Planetary Science Institute

Tucson, Arizona 85705-8331

This report covers the period from September 1994 through August 1995.

1. INTRODUCTION

Planetary Science Institute (PSI) is a non-profit scientific and educational research organization which conducts a variety of basic research programs in planetary geology and geophysics, planetary astronomy, and stellar astrophysics.

Established in Tucson, Arizona, in 1972, the Institute has research programs in spacecraft exploration of planets, satellites, and asteroids; CCD spectrophotometric observations of small bodies; lunar and planetary geology; planetary geophysics and dynamics; multi-wavelength studies of cataclysmic variables; CCD observational techniques, instrumentation, and faint object photometry; and extra-solar planet searches. Our scientists have participated in the NASA spacecraft missions *Mariner 9*, *Viking*, and *Mars Observer*, and are presently involved in the *Galileo*, *NEAR*, and *Mars Global Surveyor* missions. We are frequent guest observers on NASA astrophysics satellites such as *HST* and *EUVE* and regularly use many of the world's groundbased optical and IR observatories.

The Institute conducts research on a non-profit basis under grants, primarily from NASA and NSF. We also provide research opportunities for students in astronomy, physics, and planetary science through internships funded by the NASA Space Grant program and through the NSF Research Experience for Undergraduates program.

PSI maintains a site on the World Wide Web providing current information on our research activities and results, as well as connections to other scientific sites around the world with which we are actively involved. Our WWW site address is http://www.psi.edu/.

In January 1995, PSI joined with the San Juan Capistrano Research Institute to create a joint non-profit research organization dedicated to science and education.

2. PERSONNEL

The research staff at PSI includes Clark R. Chapman (Senior Scientist), Donald R. Davis (Senior Scientist and PSI Director), William K. Hartmann (Senior Scientist), Steve B. Howell (Research Scientist), William Merline (Research Assistant), Carol Neese (Staff Scientist), Fred Ringwald (Postdoctoral Researcher), Eileen V. Ryan (Research Scientist), Peter Tamblyn (Computer Systems Manager), and Stuart J. Weidenschilling (Senior Scientist).

3. RESEARCH PROGRAMS

3.1 Solar System

A major, ongoing project at PSI involves Chapman's participation, since the late 1970's, on the Galileo Imaging Team. Much of the work during the past year has involved planning for the imaging investigation of Jupiter and its satellites during the two-year orbital tour that begins with orbit insertion in December 1995. Merline has also participated in efforts to understand the calibration of the Galileo camera, based on imaging sequences of stars and other objects during the spacecraft's interplanetary cruise.

A significant *Galileo* research effort has involved Chapman, Merline, Ryan, and Davis concerning the asteroid Ida. The major focus of Chapman, Ryan, and Merline has been to measure and understand the size-frequency distribution of craters on Ida's surface, and implications for the age of Ida and the properties of its regolith. Davis has led an effort, involving Chapman and several outside collaborators, to understand the origin of Ida and its collisional history.

Chapman and Merline have worked with the SSI Team Leader Belton (NOAO) to understand the properties of Dactyl, a small satellite discovered by Galileo in early 1994. This included collaborative work with Zellner (Georgia Southern University) and others to use the *Hubble Space Telescope* in the hopes of finding apoapse images of Dactyl that might constrain its orbit. Although the *HST* effort did not locate Dactyl, clear constraints on Dactyl's orbit were developed that sharply limit the possible bulk density of Ida itself. From the observed orbital parameters, dynamical arguments, and *HST* constraints, the density of Ida was found to be 2.6 ± 0.5 g cm^{-3}. Chapman has taken this density constraint and combined it with spectral data on Ida to develop a case that Ida may be made of ordinary chondrite-like material. He argues that the density is too low to be consistent with the chief alternative (stony-iron material) and that the spectral imagery reveals that a ‘‘space-weathering’’ process is operating on Ida that alters its reflectance spectrum from what is measured in the laboratory for ordinary chondrites to what is typical of S-IV type asteroids, like Ida.

Chapman headed a PSI team that worked on an NSF-sponsored project to study the size distribution of the fragments of the Comet Shoemaker-Levy 9. Weidenschilling worked on theoretical modelling of the comet and made input to a groundbased observing program, led by Neese, that included Merline and undergraduate intern Gail Schneller. Observations of Jupiter and its moons were conducted on the Kitt Peak National Observatory 2.1-meter telescope, to search for optical manifestations of the impacts not only of the major fragments, but any debris in the following ‘‘wing’’ striking in the terminator region (and even on the front side) of Jupiter. The overall dimness, in the visible, of even the main impacts reduces the prospect for seeing even fainter debris impacts, but the data are still being analyzed.

