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HIGHLIGHTING THE HISTORY OF FRENCH RADIO ASTRONOMY. 7: THE GENESIS OF THE INSTITUTE OF RADIOASTRONOMY AT MILLIMETER WAVELENGTHS (IRAM)

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Abstract: Radio astronomy in France and in Germany started around 1950. France was then building interferometers and Germany large single dishes, so it was not unexpected that their first projects involving millimetre radio astronomy were respectively with an interferometer and a single dish. In this paper, we explain in detail how these two projects finally merged in 1979 with the formation of the Institute of Radio Astronomy at Millimetre wavelengths (IRAM), after a long process with many ups and downs. We also describe how Spain started radio astronomy by joining IRAM. Presently, IRAM is the most powerful facility worldwide for millimetre radio astronomy.

Keywords: radio telescope, radio interferometer, IRAM, radio astronomy, millimetre waves

Dedication: We wish to dedicate our paper to the memory of Émile-Jacques Blum (1923–2009), who played a major role in the construction of IRAM but died before he could participate in the writing of this paper. An interview made one month before his death was very useful in the preparation of this paper.

1 INTRODUCTION

In France, radio astronomy started in 1947 at the Physics Laboratory of the École Normale Supérieure in Paris, soon after WWII (see Orchiston and Steinberg, 2007). There was soon an interest in solar interferometry, when fringes were obtained at 3 cm wavelength by Jacques Arsac and Jean-Louis Steinberg in May 1952 (Lequeux et al., 2010). In 1954, the radio astronomy group moved to the Paris Observatory (Meudon), with an observing station at Nançay on grounds purchased by the École Normale Supérieure (see Orchiston et al., 2007). There, Émile-Jacques Blum (Figure 1) built a large E-W solar interferometer operating at 169 MHz. This was completed in 1956, and was followed in 1961 by a N-S solar interferometer (Pick et al., 2011). Between 1959 and 1963 James Lequeux used another interferometer at 1420 MHz which was made from two German 7.5-m diameter Würzburg antennas and was movable on rails (Orchiston et al., 2007). As early as 1953, Jean-François Denisse and Jean-Louis Steinberg proposed a larger interferometer consisting of two movable 25-m antennas, for observation of the 21-cm hydrogen line and in the continuum. However, this project was abandoned the following year, only to be replaced by Le Grand Radiotelescope, the construction of which began in 1956 and was completed in 1967 (Lequeux et al., 2010). This caused some frustration for several members of the staff who saw more future in interferometry, which at the time was rapidly being developed in Australia, in Great Britain at Cambridge and Jodrell Bank, and at the California Institute of Technology (Caltech) in the U.S.A.

Figure 1: Émile-Jacques Blum (1923–2009) around 1970 (courtesy: Observatoire de Paris, Station de Radioastronomie de Nançay).

Figure 2: The 8-mm two-element interferometer at the Bordeaux Observatory in 1973 (courtesy: *Observatoire Aquitain des Sciences de l'Univers*).

In Germany, radio astronomy started thanks to the efforts of Leo Brandt (1908–1974), an electronic engineer and radar pioneer who became in 1949 the Secretary of State of Nordrhein-Westfalen. He initiated the creation in Stockert, near Bad-Münstereifel-Eschweiler, of a radio observatory equipped initially with a Würzburg antenna, and later with a 25-m diameter radio telescope, completed in 1956 (Menten, 2008; Wielebinksi, 2007). The ownership of this Stockert radio telescope was shared by the University of Bonn and a research institute for high frequency physics.[1] It was one of the best steerable dishes at this time. After this success, the Volkswagen Foundation promised money in 1964 to build a larger radio telescope, and this stimulated the creation in 1966 of the Max-Planck-Institut für Radioastronomie (MPIfR) in Bonn. Otto Hachenberg (1911–2001), who had been teaching radio astronomy at the University since 1962, became the first Director of this Institute, and the Stockert radio telescope became his responsibility. The new instrument financed by the Volkswagen Foundation was the 100-m Effelsberg radio telescope, which was completed in 1972 (Hachenberg et al., 1973; Wielebinski et al., 2011). Thanks to these radio telescopes, Germany acquired expertise in the design and construction of large steerable dishes, while France

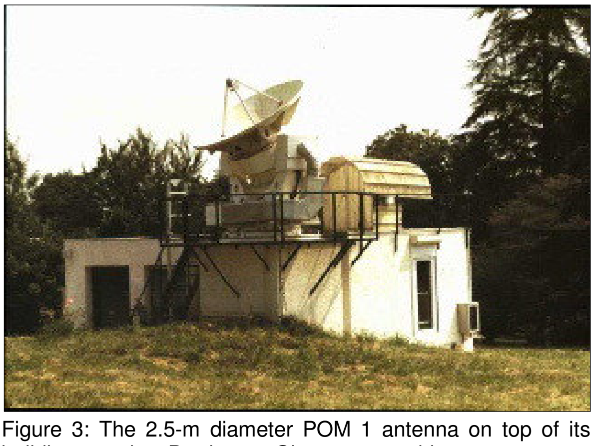

Figure 3: The 2.5-m diameter POM 1 antenna on top of its building at the Bordeaux Observatory; this antenna was previously one of the two elements of the interferometer shown in Figure 2 (courtesy: *Observatoire Aquitain des Sciences de l'Univers*).

gained expertise in interferometers. Thus it was natural that future projects in each country were oriented in these respective directions. It was also clear that the future lay in the millimetre wavelength range, which was almost unexplored in the 1950s and 1960s.

