CONSTRAINTS ON TITAN LAKE SIMILARITIES FROM THEIR SHAPES. Rajani. D. Dhingra[1] , Jason W. Barnes[1], Matthew M. Hedman[1], and Jani. Radebaugh[2], [1]University of Idaho (875, Perimeter Drive, Moscow, Idaho 83844), [2]Brigham Young University (Provo, Utah, 84602).

Abstract: We quantitatively constrain possible lake formation mechanisms on Titan using morphometry of the lakes. We quantify the shape of lakes using Elliptical Fourier Descriptor Analysis. The Fourier analysis decomposes the shape of a lake into a fourier series, and the corresponding coefficients represent a finger print of the lake shape. After testing the methodology on synthetic lakes and two kinds of terrestrial lakes, we analyze 67 Titan lake shapes on the north pole of Titan. We find that the majority of lake shape variation in Titan's lakes is from circular to elliptical followed by lakes with strong asymmetries along their short axis and lakes with strong asymmetries along their long axis. We also find that a few lakes on Titan like Myvatn, Xolotlan, Sotonera, Viedma, Muggel, and Neagh Lacus have very distinctive shapes. Letas Lacus is an extreme outlier amongst the shapes of Titan lakes with an intruding island. This demonstration shows the promise of the Elliptical Fourier Descriptor approach for testing hypotheses for Titan lake formation. Our statistical analysis divides the Titan north polar lakes into four clean shape-based groups, which might indicate either four formation mechanisms or four stages of formation of Titan's lakes.

Introduction: Titan is the only moon in our solar system with a thick atmosphere [1] and stable bodies of surface liquids owing to the methane-based hydrological cycle [2]. Most of the liquids on Titan are located poleward of about 70°N in the form of three large seas (Kraken Mare, Ligeia Mare and Punga Mare) and a couple of hundred circular or irregularly rimmed or unrimmed lakes. While the presence of a hydrological cycle might help explain how the depressions are filled with liquid methane, the formation mechanisms of the depressions still remain a mystery.

Here, we aim to constrain the lake formation mechanisms on Titan using morphometrics. We carry out a novel morphometric analysis using Elliptical Fourier Descriptor Analysis (EFDA) method.

Method: Elliptical Fourier Descriptor Analysis [3] is a method that fits the 'x' and 'y' coordinates of an outline separately. Morphometric analyses need 'x', 'y' coordinates sampled on each outline as an input. So our first step is to extract the 'x' and 'y' coordinates of the lake outlines. We use the tps-Dig software for placing landmarks on the outline. We then use the 'x' and 'y' coordinates generated by tpsDig into a R based package called MOMOCS (MOdern MOrphometriCS)[4]. The coordinate information is used to regenerate the outline shape. The fourier coefficients can be used to preform various statistical analyses like PCA and hierarchical clustering on the lake shapes.

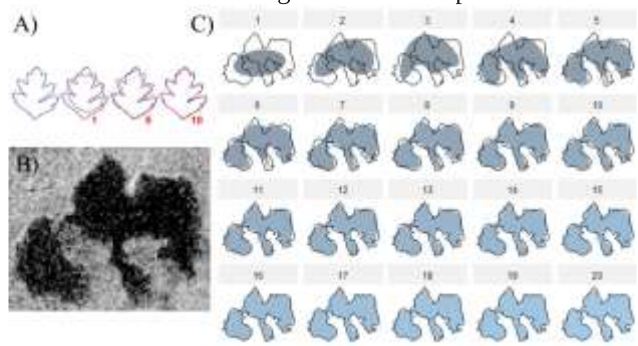

Figure 1: A) shows the methodology of Elliptical Fourier Analysis. Leaf outline is shown in blue. The red ellipse over the blue leaf outline is the first harmonic. The (fifth and) tenth harmonic regenerates the sinuosities of leaf's edge and shape. B) RADAR image of Myvatn Lacus (78^{0}N, 135^{0}W) (peculiarly shaped). Figure C) shows that by 20th harmonic the extremely complicated shape of even Myvatn Lacus can be explained quantitatively by the Elliptical Fourier Analysis

