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Cradle of Seed Black Holes: Two ULXs and a Nuclear IMBH in a Blue Compact Dwarf Galaxy

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Why do we study IMBHs?

Intermediate-Mass Black Holes (IMBHs; 10^2-10^6 $M_\odot$)

— Supermassive black holes are thought to be grown from the seed black holes which are in the intermediate mass range (i.e. IMBHs).
— Great potential targets for future Gravitational Wave search.

How do seed black holes form?

-- via mergers (i.e. stellar-mass black holes)
-- remnants of Population III stars (~ 100 $M_\odot$ @ early Universe)
-- direct collapse of pre-galactic gas discs (~10^4 $M_\odot$)

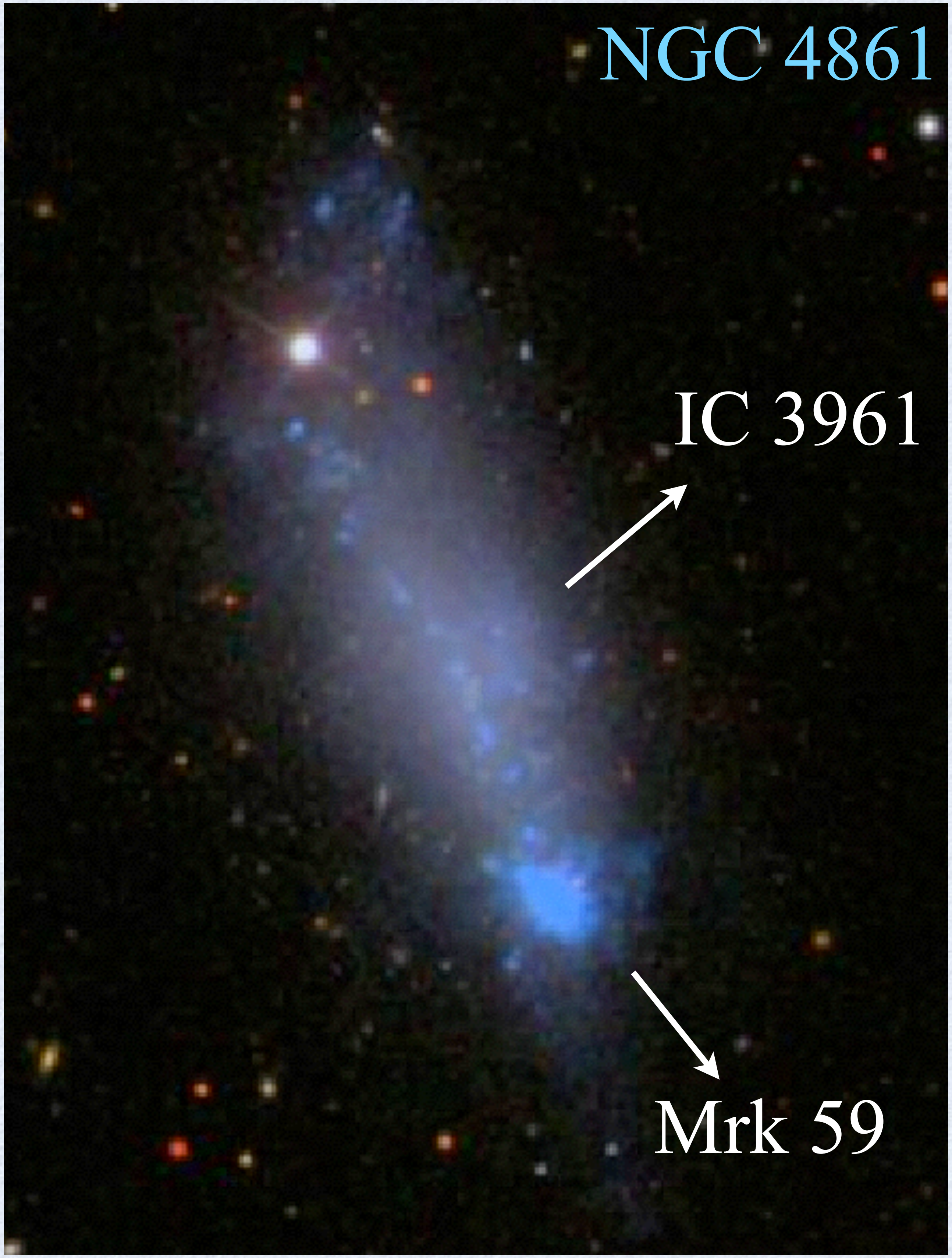
Where to search for IMBHs?

