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

D. Kastinen[1,2] and J. Kero[2]

[1]Department of Computer Science, Electrical and Space Engineering
Luleå University of Technology (LTU), Sweden

[2]Swedish Institute of Space Physics (IRF), Kiruna, Sweden

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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

Outline

Statistical

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

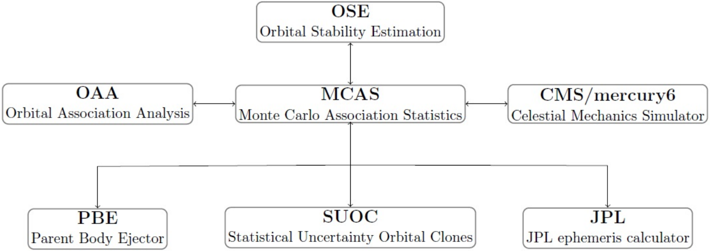
- Initial distribution
- Propagation
- Association
- Ejection
- Monte Carlo iteration
- Data flow

Outline

Module based toolbox

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

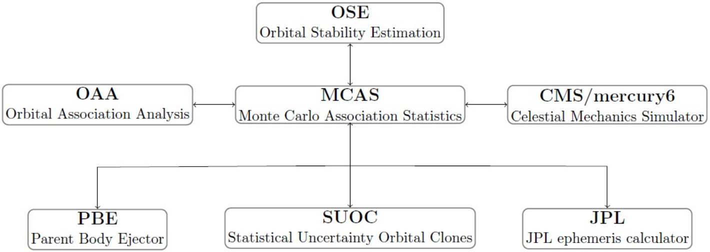
For comparison:
the N-body integrator
mercury6: 8 000 rows



Module based toolbox

Most of the code is infrastructure

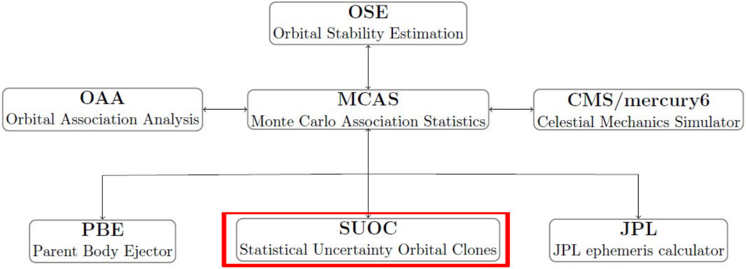
File I/O, formatting, data transformation, log systems, ect



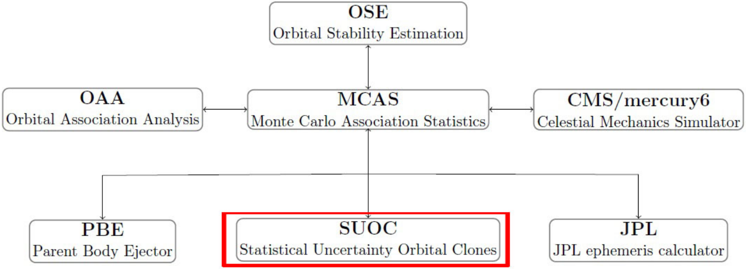
C++: balance computational speed and ease of modification

Outline

Module based toolbox

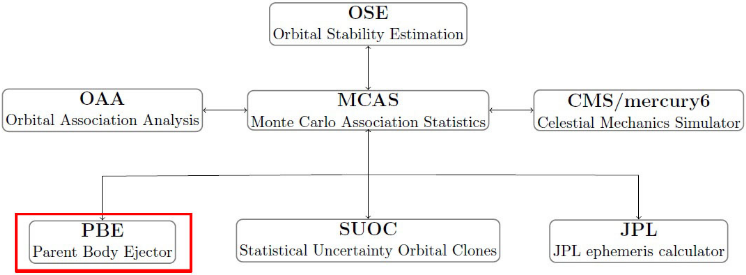


Module based toolbox

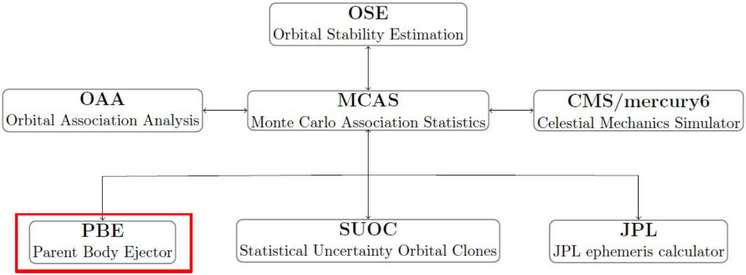


Statistical Uncertainty Orbital Clones:
Object data (e.g. observations) $\mapsto$ Orbital element distributions

