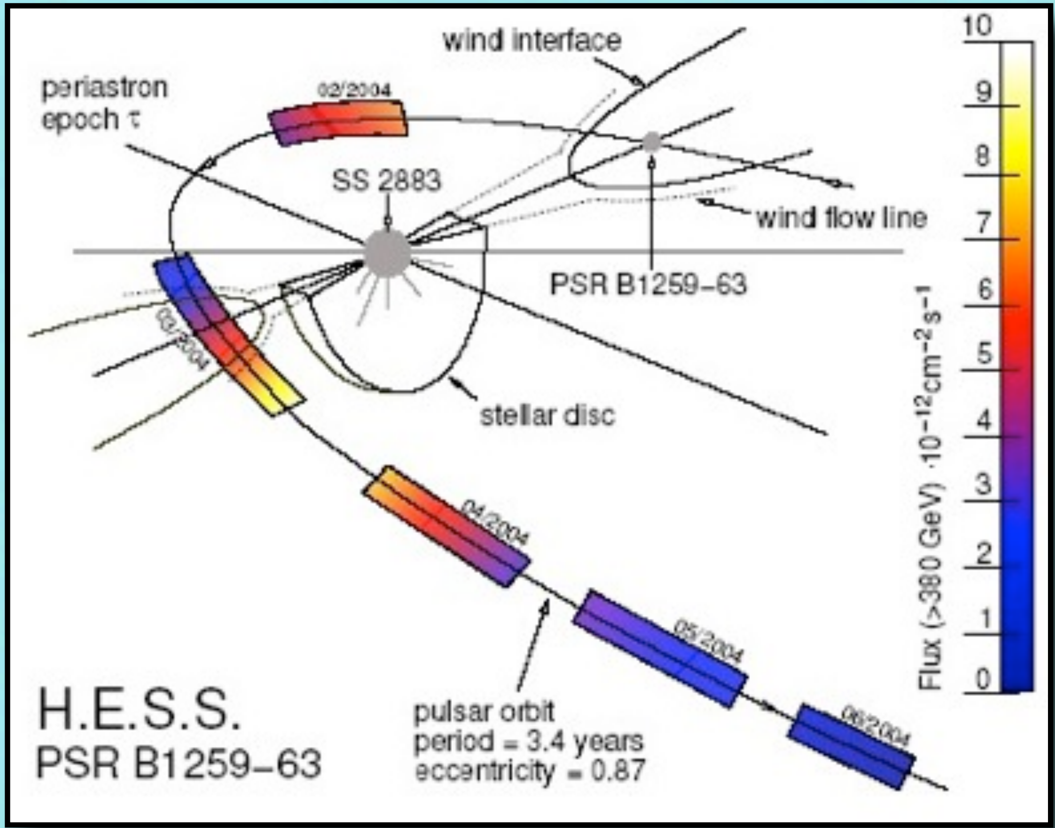
The Suzaku Conference 2011
SLAC National Accelerator Laboratory, 20-23 July 2011

Gamma-ray Loud X-ray Binaries

Yasunobu Uchiyama (SLAC)
***not* on behalf of the Fermi LAT Collaboration**

Gamma-ray Loud Binaries: Two Categories

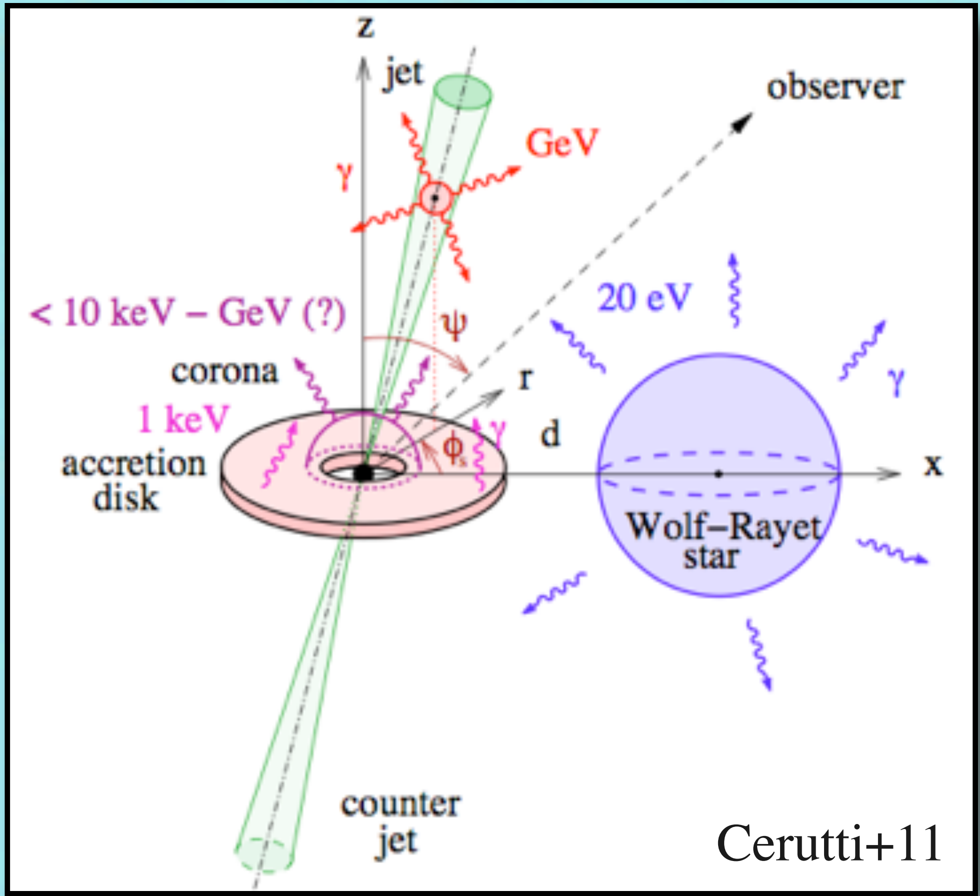
Compact Pulsar Wind Nebula



PSR B1259-63

LS 5039
LS I +61°303
HESS J0632+057
1FGL 1018.6-5856

Microquasar



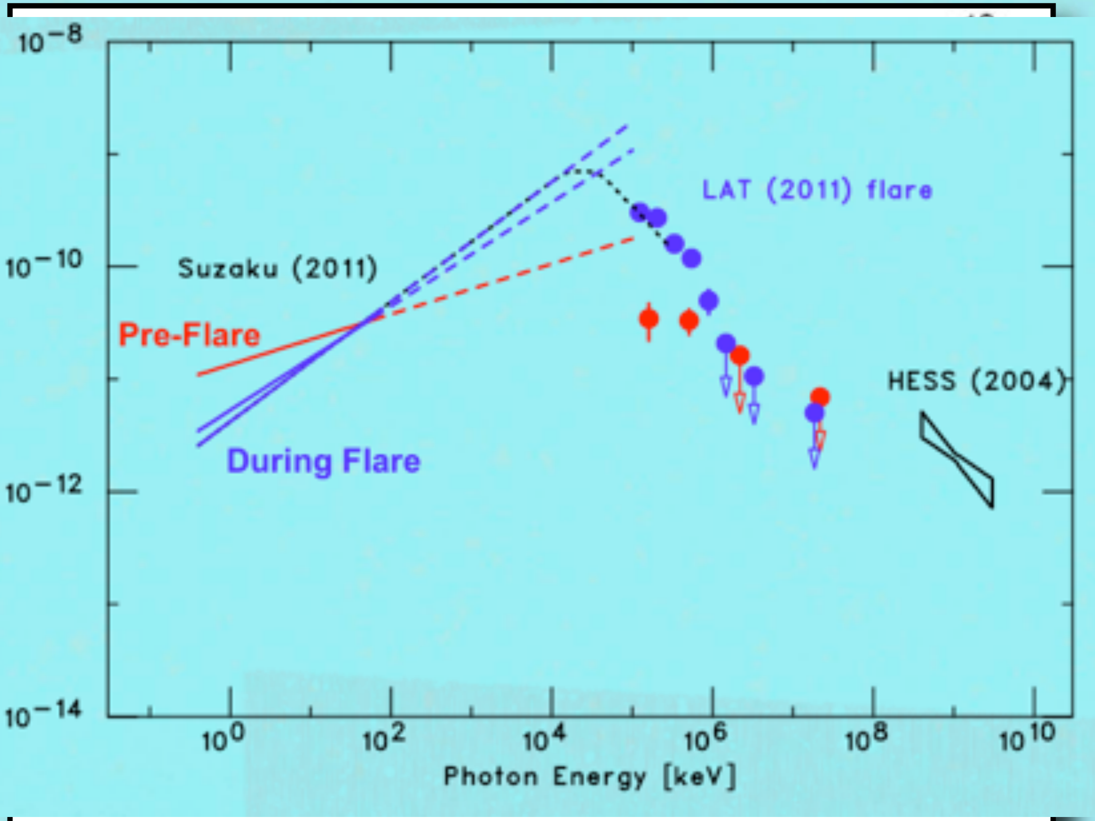
Cygnus X-3

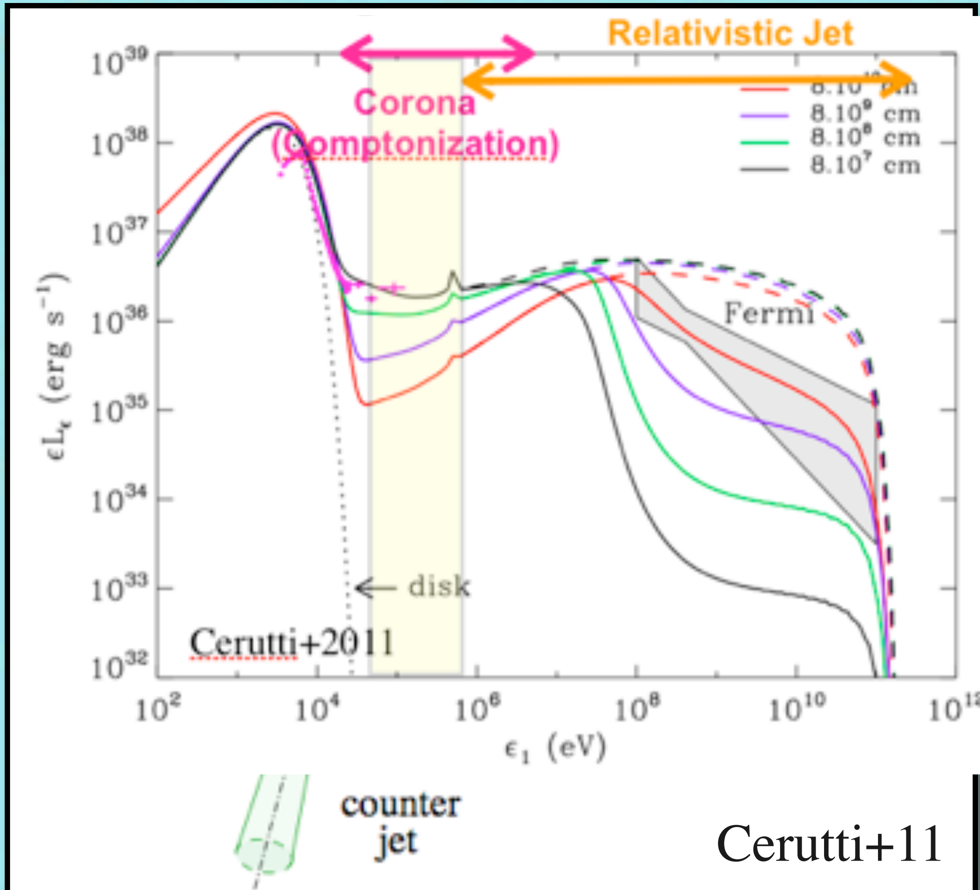
Y. Uchiyama

Gamma-ray Loud Binaries: Two Categories

Compact Pulsar Wind Nebula

Microquasar





PSR B1259-63

LS 5039
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1FGL 1018.6-5856

Cygnus X-3

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List of Gamma-ray Binaries (with orbital modulation)

- **PSR B1259-63** (**pulsar's spin-down**) **T_{orb} = 3.4 years**
  - **TeV** (HESS) & **GeV** (Fermi-LAT)
- **LS 5039** (**unknown source of power**) **T_{orb} = 3.9 days**
  - **TeV** (HESS) & **GeV** (Fermi-LAT)
- **LS I +61° 303** (**unknown source of power**) **T_{orb} = 26 days**
  - **TeV** (MAGIC/VERITAS) & **GeV** (Fermi-LAT)
- **HESS J0632+057** (**unknown source of power**) **T_{orb} = 320 days**
  - **TeV** (HESS/MAGIC/VERITAS)
- **1FGL J1018.6-5856** (**unknown source of power**) **T_{orb} = 16.6 days**
  - **GeV** (Fermi-LAT)
- **Cyg X-3** (**accretion onto BH/NS**) **T_{orb} = 4.8 hours**
  - **GeV** (Fermi-LAT/AGILE) : **transient**

