New Control System for the IRAM 30m Study—Feasibility of New Observing Modes

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Description - about this document:
This is a report on tests conducted in the OLD (current) control system in order to investigate the feasibility of some novel observing modes that are being considered for the NEW control system for the 30m.
At the URL above, the current (newest) version of this document can be found in PDF format. There is also an archive of older versions identified by date and version number.

Contents

1 Introduction

Several new observing modes have been suggested for the New Control System (NCS) for the 30m or to be used with new instrumentation, e.g., the multibeam heterodyne array HERA. Some of these would require to add some additional flexibility to existing observing modes; others require that some features be "activated" that are already foreseen; yet others are entirely new and could not be easily implemented in the current system.

Examples include: "Balanced Position Switching" using several off-source reference positions; Wobbler Switching with the wobbler rotated from its standard position angle; Wobbler in "triangular" mode to make maps; Wobbler Switching "between" elements of HERA. One common characteristic of most of these new observing modes is that they combine data as "on-source data" and "off-source reference data" from different states of the telescope system in ways that are not currently used.

Here we describe results from a first round of tests conducted in the current system, i.e., using existing features of OBS and OBSINP. Of course, most of these tests are limited to special, simplified cases of the new observing modes.

The goal is to get a clearer idea about potential benefits and problems, in particular about the data quality to be expected, and to check for limitations imposed by current hardware. This information should be helpful to decide which new ideas are most promising to pursue, and to review the priorities we have set for new observing modes in the NCS. Observing modes foreseen for the NCS are described in: "New Control System for the 30m Telescope: Specifications: Observing Modes and User Commands", Identifier - Master URL: http://www.iram.es/FutureControl30M/Specifications/Spec_OM.

NOTE: these tests are "work in progress": some data are not yet included in this report, and more tests may be desirable. In the future these tests will merge into the tests of new Observing Modes in the NCS.

2 Conclusions

- In Position Switching (PSW) the best baseline quality is achieved if the offset of the reference position is purely in Azimuth (see Section 3).
- If this mode is not possible, the baseline can be improved by using two reference positions on opposite sides of the source. In the NCS this should be developed into a general Balanced PSW mode (see Section 3).
- Wobbler Switching (WSW) with the rotated wobbler is feasible. Spectra taken with the wobbler rotated by 90 degrees, a throw of 60–240", and 20 subscans of 20 seconds, are of similar quality as those taken with the wobbler at its standard position angle (see Section 4).
- 1-sided WSW, in which the source is observed with the same wobbler position (in the same wobbler switching phase) during all subscans, gives spectra with strong baseline ripple in all tested bands (3mm and 1.3mm). (See Section 5). [This is, of course, not an observing mode used in practice at the 30m.]
- To achieve the well-known excellent flatness of baselines in WSW, it is essential that *equal* numbers of ("left" and "right") subscans are *subtracted* from each other, so that the baseline ripple is canceled out. (See Section 6). [This is, of course, routinely done with the current WSW mode at the 30m.]
- The previous 2 results cast doubt on the data quality expected from any observing modes that might: (i) combine on-source and off-source reference data taken with different positions of the wobbler and (ii) do not subtract equal numbers of subscans (or records) taken with identical wobbler parameters. This might be a problem for: (i) mapping with the triangular Wobbler mode; (ii) WSW "between pixels" of multibeam receivers. (iii) WSW combined with Spectra-Line On-The-Fly.

More tests are desirable to confirm these findings and to extend them to other values of the parameters of the observing modes.

3 Position Switching (PSW)

All Position Switching (PSW) tests were done in the Horizontal System, specifying offset positions for the reference position in Azimuth and Elevation.

We compare spectra taken with:

1. one reference position; let's call this "SimplePSW"; in particular:
   (a) reference offset only in Azimuth, "Simple Azimuth PSW";
   (b) reference offset only in Elevation, "Simple Elevation PSW";
   (c) reference offset in Elevation and Azimuth, "Simple Diagonal PSW";
2. two reference positions located symmetrically relative to the on-source position, "Double PSW", in particular:
   (a) both references offset only in Elevation, "Double Elevation PSW";
   (b) or both references offset in Elevation and Azimuth, "Double Diagonal PSW".

The main results are seen, e.g., in Figure 1:

1. The baseline quality is best for Azimuth PSW. Often it is so good, that no baseline ripple is seen.
2. For Simple Diagonal PSW and Simple Elevation PSW the data quality is worst; often a strong baseline ripple is visible.
3. For Double Elevation PSW and Double Diagonal PSW the data quality falls between the 2 previous cases. The baseline ripple is clearly reduced compared to case 2. Data from Double Elevation PSW and Double Diagonal PSW have about equal quality.

Note that there are other points to keep in mind, as can be seen in the following figures:

For some frequencies, receivers, and observing parameters the baseline can be even much worse, e.g., Figure 2. Here the baseline problems are not dominated by a ripple with a single well-defined period. But even so, Azimuth PSW gives the best results, and Double PSW is better than Simple PSW.

During the same test, data at 3mm give results similar to those in Figure 1, although the baseline ripple is much smaller or not seen at all, see Figures 3 and 4.

The amplitude of the baseline ripple increases with larger offsets of the reference position, compare, e.g., Figures 5 and 6, which show data from Simple Azimuth PSW, Simple Elevation PSW, and Double Elevation PSW with reference offsets of 3600" and 7200", respectively.

More examples are shown on the following pages, up to Figure 16.

In all our tests, Double PSW gave better results than Simple PSW, if the latter includes a reference offset in Elevation. In some tests, Double PSW gave results as good as Simple Azimuth PSW.

More tests could be done, e.g., (i) using one reference that is offset in hour-angle by the distance that "equals" the integration time per subscan, and (ii) with 2 references, one offset in elevation by -7200", the other by +3600" but using twice the integration time.

In the NCS we plan a more general PSW than those described above, which we call Balanced PSW. This will allow to use 2 or more off-source references at any position chosen by the user, and to automatically combine them with the on-source measurements in a way that is optimized to cancel out baseline ripple. One possibility could be to use one reference at a higher elevation than the source, another reference at a lower elevation, and to adjust the integration times so that the average elevation or power of the references equals that of the source.

Such a general PSW scheme is impossible in the current control system, but the tests described above show that it is very promising to pursue these ideas.

NOTE:

Observing Modes that help to cancel out baseline ripple can be very helpful for many projects. However, it is of course desirable to investigate the causes of baseline ripples, e.g., standing waves, and try to eliminate them. Moreover, there are other choices when setting up observations that help to minimize the baseline ripple, e.g., making the offsets of the reference positions as small as possible.

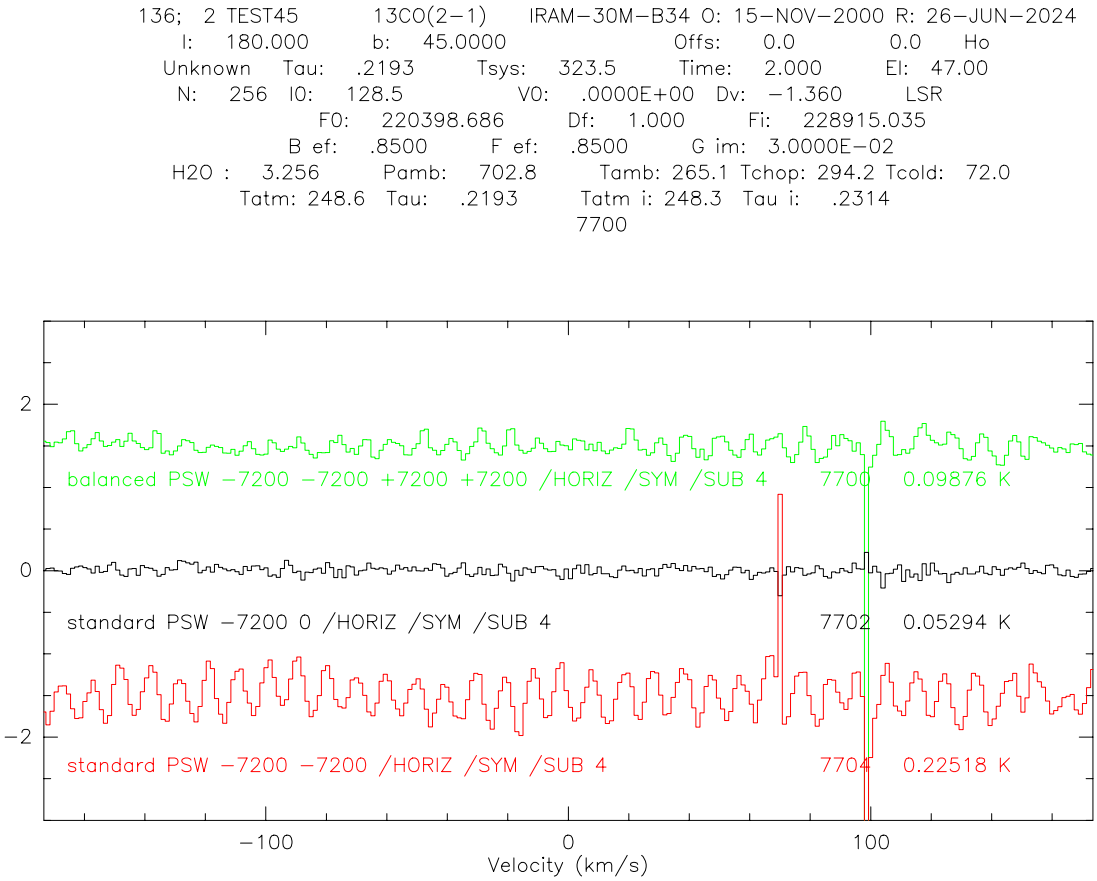

Figure 1: Position Switching on a test "source" fixed at 45 degrees elevation. Receiver B230. 1 MHz Filterbank; 256 channels. 4 Subscans of 30 seconds each. Subscan sequence: off-source reference, on, on, reference. For all reference subscans offsets are in (Az., El.).
Scan 7702: both reference subscans at (-7200",0"); "Simple Azimuth PSW".
Scan 7704: both reference subscans at (-7200",-7200"); "Simple Diagonal PSW".
Scan 7700: first reference subscan at (-7200",-7200"); second reference subscan at (+7200",+7200"); "Double Diagonal PSW".
The spectra were shifted up or down by arbitrary amounts, but the scale is the same for all. Note the differences in the amplitude of the baseline ripple.

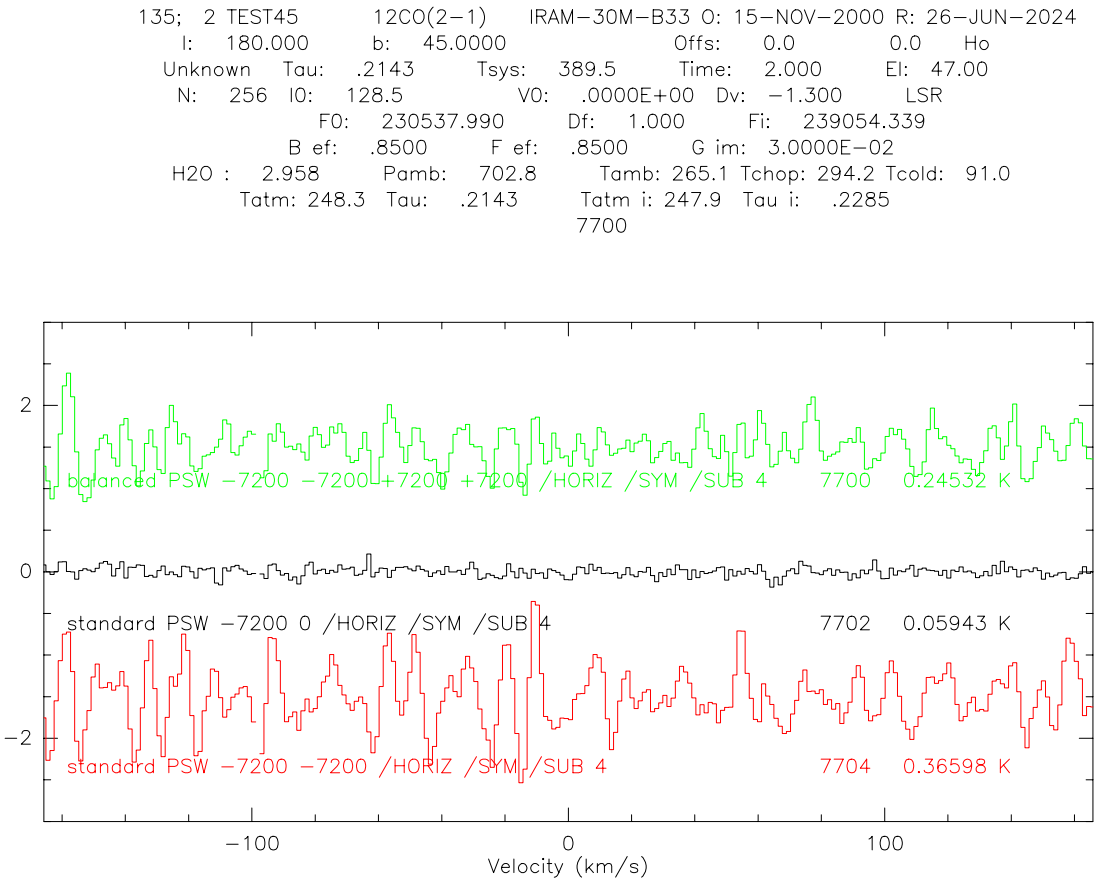

Figure 2: PSW. Receiver A230. Otherwise as in Figure 1.

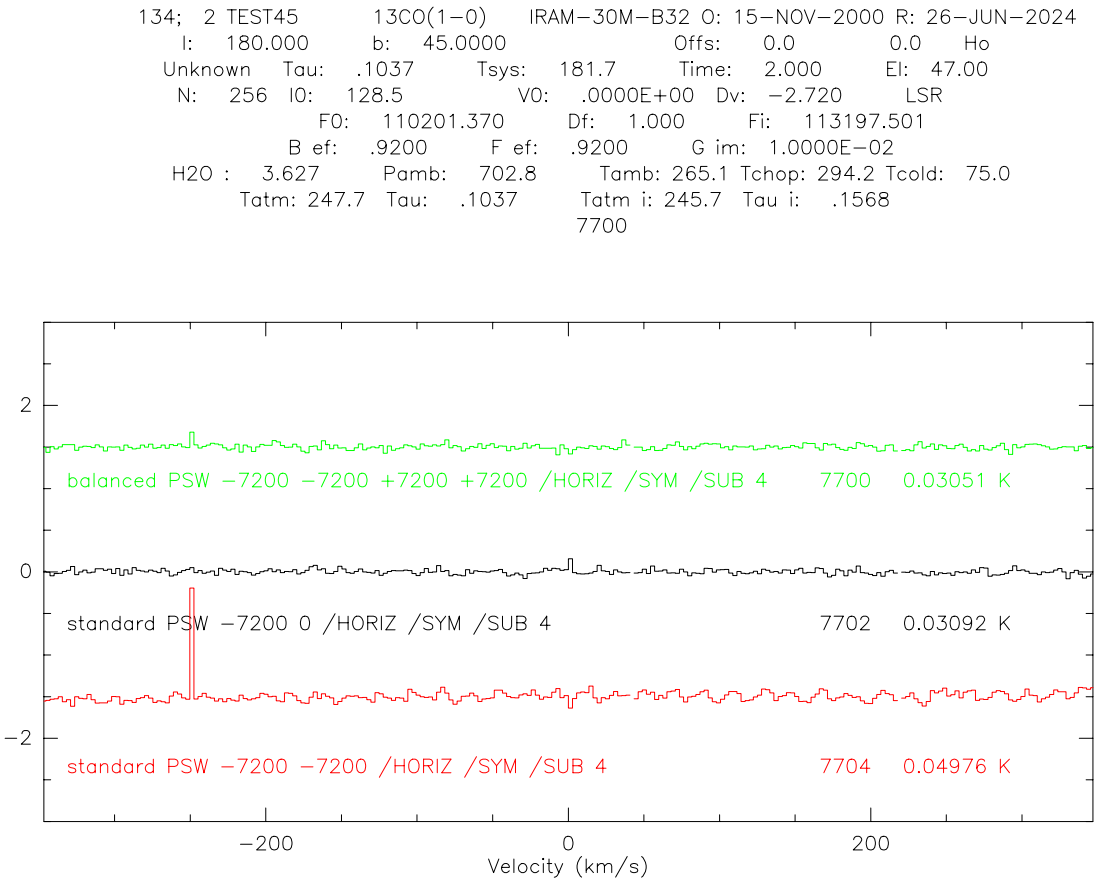

Figure 3: PSW. Receiver B100. Otherwise as in Figure 1.

