Europe's Quest for the Universe

Lodewijk Woltjer

EDP SCIENCES

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ESO and the VLT, ESA and other projects

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Cover: THE VLT Array on the Paranal Mountain. © ESO.

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Preface

What a magnificent title, "Europe's quest for the Universe"*, for the opening of this new book by Professor Woltjer, which presents and expands on two grand themes.*

Since the days of Copernicus, Galileo, Tycho Brahe and Kepler, as a research community Europe has been at the cutting edge of science, in its incessant quest to understand the universe we live in.

In this book we trace the history and development of more recent institutions such as the ESA and ESO. This is thanks to the great skill and experience of the author who, by writing this work, passes on the fruits of a unique and exceptional career.

Great pride and optimism for European science comes across on reading these pages, all beautifully illustrated. Written to a high scientific level, this book provides the reader with a top quality reference on the subjects covered, and gives us ample reason to believe in a European research environment directed firmly to the future.

The second theme is that knowledge and exploration of the universe are fundamental elements of the human psyche, a drive inherent in all of us to understand and discover our destiny.

The Universe is a magnificent question which inspires scientific and technological development. At the same time it remains that star studded sky which acts as a source of wonderment and inspiration for our thoughts and dreams.

Thank you Professor Woltjer for returning us, through this book, to the very roots of our humanity, and revealing to us such marvellous advances in understanding.

Philippe Busquin, July 2005
European member of parliament,
Former European commissioner for Research

Préface

Quel magnifique titre pour l'ouvrage de Monsieur Woltjer "Europe's Quest for the Universe" *qui exprime deux idées fortes et l'évolution de celles-ci.*

L'Europe, comme espace commun de recherche, depuis Copernic, Galilée, Tycho Brahe, Kepler, a été à la pointe de la science et de cette quête incessante de compréhension de notre Univers.

L'histoire et le développement des institutions plus récentes comme l'ESA et l'ESO sont retracés grâce à l'expérience et à la compétence de l'auteur qui, par le truchement de cet ouvrage, nous transmet les fruits d'une carrière unique et exceptionnelle.

Quelle fierté et quel optimisme pour le savoir européen à la lecture de ces pages si bien illustrées et d'un haut niveau scientifique qui contribueront à nous donner une référence de très haute qualité sur les sujets abordés et nous fournissent toutes les raisons de croire en un espace européen de la recherche tourné vers l'avenir.

La deuxième idée est que la connaissance et la conquête de l'Univers sont des éléments fondamentaux du besoin inhérent à l'homme de comprendre et de découvrir le sens de son destin.

L'Univers demeure cette magnifique interrogation qui inspire le développement scientifique et technologique mais aussi le ciel étoilé propice aux rêves, aux réflexions et à l'émerveillement.

Merci, Monsieur Woltjer, de nous replonger, grâce à votre ouvrage, aux racines de l'humanité et aux merveilleuses avancées de la connaissance.

Philippe BUSQUIN, juillet 2005

Membre du Parlement Européen,
Ancien Commissaire Européen à la Recherche

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I wish to thank Catherine Césarsky, Director General of ESO, and David Southwood, Director of the ESA Science Programme, for having contributed towards making the publication of this book possible, and EDP Sciences for taking the risk to publish it in color.

Parts of this book were written while "chercheur associé" at the Observatoire de Haute Provence ; I thank the directors Philippe Véron, Antoine Labeyrie, Jean-Pierre Sivan and Michel Boër, as well as Mira Véron-Cetty, for their support. Other parts were written while "Rossi Fellow" at the Osservatorio Astrofisico di Arcetri, and I thank the directors Franco Pacini and Marco Salvati, as well as the chairman of the Astronomy Department Claudio Chiuderi for their support. Some sections were written during visits to the Raman Research Institute in Bangalore, and I thank the directors V. Radhakrishnan and N. Kumar for the friendly reception I received there.

