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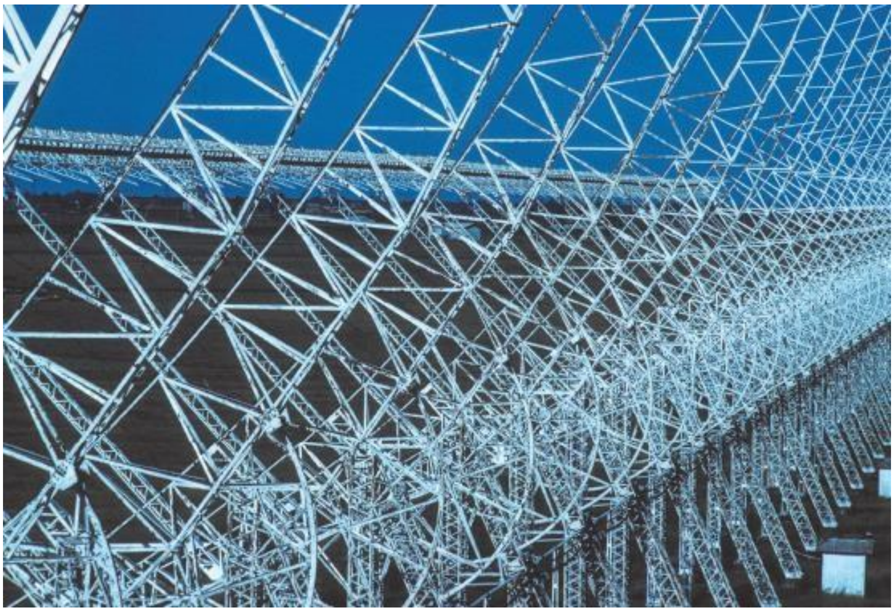

Why don't you build a radio telescope?

40 years of radio astronomy in Bologna

INAF

ISTITUTO NAZIONALE DI ASTROFISICA
ISTITUTO DI RADIOASTRONOMIA

"In a world where it is tempting to forget or ignore too much, the recapture of our collective past should be among the first projects for our future"

(Umberto Eco, lecture 'Against the loss of memory', United Nations, New York, 21 October 2013)

Original Title: *Perchè non costruisci un radiotelescopio?*
Quarant'anni di radioastronomia a Bologna

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Preface

Writing the history of the Institute of Radio Astronomy, from its origins until the year 2000, was stimulated by the memories and writings of Marcello Ceccarelli, Carla and Roberto Fanti, and Giancarlo Setti. It has been enriched with the contributions of Jan Brand, Antonino Ficarra, Liliana Formiggini, Isabella Gioia, Gavril Grueff, Stelio Montebugnoli, Mauro Nanni, Nino Panagia, Goliardo Tomassetti, Tiziana Venturi and the authors of these pages. The history was written by many hands. The prose, reflecting the style of each person who contributed, is probably not homogeneous.

Although we have tried to list all the researchers, technicians and administrators who participated in the birth and development of the Bolognese radio astronomy, we are aware of possible shortcomings and we apologize for them.

The first part of the history was taken from a speech by Carla and Roberto Fanti at the conference "The development of astronomy in Bologna from 1960 to 1990" presented at the Bologna Academy of Sciences on May 15, 2018 (Marano, 2020).

From the birth of the ROUB group (Radio Observatory of the University of Bologna) to the Institute of Radio Astronomy (IRA), the scientific and technological projects developed by the researchers have been numerous and it would be impossible to describe them all. We have therefore limited ourselves to the lines of research considered most representative and that best demonstrate the growth of astrophysical and cosmological skills that over the years have led the Institute of Radio Astronomy to play an important role in the international arena.

In any case, we would like to highlight some facts that have certainly been drivers of success: first the very close connection between radio astronomy research and technological development, then the strong interaction with the University even after the establishment of the CNR Institute, and finally the opening of the Institute to not strictly radio astronomical research.

From the very beginning, the mixture of scientific and technological research has been the engine of development for radio astronomy in Bologna: The Northern Cross was not conceived simply as an 'observatory' for scientific activity but as a real experiment in cosmology. This targeted approach was also behind the construction of the Medicina and Noto VLBI antennas.

Until the early 1990s, the radio astronomy group shared space and services with physicist colleagues. It actively participated in the scientific life of the Physics Institute of the University of Bologna and also grew thanks to the synergy with the university world.

Purely non-radio astronomy research has always been successfully carried out at the IRA. This has had a beneficial effect on the scientific life of the Institute both in terms of the broad scientific discussion that it has generated and increasing its visibility to other research groups and non-radio astronomical institutions. Main topics were the search for radio quiet quasars, clusters of galaxies in radio and X-ray, and the search in the X-ray background and in the Large

Scale Structure of the Universe. Other topics such as theoretical studies of general relativity, physics of black holes, dynamics of galaxies, IR properties of galaxies, and active galactic nuclei, will not be dealt with here, not because they are less important but because they are considered fragmentary compared to the dominant key fields of research.

This story on the birth and progress of radio astronomy in Italy and the establishment of the Institute of Radio Astronomy as with all the stories told, has set time limits. The starting moment of this adventure is natural. The decision to end this story at the end of the second millennium finds its reasons in the profound changes that took place in the basic research sector in the early 2000s. In the early months of 2000 the CNR promoted a restructuring of its network of institutes with the aim to decrease their number by combining those carrying out similar research activities. In those years the IRA grew with the inclusion of the CAISMI of Florence and the ITIS of Matera. Furthermore, on 23 July 1999, Legislative Decree 296 opened a new page of the astronomical research in Italy establishing the National Institute of Astrophysics (INAF).

1 From the Northern Cross to the Radio Astronomy Laboratory

1.1 The beginnings

"Why - G. Puppi tells me one day on the stairs of the Institute - don't you build a radio telescope?". The professor. Giampietro Puppi, who moved to Bologna from Padua, was the director of the Institute of Physics.

With these words Marcello Ceccarelli recalls, in 'Viaggio Provvisorio' (M. Ceccarelli, 1976,) with his usual joking style, the beginning of this adventure. Then Puppi was 41 years old and Ceccarelli 31: they were what today would be called 'two young men'.

G. Puppi with a group of students in the garden of the Augusto Righi Institute of Physics, in April 1958. From left to right: Luigi Monari, Vittorio Prodi, Virginio Bortolani, Lalla Delli Santi, Attilio Forino, Giampietro Puppi, Giorgio Casadei , Giancarlo Setti and Franco Casali; Photo by Alessandra Cavallini

The date of this meeting must presumably be placed in May 1959 and it is probable that Puppi's first approach with Ceccarelli happened just like that. However, it is equally likely that Puppi had been reflecting on the idea for some time. In fact, in the spring of 1959 he suggested to Giancarlo Setti to direct his thesis towards extragalactic radio astronomy, illustrating his idea of launching a great project in this discipline. G. Setti's thesis discussed the advantages for extragalactic studies and cosmology of a large telescope of the 'Mills Cross' type, which had been built in 1954 by B. Mills in Sydney (Australia). Radio astronomy was one of Puppi's many initiatives to promote new research sectors in Italian physics that could establish themselves internationally. When you want to undertake a new project, it is essential to know how to choose the right people to carry it out and this is not always easy. Puppi chose the right person, Marcello Ceccarelli, called to Bologna from Padua.

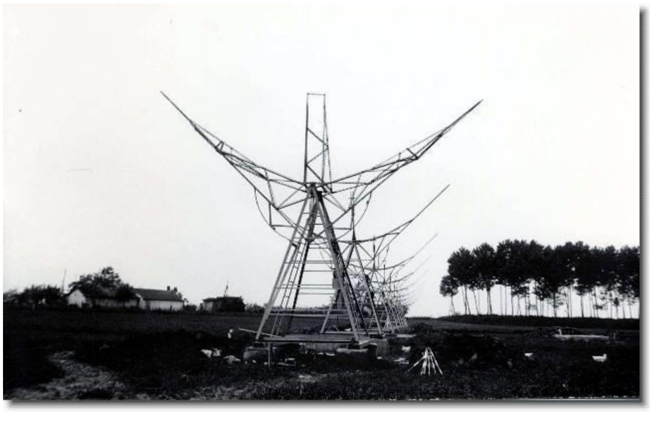
Radio astronomy was, at that time, a relatively new sector of astronomy but already consolidated internationally. After excluding that the radio sources were radio stars, it was thought that the radio emission came from galaxies and even if the quasars were not yet known, considerable progress had been made. The new discoveries had given a new powerful impulse, opening new horizons: think of the possibility of studying interstellar atomic hydrogen through the line it emits at a wavelength of 21 cm. Furthermore, radio astronomy had entered forcefully into the lively cosmological debate of the time between the supporters of the 'Theory of the Stationary State', infinite age and continuous creation of matter (Bondi & Gold, 1948), and those of the 'Big Bang' models derived from Einstein's general relativity by Russian mathematician Alexandr Friedman. An important discriminant between

the two theories is the number of radio sources counts as a function of the flux density, or rather in its form. The counts are well represented by a law of the type N (> S) ∝ $SS^{-\delta\delta}$, where N (> S) represents the number of radio galaxies with flux density > S. Usually this relationship is given in logarithmic form, i.e. Log (N> S) = -δLogS + constant, and it is referred to as Log N - Log S. The expected slope δ is at most 1.5 for the theory of the Steady State and > 1.5 for relativistic models. The extragalactic radio sources were so powerful that they could be detected at distances enormously greater than those achievable with the major optical telescopes of that time, and were therefore considered the ideal 'probes' to clarify this problem definitively. The results obtained up to then, however, were still contradictory and a future large radio telescope in Italy would have made a rapid and important contribution to the debate by being able to observe, in a short time, large quantities of radio sources with very small apparent brightness and therefore, presumably, very distant.
G. Puppi had the idea, sponsored the project, found the necessary funding and followed its development with constant interest. The project would have been financed by the Ministry of Public Education (MPI), with the establishment of a Radio Astronomy Laboratory at the University of Bologna for the scientific use and maintenance of the radio telescope (800 M lire, equivalent to about 9 M current euros).

Marcello Ceccarelli. Credits: INAF-IRA

M. Ceccarelli, a young nuclear physicist from Padua, had achieved great results coming close to the Nobel Prize, but had decided to leave sub-nuclear physics and was looking for new topics. With his latest work in nuclear physics, he 'sank' an important radio astronomy theory. The great brightness of the radio galaxies required an enormous amount of energy, the origin of which was not known.
Famous theoretical astrophysicists such as G. Burbidge and F. Hoyle, suggested that it's origin was matter-antimatter annihilation, with the consequent production, among other things, of 'gammarays'. P. Morrison calculated for Cygnus A, the strongest radio source in the north sky, the gammaray flux expected on the ground. M. Ceccarelli, using instrumentation for sub-nuclear physics mounted on balloons at high altitude, found in 1959 that the measured gamma-ray flux was less than that predicted by Morrison by at least 200 times. So there was no matter-antimatter annihilation. Some students also participated in the experiment, including Alessandro Braccesi, who later became his right-hand.

M. Ceccarelli had made the first observation in gamma-ray astronomy in the world and had thus entered radio astronomy. Courageously, he accepted G. Puppi's proposal and launched himself into a world still completely unknown in Italy. The development started very quickly. At the beginning of 1960, through an announcement in the newspapers, Gianfranco Sinigaglia, an engineer at Marelli was recruited. He left a safe job for a more uncertain but much more interesting one. For advice, contacts were quickly made with British and Australian radio astronomers such as M. Ryle, J. Hőgbom, B. Y. Mills, W. N. Christiansen, with whom relationships were established not only of esteem and collaboration but also of true friendship.
The original project was to build an instrument of the Mills Cross type: two perpendicular arms which would have been 1200 m in the East-West (EW) and 1200 m in the North-South (NS) directions, consisting of longitudinal cylinders with parabolic section, rotatable in NS around horizontal axes (Braccesi and Ceccarelli 1962). The Italian radio telescope was called 'Croce del Nord'. It would have been a transit instrument, which, if the antennas were pointed at a certain declination, would have allowed to record the radio signals continuously over 24 hours, while the sky flowed over it with the rotation of the earth.
The EW arm would have consisted of a cylindrical sector to be oriented in NS, while the NS arm would have been formed by 128 short cylinders each 47 m long and 7.5 m wide, spaced 10 m apart. For the mechanical pointing of the NS all the single elements would have been pointed. Then it would have been necessary to appropriately compensate the phases of the single signals.
A continuous reflecting surface was impractical for weight reasons and also useless for the expected working wavelength of 73.5 cm or 408 MHz. It would have been made of very thin long steel wires, 2 cm apart and supported by 23 ribs, like those that hold the planking of ships. At this wavelength, the spaces between the wires would have been invisible and the surface would have appeared to the incident radiation as continuous. The combination of the two arms would have allowed to obtain a good angular resolution of 2.5 x 2.5 arc minutes. With such an instrument it would have been possible to survey, day after day, large contiguous strips of sky, recording data with great efficiency and speed.
The project had to be downsized due to lack of funds. The EW arm was reduced by half and the NS arm by a quarter, thus bringing the Cross to take on a T shape.
Furthermore, there was no radio astronomy experience in Italy. In a letter to Alessandro Braccesi, Ceccarelli wrote: "According to Hőgbom our colossus has clay feet, and these feet are called lack of astronomical culture ..."
In June of the same year (1960) the prototype of the EW arm of the Northern Cross was built as a parabolic half cylinder of 7 x 110 m, operating at 327 MHz. This was called 'Medicinoscopio' due to its proximity to the town of Medicina.

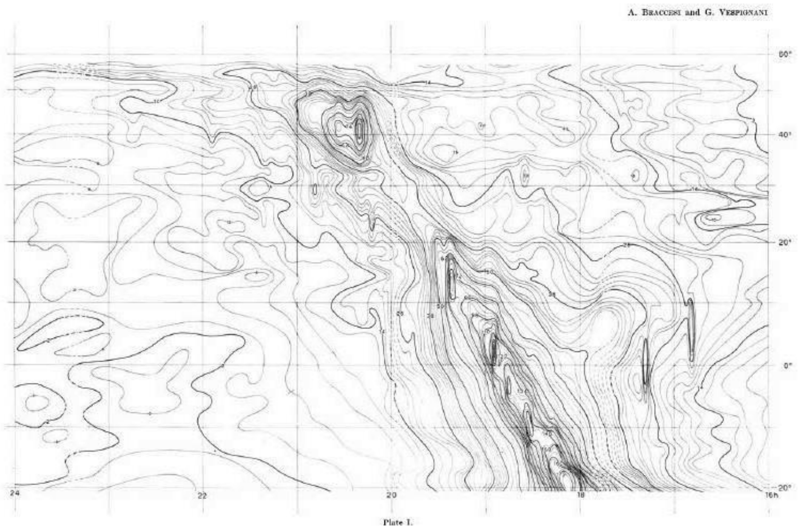


The prototype of the East-West arm of the Northern Cross under construction in 1960. Credits: INAFIRA

Together with M. Ceccarelli and G. Sinigaglia, the young Giancarlo Setti (recent graduate) and Alessandro Braccesi (still a student), plus some university technicians, took part in the construction. A historic and memorable photo, showing in addition to Ceccarelli and the aforementioned, G. Puppi, G. Righini, director of the Arcetri Observatory, and G. Mannino, director of the Institute of Astronomy of the University of Bologna, immortalizes the conclusion of this first phase.

From left: Giancarlo Setti, Gianfranco Sinigaglia, Guglielmo Righini, Giampietro Puppi, Giuseppe Mannino, Marcello Ceccarelli and Alessandro Braccesi seated. Credits: INAF-IRA

The Minister of Education G. Medici attended the first test.
In the same year, two technicians led by Engineer G. Sinigaglia began building what was probably the first Italian radio astronomy receiver at the Institute of Physics of the University of Bologna. Unfortunately, there are no longer traces of the characteristics of the receiver but from brief descriptions it is known that the employed technology made use of thermionic devices that did not have a good reputation in the scientific field for their ability to generate thermal noise and gain instability. Some specific technical measures were applied to this receiver, such as the use of professional tubes and rigorously stabilized voltage power supplies, which made it possible to make the first 327 MHz observations of the Sun and other known medium intensity radio sources. A new receiver was then built (see G. Tomassetti, 2016) in which the correlation technique was applied, destined for extraordinary developments in the following decades. This receiver allowed the publishing of a beautiful 327 MHz map of the center of our Galaxy (Braccesi and Vespignani 1964).



327 MHz image of a region of the galactic plane obtained with the 'Medicinoscopio' (Braccesi and Vespignani 1964) with the kind permission of the Italian Physical Society

1.2 The ROUB group and the East-West arm of the Northern Cross

The working group expanded by hiring other people of great quality: the engineers G. Gelato, just back from military school, C. Rosatelli, on loan from CNEN, the two young neo-PhDs, Dan Harris from Caltech and Louise Volders from Leiden, both with good astronomical skills, and a large number of very good technicians. The ROUB group (Radio Observatory of the University of Bologna) was born. With the acquisition of new scientific and technological skills, it devoted itself to the design of the 'Croce del Nord' radio telescope which would observe at 408 MHz, a frequency considered very high at the end of the 1950s and at the limit of operation of the instrumentation available in the ROUB laboratory.

The first rib of the East-West arm of the Northern Cross in the SAE workshops (Lecco) in 1962. Credits: INAF-IRA

At the beginning of 1962, a first rib was assembled at the SAE workshops in Lecco. More or less at the same time, the project for the illuminator was completed, that is, the element that captures electromagnetic waves. In August 1963, in the countryside of Medicina, Bologna, the ribs were erected and in September all the 'ironmongery' was standing. The large cylindrical-parabolic sector that constituted the EW arm of the Northern Cross stood majestically, with its extension of 600 x 35 m. During the spring of 1964 a military engineering team was employed to lay the underground coaxial cables that were to convey the collected radio signal to the recorder. The soldiers worked willingly. They were much better off than inside the barracks and very much enjoyed lunch in the 'dei Cacciatori' tavern near the site of the Cross.

The military corps of engineers involved in laying coaxial cables in 1964. Marcello Ceccarelli and Luciano Baldeschi can be recognized on the left. Credits: INAF-IRA

In 1963 movie director Michelangelo Antonioni shot some scenes of “Deserto Rosso”, one of his best known but also most controversial films at the site of the Medicina radio telescope: with the screenplay by Tonino Guerra and Antonioni himself. A car accident causes Giuliana (Monica Vitti) a shock which, worsened by the particular environment of the industrial suburb of Ravenna, in which the profession of her husband (electronic engineer) forces her to live, turns into a state of continuous depressive neurosis. Corrado (Richard Harris), a friend of her husband, feels attracted to the woman and tries to help her out of her loneliness full of nightmares, weaving with her a fleeting and bitter relationship that will only increase her depressive state. The two find themselves at a certain point at the Medicina Radio Telescope, repainted with red streaks for the film, where Corrado tries in vain to propose a new job to a technician who works there and where Giuliana asks to be able to listen to the stars. For Deserto Rosso, Antonioni was awarded the Golden Lion in Venice in 1964 for best film and Carlo Di Palma the Silver Ribbon for photography in Taormina in 1965.

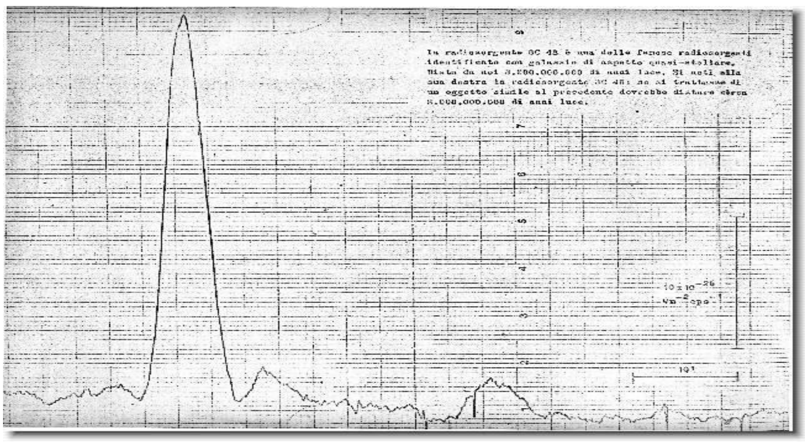
A frame from the film Deserto Rosso (1963), directed by M. Antonioni. Monica Vitti and the East-West arm of the Northern Cross in the background.

Carla Fanti had meanwhile begun to collaborate with Louise Volders in the IT sector, learning FORTRAN and developing together with her some simple algorithms for the analysis of future data. Under the pressing need to be ready to observe the radio sky with the EW arm, projects using advanced techniques were discarded and a classical receiver designed by G. Tomassetti was preferred. This instrumentation would have guaranteed stability and simplicity but with a noise temperature of over 900 °K. It was considered fine to start.

Of these years Ceccarelli wrote in his book 'Viaggio Provvisorio': "I had a lot to do. The organizational machine for the construction of the radio telescope had been put in motion and I would not have been able to stop it anymore, and this even if that machine was losing its beat every moment. Difficulty of money, of helpers, of colleagues. Whining of bureaucrats, badly tempered gears, cables that are too short, welds coming off. But in the meantime the great white skeleton, my 'ship of horses' was taking shape and soul. Probably in the standard of big business […] our work for the Northern Cross was a very small thing, but for me it was an immense, beautiful and full of desperation work".

In early October 1964, the EW arm, equipped with three 'eyes', technically 'beam', looking in three slightly different directions towards the EW, was fully assembled. On 7 October 1964 G. Sinigaglia and collaborators completed the connection of the EW arm with the receiver.

Many team members stayed until after midnight to witness the first observations. A success. You could see very well what you had to see and you could also see what was there without anyone knowing. They celebrated with salami and Sangiovese wine.



The radio source 3C48 observed with the East-West arm of the Northern Cross in 1964. Credits: INAFIRA

M. Ceccarelli in 'Viaggio Provvisorio'*: ".. I had finally seen the nib move on the paper of the recorder. Move well, move very well. It spoke of the passage of distant universes and also told of the end of many hardships and fears. I walked away from the group of my collaborators all in celebration and sat in the lonely corner of a room, without speaking, without thinking. "*

On 24 October 1964 there was the inauguration with, the Minister of P.I. Luigi Gui, the Rector of the University of Bologna Felice Battaglia, the staff of the Institute of Physics and the auxiliary bishop of Bologna, Mons. Bettazzi. It was a great success, except for a violent downpour that reduced the ground to a sea of mud, bogging down half of the cars of the participants, including that of the Minister.

Inauguration of the East-West arm of the Northern Cross in 1964. Marcello Ceccarelli on the right with Minister Luigi Gui. Credits: INAF-IRA

Having acquired this first success, the construction of the Northern Cross was far from over. The 320 m fraction of the NS arm was also built, but without being able to connect it with the EW arm, due to lack of funding.
With only the EW arm the resolving power of the instrument was excellent for those times, 4 minutes of arc in Right Ascension, but very poor in declination, 1.8 degrees, leading to uncertain positions in NS. Additionally, there was the possibility that radio sources, close in right ascension but separated in declination could simulate a single stronger radio source, so-called confusion, creating uncertainties in the data even if this was partially controllable. It was therefore necessary to put the NS arm in condition to work, even if it was only 320 m long, and to perform the correlation of the signals from the two arms. Technically there was not much to do, but….
While waiting for the activation of the NS arm, only the EW arm was used, trying to make the best possible astronomical use immediately. Unfortunately, our radio astronomy experts had left: D. Harris to Arecibo, at the beginning of 1964, and L. Volders had returned to Holland, around 1966, together with her husband, G. Gelato. But there were M. Ceccarelli and A. Braccesi to lead the many rookies, undergraduates and recent graduates who had just arrived. There was enormous enthusiasm and a great desire to work, without considering schedules, Saturdays or Sundays and other holidays, including Easter, Christmas and New Year.
The operation of the EW was unfortunately limited by the daytime presence of strong interference due to a military radio link, obviously abusive, given that the 408 MHz frequency, reserved to radio astronomy, had to be for listening only. When the source of the interference was identified M. Ceccarelli contacted the high military command, with poor results, progressively rising in level, until, losing his patience, he sent a letter to Giulio Andreotti, the then Minister of Defence, in which he wrote, using his cutting humour, that *"the high degree of inefficiency of the Armed Forces made him doubt the possibility that, in the event of an enemy attack from the east, they would be able to resist for those 40 minutes that were necessary for the American armoured division stationed in Aviano to intervene and block the invaders"*. It was the period of the cold war ... Furore among the higher ranks of the armed forces. The radio link was turned off.
In the following years, however, there were other military interferences, which damaged the observations of the radio telescope and saw some visits by the Carabinieri (military police), for suspected espionage. In some way, however, a dynamic modus vivendi was slowly reached, which in any case always made work very difficult.
Observation with the radio telescope consisted of recording the signal on three recorders, one for each 'eye or beam' of the instrument, using rolls of paper about 15 m long for 12 hours of observation. Then, the average of the three independent traces was made by hand with a pencil, by superimposing them on a table equipped with lamps that illuminated them from below, and the position and intensity of the sources were measured with a double decimetre. The calculations were done by hand, using at most the slide rule for products, divisions and trigonometry. If you were lucky you could borrow the FRIDEN mechanical calculator. This was a lot of work, done by hand, it was not possible to keep pace with the data being produced by the instrument. Meanwhile, Carla Fanti and Roberto Fanti had also entered the game by completing their degree theses on 'Quasi-stellar Radio galaxies' and 'Emission mechanisms in extragalactic radio sources', and graduating in July 1964. At the end of December 1964 the radio telescope was completed, operating only at night, the systematic observation of a sky area of about 0.45 steradians, already explored by the Parkes parabolic radio telescope, Australia, was performed. This led to a B1 catalogue containing 654 radio sources with apparent brightness, or flux density, greater than 1 Jy. The catalogue contained, in addition to all the strongest radio sources already seen by Parkes, about forty others never revealed before (Braccesi et al. 1965). At least a part of these were weak radio sources whose sum had produced the previously measured brightness, due to confusion. Subsequently, other extensive areas of the sky were observed, this time around the zenith, but the prospect of continuing the analysis of the data by hand was deemed impossible. On the other hand, calculation skills were low. G. Puppi obtained permission to access the IBM 1620 at

the Faculty of Engineering of the University of Bologna at night only and to borrow a computer technician from the National Institute of Nuclear Physics (INFN).
Under the supervision of A. Ficarra, the team began to use the so called 'mangiaspago' ('string eater'), a coordinate meter made by the INFN to measure the traces of bubble chambers. It was used overnight to digitize, with paid student manpower, the paper tracings produced by the radio telescope. The measurements were written automatically on punch cards and the data processed with the IBM 1620 to derive the position and brightness of the sources present, using software developed in house.

