The contribution of Galaxy Clusters to Diffuse Gamma-rays and Neutrinos

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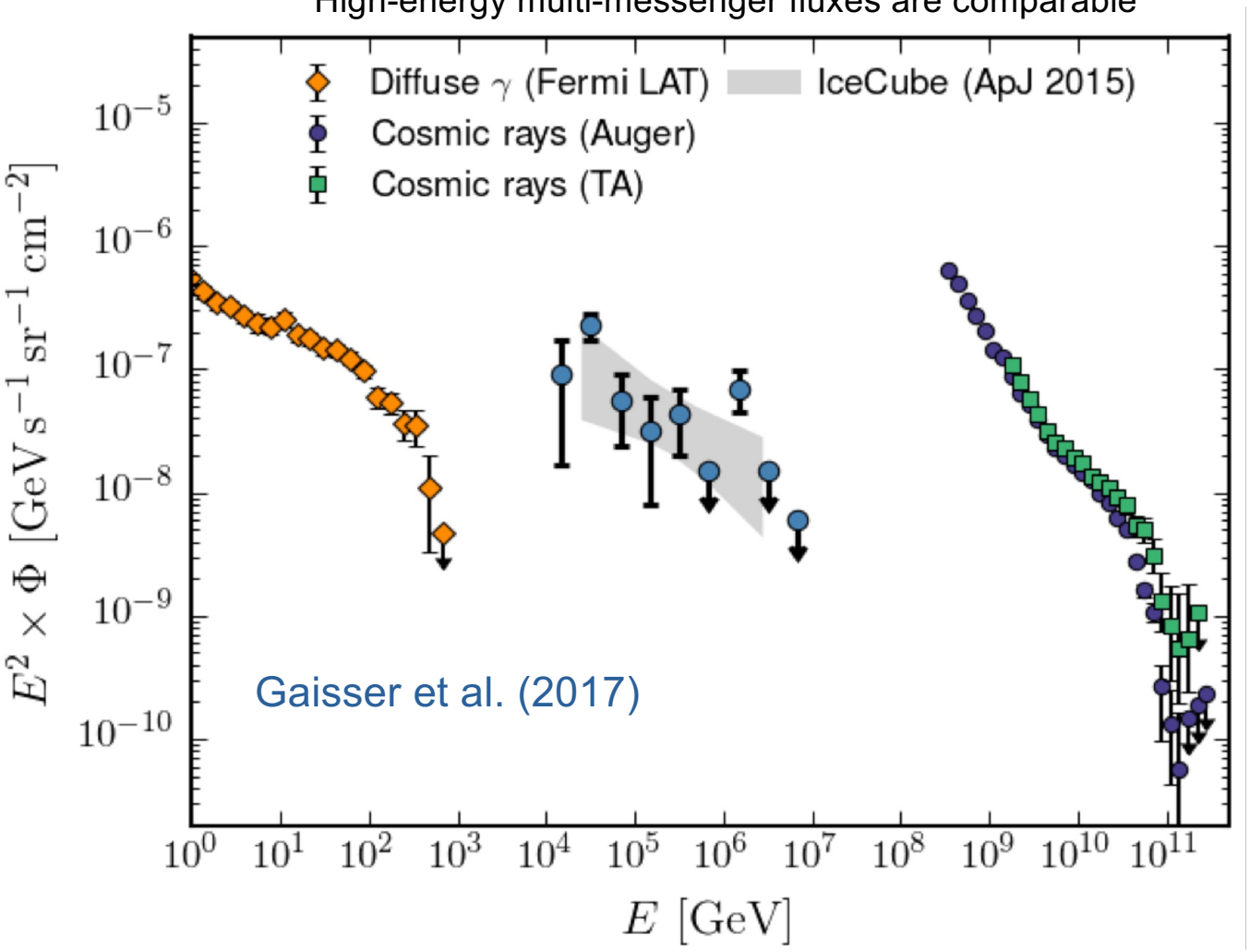
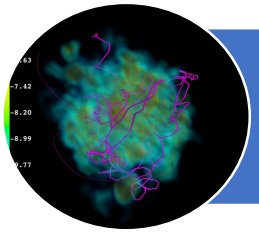
Motivation

High-energy multi-messenger fluxes are comparable

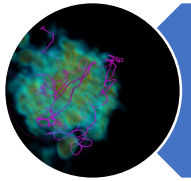


- Cosmic-rays (CRs), neutrinos and gamma rays have common origin?
- Single class of astrophysical sources can produce them?
- Galaxy Clusters are the most suitable candidates for diffuse multi-messengers: size ~ 1 Mpc, B ~ 10^{-6} G, n ~ 10^{-2} cm^{-3} and T ~ 10^{8} K

