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Subject: Final Report for NAG5-10444
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X-Spam-Score: -7.099
X-Spam-Flag: NO
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Lindley:

Below is my final report for NASA Grant NAG5-10444 (February, 2001, for 3 years, plus a no-cost extension). The report is organized according to (i) accomplishments for the objectives laid out in the original proposal, and (ii) refereed publications. Since NAG5-10444 is the predecessor of the occultation work supported in our current grant (NNG04GF25G), the "ACCOMPLISHMENTS" section has some overlap with the first year of NNG04GF25G, as NAG5-10444 ramped down.

Let me know if you need any more information.

Jim

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Summary of Proposed Goals (verbatim from the proposal summary sheet)

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Bodies residing in the outer solar system exhibit unique physical processes, and some of the lessons learned from them can be applied to understanding what occurred in the outer solar system during its formation and early evolution. Pluto, the largest known Kuiper Belt object (KBO), and its near twin Triton--an ex-KBO that has been captured by Neptune--have nitrogen atmospheres that are in vapor-pressure equilibrium with surface ice. These atmospheres are most sensitively probed from Earth by the technique of stellar occultations, which can provide the temperature and pressure profiles of these atmospheres at a spatial resolution of a few kilometers. Recent results from occultations show that the surface pressure of Triton's atmosphere has been increasing and that the shape of the atmosphere deviates from its expected spherical figure. With the occultation technique we can also learn the sizes of smaller bodies that have formed in the outer solar system: Charon, the Centaurs, and KBOs. Our proposed program involves identifying occultation candidates, predicting occultations, observing occultations, analysis of the data, and synthesis of the occultation results with other data. The main goals for our proposed work are to: (i) further observe occultations by Triton with the objectives of understanding its pressure changes, distortion, and enigmatic thermal structure (ii) determine whether the abrupt drop in Pluto's stellar occultation light curve is caused by a sharp thermal gradient near its surface or by atmospheric haze, (iii) further observations to characterize the potential collapse of Pluto's atmosphere as it recedes from the sun (information that should be of interest to the Pluto-Kuiper Express), (iv) determine Charon's radius more accurately than can be done with the mutual events to derive a better estimate of Charon's density, and (v) directly determine the size (and albedo) of Centaurs with the goal of more accurately estimating the sizes of KBOs.

ACCOMPLISHMENTS

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(Goals in the above paragraph have been repeated below, followed by our work toward achieving each goal.)

1) Further observe occultations by Triton with the objectives of understanding its pressure changes, distortion, and enigmatic thermal structure

Our portable occultation CCD (PCCD) was upgraded, in preparation for the Triton occultation of Tr231. We successfully predicted the path of this event and set up for observation of the Tr231 occultation at two sites in South Africa. Our observations were highly successful. The analysis of the Tr231 occultation data is being carried out by Mike Person, as part of his Ph.D. thesis work. We looked into possibly observing the Tr261 and Tr266 occultations by Triton, but good data for these events did not materialize.

2) determine whether the abrupt drop in Pluto's stellar occultation light curve is caused by a sharp thermal gradient near its surface or by atmospheric haze

AND

3) further observations to characterize the potential collapse of Pluto's atmosphere as it recedes from the sun (information that should be of interest to the Pluto-Kuiper Express)

Results for goals 2 and 3 can be discussed together, as they were both achieved with the stellar occultations by Pluto in July and August of 2002. We predicted these stellar occultations by Pluto and successfully observed these two events (altogether 9 light curves were obtained for the two events). We found that the Pluto's atmospheric pressure has increased dramatically since 1988 and found other changes in Pluto's atmosphere. These results were reported at the 2002 DPS meeting and in several publictions (see list below). We also published our new inversion technique, which has direct application to our Pluto and Triton occultation data sets. We found that Pluto's atmosphere is rife with extinction from the SpeX occultation data from the IRTF. We also determined that Pluto's atmosphere is significantly non-spherical. Mike Person is pursing this analysis as part of his thesis.

4) determine Charon's radius more accurately than can be done with the mutual events to derive a better estimate of Charon's density

No good occultation opportunities presented themselves for Charon during this grant, but he have been recently successful with the Charon occultation in the follow-on grant currently in force. These results have been submitted for publication and will be reported at the 2005 DPS meeting.

5) directly determine the size (and albedo) of Centaurs with the goal of more accurately estimating the sizes of KBOs.

No good Centaur occultation opportunities occurred during the grant period.

6) continued observations of KBOs (discovery, astrometry, photometry) needed to find occultation events, which can be used to find accurate diameters and to search for tenuous atmospheres.

