TeVPa 2021 @ Chengdu, China

Radio Constraints on Multi-Messenger High-Energy Emission from Galaxy Clusters

authors

Kosuke NISHIWAKI[1] / Katsuaki ASANO[1] / Kohta MURASE[2,3]

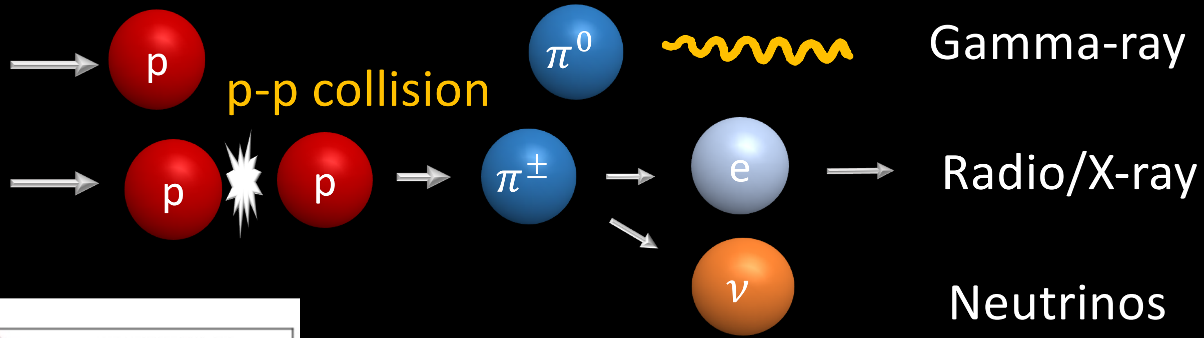
1. Institute for Cosmic-Ray Research (ICRR), University of Tokyo
2. Pennsylvania State University
3. Yukawa Institute for Theoretical Physics, Kyoto University

contact: nisiwaki@icrr.u-tokyo.ac.jp

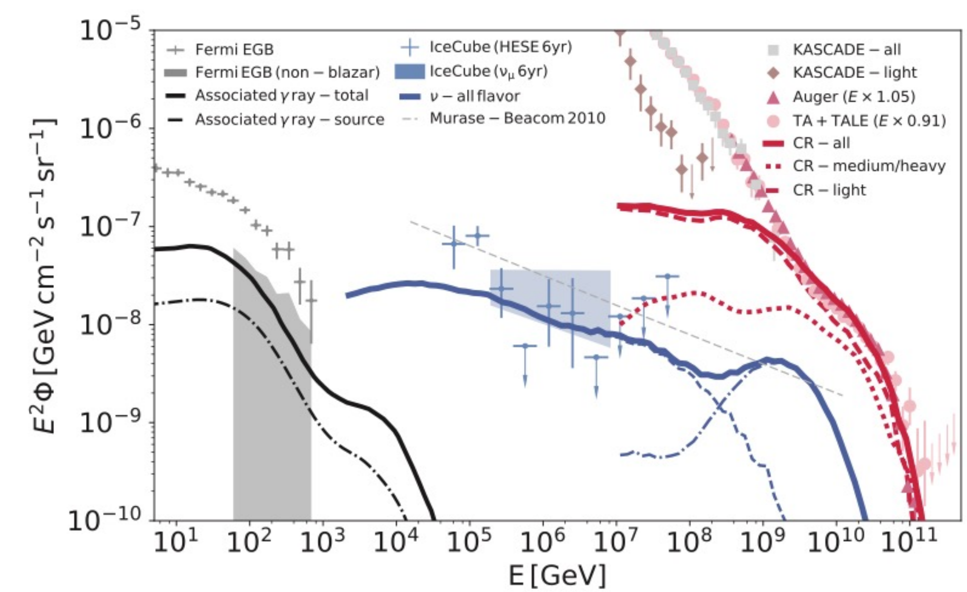
Multi-messenger from Galaxy Clusters (GCs)

Cosmic-Ray Sources

- Cosmological Shocks
- AGNs
- Galactic Outflows



[Fang & Murase 2017]

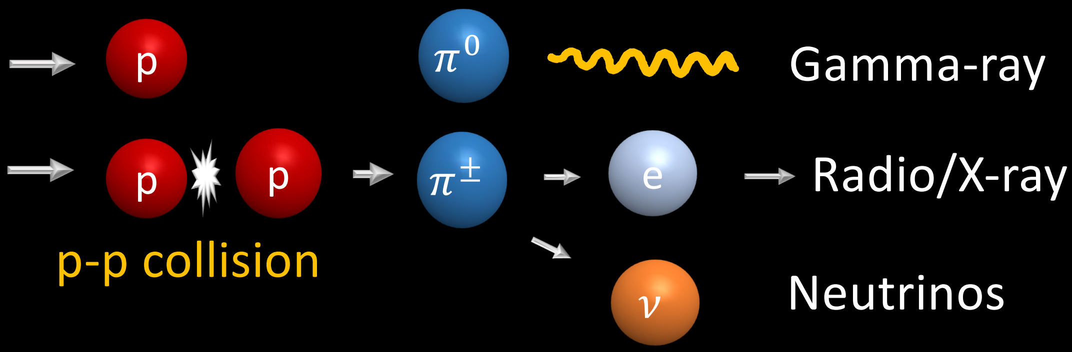


"Cosmic-Ray Reservoir" scenario

- CRs can be accelerated up to Ultra-High Energies (R ∼ Mpc, B ∼ μG)
- $E \lesssim 1$ PeV → confined in cluster volume & experience *pp* collision

