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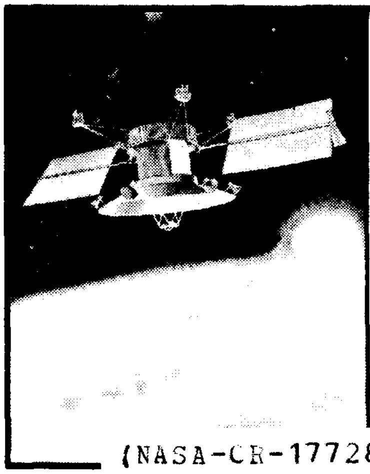

V-GRAM

A NEWSLETTER FOR PERSONS INTERESTED IN THE EXPLORATION OF VENUS

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Magellan (Formerly VRM) Update

Warren W. James

Challenger Accident Impact on Magellan

The launch accident which destroyed the Space Shuttle Challenger on January 28, 1986 is having major adverse impacts on all of the payloads that were scheduled to fly on the Space Shuttle during this decade, including Magellan (which was formerly called Venus Radar Mapper). Launch delays for the projects that were to precede us, and a reduced number of Space Shuttles, will result in increased competition for Shuttle launch services.

We do not presently know if we will be able to obtain a place on the Space Shuttle manifest for our planned launch date in 1988. This is a question that cannot be answered until the cause of the Challenger accident has been determined and corrective solutions found to prevent this kind of accident from happening again. Once that has been accomplished, NASA will revise its Shuttle payload manifest and we will know if it is possible to launch Magellan on our desired launch date. A preliminary revision to the Space Shuttle manifest shows Magellan slipping to the 1989 launch opportunity, but the Magellan project continues to work to its present schedule.

A second impact from the Challenger accident involves the use of residual Galileo hardware by the Magellan project. This problem has arisen because the launch of Galileo has now slipped from May, 1986 to a later date. Magellan needs the use of this hardware now. The Magellan project expects to receive the residual hardware according to the previously agreed to schedule, but has taken action to start the procurement of the long-lead items needed to replace this hardware so that Galileo will not be left without its spares.

A New Name for VRM

Following a two year decision-making process at NASA Headquarters, a new name has been selected for the Venus Radar Mapper (VRM) project. The new name is Magellan and we will use MGN as its abbreviation. This name is consistent with NASA's general plan of naming major planetary missions after famous historical persons, such as scientists, astronomers, and explorers. Magellan was deemed an appropriate name for VRM because it connotes exploration, discovery and circumnavigation.

Concurrent with the announcement of the new name, the project is selecting a logo. Various designs for this have been submitted and a panel is evaluating them. The selection will be announced soon.

Magellan Progress

The Magellan Project has been going through a series of reviews as it progresses toward its 1988 launch date. The Final Mission Design Review was held on February 19, 1986 and no major problems were uncovered, according to John Gerpheide, the Project Manager. The Multi-mission Image Processing Laboratory (MIPL) Baseline II Critical Design Review (CDR) was also recently held and this system was judged to be in good shape for handling our needs. Martin-Marietta has successfully completed the CDRs on all of its flight sub-systems, with the exception of one. Everything is looking good for the spacecraft.

However, the Radar Sensor and Alta reviews have revealed some design problems which have been given special attention. This has resulted in a tight schedule for building the Flight Model of the radar. An important interface test for the radar and spacecraft is to start about May.

The CDRs for the Mission Operations System (MOS) and Radar Data Processing System are both planned for the second quarter of 1986 (although the MOS CDR has now slipped a month from its original schedule). The MOS flight operations phase organization has been formed. A "tiger team" for evaluating the telemetry processing subsystem requirements has defined both the high-rate and low-rate requirements.

Significant progress has been made in defining and approving the data products needed by the scientific investigators.

THE MAGELLAN RADAR INVESTIGATION GROUP

Gordon Pettengill

Overview

The Magellan (MGN) Radar Investigation Group (RADIG) has the major responsibility for the radar science of the Magellan Mission. To do its job, the RADIG must participate in the choice of parameters for the radar system, in the design of calibration and test procedures, in planning the in-flight operations that relate to the radar system and, finally, in laying out the processing and presentation of the data. The RADIG must make sure that all aspects of the Magellan mission are capable of producing results that satisfy the scientific objectives of the Project. One of its most important tasks, of course, is to interpret the data resulting from the mission and to publish the results of its studies.

The RADIG is a collection of individual scientists, each having his own perspective and field of expertise. The RADIG will attempt to coordinate each scientist's research activities so that, in sum, they answer the major questions about the geology, geophysics, geochemistry and geological history of Venus, as described below.

The Magellan RADIG was formed out of the Synthetic Aperture Radar (SAR) and Altimetry Investigation Groups of the progenitor Venus Orbiting Imaging Radar (VOIR) Mission, and is composed of 27 scientists and engineers, who were originally chosen by the NASA Headquarters Program Office for participation in the VOIR project. All were subsequently reconfirmed for Magellan. Of these, five are foreign residents and are supported by their own governments. A list of the RADIG members and their affiliations is given in Table 1. Because of the large size of the RADIG membership, an executive subset (identified in Table 1) has been chosen to represent it in the Project Science Group (PSG), which meets quarterly during the years prior to the launch of the spacecraft in April, 1988.

To accomplish its assignment, the RADIG is organized around seven task groups, each responsible for a general task as shown in Figure 1. The task groups themselves cluster into two categories, depending on whether they are primarily concerned with some aspect of Mission design, or with the scientific interpretation of the data when received. We will be hearing more about the plans of these task groups, from their leaders, in future issues of the V-gram.

Most of the MGN data processing will be carried out at JPL, using the Multi-mission SAR Processing Laboratory (MSPL) and the Multi-mission Image Processing Laboratory (MIPL). Some specialized data processing will be done at other institutions, however, and we will hear more about these activities in future V-Grams.