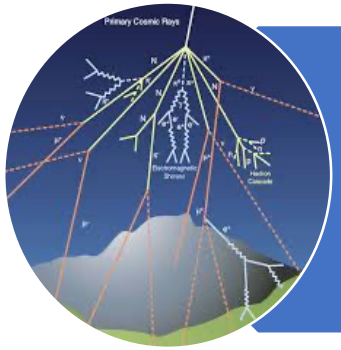
Outline



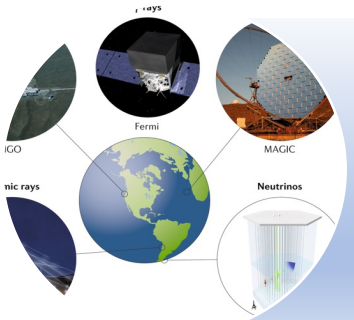
Cosmic-rays and clusters of galaxies



Propagation and interactions of cosmic rays:
MHD and Monte-Carlo simulations

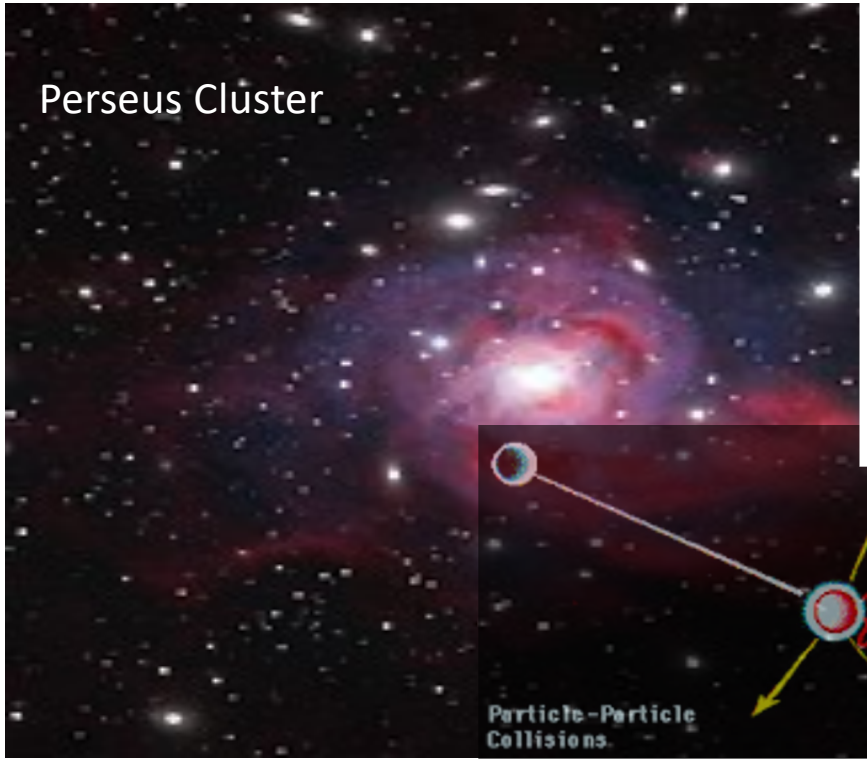


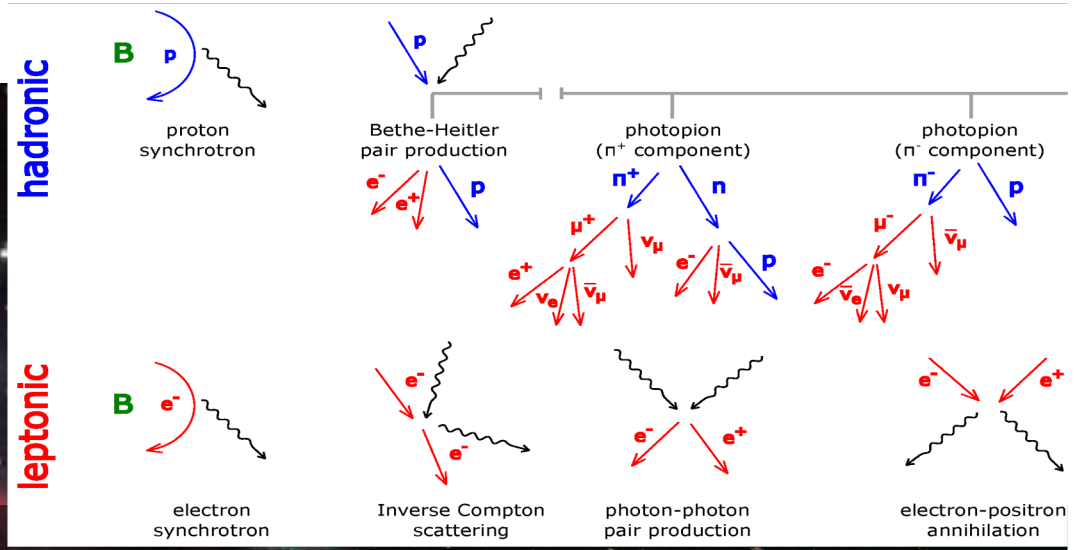
Linking complementary high-energy astrophysical messengers:
Cosmic rays, Neutrino, and Gamma rays

