ガンマ線連星LS 5039における軟X線源の効果

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OUTLINE

I. Gamma-ray binary, LS5039
II. Results of Yamaguchi & Takahara 2010
III. Introduction of synchrotron cooling
IV. Model with a soft X-ray source
V. Summary

Gamma-ray binaries

- Gamma-rays vary with orbital period

Objects	Period	Scale	Consists of …
LS 5039	3.9d	5x10^12cm	O + ?? (BH or NS)
LS I +61° 303	26d	10^13cm	Be + ??
PSR B1259-63	3.4yr	10^14cm	Be + NS
HESS J0632+057	320d	10^14cm	Be + ??
1FGL J1018.6-5856	16d	10^13cm	O + ??

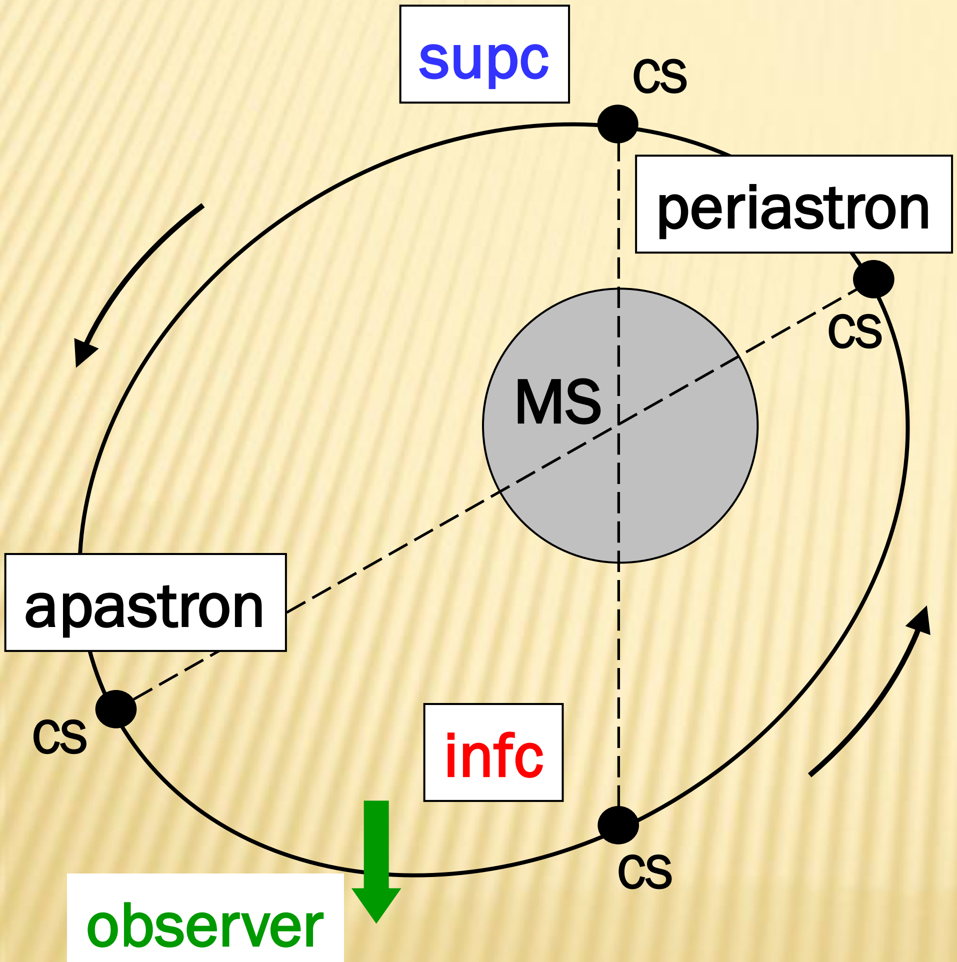
- Gamma-rays are detected as flares

Cyg X-1	5.6d	3x10^12cm	O + BH
Cyg X-3	4.8hr	5x10^11cm	WR + ??(BH or NS)

- Candidate:

AGL J2241+4454 (HD 215227(Be))

Orbital parameters of LS5039



Orbit of LS 5039(head on)

