12) Time evolution of broadband non-thermal emission from supernova remnants in different circumstellar environments

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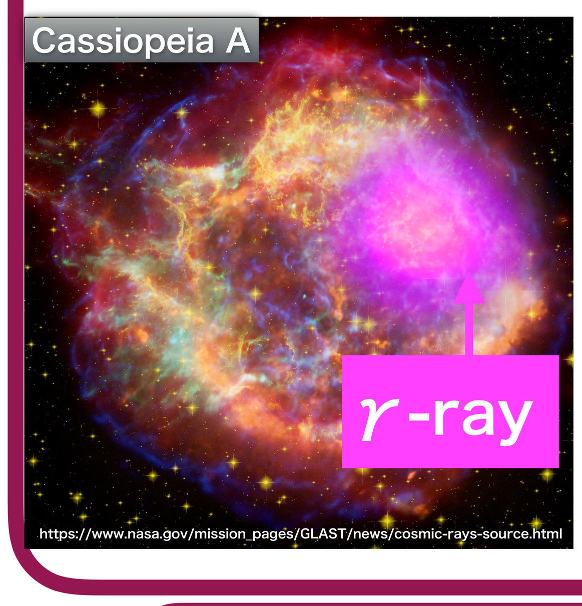
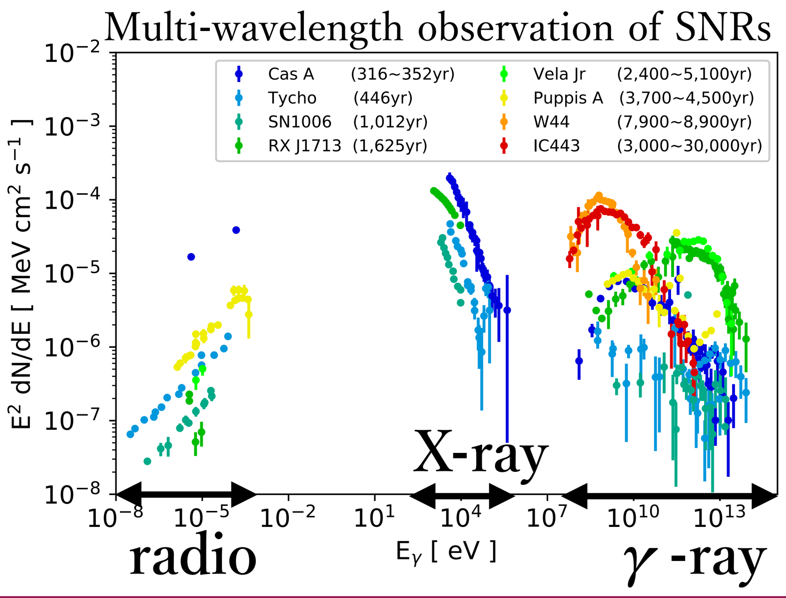
Introduction

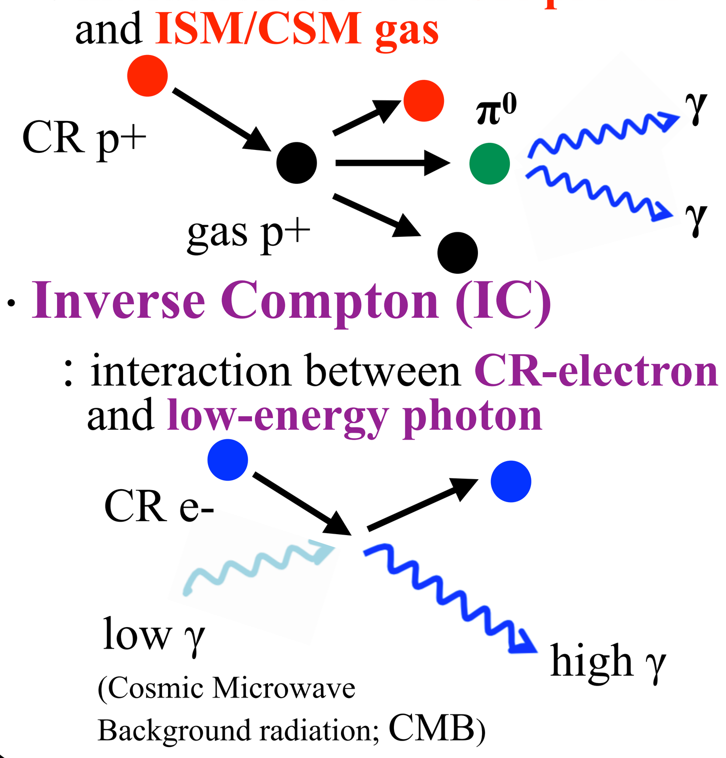
Supernova remnants (SNRs) are thought to be one of the major acceleration sites of galactic **cosmic rays (CRs)** and emit **broadband non-thermal electromagnetic radiation** owing to their interactions with the interstellar matters (ISM) or circumstellar matter (CSM).

