A statistical study of long-term variability of ultraluminous X-ray sources

— M51 & NGC4490/85 —

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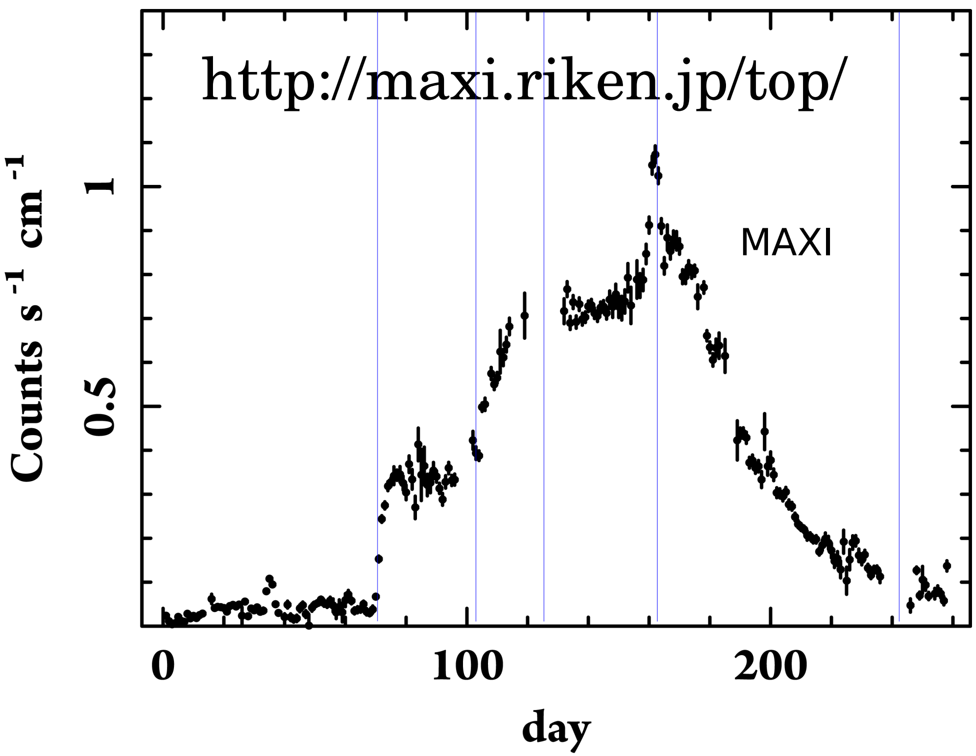
1, Introduction

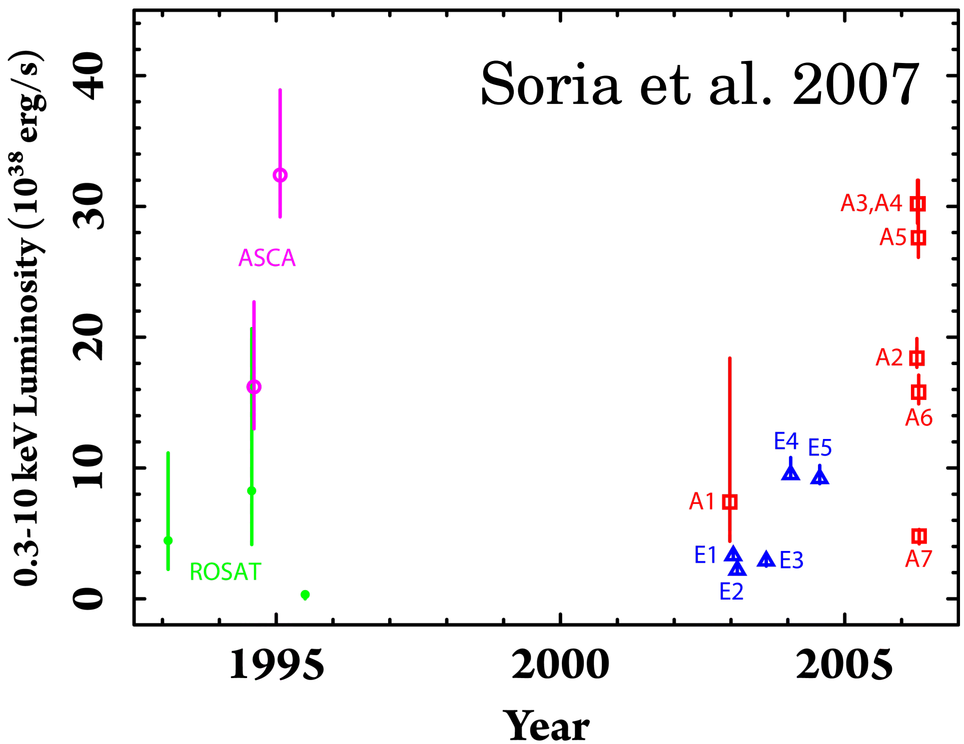
Motivation

Galactic BHB (XTE J1752-223)



Flux : high
Data set : homogeneous & continuous
State transition : clear
Timescales : days-weeks

ULX (NGC1365 X-1)



Flux : low
Data set : inhomogeneous & sparse
State transition : unclear
Timescales : unknown

Our Goal and Approach

Goal : To compare states of Galactic BHBs and those of ULXs.

Difficulties :
ULXs are much fainter, and
less frequently monitored than Galactic BHBs.