Introduction

The progress of science depends on the technological development of its instrumentation. This is particularly true for the astronomical sciences where the study of remote objects requires sophisticated and costly detection techniques. In this book I shall analyze some of the large European astronomical projects, both on the ground and in space, their development during the last two decades, and their prospects in the future. While scientific progress is intimately related to technology development, both are contingent on professionals and funding, and I shall consider the situation with regard to both of these.

This book is addressed to a varied audience: scientists who wish to see what is happening outside their own domain, students who look for fruitful areas of thesis research, functionaries who need some background for decision making, amateur astronomers interested in knowing what is going on in the profession, and also to an educated public that wants to get the flavor of what is behind the newspaper articles reporting scientific results and to know how European activities compare to what is being done elsewhere. The more detailed description of the development of the VLT, ESO's Very Large Telescope, illustrates how a large technological project gets underway and after some pitfalls reaches completion.

In the first half of the twentieth century observational astronomy was *ipso facto* astronomy done from the ground in the visible part of the spectrum. While in the USA ever larger telescopes were being built, in Europe developments were much more modest, partly owing to unsuitable meteorological conditions, but even more because private donors on the scale of an Andrew Carnegie did not exist here. In the early fifties some proposals were made to construct a large European telescope at a suitable location. Political and financial conditions for science were much improving, and in 1964 ESO, the European Southern Observatory, was founded by half a dozen countries as an intergovernmental organization; in the meantime most countries in Western Europe have become members. In writing this book, I have placed ESO at the beginning because of its increasing role in several areas of European astronomy.

The early evolution of ESO has been well described by Adriaan Blaauw in his book "ESO's Early History"[1)], so I shall give only a brief recapitulation and then sketch the origin of the VLT, which has brought Europe to the forefront of contemporary optical astronomy. Following a brief overview of the development of the astronomical sciences, subsequent chapters of the book deal with the origin, development, construction and siting of the VLT, its interrelation with the Hubble Space Telescope and with possible successors of these instruments.

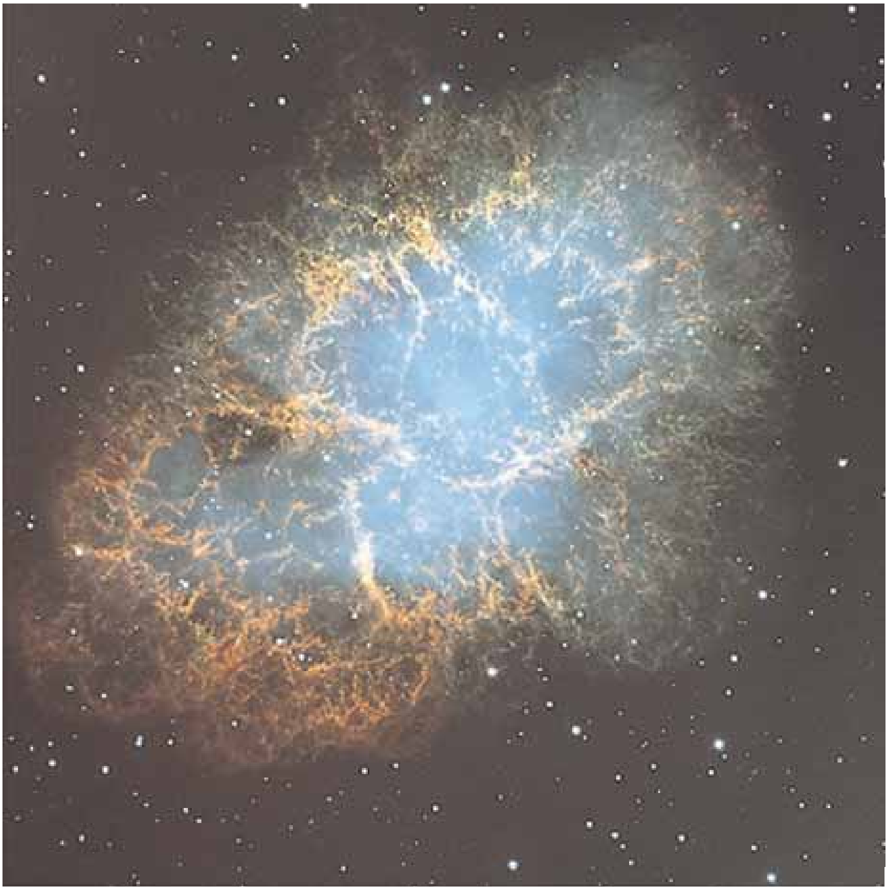
Also during the fifties radio astronomy became a major contributor to scientific progress. The European radio community has made many advances – in part by tying national facilities into a network, the EVN (European VLBI Network). The French-German-Spanish IRAM has been successful in radio astronomy at millimeter wavelengths. ESO entered this field with SEST, the Swedish-ESO Sub millimeter Telescope. ESO is the European partner in ALMA – the Atacama Large Millimeter Array, the major Europe-Japan-US venture in submm astronomy.

