Technische Universität Braunschweig

Description of the degree programme

Solar System Physics (MPO 2023) Master

Date: 09-06-2023

This translation of the German version date 09-06-2023 is provided for information purpose only.

If there is a discrepancy or inconsistency of meaning or interpretation between the English version and the original German version, the German version shall prevail.

Table of contents

Specialised deepening phase

Module name: **Planetary Bodies**						Module number: **PHY-IGeP-30**
Institution: Institut für Geophysik und Extraterrestrische Physik						Module abbreviation: **FV-PB**
Workload:	450 h	Attendance time:	140 h	Semester:		1 or 2
credit points:	15	Independent study:	310 h	Number of semesters:		1
Compulsory form:	mandatory			Sem. hours / week:		10

Courses/Main topics:
Interiors and Surfaces of Planetary Bodies (L/E)
Atmospheres and Environments of Planetary Bodies (L/E)

Attendance logic (if alternative selection, etc.):

Lecturers:
Prof. Dr. Andreas Hördt
Prof. Dr. Ferdinand Plaschke
Prof. Dr. Jürgen Blum
Prof. Dr. Jessica Agarwal
N.N. (Theoretical Physics)

Qualifications aims:
The students
- understand and are able to formulate the empirical and theoretical foundations of modern planetary science.
- apply these fundamentals to planetary problems.
- are able to independently select a suitable combination of methods for a given problem.
- analyse the problems for this purpose and trace them back to empirical and theoretical foundations.

Contents:
Planetary formation (synopsis), internal structure of planetary and small bodies, differentiation and heating, hydrostatic equilibrium, adiabatic temperature gradient, equations of state, gravitational potential, rotational dynamics, seismology, PREM, cooling processes, planetary crusts, (cryo-)volcanism, planetary magnetic fields, nuclear convection and dynamo, geophysical exploration of planets.

Primodial atmosphere and its loss, atmosphereic stratification, surfaces and winds, climate and greenhouse effect, space plasmas, magnetohydrodynamics, ionosphere, solar wind and interplanetary magnetic field (synopsis), magnetospheres and current systems, reconnection and magnetic convection, cometary activity.

Forms of Learning:
Lectures, exercises

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: oral examination (45min) or written examination (120min)

Turnus (beginning):
annual in winter semester

Responsible for the module:
Blum

Language:
English

Media forms:
Blackboard-, smartboard-, tablet lecture, projector

Literature:
J.J. Lissauer, I. De Pater, Fundamental Planetary Science. Physics, Chemistry and Habitability. Cambridge University Press, 2019.
B.W. Carroll, D.A. Ostlie. An Introduction to Modern Astrophysics (2nd edition). Cambridge University Press, 2017.
J.S. Lewis. Physics and Chemistry of the Solar System (2nd edition), Academic Press, 2004.
T. Encrenaz et al. The Solar System. 3rd Edition, Springer, 2004.
Baumjohann, W., R. Treumann, Basic Space Plasma Physics, World Scientific, 1997.
Birdsall, C.K., A.B Langdon, Plasma Physics via Computer Simulation, Taylor and Francis, 2004
Larson, W.J., J.R. Wertz, Space Mission Analysis and Design, Space Technology Library, 1999.
Lowrie, W., 2007. Fundamentals of Geophysics. Cambridge.

Rubin, Y., Hubbard, S., 2006. Hydrogeophysics, Springer. Kearey, Ph., and Brooks, M., 2002, An introduction to geophysical exploration, Blackwell.
Explanatory comment: ---
Categories (module groups): Specialised deepening phase
Requirements for this module: ---
Degree programmes: Solar System Physics (BPO 2023) (Master)
Comment on allocation: ---

Module name: **Solar System**					Module number: **PHY-IGeP-31**
Institution: Institut für Geophysik und Extraterrestrische Physik					Module abbreviation: **FV-SS**
Workload:	450 h	Attendance time:	140 h	Semester:	2 or 1
Credit points:	15	Independent study:	310 h	Number of semesters:	1
Compulsory form:	mandatory			Sem. hours / week:	10

