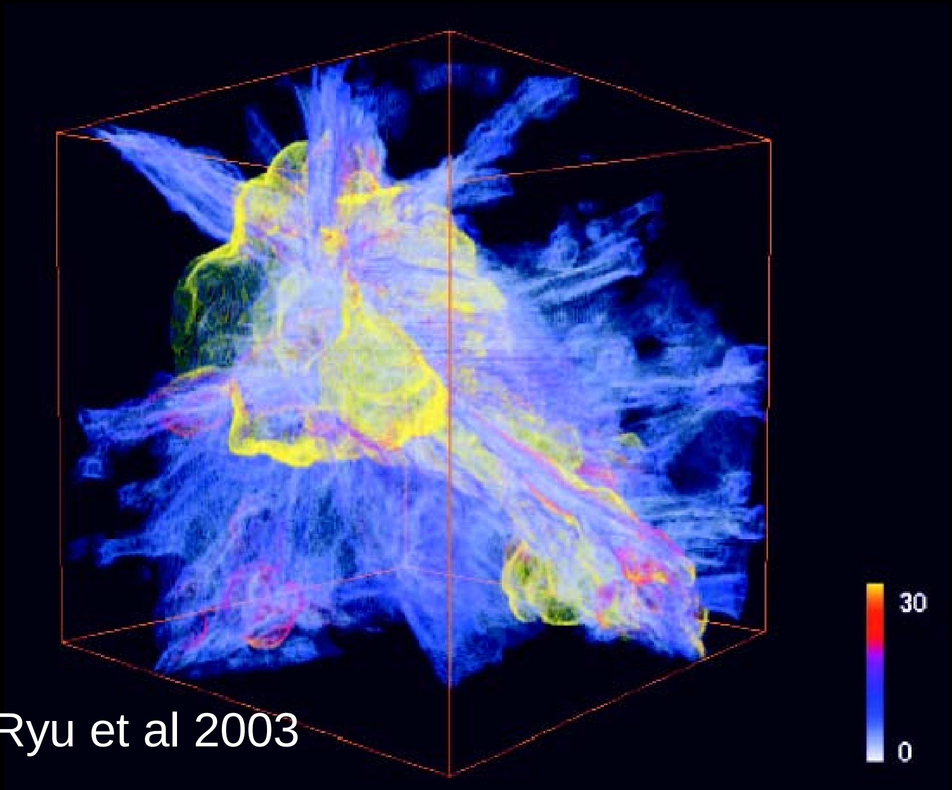
Radiation From Cosmic Rays Accelerated by Cosmological Shocks



Ryu et al 2003

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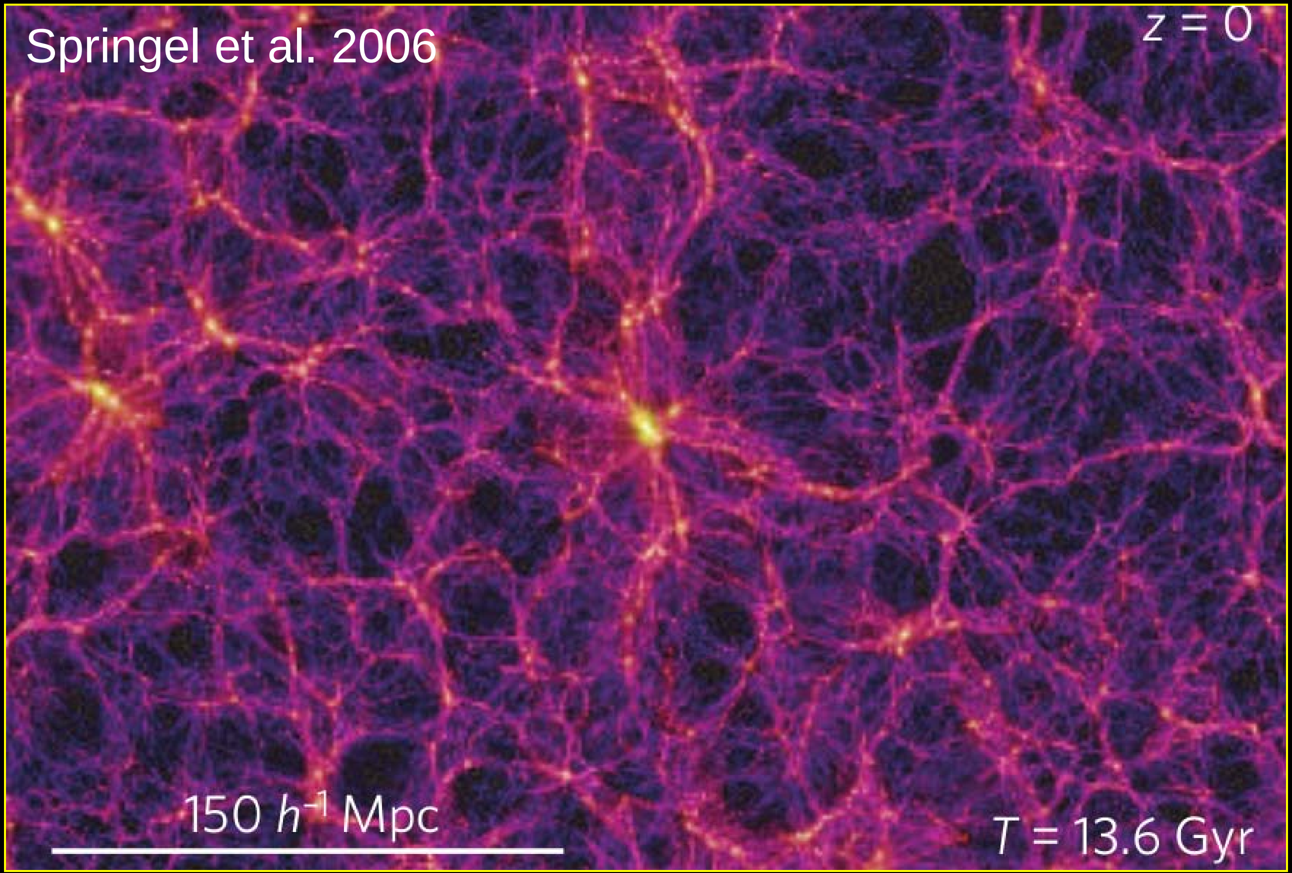
3 University of Minnesota

