The Coupled X-ray Variability in Scorpius X-1 along Its Z Track

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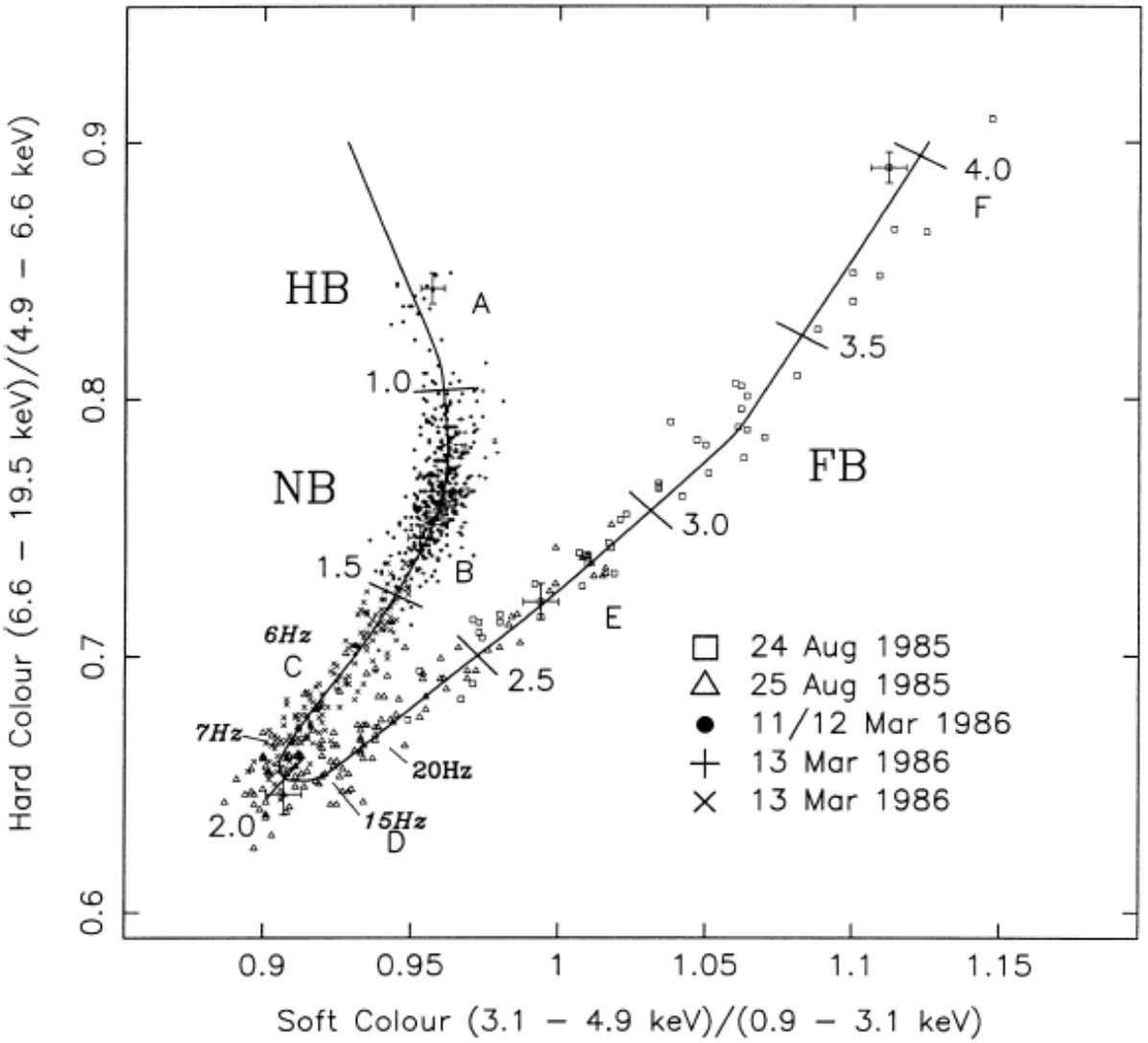
Outline

- Scorpius X-1 (Sco X-1)
- X-ray variability components
- Coupled X-ray variability
- Discussion and Interpretation

Scorpius X-1

- the first X-ray source discovered (in 1962) in the sky
- a Low-Mass X-ray Binary (LMXB)
  a neutron star (~ 1.4 solar masses)
  a donor star (~ 0.42 solar masses)
- a Z source
  trace out roughly a Z-shape in X-ray colour-colour diagram (CD)
- the brightest persistent X-ray source