potential source for diffuse neutrinos & UHECRs

Challenge for Hadronic (Secondary) Scenario

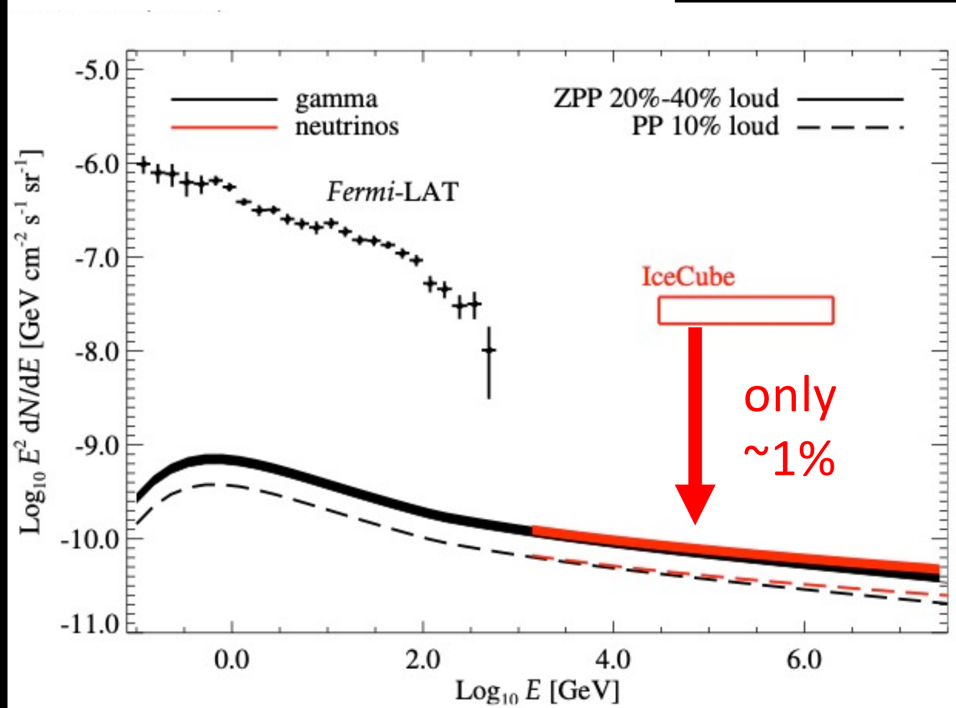


Non-detection with Fermi-LAT

[e.g., Ackermann et al. 2014]

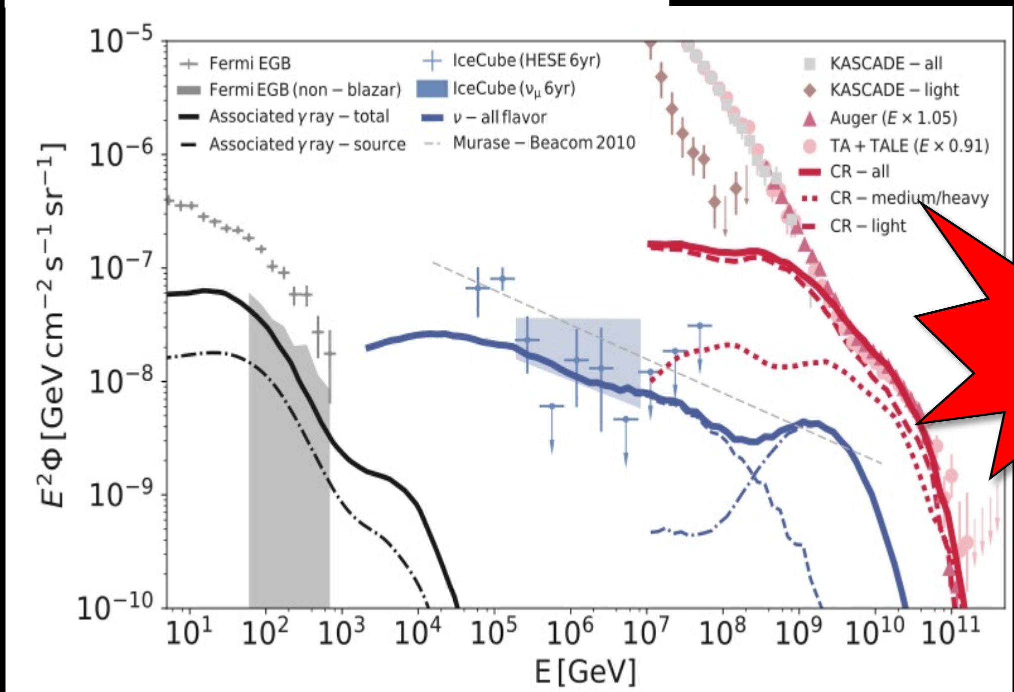
(*Possible detection from Coma : e.g., Adam et al. 2021)

[Zandanel et al. 2015]