Outline

- Introduction
- Model & Calculation
- Preliminary Results
- Discussion
- Summary

Introduction

- Cosmic web



WHIM: Warm-Hot Intergalactic Medium (10^5-10^7K)

5% in baryons

>50% baryons in intergalactic medium **(IGM)**

Gas in filaments are mostly **WHIM**

Thermal & non-thermal component of IGM. Shocks play important roles to them

- **Observation of filaments**

Lyman α/X-ray forest (Hallman et a

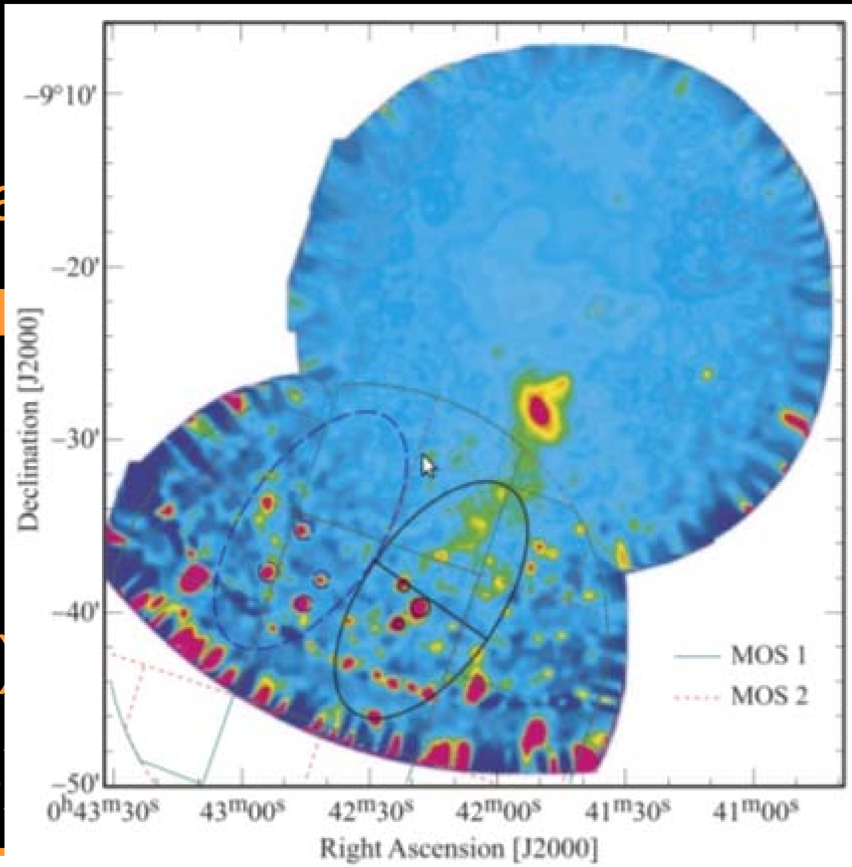
Gravitational lensing (Springel et al

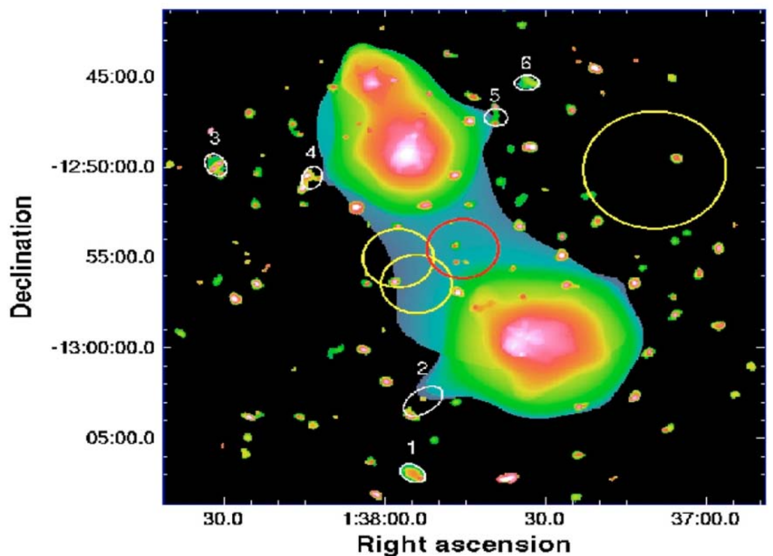
Line emission (Fang et al. 2002)

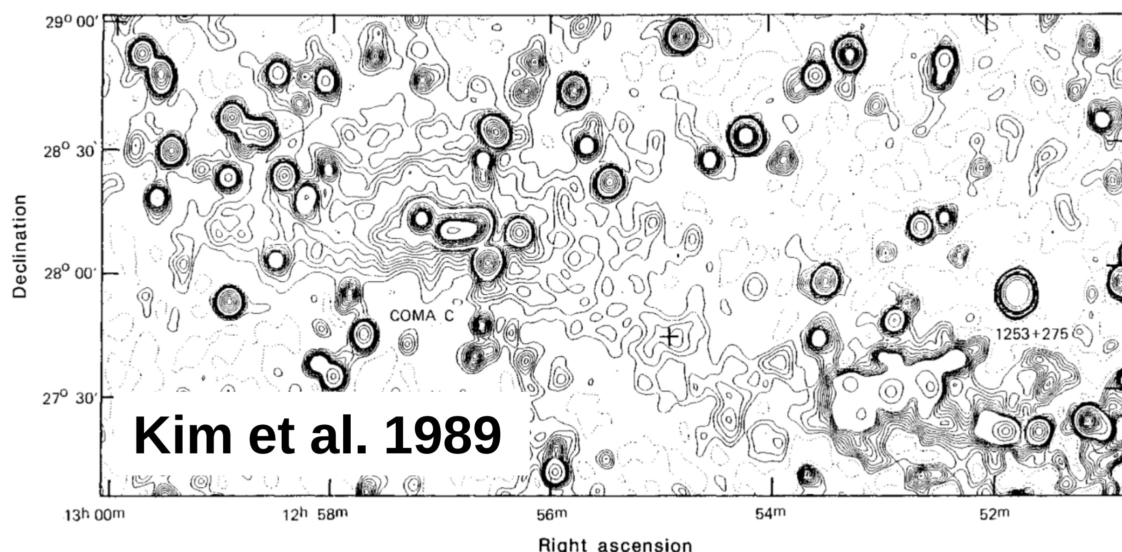
SZ effects (Hallman et al. 2007)

