

第40回天文・天体物理若手夏の学校  
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# ガンマ線連星LS5039における 多波長放射メカニズム

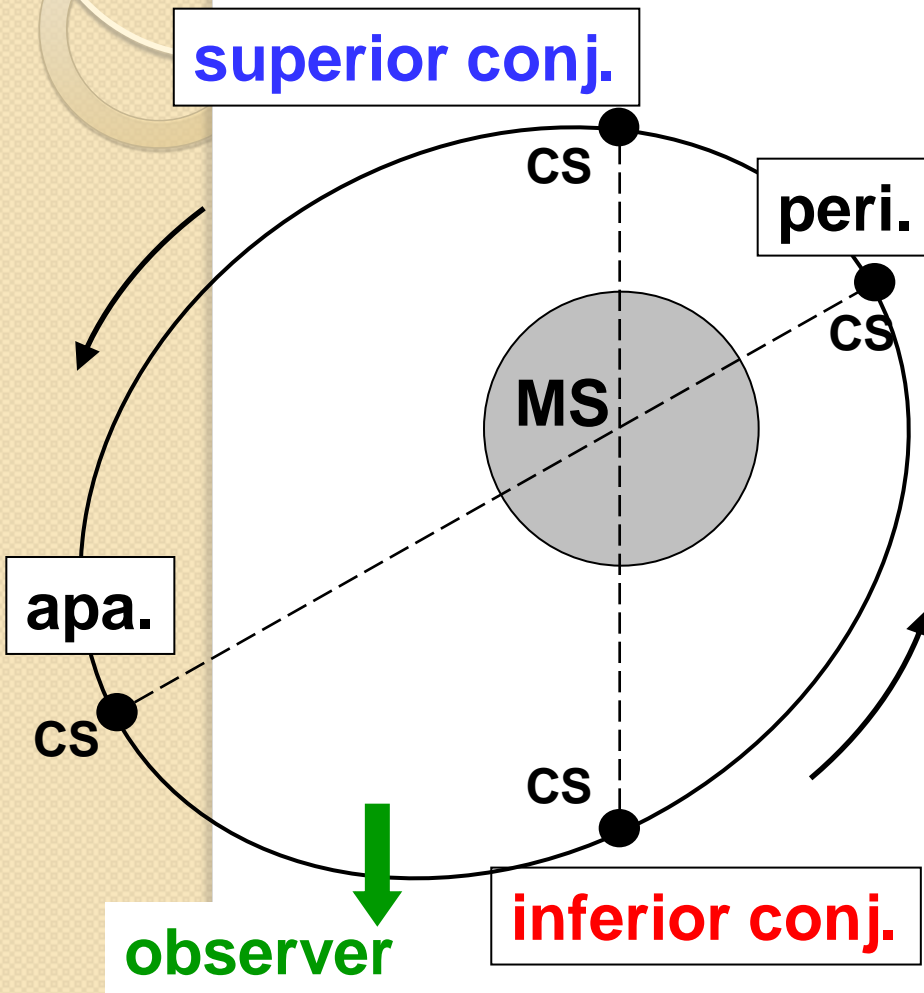
(M. S. Yamaguchi & F. Takahara, 2010, ApJ, 717, 85)

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# Outline

- I. Gamma-ray binary, LS5039
- II. Model
- III. Comparison with Observation
- IV. Discussion
- V. Summary

# Gamma-ray binary, LS5039



Orbit of LS5039(head on)