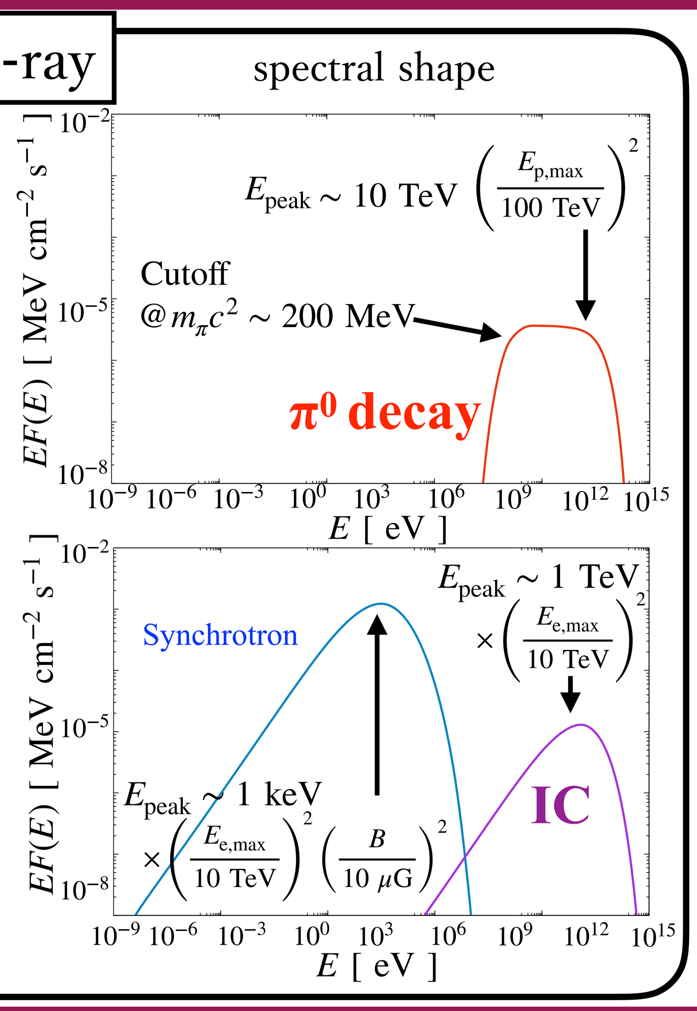




Emission mechanisms of γ-ray

- **π^0 decay**
  : interaction between **CR-proton** and **ISM/CSM gas**
- **Inverse Compton (IC)**
  : interaction between **CR-electron** and **low-energy photon**

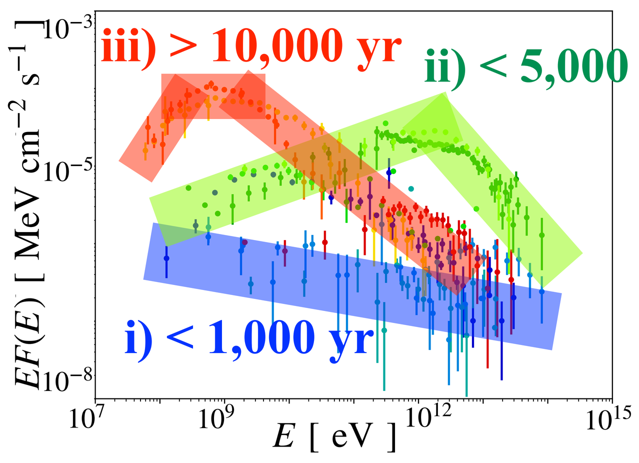




● Questions :