In the summer of 1965, during a summer school in Varenna, attended by G. Burbidge, W. Fowler, A. Sandage, K. Thorne and R. Giacconi, it was possible to circulate the first results. G. Burbidge, who was shown the preprint of the B1 catalogue, was impressed by the number of previously uncatalogued radio sources appearing there. W. Fowler repeatedly asked if the '600' of the EW was feet or someting else. In November 1965, the annual SIF Congress was held in Bologna. M. Ceccarelli was invited to make a report on the Northern Cross in the Aula Magna of the Institute of Physics, which was full of colleagues. Success among the physicists was remarkable.
The SIF (Società Italiana di Fisica – Italian Physics Society) awarded a prize of 500,000 lire to the Northern Cross, which was divided equally among all the members, technicians and graduates, of the group, twenty-four people, excluding full professors (M. Ceccarelli and G. Mannino). Carla Fanti, the only woman in the group, received the check in everyone's name.

Motivazione

"IL GRUPPO "CROCE DEL NORD" HA REALIZZATO CON IL RADIOTELESCOPIO A CROCE DI MEDICINA UNO STRUMENTO CHE, COMBINANDO ALTO POTERE RISOLUTIVO E ALTA SENSIBILITA', RISULTA COMPLETAMENTE COMPETITIVO CON I MIGLIORI RADIOTELESCOPI ESISTENTI."
HA MESSO COSI' A DISPOSIZIONE DELLA ANCORA GIOVANE SCUOLA DI RADIOASTRONOMIA ITALIANA UN MEZZO CHE PERMETTE DI DARE CONTRIBUTI DI RILIEVO NELLE RICERCHE SULLE PIU' DEBOLI RADIO-SORGENTI. DETTO PREMIO COSTITUISCE NON SOLO UN RICONOSCIMENTO DELL'ALTO LIVELLO SCIENTIFICO E TECNICO DELLA IMPRESA, MA VUOLE ANCHE SEGNALARE L'ENTUSIASMO E LA TENACIA DIMOSTRATI DAL GRUPPO NELLA PROGETTAZIONE E REALIZZAZIONE DEL RADIOTELESCOPIO."

Motivation and copy of the 500.000 lire check awarded by SIF in 1965 for the realization of the Northern Cross Radio Telescope. Credits: INAF-IRA

Carissimi,

come sapete sono stata premiata.

Siccome però non saprei in fondo che farmene di così pochi soldi, ho pensato di fare il bel gesto e di dividerli tra i miei vecchi ...... genitori.

Vi abbraccio (solo in E-W)

"La Croce del Nord"

Gianfranco Sinigaglia
Alessandro Braccesi
Carla Giovannini
Roberto Fanti
Louise Gelato
Gianni Gelato
Carlo Rosatelli
Dan Harris
Ivo Tricario
Gerardo Vespignani
Luciano Baldeschi
Ruggero Cannonetti
O.F.G. Gallieri
Roberto Trebbi
Franco Magaroli
Cesare Rizzi
Goliardo Tommasetti
Alfonso Micheloni
Alberto Bombonati
Renato Trivelloni
Giovanni Frigeri
Giorgio Tabarroni
Luciano Pizzirani
Oriano Volta

P.S. Il regolamento della S.I.F. non permette l'assegnazione di premi a professori di ruolo.

Nel regolamento però non è escluso che i professori Ceccarelli e Mannino possano accettare un invito a pranzo.

A joking letter written by the Northern Cross (i.e. by Marcello Ceccarelli) to the group that had built it. Credits: INAF-IRA

Immediately afterwards, following an exchange of letters with M. Ryle, an article was sent to the magazine Nuovo Cimento with the counts of the radio sources and a detailed analysis of the instrumental effects and of the applied corrections (Braccesi et al. 1965). On this occasion C. Fanti and M. Ceccarelli, to estimate the effect due to the confusion, which makes the function that describes the counts steeper, had developed the first Montecarlo analysis in the Bolognese radio astronomy history which was run on the IBM 1620. The random numbers employed were those from a list taken from a book by M. Ceccarelli, renormalized to become the coordinates of the radio sources of the simulated sky. The results were intermediate between those predicted by the 'Big Bang' and those of the steady state theory, albeit with considerable uncertainties due to the confusion of the weaker sources despite the attempt to apply the corrections of the Montecarlo method. Shortly afterwards, it was possible to discuss the results with the well-known cosmologist Dennis Sciama, who had come to give a seminar on the 'Theory of the Steady State'.

Beyond that, A. Braccesi had a big stroke of luck. After the summer, the first list of optically selected quasars (QSOs) by A. Sandage was published in the Astrophysical Journal. EW observations of these objects were quickly made without finding significant radio emission from any of the 15 QSOs observed at a level about an order of magnitude lower than that of the weaker Quasi-Stellar radio Sources (QSSs). A letter was sent to the Astrophysical Journal, which quickly published it. This work was remarkably successful and for a long time remained the best available on this topic (Braccesi et al. 1966a).

Other research was carried out with the EW arm alone, which produced about a dozen publications, including data on the interplanetary scintillation of 3C273 that appeared in Nature (Sinigaglia, 1966), a survey with declination between -30° and -20° (Braccesi et al. 1965), observations of various QSO samples (including Braccesi et al. 1966 a and b), of bright galaxies (Braccesi et al. 1967), of Planetary nebulae (Ficarra and Padrielli, 1968) and of a sample of 4C radio sources (Fanti C. et al. 1969) (4C catalogue: Pilkington and Scott 1965; Gower, Scott and Wills 1967).

From left: Liliana Formiggini, Carla Fanti, Roberto Fanti and Roberto Bergamini in the garden of the Institute of Physics of the University of Bologna (1967). Credits: INAF-IRA

The Medicina radio astronomy station began to be an internationally famous and in 1967 Valentina Tereshkova, the Russian astronaut and the first woman in space, where she stayed for three days aboard the Vostok 6, visited it during her stay in Bologna.

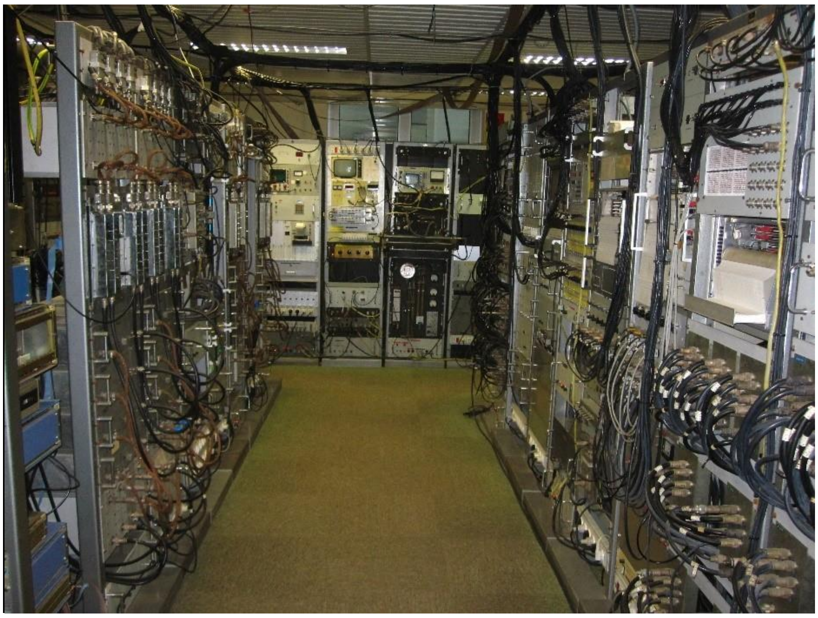
Valentina Tereshkova, Russian astronaut and the first woman in space, visiting the Medicina radio astronomy station in 1967, in the centre of the photo. On the left, M. Ceccarelli is recognizable with a hand on the head of A. Ficarra. Liliana Formiggini on her knees. A. Braccesi is next to M. Ceccarelli. Credits: INAF-IRA

1.3 The Northern Cross and the radio source catalogues

Despite these successes, the performance of EW alone was still not sufficiently attractive to the international community.

Some members of the group were sent in turns to the California Institute of Technology (Caltech), to gain experience with the Owens Valley interferometer and the telescopes at Mount Palomar: A. Braccesi between 1966 and 1967, C. Fanti and R. Fanti between 1967 and 1968, and G. Grueff between 1969 and 1970, as part of a collaboration agreement between the ROUB and the National Science Foundation of the USA both for the study of quasars, whose existence had been known by then for some years , and for the optical identification of radio sources. This collaboration included an observation campaign at the Palomar 48" telescope for the collection of photographic plates, the following analysis of the photographic material and the construction of instrumentation suitable for the purpose, with a subsequent spectroscopic study of the objects found.

M. Ceccarelli tried to establish relationships with other astronomical centres in the USA and Great Britain. After a meeting with M. Ryle, who had invited him to dinner, he wrote: *"We must be able to cross the barrier between being esteemed and being asked for. Everyone here is very friendly to me* *and I have the distinct feeling that they don't consider us underdeveloped at all. But no one needs our data yet. Until we have bargaining chips we will not be taken seriously".* As mentioned, with the radio telescope without the NS arm, there were uncertainties about the weak radio sources. Also, at the 1 Jy level, confusion was already important. The truly crucial step was the completion of the Northern Cross, with the commissioning of the NS arm. This took three years from the opening of the EW arm. During this time there had been some changes in the technology staff. C. Rosatelli and G. Gelato had moved and G. Colla had taken over. There had also been a growing involvement of G. Grueff and A. Ficarra. The delay in NS operation was due to various factors. Difficulty in obtaining funding from the Ministry and with the Board of Directors of the University of Bologna who never understood the innovative potential of the project and considered it substantially an unpleasant disturbance. At the end of 1965 the problem of the NS phasing was solved with a simple and ingenious system. Instead of using pieces of cable to adjust the phase delays between the antennas, G. Sinigaglia used the stratagem of transmission lines filled with a liquid dielectric, kerosene, which allowed the phases to be varied continuously. Meanwhile G. Tomassetti had become the 'high frequency wizard' (Tomassetti 2016). G. Colla had inherited from G. Gelato the encoder project to record the signal on magnetic tape, which would free the activity from the slavery of paper and punched cards. He also made the prototype correlator to combine data from the two arms of the Cross. In the summer of 1966 it was planned to lay the coaxial cables of the NS, but, due to various problems with the University's Board of Directors, things continued to go slowly. M. Ceccarelli, on 10 August, wrote to A. Braccesi from his vacation: *"From yours I understand that the work on the cable has not yet begun. If the cable operation could not take place, I intend to definitely attack the university administration by exploiting everyone for a St. Bartholomew's Night. And I think I can drag Puppi too".* Then Ceccarelli mentioned the very tough intervention of G. Puppi who threatened to ask the Ministry of Education to transfer the Croce del Nord project to the University of Padua. This helped not a little on the Bolognese front. However, the ministerial front remained, namely the last lot of funding for the completion of the Cross and the establishment of the 'National Radio Astronomy Laboratory'. Again Ceccarelli, in 'Viaggio Provvisorio', writes: *".... I was able to have an appointment in Rome with the Minister and intended to tell him that in this way, without money and job positions, his and our much praised 'National Laboratory of Radio astronomy 'had a very grey present and even darker future ... This time the Minister did not just limit himself to 'I hope for '. He took a decision. He took a piece of paper (you have a thousand reasons dear professor!), wrote down figures and times and phoned a General Manager who arrived immediately, very obsequiously, and took possession of the leaflet and the corresponding directives. After this, weeks and months passed but absolutely nothing happened ..."* When Ceccarelli later learned that the project to establish the National Radio Astronomy Laboratory had been definitively rejected, he commented: *" .. that treasure of the Treasury has rejected the project .."*. Having no other choice, G. Grueff, first of all, rolled up his sleeves and the following year managed to complete the work, unfortunately renouncing the completion of the NS arm, which should have had an extension of 1200 m. With the last funds available the illuminators were completed and mounted and the phase shifter system was built for the electrical pointing of the three beams of the NS arm, which became five in the future. A second generation receiver was also made, called the MARK 2, which allowed the Northern Cross to be competitive with the most important radio telescopes in the world. On the night of Christmas Eve 1967, A. Braccesi and G. Grueff were able to see the first radio sources with the Northern Cross of 600 x 320 m which had a resolving power of 3'x10'. A first batch of observations produced a preliminary catalogue of 328 radio sources at 0.2 Jy which was published in July 1968 (G. Grueff and M. Vigotti, 1968).



Interior of the control room of the Northern Cross. Credits: INAF-IRA.

Subsequently, in 1970, the B2.1 catalogue was published in the journal 'Astronomy and Astrophysics', which contained more than 3000 radio sources with apparent brightness down to 0.2 Jy, at least five times lower than that of the large catalogues existing at the time. The article on B2.1 had a strong international impact. For a few years it was the most cited internationally article among all Italian astronomy articles (Colla et al. 1970). In the following three years the systematic observations continued and the following catalogues B2.2, B2.3 and B2.4 were published, which contained in total about 10,000 radio sources (Colla et al. 1972; Colla et al. 1973; Fanti C. et al. 1974a). Members of the group had written the necessary software for the computer processing of the observations. It was possible to access the IBM computer of CNEN, now ENEA, and the analysis of the data was orders of magnitude faster and certainly a little more accurate. In parallel with the production of the catalogues, a project was started to identify the optical counterpart of the B2 radio sources, using prints of the photographic plates of the Schmidt 48” telescope from the Palomar Sky Survey (PSS).

On the side lines of the account of the scientific development of radio astronomy, we would also like to recall how a significant number of the members of the group actively participated in the political activity that characterized the student uprisings of 1968 and the following years. In 1968 the 'Augusto Righi' Institute of Physics of the University was occupied starting from February 14th. A series of 'counter-courses' began. On February 20th, the students invited the trade unions to a meeting on the problems of technological unemployment on the basis of a document developed primarily by Roberto Bergamini. A meeting for Vietnam was held on the 22nd. On March 16th the students rejected a referendum, deemed blackmail, on the resumption of exams. On March 22nd, the Director of the Institute resigned, prof. Ceccarelli, who signed the employment document, creating a 'rift' between the teaching staff. On April 8th, a group of teachers, some of whom are well-known in the scientific field, carried out a counter-occupation that had great coverage in the national media. Students picketed the entrance to isolate them and occupied the university headquarters. The agitation in Physics would continue until the beginning of May, causing among other things the resignation of the rector Felice Battaglia. We then find some of the protagonists from those days in the IRA in the following years: Roberto Bergamini, Pasquale Londrillo, Paolo Tomasi, Nando Primavera and Carlo Lari.

1.4 Impact of the B2 Catalogue

The B2 catalogue had a strong international impact. It was less extensive than the 4C Catalogue, but was much deeper. At this point the Laboratory had the bargaining chip which M. Ceccarelli had underlined. By counting the number of radio sources as a function of the flux density (LogN - LogS) the result was undoubtedly that the Universe has evolved according to the 'Big Bang' model. The first aim of the project had been achieved, even if the theory of the steady state had already died following the discovery, in 1964, of the cosmic background radiation with a temperature of 2.7 °K. Foreign colleagues began to use the B2 catalogue. For Malcolm Longair and collaborators at Cambridge the data were essential to the completion of their cosmological studies. A clear indication of the transition from being esteemed to being necessary.

Alessandro Braccesi (Centre) discussing with foreign colleagues at the 1972 YERAC. Credits: INAF-IRA

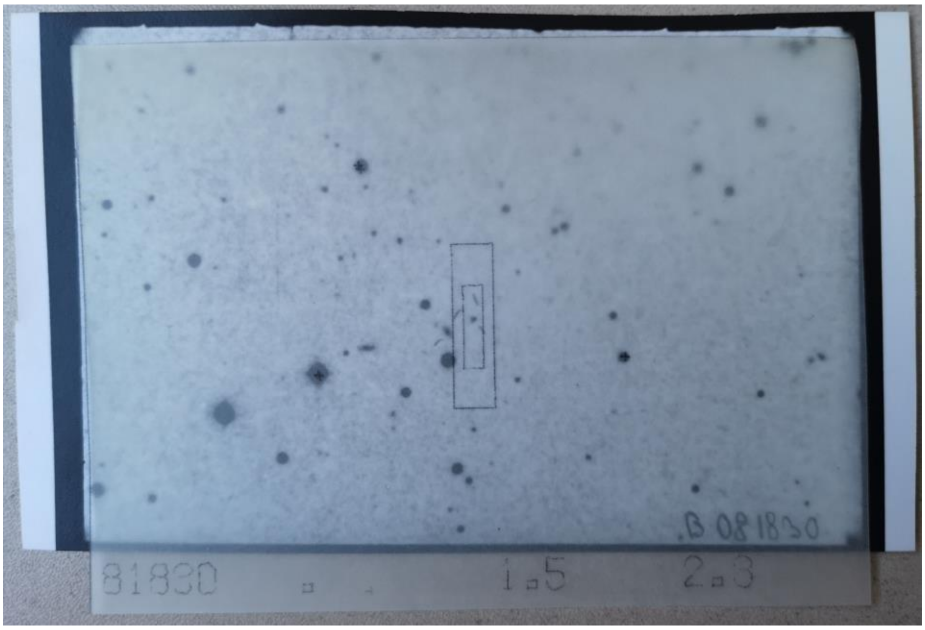
In 1970 Ernst Raimond, director of the Westerbork Synthesis Radio Telescope (WSRT), the instrument that revolutionized radio astronomy in the early 1970s, with a letter addressed to A. Braccesi invited the Bolognese radio astronomers to use the new 1200 m interferometer to observe the B2 radio sources at a different frequency, 1.4 GHz, and with better resolution (≈20") to refine the B2 positions for optical identifications. This proposal was accepted with enthusiasm and in the spring of 1971 Carlo Lari went to Leiden for three months to observe a selection of radio sources from the B2 catalogue. He returned with a lot of data, and after developing the necessary software, it was possible to obtain images of the B2 sources observed with WSRT. The results were shown to the Leiden group in a subsequent visit by C. Lari and R. Fanti. The excellent quality of the achieved results led to the establishment a lasting collaboration with Dutch colleagues and continuous access to WSRT which initially not been open to non-Dutch colleagues.

This marked the beginning of a long collaboration between the IRA and Dutch institutions. Dutch researchers such as Jet and Peter Katgert spent a year (1975) at the IRA while IRA researchers, including R. Fanti, C. Lari and P. Parma, regularly went to the universities of Leiden and Groningen. Beginning in 1980 Hans de Ruiter and later Jan Brand moved to the IRA permanently, and Raffaella

Morganti moved to Groningen. Some of the collaborations between Dutch astronomers and IRA astronomers have resulted in marriages.
Students who graduated with theses carried out at the IRA began to move to the Netherlands for their doctoral thesis project. Some of them found a job and remained in the Netherlands, others returned to Bologna or in any case to Italy.

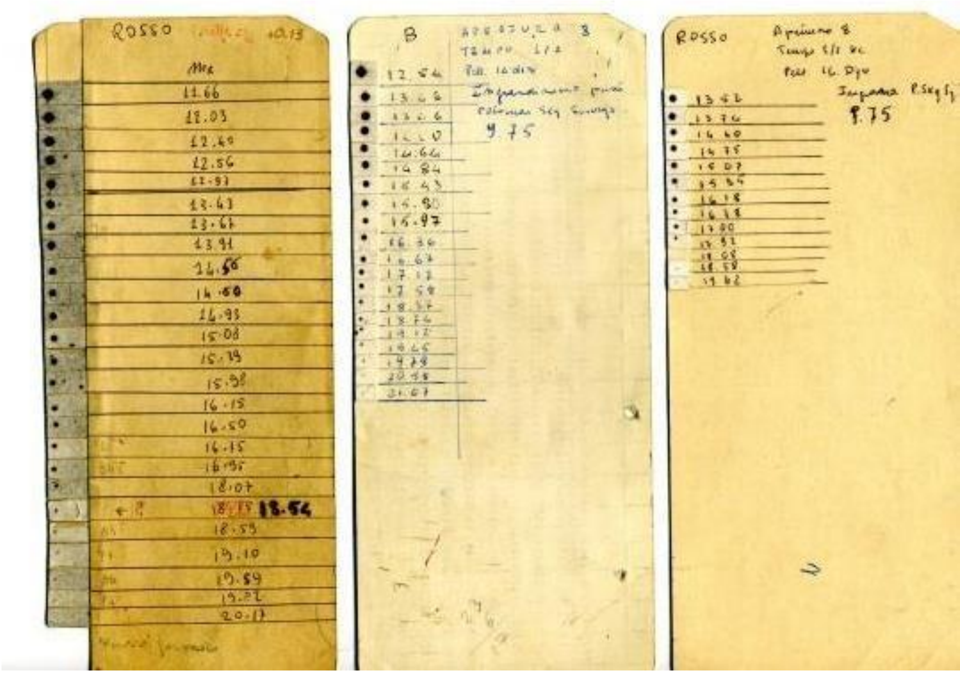
1.5 Optical identification of radio sources

To identify the optical counterparts of the radio sources, the optical objects present on the Palomar Sky Survey (PSS) prints were searched within the positional error area of the radio sources, classifying them according to their morphology. Liliana Formiggini, a CNR fellow, was involved in this work. To carry out a systematic search, identification cards were produced, called overlays, on the same scale as the PSS Prints, with the stars and the position of the radio sources marked. The cards were drawn on transparent plastic by a plotter equipped with a steel pin.



An 'overlay' showing the two rectangles drawn corresponding to two levels of uncertainty about the position of the radio source B2 0818 + 30. The overlay is placed on the Palomar Sky Survey Print. Credits: INAF-IRA

The digitized data positions of stars listed in the Smithsonian Stars catalogue were available in Bologna from prof. Aldo Kranic in the form of punch cards, contained in many cassettes. It was a matter of copying all the punch cards which were then stored on a magnetic disk. For this, the IBM 1620 computer of the Faculty of Engineering of Bologna was used. It was only available in the evening / night when it was not used by the faculty members. Aldo Spizzichino and Liliana Formiggini spent many nights in Via Saragozza, seat of the Faculty of Engineering, with a technician who had to open the door and check that everything was working properly. In practice, the very kind technician would go to sleep on the deck chair and, when the work was completed, he was woken up and closed the door. Having identified the optical object corresponding to a radio source and having measured its coordinates, the next step consisted in determining its optical magnitude through a comparison with a 'scale', that is, with a series of photos of galaxies with known magnitude.



To determine the optical magnitude of a galaxy, its image was compared with a series of photos of galaxies with known magnitude ('scaletta'). Credits: INAF-IRA

This method with the first 'overlays' was presented at the 1967 SAIt Congress in Padua, and then became commonly used for various research activities. From this almost 'prehistoric' work, the optical identification of the radio sources of the radio catalogues produced by the Northern Cross began.

Fundamental to this work was the construction, on site, of a coordinate measuring device made by modifying COSO2, built as a comparator of photographic plates for the study of quasars (see 1.6 Search for quiet radio quasars), which was subsequently interfaced to a computer (A. Callegari 1978; A. Gallerani et al. 1982; M. Vigotti and G. Grueff 1985). All the photographic work connected with the identification and the measurement of the positions of the stars on the 'overlays' was performed by Nando Primavera.
This method of identification with its special instrumentation was very successful. It was used by colleagues from other Italian institutes and also attracted foreign astronomers, for example Jet Katgert from Holland.

Franco Mantovani at work with the coordinate measuring device (COSO2). Credits: INAF-IRA

1.6 Search for radio quiet quasars

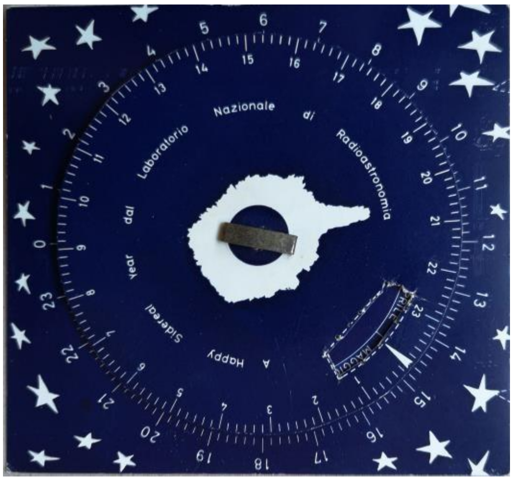
After the identification of the first quasar 3C273 in 1963, many others were added in the short span of a couple of years, both from the identification of radio sources and from objects that showed excesses in the ultraviolet on the photographic plates. However, a problem remained: with the same UV excess, the number of stars compared to quasars was enormous. An additional criterion was needed to be able to recognize them. Alessandro Braccesi, then visiting scientist at Palomar, had a brilliant intuition. The stars have a thermal spectrum and the quasars a non-thermal one, the latter could thus be distinguished by the presence of an excess in the near infrared (Band I). This facilitated the important program of defining radio quiet quasar samples in Bologna, as part of a collaboration agreement between the CNR and the National Science Foundation in the USA. This collaboration involved an observing campaign at the Palomar 48" telescope for the collection of photographic plates, the establishment of a working group at the Bologna Radio Astronomy Laboratory for the analysis of the photographic material, the construction of instrumentation suitable for that purpose, and finally a subsequent campaign of spectroscopic study of the objects found to confirm their nature. The working group in Bologna was made up of Alessandro Braccesi, Liliana Formiggini, Giuliano Colla, Antonino Ficarra, Luciano Baldeschi, and Pierluigi Cova. A. Braccesi's observation campaigns of 19671968 and 1969 produced about 100 plates and 100,000 measurements were made. The material execution of the measurements was entrusted to students with the duties of operator-scanners, including Bruno Giorgini, Ernesto Cicconetti and Valentina Zitelli. Further plates were obtained in the 1970s.

With the help of M. Ceccarelli and U. Dall'Olmo, two newly conceived instruments suitable for the data reduction program were handcrafted in the Laboratory: 1) A microscope - blink and iris photometer connected to an automatic card puncher to perform the automatic writing of photometric iris readings; 2) A microscope-comparator with image superimposition that allowed the simultaneous vision of a pair of images. These instruments were called COSO1 and COSO2, that is 'COmparator of optical Stellar Objects'. They were built in such a way as to ensure that the 36x36 cm plates of the Palomar telescope could be used.

During the protest riots of the students in the spring of '68 and the occupation of the Institute of Physics, the importance of the collaboration program with the USA was recognized by the students. Therefore L. Formiggini was allowed to enter in the morning to work in the room where the two instruments were, while the next rooms were occupied by students who controlled the Institute and slept in sleeping bags.

Data reduction was performed with the IBM 1620 computer of the Faculty of Engineering of Bologna and later also with the CDC 6600 computer of the Interuniversity Computing Centre in Casalecchio (Bologna). A first catalogue brighter than B = 19.4 on 36 square degrees covered by the photographic plates of the 48" Schmidt telescope of Palomar that A. Braccesi had brought back from the USA to Bologna, showed a very steep slope of the counts as a function of magnitude. For the first time, the presence of a strong cosmological evolution of quiet radio quasars, that is quasars that did not emit in the radio band, was highlighted (Braccesi and Formiggini 1969, Braccesi Formiggini and Gandolfi 1970). The 1969 article was reviewed by Nature (1969, vol. 224, 751) which highlighted the importance of the results obtained for cosmology by narrowing down the possible models of the universe.

