Self-regulated Stochastic Acceleration Model of Pulsar Wind Nebulae

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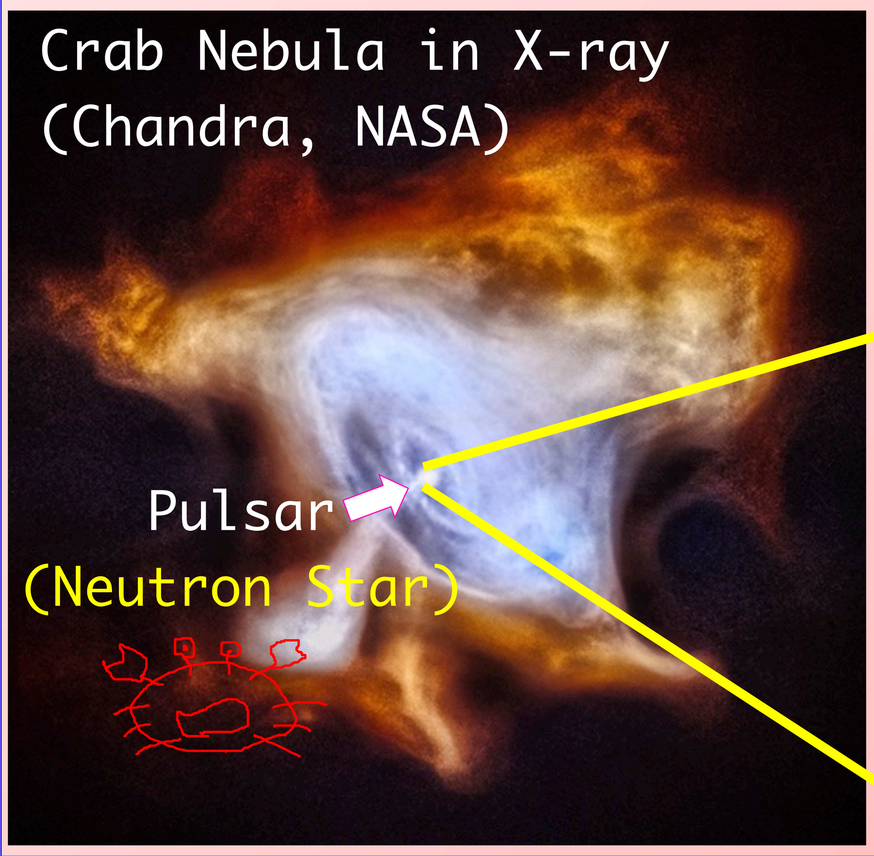
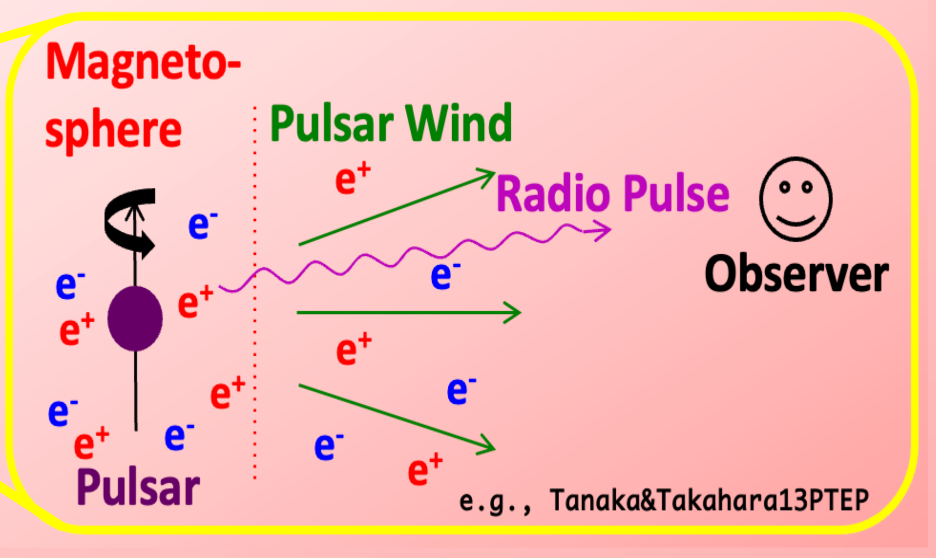
ABSTRACT

