From Meteors to Space Safety:
Dynamical Models and
Radar Measurements of Space Objects

Daniel Kastinen

Akademisk avhandling

som med vederbörligt tillstånd av Rektor vid Umeå universitet för avläggande av filosofie doktorsexamen framläggs till offentligt försvar i Ljusårssalen, Institutet för rymdfysik, Bengt Hultqvists väg 1, Kiruna, fredagen den 25 November, kl. 09:00.

Avhandlingen kommer att försvaras på engelska.

Fakultetsopponent: Dr. Detlef Koschny
European Space Research and Technology Centre (ESTEC), Noordwijk, Netherlands.

Department of Physics

Organization
Umeå University
Department of Physics

Document type
Doctoral thesis

Date of publication
04 November 2022

Author
Daniel Kastinen

Title
From Meteors to Space Safety: Dynamical Models and Radar Measurements of Space Objects

Abstract

Every day the Earth's atmosphere is bombarded by 10-200 metric tons of dust-sized particles and larger pieces of material from space called meteoroids. Dust and meteoroids come from parent bodies such as comets and asteroids, which are remnants from the formation of the solar system. In addition to natural objects, geospace contains artificial satellites and space debris that needs to be monitored to reduce the risk of collisions. Studies of all these kinds of space objects form a cross-disciplinary research field that stretches *from meteors to space safety*.

The primary goal of this thesis has been to rigorously connect measurements and their uncertainties with high-level analysis and dynamical simulations of distributions. An automated radar data analysis algorithm was developed for meteor head echo measurements. The analysis algorithm is able to produce realistic uncertainties for each individual meteor event, including the meteoroid orbit. Many of the resulting probability distributions are non-Gaussian, which needs to be accounted for. The analysis algorithm was applied to interferometric high-power large-aperture MU radar data in a case study on high altitude meteors. The study found that 74 out of 106,000 meteors appeared higher than 130 km and a few confirmed detections reached up to 150 km altitude. Comet 21P/Giacobini–Zinner is the parent body of the meteoroid stream giving rise to the October Draconid meteor shower. The meteoroid stream was simulated accounting for parent body orbital uncertainties to estimate meteor shower parameters. The simulation was able to model the unexpected mass distribution observed in the 2011 and 2012 October Draconids. It also successfully predicted a meteor outburst in 2018. Further, methods to reduce the computation time of meteoroid stream simulations using importance sampling were derived and implemented on a test model. EISCAT radar measurements were performed to study space debris from the Kosmos-1408 satellite, which had been destroyed and fragmented in orbit on 15 November, 2021. A novel method to estimate the size distribution of debris objects was developed. Data from two EISCAT radars were used to demonstrate a new initial orbit determination technique, yielding good agreement with known catalogue orbits. Finally, the detectability of near-Earth objects (NEOs) with the EISCAT~3D radar currently under construction was simulated. It was predicted that as many as seven temporarily captured NEOs, i.e. minimoons, could be discovered per year depending on the amount of allocated observation time. The predictions also show that hundreds of NEOs could be tracked yearly to improve their orbits.

Keywords
Meteors, meteor shower, atmosphere, meteoroids, meteoroid stream, small-body dynamics, solar system, comets, asteroids, near-Earth objects, space safety, space debris, radar, MU, EISCAT

Language
English

ISBN
print: 978-91-7855-902-2
PDF: 978-91-7855-903-9

ISSN
0284-1703

Number of pages
79 + 8 papers