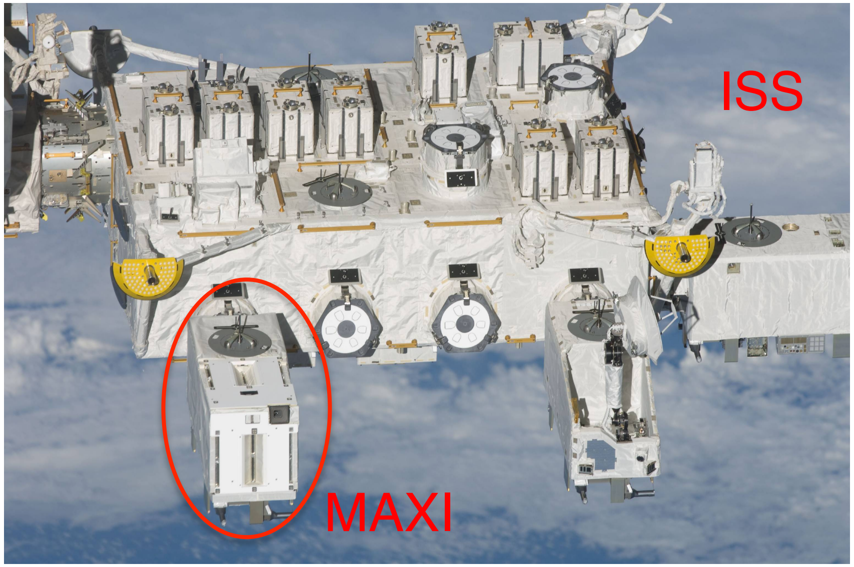

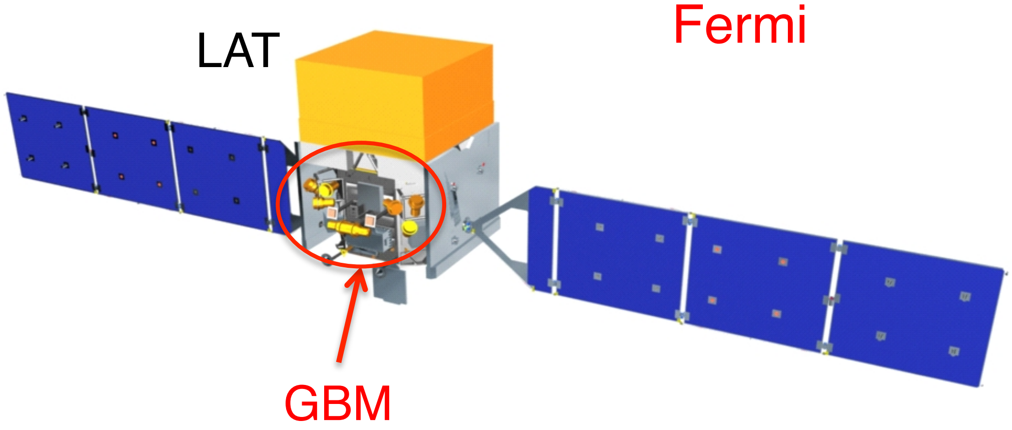

Luminosity and spin-up relation in (Be) X-ray binary pulsars with MAXI GSC and Fermi GBM

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(RIKEN MAXI Team), M. Nakajima (Nihon Univ.)

Outline

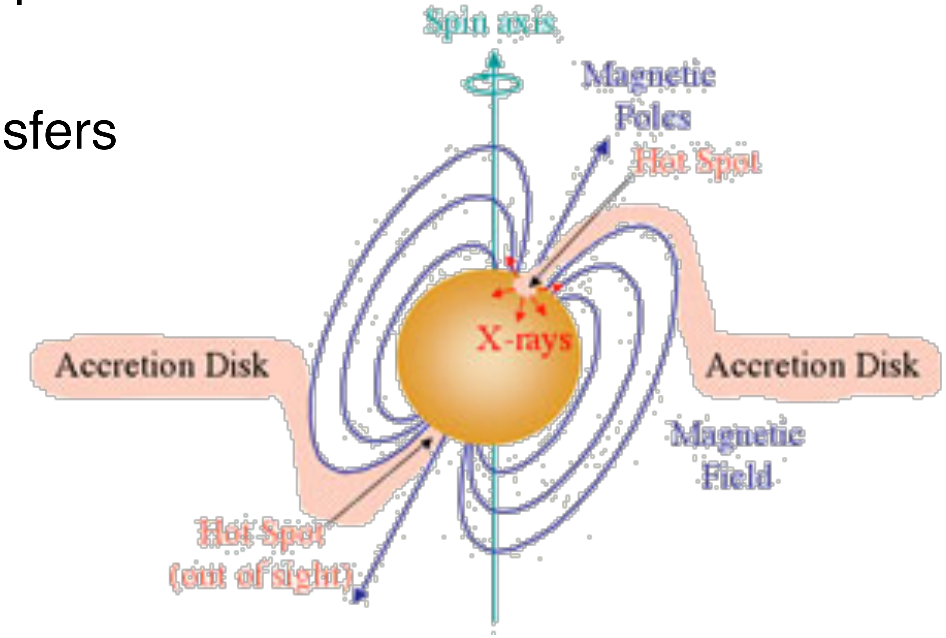
- Accretion powered X-ray binary pulsars (XBPs)
  - 3 subclasses
    - Super Giant XBP
    - Be XB,
    - Low-mass XBP
  - Typical MAXI/GSC and Fermi/GBM data

- Luminosity – spin-up relation in Be binary pulsars with MAXI/GSC and Ferm/GBM
  - Pulsar spin-up/down models (Ghosh & Lamb 1979)
  - Selection of 12 Be XBP sample
  - Data analysis, Discussion
  - Summary

Accretion-Powered X-ray Binary Pulsars (XBPs)

Magnetized NS (B~10^{12}G) + stellar companion

1. Mass-accretion through magnetic filed line
2. Emission from magnetic pole
   → pulsed emission
3. Angular momentum transfers
   → spin-up or spin-down

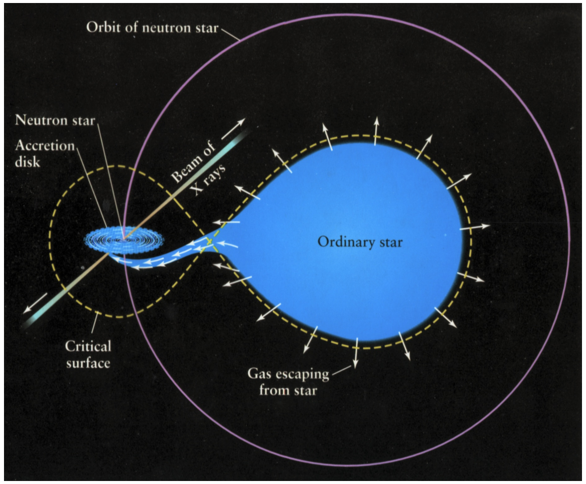


- Relation between Luminosity and P represent
  - ✓ Manner of mass-accretion flow (spherical or disk)
  - ✓ NS physical parameters, connected to *M*, *R*, and *B*

