GAIN CODES AND MAP ARTIFACTS

VLA COMPUTER MEMORANDUM NO. 169

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I. Introduction

While processing some observations in 1982, I automatically ran EXPREP on the data which increased the gain code by 2. When L mapped the source using AIPS, I found an 3mJy negative point-like artifact at the center of the map. I now have followed up on this result and report below on my systematic studies of the effects of increasing the gain code after the fact and of observing with too high a gain code. (Decreasing the gain code below the appropriate value or observing with too low a gain code will obviously lose significant high-order bits.)

II. Changing the gain code

My conclusions are based upon three sets of observations: a twelve-minute snapshot (83sep02), a one-hour synthesis consisting of six ten-minute snapshots spread over four hours (83oct21), and a full six-hour synthesis (82aug15). Because the effect scales as 2**GC, I will present only the results for a gain code of 8.

For the twelve-minute snapshot I observed a blank field centered on 02h00m00s and 70d00'00" (1950) at 4885MHz with 50MHz bandwidth in the A configuration. After editing and calibration the observations with a gain code of 0 were exported, the gain code was increased by 8 using a CANDID routine ADJGAI written by Gareth Hunt, and the data were exported again. IQUV maps (512x512) were produced from the two sets of data using AIPS and the final maps were made by subtracting the latter from the former.

The one-hour synthesis observations were similar to the snapshot, except that six ten-minute snapshots were spread over four hours. The subsequent processing was the same.

The above observations were made during test time; the six-hour synthesis was obtained from regular observations of the nuclear region of the normal spiral galaxy M51 (N5194, 1327+474). The frequency and bandwidth were the same as above but the configuration and gain code were B and 3. In the subsequent processing the gain code was increased from 3 to 8 and the map size was 1024x1024.

The result in all three cases was a point-like artifact (negative in the original map) near the map center in the I and Q difference maps and random noise in the U and V difference maps. Similar tests for intermediate gain codes showed that the magnitudes of the artifacts in the I and Q maps and of the noise levels in the U and V maps scale as 2**GC. The peaks in the three sets of I and Q maps lie within one cell of the map center; I attribute the offsets to the random noise in the maps. These results are summarized in Table 1. Figures 1-3 show clean maps made of the central regions of the three I difference maps. In addition to the central point-like artifacts, all three maps show antisymmetric structure spread over the map. Comparing the three maps shows that the antisymmetric artifacts integrate away with increased integration time and improved uv coverage, decreasing from 2.5mJy in the snapshot to 0.8mJy in the six-hour synthesis.

Table 1. Peak Magnitudes in Difference Maps

STOKES	I		Q		U	V
12-MIN SNAPSHOT	15.7mJy	(256,256)	15.7mJy	(256,256)	0.3mJy	0.3mJy
1-HR SYNTHESIS	16.0	(256,258)	16.0	(256,258)	0.13	0.13
6-HR SYNTHESIS	15.3	(512,512)	15.4	(512,512)	0.07	0.07

Similar maps made using MAPCON on MAPPER and GRIDER showed no artifacts. In MAPCON the gains and rounding are applied (apparently correctly) in the array processor.

The origin of these artifacts is in EXPVIS, as the gains are applied and the data are reformatted according to the value of the gain code. Subsequently, after the data are read into another system, maps are calculated according to

$$I_m(x,y) = 2K \sum_{\ell=1}^{L} S_{R\ell} \cos 2\pi(u_\ell x+v_\ell y) + S_{I\ell} \sin 2\pi(u_\ell x+v_\ell y),$$

or at the map center

$$I_m(0,0) = 2K \sum_{\ell=1}^{L} S_{R\ell}.$$

If EXPVIS introduces a systematic bias when it reformats the data, a negative (positive) bias will produce a negative (positive) artifact at the map center where the real terms add coherently. Away from the map center the biased data tend to add together with random phases and cancel. In maps like the UV maps in which correlators are differenced the biases will cancel.

How can EXPVIS bias the data? Rounding introduces no bias, although it may increase the noise level. Truncation of noise will introduce no bias but when applied to a positive signal will produce a negative bias and vice versa for a negative signal. Use of the ceiling and floor functions will cause positive and negative biases, respectively, for any data.

What magnitude of artifact will these processes cause? If the quantization level is x, then the bias applied to an individual datum will vary between zero and x, with an average value of x/2. Thus the magnitude of the artifact in the final map should be x/2. Thus, since the observed magnitude for a gain code of 8 is about 16mJy, the corresponding quantization level is approximately 32mJy (confirmed by examining the data in AIPS). However, for a gain code of 8 at 4885MHz, the appropriate quantization level should be 256Jy/32768 or about 8mJy. Thus, not only is EXPVIS introducing a bias, the bias at 6cm is four times larger than necessary.

III. Observing with too high a gain code

This past summer Will van Breugel reported ring-like artifacts with maximum amplitudes of a few hundred microJy in his maps for a supernova remnant that he had observed with a gain code higher than required; he used the gain code appropriate for the total flux density of the remnant rather than the maximum correlated flux density observed.

To explore the nature of such artifacts, I observed the same blank field as above with gain codes between 0 and 8. I will report here on three particular observations made in the A configuration at 4885MHz with a gain code of 8: a one-minute snapshot, a ten-minute snapshot, and a one-hour synthesis consisting of six ten-minute snapshots spread over four hours.

IQUV (512x512) maps were produced using AIPS from the three sets of data.