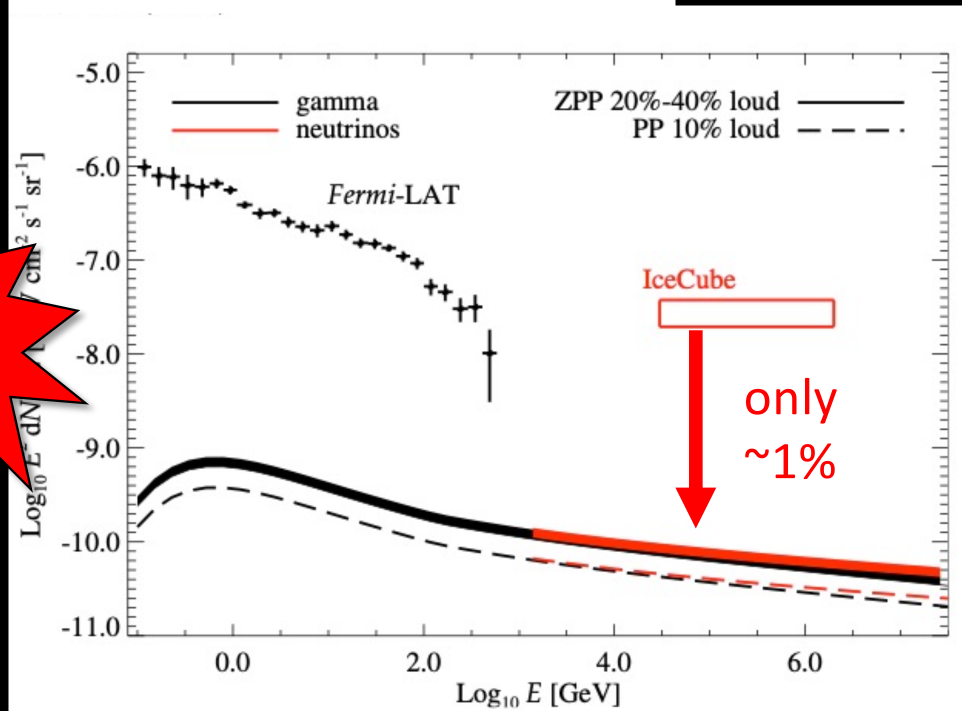


Challenge for Hadronic (Secondary) Scenario

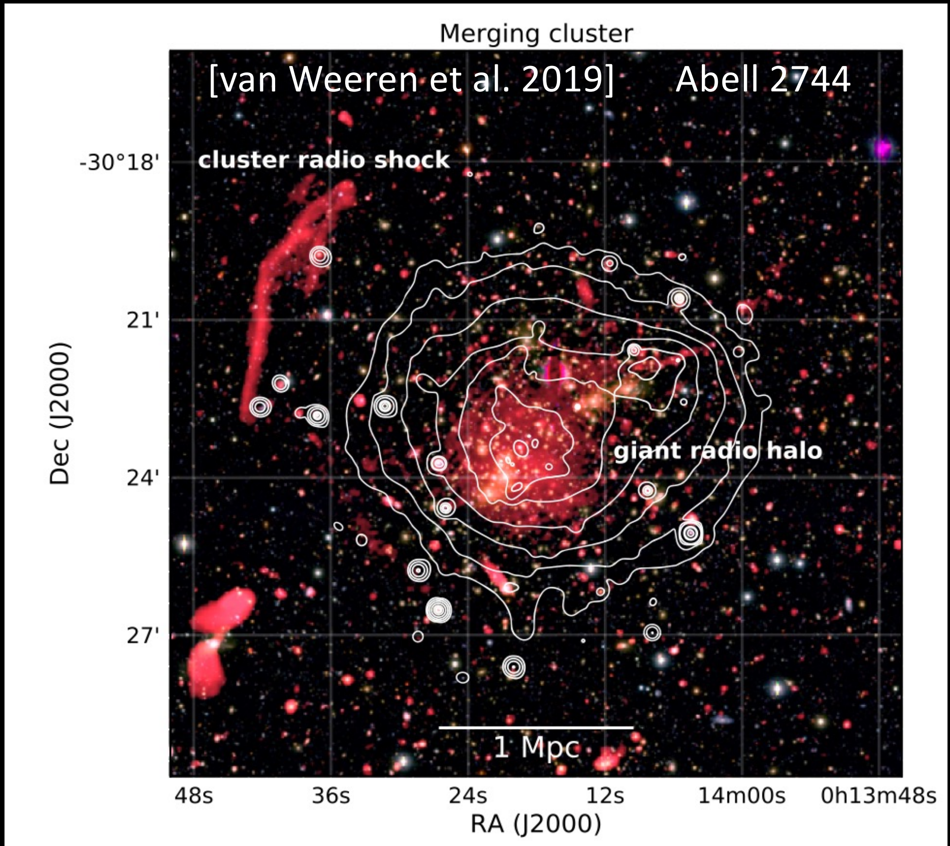
[Fang & Murase 2017]



[Zandanel et al. 2015]



Leptons: Giant Radio Halo (RH)