-- nucleus of low mass galaxies (i.e. low-Z dwarf galaxies; Baldassare et al. 2015; our study), usually very dim in X-ray (possibly due to obscuration, or low accretion)

-- off nuclear ultra-luminous X-ray sources (ULXs) with observed $L_X > 10^{41}$ erg/s (best candidate so far is HLX-1 in ESO 243-49)

-- center of globular cluster (GCs)?

Blue Compact Dwarf Galaxy NGC 4861



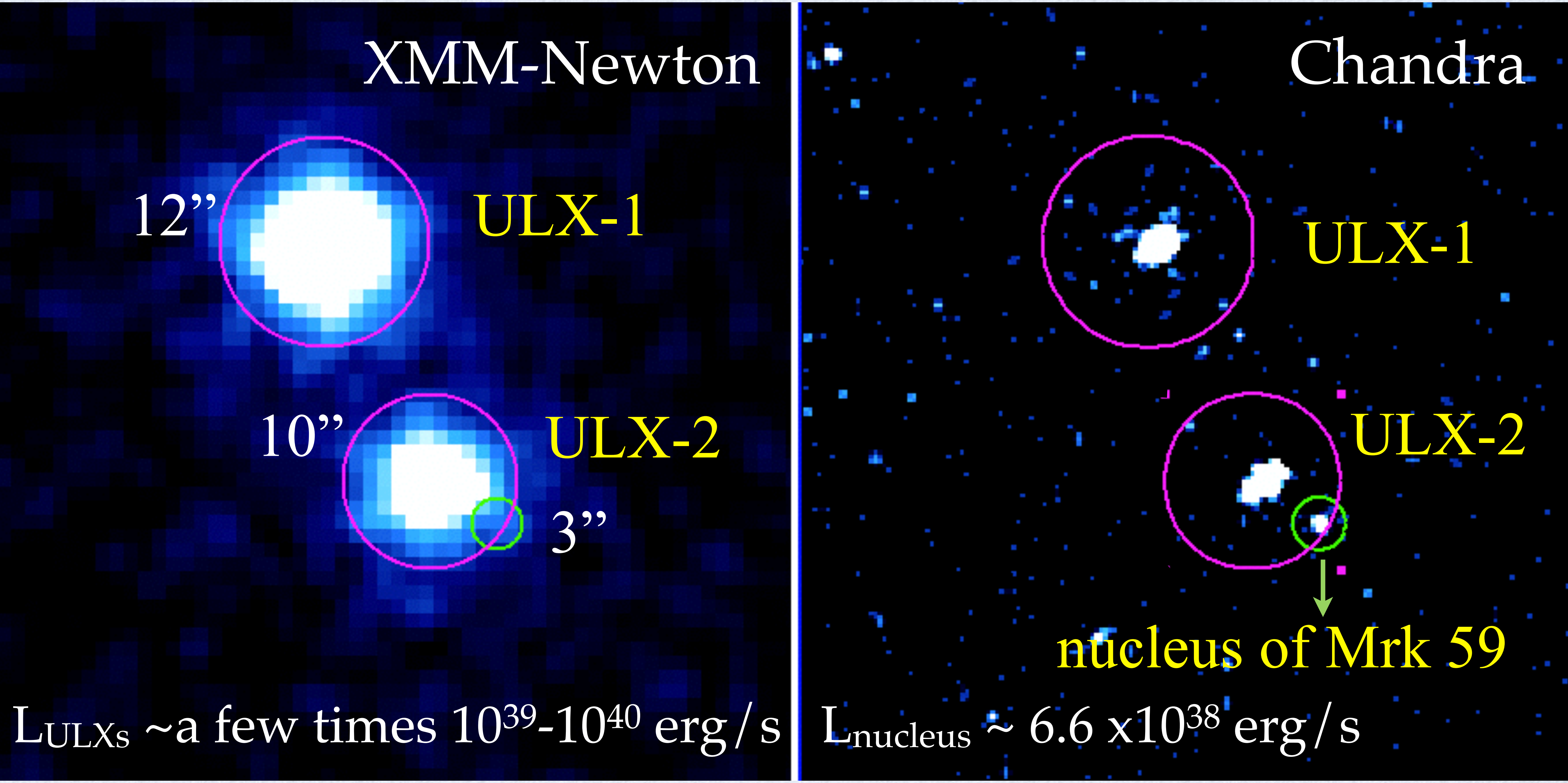
NGC 4861 belongs to a class of cometary Blue Compact Dwarf Galaxies (BCDs: the local analogue of galaxies in the early Universe).

