Comparison of gravity fields derived using ground radar and spacecraft observations for close proximity operations around asteroid 25143 Itokawa. Shankar N. Ramaseri Chandra[1] and Ronald Fevig[1], [1]Department of Space Studies, University of North Dakota, 4149 University Avenue Stop 9008, Grand Forks, ND 58202.

Scope: The purpose of this project is to determine whether ground radar derived gravity fields of asteroids are sufficient to perform close proximity operations, and also to establish the need for mapping the gravity field upon arrival at the asteroid.

Introduction: Near Earth Objects (NEOs) have now been targets of space exploration for two decades. The high interest in studying NEOs is due to the fact that they can provide in-situ resources for deep space travel, to better understand how to mitigate the threats from potential collisions with Earth and most importantly, to study the history and evolution of the solar system.

Although, ground based radar observations help to study these objects, close proximity operations help to properly analyze the interiors, mine, relocate or mitigate the threat by a NEO. There have been many spacecraft missions to asteroids like Vesta, Ceres and Itokawa. Operation of these spacecraft around the asteroids were challenging because of their irregular shapes and tenuous, irregular gravity fields. Hence, the initial characterization of the gravity field is important, and the failure to perform the mapping with the desired precision may result in mission failure.

The radar observations of Itokawa displayed a near tri-axial ellipsoid shape with semi axes 0.2815 x 0.1526 x 0.1348 km in x, y and z directions respectively [1]. A radar gravity model (RG) using the spherical harmonic approach was determined by Scheeres et al., 2004 assuming a constant density of 2.5 gm/cm^3 [2]. Hayabusa spacecraft observations indicated Itokawa is a rubble-pile with a density of 1.98 gm/cm^3 and the semi-axes of 0.3049 x 0.1369 x 0.1144 km. The shape obtained by satellite observations showed Itokawa as potato shaped with two lobes attached to one another [3]. The spherical harmonic spacecraft gravity field (SG) was derived using the shape model by Scheeres et al., 2006 [3]. In this project, we studied the orbits (change in eccentricity (e) and semi-major axis (a)) of satellites around Itokawa using both the above mentioned gravity fields.

Method: The comparison of gravity fields is done with scenarios involving close proximity orbit operations around Itokawa using AGI's System Tool Kit (STK) program. The steps involved in creating and analyzing the spacecraft trajectories include:

1. *Shape model of Itokawa*: The shape of Itokawa was modeled as a tri-axial ellipsoid using the component browser in Systems Tool Kit (STK).
2. *Satellites*: Two sets of satellites having prograde and retrograde orbits respectively with each set containing 3 satellites with semi-major axes 1.0km, 0.75km, 0.5km were simulated for two weeks around Itokawa.
3. *Gravity Fields*: The gravity models derived by Scheeres in [1] and [2] are incorporated into satellite models to simulate close proximity operations.

Results: The orbits in yellow are simulated with the radar-derived gravity field and the blue ones with the satellite derived gravity field (ref. Fig 1). The left figure shows prograde orbits and that satellite with RG is more stable than the one with SG, whereas retrograde orbits on the right shows that both are stable at 0.75km semi-major axis and behave alike under the influence of both RG and SG models.

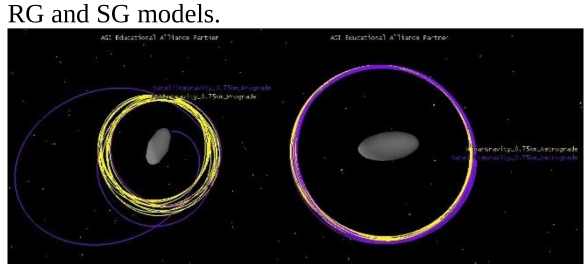

Fig 1: Prograde and retrograde satellites with 0.75km semi-major axis

For the satellites with a 0.5km initial semi-major axis the prograde satellite orbits using both the RG and SG models are unstable, while the retrograde satellite orbit with RG is partially stable compared to SG (ref. Fig 2). The retrograde satellite with SG is ejected out of the system and the satellite with RG crashed into the asteroid.

Fig 2: Prograde and retrograde satellites with 0.5km semi-major axis

The graphs below show the variations of semi-major axis and eccentricity over time (ref Figs 3 & 4). The semi-major axis (a) and eccentricity (e) in the top figure shown in blue and green, respectively, increase after a few days using the SG model, whereas the satellite using the RG model has almost constant semi-major axis (red) and eccentricity (black). In the bottom figure the value of a and e remain fairly constant in both the cases with both gravity models.

