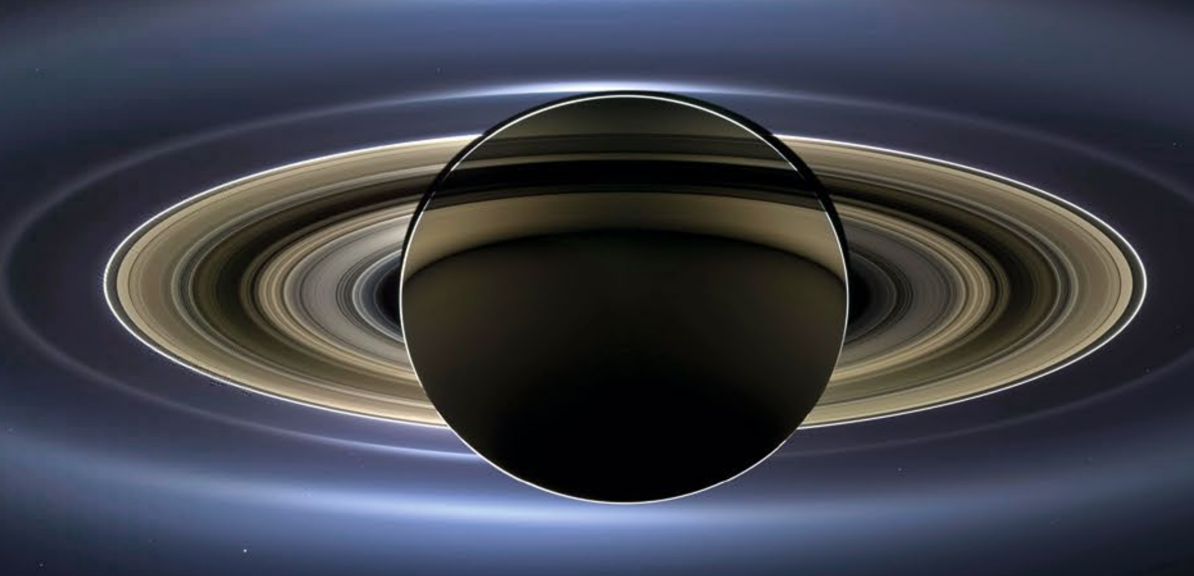
The CASSINI–HUYGENS Visit to SATURN

AN HISTORIC MISSION TO THE RINGED PLANET



Michael Meltzer

Springer

PRAXIS

The Cassini-Huygens Visit to Saturn

An Historic Mission to the Ringed Planet

Michael Meltzer

The Cassini-Huygens Visit to Saturn

An Historic Mission to the Ringed Planet

Springer

Published in association with
Praxis Publishing
Chichester, UK

PRAXIS

Michael Meltzer
Oakland, CA, USA

SPRINGER-PRAXIS BOOKS IN SPACE EXPLORATION

ISBN 978-3-319-07607-2 ISBN 978-3-319-07608-9 (eBook)
DOI 10.1007/978-3-319-07608-9
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014953013

© Springer International Publishing Switzerland 2015
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Cover design: Jim Wilkie

Project copy editor: David M. Harland

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Author's preface

> *"The only way to discover the limits of the possible is to venture past them into the impossible."*
>
> *– NASA Administrator Michael Griffin, 2008*[1]

The Cassini-Huygens mission pushed the limits of what was possible, plunging deep into a planetary system so very different from our own. From the distant Saturn system, Cassini-Huygens sent back extraordinary data and superb images that dramatically expanded our understanding of the solar system. Carolyn Porco, the Imaging Science Team leader, asserted that this mission to Saturn, as well as other robotic space journeys, were "part of a bigger human journey: a voyage … to get a sense of our cosmic place, to understand something of our origins and how we, living on Earth, came to be."[2]

Cassini-Huygens has made a noble attempt to do just this. Building on the shoulders of the Pioneer, Voyager, and Galileo endeavors, Cassini-Huygens traveled 3.5 billion kilometers (2.2 billion miles) to reach Saturn, carrying 18 sophisticated scientific experiments as well as a probe that it dispatched to the surface of Titan, a Saturnian moon that is larger than the planet Mercury.[3] Over *5,000* people from 17 countries (including the U.S.) contributed to the project. Thirty-three U.S. states participated in making Cassini-Huygens a smashing success. Moreover, this flagship mission took an important step towards answering a question that is central to our *weltanschauung,* our perception of the universe: are we, the human race and all that is alive on our planet, alone in the cosmos? Or are we joined by other forms of life on other worlds?

WHO THIS BOOK IS WRITTEN FOR?

This book is targeted for three communities: space historians, engineers who design and operate spacecraft, and planetary scientists. I have taken great pains to make this book valuable to all three of these audiences. The book traces the evolution of the mission, starting with first conceptions of how the outer solar system should be explored. The book also chronicles the long and rather tortuous route to international approval and eventual funding, and the subsequent conflicts with a new NASA Administrator on how the mission should be designed and with advocate groups in the U.S. and other countries on the use of plutonium fuel for shipboard power. It analyzes the decision-making structure that arose to manage research time aboard the Cassini-Huygens spacecraft, and why the decisions were so much more complex than on similar missions such as Galileo.

Several chapters are devoted to the engineering challenges of developing such a complicated spacecraft designed to carry out so broad a spectrum of research tasks. The detail devoted to these chapters is necessary, I believe, in order to communicate the magnitude of the achievement. The engineering chapters also provide a record of how problems were solved and the contributions of many different organizations were integrated into a coherent operation.

The final chapters of the book focus primarily on the enormous science return of the mission, a return that has dramatically altered many of our views on the nature of the Saturnian system, and by extension, on the natures of other gas giant systems. These chapters also seek to convey the sheer magnificence and beauty of the system, the interactive character of its mother planet, satellites, rings, and magnetosphere, and its dissimilarity with our own planetary system.

CASSINI AND HUYGENS: RENAISSANCE MEN

In studying the lives of Giovanni Domenico Cassini and Christiaan Huygens, I am struck by the range of their interests and the diversity of their contributions to science. The Dutch scientist Christiaan Huygens built some of the best telescopes of the day, and discovered Saturn's largest moon Titan in 1655. Examining the "strange arms"[4] of the planet that had been reported decades earlier by Galileo Galilei (who thought they might be two large moons), Huygens realized they were actually part of a thin flat ring surrounding the entire planet.[5] Huygens also devised better ways of grinding and polishing telescope lenses and patented the first pendulum clock, thus greatly increasing the accuracy of time measurement.

The Italian astronomer and mathematician Giovanni Domenico Cassini made important observations of Saturn, Jupiter, Venus, and Mars. He discovered Saturn's icy moons Iapetus, Rhea, Tethys, and Dione. In 1675 he determined that the ring around Saturn consisted of an outer and inner ring separated by a darker band, now known as the Cassini Division.[6] Furthermore, he correctly "presumed that Saturn's rings were composed of myriads of small particles,"[7] although it was another two centuries until Scottish physicist James Clerk Maxwell proved this to be the case. Cassini directed the Paris astronomical observatory and founded a dynasty of four astronomers in that city whose work spanned centuries.