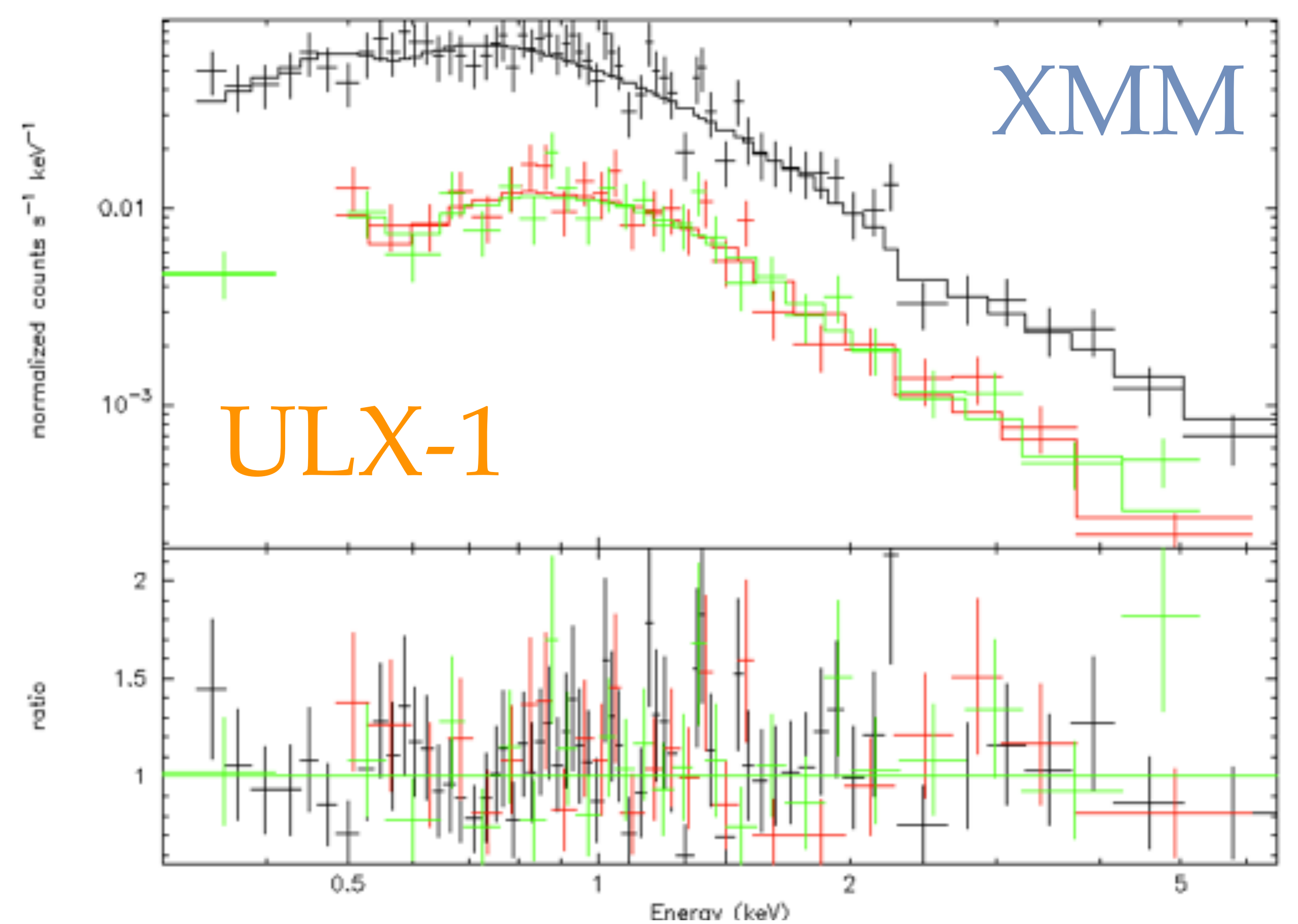
It consists of a dwarf irregular (IC 3961, a chain of HII regions) with a bright knot (Mrk 59 = I Zw 49, bright supergiant HII region).

