The early history of gravitational wave detection in Italy: from the first resonant bars to the beginning of the Virgo collaboration

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Abstract: At the very beginning of the 1970s, two experimental activities for gravitational wave (GW) detection were being carried out in Italy: one in Frascati, at the European Space Research Institute (ESRIN), performed by Karl Maischberger and Donato Bramanti; the second one set up by the group of Edoardo Amaldi and Guido Pizzella at the University of Rome. This second activity pioneered the field of cryogenic resonant bar detectors, which dominated Italian research on GWs until the 1990s, when the French-Italian project for a giant interferometric detector came into life: Virgo, led by Alain Brillet and Adalberto Giazotto. The present paper gives a brief overview of the early history of GW experiments in Italy and is the result of a historiographical research based on archival resources, scientific papers and interviews of some of the protagonists, among which is one of the authors.

Keywords: General Relativity, gravitational waves, detector, Virgo.

1. Introduction

The age of GW detection begins with the experimental work of the American physicist Joseph Weber, at the end of the 1950s. When Weber proposed for the first time the idea of an apparatus capable of vibrating at the passage of gravitational radiation and measuring the amplitude of the vibration, the very existence of GWs was a still debated theoretical question. Were GWs purely mathematical entities – an artifact related to the choice of the coordinate system in the field equations of General Relativity – or did they possess a physical reality and were they thus measurable?

Weber participated into the theoretical debate – which was then taking place with unprecedented liveliness, as part of the new growing interest in General Relativity lightened in the 1950s – publishing in 1957 a paper with John Wheeler (Weber, Wheeler 1957). The authors supported the hypothesis of a true physical meaning of these undulatory solutions of Einstein’s field equations. Furthermore, beyond the uncertainty about their existence, the extreme weakness predicted for their interaction with matter made it seem impossible to accomplish an experiment for measuring the effect of their passage. In spite of these discouraging premises, in 1959 Weber presented at the Royaumont Conference, near Paris, a work about the detectability of GWs, proposing the first experimental ideas for a GW detector (Weber 1962). His 1960 paper (Weber 1960) constituted the start of the experimental search for GWs. Weber had the merit and the audacity of bringing the discussion about the existence of gravitational radiation from the theoretical to the empirical ground. His effort has to be considered inside the wider context of the Renaissance of General Relativity, as historians call the new attitude of the scientific community towards Einstein's theory which developed between the 1950s and 1960s, bringing it back from the field of mathematics to physics.[1]

In the following years, Weber made many experimental attempts and built several prototypes of his *resonant bars* at the University of Maryland, gradually improving the facilities and the data analysis techniques. Finally, in the late 1960s he believed he had detected gravitational waves and announced the discovery in a paper (Weber 1969). He had set up five resonant bars at Maryland University and one at the Argonne National Laboratory, 1000 km away: he observed several coincidences in the data collected by all the detectors working at the same time, as if the six facilities had been crossed by the same signal coming from the sky.

> The probability that all of these coincidences were accidental is incredibly small. Experiments imply that electromagnetic and seismic effects can be ruled out with a high level of confidence. These data are consistent with the conclusion that the detectors are being excited by gravitational radiation.

These words appear in the abstract of the paper. Several experimental activities started all around the world in order to verify Weber's results, but none of these experiments – in most cases more sensitive than the original ones – could ever confirm the optimistic conclusions traced by Weber. Nevertheless, the scientific effort aimed at detecting GWs had begun. Among the first activities were the two born in Italy: in Frascati, at the freshly founded European Space Research Institute (ESRIN), and, briefly later, at the Sapienza University of Rome.