Results: Figure 1 explains the big picture Elliptical Fourier Descriptor Analysis (EFDA) methodology in panel A as a general concept. The leaf outline (shown in blue) has a synchronous point as the twig. The first harmonic is shown as a red ellipse while the tenth harmonic can be seen fitting the sinuosities of the leaf and hence it's outline shape. In panel B, we show the EFDA methodology working for one of the most peculiarly shaped lakes, Myvatn Lacus near Titan's north pole. Myvatn Lacus can be coarsely regenerated by the 9th harmonic and is faithfully matched by the 20th harmonic. We then extract the fourier coefficient for each harmonic for every shape, normalize the coefficients for the lake shape's size and rotation. The Fourier coefficients can be used to carry out statistical multivariate analysis.

Once we have the outlines of the lake and the fourier coefficients extracted, we statistically analyze the fourier coefficients in order to decipher if there is any pattern in the lakes' fourier coefficients. The left principal component plot in Figure 3 shows the variation of principal component 1 w.r.t 2 in morphological space. The first principal component varies from a circular to elliptical shape and explains 30% of the variation in the shapes. This indicates that the majority of lake shapes on Titan's north pole vary from circular to elliptical. The circular end member is best represented by Mweru Lacus and Quilotoa Lacus. Hlawga Lacus and Roca Lacus have the maximum ellipticity and represent the elliptical end member on the PC1 axis.

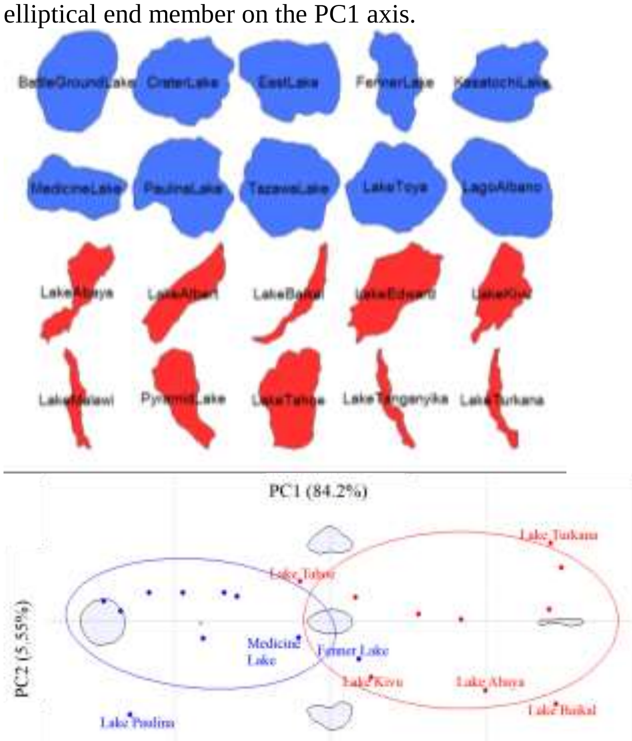

Figure 2: top panel shows the terrestrial lakes on which we chose to run EFDA. Blue lakes are the volcanic or crater lakes while red lakes are the tectonic lakes. Bottom panel shows their location in the principal component plot. We can clearly separate volcanic lakes from tectonic lakes in the morphological space. Lakes like Lake Tahoe that is in tectonic yet more circular than the other Type tectonic lakes can be seen in the circular space in the principal component plot.

