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EUROGRAV 1986–1989: the first attempts for a European Interferometric Gravitational Wave Observatory

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Abstract At the turn of the 1980s and 1990s, on the eve of the great leap in scale from the resonant bars to the long-baseline interferometers LIGO and Virgo, the four European groups then engaged in the field of interferometric gravitational wave detection in Germany, UK, France and Italy tried to set up a common strategy, with the aim of establishing a network of three long-based antennas in Europe. The paper analyzes the main causes of the failure of those early plans. An attempt is made to outline the parallels and differences with the current times, on the eve of the new leap of scale toward the third generation of gravitational wave interferometers, while the negotiations for the European-born project Einstein Telescope are taking place.

1 Introduction

In the field of gravitational wave detection there is an evident asymmetry that distinguishes the two scientific shores of the Atlantic Ocean. The two LIGO antennas in the USA endow the country with the effective ability to autonomously detect some new kind of transient gravitational signal, such as the gravitational radiation emitted by a supernova, until now still undetected. Instead, the single long-baseline interferometric detector Virgo, located in Italy, does not guarantee the European scientific community its own independence of observation.

This asymmetric situation was also true for the first detections of gravitational radiation from coalescing binary systems, when that brief, rapidly fading kind of signal was being analyzed for the first times. At least two interferometers were needed, indeed, to claim the very first gravitational wave detection, accomplished on the 14th of September 2015. At that time, Virgo was not running yet, because it was undergoing its upgrade to Advanced Virgo. Instead, the two Advanced LIGO were taking data and were able, by virtue of being a pair, to observe what had never been observed before [1].

With regard to the detection of transient signals from coalescing binaries, the situation has changed a lot today. A large number of coalescing binary systems have been observed so far by the three detectors, allowing an accurate and reliable modeling of these gravitational sources. The latter crucial improvement deeply affected data analysis and sources detectability, so that at present the single-detector observations are given credence.[1]

The case of periodic sources, up to now still undetected, is different. For continuous repetitive signals, the data can be collected and integrated over long periods of time. In this way, the signal-to-noise ratio can be enhanced, and in principle the gravitational wave (GW) can be identified by a single antenna.

In order to identify a model-free or unanticipated transient GW signal in a stream of experimental data, coincidence analysis of data streams coming from different detectors is needed. If two detectors are far from each other, the disturbances affecting them are mostly uncorrelated and thus coincidence analysis can cancel out the local noise from the data stream. In this way the probability of a random coincidence among the detectors is greatly reduced.

The so-called non-Gaussian noise (caused, for example, by micro-creeps in the mirror suspending systems or by sudden external mechanical or electromagnetic disturbances, etc.) mimics very well the signals that would be expected from GW bursts. Disturbances can be identified only in some cases, so that the corresponding event can be discarded. In a single detector, the tiny transient signal cannot be separated from the noise in which it is

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[1] Nevertheless, multiple detectors are needed for proper localization.

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buried, unless the burst signal is described by a robust model, as only recently has become the case for gravitational radiation emitted by coalescing binaries. In this favorable circumstance, one can use the known waveform to reject noise disturbances and extract the gravitational signal. Nevertheless, if the waveform model is not yet validated by observations, the only chance is to match coincidences between spatially separated detectors, to cancel out local noise.

International collaboration is thus a fundamental feature of the research field of GW detection, not only because of the scale of the challenges to develop detectors and analyze the data, but also because of the specific nature of the investigated phenomenon. The expected signals are so weak compared to the different disturbances acting on the detector, that they are buried inside noise. However, the extremely low interaction of gravitational radiation with matter also implies that the same GW will pass through different detectors located worldwide basically unmodified, i.e., without losing any energy or information about its source. The experimental problem is to capture and extract this tiny signal, which travels at the speed of light and thus hits all detectors almost at the same time, from the detector noise.

A part from allowing the detection of a GW signal, coincidence analysis is necessary to extract from the data precious information about its astrophysical source. The dimensions of the current ground-based antennas (armlength of the order of kilometers) are small compared with the wavelength of the expected radiation (starting from a few tens of kilometers to rise), so coincidence analysis techniques involving widely spaced antennas must be used to localize the sources in the sky and to obtain useful astrophysical information. This observational methodology is used since the 1960s in radio astronomy, where arrays of several radio antennas work as a single telescope many miles across, a technique referred to as VLBI (Very-Long-Base-Line Interferometer). To identify the arrival direction of a GW with sufficient precision to point telescopes for follow-up observation, the signal must be measured by at least three detectors, which can reduce incertitude on the position to two reasonably small regions in the sky.[2] The time delay between the arrivals of the signal at any two detectors determines a circle in the sky, on a plane perpendicular to the line joining the detectors, in which the source must lie. With three detectors there are two independent time delays, giving two patches on the sky, which will intersect in general at two different positions. With four or more detectors there would be a unique intersection region.[3]

In a note drafted in September 1987, Bernard Schutz, a major contributor in the field of GW research and at the time professor at Cardiff University, Wales, pointed out:[4]

> More detectors mean capturing more gravitational wave events. This is partly because of greater sky coverage, but mainly because the decreasing risk of 'random' coincidences caused by noise allows one to operate with lower thresholds and therefore to see a greater volume of space. More detectors mean also a better reconstruction of the GW, therefore more physics and astrophysics.

The prospect of ushering in the field of GW astronomy was a strong scientific argument supporting the 1980s proposals for an array of long-based GW interferometers in Europe and in the USA. The acronym LIGO (*Laser Interferometer Gravitational Observatory*), containing the word "observatory," speaks to this story.

On March 13, 1991, the physicist of Bell Laboratories J. Anthony Tyson addressed a speech as a referee of LIGO in front of the members of the House of Representatives of the USA, where he argued [57]:

> In no sense could a single LIGO be called an astronomical "observatory". This is because several high sensitivity LIGOs, spaced around the Earth, are required to unravel the information in the complex gravitational wave signature. [...] A single LIGO cannot tell what direction in the sky an event came from, and also has great difficulty in discriminating against local interference. This is therefore a natural project for international cooperation.

Tyson aimed at persuading the members of the House of Representatives that it was not worthwhile to invest so much money in such an ambitious project, which had poor chances of success and depending so heavily on international cooperation.

The interactions among the few teams working in Europe and in USA on the development of interferometric detectors in the 1980s and early 1990s responded to the need for scientific cooperation. At the same time, these interactions were aimed at supporting the political strategies adopted to negotiate with the funding agencies, as we shall see.

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[2] For long-lived sources, one detector can be enough to pinpoint the source, if the Earth's motion allows observation from multiple positions over a period of time.

[3] If the GW signal has an electromagnetic counterpart, the source may be pinpointed by ground-based and space-based astronomical observatories, as occurred on August 17, 2017, for the Kilonova event GW170817. It was the very first time that an astrophysical event was observed both in the gravitational and electromagnetic channels.

[4] Note by Bernard Schutz, *Outline case for building 3 laser interferometric detectors in Europe*, September 1987. Personal Papers of Alain Brillet, in the archives of the European Gravitational Observatory, Cascina (Pisa), Italy. From here on we will indicate Alain Brillet's Personal Papers in Cascina by the acronym PAB.

To better understand the relationships among the interferometric teams, one should recall that a self-identified gravitational wave community did not exist yet. At the time of the events narrated here, the GW experts were still quite fragmented, and constituted a small part of the larger General Relativity community. They met at general gatherings such as the Marcel Grossmann Meetings or at GRn Conferences.[5],[6] There was no coordinating framework or committee, and there were no specific conferences in which the experts of the field periodically met. All this would come later during the 1990s.

Looking at the early attempts to establish a European GW observatory can help to develop greater awareness in planning the next generation of GWs detectors, the 3G, or third-generation interferometers as they are called today—the first generation being LIGO and Virgo, the second generation constituted by Advanced LIGO and Advanced Virgo.

The author is aware of the risks and difficulties of analyzing such recent history and of trying to put it into perspective, while it is still pulsing with lively feelings and human passion, but retains important to try to reconstruct documented facts and collect testimonies from the direct protagonists, at this moment when the dawn of gravitational wave astronomy is giving rise to new very promising international collaborations.

As the GW community expands, the memory of the past, with its precious repository of humanity and living scientific experience, can inadvertently slip away, losing a significant part of information about its own origins as a community. Although not exhaustive and lacking, the author hopes that these pages may become a stimulus for reflection and further analysis.

2 A preliminary comparison between yesterday and today

The following far-sighted comment appears in a document called *Report of an Ad-Hoc Working Group on the Future of Interferometric Gravitational Waves Antennas in Europe*, which was signed in March 1988 by the leaders of the European groups then working in the field:

> The scientific case for proceeding rapidly towards the "simultaneous" construction of three detectors in Europe is an extremely strong one. An array of three detectors in Europe would give the European groups the minimum independence necessary to enable Europe to maintain its leading position in the field. Technically and scientifically the European groups have the capability to construct and operate a network that could make the first detection of gravitational waves and that could reach the critical number of three antennas that would see the birth of gravitational wave astronomy. A decision to build only, say, one European detector in the hope that the U.S. would build two would have serious disadvantages and long-term consequences: the three detectors would not be able to pinpoint sources on the sky, they could not test general relativity, and the sensitivity of the network would be only marginally adequate if the most pessimistic estimates of event rates turn out to be correct. On the other hand, three European detectors operating with an American array, built either simultaneously or subsequently, would become one of the most important astronomical instruments of the modern age.[7]

The four teams from Garching (Germany), Glasgow (Scotland), Orsay (France) and Pisa (Italy) were setting up a collaboration named *EUROGRAV*, aimed at promoting a network of interferometric detectors in Europe. Indeed, the prediction feared in their 1988 report did partially come true.

On the 14th of September 2015, a gravitational radiation emitted 1,3 billions of years ago by two colliding black holes passed through the two Advanced LIGO antennas (4 km armlength) and produced the first GW detection, a result pursued for over 50 years of experimental research [1]. The only detector capable of capturing that same signal in Europe—the 3-km-long interferometer Virgo, built near Pisa—was unfortunately turned off, subjected to an upgrading phase to Advanced Virgo. Nevertheless, the final paper of the first detection was signed by both LIGO and Virgo scientists, on the basis of a 2007 agreement on the full sharing of data, joint data analysis and common publications. To better contextualize this agreement, one should notice that during the 20 years required to build, operate and upgrade the interferometers in the USA and Europe, scientific cooperation occurred at many different levels and often people working for one experiment would later join the other, sharing expertise, data analysis formats and technologies.[8]

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[5] For a historical perspective on the General Relativity and Gravitation community, see [32].

[6] The GRn conferences are the periodic conferences on General Relativity held since the 1950s, the first periodic gathering of the field. The conference held in Bern in 1955 to celebrate the jubilee of Einstein's Relativity Theory became later known as the GR0 conference.

[7] Brillet A., Corbett I. F., Giazotto A., Hough J., Leuchs G., Schutz B. F., Tourrenc P., Winkler W., *Report of an Ad-hoc Working Group on the Future of Interferometric Gravitational Wave Antennas in Europe*. March 1988, PAB, pp. 1–10.

[8] As described by Harry Collins, the signing of this agreement was not equally supported by all the scientists in LIGO and Virgo [13].

While the 1988 prediction of a single long-baseline antenna in Europe has come true, the "most pessimistic estimates of event rates" turned out to be incorrect:[9] the collision of black holes of a few tens of solar masses, with the related detectable emission of gravitational radiation, proved to be a far more widespread event than theorized by the most conservative astrophysical models. As a matter of fact, the two Advanced LIGOs observed a second event just three months after the first one, on December 26, 2015. The second detection provided solidity to the first observation, which looked so suspiciously similar to the signals predicted by the theoretical models to seem unlikely; it was instrumental in convincing many LIGO and Virgo researchers of the reality of the first signal. Nevertheless, several months of feverish work on data analysis were needed to identify the nature of the signal with statistical significance sufficient to claim the discovery. Finally, on February 16, 2016, LIGO and Virgo jointly announced their results. The complex data analysis was indeed a joint effort of the entire LIGO-Virgo collaboration, made by about 1000 scientists from 133 scientific institutions belonging to 18 different countries worldwide.[10]

The three interferometers have grown up together, as well as the GW community around them. Advanced Virgo finally started its first scientific run in August 2017. On August 17 a thrilling LIGO-Virgo joint detection occurred. The combination of the three detections allowed to pinpoint an oblong region in the sky, covering about 28 square degrees in a banana-like shape, where the source of the gravitational radiation must be. Just 1.7 s after the gravitational wave network detected the signal, a gamma-ray burst was detected by the Fermi Gamma-ray Space telescope. The gravitational wave and gamma-ray triggers generated alerts sent out to the astronomical community. In the following hours a great number of ground-based and space-based telescope plumbed the portion of the sky pinpointed by the LIGO-Virgo collaboration, managing to identify the source within the following eleven hours. This very first joint observation of an astrophysical event through its gravitational and electromagnetic emission has been labeled as the start of multimessenger astronomy.[11]

Now that gravitational wave astronomy has come to life, it is easy to blame the missed opportunity of having a second kilometer-long antenna in Europe. During the 1980s and early 1990s, such a project was indeed discussed among the European teams active in this field, who gathered in various ad hoc meetings, workshops, and conferences. Several steps were made in order to establish a European collaboration of some sort, and the 1988 report quoted at the beginning of this paragraph, read today, shows the far-sightedness of such an approach.

Nevertheless, a picture of the field of GW antennas at the end of the 1990s shows already a completely different follow-up. No European cooperative framework had been established, nor a common plan of development in the field had been structured. The British–German project was shortened to a 600-m-armlength interferometer, called GEO 600, which later became instrumental for developing science and technology for LIGO and Advanced LIGO. In 1997 the British and German teams joined indeed the LIGO Scientific Collaboration.

On the other hand, Virgo was born in the early 1990s as a French–Italian project, funded by the French Conseil Nationale de la Recherche Scientifique (CNRS) and by the Italian Istituto Nazionale di Fisica Nucleare (INFN). The construction of the 3-km-armlength interferometer started in 1997 in the fields of Cascina, near Pisa, and was completed in 2003. Other European countries joined the Virgo experiment only afterward: National Institute for Subatomic Physics (Nikhef) in the Netherlands entered the Virgo collaboration in 2006, while Polgraw group in Warsaw and the KFKI Research Institute for Particle and Nuclear Physics (RMKI) in Budapest joined in 2010.

In 2000, CNRS and INFN founded the European Gravitational Observatory (EGO), a consortium located at the headquarters of Virgo in Cascina and aimed at ensuring its functioning and maintenance and at promoting co-operation in the field of the experimental and theoretical gravitational waves research in Europe. In early 2021, Nikhef has become an effective member.

