Comments from "Science" on ALMA Band 10 Cartridges

This subject has been discussed in recent telecons by the ASAC and by the regional science advisory committees, as well as by Science IPT. The starting point for the discussion was the following note included in the report from the Band 10 PDR:

The review board recommends that a discussion be started with the ALMA project and science IPT about the realizability of the ALMA Band 10 noise specifications and possible optimizations/tradeoffs on sensitivity and RF bandwidth. NAOJ in conjunction with NICT, ASIAA and the science IPT is asked to create *Junction Selection Criteria* which will allow the different junction technologies to be evaluated for RF performance as well as manufacturability.

We first reviewed the scientific case for equipping ALMA with receivers for this Band. There is no doubt that this case is extremely strong. The key points are:

1) Band 10 is the "high frontier" for ALMA. It is in this band that the highest angular resolution can be achieved: 0.006 arc seconds in the most extended configuration. This will be challenging but all of the other components of ALMA – antennas, LO, phase correction system, etc. – have been specified to make this possible.
2) There are several key tracers of the warm interstellar medium in this band. See figure 1.

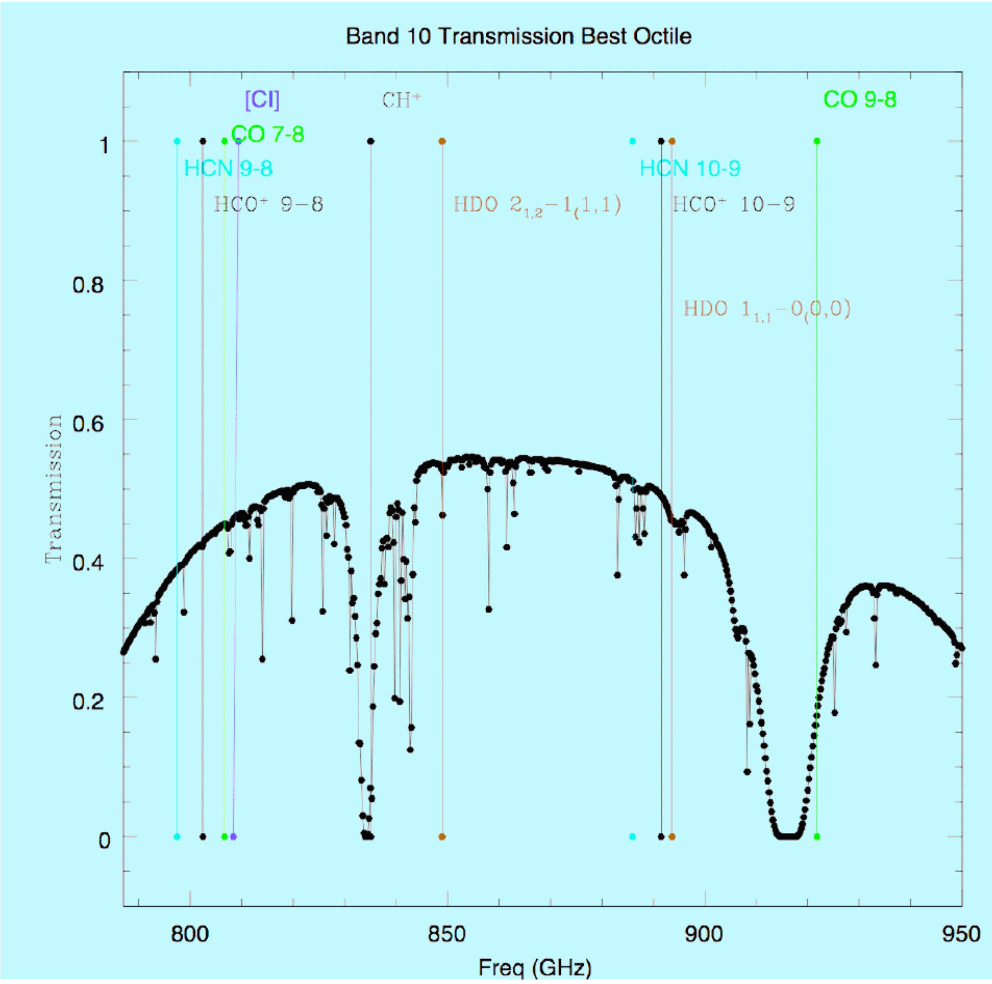

Figure 1. Atmospheric transmission and key spectral lines in ALMA Band 10.