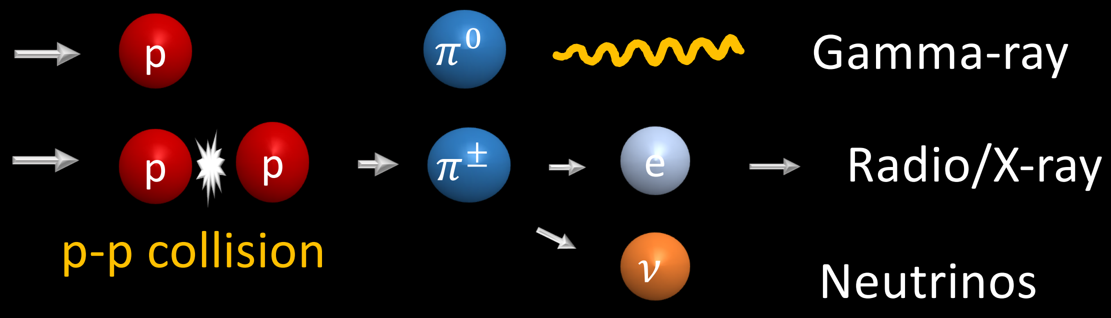


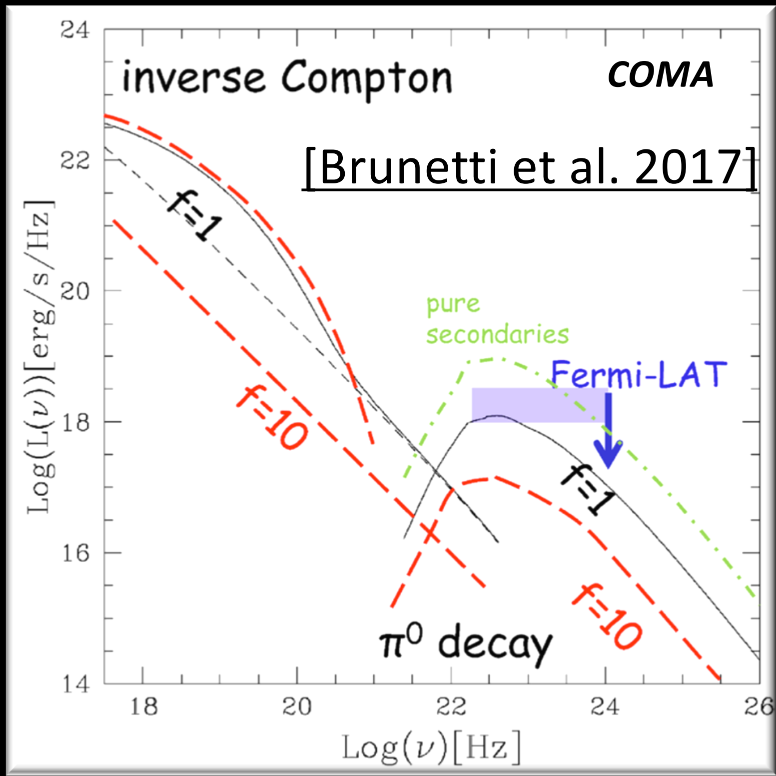
- Synchrotron radiation from relativistic electrons
- diffuse emission with ~Mpc scale
- appearance ~40%
- found in merging systems

Turbulent Re-acceleration scenario

merger-induced turbulence ⇒ wave-particle interaction

Challenge for Hadronic (Secondary) Scenario





Non-detection with Fermi-LAT [e.g., Ackermann et al. 2014]

(*Possible detection from Coma : e.g., Adam et al. 2021)

Does "Re-acceleration" revive the "hadronic" scenario ??

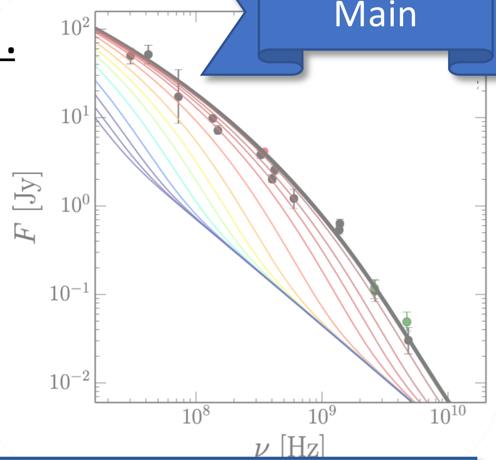
Aim : Radio constraints on hadronic model

1. Modeling Coma cluster

Today's Main

Fokker-Planck eq.
(1D in space)

- cooling
- spatial diffusion
- re-acceleration
- pp collision
- primary injection

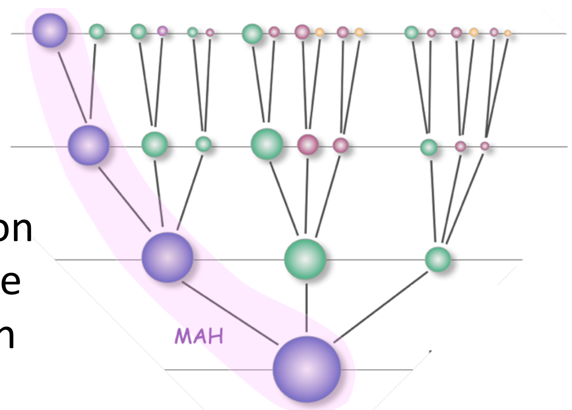


observations
- brightness profile
- radio spectrum
- gamma-ray upper-limit

2. Statistical Study

Merger Tree

- lifetime of RHs
- merger history
- turbulent injection
- mass dependence
- redshift evolution