Pulsar wind nebulae (PWNe) are the relativistic magnetized plasma bubbles powered by their central pulsars and show nonthermal radiation spectra from radio through PeV gamma-rays. The classical mysteries of pulsar-PWN physics are sigma- and kappa-problems, i.e., problems for the magnetization and the particle number of the parent pulsar wind plasma created at the central pulsar magnetosphere. Here, we study the stochastic particle acceleration by the turbulence inside the PWN in order to resolve the kappa-problem (Tanaka & Asano 2017). Our stochastic acceleration model is updated by taking into account evolution of the turbulent inside the PWN. The turbulence energy injected from the pulsar is self-regulated by accelerating the particles and the nebula expansion. The present model can reproduce the broadband (especially radio) emission from the Crab Nebula without (unrealistic) broken power-law particle injection from the pulsar. Hadrons can also be accelerated and neutrino signal would distinguish the models.

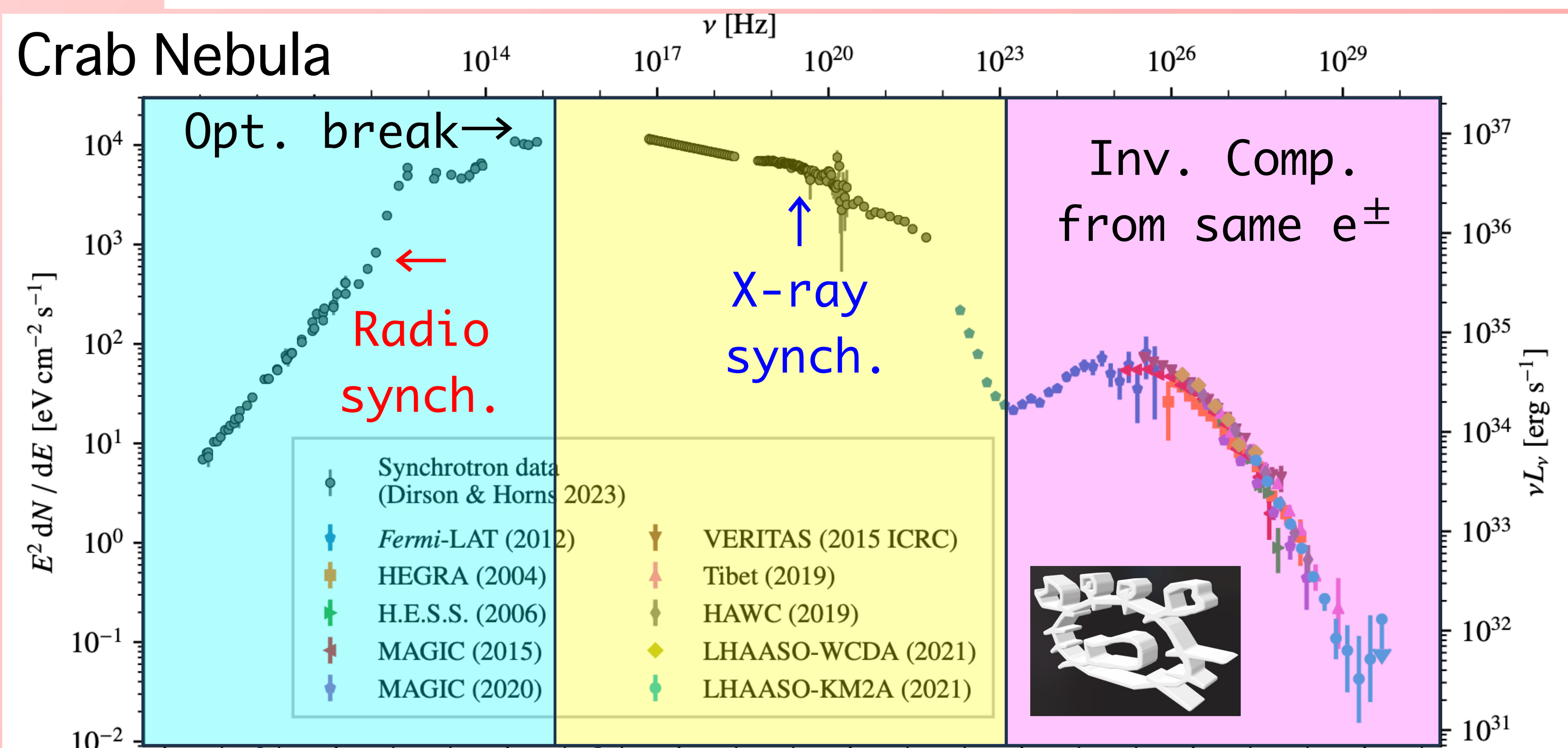
I. Energy Supply from Pulsar

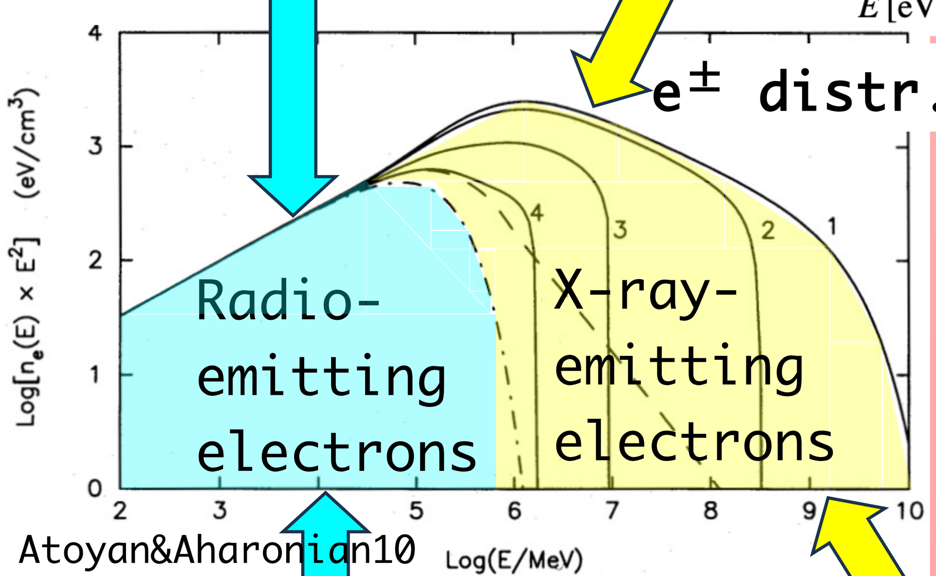


The central pulsar supplies magnetized $e^{\pm}$ & drives turbulent flow.



II. Origin of Radio-emitting e^-





Amount of radio-emitting e^- is much more than $e^{\pm}$ the pulsar can supply.

e.g., Timokhin&Harding18

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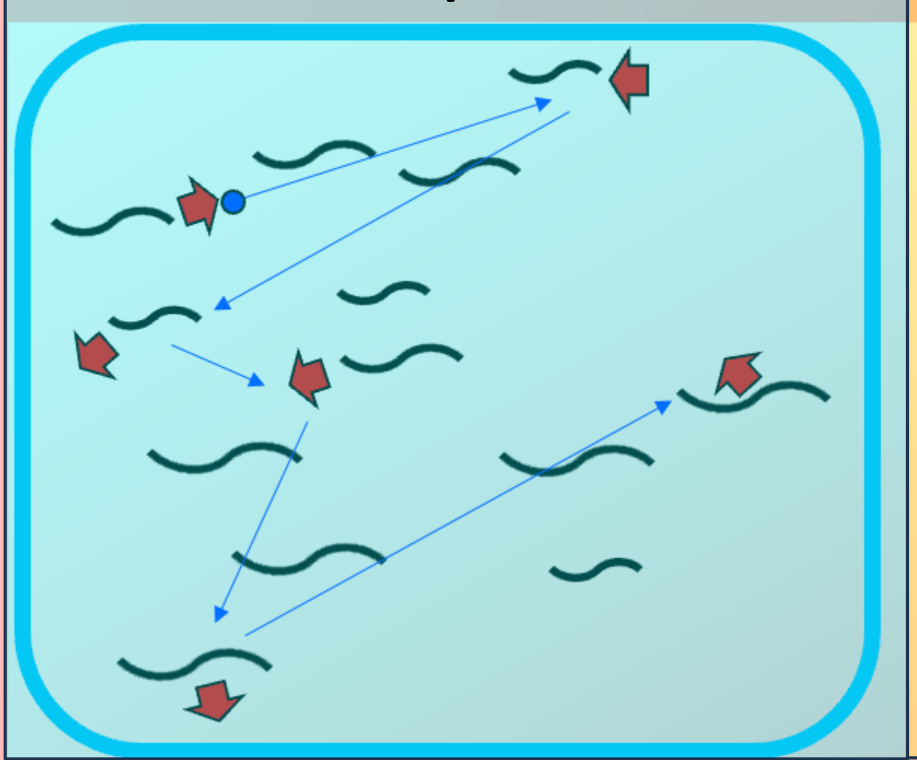
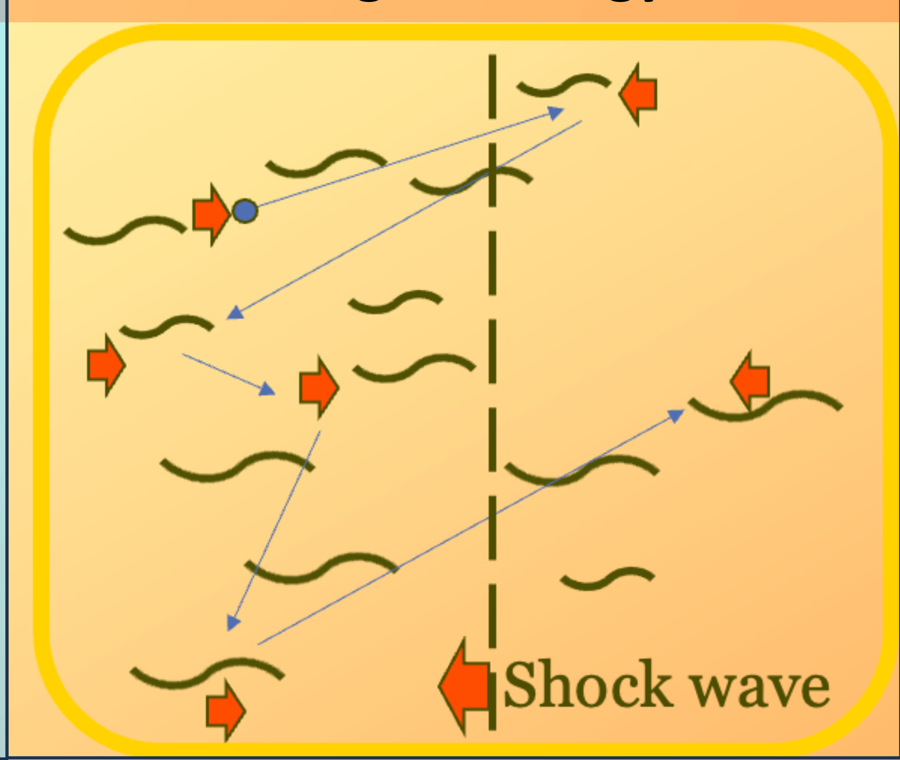
different origin and accel. mechanism?





