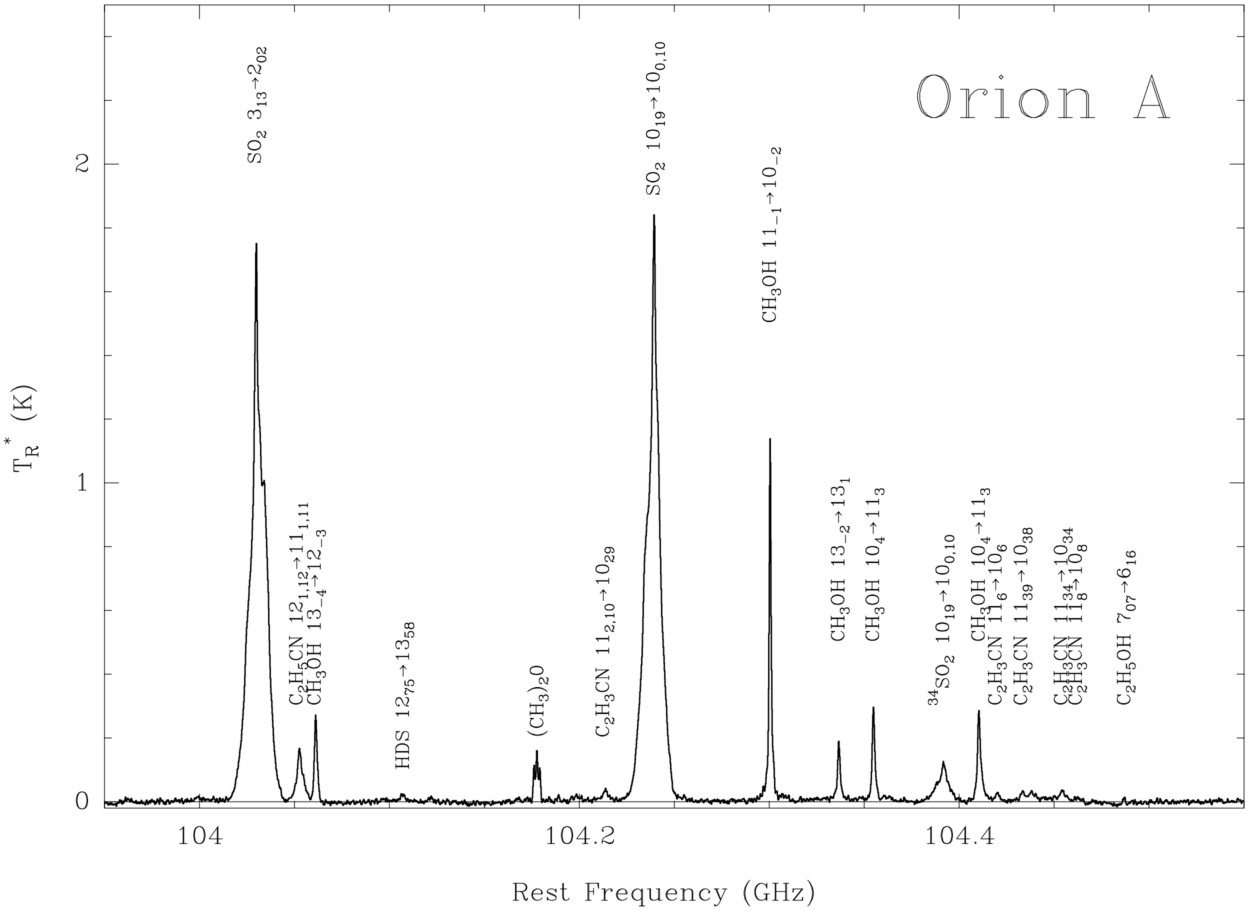

The Millimeter Autocorrelator (MAC) at the NRAO 12 Meter Telescope Basic Properties and Initial Test Results