In all three cases the maps in the four Stokes parameters showed large-scale artifacts spread over the maps. As the integration time increases and the uv coverage improves, the magnitudes of the artifacts decrease slowly and the structures of the artifacts become more coherent. This is apparent in Figures 4-6 which show the I maps for the three sets of observations. The maximum and minimum values in the four Stokes parameters for the three sets are tabulated in Table 2.

Table 2. Maximum and Minimum Values in Maps for Gain Code of 8

STOKES	I	Q	U	V
1-MIN SNAPSHOT	7.8/-14.4mJy	7.9/-10.2mJy	9.5/-14.7mJy	13.1/ -8.9mJy
10-MIN SNAPSHOT	6.6/-13.9	7.0/-12.0	7.4/-16.6	12.5/-10.3
1-HR SYNTHESIS	3.5/ -5.8	4.1/ -4.5	5.3/ -5.9	3.4/ -4.0

Figures 7-9 show the QUV maps for the 1-hr synthesis and the structures of the artifacts in these maps resemble that seen in the I map, although the minimum and maximum values differ by significantly more than the noise. For comparison, in Will van Breugel's observations (an 8-hour synthesis at 6cm with a gain code of 5), the magnitude of the artifact is about 0.3mJy

Another set of snapshots with all gain codes between 0 and 8 confirms that the magnitudes of the artifacts vary approximately as 2**GC. An instrumental origin is improbable because a simultaneous synthesis made with a gain code of 0 showed nothing above the noise. In this case EXPVIS is not the culprit since maps made with MAPCON show very similar artifacts, differing in detail because of differences in map size and convolution function.

The cause of these artifacts is obscure. The rounding that is applied to the output of the array processor is applied with random phase, which is further randomized by the calibration; the net effect of rounding should be to spread random noise around the map. The apparent negative bias does not arise in EXPVIS since the MAPCON maps show the same effect. The coherent structure is very puzzling in view of the expected random phases.

IV. Recommendations

EXPVIS should be changed so the data are properly rounded. The quantization level should be reduced to the appropriate value. EXPREP should be used only as a last resort.

The half-word floating-point format should be implemented throughout the synchronous system as soon as possible; then the gain code could easily be reset by refilling the data.

One problem still remains: the gain code for the parallel-hand correlators is inappropriate for the cross-hand correlators since the linearly polarized signals are typically 0.01-0.5 of the total intensity.

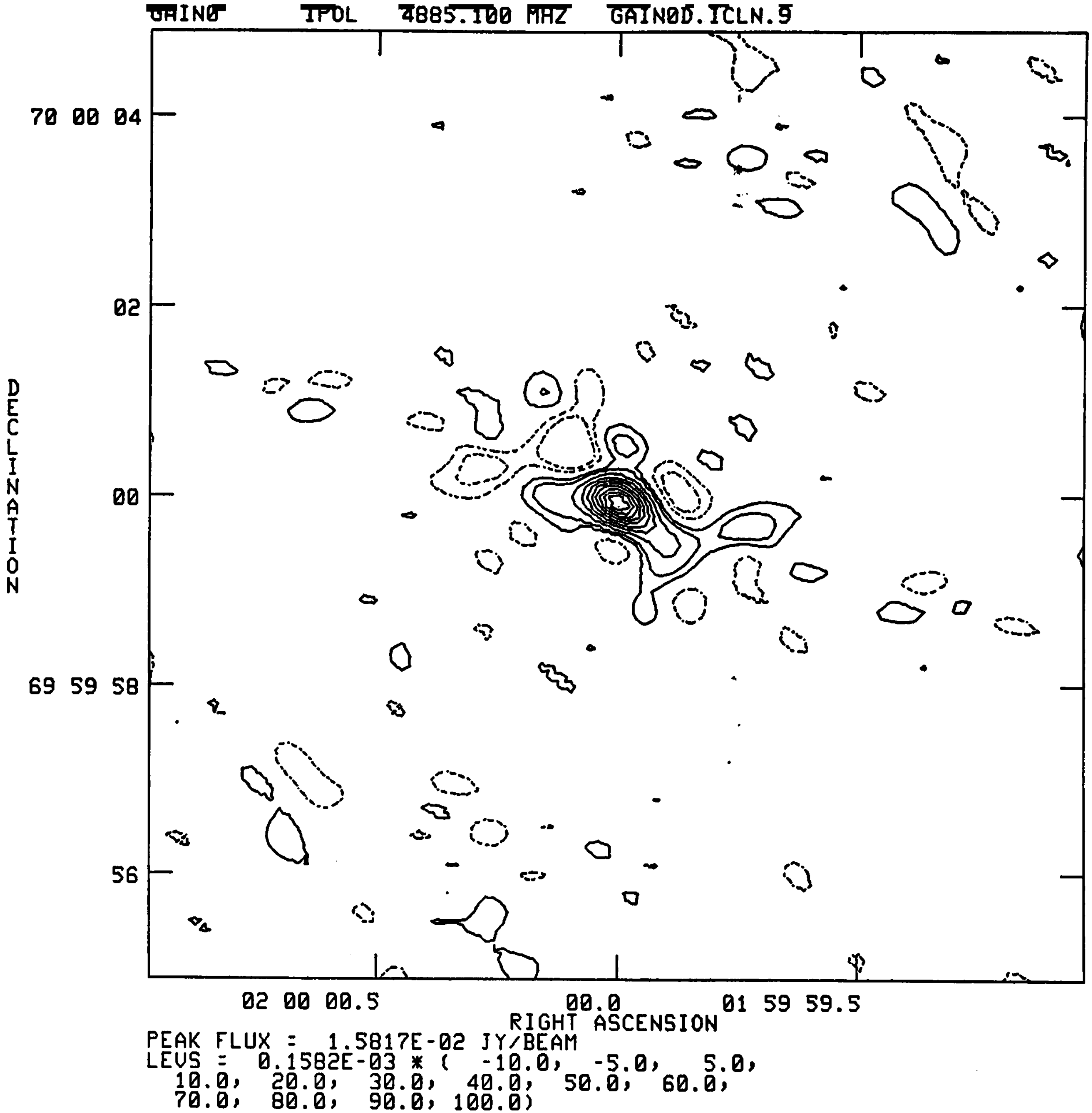


FIGURE 1. 12-Min Snapshot I Map, Gain Code Adjusted to 8.

