The ALMA Project

R. KURZ and P. SHAVER, ESO

1. Introduction

The Atacama Large Millimetre Array (ALMA) is the new name for the merger of the major millimetre array projects – the European Large Southern Array (LSA), the U.S. Millimetre Array (MMA), and possibly the Japanese Large Millimetre and Submillimetre Array (LMSA), into one global project. This will be the largest ground-based astronomy project of the next decade after VLT/VLTI, and, together with the Next Generation Space Telescope (NGST), one of the two major new facilities for world astronomy coming into operation by the end of the next decade.

The exciting science that can be done with a large millimetre/submillimetre array was summarised in an article in *The Messenger* last year (March 1998, p. 26) and the proceedings of a workshop held at ESO in 1995 (Science with Large Millimetre Arrays). It will detect and study the earliest and most distant galaxies – the epoch of the first light in the Universe. It will also look deep into the dust-obscured regions where stars are born to examine the details of star and planet formation. In addition to these two main science drivers, the array will make major contributions to virtually all fields of astronomical research.

ALMA will be comprised of some 64 12-metre, submillimetre-quality antennas, with baselines extending to at least 10 km. Figure 1 shows an artist's concept of a portion of the array in a compact configuration. Its receivers will cover the frequencies from 70 to 950 GHz. The preliminary estimated cost of the project is US$400 million (1997).

ALMA will be located on the high-altitude (5000 m) Zona de Chajnantor, east of the village of San Pedro de Atacama in Chile. This is an exceptional site for (sub)millimetre astronomy, possibly unique in the world (see article on site testing in the December 1998 issue of *The Messenger*, p. 13). The location of the site is indicated in the photographs on the cover and centre pages of this issue of *The Messenger*. Figure 2 illustrates the remarkably flat (for this altitude) topography ideally suited for installation and operation of ALMA.

The developments prior to 1998 were summarised in the March 1998 *Messenger* article. Here the important developments of the past year, along with the present status of the project, are reviewed.

2. Steps Towards a Global Project

The European Collaboration

In September 1998 the framework for the formal European collaboration in this project was drafted. It called for the establishment of a European Co-ordination Committee (ECC) to direct the European effort and a European Negotiating Team (ENT) to enter into negotiations with other prospective partners. This approach was agreed by ESO Council at an extraordinary meeting on 15 September.

The membership of both the ECC and the ENT was intended to reflect the expected ultimate financial contributions to

Figure 1: Artist's conception of ALMA in a compact configuration.

Figure 2: View (towards the north) of the ALMA site on the Zona de Chajnantor. The prominent mountain at centre-left is Cerro Chajnantor, and to the right is Cerro Chascón.

the construction and operation of the array: four members from ESO, and one each from France (which presently intends to participate separately in this project) and the U.K.

On 17 December the MoU establishing the ECC and ENT was signed by the parties that agreed to fund Phase 1 (the initial 3-year design and development phase) of the project: ESO, Centre National de la Recherche Scientifique (CNRS), Max-Planck-Gesellschaft (MPG), the Netherlands' Foundation for Research in Astronomy (NFRA) and Nederlandse Onderzoekschool Voor Astronomie (NOVA), and the United Kingdom Particle Physics and Astronomy Research Council (PPARC). In addition to defining the organisational structure for the project within Europe, this agreement committed support (in kind and cash) equivalent to at least DM 28 million for Phase 1.

At the same meeting a European Project Manager for Phase 1 was appointed (R. Kurz), and a Science Advisory Committee was established (K. Menten, chair). Subsequently a European Project Scientist has also been appointed (S. Guilloteau). With these actions the top-level structure for Phase 1 of the project within Europe is now in place.

A Joint Project with the U.S.

A resolution between ESO (on behalf of the LSA Consortium and the European community) and the U.S. National Radio Astronomy Observatory (NRAO) was signed in June 1997, in which the parties agreed to pursue the possibility of merging the European and U.S. millimetre array projects into one. Considerable work was done on joint scientific and engineering studies, but it was only with the establishment of the European Negotiating Team (ENT) that it was possible to move on to formal discussions of a joint project.