The second principal component explains 15% of the variation in the lake shapes. Positive PC2 corresponds to lakes with strong asymmetries along their short axis, while those with strong negative values of PC2 have strong asymmetries along their long axis. While Muggel Lacus represents the asymmetric lake end member on negative PC2, Xolotlan Lacus represents the end member for the (asymmetric) lake with a curvature on the positive PC2. The outliers |Myvatn Lacus, Rwegura Lacus, Sotonera Lacus, Muggel Lacus, and Feia Lacus explain that those lake shapes are peculiarly odd and rare on Titan's surface. The PC3 represents an increasing strong kidney-bean like shape.

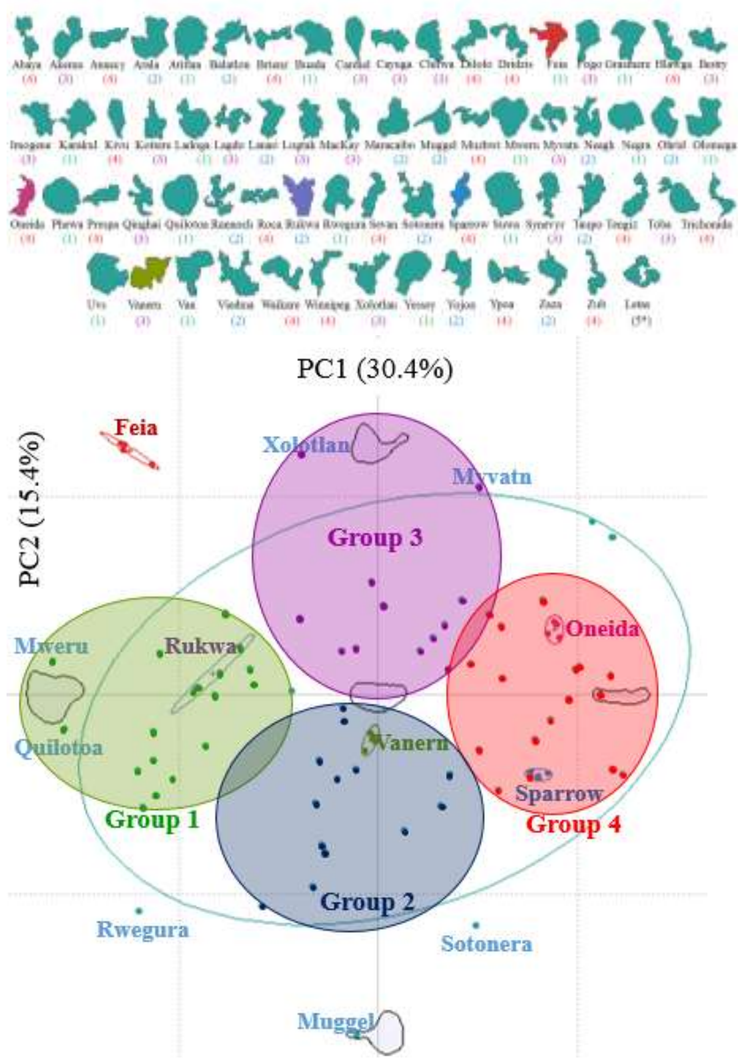

Figure 3: Top panel represents the lake shapes with their respective names on the north pole of Titan. Bottom left panel indicates the first two principal component's plot for Titan lakes (from the top panel). The shaded circles indicate the four groups of lake we observe on Titan's north pole.

Conclusions: Titan lake shapes are virtually any possible shape, and we show that the Elliptical Fourier Descriptor Analysis methodology for outline shape analysis is a robust way to decipher differences and similarities in lake outlines quantitatively. Our analyses give roughly four groups. Group 1 : round lakes; Group 2 : moderately long lakes with a strong asymmetry along their long axis; Group 3 : moderately long lakes with a strong asymmetry across their short axis; Group 4 : long lakes.

References: [1] Sagan, C., et al. 1982, *Nature* [2] Elachi, C., et al., 2006, *Nature* [3] Kuhl et al., 1982, *CGIP* [4] Bonhomme, et al. 2014, *Journal of Statistical Software*