PENITENTES AT TARTARUS DORSA, PLUTO. J.E. Moores[1], C.L. Smith[1], A.D. Toigo[2] and S.D. Guzewich[3]. [1]Center for Research in Earth and Space Science (CRESS), York University, 4700 Keele Street, Toronto, ON M3J 1P3 Canada, [2]Applied Physics Laboratory, Johns Hopkins University, Baltimore, MD [3]NASA Goddard Space Flight Center, Greenbelt, MD. Corresponding author: jmoores@yorku.ca

Introduction: Actively sublimating surfaces often form complex morphologies on Earth such as penitentes [1,2], in which deep hollows separate regular spires or ridges. We apply the theory of how these features form on Earth to the much larger regular and possibly self-organizing sublimation features observed at Tartarus Dorsa (TD) on Pluto. Refered to as 'bladed' or 'snakeskin' terrain by [3] (Fig 1) we find that these features are well described by the theoretical penitente models of [4] with spacing, orientation and growth rates matching well with observations for the methane ices observed by New Horizons (NH) [5] on Pluto. Nitrogen ices, by contrast, are not anticipated to form penitentes under the same model, also matching with observations that the bladed terrain is restricted to TD. For a full discussion of the research to be presented, the reader is directed to reference [6].

Modeling The Environment of TD: Tartarus Dorsa (Figure 1) is located approximately at 220-250ºE and 0-20ºN on Pluto. At the time of the New Horizons encounter, the near-surface atmospheric pressure and temperature were measured by the REX instrument onboard NH [7]. These were used to calibrate the atmospheric and surface energy balance models within PlutoWRF [8] and to predict the atmospheric conditions at TD over diurnal and seasonal timescales. To allow for changes in Pluto's orbit over longer timescales, simulations were run for a representative set of orbital conditions which represent a suitably weighted distribution of Pluto's orbital states over approximately the past Ga.

Theory of Penitentes: The formation of penitentes and their regular spacing arises due to a balance between three competing processes [4] which sets up a Mullins-Sekerka instability [9]. This instability allows a particular spacing to grow faster than other penitente spacings. The three relevant processes are (1) diffusion of heat in the ice or snowpack, which acts to deepen the features, (2) self-illumination, the tendency of bowl-shaped depressions to concentrate light at the center of a growing depression, which also acts to deepen the features and (3) molecular diffusion in the atmosphere above the penitentes which acts as a break or choke on the deeping process by promoting recondensation onto the icy features.

While the primary agent of deepening on Pluto is self-illumination, self-illumination itself is a scale-independent process and the competition with atmos-

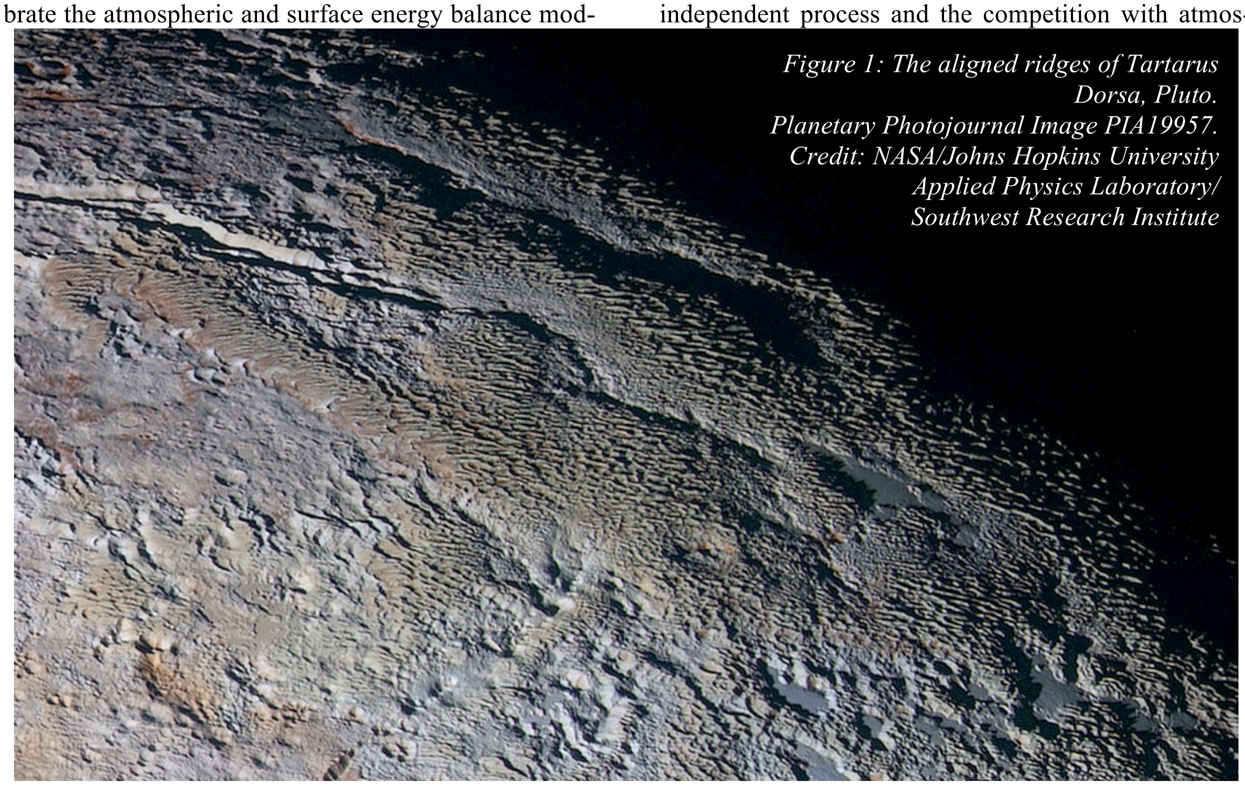

Figure 1: The aligned ridges of Tartarus Dorsa, Pluto. Planetary Photojournal Image PIA19957. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/ Southwest Research Institute

