Spectral states in NS-LMXBs observed with MAXI/GSC & Swift/BAT

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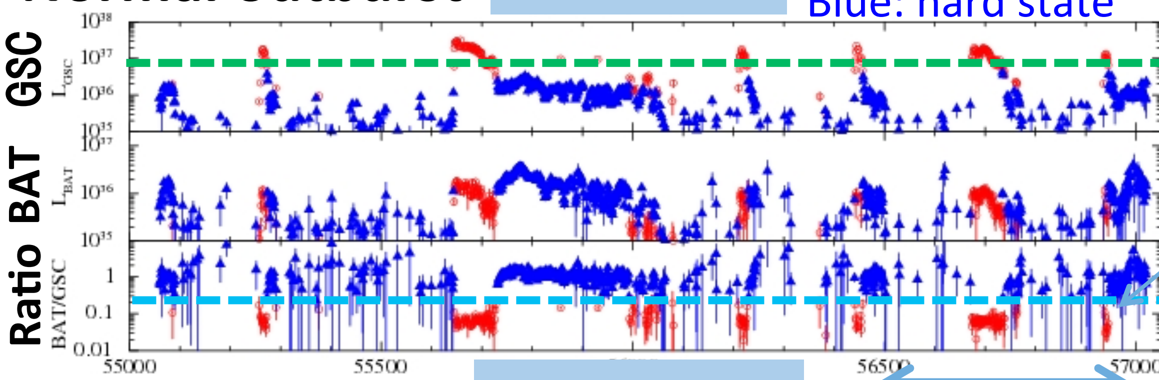
1. **Two kinds of spectral state transitions** (soft/hard transition)
   (1) Normal outburst (Asai+ 2012) **(2) Mini outburst** (Asai+ 2015)
   ※ “(2)mini outburst” as a "purr-type" of disk instability predicted by Mineshige and Osaki (1985).
2. **Two groups in a soft state of Atoll sources**
   (1) High hardness-ratio (4U 1820−30 and 4U 1735−44)
   (2) Low hardness-ratio (AqlX-1, 4U1608−52,GX 3+1,GX9+9, GX13+1, and GX9+1)
   ※ The difference would come form the surface magnetic field of neutron star (Asai+ 2016).
3. **Difference between Horizontal and Normal branch of Z sources** might be explained by the disk evaporation (Asai+ in prep).

1. Two kinds of spectral state transitions (soft/hard transition)

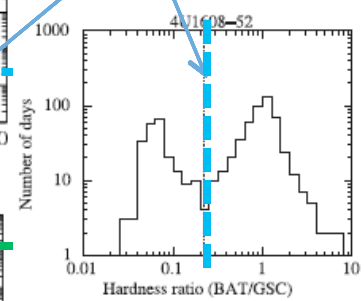
Normal outburst

4U1608—52

Red: soft state
Blue: hard state

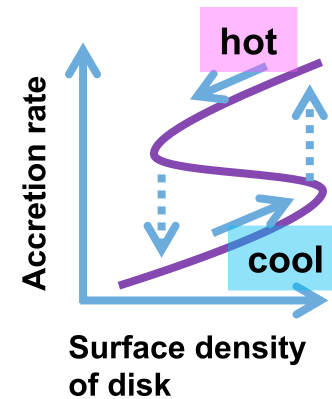


HR=0.2



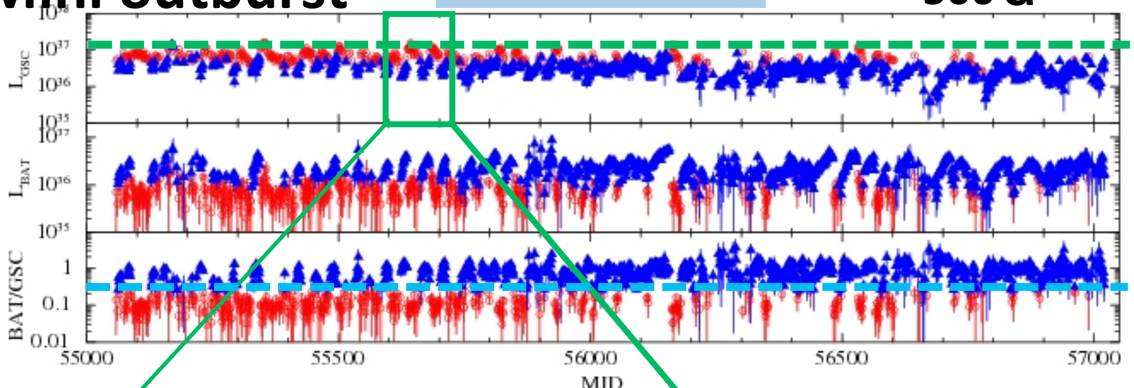
Thermal –viscous disk instability model

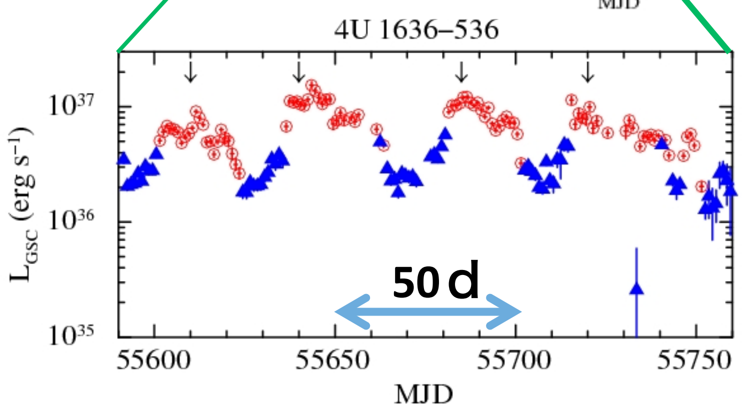
Limit cycle (S-curve)