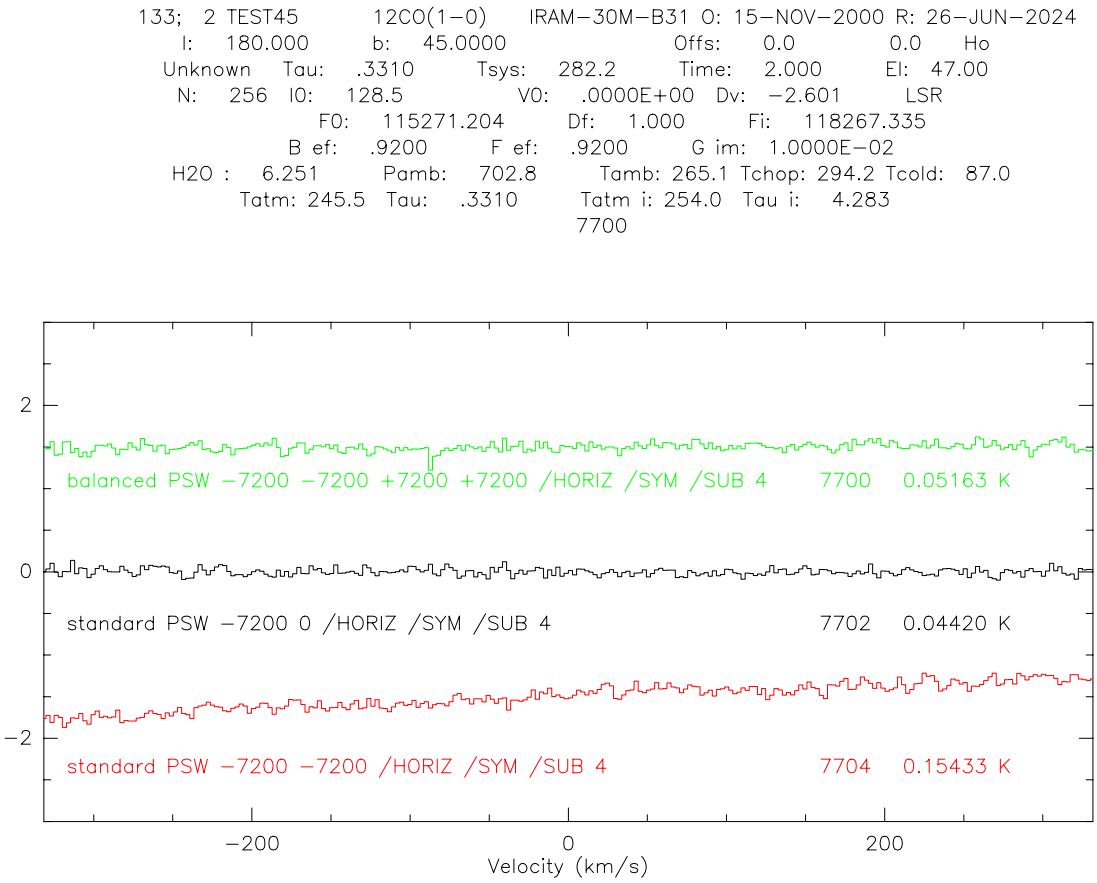

Figure 4: PSW. Receiver A100. Otherwise as in Figure 1.

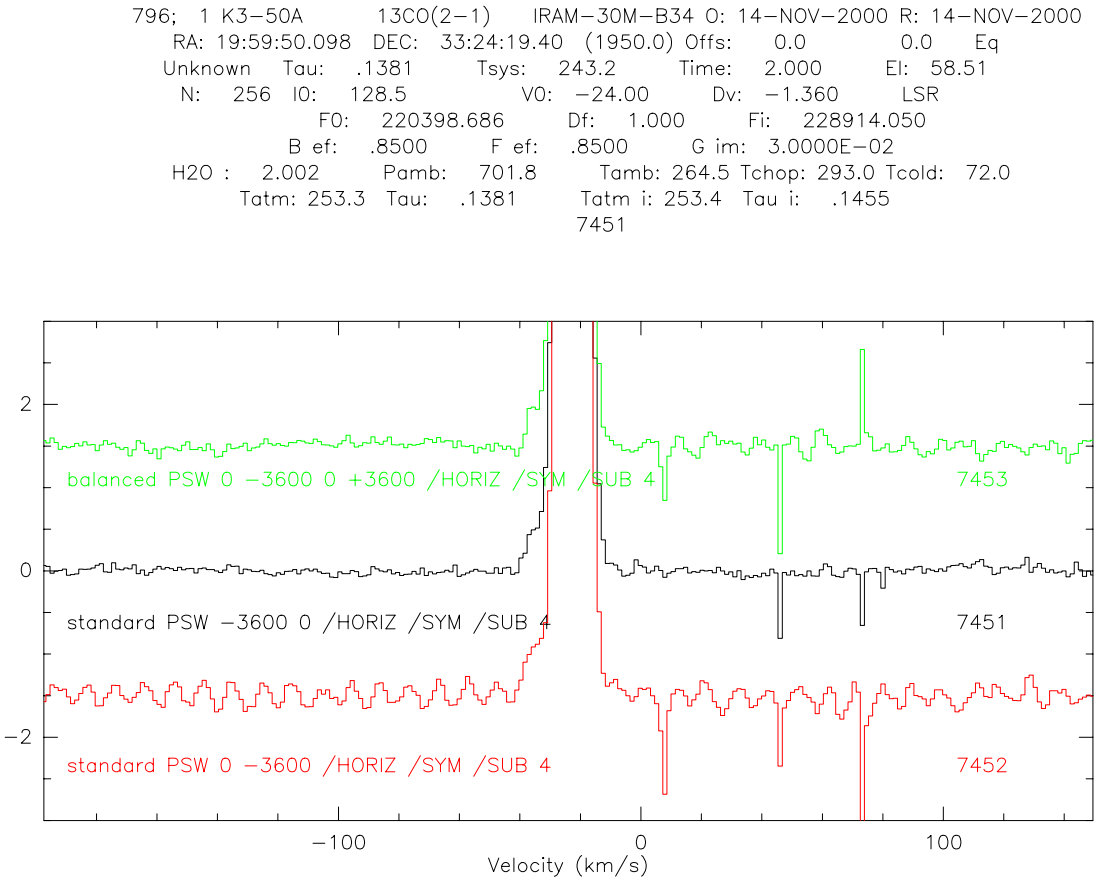

Figure 5: PSW. Receiver B230. Scan 7451: Simple Azimuth PSW, reference (-3600”,0); 7452: Simple Elevation PSW, (0,-3600”); 7453: Double Elevation PSW, (0,+/-3600”).

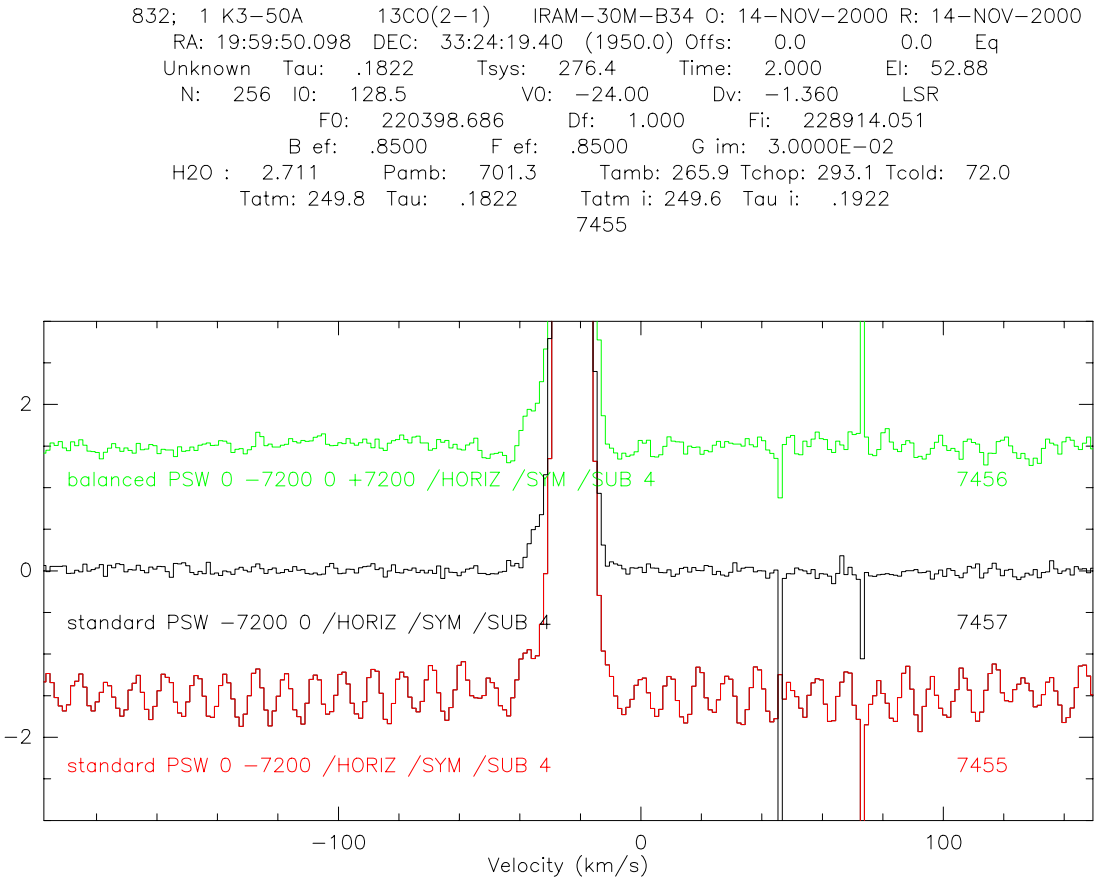

Figure 6: PSW. Receiver B230. Scan 7457: Simple Azimuth PSW, reference (-7200”,0); 7455: Simple Elevation PSW, (0,-7200”), 7456: Double Elevation PSW, (0,+/- 7200”).

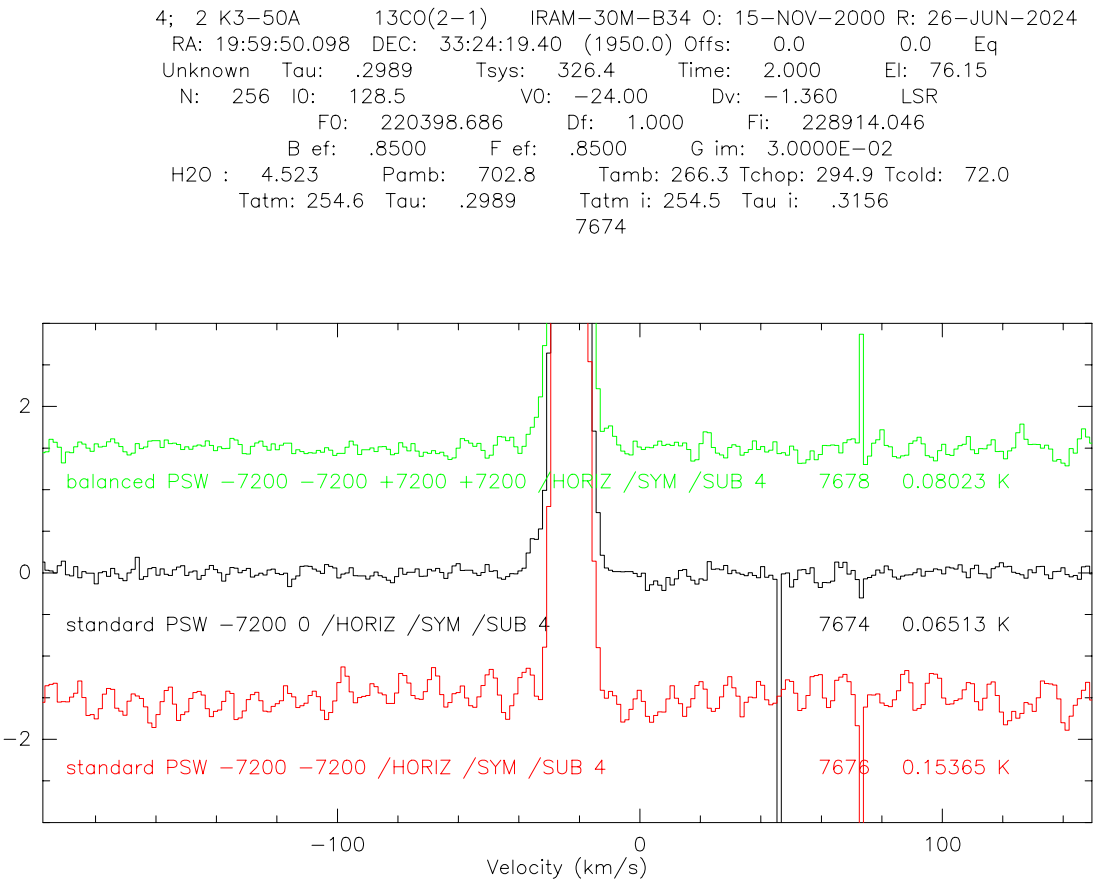

Figure 7: PSW. Receiver B230. Observing modes similar to Figure 1, but on a source, K3-50A.
Scan 7674: Simple Azimuth PSW, reference (-7200”,0);
7476: Simple Diagonal PSW, (-7200”,-7200”);
7478: Double Diagonal PSW, (-7200”,-7200”) and (7200”,7200”).

