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SPURIOUS SPECTRAL FEATURES
AT THE
NRAO 140-FOOT TELESCOPE

F. J. LOCKMAN AND L. J RICKARD

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F. J. Lockman and L. J Rickard

In radio astronomy, and particularly radio spectroscopy, the distinction between celestial signals and instrumental signals has never been too secure. The history of the field is scattered with cases (usually unpublished) of true discoveries rejected as equipment problems, such as the Australian discovery of OH maser emission. More regrettably, there are also cases of instrumental effects misinterpreted as real phenomena, such as the report of 21-cm absorption in Cyg A.

As the stability and sensitivity of receivers improve, observers tend to work to lower signal levels and uncover new varieties of spurious spectral features. The most troublesome features are by definition the ones that occur at low signal level, since they appear only after long integrations and cannot be easily verified during the observing run. Furthermore, their weak and often unpredictable nature makes them difficult to reproduce on the laboratory test stand without detailed information about the specific circumstances under which they occur. This information is generally available only for extraordinary equipment failures.

In this report, we have collected examples of spurious spectral features found by various observers at the NRAO 140-foot telescope. Of course, such spurious features are not peculiar to this telescope. But in concentrating on 140-foot data, we have been able to document a variety of effects occurring over a large frequency range. The purpose of this compendium is threefold: (1) to remind observers of the variety of possible spurious spectral features, (2) to prompt observers to report and document additional features possibly of instrumental origin, and (3) to stimulate analysis and correction of the sources of these effects.

Some observers apparently believe that effects such as those described here represent a fundamental "limit of the system". We wish to emphasize that the spurious spectral features included in this report are true aberrations, selected generally from observing runs during which good spectra of equal or better sensitivity were also obtained. Indeed, it is our experience that 140-foot systems can be well behaved over integration times exceeding 20 hours. We suspect that the notion of the "limit of the system" has served mainly to suppress discussion of spectral anomalies, and has inhibited their resolution.

This collection is in no sense exhaustive, although we present examples from eight different receivers, covering the frequency range 260-10820 MHz. We have tried to avoid effects originating in the data reduction. A number of obvious cases (e.g., the effect of having the sun in a sidelobe) are simply unavailable; astronomers rarely preserve bad data. And of course, an unknown number of effects may have missed identification as spurious, and are now part of the astronomical literature.

We thank W. B. Burton, H. Liszt, P. Bowers and B. E. Turner for sharing data and G. Behrens, W. Brundage, R. Fisher, and C. Moore for advice and assistance during the observations.

Figure 1: Spurious spectral features at 10.82 GHz, mimicking the C^+ 134α and He^+ 134α recombination lines. The data were taken with the cooled 3-cm prime focus receiver, in total power mode, 29 August 1976. (a) Orion A, 10 MHz bandwidth. The features at -5 and 55 km/s, each with $T_A \sim 0.045$ K, have widths and radial velocities close to those expected for C^+ 134α and He^+ 134α. (b) W51, 10 MHz bandwidth. The same features appear, seen this time with better signal-to-noise ratio because of longer integration time. Note that the lines are stronger, with peak $T_A \sim 0.06$ K, although the continuum emission from W51 is only half that of Orion A. (This rules out a simple residual standing wave.) The band-center frequencies of the Orion and W51 spectra differ by 1.9 MHz, yet the lines appear at LSR velocities close to those expected for the sources. This probably rules out spurious RF signals. The same spectrum was observed in both halves of the correlator (operating in parallel), but shifted by 10 channels, ruling out a correlator problem. (c) W51, 5 MHz bandwidth. The same features appear, probably ruling out baseline instability at 10 MHz bandwidth as a problem. (d) Blank sky, 5 MHz bandwidth. This spectrum was taken between spectra (b) and (c), and suggests that receiver instability was not a problem. (e). W51, 2' south of continuum peak, 10 MHz bandwidth. The source continuum intensity is about half that at the peak. The absence of the lines would have been expected if the emission were confined to the dense regions at the continuum peak.

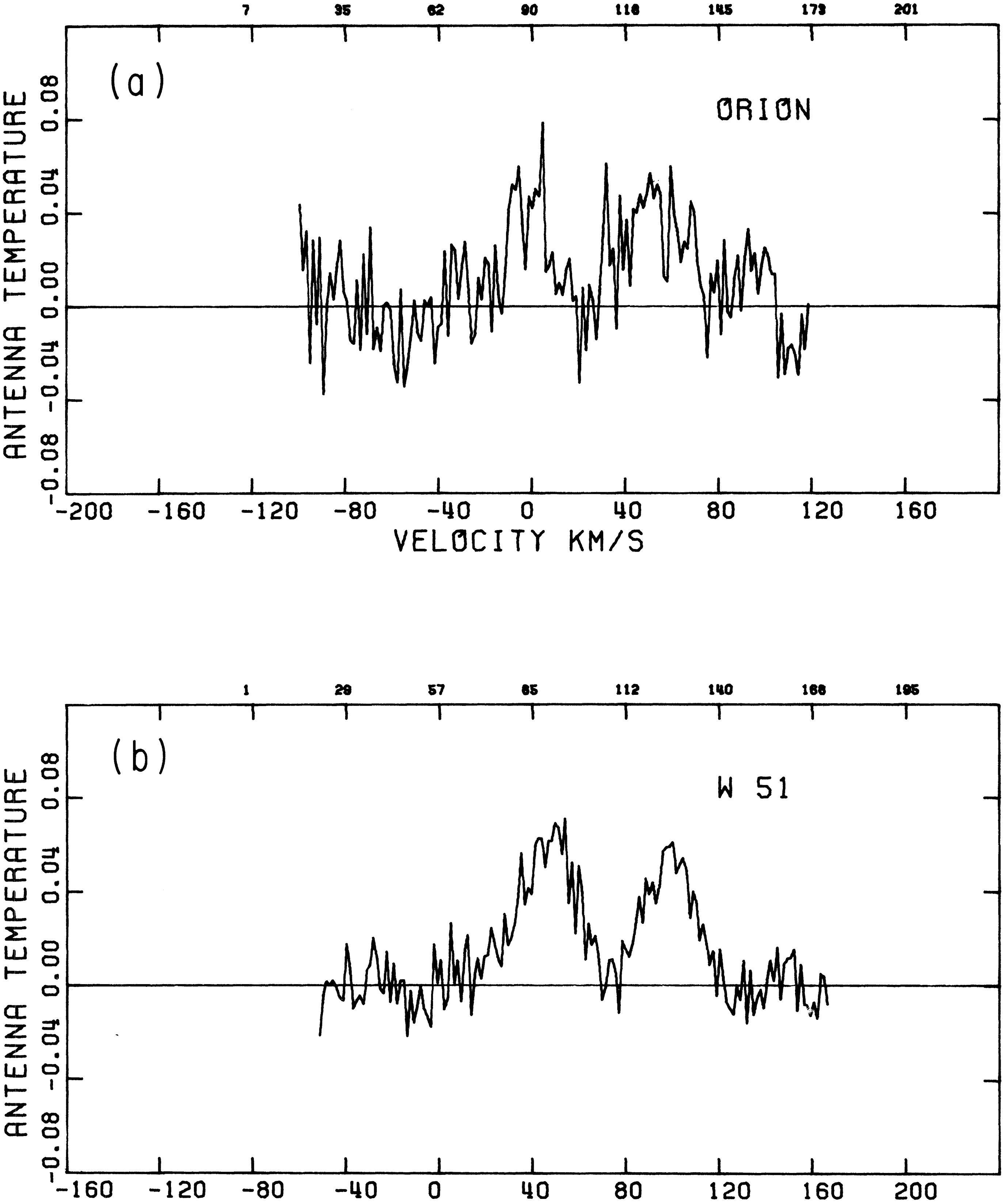
7
35
62
90
118
145
173
201
(a)
ORION
ANTENNA TEMPERATURE
-0.08
-0.04
0.00
0.04
0.08
-200
-160
-120
-80
-40
0
40
80
120
160
VELOCITY KM/S
1
29
57
85
112
140
168
195
(b)
W 51
ANTENNA TEMPERATURE
-0.08
-0.04
0.00
0.04
0.08
-160
-120
-80
-40
0
40
80
120
160
200
VELOCITY KM/S