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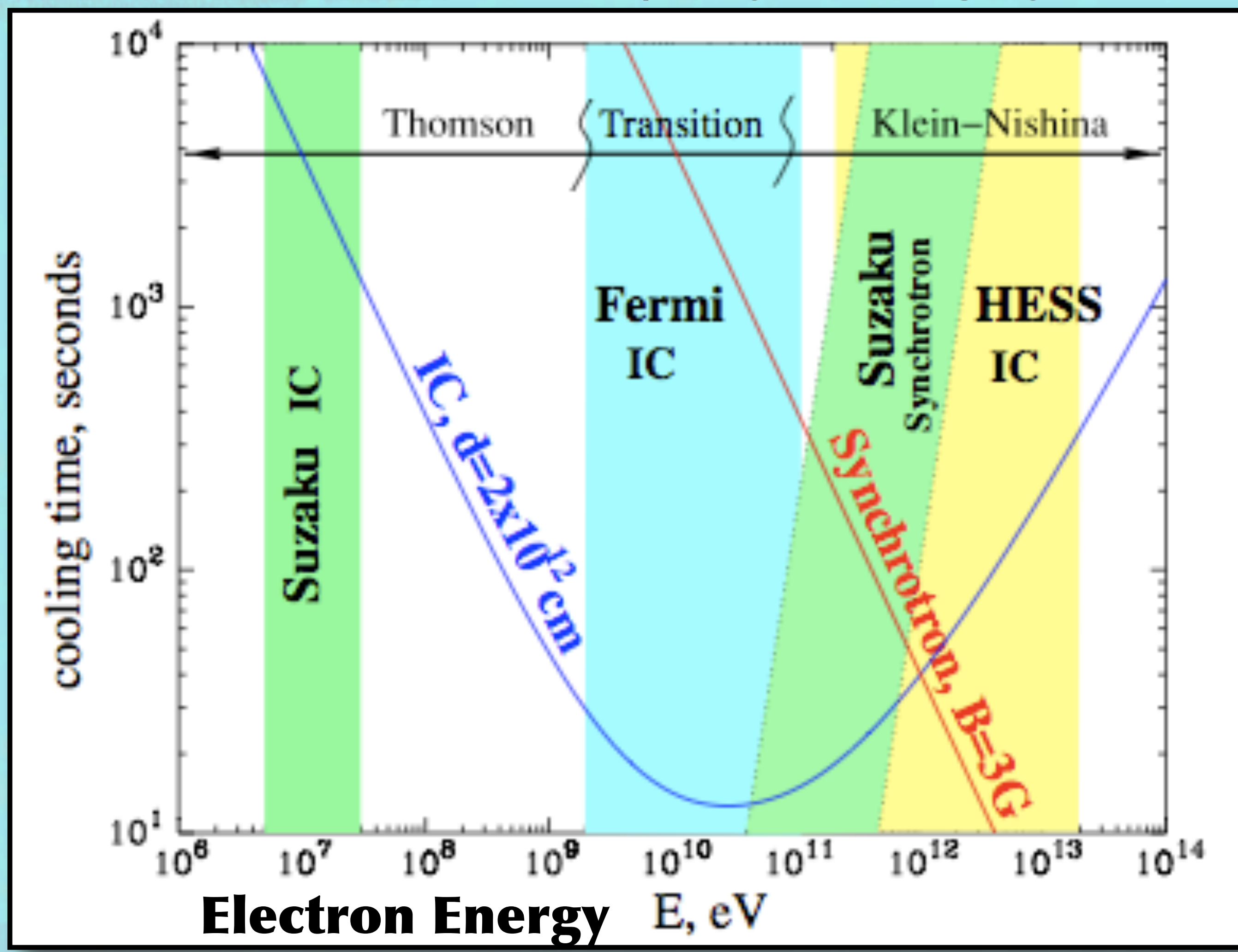
Fast Cooling of Electrons (& Positrons)

c) Mitya Khangulyan

GeV-TeV electrons
cool rapidly in the vicinity
of a massive star.



Inverse-Compton scattering
on stellar photons:
(easily Klein-Nishina regime)

$L_* \sim 10^{38}$ erg/s
$d \sim 10$ AU
$t_{cool} \sim 10$ sec (10 GeV)

Synchrotron cooling
becomes dominant E > TeV.

$B \sim 1$ G
$t_{cool} \sim 10$ sec (10 TeV)

Fast acceleration is necessary

$$t_{acc,min} = r_g/c = 1\ (E/10\ \mathrm{TeV})(B/\mathrm{gauss})^{-1}\ \mathrm{sec}$$

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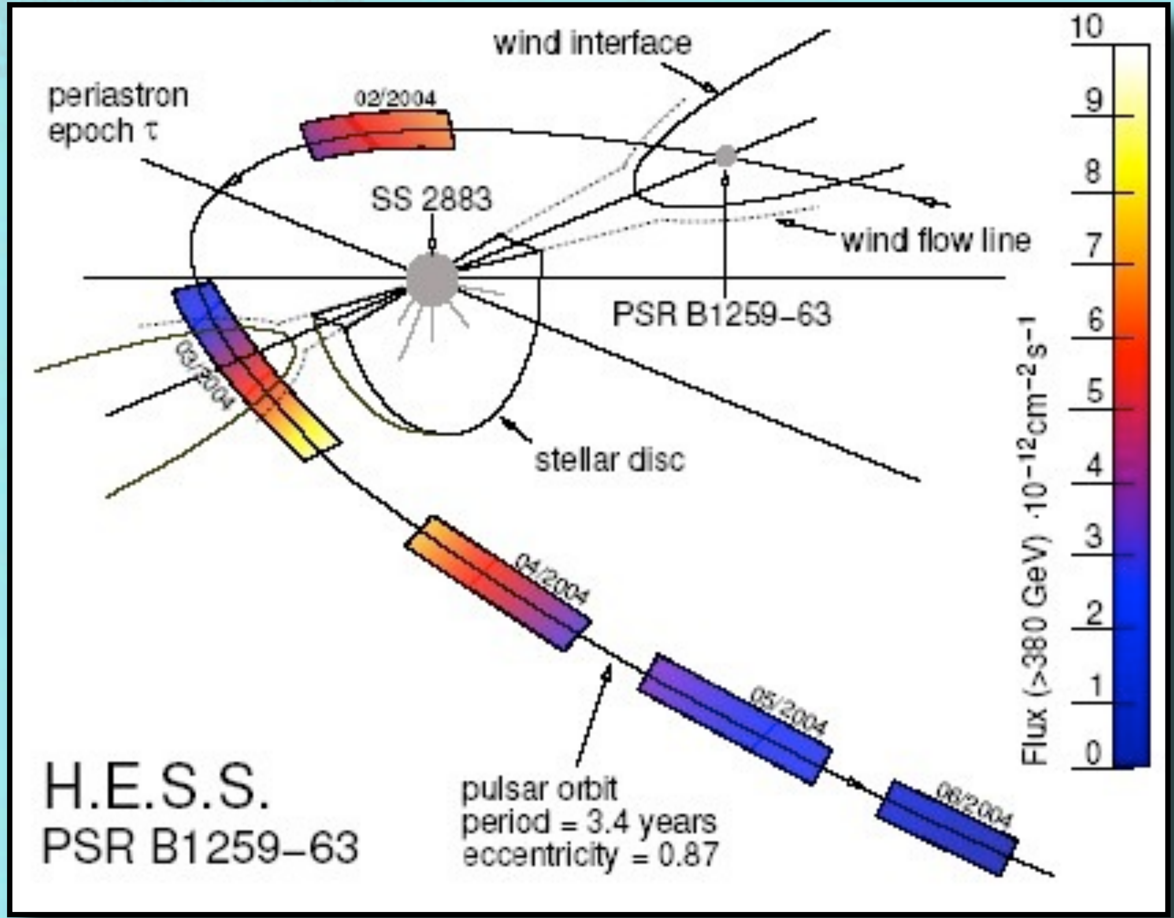
PSR B1259-63



- Period 3.4 year (e~0.87)
- R_{orb} ~ 0.7 AU (at periastron)
- LS2883 Be (O star)
  - Circumstellar Disc
- Pulsar
  - spin period: 48 ms
  - pulsation disappears near periastron
  - $L_{spin\text{-}down} = 8 \times 10^{35}$ erg/s

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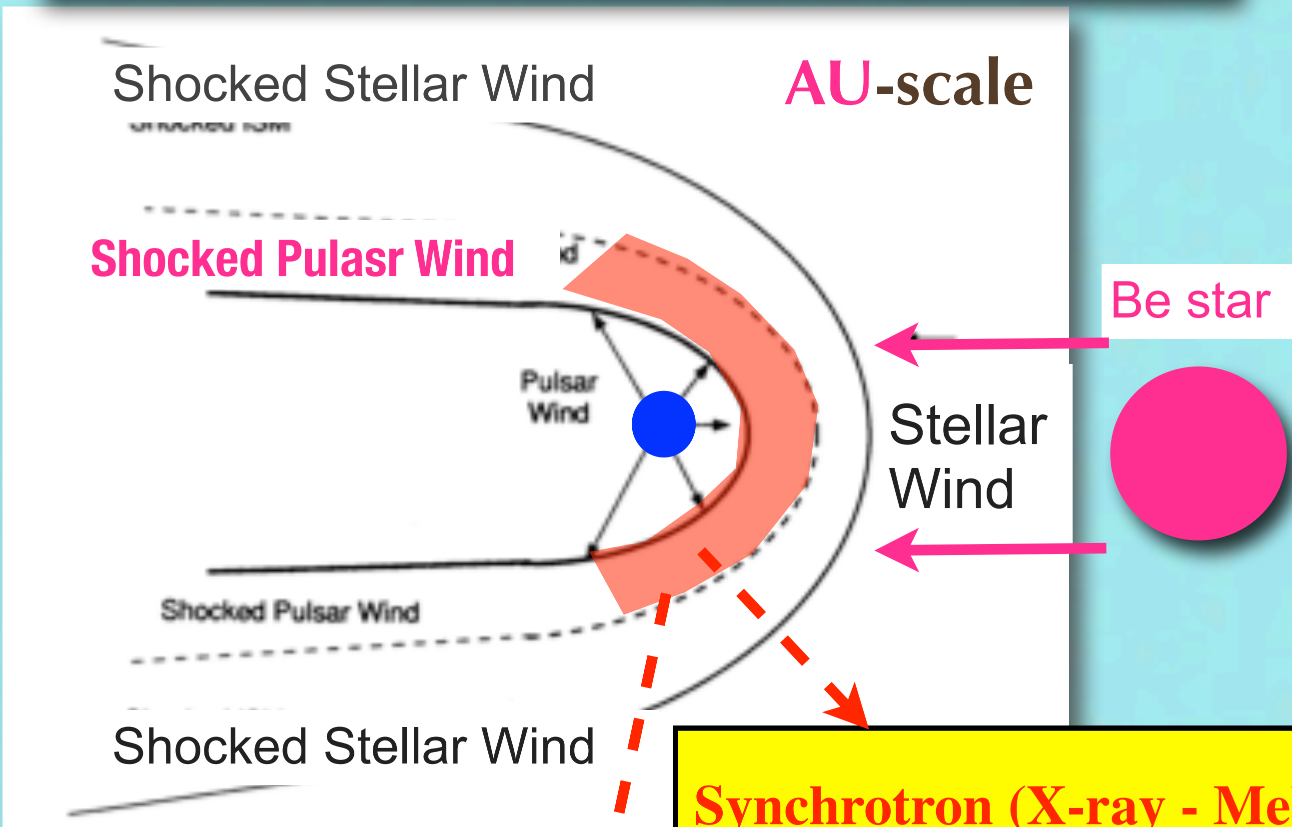
“Compactified” Pulsar Wind Nebula In Binary System

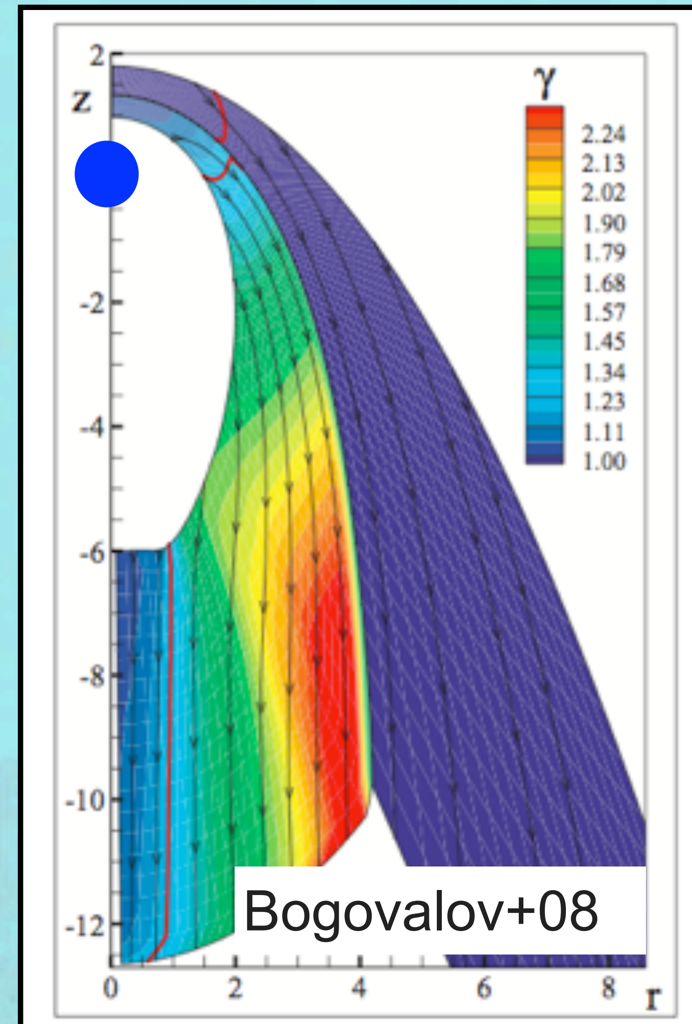
PSR B1259-63 provides unique opportunity to learn about pulsar wind on AU-scale



Synchrotron (X-ray - MeV)

Inverse-Compton emission (GeV - TeV)