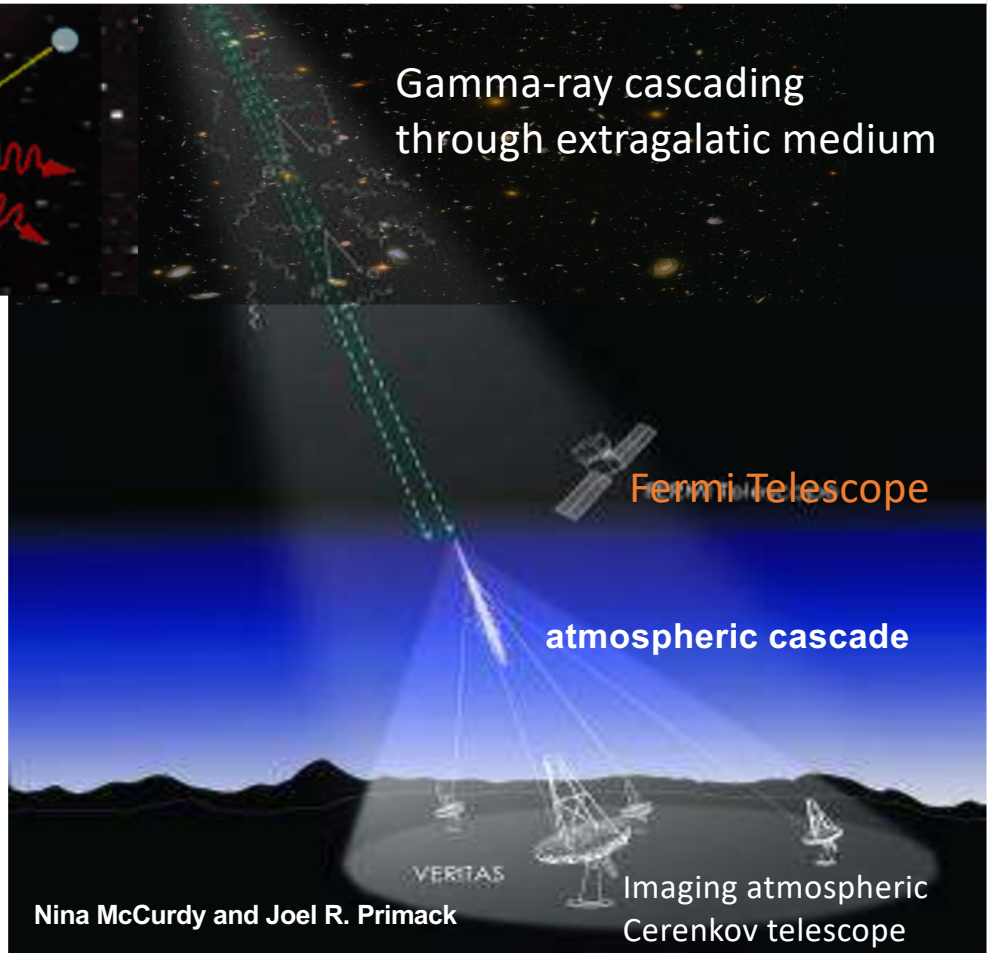


Common Multi-messenger Sources

Schematic Diagram

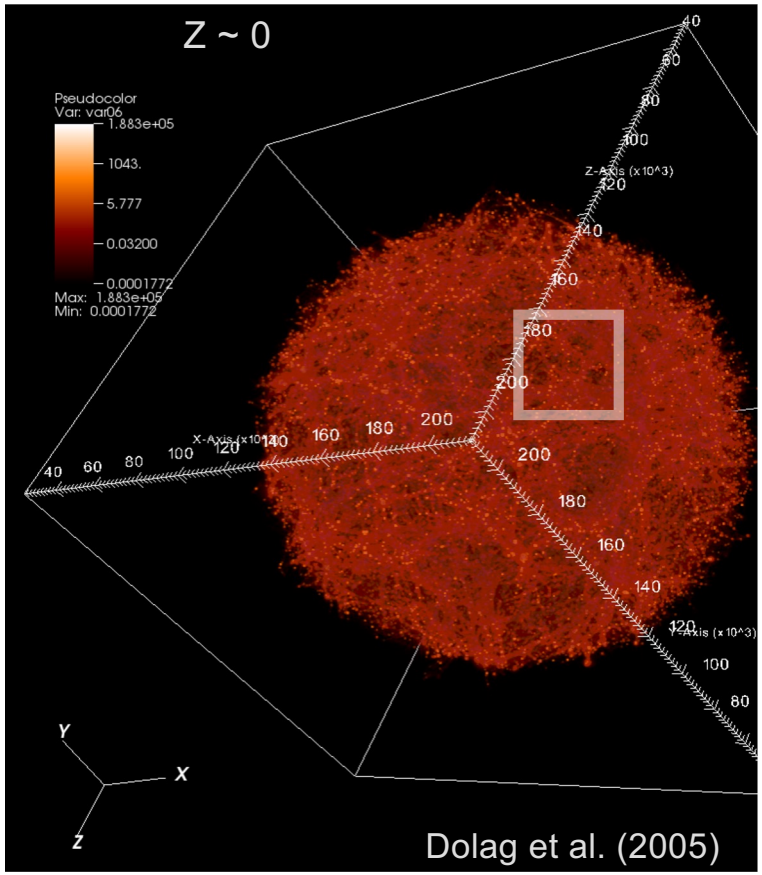


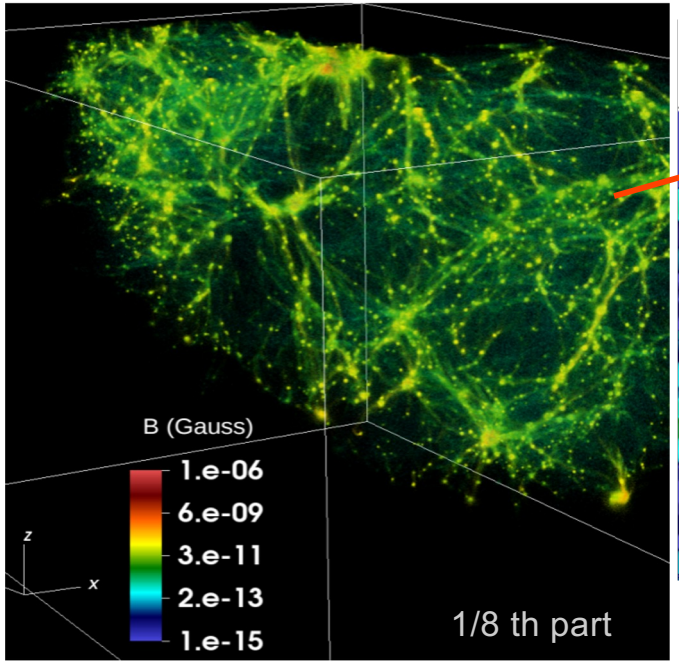


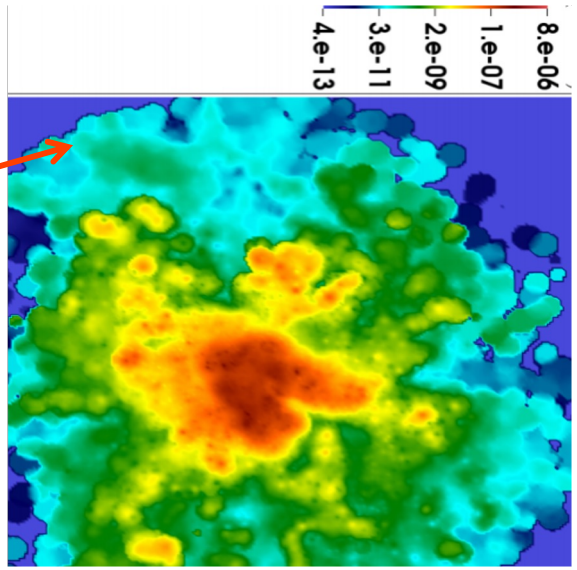


High-energy multi messengers
Emission and Observations

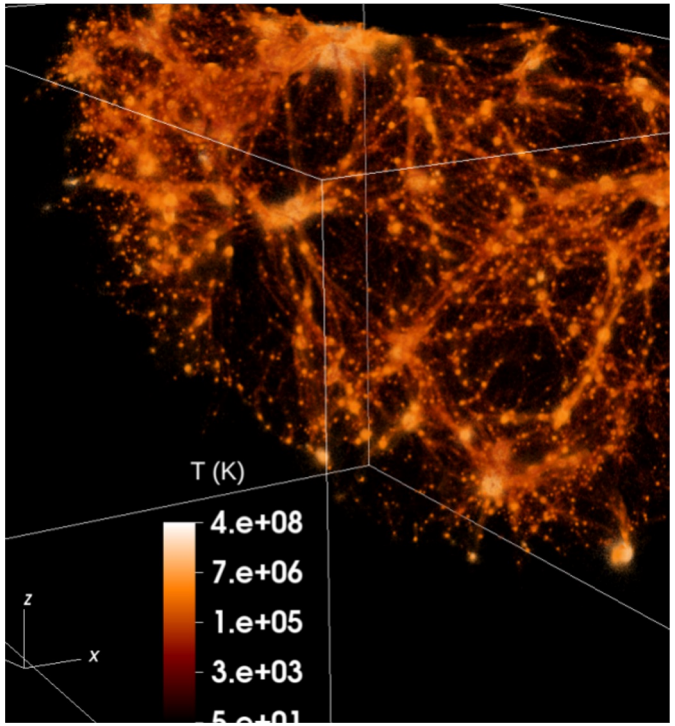
