REMOVING THE ADJACENCY EFFECT FROM IR SPECTRA OF TITAN LAKES. S. M. MacKenzie[1], J. B. Barnes[2], W. J. Miller[2], J. M. Soderblom[3] Johns Hopkins University Applied Physics Lab (shannon.mackenzie@jhuapl.edu) [2]University of Idaho, Department of Physics [3]Massachussetts Institute of Technology, Department of Earth, Atmospheric and Planetary Sciences.

Introduction: Ethane plays an important role in tracing evolution and stability of Titan's liquid hydrocarbon reservoirs due to its significantly lower volatility and increased solubility with solid hydrocarbons relative to methane [e.g. 1–3] and decreased solubility with nitrogen [e.g. 4]. Though one of the most abundant products of methane photolysis in Titan's atmosphere [e.g. 5], the observed abundance of ethane on the surface is lower than predicted if the current rate of production were active for the age of the solar system. Rather than a ~kilometer deep ocean liquid ethane [1], evidence from Cassini VIMS and RADAR suggests that ethane may not be the dominant constituent in the liquids that cover 1.1% of Titan's surface [6]. Ethane absorption features were distinguished by [7] in VIMS observations of Ontario Lacus, the largest liquid body at Titan's south pole. RADAR altimeter sounding experiments determined the liquid loss tangent of the lakes and seas [8–12]. The results for Ontario Lacus suggest that the south pole's largest lake has 51% methane, 38% ethane, and 11% nitrogen volumetrically (with $1\sigma = 45\%$)[11]. This is a higher abundance of ethane than derived from similar experiments over the north polar seas: 12% ethane at Ligeia [8], ~8% for Punga and the north basin of Kraken [10]. A separate altimetry pass over a southern section of Kraken Mare did not show a signal echo from the sea floor, suggesting that either the sea is much deeper or has a higher loss tangent–due to higher content of ethane or other absorbers–than the other seas [9].

The latitudinal distribution of the seas might drive a compositional difference between them. Whereas Punga is almost directly at the North Pole, the southern-most extent of Kraken reaches down to 54°N. Methane is more volatile than ethane, evaporating and precipitating on seasonal timescales. As precipitation should increase with latitude and evaporation decrease, the hydrological model of [13] predicts that the seas experience different influxes of methane based on their latitude, similar to how the rivers flush sediment from the Sea of Azov into Black Sea into the Mediterranean creating a salinity gradient. On Titan, the volatiles include not only dissolved solids but also liquid ethane.

Similarly, the cryogenic chemistry model of [14] predicts a gradient of compositions between the north polar seas based on the temperature gradient (albeit a few Kelvin) with latitude. Liquids should flow towards the warmest point–i.e. lower latitudes–and return via subsurface flow analogous to thermohaline circulation on Earth. During transport, methane preferentially evaporates, leaving a solution enriched in ethane at lower latitudes.

Or, lake and sea compositions might also be a function of the interactions with the lake/sea floor. Modeling by [15] suggests that lakes with an initial mole fraction of ethane less than 0.75 should become nearly methane pure due to clathrate substitution alone.

To date, we know less about the composition of Titan's small ($\leq 10^3$ km^2) lakes. Unlike most of the larger lakes and seas, the RADAR SAR observations of the small lakes show no return above the noise floor [6,16]. This implies that these small lakes are either very deep or have a higher loss tangent. The SAR observations, however, cannot determine if the higher loss tangent is caused by increased concentrations of ethane (as might be expected if the lakes are isolated and have concentrated ethane over an extended period of time) or an enrichment in radar-absorbing solutes (as would be expected if the small lakes are created via karstic processes). RADAR altimetry sounding over the Lake District constrains the depths and compositions for a handful of lakes [12].

We seek to complement these observations by interrogating the VIMS data, which includes multiple views of most of the lakes and seas albeit at varying spatial resolution. Broadening our temporal and spatial understanding of the observable presence of ethane on Titan's surface provides new insight into ethane's role on Titan. Accurately identifying the 2 μm wing triplet used by [7], however, requires careful treatment of atmospheric interference in each observation.

