Workshop on “Variable Galactic Gamma-ray Sources”
Heidelberg, 30 Nov - 3 Dec 2010

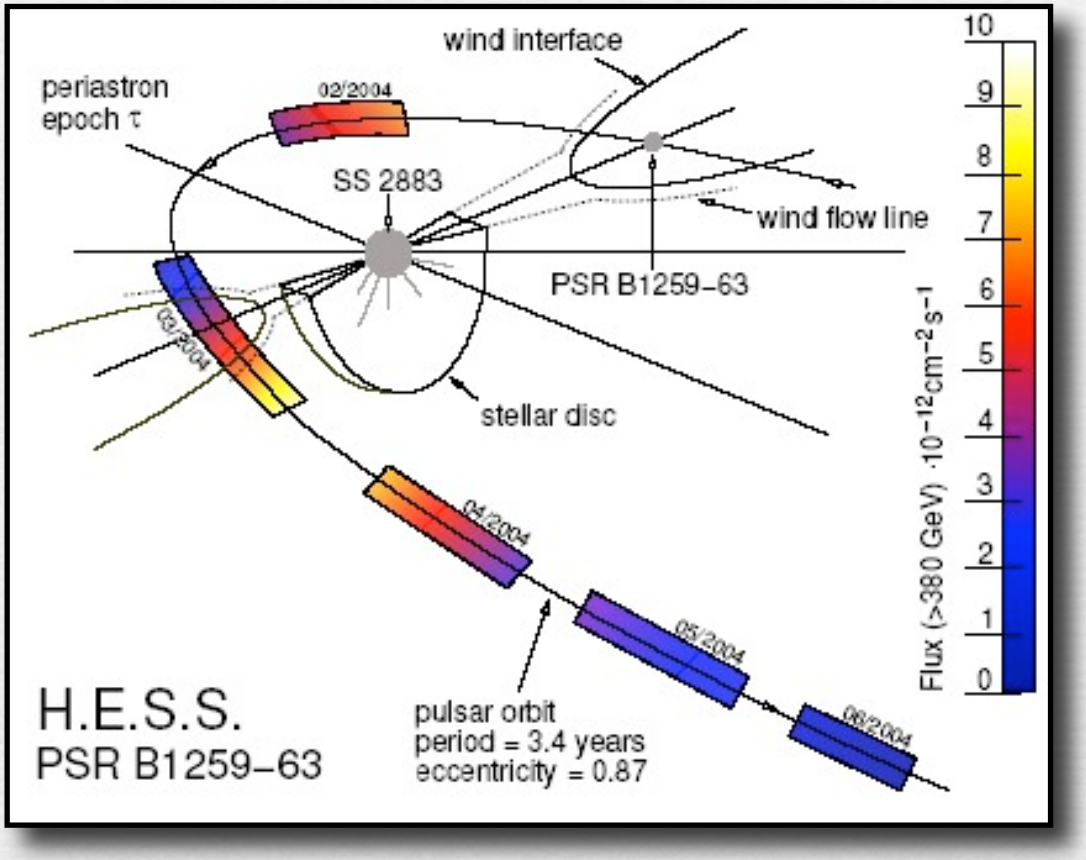
Gamma-ray Binaries @ X-rays: Spectra, Variability, ~~Morphology~~

Yasunobu Uchiyama (SLAC)

Gamma-ray-emitting X-ray Binaries

- **PSR B1259-63** (**spindown of a pulsar**)
  - orbital period: **3.4 years**
  - TeV (HESS)
- **LS 5039** (**unknown source of power**)
  - orbital period: **3.9 days**
  - TeV (HESS) & GeV (Fermi-LAT)
- **LS I +61° 303** (**unknown source of power**)
  - orbital period: **26 days**
  - TeV (MAGIC/VERITAS) & GeV (Fermi-LAT)
- **[Cyg X-1/3]** (**accretion onto BH/NS: microquasar**)
  - **X-ray = accretion disk/corona, reprocessed by surroundings**
  - Transient Gamma-ray emitters

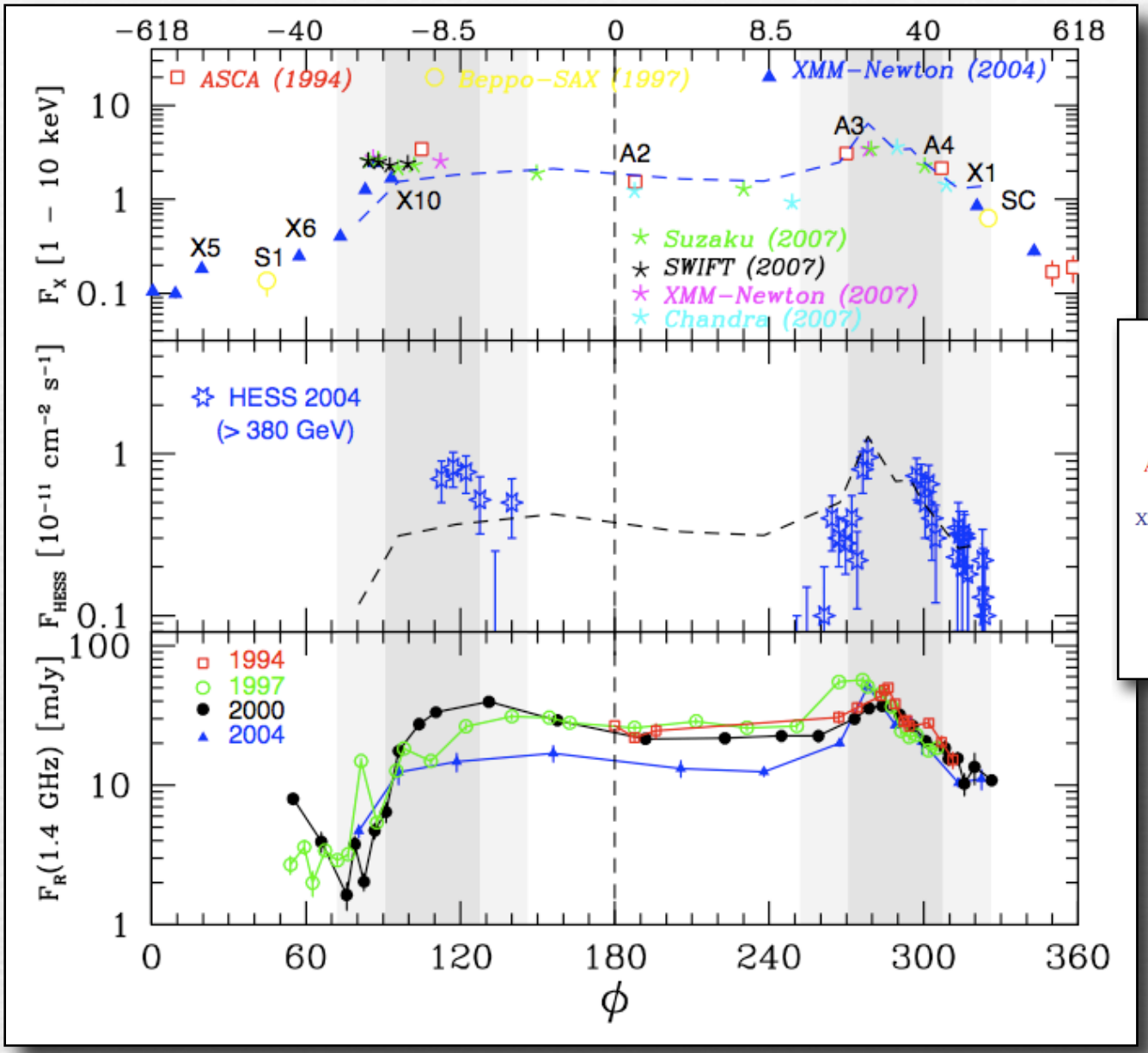
PSR B1259-63

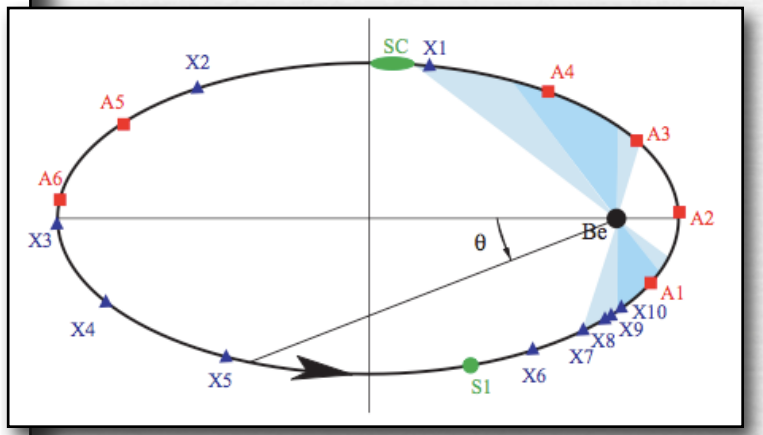


- Period 3.4 year (e~0.87)
- R_{orb} ~ 0.7 AU (at periastron)
- SS2883 B2e (10 M_{sun})
  - Circumstellar Disc
- Pulsar
  - spin period: 48 ms
  - pulsation disappears near periastron
  - $L_{spin\text{-}down} = 8 \times 10^{35}$ erg/s

