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A Simple Minded Approach to Polarization Mosaics

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A well known problem with radio polarimetric imaging with the VLA is the 'cross polarization lobes' in the primary beam (Bignell 1982). These lobes result in an apparent (anomalous) polarization for an intrinsically unpolarized source located away from the pointing center, an effect which is not corrected for in standard VLA polarization calibration. Such anomalous polarization will lead to obvious problems when using multiple pointings to image objects with sizes comparable to, or larger than, the primary beam. This memorandum outlines a simple approach to creating linear mosaics of images of the Stokes Q and U parameters which addresses the anomalous polarization problem. We emphasize that the solution presented herein is applicable to astronomical sources with a very specific morphology. A general solution to polarization mosaics remains problematic.

The problem has two parts. First is the basic problem of the increase in the anomalous polarization response of the telescope with distance from the pointing center. Figure 1A shows the observed fractional polarization for an intrinsically unpolarized point source as a function of distance from the pointing center. These data were taken in the D array at C band. The integration time was six hours. The observed fractional polarization of the source increases from less than 0.2% for the on-axis pointing, to 4.5% when the source is close to the first null of the primary beam.

Second is the problem of two dimensional structure in the 'cross polarization lobes' (see Fig. 6.6 in Bignell 1982). As a result, the observed anomalous polarization of a source at some distance from the pointing center changes as a function of parallactic angle, since the source is moving through the 'cross polarization lobe' pattern (*i.e.* the 'cross polarization lobe' pattern rotates with time). Fig. 1 B shows the observed values of Q and U as a function of parallactic angle for an intrinsically unpolarized source situated at the half-power point of the primary beam. These data were taken in the D array at L band. The observed values of Q and U vary from about -30 mJy to +30 mJy over the course of the six hour observation (or from -2% to +2% of the peak in total intensity).

This temporal variability will have dramatic effects on images of Q and U, as demonstrated in Fig. 2. Figure 2 A shows an image of U generated using all of the data from a six hour synthesis observation of an intrinsically unpolarized source situated at the half-power point of the primary beam. Figure 2 B shows an image of U generated using only 20 minutes of the data. The artifacts in Fig. 2A are the result of the variation with parallactic angle of the anomalous polarization of the source. In Fig. 2B, the fractional polarization of the source itself remains high, but the artifacts due to source variability are greatly reduced.

The astronomical situation addressed in this memorandum is one in which there is a single, bright source surrounded by extended, low surface brightness emission. The particular example used is the inclined spiral galaxy NGC 253. The observations entailed three pointings along the major axis of the galaxy, with the pointings separated by the HWHM of the primary beam, and with one of the pointings centered on the bright source (at the center of the galaxy). Observations were made at L band in D array. Data from each pointing were self-calibrated. A linear mosaic of total intensity was then generated from the images from each pointing using the LTESS program. The LTESS program performs a linear combination of images from multiple pointings, weighting according to the primary beam and using information from each pointing out to the 7% point of the primary beam (Braun 1988). The resulting total intensity image of NGC 253 is shown in Fig. 3A. The galaxy is roughly 18′x6′ in size. The surface brightness for most of the galaxy is below 50 mJy/beam, except for the nucleus, which has a surface brightness of 1.47 Jy/beam.

Polarization mosaicing involved two processes. First, in order to avoid problems arising from the variation with parallactic angle of the anomalous polarization of the nucleus in the outer pointings, the data were first divided into a series of 20 minute 'snap-shots'. This entailed a total of five snap-shots over six hours for each pointing. Deconvolved Q and U images were then generated from each snap-shot database. These images were then summed to form 'final' Q and U images for each pointing.

Second, in order to avoid the residual (anomalous) polarization of the nucleus itself (see Fig. 2B), a new parameter was added to the LTESS program allowing the user to set the level in the primary beam beyond which data from a given pointing are not used (the new program is called LPTES). Linear mosaic images of Q and U were then made from the images from the three pointings using the LPTES program, and clipping at the 60% point of the primary beam. (Recall that the nucleus was situated at the half-power point of the primary beam for the outer pointings.)