Identifying candidate absorption features.
Building upon the work of [7], we exploit the fact that the 2.018 μm absorption feature of ethane (

Figure 1 light blue line) should decrease the concavity of the 2-μm window, flattening the reflectance when liquid ethane is present relative to other surface units. We first normalize the spectrum of each pixel to the average of the VIMS bands within the 2.018 μm ethane absorption feature (λ= 2.018, 2.034, 2.051). Then, we subtract the band depth at the VIMS band closest to the center of the absorption feature. The latter is calculated by subtracting the I/F at that wavelength from the continuum, defined as the I/F at edge of the absorption feature (2.001 μm). The resulting spectrum is shown for Punga Mare (black line), nearby land (dark grey), and evaporite (light grey). The absorption feature spatially correlates with the seas

Punga and Ligeia, as well as lakes Cardiel and Muggel, but not, notably in all small lakes of the Lake District.

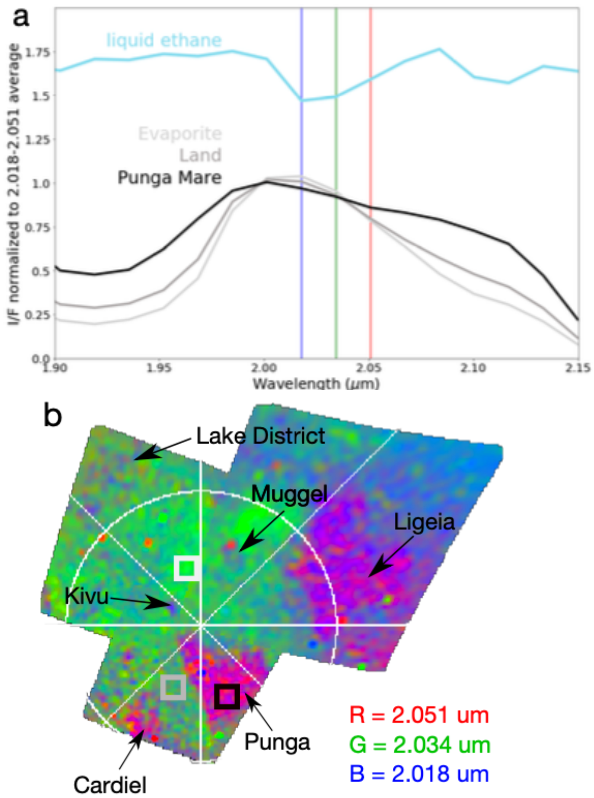

Figure 1. Comparison of surface spectra in the 2 μm window relative to the spectrum of liquid ethane sampled at VIMS spectral resolution.

The Adjacency Effect: To interpret these results, we must account for atmospheric scattering. The adjacency effect is a well-known phenomenon in remote sensing where multiple scattering in the atmosphere mixes photons from different units; dark features such as Titan's lakes are particularly susceptible [17–21]. Titan's lakes are spectrally dark, losing much of the reflected signal to specular reflections off their smooth surfaces and away from VIMS. The surrounding land is often much brighter. Haze in the atmosphere can scatter light reflected off bright material toward the detector as if it were reflected off the lake (Figure 2). Since Titan has a greater aerosol density than Earth, the adjacency effect will influence VIMS observations, likely on scales less than the atmospheric scale height (45 km) and is particularly important for dark units.

We therefore model the I/F contributions to a VIMS observation due to specular reflections off the lakes and scatterings from the shorelines. We have implemented a new formulation for determining the specular point [22] in our radiative transfer code SRTC++ [23]. Predetermining which roots of the defining quartic equations are the correct solutions allows us to solve for the specular point analytically, thereby reducing computation time. SRTC++ simulations will be used to calculate I/F contributions as a function of distance from the shoreline and relative shoreline/lake contrast.

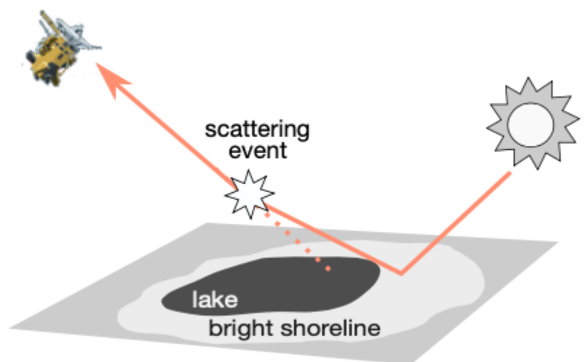

Figure 2. Illustration of how the adjacency effect may artificially brighten Titan's lakes.

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