X-ray searches of intermediate mass BHs

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Also thanks to:
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Doug Swartz *(NASA/MSFC)*
Jifeng Liu *(NAOC)*

Outline

1. Why searching for IMBHs

2. Previous unsuccessful X-ray searches

3. New criteria for more productive X-ray search

IMBHs predicted by theory

BHs with masses between ~1000—10^5 M_{sun}

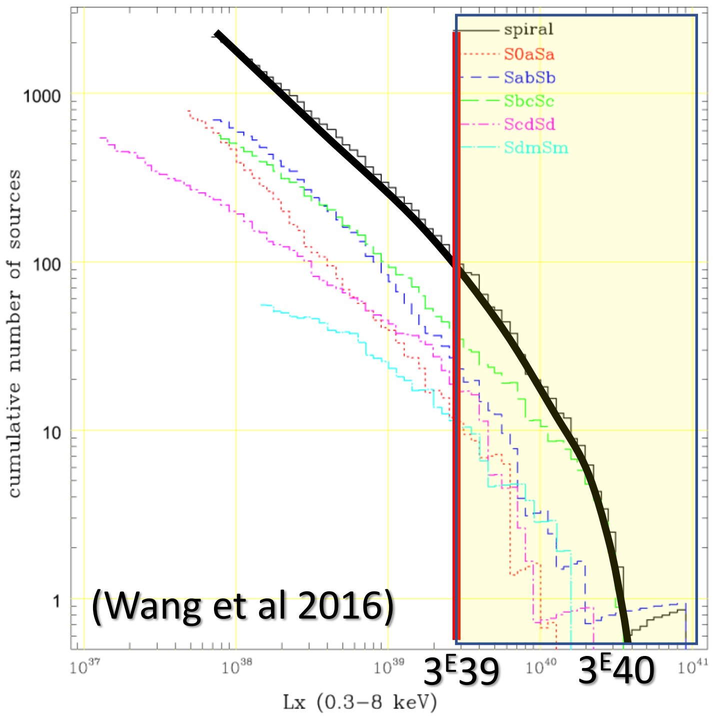
Predicted in various environments

- Seeds of supermassive BHs
- Nuclei of dwarf galaxies
- Cores of globular clusters

Can we find them as X-ray sources?

Failed search for IMBHs in ULXs

Ultraluminous X-ray sources powered by IMBHs?



Fashionable idea in early 2000s

Non-nuclear sources with Lx ~ 3E39—3E40 erg/s might contain IMBHs

Soft thermal component in those sources thought to be diskbb around an IMBH

This was proved to be wrong

ULXs = NSs or stellar-mass BHs accreting >> Eddington limit

(plus a few background AGN)

New X-ray search for IMBHs

Two environments

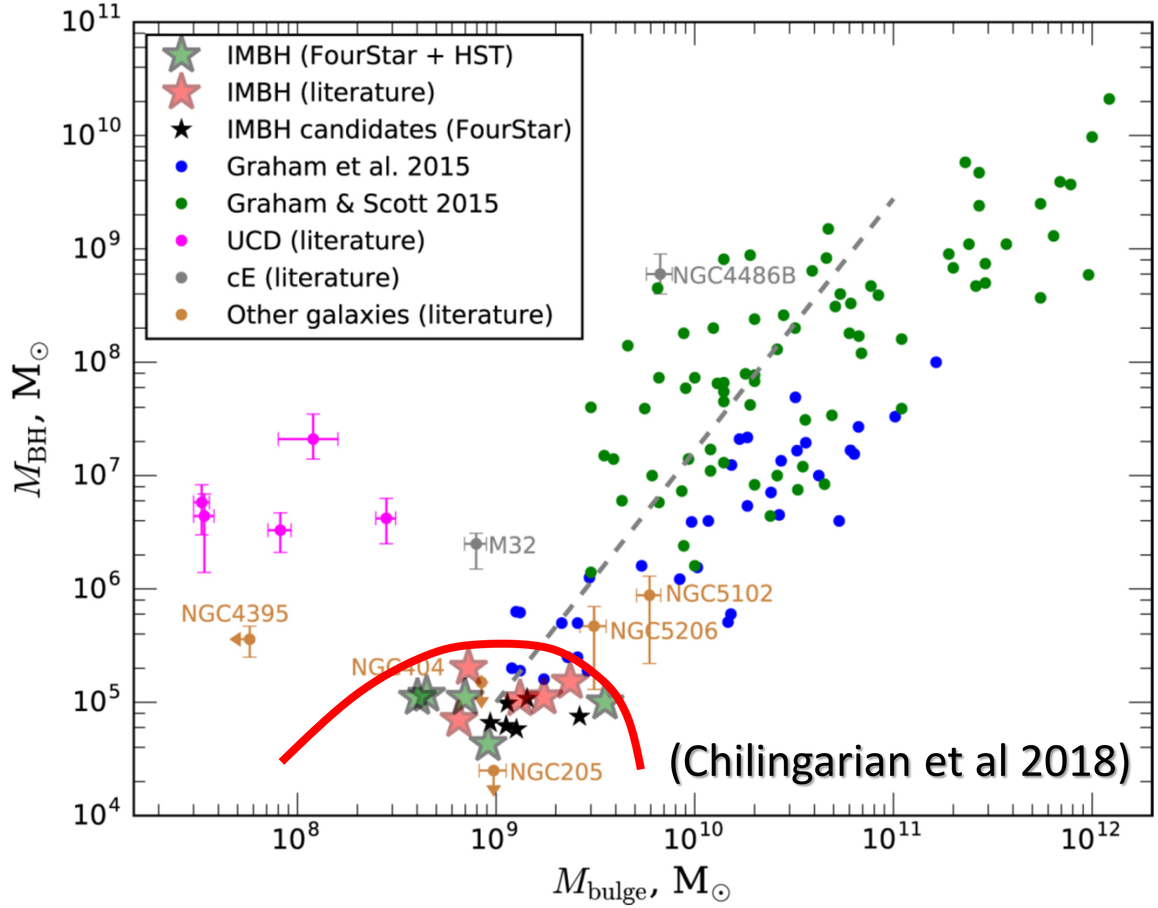
A: Nuclei of dwarf or bulgeless galaxies (Sd,Sm)

