MRD 105b- Dynamical Evolution

Data Product Overview

A dynamical model of the entire evolution of Bennu will be derived from "cascading waterfall" of collisional and dynamical evolution codes. They will track, in sequence:

1. The collisional breakup of asteroid families,
2. The collisional and dynamical evolution of fragments within those families as they migrate across the asteroid belt in response to the coupled Yarkovsky and YORP effects.
3. The dynamical evolution of Bennu-sized fragments that reach a dynamical resonance capable of taking it from the main belt to its observed orbit.

These codes are mainly "home-grown" by Bottke, who has been developing them in collaboration with several scientists over more than a decade of work. A brief description of what they can do follows.

A dynamical model of the evolution of Bennu will be derived from several collisional and dynamical evolution codes that can track (i) the collisional breakup of asteroid families, (ii) the collisional and dynamical evolution of fragments within those families as they cross the asteroid belt, and (iii) the dynamical evolution of Bennu-sized fragments that reach a dynamical resonance capable of taking it from the main belt to its observed orbit.

Overview

Bennu lives in a chaotic dynamical sea close to Earth. It was put there by a large number of stochastic events involve collisions and dynamical processes. Like a ball within a pachinko machine, the chaotic nature of Bennu's evolution makes it impossible to precisely follow its orbit backward in time to its source location. Our method for deducing its source is therefore statistical in nature, with constraints helping us to winnow to possible solutions. An analogy might be playing pachinko a million times, with the statistical trends in the machine quantified by observation and theory. Once complete, we can look at a ball at a given place and time and say something statistically useful about where it came from.

Our procedure to find the source of Bennu is as follows.

• Determine the most likely resonant escape hatch where Bennu came from in the main asteroid belt.

We have multiple steps to achieve this goal. The first is to numerically track thousands of test bodies from all known resonant "escape hatches" in the main belt to see which test bodies pass near the current Bennu orbit within some tolerance level in semimajor axis, eccentricity, and inclination (a,e,i). The bodies that achieve this can be traced back to their escape hatch in the main asteroid belt. The integrations are done using the publically available SWIFT integration package developed by Levison and Duncan (1994; Icarus). The planets Venus-Neptune are included. To achieve statistically significant results, the user will likely need access to many tens of modern processors.

Second, once the exit points are determined, we need to estimate which ones are more likely to produce Bennu from a small body flux standpoint. There is no simple way to do this other than to model the flux into each resonance from the current main belt. We do this by modeling the debiased NEO orbit and absolute magnitude distribution using the method of Bottke et al. (2002; Icarus). Here the test body integrations are combined with estimates of the observational biases associated with real NEO surveys, with the results compared with detections and accidental redetections of NEOs. The best fit provides an estimate of the strength of each NEO source, and can be used to deduce the flux of Bennu-sized bodies into those sources over time. Our work along these lines is currently being updated using Catalina Sky Survey data in collaboration with Mikael Granvik, Alessandro Morbidelli, Robert Jedicke, David Vokrouhlicky, David Nesvorny, Bryce Bolin, and Patrick Michel.

• Determine the most likely source asteroid family for Bennu

Bennu has physical and dynamical characteristics that allow us to sift the asteroid belt for the most plausible source asteroid families that statistically are most likely to be its source. They provide Bennu through a collisional cascade, with the fragments migrating in semimajor axis according to coupled Yarkovsky and YORP effects.

To find plausible candidate families, we use the publically available SDSS color and WISE albedo data bases, together with family databases provided by David Nesvorny, to search for main belt families that can plausibly provide Bennu-like objects to the main belt escape hatches over time. This means we need to determine the age and approximate size of each candidate family, how that family has collisionally evolved with time, and whether fragments form that family can reach the right escape hatch with the right dynamical characteristics within the age of the family.

Once we determine which families have colors and albedos consistent with Bennu, we eliminate all those families whose members cannot access the most probable escape hatches. Of the remainder, we do the following.

Using codes developed by David Vokrouhlicky and William Bottke over several years (see Bottke et al. 2002 and Vokroulicky et al. 2006; Icarus), we determine the ages of the families in question according to how their observed members evolve in Yarkovsky and YORP over time. Here our model results are compared to the observed results.

The size of the families is roughly determined using the methods described in Durda, Bottke et al. (2007; Icarus), where we compare the observed size distribution of the largest members of our chosen families with numerical runs of asteroid breakup generated by numerical hydrocode simulations. The families are then tracked within the collisional evolution code of Bottke et al. (2005; Icarus) to determine how many fragments are likely to exist at the age of the family. This method help us determine which families are the most plausible sources in terms of flux.

Once complete, we take our most plausible families and track the evolution of millions of Bennu-sized fragments using codes that account for the Yarkovsky and YORP effects. In this circumstance, the code are being constructed specifically for the Bennu work, and will be described in a journal article. Here we determine the flux of Bennu-sized objects to the most plausible escape hatches and compare the results of each family to one another.

The final product will be a probability that describes the likelihood that a given family was the source of Bennu. If desired, we can also provide data from these codes, in the form of binary files, that describe our intermediate steps.

This will satisfy MRD-195b

The observations required to provide the input data needed to make the data product will come from the best available measurement of Bennu's current orbit (position and velocity vectors over time). This mainly comes from astrometry data taken from radar and from the OSIRIS-REx spacecraft itself. The other input will come from our knowledge of the main asteroid belt, asteroid evolution, etc. Data from Bennu obtained by OSIRIS-REx (e.g., albedo, composition, spectra, sample analysis of key dates in Bennu history, etc.) will be used to sift through the possible outcomes. Most of these values are already in the published literature, so we do not anticipate using SPOC data for this work.

The data product will be created prior to launch, but many constraints may be updated as the mission proceeds (e.g., data on the thermal conductivity of Bennu; spectral constraints from in situ observations or sample return). The calculation will take months-years. There are many issues that need to be reconsidered from time to time, and new constraints may help us settle unknowns in the physics of asteroid evolution.

Once complete, the codes used for this data product can be helpful in helping to further explore the evolution of Bennu. For example:

• Variations of the SWIFT code can be used to determine the likely lifetime of a putative Bennu satellite
• The Yarkovsky/YORP evolution code, combined with SWIFT, can be used to determine whether the formation of the Bennu source family also produced an "asteroid shower" that affected the worlds of the inner solar system (e.g. Earth).
• The results of the Yarkovsky/YORP evolution code can be used to estimate the rate of mass shedding events on Bennu
• Many more new and interesting projects are possible.

This product can be considered science value and long term science.

The main product here will be a journal article (or more than one journal articles. The data provided here will be a set of probabilities that describes the likelihood that a given asteroid family was the source of Bennu.

The product should be considered long-term science, though it may be valuable in interpreting the results of the samples.

Data Product Structure and Organization

N/A

Data Format Descriptions

N/A

Data Product Generation

This product will be developed by CoI Bill Bottke and Collaborator David Vokrouhlicky, with input from many in the DEWG. He will use preexisting codes constructed over years of work to explore the collisional and dynamical evolution of asteroids. His work will be submitted to the OSIRIS-REx science team and peer review journals as a means to check his results.

Data Product Validation

The data will be published in a peer review journal, most likely Icarus.

Data Flow and Other Related Items

N/A