Multi-Messenger and Multi-Wavelength emission from Galaxy Clusters hosting AGNs

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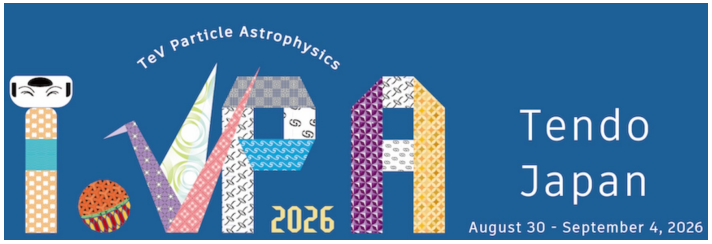
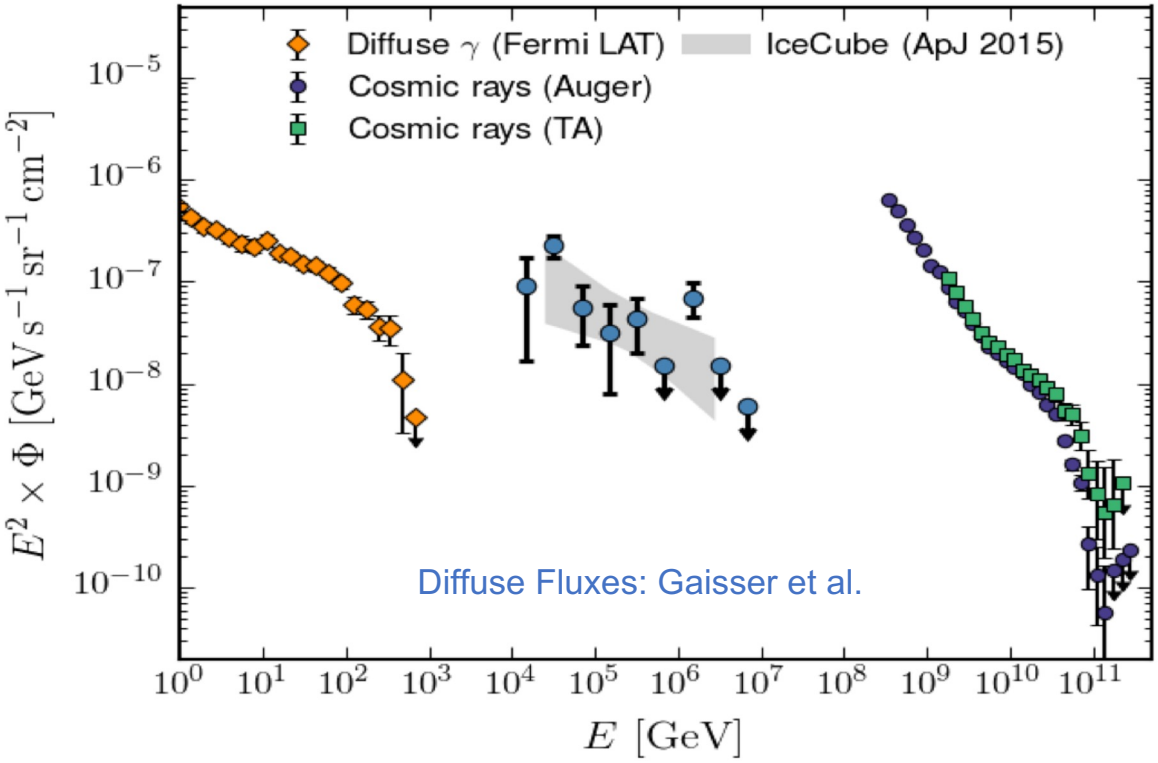


Motivation

High-energy diffuse fluxes are comparable



MAYBE

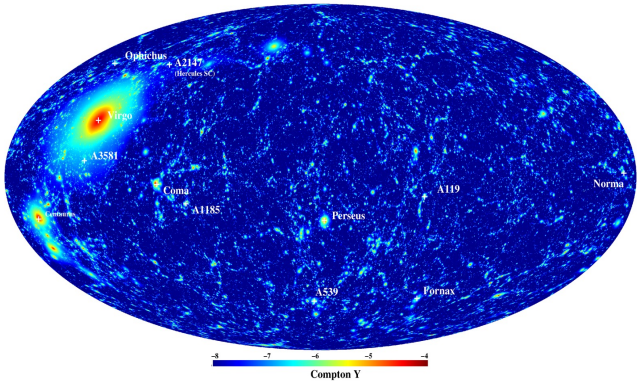
Galaxy Clusters hosting AGN are suitable candidates for diffuse multi-messenger:
size ~ 1 Mpc, B ~ 10^{-6} G,
n ~ 10^{-2} cm^{-3} & T ~ 10^{8} K