X-ray binary pulsar subgroups

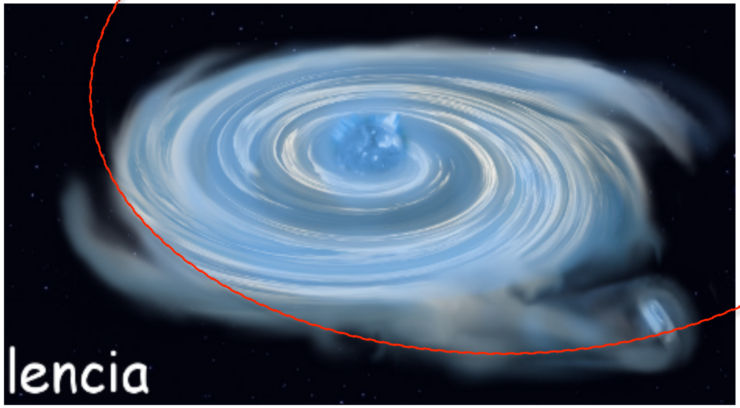
High-Mass XBP ~ 100 detected in our Galaxy

Super-Giant XBP



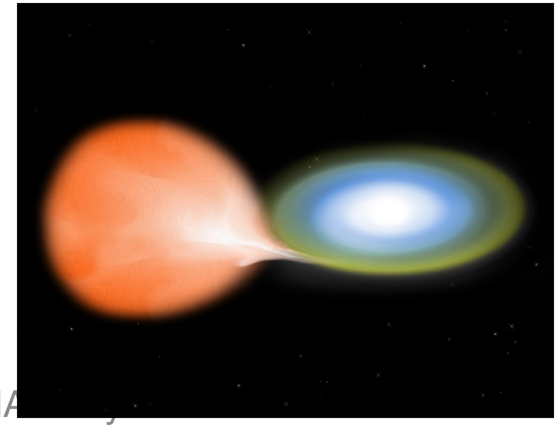
- Persistent
- Wind-fed (majority) or Roche-Lobe overflow

Be XBP



- Transient
- Outburst by orbital period
- Normal/Giant outbursts according to Be-star envelope

Low-Mass XBP ~ 3

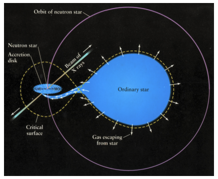


- Persistent
- Roche-Lobe overflow

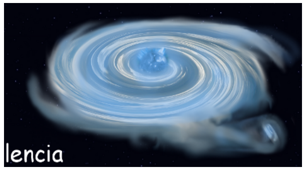
(c.f. review by Reig 2011)

Examples of L_x and P_s changes for 7 years

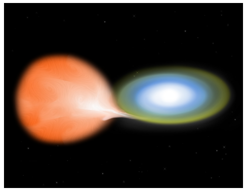
SG XBP



Be XBP

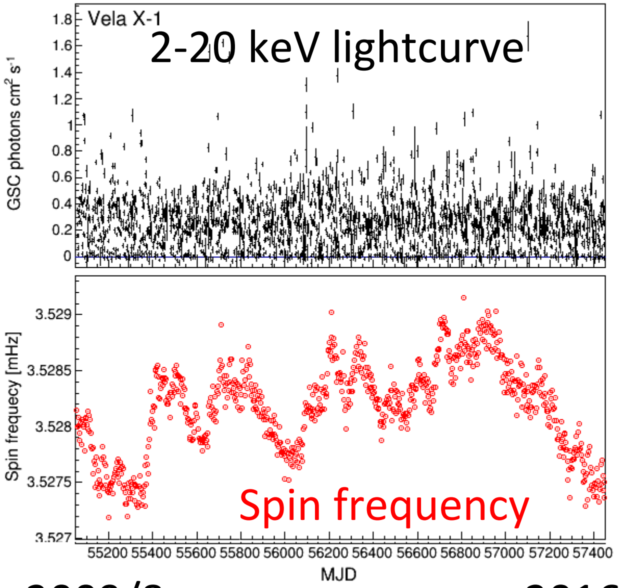


LM XBP



MAXI/GSC

Vela X-1



2-20 keV lightcurve

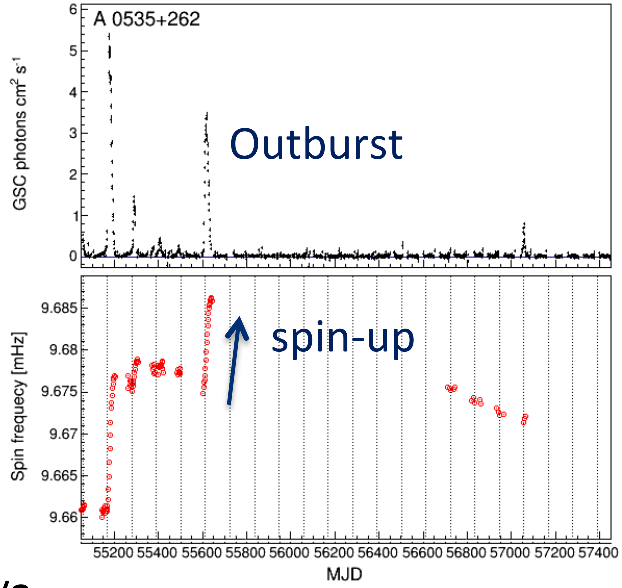
Spin frequency

2009/8

2016/3

Fermi/GBM

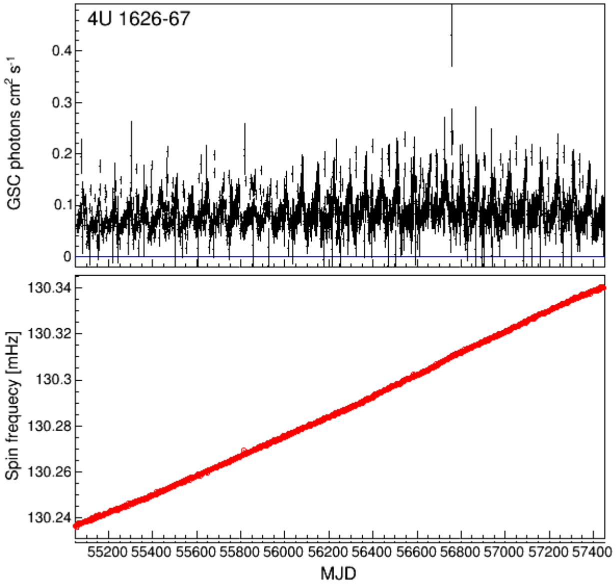
A 0535+26



Outburst

spin-up

4U 1626-67



(Takagi+ 2016)