Cosmological 3D-MHD simulation

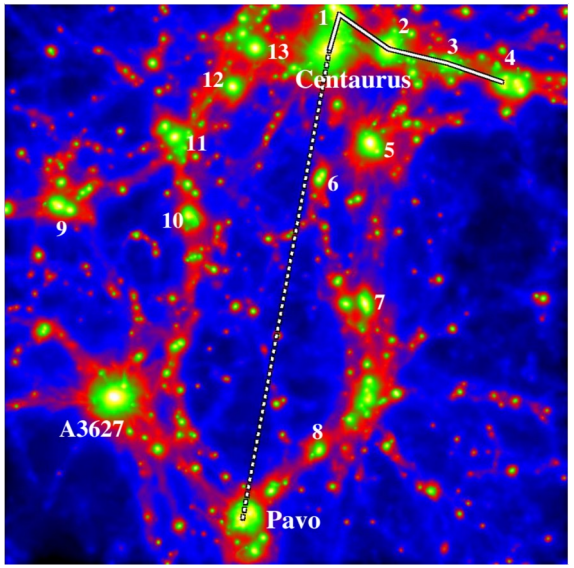






$M \sim 10^{14.5} M_{sun}$





SPH GADGET simulations
(Springel 2005)
Large-scale structure, filaments, and clusters, $z < 5.0$
seed magnetic field ~ 10^{-12} [G]
Maximum spatial resolution ~ 10 kpc