With the advent of the space age other parts of the spectrum became observable. Thus, infrared, ultraviolet, X- and gamma-ray observations allowed entirely new objects to be discovered and studied. Moreover, possibilities opened up for *in situ* exploration of the solar system. At about the same time as ESO, the precursors of the European Space Agency ESA came into being. The ESA has constructed large facilities for space research. Again I shall be brief on early ESA history, since it is described by Roger Bonnet and Vittorio Manno in their excellent short book "International Cooperation in Space: the example of the European Space Agency"[2)], while early world-wide space science developments are comprehensively covered in "The Century of Space Science" edited by Johan A.M. Bleeker, Johannes Geiss and Martin C.E. Huber[3)]. Subsequently, I deal with recent and future European scientific projects in space. Most of these have been developed in the ESA context, but also some national projects have had an important role. ESA and ESO are increasingly cooperating: The European Coordinating Facility for the Space Telescope is one example; joint studies in interferometry another. The latter may be essential in one of the most exciting astronomical subjects: the search for earth like planets and life. Also archiving the enormous data flows is a common interest of ESA and ESO.

A more sociological discussion of European astronomy follows. How many astronomers are there in the different countries and how much is spent on astronomy? The end product of the astronomical activity consists of publications, and the productivity of the different communities is evaluated. The final chapter deals with the future and the difficult selection of expensive projects in a relatively less favorable economic and political environment, but ending on a positive note: the past achievements augur well for the future in which the countries now entering the EU should also play their part.

The present book deals with European achievements and prospects which do not seem to have been described previously in a coherent way. Others have described their achievements elsewhere. Of course, comparisons are made with what other nations – in particular Japan, Russia and the US – are doing. Also cooperative projects with these countries play an important role. But is is important to realize that Europe has the full capacity to an autonomous role in science. Sometimes the necessary self-confidence seemed to be lacking among Europeans who measured their own success by how they are regarded across the Atlantic. The press services are not very helpful in this respect; even European results appear to become more respectable after a round trip across the ocean. Cooperation is a very good thing with mutual benefits. But such cooperation can only be profitable if it is based on equality, self-confidence and mutual respect. Europe has the capacity to autonomously plan its scientific future and does not have to try to fit into plans made elsewhere. It only has to strengthen its will to do so.

Two caveats should still be made. In this book I discuss mainly the larger astronomical projects. Many smaller ones are also important, but including these would require a much more voluminous tome. Secondly, when I discuss collaboration, it refers to institutional collaboration. Individuals participate in an infinite number of collaborations with fellow scientists in their researches without regard to nationality or to political factors. This contributes much to the liveliness of the field and may also be beneficial in the creation of a more harmonious world.