In order to compare the results from the various experiments, it is necessary to establish an accurate geodetic control network for Venus, and to present the various types of radar observations in a cartographic style that is useful for interpretation. The detailed specifications for the imaged and mapped products are

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just now being finalized. The principal data product that will receive wide distribution is a set of 62 maps in the standard 1:5M U.S. Geological Survey (USGS) planetary series. These maps will display the SAR data at approximately 1-km resolution, and will contain altitude contours. Beyond these, a set of about 200 photomosaics will show the entire mapped area of the planet at 225m resolution, while about 250 photomosaics using the highest resolution SAR data (on the order of 100m) will be produced for selected parts of the planet. These maps and photomosaics will be used as the basemaps when presenting data from the other experiments. Complementary data products will include a topographic map at about 10-km surface resolution with a height accuracy of better than 50 m, and special products displaying surface roughness, reflectivity, brightness temperature and emissivity.

In addition to being presented as standard cartographic maps and photomosaics, the radar data from Magellan will also be made available in annotated digital form, thus preserving its full spatial resolution and dynamic range. Careful documentation and archiving of the accumulated results from MGN form an important part of data management for this mission. Not only must the essential results be protected against deterioration over time, but the relevant engineering information needed to understand how these data were obtained must be stored so that future researchers can adequately interpret these data. Also, the system used to store these data must provide easy access for users in the general planetary science community over a period of many years.

Table 1. RADIG Members

Team Member		Affiliation
Raymond E. Arvidson	(PSG)	Washington University
Victor R. Baker		University of Arizona
Joseph H. Binsack		Massachusetts Institute of Technology
Donald B. Campbell		National Astronomy and Ionosphere Center (NAIC), Cornell University
Merton E. Davies	(PSG)	The Rand Corporation
Charles Elachi	(PSG)	Jet Propulsion Laboratory
John E. Guest		University of London
James W. Head, III	(PSG)	Brown University
William M. Kaula		University of California, Los Angeles
Kurt L. Lambeck		Australian National University
Franz W. Leberl		Independent Consultant
Harold C. MacDonald		University of Arkansas
Harold Masursky	(PSG)	U.S. Geological Survey, Flagstaff
Daniel P. McKenzie		Cambridge University
Barry E. Parsons		Oxford University
Gordon H. Pettengill	(PSG)	Massachusetts Institute of Technology
Roger J. Phillips	(PSG)	Southern Methodist University
R. Keith Raney	(PSG)	Canada Centre for Remote Sensing
R. Stephen Saunders	(PSG)	Jet Propulsion Laboratory
Gerald G. Schaber		U.S. Geological Survey, Flagstaff
Gerald S. Schubert		University of California, Los Angeles
Laurence A. Soderblom	(PSG)	U.S. Geological Survey, Flagstaff
Sean C. Solomon	(PSG)	Massachusetts Institute of Technology
H. Ray Stanley		NASA, Wallops Island
Manik Talwani		Gulf Research and Development Co.
G. Leonard Tyler	(PSG)	Stanford University
John A. Wood		Smithsonian Astrophysical Observatory

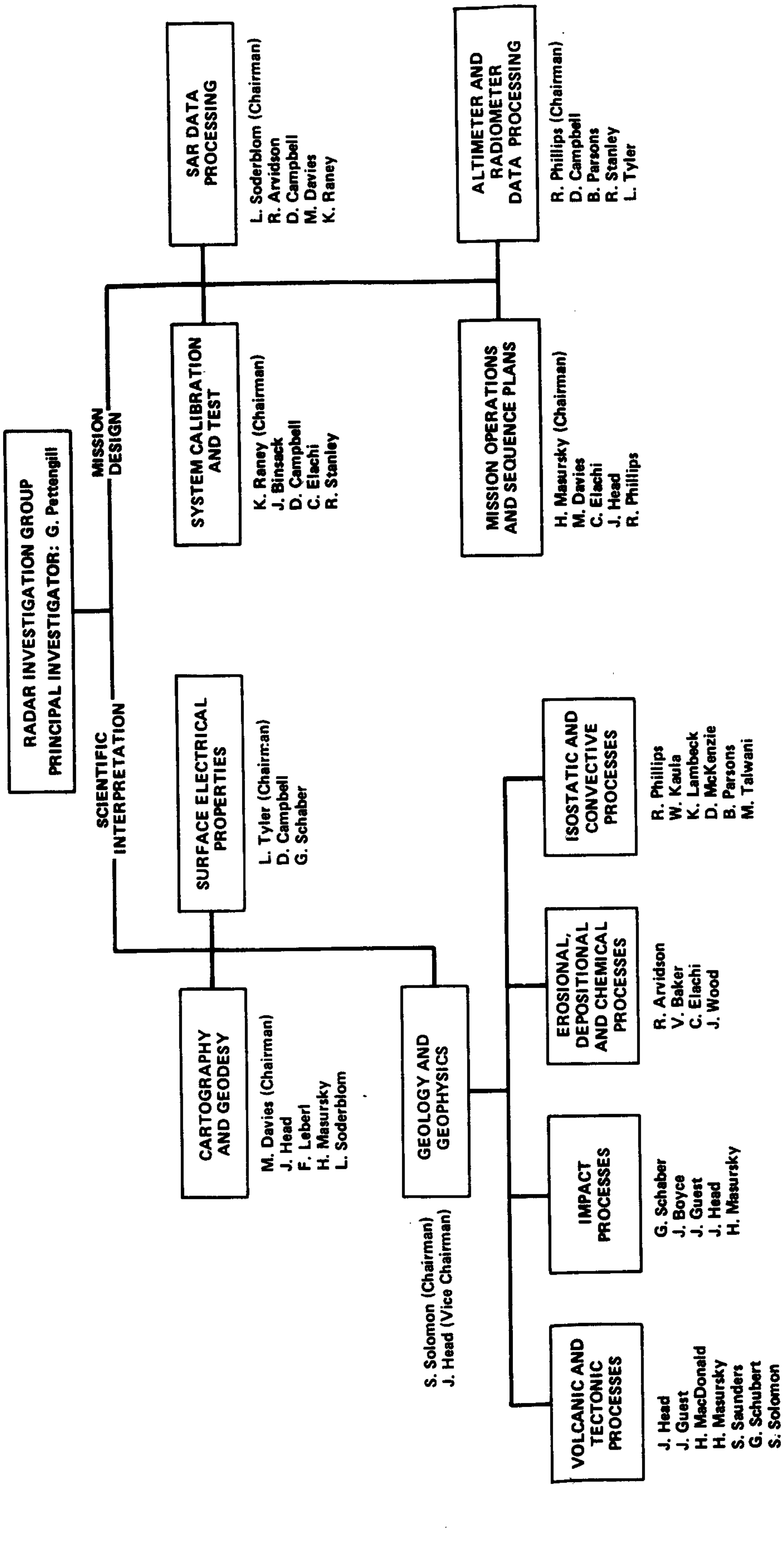


Figure 1. RADIG organization

RADIG Science Investigations

The scientific tasks planned for the MGN Radar Investigation Group (RADIG) are summarized in the following paragraphs. (For more background on the scientific questions behind the Magellan mission please refer to the article entitled, "VRM Science Background," which was published in V-gram Number 6, July 1985.)

