Course Specifications

Valid in the academic year 2023-2024

Radiative Transfer Simulations in Astrophysics (C003939)

Course size *(nominal values; actual values may depend on programme)*

Credits 6.0 **Study time 180 h**

Course offerings and teaching methods in academic year 2023-2024

A (semester 2)	English	Gent	lecture
			independent work

Lecturers in academic year 2023-2024

Baes, Maarten	WE05	lecturer-in-charge

Offered in the following programmes in 2023-2024	**crdts**	**offering**
Master of Science in Teaching in Science and Technology(main subject Physics and Astronomy)	6	A
Master of Science in Physics and Astronomy	6	A
Exchange Programme in Physics and Astronomy (Master's Level)	6	A

Teaching languages

English

Keywords

Astrophysics, radiative transfer, numerical modeling, Monte Carlo techniques, interstellar dust

Position of the course

Astronomical observations are naturally limited to the two-dimensional plane of the sky. Building a computer model of the observed objects can help us understand the underlying three-dimensional structure and physical processes. These models must properly take into account the effects of radiation transport through the interstellar medium. For example, in an average spiral galaxy, one third of the stellar radiation is absorbed by interstellar dust. The Monte Carlo technique is the most popular method to accurately simulate these effects.
This course is the logical next step after "Astrophysical Simulations". In that course, students are initiated in the art of scientific programming, focusing on simulation techniques for gravitation and hydrodynamics. This follow-up course studies simulation techniques for radiation transport, another phenomenon that is important in almost all astrophysical systems. Furthermore, the practical sessions provide a realistic setting where the student learns how to use an existing scientific code and adjust or extend it to achieve new, specific research goals.

Contents

- Interstellar dust: formation and destruction, shapes, size distribution, optical and calorimetric properties.
- The radiative transfer equation: derivation, source and sink terms, line and continuum transport, scattering by dust, dust absorption and re-emission in local equilibrium conditions.
- The photon package life cycle: Monte Carlo basics, primary emission, interactions with the dust, escape and detection, panchromatic simulations and dust emission.
- Spatial grids: grid traversal, regular Cartesian grids, hierarchical grids, Voronoi grids.
- Sampling from spatial distributions: random number generators, inversion method, rejection method, decorating geometries with spiral arms or clumps, importing hydrodynamics simulation results.

- Optimization techniques: forced scattering, continuous absorption, peel-off, composite biasing.
- Parallelization: shared and distributed memory, redistribution of parallel data between simulation phases, performance scaling.
- Inverse radiative transfer: fitting analytical models to observations, searching large parameter spaces.
- Extensions to the basic radiative transfer equation: dust heating in nonequilibrium conditions, polarization, kinematics, radiation hydrodynamics.
- Other radiative transfer simulation techniques: ray-tracing, moment method, dealing with high optical depth, benchmark efforts.

Several of these subjects are illustrated with astrophysical science cases, and the accompanying practical project links directly into many of the theoretical subjects.

Initial competences

Astrophysical Simulations (C002329)

Final competences

1 Derive the radiative transfer equation and understand its components.
2 Describe the Monte Carlo photon package life cycle and related techniques for spatial discretization, sampling from three-dimensiomal distributions, computational optimization, and parallelization.
3 Explain the pros and cons of the various techniques used in radiative transfer simulations.
4 Describe some science cases to which to radiative transfer simulations are applied and explain why they are relevant.
5 Apply a state-of-the-art radiative transfer code to basic science cases.
6 Adjust a scientific code written in C++ to specific research demands.
7 Interpret radiative transfer simulation results in a numerical and astrophysical context.
8 Orally convey the findings of a radiative transfer simulation project to experts.

Conditions for credit contract

Access to this course unit via a credit contract is determined after successful competences assessment

Conditions for exam contract

This course unit cannot be taken via an exam contract

Teaching methods

Group work, Lecture, Independent work

Learning materials and price

Syllabus in English, 10 euro.
Radiative transfer software, can be installed free of charge.

References

Monte Carlo Methods, Malvin H. Kalos and Paula A. Whitlock, Second Edition, 2008 Wiley-VCH.
Three-Dimensional Dust Radiative Transfer, Juergen Steinacker, Maarten Baes, and Karl D. Gordon, 2013, Annual Review of Astronomy and Astrophysics.
SKIRT: An advanced dust radiative transfer code with a user-friendly architecture, Peter Camps and Maarten Baes, 2015, Astronomy and Computing.

Course content-related study coaching

The lecturers are available for coaching during the semester.

Assessment moments

end-of-term and continuous assessment

Examination methods in case of periodic assessment during the first examination period

Oral assessment

Examination methods in case of periodic assessment during the second examination period

Oral assessment

Examination methods in case of permanent assessment

Assignment

Possibilities of retake in case of permanent assessment

examination during the second examination period is not possible

Extra information on the examination methods

The project is completed individually by each student. The project assignment includes installing and using a state-of-the art radiative transfer code, understanding and adjusting or extending a specific portion of the code written in C++, and interpreting the simulation results in a numerical and astrophysical context. A written project report must be submitted a few days before the oral exam during the first examination period.
The oral exam consists of two parts: a closed-book part on the theory, with time for written preparation, and an open-book part on the project.
The project report can only be submitted during the first examination period; for students who fail for the course in the first examination period and participate in the second examination period, the project report grade from the first period is automatically transferred.

Calculation of the examination mark

Theory, oral exam with written preparation, closed book: 40%
Project, individual oral exam, open book: 30%
Project report, submitted before oral exam: 30%