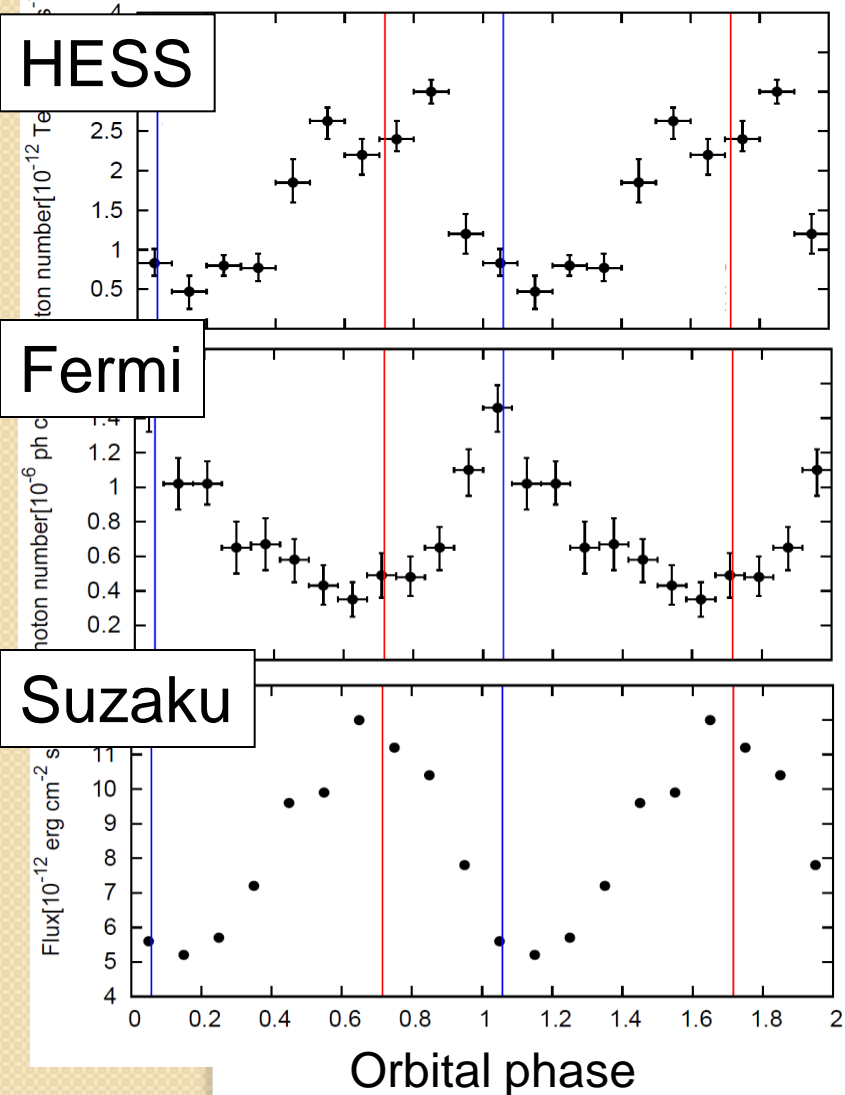
Not identified

- Compact star (CS) + Massive star (MS, O6.5)
- Orbital period: 3.9d
- Separation:
  - at periastron  $\sim 2R_{\text{star}}$
  - at apastron  $\sim 4R_{\text{star}}$
  - ( $R_{\text{star}} \sim 10^{12}$  cm)