Figure 1

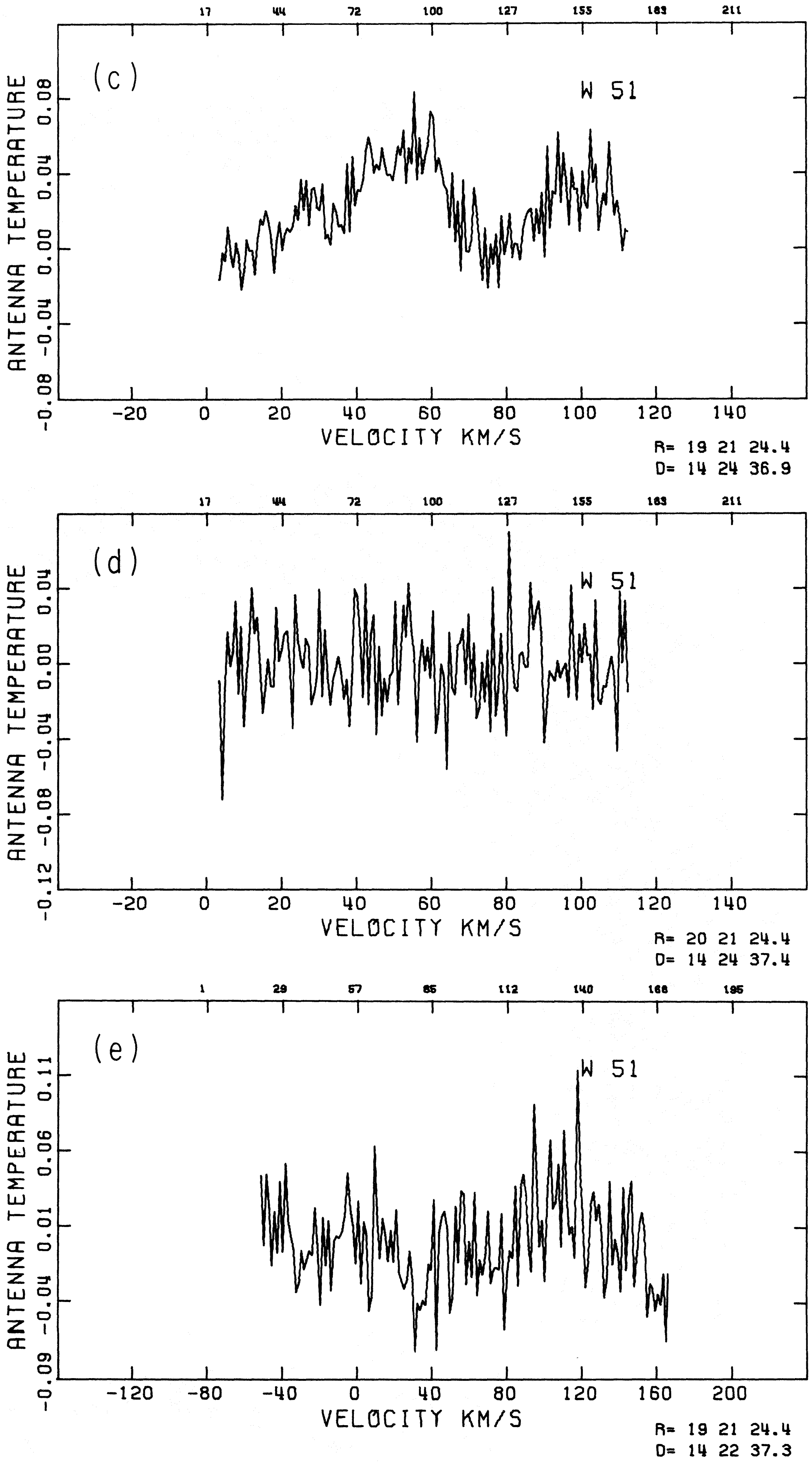
17
44
72
100
127
155
183
211
(c)
W 51
ANTENNA TEMPERATURE
0.08
0.04
0.00
-0.04
-0.08
-20
0
20
40
60
80
100
120
140
VELOCITY KM/S
R= 19 21 24.4
D= 14 24 36.9
17
44
72
100
127
155
183
211
(d)
W 51
ANTENNA TEMPERATURE
0.04
0.00
-0.04
-0.08
-0.12
-20
0
20
40
60
80
100
120
140
VELOCITY KM/S
R= 20 21 24.4
D= 14 24 37.4
1
29
57
85
112
140
168
195
(e)
W 51
ANTENNA TEMPERATURE
0.11
0.06
0.01
-0.04
-0.09
-120
-80
-40
0
40
80
120
160
200
VELOCITY KM/S
R= 19 21 24.4
D= 14 22 37.3

Figure 1

Figure 2: Absence of $C^+134\alpha$ and He^+ 134α emission. Although all the observing supported the reality of the features in figures 1 (a,b), they were questionable on other grounds. (The radial velocity was incorrect for W51, the separation of the C^+ and He^+ features implied substantially different velocities for the two regions, and the He^+ line was far too strong to be consistent with expectations from previous theory or experiment.) Hence the sources were reobserved 6-9 December 1976 with the same equipment, and the spurious nature of the original lines was established. The data were taken in the same fashion as for figure 1 (a,b), except that this time the spectra were constructed from pairs defocussed by $\pm$ $\lambda/8$. (However, there is no evidence in averages of data at a single focus of anything resembling the features in figure 1.)

We note that apparently spurious features, similar to those in figure 2 (a,b), have been observed at 10.31 GHz with the same receiver (Fourikis, N., Takagi, K., and Saito, S. 1977, Ap. J. (Letters), **212**, L33; Broten, N. W., private communication).

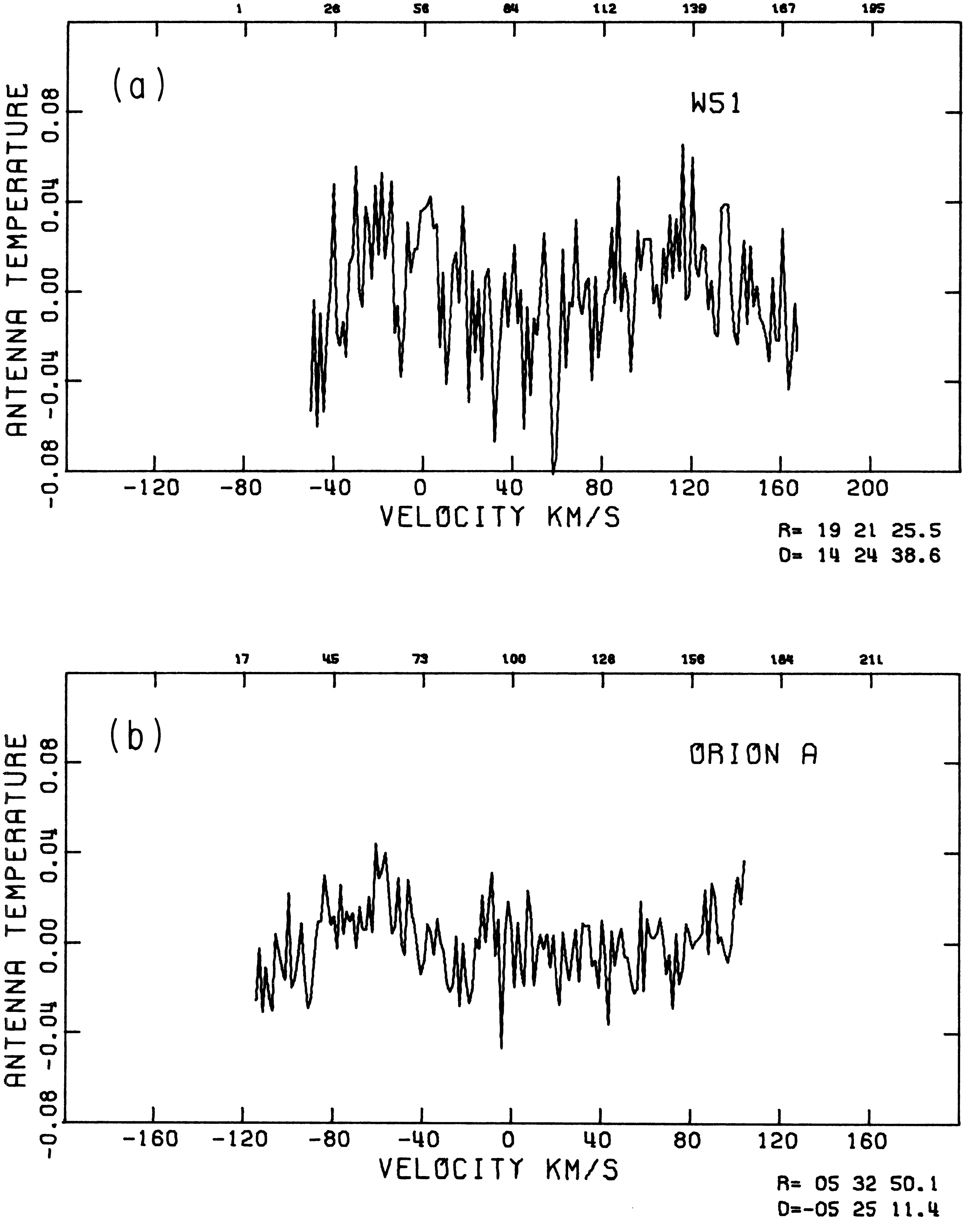
(a)
W51
1
28
56
84
112
139
167
195
ANTENNA TEMPERATURE
-0.08
-0.04
0.00
0.04
0.08
-120
-80
-40
0
40
80
120
160
200
VELOCITY KM/S
R= 19 21 25.5
D= 14 24 38.6
(b)
ORION A
17
45
73
100
128
156
184
211
ANTENNA TEMPERATURE
-0.08
-0.04
0.00
0.04
0.08
-160
-120
-80
-40
0
40
80
120
160
VELOCITY KM/S
R= 05 32 50.1
D=-05 25 11.4

Figure 2

Figure 3: Baseline structure at 4.83 GHz, confusing H_2CO observations. The data were taken 1975 November with the cooled TRG paramp, in total power mode, with 10 MHz bandwidth. (a) Apparent emission feature at anticipated velocity of H_2CO line. Observations at the Effelsburg 100-m telescope confirm that this apparent line is spurious (D. Graham, private communication). (b) Hann smoothed data. The known absorption feature, scaled down from Parkes data, has been drawn in for comparison. The true line has apparently been filled in.