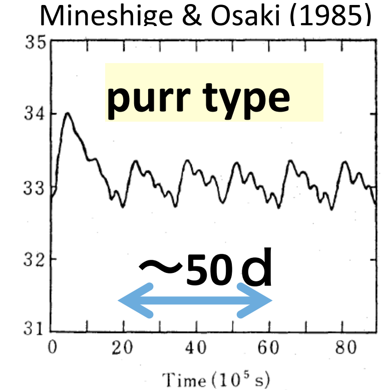
Mini outburst

4U1636—536





Mineshige & Osaki (1985)

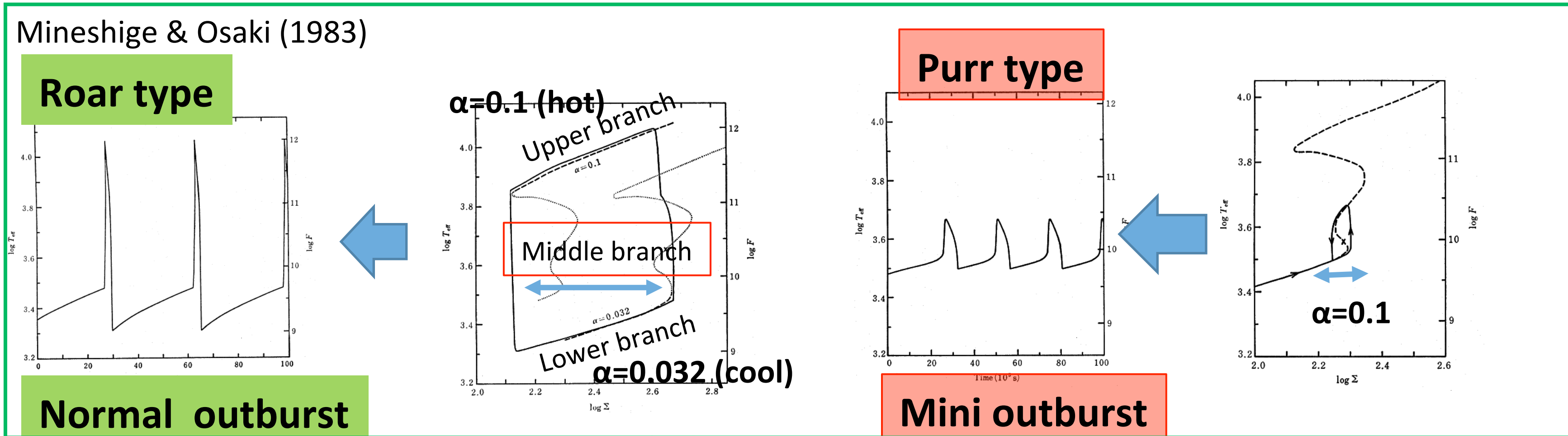


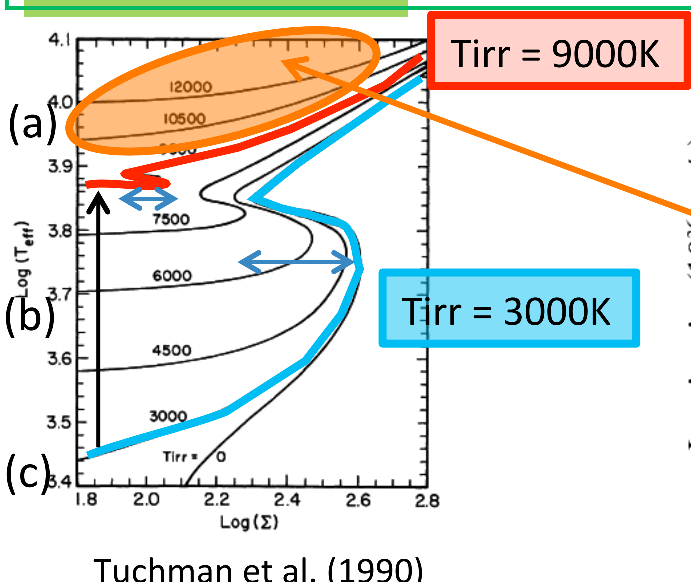
Mini outburst

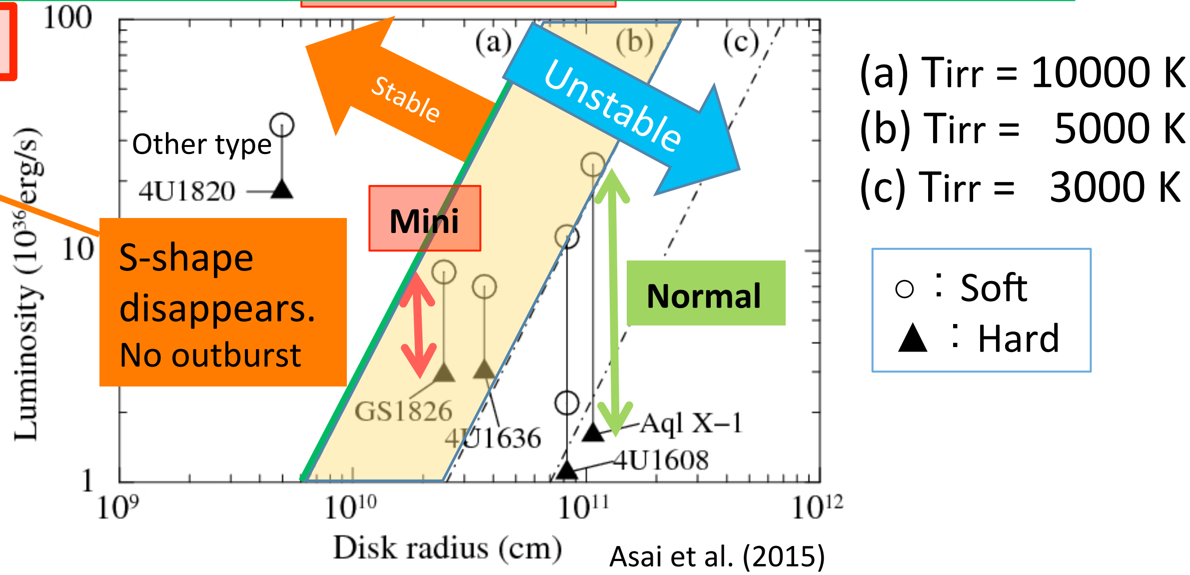
- small amplitudes
- short durations

source	Average Lx of soft state All are < 10^{37} erg/s.
4U 1636	~ 8×10^{36} erg/s
4U 1705	~ 5×10^{36} erg/s
4U 1608	~ 2×10^{36} erg/s
GS 1826	~ 5×10^{36} erg/s

1. Two kinds of spectral state transitions (soft/hard transition)







