SINGLE SCATTERING ALBEDO INDUCED UNCERTAINTY IN GRAIN SIZE ESTIMATION OF SURFACE VOLATILES ON TNOs AND KBOs. A. Emran[1] and V. F. Chevrier[1], [1]Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701 (alemran@uark.edu).

Introduction: Trans-Neptunian objects (TNOs) and Kuiper belt objects (KBOs), such as Triton [1], Pluto [2], and Eris [3], exhibit prevalence of nitrogen (N_2) and methane (CH_4) ices on their surfaces. Radiative Transfer Models (RTMs) have been used to characterize the physical and chemical properties, including abundances and grain sizes, of these ices on the outer solar system bodies. Different results in water ice (H_2O) grain size estimations have been reported on the Saturnian moons e.g., Enceladus [4]. These varied results in grain sizes have been claimed to result from the calculation of single scattering albedo rather than RTMs. Here we analyze the uncertainty in grain size estimation of pure methane and nitrogen saturated with methane (**N_2**:CH_4) ices, the most abundant volatile materials on TNOs and KBOs. To this end, we compare the single scattering albedo of these ices, which determines the grain size estimation of outer solar system regolith [4], using the Mie scattering model and two other Hapke approximations [5] in radiative transfer scattering models at near-infrared (NIR) wavelengths (1 – 5 µm).

Methods and Calculations: We use the optical constant of pure CH_4 and **N_2:**CH_4 based on the thermodynamics equilibrium of solid methane and nitrogen ices at different temperatures relevant to TNOs and KBOs surfaces. This project uses the optical constants of α-**N_2**:CH_4 at 35K (1- 3.97µm), β-**N_2:**CH_4 at 38K (1 - 5µm), and CH_4 as a proxy for **CH_4**:N_2 at 39K (1 - 5µm). We use the δ-Eddington corrected Mie single scattering albedo *w'* as compared to the estimations of *w* from Hapke approximations. The Mie *w* was calculated following the method described in [6] using the `miepython` routine, a Python module licensed under the terms of the MIT license. A variety of approximate models has been presented by [5] to calculate the *w* from particle refraction indices. Of these models, the equivalent slab model (Hapke Slab) and internal scattering/scatterer model (ISM) are widely used in planetary sciences. Subsequent studies [7-8] also presented versions of ISM for surface scattering function that was originally derived from [9]. We use a version of the approximate ISM [8] and the Hapke Slab models to calculate *w* from the optical constants of the ices found on TNOs and KBOs.

Results: Compared to ISM, the Hapke Slab approximation model predicts much closer grain-size estimation to Mie scattering results (Fig 1). In the case of pure CH_4 ice, the overall estimated grain-size differences are about 10% between the Hapke Slab and ISM for the particles with different grain radii, except for larger particles and longer wavelengths where the imaginary part of the refractive index is much larger. Similarly, in **N_2:**CH_4 systems, the average differences between the estimated grain sizes from Hapke Slab and ISM are around ~20% for wide ranges of grain size. Both Hapke Slab and ISM were found to be appropriate models for a grain size radius of 10 µm. For smaller grain-sized particles (radii of ≤5µm), neither approximate model predicts an accurate grain size owing to the Rayleigh effect. For larger grains at longer wavelengths, particularly at higher absorption coefficient values, the ISM predicted grain sizes exhibit larger anomalies compared to the Mie result.

Discussion and Conclusion: The application of the scattering (and absorption) properties of Mie spheres has been shown to be satisfactory for varied non-spherical particle shapes [11-13]. The Mie formulation accurately predicts the scattering properties of equivalent spheres of particles, even it can produce satisfactory scattering results for irregular particles [12]. Thus, the size of spherical particles from the Mie model can somewhat be analogous to non-spherical particles [4]. Our result shows that, overall, the Hapke Slab model is the more well-predicted approximate model to the Mie result using the NIR optical constants of pure CH_4 and **N_2:**CH_4 systems at different grain sizes while ISM's predictions show higher discrepancies. Thus, we recommend using the Mie calculation for radiative transfer modeling to unknown spectra of TNOs and KBOs. However, if the Hapke approximation models are to be used, we suggest using the equivalent slab model over the internal scattering model in estimating the pure CH_4 and **N_2:**CH_4 ice grain sizes on trans-Neptunian objects and Kuiper belt objects. Our study provides a guideline for the future application of RTMs in estimating the ice grain sizes at TNOs and KBOs.