pheric diffusion is necessary to cause the system to self-organize into aligned ridges. As such, the dispersion relation of [4] was used to obtain values of the ridge spacing and the orientation of those ridges was derived by using an illumination model, comparable to [10]. Conclusions about the age of the features could be made by combining an exponential growth rate for the features (as in [4] and [11]) with reasonable assumptions about the initial terrain amplitude of freshly exposed ices.

Results and Conclusions: One active period is observed for the atmosphere per orbit occurring at either the vernal or autumnal equinox, depending upon Pluto's orbital state. This active period for the atmosphere leads to two peaks in the limiting friction velocity towards the start and end of the atmospheric active period. As such, over Ma timescales, there are four separate periods when the formation of penitentes is favored (Fig 2). This leads to three different predicted orientations for growing penitentes which align with the observation of three different orientations at TD on Pluto. Additionally, at the times of formation, Pluto-WRF predictions of atmospheric conditions support the observed scale of the features. Finally, if the initial topography is assumed to be similar in scale to Pluto's youngest terrains, a formation timescale of several 10s of Ma is derived from deepening rates of approximatley 1 cm/orbit in the current era, consistent with crater-ages estimates for TD which are intermediate between Sputnik Planum (<10 Ma) and eastern Tombaugh Reggio (~1Ga) [3]. Taken together, these three lines of evidence collectively suggest that the bladed terrain is composed of penitentes.

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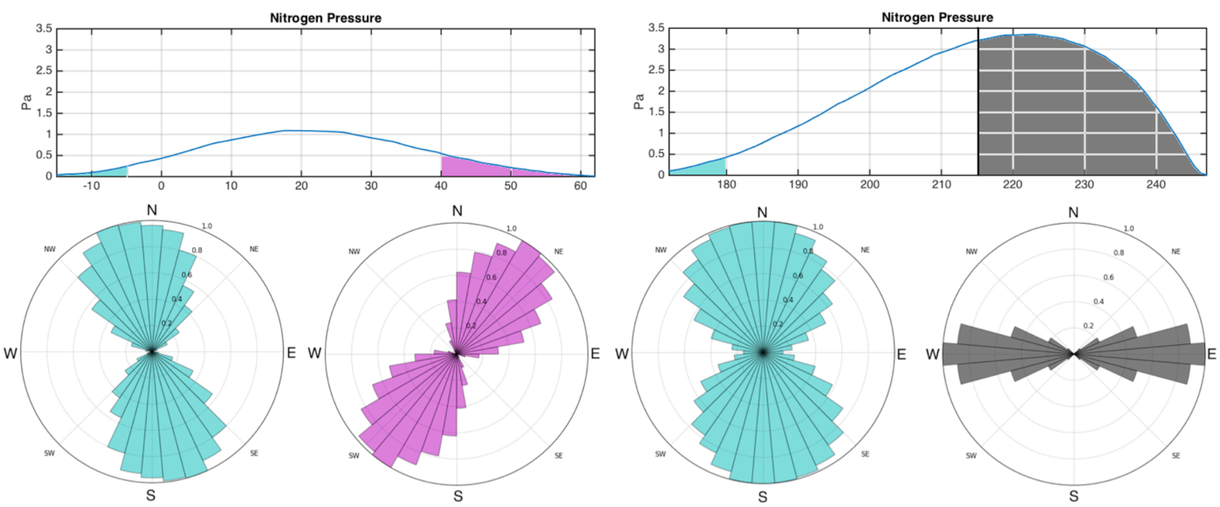

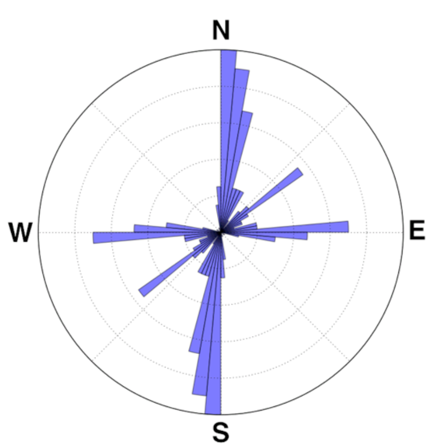

Figure 2: *Nitrogen pressure during active seasons for the atmosphere near the vernal equinox (top left) or autumnal equinox (top right). Each orbit of Pluto exhibits only one of these active periods, depending upon the alignment of the equinox with the time of perihelion. The timing of the high-friction velocity periods when penitente formation is favoured are indicated by the filled areas under each curve and the rose diagrams shown below each filled area indicate the orientation of the penitentes favoured at that time. At lower left, a rose diagram is shown of the orientations observed at TD which show all three orientations predicted by the model.*