Are Ultraluminous X-ray Sources Intermediate-Mass Black Holes?

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CEA Saclay, SAp
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Webb, Cseh, Lenc,
Godet, Barret, Corbel, Farrell, Fender, Gehrels, Heywood
2012 Science, in press

Black Hole Universe

Bamberg, 20 June 2012

Quick Answer

Some of them are likely an intermediate-mass black hole!

Quick Answer

Some of them are *likely* an intermediate-mass black hole!

Outline

- **Introduction**
- The best intermediate-mass black hole candidate ESO 243-49 HLX-1
- Unification

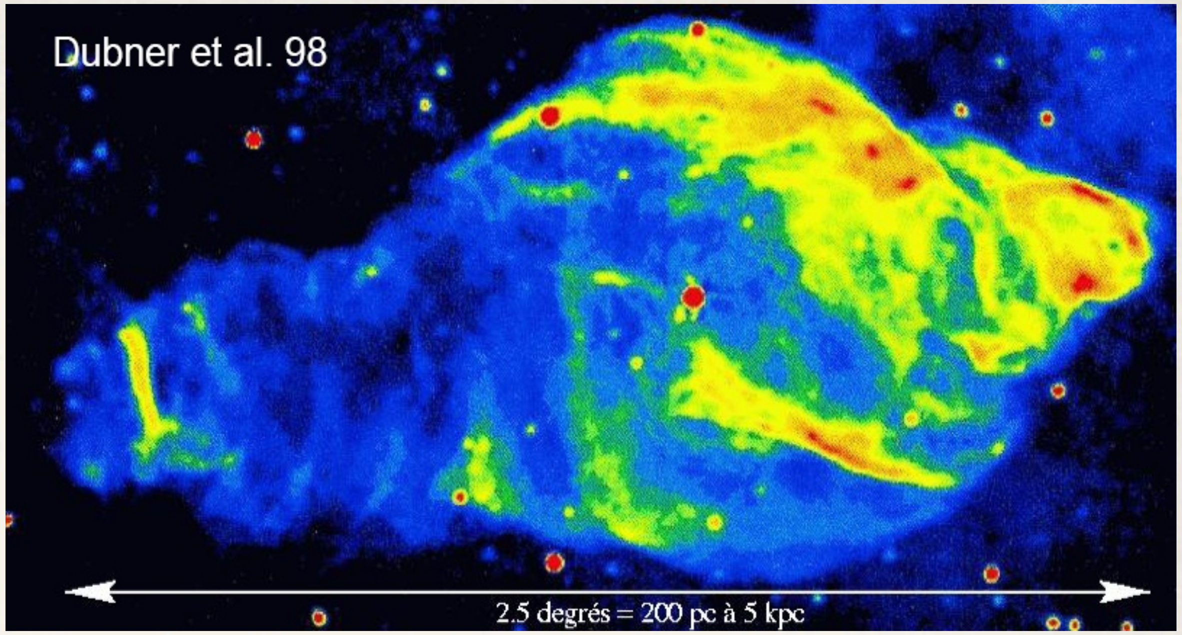
Ultraluminous X-ray Sources

- What are the characteristics of a ULX?

- off-nuclear, extragalactic
- binary systems: irregular variability (seconds to years)
- *apparent* luminosity violates the **Eddington limit** of a 20-$M_{\odot}$ object ($L_X > 3 \times 10^{39}$ erg/s)

Image credit: Heidi Sagerud

Explanations for the ULX phenomena:



1) beaming

- *mechanical beaming* (King+ 01)
geometric collimation by the inflated inner disc and outflowing wind at high accretion rates
(e.g. rotate SS433 to point to your eyes)

- *relativistic beaming* (Körding+ 02)
(X-rays from jets not from disk)

Explanations for the ULX phenomena:

2) super-Eddington accretion (Begelman 02)

- **$L > L_E$**
- increase X-ray luminosity up to a factor 10
- L does not follow T^4 law (rather inverse law)
- b: beaming factor
- soft excess, turnover, opacities τ=5-30 (Gladstone+ 09)

$$L \simeq \frac{L_{\rm E}}{b}\left[1 + \ln\left(\frac{\dot{M}_{in}}{\dot{M}_{\rm E}}\right)\right]$$

(Shakura & Sunyaev 73, King+ 08)

Explanations for the ULX phenomena:

3) intermediate-mass black hole (Colbert & Mushotzky 99)

- standard disk and accretion
- kT~ 1 keV $M^{-1/4}$

- **cool disk** of ~0.1 keV
- high black hole mass (not violating the Eddington-limit)

M_{BH}=50 -10^4 $M_\odot$

- X-ray states might be different in ULXs

(see talk Fabio Pintore)

Explanations for the ULX phenomena:

4) “mixture”

- some beaming

- and high accretion rate

- with a black hole mass of 100 $M_\odot$ (Zampieri+ 09)
(see talk Emanuele Ripamonti)

“One can fit the X-ray spectrum even with an *elephant*”
(Nowak+ 02)

Explanations for the ULX phenomena:

5) alternative objects & misidentification:

- recoiling supermassive black holes (Jonker+ 10)

- young supernova remnants

- tidal disruption events

- background AGN

For these many reasons a *bona fide* ULX is above 10^{40} erg/s

Intermediate-mass Black Holes

Intermediate-Mass Black Holes

- **ULXs** (Colbert & Mushotzky 99)

- central black hole of a **globular cluster**
(Miller & Hamilton 02, Maccarone+ 04)
surface density profile & velocity dispersion measure (M_{BH}- σ_*)

- core collapse of 100-1000 $M_\odot$ **Population III** stars
(Fryer+ 01, Madau & Rees 01)

