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The galaxy cluster Abell 2255 and the origin of its radio halo

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Abstract. We performed WSRT observations of A2255 at 18, 21, 25, and 85 cm to understand the origin of its highly polarized radio halo and to study the 3-dimensional location of the different cluster features within the ICM. We analyzed the polarimetric data through rotation measure (RM) synthesis, producing three final RM cubes. The radio galaxies and the highly polarized filaments at the edges of the central radio halo are detected in the high-frequency RM cube, obtained by combining the data at 18, 21, and 25 cm. Since the filaments show polarimetric properties similar to those of the radio galaxies located at large cluster distances, they also should be located at the periphery of the cluster, and their apparent central location should be due to projection effects. Their high fractional polarization and morphology suggest that they are relics rather than part of a genuine radio halo.
The 85 cm RM cube is dominated by the Galactic foreground. However, it also shows features associated with A2255 and in particular with the tail of the Beaver, a giant cluster head-tail radio source. The observed RM gradient between the head and the tail suggests what is the 3-dimensional location of the source within the ICM.

Key words. Galaxies: clusters: general – Galaxies: clusters: individual (Abell 2255) – Galaxies: intergalactic medium – Magnetic fields – Polarization

1. Introduction

The existence of halos and relics in galaxy clusters prove the presence of large-scale magnetic fields in the them. The study of the polarization of these features is the key to any comprehensive description of the ICM.

RM-synthesis (Brentjens & de Bruyn 2005) is a recently developed tool that can be used to analyze and interpret polarization data. By separating the polarized emission as a function of Faraday depth, this technique can give important information on the 3-dimensional structure of clusters of galaxies.

A remarkable galaxy cluster hosting significant polarized emission is Abell 2255. This nearby (z=0.0806, Struble & Rood 1999) and rich system has been studied at several wavelengths. In the radio domain, it hosts a diffuse radio halo, a relic source, and seven extended head-tail radio galaxies. Four of them lie near the cluster center, while the other three are located at a large projected distance from it ($\geq$ 2 Mpc). A study of the cluster at 21 cm through VLA observations has revealed that

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the radio halo is dominated at the borders by 3 filaments that are strongly polarized (~ 20–40%, Govoni et al. 2005).

In this paper, we present WSRT polarimetric observations of A2255 at 18, 21, 25, and 85 cm. These are aimed at studying the polarimetric properties of the cluster radio galaxies and investigate the highly polarized emission of the halo, unexpected for such a structure. RM-synthesis is used for analyzing the data.

This paper presents the observations and the data reduction in Sect. 2, shows the results in Sect. 3, and discusses them in Sect. 4.

In this paper we assume a ΛCDM cosmology with H_0 = 71 km s^{-1} Mpc^{-1}, Ω_m = 0.3, and Ω_Λ = 0.7. All the positions are given in J2000. At the distance of A2255 (~ 350 Mpc), 1′ corresponds to 90 kpc.

2. Observations and data reduction

The observations were conducted with the Westerbork Synthesis Radio Telescope (WSRT) at 18, 21, 25, and 85 cm for 144 hours in total, using different array configurations. The pointing center of the telescope, as well as the phase center of the array was directed towards RA = $17^h13^m00^s$, Dec = +64° 07′ 59″, which is the radio center of A2255. The data were processed with the WSRT-tailored NEWSTAR reduction package, following the standard procedure: automatic interference flagging, self-calibration, fast Fourier transform imaging, and CLEAN deconvolution.

At each wavelength, we produced Q and U image cubes and we inspected them to remove the channel maps affected by residual RFI and/or problems related to specific telescopes. The final images were carried through for further processing in RM-synthesis. To improve the resolution in RM space, as well as the sensitivity, at high frequency we decided to combine the 18 cm, 21 cm, and 25 cm datasets.