Courses/Main topics:
The Sun and Heliosphere (L/E)
Formation and Evolution of the Solar System (L/E)

Attendance logic (if alternative selection, etc.):

Lecturers:
Prof. Dr. Ferdinand Plaschke
Prof. Dr. Jürgen Blum
Prof. Dr. Jessica Agarwal
N.N. (Theoretical Physics)

Qualifications aims:

The students
- understand and are able to formulate the empirical and theoretical foundations of modern solar and heliospheric physics as well as the formation and development of the solar system and can formulate them.
- apply these fundamentals to astro-, heliophysical and planetological problems.
- are able to independently select a suitable combination of methods for a given problem.
- analyse the problems for this purpose and trace them back to empirical and theoretical foundations.

Contents:
Stellar structure equations, stellar nuclear fusion and energy transport, neutrinos, photosphere, limb darkening, optical thickness, sunspots, solar dynamo, coronal heating, sources of the solar wind and the interplanetary magnetic field, coronal mass ejections and eruptions, stellar evolution, Hale cycle, heliopause, interaction of the solar wind and solar radiation with dust particles.

Formation of the Sun and of planetary and small bodies, significance of relative velocities for planetary formation, frost line, pebble and gas accretion, migration, formation of moons, collisions of planetary bodies, Poynting-Robertson drag, radiation pressure, YORP effect, Yarkowsky effect, resonance, tides.

Forms of Learning:
Lectures, exercises

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: oral examination (45min) or written examination (120min)

Turnus (beginning):
annual in summer semester

Responsible for the module:
Plaschke

Language:
English

Media formes:
Blackboard-, smartboard-, tablet lecture, projector

Literature:
J.J. Lissauer, I. De Pater, Fundamental Planetary Science. Physics, Chemistry and Habitability. Cambridge University Press, 2019.
B.W. Carroll, D.A. Ostlie. An Introduction to Modern Astrophysics (2nd edition). Cambridge University Press, 2017.
Baumjohann, W., R. Treumann, Basic Space Plasma Physics, World Scientific, 1997.
Birdsall, C.K., A.B Langdon, Plasma Physics via Computer Simulation, Taylor and Francis, 2004
In addition, current review articles on the formation f the solar system are recommended in the course.

Explanatory comment:

Categories (module groups):
Specialised deepening phase

Requirements for this module: ---
Degree programmes: Solar System Physics (BPO 2023) (Master)
Comment on allocation: ---

Module name: **Hands-On Solar System Physics**					Module number: **PHY-IGeP-32**
Institution: Institut für Geophysik und Extraterrestrische Physik					Module abbreviation: **FV-HO**
Workload:	450 h	Attendance time:	336 h	Semester:	1
Credit points:	15	Independent study:	114 h	Number of semesters:	2
Compulsory form:	mandatory			Sem. hours / week:	24

Courses/Main topics:
Laboratory Solar System Physics (Internship)
Astronomy (Internship)
Data Analysis and Simulations (Internship)

Attendance logic (if alternative selection, etc.):

Lecturers:
Prof. Dr. Ferdinand Plaschke
Prof. Dr. Jürgen Blum
Prof. Dr. Jessica Agarwal

Qualifications aims:
The students
- can plan and apply the methods of numerical simulation, advanced data analysis procedures and space measurement techniques.
- develop their own empirical solution methods for problems without a sound basis and justify them.
- are able to analyse data using appropriate methods.
- can plan, set up, carry out and evaluate simple laboratory experiments.
- can derive conclusions for the relevant physical processes from the experiment results.
- can analyse and interpret astronomical observations.
- can analyse and evaluate their results in a comprehensible way in a protocol and a presentation.