Predicted by M-σ relation (and similar scaling relations)
IMBHs = probes of nuclear BH growth

B: Outskirts or halos of early-type galaxies

Cores of massive globular clusters
Remnants of accreted satellite dwarfs
IMBHs = probes of hierarchical galaxy assembly

Case A: IMBHs as nuclei of small galaxies



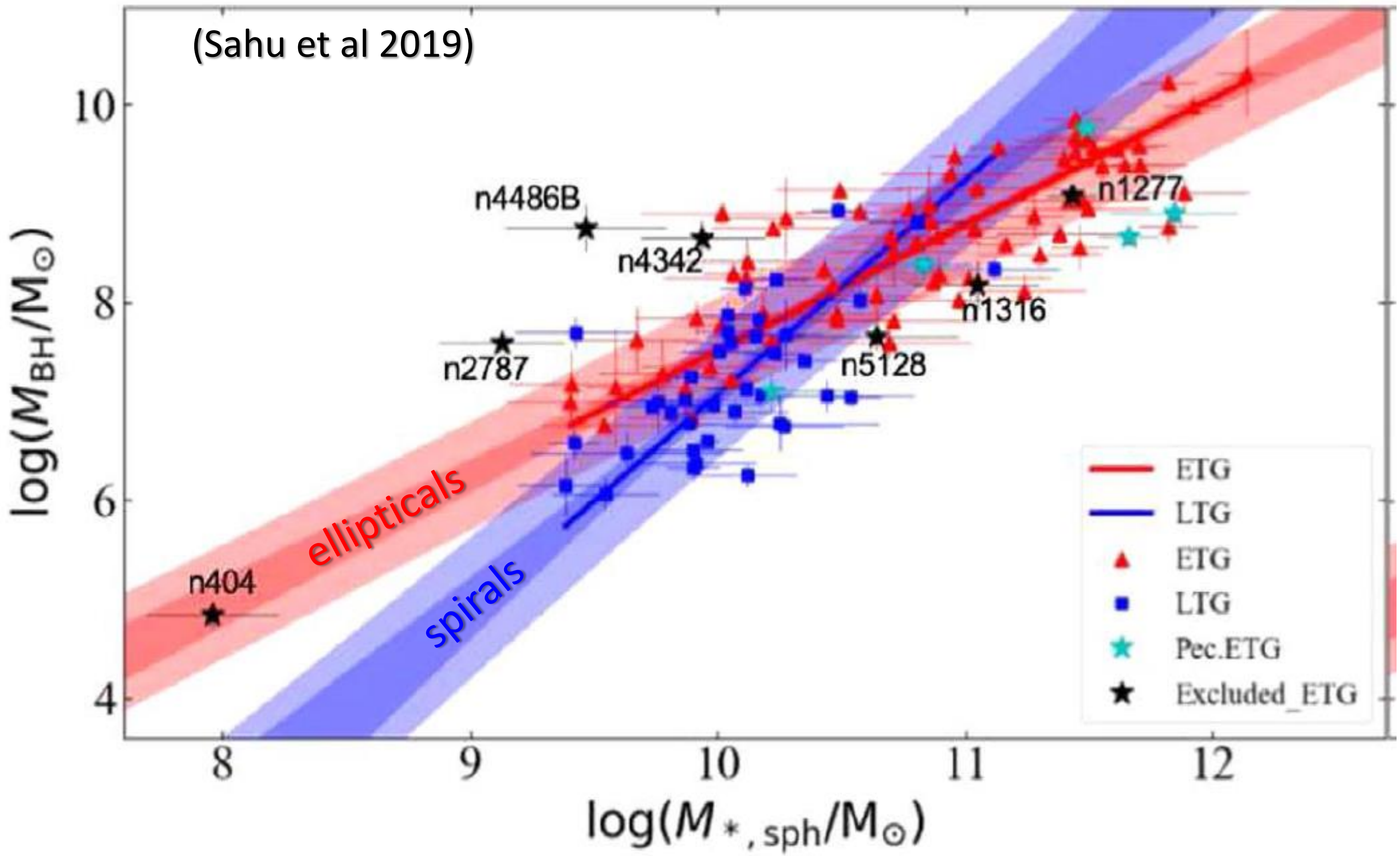
(Chilingarian et al 2018)

