Nuclear Activity in Galaxies Across Cosmic Time
Proceedings IAU Symposium No. 356, 2019
M. Pović, P. Marziani, J. Masegosa, H. Netzer, S. H. Negu & S. B. Tessema, eds.
doi:10.1017/S1743921320003531

Multi-wavelength emission from dark matter annihilation processes in galaxy clusters and dark matter sub-halos

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Abstract. Multi-wavelength emission maps from dark matter (DM) annihilation processes in galaxy clusters are produced using Marenostrum-MultiDark SImulation of galaxy Clusters (MUSIC-2) high resolution cosmological simulations. Comparison made with observational radio emission flux data (spectral shape) and the spatial distribution from the simulated emission maps show that secondary particles from DM annihilation could describe the origin of energetic particles which are the sources of the diffuse radio emission observed in large number of galaxy clusters. DM sub-halos which are dominantly composed of DM, but with very little or no gas and stellar content, are ideal objects to study the nature and properties of DM. Therefore, statistical studies of a large number of them as well the emission maps of high mass-to-light ratio DM sub-halos will not only explain the observed diffused radio emission but also provide very crucial information about the nature and properties of DM particles.

Keywords. Dark matter, galaxy cluster, sub-halo, radio emission.

1. Introduction

Large-scale diffuse radio sources have been observed by sensitive radio telescopes in many clusters (van Weeren *et al.* 2019). Various observations have shown that these emissions follow a power-law spectrum, suggesting that these sources are of non-thermal origin due to synchrotron emission produced by relativistic particles in a magnetic field (Colafrancsco *et al.* 2006). Because of the synchrotron and inverse Compton energy losses, the typical lifetime of the relativistic electrons in the intra-cluster medium (ICM) is expected to be relatively short $\sim 10^8$ yr (e.g. Sarazin 1999). As a result, the electrons suffer from difficulties to diffuse over a Mpc-scale region within their radiative lifetime (see for e.g. Feretti *et al.* 2012). To resolve these and more, several models have been proposed which describe the mechanism of energy transfer into the relativistic electron population as well as the origin of these electrons (Colafrancsco *et al.* 2006).

2. Overview

Emissions across the multi-wavelength spectrum are expected from the secondary particles, i.e., from the electrons/positrons which are by-product of the self annihilation of super-symmetric DM particles (Colafrancsco *et al.* 2006). Thus we have studied these emissions expected in galaxy clusters by considering the annihilation of the most viable DM particles, the neutralinos. We have considered neutralino masses of 35 and 60 GeV DM models with two magnetic field models, and averaged DM annihilation cross-section times velocity $< \sigma V >$ of 1.0 $\times 10^{-26}$ cm^3 s^{-1}. Applying a Smooth Particle

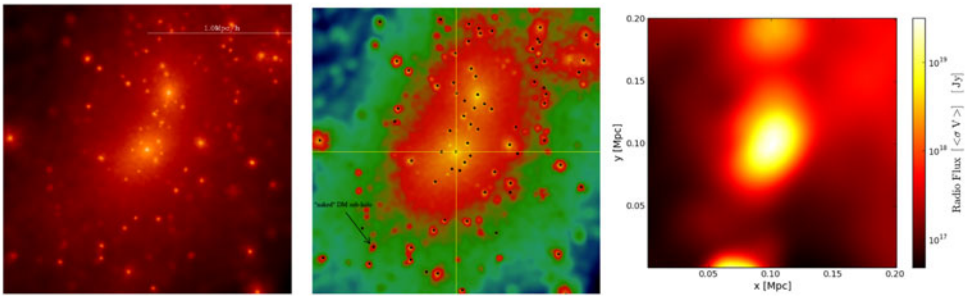

Figure 1. *Left Panel*: DM density projection maps of 2.0 Mpc diameter cluster. *Middle Panel*: Identifying DM sub-halos in the cluster. *Right Panel*: Synchrotron emission map at 110 MHz for the DM dominated sub-halo indicated by the arrow in the middle panel.

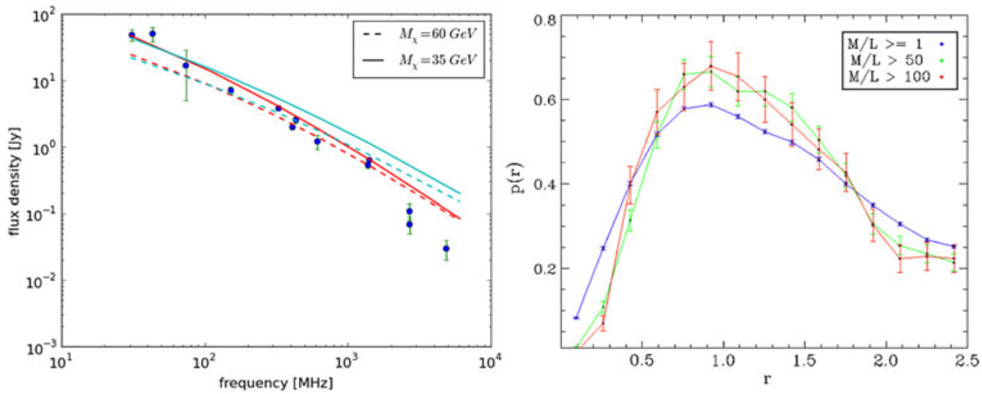

Figure 2. *Left Panel*: Flux density from synchrotron emission are compared with observations of the Coma cluster (blue data points) from Thierbach *et al.* (2003) for neutralino masses of 60 GeV (dotted curves) and 35 GeV (solid curves). Magnetic field model used are Model A, in red and Model B in cyan color. *Right Panel*: the probability distribution function of sub-halos based on their mass-to-light ratio (M/L) at a relative distance from the center of the host clusters.

Hydrodynamics (SPH) we have determined the DM densities at arbitrary locations within the cluster volume which is used to focus on the contribution of sub-halos (Fig. 1 [*Middle Panel*]) to the radio emission maps of clusters. A map showing the DM density projection is given in Fig. 1 [*Left Panel*]. A map showing the spatial distribution of the synchrotron emission of the chosen high M/L ratio DM sub-halo is given in Fig. 1 [*Right Panel*]. The flux density of synchrotron emission is compared with the observational data of Coma cluster in Fig. 2 [*Left Panel*]. The relative distance (from the center of the host clusters) of finding high M/L ratio DM sub-halos is also given in Fig. 2 [*Right Panel*].

3. Implications

We have investigated the nature and properties of DM indirectly by studying the non-thermal radio emission from their annihilation processes in simulated Coma like galaxy clusters. The DM radio flux densities for a neutralino mass of 35 GeV and the magnetic field based on Model A match best the observed diffuse radio emission of the Coma cluster (Thierbach *et al.* 2003). The fact that the flux density shows a very good agreement with the observed one without invoking a boost factor from DM sub-structures shows that the distribution of sub-structures is described well in the simulations. Even though not

https://doi.org/10.1017/S1743921320003531 Published online by Cambridge University Press

presented here, our model also predicts gamma-ray emissions. This multi-wavelength study will therefore have a strong implication to unveil both the source of the observed diffuse radio emission in clusters, and learn about the nature and properties of DM.

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