Approach :

1, ULXs in nearby galaxies. (< 5 Mpc)

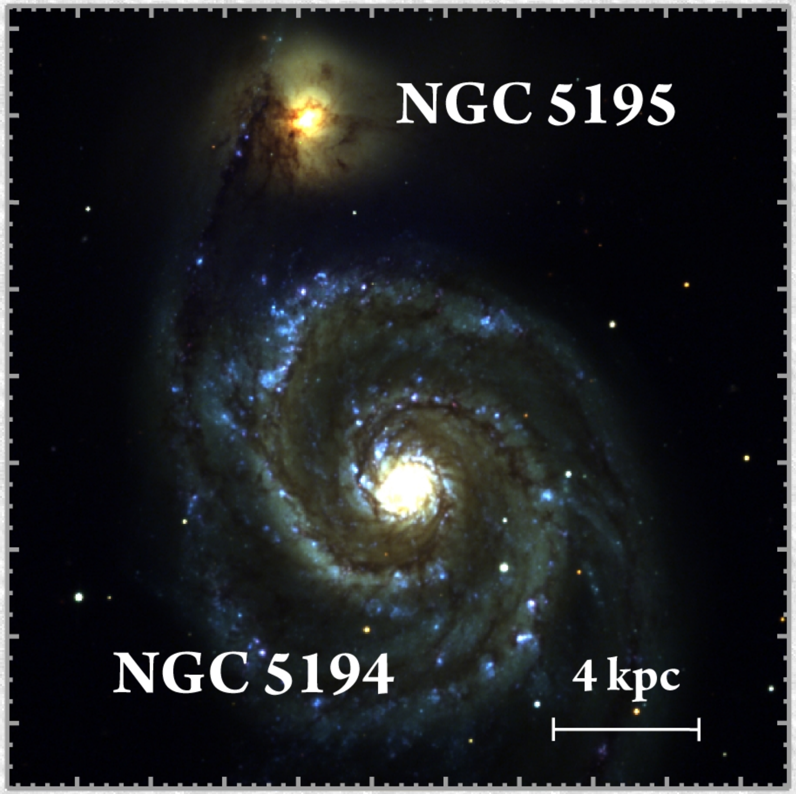
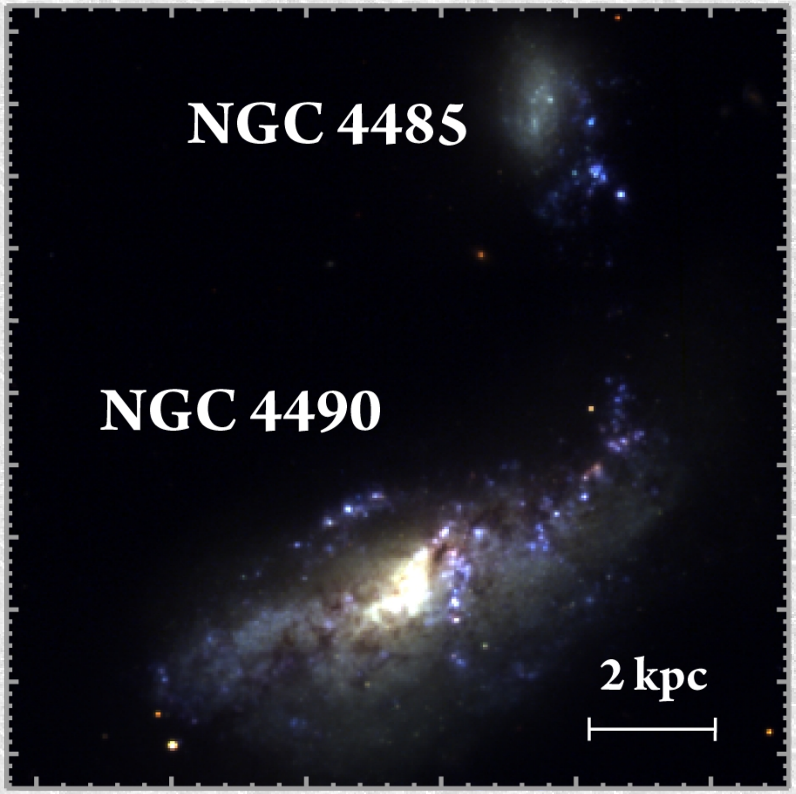
-- ULXs are relatively bright.

2, ULXs in interacting systems. (5-10 Mpc)

-- A number of ULXs is much larger.
--> Enable to monitor many ULXs simultaneously.

