Berndt Feuerbacher · Heinz Stoewer (Eds.)

Utilization of Space

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Utilization of Space

Today and Tomorrow

With 315 Figures

Springer

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Preface

Utilization of space, what for? This book attempts to answer this question!

With this volume we intend to provide a single reference for the broad field of space utilization. Of all the books we know, this is the first to cover all aspects of scientific and application oriented activities in space, even though with limits.

We have attempted to document the current state of the art and open at the same time a perspective towards the future. We also want to bridge the gap between the many popular books dealing with space, and academic textbooks on specific research fields in space science, applications, or technology.

The book addresses a professional readership, while still offering much information to interested laymen. It should well serve students of physics, geodesy, informatics, mechanical, electrical or aerospace engineering. It should give scientists at universities and research institutions an overview of the extensive opportunities offered by space investigations, and industrial engineers and managers additional insights into the commercial potential of space. It should also help decision makers in agencies, governments, and industry to understand better the multidisciplinary interrelationships between utilization aspects and space infrastructure.

Our co-authors are amongst the world's most distinguished leaders in their fields. Their respective areas of research are presented by many illustrations and focus on the central messages rather than attempting to be exhaustive. Each chapter lists references for further reading, highlighting original publications, the most relevant textbooks, and major internet resources.

We are indebted to Susan Giegerich for ironing out language and style peculiarities, and to Sonja Gierse-Arsten for helping to format the book. We are in particular grateful to NASA, ESA and DLR for permitting to use their illustrations.

Cologne, May 2005

Berndt Feuerbacher and Heinz Stoewer

Contributors

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In 1990 to 1993 he acted as a Founding Director for the institutes of Planetary Exploration and Space Sensor Technology in Berlin in their transition from the former East German Academy of Sciences. He holds 7 patents and has published 10 books, in addition to more than 170 articles in scientific journals.

Heinz Stoewer, Associate Editor

Prof. Dipl. – Ing. Heinz Stoewer, M. Sc. is President of the Space Associates GmbH, emeritus Professor of Delft University of Technology and member of several international scientific and industrial boards, such as the Board of Trustees of the International Academy of Astronautics (IAA), the Senate of the German Aerospace Society (DGLR), past Dean for Systems Engineering of the EADS/Astrium International Academy, chair of the Dutch Space Advisory Sub-Committee, Member of the Scientific Councils of the Dutch Aerospace Centers (NLR/NIVR) and the Dutch Space Research Organization (SRON), President of the International Council on Systems Engineering (INCOSE). He has authored numerous scientific/technical publications and holds prestigious national and international awards, such as the Medal of the German Parliament (Bundesrat) and exceptional NASA honours. Prof. Stoewer holds German and US degrees in technical physics, economics and systems management. He started his career in space industry in Germany (EADS) and the USA (Boeing), working on launch vehicles and human space systems. He became the first European Spacelab Programme Manager and founder of the Systems Engineering and Programmatics Department of the European Space Agency, ESA, at its Technical Centre ESTEC in The Netherlands. He served as Managing Director Utilization Programmes, in the German Space Agency, DARA, responsible for most of the national and international German space projects, until his retirement in 1995. He was Executive Chair of CEOS, the ESA Programme Board for Earth Observation and Meteorology, Member of the ESA Council and the EU Space Advisory Group.

Edward (Ed) Ashford

Ed Ashford has more than 40 years experience in the aerospace industry, during which he has worked in practically all areas of the field, in industry, the European Space Agency ESA, and academia. He started in the USA in 1962 working as a GN&C engineer. In 1970, he joined ESRO's then fledgling telecom satellite program. In ESRO and its successor ESA, he held a variety of increasingly senior posts, culminating in the early 1990 when he was appointed Head of the Communication Satellites Department. In 1997, Ed Ashford returned to the USA as Vice President (VP) for a subsidiary of Lockheed Martin Corporation. 1999, he moved to Luxembourg to work for SES ASTRA, helping to define its next generation space system. He later served as VP for Technology Development with SES GLOBAL. Since 2003 he has operated as an independent aerospace consultant. He is a Senior Member of the AIAA, past Chair of the International Astronautical Federation’s Space Communications Committee, and a member of the International Academy of Astronautics. He is author of more than 50 technical papers and three books and serves on the Advisory Board and Curriculum Committee of the Delft University of Technology’s Master for Space Systems Engineering program.

Stefan Dech

Prof. Dr. Stefan Dech, Ph.D. 1990 and habilitation 1997, at Würzburg University, is Director of the German Remote Sensing Data Center (DFD), an institute focused on earth observation services, methodological research and applications development. The institute is part of the German Aerospace Center (DLR) and is located in Oberpfaffenhofen near Munich (headquarter) and in Neustrelitz near Berlin. He has taught remote sensing at universities in Eichstätt, Munich and Heidelberg and holds an endowed chair in remote sensing at the Geographical Institute of the Bavarian Julius Maximilian University in Würzburg. He is a science consultant for diploma theses, dissertations, and habilitations in geography. Research emphases have been on operationalizing algorithms and systems processes for satellite remote sensing applications in environmental research; the conceptual design and realization of value-adding chains for generating geophysical satellite data products; desertification and GIS methodology in central Asia, and digital satellite image processing for visualization and computer animation. In 2004 he was visiting scientist at Scripps Institution of Oceanography in La Jolla, California, affiliated with the University of California in San Diego.

Ralf-Jürgen Dettmar

Prof. Dr. Ralf-Jürgen Dettmar is professor of astronomy at Ruhr-University Bochum since 1994. Born in 1955 he received his academic degrees from the University of Bonn including the doctorate in 1986 with a thesis project conducted at the Max-Planck-Institute for Radio Astronomy.

Between 1986 and 1994 he held a postdoctoral position at the University of Bonn, was a postdoctoral fellow at Lowell Observatory in Flagstaff, AZ (USA), and served as a staff member of the European Space Agency (ESA) at the Space Telescope Science Institute in Baltimore, MD (USA). His scientific interests are in the evolution of galaxies with a specialization in the interstellar medium in spiral galaxies. This particular topic requires to use observations in almost all parts of the electromagnetic spectrum and thus he has used optical and radio telescopes all over the world as well as astronomical satellites such as the Hubble Space Telescope or the XMM-Newton Observatory.

Hansjörg Dittus

Dr. Hansjörg Dittus studied Physics and Geophysics at the Ludwig-Maximilians University München, Germany, concluding in 1986 with a Ph.D. in Geophysics. In 1987, he moved to the Centre of Applied Space Technology (ZARM) of the University of Bremen, Germany, where he became Deputy Institute Director in 1990. Between 1987 and 1991 he was the Project Manager of the Bremen Drop Tower Project, a large microgravity laboratory installation. Since 1991, he also became Head of the Gravitational Physics Experimental Department (today Department of Gravitational Physics and Space Technology) at ZARM. His interests concern fundamental physics experiments (gravitation and quantum physics) under space conditions. He is member of numerous working groups for satellite and ISS Experiments (e.g. MICROSCOPE, STEP, LISA, OPTIS, HYPER). Since 2001, he is Chairman of the ESA Topical Team "Fundamental Physics on ISS".