① What's the origin of γ-ray from SNR?
② Can we see the trend in observed γ-ray?
③ What makes these trend if exists?

i) < 1,000 yr : **π^0 decay (hadronic)?**
ii) < 5,000 yr : **IC (leptonic)?**
iii) > 10,000 yr : **π^0 decay (hadronic)**



Method : CR-Hydrodynamics

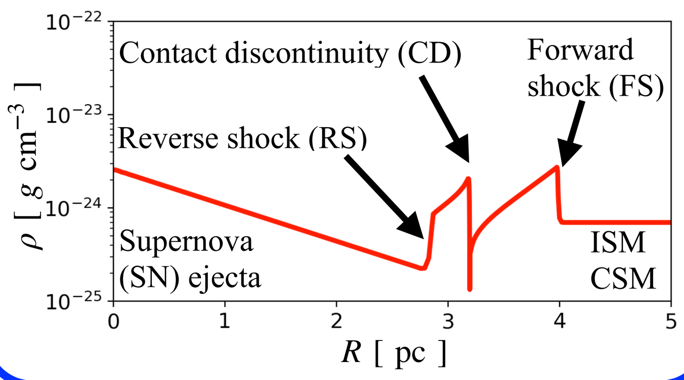
- We develop the hydro code which can **self-consistently** solve the **hydrodynamics coupling with effective particle acceleration**.
- We follow **time-evolution of γ-ray** from SNRs in **different circumstellar environments**.

Hydrodynamics

- code : VH-1
- spherical symmetric SN-like explosion
  → two ejecta model
  (i) exponential (Dwarkadas+1998)
  (ii) power-law (Truelove+1999)

$$\frac{\partial r}{\partial m} = \frac{1}{4\pi r^2 \rho} \qquad \frac{\partial E}{\partial t} = -\frac{\partial (P_{\rm tot} u)}{\partial m}$$

$$\frac{\partial u}{\partial t} = -\frac{\partial P_{\rm tot}}{\partial m} \qquad E = \frac{1}{2}\rho u^2 + \frac{P_{\rm tot}}{\gamma_{\rm eff} - 1}$$



$R_{\rm sk}$, $V_{\rm sk}$, $T_{\rm age}$, B_0, T_0 →

← $P_{\rm tot}$, $\gamma_{\rm eff}$

feedback of CR

- modify hydro eqs. & EoS using CR pressure

(i) total pressure $P_{\rm tot}$:

$$P_{\rm tot}(x) \equiv P_{\rm g}(x) + P_{\rm CR}(x) + P_{\rm B}(x)$$

gas / CR / magnetic

$$P_{\rm CR}(x) = \frac{4\pi}{3}\int_{p_{\rm inj}}^{p_{\rm max}} p^3 v\, f_p(x,p)\, dp, \quad P_{\rm B}(x) = \frac{B(x)^2}{8\pi}$$

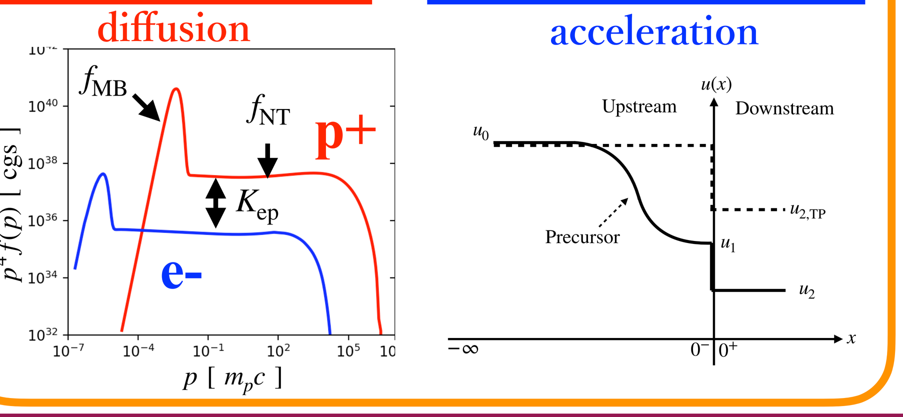
(ii) effective specific ratio $\gamma_{\rm eff}$:

$$\frac{\gamma_{\rm eff}}{\gamma_{\rm eff}-1}P_{\rm tot} = \frac{\gamma_{\rm gas}}{\gamma_{\rm gas}-1}P_{\rm gas} + \frac{\gamma_{\rm CR}}{\gamma_{\rm CR}-1}P_{\rm CR}$$