Contents:
- Set-up and execution of own laboratory experiments
- Experiments to solve space physics problems
- Analysis of empirical scientific data to solve planetological or astrophysical problems
- Interpretation of space-physical measurement series with methods of modern data analysis
- Conception/realisation of own numerical experiments
- Analysis of astronomical observations

Forms of Learning:
Internships

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: Protocol and presentation on the Laboratory Solar System Physics internship
(b) Study achievement: Protocol and presentation on the Astronomy internship
(c) Study achievement: Protocol and presentation on the Data Analysis and Simulations internship

Turnus (beginning):
Winter semester or summer semester

Responsible for the module:
Blum

Language:
English

Media forms:
Practical work, suitable software for programming and data analysis, lectures with presentation software, word processing programmes

Literature:
Bendat, J.S., A.G. Piersol, Random Data. Analysis and Measurement Procedures, Wiley, 2010.
Menke, W., 2012, Geophysical Data Analysis: Discrete Inverse Theory, Elsevier.
McMahon, D., 2007, Signals and Systems Demystified, McGraw Hill.

Explanatory comment:

Categories (module groups):
Specialised deepening phase

Requirements for this module: ---
Degree programmes: Solar System Physics (BPO 2023) (Master)
Comment on allocation: ---

Compulsory elective area Special Courses

Module name: **Computational Fluid Dynamics**					Module number: **PHY-IGeP-33**
Institution: Institut für Geophysik und Extraterrestrische Physik					Module abbreviation: **WSC-CFD**
Workload:	150 h	Attendance time:	42 h	Semester:	2
Credit points:	5	Independent study:	108 h	Number of semesters:	1
Compulsory form:	elective			Sem. hours / week:	3

Courses/Main topics:
Computational Fluid Dynamics (L)
Computational Fluid Dynamics (E)

Attendance logic (if alternative selection, etc.):
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Lecturers:
Dr. Daniel Heyner

Qualifications aims:
The students
- understand the empirical and theoretical fundaments of fluid mechanics simulations and are able to formulate them.
- apply these fundamentals to basic problems and issues in magnetohydrodynamics.
- are able to independently select a suitable combination of methods for a given problem.
- analyse the problems for this purpose and relate them back to empirical and theoretical foundations.

Contents:
- Different types of approximations
- Discretisation methods (finite differences, finite volumes, finite elements)
- Stability criteria
- Boundary conditions and boundary layers
- (MHD) turbulence
- Basics of magnetohydrodynamics and dynamo theory as an application of fluid dynamics

Forms of Learning:
Lectures, exercises

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: oral examination (20min) or written examination (60min)

Turnus (beginning):
Summer semester or winter semester

Responsible for the module:
Heyner

Language:
English

Media forms:
Blackboard-, smartboard-, tablet lecture, projector

Literature:
- Ferziger, Computational Methods for Fluid Dynamics, 2019
- Versteeg, An Introduction to Computational Fluid Dynamimcs, 2007
- Davidson, An Indroduction to Magnetohydrodynamics, 2001
Further literature will be announced in good time before the start of the lecture.

Explanatory comment:

Categories (module groups):
Compulsory elective area Special Courses

Requirements for this module: Module 1 or module 2
Degree programmes: Solar System Physics (BPO 2023) (Master)
Comment on allocation: ---

Module name: **Space Plasma Physics**					Module number: **PHY-IThPh-22**
Institution: Institut für Theoretische Physik					Module abbreviation: **WSC-SPP**
Workload:	150 h	Attendance time:	42 h	Semester:	2
Credit points:	5	Independent study:	108 h	Number of semesters:	1
Compulsory form:	elective			Sem. hours / week:	3

Courses/Main topics:
Space Plasma Physics (L)
Space Plasma Physics (E)

Attendance logic (if alternative selection, etc.):
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Lecturers:
N.N. (Theoretical Physics)

Qualifications aims:
- Acquisition of basic knowledge of plasma physics, the application of this knowledge to questions of extra-terrestrial plasmas and application of the acquired knowledge to phenomena in space
- Computational, content-related and practical handling in the treatment of physical problems of space plasma physics.

Contents:
Basic scales of a plasma, plasma models, Vlasov equation, Landau damping, MHD model, multi-fluid models, waves in plasmas, plasma instabilities, non-linear aspects and turbulence.