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Contents

1 Introduction

The Millimeter Autocorrelator (MAC) is a new autocorrelation spectrometer which has been installed at the NRAO 12 Meter Telescope in September of 1998. Designed as a replacement for the Hybrid Spectrometer, the MAC follows closely the GBT correlator design and uses the same type of correlator chips, and has been designed to support the existing 1.3 mm and 3 mm, and any future, multi-beam systems on the telescope. The MAC has an instantaneous bandwidth of 800 MHz, which corresponds to a correlator clock rate of 100 MHz. This is a great improvement over the old hybrid correlator system, which only supported 300 MHz in 8-beam mode. This wider bandwidth capability should make the MAC much more useful extragalactic observations. The MAC does not rely on hybrid technology, so will avoid the platforming and ramping problems which existed in old hybrid correlator.

Note that the information given in §5 will quickly become out of date as we continue to improve the performance of the MAC. For regularly-updated information on the MAC, see the NRAO 12 Meter Telescope status page at http://www.tuc.nrao.edu/status.html.

2 Basic Properties

Table 1 lists the MAC bandwidth modes currently available. Note that the "frequency sampling" listed in this table is not the true spectral resolution. Since we use Hanning smoothing before the FFT to suppress aliasing, the true spectral resolution is:

$$\begin{aligned} \text{Spectral Resolution} &= 2.0 \times \text{Frequency Sampling} && (1) \\ &= 2.0 \times \Delta\nu && (2) \end{aligned}$$

See Appendix D in the Users Manual for the 12m Millimeter-Wave Telescope for further information on frequency sampling and spectral resolution. Table 1 lists the spectral resolution for each bandwidth mode. Note that it is the "frequency sampling" ($\Delta\nu$) and not the "spectral resolution" that is written to the data headers.

3 Sensitivity Calculations

To calculate the rms sensitivity of a spectrum from the MAC, one must use a slightly modified version of the radiometer equation

$$\sigma_{mac} = \frac{\alpha T^*_{sys}}{\eta_{spec}\sqrt{\Delta\nu_{sb} t_{int}}} \qquad (3)$$

Table 1: Millimeter Autocorrelator (MAC) Configurations

Total Bandwidth (MHz)	Useable Bandwidth[1] (MHz)	Channels	$\Delta\nu^2$ (kHz)	Spectral Resolution (kHz)
2 IF Modes				
800	600*	2048	390.6	781.2
800	600	4096	195.3	390.6
400	300*	4096	97.6	195.3
400	300	8192	48.8	97.6
200	150*	8192	24.4	48.8
200	150	16384	12.2	24.4
100	75*	16384	6.1	12.2
100	75	32768	3.0	6.1
4 IF Modes				
800	600*	1024	781.2	1562.0
800	600	2048	390.6	781.2
400	300*	2048	195.3	390.6
400	300	4096	97.6	195.3
200	150*	4096	48.8	97.6
200	150	8192	24.4	48.8
100	75*	8192	12.2	24.4
100	75	16384	6.1	12.2
8 IF Modes				
800	600*	512	1562.5	3125.0
800	600	1024	781.2	1562.0
400	300*	1024	390.6	781.2
400	300	2048	195.3	390.6
200	150*	2048	97.6	195.3
200	150	4096	48.8	97.6
100	75*	4096	24.4	48.8
100	75	8192	12.2	24.4

[1] The useable bandwidth takes account of the 75% efficiency of the analog filters.
[2] **NOTE:** This is the frequency sampling interval, not the FWHM channel width.
All values in this table refer to each IF.
Modes tagged with a $*$ are produced by dropping the last half of the lags.

where

$$
\begin{aligned}
\alpha &\equiv \text{observing mode scale factor,} \\
&= 2.0 \text{ for position and beam switched measurements,} \\
&= \sqrt{2.0} \text{ for frequency switched measurements,} \\
T^*_{sys} &\equiv \text{the system temperature on the } T^*_R \text{ scale,} \\
\eta_{spec} &\equiv \text{the spectrometer efficiency,} \\
&= 0.809 \text{ for the two-bit three-level MAC,} \\
\Delta\nu_{sb} &\equiv \text{the sensitivity bandwidth for the spectrum,} \\
&= 2.667 \times \Delta\nu, \\
t_{int} &\equiv \text{the total integration time for the scan}
\end{aligned}
$$