EXAMPLES OF WHAT THE MISSION ACHIEVED

The impressive range of scientific contributions emerging from the Cassini-Huygens international exploration effort are in some ways reminiscent of its namesakes' many and varied contributions. It was the last in an era of multi-billion dollar expeditions that extensively explored celestial bodies throughout our solar system. The Cassini-Huygens project was also a proving ground for new observational technologies and for a novel spacecraft design approach. Finally, it was "emblematic of international cooperation and shared investment in space exploration,"[8] creating a new template for mission organization. In fact, it was the strong international support for Cassini-Huygens that probably kept it alive during adverse times in its development.

The Cassini-Huygens spacecraft that took off from the Cape Canaveral complex in Florida on 15 October 1997 was conceived, designed, and built in order to provide "unprecedented information on the origin and evolution of our solar system."[9] The data that its suite of instruments collected have certainly achieved this, and much more as well. In particular, Cassini-Huygens has provided valuable insights into how the chemical building blocks of life are formed.

Science returns and engineering achievements

The spacecraft had a daunting task – to travel between the planets for nearly seven years, whipping twice by Venus, then by Earth and finally by Jupiter to gain speed from those bodies' gravitational fields and attain its ultimate objective of the Saturn system. There, Cassini-Huygens initiated its multi-year study of the mother planet and its rings, satellites, dust, and magnetic field.[10] The mission had to overcome not only enormous technical challenges to be successful, but also political and societal ones. Successful negotiations with the U.S. Congress, the European Space Agency (ESA), and the Italian Space Agency (ASI) ensured funding of well over $3 billion to make the trip to Saturn a reality. This took an extensive international cooperative effort that included a program to justify the use of plutonium aboard the spacecraft.

Cassini-Huygens was one of the largest interplanetary vessels ever launched, only exceeded by the two Phobos craft that the Soviet Union sent to Mars in the late 1980s, neither of which was entirely successful. When Cassini-Huygens was fully fueled, it weighed 6.1 tons (5,574 kilograms) and the mass of its fuel was more than the entire mass of the Galileo and Voyager spacecraft combined.[11]

Cassini-Huygens' initial mission was to study the Saturn system for four years. This included examining the planet's atmosphere and magnetic field, its extensive rings, and its many moons. These observations revealed a planet with "huge columns of thunderstorms … producing lightning bolts 10,000 times stronger than the most powerful on Earth"[12] and superfast winds reaching speeds of 1,800 kilometers (1,118 miles) per hour near its equator.[13]

The mission was a rare opportunity to gain insight into major scientific questions about the creation of the solar system and the conditions that led to life on Earth, in addition to numerous questions specific to the Saturnian system.[14] Among the key scientific goals was a thorough characterization of the large moon Titan, thought to resemble a frigid, primordial Earth. Like the early Earth, Titan has a nitrogen-rich atmosphere. Complex organic molecules constitute the haze that obscures its surface from view. These molecules must eventually fall to the surface in the same way that organic molecules fell from Earth's sky at the time life originated on our planet. For this reason, understanding the chemistry of Titan's atmosphere and surface may be key to understanding the evolution of early life on Earth.[15]

The study of Titan was in part accomplished by ESA's Huygens Probe, released from the main Cassini Orbiter to descend by parachute through Titan's atmosphere, using its instruments to directly sample and observe the atmosphere to determine its composition and characteristics. The results were astonishing. To everyone's delight, the Probe continued to operate on the surface of the moon.

In addition to the Huygens Probe, the mission's Titan studies were carried out by a radar on the Cassini Orbiter that beamed signals in through the opaque atmosphere. The reflected signals were processed into images of an amazing landscape.[16] Imaging radar has been used for many other planetary exploration applications as well, such as for mapping cloud-covered regions of the Earth where other instruments cannot "see" the surface. Radar was also used on NASA's Magellan spacecraft to produce a global terrain map of cloud-shrouded Venus.[17]

Saturn's rings were another principal target for study. Explorations by the two Voyager spacecraft showed that the rings are composed of thousands of individual rings, and made largely of ice particles ranging in size "from sugar grains to small houses."[18] Slight color variations indicated the presence of rocky material as well.

The flyby Voyager observations showed a wide range of unexplained phenomena in the rings, including various wave patterns, small and large gaps, clumping of material, and small "moonlets"[19] embedded in the rings. These discoveries helped set the research agenda for Cassini-Huygens. One of the most interesting phenomena that has been detected is the strange "housecleaning" action of the A-ring, which soaks up material gushing from the fountains of Saturn's tiny ice moon Enceladus, 100,000 kilometers (62,000 miles) away.[20]

Long-term, close-up observations of the rings by the Cassini Orbiter are helping to resolve whether the rings are material left over from Saturn's primordial creation or remnants of one or more moons shattered either by comet or meteor strikes or by tidal disruption effects.[21] Detailed studies of Saturn's rings provide important data for theories of the origin and evolution of the dust and gas from which our solar system's planets first formed. Studies of the Saturnian system might also provide insight into the larger disk systems in our universe such as our own spiral galaxy, the Milky Way.

The orientation of Saturn's ring plane relative to the Sun varies during the planet's orbit. The changing angle of sunlight incident on the rings dramatically alters their visibility. Cassini-Huygens' arrival at Saturn in 2004 was timed for optimum viewing of the rings, during a period when they were well-illuminated by sunlight. Upon arrival at Saturn, the tilt of the ring plane and resulting illumination angle allowed Cassini-Huygens' instruments an unsurpassed view of the ring disk. Orbiting Saturn, the spacecraft was able to detect small moonlets inside the rings, determine the composition of the particles, determine the effects of magnetic field interaction with the rings, and conduct intensive observations of the ring dynamics.[22]

Cassini-Huygens examined many of Saturn's moons besides Titan, and one of the most interesting turned out to be tiny Enceladus, made almost entirely of water ice with relatively few signs of impacts, indicating a largely young and active surface. Enceladus was one of the mission's major surprises. A 500 kilometer satellite that space scientists had once thought was just an inert ball of ice and rocks,[23] proved to be a tremendously vibrant little sphere with "water spewing out of it."[24] The presence of liquid water is one of the requirements for life as we know it, so its discovery on Enceladus caused a stir in the space science community. The Cassini Orbiter then analyzed the possible sources of heat that could melt the interior, searched the moon for geyser-like water-and-ice volcanoes,[25] and "tasted" the particles that were being ejected, finding them to contain surprising amounts of organic materials (another requirement for life) that were some 20 times the density expected.[26]

The moon Iapetus was another rewarding subject of study because of its unique surface: half the moon is covered with a snow-bright substance, while the other half is covered with something as dark as asphalt that is thought to be a complex organic material. Cassini-Huygens helped determine the satellite's surface composition and discover what the dark material is and whether it came from within the moon or was deposited from another source.[27] The mission also found an equatorial mountain range twice the height of Mount Everest on the heavily cratered moon. In addition, it found evidence that Saturn's moon Phoebe "is an outsider that wandered in from deep space and was captured by the planet's gravity."[28] The surface of this strange moon is more diverse than any other body in the solar system except Earth. And one more of the many phenomena Cassini-Huygens discovered was a "Trojan moon,"[29] a 3 mile wide midget that orbits Saturn in harmony with the larger moon Dione. Such moons are known to exist only in the Saturn system.