- Changes reflecting the stellar wind.
- MAXI studies (Doroshenko+2013, Malacaria+2016)

Be XBPs

✓ Transient outbursts

✓ Large intensity and period swings

✓ Good to study luminosity – spin-up relation

Luminosity – spin-up relation in Be binary pulsars

with MAXI/GSC and Ferm/GBM

L_X-P relation from theoretical model (Ghosh & Lamb 1979)

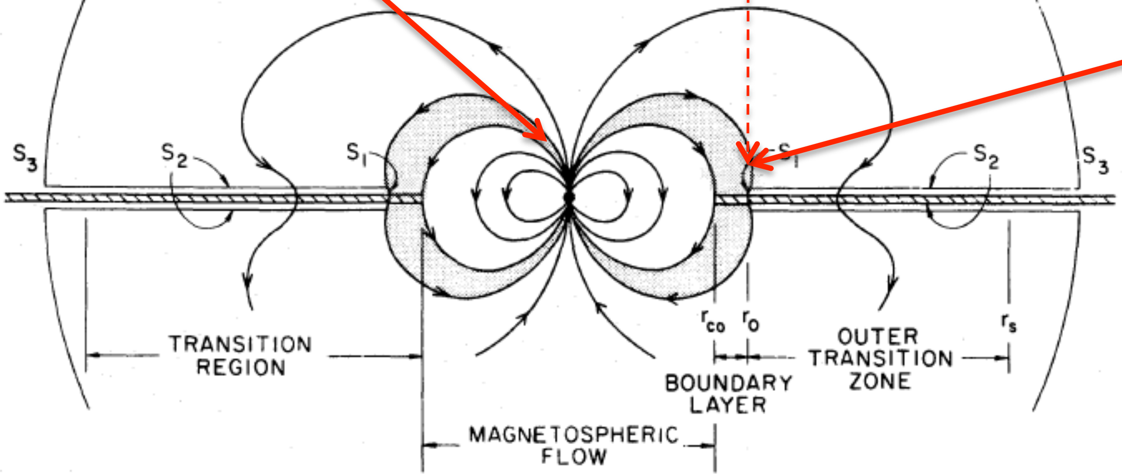
Interaction between accretion disk and pulsar magnetosphere

Cyclotron Resonance Scattering

$\mu_{30} = 1/2\, B_{12} R_6^3$

Angular momentum transferred to NS at

$0.52 r_A = 1.7\times10^8\, M_{17}^{-2/7} \mu_{30}^{4/7} M$



Quasi-Periodic Oscillation

- A 0535+26 (Finger+1996)
- GX 304-1 (Devasia+2011)
- EXO 2030+376 (Angelini+1989)

$$-P = 5.0\times10^{-5}\, \mu_{30}^{2/7}\, n(\omega_s)\, R_6^{6/7}\, M_{\odot}^{-3/7}\, I_{45}^{-3/7}\, P_{1s}^2\, L_{37}$$

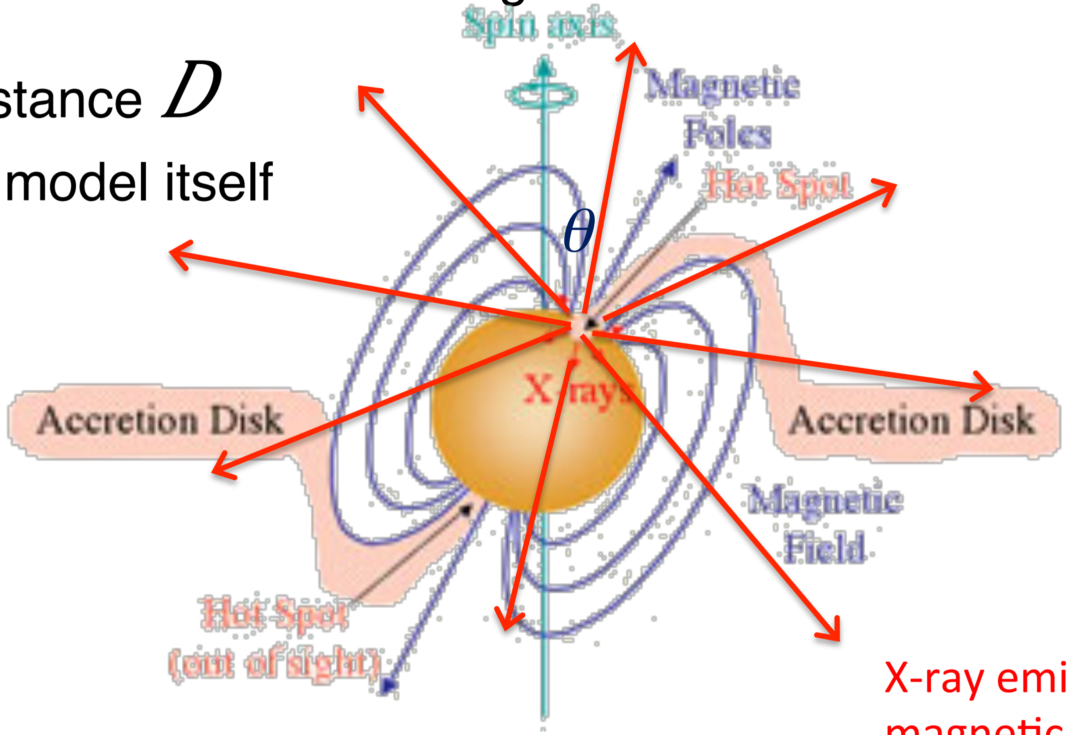
- The relation is roughly confirmed by observations in a precision of about an order of magnitude (Bildsten+1996, …)
- To constrain NS parameters (M-R relation), need careful calibration of the model

Unknown factor in GL79 model application

- Beam fraction fb (pencil /fan pattern, angle)

$$L=4\pi fbD\uparrow 2 \;,\; fb\neq 1$$

- Angle between rotation and magnetic axes $\theta\neq 0$
- Source distance D
- Fidelity of model itself



