Identification of Crystallized Ice on Kuiper Belt Objects

Victoria Hartwick

Department of Astronomy-Physics, University of Wisconsin-Madison

Abstract

The processes responsible for the presence and preservation of crystallized ice on Kuiper Belt Objects are presently unknown. However, a correlation between KBO radial size and its presence is potentially illuminative of dynamical and inter-object interactions throughout the history of the solar system. By analysis of three filter NIR observations of four Kuiper Belt Objects in combination with later observations, we hope to construct rough NIR spectra that indicate the presence or non-presence of crystallized ice on an object and together with other spectra confirm any existing correlations. My objective for the summer is to proceed with data reduction and analysis of my October observations of four Kuiper Belt Objects. Together with new observations in July, I can then construct up to 12 rough spectra and identify the presence of crystallized ice on objects of varying radii. A correlation between radial size and presence of crystallized ice will provide important information about the feasibility of current theorized processes for its creation and preservation.

Background Research

The Kuiper Belt consists of an estimated >100,000 of primarily icy objects ranging in size from less than one kilometer to several hundred kilometers (the largest being the newly classified dwarf planets: Eris, Pluto, etc). The Kuiper Belt extends over an average distance of 100 AU ranging from approximately 40 AU up to 150 AU or more. This extremely large volume of space limits the amount of interaction between Kuiper Belt objects and contributes to the pristine nature of KBOs. The study of KBOs is then an exploration of the initial conditions of our forming solar systems that probes the ingredients of the protoplanetary disk from which the eight planets formed. However, some dynamical processes have occurred over time. An explanation for the presence of crystallized ice on the surface of some observed KBOs may shed light on some of these past and current processes.

The presence of crystallized ice as a common surface component of Kuiper Belt Objects represents an unsolved mystery in our understanding of the evolution of the solar system. Both its initial formation and continued presence despite bombardment by cosmic rays and solar photons are unexplained. Current models suggest a variety of methods to explain both the formation and preservation of crystallized ice on objects that reside at an average distance of 40 AU. The initial creation requires heating of KBOs to a temperature double their current one of 40 to 50 K[1]. Ice formed at 40K does not have enough energy to crystallize and is instead amorphous. Dismissing the possibility of an outward migration of KBOs after formation to their present position, a number of proposed processes could provide the heat needed to allow for the formation of crystallized ice in situ: (1) the conversion of gravitational potential energy to heat during the object's formation; (2) the decay of radionuclides trapped in recesses in amorphous ice; or, (3) bombardment by micrometeorite impacts. The successful determination of each hypothesis' validity would give valuable information about the conditions of the protoplanetary disk from which the KBOs formed. For example, a materially diverse disk would provide ample opportunity for trapped radionucliotides in amorphous ice. Their decay and the subsequent heating of amorphous ice could lead to its crystallization. Similarly, formation of objects by core accretion could lead to the presence of a potentially large number of micrometeorites in a more mature disk. Evidence supporting the third process for crystallization of ice would validate hypotheses for an abundantly populated early protoplanetary disk. However, once the ice is crystallized, there is the additional problem of its preservation in the face of constant irradiation by high-energy solar photons and cosmic rays, which return the ice to its amorphous form. Since these two processes can independently amorphosize all ice well within the lifetime of the solar system (within < 1 Myr) [3], the persistence of crystallized ice requires either the continual annealing or resurfacing of new crystallized ice on the KBO. An additional set of models predict (1) cyrovolcanism, (2) impact gardening, or (3) thermal jostling as possible methods of recreating or resurfacing crystallized ice.

Models for both the original creation and preservation of crystallized ice predict an observable correlation between the size of KBOs and the presence of crystallized ice. We can confirm the presence of crystallized ice on a KBO from construction of NIR spectrum of KBOs. The spectrum of crystallized water ice contains a unique spectral line at 1.65 um. KBOs that show this spectral line have surface crystallized ice. Those that do not have only amorphous ice. A survey of KBOs looking specifically for the 1.65 μm spectral line diagnostic of crystallized ice is necessary to gain a better understanding of ongoing processes, of which the viability of several is strongly dependent on radial size. Of the total six proposed methods for the formation and preservation of crystallized ice formation, half are only possible on KBOs with a radius greater than 500 km [1]. Cyrovolcanism, conversion of gravitational potential energy to heat, and decay of radioactive nuclii, processes that require internal differentiation, large mass, and sufficient capturing ability respectively, are impossible on objects with small radii. Even impact gardening, though theoretically possible on all KBOs, is significantly more probable on large objects with greater surface areas. Observations supporting these processes would reveal a distinct split between large bodies with crystallized ice and small bodies with amorphous ice. Conversely, micrometeorite impact and thermal jostling are possible on all KBOs and therefore the distribution of crystallized ice among KBOs would be independent of size.