Z track



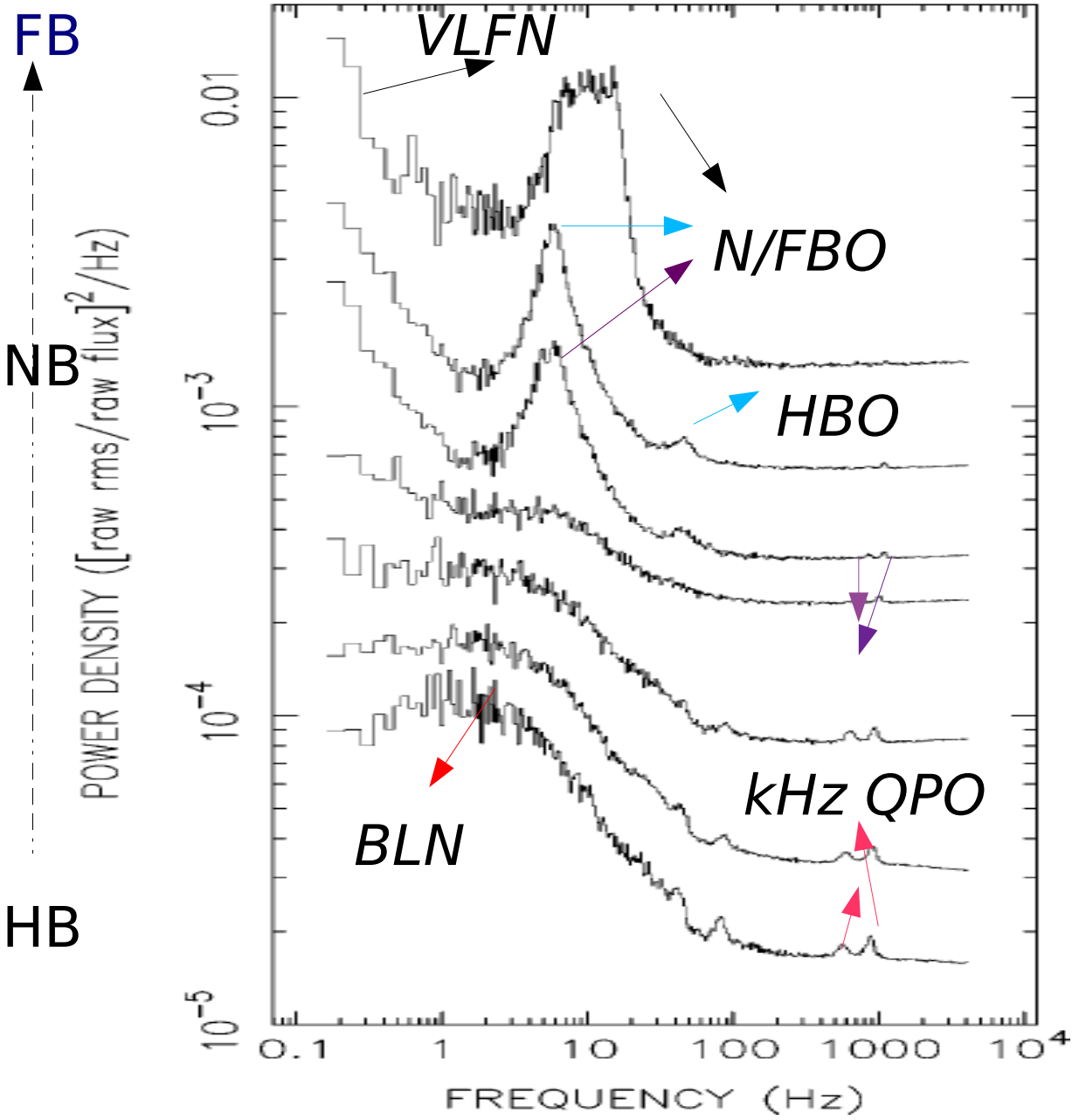
S. W. Dieters & M. van der Klis 2000

HB:
Horizontal Branch

NB:
Normal Branch

FB:
Flaring Branch

Variability along Z track



1.normal/ flaring-branch oscillation (**N/FBO**) (6-20 Hz)

2.horizontal-branch oscillation (**HBO**) (~45 ~90Hz)

3.kilohertz quasi-periodic oscillation (**kHz QPO**)
lower ν_1
upper ν_2

4.Very low-frequency noise (**VLFN**)

5.Band-limited Noise (**BLN**)

van der Klis & A. D. Wijnands 1997, ApJ

Timing properties along its Z track

1.The kHz QPO frequency is always correlated with position in the tracks in the CD.

2.From HB to upper NB the BLN becomes weaker.

3.The NBO on the NB seems to emerge from the BLN. (but not true)