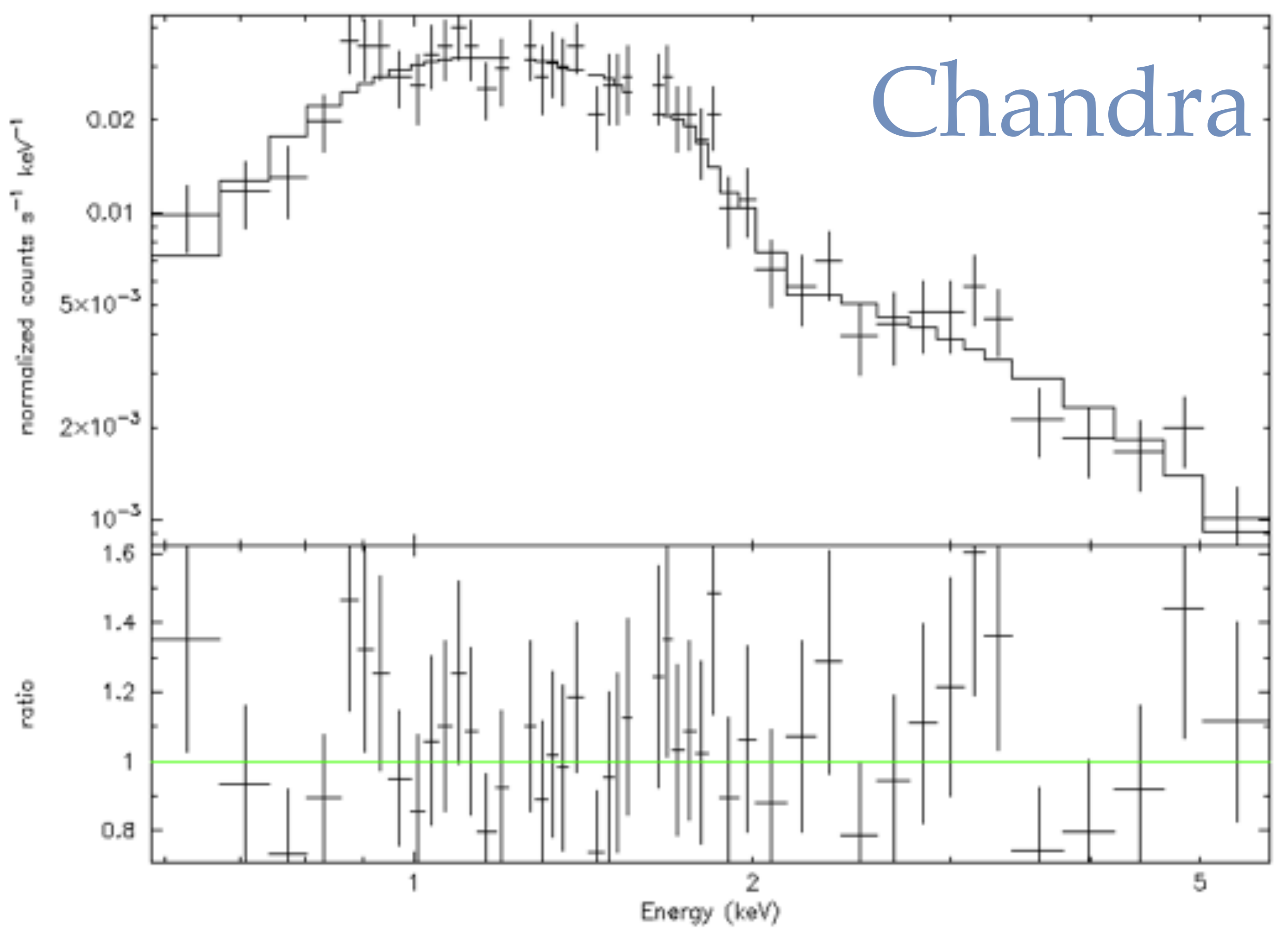
It is a relatively young star-forming galaxy with very low metallicity:
$Z \sim 0.13\ Z_\odot$ (Mapelli et al. 2011)

