Multi –messenger Emission from Galaxy Clusters hosting AGN

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Motivation

Why Clusters
Large size (~ 1 Mpc),
Strong magnetic field (~ 1 uG),
High temperature (~ 10^8 K)

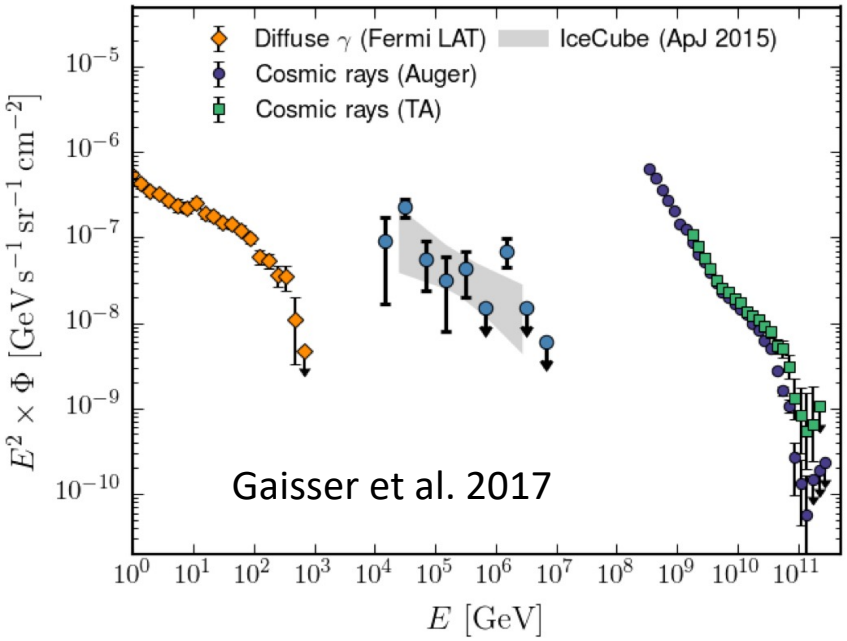
Focus: Cluster hosting AGNs
Perseus cluster NGC 1275

Experiments: IceCube-Gen2, KM3Net, CTA, LHAASO, TA

Developing a comprehensive numerical framework:
MHD + Monte-Carlo Simulations

- ❖ Exploring acceleration and emission mechanisms of cosmic messengers.
- ❖ Providing crucial space distribution constraints for future observatories.

Questions
Does the multi-messenger have common origin:
Produce by a single class of sources?
Origin of Diffuse Gamma-ray and Neutrino Backgrounds?