These and other scientific returns and engineering achievements are examined in depth in subsequent chapters. The benefits of Cassini-Huygens were not limited, however, to the capabilities of the spacecraft and its discoveries. Also of note were the many ways in which the mission impacted an audience much wider than simply the space science community.

Technological benefits from the mission

Challenging scientific enterprises often result in technological advances which are applicable to other, unrelated fields. Such was the case with Cassini-Huygens, whose development efforts generated a range of benefits for industry, business, and the environment, including:

- The computerized resource trading system to resolve the conflicting cost, data rate, and electrical power needs for the spacecraft's science instruments and other subsystems. This tool has been utilized by California's South Coast Air Quality Management District (AQMD) in its implementation of market-based regulation of air pollution.[30]
- A solid-state recorder with no moving parts. It has found applications in a variety of fields from aerospace to consumer electronics to the entertainment industry.
- Integrated circuit advances such as new application-specific integrated circuits (ASIC) that can replace one hundred or more traditional chips and thereby reduce mass.[31]
- A solid-state power switch for eliminating transient current surges and extending parts' lifetimes and efficiencies.[32]
- Inertial reference unit gyros with greater reliability and less vulnerability to mechanical failure because they contain no moving parts.[33]

These and other innovations that emerged from the mission's engineering efforts have found use on other NASA projects, in other U.S. agencies, and in American industry. Technological spinoffs from Cassini-Huygens are discussed in detail later in this book.

Cassini-Huygens' partnership with academic research institutions

Roughly one-quarter of the budget for developing the instruments for Cassini-Huygens went to leading academic research institutions across the U.S., such as the Applied Physics Laboratory of Johns Hopkins University, University of Chicago, University of Colorado, University of Arizona, and University of Iowa. The advanced remote-sensing instruments Cassini-Huygens carried were of higher resolution and operated at higher data rates than previous instruments used on missions to the outer planets. Researchers and graduate students working on the state-of-the-art devices devoted as much as half of their entire science and technology careers towards the development, operation, and data return of these instruments.[34]

Maintaining a unique R&D capability

Cassini-Huygens was a major element in the U.S.'s highly productive program of exploring the solar system with robotic spacecraft. It employed the unique skills of more than 800 individuals in science, technology, and related positions at NASA's Jet Propulsion Laboratory (JPL), and distributed additional work among more than 2,200 others in academia, business, and industry in 33 states.[35]

International cooperation

Cassini-Huygens was a cooperative venture of NASA, ESA, and ASI and formed a vital foundation upon which future U.S.-European space science can be based. In fact, fiscal restrictions in both the U.S. and Europe make the merging of planetary exploration programs increasingly attractive. Cassini-Huygens was an opportunity for spacefaring nations to share in both the investment and the science return of the most ambitious and challenging of explorations.[36]

European contributions

The value of the European contributions to the Cassini-Huygens mission totaled $660 million. Europe's cooperation and its scientific and engineering expertise were of enormous benefit to the mission's success.

International partnerships greatly expanded the scientific depth and breadth of the activities. Foremost in Europe's input to the mission was development and operation of the Huygens Probe that was provided primarily by ESA, and the Cassini Orbiter high-gain antenna supplied by ASI.[37] More than 135 scientists and a similar number of engineers from sixteen European countries supported the hardware, software, and scientific analysis of the twelve Orbiter and six Probe investigations. Continued exploration of the solar system will require similar international cooperation.[38]

The international nature of the mission turned out to have an additional benefit as well, and a very major one. The cross-border sharing of responsibilities appealed to the U.S. Congress. In fact, Cassini-Huygens "likely would have fallen prey to budget cuts if not for the emphasis on space exploration as a venue for international cooperation."[39] This will be discussed in more detail in Chapter 2, in the sections on 1990s congressional negotiations and on Administrator Dan Goldin.

THEMES EXPLORED IN THIS BOOK

Issues of risk

To make Cassini-Huygens a reality, NASA had to confront a difficult conflict in U.S. society: our need to explore new frontiers versus our aversion to risk. NASA astronaut Michael Foale has written of "the public expectation for success"[40] in all endeavors, and the shock that ensues when major efforts such as space missions fail. This conflict has grown more, not less, severe during the decades since our space program began. Contrast the outrage that swept the U.S. when several NASA Mars missions of the 1990s failed, versus the attitude of NASA Administrator James Webb decades earlier regarding the Mercury Redstone flights: "We must keep the perspective that each flight is but one of many milestones we must pass. Some will completely succeed in every respect. Some … will fail. From all of them will come mastery of the vast new space environment on which so much of our future depends."[41]

Webb's perspective was not shared by all. For instance, William Coughlin, the editor of the aerospace journal *Missiles and Rockets*, savagely attacked the failures of JPL on the Ranger lunar exploration program, calling it a disgrace. He referred to the Ranger program itself as a "lunar debacle."[42] This was after the failure of Ranger 6's television telemetry system to transmit high resolution, close-up photographs of the lunar surface.[43] But key members of Congress had views that were far more forgiving. George P. Miller, chairman of the House of Representatives Committee on Science and Astronautics, maintained his faith in NASA and JPL. He considered the accuracy of the Ranger 6 flight path and the craft's overall performance to have rendered the mission "an accomplishment of the first order,"[44] despite the failure of its television system. He understood, it seemed, that some failures were necessary to eventually achieve fully successful lunar exploration missions, and recognized the significance of the fact that most of the spacecraft's systems had indeed functioned correctly.

Representative Joseph Karth, subcommittee chairman of the House Committee on Science and Astronautics, was another Congress person who accepted a certain risk of failure in order to achieve lofty objectives. He firmly supported continuation of the Ranger program, and held that if even two out of the three remaining Ranger missions were successful, the program would have been well worth all the money spent on it.

U.S. citizens have perceived different types of risks on different NASA missions. When Alan Shepard entered his Mercury capsule on 5 May 1961 to be launched atop a Redstone rocket, many people feared that he might not return to Earth alive. On Cassini-Huygens, however, the perceived risks were of different types. The *technical* risks were huge: would this enormously expensive mission actually make it to Saturn in working condition and fulfill its many objectives, under the guidance of a control crew located 750 million miles away?