- Compact star (CS) + Massive star (MS, O6.5)
- Period : 3.9 days
- Separation

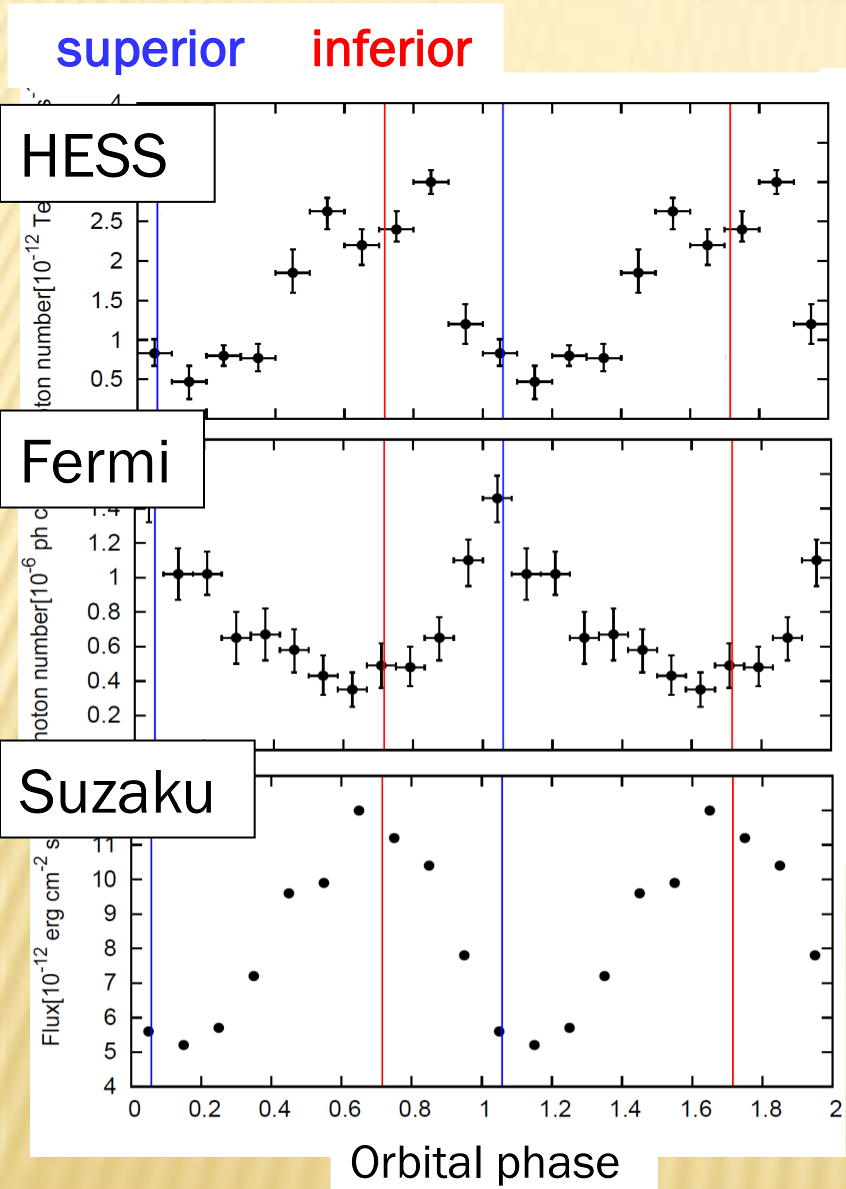
  at periastron... ~2R_{star}

  at apastron...~4R_{star}

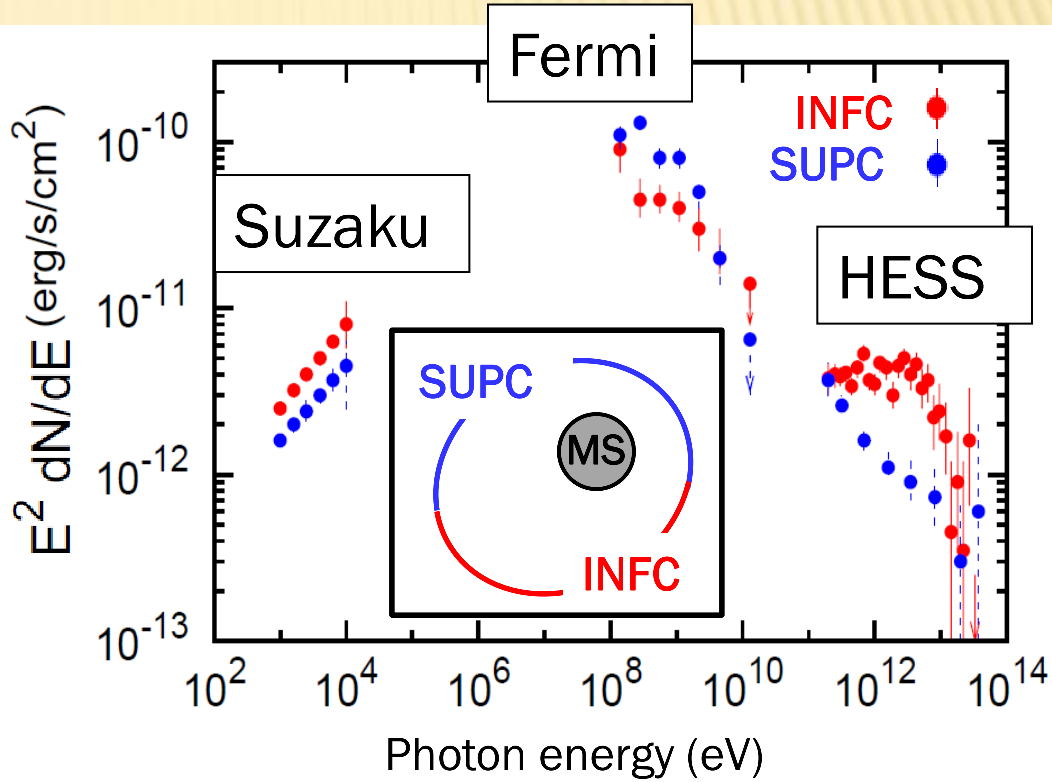
  (R_{star}~ 10^{12} cm)

