AN ANALYSIS OF GALILEO DATA FOR LINE-OF-SIGHT GRAVITY ANOMALIES ON EUROPA.

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Introduction: Europa's potential for life greatly increases if its interior is volcanically active [1]. Due to its subsurface ocean between a rocky interior and a surface ice shell, Europa is among the most promising environments in the Solar System where extraterrestrial life could exist [2, 3]. Life, however, requires a source of energy [4], and volcanism could be providing it in the same way it does for hydrothermal-vent ecosystems on the ocean floors of Earth [5, 6]. In that sense, the question of whether there is silicate volcanism in Europa is directly linked to the question of its ability to harbor life.

The existence of volcanism is tied to background heat flux. The higher the heat flux, the more volcanically active a world could be. Heat flux has other consequences, like determining the rigidity of the lithosphere and therefore its ability to hold topography. The higher the heat flux, the less rigid the rock, which leads to less support for topography. The opposite happens at lower heat flux, where more support for topography is expected due to colder more supportive rock.

In turn, the lithosphere's ability to support topography has an impact on gravity. Gravity anomalies are deviations from the expected gravitational field that manifest due to displaced masses, such as fluctuations at interfaces between layers of different densities (e.g., topography on the sea floor). Without material strength from the lithosphere, any topography would need some other mechanism of support, usually interpreted as arising from buoyancy. For example, if topography is fully supported by buoyancy in the crust-mantle boundary, the floating crustal mass would equal the displaced mass on the mantle (i.e., Airy isostasy). Because equal masses are involved, the gravity signal would be small. When topography is fully supported by the lithosphere, a full expression of this topography in the gravity signal occurs because no mass compensation is involved. Most cases lay in between these two endmembers, with stronger gravity anomalies if the lithosphere is rigid and smaller ones if the lithosphere is weak.

Currently, the best available method to assess whether the silicate interior of Europa is volcanically active is the measurement of the gravity anomalies at the rock-ocean interface [7]. The starker the contrast between the layer densities, the more likely the anomaly will be detected. In Europa, the rock-water interface is where the density contrast is the greatest. For mass anomalies wider than ~1000 km in scale, the rock-water interface dominates the signal over anomalies that might be coming from contrasts between ices of different densities at the surface or the base of the ice shell [7]. Hence, topography at the rock-water interface can be detected by measuring gravity anomalies, and then tied to volcanism [7, 8].

Thus, the size range of the gravity anomalies is informative. Small anomalies (everywhere < 250 mGal) might indicate high heat flow, and an increased chance of volcanism. If the anomalies are strong (more than 250 mGal), it means that the lithosphere is thick and supportive, pointing to lower background heat flux and less volcanism, reducing the potential for life [7].

Galileo mission data were used to analyze Europa's gravitational field, leading to the determination of Europa's basic interior structure (e.g., [9]). The analysis of its gravitational field was further refined in subsequent studies. The most recent update on Europa's gravitational field [10] was achieved by re-analyzing Galileo tracking data, taking advantage of Juno mission data on Jupiter, and orbit determination techniques developed for Cassini. This study reconstructed the Galileo spacecraft trajectory around Europa and modeled all sources of accelerations that can explain the observed motion of the spacecraft. The motion of the Galileo spacecraft causes a doppler shift in the microwave signal detected by the Deep Space Network. Part of the motion of the spacecraft is due to Europa's gravitational pull, and part of it comes from other sources such as the gravitational pull from other bodies in the Solar System. Modeling the Doppler shift from these sources allowed for their removal from the observed Doppler velocity data. Europa's gravitational shape was modeled up to second degree and order, meaning that Europa was simplified into a layered sphere with an equatorial bulge and polar flattening due to its rotation, and a tidal bulge due to Jupiter's gravity. The gravitational pull from Europa up to second degree was modeled and removed from the doppler velocity data as well, leaving residual Doppler velocities that cannot be explained by any of the sources mentioned above. If a pattern is found within these residuals, it could be due to finer-scale sources of gravity in Europa like mass anomalies.

