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Water Ice Abundance on Trans-Neptunian Objects

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Abstract:
The surface ices on trans-Neptunian objects (TNOs) can provide essential information about the thermal/chemical histories of primordial planetesimals in the outer solar system regions, which allows us to promote better understanding of the formation and evolution of planets and small bodies in the early solar system. H_2O ice is known to be the most common icy components on the surfaces of large TNOs, however, spectroscopic survey observations reported that none or only small amounts of H_2O ice were detected on most of small/medium-sized TNOs. It is still uncertain whether such objects truly lack H_2O ice on their surfaces or not, and if so, what mechanism causes the surface ice depletion. We propose investigation of H_2O ice abundance on the surfaces of TNOs in a wide size range using the survey data obtained by WEI with several filters such as $F158$.

Water Ice Abundance on Trans-Neptunian Objects

Background

Trans-Neptunian objects (TNOs) are a small-body population located beyond Neptune's orbit, They are believed to be remnants of primordial planetesimals formed at the early stage of the planet formation process in our solar system. Since these objects are located in the cold environment far from the Sun enough for volatile compounds to condense and remain in the solid phase, their surfaces could be rich in ices which are primitive materials formed in the early solar system and/or their secondary products generated through chemical modification induced by heating and ultraviolet/ionizing radiation. The composition of the surface volatiles provides essential information about the thermal and chemical histories of planetesimals and leads us to understanding of the physical and chemical conditions in the outer protoplanetary disk as well as the thermal evolution of TNOs. In fact, various kinds of ices such as H_2O, CH_4, CH_3OH, C_2H_6, CO, and NH_3, were detected from the objects in the outer solar system including outer planet satellites, dwarf planets, and TNOs (e.g., Barucci & Merlin 2020).

In the trans-Neptunian regions, the largest objects corresponding to dwarf planets such as Pluto, Eris, Makemake, and Sedna are known to have CH_4 ice-rich surfaces, while most TNOs exhibit reflective spectra dominated by H_2O ice (e.g., de Bergh et al. 2013). The existence of H_2O ice on TNOs can be identified by the characteristic absorption bands at 1.5 μm and 2.0 μm wavelengths in their near-infrared reflective spectra. The depth of these features represents the spectral fraction of H_2O ice on the surface. The abundance of H_2O ice has been investigated from a number of TNOs and Centaurs (a small-body population located between Jupiter and Neptune) by several spectroscopic surveys performed with 8–10 meter telescopes (e.g., Barkume et al. 2008; Barucci et al. 2011; Brown et al. 2012). These studies pointed out a trend of the surface H_2O ice fractions with body size that large objects such as Charon (Pluto's largest moon), Haumea, Orcus, Gonggong, and Quaoar have H_2O ice-rich surfaces, while none or only small amounts of H_2O ice were detected on most objects smaller than $\sim$800 km in diameter (see Figure 1).

The exception is the Haumea collisional family members that are considered to be originated from fragments of Haumea's mantle ejected due to a disruptive impacts and exhibit strong spectral features of H_2O ice even on small objects of diameter less than 500 km (Brown et al. 2007). This fact may indicate that it is not always impossible for small objects to retain H_2O ice on their surfaces. In addition, a spectrum with no or very weak features does not necessarily imply an ice-poor surface because the absorption signatures are masked if H_2O ice contains particulate dark contamination (Clark 1982).

It is obvious that our understanding is still limited to the H_2O ice abundance on TNOs. Measurements with higher accuracy for H_2O ice abundance on a number of small to mid-sized TNOs are required to examine whether these objects truly lack H_2O ice on their surfaces or not, which would be a crucial clue to develop our interpretation to the trend of the ice fraction increasing with size, though it is difficult even by using the present largest ground-based telescopes due to faintness of these objects.