Observations of LS 5039

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



Light curves



Phase-averaged spectra

- TeV & GeV anticorrelate
- TeV & X correlate

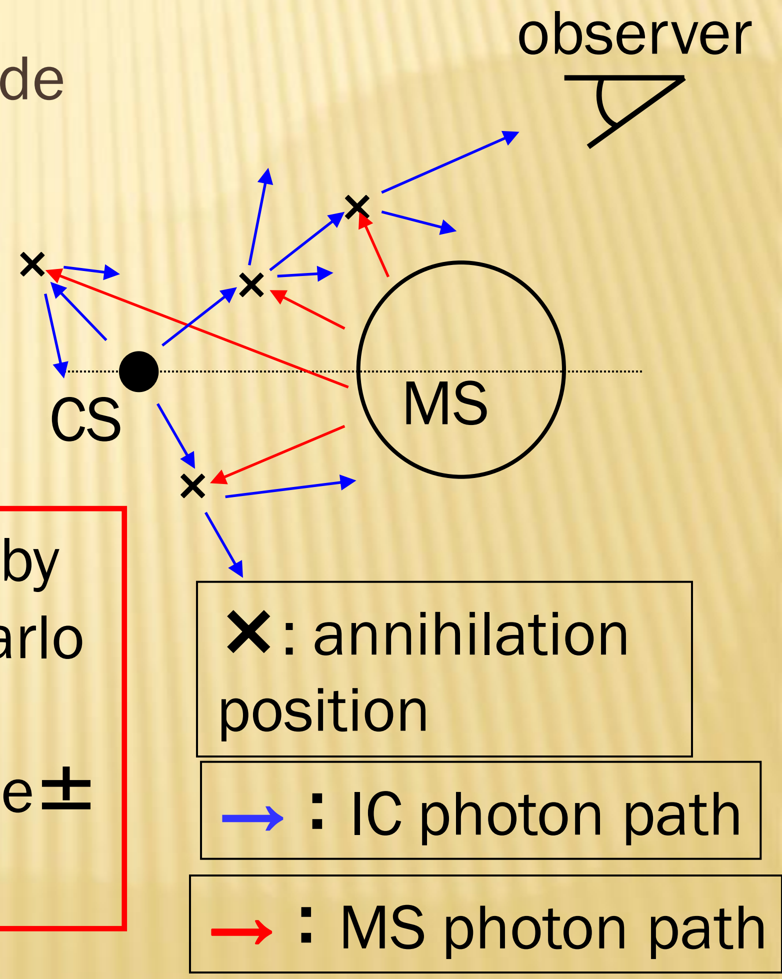
Why is this ?

Model (Yamaguchi & Takahara 2010)

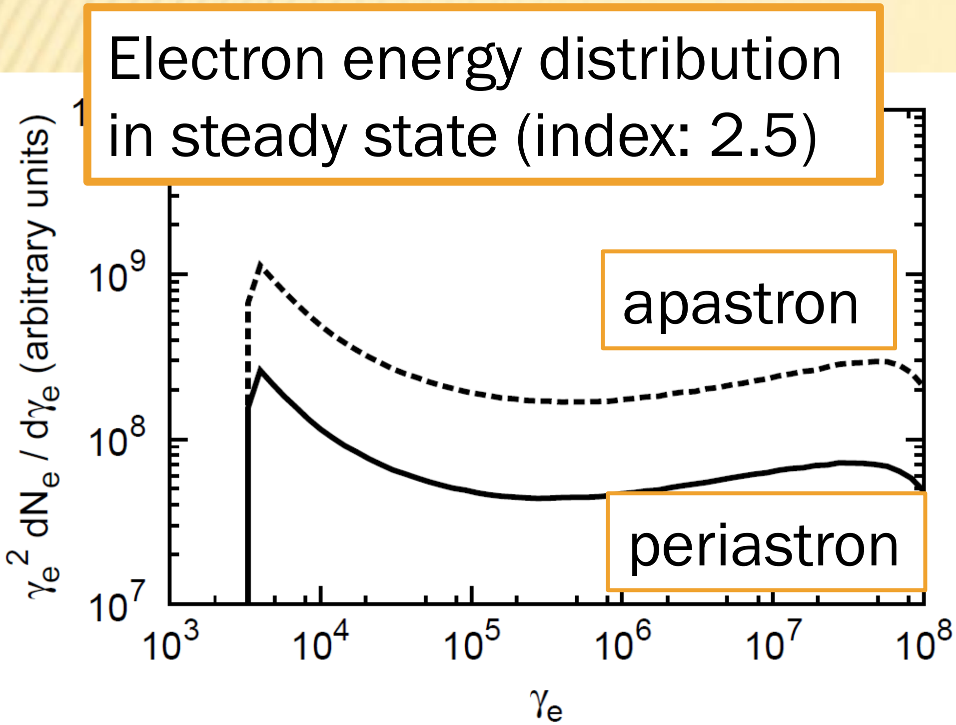
- Constant and isotropic injection of electrons at CS (power-law distribution)
- Cooling only by IC process → cascade
- Electrons emit photons at the injection or creation sites
- The uniform magnetic field

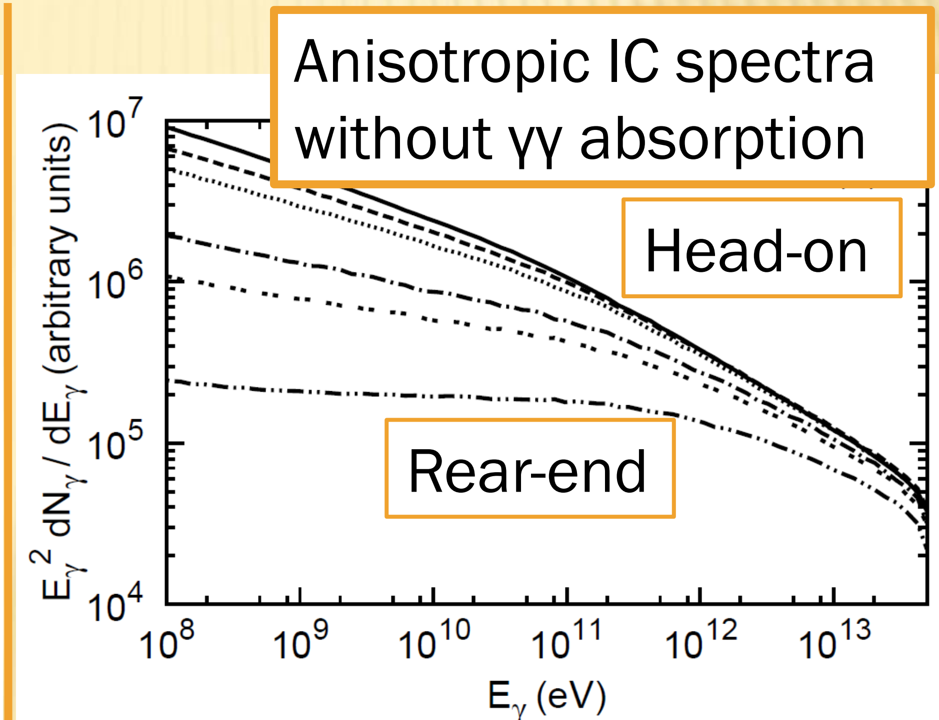
We calculate spectra and light curves by
① the cascade process with Monte Carlo method (GeV to TeV)
②the synchrotron emission using the e± distribution for B = 0.1 G (X-ray)

