Probing the Pulsar Wind in the TeV Binary System

-PSR B1259-63/SS2883-

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Outline

1, Introduction

-TeV binaries

-Fermi observation

-PSR B1259-63/Be star system

-Observed emission properties

-Pulsar wind

2, Study pulsar wind of PSR B1259-63

-Emission model (electrons and positrons)

-Fitting X-ray data

-Pulsar wind properties (σ, Lorentz factor) at 1AU scale

1, Introduction

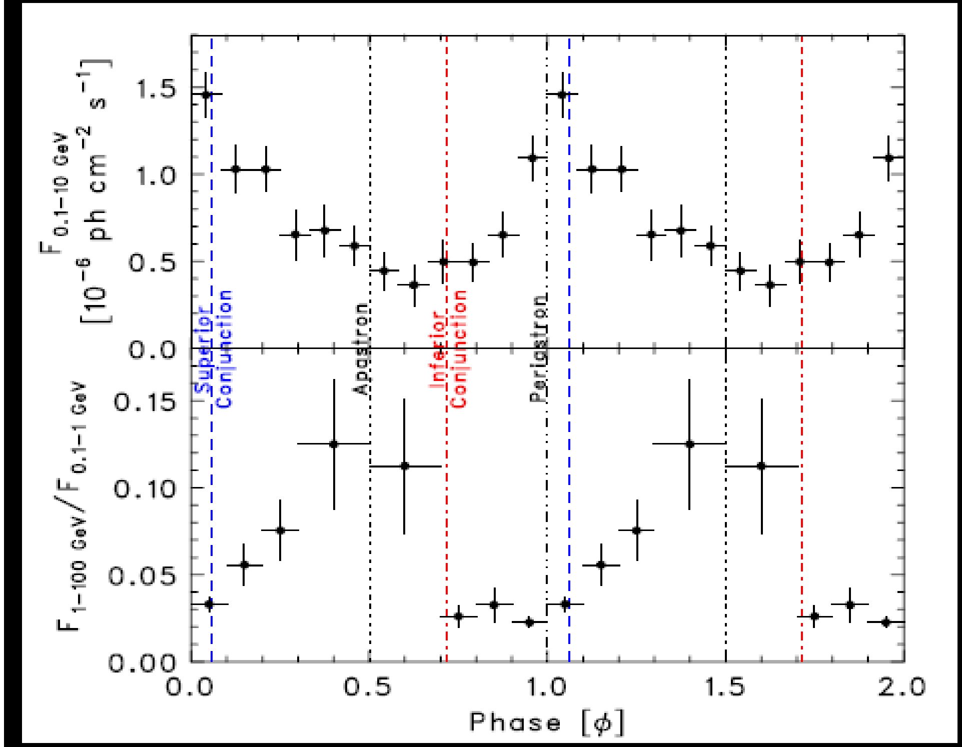
TeV binaries

- PSR B1259-63/SS2883; Be+Pulsar
- LS I+61 303 ; Be+NS or BH
- LS 5039 ; O+NS or BH
- HESS J0632+057 ; Be+??

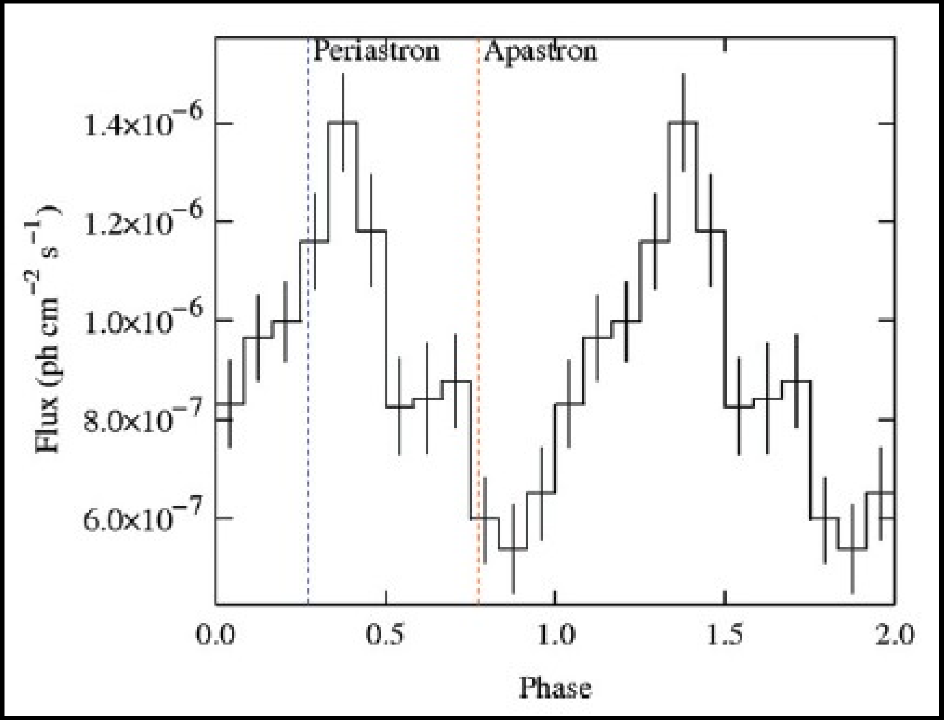
LS I+61 303 and LS 5039 can bee seen by Fermi (Abdo et al. 2009)

