5

Foreign Affairs

"It is our true policy to steer clear of permanent alliance
with any portion of the foreign world."

George Washington, farewell address, 1796

Funding Hurdles

The path was long for the MMA as it progressed from the time of the proposal submission to NSF, through the subsequent review, en route to being funded. Myriad hurdles had to be overcome. None could assure success; any could lead to failure. Several of the gatekeepers were committees that met on a regular schedule, for example, the NRAO Users and Visiting Committees, the ACAST, and the MPS Advisory Committee. A strong endorsement of the MMA in each of their reports was necessary to sustain the momentum of the project. While the NRAO committees, composed of radio astronomers, could be counted on for enthusiasm, most of the ACAST were in other fields of astronomy and needed to be convinced of the power of the MMA to address questions that they themselves regarded as important. Luckily, a demonstration of that power became available.

In the summer of 1991, Bob Brown was intrigued by a preprint of a scientific article received by the NRAO Library. The authors had identified an infrared source, IRAS F+10214, with a galaxy at a redshift of 2.3 (more than 30 billion light-years away). An infrared source detected at this distance was sure to be a highly luminous infrared galaxy. In turn, infrared emission indicates the presence of star formation regions in molecular clouds of dust and gas. Brown wanted to search for the molecular gas. At first, he considered searching for the lowest frequency spectral line of carbon monoxide using

the 140 Foot Telescope in Green Bank, where he had previously searched for highly redshifted atomic hydrogen. Instead, he agreed to Vanden Bout's suggestion that they look for a higher frequency CO spectral line using the 12 Meter Telescope. Despite the poor observing conditions – it was summer, the rainy season on Kitt Peak – they detected the targeted molecular line. The discovery paper[1] they published was flawed. Systematic errors in the data made the line appear stronger than it actually was, but the detection was real. Furthermore, it was at a redshift more than 10 times larger than any previous CO detection in an external galaxy. When the spectrum was shown to the ACAST as part of a report on MMA progress, the members immediately grasped the potential of millimeter wave facilities for the study of star formation in the early Universe.

With a strong endorsement from the ACAST, Hugh van Horn, Director of the NSF Division of Astronomical Sciences, could speak forcefully at the NSF in support of the MMA project. On their exploratory trip to the high area above San Pedro de Atacama, Harris and van Horn had been awed by the potential for astronomical observations afforded by clear, dry skies of the high-altitude plateau. Harris became a strong advocate within the NSF for the MMA. As was noted previously, the MMA had received a high ranking for major ground-based projects from the report of the 1990 Decadal Survey of Astronomy and Astrophysics. The MMA was ranked second, behind the Gemini North optical/infrared telescope, near the top of the list for new, large, NSF projects. Gemini was organized as an international partnership, portending the next hurdle for the MMA.

International Participation

Organizing large NSF projects as international partnerships became fashionable while Bloch was the NSF Director. He had attended a meeting in Europe organized by the heads of European science funding agencies to discuss the benefits of international participation in future large projects. One perceived benefit was cost savings. The Gemini Observatory is an early example of an NSF international project in astronomy. Undoubtedly, the sharing of construction costs among foreign partners appealed to the US Congress as they reviewed NSF's budget requests for Gemini. That initial funding success made it clear that in the future all large projects proposed to NSF would be wise to include international partners.

Faithful to George Washington's dictum, NRAO had long avoided international cooperation in telescope operations. The sole exception involved the quest for the longest possible baselines for Very Long Baseline

Interferometry (VLBI) observations. These had to span the globe and inevitably led to joint operations with organizations in other countries. While welcoming qualified observers from other countries to use its telescopes, the construction and operation of those telescopes was strictly held as NRAO's sole responsibility. When the 25 Meter project was struggling for funding, Peter Mezger, a director at the Max Planck Institut für Radioastronomie (MPIfR), offered to partner in a 25 m telescope on Maunakea in Hawaii. The NRAO director at the time, Dave Heeschen, declined the German partnership. During the construction of the VLBA, Canada offered its Dominion Radio Astrophysical Observatory site as the location for an antenna. NRAO demurred, placing it nearby in northeast Washington State. To overcome this tradition of independence required direct orders from NSF.