2 THE INITIAL IDEAS

In France, the first ideas about a millimetre interferometer arose in 1964, when Blum replaced Denisse as the Head of the Paris Observatory's Radio Astronomy Department and of the Nançay field station. At that time, Blum was building the first three receivers for Le Grand Radiotelescope in collaboration with Jean Delannoy, Émile Le Roux and Léonid Weliachew (1936–1986), but his main interests were already in interferometry and in the millimetre wavelength range.

By a fortunate coincidence, Bordeaux Observatory and the University of Bordeaux wanted to enter radio astronomy at this time, so Blum and Delannoy had little difficulty convincing Pierre Sémirot (1907–1972), the Director of the Observatory, and Roger Servant (1909–1987) and André Charru (1931–2003) —both of whom were professors at the University and members of its ultra-hertzian optics laboratory—to build a millimetre interferometer at the Observatory. Starting in 1966, this resulted in the financing of a prototype interferometer with two fixed 2.5-m diameter antennas on altazimuth mounts, working at 8 mm (Delannoy et al., 1973) which was designed to observe the Sun (see Figure 2). Delannoy then moved to the Bordeaux Observatory to build this interferometer. Construction began in 1967, and the instrument was finished in 1973. It was used successfully over a number of years for solar observations, then it was dismantled. One of the antennas, christened the 'Petite Opération Millimétrique 1' (POM 1; see Figure 3) remained in Bordeaux (Baudry et al., 1980), while the other (POM 2) was given to the newly-created observatory in Grenoble and installed on Plateau de Bure near Gap (Hautes-Alpes) in 1986 (Castets et al., 1988).

The few scientists who took an active part in the construction of Le Grand Radiotelescope at Nançay in rather difficult conditions were exhausted by the time of its completion in 1967, and partially lost interest in this instrument. Steinberg left to work full-time in the Space Radio Astronomy Laboratory that he had created in Meudon, while Blum spent six months at Charlottesville (Virginia) at the National Radio Astronomy Observatory (NRAO) in order to become familiar with millimetre techniques. This was when construction of the Very Large Array (VLA) was beginning so Blum could see what a major radio astronomy project was really about, and he was conscious of the importance of the receivers in such a project. He also realized that financing a large instrument would probably be easier than financing a small one, at least in a European context. He also met Peter Mezger, who was then at the NRAO and later was to be his main interlocutor at the MPIfR. For his part, Lequeux, with a few enthusiastic young scientists, founded the first Infrared Laboratory at the Meudon Observatory. They used a balloon to obtain the first submillimetre spectrum of the Sun, and installed a small submillimetre observatory at the Gornergrat in Switzerland at an altitude of 3,200 m, where they measured atmospheric transmission. They also calculated this transmission as a function of precipitable water (Lequeux, 2009: 135-136). In the summer of 1968, Lequeux left for a year to Caltech where he observed with the 2 × 25-m interferometer at the Owens Valley Radio Observatory (OVRO). Clearly, the time was ripe in France for a millimetre interferometer.

3 THE FIRST REQUESTS FOR FINANCING

At the end of 1967 a group of French radio astronomers, including Blum and Lequeux, met several times with Ronald J. Allen, a Canadian scientist who was a Post-doctoral Fellow at Meudon, in order to elaborate a plan for the future. They proposed a medium-size project costing 10 million francs (10 MF)—equivalent to 11 million in 2008 Euros (11 M€),[2]—and involving an interferometer between the Le Grand Radiotelescope at Nançay and one or two 40-m dishes movable on N-S rails. They also proposed a larger project: a national instrument or participation in a European project in the centimetre-millimetre domain, which could be either a large single dish or an interferometer. The requested sum for this more ambitious project was 20 MF (≈22 M€), as a part of a large instrument estimated at about 150 MF (≈170 M€).

The scientific motivations for going to millimetre wavelengths were rather vague at this time. One of the arguments was that the synchrotron radiation from quasars was expected to become optically thin at millimetre wavelengths, allowing scientists to penetrate deeper into the cores of these objects. This was also the case for the thermal radiation of very compact HII regions and planetary nebulae. One also hoped to study the thermal radiation from the planets and to detect that of their satellites, because it was stronger at shorter wavelengths. The best argument, although not easily accepted by financing authorities, was that one could hope for unexpected discoveries in this almost unexplored wavelength range. The report of the French radio astronomers, dated February 1968, summarized the arguments:

> The centimetre and millimetre domain (from 1 mm to 21 cm) is certainly the richest in possibilities because it is there that radio sources exhibit anomalies in their continuum spectrum and time variations, and also that the line spectrum is by far the richest and the most interesting.
>
> The cosmological problems that will certainly be central to investigations in the coming years will be approached with the highest chances of success by large instruments at centimetre wavelengths.
>
> Finally, the relation with the almost unknown infrared and submillimetre domains gives to millimetre instruments a particular interest. (Préparation …, 1968: 2; our translation).

The mention in 1968 of a rich line spectrum in the millimetre range is of interest. Clearly the proponents were thinking of recombination lines of hydrogen and other elements, and also of rotation lines of interstellar molecules, of which only a few were known at this time. The discovery in 1970 by Penzias and Wilson of many interstellar molecules through their millimetre lines was to give a new impetus to the field and better arguments for the project.

As for interferometry, it was claimed in the report that this would allow better angular resolution than a single dish, and good positions allowing identification of radio sources with optical objects: this was indeed one of the main objectives of the OVRO interferometer, which was then meeting with much success (see Cohen, 2007). It was also thought that an interferometer would be better suited than a single dish to observe very faint sources since these would produce a coherent signal on the different antennas while the atmospheric thermal noise would be uncorrelated. In more practical terms, construction of an interferometer looked easier, at least in France, than that of a large single dish, and the French radio astronomers had strong expertise in the relevant techniques. In addition, one could begin small and progressively enlarge the instrument by extending the baselines and adding more antennas.