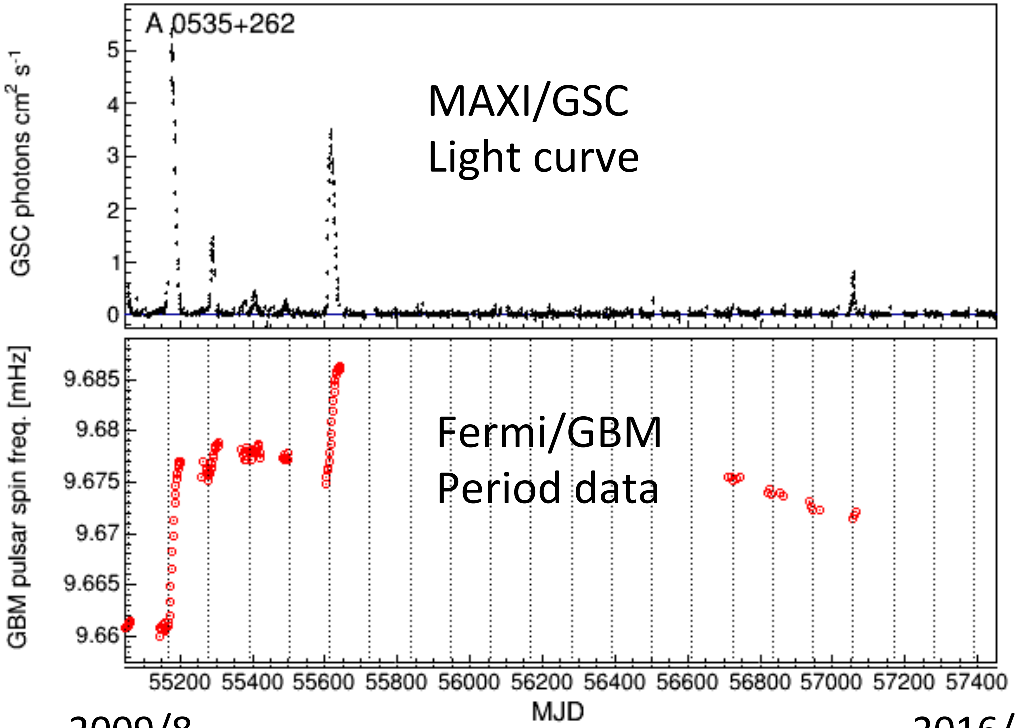
X-ray emission from magnetic pole

MAXI/GSC and Fermi/GBM data for Be XBPs

- ✓ Long-term (7 year) continuous data in both Intensity and pulse period
- ✓ Energy band 2-30 keV (GSC) matchs the main XBP emission.

