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Abell 2256 – Observing a Mpc^3 Nonthermal Laboratory

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Abstract. The galaxy cluster Abell 2256 is in the violent stage of a giant cluster merger event. Evidence of this merger is seen in the X-ray substructure of ROSAT images (Briel et al. 1991). Radio images reveal the complex nature of this cluster: a synchrotron halo, several head-tail radio galaxies, and two extended irregular and sharp-edged regions of diffuse radio emission – so called radio relics (Figure 1). The relics are believed to be powered by the energy input of the merger shock into an old (relic) relativistic electron population. This theory is supported by the observed radio polarization properties of the relics which closely match the polarization predicted by Enßlin et al. 1998 to result from synchrotron emission in shock-compressed magnetic fields. We report on an on-going project designed to obtain detailed Faraday rotation measure maps of these radio relics. The differential "Faraday screen" effect over extended radio sources allows us to study the magnetic field distribution inside these sources and in the foreground Faraday rotating medium.

1. Complex Radio Emission

We have undertaken observations of the complex radio emission in Abell 2256 at four wavelengths near 20 cm and two wavelengths near 6 cm with the NRAO[1] Very Large Array (VLA). These observations were carried out in the compact C and D configurations in order to provide the required sensitivity to diffuse large-scale structure. The observations were undertaken in full polarization mode and thus provide maps in all four Stokes parameters. Our VLA observations reveal that the spectral index across the G relic in Abell 2256 is remarkably uniform at $\sim$ -1.0 between 20 cm and 6 cm. This spectral index is steeper than the value of -0.37 found between 90 cm and 20 cm by Rottgering et al. (1994) and is closer to that of Kempner & Sarazin (2000). Note that this spectral index is still much flatter than that of the radio halo (which preliminary estimates indicate is steeper than -2.0). The radio relics have linear polarization fractions of up

[1]The National Radio Astronomy Observatory (NRAO) is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

to 40% with the majority of the relic region covered by polarization fraction of over 30% ! We place an upper 2σ limit of 20% on the polarization of the halo.

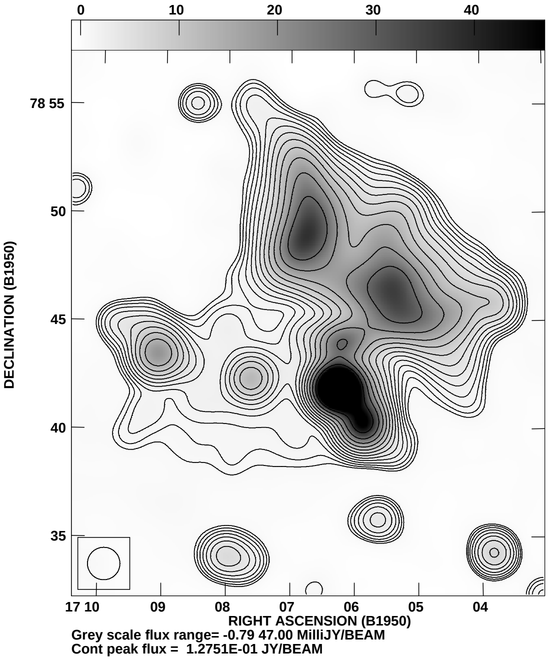

Figure 1. VLA D-array total intensity image at 1369 MHz of the Galaxy cluster Abell 2256. Contours increase by $\sqrt(2)$ from 2 sigma. The radio halo and relics (G & H) are labelled. The central halo has a diameter of 580 kpc, the G-relic has a scale of 330 kpc x 700 kpc, while that of the H relic is 570 kpc x 450 kpc. There are a number of other head-tail and compact sources visible in this field. The naming convention is from Bridle & Fomalont (1976).

2. Faraday Rotation Measure Analysis

The highly polarized nature of the radio relic region provides us with a sensitive Faraday screen to probe the magnetic field strength and structure in the foreground cluster medium. The Faraday rotation measure is given by $\mathrm{RM} \propto \int \mathrm{n_e B_{||}} d\ell$ where $\mathrm{n_e}$ is the electron number density and $\mathrm{B_{||}}$ is the line of sight component of the magnetic field. The rotation measure across the G and H relics determined from four wavelengths near 20 cm is very smooth across the entire relic region with typical values around -40 rad/m^2. The autocorrelation function of the RM map suggests the presence of very large scale order in the Faraday rotating medium. Using the observed Faraday rotation measure it is possible to recover the intrinsic magnetic field direction in the relic region. These intrinsic magnetic field directions are shown in Figure 2. The magnetic fields trace the brightest part of the ridge in both the G and H relics.