That order came while Neal Lane was NSF Director. Lane had been heavily lobbied to fund the MMA proposal in an effort organized by John Bahcall, chairman of the 1990 Decadal Survey. The MMA was Bahcall's personal top priority for a new large ground-based facility, and he had asked colleagues who knew either Lane or members of the National Science Board to write and urge funding for the project. The pressure reached the point where NRAO, through AST, was told to "*call off the dogs*." But Lane did respond. On 13 May 1996, he invited Vanden Bout to a breakfast meeting away from his NSF office. He said he intended to include design and development funding in the NSF budget request but, importantly, insisted that the project had to be international. Lane shared Bloch's belief that international projects sold better in the US Congress. A person present pointed out the obvious – successful funding would depend on a champion of the MMA in the Congress. Typically, that would be a senator from the state where the project was to be built. "*Who is the Senator from Chile*?" he asked. Vanden Bout opined that the champion could be Senator Pietro V. ("Pete") Domenici of New Mexico. In fact, Domenici's help turned out to be critical.

Soon after that meeting, Lane had the opportunity to seek support from NASA for the MMA when he found himself seated at a dinner next to Dan Goldin, the NASA Administrator. He mentioned the MMA and its potential for detecting planet formation around nearby stars. Goldin had not heard of the MMA, but was intrigued and wanted to learn more. As a result, Vanden Bout visited Charles Pellerin, then head of NASA's Astronomical Science Division, to sell the MMA as part of NASA's Origins Program. The visit did not go well. Pellerin had established a hard-and-fast rule: NASA does space projects and NSF does ground-based projects. To emphasize the point, he handed Vanden Bout a Washington DC Metro ticket and said, "*I think NSF is near the Blue Line Ballston Station*."

Selling the MMA Abroad

NRAO's first approach to an international collaboration for the MMA was to seek minority partners in Europe, specifically, the Netherlands. Vanden Bout made a trip to the Netherlands on 13–19 February 1995. Visits were scheduled for talks at the Universities of Groningen and Leiden. Vanden Bout and Ewine van Dishoeck were accompanied by Anneila Sargent of Caltech, who addressed potential participation of the Netherlands in the OVRO and BIMA arrays. Immediately prior to the talks, the Netherlands Committee on Astronomy met to discuss joining the MMA. They concluded that negotiations should begin with possible millimeter astronomy partners and that a proposal should be prepared at the level of 30 million Dfl for Dutch participation. Professor van Dishoeck, a prominent astrochemist and millimeter astronomy enthusiast at the University of Leiden, led the writing of a proposal[2] to the Netherlands Research Council (NWO) requesting funding for a 10 percent partnership in the MMA. The amount requested was $20 million over three years beginning in 1997.

NWO sent the proposal to five referees, one each in the United States, Germany, France, Japan, and England. Their reports[3] were uniformly positive regarding the scientific goals but mixed on whether joining the MMA was the best way to realize those goals. The referee from France wrote a long report that pointed out the shortcomings of the MMA, which was too small in his opinion, and the advantages of joining an all-European effort to build a much larger array, the Large Southern Array (LSA) (to be discussed shortly). At the same time, prompted by IRAM, the Secretary General of the Max Planck Society wrote to Reinder van Duinen, head of NWO, urging consideration of a partnership with IRAM on a large millimeter array. The letter[4] contained the prescient statement: "*Noting that there is also interest in the Japanese radioastronomical community to build a large millimeter array in the southern hemisphere, several future scenarios can be envisaged, including one of truly international collaboration in which the MMA, the LSA, and the Japanese project would all be co-located.*" All this gave NWO pause and on 17 April 1996, the proposers were informed by Harvey Butcher, head of the Netherlands Foundation for Radio Astronomy (NFRA), that the proposal had been declined.

Amidst discussions between NRAO and European partners to explore a merger of the MMA and LSA, Canada was approached as a potential US partner. After many presentations, discussions, and recommendations from advisory groups, an agreement with Canada, called the North American Program in Radio Astronomy (NAPRA), a play on the acronym for the North American Free Trade Agreement (NAFTA), was signed in September of 2001 between NRAO and the Herzberg Institute of Astronomy and Astrophysics (HIAA) and

the National Research Council (NRC) of Canada whereby the Dominion Radio Astrophysical Observatory would construct a new signal correlator for NRAO's Very Large Array in exchange for considering Canadian applicants for NRAO observing time on the same basis as US applicants, including time on the MMA-LSA merger, by then called ALMA. NRAO had always in its Open Skies policy considered qualified applicants for observing time equally no matter their country or institutional affiliation. But the possibility that this might change if the project partnership turned international was an incentive to join NAPRA; the division of observing time on existing international observatories was intended to be in proportion to the partners contributions to construction and operation. In time, Open Skies became an NSF policy for all its astronomical facilities, international or not, and the NAPRA agreement became moot. The NAPRA agreement expired in 2011, before ALMA became operational.