Our proposal

As mentioned above, the H_2O ice distribution among small/mid-sized TNOs is currently not known for certain yet due to lack of their spectral data with high accuracy. Further observational studies are required to understand their surface property and its relation with body size. We are planning to use the High Latitude Wide Area Survey data with WFI for investigating H_2O ice abundance on TNOs of various sizes. Figure 2 shows the near-infrared reflectance spectra of H_2O ice in crystalline and amorphous states with the transmission curves of WFI's filters. The $F158$ filter is suitable for detecting the characteristic absorption band of H_2O ice at 1.5 μm The photometric data set with the $F106$, $F129$, and $F158$ filters can provide us an effective indicator to to diagnose the presence of H_2O ice on TNOs. $F184$ and $F213$ are also useful for measuring the absorption depth of the 2.0 μm band. High sensitivity of Roman/WFI allows us to realize this observation for small-sized TNOs down to 100 km in diameter (see Figure 3). The candidates objects that are identified to contain H_2O ice on their surface by WFI photometry will be observed in more detail by spectroscopic facilities, e.g., Subaru Telescope/ULTIMATE-SUBARU and TMT/IRIS. We also plan to perform 3 μm imaging observations with GREX-PLUS.

We would like to observe more than 100 TNOs using the High Latitude Wide Area Survey data to statistically study the relationship between the H_2O ice abundance and the body size, dynamical class, optical colors, and other properties. Our minimal requirements are

- Filters: $F106$, $F129$, $F158$
- Location of surveyed area: low ecliptic latitude fields within $\pm 30^\circ$.
- Total survey area: more than 50 square degrees
- Depth of each epoch: 25.0 AB mag
- Cadence: five or more visits at intervals of at least one hour within one week for each filter

In addition, we have the following requirements for our optimal observational strategies:

- $F184$ and $F213$ data for measuring the absorption feature of H_2O ice at 2.0 μm
- Prism slitless spectroscopy with at least three orientations
- Multi-band photometry with $F129$ and $F158$ within one week

References

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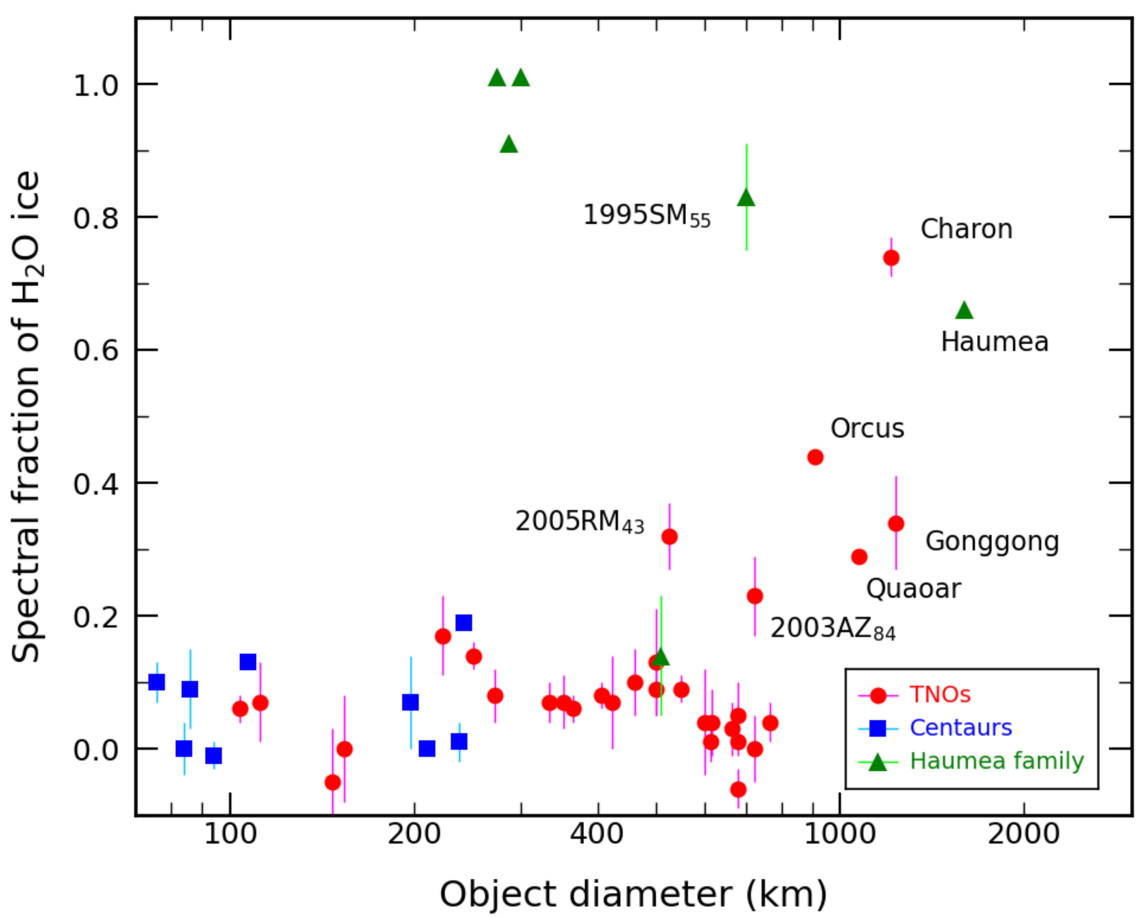