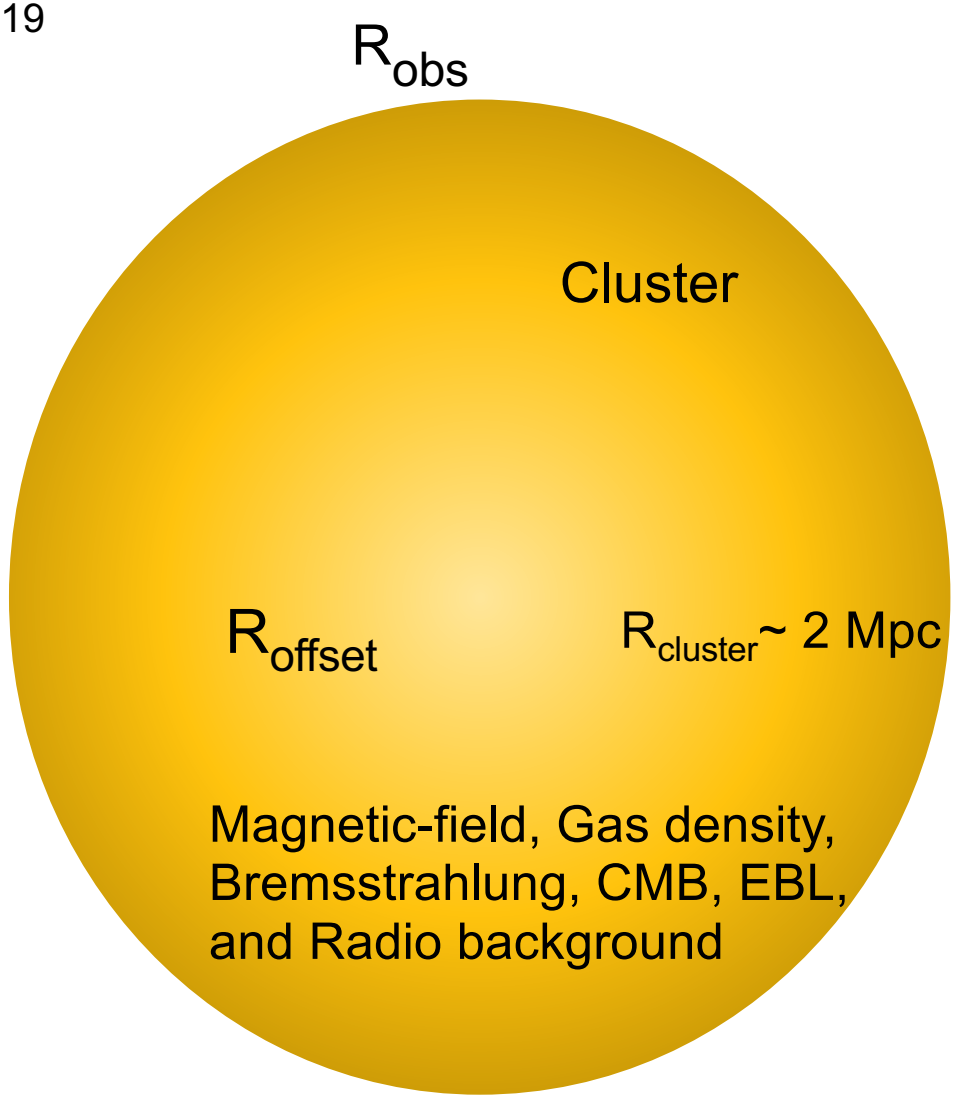
CR Propagation Simulation

Mass range: $10^{12} < M/M_{\odot} < 10^{15.5}$

Injected CR (proton) energy range:
Gamma-rays: $10^{11} < E/eV < 10^{19}$
Neutrinos: $10^{14} < E/eV < 10^{19}$