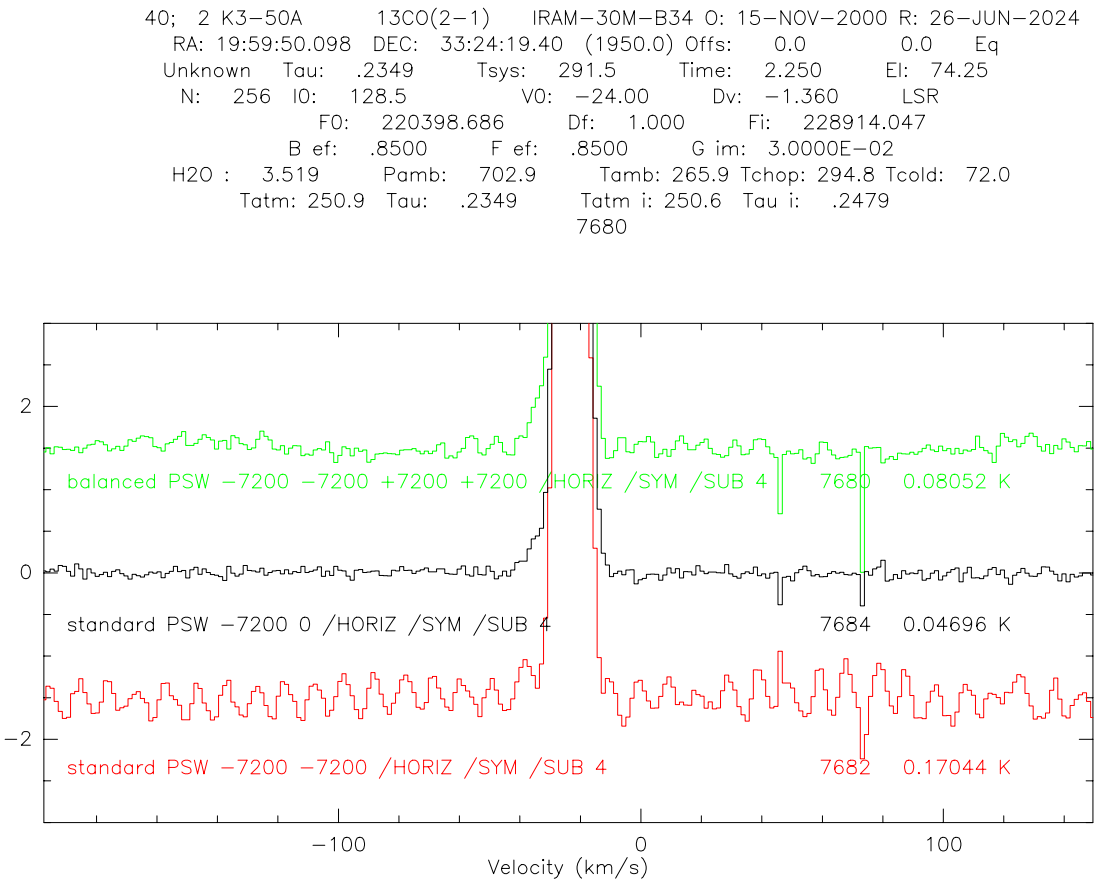

Figure 8: PSW. Receiver B230. Observing modes similar to Figure 1, but on a source, K3-50A.
Scan 7684: Simple Azimuth PSW, reference (-7200”,0);
7682: Simple Diagonal PSW, (-7200”,-7200”);
7680: Double Diagonal PSW, (-7200”,-7200”) and (7200”,7200”).

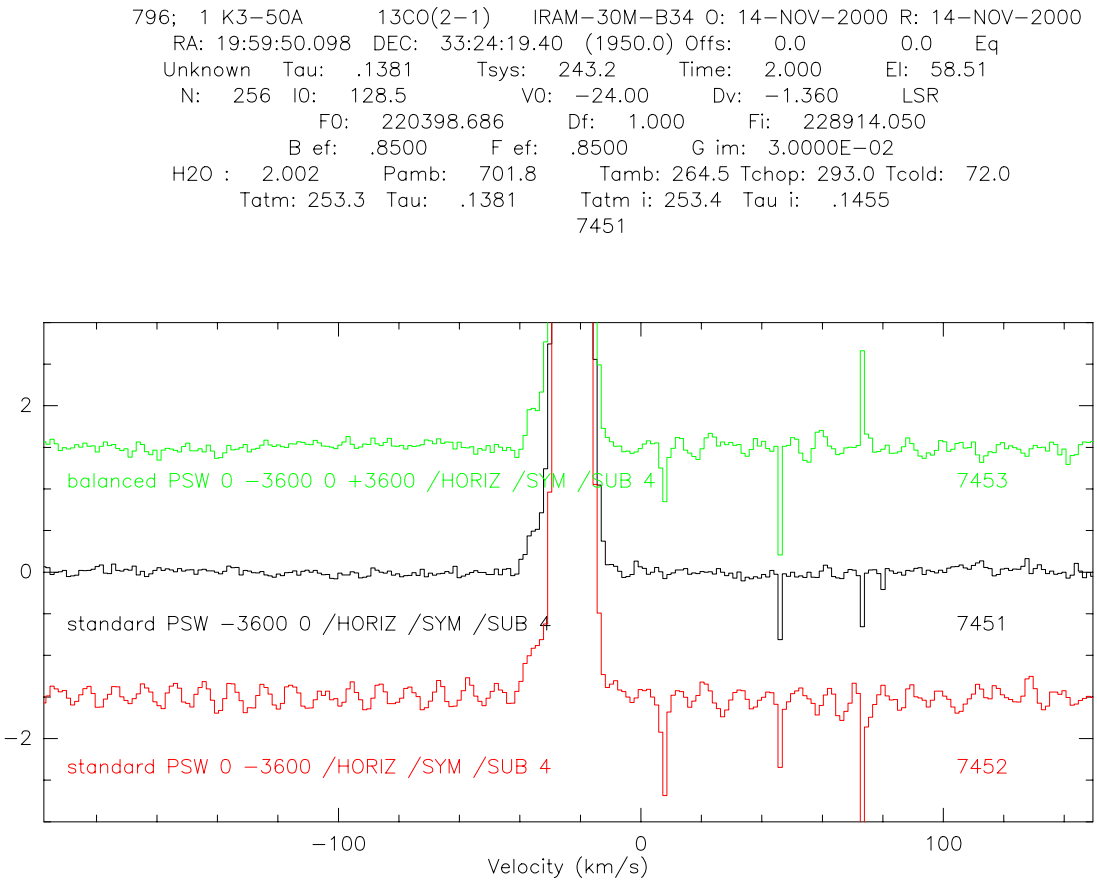

Figure 9: PSW. Receiver B230.
Scan 7451: Simple Azimuth PSW, reference (-3600”,0);
7452: Simple Elevation PSW, (0,-3600”);
7453: Double Elevation PSW, references (0,-3600”) and (0,3600”).

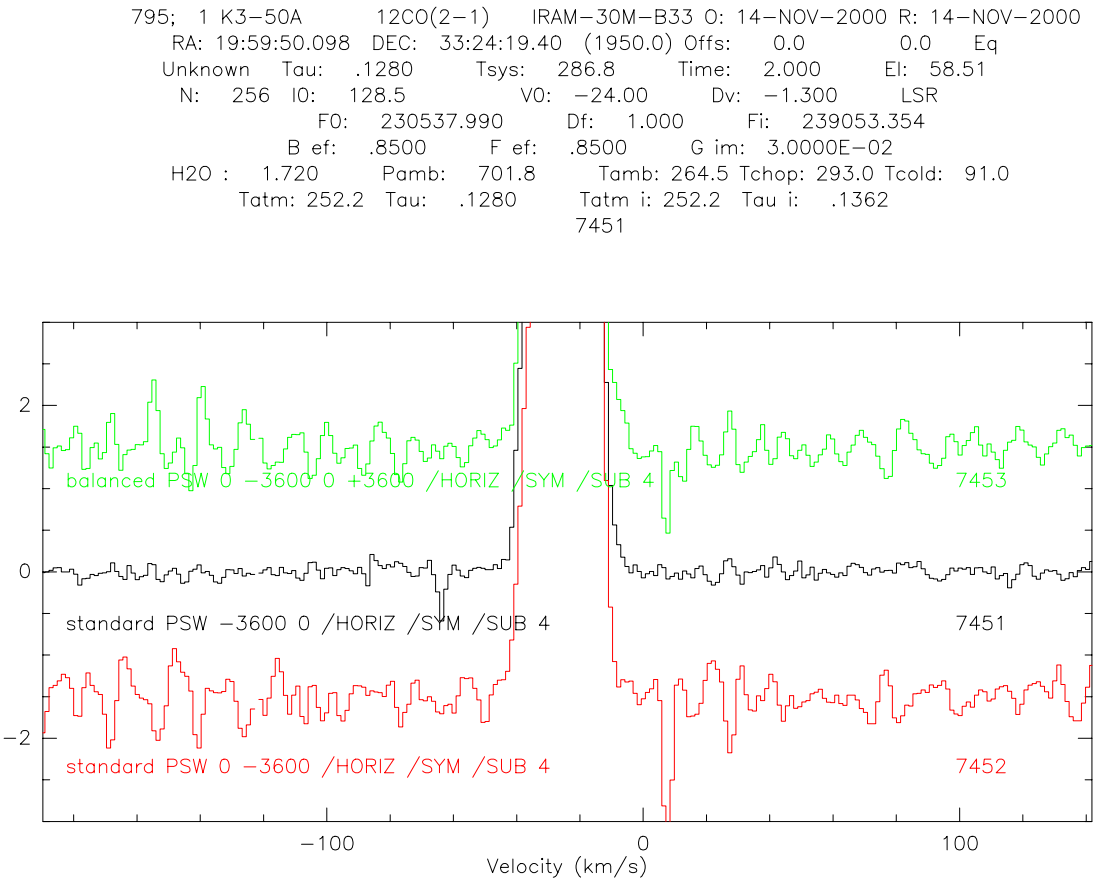

Figure 10: PSW. Receiver A230. Otherwise as Figure 9.

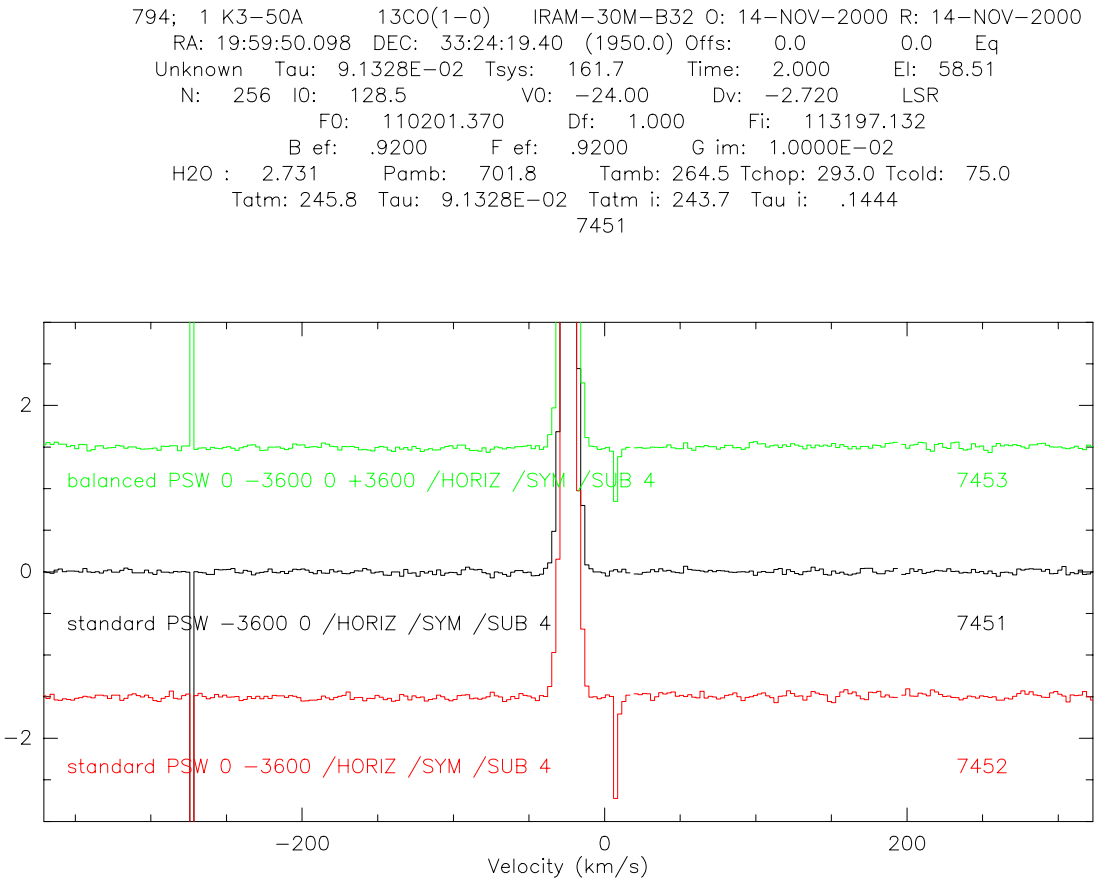

Figure 11: PSW. Receiver B100. Otherwise as Figure 9.

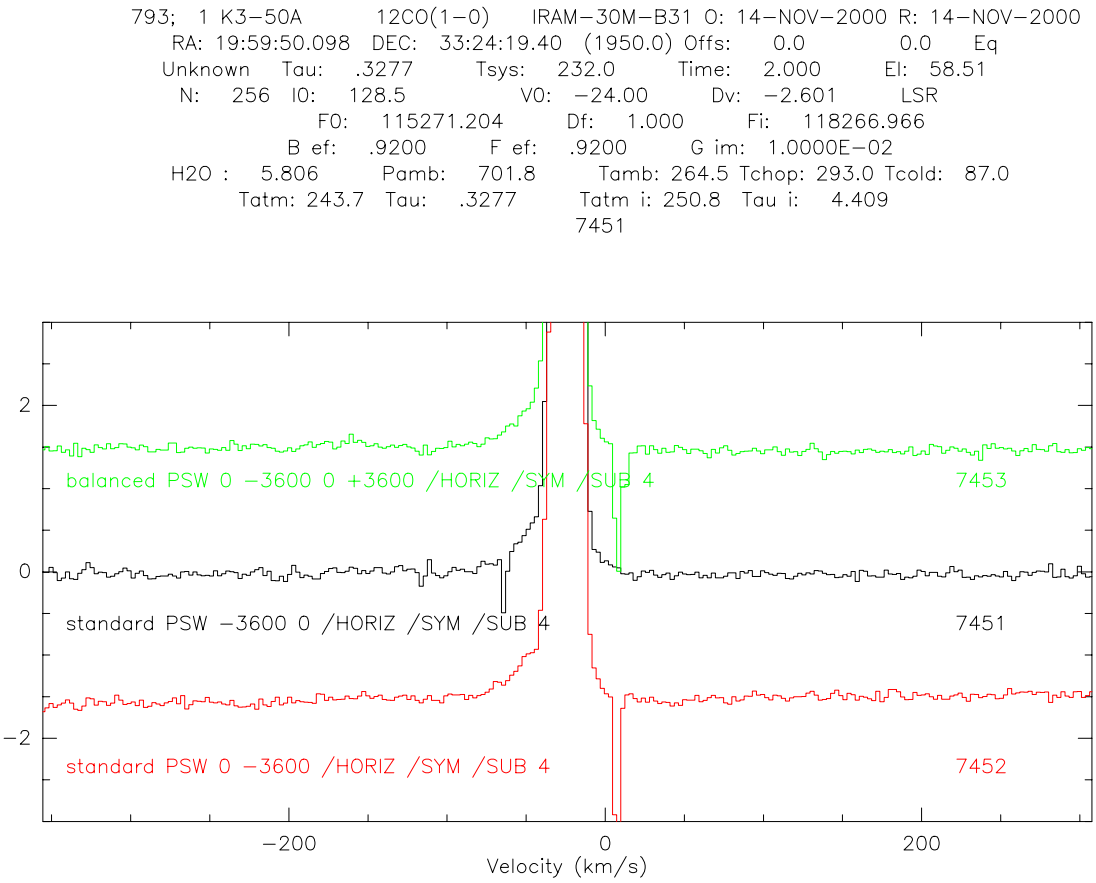

Figure 12: PSW. Receiver A100. Otherwise as Figure 9.