The Crab Nebula. First catalogued by Messier as M1, it was named by Lord Rosse who observed it in the middle of the 19th century with his six foot telescope in Ireland. It is the expanding remnant of the supernova which was extensively observed in 1054 in China and Japan. The Nebula remained mysterious until 1968 when a pulsar – a rotating neutron star – was discovered at its center. The strong magnetic fields of this star accelerate cosmic rays, including energetic electrons which produce synchrotron radiation in the nebular magnetic fields. That radiation is observed from the longest radio waves at 30-m through infrared, visible and ultraviolet light to the hardest X- and gamma-rays. In visible light it is seen as a smooth bluish continuum. The reddish filamentary structures on the image are due to emission lines from gas ionized by the ultraviolet radiation. Since almost all important cosmic processes may be studied in the Crab Nebula, it has been called the Rosetta stone of astrophysics. The image was taken with the FORS instrument (PI Immo Appenzeller) attached to ESO's VLT, the Very Large Telescope.

I.
The Development of European Astronomy during the 20th Century

Praised be your intellect, you interpreters of the heavens, you who understand the Universe, discoverers of a theory by which you have bound gods and men.

Gaius Plinius Secundus[1)]

A visitor to one of the hundred odd observatories in the world early in the 20th century would have found some astronomers at work during the night at telescopes with diameter generally less than a meter. Some would peer through an eye piece and note down their findings, but photographic plates were coming into widespread use which gave a more quantitative and less subjective record of the observations. Mostly the astronomers would be measuring the positions of planets, asteroids and stars. By a comparison with previous observations they also determined their motions across the sky. The brightness (generally denoted magnitude) and the color of the stars were also ascertained, and some of the more venturesome professionals had begun to use spectrographs with which the stellar light could be split into different wavelength bands. This allowed the detection of absorption and emission lines in the spectra. By measuring their wavelengths precisely and comparing these with the wavelengths at which gases in the laboratory emitted or absorbed radiation, they could identify the main chemical elements present in the stellar atmospheres. Variable stars were also extensively studied, different types were recognized and their detailed characteristics identified.

If he returned during the day, the visitor at the larger observatories would see numerous employees at work who would make the extensive calculations needed to establish catalogues of positions and motions of celestial bodies and to compare the results with theoretical models. Calculations were made with multiplication tables, tables of logarithms or very simple mechanical machines.

The photographic plates used behind the telescopes were terribly inefficient; less than 1% of the incoming light (or as one would frequently say nowadays: of the incoming "photons") was actually detected. Nevertheless, progress was made. By 1920 the magnitudes, colors, spectra and motions of many thousands of stars had been determined, and some ideas had been formed about their distances. So one could begin to construct more fact based models of how the stars are distributed in space. In fact, most stars were found to belong to a flattened system, with the Milky Way globally corresponding to its plane of symmetry. In this "universe" systematic streaming motions were suspected. Somewhat later it was concluded that the whole system is rotating. Whether there was anything outside this "universe" was unclear. Subsequently, evidence was found from photographic plates taken with the new 100-inch telescope on Mt. Wilson, California, that the faint luminous patch called the Andromeda Nebula was an independent stellar system, far away from our Milky Way Galaxy. Other "nebulae" were also resolved into stars and the "universe" was gradually growing in extent (Figure I, 1a).

Figure I, 1a. VLT image of the spiral galaxy NGC 1232; blue light comes from massive young stars which have formed recently in the spiral arms, while the yellow light around the center is contributed by older stars formed earlier in the history of the galaxy. To the left is a dwarf galaxy tied gravitationally to NGC 1232.