A further plea for the new facility was written by Blum in January 1970. There were now budgetary restrictions for research and it was clear that an interferometer between Le Grand Radiotelescope at Nançay and movable antennas had to be abandoned. Meanwhile, the chance of obtaining the requested 20 MF for the other project was small, because the total amount foreseen for allocation to astronomy during the 6th Plan, starting in 1971 (at this time research was planned in periods of five years), was only 27 MF (≈ 27 M€). However, Blum (1970: 3; our translation) insisted that

> A large new instrument is necessary to replace the large [Nançay] radio telescope … This radio telescope is presently in full productivity. In a year, [the Effelsberg 100-m radio telescope] will begin to be a competitor, and it is probable that within 5 to 6 years there will be a risk that the originality of the scientific programs will decrease.

Another competitor not mentioned in this submission, but one that was even more powerful than the 100-m radiotelescope, was the Westerbork array, which had only just been inaugurated (see Raimond, 1996), as it was more sensitive than Le Grand Radiotelescope at Nançay, especially at 21-cm, and could obtain images of radio sources. The idea of a single dish was then abandoned by the proponents of the French project (at that time Blum, Delannoy, Encrenaz and Lequeux), who were all in favour of an interferometer. Eventually, their proposal was accepted for the 6th Plan, but with a reduced scope and without a financial commitment. Nevertheless, this acceptance could be considered as official approval, a necessary but not sufficient condition for financing. This was to be the beginning of an eight-year struggle.

During these eight years, the main interlocutors of the proponents on the French side were Bernard Grégory (1919–1977; Figure 4) and then Robert Chabbal, General Directors of the Centre National de la Recherche Scientifique (CNRS); Pierre Creyssel (1933–2007; Figure 5), Administrative and Financial Director of the CNRS; Jean Delhaye (1921–2001), Director of the Institut National d'Astronomie et de Géophysique (INAG) of the CNRS; and Pierre Charvin (1931–1991), Scientific Secretary of INAG for astronomy. On the German side, they were Reimar Lüst (Figure 6) and Friedrich Schneider, who were President and General Secretary respectively of the Max-Planck-Gesellschaft zur Förderung der Wissenschaften (MPG).

Figure 4 (left): Bernard Grégory (courtesy: *Archives du CNRS*).
Figure 5 (right): Pierre Creyssel (courtesy: *Archives du CNRS*).

4 REVIVAL OF RADIO ASTRONOMY AT THE ÉCOLE NORMALE SUPÉRIEURE

For a start, Blum was told by the INAG that there would be no funding for the project before 1975. Nonetheless, a project team, led by Patrick Dierich, was organized by the radio astronomers, and a technical team of six people under Gérard Beaudin started studies in Meudon in January 1972. Then, unexpectedly, a fresh opportunity soon arose through the creation of a new laboratory for millimetre radio astronomy in France.

In 1973, Yves Rocard (1903–1992), the Director of the Physics Laboratory at the École Normale Supérieure (ENS, where French radio astronomy had started), retired. At this time there were three main research foci of this Laboratory: quantum optics, solid state physics and theoretical physics. Rocard's successor, Jean Brossel (1918–2003), was very interested in radio astronomy, presumably due in part to the influence of Charles Townes, who had spent lengthy periods at the laboratory and in the 1970s had made vibrant pleas for the possible detection of interstellar molecules via their millimetre lines. Aided by his collaborator, Michel Glass, Brossel decided to set up a new Laboratory for Millimetre Radioastronomy, and this was created in 1975 under the leadership of Pierre Encrenaz, but with close ties to the radio astronomy group at Meudon. Françoise Combes, Denis Crété, Edith Falgarone and Robert Lucas soon joined the scientific staff, then Alain Omont and others in following years, along with a number of graduate students. For their observations they used three American millimetre radio telescopes, located at Kitt Peak National Observatory in Arizona, McDonald Observatory in Texas and the Aerospace Corporation in El Segundo, California, which were the only ones available at that time. Several distinguished colleagues visited the Laboratory for more than three months, including Harm Habing, Arno Penzias, Paul Richards, Ken Tucker, Robert Wilson and Gerard T. Wrixon.

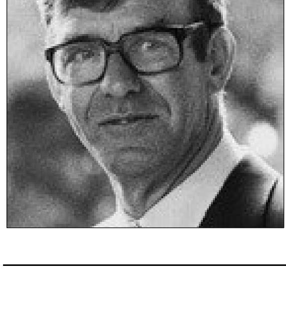

Figure 6 (left): Reimar Lüst (courtesy: Max-Planck-Gesellschaft).

Two engineers from the Physics Laboratory formed the technical staff, along with two other people. Working in close collaboration with those at Meudon, they constructed millimetre detectors and closed-circuit helium cryogenerators in order to cool the receiver front-ends. A state-of-the-art prototype millimetre receiver using these new techniques was built for the CO line at 115 GHz by the Meudon and ENS groups and technicians from the Bordeaux Observatory, under the leadership of Gérard Beaudin. In 1976 this was completed, and it was installed for testing on the POM 1 radio telescope.

The crucial element of radio astronomy receivers, which are all heterodyne, is the detector junction, a non-linear element where the signal from the antenna combines with that of the local oscillator. In the 1970s, the only ones working at millimetre waves were Schottky junctions in which a tiny wire (the so-called whisker) made a contact with a semiconductor, generally gallium arsenide. They were not available in Europe, so that the ENS group invited to Paris one of the key people from the Sperry Rand Corporation which produced these junctions in the USA. As a reward, he brought a few of these precious detectors (Figure 7), and they were used for the prototype receiver.