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



Electron distribution and anisotropic IC pectra





- KN effect flattens the electron distribution
- The electron number is larger at apastron due to suppression of IC cooling

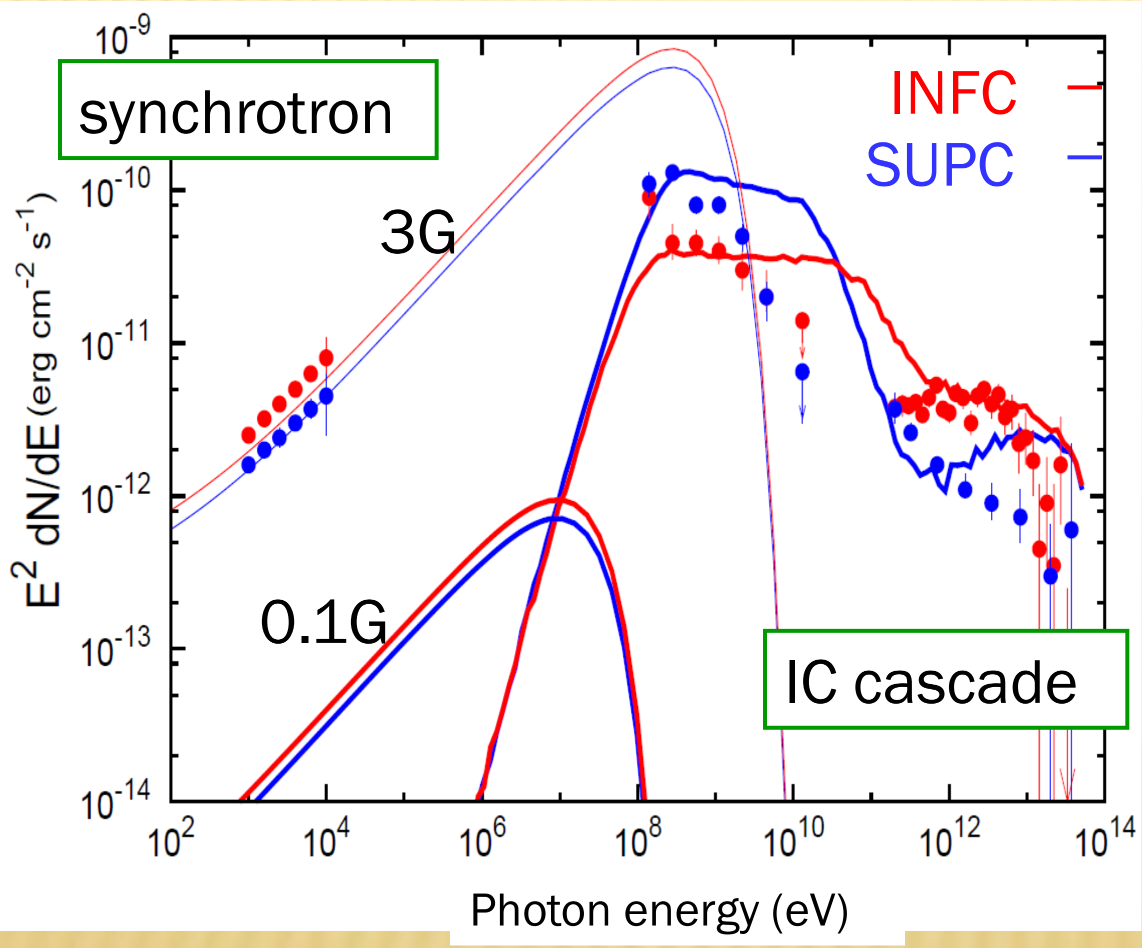
- Anisotropic IC emission of head-on collision is more intense since collision rate is higher
- Anisotropy is suppressed by KN effect at higher energy

Comparison with observations (spectra)