2. The European Space Research Institute and the search for GWs

ESRIN was born in the 1960s as a facility of the European Space Research Organization (ESRO): a laboratory for studying physical and chemical phenomena in space, gathering experts from specialized fields of theoretical and experimental physics, chemistry and plasma physics. The cornerstone ceremony of ESRIN was celebrated on September 27, 1968, with an inauguration speech by the Director General of ESRO, the theoretical physicist Hermann Bondi, one of the protagonists of the debate on the

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[1] For more details about the Renaissance of General Relativity, see the talk by R. Lalli at the XXXVI SISFA Congress (Naples, October 4-7, 2016).

existence and measurability of GWs during the Renaissance of General Relativity. It was not by chance that one of the first activities at the new laboratory was the construction of a Weber-type detector, initiated already in 1969. The enterprise was undertaken by the German electronics engineer Karl Maischberger and the Italian physicist Donato Bramanti, assisted by the German technician D. De Loie, expressly assigned by ESRIN to the GW experiment.

It is interesting to note that the beginning of this experimental research was stimulated by the theoretical physicist Bruno Bertotti, a former student of Erwin Schrödinger, who had worked at Princeton University besides John Wheeler and Robert Dicke, giving relevant contributions in the field of General Relativity.[2] In 1972 Maischberger and Bramanti published a first paper reporting about their activity, in which they acknowledged "the valuable suggestions from Prof. J. Weber" and thanked "Prof. B. Bertotti for initiating this work at ESRIN" (Bramanti, Maischberger 1972).

Bramanti and Maischberger's resonant detector was a *room-temperature* aluminum cylinder, as Weber's, 153 cm long, with a diameter of 70 cm and weighing 1580 kg, suspended by a steel wire in a vacuum chamber at 5 x 10^{-4} torr. An explicit optimism transpires from the paper:

> We have decided to repeat Weber's experiment not only to check his results, but because so far, it seems to be the most sensitive device for detecting gravitational waves.

Furthermore, it was planned to install a coincidence network with Weber's detectors at the University of Maryland and the "Weber copy at the Max-Planck Institut in Munich", where Heinz Billing and Walter Winkler had started in 1971 a Weber-like experiment.[3] As Winkler recounted to the authors of this paper, he met Maischberger presumably in 1971 at a conference, where the ESRIN scientist gave a speech about the Frascati detector. Winkler was not aware of the GW activity in Frascati before, nor did he know Maischberger. Afterwards he contacted Maischberger and the two decided to establish a collaboration, which gave birth to the Munich-Frascati experiment. In the meantime, a British computer scientist, Donald Parkinson, had joined the ESRIN team and collaborated to the data analysis of the detector in Frascati (Bramanti *et al.* 1973). Between 1971 and 1973, ESRO was changing the destination of ESRIN, gradually transforming the space physics laboratory in a canter for Space Documentation and for the development of the Information Retrieval Service database. The GW experiment at ESRIN continued until 1975, thanks to the financial support received from the Max Planck Institute in Munich, which took over the activity. Between July 1973 and January 1975, the detectors in Munich and Frascati worked simultaneously for 350 days. It was the most sensitive room temperature Weber type experiment accomplished so far. As J.L.

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[2] Bertotti was in Princeton in the years 1958-1961. Among his publications of that period, we remember the fundamental work on the so-called Bertotti-Robinson solution of Einstein's equations (Bertotti 1959).

[3] In Munich the experimental work on bar detectors started on January 1st, 1971, when the young physicist Walter Winkler was hired to work on this topic under Billing's supervision. By 1976 Billing's gravitational team in Munich was composed by Walter Winkler, Albrecht Rudiger, Lise Schnupp, Roland Schilling, Peter Kafka. (Source: email-interview released by Walter Winkler to Adele La Rana, 15/9/2016).

Levine remembers in his historical review about the early years of GW detectors, at the time of room temperature bars the Munich-Frascati experiment unquestionably provided the most stringent test of all for the detection of gravity waves. However, it did not confirm Weber's results (Levine 2004).[4] Nor did the experiment in triple coincidence set up among the Munich-Frascati detectors and the resonant bar at the Observatory of Meudon (Paris), built by the group of Silvano Bonazzola (Bonazzola *et al.* 1973).