The resulting polarized intensity image is shown in Fig. 3C. It can be seen that this combination of processes removes effectively the artifacts due to variation with parallactic angle of the anomalous polarization of the nucleus, and the residual polarization of the nucleus itself. The noise on this image is about 70 μJy, which is close to theoretical. It should be noted that the noise on the LPTES image is not uniform across the image, as it is (roughly) when using the normal LTESS algorithm.

For comparison, in Fig. 4 are shown three images of the polarized intensity from NGC

253 generated in different ways. Fig. 4A shows an image generated using only the central pointing. The increase in the noise at the edges of the field in Fig. 4A is due to the response of the primary beam. Fig. 4B shows a polarization mosaic image generated with the LPTES program in the same way as Fig. 3B, but the input Q and U images were generated by imaging all the data at once (*i.e.* without imaging in 'snap-shots'). The noise in Fig. 4B is 180 μJy/beam, or roughly 2.5 times that in Fig. 3C. This higher noise level is the result of imaging artifacts arising from the variation with parallactic angle of the anomalous polarization of the nuclear source in the outer pointings. And Fig. 4C shows an image generated by imaging Q and U in 'snap-shots', but then using the LTESS program to sum the pointings (*i.e.* clipping at the 7% point of the primary beam). In this case the residual (anomalous) polarization of the nucleus remains high.

References

Bignell, R.C. 1982, in *Synthesis Mapping*, eds. A.R. Thompson and L.R. D'Addario, NRAO, Greenbank, WV.

Braun, R. 1988, *Millimeter Array Memo. no. 46*, NRAO, Socorro, NM.

Figure Captions

Figure 1A: The fractional anomalous polarization of an intrinsically unpolarized source as a function of distance from the pointing center. Data was taken in the D array at C band. The integration time was 6 hours.

Figure 1B: The anomalous polarization (Stokes Q and U) of an intrinsically unpolarized source situated at the half power point of the primary beam, as a function of parallactic angle. The total flux density of the source is 1.47 Jy. The data was taken in D array at L band.

Figure 2A: An image of Stokes U for an intrinsically unpolarized source situated at the half-power point of the primary beam, generated from a six hour synthesis observations at L band in D array. The total flux density of the source is 1.47 Jy. The image has been CLEANed with a restoring beam of $70''$x$40''$, oriented north-south. This restoring beam is used in all subsequent images.

Figure 2B: The same as Fig. 2B, but now using data from a single 20 minute integration.

Figure 3A: A total intensity 'linear mosaic' image of NGC 253 made using three pointings along the major axis, and using the LTESS program to combine images from the three pointings.