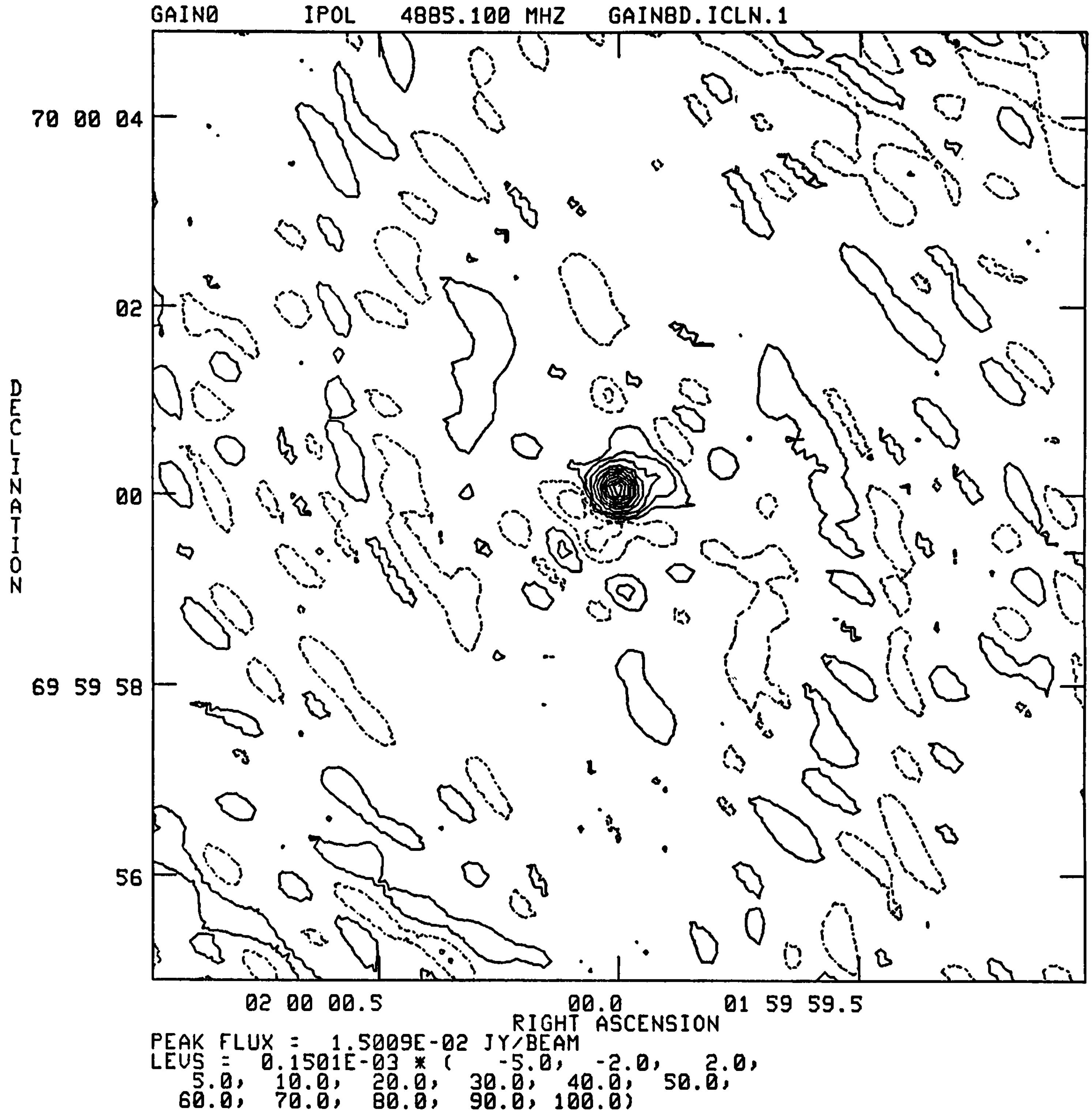


FIGURE 2. 1-Hr Synthesis I Map, Gain Code Adjusted to 8.