Redshift = $z < 5.0$

R_{offset}= 300 kpc, 1 Mpc

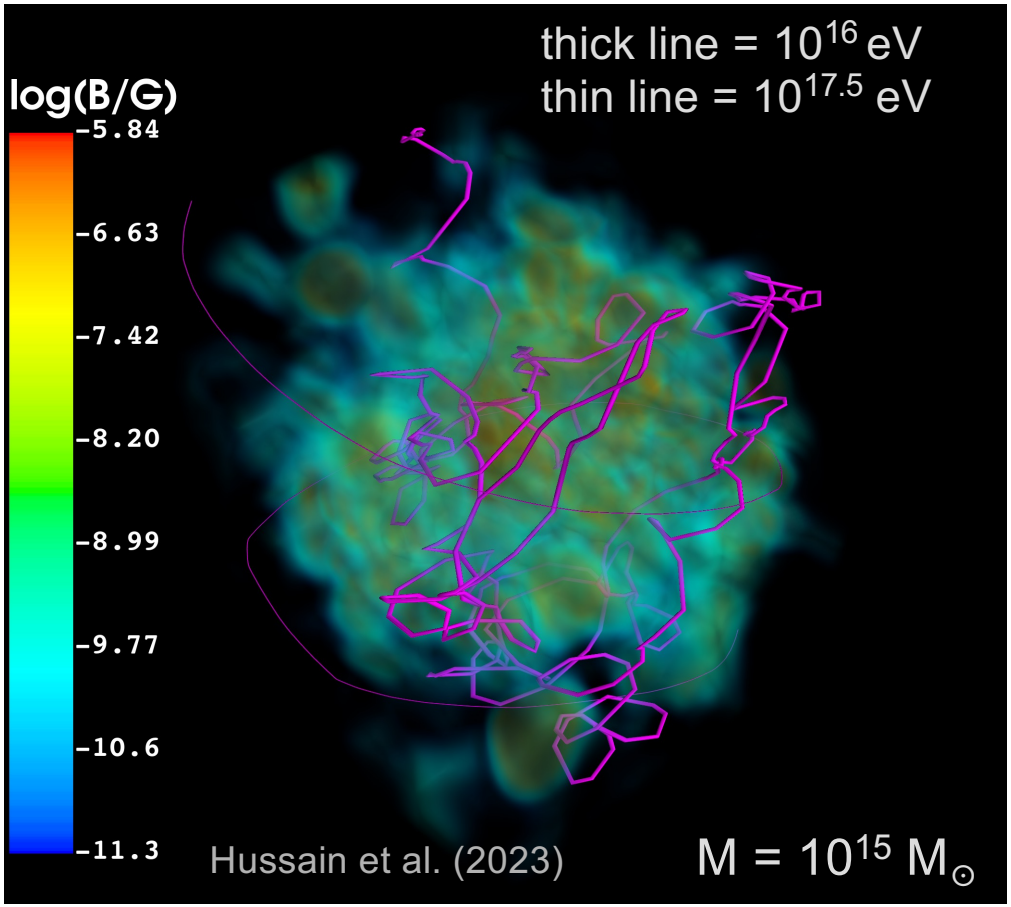


CR trajectories inside a Cluster

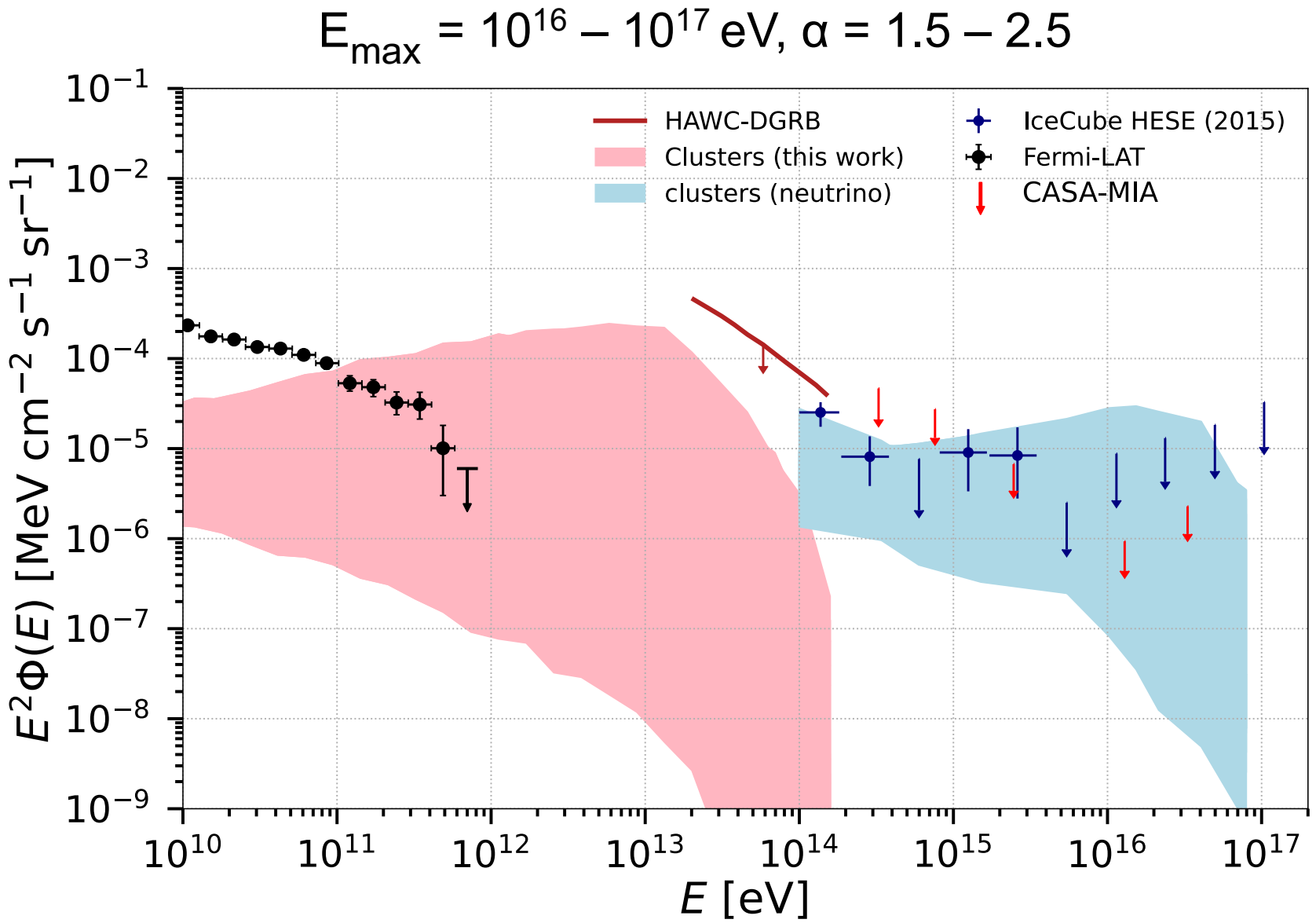
For $E = 10^{17}$ eV, $B = 10^{-6}$ G,
Larmor Radius ~ $1.08(E/10^{15}\ \text{eV}) / Z\ (B/\mu\text{G})$ pc ~ 100 pc

Low energy ($<10^{17}$ eV) CRs: Diffusive
High Energy ($> 10^{17}$ eV) CRs: Semi-diffusive or Ballistic