The effort to use *Galileo*'s camera to directly image the actual impacts of Comet Shoemaker-Levy 9 into Jupiter (due to *Galileo*'s favorable perspective angle) was led by Chapman. Together with other members of the Imaging Team, Chapman and Merline performed preliminary analyses of images of the impacts of fragments K, N, and W. Chapman also participated in developing a synthesis of the phenomena of the first minute or so of impacts during the SL9 IAU

Colloquium in May, 1995. Further efforts to reduce and understand the Galileo imaging data for SL9 will commence under a joint NSF/NASA SL9 data analysis program.

Chapman continues to work on the potential hazard to civilization posed by impacting asteroids and comets. Although the chances of a major catastrophe are extremely low, the consequences would be unprecedented, resulting in an annualized fatality rate comparable with other natural hazards. Chapman served as a consultant to the Shoemaker Committee, appointed by NASA after Congressional mandate during "comet-crash week," which provided the technical definition for an international telescopic search program. The most recent review about the nature of this hazard, authored by D. Morrison, C. Chapman, and P. Slovic, appeared in early 1995 in the Univ. of Arizona Space Science Series volume, *Hazards Due to Comets and Asteroids*.

In autumn 1994, Chapman was selected to participate in the forthcoming *Near Earth Asteroid Rendezvous* (*NEAR*) mission as a member of the imaging/spectroscopy team. Work has been proceeding on specifying filters and other parameters for the Near Infrared Spectrometer (NIS) and the Multipectral Imager (MSI). Groundbased calibration efforts have also been carried out prior to integration of the instruments into the spacecraft, which is being readied for a February 1996 launch. Chapman has been particularly involved in assessing the potential opportunity of an en-route fly-by of a C-type asteroid, Mathilde.

Davis, Ryan, Farinella (Univ di Pisa, IT), and Marzari (Univ di Padova, IT) furthered studies of the collisional evolution of small bodies of the solar system. Specific topics addressed were:

(1) Computer simulations were carried out of the collisional disruption of large asteroids to form the observed dynamical families. This study was the first to use both the size distribution and the orbit distribution of family members to constrain the size of the parent body and the collisional evolution that occurred in the family subsequent to its formation.

(2) An investigation was conducted concerning the Vesta family, whose minor members have spectral features very similar to those of Vesta itself and of the HED meteorites (Marzari *et al.* 1995, submitted to A&A). This family was probably formed by one or a few giant cratering events over the last Byr, which ejected fragments up to 10 km in diameter at speeds of several hundred m/s. The known properties of the HED meteorites are being interpreted within this scenario.

(3) A study of the collisional evolution of Kuiper Belt Objects (KBOs) was initiated using the methodology developed for exploring asteroid collisional evolution. The volume of space occupied by the orbits of KBOs is much larger than that of the asteroids, thus the intrinsic collision rate for KBOs is about 2000 times less than among the asteroids. However, the number of KBOs is several thousand times the number of asteroids at comparable sizes, hence the actual collision rate within the KBO population is high enough to produce substantial collisional evolution over the age of the solar system. Analysis of the effects of such collisions, including the likelihood that fragments are injected into dynamical resonances and are transported to the inner solar system to become short period comets, is currently being carried out.

(4) Marzari *et al.* (1995) showed that the collision rate among the Trojan asteroids is comparable to that in the main asteroid belt. Collisional evolution studies of this population are currently underway. In particular, emphasis will be placed on understanding the role of collisions in destabilizing the orbits of Trojan asteroids, causing them to leak out of the cloud and becoming part of the Jupiter family of comets (or other small bodies; see Marzari *et al.*1995, A&A 299, 267).

Ryan has been working with a 2D numerical code to model collisions. The ability to characterize the outcome of an impact event of any size given a particular set of initial conditions is applicable to many problems: asteroid impacts on planetary surfaces, collisional evolution of the asteroid belt, asteroid family formation, planetesimal accretion, ring particle dynamics, and meteorite delivery mechanisms. The 2D code has successfully reproduced fragment size and velocity distributions from laboratory impact experiments, and has been used to model fragmentation as a function of target size. Ryan and Melosh (LPL, U. Ariz.) have recently used the code to investigate the circumstances under which large impacts both shatter and disrupt an asteroid. It was found that asteroids are very likely to have a rubble pile internal structure, since larger bodies (more than 10 km in diameter) can be completely shattered by impacts well below the threshold for disruption and dispersal of their fragments.

