University of Hawai'i at Mānoa

Institute for Astronomy
2680 Woodlawn Drive • Honolulu, Hawai'i 96822

15 September 1997

Ms. Mildred Garner
Grants Officer
NASA Goddard Space Flight Center
Code 216
Greenbelt, MD 20771

SUBJECT: Progress Report, Grant NAG 5-4669

Dear Ms. Garner,

Enclosed is the progress report for the subject grant entitled, "The Solar System Beyond Neptune," under the direction of Dr. David C. Jewitt. This report covers the period 1 April - 31 December 1997 and is the second year of a three year award. Also provided is the third year budget for the period 1 January - 31 December 1998.

If you have any questions please contact Chris Kaukali, Administrative Officer, at 808-956-7562, or email, kaukali@uhifa.ifa.hawaii.edu.

Please ensure that all correspondence is directed to Mr. Marvin S. Enokawa, Director, Office of Research Services, 2530 Dole Street, Sakamaki D-200, Honolulu, Hawaii, 96822.

Thank you for your continued support of this project.

Sincerely Yours,

C G Wynn-Williams

Gareth Wynn-Williams for
David C. Jewitt
Principal Investigator

ENDORSEMENT:

for Marvin S. Enokawa
Director
Office of Research Services

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A progress report for

THE SOLAR SYSTEM BEYOND NEPTUNE

Institute for Astronomy, University of Hawaii

2680 Woodlawn Drive

Honolulu, HI 96822

David Jewitt

Goals

The aim of this research is to assess the contents of the trans-Neptunian solar system. Previously thought to be empty, the region beyond Neptune is now known to hold a vast abundance of bodies dating from the earliest phases of the solar system. We have pioneered the application of charge coupled device (CCD) surveys as a means to locate and identify Kuiper Belt objects. The present research aims to drive these techniques to their limit, in order to increase the observational sample as much as possible.

Accomplishments

In the second year of this grant we have done the following:

1 We have developed and refined a software package ("MODS") and operating strategy to handle data from the University of Hawaii 8192 x 8192 pixel CCD camera. This is the largest camera in astronomical use in the world. It presents unprecedented problems in data handling and storage, when used in survey mode. We have used the 8k array to advance our surveys of the trans-Neptunian solar system. With graduate student Chadwick Trujillo, we have arrived at a system for the nearly automatic detection of moving objects in survey data. A paper about MODS is in press (Trujillo and Jewitt 1997).

2 We have used the 8k array at the University of Hawaii 2.2-m telescope to discover 15 new Kuiper Belt Objects, increasing the known sample of such objects (by about one third) to 57. The orbital properties are summarized in Fig. 1