The ENS group also developed a closed-circuit helium cryogenic system giving a cooling power of 1 watt at 2 K, and another system using acoustic waves in a 'pulsed gas tube'. Unfortunately these developments did not generate interest within the French Air Liquide Company, which lost in this way an early opportunity to commercialize cryogenerators. These machines are currently in widespread use for the many millimetre receivers under construction and for medical applications like magnetic resonance imaging.

5 DEVELOPMENTS IN GERMANY AND PROBLEMS IN FRANCE

During those years, interest was also growing at the MPIfR in the millimetre wavelength domain, but the situation was considerably easier than in France. In 1971, the 100-m radiotelescope was already in the final stages of construction, and the MPIfR was dreaming of a large millimetre radio telescope and was looking for finance from the Volkswagen Foundation. This was subsequently obtained, and under the supervision of Peter Mezger—who was appointed as another Director of the Institute—work started on millimetre receivers and on bolometers for the millimetre-submillimetre range.

On the psychological side, the situation was different in the two countries. The Germans had a remarkable new large radio telescope which could be used down to 1 cm wavelength. It was mainly under the responsibility of Richard Wielebinski, who was one of the three Directors of the MPIfR. Meanwhile, millimetre radio astronomy was the domain of another Director, Peter Mezger, so that there were no strong grounds for internal competition. In France, Le Grand Radiotelescope at Nançay was much less versatile than the Effelsberg dish and in practice was only usable down to 10 cm or so (see Lequeux et al., 2010). As we have seen, these limitations were used as an argument in favour of their proposal by those promoting the millimetre interferometer. These people held the power in the radio astronomy group, Blum being the only Director, backed by several of the most active scientists of this group. However the millimetre project was seen by the other members of the Laboratory, and especially by the technical personnel, as a competitor which was diverting means and people from their own activities. Long-standing uneasy feelings arose, resulting much later in a splitting of the Radio Astronomy Department into 'millimetre', 'decimetre' and 'solar' radio astronomers. The millimetre project found little support also amongst the financing authority, the INAG, which was dominated by 'classical' astronomers not much interested in radio astronomy. The INAG gave priority to the Canada-France-Hawaii 3.60-m telescope, which was to absorb most of the funding for several years. This was the main difficulty encountered by Blum and the other proponents of the new project. The problems described in this paragraph are the subject of a very interesting study (Darmon, 1981) which was quite useful in the preparation of this paper.

Another point of friction between Blum and the INAG was Blum's idea of setting up a Visiting Committee for his Radio Astronomy Department. While this was common practice in foreign radio astronomy institutes (e.g. Blum was a member of the MPIfR *Fachbereit* and of the *Foreign Advisers Committee* of SRON, the Netherlands Foundation for Radio-astronomy), it was rejected by the French scientific authorities who were anxious to preserve their prerogatives. Blum never succeeded in getting an official Visiting Committee, but he gathered every few years an unofficial one consisting of several foreign experts. This turned out to be very useful for the development of the millimetre project, because Blum had no difficulty in convincing three foremost colleagues to give their advice on the project at a crucial time, as we will see later.

6 TOWARDS AN INTERNATIONAL PROJECT

Given the unlikely prospect of funding a national project in France in 1971, a possible solution was to propose a European one. Following the initiative of the Dutch astronomer Jan Oort (1900–1992), a member of Blum's unofficial visiting committee, some contacts had already been made between the main European radio astronomy institutes, but with little success. Moreover, the French were not initially in favour of an international project, preferring to start small and to extend later their own project. They thought of beginning with two 25-m antennas that were good at 8 mm, an obvious adaptation of the 1953 interferometry project, and to add other 25-m dishes later. But the future became even bleaker when a new project competing for money was officially announced in January 1972: an ionospheric incoherent scattering sounder named the *European Incoherent SCATter facility* (EISCAT), which was also to be financed by the INAG. However, the millimetre project was not completely abandoned, as a modest sum of 0.7 MF (≈0.43 M€) was allocated in 1973 for technical developments and site studies. But the proponents were urged by the INAG to search for international cooperation.

The opportunity came from the Committee for scientific and technological policy of the *Organization de Coopération et de Développement Économique* (OCDE), which discussed 'mega-science' projects starting with astronomy. At its meeting held in Paris on 27 and 28 February 1973, cooperation in millimetre radio astronomy between France, Germany and Great Britain was recommended. The representatives for science of the three countries seized this opportunity and, after several meetings, decided on 2-3 August 1973 to finance a European laboratory to build diodes for millimetre mixers. We have seen that these diodes were then only produced in the USA. They were so crucial that the European countries wanted an independent source. The idea of a devoted European laboratory was strongly pushed by R.E. Jennings in UK, Mezger and Gispert Winnewisser in Germany, Blum and Encrenaz in France, and also by Erik Kollberg in Sweden, a country which was also developing millimetre astronomy. The laboratory was installed in Cork (Ireland) in 1974. It was directed by Gerard T. Wrixon, an Irish-born scientist who came from the Bell Laboratories.[3] The first junctions were produced in 1977, with satisfactory results at 115 GHz (Figure 8).

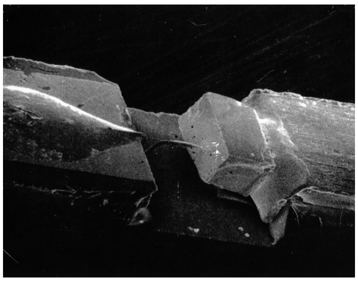
Figure 7: Electron micrograph of a Schottky junction used in millimetre receivers in the mid-70s; a whisker touches a gallium arsenide crystal (courtesy: Laboratoire de Physique, École Normale Supérieure).