Coupled X-ray variability

in the NB

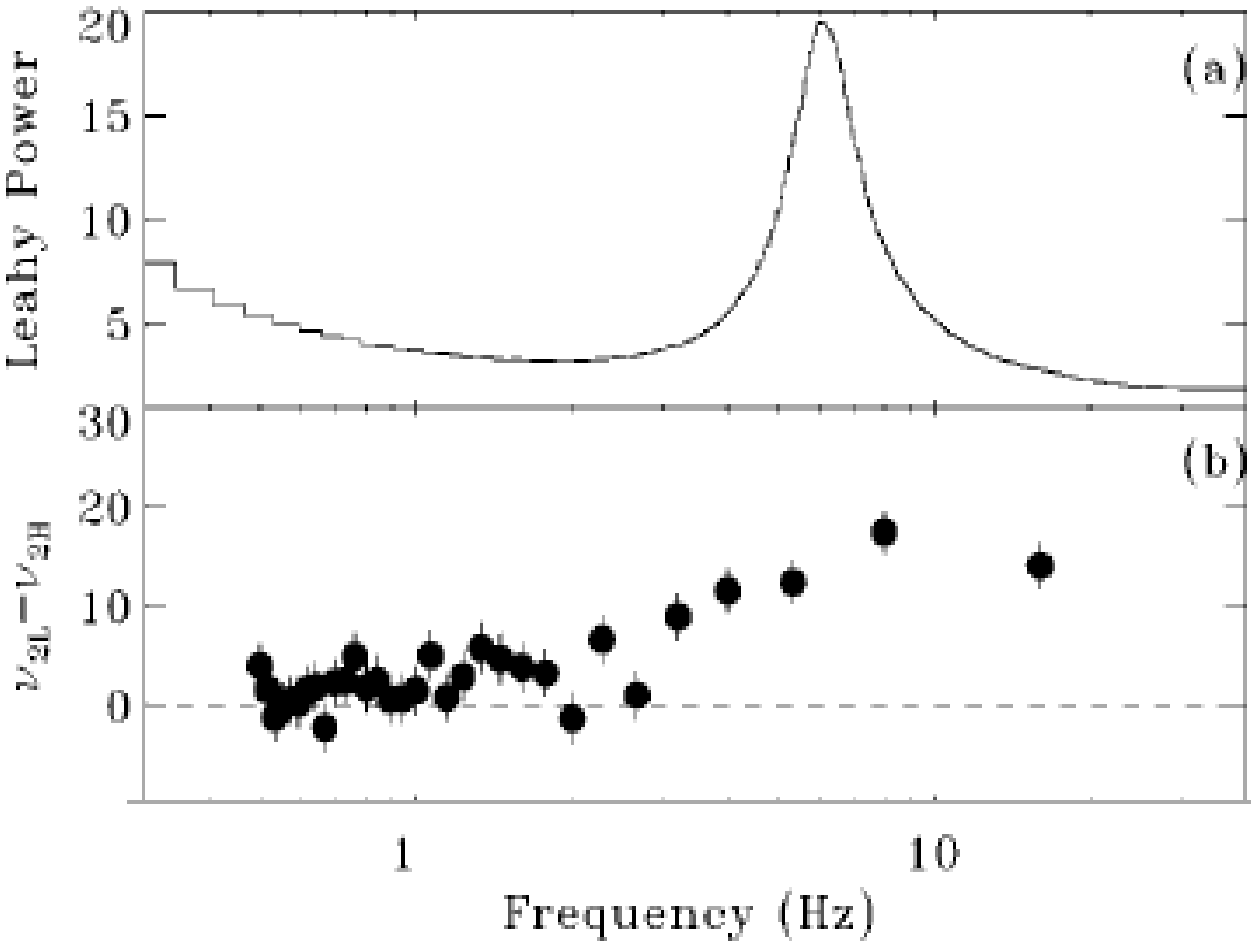
1. kHz QPOs & NBO
   Dependence of kHz QPOs on the NBO phase
   (Yu et al., 2001, ApJ)

2. HBO & NBO
   Coupling between the 45 Hz HBO and the NBO
   (Yu., 2007, ApJ)

in the upper NB and in the HB

3. kHz QPOs & BLN
   Dependence of kHz QPOs on the BLN phase
   (our work)