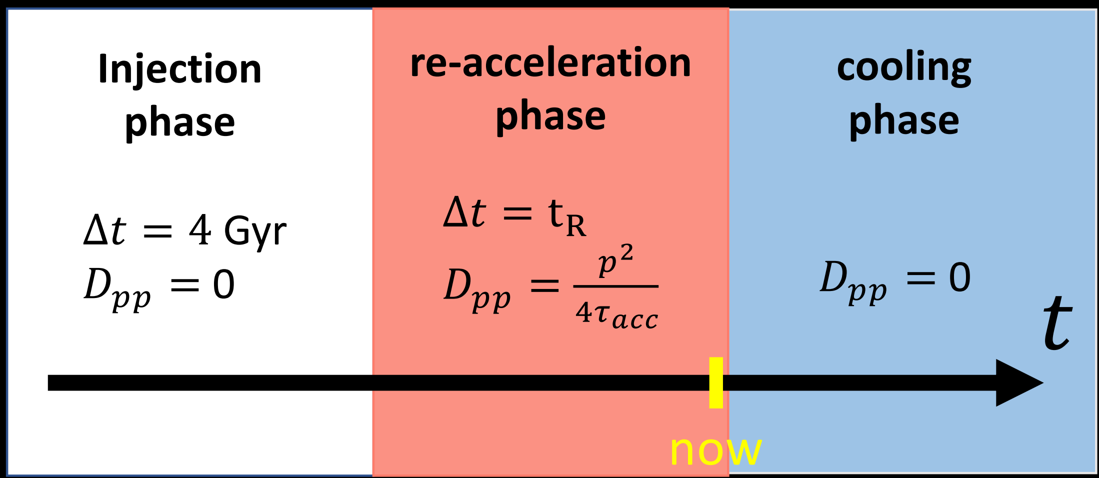


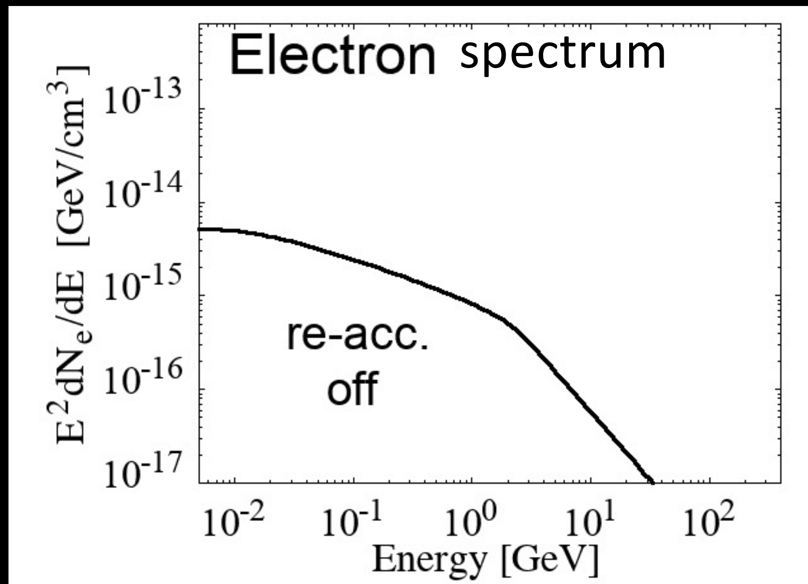
observation
- occurrence of RHs (~40%)
- $P_{1.4} - M_{500}$ scaling relation

1. Fokker – Planck equation

$$\frac{\partial N_e}{\partial t} = \frac{\partial}{\partial p}\left[N_e \frac{dp}{dt}\right] + \frac{\partial}{\partial p}\left[D_{pp}\frac{\partial N_e}{\partial p} - \frac{2}{p}N_e D_{pp}\right] + \frac{\partial}{\partial r}\left[D_{rr}\frac{\partial N_e}{\partial r} - \frac{2}{r}N_e D_{rr}\right] + Q_e^{pri} + Q_e^{sec}$$

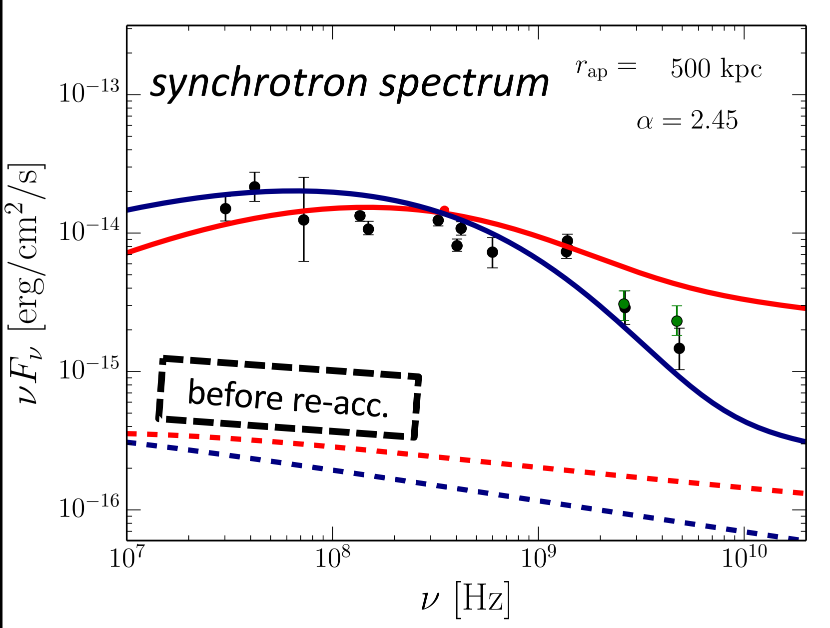
cooling — re-acceleration — diffusion — primary — secondary





[Ref: Nishiwaki et al. (2021), ApJ in press, arxiv : 2105.04551]