2, Observations & Analysis

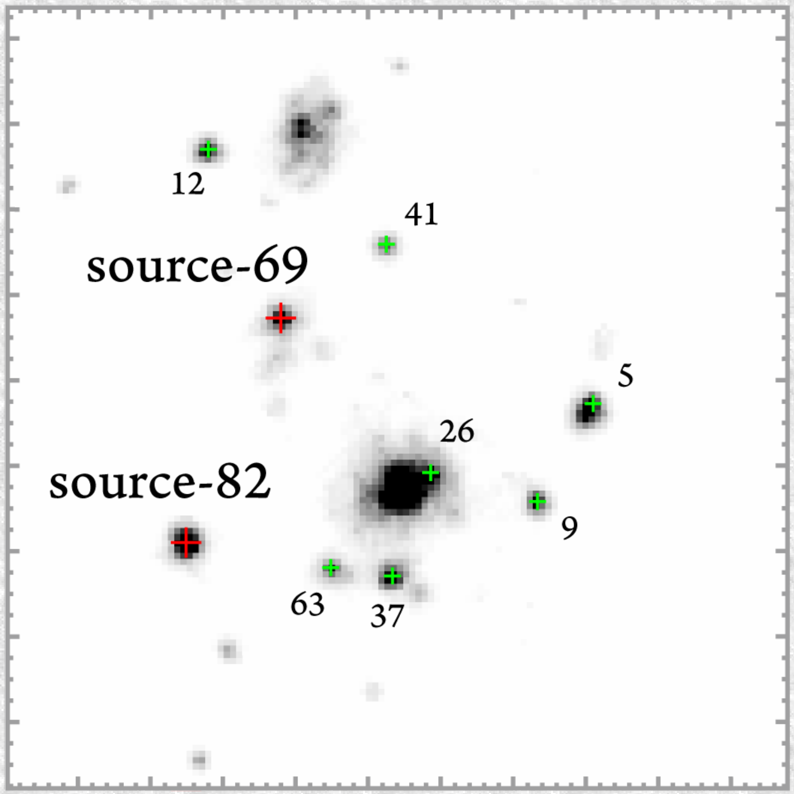
Targets – Optical images (SDSS)

M51 (NGC5194/95)	NGC4490/85
	

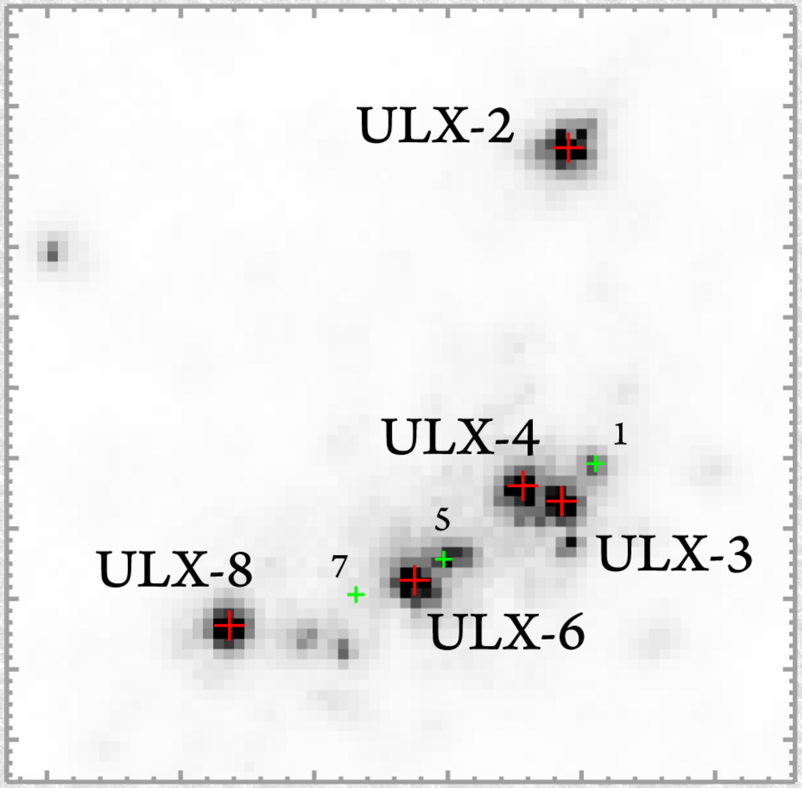
	M51 (NGC5194/95)	NGC4490/85
Distance	~8.4 Mpc	~8 Mpc
Star formation rate	~4 $M_{\odot}$/year	~4.7 $M_{\odot}$/year

Targets – X-ray images (XMM-Newton)

M51 (NGC5194/95)



NGC4490/85



	M51		NGC4490/85	
Number of ULXs	9	Terashima & Wilson (2004) Dewangan et al. (2005)	8	Roberts et al. (2002) Fridriksson et al. (2008) Gladstone & Roberts (2009)
ULXs w/ > 1000/s/obs	2		5	

Observations

Galaxy	Date	Observatory	t_{exp} (ks)
M51	2000/06/20	*Chandra*	14.9
	2001/06/23	*Chandra*	26.8
	2003/01/15	*XMM-Newton*	21/19
	2003/08/07	*Chandra*	48.0
	2005/07/01	*XMM-Newton*	49/47
	2006/05/20	*XMM-Newton*	53/52
	2006/05/24	*XMM-Newton*	37/35
NGC4490/85	2000/11/03	*Chandra*	19.5
	2002/05/27	*XMM-Newton*	17/12
	2004/07/29	*Chandra*	38.5
	2004/11/20	*Chandra*	39.6

Chandra ... ACIS-S *XMM-Newton* ... MOS/pn

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	2002/05/27	*XMM-Newton*	17/12
	2004/07/29	*Chandra*	38.5
	2004/11/20	*Chandra*	39.6

M51: 2src × 7obs = 14smp

NGC4490/85: 5src × 4obs = 20smp

Definition :