Not by chance, EGO is on the frontline in coordinating and promoting Einstein Telescope (ET), a next generation interferometric detector, the first to be born as a European collaboration [45] (http://www.et-gw.eu/). ET has reached a relevant milestone on June 30, 2021: it has been included in the 2021 updated Roadmap of the European Strategy Forum on Research Infrastructures (https://www.esfri.eu/latest-esfri-news/new-ris-roadmap-2021).

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[9] *"Recent estimates of the number of events per year that one could expect a network to observe have been made by the European theoretical groups on the basis of the physics of the sources and the expected sensitivities of arrays of detectors. Assuming a broadband strain sensitivity equivalent to* 10^{-22} *in 1 kHz bandwidth, even the most pessimistic assumptions lead to event rates of a few per year for the primary sources mentioned above* [Author's note: coalescing binary systems], *and optimistic rates reach several million per year for coalescing binary systems."* Quotation from: Brillet A., Corbett I. F., Giazotto A., Hough J., Leuchs G., Schutz B. F., Tourrenc P., Winkler W., *Report of an Ad-hoc Working Group on the Future of Interferometric Gravitational Wave Antennas in Europe.* March 1988, PAB, p. 5.

[10] The about 1000 scientists who signed the discovery paper [1] work for different scientific institutions located in the following countries: Australia, Belgium, Brazil, Canada, China, France, Germany, Hungary, India, Italy, Japan, Korea, Netherlands, Poland, Russia, Spain, UK and USA.

[11] Actually, one should speak of "multimessenger astronomy with GWs as a messenger." One may argue indeed that multimessenger astronomy started with the explosion of SN1987A, the first supernova to be observed through all its electromagnetic spectrum and through its neutrinos.

The transition to this new generation of interferometric detector will involve a change in the scale of the proportions of the one that occurred with the advent of LIGO and Virgo in the 1990s. It is thus natural to look back at the first negotiations for a European network of interferometric gravitational wave detectors and observe some parallels and some significant differences.

At the time of the 1988 document, the European physicists involved in the field were no more than a few tens. When the community grew to hundreds of people, the memory of those early attempts to plan a European network gradually faded away. The letters, reports, meeting minutes and documents of that period, kept by few of the scientists then involved, are here analyzed for the first time.[12] Furthermore, these primary archival sources provided precious material to make in-depth interviews with the protagonists of the story. The present historical investigation allows to address some questions born among the scientific community, which are particularly relevant now that negotiations are on their way for the next generation detector to be built in Europe: Why would Europe only build one long-baseline interferometric detector if detection needed at least two and gravitational astronomy at least three? What were the main factors opposing the achievement of a collaboration, which had so strong advantages for everyone? Can we learn something from the history of European GW research that can help the present European collaborations in order to plan the future next-generation observatories, as Einstein Telescope?

3 Exploring interferometric GW detection in the 1980s: the European teams

Three small teams were pioneering the field of laser interferometry for GW detection in Europe in the 1980s: the group at the Max Planck Institute of Quantum Optics, in Garching, directed by Heinz Billing[13] and, after his retirement in 1982, by Gerd Leuchs from 1985–1990;[14] the team founded in Glasgow by Ron Drever and, after his leaving for Caltech in the early 1980s, led by Jim Hough;[15] and the team of Alain Brillet in Orsay (Paris).[16] The British, French and German teams provided fundamental research and development results, which later were crucial in supporting the approval of the LIGO and Virgo projects in the early 1990s.[17]

The Garching group had started its activity in the field of GW research in early 1971, setting up a Weber-type room-temperature bar resonator, which worked in coincidence with a similar device located in Frascati (Italy) and provided the most stringent test so far for the detection of gravity waves [38]. Then, in 1975, the team began to work at developing Rainer Weiss' ideas on interferometric detection [61]. With their 3-m prototype, they were the first to reach the shot noise limit[18] in 1982: a significant achievement, as it meant that they had identified "all relevant noise sources, understood them well enough, found means and ways to reduce them sufficiently for

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[12] A preliminary analysis, aimed at describing the origins of Virgo, has been carried out by the author in a previous work [34].

[13] The team in Garching was composed of Heinz Billing (retired in 1982), Walter Winkler, Karl Maischberger, Albrecht Rüdiger, Rolland Schilling, Lise Schnupp, David Shoemaker (1984–1986), Gerd Leuchs (who joined in 1985 and left in 1990). For an historical perspective on the Garching team, see [7].

[14] Gerd Leuchs had been called by Herbert Walther to lead the group, but his position was weak inside it, as he was a newcomer in the field of GWs and also the youngest of the group. In 1990 Leuchs left the field of gravitational waves and Karsten Danzman was appointed new project leader for gravitational wave research at the Max Planck Institute of Quantum Optics in Garching.

[15] The Glasgow group was composed by Ron Drever (who went half time to Caltech in 1979 and full time in 1984 to work on the 40 m prototype), Jim Hough, S. Hoggan, G. A. Kerr, J. B. Mangan, B. J. Meers, G. P. Newton, N. A. Robertson, H. Ward.

[16] The group in Orsay was formed by Alain Brillet, Catherine Nary Man, Jean-Yves Vinet and David Shoemaker (since 1986 up to 1989, when he returned to MIT). Dan Dewey, a post-doc coming from MIT as had Shoemaker, joined the team for a short period (summer 1989). David Shoemaker met Alain Brillet at the Marcel Grossman Meeting in Rome in 1985 and at a conference on quantum optics of the Max Planck Institute held at Schloss Ringberg in the South of Germany. Afterward he was invited to go to Orsay by Alain Brillet, to work at his PhD. So in 1986 Shoemaker moved from Garching, where the group was facing many problems about the new leadership and organization after Billing's retirement, and joined the group in Orsay. Interview by the author with David Shoemaker, Geneva, August 27, 2017.

[17] Written email interview with Walter Winkler, Winkler's reply to the author of May 26, 2016; interview by the author with Jim Hough and Bernard Schutz, CERN (Geneva), August 28, 2017; interviews by the author with Alain Brillet, Nice, Avril 27–28, 2017 and Cascina, July 17–18–19, 2017.

[18] Written email interview with Walter Winkler, Winkler's reply to the author of May 26, 2016; interview by Peter Collins with Peter Kafka from the Garching group, http://sites.cardiff.ac.uk/harrycollins/webquote/. Photon shot noise is due to the statistical fluctuation of the number of photons detected by the photodiode, at the output of the interferometer. Therefore, if the shot noise is the limiting factor, the sensitivity of the interferometric detector increases with the square root of the laser power: four times more laser power means twice as much sensitivity. The topic was described by Winkler in a milestone conference devoted to Experimental Gravitation and held in Pavia in September 1976 [62].

the shot noise level at that time and compatible with the rest of the setup."[19] By 1985, the Garching group was operating a 30-m delay line interferometer, again reaching the shot noise limit—now corresponding to a 10 times lower strain noise, consistent with the 10 times longer arm length [47,48].

As well as the German physicists, Glasgow team had begun research activity on bar detectors in the early 1970s and migrated to interferometric techniques at about the same time as Garching. During the 1980s, they developed a 10-m prototype with comparable performance, but testing the use of Fabry–Perot cavities instead of delay lines to enhance the optical length of the interferometer arms.[20] Fabry–Perot cavities were proposed by Ron Drever as an alternative to delay lines in 1980, and the technique was developed in Glasgow (10 m prototype) and at Caltech (40 m prototype) [20–22,42,53]. Drever's experimental team established a fruitful collaboration with the theoretical group led by Bernard Schutz at the University of Wales in Cardiff, dealing with in many aspects of GWs including sources, data analysis of GW signals and networks.

Unlike the British and the Germans, Alain Brillet's team in Orsay had no previous experience with resonant antennas. Some brief experimental activity with bar resonators had been carried out in France by the group of Silvano Bonazzola at the Meudon Observatory (Paris Observatory) in the early 1970s. They had run a Weber-type experiment in coincidence with the ones in Munich and in Frascati [2], but no experimental follow up had come afterward.[21] In 1982, Brillet initiated a research activity on interferometric GW detection, setting up a small laboratory hosted by the Center for Nuclear Spectroscopy and Mass Spectrometry in Orsay (Paris).[22] Brillet had gained considerable expertise in the field of metrology and laser technology, as a research engineer of the CNRS at the Laboratoire de l'horloge atomique (Orsay) since 1970. The early experimental activity of his team in Orsay—the *Groupe de Recherche sur les Ondes Gravitationnelles* (GROG)—concerned the development of interferometric techniques and laser technology, focusing especially on the reduction of shot noise and on the enhancement of power laser stability.

By 1987, both the Orsay and the Garching groups had successfully demonstrated *light recycling*. The idea of this innovative technique had been first explicitly suggested by Ron Drever in the early 1980s [22], as we will discuss later, and developed into theory by Jean-Yves Vinet [58]. It allows to increase light power in the interferometer and hence to improve sensitivity.[23]

In addition to the specialists in optics, there was a fourth experimental group, which had been working independently since 1983 on a completely different and complementary topic, and which was led by Adalberto Giazotto in Pisa.[24] The Italian team was developing special seismic isolators in order to reduce disturbances acting on a test mass at low frequencies down to 10 Hz, the frequency range where GWs produced by a significant number of pulsars were supposed to be detectable. In interferometric detectors, the test masses are the mirrors of the interferometer. These must be isolated as much as possible from external noise, and especially from seismic noise in the frequency range 10 Hz to a few KHz, in order to observe the tiny signal from the passage of a GW. A

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[19] Written comment by Walter Winkler, email to the author of March 23, 2019. Winkler also pointed out: "At that time, we had also solved all the relevant problems such as the stabilisation of the laser beam in frequency and geometry, servo systems, scattered light contributions, vacuum requirements and data acquisition. Otherwise, we would not have got to the shot-noise level as set by the laser-power!"

[20] In order to obtain maximum signal response from an interferometric antenna, the distance between the test masses (i.e., the suspended mirrors) should be of the order of 1/4 of the wavelength of the GW. This means that for signals of kHz frequency the armlength of the interferometer should be a multiple of 100 km. For a ground-based antenna one can obtain effective lengths of the right order by folding the light paths in the interferometer arms, using either delay lines or resonant cavities such as the Fabry–Perot cavity [29]. In an optical delay line, the light bounces back and forward between the mirrors, which have a slight curvature, so that the beams do not fall on top of each other. After a well determined number of bounces, the light returns to where it started and exits through a hole in one of the mirrors. A major disadvantage of the delay line is that mirrors have to be large enough to allow sufficient bounces to take place without interference among the beams. A Fabry–Perot cavity is composed by two special mirrors, which are positioned in parallel: the light entering the cavity is reflected back and forth between the mirrors, with the beams falling on top of each other. At every reflection, a small part of the light comes out from one of the mirrors (which is not fully reflecting: semi-transparent mirror) and the outcoming rays interfere with each other, producing interferometric rings.

[21] It is interesting to note that Silvano Bonazzola came from the relativistic school of Carlo Cattaneo in Rome, who had been on his part a student of Tullio Levi Civita. For more details see [5,6].

[22] Brillet became interested in interferometric detectors while spending 2 years as a post-doc at the Joint Institute for Laboratory Astrophysics (JILA) University of Colorado in Boulder (1977–78), in the group led by John L. Hall. Here Brillet had the chance to meet Peter L. Bender, who was conceiving a project to build a space interferometer for GWs, the future Laser Interferometer Space Antenna (LISA) [23].

[23] The Fabry–Perot cavities, the Nd-YAG laser and light recycling are all features that have been adopted both by Virgo and LIGO.

[24] The group was originary composed by Adalberto Giazotto, Diego Passuello, E. Campani, G. Finzi Contini, A. Stefanini, shortly later joined by H. Kautzky, V. Montelatici, Angela Di Virgilio and R. Del Fabbro. They were working in a small laboratory built up in San Piero a Grado, close to Pisa.

crucial role is played by the suspensions of the mirrors. Giazotto and his team became pioneers of a very special suspension system, based on multipendular stages, which would be called *superattenuator*.[25],[26],[27]

4 First contacts and interactions among the European groups

The first contacts between Brillet and the scientists from Garching and Glasgow date back to 1979.[28] The occasion was the second *Marcel Grossmann Meeting on Recent Developments in Theoretical and Experimental General Relativity, Gravitation, and Relativistic Field Theories*, which, as the first one in 1975, was held in Trieste. The meetings had been founded by Remo Ruffini and Abdus Salam and up to the 1990s represented, together with the *GRn* conferences, the main periodical gatherings where the experts of GW detection had the opportunity to meet. At that time, as already mentioned, GW scientists did not have their own conferences or coordinating committees. They still did not form an autonomously identified community; they were few and constituted a small part of the larger General Relativity community. The process toward the establishment of a well-identified field of research with its own reference community would find its first milestones in 1997, with the emergence of the *Edoardo Amaldi Conference on Gravitational Waves* as the first dedicated periodic conference of the field, and with the contextual foundation of the *Gravitational Wave International Committee* (GWIC) [14].[29]

It is interesting to note that at the 1979 conference in Trieste (MG2), a specific section devoted to GWs was organized for the first time and chaired by Ron Drever and by Guido Pizzella, the Italian physicist who 8 years before had given birth to the Italian experimental research on GWs besides Edoardo Amaldi. It is worth mentioning that between the first and the second MG meeting, a relevant astronomical survey had started to give a strong impulse to the field of GW research: the observation over a period of about 5 years of the Hulse–Taylor binary pulsar, as will be discussed later in this paper. Significantly, two of the four plenary invited lectures of MG2 were about gravitational radiation: one by J. H. Taylor "Gravitational radiation and the binary pulsar" and the other by Edoardo Amaldi "Recent progress in gravitational wave detection." Here Alain Brillet met for the first time Ron Drever and the French theoretician of General Relativity and gravitational radiation Thibault Damour, and also Rüdiger and Schilling, who were presenting the first results of Garching's 3-m interferometric prototype and their first mode cleaner[30] [39].

Three years later, another relevant and peculiar gathering contributed to strengthen relations between the three European optical groups. In August 1981, the main promoters of GW detectors based on laser interferometry met in a conference promoted by the NATO Advanced Study Institute and held in Bad Windsheim, Germany, which was

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[25] For more a more detailed account of these early times of the French and the Italian teams and their interaction, see [34].

[26] The experimental activity started in San Piero a Grado (Pisa), in 1983–84 with the name *Interferometro per la Riduzione Attiva del Sisma* (IRAS) [25]. After a few early attempts [34,44], the Pisa group turned to a new approach, based on passive attenuation in 6 DOFs: passive filters having very low vertical and relatively low rotational resonance frequencies. The idea of Giazotto was to use a multipendular suspension, in order to dissipate the vibrational energy along the chain and insulate the last pendular stage from movement of the earth, where the mirrors of the interferometer would hang. After trying different solutions and adding up new ideas step by step, this new approach proved successful and allowed the development of the *superattenuators* of Virgo.