At the same time, the IBM Watson Research Center at Yorktown Heights (New York) and the Bell Laboratories at Murray Hill (New Jersey) were beginning developments on supraconductor-insulator-supraconductor (SIS) junctions which were expected to be better than the Schottky ones. The Meudon and École Normale groups decided to enter the field, in spite of unfavourable advice from the Solid State Physics Laboratory at the École Normale Supérieure. They worked on niobium/magnesium oxyde/niobium SIS junctions which indeed proved later to be the way to go. In Garching near Munich in Germany, similar SIS junctions, first using lead, then niobium, were built successfully by Karl Heinz Gundlach and Hans Hartfuss in the Max-Planck-Institut für Plasmaphysik for diagnostics of plasma radiation in machines for fusion studies. Gundlach and Hartfuss moved to IRAM at its creation in 1980 in order to continue the development

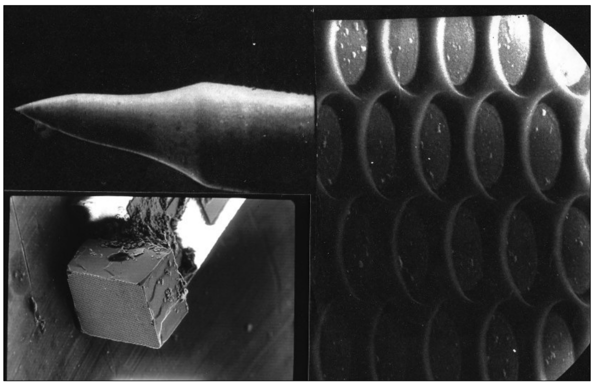
Figure 8: Electron micrographs of a Schottky junction built in the Cork laboratory in 1977. Bottom left: the substrate block with small pits where the whisker can make contacts, general view. Top left: the whisker point. Right: the network of pits. The two last images are taken with much larger magnification than the first one (courtesy: Laboratoire de Physique, École Normale Supérieure).

and fabrication of SIS junctions for the IRAM receivers.

Let us return to 1973. On 6 August the OCDE representatives also decided to create a *Scientific Advisory Group for Millimetre Astronomy* (SAGMA). On 8 October 1973 this group defined a European millimetre project, that they estimated at 36.6 million Deutschmarks (equivalent to 54 M€). It would consist of a 30-m radio telescope built by the Germans from 1976 on and financed mainly by the Volkswagen foundation outside this budget, and an interferometer built in two steps: first a 10-m antenna constructed by Great Britain, to be ready in 1975, followed by three additional 10-m antennas which would be operational by the end of 1978. The choice of 10-m for the diameter was dictated by the British. The two instruments would be placed at a common site, for which studies would start in 1974, shared between the three countries.

The Germans started immediately by establishing a contract with ARGE (the Krupp-MAN consortium) in order to study the 30-m radio telescope. They had their own ideas about a suitable site: they wanted to avoid France, because they were afraid of political instability and strikes and also because two German-French scientific institutes (the Max von Laue-Paul Langevin Institute in Grenoble and the Grenoble Laboratory for Intense Magnetic Fields) were already installed in France. So they looked at possibilities in the Sierra Nevada in southern Spain and on Mauna Kea in Hawaii. However the French were reluctant to go to Hawaii.

Unfortunately, by this time research in Great Britain was suffering from serious financing difficulties, and in January 1974 they withdrew from the EISCAT project and warned that they might also have to withdraw from the millimetre project. However, as a safeguard they decided to participate in the site testing which was to be conducted over four months during the summer of 1974. Possible sites, which had to be at high elevation where there was little precipitable water in the atmosphere, and sufficiently flat to accommodate an interferometer, were selected from detailed maps and meteorological archives. Mountains in France, the Atlas Mountains in Morocco, the Sierra Nevada and the Canary Islands were all considered, but Morocco was eliminated because of difficulties in the logistics, southern Spain because no sufficiently flat site was obvious at high elevations and the Canary Islands because the possible sites were protected areas. Three possible sites remained in France after Blum, Dierich and Lequeux had made a number of visits and taken some topographic measurements: the Pla de la Padrille near Font-Romeu in Pyrénées-Orientales, the Plateau de Bure in Hautes-Alpes and the Causse de Montbel in Lozère. British, German and French personnel then carried out studies at these three sites, which included the measurement of precipitable water with a specially-designed infrared hygrometer. The Plateau de Bure, at 2550 m elevation, turned out to be by far the best of these sites.

In 1975, 2 MDM (about 2.3 M€) were allocated to the project by the Max-Planck-Gesellschaft, which had already spent 3 MDM on it. The financial situation was much less favourable in France: only 1.03 MF (≈0.66 M€) were allocated in 1975, whereas the proponents of the interferometer were hoping for a financial allocation similar to the German one. Moreover, Great Britain withdrew completely from the project in April 1975, and decided instead to join with the Netherlands and construct its own millimetre facility. The result was the 15-m James Clerk Maxwell radio telescope in Hawaii, which became operational in 1987.

SAGMA then considered it necessary to find another partner. The NRAO was approached but declined, so any possibility of installing the instruments in Hawaii vanished. Spain was considered in the summer of 1975 (see later), but it was judged premature by Blum and others to start negotiations because of the uncertainties in the political situation before and after the death of Franco on 20 November 1975. However, the German collaborators insisted on siting the 30-m radio telescope in southern Spain, preferably at Calar Alto, where there was already a German-Spanish optical observatory. The official reason was that this location offered better access to the Galactic Centre than the French site, but in reality the MPG also wanted to smooth out political difficulties that had arisen from a previous near-colonialist attitude at the Calar Alto Observatory. As it happened, Calar Alto turned out to be a poor site for millimetre observations, and after a short site study Pico Veleta in the Sierra Nevada, which was at a much higher altitude, was favoured.[4] Blum and Jesús Gómez-González carefully reconsidered the idea of installing an interferometer in this area (see later), but with no positive outcome.

