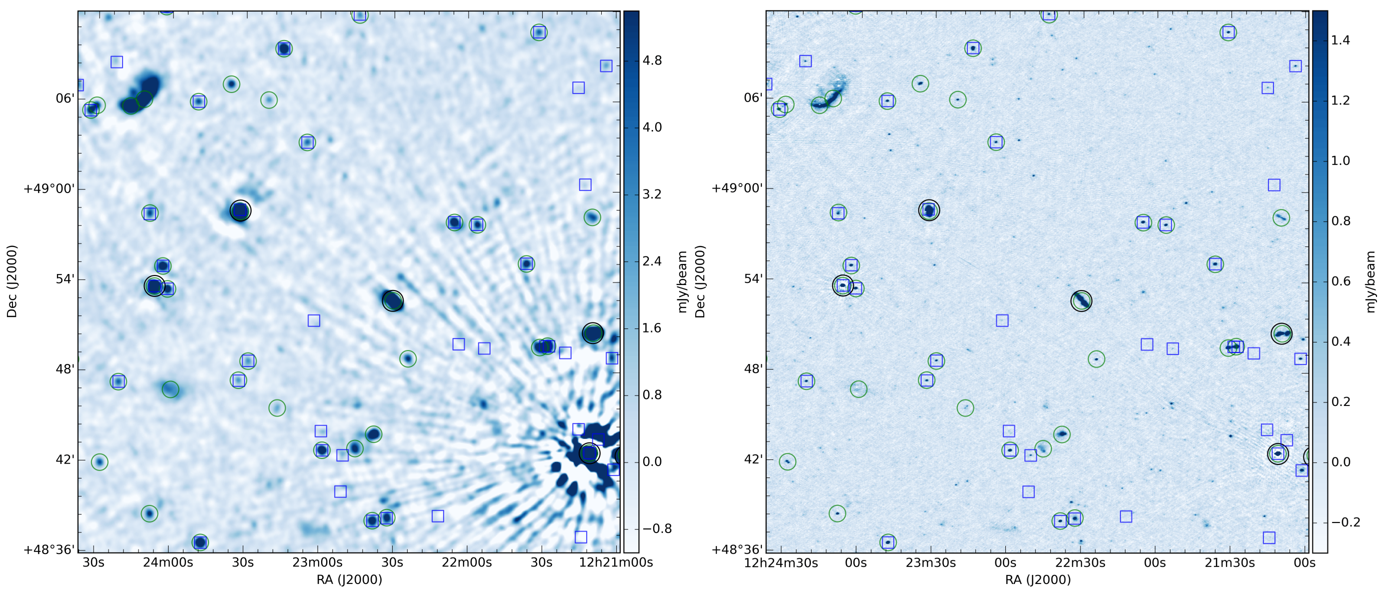

Fig. 13. Comparison between the direction-independent calibrated images and those we expect from direction-dependent calibration. *The right panel* shows a high-resolution, high-fidelity, approximately thermal noise limited image that was created using the facet calibration method. *The left panel* represents the same region in our direction-independent calibrated images. The colour scales on both images is between −3 and 10 times the noise where the direction-independent calibrated image noise is 360 μJy/beam and the facet calibrated image noise is 100 μJy/beam. The green circles show the positions of sources detected at seven times the noise in the direction-independent LOFAR image. The larger black circles and blue squares indicate entries in the TGSS and FIRST catalogues, respectively.

include post-merger turbulence and shock fronts, respectively. The LoTSS survey is expected to reveal many new examples of such emission and to characterise known examples in great detail (e.g. Cassano et al. 2010). In the preliminary data release more than 30 massive, Sunyaev Zel'dovich detected galaxy clusters (Planck Collaboration XXXII 2015) lie within the mapped region. This offers the opportunity for detailed studies of interesting objects and a large unbiased study to further understand the prevalence of radio halos and radio relics and to figure out in which clusters they occur.