Rupert Gerzer

Prof. Dr. Rupert Gerzer is Head of the Institute of Aerospace Medicine at the German Aerospace Center in Cologne since 1992 and Professor and Chairman of the Institute of Aerospace Medicine at Aachen University since 1993. He is a medical doctor with training in molecular and clinical medicine (University of Heidelberg, 1977-1980; Vanderbilt University, Nashville, USA, 1981-1983 and University of Munich, 1984-1992).

He has authored and coauthored over 200 publications and participated as a scientist and in his present function in many space missions. In 2003, he received the life science award of the International Academy of Astronautics. He served as President of the German Society for Aerospace Medicine from 1999 to 2001 and as Trustee of the International Academy of Astronautics since 2000.

Hartmut Graßl

Prof. Dr. Hartmut Graßl is a physicist by training, but spent his scientific career in geosciences, in particular meteorology. Trained at the University of Munich in radiative transfer he started in his Ph.D. work (1967 to 1969) with remote sensing by deriving cloud droplet-size distributions from spectral solar radiances, when pointing a multi-channel spectrometer to the sun. Since he left Munich for the University of Mainz (1971) his main interest became optical properties of aerosol particles, both in the solar and terrestrial spectral domain, and their influence on clouds in a mix of experimental and radiative transfer model studies.

Directing institutes at the GKSS Research Centre in Geesthacht and Hamburg (Meteorological Institute of the University and Max Planck Institute for Meteorology) he also engaged in the transfer of knowledge from science to the public and to policy makers. From 1994 to 1999 he was Director of the World Climate Research Programme based at the World Meteorological Organization, WMO, in Geneva, Switzerland. He is a sought after expert on matters of climate and global change, advising many of the world's leading agencies and scientific organizations.

Günter Hein

Prof. Dr. Guenter W. Hein is Director of the Institute of Geodesy and Navigation of the University FAF Munich, Germany. He studied Surveying Engineering and Satellite Geodesy at the Universities in Mainz, Stuttgart and Darmstadt where he got also his Ph. D. and worked as a scientific research associate. After his habilitation in gravity gradiometry he became a "Privatdozent". At the age of 33 years he was appointed full professor at the University FAF Munich. His work in GPS had already started when he formed a research group that did pioneering R&D in the field of real-time kinematic GPS positioning and GPS/INS integration. He has contributed to more than 200 scientific publications in Geodesy and Satellite Navigation, has received over 100 research grants, was a Visiting Senior Scientist at the U.S. National Geodetic Survey, a visiting professor at the University of New South Wales in Sydney, at the University of Maine, and is a member of various national and international associations. He received Best Paper Awards in 1988, 1991 and 2000 from the U.S. Institute of Navigation. He is currently the European Technical Representative on the Institute of Navigation's Satellite Division Executive Committee, an instructor for Navtech Seminars, Inc. and Guest Professor in the Space Systems Engineering Master Program of Delft University. He is a member of the Advisory Boards of GPS World and Galileo's World. He is a member of the European Commission's Galileo Signal Task Force and joined as a German delegate and technical expert for the negotiations between the EU and the US on the interoperability of GPS and Galileo in the last years. In Sept. 2002 he received the prestigious Johannes Kepler Award of the US. Institute of Navigation, the the highest worldwide award in satellite navigation.

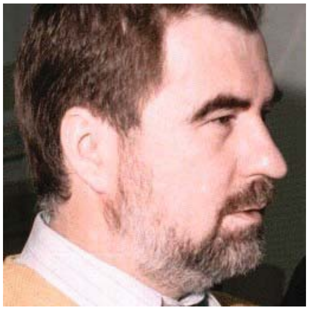
Ruth Hemmersbach

Dr. Ruth Hemmersbach is a zoologist and cell biologist in the Institute of Aerospace Medicine of the German Aerospace Center (DLR) in Cologne and teaches at the Rheinische Friedrich–Wilhelms University of Bonn, Germany. She has been active in gravity-related research on cellular systems for more than 20 years, e.g. as principal investigator for several biological experiments under varied gravitational stimulation in microgravity (parabolic flights and space shuttle), functional weightlessness (clinostats), and hypergravity (centrifuges). In 1991 she received the Junior Scientist Award of the DLR, in 1992 the Zeldovich Award of the COSPAR Life Sciences Group. She has published several papers and written a book related to ”Gravity and the behavior of unicellular organisms”.

Gerda Horneck

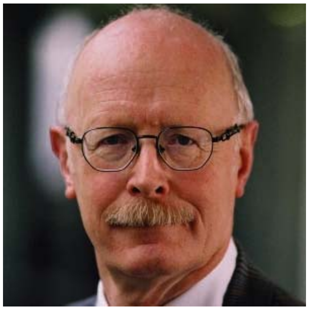
Dr. Gerda Horneck is former Deputy Director of the Institute of Aerospace Medicine at DLR and former Head of the Division of Radiation Biology at the Institute. She is trained in microbiology, radiation biology and genetics. Since Apollo 16, she has coordinated several national and European space projects in the fields of radiation biology, cell biology, and exobiology, and has recently led a study on human survivability in exploratory missions. She has been advisor to national and international space agencies in space-related issues and is author of several books related to astrobiology and search for life in space.

Ralf Jaumann



Dr. Ralf Jaumann, Ph.D. and habilitation at Munich University, is head of the Planetary Geology Section of the DLR Institute of Planetary Research in Berlin. He teaches Planetary Sciences at the University of Munich. His involvement in space missions comprises instrument development as well as scientific investigations for the exploration of Mars (ESA Mars Express), Saturn (NASA/ESA Cassini/Huygens), Venus (ESA Venus Express Mission), Comets (ESA Rosetta Mission) and Asteroids (NASA Dawn Mission). His many publications are devoted to the origin and evolution of planetary bodies, the composition of planetary surfaces and geologic processes in the solar system. He was visiting scientist at the University of Hawaii, the NASA Jet Propulsion Laboratory in Pasadena and the Brown University in Providence, USA.

Tillmann Mohr



Dr. Tillmann Mohr studied mathematics, physics and meteorology at the universities of Würzburg and Frankfurt. He graduated 1970 with a thesis on tropical meteorology. In 1965 Dr. Mohr joined the German Meteorological Organization. Serving in different functions in the Central Office he was appointed as its President in 1992. His involvement in satellite activities started in 1971 with ESRO, later ESA, as member and chairman of working groups and program boards of the METEOSAT program. Under his chairmanship the preparations for the establishment of the European Meteorological Satellite Organization, EUMETSAT in Darmstadt, Germany, were finalized. After its establishment in 1986 he headed the German delegation to the EUMETSAT Council and served 1989 – 1993 as chair of its Policy Advisory Committee. In 1995 he was appointed Director General of EUMETSAT, a position which he served until July 2004. In Nov. 2004 he accepted the position as Special Advisor on Satellite Matters to the Secretary General of the World Meteorological Organization.