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

is fitted →

Inclination angle: 30°
Power-law index: 2.5

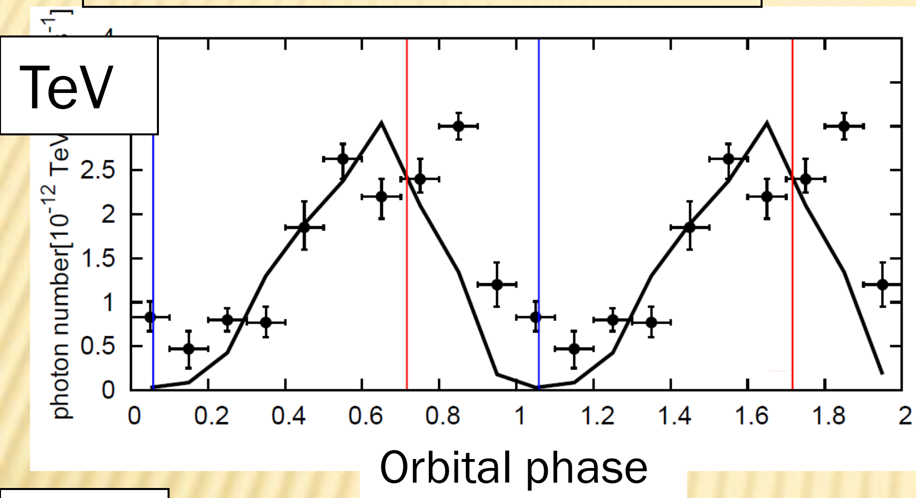


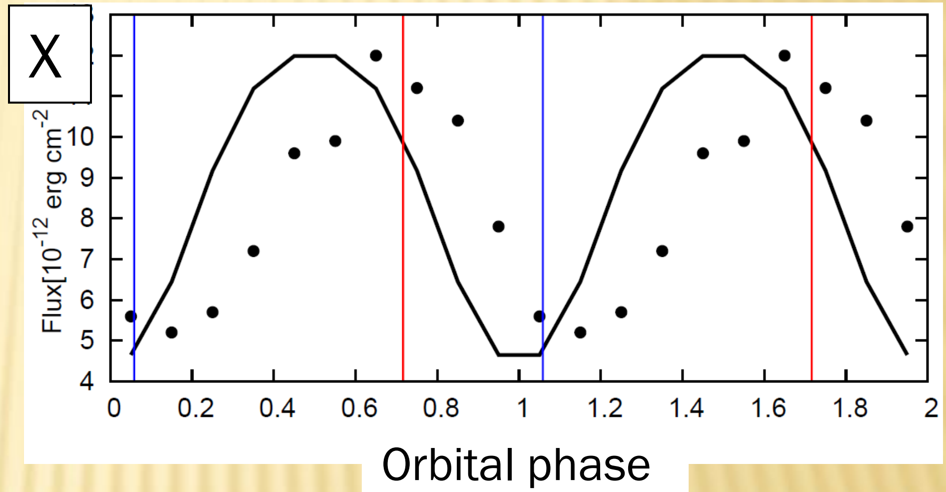
- Qualitative fit to observations
- No fit to X-ray observations when B = 0.1G
- When 3G, the best fit

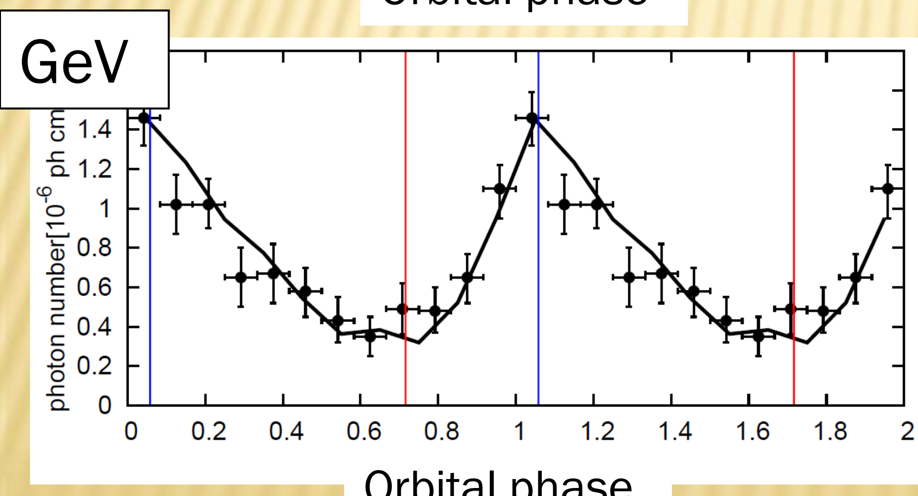
Under this, synchrotron cooling is dominant

Comparison with observations (light curves)

Inclination angle: 30°
power-law index: 2.5







TeV: roughly reproduced
GeV: well reproduced
X-ray: a phase difference

(numerical results are normalized with maxima of observation)

Modulation mechanism in TeV, GeV and X-ray

- TeV: absorption is dominant

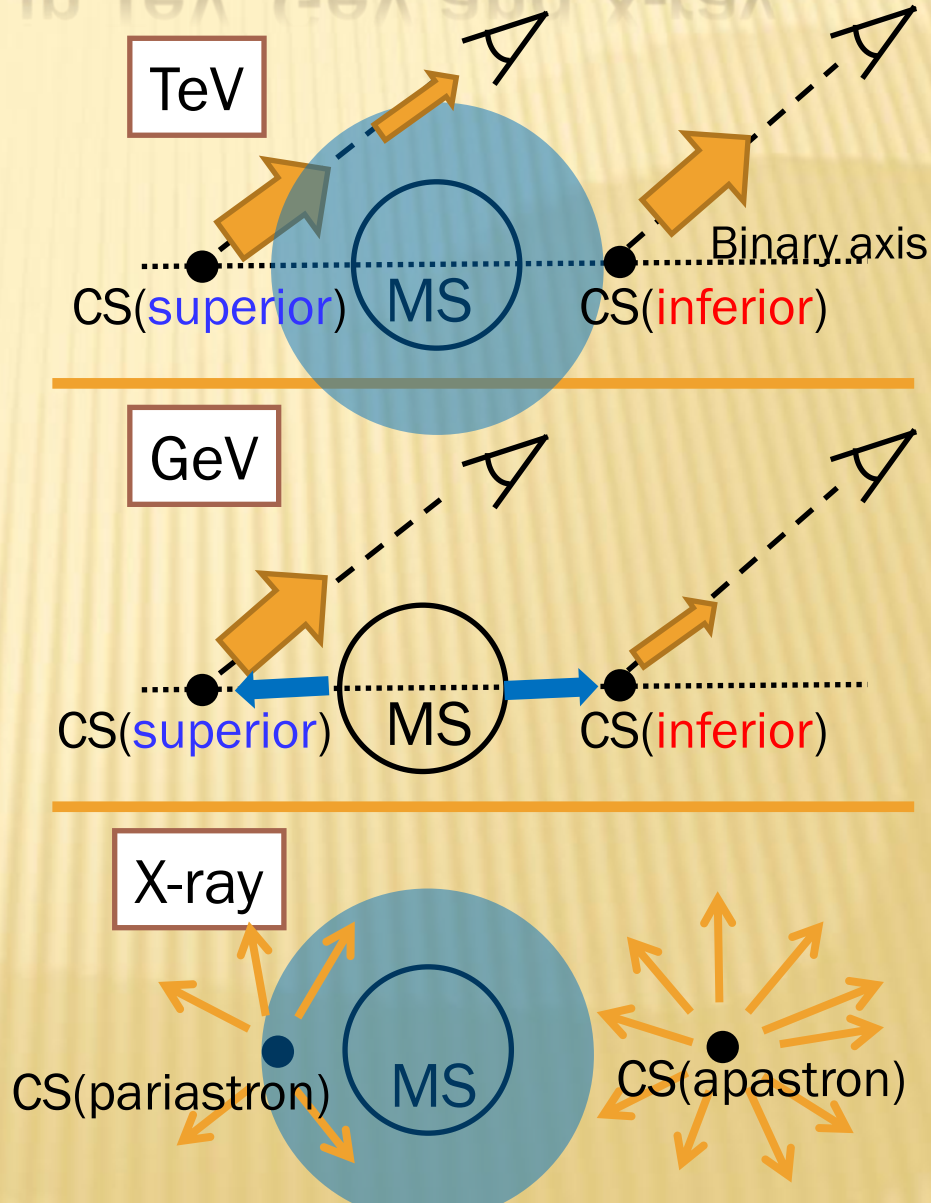
  At supc, flux is smaller than infc by the large density of stellar radiation field