3. Results: the RM cubes

The high-frequency RM cube[1] covers a field of view of 1.5°× 1.5° and synthesizes a range of Faraday depths between –1000 and +1000 rad m^{-2}, with a step of 10 rad m^{-2}. It has an rms-noise level of 10 μJy beam^{-1} and a resolution of 28″ × 30″. The filaments at the borders of the central radio halo and all the cluster radio galaxies are here detected (see e.g. the frame at ϕ = 30 rad m^{-2} in Fig. 1).

The 85 cm RM cube[2] covers a field of view of 6° × 6° and synthesizes a range of Faraday depths between −400 rad m^{-2} and +400 rad m^{-2}, with a step of 4 rad m^{-2}. It has an rms noise of 45 μJy beam^{-1}, the lowest achieved at such a long wavelength to date. This RM cube is dominated by the Galactic foreground, but it shows also features that suggest an association with continuum structures belonging to the cluster. In particular, polarized signal is detected at Faraday depths between −32 rad m^{-2} and < −24 rad m^{-2} and it is associated with the tail of a giant cluster head-tail radio galaxy, named Beaver.

3.1. Rotation measure structure

We extracted Faraday spectra along various lines of sight within the cluster radio galaxies and the filaments (see Fig. 11 and 13 in Pizzo et al. 2011) . We computed also the RM maps of the sources by applying masks (derived from the 25 cm total intensity image) to the high-frequency RM cube. The RM value for each pixel within a source was derived by fitting a Gaussian profile to the observed RM distribution (see Fig. 13 and 14 in Pizzo et al. 2011).

The Faraday spectra of the radio galaxies and the filaments have different levels of complexity, with the sources nearest (in projection) to the cluster center showing the most complex spectra. This property reflects on the complexity of the RM distributions of the same sources, which are characterized by a complex and non-Gaussian profile. On the other hand, the filaments and the external radio galaxies have simple Faraday spectra, characterized by mainly one peak and gaussian RM distributions with small <RM> and σ_{RM} values.

[1] A2255_18_21_25CM.gif, only available in electronic form at the A&A website.

[2] A2255_85CM.gif, only available at the A&A website.

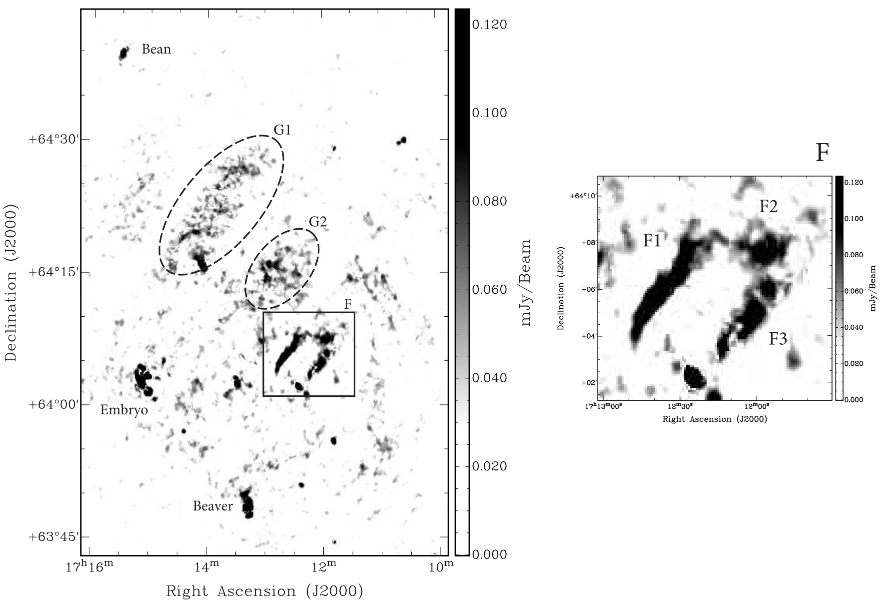

Fig. 1. Left panel: polarized intensity (in units of mJy beam^{-1} RMSF^{-1}) in the field of A2255 from the high-frequency RM cube (18 cm + 21 cm + 25 cm) at $\phi = +30$ rad m^{-2}. Bean, Embryo and Beaver are cluster radio galaxies, while G1 and G2 are Galactic features. Right panel: zoom into the region where the three radio filaments are located.

