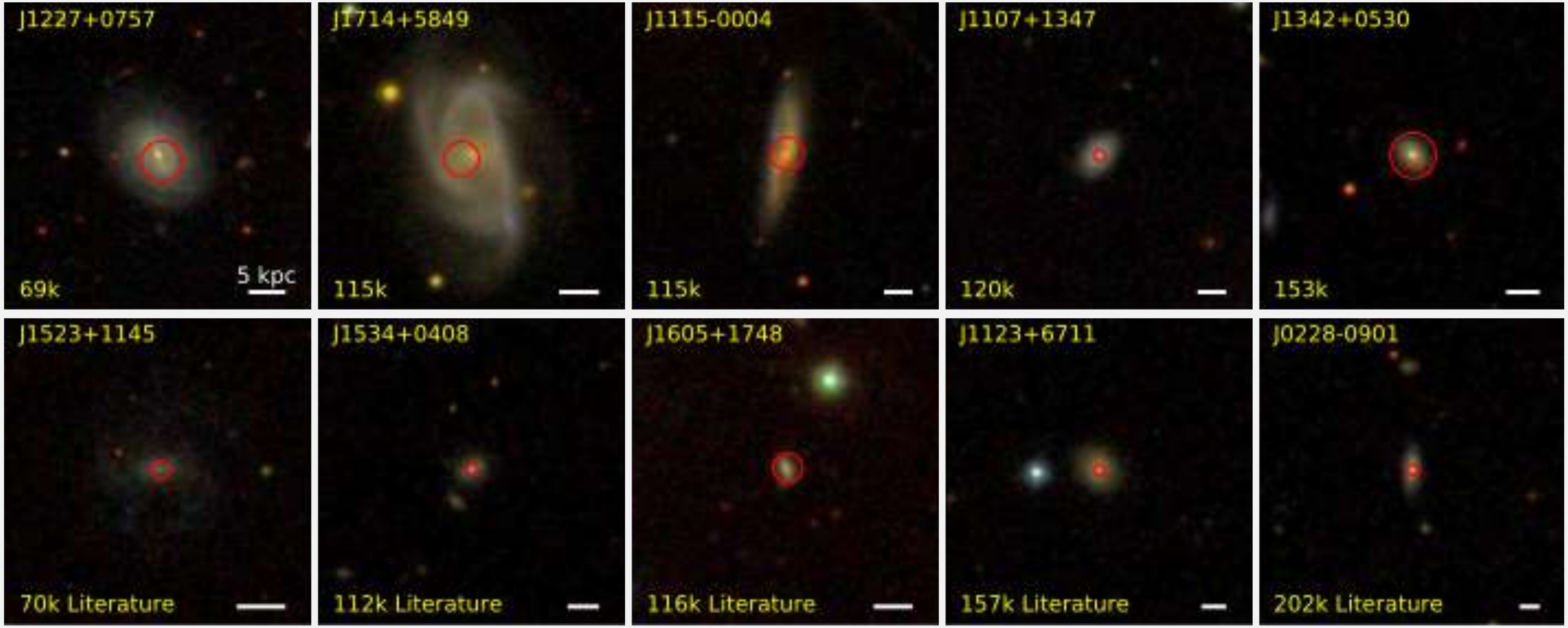
$$L_{edd} = \frac{4\pi G M m_p c}{\sigma_T} \approx 10^{38}\frac{M}{M_\odot}\,\mathrm{erg}\cdot\mathrm{s}^{-1}$$