1.kHz QPOs & NBO

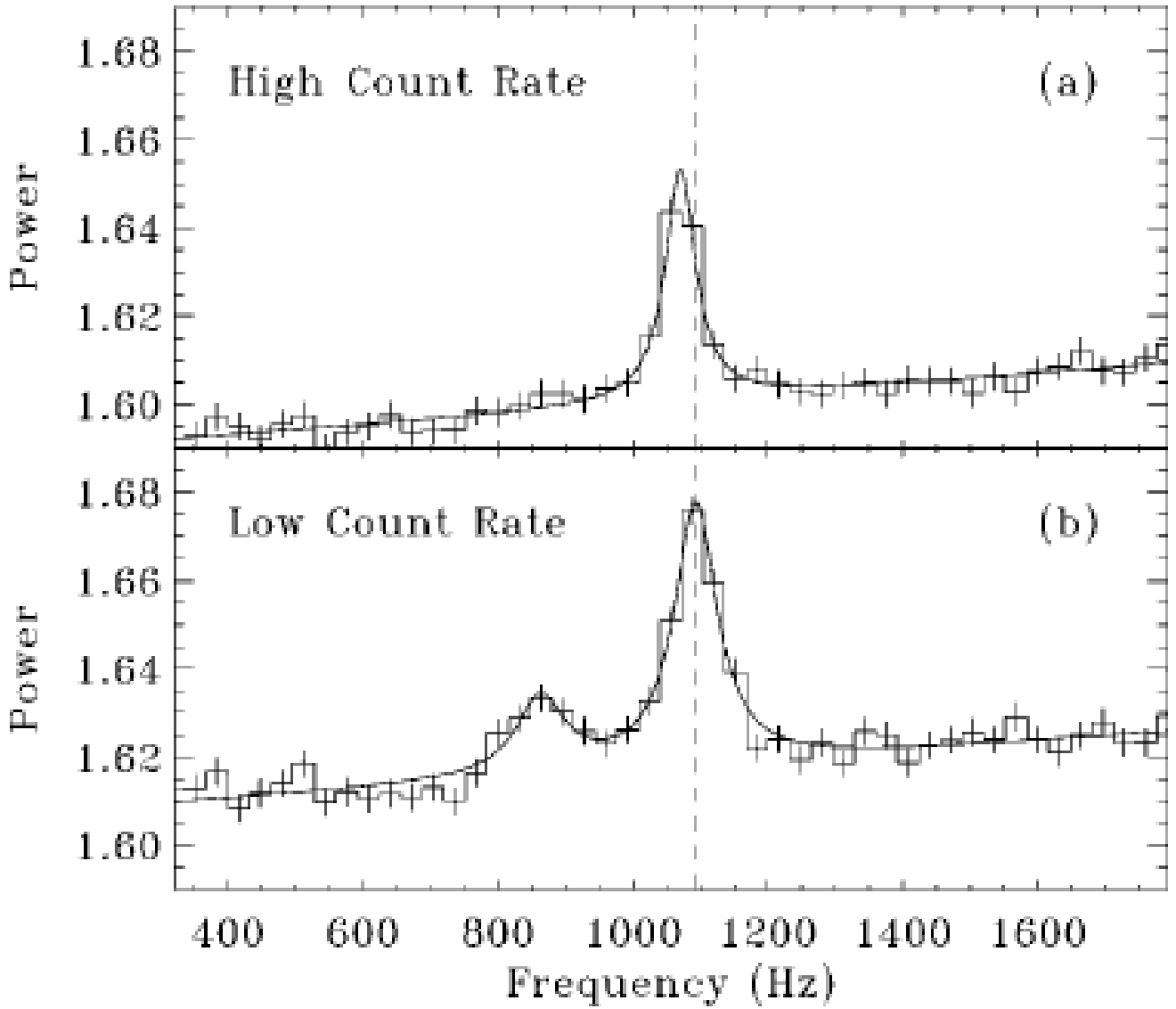


Yu et al., 2001, ApJ

ν_{2L} :
the frequency of upper kHz QPO with low count rate

ν_{2H} :
the frequency of upper kHz QPO with high count rate

The upper kHz QPO is anti-correlated with the count rate on the NBO timescale.

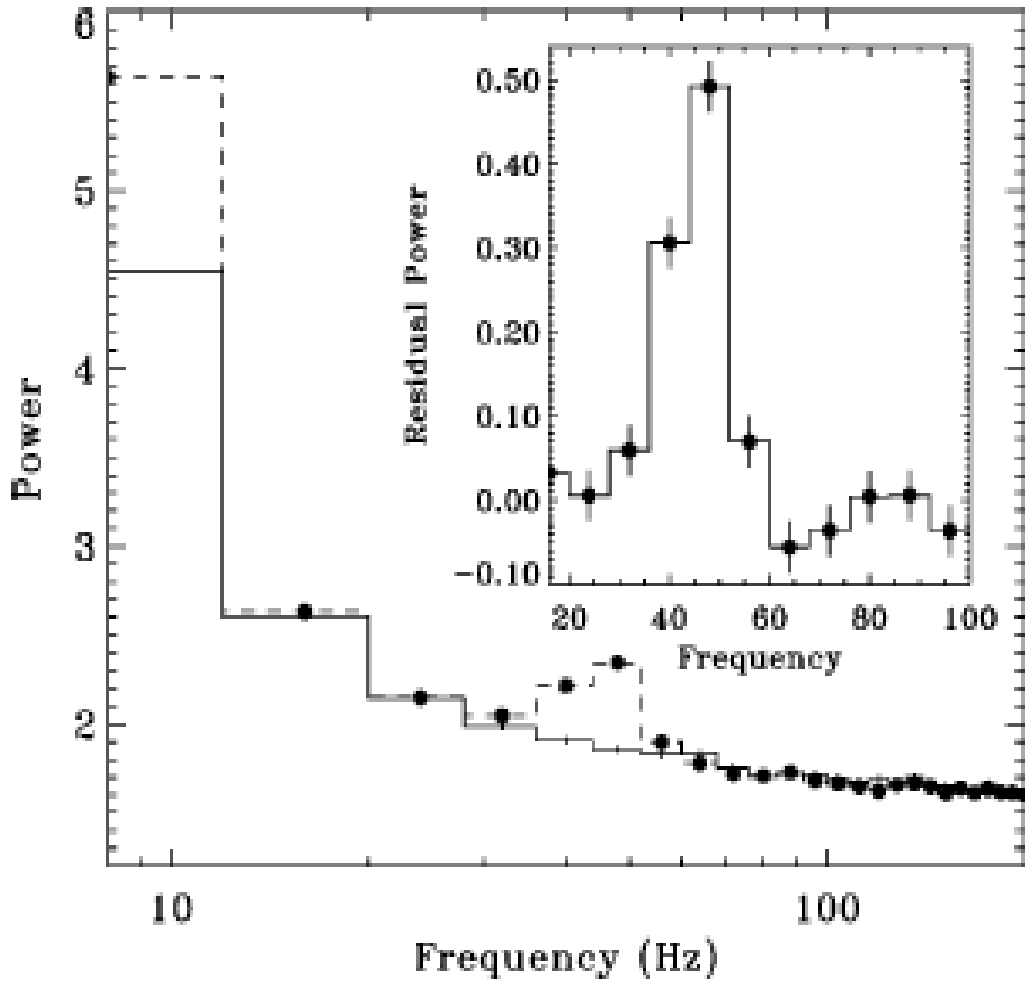


Yu et al., 2001, ApJ

timescale: 0.0625 s

The lower kHz QPO becomes weaker with increasing count rate on the NBO timescale.