As a consequence, the millimetre project faced two big difficulties: (1) a severe lack of money, due to competition from other projects in France and withdrawal of the British, and (2) the fact that no single site suited the needs of the two partners. In order to resolve this deadlock, Grégory and Creyssel for the CNRS, and Lüst and Schneider for the MPG—all of whom had supported the project from the beginning—with Blum's help decided to set up a panel of international experts to formulate recommendations. This panel consisted of three well-known radio astronomers: Bernard Burke (from the Massachusetts Institute of Technology), Ken Kellermann (from the NRAO) and Paul Wild (1923–2008), Chief of the CSIRO's Division of Radiophysics in Australia. They met in June 1976, visited sites and institutes and on 26 June provided the following conclusions

> The Plateau de Bure is by far the better of the two sites to locate the interferometer, even though the latitude is higher than ideal.
>
> The Pico Veleta is by far the better of the two sites to locate the 30 m telescope, even though it is remote from centres of relevant expertise and is a relatively inconvenient place to live.
>
> We believe that to choose between the two sites would favour one instrument at the expense of the other.
>
> The *modus operandum* described in the SAGMA report places the main emphasis for controlling and developing the project separately in the two parent institutes.
>
> … We believe that the centre of the cooperative programme should be located in an observatory headquarters. …We suggest that Grenoble would be a highly suitable city in which to locate the headquarters owing

to its concentration of scientific and technical activities and its proximity to one of the sites being proposed [Plateau de Bure, at 90 km] (cited in Darmon, 1981: 180-181).

Retrospectively, it is clear that the experts had little choice when drawing their conclusions. However, their support for the project in general, for utilising two different observing locations and for siting the headquarters in Grenoble was crucial for the success of the project. The suggestion of Grenoble as the headquarters came as a result of a proposal by the President of the University, Michel Soutif, to build the new institute on the University grounds, together with a new astrophysics laboratory (which was indeed created and later became an astronomical observatory).

In spite of some reservations from Mezger about the choice of Grenoble—which was not so easily accessible from Bonn—the conclusions of the experts were accepted by the MPG and the CNRS, and the *Conseil de Direction Provisoire Intérimaire* (Provisional directorate) was created. This was led by Wolfgang Hasenclever, a former Director of the von Laue-Langevin Institute in Grenoble. This Council started work immediately on the possible statutes of the new institute, which was named the Joint Institute for Millimetre Radioastronomy (JIMA).

7 THREE YEARS LOST BEFORE THE FINAL DECISION

Unfortunately the situation in France did not improve in spite of all this progress. Grégory left the Directorship of the CNRS in July 1976, only to be replaced by Chabbal who was much less in favour of the project. Fortunately, Creyssel was still there to support it. Grégory became *Délégué Général à la Recherche Scientifique et Technique*, an important position from which he could still exert some pressure in favour of the project, and he was soon to act. At the beginning of December 1976 he and Jacques Sourdille (1922–1996), State Secretary for Research, spent two hours at the École Normale Supérieure. They started by visiting the Physics Laboratory and discussed the radio astronomy project with the Director, Brossel. The latter was so supportive of this project that he said that the École Normale Supérieure had enough funds to buy the land at the Plateau de Bure if necessary—just as it did in 1953 to form the Nançay radio astronomy field station. Suitably impressed, Grégory then wrote an enthusiastic report in which he recommended that France finance the whole project, even if Germany failed to contribute. Clearly this went against the wishes of Chabbal, the new Director of the CNRS, yet Grégory continued to actively support the project until his sudden death a year later, on 24 December 1977.

The French budget for JIMA for 1977 and even 1978 was uncertain, to say the least. To worsen the situation, the MPG was short of money in 1977 and had to delay financing of the new institute until 1978, but it did give a firm commitment. In France, after difficult discussions, 2.5 MF (≈1.3 M€) were allocated on 28 June 1977 by Sourdille for 1977 *and* 1978, this sum being blocked for the time being! In view of the new delays implied by the lack of funding, the two main French proponents, Blum and Lequeux, on 4 July 1977 sent separate letters to the INAG by which they announced their resignation from the project team. Shocked, the MPG put pressure on the CNRS-INAG to proceed with the project, so the INAG designated Encrenaz and Weliachew as substitutes for Blum and Lequeux. All this turmoil had some effect on the CNRS, with the consequence that at a meeting of the MPG in Düsseldorf on 29 November 1977 Chabbal presented a new funding plan for the French participation in the project: 83 MF (≈42 M€) to be spread over eight years, from 1978 to 1985. This looked very slow, but at least the whole project was saved. At this meeting, the two partners even appointed a Project Manager, K. Johnsen, who had previously been Project Manager at CERN in Geneva. For the time being, 0.5 MF (≈0.25 M€) were allocated to the French radio astronomers in order for them to test their millimetre receiver on the POM 1 antenna in Bordeaux. Blum and Lequeux rejoined the project on 8 February 1978, at the request of the INAG.

The way was now open to finalize the creation of the new institute, and the formal agreement creating IRAM was signed between CNRS and MPG on 2 April 1979. According to this document, both instruments should be able to operate down to a wavelength of 1.8 mm, and the interferometer should have a total area of 300 m^2.

