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Strong magnetic asymmetries in weakly interacting spirals

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We investigate the influence of cluster environment on the structure and evolution of magnetic fields and the interstellar medium in the Virgo cluster spiral NGC 4254. Our sensitive interferometric (VLA) and single dish (Effelsberg) radio polarimetric observations reveal several magnetic spiral arms displaced from optical ones. However, the southern arm, particularly bright in polarized emission, lacks an optical counterpart. In this area the magnetic pitch angle is very small. On the contrary, the northern part of the galaxy with more diffuse total radio emission shows a significant radial component of the magnetic field. At 1.4 GHz the galaxy shows an extended polarized envelope with a highly regular magnetic field extending further than any star-forming region. The regular component enters the cluster environment and can enrich the cluster-scale magnetic field. Our XMM-Newton observations reveal that the broadband X-ray emission of the hot gas emerges from almost the whole galaxy disk and is tightly associated with regions of star formation. The distribution of X-rays does not show any sign of stripped hot gas around the galaxy disk and rules out strong ram pressure of the hot cluster gas. Magnetic asymmetries and slightly perturbed H I and optical emission probably manifest weak tidal interactions of NGC 4254 with other Virgo cluster members: the dark galaxy VIRGOHI 21 or NGC 4262. We also compare polarimetric properties of NGC 4254 with other Virgo cluster spirals which we currently observe systematically with the Effelsberg radio telescope.

1 Radio observations

The cluster environment (ICM) is known to affect galaxies in clusters in various ways, causing H I deficiency, truncation of star formation by ram pressure stripping, changing chemical evolution of the interstellar medium (ISM), and morphological transformations. In this work we study how the cluster environment can change the galaxy-scale magnetic field.

Our target, the Virgo cluster spiral NGC 4254, is located 1.2 Mpc from the cluster centre to the north-west direction. In the optical band the galaxy displays an unusual spiral pattern dominated by a three-arm structure and showing large-scale, vigorous star formation. The H I distribution (Phookun et al. 1993) reveals predominantly a one-arm spiral and out-of-disk components. Recent H I observations (Minchin et al. 2005) indicate a faint bridge connecting the large-mass dark galaxy VIRGOHI 21 with NGC 4254. However, in the numerical modelling of Vollmer et al. (2005) the H I emission was interpreted as a joint action of tidal forces caused by the nearby spiral NGC 4262 and weak ram-pressure forces due to the passage of NGC 4254 through the hot cluster medium.

We performed high-sensitivity radio polarimetric observations of NGC 4254 at 8.44 GHz, 4.86 GHz, and 1.43 GHz using the NRAO[1] VLA in D and C arrays. To improve sensitivity to extended emission we also merged the data with single dish observations obtained with the Effelsberg radio telescope[2]. The total radio emission in NGC 4254 at 4.86 GHz is asymmetric as it has been seen already in low resolution observations by Soida et al. (1996). It resembles the optical one, but extends further to the north and exhibits a two-arm spiral pattern in the inner disk.

The distribution of polarized intensity reveals a sharp, bright ridge in the southern disk *outside* of the close spiral optical arm. This can indicate field compression by an external agent. The radio tail extending to the north and NE shows signs of high polarization (above 50%), meaning a rather low degree of field twisting. The magnetic vectors show in general a regular pattern filling almost the whole galaxy disk and forming magnetic arms mostly lying outside or between the optical arms. The magnetic vectors (Fig. 1, left) follow the gas flows, like in 'grand design' spirals, being nearly azimuthal in the polarized ridge and much more inclined in the north.

We report the discovery of a polarized radio envelope of NGC 4254 at 1.43 GHz with very regular magnetic field ex-

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[2] The 100-m telescope at Effelsberg is operated by the Max-Planck-Institut für Radioastronomie (MPIfR) on behalf of the Max-Planck-Gesellschaft.