Nonlinear diffusive shock acceleration (NLDSA)

- solve diffusion-convection equation at shock using semi-analytic model (Capliori+2010a,b)
- "thermal-leakage" injection (Blasi+2004,2005)
- Magnetic field amplification (MFA) (Bell+1978a,b)

$$\underbrace{\{u(x) - v_A(x)\}\frac{\partial f(x,p)}{\partial x}}_{\rm convection} - \underbrace{Q(x,p)}_{\rm injection} = \underbrace{\frac{\partial}{\partial x}\left\{D(x,p)\frac{\partial f(x,p)}{\partial x}\right\}}_{\rm diffusion} + \underbrace{\frac{d\{u(x)-v_A(x)\}}{dx}\frac{p}{3}\frac{\partial f(x,p)}{\partial p}}_{\rm acceleration}$$



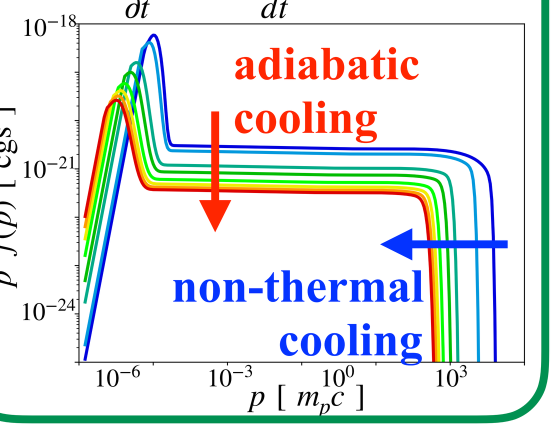
$f_p(x,p)$, $f_e(x,p)$ →

←

radiation cooling

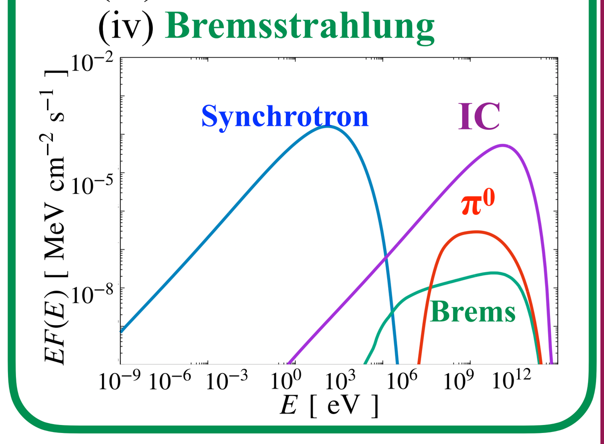
- considering energy-loss due to
  (i) non-thermal radiation
  (ii) adiabatic expansion