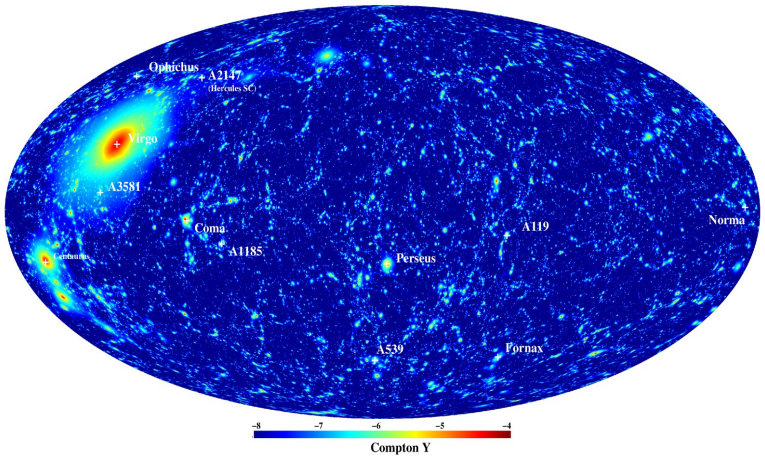
MHD Simulations

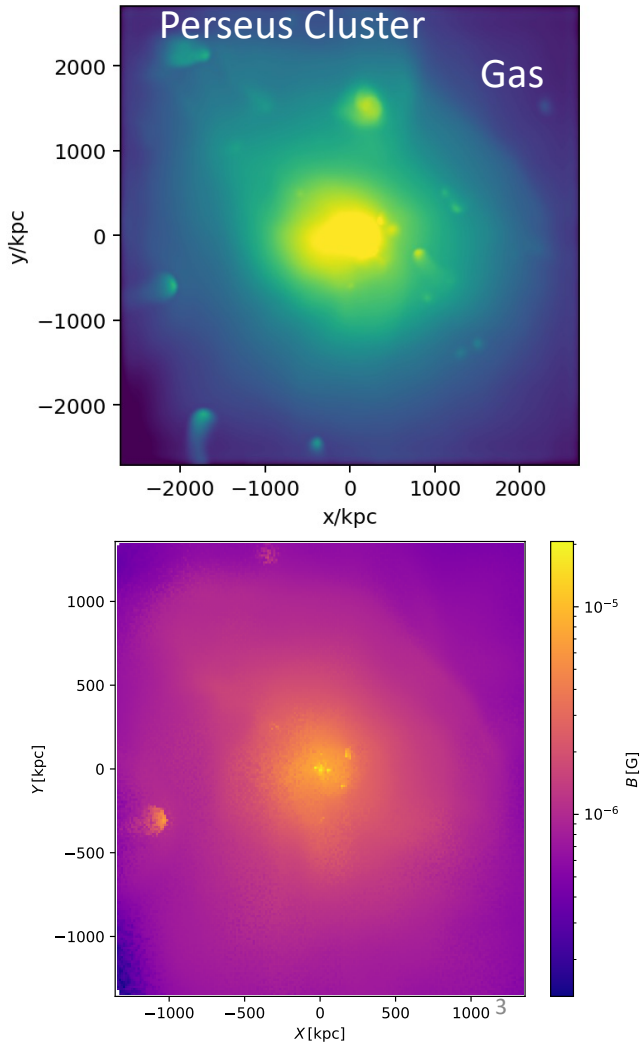
Simulation of the LOcal Web - SLOW

K. Dolag et al. MHD simulations

https://www.usm.uni-muenchen.de/~dolag/Simulations/

Clusters in MHD SLOW simulation are cross-identified with Planck survey





MHD + Monte Carlo simulations

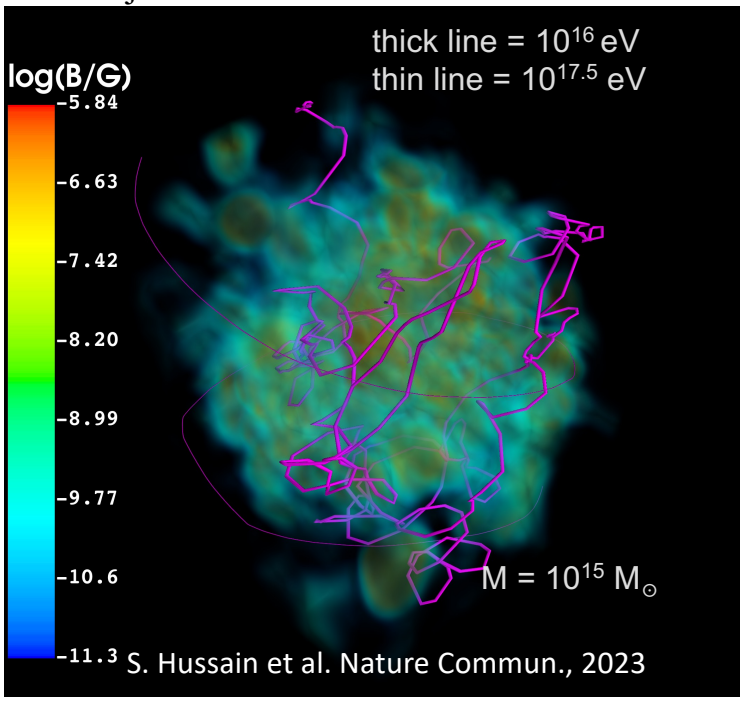
CR Properties in ICM
Injection spectra: spectral index, cutoff energy
Spatial distribution: CR injection follows the gas density in ICM
Composition: protons and heavy nuclei
Confinement & transport: magnetic field control diffusion, streaming, escape
Fraction of thermal energy → CR acceleration, regulates non-thermal emission