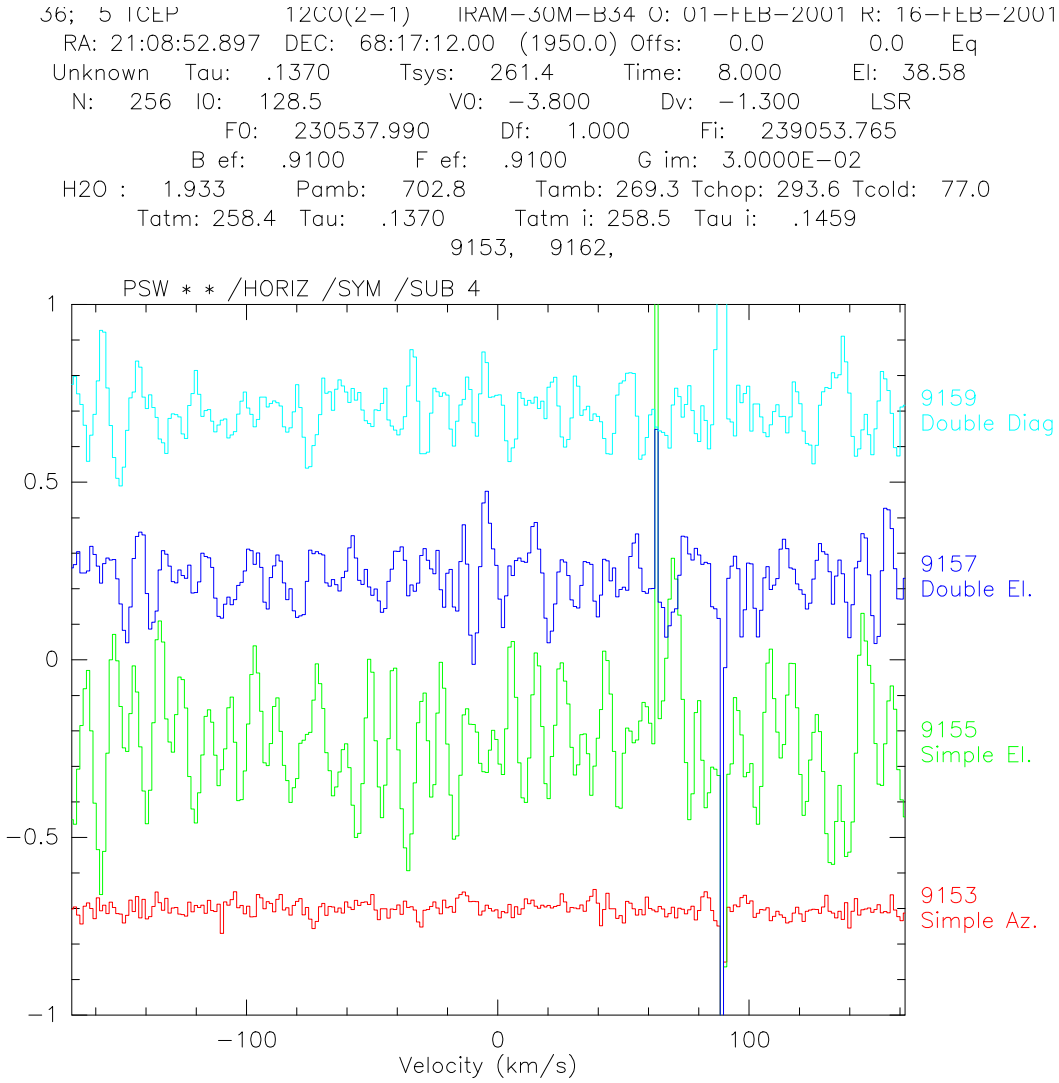

Figure 13: Receiver B230.
Observing modes similar to that in Figures 1 and 7.
Scan 9153: Simple Azimuth PSW, reference at (-7200”,0);
Scan 9155: Simple Elevation PSW, (0,-7200”);
Scan 9157: Double Elevation PSW, references at (0,-7200”) and (0,+7200”) ;
Scan 9157: Double Diagonal PSW, (-7200”,-7200”) and (+7200”,+7200”).

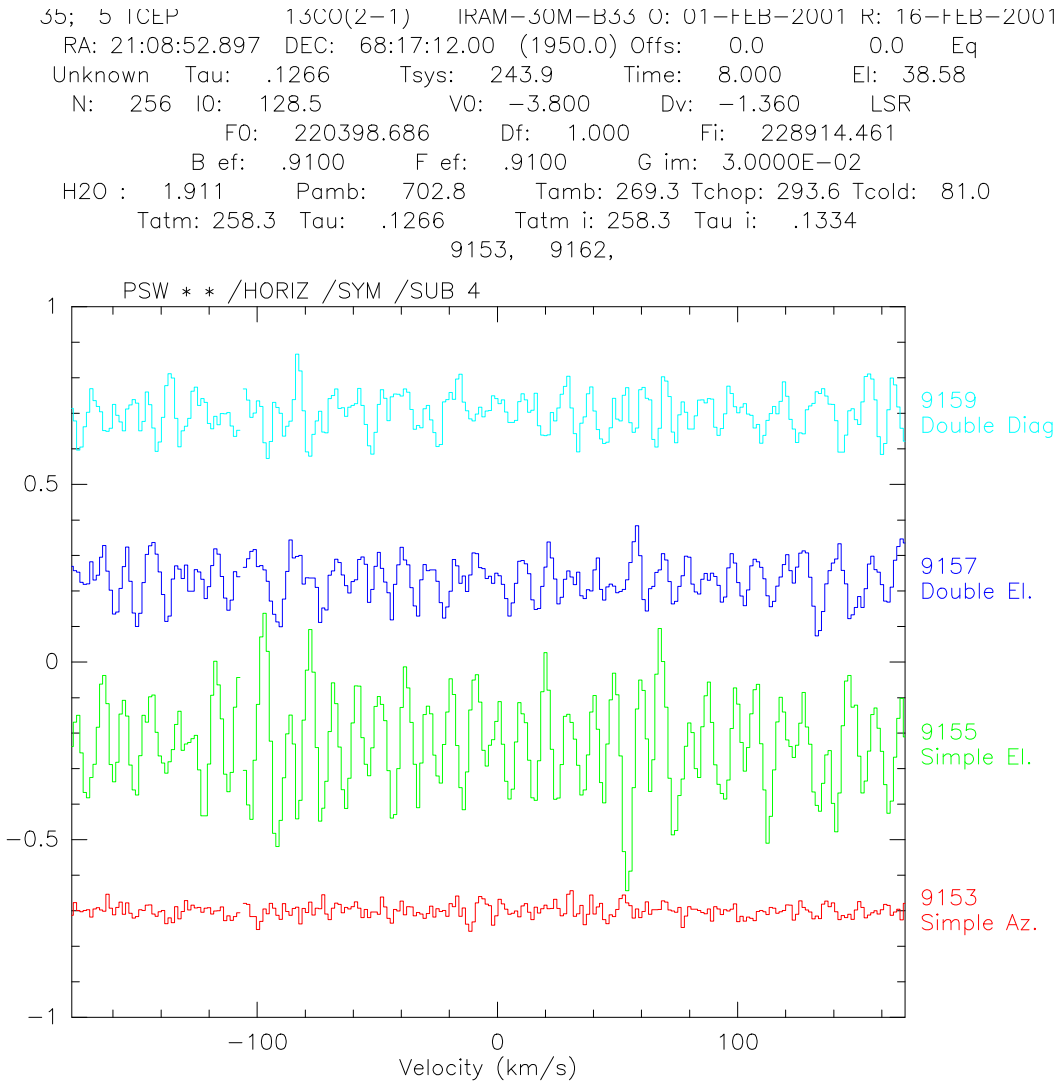

Figure 14: Receiver A230. Otherwise as Figure 13.

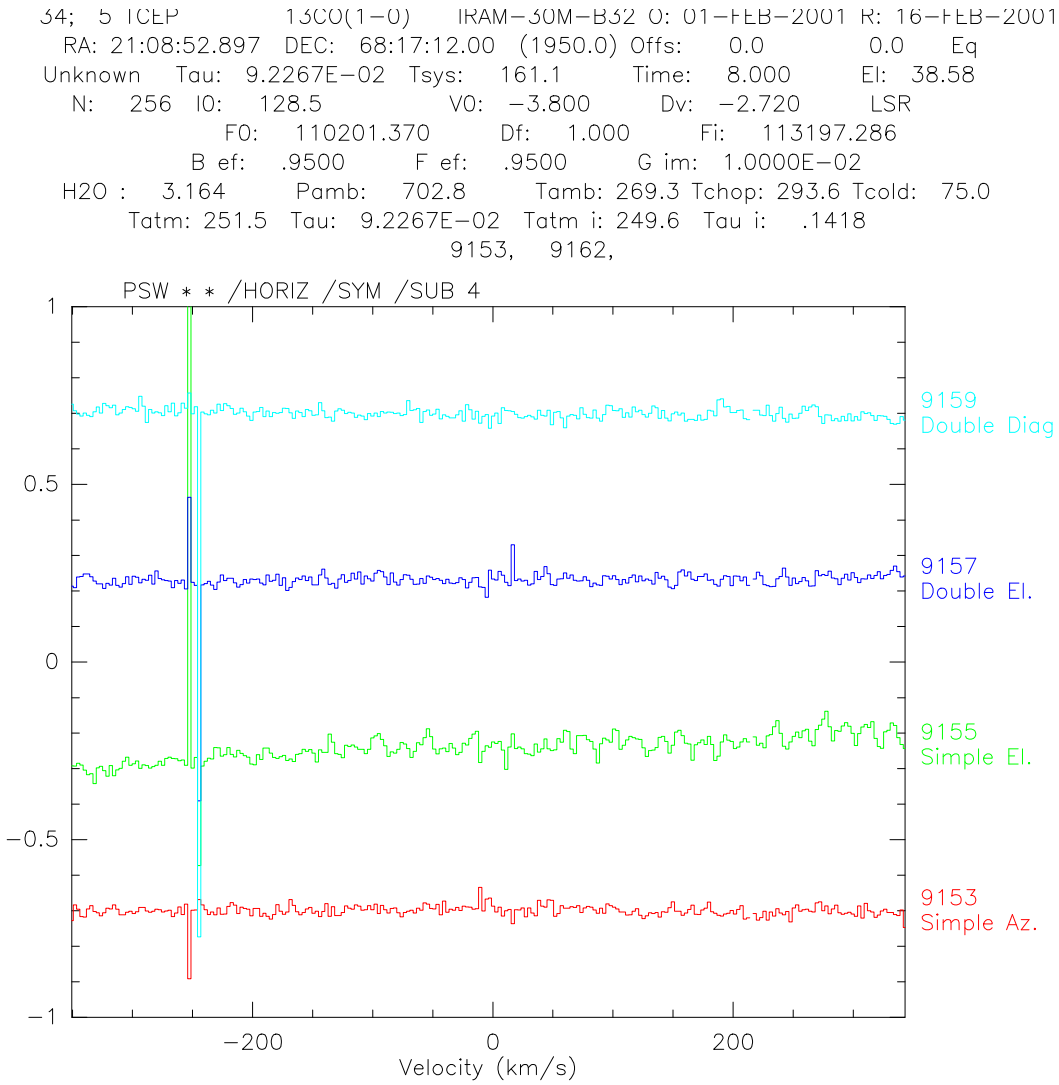

Figure 15: Receiver B100. Otherwise as Figure 13.

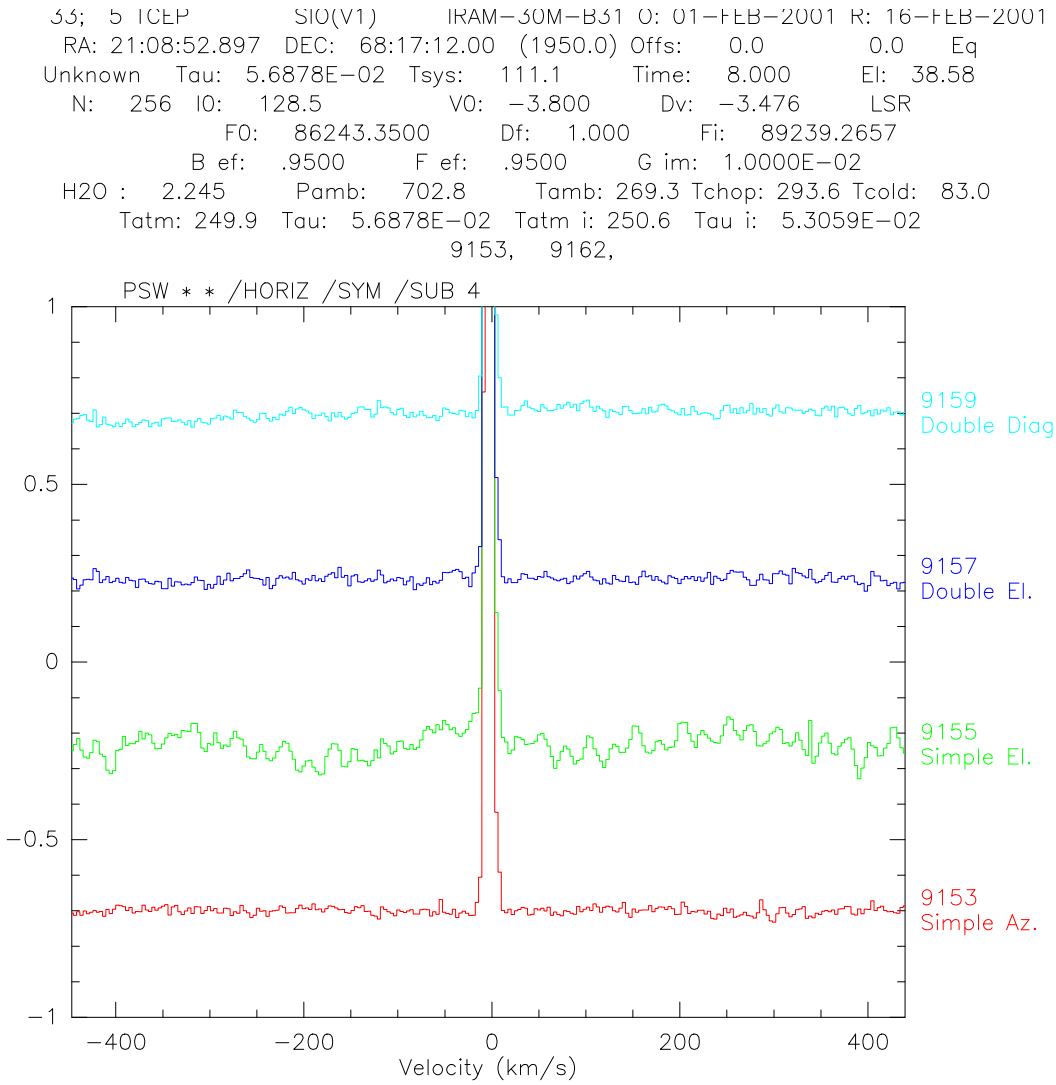

Figure 16: Receiver A100. Otherwise as Figure 13.

4 Wobbler Switching (WSW) with Rotated Wobbler

Hardware exists at the 30m that allows to rotate the complete subreflector, including the wobbling mechanism, around its symmetry axis. For historical reasons the corresponding rotation angle is sometimes called "Polarisation Angle"; the commands in OBSINP to set this angle are SPOS, OPOS, etc. We prefer to call it the "Wobbler Position Angle".

Up to now, for all observations, this angle is set so that the wobbling is "along azimuth", i.e., at constant elevation. This standard value is set in OBSINP by the commands:
`SBAS 0` (i.e., horizontal system)
`SPOS 0D` ,
however on some displays, e.g., the color monitor, this is shown as a value of 360 degrees. (WARNING: `SPOS 360D` apparently tries to set the angle outside its currently allowed range!)

We took spectra in WSW with the wobbler in its standard position, Position Angle = 0 or 360 degrees, and rotated by = 90 degrees (`SBAS 0; SPOS 450D`), i.e., at Position Angle = 90 or 450 degrees. These tests have 2 goals: (i) to confirm that the Wobbler works when it is rotated; (ii) to compare the data quality for WSW with rotated and unrotated Wobbler.

When the Wobbler is not in its standard position, the position offsets for the on-source and off-source reference subscans must be set manually with OBSINP commands.

Our tests indicate that the data quality does not depend on the Wobbler Position Angle, see Figures 17–20. These plots are for a wobbler throw of 120"; our tests with throws of 60" and 240" give similar results.

More tests are needed, with the Wobbler rotated by other angles, e.g., 45 degrees, and with longer integration times.

