The intra-cluster magnetic field power spectrum in Abell 2382

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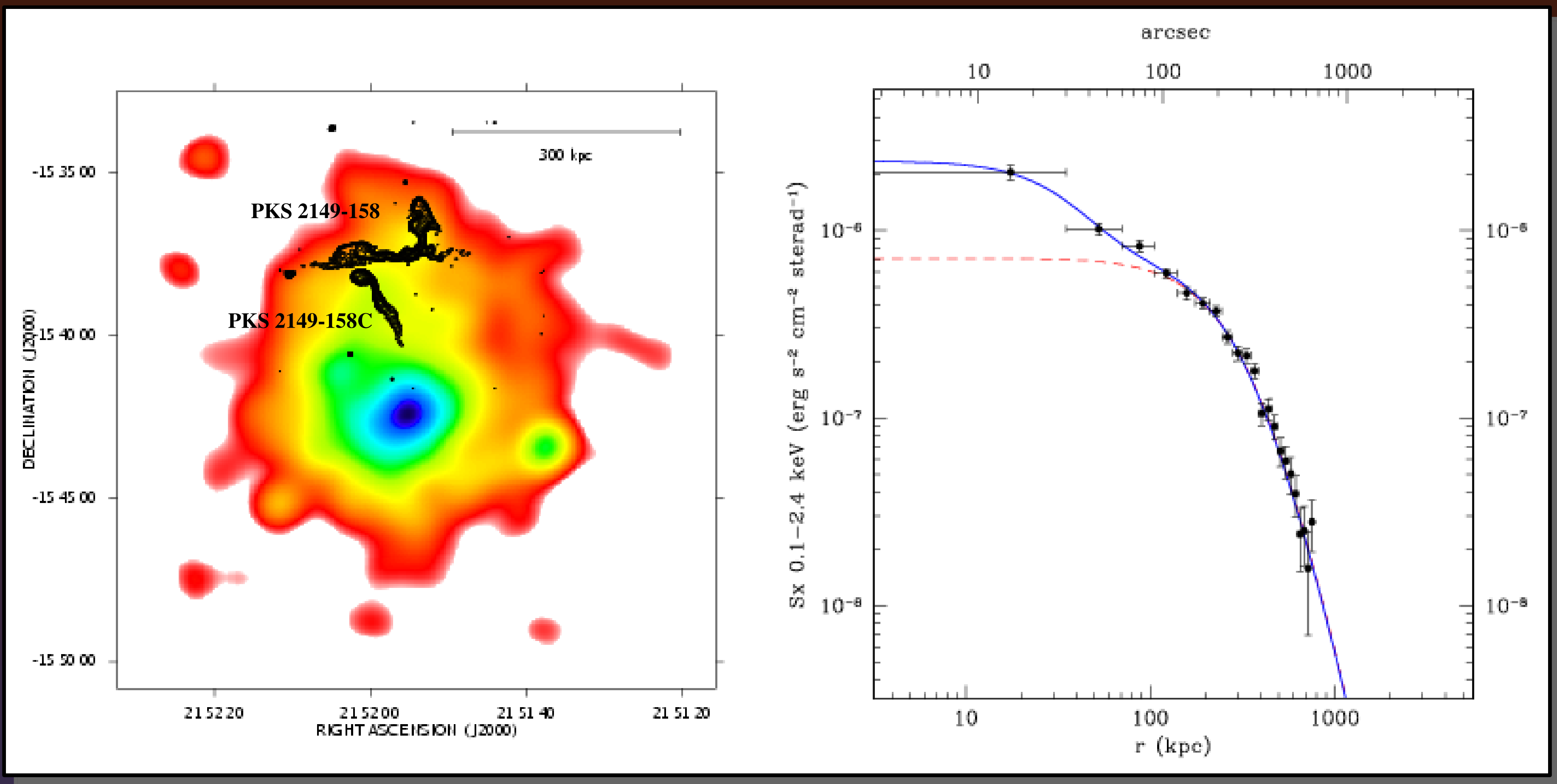
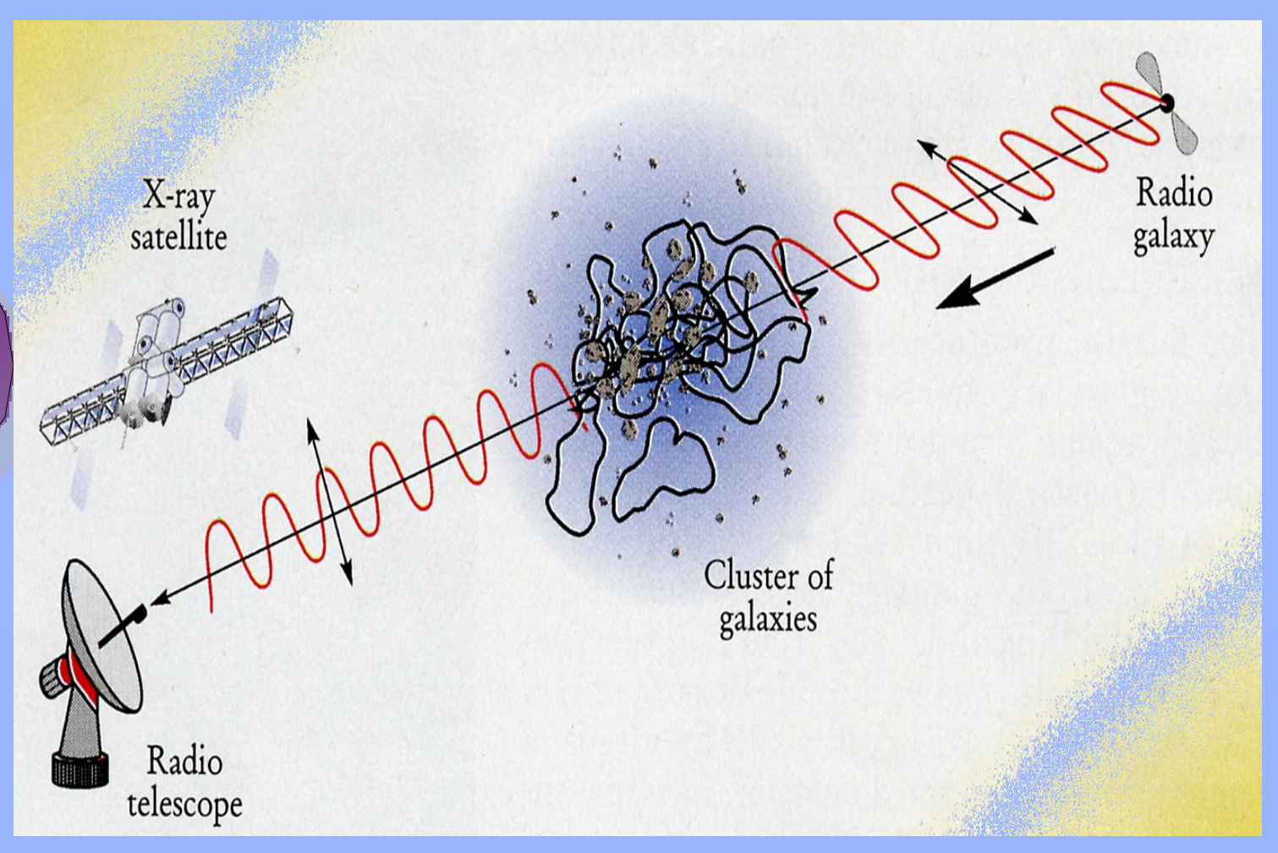
The intra-cluster medium in clusters of galaxies is known to possess a magnetic field, but its origin and properties are not well known (see e.g. the review by Govoni & Feretti 2004, Carilli & Taylor 2002, and references therein). The strongest evidence for the presence of cluster magnetic fields comes from radio observations. Magnetic fields can be investigated through the conjunction of radio and X-ray data. Indeed, one of the key techniques to get information about the cluster magnetic field strength and geometry is the Faraday rotation analysis of polarized radio galaxies. The magnetized plasma that is present between an observer and a radio source changes the properties of the polarized emission from the radio source. Therefore, the magnetic field strength can be determined, with the help of X-ray observations of the hot gas, through the investigation of the Faraday Rotation Measure (RM) of radio sources located inside or behind the cluster. On the basis of the available RM images, increasing attention is given in the literature to the power spectrum of the intra-cluster magnetic field fluctuations. Several studies (Ensslin & Vogt 2003, Murgia et al. 2004) have shown that detailed RM images of radio galaxies can be used to infer not only the cluster magnetic field strength, but also the cluster magnetic field power spectrum.