<u>Update from the previous works with BASTE, Fermi/GBM alone,</u>

A0535+262 P_{orb}=111d

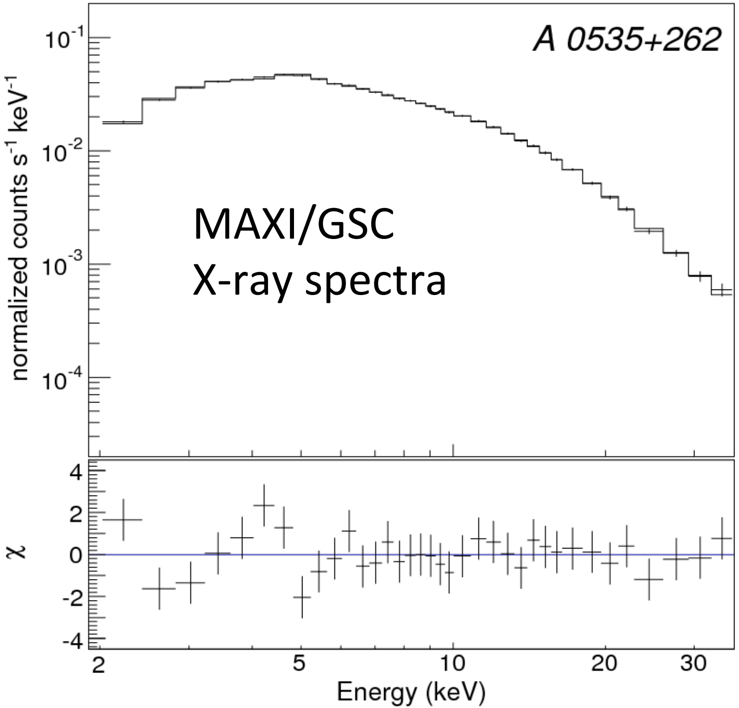


MAXI/GSC
Light curve

Fermi/GBM
Period data

2009/8

2016/3



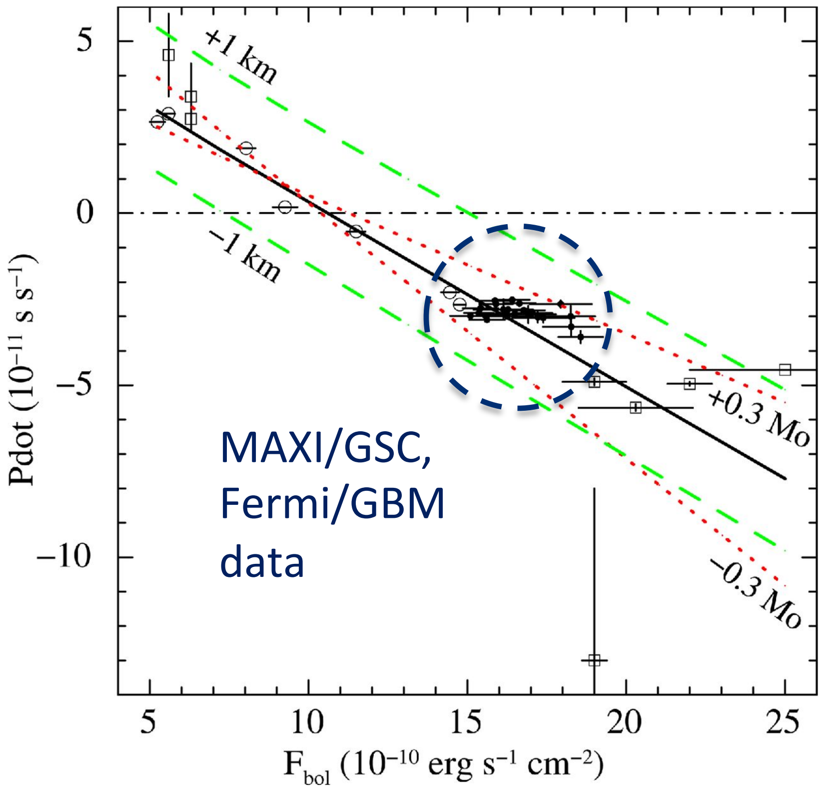
MAXI/GSC
X-ray spectra

2 keV

30 keV

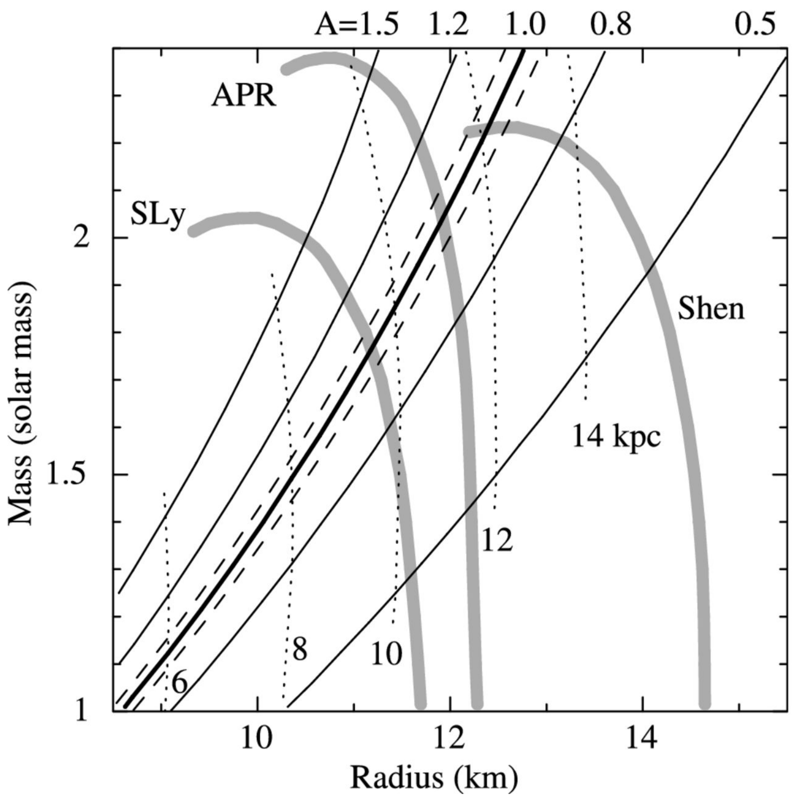
LM-XBP 4U 1626-67 (Takagi et al. 2016)

$P-Fx$ relation



MAXI/GSC,
Fermi/GBM
data

Constaint on $M-R$



- Large distance uncertainty
- Assumption
  - Beaming fraction = 1 ($L=4\pi FD\uparrow 2$)
  - Rotation axis and magnetic axis aligned
  - Ghosh & Lamb model fidelity

Selection of target Be XBPs (12 samples)

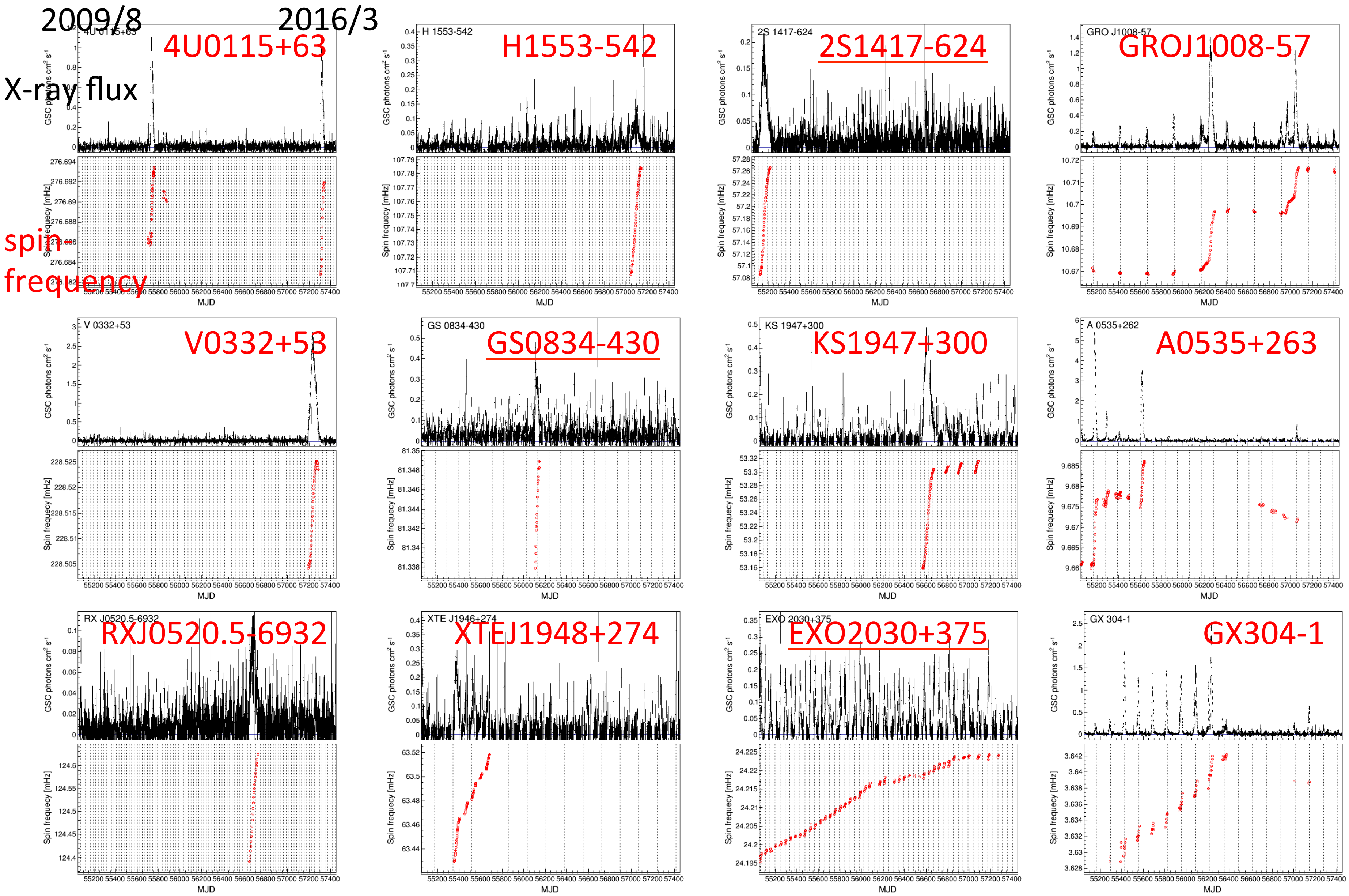
Source name	P_{spin} (s)	P_{orb} (d)	e	Spec.Type	D (kpc)	B (10^{12}G)
4U 0115+63	3.6	24.3	0.34	B0.2 Ve	7±0.3	1.0
V 0332+53	4.3	34.7	0.37	O8.5 Ve	6±1.5	2.7
RX J0520.5-6932	8.0	23.9	0.03	O8 Ve	50±2	2.8
H 1553-542	9.2	30.6	0.04	B1-2 V	20±4	3
GS 0834-430	12.3	105.8	0.12	B0-2 III-Ve	5±2	---
XTE J1946+274	15.8	169.	0.33	B01 IVVe	8.7±1.2	3.1
2S 1417-624	17.5	42.1	0.45	B1 Ve	11±5	---
KS 1947+300	18.7	40.4	0.02	B0 Ve	10.4±0.9	1.1
EXO 2030+375	41.3	46.0	0.41	B0 Ve	6.5±2.5	---
GRO J1008-57	93.5	249.5	0.68	B0e	5.8±0.5	6.6
A 0535+262	103.	111.1	0.47	O9.7 IIIe	2.1±0.5	4.3
GX 304-1	275.	132.2	0.52	B0.7 Ve	2.4±0.5	4.7

- Optical companion is certainly identified as Be star. Distance estimate by optical data.
- Binary orbital elements are determined.