Module based toolbox

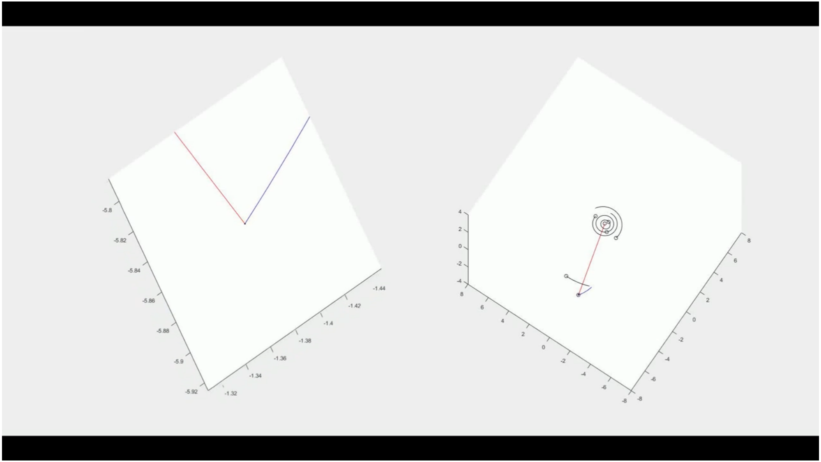


Module based toolbox



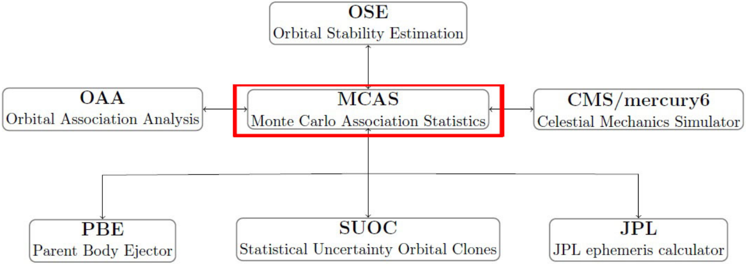
Parent Body Ejector:
Initial parent body data (e.g. orbit and comet type) $\mapsto$ Set of ejected particles

Module based toolbox

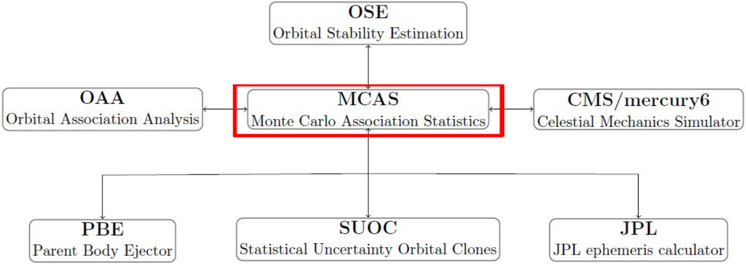


https://www.youtube.com/watch?v=MVUXAg1f88A

Module based toolbox



Module based toolbox



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

Module based toolbox

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...

Outline

The case study

Purpose of 21P/Giacobini-Zinner case study:

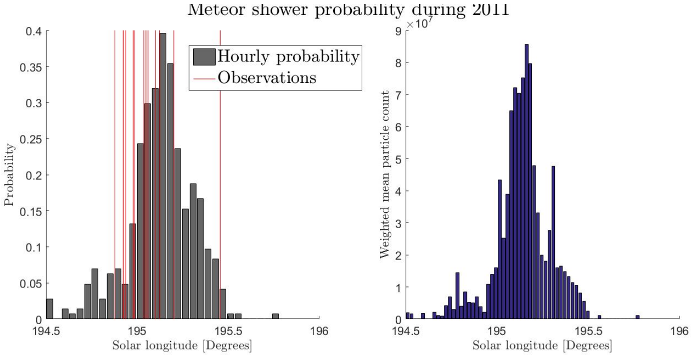
- Proof of concept
- Implementation validation
- Investigation of mass power law deviations
- Temporal development of orbital associations