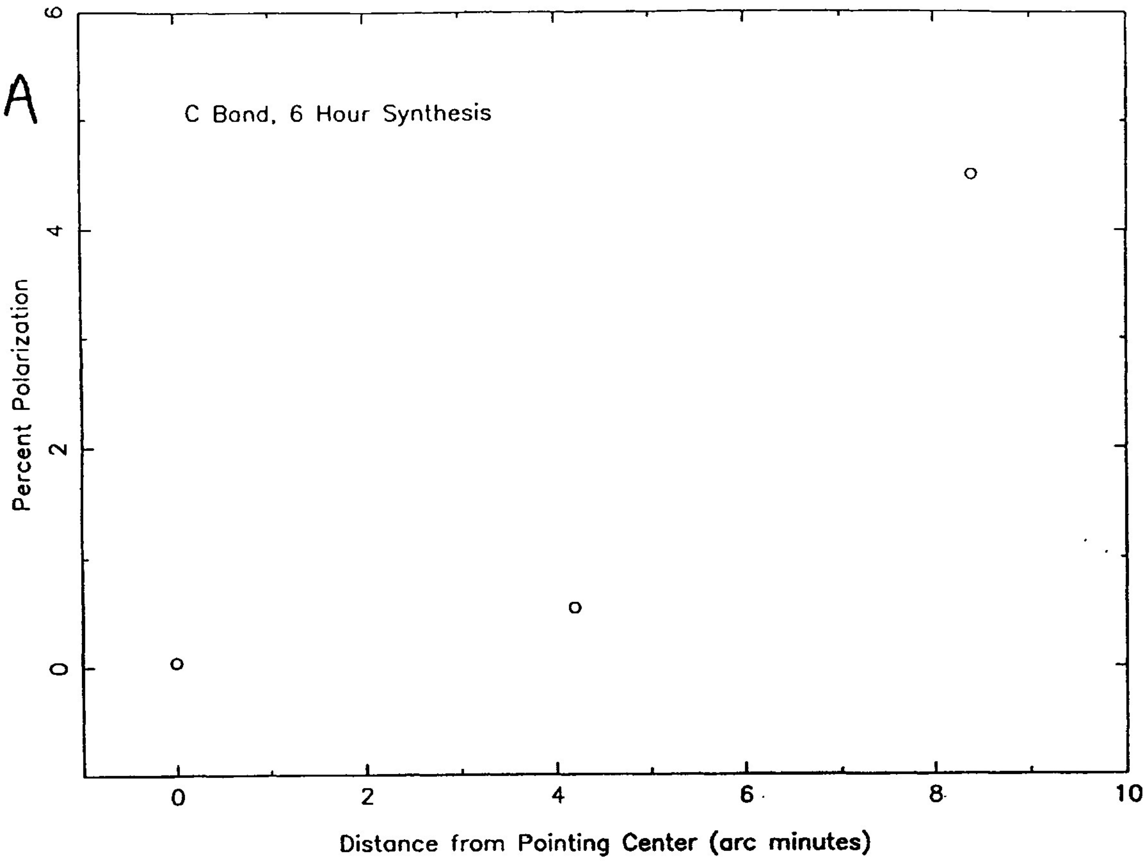
Figure 3B: A polarized intensity image of NGC 253 made by imaging in 'snap-shots' and using the LPTES program to combine images of Q and U from the three pointings. The primary beam was clipped at the 60% point. The X marks the position of the nucleus.

Figure 4A: A polarized intensity image of NGC 253 made using data from the central pointing only.

Figure 4B: A polarized intensity image of NGC 253 made by imaging all the data at once, and using the LPTES program to combine Q and U images from the three pointings. The primary beam was clipped at the 60% point.