[27] The name *superattenuator* was given by Hans Kautsky [27, p. 5]. It is worth noting that LIGO's suspensions are not based as Virgo on a passive attenuation system but instead on a combination of active (high-gain servo control) and passive (final mirror suspensions).

[28] The British and German groups had been interacting already in the years before, since their activity on resonant bars. They had presented early results in laser interferometry in the *International meeting on Experimental Gravitation*, organized by the Italian theoretical physicist and relativist Bruno Bertotti in Pavia (Italy), in 1976, which became a milestone conference in the field of GW detection.

[29] Today the Edoardo Amaldi Conference on GWs is one of the most important international gatherings in the field of GWs. The first one was organized in Frascati in 1994 by the Italian physicist Eugenio Coccia; the second conference, in 1997, took place in Geneva at CERN, with a massive participation of the GW community. During the latter conference, the GW International Committee (GWIC) was born, under the chairmanship of the Caltech physicist Barry Barish, at the time Principal Investigator of LIGO. On that occasion, it was established to organize the next conference at Caltech (1999). Since then, the Edoardo Amaldi Conference on GWs takes place every 2 years in a different country of the world and concerns all the aspects of GW research, from theoretical models of astrophysical sources to detectors and signal processing. About Edoardo Amaldi and GWs see [36]. For further details on Italian physicists see [33] and references therein.

[30] Already at this stage, the group from Garching express in their paper a clear idea for the future: "The long range goal of the Munich project is a Michelson interferometer of very long path length (100 km), illuminated with high laser power (100 W), sensitive enough to detect Virgo cluster events" [39, p. 1].

significantly devoted to experimental General Relativity *and* quantum optics[31] [41]. Among the participants were Eugene Wigner, John Wheeler, Gerd Leuchs, Kip Thorne, Jim Hough, Ron Drever, Karl Maischberger, Vladimir Braginsky, Carlton Caves, Alain Brillet and the Frenchman Christian Bordé, co-founder of the Laboratory of laser physics at the University of Paris North.[32] On this early occasion Ron Drever suggested the idea of light recycling, a "technique for reuse of previously wasted light" [22]. Though not addressed explicitly, the basic experimental set up for light recycling appears also in Roland Schilling's contribution to that same conference[33] [46].

Nevertheless, it is Drever's contribution to a subsequent relevant gathering, organized in France by Nathalie Deruelle and Tsvi Piran, to be usually cited as the first presentation of the concept of recycling [19]. Held in a location close to Mont Blanc in June 1982, the *École des Houches* brought together about sixty experimentalists, theoreticians and astrophysicists for about 3 weeks.[34] According to Deruelle and Lasota [18], Drever benefited on that occasion from a discussion with Roland Schilling on light recycling.

A particularly relevant experimental issue was indeed finding an appropriate solution for the laser source. 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 address were shot noise and laser noise. This required an extremely stable and powerful laser. The path to follow was power recycling, which would allow to reduce the power required from the laser by recycling the light coming back from the interferometer. The idea proposed by Drever and Schilling was fully developed into theory by Jean-Yves Vinet [58] and successfully proven experimentally in Orsay[35] and in Garching.

An important role in those early times was played by Philippe Tourrenc, a French theoretical physicist, who was then director of the Laboratory of Cosmology and Relativistic Gravitation at the Institut Henri Poincaré. Not only did he provide Brillet's team with all his institutional support, but he also actively promoted the establishment of a collaboration among the European groups. With the encouragement of Tourrenc, the groups of Glasgow, Garching and Orsay made a first joint application in 1985 for a European Twinning grant in the EEC stimulus program. The European Commission twinning award supported the development of high-energy lasers (YAG lasers) in Orsay, the study of high reflectivity mirrors in Glasgow and the organization of European workshops, such as the ones held in 1985 at Schloss Ringberg, Germany, and in 1986 in Chantilly, France.[36] The joint application for this European grant was the first formal action toward a European collaboration for GW research.

Other milestone gatherings in those early times were: (1) the conference *Journées Relativistes*, organized in May 1984 by Tourrenc in Aussois (France), where the Glasgow group first presented its ideas for a 1-km-long GW

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[31] At the meeting in Bad Windsheim all physicists from the GW group at the Max Planck Institute of Quantum Optics in Garching reported on the status of their work. In particular, Winkler described the problem of scattered light, which they had recently encountered.

[32] The Laboratoire de Physique des Lasers de l'Université Paris-Nord was born in 1972. In 1981–82 Christian Bordé was its director.

[33] In Schiller's paper for the proceedings of the 1981 conference in Bad Windsheim [46], figure 10 shows a proposed scheme for the Michelson interferometer, where the input light is brought to interference with the returning light, but on a separate beam splitter. The difference between Schilling's and Drever's 1981 schemes is that Drever was proposing an additional resonant optical cavity, while Schilling was focusing on a "stabilizing function."

[34] As the 1981 conference in Bad Windsheim, also the Les Houches summer school on gravitational radiation was financially supported by the NATO Advanced Study Institute.

[35] Brillet A., Personal notes on the history of Virgo. February 20, 2013, PAB. Using Argon lasers, the only high-power single-frequency laser available at the time, 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 the efficiency of power recycling. In addition, the choice and the study of infrared light Nd-YAG lasers (wavelength 1064 nm) to replace the noisy and unreliable Argon lasers was a major contribution of the physicists in Orsay to interferometric detectors [49]. In the 1989 LIGO proposal and in the 1989 British–German project, the privileged solution for the laser source was the use of green light, produced by doubling the frequency of a Nd-YAG laser and thus obtaining a 532 nm wavelength [30,59]. Such a wavelength was close to that of Argon lasers and was preferred, because shorter wavelengths allowed smaller beam diameters leading to smaller optical components. Furthermore, visible light was easier to work with and reduced shot-noise, which, for a fixed laser power, decreases with the square root of the optical frequency. However, in a power-recycling scheme, the optical losses due to scattered light are much larger in the visible than in the infrared frequency range. Scattered light noise was (and *is*) a crucial problem to face in a GW interferometric detector. For this reason, in the second half of the 1980s the Orsay group was developing and testing the solution of infrared light, differently from what the other optical groups in Europe and in USA were proposing. As a PhD student, David Shoemaker contributed to this experimental activity in the Orsay group in the years 1986–89. Already the 1987 French–Italian proposal discussed the possibility of using the 1064 nm Nd-YAG laser source. The 1989 Virgo proposal definitely envisaged the use of infrared light, while the British–German GEO 600 and the American LIGO turned from green light (supplied by an Argon Ion laser) to the 1064 nm wavelength only during the 1990s.

[36] Letter from Alain Brillet to Adalberto Giazotto, May 12, 1986, PAB. A second European grant was obtained shortly later and benefited also the Italian team. The grant supported the organization of a third workshop, held in Sorrento in 1988, and "allowed some collaborative work (and common publications)" [10, p. 190].

antenna; (2) the MG4, held in Rome in 1985, where Brillet and Giazotto met for the first time, and where the Garching team presented a detailed plan for a 3 km long detector.

The IV MG was important, especially for the future French–Italian project Virgo. When Alain Brillet and Adalberto Giazotto first met at the conference in Rome, they realized they had been working for several years on two complementary fundamental features of GW interferometric antennas. Brillet recalls their encounter in the following lines:[37]

> In 1985, at the meeting MG4, in Rome, Jean Yves Vinet presented his theory of recycling, which confirmed the intuitions of Ron Drever, and Adalberto Giazotto presented the first results of a high-performance seismic isolation system he was developing in Pisa, initially with the aim of developing bars capable of operating at low frequency to detect pulsars, but also capable of isolating the mirrors of an interferometer, in the frequency range from 10 Hz to 10 kHz. The idea was all the more interesting as the most important detection range for a terrestrial detector seemed to evolve towards the low frequencies: the favourite source was initially the explosion of a supernova, supposed to radiate mainly towards 1 kHz, but, on the one hand, the work of Silvano Bonazzola showed that the intensity of this radiation was uncertain, and probably low, and on the other hand, the coalescence of a binary system of Hulse-Taylor neutron stars was well modelled and may be more common, but would rather radiate around 100 Hz, or even less in the case of a binary black holes.

Many years later, Giazotto described that happy encounter as “certainly planned by fate” [27].

5 From narrow-band to wide-band detectors

In 1974, Hulse and Taylor had observed for the first time a binary system composed of a pulsar orbiting a neutron star [15,31]. In their discovery paper, they highlighted that the star couple—called PSR1913+16—provided a nearly ideal laboratory for testing General Relativity, because it displayed “an accurate clock in high-speed, eccentric orbit and a strong gravitational field” [31]. Observing the system over several years allowed to prove that the orbit of the pulsar was gradually shrinking, following with great accuracy the prediction for the energy loss due to GW emission [54,55,60]. Besides being a new confirmation of Einstein’s theory, these astrophysical observations constituted the first indirect proof of the existence of GWs.

The scientific evidence coming from the PSR1913+16 system was instrumental for the research field of GW detection, and provided a strong motivation for the development of the interferometric antennas. The astrophysical sources considered so far as possible emitters of detectable GWs had been the supernova explosions, with expected gravitational signals peaking at around 1 kHz. Bar detectors had resonant frequencies around 1 kHz, and were sensitive to a very narrow frequency band centered on that value. Therefore, resonant bars, including cryogenic ones, were optimized for the observation of supernova signals. On the other hand, the discovery of the first binary pulsar hinted at the possibility of detecting signals spanning a wider frequency spectrum.

According to GR models, a system made up of two massive objects inspiralling into each other under mutual gravitational action radiates an almost periodical gravitational signal, whose frequency and amplitude increase over time. Binary systems radiate the most energetic GWs during the last stage of their inspiral, the so-called coalescence. At this stage, the bodies orbit very close to each other at extremely high speeds, emitting a distinctive gravitational signal rapidly growing in amplitude and frequency (*chirp* signal). In order to observe and follow the evolution of this kind of signal spanning over a wide range of frequencies, a detector sensitive to a large bandwidth is needed. The transition from supernovas to coalescing binary systems as the most promising sources of detectable GWs is a fundamental issue in the history of GW detectors. It is an important change of viewpoint, which contributed to the universal adoption of interferometric detectors, to widen the window of detectability to include not only gravitational pulses radiated by supernovas, but also periodical or quasiperiodical signals with frequencies lower than 1 kHz.

Aside from coalescing binary systems, other sources had attracted the attention of gravitational wave hunters, in particular Adalberto Giazotto. During the 1980s, radio telescopes were detecting an increasing number of pulsars. Many of these spinning stars were observed to slow down over time, although with a very low spin-down rate, increasing their rotation period by less than a few microseconds per year. Spin-down is related to energy loss due to various mechanisms, including magnetic dipole radiation and eventually GW emission.

To radiate GWs, a spinning neutron star must have some asymmetry in its shape, like for example a bump or a hill. In the 1980s many fast pulsars had been observed, showing rotation slow-down to be possibly attributed to GW emission in the range of frequencies just above 10 Hz—pulsars with a rotation rate of more than 5 cycles per

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[37] Brillet A. Personal notes on the history of Virgo, February 20, 2013, PAB.

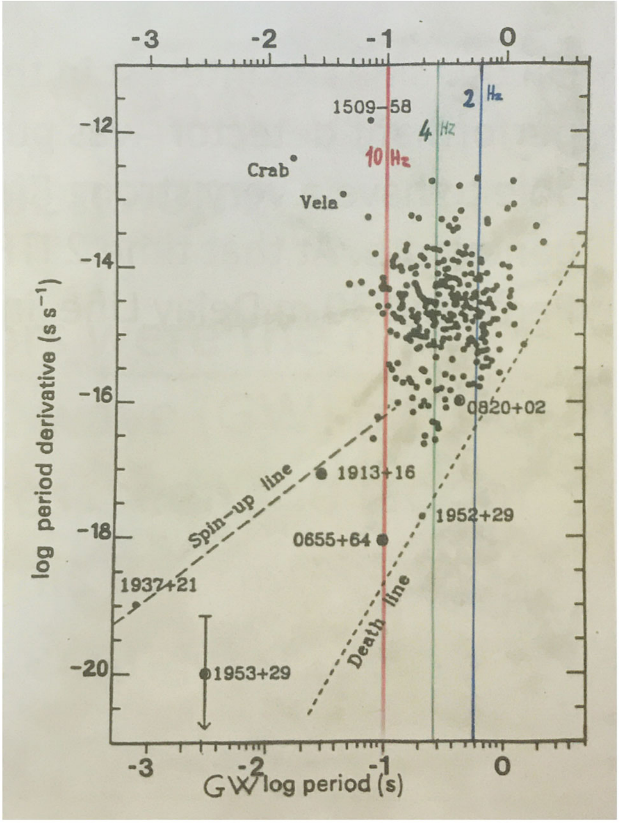

Fig. 1 The plot displays the distribution of pulsars undergoing rotation slowdown, versus emission period. Giazotto used to show this plot to promote the effort towards seismic noise reduction down to 10 Hz. Up to 1981, about 330 pulsars had been discovered [Manchester and Taylor 1981]. Today we know that there are over 430 known pulsars spinning fast enough for their gravitational wave emission to be in the sensitive frequency band of Virgo and LIGO (from about 20 to 2000 Hz). See the Australia Telescope National Facility Pulsar Catalogue

second.[38] These fast-rotating pulsars were an important stimulus for Adalberto Giazotto's work on seismic noise isolation (Fig. 1).[39]

So Giazotto was not only thinking about transient signals, such as the ones emitted by supernovas or coalescing binary systems. He was pointing at continuous sources: fast rotating pulsars and binary pulsars, whose gravitational signals have not yet been detected at the time of the publication of the present paper. Aiming at the very first detection of a GW, a continuous source was very appealing, because in principle its gravitational signal could be integrated over time and thus detected by a single antenna.

Adalberto Giazotto had been working in the field of particle physics since his graduation in Rome, in 1964. He had participated in experiments at CERN, while being researcher at the University of Pisa. His interest in GWs awoke in the early 1980s. Stimulated by the observation of the many new pulsars made through the Australian Radiotelescope in Narrabri [40], in 1982 Giazotto submitted to the PISA INFN section a detailed internal report, which summarized the theory and noise evaluation of GW interferometric detection, analyzing in detail the low frequency region [24]. In his note, Giazotto significantly argued that an important peculiarity of interferometric antennas "is that one can in principle detect not only gravitational pulses, but also periodical sources" and

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[38] Gravitational wave signals are expected at a frequency related to the rotation rate of the astronomical system, typically at twice this value. The orbital period of a binary system, as well as the rotation period of a single pulsar, changes over time, thus also the frequency of the emitted gravitational signal is time-dependent, being at every instant equal to twice the instantaneous orbital frequency—for a pulsar, it is equal to twice the instantaneous rotation rate. While the orbital period of a binary system reduces over time, the rotation period of a pulsar may decrease as well as increase. Pulsars can be accelerated through accretion of material; or they can be decelerated through interaction with a surrounding medium or by radiation of GWs.