Radio observation (Kim et al. 1989)

X-ray emission (Werner et al. 2008







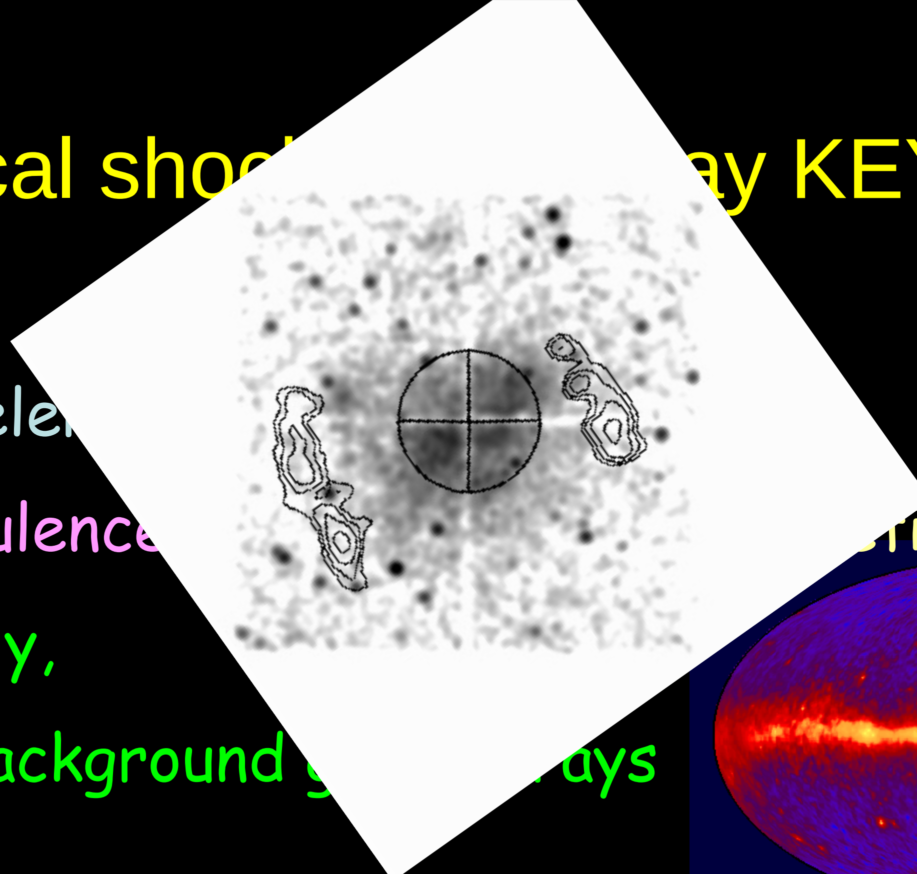
- Cosmological shoc ay KEY roles in the IGM

