CONSTRAINING THE COMPENSATION STATE, STRUCTURE AND GEOPHYSICAL EVOLUTION OF SPUTNIK BASIN ON PLUTO.

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Introduction: New Horizon's mission to Pluto in 2015 revealed Sputnik basin, a 1700 km by 1000 km wide, elliptical impact basin in Pluto's equatorial region [1]. The basin contains a ~3-10 km thick deposit of surface volatiles, including N_2 ice, referred to as Sputnik Planitia [1-4]. Sputnik basin is thought to have reoriented through true polar wander to align with Pluto's tidal axis, suggesting that the basin represents a large positive mass and gravity anomaly [3-4]. The network of faults surrounding the basin support this interpretation [3]. Based on these observations, previous studies have proposed that Sputnik basin was isostatically compensated by a high density, subsurface ocean layer ~100 km below a thin ice shell prior to loading of the N_2 ice [4-6] . However, the New Horizon's flyby of the Pluto system did not provide any spatially resolved gravitational data and thus there is no direct constraint on the compensation state of Sputnik basin.

We use a novel approach to constrain the gravity field, thereby shedding light on the compensation state and structure of Sputnik basin. Because a low viscosity material should conform to an equipotential, we assume that the topography of the N_2 ice on the floor of Sputnik Planitia follows Pluto's geoid, aside from minor variations associated with convective flow [6]. Thus, high resolution topography over Sputnik Planitia [2] provides a measurement of the geoid. Under this assumption, we model the local gravity field over the center of the basin for a range of compensation states [7,8] and compare the observed and predicted geoids. The geoid on the basin floor is primarily sensitive to the compensation state of the basin and the N_2 deposit contained therein, with second order effects from shell-thickness and the density contrast across the shell-mantle interface, which we also explore in this study.

Methods: We utilized the updated Digital Elevation Model (DEM) created from high resolution images obtained by the Long Range Reconnaissance Orbiter (LORRI) and the Multispectral Visible Image Camera (MVIC) at a horizontal resolution of ~300 m/pixel (Fig. 1) [2,9]. The southern hemisphere of Pluto was not imaged by New Horizons, so the data was interpolated to fill in this hemisphere as well as data gaps in the northern hemisphere. We then derived the spherical harmonic coefficients of topography.

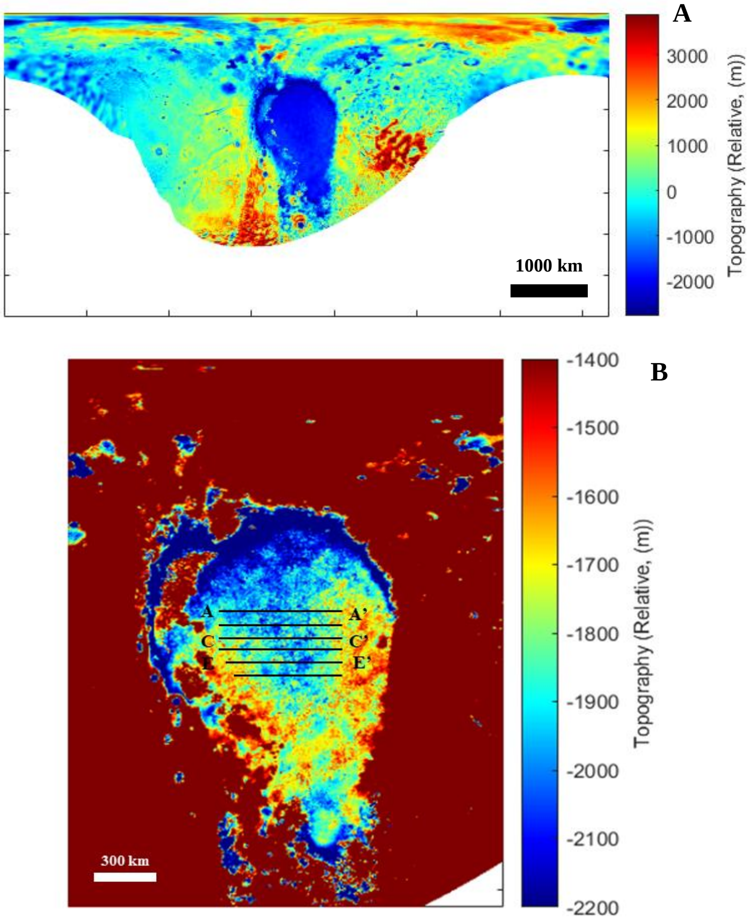

Figure 1: **High resolution DEM Pluto (global, A) and Sputnik Planitia (l76° E, 24° N, B) referenced to mean planetary radius of 1188.3 km. Six topography and geoid profiles were taken across the floor (shown in black) and averaged.**

To model the gravity field and geoid from the surface and base of the ice shell, we use the finite amplitude approximation of gravity from topography [7]. We calculate the local gravity field at radius of 1186.5 km, consistent with the elevation of the surface of Sputnik Planitia. Since the thickness of the volatile layer is poorly constrained, we model the structure of the basin by assuming a range of degrees of compensation for the observed topography. We represent the amplitude of the relief at the base of the shell in a state of isostasy as the condition of equal pressures at equal depths [8]. Our nominal model has an ice shell thickness of 80 km, though we also vary the ice shell thickness from 50 km to 350 km [4,5]. We also considered several cases for the density contrast across the compensating interface at the base of the shell: a pure ice shell (density = 905 kg/m^3) overlaying either a pure water layer (density = 1000 kg/m^3), an ammonia-rich melt at eutectic temperature (density = 946 kg/m^3, [10]), a silicate- rock mixture (density = 1846 kg/m^3), or a solid silicate rock layer (density = 3000 kg/m^3). The material contrast across the compensating interface will depend on the internal structure of Pluto. Models were evaluated using the RMS misfit between our modeled geoids and an average topographic profile (Fig. 1B) taken across the floor of Sputnik basin.