Y. Uchiyama

PSR B1259-63: Light Curves

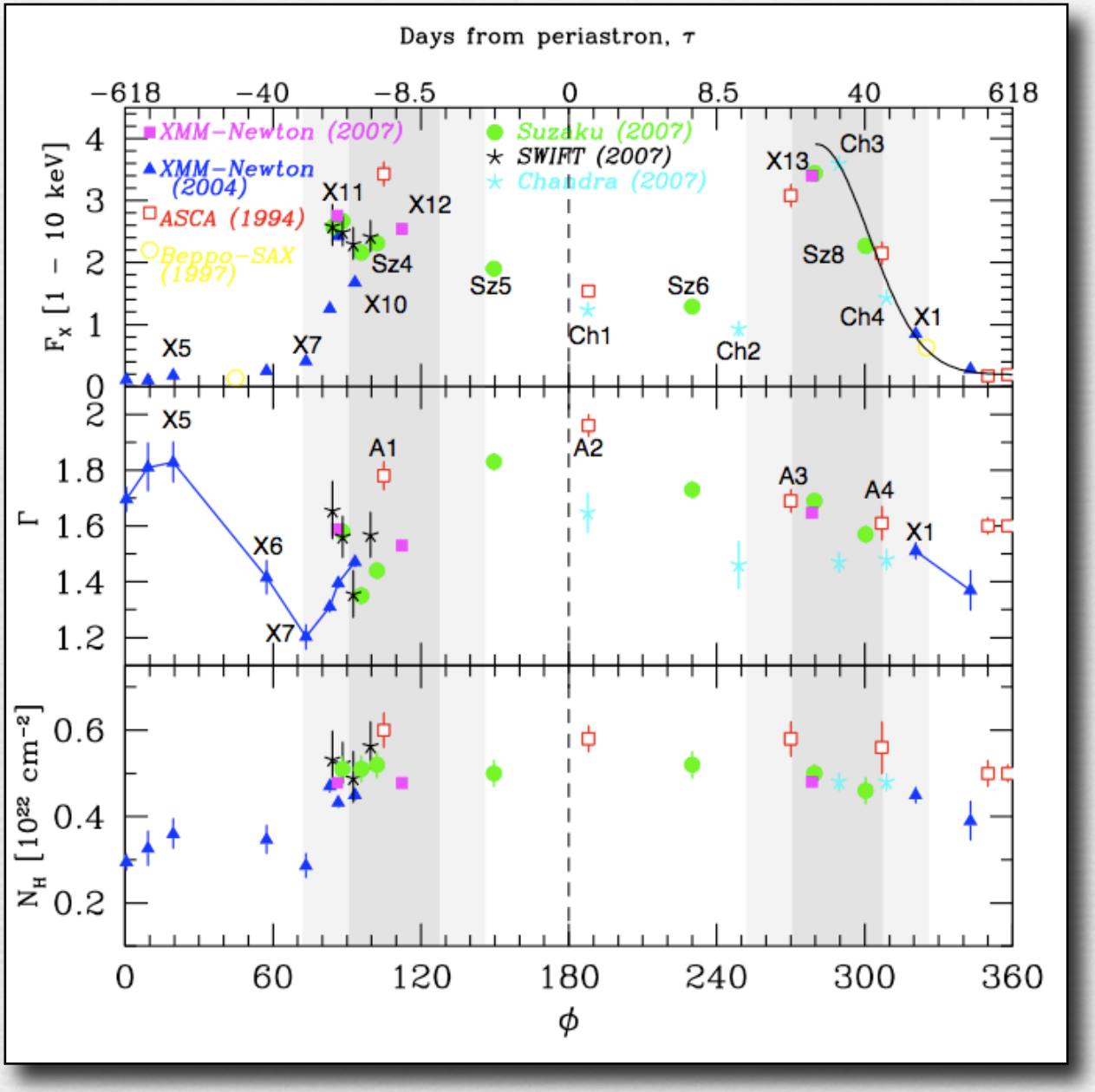




Compiled by Chernyakova+09

Y. Uchiyama

PSR B1259-63: X-ray Evolution

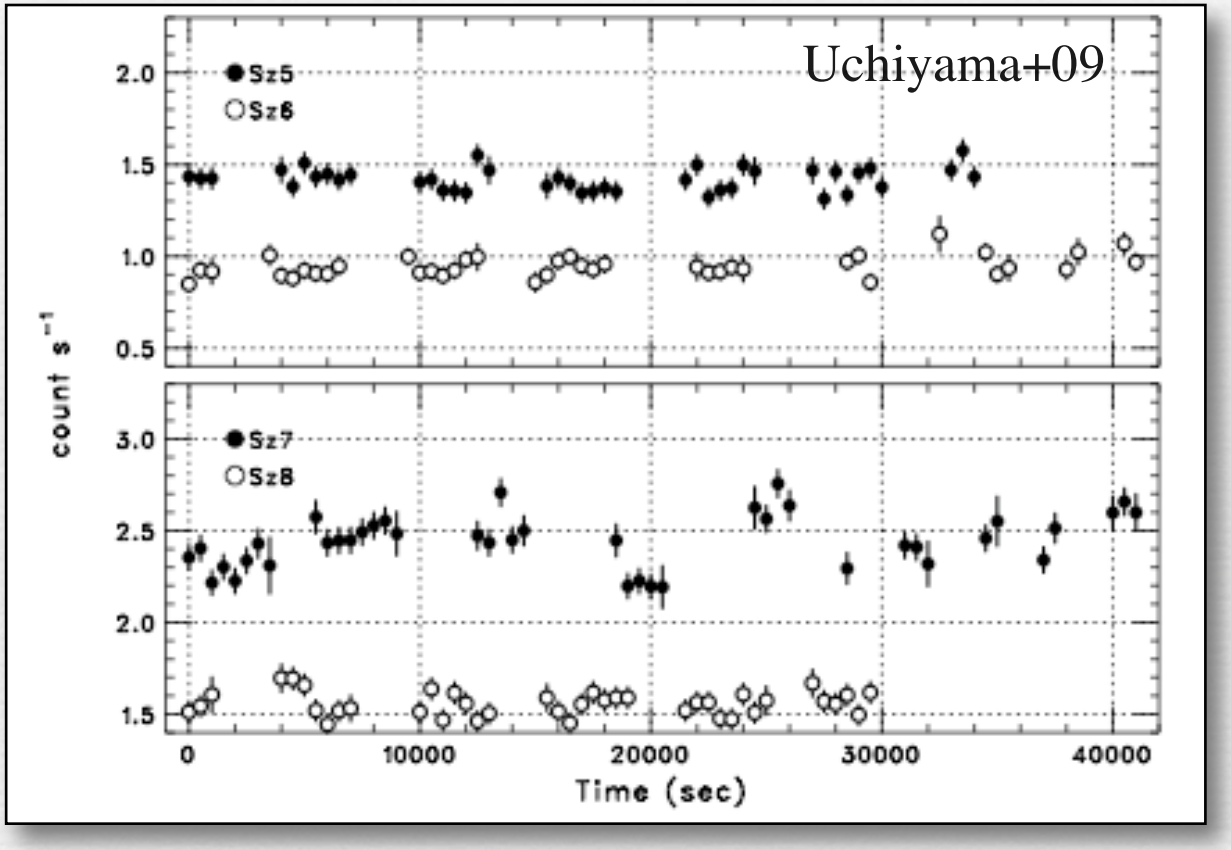


Compiled by Chernyakova+09

- Power-law
  - **Γ =1.2 - 2.0**
  - **Δ(electron index)=1.6**
- Absorption
  - modest column density
  - increase at disk entrance
- No pulsation found

Y. Uchiyama

PSR B1259-63: Hour-scale Variability



Periastron (out of disk)
= constant emission
(on day-scale)

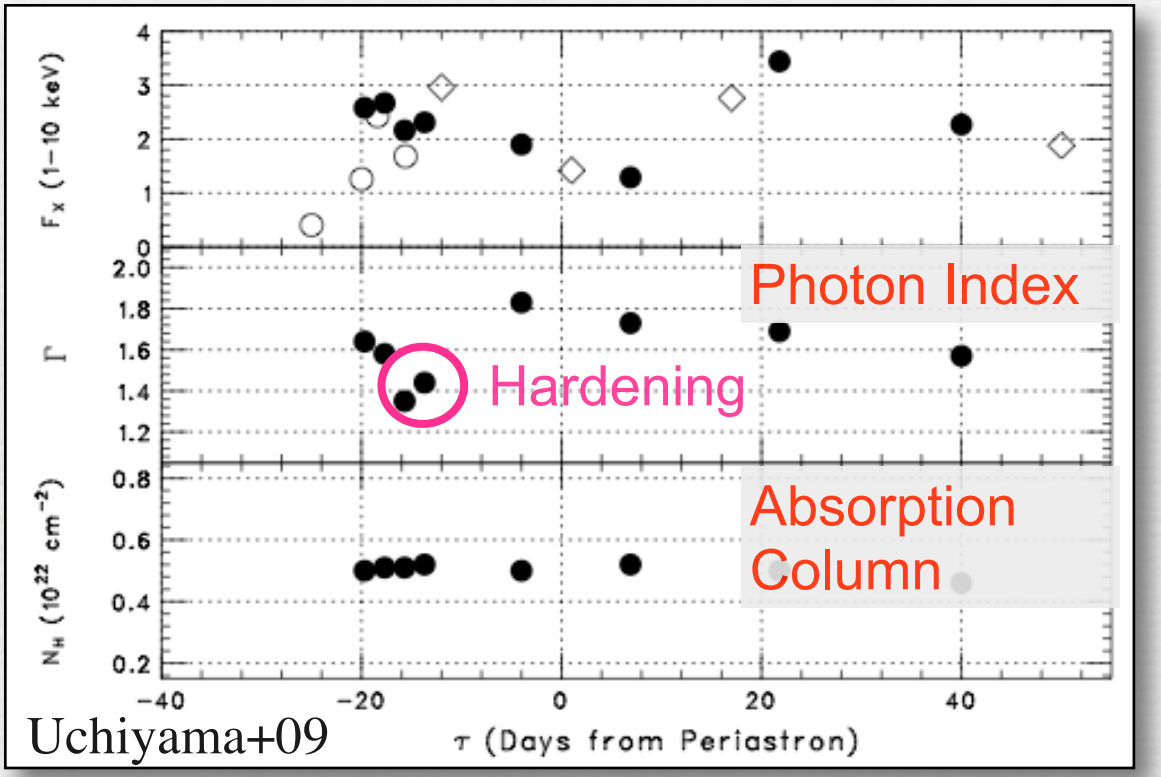
2nd disk transit
= hr-scale variability
(fluctuating at 20% level)