Ryan and Davis have been working to gather experimental data on the collisional disruption of cooled metals to add to the extensive database that exists for rock fragmentation. The data obtained from this type of analysis is used to better understand collisional processes in the solar system. A series of high-velocity (> 2 km/s) impact experiments was conducted at the Ames Vertical Gun Range (AVGR) to measure the impact strength of actual Gibeon iron-nickel meteorites cooled below the brittle-ductile transition temperature. Temperatures of asteroids in the main belt are around 150 K, below the expected transition. It was found that the meteorite targets underwent brittle fracture at a temperature of 167 K. The resulting fragment size distribution was characterized by the two-slope power law often observed for rock targets. The impact strength derived for the Gibeon material was 500 times larger than that found for basalt targets. Fragment ejecta velocities were on the order of 100's of meters per second. Ursillo and Baccus (undergraduate interns) have been involved in the data reduction for the laboratory impact experiment program.

Merline is completing his Ph.D. dissertation, in which he is investigating small amplitude oscillations of the K giant star Arcturus. He played a major role in the Galileo imaging experiment of the Comet Shoemaker-Levy 9 impact into Jupiter, as well as participating in a groundbased program to study the impacts. He was involved in investigations of asteroid Ida and its newly-discovered moon Dactyl, following the Galileo flyby.

Merline and Howell continue to improve and find new applications for their CCD model and CCD simulation code. In the past year, they have sucessfully applied the model to

LONEOS (Lowell Observatory Near-Earth Object Survey) in an attempt to model planetary transits across stars in hopes of using LONEOS to search for planetary systems. The model was also used to plan for groundbased and Galileo observations of the SL9 crash into Jupiter, as well as to model the NEAR imager and to optimize a sky-brightness survey.

Weidenschilling continued theoretical studies and numerical modeling of the formation of planetesimals in the early solar nebula. He showed that the presence of gas prevents small-scale gravitational instability in a layer of particles, regardless of their sizes (Weidenschilling 1995). Growth of planetesimals is due to collisions driven by drag-induced orbital decay. The size-dependence of the decay rate tends to produce a narrow size distribution of 100m-scale bodies; this effect may be responsible for structural inhomogeneities in cometary nuclei.

Weidenschilling and Davis are also conducting numerical simulations of the accretion of planets from planetesimals. They employ a multi-zone code that allows gravitational and collisional interactions of bodies over a range of heliocentric distance, and includes both a continuum mass distribuition of small bodies and large discrete protoplanets on individual orbits. The code is able to model growth of lunar- to Mars-sized bodies in the terrestrial region over model times of 1 My. With undergraduate intern Diaz, they are exploring methods to extend the simulations to later times using explicit integration of the orbits of the largest bodies.

Hartmann is a Participating Scientist on the NASA Mars Global Surveyor imaging team and a Co-Investigator on the Russian Mars-96 mission. Hartmann is continuing his studies of planetary surface evolution through a grant from the NASA Planetary Geology Program. Emphasis is on erosion/atmosphere effects on the crater size distribution as an indicator of past surface and climate environments. This work has involved collaborations with Engel (U of Ariz.), Sagan (Cornell), Lunine (U of Ariz.), Chyba (Cornell), Gaskell (JPL), and undergraduate intern Herndon. For the National Science Teachers Association and The Planetary Society, Hartmann recently completed a compendium of high-school level interdisciplinary lessons centered around impact cratering during Earth and planetary history (1995, in press at NSTA). As auxiliary activities, Hartmann continues updating his several college-level astronomy textbooks, supplies his own paintings of astronomical subjects to international publications, and serves on the Board of Trustees of the San Juan Institute.

Davis, Neese, and Tholen (U of Hawaii) constitute the Asteroids Subnode of the Small Bodies Node of the Planetary Data System (PDS). The purpose of the PDS is to archive spacecraft and earthbased planetary data in a fully documented and accessible form for current and future researchers. The Asteroids Subnode contributes to this effort by identifying asteroid-related data for inclusion in PDS, preparing and documenting the data, conducting external peer reviews of these datasets, and serving as a source of information to researchers needing access to asteroid data. In the past year, they have prepared a collection of both groundbased and Galileo spacecraft data on the asteroids Gaspra and Ida, as well as a number of other asteroid datasets. The Asteroids Subnode is also overseeing the archive planning for the NEAR mission to the asteroid Eros.