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Prof. Ratke held positions at the Vereinigte Aluminium Werke Bonn, the Technical University in Clausthal, the Max-Planck-Institute for Metals Research in Stuttgart and visiting positions at the Technical University of Miskolc, Hungary and the University of Iowa. He has received the Georg-Sachs-Award of the German Society of Materials, Acta Metallurgica et Materialia Outstanding Paper Award, Senior Scientist Award of the DLR, the Silver Medal of the University of Miskolc and innovation award of the city of Cologne. He has published over 180 papers in the areas of corrosion, powder metallurgy, in-situ composites, polyphase solidification, coarsening and aerogels, is publisher of two books and has written a monograph on coarsening processes.

Johannes Schmetz

Dr. Johannes Schmetz is the Head of Meteorology, a Division in the Programme Development Department of EUMETSAT in Darmstadt, Germany. His Division develops meteorological satellite applications and covers the scientific and technical meteorological aspects of current and future satellite programs of EUMETSAT.

Dr. Schmetz received a Doctoral degree from the University of Cologne in 1981 on the topic of cloud-radiation interaction. He worked as research scientist at the Max-Planck-Institute for Meteorology in Hamburg and then as Senior Scientist with the European Space Agency (ESA). In 1995 he joined EUMETSAT in his current position.

Dr. Schmetz obtained the habilitation at the Johann-Wolfgang-von-Goethe-University of Frankfurt where he teaches courses in meteorology. He authored over 60 peer reviewed journal articles and serves on various international committees.

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Prof. Dr. Tilman Spohn is Director of the Institute of Planetary Research of the German Aerospace Research Center in Berlin and Professor for Planetology at the Westfälische Wilhelms-University in Münster. He was trained in physics and geophysics at the University Frankfurt, where he received his Ph.D. in 1978. Tilman Spohn is member of the Space Science Advisory Committee of ESA and President of the Planetology Section of the American Geophysical Union. His scientific interest is focused on geophysics and thermodynamics of planetary bodies, comet physics, and dynamics and evolution of terrestrial planets. He participated scientifically in many space missions including Rosetta and Mars Express, and published more than 100 papers in scientific journals.

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In 1999 he became Assistant Professor at Delft University of Technology. His major areas of interest are on the interface between earth and planetary sciences and space geodesy, including post-glacial rebound, post-seismic deformation and rotational and gravitational variations. He is a member of ESA's GOCE satellite mission advisory group and president of the Geodynamics Division of the European Geosciences Union (EGU).

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Dr. Ir. Pieter N.A.M. Visser graduated in aerospace engineering at Delft University of Technology (1988) where he later obtained his doctor's degree (1992). After spending a year at the Center for Space Research at the University of Texas at Austin, he returned to Delft, where he now has the position of Associate Professor. His major areas of interest are orbital mechanics and observation of the earth's gravity and magnetic fields by space-borne techniques. He is member of several European Space Agency mission and science advisory groups (GOCE, Swarm, CryoSat, METOP) and chair of the Technical Panel on Satellite Dynamics of the Committee on Space Research (COSPAR).

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Overleaf image: The moon rising in the earth atmosphere (DLR)

1 Space Utilization

by Berndt Feuerbacher

The space age began on October 4, 1957 near the city of Leninsk (today: Baikonur), when a Russian Semjorka Rocket launched the first orbiting satellite "Sputnik." The characteristic "beep" received by many stations all over the world acoustically opened a new era, marked by the ability of mankind to access space. Starting from this event, outstanding progress has been made worldwide, including historical moments like the first step of a human on the moon. The technical challenge of space flight and astronautics is fascinating and innovating. Its final justification emerges from the benefit the utilization of these technical systems will bring to mankind. The present volume focuses on this point, discussing the utilization of space technology in all areas of application from scientific research to commercial applications on earth.

1.1
Space Has Changed Our Life

Space pervades our life in many aspects, sometimes quite obviously, in other cases largely unnoticed. Being a major source of innovation, it contributes to the improvement of welfare and quality of life. Space research as a source of knowledge expands the understanding of our origin and puts our position in the universe in perspective. From the viewing position in space, our home planet is seen in all its beauty and vulnerability. The fascination of space inspires our youth and opens their minds for science and technology. The space industry is an important factor in economic growth and international competitiveness. It is a driver for the development of technical progress. Space technology is also recognized as an important ingredient of national security and, even though this seems to be a contradiction, to international cooperation.

In the following, a few examples will be given to demonstrate the impact space activities have on our daily life.

Technological and Economic Impact

As we walk along the street and see the large number of satellite dishes on private homes and public buildings, the impact of *space communication* on society is apparent. Much less obvious is the role space plays in today's international broadcast systems. We expect video images from an event on the other side of the globe within hours in the newscast on our home TV screen. This is only possible using broadband space transmission channels.

In the 1970s space communication satellites started to revolutionize intercontinental communication by replacing transoceanic cables. We got used to a rapid response on the telephone, free of noise and echo effects. In the meantime, glass fiber cables can do the job in a similar way. Space communication now concentrates on other markets and improved technologies expanding the available bandwidth, for example for high-speed internet access. One important task is information dissemination in large-area developing countries, where surface cabling or wireless networks do not exist and the population is excluded from the benefits of the information society. A continuous increase in communication demand is expected globally, where space based techniques, particularly in the broadband regime, will contribute their share.

Satellite navigation is a common tool today, and modern cars are widely equipped with suitable devices to find the way on the road. In principle, we could use road signs or ask somebody, but on sea this becomes difficult and the impact of space technology is more apparent. Space navigation systems are used today in many applications to provide positioning down to the sub-centimeter scale and time

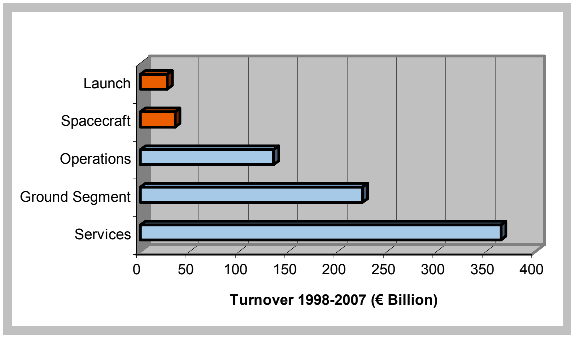

Figure 1-1: Value added projection for worldwide space communication and navigation, extrapolated over the time frame 1998 to 2007. Note the turnover on the ground (operations, ground segment, and services) is about ten times the space investment (European Commission 2001)

information on the nanosecond level. Apart from navigation on the ground, on the sea and in the air, it supports industries like agriculture and construction and helps to save lives. Most citizens are unaware of the fact that basic public services of our society, like telecommunication networks and energy provision, depend crucially on the global high precision time information provided by navigation satellite systems.

