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The main goal of this project is to physically characterize the small outer solar system bodies. One of planetary science's highest priorities is an understanding of the dynamics and physical properties of the outer solar system small bodies. The measurement of the size distribution of these bodies will help constrain the early mass of the outer solar system as well as lead to an understanding of the collisional and accretional processes. We will increase the database of comet nucleus sizes making it statistically meaningful to compare with those of the Trans-Neptunian Objects.

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Annual Progress Report

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"Distant Comets in the Early Solar System"

April 1, 1999 to March 31, 2000

Submitted by

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Distant Comet in the Early Solar System - Yr 1 Progress Report

K. J. Meech

1 Program Purpose and Objectives

The main goal of this project is to physically characterize the small outer solar system bodies. An understanding of the dynamics and physical properties of the outer solar system small bodies is currently one of planetary science's highest priorities. The measurement of the size distributions of these bodies will help constrain the early mass of the outer solar system as well as lead to an understanding of the collisional and accretional processes. A study of the physical properties of the small outer solar system bodies in comparison with comets in the inner solar system and in the Kuiper Belt will give us information about the nebular volatile distribution and small body surface processing. We will increase the database of comet nucleus sizes making it statistically meaningful (for both Short-Period and Centaur comets) to compare with those of the Trans-Neptunian Objects. In addition, we are proposing to do active ground-based observations in preparation for several upcoming space missions.

With this progress report, a new E/PO request is being submitted. PI Meech is engaging in an extensive eduational outreach effort in the area of Origins which is directly related to this research. The five-year NSF-Teacher Enhancement program covers most but not all of the costs of the three-week summer program. With this proposal, we seek to broaden the scope of the workshop.

2 Observing

This project is supporting the thesis work of graduate student James (Gerbs) Bauer, and is partly supporting the postdoctoral work of Yanga Fernández who arrived in 1999 October. In addition, collaborations are beginning with NATO Post-doctoral Fellow Jana Pittichova (Slovak Republic), who is resident at the Institute for Astronomy and working with the PI. Gerbs Bauer is pursuing a thesis looking at a comparison of the physical properties (optical and near IR) of Centaur objects and small outer solar system satellites. Yanga Fernández is studying the properties of comet nuclei (optical and IR), and Jana Pittichova is pursuing theoretical models of dust coma of comets in the database of the PI. This grant is supporting some follow-up observations for her work. The observing focus for the PI was to look at properties of comet nuclei, in particular in support of the Deep Impact mission.

During the first year of this grant, 35 nights of observing have been completed (mostly for the thesis work of Bauer, and Deep Impact mission support). An additional 13 nights are scheduled in the next 2 months. Table 1 summarized the observing status.

3 Science Results

3.1 Deep Impact Mission Support

The Deep Impact Mission will send a 500 kg impactor to create a crater on the nucleus of comet P/Tempel 1 to reveal sub-surface materials. Our primary scientific goal is to understand the difference between the interior of a comet and its surface. Current and planned missions will investigate the heterogeneity of surface structure and composition, and will explore comet diversity. However, observations and theoretical models cannot tell us the depth at which cometary pristine material lies. The DI mission will provide information about the interior of a comet by excavating a crater to: (*i*) observe how the crater forms, (*ii*) document the final state of the crater, (*iii*) measure the composition of the hot ejecta from the crater, and (*iv*) determine the changes in the natural outgassing produced by the impact.

Prior to the encounter, we need to characterize the nucleus of P/Tempel 1. In order to design the autonomous targeting software and mission instrumentation, it is crucial to know what the expected

