The highest (5000 m) and fastest (17 peta-operations/second) computer ever used at an astronomical site — the ALMA Correlator. Here the first quadrant is shown in place at the ALMA Operations Site (AOS) Technical Building.

Credit: ESO/A. Wicenec

The ALMA Correlator: Performance and Science Impact in the Millimetre/Submillimetre

Alain Baudry[1 2]

[1] University of Bordeaux, LAB, France
[2] European ALMA Project Office, ESO

The basic properties of digital correlation are introduced and the main blocks that form the correlator system designed for the ALMA main array are described. Some technical challenges and the performance of this system are presented, together with examples of observational modes, total bandwidths and spectral resolutions. The high flexibility of the ALMA correlator is emphasised and its ability to bring new data in molecular line or continuum astrophysics projects is discussed.

ALMA signal processing and correlation

The Atacama Large Millimeter/submillimeter Array (ALMA), under construction at the 5000-metre high altiplano of northern Chile, will explore the Universe in the millimetre/submillimetre wave range up to 1 THz (300 micrometres). With an impressive collecting area of 50 + 16 large antennas moveable over an area from about 150 m to more than 15 km in diameter, ALMA offers an unprecedented angular resolution and imaging capability (see Haupt & Rykaczewski, 2007). The 50+ (up to 64) 12-metre antennas form the ALMA main array; four 12-metre and twelve 7-metre antennas form the ALMA Compact Array (ACA). The radio waves, once they have been captured with the ALMA antennas, are converted into low frequency signals (while preserving the phase information of the incoming waves), digitised in specific modules and finally combined in a large digital machine, named the correlator. The digital correlator is the system combining the outputs of all antennas, as selected in the array, to detect the astronomical source power by measuring the cross-correlation coefficients of all antenna pairs in addition to the auto-correlation coefficients of each antenna. From these coefficients, and by further processing of the data, images of the astronomical sources are obtained. In mathematical terms the source image is directly related to the Fourier transform in the spatial frequency domain of the cross-correlation functions (or the interferometer complex visibilities). Moreover, time offsets or time lags are easily implemented in digital systems and thus the spectral information contained in the observed sources is also available from a digital correlator; the correlation lag functions and the astronomical spectra are related by a time/frequency Fourier transform.

There are two main correlator architectures: (a) the XF architecture where the X-part (cross- or auto-correlation part) is performed first and the Fourier transform (F-part) is applied at a later stage to analyse the source spectral properties; (b) the FX architecture where the Fourier transform is performed first. In terms of signal processing the XF or FX approaches are equivalent. ALMA has adopted two different types of correlator. One FX correlator constructed by a Japanese team processes the signals collected by 16 antennas of the ACA. The second correlator, constructed by an NRAO/European "integrated team", processes up to 64 ALMA antennas. It is a highly flexible "Digital hybrid XF" design in which the 2 GHz input baseband is digitally split into several sub-bands to enhance the spectral resolution, a concept first proposed in the European Second Generation Correlator (2GC) study. The Digital Hybrid XF correlator now merges the main ideas from the initial NRAO parallel array XF architecture with the frequency division scheme of the 2GC study. More generally, it is important to stress that digital filtering/processing offers great advantages with respect to analogue signal processing: reproducibility of performance, stability with respect to temperature drifts, easier calibration and higher flexibilty.

Specifications and architecture

The hardware sub-systems, in which the digital filtering and correlation functions have been implemented for the ALMA main array and the associated firmware, form what is referred to as the ALMA baseline correlator system (see specifications in Table 1).