[39] Giazotto used to quote Richard (Dick) Norman Manchester's work on pulsar observation at the Australian Radiotelescope in Narrabri as a fundamental scientific motivation for starting his experimental activity in the field of GWs. See for example [40]. Interview by the author with Adalberto Giazotto, Cascina, July 11–12, 2016.

expressed the “hope that strong unpredicted sources of periodical GWs, which could be detected with a relative ease, exist in space” [24, pp. 1–2] [34].

As a consequence of this view, since its very first proposal 5 years later, Virgo’s goal was to reach sensitivity down to 10 Hz.

6 Early proposals for interferometric detectors in Europe

The first European team to make an official proposal for a full-sized interferometric detector was Garching. In 1985, they submitted the report “Plans for a Large Gravitational Wave Antenna in Germany” to the Max Planck Institute of Quantum Optics. An updated version followed in 1987 [37,63,64].

> After encouraging progress with the 30 m prototype, the GW group at the Max-Planck-Institut für Quantenoptik are increasing efforts towards a full-sized antenna. Arms 3 km in length are proposed, as a trade-off mainly between cost and the influence of thermal mirror motions. [63]

Among the requirements, it is underlined that

> the strongest sources of such radiation will have only short duration, and therefore the search must be made in a relatively wide frequency band. [...] To guard against spurious signals due to local noise sources, verification with at least one further interferometer is required. The interferometers used in coincidence should – if possible – be separated by distances in the range of 1000 km. Collaboration with experimental groups in the other countries is highly desirable. [63]

It is interesting to note that an alternative hypothesis, due to Rüdiger, to that of the two-arm interferometer appears in this first German proposal: a triangular interferometer, the scheme proposed for the current Einstein Telescope project and for the Laser Interferometer Space Antenna (LISA, the first future space-based GW detector).

The Glasgow group suggested a first plan for the development of a 1 km interferometer in Scotland at a conference held in Aussois, France, in 1984 and organized by Philippe Tourrenc[40] [28]. A detailed design study was prepared with the engineering support of the Rutherford Appleton Laboratory, led by Ian Corbett, and presented to the UK Science and Engineering Research Council (SERC) in May 1986 [29]. The proposal envisaged a Fabry–Perot interferometer with 1 km arms or longer at either of two sites in Central Scotland. It also contemplated the possibility of installing four separate interferometers in the same vacuum system, two full length and two half length. The separate devices “should allow discrimination against the effects of random outgassing from the walls of the vacuum system and against residual seismic effects and laser fluctuations.” Such a detector system was conceived to allow stand-alone detection of some kinds of gravitational signals:

> While many experiments such as locating the direction of pulsed sources require operation with other detectors round the world, it is important that some experiments can be carried out on the instrument in a stand-alone way. These could include searches for periodic sources [...]. [29, pp. 52–53]

On the French side, in 1982–84, Brillet’s team was supported by the Institut National d’Astrophysique et de Géophysique (INAG) to make a cost evaluation for a 1 km arm interferometer, to be built in Nançay. Here some measurements of seismic noise were accomplished. Nevertheless, the cost evaluation was quite underestimated, like all proposals made in those early years. In 1986, a preliminary proposal for a large GW antenna in France was placed in low priority on the list of the future *Très Grande Équipement*, preceded in the field of basic sciences by the Very Large Telescope.[41] Afterward, no further step was made in the direction of a solely French interferometer.

The British and German proposals were both focused on a frequency range spanning from a few hundred hertz to a few kHz. The 1985 Garching proposal argued:

> A limitation of the usable frequency range is given at the low-frequency end by the steep increase of many optical and mechanical noise contributions, particularly of the seismic noise. To extend the frequency range to a lower limit of 100 Hz will already be a very difficult task. [64, p. 2]

As already underlined, the 10 Hz goal was, instead, the distinctive feature outlined by the French and Italians in their first joint proposal, presented to the Italian INFN (Istituto Nazionale di Fisica Nucleare) in May 1987. Since Brillet and Giazotto’s first encounter in Rome, in 1985, it took indeed a couple of years to officially start the French–Italian collaboration. Nevertheless, the new-born partnership took the other European groups by surprise, as described in the next paragraphs.

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[40] In the same year Caltech and MIT signed an agreement for the joint design and construction of two analogous facilities in USA.

[41] Brillet A. Personal notes on the history of Virgo, February 20, 2013, PAB.

7 Attempts for a shared strategy

The three European optical groups had been already collaborating and taking advantage of a shared European grant in 1985, as said. Furthermore, the possibility of a wider scientific collaboration was being discussed with the American teams of MIT and Caltech, where the leading figures were Rainer Weiss (MIT), Kip Thorne and Ron Drever (Caltech). A meeting was held in Cardiff in February 1986, with the purpose of shaping an international network for promoting projects in interferometric detection. On that occasion, some "notes and suggestions for an International collaboration on gravitational radiation research using laser interferometers" were produced and sent to Brillet by Weiss and Drever.[42] The cover letter from Drever and Weiss, dated March 18, 1986, reported the contents of the meeting:

> [...] suggestions were made about the potential advantages of arranging some form of international collaboration between the experimental groups working in this field in Europe and the USA, in part to improve the informal contacts and collaboration which are already taking place and benefitting all the groups. We are aware that possibilities for such collaboration are being discussed in Europe.[43]

The general aims of such a collaboration were concisely outlined in the attached notes: improving the rate of progress of gravitational radiation research using laser interferometers; facilitating provision of adequate support in each country by government or other funding agencies; promoting coincidence and cross-correlation searches for, and studies of, GWs; etc. It is worth to note that this document already foresaw collaboration on data acquisition, data formats and analysis, both hardware and software and collaboration in design and development of particular items of equipment or facilities, in particular the area of optical and electro-optical components.[44]

On the US front, things were proceeding, albeit with various difficulties, as indeed in Europe. By the early 1980s Rainer Weiss (MIT) had led a feasibility study for a long-based interferometer, with financial support by the National Science Foundation (NSF) [Weiss et al.]. LIGO's so-called *Blue Book* was submitted to NSF in October 1983. By that same time, Ron Drever had built a 40-m interferometer at Caltech. The two experimental groups were necessarily destined to establish a partnership if they were to obtain funding from the NSF. MIT and Caltech had thus signed an agreement for the joint design and construction of LIGO in 1984, with the approval of the National Science Board to LIGO development plan. The administrative headquarters were set at Caltech, with joint leadership by Ron Drever, Kip Thorne (both at Caltech) and Rainer Weiss (MIT). Nevertheless, the 1984 agreement was defined as a "shotgun wedding," as the interactions between Drever and Weiss were uneasy since the very start [12].

At the time of Cardiff's meeting (February 1986), the US teams were thus working together at LIGO planning. In November 1986, representatives from the European groups would participate in the workshop on "Gravitational Wave Physics and Astronomy," especially organized by the MIT group for the US-refereeing panel. On that occasion, the external committee, appointed by NSF, examined the planning for LIGO and the state of the entire world-wide field of GW physics, and finally endorsed LIGO's scientific case.[45] From the correspondence between the protagonists of those early times preserved in Brillet's papers, it is clear that setting up some form of collaboration and a shared strategy seemed important to support both the American and European projects.

Giazotto had not been invited to join the meeting in Cardiff in February 1986, nor the previous meetings and initiatives among the European groups. At that early stage, he was not a natural interlocutor for the other groups. His research activity did not concern laser physics and interferometry, felt as the core of the new generation of antennas, nor theoretical aspects of GWs. He had not taken part in the milestone gatherings in Bad Windsheim (1981) and at Schloss Ringberg (1985), nor was he present at the *Journées Relativistes* in Aussois (1984) or at the meeting in Chantilly (1986). The group in Pisa was working on a completely different topic with respect to the other experimental teams, and chronologically it was also the last to enter the field of GW detection.

From reading the British and German proposals, one understands that the mechanics for suspending the mirrors was felt as a second order problem, something to look at in the future.[46] In the very small world of interferometric

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[42] Letter by R.W.P. Drever and R. Weiss to A. Brillet, March 18, 1986, PAB.

[43] Ibid.

[44] The group in Cardiff, in particular, focused on data analysis and on networks. Schutz and Massimo Tinto published two papers on antenna patterns and the capabilities of an interferometric network as a function of the number of detectors and their arrangement on the earth [51,52]. Further work was done in Cardiff by Tinto, Sanjeev Dhurandha and Andrzej Kròlak.

[45] The joint Caltech/MIT proposal for LIGO construction would be submitted to the NSF in 1989 [59].

[46] Alain Brillet remembers having a conversation with Rainer Weiss, in which Weiss expressed the opinion that seismic isolation would not be the main problem at 10 Hz, and that one should face the very difficult task of low frequency isolation later, after the first detection had been made. However, the challenge of reaching high sensitivity in the region of 10 Hz turned out to be a fundamental feature, in particular considering the frequencies of the first signals detected by LIGO and Virgo about 30 years later. The first signal, detected on September 14, 2015, was a chirping waveform lasting about two-tenths of a second with a frequency spanning rapidly from 35 to 250 Hz.

GW detection, optics was by far the most relevant field of research. At that early stage, the low-frequency strategy studied by the Pisa group appeared beyond the main and challenging problems of GW detection, which were basically related to laser technology and interferometry.[47]

An interesting comment was shared with the author by Stefano Vitale, who has been co-Principal Investigator of the ultra-cryogenic bar Auriga in Padova and Principal Investigator of the LISA Technology Package payload on board the LISA Pathfinder mission of ESA.[48] Vitale points out that laser interferometry and free fall of the test masses are the fundamental principles underlying GW detection, an indissoluble combination not always valued among the experts in GW interferometric detectors. The future space-based interferometer LISA (Laser Interferometer Space Antenna) is developed precisely to solve the problem of the free fall of the test-masses and to achieve sensitivity to the very low frequencies, that cannot be reached on the earth due to the seismic noise barrier.[49]

Vitale observes that Giazotto, dedicating himself to mechanics for seismic isolation, in a certain sense was following the Galilean tradition of studying the free fall of bodies, whereas the field of quantum optics was a prerogative of the teams from beyond the Alps.[50]

Unlike the members of the other European groups, Giazotto came from particle physics, and was an *outsider* in the field of GW research. So it is not surprising that he was not invited to participate in the *European gravitational detector working party*, which was being planned among the other European teams in March–April 1987.

8 The European gravitational detector working party

In those early efforts for establishing a European network, a leading role was held by the particle physicist Ian Corbett, who was at the time director of the Rutherford Appleton Laboratory in Chilton. Later, from 1990 to 2001 he would held senior positions in the UK funding agencies SERC and then PPARC, with responsibility for a wide range of projects in astronomy and particle physics. His involvement in the GW field would be limited to these early times, so few scientists remember today his commitment.

On April 24, 1987, Ian Corbett had sent to his colleagues a note, in which he proposed some topics to be discussed by the working party. He argued that the party's task was "to produce a report to be submitted to the three funding bodies which have so far been approached: BMFT,[51] CNRS and SERC."[52] The report should have presented

> a unanimous view of a collaborative European approach to the construction and operation of interferometric GW detectors. [...] It should address and offer solutions to technical problems, provide realistic cost envelopes for a limited range of options, and present and evaluate models for the organization and management of the collaborative project.[53]

In this respect, the working party would have to

> produce arguments which convince the funding agencies not only of the importance and timeliness of the science and technological feasibility of the project, but also of the ability and determination of the separate groups to work together.[54]

Ultimately, the conclusions and recommendations of the working party would have to

> provide a negotiating framework for the funding agencies, and form the basis of any approach which might be made to other funding bodies, national or European.[55]

Among the topics outlined by Corbett, there were relevant scientific and strategic questions such as the following: *While we are convinced that there should be at least two detectors in Europe, what are the cogent scientific arguments*

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[47] Interview by the author with Jim Hough and Bernard Schutz, CERN (Geneva), August 28, 2017.

[48] LISA stands for Laser Interferometer Space Antenna. LISA Pathfinder was launched in 2015 and successfully tested LISA technologies, paving the way for the LISA mission envisaged for 2034.

[49] Interview by the author with Stefano Vitale, February 19, 2019, Rome. For further details about LISA position sensing technology, one may see [11,17] and references therein.

[50] Ibid.

[51] Bundesministerium für Forschung und Technologie (BMFT) was the *German Federal Ministry for Research and Technology*, headquartered in Bonn, today part of the Bundesministerium für Bildung und Forschun (BMBF), i.e., *Federal Ministry of Education and Research.*

[52] Note by Ian Corbett, European gravitational detector working party, pp. 1–2, April 24, 1987, PAB.

[53] Ibid.

[54] Ibid.

[55] Ibid.

to justify this? How many antennae should we attempt to argue for? Is there a minimum/optimum separation between the antennae? What is the minimum arm length? What is the long-term role of the prototype detectors (Garching and Glasgow)?[56]

The working party was supposed to address organizational issues as well, the latter being strongly intertwined with scientific arguments: *What are the arguments for building the antennas simultaneously? Do we have the resources to build and commission them simultaneously? How much can be done in common, how much should be done in common, and how much must be done in common? Should we have a common data acquisition, storage and analysis philosophy from the start?*[57]

Particularly significant questions concerned the possible collaborative scenarios. What was the kind of framework which would work best for a European collaboration in GW detection?

> **Do we envisage a single co-ordination and management committee for the whole project comprising several antennae and many interferometers? Should this committee have financial authority delegated by the funding agencies, or should the various national groups contribute in equipment and manpower, under their control? How do we maintain the integrity of the national groups? How do we minimize bureaucracy while retaining accountability? What existing collaborative projects could provide a useful model? (or, conversely, indicate things to avoid!)**.[58]

The questions addressed by Corbett seem to fit perfectly into the current negotiations for the future Einstein Telescope. In the early times, the European working party of the small world of GW detection was planning to discuss the important matters outlined by Corbett during its first meeting, to be held at the Rutherford Appleton Laboratory in Chilton, UK, in the month of June. Nevertheless, while Corbett's note about the possible collaborative schemes was circulating among the working party in late April, the British and German groups were unaware that Brillet and Giazotto were about to present a joint proposal to INFN in the following month of May.

9 The French–Italian alliance

The collaboration between Orsay, Glasgow and Garching was unavoidably characterized by some competitiveness, as all of the three teams were working in the field of optics, the *hot* topic of GW interferometers. Instead, the Pisa group offered a truly complementary competence. The mutual interest of the groups in Orsay and Pisa for collaborating was a natural consequence of this complementarity.