Data from the SAR, altimeter and radiometer experiments will be used to identify the major surface units on Venus and to describe, as quantitatively as possible, their radar scattering behavior, radiothermal emissivity and altitude. This description will include not only the mean values of the observed properties, but also their variations within a given surface unit.

The members of the RADIG will identify the types of geological processes that produced the observed surface units on Venus. This characterization will be done based upon experience with the Earth and the other planets, as well as by comparisons with laboratory experiments and computer simulations. This will involve doing a geological mapping of a limited number of areas and a comparison of geological inferences with measurements of various properties of the surface of Venus.

The geologic evolution of Venus will be studied by formulating hypotheses concerning the evolution of geological features in selected study areas, and then testing these hypotheses for consistency with the available data concerning the surface of Venus. These studies will be based upon traditional methods of stratigraphy using superposition relations amongst the surface features to deduce their relative ages.

The members of the RADIG will identify any correlations between inhomogeneities in the gravitational field of Venus and the long-wavelength component of its topography using data from the SAR and altimeter experiments, which will identify specific features on the surface of Venus, and the gravity experiment, which will provide a measurement of the gravitational field of Venus. This effort will be undertaken jointly with the Gravity Investigation Group (GRAVIG), with whom the RADIG will develop hypotheses to explain the observed correlations, as well as methods for testing them.

All of the data from the above investigations will be synthesized and used in an attempt to infer the likely geological and geophysical evolution of Venus as a planet. This synthesis will be used to compare the evolution of Venus to the other planets of the solar system so that we may better understand the history of the solar system and the physical processes occurring on the planets over geologic time.

The following paragraphs discuss some of the specific science questions that will be addressed by the activities of the RADIG.

Volcanic and Tectonic Processes

Earth-based and Venera 15/16 radar images of the surface of Venus have demonstrated widespread evidence for volcanic activity. A goal of the RADIG is to provide a detailed global characterization of volcanic landforms on Venus and an understanding of the mechanics of volcanism in the Venus context. Of particular interest is the role of volcanism in transporting heat through the lithosphere of Venus. While much of this goal will be accomplished by a careful analysis of images of volcanic features and of the geological relationships of these features to tectonic and impact structures, an essential aspect of characterization will be an integration of image data with altimetry and other measurements of surface properties. For instance, since volcanism is highly dependent on lithostatic pressure, it should be possible to determine if variations in load resulting from differences in relief have led to differing styles of volcanism. One possibility is that flood volcanism occurs only in lowland regions, and that shield volcanism is found only in higher areas, with pyroclastic deposits violating this rule. Such ideas will be tested using altimetry data combined with identification of volcanic constructs and flows from the SAR images. Measurements of relief and its associated volume (the areal sum of relief), when combined with knowledge of the local geopotential field, may reveal the geomorphological aspect of magma dynamics. Measurements of longitudinal and transverse slope, flow margin relief, and flow surface relief will also provide powerful constraints on mechanisms and rheological and material properties of lava flows, as embodied in viscous fluid flow models.

A parallel goal is the global characterization of tectonic features on Venus and an appreciation of the tectonic evolution of the planet. This goal addresses issues on several scales. On the scale of individual tectonic features we are interested in the mechanical nature of the faulting process, the documentation of geometry and sense of fault slip, and the relationship between mechanical and thermal properties of the lithosphere. On a somewhat broader scale, we are interested in linking groups of features to specific processes (e.g., uplift, orogeny, gravity sliding, flexure, compression or extension of the lithosphere) and in testing quantitative models for these processes against SAR images and supporting topographic, gravitational and surface compositional data. On a global scale, we are interested in whether spatially coherent, large-scale patterns in tectonic behavior are discernible, patterns that might be related to an organized system of plates or to mantle convective flow.

Impact Processes

The final physical form of an impact crater has meaning only when the effects of the cratering event and any subsequent deformational modification of the crater can be distinguished. To this end, a careful search of the SAR images will attempt to locate and document both relatively pristine and degraded impact craters, together with their ejecta deposits, in each size range, as well as to distinguish impact craters from those of volcanic origin. The topographic measures of depth to diameter ratio, stratigraphic relationships (e.g., a graben that cuts through an older volcano), geomorphological evidence of degradation and counts of crater number-size density all provide information through which the relative temporal evolution of large areas of the surface of Venus can be reconstructed.

Erosional, Chemical and Depositional Processes

The nature of erosional and depositional processes on Venus is poorly known, primarily because the diagnostic landforms typically occur at a scale too small to have been resolved in Earth-based or Venera 15 and 16 radar images. MGN images will be carefully examined for evidence of such processes, including wind-eroded terrains, landforms produced by deposition (e.g., dune fields), landslides and other downslope movements, as well as aeolian features such as radar bright or dark streaks "downwind" from prominent topographic anomalies. One measure of weathering, erosion and deposition is provided by the extent to which soil (e.g., porous material as implied by its relatively low value of bulk dielectric constant) covers the surface. The existence of such material, and its dependence on elevation and geological setting, provides important insight into the interactions that have taken place between the atmosphere and the lithosphere.

The ratio of deuterium to hydrogen in the current atmosphere of Venus is consistent with the hypothesis that Venus had relatively large amounts of water at some time in its geologic past. Because of this possibility, the SAR images from Magellan will be searched for evidence of past episodes of fluvial activity (e.g., drainage systems) and for lakebeds and coastal signatures (e.g., strandlines and ancient river deltas).