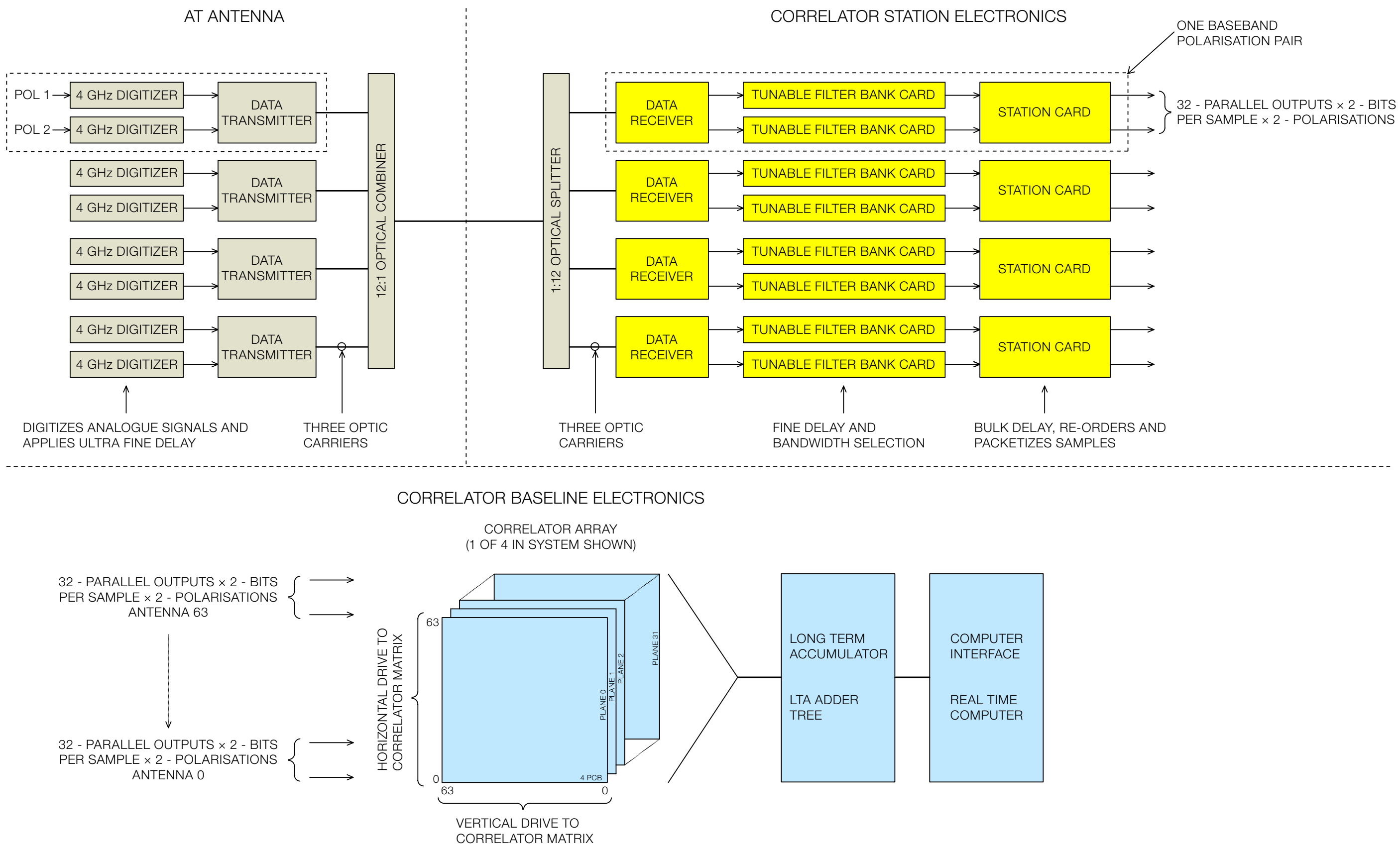
The ALMA correlator designers have faced two major challenges, driven by the main science goals in the millimetre and submillimetre: (a) process a broad signal bandwidth of 16 GHz (8 GHz per polarisation) from each of 64 antennas (each antenna provides 96 Gbits/s); (b) extract from the input band various spectral windows and provide flexible spectral resolutions. Figure 1, adapted from Escoffier et al. (2005), presents the baseline correlator system schematically. This includes "correlator station electronics" boards processing the digitised data streams from each antenna in the array and "correlator baseline electronics" boards providing the interferometric cross-products from up to 2016 independent antenna pair combinations (for 64 antennas).

We briefly describe below some of the main parts of the ALMA correlator and refer to the main blocks in Figure 1:

Filtering: After digitisation and time demultiplexing of the antenna signals for each baseband, frequency division is accomplished in the Tunable Filter Bank (TFB) boards placed in the station electronics racks. These boards divide the 2 GHz baseband into 32 frequency-mobile sub-bands of 62.5 MHz. Each sub-band is independently processed, assigned to one of the 32 correlator

Item	Specification
Antennas	Up to 64 (up to 2016 interferometric baselines)
Baseband inputs per antenna	8 x 2 GHz
Input sample format	3-bit, 8-level at 4 Gsample/s
Output correlation sample format	2-bit, 4-level or 4-bit, 16-level
Processing rate	125 MHz
Spectral points per baseband (Frequency Division Mode)	Up to 8192 per correlator quadrant
Spectral points per baseband (Time Division Mode)	64, 128 or 256 per correlator quadrant
Polarisation products	1, 2 or 4

Table 1. Main top level specifications of the ALMA baseline correlator



"planes" (see below) and the resulting spectra are later stitched together to form a final spectrum with 32 times more spectral channels across the original baseband. Distributing the correlator plane resources to fewer than 32 digital filters narrows the input bandwidth and increases the spectral resolution. The 62.5 MHz sub-band is extracted from 2 GHz in a three-stage digital filter structure implemented in a programmable logic device (or Field Programmable Gate Array, FPGA). The last stage determines the final filter sub-band characteristics and enables the bandwidth to be further narrowed to 31.25 MHz by downloading a specific set of pre-calculated digital weights.