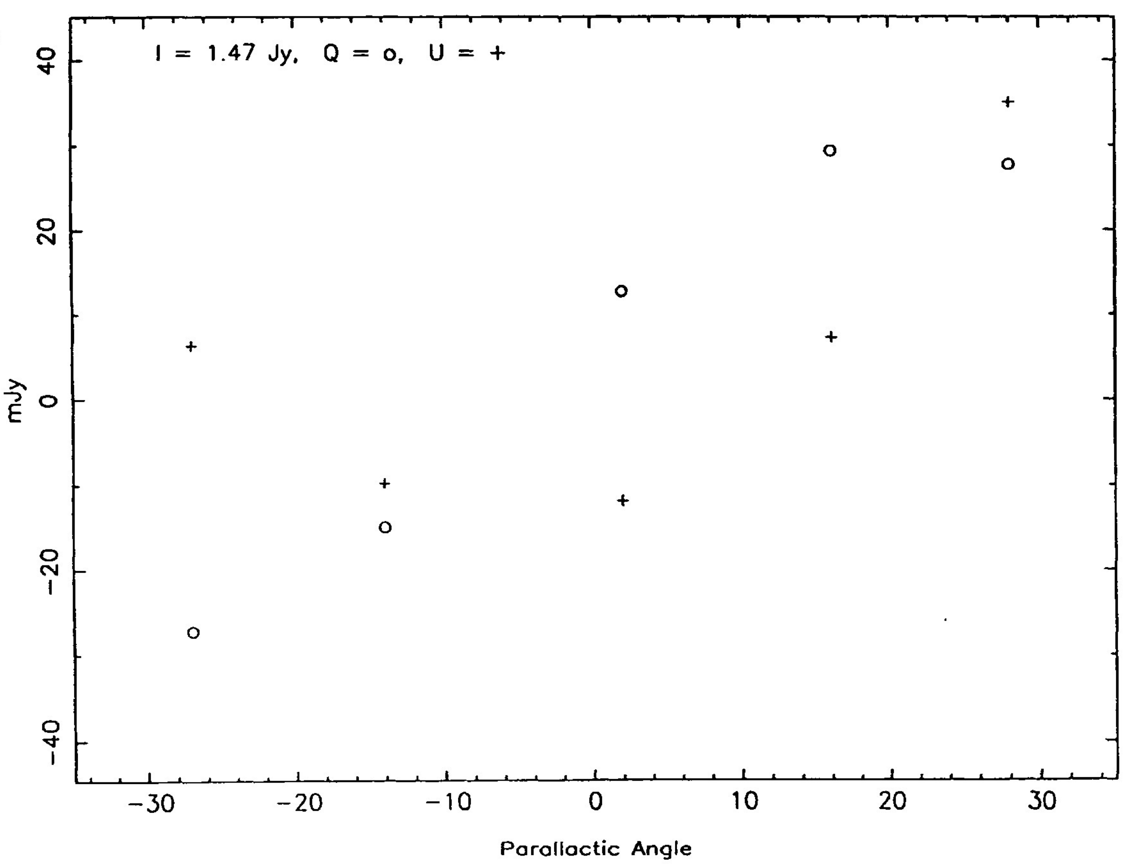
Figure 4C: A polarized intensity image of NGC 253 made by imaging in 'snap-shots', and using the LTESS program to combine Q and U images from the three pointings.

1A



C Band, 6 Hour Synthesis
Percent Polarization
Distance from Pointing Center (arc minutes)

1B



I = 1.47 Jy, Q = o, U = +
mJy
Parallactic Angle

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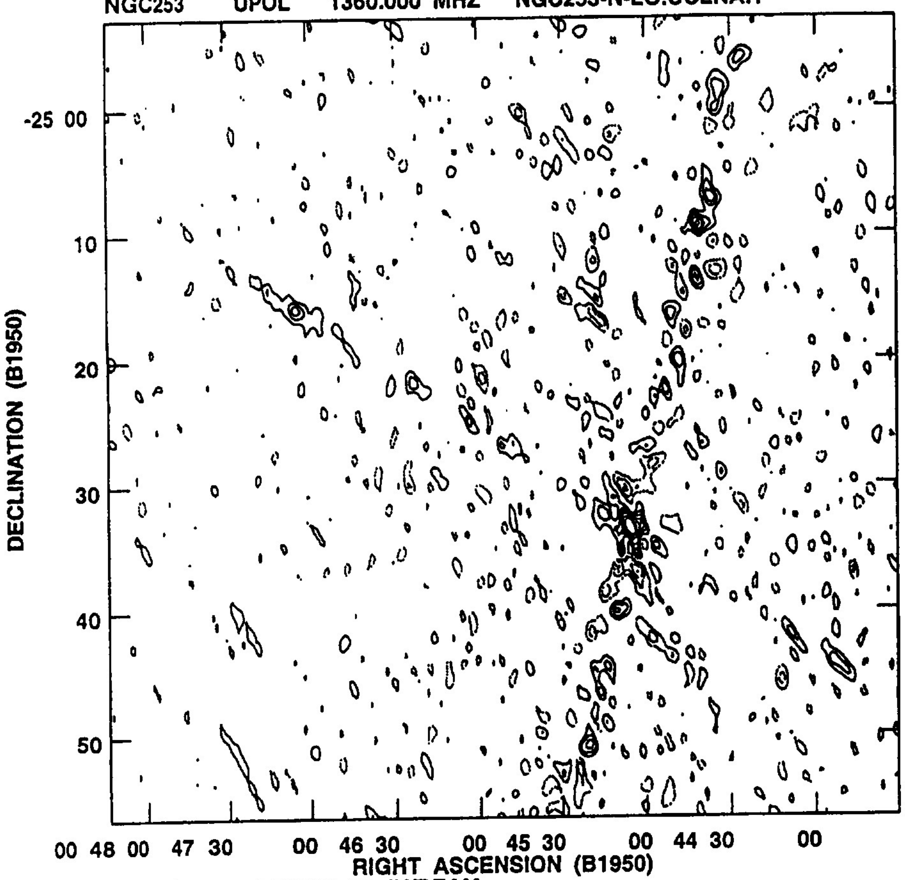
NGC253 UPOL 1360.000 MHZ NGC253-N-LO.UCLNA.1