Thousands of people in this country also saw a frightening risk to human life and health. Cassini-Huygens carried over 70 pounds of plutonium onboard, and the fear was that, if the spacecraft crashed on Earth, this dangerous material would be spread far and wide. While years of detailed analyses by NASA have demonstrated that the devices carrying the plutonium are extremely rugged and resistant to releases of this substance, even under severe accident conditions,[45] many people argued the mission was too dangerous to launch and the government was not telling the public about the true risks involved.[46]

Influence of previous missions

A recurring theme throughout the book is the relationship of the final configuration of the Cassini-Huygens mission to the problems and successes of its predecessors. The book seeks to communicate how the Cassini-Huygens mission is both a unique achievement in its own right and the evolutionary product of earlier undertakings, in particular the Galileo, Voyager, and Pioneer expeditions to the outer solar system. Of special interest are the influences that the serious problems encountered by the Galileo mission to Jupiter had on the design of the Cassini-Huygens spacecraft and its operations.

Adaptability to unforeseen problems

Cassini-Huygens' success depended on its ability to adapt quickly and effectively to factors such as equipment malfunctions and breakdowns in communication between spacecraft and Earth. The mission team's philosophy of designing redundancy into a broad range of spacecraft components and systems proved invaluable for keeping the ship running during a long, distant mission and keeping the scientific discovery data flowing to the NASA and ESA teams. This book discusses a collection of different incidents in which redundancy was key in working through serious issues.

The book also discusses the adaptability of the Cassini-Huygens mission team itself in responding to unforeseen situations. One example of an ingenious way the team addressed a potentially mission crippling issue, that is examined in detail later in the book, concerned a Doppler shift communications-link problem that threatened to severely impair the data flow from the Huygens Titan Probe.

Cross-border challenges

The abovementioned communications-link problem was an example of an issue that can arise in a complex mission involving numerous cultures and ways of conducting business, often without the necessary transparency. The root causes of this and other serious incidents, such as the near-loss of vital data during a measurement of Titan's winds, arose in part because of the enormous difficulty of melding the contributions of multiple countries and organizations into a coherent whole.

DATA SOURCES USED FOR THIS BOOK

One of my major research activities was obtaining archival material from the NASA Historical Reference Collection (NHRC) and Jet Propulsion Laboratory (JPL). In particular, these contained invaluable sources of correspondence between mission managers, engineers, NASA administrators, and government officials, including congressional staff. These archives also supplied numerous operations manuals as well as meeting and operations reports. Some archival material was also obtained from Ames Research Center (ARC), Glenn Research Center (GRC), and ESA and ASI sources. GRC had data on launch vehicle design and testing as well as launch operations. NASA's online Planetary

Data System (PDS) archive also had useful information that included mission profiles, planning documents, and graphics.

Oral historical data was obtained in numerous interviews from NASA and mission managerial staff, especially JPL, ESA, and ASI managers, as well as from mission scientists, engineers, and operations staff.

Extensive searches of the existing literature were performed to gather information about all phases of the mission, from initial conception through the science return. Relevant publications included not only technical papers and books, but also those pertaining to the organizational and management challenges of Cassini-Huygens. Documents regarding the use of plutonium aboard the spacecraft were obtained from the U.S. Environmental Protection Agency and Department of Energy. The above sources were supplemented with numerous articles in popular journals, newspapers, and other periodicals.

OVERVIEW OF THE BOOK'S PARTS AND CHAPTERS

Part I traces Cassini-Huygens' evolution from initial concepts of how to explore the outer solar system through the mission's eventual funding and subsequent attempts to cancel it. Chapter 1 focuses on the political, scientific, and societal motivations for developing Cassini-Huygens, and outlines the project's history from outer solar system exploration concepts in the 1950s through the initial vision formulated in the 1970s and the development of a mission aimed at exploring Saturn and its rings, satellites, fields, and particles. This chapter accents the multi-country, collaborative nature of the mission, and in particular how the perceived benefits of international cooperation helped keep the mission alive in the face of NASA budget limitations. Europe's evolving role in collaborations with the U.S. is documented, from being a junior contributor on early projects through to the NASA-ESA-ASI partnership of the Cassini-Huygens mission. Challenges to international cooperation are examined, such as NASA's difficulty in making long-term, multi-year fiscal commitments, due to its annual dependence on the budget assigned by Congress; and the complicated task of manufacturing critical sections of the spacecraft on different continents and ensuring they all interface correctly. The different funding processes used by NASA and ESA to secure support for their shares of the mission are also analyzed.

Chapter 2 discusses how NASA, ESA and ASI formed a powerful international coalition to develop the Cassini-Huygens mission in the face of U.S. congressional budget reductions and repeated threats of mission cancellation. Also examined is the complex relationship that NASA Administrator Dan Goldin had with the mission. This chapter reviews the debate as to the most effective means of exploring the outer solar system.

The aim of Part II is to convey what an achievement it was to develop such a complicated, capable spacecraft. Chapter 3 details the design history of the Cassini spacecraft, examining how its design was influenced by Galileo and other mission experiences. The part that ASI played in developing key equipment for the Orbiter is examined, and the capabilities of the spacecraft's twelve scientific experiments are discussed. Chapter 4 reviews the development of the Huygens Probe for Titan, the largest Saturnian moon, and analyzes its science experiments. The chapter discusses the complex relationships and cooperation between NASA, which would launch the spacecraft and have responsibility for the entire Cassini-Huygens mission, and ESA, which oversaw the design and fabrication of the Probe. Chapter 5 analyzes the task of interfacing components produced by NASA, ESA, and ASI. Characteristics of the Titan 4B/Centaur launch vehicle are also studied, as well as Lewis (Glenn) Research Center contributions to the vehicle and to launch operations.

Chapter 6 reviews arguments for and against the controversial use of plutonium-powered radioisotope thermoelectric generators (RTG) for onboard electricity and radioisotope heater units (RHU) for temperature control. Risk analyses performed in order to assess the dangers of using RTGs on Cassini-Huygens are discussed, along with the worst-case scenarios that might have occurred had the spacecraft crashed. The chapter considers the legal challenges and demonstrations organized to stop the use of plutonium fuel, discusses myths and truths about various plutonium isotopes, characterizes the isotopes used on Cassini-Huygens, and analyzes the safety features employed. It also discusses the political challenges of obtaining plutonium 238 for future outer solar system missions, either by buying it from another country, or by restarting manufacturing operations in the U.S.

Part III focuses on the flybys, gravity assists, and scientific observations that Cassini-Huygens carried out during its voyage from Earth to Saturn. It also discusses the Probe mission to Titan after arrival at Saturn, and the features and dynamics of the Orbiter's tour of the Saturnian system, including the organizational structure that achieved this success.

Chapter 7 examines the characteristics of the spacecraft's trajectory, including gravity assists from Venus, Earth, and Jupiter, as well as the trajectory correction maneuvers that were needed to reach Saturn and satisfy mission objectives. The joint observations of Jupiter by Cassini-Huygens and Galileo are examined, and Cassini-Huygens' arrival at the Saturn system, including its one and only flyby of the moon Phoebe, are reviewed. Chapter 8 discusses a crisis involving the radio link between the Probe and the Orbiter that was discovered during the cruise to Saturn, and how it was related to the complexities of effective communication on a large international mission with many players.