Two interesting examples for detailed cluster studies are Abell 1550 (z = 0.254) and Abell 1682 (z = 0.226) whose low-frequency emission we show in Fig. 15. Abell 1550 was previously studied by Govoni et al. (2012) who concluded it was in a merging state after identifying an extension in the ROSAT X-ray emission and a displacement between the centroids of the X-ray emission and the optical galaxy distribution; using VLA observations they also detected diffuse radio emission from the ICM with a total 1.4 GHz flux density of 7.7±1.6 mJy and classified this as a radio halo. The steep spectrum (α is typically less than −1 for radio halos) implies that the total emission from the ICM should exceed ∼70 mJy at 150 MHz. In the LoTSS preliminary data release images at 12h29m05s +47°37′00″ there is a tentative detection of faint diffuse emission that appears to be associated with the ICM of Abell 1550, but there are several complex sources within the region of emission. Re-processing of the LOFAR data at higher angular resolution and sensitivity would allow the diffuse emission associated with the ICM to be precisely distinguished from contaminating radio sources to confirm this radio halo and further characterise it to provide additional insights into the dynamical state of this cluster. The galaxy cluster Abell 1682 has been well studied at radio frequencies from 150 MHz to 1.4 GHz by Venturi et al. (2008, 2011, 2013), and Macario et al. (2013). The cluster contains various regions of diffuse emission, arguably the most interesting of which is the faint emission around 13h06m56s +46°32′32″. This very steep spectrum ($\alpha_{240}^{610} = -2.09 \pm 0.15$) diffuse emission lies in a trough between two main regions of X-ray emission from the intra-cluster medium, and is thought to be either the brightest region of an underlying radio halo, a dying radio galaxy, or possibly even a radio relic (e.g. Macario et al. 2013). If it is a radio halo then it falls into the category of ultra-steep radio halos and these objects, of which only a few are known, are predicted by some models describing the origin of radio halos (see Cassano et al. 2006 and Brunetti et al. 2008). A detailed of analysis of LOFAR

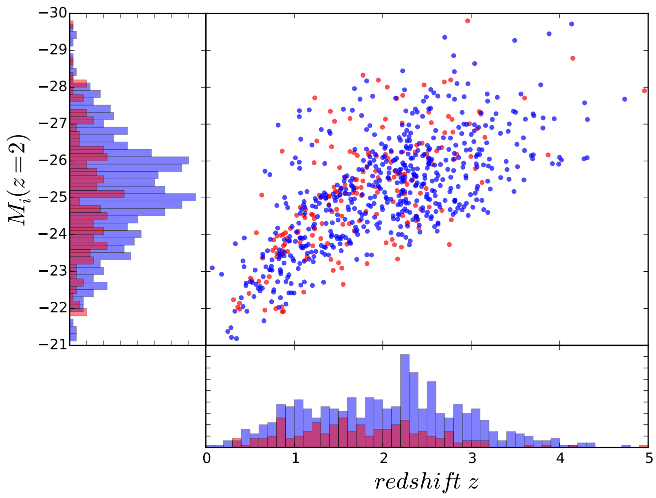

Fig. 14. Distribution of quasars in the magnitude-redshift space for the BOSS radio-loud quasars (Pâris et al. 2014) inside the survey footprint. Whilst 551 radio quasars are detected in both the FIRST and LOFAR images (blue circles), LOFAR is able to detect a further 191 that are not detected in FIRST (red circles). The absolute magnitude in the i band at z = 2 M_i (z = 2) is calculated using the K correction from Richards et al. (2006). The left and bottom panels show the M_i (z = 2) and redshift histograms.