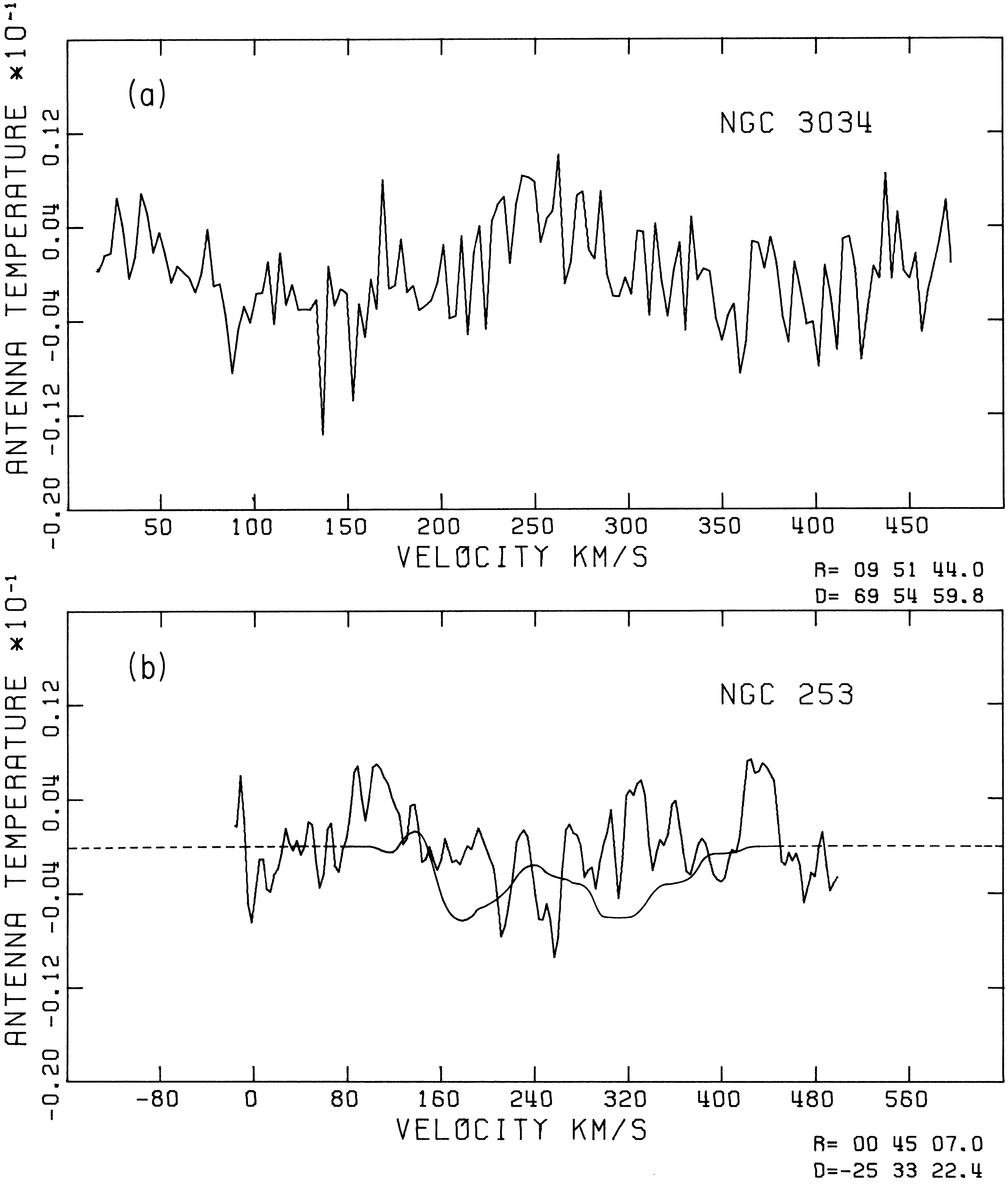
(a)
NGC 3034
ANTENNA TEMPERATURE *10⁻¹
0.12
0.04
-0.04
-0.12
-0.20
50
100
150
200
250
300
350
400
450
VELOCITY KM/S
R= 09 51 44.0
D= 69 54 59.8
(b)
NGC 253
ANTENNA TEMPERATURE *10⁻¹
0.12
0.04
-0.04
-0.12
-0.20
-80
0
80
160
240
320
400
480
560
VELOCITY KM/S
R= 00 45 07.0
D=-25 33 22.4

Figure 3

Figure 4: Spurious spectral features near *4.9 GHz*, mimicking H110α recombination-line emission from NGC 253. The data were taken with the *6/25 cm cooled Cassegrain receiver*, in total power mode, with 10 MHz bandwidth. The source continuum temperature was a few Kelvins. The displayed spectrum is the average of peak focus data obtained with independent front-end and correlator channels. The spurious features appeared at about equal intensity in each channel, suggesting that the problem did not arise in a single receiver, IF line, or correlator. The features appeared in each of several days' observations, but were most noticeable in the last day's data. Other sources observed showed no similar features. The intensities and velocities of the apparent H110α features were consistent with radio continuum and 21-cm data for this galaxy. Yet subsequent observations with the TRG cooled prime focus receiver showed no lines to a level $\lesssim$ 1/3 of the features seen here. Observations with the Algonquin 46-m telescope (Seaquist, E. R., and Bell, M. B. 1977, *Astr. and Ap.*, **60**, L1) confirm that these signals were spurious.

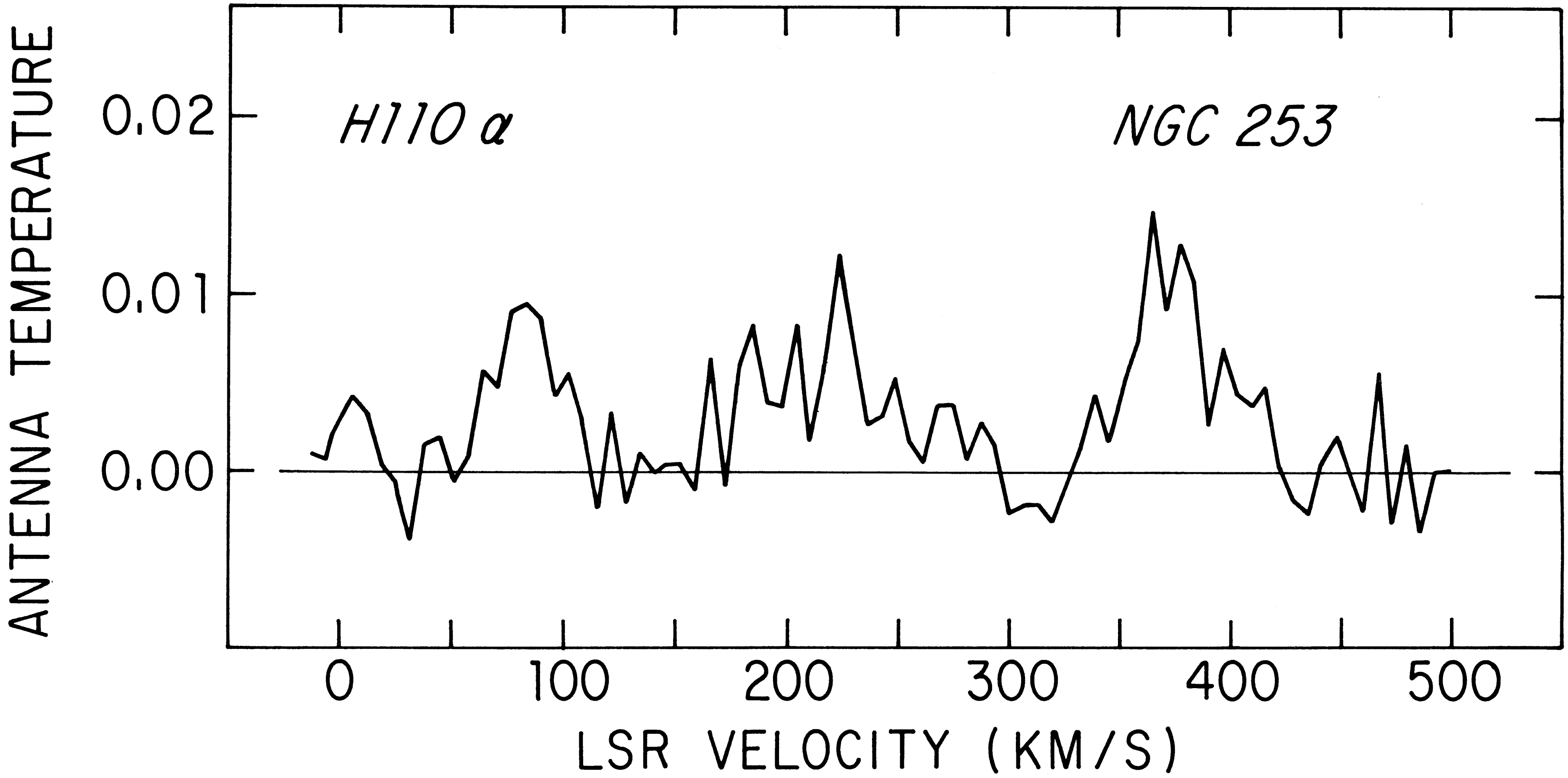
ANTENNA TEMPERATURE
0.02
0.01
0.00
$H110\alpha$
NGC 253
0
100
200
300
400
500
LSR VELOCITY (KM/S)