Figure 1: The plot of spectral fraction of H_2O ice (Brown et al. 2012) vs. body size for TNOs (including Charon; red circles), Centaurs (blue squares), and Haumea family members (green triangles).

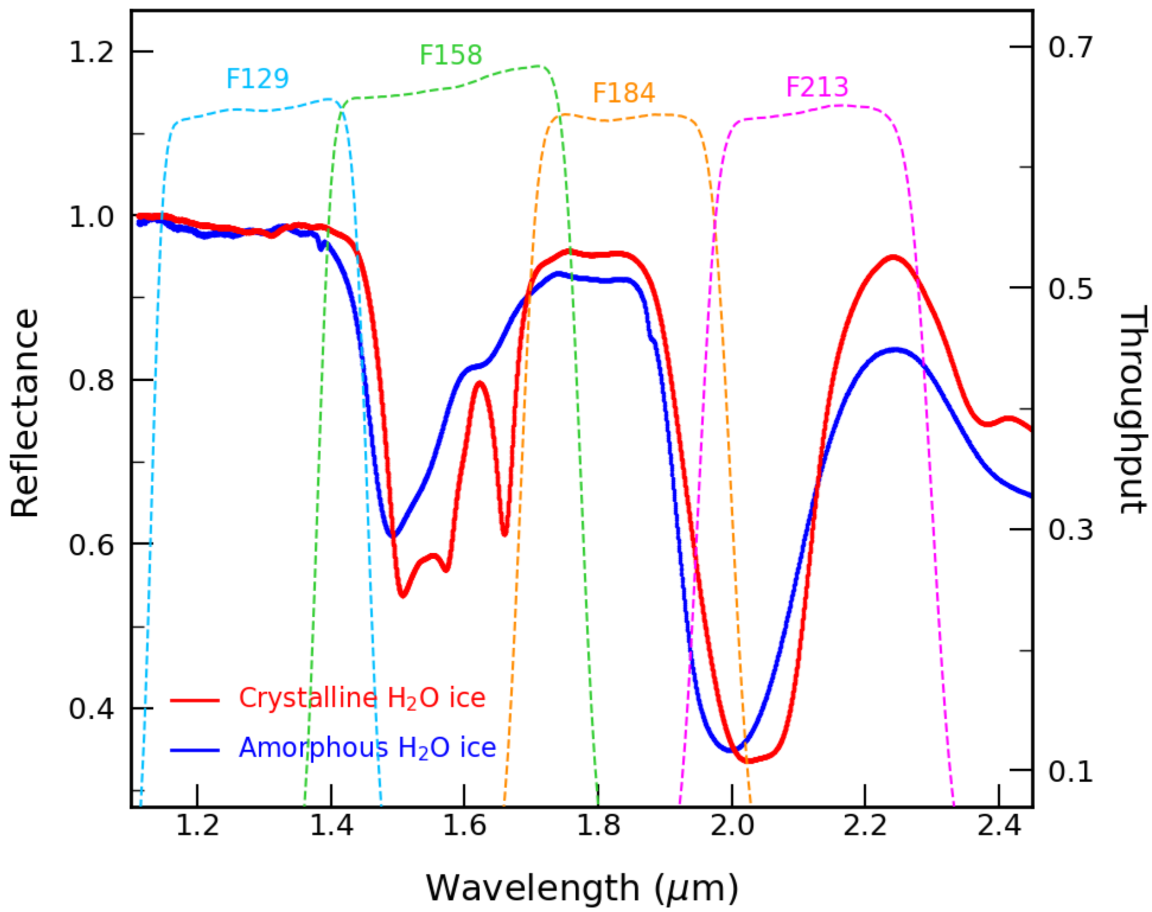

Figure 2: Near-infrared reflective spectrum of crystalline H_2O ice in crystalline (red solid line) and amorphous (blue solid line) states at 60 K with the transmission curves of WFI's filters (dashed lines).