Background: Magnetic-field, Gas density, Bremsstrahlung radiation, CMB, EBL, and Radio background

Interactions: photohadronic, photonuclear, hadronuclear, and electromagnetic cascade

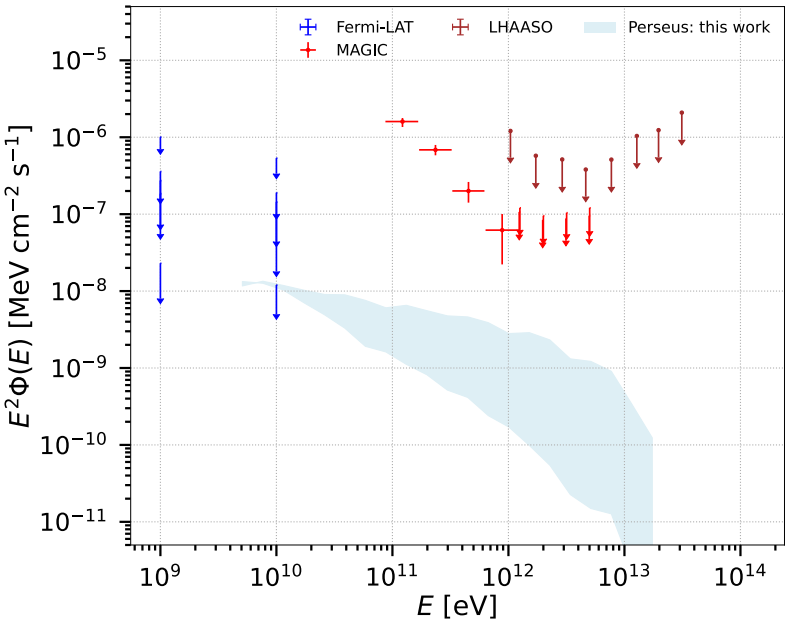
MHD simulations: Magneticum, SLOW & TNG-Cluster
Monte-Carlo code: CRPropa3

CR trajectories inside a Cluster



$E_{CR} < 10^{17}$ eV: Diffusive
$E_{CR} > 10^{17}$ eV: Semi-diffusive or Ballistic

