Robotic Exploration of the Solar System

Part 2: Hiatus and Renewal 1983–1996

Paolo Ulivi with David M. Harland

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Foreword

The series *Robotic Exploration of the Solar System* by P. Ulivi and D. M. Harland is, first of all, a monumental chronicle of the amazing adventure that in the last 50 years allowed mankind to visit and understand the immense and eerie domain of the solar system, with its hidden nooks and unexpected peculiarities, providing data, images and in some cases samples. The story is told with an extraordinary amount of factual and technical details, mostly arranged to trace each project from its conception to engineering design, to construction of the spacecraft, execution of the actual mission, data analysis and, finally, publication of the results. Most of these details are not known even to the communities of experts: temporary reports, especially if technical, are seldom published and are easily forgotten or lost. The style of this series is one of first class journalism: the story unfolds in a fascinating and easy-going way, without difficult digressions at the physical and engineering level. But the content is in no way superficial or vague: the accuracy of the information is confirmed not only by its exhaustive quantitative level, but also by the supporting primary documents quoted in the bibliography. Any future historical study of space exploration will have to be based on this chronicle. Much of its content refers to details of the instrumentation on each spacecraft, and to the manner in which the mission was accomplished. The design, making and testing of instruments for use in space is not an easy task. Conditions in space are often prohibitive, as, for instance, near the Sun, owing to its radiation and solar wind. Systems must reliably function for years without any check and repair. Extraordinary sensitivities for various physical quantities, like very weak magnetic fields and high-energy particles, are required. The possibility of storing on board very large amounts of data, processing it and sending it back to Earth is an essential condition for success. To reproduce space conditions on the ground to test systems is difficult, if not impossible.

I have been a Principal Investigator of the Ulysses mission, which is described in this volume. Launched in 1990, it conducted for the first time a deep exploration of the solar system environment outside the ecliptic plane in which most of the planets orbit the Sun – with outstanding results, as announced in the journal *Nature* on 3 July 2008. In the near future, after 18 years, its operation will terminate, not because of instrument problems, but because its radioisotope fuel is nearly exhausted.

The word ‘robotic’ in the title of this series points to an important controversy in space exploration: is direct human involvement necessary, or even advisable? For example, is the International Space Station commendable from the scientific point of view? I am clear on this point: the extraordinary developments in remote-sensing, software and control make a human presence on an orbiting machine for exploration useless for most of the time, costly and dangerous. Even when the round-trip time of a radio signal from Earth takes hours – such as in the descent of the Huygens probe to the surface of Titan, Saturn’s large satellite (a mission that will be discussed in the next volume of this series) – an unmanned probe can work very well, even though the control from Earth is delayed and an immediate reaction to unforeseen conditions impossible. The system on Huygens, on the basis of pre-planned choices, was able to decide autonomously which actions to take on the basis of the physical conditions it encountered in the descent.