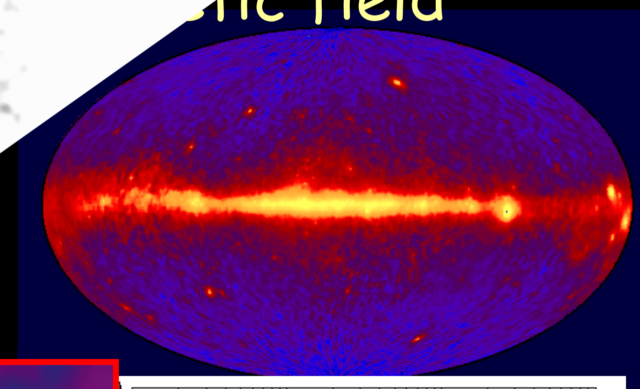
Heating   Accele

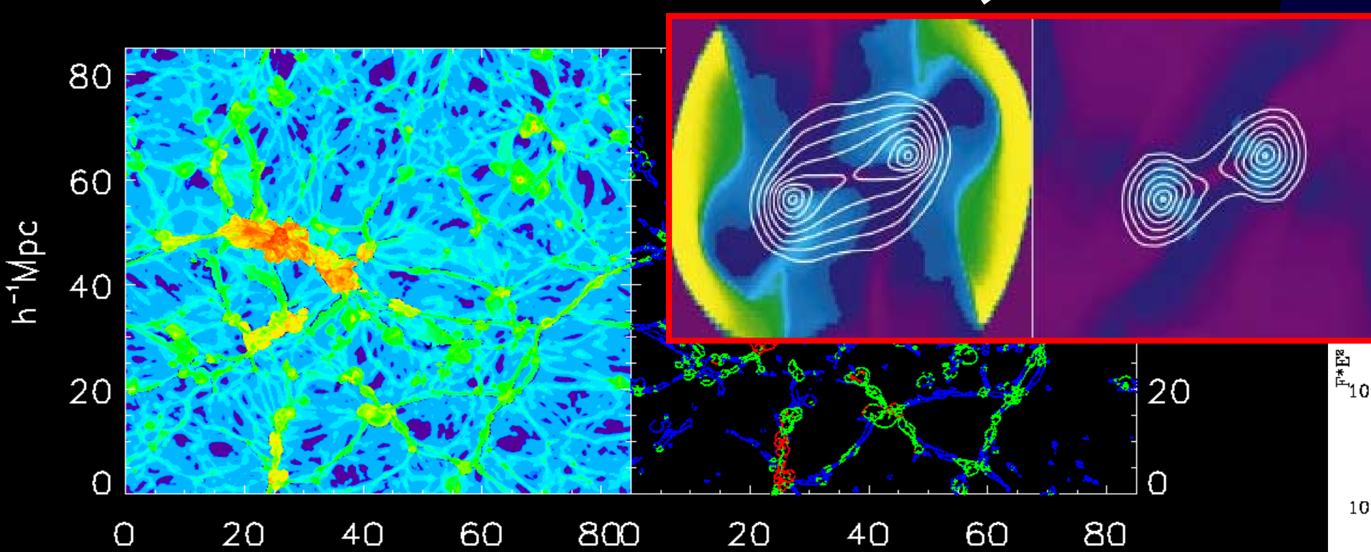
Inducing turbulence tic field

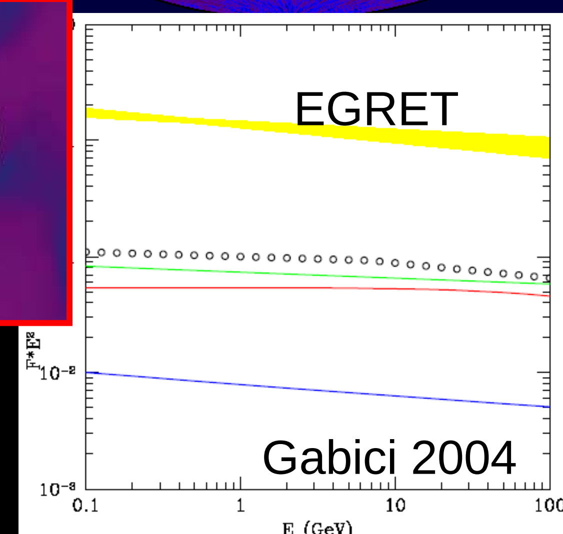
Observationally,

radio relics, background g ays









- Possible future detection from non-thermal components in filaments

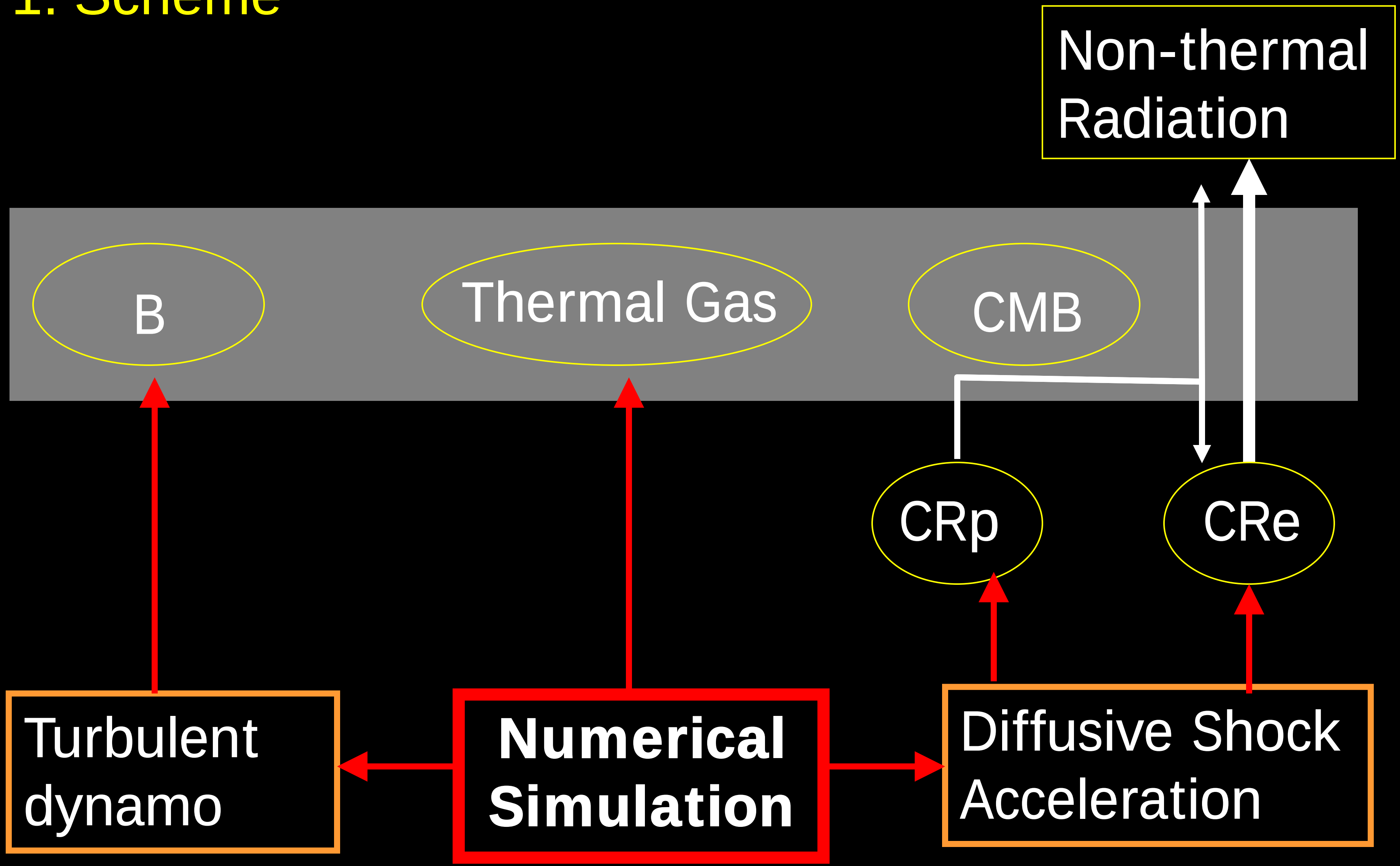
IG Magnetic Fields (<0.1uG)

CRs (P_{CR} / P_{th} >~ 10%)

We need to study the Radiation from CRs in IGM, which are injected by cosmological shocks.

Model & Calculation

1. Scheme



2. Assumptions:

- Cosmological shocks are the only source of CRs, other sources like AGN, SNR, GRB, dark matter are ignored.
- CR energy spectrum are determined from the temperature and density. The energy spectra are calculated from shocks with the same temperature and density.