In the region between (a) and (b) where the irradiation is moderate, the middle-branch becomes narrow. Then the purr-type instability would occur. Therefore, we interpreted mini-outbursts were caused by X-ray irradiation.

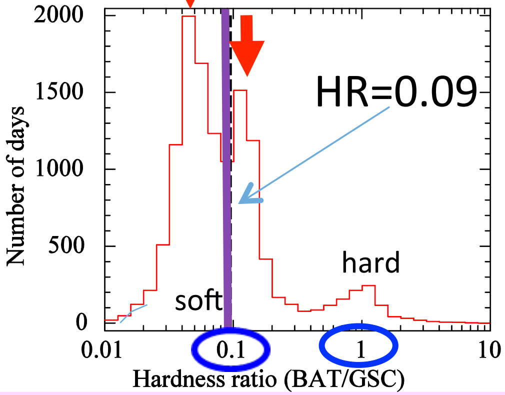
2. Two groups in soft state of Atoll sources

Distributions of hardness ratios of BAT/GSC

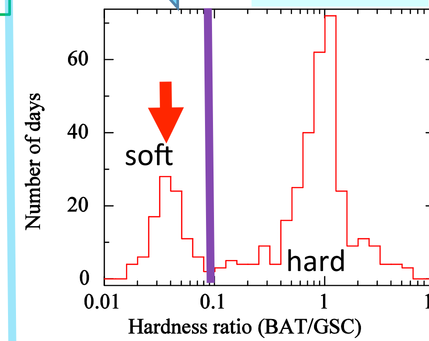
The distributions of the soft state are divided into two groups.