Following three meetings this year between the ENT and the U.S. National Science Foundation (NSF), a Memorandum of Understanding concerning the design and development phase of a joint array (Phase 1) has now been signed. This commits the signatories both to collaborate in Phase 1, and to endeavour to obtain approval and all necessary funding for collaborative participation in a single project for the construction and operation phase (Phase 2).

The basic principle is that of a 50/50 partnership between Europe and the U.S., with joint overall direction. In the construction phase it is expected that there will be a governing board representing all signatories to the agreement, and a small, co-located global project team led by a single Project Director. There will also be a European Project Office leading the European effort and a U.S. Project Office for the U.S. side. In the operations phase the array will be run by an ALMA Observatory established as a legal entity in Chile, controlled and funded equally by Europe and the U.S.

A Three-way Partnership?

Japan has also been working towards a project of this kind, the Large Millimetre and Submillimetre Array (LMSA). It was decided over a year ago that the LMSA would also be located in the Zona de Chajnantor, and so a collaboration of some kind seemed obvious (in fact, all three groups have been collaborating for years on site testing activities).

Late last year the Japanese astronomical community decided that it would be best to fully merge its project with the European and U.S. projects into one global project. As all three projects are comparable in scale, it was natural to consider an equal three-way partnership. In this case the total array may be a US$600-million project consisting of as many as 96 antennas, giving a total collecting area of over 10,000 m^2 – the original target specified by the European astronomical community to satisfy the cosmological objectives.

The first informal three-way meeting between Europe, the U.S. and Japan to discuss the combined project took place in Washington in February, and a joint resolution was signed in March. Japan also participated in the recent meeting at which Europe and the U.S. signed their MoU, and it is understood that this MoU could be expanded to include Japan. It is hoped that a complete three-way MoU can be signed within the coming months.

Developments in Chile

The Chilean government has set aside a large part of the Zona de Chajnantor as a scientific preserve under the stewardship of CONICYT. Under the terms of the March 1999 resolution, a joint approach will be taken to obtain joint use of this land for ALMA. Following initial discussions with ESO acting on behalf of Europe, the U.S., and Japan, Chile has established a negotiating team with representation of all relevant elements of the Chilean government and led by the Foreign Ministry.

3. Phase 1 Activities

Phase 1 is the design and development phase, extending from 1999 through 2001. In concert with NRAO, the objective of Phase 1 is to completely define a joint programme to construct and operate ALMA (Phase 2). This definition will be the basis for a European proposal for Phase 2 to be submitted not later than June 2000. The products of Phase 1 will include:

- the scientific rationale reflected in unambiguous top-level scientific requirements
- the technical approach and preliminary design validated by demonstrated performance on prototype components or subsystems, including prototype antennas provided by the U.S. and Europe
- the management approach for Phase 2 and a precise division of responsibilities for deliverables embodied in executed agreements between the participants
- the schedule and cost-to-completion derived from a detailed project work breakdown structure with commitment by the participants to deliver the elements for which they are responsible for the estimated cost.

This is a joint activity between Europe and the U.S., as the two projects have been united and brought into phase. The total resources available are US$26 million (U.S.) and DM 28 million (Europe). Efforts are being made to assure that the activities on the two sides of the Atlantic are complementary, and are not duplicated except in those areas where overlapping studies are desirable. The major expenditure will be for the construction of two prototype antennas, one in Europe and one in the U.S.

Figure 3: Several participants from the VLT inauguration ceremony visited the Chajnantor site on 7 March 1999. These include the present Director General Riccardo Giacconi, the Director General designate Catherine Cesarsky, State Secretary Dr. Charles Kleiber (Director of the Swiss Science Agency), and several Council members.