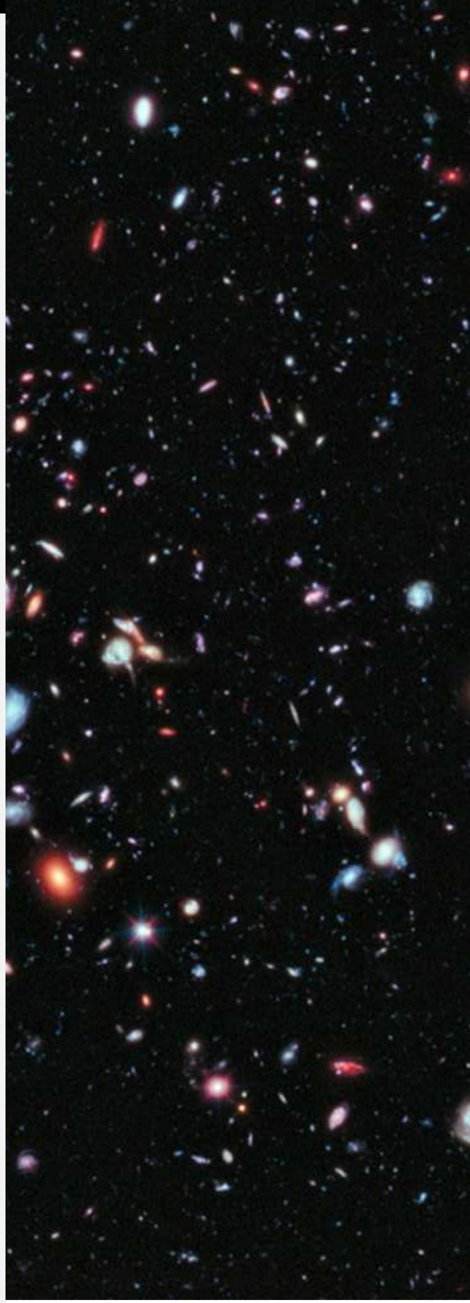
RESULTS OF THE ANALYSIS OF 1M SPECTRA

305 IMBH candidates with $M_{BH} < 2 \times 10^5\ M_\odot$ (**10** with X-ray)

1928 light-weight SMBH candidates with $M_{BH} < 10^6\ M_\odot$