Detection of a point-like X-ray source = signature of nuclear BH

Need arcsec resolution especially for starforming galaxies

Chandra still the most suitable observatory

Case A: IMBHs as nuclei of small galaxies



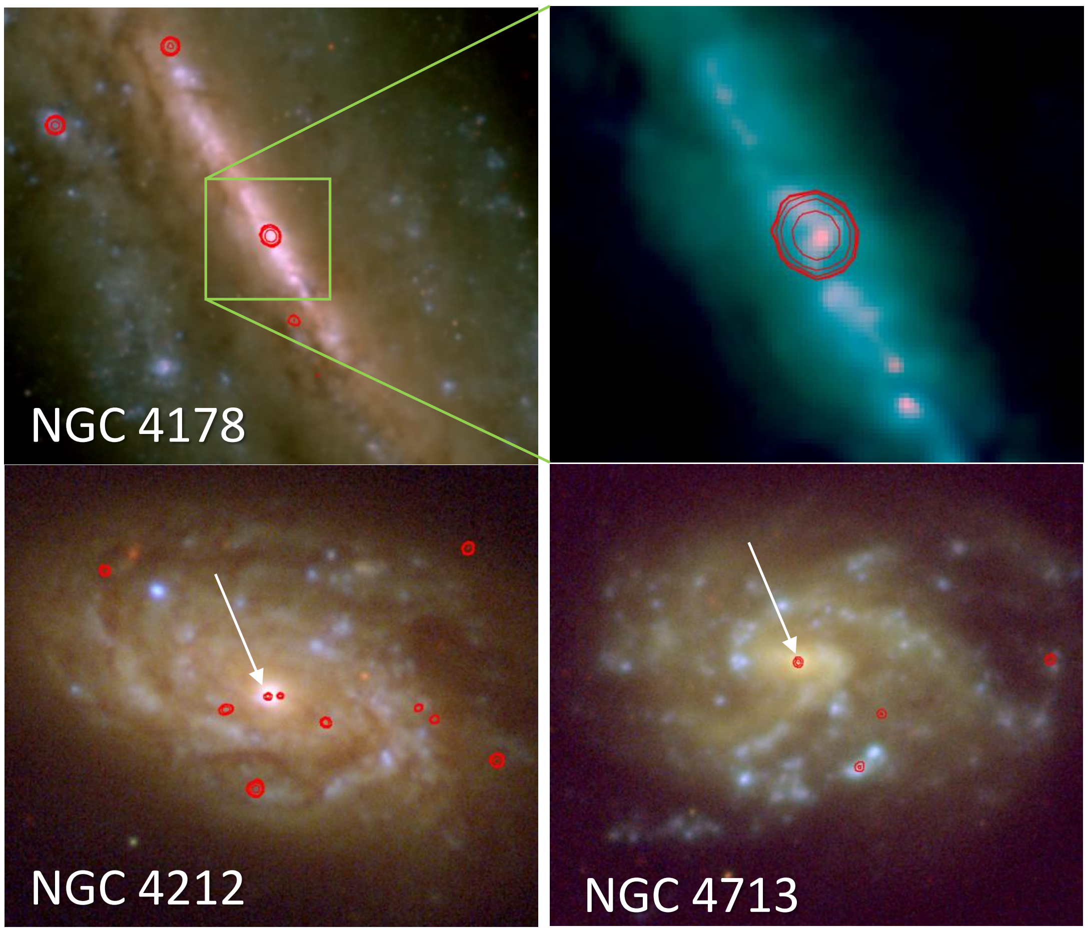
Test of proposed difference between IMBHs in E and S galaxies

Case A: IMBHs as nuclei of small galaxies

Candidate IMBHs in spiral galaxies of the Virgo Cluster

Chandra Virgo Spirals Survey: snapshot of 75 Virgo spirals down to Lx ~ 5 x 10^{38} erg/s

Graham, Soria & Davis (2019) -- Graham, Soria, et al (2021) -- Soria et al (2022)



Optical studies of a galaxy predict that it has a nuclear IMBH ($M \sim 1E4—1E6\ M_{sun}$)