Distance ~ z = 0.003+/-0.00001
~11 Mpc

X-Ray Sources in NGC 4861 (XMM & Chandra)







XMM-Newton (PN+MOS1,2)

Power-law model:

NH~ 1.3×10^{21} cm^{-2}

Photon Index ~ 2.46 (+/-0.1)

Power-law+diskbb model:

NH~1.5×10^{21} cm^{-2}

Photon Index ~ 2.02 (+/-0.21)

Tin ~ 0.21 KeV

(disk contribution ~ 35%)

(VH state => Eddington/
or Super-Eddington Accretion)

ULX-1 is probably a massive black hole with M ~ 90 $M_\odot$ (non Super-Eddington) or M > 9 $M_\odot$ with extreme super-Eddington

(3 $M_\odot$ < M_{BH} < 30 $M_\odot$ for ULX-2)

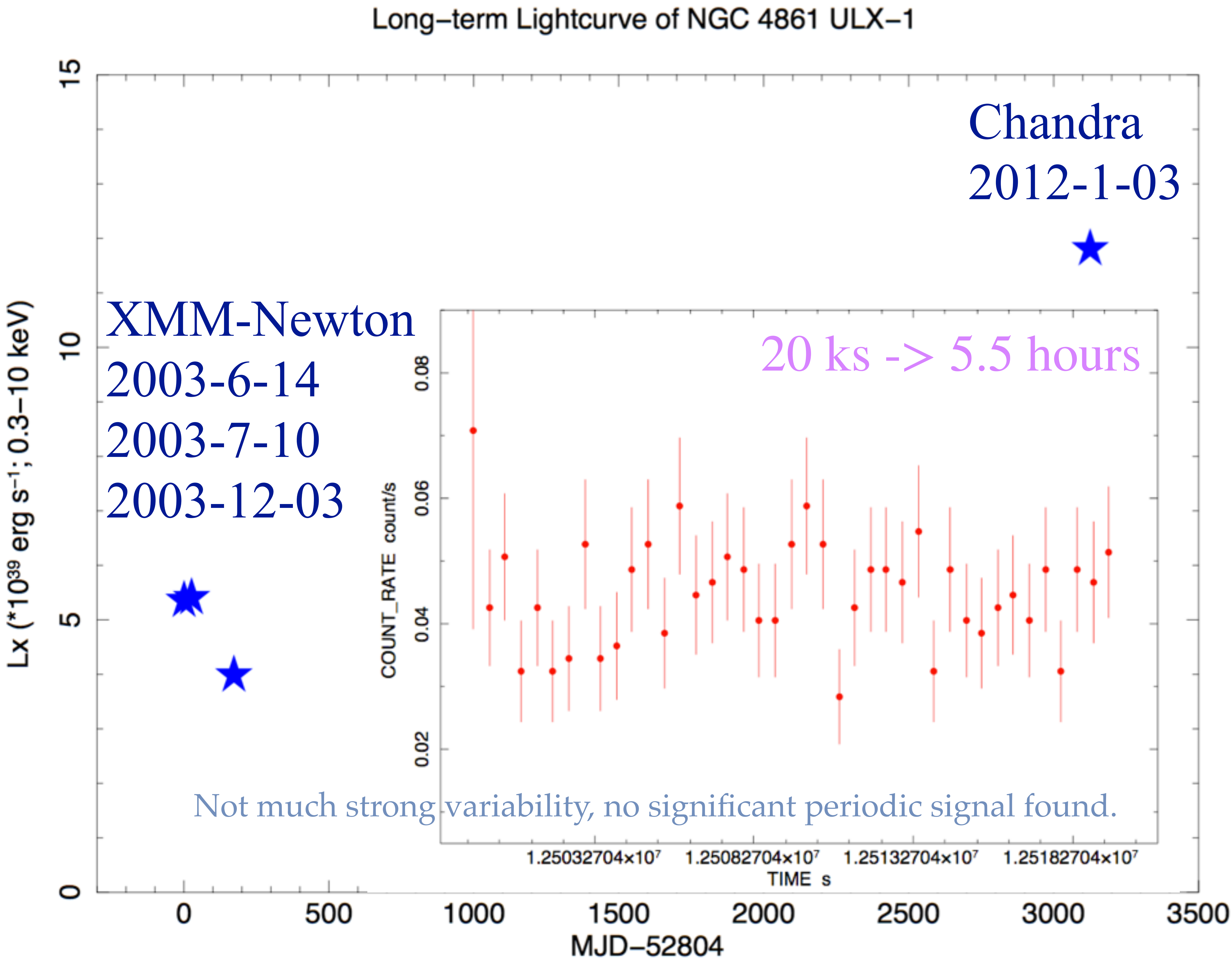
=> Massive Stellar BHs/ or
Hyper-massive BHs