Of particular importance is the neutral atomic carbon line [CI] at 809 GHz. Observations of this line, especially when taken together with the [CI] line at 492GHz, which lies in ALMA Band 8, provide measurements of the physical and chemical conditions at the interfaces between dense molecular clouds and the more diffuse atomic and ionized regions. The lines of CO, HCN and HCO^+ which also lie near 800 GHz are ideal tracers of the hot dense molecular regions and for deriving conditions in them. The two HDO lines are also of great interest, the one at 893 GHz being the ground-state transition.

3) Band 10 will be particularly valuable for observations of the red-shifted emission from ions, especially the 158 micron line of [CII] which has long been known to be one of the main means by which the interstellar gas looses energy and hence cools. For the specified bandwidth, this line will be observable over the redshift range z = 1 to 1.4, which is of course a very interesting epoch in terms of galaxy evolution. Other important atomic lines, including those from NII, OI and OIII are observable from star-burst galaxies in higher redshift ranges. Some estimates of the expected fluxes and of ALMA's sensitivity are given overleaf. It is seen that a Milky Way galaxy at Z ~ 1.2 should be detectable in a relatively short integration time but that the other lines will be more difficult to observe and require the very best achievable sensitivity.

4) Continuum emission from dust is very strong at these wavelengths. Such observations will form an important part of the Band 10 program. Angular resolution of order 0.006" may well be critical in work on proto-planetary disks – to see gaps, etc. More generally the ability to define this part of the spectral energy distribution of the emission from a wide range of both galactic and extra-galactic objects will be extremely valuable, especially for deriving temperatures and properties.

5) Finally spectral-line surveys of hot dense molecular regions have already established that this Band is extremely rich in lines from complex molecules. Almost all of these also have transitions in other ALMA bands, but Band 10 will certainly be useful for multi-transition studies.

We therefore concluded that the need to equip ALMA properly for Band 10 is not in question.

The questions of performance and possible trade-offs of band-width and sensitivity were then discussed. There are a number of issues that need to be taken into account here.

1) Although the sensitivity of the mixers remains the single most important contribution to the overall performance, with the present specification for the receiver noise of Trx = 230K DSB we are already approaching the background-limited condition. Other contributions to the system temperature are such that a mixer noise temperature of about 165K would be needed to achieve Trx = 230K. With, for example, an atmospheric transmission of 0.45 the system temperature would then be about 950K. Reducing the mixer noise by 10% would in that case only reduce the system temperature by about 5%.

2) The integration time required to reach a given sensitivity scales with the inverse square of the system temperature, so achieving the low noise remains very important.

3) The atmospheric transmission sets natural limits on the useable range of frequencies and the ideal situation would of course be for the atmosphere to be the only limit on the bandwidth. In practice the limitations on mixer technology are bound to play a role. Figure 2 shows (speculative) examples of what forms the curves of receiver sensitivity might plausibly take, depending on what technology is deployed, and the resulting system temperatures when atmospheric absorption and emission and other losses are taken into account.

4) Recent models of the emission of the key atomic lines by Roberto Maiolino were used to estimate fluxes of galaxies and these have been plotted, along with the expected sensitivity of the full ALMA system are plotted in Figure 3.

   Based on this analysis, the strong view of the science team is that meeting the full specifications in terms of <u>both</u> sensitivity <u>and</u> bandwidth remains important for the scientific productivity of Band 10 and that this should remain the goal of the development program. In particular we strongly support the recommendation of the PDR panel to focus on the development of high current-density junctions. If in the end it proves necessary to make some compromises then it is clear that a reduction in either the sensitivity or the bandwidth would have some effect, but that at the sort of levels considered here this would be by no means disastrous to the scientific outcome.

In general galactic observations will benefit from having the best sensitivity in roughly the lower half of the band, whereas extra-galactic work will be able to cover a wider range of redshifts if the bandwidth can be maintained. It would be premature to decide the balance between these right now, since the performance curves considered here are entirely speculative, but the analysis already given illustrates the issues that need to be taken into account. Should the development program reach a point where specific choices based on real measurements need to be made, then it should be straight-forward to make a well-justified recommendation.