Number of samples = source × observation

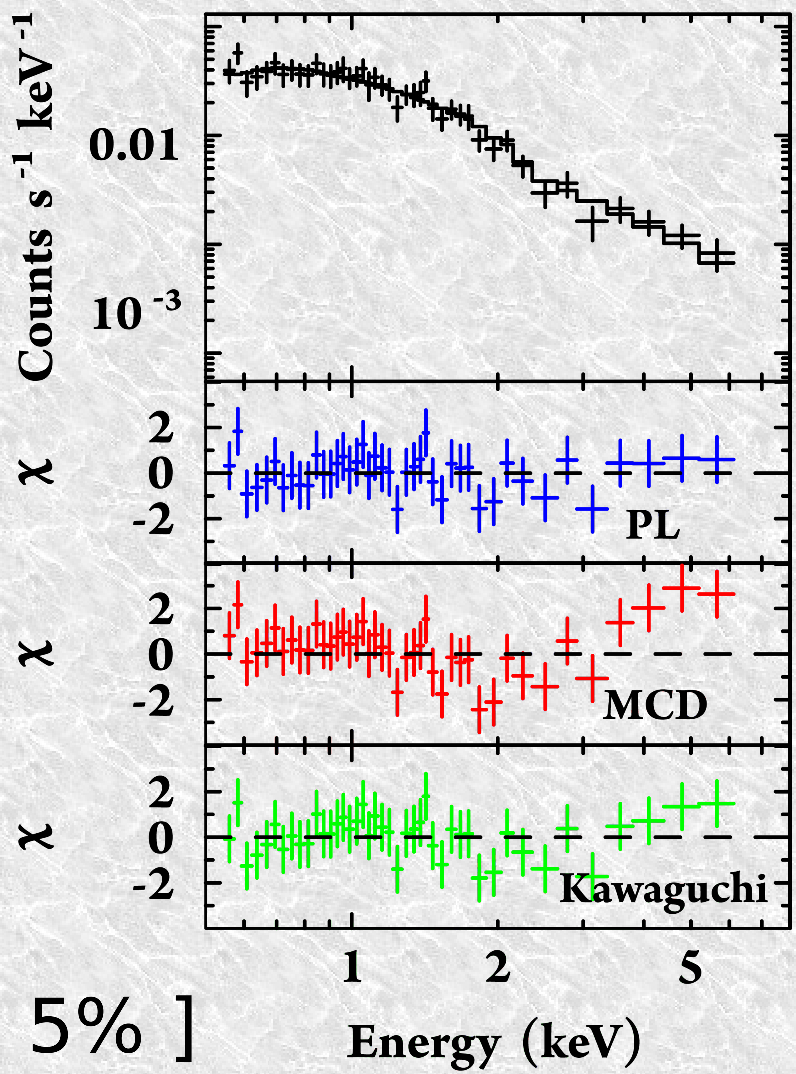
34 samples

Chandra ... ACIS-S *XMM-Newton* ... MOS/pn

Fitting Models

Name (parameters)	Spectral shape	Physical picture
Power-law (Γ, flux)	Power-law	Comptonization
Multi-color disk (T_{in}, flux)	Convex	Standard disk ($L_x \propto T_{in}^4$)
Kawaguchi ($\dot{M}$, M_{BH}, flux)	Convex	Slim disk ($L_x \propto T_{in}^{\beta}$, β<4)

