National Aeronautics and Space Administration

Improving shape modeling algorithm for asteroids and comets: a step toward automation

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Program: Strategic Initiative

Project Objective:

We proposed to improve the existing *Shape* software (Hudson, 1994; Magri et al., 2007) that inverts radar observations, echo power spectra and delay-Doppler images, into 3-D shapes and spin states of small bodies (Figure 1). Shapes and physical properties of small bodies are important for the field of planetary science, space missions, and planetary defense.

The *Shape* software is a library of routines written in the C-programming language that runs on Linux and Mac platforms. The current shape modeling process is slow (weeks to many months) because it needs to optimize a very large set of parameters, and because it strongly depends on inputs from the user. Our primary objective was to reduce the number of parameters controlled by a user and thus simplify the shape modeling process. This was the first step on a path to automatic shape modeling process.

FY18/19 Results:

We have 1) identified eight input parameters in Shape algorithm that do not require to be controlled by a user, 2) added software modifications to the existing C code library, 3) streamlined the execution of the fit, 4) integrated grid search functionality on size, spin rate, and pole direction, 5) integrated Monte Carlo search functionality based on *a priori* combinations of size, spin rate, and pole direction, and 6) added an automatic generation of plots that summarize search results (Figures 2-4). The software now structures the output in a set of subdirectories according to the type of parameter search that was preformed (e.g. pole, size, spin, Monte Carlo). The program ranks the fits from lowest chi-square value to the highest. Furthermore, inside each of these directories are two more directories named BestFits and WorstFits. The BestFits directory holds the fit results with the chi-square values within the 5% of the minimum value achieved for that grid search. These are the models that are used for advancement from the ellipsoid level fit to harmonic and vertex shape models. We applied the updated software to the case of Near-Earth asteroid (NEA) 2018 EB.

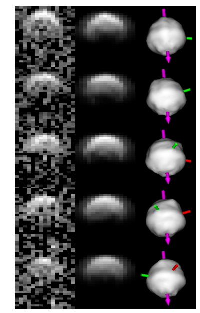

Figure 1. *Shape* software is used to reconstruct 3-D shapes of small bodies.

Benefits to NASA and JPL:

To date (Sep 2019), the Arecibo and Goldstone radar facilities have observed 880 NEAs, 138 main belt objects, and 21 comets (https://echo.jpl.nasa.gov/asteroids/index.html). Most of these objects (>80%) were observed within the past 15 years. We have been adding 80-100 objects to the radar database every year since 2013. The data sets vary from very detailed, where high-resolution delay-Doppler images (some obtained with resolutions as fine as 1.875 meters/pixel) cover many rotations of an object, to sparse, with only a basic detection of an object in Doppler frequency. We currently have reconstructed shapes of ~30 objects. We estimate that at least 100 radar data sets are suitable for detailed shape reconstruction, and that we can estimate a shape of the convex hull for at least another 200 objects. Significant improvements in the performance of the shape modeling approach would dramatically increase the number of shape models of asteroids and comets. This would have multiple benefits for JPL's missions and programs. From the basic science perspective, we would be able to expand from studies of the individual objects to studies of the overall population of small bodies. How did these bodies form and evolve? Which physical processes left their fingerprints on the shapes and other physical properties (e.g. spin states) of asteroids and comets? Furthermore, objects with 3-D shape models make better mission targets because they allow for detailed science and navigation planning well in advance. To date, radars have observed 23 small bodies that were/are mission targets (https://echo.jpl.nasa.gov/~lance/radar.small.body.mission.targets.html). In the future, a shape of an asteroid would be particularly important when planning an asteroid deflection mission. Radar-based shape models are also important for the near infra-red (IR) space telescopes such as WISE/NEOWISE. These surveys not only discover asteroids and comets, but they also estimate their sizes. The sizes are determined by fitting thermal models to the IR data. Thermal models strongly depend on reliable size calibrators such as spacecraft images, radar shape models, and occultation data. Radar data are by far the most numerous. To date, more than 200 near-Earth objects have been observed both by radar and WISE/NEOWISE, and this number will increase rapidly with the onset of the future IR space telescope.

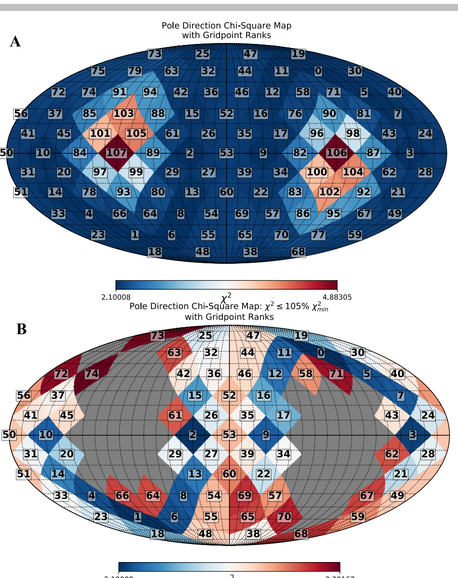

Figure 2. Pole grid search visualization for NEA 2018 EB. **A)** Grid points annotated with their respective rank from lowest to highest chi-square value. **B)** only displaying chi-square values 105% that of the minimum chi-square value. The best pole solution (long, lat) is 112 deg, 58 deg.

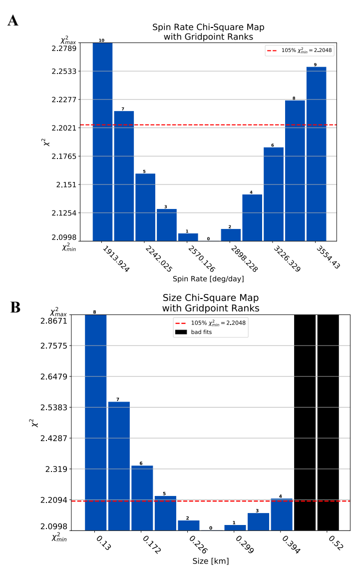

Figure 3. A) Spin grid search visualization for NEA 2018 EB. The best solution has a period of 3.17 h. **B)** Size grid search visualization. The best solution has 260 m diameter.

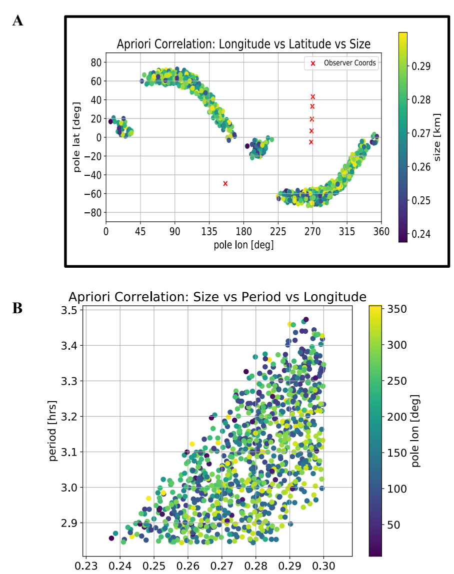

Figure 4. A) Pole direction and size correlation for the Monte Carlo grid search for NEA 2018 EB. **B)** Size and period bounds correlation.

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Publications:

Binaries Asteroids 5 workshop abstract, "Radar and lightcurve observations of binary near-Earth asteroid 2018 EB", Brozovic et al., 2019

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