Input state

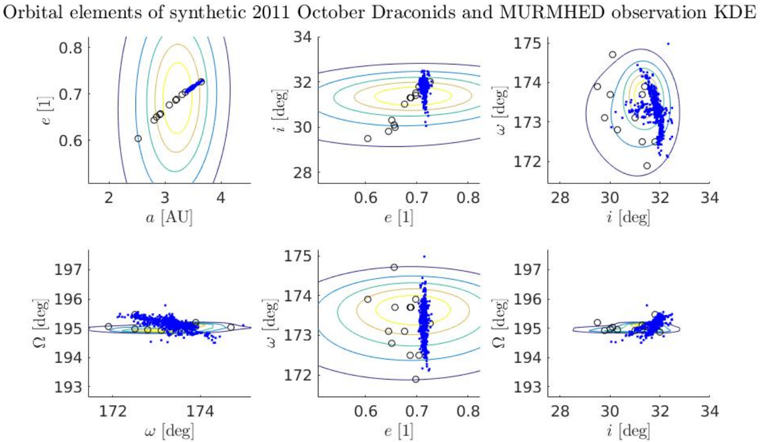
- Ejected material between 1866 and 1972
- Ejection model by (Hughes 2000)
- Each of the 17 perihelion passages sampled with 50 clones
- 6 714 499 test particles propagated
- Particles within Earth Hill Sphere considered meteors (43 637 total)
- Execution time on 2 personal computers: 1 week

Outline

2011 October Draconids



2011 October Draconids



Outline

The case study

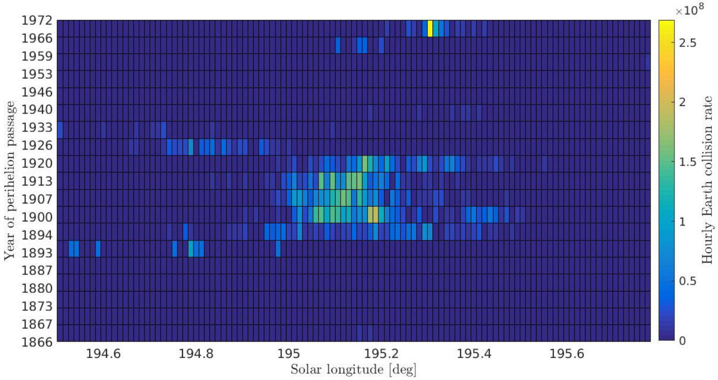
Usually the mass ratio's (amplitude/duration) is considered a simple power law (mass index).

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

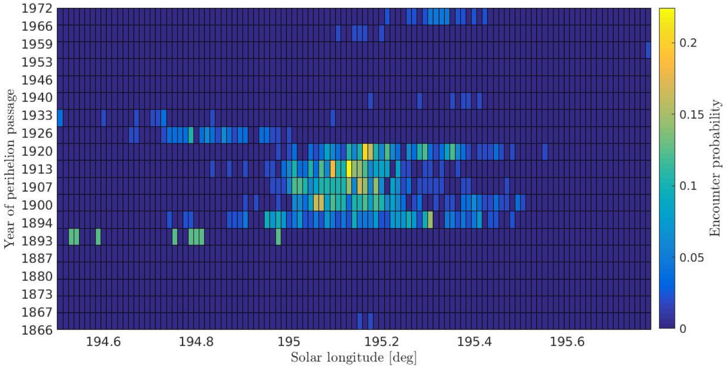
- 2011 October Draconids followed the power law
- 2012 did not

Why? How? Observational bias or meteoroid stream physics?

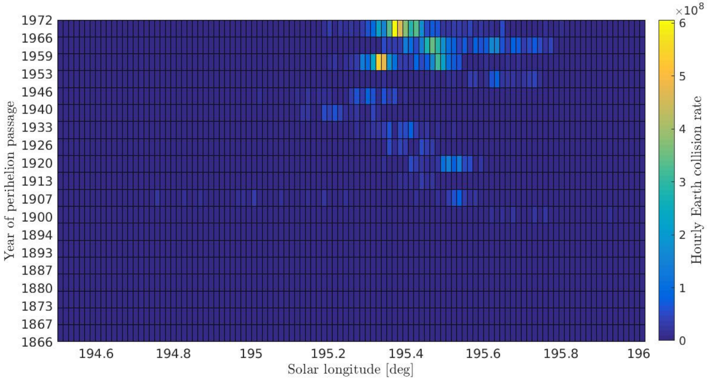
2011 October Draconids mean encounter rates