Chandra (ACIS-I)

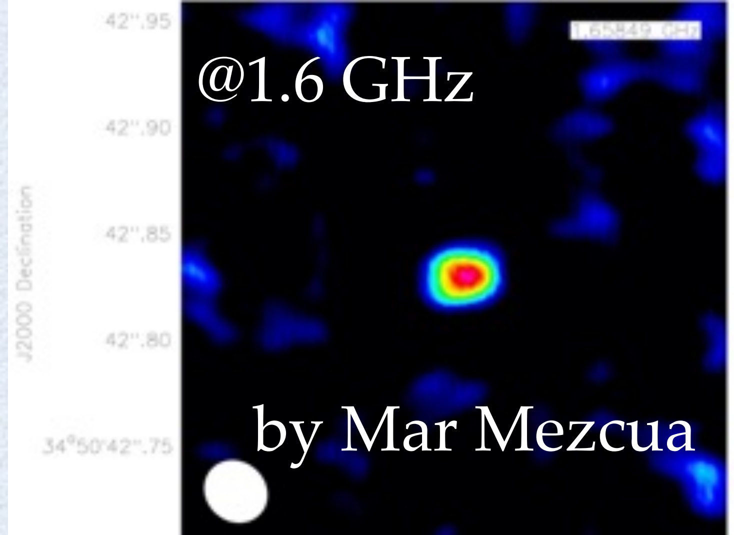
Power-law model:

NH~ 1.4×10^{21} cm^{-2}

Photon Index ~ 2.21 (+/-0.14)