Appendix F in the Users Manual for the 12m Millimeter-Wave Telescope gives a detailed discussion of the radiometer equation for position switched measurements. Further details on frequency sampling, spectral resolution, and sensitivity bandwidth in spectrometers can be found in Appendix D of the Users Manual for the 12m Millimeter-Wave Telescope.

4 Initial Test Results

4.1 Spectral Channel Width Measurements

We measured the width of a spectral channel in the MAC by inserting a test signal of width 4 kHz into the center of the IF. Figure 1 shows the results of this test done with the MAC configured in its 2 IF, 600 MHz bandwidth, 195 kHz spectral sampling mode. Since the true spectral resolution is twice the spectral sampling width for the MAC, these measurements confirm the design goals.

4.2 Frequency Axis Measurements

We checked the assignment of frequency to a specific channel by observing SGRB2(OH) simultaneously with the 2000 kHz filter banks and the MAC in its 2 IF, 600 MHz bandwidth, 195 kHz frequency sampling mode. A rest frequency which was known to include several astronomical molecular transitions provided several reference marks for this comparison. Figure 2 shows the results of this comparison. The correspondence between the MAC and the 2000 kHz filter banks is excellent.

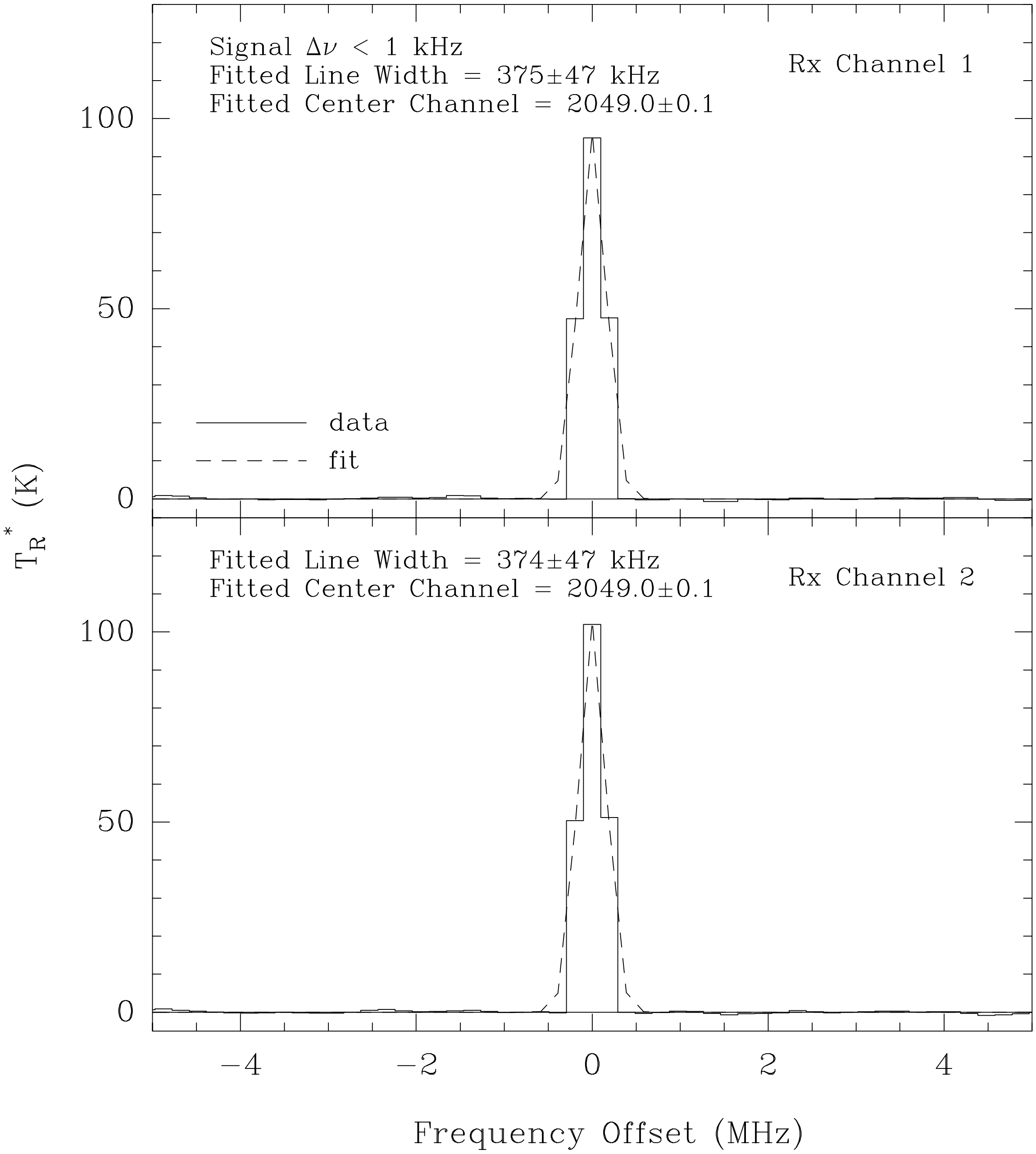

Figure 1: Channel width test results. Note that the test signal is spread over three channels due to the default Hanning smoothing function used.