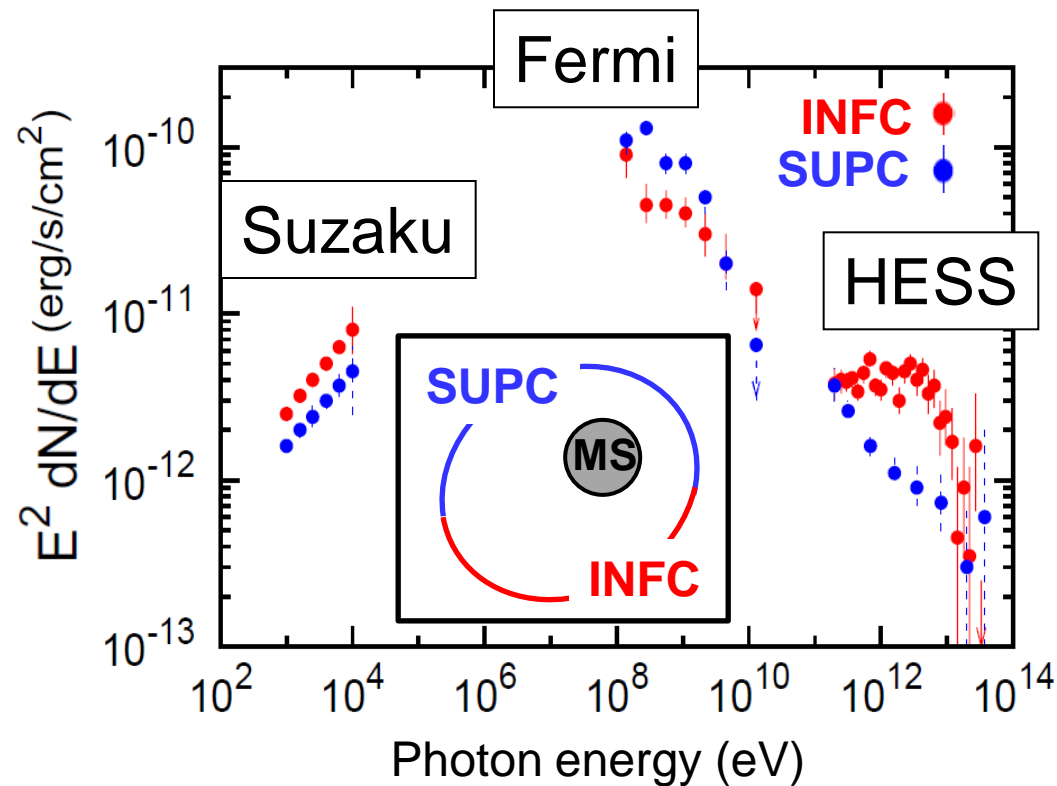
# Observations of LS5039

F. Aharonian, et al., 2006, A&A, 460, 743  
 A. A. Abdo, et al., 2009, ApJL, 706, 56  
 T. Takahashi, et al., 2009, ApJ, 697, 592

superior inferior



Light curves



Phase-averaged spectra

- TeV & GeV anticorrelate
- TeV & X correlate

Why is this ?

# Radiation processes in LS5039

## Radiation processes of $HEe^\pm$

- Inverse Compton(IC)
- Synchrotron
- Photon pair annihilation

## Cooling processes of $HEe^\pm$

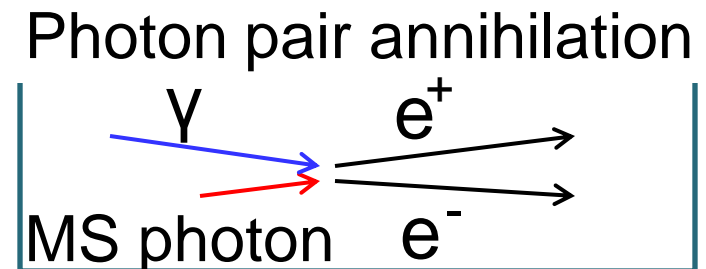
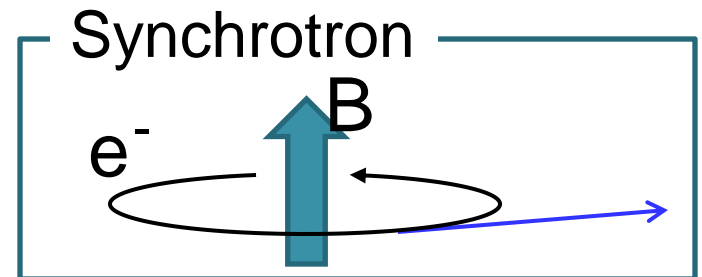
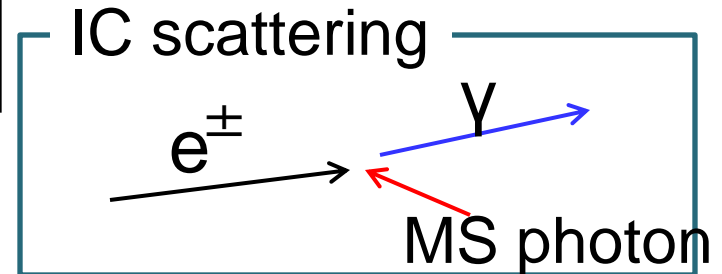
- IC cooling
  - Synchrotron cooling
- Dominant process depends on B

If only IC cooling  
(it means small B)



IC scattering  
Photon pair annihilation

occur a chain reaction(**cascade**)



# Previous works

- TeV-GeV anticorrelation (Bednarek 2006)  
Under the assumption of only IC cooling,  
the cascade process was calculated  
→ TeV&GeV anticorrelated by the cascade process  
**Synchrotron calculation was not performed**  
**No comparison with observations**  
(This paper was published before latest observations)
- TeV-X correlation (Takahashi et al. 2009)  
It was explained qualitatively that X-ray modulated  
**No reproduction of X-ray variation by computation**  
it is necessary to explain the X-ray  
modulation with calculation !!