In fact, Canada did join the United States in the ALMA project. Prior to the NAPRA Agreement, a letter of intent to do so was signed by Arthur Carty, President of the NRC of Canada, and Rita Colwell, NSF Director. That intent was realized in June 2003 with the signing by these parties of an agreement whereby Canada would contribute about 10 percent of the North American obligation to ALMA construction. US and Canadian observing time was to be pooled. Further agreements between NRAO and HIAA/University of Calgary defined the structure of the partnership and the deliverables.

Europe's Large Southern Array

As has been alluded to throughout, the NRAO was not the only group to realize that a millimeter wave interferometer should be the next major astronomical facility to answer the pressing scientific questions of the era. We'll take our narrative back a few years in order to track the activity of the European radio astronomers at the time. The concept that led to the Large Southern Array (LSA) was the brainchild of Roy Booth, director of the Onsala Space Observatory (OSO) in Sweden. In response to Booth's proposal to establish the Sweden-ESO Submillimetre Telescope (SEST), Lo Woltjer, ESO Director General at that time, agreed to a partnership with OSO and to place the new single-dish telescope at ESO's La Silla site. Peter Shaver, ESO staff scientist, was appointed to be the liaison for the project. SEST operated from 1987 to 2003, and its output clearly demonstrated the scientific potential of millimeter/submillimeter observations in the southern hemisphere. The telescope was a copy of the antennas used in the IRAM interferometer on the Plateau de Bure, near Grenoble, France. Booth's concept, the so-called Southern Millimetre Array, was more or less a southern hemisphere version of the IRAM interferometer: (10)

8 m diameter antennas were to be located in what he called Millimeter Valley below ESO's Paranal Observatory. He presented this concept at the end of the second SEST Users Meeting at ESO Garching, 22–23 May 1991. Bob Brown was invited to the meeting[5] and presented the plans for the MMA.

In December 1991, the first meeting of the Southern Millimetre Array Working Group[6] (SMAWG) was held at IRAM. It had 10 members and was chaired by Booth. Arriving late, following some discussion of the science case and array concepts, IRAM staff scientist Dennis Downes presented a compelling argument for what became the defining characteristic of the LSA. He knew the story of IRAS F+10214 and pointed out that Brown and Vanden Bout's detection of CO at a redshift of 2.3 effectively opened the high-redshift Universe to millimeter observations. In a later conference presentation,[7] Downes noted that, "*… for the first time, radio astronomy can study thermal dust emission and thermal line emission from cool, neutral molecular matter at epochs close to the formation of galaxies, …*" However, IRAS F+10214 was gravitationally lensed, that is, the signal was focused and magnified by a factor of order 10 by an intervening galaxy along the line of sight. Such systems were certainly rarer than un-lensed high-redshift galaxies. To study star formation in the large, un-lensed population would require an array with a huge collecting area, 7,000–10,000 m^2, something like (40) 15 m diameter antennas. From then on, the European millimeter array was to have a large collecting area. Hence, its name became Large Southern Array.

Following this meeting, a search was begun in Chile for a suitable site. Since the LSA science goals were focused on using the CO transitions at 115 and 230 GHz and not at higher frequencies, the search could be satisfied by an area offering 10 km antenna spacings (about 1 arcsecond resolution) at the elevation of the salt flats south of San Pedro de Atacama. Site studies were led by Angel Otárola, in partnership with a Japanese team who were also considering a site in Chile for their project, the LMSA. As was discussed in the previous chapter, the two sites of principle interest to the LSA were Pampa El Chino at 3,300 m and Pampa San Eulogio at 3,750 m elevation, respectively. Both lay side by side at the southern end of the Salar de Punta Negra, 80 km east of the Escondida copper mine.

The European millimeter astronomers continued to have meetings that discussed plans for the LSA and searched for means to get it built. The underlying assumption was that IRAM would lead the project. But the IRAM director, Michael Grewing, was never presented with the right circumstances to seize the opportunity. Meanwhile, the current Director General of ESO, Riccardo Giacconi faced two tasks: finishing construction of the VLT and finding the means to operate it within ESO's budget. The latter meant scaling back or even closing the La Silla site, ESO's first observatory. He asked for reviews of all

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activities there, including SEST. It is ironic that Giacconi's wish possibly to close SEST would lead to ESO's participation in ALMA. Shaver was charged with producing a justification of SEST, and quickly rallied the community to produce a document of 120 pages presenting its science accomplishments at millimeter wavelengths and concluding with a proposal that ESO provide support for an LSA. On 5–6 May 1994, that document,[8] entitled *(Sub)Millimetre Astronomy at ESO*, was favorably reviewed by the ESO Scientific Technical Committee (STC). The STC was chaired by Steve Beckwith, a director of the Max Planck Institut für Astronomie (MPIA) in Heidelberg, Germany, an infrared astronomer interested in star and planet formation. The STC endorsed the five points[9] made by the SMAWG: (1–3) The productivity of SEST, the recommendation for continued support of SEST, and the need for development of instrumentation for SEST; (4) the conclusion that the future of millimeter wave astronomy lay in large arrays; and (5) the need for a permanent millimeter advisory group. By October 1996, all these points had been fulfilled.