For the Pisa group, it was highly desirable to team up with the French optics specialists. It was an excellent chance to enter the mainstream of experimental GW research and become part of the nascent European collaboration. On the French side, an alliance with the Italians would have strengthened the position of the Orsay group in the European context, and helped in reaching a critical mass to promote a joint GW project before the CNRS.

The small team of Brillet was living indeed a very peculiar situation, as their activity was not included in the framework of the *Institut national de physique nucléaire et de physique des particules* (IN2P3), an autonomous institute of the CNRS. No nuclear or particle physicist was directly involved, unlike in Italy, where Giazotto himself and his main supporters inside INFN were high energy physicists, used to big experiments and to their complex organization. In Italy, Virgo was supported from the very beginning by several scientists of INFN, experienced in Big Science.

Pierre Lehman, director of IN2P3 (1983–1992), had a genuine interest in Brillet's experimental activity. Nevertheless, the field of GW detection did not have enough critical mass in France to appear as a priority in CNRS agendas. IN2P3 did not have a consolidated experimental tradition in GW research, nor a network of experimental physicists supporting the idea of GW detection, as was the case, instead, of INFN in Italy.[59]

Here, the experimental activity for GW detection had started already in 1971, promoted by Edoardo Amaldi and Guido Pizzella in Rome. Their research aimed at building cryogenic resonant bar detectors had been supported from the early 1970s by CNR (*Consiglio Nazionale delle Ricerche*, the National Research Council), and later by INFN. In the 1980s Amaldi's and Pizzella's team had an international leading role in the field of cryogenic resonators for GW detection [36]. Their cryogenic bar *Explorer*—3 m long, weighing 2300 kg—was built at CERN, and was the first antenna to reach its nominal sensitivity and stability over long periods (1990). For several years, it was the most sensitive GW detector in the world. In an interview with the author of the present paper, Brillet argued:

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[56] Ibid.

[57] Ibid.

[58] Ibid.

[59] Interviews by the author with Alain Brillet, Nice, April 27–28, 2017, and Cascina, July 17–18–19, 2017. Unlike in Italy, French research activity on GW detection was supported by theoretical physicists and astrophysicists.

Fig. 2 The picture shows Virgo (Pisa), with its 3 km-long orthogonal arms. Besides Virgo and indicated by an arrow and a circle, lays the 3 m long cryogenic bar Explorer, which was dismantled and moved from CERN to Italy in 2012. The picture gives an idea of the huge change in scale related to the transition from resonant bar detectors to interferometers

> the activity of Amaldi and Pizzella caused the National Institute for Nuclear Physics to develop a specific culture and interest in this experimental field, whereas this did not take place in France (Fig. 2).[60]

The good reception given by INFN to the idea of a large project for the detection of GWs was certainly favored by the peculiar circumstances of Italian research. Looking from a broad perspective, Italian particle physicists were culturally prepared to what we call today multimessenger astronomy. The Italian longstanding tradition in cosmic ray studies was a fertile ground for new ideas concerning the detection of still unobserved cosmic messengers. The physics of cosmic rays, at first aimed at the study of particles and of their interactions, had been gradually becoming an instrument for probing the phenomena of the cosmos originating them [3,4]. Furthermore, it is worth noting that by the second half of the 1980s, Italy was at the frontier of astroparticle physics with the beginning of operation of Gran Sasso labs, hosting the MACRO facility (Monopole, Astrophysics and Cosmic Ray Observatory), a general-purpose probe which appeared as a natural extension of the Italian tradition of cosmic ray physics [8].

Brillet's team had no solid roots in French scientific institutions. Furthermore, in the tripartite collaboration with Glasgow and Garching, it ran the risk of having a subordinate role. Not only had the British and German groups started their experimental activity several years before Orsay (in the early 1970s), pioneered GW interferometry and possessed small scale prototypes (30 m delay-line interferometer in Garching, 10 m Fabry–Perot interferometer in Glasgow), they had also been working together more closely. They shared a similar scientific approach, based on testing technologies on prototypes before upgrading them to a full-scale interferometer. Not by chance, the 1986 British proposal highlighted the special scientific relationship between Glasgow and Garching, and stressed the differences in timing and organization with respect to the Orsay group:

> Our advances in this field, together with the work at the Max Planck Institute at Garching, have led directly to the development of similar work at California Institute of Technology which in turn has stimulated a stepping up of related research at MIT and has encouraged the start of a similar programme in France. An extensive programme for gravitational wave research with laser interferometers is now being planned in the USA and in Germany and is being considered in France. [29, p. 2]

The testing on prototypes was a fundamental feature of both the British and German experimental activity [28,48]:

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[60] Ibid.

> The existence of this well understood interferometer [Author's note: 10 m prototype in Glasgow] gives a powerful development tool for the long baseline detector. This will enable us to test and prove many of the necessary techniques during the construction phase of the new detector, and should allow a more efficient start to be made to its commissioning programme. [29, p. A.16]

The prototype-approach would constitute there on a sharp distinction between the British–German groups respect to the French–Italian, and one of the major scientific reasons for conflict, as shall be discussed in the next paragraphs. A few years later, testing the feasibility of coincident measurements and analysis between the two prototypes will be indeed a fundamental requirement to submit a joint German-British proposal to SERC and BMFT [30].

The different experimental approaches of the European teams could have constituted an advantage and could have resulted in an enrichment of the scientific dialogue. Instead, these diversities had the effect of sharpening competitiveness and became focus points of inter-personal tensions.

Brillet expressed his concern about establishing a European peer-collaboration in a letter to Giazotto, written in June 1987, a few weeks after the presentation of the joint proposal to INFN and shortly before the meeting at the Rutherford Appleton Laboratory. Significantly, Brillet argued that it was very important for the French and the Italians to show up together as a third group with its own project. In his view, this would allow to have a sufficient weight in the discussions for a future European collaboration.[61]

10 The first French–Italian proposal, May 1987

By 1986 Giazotto had found new allies in Italy: the team led by Leopoldo Milano in Naples was the first to join the new ambitious endeavor, and committed to develop the digital control system for the interferometer alignment. Also Innocenzo Pinto from the University of Salerno and a group from the CNR in Frascati, led by Franco Bordoni, took part in the early plans for a long-baseline GW detector. It is worth noting that none of the Italian physicists participating in the project had any experience in optics. Therefore, the collaboration with Brillet's team was crucial to start the project and formulate a concrete proposal to be presented to INFN. The first joint document suggesting the plan for a long-based GW interferometric antenna was submitted to INFN in May 1987:[62] "Proposta di Antenna interferometrica a grande base per la ricerca di Onde Gravitazionali" [9].

The Italian language used for this first proposal clearly shows that the initiative came mainly from the Italians rather than from the French team. On the Italian front, there was a fair amount of pressure to submit a proposal to INFN in time for its next 5-year funding plan (*Piano quinquennale 1988–93*). Giazotto must have considered the time ripe for taking a step forward, now that four Italian groups had joined, forming a critical mass. An essential factor encouraging Giazotto to speed things up was that influential members of the INFN directorate were looking favorably at the possibility of building a large GW interferometer in Italy. Giazotto's supporters were indeed the President of INFN Nicola Cabibbo, the chairman of INFN Commission II Paolo Strolin and Marco Napolitano, who was Director of the INFN section of Naples and in 1989 became a member of the INFN executive committee and deputy president.

Best known for his outstanding work on the weak interaction, Nicola Cabibbo was President of INFN from 1983 to 1992. He was instrumental in supporting the GALLEX project for solar neutrinos at Gran Sasso Labs, thus opening up a European way to solar neutrinos. He was part of the same community in Rome where Amaldi and Pizzella had been giving birth to Italian GW research, and had a wide and deep culture for actively supporting the new experimental ideas. As INFN President, he enthusiastically endorsed the project of an Italian–French interferometer. When his mandate expired, the baton passed to his successor, another authoritative Italian theoretical particle physicist supporting the Virgo project: Luciano Maiani, President of INFN in the years 1993–1998 and

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[61] Letter from Alain Brillet to Adalberto Giazotto, June 1987, PAB.

[62] The "Proposal for a large based interferometric antenna for the search of gravitational waves" was signed by the following people: 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); the group from Naples University 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) [35].

Director General of CERN in 1999–2003. One year after his inauguration as President of INFN, Maiani signed the final agreement with the CNRS for the construction of Virgo. As INFN deputy president in the years 1989–1994, Marco Napolitano played a major role in the process toward the final approval of the Virgo in June 1994, as well as Paolo Strolin, in charge as chairman of INFN Commission II in 1987–1993, the INFN commission for astroparticle research. Significantly, all the four scientists came from particle physics, had worked at CERN, and had diversified experiences in Big Science, just as Giazotto. Another prominent supporter of Virgo was Massimo Cerdonio, one of the pioneers of the Italian cryogenic resonant bars. Following a proposal by Maiani, in May 1994 he was appointed referee of the Virgo project for the INFN executive committee. His mandate lasted 6 years, in the crucial period of the beginning of the works for the construction of Virgo.[63]

Retrospectively, Giazotto's haste in submitting the 1987 proposal to INFN appears well justified. One may observe that while the document was being drawn up in Italian, negotiations among Italians and French were still taking place, as well as inside the French scientific community [34]. Brillet was well aware that CNRS was not ready yet to fund a joint project.[64] This state of affairs may also explain why the French–Italian team let the British and German teams know so late about their shared proposal.

The project was introduced to INFN as a natural evolution of an experimental research activity already well established in Italy and appreciated internationally. The proposal's introduction stated, indeed, that a long-based interferometric antenna "would allow France and our Country, already excelling in the technology of cryogenic resonant bar detectors, to keep a high technological level also in this very complex research field" [9].

To understand the relevance of INFN's background in GW research for the start of Virgo, it is worth to note that Giazotto's team was as small as Brillet's, and that in 1987 Giazotto did not have any influential position in Italian physics nor in INFN.[65] Among the small international community of GW interferometers his position was weak as well, as we have already highlighted.[66]

Nevertheless, besides INFN's "sensitivity" to GW physics, one must also consider Giazotto's and Brillet's ability in supporting the project with very persuasive scientific arguments, as pointed out by Paolo Strolin:

> Brillet and Giazotto were not promoting, instead they were exposing their ideas, they were very convincing and the scientific challenge was extremely stimulating, impossible as it seemed.[67]

The 1987 proposal underlines the main feature distinguishing the proposed antenna from the German, British and American projects: "we will attempt to be the first in exploring the low frequencies" as "the Italian group achieved an expertise in the low frequency strategy, which is not comparable to any other in the world" [9].

The paragraph "Justification of the project in the wider international context" highlighted a remarkable argument:

> If for some time this project were to be the only one, it is clear that the emphasis should be placed on the "low frequency strategy": in fact periodic systems such as coalescing binaries are the only sources that can be unambiguously detected by a single antenna. [9, p. 10]

In Giazotto and Brillet's perspective of the time, the low frequency strategy was the key to being independent from the fate of the other interferometric detector projects. In the most optimistic hypothesis—the paragraph continued—the building of five interferometric detectors (3 in Europe and 2 in USA) would allow to usher in the brand new field of GW astronomy and to test GR with unprecedented accuracy. Nevertheless, in case the French–Italian facility was to remain "for some time the only one," it "would be of enormous importance to the international scientific community, as it could also serve as a test laboratory for components and technologies" [9, p. 10].

As already mentioned, in the case of periodic sources, the data can be collected and integrated over long periods of time, so to enhance the signal-to-noise ratio. This argument is analogous for the radio-astronomy detection of pulsars and hence is justifiable. However, at that time, the French–Italian team was not aware of the problem of

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[63] Interview by the author with Luciano Maiani, March 22, 2019.

[64] Interviews by the author with Alain Brillet, Nice, April 27–28, 2017, and Cascina, July 17–18–19, 2017.

[65] Adalberto Giazotto became director of research in INFN only in 1989. In the INFN career, this position is comparable to the role of full professor at the university.

[66] Interview by the author with Angela Di Virgilio, Cascina, November 10, 2017.

[67] Interview by the author with Paolo Strolin, Naples, November 2017. Translation from Italian to English by the author.

the *Doppler effect*.[68] Furthermore, as pointed out by Bernard Schutz, the focus on low-frequency continuous-wave detection was controversial and regarded as shaky from the point of view of theory and astrophysics:

> There is a serious flaw in going to low frequencies, in that in General Relativity the amplitude of the waves is proportional to the deformation carried by the spinning pulsar times the square of its spin frequency. So if you go to low frequency with a given sensitivity, you need bigger and bigger deformations. It is true that we had no *a-priori* bounds on how big the deformations could be, but we had limits from observed pulsars like the Crab, which are gradually spinning down: if all the Crab spindown is due to GW energy loss (an extreme supposition) then this tells us the deformation. If you put the same (or, realistically, a smaller) deformation onto a low-frequency pulsar (say a factor of 5 lower) then its GW amplitude will be 25 times smaller, and this sets an unrealistic target for the sensitivity near 10 Hz.[69]

The goal of low frequencies and of autonomous detection of continuous signals would keep being an important distinctive feature for Virgo and Virgo scientists in the following years, and a controversial matter among the GW community. In Schutz's opinion, these goals distorted the priorities of the Virgo project.[70] Nevertheless, although continuous sources have not yet been detected while the author is writing the present paper, reaching low frequencies has all the same been instrumental for focusing the Virgo team on a concrete goal.

Brillet and Giazotto battled side-by-side since the start also regarding a second relevant matter of scientific approach: to avoid making a small prototype and to work directly on a full-scale interferometer. They had to persuade the funding agencies that this was a well-founded and optimized choice. They argued that

> [...] only a limited amount of data obtained from experimentation on a 30-m prototype can be extrapolated with confidence to be used for an interferometer one hundred times longer; we believe that an interferometer of this length will present issues that can be solved only by investigating them on a full-scale prototype. [9, p. 51]

According to Brillet and Giazotto, the technical and scientific features should be tested in a full-scale facility, because the extremely high sensitivity aimed at is obtainable only with that arm length. As already mentioned, the scaling problem, or the topic "prototype versus full scale interferometer," became in the following years one of the bones of contention between the French–Italian teams and the British–German ones, as recounted to the author by some of the main protagonists of the story (Brillet, Giazotto, Hough, Schutz, Shoemaker).[71] As admitted by Giazotto and Brillet in their interviews with the author, behind the plan to build directly a full-scale interferometer, there was also the desire not to lag behind the British and German teams, who were already far ahead with experimentation on their small-scale prototypes.