1 bin = 500 sec

Y. Uchiyama

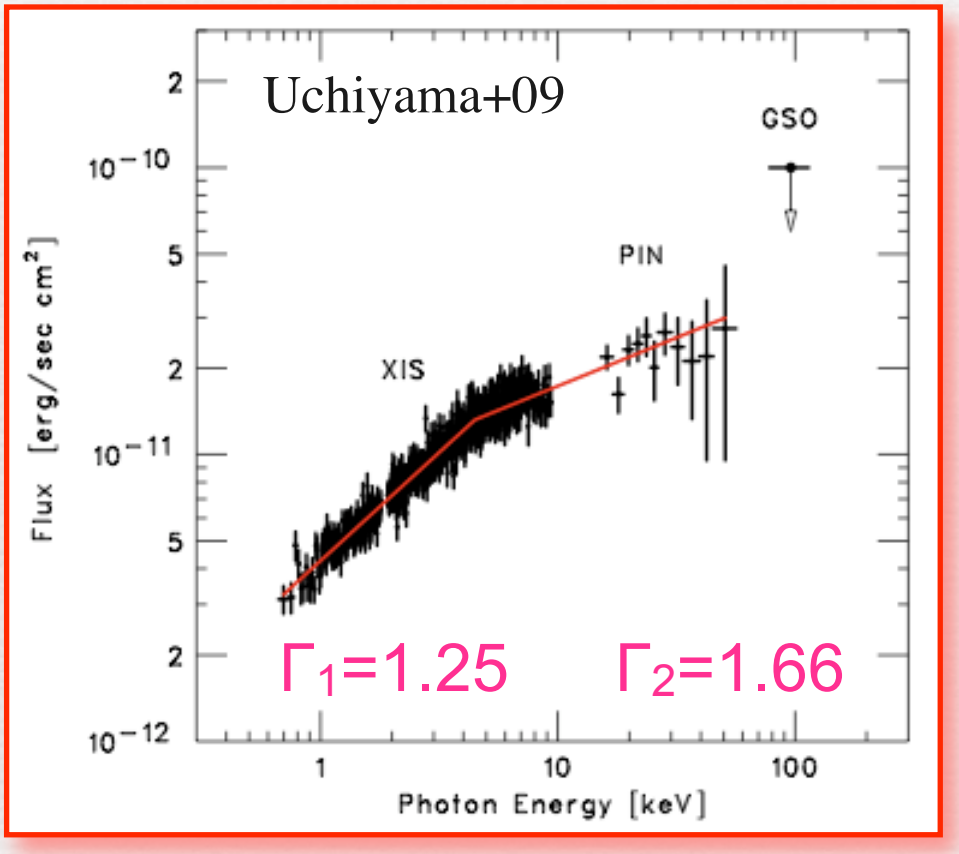
PSR B1259-63: *Suzaku* Broadband Spectra

Spectral Evolution



0.5-10 keV X-ray : **power-law** shape

Spectrum in 0.5-60 keV

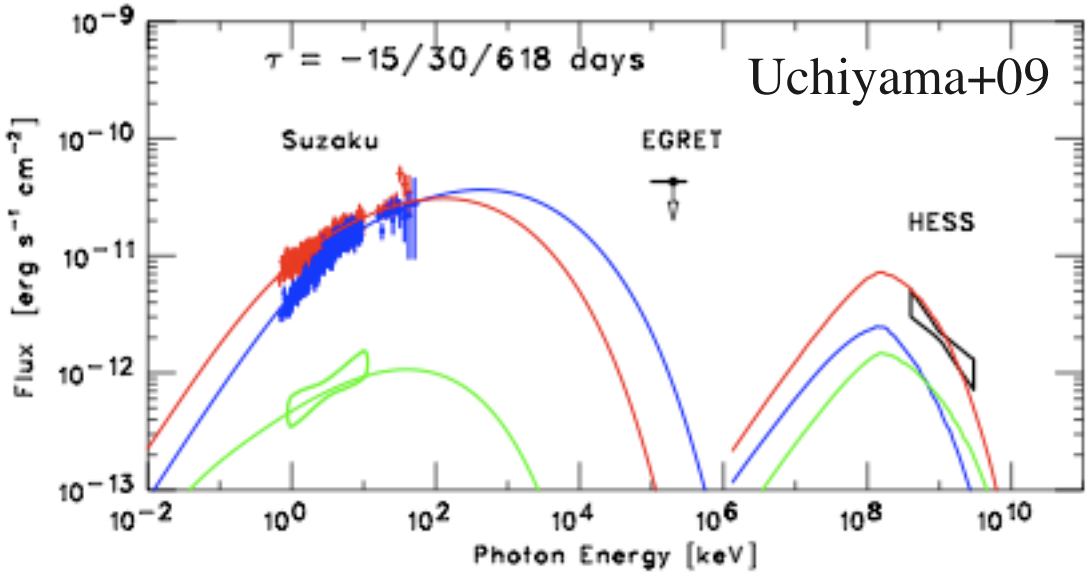


Hardening = Break Appearance

Y. Uchiyama

PSR B1259-63: **Synchrotron** X-ray Model

"Compactified" Pulsar Wind Nebula Scenario



τ		ϵ	σ	γ_1	p	E_m (TeV)	ζ	ξ
−15 days	···	0.1	0.01	4×10^5	1.9	10	0.05	3
+30 days	···	0.1	0.01	4×10^5	1.9	10	0.15	10
+618 days	···	0.1	0.01	4×10^5	1.9	10	0.50	2

Notes. ϵ (a fraction of the spin down power channeled into the accelerated $e^{\pm}$ pairs), σ (the magnetization factor of the pulsar wind), γ_1 (the Lorentz factor of the pulsar wind), p (the acceleration index), $E_m = \gamma_m m_e c^2$ (the maximum energy of accelerated pairs), $\zeta = r_s/d$ (the distance of the termination shock from the pulsar divided by the pulsar-Be star separation), and ξ (the parameter to describe the adiabatic loss rate).