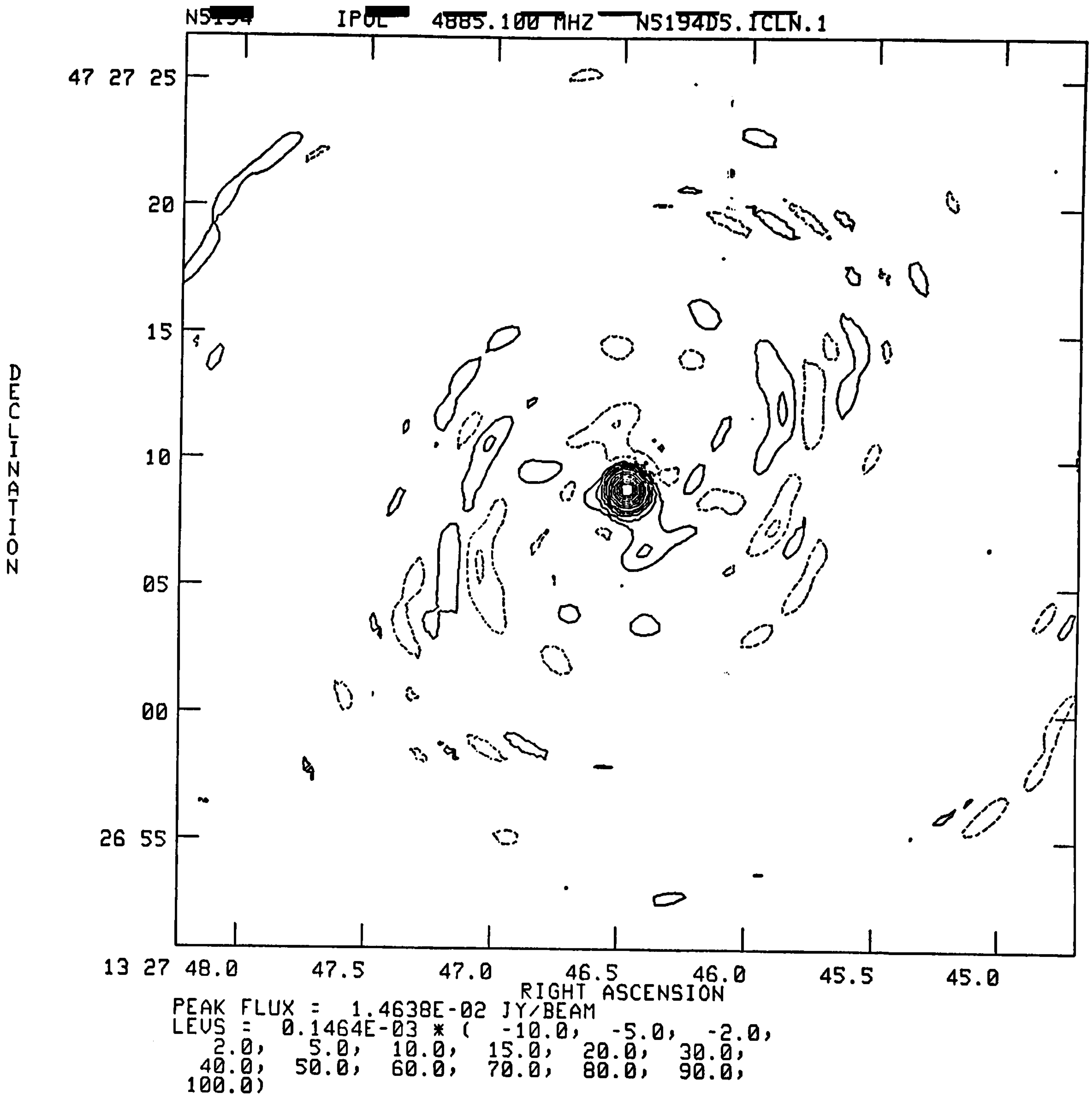


FIGURE 3. 6-Hr Synthesis I Map, Gain Code Adjusted to 8.