Here we present the results of a polarimetric study conducted with the Very Large Array (VLA) at 20 cm and 6 cm of the three radio galaxies PKS 2149-158 (A and B) and PKS 2149-158C in the cluster Abell 2382, observed by the Rosat satellite in the 0.1-2.4 keV band . A2382 is an ideal case to study RM along different lines-of-sight because PKS 2149-158 and PKS 2149-158C are quite extended, both in angular and linear size, and thus they are ideal targets for an analysis of the rotation measure distribution: detailed RM images can be constructed which can serve as the basis of an accurate study of magnetic field power spectrum.



Left panel: total intensity radio contours of galaxies PKS 2149-158 and PKS 2149-158C at 6 cm superposed on the Rosat PSPC image of A2382 in the 0.1-2.4 keV band. **Right panel: X-ray surface brightness profile of A2382 in the** 0.1-2.4 keV band. Because a strong emission core is present in the inner 100 kpc of the cluster, the profile cannot be described by a simple beta-model. A double beta-model provides a better fit for the gas density. The fits of the single and double are shown as dashed and solid line, respectively. There is indeed the possibility that A2382 is a cooling core cluster, although new spectroscopic X-ray observations are required in order to confirm the hypothesis.

Polarized radiation from cluster and background radio galaxies may be rotated by the Faraday effect if magnetic fields are present in the intra-cluster medium.



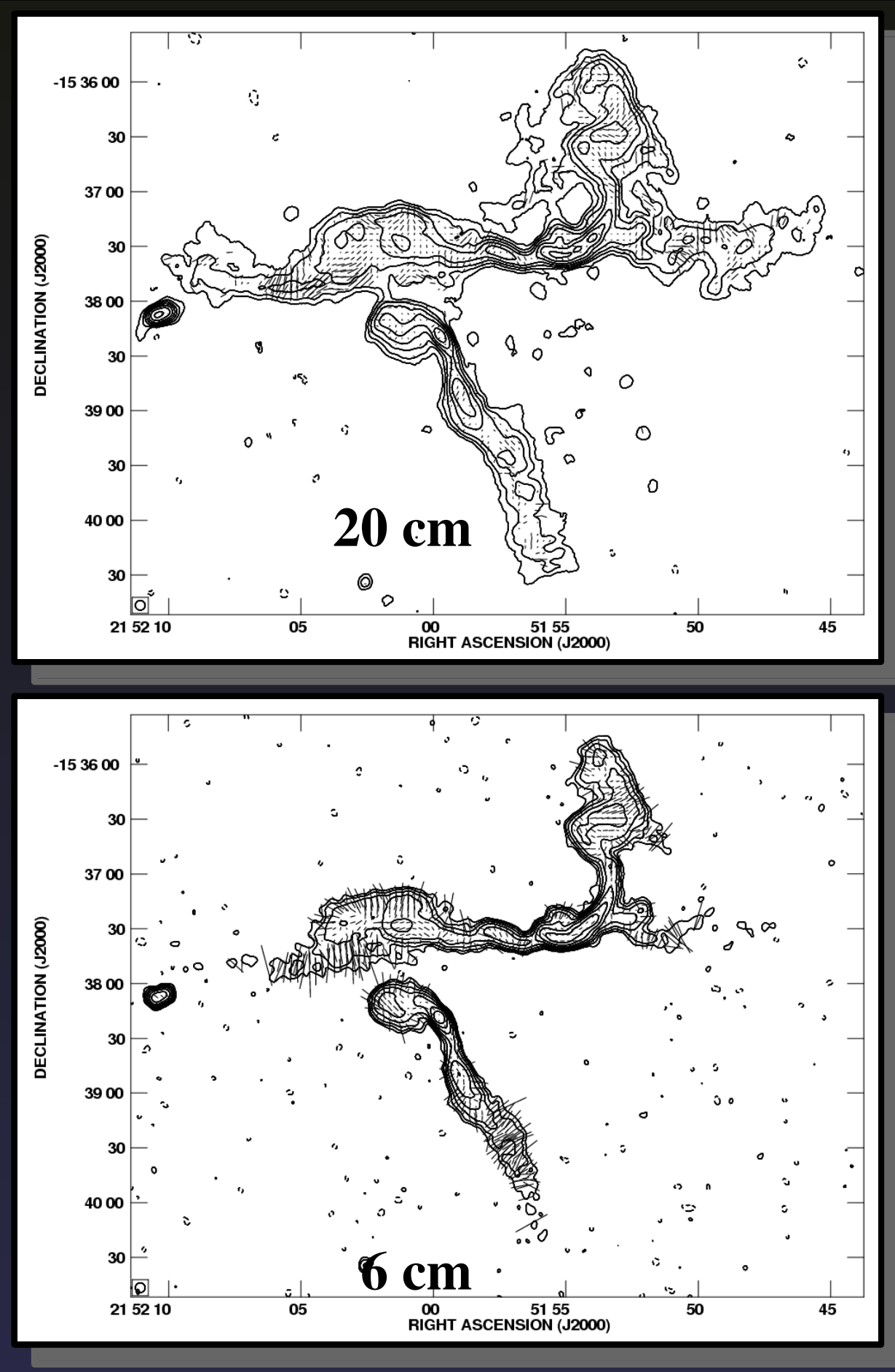
Linearly polarized radio waves passing through a magnetized ionized medium suffers a rotation of the plane of polarization:

$$\Phi_{obs}(\lambda) = \Phi_0 + \lambda^2 RM$$

where Φ_{obs} is the position angle observed at a wavelength, Φ_0 is the intrinsic position angle and RM is the Rotation Measure.
The RM is related to the electron density (ne) and the magnetic field along the line of sight (B), through the path integral across the intracluster medium:

$$RM \propto \int n_e B \, dl \qquad \text{(Eq.1)}$$

Thus, given a model for the electron density distribution, obtainable from X-ray observations, we can reconstruct the magnetic field B inverting Eq. 1.



Total intensity contours and polarization vectors at 20 cm and 6 cm of PKS 2149-158 and PKS 2149-158C. The angular resolution is 5.3" x 5.3". The lines give the orientation of the electric vector position angle (**E**-field) and are proportional in length to the fractional polarization (10" = 50%).

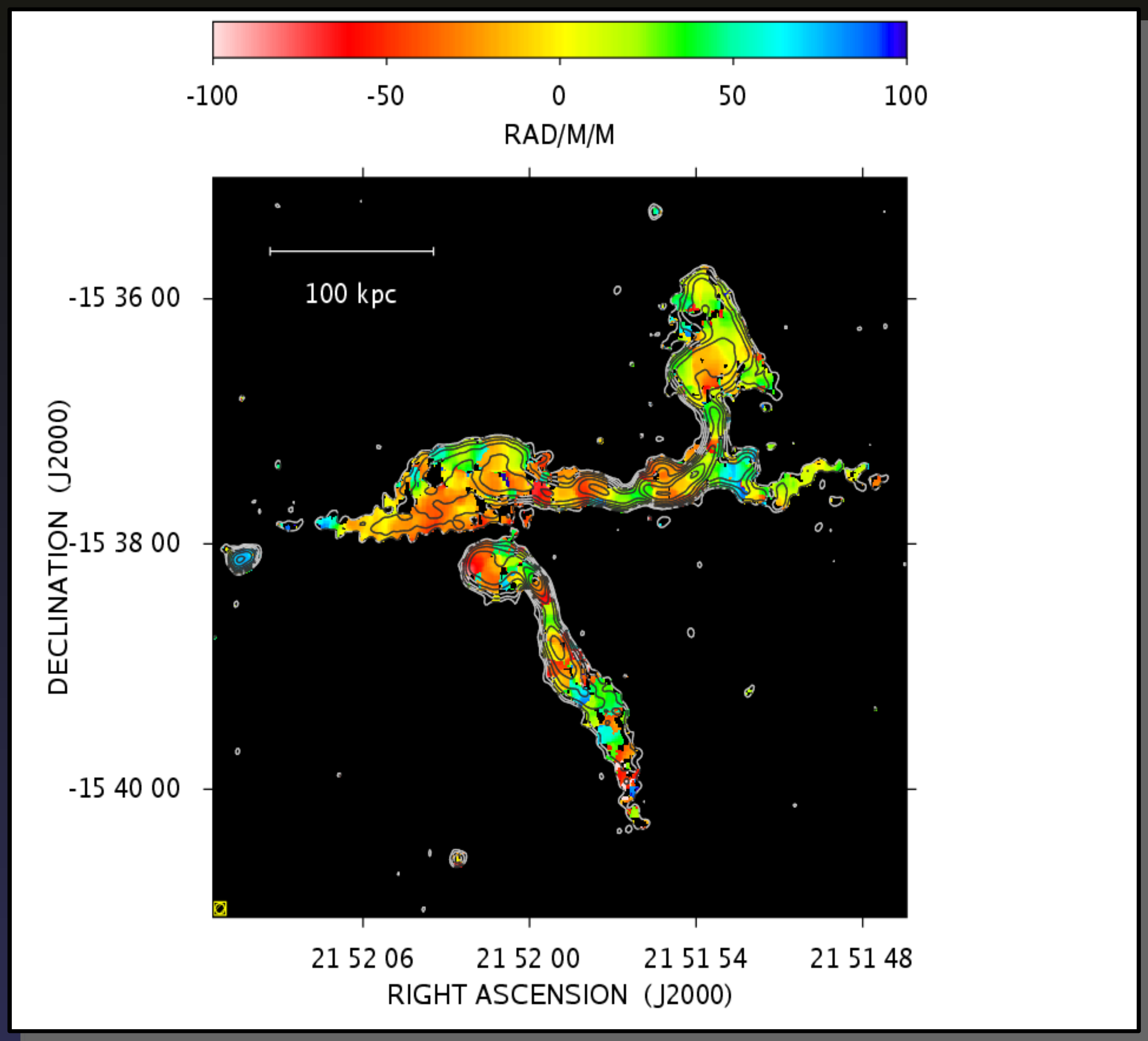
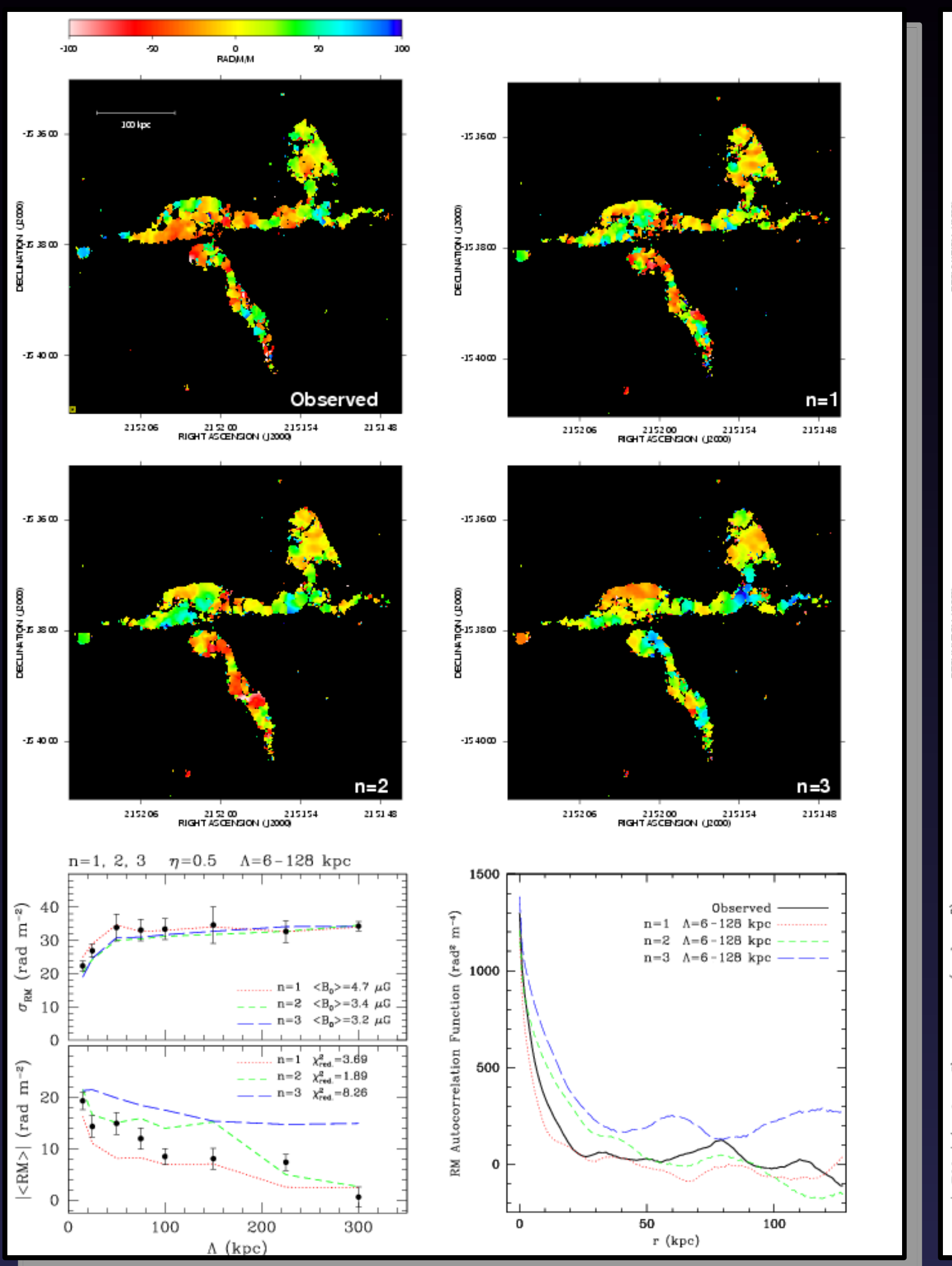