A substantial step forward in the research and study of the properties of radio quiet quasars occurred with the works of Formiggini et al. (1980) and Braccesi et al. (1980), in which the in-depth examination of the central parts of the Palomar plates allowed the selection of a sample of radio quiet quasars with blue magnitude greater than 20. The analysis of these objects showed a strong evolution in the density of the luminosity function of quasars.



Cardboard pocket 'clock' that allows you to switch from solar time to sidereal time and vice versa. A small tool very useful for knowing the local time of rising and setting of a radio source to be observed. Credits: INAF-IRA

2 From the Radio Astronomy Laboratory to the CNR Radio Astronomy Institute

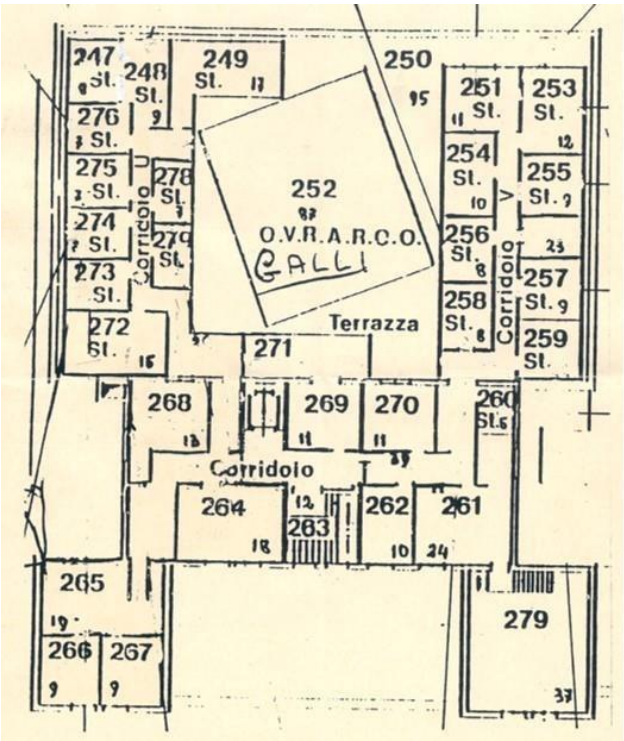
An important point remained unresolved, i.e. to give radio astronomy an institutional structure. The 'National Radio Astronomy Laboratory' operation of the Ministry of Pubblica Istruzione had failed and it took many steps to convince the CNR to take charge of the Northern Cross and Italian radio astronomy. This happened successfully at the end of 1970 thanks also to the fundamental role played, once again, by G. Puppi. The CNR established the Radio Astronomy Laboratory, which later became the Institute of Radio Astronomy (IRA) in 1979. G. Setti having returned to Bologna in 1967, after being in Leiden (The Netherlands) and in Rome at the Frascati Astrophysics Center, created a group of theoretical astrophysics linked to the ROUB, including C. Lari, R. Bergamini and P. Londrillo. G. Setti was the first director of IRA. Appointed in 1970 he remained director until 1992. Under his direction, the institute expanded its number of researchers, and is scientific research interests. It was under his direction and with his contribution that the VLBI project came about. When G. Setti, in 1982, obtained the position of Scientific Director of ESO, in Garching (Germany), he first appointed Gavril Grueff as Acting Director, and then from 1986 Lucia Padrielli. Lucia took over the full management of IRA from 1992 to 1999.

The University of Bologna, owner of the Northern Cross, assigned its management to IRA and agreed a contribution to its running costs. Later the CNR bought the land on which the Cross stands. Through the Laboratory/Institute of Radio Astronomy, the CNR guaranteed regular funding for research and instrumentation, tenure positions for researchers, technicians, and funding for developments both technical and IT. Within acceptable times, various positions were made available, including those for technicians and researchers.

The initial nucleus of personel was formed by Roberto Bergamini, Alberto Bombonati, Giuliano Colla, Pierluigi Cova, Carla and Roberto Fanti, Antonino Ficarra, Enzo Gandolfi, Liliana Formiggini, Gavril Grueff, Carlo Lari, Franco Magaroli, Bruno Marano, Alfonso Micheloni, Lucia Padrielli, Cesare Rizzi, Giancarlo Setti, Gianfranco Sinigaglia, Paolo Tomasi, Goliardo Tomassetti and Mario Vigotti. The link with the University of Bologna remained very strong thanks to free collaboration contracts envisaged by the CNR for university professors who were able to continue their research activities within the Institute.

The headquarters of the Radio Astronomy Laboratory and then of the IRA as an institute of the CNR, was located in prefabricated ‘shacks’ of wood with only a little insulation placed on the roof terrace of the Physics Institute of the University of Bologna, in Via Irnerio 46. It could be reached via a freight elevator or through the staircase of the building up to the second floor continuing along a narrow staircase to the roof. We do not have pictures of these premises however here is a brief description. Two barracks arranged parallel to eachother made up the major part of the Institute. Each housed small offices, whose doors were always left open by their occupants, arranged on either side of their central corridors. The restricted environment prevented any form of privacy. Each of the corridors housed a single telephone, set in one corner. When the phone rang, the nearest person lifted the handset and then called out to the recipient of the call. The offices were well heated in the winter ... and unfortunately also in the summer. A third cabin, which housed the instrumentation for a physicists' experiment on cosmic rays, was interposed between the two IRA barracks and its noisy air conditioning system mingled with the noises produced by the normal activity of researchers. The structure of the barracks was built with fireproof panels. It was demonstrated that they resisted fire when a short circuit caused a fire in the dark room and the flames went out without spreading to the other rooms. The panels were less resistant to water.

Each rain infiltration, and they were frequent especially after a few years from construction, caused serious damage. Several offices, including the one that housed the acting Director Lucia Padrielli, showed abnormal deformations and halos in the ceiling. The only masonry rooms were the microwave laboratory, located downstairs, the secretariat and the IRA library, which were housed in the upper part of the two towers that characterize the front of the Institute of Physics. They were rooms badly lit by the lunettes of the upper part of the windows of the facade of the building. It was a mystery how it was possible to do research in those conditions but it was and even well! The barracks were dismantled when IRA moved to the CNR Research Area in 1993.



Occupazione 3 Piano Istituto A. Righi in data 1974 (?)

247 8 m2 Kurt Weiler
248 9m2 laureandi
249 17m2 lab Donati (OVRARCO)
250 spazio terrazzo intorno Lab. OVRARCO
251 11m2 Bergamini
252 Lab OVRARCO (Galli)
253 12m2 Fanti C e Lari
254 10m2 Tomasi
255 8m2 FantiR
256 8 m2 terminale CNEN
Tra 255 e 257 spazio x incontri
257 9m2 Ficarra
258 8m2 Parma e Gioia
259 9m2 Padrielli
260 8m2 Marano
261 22 m2 Laboratorio (lastre, misuratore coordinate, plotter ecc)
262 10m2 Laboratorio Fotografico (Primavera)
263 Atrio - scale
264 18m2 Biblioteca e Lab. Grafico (Baldeschi)
265 10m2 Materiale amministrazione (Archivio)
266 9m2 Arbizzani (Segretaria Amministrativa)
267 9m2 Volta P. e Zanlungo P (segreteria - dattiloscritti)
268 12m2 Galli
Ascensore
269 15m2 Laboratorio Fotografico
270 8m2 Formiggini
271 10m2 Camera Oscura
272 18m2 Setti (Direzione)
273 8m2 Grueff
274 6m2 Vigotti
275 6m2 Vettolani e Zamorani
276 6m2 Panagia
277 6m2 Studio ROUB (materiale Medicina di Grueff)
278 6m2 Laboratorio ROUB-Grueff

Map and occupation of the shacks located on the terrace of the Physics Institute of the University of Bologna, home to the Radio Astronomy Laboratory, later the Institute of Radio Astronomy. Credits: INAF-IRA

In the period 1972-76, under CNR management, a robust updating of the Northern Cross occurred. The NS arm was cut lengthwise, and the antennas, which had become about 23.5m long, were redistributed to obtain a 600m arm, doubling the total resolving power (2.6 'x 4.8') of the Northern Cross. In 1976, fourteen receivers were installed in the Northern Cross, for whose design all the experience and knowledge available to IRA technologists was exploited (Tomassetti 2016). Receiver noise temperatures below 100 ° K, albeit only slightly were finally reached.

Radical changes to the electronics, data processing and management software made the Northern Cross function as a multiple interferometer with 6 EW sections by 8 NS sections, ensuring the production of improved data. The data acquisition of the Northern Cross was managed by one of the first SELENIA computers, the GP16 (Ficarra et al. 1977).

In those years Romano Andalò and Gemma Cevenini also worked at the station.

Until 1980, work at Medicina took place in prefabricated shacks supplied by ENI that were not exactly elegant, but were very welcoming. They contained the mechanical workshop, offices, the classroom for students and visitors, a kitchenette, a large laboratory, and services. Over time and due to poor maintenance the shacks began to deteriorate. Finally, the entrance door to the station could no longer be closed. The only brick part of the station was inhabited by the caretaker Renato Trivelloni. It could happen that in the middle of the night the researcher at work in the noisy receiver room would suddenly hear himself greeted with a vigorous: “Good evening. Everything good!" by someone who entered unnoticed. Fortunately, the Carabinieri (military police) from the nearby Portonovo barracks were always patrolling.

Until 1980, the work at the Medicina radio astronomy station was carried out in very Spartan prefabricated barracks. Credits: INAF-IRA

From the beginning of the 80s, for about three years, Medicina became also the construction site for the new station, which made scientific and technical activities very difficult. The result, however, was a completely renovated station.

Beginning in 1982, a new data acquisition system of the Northern Cross was designed and built around an Apple II Plus with a memory of 48K. This little machine was more than enough to control the correlator desk, place kerosene in the NS arm, set variable delays in the NS chains, capture the EW and NS chain data and store it on a Mactronics tape drive, managed via IEEE-488 with a routine written by Gianni Comoretto. With this new system a new catalogue was produced, the B3 Catalogue (Ficarra, Grueff and Tomassetti 1985) of 13354 sources, at a limiting flux density of 0.1 Jy, a factor of two lower than that of the B2. The B3 catalogue had a notable impact at international level, also due to the innovative technique with which the observations were made.
In the same years, technological research continued focussing on the reduction of the system temperature which is given by the sum of the noise temperature of the receiver, about 100 °K, the temperature of the sky, which, at 408 MHz is about 40 °K, and the predominant part, i.e. the temperature of about 300 °K of the transmission lines. Having abandoned the possible but very complex solution of installing the receivers directly at the output of each of the six antenna sections, it was decided to use a new transistor that would have guaranteed a temperature below 50 °K. New amplifiers were then built and distributed along the EW arm. The new 'front-ends' were placed in a thermostatically controlled environment inside six waterproof containers for transporting milk, used by the farms surrounding the Medicina radio station. These latest improvements brought the system temperature close to 150 ° K (Tomassetti 2016).

Between the 70s and 80s the IRA staff increased considerably with the hiring of R. Ambrosini, I. Gioia, T. Maccacaro, F. Mantovani, S. Montebugnoli, N. Panagia, P. Parma, G. Vettolani, G. Zamorani. The university component was also expanded with S. Facondi, L. Feretti, G. Giovannini and L. Gregorini. In those years there was also an increase in the number of degree theses and later of doctoral theses produced by students within the IRA on the scientific issues of the institute. All this created an atmosphere of mutual exchange, between the University and IRA, which allowed growth in both the scientific and technological fields for both institutions. In those years, researchers had the opportunity of international exchanges through the 5 'Schools of Erice', directed by G. Setti within the 'International School of Astrophysics', which were held in 1972, 1974, 1977 and 1979 in Erice (Trapani) and in 1975 in Urbino (Pesaro). In addition to promoting scientific collaboration, these schools made it possible to raise awareness of the IRA internationally.

School of Erice (1979). From the left kneeling: Bruno Marano, Marino Mezzetti, Edoardo Trussoni, Amerigo Setti, Paola Parma, Leonardo Setti, Loretta Gregorini. From left standing: Hans de Ruiter, Monica Tosi, Gianni Zamorani, Luigina Feretti. Credits: INAF-IRA

In 1983, the PhD in Astronomy was activated at the University of Bologna. IRA researchers also actively contributed to it. The first to obtain the title of PhD, were Alberto Buzzoni, Raffaella Morganti with a thesis on the properties of low-power radio galaxies and Anna Rogora with a thesis on the quasars of the B2 catalogue. Since then, the radio astronomers trained at the Bolognese doctoral school have been numerous and the vast majority of them have found jobs in universities and research institutions both nationally and internationally.

The Bolognese radio astronomers actively contributed to the initiative launched by the European radio astronomy community in 1968, to annually organize the "Young European Radio Astronomers Conference" (YERAC). For many participants this is their first opportunity to present their own work in an international meeting. It also offers the opportunity to meet colleagues from other countries with whom they often start fruitful collaborations that last over the years. The Institute of Radio Astronomy has organized three YERACs (1972, 1980, 1996) that have remained in the memories of many for both their scientific content and friendly atmosphere.

Participants in the 1980 "Young European Radio Astronomers Conference" (YERAC) photographed on the steps of the Institute of Physics of the University of Bologna. Credits: INAF-IRA

From 1980 to 2000 other people joined the research staff of the Institute: Raffaella Morganti, Tiziana Venturi, Alfredo Gallerani and Alesssandro Orfei in Bologna and Medicina; Luigina Feretti moved from the University of Bologna staff to the IRA staff; Carlo Stanghellini, Corrado Trigilio, Gino Tuccari and Grazia Umana in Noto. Daniele Dallacasa joined the university staff. Mauro Nanni, Franco Tinarelli and Marco Tugnoli took up their duties in the computer centre. To operate the new 32 m dish Claudio Bortolotti, Alessandro Cattani, Andrea Maccaferri, Giuseppe Maccaferri, Sergio Mariotti, Marco Morsiani, Mauro Roma, Giampaolo Zacchiroli and Jader Zini joined the Medicina staff.

A significant event in the life of IRA was the move from the Augusto Righi Institute of Physics to the new campus of the CNR. In 1991, anyone passing through the Gobetti roundabout could see a large construction site at work. With the foundations already completed, the walls of the future CNR Research Area began to be built. The construction lasted a long time and finally at the end of 1992 we began to discuss the layout of the various institutes and how to the organize the spaces. For IRA, the Director Lucia Padrielli, assisted by Ficarra and Nanni, followed the work in detail and we began to think about the move.
The transfer to the new location was expected and desired because, as mentioned above, the 'shacksì on the roof of the Physics Institute in via Irnerio 46 were now unfit for habitation, with water infiltration in winter and the heat of summer. In addition, the increase in staff members, and the new computing needs, made it almost impossible to continue working in the former location. However, there were also concerns about the move. Moving to the periphery of Bologna, although together

with all the other CNR Institutes, meant moving away from the University, the students, and the Physics Institute where the IRA was born and developed. The fear of losing contact with the university component was strong.
Those were days of hectic activity: filling and closing boxes, deciding what to keep and what to discard in times when paper was the main if not the only support, it was not easy.

In October 1993 the move was over. Being in new bright and air-conditioned surroundings, without problems for parking, with large spaces for the library, for meeting rooms and for the computer centre, met with the favour of all. In order not to suddenly lose contact with the old headquarters and the university environment, a free shuttle service was organized, which lasted a few months. The shuttle bus connected the Institute of Physics to the CNR research Area in Gobetti 101 a couple of times every day.
In a short time, the advantage of having large spaces and equipment began to prevail over the problems of distance. The feared detachment from the university world did not happen and soon undergraduates and doctoral students began to frequent the new location.

Finally, it needs to be remembered the fundamental work of the Administration and the Secretariat for all the activities of the Institute for both management of funds such as budgets, final balances, purchases and missions, and for organizational support for meetings, conferences, occasional events. The administrative manager was Brunella Arbizzani, assisted by Paola Volta and Paola Zanlungo, and later by Paola Cesari, Luca Minerva, Maria Rezzaghi, and Margherita Tassinari. At that time, there were no text writing programs, such as TEX, LATEX or WORD, so the secretariat took charge of typing scientific articles, while the figures were drawn by Nando Primavera, Luciano Baldeschi and Vittorio Albertazzi. The articles, were submitted to scientific journals by post in paper form. The time needed to publish a paper was much diluted compared to now!

Lucia Padrielli, director of the IRA from 1993 to 1999, when she was appointed member of the Board of Directors of the CNR. Credits: INAF-IRA

3 Science with The Northern Cross

In addition to the publication of radio catalogues, much research has been carried out with data obtained from the Northern Cross. Here only a few examples are described to show the wide scientific panorama to which the results of the observations with the radio telescope have contributed.

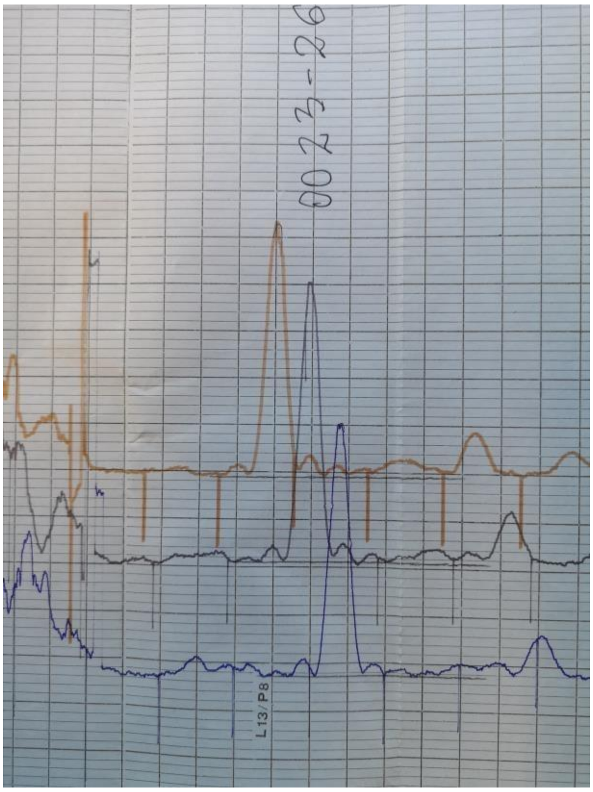
Thanks to the work of optical identification, the sources of the B2 catalogue were compared with the galaxies of the available optical catalogues (de Vaucouleurs, G. and de Vacouleurs, A. 1964; Zwicky, Herzog and Wild 1963, 1966). Possible candidates for identification were then observed with the WSRT radio telescope to eliminate spurious identifications and thus obtain a sample of B2 radio galaxies (Braccesi et al. 1970, Fanti R. et al. 1973) whose significant scientific impact is discussed in more detail below.

In the vast field of research conducted with the Northern Cross, a study of the properties of quasars could not be missing. In the early 1970s, around 200 quasars were known. Of these, only a small part belonged to statistically well-defined samples such as 3CR and 4C. Consequently, the studies of their properties were problematic. It was therefore natural, after the production of the B2 catalogue, to proceed with the selection of quasar candidates, to improve the knowledge of this class of objects, and to identify objects with radio power weaker than the limits of the 3CR and 4C Catalogues. 116 candidates were extracted (Bergamini et al. 1973, Fanti C. et al. 1975a) with flux density ≥ 200 mJy, identified with stellar objects visible on the Palomar Sky Survey and characterized by the ultraviolet excess typical of quasars. The sample was subsequently filtered using accurate radio positions obtained from observations at 6 cm with WSRT (part of the work constituted the subject of the thesis in Physics by Gabriele Giovannini), and multi-coloured plates obtained at the 48” Schmidt Telescope of Mount Palomar by A. Braccesi. The final sample consisted of 74 quasars with radio flux density >200 mJy and apparent blue magnitude <21. Important results were obtained from subsequent 1.4 GHz observations with WSRT. The radio sources showed mainly double structures often asymmetrical, called 'one-sided', or not resolved, spectra with high frequency flattening demonstrating the existence of a compact component with flat or inverted spectrum, counts consistent with density evolution in a Friedman's Universe, and the luminosity function in remarkable agreement with that of the nuclei of elliptical galaxies (Fanti C. et al. 1975b, 1977, Fanti R. et al. 1979). These studies contributed to derive the unified model of radio sources, especially at low power.

In the 1980s the sample of weak quasars was also observed with the VLA at 5.0 GHz. The data were processed and analysed by A. Rogora for her doctoral thesis. The images obtained for the B2 quasars, show a high percentage of triple radio sources with a misalignment of the lobes with respect to the nucleus - much greater than that found for the 3C quasars. This suggests that, being weaker, they are strongly influenced by the external medium, i.e. are confined and distorted.

An extensive research done in the 70s was that concerning the variability of radio sources. The variability of radio sources at frequencies greater than 1 GHz was well known and studied, but current theories did not foresee conspicuous variations at low frequencies, unless by invoking extreme superluminal phenomena and unacceptably high brightness temperatures. However, phenomena of low frequency variability were increasingly reported. A more in-depth study was therefore needed. In 1975, under the guidance of Carla and Roberto Fanti and Lucia Padrielli, a systematic programme of observations at 408 MHz of a sample of likely variable sources began with the EW arm of the Northern Cross. It lasted until the 1990s.The sample grew to 125 objects. A. Ficarra, L. Gregorini and F. Mantovani collaborated on the monthly observations.

The observing technique consisted in pointing the EW arm at the Declination of each source in the list, and awaiting its transit over the radio telescope. As it passed by, the point-like profile of the radio source was drawn on the card recorder. From its height, the flux density of the object was derived. All pointing operations were carried out manually on average every twenty minutes, by supplying power to the electric motors that allowed the EW arm to move. Mechanical problems sometimes occurred to the adaptor placed on the ribs of the radio telescope. Their mechanics were not designed to withstand frequent changes in position. The observing session lasted three days (and nights) regardless of the weather conditions. The researchers took turns every eight hours. The results of the monitoring of the sources variability were published in several articles, including Fanti C. et al. (1983c) and Bondi et al. (1996a).



Observation of the variable source 0023-26 with the East-West arm of the Northern Cross. The three traces on paper correspond to three slightly different EW directions, technically called 'beams'. Credits: INAF-IRA

One evening, between 26th and 27th November 1977, the sky was threatening snow. The NS arm antennas not used in the observations were placed in the rest position. The long EW antenna kept moving even as it started to snow. The recordings were good and it was decided to continue. At about three in the morning, the supply of electricity failed and the station remained in the dark. All that was left for the only observer present to do was to reach the bedroom by groping in order to notify the researcher of the next shift by telephone in time so he could avoid the trip through the blizzard to reach the radio telescope. When around six he tried to call, the telephone lines too were cut off. Meanwhile, the sky was clearing even though the snow continued to fall. The sight that presented itself was worse than a nightmare. Most of the NS antennas had collapsed to the ground or were distorted under the weight of the snow. Shortly before eight A. Ficarra, on time as always, reached the station for the shift change. He was the second witness to the devastation of the NS arm of the Northern Cross. The EW arm, on the other hand, showed no apparent damage to the metal structure.

By pure chance, when the power supply went off, the antenna was in the rest position. Certainly having moved it for frequent pointing had contributed to shaking the heavy snow that was falling from the structure. After the first moments of anger and sadness for the devastation of the NS arm, projects and work began to restore it. The NS arm returned to being functional after a few months.

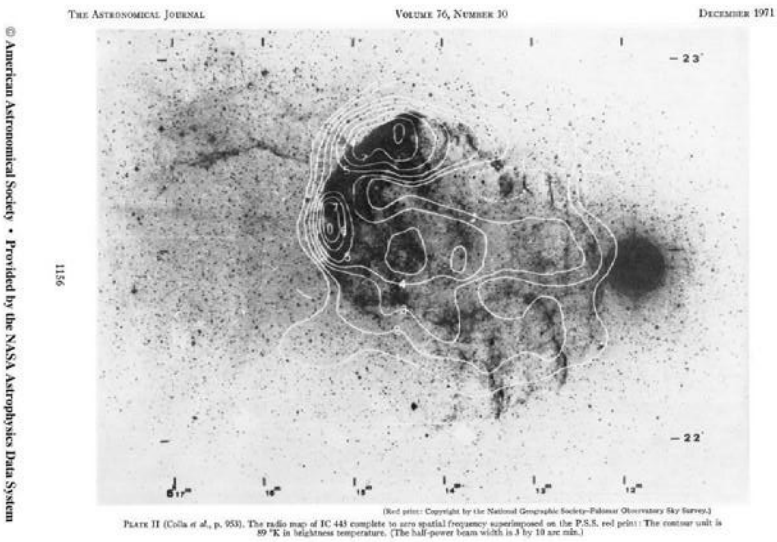
Around the years 1979-1980, the collaboration with M.F. Aller and H.D. Aller of the University of Michigan provided simultaneous observations of variable sources at 408 MHz, and 4.8, 8.0, 14.5 GHz. This joint work revealed the existence of three different behaviours, which can be summarized as: i)variability in flux density only at metric wavelengths; ii) continuity in time and amplitude of the variations in flux density from high to low frequencies; iii) variations at all frequencies, uncorrelated with each other, presumably through the superposition of the first two cases.
The result suggested two different causes for the variability. An intrinsic one, the second in the above list, due to the relativistic expansion of plasmoids radiating by the synchrotron mechanism according to the van der Laan model (1966), and an extrinsic mode, the first in the above list, due to scintillation in the interstellar medium of the Galaxy, a plausible phenomenon, but still unknown at the time. To verify the two hypotheses it was envisaged to obtain images of the radio sources with resolutions of the order of thousandths of an arc second (mas). Hence the stimulus to undertake the observations using the antennas of the global VLBI network at 18 cm. In those days the VLBI network was still in a pioneering operational phase, as will be illustrated later. The VLBI observations, repeated over time (1980, 1981, 1987) showed that structural changes or the birth of new components were correlated with the increase in flux density for sources whose variability is due to intrinsic causes. For the other radio sources, parameters such as index and period of variability revealed a good correlation with galactic latitude, proving that the variability is external to the radio source and occurs in the Galaxy. The dimensions of the radio structures allowed the estimation of the size of the irregularities in the interstellar medium responsible for the scintillation, and the speed by which these irregularities move. The theoretical treatment of this phenomenon was carried out in collaboration with Steven Spangler of the University of Iowa (USA) (Spangler et al. 1989). The interpretation of the low frequency radio variability of extragalactic sources was the subject of Marco Bondi's doctoral thesis (Bondi et al. 1994).