Perseus cluster: gamma-ray picture

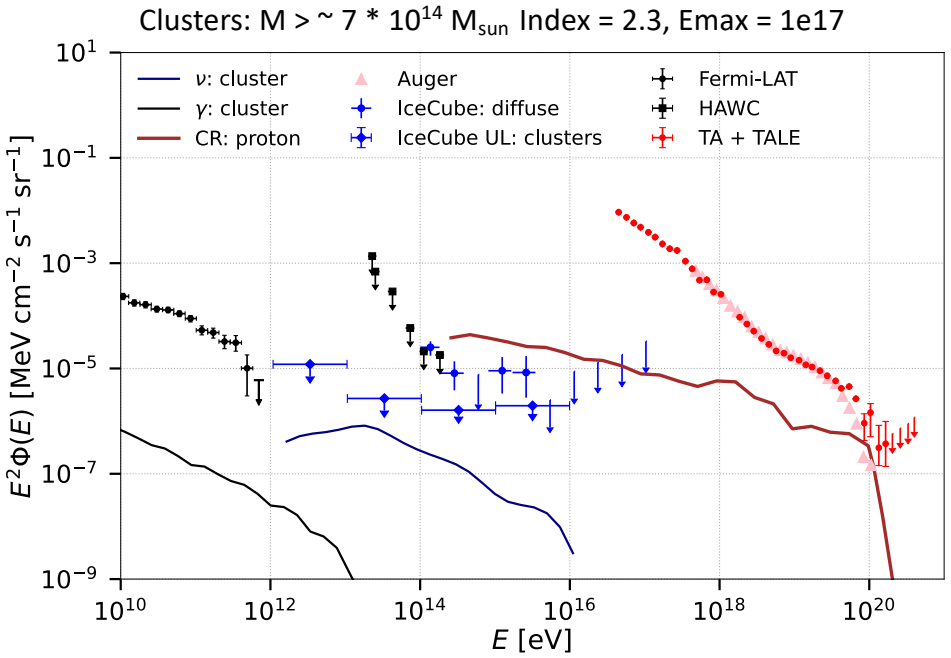


Parameters:
Spectral Index = 2.0 – 2.5
Emax = 1e16 - 1e17 eV
X_CR = E_CR / E_thermal ~= (1-2) %

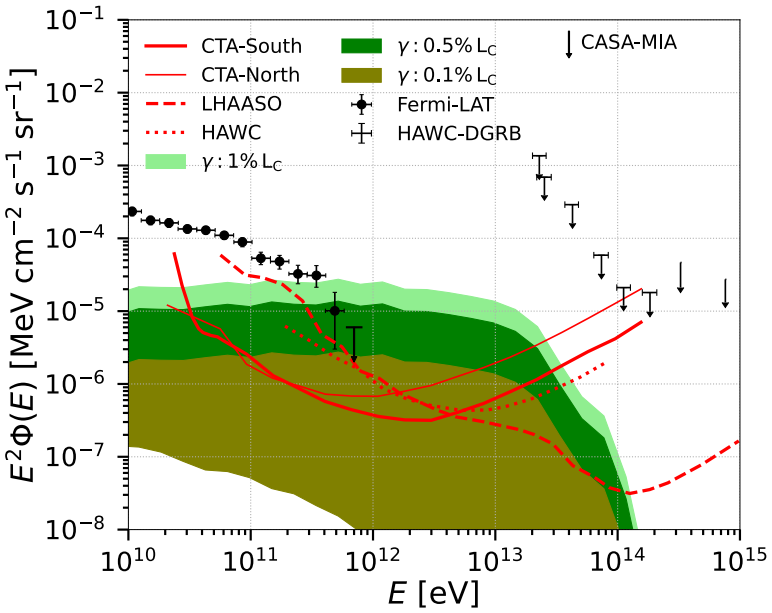
- Our flux is well below the upper limits provided by LHAASO.
- MAGIC observations of NGC1275 are significantly higher than our results.
- Comparable with Fermi-LAT upper limits for five massive clusters, top to bottom: A400, A3112, A1367, Coma, EXO0422.

Multi-messenger emission from Perseus-like sources within 75 Mpc

- Perseus-like clusters within 100 Mpc
- TA predicted the CR source in the direction of Perseus-Pisces Supercluster
- Our CR flux is below the TA and Auger observations
- Corresponding Neutrino flux is comparable with IceCube upper limits



Diffuse gamma-ray observations



Clusters:

- 1e13 < M / M_O < 5e15
- Redshift z > 5
- Spectral Index = 2.0 – 2.5
- Emax = 1e16 - 1e17 eV

Sensitivities of CTA and LHAASO are comparable with our results

Summary

The following aspects can impact our results:

- ❖ CR composition involving heavy elements like iron (Fe)
- ❖ the intergalactic magnetic field
- ❖ AGN feedback is not considered in the MHD simulations

AGN feedback: Regulates Gas Cooling, Shapes Gas & Drives Outflows and accelerate CRs through shocks and relativistic jets.

Near-term future observations by LHAASO, CTA, IceCube-Gen2, and KM3Net would be able to establish clusters as new class of high-energy multi-messenger sources.

- Thanks