Correlation: All independent cross-products for all 64 antennas are derived from the 32 correlator planes of the baseline electronics boards (see Correlator Array in Figure 1, lower). A correlator plane is a 64 x 64 matrix formed by four printed circuit boards, each with several assembled specific integrated circuits (the correlator chips) in which the signal is multiplied by its time- (or lag-) shifted version to derive the correlation coefficients. Each basic 256-lag circuit in a single correlator chip is driven by the two polarisation signals sent from each receiver band and there is the further ability to address fewer lag blocks in the chip to support double polarisation modes or a full Stokes parameter analysis of the incoming waves.

Two other system aspects are critical: signal digitisation and data transmission from station electronics to correlator board electronics. Prior to digital correlation, the analogue baseband signals are converted to digital samples in a digitiser module specifically designed for ALMA. These modules, plugged into the antenna digital racks, are not part of the correlator system, but their reliability and efficiency are essential in the signal processing chain. The data encoding is made on 3 bits and corresponds to a theoretical 96% correlation efficiency. Because the ALMA correlator cannot process the data at the 4 GHz sampling rate (for 2 GHz input baseband), the

Figure 1. Block diagram of the ALMA 64-antenna correlator showing the main components of the correlator antenna and correlator baseline electronics (adapted from Escoffier et al., 2005). The digitiser and data transmitter boards at the antennas are also shown. The digitised data flow is carried to the correlator system by optical fibres.

digitiser also includes a time-demultiplexed stage consistent with the 250/125 MHz clock rates. The correlator system is a synchronous machine with a very large number of filter and correlator boards (1024) in many racks that makes data transmission a difficult problem. The processing clock rate in all racks is at 125 MHz, but the station rack to correlator rack communication system involves 16384 cables working at 250 MHz. The output phases of these cables are remotely controlled and adjusted at the link frequency for error-free data transmission.

The correlator system is basically organised by quadrants, each quadrant processing one baseband pair, to accommodate four baseband pairs for two polarisations per antenna. This architecture makes it possible to enhance

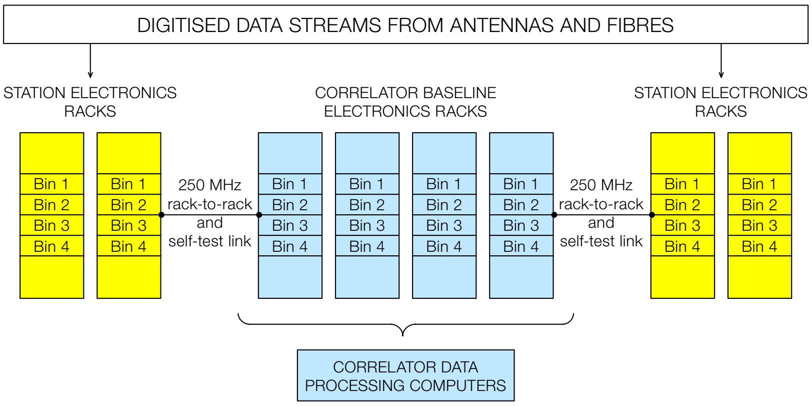


Figure 2. Schematic layout of one quadrant of the correlator system. Station and correlator baseline printed circuit boards are distributed in bins and racks and the correlator outputs are passed to the long-term accumulation boards and the real-time correlator data processing computers.

the total bandwidth, if that were to be required, by adding another quadrant. Figure 2 shows the schematic layout of a single correlator quadrant. There are 32 racks in total (8 racks per quadrant) with, in addition, power supply racks and the Correlator Data Processor and Correlator Control computer racks. All racks and computers are installed in the correlator room of the 5000-metre altitude Array Operations Site (AOS) technical building (see photograph on p. 5).