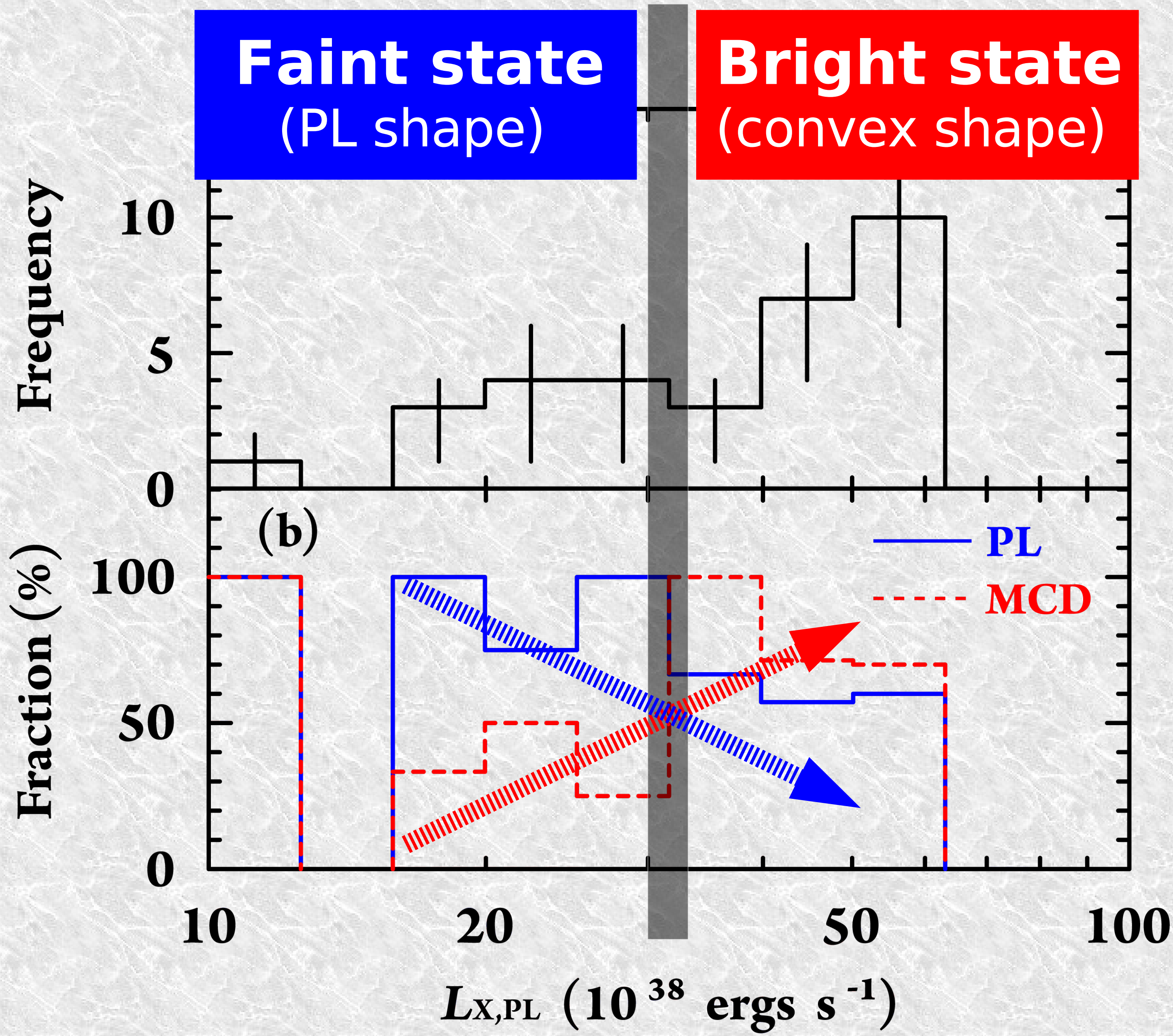
example: M51 source-82



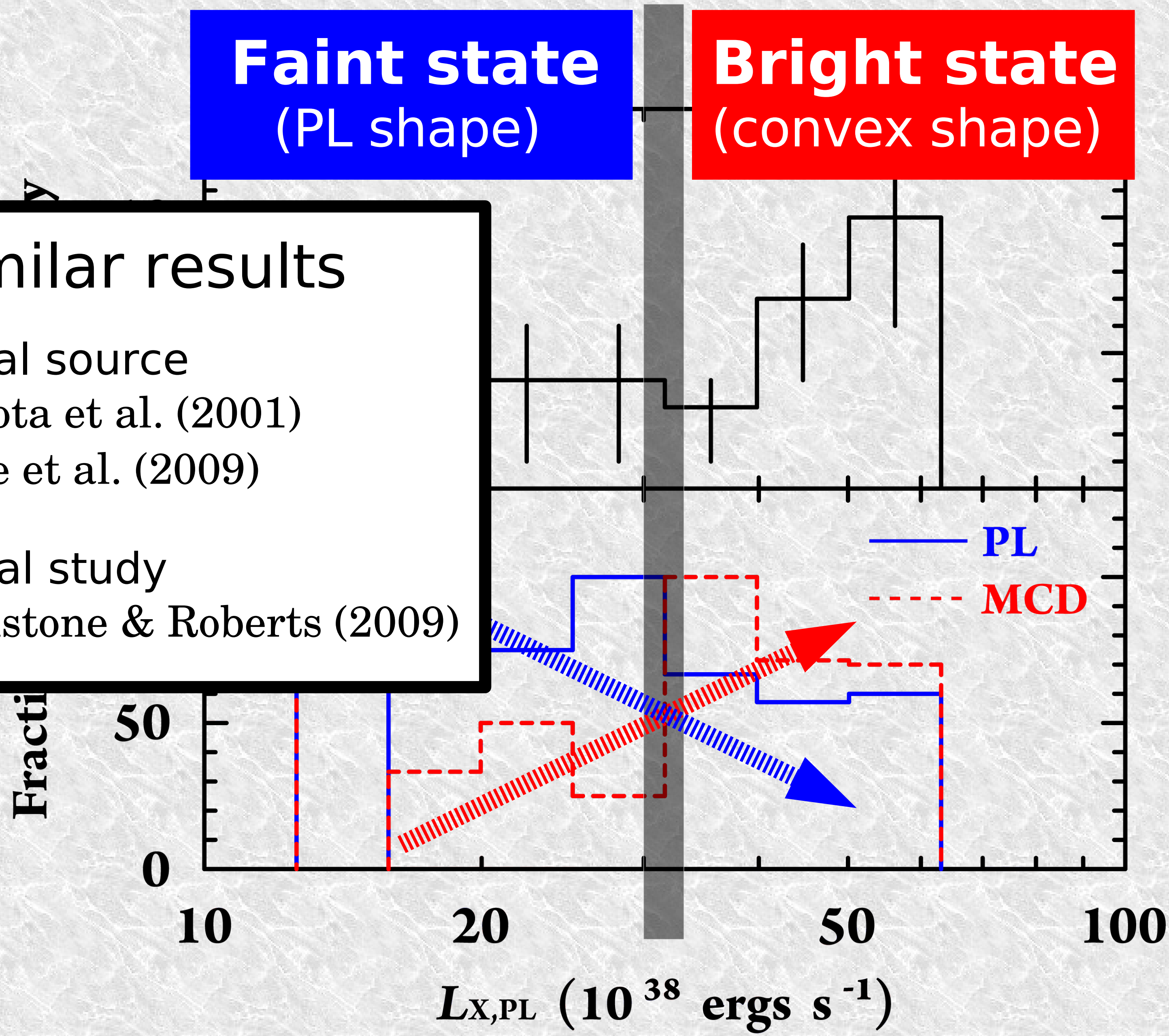
Fitting successful =
[A null hypothesis probability > 5%]

3, Results & Discussion

Results


Faint state
(PL shape)
Bright state
(convex shape)
Frequency
10
5
0
(b)
PL
MCD
Fraction (%)
100
50
0
10
20
50
100
$L_{X,PL}$ (10^{38} ergs s^{-1})

Results



Similar results

Individual source
— Kubota et al. (2001)
— Isobe et al. (2009)