We search for point-like X-ray emission from the nucleus

IMBH masses constrained by relations between L_X, $L_{H\alpha}$, L_{5GHz}

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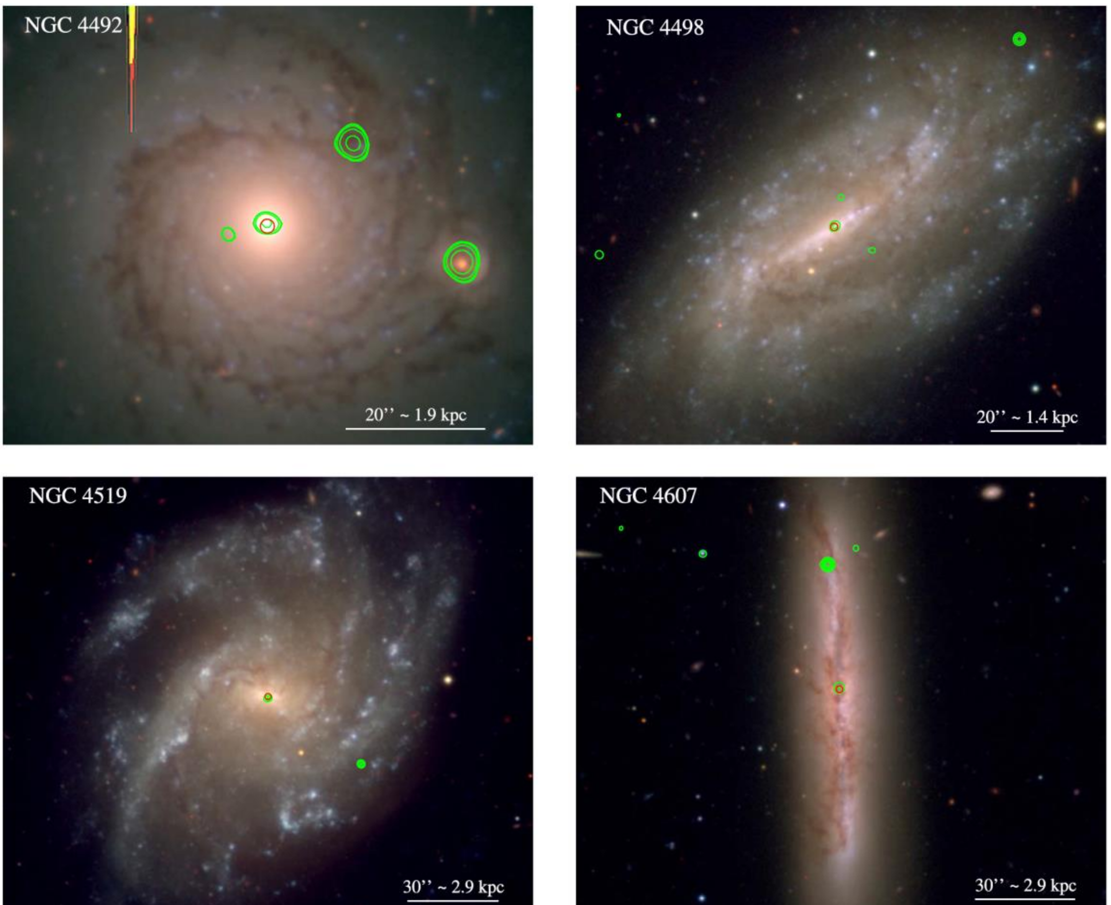