The existence of a thick and cloudy atmosphere precludes infrared, visual, ultraviolet, x-ray or gamma-ray observation of the surface of Venus from orbit. Thus, it is impossible to obtain information on a global basis about the surface composition or mineralogy using standard remote-sensing techniques. Measurements of the surface composition at the Venera lander sites is possible, but this provides only highly localized information that is of limited utility when investigating global compositional trends.

Radar and radio observations of Venus from the Earth, and from the Pioneer Venus and Venera 15/16 orbiters, have disclosed that very often the tops of elevated regions possess both anomalously high normal-incidence radar reflectivity (as high as 0.44) and anomalously low radio emissivity (as low as 0.56).

In the absence of liquid water, which is known from a variety of evidence not to be present today on Venus, it is necessary to assume an unusual (in terrestrial experience) surface composition to explain the large values of dielectric constant implied by these observations. The most acceptable of the current hypotheses requires significant amounts of electrically conducting materials in the surface. If these are iron sulfides, as some chemical inference suggests, they may possibly result from volcanic activity. The good spatial resolution of the MGN instrumentation, both in determining the surface reflectivity from the altimetric observations and in measuring the emissivity from radiometric observations, promises to outline the structure of these regions in far greater detail than is now available and may shed light on their origin. These results will be applied to testing hypotheses for regional and global buffering of atmospheric composition by reactions with crustal materials.

Isostatic and Convective Processes

Topography and gravity are intimately and inextricably related, and must be jointly examined when undertaking geophysical investigations of the interior of a planet, where isostatic and convective processes dominate. Topography provides a surface boundary condition for modeling the interior density of Venus.

In the simplest approach, the gravitational effect of topography is removed from the observed gravity (loosely, the free-air gravity), with the resultant Bouguer gravity anomaly becoming a function of the interior density distribution only (assuming a valid density is used in removing the effects related to topography).

A second approach to interrelating gravity and topography involves the dimensionless admittance function, which is the ratio of the spectrum of the free-air gravity to that resulting from the topography alone. Spectrum here means the spatial wavelength dependence, i.e., the spherical harmonic degree and order on a global basis and Fourier wavenumber (or harmonic), on a local or regional basis. The simplest theoretical (model) admittance functions are those associated with isostatic compensation. True mechanical models involve flexure and dynamic compensation against buoyancy flows (i.e., convection) in the interior.

Modeling of the interior density using gravity data is, of course, non-unique. Meaningful interpretation rests on integrating other data sets and/or incorporating specific mechanical models of the interior. For example, a single density structure underlying the known topography cannot be uniquely identified; rather, a multitude of structures can all be modeled. Each of these structures could potentially correctly produce potential fields matching the one observed by the gravity experiment. The interface can be at any depth; the greater the depth, the larger the density contrast. Thus, professional scientific judgement and correlative data from other experiments will be needed to eliminate the implausible models for density structures.

The thickness of the elastic lithosphere of Venus, i.e., that outer region of the planet which behaves elastically over geologically long periods of time, is of special interest. The base of this zone is likely to be defined by a specific isotherm whose location depends on the particular temperature-dependent flow or creep properties of the material underneath. If this isotherm can be mapped in space and time, then models for the thermal evolution of the planet can be developed. The key to determining lithospheric thickness variations in space and time is through flexure studies. If a mass load (e.g., a shield volcano or a mascon) is placed on the planetary surface, then the elastic lithosphere will flex under the load. The controlling parameter is the flexural rigidity which is dependent on the elastic constants and lithospheric thickness.

Crucial to applying estimates of flexural rigidity to the task of unraveling the thermal history is an estimate of when the load was emplaced. Thus, age determinations derived by various geologic techniques are essential to this scheme, despite the known inadequacies of current dating procedures.

RADIG Team Organization

A synopsis of the areas of responsibility assigned to each of the seven Task Groups is given below.

The Cartography and Geodesy Task Group (M. Davies, chairman) will require extensive data sets where the radar observations frequently overlap at high latitudes, in order to set up a preliminary geodetic control network for the planet on which the USGS maps may be laid, and from which improved estimates of pole position and rotation rate may be derived.

The Surface Electrical Properties Task Group (G. L. Tyler, chairman) will work with the radar scattering intensities obtained from both the SAR and altimetry operating modes, as well as with the thermal emission data obtained from the radiometry mode, in order to determine the electrical properties of the surface.

The Geology and Geophysics Task Group (S. Solomon, chairman) is charged with meeting the scientific objectives which constitute the core of, and have largely justified, the Magellan Mission. With 19 members, it is by far the largest of the task groups. Because of its size, it has been broken down into four subgroups: a) Volcanic and Tectonic Processes; b) Impact Processes; c) Erosional, Depositional and Chemical Processes; and d) Isostatic and Convectional Processes. While these specialized processes provide a convenient framework, it is recognized that many, if not most, studies of the surface and interior will embrace more than one of them. Participation in these subgroups, and the consequent division of effort among the task group's membership, will be fluid.

The System Calibration and Test Task Group (R. K. Raney, chairman) is responsible for monitoring the radar test procedures and associated support equipment established by the Project and its contractors. While not carrying the prime responsibility for the performance of the radar system, this Group will provide advice from the users' point of view and will attempt to make sure that the calibration and performance of the radar meet the needs of the scientists.

The SAR Data Processing Task Group (L. Soderblom, chairman) is charged specifically with monitoring the design of the algorithms and data flow involved in the Multimission SAR Processing Facility's handling of Magellan SAR data.

The Altimeter and Radiometer Data Processing Task Group (R. Phillips, chairman) monitors the algorithms and data flow from the altimeter and radiometer instruments through the various processing steps to a final product.

Finally, the Mission Operations and Sequence Planning Task Group (H. Masursky, chairman) is charged with closely monitoring the Project's plans for scheduling and operating the spacecraft once in orbit, in order to ensure maximum surface coverage and scientific return from the radar component of the mission.