2.HBO & NBO



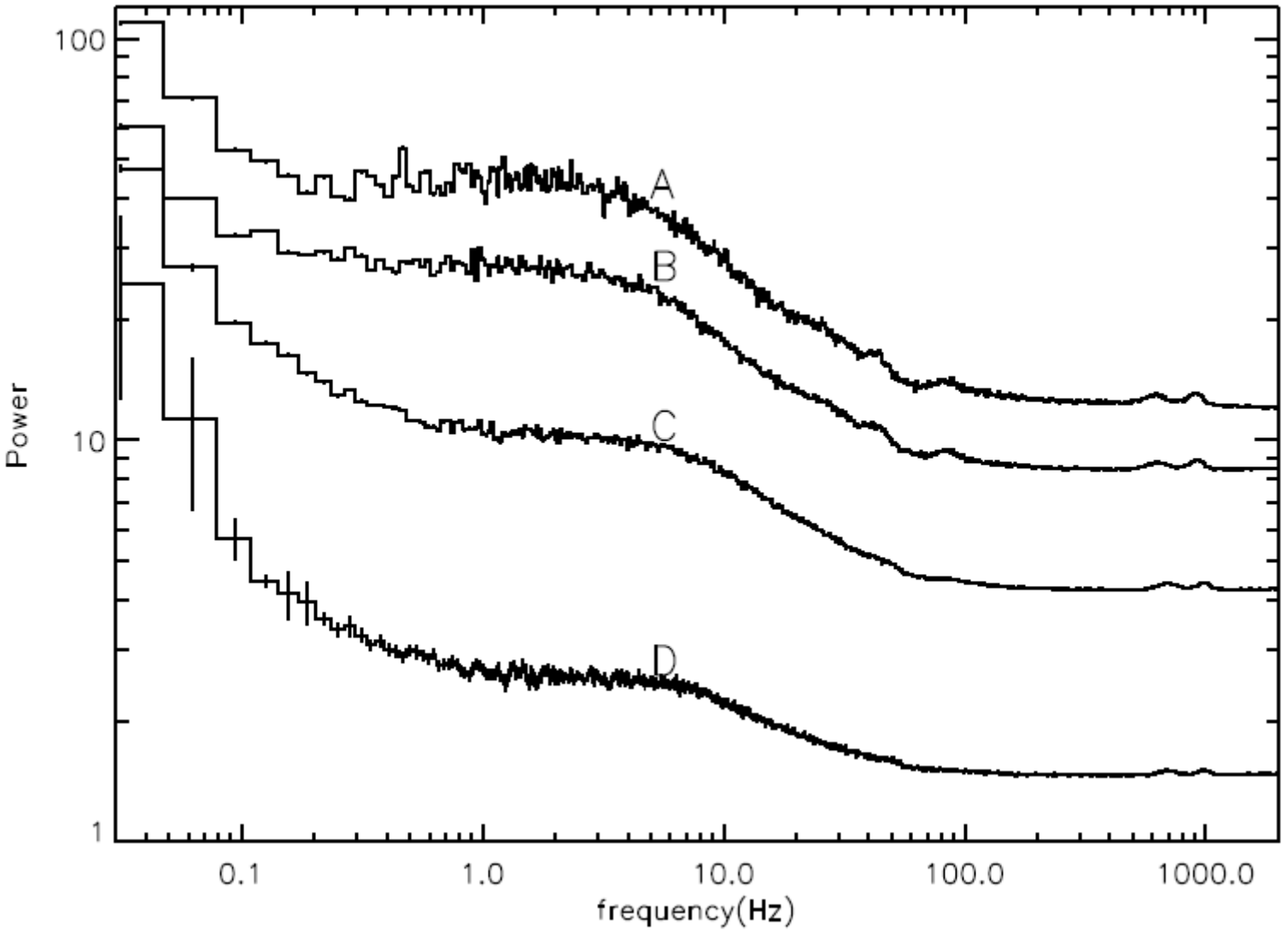
Yu., 2007, ApJ

NBO phase of high flux (filled circles)

NBO phase of low flux (crosses)