ε = 0.1
accelerated pair / spin down power

σ = 0.01
magnetization factor

$\gamma_1 = 4 \times 10^5$
wind Lorentz factor

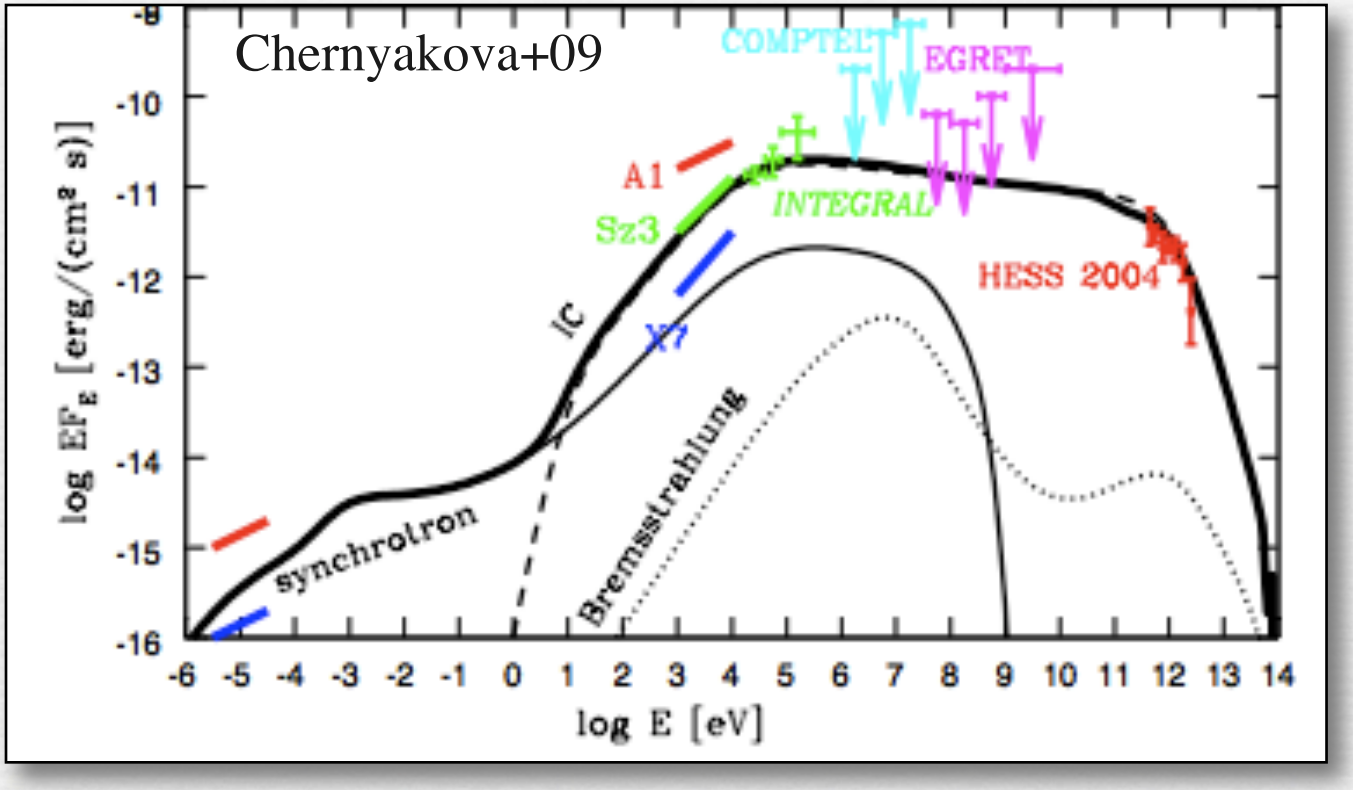
X-ray break position

p = 1.9
acceleration index

E_m = 10 TeV
maximum energy

Y. Uchiyama

PSR B1259-63: **IC** X-ray Model



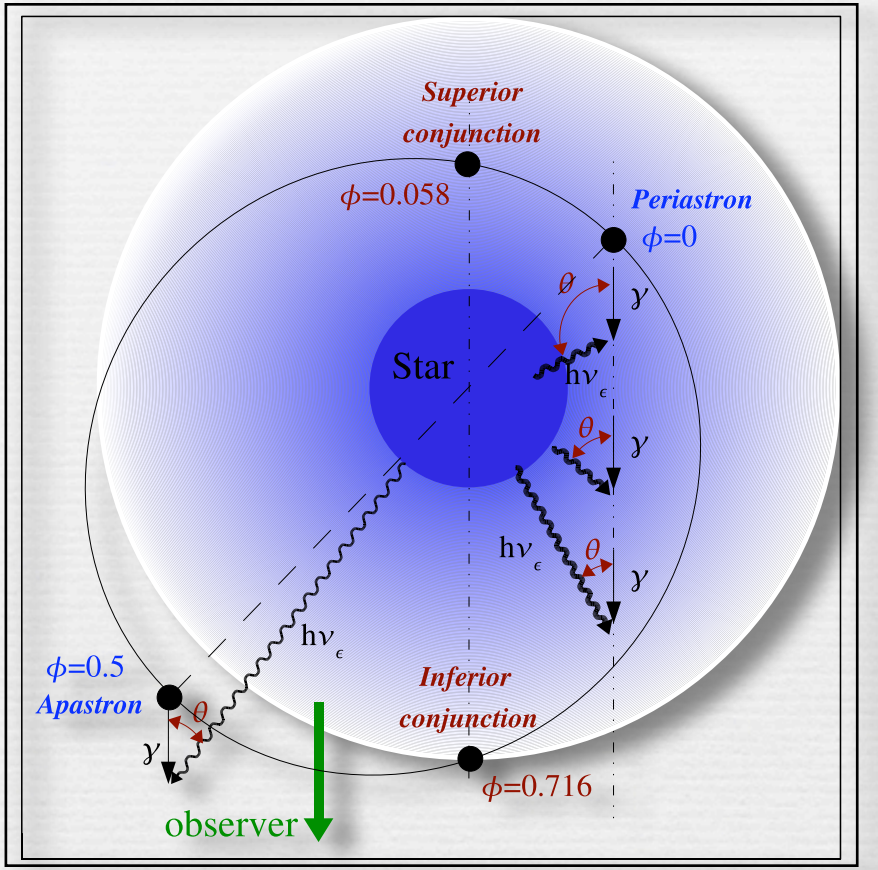
X-ray spectral break:
Enhanced Coulomb losses in the stellar wind?

- **Fermi-LAT** (0.1-300 GeV) observations during the next periastron passage (Dec 2010!) may detect GeV gamma-rays.
- Future **X-ray polarimetry (like GEMS)** may give a definitive answer about synchrotron vs IC.

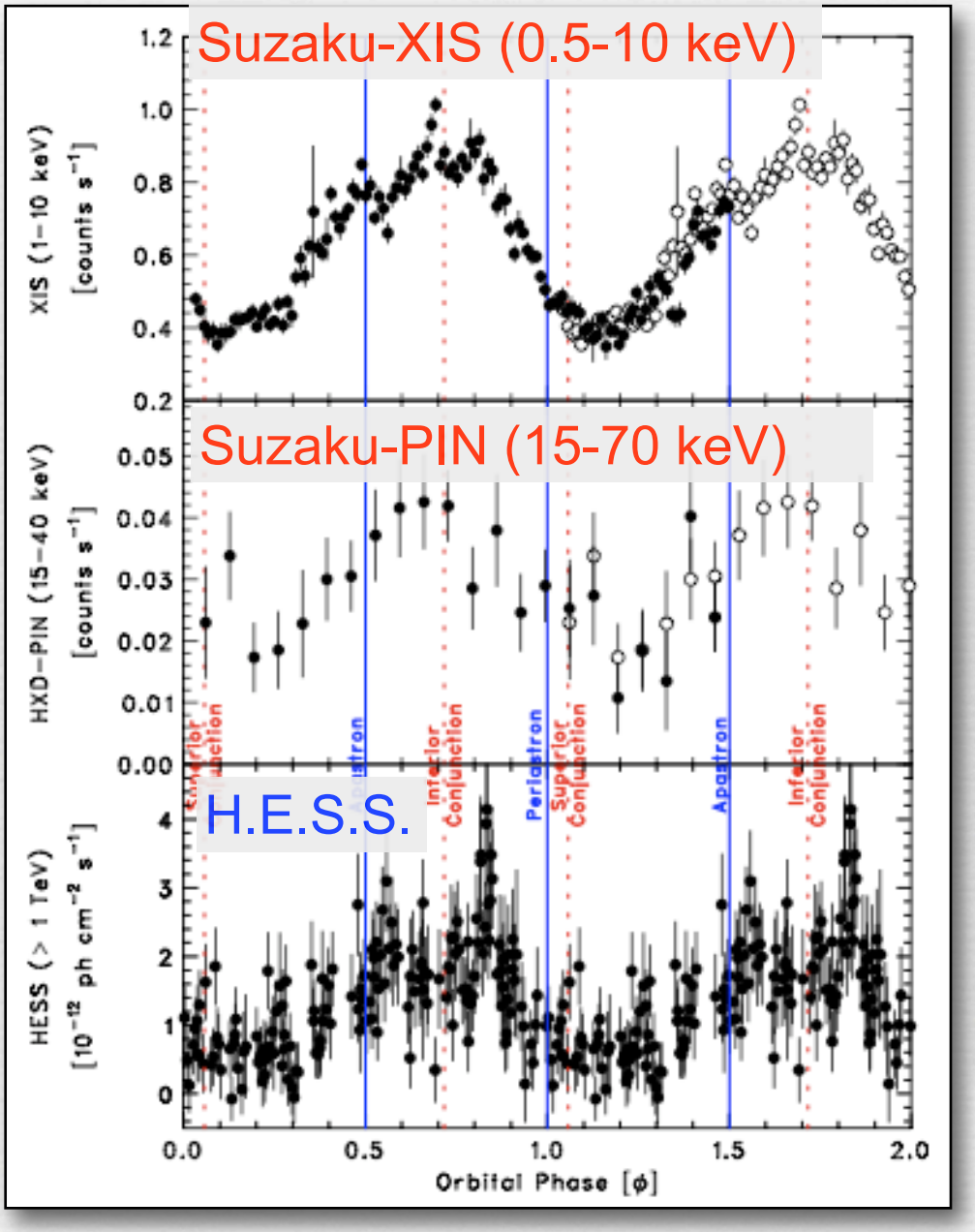
Y. Uchiyama

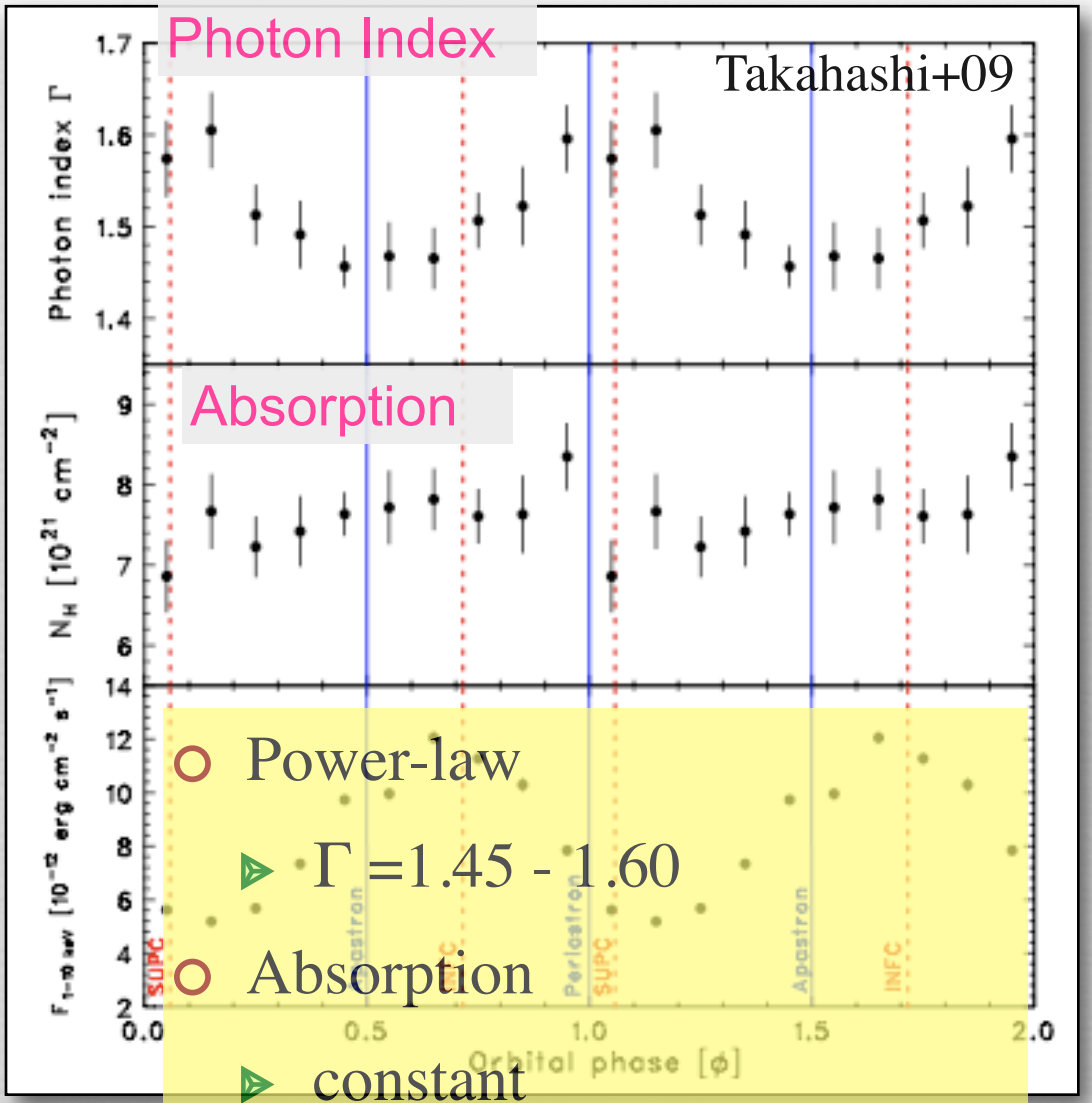
LS 5039

- Period 3.9 days (e~0.3)
- R_{orb} ~ 0.1 AU
- O6.5V(~20 M_{sun})
- Compact object
  - Unknown (1.5-5 M_{sun})
- Relativistic outflow
  - extending to ~10 AU
- **No evidence for accretion disk**