In 1975 the Frascati detector was dismantled and later rebuilt in Garching, where Billing's team had moved in the meantime; it was the definitive end of ESRIN's brief GW activity. Maischberger was integrated into Billing's group, which had turned its interests to interferometric detectors around 1974.[5] The first paper (Gertsenshtein, Pustovoit 1962) proposing an interferometric method to detect gravitational radiation was published in 1962 by the Russians M.E. Gertsenshtein and V.I. Pustovoit. However, it remained quite unknown. The idea spread out through the 1971 article by R.L. Forward and others (Forward *et al.* 1971) and especially through the 1972 report by Rainer Weiss, Electromagnetically Coupled Broadband Gravitational Antenna (Weiss 1972). The latter contained the first detailed analysis of the noise sources of an interferometric detector for GWs, of its sensitivity and its best mode of operation, providing an estimate of the scale-kilometer arm length needed to detect predicted sources. When Billing's group started the experimental activity on interferometers for GW detection, Rainer Weiss had not yet obtained funding for his own experiments, but offered his support to the German team. The contacts between the German group and the Americans date back to that period and were destined to strengthen in the following years, providing the premises for the future GEO-LIGO collaboration. Garching's 30-meter interferometric prototype was the first in the world to reach the shot-noise limit, paving the way to development of the giant interferometers LIGO.

3. The start of GW research in Rome: the cryogenic detectors

The Italian research activity for GW detection had its true start with the birth of the group led by Edoardo Amaldi and Guido Pizzella at the Physics Institute of the University of Rome. The aim of Amaldi's group was not to reproduce Weber's experiment, as Bramanti and Maischberger, but to build a more sensitive device, a second-generation detector: a *cryogenic* resonant bar. This long-term activity began in 1970 and lasted until the turning-off of the cryogenic resonant bar Nautilus at the National Laboratories in Frascati, in 2016, after the announcement of the first GW detections by the LIGO-Virgo collaborations (Abbott *et al.* 2016a, b). The roman experience had a deep impact on the development of the field in Italy, especially because of the scientific authoritativeness of Edoardo Amaldi, who became one of the main ambassadors of GW research in the world.[6]

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[4] Main papers by the Munich-Frascati collaboration are (Billing *et al.* 1975; Kafka, Schnupp 1978).

[5] Source: email-interview released by Walter Winkler to Adele La Rana, 15/9/2016.

[6] The *Edoardo Amaldi Conference on Gravitational Waves* – organized for the first time in Frascati in 1994 (June 14-17) – was the first International gathering explicitly dedicated to the field and became a periodic appointment, which takes place every two years in a different location in the world.

It is worth to notice that the GW activity at the University of Rome was born as the first long-based coincident experiment involving groups from two different countries.

It started indeed as a joint endeavor with the teams of William Fairbank at Stanford University and the team of William Hamilton at Louisiana State University, envisaging the construction of three *cryogenic* resonant bar detectors, cooled to 0.003 K, to be installed in the three locations.

During the 1960s Edoardo Amaldi had made several attempts to found a research group on GWs in Rome. His interest for experiments on gravity arose in the late 1950s, in the context of the Renaissance of General Relativity, and grew up with the flourishing of relativistic astrophysics in subsequent years. Already in 1959 he had set up with his colleague Mario Ageno an experiment to study the possible effect of gravity on the beta decay constant, following a suggestion by Bruno Touschek (Bonolis, La Rana 2016). In the role of president of IUPAP he was aware of the new lymph flowing in the field of gravitation studies and was attentively following the experimental developments, as the investigations of Robert Dicke at Princeton about the equivalence of inertial and gravitational mass. On January 26, 1960 Amaldi took some notes in his diary about the talk given that day at the Institute in Rome by the Russian physicist Dmitri Ivanenko, titled *Remarks on transmutation of matter into gravitation.* Amaldi wrote down that it was necessary "to study gravitational waves, because it is not sure they exist".[7] This happened several months before the Varenna School on the Experimental Tests of Gravitational Theories (June 19-July 1), where Amaldi heard about Weber's resonant bar detectors.