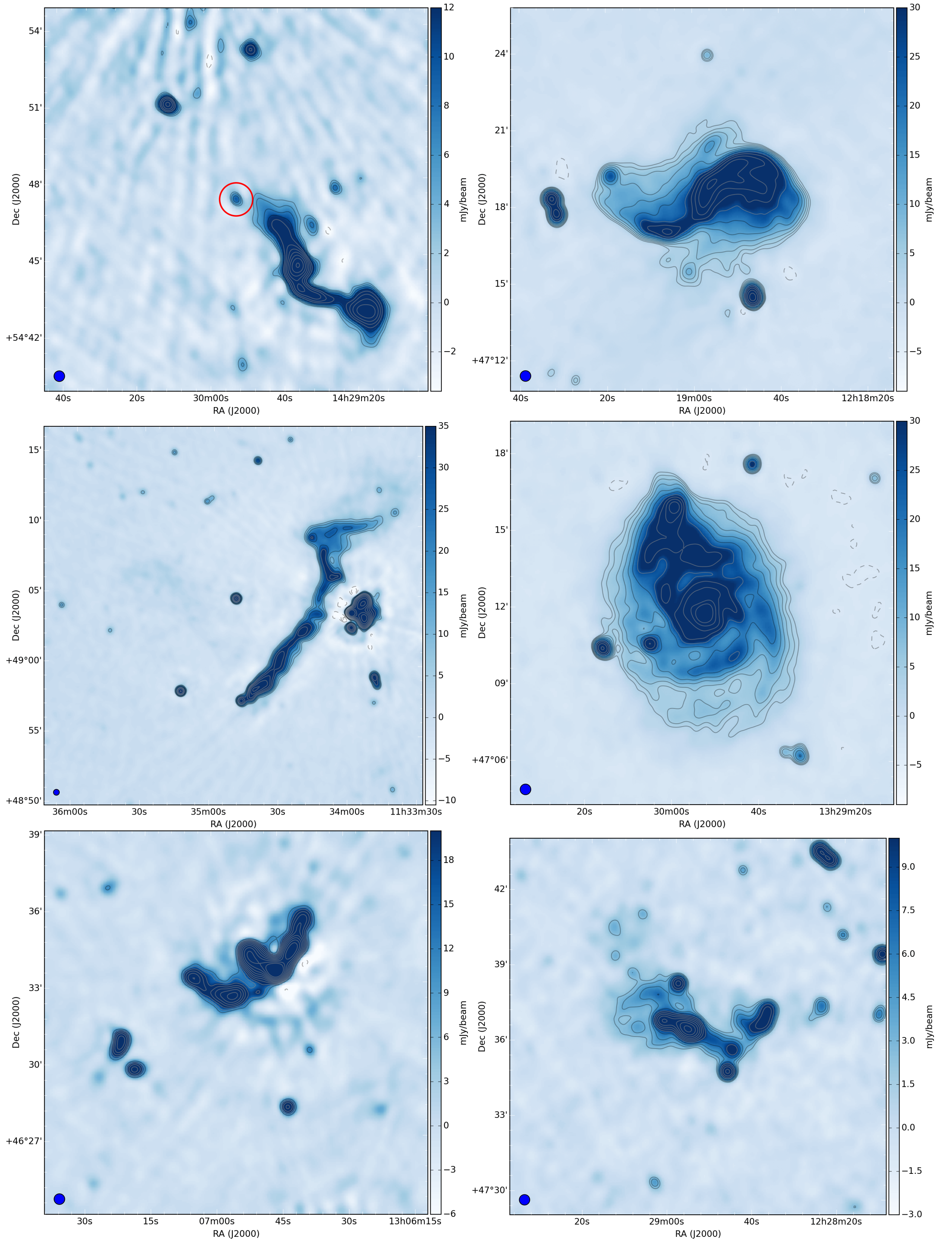

Fig. 15. Sample of rare objects whose low-frequency emission we characterised in the 25″ resolution preliminary data release images, which are now available for download in FITS format. Clockwise *from top left*: The z = 6.21 quasar J1429+5447 (circled); the nearby galaxies M 106 and M 51; the merging galaxy clusters Abell 1550 and Abell 1682; and the Mpc-scale tailed radio galaxy IC 711 that resides in the galaxy cluster Abell 1314. The contours and colour scale vary between images and were chosen to best emphasise the structure of each object. The synthesised beam is shown in the bottom left corner of each image.