- ***CRs, neutrinos and gamma rays have common origin?***
- ***Single class of astrophysical sources can produce them?***

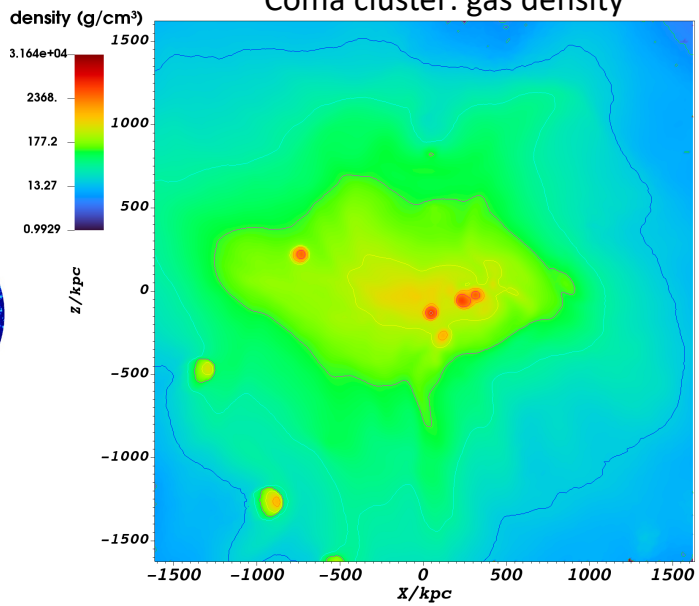
MHD Simulations of Galaxy Clusters hosting AGN

MHD simulation provides the background environment of galaxy clusters across redshift

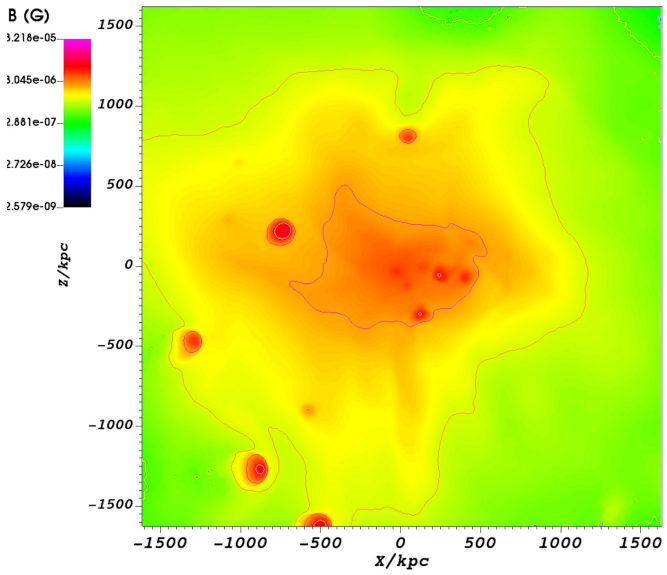
MHD SLOW simulation: cross identified local galaxy clusters within 500 Mpc
Dolag et al. 2023



Coma cluster: gas density



Coma cluster: BField



MHD + Monte Carlo simulations

SLOW Sim.: Magnetic-field, Gas density, Bremsstrahlung radiation
Background photo fields: CMB, EBL, and Radio background