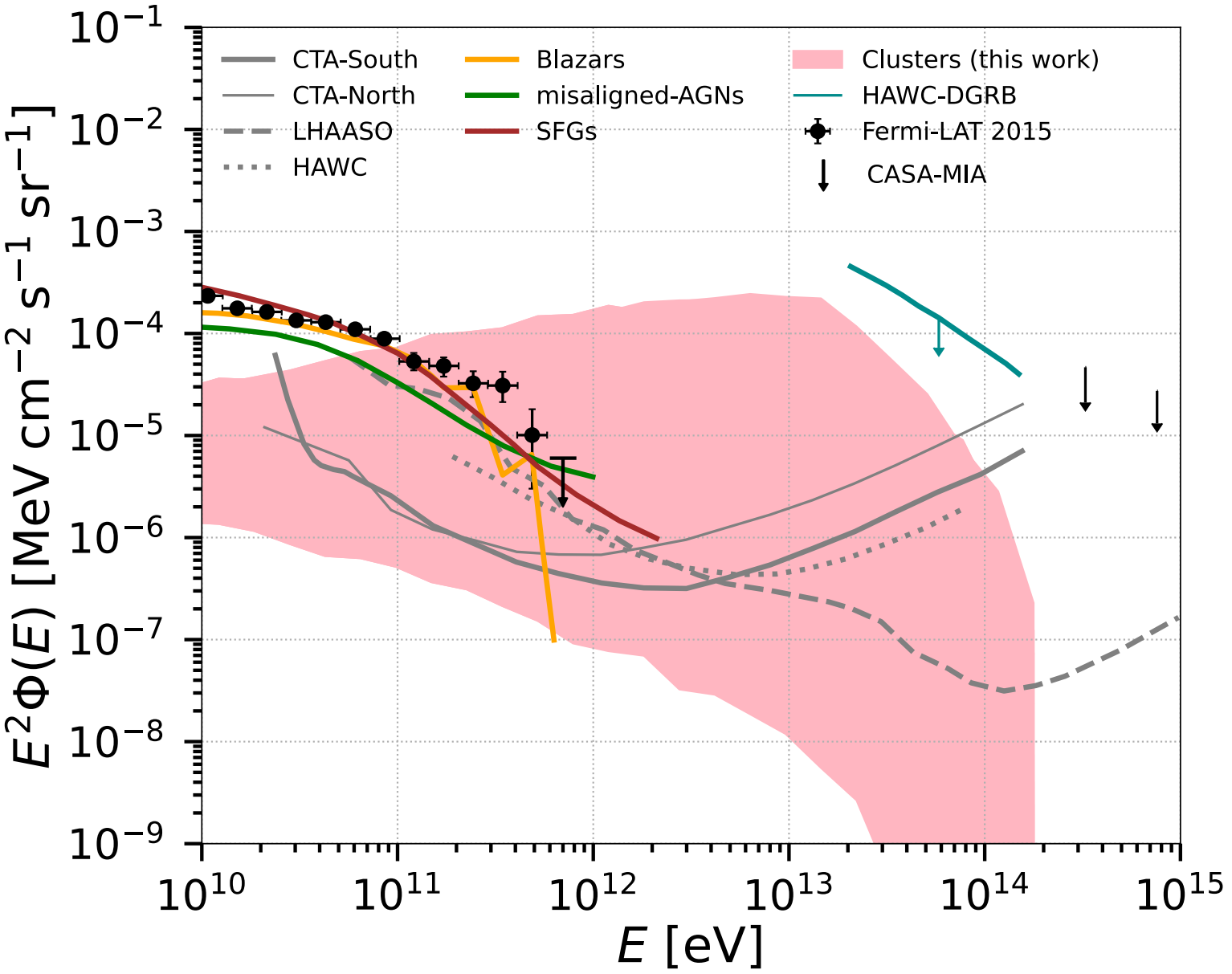
Combined cosmological MHD simulations with Monte Carlo simulations



Gamma-rays and neutrinos from clusters of galaxies



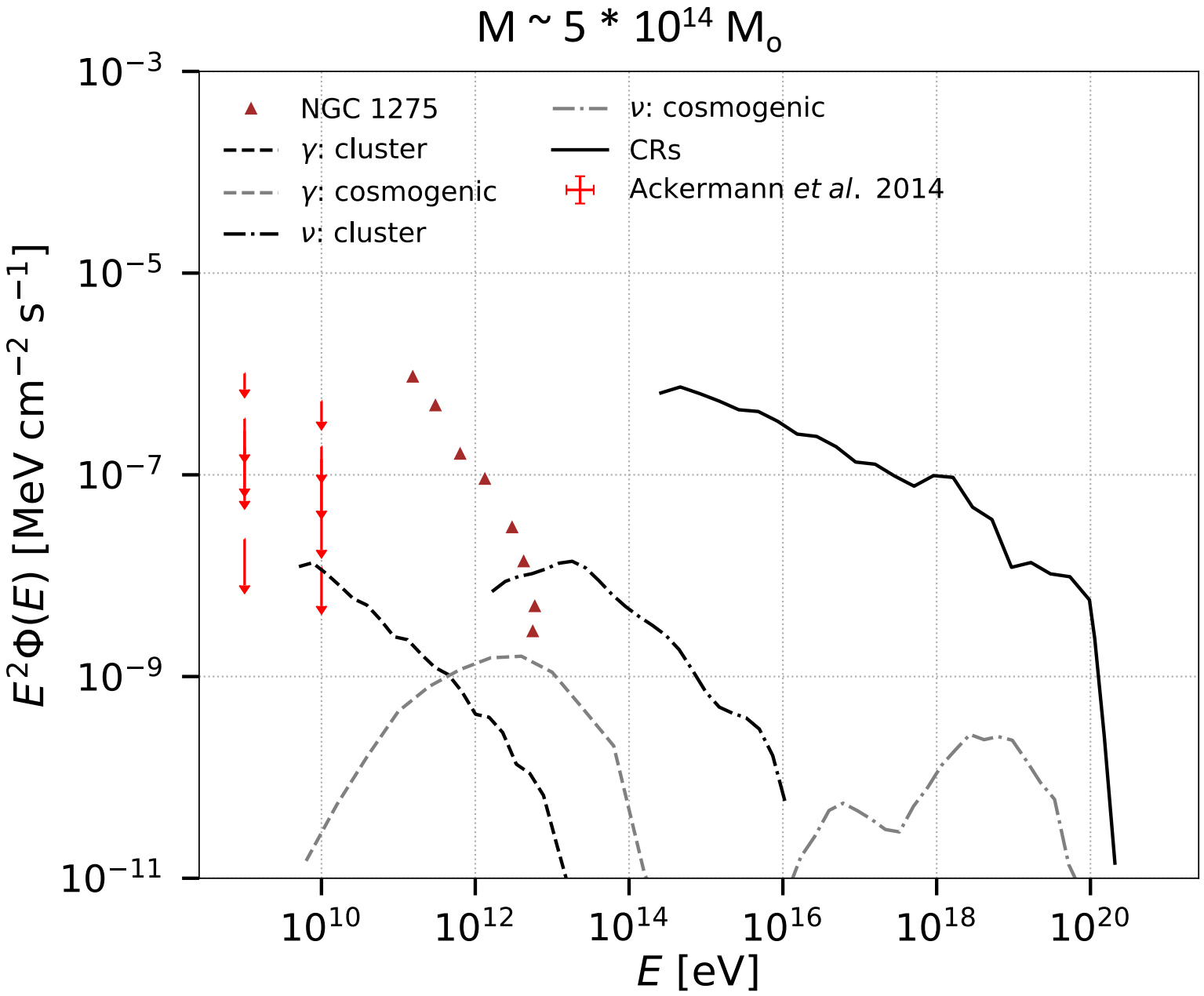
Different Source Contributions and Observations