Over estimate primary electrons;

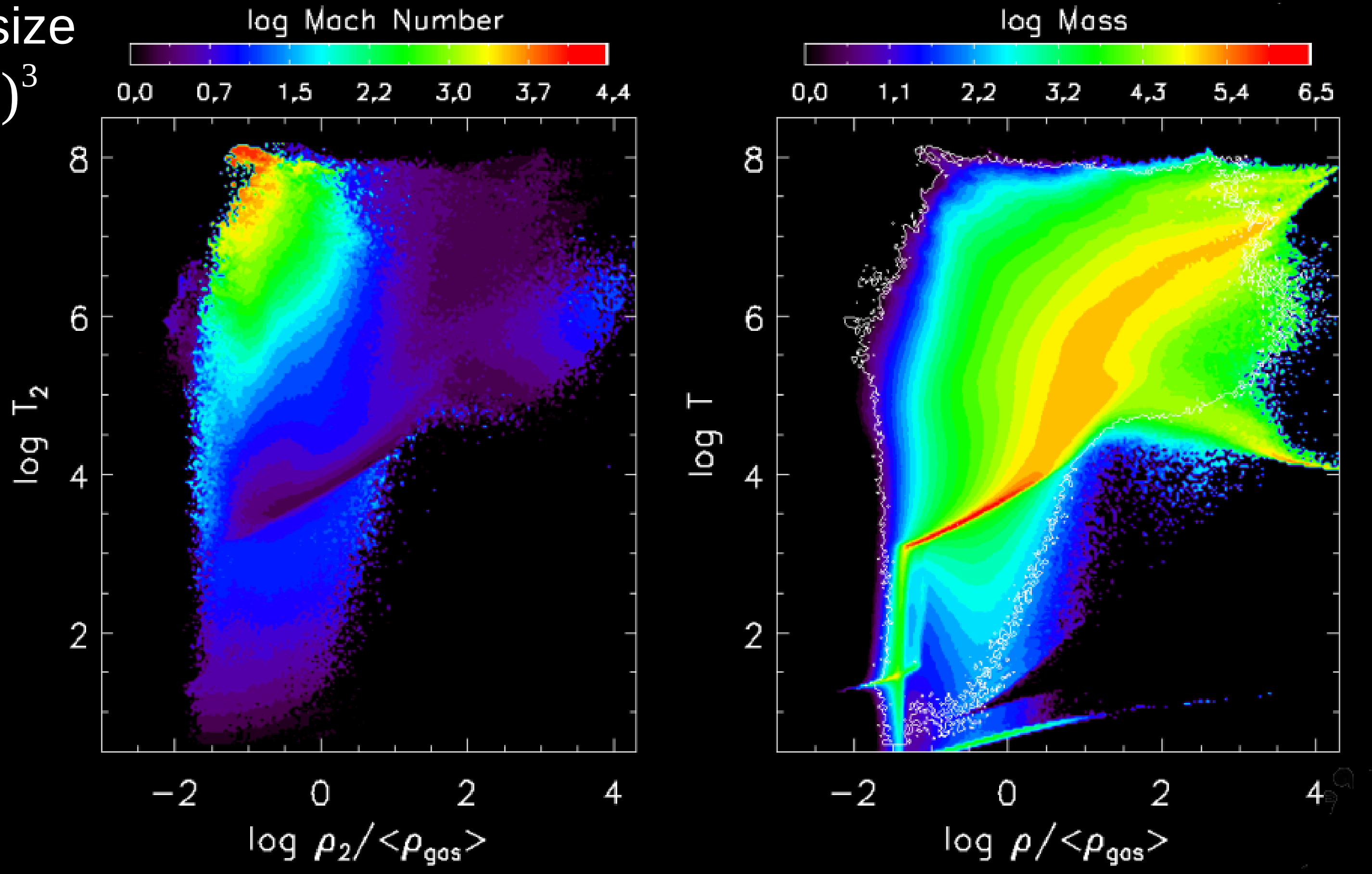
Underestimate CRp and secondary CRe due to CR accumulation;

- **Simulation**
  - Hydrodynamic simulation
  - ΛCDM Cosmology

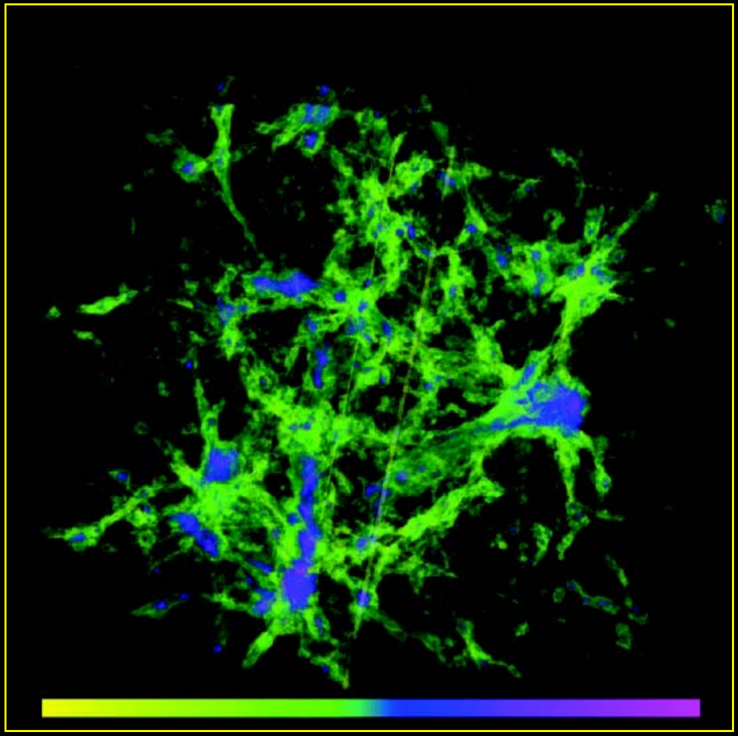
    $\Omega_b = 0.048,\ \Omega_m = 0.31,\ \Omega_\Lambda = 0.69,\ h \equiv H_0/(100\ \mathrm{km\ s^{-1}Mpc^{-1}}) = 0.7,\ \sigma_8 = 0.89$
  - Comoving size