Hydrodynamical structure:
relativistic wind
vs non-relativistic wind



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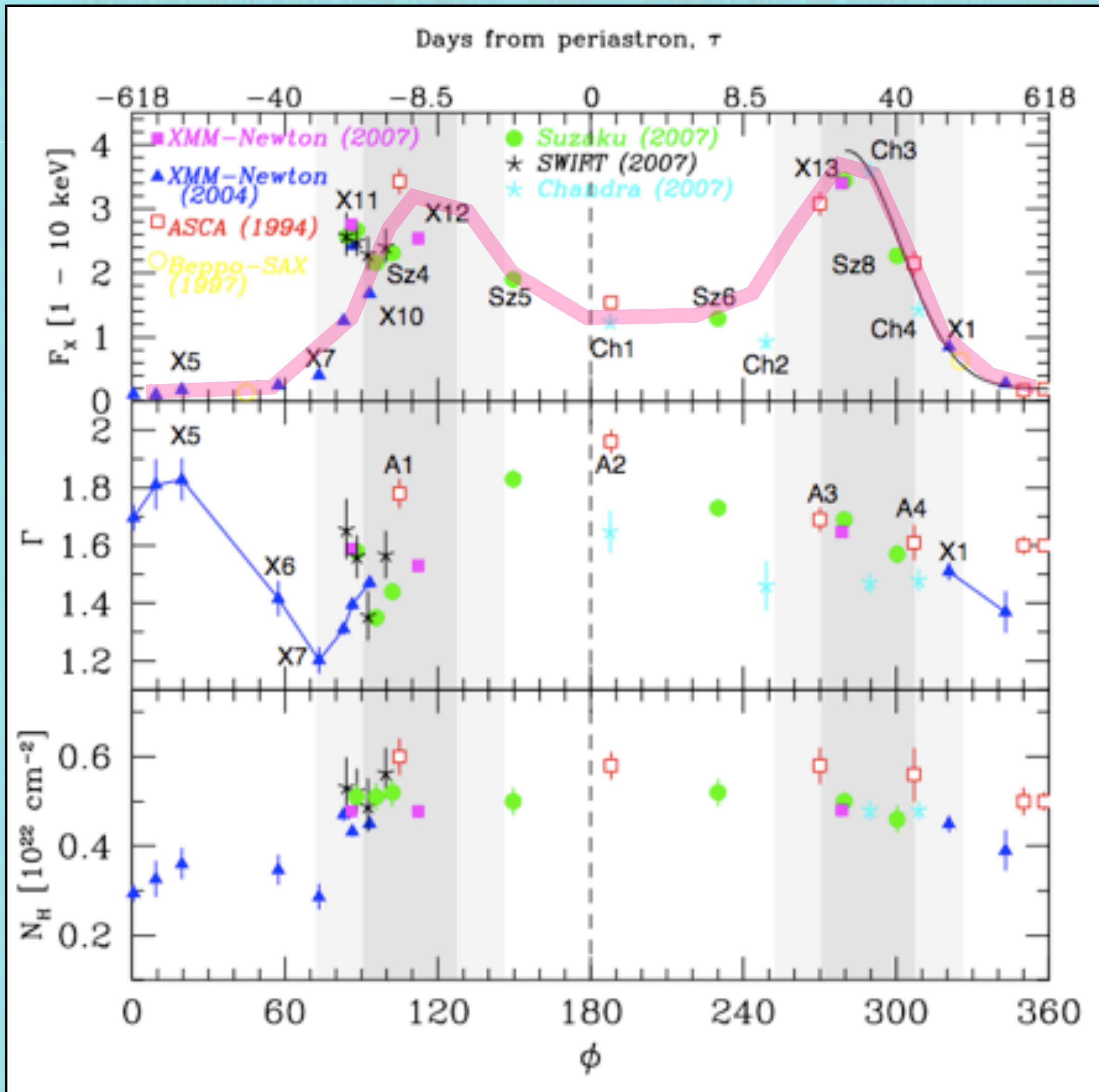
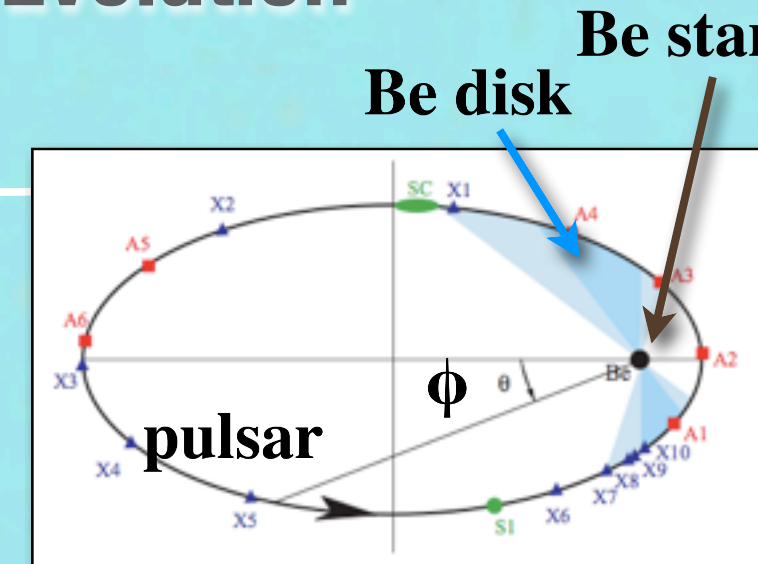
PSR B1259-63: X-ray Evolution



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

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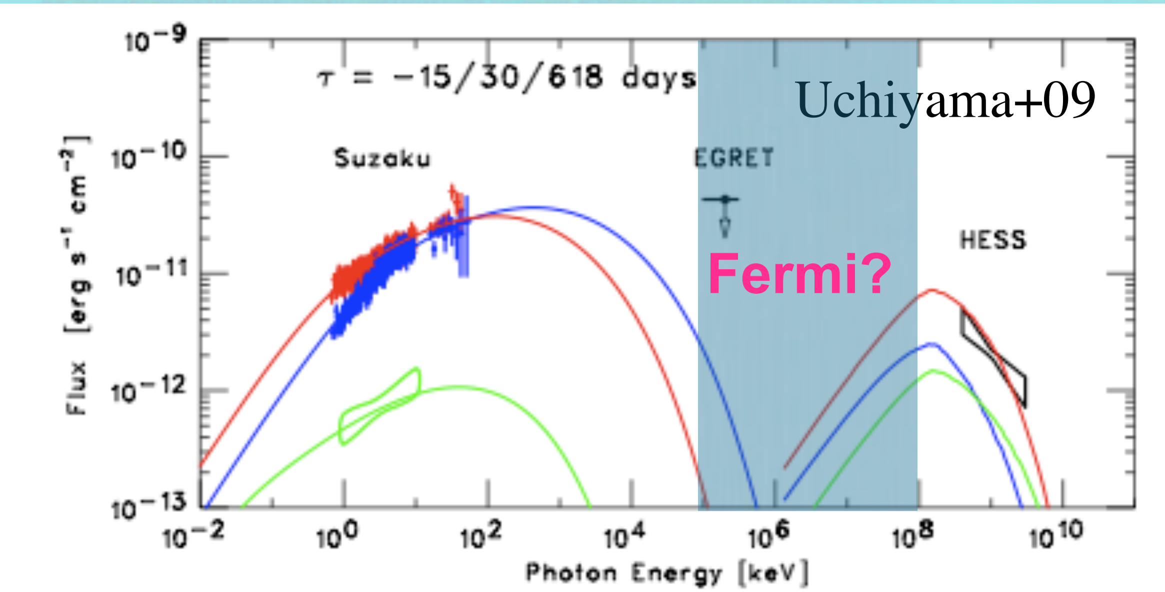
PSR B1259-63: Synchrotron+IC Model

Compactified PWN 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).

$\varepsilon = 0.1$

$\dfrac{\text{accelerated pair}}{\text{spin down power}}$

$\sigma = 0.01$ (poorly constrained)

magnetization factor

$\gamma_1 = 4\text{x}10^5$

wind Lorentz factor

X-ray break position

(Astro-H will check it)

$p = 1.9$

acceleration index

$E_m = 10$ TeV (or larger)

maximum energy

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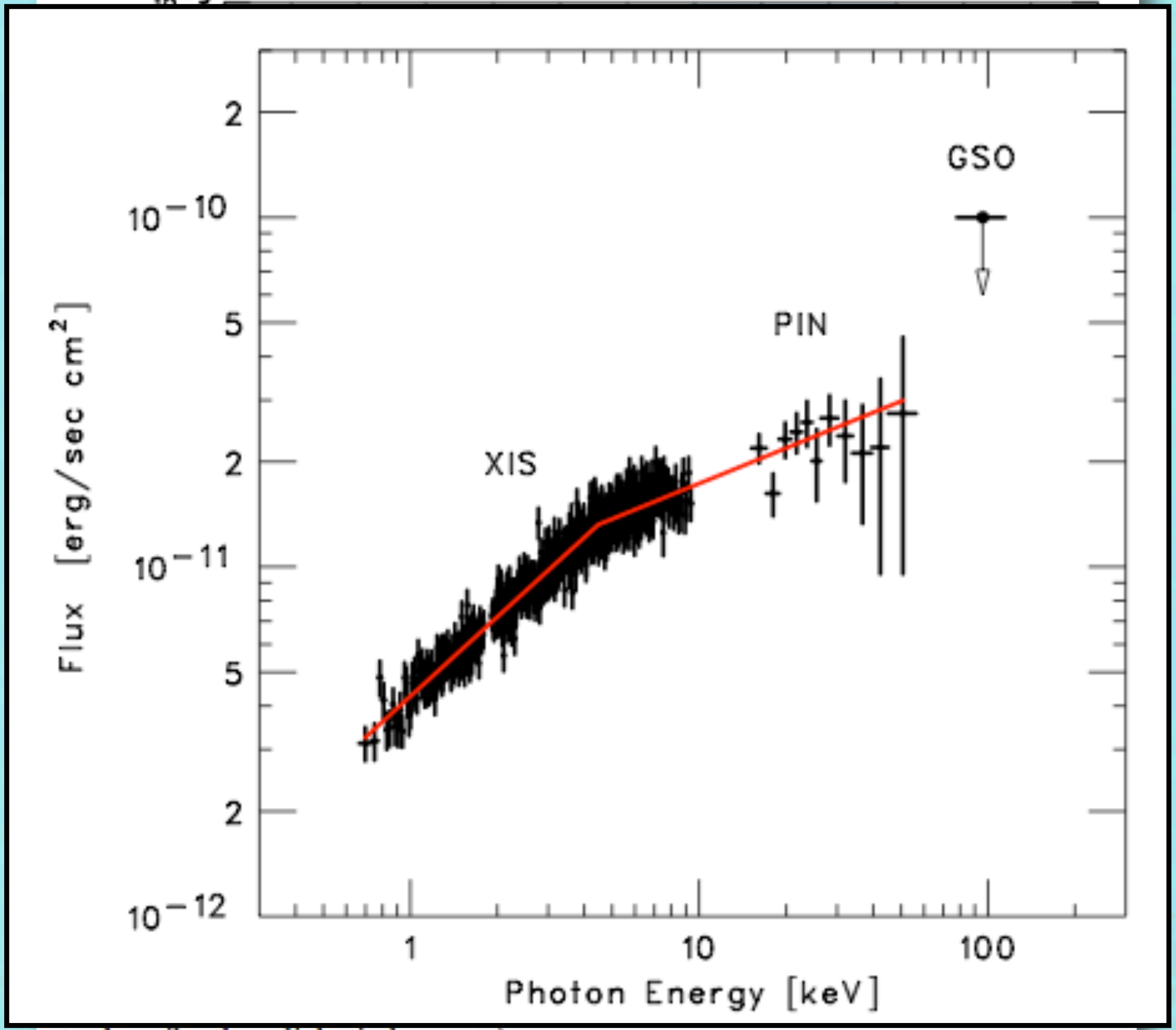
PSR B1259-63: Synchrotron+IC Model

Compactified PWN Scenario



to describe the adiabatic loss rate).

$\varepsilon = 0.1$
$\frac{\text{accelerated pair}}{\text{spin down power}}$

$\sigma = 0.01$ (poorly constrained)
magnetization factor

$\gamma_1 = 4\text{x}10^5$
wind Lorentz factor

X-ray break position
(Astro-H will check it)

