Planetary Science Institute

Tucson, Arizona 85705

The Planetary Science Institute (PSI) is a non-profit research and educational institute with divisions in Tucson, AZ, Laguna Niguel, CA, and Seattle, WA. PSI conducts a wide variety of basic research and educational activities in planetary science, geology, astronomy, and astrophysics. For more information about PSI, see the Institute web site at **www.psi.edu**.

The following report covers Institute activities from November 2001 through October 2002.

1. SCIENTIFIC STAFF

Dr. Donald R. Davis, Senior Scientist, PSI Director
Dr. Thomas McCord, Senior Scientist, NW Division Director
Dr. Steve Howell, Senior Scientist,
Head of Astrophysics Group
Dr. David A. Crown, Senior Scientist
Dr. Gary Hansen, Senior Scientist
Dr. William K. Hartmann, Senior Scientist
Dr. Stuart J. Weidenschilling, Senior Scientist
Dr. Bruce Betts, Research Scientist
Dr. Jennifer Grier, Research Scientist
Dr. Charles (Karl) Hibbitts, Research Scientist
Dr. Steve Kortenkamp, Research Scientist
Dr. Melissa Lane, Research Scientist
Dr. Carol Neese, Research Scientist
Dr. Elisabetta Pierazzo, Research Scientist
Dr. Elizabeth Turtle, Research Scientist
Dr. Cathy Weitz, Research Scientist
Dr. Mark Everett, Postdoctoral Researcher
Kunegunda Belle, Graduate Research Assistant
Daniel C. Berman, Graduate Research Assistant
Mark Huber, Graduate Research Assistant

2. STAFF CHANGES IN 2002

The Northwest Division of the Planetary Science Institute was formed in January. It currently consists of three researchers: Drs. Gary Hansen, Charles Hibbitts and Thomas B. McCord (Division Director). The Division's offices are located near Winthrop, WA. The NW Division conducts basic research into the origin and evolution of the solar system, and it is heavily involved in five NASA and ESA space missions, including Galileo, Cassini, Mars Express, Rosetta, and DAWN.

David Crown joined the Mars group in Tucson this spring and is setting up a Mars lab for photo-geological interpretation.

Elisabetta Pierazzo joined PSI as a full-time Research Scientist in February 2002.

Elizabeth Turtle joined PSI as a part-time Research Scientist in June 2002.

Graduate students Kunegunda Belle and Mark Huber received their Ph.D.'s during 2002. Dr. Huber left to take a postdoctoral position at the University of British Columbia.

3. RESEARCH PROGRAMS

3.1 Origin and Evolution of the Solar System

PSI continues to be an active center for research into the origins of the bodies in our solar system and planetary systems in general. Dr. Davis was first author of a chapter on the collisional evolution of small body populations for the forthcoming book, *Asteroids III*, in the University of Arizona Press Space Science Series.

Weidenschilling has investigated the formation of binary objects in the outer fringes of the solar system. Recent observations have shown that about 1% of the known population of bodies in the Kuiper belt beyond Neptune consists of gravitationally bound pairs. Typically two nearly equal-sized objects of diameter $\sim$ 100 km orbit each other with separation of tens of thousands of km, and an orbital period of several years. They appear to be primordial, surviving from the beginning of the solar system. Weidenschilling showed that during the growth stage of planetesimals when orbital eccentricities were low, there was a substantial probability that any collision between two such bodies occurred in the vicinity of a third body. Most collisions dissipated enough energy so that the merged body would remain gravitationally bound to the other. This process appears to be efficient enough to explain the observed abundance of trans-neptunian binaries. These results are in press in *Icarus*.

Weidenschilling has continued studies of the early evolution of the asteroid belt. Short-lived radioactive elements that were present in the early solar system were an important energy source that could cause heating and melting of planetesimals. The lifetimes of these elements were comparable to the timescale for accretion in the asteroid region, so the thermal histories of asteroids depended on how fast they grew. Weidenschilling has collaborated on this problem with A. Ghosh and H. Y. McSween, Jr. (U of Tennessee), who used results from the PSI accretion code as inputs for their thermal modeling. This approach provides more realistic estimates of temperatures within asteroids, and has promise of explaining many properties of meteorites. A paper is in press in *Meteoritics and Planetary Science*.