Fermi observations of TeV binaries

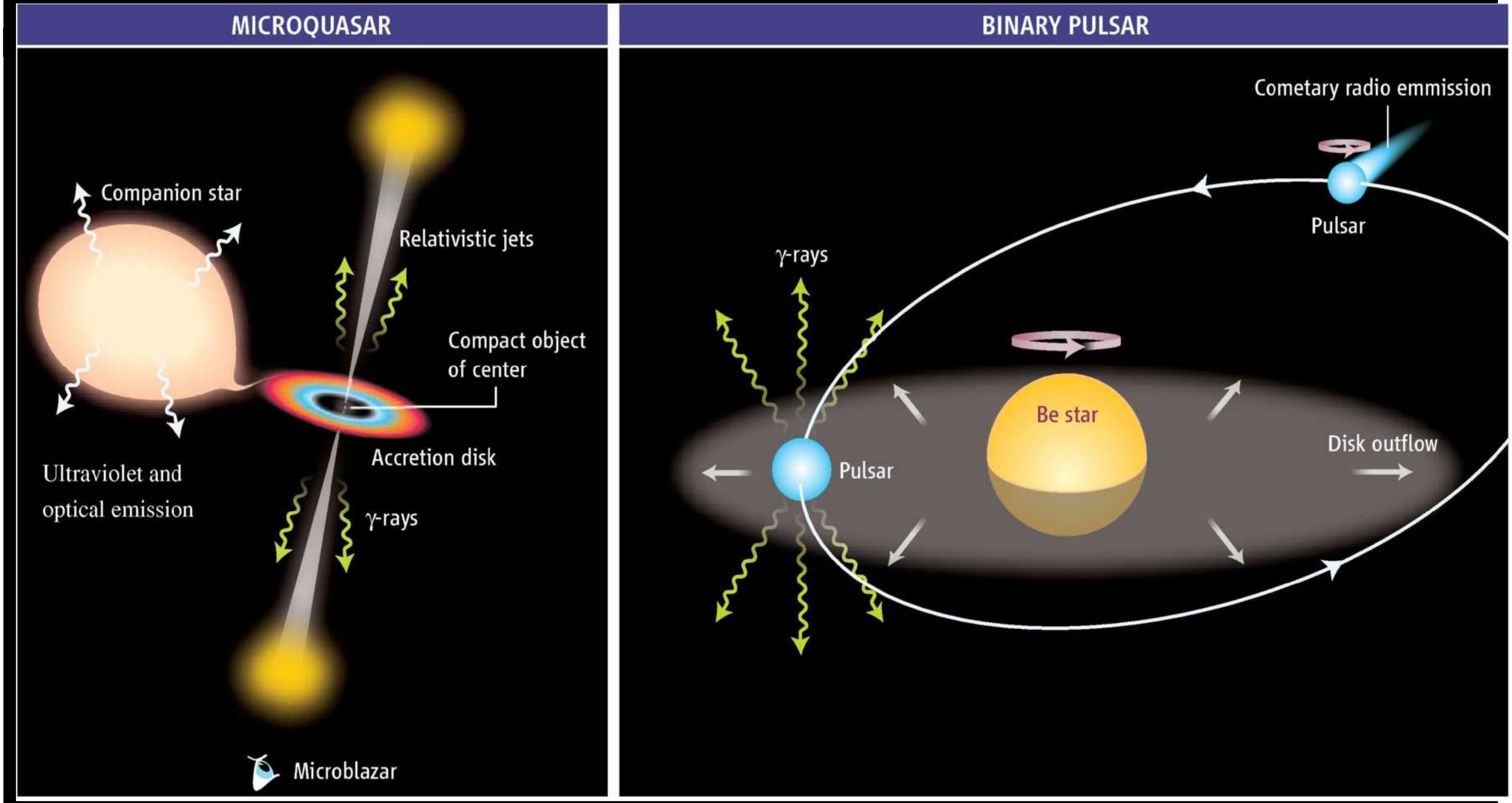
LS 5039



LS I+61 303

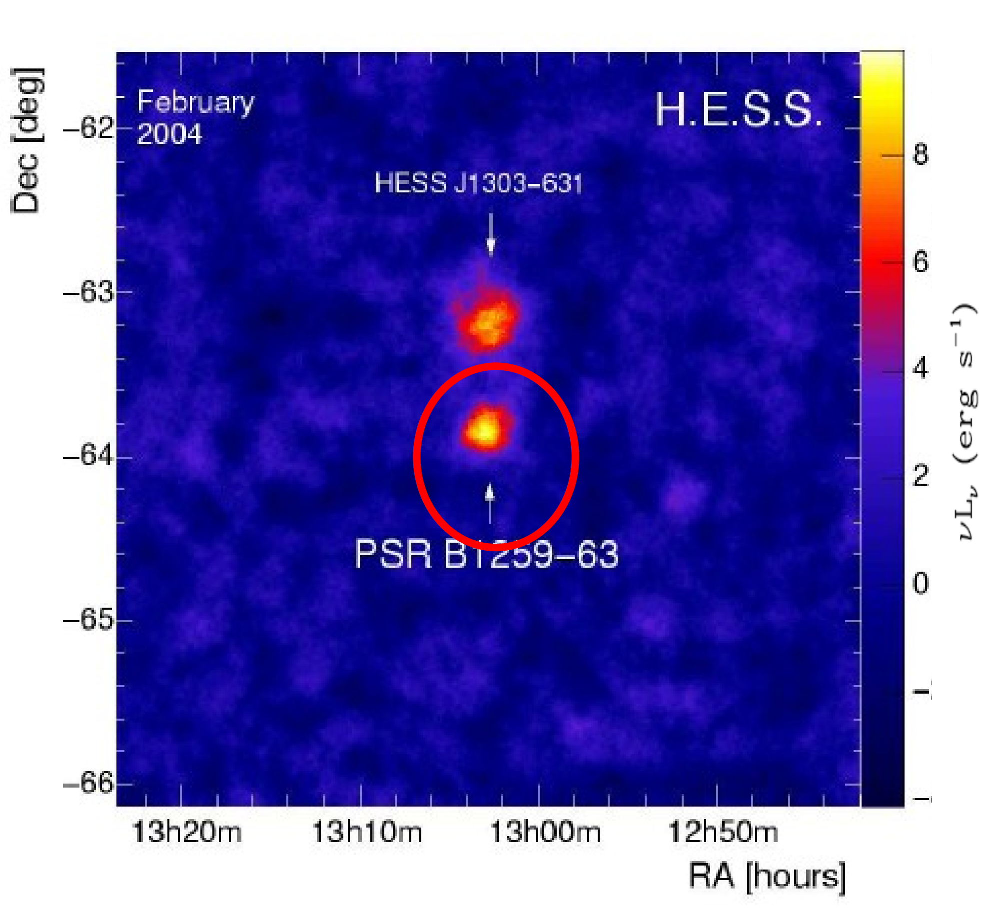


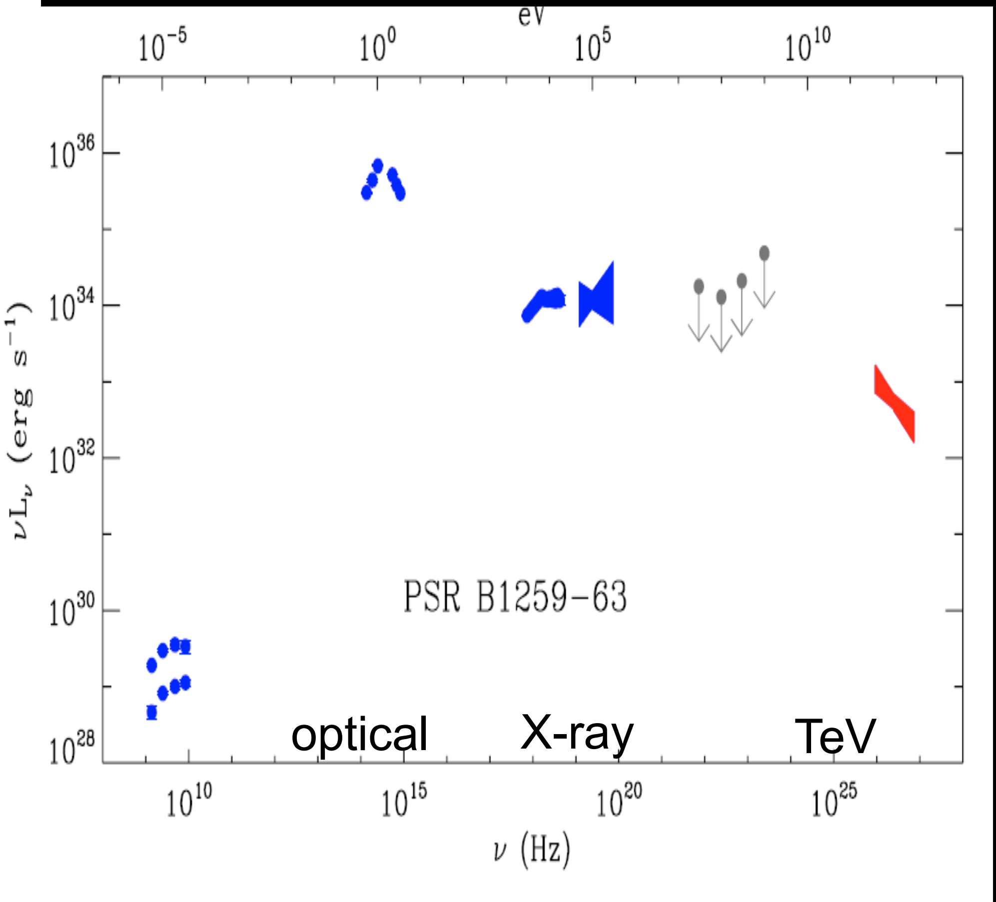
Micro-quasar or Pulsar binary?



PSR B1259-63/SS2883

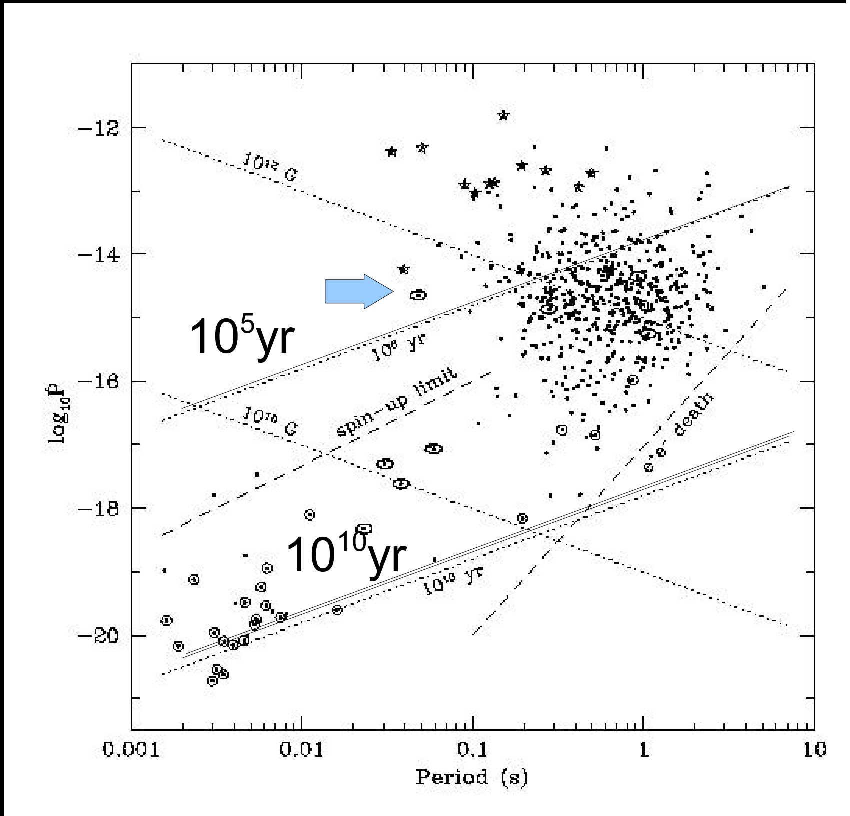
(Aharonian et al. 2005,)