However, Amaldi's attempts to start a GW activity during the 1960s were not successful. At the end of the decade, his hopes were on a young and brilliant student, Remo Ruffini, who spent with Amaldi's strong support a period at Princeton University, training on gravitation with Robert Dicke and with John Wheeler and visiting Weber in Maryland. Amaldi's explicit aim was setting up "an experimental group working in this field at the return of Ruffini".[8]

The story went differently with respect to Amaldi's expectation. His plans could finally come true thanks to the return from the United States of his young assistant Guido Pizzella, who became the actual leader of the new research.

Pizzella had spent several periods in USA, working mainly with James van Allen at Iowa University, where he achieved his PhD in 1962. Since 1963, Pizzella coordinated the group for space research in Rome, working at the first ESRO mission for solar wind measurements, the experiment S.73 flying on the satellite Heos-1.[9] He continued to make long stays in USA, until summer 1970, when he definitely came back to Italy with the idea of beginning an experimental activity in fundamental physics. He hesitated between the brand new field of cosmic background radiation – observed for

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[7] The quoted documents belong to Amaldi's Archive at the Physics Department of Sapienza University of Rome.

[8] Letter from Amaldi to Reimar Lüst (who was about to become the Vice President of ESRO, in 1968), July 7 1967. Amaldi strongly supported Ruffini's application for a European Space Research Organization (ESRO) fellowship, which would allow him spending two years in USA.

[9] Heos-1 was the first European spacecraft to reach interplanetary space. It was launched in December 1968. For the solar wind experiment, see: (Bonetti *et al.* 1969).

the first time six years before – and the field of the gravitational wave detection, stimulated by Weber's recent claims of discovery.[10]

Finally in September 1970, Pizzella proposed to Amaldi to begin a research activity for GW detection in Rome. Already in January 1971 Amaldi received confidentially from Remo Ruffini the Stanford and Louisiana proposal for a detector consisting in a 5 ton aluminum bar, cooled to very low temperature (0.003 K) and employing a SQUID amplifier coupled to a resonant transducer. Three months later, Pizzella visited with Massimo Cerdonio, Renzo Marconero and Ivo Modena the facilities at Stanford University and Louisiana University, and the Bell Telephone Laboratory, where J. Anthony Tyson had constructed a GW Weber-type detector. Led by Hamilton they also went to the Mississippi-NASA Test Facility Center, in charge of constructing the cryostats to be set up at the Universities of Stanford and Louisiana.

The experimental activity started at the Laboratories *SNAM-Progetti* of the ENI group, located in Monterotondo (not far from Rome), whose director was Giorgio Careri, the renowned expert of low-temperature physics at Sapienza, and where a new helium liquefier was being set up. By 1974, also the physicists Gian Vittorio Pallottino, Franco Bordoni and Umberto Giovanardi had joined the team.

While the ESRIN experiment was intended to reproduce Weber's results in a short time, building room temperature detectors, Amaldi and Pizzella's project was much more ambitious, as it aimed at the second generation resonant bar detectors: this meant that it was a long-term project, which would take many years (Pizzella 2016). The technology needed to cool down an aluminum bar weighing several tons to cryogenic temperatures was not straightforward and the first attempts to build directly a big cryostat failed. The group then began experiments on smaller cryostats at the physics institute in Rome.

The plans changed many times, due to technical and logistic difficulties. In the second half of the 1970s the *SNAM-Progetti* Laboratory suffered the economic crisis and closed. Amaldi managed to move the big cryostat activity to CERN, the only place eligible to host and provide technical assistance to such a big scale cryogenic experiment. In this initiative, Amaldi was strongly supported by Emilio Picasso, Director of the Experimental Facilities at CERN. The gravitational antenna was called Explorer and began to work in the 1980s. It consisted in a cylindrical aluminum (Al5056) bar of 2300 kg, 3 m long and with a diameter of 60 cm, cooled through liquid helium down to 2.6 K. Its resonant frequencies were 906 Hz and 923 Hz.