GOAL:

Allow any Position Angle for the Wobbler, specified in the Horizontal or in the User's celestial coordinate system. To make this practical, the physically possible range of the Wobbler Position Angle must be increased, and the necessary additional pointing corrections must be applied automatically (see "NOTES").

NOTES:

When the Wobbling Subreflector is rotated from its standard position, additional pointing corrections, on the order of 50", have to be applied. Juan Peñalver has done tests that show these additional pointing offsets as a function of the Wobbler Position Angle, and how these offsets can be decreased.

Similarly one might expect the focus to depend on the Wobbler Position Angle. Up to this point, however, our tests indicate that the Z-focus is independent of the Postion Angle.

Hardware limitations restrict the currently usable range for the Wobbler Position Angle to about +/- 90 degrees relative to its standard position.

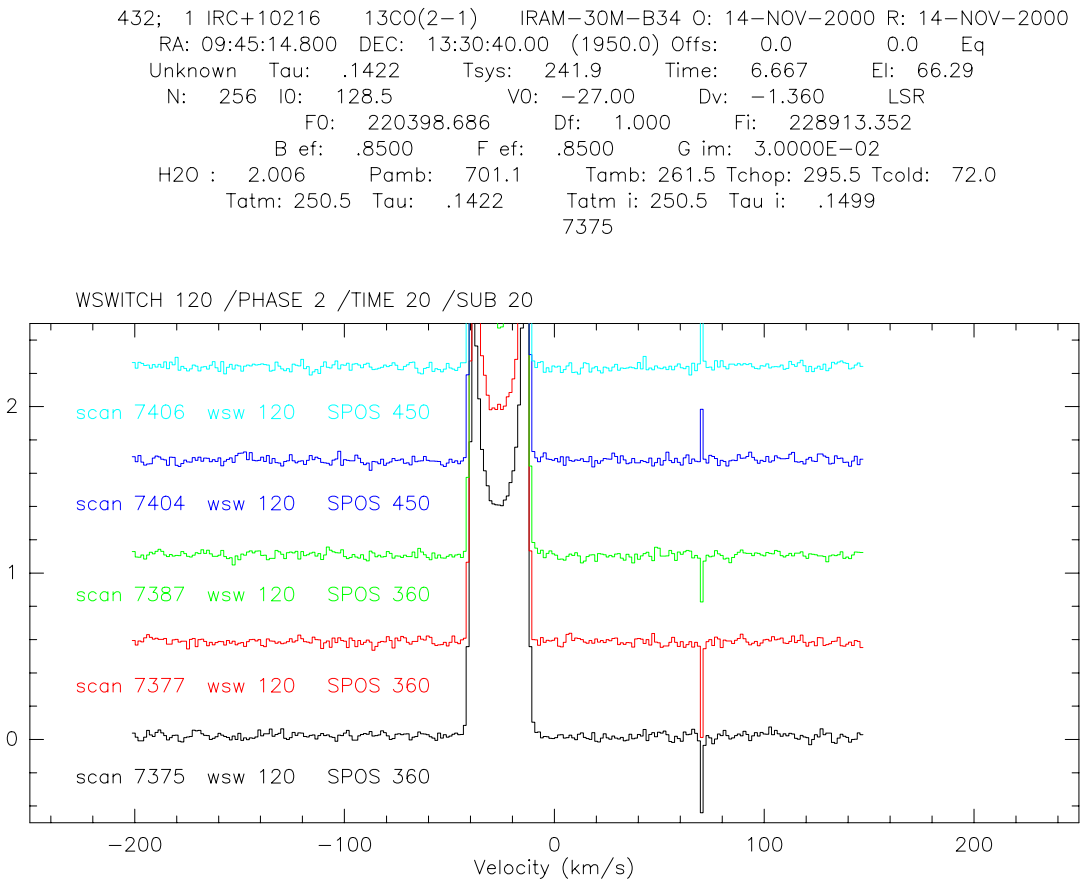

Figure 17: WSW with Rotated Wobbler. Receiver B230. Wobbler throw 120 arc seconds; time per phase 2 seconds; time per subscan 20 seconds; 20 subscans. Data labelled with SPOS 360: Wobbler in standard orientation; SPOS 450: Wobbler rotated by 90 degrees. The spectra were shifted up or down by arbitrary amounts, but the scale is the same for all.

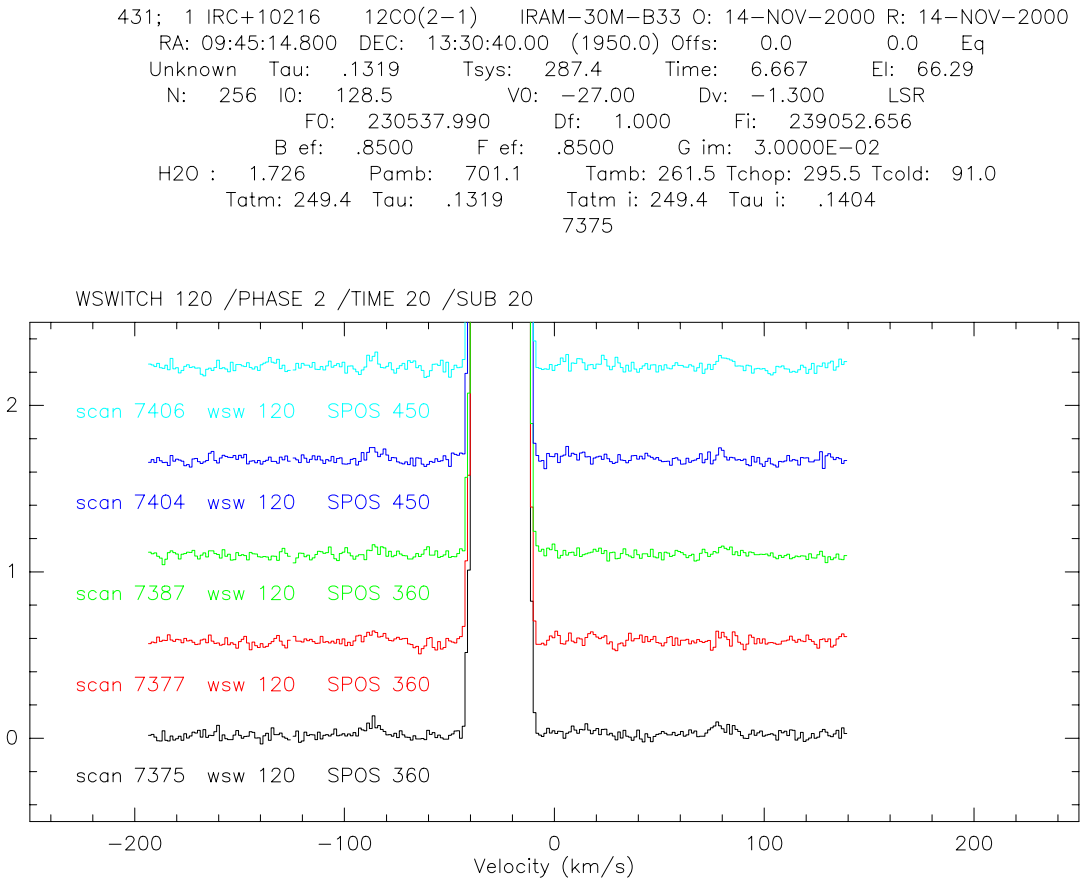

Figure 18: WSW with Rotated Wobbler. Receiver A230. Otherwise as Figure 17.

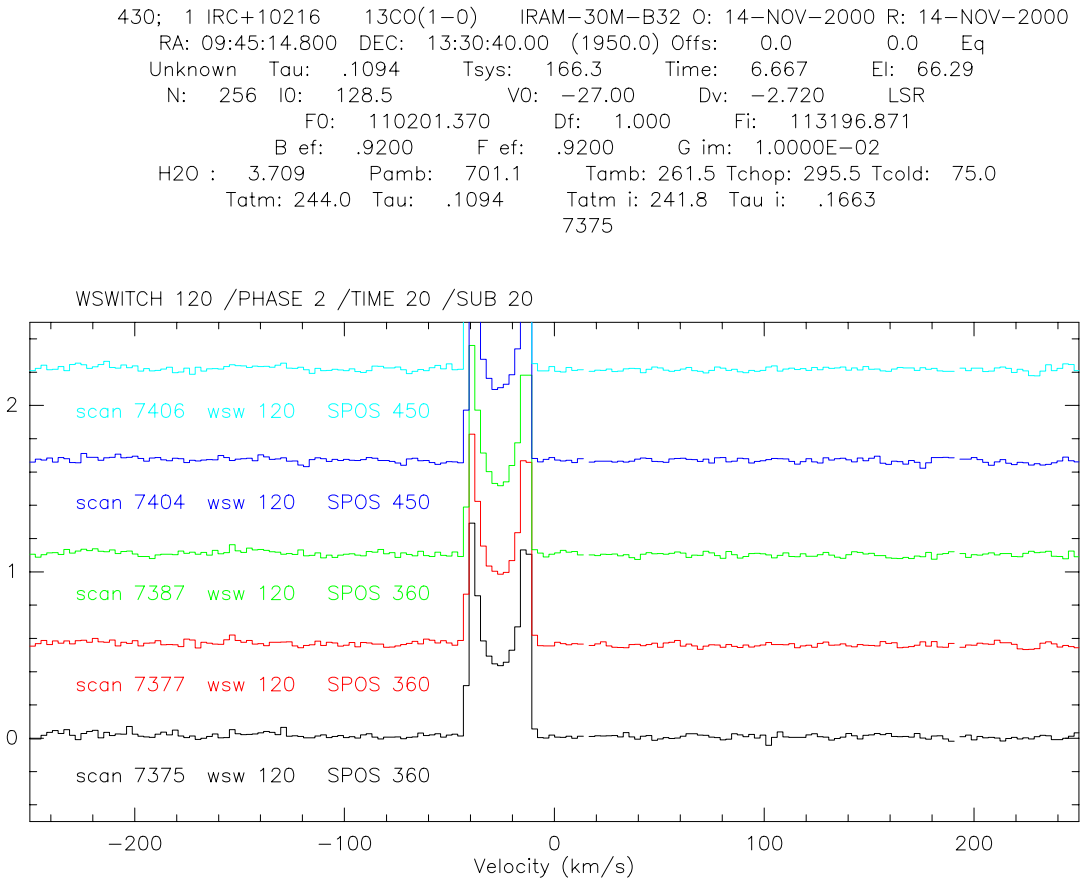

Figure 19: WSW with Rotated Wobbler. Receiver B100. Otherwise as Figure 17.

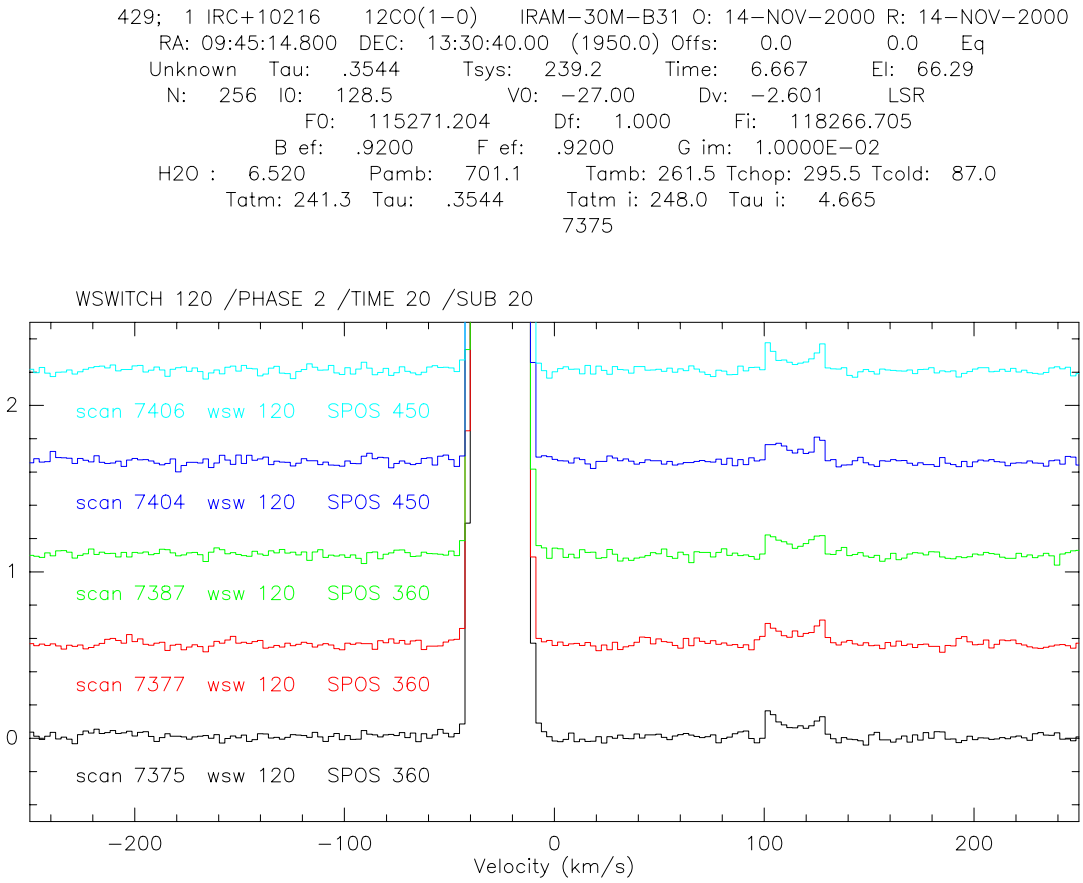

Figure 20: WSW with Rotated Wobbler. Receiver A100. Otherwise as Figure 17.

5 Wobbler Switching (WSW) — no Subscan Differencing

During Wobbler Switching, the wobbling secondary switches —in Azimuth— in a cycle with 2 switching phases between 2 positions that are symmetrical relative to the Wobbler zero position, i.e., the position of the secondary during all other observing modes. The on-source position is in the beam during one of these 2 phases, an off-source reference is in the beam during the other phase; and data from the two phases are subtracted.

It has been well-known since the implementation of WSW at the 30m that spectra obtained applying this switching mode alone have poor baselines (CT, private communication). However, there is an easy method to cancel out these baselines; and this method is always used for standard WSW at the 30m.

After each subscan taken as described above, the telescope is repointed so that during the next subscan the on-source position is seen in the *other* switching phase, i.e., with the other of the 2 Wobbler positions. The baseline ripple in this second subscan is very accurately the same as in the first subscan, and in the *difference* of the 2 subscans the baseline ripple cancels out, while the signal from the source remains —as well as noise, of course. During a WSW scan an *equal* number of subscans is taken with the 2 telescope pointings and combined, thus assuring an excellent cancellation of the baseline ripple and the well-known quality of the spectra, which have very flat baselines over the full bandwidth of the receivers.

As part of our tests we took some data to demonstrate these facts; and to investigate how important it is to combine an *equal* number of subscans with the 2 telescope pointings. These are important issues because one can imagine various potential observing modes that would not allow to follow the standard scheme described above.

Let's call the standard WSW mode "2-sided WSW", and the 2 types of subscans "left" and "right". We call WSW which has the on-source position in the same phase for all subscans "1-sided WSW", and WSW with an unequal number of left and right subscans "mixed WSW". We discuss 1-sided WSW in this Section 5 and in Section 7, and mixed WSW in Section 6.

Our test results from 1-sided WSW compared to 2-sided WSW confirm what has been explained above: (Figures 21–24). Even for small throws, spectra from 1-sided WSW show a clear baseline ripple for all 4 receivers. Spectra from 2-sided WSW have flat baselines for all receivers and all wobbler throws.

NOTE:

For 1-sided WSW the position offsets for the subscans were set with OBSINP commands, and calibrated spectra were computed with special procedures in `otfcal`.