- GeV: IC anisotropy is dominant

  At supc, flux is larger than supc by head-on collision of IC scattering

- X-ray: e± number variation by IC cooling

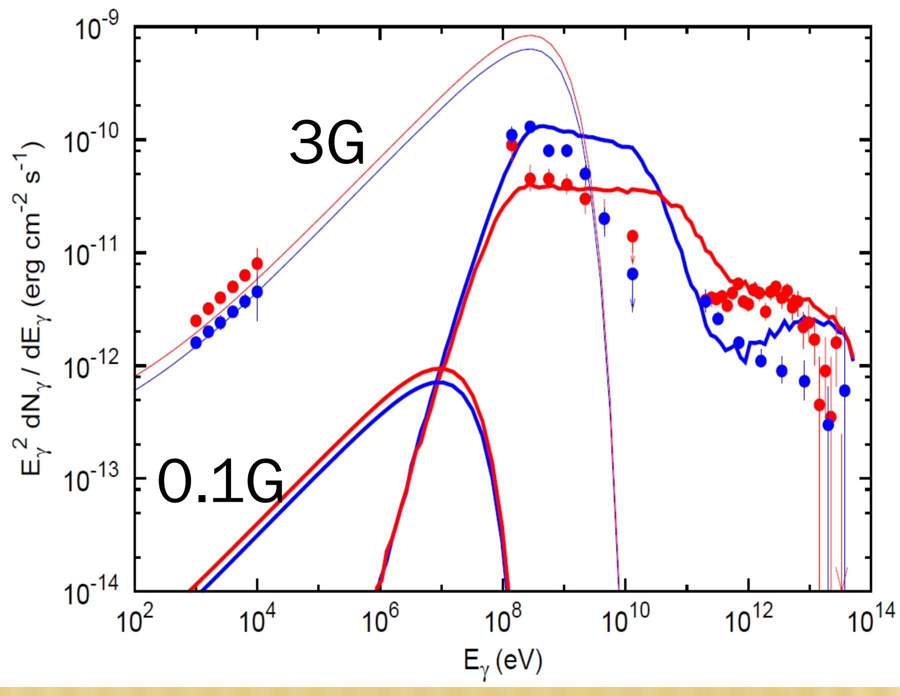
  At periastron, the e± number in steady state is smaller than apastron by IC cooling in the large density of stellar radiation field, so emissivity by synchrotron is smaller, therefore flux is smaller