# Model

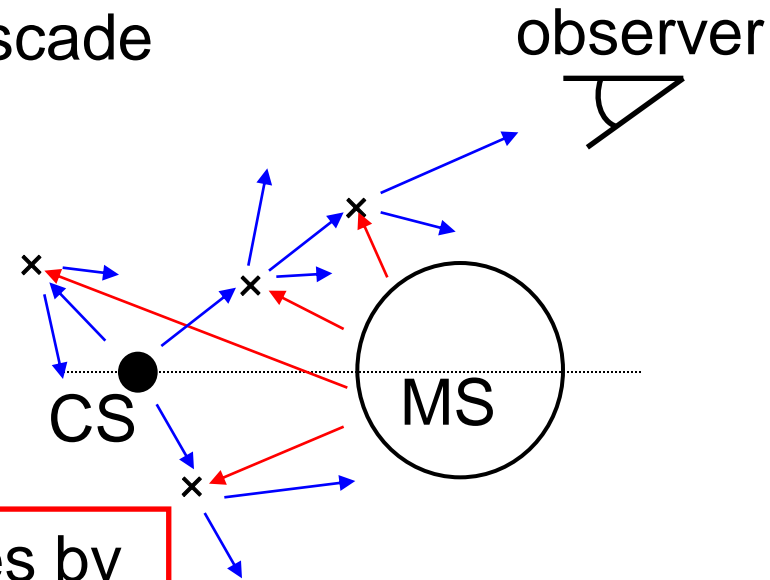
- Constant and isotropic injection of electrons at CS (power-law distribution)
- **Cooling only by IC process** → cascade
- Electrons radiate photons at the injection or creation sites
- The uniform magnetic field



We calculate spectra and light curves by

- ① the cascade process with Monte Carlo method (GeV to TeV)
- ② the synchrotron emission using the  $e^\pm$  distribution for  $B = 0.1 \text{ G}$  (X-ray)

(parameters: the inclination angle & the power-law index of injected electrons)



× : annihilation position

→ : IC photon path

→ : MS photon path

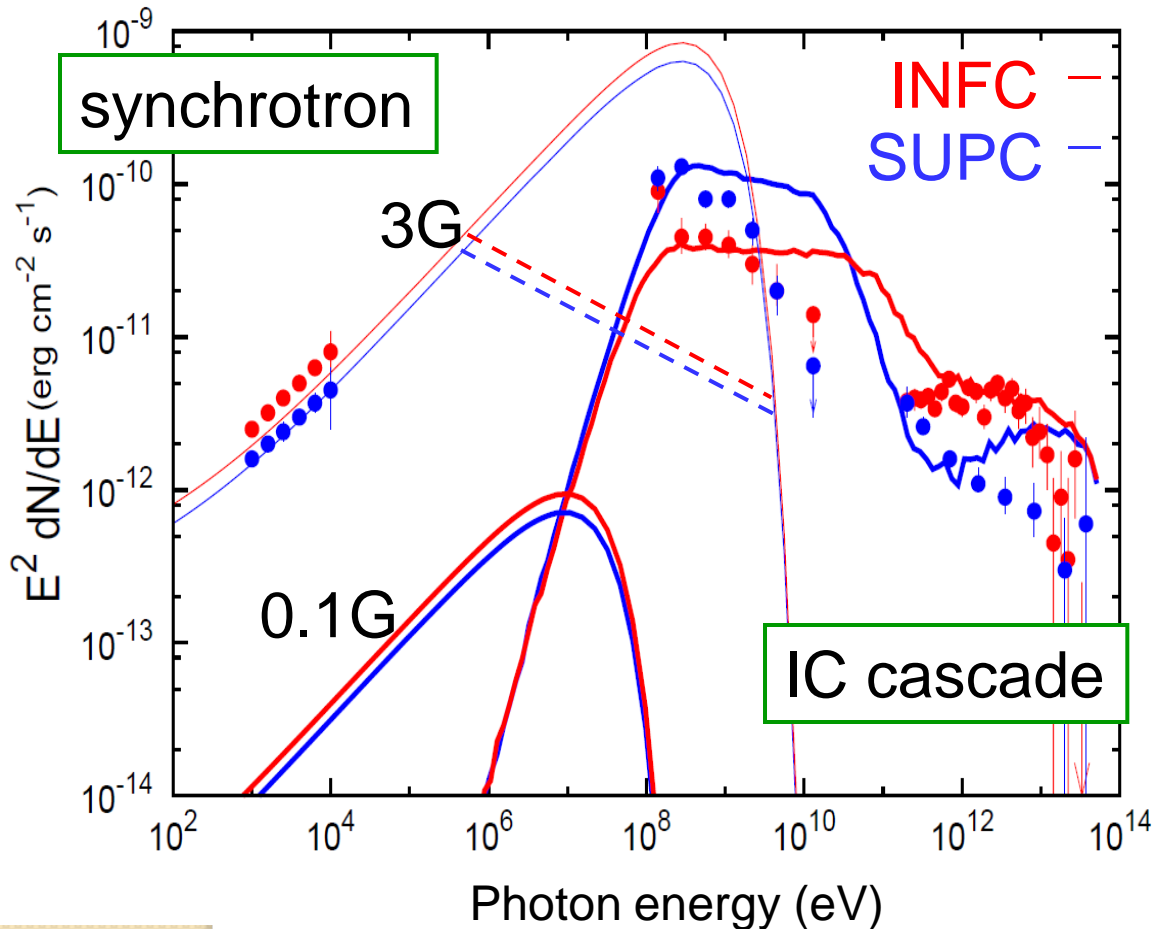
# Comparison with observations (spectra)