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2.000, 4.000, 6.000, 8.000, 10.00, 15.00,
20.00, 60.00, 120.0)

2A

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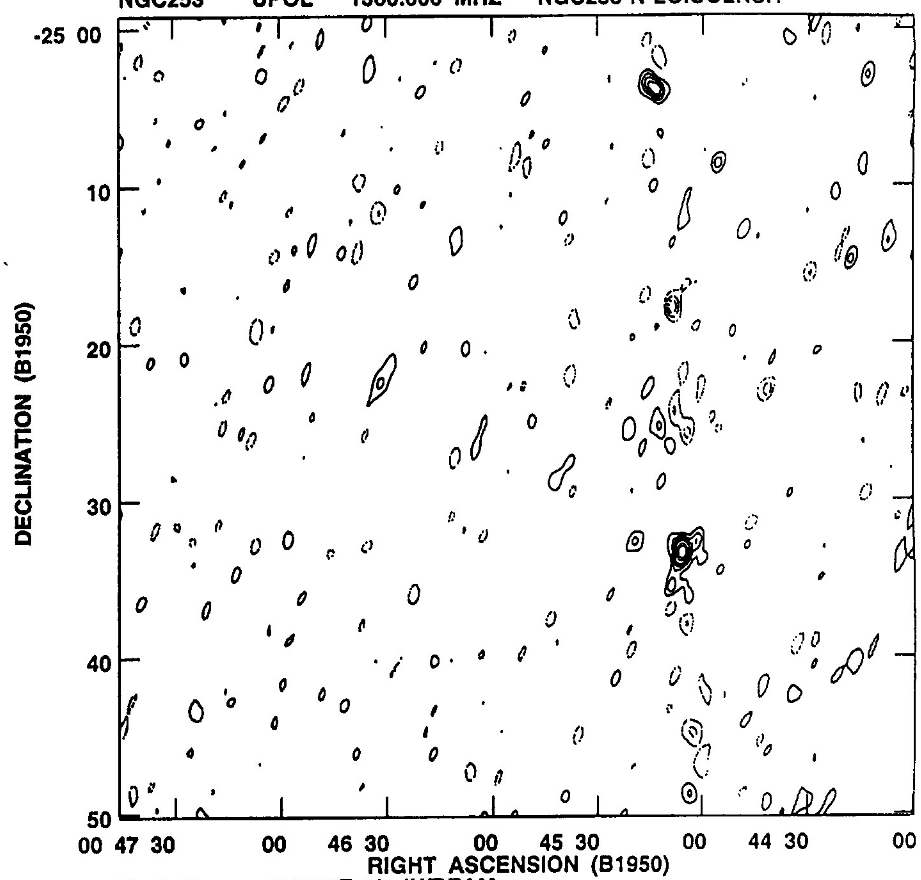

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20.00, 60.00, 120.0)