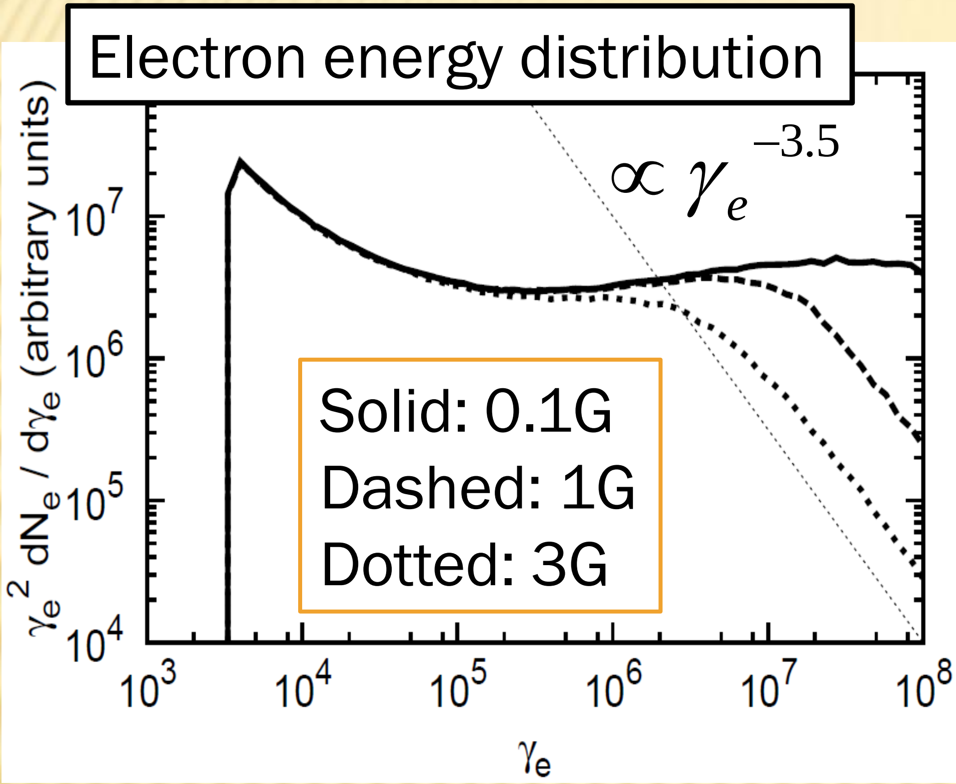
Problems of this model

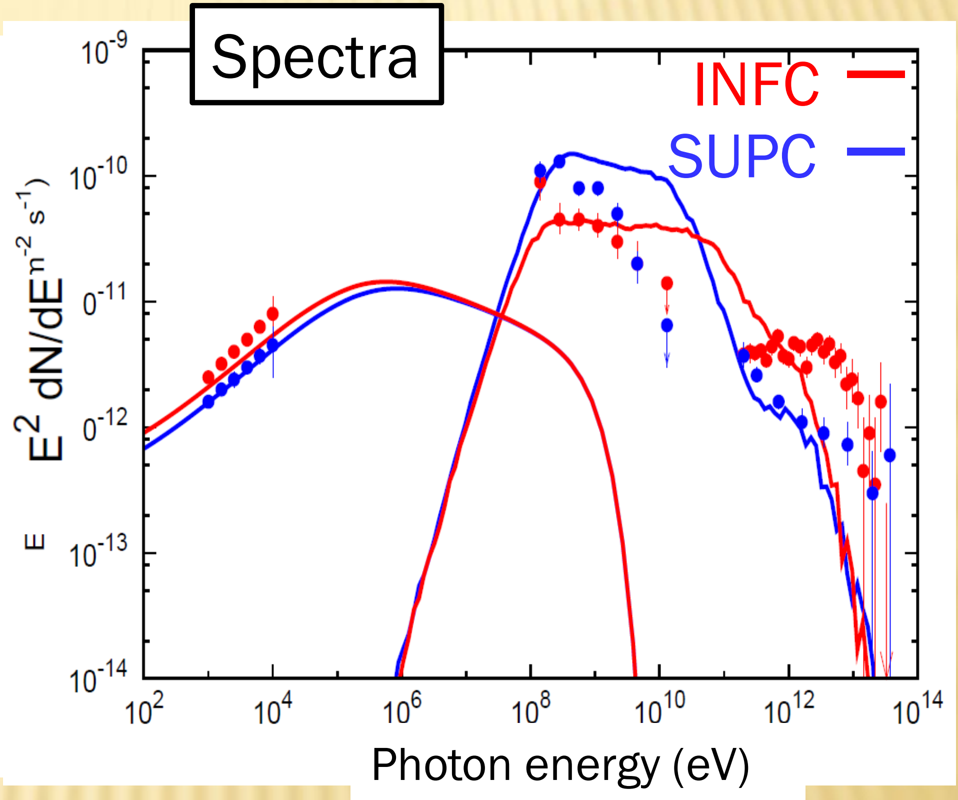
- Shortage of X-ray flux
- 3 G is required for the reproduction of Suzaku data if synchrotron emission is responsible for X-ray
- Higher energy electrons are affected by synchrotron cooling under 3 G → include the synchrotron cooling

- Excess of 10 GeV flux
- Assume that cutoff at a few GeV is due to γγ absorption by higher energy photons (~ 100 eV)



Spectra including synchrotron cooling





- Suzaku data are well fitted
- Highest energy gamma-rays are not emitted
- This implies the necessity of 2 component model

Model with 100eV photons

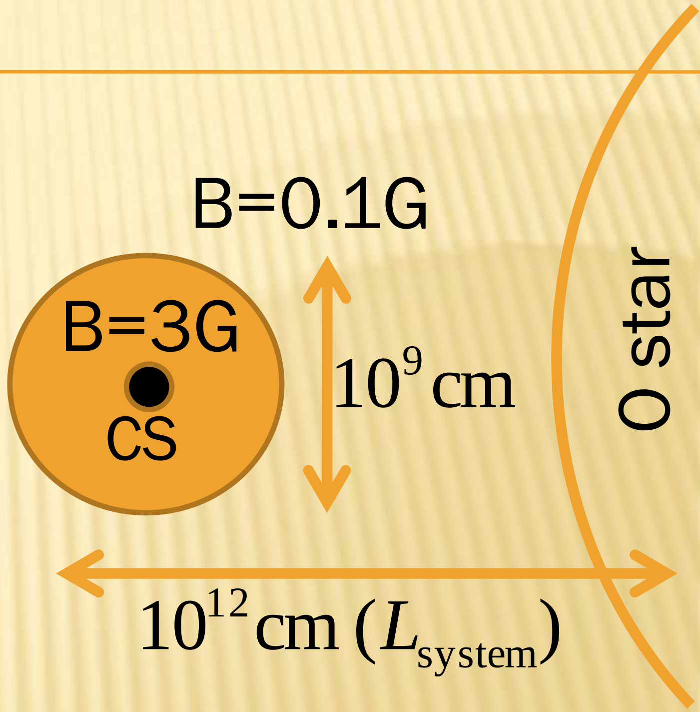
Requirement for 100eV source

- No influence on Suzaku data

  ⇒ $L_{100\mathrm{eV}} \leq 10^{34}\,\mathrm{erg\ s^{-1}}$

- Optical depth τ > 1

  ⇒ $R_{100\mathrm{eV}} \leq 10^{8}\,\mathrm{cm}$ (if thermal)