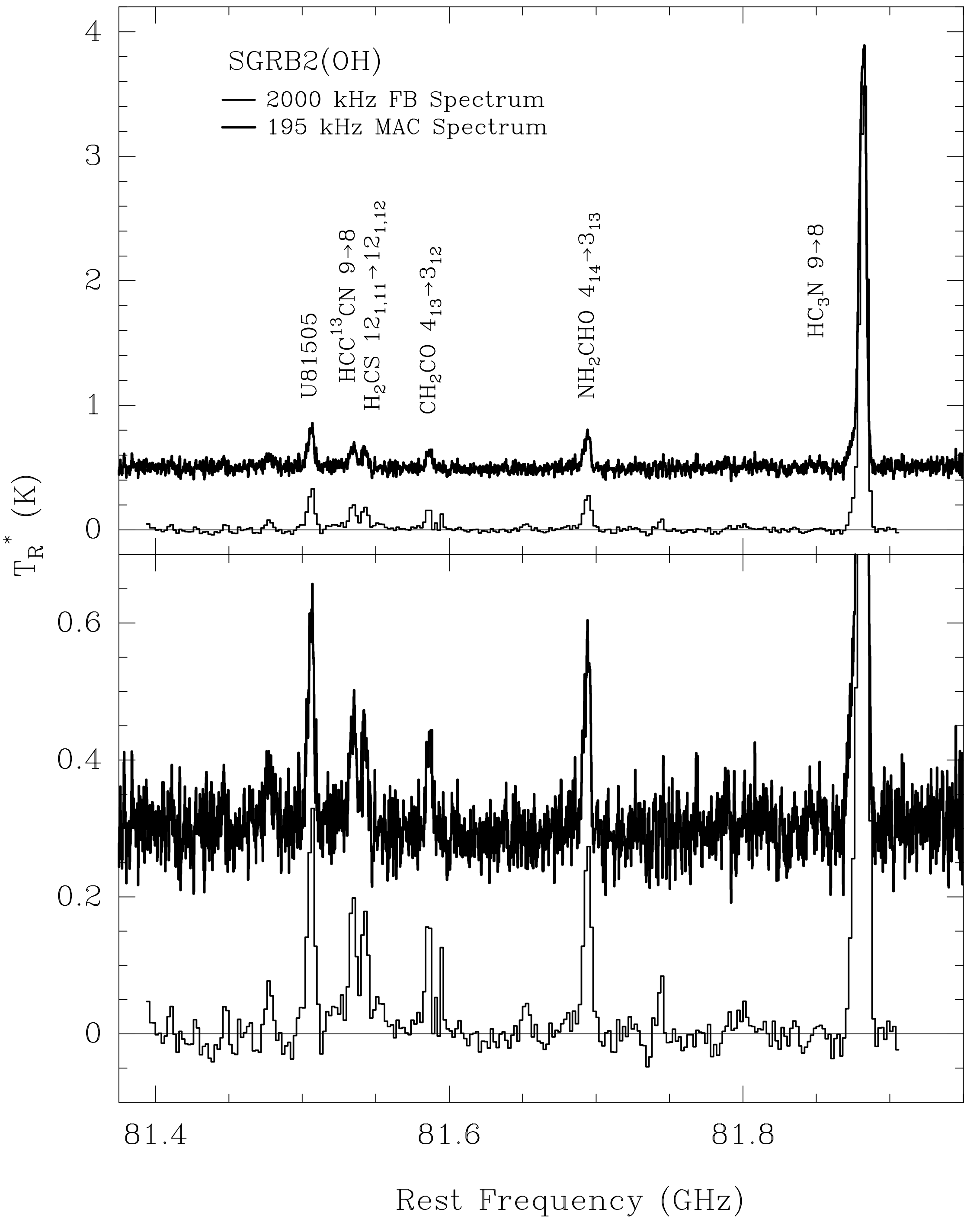

Figure 2: Comparison between the 2000 kHz filter banks and the MAC. The upper plot shows the full scale for the spectra, while the lower plot zooms in on the smaller scale molecular line structure in these measurements. The correspondence between these two spectrometer measurements is excellent.

4.3 Line Shape Measurements

To check the representation of spectral line shapes through the MAC, we compared filter bank and MAC measurements of two sources at two different frequencies. Figure 3 shows the results of these measurements. The MAC produces spectral line shapes in near-exact agreement with those produced by the filter bank spectrometers.

4.4 Noise Versus Integration Time

Integration tests for up to 15 hours have shown that the MAC integrates down as indicated theoretically in Equation 3.

4.5 2 IF Mode Comparison

To check the consistency between the four bandwidth selections within the 2 IF modes, measurements of Orion-KL at a rest frequency 104250.0 MHz were made. Figure 4 shows the results of these measurements. All four bandwidth modes produce consistent spectra.

5 Known Problems

In the following we list the current known problems with the MAC. Except for the problem that UniPOPS does not process the 75 MHz/32768 channel mode, we will solve these problems over the next few months.

- UniPOPS does not process the 75 MHz/32768 channel bandwidth mode. The CLASS program can process all MAC bandwidth modes.
- On-The-Fly observing is not available.
- There is spurious emission from the 4th and 5th harmonics of the downconverter in the IF distribution modules which leaks in at the offset frequencies listed in Table 2. The amount of leakage is largest in polarization 1 for all modes.
- 4IF mode does not currently work (this is actually due to a problem with the software which drives the IF modules).

Table 2: Spurious Harmonic Emission Frequencies

Bandwidth (MHz)	4^{th} Harmonic Offset Frequency (MHz)	5^{th} Harmonic Offset Frequency (MHz)
600	-270.2703	37.1620
300	-281.5788	23.0265
150	-281.0811	23.6485
75	-275.6757	30.4055