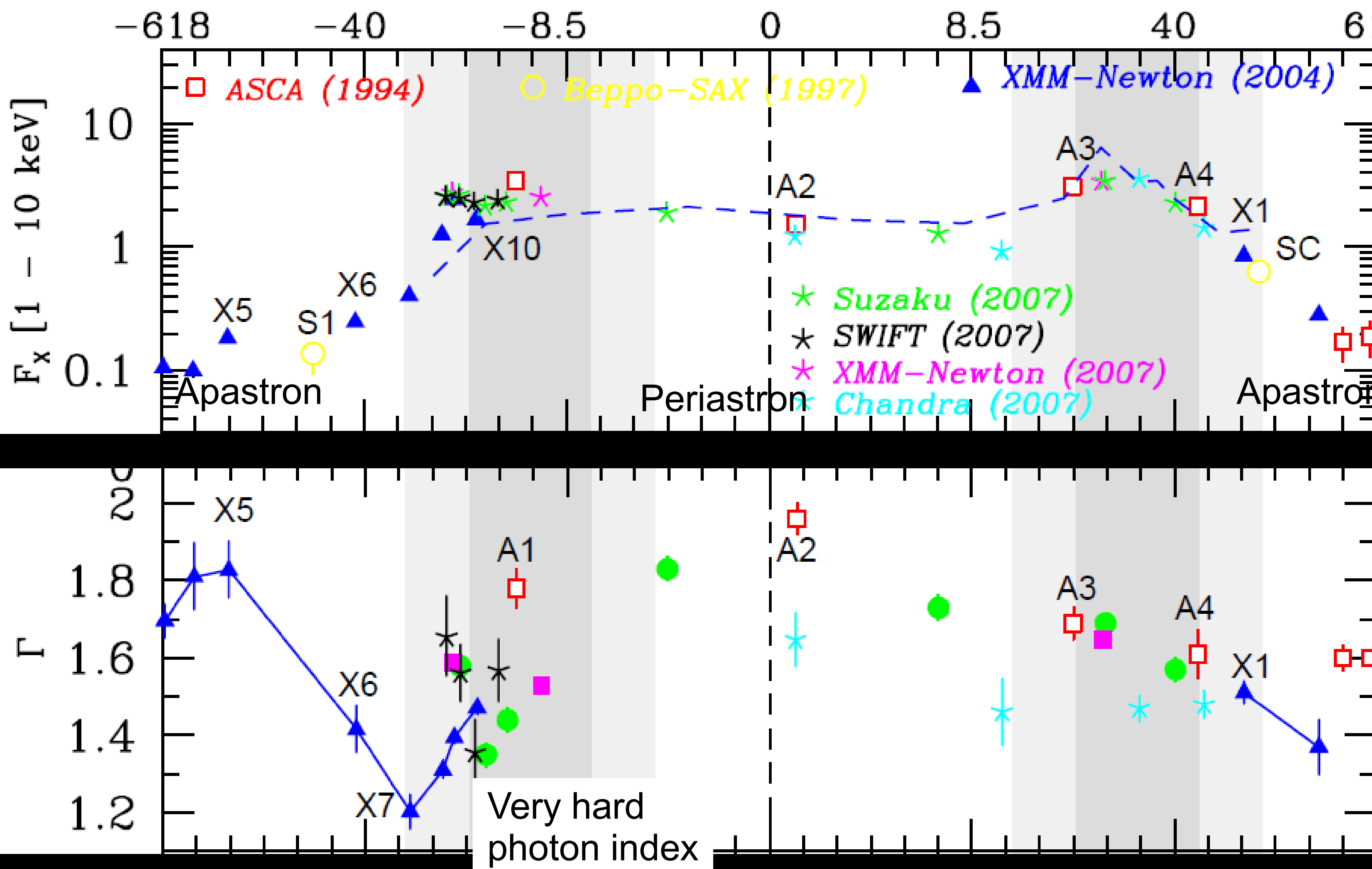
PSR B1259-63 + SS 2883 system

- PSR B1259-63; P~48ms (pulsed radio), L_{sp}~8 10^{35}erg/s
- SS2883; Be star
  - M~10Msun, R~10Rsun
- Eccentricity ~0.87, Po~3.4yr
- Periastron Rp~0.7AU and Apastron Ra~10AU
- d~2kpc

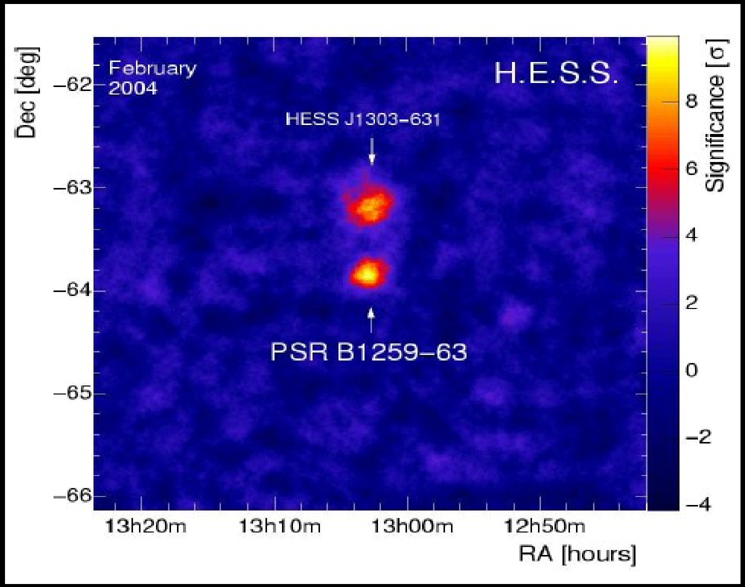


(Cheryakova et al. 2009)

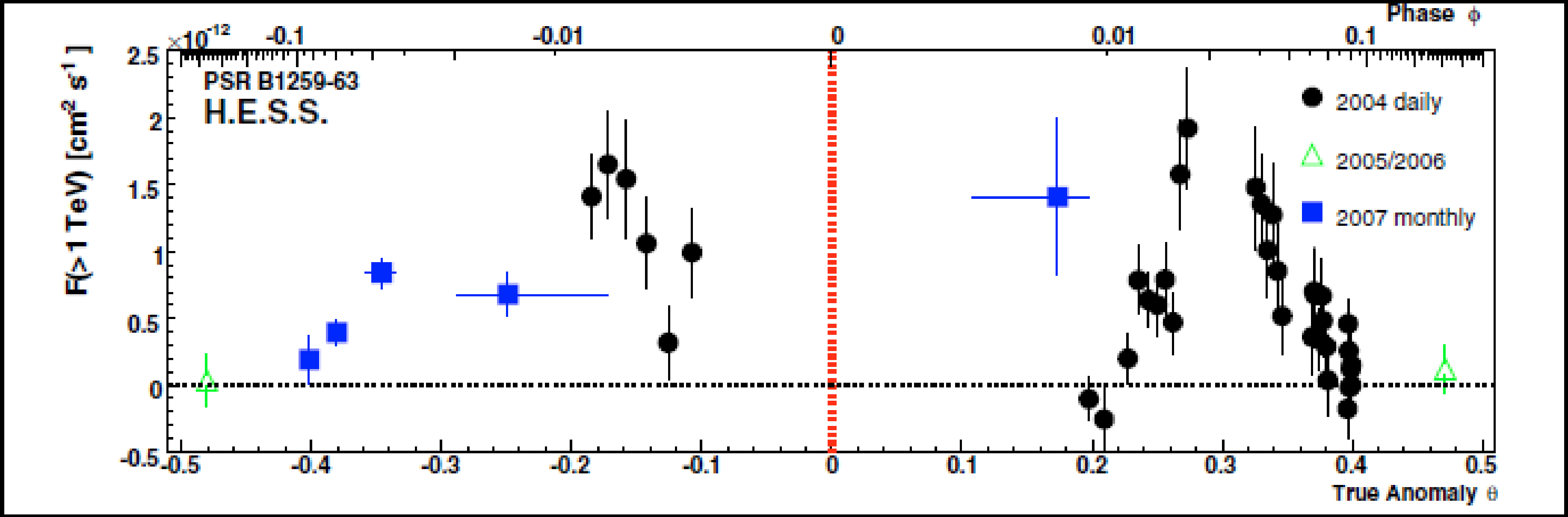
Light curve (X-ray)



Light curve (TeV)



(Aharonian et al. 2005,2009)



PSR B1259-63/SS2883

- Pulsar wind and stellar wind interaction

-the particle acceleration at the shock

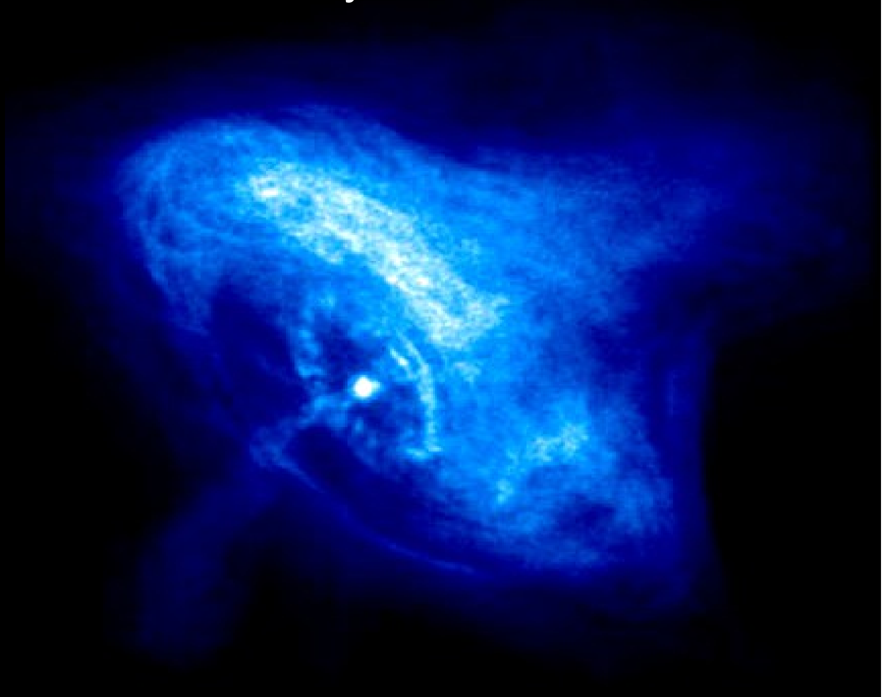
1,Leptonic model
(Tavani & Arons 1997; this study)
-synchrotron radiation and Inverse Compton process by the shock accelerated electrons/positrons