- variation in GeV band
- ratio of TeV to GeV flux

is fitted



Inclination angle:  $30^\circ$   
Power-law index: 2.5



- Qualitative fit to observations
- No fit to X-ray observations when  $B = 0.1 \text{ G}$

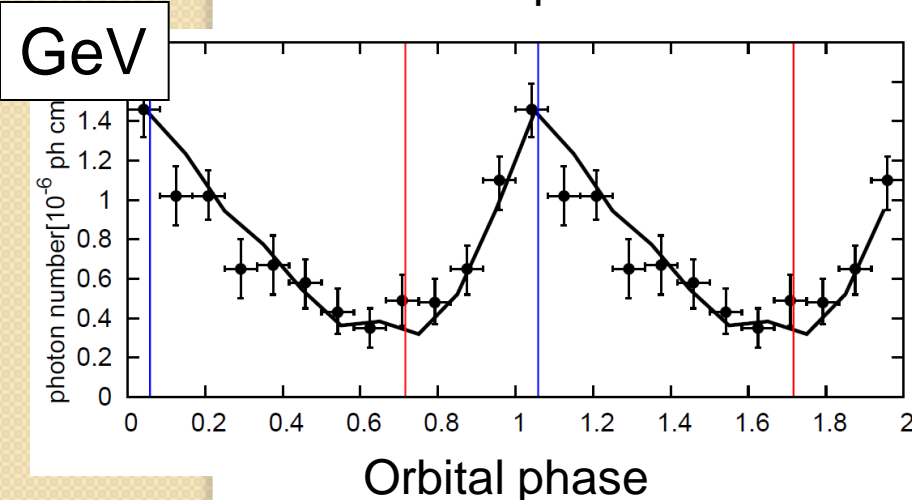
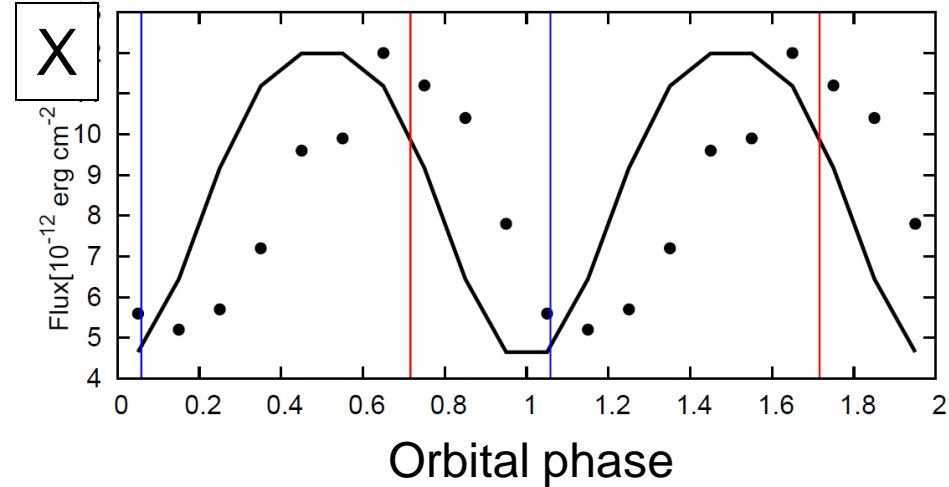
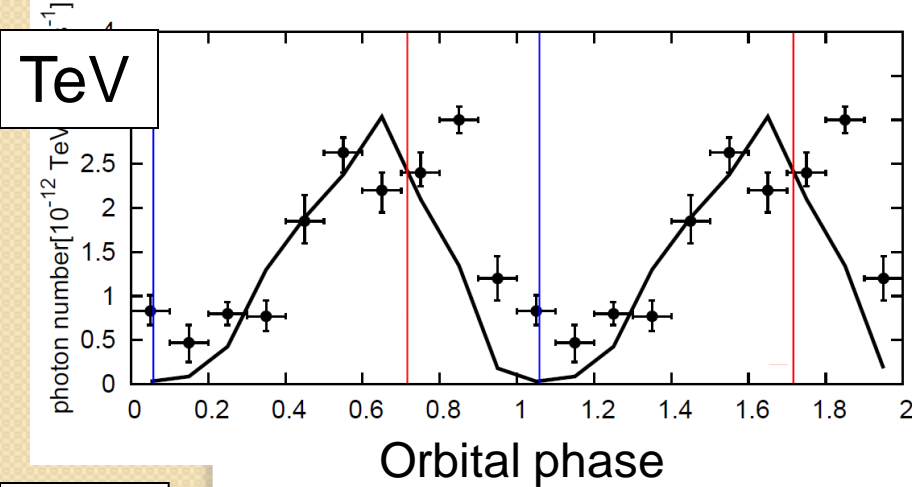