Methods to extract finer-scale gravity (beyond degree 2) have been developed and applied to Ganymede flyby data, leading to the discovery of mass anomalies [11]. These methods were improved [12], and additional mass anomalies were found. The improvement came from applying a variable-width Gaussian filter to smooth out noise, which adjusts the level of smoothing based on the altitude of the spacecraft. This technique results in less smoothing when the spacecraft is close to the moon and the gravity signal is stronger, and more smoothing when the spacecraft is farther away. In that way, the variable width takes advantage of the inverse proportionality of gravity with the square of altitude.

Here, we use the Doppler-velocity residuals from flyby E6 of the Galileo spacecraft over Europa [10], and apply a variable-width Gaussian filter to examine the residuals for patterns.

Methods: The Doppler residual velocities from the E6 flyby of the Galileo spacecraft around its closest approach are smoothed using an altitude-dependent filter, and then differentiated numerically into gravitational accelerations.

Variable-width Gaussian filter. First, we smooth the doppler velocities using a variable-width Gaussian filter. This technique [12] averages the Doppler velocities at each point in time with those of its neighbors. The average is weighted by a Gaussian distribution. The width of the Gaussian is set to be dependent on the altitude on the spacecraft, making it narrower the closer the spacecraft is to Europa. For the altitude data, the 2007 Galileo trajectory reconstruction archived at the NAIF website is used. Flyby E6 did its closest approach on 20 February 1997, reaching an altitude of 587 km. Only up to ~30 minutes before and after the closest approach is included in the analysis, due to attenuation of the signal by altitude, and gaps in the flyby data.

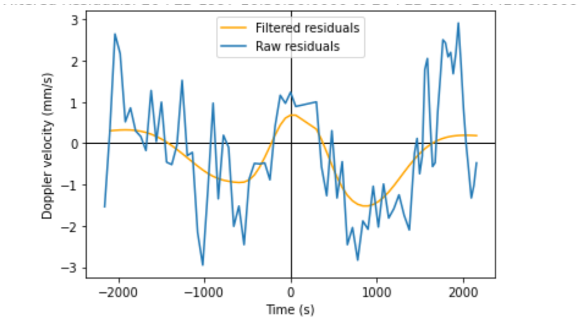

Figure 1. Raw Doppler velocity residuals [10], and smoothed Doppler velocities around closest approach for flyby E6 of Galileo around Europa. Fluctuations in the smoothed signal are comparable in scale to the noise in the raw residuals.

Numerical differentiation. Accelerations along the line of sight are obtained by numerically differentiating the Doppler velocities. These values are the accelerations Galileo experienced at each point in time that could result from the unexplained portion of the gravitational pull (e.g., mass anomalies in Europa).

Results and Discussion: Because the magnitude of the smoothed signal is comparable to the noise in the raw residuals, no robust pattern is found (Figure 1), and gravitational accelerations derived from flyby E6 are very small in magnitude (Fig. 2), indicating no regional gravity anomalies. Lack of detection could mean that there were not any anomalies to detect over this point on Europa or, more likely, that any anomalies were rendered undetectable by attenuation to the ~600 km closest-approach distance. (The maximum gravity anomaly of realistic periodic topography of a wavelength comparable to this distance should be sub-mGal in scale.) There are no implications for mass anomalies on Europa in general, since only one distant flyby is analyzed here.

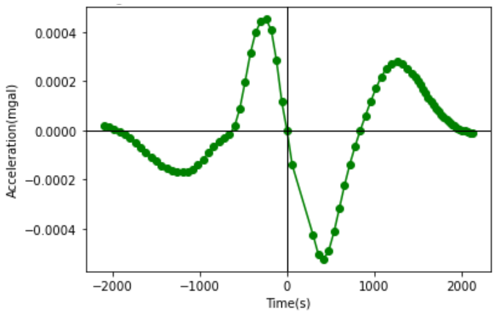

Figure 2. Accelerations derived from Doppler velocities in Figure 1.

Conclusions: Despite the reprocessing of the Galileo tracking data [10] and application of a more robust noise filter [12], we find no gravity anomalies after analysis of the doppler residuals of flyby E6, expected because of the large closest-approach distance. However, a data pipeline is established, and new data coming from the Juno mission for Ganymede, Callisto, and Europa could be readily analyzed, with relevant information on gravity anomalies extracted for each flyby. This pipeline also paves the way for the Europa Clipper and JUICE missions.

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