In both communication and navigation the most far reaching economic impact is made by the *value added*, not by building satellites and launching them. This is illustrated in figure 1-1, showing the value added chain of the global commercial market in an extrapolation from 1998 to 2007 (European Commission 2001). The expenditure in space, such as for satellite manufacturing and launch, is small compared to the turnover achieved on the ground. This demonstrates the lever action of space investment: a dollar spent in space leads to nearly 10 dollars turned over on the ground. For space navigation systems, this becomes quite apparent. The satellites generate a set of numbers relating to spatial coordinates and time. It is only the added value of the receiving system on the ground that converts these numbers into information useful for the customer, like road guidance or information for a search and rescue operation.

We all have become accustomed to the daily *weather report*, including a satellite map on TV, and benefit from its pretty high reliability. We know with some certainty the weather of tomorrow, which in past centuries used to be just a bit more than a matter of educated guessing. Obviously for agriculture and tourism weather predictions for a full week are invaluable. But the global view of space based weather services provides even more benefits. They warn of severe events like tropical storms, they contribute to the observation of our climate, including the influences of human activity, and they provide reliable high-altitude wind field measurements to safely guide air traffic on routes minimizing fuel consumption.

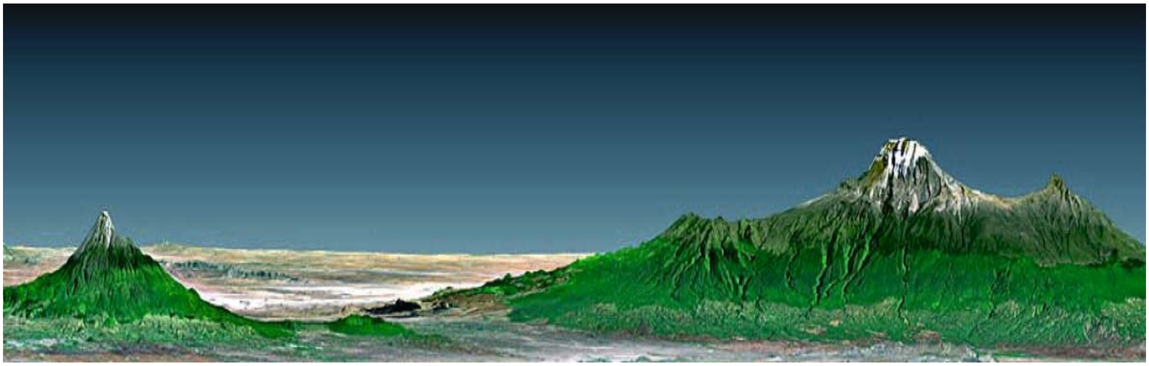

Figure 1-2: A three dimensional view of Mount Kilimanjaro taken from space. This image was obtained during the SRTM mission using radar interferometry. Apart from the spatial information it delivers height resolution of 6 m on a global scale. The color coding was introduced later to indicate heights (NASA/USGS)

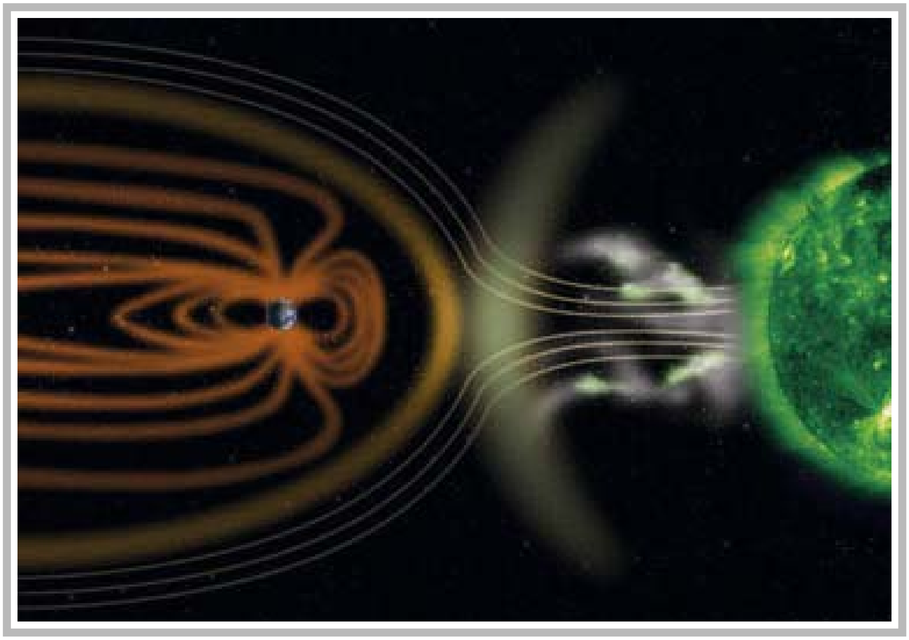

Figure 1-3: Schematic representation of Sun-Earth relations indicating solar wind flux emanating from the Sun. The magnetosphere protects the immediate Earth environment from hazardous radiation and particle impacts (DLR/ESA)

Many aspects of *earth observation* are of direct benefit to society. High resolution images are available for all kinds of purposes with only short delays from virtually any place in the world. Spectroscopic resolution gives additional value to agriculture and forestry applications. Radar techniques ease restrictions of cloud-free skies and solar illumination. In addition, radar interferometry is now able to map the earth in three dimensions with an accuracy hitherto unknown (figure 1-2). These new developments continue to integrate into our daily life in a way that is often not noticed on a short time scale, but with massive impact in the long run.

Space medicine is widely seen as a service for astronauts. This in fact was the origin of medical research in space. Today the focus is mainly on health care for everybody. The space microgravity environment allows study of a number of phenomena normally experienced with aging, but on a much shorter time scale and, in some instances, in a reversible way. Among these are cardiovascular diseases, bone demineralization, muscle atrophy, and problems with the vestibular system, the human organs for gravity sensing responsible for body equilibrium. Beyond this there is a major general impact of space medicine on human health care. In common life, the patient visits his physician, and medicine is based to a large extent on statistical experience with case studies including many patients. This is different in space medicine, where very few patients, the astronauts, require an individual rather than statistical approach, and they cannot visit their doctor from orbit. With recent advances in telemedicine, stimulated by space developments, a change of paradigm is entering health care, whereby the individual patient moves into the center of interest, with additional possibilities to consult specialist medical expertise remotely.

Scientific and Cultural Impact

Space research has led to a wealth of scientific discoveries. A number of these findings made by means of space techniques had a major impact on our present thinking, not only among scientists, as one would expect, but also on society at large.