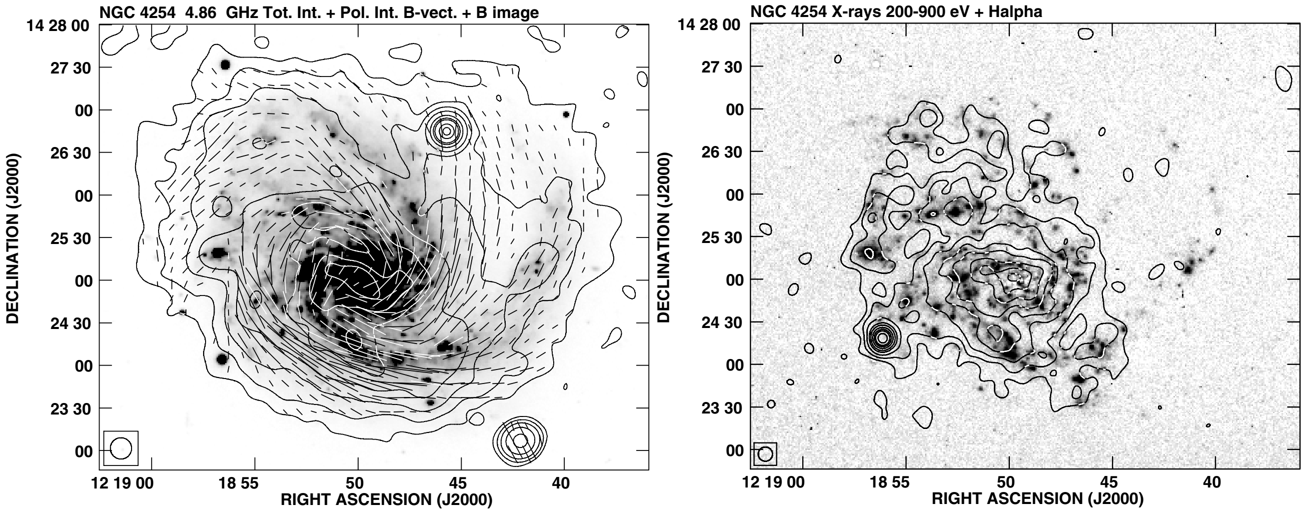

Fig. 1 *Left*: Merged VLA+Effelsberg data in contours of total radio intensity at 4.86 GHz at a resolution of 15″ with magnetic vectors of the polarized emission, overlaid onto the optical DSS blue image. Contours are at 30, 80, 160, 320, 640, 1280 μJy/b.a. *Right*: X-ray emission in the 0.2–0.9 keV band from the XMM-Newton EPIC camera in contours, at a resolution of 10″, overlaid onto the Hα image (from Knapen et al. 2004).

tending further than the warm and hot gas components and any star-forming region. This envelope can spread out magnetic field into the ICM and enrich the cluster-scale magnetic field.

2 Influence of cluster environments

We observed NGC 4254 with XMM-Newton[3] in the energy band of 0.2–12 keV. The soft X-ray emission reveals that the hot gas comes almost from the whole galaxy disk and is tightly associated with star-forming regions (Fig. 1, right). The distribution of X-rays does not show any hot gas tail in the north or gas compression in front of the southern galaxy disk, expected in case of strong ram-pressure stripping. Thus, NGC 4254 is not affected by strong gas stripping in concordance with the low HI deficiency and untruncated Hα emission. However, the ram pressure seems to be needed to compress the magnetic field in the southern galaxy disk, but it must be weak, with nearly no mass loss.

The ram pressure does not affect the stars and could not alone disturb the spiral arms to the observed, asymmetrical pattern. The double-arm structure visible in the total intensity radio maps, and especially the strong southern arm, is thus probably triggered by tidal interaction with another cluster entity: the dark galaxy VIRGOHI 21 or NGC 4262. Additionally, like in the Antennae galaxies (Chyży & Beck 2004), tidal interaction can induce strong star formation and enhance the anisotropic component of the magnetic field. A range of HI clumps encircling the disk of NGC 4254 (Phookun et al. 1993) also suggests that the remains of the interaction could hit the southern part of the disk and compress the magnetic field by ram-pressure forces.

[3] XMM-Newton is an ESA science mission with instruments and contributions directly funded by ESA Member States and NASA.

In view of this study NGC 4254 seems to belong to the class of young members of the Virgo Cluster entering its periphery. It experienced tidal perturbation with another cluster member and is affected by small ram pressure forces of hot or cold gas. NGC 4254 is not the only such case. Our systematic polarimetric survey of the Virgo Cluster galaxies with the Effelsberg telescope (Chyży et al., in prep.) shows that also other spirals have distorted magnetic field structures and often reveal polarized ridges at the galactic disk edges. We believe that they also, as NGC 4254, are influenced by the cluster environment and they produce magnetic feedback to the cluster medium. Compression of magnetic fields by tidal interactions or by ram pressure forces and their injection to the ICM was probably much stronger in dense clusters of the early Universe. Thus, the studies of galactic magnetism in nearby clusters have powerful cosmological relevance.

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