This work was carried out with our participation in the Deep Ecliptic Survey, with our colleagues at Lowell Observatory and other institutions. This survey discovered about 500 KBOs with preliminary designations, and the largest of these have been selected to be targets for our stellar occultation work. This enterprise also includes the largest KBOs identified by other surveys (most notably that of Brown, Trujillo, and their colleagues). For nearly a year now, we have been obtaining accurate astrometric data for these objects with observing runs at Lowell and CTIO. Soon we will have a good occultation candidate list and begin a major observational campaign for KBO occultations with our new high-speed CCD cameras (supported by NASA in a separate grant).

REFEREED PUBLICATIONS (NAG5-10444)

This list includes publications that appeared during the grant period and those publications for which the work was completed during the grant period.

Buie, M. W., R. L. Millis, L. H. Wasserman, J. L. Elliot, S. D. Kern, K. B. Clancy, E. I. Chiang, A. B. Jordan, K. J. Meech, R. M. Wagner, and D. E. Trilling 2003. Procedures, resources and selected results of the Deep Ecliptic Survey. Earth, Moon, and Planets 92, 113-124.

Chiang, E. I., A. B. Jordan, R. L. Millis, M. W. Buie, L. H. Wasserman, J. L. Elliot, S. D. Kern, D. E. Trilling, K. J. Meech, and R. M. Wagner 2003. Resonance occupation in the Kuiper belt: Case examples of the 5:2 and 1:1 resonances. Astron. J. 126, 430-443.

Elliot, J. L., A. Ates, B. A. Babcock, A. S. Bosh, M. W. Buie, K. B. Clancy, E. W. Dunham, S. S. Eikenberry, D. T. Hall, S. D. Kern, S. K. Leggett, S. E. Levine, D.-S. Moon, C. B. Olkin, D. J. Osip, J. M. Pasachoff, B. E. Penprase, M. J. Person, S. Qu, J. T. Rayner, L. C. Roberts Jr., C. V. Salyk, S.

P. Souza, R. C. Stone, B. W. Taylor, D. J. Tholen, J. E. Thomas-Osip, D. R. Ticehurst, and L. H. Wasserman 2003. The recent expansion of Pluto's atmosphere. Nature 424, 165-168.

Elliot, J. L., and S. D. Kern 2003. Pluto's atmosphere and a targeted-occultation search for other bound KBO atmospheres. Earth, Moon, and Planets 92, 375-393.

Elliot, J. L., S. D. Kern, K. B. Clancy, A. A. S. Gulbis, R. L. Millis, M. W. Buie, L. H. Wasserman, E. I. Chiang, A. B. Jordan, D. E. Trilling, and K. J. Meech 2005. The Deep Ecliptic Survey: A search for Kuiper belt objects and Centaurs. II. Dynamical classification, the Kuiper belt plane, and the core population. Astron. J. 129, 1117-1162.

Elliot, J. L., M. J. Person, and S. Qu 2003. Analysis of stellar occultation data. II. Inversion, with application to Pluto and Triton. Astron. J. 126, 1041-1079.

Millis, R. L., M. W. Buie, L. H. Wasserman, J. L. Elliot, S. D. Kern, and R. M. Wagner 2002. The Deep Ecliptic Survey: A search for Kuiper Belt objects and Centaurs I. Description of methods and initial results. Astron. J. 123, 2083-2109.

Osip, D. J., S. D. Kern, and J. L. Elliot 2003. Physical characterization of the binary Edgeworth-Kuiper Belt object 2001 QT297. Earth, Moon, and Planets 92, 409-421.

Pasachoff, J. M., S. P. Souza, B. A. Babcock, D. R. Ticehurst, J. L. Elliot, M. J. Person, K. B. Clancy, L. C. Roberts Jr., D. T. Hall, and D. J. Tholen 2005. The structure of Pluto's atmosphere form the 2002 August 21 stellar occultation. Astron. J. 129, 1718-1723.

Person, M. J., J. L. Elliot, K. A. Emanuel, B. A. Babcock, A. S. Bosh, M. W. Buie, E. W. Dunham, S. S. Eikenberry, D. T. Hall, S. E. Levine, J. M. Pasachoff, L. C. Roberts Jr., S. P. Souza, B. W. Taylor, and D. J. Tholen 2005. Pluto's asymmetric atmosphere. Icarus (submitted).

Trujillo, C. A., J. X. Luu, A. S. Bosh, and J. L. Elliot 2001. Large bodies in the Kuiper belt. Astron. J. 122, 2740-2748.