Table 1: Successful Observing Runs

Date	#Nts	Telescope	Program	PI	Status
99/01/19	3	UH2.2m+CCD	Centaurs	GB	1
99/03/16	1.5	UH2.2m+CCD	Centaurs	GB	2
99/03/18	2.5	UH2.2m+CCD	Nucleus Rotation Tempel 1	KM	3
99/04/01	0.5	CFHT+AO	Chiron Coma	KM	4
99/05/08	3	UH2.2m+CCD	Centaurs (1995 GO) & T1	GB	5
99/05/28	2	UH2.2m+CCD	Calbration runs	GB	4
99/06/06	0.5	UKIRT+CGS4	Small Body Spectra	GB	6
99/07/14	2	UH2.2m+CCD	P/Tempel 1 Rotation	KM	3
99/08/12	3	UH2.2m+CCD	Comet Wild 2 Rotation	GB	7
99/08/15	2	UH2.2m+CCD	Centaurs	GB	7
99/09/06	0.2	KeckII+LRIS	Centaurs Coma search	KM	8
99/09/07	1	UH2.2m+CCD	Centaur coma search	GB	7
99/09/22	3	UH2.2m+CCD	P/Tempel 1 Rotation	KM	3
99/11/17	3	UH2.2m+CCD	Comet Nuclei Properties	YF	8
00/01/14	5	UH2.2m+CCD	Comet Nuclei Properties	YF	8
00/01/17	1	KeckI+LWS	Comet Nuclei Properties	YF	8
00/01/23	1	JCMT+B3I	HCN Observations-Tempel 1	LW	9
00/02/23	1	UH2.2m+CCD	P/Tempel 1 Calibration	KM	8
00/05/00	N/A	UH2.2m+CCD	P/Tempel 1 Dust Models	KM	10
00/05/22	7	UH2.2m+CCD	Centaur rotation / coma	GB	11
00/06/10	4	UH2.2m+CCD	Nucleus properties	YF	11
00/06/10	1	Keck1+LWS	Nucleus properties	YF	11
00/07/08	2	UH2.2m+CCD	P/Tempel 1 Dust Models	KM	11

Notes on Status: [1] Data reduced, prelim results in Bauer *et al.* 1999; [2]Weather poor, not yet reduced; [3]Reduced. Presented at 1999 DPS (Meech *et al.* 1999); paper in progress; [4]Poor weather; [5]Meech *et al.* 1999; centaurs being reduced; [6]Data reduced; draft paper complete (Bauer *et al.* 2000; [7]Unreduced; [8]Reduced, paper in preparation; [9]No detection; will have upper limit - reduction in progress; [10]Observations ongoing; images from 3 nights available - service observing, being reduced; [11]Future observations scheduled.

observational environment will be upon arrival. This includes the size and reflectivity of the nucleus, its axial ratio, rotational state, and surface brightness relative to that of nearby dust. Critical among these parameters, possibly the hardest to determine and most demanding of telescopic observing time, is the nucleus rotation state – particularly if it is in an excited state. The observations during this year of funding focussed on trying to get information on the rotational state.

The data from 1999 March showed a very unusual light curve, shown in Figure 1 (Meech *et al.* 1999). The data suggest that the mean effective radius is about $r_N = 2.5$ km for a 4% albedo, and the nucleus is highly elongated ($> 2.5:1$). We searched for periodicities in the data using the WindowCLEAN algorithm, but found that we currently do not have enough data to determine the rotation period of the comet, however, it is likely to be in an excited spin state. Calibration of all of the other runs (which were taken during slightly non-photometric conditions; and has now been accomplished during 2000 Feb) was required before all of the light curve data could be combined.