    $(85\ h^{-1}\mathrm{Mpc})^3$
  - Grids

    1024^3



- Magnetic field
  - Methods of detection:
    - Faraday Rotation;
    - Radio & HXR surface brightness;
    - Zeeman splitting;
    - polarization of star light
  - Possible origin:
    - Jets from AGN, stellar winds,
    - Merger and turbulence
  - Our model: turbulence dynamo *(Ryu et al. 2008)*



- CR energy spectra

Primary CRs

Spectrum: test-particle

$$\alpha = \frac{r+2}{r-1}, \quad r = \frac{4M^2}{M^2+3}$$

$$p_{inj} = 5\sqrt{kT_2 / m_p c^2}$$

$$p_{\max} : \tau_{acc} = \tau_{cool}$$

Normalization:

$$\frac{F_{CR}}{F_{th}} = \frac{\eta F_{ki}}{\delta F_{ki}} \sim \varepsilon_{CR} = \frac{\eta}{\delta} \varepsilon_{th}$$

$$\xi_e = 0.01$$

Secondary CRe

Experimental data;

Monte Carlo simulation

Production :

$$p + p \rightarrow \pi^0 \pi^\pm$$

$$p + \gamma_{CMB} \rightarrow \boxed{e^\pm}$$

$$p + \gamma_{CMB} \rightarrow \pi^0 \pi^\pm$$

$$\pi^0 \rightarrow 2\gamma$$

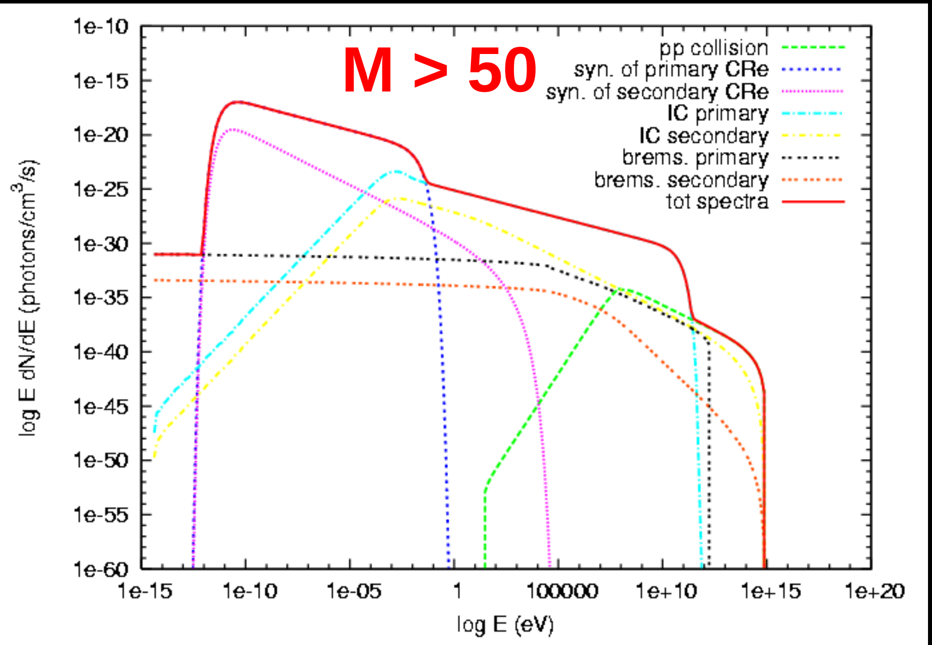
$$\pi^\pm \rightarrow \nu \bar{\nu} \mu^\pm \rightarrow \nu \nu \nu_e \bar{\nu}_e \boxed{e^\pm}$$

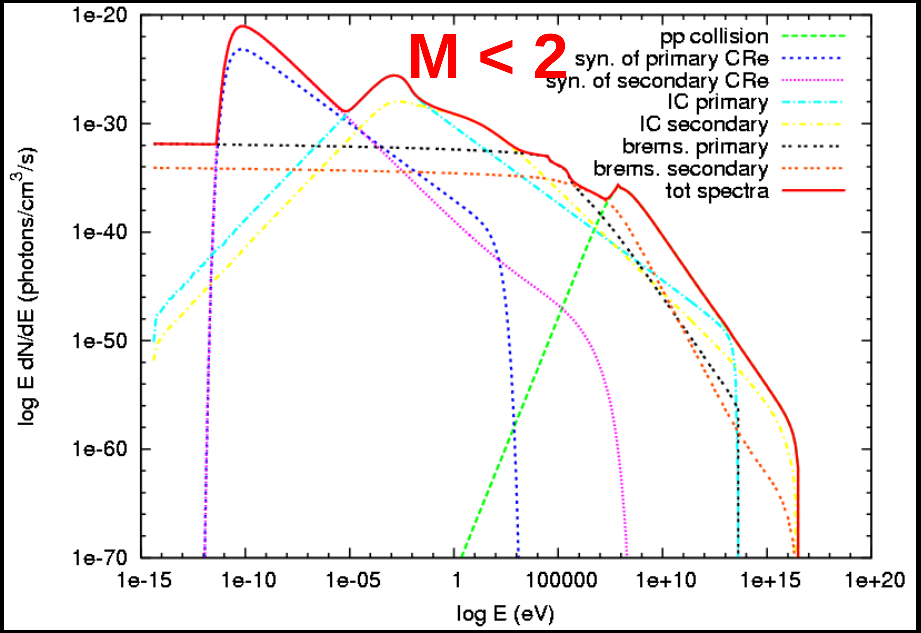
Distribution :

$$\frac{\partial}{\partial E_e} \left(\dot{E}_e f_e(E_e) \right) = q_e \left(E_e \right)$$