Technical challenges and performance

Novel hardware or firmware developments have been made to meet the ALMA baseline correlator specifications. Two examples are given for illustration: the digital filter subsystem conceived by the European team; and the correlator chip designed by NRAO. Several original aspects of the TFB design concern the ability to move sub-bands and implementation of the firmware required to meet the challenging filter specifications (e.g., high stop band rejection, low baseband ripple and low power dissipation). All filter functions must be implemented without exhausting the resources available in high performance FPGAs purchased from industry. We have selected a large FPGA with recent 90-nanometre technology to implement two 62.5 MHz sub-band filters in one FPGA. A matrix of 4 x 4 FPGAs is required for frequency division of each baseband and these 16 devices are assembled on a multi-layer TFB board together with other components (fine interferometric delay tracking is implemented in other small FPGAs). Several difficulties were met and solved during the industrial production phase of the TFB cards. These included questions as diverse as the Ni–Au finishing of the cards for long term protection or definition of the optimum temperature profile for reliable assembly of components free of lead (to meet the EC directive on Restriction Of Hazardous Substances). Special test equipment and test procedures were developed to validate the digital filter functionality and check the industrial production quality. This testing was required because of the complexity of the printed circuit board, the large number of ball grid array connections to each board for each large FPGA and the large number of TFB boards to be produced (512 for 8 basebands per antenna x 64 antennas, see Figure 3).

The ALMA correlator chip is a specific, highly integrated microcircuit providing an unsurpassed number of multipliers in a single custom-made chip. There are 4096 multipliers (also named “lags”) per chip providing 2-bit x 2-bit multiplication, 20 bits of integration and secondary storage for readout of the correlation coefficients. The 32 768 chips required for full operation of the four quadrants have been industrially produced. Use of these chips in the correlator environment of the integration centre and of the ALMA high site has proved to be extremely reliable. The correlator chip resources can also be combined to provide 4-bit x 4-bit multiplication so that the quantisation efficiency is enhanced, thus improving ALMA’s interferometric sensitivity overall.

The correlator system is a very large specific computing machine. With 4096 multipliers per chip performing 2-bit correlation at a 125 MHz clock rate and for 64 chips per correlator board, the number of operations performed per second in the full system is 1.7 x 10^{16}. The computing power in a single TFB board is already impressive. With several hundreds of multi-bit (typically 8 to 16) adder and multiplier stages implemented in one digital filter, around 10^{12} operations per second are performed in a board. The correlator output streams must reach a reasonable rate for final processing and archiving. From the basic accumulation mode of the ALMA correlator chip, the Long Term Accummulator (LTA in Figure 1) transfers 16, or integer multiples of 16, milliseconds of integrated data to

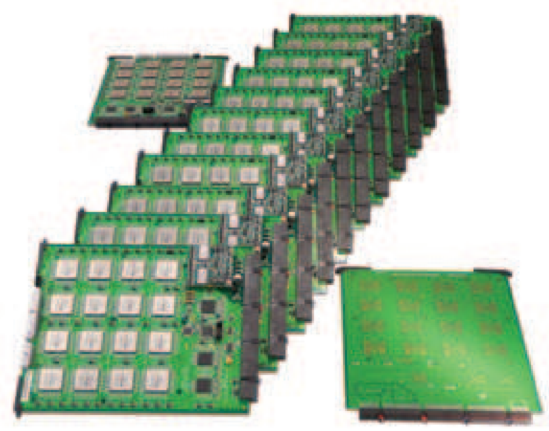


Figure 3. A small series of boards required for digital filtering before correlation. 512 boards have been produced and functionally tested for the full four-quadrant system.

the "real-time computer system" to process the correlation coefficients further. The maximum correlator output capacity reaches 1 GByte/s (in 16 data streams) or 256 MByte/s per correlator quadrant (in four data streams). Lowering the output rate is equivalent to sacrificing interferometric baselines.

Because the ALMA baseline correlator is such a large machine, power dissipation is a difficult task at the high altitude AOS, where the air density is roughly half that at sea level. There was an initial concern with the TFB boards because they implement several functions (and thus dissipate much power) and are plugged in racks where the air circulation is slowed down for practical reasons. With 75 W dissipated power per TFB board, the first engineering goal of 100 W was well met. The latest firmware optimisation and the develoment of a newer filter design have further reduced the dissipation below 60 W. This new performance lowers the temperatures inside the FPGAs, leading to a longer lifetime of these components. Based on the power dissipation measured at the high site with the first quadrant, we anticipate a total power dissipation of 150 kW for the four-quadrant system including the real-time data processor and control computers.