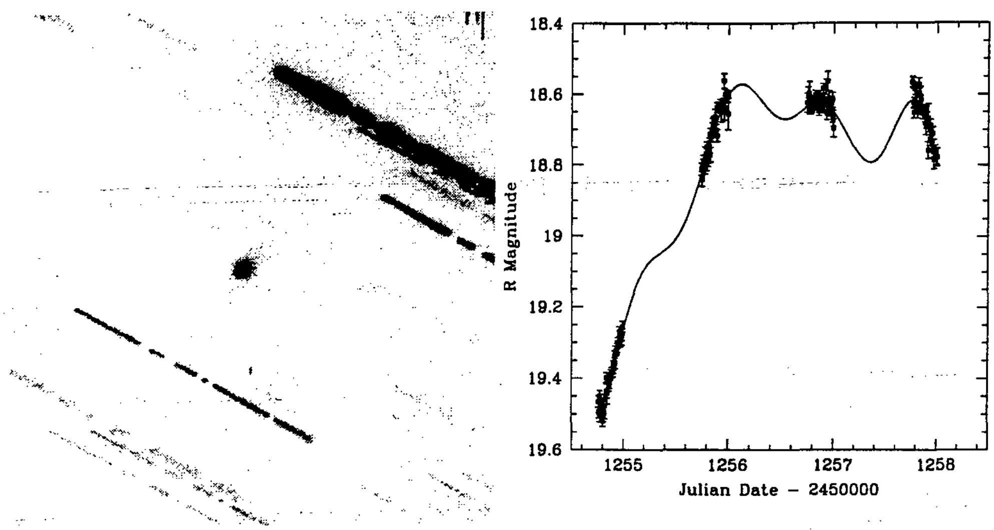

Figure 1: (a) Composite 10,500 s image of P/Tempel 1 from 1999 March when the comet was at $r = 2.88$ AU (b) Composite lightcurve from 4 nights during 1999 March. The fit combines the first 3 harmonics of a 3.84 dy period.

3.2 Nucleus Properties

Observations of the Trans-Neptunian Object 1996 TO_{66} were made performed during three runs (from 1997 Aug. through 1998 Sep.). The magnitude of the object presents some significant variations with time, corresponding to a rotation period of 6.250±0.029h. The phased lightcurve presents a nearly symmetric double-peaked aspect, with a full amplitude of 0.12 mag. The average magnitude ($R = 21.15$) was converted into a mean radius of 326±7 km. The color of the object has been measured at different epochs, and shows some marginally significant changes. At all epochs, the objects is among the bluest of the outer Solar System. The lightcurve changed its amplitude and shape between the first and last runs. We were able to model this change with an albedo change on the nucleus due to activity.

Additional data were obtained with the Keck telescope during 1999 Sep. on TNO 1994TB, which was previously reported to possibly have coma, in order to search for activity. This data is currently being analyzed.

Yan Fernádez is investigating nucleus properties through simultaneous optical and thermal infrared imaging of suitable comets. He has been studying the physical properties of both active and dormant comets. Visible-band imaging was obtained of Comet LINEAR C/1999 S4, which is making its first passage from the Oort Cloud through the inner Solar System and will pass less than 0.4 AU from Earth in mid-2000. The objectives of this study are: (*i*) observe the comatic morphological structure and dust production of this comet as it approaches perihelion, and (*ii*) estimate the optical cross section of the nucleus to complement forthcoming infrared observations. Archival visible-band imaging of the asteroid/dormant comet Phaethon are being reduced and analyzed. Time series of photometry of this object show the variation due to rotation, and such data exist at several different locations in the orbit. This will constrain the orientation and rate of the body's spin axis. Furthermore, photometry at the many phase angles of observation (out to 85 degrees) will constrain the object's phase law and thus a gross characterization of Phaethon's surface roughness. Yan is being supported for 1/3 of his time on this project.

3.3 Centaurs and Small Satellites

This is the focus of the thesis work of G. Bauer. It is thought that the origin of the Centaurs is the Edgeworth-Kuiper Belt, the predicted reservoir of the current short period comet population. Only one Centaur, 2060 Chiron, has been shown to have cometary activity. Bauer's thesis involves an observational survey of these bodies to obtain detailed characterization of their physical properties. This investigation includes obtaining light curves, searching for comae, and obtaining NIR surface spectra. He is also planning to compare these objects to small outer planet satellites which may be captured bodies, in part to understand origins and surface evolutionary processes. The work this year has largely focussed on Centaur light curves and colors. He obtained a good data set on the Centaur $1997CU_{26}$ at the UH 2.2m telescope in January of 1999, in order to determine the rotation period and to do a deep search for coma. The data were insuffient to unambiguously determine the period, but it is near 12.4 hours. This paper is being written up for publication.

UKIRT observations of Miranda taken in 1999 June for comparison with surface properties of Centaur objects reveal strong water ice signatures. The spectra confirm the existence of a 2.0 μm water feature previously found. They also show a second feature at 1.5 μm. The spectra are characteristic of a mostly water ice surface with the slight presence of carbonaceous or silicate contaminates. This paper (Bauer *et al.* 2000) is being written up; most of the work is done, we are just waiting for some collaborative work with T. Roush on spectral modelling.

3.4 Mission Support

In addition to the *Deep Impact* mission support, the PI is undertaking observing programs to support the *Stardust* mission through extensive observations of 81P/Wild 2. The first research paper on this target has been completed (Meech & Newburn, 2000), and an extensive additional dataset awaits analysis.