- When 3G, the best fit  
The value with which synchrotron cooling dominated IC cooling



# Comparison with observations (light curves)

Inclination angle:  $30^\circ$   
power-law index: 2.5



TeV & GeV anticorrelate,  
TeV & X-ray correlate !  
(X-ray shows a delay)

(numerical results are normalized with maxima of observation)

# Discussion 1: TeV-GeV anticorrelation

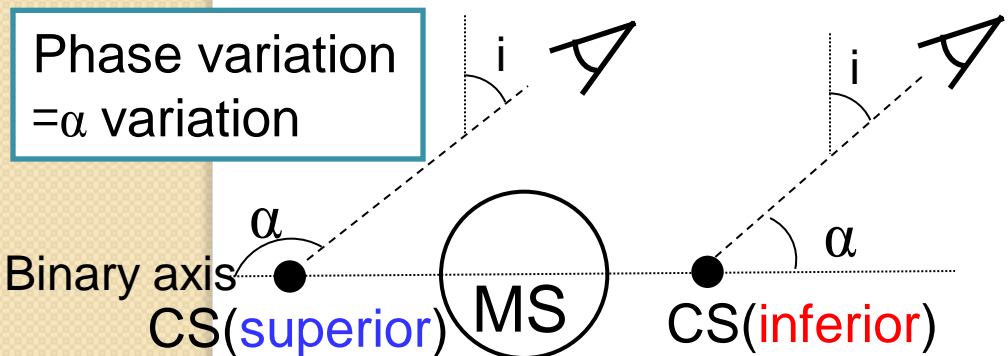
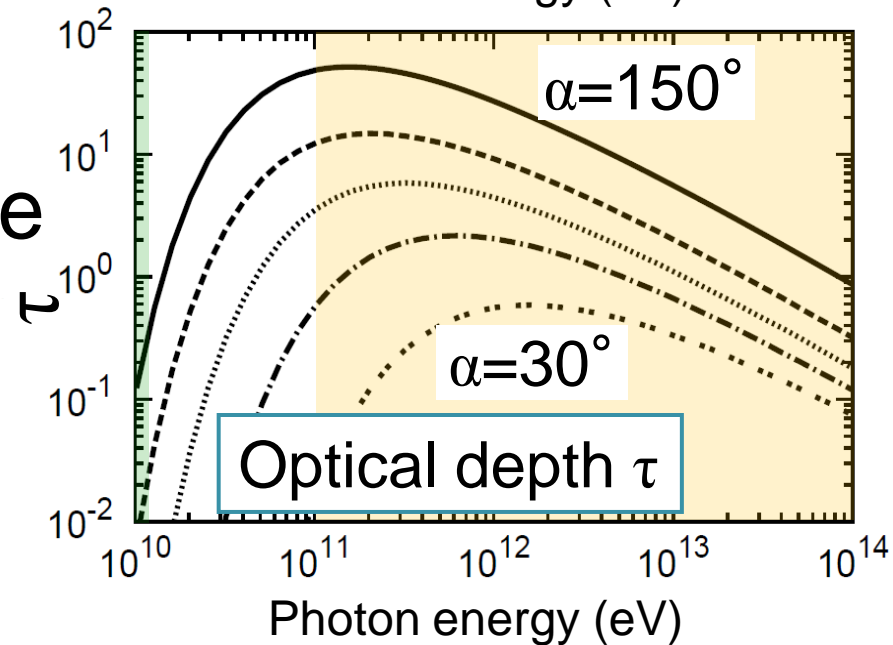
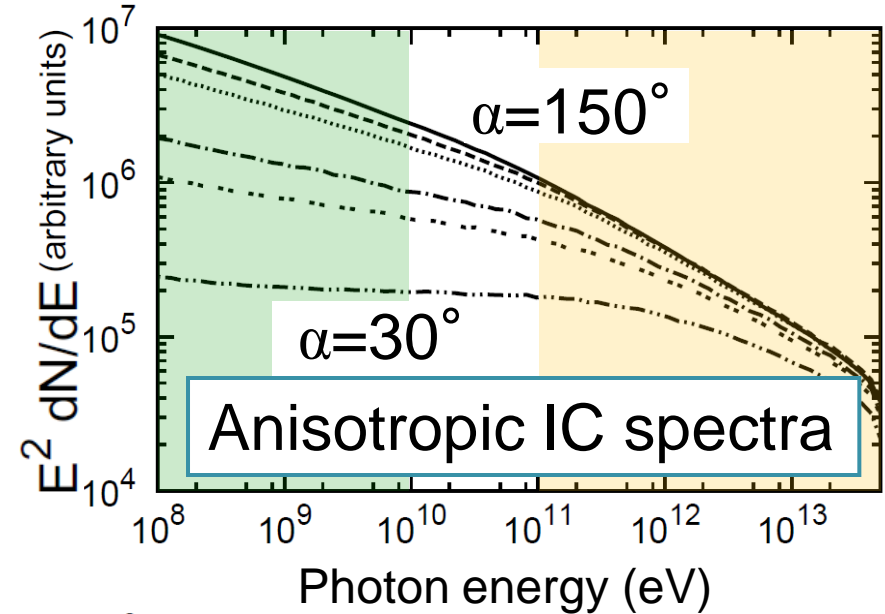
GeV (<10 GeV)