Statistical study
— Gladstone & Roberts (2009)

Discussion (1-1) – Bright state

NGC4490/85 ULX-8 within the bright state

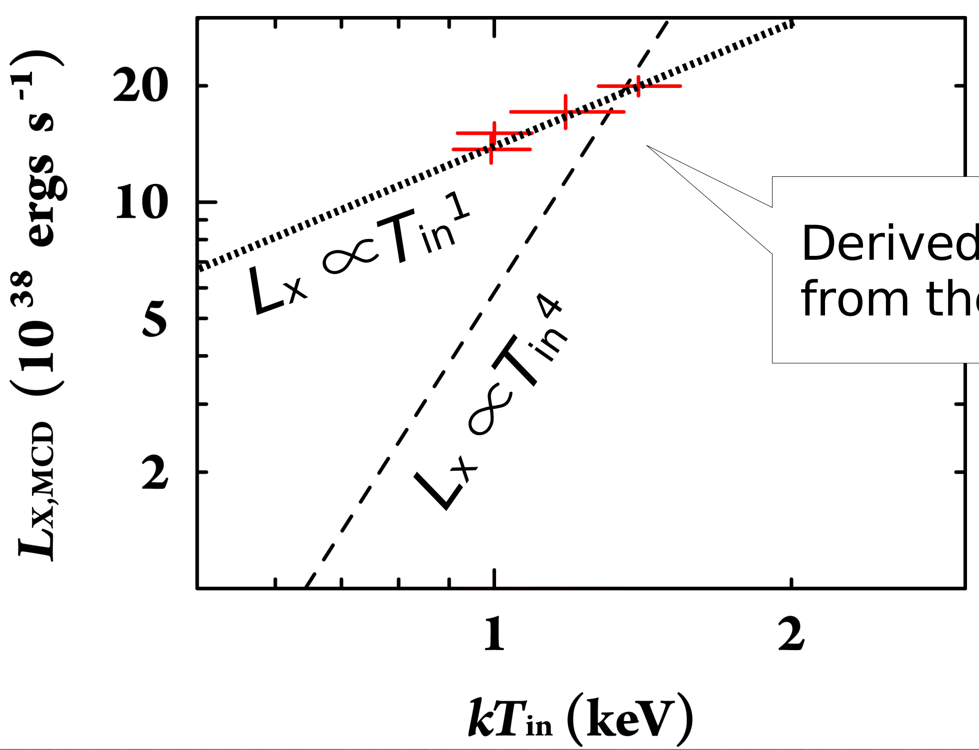
Convex shape -> ~~MCD or~~ Kawaguchi

Reason 1:

$L_X \propto T_{in}^{\beta}$, $\beta \sim 1^{+0.7}_{-0.4}$ (<4)

Reason 2:

Constant BH mass



Derived parameters from the MCD model

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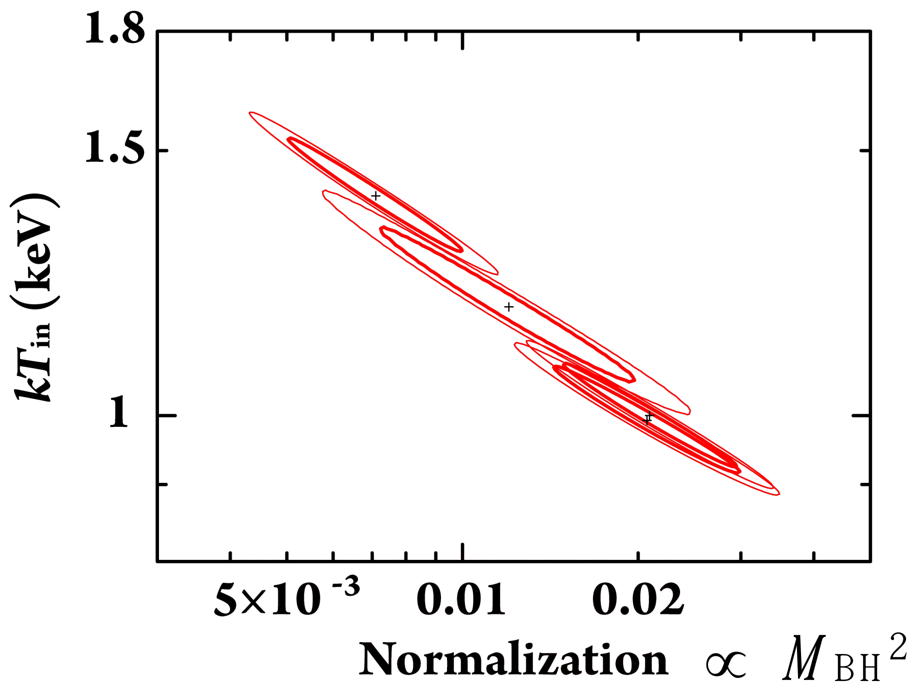