Distance error ~ 20%

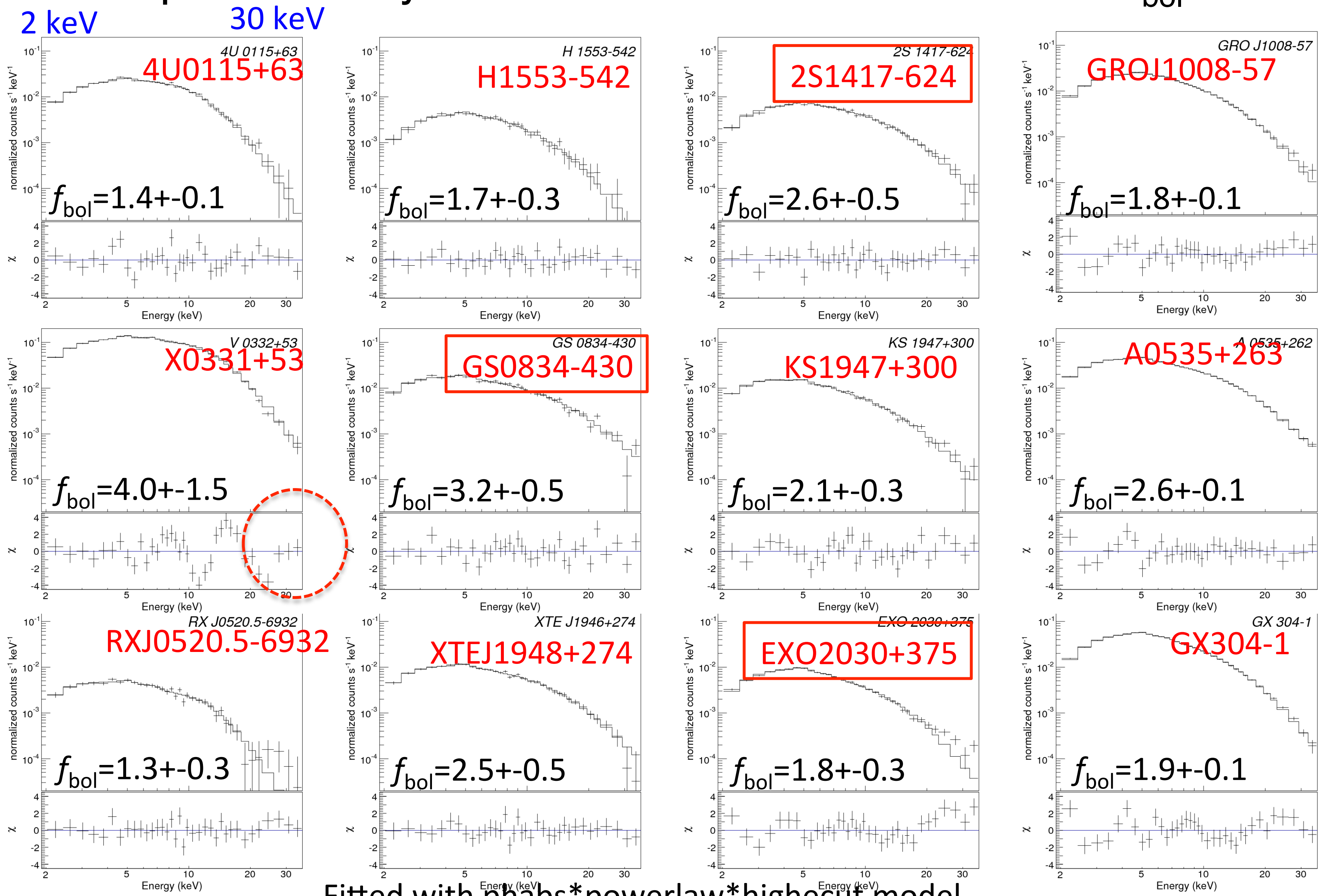
- Significant large outbursts were observed by MAXI GSC and Fermi GBM.
- Cyclotron-resonance feature are mostly obtained.