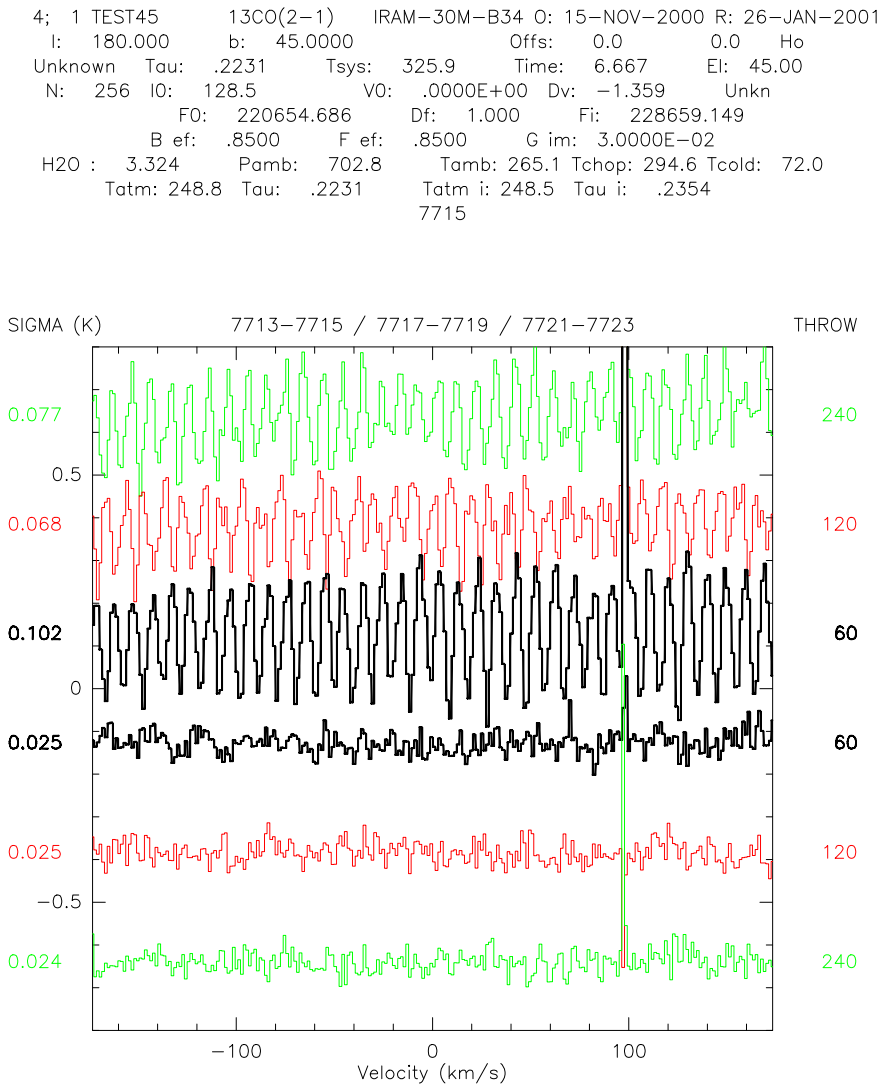

Figure 21: Wobbler Switching. Receiver B230. Time per phase 2 seconds; time per subscan 20 seconds; 20 subscans.
Bottom 3 spectra: standard 2-sided WSW with throws 240, 120, 60 arc seconds.
Top 3 spectra: 1-sided WSW with throws 60, 120, 240 arc seconds.
The spectra were shifted up or down by arbitrary amounts, but the scale is the same for all. Note the differences of the baseline ripple.

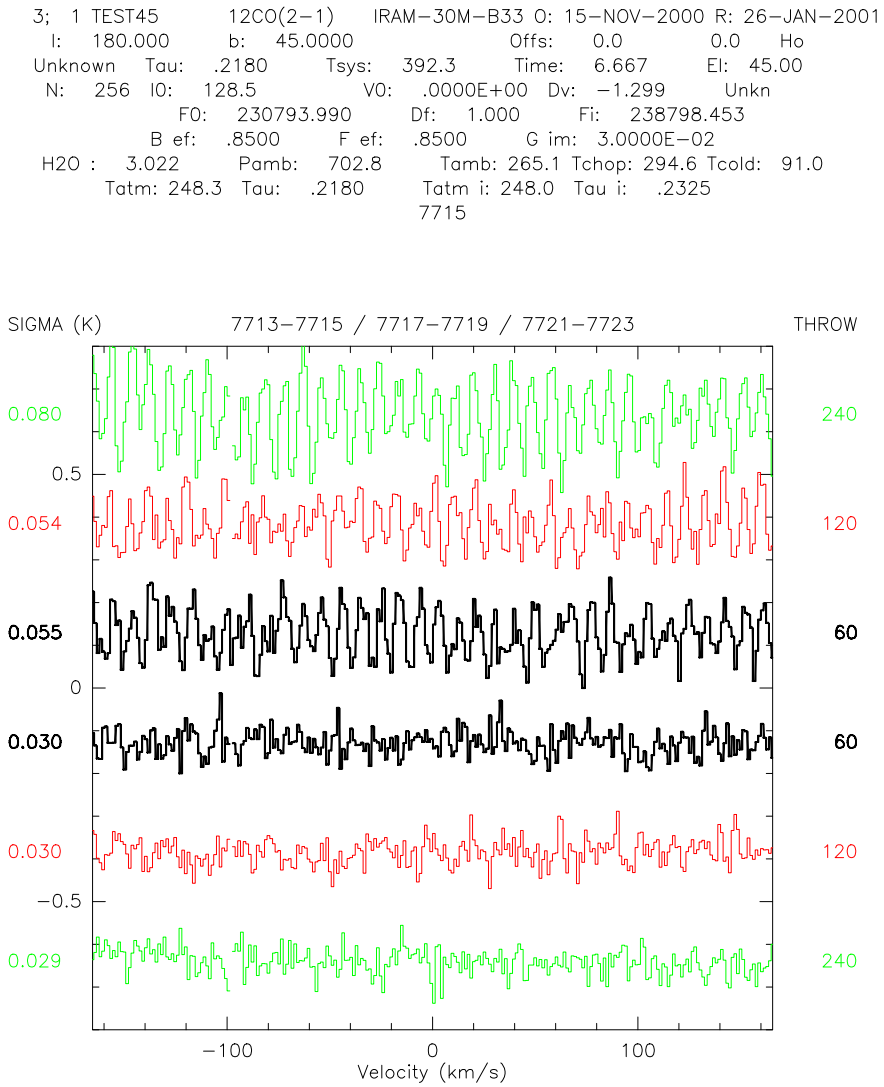

Figure 22: Wobbler Switching. Receiver A230. Otherwise as Figure 21.

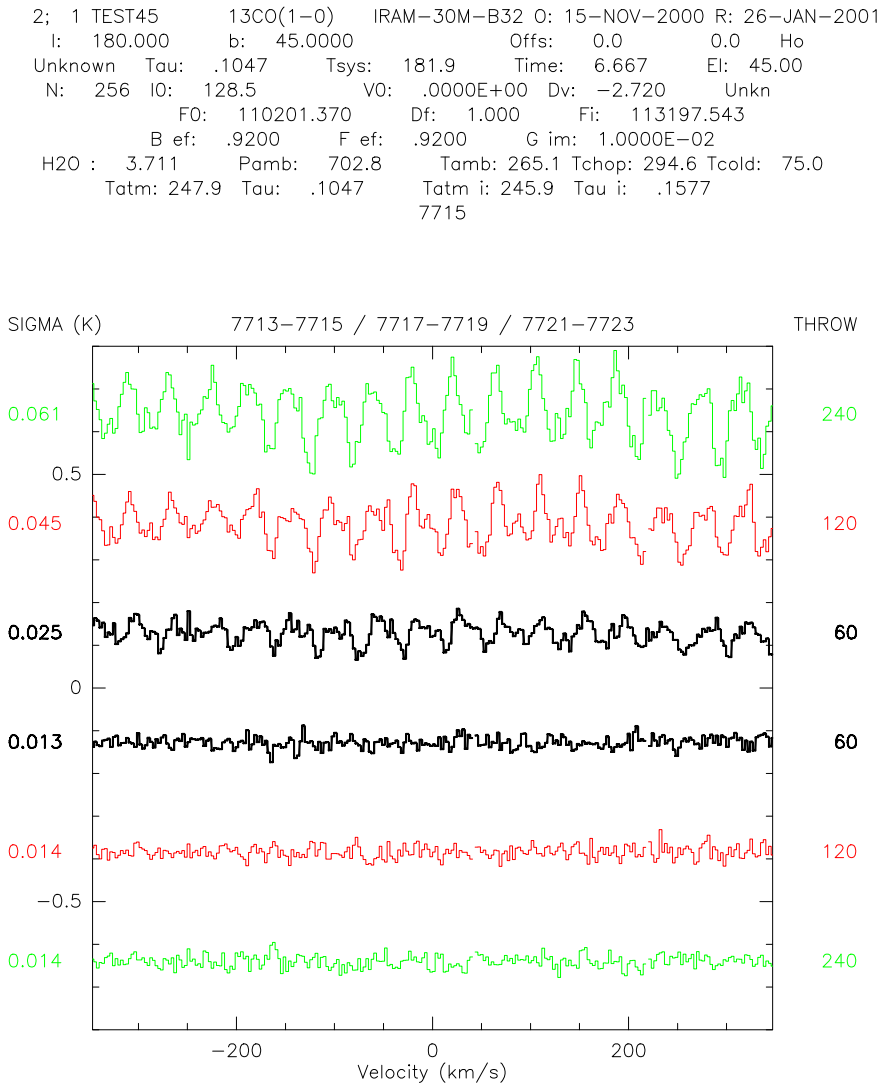

Figure 23: Wobbler Switching. Receiver B100. Otherwise as Figure 21.

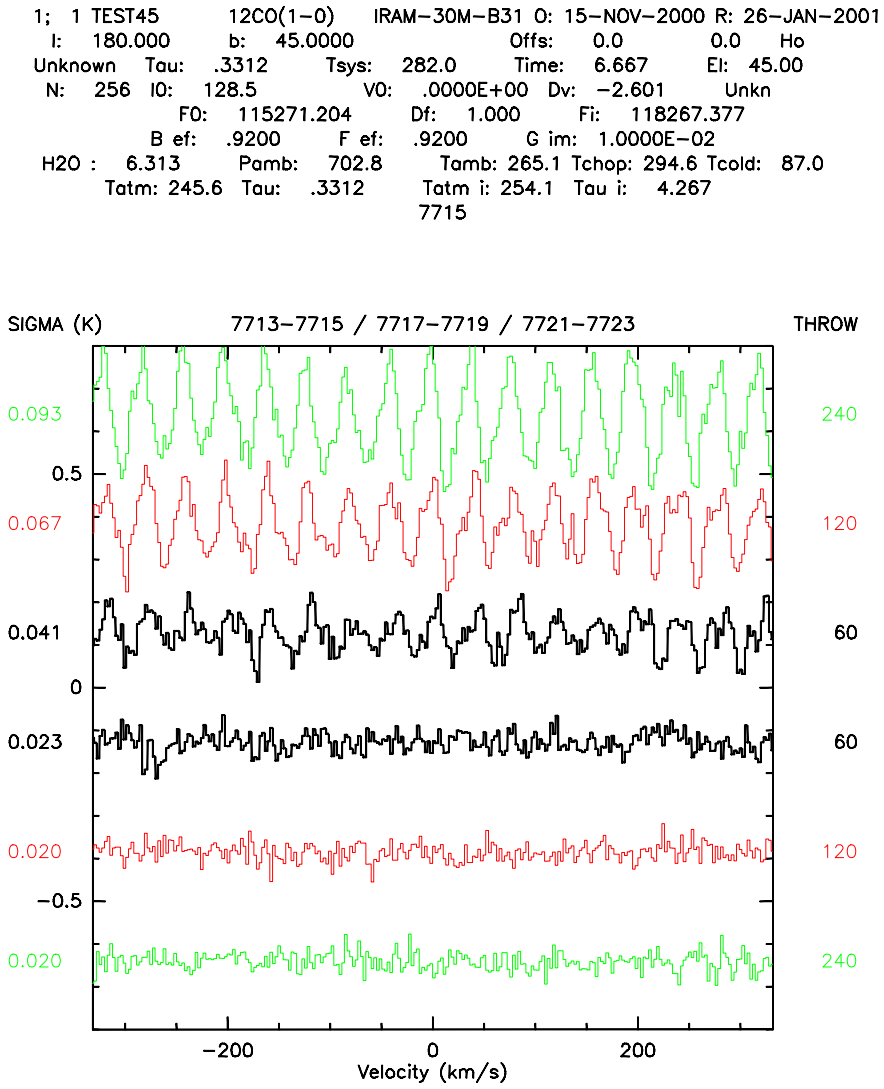

Figure 24: Wobbler Switching. Receiver A100. Otherwise as Figure 21.

6 Wobbler Switching (WSW) — partial Subscan Differencing

To investigate the data quality that can be expected if one combines an unequal number of "left" and "right" subscans, we took data from a standard 2-sided WSW scan with 20 subscans. We then look at different combinations, each with a total of 10 subscans, some of which are left and some right, of course all with the appropriate sign (Figures 25–28).

For all receivers, the baseline quality is best for an equal number of left and right subscans, and worst for combinations like 9+1 or 1+9. A particularly striking example are the data from the A100 receiver (Fig. 28): a weak line appearing at velocities around 100–130 km/s is seen with confidence only in the 5+5 combination.

The RMS of emission free channels provides an approximate measure of the baseline quality, although it is not a particularly good measure for periodic baseline ripples. When the RMS is plotted as a function of the number of left subscans in a combination of 10 subscans (Figure 29), its minimum is at or near 5 for all receivers, i.e., it is lowest for a combination that is the same as in standard 2-sided WSW. In the case of the A230 receiver this minimum is not as deep as for the other receivers, obviously because in this case the baseline ripple and the noise are about equally strong.

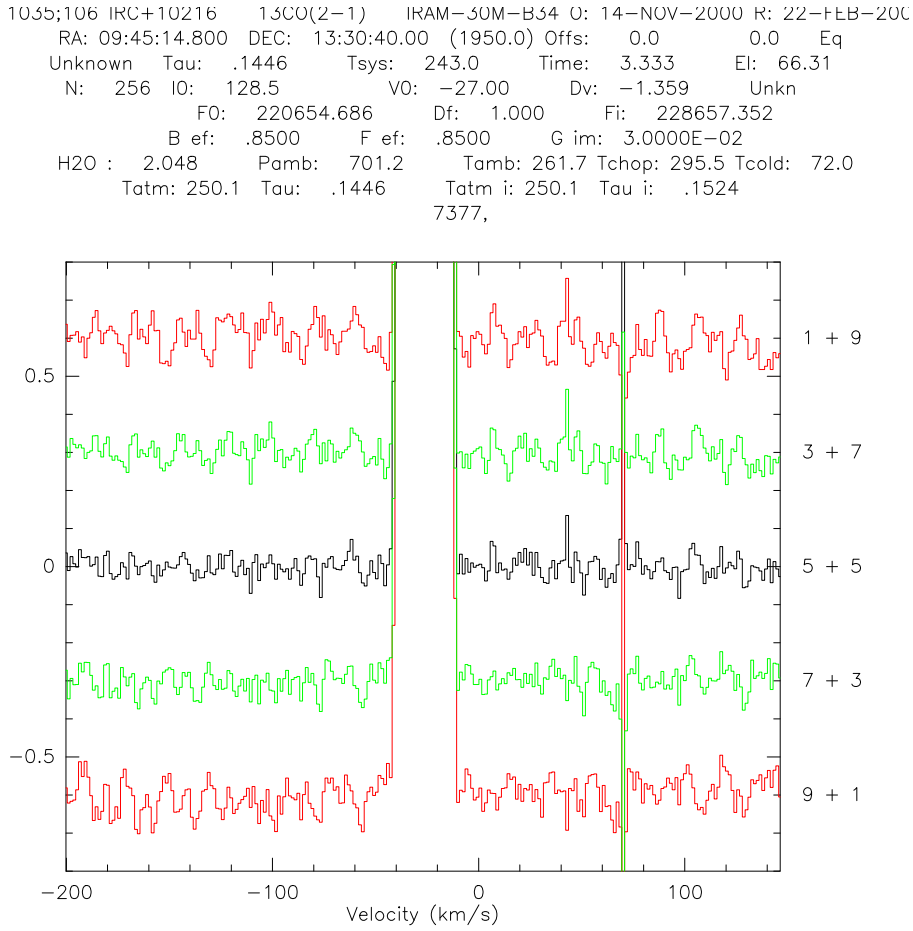

Figure 25: mixed WSW— partial Subscan Differencing. Receiver B230. One scan taken in standard 2-sided WSW; time per phase 2 seconds; time per subscan 20 seconds; 20 subscans. However, only 10 subscans were used for the spectra plotted here, from top to bottom:
1 "left" + 9 "right" subscans;
3 "left" + 7 "right" subscans;
5 "left" + 5 "right" subscans;
7 "left" + 3 "right" subscans;
9 "left" + 1 "right" subscans.
The spectra were shifted up or down by arbitrary amounts, but the scale is the same for all. Note the differences of the baseline ripple.