First operational results and installation at AOS

In parallel with the construction of the large 64-antenna correlator, two scaled-down models of the large machine have been made. One for the ALMA Test Facility (ATF) consisting of two prototype antennas at the NRAO VLA site (Very Large Array, New Mexico) and one for the 3000-metre high ALMA Operations Support Facility (OSF) site. The first scaled-down model was moved to the ATF site in 2007 and used through to the end of 2008. First successful end-to-end interferometric operation was demonstrated on the sky in January 2008 in the direction of the Orion Nebula (see Laing, 2008) where many spectral lines were observed at the expected frequencies. The second two-antenna correlator was installed at the OSF in 2008. It is used to test the production antennas and the associated equipment before they are moved to the AOS.

Figure 4. Front panel image of two bins in a Station Electronics rack showing TFB cards, station cards and other system cards (see Correlator Station Electronics in Figure 1). The pairs of holes seen in front of each TFB card allows cool air from the correlator room to be blown into the rack.

The first quadrant of the 64-antenna correlator has been shipped to Chile, installed in the AOS technical building and was successfully commissioned in the summer of 2008 (Figure 4). The air circulation from the floor up to the top of the station racks and temperature throughout the bins and racks are remotely controlled. The 64-antenna correlator room is next to the antenna "patch panel" room, which enables the fibre outputs of each antenna pad to be physically connected to the correlator inputs. The patch panel supports connections to about 200 antenna pads for all moveable 50 + 16 antennas and allows the ACA antenna data to be processed in the ALMA baseline correlator. When all 50 antennas of the main array are combined in the 64-antenna correlator with 14 of the 16 ACA antennas we then reach the ultimate ALMA sensitivity. For compact sources the sensitivity may be improved by about 8% with respect to the main array alone and all calibration sessions are performed more quickly. The ACA 16-antenna correlator has also been installed on the high site. Processing the same data (up to 16 antennas) in two different correlators is of great value for an advanced comparison of these two large machines, whose specifications are similar (except that the ACA correlator processes 16 instead of 64 antennas). In the Japanese FX-type correlator, spectral averaging is performed after the F-part and the correlation is directly performed in 4 bits, but these details should remain invisible to the astronomers; only the effective spectral resolution should differ slightly.

Correlator modes for astronomical science

The ALMA baseline correlator supports a broad variety of observing modes, which may be classified into two main categories, the Time and Frequency Division Modes (TDM and FDM). In the TDM operation mode there are 32 parallel correlator planes, each processing, at 125 MHz, one-millisecond signal time slices from the digitised input baseband, and the correlator behaves as a pure XF system. In the FDM operation mode each of the 32 sub-bands in the 2 GHz input baseband is processed in one of the 32 correlator planes, or fewer subbands are processed by all planes to enhance the spectral resolution. The TFB filter boards are designed to support both

Total Bandwidth	Resolution (Nyquist, kHz)	Resolution (Double Nyquist, kHz)
2 GHz	244	488
1	122	244
500 MHz	61	122
250	30.5	61
125	15.3	30.5
62.5	7.6	15.3
31.25§		3.8§

Table 2. Bandwidth and resolution for 2-bit correlation with one 2 GHz baseband processed per correlator quadrant in frequency division operation mode (FDM).

§ Available with specific digital weights downloaded in last stage of the digital filter.

TDM and FDM, the data being directly sent to the final requantisation stage of each TFB board in the TDM operation mode. Examples of the spectral resolution achieved in FDM observing modes, for the case of only one baseband processed per quadrant, are given in Table 2 for different input bandwidths. Nyquist sampling is the basic working model of the correlator, but double Nyquist sampling is also available to improve the correlation efficiency (7% better) at the expense of lower correlator resources and so lower spectral resolution. The maximum resolution achievable, 3.8 kHz, enables extremely detailed spectral studies to be carried out.

If two basebands are processed per quadrant, the resolutions shown in Table 2 are twice as poor. There is another degradation by a factor of two with the additional polarisation cross-products required for a full Stokes parameter analysis. In order to improve the correlation efficiency, 4-bit correlation is also supported, but the frequency resolution is now four times poorer than that shown in Table 2. Double Nyquist sampling is also available with 4-bit correlation; it does not improve the already high efficiency much, but decreasing the spectral resolution speeds up the data dump rate. About 70 different observing modes are available with only a few TDM modes. TDM is to be preferred for fast dump rates (16 ms minimum) and moderate resolution (31.25, 15.6 or 7.8 kHz) across 2 GHz.

The 64-antenna correlator has the ability to move spectral sub-bands within the input baseband and to split one correlator quadrant into independent sub-units so that several options are supported: (a) high resolution in a given spectral region from 2 GHz to 62.5 MHz (or 31.25 MHz) with 62.5 MHz sub-bands tunable anywhere within 2 GHz; (b) multiple disjoint spectral regions fitting within 2 GHz but with the same spectral resolution, sensitivity and polarisation options; (c) multi-spectral resolution over different bandwidths to zoom on specific spectral features. All quadrants are independent and these different modes could also be implemented simultaneously with overlapping quadrants.