Chilingarian et al. ApJ 2018, 863, 1



NEW CONFIRMED SAMPLE OF BONA FIDE IMBH

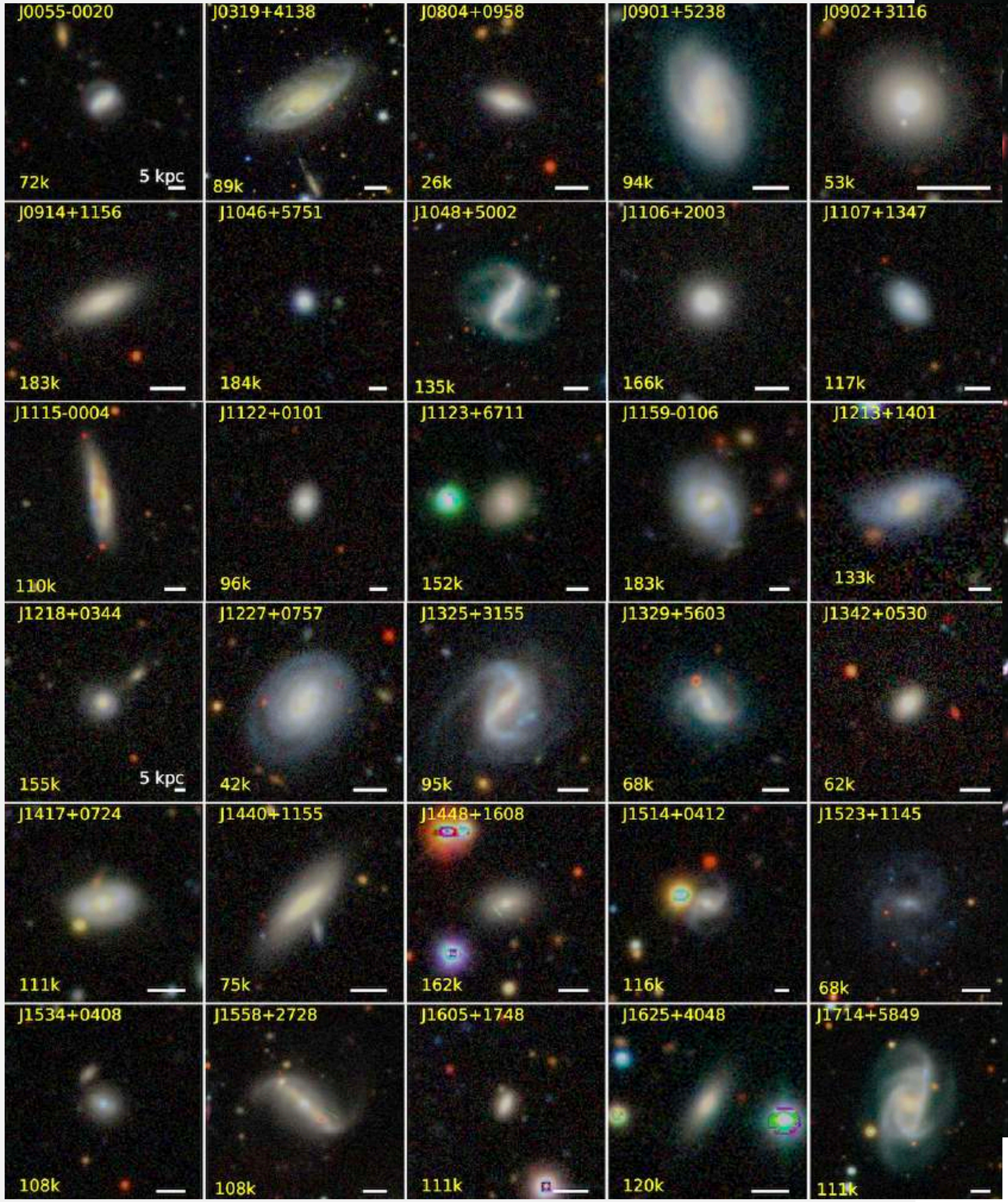
30 IMBHs (10 previously known from the literature)