The first coincidence measurements between the cryogenic resonant-mass detectors of Louisiana State University (Allegro, Baton Rouge), Rome (Explorer, Cern), and Stanford (Palo Alto) were accomplished in 1986. The antennas were still far from design sensitivity, too vulnerable to non-thermal noise, and not stable (less than 3 days of continuative operation). In 1990 Explorer became the first antenna reaching the nominal sensitivity and stability over long periods. For several years it has been the most sensitive experiment for GW detection, setting upper limits to the main GW source candidates. While the 1990s are the golden age of cryogenic resonant bars, they

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[10] Source: interview released by Guido Pizzella to Adele La Rana, 11/7/2015.

are also the years in which the plans for the new generation of GW detectors – the giant interferometric antennas – take the wind, with the projects LIGO and Virgo.

A timid attempt to explore the interferometric alternative was undertaken in Rome in 1976, through the undergraduate thesis work of two students, Massimo Bassan and Livio Narici. The supervisors were Amaldi and Pizzella, but the research did not have further developments.[11]

The choice made by Amaldi's group – to bet on cryogenic resonators and not, as Billing's team in Garching, on interferometry – had of course its weight on the evolution of GW research in Italy. A detailed analysis of the reasons and implications of this choice is still a matter of historical investigation. The high level research carried out and the great international expertise acquired has given the Italian group a leading role in the field. Furthermore, the importance of the political support given by Guido Pizzella to the LIGO and Virgo projects should not be neglected in this analysis.

4. Hints on the origins of the Virgo project

The idea of a French-Italian collaboration for GW detection was born from the encounter of two researchers with very different scientific backgrounds: the French expert in optics Alain Brillet and the Italian particle physicist Adalberto Giazotto. They met for the first time in 1985, at the IV Marcel Grossman Meeting (MG4) in Rome and realized they had been working since few years at two complementary fundamental features of GW interferometric antennas. Brillet's group in Orsay was working on lasers and optical metrology; Giazotto's team in Pisa was developing sophisticated multipendular suspensions for the mirrors of the interferometer, in order to attenuate the seismic noise acting on them.

Brillet became interested in interferometric detectors after his PhD in Orsay, while spending two years at the University of Colorado in Boulder (1977-1978), in the group of John L. Hall. Here Brillet had the chance to come in contact with Peter L. Bender, who was conceiving a project to build a space interferometer for GWs, the future LISA (Laser Interferometer Space Antenna) (Faller *et al.* 1985). Back in Orsay UPMC, Brillet was at the 1979 Marcel Grossmann Meeting in Trieste, where he met Ron Drever – who had shortly before invented power recycling and was implementing it in Glasgow – as well as Rüdiger and Schilling, who were presenting the first results of Garching's interferometric prototype and their first mode cleaner (Maischberger *et al.* 1979).

Briefly after, Brillet began to discuss with the experimentalist Christian Bordé and the theorists Philippe Tourrenc and Jean Yves Vinet the idea of investigating in France the interferometric approach. He visited Rai Weiss at MIT, receiving help and encouragement. An experimental activity began in Orsay in the early 1980s, led by Brillet and soon joined by the young student Nary Man and later by other young researchers, as David Shoemaker.

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[11] See the paper by Bassan and La Rana in these proceedings.

During the years 1982-1985, the team did not receive regular funding but had many small contracts for research coming from the physics department of CNRS, the French military, the European Community and private enterprises.

The main activities concerned optical metrology, reduction of shot-noise and enhancement of power laser stability. Particularly relevant was finding an appropriate solution for the laser source. As Brillet later described (Brillet 2009): "The main challenge was to convince the community that it could be possible to split the dark fringe into more than ten billion, which required an incredibly stable and powerful laser". In the frequency range of the most promising astrophysical candidates considered at the time – supernovae, emitting GWs around 1 kHz – the main noise sources to face up were shot noise and laser noise. The path to follow was Drever's recycling, the technique recently invented to reduce by a large factor laser power required by GW interferomers, which had not yet been proven by an experiment or even by calculation (Brillet 2009). Using Argon lasers – the only high power single frequency laser available at the time – Nary Man and the French team showed that the sensitivity of a Michelson-Fabry-Perot interferometer (up to 2 Watts) is effectively limited by shot noise and demonstrated for the first time the efficiency of power recycling. In addition, the choice and the study of green light Nd-YAG lasers, to replace the noisy and unreliable Argon lasers, was a relevant step undertaken by the group in those early years.