2, Hadronic model
(Kawachi et al. 2004; Chernyakova et al. 2006)
-proton-proton interaction
-π0-decay, SR and IC from the higher generated pairs)

Leptonic Model

- Same physics with the emission from pulsar wind (PW) nebula around isolated pulsars (such like the Crab)
- Interaction between PW and ISM makes a shock at r~0.1pc from the pulsar.
- S.R. and I.C. produce electromagnetic wave in radio to TeV energy bands.
- Diagnostic tool PW at 0.1pc scale (Kennel & Coroniti 1984)

Crab synchrotron nebula



Kennel and Coroniti (1984)

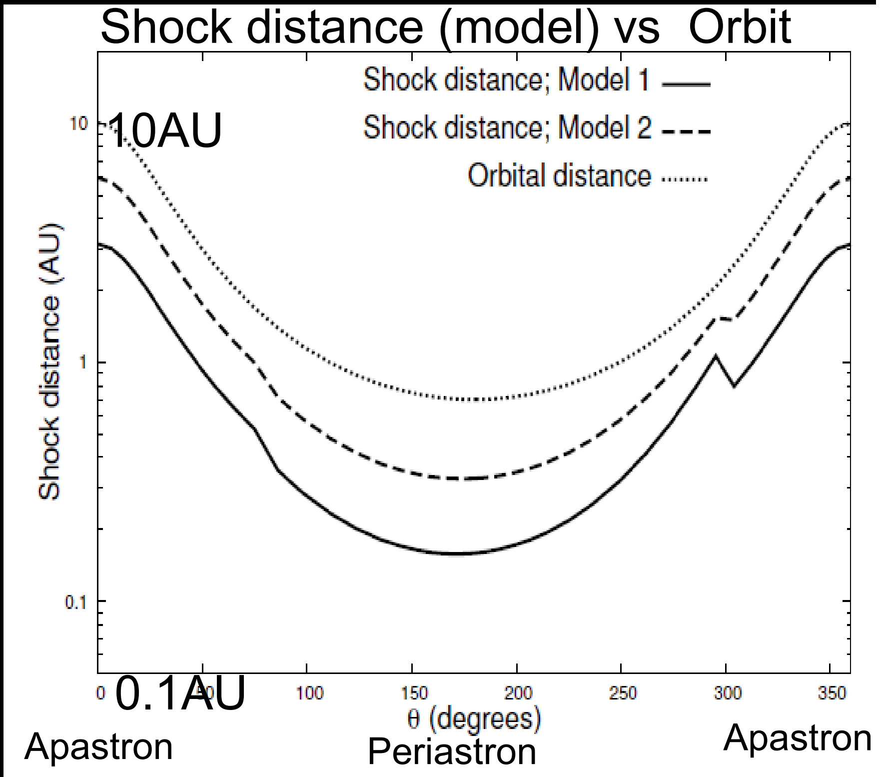
$$\sigma = \frac{\text{Eelectro-Magnetic energy flux}}{\text{Particle energy flux}}$$

- $\sigma \sim 0.03 \ll 1$ at 0.1pc from the pulsar
- $\sigma \sim 10^3$-10^4 near the pulsar
- Energy conversion (~97%) from the EM energy to particle energy

σ paradox

Shock distance in pulsar binary system

- The shock stands at r~0.1-1AU
  -Pulsar wind pressure
  =Stellar wind pressure
- The observed emissions reflect the properties of pulsar wind
  → We can discuss the properties of the pulsar wind more closer to the pulsar



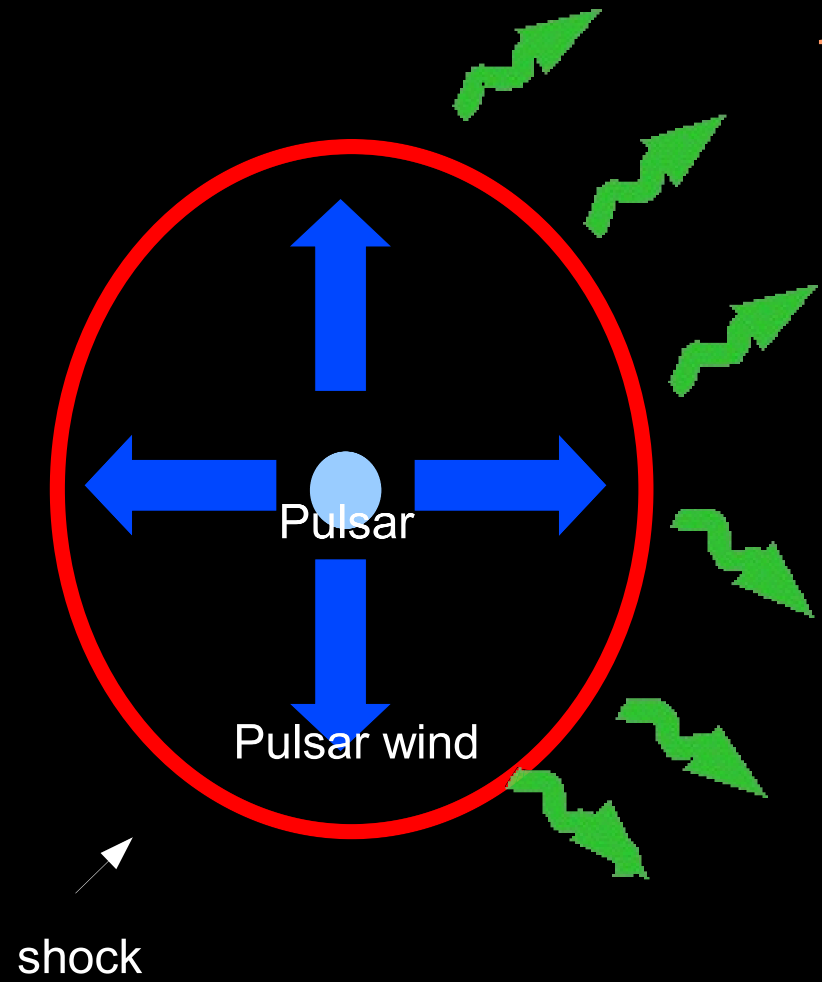
Purpose

- What are the properties of the PW at 0.1-1AU scale?
- Can the Leptonic model explain X-ray and TeV observations (spectral index and light curves) of entire phase?

We fit the X-ray data by an emission model, in which the properties of the pulsar wind (e.g. Lorentz factor) are used as the fitting parameters.

2, Study pulsar wind of PSR B1259-63

Model (geometry)



- Spherical axi-symmetric model
- Pulsar wind carries pulsar spin down luminosity (8 10^{35} erg/s)
- Ignoring effects of ions
- Efficiency of the acceleration at the shock is 100%

Model (Stellar wind)

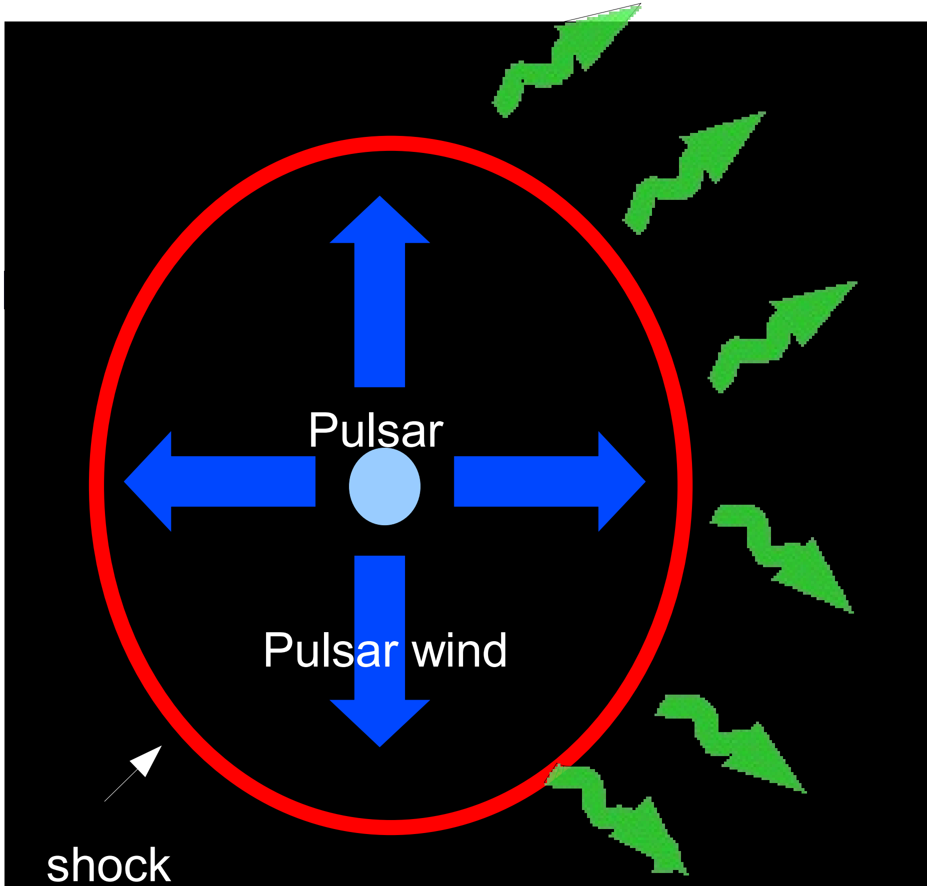
- Stellar wind Model

  -Polar wind + Equatorial disk-like wind

- Polar wind
  -mass loss rate 10^{-9} – 10^{-8} Msun yr^{-1}

- Equatorial disk wind
  -mass loss rate 10^{-7} Msun yr^{-1}

- Pulsar wind mainly interacts with the disk wind at
  -20days<τ<100days



Physical properties of P.W.