Data of selected 12 Be XBPs for 7 years



Surface *B* is not measured

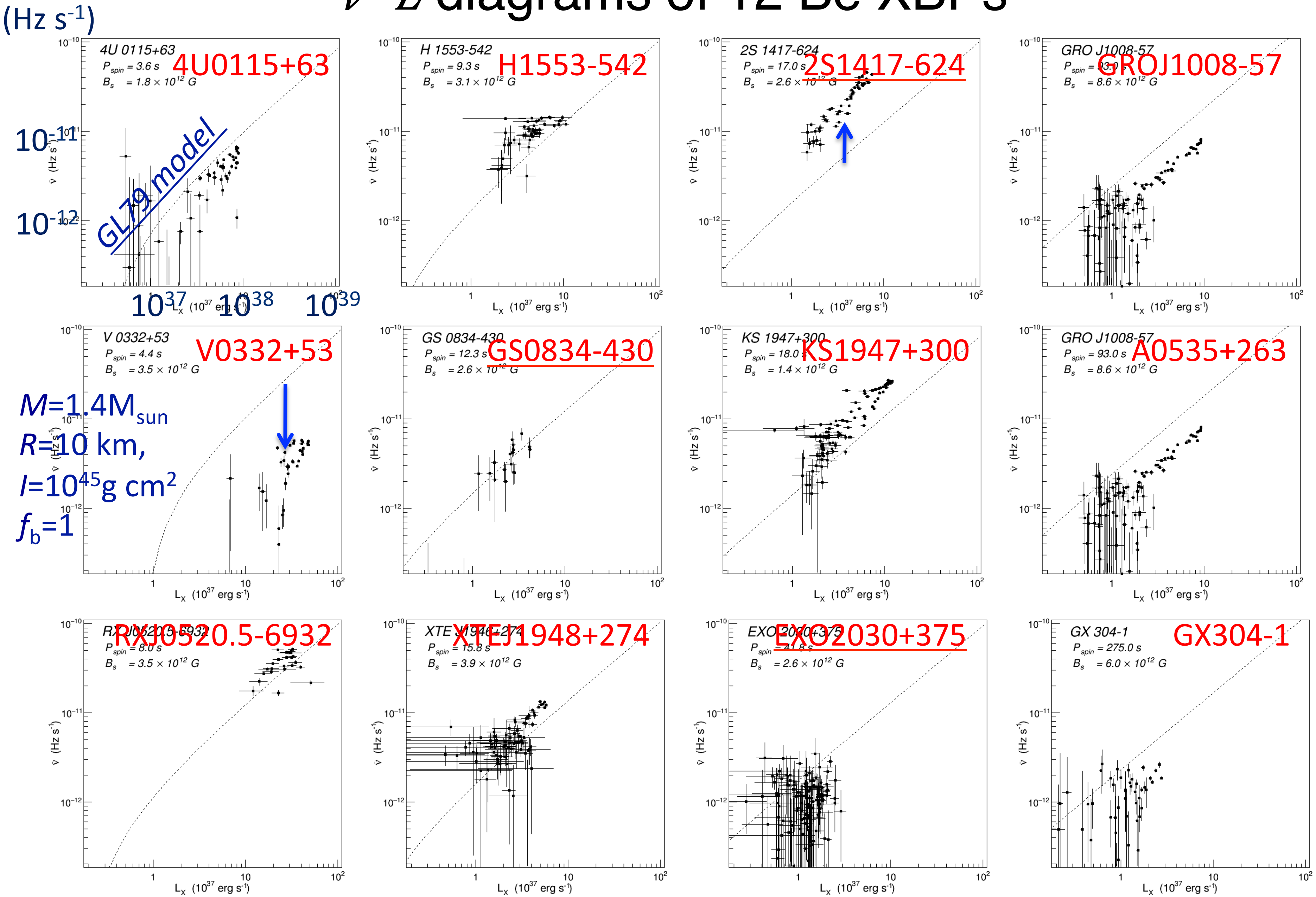
Spectral analysis for bolometric correction factor f_{bol}



Fitted with phabs*powerlaw*highecut model.