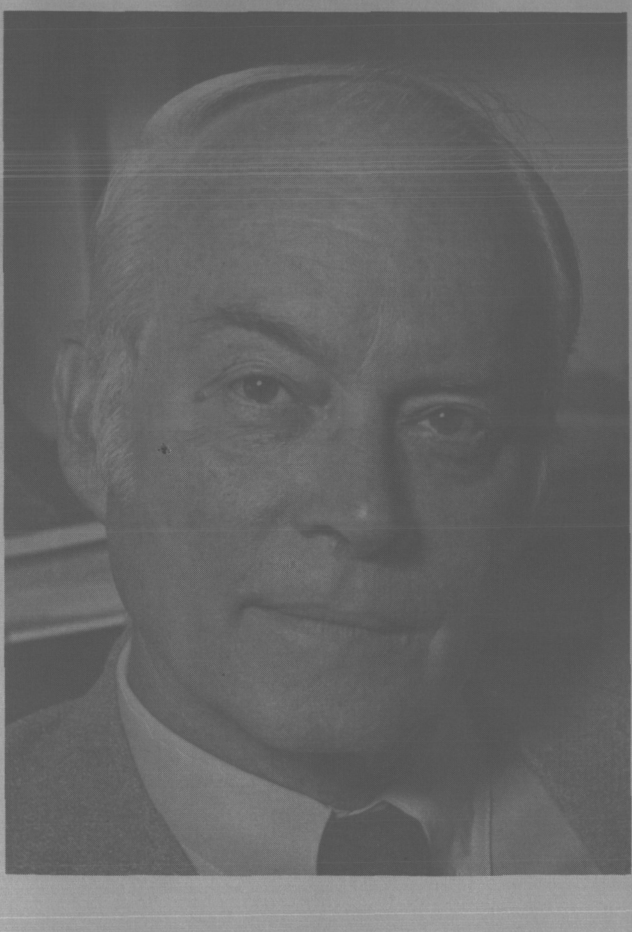
While not formally under the RADIG's control, the Data Products Working Group (DPWG), reporting directly to the PSG, plays a very important role that interlocks strongly with the RADIG Task Groups. The DPWG coordinates the data needs of both the RADIG and the Gravity Investigation Group (GRAVIG) and makes recommendations to the relevant Project facilities as to the form and distribution of the final digital and photographic products. The function and decisions of this important Group will be described in later issues of the V-Gram.

Biography

Dr. Gordon H. Pettengill, Principal Investigator for the radar experiments carried on the Magellan Project, is probably best known for his discovery in 1965 of the 3/2 spin-orbit resonance of Mercury, using radar astronomical techniques. In fact, his name has also been closely linked to much of the development of radar astronomy since its early years in the late fifties. Beginning with the first application of coherent earth-based radar to studies of the moon in 1959, his observations have embraced Mercury, Venus, Mars, several asteroids and comets, the Galilean satellites of Jupiter and the rings of Saturn. He was the Principal Investigator for the Radar Mapper Experiment carried out on the Pioneer Venus Orbiter from 1978 through 1981.

Dr. Pettengill received a B.S. in physics from MIT in 1948, and a Ph.D. in physics from U.C. Berkeley, in 1955. Since then he has been affiliated primarily with MIT, first with Lincoln Laboratory and then, since 1970, as a Professor in the MIT Dept. of Earth, Atmosphere and Planetary Sciences. Leaves of absence enabled him to serve as Associate Director, 1963 - 1965, and as Director, 1968 - 1970, of the Arecibo Observatory in Puerto Rico. Since 1984 he has been Director of the MIT Center for Space Research.

Dr. Pettengill is a member of both the American and National Academies of Science, and currently lives with his family in Concord, Massachusetts.



The Magellan Gravity Investigation Group

William Sjogren
Warren W. James

Overview

The Magellan Gravity Investigation Group (GRAVIG) is a group of 9 investigators who are responsible for the determination of the gravity field of Venus using the Magellan spacecraft. They will do this by analyzing data from the Earth-based Doppler radio tracking of the Magellan spacecraft during the orbital phase of its mission. This group will work in conjunction with the Radar Investigation Group (RADIG) to develop models of the internal structure of Venus that fit the gravity observations. These models will also incorporate measurements of the surface topography and structure of Venus as measured by the Magellan SAR and altimeter and will be constrained by deductions based on geological and geomorphological studies of the Synthetic Aperture Radar (SAR) images. These models, in turn, will constrain scenarios for planetary formation and thermal history and will serve as an important source of information for comparative planetology studies.

The GRAVIG is composed of two teams of American and French scientists who will use different software and data reduction techniques to analyze the gravity data. The use of independent analysis techniques will provide important cross checks on the calculations and improve our confidence in the estimated gravity field parameters and modeling results.

Unlike the members of the RADIG, who will receive their primary data during Magellan's nominal mission, the members of the GRAVIG will have to wait for the extended mission before they can obtain their primary data. Magellan's nominal mission will be the first 251 days following Venus Orbit Insertion (VOI). This will provide eight days to check out the spacecraft following its arrival at Venus and 243 days to map the entire planet. The extended mission will be that portion of the mission starting 252 days after VOI. The reason for this is explained by the way that the gravity data is obtained.

In order to obtain any gravity data the spacecraft must be continuously tracked, with its high-gain antenna pointed toward the Earth so that it can serve as a tracking transponder. The highest resolution gravity data will be obtained when the spacecraft is at its closest range to Venus, i.e., when the spacecraft is near the periapsis of its orbit. However, during the nominal mission, the time around periapsis will be dedicated to obtaining SAR images of the surface of the Venus and the high gain antenna will be pointed toward Venus so that it can be used to obtain those images. Since the high gain antenna cannot be pointed toward the Earth for tracking purposes during the near periapsis part of the spacecraft orbit during the nominal mission it will be impossible to obtain high resolution gravity data during that phase of the mission. However, during the nominal mission there will be a period of two hours on each orbit where higher altitude gravity data will be acquired. These data will be obtained as a part of the normal spacecraft tracking activities and will be used in conjunction with Pioneer Venus Orbiter data to produce a revised model for the global gravity field of Venus. The acquisition of high resolution gravity data must, however, wait for the extended mission.

The low resolution gravity map obtained during the nominal mission will be somewhat degraded because of two constraints related to the orbital geometry of the Magellan mission. First, during the first 100 days of the mission the spacecraft will be occulted for short periods during the times when the gravity data can be obtained. This will cause the loss of modest amounts of tracking data, which will in turn cause a degradation of the gravity data. Second, toward the end of the primary mission the sun will be between Venus and the Earth (this is called solar conjunction) and radio frequency interference from the sun will degrade the tracking data significantly and lower its quality.