σ ; magnetized parameter

$$\sigma = \frac{\text{Eelectro-Magnetic energy flux}}{\text{Particle energy flux}}$$

Γ_1 ; Lorentz factor of the wind

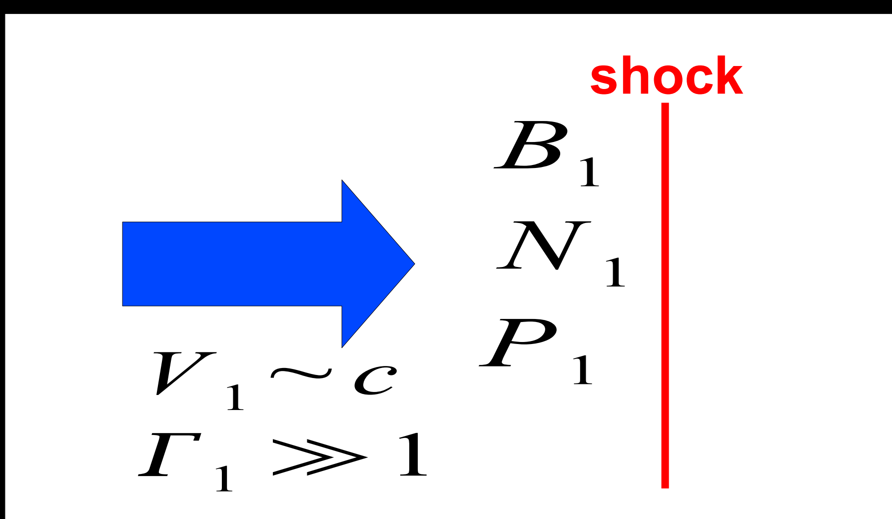
→ Fitting parameters

Magnetic field $B_1^2 = \frac{L_{sp}}{r_s^2 c} \frac{\sigma}{1+\sigma}$

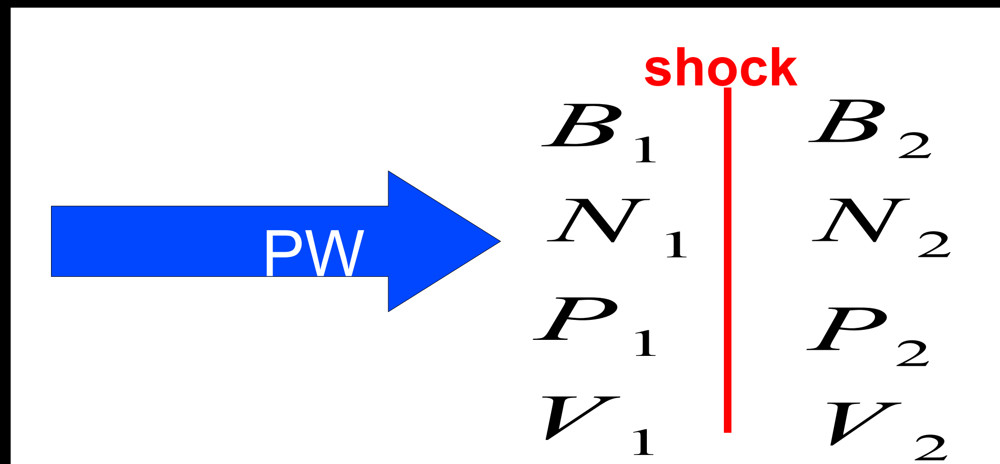
Particle number density

$$N_1 = \frac{L_{sp}}{4\pi r_s^2 \Gamma_1 m_e c^3 (1+\sigma)}$$

$P_1 = 0$ Zero gas pressure



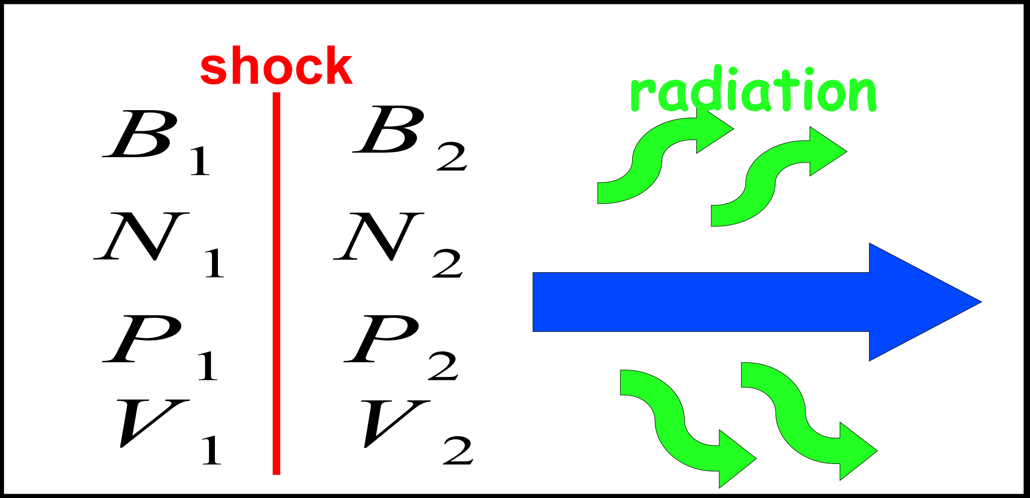
Rankine-Hugoniot relation



$$N_1 V_1 = N_2 V_2 \qquad V_1 B_1 = V_2 B_2$$

$$\gamma_1 \mu_1 + \frac{E B_1}{4\pi N_1 V_1} = \gamma_2 \mu_2 + \frac{E B_2}{4\pi N_1 V_1}$$

$$\mu_1 u_1 + \frac{P_1}{N_1 V_1} + \frac{B_1^2}{8\pi N_1 V_1} = \mu_2 u_2 + \frac{P_2}{N_1 V_1} + \frac{B_2^2}{8\pi N_1 V_1}$$



$$f_2(\Gamma) \propto \Gamma^{-p}$$

Γ1<Γ<Γmax; Γ1; Lorentz factor of un-shocked pulsar wind
Γmax; Larmor radius = System size
1.5<p<3; Model parameter
(Baring 2004)

$$\frac{d\gamma}{dt} = \left(\frac{d\gamma}{dt}\right)_{ad} + \left(\frac{d\gamma}{dt}\right)_{rad}$$ **Energy loss rate**

$$f(r,\Gamma) = (N/N_2)\, f_2(\Gamma_0)\, d\Gamma_0 / d\Gamma$$

Fitting

Model parameter;