The first meeting of the ESO Millimetre Advisory Group was held in August 1994. It had 10 members, among them Booth, Grewing, Shaver, and Butcher. It recommended preparation of a concept document, starting a design study, and holding a workshop on relevant topics. In April 1995, a memorandum of understanding (MOU)[10] was concluded between OSO, ESO, IRAM, and NFRA to pool resources for a study of a large millimeter array in the southern hemisphere and prepare a report within two years. Downes wrote a brochure that presented the concept, published in October 1995. The feasibility studies were then organized. And on 11–13 December 1995, Shaver organized a workshop that was held at ESO's headquarters in Garching, Garmany, on science with large millimeter arrays. The workshop hosted 95 participants, overwhelmingly European, but including attendees from Australia, Canada, Chile, Japan, Mexico, and the United States. Among the many contributions, Downes presented a detailed description of the planned LSA. This was followed by examples of extragalactic and cosmological studies, as well as galactic and solar system studies. James Lequeux discussed the synergy between the LSA and the VLT. The concluding remarks were made by Lo Woltjer. He summarized the case[11] powerfully: "*The scientific case for such an array is overwhelming … a perfect counterpart to the Hubble Space Telescope with comparable resolution but unhindered by dust opacity … highly complementary to the VLT*."

At its 30–31 October 1996 meeting in Milan, the STC reviewed the progress that had been made and endorsed the LSA as a possible ESO project. Beckwith recalls[12] the STC initially being concerned that the LSA would compromise the plans for the OverWhelmingly Large Telescope (OWL), a 100 m diameter optical telescope proposed as ESO's next step after the VLT. When it was realized that

this behemoth lay many years in the future, the committee recognized not only the scientific potential of the LSA but also that it could be a budgetary bridge between the VLT and OWL. The STC report favorably impressed Giacconi although he was heard to remark,[13] "*Let's not go overboard*."

The Large Southern Array

The European initiative for a large millimeter array arose rapidly in the mid-1990s, and it was a very exciting time. A number of unrelated developments remarkably coincided to make such a facility possible.

By the early 1990s, European millimeter astronomy was quite well established. Sweden and ESO operated a 15-Meter Telescope (SEST) in Chile, and IRAM operated a 30-Meter Telescope in Spain and an array of four 15-meter antennas in France. The idea of building a similar array in Chile, proposed by Roy Booth, was under discussion. But it was drastically revised by the startling discovery at NRAO of CO line emission from a $z = 2.3$ galaxy. Suddenly it was realized that we could potentially see the earliest galaxies in the universe using a very large array, one with a total collecting area of 10,000 m^2.

But how could such a giant project be funded and operated? In early 1994, ESO's Director General was looking to provide funds for VLT operations, and SEST was in his sights. He asked for a report, and got a surprise: not only was SEST strongly supported, ESO was also asked to provide support for a huge new millimeter array. His later response to the enthusiasm: "*This could be ESO's next major project!*"

There followed a few hectic years of scientific and technical studies. The scientific case was overwhelming. Such an array could see into the hearts of star-forming regions, with the same resolution as the HST but unhindered by dust obscuration. It could detect the most distant star-forming galaxies and follow their evolution over the history of the universe. And it could study their detailed chemistry using a forest of molecular spectral lines. Operating at millimeter and submillimeter wavelengths, it would be at the crossroads of radio and optical/infrared astronomy, so it attracted great interest from both communities. The technologies required to build high-precision mobile antennas that could operate in the open at an altitude of 5,000 m, using receivers with sensitivities approaching the quantum limit, were rapidly being developed.

Happily, similar developments were underway at the same time in both the United States and Japan. There was close communication between

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the three groups, and, given the magnitude and cost of the projects, collaboration and finally a merger of all three took place. The complexities of organizing and running a single huge observatory were ultimately overcome, resulting in the magnificent ALMA observatory that was inaugurated in 2013.