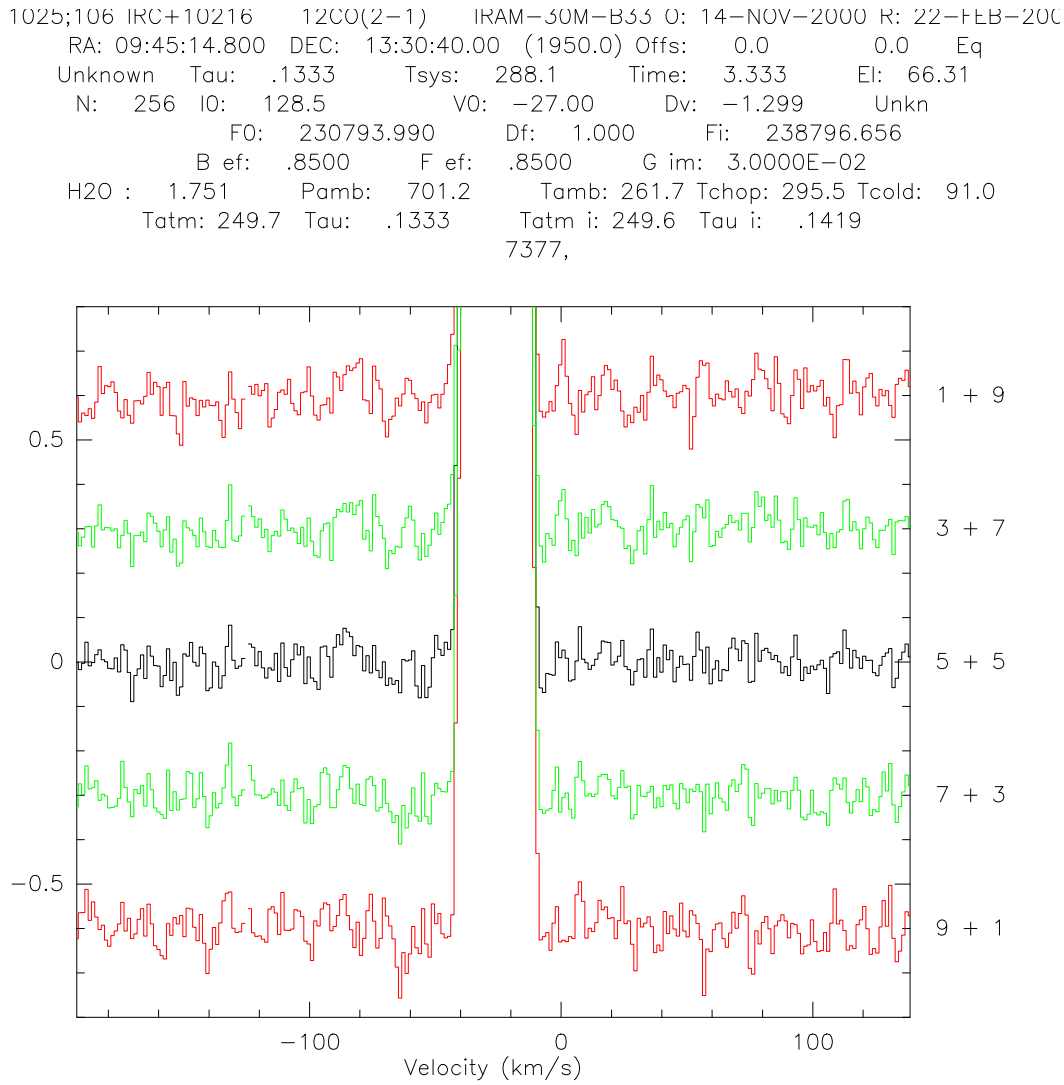

Figure 26: mixed WSW. Receiver A230. Otherwise as Figure 25.

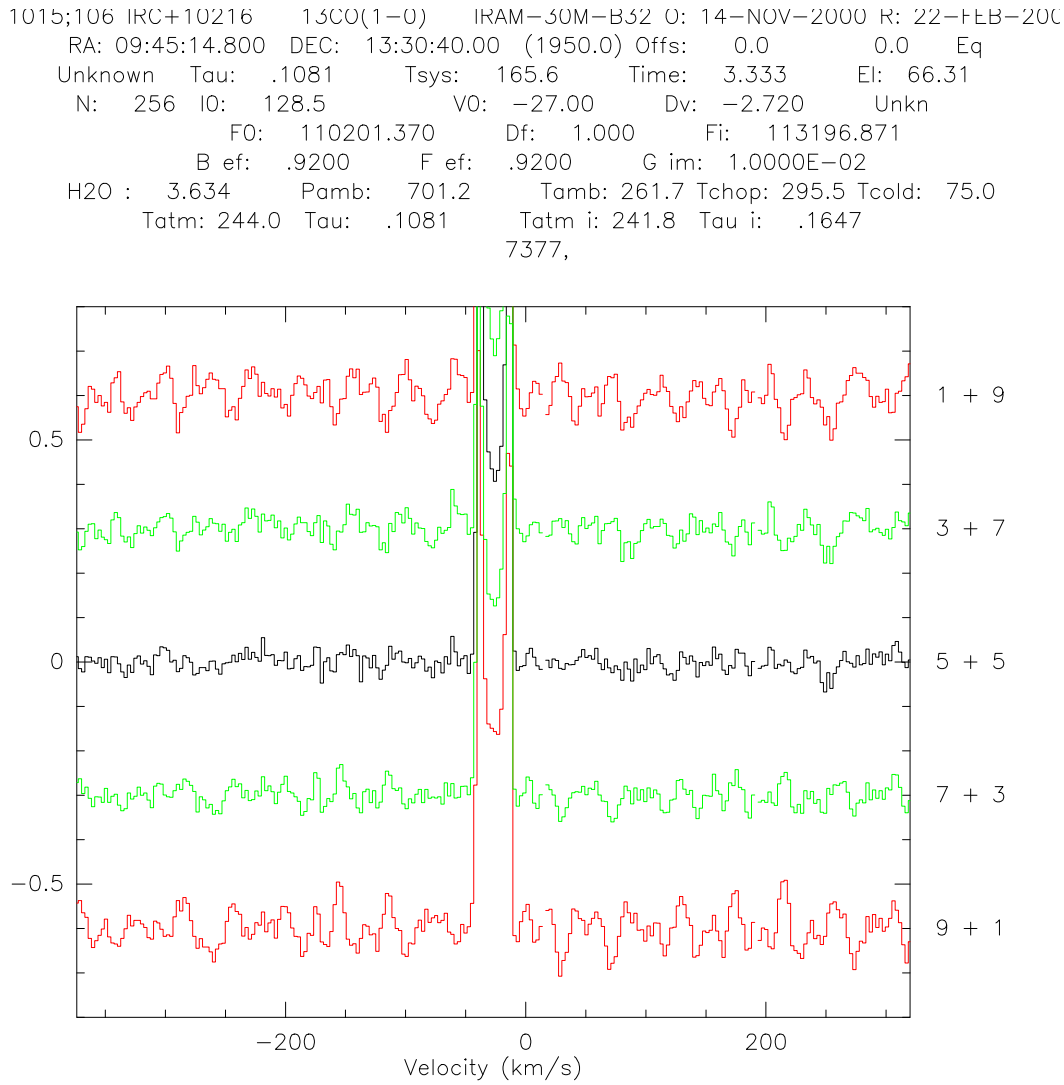

Figure 27: mixed WSW. Receiver B100. Otherwise as Figure 25.

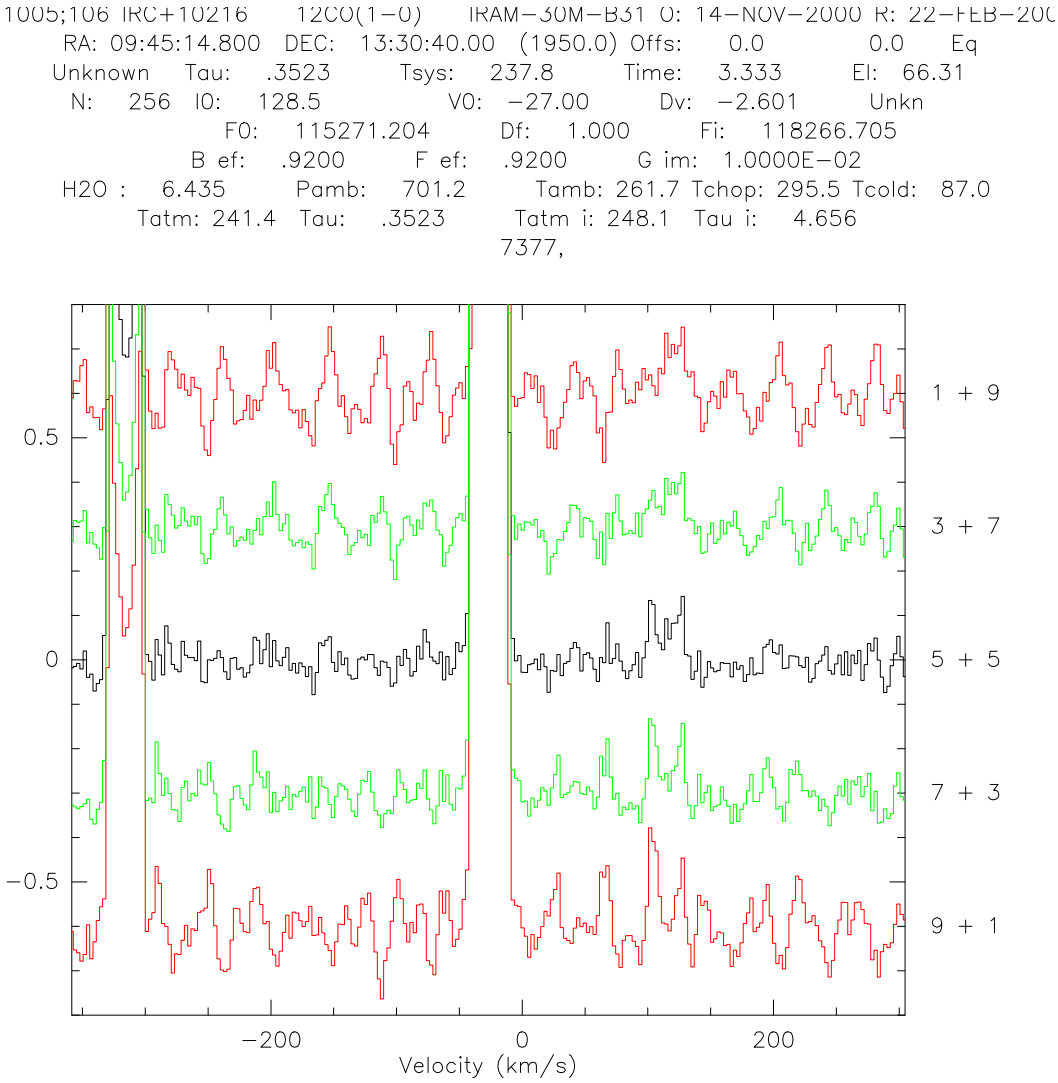

Figure 28: mixed WSW. Receiver A100. Otherwise as Figure 25.
Note the weak line at about 100 to 130 km/s.

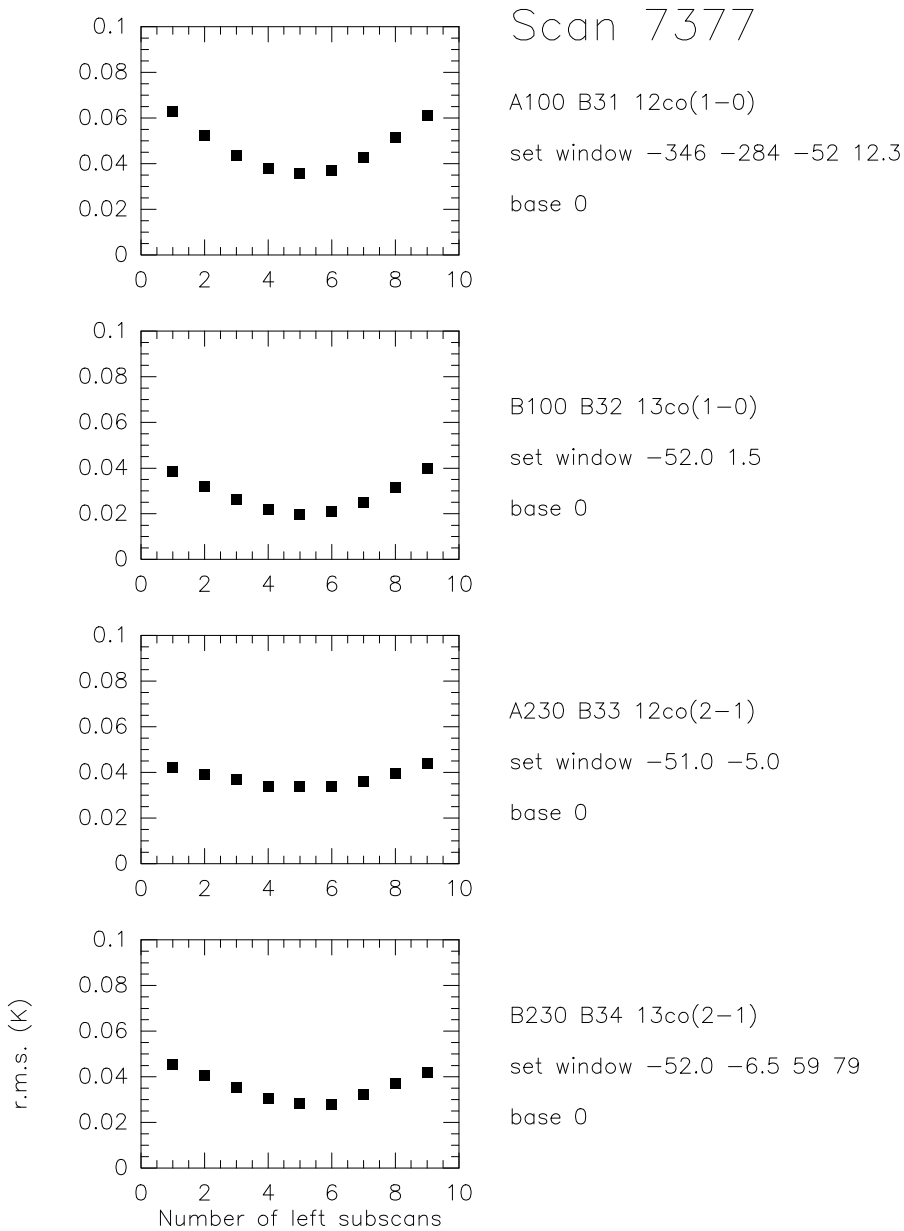

Figure 29: mixed WSW. Same observations as in Figures 25–28. Spectra obtained by combing 10 subscans. Shown is the RMS of emisssion free channels as a function of the number of "left" subscans. The minima are at or near 5, i.e., for an equal number of "left" and "right" subscans, equivalent to standard "2-sided WSW".