The top-level organisation of the European project team is shown in Figure 4. The programme office is made up of the European Project Manager and Project Scientist plus a European Deputy Project Manager, Richard Wade from Rutherford Appleton Laboratory in the U.K. The seven working teams are led and managed by the following:

- Management: Richard Kurz from ESO
- Science & System: Stephane Guilloteau from IRAM
- Antenna: Torben Andersen from Lund Observatory
- Receiver Subsystem: Wolfgang Wild from NOVA/SRON Groningen
- Backend Subsystem: Alain Baudry from Observatoire de Bordeaux
- Software & Control: Michele Peron from ESO
- Site: Lars-Åke Nyman from OSO/SEST

The elements of the NRAO work breakdown structure for MMA that correspond to the various elements of the European organisation and the NRAO Division Heads for these elements are shown below the European organisation.

The Team Managers are responsible for planning, co-ordinating, monitoring and

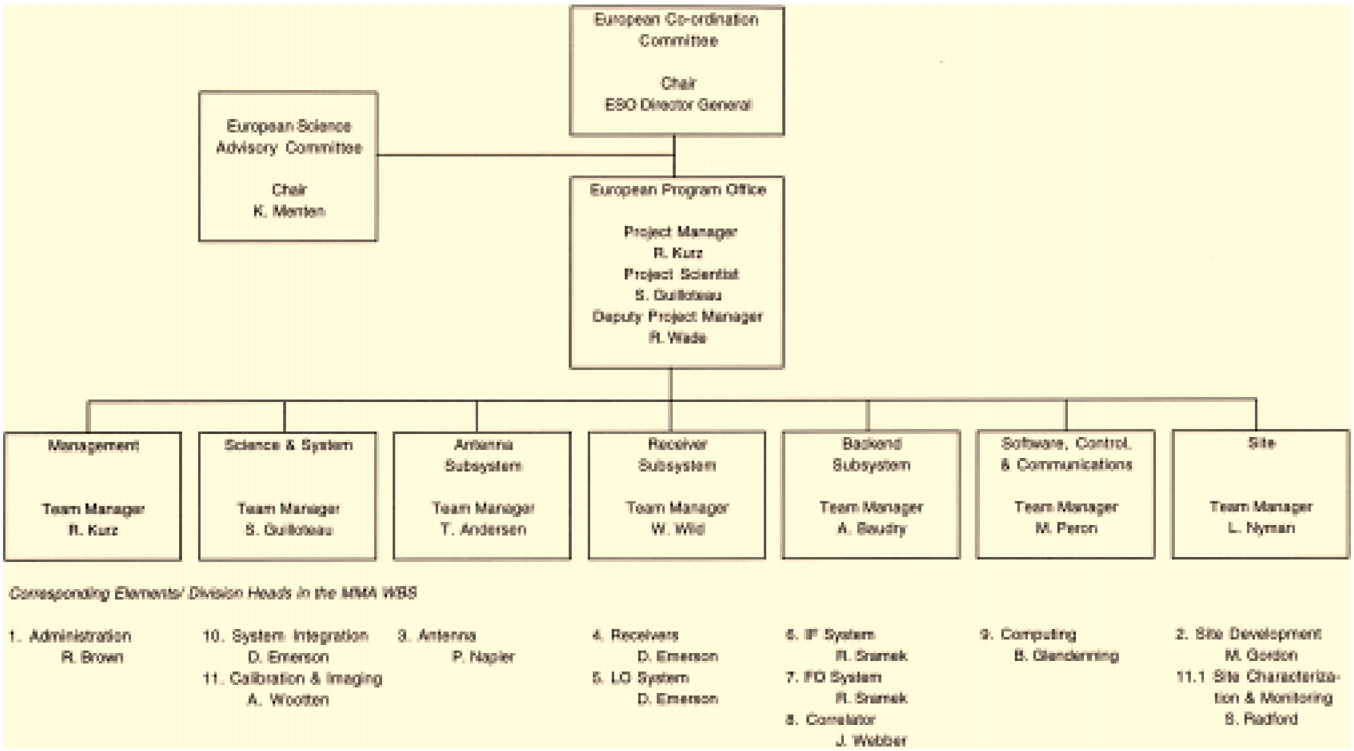

Figure 4: European Phase 1 Organisation.