In the meantime, the astrophysicists had been observing a growing number of pulsars detected with radio telescopes. The discovery of the first binary system composed of a pulsar orbiting a neutron star dated back to 1974 and was achieved by Russell Hulse and Joseph Taylor (Hulse, Taylor 1975). In their 1975 paper, the two American physicists highlighted that the binary configuration provided a nearly ideal laboratory for testing General Relativity, "including an accurate clock in high-speed, eccentric orbit and a strong gravitational field". The observation over several years of the discovered system – called PSR 1913+16 – showed that the orbit of the pulsar was slowly shrinking over time, following with great accuracy the curve predicted by General Relativity for the energy loss due to GW emission (Taylor, Weisberg 1982). These results constituted the first indirect proof of the existence of GWs.[12] The scientific evidence coming from the observation of the PSR 1913+16 system provided a strong support to the decision of starting the new expensive projects for GW detection: the kilometric interferometers LIGO and Virgo.

Adalberto Giazotto had been working in the field of particle physics since his graduation at the University of Rome, in 1964. He participated in the electro production experiments and in the study of the form factors of mesons, accomplished by the group of Edoardo Amaldi and Gherardo Stoppini in Frascati, and then continued his activity in the laboratory of Daresbury in Great Britain and afterwards at CERN, in the experiments

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[12] Hulse and Taylor were awarded the Nobel Prize in Physics in 1993, for discovering the pulsar and showing it would make possible this particular gravitational wave measurement. From Taylor's Nobel Lecture: "The clock-comparison experiment for PSR 1913+16 thus provides direct experimental proof that changes in gravity propagate at the speed of light, thereby creating a dissipative mechanism in an orbiting system. It necessarily follows that gravitational radiation exists and has a quadrupolar nature".

NA1 and NA7 led by the Pisa group (Bemporad, Bonolis 2012). His interest in GWs awoke in the first 1980s, as he aimed at starting a new experimental activity in fundamental physics. Stimulated by the observation of many new pulsars made through the Australian Radiotelescope in Marrabra, Giazotto focused on gravitational sources, which could emit GWs with frequencies starting from a lower limit of 10 Hz. It was a fundamental change of the point of view, as, up to then, the privileged GW sources considered for detection had been the supernova explosions, with peaks expected around 1 kHz. The bar detectors had resonant frequencies around this value and their narrow band of observation was optimized for that kind of source. Instead, Giazotto turned his attention to low frequencies, which presented seemingly insuperable experimental problems, due to seismic noise acting on the detectors components. In order to enlarge the bandwidth of detection to low frequencies, it was necessary not only to switch to interferometric detectors but also to study and build a new kind of seismic isolator for the mirrors of the interferometer. In 1982 Giazotto submitted to the PISA INFN section a detailed internal report (Giazotto 1982). The experimental activity started in San Piero a Grado (Pisa) in the early 1980s with the name IRAS (*Interferometro per la Riduzione Attiva del Sisma*). The idea of Giazotto was to use a multipendular suspension for the mirrors, in order to dissipate the vibrational energy along the chain and insulate from Earth's movement the last pendular stage, where the mirror hangs.