Peter Shaver
European Southern Observatory (retired)
Woollahra, Australia

Japan's Large Millimeter/Submillimeter Array

Another project that paralleled those of the MMA and LSA was being developed in Japan. At first, it was called the Large Millimeter Array (LMA). Experience with the NRO millimeter interferometer, in the Japanese mountains a few hours from Tokyo, had made it clear that a much larger collecting area and longer baselines were required to study the astronomical topics of current interest. As early as 1983, the Japanese had proposed to increase the number of 10 m diameter antennas in their array from 5 to 30.

One evening during the International Astronomical Union (IAU) Symposium #115 titled *Star Forming Regions*, which was held in Tokyo in 1985, Vanden Bout broached the topic of possible cooperation between the MMA and LMA with Japanese colleagues Masaki Morimoto and Norio Kaifu. Morimoto was a pioneer of radio astronomy in Japan and Kaifu a rising star in Japanese astronomy. Although interested, the Japanese radio astronomers said it was too early for any formal arrangement. Their focus was on the Subaru (optical/infrared) Telescope, which was planned to be constructed in Hawaii in the early 1990s. The year after the IAU Symposium, Vanden Bout visited the NRO headquarters to continue the discussion with Morimoto and his colleague Masato Ishiguro on partnering with the MMA, and to see their facility first-hand.

By 1987, the Japanese had a plan[14] that called for (50) 10 m antennas to be built on the best site that could be found in the world. The project name was changed to the Large Millimeter/Submillimeter Array (LMSA). The emphasis now was on operating at submillimeter wavelengths, which the Nobeyama site could not support. Consequently, the search for the LMSA's potential site began in 1992, both in Chile and in Hawaii. Having the LMSA sited near the Subaru Telescope, on Maunakea, was attractive due to the potential cost savings associated with shared facilities; each of the NRAO and ESO projects had also been through this thought process in their respective searches. Furthermore,

travel from Japan to Hawaii is much more convenient than travel to Chile, which is normally accomplished by going via the United States or even Europe. It took many years before the choice was made, but over those years the search increasingly focused on a site in northern Chile inland of Antofagasta, called Río Frío, at an elevation of 4,200 m, in the Domeyko mountain range roughly halfway between Paranal and the Andes Mountains inland. They also studied a site called Pampa la Bola (the literal translation is *Boron Prairies* as this was the prime location for boron deposits in Chile) where they would later place a single-dish submillimeter telescope. A potential site in northwest China was searched, but they could not find a better site than the one in Chile.

During those years, there were several meetings between NRAO and NAOJ, relevant to their respective MMA projects. At one such meeting, in the New Otani Hotel on Kimana Beach in Honolulu, Don Hall, director of the IfA, appeared unannounced. He was eager to have the IfA enjoy special access to a major MMA on Maunakea and was annoyed that the two observatories had arranged a meeting in Hawaii to discuss their plans without giving him notice. The oversight was deliberate – the meeting was held to discuss siting the projects in Chile, not on Maunakea. After Hall was told of NRAO's intention to site the MMA in Chile, he said he would not try to block the decision. However, were NRAO to take the LMSA with them to Chile, he would have Hawaii's Senator Daniel Inoue stop funding for the MMA in the US Congress. Later, Japan did choose Chile for the LMSA site, but if Hall ever called Inoue, the senator did not act.

The IAU Colloquium #140 – *Astronomy with Millimeter and Submillimeter Wave Interferometry* held at Hakone, Japan in 1992 – was the first international meeting devoted to millimeter and submillimeter wave interferometry, and provided a good opportunity to develop ideas about collaboration among large interferometer projects. On 8–9 March 1994, Vanden Bout and Brown visited NAOJ in Mitaka, and collaboration between the MMA and LMSA was officially discussed for the first time. An agreement[15] between NRAO and NAOJ was signed on 12 June 1995 to collaborate in the study of potential sites in Chile for the LMSA and MMA. On 8–10 November 1995, Vanden Bout participated as a member of the NRO visiting committee. The committee endorsed the LMSA project with enthusiasm.

Just after the meeting, Bob Brown and Peter Napier visited the NRO with Vanden Bout to see, among other areas, the electronics laboratories. The photograph in Figure 5.1 was taken at the Kiyosato Resort just prior to this visit. They were struck by the contrast between NRAO, where antenna maintenance and electronics development were done by observatory staff, and NRO, where these functions were accomplished by employees of Japanese industry, under contract

Figure 5.1 Left to right: Paul Vanden Bout, Peter Napier, Masato Ishiguro, and Bob Brown. Courtesy of M. Ishiguro, reproduced by permission.

from NRO and supervised by NRO scientists. Soon after, a workshop was held on 16–19 March 1997 in Tokyo called *Millimeter and Submillimeter Astronomy at 10 MilliArcSeconds Resolution*, under the cooperative research program supported by the Japan Society for the Promotion of Science and NSF. The workshop was well attended with participants from Europe as well as the United States and Japan. Discussion at the workshop was based on the feasibility of a conceptual array – the Atacama Array – that consisted of (40) 8 m diameter MMA antennas and (50) 10 m diameter LMSA antennas, the latter capable of observing submillimeter wavelengths. The arrays were either to operate independently or in a combined mode, a model that was later adopted when the Japanese entered ALMA. The sense at the conclusion of the workshop was that the United States and Japan might well have the basis for a partnership.