7 Wobbler Switching (WSW) — Scan Differencing

The baseline ripple in "left" and "right" WSW subscans taken under the same conditions is very nearly identical. This is seen in Figures 30–33, where we compare data from a standard 2-sided WSW scan and two 1-sided WSW scans—one with only right and one with only left subscans.

The baselines in the average of the two 1-sided WSW scans, while not as good as in the 2-sided WSW scan, are remarkably flat. This suggests that the baseline ripple can be cancelled rather well, even by combining left and right subscans that were taken several minutes apart.

It would be worthwhile to investigate how long the subscans can be in standard 2-sided WSW without compromising the quality of the baseline. In WSW the overhead time between subscans is large, and its fraction can be reduced if the subscans are as long as possible.

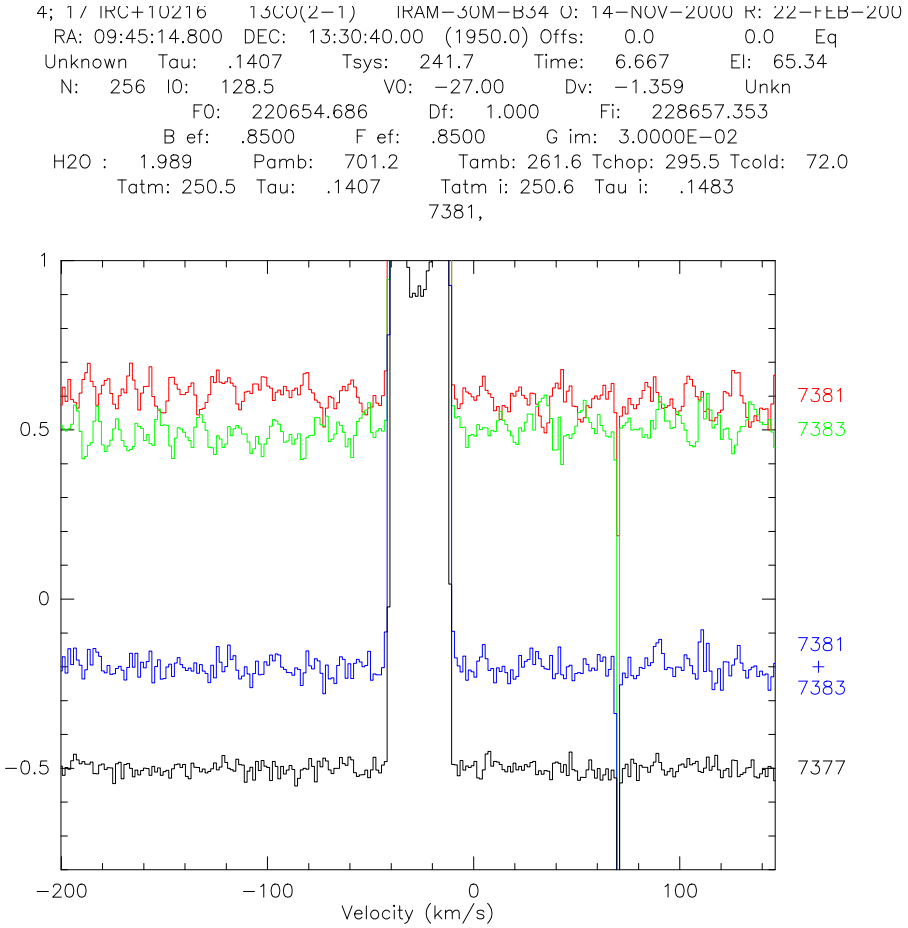

Figure 30: Wobbler Switching — Scan Differencing. Receiver B230. Time per phase 2 seconds; time per subscan 20 seconds; 20 subscans.
Scan 7377 is standard 2-sided WSW; scans 7381 and 7383 are 1-sided WSW, one with only left the other only right subscans. (All data were processed so that the lines from the source have the correct, positive sign; therefore the baseline ripple in 7381 and 7383 appears with opposite signs!) Also shown is the average of scans 7381 and 7383.
The spectra were shifted up or down by arbitrary amounts, but the scale is the same for all. Note the differences of the baseline ripple.

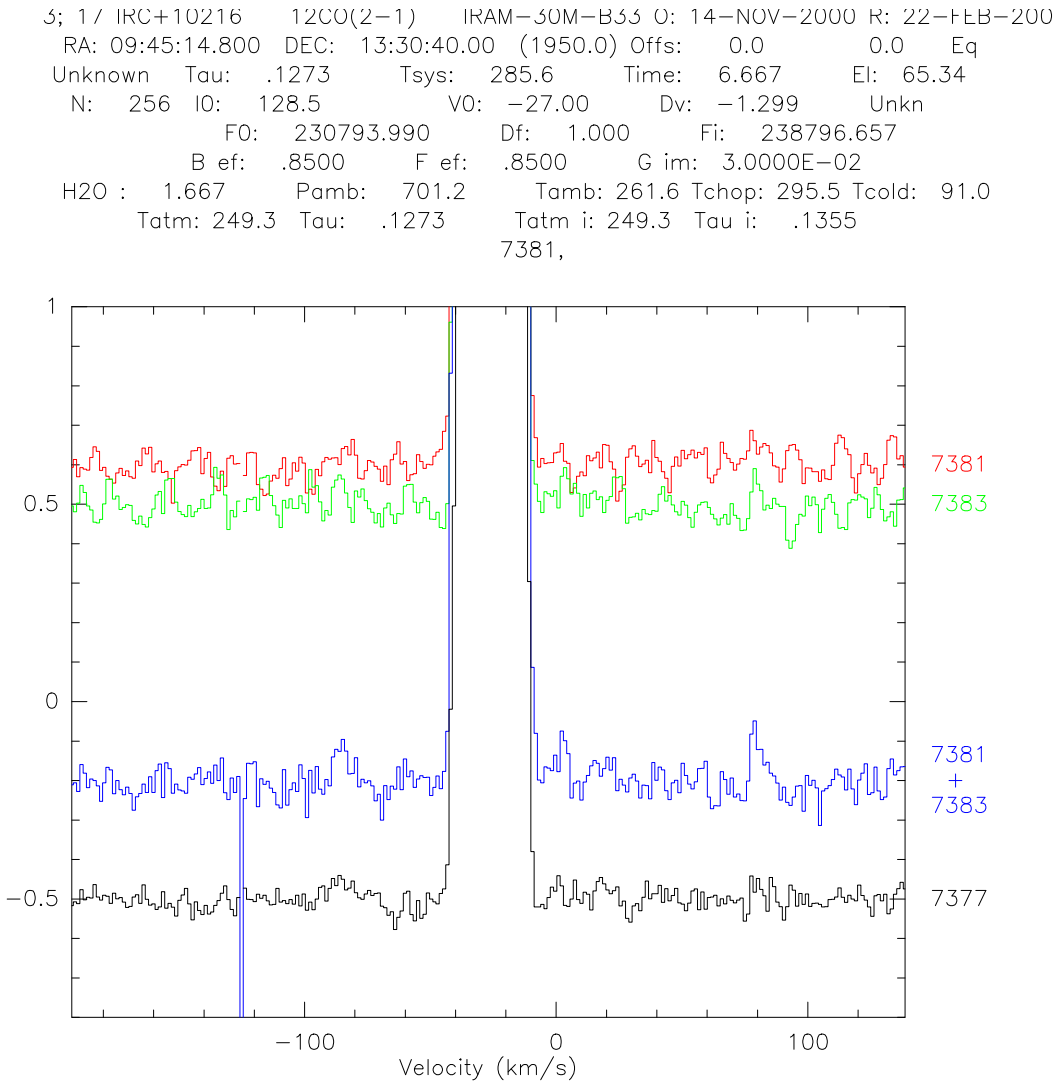

Figure 31: Wobbler Switching — Scan Differencing. Receiver A230. Otherwise as Figure 30.

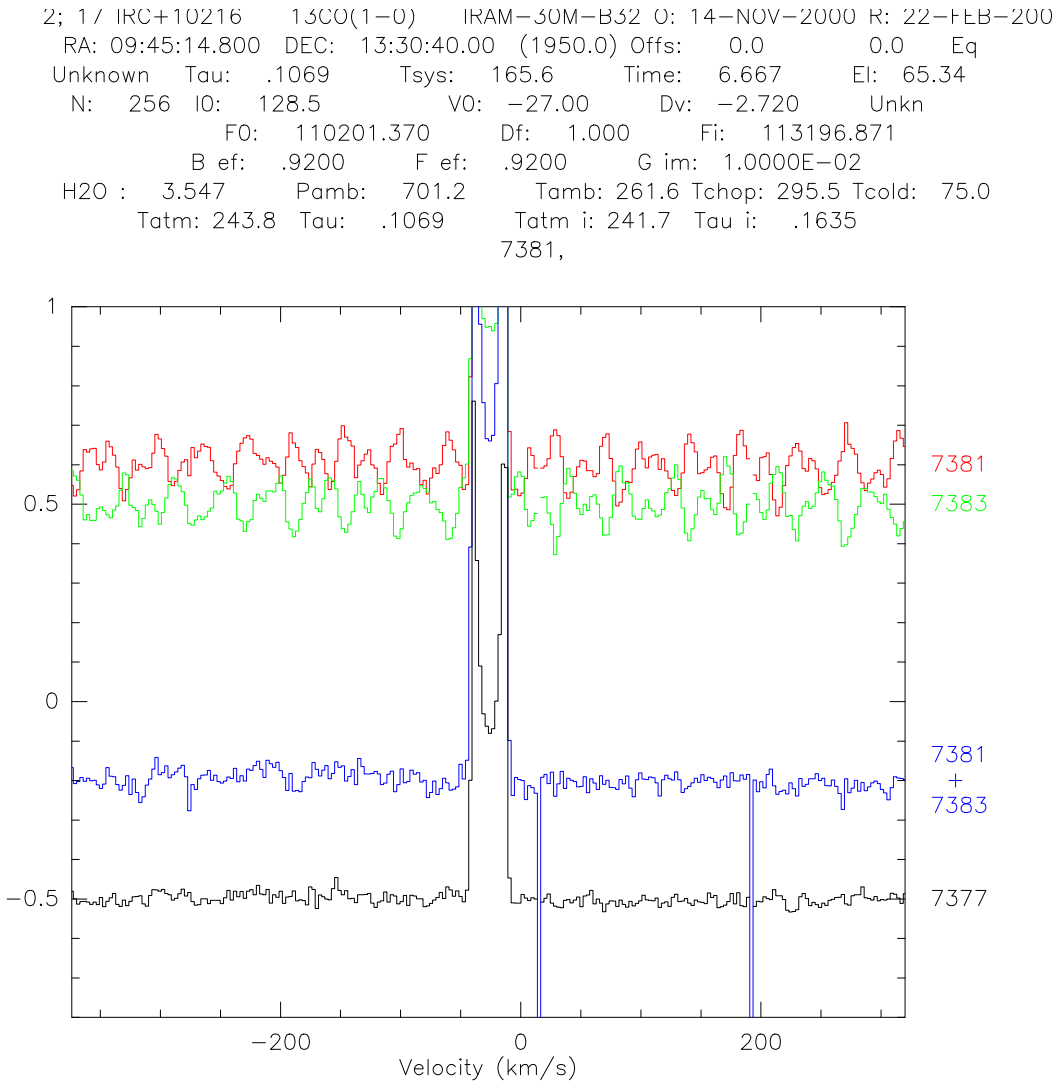

Figure 32: Wobbler Switching — Scan Differencing. Receiver B100. Otherwise as Figure 30.

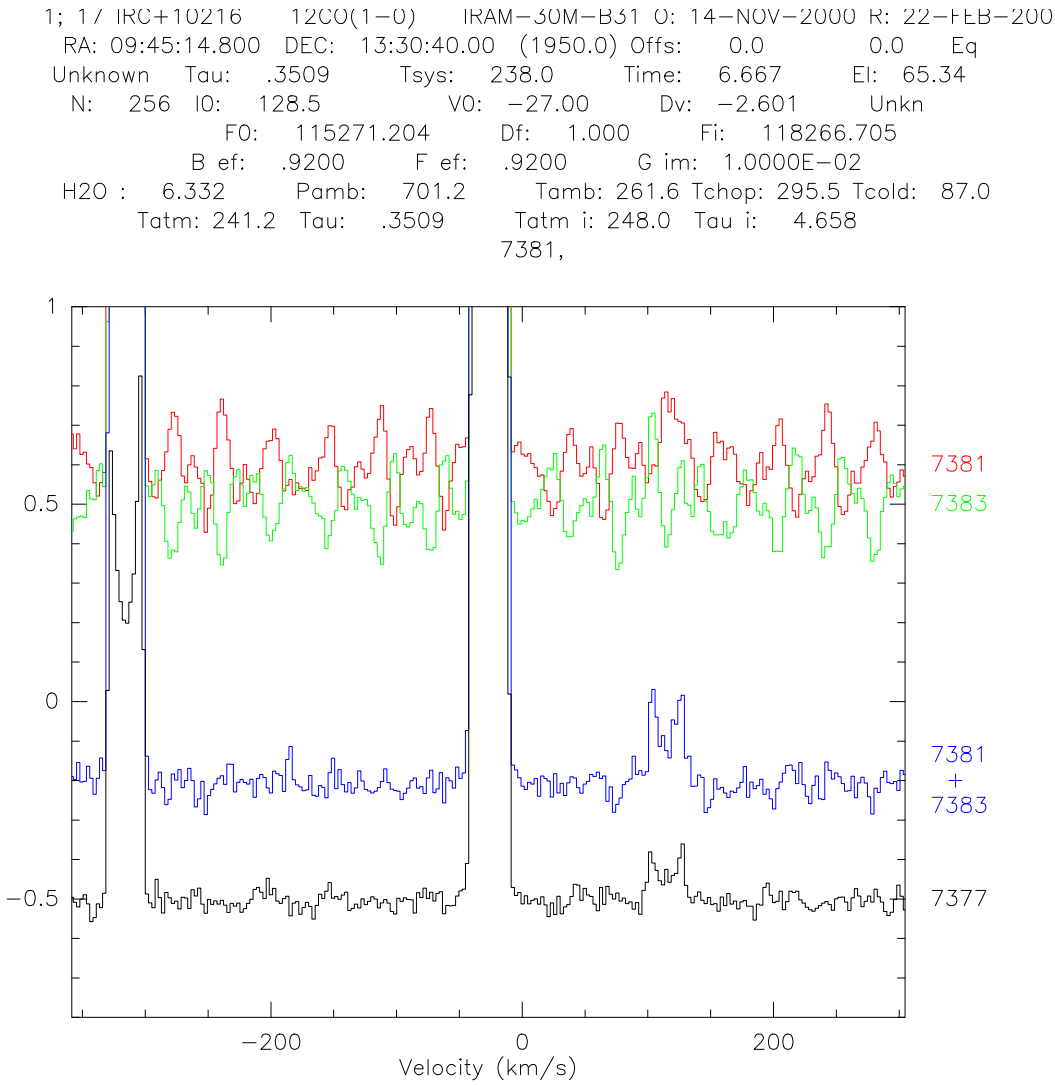

Figure 33: Wobbler Switching — Scan Differencing. Receiver A100. Otherwise as Figure 30.