Results: The topography across the floor of Sputnik basin shows a N-S topographic gradient of ~150 m even after correcting for rotational flattening, consistent with a latitudinal gradient in N_2 accumulation [11-12]. A prominent trough at the edge of the basin floor outside of a ring of mountainous blocks may also be associated with local N_2 transport as climate modeling predicts condensation of N_2 ice and subsequent glacial flow at the southern edge of the basin over the past 2 million years [11]. However, there is no net E-W topographic gradient, and no net E-W transport of N_2 expected, and so E-W profiles across the basin are expected to follow the geoid. The average topographic profile shows a vertical relief of ~250 m which is greater than the expected relief of local N_2 convection of ~10-50 m [6]. We see the same shape and relief predicted in the geoid model (see above), further confirming our assumption that topography N_2 convection does not disturb the topography of Sputnik Planitia enough to result in a significant deviation from the geoid, or the concave up shape of the geoid in this case.

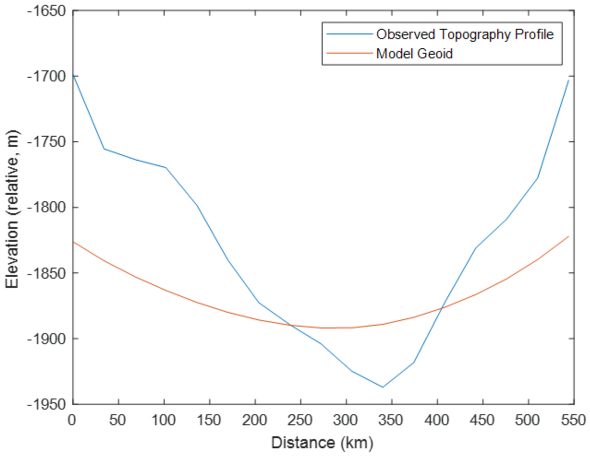

***Figure 2*: Observed average topography profiles (blue) across Sputnik Planitia compared to the best fit geoid model (orange).**

The topographic profile across Sputnik Planitia is concave up, consistent with a negative geoid anomaly over the basin (Fig. 2). Our comparison of the geoid models to the topography of Sputnik Planitia shows that an under-compensated basin provides the best fit with a degree of compensation of ~0, with an RMS of ~212 m. The corresponding free air gravity anomaly is -85 to -95 mGal. The best fit compensation state depends on the shell thickness and the concavity of the geoid can also be fit for an isostatic basin with a shell thickness of >300 km. However, an overcompensated basin with a positive geoid anomaly cannot fit the data. The best fit compensation state remained the same across all tested scenarios of density contrasts across the shell-mantle interface.

An under-compensated basin, as seen in our results, would indicate that Sputnik basin today is at most partially compensated by an uplifted, dense liquid water ocean and is characterized by a mass deficit. However, the basin in the past may still have been have been overcompensated with a positive geoid anomaly but evolved to an under-compensated state due to refreezing of the subsurface ocean or viscous relaxation of the deeper warmer ice. Alternatively, an isostatically compensated basin with a thick ice shell (> 300 km) also provides a good fit.

Future Work: Additional analyses using stereotopography derived only from LORRI data will provide a more accurate model of the relief of Sputnik Planitia. With this updated Pluto topography dataset, we plan to further constrain the compensation state of Sputnik basin using our current methodology. Future models will directly represent an initially isostatic basin with a flexurally supported N_2 deposit, which is expected to better match the concavity of the geoid indicated by the topography data. We can then explore the range of compensation states and shell thicknesses consistent with the relief at the surface of Sputnik Planitia. The compensation state of Sputnik basin today, together with its compensation state in the past [3-4], can reveal information about the subsurface structure and evolution of Pluto as a whole.

References: [**1**] Stern, et al., (2015), *Science*, 350. [**2**] Schenk, et al., (2018), *Icarus*, 314, 400-433 [**3**] Keane, et.al., (2016), *Nature* 340, 90-93 **[4]** Nimmo, et.al., (2016), *Nature* 540, 94 [**5**] Johnson, et al., (2016) *68-77*. [**6**] Mckinnon. et al., 2016, *Nature* 534, 82. [**7**] Wieczorek, (2007), *Treatise Geophys.* 10, 164-206. [**8**] Hemingway and Matsuyama, (2017), 7695-7705. [**9**] Moore, et al., (2016), *Science 351*(6279), 284-1293 [**10**] Hammond, et al., (2018), *JGR: Planets*, 132(12), 3015-3118. [**11**] Bertrand, et al., (2018), *Icarus* 309, 277-296. [**12**] Umurhan, et al., (2016). [**13**] Solomon and Head, (1980), *Reviews of Geophys.* 18(1), 107-141