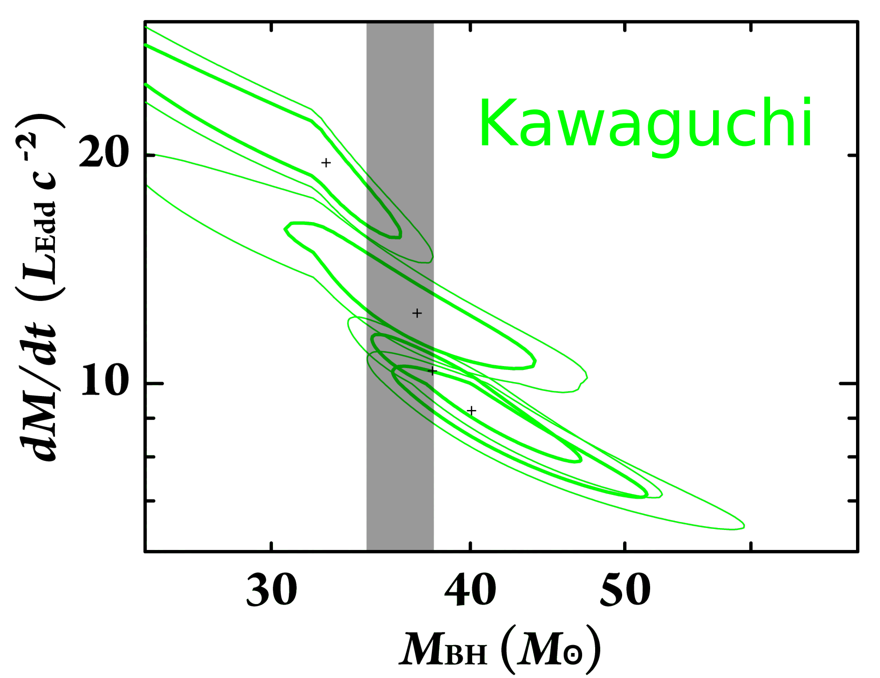

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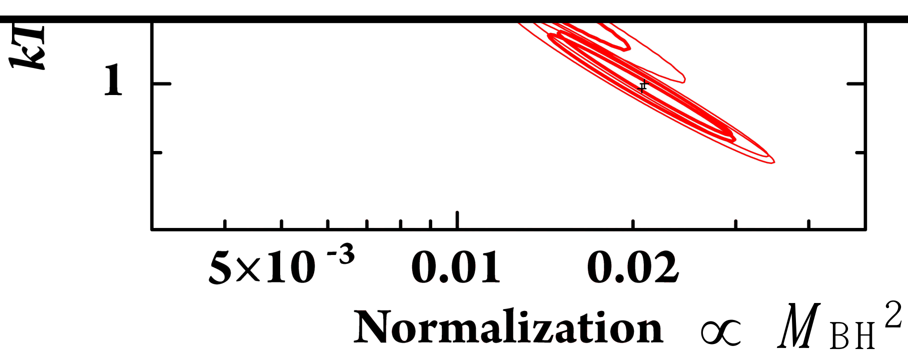
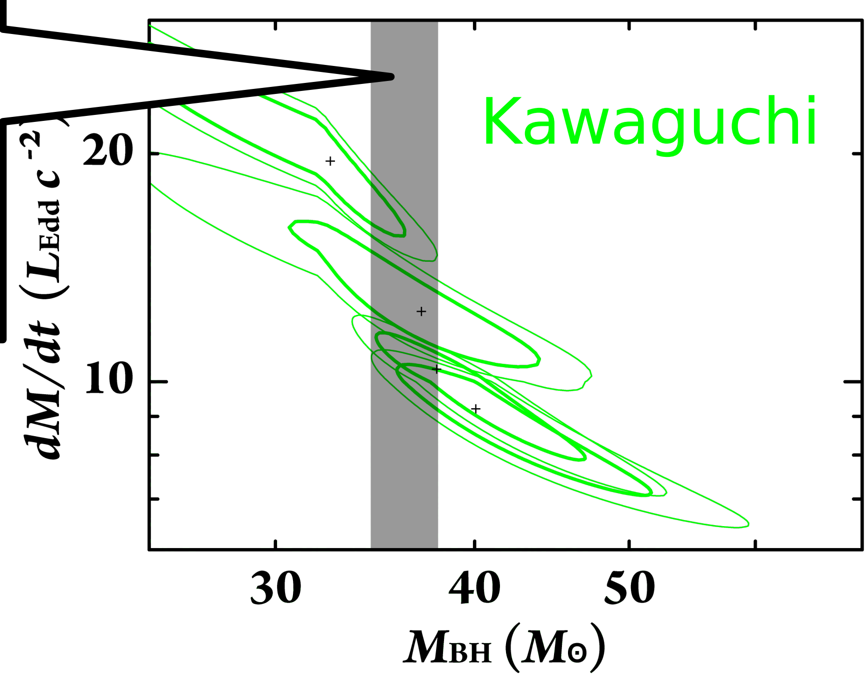
Constant mass range:
37±2 $M_\odot$ (90% confidence)

Eddington ratio: 0.58-0.90





Discussion (1-2) – Faint state

M51 source-82 within the faint state

Power-law (Γ~1.8-2.6)

Reason 1:

None of the samples is explained by the MCD model.

Date	Null Hypothesis probability
2000/06/20	4.4e-2
2001/06/23	5.6e-6
2003/01/15	1.7e-4
2003/08/07	3.3e-5
2005/07/01	3.3e-6
2006/05/20	2.7e-5
2006/05/24	9.4e-3

Reason 2:

No constant BH mass derived by the Kawaguchi model.