The 1987 proposal was drawn up in Italian with great haste and submitted to INFN in time to be evaluated for inclusion in the 5-year financial plan. The other European groups were caught by surprise. They were aware of the connections being established between Pisa and Orsay, but not that a joint proposal was underway. The French–Italian initiative was defended on the grounds of necessity and urgency, as highlighted in the acknowledgments:

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[68] Alain Brillet's comment, email to the author of March 2019. In an email to the author of April 9, 2019, Jim Hough pointed out that "coherent averaging when looking for pulsars was not easy because of the Doppler shift effects, etc., and this was being ignored by Adalberto and Alain, as Alain underlined." Hough had a background in pulsar research, because in 1970 he had been searching for pulsars looking for the phase fluctuations in low frequency radio signals. Further explanation was provided to the author by Sergio Frasca, one of the veterans of the GW team at Sapienza University in Rome and respected data analyst. Frasca explained to the author that there are two main effects that complicate the description of the expected signal from continuous sources: the Doppler effect due to the motion of the Earth (of rotation and revolution) and the amplitude and phase modulation due to the apparent variation of the source direction. The former was well known, so "ignoring it was extremely naïve." Frasca points out that, however, "Adalberto had in mind not to reveal the individual sources, but the whole, seen as a background." Indeed, if there are many sources, "the signals would add up to form a kind of background noise, which would have been observed with a sidereal modulation due to radiation antenna pattern and the galactic asymmetry of sources." In this case, Frasca states, the Doppler effect is negligible. Due to the Doppler effect's particular signature over long periods, we can be sure that we are revealing a gravitational signal; even with only one antenna, the position of the source can be established with great precision. By studying amplitude and phase modulation, various pieces of information on the source can be deduced; for example, how it is oriented. Frasca comments that the paper by Giazotto et al. "Gravitational waves emitted by an ensemble of rotating neutron stars" [26] was published in 1997, but "Giazotto had been talking about this long time before." Written comment by Sergio Frasca, email to the author of March 20, 2019.

[69] Written comment by Bernard Schutz, email to the author, April 7, 2019.

[70] Ibid.

[71] Interviews by the author with: Alain Brillet, Nice, April 27–28, 2017, and Cascina, July 17–18–19, 2017; with Adalberto Giazotto, July 11, 12, 13, 2016; with Jim Hough and Bernard Schutz, CERN (Geneva), August 28, 2017; with David Shoemaker, Geneva, August 27, 2017.

> We are very grateful to the groups who have written before us analogous proposals [...]; we are sorry that, due to our tight schedules, we could not collaborate more closely and directly with them and, in particular, we have not quoted their more recent results; we count on their help to remedy to this lack. [9, p. 65]

The French–Italian initiative was announced to the British and German teams at the first meeting of the *European GW detectors working party*, held in the month of June 1987 at the Rutherford Appleton Laboratory.

11 The early heated gatherings of the European GW working party

The first meeting of the working party was organized by Ian Corbett in Chilton on June 17, one month after the submission of the French–Italian proposal to INFN. The people present were: Brillet, Corbett, Hough, Leuchs, Schutz, Tourrenc and Winkler. Giazotto, as already said, had not been invited.

The unexpected announcement by Brillet and Tourrenc regarding the French–Italian project just submitted to the INFN was greeted with disappointment by the members of the other groups. As noted by Ian Corbett in the minutes drawn up the following day (which were "not for general circulation"), "there was some criticism of the way the proposal to the INFN had been prepared without informing or consulting the other groups in the EC collaboration."

Interestingly, the first draft of Corbett's minutes reported that the French–Italian proposal was aimed at building a long-baseline interferometer in Nançay, the site originally considered for the French project[72]. Tourrenc made several corrections to the draft, also removing the sentence about Nançay.

On July 16, 1987, Corbett wrote to Tourrenc, observing that "although the preparation and presentation of this proposal generated some ill-feeling," he hoped they can put all this behind them and "co-operate in helping each other's proposals in every way possible".[73] He also pointed out that "open and honest dialogue is absolutely essential".

Up to then the British, French and German teams had discussed and aimed to pursue a common strategy, to promote their national projects before the funding agencies. As described earlier in this paper, the three teams were lately shaping a working party to establish a joint long-term action line. The form of collaboration had still to be discussed and agreed among the teams, identifying the best strategy to support the various national projects. Compared to the original Nançay proposal, the British and the German projects appeared the more likely to survive. Nevertheless, three well-spaced and appropriately oriented antennas would have allowed Europe to have its own GW observatory, regardless of what would happen to the US project for LIGO. In this perspective, the Orsay, Garching and Glasgow teams should have submitted their national proposals as part of a large-scale European project, which would hopefully be the winning card before the funding agencies.

The unexpected presentation of the French–Italian project to INFN violated this delicate strategy, and showed a disunited community, a picture contradicting the declared intention of forming a European network. The document itself confirmed this picture. An example for all: by not citing the most recent works by the British and German groups, the French–Italian proposal weakened the scientific credibility of a joint venture, and put the other groups in a very embarrassing position with the national funding agencies.[74]

On June 19, INFN agreed to include the proposal for a long-based interferometric GW detector in the 1989–1993 5-year planning. The financial plan would be submitted to the Italian Ministry of Research in December. Tourrenc announced this positive result to the other European groups in a letter of June 29, 1987. He emphasized that the achievement would have helped everyone. He also addressed some relevant scientific topics still to be investigated and discussed: "What is a minimum array? Do we have to take collectively a low frequency goal?".[75] The most difficult issue, however, remained the form of collaboration to establish:

> We do not know if we are tied together in order to collect money for individual projects (more or less open to other cooperants) or if we are trying to build a collective array.[76]

The working party planned to discuss these issues during the second meeting, which was held in Paris on September 30. This time Giazotto participated besides Brillet, Corbett, Leuchs, Robertson (on behalf of Hough), Schutz, Tourrenc, Winkler. Schutz and Tourrenc had prepared two independent studies, which outlined the case for building

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[72] Ian Corbett, Notes on first meeting of European Gravitational Wave Detector Working Group—June 17, 1987, Rutherford Appleton Laboratory, Chilton (Oxfordshire), p. 2, PAB.

[73] Letter by Ian Corbett to Philippe Tourrenc, July 16, 1987, PAB.

[74] Interview by the author with Jim Hough and Bernard Schutz, CERN (Geneva), August 28, 2017.

[75] Letter by Philippe Tourrenc to A. Brillet, I. Corbett, J. Hough, G. Leuchs, B. Schutz and W. Winkler, Jume 29, 1987, PAB.

[76] Ibid.

3 laser interferometric detectors in Europe. During the meeting, an agreement was reached on the calculations needed to support the case for having at least three European antennas.[77]

Up to then, the action line had been pragmatically oriented toward a *minimum array* of two antennas 1000 km apart, which would give reasonable time difference resolution. Germany and UK appeared to have the best chances of hosting their own antennas. With the entry of the Italian-French proposal, the scenario had widened. The concrete perspective of building a three-detector network in Europe—a true GW observatory—was a relevant scientific goal, strongly supporting individual national projects as well as a European collaborative endeavor.

The working party had as its first task to draw up a report, describing the scientific aims and motivations of a European collaboration. Such a document would be the identity card of the collaboration before the national funding agencies (BMFT, CNRS, INFN, SERC). The contents of the report were discussed in the September gathering, in Paris. Corbett reported about the intentions of the European Commission, which "did not appear to be planning to offer support in the construction of large facilities, but would assist in their operation and development." So in the report to be prepared, "no reference to EC funding for the big detectors should be made".[78]

> [The report] would outline the science possible with three detectors (plus two in the USA) and then show what would be lost if the number were reduced to two and then one [and it would] indicate that Europe could do some good science without the US detectors.[79]

The report would also summarize the history of the European experimental activity in the field and it "would emphasize the current position of European leadership and the fact that a collaborative European project for three antennas was the logical step for the present situation."[80]

Corbett's minutes also report a hypothetical funding scenario. The four countries involved would have made available the following amounts of money (Millions of British pounds), ideally spread over a decade: Italy (10–15), Germany (15), Great Britain (5–7) and France (5).

Tensions and controversies preceded and followed the meeting in Paris, as shown by the heated correspondence among the members of the working party. The main bone of contention was how to shape the collaboration and the degree of coordination/independence that the groups would have in this framework. Looking forward to the meeting, Corbett had prepared some notes about the possible forms of collaboration to undertake and to discuss in Paris.[81] He suggested that the working party may become a Coordination Committee, with a rotating chairman, which would look after "the EEC funded collaboration" and "the interactions, on behalf of the collaboration as a whole, with the funding bodies." Corbett underlined that "within the collaboration, groups would continue to be free to work in their own way" and "seek support for their own project," but they "should also make it clear to their funding bodies that their project has to be seen as part of a collaborative European effort with the full backing of the other groups, and that it is not in competition with the other proposals".[82]

The French group received Corbett's proposal very coldly, as expressed by Brillet in his reply, on September 16:

> We wish to keep this technical collaboration distinct from an eventual 'political' collaboration, because it involves individual initiatives and would suffer from the necessary rigidity of an organized structure. Furthermore we don't see the necessity of (and we don't feel any pressure for) transforming our present working group into a formal Coordinating committee, with its monitoring and organizing power. We don't want to compromise the funding of the Italo-French project and we don't know yet what would be the consequences of the existence of this committee, so we prefer to keep the present informal group as it is, for now.[83]

Brillet's lines show an underlying distrust in a centralized co-ordination body. The French team appeared to fear an unfamiliar ground such as a "political collaboration," rather than a purely scientific collaboration, moreover in an environment that, however small, was already permeated by a sharp competitiveness.

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[77] It is worth noticing that in the month of July there had been in Cardiff the first ever Gravitational Wave Data Analysis Workshop (6–9 July 1987), sponsored by NATO and joined by groups from all over the world. All the interferometer groups and most of the bar-detector groups attended, but not the Pisa team. The organizing committee was formed by Bernard Schutz from University College (Cardiff), Peter Michelson from Stanford University, Guido Pizzella from University of Rome, Roland Schilling from the Max Planck Institute in Garching. Corbett chaired a round-table discussion about data exchange, to facilitate joint analysis, whose report is in the proceedings of the workshop. It was aimed at a fully international networking effort.

[78] Ian Corbett, Notes on the second meeting of European Gravitational Wave Detector Working Group—September 30, 1987, Paris, in a letter from Corbett sent to Alain Brillet on October 2, 1987, PAB.

[79] Ibid.

[80] Ibid.

[81] Letter from Ian Corbett to the members of the European Gravitational Wave Working Party, September 4, 1987, PAB.

[82] Ibid.

[83] Letter from Alain Brillet to the Members of the European Gravitational Wave Detector Working Group about Corbett's proposals for the second meeting (to be held in Paris on September 30, 1987), September 16, 1987, PAB.

Read today, the reply of Corbett sounds quite prophetic:

> If I look at what exists, from the point of view of an outsider, I see co-operation but I do not see a collaboration. A collaboration needs objectives, agreements, structures and mechanisms, as exist within the EEC-sponsored collaborations. Unless these exist, no outside body will believe there is a true collaboration, and unless there is a true collaboration the case for three antennas in Europe is considerably weakened, because there is no cohesion in the programme. I believe the European effort has reached the point where it would be both timely and helpful to form a collaboration, broadly within the framework I suggested. We may not form the collaboration in Paris next week, but we could agree the general principles. [...] If people are saying that they believe their own interests would be better served by continued co-operation but not by formal collaboration, so be it. But I would regret it, and see it as a lost opportunity.[84]

A compromise was apparently reached during the gathering in Paris. In the minutes, Corbett reported that

> [a form of collaboration] should now come into being, with the clarification that the Coordinating Committee would have no executive power and could not direct the work of any group, functioning by consensus [...].[85]

The collaboration was named *EUROGRAV*[86].

Within November 1987, Corbett had traced the first draft of the EUROGRAV report and had sent it to the members of the working party. The document raised several criticisms, especially from Orsay and Garching. The scientific contribution of Glasgow to the development of interferometric detectors appeared to be highlighted more than the others by the French and German teams. As a consequence, the leader of Garching group Gerd Leuchs pointed out:

> We think it serves our common goal best if the various achievements from all groups are stressed on an equal basis, also with respect to priorities of chronology. [...] We consider it preferable not to start on a petty competition as to which group has contributed or first discovered or solved this or that particular part. If we tried that, it might take ages until we can agree on a draft.[87]

Also Tourrenc attacked the draft, in a heated letter to Corbett of November 29. He peremptorily stated that the report had to be rewritten, as it represented a step backward on the path toward collaboration. In his sharp lines, Tourrenc accused the British team of not trusting the scientific reliability of the French–Italian group, on the basis that the latter did not intend to build a prototype. According to Tourrenc, Glasgow feared that the British funding agencies may refuse to support their project if they allied with the "Latins," because the latter did not show sufficient experience and scientific credibility in the field.[88]

Recently, Jim Hough has made an *a posteriori* reflection about the animated scientific controversies of the time.[89] He stated that, in their 1987 proposal, the French–Italian team had underestimated the problem of thermal noise, because they were focusing on the low frequency strategy to detect gravitational signals from pulsars. By working on the prototype in Glasgow, Hough's group had learned that thermal noise was a major obstacle to aiming at the low frequencies. By ignoring the thermal noise, one "made the sensitivity at low frequencies look very much better than we believed could be realistically achievable." The choice of the Glasgow team was thus, as we have said, to concentrate "on reducing the thermal noise in the suspensions, not worrying so much about low frequency isolation."[90]

Concerning the low-frequency goal, also Leuchs was skeptical at the time. In a letter to Tourrenc of August 28, 1987, he stated: "It is not clear to us that we want to concentrate on low frequency operation, which seems to be a little further in the future."[91]

Clearly, the European teams had different scientific priorities. While for the German and British teams the low frequency goal was something to address in the future, for the French–Italian group it was a problem to solve in the first place. These differences may have turned out to be very useful complementary approaches, but instead contributed to fuel the tensions between the groups and drive them away.

It might be hypothesized that the benchtop-experiment background of the optical teams also played a role in the feeling of mutual mistrust, which shows up in the correspondence of that period; the scientists involved were not accustomed to extensive collaborations.

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[84] Letter from Ian Corbett to Alain Brillet and Philippe Tourrenc, September 24, 1987, PAB.

[85] Ian Corbett, Notes on the second meeting of European Gravitational Wave Detector Working Group—30 September 1987 Paris, p. 3, in a letter from Corbett sent to Alain Brillet on October 2, 1987, PAB.

[86] At this stage also the possible participation of Spain was being investigated and discussed during the Paris meeting.

[87] Letter from Gerd Leuchs to Alain Brillet (also sent to Ian Corbett and Philippe Tourrenc), December 1, 1987, PAB.

[88] Letter from Philippe Tourrenc to Ian Corbett, November 29, 1987, PAB.

[89] Written comment by Jim Hough, email to the author of April 9, 2019.

[90] Ibid.

[91] Letter from Gerd Leuchs to Philippe Tourrenc, August 28, 1987, PAB.