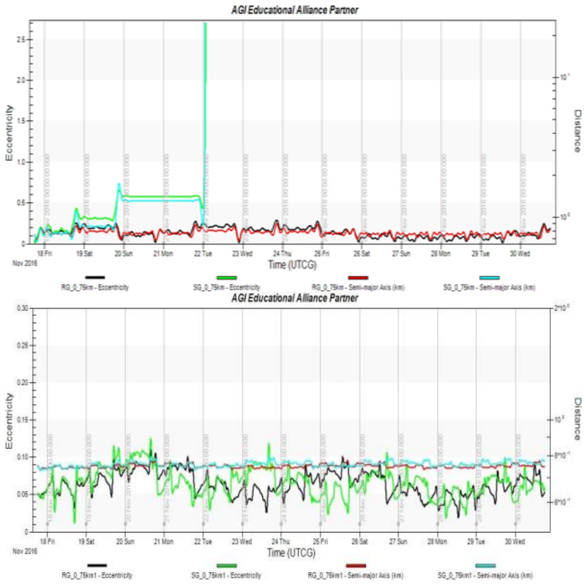

Fig 3 & 4: Variations in ‘a’ and ‘e’ for 0.75km initial semi-major axis

In similar fashion, graphs of ‘a’ and ‘e’ over time are generated for satellites with 0.5km initial semi-major axes in both prograde and retrograde orbits (ref. Figs 5 & 6). For prograde orbits the satellites display chaotic behavior for both gravity models, with both the satellites crashing into the asteroid over short timescales. The values of ‘a’ and ‘e’ change drastically in a couple hours. In contrast, the retrograde satellites are partially stable for a day and show the same trend as prograde satellites. It is observed that the retrograde satellite using the RG model orbited the asteroid for a longer duration while the satellite using the SG model showed more chaotic behavior, along with increases in ‘a’ and ‘e’.

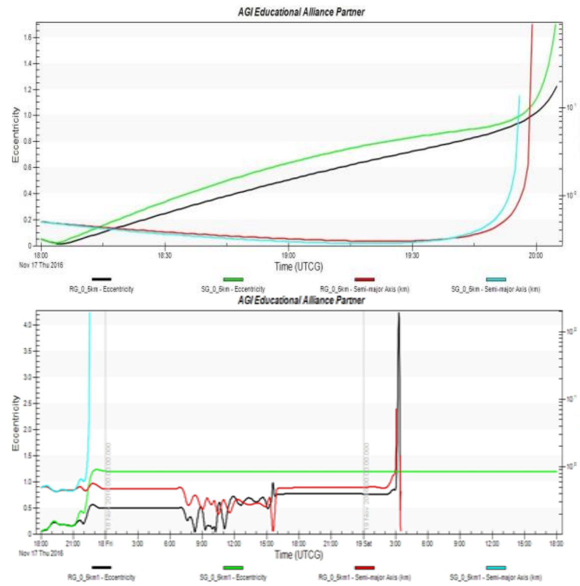

Fig 5 & 6: Variations in ‘a’ and ‘e’ for 0.5km initial semi-major axis

Conclusions: The chaotic behavior and dynamics of satellites in this scenario can be explained by two phenomena. First, it is observed that retrograde orbits are more stable around Itokawa and more suitable to perform close proximity operations. This is in agreement with results reported by Scheeres [3]. Second, the irregularities in the gravity field are poorly represented by the RG model and hence the satellites have stable orbits. Conversely, the satellites using the SG model better model the real dynamic environment of Itokawa, with chaotic orbits ejecting them out of the system or crashing into the asteroid.

Hence, the radar derived gravity field (RG) is not sufficient to perform near surface orbit operations due to less precision of the shape model and the gravity field. The satellite derived gravity field (SG) is assumed to be more precise than the radar derived gravity model due to higher precision in the shape model and gravity field.

Future work: We plan to model the gravity field using better techniques like the ellipsoidal harmonic gravity model to study the dynamic environment closer to the surface. The variations in densities will be considered while modeling gravity fields since most of the current models consider constant densities.

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References: [1] Ostro, S.J. et al. (2004) *Meteoritics & Planet. Sci., 39(3),* 407-424.
[2] Scheeres, D.J et al., (2004) AIAA 2004-4864.
[3] Scheeres, D.J et al., (2006) AIAA 2006-6661.