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A Photometric System for Detection of Water and Methane Ices on Kuiper Belt Objects

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Abstract

We present a new near-infrared photometric system for detection of water ice and methane ice in the solar system. The system consists of two medium-band filters in the K-band region of the near-infrared, which are sensitive to water ice and methane ice, plus continuum observations in the J-band. The primary purpose of this system is to distinguish between three basic types of Kuiper Belt Objects (KBOs) --- those rich in water ice, those rich in methane ice, and those with little absorbance. We present proof-of-concept observations of 51 KBOs using our filter system, 21 of which have never been observed in the near-IR spectroscopically. We show that our custom photometric system is consistent with previous spectroscopic observations while reducing telescope observing time by a factor of 3. We use our filters to identify Haumea collisional family members, which are thought to be collisional remnants of a much larger body and are characterized by large fractions of water ice on their surfaces. We add 2009 YE7 to the Haumea collisional family based on our water ice band observations which indicate a high amount of water ice absorption, our calculated proper orbital elements, and the neutral optical colors we measured, V-R = 0.38, which are all consistent with the rest of the Haumea family. We identify several objects dynamically similar to Haumea as being distinct from the Haumea family as they do not have water ice on their surfaces. In addition, we find that only the largest KBOs have methane ice, and we find that Haumea itself has significantly less water ice absorption than the smaller Haumea family members. We find no evidence for other Kuiper Belt families.

1. Introduction

Detecting ices on small outer solar system bodies is of utmost importance because the presence of the most volatile ices, such as methane ice, may indicate primordial surfaces. The most massive of the known Kuiper Belt Objects (KBOs) such as Eris and Pluto, cannot retain surface ices for the age of the solar system even under moderate heating, temperatures of >70 Kelvin [1]. Thus, an inventory of volatile ices on the KBOs has the potential to provide a useful metric of historical heating.

Most ices of interest are bland or nearly so at visible wavelengths, but many show prominent absorption features at near-infrared wavelengths. In this work, we introduce a simple custom-bandpass three filter system which allows us to discern between KBOs with water ice, methane ice and relatively bland surfaces. We have undertaken proof-of-concept observations which demonstrate that these filters are indeed consistent with spectroscopic observations yet typically require 1/3 of the telescope time of spectroscopic works. In addition, we have observed all of the Haumea family candidates brighter than V = 22 from [2] and we identify which members have surfaces rich in water ice. This work is based on [3].

2. Results

The results of our work are presented in Figure 1. The basic goal of this work is to demonstrate that our custom filter bandpass can distinguish between the three basic types of bodies observed in the Kuiper Belt: water ice, methane ice and neutral reflectance. This trend is readily apparent as the vast majority of objects fall into the neutral category in the upper right. Most bodies with ice detection have water ice and occupy the left part of Figure 1. The two known bodies with methane ice, Makemake and Eris are shown in the bottom right of the figure, clearly separated from all other objects.

3. Figures

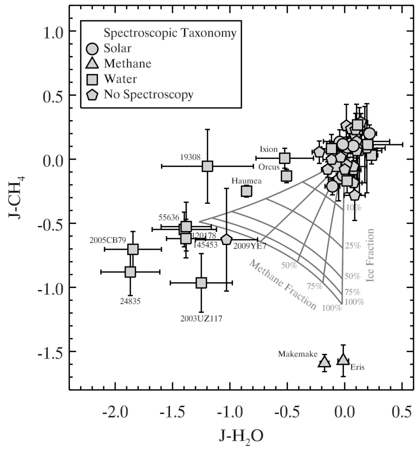

Figure 1: Combined photometry for all objects. Data symbol position is computed from our photometric survey. Data symbol shape is determined from published spectroscopy by other researchers. Objects clearly fall into three groups: Methane (Eris and Makemake), Water (Haumea family members now including 2009 YE7, Ixion, and Orcus) and Neutral / low absorption (all others). In general there is a strong correlation between our photometric work and published spectroscopic works for those bodies observed by both. The triangular grey grid represents colors expected for synthetic objects with varying percentages of methane, water and total ice fraction. The vertical axis of the grid labeled "Ice Fraction"' represents total ice fraction (water and methane combined) with the remainder being represented by a neutral absorber. The diagonal axis labeled "Methane Fraction" represents the total fraction of ice that is methane ice, with water ice being the remainder of the ice fraction.

4. Summary and Conclusions

We find the following in this work:

1. Our custom photometric work can identify KBO surfaces with a factor 3 less telescope time than similar quality spectroscopic works. We can discriminate neutral bodies from water and methane ice bodies with >15% absorption depths, which corresponds to approximately >10% surface fractions of ices for simple models of KBO surfaces.
2. We identify 9 Haumea family members including a new object 2009 YE7, which is consistent in visible color, water ice depth and proper orbital elements with the rest of the Haumea family. We reject several objects with dynamics similar to Haumea because they do not have surface water ice.
3. We find that the smallest Haumea family members systematically have deeper water ice absorption than Haumea to 6 sigma confidence. This observation is consistent with a collisional origin for the system.
4. We identify two non-Haumea bodies with water ice in 3:2 mean-motion resonance with Neptune (Orcus and Ixion). Combining this with previous spectroscopic studies demonstrates that moderate water ice is pervasive throughout all Kuiper Belt dynamical classes.
5. Outside the Haumea family, we find no evidence for any correlation between body size and water ice fraction.
6. We find that only the largest KBOs harbor methane ice, which is consistent with arguments of volatile loss timescales based on surface gravity, such as presented by [1].

4. Acknowledgements

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