$$\frac{\partial n(E)}{\partial t} = -\frac{dE}{dt}n(E) + Q(E)$$



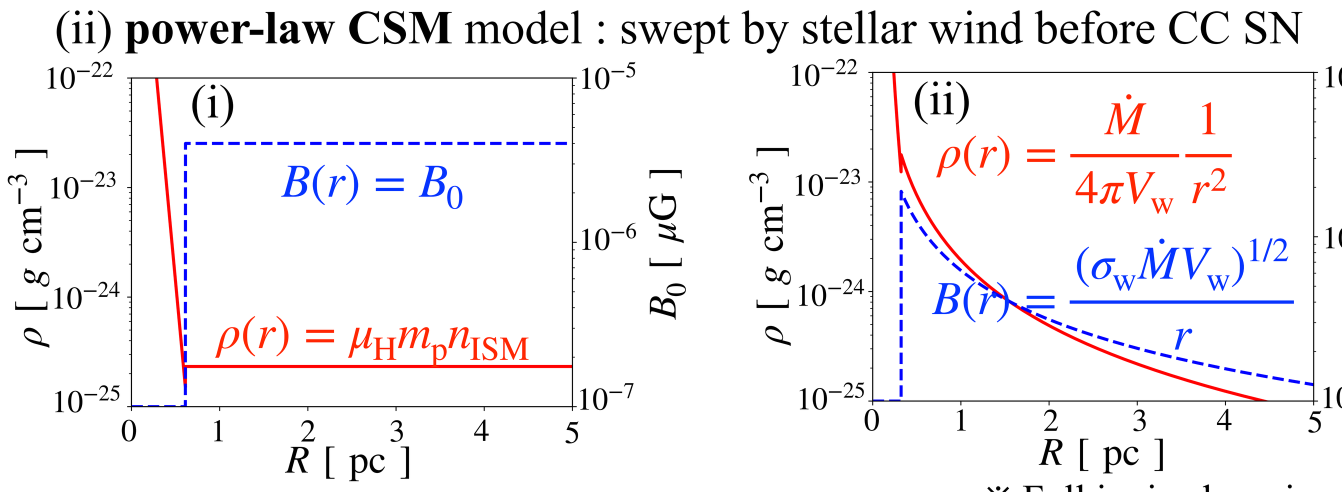
non-thermal emissions

- 4-components as emission
  (i) **π^0 decay**
  (ii) **Synchrotron**
  (iii) **IC**
  (iv) **Bremsstrahlung**



Environment model

- We prepare two environment models
  (i) **uniform ISM** model : the environment as Type Ia SN
  (ii) **power-law CSM** model : swept by stellar wind before CC SN



※ Full ionized gas is assumed

Table 2. Model parameter

Model	$M_{\rm ej}$ [$M_\odot$]	$n_{\rm ISM}$ [cm^{-3}]	$\dot{M}$ [$M_\odot$ yr^{-1}]	$V_{\rm w}$ [km s^{-1}]	$\dot{M}_2$ [$M_\odot$ yr^{-1}]	$V_{\rm w,2}$ [km s^{-1}]	$\chi_{\rm inj}$
A0[a]	1.4	0.3	-	-	-	-	3.6
A1	1.4	0.01	-	-	-	-	3.6
A2	1.4	0.1	-	-	-	-	3.6
A3	1.4	1.0	-	-	-	-	3.6
A4	1.4	0.01	-	-	-	-	4.0
A5	1.4	0.1	-	-	-	-	4.0
A6	1.4	1.0	-	-	-	-	4.0
B0[b]	3.0	-	7.5×10^{-6}	20	-	-	3.75
B1	3.0	-	1.0×10^{-6}	20	-	-	3.75
B2	3.0	-	1.0×10^{-5}	20	-	-	3.75
B3	3.0	-	1.0×10^{-4}	20	-	-	3.75
B4	10.0	-	1.0×10^{-6}	20	-	-	3.75
B5	10.0	-	1.0×10^{-5}	20	-	-	3.75
B6	10.0	-	1.0×10^{-4}	20	-	-	3.75

[a] All model A use an exponential profile for ejecta, $E_{\rm SN} = 10^{51}$ erg, $T_0 = 10^4$ K, and $d_{\rm SNR} = 3.2$ kpc.
[b] All model B use a power-law profile for ejecta, $n_{\rm pl} = 7$, $E_{\rm SN} = 10^{51}$ erg, $T_0 = 10^4$ K, and $d_{\rm SNR} = 1.0$ kpc.