Peak value
- HR ＜0.09
- HR ＞0.09

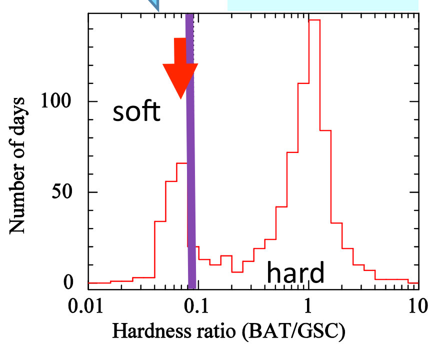
All nine sources



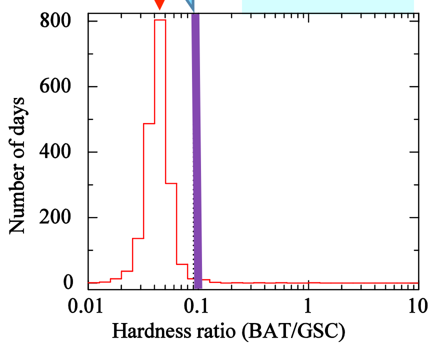
AqlX-1



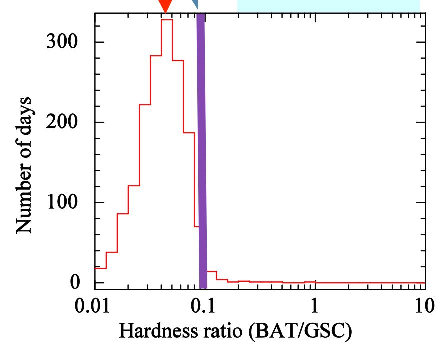
4U1608



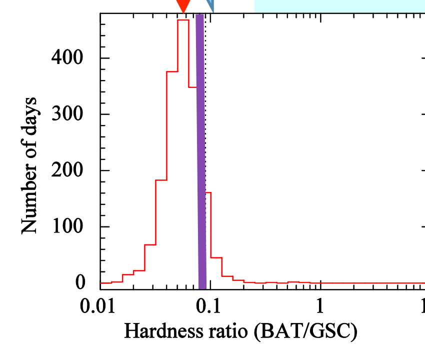
GX9+1



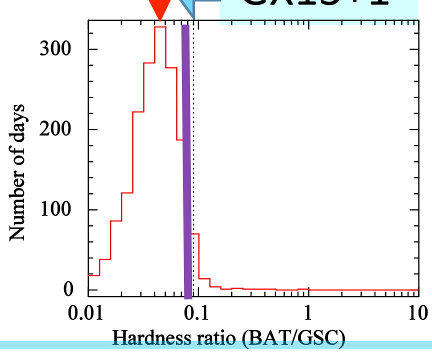
GX3+1



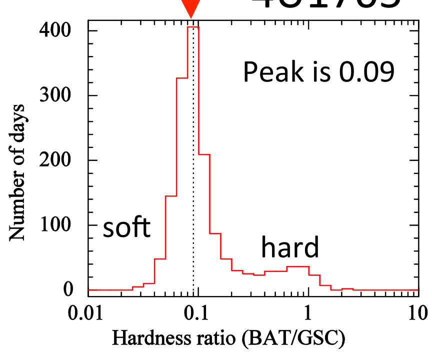
GX9+9



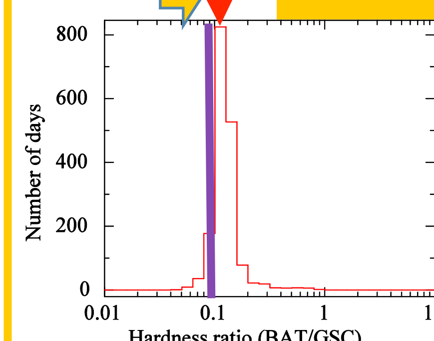
GX13+1



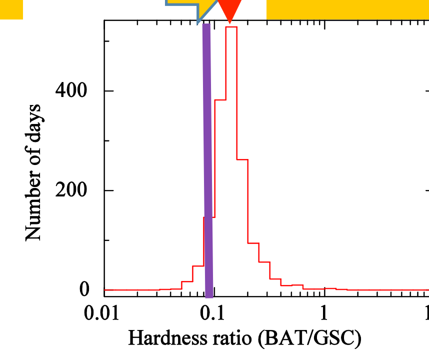
4U1705



4U1820



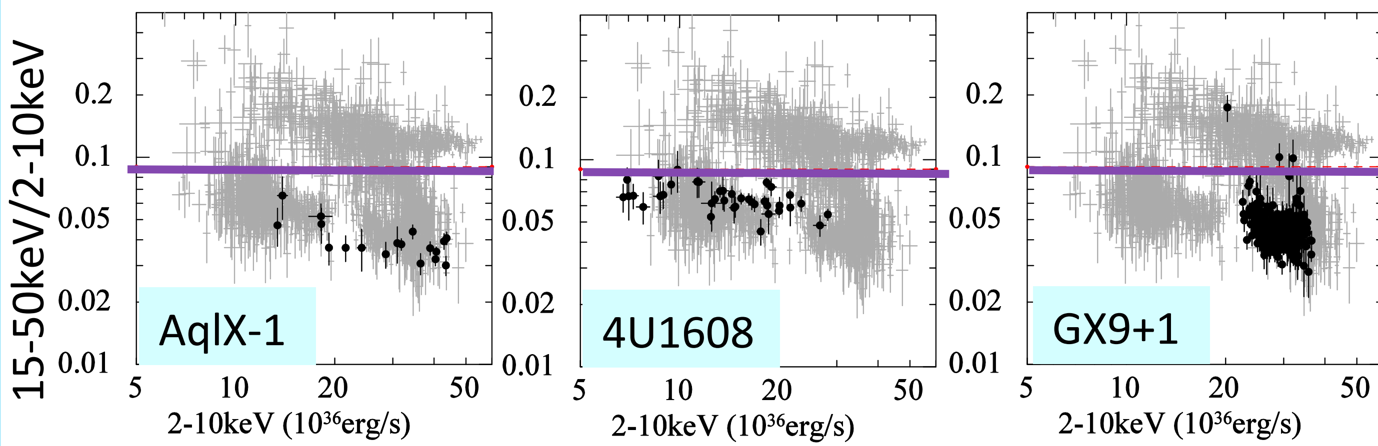
4U1735

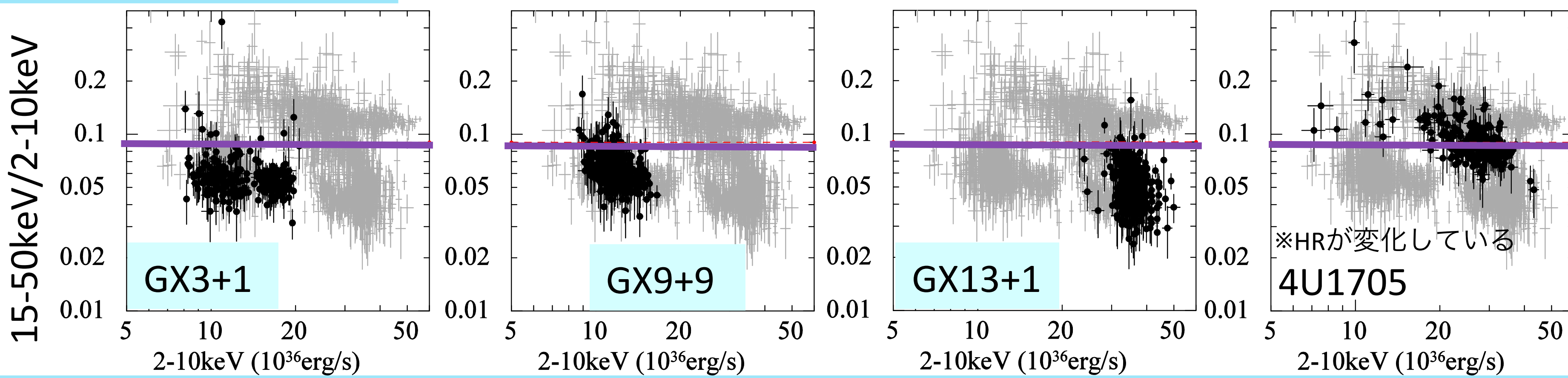


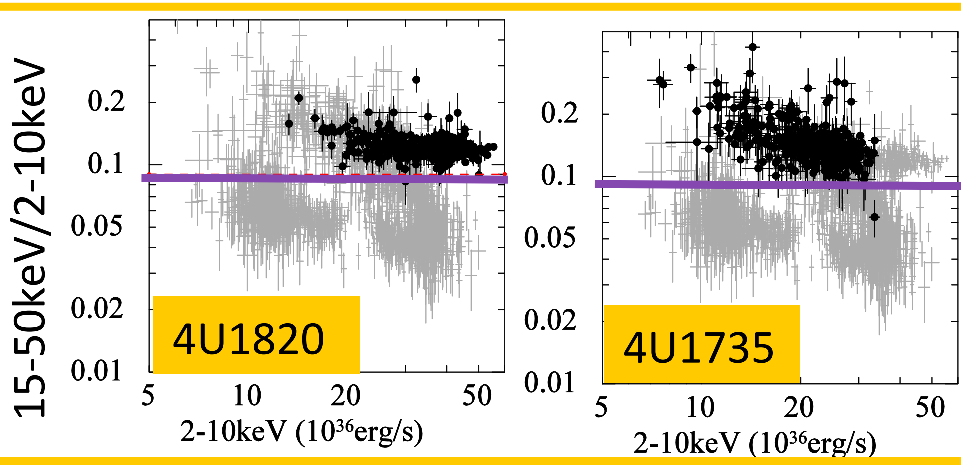