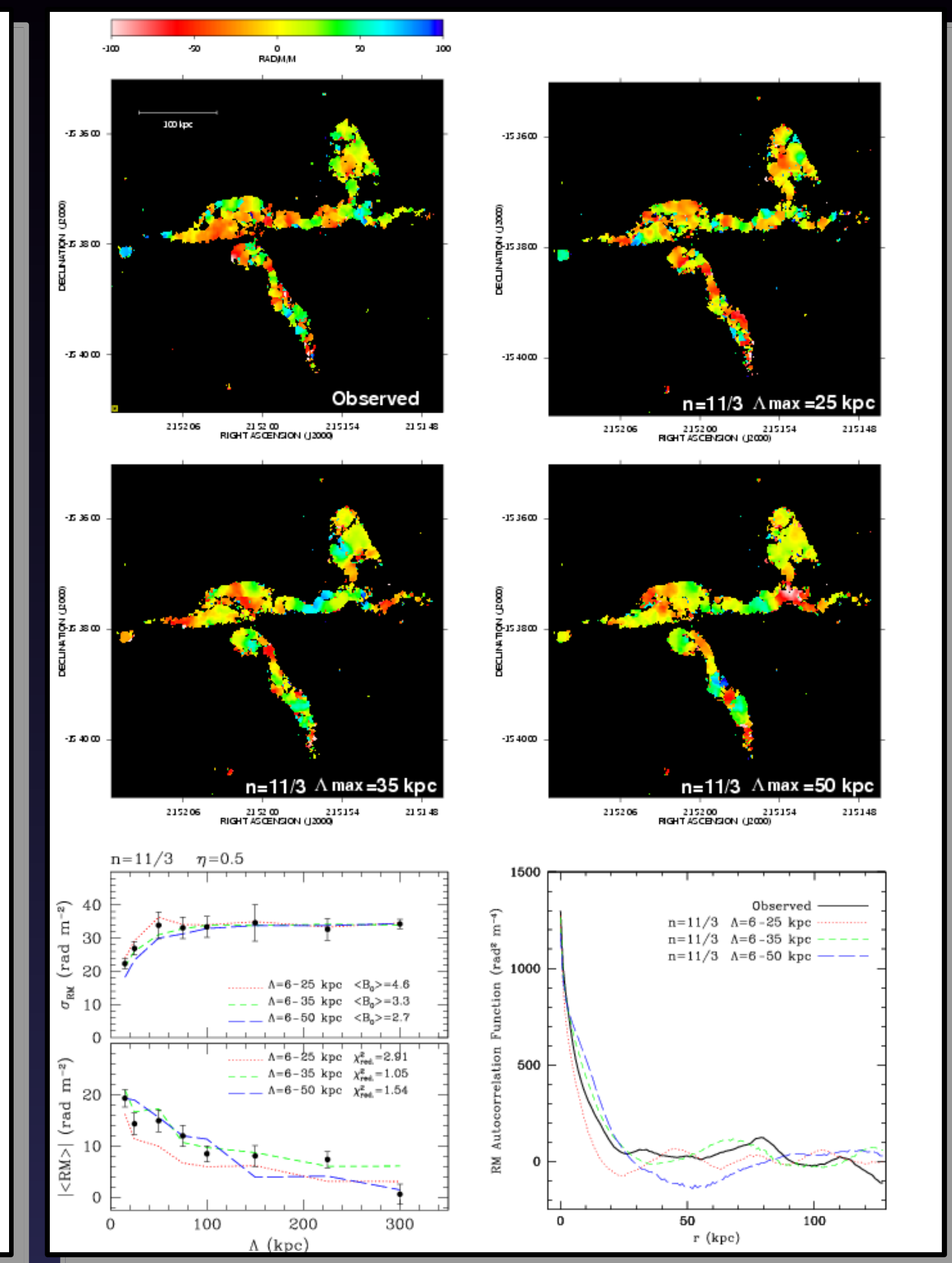
Image of the rotation measure computed using the polarization maps at the frequencies 1.46, 1.66, 4.83 and 4.88 GHz. Contours refer to the total intensity image at 6 cm.