III. Stoch. Acc. Model and A Result

One-zone stoch. acc. model (Tanaka&Asano17) is improved by considering evolution of turbulence.

$$\frac{\partial}{\partial t}N(\gamma,t)+\frac{\partial}{\partial\gamma}\left[\left(\underbrace{\dot{\gamma}_{\rm cool}(\gamma,t)}_{\rm cooling}-\underbrace{\gamma^2 D_{\gamma\gamma}(\gamma,t)\frac{\partial}{\partial\gamma}\frac{1}{\gamma^2}}_{\rm stoch.\ acc.}\right)N(\gamma,t)\right]=\underbrace{Q_{\rm PSR}(\gamma,t)}_{\rm from\ PSR\ (shock)}+Q_{\rm ext}(t)$$

Accelerating e^- & p^+ (ion) by decaying turbulence.

$$D_{\gamma\gamma}=\frac{\gamma^2}{2t_{\rm acc}},\quad t_{\rm acc}(t)=\tau_{\rm acc}\frac{\eta_{\rm T}E_{\rm rot}}{E_{\rm T}(t)}$$

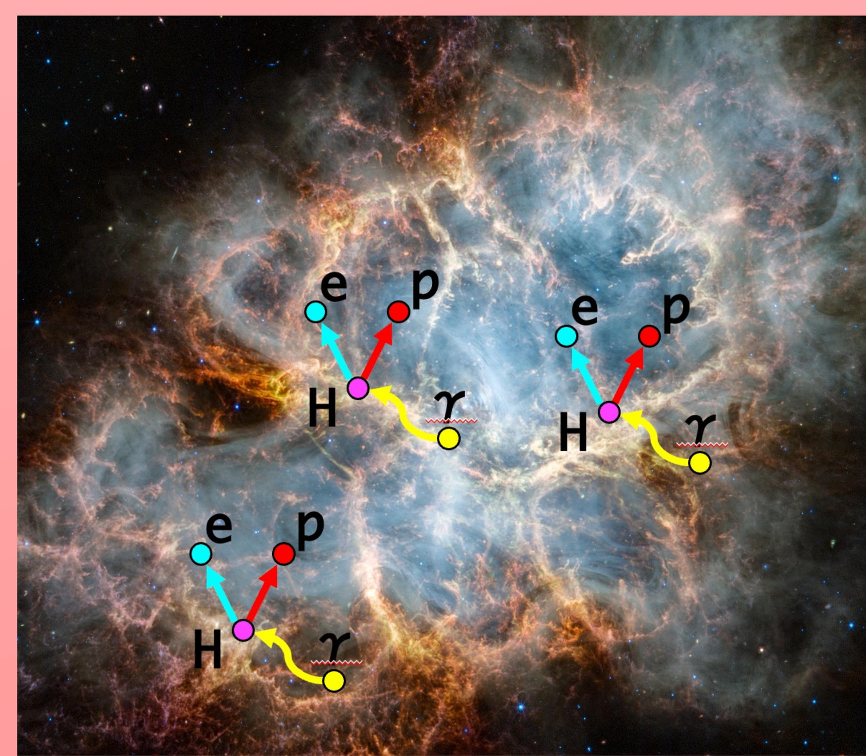
Turbulence evolution

$$\frac{dE_{\rm T}}{dt}=\eta_{\rm T}L_{\rm spin}-\frac{E_{\rm T}}{t_{\rm adi}(t)}-\left(\frac{\delta E_{\rm T}}{\delta t}\right)_{\rm damp}$$

e^- + p^+ (ion) injection from filaments by photoionization.

$$Q_{\rm ext}(\gamma,t)=f_{\rm inj}4\pi R_{\rm PWN}^2(t)v_{\rm PWN}(t)\,n_{\rm ej}(R_{\rm PWN}(t))\delta(\gamma-\gamma_{\rm inj})$$