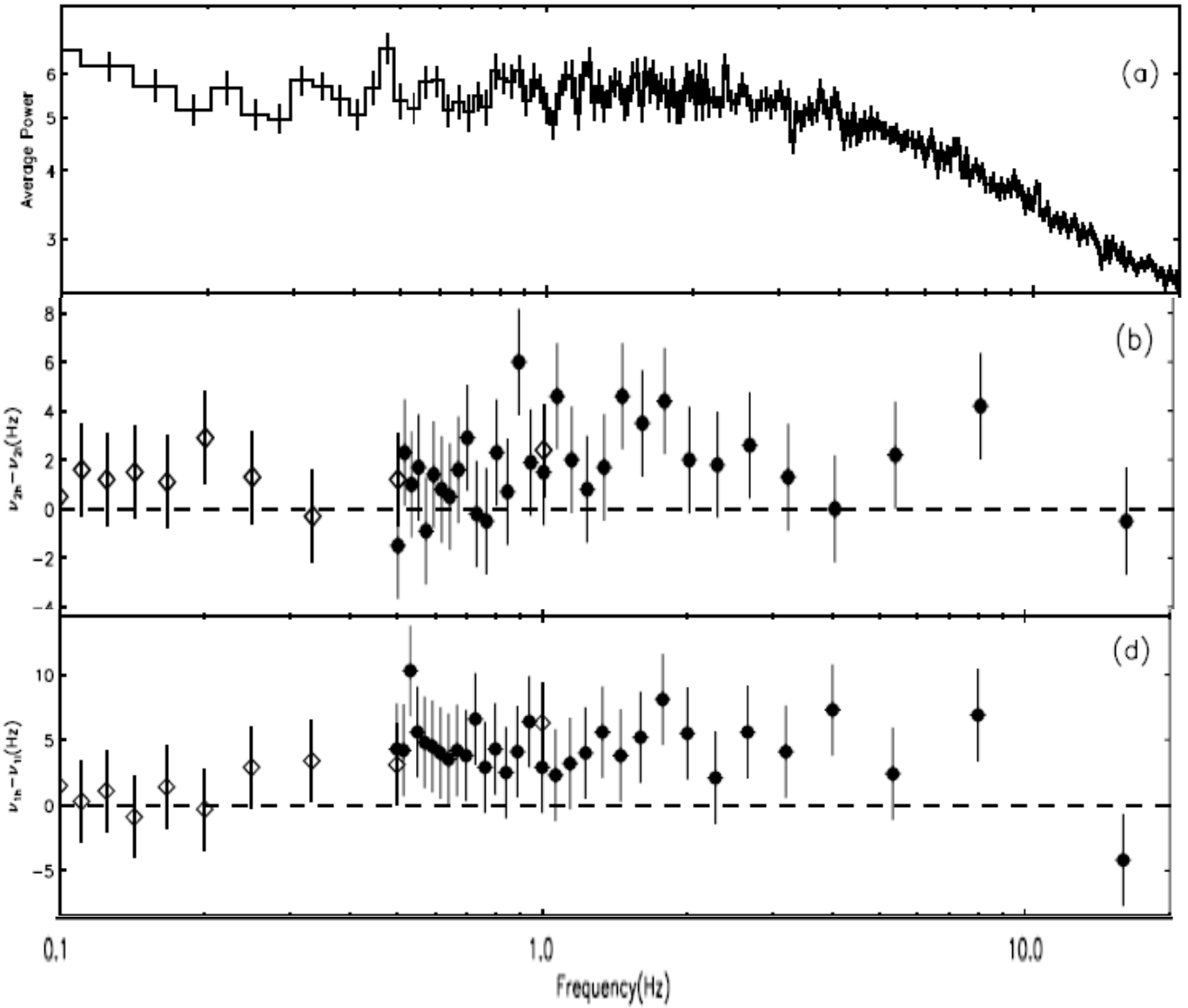
The HBO becomes stronger with the increasing count rate on the NBO timescale.