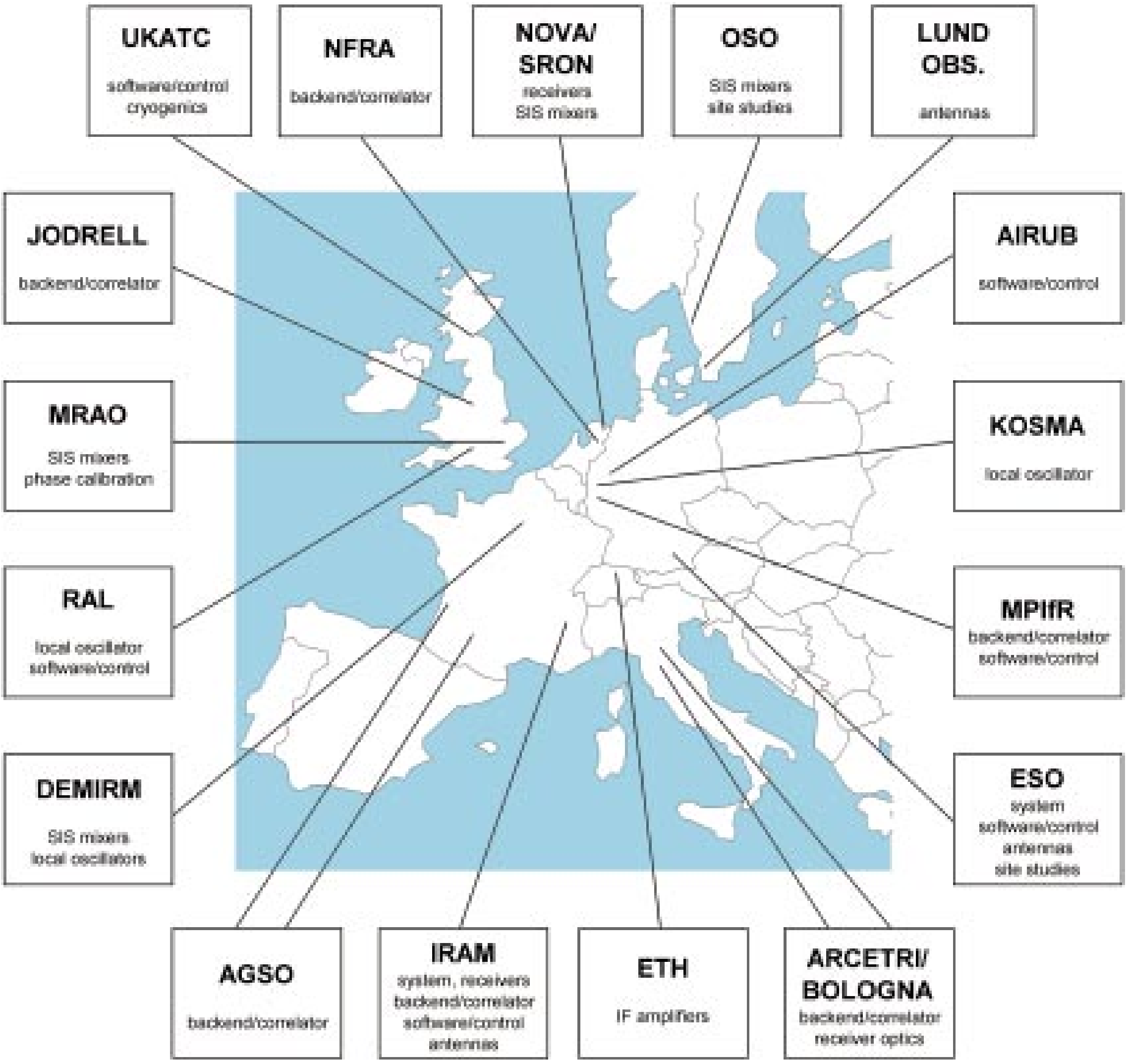

Figure 5: European institutes participating in ALMA.

reporting the work in their area. Figure 5 indicates the diversity of European institutions that are expected to participate in ALMA and their indicated areas of interest. The exact makeup of the seven working teams is still being worked out and the expected activities of the teams are outlined below.