At the suggestion of R. Fanti, a study of the radio properties of spiral galaxies was started. In 1980 an article was published which presented the observations at 408 MHz of an optical sample of these galaxies (Gioia and Gregorini 1980), which then allowed their different properties to be studied such as the Luminosity Function and the dependence of radio emission on various optical parameters. To deepen the study of the sample observations at higher frequencies were needed. It was thanks to Chris Salter, who suggested the possibility of observing these galaxies with the Effelsberg 100-m radio telescope (Bonn, Germany). This started a very long and fruitful collaboration with German colleagues. To access the radio telescope an internal collaborator was necessary. C. Salter put Isabella Gioia and Loretta Gregorini in contact with Uli Klein, then a student of the University of Bonn. Spiral galaxies were observed at 4.8 GHz and 10.7 GHz, allowing the derivation of their spectral indices in the frequency range from 408 MHz to 10.7 GHz (Gioia, Gregorini and Klein 1982). This result was very successful in the international literature. The project also made it possible to open a collaboration with German colleagues which continued for many years on various topics.
Clusters of nearby galaxies were also observed with the Northern Cross: see chapter 4.2.

As soon as the B3 catalogue was available, a sample of radio galaxies and weak quasars was selected following the working scheme used with the B2 catalogue. The colleagues of the NRAO (USA) invited G. Grueff and M. Vigotti to observe a sample of 1049 radio sources with the VLA at 1.4 GHz, at a resolution of 15”, fundamental for deep optical identification and cosmology. The B3-VLA catalogue was the outcome which was published in Vigotti et al. (1989, 1990). Subsequently M. Vigotti and L.

Gregorini, in collaboration with Uli Klein and Karl-Heinz Mack of the Radioastronomisches Institut der Universität in Bonn (Germany), observed with the Effelsberg 100-m radio telescope all the sources listed in the B3-VLA at six different frequencies, between 151 MHz and 10.6 GHz. For a long time this remained the best existing multi-frequency catalogue (Vigotti et al. 1999; Murgia et al. 1999). Furthermore, for these sources, the optical identifications were performed with the 48" Palomar plates. From a first selection of about 1000 candidates (Vigotti et al. 1989, 1990, Lahulla et al. 1991) a final sample of 125 quasars with a limiting flux density at 408 MHz of 100 mJy was obtained (Vigotti et al. 1997). It became the subject of subsequent observations in optical, infrared and at several radio frequencies with the VLA. For all the quasars brighter than magnitude 20, the determination of the redshift was obtained at the 2.2 and 3.6 meter telescopes of Calar Alto in Spain (Vigotti et al. 1999).

The potential of the Northern Cross for studies of extended radio sources was demonstrated by a couple of papers concerning the observation of the supernova remnant IC 443 (Colla et al. 1971a) and of the Cygnus Loop (Colla et al. 1971b) in which the exceptional coincidence between the radio filament structure and that observed in the optical was highlighted.



Radio map (contours) of the IC433 supernova remnant observed at 408MHz with the Northern Cross superimposed on the optical image of the Palomar Sky Survey Print. © AAS. Reproduced with permission

At the beginning of the 1970s, preliminary studies had shown how the presence of extended radio sources in the B2 catalogue was concentrated in the region of the galactic plane. In collaboration with Marcello Felli and Gianni Tofani of the Arcetri Astrophysical Observatory and with Chris Salter, fellow of the European Program of the Royal Society, an observational program was started with the EW arm of a region around the galactic plane, with the aim of obtaining the positions of the point sources, accurately measuring their flux densities and determining the structure of the extended sources. The BG (Bologna Galactic) catalogue was published with a list of 586 objects with flux density greater than 1.2 Jy (Fanti C. et al. 1974b). The study of their distribution as a function of galactic latitude showed that the point sources had a uniform distribution with respect to the galactic plane, and therefore were, in most cases, extragalactic, while the extended ones thickened around the galactic plane and were therefore predominantly galactic. This work was followed by an analysis to establish the nature of the point sources (Fanti C. et al. 1975c) and by a second work focused on the extended sources (Felli

et al. 1977). Once their characteristics had been catalogued and measured, these sources were compared with those reported in the catalogues then available in literature. Further observations led to the discovery of 6 new supernova remnants (Bonsignori-Facondi and Tomasi 1979) increasing by 40% the number of these objects in the galactic longitude zone between 15 and 245 degrees.
Observations were then planned with the Dutch WSRT radio telescope and with the Effelsberg 100 m dish to improve knowledge of the extended sources of the BG catalogue. The goal was to verify whether they were galactic or extragalactic objects and, for the galactic sources, to discriminate between HII regions and supernova remnants. More detailed information was requested on their structure and radio emission at higher frequencies. New galactic sources were identified thanks to observations at 1.4 GHz with WSRT (Fanti C., Mantovani and Tomasi 1981). From the observations of sources taken from the BG catalogue and made with the Effelsberg 100-m radio telescope at different frequencies, various papers were then published (Mantovani et al. 1982a, 1982b, 1985).
As a result, the collaborative relationships between researchers from WSRT and the Max-PlanckInstitut für Radioastronomie in Bonn with IRA researchers increased, relationships that would later be consolidated thanks to the VLBI project started at IRA in those years.

During the early 1980s, during the construction of the new Medicina station, S. Montebugnoli and R. Barbieri took part to the continuous observations, Saturday and Sunday included, of the galactic radio source SS433 for which S.R. Bonsignori-Facondi was Principal Investigator. SS433 is a star system in which the main component is a black hole or a neutron star and is the first micro quasar discovered. For many years the data concerning the flux density variations of this source were recorded, then published in Bonsignori-Facondi et al. (1986).

In the early 1990s, a dedicated system for the observation of millisecond and sub-millisecond pulsars was designed and installed for observations with the E-W arm (D'Amico et al. 1996). This made it possible to observe a sample of radio pulsars in conjunction with the Compton Gamma-Ray Observatory mission between 1991 and 1995. From the analysis of the pulse profiles, the values of the period, the derivative of the period and the position of 55 pulsars were obtained.

4 Science with modern interferometers: the WSRT, the VLA and the ATCA

In the mid-1970s, thanks to large interferometers like WSRT, VLA and later VLBI, general interest had shifted from the cataloguing of radio sources to the studies of their physics and their evolutionary models. The high angular resolution achieved with these new instruments made it possible to better study their radio morphology providing information on energy transport and on the interaction between the radio emission and the external environment. The multi-frequency studies made it possible to derive the spectrum of the radio emission, allowing the evaluation of the age of the radio source in case of steepening at high frequency or revealing the existence of compact structures in case of flattening. Finally, the detection of polarized emission gives information on the magnetic field in both the radio source and in the surrounding medium.
Observations made with these instruments made it possible to achieve radio sources structures from large to small scales, providing information useful to discriminate between theoretical models. These investigations while clarifying important doubts at the same time gave rise to new questions: how the energy produced in the nucleus of galaxies was transferred to the external component called lobes? what about the possible interaction between the jet and the environment when the lobes were not aligned with the nucleus and the jets? and finally, could the new data contribute to explaining the evolution of a radio source? Several projects started in these areas of investigation in Bologna, mainly exploiting the policy of open access to WSRT and VLA for external users.

4.1 Radio galaxies

The investigation of a complete sample of 105 radio galaxies of low luminosity with Log P (W/Hz) ≤24, and relatively close with z <0.2 and visual magnitude <17, obtained by identifying the radio sources of the B2 catalogue with bright galaxies, fits into this scientific context.
The redshifts were obtained thanks to the collaboration with M.H. Demoulin-Ulrich of Kitt Peak and Mc Donald Observatory (USA).
This sample is mentioned in the literature as 'The B2 sample of radio galaxies'. The powerful radio galaxies selected from the 3C catalogue had already been extensively studied. This sample of radio galaxies weaker than those of the 3C catalogue, has been studied for many years with WSRT and VLA at diverse frequencies and resolutions. Many were the IRA people involved in this research: C. and R. Fanti, I. Gioia, C. Lari, R. Morganti, M. Murgia, P. Parma, H. de Ruiter and A. Capetti. The investigation of this sample has become one of the institute's most interesting research areas and has involved Italian and foreign collaborators. Many dissertations and two doctoral theses have used the observational data obtained over the years.
The sources were initially observed with the WSRT with short observations called 'short cuts'. The data reduction was made in Bologna with programs developed by C. Fanti. The radio sources with the most interesting structure became the subject of long-term observations again with WSRT at 610, 1400, 5000 MHz. For their data reduction and analysis, P. Parma went to Groningen for 9 months from October 1976, where she worked in collaboration with R. Ekers of the University of Groningen. R. Ekers thus began a collaboration that lasted many years with several scientific staff members of the Institute of Radio Astronomy. Until 1980, P. Parma spent three months a year in Groningen to continue working in collaboration with the Dutch. In 1980, the new GIPSY radio data reduction package went into operation in Groningen, a real breakthrough in this field! GIPSY strongly inspired the NRAO programmers when they wrote AIPS, the VLA data reduction package.
Observations with WSRT of the weak radio sources highlighted, for the first time, the presence of two symmetrical jets with respect to the nucleus. The first introduction to the properties of weak radio sources with dimensions greater than 50 kpc was presented by Ekers et al. (1981). It is with the WSRT observations that a radio source with X-shaped structure was first discovered (B2 0055 + 26) later also observed with the VLA (Ekers et al. 1978). With the VLA it was proposed to observe the whole ' B2 sample of radio galaxies' at 1.4 and 5 GHz with three different resolutions. This project allowed a detailed investigation in to the structure of weak radio sources. At least 50% of these objects showed the presence of double and symmetrical jets and spheroidal lobes characterized by a lack of 'hotspots'. In some case such as 3C 31, the jets turn into long filaments with decreasing brightness. The complete discussion of the properties of weak radio sources was presented in de Ruiter et al. (1990). Some more interesting objects, became the subject of longer observations for more detailed study. See for example B2 0055 + 26 (NGC 326) and B2 1637 + 29 (Ekers et al. 1978 and Murgia et al. 2001).
The observations at 1.4 and 5 GHz allowed the determination the spectral indices of the lobes and consequently the average life of the electrons responsible for the radio emission. It was found that the weak radio sources tend to be older than the more powerful radio sources (Parma et al. 1999). A following collaboration with theoretical astrophysicists like G. Bicknell and R. Laing provided further important explanation of the mechanisms of formation of jets and lobes (Bicknell et al., 1990, Laing et al., 1999).
Observations were also made in the X-ray band and with the Hubble Space Telescope (HST) in collaboration with the University and the Turin Observatory. The observations with the HST showed that most of the galaxies associated with the B2 radio sources show disks of nuclear dust. Furthermore, the optical brightness of galaxies was found to have flat distribution close to the nucleus suggesting that the presence of a radio source affects the distribution of stars in a galaxy (Capetti et al. 2000).

'The B2 sample of radio galaxies', together with the powerful radio sources selected from the 3C catalogue, represents the main source of information on radio sources in the local Universe.

An important tool for studying the physical and evolutionary properties of radio galaxies is the Luminosity Function (FdL), which expresses the probability of radio emission as a function of radio power in a complete sample of objects, i.e. statistically representative, within a unit volume at a certain cosmological era. In addition, the 'bivariate' FdL is introduced, which represents the probability of radio emission as a function not only of radio power but also of optical brightness. The studies conducted at the IRA, using the B2 sample and other literature data, were among the first published in this field. They showed that the probability for a galaxy becoming a radio source strongly depends on its optical brightness (Colla et al. 1975, Auriemma et al. 1977).

A specific problem in this type of analysis was however caused by the limited sensitivity of the radio telescopes, so that the faintest galaxies were not detected and therefore there was only an upper limit to their radio power. Furthermore, having to divide the total sample into different ranges of radio power and optical magnitude, the number of objects present in each bin was very small, so it was important not to neglect the information related to the limits. At the end of the 1970s, R. Fanti developed a method for calculating the bivariate Luminosity Function, also taking into account the radio upper limits, and thus anticipating the statistical studies related to 'Survival Analysis' applied to astrophysics. The method introduced by R. Fanti was widely used in the following years by IRA researchers and foreign colleagues, among others E. Hummel (Holland) and E. Sadler (Australia).

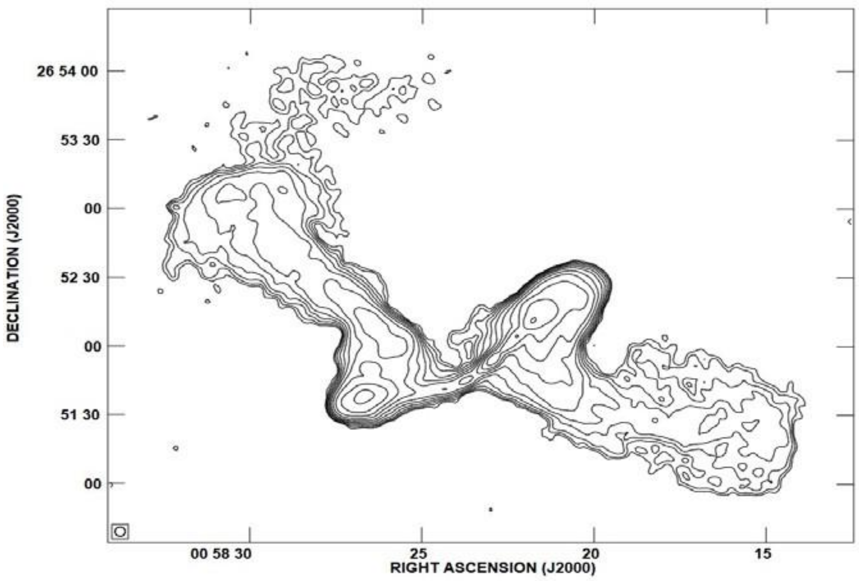


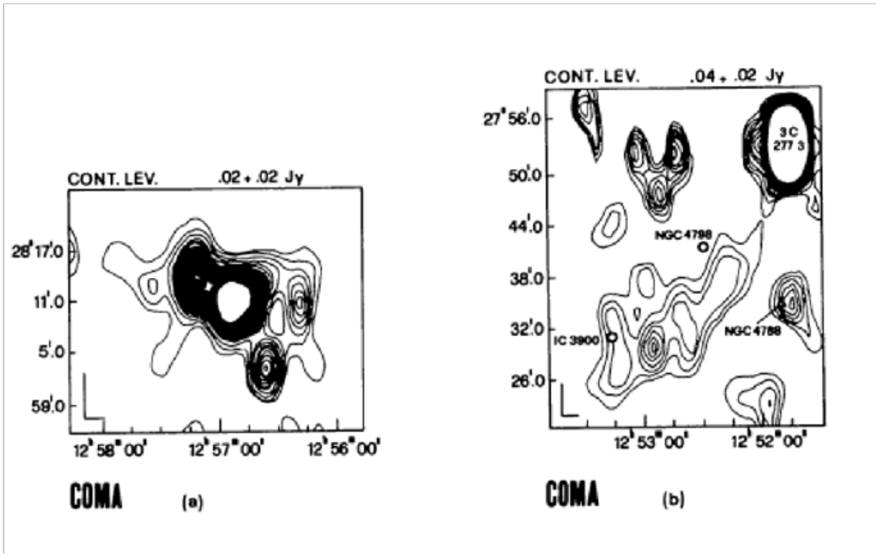
Image of the radio source B2 0055 + 26 (NGC 326), obtained with the VLA, combining observations at 1.4 GHz with two different resolutions (Array A and C) (Murgia et al. 2001). Reproduced with permission © ESO.

4.2 Clusters of galaxies

With the discovery in the second half of the 1970s that clusters of galaxies are made up of galaxies and intergalactic gas, the importance of studying the radio emission of galaxies in clusters was highlighted in order to understand if the interaction with intergalactic gas was affecting their morphology and/or their likelihood of becoming radio sources.

The first study of clusters carried out by IRA scientists was undertaken in the late 1970s with the WSRT radio telescope by C. Lari and collaborators, who observed B2 radio galaxies belonging to 150 clusters. These data proved that galaxies in clusters have different morphological and physical properties than those of isolated galaxies. Preliminary results of that investigation were presented at the “The Large Scale Structure of the Universe” congress, organized in Tallin, Estonia, in 1977 (Lari and Perola, 1978). At the same time, observations were reported in the literature that showed the existence of sources of diffuse emission of uncertain nature in clusters such as Coma and A2256. These sources were called 'halos' if detected in the centre of the cluster and 'relics' if located in peripheral regions.

A question arose: does the diffuse emission in clusters originate from individual radio galaxies, or rather from the intergalactic gas? This question gave rise to the idea of observing a few nearby clusters at 408 MHz with the Northern Cross, an instrument particularly suitable for revealing extensive and diffuse sources of emission. The existence of halos was thus confirmed in Coma and A1367, and the relic 1253 + 275 was discovered on the outskirts of Coma (Ballarati et al. 1981). The Coma cluster was subsequently the subject of numerous studies involving various IRA researchers and is still the subject of experimental study and theoretical debate.



Images of the Coma cluster obtained with the Northern Cross: on the left the centre of the cluster with the emission from radio galaxies and part of the diffuse Coma C emission; on the right the relic 1253 + 275 discovered by these observations on the outskirts of the cluster (Ballarati et al. 1981). Reproduced with permission © ESO.

In November 1978, the satellite for observations in the X-ray band, HEAO-2, later renamed 'Einstein Observatory', was launched. It was the first X-ray satellite capable of producing images. A real revolution was expected in the knowledge of clusters of galaxies. This stimulated Harry van der Laan, scientific director of the Leiden Observatory in the Netherlands, to launch an observational project with WSRT of clusters included in the Einstein Observatory programme, with the aim of better understanding the relationship between radio emission and X-ray emission. The project was called 'RADEX'. The Bolognese colleagues were invited to take part in the plan to observe clusters in Abell's catalogue for which radio data were missing. In October 1979, sixty-three clusters were observed with WSRT at 1.4 GHz. A hundred faint radio sources associated with galaxy clusters were revealed. Unfortunately, the 'EX' part of RADEX didn't function. In fact, the X-ray data were used by the American colleagues to make the first morphological classification of clusters and to propose the first hypotheses on their evolution, neglecting the comparison with the radio emission.

The papers presenting the WSRT survey (Fanti C. et al. 1982, 1983a, 1983b) included as authors the vast majority of the IRA staff members at that time: C. and R. Fanti, L. Feretti, A. Ficarra, I Gioia, G. Giovannini, L. Gregorini, F. Mantovani, L. Padrielli, P. Parma, P. Tomasi, G. Vettolani. The radio observations were complemented, for the closest clusters, by deep optical images and spectroscopic data obtained by B. Marano and V. Zitelli with the Loiano telescope making it possible to identify the optical counterparts of the radio sources and to determine their properties. The radio galaxy sample produced was good enough to allow statistical considerations. It was pointed out that a great difference in morphology exists between radio galaxies inside and outside a cluster. The former contains a large percentage of the so called tailed radio sources, in which jets and lobes are not aligned with the originating galaxy but appear as 'two tails' left behind by the motion of the galaxy. Those with 'open' tails (Wide Angle Tail -WAT) are preferably associated with the brightest elliptical galaxies at the centre of the clusters. The 'narrow' tails (Narrow Angle Tail-NAT or Head Tail-HT), are randomly oriented in the cluster. Furthermore, the WATs seem to move outwards at a slower speed than the HT. The Radio Brightness Function for galaxies in cluster does not differ significantly from that of galaxies that are isolated or in small groups. Since the density of galaxies in Abell clusters is at least 10 times greater than that of isolated galaxies or in small groups, the conclusion was that the density of galaxies in a certain region does not affect the probability of a galaxy becoming a radio source. The most important element for a galaxy to produce radio emission is that the galaxy is a giant elliptical galaxy.

The radio study of clusters at IRA continued to develop in the following years, playing an increasingly important role, becoming a key topic that led to competitive results at the international level. Numerous studies involved both radio galaxies and individual clusters, using WSRT, Effelsberg and VLA. Of particular importance was the study of the Coma cluster, galaxies and diffuse sources, conducted by G. Giovannini, L. Feretti and on which T. Venturi did her doctoral thesis.

The analysis of the interaction between radio galaxies and their environment, which it had not been possible to carry out within the RADEX project, was developed in the following years making use of data extracted from scientific papers. IRA researchers were the first to compare the radio emission of galaxies and the X-ray emission due to their environmental medium (Morganti et al. 1988, Feretti et al. 1990). The studies continued in the second half of the 1990s, using X-ray data from the ROSAT satellite, thanks to the collaboration of L. Feretti and G. Giovannini with H. Böhringer of the MaxPlanck-Institute for Extraterrestrial Physics (MPE) for clusters, and by R. Fanti, L. Feretti, P. Parma with E. Trussoni of the Astronomical Observatory of Turin, S. Massaglia of the University of Turin and W. Brinkmann of the MPE for radio galaxies of the B2 catalogue. From the comparison between the pressure inside the radio-emitting regions and the pressure of the ambient medium derived from the X-ray data, it turned out that the minimum pressure inside the radio source appears lower than the external pressure of the surrounding gas. This apparent imbalance allowed statements to be made about the physical conditions of the radio sources. For example, the radio source is not in the minimum energy state, or the principle of equipartition of the energy i.e. the amount of energy associated to the magnetic field present throughout the volume of the radio source equals the energy associated to electrons and protons besides the absence of low energy electrons, are not valid (Feretti, Perola and Fanti 1992, Feretti et al. 1995a). A further implication is that a significant amount of thermal plasma may exist within the radio emitting plasma, which contributes significantly to the internal pressure. Observations of different tailed radio galaxies carried out with the Effelsberg and VLA radio telescopes, demonstrated that their structure is due to the dynamic pressure exerted by the intergalactic medium on the moving radio galaxies. It was determined that the bending conditions were satisfied if the speed of the jets is of the order of a few thousand km/s. Polarization studies also highlighted that the properties of the surrounding intergalactic medium are consistent with what was revealed by X-ray observations (Giovannini, Feretti and Gregorini 1987, Mack et al. 1993). On the properties of the lobes of radio galaxies, through the study of their radio emission by the Inverse Compton mechanism, Gianfranco Brunetti discussed his doctoral thesis.

In some clusters, extended diffuse regions of radio emission not associated with galaxies in the cluster later named 'halos' or 'relics', were revealed. They proved the existence of both relativistic electrons and magnetic fields in the intergalactic medium. Their study opened up a broad field of both observational and theoretical research at IRA. After the study of typical objects such as Coma C and 1253 + 275 in the Coma cluster, different clusters showing halos and relics were studied, greatly contributing to the knowledge of this class of objects for which the available information were scarce and fragmentary. In IAU Symposium 175 'Extragalactic Radio Sources', held in Bologna in 1995, to celebrate the 100th anniversary of Guglielmo Marconi's first overseas radio transmission experiment, there was a wide discussion of the investigation done on radio sources’ extended emission in clusters. The grounds were laid for future studies that produced fundamental results such as the correlation between diffuse source of emission and the evolutionary history of the clusters.

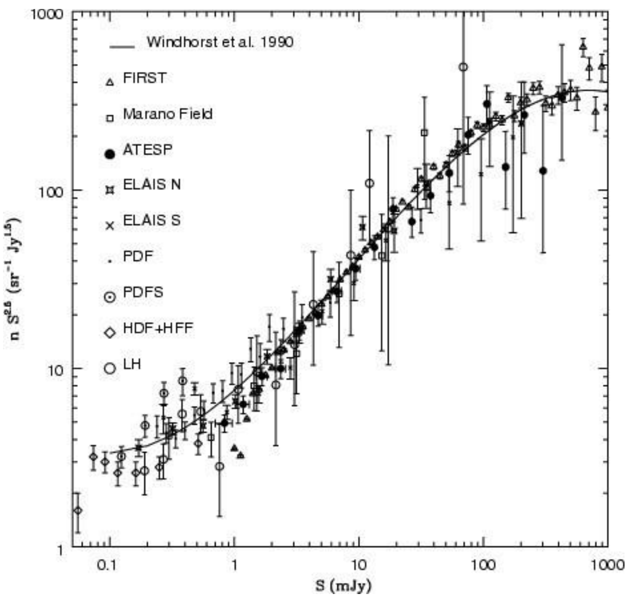
A search for diffuse sources in clusters in the full sky survey of the VLA at 1.4 GHz, namely the NRAO VLA Sky Survey (NVSS), produced the first catalogue of about 20 clusters containing halos and relics (Giovannini, Tordi and Feretti 1999). Further high-sensitivity radio observations with the VLA made it possible to establish that clusters containing diffuse radio emission are all characterized by high X-ray luminosity and have different sub-condensations. For the first time, the hypothesis was advanced that the formation of extended diffuse sources was linked to the existence of recent 'merger' processes, that is, the aggregation through which the clusters are formed and evolve. Theoretical studies were added to the observations which proved the link between radio emission and re-acceleration of the cosmic rays responsible for the radio emission, through turbulent motions and 'shocks' in the intergalactic medium of clusters which were in the 'merger' phase (G. Brunetti 1999; G. Setti, Brunetti et al. 1999). A lively scientific debate also started on the high energy X-ray band emission detected with the BeppoSAX satellite produced by the Inverse Compton effect (Fusco-Femiano et al. 1999). The study of the statistical properties of clusters, their structure, luminosity function, and presence of diffuse radio emission, was extended to the southern sky observing clusters in the 'Shapley concentration' with the Australian MOST and ATCA radio telescopes (Venturi et al. 1997a, 1997b, 1998).

IRA scientists had the great merit of combining the radio study of clusters with halos with X-ray studies to obtain information on the relationship between hot plasma and relativistic plasma. In April 1999 a Workshop entitled "Diffuse Thermal and Relativistic Plasma in Clusters" was held at Ringberg Castle, Germany, organized by H. Böhringer and P. Schücker for the X-ray part, and by L. Feretti for the radio part, at which several IRA scientists attended. That was the first international congress dedicated to the comparison between thermal and non-thermal components in clusters.

Since the diffuse radio emission in clusters is due to relativistic electrons and magnetic fields, an obvious development was to study the magnetic fields in clusters with independent methods, like the analysis of Faraday rotation. The first investigation was related to the magnetic field in Coma (Feretti et al. 1995b) followed by A119 (graduation thesis of Federica Govoni) and many others. A numerical method was developed for the interpretation of observational data. From these studies it emerged that the existence of magnetic fields on scales of some Mpcs is quite common. Federica Govoni carried out her doctoral thesis on the properties of magnetic fields. The question on how these cosmic magnetic fields are produced, on how they evolve, and which role they play in the formation and evolution of the large-scale structure is still open. This is a field in which IRA scientists have achieved international leadership.