8 SPAIN JOINS IRAM

Radio astronomy in Spain began in 1971 when Jesús Gómez-González, then a fresh graduate student, was sent by the Universidad Complutense de Madrid to the Paris Observatory (Meudon) to obtain a Ph.D. in this field. The University's idea was to create in its Department of Electromagnetism a small group of radio astronomers who would be able to use the new 64-m antenna that NASA was installing at its Robledo de Chavela tracking station (60 km N-W from Madrid) during its 'idle time'.

Gómez-González stayed at the Department of Radioastronomy in Paris from 1971 to 1974, at the time when the French and German projects on millimetre radio astronomy were converging into what would eventually become IRAM. Accordingly, Blum asked Gómez-González to take part in the site study by examining maps of the Sierra Nevada region for possible sites for the interferometer (as by this time it was already clear that the 30-m dish would be installed in southern Spain). This search continued in 1976 when Blum and Gómez-González took a trip by road from the Calar Alto Observatory (which had just been dedicated) to Granada and personally inspected various possible sites, but none was found to be convenient. In this way, radio astronomy in Spain and IRAM were connected from the very first moments of their respective developments.

By the end of 1974, when Gómez-González returned to Spain, interest in radio astronomy had shifted from the University to the Royal Observatory in Madrid, which was a Department of the Instituto Geográfico Nacional (IGN). At this time, the Observatory had ordered a 14-m millimetre radio telescope from the U.S. Company ESSCO. The IGN agreed that Gómez-González should move to the Observatory and take charge of the new radio telescope which was subsequently installed at the Yebes Observatory in 1976-1977. Direct contacts took place with three radio astronomers at the MPIfR, Jaap Baars, Albert Greve and Johann Schraml, who were sent by Mezger to help

Figure 9: Rodolfo Núñez de las Cuevas in about 1980.

with the commissioning and calibration of the 14-m dish. In 1975, it became clear that when the time was right the IGN should become the Spanish partner in the IRAM project, as its Director, Rodolfo Núñez de las Cuevas (Figure 9), warmly supported that idea. In 1977, Blum and Encrenaz had their first contact with the IGN in Madrid, and in 1979 Núñez de las Cuevas and Gómez-González held a meeting with Creyssel at the CNRS headquarters in Paris, to define the conditions of an IRAM-IGN association. It was agreed that the IGN would contribute by giving the land on Loma de Dilar (near Pico Veleta) where the 30-m dish was to be installed, and by also supplying a 600-m^2 building (which was later

Figure 10. The 30-m millimeter telescope of IRAM at Pico Veleta (courtesy: IRAM).

enlarged to 800 m^2) for offices and laboratories which would served as the IRAM headquarters in downtown Granada. As compensation, the IGN would obtain up

Figure 11: A recent view of the IRAM interferometer on Plateau de Bure, with its 6×15-m antennas. The large shelter in the background is used for antenna construction and maintenance (courtesy: IRAM).

to 10% of the observing time with the two IRAM instruments, the 30-m dish and the interferometer. The IGN would also nominate the Co-director of the IRAM installations in Spain, who would attend IRAM Executive Council meetings as an observer. On 16 May 1980 the IRAM-IGN Association Agreements were signed in Granada.

In 1982 Michel Guélin was appointed as the Director of the IRAM-Granada Station and, in 1983, Gómez-González moved there as the Spanish Co-director. A very enthusiastic group of German, French and Spanish astronomers, engineers and technicians worked hard during the following years to put the 30-m radio telescope and the Granada Station into operation. In 1986 the radio telescope started astronomical observations, and on 14 September 1987 it was officially dedicated by the Ministerio de Fomento of Spain. While this Ministry covered mainly public works, town planning and transportation, it also included astronomy, geodesy and geophysics.

In the IRAM-IGN agreement of 1980 it was foreseen that the IGN could later negotiate its participation in IRAM as a full member. This materialized in 1990, when IGN joined IRAM as a full member with a financial contribution of 6% of the total budget. In 1996, a special contribution by the IGN of 33% of the construction cost of the fourth interferometer antenna of the Plateau de Bure opened the way for the interferometer to be developed to its present capacity with six antennas.

9 CONCLUDING REMARKS

The first Director of IRAM was Peter Marinus de Jong who, like Johnsen, came from CERN. Blum, Delannoy and Weliachew, plus Michel Guélin and Bernard Lazareff, left Meudon or Bordeaux to join IRAM in Grenoble. At the same time, the University of Grenoble created an astrophysics laboratory (now the Laboratoire d'Astrophysique de l'Observatoire de Grenoble = LAOG) directed by Alain Omont, and Robert Lucas moved from the École Normale Supérieure to this Laboratory, working for IRAM. Similarly, Jaap Baars, Dennis Downes, Hartfuss, Albert Greve and Gundlach moved to Grenoble from Bonn or Munich. Many graduate students came from Spain to Meudon, Bonn and Grenoble to become acquainted with millimetre radio astronomy.

The 30-m IRAM radio telescope was put into operation in 1985-1986 (Figure 10), and at the time was the largest antenna in the world working down to 1 mm wavelength. On the other hand, the delay in the financing of the IRAM interferometer was such that there were already three other millimetre interferometers in operation by the time it was completed: the Owens Valley Radio Observatory and Berkeley-Illinois-Maryland (BIMA) arrays in California and the Nobeyama array in Japan. Observations at the Plateau de Bure started in 1989, twenty-three years after the first plans were discussed. When observations began there were only three 15-m antennas with a total area of 530 m^2 instead of the foreseen 300 m^2, moving on relatively short baselines.[5] Since then, the number of antennas has been increased to six, and the two baselines lengthened, the maximum separation now being 760 m (Figure 11). Just before this journal went to press the heartening news was received that funding has now been approved for the installation of four more antennas. It is hoped that two more will be added in the future, bringing the total to twelve 15-m antennas, and that the baseline will be extended to 1,600 m. This will make the IRAM arrray by far the most powerful millimetre interferometer in the Northern Hemisphere, and almost equivalent to the ALMA array in Chile.