- $\tau \ll 1 \rightarrow$  no absorption  
 $\rightarrow$  **correlates with  $\alpha$**

TeV (>100 GeV)

- $\tau$  and  $\alpha$  correlate
- IC spectra:  
 smaller  $\alpha$  dependence  
 $\rightarrow$  **anticorrelates with  $\alpha$**

**GeV&TeV anticorrelate**



# Discussion 2: TeV-X correlation

X

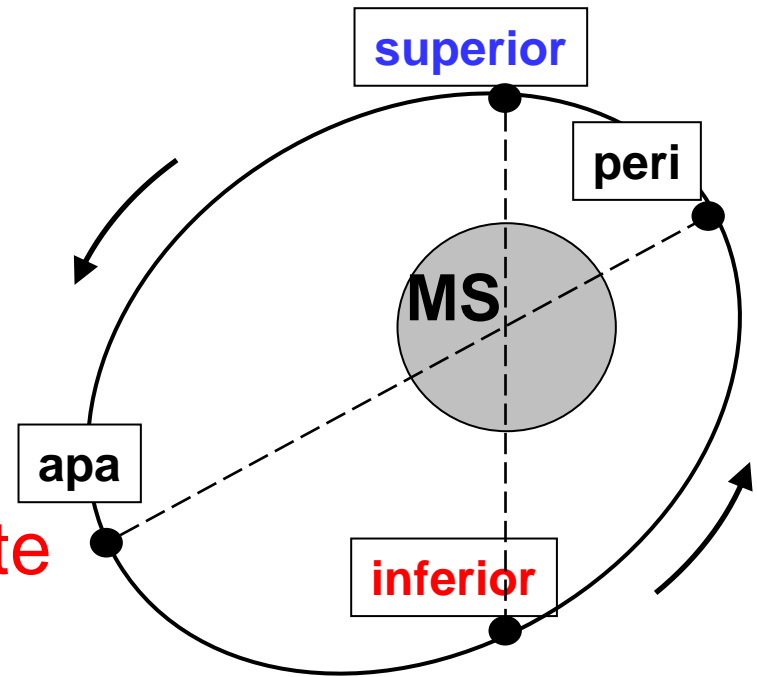
- The flux  $\propto$  number of  $e^\pm$
  - The number of  $e^\pm \propto$  separation
- X & the separation correlate