$p = 1.9$
acceleration index

$E_m = 10$ TeV (or larger)
maximum energy

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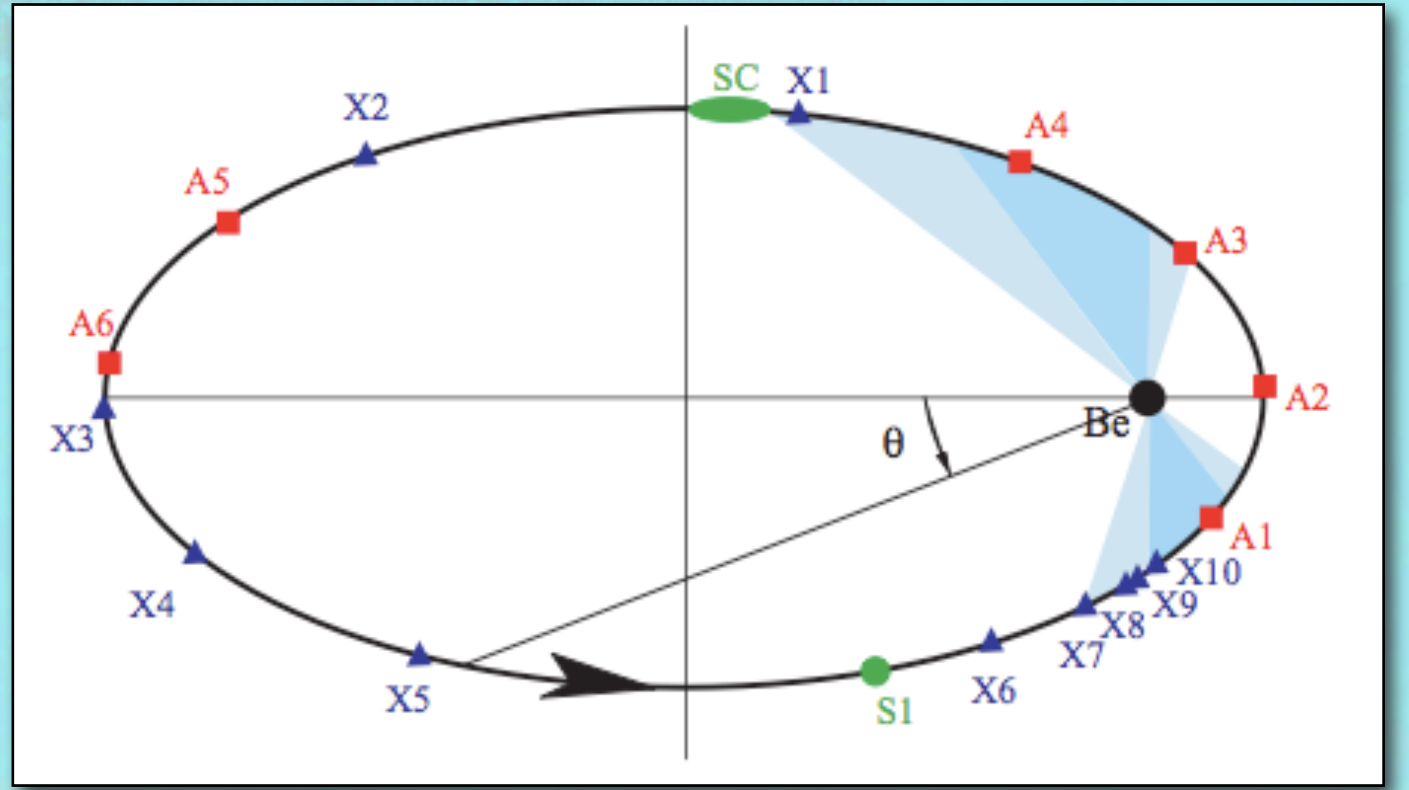
Orbital period ~ 3.4 yr



Periastron passage: Dec 15 (2010)

the 1st periastron for Fermi-LAT
the 2nd periastron for Suzaku

The next one: April (2014) Astro-H?

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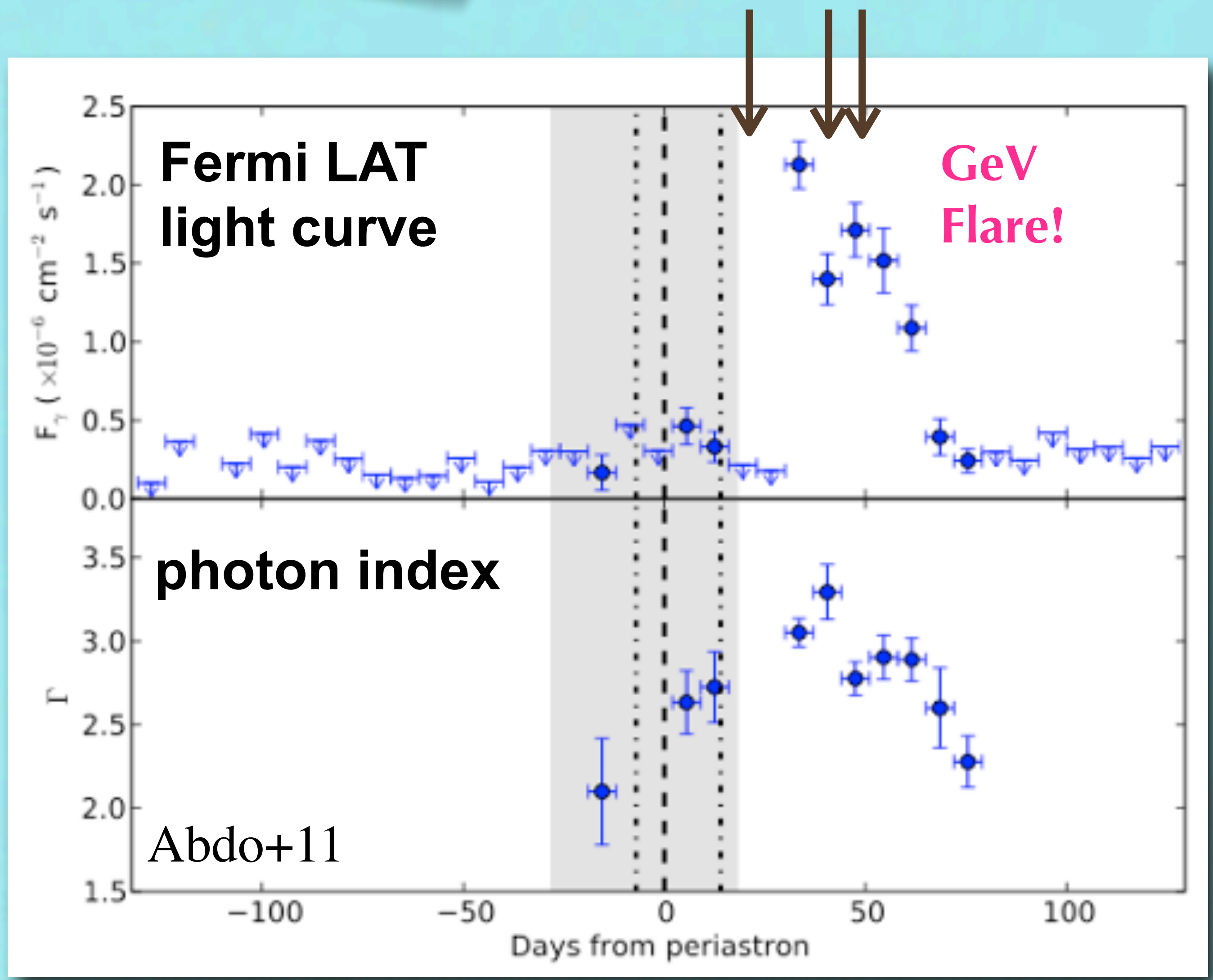
PSR B1259-63: Fermi-LAT Detections

Fermi-LAT surprised us:
GeV flare after periastron

Suzaku Observations (Uchiyama)
80 ks, 40 ks (ToO), 20 ks



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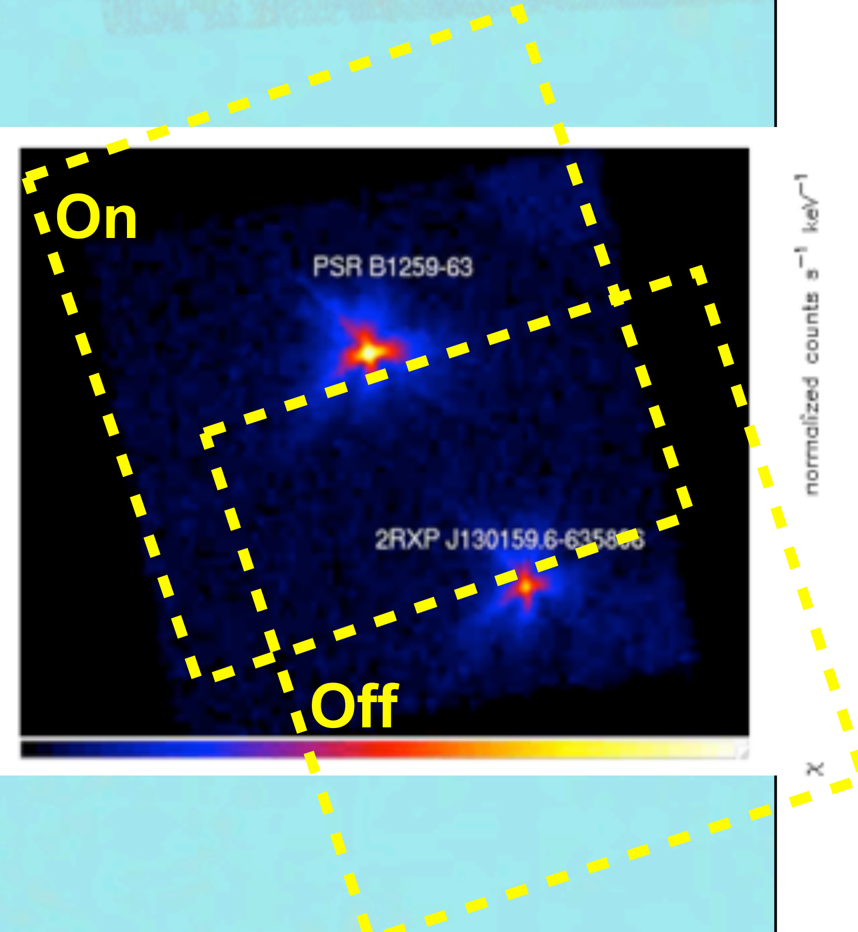
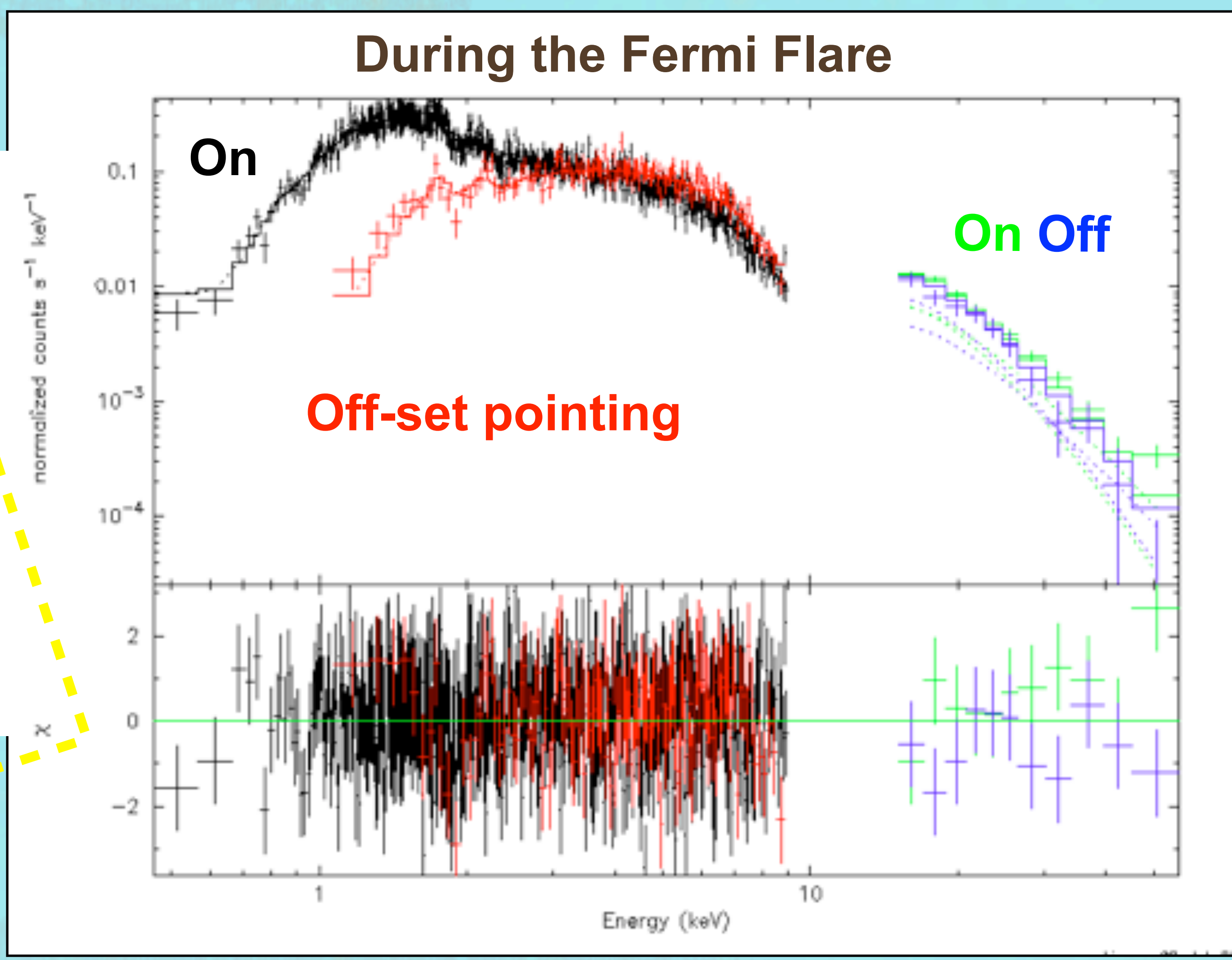
PSR B1259-63: Suzaku Observations





PSR B1259:

N_H = (0.513-0.518)x10^{22} cm^{-2}

Γ = 1.53-1.56

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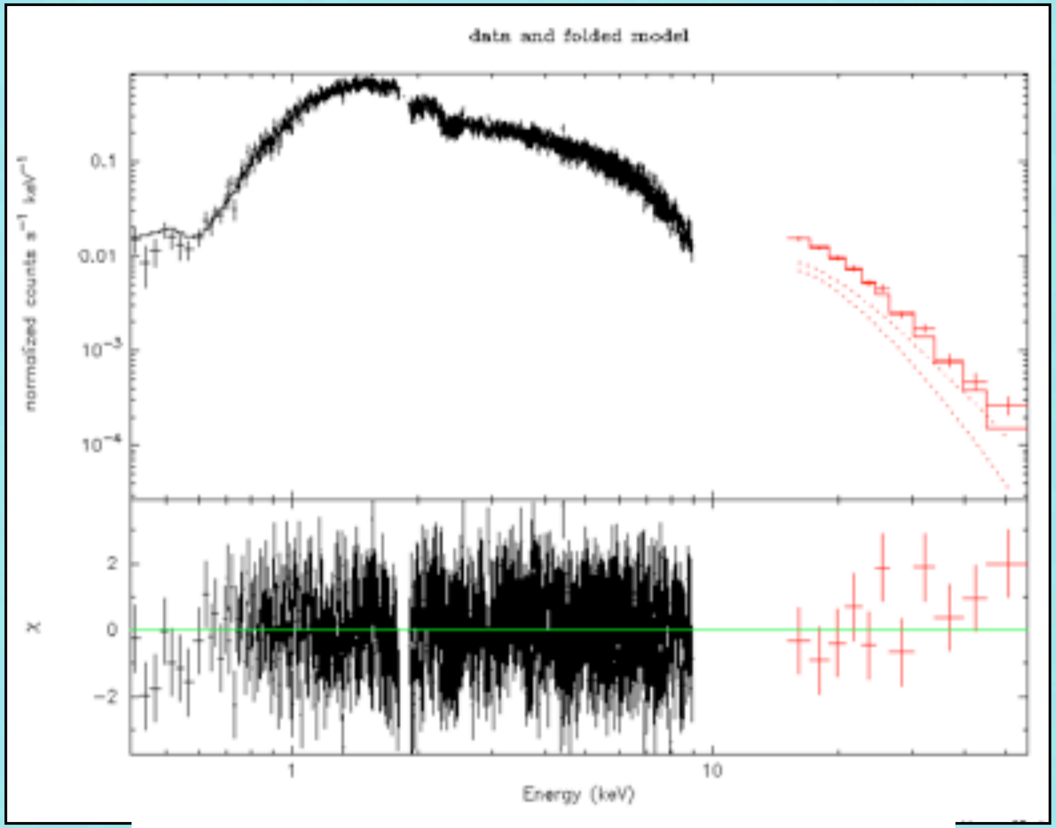
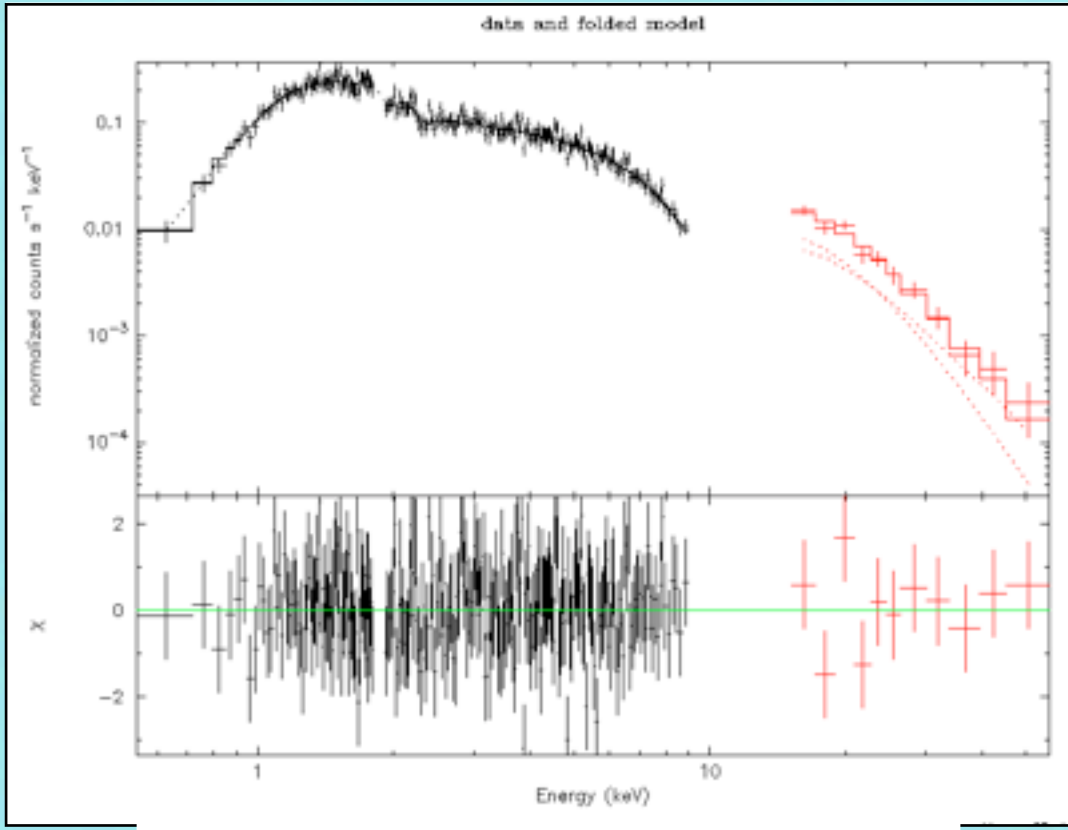
PSR B1259-63: Suzaku Observations

Pre-Flare



PSR B1259:
N_H = (0.573-0.575)x10^{22} cm^{-2}
Γ = 1.76-1.78

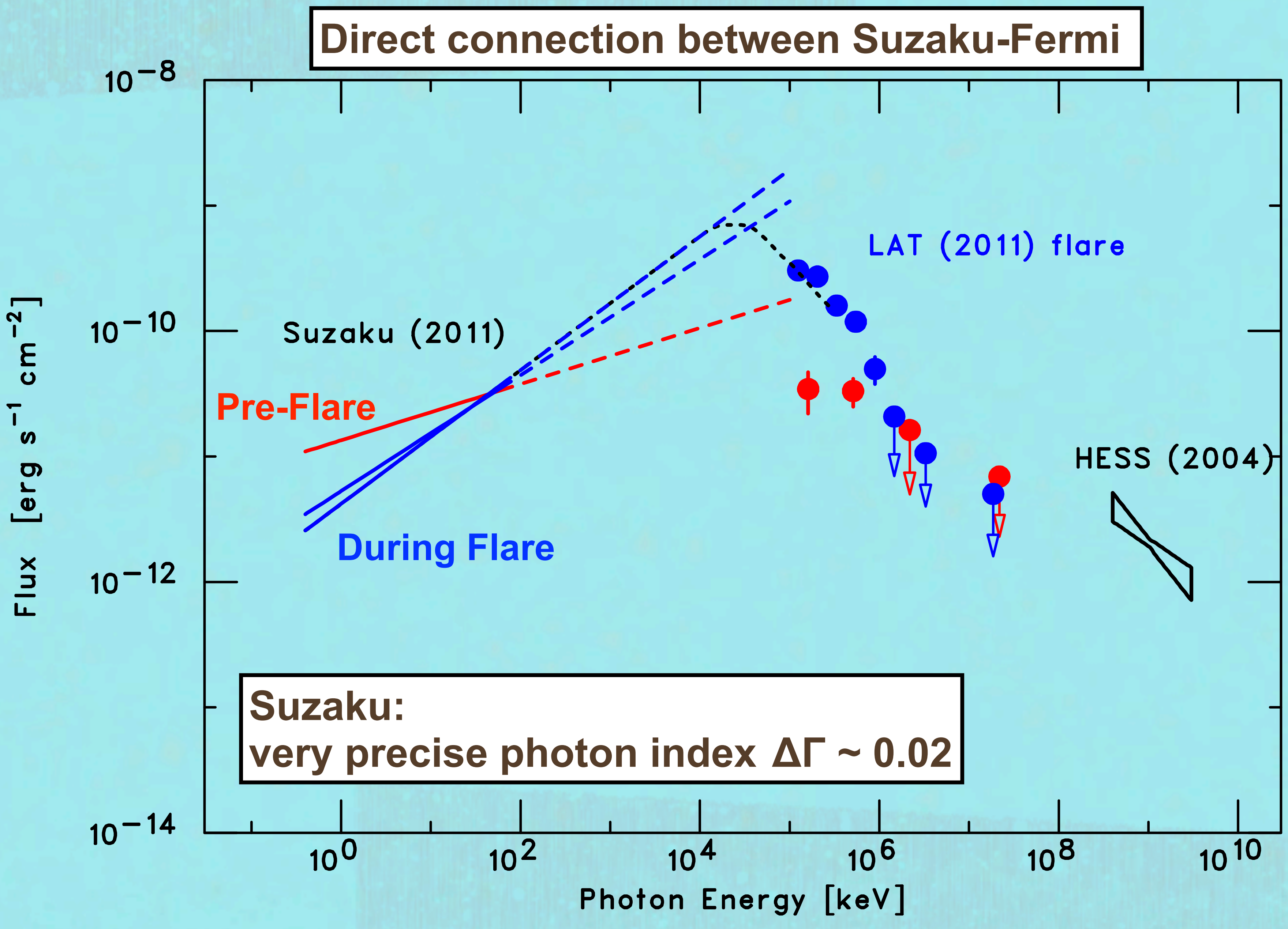
During Flare



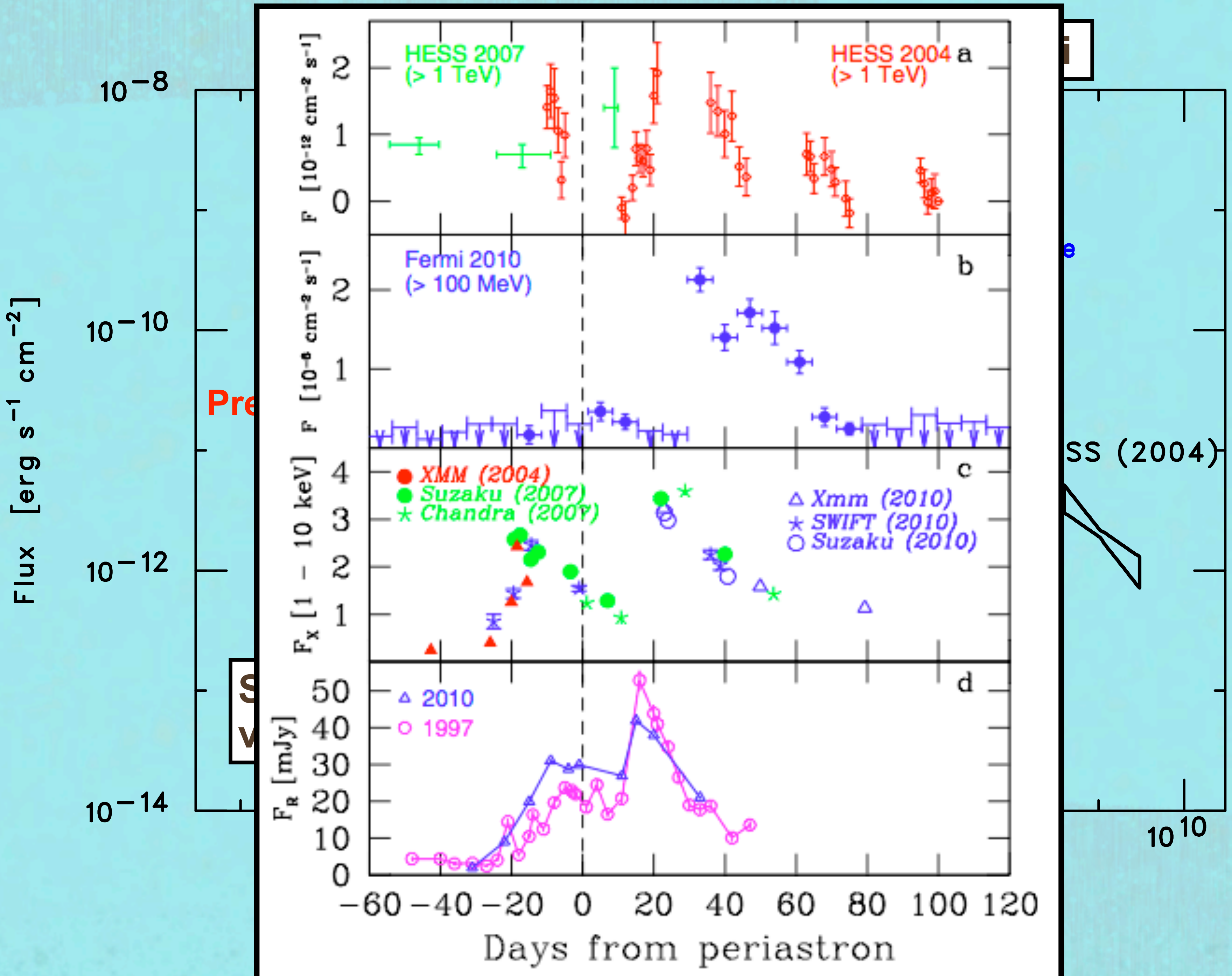
PSR B1259:
N_H = (0.491-0.499)x10^{22} cm^{-2}
Γ = 1.42-1.50

A "hard" straight power law up to 60 keV (for the first time)