Following the discovery of the earth radiation belts by an instrument of James A. van Allen in 1958 on the Explorer 1 satellite, the first major achievement in the scientific exploration of space was the detailed investigation of the e*arth magnetospher*e (figure 1-3). Stimulated by the observation of polar light phenomena and theoretical predictions on their origin,

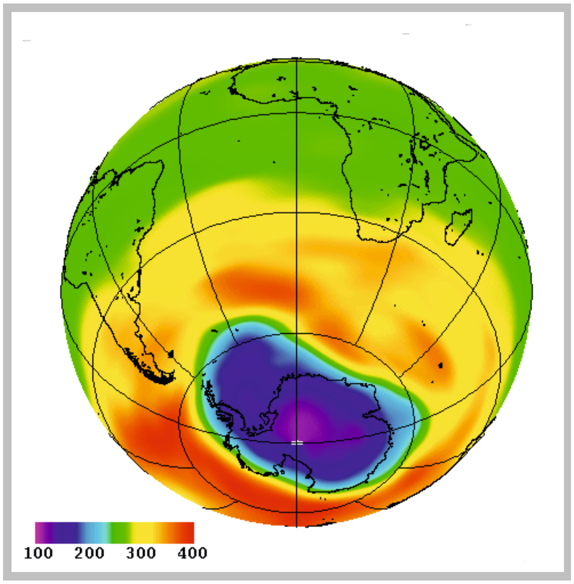

Figure 1-4: Ozone depletion over the Antarctic as observed by the Global Ozone Monitoring Experiment (GOME) on the Earth Resources Sensing (ERS) satellite of ESA. The image is composed of data obtained on 11 October 1996. The color scale on the lower left indicates the ozone column height in Dobson units (ESA/DLR)

the interaction of the earth magnetic field with that of the sun and the solar wind was studied by means of sounding rockets and satellites in near-earth or highly eccentric orbits. This resulted in a detailed understanding of structure, dimension and operation of the magnetosphere, which protects life on earth from high-energy radiation. Today continuous observation of the sun-earth interaction gives us real time information on "space weather", the dynamic processes in the earth magnetic environment.

In 1985 the British Antarctic Survey alarmed the world by demonstrating a depletion of the ozone layer in the upper atmosphere over the Antarctic region. Soon space instruments were used, in particular the Total Ozone Mapping Spectrometer (TOMS) on board various satellites, and later the Global Ozone Monitoring Experiment (GOME) on the Earth Resources Sensing (ERS) satellite, to provide a global view of ozone distribution, confirming the dramatic formation of an *ozone hole* (figure 1-4). This was the first evidence for the nowadays widely accepted fact that anthropogenic influences are introducing a change in our environment on a global scale. It was particularly frightening as it led to the depletion of an essential constituent of the atmosphere which protects life on earth from hazardous ultraviolet radiation of the sun. These and other observations (like the greenhouse effect) indicate a change in world climate originating from human activity, which is a scary view and led to a change in mentality on a global scale. Major efforts by the governments of several nations to counteract such developments were initiated, including worldwide treaty initiatives. Today continuous observations monitor the ozone level in the atmosphere from space on a routine basis. Their results lead to a better understanding of the chemistry and dynamics involved, but do by no means reduce the alarming facts calling for global countermeasures.

In 1964 Arno Penzias and Robert Wilson, two engineers at the Bell Telephone Laboratories, searched for the source of noise in a microwave horn antenna and discovered the *cosmic background radiation*. This soon was identified as a fundamental breakthrough and was lauded with the Nobel Prize in Physics in 1978. Following earlier theoretical predictions, the discovery confirmed the Big Bang theory of the origin of our universe, but only rudimental information was possible from the ground due to disturbances arising from the "hot" earth. Space observations initiated by the Cosmic Background Explorer (COBE) confirmed the shape of the

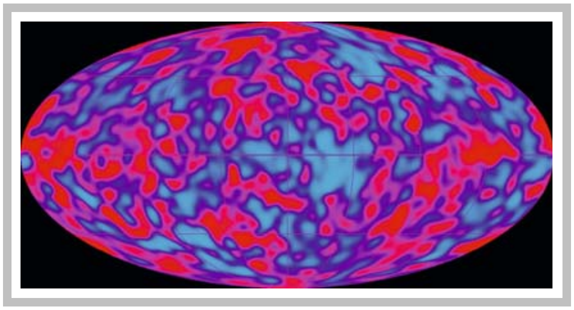

Figure 1-5: Cosmic background radiation as observed by the Cosmic Background Explorer COBE satellite in 1992. The structures represent tiny fluctuations in the sky brightness at a level of one part in one hundred thousand. The radiation is a remnant of the Big Bang, and the fluctuations are the imprint of density contrast in the early universe (NASA)

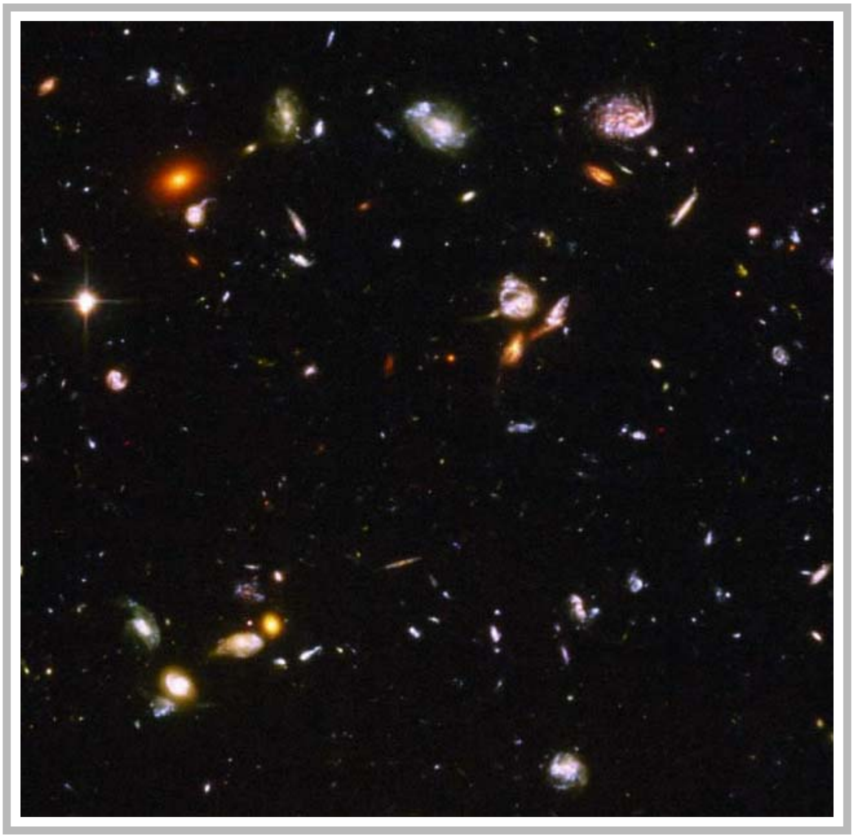

Figure 1-6: Ultra Deep Space image taken by the Hubble Space Telescope in 2004. It results from a total exposure time of more than 11 days over 400 orbits. It sees young galaxies just 800 million years after the Big Bang, in the so called "dark ages" when the first stars reheated the cold, dark universe. They reveal shapes far different from the older galaxies seen today (NASA)

spectrum as relating to a blackbody at 2.7 K, and allowed first measurements of the spatial structure of this radiation (figure 1-5). Our present understanding of the early development of the universe, the formation of stars and galaxies, relies to a large extent on these and later space measurements of the cosmic background radiation.