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↓

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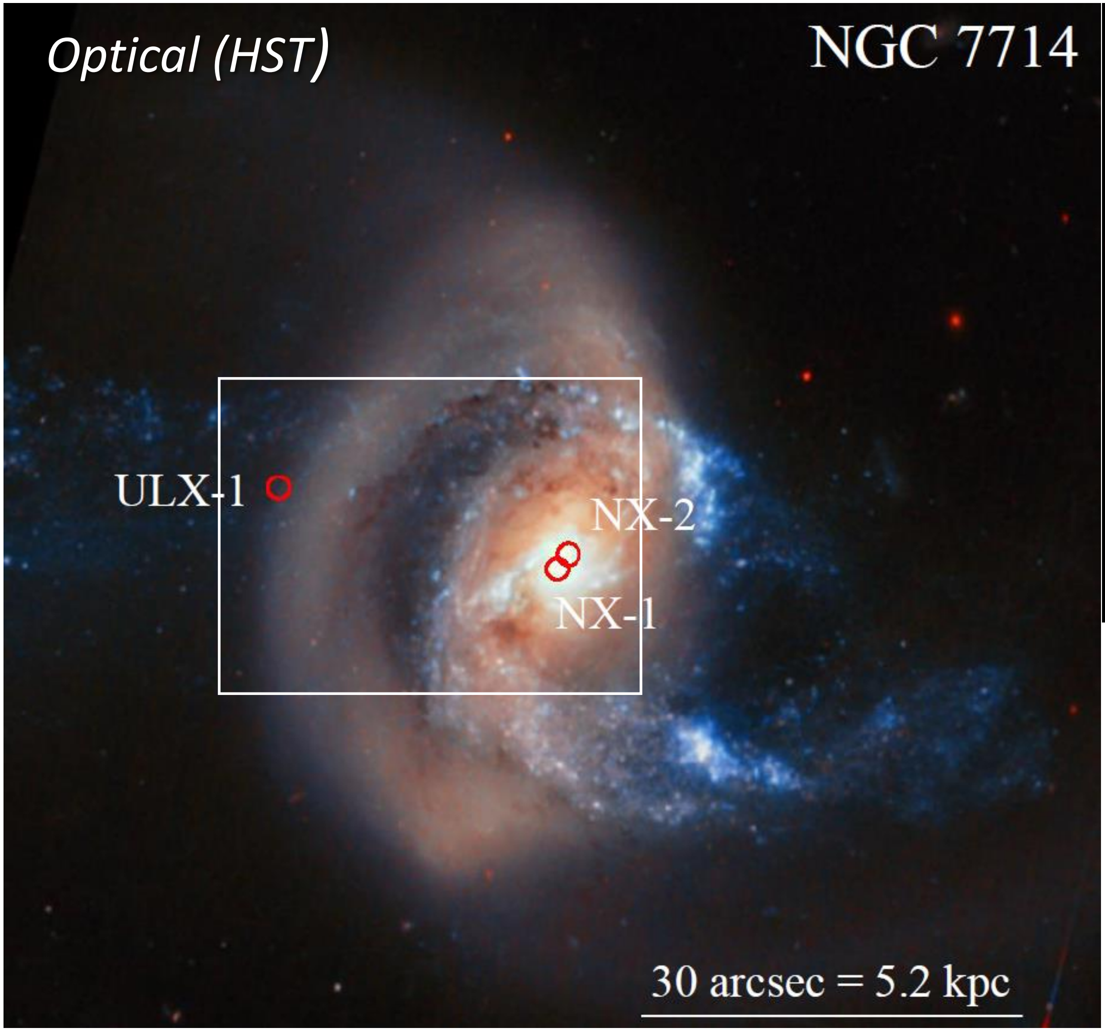
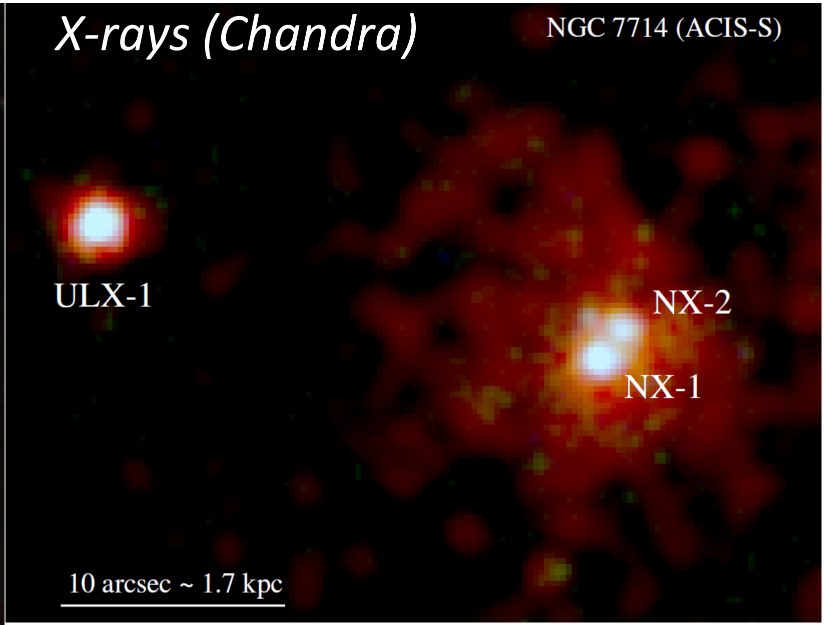
Case A: IMBHs as nuclei of small galaxies

Candidate nuclear IMBHs in the starburst galaxy NGC 7714





Study of a collision between galaxies

Double X-ray nucleus?

2 IMBHs in the process of merging?

(Soria et al 2022, in prep)

Case B: IMBHs in old E/S0 halos

Massive spheroidals = fossil record of (many) minor mergers

Timescale for sinking to the main nucleus > Hubble time

No current star formation in old halos

- No confusion with young ULXs in X-rays
- Blue optical counterpart stands out

Not too close to the nuclear region of a major Elliptical

Reduce bg emission from diffuse hot gas

Case B: IMBHs in old E/S0 halos

Selection criteria:

No confusion with ULXs

- In the halo of an E/S0 galaxy
- L_x ~ 10^{41}—10^{43} erg/s
- Thermal (diskbb) spectrum
- kT ~ 0.2—0.4 keV (X-ray photon index > 3)
- Blue optical counterpart

No confusion with AGN

High/soft state of an IMBH

No other type of X-ray source with those properties

Case B: IMBHs in old E/S0 halos

Test of selection criteria:

from the 4XMM-DR11 catalog (Tranin et al 2022, Webb et al 2022)

within 300 Mpc

↓

Three (already-known) outstanding candidates

- HLX-1 in the Phoenix Cluster (d ~ 95 Mpc)
  (various studies by Farrell et al, Webb et al, Soria et al)
- 4XMM J161534.4+1927 (d ~ 130 Mpc)
  (Albert Kong, in prep)
- J2150-0551 (d ~ 250 Mpc)
  (D Lin et al 2018, 2020)