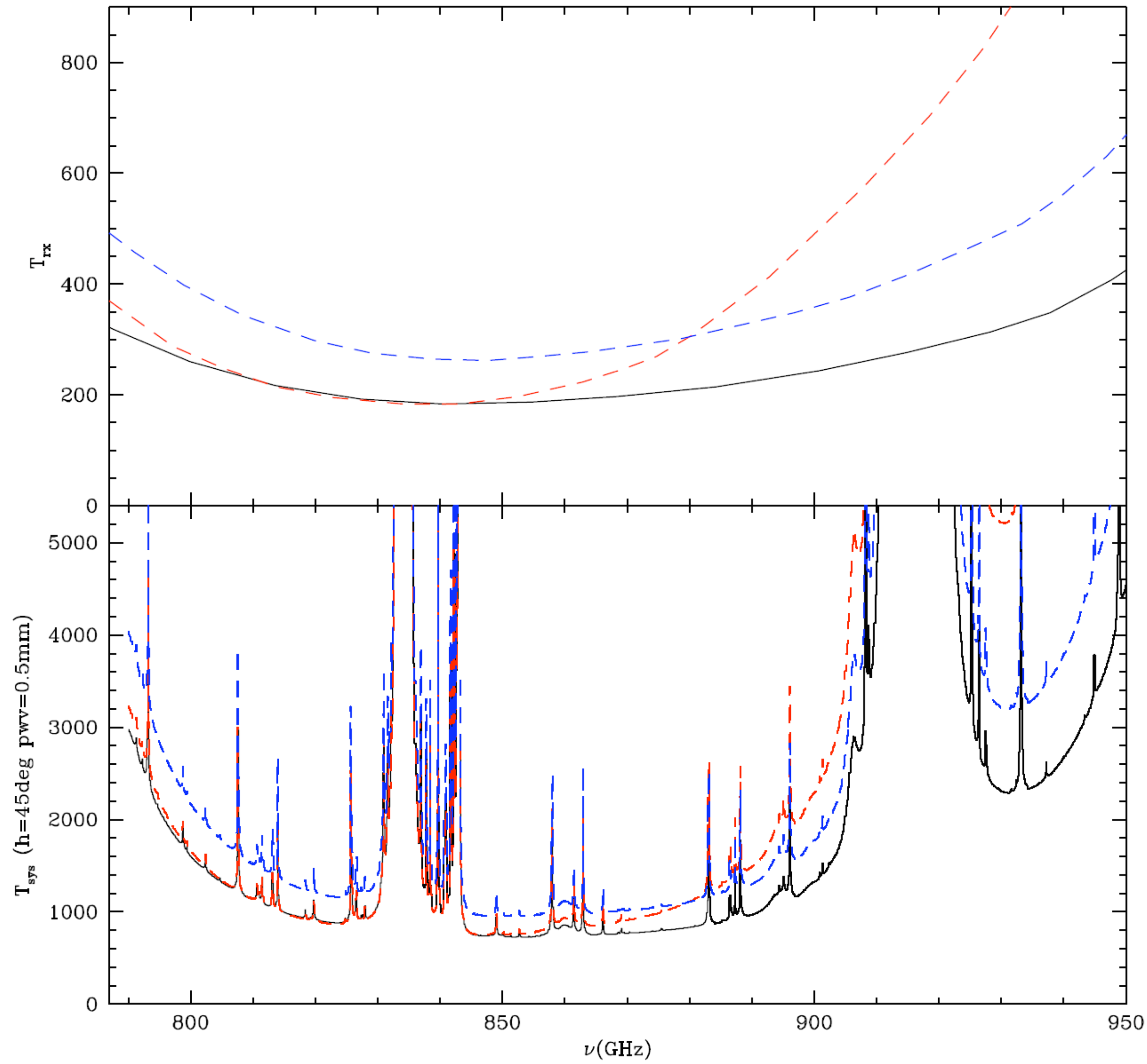

Figure 2. Top: Assumed models of the receiver noise. Black solid line represents a receiver that meets the full ALMA specification, i.e. Trx below 230K from 795 to 925 GHz and below 344K over the whole band 787 to 950 GHz. Blue dashed line is a receiver with the same bandwidth but 50% higher noise temperature. Red dashed line shows a receiver with a narrower response reaching the ALMA noise requirement over the lower half of the band.