The Hubble Space Telescope had a bad start when it was launched in April 1990. Due to an avoidable manufacturing error in the optical system the images returned were disappointingly blurred. This situation changed after the repair action three years later, which revealed the incredible power of astronomical imaging from space. The beautiful pictures showing spectacular exotic worlds in our universe are now common property, and most people appreciate them simply for their decorative appearance. Astrophysical breakthroughs are reported at high frequency from the Hubble Telescope, but the most dramatic results arise from views in areas of the sky that are virtually empty. Very long exposures in such dark fields reveal galaxies very far away and therefore very young. The recent Ultra Deep Field observation (figure 1-6), obtained with over a million seconds exposure time, sees very young galaxies, just 800 million years after the Big Bang, that look quite different from those we see today. Much has been learned about the evolution of our universe from such results, but most importantly detailed measurements lead to the conclusion of an *accelerated expansion of the universe*. This is in contradiction to current cosmological theories on the development of the universe and has led to the postulation of "Dark Energy" related to Einstein's cosmological constant. Science presently is not able to integrate these results in the existing theoretical framework, so we can expect a major overthrow of cosmology in the near future.

1.2
The Development of Space Utilization

Three phases follow each other in time, with substantial overlaps, in the development of space utilization. Those can be categorized in:

- The technology race
- Scientific exploration
- Early commercial utilization
- Exploitation in the service of society.

1.2.1
The Technology Race

The early driver of space exploration was the technology race between superpowers. Military interest in space technology, based on ballistic missile systems both for defense and deterrence purposes, and belief in global leadership through manned stations in space sustained an industrial machinery that found public resonance in a cold war environment. Enormous financial means were provided by governments to celebrate spectacular pioneering ventures as achievements of their respective system, capitalist or communist. This spirit created the Luna program of the USSR and the Apollo program of the United States (figure 1-7). Some of the first flights to planets of our solar system also fall under this category. It is a characteristic of this phase that, while scientific objectives were promoted and pursued, they served mainly as fig leaves for the public. This is apparent from the fact that priorities during development and operations were clearly set for successful technological performance, while scientific requirements were subordinate. Outstanding scientific achievements were nevertheless possible.

Figure 1-7: Astronaut John W. Young, commander of the Apollo 16 lunar landing mission, jumps up saluting the U.S. flag at the Descartes landing site during the first Apollo 16 extravehicular activity (EVA-1). Astronaut Charles M. Duke, Jr., lunar module pilot, took this picture. The Lunar Module "Orion" is on the left. The Lunar Roving Vehicle is parked beside the module. Stone Mountain dominates the background in this lunar scene (NASA)

1.2.2
Scientific Exploration

While Sputnik 1 was just a small radio transmitter in orbit, with no function except to demonstrate its existence, the first U.S. satellite Explorer-1 carried a scientific payload designed by J. A. van Allen in the form of a Geiger counter to measure cosmic rays. The observation of an unexpected over saturation of the detector in some orbital positions led to the discovery of the radiation belts and initiated fruitful research on the earth magnetosphere.

Science made efficient use of the early flights to the moon and to planets. The results of the Apollo program led to a better understanding of our planetary system; for example it clarified conflicting theories on the origin of our moon. Today we know that the moon was not an independent body caught by the earth, but rather originated from the earth in a violent collision with a smaller body.

After the early flyby missions of Mariner spacecraft to Mars and Venus, our perception of the solar system was influenced by the breathtaking views of planetary bodies provided by the images transmitted by the Pioneer-Voyager pair of deep space probes (figure 1-8). Photographs of all planets and many moons gave impressions of strange and unexpected worlds. Together with the results of remote sensing measurements, a wealth of scientific information was obtained. Insights from comparative planetology allowed conclusions on the development and destination of our Earth.

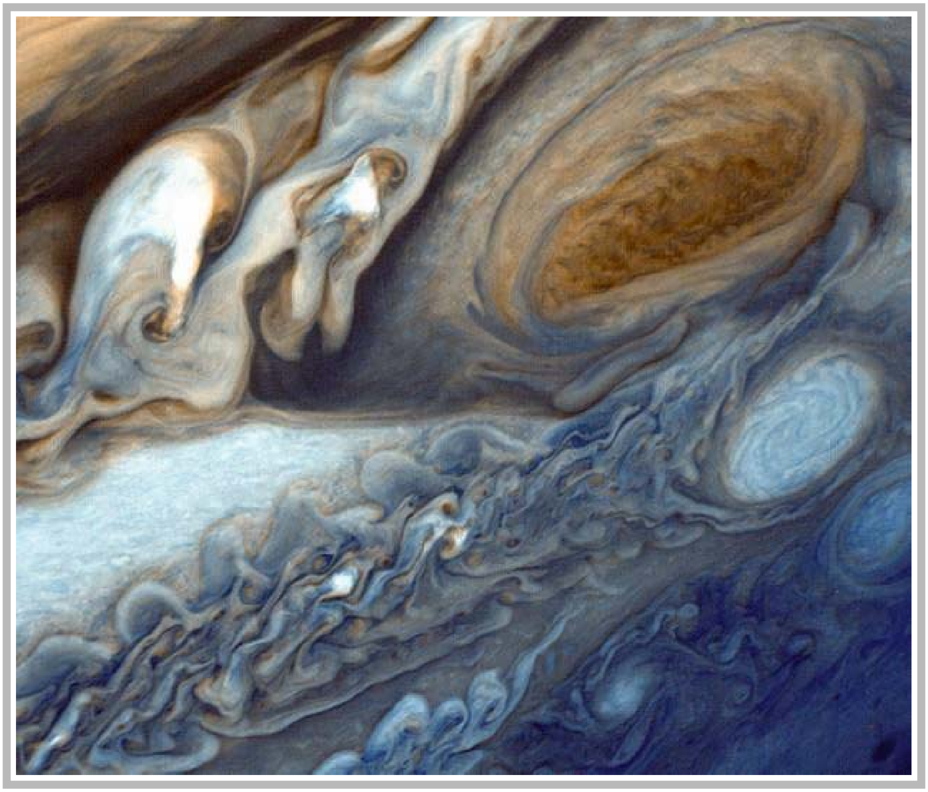

Figure 1-8: This view of Jupiter's Red Spot area was taken by Voyager 1 in 1999. The image was assembled from three black and white negatives taken through color filters and recombined to produce the color image. The structure relates to dynamic eddy currents in the Jovian atmosphere which appear stable over centuries (NASA)

Observation platforms in space, overcoming the limitations imposed by the earth atmosphere, opened new spectral windows for astronomical observations. Since the discovery of cosmic X-ray sources by Giacconi in 1962, which brought him the Nobel Prize in Physics in 2002, instruments making accessible the energetic spectral regions of X-rays and γ-rays revealed exotic objects like neutron stars or black holes and gave insight into the late stages of stellar evolution. The infrared wavelength region provided information on the birth of stars and planetary systems. With the Hubble Space Telescope, observation from space included, for the first time, also the visible wavelength region, which is accessible from ground. This gave rise to massive criticism, as many astronomers opposed this development, arguing that such results could be achieved better on Earth, provided comparable resources were invested. Their concerns seemed justified when the first defocused images were received on the ground. Since the correction of the optical system however, the results surprised not only professional astronomers but also the general public. With the unprecedented views into extreme deep space regions, this venture has justified itself in an overwhelming way.