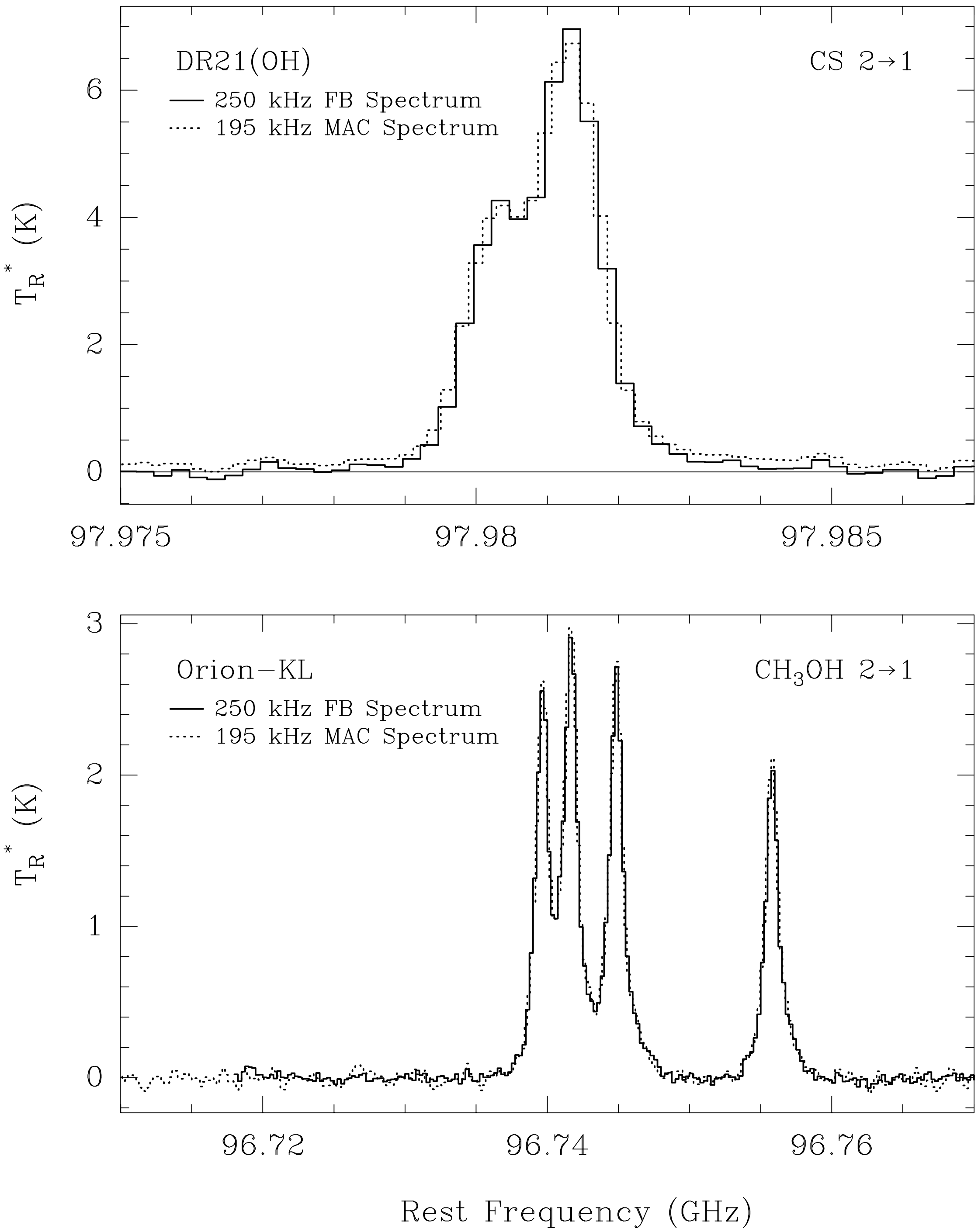

Figure 3: Comparison between the 250 kHz filter banks and the MAC. The upper plot shows measurements of the CS J=2 $\rightarrow$ 1 line from DR21(OH). The lower plot shows measurements of the CH_3OH J=2 $\rightarrow$ 1 transition from SGRB2(OH). As was the case with the frequency axis comparison, the correspondence between these two spectrometer measurements is excellent.