When Brillet and Giazotto met at the MG4 (June 17-21), the latter was presenting the first results from IRAS (Giazotto *et al.* 1986). The collaboration between Pisa and Orsay had its start and, already in May 1987, four Italian groups and the one from France led by Brillet signed the First Proposal for a French-Italian ground-based Interferometric Antenna. The teams involved were the following: the French group from CNRS and the Université Pierre et Marie Curie in Orsay, Paris (A. Brillet, C.N. Mann, D. Shoemaker, P. Tourrenc, J.-Y. Vinet); the team from Pisa INFN section and Pisa University (R. Del Fabbro, A. Di Virgilio, A. Giazotto, H. Kautsky, V. Montelatici, D. Passuello, A. Stefanini); the group from the University of Naples "Federico II" (F. Barone, R. Bruzzese, A. Cutolo, M. Longo, L. Milano, S. Solimeno); the teams from Frascati CNR (F. Bordoni, F. Fuligni, V. Iafolla) and from the University of Salerno (I. Pinto).

In 1989 the Virgo Project was finally defined.[13] New groups entered the endeavor in 1992: Perugia INFN section, LAPP (Annecy), IPN (Lyon), Florence University, Sapienza and Tor Vergata Universities of Rome, Genova University and the Padova-Trento group. In June 1992, the French Minister Hubert Curien approved officially the Virgo Project, while a year later the Provisional Virgo Council formed and also INFN gave its approval. The final agreement between the French CNRS and the Italian INFN was signed in 1994, on June 27, by the President of INFN Luciano Maiani and the President of CNRS Francois Kourilsky. The interferometer would be built in Cascina, near Pisa, with a 76 MegaECU funding (European Currency Unit), about 50 million euros. The construction began in 1997, after a long dealing for the expropriation of the

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[13] In addition to the previous groups, also the ones from CNRS-Université Paris VI, from the Observatoire de Meudon, from the University of Illinois and the University of San Paolo signed the 1989 Virgo Project.

fields in Cascina, owned by more than 100 different landlords.[14] Alain Brillet and Adalberto Giazotto were the Project Leaders, alternating their role every three years.

The Virgo group in Naples, led by Leopoldo Milano, implemented a prototype of bi-pendular suspension interferometer with 3-meter armlength. The effort was shared by several young researchers: Fabrizio Barone, Enrico Calloni, Rosario De Rosa, Luciano Di Fiore, Aniello Grado, Guido Russo (Barone *et al.* 1995a, b; 1996). The interferometer, which was the first in the world to be operated with digital controls, has pioneered the technology, which in the following years was adopted for all the long-based interferometric detectors.

5. Open questions

Why was not Virgo born as a European project instead of a French-Italian endeavor? Why Europe does not have two Virgo interferometers as USA has two LIGO?

These questions are strongly addressed by the scientists and stakeholders of the GW community, especially after the first detections made by the LIGO interferometers.

During the 1980s, several attempts were made by Alain Brillet and Adalberto Giazotto in order to stimulate a wider collaboration. Giazotto had some contacts with Maischberger for a shared project. In a recent article published on *Ciel & espace*, also Brillet mentions his own efforts for a European interferometer, involving also German and English groups (Brillet 2017). The different starting times of the research activities did not favor the cooperation. The teams in Glasgow and in Garching had begun their research activity on interferometric detectors several years before the French. In September 1989, several British and German groups signed a “Proposal for a joint German-British Interferometric GW detector”. However, the project failed after the unification of Germany and the change in the financial priorities of the country. Other reasons why Virgo was not born as a European experiment are related to scientific divergences among the European groups, especially on the type of interferometer to be built (Fabry Perot versus Delay Lines) and on the choice of the site for the detector. In 1988 a European Collaboration Meeting on Interferometric Detection of GWs took place in Sorrento (September 30-October 3), where the idea of a European Interferometer was discussed, but again the attempt had no success.

Further investigations are needed to better understand the dynamics that stimulated the birth of a French-Italian agreement for a joint GW interferometer instead of an extended European collaboration, as envisaged between the late 1970s and early 1980s.

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[14] In 1995, September 25, the *Gazzetta Ufficiale* published the expropriation resolution of the Italian Minister of Public works, for the fields in Cascina chosen as the best site to build the Virgo interferometer.

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