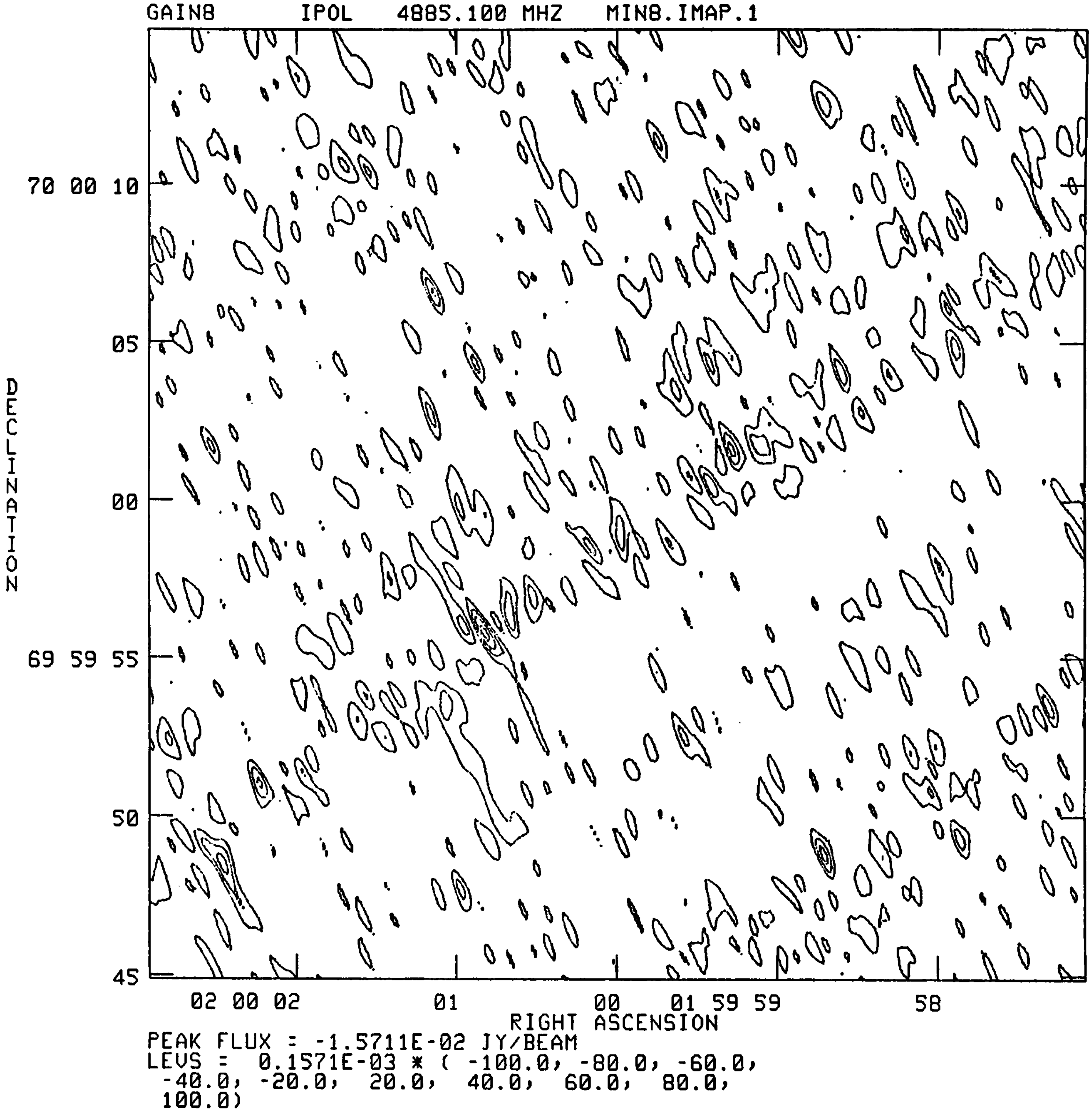
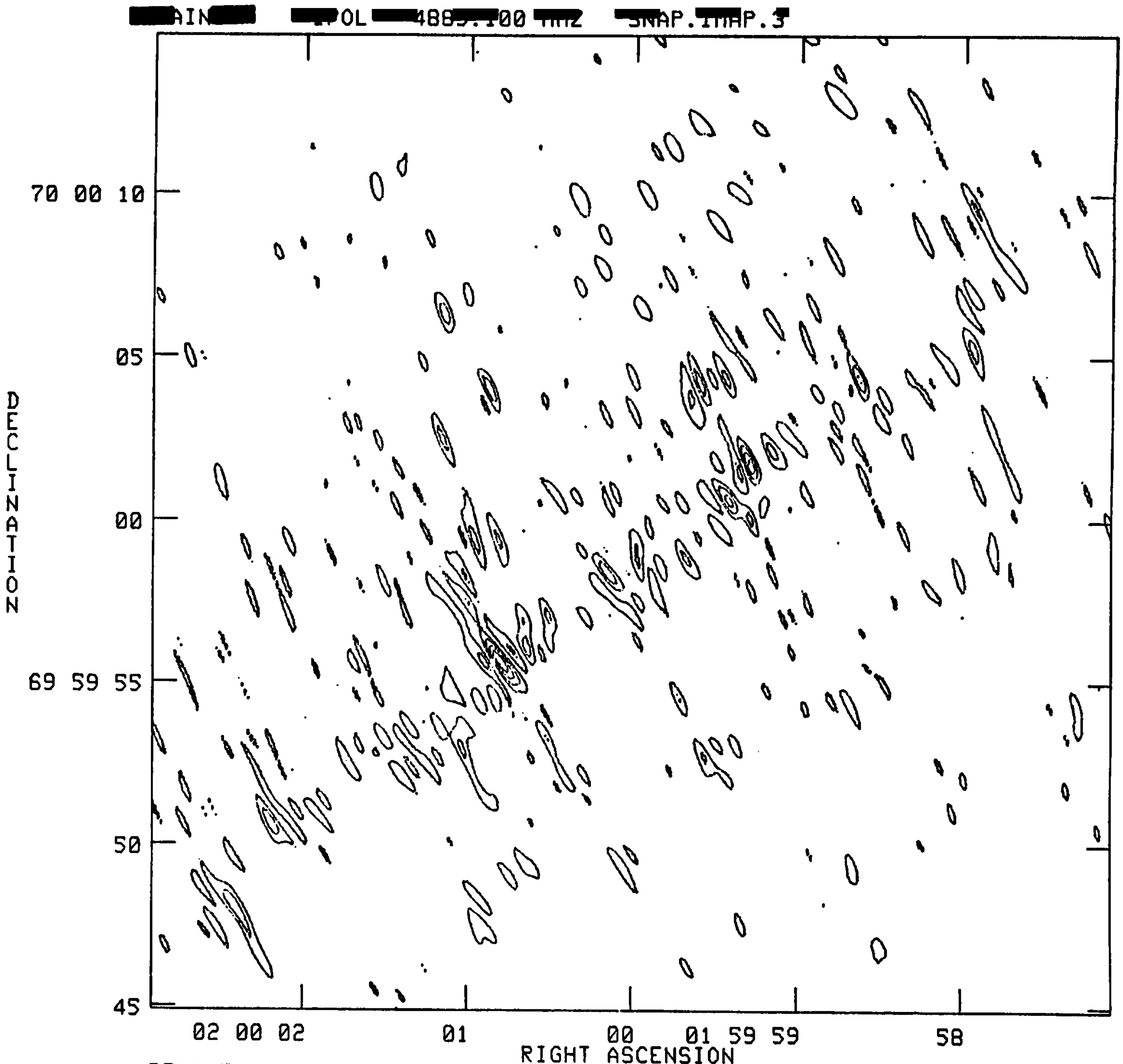


FIGURE 4. 1-Min Snapshot I Map, Observed with Gain Code 8.