2. Two groups in soft state of Atoll sources

Hardness-luminosity diagram of nine NS-LMXB

※Gray backdrop is the all nine sources.







The difference between the two groups would be due to the size of the Compton cloud. The group with large HR (>0.09: 4U 1820–30 and 4U 1735–44) would have larger Compton cloud than the other group with HR smaller than 0.09.

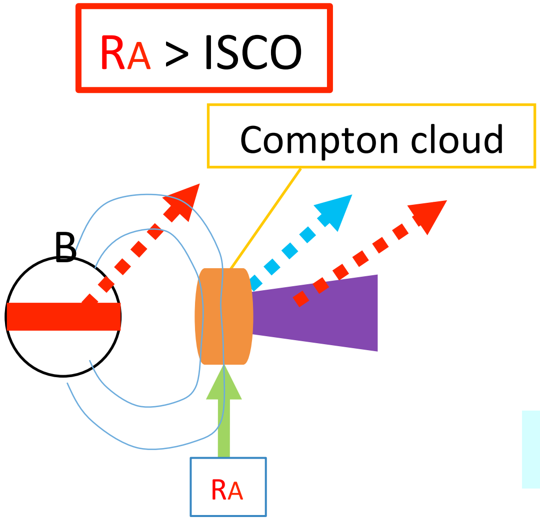
2. Two groups in soft state of Atoll sources

Alfven radius (RA) depends on luminosity

(Ghosh & Lamb 1979, Matsuoka & Asai 2013)

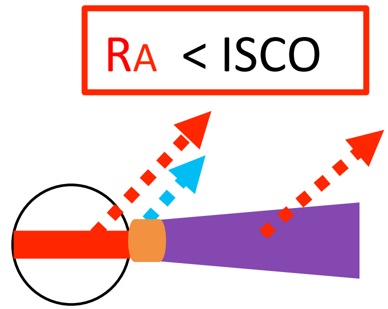
$R_A = 1.9\times10^6$ cm $L_{37}^{-2/7} B_8^{4/7} M$