Modeling Coma cluster

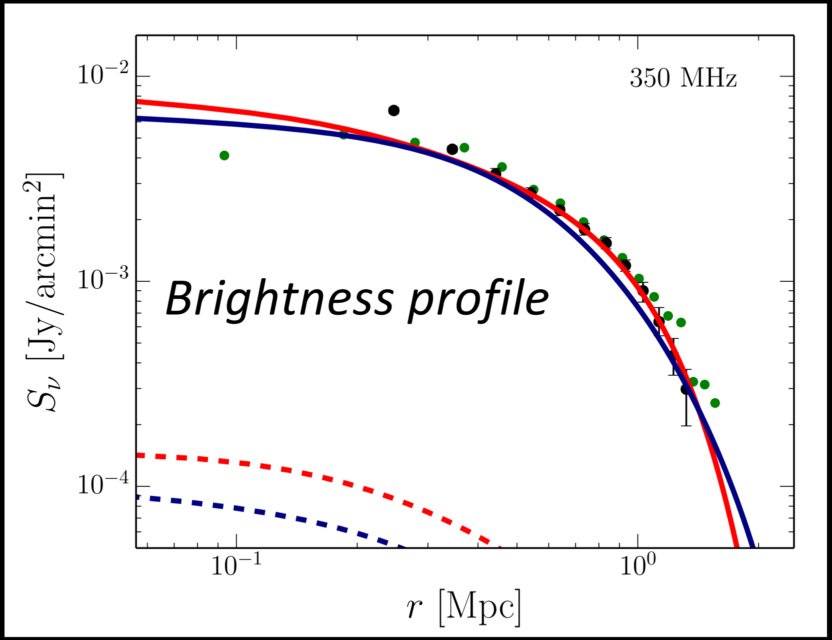


spectral shape

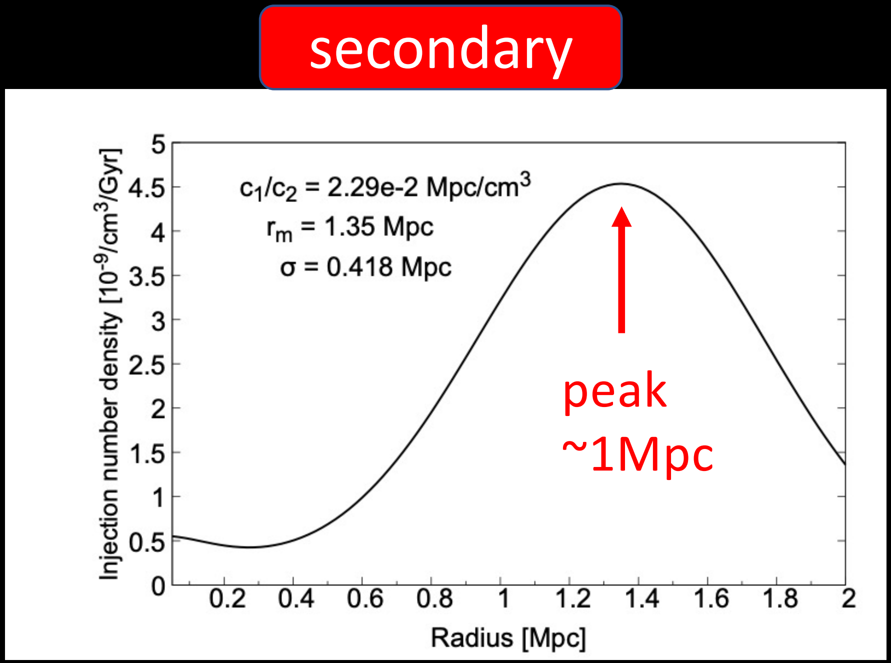
-> re-acceleration timescale : $t_{acc} \approx 300$ Myr

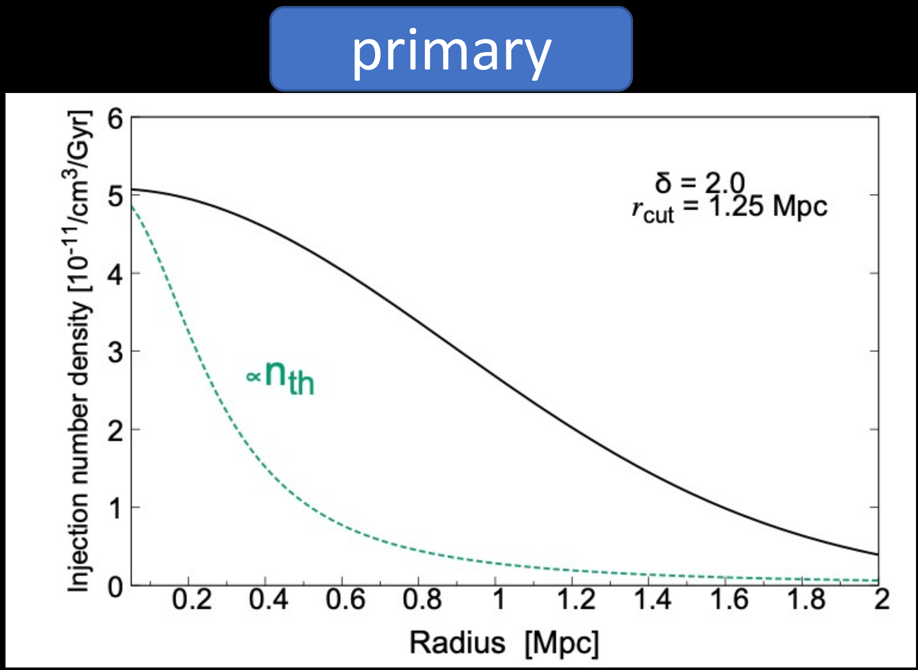
assuming ~ μG magnetic field (cf: Bonafede+2010)

- primary-secondary ratio: f_{ep}
- secondary scenario: $f_{ep} = 0$
- primary scenario: $f_{ep} = 0.01$ (our Galaxy)



Injection from the outer parts?

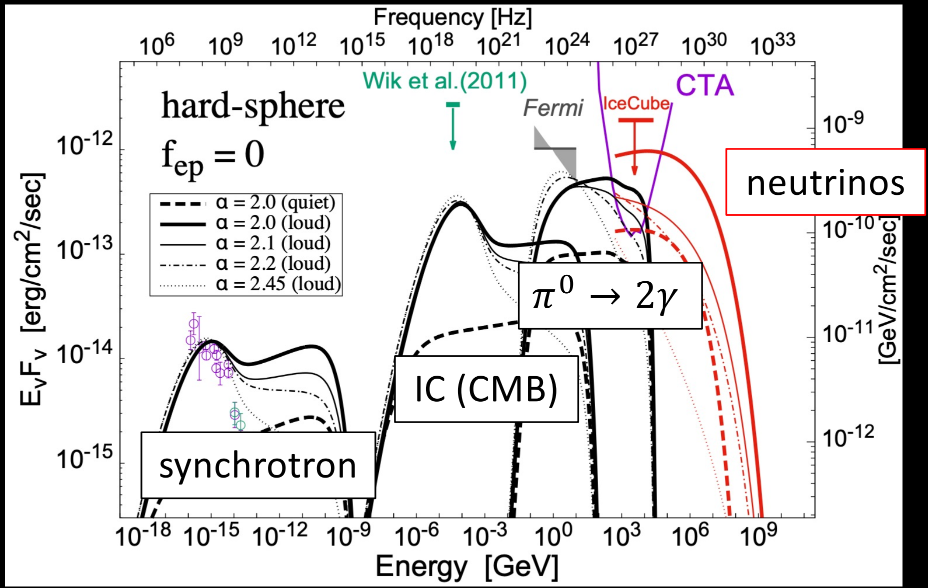




(*Another possibility: e.g., radially flat (increasing) turbulence, e.g., Pinzke et al. 2017)