Tourrenc and Corbett met in Paris a few days after the heated letter by Tourrenc (December 2–3), and ultimately clarified many points. That same month, the French–Italian project was approved by the Italian Ministry of research, and included in the 5-year plan of INFN (1988–1993). The final EUROGRAV report was agreed only three months later, in March 1988.

12 The 1988 EUROGRAV report

The EUROGRAV report was signed by all the members of the working group: Alain Brillet (CNRS, Université Pierre et Marie Curie, Paris), Ian F. Corbett (Rutherford Appleton Laboratory, Chilton), Adalberto Giazotto (INFN section of Pisa and University of Pisa), Jim Hough (University of Glasgow), Gerd Leuchs (Max Planck Institute of Quantum Optics, Garching), Bernard Schutz (University College, Cardiff), Philippe Tourrenc (CNRS Université Pierre et Marie Curie, Paris), Walther Winkler (Max Planck Institute of Quantum Optics, Garching).[92]

The document was sent to the national funding agencies BMFT, CNRS, INFN and SERC, and aimed at highlighting the relevant scientific case of having at least three interferometric detectors in Europe and at presenting the EUROGRAV collaboration as the coordinating body capable of developing the network. Some significant paragraphs from the report are the following.

> The European groups currently involved in the development of interferometric gravitational radiation detectors have agreed to form a collaboration, EUROGRAV. All members of the collaboration will work towards establishing the best possible European network compatible with funding and other restrictions, with the aim of establishing a gravitational astronomy. [...] EUROGRAV extends to all aspects of the development of long baseline interferometric detectors and is a logical extension of the existing EC supported programme of research and development.
>
> The collaboration functions through a Coordination Committee, which is representative of all the interests involved in the observation of gravitational radiation by interferometric means. This Committee meets at least three times per year to coordinate and review
>
> (a) the EC funded collaborative programme,
> (b) the various working parties (see below),
> (c) interactions with external bodies on behalf of the collaboration.
>
> The Committee chooses a "spokesman" who will act as the interface between the collaboration as a whole and the outside world, and who could, for example, be expected to speak for the collaboration at conferences etc.
>
> Through the Committee, five specialist working groups to study five immediately important topics (vacuum systems, seismic isolation, optics, experimental facilities and data acquisition, and data analysis) have already formed and coordinators chosen from among the Committee members. These working groups will study common design requirements and problems, and will aim at evolving uniformly acceptable cost effective technical solutions. The starting point, in all cases, will be the existing proposals, for which a great deal of preliminary conceptual design work has been completed.[93]

After these premises describing unitary coordination, come the paragraphs below, claiming scientific, managerial and financial autonomy for the various national groups:

> It must be stressed that the aim is not to arrive at a single design for three absolutely identical antennas, but rather to ensure the adoption of optimised solutions where there is scientific and technical evidence for the existence of such solutions. In addition, of course, duplication of effort will be avoided, so that there should be very significant savings of both direct and indirect costs.
>
> There are certain areas, for example in the choice of Fabry-Perot or delay line optical systems, where the superiority of one approach over another has not yet been demonstrated. In some cases, of which the above is an example, it may not be possible to establish that superiority, if any, without constructing a full, long-baseline, interferometer. It is important, and has been accepted by all the working groups, that a flexible approach to these problems is adopted from the outset. The final designs that evolve will be capable of easy modification, so that even quite major technological changes can be incorporated at a later stage.
>
> Within this collaborative framework the different groups will retain their independence, scientific and financial, and this will be maintained when the construction and operation of antennas is under way. It is envisaged that, in general terms, the finances would be handled by a series of bi-lateral agreements between the various

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[92] Brillet A., Corbett I. F., Giazotto A., Hough J., Leuchs G., Schutz B. F., Tourrenc P., Winkler W., *Report of an Ad-Hoc Working Group on the Future of Interferometric Gravitational Wave Antennas in Europe—March 1988*, PAB, pp. 1–10.

[93] Ibid., pp. 8–9.

> funding bodies involved in the construction of an antenna. It is appreciated that many practical details would remain to be settled before collaborative construction of a network of detectors could begin, but it is felt that the outline framework agreed is sufficiently simple and flexible to allow a solution acceptable to all parties.[94]

In order to underline the scientific relevance of building at least three antennas in Europe, the report presents a comparison of the performance of different sized networks of detectors worldwide, spanning from five USA–Europe large interferometers to one.[95]

> Recent studies [...] have shown how significantly a coordinated network improves the sensitivity and the event rate, and thus the scientific return of the detectors over earlier estimates based on their operation in a simple two-detector coincidence mode. The efficiency of an array (the fraction of all events it can capture) increases dramatically with the number of interferometers. The volume which can be observed increases by a factor 1.7 from two to three antennas and by a factor 3 from three European antennas to five US-Europe antennas. Several other examples could be put forward but of course the efficiency is not the only point to be considered; given finite resources, a considered balance has to be made in choosing between more detectors and better thresholds in each.[96]

The analysis presented in the EUROGRAV report fostered the need for three European detectors, so supporting all the projects at stake in Europe: the British, the German, and the French–Italian. For the first time, the name *Virgo* is appearing in this document, as a designation for the French–Italian plan.

> A network of three antennas has such a large advantage over only two antennas that it must be a reasonable European goal to build three detectors, which should define as large a triangle as possible (for the best directional resolution). Such a network would be capable of providing extremely useful scientific information on its own, regardless of what happens elsewhere in the world.[97]

A remarkable scientific argument supporting the three-detector minimum array had been provided by Bernard Schutz in 1986 [50,56]. Schutz had discovered that signals from binary systems close to coalescence carry information about their distance, allowing for the measurement of the Hubble Constant, whose value then was yet very uncertain. The task needed a minimum of three detectors, and provided a strong argument motivating the funding of an array of interferometers: it was a concrete astronomical goal, especially in view of the likely occurrence rate of coalescing neutron-star binaries.[98] The conclusive lines of the 1988 Report were addressed to the funding agencies:

> The European funding bodies involved in the proposals are invited to endorse the formation of a collaborative European programme directed towards construction of a network of detectors, and discuss how the best objectives of that programme can be realized in order that European science can capitalize on its past investment and present scientific and technological lead.[99]

13 The changing conditions in Europe

The circumstances outside and inside the small world of European interferometric detectors were rapidly changing. As a result, the 1988 EUROGRAV report very rapidly became obsolete. In September 1989 the teams in Glasgow and in Garching submitted to SERC and BMFT a joint proposal for a single 3 km interferometric GW antenna, to be built either in Scotland or in Bavaria [30]. The idea of a shared project was born from two referees of the British and German funding agencies. At that time, Ian Corbett was head of SERC's astronomy program, and during a meeting in Bonn he had the chance of discussing the matter with Hermann Schunck, who was directing the Fundamental Research Unit of BMFT[100] since 1987. Corbett was clearly aware that SERC would not have undertaken alone an expensive and demanding enterprise such as the construction of an long-baseline GW detector. A further problem was that the GW project was competing with several British astrophysical endeavors, which

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[94] Ibid., p. 9.
[95] Ibid., pp. 4–8.
[96] Ibid., p. 5.
[97] Ibid., p. 7.
[98] This argument was discussed with Bernard Schutz. Written comment by Bernard Schutz, email to the author, April 7, 2019.
[99] Brillet A., Corbett I. F., Giazotto A., Hough J., Leuchs G., Schutz B. F., Tourrenc P., Winkler W., *Report of an Ad-Hoc Working Group on the Future of Interferometric Gravitational Wave Antennas in Europe—March 1988*, PAB, p. 10.
[100] Skype Interview by the author with Ian Corbett, November 24, 2017.

served a much larger community and which therefore benefited from a greater support in the funding agency.[101] On the German side, Schunck recalls[102]

> Around 1989 the idea of building a large interferometer crystallized to be physically highly interesting, technically viable, with a price tag of 150 Million DM (i.e., 75 Million €) and thus financially within range of becoming reality. One could envisage a cost sharing between the regular budget of the MPS [Author's Note: Max Planck Society], a grant of the BMFT and support by the state pledging to site the interferometer. Since in 1989 the British group had given up plans for an own project, a fourth partner was in sight. The project had prominent support within the MPS by its Vice-President Herbert Walther, Director of the MPQ.

Later, in 1990, Herbert Walther was responsible for appointing Karsten Danzmann new leader of the German group.[103] As observed by Danzmann,[104] it was very natural for the British and German researchers to team up, because they both had been working in parallel on their prototypes and had already done a data run together, making coincident analysis, a relevant achievement underlined in their 1989 joint proposal:

> With our prototypes in Garching and Glasgow we have achieved some of the best sensitivities with laser interferometers. In addition we have recently demonstrated the potential for long term operation of laser interferometric detectors by carrying out a 100 hour period of coincident observation using the 30 m arm length delay line system at Garching and the 10 m arm length Fabry-Perot based system at Glasgow.[105]
> Well known noise sources, particularly thermally excited vibrations of the mirror substrates, but also the fundamental limit due to the Uncertainty Principle, do not allow the present prototype detectors to be upgraded to the sensitivity level required for a realistic prospect of detecting gravitational wave signals from predicted sources. The British and German groups are now committed to a joint proposal for such an instrument. The prototype detectors will henceforth provide a testbed for new technologies, techniques, and concepts before they are implemented in the full-scale detectors. [30]

Nevertheless, in between the submission of the German-British proposal and Danzmann's appointment in Garching, a major event in history took place: on 9 November 1989 the East German government announced the opening of the border between East and West Germany, heralding the demise of the Berlin Wall.

Schunck remembers how suddenly the fate of the German-British proposal changed.

> Within the ministry the idea of starting a new big project in physics caught us on the wrong foot. Politically, all new initiatives were focused to the unification process of Germany. Financially, BMFT had the (new and challenging) responsibility for a country in the process of unification. The BMFT neither got any budget to take up that new responsibility, nor any extra personnel. But there was another reason of psychological importance. BMFT had started a huge investment program in Physics in the middle of the 80s, including building a huge HEP-accelerator (HERA) in Hamburg (with prominent participation of Italy, by the way), an enlargement of experimental possibilities for nuclear Physics in Darmstadt, a new nuclear research reactor in Berlin, an X-ray satellite for MPS and some more. All these projects proved to be highly successful by the way. The political leadership of BMFT had the clear feeling that all this was enough for Physics [...].[106]

This situation was not at all favorable to proposing a new project, and Schunck was told to stop supporting the proposal.[107]

> My immediate judgment what this drawback meant to GW research was: not just an usual missed opportunity like any other, but a missed star hour of the history of Physics in Germany. I understood the importance of

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[101] Interviews by the author with Alain Brillet, Nice, April 27–28, 2017, and Cascina, July 17–18–19, 2017; Skype Interview by the author with Ian Corbett, November 24, 2017.

[102] Written interview by the author with Hermann Schunck, email to the author, May 14, 2019.

[103] Karsten Danzmann interviewed by the author in Rome, February 19, 2019. Herbert Walther, director of the Max Planck Institute of Quantum Optics, proposed to Karsten Danzmann, who was working at the time at Stanford University, to take over the position left by Gerd Leuchs, who had decided to start working in industry.

[104] Karsten Danzmann interviewed by the author in Rome, February 19, 2019.

[105] As pointed out by Bernard Schutz the 100-hour run was mandated by BMBF and SERC as part of a demonstration that the groups were ready to scale up. In early 1989 the two prototypes took data in coincidence for 100 h—known as the "100 hour run", and the Cardiff group was responsible for doing the data analysis. The loss of funding when SERC pulled out later that year made it hard to complete the analysis. A part from the paper [43], most of the analysis remained unpublished, in a series of Cardiff PhD theses. The learned lessons went into a proposal for a GW data format, that was circulated among the other groups. Schutz states that the proposal "had a significant, although unacknowledged, influence on the 'frame' format that is now universally used." Written comment by Bernard Schutz, email to the author of April 7, 2019.

[106] Written interview by the author with Hermann Schunck, email to the author, May 14, 2019.

[107] Ibid.

> GW as the last great prognosis stemming from General Relativity that had not been proven experimentally. And I had the clear vision that the first group to do this would travel to Stockholm. Working as a research administrator you do not have many chances like that, if any.[108]

Karsten Danzmann described the situation in a July 5, 1991, letter to Rochus Vogt, at the time director of the LIGO project:

> German unification is taking a huge toll on the BMFT budget. Thousands of scientists from the east have to be laid off or taken over. But both options are expensive. The research institutes of the old eastern academy of sciences have to be dissolved and new structures have to be built up, and so on... It is not only money, but also manpower. Everybody at BMFT is so busy restructuring the East that nobody has time to even think about Gravity waves.[109]

Big history had intercepted the small community of GW researchers. In the following years, the reunification of Germany would drastically influence the fate of the joint British–German project, resizing the scientific ambitions of the allied teams together with the dimension of the future antenna, which was shortened to a 600 m arm length interferometer, called GEO 600.[110]

At the turn of the 1980s, the funding situation for scientific research was considerably dimmed also on the British front, due to an economic downturn, which also put an end to Margaret Thatcher's role as Prime Minister and Leader of the Conservative Party in November 1990. In January 1991, Sir Mark Richmond, chairman of SERC, received a letter in support of the 3 km GEO signed by Brillet, Giazotto and Tourrenc, and replied on February 1 in these terms:

> [...] the overall SERC funding position for 1991-92 and subsequent years has been seriously undermined by the very poor Public Expenditure Survey outcome for science announced in November 1990. [...] In the short term SERC is having to consider delaying participation in several projects by up to 5 years; GEO may well be one of these projects.[111]

It should be noted that at the end of 1989 Corbett had moved from Rutherford Appleton Laboratory to Swindon, the headquarters of the SERC, to be responsible for the funding of all SERC activities in astronomy and particle physics. He therefore could not remain connected in any way with the gravitational wave projects. As pointed out in a comment to the author of this paper,[112] he was responsible for drafting Richmond's reply quoted above, and deliberately left the door open for a possible funding decision at some future time.

In the same period of these major events in Germany and UK, the French–Italian team was undergoing a rosier situation. In the same year of German Reunification, the Virgo Project was submitted to INFN and CNRS [10]. At this stage also, a privately owned plot of land in Cascina, near Pisa, was suggested as the most promising site for locating the future interferometer. On June 27, 1994 the agreement for the construction of Virgo was finally signed by the president of CNRS Francois Kourilski and the president of INFN Luciano Maiani; the works in the site of Cascina started 3 years later, in 1997.

The British and the German teams made the joint proposal for a 600 m laser-interferometric GW antenna in 1994. The building of GEO 600 started in September 1995 on land close to the University of Hannover, where the group led by Danzmann had moved in the meanwhile [16].