Science and System. Although Europe and the U.S. are in agreement on most of the top-level scientific requirements for ALMA, further definition is required for specific items. A joint science working group will recommend requirements for total power measurement, frequency bands, intermediate frequencies, etc. Early definition of a concept of operations for the full array will be a joint task. This is especially important as a prerequisite to defining the software, control, and communications requirements. A joint array configuration working group will analyse and recommend array configurations taking into account the characteristics and topography of the site. In addition to the joint activities, on the European side we will analyse, prototype, and evaluate radiometric phase calibration techniques using the 183 GHz water line. On its side, the U.S. will investigate total power mode techniques and radiometric phase calibration using the 22 GHz line.

Antennas. The European antenna team will be centred at Lund Observatory with support from ESO and IRAM. Effort in the antenna area is focussed on the design, construction, assembly, and testing of prototype antennas by both the U.S. and Europe. The U.S. has taken the lead in compiling the specifications for the prototype antenna. In the last several months this effort has become a fully joint effort. Each side will procure a prototype antenna satisfying the common technical requirements. These procurements will be closely co-ordinated. The European contract will be technically monitored by the antenna team and administered by ESO's Contracts and Procurement organisation. We will jointly evaluate and test these antennas, individually and as a single-baseline interferometer. Finally, both sides will investigate metrology techniques for possible evaluation on the prototype antennas.

Receivers. The receiver area will have participation from a large number of institutes in Europe, as indicated in Figure 5. There will be a single joint European/U.S. design of the receivers at the subsystem level. A wide range of component development activities are proposed on the U.S. and European sides – SIS junctions and mixers at different frequencies, photonic and conventional local oscillators, and a multi-channel cryostat. A near-term aim of the planning in this area will be to reduce duplication and overlap in the developments. Both sides will do production planning and cost estimation for the full array receivers and NRAO plans to build and test a prototype receiver. NRAO will also design and produce the receivers to be used in evaluating both prototype antennas (these are not prototype receivers for the full array).

Backend Electronics. As in other subsystems, a joint backend design will be developed at the subsystem level. Both sides will pursue development and testing of fibre optic signal transmission with emphasis on analogue techniques in the U.S. and digital techniques in Europe. The U.S. will build a correlator based on an existing design to be used in testing the two prototype antennas in a single-baseline interferometer configuration. They will also design and carry out component development for a quarter-size correlator (inputs from up to 32 antennas), again based on existing technology. During Phase 1, Europe will concentrate on de-

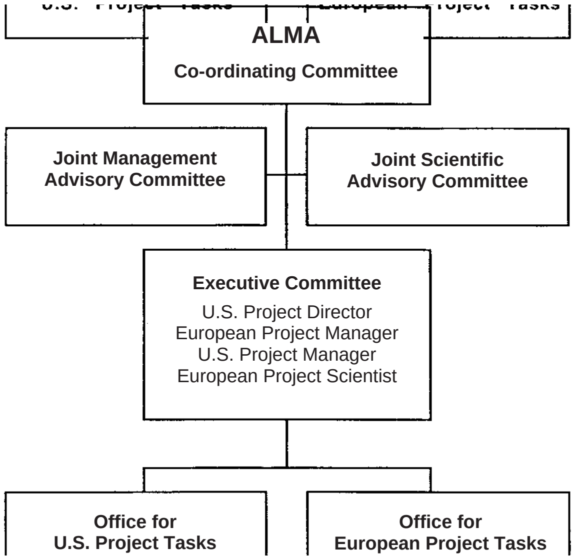

Figure 6: Joint U.S./European Phase 1 Management Structure.

signing an advanced (second-generation) correlator that would exploit the latest in microelectronics capability. The decision to proceed with either a scaled-up U.S. design or the European advanced correlator will be made early in Phase 2.

Software, Controls, and Communications. Joint definition of the software, controls, and communications requirements based on the concept of operations generated by the Science & System team will be the first task. Following this, a joint top-level software, controls, and communications subsystem design plus joint definition of the software development environment will be performed. ESO will lead the effort on software engineering to define the standards and processes to implement the software and control subsystems. Once this framework and the overall subsystem is specified and designed, responsibility for development of the various subsystems will be distributed amongst the participating institutions. In Phase 1 this will include development of the first increment of common software in Europe. The U.S. will take the lead in development of the sofware needed for evaluation and testing of the prototype antennas, both singly and as an interferometer.