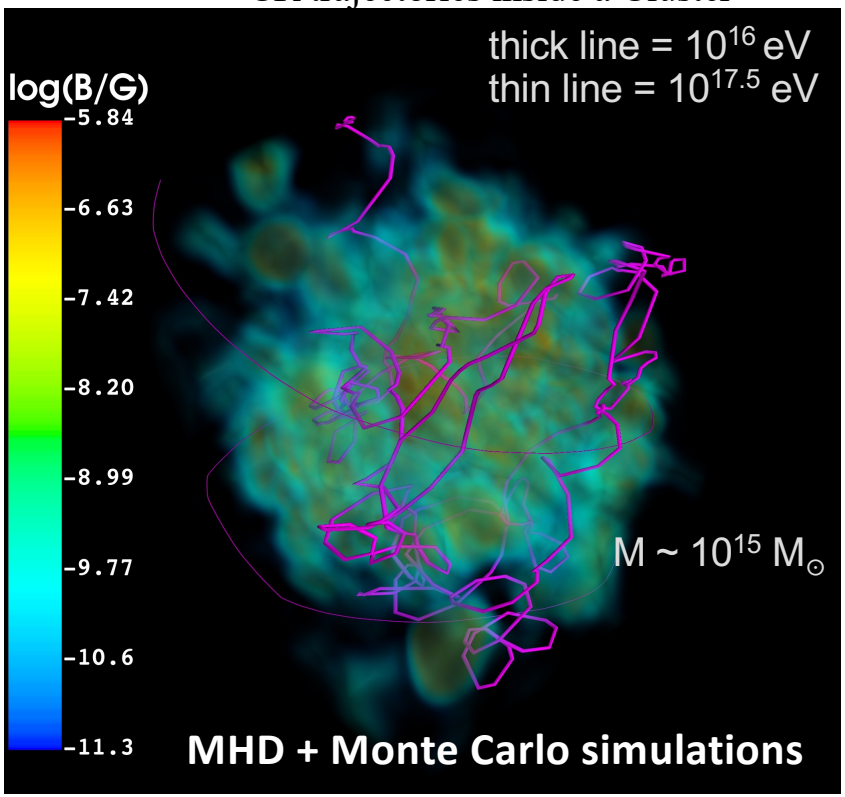
Monte-Carlo code: CRPropa3
Cosmic Ray Propagation
(Hadronic and leptonic)

Interactions: photohadronic, photonuclear, hadronuclear, and electromagnetic cascade

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

Computationally very expensive: Tackled with AI/ML

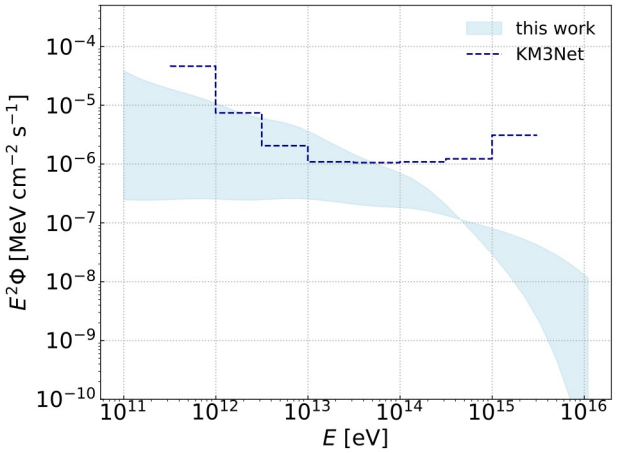
CR trajectories inside a Cluster

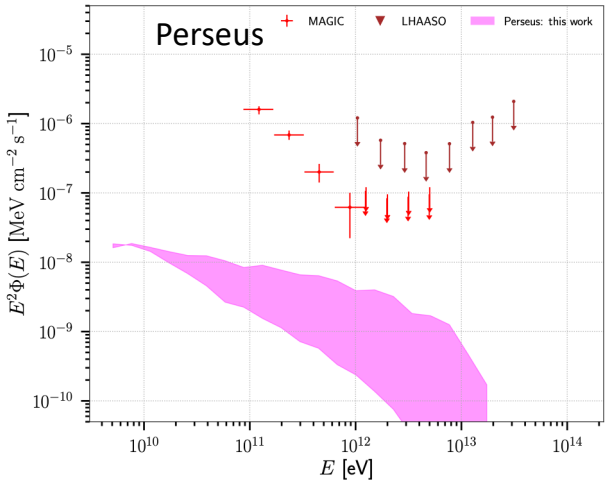


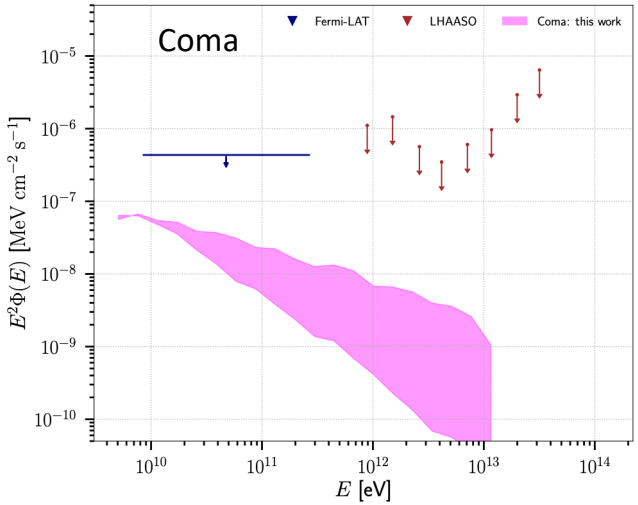
Hussain et al. Nat. Commun.