PSR B1259-63: Suzaku & Fermi-LAT

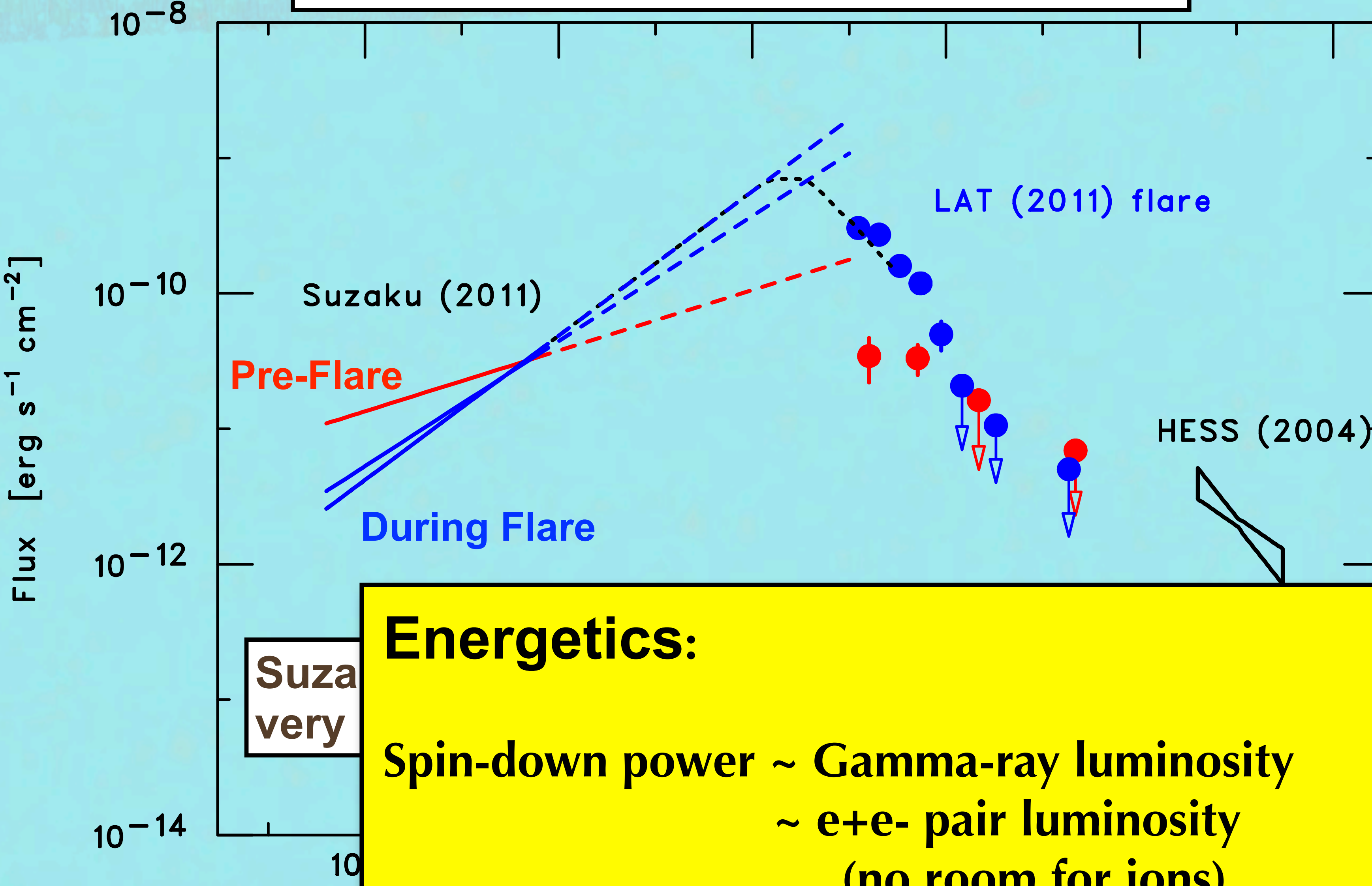


PSR B1259-63: Suzaku & Fermi-LAT



PSR B1259-63: Suzaku & Fermi-LAT

Direct connection between Suzaku-Fermi



Energetics:

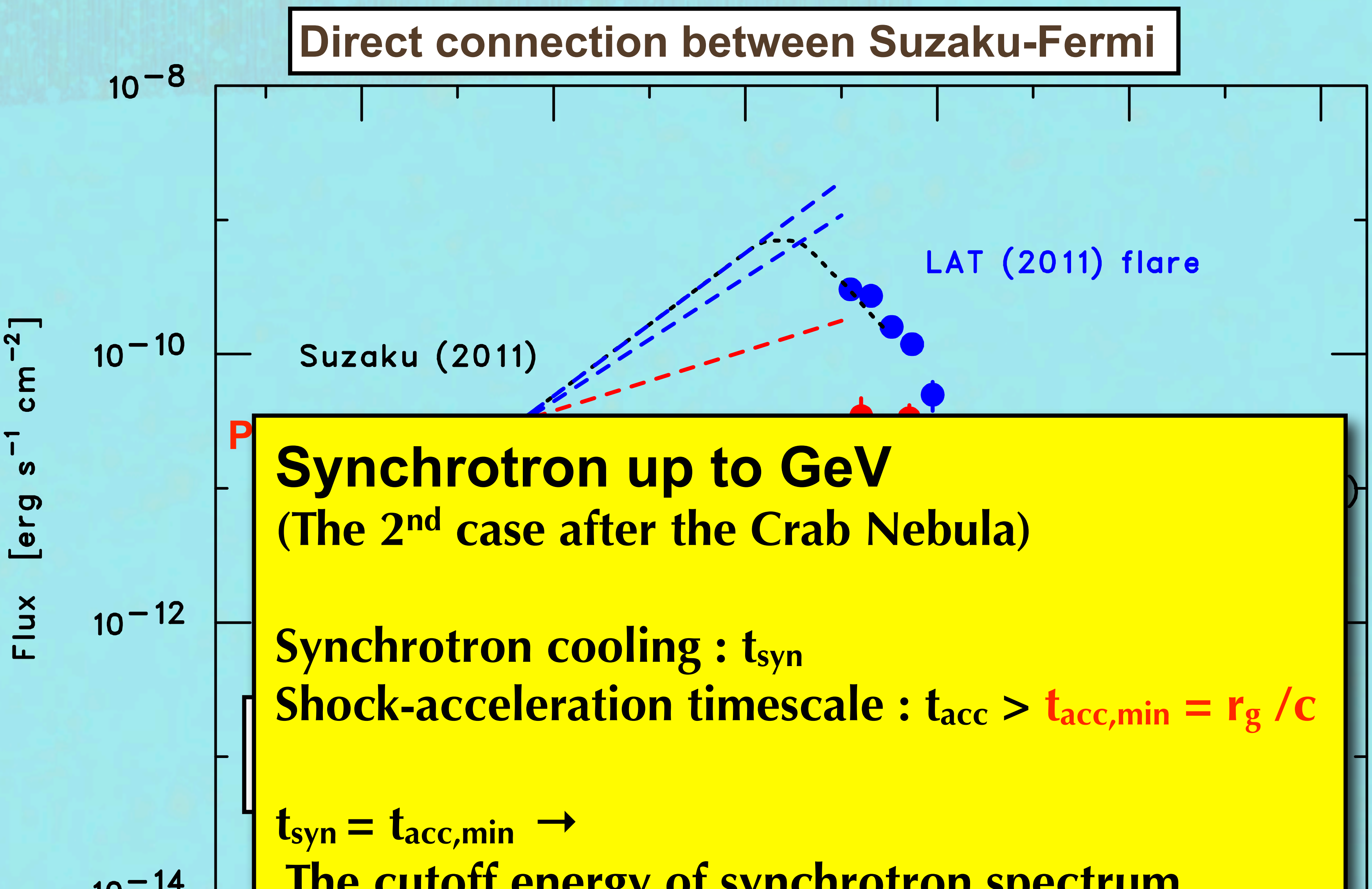
Spin-down power ~ Gamma-ray luminosity

~ e+e- pair luminosity

(no room for ions)

Doppler boost with Γ ~ 2?

PSR B1259-63: Suzaku & Fermi-LAT



Synchrotron up to GeV

(The 2nd case after the Crab Nebula)

Synchrotron cooling : t_{syn}

Shock-acceleration timescale : $t_{acc} > t_{acc,min} = r_g / c$

$t_{syn} = t_{acc,min}$ →

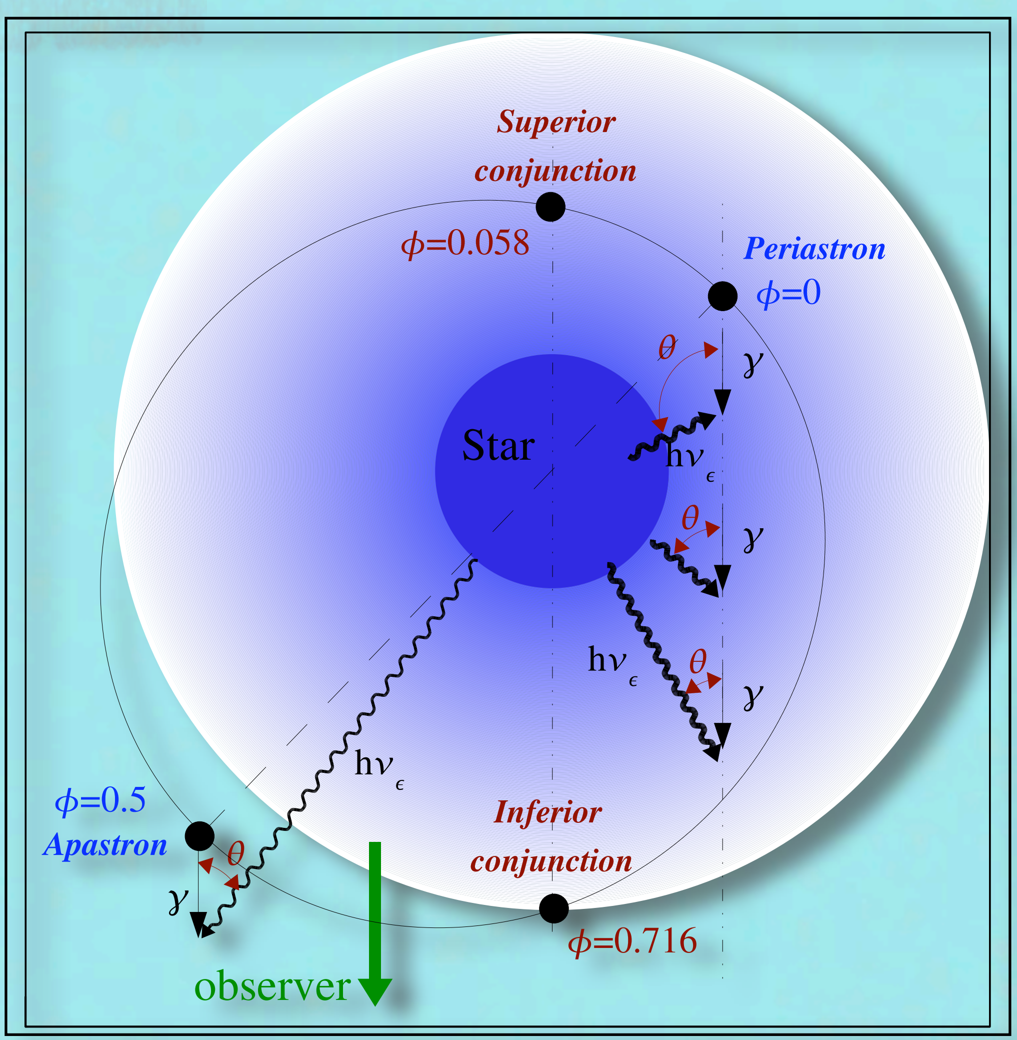
The cutoff energy of synchrotron spectrum

$\varepsilon_c = (9/4)mc^2/\alpha_f$ = 160 MeV (electron)

= 300 GeV (proton)