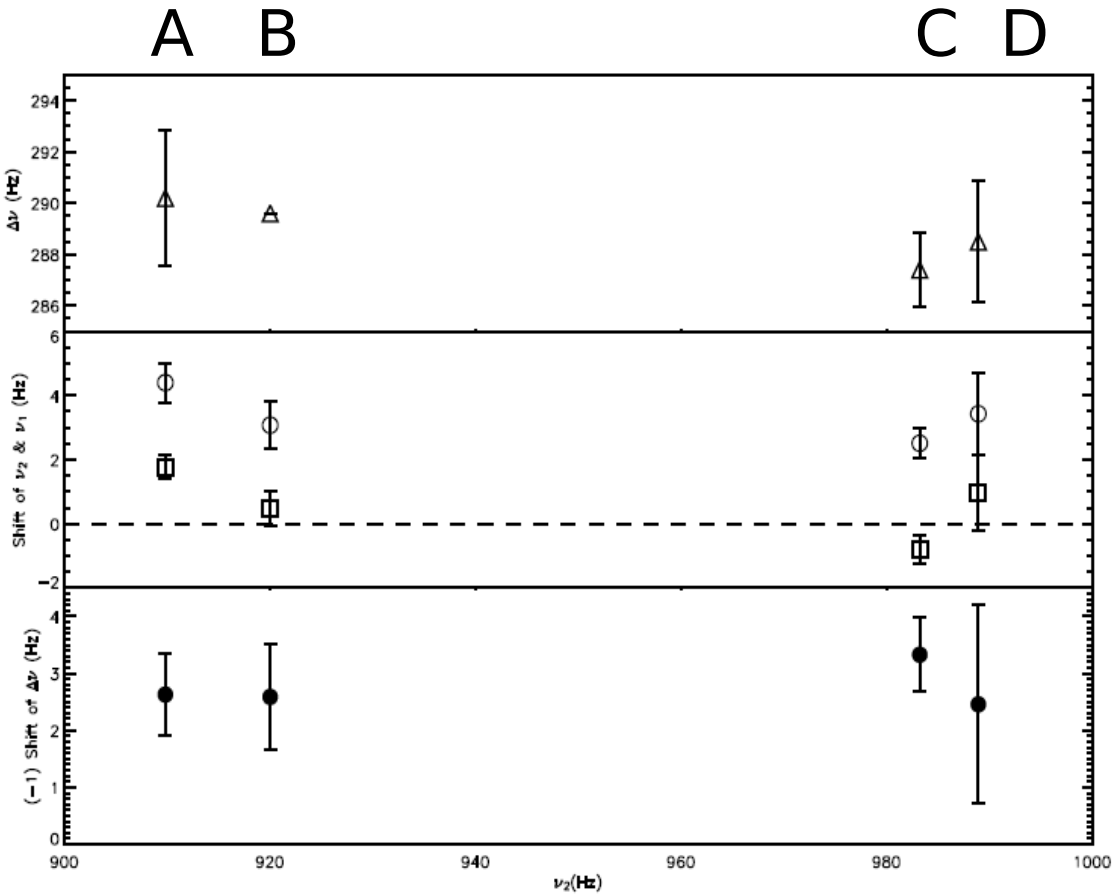
3.kHz QPO & BLN



HB

upper NB


(a)
Average Power
(b)
$\nu_{2h}-\nu_{2l}$(Hz)
(d)
$\nu_{1h}-\nu_{1l}$(Hz)
0.1
1.0
10.0
Frequency(Hz)



circles:
average shift of the lower kHz QPO frequency
squares:
average shift of the upper kHz QPO frequency

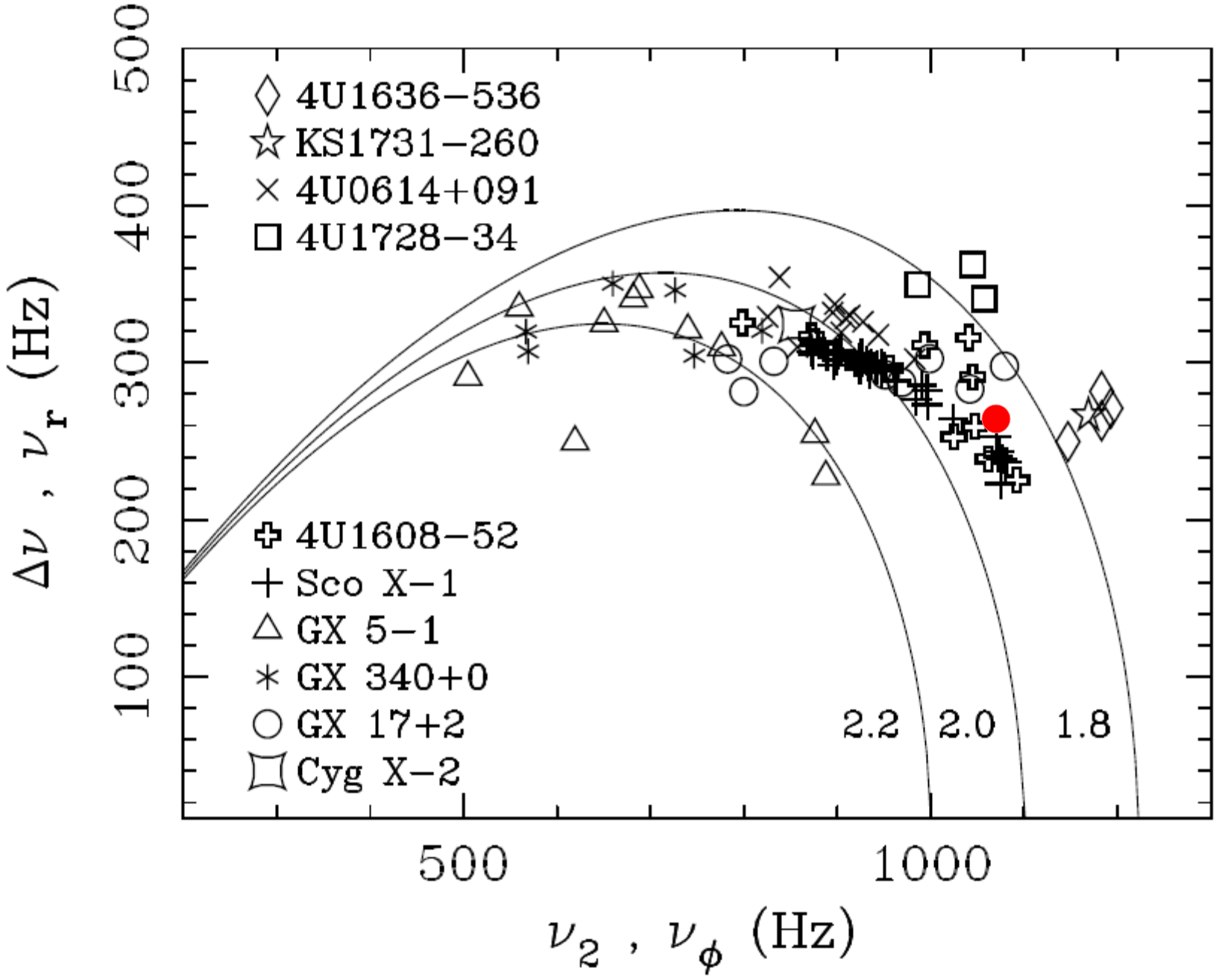
1.Both the upper and lower kHz QPO frequencies are positively correlated with the flux variation on the BLN time scales in the HB.