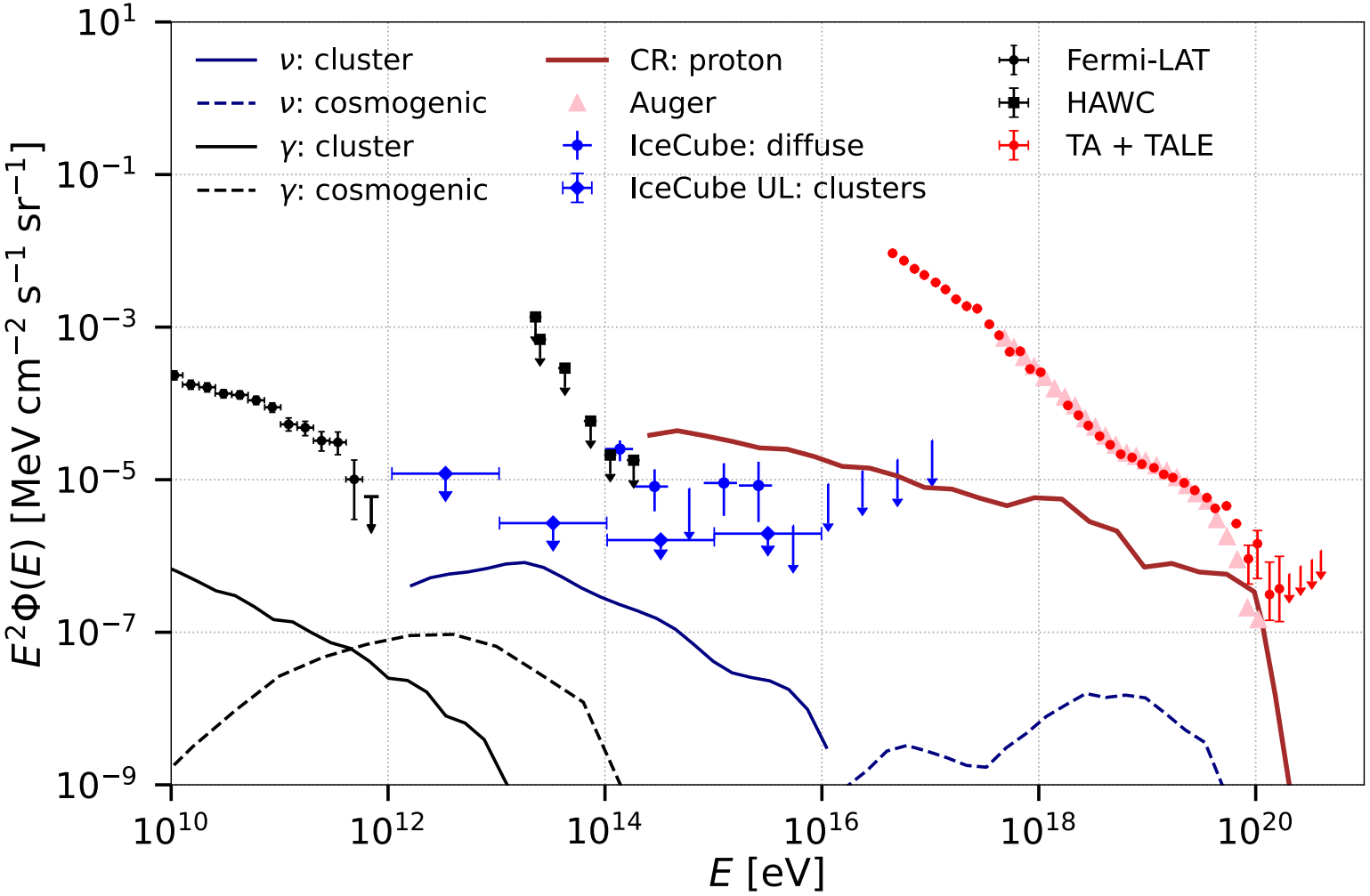
Multi-messenger from Perseus-like Cluster

NGC 1275:
SALON 1996 – 2012

Fermi-LAT:
Cluster gamma-ray upper limit



Multi-messenger from Perseus-like Sources



Perseus-like clusters can contribute to UHECRs to a fairly large fraction

Summary and Conclusions

- Contribution of clusters of galaxies to the observed diffuse neutrinos and gamma-rays
- Most important channels to produce high-energy photons and neutrino are: inelastic proton-proton collisions and CRs interactions with the CMB

Neutrino flux from clusters is comparable with observations of the IceCube, especially between the energies 100 TeV and 10 PeV Hussain et al., MNRAS (2021)

Gamma-ray flux from clusters can contribute up to 100% to the diffuse gamma-rays above 100 GeV observed by the Fermi-LAT Hussain et al., Nat. Comm. (2023)

Perseus-like sources can contribute to a sizeable percentage to UHECRS

These results might be confirmed by LHAASO, upcoming CTA and IceCube-Gen2, GRAND…

Summary and Conclusions

Diffuse neutrino and gamma-ray background

Prominent sources: AGNs and Blazars

Contribution from local clusters of galaxies

Perseus cluster: Source of UHECRs and gamma rays

Prominent sources: NGC 1275 radio galaxy and IC 310

Gamma-ray study from clusters can provide the constraints on decaying dark matter

Common Multi-messenger Sources

Thanks