PEAK FLUX = -1.3937E-02 JY/BEAM
LEVS = 0.1394E-03 * (-100.0, -80.0, -60.0, -40.0, -20.0, 20.0, 40.0, 60.0, 80.0, 100.0)

FIGURE 5. 10-Min Snapshot I Map, Observed with Gain Code 8.

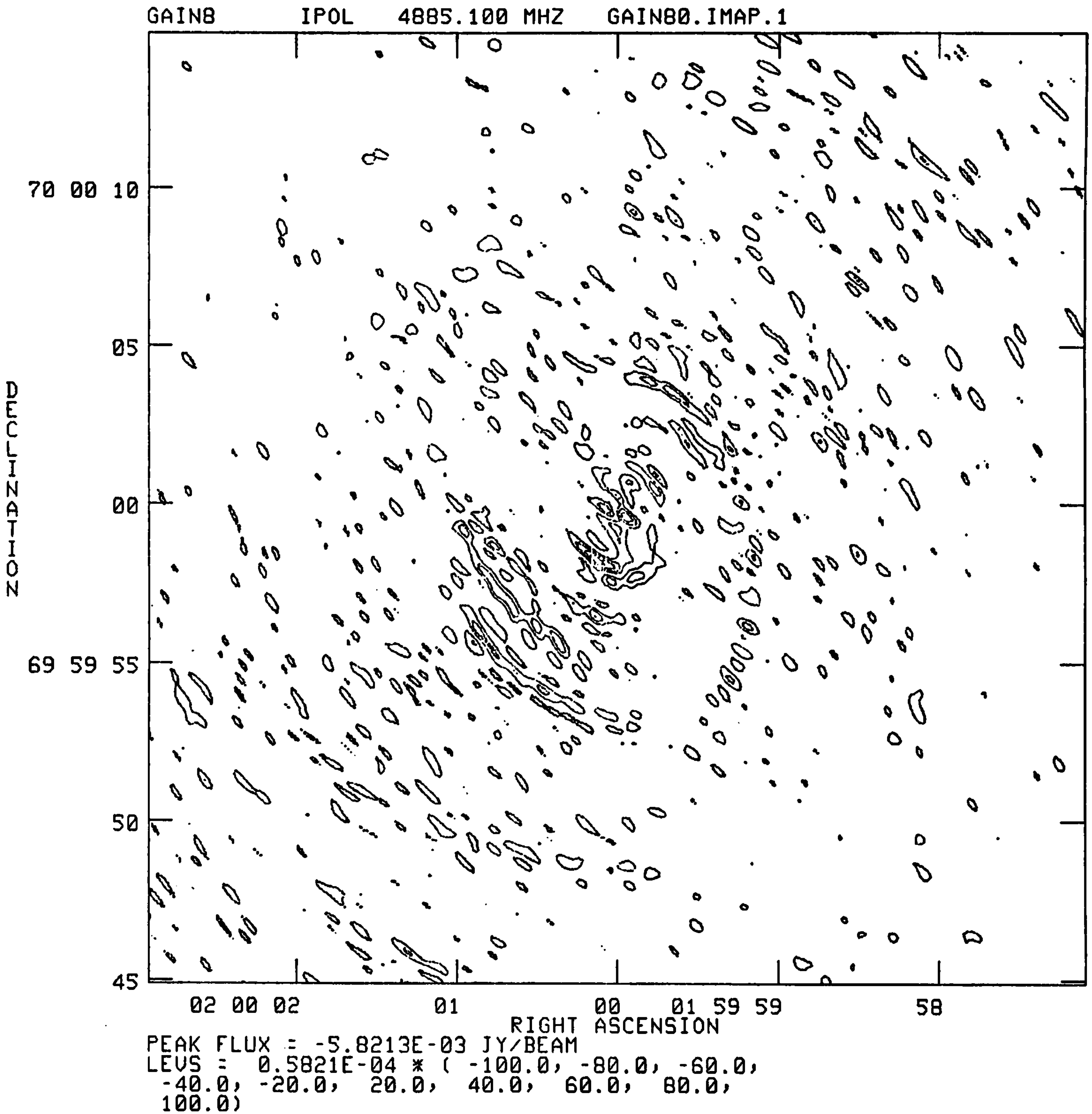


FIGURE 6. 1-Hr Synthesis I Map, Observed with Gain Code 8.