Methods

In October 2009, we conducted a preliminary survey at WIYN telescope of ten Kuiper Belt objects of varying size (nine with radii less than 500km and one with a radius greater than 500km) observing with the J, H and [FeII]-45 filters at 1.250, 1.651 and 1.668 μm to search for the 1.65 μm crystallized ice line. Object size was estimated from its absolute magnitude and a predicted albedo of 0.25 to 0.05 using the Minor Planet Electronic Circulars conversion table [5].

Each object was observed for a total of three hours in three filters. Integration time per individual image varied with filter. Observations in J had 100 second integration times and were performed using Fowler I. Observations in K had 75 second integration times using Fowler I, and observations in [FeII]-45 had 240 second integration times using Fowler 4.

Data was reduced in the standard way using IRAF. In images where no object was identified, we used background objects with known visual magnitudes to find the minimum observed magnitude in the image.

Results

A total of 10 objects were observed, however, due to inclement weather, of these 10 only 2 received the total planned integration time (OR10 and TG422). Individual images were stacked to create 3 final images of each object (one for each filter – J, K and FeII-45). Comparison of the final images with 2MASS and SDSS has allowed for tentative identification of Kuiper Belt objects in filters J and K for two sets (2007 VK305 and AS13, both from the first night of observation). Of the images in which background sources have been identified, we are fairly confident that observations were deep enough in each filter. On average our observations reached magnitudes of 21^{st} to 23^{rd} magnitude in V.

Conclusion

Unfortunately, while Kuiper Belt Objects were identified in individual images, we were not able to identify a KBO in each image in the set of three (J, K and FeII-45). Because of this we are unable to construct a rough NIR spectrum which would in turn enable us to identify the presence or nonpresence of the crystalline ice absorption line at 1.65 um. Because our objects are near the magnitude limit of the WIYN telescope, the best solution to our problems would be longer integration times. However, weather conditions at Kitt Peak have made this very difficult.
We do not currently have plans for another observing run.

Figures

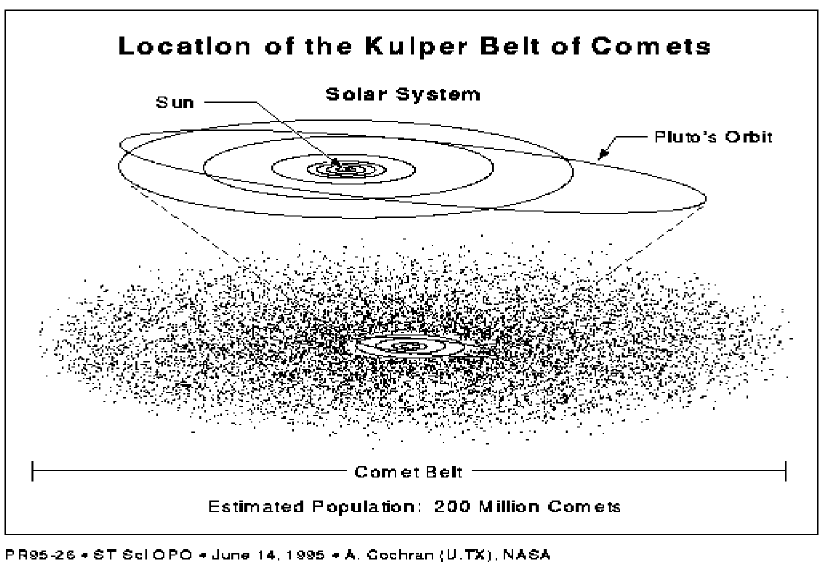

Figure 1: Basic Diagram of the Kuiper Belt. Orbit of Pluto indicated
[http://wps.prenhall.com/esm_chaisson_astronomytoday_5/21/5409/1384765.cw/content/index.html]