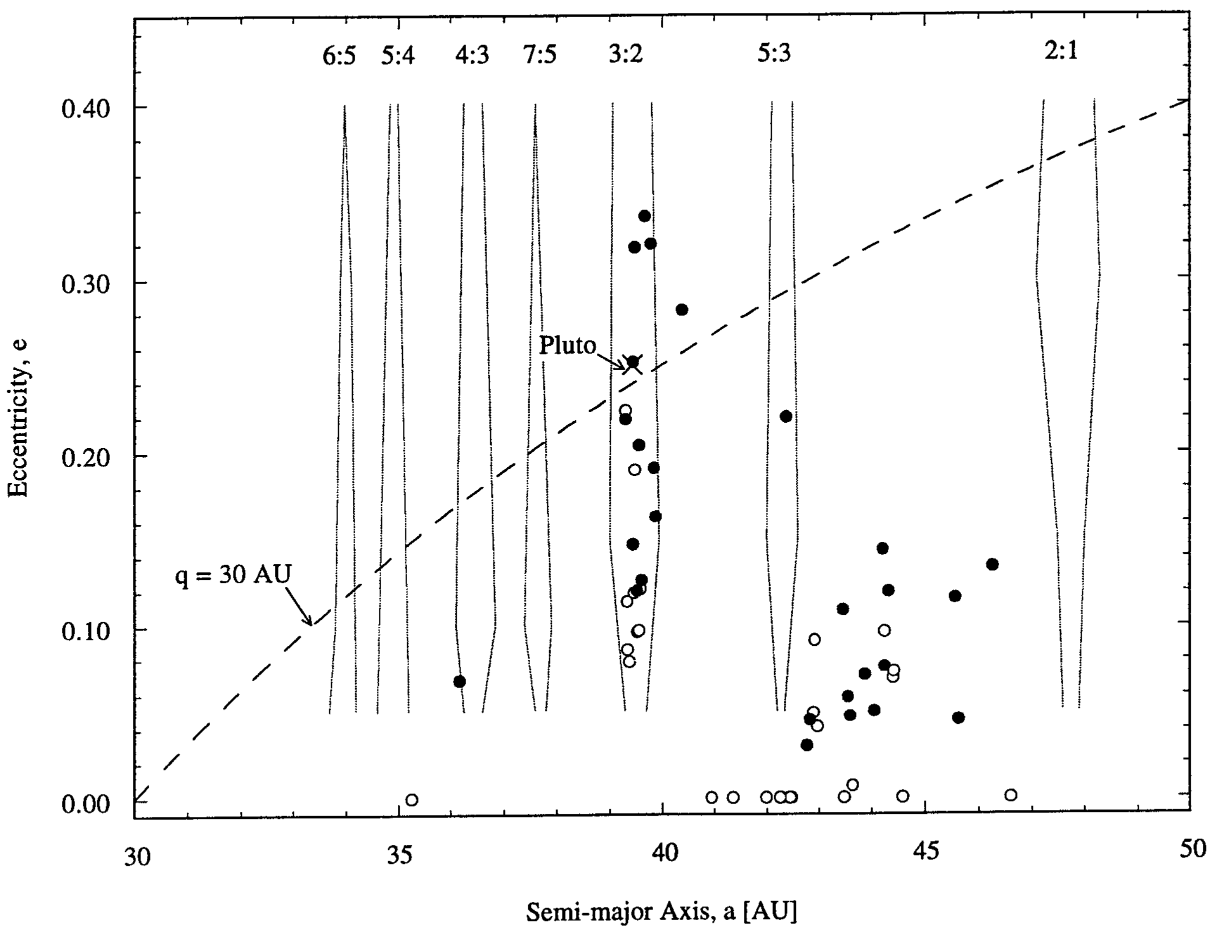

Fig. 1 Semimajor axis vs. eccentricity for the known Kuiper Belt objects. Most of the objects are from past and on-going Mauna Kea surveys. Objects observed at N > 1 opposition are shown with solid circles. Hollow circles mark objects so far detected at only one opposition. Orbits of the latter are presumably less reliable than those of the former. The location of the major mean-motion resonances are marked and labelled. Pluto, in the 3:2 resonance, is marked with an X. Objects above the dashed line have perihelion distance inside the orbit of Neptune.

3 We have firmly established that 40% of the Kuiper Belt Objects are in the 3:2 mean-motion resonance with Neptune, and that the other main resonances are at best weakly populated.

4 We have identified a new dynamical class in the Kuiper Belt, through the new object

1996 TL66 (Luu *et al.* 1997). This body differs from previously known Kuiper Belt Objects in having a highly eccentric orbit and a semi-major axis near 80 AU (it is too extreme to be plotted in Fig. 1). 1996 TL66 may be the first recognized example of a class of scattered objects, first discussed in the literature by Julio Fernandez in the mid-1980's. These scattered objects form a fat disk beyond the previously known Kuiper Belt. The full significance of these objects is not yet clear. They may have been injected into this region during the early phases when strong Neptune (and Uranus) perturbations were clearing the inner belt and populating the Oort Cloud. Scattered KBOs might supply some or all of the short-period comets.

5 It is important to obtain follow-up astrometry of newly discovered Kuiper Belt objects, in order to determine their orbital elements with confidence. We have made a substantial observational effort to recover Kuiper Belt objects, and have been responsible for a majority of the follow-up astrometric observations obtained to date.

6 We published optical photometry of KBOs (Luu and Jewitt 1996) and obtained both optical and near-Infrared photometry of others using the Keck 10-m telescope.

7 We were invited to write popular-level accounts of our Kuiper Belt research for American Scientist and Astronomy Magazine, and have started work on these.

8 The PI was invited to speak about his Kuiper Belt research astronomy meetings in Taiwan, China, Japan, Switzerland and Slovakia, as well as at a number of universities in the United States. Written versions of earlier invited reviews for the Asteroids, Comets, Meteors '96 meeting in Versailles, France and the Stardust (Santa Clara) meeting were completed. The former is in press (Jewitt and Luu 1997a) and the latter is published (Jewitt and Luu 1997b).

9 University of Hawaii graduate student Jun Chen completed her PhD thesis with me on a study of the 1:1 resonance populations of the gas giant planets.

Plans for Year 3

1 In Year 3, we intend to use the 8k CCD to cover 100 sq. deg. to magnitude 22.7, and expected to detect several 10's of new Kuiper Belt objects. The science goals of this survey are:

i) Current data suggest the existence of a turn-down in the size distribution of Kuiper Belt objects at large sizes ($D \geq 600$ km?). However, the evidence for the turn-down is largely based on old photographic data. With the 8k CCD, we will for the first time cover a large area of sky to moderate depth in order to assess the density of large (bright) objects.

ii) Do Trojans (1:1 mean motion resonance objects) exist in association with gas giant planets other than Jupiter? The Jovian trojans are well known and abundant, and there is no known theoretical reason why other gas giants should not also hold Trojans, yet none have been found. We will survey for Trojans automatically, by selecting Kuiper Belt fields which fall along lines of site passing through the 1:1 libration clouds.

iii) We aim to detect large, bright (rare) KBOs that will then be made available for physical study using Keck and other large facilities.

2 We will obtain physical observations of the brightest Kuiper Belt Objects revealed by the 8k CCD survey. These will include broadband optical (BVRI) and near-infrared (JHK) measurements, together with low resolution spectra in appropriate cases.

3 We will continue to obtain follow-up astrometry of Kuiper Belt objects, for the purposes of orbit refinement. Data collected for this purpose will be provided to Brian Marsden at the Center for Astrophysics, Harvard, and publicized through the Minor Planet Electronic Circulars.

This research will continue to benefit from the collaborative efforts of Prof. Jane Luu (Harvard University) as well as UH graduate student Chad Trujillo. Chad Trujillo will begin his PhD thesis with me in late 1997.

Publications of Year 2

J. Luu and D. Jewitt (1996). "Color Diversity Among the Centaurs and Kuiper Belt Objects", Astron. J., **112**, 2310.

D. Jewitt and J. Luu (1997a). "Kuiper Belt: The Solar System Beyond Neptune". Invited review for Asteroids, Comets, Meteors '96, held Versailles, France, July 8 - 12 1996. In press.

D. Jewitt and J. Luu (1997b). "The Kuiper Belt". In Stardust to Planetesimals , edited by Y. V. Pendleton and A. Tielens, Astronomical Society of the Pacific Conference Series Volume 122, San Francisco, pp. 335 - 345.

J. Luu, B. Marsden, D. Jewitt, C. Trujillo, C. Hergenrother, J. Chen and W. Offutt (1997). A New Dynamical Class in the Outer Solar System. Nature, **387**, 573.

Trujillo, C., and Jewitt, D. (1997). Moving Object Detection Software (MODS). Astron. J., in press.