Spectral line and continuum astrophysics

The ALMA baseline correlator, with its flexible resolution and ability to analyse multi-spectral windows, is extremely well adapted to any type of spectral work. Two parameters are of interest, the total bandwidth and the spectral resolution:

Total bandwidth: Table 3 shows the typical total velocity coverage required for line analysis in a number of Galactic and extragalactic molecular sources, or in planets, and the corresponding total bandwidths at two widely separated frequencies (around 90 GHz where molecular transitions from HCO^+ or HCN are observed, and around 602 GHz where methanol is present). These frequencies fall in the ALMA receiver Bands 3 and 9, respectively. They have been arbitrarily selected to illustrate our discussion on required bandwidth. The total velocity coverage corresponds to the expected velocity extent at the base of the line profile with some additional spectral noise channels on each side of the line feature(s) of interest to provide a reference intensity level.

The maximum bandwidths that the baseline correlator can process match rather well with the total bandwidths in Table 3. These maximum bandwidths are: 2 or 1 GHz, 500, 250, 125, 62.5 or 31.25 MHz, with one quadrant; 4 GHz with two quadrants; or 8 GHz with four quadrants.

Spectral resolution: The various resolutions available with the baseline correlator are suited to a large variety of astrophysical environments. Table 2 gives examples, but there are more selectable modes with the 4-bit correlation and polarisation cross-products options. We give a few examples. About 1 MHz resolution is convenient to provide many details in the CO J = 2–1 line of many nearby galaxies or in energetic galactic outflows. This can be achieved, for

Source	Typical Total Velocity Coverage (km/s)	Total Bandwidth 90 GHz, 602 GHz
Galactic Sources		
Energetic Outflow in Young Stellar Objects	600	180 MHz, 1.2 GHz
Spectral Line Survey	300	90 MHz, 600 MHz
Orion, Galactic Centre	80–160	24–48 MHz, 161–321 MHz
Compact H II regions	40	12 MHz, 80 MHz
Molecular Cloud Spectra	10–40	3–12 MHz, 20–80 MHz
Dark Clouds	5	1.5 MHz, 10 MHz
Extragalactic Sources		
Nearby Galaxies (≤ 200 Mpc)	≤ 2000	≤ 0.6 GHz, ≤ 4 GHz
Highly Redshifted Sources		As large as possible
Planets		
Pressure Broadened Lines	1000–3000	0.3–0.9 GHz, 2–6 GHz

Table 3. Examples of total velocity coverage required for line observations of Galactic and extragalactic sources.

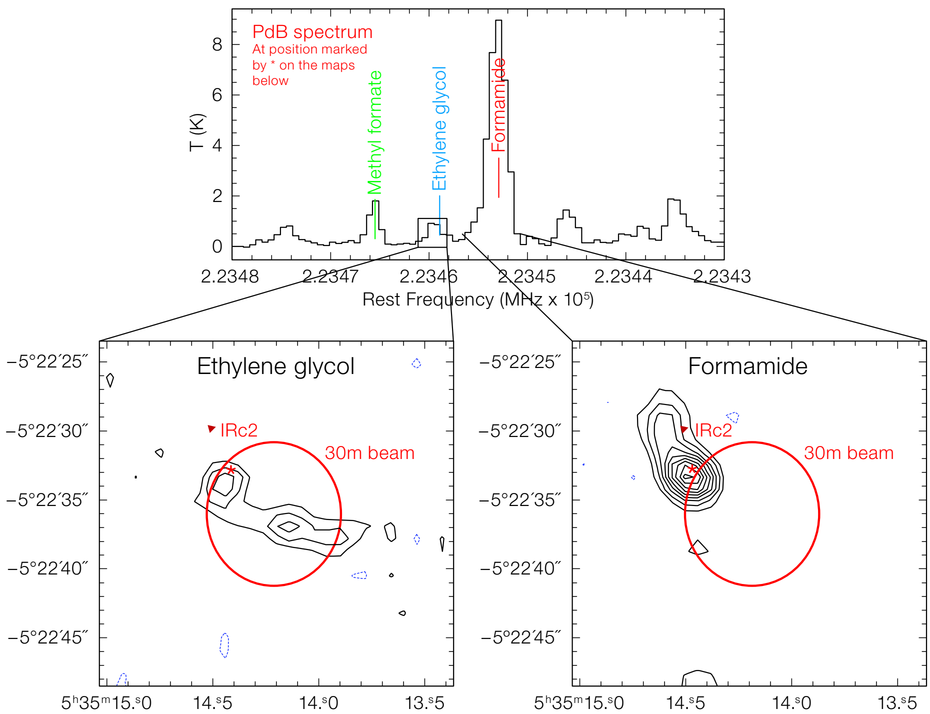
example, with 1 GHz total bandwidth in the Nyquist sampling TFD mode and with the high sensitivity 4-bit option; the resolution for the CO J = 2–1 line is then 1.3 km/s. At the higher frequencies of CO, one may either bin the spectral channels or use the coarser resolution of the TDM mode (7.8–31 MHz). On the other hand, there are a number of interesting astrophysical cases where velocity resolutions as high as 0.02–0.05 km/s are required: study of protostellar discs, dark molecular clouds, wind velocities in planets or thermal line widths in comets. In ALMA Band 3 for instance, around 6 kHz resolution is needed to reach 0.02 km/s and the observing modes providing 3.8 or 7.6 kHz are thus well suited. Analysis of Zeeman splitting or cosmic maser lines also requires high resolutions.