10 of 30 with high accretion rates

141 objects with $M_{BH} < 10^6\ M_{sun}$

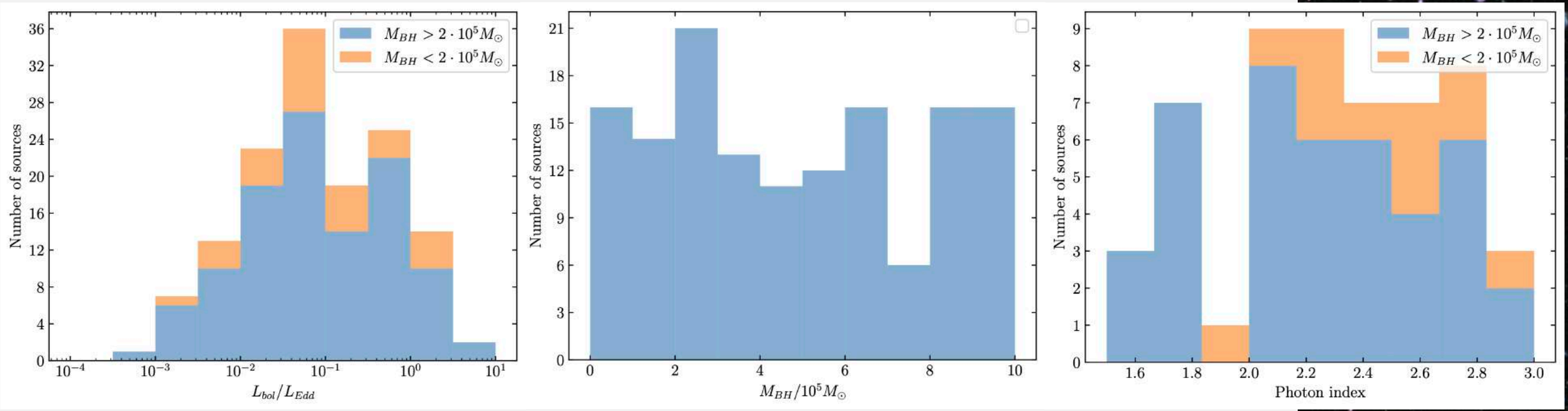
49 of 141 with high accretion rates

13 IMBH candidates with non-detections in X-rays
- selected by mistake
- or just the effect of a lack of exposure time?

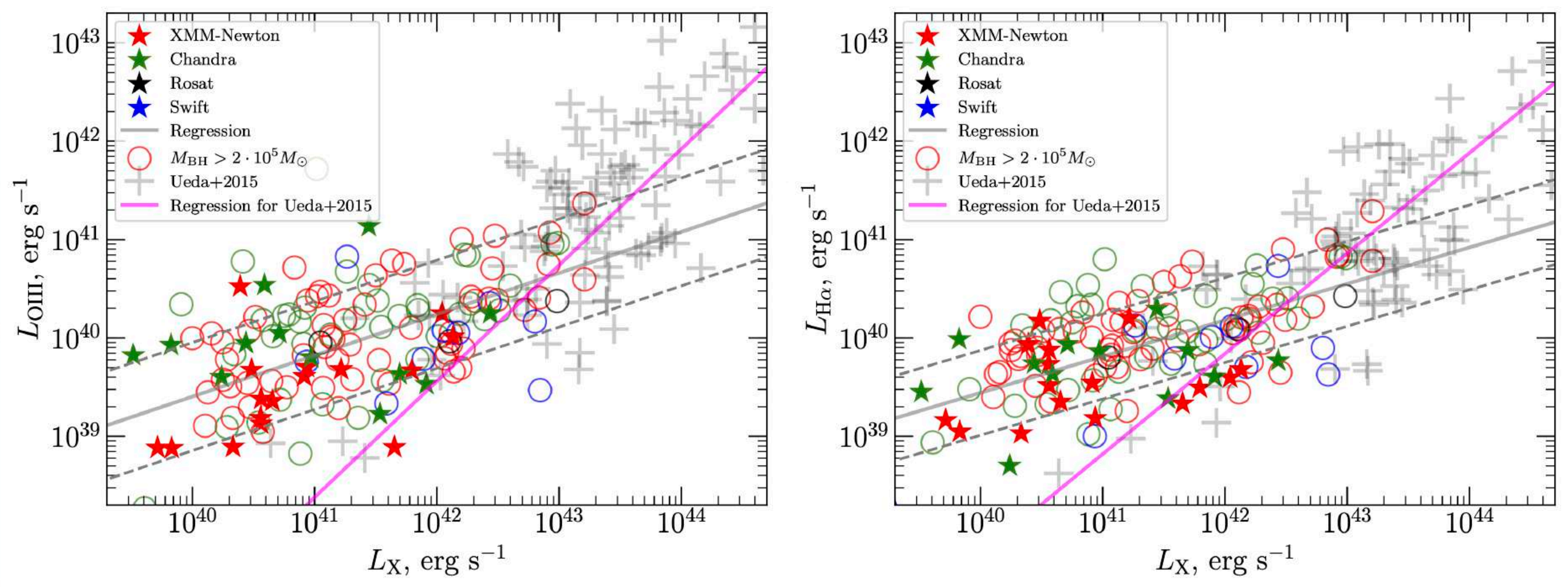


SAMPLE STATISTICS

- All X-ray spectra of IMBHs are soft (Photon index > 2)
- IMBHs and light-weight SMBHs have similar Eddington ratio distributions



RELATIONS BETWEEN X-RAY AND OPTICAL EMISSION LINE LUMINOSITIES



CONCLUSIONS

- The presence of observed IMBHs supports the theory of the SMBHs formation from low-massive seeds
- High accretion rates in a statistically significant fraction (30%) of the sample indicate the possibility of a significant contribution of accretion to the growth of BHs
- All X-ray spectra of IMBHs are soft (Photon index > 2)
- The slope of L_X-$L_{[OIII]}$ and L_X-$L_{bH\alpha}$ relations changes in low-mass regime

Thank you!