The leadership of Danzmann in the Garching group contributed to mark a new stage of the relationships among the different teams. The attempts to establish a European collaboration were thus resumed in the early 1990s in the spirit of having two European interferometers, a rescaling following the reduction of funds for basic research in UK and in Germany. A future work will analyze the second phase of the EUROGRAV, taking place in the early 1990s. Nevertheless, it is now possible to draw some conclusions about the first period of negotiations discussed so far.

14 Concluding remarks: main reasons for the failure of the early EUROGRAV collaboration

In his note[113] of April 1987, Corbett addressed the question of what existing collaborative projects could provide a useful model for establishing in Europe a network of interferometric GW antennas. Thirty years later, Michele

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[108] Ibid.

[109] Letter from Karsten Danzmann to Robbie Vogt on July 5, 1991 and forwarded to Alain Brillet on July 8, 1991, PAB.

[110] For a detailed analysis of the history of GW research in Germany see [7].

[111] Letter from Mark Richmond to Alain Brillet, Adalberto Giazotto and Philippe Tourrenc, February 1, 1991, PAB.

[112] Written comment by Ian Corbett, email to the author, April 1, 2019.

[113] Note by Ian Corbett, European gravitational detector working party, pp. 1–2, April 24, 1987, PAB.

Punturo, one of the founders of the ET project, addressed an analogous question in his talk[114] at the LIGO Scientific Collaboration-Virgo Meeting held at CERN in 2017.

Punturo quoted the *options for global project governance* highlighted on that same occasion by Gary H. Sanders,[115] a key figure in the making of LIGO. In the range of possibilities described by Sanders, the strongest collaboration scheme is the intergovernmental (treaty) organization, the one exemplified by CERN itself. On the other hand, the second lightest option is the 2007 agreement between Virgo and LIGO on the full sharing of data, indicated by Sanders as a governance between *non-coordinated separate, but related, existing executive organisations.*

At the time of EUROGRAV's attempts, in the astrophysical community a variety of approaches to international cooperation was already on the floor since a long time. In radio astronomy, Very Long Baseline Interferometry (VLBI) had a history of international cooperation dating back to the 1960s, which developed within the scientific community independently of governmental agreements. On the other side, the European Southern Observatory (ESO) was founded in October 1962 as a convention among governments, signed by Belgium, France, Germany, the Netherlands and Sweden. Usually, funding for international collaboration came from national science agencies, but ESO was directly financed from the member governments, separately from the national agencies.

Another kind of collaborative setup was represented by the already mentioned experiment GALLEX at Gran Sasso Labs, for the detection of solar neutrinos, strongly supported by INFN President Nicola Cabibbo. Instead of a central organization, the participants cooperated by providing the necessary staff and funds for their particular responsibilities, similarly to what happens for space missions.

It is reasonable to think that a governance scheme for EUROGRAV should have been inspired by some model coming from the astrophysical environment. The word "observatory" stands for a long-term facility, built for the lasting purpose of observing the skies. Paving the way toward gravitational wave astronomy would have to rely on the "observatory approach,‘ rather than on the "detection approach," which was instead a usual feature of particle physics experiments.

Nevertheless, one has to consider that at the time of the 1988 EUROGRAV report, the detection of a GW seemed already an extremely optimistic enterprise to most of the scientific community. The chances of success appeared to be very slight, also considering the long-term perspective required for the huge leap of scale toward building and running long-based interferometric antennas.

To have an idea of the change in scale, one should consider that INFN had spent about 200 million Italian lire in the early 1980s to build the cryogenic bar Explorer at CERN, and the team was made up of about ten scientists coming from Rome. Virgo, funded by INFN and CNRS, had a total cost of about 45 billion Italian lire and the number of people involved, coming mainly from Italy and France, rapidly grew about ten times compared to Explorer. For ET, the estimated cost to date is around 1.5 million euros, with about 750 scientists participating in the endeavor from all Europe.

At the time of the first LIGO and Virgo proposals, a substantial part of the scientific community was sceptical about investing such a great amount of public money for a research activity with such uncertain perspectives, especially given that there was great pressure to invest in competing projects, such as the LHC, ESO VLT and several space missions.[116]

Nevertheless, the 1988 EUROGRAV report highlighted how the scientific case for building an array of European GW interferometric antennas was indeed a relevant one: a GW network of detectors would have allowed the European scientists to be at the forefront of the new astronomy. It would also mean for European science to "capitalize on its past investment and present scientific and technological lead."[117] European cooperation was the key to achieve these goals.

What went wrong? What were the main factors opposing the achievement of a collaboration, which appeared to be instrumental in pursuing the ambitious goal of gravitational astronomy? Why did the European groups, which

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[114] Michele Punturo, *Third Generation Perspective: Toward a 3G GW network*, LSC-Virgo Meeting, CERN—Geneva, 2017 August 28—September 1.

[115] Gary H. Sanders, *Models for governance of scientific megaprojects*, Joint gravitational waves and CERN Meeting, CERN—Geneva, 2017 September 1.

[116] In the previous paragraphs we already quoted Anthony Tyson's speech to the members of the House of Representatives of the USA, on March 13, 1991. Tyson attacked the LIGO project with these words: "The following example may help us grasp the magnitude of the task. Imagine this distance: travel around the world 100 billion times (a total of 2400 trillion miles, or one million times the distance to Neptune). Take two points separated by this total distance. Then a strong gravitational wave will briefly change that distance by less than the thickness of a human hair. We have perhaps less than a few tenths of a second to perform this measurement. And we don't know if this infinitesimal event will come next month, next year, or perhaps in 30 years" [57]. Looking at the first signal ever detected by LIGO, one can truly consider how descriptive Tyson's words were and how incredibly difficult is the task effectively accomplished 24 years later.

[117] Report of an Ad-Hoc Working Group on the Future of Interferometric Gravitational Wave Antennas in Europe—March 1988, PAB.

were at the time leading the experimental field of GW interferometry, not join forces to build a European GW observatory with at least two detectors of kilometric dimensions in Europe?

Different factors played an important role, as we have seen. Some factors were contingently linked to the relationships among the small groups of physicists working at GW interferometric detectors, while others were related to the particular historical moment experienced by the research field. External events also had a dramatic influence, as mentioned above, in particular the reunification of Germany and, as Ian Corbett points out, the change in overall research funding priorities in UK, which had reduced the support for basic research in the physical sciences, in favor of life sciences and applied science.[118]

The main internal difficulties identified through the present historical analysis have been anticipated from a different perspective in a previous work by the author [34], and can be here summarized in four arguments: (1) the uneasy transition from bench-top experiments to Big Science; (2) the centripetal/centrifugal forces, i.e., the uneasy balance between national ambitions and international collaboration; (3) the prototype/non-prototype controversy; (4) the absence of a coordinated GW community.

1. The carrying out of a long-based interferometric antenna required a true change of scale in terms of number of people involved and of funding, as we have argued. A comparable change of scale was the one experienced by the field of particle physics in the 1950s and 1960s, with the advent of large research centers such as Brookhaven National Laboratories in USA and CERN in Europe, with their highly sophisticated accelerating machines Cosmotron and the Proton Synchrotron.
   Unlike in a particle accelerator, however, the events detectable by a GW antenna are random, not repeatable nor reproducible in a laboratory. Furthermore, the detectability of unmodeled transient events and the measurement of fundamental physical quantities, such as the localization of the astrophysical source and the polarization of the gravitational signal, are possible only by means of a network of antennas.
   In this sense, GW detectors are much more similar to astrophysical observatories such as gamma ray telescopes and radio telescopes, which have to work in a coordinated way to extract as much information as possible from incoming signals.
   It was not only matter of transition from bench-top experiments toward Big Science, but toward a very highly coordinated Big Science. The needed structure was, indeed, not a centralized experimental center as CERN, but two or more research centers located in different and well-spaced sites, working as a single machine. Among the governance schemes described by Gary Sanders at CERN in September 2017, a possible choice should have been something stronger than the current LIGO-Virgo collaboration, such as the option *international coordination of separate, but related, existing executive organizations.*
   However, the kind of organizational expertise needed for the change of scale was not possessed by the laser interferometry experts in Garching, Glasgow and Orsay, who were used to working in small and autonomous teams at bench-top experiments. The European grants shared by the teams did not affect this autonomy, leaving the groups free to conduct their own separate research activities in the framework of a very rarefied cooperation.
   It is not by chance that in the early negotiations for giving birth to EUROGRAV, the particle physicist Ian Corbett had taken such an active part as an outsider of the field, having an expertise in the large collaborations at CERN and familiarity with large international collaborations in astronomy and space science. It is also meaningful that in 1987 Adalberto Giazotto, another particle physicist, caused havoc among the interferometric groups, by successfully landing a GW interferometer project on a national funding roster. In the following years the *forma mentis* and the organizational tools of Big Science were in a certain sense introduced in LIGO and Virgo mainly through the involvement of many scientists coming from particle physics, who became either supporters or active part of the projects, such as Barry Barish and Gary Sanders for LIGO, and Adalberto Giazotto and Nicola Cabibbo in Virgo. Nevertheless, the project of establishing a gravitational observatory in Europe, that is, a network of antennas rather than a single detecting machine, did not succeed, to some extent because the more purely astrophysical vision failed to emerge among the European groups.

2. The second argument—i.e. the centripetal versus centrifugal forces—is strongly connected to the first one. The tension between being engulfed by a European collaboration and maintaining one's own independence was the mirror of the competitiveness and of the individualistic drives of the single groups, which, in dealing with their funding agencies, feared not finding the winning strategy. To some extent the collaboration was considered as instrumental in inducing the funding agencies to approve their projects, but it was also felt as possible ballast that could slow down the approval of national projects. The different scientific approaches and backgrounds of the various teams were intertwined with the different national scientific environments. In the attempts to establish a shared agreement, the proposed EUROGRAV appears to some extent as a façade, a useful strategy before the funding agencies, which nevertheless hid a disunity of views deep enough to undermine a real

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[118] Written comment by Ian Corbett, email to the author, April 1, 2019.

collaboration. In the case of the American LIGO, the existence of a single funding body, the National Science Foundation, required a unanimity of all groups proposing LIGO as a prerequisite for funding. In comparison, to arrange agreements among financing bodies from different European countries was a much more difficult task.
The case for the future ET is significantly different, foreseeing a single European facility. In this case, effective pan-European collaboration will depend very much upon each partner country maintaining a strong national program and infrastructure for the proper exploitation of the international observatory. Domestic and international programs must complement each other, as happens for CERN.

3. The French–Italian and British–German teams did not share the same scientific approach to building the detectors; in particular, they did not agree on the need for working on a prototype before building a full-scale interferometer. The British and German groups had been working on their prototypes in Glasgow and in Garching for several years, learning and gaining experience in the field and trying different solutions. They were sceptical of the French–Italian choice of bypassing the construction of a prototype and immediately building the final interferometer, without testing various technologies and measurement principles in a smaller and more easily controllable facility.
   On the other side, Brillet and Giazotto claimed that to test properly such cutting-edge experimental setups, intended for unprecedented accuracy measurements, it was essential to work at such a scale. In particular, they argued that none of the components of a small prototype would meet the requirements needed in a real detector, and that after the development of a prototype device, the specifications would change for the next one, which would lead to circular efforts and wasting time. From Brillet's and Giazotto's point of view, since the final component specifications could be calculated, it was more efficient to develop each individual component—seismic isolation, laser, mirrors and so on—to assemble them into a suitable full-size infrastructure. It was a methodological contraposition, strongly related to the scientific arguments used to support the requests for funding. BMFT and SERC would not take the risk of financing a full-size interferometer, without the evidence that it was possible to build and operate smaller equipment. The approval of the 1989 German-British project was indeed subject to demonstrating the feasibility of coincident measurements, accomplished with the two prototypes for a continuative period of time of 100 hours. For the British and German teams it was thus fundamental to proceed step by step, and demonstrate the principles of operation on the small-scale before embarking on a large and expensive undertaking. The arguments produced by Brillet and Giazotto to convince INFN and CNRS were completely different and justifiable as well. Nevertheless, at the time this divergence constituted a serious obstacle to establishing a shared strategy before the funding agencies and thus finding a form of advantageous collaboration.

4. During the 1980s, the organizational and institutional conditions for a wider collaboration might have been facilitated by closer contacts with all the scientists working in the field of interferometric detection of GWs. This was not the case, because the GW experts were still quite fragmented, lacking specific dedicated periodic gatherings or coordinating bodies, which could define an identity for the GW community. GW scientists met at general gatherings such as the Marcel Grossmann Meetings or at GRn Conferences. The interferometry experts participated in the conferences devoted to quantum optics, but there was no meeting or specific institution which could bring together all the different skills required by the field. The Edoardo Amaldi conference on GWs was held for the first time in 1994, in Frascati, and in the following years became the cornerstone gathering of the field. Indeed, during the second Amaldi Conference, organized at CERN in 1997, the Gravitational Wave International Committee (GWIC) was born as a working group inside the International Union of Pure and Applied Physics, with Barry Barish as the first chairman (1997–2003).

In 1997 the scientists of GEO 600 established with the LIGO researchers the LIGO Scientific Collaboration. The British and German teams provided fundamental contribution to LIGO; the successful development of advanced technology with the GEO 600 interferometer was one of the keys to the success of the American detectors.

Ten years later, Virgo and LIGO signed the already mentioned agreement on the full sharing of data, joint data analysis and common publications. The establishment of these two wide and interconnected alliances does not mean that there hasn't been direct cooperation among the French–Italian and British–German groups. There has been indeed a sharing of knowledge and of people, and coordinated efforts on a truly international level. However, it is not possible to ignore the fact that despite the early plans for a European observatory, the original European teams signed up to an official collaboration with LIGO rather than among each other.

The presence of two long-arm detectors in the USA and only one in Europe is experienced with regret by many European veterans of the field and with unfocused fatalism by many of the younger ones. Nevertheless, better times are now coming, while the Einstein Telescope (ET) project is making its way, and will hopefully be the first pan-European ground-based GW interferometer.

Challenges similar to the ones investigated in the previous pages are present in the negotiations for ET. What kind of collaborative framework should be set up? What kind of agreements should be made? Between the national funding agencies or between the governments? How to interact with the European Union? How to interact with the USA? In competition or in collaboration? Under a common management? What is best for the science? How to organize the work, the facilities, the management of the scientific collaboration? How to interact with the astrophysical community? Where to build the observatory?

Compared to the early EUROGRAV times, the GW physicists are now a large and well established community, which is building its identity and its own path in the global network of Big Astronomy, blending boundaries in what has been called the new discipline of multimessenger astrophysics, combining information from photons, cosmic rays, neutrinos, and gravitational waves emitted by cosmic sources.[119] The new leap in scale now required to reach the next ambitious astrophysical frontiers calls again for a wider coordination, and while being an unprecedent challenge, the starting point is certainly brighter than before.

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