Chapter 9 provides details of the Huygens Probe's mission, including operations to transport it to Titan, establishment of the Orbiter-Probe relay radio link, and the penetration of the moon's atmosphere. The Doppler Wind Experiment problem and its root causes are examined. Finally, the science return from the Probe's mission is discussed. Chapter 10 details the Prime Mission tour conducted by the Orbiter, the Cassini Equinox Mission, and the Solstice Mission, including descriptions of Saturn orbits, Titan flybys, close and distant flybys of other satellites, and observations of the ring system and magnetosphere. This chapter discusses the process of choosing trajectories and assigning research opportunities. Planning and management issues on the Galileo mission to Jupiter are contrasted with those on Cassini-Huygens. The orbital dynamics for Cassini-Huygens and how it employed Titan gravity assists for fuel conservation and guidance are examined, as well as planetary protection issues for bodies that might harbor life. Finally, the impact of a management change on the Cassini-Huygens team is examined.

Part IV reviews the mammoth science return from Cassini-Huygens' observations of Saturn and its magnetosphere (Chapter 11), its myriad rings (Chapter 12), its icy moons, in particular the active satellite Enceladus (Chapter 13), and its giant veiled moon Titan (Chapter 14). This part of the book documents the leap in understanding of the Saturnian system provided by Cassini-Huygens over that from the Pioneer and Voyager flybys and from Earth-based studies. Moreover, this section explains how these new findings have rewritten the textbooks on the meteorological and magnetic processes operating on Saturn, the sculptural and multivariate natures of its myriad rings, and the startling connections between the mother planet and its satellites, rings and magnetosphere.

Michael Meltzer
Oakland, CA, USA

REFERENCES

1. Michael Griffin, "Speech by NASA Administrator Michael Griffin: The Magic of Science," referring to the observations of Arthur C. Clarke, http://www.spaceref.com/news/viewsr.html?pid=29217, 33rd International Conference on Infrared, Millimeter, and Terahertz Waves, California Institute of Technology (Caltech), Pasadena CA (15 Sep. 2008).
2. Carolyn Porco, "Fly Me to the Moons of Saturn," http://www.ted.com/talks/view/id/178, speech to the TED Conference, Monterey CA, 7 March 2007.
3. NASA-JPL, "Mission Overview: Quick Facts," http://saturn.jpl.nasa.gov/mission/quickfacts/, accessed 28 Mar. 2010; CNN, "Last of the Mega-Missions," http://www.cnn.com/SPECIALS/space/cassini/mission/, Cable News Network, 1997.
4. Charley Kohlhase, "Meeting with a Majestic Giant: The Cassini Mission to Saturn," *Planetary Report* (July 1993):5, NHRC 17908 Cassini Probe (81–97 Aug).
5. ESA, "Solving the Puzzles of Saturn and Titan," http://www.esa.int/SPECIALS/Cassini-Huygens/SEM3782VQUD_0.html, accessed 26 Jan. 2009.
6. ESA, "Solving the Puzzles of Saturn and Titan." Astronomers later determined that Saturn was really encircled by a system of several distinct rings
7. SEDS, "Giovanni Domenico Cassini (June 8, 1625 - September 14, 1712)," https://www.forum.seds.org/messier/xtra/Bios/cassini.html, *Messier Catalog,* Students for the Exploration and Development of Space (SEDS), 17 Sep. 2006, accessed 23 Apr. 2008.
8. Anne Eisele, "Cassini Mission Marks Last of Big Spenders," *Space News,* 6–12 Oct. 1997, p. 4, NHRC 17908 Cassini Probe (81–97 Aug).
9. NASA, "Cassini," *Flight Project Data Book,* 1995, p. 121, 14294 Cassini/Saturn/Huygens Probe; Background, Fact Sheets & Brochures (1979–1996).
10. NASA-JPL, "The Cassini Spacecraft and Huygens Probe," JPL Cassini public information, March 1996, 14294 Cassini/Saturn/Huygens Probe; Background, Fact Sheets & Brochures (1979–1996).
11. NASA-JPL, "Cassini Spacecraft and Huygens Probe." http://saturn.jpl.nasa.gov/files/space_probe_fact.pdf (JPL 400–777, May 1999).
12. Space Today Online, "Current Events at Saturn," http://www.spacetoday.org/SolSys/Saturn/CassiniSaturnNews.html, Exploring Saturn, spacetoday.org (20 Sep. 2005).
13. Jim Wilson (ed.), "A Gas-Giant with Super-Fast Winds," http://www.nasa.gov/mission_pages/cassini/whycassini/planet.html, NASA Cassini-Huygens Mission to Saturn Web site, 26 May 2004.
14. JPL, "Scientific Benefits of the Cassini Mission," Insert A in "Integrated JPL General Comments - Cassini Draft Environmental Impact Statement (10/1 9193 SAIL Draft)," in Richard J. Spehalski memos, November 1993, JPL-Cassini CASTL; *ScienceDaily,* "Cassini Flyby Of Saturn Moon Offers Insight Into Solar System History," http://www.sciencedaily.com/

releases/2008/10/081006180819.htm (7 Oct. 2008); NASA-JPL, "Saturn Propellers Reflect Solar System Origins," http://saturn.jpl.nasa.gov/news/newsreleases/newsrelease20100708/ (8 July 2010); C.D. Parkinson et al., "Enceladus: Cassini Observations and Implications for the Search for Life," *Astronomy and Astrophysics* 463 (2007):353–357.

