A Monte Carlo type simulation toolbox for solar system small body dynamics

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June 7, 2016
Outline

1. Introduction
   - Motivation

2. Software
   - Overview
   - Module overview

3. Input state
   - 21P/Giacobini-Zinner

4. Some results
   - October Draconids validation
   - 2011 - 2012 October Draconids

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Motivation for the statistical approach:

- Chaos expand orbital uncertainties when systems are propagated
- Many orbital uncertainties are non-Gaussian
- It is useful to find the distribution of possible scenarios
- ...
Motivation for the module approach:

- Minimize the amount of "re-inventing the wheel"
- Make the toolbox as versatile as possible
- Create a "laboratory" for models and meteoroid streams
- Eventually make the code open-source and easy to adapt
- ...
Module based toolbox

To set up a testing platform for the statistical approach I needed:

A set of programs to handle

- Initial distribution
- Propagation
- Association
- Ejection
- Monte Carlo iteration
- Data flow
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Module based toolbox

Monte Carlo Module: 14,000 rows
Parent Body Ejector: 7,500 rows
Orbital Association Module: 4,000 rows

For comparison:
the N-body integrator
mercury6: 8,000 rows
Overview

Module based toolbox

Most of the code is infrastructure
File I/O, formatting, data transformation, log systems, etc

OSE
Orbital Stability Estimation

OAA
Orbital Association Analysis

MCAS
Monte Carlo Association Statistics

CMS/mercury6
Celestial Mechanics Simulator

PBE
Parent Body Ejector

SUOC
Statistical Uncertainty Orbital Clones

JPL
JPL ephemeris calculator

C++: balance computational speed and ease of modification
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Statistical Uncertainty Orbital Clones:
Object data (e.g. observations) $\rightarrow$ Orbital element distributions
Module based toolbox

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Parent Body Ejector:
Initial parent body data (e.g. orbit and comet type) $\rightarrow$ Set of ejected particles

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https://www.youtube.com/watch?v=MVUXAg1f88A

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Monte Carlo Association Statistics:
Connecting everything, handles the total simulation

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So far:

- 4 cometary ejection models (3 sublimation, 1 user function)
- 2 integrators (Symplectic, electromagnetic effects, ...)
- 4 orbital similarity functions (e.g. D-criteria)
- And so on...
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The case study

Purpose of 21P/Giacobini-Zinner case study:

- Proof of concept
- Implementation validation
- Investigation of mass power law deviations
- Temporal development of orbital associations
Input state

- Ejected material between 1866 and 1972
- Ejection model by (Hughes 2000)
- Each of the 17 perihelion passages sampled with 50 clones
- 6 714 499 test particles propagated
- Particles within Earth Hill Sphere considered meteors (43 637 total)
- Execution time on 2 personal computers: 1 week
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October Draconids validation

2011 October Draconids

Meteor shower probability during 2011

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2011 October Draconids

Orbital elements of synthetic 2011 October Draconids and MURMHUD observation KDE
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The case study

Usually the mass ratio’s (amplitude/duration) is considered a simple power law (mass index).

By comparing radar and visual meteors (Ye et al., 2013b), (Fujiwara et al., 2016):

- 2011 October Draconids followed the power law
- 2012 did not

Why? How? Observational bias or meteoroid stream physics?
2011 October Draconids mean encounter rates
2011 October Draconids probability distribution

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2012 October Draconids mean encounter rates

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2012 October Draconids probability distribution
Mass transfer functions

Normalized difference in mass distribution 2011 - 2012

$f < 0 \leftrightarrow 2012$ higher abundance

$f > 0 \leftrightarrow 2011$ higher abundance

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Mass transfer functions

Normalized difference in mass distribution 2011 - 2012

\[ f < 0 \rightarrow 2012 \text{ higher abundance} \]
\[ f > 0 \rightarrow 2011 \text{ higher abundance} \]

Thank you for listening!
2011 October Draconids Mass transfer functions

Most probable mass flux configuration

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2012 October Draconids Mass transfer functions

Most probable mass flux configuration

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Predictions

Most probable yearly meteoroid encounter rate

- Yearly flux
- Examined meteor storms
- Predicted meteor storms

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Adopted from "OpenOrb: Open-source asteroid orbit computation software including statistical ranging"

by GRANVIK et al.