However, the nominal mission will end following solar conjunction and it will then be possible to obtain good gravity data during the extended mission. Starting 390 days after VOI there will be a period of 260 days during which the orbital geometry will allow the acquisition of high quality tracking data. Additionally, by that time the primary objective of the mission, i.e., mapping over 70% of the surface of Venus at better than 1 km resolution, will have been completed. It will then be possible to use the periapsis parts of the spacecraft orbit to obtain gravity data instead of SAR imaging. However, the acquisition of gravity data will not require the use of all of the spacecraft orbits, so it will be possible to mix in the acquisition of supplemental SAR imaging observations with the acquisition of the gravity data, i.e., on each day one orbit could be used to obtain gravity data and seven orbits could be used to obtain SAR images. This period of time will be sufficiently long to allow the acquisition of high resolution gravity data through 360° of Venus longitude. It is during this time that the members of the GRAVIG will obtain their primary data.

GRAVIG Scientific Objectives

Gravity and altimetry data obtained from the Pioneer Venus Orbiter (1978-1982) have laid the present foundation for the geophysical modeling of the Venusian interior. There is a significant correlation between the gravity field of Venus and its topography. This is very different from the situation on the Earth, the Moon or Mars. All of these planets have different amounts of correlation between their topography and the large scale structure of their gravitational fields. This fundamental difference suggests that there are major differences between the processes acting within Venus and these other objects. The amplitude of the gravity anomalies on Venus are comparable in amplitude to those observed on the Earth, although they are much smaller than those observed on the Moon and Mars.

The objectives of the GRAVIG will be to enhance the existing gravity data set so that more detailed modeling can be performed. These models will be used in an attempt to answer such scientific questions as:

1) What is the nature of mantle convection in Venus?

2) To what extent is the continental sized feature known as Aphrodite in isostatic equilibrium?

3) How does the thickness and flexural rigidity of the lithosphere vary with location and geologic province?

4) What is the deep structure of Beta Regio and Alta Regio that causes their large gravity anomalies?

The analysis of gravity data alone (i.e., without correlation with other data types) can provide a basic picture of the mass distribution within Venus, including the orientation of its moments of inertia and the roughness and power spectrum of its gravity field. However, to go beyond that basic picture will require the combined efforts of both the GRAVIG and RADIG teams. Working together they will produce realistic geophysical models that are consistent with observations from all relevant instruments. For example, SAR imaging of specific structures will provide important constraints on the interpretation of the associated gravity anomalies. The altimeter will supply topographic data, but assumptions must be made concerning the density of the topography to estimate the loads on the lithosphere. However, the gravity experiment will provide data that can constrain those assumptions. The response of the elastic lithosphere of Venus to those applied loads will be reflected in the signature of the gravity data and will allow geophysicists to model the properties of the interior of Venus.

Since the models used to explain the gravity data are intrinsically non-unique (i.e., it is always possible to generate more than one model that can explain any set of gravity data), the members of the GRAVIG will rely heavily on the other experiments to help constrain the model parameters to realistic values. This will rule out some models and add relevance to others, thus permitting more credible inferences to be made on the planet's structure and evolution.

GRAVIG Data Requirements

The data required for the gravity experiment consists primarily of Earth-based, 2-way coherent Doppler radio tracking of the orbiting spacecraft at an X-Band frequency. During the nominal mission these data will be obtained when the spacecraft is not near the periapsis part of its orbit; they will be used to determine the orbit of the spacecraft and to produce a low resolution gravity map of the planet. If X-Band data cannot be obtained, S-Band data will be used.

Additional data will be needed in order to reduce the raw tracking data. This data will involve accurate mass and cross section measurements of the spacecraft, descriptions of the spacecraft attitude as a function of time (these are needed in order to properly account for solar pressure and atmospheric drag perturbations on the spacecraft orbit), data concerning any spacecraft propulsive maneuvers (so that changes in the spacecraft orbit caused by those maneuvers can be separated from perturbations caused by the gravitational field of the planet), information relating to the performance of the radio system, and accurate descriptions of the locations of the Deep Space Tracking Network (DSN) antennas (these are needed to properly convert the tracking data into a measurement of the acceleration of the spacecraft).

During the extended mission it will be possible to track the spacecraft during the near-periapsis portion of its orbit and thus obtain high resolution gravity data. The spatial resolution of the gravity data has approximately the same scale as the altitude of the spacecraft during the time when it is being tracked. Thus, when tracking the spacecraft during periapsis, it will be possible to obtain gravity data with a spatial resolution of approximately 250 km. The frequency of the near-periapsis trackings is controlled by the time that it takes for the spacecraft ground track to move approximately 250 km so that new parts of the planet's gravitational field can be sampled. Since the spacecraft will shift accelerations will then be compared to the accelerations that would be produced by various models for the density structure of the Venusian interior. These models will incorporate the topography data produced by the altimeter experiment and other constraints and assumptions as agreed upon by the GRAVIG and RADIG working groups.

Although the above three approaches will be emphasized during the primary mission, other analyses combining the existing Pioneer Venus Orbiter data with the Magellan data will also be performed.

Whereas the American team will be estimating new parameters for the gravity field of Venus using just the data from the Magellan mission, the French team will combine the previous Pioneer Venus Orbiter data with the Magellan data so that they can produce a gravity field estimate for Venus. Their model will use spherical harmonic coefficients to describe the field.

Since all of the French software is independent of the American software, any similarity in the results from the two teams will significantly increase the confidence in the results. This is similar to activities that were done previously with the analysis of the data relating to the Martian gravitational field obtained by the Mariner 9 and Viking spacecraft.

In the extended mission, when high resolution data from periapsis are obtained, solutions for spherical harmonic coefficients of degree and order 18 to 36 will be attempted using additional data from the Pioneer Venus Orbiter. Once the gravity field parameters (i.e., the spherical harmonic coefficients for the Venus gravity field) are established, a combined effort of the French-American GRAVIG team members and the RADIG geologists and geophysicists will produce models for "best-fit" parameters to gravity, topography, and other geophysical constraints.

In addition to being scientifically interesting in their own right, the refined gravity field models may make it possible to reprocess and improve some of the altimeter and SAR data using more accurate estimates of the spacecraft trajectory. This could significantly improve the quality of those other observations.