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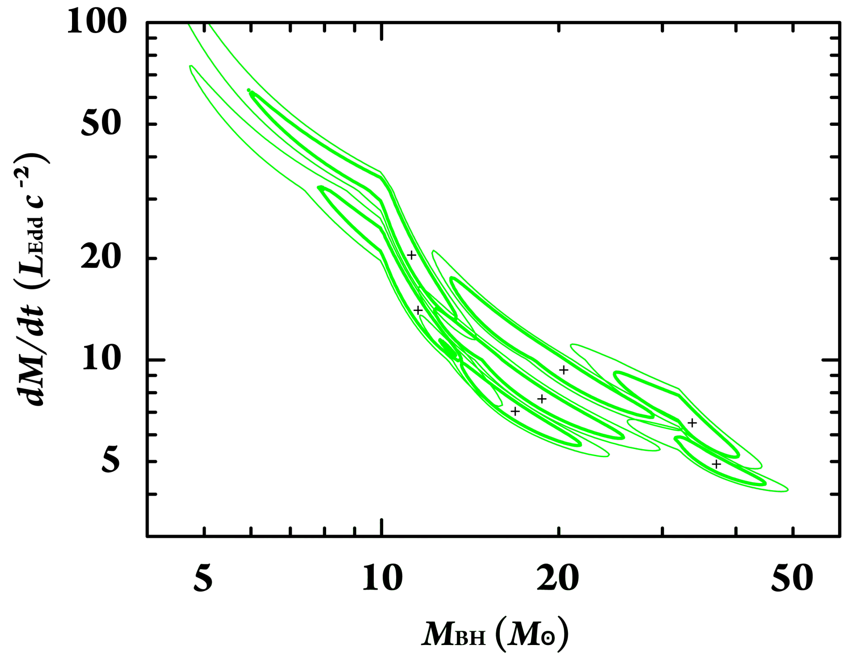

Discussion (2) – Relation with Galactic BHBs

Galactic BHBs

State name	Eddington ratio	Spectral shape	Model
Apparent standard state	~0.4	Convex	Slim disk? (Kubota & Makishima 2004)
Very high state	>0.2	Power-law like	Γ>2.4 (McClintock & Remillard 2006)
High-soft state	>0.1	Convex	Standard disk
Low-hard state	0.01-0.04	Power-law	Γ~1.7 (McClintock & Remillard 2006)

ULXs

State name	Eddington ratio	Spectal shape	Model
Bright state	0.58-0.90 (assuming the mass of 37 $M_\odot$)	Convex	Slim disk
Faint state	0.29-0.50 (assuming the mass of 37 $M_\odot$)	Power-law	Γ~1.8-2.6

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Hypothesis-I

Hypothesis-II

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ULXs are extreme stellar mass BHs (<40 $M_\odot$) in the two highest luminosity states.

4, Summary

Summary

We analyzed the X-ray spectra of seven ULXs in the two interacting galaxy systems M51 and NGC4490/85.

From the luminosity distribution, we define the two state: the **bright** state and the **faint** state. The **bright** state has a convex spectral shape, the **faint** state has a PL spectral shape.

From NGC4490/85 ULX-8, all the spectra can be reproduced by the Kawaguchi slim disk model with BH mass of 37±2 $M_{\odot}$.

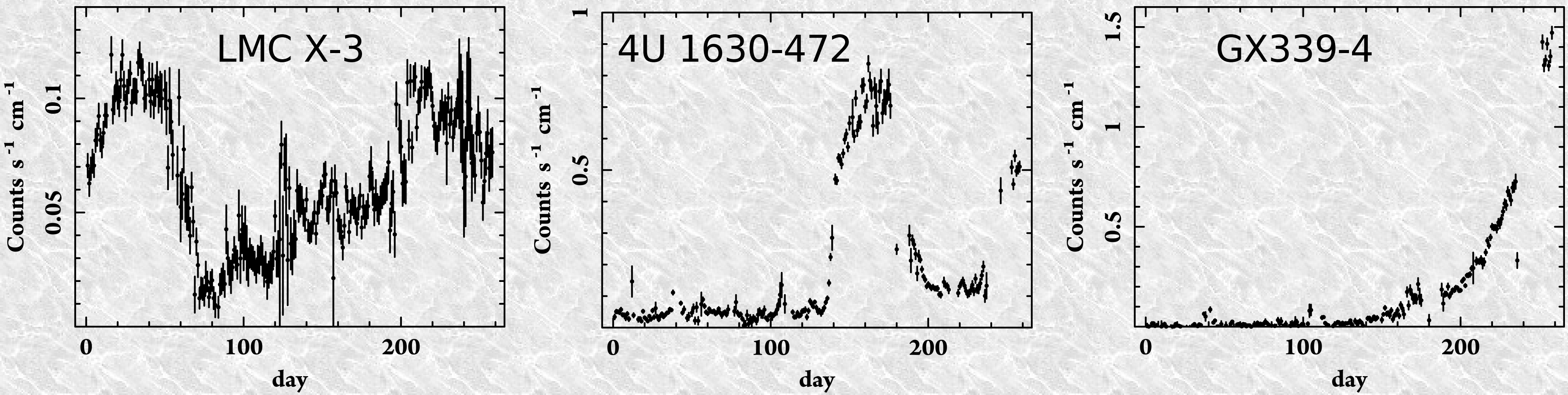
We proposed that the **bright** state of ULXs corresponds to the apparent standard state of Galactic BHBs, and the **faint** state corresponds to the very high state.

We speculate that ULXs are extreme stellar mass BHs (<40 $M_{\odot}$) in the two highest luminosity states.

Future Work

We will further investigate the relation between the states of Galactic BHBs and ULXs.

~20 Galactic BHBs using *MAXI*



~300 ULXs using *Chandra* (~800 observations)