Case B: IMBHs in old E/S0 halos

HLX-1

$L_{(0.3\text{-}10\ keV)}$ varies between ~ 2e40 erg/s – 1e42 erg/s

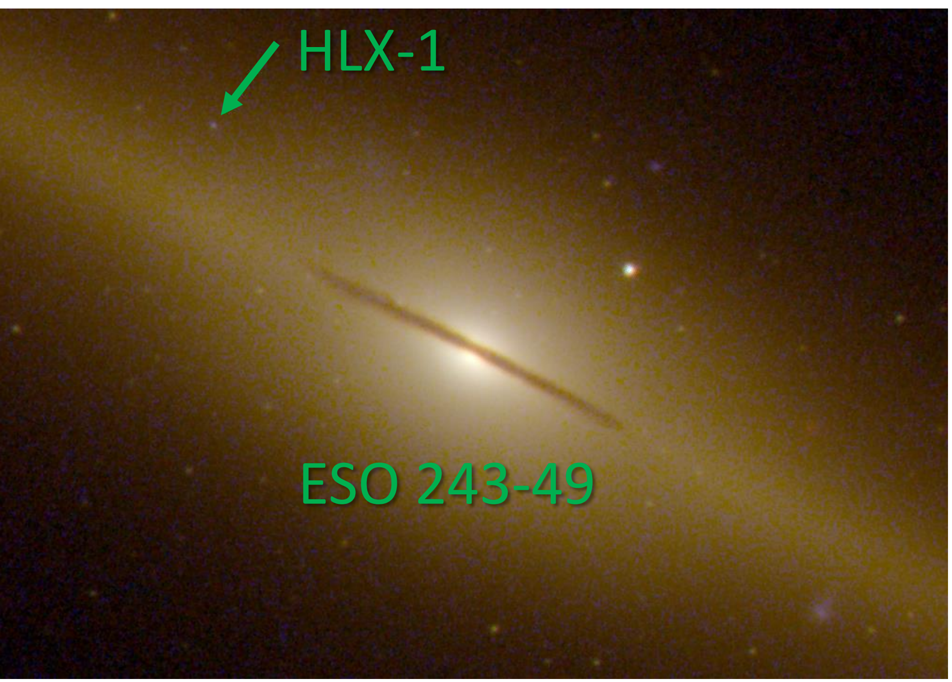
kT_{in} ~ 0.25 keV, L ~ T^4

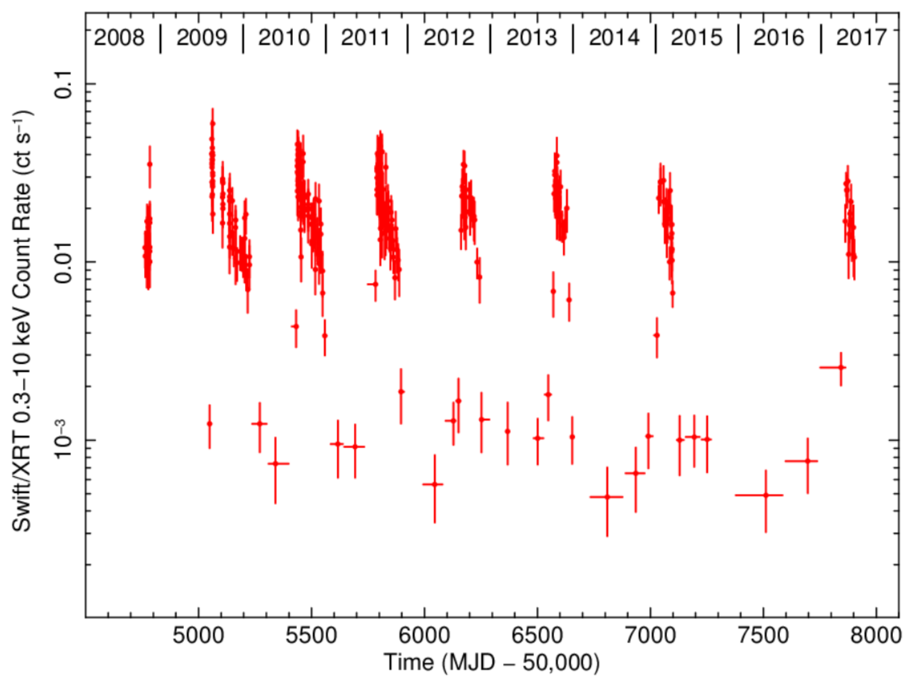
M ~ 20,000 M_{sun} (Soria et al 2017)

Radio flaring seen during the hard to soft transition (Webb et al 2012)

Optical counterpart with M_V ~ -11 mag + narrow Ha emission

(Soria et al. 2010,2012,2013,2017, Wiersema et al. 2012, Farrell et al. 2014)