2.On the BLN time scales $\Delta \nu$ decreases by about 2~4 Hz with increasing upper kHz QPO .

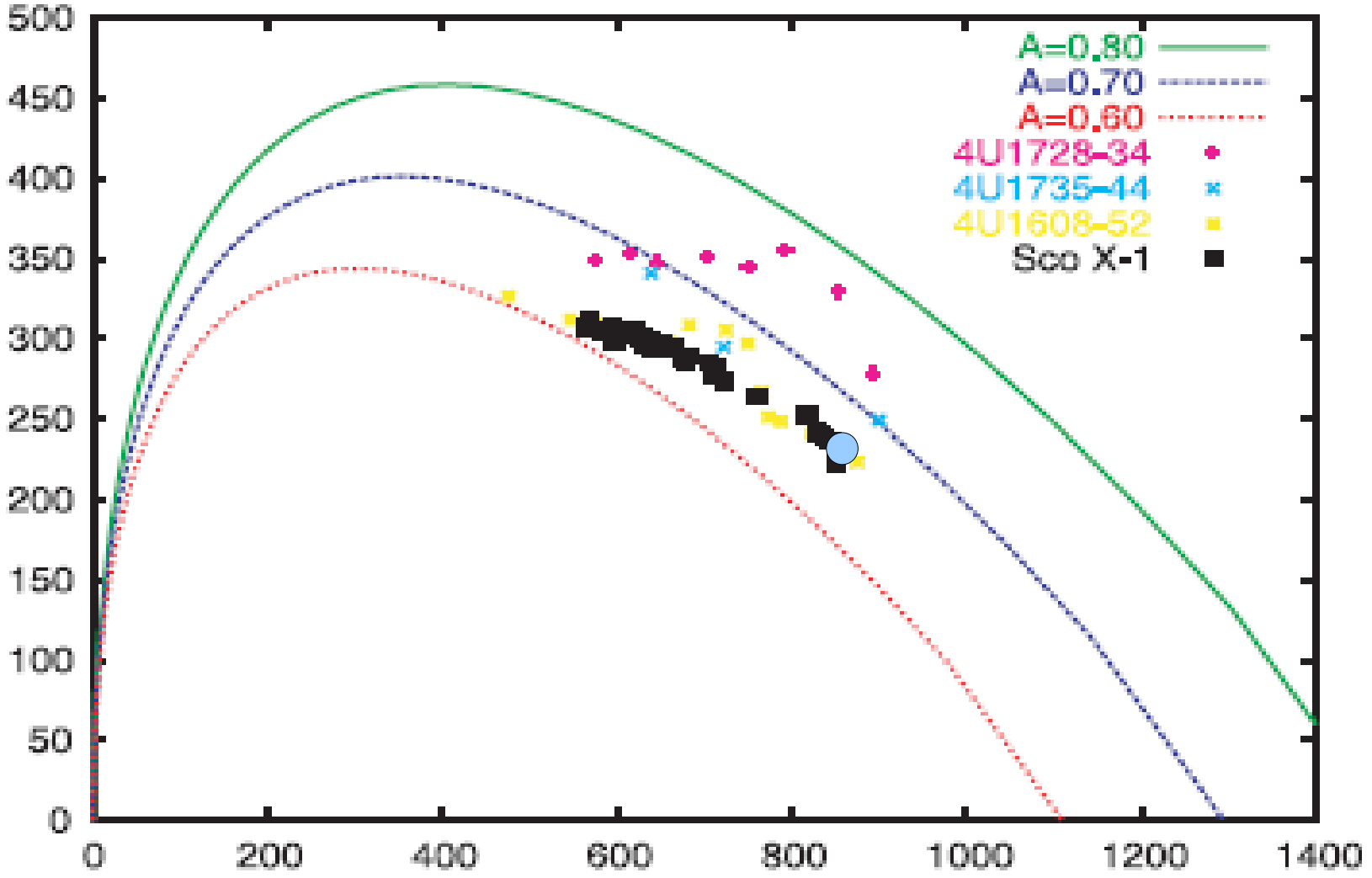
Discussion and Interpretation

- The flux variation associated with the NBO probably originate from inside the inner disk radius.
- The flux variation associated with the BLN probably originate from the mass accretion rate variation in the accretion flow.
- The Δv measured on longer timescales are not accurate , e.g., could be much more smaller.

relativistic precession model (*Stella & Vietri 1998*)



Thanks !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A=0.70
A=0.60
4U1728-34
4U1735-44
4U1608-52
Sco X-1
500
450
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
1200
1400