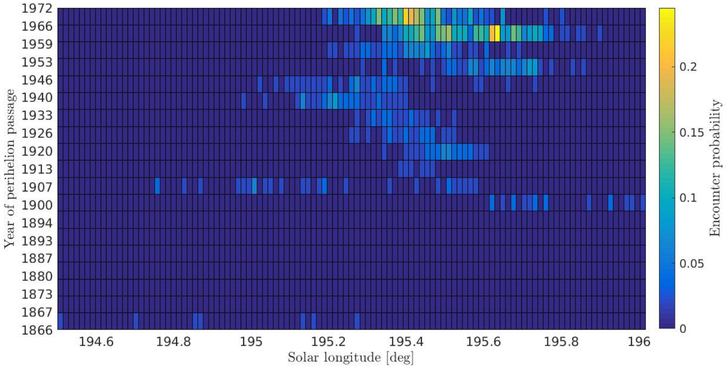
2011 October Draconids probability distribution



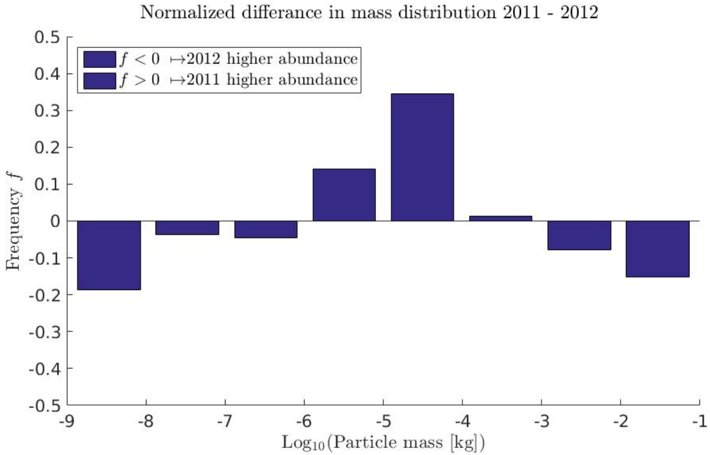
2012 October Draconids mean encounter rates



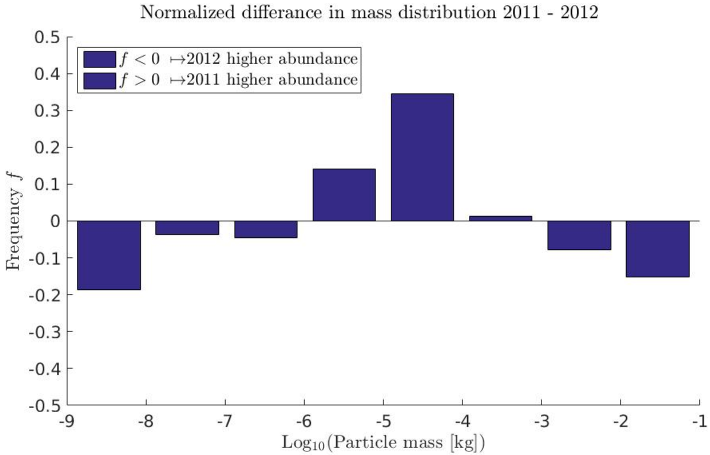
2012 October Draconids probability distribution