Forms of Learning:
Lectures, exercises

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: oral examination (20min) or written examination (60min)

Turnus (beginning):
Summer semester or winter semester

Responsible for the module:
N.N. (Theoretical Physics)

Language:
English

Media forms:
Blackboard-, smartboard-, tablet lecture, projector

Literature:
Baumjohann, W., R. Trumann, Basic Space Plasma Physics, Imperial College University Press, 1996

Explanatory comment:

Categories (module groups):
Compulsory elective area Special Courses

Requirements for this module:
Module 1 or module 2

Degree programmes:
Solar System Physics (BPO 2023) (Master)

Comment on allocation:

<table>
<tr><td colspan="5">Module name:
Planetary Magnetospheres</td><td colspan="2">Module number:
PHY-IGeP-34</td></tr>
<tr><td colspan="5">Institution:
Institut für Geophysik und Extraterrestrische Physik</td><td colspan="2">Module abbreviation:
WSC-PM</td></tr>
<tr><td>Workload:

Credit points:

Compulsory form:</td><td>150 h

5

elective</td><td>Attendance time:

Independent study:</td><td>42 h

108 h</td><td colspan="2">Semester:

Number of semesters:

Sem. hours / week:</td><td>2

1

3</td></tr>
<tr><td colspan="7">Courses/Main topics:
Planetary Magnetospheres (L)
Planetary Magnetospheres (E)</td></tr>
<tr><td colspan="7">Attendance logic (if alternative selection, etc.):
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<tr><td colspan="7">Lecturers:
Prof. Dr. Ferdinand Plaschke</td></tr>
<tr><td colspan="7">Qualifications aims:
The students
- understand the empirical and theoretical fundaments of plasma physics of planetary magnetospheres and are able to formulate them.
- apply these fundamentals to problems in planetary magnetospheres.
- are able to independently select a suitable combination of methods for a given problem.
- analyse the problems for this purpose and relate them back to empirical and theoretical foundations.</td></tr>
<tr><td colspan="7">Contents:
Basic plasma physics, single particle motion, gyration, drifts, magnetic bottle, adiabatic invariants, distribution functions, Vlasov equation, magnetohydrodynamics, frozen-in theorem, MHD waves, flow around an obstacle, discontinuities, shocks, Rankine-Hugoniot relations, magnetospheric regions, bow shock and magnetopause, influence of the interplanetary magnetic field, magnetic reconnection, magnetospheric and ionospheric convection, Dungey-cycle, ionospheric conductivities, current systems.</td></tr>
<tr><td colspan="7">Forms of Learning:
Lectures, exercises</td></tr>
<tr><td colspan="7">Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: oral examination (20min) or written examination (60min)</td></tr>
<tr><td colspan="7">Turnus (beginning):
Summer semester</td></tr>
<tr><td colspan="7">Responsible for the module:
Plaschke</td></tr>
<tr><td colspan="7">Language:
English</td></tr>
<tr><td colspan="7">Media forms:
Blackboard-, smartboard-, tablet lecture, projector</td></tr>
<tr><td colspan="7">Literature:
Baumjohann and Treumann: “Basic Space Plasma Physics“, 3rd edition, 2022
Russel, Luhmann, and Strangeway: “Space Physics: An Introduction”, 2016
Kallenrode: “Space Physics: An Introduction to Plasmas and Particles in the Heliosphere and Magnetospheres”, 2001</td></tr>
<tr><td colspan="7">Explanatory comment:
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<tr><td colspan="7">Categories (module groups):
Compulsory elective area Special Courses</td></tr>
<tr><td colspan="7">Requirements for this module:
Module 1 or module 2</td></tr>
<tr><td colspan="7">Degree programmes:
Solar System Physics (BPO 2023) (Master)</td></tr>
<tr><td colspan="7">Comment on allocation:
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</table>

Module name: **Planetary Magnetism and Dynamo Theory**					Module number: **PHY-IGeP-35**
Institution: Institut für Geophysik und Extraterrestrische Physik					Module abbreviation: **FV-SC**
Workload:	150 h	Attendance time:	42 h	Semester:	2
Credit points:	5	Independent study:	108 h	Number of semesters:	1
Compulsory form:	elective			Sem. hours / week:	3