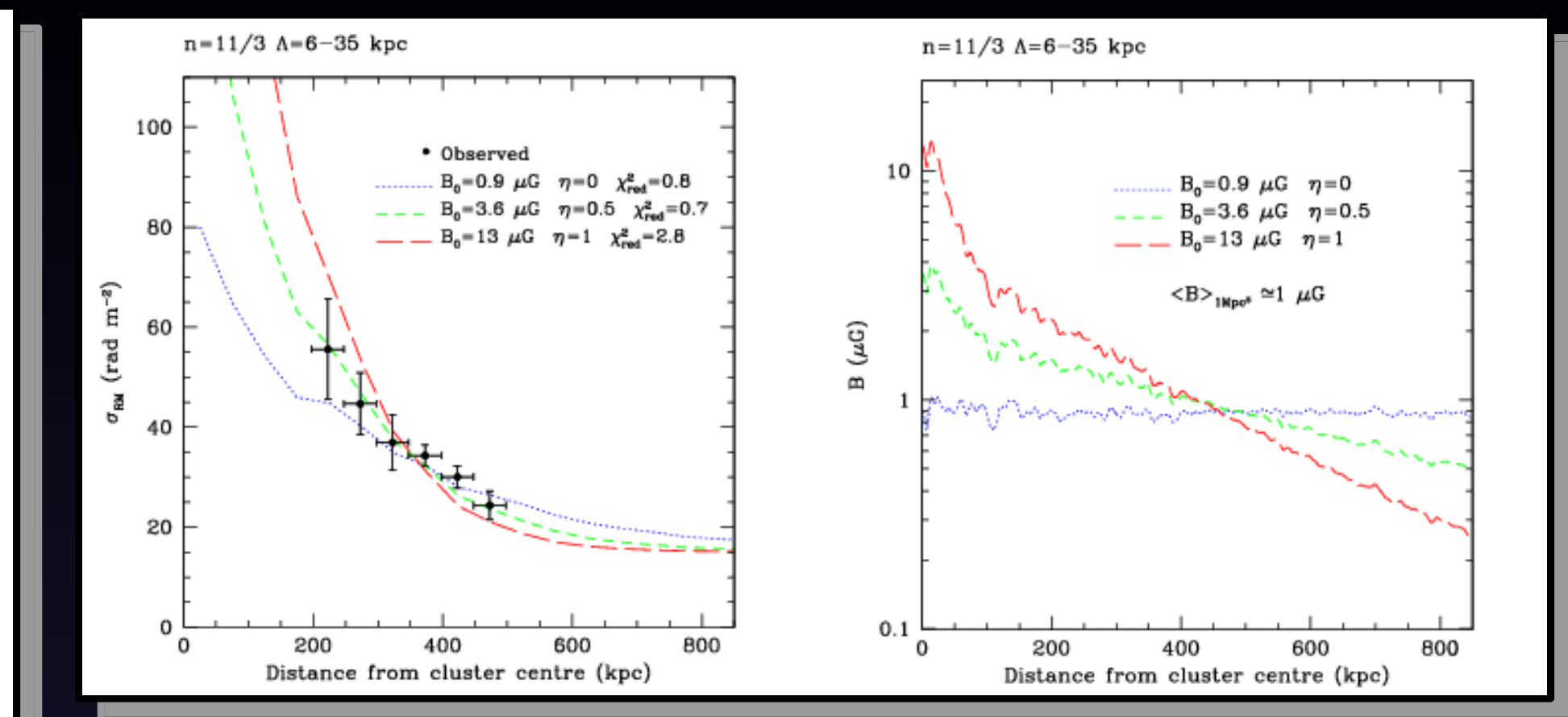
The software package **FARADAY** (Murgia et al. 2004) permits the study of cluster magnetic fields by comparing the observed RM with simulated RM images obtained by considering three-dimensional multi-scale cluster magnetic field models. In fact, given a three-dimensional magnetic field model and the density distribution of the intra-cluster gas, **FARADAY** calculates the expected RM image by integrating Eq.1 numerically. In the specific case of A2382, the integration is performed from the cluster center up to three core radii (~1.1 Mpc) along the line-of-sight, i.e. both sources are supposed to lie in a plane which is perpendicular to line-of-sight and intercepts the cluster centre. For the gas density we assume the double beta-model derived from the fit to X-ray surface brightness profile. For the intra-cluster magnetic field we adopt a power law power spectrum characterized by the following five free parameters:

Magnetic field model parameters

B_0	Average magnetic field strength at the cluster centre
n	Power spectrum spectral index; $\lvert B_k\rvert^2 \propto k^{-n}$
Λ_{min}	Minimum scale of the magnetic field fluctuations
Λ_{max}	Outer scale of the magnetic field fluctuations
η	Magnetic field radial profile slope; $\langle \mathbf{B}\rangle(r) = \langle B_0\rangle \left[\frac{n_e(r)}{n_0}\right]^\eta$







The analysis of the radially average RM profiles presented in the above plots shows that the best fit of the data is obtained with **η**=0.5 and **<B$_0$>** =3.6 µG. This value of **η** corresponds to a magnetic field whose energy density decreases from the cluster center as the square root of the gas electron density. The average magnetic field strength over the central 1 Mpc^3 is about 1 µG.

By using a source model of the intrinsic polarization, **FARADAY** produces, at each frequency and with the same noise as the data, the expected polarization images corresponding to the simulated RM. Furthermore, we can take into account both the beam and bandwidth depolarization effects. The synthetic polarization images can be then processed as they were real data, resulting in final simulated RM images which are filtered with the same algorithm as the observations. By comparing the observed and the simulated RM images, we conclude that the data are consistent with a power law magnetic field power spectrum with the Kolmogorov index n=11/3 while the largest scales of the magnetic field fluctuations are of the order of Λ_{max}=35 kpc. However, because of the degeneracy existing between n and Λ_{max}, the observed RM can be quite well explained also by a shallower power spectrum with n=2 and Λ_{max}=128 kpc.
From the observed depolarization levels we also found a constraint to the minimum scale of the magnetic field fluctuations: Λ_{min} ~ 6 kpc.

Reference

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