Data Products

The data products that will be produced by the GRAVIG using the processed Doppler tracking data will include the following items:

1.) Spherical harmonic coefficients that will describe the geoid of Venus. The coefficients and their uncertainties will be tabulated on hard copy and on magnetic tape.

2.) Line-of-sight accelerations on each orbit of periapsis data. It is anticipated that no data will be acquired during the primary mission, but at least one orbit per day will be acquired after VOI + 390 days. These will be plotted on hard copy and magnetic tape (see figure 1).

3.) Gravity field power spectrum (see figure 2).

4.) Gravity anomaly map (in milligals).

5.) Geoid map (in meters) (see figure 3).

Products that will result from combining gravity and topography data will include:

1.) Bouguer gravity maps.

2.) Isostatic anomaly maps.

3.) Admittance function curves.

4.) Parameter values for proposed internal structure models.

Organization of the GRAVIG

The American component of the GRAVIG is lead by Mr. William Sjogren of the Jet Propulsion Laboratory (JPL). Mr. Sjogren is the Principal Investigator for the American portion of Gravity Investigation, along with Dr. Mohan Ananda as a Co-Investigator. Two additional team members will be selected during the operations phase of the mission. One will be a navigation analyst who will coordinate the interface between data processing and

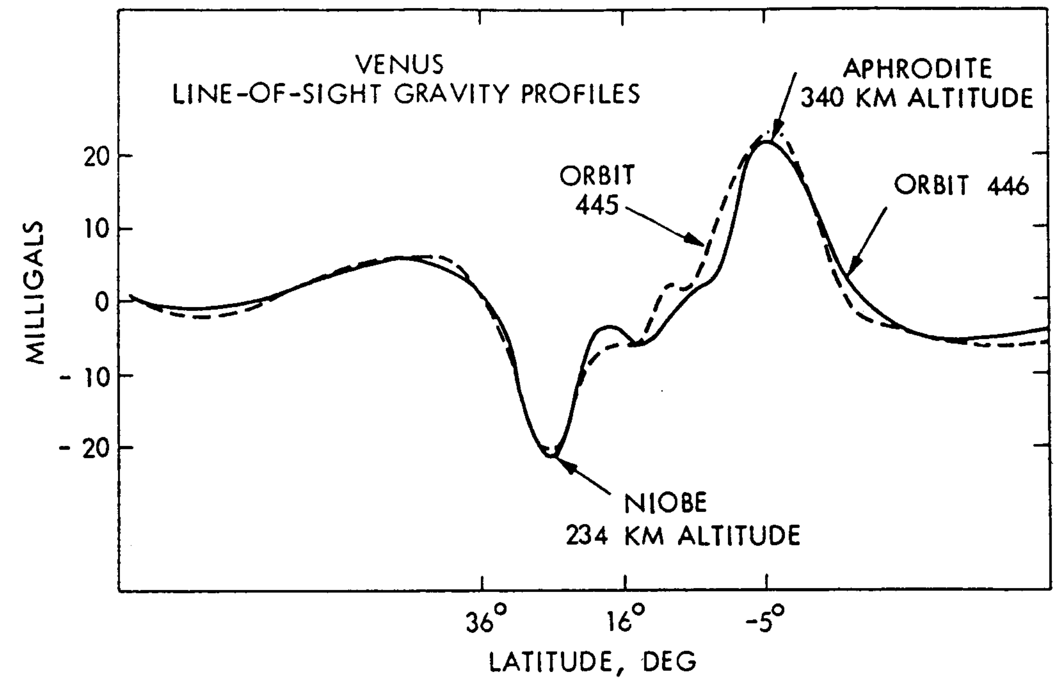


Figure 1. Acceleration profiles from Pioneer Venus Orbiter

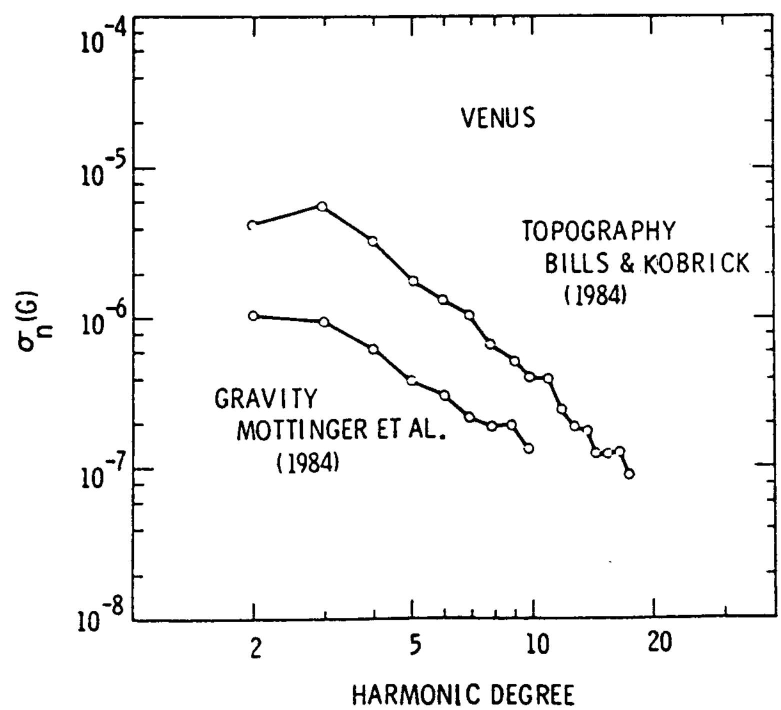


Figure 2. Power spectra from Pioneer Venus Orbiter

navigation and the other will be a geophysicist who will help with the definition of internal structure parameters.

Mr. Sjogren will lead the activities for the Gravity Investigation and will coordinate the gravity experiment between the GRAVIG and the project. He will also monitor the X-Band downconverter system to assure that quality data are received for the experiment. He will inform the French team of current status, problems, etc. so that effective communications are maintained between the two elements of the GRAVIG. He will review all aspects of the American effort and be most heavily involved in the detailed correlation of gravity and altimetry. He will be responsible for monitoring all reports produced by the GRAVIG.

