

University of Hawaii

Annual Progress Report

Submitted to the

National Aeronautics and Space Administration

Contract No. NAG5-6561

"Spectroscopic Observations of the Planets"

July 1, 1998 to June 30, 1999

Submitted by

Tobias C. Owen
Principal Investigator
Institute for Astronomy
University of Hawaii

19990511 086

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

ANNUAL PROGRESS REPORT NAG 5-6561

During the past two years, the research supported by this grant has focussed on isotopic ratios in comets and in the atmosphere of Titan, and the determination of surface compositions of outer solar system bodies. Titan exhibits a terrestrial value of $^{12}\text{C}/^{13}\text{C}$ but $^{14}\text{N}/^{15}\text{N}$ is highly depleted compared with Earth indicating massive escape of nitrogen from Titan. The H_2O in Comets Hale-Bopp and Hyakutake is enriched in deuterium by about a factor 2 compared with ocean water (SMOW) while D/H in Hale Bopp's HCN is 14 times the SMOW value. $^{12}\text{C}/^{13}\text{C}$, $^{14}\text{N}/^{15}\text{N}$ and $^{32}\text{S}/^{34}\text{S}$ in Hale-Bopp all have terrestrial values. These results have interesting implications for the origin of comets and for the delivery of volatiles to the inner planets. We discovered evidence for transient clouds on Titan and indications of the presence of water ice on this satellite's surface. The dark leading hemisphere of Iapetus appears to be covered by a nitrogen-rich organic compound that is mixed with six-micron ice crystals and a dark, neutral substance resembling amorphous carbon.

This year we plan to improve presently available values of $^{12}\text{C}/^{13}\text{C}$ and $^{16}\text{O}/^{18}\text{O}$ on Mars, using high resolution near-IR spectra of Martian CO_2 and H_2O . We will search for evidence of depletion of ^{16}O on Titan, to see if oxygen has been escaping with nitrogen. We will continue our near-IR studies of Titan to search for new molecules, re-measure the CO abundance and improve constraints on surface composition. We will complete the analysis of the darkside material on Iapetus and initiate a program to compare this material with the dark matter on other outer solar system objects. The Gemini and Subaru 8-meter telescopes on Mauna Kea will become available in 2000, and will have spectrometers capable of recording the 2.85-4.15 μm spectrum of these small bodies. At the same time, NIRSPEC on Keck will enable a definitive investigation of atmospheric methane on Pluto and Triton and the 1-0 CO band on Titan. We plan to use the JCMT to search for evidence of H_2S on Uranus and Neptune.

PUBLICATIONS 1997-PRESENT

- "Mars: Was there an Ancient Eden?" T. Owen. In *Astronomical and Biochemical Origins and the Search for Life in the Universe*, ed. C. B. Cosmovici, S. Bowyer and D. Werthimer (Editrice Compositori: Bologna) 203 (1997).
- "The Detection of Water Ice in Comet Hale-Bopp" by J. K. Davies, T. L. Roush, D. P. Cruikshank, M. J. Bartholomew, T. R. Geballe, T. Owen, C. de Bergh. *Icarus* 127, 238 (1997).
- "Millimeter and Submillimeter Heterodyne Observations of Titan: Retrieval of the Vertical Profile of HCN and the $^{12}\text{C}/^{13}\text{C}$ Ratio" T. Hidayat, A. Marten, B. Bézard, D. Gautier, T. Owen, H. Matthews, and G. Paubert. *Icarus* 126, 170-182 (1997).
- "The Surfaces of Pluto and Charon" D. P. Cruikshank, T. L. Roush, J. M. Moore, M. V. Sykes, T. Owen, M. J. Bartholomew, R. H. Brown, K. A. Tryka. In *Pluto and Charon*, ed. D. J. Tholen and S. A. Stern (Tucson, Univ. of Arizona Press) p. 221-268 (1997).