Figure 4

Figure 5: The 140-foot standing wave, observed with the cooled 9-cm prime focus receiver, near 3.2 GHz. The data were taken in total power mode, with 10 MHz bandwidth and negligible source continuum. The spectra shown are differences of pairs of scans defocussed ± λ/8 and pointing at the same sky position. Spectrum (a) was obtained with feed position angle 90°, spectrum (b) with feed position angle 180°. The variation of the amplitude, frequency, and phase of the standing wave with feed alignment is not uncommon. The original standing wave, as described by Weinreb in 1967, arose from reflections between feed and paraboloid and had the characteristic periodicity c/2L = 7.5 MHz. Fisher has recently (May 1977) reanalyzed the telescope, using a 3 GHz reflectometer at prime focus. In the absence of modifications (such as absorber and spoiler plates on the Cassegrain house), he found three approximately equal reflections between prime focus and parts of the Cassegrain house (with periods of 10.9, 10.4, and 9.5 MHz) plus weaker reflections off the inner panels of the paraboloid (at 8.0 and 7.6 MHz) and off the crack between the intermediate and outer surface panels (at 7.1 MHz). Theoretically, shorter period baseline structure can also occur, as higher harmonics of these ripples. However, the importance of these multiple reflections is not yet established in practical context.

The defocussing technique--observing with the feed shifted alternately +λ/8 and -λ/8 from peak focus--generally produces well-behaved spectra. We feel that few, if any, of the spurious features shown in the other figures arise from this type of reflection.

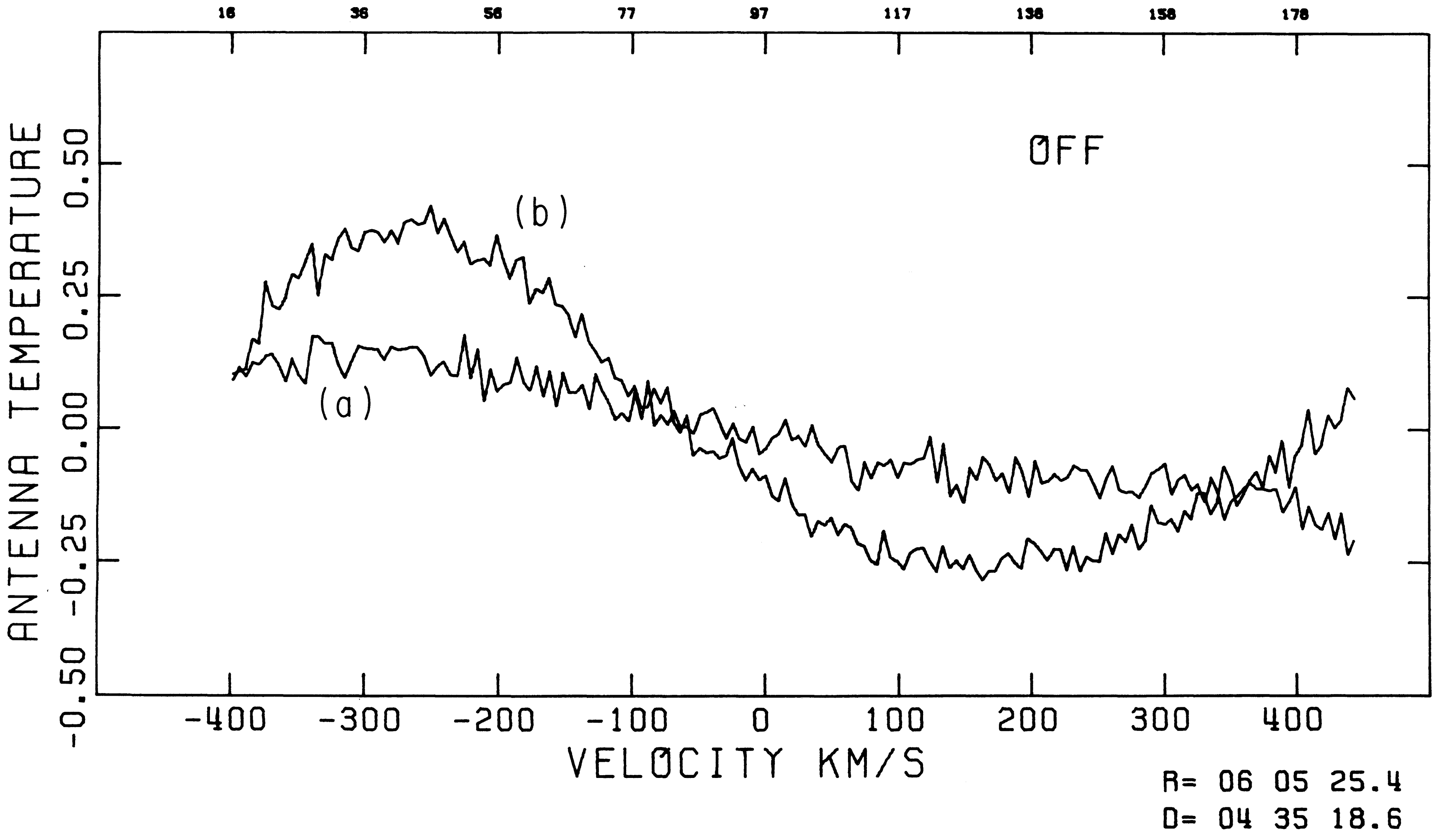
16
36
56
77
97
117
138
158
178
ØFF
(b)
(a)
ANTENNA TEMPERATURE
0.50
0.25
0.00
-0.25
-0.50
-400
-300
-200
-100
0
100
200
300
400
VELØCITY KM/S
R= 06 05 25.4
D= 04 35 18.6

Figure 5

Figure 6: Spurious spectral features near 3.25 and 3.17 GHz, confusing the He126α and H127α recombination lines. The data were taken September 1977 with the 9-cm cooled prime focus receiver. (a) 3.25 GHz data from the B channel of the receiver, obtained in total power mode, with 5 MHz bandwidth. The displayed spectrum is the average of two scans, taken at offsets of $+\lambda/8$ and $-\lambda/8$ from the peak focus. The source continuum temperature was ∿25 K. The emission from -150 to -60 km/s is spurious. It appeared in all observations, with its antenna temperature always 0.6-0.7% of the source continuum temperature. The A channel of the receiver did not show any similar features to a level ∿ 1/5 of the feature seen in the B channel. (b) True spectrum, observed in almost exactly the same way as (a). The sole difference is that noise, in the amount of the source continuum, was added to the off-source scans. Clearly, noise injection has removed the spurious features. (c,d). Similar spurious features at 3.17 GHz, seen this time in both receivers. The source continuum temperature was ∿15 K. The observing procedure was identical to that of (a). While the spurious emission appears in both front-end channels, it is more than 50% stronger in channel B.

