FINAL TECHNICAL REPORT

"VISIBLE AND INFRARED INVESTIGATIONS OF PLANET-CROSSING ASTEROIDS AND OUTER SOLAR SYSTEM OBJECTS"

NASA Grant No. NAGW 2019

David J. Tholen
Principal Investigator
University of Hawaii at Manoa
Institute for Astronomy
2680 Woodlawn Drive
Honolulu, Hawaii 96822

Period Covered
January 1, 1990 to December 31, 1991

Visible and Infrared Investigations of Planet-Crossing Asteroids and Outer Solar System Objects
Final Technical Report

Personnel who received research support under this grant included Dr. D. J. Tholen (principal investigator), Dr. J. R. Spencer (postdoctoral researcher), and Mr. J. D. Goldader (graduate student).

A major effort was directed toward 951 Gaspra in preparation for the *Galileo* encounter in October 1991. Most of the observational work involved photometry, for purposes of investigating the rotational state and phase function of the asteroid to help plan the encounter, and astrometry, for purposes of navigating the spacecraft to the object. We have also worked with radiometric data obtained with the IRTF at NASA's request, for which simultaneous visible photometry was acquired with the University of Hawaii 2.24-m telescope. Graduate student J. D. Goldader assisted with much of the observational work, as well as the data reduction and analysis. The results from the observations made during the 1990 opposition were published by Goldader *et al.* (1991). The main results reported in this paper include a rotational period of 7.04246 hours, an absolute visual magnitude of 11.8026, a slope parameter of 0.285, an early estimate of a high obliquity, an infrared spectrum indicating an olivine-rich composition, and 13 astrometric positions. A second paper describing the results from the 1991 opposition was submitted to *Science* in hopes of getting some important results out before the encounter, but *Science* expressed no interest in any pre-encounter ground-based results; they wanted only post-encounter spacecraft results. As a result, it became necessary to rewrite this paper for another journal; this effort is in progress as this report is being written (Tholen *et al.* 1992). This second paper includes the results from the radiometric work at the IRTF, which provided an effective diameter of 12.4 km, which when corrected for aspect and shape, yields dimensions of approximately 16 by 11 by 11 km. The resultant albedo is 22 percent. The paper also includes new lightcurve photometry that confirms the earlier suspicion of a high obliquity, and 16 more astrometric observations. It should be noted that this project was the third largest contributor of Gaspra astrometry to the *Galileo* navigation team, and it is now known that the navigation was excellent.

We also participated in an international collaboration to more accurately determine the orientation of Gaspra's spin axis by pooling all available photometry of the object. This effort was coordinated by P. Magnusson, and the results from that work are in press (Magnusson *et al.* 1992).

Other spacecraft targets for which photometry and astrometry were obtained included 66 Maja, 243 Ida, 302 Clarissa, 449 Hamburga, and 739 Mandeville. The observations were obtained with the understanding that changes in launch dates could result in changes in target asteroids, with the result that only the 243 Ida data are currently applicable to a possible spacecraft flyby.

Photometric monitoring of asteroid-turned-comet 2060 Chiron was continued throughout the duration of the grant period. No major changes in brightness as significant as the late-1987-early-1988 outburst were detected. Those earlier results appeared in the literature during the grant period (Hartmann *et al.* 1990). Another asteroid suspected of being a dead comet, 944

Hidalgo, reached perihelion during the grant period. Photometric and astrometric observations were made of this object to look for possible emission features (utilizing the International Halley Watch filter set), possible evolution in the colors of the object, and non-gravitational forces. None of the observations yielded any evidence of cometary behavior.

During the grant period, one observing run was dedicated to expanding the sample of outer belt asteroids (primarily Hildas and Trojans) for which spin and shape statistics are available. Eight additional objects were observed. Analysis of the data continued, and one paper based on a synthesis of these data and published data on comets was written (Hartmann and Tholen 1990). In this paper, we hypothesize that the elongated shapes of comets and outer belt asteroids may result from volatile loss processes, a mechanism that can also explain comet splittings.

Near-infrared spectroscopy of outer belt asteroids continued in collaboration with D. P. Cruikshank and W. K. Hartmann. The identification of a 2.2 micron absorption feature in the spectra of some low albedo asteroids, comets, and planetary rings and satellites may represent the detection of C triple-bond N, with implications for the origin of the organically-rich carbonaceous meteorites (Cruikshank *et al.* 1991a).

We also published our earlier results on the discovery of Vesta-like objects among the near-Earth asteroid population (Cruikshank *et al.* 1991b), which are likely sources for the eucrite, howardite, and diogenite meteorite populations. This discovery represents the strongest link between terrestrial meteorites and Earth-approaching asteroids found to date.

Some time was spent assisting doctoral candidate D. T. Britt (Brown University) with his principal component analysis of meteorite spectra. The spectra were convolved with transmission curves for the filters used in the Eight Color Asteroid Survey, to produce synthetic meteorite spectra in that system, thus permitting a direct comparison of results from the principal component analyses. Because of the connection between meteorites and Earth-approaching asteroids, this was considered an appropriate activity under this grant. The resulting paper is currently in press (Britt *et al.* 1992).