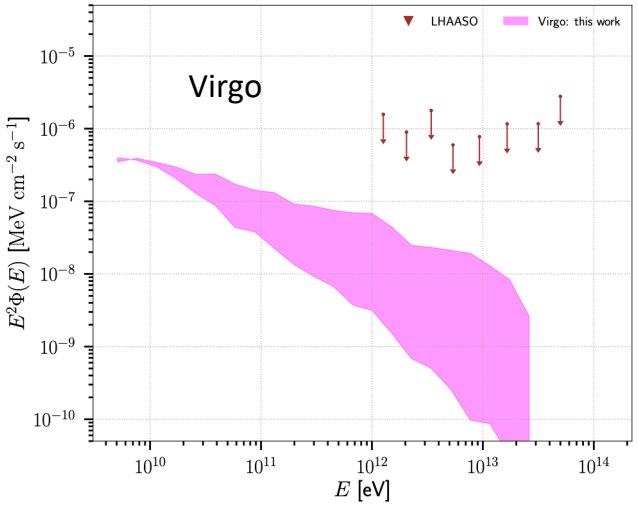
Gamm rays and neutrino from individual clusters

Parameters:
Index = 2.0 - 2.5
$E_{max} = 10^{16} – 10^{17}$ eV
$X_{CR} = E_{CR} / E_{thermal} = 0.01$