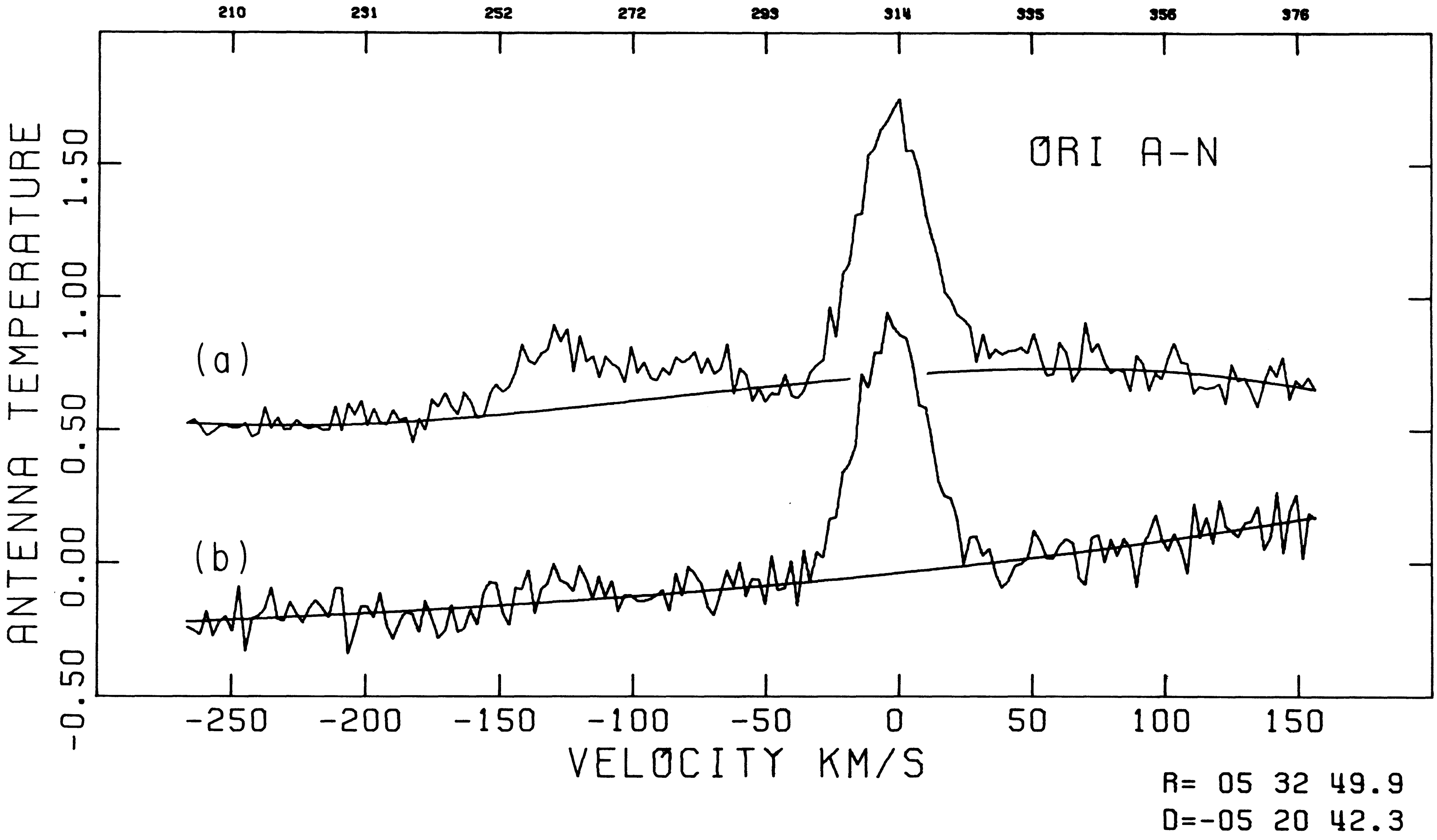
210
231
252
272
293
314
335
356
376
ØRI A-N
(a)
(b)
ANTENNA TEMPERATURE
-0.50
0.00
0.50
1.00
1.50
-250
-200
-150
-100
-50
0
50
100
150
VELØCITY KM/S
R= 05 32 49.9
D=-05 20 42.3

Figure 6

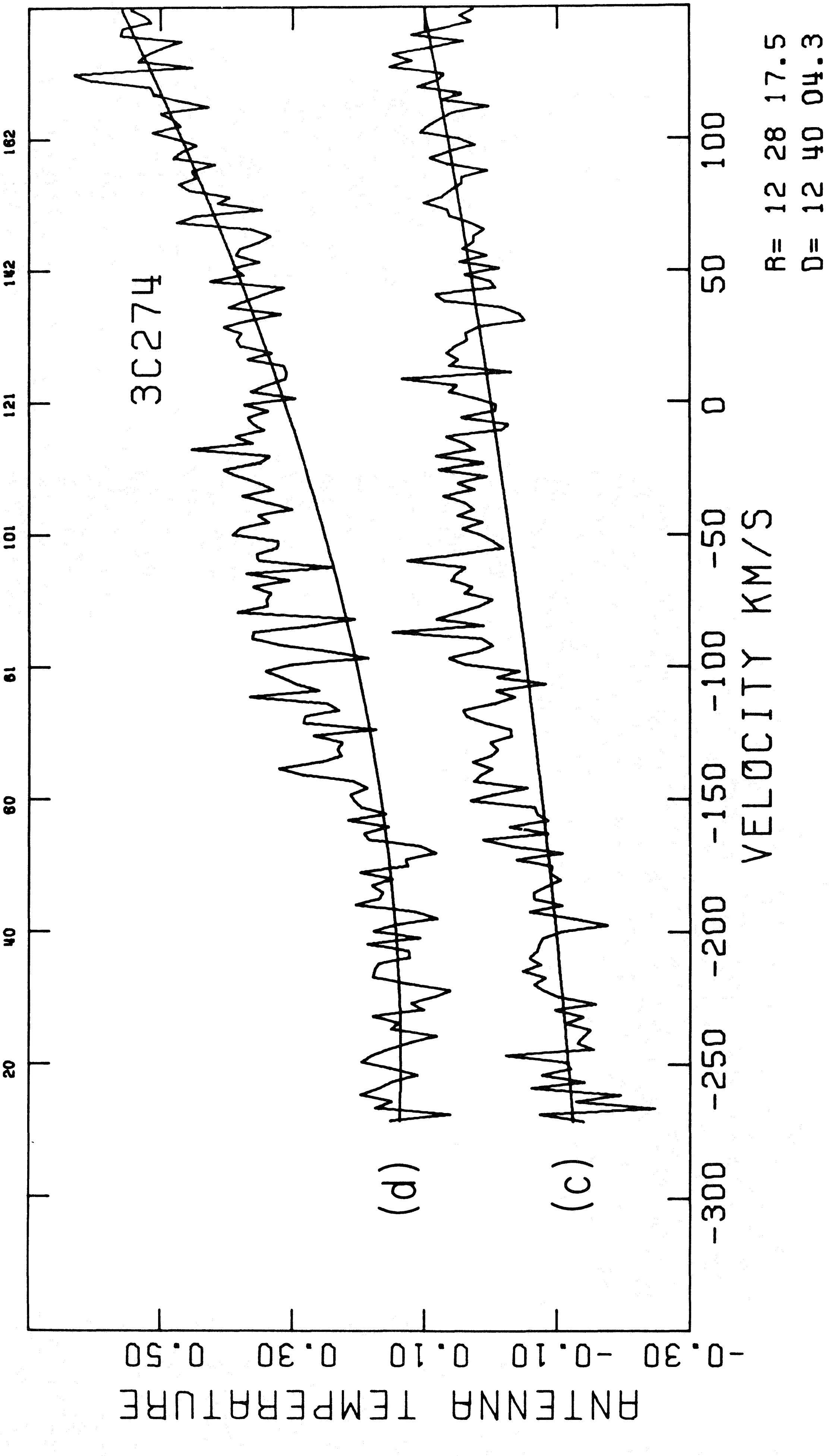
3C274
(d)
(c)
VELOCITY KM/S
ANTENNA TEMPERATURE
-300
-250
-200
-150
-100
-50
0
50
100
-0.30
-0.10
0.10
0.30
0.50
20
40
60
81
101
121
142
162
R= 12 28 17.5
D= 12 40 04.3

Figure 6

Figure 7: Development of a spurious emission feature at 1.72 GHz. Data were taken with the cooled 18-cm prime focus receiver, at sky positions each separated by $\sim 1\overset{\circ}{.}5$ and with no observed continuum emission. The telescope elevation was $\sim 40°$, and the hour angle was always between 4^h and 5^h west. There was no evidence of receiver instability or interference in the total power record. Note that the spurious feature at 50 km/s slowly builds up in the first four scans, and then vanishes when the local oscillator was shifted for the last scan. B. Turner notes that this spurious signal appeared occasionally in 1720 MHz spectra, observed with front-end channel B and correlator B, but never in 1667 MHz spectra, observed with front-end channel A and correlator B. This suggests, then, that the problem was in front-end channel B.