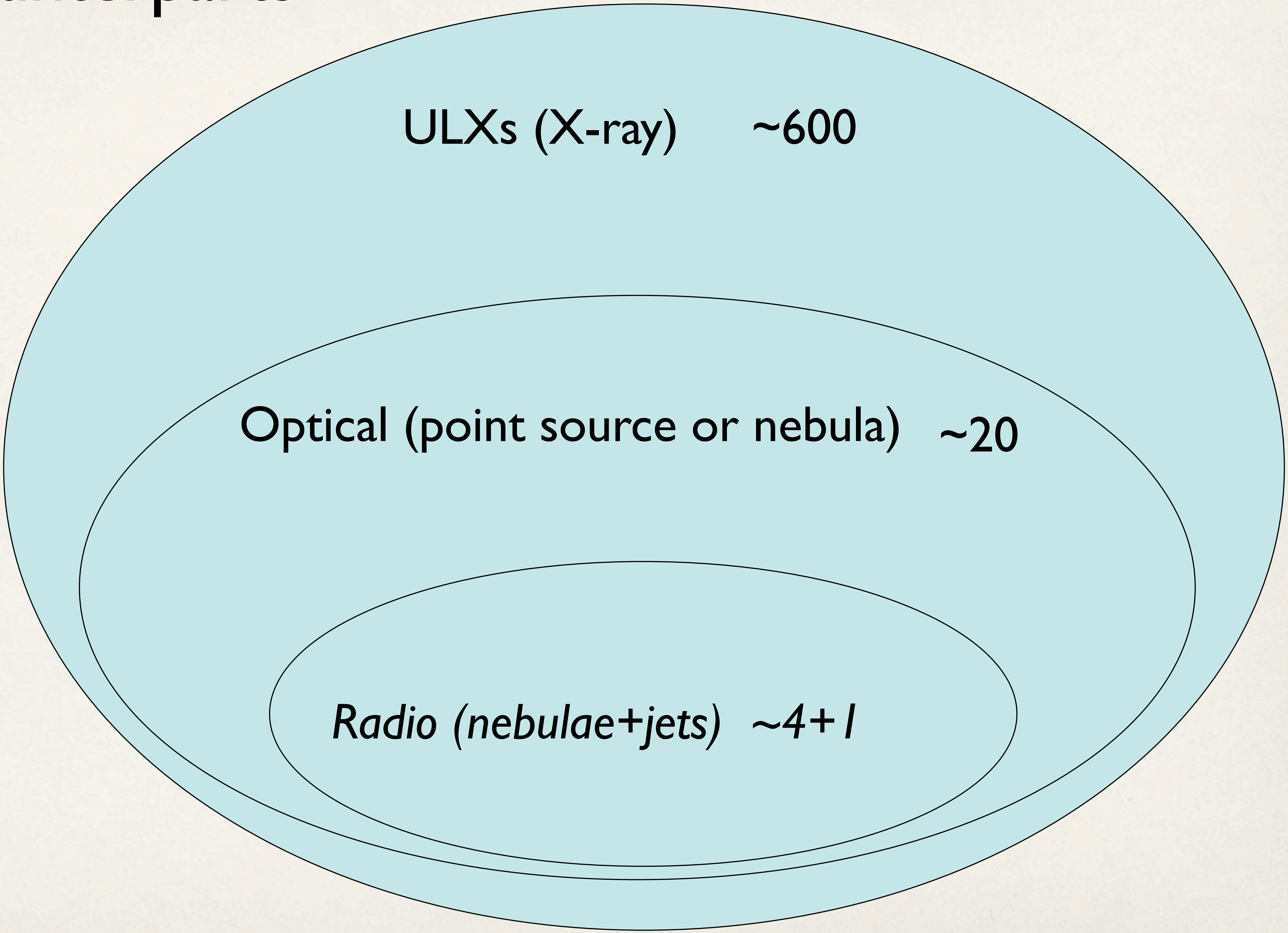
- **seeds of supermassive black holes** at high redshift
(Ebisuzaki+ 01)

- hosted by young dense **star clusters**
(Portegies Zwart+ 02,04)

How to test scenarios?

- dynamically constrain mass via optical spectroscopy (M)
- use the environment as a calorimeter (beaming)
  (see next talk by Manfred Pakull)
- feedback on environment (hyperaccretion)
- estimate accretion rate (M)
- evenly populated mass range? (M)
- scale invariance of jets? (M)

Counterparts



- Introduction
- **The best IMBH candidate ESO 243-49 HLX-1**
(Webb, Cseh, Lenc, Godet, Barret, Corbel, Farrell, Fender, Gehrels, Heywood 12)
- Unification

The Best IMBH Candidate(s)

New class is called *Hyperluminous X-ray Sources* (HLXs)

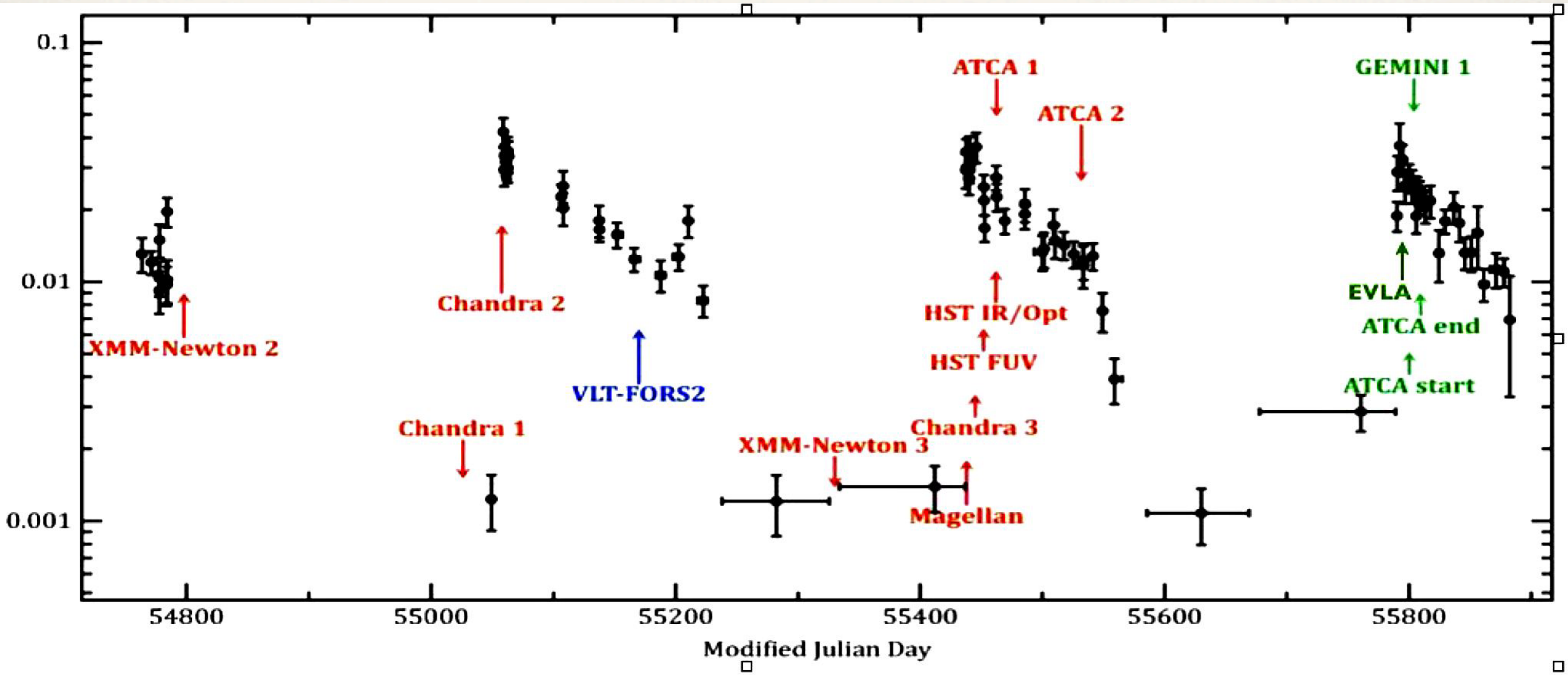
- ESO 243-49 HLX-1:

  L_x=1.1 x 10^{42} erg/s in the 0.2-10 keV band (Farrell+ 09)
  d=95 Mpc (Wiersema+ 10)

- Other HLXs:
  ~10 ULXs known to have **L_x >10^{41} erg/s**
  (Gao+ 03, Walton+ 11, Sutton+ 12)