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**



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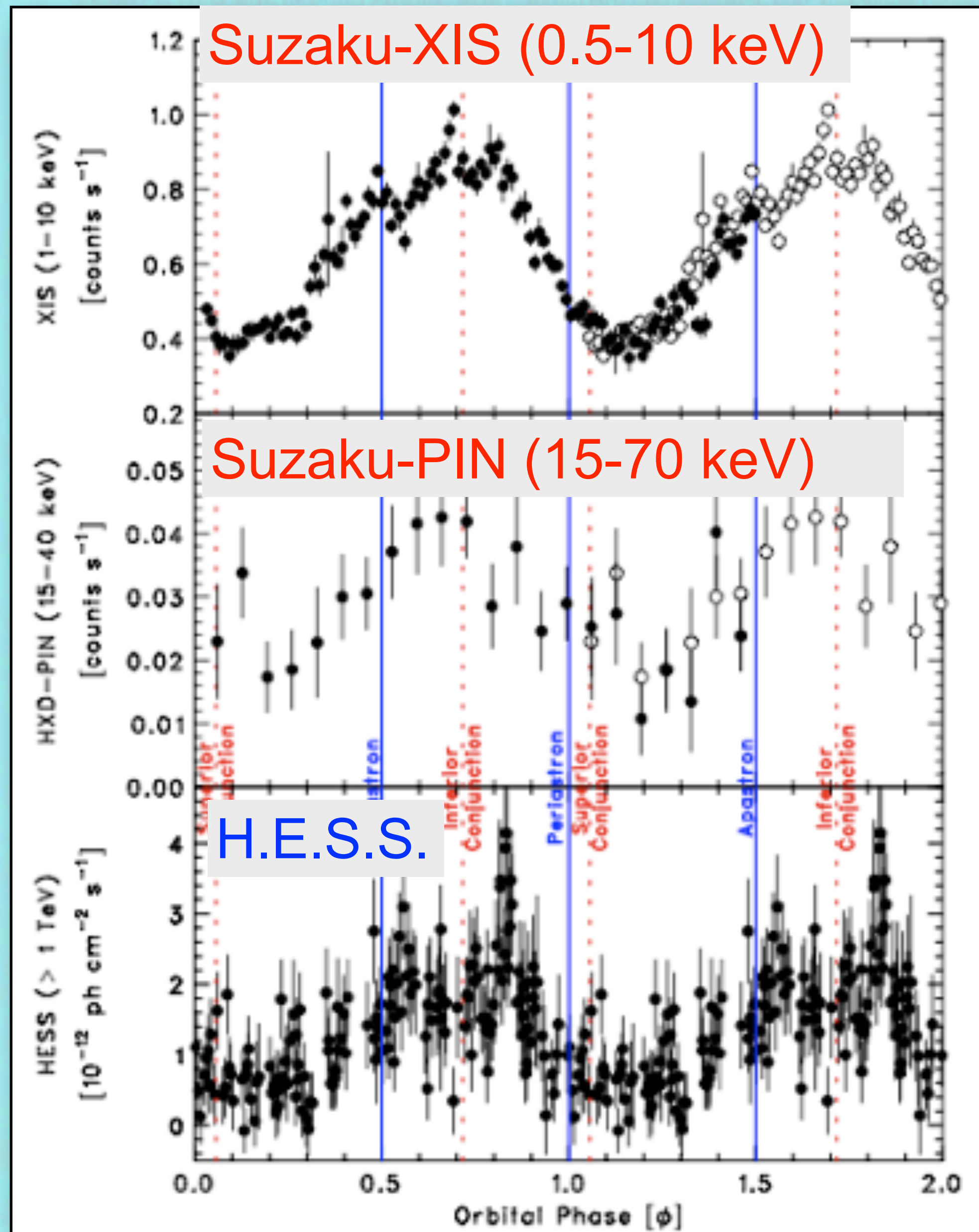
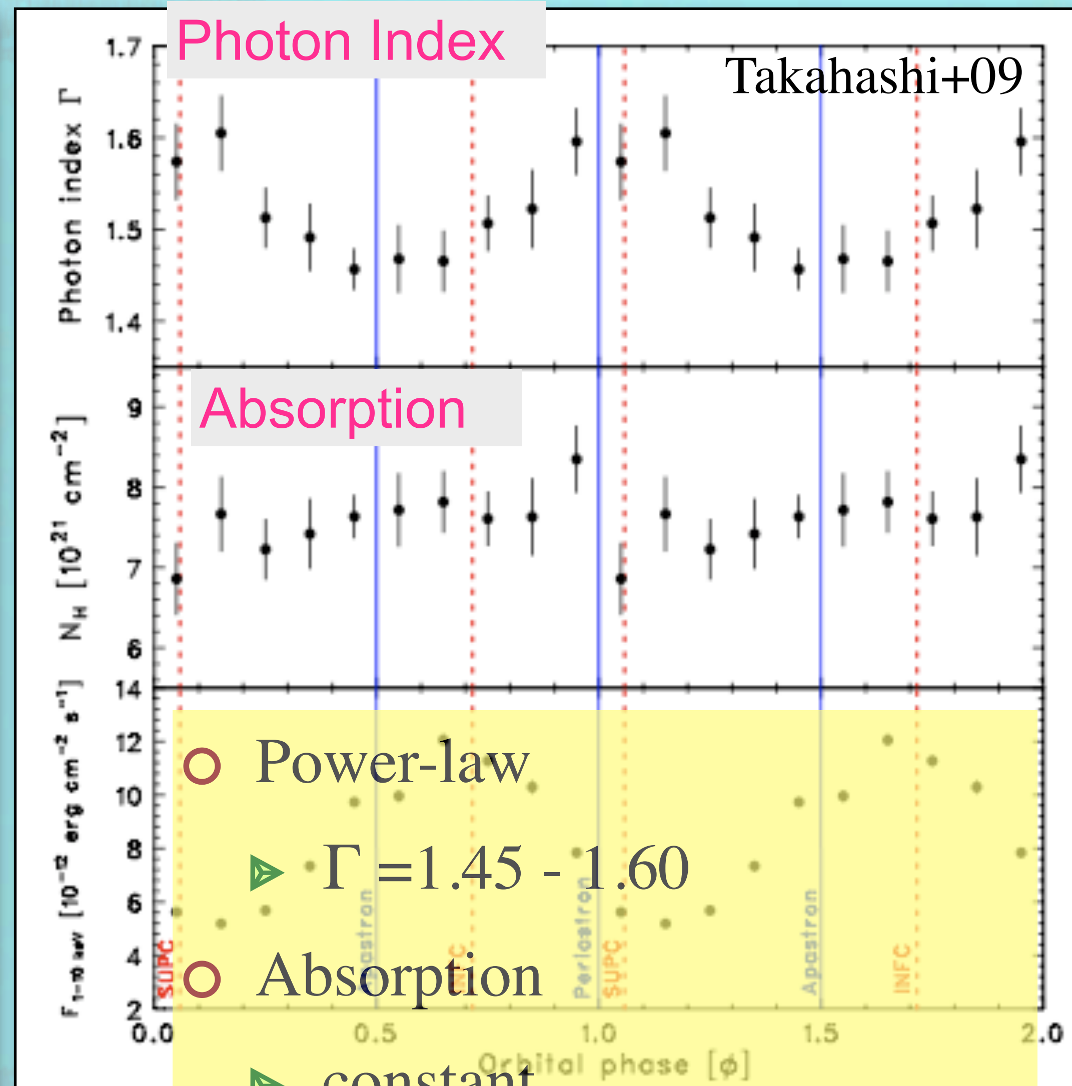
LS 5039: Suzaku continuous 1.5 orbit





- 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

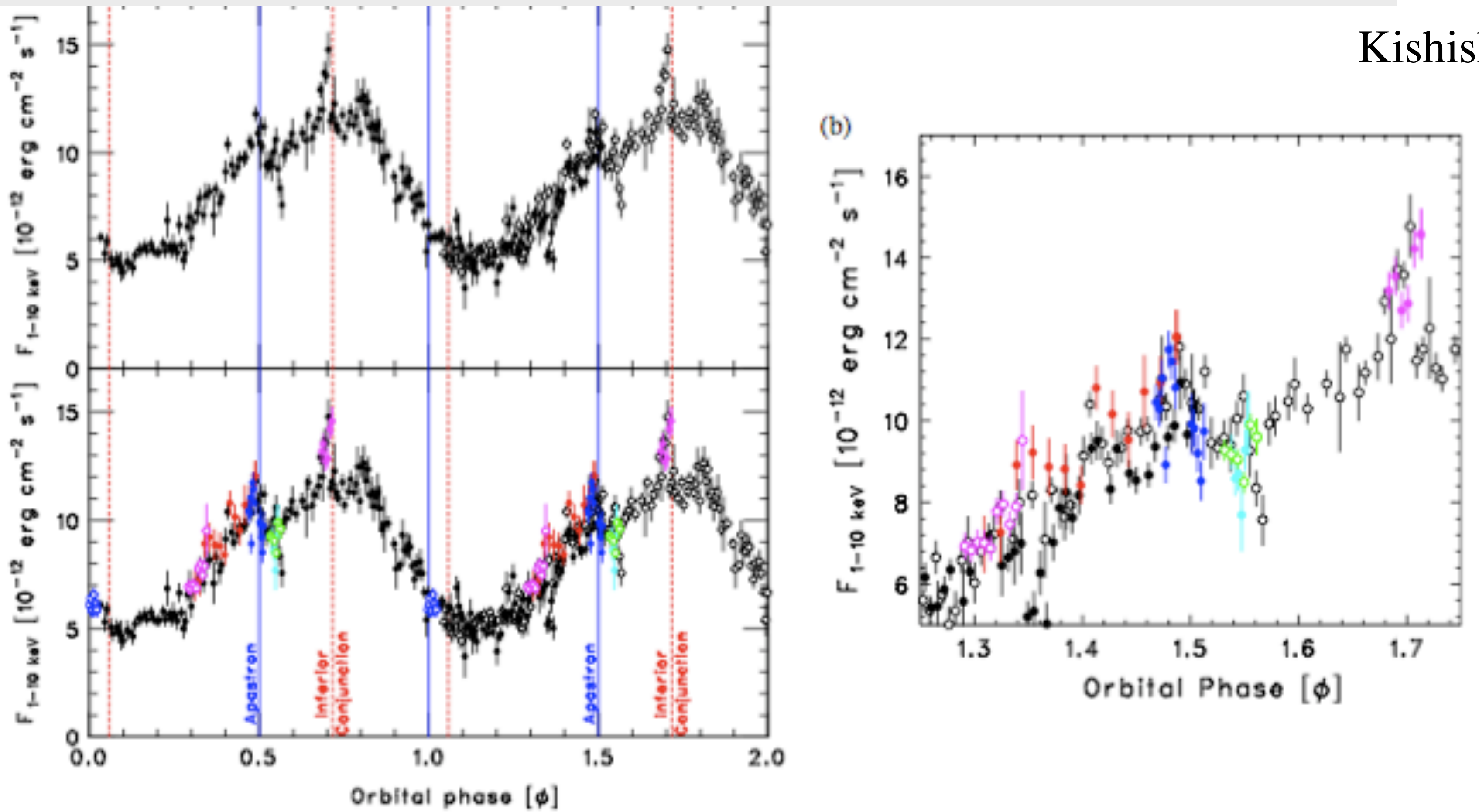


Figure 2. (a) Orbital light curves in the energy range of 1–10 keV. Top: *Suzaku* XIS data with a time bin of 2 ks. Overlaid in the range of $\phi = 0.0$–2.0 is the same light curve but shifted by one orbital period (open circles). Bottom: comparison with the past observations. Each color corresponds 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 $1.2 \leqslant \phi < 1.8$.

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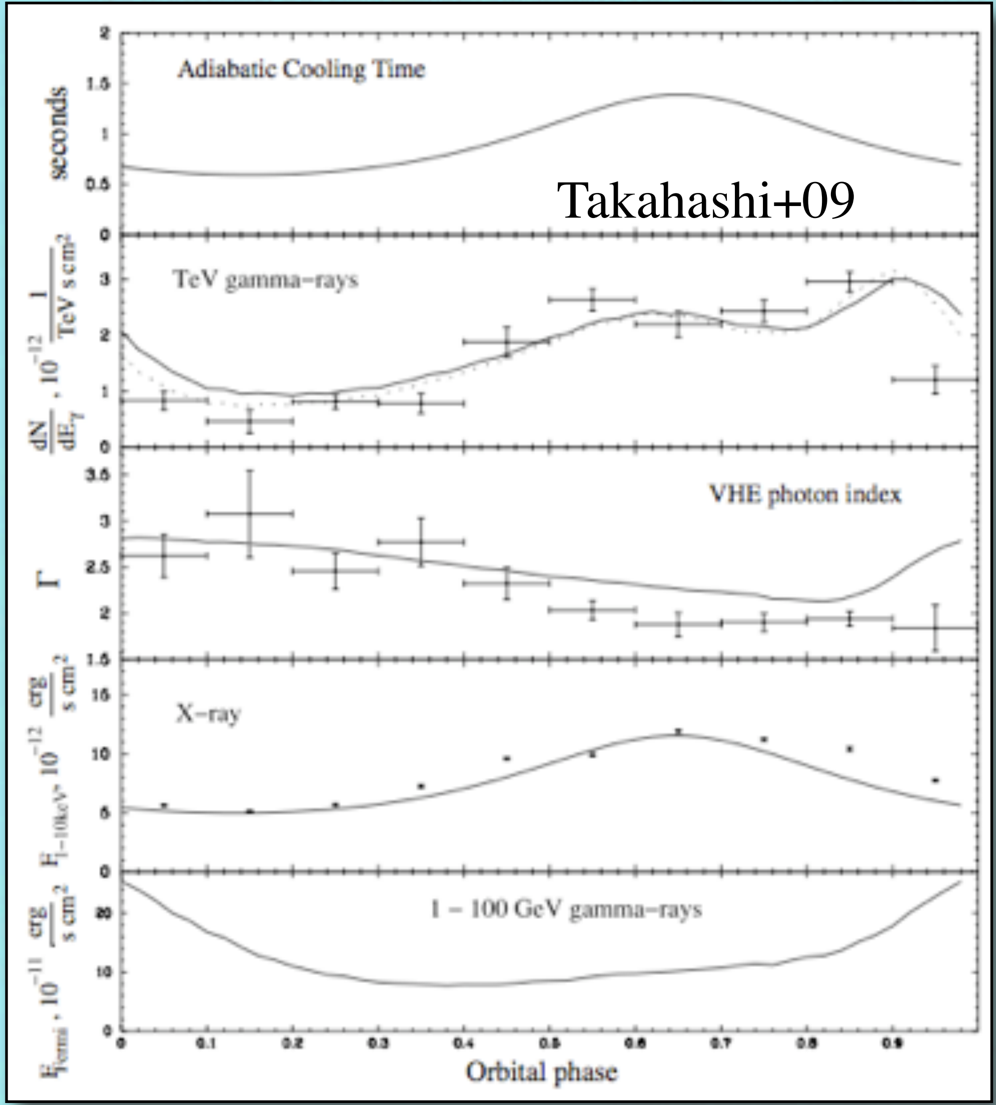
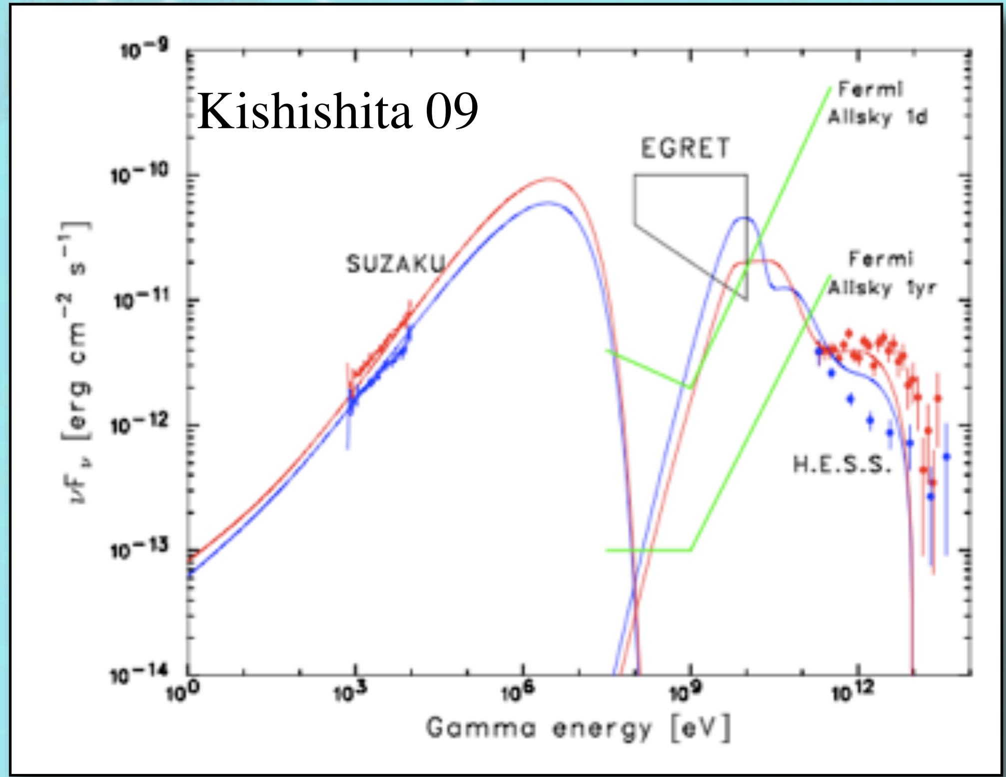
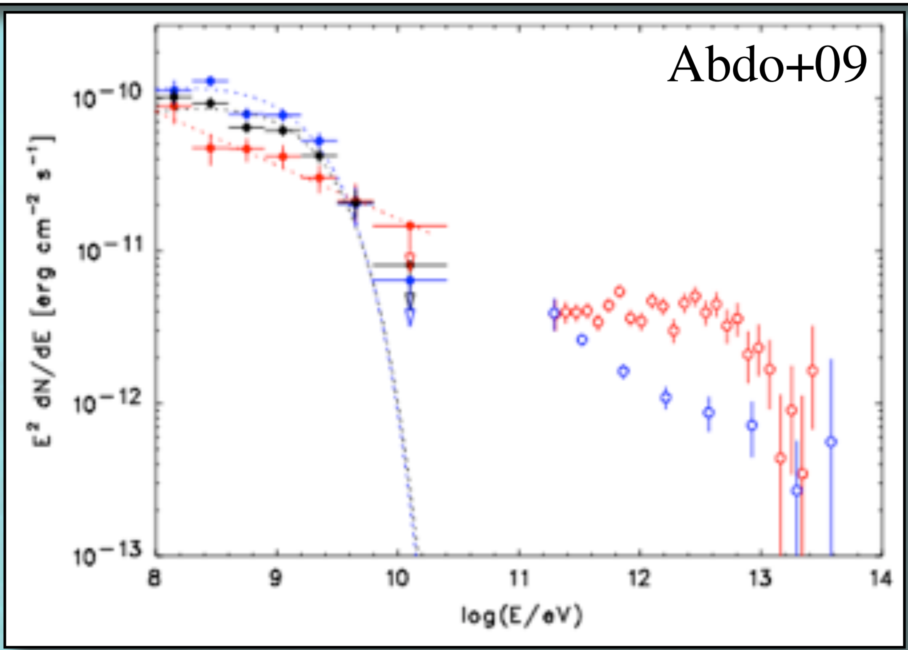
LS 5039: Synchrotron(X)-IC(TeV) Model