Kortenkamp has been working with Renu Malhotra (U of Arizona) and Doug Hamilton (U of Maryland) studying the origins of small solar system bodies with the intention of developing better constraints on theories of giant planet formation and early evolution. There are three specific populations of small bodies that Kortenkamp's group is currently investigating — existing Trojan asteroids of Jupiter, missing Trojan-type objects of Neptune, and irregular satellites of the giant planets. The conventional mechanism of Trojan formation is solar nebula gas drag trapping of planetesimals into 1:1 resonance with a protoplanet. Kortenkamp's numerical modeling of the Trojan formation process revealed that a significant fraction of planetesimals could be temporarily trapped very near the protoplanet in an unusual 1:1 co-orbital resonance. These resonant planetesimals can have very low-velocity encounters with the protoplanet in either the prograde or retrograde direction. A tenuous circumplanetary disk would aid the protoplanet in accreting planetesimals from this resonant population. Kortenkamp suggests that this resonant accretion process could help protoplanets reach Neptune- to Uranus-mass and possibly account for the numerous prograde and retrograde distant irregular satellites of the giant planets.

McCord, with collaborators T. Suntharampillai (PNNL) and T. Orlando (Georgia Tech), is leading an ongoing effort to understand the behavior of hydrated and hydroxylated minerals and molecules on solar system object surfaces, especially on Mars and beyond. The effort has so far concentrated on hydrated salt minerals that the division team has reported as present on Europa and Ganymede. During the past year, the team has conducted several experimental sessions at both the Pacific Northwest National Laboratory (PNNL) in Richland, WA and at a Georgia Institute of Technology laboratory in Atlanta, GA. These sessions were directed at determining the thermal stability and the behavior of hydrated salt minerals under electron and ion bombardment.

Hibbitts began a program to determine mechanisms by which the CO_2 and SO_2 found on the icy Galilean satellite surfaces might be produced. The PNNL facilities are used to bombard spectral analogues of the non-ice material(s) on these satellites (some containing carbon) in vacuum with MeV ions of hydrogen, oxygen, and sulfur. Two experimental runs were made over the past year and the results are under analysis.

McCord and C. Sotin (U of Nantes, France) carried out a program to put bounds on the possible thermal evolution scenarios that objects like Ceres might have followed. The goal is to predict the surface and interior conditions of Ceres to help plan the DAWN mission. This past year an attempt was made to determine the best known properties of Ceres and develop a review of these. They used and modified Sotin's thermal evolution models, originally developed for Titan, to treat Ceres. An article describing the results is in preparation.

Pierazzo is contributing to the origin and evolution research through her studies of how impacts affect water content over the age of the solar system in planetary bodies, in collaboration with Canup (SwRI) and Asphaug (UC Santa Cruz), and in asteroidal regoliths, in collaboration with Rivkin (MIT) and Horz (NASA-JSC), and Cintala (NASA-JSC). She also continues investigating the role of impact cratering in the evolution of planetary surfaces, in collaboration with the U of Arizona impact group led by Melosh.

In terms of origin and evolution of planetary biospheres, Pierazzo is continuing her research on the environmental and climatic effects of large impacts on the Earth, in collaboration with Hahmann (U of Arizona) and Sloan (UC Santa Cruz), and on the delivery of complex organic material on planetary surfaces, in collaboration with Chyba (SETI Inst.).

3.2 Mars Research

Hartmann remains on the imaging team of NASA's Mars Global Surveyor project and pursues Martian surface cratering chronology and evolution. He received the Runcorn-Florensky Medal at the meeting of the European Geophysical Union in Nice in April 2002, shared with G. Neukum (Max Plank Inst), for their joint work on Mars cratering chronology. Hartmann organized a second week-long workshop at the International Space Science Institute (ISSI), Bern, with I. Nemtchinov and O. Popova (Inst. for Dynamics of Geospheres, Moscow), to model crater clusters on Mars. Hartmann also pursued work on evidence from lunar meteorites and other sources, raising doubts about cataclysmic cratering of the moon 3.9 Gy ago. Papers on these topics are in press or submitted.

