PYMADOC & PYCRE: PYTHON SCRIPTS TO STUDY THE ORBITAL AND COLLISIONAL EVOLUTION OF METEOROIDS AND THEIR EVOLVING COSMOGENIC NUCLIDE INVENTORIES

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Introduction: Cosmogenic nuclides (both stable and radioactive; e.g., ^{21}Ne and ^{26}Al, respectively) are tracers of a meteorite's exposure to cosmic rays as a meter-sized object in space [1], allowing us to study the processes of meteorite delivery to Earth, including collisional erosion, the effects and relative importance of different non-gravitational forces, and of orbital resonances. Additional information on the origin of a meteorite might be provided (if known) from the local time of the fall (morning vs. afternoon; e.g., [2]), or from the heliocentric orbit of the meteoroid reconstructed from the fireball observed by ground-based cameras or camera-networks (e.g., [3-5]). At the other end of the delivery path, most meteoroids were originally ejected from the asteroid belt, and some might be related to one of the many asteroid families [6]. There is currently no widely available computational model to trace the orbital evolution of meteoroids from their origin to their fall. Here I describe two scripts, written in the accessible Python language, to model the orbital evolution of meteoroids (*PyMADOC* for "Python model for Meteoroids, Asteroids, and Dust Orbital and Collisional evolution") and the corresponding evolution of their cosmogenic nuclide inventories (*PyCRE* for "Python model for Cosmic Ray Exposure") based on a cosmogenic nuclide model [7].

Methods: *1. PyMADOC*: The user can define a population of meteoroids (e.g. size range and power-law size-frequency distribution; rotation rate depending on size; bulk density; surface thermal conductivity), either ejected from a single point with a characteristic velocity, or sampled at random from a region of the semi-major axis, eccentricity, inclination (a, e, i) parameter space. The orbits of the objects are then evolved under the effect of Poynting-Robertson drag [8] and the Yarkovsky effect (e.g., [9]). Objects are also collisionally eroded: collisions with background objects (as a function of their position in the asteroid belt) lead to rotational resets and disruptions [10] (the latter using a size-dependent strength [11]). Collision fragments can be tracked. When objects wander into one of the strong orbital resonances (3:1, 8:3, 5:2, 7:3, 9:4, 2:1, υ_6), they are removed from the simulation with a probability scaled to the characteristic lifetime of test-particles within that resonance [12]. *2. PyCRE*: Working with the list of objects provided by PyMADOC, PyCRE reconstructs the characteristic probability distribution of the inventory of a cosmogenic nuclide (e.g., ^{21}Ne as shown in Fig. 1) in each meteoroid, based on its collisional history and a given production rate model (in this case: [7]). Both scripts can be run on a desktop computer (as long as Python is installed), typically taking no more than a few hours to process ~10^5 objects over a simulated time of a few million years.

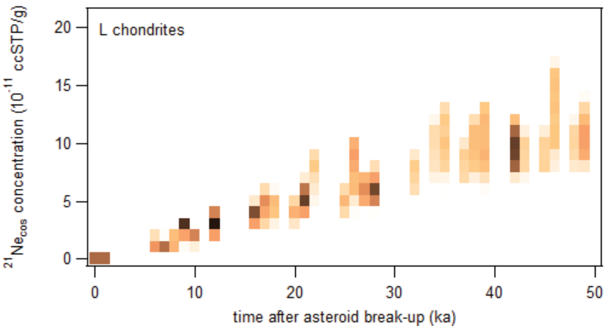

Fig. 1: Processed model output: the cosmic-ray produced ^{21}Ne inventory of L chondrites ejected by the 5:2 resonance after a large, near-by asteroid break-up (n ~50 ejected objects, R=0.1-5 m). Color corresponds to a probability distribution at each time-step (darker = higher).

Discussion & Outlook: Eventually, the goal of this effort is to compare simulated objects from different regions of the asteroid belt, and their cosmic-ray exposure age histograms, with the observed histories of meteorites. The PyMADOC model currently has some short-comings: it neglects the YORP effect, and the treatment of orbital resonances is very simplistic, not allowing the direct determination of post-ejection orbital parameters and the probabilities of encounters and collisions with the Earth. Furthermore, the outcome depends significantly on the background population (the number of objects, their intrinsic collisional probability and collisional velocity), which thus needs to be modeled with more detail. Future iterations of the model will address these problems, although some parameters, like the size of the population of meter-sized objects in the asteroid belt, are notoriously difficult to constrain [13].

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