4.3 Survey of weak radio sources

At the end of 1993, during a visit by R. Ekers, director of the new Australian Telescope Compact Array (ATCA) radio telescope, the possibility of making radio observations of the sky area covered by the redshift survey ESO Slice Project (ESP) was discussed (see Chapter 9). This was how the survey of weak radio sources named ATESP originated to which L. Gregorini, P. Parma, H. de Ruiter and G. Vettolani participated along with Australian colleagues. ATESP was also the subject of the doctoral thesis of I. Prandoni, financially supported by the CNR-CSIRO agreement. ATESP was made up of 16 regions (mosaics) covering an area of 26 square degrees at declination of - 40 degrees observed with a uniform sensitivity of 79 microJy in 1994-1995. At the time it was the most extensive survey performed at low flux density (Prandoni et al. 2000) with the best determination of low flux radio source counts (0.7 < S < 2 mJy, Prandoni et al. 2001a). Further studies of their optical properties, in which A. Zanichelli also participated, established the optical counterparts of the weak radio source population, which changes drastically passing from mJy to sub-mJy flux densities. "Early-type" galaxies (such as elliptical and S0 galaxies) dominate the mJy population, while galaxies with extensive star formation become important in the sub-mJy regime (Prandoni et al. 2001b). In the following years the composition of the radio weak population was widely discussed in the international literature.



Counts obtained using the weak radio sources of the ATESP 1.4GHz survey compared with those of several other samples. The counts show the number of radio sources that have flux densities within a defined range (Prandoni et al. 2001a). Reproduced with permission © ESO.

Other surveys of weak radio sources were performed on the Lockman Hole area (de Ruiter et al. 1997) for which a deep X-ray survey was also available, and on the Marano field that had available the catalogue of the weakest radio quiet quasars (Gruppioni et al. 1997).

4.4 Supernova remnants

Important, at the turn of the 1980s, were the theoretical and observational works on Supernova remnants carried out by N. Panagia, who moved to IRA from IAS in Rome and by Kurt Weiler, visiting scientist at IRA. Weiler and Panagia (1978) introduced the term 'plerione' (plerion, full) to indicate the class of supernova remnants that did not exhibit the classic ring shape structure, but showed diffuse emission caused by winds originating from the central pulsar, such as in the Crab Nebula. It was also shown that this type of nebula are high energy emitters in both X-ray and gamma-ray. Spectroscopic studies of supernovae in the ultraviolet were then carried out which showed that the explosion had occurred by ejecting various shells into circumstellar space at different times (SN1979c, Panagia et al. 1980). Therefore, for the first time degeneration was defined in the classification of 'type I' supernovae by identifying different classes of objects (Panagia 1984), a result of considerable importance as 'type Ia' supernovae are the most important cosmological standard candle used to determine the scale of cosmological distances.

5 The Very Long Baseline Interferometry (VLBI) project

In the late 1960s, a group of Canadian radio astronomers (Broten et al. 1967) and some American groups (Brown, Carr and Blok 1968; Bare et al. 1967; Moran et al. 1967) were able to obtain interference fringes by combining signals recorded by single antennas not physically connected to each other, but separated by hundreds to thousands of kilometres. The new observational technique was called Very Long Baseline Interferometry (VLBI).
The results achieved in the study of radio sources and the potential scientific implications deriving from observations with higher resolution than that obtainable with classical interferometers, further encouraged the development of the observational technique. In 1972 an observation carried out using the radio telescopes of Westford, Massachusetts, and Simeiz in Crimea, at 22 GHz demonstrated the great angular resolution that was achievable, in that case 0.2 thousandths of an arc second, which allowed the observation of compact regions at the centre of radio galaxies and quasars and to possibly measure their structural variations. In 1971, Alan Whitney and his collaborators (Whitney et al. 1971) discovered superluminal motions, i.e. displacement motions apparently occurring at speeds greater than that of the velocity of light between two central regions of quasars. The proper motions of water masers in galactic sources were then measured (Genzel et al. 1981). The enormous potential of the VLBI technique in applications of astrometry and geodesy was soon understood (Gold 1967, Whitney et al. 1976). NASA and other United States agencies began to establish collaborations for geodetic observations by developing specific data acquisition and data correlation systems.

The US VLBI Network (NUG) was operational in the United States from 1975. This network was able to manage six observing sessions per year with the radio telescopes of Green Bank, OVRO, Haystack, Iowa, Fort Davis. The National Radio Astronomy Observatory suggested setting up 'An Intercontinental VLB Array' (1977) adopting the concept of 'absentee observing'. A service was set up to take care of the observations. A collaborator at each telescope was not required as had been normal up until then.
In 1979 Haystack (MIT) developed a new VLBI data acquisition terminal for geodynamic applications called MKIII, capable of recording with a bandwidth of 28, 56, and 112 MHz at up to 224 Mbit per second. It represented a remarkable technological advance, which led to a significant increase in the sensitivity of VLBI observations compared to the previous MKII system which recorded on a 2 MHz band using VHS videotapes.
Great advances were also made in interferometric data analysis software. The introduction of the CLEAN algorithms (Högbom, 1974), and of 'phase closure' in VLBI (Rogers et al. 1974) and its use in the

production of synthetic images (Wilkinson et al. 1977), made it possible to obtain images of radio sources with a resolution of one thousandth of an arc second.

Interest in the use of the VLBI technique for the observation of radio sources which showed a pointlike structure when observed with classical interferometers also grew enormously in Europe. Radio astronomers remember as legendary the discussion in the MPIfR canteen on 7th April 1975 between the directors of European radio astronomy observatories, Ivan Pauliny-Toth, Eugen Preuss, Roy Booth, and George Miley, about the possibility of setting up a European VLBI network. Some European radio telescopes were already taking part in the observations of the American network.
The first all-European VLBI experiments was carried out in 1976. Two years later the three-station MkII correlator came into operation at MPIfR in Bonn, Germany to correlate data recorded on VHS videotapes. The Jodrell Bank, Onsala, Dwingeloo and Effelsberg radio telescopes took part in the first experiment correlated in Bonn. Among the objects observed at a wavelength of 18 cm was the radio source 3C309.1, whose image was only published years later (Kus et al. 1981): a discouraging indication of the long times that elapsed between the preparation of a VLBI observing project and the publication of its results. In 1978 an "International VLBI Conference" was held in Heidelberg, Germany, of which unfortunately there are no records.

5.1 The beginning

In the 1970s, Bologna began to think about how to improve the observational and technological potential in the radio band by designing a flexible instrument of international interest, aimed at higher frequencies than the 408 MHz of the Northern Cross. Initially a large interferometer was thought of, but WSRT already existed and the VLA was becoming operational. Furthermore, there was neither the manpower nor the finance to tackle a project of that size. But still, there was the interesting option of joining the VLBI venture that had been talked about for a decade, but which was still operating only at a pioneering level.

In 1978, the idea materialized that a possible development of the Italian radio astronomy infrastructure could be achieved by building an orientable parabolic radio telescope, which would allow participation in long-base line interferometric observations in a network of radio telescopes. The original proposal to the CNR in 1978 was to build three twin radio telescopes capable of working up to 20-30 GHz, the first to be placed at the Medicina radio astronomy station, the second in the southern tip of Sicily and the third in Sardinia. The choice was discussed with European radio astronomy centres in order to optimally extend the VLBI network for both astronomical and geodetic studies. With this aim the diagrams that provide the performance of a network based on the distribution of the various radio telescopes (coverage of the u-v plane), made by Carla Fanti, were used. Due to the scarce availability of funds, the project had to be limited to just 2 antennas. The new infrastructure was illustrated by G. Setti at the Strasbourg International Workshop "Terrestrial and Space Techniques in Earthquake Prediction Research" (Setti 1979). The intention was to build two adjustable parabolic antennas of 25 meters in diameter, capable of observing up to centimetre wavelengths, about 22 GHz: one to be installed in Medicina, a radio astronomy station with competent personnel, the second in Sardinia or in Southern Italy. The two antennas would work in connection with the European and American VLBI networks. It was reported that there was a good chance that the project would start by 1979, be finished in five years, and that the first antenna in Medicina would become operational within three years.

In the realization of the Italian VLBI Project, it was decided to build two antennas of 25 m in diameter, adapting the design of the VLA antennas of Socorro, New Mexico of the NRAO. A mail exchange began between G. Setti and the NRAO engineers regarding the parabolic antenna, replicated 27 times to build the fantastic American interferometer. Having obtained the drawings of the VLA parabolic dish, they tried to understand what its cost could be by adopting an Azimuth movement on a rail fixed on a foundation. One of the companies involved was the S.A.F.I.T of Milan. Another was 'DB Macchine SPA' which made a cost estimate in September 1979. For an antenna, the expected cost was 655 million lire (equivalent to about 2 M euros today). By ordering two, the total cost would become 1 billion and 250 million lire. Delivery could take place within twelve to fourteen months from the order. Subsequently, 'DB Macchine SPA' informed IRA that one of the companies with which it operated in the field of telecommunications antennas, TIW SYSTEMS, INC. was also interested. Installed and functioning, the two antennas designed by TIW would cost a total of 1 billion and 70 million lire excluding foundations.

For the analysis of the terrain to locate the antenna at Medicina, the Technical Study of Eng. Giorgio Conti, Bologna, was chosen. Meanwhile in August, the CNR Administrative Council had approved the financing of the VLBI 'equipment' to be paid by chap. 412193 - Expenses of the Budget for the financial year 1979 - for an amount of 1,2 billion lire.

In December 1979, IRA made a proposal to purchase a large diameter antenna, of 'about' 25 m, and a Mark III data acquisition system for astronomy and geophysics produced by the NEROC Haystack Observatory. It is striking that the proposal, addressed to the CNR, contained an uncertainty in the diameter of the antenna in a document that detailed the specifications required for the dish. This vagueness in the diameter suggests that negotiations were underway with the TIW. In fact, on October 16th 1980 G. Setti informed the CNR that the preference was for the 32 m paraboloid designed by TIW. In addition to having an area almost double than that of the 25 m dish, the project provided for the rooms for housing equipment and staff in the foundation plinth. The cost of two dishes ordered together became 1,111,145 US dollars (approximately 2.8 M euros today). Following the negotiations, the SAE was commissioned to build the antenna structure, and 'DB Macchine SPA' to build the antenna panels.

The President of the CNR Ernesto Quagliarello ordered the purchase on December 31, 1980. The expense represented part of a commitment planned over 4 years in the Large Equipment Expenditure Items of General Scientific Interest.

The design of the antenna support foundations had to take into account specifications that required elastic deformations of less than 0.1 mm. The construction of the base was entrusted by the CNR to SAE in June 1981 based on a project by Eng. Conti. About twenty days later, the commission in charge: G. Setti, president, A. Bombonati, G. Grueff for the IRA, G. Curioni, M. Catarzi, N. Speroni, G. Tofani for the Arcetri Astrophysical Observatory involved in the project, B. Hooghoudt external consultant for the CNR, sent to the CNR the factory acceptance text of the first VLBI antenna that had been produced.

Assemblers at work in 1982 to complete the support structure of the primary mirror of the 32m diameter parabolic antenna at the Medicina radio astronomy station. Credits: INAF-IRA

5.2 Birth of the European VLBI Network (EVN)

In 1984 IRA was among the founding institutes of the "Consortium of European Radio Astronomy Institutes for Very Long Baseline Interferometry" established on July 24th. The Consortium drew up a statute signed by R. Booth director of the Onsala Space Observatory, W. Brouw director of The Netherlands Foundation for Radio Astronomy - Westerbork, P. Metzger, director of the Max-PlanckInstitut für Radioastronomie, F. Graham Smith director of Nuffield Radio Astronomy Laboratories - Jodrell Bank, and by G. Setti director of the Institute of Radio Astronomy. G. Setti was appointed Chairman of the Board of the EVN Consortium. In that capacity in December he recommended to the President of the CNR L. Rossi Bernardi that the Consortium should recieve official recognition from the European Science Foundation.

The first meeting of the EVN Consortium in 1985. To the left of the short side of the table G. Setti chairman of the Board

From the first observations started in 1980, EVN also operated with an 'open skies' policy. The observation proposals could therefore be submitted by any scientific member of a research institution. The EVN guaranteed the data recording at each antenna to any radio astronomer even if he was not a member of one of the VLBI network institutes. The EVN Program Committee (EVNPC) in charge of examining the proposals initially comprised five representatives of the Consortium's founding observatories (Effelsberg, Westerbork, Jodrell Bank, Onsala and Bologna) and three 'nonVLBI' members. R. Fanti was the first scientist appointed as a member of the EVNPC to represent IRA. The EVNPC met three times a year to review the projects submitted in response to the 'Calls for Proposals' published in February, June and October 1st each year. The four EVN telescopes were able to observe at 1.4, 1.6 and 5.0 GHz. In 1983 the frequency of 610 MHz was also added.

5.3 Technological development

In parallel with the construction of the dish, the IRA technology sector had to be readied to acquire radio observations following the VLBI specifications.

Already in May 1979, IRA informed the Ministry of Posts and Telecommunications that it intended to apply to the International Frequency Registration Board (since 1992 the Radio Regulation Board) for the radio frequencies ranging in the band from 600 MHZ to 24 GHz. The data acquisition system would have started its first tests in mid-1981 and would have become operational in January 1983 with the first antenna located in Fiorentina, a hamlet of Medicina, in the province of Bologna, while a second antenna would have been built in Southern Italy or in the islands. The possible construction of a fully steerable 8 m diameter mobile paraboloid, which could be operated anywhere nation-wide was also mentioned. The antennas, it was added, would observe 24 hours a day seamlessly, with receivers operating from 600 MHz to 24 GHz with a bandwidth ranging from 8 MHz to 400 MHz depending on the observing frequency.
The experience gained in making receivers for the Northern Cross in the 1960s proved to be useful to the IRA microwave laboratory staff in designing and building newly conceived receivers to be mounted

on the new dishes. They had to respond to the request by the observers to have available microwave 'front-ends' with very low noise temperatures together with accessories such as mixers, local oscillators and more, still not available on the market.

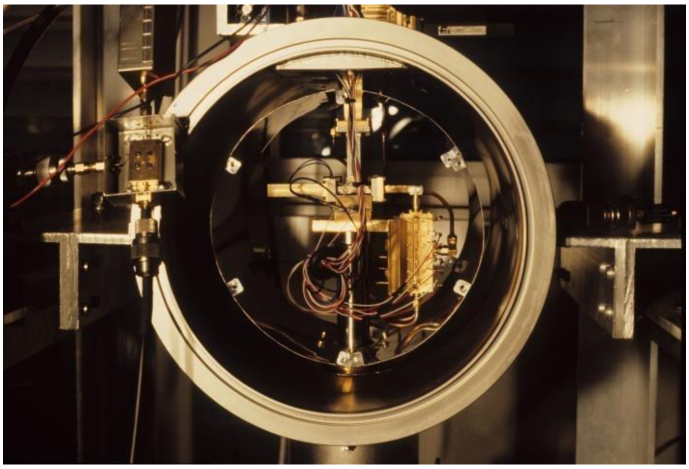


Image of the first cooled receiver designed by the IRA microwave laboratoryhe interior of the DEWAR, the cryogenic container for liquid nitrogen. Keeping the receiver at temperatures of the order of 10 °K limits strong white noise, partly caused by the receiver itself, which is superimposed on the weak radio astronomy signal. Credits: INAF-IRA

Around 1982 High Electron Mobility Transistors (HEMTs) were put on the market. These belong to the class of field effect transistors (FETs), widely used in Medicina in the correlators designed by G. Sinigaglia. Manufacturers guaranteed noise temperatures of the order of 150 °K in the 10 GHz band for HEMTs with power gains greater than 6 dB. Reliable American sources claimed that such devices could have operated even at cryogenic temperatures of 15 °K. The hope was to create a prototype capable of improving on the specifications declared by the manufacturer. In the USA and Europe, printed circuit-type solutions were under test with modest results. This solution was proposed by G. Tomassetti and successfully tested in the IRA laboratories in Medicina. The receiver, called 'scatolino'(small box), cooled to 10 °K was able to guarantee a gain in the 10 GHz band of just under 10 dB and a noise temperature of about 50 °K. Considered a 'bomb' for that time, the design of the receiver had wide resonance in the radio astronomy field worldwide.
A two-channel receiver for observations at 22.3 GHz was then designed and built. The two 'front-ends' and the HEMT mixers were housed inside a vacuum chamber at a physical temperature of 15 °K. The frequency multiplier was also produced at the IRA. It was able to work at a system temperature of only 50 °K. The Medicina dish became one of the few EVN radio telescopes capable of observing at this frequency stand alone and in a network with the VLBI technique (more details in chapter 7). Thus thanks to G. Tomassetti and the contribution of R. Ambrosini, A. Orfei and G. Tuccari (in Noto), the IRA became an international point of reference in this field.

In the development of the VLBI project, the IRA worked in strong connection with the "Center for Infrared Astronomy and the Study of the Interstellar Medium" (CAISMI) hosted at the Arcetri Astrophysical Observatory in Florence. CAISMI was a CNR centre dedicated to the development of radio and infrared band technologies and to investigations of the physics of extragalactic objects and star formation. In the 1980s it was in charge for building TIRGO, a 1.5-meter infrared telescope located on Gornegrat in the Swiss Alps (P. Salinari, 1982), which it has managed ever since.

The competence of the CAISMI technologists proved to be very useful in the application of cryogenic techniques developed to obtain receivers with low noise temperature for the new dishes. The electromagnetic analyses they carried out on the behaviour of the antennas turned out to be crucial (Bolli et al. 2000). The greatest collaboration between IRA and CAISMI has been in designing high frequency receiving systems at 22 and 43 GHz, which included directional couplers, polarizers and corrugated feed horns. In parabolic dishes the feed horn is the antenna used to transmit radio waves between the receiver and the parabolic reflector. To design them, powerful software packages for simulations and analysis were developed with particular attention to the implementation of new electromagnetic techniques (for example Gentili 2002).

5.4 VLBI observations begin

G. Setti at 09:58 on April 3, 1984, sent a telex to the President of the CNR Ernesto Quagliariello:
"Dear President,
It is with great satisfaction, mine and all of the staff members, that I wish to inform you that the first VLBI connection experiment, which took place last Monday (March 26, 1984) between the new radio telescope of Medicina and that of Effelsberg (Bonn), was perfectly successful.
The interference fringes relating to the radio source observed are clearly evident and have also allowed us to determine the position of our antenna with great precision.
This pays back with full success the activation of the radio telescope which from now on will enter the European and world network. Best regards.
Giancarlo Setti "

This first test, like many of the observations made later, used a data acquisition terminal called MarkII which recorded the radio signals received by the antenna on VHS magnetic tapes, then in use for recording on video cassettes. The Mark II system was built in the digital laboratory of Medicina (Comoretto and Gallerani 1985), together with the modified heads of the VHS recorders needed to adapt the recording format to the VLBI standard.

In 1985 G. Grueff submitted to the CNR the memorandum entitled 'Development prospects for the VLBI Project in relation to possible funding for the promotion of Scientific Research in Southern Italy'. Some parts of the memorandum are of particular interest. It was suggested that Italy be equipped with a standard MKIII four-station correlator through an investment of 1,600 million lire (approximately 2.1 M current euros), to provide a qualified astronomical and geophysical service to the European scientific community. The Italian Space Agency, which had built a radio telescope near Matera, was also interested in geodynamics and the tracking of space probes. The scientific value of the Italian VLBI project would have increased with the creation of local dedicated 'data processing' structures, i.e. a correlator.
The CNR made itself available to finance the purchase of a MarkIII terminal and a magnetic tape recorder for the Medicina station. The 1-inch tape, wrapped on a 14-inch diameter spool, was 2.7 km long. On each tape, 10 Gbits of data could be recorded on 28 tracks. Different recording modes were possible at different bit-rates. Each track could record up to 8 Mbits/s. The maximum bit-rate was 224 Mbit/s. Compared to the MKII system, it allowed an increase in observation sensitivity of a factor of seven. The terminal had fourteen independent 'Base Band Converters' (BBCs) for the conversion of the sky frequency to the medium frequency, which made it particularly suitable for geodynamic observations. In 1982 the first European VLBI correlator, able to correlate data recorded with the MKIII terminal, was already working at the MPIfR in Bonn.

When the MarkIII terminal was delivered to Medicina, it turned out that this complicated data acquisition system had been damaged during transport. Once repaired and installed, a test observation was immediately arranged between Effelsberg and Medicina. Obtaining interference fringes would have validated the data acquisition system. After sending the tape to the correlator in Bonn, all the staff waited for the response. Negative! No fringes.

It could also be due to a malfunction of Effelsberg's MKIII, the Medicina researchers thought, after a thorough check of the local MarkIII, to mitigate their frustration. In fact, it seemed that everything was fine. Then it was discovered that the connector of the cable that carried the signals from the BBCs to the recorder was disconnected, a disconnection that had escaped control as the connector appeared to be properly inserted. An unintentional bump while moving around the terminal could easily have caused it to be actually disconnected. Confident that this was the cause of the malfunctioning, a new test was organized with Effelsberg on December 6, 1984. The two telescopes observed the powerful radio source BL Lacertae. The tape recorded in Medicina was quickly shipped to the correlator and the agonizing wait of the entire IRA staff began. This time magnificent interference fringes appeared on the correlator control screen. On 11 December 1984, G. Grueff was able to communicate to S. Martellucci, President of the National Physics Committee of the CNR, that the experiment with the MarkIII terminal had been a success. The experiment, Grueff wrote, allowed the verification of the performance of three important components of the Medicina radio telescope: a low noise, 100 °K, wide band, 500 MHz, and double circular polarization receiver operating at 10.7 GHz fully developed by IRA; a Standard Frequency Hydrogen Maser unit intended for the future Station of Noto (SR); and finally the MKIII broadband data acquisition terminal for VLBI.

The VLBI MKIII terminal of the Medicina station. On the left, the devices for converting the observation frequency to medium frequency, the 14 Base Band Converters, and the apparatus that prepares the signal before being sent to the magnetic tape recorder on the right. Credits: INAF-IRA

G. Grueff enclosed with the letter a copy of the congratulatory telegram sent by the person responsible for the correlator at MPIfR and letter from the Caltech Correlation Centre with positive judgments on the quality of the recorded data provided up to then by the Medicina antenna. Grueff concluded his letter by emphasizing that the VLBI Project was proceeding positively despite difficulties and delays relating to the construction of the second antenna for the Noto (SR) station.

The Scientific Council of IRA composed of GC Perola, G. Grueff, L. Padrielli, M. Vigotti, S. Montebugnoli, C. Barbieri and F. Pacini, in the meeting of 26 June 1984 heard a report by the Acting Director G. Grueff, on the status of the VLBI project. The situation at the Medicina station was considered very satisfactory. The antenna met the specifications required for pointing accuracy, mirror surface efficiency, frequency and sample stability, etc. A few days later the Commission for the Final Acceptance of the VLBI Parabolic Radio Telescope at the Medicina Station composed of G. Setti, G. Tofani, G. Grueff and A. Bombonati, unanimously expressed itself in favour of its definitive acceptance. The initial design of the Medicina antenna had been modified from the original design. An unexpected response of the ground to static stresses had required an increase in the number of support posts and simultaneously, a decrease in the static loads affecting them. It was then decided to build a separate building to house the equipment, instead of placing it, as originally planned, within the foundation. The result was a foundation with excellent rigidity and stability and a more rational arrangement to house technicians, scientists and the instrumentation.

Inauguration of the 32 m dish of Medicina on October 18, 1983. Top: Iole and Giancarlo Setti throw the traditional bottle of sparkling wine. Below: The Northern Cross and the dish. Credits: INAF-IRA

5.5 A second antenna: Noto

The location of the antenna in Noto, in the province of Syracuse, was established in November 1981 in a meeting between IRA representatives: R. Ambrosini, G. Grueff, and G. Tofani, and representatives of the CNR Geodynamic Finalized Project: P. Scandone of the Institute of Geology of Pisa, and L. Vezzani of the Institute of Geology of Turin. The geophysical community was interested in geodynamic measurements with the VLBI technique.
From the astrophysical point of view there were no presupposition on where to place the second antenna. A location far south was preferred by the IRA people to increase the angular resolution of the EVN in the North-South direction. The areas of the Italian territory that were most suitable for the measurement of regular, therefore interpretable, movements of the earth's crust were Sardinia, the triangle Augusta, Comiso, Pachino on the southern tip of Sicily, and Puglia excluding the Gargano area. The location in Sardinia was considered not a priority since the island is connected to the plate of Central Europe where VLBI antennas were already in operation. Among the other two areas indicated by the geophysicists, southern Sicily was preferred. The place was later defined with the advice of L. Vezzani and F. Ghisetti, a location near fractures or areas of geological instability. The choice fell on 'Case di Mezzo' in the Renna Bassa district near Noto.
In January 1982, the President of the CNR wrote to the Mayor of Noto communicating the intentions of IRA and what was the logistical support necessary for the installation of the radio telescope. The Municipal Administration of Noto ensured maximum support for the project. The radio astronomy station needed about 1.5 hectares of land and information relating to its stratification before the final selection site was made.
It was necessary to involve the Sicilian Regional Government. G. Setti sent a memorandum in January 1983 to the President Hon. Calogero Lo Giudice concerning the definition of the project which included urbanization works and buildings for an estimated cost of 1,950 million lire (equivalent to 3.2 M current euros currently). In the meantime, the CNR Property Assets Service was asked to proceed as soon as possible with the purchase of the necessary land, while the Municipal Council of Noto requested the Regional Government to proceed with the financing of the VLBI project. In July, the Sicilian Regional Assembly approved the bill presented by President Lo Giudice for the 'Construction of a radio astronomy station in the municipality of Noto' with an estimated cost of 1,800 million lire. The following year, SAE was entrusted with the design and construction of the support foundation, power systems and service rooms for the radio telescope. The metal structure of the antenna was available already.
There was concern about finding the necessary personnel for the management of the Station. G. Setti wrote to the CNR President L. Rossi Bernardi, to the General Manager M. Moretti and to the President of the Physical Sciences Committee S. Martellucci, on the urgent need for a minimum of ten new personnel. He wrote 'it is considered essential that the said personnel, at least in part, be able to receive adequate training at the Radio Astronomical Station of Medicina before starting activities at the Radio Astronomical Station of Noto'. The station was expected to be completed by SAE in 1986 through a 'turnkey' contract. The reaction of the CNR was not immediate. Still in May 1986 the bureaucratic process to get the concession for the construction of the station was not completed. It would be necessary to wait until the end of 1986 for the building permit to be obtained for SAE. The construction, according to the contract, had to be finish by October 17, 1988. To follow progress, the Administrative Council of the CNR appointed a Working Group in the persons of G. Tofani, N. Speroni, P. Tomasi, M. Morsiani, A. Bombonati, as support to the 'Inspection Commission for the activity in progress and final acceptance' composed of V. Aliberti, A. Caruso, A. Fasulo and D. Carrara.