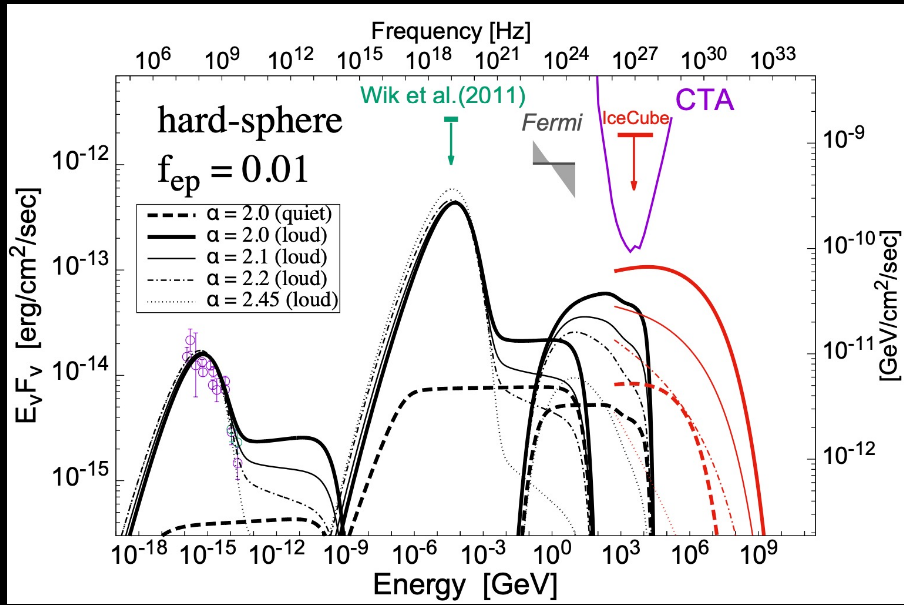
Multi-wavelength spectrum

secondary



- relatively hard spectra
- under the Fermi-LAT limit
- gamma-ray available with future experiments (e.g., LHAASO, CTA)

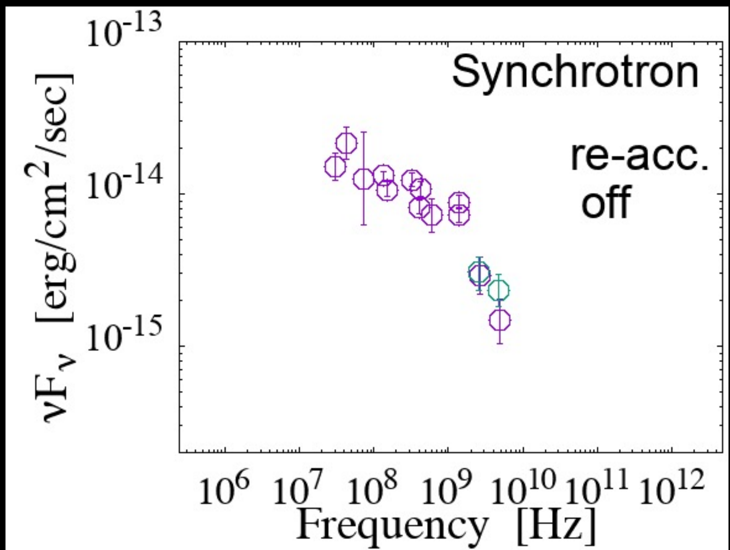
primary



- relatively soft spectra
- better match to the radio data

Lifetime of the RH

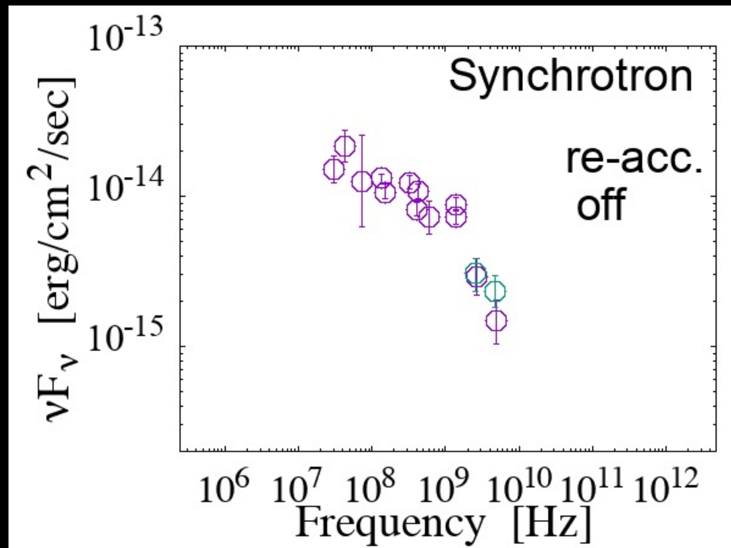
secondary



$t_{RH} \gg$ 1 Gyr ($\nu \gtrsim$ 1GHz)