Calculate bolometric correction factor from the 2-30 keV photon flux

$\dot{\nu}$-L diagrams of 12 Be XBPs



M=1.4M$_{sun}$
R=10 km,
I=10^{45}g cm^2
f_b=1

B =2x10^{12} G assumed

ν-L relation : data-to-model ratio η

GL79 model $\nu_{GL}(L)=K_{GL}L_{37}^{6/7}$

$R=10$ km

$M=1.4M_{\odot}$

$I=10^{45}$ g cm2

$f_{beam}=1$

f_{bol}

$\mu_{30}=1/2\,B_sR^3$

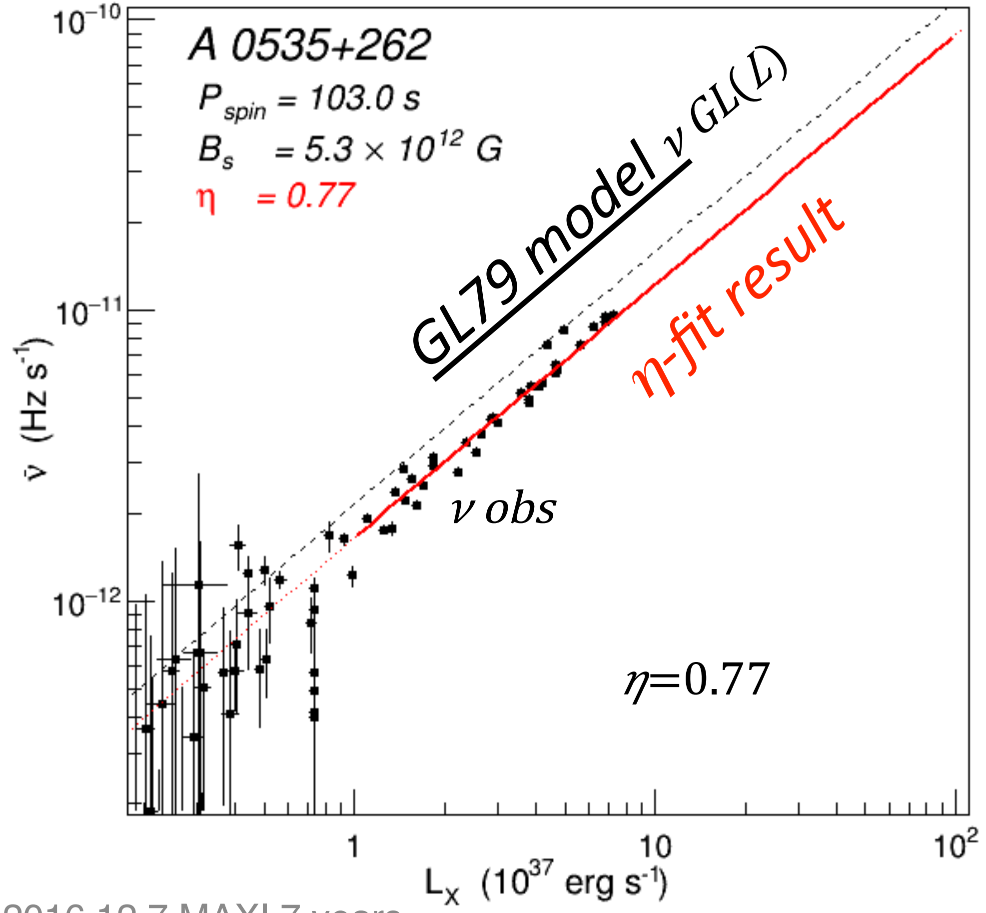
D

X-ray spectral analysis

Cyclotron resonance energy

Optical companion

Sample: A 0535+26



GL79 model $\nu_{GL}(L)$

η-fit result

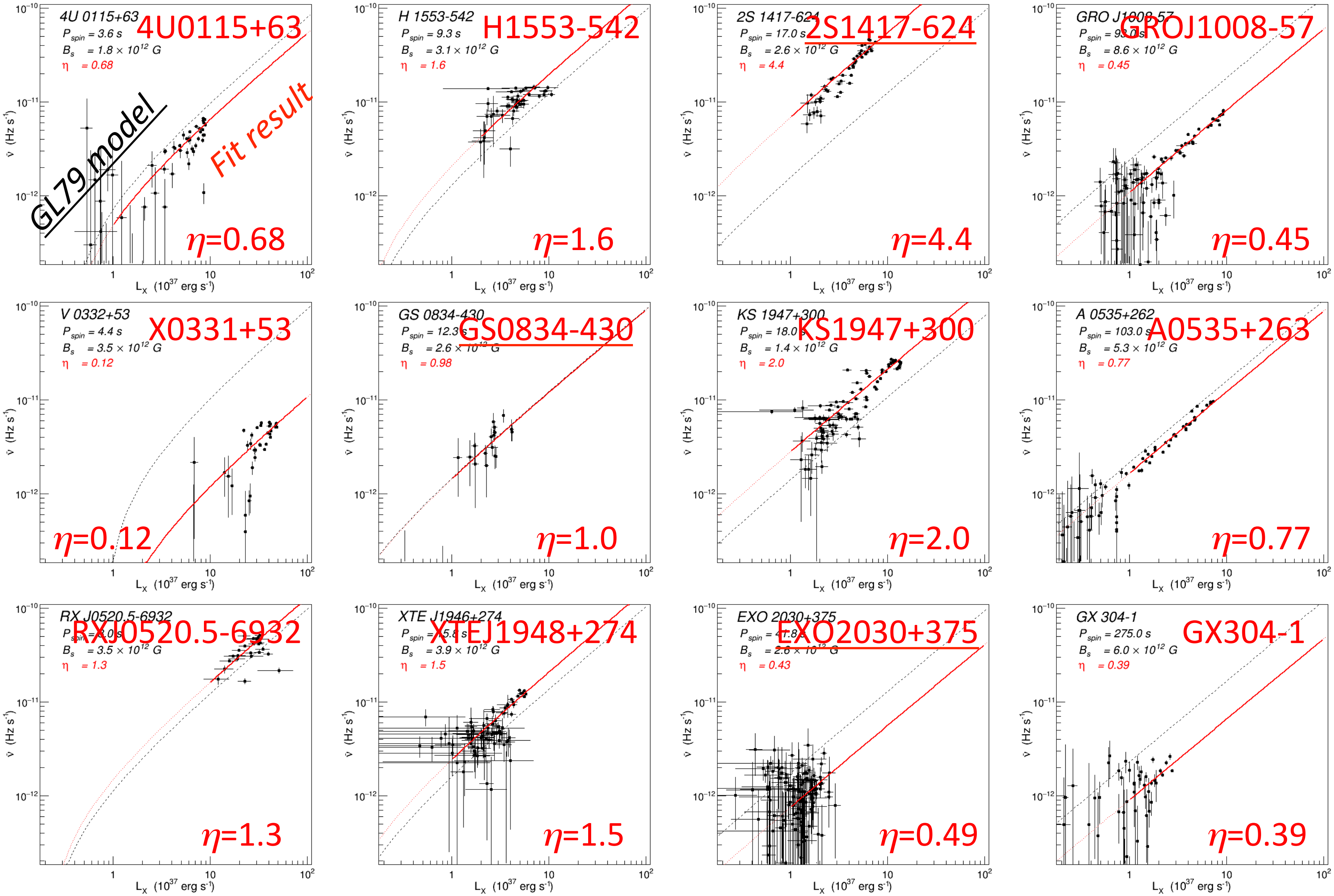
ν_{obs}

$\eta=0.77$

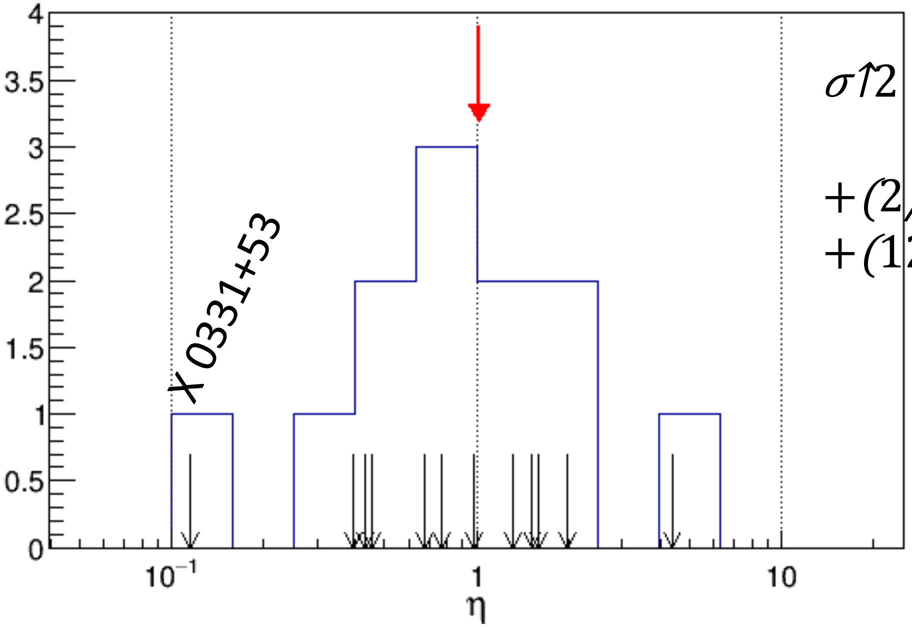
Fit with correction factor: η

$\eta=\nu_{obs}/\nu_{GL}(L)$

$\dot{\nu}$-L diagrams: η model fit



Histogram of spin-up correction factor η



Variance of η

$$\sigma^2(\log\eta) = (10/7)^2\,[\sigma^2(\log MR)] + (6/7)^2\,[\sigma^2(\log fb) + \sigma^2(\log fbol)] + (2/7)^2\,[\sigma^2(\log Ea)] + (12/7)^2\,[\sigma^2(\log D)]$$

Contribution of $\Delta D/D \sim 20\%$

$\sigma\eta/\eta \sim 1.4$

Assuming $\Delta fb/f \sim 50\%$

$\sigma\eta/\eta \sim 1.7$

Average $\langle\eta\rangle = 1.0 \pm 0.25$ (68%)

Standard dev. $\sigma\eta/\eta = 2.1$

(excluding X331+53)

Summary

- The luminosity – spin-up relation of 12 Be XBPs are analyzed by using 7-years MAXI/GSC and Fermi/GBM data

- Observed relations for 11 targets largely agree with the GL97 model within a correction factor η of ~0.4-4
  - Confirmed the previous results.
  - Average $\langle\eta\rangle = 1.0 \pm 0.25\ (68\%)$ confirm the GL97 model fidelity
  - $\eta \sim 0.1$ for X 0332+53. Distance estimate may be wrong.

- The dispersion of correction factor is explained by assumed parameter errors, which are mainly on
  - Emission beam fraction, $\Delta fb/f \sim 50\%$
  - Distance, $\Delta D/D \sim 20\%$

- To better constrain the M-R relation, careful assessment of emission beaming fraction and distance are important.