15. ESA, "Life on Titan?" http://www.esa.int/esaMI/Cassini-Huygens/SEM696HHZTD_0.html, accessed 12 May 2011; NASA-JPL, "Is Titan Considered a Likely Place to Look for Life?" http://saturn.jpl.nasa.gov/faq/FAQTitan/, accessed 12 May 2011.
16. Planetary Society, "Cassini RADAR," http://www.planetary.org/explore/topics/cassini_huygens/instrument_radar.html, accessed 8 July 2009; Tony Freeman, "What is Imaging Radar?" http://southport.jpl.nasa.gov/desc/imagingradarv3.html, NASA/JPL Imaging Radar Program, 26 January 1996; Margaret Cheney, "Radar Imaging," http://www.ima.umn.edu/imaging/T9.19-23.05/activities/Cheney-Margaret/radartutorialpart1.pdf, 18 Sept. 2005.
17. NASA-JPL, "Magellan Mission to Venus," http://www2.jpl.nasa.gov/magellan/.
18. JPL, "Scientific Benefits."
19. O. C. Winter et al., "Moonlets Wandering on a Leash-Ring," http://www.agnld.uni-potsdam.de/~frank/Winter_07.pdf, *Mon. Not. R. Astron. Soc.* (2007):L1; Jim Schefter, "Return to Saturn," *Popular Science* (Jan. 1982):54.
20. Bill Steigerwald (Goddard Space Flight Center), "Saturn Has a 'Giant Sponge," JPL news release, 5 Feb. 2008.
21. Robin M. Canup, Origin of Saturn's Rings and Inner Moons by Mass Removal from a Lost Titan-sized Satellite," http://www.nature.com/nature/journal/vaop/ncurrent/full/nature09661.html, *Nature* (online version published 12 Dec. 2010).
22. NASA-JPL, "Cassini-Huygens Mission to Saturn," http://saturn.jpl.nasa.gov/files/mission_fact.pdf, Cassini Program Outreach, JPL 400–776 5/99; NASA-JPL, "Scientific Benefits of the Cassini Mission," Nov. 1993.
23. Bob Mitchell, interview by author, JPL, Pasadena CA, 5 Feb. 08.
24. Mark Dahl, interview by author, NASA HQ, Washington D.C., Sept. 07.
25. NASA-JPL, "Scientific Benefits of the Cassini Mission," Nov. 1993.
26. Carolina Martinez and Dwayne Brown, "Cassini Tastes Organic Material at Saturn's Geyser Moon," JPL news release 2008–050, 26 Mar. 2008.
27. Dale P. Cruikshank, "Hydrocarbons on Saturn's satellites Iapetus and Phoebe," *Icarus* 193(2) (Feb. 2008):334–343; Bill Arnett, "Iapetus," http://nineplanets.org/iapetus.html, updated 13 May 2005; NASA-JPL, "Scientific Benefits of the Cassini Mission," Nov. 1993.
28. Space Today Online, "Current Events at Saturn," http://www.spacetoday.org/SolSys/Saturn/CassiniSaturnNews.html, Exploring Saturn, spacetoday.org (20 Sep. 2005).
29. Ibid.
30. "Scientific Benefits of the Cassini Mission," Insert A in "Integrated JPL General Comments - Cassini Draft Environmental Impact Statement (10/1 9193 SAIL Draft)," in Richard J. Spehalski memos, November 1993, JPL-Cassini CASTL.
31. "Scientific Benefits of the Cassini Mission," Insert A in "Integrated JPL General Comments - Cassini Draft Environmental Impact Statement (10/1 9193 SAIL Draft)," in Richard J. Spehalski memos, November 1993, JPL-Cassini CASTL.
32. "Scientific Benefits of the Cassini Mission," Insert A in "Integrated JPL General Comments - Cassini Draft Environmental Impact Statement (10/1 9193 SAIL Draft)," in Richard J. Spehalski memos, November 1993, JPL-Cassini CASTL.
33. "Scientific Benefits of the Cassini Mission," Insert A in "Integrated JPL General Comments - Cassini Draft Environmental Impact Statement (10/1 9193 SAIL Draft)," in Richard J. Spehalski memos, November 1993, JPL-Cassini CASTL.

34. "Scientific Benefits of the Cassini Mission," Insert A in "Integrated JPL General Comments - Cassini Draft Environmental Impact Statement (10/1 9193 SAIL Draft)," in Richard J. Spehalski memos, November 1993, JPL-Cassini CASTL.
35. "Scientific Benefits of the Cassini Mission," Insert A in "Integrated JPL General Comments - Cassini Draft Environmental Impact Statement (10/1 9193 SAIL Draft)," in Richard J. Spehalski memos, November 1993, JPL-Cassini CASTL.
36. "Scientific Benefits of the Cassini Mission," Insert A in "Integrated JPL General Comments - Cassini Draft Environmental Impact Statement (10/1 9193 SAIL Draft)," in Richard J. Spehalski memos, November 1993, JPL-Cassini CASTL.
37. "Scientific Benefits of the Cassini Mission," Insert A in "Integrated JPL General Comments - Cassini Draft Environmental Impact Statement (10/1 9193 SAIL Draft)," in Richard J. Spehalski memos, November 1993, JPL-Cassini CASTL.
38. "Scientific Benefits of the Cassini Mission," Insert A in "Integrated JPL General Comments - Cassini Draft Environmental Impact Statement (10/1 9193 SAIL Draft)," in Richard J. Spehalski memos, November 1993, JPL-Cassini CASTL; Robert T. (Bob) Mitchell email to author, 16 Feb. 2010.
39. CNN, "Last of the Mega-Missions," http://www.cnn.com/SPECIALS/space/cassini/mission/, Cable News Network, 1997.
40. Michael Foale, "Remarks," p. 258 in *Risk and Exploration: Earth, Sea, and the Stars,* NASA SP-2005-4701, 2005.
41. James E. Webb statement on 1 May 1961, "Official NASA Biography," http://www.astronautix.com/astros/webb.htm, in Mark Wade, *Encyclopedia Astronautica,* accessed 30 Jan. 08.
42. R. Cargill Hall, "The Worst of Times," Chapter 16 in *Lunar Impact: A History of Project Ranger* (Washington D.C.: NASA History Division SP-4210, 1977, updated 27 November 2006).
43. Robert J. Parks and H. M. Schurmeier, "Ranger to the Moon," *Engineering and Science* XXVIII(I) (1964):8.
44. Hall, "The Worst of Times."
45. U.S. Department of Energy, "What is an RTG?" (and other questions), Sept. 1997, 14294 Cassini/Saturn/Huygens Probe; Background, Fact Sheets & Brochures (1979–1996).
46. Kathy Sawyer, "Plutonium-Powered Cassini Revives Spacecraft Debate," Wash. Post, 12 Oct. 1997, p. A22, NHRC 5132 Cassini (Sept. 1997-Oct. 14, 1997).

Contents

Part III From Earth to Saturn

Part IV A great natural laboratory

Part I
Creating a new expedition to Saturn

Part I traces Cassini-Huygens' evolution from initial concepts of outer solar system exploration in the 1950s through the development of an international collaboration aimed at exploring Saturn and its ring system, moons, fields, and particles. This part considers the basic question of how best to explore the outer solar system.

1

Conceiving and funding the mission

> *"The Cassini-Huygens mission will probably help answer some of the big questions … about origins and where we came from and where life came from."*
>
> – Robert (Bob) Mitchell, Program Manager
> of the Cassini-Huygens Mission[1]

The mysteries of Saturn, its rings, its fields and particles, and its moons, have enticed and perplexed scientists for many years. The Cassini-Huygens mission sought to shed light on these mysteries by exploring the entire Saturnian system in greater depth than had ever been attempted before, using the largest and most sophisticated interplanetary vehicle that NASA had ever built or launched. This book examines all aspects of the project: its conception and planning; the political processes, engineering, and development necessary to make it a reality; its 2.2 billion mile (3.5 billion kilometer) journey to the ringed planet; and what it found there.

This chapter begins with early visions of how the outer solar system should be explored and examines how they evolved into the Cassini-Huygens mission. What is most interesting to me are the factors that played key roles in creating the mission. The commitment of articulate, influential scientists of vision was required, and it was essential that they represented not only the U.S., but also the European space community.