※ $M_{1.4}$ (1.4Mo)、 R_6 (10



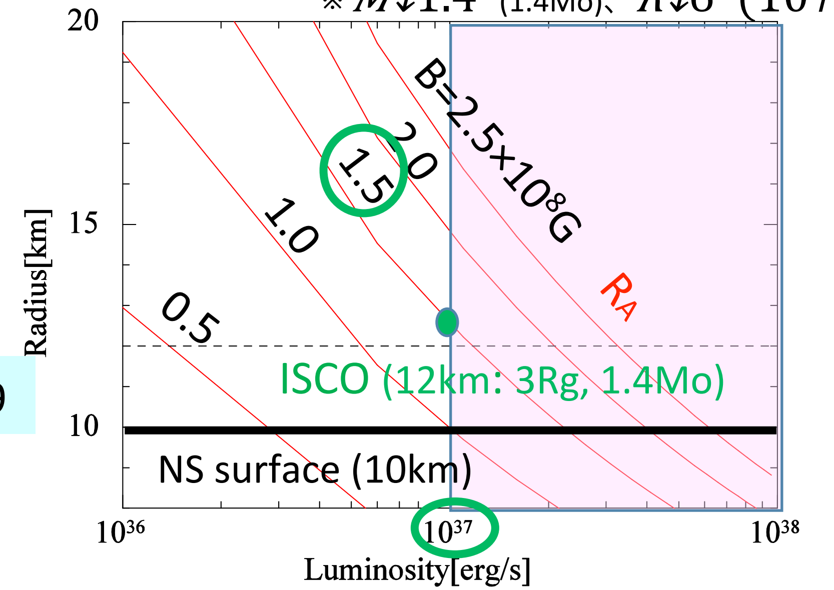
Peak value of HR >0.09

4U 1820−30, 4U 1735−44



Peak value of HR <0.09

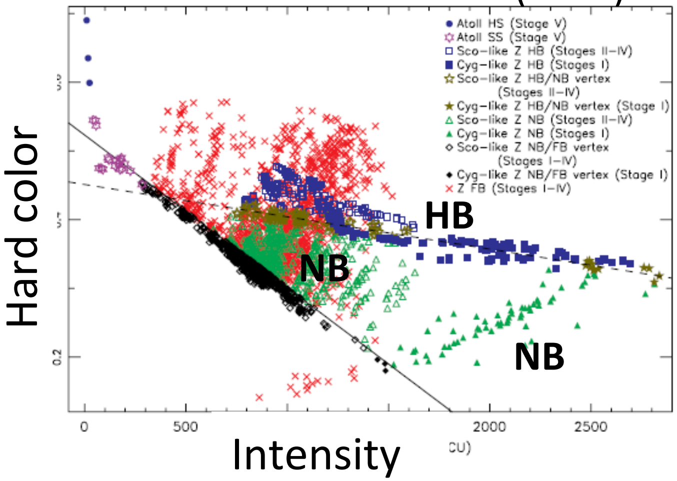
Other Atoll sources

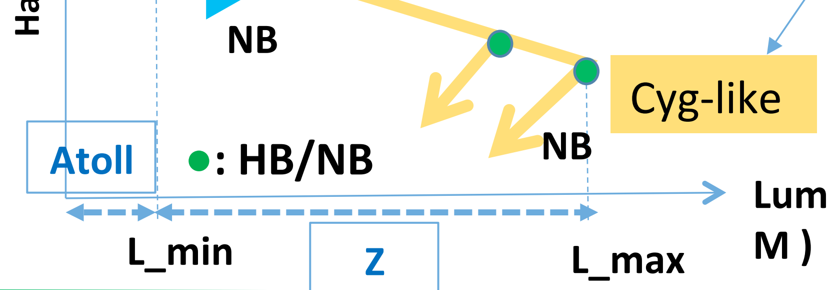


- **When RA is larger than the ISCO, the accretion flow would be stopped and spread around RA. Then the relatively large Compton cloud would be created. Then, the HR would become large (> 0.09).**
- **We can derive the lower limit of B of the NS from the lower limits of luminosity. Since the HR of 4U 1820−30 and 4U 1735−44 is large, B is estimated as B ≳2.5 × 10^8 G.**

3. Horizontal branch and Normal branch of Z source

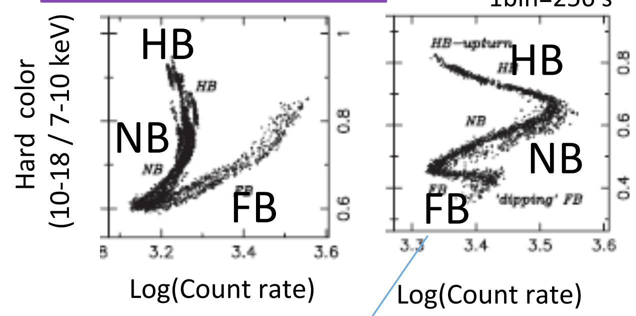
XTE J1701 : Lin et al. (2009)