IRAM would never have come into existence without the commitment, tenacity and diplomatic skills of Peter Mezger and Émile-Jacques Blum.

10 NOTES[6]

1. This institute was part of a "Society for the Promotion of Astrophysical Research" which was later renamed the "Research Society for Applied Sciences" (FGAN). This institute carried out military research in radar technology, and in the late 1960s obtained a 34-m parabolic antenna inside a 49-m radome at Wachtberg near Bonn, making the Stockert antenna 100% available for radio astronomy. Today the Wachtberg antenna is used for the detection of near-Earth objects (pers. comm., Hilmar Duerbeck, June 2011).
2. We give for all the sums their equivalent in Euros in 2008, based on a comparison of the costs of living at their epoch and at present. This conversion was established by the Institut National de la Statistique et des Études Économiques (INSEE) and is available on: http://www.insee.fr/fr/themes/indicateur.asp?id=29&page=achatfranc.htm
3. In 1981 Wrixon became the Director of the National Microelectronics Research Center of Ireland, then in 1999 President of the University College in Cork.
4. The 30-m radio telescope is at an elevation of 2850 m. The summit of the Sierra Nevada, the Mulhacén, at 3482 m, was intially considered, but the meteorological conditions were so harsh there that it was soon abandonned.
5. The decision to increase to 15 m the diameter of the antennas of the Plateau de Bure interferometer was taken because of the competition with the OVRO millimetre interferometer which had 10-m antennas.
6. This paper brings to an end the series of research papers on early French radio astronomy. What started off as a small-scale project with just four French collaborators and a cut-off date of 1961, grew into a much more ambitious program with seven different papers, additional co-authors and a much-extended end-date. We hope that in the future this series of papers will serve to inspire other French astronomers to document and write up important aspects of their radio astronomical heritage and share it with international colleagues.

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Professor Pierre Encrenaz started working in radio astronomy in 1968, first with Arno Penzias at Princeton then with James Lequeux at Paris Observatory (Meudon). He obtained his Ph.D. in 1972, joined the Observatory the following year, and from 1975 to 1979 was the Sub-director of the Physics Laboratory at the École Normale Supérieure. In 1975 he founded a laboratory of millimetre radio astronomy at the École; this is still active today, and staff work in close collaboration with those at the Paris Observatory. In 1995, he became full Professor of Astronomy at the Université Pierre et Marie Curie in Paris. Pierre played a major role in developing millimetre radio astronomy in France and was much involved in the genesis of the IRAM project. He has been a member of the IRAM Executive and Scientific Councils. With Gérard Beaudin, he was responsible for the construction of one of the submillimeter receivers on the HERSCHEL satellite and had a participation in the microwave instrument for the ROSETTA orbiter. Pierre recently retired, and he is currently working on the results of observations made with HERSCHEL and CASSINI-HUYGENS. He has been a member of the Acad-

émie des Sciences since 2000.

Dr Jesús Gómez-González obtained his Ph.D. in physics at the Universidad Complutense of Madrid in 1974, then spent three years in the Department of Radio Astronomy at the Paris Observatory (Meudon) and nine months at the National Radio Astronomy Observatory in the USA. Between 1989 and 2002 he was the Director of the National Astronomical Observatory of the National Geographical Institute of Spain (IGN); since then he has been Deputy Director for Astronomy, Geodesy, and Geophysics at the IGN in the Ministerio de Fomento. He was the first Director of the Yebes Radioastronomy Observatory, where he was responsible for the development of the instrumentation and laboratories, and in particular for the construction of the 40-m millimetre radio telescope and its incorporation into the Astronomy and Geodesy networks for very long baseline interferometry (EVN and IVS). Later, he was also appointed as the first Co-director of the IRAM Granada Station, and was a member of the executive boards of IRAM, EVN and JIVE (founding member and President of the latter for the period 2009-2011). Jesús has been the first and the main promoter of radio astronomy in Spain.

Dr James Lequeux started radio astronomy in 1954 as a student. After a long military service, he observed the structure of continuum radio sources with an interferometer at Nançay and obtained a Ph.D. in 1962. Then he worked on the construction of Le Grand Radiotelescope at Nançay, and in 1966 founded the first infrared astronomy group at Meudon. He was deeply involved in the genesis of the IRAM project. Later, he was also involved in the scientific programs associated with the Infrared Space Observatory (ISO) as an associate scientist. For 15 years James was one of the two Editors-in-Chief of the journal *Astronomy & Astrophysics*. After a career in various fields of astrophysics, involving mainly research on interstellar matter and the evolution of galaxies, his post-retirement interests turned to the history of astronomy. He has now published several books and a large number of papers in this field, including six papers in this Journal.

Dr Wayne Orchiston is an Associate Professor in the Centre for Astronomy at James Cook University in Townsville, Australia. After serving with the CSIRO's Division of Radiophysics from 1961 to 1968 he worked in other scientific fields before returning to astronomy during the 1980s. He has a particular interest in the history of radio astronomy in Australia, Britain, France, India, Japan and New Zealand, and is the founder and current Vice-Chairman of the IAU Working Group on Historic Radio Astronomy. Wayne has published extensively, and edited the books *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth* (Springer, 2005) and *Highlighting the History of Astronomy in the Asia-Pacific Region* (Springer, 2011) which contain substantial sections on the history of radio astronomy. In 2011 Springer will also publish a book by Wayne and co-authored by Woody Sullivan, on the history of Australian radio astronomy. Since its founding in 1998, Wayne has been Editor of the *Journal of Astronomical History and Heritage*.