The Shimogamo Saryo sits on the bank of the Takano River in the heart of the Kyoto geisha district. Founded in 1856 as an *ochaya*, or traditional tea house, it continues today as a Michelin Star restaurant celebrated for its traditional Kyoto cuisine. It was the scene for a dinner in August 1997 that celebrated the developing partnership between NAOJ and NRAO. Keiichi Kodaira, Norio Kaifu, Paul Vanden Bout, Bob Brown, Bob Dickman, and their wives enjoyed an elaborate meal and copious amounts of sake. The dinner had been arranged

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by Masato Ishiguro, who did not attend. He secured the reservation and negotiated a reduced price by arguing that the guests were distinguished astronomers and the conversation that night would lead to something important for the national astronomy program of Japan (the Atacama Array).

On 24 March 1998, an agreement[16] to cooperate in the protection of the Chajnantor and nearby Pampa la Bola sites, technology development, and discussion with ESO to include the LSA in a three-way partnership was signed at a meeting in Hawaii.

The MMA and LSA Become One Project

Around the time of the Tokyo workshop, the thinking in Europe, and specifically at ESO, was coming to the conclusion that an international partnership that included countries beyond Europe would be preferable when building a large millimeter array. Giacconi had grown to appreciate the scientific potential of radio astronomy, in particular, millimeter/submillimeter astronomy. The endorsement by the STC and the strong justification for a large millimeter array given by Woltjer were all Giacconi needed as reason to proceed. He was aware of the discussions NRAO had with the Japanese about a merger of the MMA and LMSA they called the Atacama Array, and he did not want to be left out. Furthermore, he needed a means of preserving the current level of the ESO budget, which was poised to decline with the completion of the VLT, until the time OWL[17] could be started. The LSA would also preserve ESO's expert workforce, which had been built up to complete the VLT. In April 1997, the report[18] of the IRAM/ESO/OSO/NFRA group became available. It reiterated the scientific case and set out the specifications for the LSA. At the 4–5 June 1997 meeting of the ESO Council,[19] the LSA was discussed, and Giacconi was encouraged to "*continue exploratory talks … on an international level.*" In early June 1997, he called Vanden Bout and proposed a meeting to discuss merging the MMA and LSA.

The call took Vanden Bout by surprise. He had failed to keep up with the changing attitude toward millimeter astronomy at ESO. His last conversation with Giacconi had been the previous October, at a meeting of the Spanish Astronomical Society in San Sebastián. After his talk on the MMA, Giacconi had chided him for trying to pick off European countries one at a time as partners of the MMA. There was no hint that he was warming to the idea of merging the LSA with the MMA. In retrospect, a merger of the European and US projects, not to mention the Japanese project, was inevitable. It would have been crazy to build three independent arrays, all in Chile, all with the same scientific goals. But at the time, the only partnership being discussed was the Atacama Array between the United States and Japan.

Now Europe wanted to talk. It was important to act promptly, as NRAO had learned that the NSF was seriously considering funding the design and development work for the MMA. If the project were to change significantly in scope, NSF needed to be informed. There was a need to meet as soon as possible. Giacconi felt rushed when told of the urgency and accused Vanden Bout of pulling the "train is leaving the station" ploy. Significantly, both agreed that the merged project would be the sum of the MMA and LSA, not one of those projects at half the cost to each side. Their conversation concluded with two remarks that came to define the management structure of ALMA. Giacconi said, "*We will not be less than 50 percent partners.*" "*Neither will we*," was the reply. Giacconi agreed to come to NRAO as soon as it could be arranged.