- **Cannot be explained** with beaming or hyperaccretion

Observations of HLX-1



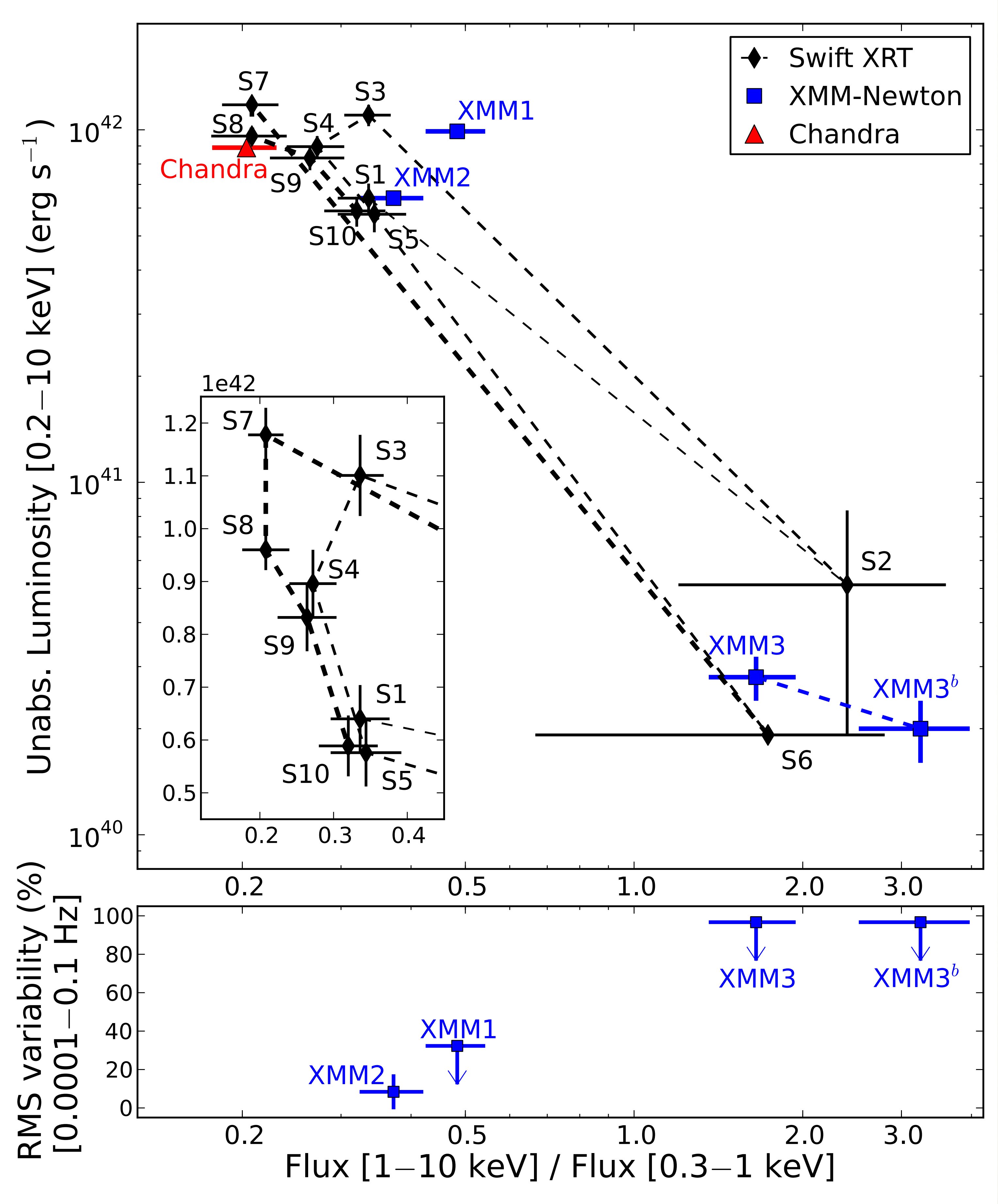
Swift/XRT light curve 2008-2011, FRED pattern