Fear of losing our world leadership in space exploration was a strong motivator in convincing Congress and the White House to undertake this mission. The outspoken support of a national heroine and cultural icon was also valuable, as were the political advantages of carrying out a major flagship effort in close partnership with Europe. And underlying all these factors was simply our basic curiosity about what goes on out there, in the distant part of our solar system where gas giants dwell.

M. Meltzer, *The Cassini-Huygens Visit to Saturn*, Springer Praxis Books,
DOI 10.1007/978-3-319-07608-9_1

1.1 THE PATH TO CASSINI-HUYGENS

> *"Only when we have flown missions to every part of the solar system will we have the vital statistics of all its components and be able to turn back the pages of the book of cosmology to the origins of our own world, and perhaps of the universe itself."*
>
> – Arthur C. Clarke[2]

1.1.1 Early work on outer planet missions

Soon after NASA was formed, its scientists began to envision what outer solar system explorations, still many years in the future, might look like. In 1959, JPL scientist Ray Newburn, Jr. developed several mission concepts for investigating the portion of our solar system beyond Mars. He foresaw *deep space flights* that would pass only through interplanetary space, making observations and measurements as they went. *Flybys,* on the other hand, would have brief encounters with planets. Although the data collected would be restricted by limits on time, flyby missions could study several different planets during one trip. Flyby data might be compared to observations taken through the windows of a tourist bus: brief, but varied. *Orbiter* missions would involve long-term trajectories around target planets and permit in-depth data collection. Finally, *planetary entry* and *lander* missions would penetrate planetary atmospheres, enabling observations that could not be obtained by missions flying above the atmosphere.[3]

In 1965, Caltech graduate student Gary Flandro made a calculation that proved important for the feasibility of missions to Saturn and other outer planets. Flandro used the work of Michael Minovitch, a graduate student from University of California Los Angeles, who had been investigating a spacecraft mission strategy called "gravity-assist," in which a planet's gravitational field is used to modify a craft's trajectory. Minovitch's and Flandro's work demonstrated that one spacecraft could use gravity assists to visit Jupiter, Saturn, Uranus *and* Neptune on one mission, if the planets were aligned just so. Gravity assists allow far more to be accomplished in a mission with a given amount of fuel and launch energy, because such maneuvers can greatly augment a spacecraft's velocity and kinetic energy and increase the amount of mass that can be flown.[4] Throughout NASA's years of space travel, gravity assists have significantly reduced the fuel and vehicle weight requirements needed to reach the outer planets. Both the Pioneer and Voyager programs depended on these maneuvers to accomplish all that they did.[5]

Serious planning for specific outer solar system missions began only a little more than a decade after Newburn's conceptualizations. By the early 1970s, with Mars and Venus already being explored by flyby and orbiter spacecraft, many astronomers identified *outer* solar system targets for exploration. In 1972, NASA released a Space Vehicle Design Criteria Monograph that envisioned the environment that a spacecraft would encounter at Saturn, including aspects of its gravity field, charged particles, ring particles, and atmospheric structure and composition.[6] Scientists of the time also focused particular attention on Saturn's largest satellite, Titan.[7] It is a moon large enough to hold onto its own atmosphere and was especially fascinating because Earth-based observations suggested that its surface might be "covered with higher hydrocarbon compounds of the type which were the basic building blocks of life on our planet."[8] Furthermore, observations suggested that Titan might have a surprisingly warm atmosphere 20 times more massive than that of Mars, although not made up of oxygen and nitrogen like ours, but rather of methane and hydrogen. Titan's environment was suggestive of Earth's several billion years ago, during the early stages of the evolution of life. Titan thus might yield information on the types of primordial material from which the solar system formed, as well as the "nature of chemistry which led to the origin and evolution of life on the planet earth."[9]

1.1.1.1 The Space Science Board's 1975 report

A guide for Saturn mission planning of the late 1970s and the 1980s was the Space Science Board[10] (SSB) of the U.S. National Academy of Sciences' *Report on Space Science 1975*. The Board adopted the recommendations made by its Committee on Planetary and Lunar Exploration (COMPLEX) regarding goals for future missions. Noting that the Pioneer 11 and Voyager 1 and 2 flyby missions, if successful, would complete a *reconnaissance phase* of Saturn investigation, COMPLEX envisioned a range of objectives for subsequent expeditions:[11]

- Intensive investigation of Saturn's atmosphere
- Determination of satellite surface chemistry and properties
- Ring particle analyses
- Intensive examination of Titan
- Atmospheric dynamics and structure investigations
- Comparative planetology of the satellites.

1.1.1.2 The Saturn orbiter/dual probe study

In 1977, NASA initiated a Saturn Orbiter/Dual Probe (or "SOP^2") Study,[12] a joint effort between NASA's Jet Propulsion Laboratory (JPL) and Ames Research Center to define the science objectives and instrumentation required for a Saturn mission. Management responsibilities for the study were given to JPL, while Ames' task was definition of the entry probes. The investigation was conducted in a manner similar to "Jupiter Orbiter with Probe,"[13] the conceptual study that eventually led to NASA's Galileo mission to Jupiter.

1.1.1.3 The Saturn system conference

NASA held a conference in February 1978 in Reston, Virginia in order to provide comprehensive scientific input to those scientists and engineers working on plans for the SOP^2 mission, and toward this end, produced a 400-plus page "compendium of the present knowledge of Saturn, its satellites, its rings, and its magnetosphere."[14] The document also described the current state of Saturn mission planning and the expected state of knowledge once the Voyagers flew by the planet in 1980 and 1981. The next phase of exploration would logically be one in which long-duration studies of the Saturn system would be made.[15] This suggested an orbiting rather than flyby spacecraft with the propulsive capability to tour the Saturn system's many points of interest, as well as one or more probes to provide in situ measurements of the most compelling targets, in particular Titan and Saturn themselves. One of the mission strategies discussed at great length at the conference was SOP^2, which encompassed atmospheric probe exploration of both Saturn and Titan, as well as a Saturn orbiter performing multiple satellite encounters.[16] At the time of this conference, a popular vision for the SOP^2 spacecraft was to closely model its orbiter on the Galileo Jupiter orbiter that was then being designed, and to derive the two SOP^2 probes from that mission's probe.[17] This vision would change radically before the final design for the spacecraft was chosen.

1.1.1.4 The Martin Marietta Titan probe study

NASA contractor Martin Marietta also helped define a Saturn mission, and in 1978 produced a briefing[18] as part of a Titan probe study that raised a range of questions regarding mission concepts.[19] Some questions pertained to the moon's atmosphere and its implications for the design of an appropriate probe. NASA needed to know what Titan's atmospheric pressure was. The Agency thought that the Voyager flyby spacecraft, both of which were launched in the summer of 1977, would be able to determine the surface pressure to within a few percent. These observations would be supplemented with ground-based measurements. Besides affecting probe design, the atmospheric pressure would also influence mission operations and descent time. For instance, a thin atmosphere model with a surface pressure of 17 millibars (mb) or 17 thousandths the pressure at Earth's surface would result in a descent of 30 minutes, while a thick atmosphere model with a pressure as high as 21 bars predicted that the descent would last between 4 and 8 hours.