The word ‘exploration’, usually romantically understood as the strenuous efforts of daring and often irresponsible people to survey unknown lands and civilizations, has acquired another meaning: instruments provide us with eyes and sensors far more powerful and penetrating than our own senses, supported by a vast memory capacity. The accounts in this series impressively confirm this view. This leads me to my final topic: the use of robotic space probes in the solar system to understand the structure of space and time. As the *Oxford English Dictionary* explains, the primary meaning of the verb ‘to explore’ is to investigate; to survey an unknown land is secondary. Most emphatically, the main purpose of the exploration of the solar system is not the sheer collection and cataloguing of images and data in very great quantities; it is the rational understanding of the structure, the history and the functioning of the physical objects that they refer to. In 1958, at the beginning of space exploration of the solar system, the conceptual framework was already set up and well accepted: first, planets and other large bodies move according to the laws of gravitation devised by Isaac Newton and applied to an exceedingly refined degree by mathematicians in France and England in the nineteenth and twentieth centuries; secondly, the origin of the planetary system in the collapse of a rotating interstellar cloud of gas and dust, at the centre of which the Sun began to shine 4.56 billion years ago, was a well established scenario. Space exploration did not change this general framework, but it opened up unexpected windows and led to extraordinary discoveries, two of which I shall quote. Planets and their satellites are not point-like, as assumed in the Newtonian model; their finite size gives rise to new forces and tidal effects that significantly influence the evolution of the system, and these have been extensively investigated with space probes. In 1979 Voyager 1 discovered a few active volcanoes on Io, one of Jupiter’s moons. In fact, their existence had been predicted by S.J. Peale and his collaborators at the University of California at Santa Barbara, on the basis of tidal forces exerted on Io by the nearby moons Europa and Ganymede. Space probes have also allowed immense progress in the investigation of planetary atmospheres, in particular on their composition, their evolution, and how they are maintained or replenished in spite of their continuous loss to space. Again, the traditional laws of chemistry and physics are not under question here; but no theory can predict or even explain the wealth of interlocking phenomena and complex behaviours, which often can be revealed and understood only with in-situ observations. A striking example is the recent discovery of extensive water activity on the surface of Mars in the geological past; of course, this has a bearing on the possible presence of life. But acceptance of physical laws can never be uncritical; indeed, the statement that a natural law is correct is idle and logically inconsistent, as there is no way to test it; one can only say, in the negative, that a given physical law is self-contradictory or conceptually inadequate, or that it disagrees with observations. It is well known, for example, that the Newtonian law of gravity works very well in most cases, but on both counts it is unacceptable. Minor anomalies in the motions of planets and the propagation of light in the solar system that are inexplicable by it are a quantitative consequence of the theory of general relativity announced by Albert Einstein in 1915; this theory is the currently accepted framework. The large computer programs used to predict and control the motions of interplanetary probes are in fact based on a fully relativistic mathematical scheme, and they include as an essential part the appropriate corrections to Newtonian theory to take account of relativity. A major question faced by theoretical physicists is: how, and at what quantitative level is general relativity violated? Space probes play a very important role in addressing this fundamental issue. They orbit the Sun at very large distances in an environment which is practically empty, and free from Earth's gravity and mechanical disturbances like microseisms. The sophistication of measurements using space probes of time intervals, distances and relative velocities is improving all the time, and such measurements have allowed the predictions of general relativity to be tested to a very high degree of accuracy. Remarkably, more than 90 years after its discovery, Einstein's theory is still unchallenged; but the assault is mounting, with a number of new missions in preparation to explore the deep nature of gravitation. An important experiment was carried out in 2002 by the Cassini spacecraft, which was cruising through interplanetary space to Saturn. Its radio system and a specially built antenna at NASA's Deep Space Network complex at Goldstone, California, enabled the relative velocity between them to be measured to an unprecedented accuracy, and made possible a new test of a relativistic effect of the Sun's gravitational field on the propagation of radio waves. No discrepancy from the prediction of general relativity was detected. It is quite remarkable that space probes are able not only to explore the mechanisms by which the objects in the solar system work, but also to investigate the very nature of space and time.

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Author’s preface

The first part of *Robotic Exploration of the Solar System* ended with launches in 1981, but related missions in flight at that time through to their completion. This second part covers missions launched between 1983 and 1996, employing the same “spotter’s guide to planetary spacecraft” approach. While the period covered is short, and was marked by a frustrating hiatus with rare missions, it saw the debut of new players, the decline of another, and a number of triumphs and failures. It was also marked by the ‘Christmas tree’ approach to planetary exploration which on the one hand caused a dearth of planetary missions and on the other hand a number of missions that produced an overwhelming return of results, not all of which were able to be included in this book. The period was also shaped by some peculiar external conditions: the American emphasis on human spaceflight and Shuttle flights, which deprived planetary missions of badly needed funds; the Challenger accident which derailed those few projects that had managed to survive; and finally the Strategic Defense Initiative, which provided technology for the low-cost revolution in deep-space missions of the 1990s. The low-cost approach, too, would soon dramatically show its shortcomings, but these will be left to future volumes in the series.

Paolo Ulivi
Milan, Italy
July 2008

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I must thank David M. Harland for his support in reviewing and expanding the subject, and Clive Horwood and John Mason at Praxis for their help and support. I must thank Bruno Bertotti for sharing with me some of his recollections of working as scientist on these missions and for writing the Foreword. And I am grateful to David A. Hardy of www.astroart.org for the cover art, which was originally made for the Particle Physics and Astronomy Research Council of the UK government. Although I have managed to identify the copyright holders of most of the drawings and photographs, in those cases where this has not been possible and I deemed an image to be important in illustrating the story, I have used it and attributed as full a credit as possible; I apologise for any inconvenience this may create.

The most special thank-you of course goes to Paola, the wonderful brown-eyed planet of which I am the sputnik.