Most of the early observatories had been constructed on small hills in the neighborhood of towns. As the towns grew and street lighting increased, they were sometimes moved a bit further out. In Europe most observatories were located in unfavorable climates, and in the north east of the US the situation was not much better. Turbulence in the atmosphere caused the stellar images to be smeared out over several arcseconds on the photographs. This made it hard to detect faint stars. It was G.E. Hale who decided that the solution was to go to the calmer skies in California. Raising enough private money, he founded the Mt. Wilson Observatory, which would be equipped with a 60-inch and later a 100-inch telescope. When the city lights of Los Angeles became too strong, a more distant site was developed at Mt. Palomar. As a result of these developments, the Californian astronomers were able to take the lead in investigating fainter stars and galaxies, and thereby to explore a much larger part of the Universe. This led to the discovery of the expansion of the Universe – the fact that more and more distant galaxies move away from us at larger and larger speeds. In our own Galaxy stellar populations with different chemical compositions were recognized. The important conclusion followed that most of the chemical elements were not created in the birth of the Universe, but have their origin in processes in the deep interior of stars. When stars die they may eject gas containing these elements out of which new stars may form (Figure I, 1b).

Some of the European countries had founded observatories in their colonial empires, the UK in S. Africa, Australia, Canada and India, the French in Algeria, and the Dutch in Indonesia. Also Germany had considered the possibility. While these observatories collected useful data on a variety of objects, in particular on parts of our Galaxy invisible from Europe, they hardly contributed to a redirection of efforts in the mother countries. Of course, a few individual researchers could make visits to the Californian institutions, but most European observatories continued with the types of research they had been performing before. In addition, the second world war had a very damaging effect. So by 1949, when the 200-inch telescope at Mt. Palomar was inaugurated, the astronomical center of the world had largely moved to the US.

In theoretical astrophysics much strength remained in Europe. This had led to a basic understanding of conditions in the stellar atmosphere and interior and of the nuclear reactions which produce the luminous energy radiated from the surface. A beginning had been made with studies of stellar evolution, while also the dynamics of our Galaxy and the orbits of stars therein were being explored. However, the rise of theoretical physics in the US (in part due to European refugees) and the early availability there of powerful computers also threatened the European pre-eminence in the theoretical domain.

Four very different developments led to a rebirth of European observational astronomy: the discovery of radio waves from cosmic sources,

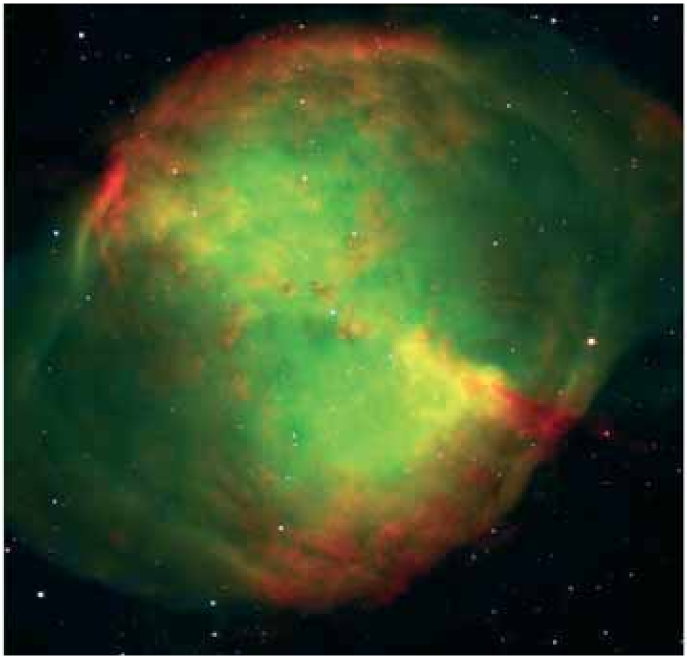


Figure I, 1b. VLT image of the "planetary nebula" M27, a gaseous shell ejected by the star at the center. The interstellar gas may become enriched in elements synthesized in the star, which now ionizes and excites the shell. Different densities and temperatures in the gas lead to different emission lines and thereby to different colors in this image.

the availability of government money for research, the development of air travel and European cooperation. Soon space research would add further possibilities for observations of celestial X- and gamma-radiation and in the infrared part of the spectrum. In the appendix to this chapter the definition and units of measurement of the electromagnetic spectrum are indicated for future reference.