The meeting took place within the month, on 25–26 June 1997 in the NRAO Charlottesville auditorium. The Europeans and Americans faced each other across a large U-shaped arrangement of tables, the two sides opposite one another.[20] Neal Evans, from U. Texas (Austin), thought it looked like the negotiation of a truce between two Mafia dons. But the meeting was cordial, and agreements were easily reached on the top issues. By the morning coffee break of the second day, it had been decided to study a nominal array of sixty-four 12 m diameter antennas, capable of submillimeter observing, on the high Chajnantor site near San Pedro de Atacama. A journal[21] kept by Bob Brown documented in handwritten notes the comments by various participants. There were no serious arguments because everyone got what they wanted: the Europeans a large collecting area, the Americans the broadband operating capability that the high site supported. Without any authority to do so, Giacconi and Vanden Bout signed the resolution[22] shown in Figure 5.2 to cooperate in the exploration of a merger of the LSA and MMA. Ed Churchwell is quoted[23] as saying, "*Although there are outstanding unresolved questions, I believe this was a watershed meeting*." Torben Andersen[24] recalls riding to the airport with Giacconi after the meeting: "*… he was quite happy with the outcome of the meeting, because it was finally cemented that ESO would be the counterpart in Europe*." The US side was also happy. The MMA was now part of an international project as NSF required.

The agreement toward this merger of the MMA and LSA had come on the heels of the very successful workshop in Tokyo which had led to the Atacama Array concept, an idea shared by NRAO and NRO. The Japanese, understandably, were shocked and felt blindsided by the signed resolution between NRAO and ESO, with its mere mention of continued cooperation with the Japanese project. To make matters worse, Ishiguro was visiting the NRAO electronics laboratory while the resolution was being hashed out nearby. It was an acutely embarrassing situation, caused by Vanden Bout's failure to give Ishiguro advance notice of the meeting. He met with Ishiguro to apologize and to assure

RESOLUTION

Whereas the development of millimeter-wavelength astronomy has shown the potential of large millimeter interferometric arrays for revealing the origin and evolution of stars and planetary systems, of galaxies, and of the Universe itself; the communities in the United States and Europe have proposed the construction of the Millimeter Array (MMA) and the Large Southern Array (LSA), respectively; and there is an opportunity through cooperation to achieve more than either community planned; we, as the observatories responsible for these projects and with the support of our communities, resolve to organize a partnership that will explore the union of the LSA and MMA into a single, common project to be located in Chile. Specifically, this partnership will study the technical, logistical, and operational aspects of a joint project. Of particular importance, the two antenna concepts currently under consideration will be studied to identify the best antenna size and design or combination of sizes to address the scientific goals of the two research communities. In doing so we will work through our observatories, utilizing the expertise in millimeter astronomy resident in research groups and institutions in our communities. Finally, we recognize that there are similar goals for millimeter astronomy in Japan, and cooperative activities with that project will continue.

R. Giacconi

European Southern Observatory

P. Vanden Bout

National Radio Astronomy Observatory

26 June 1997

Figure 5.2 The resolution between NRAO and ESO in which the parties agreed to explore a merger of the LSA and MMA into a common project. Credit: NRAO/AUI/NSF, CC BY 3.0.

him of NRAO's and ESO's sincere commitment to bring Japan into the project. However, it would be seven years before Japan officially joined the partnership. Finally, on 14 September 2004, Japan formally entered the ALMA partnership under a provision of the Bilateral ALMA Agreement, bringing to ALMA a compact array of twelve 7 m antennas, four 12 m antennas, a correlator, and three additional receiver bands for the large array. Later, in 2015, the Trilateral ALMA Agreement was signed, formally committing NSF, ESO, and Japan, to a three-way partnership for the operation of ALMA.[25] Two books[26] have been written about ALMA from a Japanese perspective.

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Needless to say, news of the resolution with ESO was well received at the NSF. Never mind that it was unauthorized and unofficial. The MMA now satisfied the requirement to be an international project. In May of the following year, the National Science Board authorized $26 million from the Major Research Equipment account for MMA Design and Development for FY1998–2000 upon "*formal establishment of an international partnership*." It would be two more years before the NSF signed an MOU with ESO that officially merged the LSA and MMA. And another two years before the first construction money was made available. Still, several hurdles had been cleared.

Notes

1 Brown and Vanden Bout (1991) reported data that suffered from systematic noise due to the poor observing conditions at Kitt Peak that (and every) summer. They were forced to observe through the fabric cover of the telescope dome some of the time. The result was an overestimate of the CO line strength. (Later observations by Radford et al. (1996) using the 12 Meter Telescope gave the correct line strength, in agreement with measurements at several other millimeter telescopes.) That and a faulty analysis of the data led them to conclude that they had detected a supermassive galaxy in formation. Further observations and a proper analysis by Solomon et al. (1992) showed that the data could be modeled by a large star-burst galaxy that was gravitationally lensed, magnified 11 times by an intervening galaxy.