2B

3A

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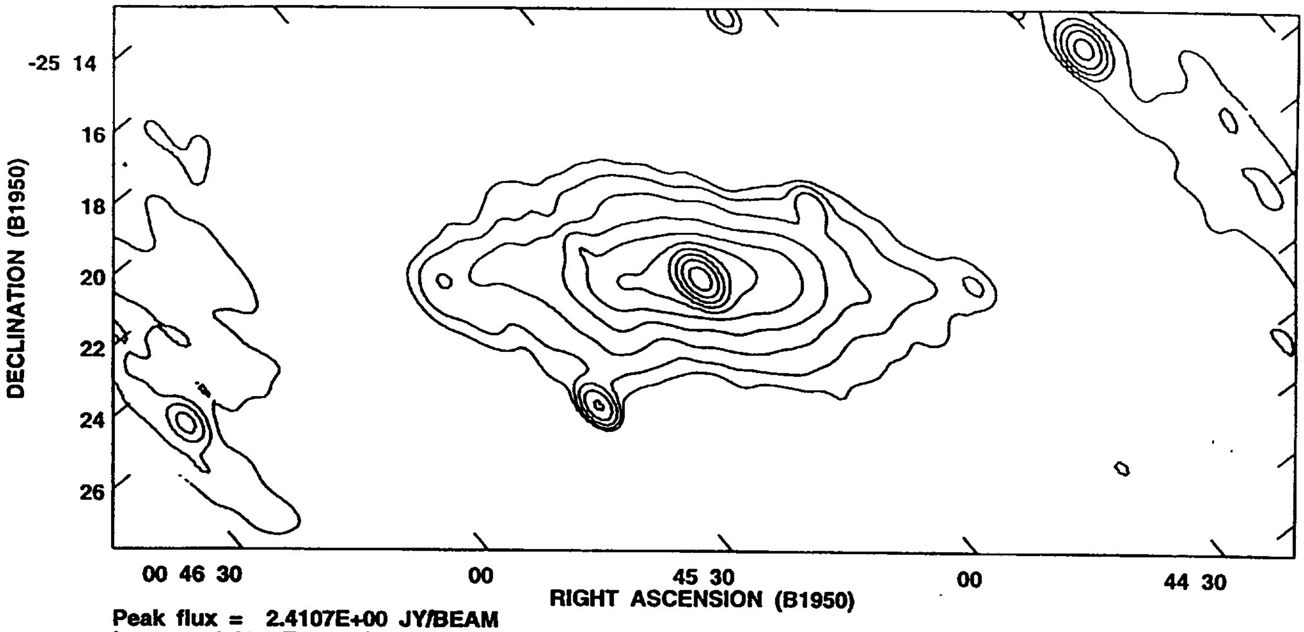
NGC253 IPOL 1465.000 MHZ NGC253-LLCD.HGEOM.3



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3B

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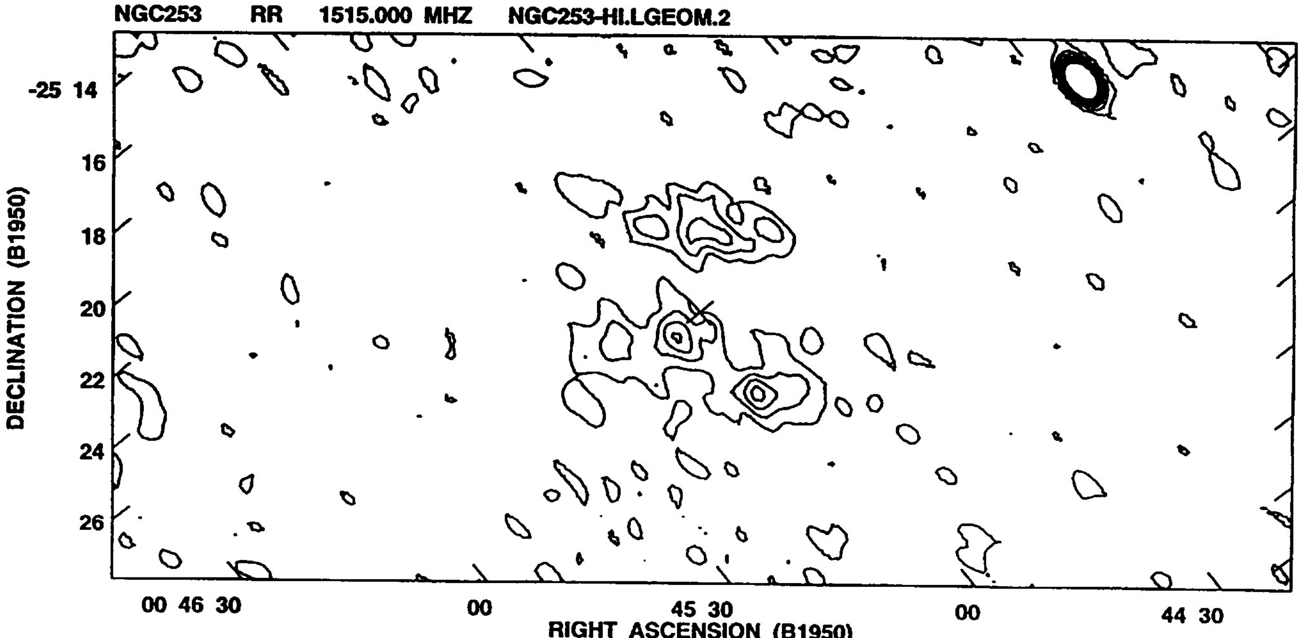
NGC253 RR 1515.000 MHZ NGC253-HI.LGEOM.2