Work with postdoc Jana Pittichova is ongoing to analyze data relevant to the proposed *Comet Nucleus Sample Return Mission*, as well as providing information for the *Rosetta* mission, and *CONTOUR.*

4 Associated Activities

4.1 Bioastronomy Conference

In relation to the research being conducted under this grant, the PI was the local organizer for the 1999 Bioastronomy meeting, held on the Kohala Coast 1999 August 2-6. Several supplements to this research grant were given in support of this meeting. These will have separate progress reports, however a brief report is presented below.

The meeting was held from August 2-6 at the Hapuna Beach Prince Hotel on the big island of Hawaii, and was attended by 169 scientists, 17 students, six members of the press, and 21 guests, for a total of 213. This meeting was an opportunity to integrate the expanding interests of the multidisciplinary field of astrobiology. The scope of the scientific program (of 144 papers) covered topics such as interstellar organic molecules in interstellar and planetary space, origin and evolution of planetary systems, the detection and characterization of extrasolar planets, comets, asteroids and the role of small bodies in the origin and evolution of life, Earth as a living planet, life in extreme environments, transport of life between planets, the evolution of life and intelligence and progress in the search for extraterrestrial technology and life. In addition to the exciting and diverse presentations made in the scientific sessions, conference attendees were able to participate in several unique ancillary programs. The PI is co-editor of the Proceedings.

In an effort to more broadly disseminate the highlights of the bioastronomy / astrobiology field, a teacher workshop was run concurrently with the conference on Wednesday August 4, and was hosted by the NASA Life Sciences Outreach Program and the NASA Astrobiology Institute outreach Office. The program enabled 50 local Hawaiian K-12 teachers to interact with the scientific meeting participants for mutual benefit. The educational program included keynote presentations by Bruce Jakosky and Karen Meech.

4.2 Educational Outreach

The PI is involved in a large number of outreach activities related to this project:

- *The Annual IfA Open House* – The IfA's Open House is an opportunity to show the general public what work it does. The PI ran a "build-a-comet" hands on activity during the program, and gave a public presentation on comet missions.
- *The Toward Other Planetary Systems Workshop* – ran from June 13-July 1, 2000 for local and Pacific-affiliated science and math high school teachers and students. The goal is to engage in systemic reform in the Hawaii and Pacific school systems, by introducing one of Hawaii's great strengths into the curriculum: origins-related astronomy.
- *Ask An Astronomer* – A spin-off of the TOPS program, this service to the community will route questions submitted over the WWW from teachers, students and the general public to volunteer IfA faculty and graduate students who will answer them in a timely fashion. The resource may be accessed through the TOPS web page. **http://www.ifa.hawaii.edu/tops**

5 Publications

- A'Hearn, M. F., Meech, K. J., Belton, M. J. S., Kissel, J., McFadden, L., Melosh, J., Sunshine, J. & Veverka, J. 2000, "Deep Impact – Exploring the Interior of a Comet", in *Bioastronomy 1999 Proceedings*, ed. G. Lemarchand & K. Meech, in press
- Bauer, G., & Meech, K. J. 1999, "Ground-Based Observations of Centaurs: Searching for Faint Coma", *BAAS*, **31**, 1095
- Bauer, J. M., Owen, T., Meech, K. J., Geballe, T., & Roush, T. 2000, "The Spectral Signature of Water-Ice on Miranda", in preparation
- Hainaut, O. R., Delahodde, C. E., Boehnhardt, H, Dotto, E., Barucci, M.A., Meech, K. J., Bauer, J., West, R. M., Doressoundiram, A., Tozzi, G. P. 1999, "Cometary Activity in TNOs: A Status Report", *BAAS*, **31**, 1115
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- Meech, K. J., Bauer, J. M. & A'Hearn, M. F. 1999, *BAAS*, **31**, 1120
- Meech, K. J. 2000, "Cometary Origin & Evolution", in *Bioastronomy 1999 Proceedings*, ed. G. Lemarchand & K. Meech, in press
- Meech, K. J. & R. L. Newburn 2000, "Observations and Modelling of 81P/Wild 2", submitted
- Meech, K. J., Bauer, J. M., Hainaut, O. 2000, "Rotation of Comet 46P/Wirtanen", in *ESA Special Publication on the ROSETTA Mission*, in press.