Site. Europe, the U.S. and Japan have all been collaborating on site testing in Chile for several years, and there is now complete agreement on the Chajnantor site. The equipment from all groups is now located there and co-ordinated in a common test campaign. Europe is responsible for operation and first-line maintenance of the characterisation equipment at Chajnantor. Analysis and interpretation of the site characterisation data is a joint task. Negotiations with Chile to gain the necessary rights of access to the site will be conducted jointly. Geotechnical and environmental studies will also be part of Phase 1, with Europe administering the study contracts. NRAO has already done a significant amount of site development planning and produced a first comprehensive cost estimate. This will continue as a joint activity, leading to the bid packages that are expected to be one of the first major contracting activities of Phase 2.

Management. Overall Phase 1 management and co-ordination will be a joint activity (see Figure 6) with each side managing their respective project tasks. The major task in the management area, in addition to managing the Phase 1 work, will be the complete programmatic definition of Phase 2, including the management structure, the detailed definition and division of work between the U.S. and Europe, and estimation of the cost to complete the full array. We will work with NRAO to build a complete parametric cost model in accordance with the work breakdown structure. This model will be built in parallel with the scientific end-to-end performance model based on the same parameters. Operational analysis to determine the most cost-effective approach to developing the facilities in Chile and to assembling and operating the array will be an essential part of fully defining Phase 2.

4. The Major Milestones Ahead

Phase 1 of this project has moved into high gear, and the timescales are tight. The upcoming major milestones are as follows:

- October 1999: award of the prototype antenna contracts
- November 1999: completion of joint Europe/US management plan
- May 2000: completion of Phase 2 proposal
- December 2000: approval of Phase 2 by ESO Council
- December 2000: signing of international agreement for Phase 2
- July 2001: prototype antenna delivery, system PDR

Phase 2 begins in 2001. A joint array preliminary design review will take place in the middle of that year, and the site development will start. By 2005 there should be sufficient antennas on site for a subarray to begin operation. The complete array should be available by 2009.

More information on the project can be found at the ALMA web site,
http://www.eso.org/projects/alma/

A FIRST FOR THE VLT

OBSERVATIONS OF THE GAMMA RAY BURST GRB990510, AND DISCOVERY OF LINEAR POLARISATION

International teams of astronomers are now busy working on new and exciting data obtained in May with telescopes at the European Southern Observatory (ESO).

Their object of study is the remnant of a mysterious cosmic explosion far out in space, first detected as a gigantic outburst of gamma rays on May 10, GRB990510.

Gamma-Ray Bursters (GRBs) are brief flashes of very energetic radiation – they represent by far the most powerful type of explosion known in the Universe and their afterglow in optical light can be 10 million times brighter than the brightest supernovae. The May 10 event ranks among the brightest one hundred of the over 2500 GRBs detected in the last decade.

The new observations include detailed images and spectra from the VLT 8.2-m ANTU (UT1) telescope at Paranal, obtained at short notice during a special Target of Opportunity programme. This happened just over one month after that telescope entered into regular service and demonstrates its great potential for exciting science.

In particular, in an observational first, the VLT measured linear polarisation of the light from the optical counterpart, confirming that synchrotron radiation is involved. It also determined the redshift of the host galaxy of GRB990510, $z = 1.619$, corresponding to a distance of more than 7,000 million light-years to this GRB (assuming a Hubble Constant $H_0 = 70$ kms^{-1} Mpc^{-1}, a mean density Omega$_0$ = 0.3 and a Cosmological Constant Lambda = 0).

This is an excerpt of the ESO press release of 18 May 1999 where more information on the science and organisation of this collaboration can be found including the name of the astronomers who participated in this investigation and the web site address of their institutes.

The full text and 7 pictures are at: www.eso.org/outreach/press-rel/pr-1999/pr-08-99.html