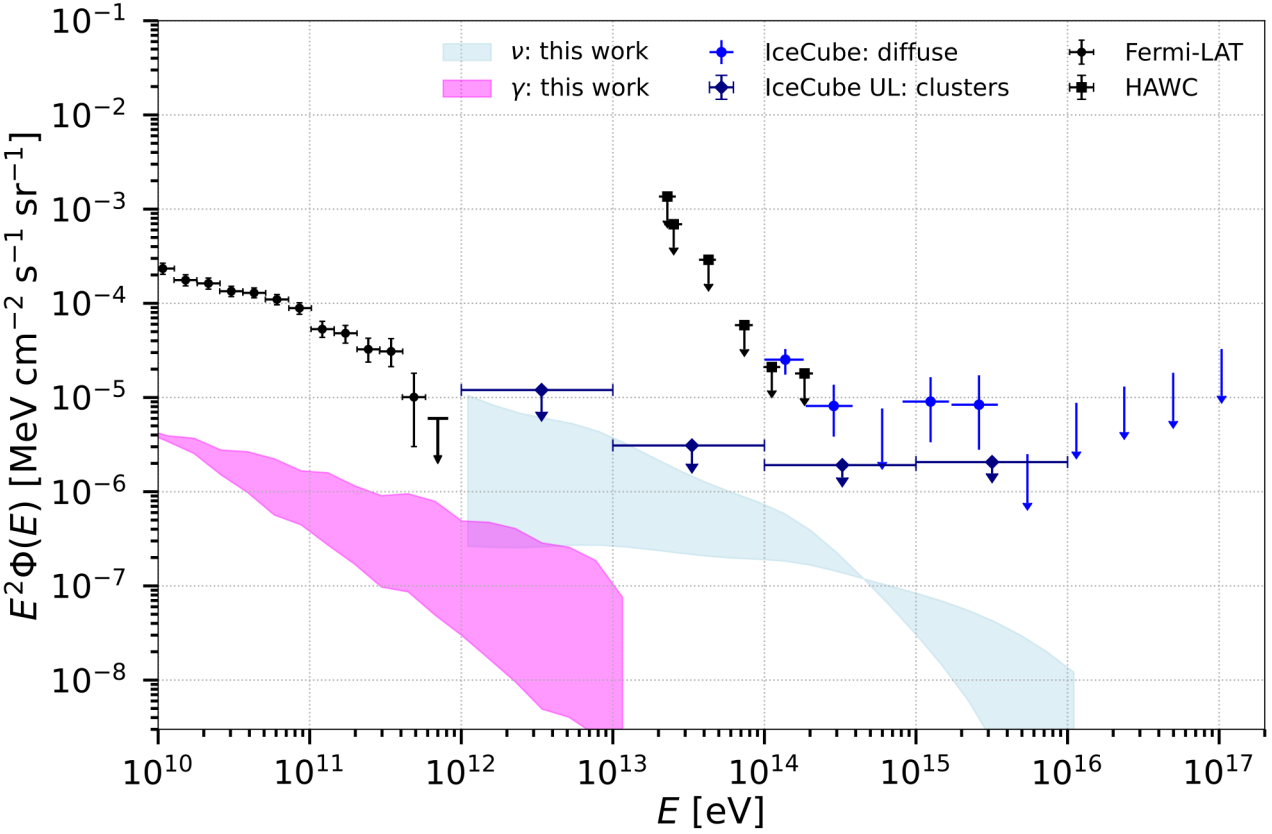


Integrated Gamma-ray and Neutrino Emission from Galaxy Clusters

Galaxy Clusters (GC):
within 500 Mpc & M > 10^{14} M_{sun}

GC contribution to diffuse
Gamma-ray background is limited

GC contribution to diffuse
Neutrino background is comparable
with the IceCube upper limits