The phenomenon of weightlessness has stimulated the imagination of scientists, engineers and space enthusiasts from the early days. New requirements and design criteria had to be taken into account in the development of spacecraft and instruments, for example depletion of fuel tanks without the assistance of gravity. It has been reported that Herrmann Oberth, one of the early space pioneers, studied the behavior of liquids in a bottle by jumping from a diving platform into a swimming pool in the early 1920s.

Early attempts to study the effects of weightlessness in space flight were of rather heuristic nature. The first scientifically prepared experiments took place during the Skylab mission. The results led to widespread enthusiasm and adventurous predictions about future commercial utilization, such as huge factories in space. The development of Spacelab (figure 1-9) in Europe and its first flight in 1983, jointly by NASA and ESA, introduced laboratory conditions for investigations in a space microgravity environment. This laid a scientific basis for extensive qualitative and quantitative measurements. A rapid development was initiated that delivered novel results and insights in specific areas of physics, materials science, human physiology and biology. Some of these early ideas were revealed as flops, others led to promising results. Predictions for mass production in space had soon been disproved. Results from space experimentation led to the clarification of scientific discrepancies and to applications on earth. Industrial methods on earth have been improved and new processes could be developed.

Research on Spacelab led to a wealth of scientific results in many disciplines. The absence of gravitational convection, sedimentation and hydrostatic pressure are the prominent features, so new results have been obtained in systems that contain at least one phase in liquid form, like solidification or phase separation phenomena. In biology, novel results on graviperception in plants and the role of the cytoskeleton in cells have been achieved. Physiologists investigated the function of the human organs perceiving gravity, the cardiovascular system, the skeleton, and the lungs.

Figure 1-9: Working atmosphere in the shirt-sleeve research environment of the Spacelab D2 science module during the 1993 STS-55 mission. Astronaut Jerry L Ross examines a sample tube at the “Werkstofflabor” rack, left, Bernard A. Harris, holding his arm, waits to have his blood drawn by Hans Schlegel (right). Wearing the baroreflex collar and waving is Ulrich Walter (DLR)

1.2.3
Early Commercial Utilization

Communication is the prominent field in commercial space utilization as it earns good money for the private investor. We will, however, include in the present discussion those application fields that rely, at least initially, on funding from the public sector, which extends the present considerations to navigation, earth observation and meteorology.

The potential of a global overview to observe the atmosphere for weather predictions was recognized very early in the space age. In 1960, NASA launched its first weather satellite under the name Television Infrared Observation Satellite (TIROS) into a polar sun synchronous orbit at 900 km altitude. The very first image of cloud formations, obtained by the on-board Vidicon camera, is shown in figure 1-10, allowing comparison with the progress made today as described in chapter 5. In the following years, dedicated satellite systems have been developed and operated in a continuous manner in the U.S. (GOES series, commencing in 1975), in Europe (Meteosat since 1977) and in Japan (GMS 1977), providing an increasing number of information channels beyond the daily weather chart on the TV screen.

The capability of land surface observation from space was first used routinely in the military sector for spy and reconnaissance purposes. High resolution imaging required low orbits but had the disadvantage of short spacecraft lifetimes. Photographic films were exposed and retrieved after traveling through the atmosphere to the ground for development and evaluation. These systems were later replaced by electronic cameras, which simplified operations and gave much more rapid access to the data. Major improvements in optical and electronic technology have been made for military or scientific purposes. Early attempts were made to enter the commercial markets with products of space imagery, like the commercialization of the French SPOT satellite in the SPOT IMAGE company. To date specialized products, tailored to the demands of the customer, can be obtained from several companies throughout the world. Commercial satellites are in orbit that deliver images with a resolution of well

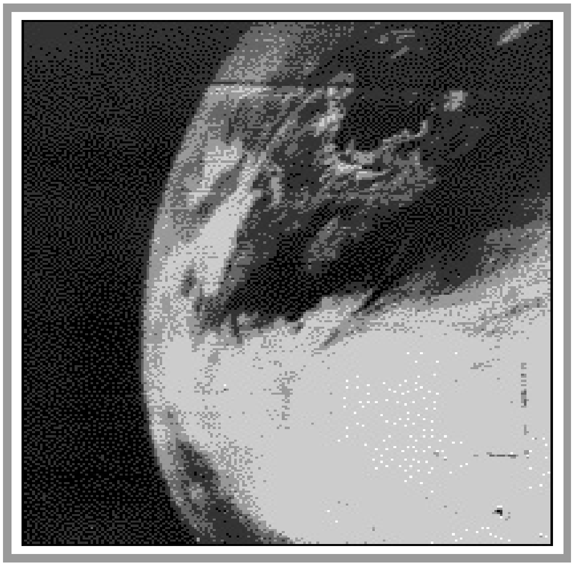

Figure 1-10: The very first television picture from space, taken by the TIROS 1 satellite on April 1, 1960 (NASA)

below 1 m, which are sold successfully to paying customers.

In communication technology, space exhibits attractive features. For any communication using electromagnetic waves, bandwidth and thus transmission capacity increases with frequency. On the other hand, diffraction effects also increase with frequency, so wave propagation is then more along straight lines like light. Therefore, higher and more closely spaced transmission stations are required. The geostationary orbital position is the highest conceivable transmission tower, as first pointed out by the ingenious author Arthur C. Clarke (1945). Following early communication demonstrations using the passive reflector satellites Echo 1 and 2 (30 m reflecting spheres visible to the unaided eye from the ground at night), the first commercial communication satellite was brought into orbit by the AT&T company. This active relay satellite enabled the first transatlantic television transmission in 1962. Due to a low orbit, transmission periods were limited by the brief visibility. This restraint was overcome by the first geostationary satellite Syncom 2 orbited by the Hughes Aircraft corporation, still with an inclination of 28°. Its successor Syncom 3, positioned in an equatorial geostationary orbit, was used efficiently for television broadcasting of the 1994 Olympic Games in Tokyo.