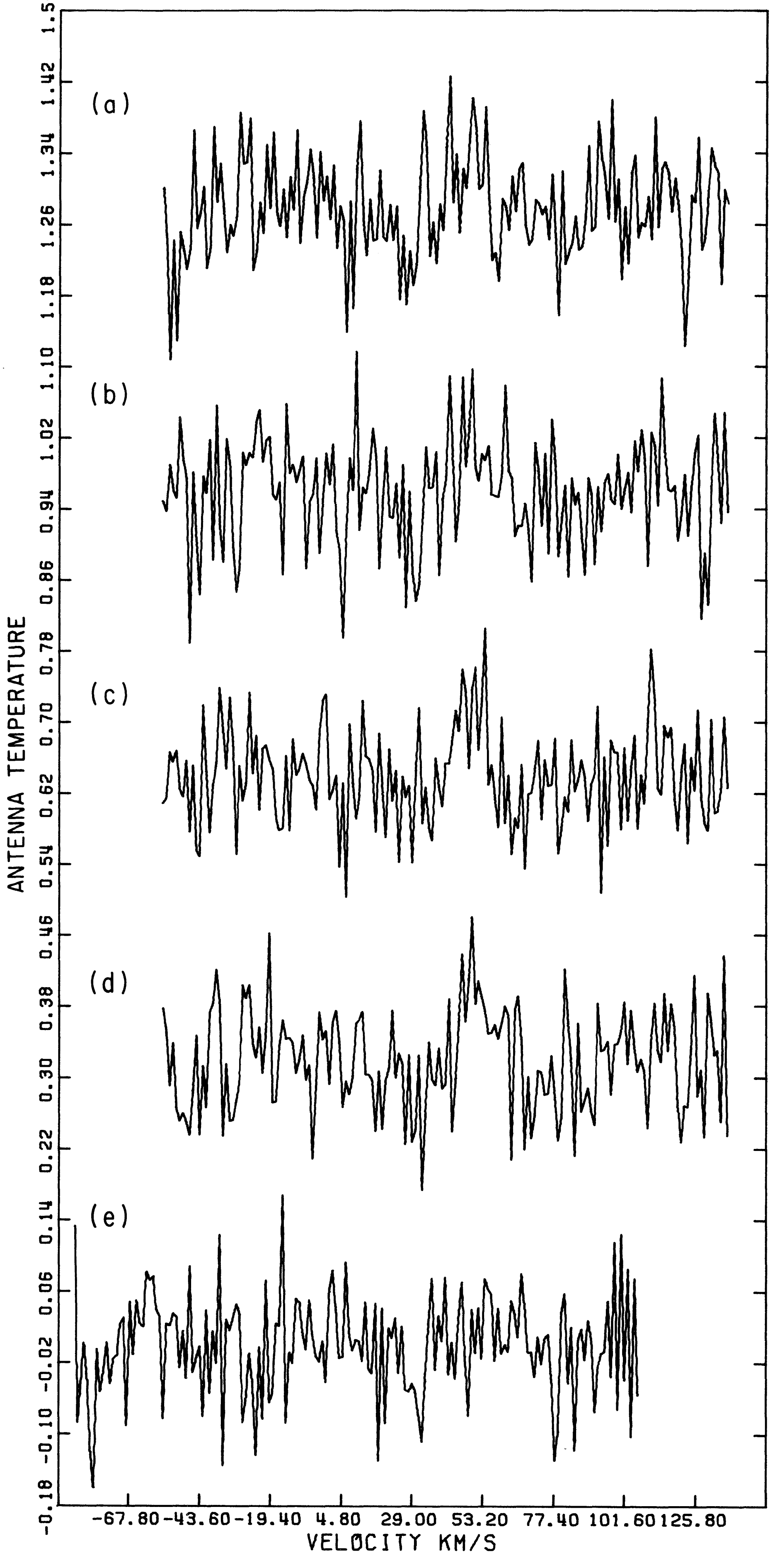
ANTENNA TEMPERATURE
1.50
1.42
1.34
1.26
1.18
1.10
1.02
0.94
0.86
0.78
0.70
0.62
0.54
0.46
0.38
0.30
0.22
0.14
0.06
-0.02
-0.10
-0.18
(a)
(b)
(c)
(d)
(e)
-67.80
-43.60
-19.40
4.80
29.00
53.20
77.40
101.60
125.80
VELOCITY KM/S

Figure 7

Figure 8: Spurious spectral feature at 1.42 GHz, confusing the H166α recombination line. The data were taken with the cooled 21-cm prime focus receiver, in total power mode, with 5 MHz bandwidth, and are Hann smoothed (a) Data taken 1974 January. The emission above 100 km/s is spurious. It appeared in both front end channels, but was about twice as strong in one receiver as in the other. The receiver in which it appeared stronger was showing slight refrigerator modulation. The spurious emission vanished from both channels when the receiver box was rotated 90°. The source continuum temperature was ∿3K. (b) Data taken 1974 November, with the same equipment and observing procedure. Further observations in 1975 confirmed that this was the true spectrum.

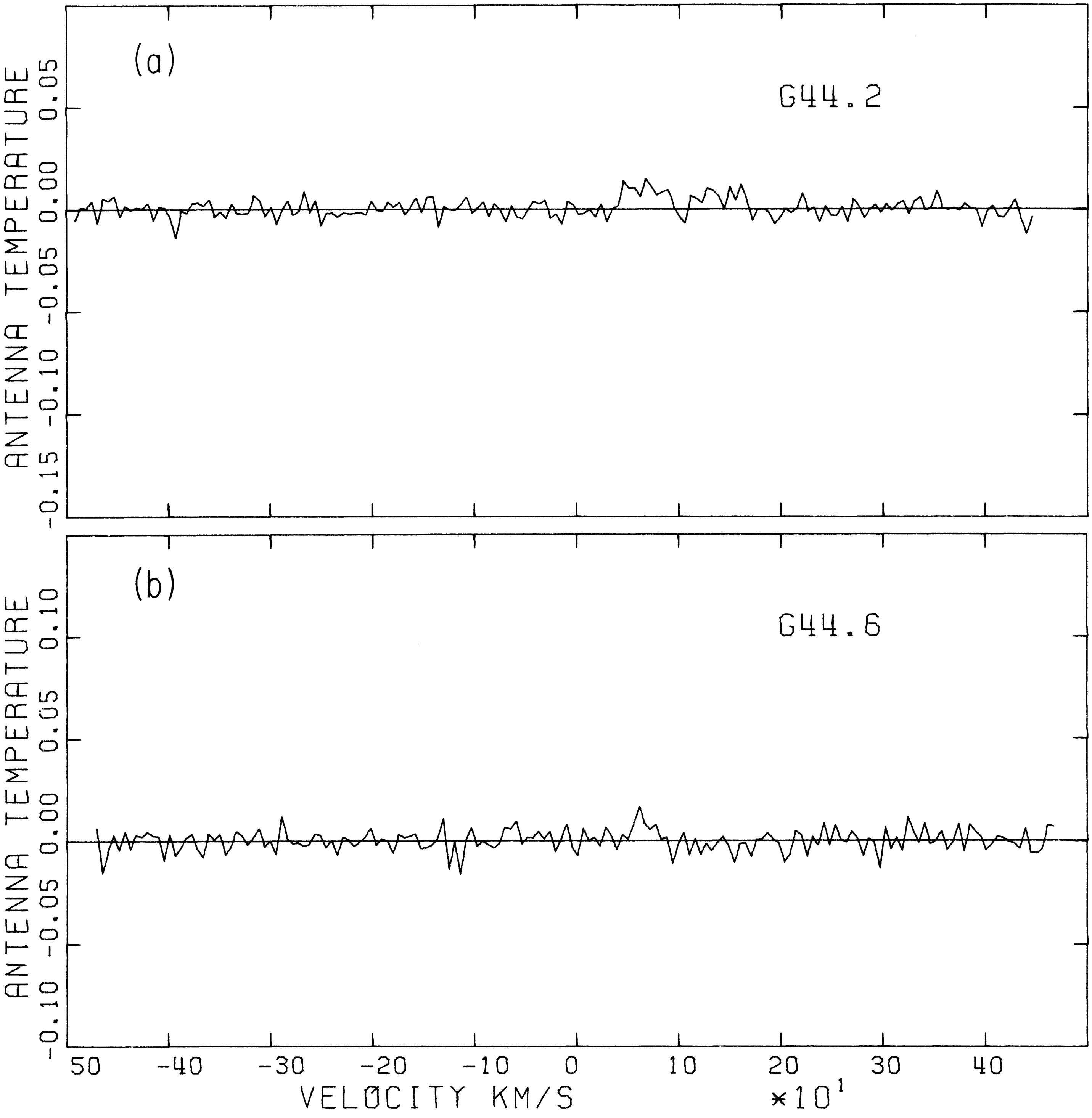
(a)
G44.2
ANTENNA TEMPERATURE
0.05
0.00
-0.05
-0.10
-0.15
(b)
G44.6
ANTENNA TEMPERATURE
0.10
0.05
0.00
-0.05
-0.10
50
-40
-30
-20
-10
0
10
20
30
40
VELØCITY KM/S
*10¹

Figure 8

Figure 9: Baseline structure at 1.42 GHz, observed 1977 January with the cooled 21-cm prime focus receiver, in total power mode, with 5 MHz bandwidth. The displayed spectrum is the difference of two blank sky observations separated by ∿30° in sky position and ∿10 min. in time. The data were taken at night. The observed positions had negligible continuum emission. A linear baseline has been removed. Slight refrigerator modulation was visible at a level ∿2% of the system temperature. Similar features appeared, intermittently in emission or absorption, over a period of several days.