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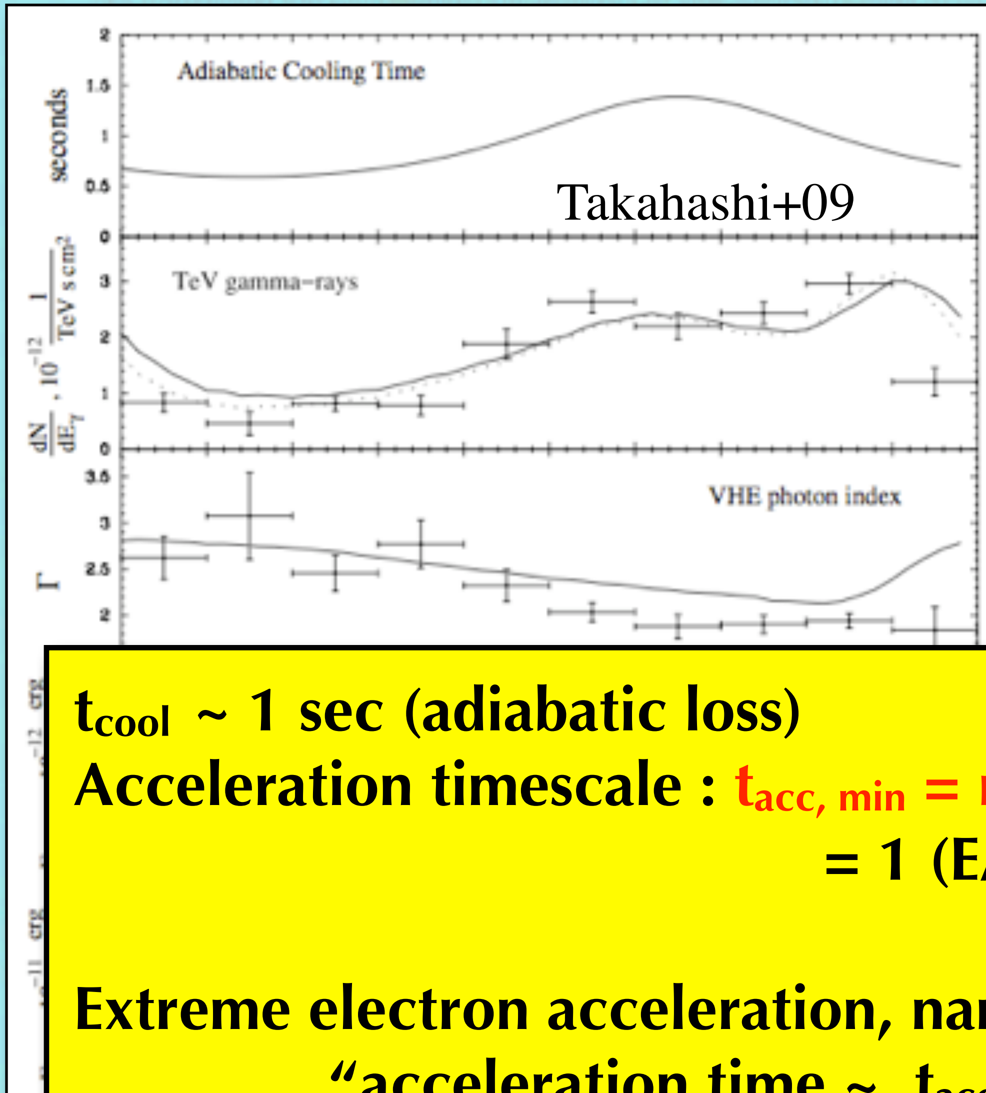
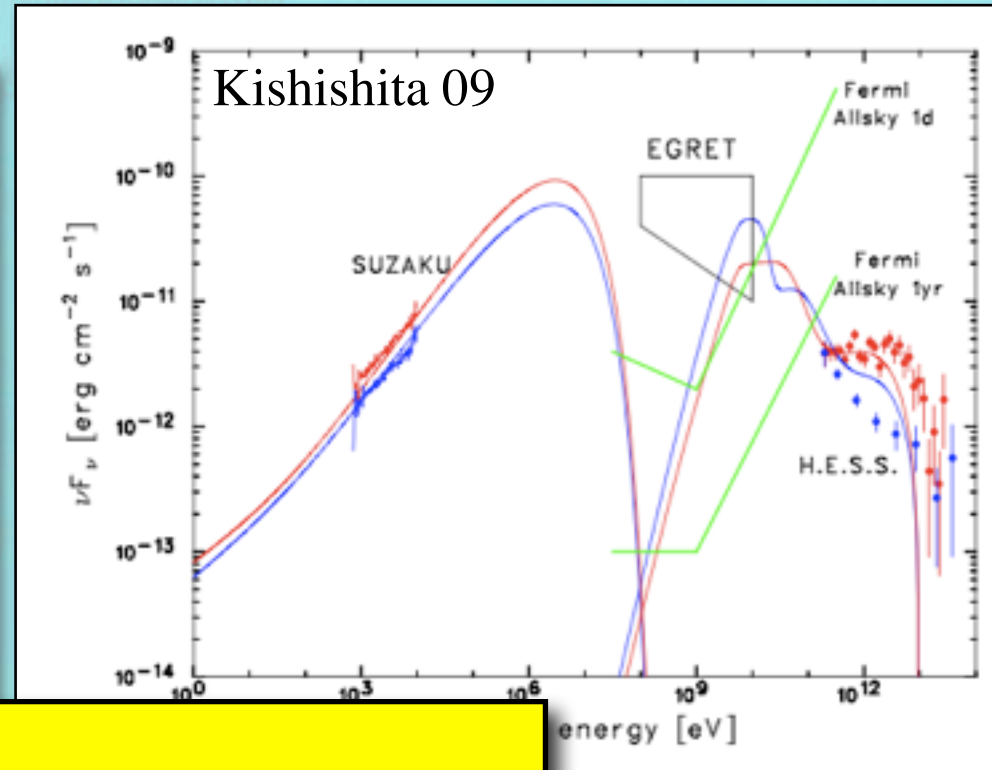
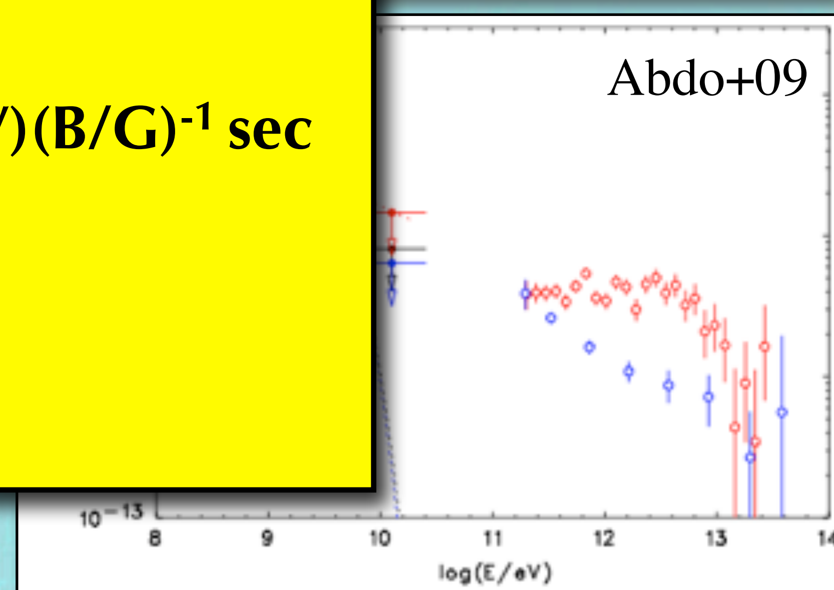
LS 5039: Synchrotron(X)-IC(TeV) Model







t_{cool} ~ 1 sec (adiabatic loss)

Acceleration timescale : $t_{acc,\,min} = r_g/c$

$= 1\ (E/10\ \mathrm{TeV})(B/G)^{-1}$ sec

Extreme electron acceleration, namely

"acceleration time ~ $t_{acc,\,min}$"

must be realized.

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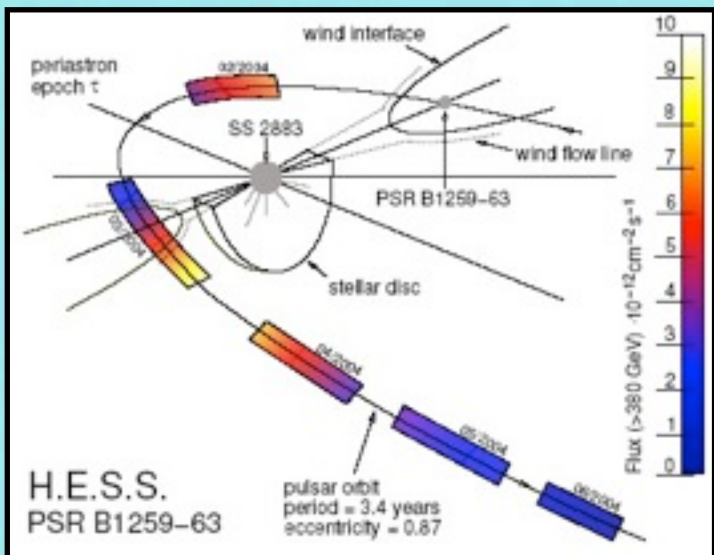
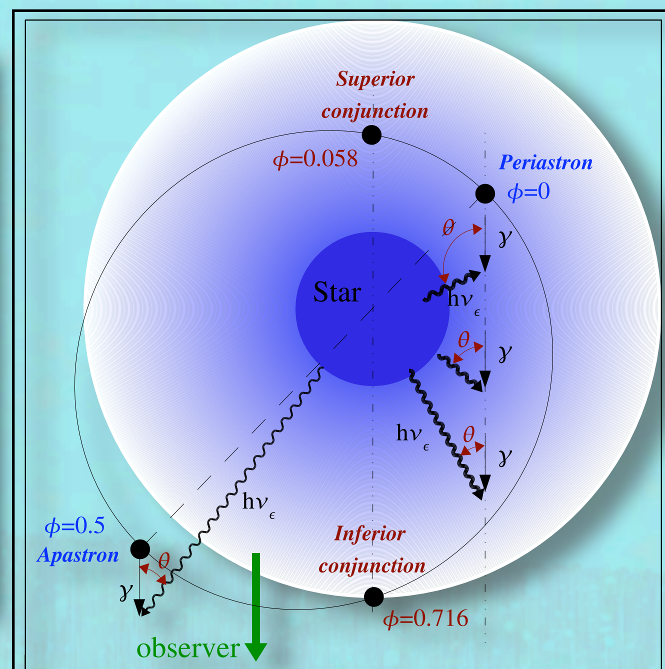
Summary
Extreme Electron Accelerators In Our Galaxy

Acceleration timescale : $t_{acc} \sim r_g / c$

PSR B1259-63



LS 5039



The Crab Nebula