Periodic outburst: ~367 days

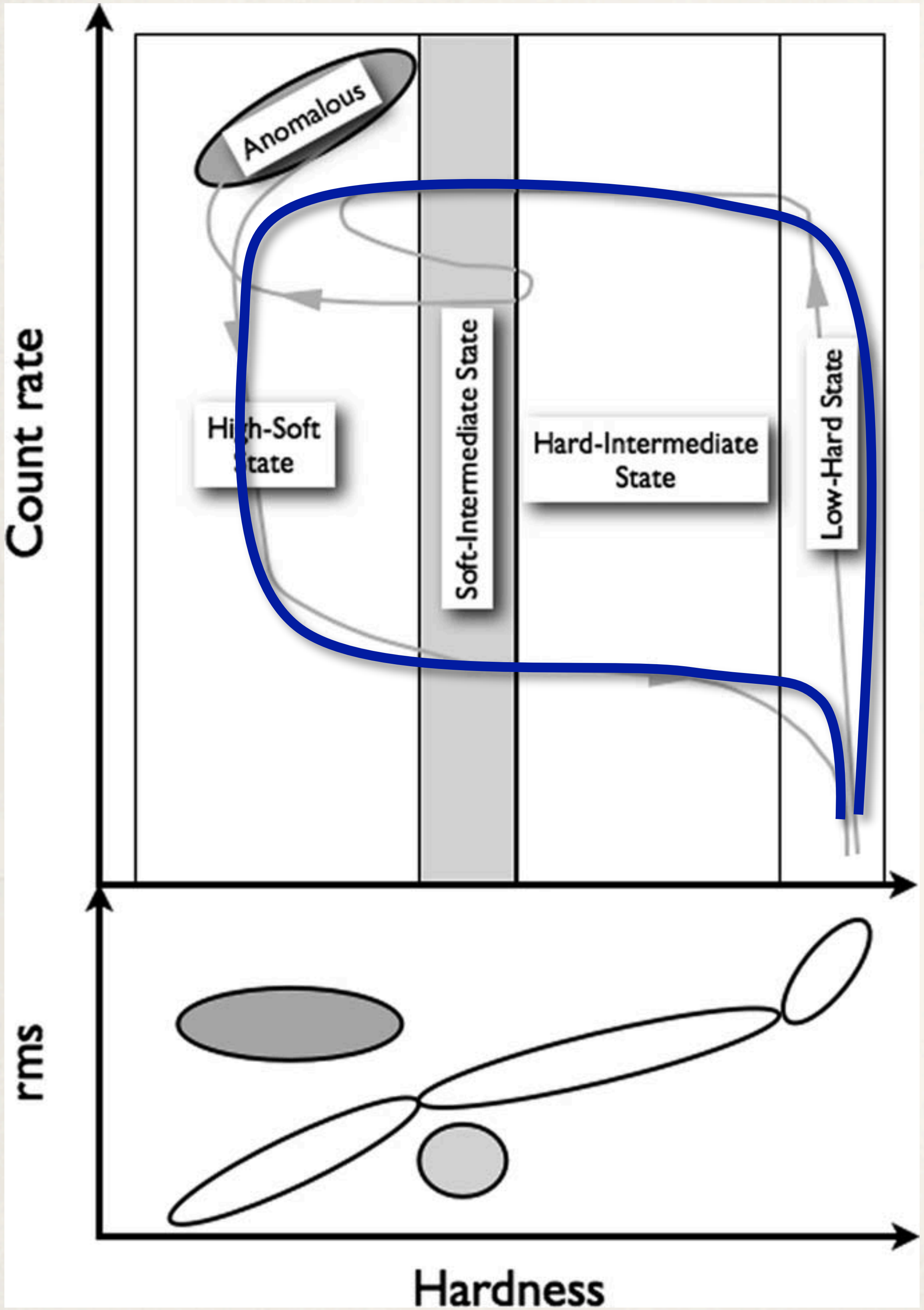
Hardness-Intensity Diagram of HLX-1

State transition

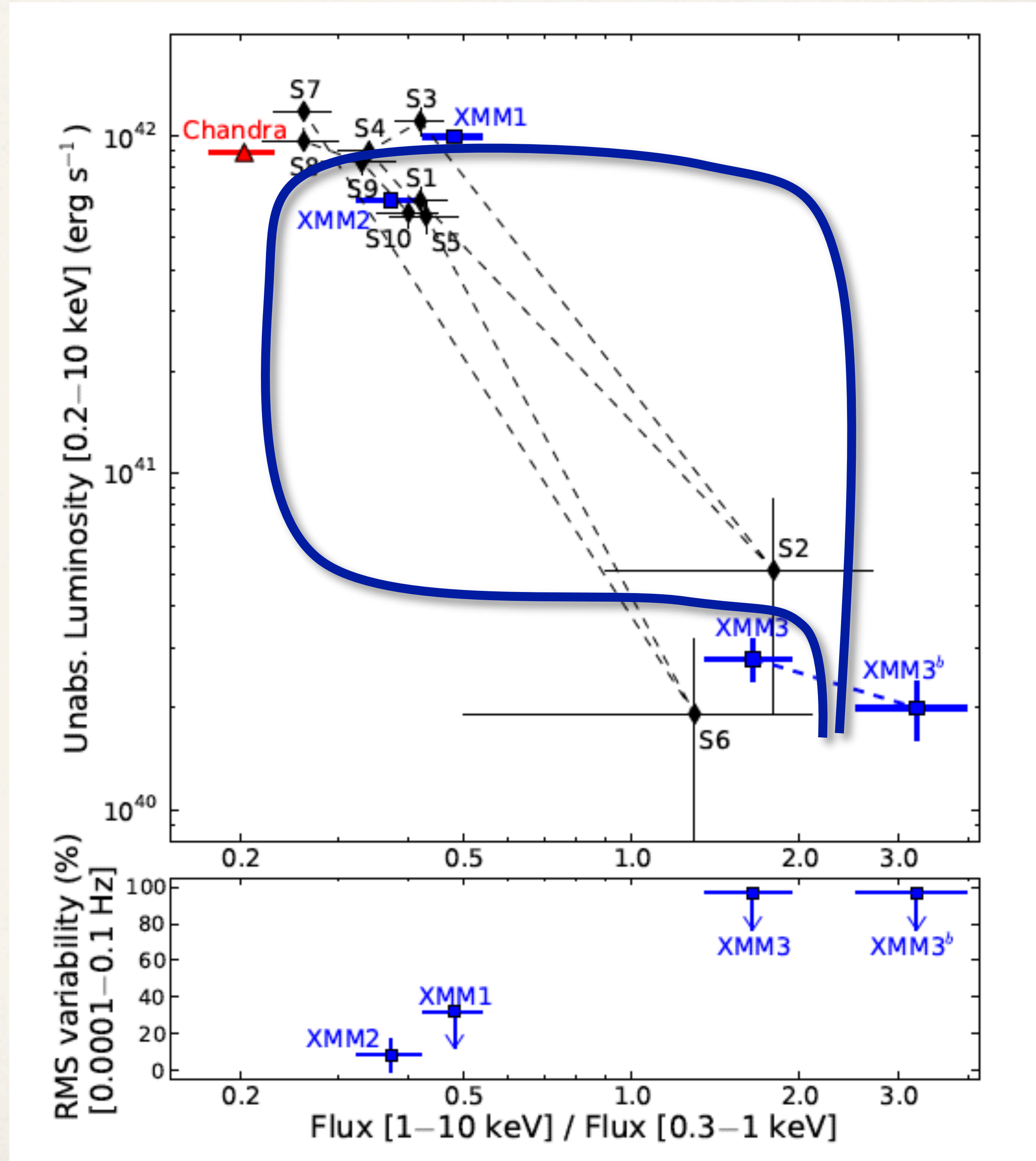
(Servillat+ 11)



Hardness-Intensity Diagram



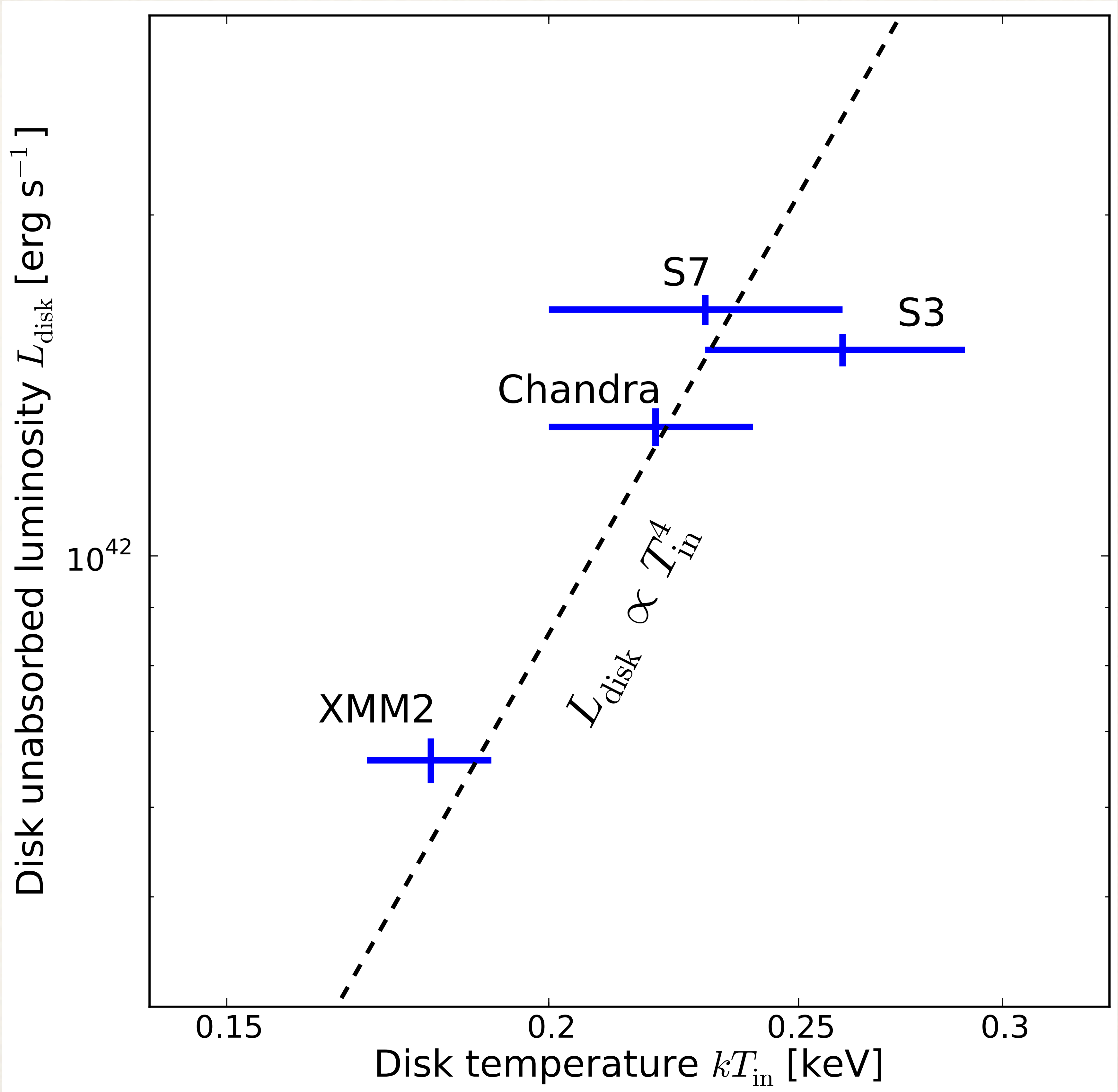
(Belloni+ 10)