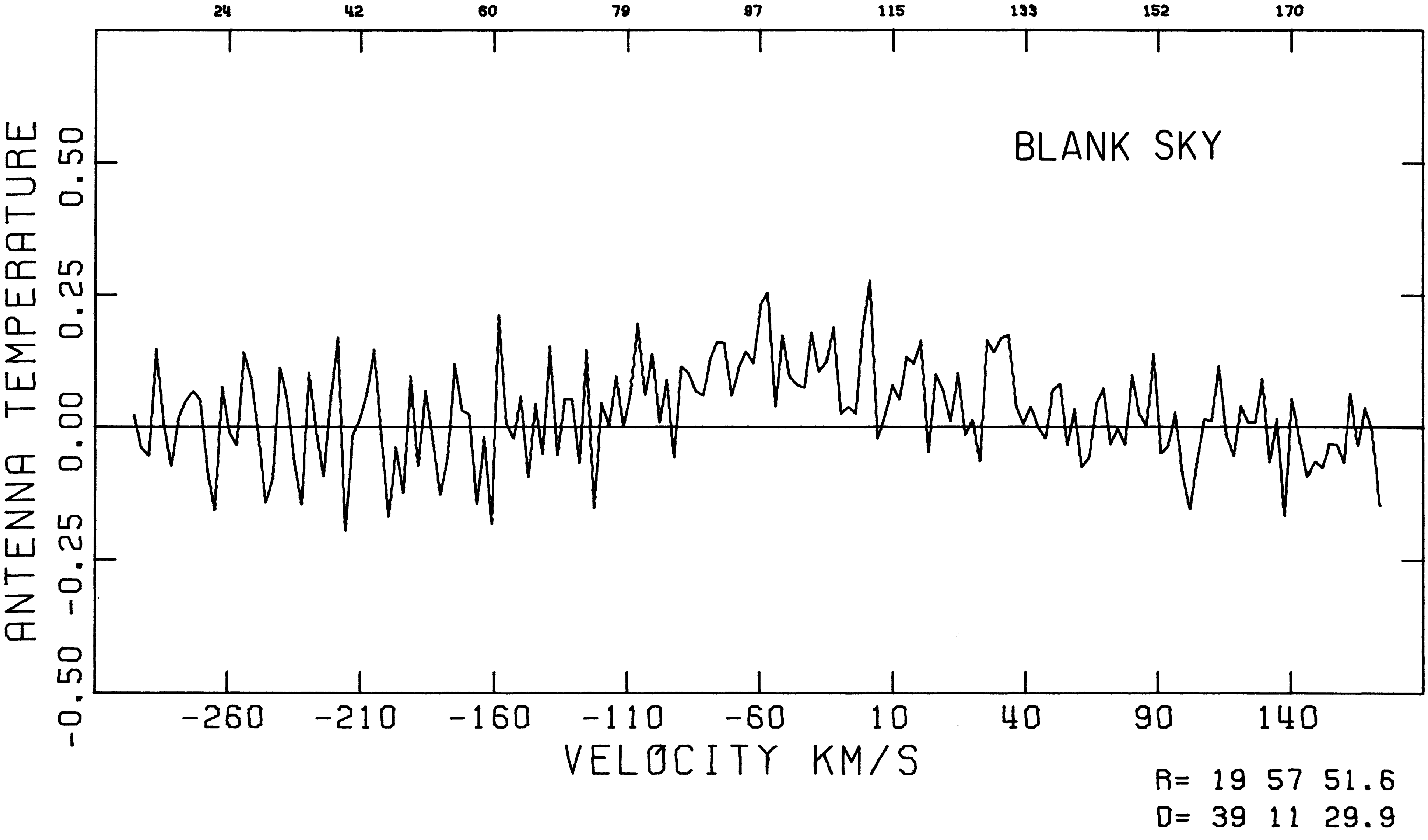
24
42
60
79
97
115
133
152
170
BLANK SKY
ANTENNA TEMPERATURE
0.50
0.25
0.00
-0.25
-0.50
-260
-210
-160
-110
-60
10
40
90
140
VELØCITY KM/S
R= 19 57 51.6
D= 39 11 29.9

Figure 9

Figure 10: Spurious spectral feature at 1.42 GHz, confusing the H166α recombination line. (a) Data taken 1975 January/February with the 21-cm Cassegrain receiver, in total power mode, with 5 MHz bandwidth. The continuum temperature was $\sim$5K. The data have been Hann smoothed, and a linear baseline was removed. The broad emission is similar to that shown in figure 5, although the latter involved a different receiver. (b) Data taken 1975 June, with the cooled 21-cm prime focus receiver. Observational parameters were the same as for (a). (These data have not been smoothed.) Note that the spurious feature in (a) completely masked the true emission feature seen in (b).

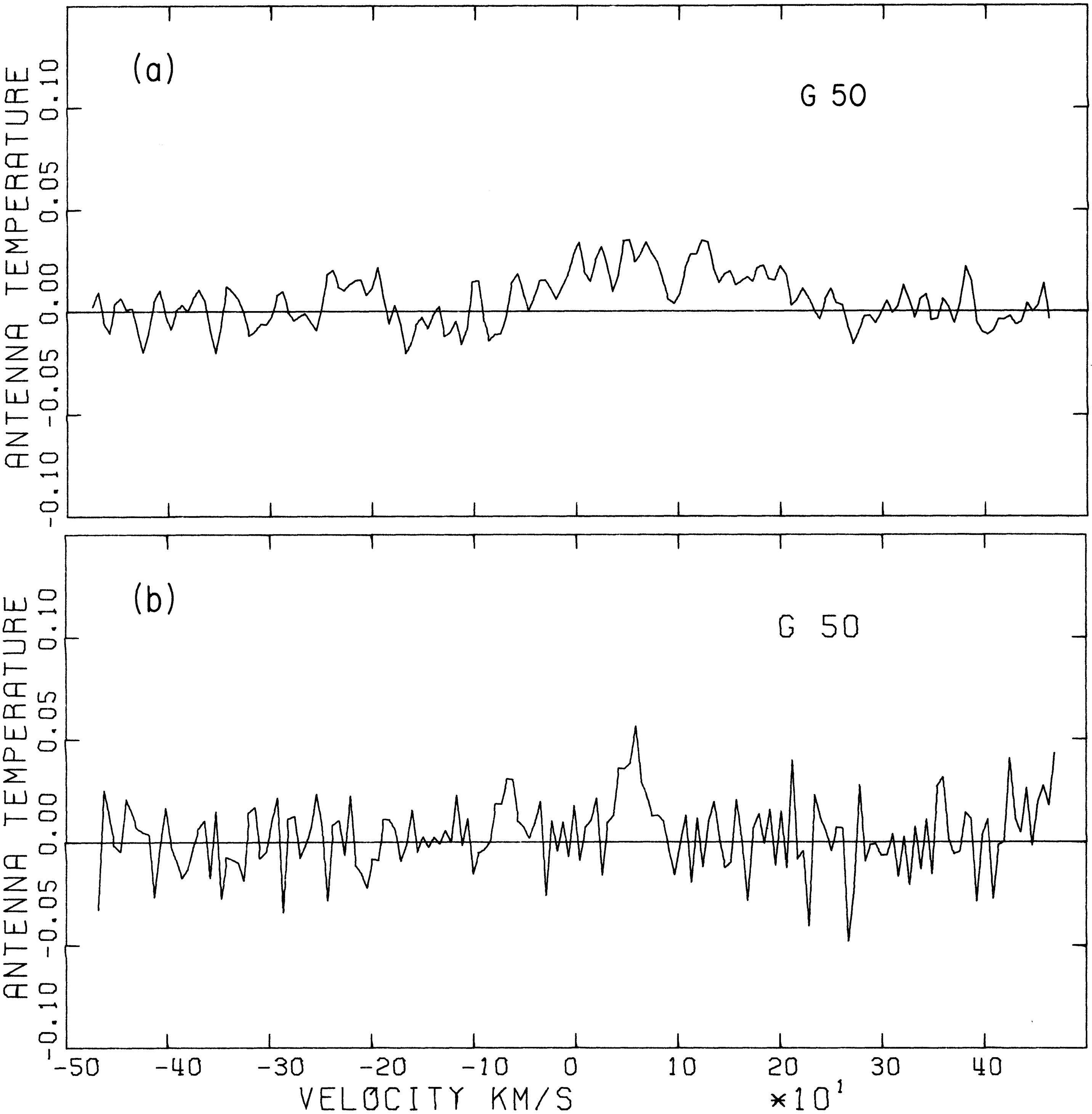
(a)
G 50
(b)
G 50
ANTENNA TEMPERATURE
-0.10
-0.05
0.00
0.05
0.10
-50
-40
-30
-20
-10
0
10
20
30
40
VELOCITY KM/S
*10¹

Figure 10

Figure 11: Spurious signals resulting from IF cables. The spectra are 480 MHz data taken with the 250-500 MHz prime focus receiver, in total power mode, with 2.5 MHz bandwidth. (a,b) Spurious signals in the two front-end channels. The IF cables were 7/8" Spiraline. (c,d) Spectra taken at the same sky position, same frequency, same integration time, after switching to a continuous run of RG9 cable. Signals similar to those in (a,b) were also observed at 260 MHz, and also vanished when the cables were changed.

