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The surface compositions of Kuiper belt objects

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Abstract

Objects in the Kuiper belt are difficult to study in detail, even with the best telescopes available. Therefore, for many years, studies of the compositions of these objects were relegated to collections of moderate-quality spectroscopic and photometric data that remained difficult to interpret. Much early effort was put into simple correlations of surface colors and identifications of spectral features, but connecting these observations to a larger understanding of the region remained elusive. The past decade, however, has seen a blossoming in our understanding, a product of the discoveries of larger—and thus easier to study—objects, continued collection of high-quality photometric and spectroscopic observations, and continued work at the laboratory and theoretical levels. Today, we now know of many of the processes that affect these objects' surface compositions, including atmospheric loss, differentiation and cryovolcanism, radiation processing, the effects of giant impacts, and the early dynamical excitation of the Kuiper belt. We use our new understanding to build a comprehensive framework for the compositions and their causes.

1. Introduction

Much of the previous work on the surface compositions of objects in the Kuiper belt has focused either on detailed modeling of individual objects or on statistical descriptions using a limited number of parameters of the objects. We, instead, approach the question from a physical and chemical standpoint and try to identify both the types of surfaces on Kuiper belt objects and the processes responsible for them. In doing so, we have identified seven distinct types of surfaces in the Kuiper belt, most of which have plausible physical explanations, though some of which can only be empirically described.

2. The seven types of Kuiper belt surfaces

1. **The large objects.** In previous work we focused on the compositions of the largest objects in the Kuiper belt and found that their surfaces can be explained by simple considerations of volatile retention. These Kuiper belt objects with the most volatile-rich surfaces have spectral signatures of methane ranging from extreme (Makemake) to subtle (Quaoar, 2007 OR10).

2. **The Haumea family.** Haumea and its family are the only known objects to show signatures of nearly pure water ice, a result of a giant impact into a large differentiated body which left a single high density ice covered remnant as well as a family of low density icy fragments. These pure water ice surfaces are able to be retained on billion year time scales.

3. **The mid-sized icy objects**. Objects between about 400 km and 1000 km in diameter are the most varied in behavior. Some (Charon, Quaoar, Orcus, 2007 OR10, 2003 AZ84, others) show moderately deep water ice absorption on their surfaces, with a clear trend for more ice on the larger objects. In the case of Charon and Orcus, ammonia is also detected. This water ice on the surface appears to be a signature of post-formation cryovolcanism.

4. **The mid-sized non-icy objects.** Many objects in this size range do not show elevated water ice signatures, however, yet their surface properties appear different from the smaller objects, discussed below. We currently have no understanding of the surfaces of these objects.

5. **The small neutral objects.** We now know that the small objects – which overlap the size range of the known Centaurs – bifurcate into two color classes identical to the Centaurs. There is variation within the class;

objects which are slightly redder also have slight water ice absorption features, suggesting a mixing line between a neutral material and a slightly red water laden material. These objects have albedos of ~4%.

6. **The small red objects.** The small red objects exhibit a similar behavior to the small neutral objects: the reddest of the red objects have increasingly larger amounts of water ice and also, in this case, methanol, suggesting a mixing line between a neutral material (perhaps the same neutral material as the neutral objects) and a very red water and methanol laden material. These objects have albedos of ~10%.

7. **The cold classical Kuiper belt objects.** These objects appear likely to have formed *in situ* beyond 40 AU and retain unique surface characteristics from this formation location, including red colors (which overlap the range of the colors of the small red objects) and also high albedos of ~20%.

3. Conclusions

To date, all know objects in the Kuiper belt fit into this general classification scheme. For the first time we have a comprehensive understanding of the diversity of Kuiper belt surfaces and, in many cases, their causes. Much ignorance remains, however, with several of our largest knowledge gaps being an understanding of the non-ice mid-sized objects, the mixing materials for the small objects, and the actual composition of the cold classical objects.