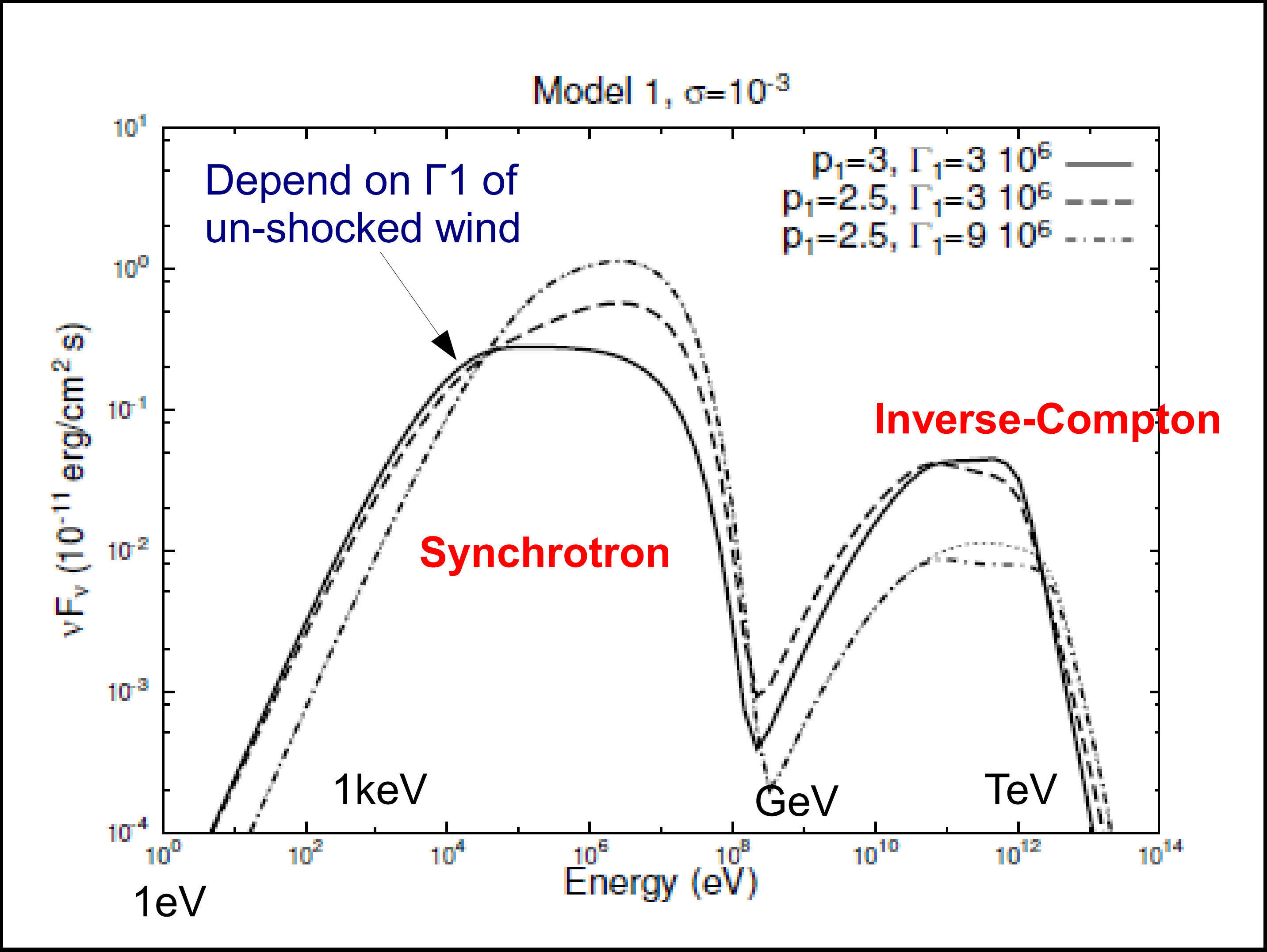
1 magnetized parameter σ
2 Lorentz factor of unshocked pulsar wind Γ1
3 Power law index of the shocked particles P1

Fitting each X-ray data (flux and photons index) at different orbital phase

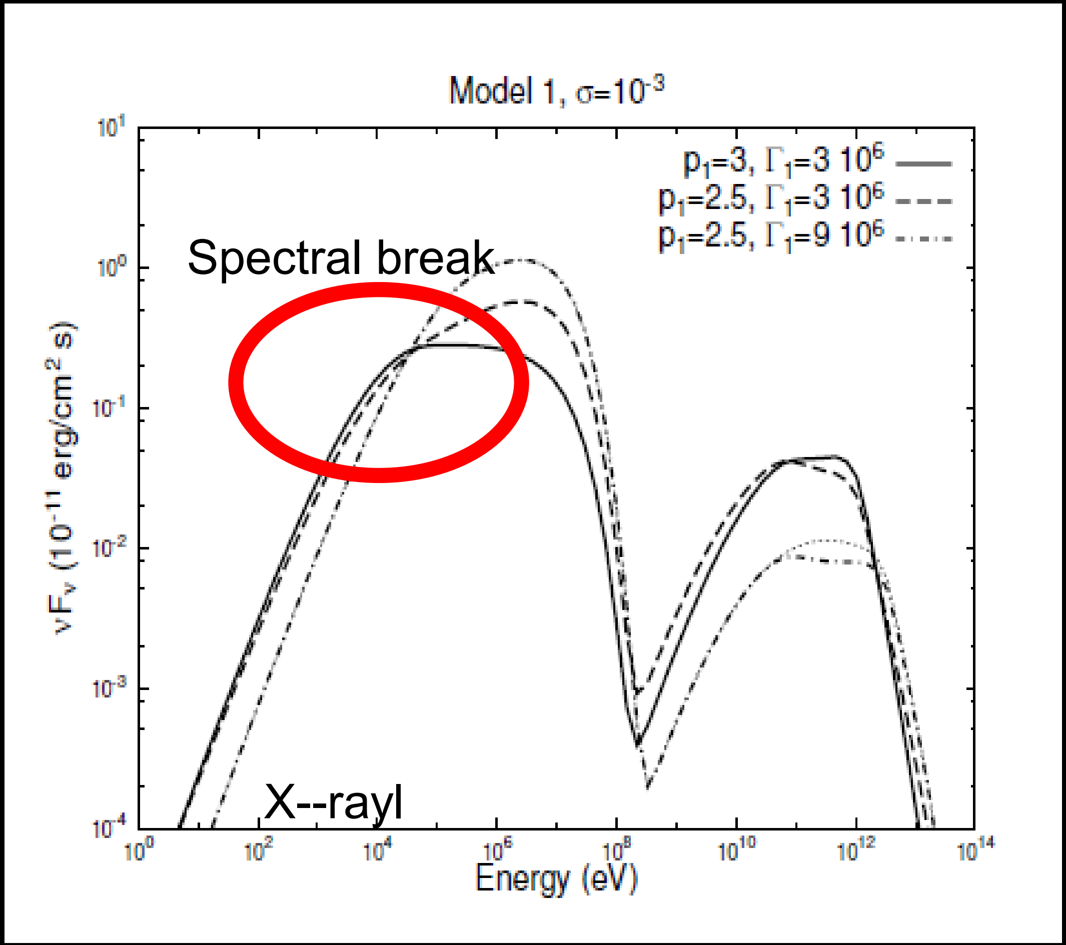
(1) σ and Γ1; variable parameters
Photon index is fixed at p1=3 for entire orbital phase

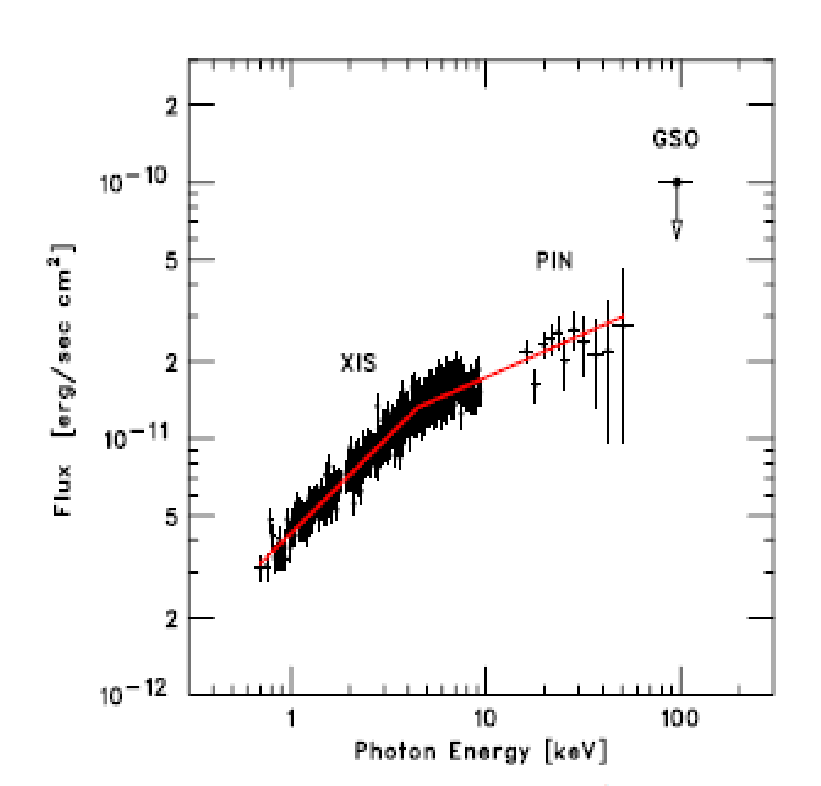
Results

Results;General feature of spectrum

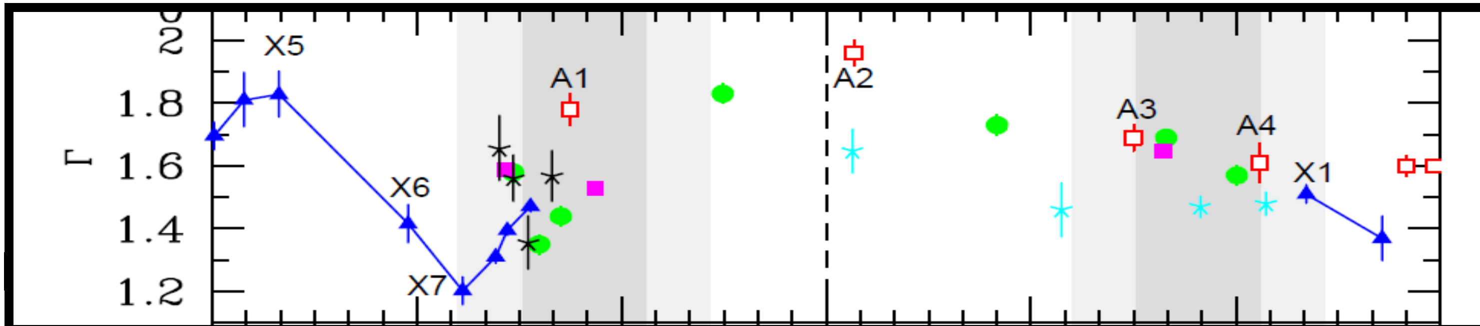


Very hard spectrum (p<1.5)