Courses/Main topics:
Planetary Magnetism and Dynamo Theory (L)
Planetary Magnetism and Dynamo Theory (E)

Attendance logic (if alternative selection, etc.):
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Lecturers:
Dr. Daniel Heyner

Qualifications aims:
The students
- understand and are able to formulate the empirical and theoretical foundations of dynamo theory.
- apply these fundamentals to dynamo models in the laboratory as well as to models in the context pf planetary bodies.
- are able to independently select a suitable combination of methods for a given problem.
- analyse the problems and trace them back to empirical and theoretical foundations.

Contents:
What is a dynamo? Where do dynamos occur in space? Magnetic field of the Earth and other planets, Induction equation. What drives convection? Experimental dynamos. Dynamo simulations.

Forms of Learning:
Lectures, exercises

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: oral examination (20min) or written examination (60min)

Turnus (beginning):
Summer semester or winter semester

Responsible for the module:
Heyner

Language:
English

Media forms:
Blackboard-, smartboard-, tablet lecture, projector

Literature:
- Lowrie, Fundamentals of Geophysics, Cambridge, 2007
- Hulot, Magnetic Field of the Earth
- Olson, Planetary Magnetism
- Chandrasekhar, Hydrodynammic and Hydromagnetic Stability
- Jacobs, Geomagnetism
- Davidson, An Indroduction to Magnetohydrogynamics, 2001
- Cardin, Dynamos
- Olson, Core Dynamics
Further literature will be announced in good time before the start of the lecture.

Explanatory comment:

Categories (module groups):
Compulsory elective area Special Courses

Requirements for this module:
Module 1 or module 2

Degree programmes:
Solar System Physics (BPO 2023) (Master)

Comment on allocation:

Module name: **Stellar Astrophysics**						Module number: **PHY-IGeP-36**
Institution: Institut für Geophysik und Extraterrestrische Physik						Module abbreviation: **WSC-SA**
Workload:	150 h	Attendance time:	42 h	Semester:	2	
Credit points:	5	Independent study:	108 h	Number of semesters:	1	
Compulsory form:	elective			Sem. hours / week:	3	

Courses/Main topics:
Stellar Astrophysics (L)
Stellar Astrophysics (E)

Attendance logic (if alternative selection, etc.):
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Lecturers:
Prof. Dr. Jürgen Blum

Qualifications aims:
The students
- understand and are able to formulate the empirical and theoretical foundations of star formation, stellar structure and stellar evolution.
- apply there fundamentals to specific problems.
- are able to independently select a suitable combination of methods for a given problem.
- analyse the problems and trace them back to empirical and theoretical foundations.

Contents:
Physical understanding of the following stellar evolutionary phases: Star formation (molecular clouds, protostars, TTauri stars, Herbig Ae/Be stars), main sequence stars (stellar structure, energy production, energy transport), post-main sequence stars (RGB stars, AGB stars, supernovae, planetary nebulae), final phases of stellar evolution (white dwarfs, neutron stars, black holes).

Forms of Learning:
Lectures, exercises

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: oral examination (20min) or written examination (60min)

Turnus (beginning):
Summer semester or winter semester

Responsible for the module:
Blum

Language:
English

Media forms:
Blackboard-, smartboard-, tablet lecture, projector

Literature:
B.W. Carroll, D.A. Ostlie. An Introduction to Modern Astrophysics (2nd edition). Cambridge University Press, 2017.