LS 5039: *Suzaku* continuous 1.5 orbit



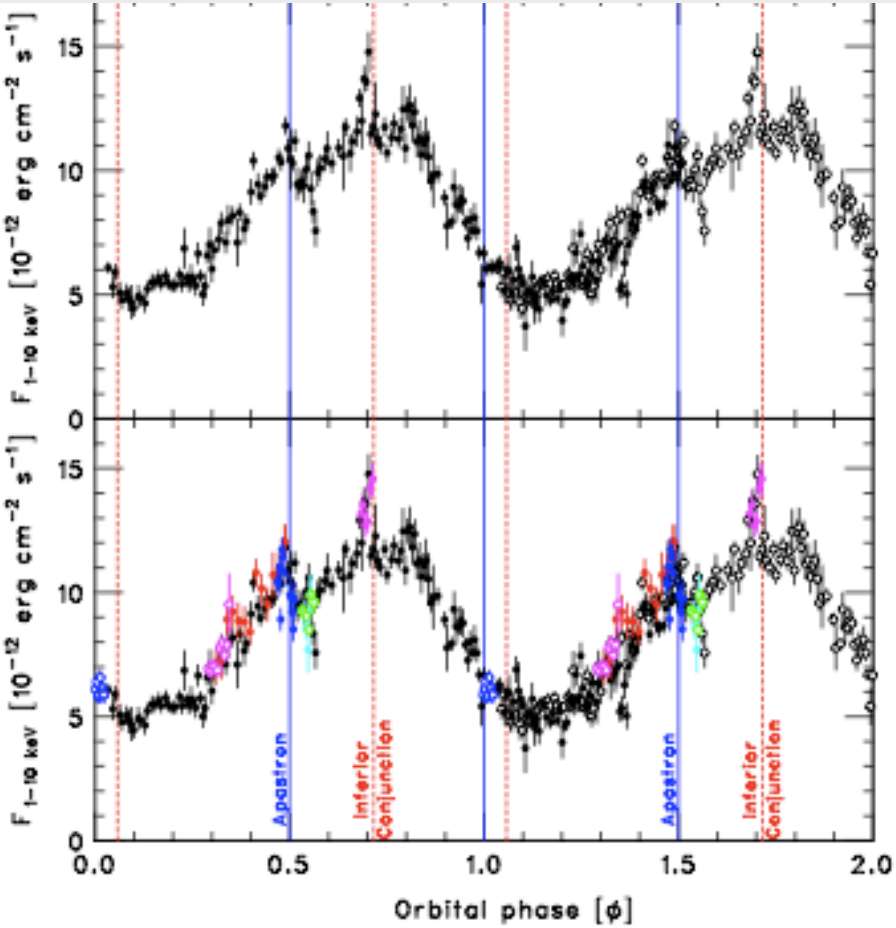


- Power-law
  - Γ =1.45 - 1.60
- Absorption
  - constant
  - modest column density
- No pulsation found

LS 5039: Long-term Stability

ASCA (1999), XMM-Newton (2003,2005), Chandra (2004), Suzaku (2007)

Kishishita+09



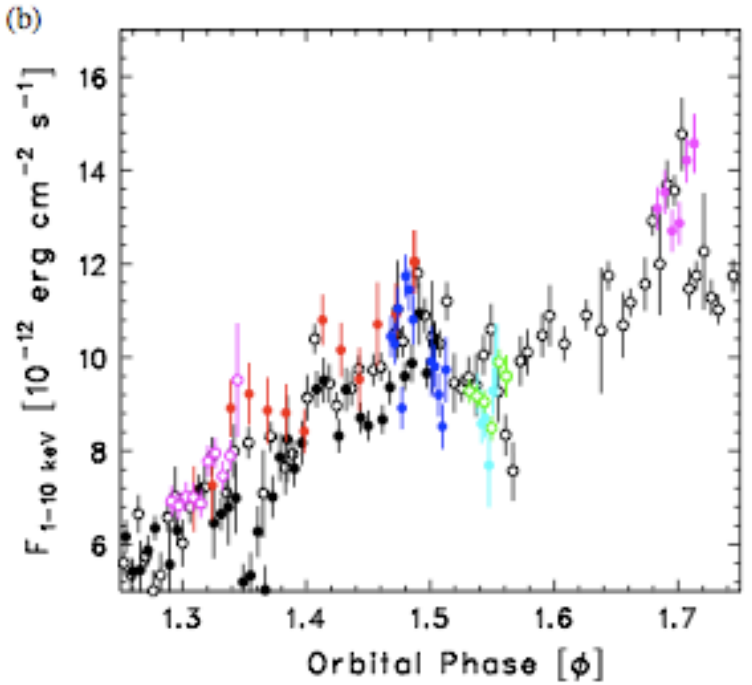
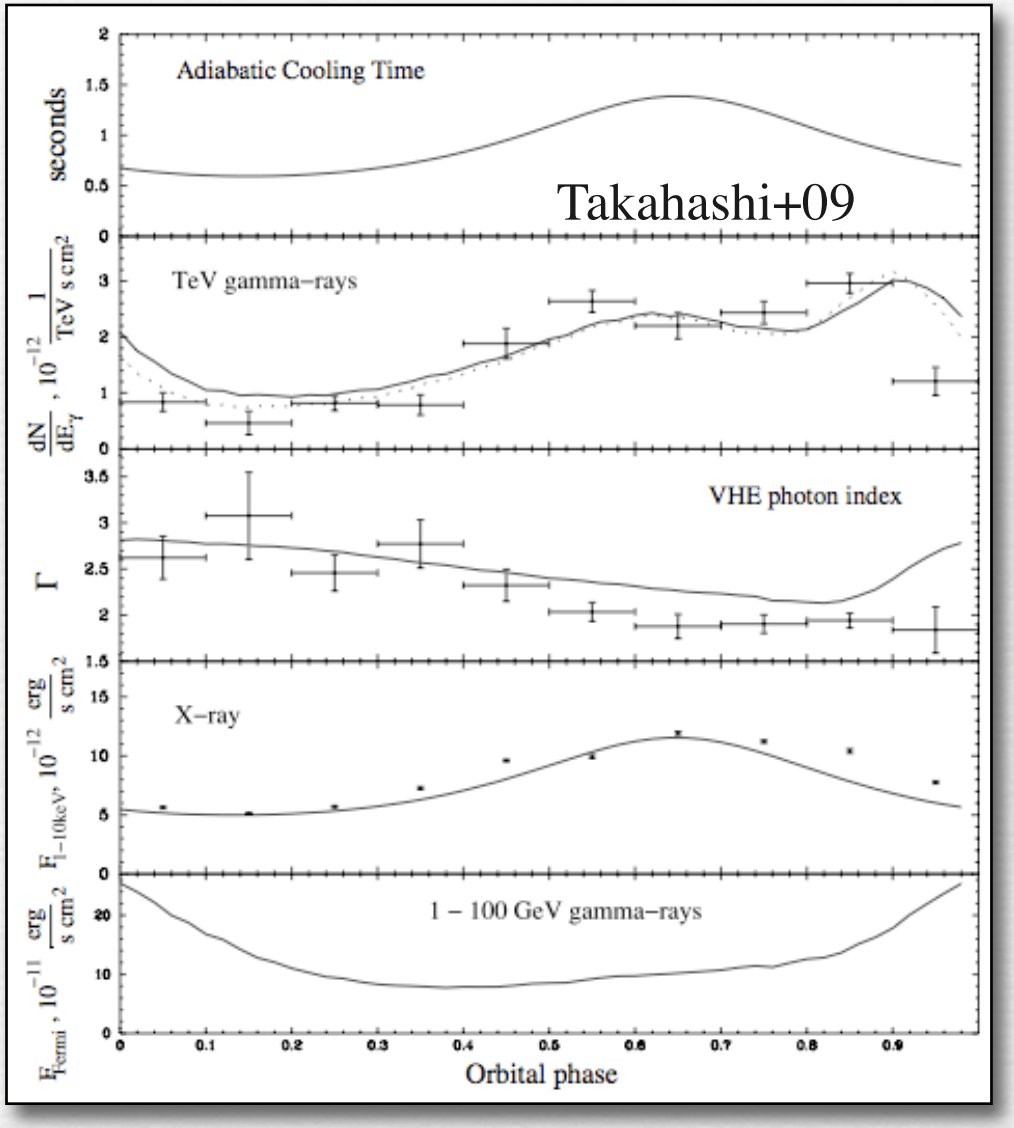
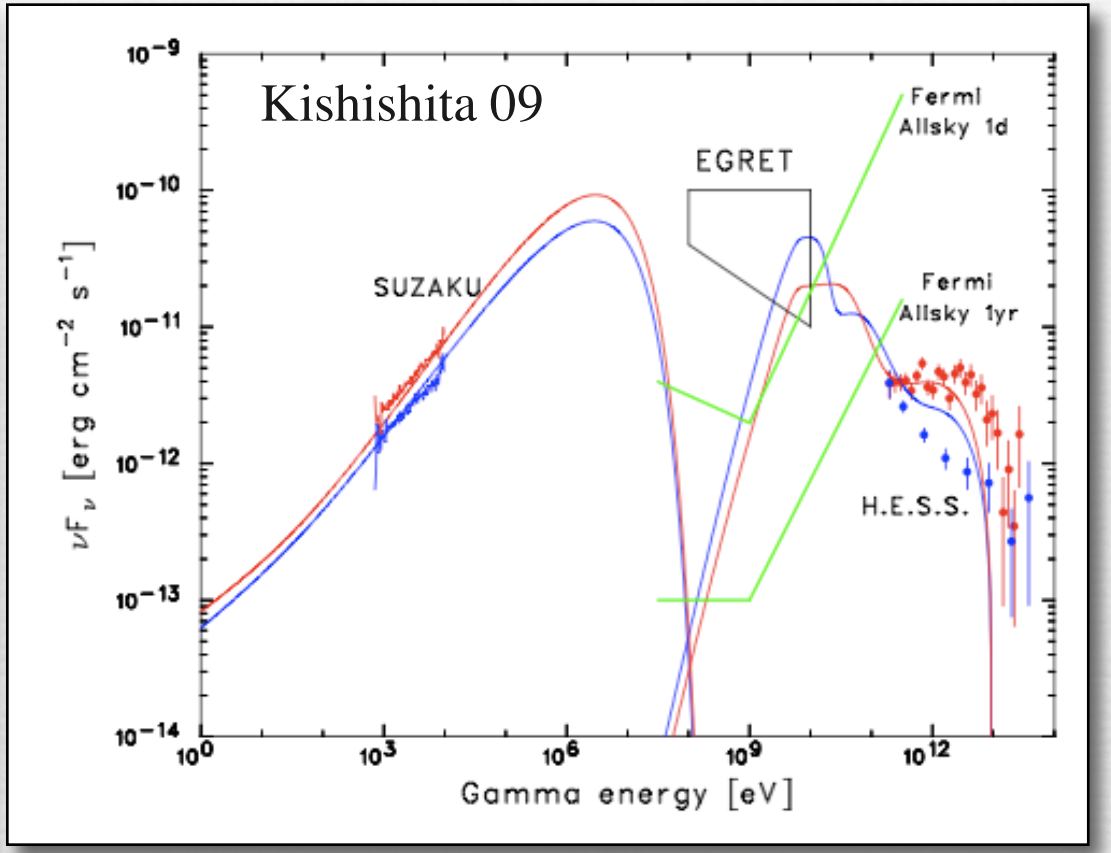