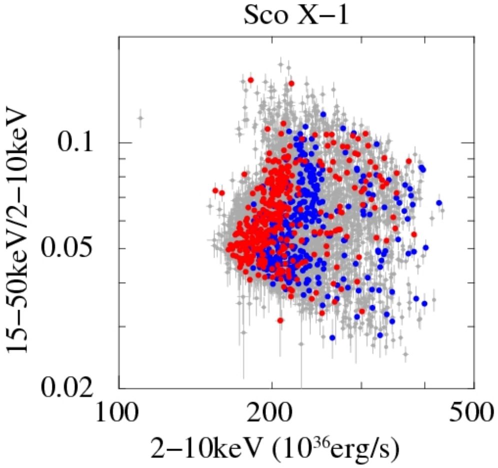


HID of Z sources

Homan+ 2010
1bin=256 s

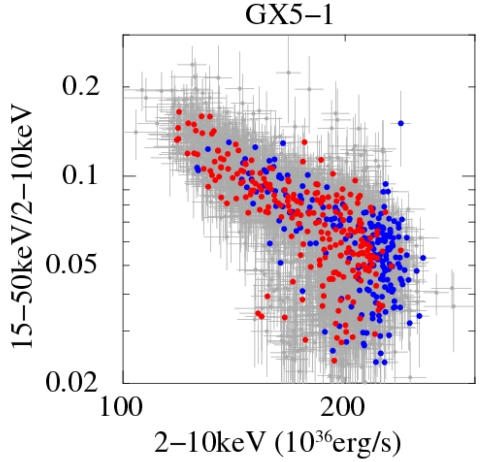


Sco-like



●MJD 55100—55150
●MJD 55800—55850

Cyg-like



●MJD 55100—55150
●MJD 55600—55650

High luminosity: Cyg-like, a long HB
Low luminosity : Sco-like, a short HB

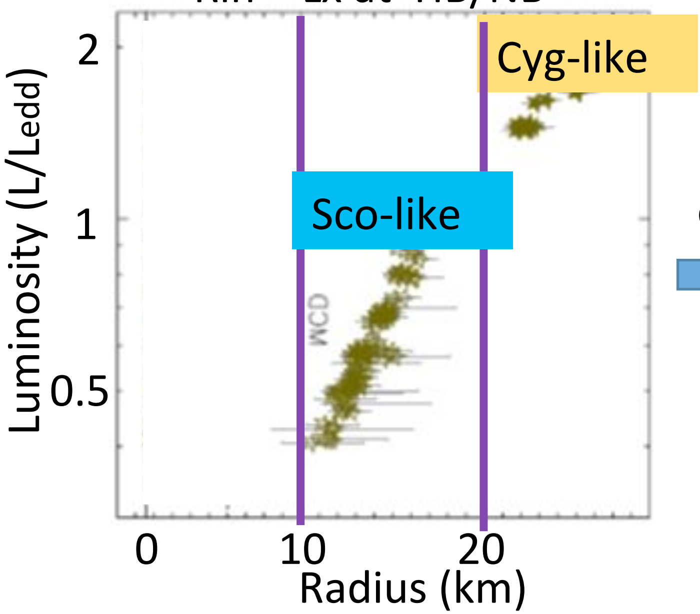
Transition luminosity from HB to NB also changes.

What is the meaning of the transition point?

3. Horizontal branch and Normal branch of Z source

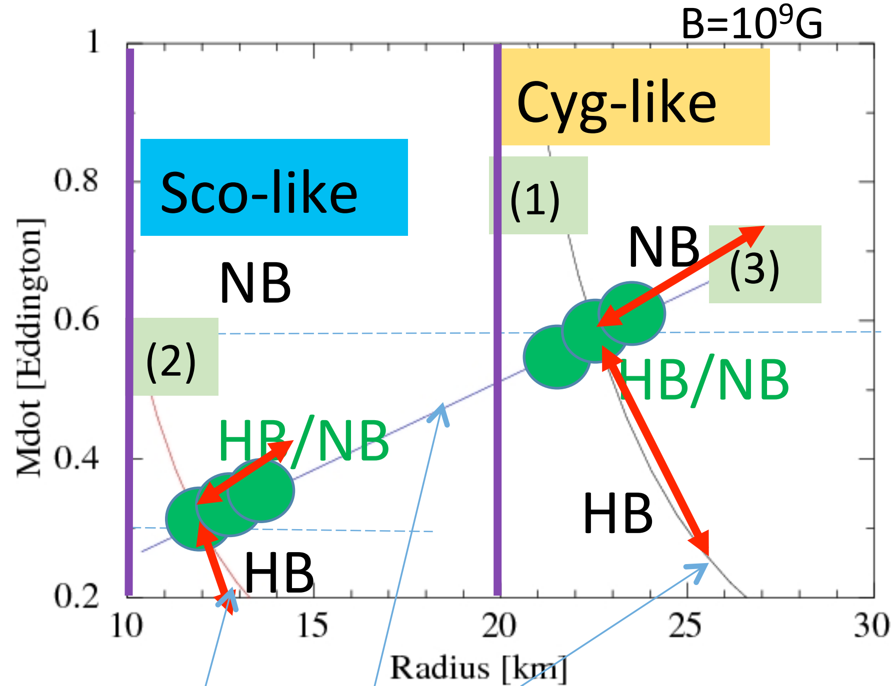
XTE J1701 (Lin+ 2009)

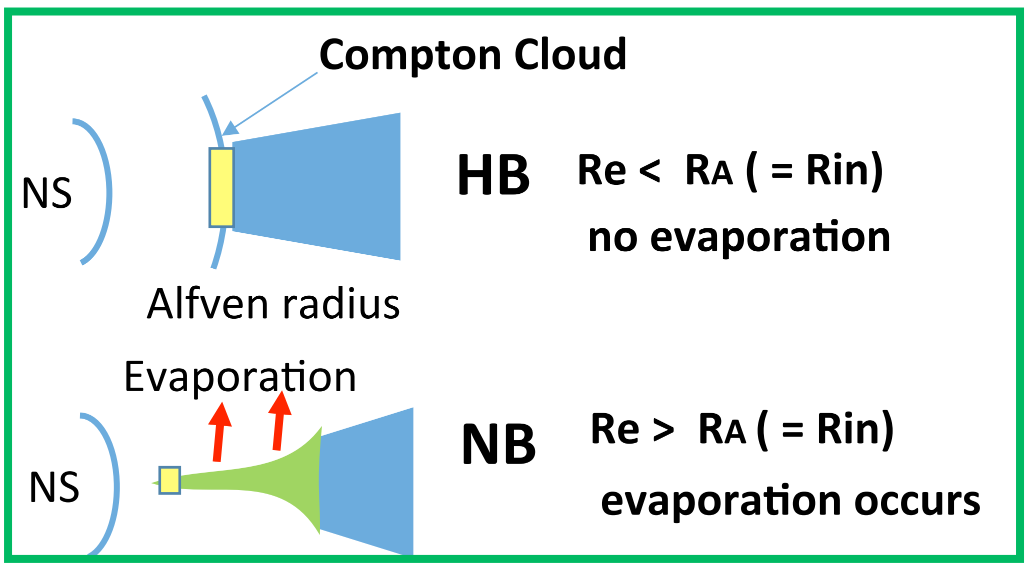
Rin – Lx at HB/NB



In the case of B～10^9G

Rin = RA





●Alfven radius :RA(Campana+ 1998)

(1) Disk-like Radiation-pressure dominant

(2) Disk-like Gas-pressure dominant

●Critical radius : Re (Fukue 2004)

(where evaporation occurs)

(3) Standard critical accretion disk

Spectral states in NS-LMXBs observed with MAXI/GSC and Swift/BAT

1. Two kinds of spectral state transitions (soft/hard transition)

(1) normal outburst (Asai+ 2012)

↕

Roar type (transition between branches with different α-values)

(2) mini outburst (Asai +2015)

↕

Purr type (transition between branches with the same α-value)

※ The instability predicted by Mineshige and Osaki (1985).