- "The Relevance of Titan and Cassini/Huygens to Pre-biotic Chemistry and the Origin of Life on Earth" T. Owen, F. Raulin, C. McKay, J. I. Lunine, J.-P. Lebreton and D. L. Matson. In *Huygens: Science, Payload and Mission*, ESA SP 1177, p. 231-233 (1997).
- "From Planetesimals to Planets: Contributions of Icy Planetesimals to Planetary Atmospheres" T. Owen. In *Stardust to Planetesimals*, ed. Y. J. Pendleton and A. G. G. M. Tielens (Astron. Soc. Pac. Conf. Series) **122**, 435-450 (1997).
- "First Ground-Based Adaptive Optics Observations of Neptune and Proteus" F. Roddier, C. Roddier, A. Brahic, C. Dumas, J. E. Graves, M. J. Northcott, and T. Owen. *Planet. Space Sci.* **45**, 1031-1036 (1997).
- "High-resolution Ten-micron Spectroscopy of Ammonia and Phosphine Lines on Jupiter" L. M. Lara, B. Bézard, C. A. Griffith, J. H. Lacy, and T. Owen. *Icarus* **131**, 317-330 (1998).
- "Measurements of $^{12}\text{C}/^{13}\text{C}$, $^{14}\text{N}/^{15}\text{N}$ and $^{32}\text{S}/^{34}\text{S}$ Isotope Ratios in Comet Hale-Bopp (C/1995 01)" D. C. Jewitt, H. E. Matthews, T. Owen, and R. Meier. *Science* **278**, 90-93 (1998).
- "A Determination of the HDO/H₂O Ratio in the Comet C/1995 01 (Hale-Bopp)." R. Meier, T. Owen, H. E. Matthews, D. C. Jewitt, D. Bockélee-Morvan, N. Biver, J. Crovisier, D. Gautier. *Science* **279**, 842-844 (1998).
- "Deuterium in Comet C/1995 01 (Hale-Bopp): Detection of DCN" R. Meier, T. C. Owen, D. C. Jewitt, H. E. Matthews, M. Senay, N. Biver, D. Bockélee-Morvan, J. Crovisier and D. Gautier. *Science* **279**, 1707-1710 (1998).
- "Deuterated Water in Comet C/1996 B2 (Hyakutake) and its Implications for the Origin of Comets" D. Bockélee-Morvan, D. Gautier, D. C. Lis, K. Young, J. Keene, T. Phillips, T. Owen, J. Crovisier, P. F. Goldsmith, E. A. Bergin, A. Despois and A. Wootten. *Icarus* **133**, 147-162 (1998).
- "Millimeter and Submillimeter Heterodyne Observations of Titan: The Vertical Profile of Carbon Monoxide in its Stratosphere" T. Hidayat, A. Marten, B. Bézard, D. Gautier, T. Owen, H. E. Matthews, and G. Paubert. *Icarus* **133**, 109-133 (1998).
- "Transient Clouds in Titan's Lower Atmosphere" C. A. Griffith, T. Owen, G. A. Miller and T. Geballe. *Nature*, **395**, 575-578 (1998).
- "The Composition of Centaur 5145 Pholus" D. P. Cruikshank plus 12 authors including Owen. *Icarus* **135**, 389-407 (1998).
- "From the Interstellar Medium to Planetary Atmospheres via Comets" T. Owen and A. Bar-Nun. *Faraday Discuss.* **109**, 453-462 (1998).
- Near-Infrared Spectroscopy of Low-albedo Surfaces of the Solar System: Search for the Spectral Signature of Dark Material" C. Dumas, T. Owen, M. A. Barucci. *Icarus* **133**, 221-232 (1998).
- "The Origin of the Atmosphere" in *The Molecular Origin of Life*, ed. André Brack (Cambridge University Press, Cambridge) 13-34 (1998).

TCO:dst4/23/99

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0708-0188	
<small>Public Reporting Burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, reviewing and collecting the data, and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this data collection, including suggestions for reducing the burden, to Washington Headquarters Service, Directorate for Information Operations and Services, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0708-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE May 4, 1999	3. REPORT TYPE AND DATES COVERED 6/1/98 to 7/30/99		
4. TITLE AND SUBTITLE " Spectroscopic Observations of the Planets "			5. FUNDING NUMBERS NAG5-6561	
6. AUTHOR(S) Tobias C. Owen				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Hawaii Institute for Astronomy 2680 Woodlawn Dr. Honolulu, HI 96822			8. PERFORMING ORGANIZATION REPORT NUMBER 6-55417	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) NASA Goddard Space Flight Center Greenbelt, MD 20771			10. SPONSORING / MONITORING AGENCY REPORT NUMBER NAG5-6561	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The research supported by this grant has focused on isotopic ratios in comets and in the atmosphere of Titan, and the determinations of surface compositions of outer solar system bodies.				
14. SUBJECT TERMS Titan, isotopic ratios			15. NUMBER OF PAGES 3	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102