References: [1] Cruikshank et al. (1993) *Science*, *261*, 742-745. [2] Owen et al. (1993) *Science*, *261*, 745-748. [3] Dumas et al. (2007) *A&A 471,* 331–334. [4] Hansen (2009) *Icarus 203,* 672–676. [5] Hapke (1993) *Camb. U. Press*. [6] Wiscombe (1979) *National Center for Atmospheric Research.* [7] Hapke (2005) *Camb. U. Press*. [8] Hapke (2012) *Camb. U. Press*. [9] Hapke (1981) *JGR 86,* 3039-3054. [10] Savitzky et al. (1964) *Anal. Chem. 36*, 1627–1639. [11] Grenfell et al. (2005) *JGR 10* D17. [12] Neshyba et al. (2003) *JGR 108*, D15. [13] Grenfell and Warren (1999) *JGR 104*, D24.

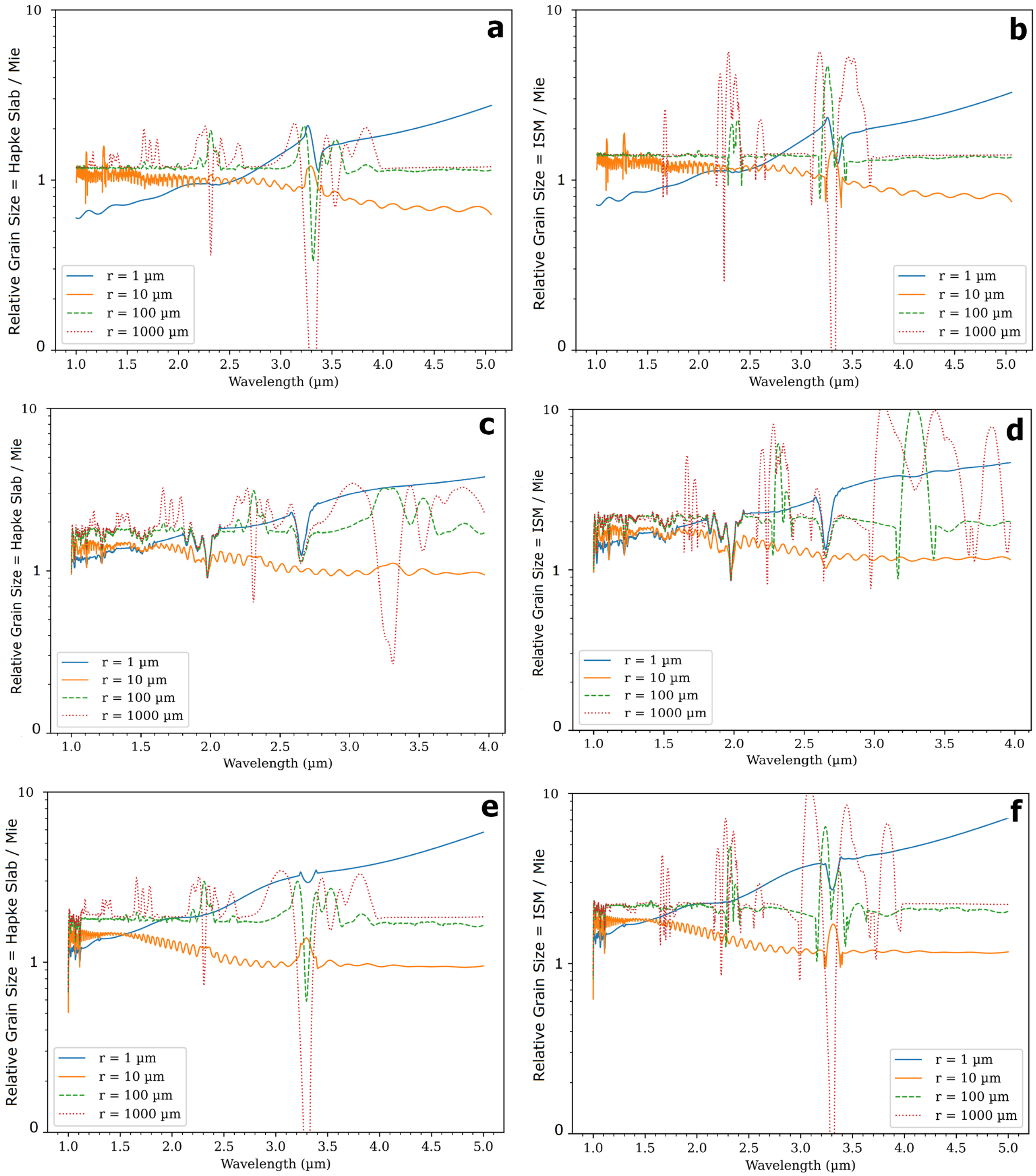

Fig 1: Grain sizes determined from the Hapke Slab (left column) and ISM (right column) using spectra calculated using the Mie model at different particle radii of 1, 10, 100, 1000 µm for pure CH_4 ice at 39K (top row), α-**N_2**:CH_4 at 35K (middle row), and β-**N_2**:CH_4 at 38K (bottom row). The resulting grain sizes are normalized to the input grain sizes. The plots were smoothened using the *Savitzky-Golay* filter [10].