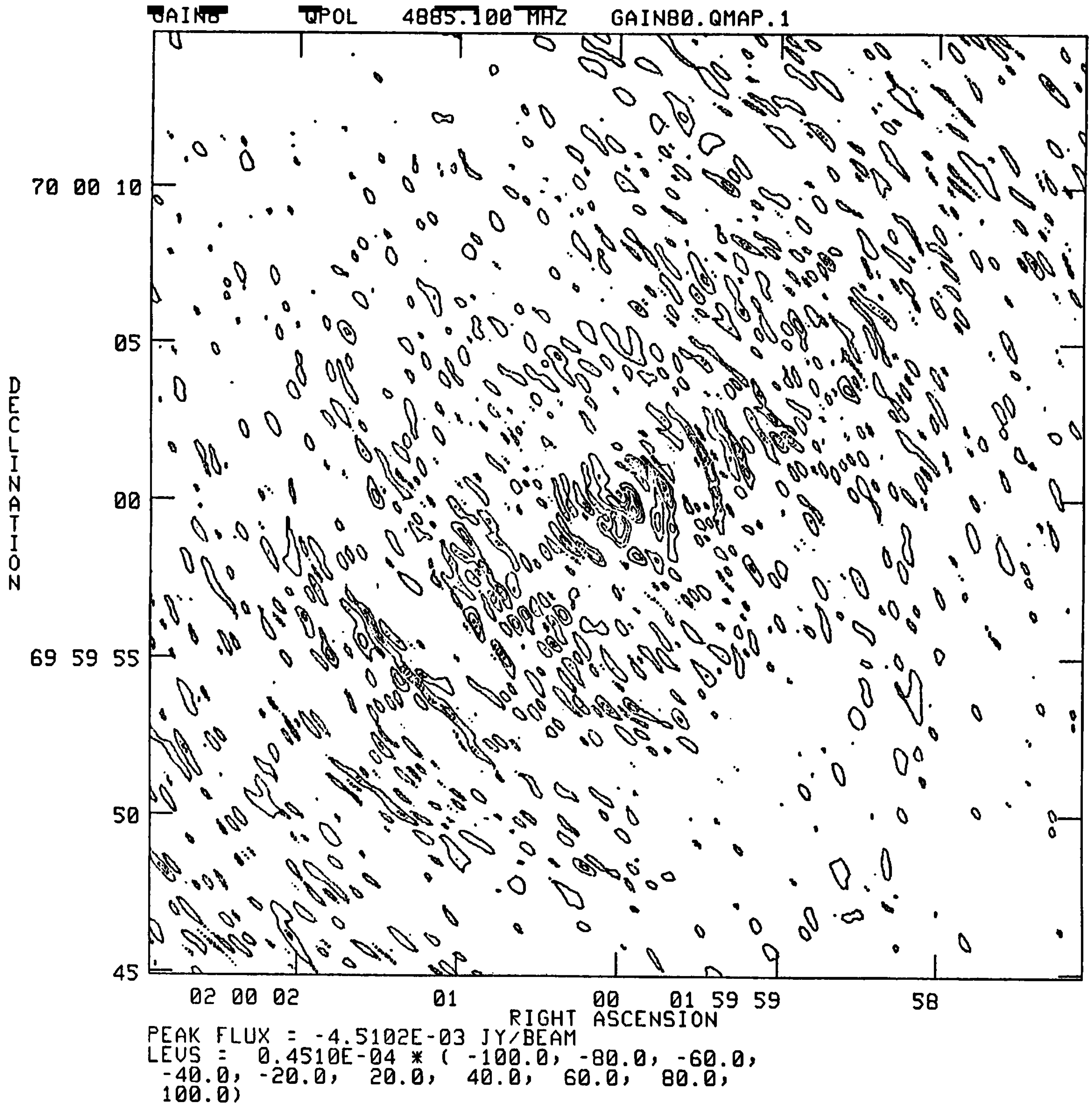


FIGURE 7. 1-Hr Synthesis Q Map, Observed with Gain Code 8.