Cosmic radio waves had been serendipitously discovered in 1933 by K. Jansky, an engineer at AT&T, but until the end of the war only some very limited follow up had been done. So the field was wide open. The poor climate in Europe did not matter, since radio waves pass through clouds and atmospheric turbulence unhindered, except at short mm wavelengths. Some of the leftover military radar equipment could be quickly converted to astronomical use, and so the cost of the first radio telescopes was modest. It soon turned out that the scientific returns were very large. Radio emission due to cosmic ray electrons throughout the Galaxy could be extensively studied.

The 21-cm emission line emitted by diffuse interstellar hydrogen gas provided a means for studying the whole galaxy without the problems associated with absorption by interstellar dust which had stymied the attempts to derive its structure by observing stars. Discrete sources of radio emission were discovered which turned out to be frequently associated with remote galaxies. So here was a whole new universe, and scientists in Europe, Australia and the US started its study at about the same time in conditions of equality (Figure I, 2). However, the radio sources that were discovered had to be identified with visible objects to determine their nature and distances. Since even strong radio sources are frequently very faint optically, this still required the large telescopes in the western US.

An important contribution to the American prominence in astronomy had been made by the availability of ample private money. During the period of the wildest capitalism huge fortunes had been built, and some of the owners of these or their heirs were fascinated by the astronomical universe or liked having telescopes carry their names. Thus, Carnegie had financed Mt. Wilson and Hooker had contributed much to the cost of the 100-inch telescope. Even very recently the Keck Foundation provided an important part

Figure I, 2. The 76-m radio telescope near Manchester. Completed in 1957, it illustrates the rapid growth of radio astronomy in Europe after the war. For 15 years it was the largest radio telescope in the world.

of the funding for the two 10-m telescopes at Mauna Kea, Hawaii. No similar tradition existed (or exists today[2)]) in Europe, and so most observatories lived a more precarious existence. After the war, and because of the important role science and technology had played for the winning side, this changed and governments began to consider it their function to sponsor research. With radio astronomy having some connections to radar and telecommunications, both funding and competent engineers were available.

Typical optical observatories had resident staff. Especially in poor climates it was necessary to use every clear hour, and this could be done only when the astronomer lived on the site. However, with air travel becoming cheaper and faster, a different *modus operandi* became possible in which observatories could be located in optimal places anywhere in the world and astronomers would travel there just for an observing period – initially months or weeks, nowadays frequently no more than a few days.

Constructing large observatories in remote places was expensive. To provide adequate funding remained difficult for individual governments. With Europe gradually becoming more unified, it seemed appropriate to consider the possibility of financing expensive scientific installations on a wider basis. Thus, CERN – the European center for nuclear and particle physics – was founded at an early date. Later ESO, the European Southern Observatory, and ESA, the European Space Agency, followed. These collaborations created the intellectual and financial basis for Europe to have the ambition to compete on the world level. By now, more than a third of all astronomy spending in Europe is done on a European rather than on a national basis.

Few things happen very fast in Europe and it took a rather long time before ESO was organized. Its first "large" (3.6-m) telescope was completed only in 1976, some 23 years after it had been first proposed. In the meantime, other telescopes of similar size were being developed by several countries. Not surprisingly, many European astronomers wanted to continue to do the things they had done before: to study the distribution and motion of the stars in our Galaxy, variable stars of every kind, the motions of double stars, stellar atmospheric structure, comets and asteroids. Even though valuable research was done in these areas, European optical astronomy lacked some of the excitement that prevailed on the other side of the Atlantic, where the unknown deeper reaches of the Universe were being explored. The difference in astronomical orientation is conspicuous if one compares the ambitions for the Palomar 200-inch telescope and that for ESO. In his 1928 proposal for the construction of a 200–300-inch telescope, Hale[3)] indicates the principal areas of research which three quarters of a century later have lost none of their interest, though today we might phrase them somewhat differently. The topics were:

The structure of the Universe.

The structure of our Milky Way Galaxy.

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