Spectral break observed by SUZAKU (Uchiyama et al. 2009)



σ and Γ1; variable parameters; photon index p1=3

Apastron Periastron Apastron

Orbital phase		X3	X6	X7	S1	S4	A5	A2	S6	A3	X1	X2	A6
Fitting parameters	$\sigma\ (\times 10^{-3})$	0.8	1.2	2.2	2.1	11	11	15	6.2	70	9.2	3.3	1.7
$(p_1 = 3)$	$\Gamma_1 (\times 10^6)$	8.5	7.6	7.8	1.1	1.7	0.57	0.3	1	0.8	2.8	8	6.5
$F_{0.02-10^2\mathrm{GeV}}$	$(10^{-11}\mathrm{erg/cm^2s})$	0.017	0.1	0.19	2.3	2	5.8	12	4.3	4.8	0.46	0.028	0.028

1, We can fit all X-ray data with the present model

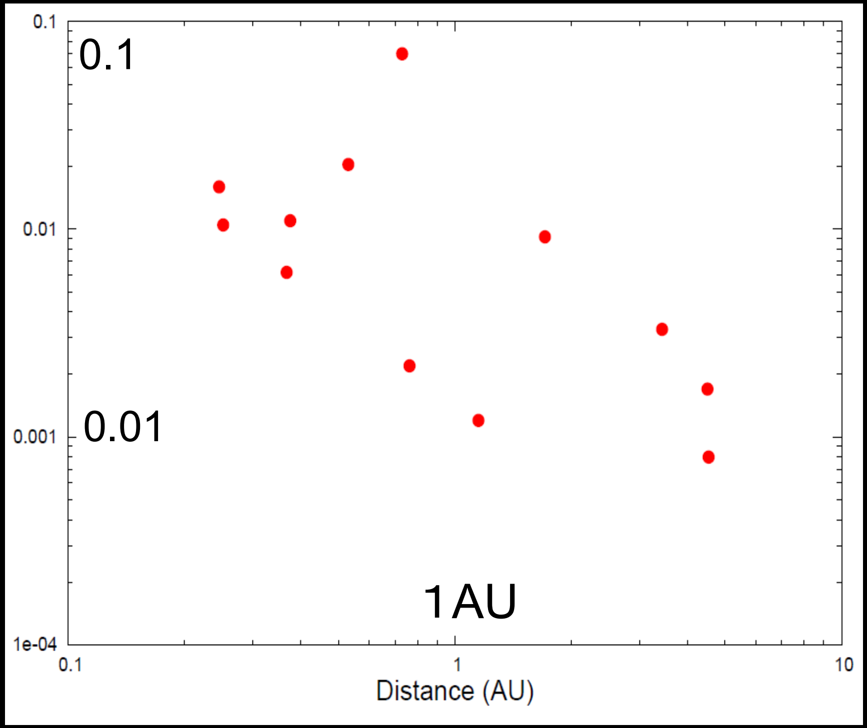
2, $\sigma \sim 10^{-3}$-$5\times10^{-2} \ll 1$ (99.9%-95%) (if σ=1 50%)

3, $\Gamma 1 \sim 3\times 10^{5}$-$10^{7}$

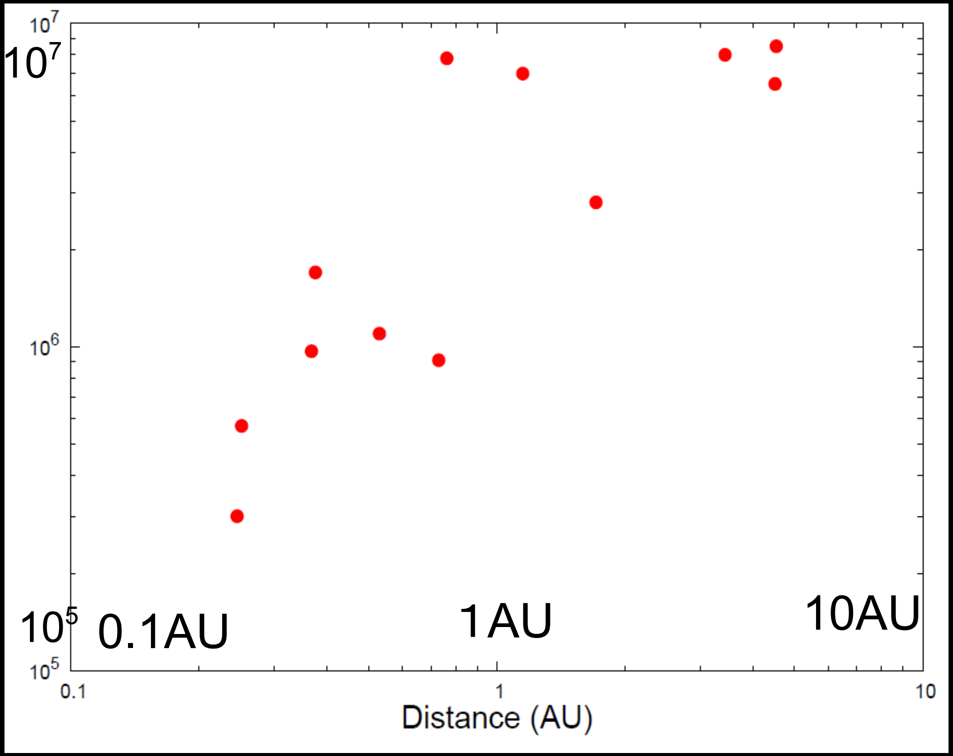
4, photon index <1.5 is obtained with p1~3