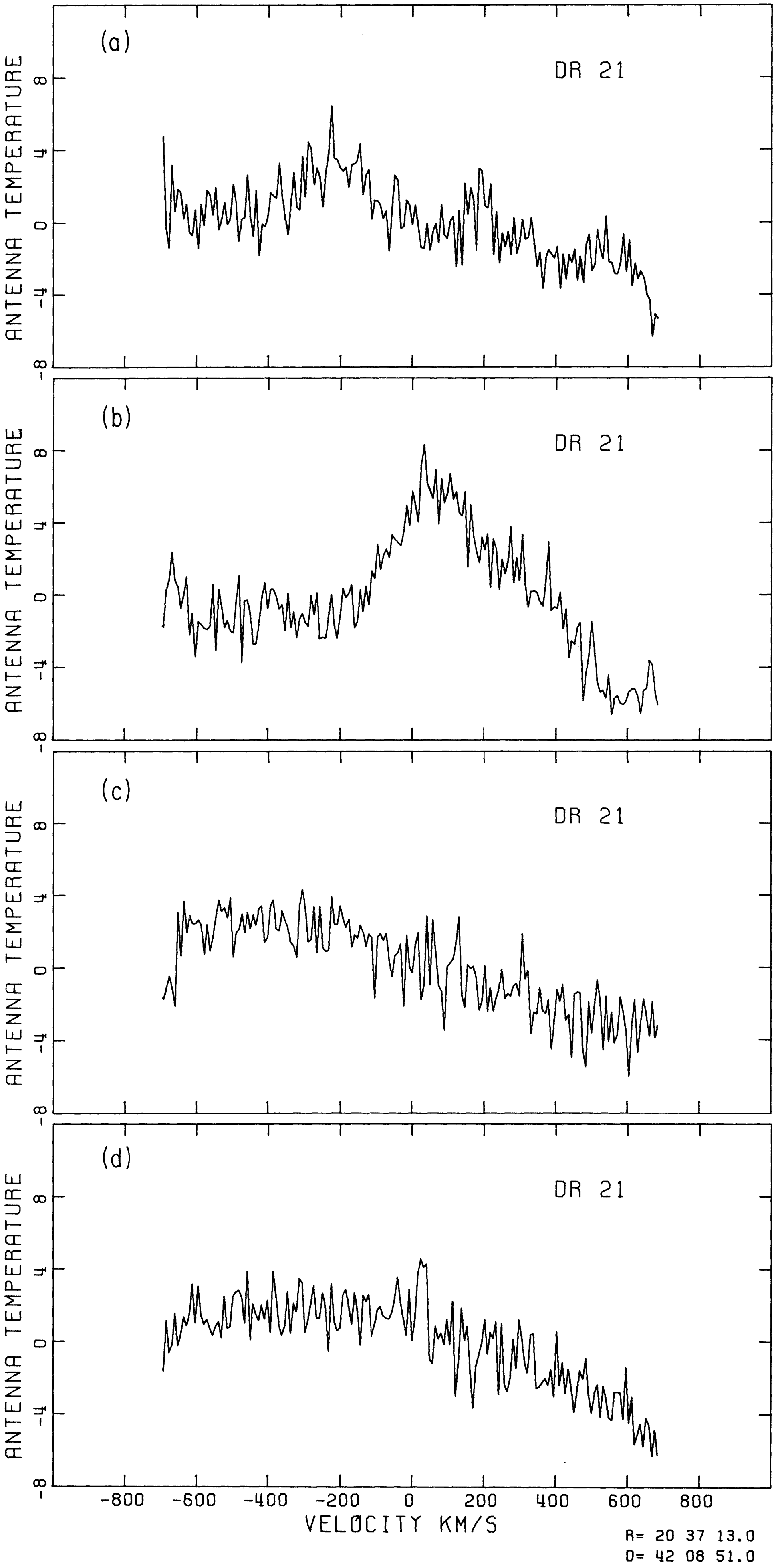
(a)
DR 21
(b)
DR 21
(c)
DR 21
(d)
DR 21
ANTENNA TEMPERATURE
8
4
0
-4
-8
-800
-600
-400
-200
0
200
400
600
800
VELOCITY KM/S
R= 20 37 13.0
D= 42 08 51.0

Figure 11

Figure 12: Spurious features observed near 480 MHz on blank sky. The data were taken in total power mode, with 2.5 MHz bandwidth, and using RG9 IF cable. There was no apparent interference or other malfunction. These features resemble those produced in the Spiraline cables earlier in the same run (c.f. figure 9). But after they appeared, these signals persisted for only three 10-minute on-off pairs, becoming weaker with time, and then vanished altogether--behavior quite unlike typical cable problems. A subsequent two hours of integration at the same position showed no evidence of instrumental effects.

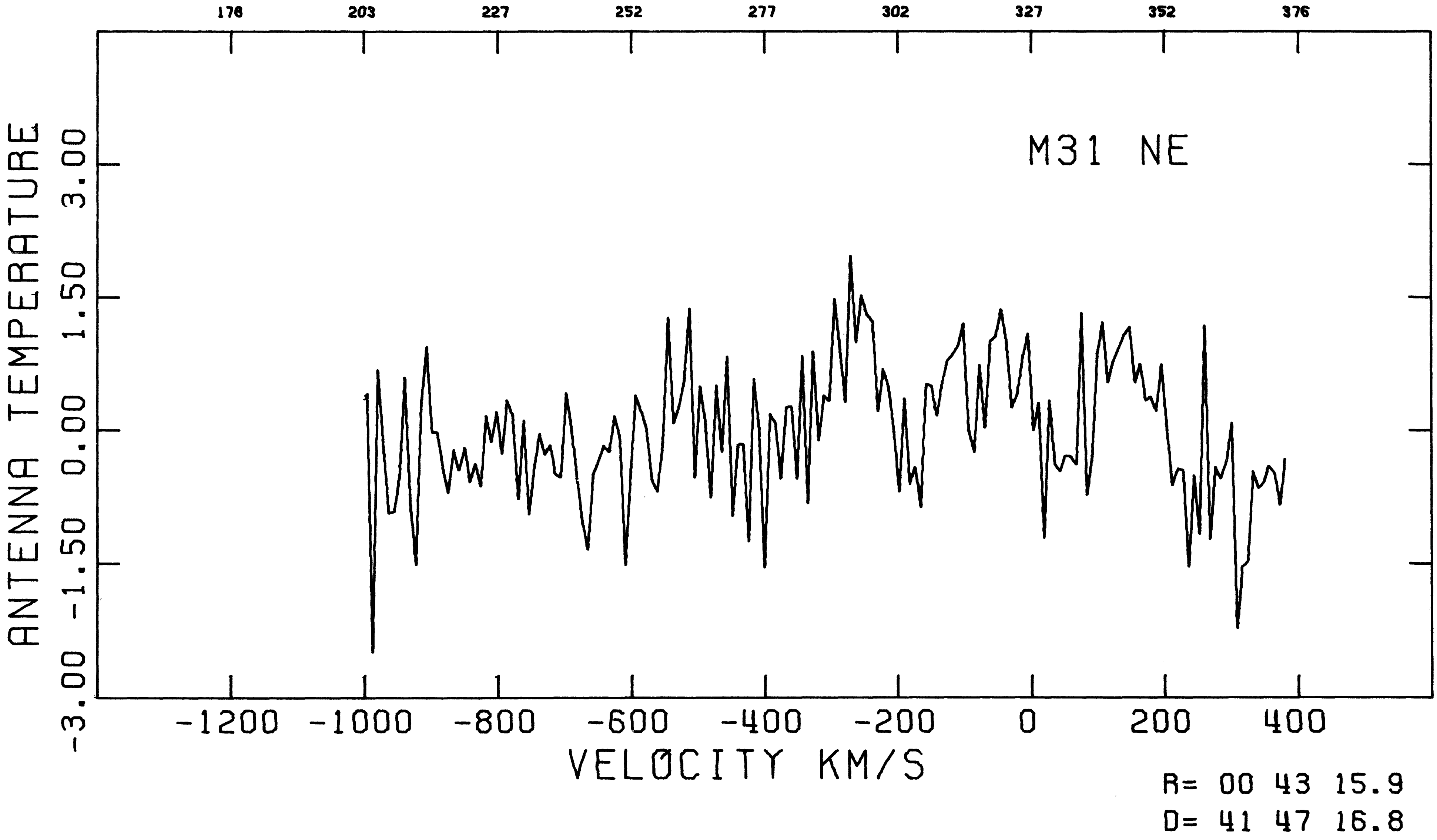
M31 NE
ANTENNA TEMPERATURE
-3.00
-1.50
0.00
1.50
3.00
VELØCITY KM/S
-1200
-1000
-800
-600
-400
-200
0
200
400
176
203
227
252
277
302
327
352
376
R= 00 43 15.9
D= 41 47 16.8

Figure 12