In 1986 G. Grueff's mandate as Acting Director of IRA expired. The new Acting Director appointed was L. Padrielli. G. Grueff was able to dedicate more time to following the construction of the Noto

antenna. In the meantime, the CNR had not yet taken steps, despite countless requests, to hire the personnel required to operate the station. However, the construction of the antenna proceeded. There were concerns about the quality of the concrete used for the foundation of the antenna and there were fears for the stability of the foundations. After verification and consultation, the antenna was finally finished and in November 1988 the commission in charge (L. Padrielli, G. Grueff, A. Bombonati) informed the CNR that the acceptance tests had been carried out and that the parabolic dish responded to the requested specifications.
The Noto station was inaugurated on October 28th, 1988.
The Presidential Council of the CNR, in the meeting of 18th May 1989 approved the establishment of a section of IRA in Noto with four technical-professional collaborators, six technical-professional assistants, two operators and an administrative assistant.
The station was in a hurry to become operational. L. Padrielli wrote a letter to the CNR Property Assets Service in November 1989 requesting 'the early delivery of the radio astronomy station of Noto'. With numerous inspections, the IRA staff had verified that the works envisaged in the contract had been carried out correctly.
The necessary personnel for the Noto station was therefore hired for its management and Salvo Buttaccio, Corrado Contavalle, Carmelo Nicotra, Leonardo Nicotra, Carlo Nocita and Luigi Papaleo took up service.

In 1989 the Public Broadcasting Service, an American television network, made a film on the VLBI technique by visiting American and European stations, including Noto, which were involved in the observation of NGC 1275. The film, included in the TV series "The Astronomers", was a great success with the public.

At the end of 1988, Italy therefore had three antennas for VLBI observations: The Medicina dish inaugurated in 1983, that of Noto in 1988 and the 20 m dish in Matera of the Italian Space Agency inaugurated on 17 December 1983.
The Medicina and Noto antennas were part of the European VLBI Network from when they came into operation. The Matera antenna, dedicated to VLBI geodynamic observations, would join the EVN in 1995 by participating on request only in S/X band observations.

The 32 m diameter antenna inaugurated on October 28th, 1988 near Noto (SR). To the left of the antenna the buildings of the radio astronomy station. Credits: INAF-IRA

The interest aroused in the Italian scientific and political communities, the significant monetary costs, and the impact that the VLBI project would have on radio astronomy and astrophysical studies were all appreciated internationally. Subsequently the International Astronomical Union (IAU) approved the IRA's proposal to organize Symposium No. 110 entitled "VLBI and Compact Radio Sources" (see chapter 5.7).
To increase the involvement of the IRA antennas in the observation activities of the American VLBI network, it was necessary to become Associate Members of the U.S. VLBI Network Consortium which was formed in November 1981. It included Caltech, the Harvard-Smithsonian Centre for Astrophysics, the Massachusetts Institute of Technology, the University of California at Berkeley, and the University of Iowa. The 'Memorandum of Agreement among Member Institutions' was signed by the IRA Director G. Setti and the Acting Director G. Grueff on February 22, 1986. In Europe only the MPIfR was associated with the American VLBI network, while two other associated institutions were American, the Jet Propulsion Laboratory and the Naval Research Laboratory. In April, G. Grueff attended the meeting of the American VLBI Consortium Committee, where the IRA's request to join the Consortium was unanimously approved and Grueff was hailed as a new member of the Consortium Committee. The institute found itself in very qualified company.

The final chapter of Grueff's memorandum 'Prospects for the development of the VLBI Project in relation to possible funding for the promotion of Scientific Research in Southern Italy' advocated the construction of a third VLBI station, to complete the original VLBI Project which indicated the regions of Sicily, Puglia, and Sardinia, as all interesting from the geophysical point of view. Sardinia would was particularly suitable for hosting a third antenna, the construction of which was expected to cost 5 billion lire. At that point, it was argued, that Italy would become the most important partner of the European and American VLBI network.

5.6 Towards a third antenna: Sardinia Radio Telescope (SRT) project

The original VLBI project, as mentioned in chapter 5.1, involved constructing three dishes. While the construction of the Noto station was beginning, the construction of a third station in Sardinia was proposed, equipped with a parabolic antenna with a 'minimum' diameter of 32 meters.
The document drawn up by G. Setti is dated 21 February 1987 and was entitled: 'Proposal for a research initiative with the special funding of the Cassa del Mezzogiorno' (Funds for the Southern Italy).
The scientific motivation concerned geodynamics and radio astronomy. The 'Progetto Finalizzato Geodinamica' (Geodynamics Project Plan) by itself had previously indicated as a priority the installation of an antenna on the southern tip of Sicily. Other key sites were Puglia and Sardinia. In Basilicata, close to the Apulian region, there was already the ASI antenna. For geodynamic purposes it was thus more useful to place a third antenna in Sardinia. For astronomy in this way, an Italian VLBI antenna system complementary in angular resolution with other interferometric systems such as the English MERLIN and EVN itself would have been set up that would profitably contribute to the astrophysical study of radio sources.

The idea of building a radio telescope in Sardinia took shape in 1990 during a meeting between Luciano Guerriero, then President of the Italian Space Agency (ASI) and G. Setti, Director of the IRA. A large radio telescope in Sardinia was believed to be capable of opening new interesting perspectives for the development of radio astronomy research in Italy and for ASI programs connected with the Deep Space Network (DSN) for Radio Science experiments. L. Padrielli, Acting Director of the IRA and G. Grueff were informed about the content of the conversation. It was thought that a large dish with a diameter of 60-70 m, capable of operating with good efficiency at frequencies up to 100 GHz, would represent an excellent opportunity for radio astronomy research and a significant contribution to the EVN.

At the end of 1990 ASI invited IRA to submit a proposal for the feasibility study of an antenna of at least 64 m in diameter. It had to contain a cost estimate and an assessment of its scientific potential and space applications with in an international scenario. The IRA project was approved by ASI in 1992 and was endowed with a fund of 230,000 euros. CAISMI was associated with the project and G. Grueff was recommended as project manager.

The international tender for the feasibility study was won in 1993 by TIW Systems Inc. of Santa Clara, USA, one of the five participants. In March two years later, the project for a 64 m diameter antenna capable of observing at frequencies up to 100 GHz was presented by IRA at ASI headquarters. Its cost, excluding taxes, was estimated to be 36 million euros.

With the collaboration of the Cagliari Observatory, contacts were established with the Sardinian Regional Government for the location of the antenna. A campaign was undertaken to select the site taking into account atmospheric conditions and electromagnetic interference. The chosen site, in the Municipality of San Basilio in the Province of Cagliari, was approved by the Sardinia Region in May 1998.

There was still the not simple problem of finding the necessary funds for its construction. From 1994 ASI had to deal with changes in management and financial resources. Even the CNR was reluctant to commit to a project that required substantial funding. The Ministry of University and Scientific and Technological Research (MURST) remained interested in the project in line with its policy of expanding research activities in Sardinia, and was supported in this by the positive opinion expressed by the Council for Astronomical Research (CRA). Strong support for the project came from the Jet Propulsion Laboratory in anticipation of the Radio Science experiment planned for the joint NASA/ESA/ASI Cassini-Huygens interplanetary robotic mission, whose launch was scheduled for October 15th, 1997 with the task of studying the Saturn system, including its moons and rings. ASI was also interested in the possible involvement of the Sardinian radio telescope in future missions in deep space as an element of the NASA Deep Space Network.

Based on the official and documented request of IRA, MURST verified the possibility of financing the construction of the Sardinian Radio Telescope SRT with EU funds for the development of research in disadvantaged areas of Southern Europe. In the meantime, Minister Luigi Berlinguer decided to apply the law (L.D. 488/92) for the promotion of research in Southern Italy, assigning a considerable budget for the purpose. IRA resubmitted the SRT project to MURST in July 1996, also proposing to finance an improvement in the performance of the Noto antenna by mounting actuators under its mirror panels, with the aim was to preserve its parabolic shape by correcting effects such as gravity, wind, temperature variations. The radio telescope could thus operate with better efficiency especially at millimetre wavelengths. This step was considered useful to gain necessary experience in anticipation of the construction of a large diameter antenna like SRT.

One of the panels of the Noto antenna (SR) supported by an actuator (left); measurements on the parabolic surface were carried out at night to minimize thermal effects on the mirror structure (right). Credits: INAF-IRA

In September 1997, MURST approved a funding of 31 million euros for the 'Radio astronomy Cluster', of which 2% should to be used to improve the performance of the Noto antenna.
Responsibility for the execution of the SRT project was assigned to the CNR, actually to the IRA. The importance of the participation of ASI and of the Sardinia Region was also recognized. The planned budget was lower than the estimates of the feasibility study, but it was considered sufficient to build the main structure of SRT. MURST, towards the end of 1997, requested the executive project from IRA. The persons responsible for the procedure were L. Padrielli, who had become Director of IRA, G. Grueff, Project Manager, and G. Setti, Scientific Director. The project was approved by MURST only in May 1999. Meanwhile, CNR, ASI and the Sardinia Region signed an agreement that defined commitments and forms of collaboration. To accelerate the construction of SRT, in March 1999 ASI awarded Vertex RSI, the company that had incorporated TIW Inc., a contract for the drafting of the executive project under the supervision of G. Grueff, draft was completed in two years and made available to ASI in March 2001. For its part, the Sardinia Region through the Cagliari Observatory financed the construction of the antenna’s foundations and the infrastructures for 5.2 million euros.
After 2000, the construction continued, not without complications, which delayed the inauguration of SRT until 30 September 2013. More details on the SRT project are available in the contribution of G. Setti (2006) 'Synthetic history of the SRT project'.

5.7 Scientific developments of the VLBI

In parallel with the technological development for the construction of the VLBI antennas, the scientific staff of IRA began to investigate the astrophysical aspects related to the new technique. The greatest interest in radio astronomy was, and still is, aimed at high frequencies and high angular resolution.
At the beginning of 1980 the observations of compact sources at 18 cm started with the collaboration of several international scientists such as N. Bartel, K. Weiler, J. Romney, Nan Rendong, L.B. Baath, L. Kogan, L. Matveenko, I.G. Moiseev, G. Nicolson. A suitable software was developed locally to process VLBI data, which remained in use for a long time, gradually replaced by the “Difmap” software developed at Caltech and by AIPS written to process VLA data and later adapted for processing also VLBI data.
As previously mentioned, starting from 1975 a group of IRA researchers coordinated by C. and R. Fanti and by L. Padrielli became interested in understanding the nature and properties of low frequency variable radio sources (LFV), observed periodically with the Northern Cross. Understanding the phenomenon of variability required knowledge of their structure on angular scales of the order of one thousandth of a second of arc. Not surprisingly, the first VLBI observations proposed by IRA

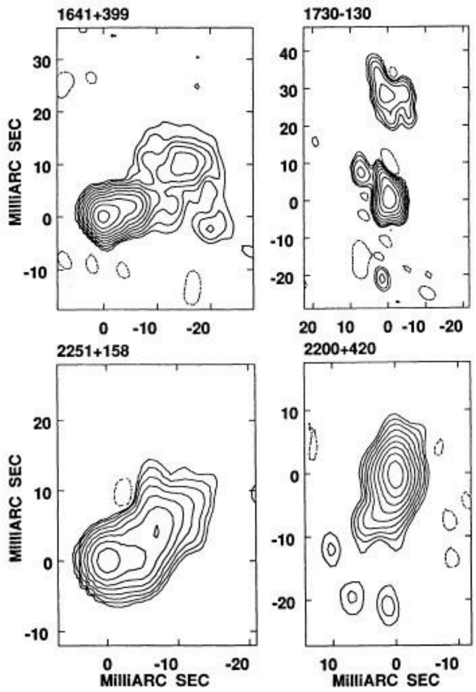
researchers concerned the cores of these sources. In 1980-81 L. Padrielli and A. Ficarra went to Bonn to the MPIfR for the correlation of MarkII observations at 18 cm of 25 LFV whose structure was not known and of four sources of known structure used as calibrators. The observations, in which seven European and American radio telescopes participated, lasted fortyeight hours. The maps, called 'hybrid' because they were produced using 'phase closures', were independently produced at IRA, MPIfR and MIT. The preliminary results obtained for two sources were presented by L.I. Matveyenko et al. (1982), while the results on the whole sample appeared in J. Romney et al. (1984).

In 1981 F. Mantovani went for a year to MPIfR to work with the VLBI group and gain experience in the technique as well as to produce VLBI images of the LFVs. In October 1981, L. Padrielli, A. Ficarra and F. Mantovani, together with seven other MPIfR researchers, were invited to the USSR on an official scientific visit by L.I. Matveyenko. They visited the Academy of Sciences in Moscow and Leningrad and the Simeiz VLBI station in Crimea. In working meetings the results obtained by the monitoring programme with the East-West arm of the Northern Cross on the LFVs and their preliminary images obtained processing the VLBI data set were presented. The first epoch of VLBI observations was followed by a second epoch. All the hybrid maps of this second series were produced at IRA on the VAX 11/780 of the Computing Centre of the institute using AIPS (Padrielli et al. 1986).

The members of the delegation of the Institute of Radioastronomy and of the Max-Planck-Institut für Radioastronomie who visited the USSR in 1981 at the invitation of the Academy of Sciences. Lucia Padrielli is visible in the first row in the centre of the image; Tonino Ficarra is fourth from the right. Credits: Franco Mantovani

The VLBI observations showed that only the sources whose variability occurred from low to high frequencies with continuity, indicating that the variability was intrinsic to the radio source, showed structural changes. For the others, the variability was to be attributed to the scintillation of the signal caused by the interstellar medium, a sort of variability called extrinsic (Padrielli et al. 1991). These interpretations of the variability phenomenon were preliminarily presented at the 1987 IAU Symposium 'The Impact of VLBI on Astrophysics and Geophysics' in Cambridge, USA and at the IAU General Assembly in 1988 in Baltimore, USA. There was a third epoch of VLBI observations of LFVs made in 1987 using twelve antennas. The recorded data set was then correlated with the 10-stations

Block2 correlator of the Caltech by F. Mantovani. The comparison between the three epochs appeared in M. Bondi et al. (1996b).



Images of 4 of the 20 low frequency variable sources observed at 1.67 GHz with the VLBI technique from a set of 11 radio telescopes: Effelsberg (Germany), Jodrell Bank (GB), Medicina (Italy), Simeiz (Crimea), Hartebeesthoek (South Africa), Green Bank (USA), Haystack (USA), Maryland Point (USA), North Liberty (USA), Fort Davis (USA) and Owens Valley (USA) (Bondi et al. 1996b). Reproduced with permission © ESO.

The number of antennas participating in the Global VLBI observations with the involvement of American and European antennas continued to grow making the correlation phase longer because the existing correlators were capable of combining data from only a few stations at a time. At Caltech the Block2 correlator had replaced the 5-station Block0 which was to be dismantled. IRA proposed to JPL and Caltech, owner and manager of the correlator, to take over Block0 and reassemble it at the Medicina Station. Three antennas, Medicina, Noto and Matera, would soon enter the observation phase in Italy, and plans were made to build a new antenna. Having a correlator would give the Italian network considerable management autonomy for ad hoc VLBI observations. The proposal was accepted and Giuseppe Maccaferri and Franco Mantovani left for Pasadena, headquarters of Caltech, to make an inventory of the documentation relating to Block0, take a copy of the management software and check the state of the hardware. The correlator's transport was organized in June 1987 and the Medicina technicians immediately set to work to bring it back to full functionality (Gallerani et al. 1989, 1991). The operation allowed the staff to gain experience in the important correlation phase and the researchers to manage the data of the experiments without resorting to the correlators of MPIfR and Caltech.

Block0 was classified for a long time as 'sensitive material' by the Americans and its transfer to nonaligned countries was prohibited. Every year after its transfer, a military attaché came to the Medicina Station to verify that the correlator was still present. The verification continued even when Block0, which had in the meantime become obsolete due to the introduction of the VLBI MarkIII data acquisition system, moved to the Medicina Station Visitor Centre.

Thanks to the experience gained in the use of the VLBI technique, F. Mantovani was appointed 'VLBI Friend' for the Medicine station. This figure had the task of following the VLBI observations locally on behalf of the EVN. Thereafter, T. Venturi, after spending more than a year at Caltech, held this role for about a decade.
The study with the VLBI technique of sources detected at 408 MHz with the Northern Cross was not limited to the LFV, but also included detailed observations of radio galaxies of sample B2, such as NGC4278 (Schilizzi et al. 1983). From June 27th to July 1st 1983 Bologna was the seat of the IAU Symposium 110 “VLBI and Compact Radio Sources”, one of the most successful conferences in the memory of many of the participants. The congress, organized by R. Fanti, K.I. Kellerman and G. Setti, highlighted the importance of the studies through VLBI observations and the relevant contribution in the international context of radio astronomical research in Bologna. The most famous international radio astronomers were part of the Scientific Committee. The conference saw a very large participation of researchers from all over the world. The numerous talks of over 150 participants demonstrated the scientific importance of these studies. The credibility of Bolognese radio astronomy grew considerably in their eyes due to competence in the sector, organizational capacity and scientific influence.

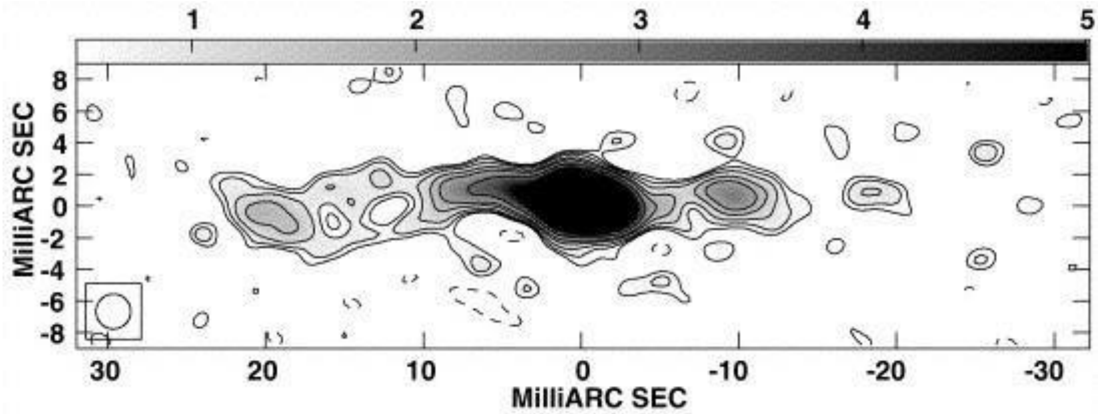
In this period the attention of radio astronomers and in particular of IRA researchers focused on powerful and compact sources that showed a steep radio spectrum, a characteristic that was considered anomalous. The compact sources, in fact, statistically showed flat spectra, that is radio flux density that was very similar at different observing frequencies. The steep spectrum sources generally showed a radio structure of the order of a second of arc. They were classified as Compact Steep Spectrum Radio Sources (CSS) and their scientific importance became increasingly evident (Fanti C. et al. 1984, 1985). On this topic Daniele Dallacasa carried out his doctoral thesis.
Similarly, a class of objects characterized by convex spectra peaking around 1 GHz was identified, which were called GHz-Peaked Spectrum Radio sources (GPS) and were the subject of Carlo Stanghellini's doctoral thesis (Stanghellini et al. 1998).
Two models were proposed to explain the characteristics of these radio sources. One ascribed their small diameter to confinement caused by the external medium (van Breugel et al. 1988). The second, supported by the Bolognese radio astronomers, implied that they were small sources since they were young. The two models were discussed in various conferences, among others the "Compact Steep Spectrum & GHz-Peaked Spectrum Radio sources" workshop organized in Dwingeloo, the Netherlands (C. Fanti, R. Fanti et al. 1990), and in several articles published in international journals.
Roberto and Carla Fanti, taking advantage of the large amount of data that had been collected, built a model in which the GPS/CSS were identified with the initial phase of large radio sources. They made use of classical evolutionary models (Scheuer 1974, Baldwin 1982) and of models proposed for the interstellar and intergalactic medium available at that time. Furthermore, they considered a continuous energy supply to the lobes from the nucleus and energy losses caused by the expansion of the lobes themselves. In their model the refuelling process initially prevails and therefore the brightness increases, the lobes expand and the loss of energy begins to counteract the increase brightness. Finally, the energy losses dominate and the brightness definitively decreases. It is therefore plausible that radio sources are born as HFP/GPS (High Frequency Peakers), evolve into CSS and eventually become extended radio sources (Fanti R. et al. 1990, Fanti C. et al. 1995).
Observations at 230 GHz of a sample of CSS/GPS (Murgia et al. 1999) showed that their spectrum further steepens at high frequency, which implies an age at least one hundred times lower than the age of extended radio sources. The GPS then turned out to be younger than the CSS. Estimating the radio sources age was the topic of the doctoral thesis of Matteo Murgia.
The high angular resolution VLBI images also showed interesting cases of strong interaction of the radio emission with the surrounding interstellar medium. Knowledge of the properties of the nuclear

regions of radio sources was thus increasing. Examples worth mentioning are the VLBI polarization observations of the quasar 3C119 (Nan RenDong et al. 1991) and 3C138 which demonstrated the distribution of the magnetic field in the central region of these radio sources (Dallacasa et al. 1995).

Also in this period, questions were raised about the possible differences between quasars, BL Lacs and the powerful radio galaxies classified as FRII (Fanaroff and Riley 1974) and the weaker FRI radio galaxies predominant in the B2 catalogues. VLBI observations of powerful sources had shown the existence of compact nuclei and jets on the scale of milli-seconds of arc and often the presence of relativistic motion between components inside the structure. In some cases the structural variations were measured to have apparently superluminal motion, i.e. move at faster than the speed of light. Speeds higher than the speed of light were interpreted as a geometric effect, due to the fact that the relativistic jet observed was oriented at a small angle to the observer's line of sight.

The case for the weaker FRI radio galaxies was quite different. VLBI observations with the sensitivity needed to observe their faint nuclei were not available. The symmetry with respect to the nucleus and the characteristics of the FRI jets on the arc second scale, combined with the weak brightness of the nuclei suggested that the jets of these sources had different characteristics, in particular they did not have relativistic speeds. It was not fully understood if and how the observed differences in structure on large scales between the FRI and FRII were connected to their nuclear properties.

Incorporating the new Medicina 32-m dish in the EVN strongly increased the sensitivity of the array. In 1985 and 1986 a first VLBI experiment was planned recording the data with the MK III data acquisition system and the antennas of Onsala, WSRT, Effelsberg, Jodrell-Bank, Medicina and Haystack. Sixteen low-power sources were observed. A statistical study of their nuclear properties was then carried out on a complete sample made up of twenty-seven high and low power radio galaxies. This first project was followed by detailed observations of FRI type radio galaxies such as NGC315, B2 0836+29, 3C465 and in particular 3C338, the first radio galaxy exhibiting two symmetrical jets (Feretti et al. 1993) and 1144+35 one of the few low power sources beyond M87 with a superluminal proper motion (Giovannini et al. 1999).



VLBI map of radio galaxy 3C338 characterized by the presence of 2 symmetrical jets. The angular resolution is 2.2 mas (Feretti et al. 1993). © AAS. Reproduced with permission.

These studies revealed that even the FRI show compact nuclei and jets with relativistic motions. However, in the powerful radio sources the jets have relativistic speeds from the nuclear regions up to the hot-spots in the lobes, in weak sources the jets slow down within a few kpc from the core. The presence of relativistic jets in the nuclear regions of both the FRII and the FRI was confirmed by the correlation found between nuclear power and total power in radio sources (Feretti et al. 1984; Giovannini et al. 1988). This was valid for both powerful and weak radio galaxies, and for quasars and BL Lac type objects.

In 2001 an article was published summarizing all the VLBI results achieved in this area from 1990 to 2000, confirming the validity of the unified models for high and low power sources (Giovannini et al. 2001).

In 1988, demonstrating the growing interest on the part of the scientific community for high angular resolution observations made possible by the VLBI technique, the NATO School "VLBI Technique and Applications" was organized near Bologna, directed by M. Felli of the Astrophysical Observatory of Arcetri and R. Spencer of the University of Manchester, Jodrell Bank.

In February 1997 the HALCA satellite was launched by the Japanese Space Agency JAXA for the VSOP project (VLBI Space Observatory Program). This represented the beginning of the space VLBI era. Thanks to the connection between the VLBI antennas from ground and the one orbiting in space, the observational capabilities of VLBI observations significantly increased.

The IRA actively contributed to the project thanks to the participation of the Medicina and Noto antennas in the observations. In particular, the Noto antenna was one of the antennas dedicated to observations for the VSOP survey project which aimed to observe the 400 brightest compact sources at 5 GHz (Fomalont et al. 2000). Among the various approved programs was a 'Key Project' proposed by IRA (P.I. T. Venturi) to observe a selected group of highly variable low frequency sources at 22 GHz. Unfortunately, the observations at that frequency were spoiled by damage to the receiver on board the spacecraft during the satellite launch phase. IRA researchers also participated in observations of single sources such as 3C 446 and Markarian 501. The observations of Markarian 501 led to the discovery of a limb-brightened jet in the central region of this BL Lac (Giovannini et al. 2000; degree thesis by M. Giroletti).

Lucia Padrielli with colleagues in a moment of relaxation at the end of an EVN meeting at Onsala Space Observatory in Sweden. From the left Ralf Spencer (Jodrell Bank), Ger de Bruyn (Westerbork), Richard Porcas (MPIfR), Peter Scheuer (Cambridge), Malcolm Walmsley (Arcetri), Andrzej Kus (Torun). Credits: INAF-IRA

5.8 VLBI and Geodesy

VLBI studies for geodesy began in the USA in the late 1960s, with the aim of revealing changes in the position of the terrain in the region of the San Andreas Fault in California, where the Pacific plate meets the North American plate. Also for Italy, a highly seismic area, geodesy studies have always had a role of fundamental importance.

At the end of 1986, the Medicina radio telescope was equipped with an S/X band receiver, 2.3/8.4 GHz, for geodynamic observations. IRA signed an agreement with the National Oceanic and Atmospheric Administration of the USA, officially becoming part of the IRIS (Incorporated Research Institutions for Seismology) network.
The first IRA test of VLBI observations for geodynamic purposes took place with the participation of the Medicina 32-m dish in the SARG project, designed to measure the motion of the terrestrial poles making use of long baselines in the North-South direction. It was scheduled from 31st January to 7th February 1987. On that occasion the new S/X band receiver (uncooled) was tested. This was the only receiver one among those available to be placed in the primary focus of the antenna. Mounting the S/X receiver in the primary focus involved disassembling the sub-reflector, i.e. the 800 Kg secondary mirror. The full operation required a day's work in good weather conditions and with some risk to the operators. The quality of the data proved to be better than that of the other observatories involved, and received congratulations from James Campbell, member of the IRIS Commission for Germany and S. Shapiro, Chairman of the IRIS Board.
In December of the same year the cryogenically cooled S/X band receiver became available. The system temperature of the antenna decreased from 180 °K to 90 °K in the S band and from 210 °K to 100 °K in the X band. Also in 1987, Medicina participated in several observations of the NASA Crustal Dynamics Project program "International Radio Interferometric Surveying" programmed for the determination of UT1, the Universal Time of Earth's rotation.
In April 1988 the "6th Working Meeting on European VLBI for Geodesy and Astrometry" (Tomasi, 1988) was held in Bologna in recognition, by the geodynamic community, of the importance of the entry into the network of the Medicina antenna to be followed shortly by that of Noto.
The construction at the Medicina Station of a platform to host the 'Mobile Satellite Laser Ranging' telescope, and the installation of antennas for the Global Positioning System was also planned thanks to the contribution of the National Space Plan. The Global Positioning System was the result of a collaboration with the Geophysics group of the Physics Department of the University of Bologna. Medicina was thus becoming one of the 'fundamental stations' for geodynamics, having in co-location various observational techniques.