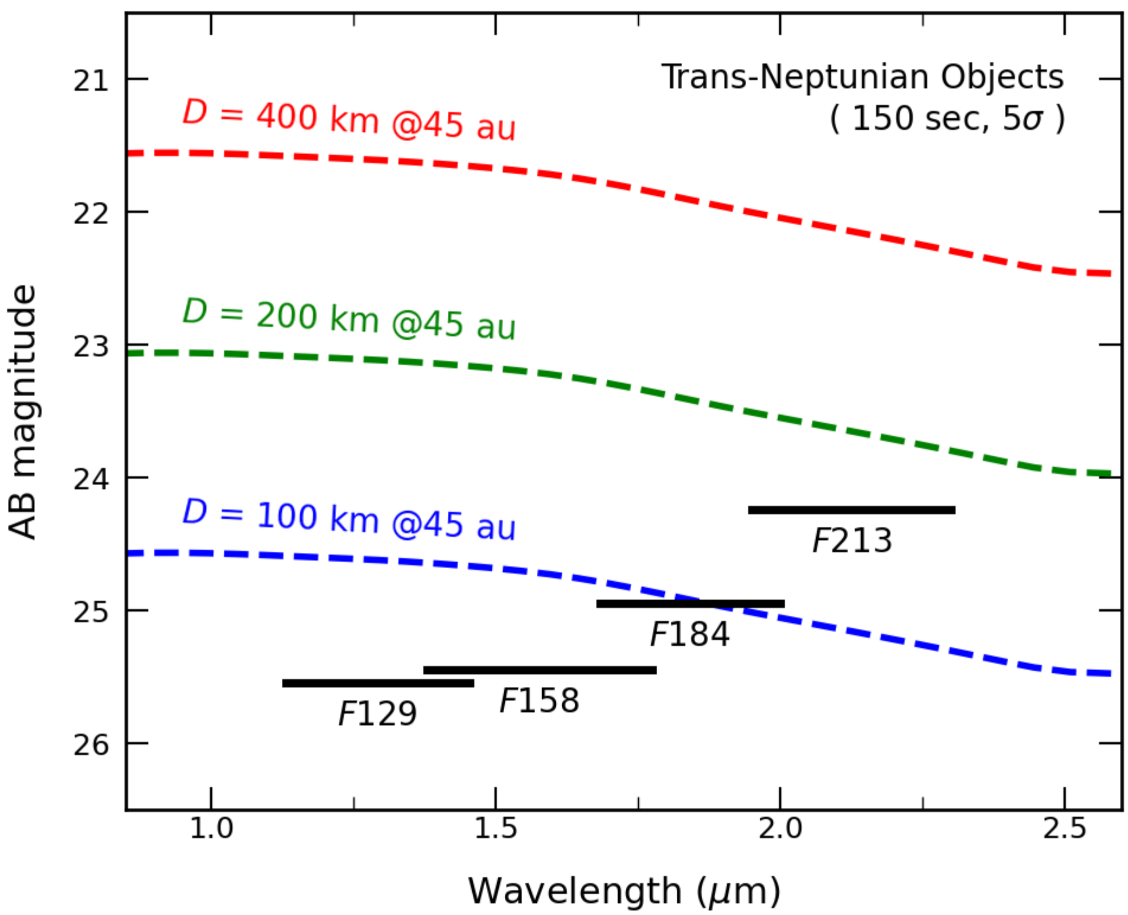

Figure 3: Brightness of TNOs with diameters of 100 km, 200 km and 400 km (blue, green, and red dashed lines, respectively) with WFI's sensitivities (solid lines).