The ALMA baseband correlator will be configured for a number of broadband continuum projects in Galactic or extragalactic sources. The TDM mode is ideal for processing 2 GHz bandwidths with low spectral resolution in single, double or full polarisation observing modes. In all modes, combining independent quadrants broadens the total bandwidth if that were necessary. Moderately broad bandwidth will be sufficient in projects such as the thermal dust temperature study of Galactic young stellar objects and polarisation imaging of dust in young objects or molecular clouds in order to investigate the role of the magnetic field. FDM modes with 0.5–1 GHz bandwiths may often be appropriate depending on the selected receiver band. There is always the option to perform continuum and spectral line observations simultaneously with overlapping quadrants. For example 2 GHz continuum with low spectral resolution in TDM mode can be combined with higher FDM frequency resolution mode in 2 GHz or lower bandwidth.

An outstanding tool for molecular complexity

The ALMA correlator will offer new opportunities to help understand the complexity observed in the molecular Universe. Complexity refers to aspects as different as the identification or discovery of new molecules in the interstellar medium or in circumstellar envelopes, the relationship to astrobiology and the roots of prebiotic chemistry in the interstellar gas, the range of different environments in our Galaxy and distant galaxies, etc. Extremely rich spectra and complex molecules, prebiotic or not, have been observed with several existing millimetre-wave telescopes in a broad range of objects (very young stellar objects, pre-stellar cores, nearby or starburst galaxies, etc.). In the Orion Nebula or in the Galactic Centre, crowded line spectra and "forests" of lines have been observed, so that identification of the molecular carrier of a given line becomes difficult. An example of the crowded spectra obtained with the IRAM interferometer is given for Orion-KL, a massive star-forming region, around 223 GHz (see upper panel of Figure 5, adapted from Favre et al., 2008). An even more extreme case is that of Sgr B2(N) where Belloche et al. (2008) detected about 100 lines every 1 GHz around 100 GHz. From 88 transitions free of any spectral contamination, and from line maps in a subset of these lines, Belloche et al. have identified the complex amino acetonitrile molecule — a potential precursor of glycine. Crowded line spectra are expected in several ALMA submillimetric bands and spectroscopic databases or new techniques to predict spectral confusion may become essential. Despite these difficulties we believe that the ALMA correlator will greatly contribute to molecular astronomy in the mm/submm domains because of the following advantages: (a) in a broad bandwidth many lines are detectable at once and this allows the observer to identify the regions in crowded line spectra with less confusion; (b) multi-spectral resolution and very high spectral resolution help to resolve line blends; (c) multi-spectral windows offer the ability to compare properties of various molecules in the same source; (d) resolution can be traded for sensitivity options or polarisation modes. Of course, in complex molecular sources, and with adequate sensitivity, interferometric maps showing different spatial distributions may also help in the spectral confusion problem (see lower panel in Figure 5 showing good spatial separation of moderately blended lines).

Figure 5. Upper panel: Cross-correlation spectrum of the Orion Nebula showing spectral features of complex molecules observed with the IRAM interferometer around 223 GHz. **Lower panel:** Spatial distribution of the ethylene glycol and formamide molecules obtained with the IRAM interferometer; the red circle corresponds to the spatial extent of the 30-metre telescope beam.