4. Discussion: the radio galaxies and the filaments

Several studies of the RM distributions of extended radio galaxies in clusters have pointed out that there is a significant trend between the observed RM distribution and the projected distance of the source from the cluster center (e.g. Feretti et al. 1999): the smaller the projected distance from the cluster core, the higher $\sigma_{\rm RM}$ and <RM>. This result suggests that the external Faraday screen for all the cluster sources is the ICM of the cluster, which modifies the polarized radio signal depending on how much magneto-ionized medium it crosses[3].

In our data, the radio galaxies of A2255 clearly follow such a trend. Therefore we conclude that also for this cluster the external screen for the radio galaxies is the ICM. This affects not only the RM distribution of the cluster radio galaxies, but also the complexity of their Faraday spectra. Radio galaxies at different projected distances from the cluster center show Faraday spectra with different levels of complexity. Since the co-location along the line of sight of multiple emitting and Faraday rotating regions produces Faraday spectra with multiple peaks (Brentjens & de Bruyn 2005), we conclude that the radio galaxies showing the most complex spectra (and accordingly the

[3] It is worth noting that the RM observed towards cluster radio galaxies may not be entirely representative of the cluster magnetic field if the RM is locally enhanced by the compression of the ICM from the motion of the source through it. However, this hypothesis is ruled out because Clarke (2004) showed that the RM distribution of point sources seen at different impact parameters from the cluster center has a broadening towards the center of the cluster. This result reveals that most of the RM contribution comes from the ICM.

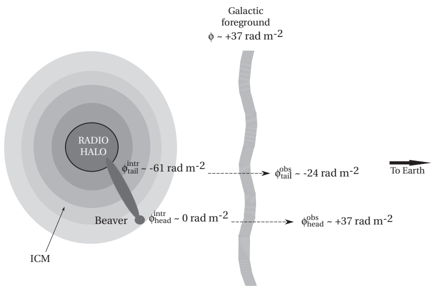

Fig. 2. Possible 3-dimensional location of the Beaver radio galaxy within A2255. The gray-scale for the ICM represents an increasing electron density of the plasma towards the cluster center. Our Galaxy contributes to the observed Faraday depths (ϕ_{head}^{obs} and ϕ_{tail}^{obs}) at which the head and the tail appear in the RM cubes.

broadest RM distributions) are likely to be located deep inside the ICM or behind the cluster. On the other hand, the radio galaxies showing the less complex spectra (and the smallest RM distributions) likely lie in the external regions of the ICM.

Our polarimetric data confirm the strong polarization of the filaments and add important information that can help to explain their nature. The filaments show similar polarimetric properties to those found for the external radio galaxies of A2255. Their RM distributions are characterized by low values of σ_{RM} and <RM>, with Faraday spectra showing only one peak. These results suggest that the filaments are not located deep in the ICM, but at the periphery of the cluster and in particular in its foreground. Therefore, their observed central location should be considered as due to a projection effect. *On the basis of the elongated shape and the high degree of linear polarization of the filaments, we argue that they are relics rather than part of a genuine radio halo.*

4.1. The Beaver radio galaxy

The head and the tail of the Beaver radio galaxy are detected at ~ +37 rad m^{-2} and between -32 rad m^{-2} and –16 rad m^{-2}, respectively (see Fig. 15 in Pizzo et al. 2011). This RM gradient suggests the possible location of these two components within A2255. Since the head has the typical RM values of our Galaxy towards A2255 (Pizzo et al. 2011), it should lie at the outskirts of the cluster, where only a small portion of ICM is crossed by the radio signal before reaching the observer. That the tail appears at negative Faraday depths, instead, implies that it should be located deeper in the ICM. Therefore, the Beaver could not lie in the plane of the sky, but with the tail pointing towards the central radio halo, possibly connecting with it (see Fig. 2). This interpretation is supported by the common spectral index values found for the end of the tail and the southern region of the halo (Pizzo & de Bruyn 2009).

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