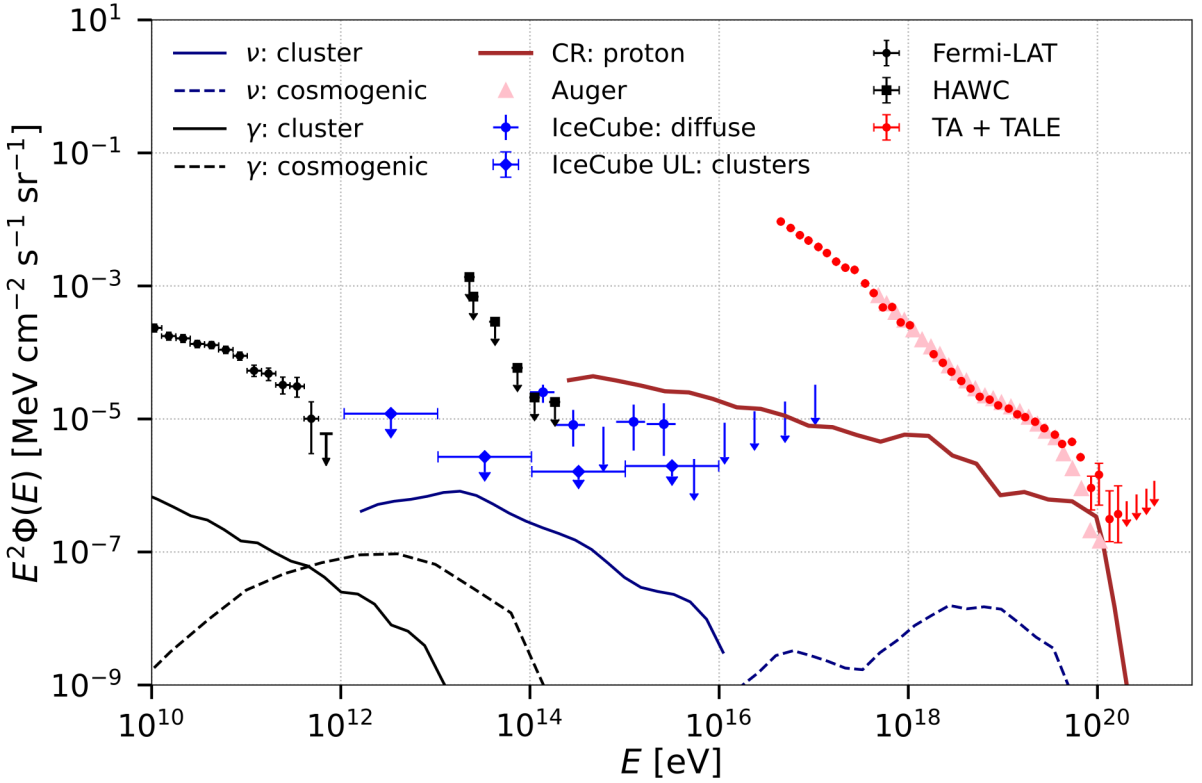


S. Hussain et al. 2026

High Energy Multi-messengers

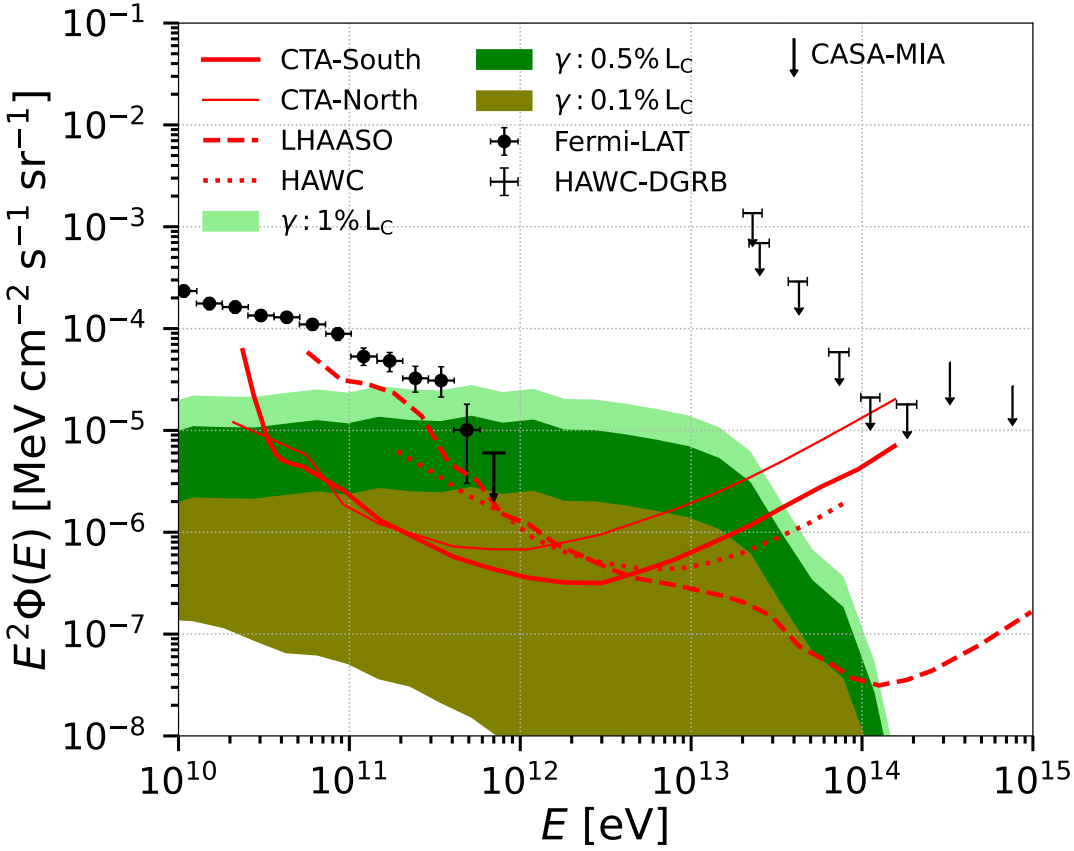
Perseus like source within 100 Mpc

Spectral index 2.3 & Emax = 1e17 eV



Future Observations

Comparing with sensitivities
Of gamma-ray observatories



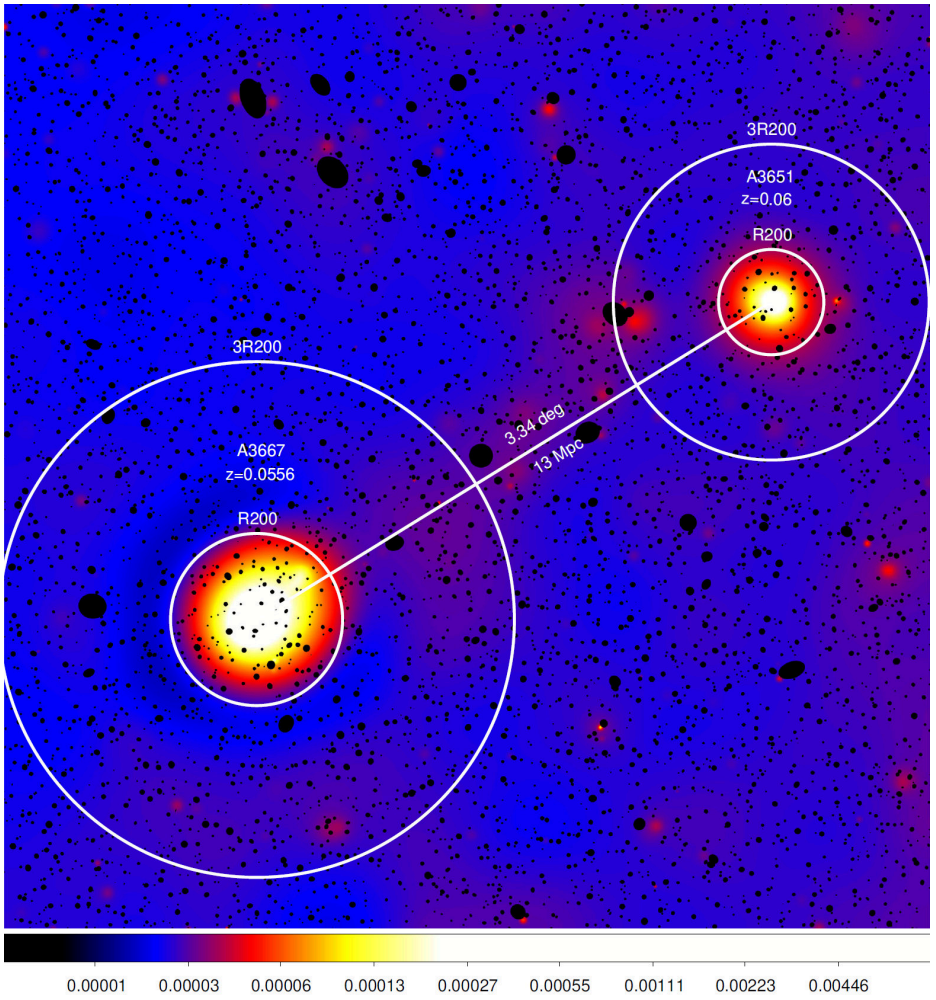
Multi-Messenger Testing: Facilities like POEMMA can determine if cluster-center AGNs generate detectable high-energy gamma-ray and neutrino signatures.