(Servillat+ 11)

Follows L~T^4 law

(Servillat+ 11)



Radio observations of HLX-1 2010

with the Australia Telescope Compact Array (ATCA)

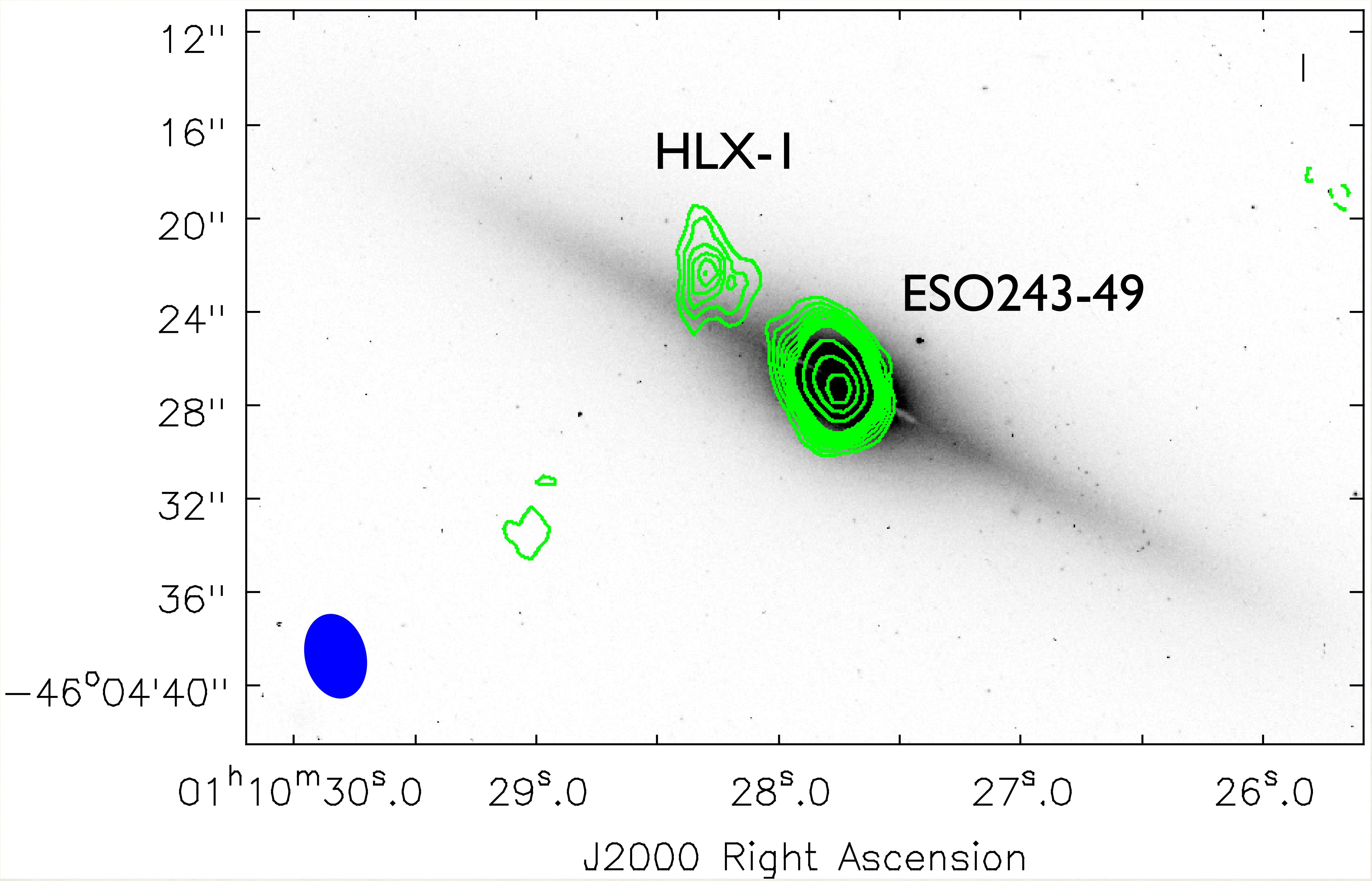
Array configuration: baselines up to 5km & 6km
@ 5.5 GHz & 9 GHz central frequency.
Bandwidth 2 GHz, expected rms level is ~10 uJy/beam.

13 Sep 2010	12 hr total integration time
3 Dec 2010	12 hr
26 Aug 2011	8.5 hr
31 Aug 2011	8.5 hr
1 Sep 2011	8.5 hr
3 Sep 2011	8.5 hr
4 Sep 2011	12 hr