Fitting σ and Γ1 vs. distance from the pulsar

σ vs. Dis

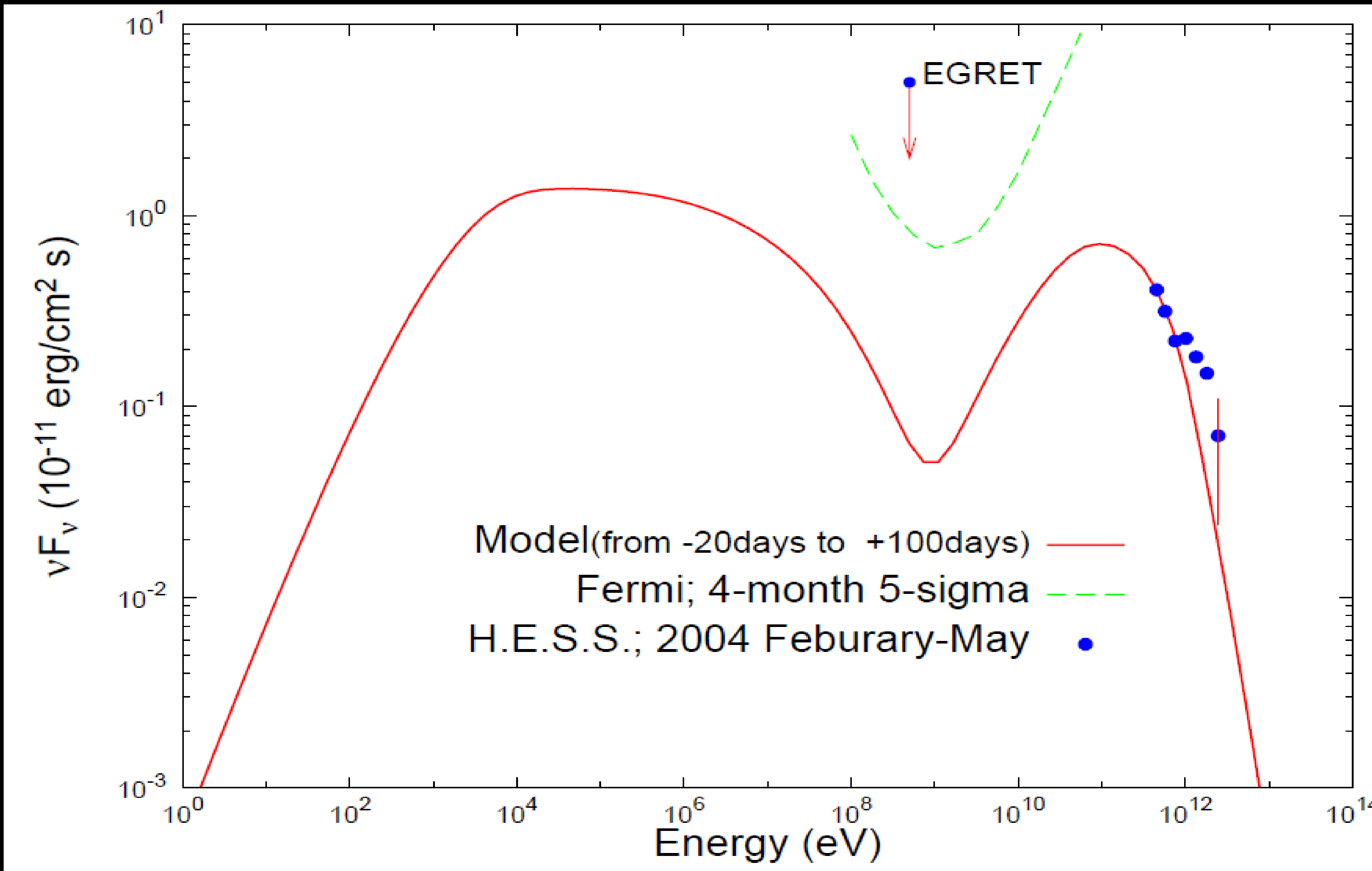


Γ 1 vs. Dis

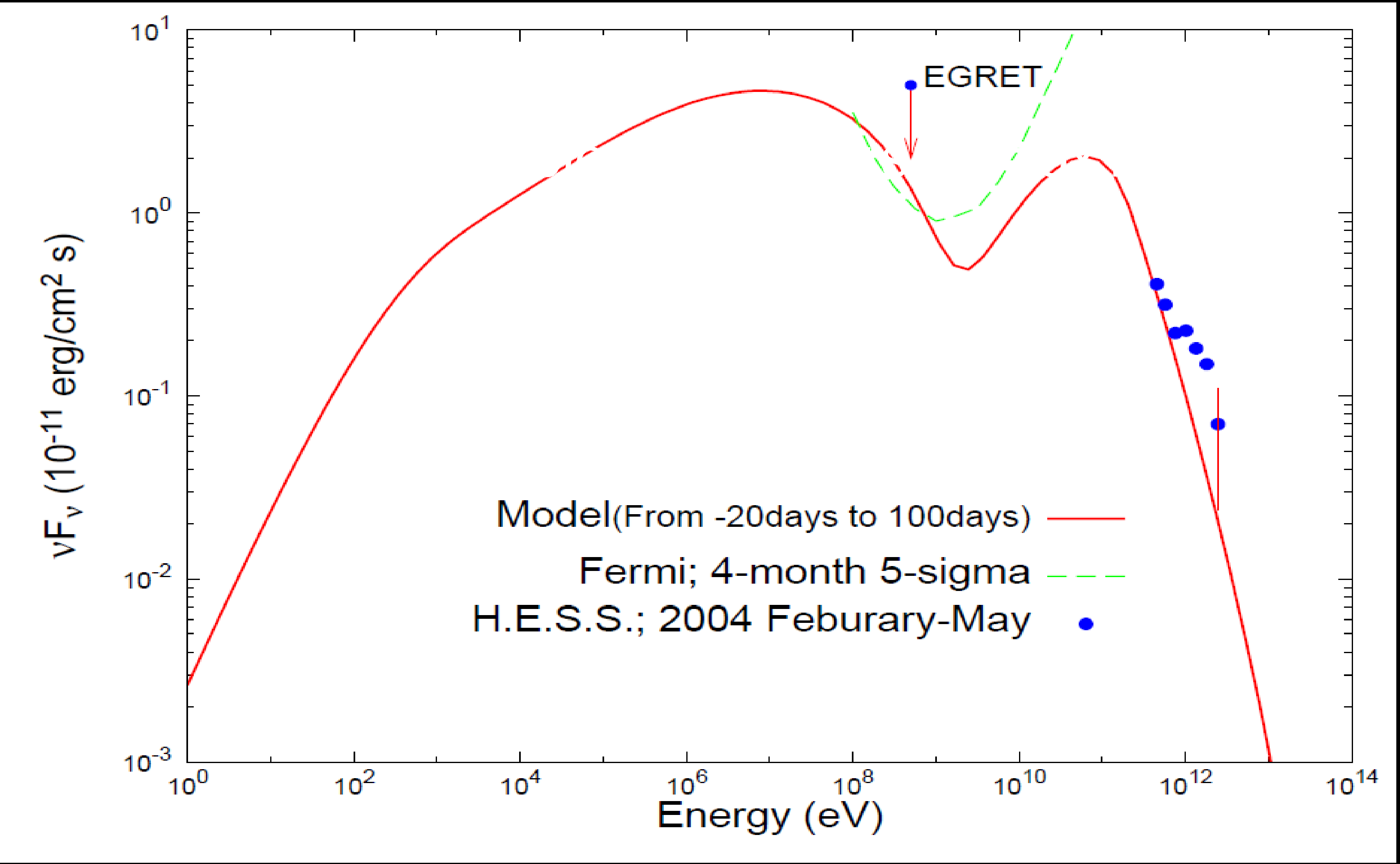


Shock distance from the pulsar

Spectral energy distribution



(2) σ and photon index p1; variable parameters; Γ1=5x10^5

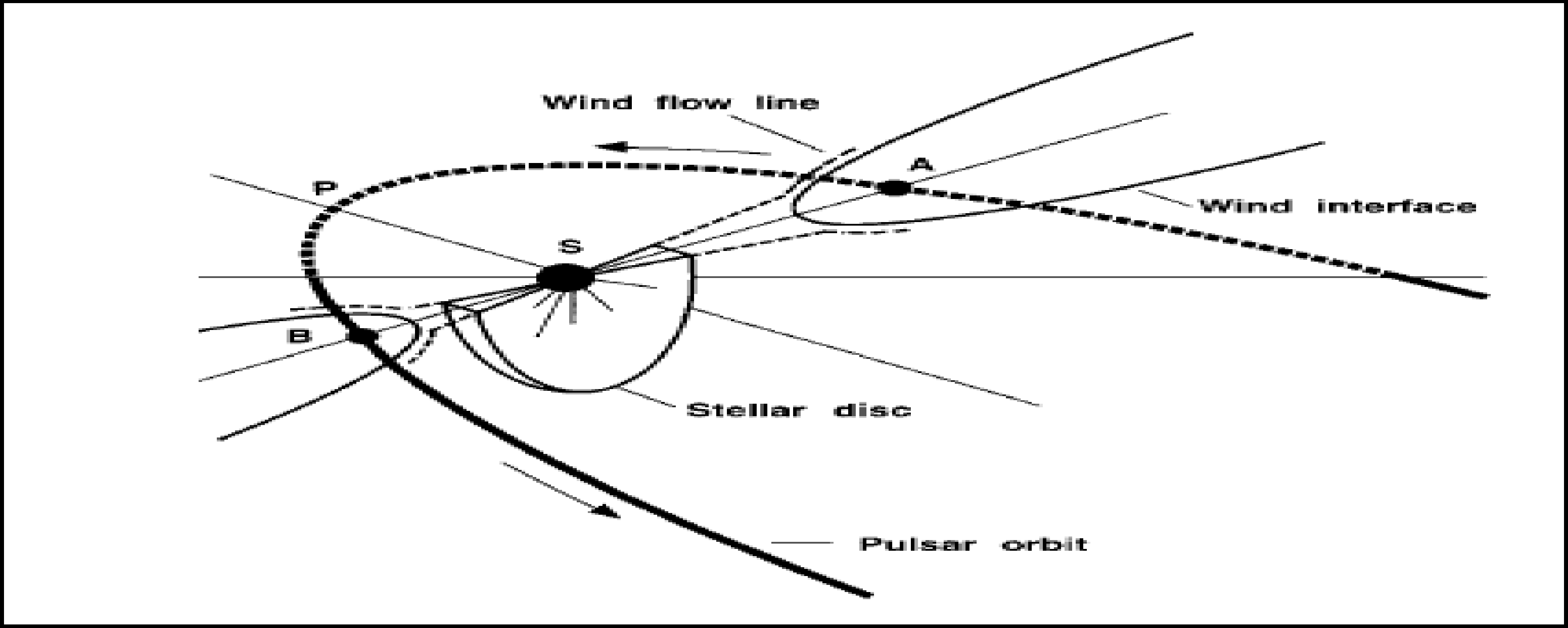


Next periastron passage is in Dec. 2010.

Summary

- Leptonic model can explain X-ray data and TeV observations
- $\sigma << 1$; At 1AU scale, the energy conversions from the magnetic energy to the particle energy will be already done (~99%).
- σ decrease with distance, and Γ decrease with distance
- Hard spectrum in X-ray bands is explained by the lower cut-off of the synchrotron spectrum of by a power law index P1>2.
- Fermi can constrain the emission model and the power law index of the accelerated particles.

- Pulsar wind and stellar wind are interacting
- Orbital modulation



Johnston et al (1999)

(2) σ and P1; variable parameters; Γ1=5x10^5

Orbital phase		X3	X6	X7	S1	S4	A5	A2	S6	A3	X1	X2	A6
Fitting parameters	σ ($\times 10^{-3}$)	2	5	40	40	80	9	7.5	7.9	10	25	12	5
($\Gamma_1 = 5 \times 10^5$)	Index p_1	2.1	1.62	1.45	2.35	1.99	2.8	3.2	2.57	2.55	2.2	1.72	2.2
$F_{0.02-10^2\mathrm{GeV}}$	(10^{-11}erg/cm^{2}s)	0.79	6.8	123	17	66	8.6	9.6	11	13	11	5.6	0.88