Comenius University in Bratislava

Faculty of Mathematics, Physics and Informatics

Spatial density and model of meteoroid population

Dissertation thesis

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Abstrakt

Inštalácia viacstaničných sietí meteorových kamier umožňuje okrem iného aj určenie celkového toku meteoroidných častíc. Priame meranie však nie je možné, pretože získané dáta sú zaťažené značnými systematickými chybami a výberovými efektami. V tejto práci predkladáme dve metódy odstránenia výberových efektov. V práci sme použili dáta z kamier AMOS, vyvinutých a prevádzkovaných na FMFI UK.

Prvá metóda je založená na postupnej identifikácii a odstraňovaní výberových efektov, ktoré ovplyvňujú pozorované frekvencie meteorov v zemskej atmosfére. Vplyv uvažovaných efektov sme odhadli na základe kalibrácie systému s vizuálnymi pozorovateľmi. Druhou popísanou metódou je simulácia meteoroidov vstupujúcich do zemskej atmosféry. Na zaznamenané dráhy virtuálnych meteorov boli aplikované zvolené výberové kritériá a výsledný štatistický súbor bol uložený do databázy. Tieto dáta sme následne analyzovali štatistickými metódami a porovnávali s observačnými dátami z kamier AMOS. Celý proces sme následne mnohokrát opakovali s modifikovanými parametrami až do nájdenia najlepšej možnej zhody s observačnými dátami a následne odhadli výsledný tok pre meteorický roj Perzeíd.

Kľúčové slová: meteor, meteoroid, tok, model, pozorovanie, výberové efekty

Abstract

The primary aim is to develop and test a model of distribution of small particles

Keywords: meteor, meteoroid, population, video, flux, model, debiasing, AMOS

Contents

Chapter 1

Introduction

You saw sagacious Solomon,
You know what came of him,

Edsger Dijkstra

1.1 Reduction to Earth's sky

While the primary model describes the actual distribution of meteoroid particles in space around the Earth, it is not possible to compare this directly to observations.

models developed from data obtained from Earth-based observations are different.

Typically we do not consider individual particles, but the entire stream and its elliptical orbit around the Sun.

the ascending or the descending node of the orbit must lie very close to the orbit of the Earth.

The final product would thus be a five-dimensional map of distribution of meteor activity, with independent variables being

- the **temporal coordinate**, representing the variation of meteor activity in time;

- the **mass spectrum**, describing the distribution of meteoroid masses, typically in terms of *mass index s*;

- and the **velocity spectrum**, describing the velocities of objects passing through this point, which can be in turn described by

  – two spatial coordinates, the **right ascension and declination** of the radiant, or α and δ;

  – and **speed** v.

described by the **meteor activity function**

$$M(t, \vec{v}, m) \equiv \rho(\lambda_{\odot}, \delta, \alpha, v, m). \tag{1.1.1}$$

In visualisations it is natural to keep the spatial and temporal dimensions, that is, right ascension and declination are displayed as spatial coordinates using one of suitable projections, while time evolution of streams is best displayed in sequence of images. Displaying the secular evolution of one stream can be performed by comparing the state of the function M at the same $\lambda_{\odot}$ in successive years.

[1]

Within this map we are able to distinguish two main features:

- the **sporadic background**, which forms the main contour lines of the maps, the "terrain";

- and the well-defined, sharp peaks, representing the **meteor showers**. very narrow in the speed dimensions;

Due to influences of various acting forces, such as differences in initial velocities with respect to the parent body, tidal disruptions, perturbations arising from close encounters with large bodies of the Solar System, Poynting-Robertson effect, etc., the stream gradually widens and disperses in all components until it can no longer be distinguished from the background.

1.1.1 Time

In examining the evolution we may recognize two distinct components:

- the **periodic component**, emerging as the result of the Earth orbiting the Sun. This coordinate can be thus expressed in terms of the **longitude of the sun** $\lambda_{\odot}$.
- the slowly-varying **secular component**, associated with appearance of new meteoroid streams and gradual decay of older streams which are not replenished.

  The peaks produced by meteor showers appear abruptly after the parent body passes through the vicinity of the Earth, producing small meteoroid due to heating or outgassing. Returns of parents bodies on periodic orbits, such as comets 1P/Halley or 109P/Swift-Tuttle, result in resupply of meteoroid material, and thus form an extra periodic component, included in the secular evolution of the stream.

Chapter 2

Proposed algorithm

2.1 Simulation in the Solar System

The simulation

including the gravitational influence of the parent body and then

on the order of 100 radii.

With ephemerides taken from the JPL Horizons system [?]. The simulation computes the positions of the large bodies of the Solar System, most importantly the Sun, the eight planets and the Moon. Then the test particles

Optinally, positions of massless bodies can be offloaded to a Graphics Processing Unit (GPU). Using a GPU is particularly well suited to massively parallel problems, such as simulation of non-interacting test particles.

Any particle intersecting the cross-section of the Earth is marked as detected and will be examined further. Alternatively, in order to reduce the number of trials, we may employ a larger artificial detector.

as long as the spatial density is only varying on scales much larger than the radius of the Earth, temporal variations in activity will be small. This assumption is not universally valid, as some younger meteor showers often produce dense, narrow filaments, which can be observed as short but intensive outbursts of heightened meteor activity. A suitable example are the November alpha-Monocerotids, with a period of significantly heightened activity spanning only about thirty minutes in 2019 [?].

By comparing the orbital speed and the diameter of the Earth we can see that the Earth moves to a completely different position with respect to the stream within several minutes. This means that variations in activity are not going to be significant when crossing an old stream, whose radius may be on the order of millions of kilometres, but will be of extreme importance with young, narrow filaments.

The duration of visible activity also depends on the exact shape of the stream and its orientation with respect to the orbit of the Earth. The worst case is encountered with streams with high inclinations, where meteors seem to arrive from a direction perpendicular to the direction of movement. The

and thus is almost perpendicular to the Earth's instantaneous velocity vector.

termined sphere centered on the Earth but with radius increased by about order of magnitude –

2.2 Simulation in the atmosphere

To simulate the atmospheric entry we used Asmodeus [?], [1]. Once a particle is selected for atmospheric entry, its velocity is transformed to the ECEF reference frame and

the simulation considers four forces acting on the particle:

- the drag force, acting against the instantaneous velocity vector of the particle;
- the gravitational force, pulling the meteoroid towards the centre of the Earth;
- the fictitious **centrifugal** force, which pushes the particle away from the axis of rotation of the Earth;
- and the fictitious **Coriolis force**.

On the length and speed scales encountered in the simulation the fictitious forces can be safely neglected, their influence is significant only during the dark phase of flight, should the meteoroid survive the entry as a meteorite.

Bibliography

[1] Martin Baláž, Juraj Tóth, Robert Jedicke, and Peter Vereš. ASMODEUS meteor simulation toolset. **Planetary and Space Science**, in prep.