Crown pursues research in planetary geology, physical volcanology, and remote sensing. Current studies focus on various topics regarding the geology and geologic history of Mars, including eruption styles and volcanic history, formation of outflow channels, emplacement and climatic implications of debris aprons, and highland degradation. Crown is also presently involved in the production of geologic maps of quadrangles on Mars (ten 1:500K-scale quadrangles) and Venus (two 1:5M-scale quadrangles) as part of a collaborative program between NASA and the US Geological Survey (USGS). Additional work includes studies of volcanic terrains on Earth, Mars, Venus, and Io using a combination of field investigations, remote sensing, statistical analyses, and lava transport models.

Lane's research concerns the search for and identification of sulfates and chlorides on Mars. Her approach is to study sulfate and chloride minerals in the laboratory using a thermal emission spectrometer, an instrument that simulates the Thermal Emission Spectrometer (TES) on Mars Global Surveyor and the Thermal Emission Imaging System (THEMIS) on Mars Odyssey that are both currently in orbit around Mars. Having been selected as a Participating Scientist for the Mars Odyssey mission, Lane is studying the newest data from THEMIS to investigate the presence of salt minerals on Mars. In addition, she has been investigating the utility of the visible and thermal images from THEMIS for conducting crater population studies for estimating the ages of the exposed Martian surfaces. Finally, she has been working on understanding the geologic processes that generated the coarse-grained hematite mineralogy detected in the equatorial regions of Mars.

Weitz is currently a visiting scientist at NASA Headquarters. She is the Program Scientist for the Mars Exploration Rover (MER) and Mars Express missions. She is responsible for overseeing the science on these missions and was recently involved in the selection of new scientists to the MER mission. In addition to her duties at Headquarters, she also finds time to do research on Mars, including mapping a potential landing site for the MER mission in Melas Chasma. She is now working on rock coatings from Hawaiian and Mt. Etna basalts for comparison to spectra taken of Mars surfaces. Weitz is also a Co-Investigator on the HiRISE camera that will fly to Mars as part of the Mars Reconnaissance Orbiter spacecraft in 2005.

Grier is leading a project to assess relative and absolute chronologies of the various volcanoes in the Tharsis region of Mars. In particular, she is examining effects of high altitude dust drifts, observed on Olympus Mons and other volcanoes, in the preservation of impact craters.

Hansen is leading a project to determine infrared optical constants for Martian dust, needed for modeling dusty polar deposits. These are derived from infrared aerosol dust spectra returned by Mariner 9. He is also studying the composition, physical properties, and radiative balance of the Martian polar caps, as revealed by data from the infrared spectrometer on the Mars Global Surveyor spacecraft. MOLA and MOC data are also used to help determine surface brightness at shorter wavelengths.

Turtle, Hartmann, Crown, and A. Pathare (UCLA) are combining spacecraft observations and numerical modeling to investigate the formation of debris aprons and softened terrain on Mars. Initial results, reported in several abstracts, indicate short timescales (2×10^4 years) for deformation in typical Martian systems, which in turn raises questions of ice sources in systems that appear to be very young.

Turtle, Crown, and undergraduate student J. Greenham (Caltech) worked to characterize in detail the debris aprons and softened impact craters observed east of the Hellas impact basin.

Berman has been involved in several crater-counting projects and has worked with Crown on studies of debris aprons. A paper by Berman and Hartmann, on the history of the Marte Vallis system of young fluvial outflow channels, appeared in *Icarus* this year.

3.3 Solar System Observational Programs

McCord, Hibbitts, Hansen, and graduate student K. Stephan (DLR, Berlin) are studying hydrated non-ice material on Ganymede using the NIMS spectra and the new calibrations developed by the NW Division. Stephan contributed a presentation on the subject to the European Geophysical Society meeting in Nice in April and at the EuroJove Conference in Lisbon in June.

Hibbitts led an effort to determine the spectral nature and identify the composition of the non-ice material on Callisto. This involves removing the effects of water ice on the spectra of areas of the Callisto surface and analyzing the residual.