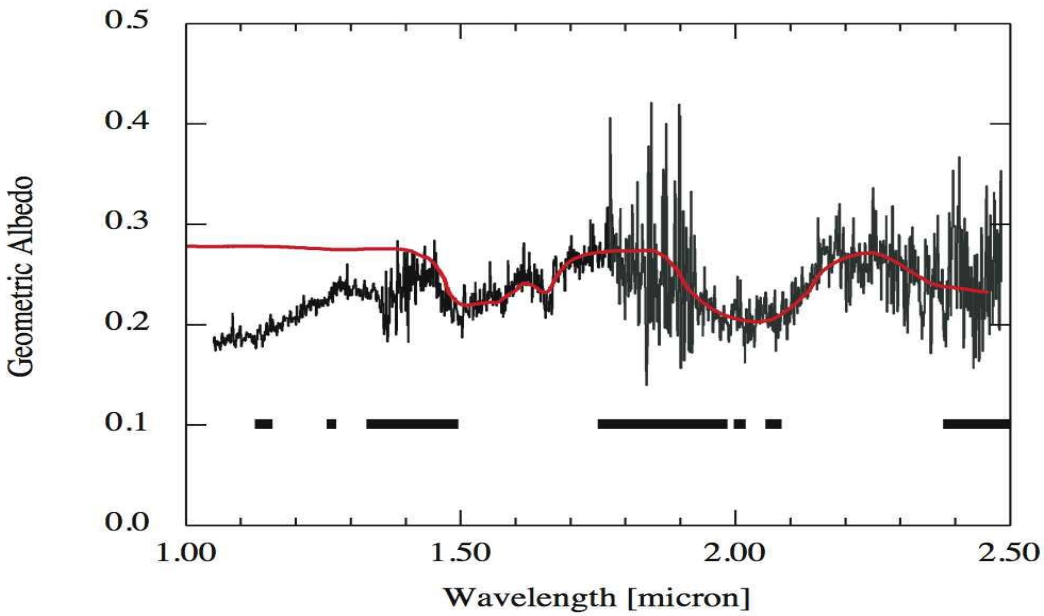

Figure 2: Example NIR reflectance Spectra of Quaoar (black) compared with reflectance spectrum of water-ice (red). Sharp dip at 1.65um is indicative of crystallized rather than amorphous ice. [2]

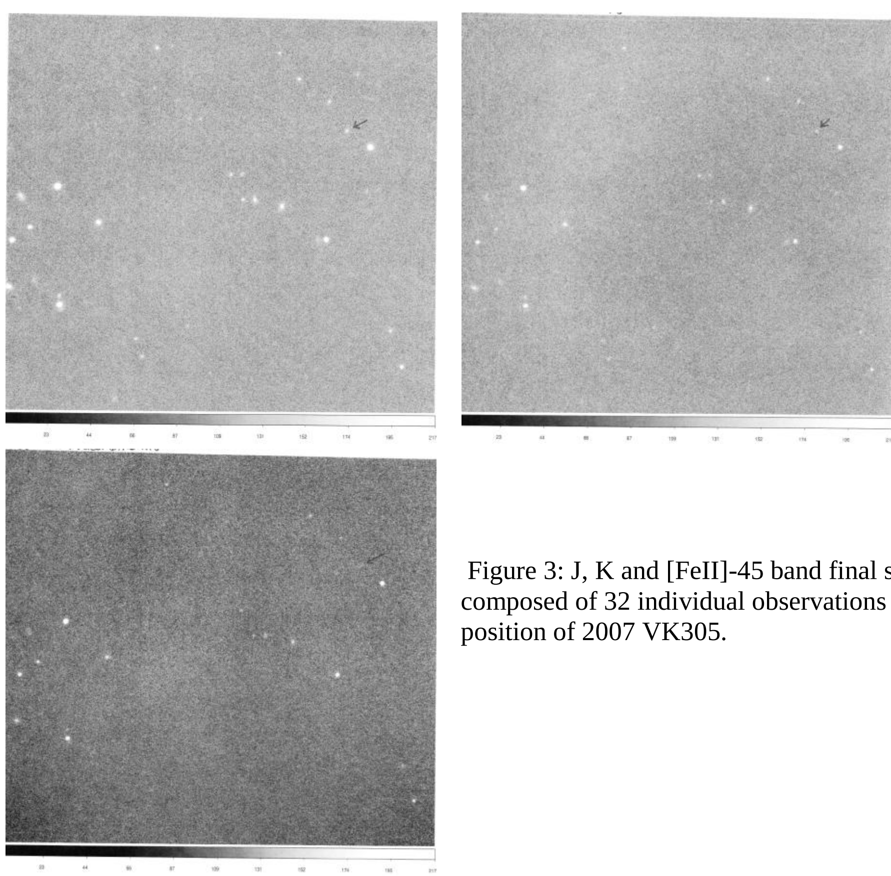

Figure 3: J, K and [FeII]-45 band final stacked image of 2007 VK305 – composed of 32 individual observations per filter. Arrow indicates position of 2007 VK305.

Works Cited

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[3] Cook, J.C., Desch, S.J., Roush, T.L. Near-Infrared Spectroscopy of Charon: Possible Evidence for Cryovolcanism on Kuiper Belt Objects 2007. The Astrophysical Journal 663 issue 2:1406-1419.

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