Thanks

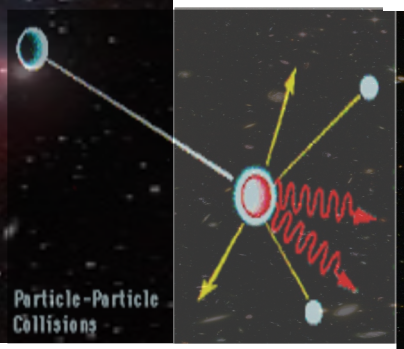
Currently working

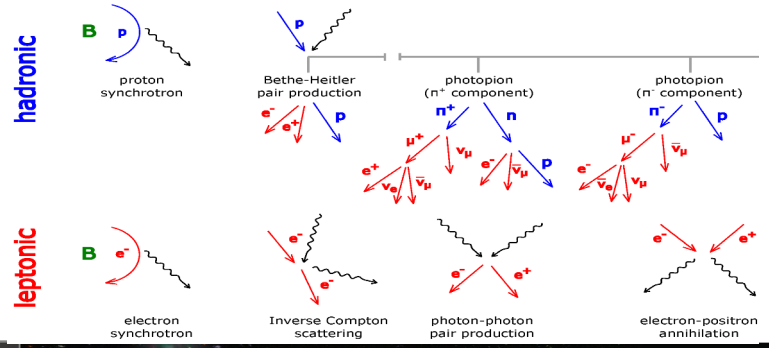
Galaxy cluster
A3667 (SPT-CL J2012-5649) z=0.0556
Gamma-ray detection by Fermi-LAT with high significance

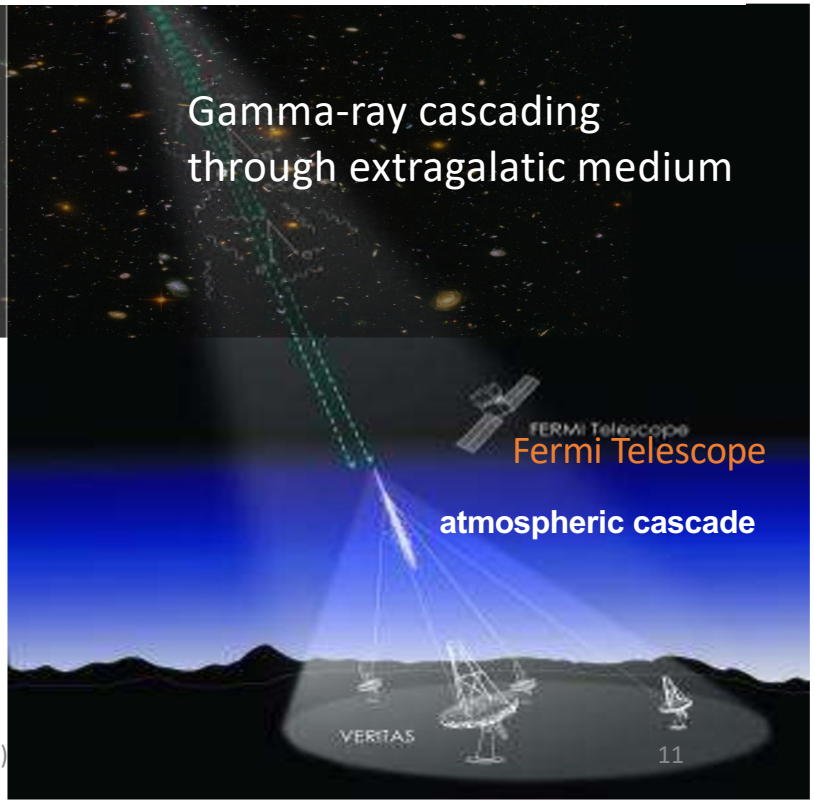
Focusing this source
Distinguishing between central source
Outskirt admission.