2. Two groups in a soft state of Atoll sources (Asai +2016).

(1) High hardness ratio (4U 1820–30 and 4U 1735–44)

Rin = Alfven radius, B > 2.5×10^8 G

(2) Low hardness ratio (AqlX-1, 4U1608–52,GX 3+1,GX9+9, GX13+1, and GX9+1)

Rin =ISCO, B < 2.5×10^8 G

3. Difference between Horizontal and Normal branch of Z sources

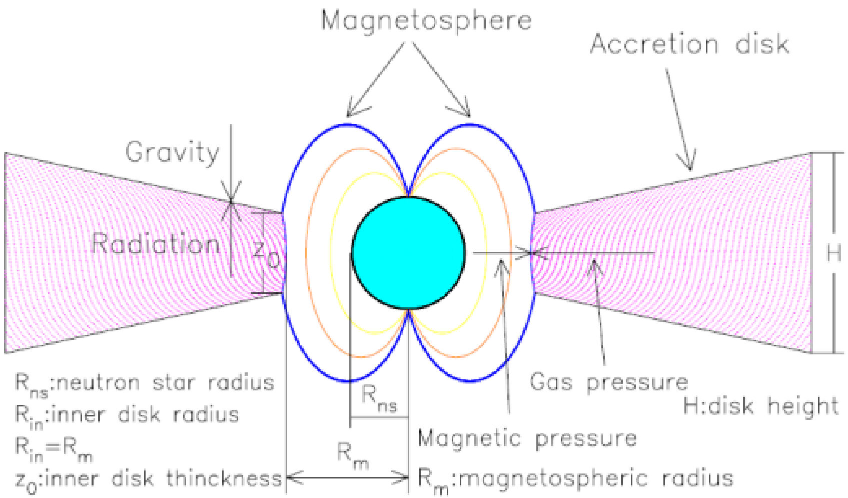
HB: Rin = Alfven radius, **no evaporation**

(Asai+ in prep).

NB: Rin = Evaporation radius (or Alfven radius) , **with evaporation**

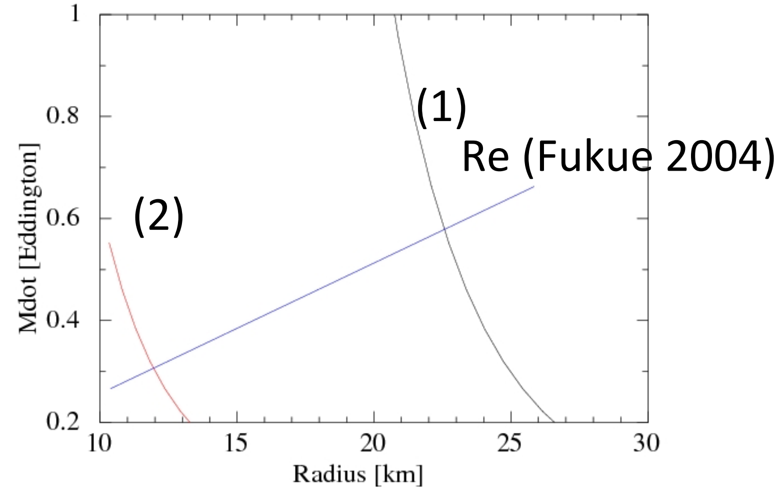
Evaporation point (HB/NB trans. pt.) varies with disk status.

Ding et al. (2011)



- During the Z-source stages, because the disk is thickened by radiation pressure, the gas pressure from the disk decreases, the magnetosphere expands, and then the inner disk radius increases.

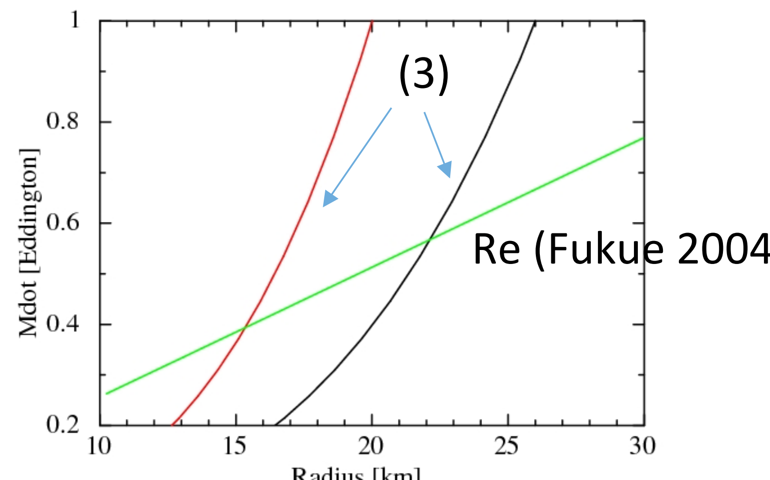
- Therefore, during the Z-source stages, the inner disk radius could be set by the magnetospheric radius and it should vary with the mass accretion rate .



Campana et al. (1998)

$(1)\ r_m \propto M^{-2/13}$

$(2)\ r_m \propto M^{-46/187}$



$(3)\ r_m \propto M^{2/7}$