3.2 Astrophysics

Howell continued his ongoing observational study of tremendous outburst amplitude dwarf novae (TOADs). Collaborating with Szkody (U Wash), and others, Howell has used many groundbased observatories, as well as *IUE* and *HST* to provide an understanding of the accretion process and outburst mechanisms in dwarf novae. Low mass transfer rates and very low viscosity material combine to yield infrequent large amplitude outbursts and intrinsically faint systems. UV spectroscopy during outburst shows that the TOADs have very strong winds and possible mass ejection.

Using observations made with *IUE* and *EUVE*, Howell and collaborators Sirk (UC Berkeley), Mason (MSSL), and undergraduate intern Herzog, have been involved in a detailed study of accretion in AM Her systems. A three-dimensional model has been developed and fitted to EUV photometric observations to reveal that the accretion regions are fairly small is size, complex in shape, and *not* consistent with a flat surface-contained spot. In addition, evidence exists which is consistent with mass accretion being blobby and highly variable on short timescales, as well as providing large grey absorption within the accretion stream near the white dwarf surface. *IUE* observations of a number of AM Hers have revealed evidence for a connection between the UV emission line strengths and the strength of the white dwarf magnetic field.

Using the facilities atop Mauna Kea, graduate student Sproats (University College London), Howell, and Mason (MSSL), are studying faint dwarf novae and other cataclysmic variables in the IR. A large survey of dwarf novae distances and absolute magnitudes has just been submitted to MNRAS, revealing the presence of very faint systems having M_V's of 11 to 14. The first IR spectra of short-period dwarf novae have been obtained and analysis is in progress. Submillimeter observations with the JCMT have been obtained by Howell, Robson (JACH/JCMT) and Herzog. These observations are the beginnings of a study to search for evidence of mass loss in the TOADs.

Howell was involved in the FRESIP workshop which studied methods by which a dedicated satellite observatory could be used to discover earth-sized planets in orbit around other stars. Howell, working with principal investigator Bowell and Koehn (Lowell Obs.), is beginning a project which, while designed to discover Near-Earth Objects, will also provide data useful to testbed groundbased photometric techniques of transit observations of extra-solar planets.

In collaboration with Usher (PSU) and Mitchell (GSC), Howell continued his work on variable extragalactic objects. Using the complete sample provided by the US survey of UV excess objects, faint B and white dwarf stars in the galactic halo as well as highly variable extragalactic sources are being studied.

Howell has been active in working with amateur groups from around the world, particularly with respect to outburst and monitoring observations of dwarf novae. Also, Braeside

Observatory and its director, R. Fried, along with co-I's Howell and Kaitchuck (Ball State), were the recipients of an NSF award and have just recently completed construction of their CCD imager. This instrument has already started observations of cataclysmic variables for a project directed by Howell.

The following University of Arizona undergraduate students worked with Howell during this time period: Adrienne Herzog, Adriana Reyes, and Gabriel Benedek. Graduate students Jason Glenn (U. Ariz.) and Lee Sproats (University College London) also worked with Howell. Postdoctoral Researcher Fred Ringwald joined the Astrophysics Group in August 1995.

Howell is a member of the *Extreme Ultraviolet Explorer* users group (1994–1996) and serves as a scientific advisor for *CCD Astronomy* magazine.

Ringwald's research has centered around cataclysmic variable binary stars and their evolution. In addition to carrying out detailed studies of individual systems, he has completed a population study, a spectroscopic atlas of classical novae that had outbursts between 1783 and 1986. The spectra were taken with the philosophy that ''novae are like friends, the older, the better,'' in the hope of seeing evolutionary effects on the timescale of decades to centuries. They show surprisingly little evidence of nova hibernation, or of any changes at all, aside from the fading of their nebular lines. Indeed, old novae look remarkably similar to each other, except for effects wholly attributable to their orbital inclinations.

3.3 Instrumentation

Neese, Davis, Chapman, Howell, Mannery (U of Washington) and Corbally (Vatican Observatory) are now in the construction phase of building a compact low-resolution spectrograph designed to cover the entire optical range of 3500–11000 Å in a single exposure. The principal project for which this spectrograph is being built is the taxonomic classification of faint main-belt asteroids, particularly the members of selected dynamical families. With their broad-featured reflection spectra with diagnostic features across the visible range, asteroids are well suited to study by a spectrograph of this design. The spectrograph will also be used for a variety of other projects including cataclysmic variables and the MK classification of halo stars. The spectrograph is scheduled for first light at the VATT telescope on Mt. Graham in December 1995.

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