Following the publication of a new study of asteroid families by Zappala *et al.*, and the identification of a significant Vesta family therein, we undertook colorimetric observations of these Vesta family members. The first two spectra to be obtained are fairly unique, therefore the acquisition of reflectance spectra for additional family members is warranted, as they come to opposition.

A unique target of opportunity was discovered during the grant period, namely asteroid 1990 MB, which turned out to be the first (and only) known Trojan asteroid of Mars. Unfortunately, this discovery became known only well after opposition, when it was quite faint. An attempt to obtain meaningful colorimetry yielded only the hint that the object might be redder than the Sun. Three astrometric observations were obtained, however, that assisted with the identification of this object as a Mars Trojan. Additional observations are planned for the next opposition in 1992.

J. R. Spencer continued his investigations into the thermal properties of asteroids. His rough-surface model was published during the grant period (Spencer 1990). Observational work

centered around an attempt to measure the thermal inertia of asteroid surface materials via the observation of thermal emission from the dark side (unilluminated by sunlight) of an asteroid. For this project, daytime observations of an Apollo- or Aten-type asteroid are required, and only one, (4197) 1982 TA, proved to be suitable for this work (although a much better opportunity will occur this December with the close passage of 4179 Toutatis). The observations show that the so-called "Standard Thermal Model" grossly overestimates the thermal flux at high phase angles.

Lastly, colorimetric, astrometric, and lightcurve observations of Earth-approaching asteroids continued as new discoveries were announced. Previously known objects making favorable apparitions were also observed. The list of successfully observed asteroids includes (1951) Lick, (3103) 1982 BB, (4775) 1927 TC, 1989 WM, 1990 DA, 1990 OA, 1990 OL, 1990 SA, 1990 SB, 1990 SM, 1990 SQ, 1990 SS, 1991 AQ, 1991 EE, 1991 JR, 1991 JW, 1991 JX, and 1991 JY. The last of these, 1991 JY, appears to be yet another Vesta-like object among the Earth-approaching population, making it the fourth known (and yet other than Vesta itself, none have been found in the main belt).

Bibliography

Refereed Literature

BRITT, D. T., D. J. THOLEN, J. F. BELL, AND C. M. PIETERS 1992. Comparison of asteroid and meteorite spectra: Classification by principal components analysis. *Icarus* (submitted).

CRUIKSHANK, D. P., L. J. ALLAMANDOLA, W. K. HARTMANN, D. J. THOLEN, R. H. BROWN, C. N. MATTHEWS, AND J. F. BELL 1991a. Solid C-N bearing material on outer solar system bodies. *Icarus* **94,** 345-353.

CRUIKSHANK, D. P., D. J. THOLEN, W. K. HARTMANN, J. F. BELL, AND R. H. BROWN 1991b. Three basaltic Earth-approaching asteroids and the source of the basaltic meteorites. *Icarus* **89,** 1-13.

GOLDADER, J. D., D. J. THOLEN, D. P. CRUIKSHANK, AND W. K. HARTMANN 1991. Galileo support observations of asteroid 951 Gaspra. *Astron. J.* **102,** 1503-1509.

HARTMANN, W. K., AND D. J. THOLEN 1990. Comet nuclei and Trojan asteroids: A new link and a possible mechanism for comet splittings. *Icarus* **86,** 448-454. [52.102.006]

HARTMANN, W. K., D. J. THOLEN, K. J. MEECH, AND D. P. CRUIKSHANK 1990. 2060 Chiron: Colorimetry and cometary behavior. *Icarus* **83,** 1-15. [51.098.061]

MAGNUSSON, P., M. A. BARUCCI, R. P. BINZEL, C. BLANCO, M. DI MARTINO, J. D. GOLDADER, M. GONANO-BEURER, A. W. HARRIS, T. MICHALOWSKI, S. MOTTOLA, D. J. THOLEN, AND W. WISNIEWSKI 1992. Asteroid 951 Gaspra: pre-Galileo physical model. *Icarus* (submitted).

SPENCER, J. R. 1990. A rough-surface thermophysical model for airless planets. *Icarus* **83,** 27-38.

THOLEN, D. J., J. D. GOLDADER, T. M. HERBST, J. R. SPENCER, W. F. GOLISCH, AND D. M. GRIEP 1992. Radiometry, photometry, and astrometry of 951 Gaspra in 1991. In preparation.

Astrometry

Astrometry for minor planets has been published in the following *Minor Planet Circulars*:

MPC 18880 (1991)	MPC 17710 (1991)	MPC 16801 (1990)
MPC 18676 (1991)	MPC 17709 (1991)	MPC 16669 (1990)
MPC 18512 (1991)	MPC 17522 (1991)	MPC 16331 (1990)
MPC 18336 (1991)	MPC 17492 (1991)	MPC 15967 (1990)
MPC 18335 (1991)	MPC 17105 (1990)	MPC 15948 (1990)
MPC 18034 (1991)	MPC 16956 (1990)	MPC 15810 (1990)