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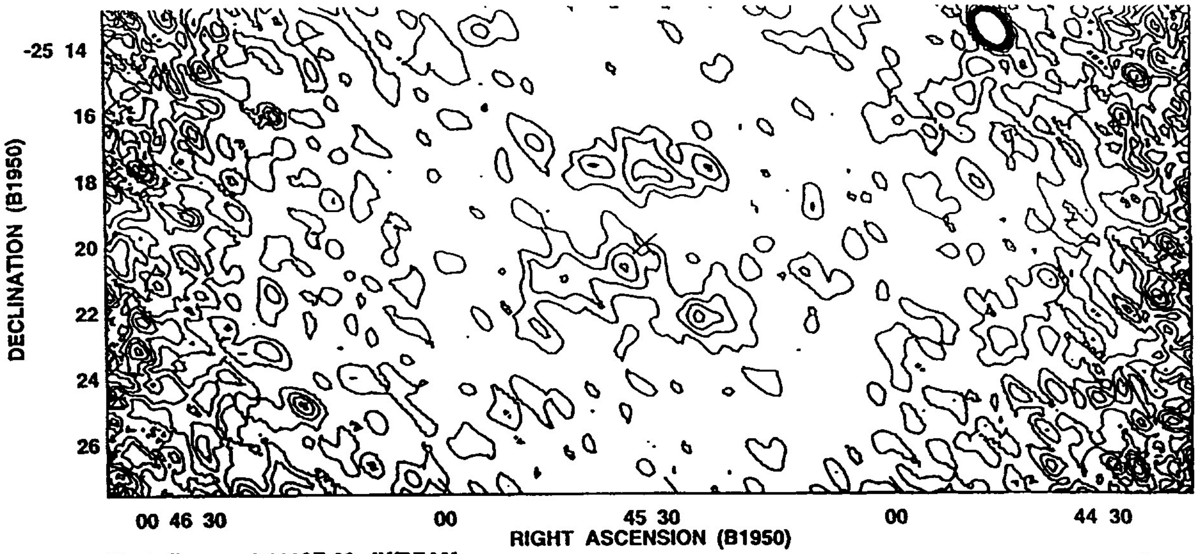
4A