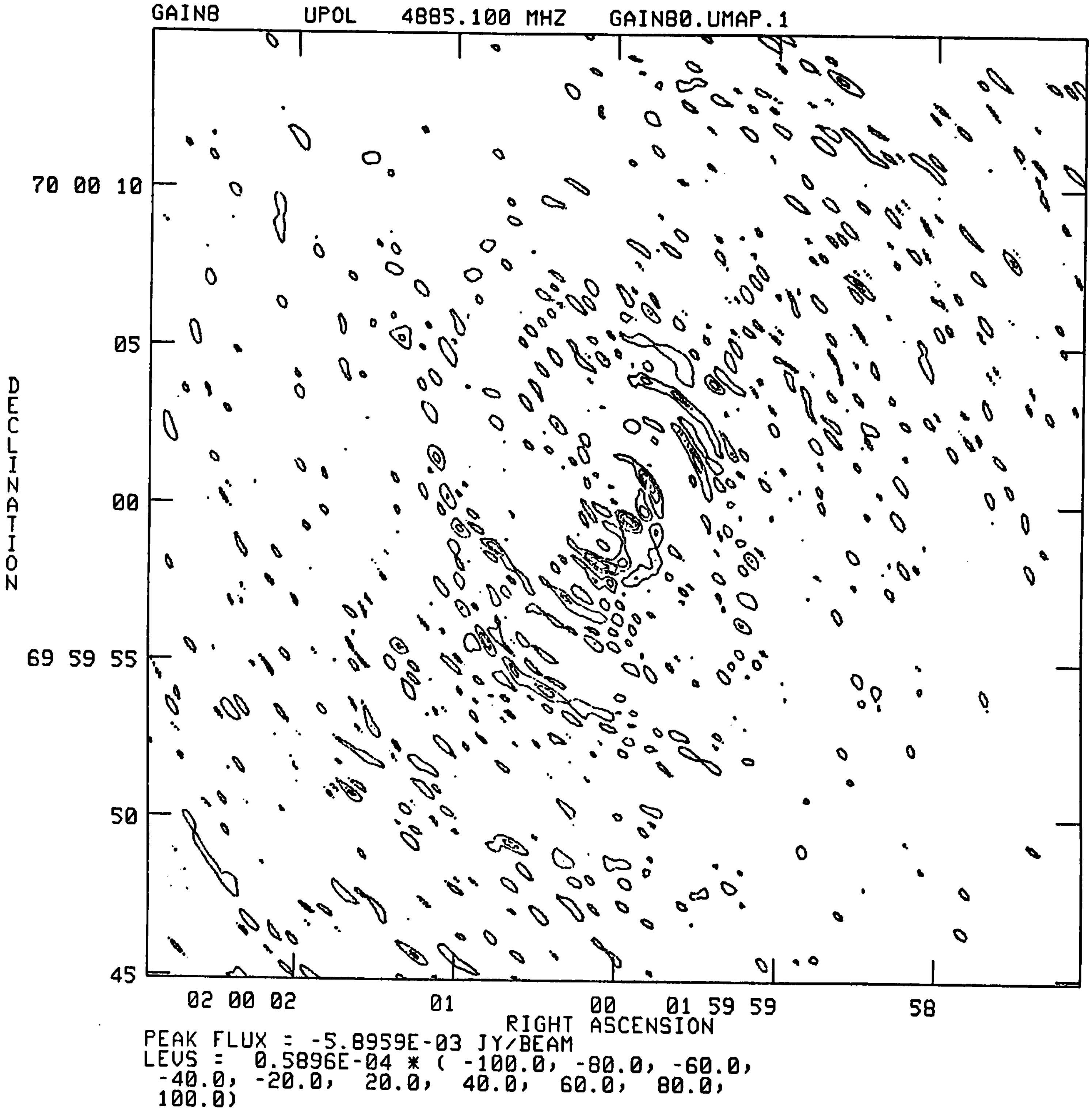


FIGURE 8. 1-Hr Synthesis U Map, Observed with Gain Code 8.

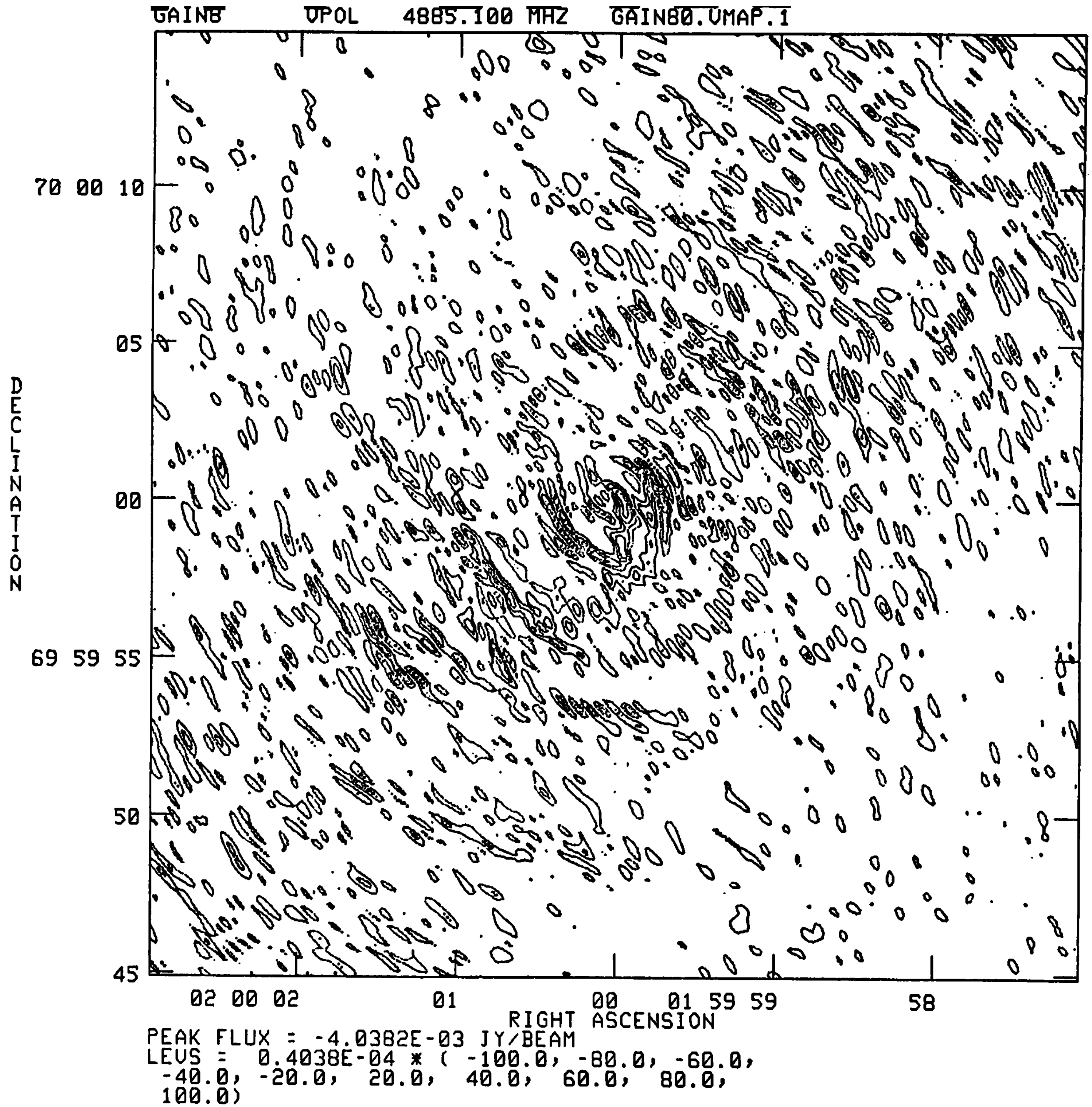


FIGURE 9. 1-Hr Synthesis V Map, Observed with Gain Code 8.