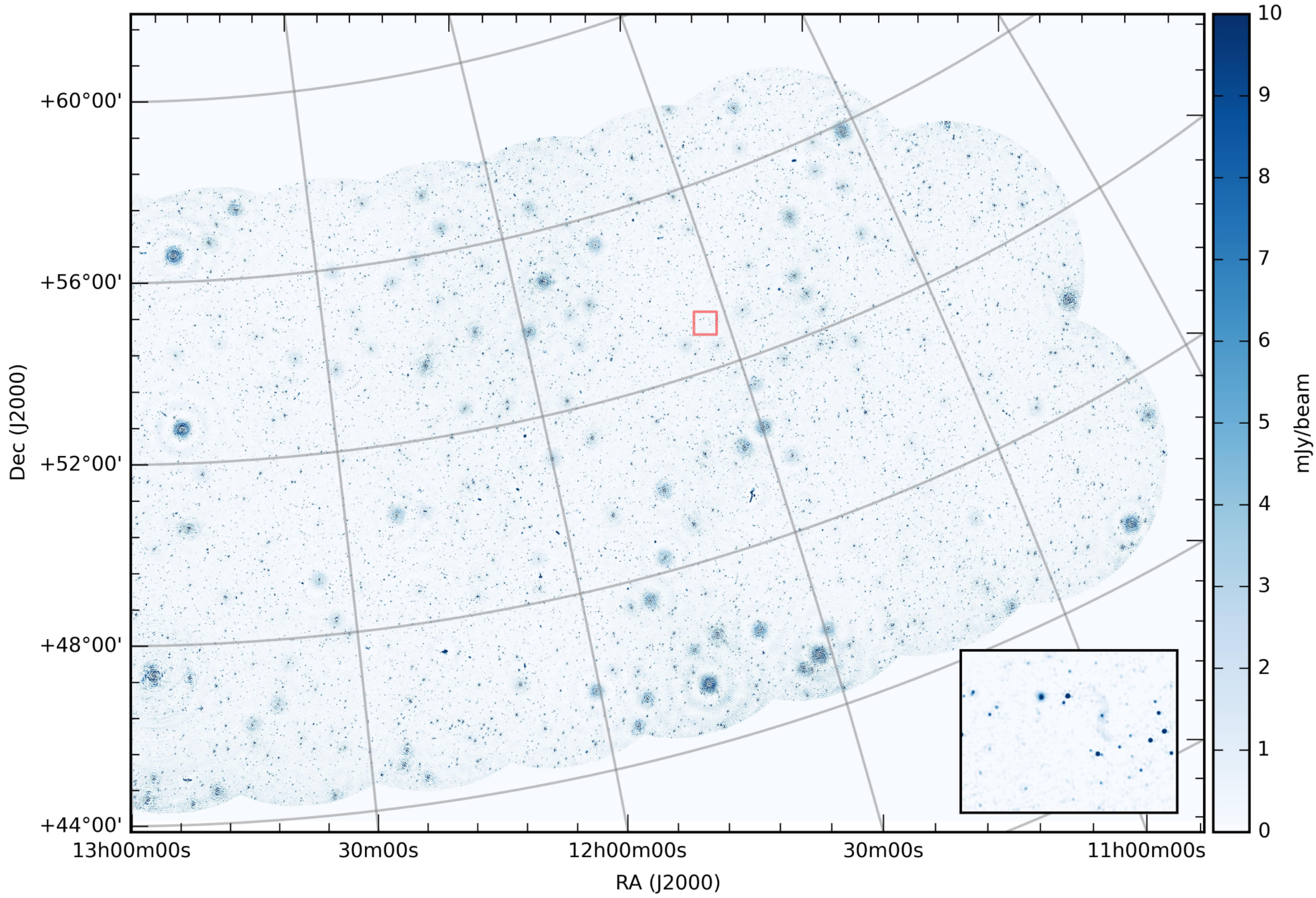

Fig. 16. Western half of the HETDEX Spring Field. A 0.5° × 0.5° image of the region outlined in red is shown in the bottom right corner.

HBA and LBA data of Abell 1682 is being conducted to produce sensitive high- and low-resolution images to further constrain the spectral properties of the radio emission and thoroughly assess its origin (Clarke et al., in prep.).

It is thought that the Square Kilometre Array (SKA) will detect approximately a million tailed radio galaxies (Johnston-Hollitt et al. 2015) and, similarly, LoTSS will detect a substantial number to facilitate interesting statistical studies. However, few tailed radio galaxies are more spectacular than IC 711 (z = 0.034) which, at a length of ~1 Mpc, is one of the longest known tailed radio galaxies (see e.g. Vallee & Wilson 1976). Detailed studies of tailed radio galaxies like this provide a history of their motion and of the interaction between the tails and ICM. For example, the oldest region of the tails of IC 711 is thought to be ~2 Gyr old, and the multiple intensity variations along the structure are thought to be caused by in situ reacceleration, whereas the abrupt increase in the width of the tail close to its northern edge may reflect a sudden change in the jets physical conditions within the optical nucleus ~1.6 Gyr ago or the properties of the surrounding ICM (Vallee 1988). The LoTSS observations of IC 711 that are presented in Fig. 15 are by far the most sensitive low-frequency observations of this object. A careful analysis may reveal that the jet is even longer than previously known, and by combining with higher frequency measurements, the spectral index variations within the tails can be accurately mapped to help further understand the particle acceleration mechanisms within the tails.

Along with such examples of spectacular and peculiar sources, the survey can also be used to provide crucial insights into the dynamics, energetics, and duty cycle of the radio galaxy population as a whole. The LOFAR studies of individual active (e.g. Orrù et al. 2015; Harwood et al. 2016; Heesen et al. 2016) and remnant (Shulevski et al. 2015b; Brienza et al. 2016) radio galaxies have already expanded our understanding of radio galaxies at low frequencies, but studies of the larger sample of sources that we have imaged will provide the opportunity to determine the applicability of these findings to the population as a whole.

11. Summary

In this publication we described the LoTSS, for which we aim to produce high-fidelity images of the entire northern sky with a resolution of ≈5″ and sensitivity of ≈100 μJy/beam at most declinations. We summarised a survey strategy that should allow us to reach these ambitious observational aims. This consists of 3170 pointings that are each observed for 8 h with frequency coverage from 120 to 168 MHz and archived with sufficient spectral and time resolution to allow future spectral line studies and subarcsecond resolution imaging. The survey was initiated in mid-2014 in the region of the HETDEX Spring Field. As of November 2016 we will have observed 20% of the sky above a declination of 25° and we are preparing to further increase our observing rate.