Larger separation  $\rightarrow$  thinner field  
 $\rightarrow$  longer cooling time  
 $\rightarrow$  larger number of  $e^\pm$

TeV

- Larger  $\alpha \rightarrow$  smaller flux
  - When  $\alpha$  is large, the separation is small
- TeV & the separation correlate

➔ X & TeV correlate



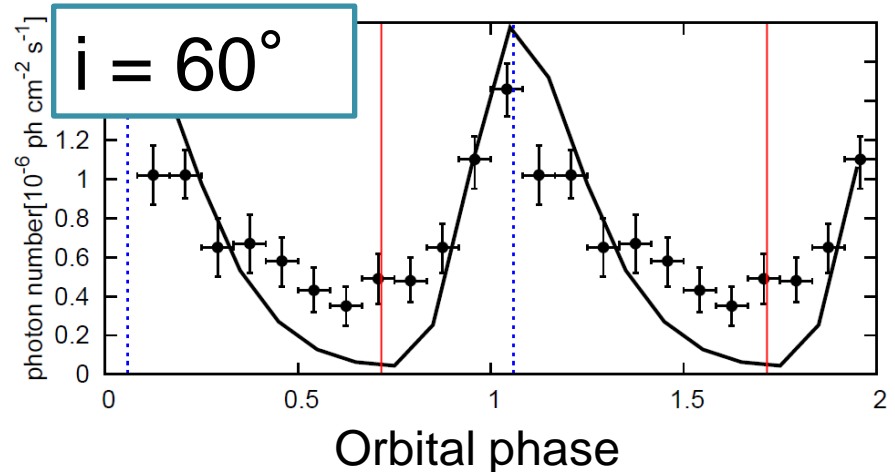
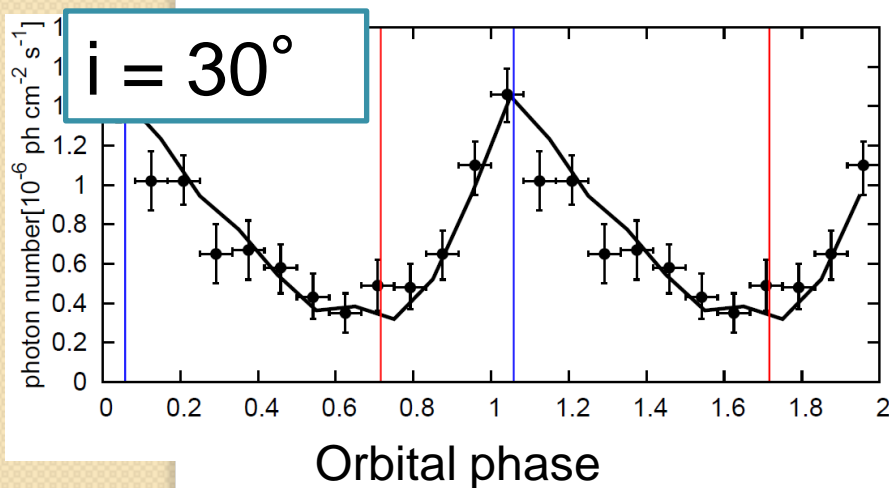
# Discussion 3: Constraint on the mass of CS

- GeV flux depends on the angle  $\alpha$
- The amplitude of  $\alpha$  depends on the inclination angle  $i \rightarrow$  GeV flux amplitude depends on  $i$

The observational data imply  $i \sim 30^\circ \pm 10^\circ$



$\rightarrow$  The mass of the compact star  $\sim 2.5\text{-}5 M_{\text{sun}}$

$\rightarrow$  **The compact star is a black hole**



# Summary

In LS5039, injection of  $e^\pm$ , disregard of synchrotron cooling

- Observed spectra and light curves are qualitatively reproduced
- The  $\alpha$  dependence of the absorption and the IC spectra  TeV & GeV anticorrelation
- The variation with the orbital phase of the number of  $e^\pm$  and the orbital geometry  TeV & X correlation
- Constraint on the inclination angle implies the compact star is a black hole