Figure 2. (a) Orbital light curves in the energy range of 1–10 keV. Top: *Suzaku* XIS data with a time bin of 2 ks. Overlaid in the range of $\phi = 0.0$–2.0 is the same light curve but shifted by one orbital period (open circles). Bottom: comparison with the past observations. Each color corresponds to *XMM-Newton* (blue, cyan with each bin of 1 ks, and green with each bin of 2 ks), *ASCA* (red with each bin of 5 ks), and *Chandra* (magenta with each bin of 2 ks). Fluxes correspond to unabsorbed values. The blue solid lines show periastron and apastron phase and the red dashed lines show *superior conjunction* and *inferior conjunction* of the compact object. (b) Close up in $1.2 \leqslant \phi < 1.8$.

LS 5039: **Synchrotron(X)**-IC(TeV) Model

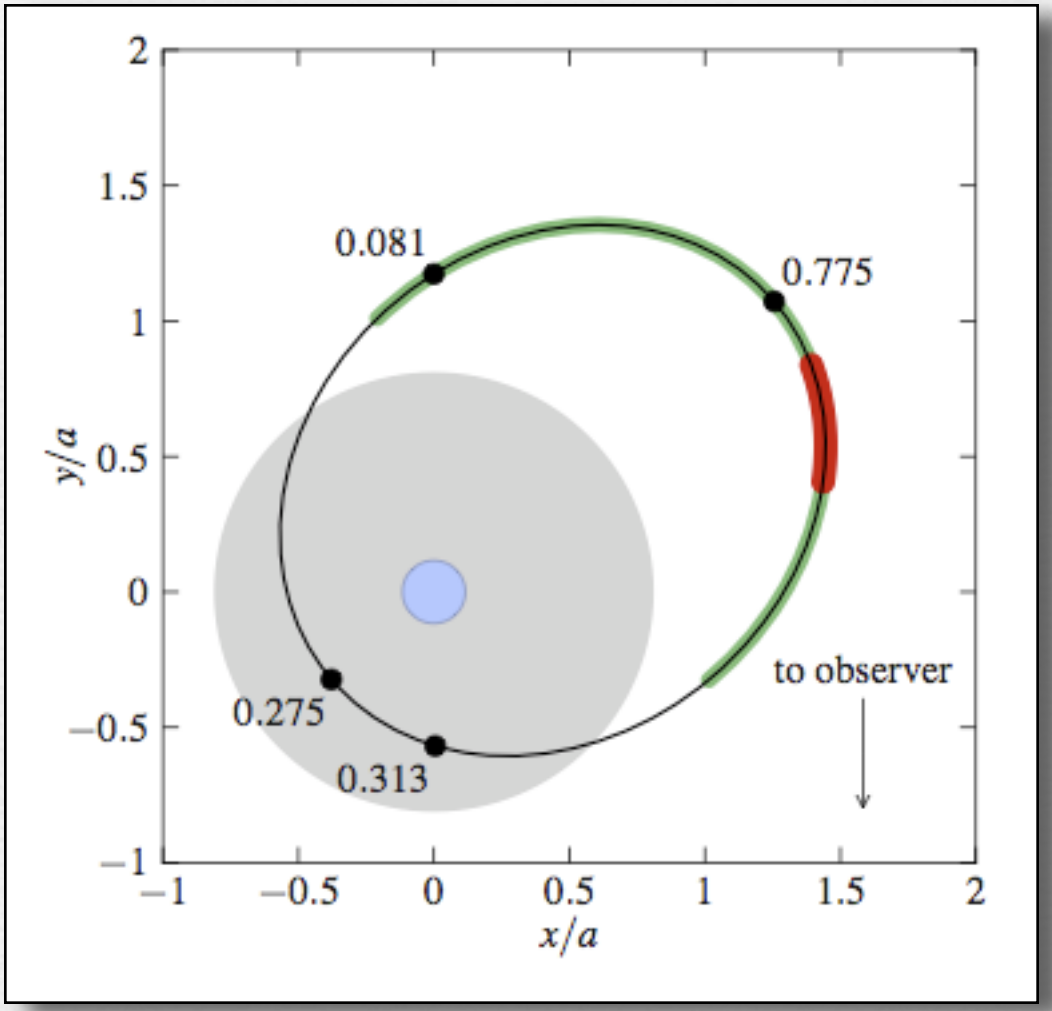




Y. Uchiyama

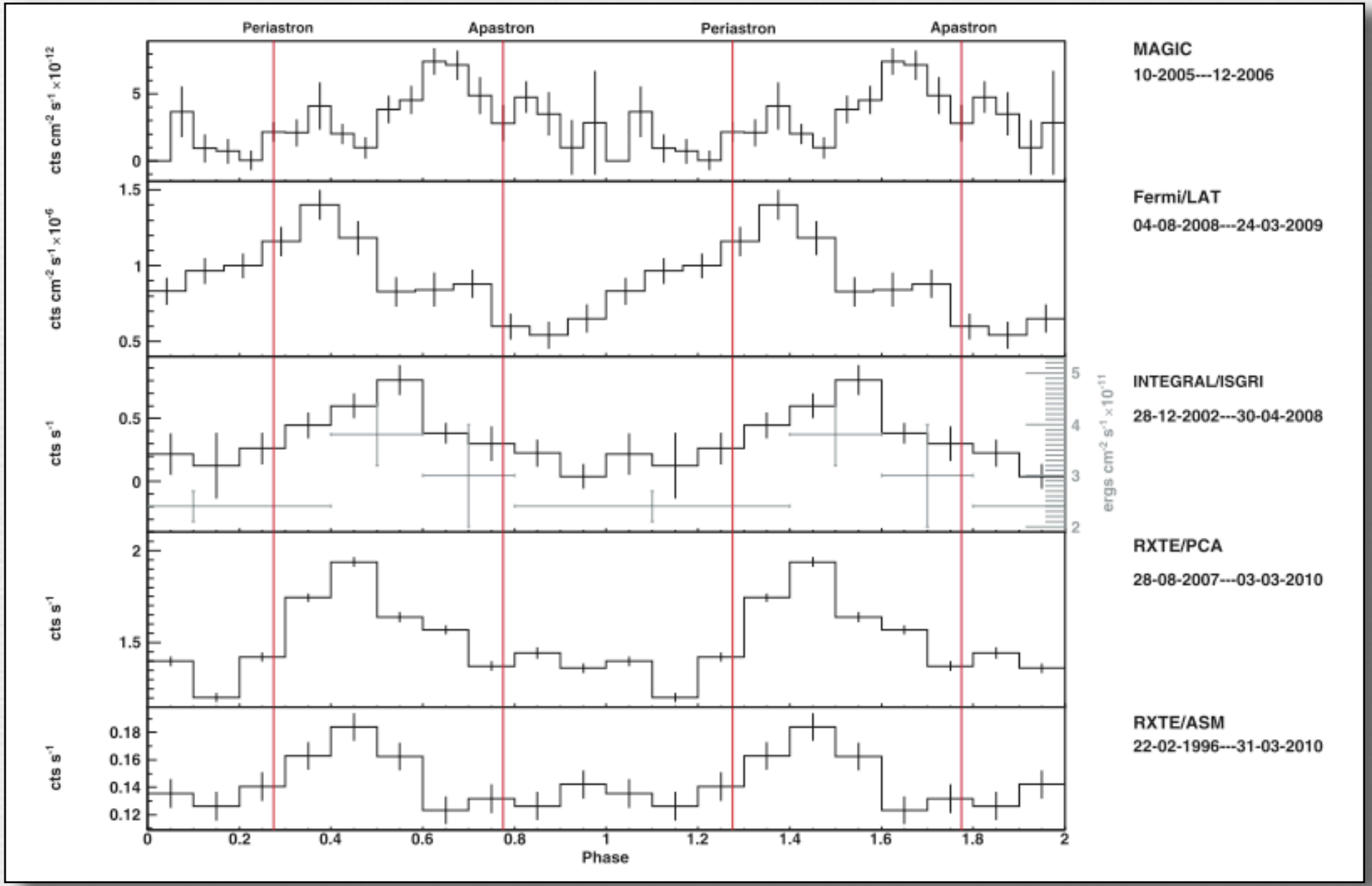
LS I +61° 303

- Period 26.5 days (e~0.54)
- Super-orbital modulation 4.6 yr in radio
- R_{orb} ~ 0.1 AU
- B0 Ve (~12 M_{sun})
- Compact object
  - Unknown (1-4 M_{sun})
- Relativistic outflow
  - extending to ~20 AU
- **No evidence for accretion disk**