The work of Dr. Ananda will primarily involve the study of the gravity field of Venus by the analysis of the variations in the orbital elements of the spacecraft orbit. Therefore he will be responsible for the software development, checkout and data reduction results for this effort. He is presently associated with the Aerospace Corporation.

One of the new GRAVIG members will be responsible for the overall software checkout to assure the possibility of exchanging the inputs and outputs between the various software packages used by the GRAVIG. This will be needed to cross-check their results. This will be done for both the United States and the French software. This person will also be involved with the correlation between the gravity and altimetry data, as well as providing geophysical interpretation for all gravity reports.

The other new GRAVIG member will coordinate the activities between the GRAVIG and the navigation team. During real time operations he will monitor data acquisition and quality. He will select the data set for the 6th degree and order spherical harmonic field reduction, and be responsible for the final report on this solution.

The French portion of the GRAVIG is led by Dr. Michel Lefebvre, who is the Principal Investigator for the French group. He has three Co-Investigators: Dr. Georges Balmino, Dr. Nicole Borderies and Mr. B. Moynot, as well as a technical aide, Mrs. N.

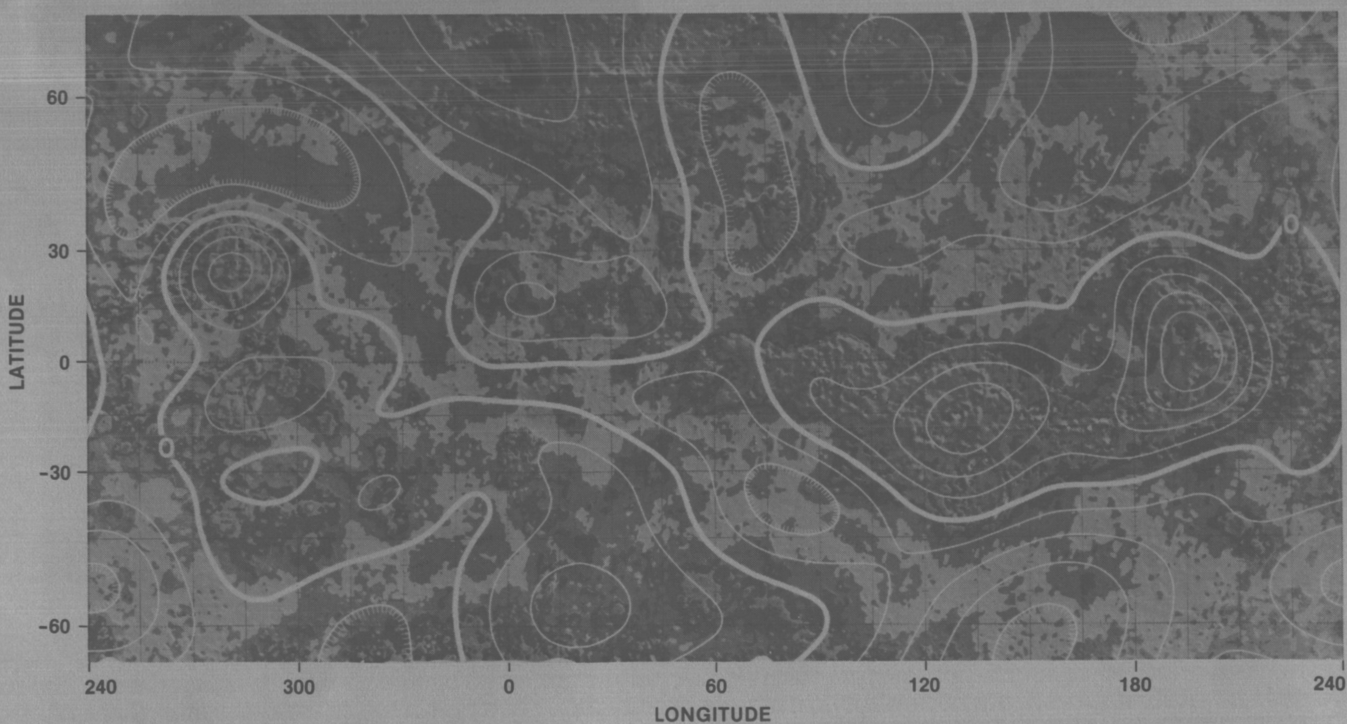


Figure 3. Geoid map as determined from Pioneer Venus Orbiter data (10th degree + order)

Vales. They all reside in Toulouse, France and work for CNES, the French space agency. All costs of the French team (i.e., salaries, travel, data analysis, etc.) are paid for by the French government.

Dr. Lefebvre will provide coordination between the geophysical investigations of the French and U.S. Teams. He will assist in developing functional requirements for the gravity investigation, perform data analysis and interpretation for the Gravity Investigation and serve on the Project Science Working Group.

Dr. Balmino will be responsible for producing the French results on the spherical harmonic coefficients of the gravity field and will participate in the geophysical analysis of the data.

Dr. Borderies will participate in software modifications needed for the implementation of VLBI and Delta-VLBI data processing. She will participate in the analysis and interpretation of the tracking data for gravity and geophysics of the interior of Venus.

Mr. Moynot will participate in the computation of the spherical harmonic coefficients of the Venus gravity field. He will be responsible for providing the error model for the geophysical modeling.

Mrs. Vales will provide technical help for software modifications, data archiving and data processing.

Biography

William L. Sjogren joined the staff of the Jet Propulsion Laboratory in 1962 after completing his MS in Applied Math at Northwestern University in Evanston, Illinois. Initially his efforts involved the navigation of the Ranger and Lunar Orbiter missions. In 1965 he became involved with gravity field determinations and subsequently in 1968 he and a JPL colleague discovered the lunar mascons. Since then he has been continually involved with planetary data analysis, being the Principal Investigator for the gravity experiments on Apollos 14-17, Viking, Pioneer Venus Orbiter and Magellan. He has twice received the NASA Scientific Achievement Award and was the recipient of the Magellanic Premium of the American Philosophical Society. He has been on numerous NASA working groups and is now on the NASA Planetary Cartography Working Group. He is a member of the IAU, AAS, AGU and Sigma Xi. He is presently the supervisor of the Solar System Dynamics Group in the JPL Navigation Systems Section.

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