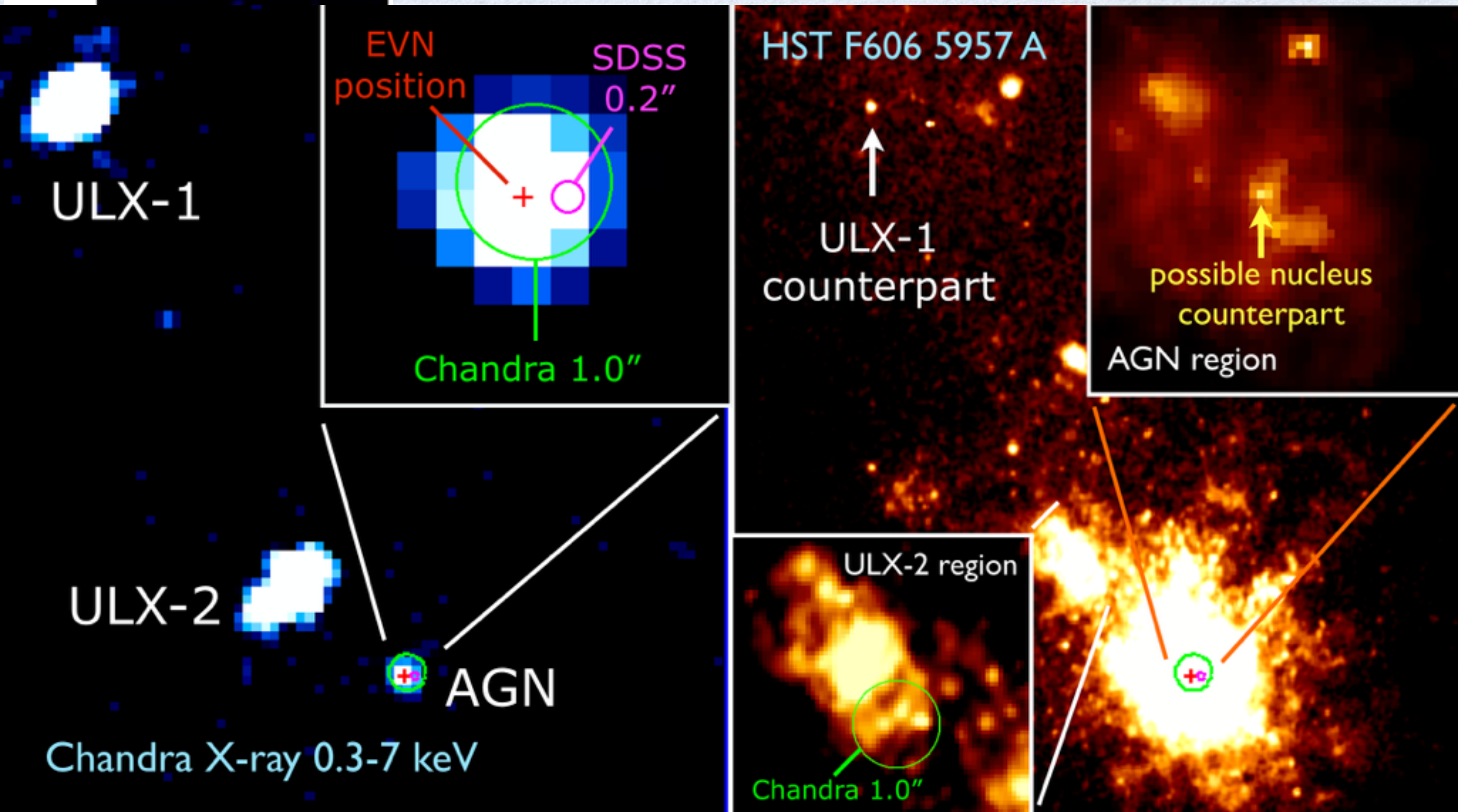


Long−term Lightcurve of NGC 4861 ULX−1
Chandra
2012-1-03
XMM-Newton
2003-6-14
2003-7-10
2003-12-03
20 ks -> 5.5 hours
Not much strong variability, no significant periodic signal found.
Lx (*10^39 erg s^−1; 0.3−10 keV)
MJD−52804
COUNT_RATE count/s
TIME s
1.25032704×10^7
1.25082704×10^7
1.25132704×10^7
1.25182704×10^7



An Intermediate Mass Black Hole in the center of Mrk 59

Yang et al. in prep.



Mass Estimation of Mrk 59 Nuclear Black Hole

$L_X \sim 6.6 \times 10^{38}$ erg/s (2-10 keV, d=11 Mpc).