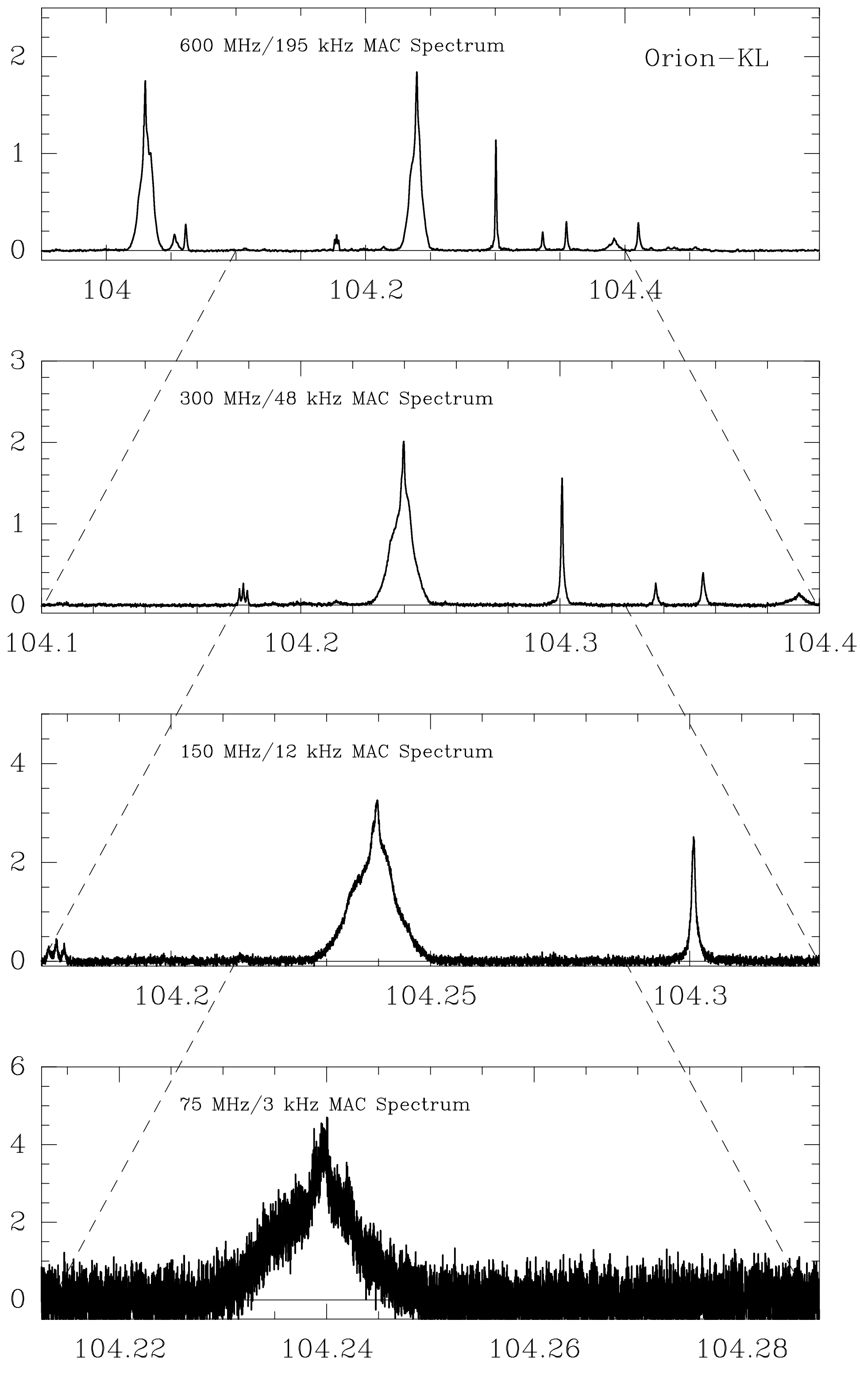

Figure 4: Comparison between the four bandwidth possibilities available with the 2 IF modes of the MAC. The dashed lines indicate the spectral regions blown-up with successively higher resolution spectra.