The CALC/SOLVE programs used for post-correlation VLBI geodynamic data analysis and SKED and DRUG for planning the observations were installed on the HP-1000 E-Series computer that also drove the antenna and the MKIII data acquisition terminal. Thus the foundations were laid for the development of geodesy studies at IRA. In June 1987, as a further step in confirming the IRA's intention to invest in this sector, a cooperation agreement was signed with the National Oceanic and Atmospheric Administration of the USA and with the Crustal Dynamics Project of NASA.
Meanwhile, the number of European radio telescopes involved in the geodynamic VLBI observations continued to grow. Several projects were organized under the aegis of the European VLBI for Geodesy and Astrometry (EVGA) involving Effelsberg and Wettzell in Germany, Onsala in Sweden, Metsahovi in Finland, WSRT in Holland, Robledo in Spain and the two Italian antennas of Matera and Medicina.
EVGA submitted a request for financial support to the European Community. For the period 19931996 the project received scholarships under the 'Science' programme. For phase two of the project (1996-2000) the group received financial support through the 'Training and Mobility of Research' (TMR)

program. The project was named 'Measurement of Vertical Motion in Europe by VLBI'. The grant included funding for five temporary postdoctoral positions to be awarded to visiting researchers. The grants were made available to institutions from four European countries. Spain, Sweden, and Germany were awarded one scholarship each, Italy was awarded two scholarships to be used at IRA (Campbell, 1996, 11th EVGA meeting, Onsala, SE).

This was IRA's first participation in an EU funded project. The aim was to treat tropospheric refraction which causes excess signal delay during the observations. A similar effect is also found in GPS observations. The purpose was to optimize the analysis to improve the measurement of the vertical component of the motion of the sites where the VLBI and GPS antennas are located. The aim was to obtain a reliable estimate of the variation in the vertical position of the stations, a useful contribution to geophysical studies on the rise of the earth's crust, subsidence phenomena and sea level changes.

Group photo at the end of a workshop of European researchers in Geodesy and Astrometry organized by the IRA at the Radio Astronomical Station of Noto in 1991. At the center Lucia Padrielli, Director of the IRA.

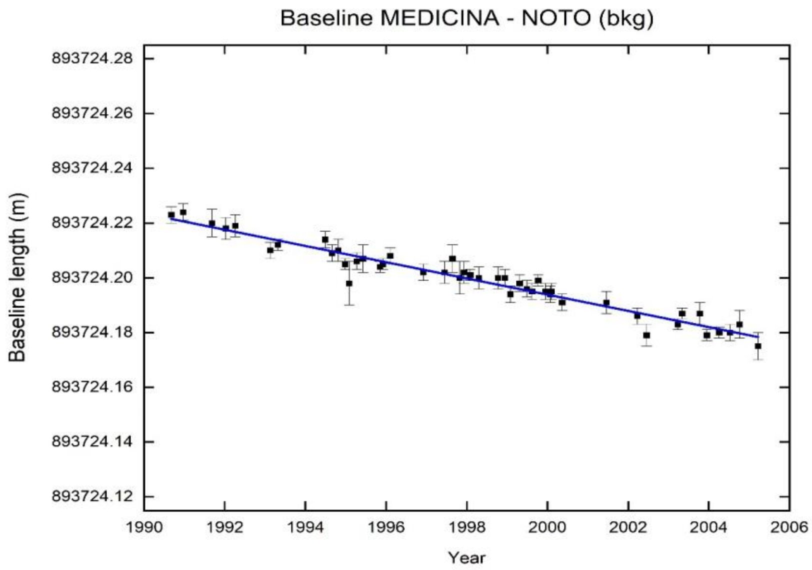
Some of the participants in the "10th Working Meeting on European VLBI for Geodesy and Astrometry" organized at the Space Geodesy Center “G. Colombo "in Matera on 24th-25th May 1995 (from left: Franco Mantovani (IRA), Richard Porcas (MPIfR), Paolo Tomasi (IRA and ITIS), Walter Alef (MPIfR), Alessandro Orfei (IRA). In the background the Matera VLBI antenna). Credits: INAF-IRA

Shortly the IRA became an important member of the geodynamic International VLBI Service (IVS). Its two antennas regularly participated in network observations with European, American, Russian, Japanese and South African radio telescopes under the pressure in particular of P. Tomasi appointed member of the IVS Directing Board.
The IRA became one of the IVS Data Analysis Centres, that required knowledge of the data analysis programs and some critical ability to compare the results obtained by the other IVS centres. The software needed to analyse the geodynamic VLBI data was implemented on the computers of the IRA computing centres. The first measurements of the linear separation between the Noto and Medicina antennas were carried out with an accuracy of less than a millimetre. The distance decreases over time at a rate of a few millimetres per year caused by pressure from the African plate.

L. Padrielli, the acting Director of IRA, wrote in a letter to the President of the CNR L. Rossi Bernardi dated 1st July 1991*: 'A few days ago I sent information relating to VLBI experiments in geodynamics with the Noto Station, which allowed the detection of a trend of displacement of the plate relative to southern Sicily compared to Central Europe. The result is in line with the theories, but is nevertheless of exceptional scientific interest, because it allows us to significantly improve knowledge of the dynamics of the Mediterranean area'.*

The IRA established direct partnerships with the United States National Ocean and Atmospheric Administration, interested in obtaining measurements of the Earth's rotation period with the accuracy of 0.1 milliseconds. In collaboration with the Goddard Space Flight Center, the Mars Pathfinder was observed rotating around Mars to determine the ephemeris of its orbit around the red planet, greatly reducing its uncertainty.

In 1993 the CNR founded the Institute of Space Technology and Informatics (ITIS) based at the Space Geodesy Center of the Italian Space Agency. P. Tomasi was appointed as its Director and moved to Matera, the headquarters of ITIS. Several young people who were already collaborating with him in Bologna decided to follow. As funding grew, the first Italian group dedicated to studies of VLBI geodynamics, observations and data analysis with the satellites of the Global Positioning System and remote sensing with SAR (Synthetic Aperture Radar) was formed. ITIS quickly became an international reference point. With the Legislative Decree of 30th January 1999, n. 19. 'Reorganization of the National Research Council', ITIS was merged with IRA and the research group moved from Matera to Bologna, to the new IRA headquarters in via P. Gobetti 101, in the CNR Research Area.



Base length variation rate between the Medicina and Noto antennas obtained from VLBI data. The data up to 2005 confirm the 1999 result obtained by Tomasi, Rioja and Sarti (1999): the distance between Medicina and Noto is shortening at a speed of 3.1 ± 0.3 mm / year.

6 Activities at Noto Station

With the inauguration of the Noto antenna, in 1988, a period of intense commitment to the new station by all IRA staff ended and the need arose to obtain dedicated personnel for the operation of the station and for the development of research activities. In 1989, as part of the rebalancing of the distribution of personnel for research in Southern Italy, 8 personnel were assigned to the Noto station: 4 graduates and 4 technicians. Gino Tuccari was appointed responsible for the technical and technological aspects.
The first participation of the Noto 32-m dish with the only receiver then available, one at 10.7 GHz, in VLBI observations together with the unified EVN and American networks was in April 1989. In the same year, the Noto dish also made the first geodetic VLBI observations using receivers and an acquisition system borrowed from NASA, to replace the Matera antenna not yet operational. The technological activity at the station over the years involved the implementation of new receivers and making improvements in both hardware and software.
From the point of view of scientific research, it is worth mentioning an Italian-Spanish collaboration for the discovery of sources to be used as phase calibrators in VLBI experiments for astrometry.

In addition to the activities related to the VLBI, the research at the Noto station mainly concerned the study of stars. The discovery that stars in a large range of masses and temperatures exhibit radio emission dates back to the early 1970s. Stellar radio sources include both thermal and non-thermal coronas, transition regions, chromospheres, stellar winds, and interacting binary systems. The bright radio emission is free-free thermal, and originates in stellar winds and is therefore linked to a large loss of mass. The non-thermal emission is gyro-synchrotron connected to a strong, often variable magnetic field. In active stars the radio emission is characterized by so-called 'quiescent' periods, i.e. emission without impulsive phenomena, or 'flares', with a slowly variable flux density of the order of several tens of mJy, and by active periods with strong emissions up to Jy.

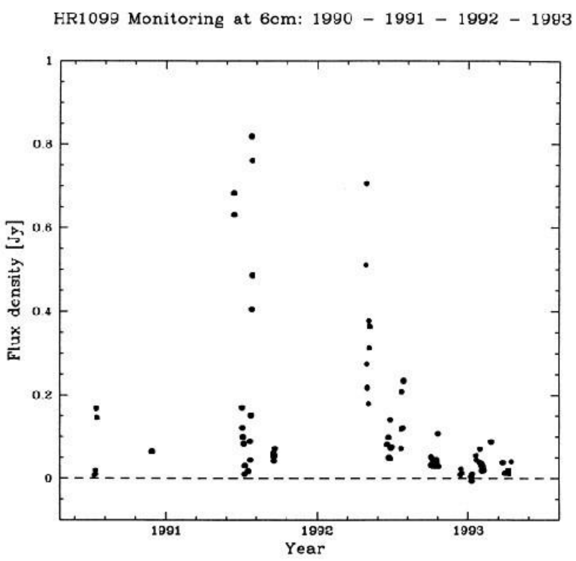
The first investigations at IRA were undertaken by Grazia Umana and Corrado Trigilio, concerning the RS CVn narrow binary systems and the Algol binary systems, characterized by strong radio emission and intense variability. A survey of binary systems of the Algol type, carried out with the VLA at 6 cm, detected radio emission from many systems of this type, with variable flux density and flares. It emerged that the radio emission is not attributable to the free-free thermal emission of the corona, but that it is of non-thermal nature. A two-component model, a compact nucleus and an extended region, was proposed. Strong magnetic fields were revealed, i.e. about 100 G in the compact component and about 20 G in the extended component. It was also discovered that the Algol-type systems show correlation between quiescent radio emission and X-ray emission, therefore they look very similar in radio to the RS CVn systems (Umana, Catalano and Rodonò 1991; Umana et al. 1993; Umana, Trigilio and Catalano 1998).

Chemically peculiar stars, that is stars characterized by an overabundance of certain chemical elements and by magnetic fields of the order of 1000 Gauss in which free-free thermal radio emission was expected to be produced by the presence of strong and powerful stellar winds were also observed with the VLA. Contrary to predictions, it was highlighted that these objects are very similar in radio to active stars. They typically have flat spectra, quiescent emission characterized by modest circular polarization, and flares. Therefore, the emission could not be of thermal origin. It was deduced that the radio emission was non-thermal and that it was produced by electrons accelerated in the shocks formed in an inhomogeneous stellar wind. Finally, it was suggested that this emission was due to rotational modulation, probably linked to a misaligned magnetic field (Leone and Umana 1993; Leone, Trigilio and Umana 1994; Leone, Umana and Trigilio 1996).

In subsequent years, the study of bhot bright OB-type stars, characterized by thermal radio emission due to the presence of strong stellar winds, was carried out. It emerged that these objects also show evidence of non-thermal emission due to accelerated electrons in inhomogeneous stellar winds, and an estimate of the mass loss (of the order of 10^{-6} - 10^{-5} solar masses/year) that correlates with bolometric brightness was obtained (Scuderi et al. 1998).

In 1989 a monitoring programme was proposed with the Noto radio telescope used as a single-dish. The aim was to analyse the variability of active star systems, their flare statistics and the connection between their active and quiescence periods. Also the scope was to obtain indirect information on the morphology of their emitting regions and to study possible correlations with other activity diagnostics. Observations with the Noto paraboloid at 5 GHz lasted for several years. Extremely variable phenomena were revealed, in contrast to evolutionary models that interpreted the quiescent phase as the final phase of a flare (Trigilio et al. 1993; Trigilio, Leto and Umana 1998). In the source HR 1099, several minor flares, the presence of a stable magneto-spherical structure and the correlation between the radio flux and the fraction of the photosphere covered by spots were observed (Umana et al. 1995).

One of the purposes of monitoring objects with the Noto radio telescope was to select objects for targeted VLBI observations, with the aim of spatially resolving the emission of flares, and following their evolution. The VLBI observations, carried out for several individual objects of different types, confirmed the two-component model, determined that the flares occur in the nucleus, while the emission of the extended halo corresponds to lower-level quiescent radiation, with evidence of expansion of the radio source when the flare decreases (Trigilio, Umana and Migenes 1993).



The star radio HR1099 observed at 5 GHz with the Noto 32-m dish from 1990 to 1993. The flux density is shown as a function of time. The 'flares' of this active star are evident (Umana et al. 1995). Reproduced with permission © ESO.

Furthermore, the antennas of Noto and Medicina devoted a significant fraction of their observing time to the investigation of variability in extragalactic sources. Among these programs, the study of the variability of Blazars achieved high visibility. Blazars, active galactic nuclei with a relativistic jet directed towards the observer, are powerful, highly variable sources that emit throughout the electromagnetic spectrum. With the idea of increasing the hitherto small number of Blazars, that possessed multi-frequency studies and would allow the spectral distribution of energy from X-ray to gamma-ray to be obtained, a campaign of monthly observations was started with the 32-m antennae of Medicina and Noto of a sample of 23 sources selected from the list of objects observed by the BeppoSAX X-ray satellite (Venturi et al. 2001). The 4-year observations (1996-1999) were made at 5 GHz and 8.4 GHz, to which data at 22GHz were added for a period of one and a half years. All but one of the sources showed radio variability during the four years of observation. A statistical analysis suggested different characteristics of variability, from clearly visible flares to recurrent variability to complex light curves.

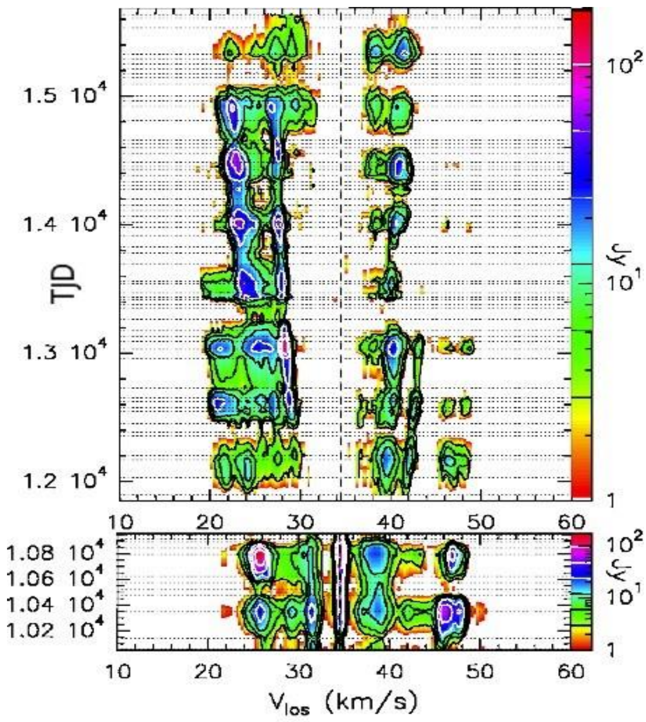
7 Use of the Medicina antenna as a single instrument

7.1 Molecules in space

Although Medicina's 32-m antenna was intended to be part of the VLBI network, researchers soon began exploring the possibility of using the telescope as a 'single-dish' instrument for spectroscopic observations. One of the first scientist to use the 32-m antenna in this way was Flavio Scappini, from the Institute of Molecular Spectroscopy (CNR), who in 1986 detected cyanodiacyletylene (HC_5N) at 10.7 GHz (Comoretto et al. 1988) in the Taurus molecular cloud, using the auto-correlator developed, among others, by Gianni Comoretto, then at the IRA, section of Florence, as a backend. In Arcetri the radio astronomy group, led by Marcello Felli, became interested in the use of the Medicina antenna for radio spectroscopy thus recognizing the possibility of acquiring scientific and technological skills. During the tests performed with the auto-correlator, various receivers were used to observe the recombination lines of hydrogen and HC_5N (10.7 GHz), H_2CO (5 GHz), OH (1.7 GHz) and H_2O (22 GHz).

In the search for a field of investigation in which the instrumentation (antenna + receiver + backend) could be competitive, it was decided to concentrate on the emission of H_2O masers, to perform a survey to look for new sources and investigate their emission variability in a systematic way. Quoting Felli (1987): *"The study of the variability of H_2O masers, although known from the first observations, has been almost completely neglected due to the impossibility of having telescope time for prolonged periods and uniformly distributed over sufficiently long periods of time. It is in this field that the instrument could find its natural place".*

The Florence group (Arcetri Observatory and IRA Florence Section) thus began a program of H_2O maser observations, first re-observing all known masers in star-forming regions and in the envelopes of evolved stars above a declination of -30°, and then looking for new masers in similar sources. A homogeneous catalogue was created (see Brand et al. 1994 and references therein), which became heritage for the entire scientific community and was used for several subsequent projects.
Numerous other research programs that involved observations of water masers with the Medicina radio telescope were carried out in the 1990s mainly by the Arcetri group and by Giorgio Palumbo (then CNR-TESRE) and his students. Research on masers was also extended to IRA at Bologna when Jan Brand, one of the members of the Arcetri radio group, moved to Bologna in 1992. The study of masers in star forming regions was the subject of Luca Moscadelli's doctoral thesis. The group from Florence and Bologna began a long-term program to monitor maser variability in 43 star-forming regions and 22 evolved stars, which lasted well beyond 2000. Although observation of H_2O masers remained the main spectroscopic activity at the Medicina radio telescope 'single-dish', the emission lines of other molecules were successfully observed not only by local but also by external users external users, for example the 6.7 GHz methanol (CH_3OH) masers (Slysh et al. 1999). The results obtained with the Medicina observations stimulated local and national interest, as demonstrated by the three conferences on "Molecules in space and in the laboratory" held in Bologna (1989), Rovereto (1993) and Carloforte (1999). The study of molecular gas in the Galaxy and in other galaxies, especially at higher frequencies (wavelengths mm and sub-mm wavelengths) has become an active research field in Italy.



The figure shows the flux density versus velocity, as a function of time, for the emission of the water maser of the Mira variable, IK Tau. Each horizontal dotted line indicates an observation. The time is expressed in truncated Julian Date. The observations were made with the Medicina antenna from 12/12/1995 to 18/3/2011. The maser emission varies following the star's optical period of 461 days with a delay of 51 days. These data, represented in a slightly different way, appeared in Brand et al. (2018).

7.2 Search for Extra-Terrestrial Intelligence (SETI)

In June 1990, with the support of G. Grueff and G. Setti, S. Montebugnoli participated in the conference of Bio-astronomy in Val Cenis in the French Alps, where he proposed the candidacy of the Medicina station to enter the SETI observation circuit. However, a very high resolution, around 1 Hz, spectrum analyser needed to actively contribute to the observations was still missing.
S. Montebugnoli started with the construction of a SETI mini-spectrometer for the 32-m dish by exploiting the components available in stock and testing the speed of new devices capable of calculating the FFT on data obtained by directly sampling the radio frequency converted to the base band. At the bio-astronomy conference in Santa Cruz, USA, in 1993, researchers from the Jet Propulsion Laboratory talked about the impact of comet Shoemaker Levy 9 with Jupiter's upper atmosphere that should occur the following year. This event offered a good opportunity to ask for funds to finish the spectrometer and be able to observe the impact with a fast new machine with high frequency resolution. The computation component which was the most expensive was still missing. With the support of L. Padrielli, Director of IRA, which was fundamental, and a loan from A. Bombonati, Director of the CNR Area in Rome, it was possible to purchase the computer units in the USA. This funding scenario arose from the collaboration between S. Montebugnoli and C. Cosmovici of IFSI CNR, Rome. It was a race against time to complete the spectrum analyser because the comet would appear in July.
The MSPEC 0 spectrometer was thus built, and based on the calculation of the power spectrum from the data obtained by directly sampling the radio frequency. This instrument, which could provide a

power spectrum every 5-10 seconds, made it possible to correct the very rapid Doppler shift due to the high rotation speed of Jupiter. After months of manual data reduction in the absence of postprocessing software, the emission line at 22 GHz from water molecules was found, produced by the impact of fragments of the comet with Jupiter. The scientific interpretation was entrusted to the group composed of C. Cosmovici, P. Colom of the Paris-Meudon Observatory, and S. Pogrebenko of Dwingeloo, Holland. The result was of great importance because it proved that comets are indeed capable of depositing water and other molecules in planetary atmospheres. It was also demonstrated that a high-performance analyser designed for SETI could be advantageously used for other types of observations. S. Montebugnoli, C. Cosmovici and L. Padrielli presented the results of the observations of the comet's impact on Jupiter in a crowded press conference in the Sala Marconi, lecture hall of the CNR in Rome, in July 1995.

In 1996, with a loan of 4 million lire, a SETI Serendip IV system operating in 'piggyback mode' was purchased from the University of Berkeley so that observations could be made in parallel with the ongoing scientific ones without disturbing them, and was capable of memorizing suspicious signals on a hard drive. Originally, the system consisted of the 'main frame', the A/D converter and a 4 MHz bandwidth card with 4 million channels. Further expansion cards were added donated by the SETI Institute and by IFSI in Rome. A 0.7 Hz resolution spectrometer was thus created and observations were made in 'piggyback mode' for 10 years by Stelio Montebugnoli and Jader Monari. Many suspicious signals were detected, but unfortunately none was confirmed.

8 X-ray astronomy and X-ray background

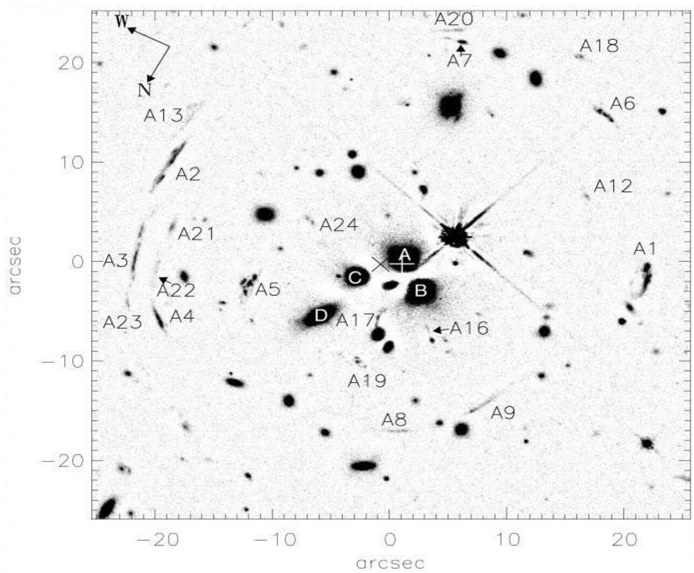
The energy density of the sky in X-rays is dominated by a diffuse radiation of cosmic origin: the X-ray background, discovered in 1962 by Giacconi et al (1962). In the data set from observations made with a rocket launched to study the X-ray emission of the Moon, they identified the first extrasolar X-ray source (Sco-X1) and the X-ray background. The latter is a completely isotropic signal not coming from identifiable objects. It was hypothesized that a possible source could be a uniform plasma at a temperature of 100 million degrees (Bergamini, Londrillo and Setti 1967).

G. Setti and L. Woltjer (1973), after the X-ray detection of quasar 3C273, suggested that quasars, if they had the same X-ray brightness as 3C273, could have contributed much of the observed X-ray background radiation. This hypothesis was reiterated a few years later on the basis of the X-ray emission of four quasars (Setti and Woltier 1979).

However, in the 1980s the origin of the X-ray background was still much debated. There were researchers who supported the importance of the contribution of thermal gas that permeated the whole Universe, given that at low energies the spectrum resembled a Bremsstrahlung spectrum.

At this time, data on hundreds of quasars was accumulated from the X-ray astronomy satellite Einstein, suggesting that a very large fraction of the X-ray background radiation was indeed constituted by the emission of quasars. G. Zamorani and T. Maccacaro, researchers of IRA and Visiting Scientists at the Center for Astrophysics (CfA) in Cambridge, Massachusetts USA made a fundamental contribution to the study of quasars in the X-ray band (Zamorani et al. 1981). R. Giacconi and G. Zamorani (1987), after subtracting the contribution of the known sources, calculated that the spectrum of the X-ray background was no longer compatible with that of a hot gas, G. Setti and L. Woltjer (1989) showed that the only possible solution was that the residual background also came from the contribution of point sources. These sources were then identified, confirming their thesis, by "second generation" X-ray satellites such as Chandra and XMM. On this subject Andrea Comastri discussed his doctoral thesis.

In the same period, T. Maccacaro and I. Gioia, Visiting Scientists at CfA, produced a fundamental work for X-ray astronomy, the so-called 'Einstein Medium Sensitivity Survey' (EMSS), which initially included 112 sources, extracted as 'serendipitous' from the majority of Einstein's pointings (Gioia et al. 1984). An extension of the EMSS (Gioia et al. 1990a) finally provided a sample of 835 sources in the 0.3-3.5 keV band. All the sources were then finally identified through many years of planned observation campaigns at various optical telescopes around the world in both the Northern and Southern hemisphere. Observations were also made at 6 cm with the VLA for the extragalactic sources, both to be sure of the correctness of the identification (Einstein's position error was about one minute of arc) and to study the radio to X-ray properties of the various samples. The EMSS has catalogued different classes of objects making a fundamental contribution to the studies on quasars, galaxy clusters, starforming galaxies and other types of objects (including active and binary stars). However, the most interesting discoveries came from the study of galaxy clusters. In addition to the evolution of their Xray Luminosity Function (fewer high luminosity X-ray clusters in the past, Gioia et al. 1990b) in agreement with a hierarchical formation of the Universe, a large number of gravitational arcs or lenses were also found in the selected clusters from the X-ray band (Gioia and Luppino 1994). All the clusters were later observed at the VLA to construct the bivariate Luminosity Function relating the radio power to X-ray luminosity and to study the relationship between the X-ray luminosity and the temperature of the clusters. These latter studies were carried out using archival images from the Chandra satellite and were later part of Marica Branchesi's doctoral thesis. Furthermore, the EMSS showed that the active nuclei of galaxies constitute the dominant part of the emitting objects in the X-ray band and that they contribute about 80 percent to the X-ray emission of the X-ray background (Maccacaro, Gioia and Stocke 1984).