Preliminary Results

- Typical spectra of shocks





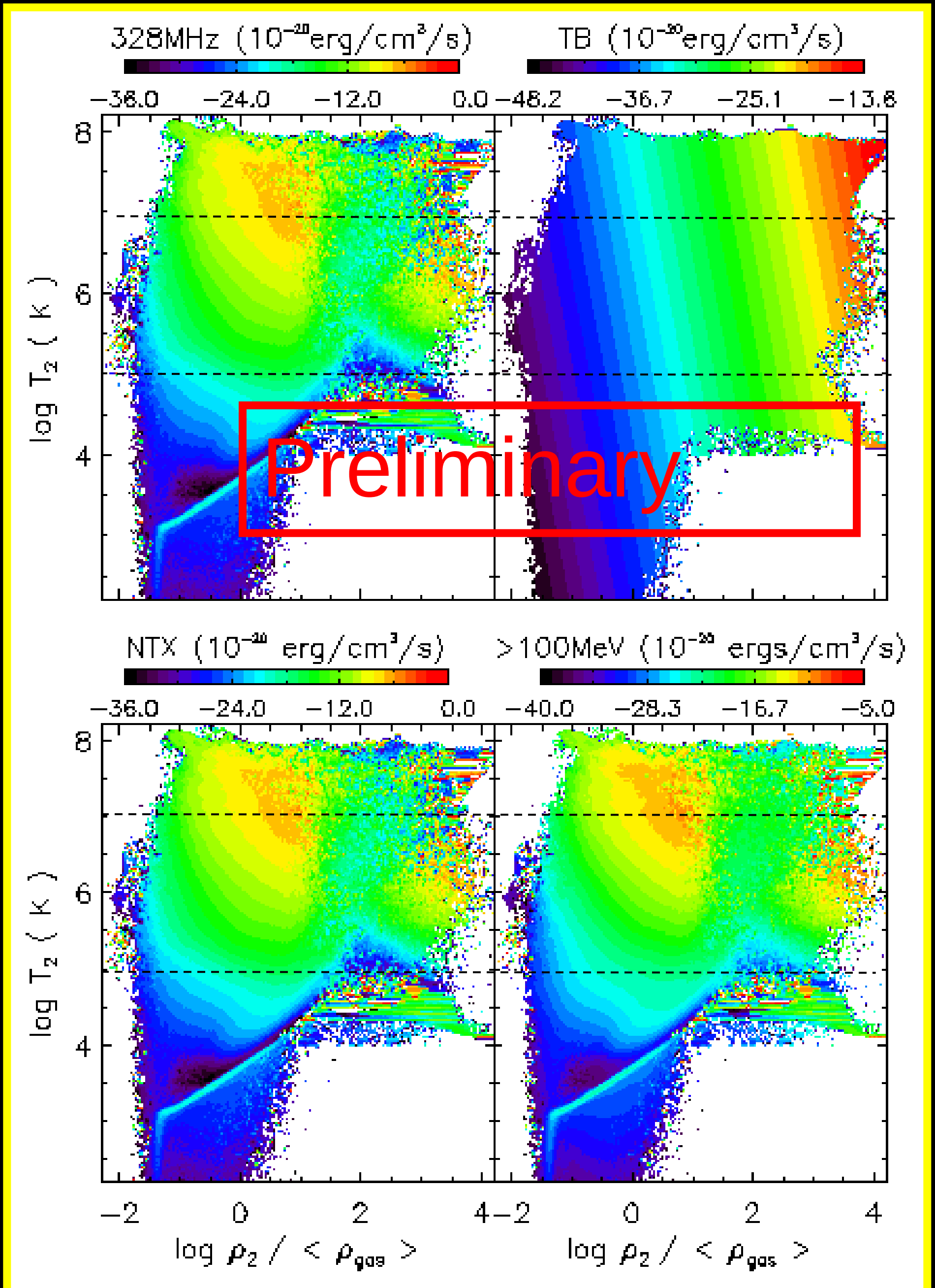
1. **At strong shocks, the radiation are dominated by the primary electrons.**

   At weak shocks, the spectra are so steep that several radiative process have the chance to dominate at some band

2. **Secondary electrons are comparable to primary electrons only in weak shocks.**

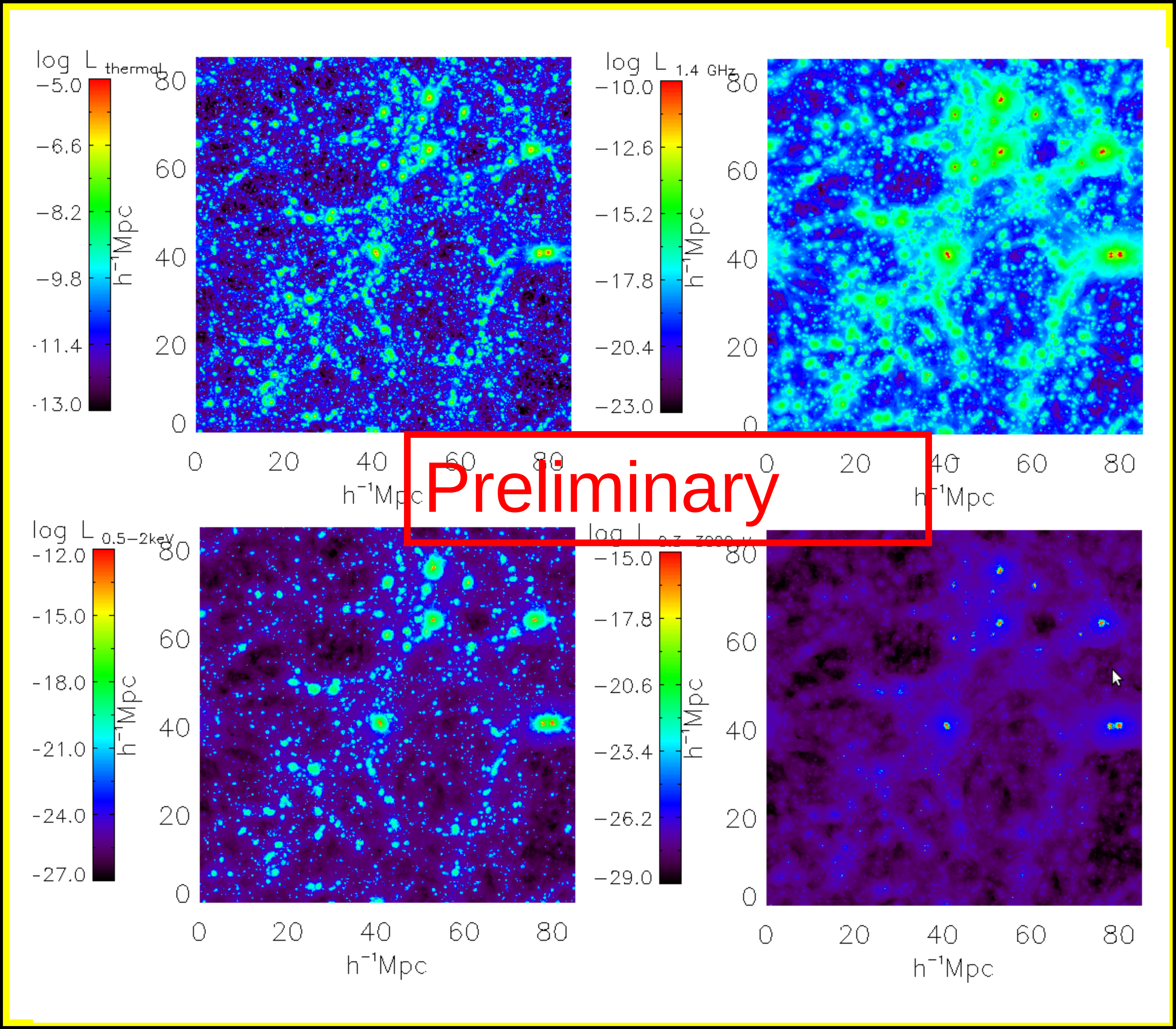
We use the averaged spectra as the emissivity of IGM