Observations of HLX-1: visit to Oz

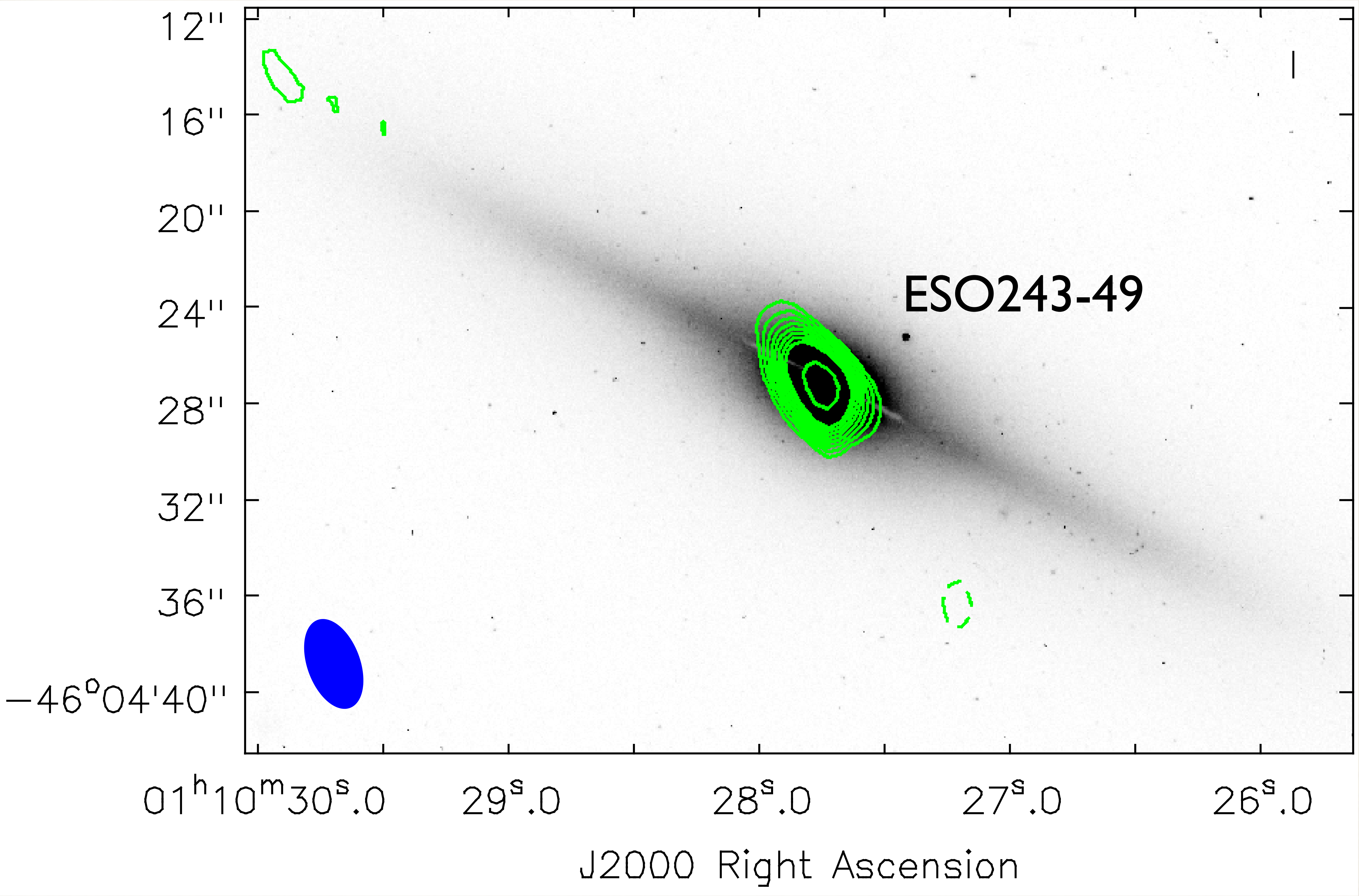
ATCA

First Detection of Jet Ejection Events



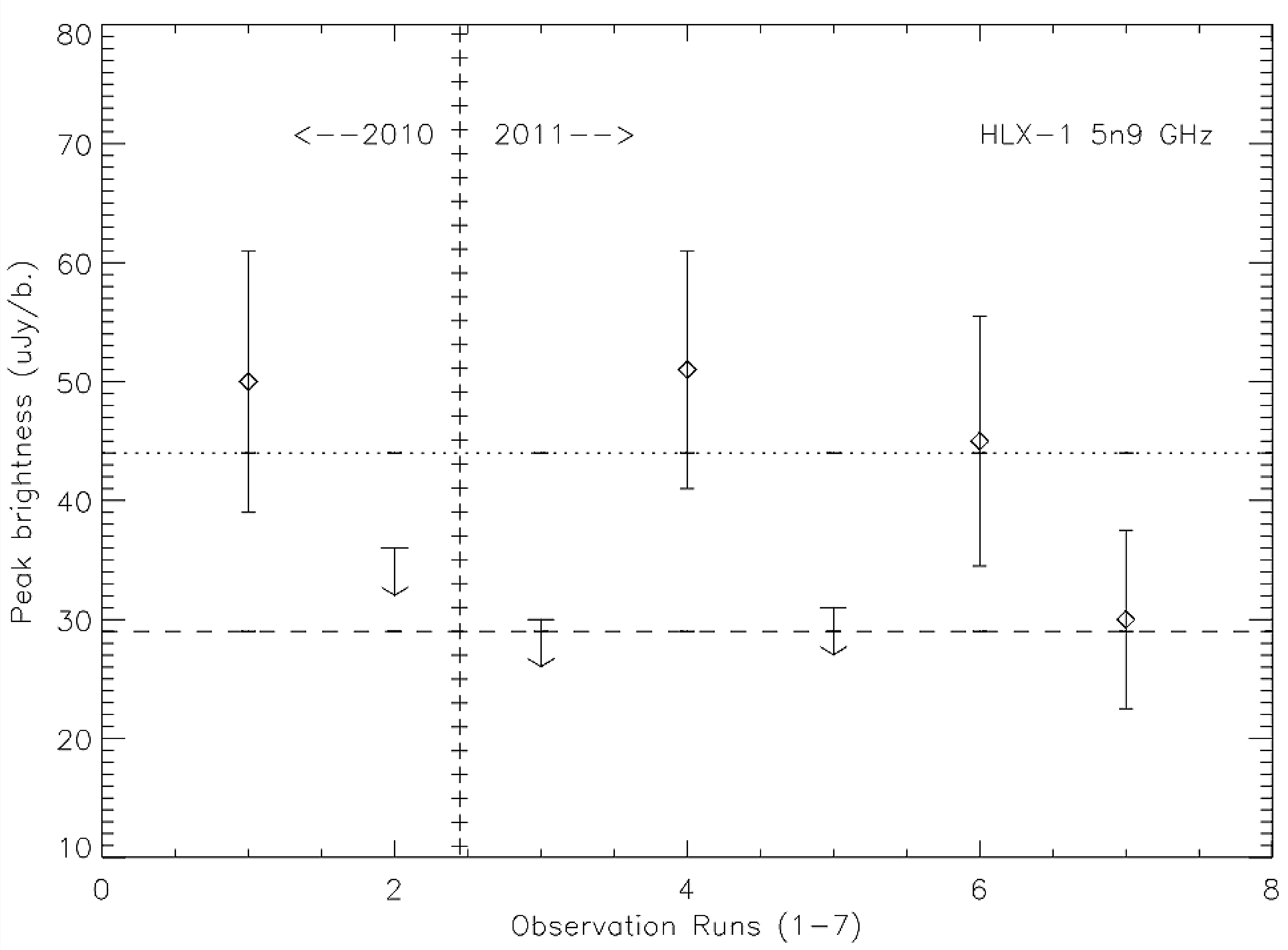
(Webb, Cseh, Lenc+ 12, Science, in press)

Non-Detection of HLX-1



(Webb, Cseh, Lenc+ 12, Science, in press)

Variability



What is expected?

- GBHBs have flares up to 1-10 Jy
- Scaling simply by distance and linear mass:

1) S~ 45 uJy

2) M~ $5 \times 10^{3...4}$ $M_{\odot}$

- Flares occur above 10% of the Eddington rate:

3) M~ $9 \times 10^{3...4}$ $M_{\odot}$

- Fundamental Plane: the hard state radio flux

4) S~2 uJy

Observational Results

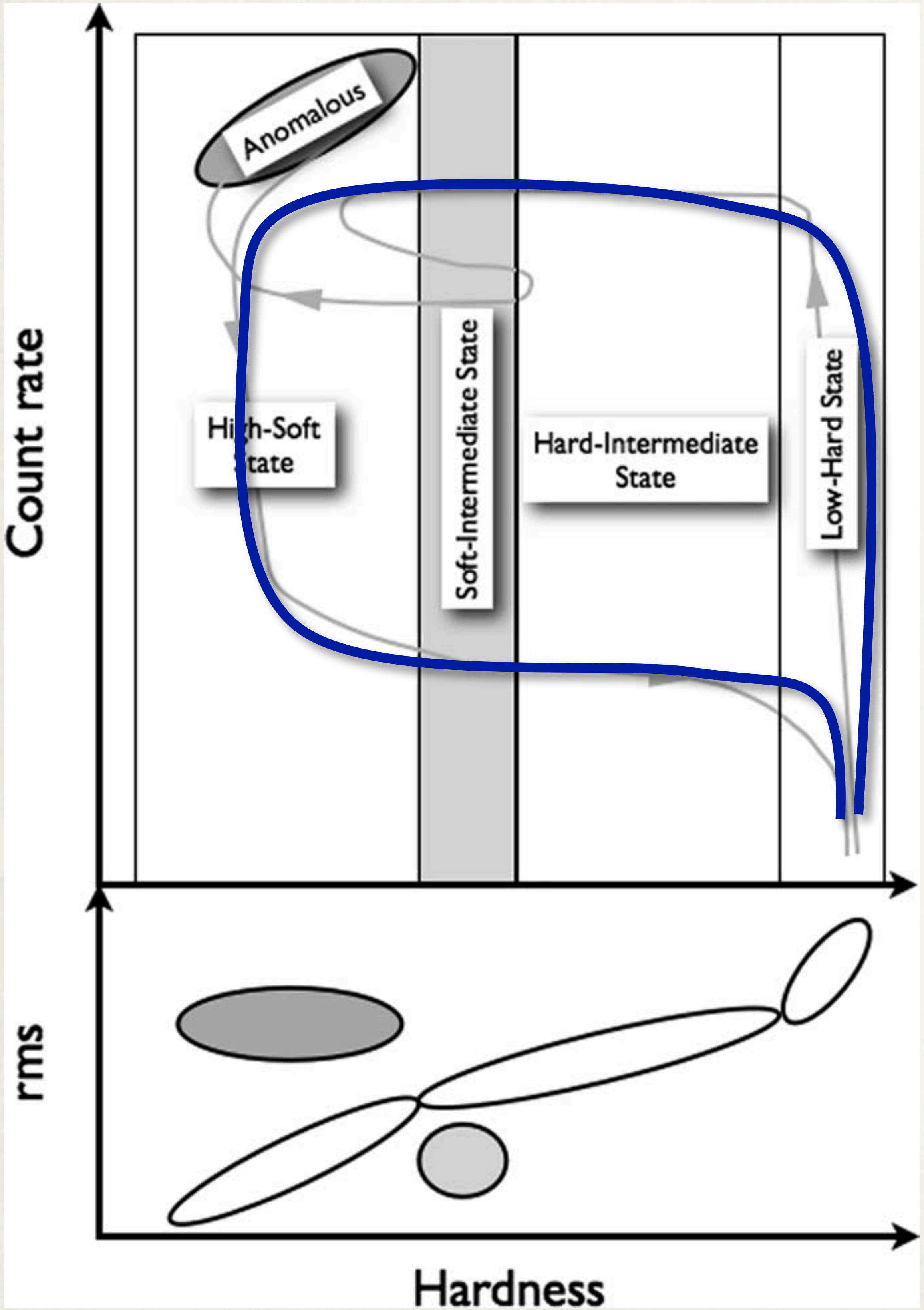
- S = 35-68 uJy/b
- X-ray modelling suggests, mass is $\sim 10^4 M_\odot$
  (Godet+11, Davis+11, Servillat+11)
- Flaring emission is 10-100 above non-flaring continuum emission.

Future Observations

- We got 70 hrs and already accepted 36 hrs more (PI Webb)
- Get spectral index?
- Evolution of flares
- Variability
- EVLA proposal 10 times 1-hr long observations (PI Cseh)
(1 hr EVLA equivalent of 12 hrs ATCA)

Unification

Hardness-Intensity Diagram



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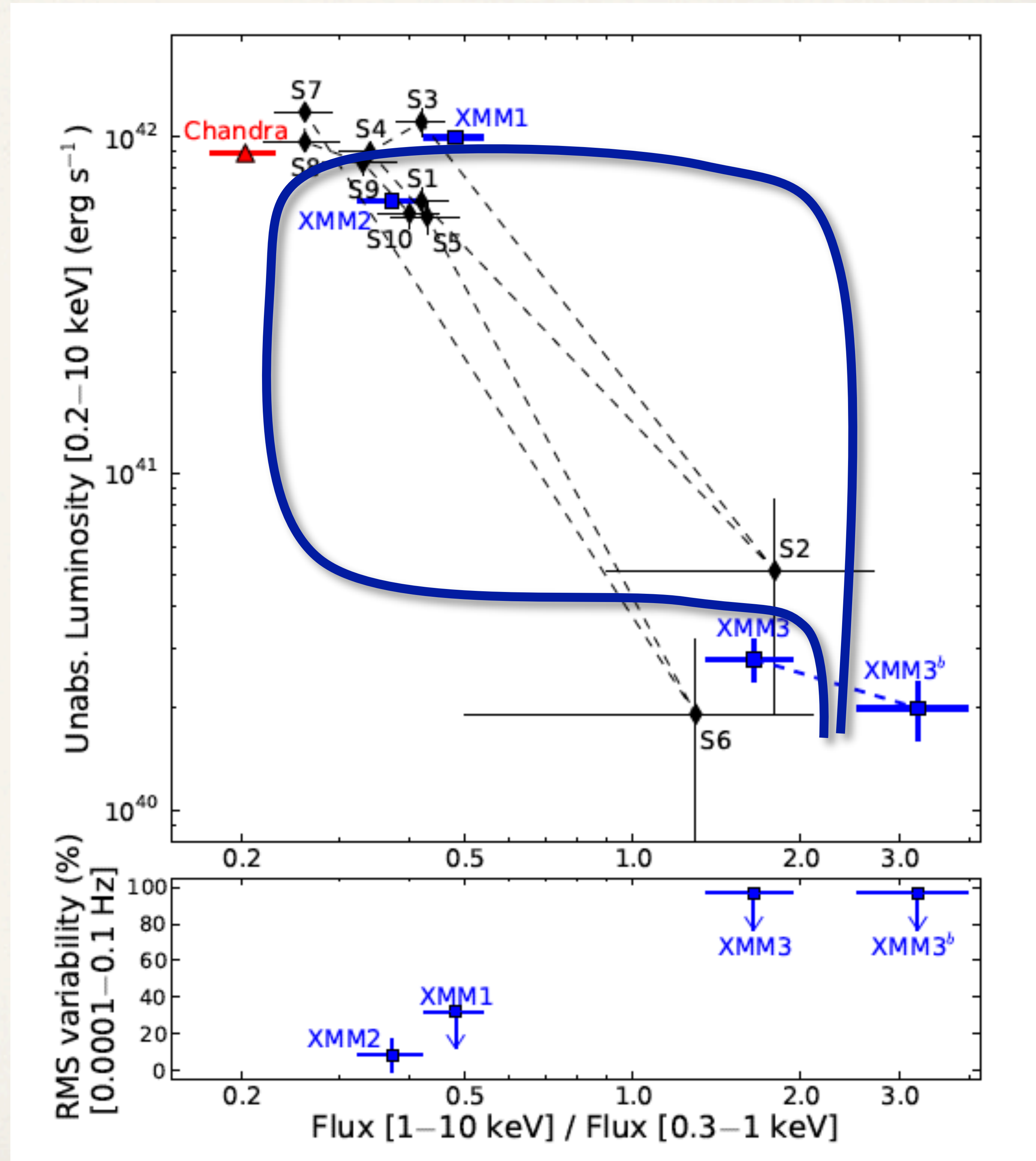
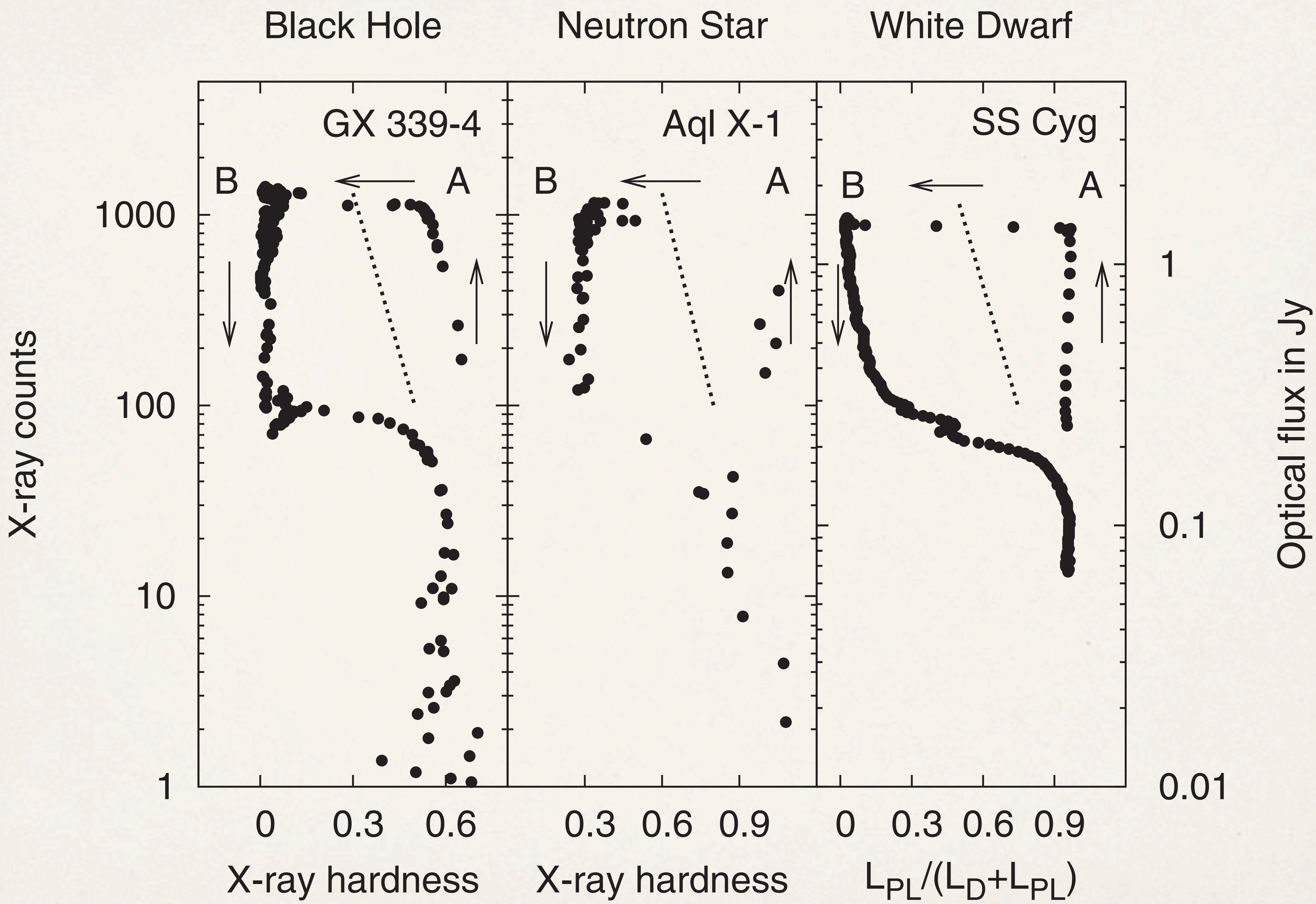