Case B: IMBHs in old E/S0 halos

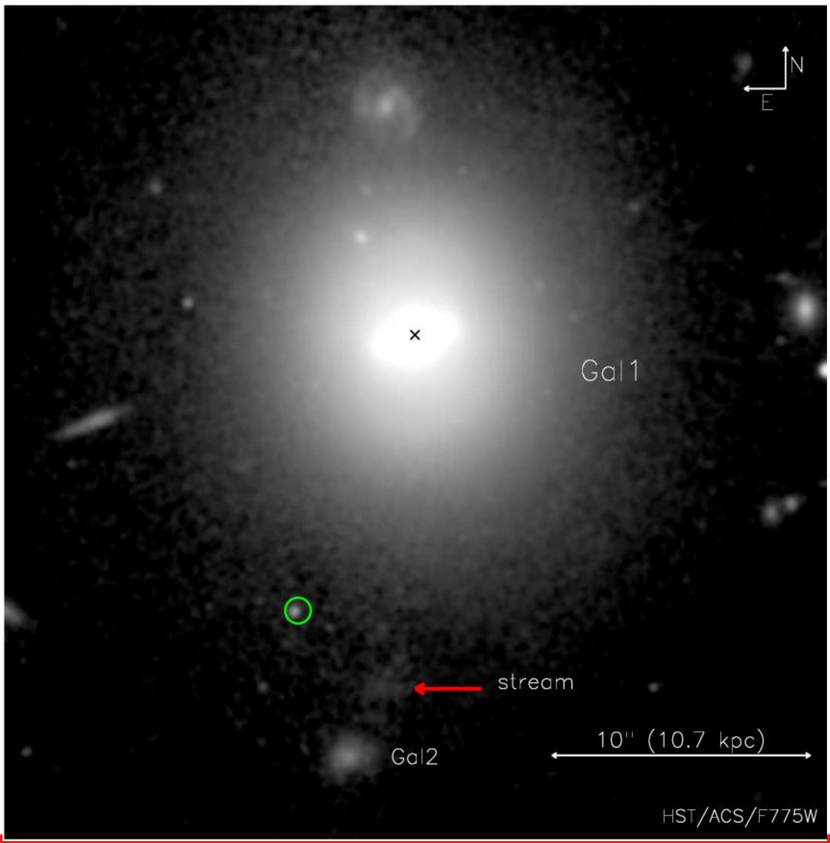
J2150-0551

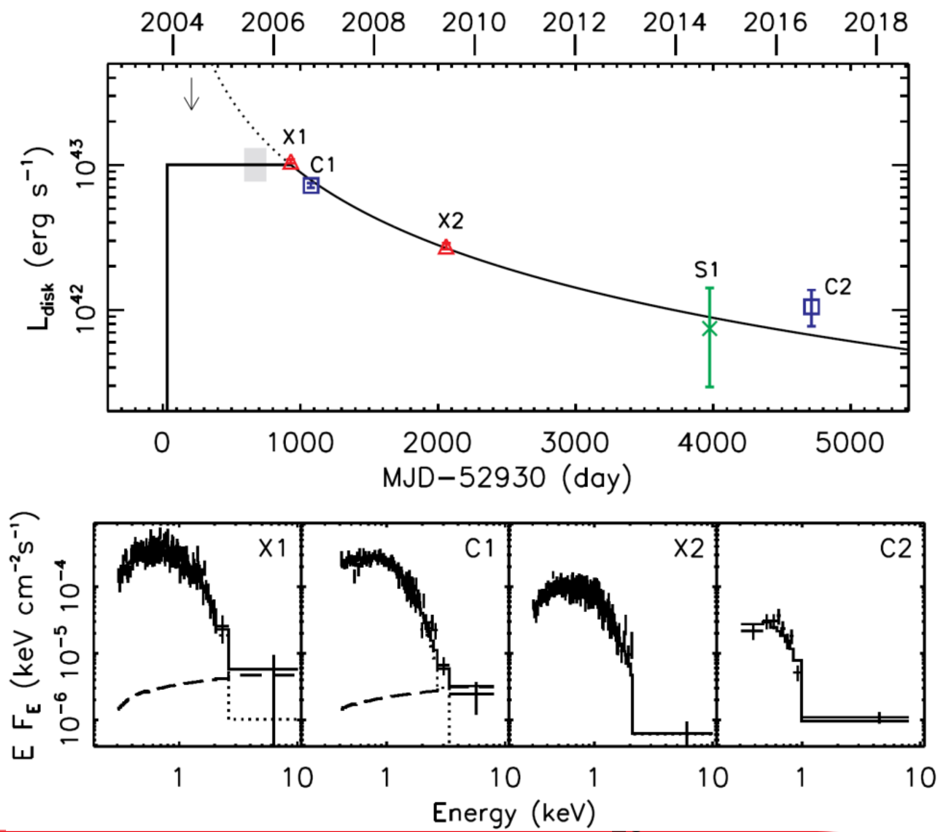
TDE by an IMBH

$L_{(0.3\text{-}10\ keV)}$ peaked at ~ 1e43 erg/s then decayed

kT_{in} ~ 0.15—0.30 keV, L ~ T^4

M ~ 50,000—100,000 M_{sun} (Lin et al 2018)