Future possibilities — near and longer term

The first quadrant of the baseline correlator system installed in the AOS technical building (see p. 5) supports up to 16 antennas. It is available for interferometric commissioning tasks and it meets the conditions for early science requiring 16 antennas and a basic set of spectral line modes. The first call for ALMA proposals is expected around 2011. One may anticipate that several FDM and TDM operational modes including double or full polarisation modes with different total bandwidths will be scheduled for early science. The second correlator quadrant will be installed in 2009 and the third and fourth quadrants, required to support up to 64 antennas, could be assembled by the end of 2010.

Other correlator configuration modes will become available in the future. Sub-arraying, namely the ability to process independent subsets of antennas operated in different modes, is an important ALMA feature. Initial implementation of two sub-arrays is a high priority. For instance, one group of antennas will map a source, while just one other antenna will perform single dish observations, or one sub-array will track a source while the second one will perform antenna commisioning tasks. Each correlator quadrant may support more than two sub-arrays.

The summed output signals from two or more antennas in the array will also be available in the correlator to form a big single antenna which can be combined with other antennas located on other continents to provide extremely high spatial resolution. This observing mode, named Very Long Baseline Interferometry (VLBI), will require some additional equipment at the AOS, but will certainly be used in the future. Pulsar observations may be supported as well, provided that pulsar period models can be implemented and that the ALMA receiver bands are of interest in pulsar astrophysics.

Finally, thanks to the ACA patch panel and the 16-antenna correlator being installed next to the 64-antenna baseline correlator, the following can be achieved: (a) the overall ALMA sensitivity can be enhanced by combining all data from a maximum of 64 antennas; (b) calibration of the twelve smaller 7-metre antennas can be efficiently accomplished when they are cross-correlated with all other 12-metre antennas; (c) comparison and cross-calibration of the ACA and baseline correlator performance becomes easier. ALMA science will benefit from these future possibilities.

Acknowledgements

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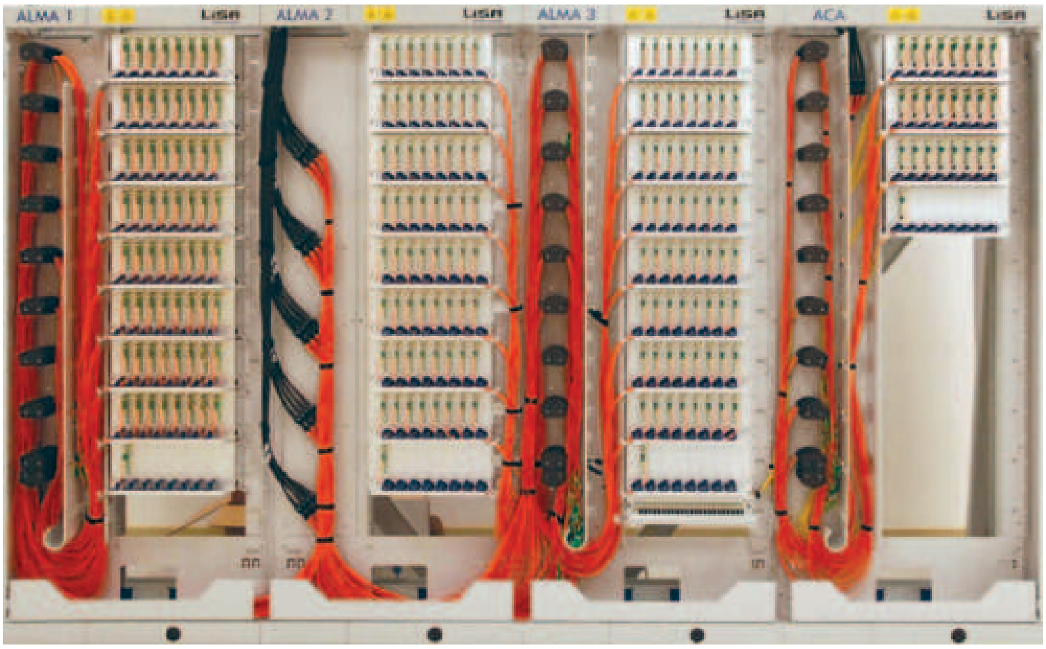

The ALMA Optical Fibre Network Patch Panel, shown left, was successfully installed in the AOS technical building at 5000 m altitude on the Chajnantor Plateau in December 2008. The Patch Panel, an ESO deliverable to ALMA, is used to send the Central Local Oscillator signal to all the ALMA antennas on Chajnantor, to receive the astronomical signals and redirect them to the Amplifier and Demultiplexer, before the real correlation takes place in the ALMA Correlator.