Hansen is studying the occurrence and distribution of amorphous and crystalline ice on the icy Galilean satellites, using Galileo NIMS spectra. It is envisioned that other properties such as absolute abundance and grain size will also be obtainable, once the NIMS spectra have an improved calibration.

Davis and Neese, with collaborators Gladman, Holman, Scholl, and Petit, continued their program to characterize the size distribution of small mainbelt asteroids. The data, taken during an observing run at the KPNO 4-m telescope with the MOSAIC camera in March 2001, included over 500 mosaic images covering an area of nine square degrees to a limiting magnitude of about R=23.5. During the first half of 2002, a massive automated moving-object detection program was used to detect the asteroids in all these frames and calculate photometry and astrometry for them. Approximately 1000-1300 asteroid detections were made on each night of the run, which tracked the same set of asteroids from night to night. These detections are now being linked across the ten-night time-base of the run to determine rough orbits for the asteroids. This program will result in the determination of the mainbelt size distribution down to sub-kilometer sizes.

3.4 Astrophysics Program

Observational work was continued by Howell and collaborators P. Szkody (U Washington), B. Gänsicke (U of Southhampton) and E. Sion (Villanova U). They obtained the final cycle of HST STIS spectra for their large project on determination of the temperature, mass, and other properties of white dwarfs residing in cataclysmic variables. Results show that, in general, the shortest orbital period systems have the oldest, coolest white dwarfs. Some stars show evidence for accretion belts and most appear to have non-solar abundances.

Howell and Everett finished their initial analysis of a study of ultra-high precision ($\sim$ 1 mmag) CCD photometry as a precursor to a planned search for transits by extra-solar planets. This search is expected to start in 2003 and to make use of the 1.3m telescope located on Kitt Peak, in collaboration with C. McGruder (Western Kentucky U). Refurbishment of this telescope facility has occurred over the past 1.5 years including complete rewiring, all new computer equipment and control, optics recoating, and a new CCD camera. The 1.3-m telescope is run by a consortium consisting of Western Kentucky University, Villanova University, South Carolina State University, and the Planetary Science Institute.

Howell, T. Harrison (New Mexico State U) and A. Adamson (JACH) continued their work on IR spectroscopy of the mass donor stars in interacting binaries, and have noted that many seem to have odd abundances, consistent with CNO processed material. During this interval, the first IR time-resolved spectroscopy of a CV in superoutburst was obtained, revealing spiral structures in the accretion disk. Two CVs were observed which are in a non-interacting state, and optical and IR spectroscopy show them to be white dwarf / brown dwarf pairs.

Howell and E. Mason (ESO) continued their work on high time and spectral resolution spectroscopy of accretion disks. They made use of ESO/VLT time to to obtain optical spectroscopy of high S/N is order to produce detailed line profile spectroscopy and to match with disk models allowing a search for non-Keplerian motions as well as gas stream and blob effects within the disk. Additionally, these investigators used the ESO/NTT to begin a long-term study of known and candidate faint interacting binaries in the old disk/halo of our Galaxy. The white dwarfs in these systems are likely to make up the majority of the Galactic dark matter.

The Faint Sky Variability Survey (FSVS), using the wide-field camera on the INT, ended during this time period and Howell, Everett, Huber, and collaborators P. Groot and P. Vreeswijk (U of Amsterdam) have made an on-line, reduced database available as well as produced numerous results in the literature. The survey examined over 20 square degrees of sky from V=17.5 to >24th magnitude, providing BVI imagery as well as time-series observations in V.

High energy observations of magnetic cataclysmic variables were continued by Howell, Belle, and A. Schwope (Potsdam) using data from the EUVE, ROSAT, and Chandra satellites. Emphasis was placed on multi-epoch and multi-wavelength study resulting in new discoveries of correlations across energy bands and revealing details of accretion processes.

Howell continued his participating as a science team member on the Kepler mission (chosen as a Discovery mission by NASA in 2002) and started his work as an associate team member on GALEX.