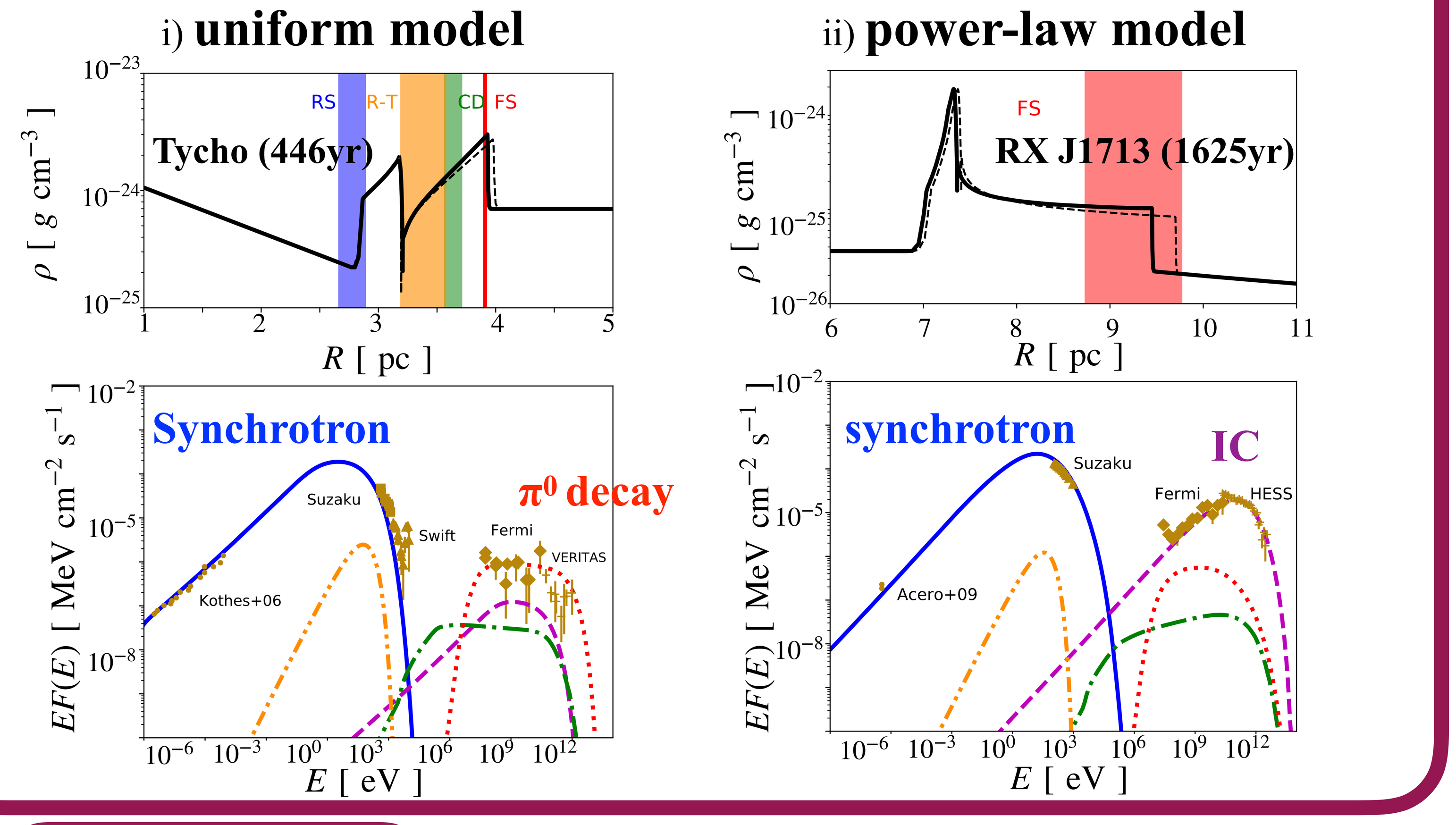
→ Free parameters : ejecta mass $M_{\rm ej}$, explosion energy $E_{\rm SN}$,
ISM number density $n_{\rm ISM}$, magnetic field B_0,
CSM mass-loss rate $\dot{M}$, wind velocity $V_{\rm w}$, magnetization ratio $\sigma_{\rm w}$

↪ fixed from calibration test using observation data of SNRs except $n_{\rm ISM}$, $\dot{M}$