Extremely long gas filament discovered in X-rays
(Dietl, J., et al., 2024, A&A, 691, A286)

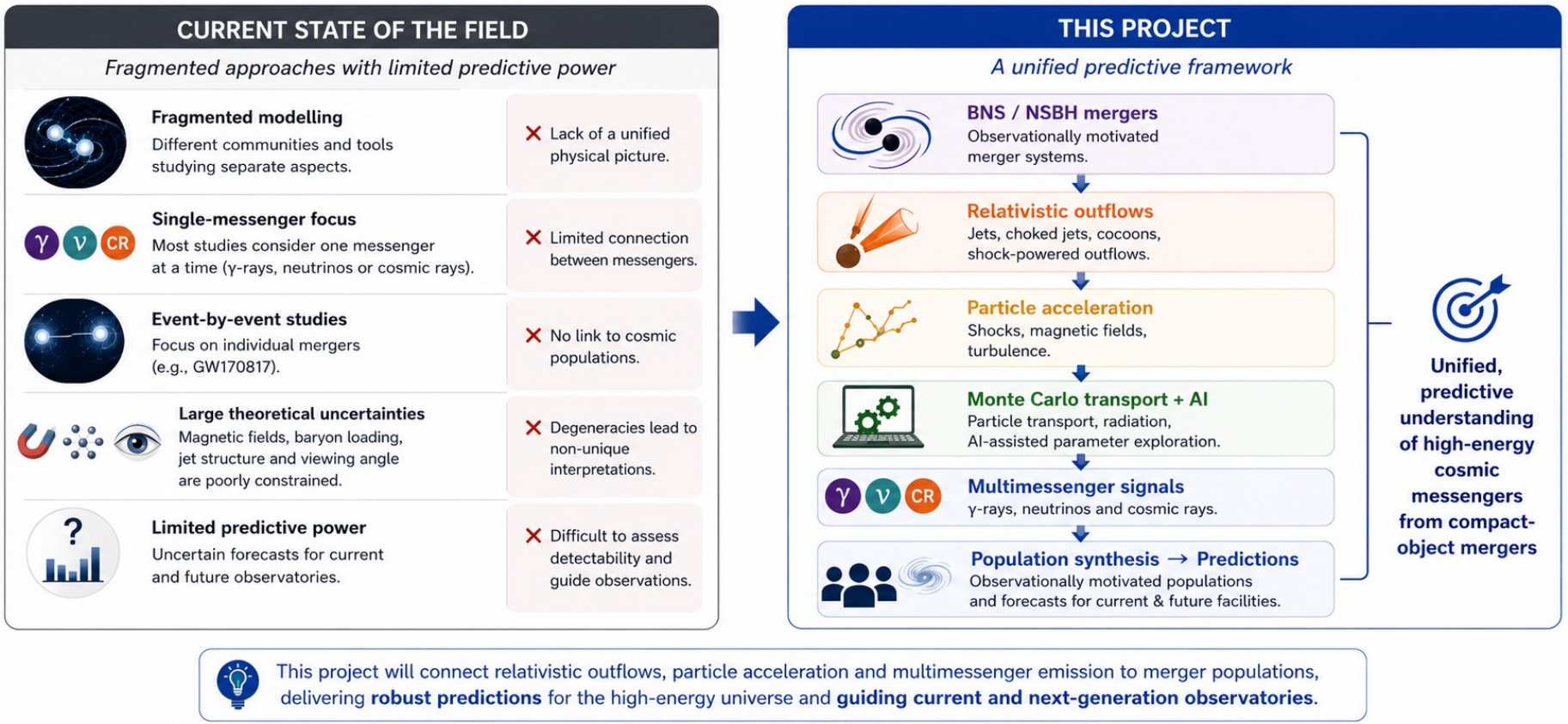






Methodology

Currently Working……..



Actively seeking postdoctoral opportunities and collaborative projects in multimessenger astronomy.
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