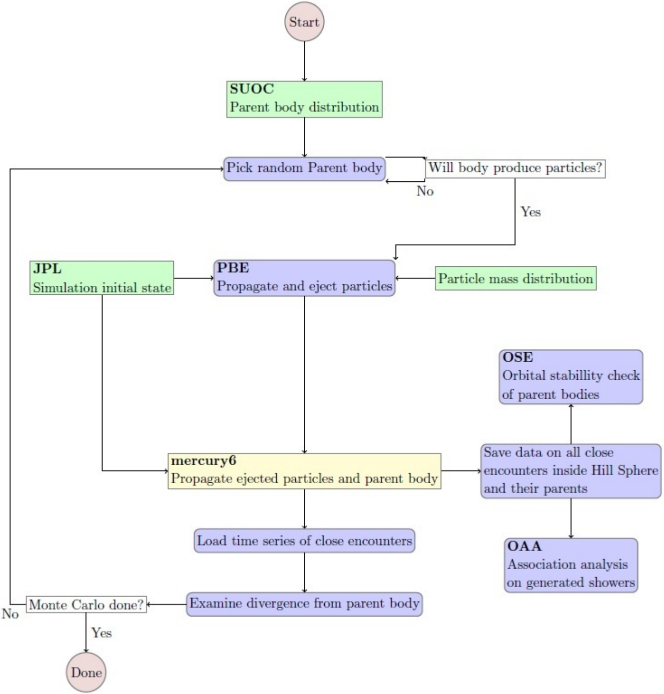
Mass transfer functions



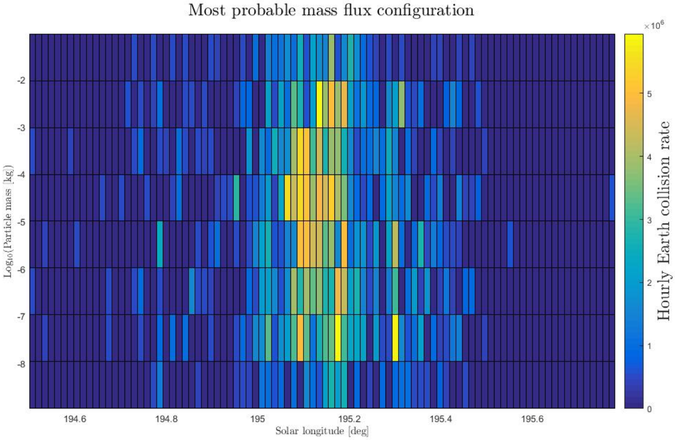
Mass transfer functions



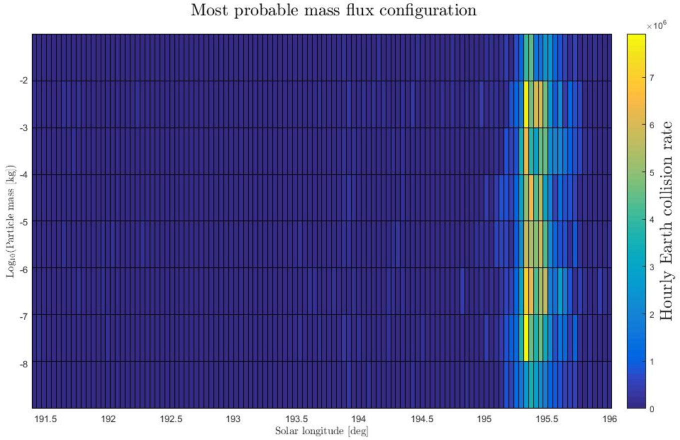
Thank you for listening!


Start
SUOC
Parent body distribution
Pick random Parent body
Will body produce particles?
No
Yes
JPL
Simulation initial state
PBE
Propagate and eject particles
Particle mass distribution
OSE
Orbital stabillity check
of parent bodies
mercury6
Propagate ejected particles and parent body
Save data on all close
encounters inside Hill Sphere
and their parents
Load time series of close encounters
OAA
Association analysis
on generated showers
Monte Carlo done?
Examine divergence from parent body
No
Yes
Done

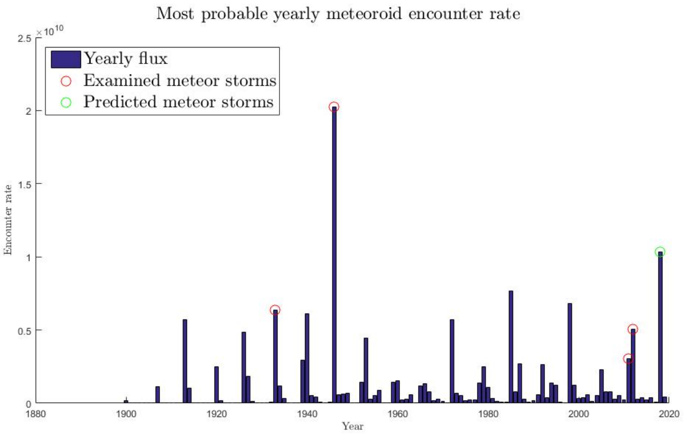
2011 October Draconids Mass transfer functions



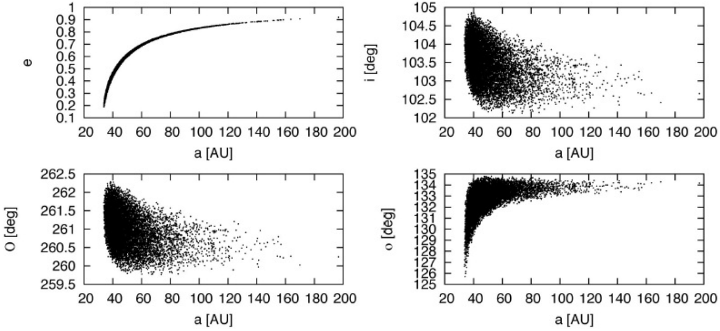
2012 October Draconids Mass transfer functions



Predictions



Statistical Uncertainty Orbital Clones



Adopted from "OpenOrb: Open-source asteroid orbit computation software including statistical ranging"
by GRANVIK et al.