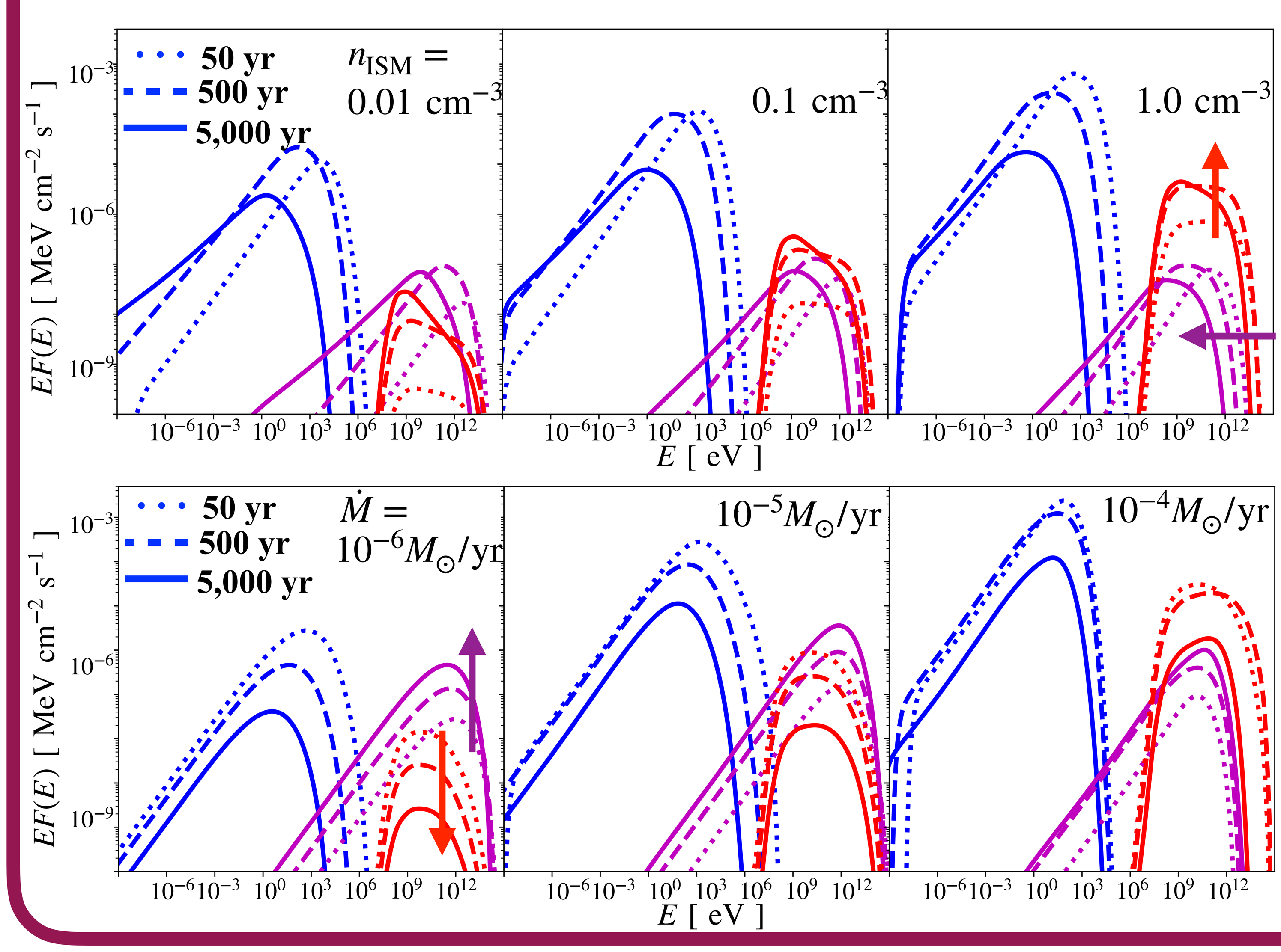
Calibration test

To fix many SNR and DSA parameters, we reproduce the hydro and multi-wavelength observations at the same time.

i) **uniform model** ii) **power-law model**



Results : time-evolution of SED



★Main results

i) **uniform model**
- **π^0 decay** : constantly **increase** ↑
- **IC** : **shift** to lower energy ←

ii) **power-law model**
- **π^0 decay** : constantly **decrease** ↓
- **IC** : constantly **increase** ↑

These trends are affected by 2 factors :
(i) shocked mass i.e. **density**
(ii) energy-loss by synchrotron i.e. **B-field**

Summary

(i) We find that the time-evolution of γ-ray is characterized by density and B-field of cirucmstellar environment.

(ii) We acquire the relationship between γ-ray spectrum and the circumstellar environment.

		$T_{\rm age}$ = 50 yr	500 yr	5,000 yr	> 10,000 yr
previous picture		No obs.	hadronic	leptonic	hadronic
uniform ISM	0.01 cm^{-3}	leptonic	leptonic	leptonic	
	0.1 cm^{-3}	leptonic	mixed	hadronic	
	1.0 cm^{-3}	hadronic	hadronic	hadronic	
power-law CSM	10^{-6} $M_\odot$/yr	mixed	leptonic	leptonic	
	10^{-5} $M_\odot$/yr	hadronic	mixed	leptonic	
	10^{-4} $M_\odot$/yr	hadronic	hadronic	mixed	

Acknowlegment

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