enhanced injection from
re-accelerated protons

primary

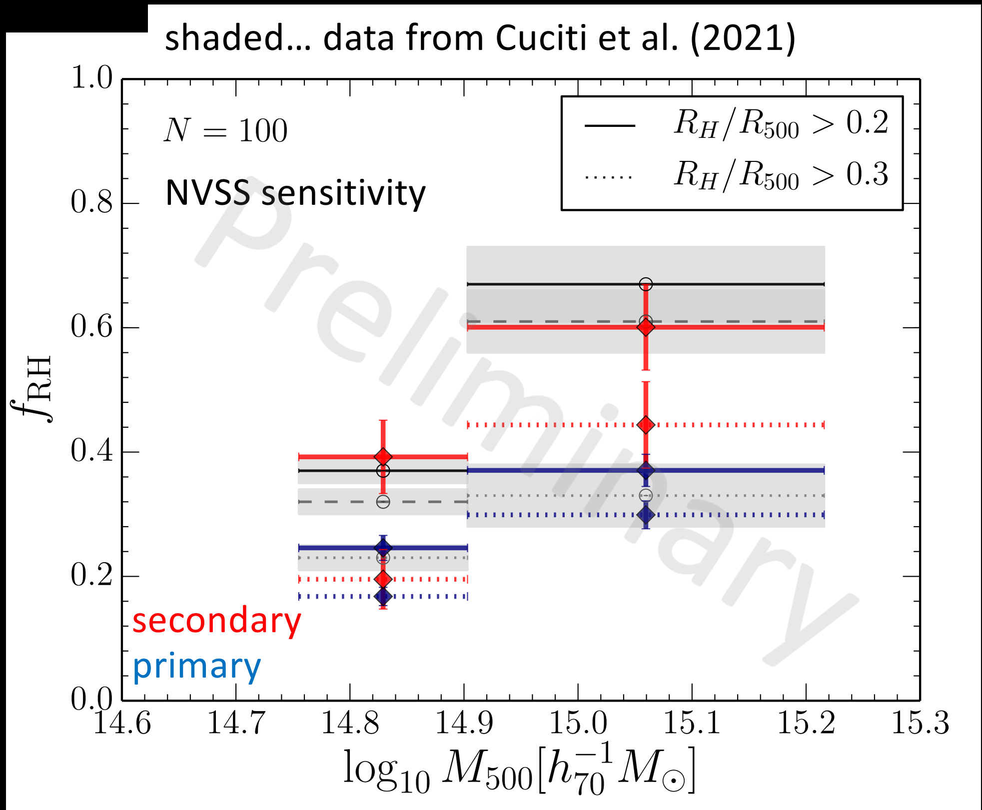


$t_{RH} \approx$ 300 Myr

(cooling/re-acceleration timescale)

[e.g., Cassano & Brunetti 2005, Cassano+2016]

Occurrence of RHs



- <u>Onset condition</u>

1. merger kinetic energy -> turbulent acceleration

$$\epsilon_{turb}(M,\xi,z) = \eta_{CR} f_{baryon} \epsilon_{kin}(M,\xi,z)$$

2. above threshold -> onset

$$\epsilon_{turb}(M,\xi,z) > \chi_{CR}\, \epsilon_{ICM}(M,z)$$

	η_{CR}	χ_{CR}	t_{RH}
secondary	0.15	1%	∞
primary	0.25	0.05%	300 Myr

$\sim 10\%$ similar to Coma

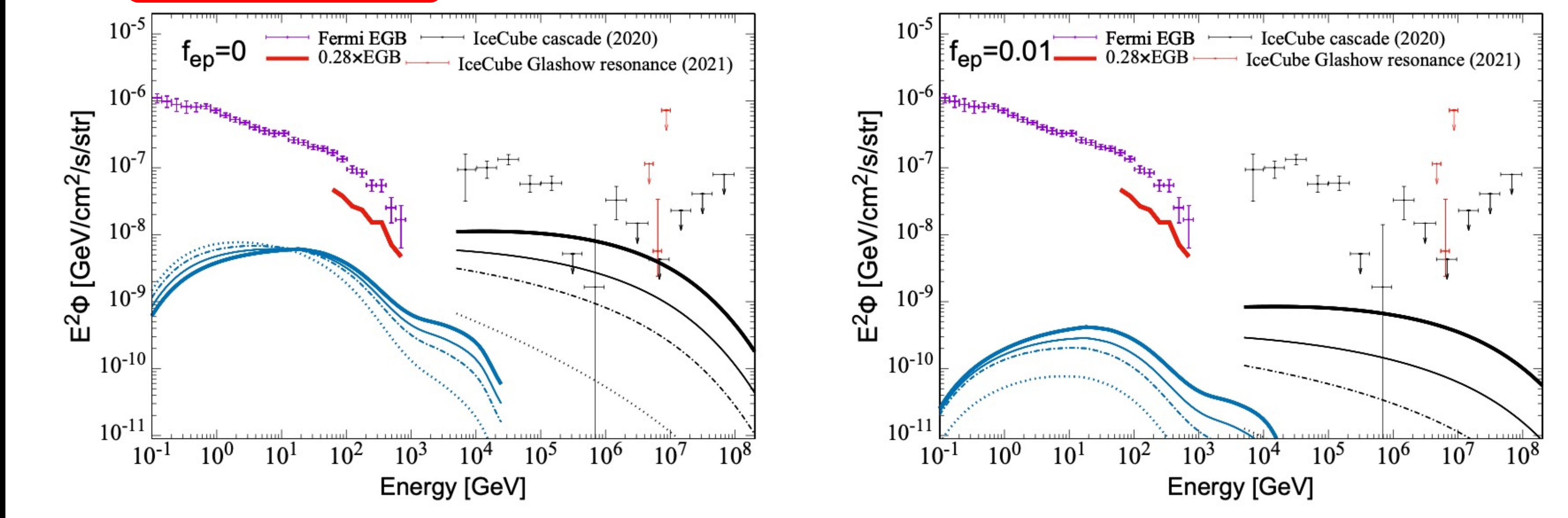
<u>"secondary + re-acceleration" scenario would also explain statistical properties!</u>

High-Energy Backgrounds

secondary

NOTE : Very Approximate

primary



We have assumed …

- $L_\gamma \propto M^{\frac{5}{3}}$, normalized with Coma flux
- $f_{RH} \approx 0.4$ at all mass and redshift
- injection from cosmological shocks

more optimistic result could be available from AGN injection model [e.g., Fang & Murase 2017]

Summery

- Challenge on hadronic scenario
  - non-detection with Fermi-LAT
  - re-acceleration model can explain RH under the gamma-ray limit

- Comparison between primary & secondary scenario
  - lifetime can be considerably different (secondary $\gg$ 1Gyr , primary $\approx$ 300 Myr)
  - both can explain Coma spectrum & statistical property

- High-energy backgrounds from GCs
  - sizable contribution to the IceCube flux is expected
  - AGN injection model would provide more optimistic result