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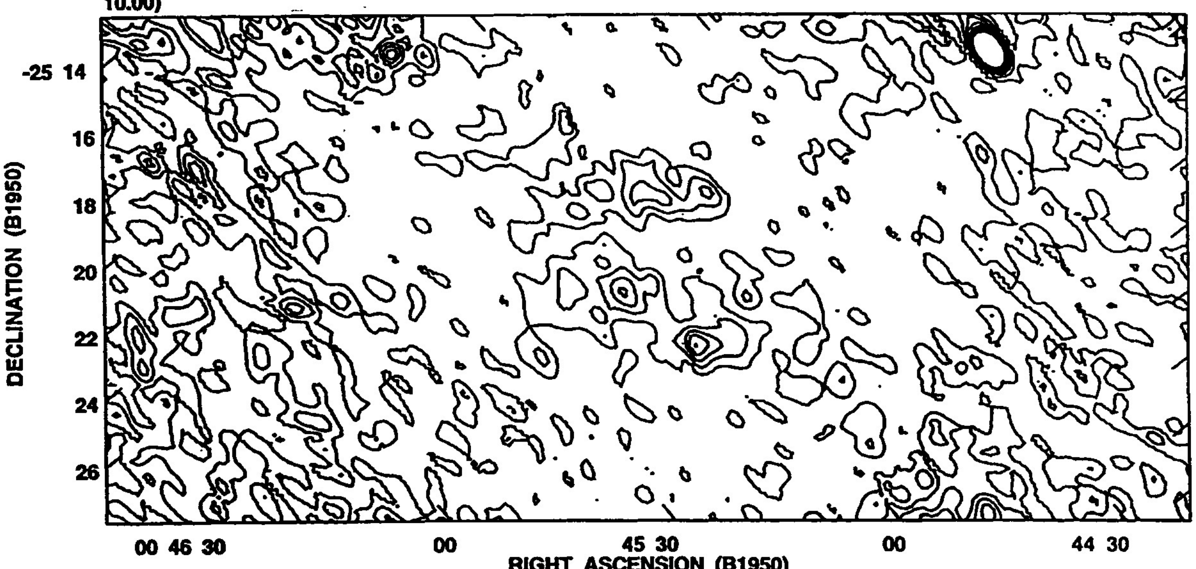
4B



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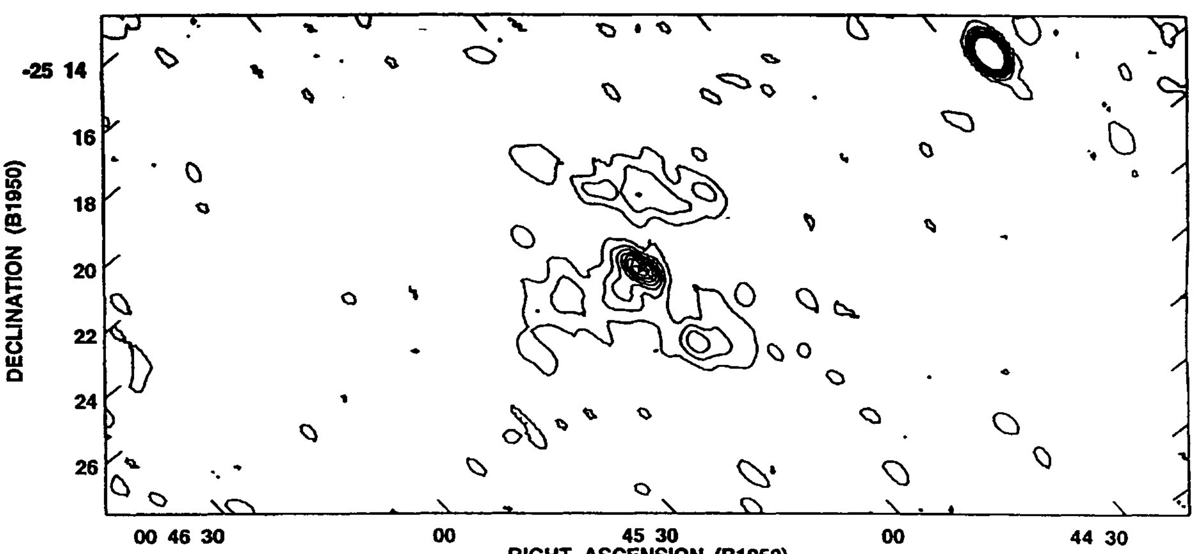
4C



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