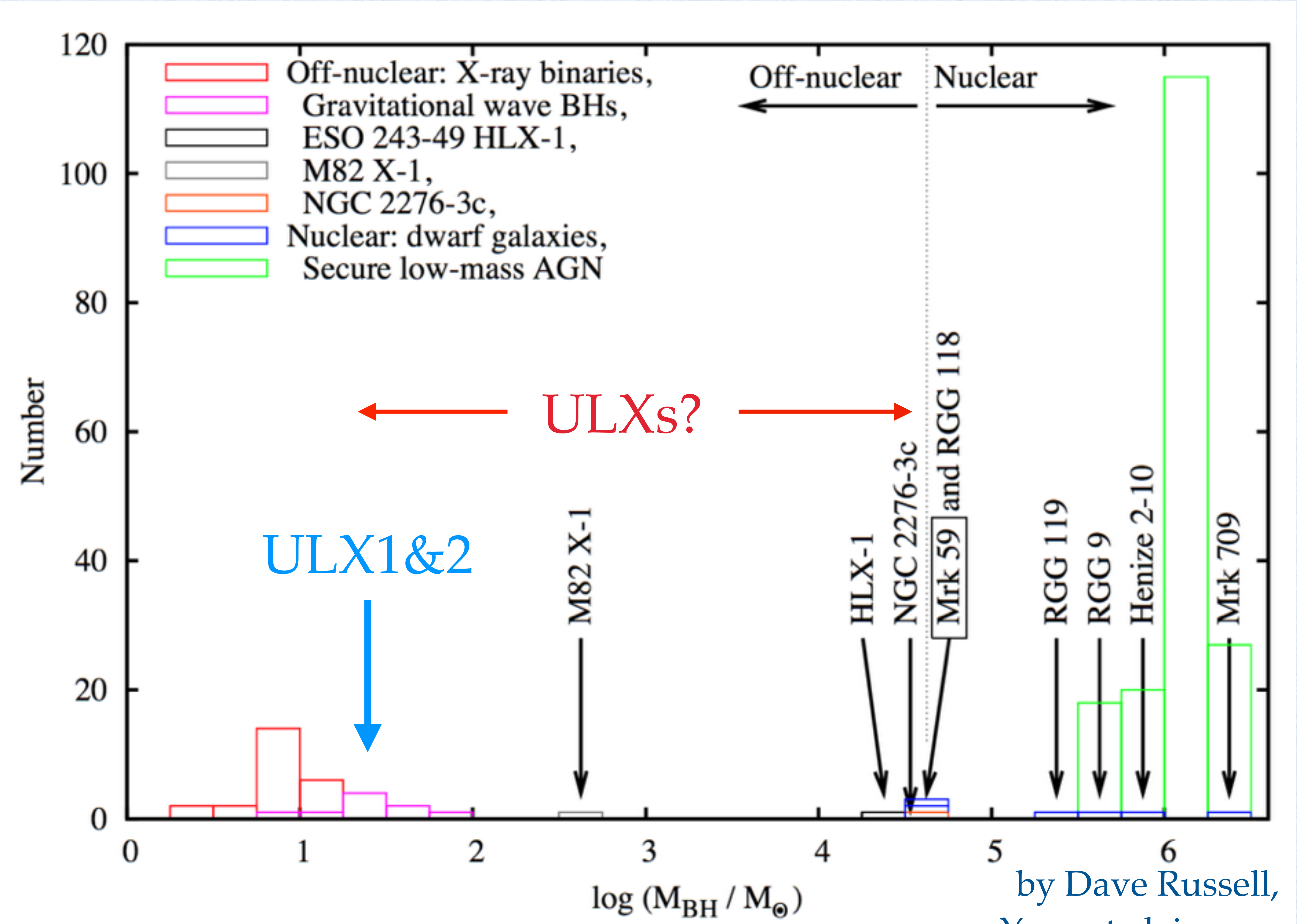
$L_R \sim 2.3 \times 10^{34}$ erg/s @ 5GHz.

Using the fundamental plane relation for accreting BHs:

$\log L_R = 4.8 + 0.78 \log M_{BH} + 0.67 \log L_X$ (Gultekin et al. 2014)

We get $M_{BH} \sim 4 \times 10^4 M_\odot$! => IMBH (uncertainty ~ 0.7 dex)

Black Hole Mass Distribution



by Dave Russell,
Yang et al. in prep.

Summary

There are three X-ray sources (2 ULXs + 1 IMBH) in the BCD galaxy NGC 4861. The black hole mass of these sources ranges from several tens to several tens thousand solar masses.

The two ULXs are in "Very High" state, indicating super-Eddington accretion, meaning that the black holes are accreting materials from their surroundings very efficiently and might grow heavier through time.

We demonstrate that the low-metallicity, star-forming BCDs are the ideal place to search for seed black holes /or massive stellar black holes, and thus good potential targets for future GW search (i.e. Advanced LIGO/ Virgo, LISA, TianQin).

Our finding of the active IMBH bridges the gap between supermassive and stellar-mass accreting black holes and provides the observational evidence that BCD galaxies might truly be the building blocks of larger galaxies.