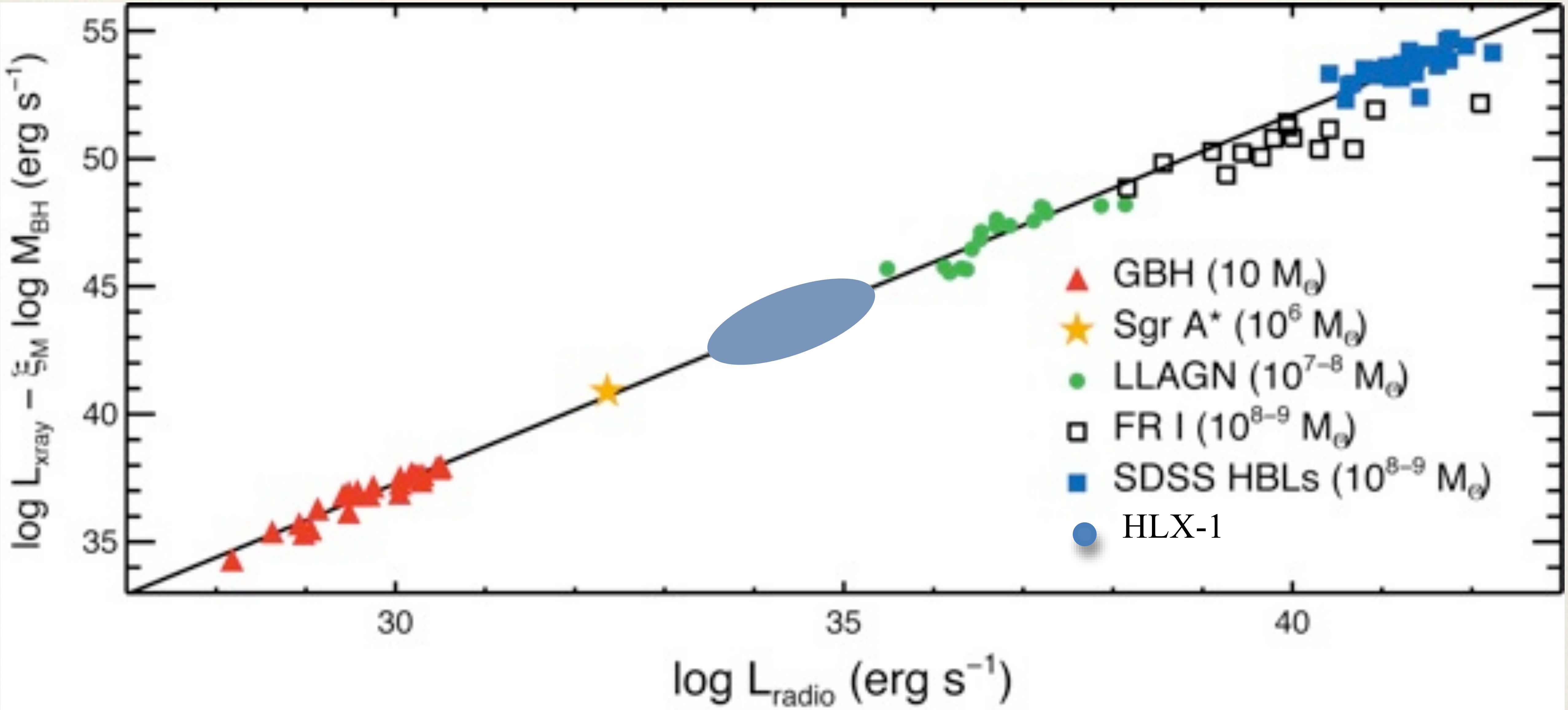
(Servillat+ 11)

Unification



(Körding+ 08)

Mass Scaling



(Plotkin+ 12)

More on the FP:
Sera Markoff, Andrea Merloni, Sebastian Heinz, Stephane Corbel, Rich Plotkin

Summary & Conclusions

- HLX-1 is **the best IMBH candidate**
- Periodic outbursts**, X-ray state transitions, $L \sim T^4$**

- Same phenomenology as in GBHBs
- $M_{BH} \sim 10^4 \ M_\odot$

- **First radio flares** from a HLX
- During state transition

- Good candidate to fill the gap between GBHBs and SMBHs

Thanks for your attention!

Questions?

More on HLX-1

- Origin of HLX-1

- Might be a stripped dwarf galaxy
- HST shows evidence for a young,10 Myr stellar population
(Farrell+ 12)

- Binary model:

X-ray light curve modeled with
tidal stripping of companion star in orbit around IMBH
(Lasota+ 11)