The final Martin Marietta study considered three classes of Titan atmospheric entry probes: one that would conduct atmospheric science only, another that would land and carry out limited surface science, and a third that would perform extended mission studies on the moon's surface. The study concluded that the middle option of limited surface exploration was a feasible and worthwhile, yet reasonably low risk alternative that could be performed without the need to develop new technology, and indeed could use hardware inherited from other probe missions.[20] As will be shown in later chapters, the favored Martin Marietta alternative closely resembled the actual course of the Huygens Probe mission.

1.1.2 The Voyager missions

Voyager 1 traveled past Saturn on 12 November 1980 and Voyager 2 flew by on 25 August 1981,[21] approaching to within 100,000 kilometers (60,000 miles). Although Pioneer 11 had visited Saturn several years earlier, it was the Voyagers, according to Andy Ingersoll, a meteorologist at California Institute of Technology (Caltech), that really "changed our perceptions"[22] of the planet. The Voyagers were equipped with so many more instruments and so many more capabilities per instrument, that their dramatic observations of the Saturn system awed scientists around the world and led to demands for a follow-up.

A close flyby of Titan revealed the moon to be larger than the planet Mercury and veiled by a thick layer of photochemical haze. The atmosphere is so dense that at the surface the pressure is 60% greater than on Earth's surface.[23]

Voyager data revealed that the mother planet Saturn was no less fascinating. On Earth, winds are driven by solar energy, so it might be expected that this would be the case with other planets. At Saturn's distance from the Sun, where there is only about 1% the solar energy per unit area experienced on our planet, the winds ought to be much gentler. But they're not! They blow far stronger.[24] Near Saturn's equator, the Voyagers measured wind speeds of 500 meters per second (1,100 miles an hour). Furthermore, Saturn is the only planet less dense, overall, than water. This means that "if a lake could be found large enough, Saturn would float in it."[25]

Voyager observations of Saturn's ring system revealed even greater surprises as well as very perplexing puzzles. The spacecraft found unexplained gaps in the ring system, as well as sections that are subdivided into strands that appear to be braided together in places. There are also "spokes" on the ring system, so named because they resemble the spokes of a bicycle wheel. Intriguingly, some of the spokes, those thought to have formed most recently, appear to co-rotate with the planet's magnetic field.[26]

Voyager observations indicated a complex planet-moon-ring system that needed to be further explored. The resolve to return to Saturn thus arose naturally from the science return of these missions.

It was shortly after the Voyager flybys that an influential alliance arose between three scientists, one from the U.S., one from France, and one of Chinese origin.

1.1.3 The Horizon2000 programme

In the early 1980s, ESA established the Horizon2000 programme, which aimed at using "a modest but predictable science budget as daringly as possible, by defining ambitious missions affordable over a large period of time, spanning from 1985 to 2005."[27] Horizon2000 envisioned major "cornerstone missions" as well as medium-sized endeavors with more focused objectives and smaller budgets. What eventually became the Titan probe effort was the first of Horizon2000's medium-sized mission concepts. As described in the next section, the first proposals for a probe to Titan were submitted in 1982 by an international team of scientists in response to a general call by ESA for potential Horizon2000 projects.

1.1.4 A special collaboration campaign for the Saturn mission

Tobias (Toby) Owen, an atmospheric scientist from the U.S., met French planetary scientist Daniel Gautier in the early 1970s. They became friends and so did their families. Owen later said that their strong personal relationship augmented all they were able to accomplish. He once explained that, in regard to developing space missions, "you have to overcome a lot of inertia and absorb a lot of defeats yet keep going. Agencies will not do that, only people who care enough."[28] Owen envisioned a new regime of space exploration by many different nations all working together. Although he was ultimately frustrated by how separately NASA and ESA operated in exploring space, his collaboration with Gautier yielded some very positive results, especially regarding Cassini-Huygens.

The first attempts to sell a return-to-Saturn-and-Titan concept did not meet with success. France's National Center for Space Exploration (CNES) told Gautier that such a project would be far too costly unless he could find partners. Owen received a similar response from NASA. The Agency was actually thinking about sending an orbiter to study Saturn, but believed adding a Titan probe would be too expensive. Nevertheless, Owen and his colleagues thought that a Galileo-style probe would fit the bill nicely. Such a probe had already been designed and built by NASA's Ames Research Center and vetted at Jupiter. Owen did not understand why NASA went on to reject the use of such a probe, but suspected that rivalry between JPL and Ames, the developer of the Galileo probe, might have been the deciding factor.[29]

In the early 1980s, Owen became chairman of NASA's Solar System Exploration Committee (SSEC), which was concentrating at the time on outer planet mission plans. Its vision was to explore Saturn as a logical step after Jupiter and to include both a Titan probe/radar mapper *and* a Saturn probe, as well as an orbiter. Flying separate missions to Saturn and Titan was also considered.

At the same time as Owen and SSEC were developing exploration strategies, Daniel Gautier was preparing a similar study in response to ESA's call for mission proposals from the European space science community. He had been approached by Wing Ip, a Taiwanese plasma scientist working at Germany's Max Planck Institute, who had an interest in outer planet missions, and the two joined efforts to prepare a proposal. Ip also spent considerable effort eliciting support from the European space science community for a Saturn orbiter mission which would, among other things, further examine the planet's magnetosphere. In addition, Ip conceived of naming the mission "Cassini" after the Renaissance-era Italian scientist who had been invited to France to run the Observatoire de Paris.

1.1.5 The International Solar Polar Mission

The momentum for an international mission to Saturn appeared to be building, but then the U.S. made a decision that dealt a severe blow to Europe's trust in our country's space program and in the wisdom of partnering with it. NASA had agreed to partner with ESA in a two-spacecraft project, the International Solar Polar Mission (ISPM) that would simultaneously explore different high-latitude regions of the Sun. ESA had invested heavily in the effort. But then in 1981, impacted by the reductions in space funding that President Ronald Reagan and his Administration demanded, the U.S. decided to cancel construction of the NASA spacecraft for this mission. The *European* spacecraft did eventually launch, however, under the mission title of *Ulysses*.[30]

President Reagan was not by any means an enemy of the U.S. space program. He did express interest in revitalizing it, although he never made the space program a vital national goal as it had been during the 1960s under Presidents Kennedy and Johnson. Reagan believed that major government spending reductions were needed in many sectors to counteract the expanding economic problems that had begun in the 1970s, and his austerity measures significantly impacted NASA's activities as well as those of other agencies.[31]

George Keyworth, Science Advisor and Director of the Office of Science and Technology Policy under the Reagan Administration,[32] was heavily involved in the fiscal restrictions imposed on NASA, and even recommended that "all new planetary space missions for at least the next decade"[33] be halted. He favored a policy shift away from