Y. Uchiyama

LS I +61° 303: Light Curves

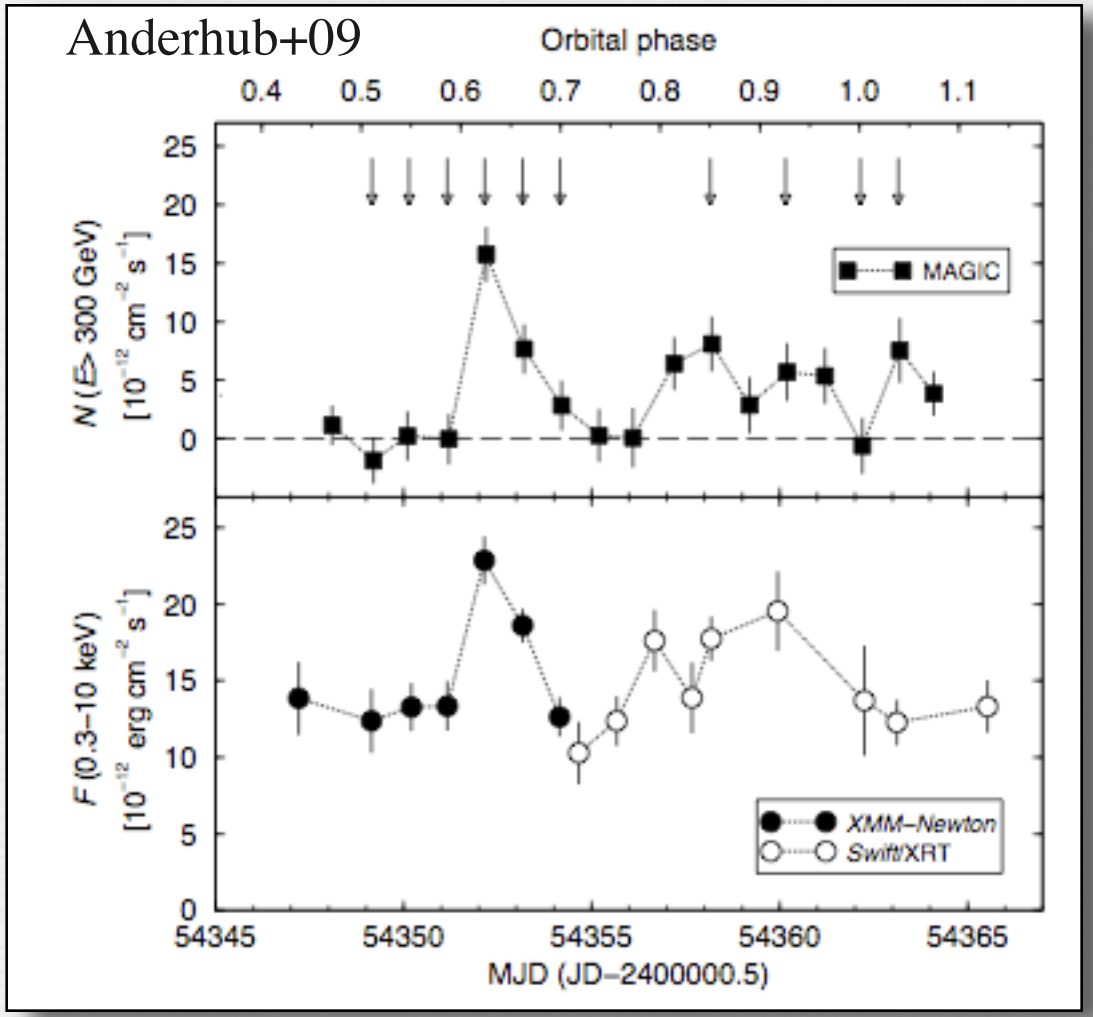


Compiled by Zhang+10

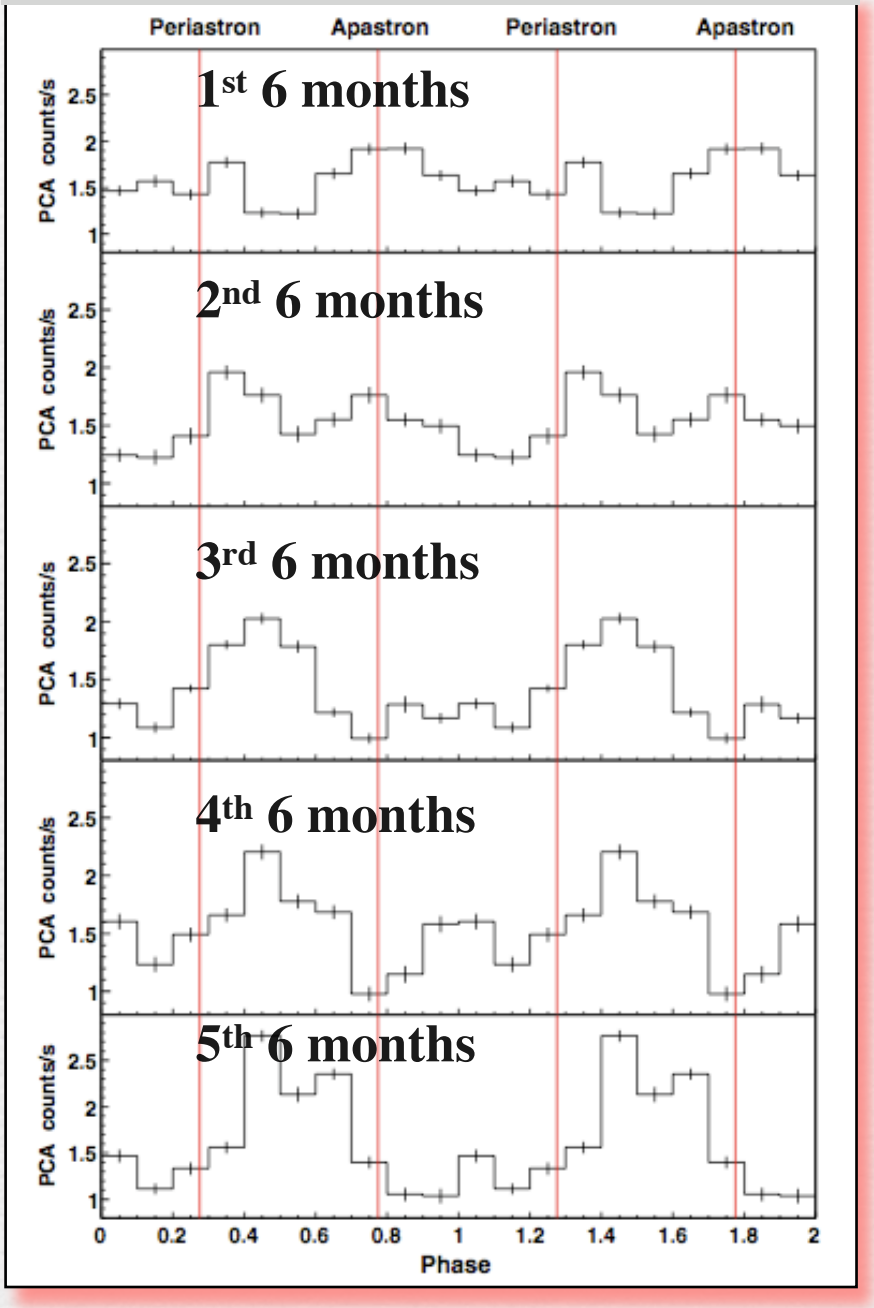
Y. Uchiyama

LS I +61° 303: X-ray Lightcurves

X-TeV correlation?