2 A copy of the proposal can be found at NAA-NRAO, MMA, MMA Planning, Box 3.

3 The referee's reports can be found at NAA-PVB, ALMA, ALMA: The Story of a Science Mega-Project. https://science.nrao.edu/about/publications/alma.

4 The letters can be found at NAA-PVB, ALMA, ALMA: The Story of a Science Mega-Project. https://science.nrao.edu/about/publications/alma.

5 Brown's notes taken at the SEST Users Meeting can be found at: https://library.nrao.edu/public/memos/alma/misc/ALMAU_10.pdf.

6 The membership of the working group was Roy Booth (OSO), chair, Lars Bååth, (OSO), Peter Dewdney, (DRAO), Dennis Downes (IRAM), Michael Grewing (IRAM), Stepháne Guilloteau (IRAM), Frank Israel (Leiden U.), Peter Shaver (ESO), Tom Wilson (MPIfR), and Masato Ishiguro (NRO). Ishiguro was unable to attend this first meeting. From Booth (1994).

7 Downes presented his vision of the future of millimeter astronomy at the XVII ESLAB Symposium, held at ESTEC in Noordwijk, the Netherlands, 10–14 May 1993 (Downes, 1994), p. 133. He argued that the future lay in the millimeter band and that a mm array capable of studying galaxies in the early Universe should have a collecting area of 10,000 m^2, an angular resolution of 0.1 arcseconds at 2.6 mm wavelength, and a site with 10 × 10 km area of flat terrain above 2,000 m elevation in a dry climate.

8 NAA-PVB, ALMA, ALMA: The Story of a Science Mega-Project. https://science.nrao.edu/about/publications/alma.

9 The report with appendices by P. Shaver to the STC at their meeting of 30–31 October 1996 can be found at: NAA-PVB, ALMA, ALMA: The Story of a Science Mega-Project.

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10 Ibid., Appendix D.
11 Ibid., Appendix F.
12 Beckwith to Vanden Bout, private communication.
13 Shaver to Vanden Bout, private communication.
14 A description of the LMA was given in 1992 at IAU Colloquium 140 (Ishiguro, M., 1994). Instead of adding 25 antennas to the NMA, the concept was "*extended to an array that would realize sub-arcsecond resolution imaging at very high frequencies. The LMA may consist of 50 10-m antennas and will be covering observing frequencies from 35 to 500 GHz* (*possibly 650 and 800 GHz*)." Site testing for the LMA was focused on northern Chile, as atmospheric data on Maunakea was available from other groups. By 1997, the project, now the LMSA, was presented at IAU Symposium 170; see Ishiguro (1997). See also Ishiguro (1998).
15 The agreement to jointly study potential sites can be found at NAA-NRAO, ALMA, ALMA Multi-Institutional Agreements. https://science.nrao.edu/about/publications/alma.
16 The agreement between NRAO and NAOJ to cooperate in the study and protection of the Chile sites can be found at NAA-NRAO, ALMA, ALMA Multi-Institutional Agreements.
17 Beginning with Catherine Cesarsky's tenure as ESO Director General, OWL evolved into the Extremely Large Telescope (ELT), which has a 39.3 m diameter aperture and is at the time of the writing of this book under construction.
18 The IRAM/ESO/OSO/NFRA report can be found at: NAA-NRAO, MMA, MMA Planning, Box 6. https://science.nrao.edu/about/publications/alma.
19 Claus Madsen notes this in his history of ESO (Madsen, 2012), p. 376.
20 There is no complete record of who attended the meeting, but from Brown's journal notes and from the memories of those who confirmed to the authors that they had attended, we can state that the following were present for the United States: Paul Vanden Bout, Bob Brown, Peter Napier, Neal Evans, and Ed Churchwell. Unfortunately, the only available records of the meeting yield an incomplete list for the US side. Madsen (2012) lists those present from Europe as: Riccardo Giacconi, Peter Shaver, Roy Booth, Stepháne Guilloteau, Torben Andersen, Dietmar Plathner, and François Viallefond.
21 Brown's journal can be found at: NAA-RLB, Calendars and Journals.
22 A copy of the resolution is in NAA-NRAO, MMA, MMA Planning, Box 6. https://science.nrao.edu/about/publications/alma.
23 Madsen (2012), p. 376.
24 T. Andersen to P. Vanden Bout, private communication.
25 A condensed account of the development of the MMA, LSA, and LMSA, and their eventual merger into ALMA was given at the *Dusty Universe* conference (Vanden Bout, 2005).
26 For accounts of the ALMA project from a Japanese perspective see Ishiguro (2009) and Yamane (2017).