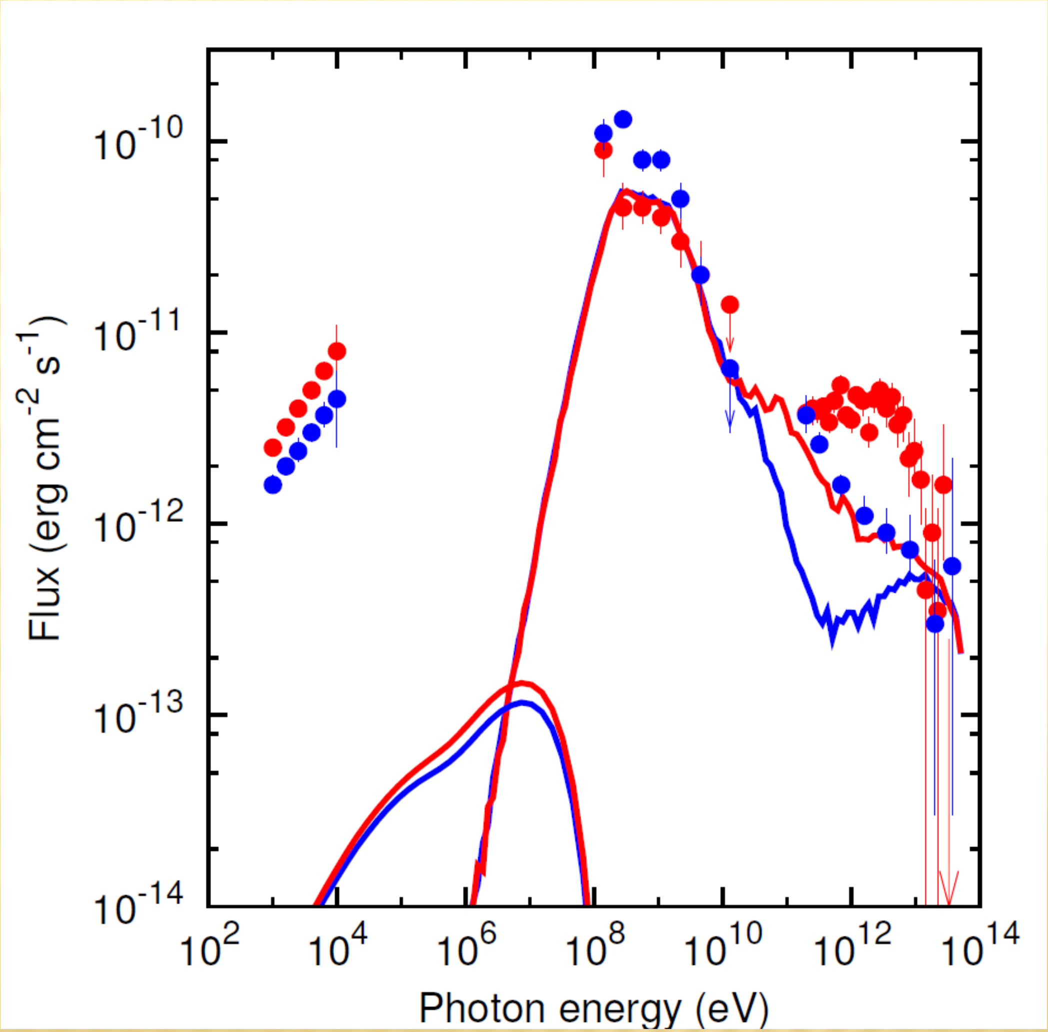
Electron injection

- e± are accelerated up to 1TeV and emit near 100 eV source where B=3G ($r_{\mathrm{gyro,max}} \sim 10^{9}\,\mathrm{cm}$)
- e± are accelerated from 1 to 30TeV and emit far from 100 eV source where B=0.1G ($r_{\mathrm{gyro,max}} \sim L_{\mathrm{system}}$)

⇒ we calculate cascade with 100eV photons near the source, and with stellar photons far from it

Results

$$i = 30^\circ,\ 1\,\mathrm{GeV} \le E_{e,\mathrm{inj}} \le 50\,\mathrm{TeV}(\mathrm{index}:2.5)$$



- GeV spectra match the Fermi data
- But…
- X-ray spectra terribly underestimate
- TeV spectra underestimate
- No orbital variation in GeV & X-ray band

Discussion

Underestimation at X-ray

- Target photons are changed to 100eV photons, so photon density increases → IC cooling time becomes short → the number of e± decreases

$$U_{100\mathrm{eV}}/U_{\mathrm{Ostar}} \sim L_{100\mathrm{eV}}/L_{\mathrm{Ostar}}\,(R_{\mathrm{Ostar}}/R_{100\mathrm{eV}})^2 \sim 10^3$$

No variation in GeV & X-ray band

- Y&T 2010: e± scattered off stellar photons → each flux modulates by the anisotropy of IC scattering
- In this study, they scatter off isotropic photons → emerging photons with GeV & keV have isotropic distribution → No modulation in GeV & X-ray band

Summary

- For LS 5039, we calculate photon propagation including cascade process (without synchrotro cooling)

  → results imply the necessity of synchrotron cooling and show the difference of cutoff energy ~ GeV from Fermi obs.
- So we introduce...
- I. Synchrotron cooling

  → 2 component model required if X-ray is due to synchrotron process
- II. 100eV photon source to reproduce 10GeV spetra

  → 10GeV spectra match Fermi obs but...

  X-ray flux is underestimated (by large photon density)

  X-ray & GeV have no variation (by isotropy of 100eV)

Prospect

- With 100eV source, we introduce orbital variation of injection (as in Owocki et al. 2010, proceeding)

  → the problem is the deficiency of X-ray flux

  → IC scattering origin?
- Without 100eV source, we regard GeV cutoff as high energy cutoff of injected e±

  → the problem is the origin of TeV emission

  → the hadronic process? (e.g. p-p or p-γ)

  or leptonic 2-compoment model?