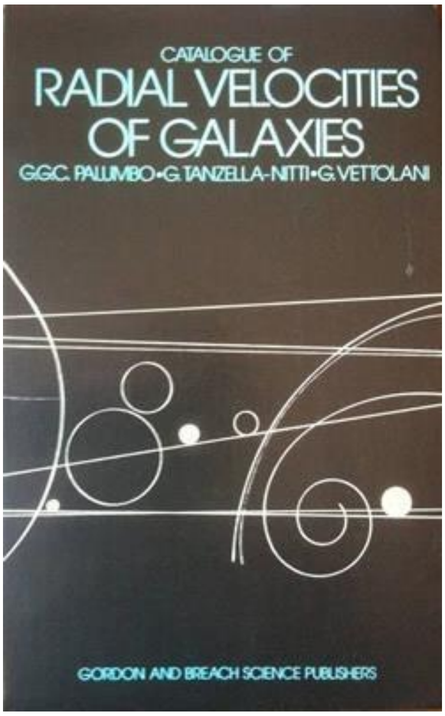


Hubble Space Telescope image of the cluster of galaxies MS0440 + 0204 selected in X-ray from the EMSS. The gravitational arc systems present in the image are actually amplified images of distant galaxies that lie behind the clusters (Gioia et al. 1998.) © AAS. Reproduced with permission.

9 Large-scale structure

In the seventies, several studies highlighted the fact that the distribution of galaxies in the nearby universe was anything but homogeneous. The galaxies seemed to be concentrated in superclusters, that is, in areas of the sky where there were clusters of galaxies connected by bridges and filaments of galaxies that delimited sub-dense or even empty areas.

With the entry into operation of the 1.5-meter telescope of the University of Bologna in Loiano, it was possible to measure the radial velocity of galaxies up to magnitudes 14-15. Efforts were concentrated above all in the region of the Perseus supercluster, obtaining a mapping of the region that definitively showed the existence of a filament extended over at least 100 Mpc in the southern galactic pole (Focardi, Marano and Vettolani 1984). The observational effort to collect galaxy redshifts one by one was substantial and it was imperative not to waste observation time. For this reason, in addition to the obvious scientific motivation to carry out a large-scale mapping of the sky's structure, G. Palumbo, G. Tanzella-Nitti and G. Vettolani (1983) compiled, at the end of the seventies, a catalogue containing all galaxy redshifts (8250) published up to December 1980.



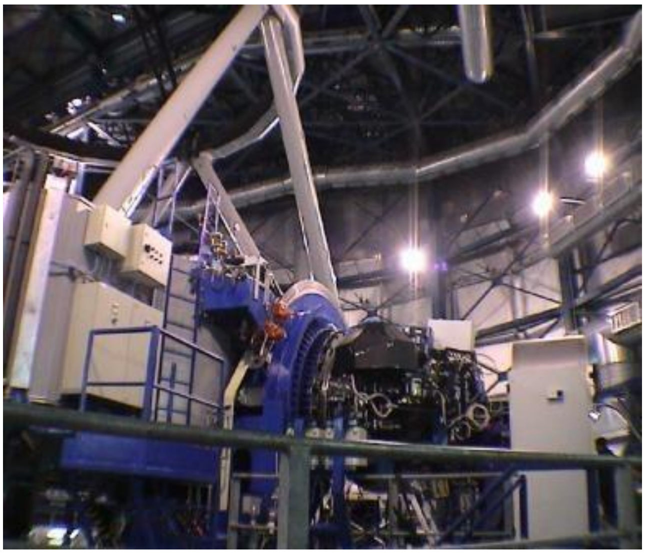
Cover of the catalogue containing all galaxy redshifts (8250) published up to December 1980 (Gordon e Breach Science publishers)

By the eighties the scientific community had accepted the new paradigm that galaxies are distributed in the Universe in clusters and superclusters that surround empty regions. Therefore, new fields of interest related to the large-scale structure of the Universe began to appear on the horizon, for example the study not only of geometry, but also of dynamic and clustering properties (correlation functions and their evolution) and the study of evolution of galaxy clusters and galaxies in superclusters as a function of cosmic time. These new themes required the measurement of redshifts of large samples of galaxies in large areas of the sky.
An 'all-sky' catalogue of clusters with redshifts measured and estimated by photometric properties is placed in these new areas of research. Among the main results were the discovery and study of the physical characteristics of the Shapley Concentration (Scaramella et al. 1989) and the study of

largescale motions in the direction of the Great Attractor, the direction in which the Local Universe moves as revealed from the measurements of the dipole anisotropy of the cosmic background.

In 1985 a group consisting mainly of researchers from IRA and the Observatoire de Meudon in France proposed the ESP survey (ESO Slice Project, PI Vettolani) as a 'long term program' which was approved in 1991 thus guaranteeing an adequate number of nights to carry out the survey. The ESP survey covers a region of about 23 square degrees of sky in a region close to the South Galactic Pole and measured the redshifts of 85% of the brightest galaxies of magnitude b=19.4 (which represented a fairly high level of completeness at that time) for a total of about 3400 galaxies (Vettolani et al. 1997). Perhaps the most important result of ESP was the very accurate determination of the Luminosity Function of galaxies (Zucca et al. 1997) which indicated the presence of an important under-density in the number of galaxies in the nearby Universe.

In the second half of the 1990s, it became increasingly clear that in order to address the problem of the evolution of the physical properties of the spatial distribution of galaxies and the temporal evolution of their stellar populations it was necessary to extend the area and depth (limiting magnitude) of surveys of redshift. In other words, a new generation of instruments (spectrographs) of greater efficiency and capable of making measurements of many objects in sufficiently large areas (+ i.e. 30 arc minutes in diameter) or of high 'multiplex gain' was needed. As part of the new instrumentation for the Very Large Telescope (VLT) Delabre, D'Odorico and Vettolani (1994) proposed a camera and a multi-aperture spectrograph with low resolution in the visible, specialized for redshift surveys of faint galaxies (magnitude 22 in the band I).
The VIMOS spectrograph was built both to maximize the number of spectroscopically observable galaxies in a single observation on 4 channels covering the entire field of view of the VLT's Nasmyth focus (4x7x8 arc minutes), and to obtain images together with the spectra. The numbers involved for spectroscopy range from 1000 objects for low resolution spectroscopy (typical for redshift measurement) up to 400 objects for medium resolution spectroscopy (to also obtain some dynamic information). VIMOS was proposed to ESO by a consortium that included, in addition to the IRA, IFCTR CNR in Milan and the Observatories of Capodimonte, Bologna and Brera, and French institutes led by LAM of Marseille.



The VIMOS spectrograph mounted on the Nasmyth focus of the UT3 Melipal telescope of the VLT. Credits for the photo European Southern Observatory ESO / G. Sciarretta.

The consortium was rewarded by ESO with the assignment of about 100 observation nights, used in the years after 2000 for the VIMOS survey which helped to change the panorama of the evolution of galaxies and cosmic structures with the observation of a sample of about 10,000 galaxies up to great distances, i.e. up to z = 5 (Le Fèvre et al. 2003).

10 The Computing Center

The first non-mechanical calculator of IRA was an Olivetti Logos which offered four operation electronic calculation and some simple mathematical functions. It was 1972.
The computing centre of the National Nuclear Energy Committee (CNEN) which in the 1960s had the largest Italian scientific computer was used for reading the recordings of the Northern Cross and for the programs of data reduction. The CNEN was located near Porta Mazzini (Bologna). With the entry of the Radio Astronomy Laboratory into the CNR in 1970 it was no longer possible to use this computer centre and so the IBM 360 computer of the CNR at the National University Centre for Electronic Computing (CNUCE) in Pisa was pressed into service.
When software programmes for interferometric data processing became available, three terminals were acquired, one, the most highly requested, consisted of a tele-printer connected by telephone with CNUCE which transmitted at a speed of 300 characters per second (2.4 Kbit/s) highly, and two that transmitted at a speed of 110 characters per second. The operators of the Pisa computer centre were asked to mount the magnetic tapes and retrieve the printouts with the processed results. The internet network was not available at that time. To transmit cards, tapes and printouts between Bologna and Pisa, couriers were used to transport large wooden boxes containing the precious material back and forth. It was called 'broadband transmission'. We had to wait three days to know the result of the data analysis.

The punched cards were sent by courier from Bologna to the National University Centre for Electronic Computing (CNUCE) in Pisa. The results of the elaboration went the opposite way. Credits: INAF-IRA

After some time, a printer with an attached punch card reader was recovered and connected with CNUCE. The printer was huge. It occupied an entire room and allowed the programs written on punch cards to be sent out and the results obtained to be printed out after a few hours. With the fastest terminals, 4.8 Kbit/ s, 'graphic prints' could be obtained consisting of numbers that corresponded to the pixel values in the image, allowing the results to be seen ... almost immediately. A portion of the map appeared on the terminal screen which could then be printed, then another portion, ... and so on, until the image was complete. It took some time to complete the printing of a radio source map. Sometimes the connection to the computer was lost and the printing process had to be restarted. Data transmission was rather slow and waiting in front to the terminal was really boring. To overcome this, the technicians built, following a suggestion by A. Ficarra, a timed 'mechanical finger' that pressed the print button on the terminal at time intervals corresponding to that taken by the image, which was a sequence of numbers, to form on the terminal screen. This was enormous progress at the time. A curious aspect was that the advancement of the printing sheets of the huge printer was regulated by a strip of punched paper that frequently deteriorated and had to be replaced by another one made by hand.

The first IRA computer centre took shape in 1981 with the purchase of a VAX 11/780 computer from DIGITAL, an American company. The CPU had a computing capacity of 1 MIPS, a 512 Kbyte RAM central memory and a mass memory, that is a disk, with a capacity of 64 Mbytes which contained the operating system, programmes and user data. The computer was connected to 5 VT100 terminals with speeds of 9.6 Kbit/s and to a tape drive. Each tape had a capacity of 20 Mbytes. The computer centre was housed in via Irnerio 46, in the cellars of the Institute of Physics of the University of Bologna. It occupied a room of about 25 square metres. The purchase price was considerable, around 300 million lire (about 650,000 current euros). Later, a couple of VT125 graphics terminals were also purchased. The availability of terminals led to a significant increase in users who quickly learned to use the new computer, much simpler than the IBM 360 in Pisa. It became necessary to book the use of the computer including during the night and during holidays. Particularly critical was the 'mass memory' consisting of a removable disk housed in a reader the size of a washing machine. To overcome its lack of space, a second disk was bought out of necessity on which a second operating system and a new software (AIPS) brought from the USA by C. and R. Fanti, were installed. AIPS stands for Astronomical Image Processing System, a software package developed to process and analyse data acquired with the Very Large Array. Developed by the NRAO in 1978, it has been used for several decades all over the world for interferometric data analysis. It is still in use today even if in 2011, with the advent of ALMA, the package called CASA (Common Astronomy Software Application) has become the official tool for processing interferometric data set.

The disk with AIPS could replace the original disk in the reader at weekends and at night to allow the use of this new software to analyse the data from the VLA, and subsequently also from WSRT and the VLBI.

The purchase of a second disk reader made it possible to finally have AIPS online even on weekdays. It was soon realized that the processing of radio images with AIPS required too many hours of calculation on a computer that now also housed users from several CNR institutes and from the Bologna Astronomical Observatory. Funds, about 110 M lire, were therefore found to purchase an Array Processor, a vector mathematical coprocessor, which improved the calculation speed of AIPS by a factor 20-30. The first Versatec electrostatic plotter was also purchased, which allowed the printing of black and white images replacing the printouts that represented the radio sources as a grid of numbers.

VAX 11/780 from DIGITAL purchased in 1981. It was the first calculator of the IRA Computer Centre. Mauro Nanni mounting a tape. Credits: INAF-IRA

The CNR commissioned IRA to manage the computer centre, which was already a reference point for users from five different institutes of the CNR, the Institute of Astronomy of the University of Bologna, the Arcetri Astrophysical Observatory of Florence, and the Institute of Nuclear Physics (INFN). IRA made available to the computer centre a graduate and technician, in the persons of A. Ficarra and M. Nanni. Quoting from internal Report IRA 62/81 (A. Ficarra and M. Nanni 1981): *"The aim of those who manage the centre is to gradually develope the use of the computer to reach its full potential, that is, not only as a pure performer of calculations, but also as a system that acquires data from instruments, manages processes in real time, and allows interactive processing of colour images etc ... The intention will be to enhance processing with all the software that can be transferred from other centres, obviously favouring applications in the field of optical and radio astronomy, but also trying to equip the centre with everything that can be useful to the scientific community in general".*

It was a real leap forward, a first step towards a coordinated management of computation that gave a strong impetus to the research of the IRA and represented the basis for development in a sector that later qualified IRA in Italian astronomical research.

Aware of the potential of the computer centre, the CNR was asked to increase the staff with two 'technical-professional collaborators' to manage the VAX operating system, two 'technicalprofessional assistants' as operators, and an administrator to manage accounts, users, orders and invoicing. The hope of equipping the centre with the required personnel clashed with the block of recruitment in place at the CNR in this period. It became essential for users to adapt to a form of 'selfmanagement' of the system to enhance the scientific libraries and perform technical-bureaucratic tasks. It was necessary to maintain contact with other radio astronomy data analysis centres, mainly foreign, and to install the software they made available for use. The CNR's political and bureaucratic difficulties with the hiring of necessary staff and delays in purchasing, frustrated any attempt to plan the development of the IRA computer centre. Despite these difficulties however, it was possible to obtain recognition as a 'computing centre for the CNR in the region of Emilia Romagna'. This led to the introduction of a fee for the use of computing resources and a significant increase in the number of users made up of researchers from the CNR Institutes of the region. In the mid-1980s, the computer

centre could count on about 250 regular users. One of the reasons that limited the CNR's investment in the Bologna IRA computing centre was its proximity to CINECA, already considered the largest Italian computing centre at the time, and to which part of the CNR users also turned.
In those years, access to computing resources could be done using local terminals or by connecting via modems (4.8-9.6 Kbit/s). By officially becoming the IRA computing centre a 'supplier centre', it was inserted into the network in which CNUCE of Pisa was the star centre, and with the OSIRIDE project (OSI on the Italian Heterogeneous Data Network) the first uncertain steps began to be taken in discovering data transmission networks.

In parallel with the transfer to the VAX/VMS of radio astronomy programmes that ran on the IBM at CNUCE ('Reduction of data obtained with the Northern Cross': Nanni 1981, 'Computer programs for reduction of VLBI data': Fanti C. 1981), or programmes coming from other radio astronomy institutes ('MPIfR NOD3 library to reduce observational data of the Effelsberg radio telescope: Tomasi 1981,' Westerbork library for short observations': Feretti et al. 1981), new software was implemented to interface VLBI data with AIPS, MERLIN and WSRT (Stirpe 1984). The applications that were brought to the VAX by colleagues from the University, the Astronomical Observatory and other CNR institutes also grew.

In the early 1980s, data visualization techniques were taking their first steps. Monochromatic terminal graphics were a notable advance when compared to the 'number and cross' graphics that could be produced on printer printouts. Along with the VAX, an 'Aydin 5216 pictorial terminal' which could represent 256 colours on a 1024x1024 pixel monitor which cost 80,000 US dollars was purchased. The creation of a driver in assembler language to make the monitor operate with the AIPS software required many months of work. In the end it became the most important tool for analysing radio astronomy images. Later the much more efficient IVAS was purchased for the same purpose.

Carla Fanti while working on the IVAS pictorial terminal, an important tool for analysing radio astronomy images. Credits: INAF-IRA

With the building of new and more powerful radio telescopes, the volume of the corresponding data set grew, and with it the need for faster tools for calculating the Fast Fourier Transforms (FFT) essential for the analysis and synthesis of images. Added to this was the increase in the number of users of the computer centre, in particular users of the Institute of Marine Geology who were developing software based on FFT for the study of the seabed. An efficient calculation of FFTs was also required for seismic analysis in the research for oil sites. A computer by CONVEX, a Texas company that produced computers equipped with vector processors, was the possible solution.
IRA and the Institute of Marine Geology made a joint proposal for financial support to buy a CONVEX machine, and obtained 1 billion lire (corresponding to 1.1 M in current euros) from the CNR. In 1989 a CONVEX C210 computer was purchased becoming the first Unix machine in the computer centre. It had a 10 MIPS computing capacity, 128 Mbyte central memory and a 4 GByte mass memory. Both VAX and CONVEX, found their location in the narrow basement of the Institute of Physics of the University of Bologna.
The computer centre performed the function of 'computing service provider centre specializing in the processing of signals and images'. It was also frequented by colleagues from other disciplines who could thus evaluate whether the available image processing techniques could meet their needs.

In the early 1980s, as part of the Astronet Project promoted by the National Astronomy Group of the CNR, a software called 'Distributed Information Retrievel for Astronomical files' (DIRA) was developed at IRA by the 'Data base and Documentation' group. It was able to manage astronomical catalogues, extract information, represent it graphically and build a user database structure. Further demands for both research and computing architecture solicited the rewriting of the software. In 1995 DIRA2, was born to handle a database of 270 catalogues, for a total of 27 million records, which was accessible through the web. It was soon adopted by the national and international astronomical community, becoming in the successive years an important tool for scientific research (Nanni and Tinarelli 1993).

At the end of the ‘80s, the CNR, together with INFN, ENEA and the University, established the national research network GARR (Group Harmonization of Research Networks). The IRA computer centre, thanks to the experience gained connecting provider centres that used an IBM proprietary technology (EARN / BITNET), selected for its connection to the GARR a proprietary Digital technology (DECNET) used by both INFN and Astronet. These were also the years of the 'protocol war' between EARN and DECNET, supported by their respective companies, and ISO-X25, supported by the international telecommunications and TCP/IP union born in the American defence laboratories (DARPA). The 'war' risked the creation of separate networks that would have talked to each other with great difficulty. Finally, the versatility of TCP/IP prevailed and the Internet became 'the network' as we now know it. The IRA computer centre took part in the development of the CNR network at both national and local level promoting establishment of the 'Area IT Commission' which would develop the project and manage the IT network of the new 'Bologna Research Area'. Subsequently, the computer centre contributed to the creation of the Lepida regional network obtaining in 2003 the connection at 10Gbit/s of the Medicina radio telescope to the network.

With the move of IRA to the CNR Research Area in 1993, the computer centre obtained a machine room of about 100 square meters, an adequate air conditioning system and a power supply system guaranteed by UPS and uninterruptible power supplies. The transfer involved the CONVEX, a VAX-750 that had replaced the VAX-780 and some Unix work-stations.
Over the years, the IRA computing centre has hosted and managed the service machines of the research Area, Dec/ Alpha and Silicon Graphic servers purchased in partnership with other Institutes, as well as the equipment of the campus FDDI (100 Mbit / s) network and the router for connection to

the GARR network (2 Mbit / s). In 1992, an operating system similar to Unix, easy to install and connect to the Internet and created for fun by a Norwegian student, began to be tested on the institute's PCs. Linux operating system would play a very important role in the development of the IRA computer centre, allowing it to build powerful and economical workstations and servers using the same Intel architectures on which Microsoft products ran. In 1995 with funding from the Information Technology Committee of the CNR, IRA purchased the Digitized Sky Survey (DSS, NASA) on 102 CDROMs that contained photographic images of the whole sky. These images were made available to the community via the Web using a CDROM Jukebox for which a specific software was written, SKYEYE, one of the first applications in Italy in which a hardware tool was driven via the Web. When large Data Centres (ESO, NASA, Strasbourg astronomical Data Centre) made available the services to access catalogues and image archives to the international community through the Web and fast networks, L. Padrielli and M. Nanni wondered if it was not appropriate to invest in this sector to try to stay competitive. The battle would have been too one sided, and they decided to abandon DIRA2 and SKYEYE which however would continue to be used for another decade.

The CDROM Jukebox that contained the 102 CDROOMs of the Digitized Sky Survey (DSS, NASA) with photographic images of the whole sky. These images were made available to the community via the Web using a specific software, SKYEYE, one of the first applications in Italy in which a hardware tool was driven via the Web (1995). Credits: INAF-IRA

In 2000, thanks to the development of the network, the computer centre was being organized in a client/server architecture, where software applications and data were made available on central server disks (30 Gb of shared space) while for radio data analysis 50 Linux workstations were available, each with a capacity (100 MIPS, 256 MBy RAM, 1200x1024 pixel 4M colour monitor) much superior the CONVEX purchased at the end of the 80s.

The Machine Room of the IRA Computing Centre in the buildings of the CNR Research Area at the end of the 1990s. Credits: INAF-IRA

Concluding remarks

The birth of radio astronomy in Italy took place in the university environment. Farsighted and competent people sensed the great potential of this sector of astronomical research and dedicated themselves to it with engaging enthusiasm. The original university group gradually expanded with the growing needs in the management of the infrastructure and in new areas of scientific research. In 1970 there was a strong institutional transition when the CNR established the Radio Astronomy Laboratory, as a centre for the development of Italian radio astronomy, which was then entrusted with the management of the Northern Cross.

In the new laboratory which later became the Institute of Radio Astronomy, the connection with the university continued to be very close. The professors officially associated with the institute always benefited from an office at IRA headquarters and all of the services needed to carry out high-level scientific research.
IRA became one of the primary sites where students worked on astronomical theses. This last adjective has been used to highlight an important and extremely enriching aspect in the concept of doing research within the IRA, i.e. its interdisciplinary character. The skills of the researchers from the radio band extended to the optical, to X-rays, and to infrared, in a blend of interests that broadened minds and generated research with a broader astrophysical vision. The same applies to the technological sector where design in calculation, in microwaves, in electro-mechanics, and in timefrequency measurements progressed in parallel.
Researchers within the IRA were motivated by a great interest in research that made them endure the shortages of personnel and funding and the bureaucratic burdens of their work. Despite the different views that often generated discussions on which research had to be privileged, the common aim of the IRA researchers has always been to establish the institute nationally and internationally. The role in their scientific field and the progress of the institute were considered as priorities.

It should be noted that the scientific and technological activity of the institute was able to develop thanks to the support of the administrative staff and the qualified collaboration of the always available and efficient technical staff.

This story ends in 2000 but obviously the history of the Radio Astronomy Institute continues. Over the years, the members of the IRA have expanded their research fields, international collaborations and presence in international organizations and have become reference points for the design of future radio astronomy instrumentation. This adventure that began in Medicina in the lower Po valley in the early 1960s continues successfully.

List of acronyms

AIPS	Astronomical Image Processing System
ALMA	Atacama Large Millimeter Array (ESO-USA-Japan)
ASI	Agenzia Spaziale Italiana
ATCA	Australia Telescope Compact Array
ATESP	AT ESO Slice Project
BBC	Base Band Converter
B2	Bologna catalogo di radiosorgenti 2
B3	Bologna catalogo di radiosorgenti 3
CAISMI	Centro Astronomia Infrarossa e Studio Materia Interstellare
CASA	Common Astronomy Software Application
CfA	Center for Astrophysics, Cambridge (USA)
Caltech	California Institute of Technology (USA)
CERN	Conseil Europeen pour la Recherche Nucleaire
CNEN	Consiglio Nazionale Energia Nucleare poi ENEA
CNUCE	Centro Nazionale Universitario Calcolo Elettronico
CNR	Consiglio Nazionale delle Ricerche
CRA	Consiglio per le Ricerche Astronomiche
CSS	Compact Steep Spectrum Radio Sources
CSIRO	Commonwealth Organization Scientific Industrial Organization (Australia)
DIRA	Distributed Information Retrieval from Astronomical files
ENEA	Ente Nazionale Energie Alternative
ESA	European Space Agency
ESO	European Southern Observatory
ESP	ESO Slice Project
EVGA	European VLBI for Geodesy and Astrometry
EVN	European VLBI Network
EVNPC	EVN Program Committee
EW	Est-Ovest
FET	Field Effect Transistor
FFT	Fast Fourier Transform
FRI	Radiogalassie di tipo I secondo Fanaroff & Riley (1974)

FRII	Radiogalassie di tipo II secondo Fanaroff & Riley (1974)
GIPSY	Groningen Imaging Processing System (Olanda)
GPS	GHz-Peaked Spectrum Radio Source
GPS	Global Positioning System
HALCA	Highly Advanced Laboratory for Communications and Astronomy
HEAO	High Energy Astronomical Observatory (USA)
HEMT	High Electron Mobility Transistor
HFP	High Frequency Peakers
HST	Hubble Space Telescope
IFSI	Istituto di Fisica Spazio Interplanetario
IAS	Istituto di Astrofisica Spaziale
IAU	International Astronomical Union
IFCTR	Istituto Fisica Cosmica e Tecnologie Relative (CNR)
INFN	Istituto Nazionale Fisica Nucleare
IRA	Istituto di RadioAstronomia
IRIS	Incorporated Research institutions for Seismology
ITESRE	Istituto Tecnologie e Studio Radiazione Extraterrestre
ITIS	Istituto di Tecnologie Informatiche Spaziali
IVS	International VLBI Service
JAXA	Japan Aerospace eXploration Agency
LAM	Laboratoire Astronomique Marseille (Francia)
LFV	Low Frequency Variables
MERLIN	Multi-Element Radio Linked Interferometer Network (UK)
MIT	Massachusetts Institute of Tecnology (USA)
MOST	Molonglo Observatory Synthesis Telescope (Australia)
MPE	Max-Plank-Institute für Extraterretrische physik (Germania)
MPI	Ministero Pubblica Istruzione
MPIfR	Max-Plank-Institute für Radioastronomie (Germania)
MSS	Medium Sensitivity Survey
MURST	Ministero della Università e Ricerca Scientifica e Tecnologica
NASA	National Areonautics and Space Administration (USA)
NAT	Narrow Angle Tail
NRAO	National Radio Astronomy Observatory (USA)
NS	Nord-Sud
NVSS	NRAO VLA Sky Survey
OVRO	Owens Valley Radio Observatory (USA)
PSS	Palomar Sky Survey
QSO	Quasi Stellar Object
QSS	Quasi Stellar Source
ROSAT	ROentgenSATellit (Germania)
ROUB	Radio Osservatorio Università di Bologna
SAIT	Società Astronomica ITaliana
SIF	Società Italiana di Fisica
SETI	Search Extra-Terrestrial Intelligence
SN	Supernova
SRT	Sardinia Radio Telescope
TIRGO	Telescopio Infrarosso Gornergrat Observatory

UT	Universal Time
VIMOS	Visual Imager and Multi-Object Spectrometer (ESO)
VLA	Very Large Array (USA)
VLBI	Very Long Baseline Interferometry
VLT	Very Large Telescope (ESO)
VSOP	VLBI Space Observatory Programme
WAT	Wide Angle Tail
WSRT	Westerbork Synthesis Radio Telescope (Olanda)
YERAC	Young European Radio Astronomers Conference
4C	Fourth Cambridge Catalogue

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