Since ancient times, navigation techniques have made use of the sky to determine geographical latitude at sea. But only the development of long term accuracy in portable clocks enabled a full determination of position by including knowledge of the longitude. Precise navigation demands from the military side, especially for atomic submarines, led to the development of the “Transit” satellite navigation system in 1994, which was released for public use in 1997. This was succeeded by the Global Positioning System (GPS) in the U.S. and the Global Navigation Satellite System (GLONASS) in the USSR, both still in use today. Modern navigation satellite systems rely on accurate signal transit time measurements and are therefore technically very demanding. They require a constellation of several spacecraft on well defined orbits with high precision atomic clocks on board. The widespread use of these systems in a commercial environment stimulated a worldwide industry for receivers and application products.

1.2.4
Exploitation in the Service of Society

A fourth phase, characterized by a balance between operational and scientific utilization of space, has been triggered by the reduction of public funds for space activities, which is partially compensated by the much larger commercial investments made in the primary (producing) and secondary (supporting) industrial sectors. This phase is predominant today, so the bulk of this volume will be concerned with it.

With the end of the cold war the support for a technology race is fading away and space activities are increasingly driven by demand. Societies restrict spending to areas that hold promise of fulfilling their pressing demands, such as

- economic growth and employment
- industrial competitiveness
- sustainable development
- security and defense
- scientific progress.

National space policies evolve in many societies, giving various relative emphases to the points above.

Utilization Field	View to		Local	Environment			Global/Cosmic
	Earth	Space	Presence	Vacuum	Radiation	Microgravity	Dimensions
Earth Surface	●●●						
Climate and Environment	●●●	●					●
Weather	●●●	●					●
Geodynamics	●●●						●
Astronomy and Astrophysics		●●●	●	●	●●		●●
Solar System Research		●●●	●●●	●	●●		●●
Communication	●●●						●
Navigation							●
Technology				●●	●	●●●	●
Fundamental Physics			●●		●	●●●	●●
Materials Science						●●●	
Life Sciences			●●		●	●●●	●

Table 1-1: The utilization fields discussed in this volume make use of specific qualities in space. The number of bullets schematically indicates their importance for the respective field

An important additional factor is international partnership, which helps to advance cooperation and peace worldwide. The International Space Station, presently in orbital assembly, is an excellent example. With more nations active in space, some of them even joining the small group of human space faring nations (like China), partnership becomes progressively more relevant.

1.3

Space Qualities for Utilization

Space offers a variety of special qualities that may be utilized for scientific, technical, or commercial objectives. From the orbital position, the view back to the earth surface is unique, and the view into the universe is unobstructed by atmospheric influences. Robotic presence in space allows the sampling of particles and fields or material from planetary bodies. Human presence adds flexibility and brainpower for complex tasks and research. Outside the earth atmosphere a high vacuum is encountered with a near infinite pumping speed. A spacecraft is subject to a complex radiation environment quantitatively and qualitatively different from that on earth. During space flight without propulsion, gravitational acceleration is compensated, leading to the phenomenon of “microgravity.” Space also allows practically unlimited use of spatial dimensions, for example for long baseline interferometry or gigantic detectors for gravitational waves. Table 1-1 shows how the various space utilization fields make use of these special qualities.

1.3.1

Unique Viewing Positions

View to Earth

One of the most fascinating experiences of astronauts in orbit is the view back to Earth. It shows our home planet in a global view, with its thin and vulnerable atmosphere, in an unusual perspective (figure 1-11). In fact the images we received from space contributed to a change of our present perception of our living environment from a local to a global point of view. Modern methods of earth observation continue to provide intriguing pictures of the earth surface revealing, with astonishing details, structures of anthropogenic or natural origin not perceivable from the ground. Weather forecasts provide us on a routine daily basis with information on cloud coverage, wind and rain expectations on scales sufficient to allow reliable predictions for several days. Investigations of the atmosphere in the top-down direction from space, looking from the thinner into the more dense regions of the height profile, measure con-

Figure 1-11: Clouds and sun glint over the Indian Ocean as seen during the STS-96 mission from the Space Shuttle Discovery (NASA)

stituents and physical state as a function of altitude not achievable from ground. Observation of the earth and sun from space provides insight into the development of the global climate and the impact of human influences. In addition to passive methods of earth observation that rely on natural radiation like solar illumination or thermal emission, active systems carry their own radiation source and therefore are independent of day and night cycles or even clouds, if the source is able to penetrate them. This is the case for radar satellites, as discussed in chapter 3, but also for lidar instruments that use the backscattered radiation of an emitted laser beam to study aerosols and atmospheric constituents.

A special case is the observation of geodynamics from orbit as described in chapter 6. Here the earth gravity field is measured with high precision, giving information on static and dynamic processes such as mantle dynamics (continental drift) and crustal deformation, both important inputs to the study of earthquakes. Other observed features include magnetic pole motion, water and ice storage or ocean topography

The unique position in space also creates new opportunities for communication. An elevated position like a transmission tower expands the surface area reached by the transmitted signals, so it is obvious that the orbital location can be very attractive.

Observers of the earth surface prefer low earth orbits (LEO) if the objective is to look at details with high resolution. Here the limits will be given by the drag forces of the residual atmosphere and thus the lifetime of the spacecraft. Military satellites in 200 km orbits are reported to provide resolution of football-sized objects from space. Generally, if large surface coverage is a requirement, an orbit of high inclination will be chosen. As the orbital plane is inclined to the equatorial plane, the earth rotates under the satellite, exposing new areas to the nadir view of the payload. For a spacecraft on a typical LEO orbit of roughly 300 km altitude, the earth rotates 22.5 degrees or 2,500 km at the equator during a 90 minutes orbit, leading to a footprint coverage as shown in figure 1.12. If total coverage of the globe is a requirement, a polar orbit will be chosen. Special polar orbits make use of the perturbations due to the oblateness of the earth to introduce a precession such that the orbital plane rotates with the sun and therefore has a constant sun angle. These orbits, termed sun synchronous, see a particular site on the ground always under the same solar elevation, i.e. at the same time of day.

Some earth observation or communication objectives require rapidly repeated or continuous coverage of ground positions. Outside the geostationary orbit, this is obviously not possible using a single

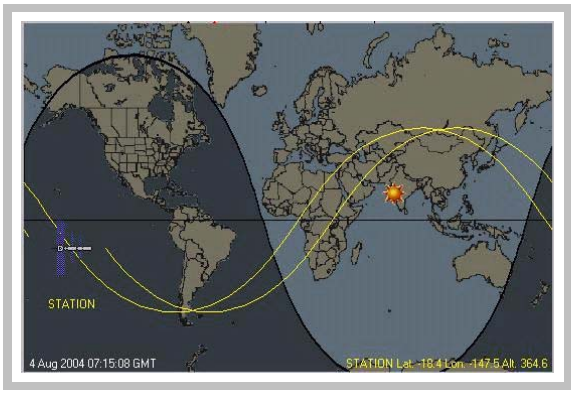

Figure 1-12: Ground track of the International Space Station in orbit at 350 km altitude and 56 degree inclination. As the Earth rotates under the station, the footprint shifts between orbits