f_{inj}: ~ $O(10^{-5})$, γ_{inj} ~ 1



Applied to Crab

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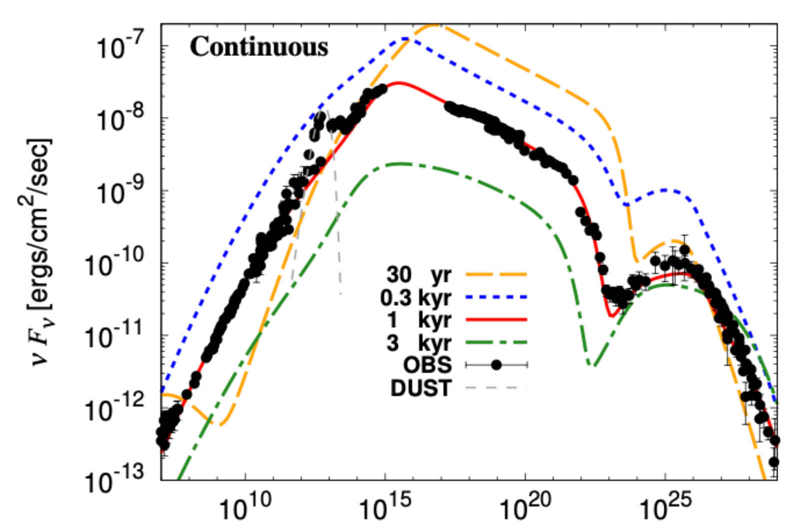
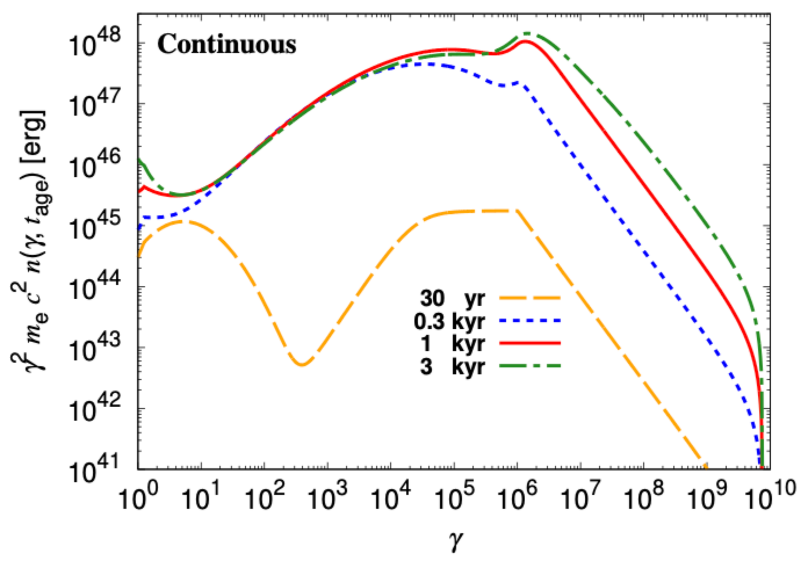
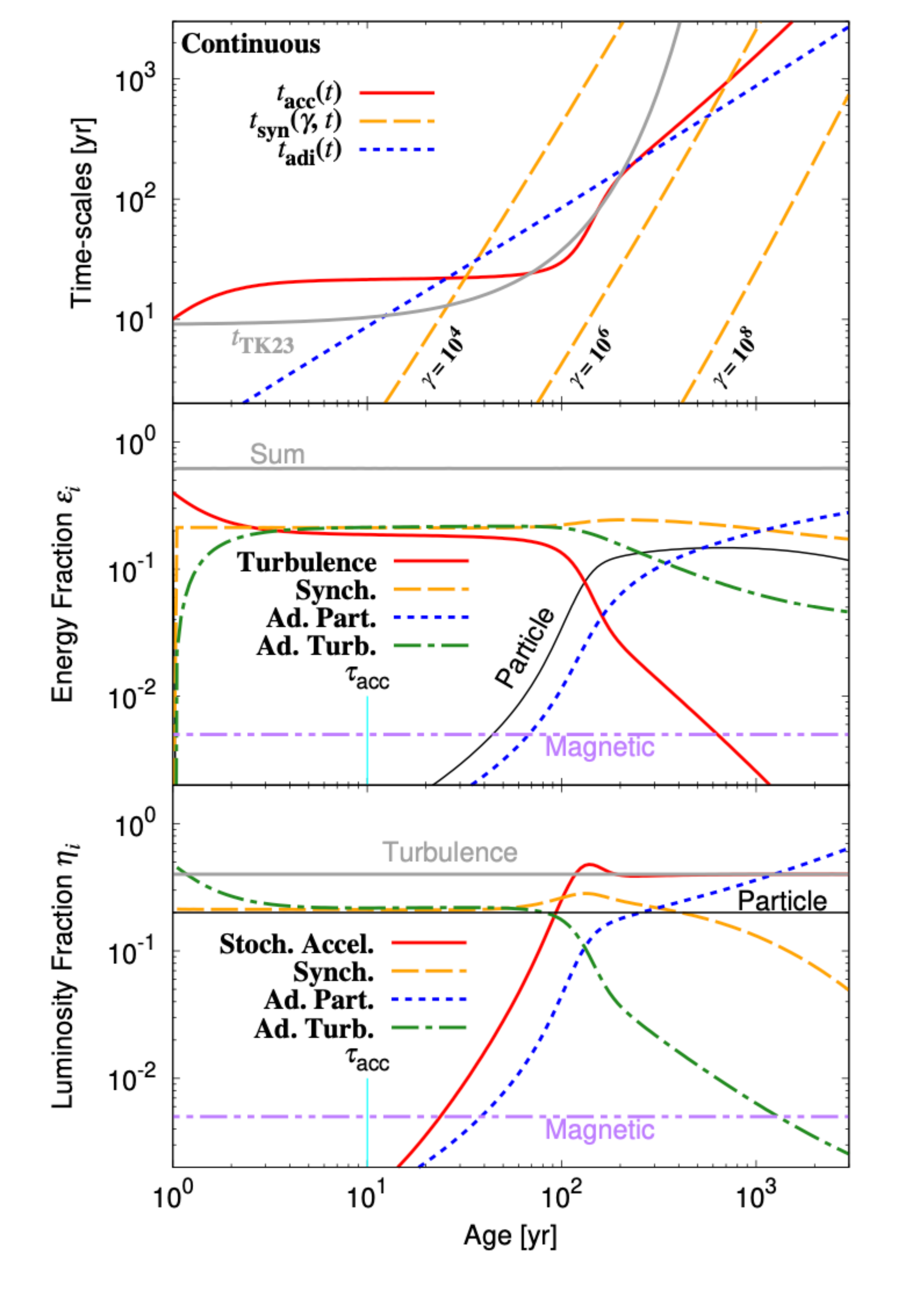


(a) The spectral energy distribution



(b) The particle energy spectra



(c) Evolution of the typical time-scales (top), the fractional energies (middle) and luminosities (bottom)

IV. Summary

- turbulence injection from pulsar
- considering decay of turbulence
- reproduce reproduce the Crab obs. with τ_{acc} < 10 yr
- may accelerate hadrons → neutrino from PWNe?
- study of multi-band spatial structure required.

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