Unstable orbital modulation



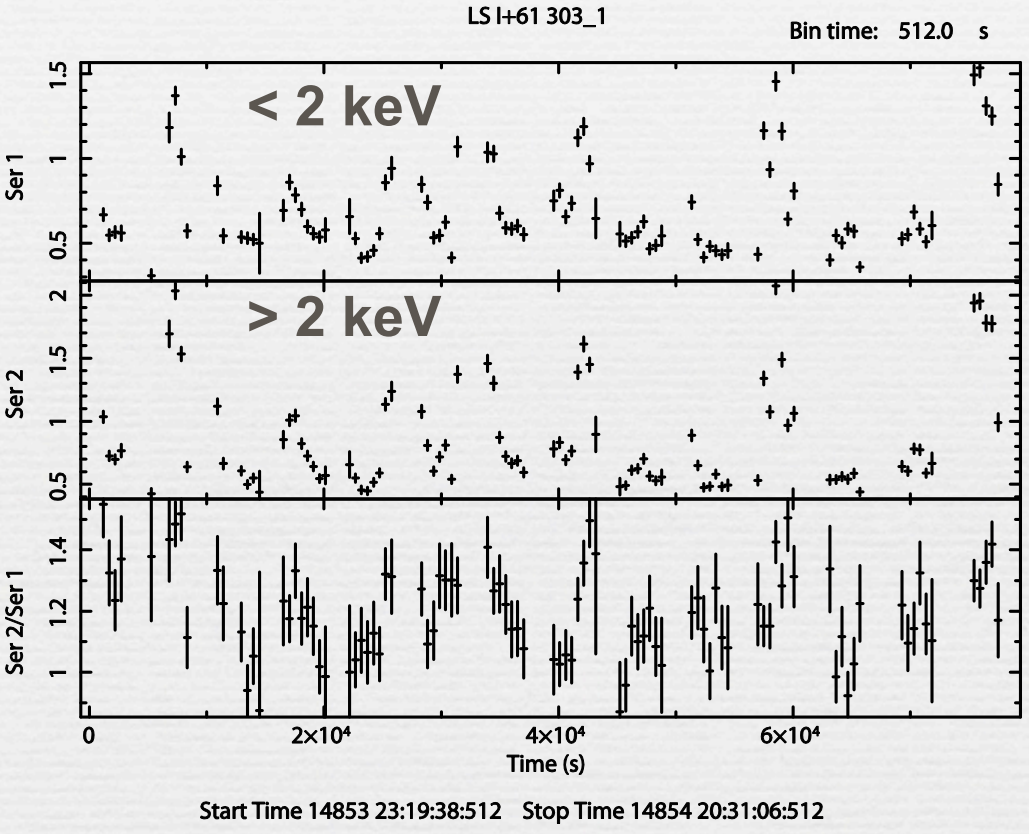
Torres+10

Y. Uchiyama

LS I +61° 303: Hour-scale Variability

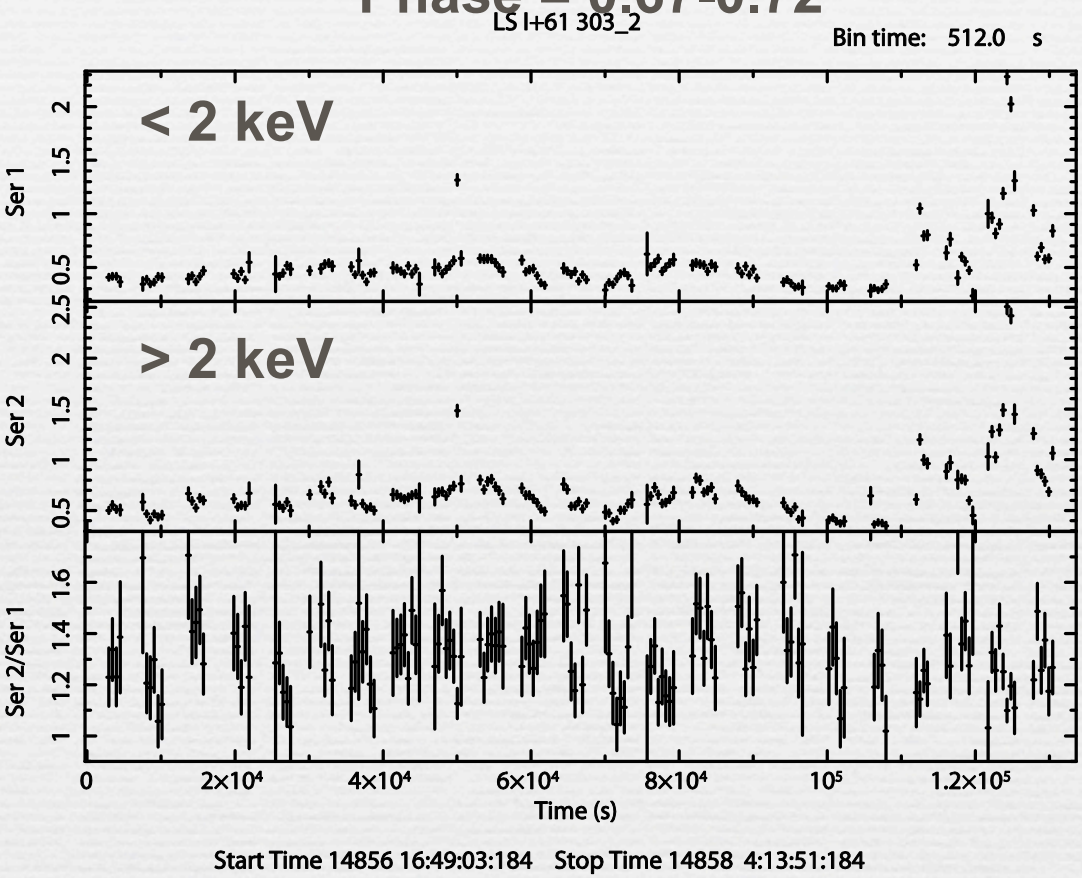
Suzaku Observations (Takahashi+ in prep.)

Phase = 0.56-0.60



1 bin = 512 sec

Phase = 0.67-0.72

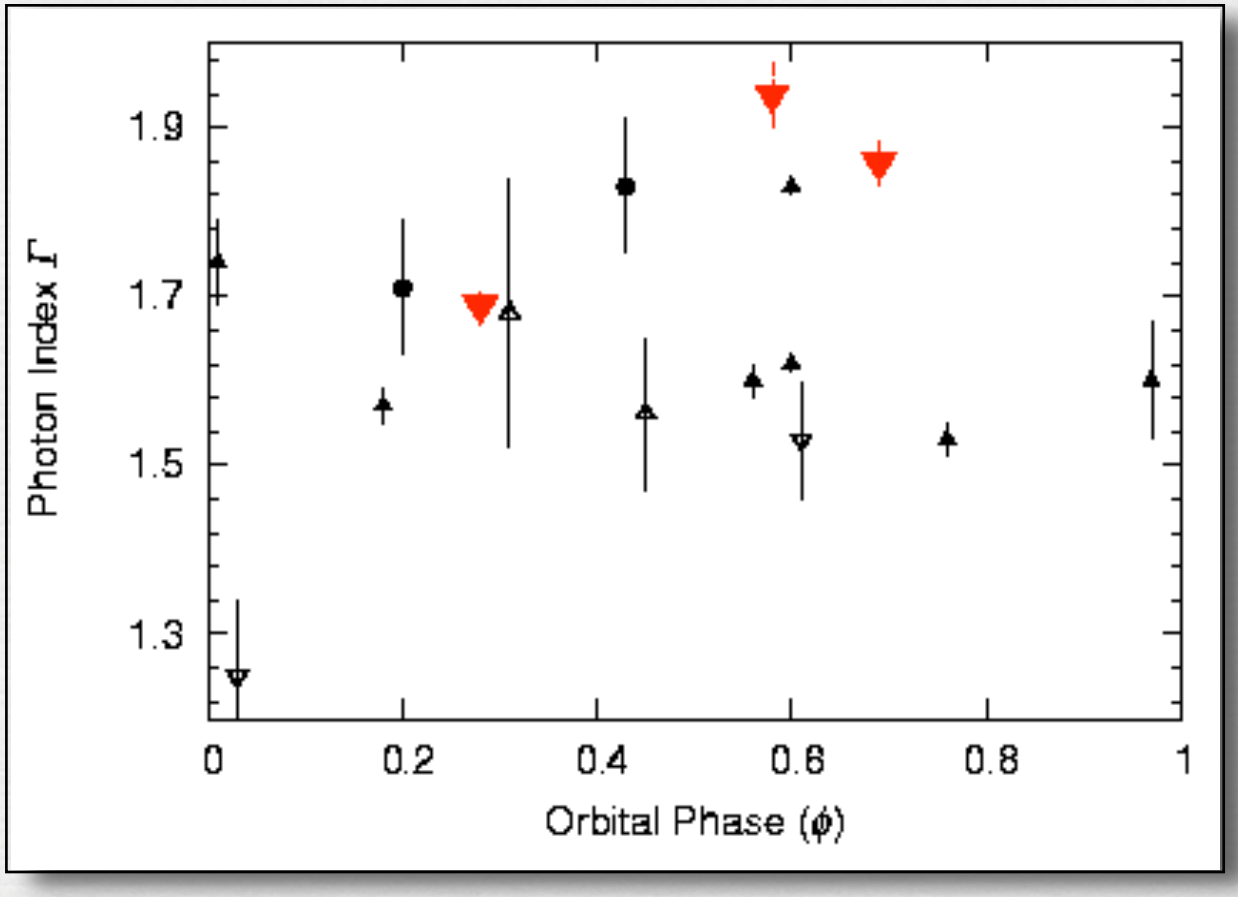


1 bin = 512 sec

Y. Uchiyama

LS I +61° 303: X-ray Photon Index

Γ as a function of phase



- Power-law
  - Γ =1.25 - 1.95
- Absorption
  - modest column density
- No pulsation found

Rea+10

Summary of X-ray Properties

Luminosity

- **PSR**: Lx ~ $10^{33\text{-}34}$ erg/s, **LSI+61**: Lx ~ 10^{34} erg/s, **LS5039**: Lx ~ 10^{34} erg/s

Spectral shape

- **PSR**: Γ = 1.2-2.0 (break), **LSI+61**: Γ = 1.2-2.0, **LS5039**: Γ = 1.45-1.60
- **PSR**: N_H = 0.3-0.6, **LSI+61**: N_H = 0.6-0.7, **LS5039**: N_H = 0.7-0.8 (10^{22} cm^{-2})

Hour-scale variability

- **PSR**: 20%, **LSI+61**: 300%, **LS5039**: 20%

Stability of orbital modulation

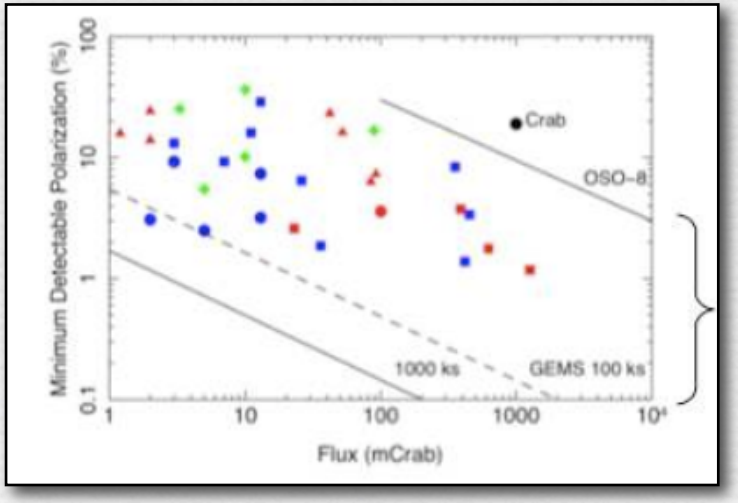
- **PSR**: some orbit-orbit changes, **LSI+61**: large changes, **LS5039**: no changes

Correlation with TeV

- **PSR**: YES, **LSI+61**: ?, **LS5039**: YES

Anti-correlation with GeV

- **PSR**: ?, **LSI+61**: ?, **LS5039**: YES



Y. Uchiyama