4. MISSIONS

4.1 Galileo

Galileo is a NASA mission that has been orbiting Jupiter since late 1995. NW division researchers have been very active with the Near Infrared Mapping Spectrometer (NIMS) instrument on Galileo. Their science focus within the NIMS team is on the surface composition of the icy Galilean satellites. The topics addressed include the source and distribution of CO_2 and other molecules and the types and grain sizes of water ices on the satellite surfaces and the nature of the hydrated minerals on Europa and Ganymede.

4.2 Cassini

Cassini is a NASA-ESA mission to orbit Saturn. The spacecraft passed Jupiter in December of 2000 and will reach Saturn in 2004. NW division researchers are involved with the Visual and Infrared Mapping Spectrometer (VIMS). The major activity this year has been planning the measurement scenarios for the anticipated Saturn orbits. NW division researchers also lead the radiometric calibration effort and were active in improving the calibrations for the VIMS Team.

4.3 Mars Express

Mars Express is a European-led mission to orbit Mars. It is to be launched in May of 2003. The NW division is involved in the High Resolution Stereo Camera (HRSC) led by Germany; the OMEGA, an imaging spectrometer led by France; and the PFS, a broadband interferometric spectrometer led by Italy. During the past year the emphasis has been on developing the dark-current calibration for the HRSC, which also involves harmonic pickup removal. Further, the Co-I, McCord, is chairing the Spectrophotometric Working Group, with the central task of optimizing the four-color spectral data volume and quality, calibration, analysis and science return.

4.4 Rosetta

Rosetta, to be launched in January of 2003, is an ESA-led mission to achieve a comet rendezvous, after passing several asteroids, and then follow the comet through one orbit. The NW division involvement is both in the Visible, Infrared and Thermal Imaging Spectrometer (VIRTIS) and the Planetary Fourier Spectrometer (PSF), both led by Italy. Efforts this past year centered on analyzing the ground radiometric calibration.

4.5 DAWN

DAWN is the latest NASA Discovery mission to be selected, in December 2001. It is to orbit both the small planets Vesta and Ceres and is the first science mission to use ion propulsion. DAWN Co-I, McCord, with the assistance of Hansen and Hibbitts, is developing science definition, especially for Ceres, and is leading the team effort under the Team Leader, C. Russell, to coordinate the European instrument contributions, a camera and an imaging spectrometer.

5. EDUCATION

The California division had another successful year with the science field trip program. To date in the 2001-2002 school year, 41 trips have been hosted, serving 2112 students of grades 3 through 6. The programs include hands-on science activities based on the California State Board of Education Science Content Standards, and are very popular with the participants, both students and teachers.

In addition, the educational aspects of PSI include supporting and mentoring young scientists in postdoctoral fellowships, as well as employing undergraduate and graduate students from local universities and schools, who are working on senior projects, M.S. and Ph.D. degrees, or short-term research projects. PSI participates in the NASA Space Grant program, regularly working with 1-3 undergraduate students per year, and the NSF Research Experiences for Undergraduates (REU) program which provides a nationally competitive summer research program for second and third year B.S. students.

6. OTHER ACTIVITIES

Davis and Neese constitute the asteroid subnode of NASA's Planetary Data System Small Bodies Node (PDS/SBN). A number of new asteroid data sets were collected and prepared for archiving, including Eros shape models from NEAR data, other small bodies shape models, asteroid albedos, and asteroid densities. A number of major updates to existing asteroid data sets were also completed. An external peer review of these asteroid data sets was held at PSI in May 2002, resulting in the ingestion of fifteen data sets into the archive. Archiving of both raw and higher-level data products from the NEAR mission was completed in the past year. In addition, discussions were initiated with the Japanese Muses-C project, a sample-return mission to an asteroid, regarding archiving their mission data in PDS.

Davis is actively involved with light pollution issues and currently is the president of the International Dark-Sky Association and is a member of the Tucson/Pima County Outdoor Lighting Committee. He chaired the inaugural year of the Federal Relations Subcommittee of the Division of Planetary Sciences of the American Astronomical Society.

PUBLICATIONS

The publication list includes all papers published or submitted in 2002 by the permanent staff.

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