Bottom: Corresponding system temperatures for good conditions and air mass 1.4 calculated using the ATM atmospheric model.

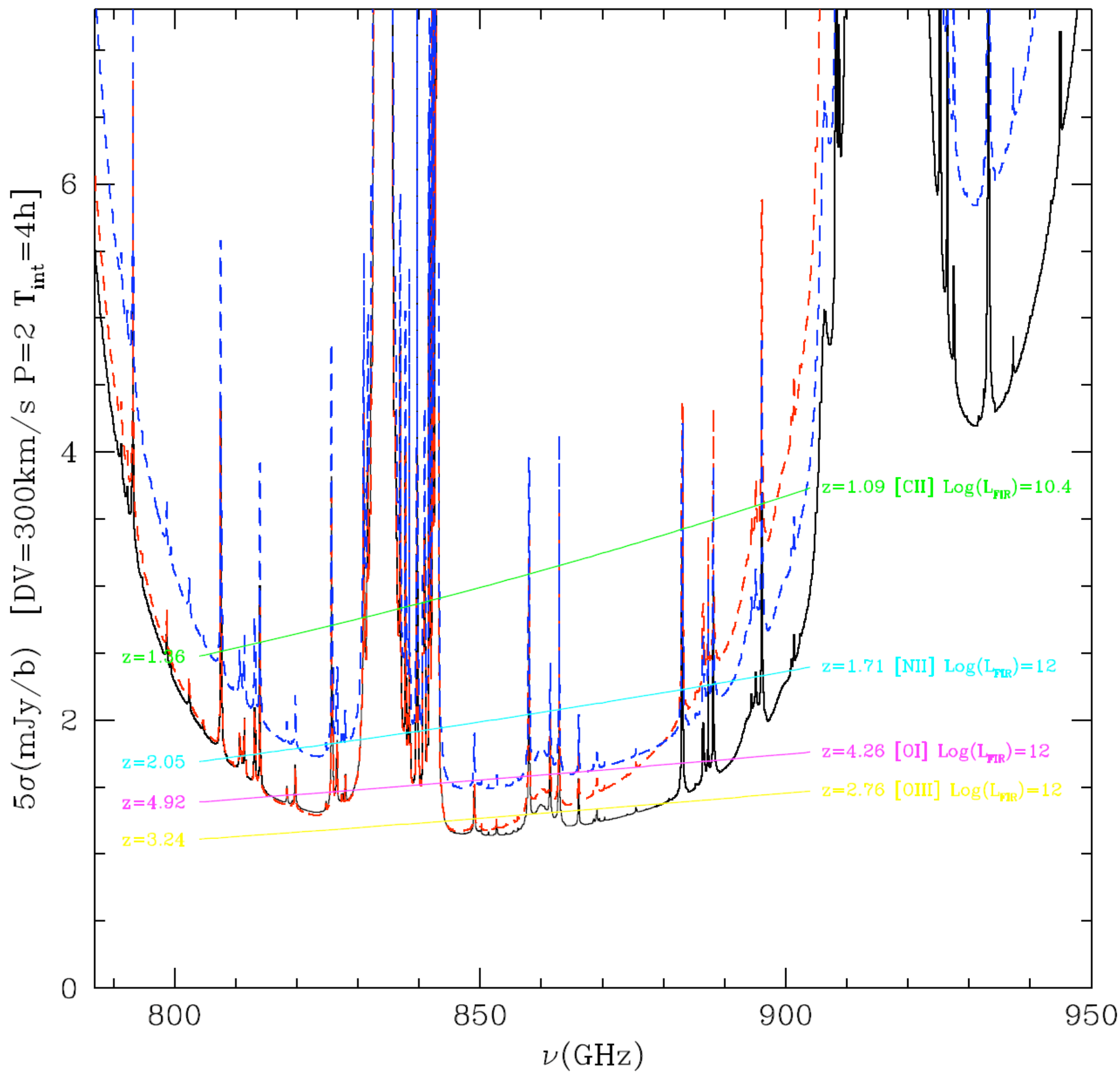

Figure 3. Derived flux sensitivities for ALMA (5-sigma with 4 hours of integration) for the different assumptions in figure 2, together with estimates of the red-shifted line emission from a galaxy like the Milky Way (for [CII]) and from starburst galaxies (for the other lines).