- Contour of emissivity



Projected Image

Non-thermal emission is more extensive.



Discussion

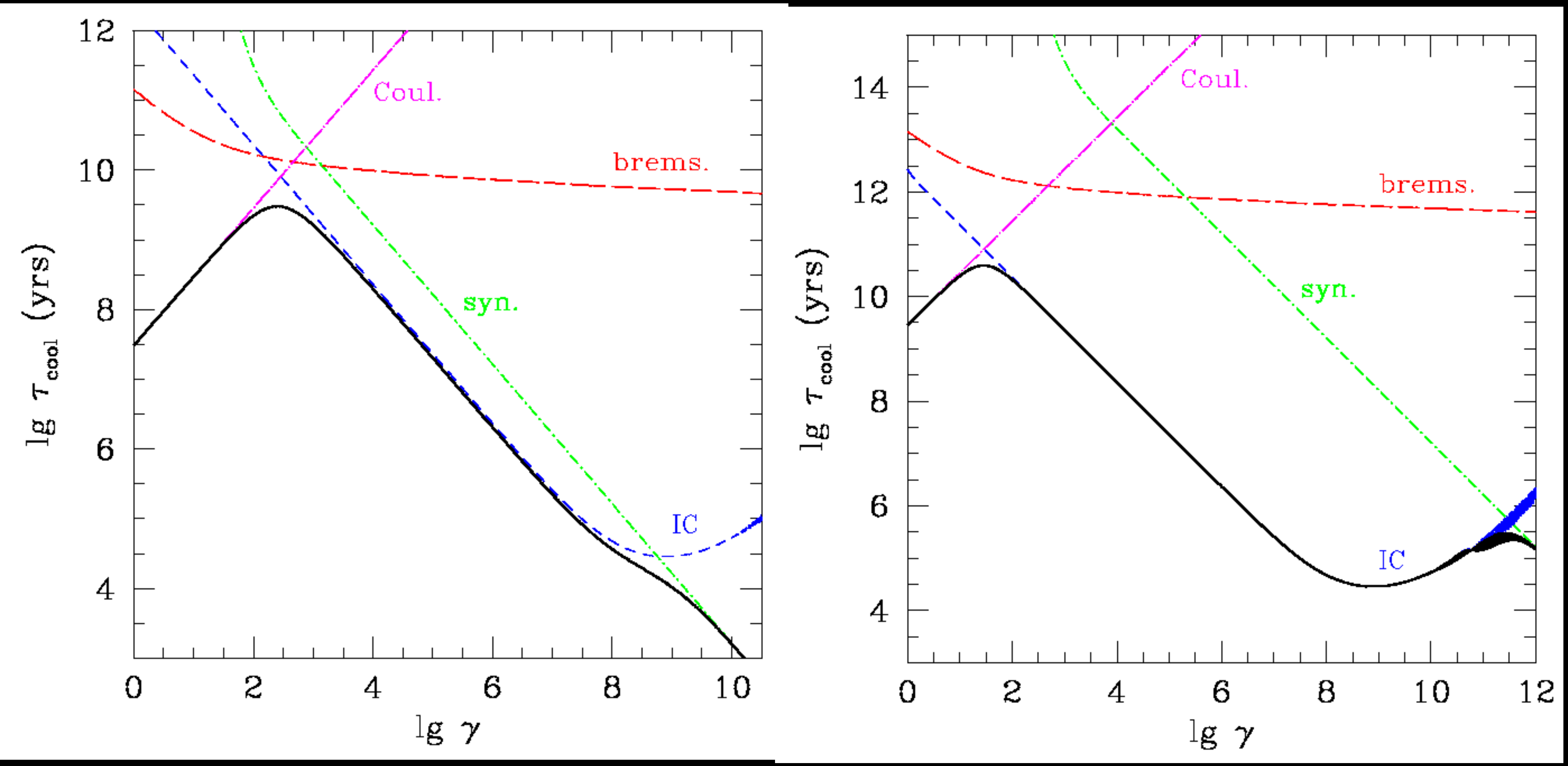
- Overestimate the primary electrons and underestimate the secondary electrons
- Purely theoretical results

The radiative processes are the same to those in clusters where gamma-rays is theoretically estimated to be detectable by present observatories, however, in some range we still cannot.

Summary

- We calculate the multi-frequency non-thermal radiation from CRs in the filaments;
- Primary CR electrons dominate the spectra;
- Radiation from CRs are more extensive than thermal radiation.

- CRe cooling



Coul.
brems.
syn.
IC
lg τ_{cool} (yrs)
lg γ
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