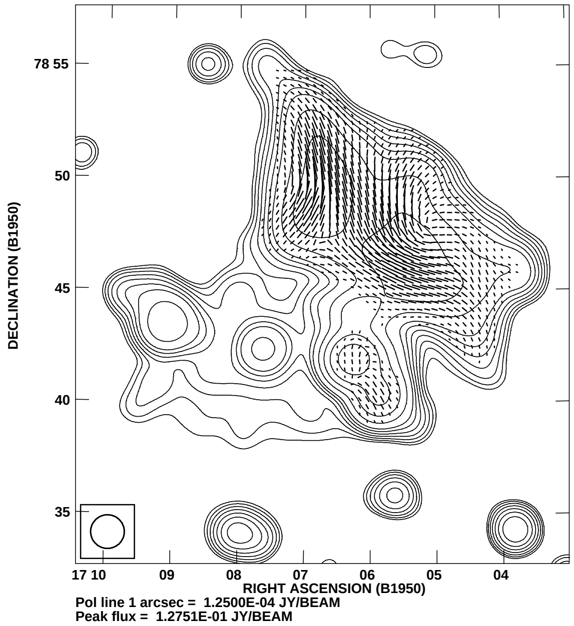

Figure 2. Total intensity 20 cm contours with the Faraday-corrected magnetic field vectors. Note that the contour spacing increases by 2 sigma at high flux levels to minimize confusion with the field lines in the relics. The length of the magnetic vector is proportional to the polarized intensity at that position. In general the magnetic field lines tend to trace along the bright ridges in both relics.

3. Two Possible Merger Geometries

If the complex radio emission observed in Abell 2256 is a result of the merger process, it may be possible to use the radio features and spectral indices to place constraints on the geometry and stage of the merger event. In Figure 3 we provide sketches of two possible merger geometries for this cluster. In the figure on the left we sketch an early merger geometry consistent with the location of the merger shock as determined by the numerical Hydro/N-body code of Roettiger et al. (1995). In this geometry the relic is located on the backside of the cluster with the line of sight passing through a large fraction of the intracluster medium. This model leaves it somewhat difficult to understand the steep spectral index halo if it is connected to the current merger. In the figure on the right we present a second possible geometry where the shock has proceeded well past core passage. The spectral index of the halo *might* then reflect the energy loss in the particle population since core passage. In *both geometries*, the flatter spectral index of the relics *indicates* that the relics are located closer to the current position of the shock.

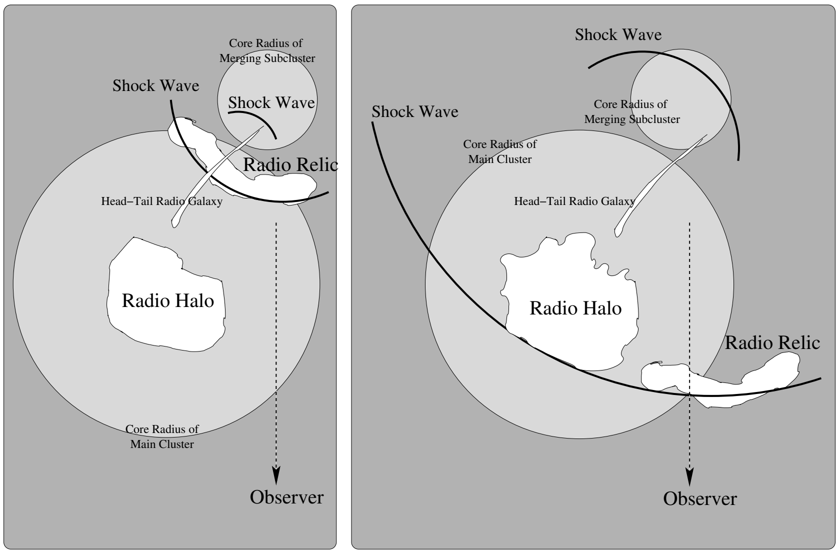

Figure 3. Sketches of two possible geometries for the merger-induced generation of the complex radio emission in Abell 2256. Left: the merger is in an early stage with the shock penetrating only a small distance into the cluster medium. In this geometry the shock has re-accelerated the particles in the relic but has not yet reached the central regions of the cluster. Right: the merger is in a later stage with the shock having proceeded well past the core regions of the cluster.

4. References

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