Case B: IMBHs in old E/S0 halos

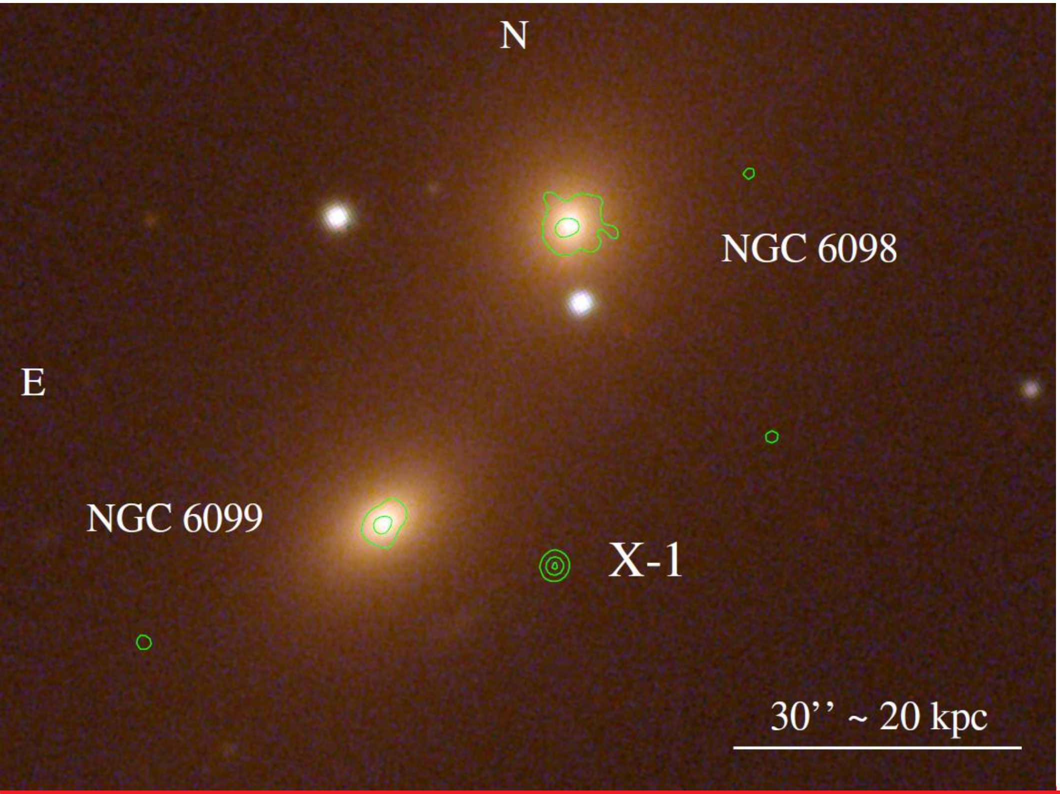
4XMM J1615

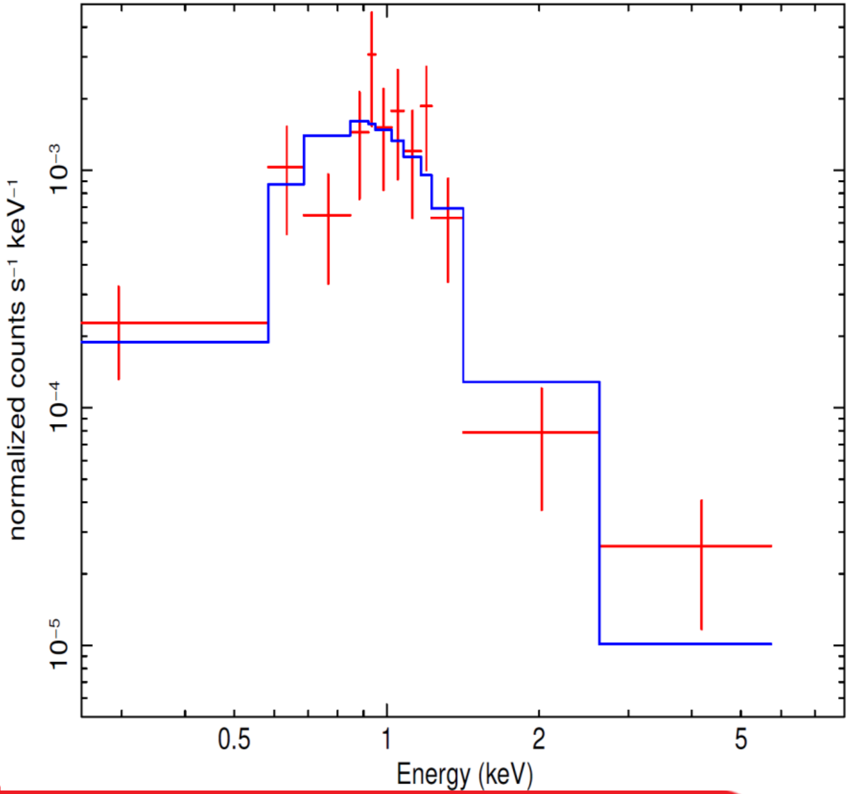
$L_{(0.3\text{-}10\ keV)}$ varies between ~ 7e40 erg/s – 6e42 erg/s

kT_{in} ~ 0.2 keV

M ~ a few 10^4 M_{sun} (A.K.H. Kong et al, in prep)

Keck observations of the opt counterpart approved for 2022B





Case B: IMBHs in old E/S0 halos

Low gas density in E/S0 halos

→ Accretion from a companion star or TDE

→ Must be transients

→ Good targets for *EP*

4XMM covers ~1200 sq deg ~ 3 percent of the sky

↓

EP may discover many more candidates

(*XMM-Newton* and *Chandra* for follow-up)

Limiting flux ~ 10^{-12} erg/cm2/s → L ~ 10^{42} erg/s at 100 Mpc

EP can detect sources similar to HLX-1

Conclusions

Very few IMBHs discovered in X-rays so far

Probably because:

- They are transient, with short duty cycle
- We have been looking in the wrong places
- We covered only 3% of the sky

IMBHs in the nuclei of bulgeless disk galaxies

→ *Targets for Chandra*

IMBHs in the halo of E/S0 galaxies

→ *Suitable target for EP (+eROSITA)*