Explanatory comment:

Categories (module groups):
Compulsory elective area Special Courses

Requirements for this module:
Module 1 or module 2

Degree programmes:
Solar System Physics (BPO 2023) (Master)

Comment on allocation:

Module name: **Extrasolar Planetary Systems**						Module number: **PHY-IGeP-37**
Institution: Institut für Geophysik und Extraterrestrische Physik						Module abbreviation: **WSC-EPS**
Workload:	150 h	Attendance time:	42 h	Semester:	2	
Credit points:	5	Independent study:	108 h	Number of semesters:	1	
Compulsory form:	elective			Sem. hours / week:	3	

Courses/Main topics:
Extrasolar Planetary Systems (L)
Extrasolar Planetary Systems (E)

Attendance logic (if alternative selection, etc.):
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Lecturers:
Prof. Dr. Jürgen Blum

Qualifications aims:
The students
- understand and are able to formulate the empirical and theoretical foundations of the discovery and structure of extrasolar planets and their systems.
- apply there fundamentals to specific problems.
- are able to independently select a suitable combination of methods for a given problem.
- analyse the problems and trace them back to empirical and theoretical foundations.

Contents:
Synapse of solar system architecture; methods of exoplanet detection and characterisation; properties of exoplanets, especially mass distribution, orbits, multiple systems, resonances, mass-radius relationship and internal structure, atmospheres; comparisons with the solar system and lessons learnt on the formation and evolution of planetary bodies.

Forms of Learning:
Lectures, exercises

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: oral examination (20min) or written examination (60min)

Turnus (beginning):
Summer semester or winter semester

Responsible for the module:
Blum

Language:
English

Media forms:
Blackboard-, smartboard-, tablet lecture, projector

Literature:
H.J. Deeg, J.A. Belmonte (Hrsg.). Handbook of Exoplanets. Springer International Publishing AG, 2018.
In addition, curremt review articles on the formation of the solar system are recommended in the course.

Explanatory comment:

Categories (module groups):
Compulsory elective area Special Courses

Requirements for this module:
Module 1 or module 2

Degree programmes:
Solar System Physics (BPO 2023) (Master)

Comment on allocation:

Module name: **Data and Signal Analysis**						Module number: **PHY-IGeP-38**
Institution: Institut für Geophysik und Extraterrestrische Physik						Module abbreviation: **WSC-DSA**
Workload:	150 h	Attendance time:	56 h	Semester:	2	
Credit points:	5	Independent study:	94 h	Number of semesters:	1	
Compulsory form:	elective			Sem. hours / week:	4	

Courses/Main topics:
Data and Signal Analysis (L)
Data and Signal Analysis (E)

Attendance logic (if alternative selection, etc.):
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Lecturers:
Prof. Dr. Ferdinand Plaschke

Qualifications aims:
The students
- understand and are able to formulate the empirical and theoretical foundations of time-series analysis.
- apply these fundamentals to problems of analysing measurement data.
- are able to independently select a suitable combination of methods for a given problem.
- analyse the problems and trace them back to empirical and theoretical foundations.

Contents:
Definitions, sampling rate, Nyquist frequency, expectation value, ergodic hypothesis, estimator, bias, probability density functions and their determination, moments, law of large numbers, confidence intervals, Z-transform, covariance and correlation, linear regression, method of the analytic signal, Fourier-transform, spectra, leakage, window functions, polarization analysis, empirical mode decomposition, short term Fourier-transform, wavelets, scalograms, minimum variance analysis, basics of filter theory, transmission systems, impulse response, stability

Forms of Learning:
Lectures, exercises

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: oral examination (20min) or written examination (60min)

Turnus (beginning):
Winter semester

Responsible for the module:
Plaschke

Language:
English

Media forms:
Blackboard-, smartboard-, tablet lecture, projector

Literature:
Woyczynski: “A First Course for Signal Analysis“, 2019
McMahon: “Signals & Systems Demystified”, 2006
Glassmeier and Motschmann: “Comments on Time-Series Analysis”, 1995
Paschmann and Daly: “Analysis Methods for Multi-Spacecraft Data”, 1998

Explanatory comment:

Categories (module groups):
Compulsory elective area Special Courses

Requirements for this module:
Module 1 or module 2

Degree programmes:
Solar System Physics (BPO 2023) (Master)

Comment on allocation:

Module name:	Module number:
Geophysical Modelling	**PHY-IGeP-39**
Institution: Institut für Geophysik und Extraterrestrische Physik	Module abbreviation: **WSC-GM**

Workload:	150 h	Attendance time:	56 h	Semester:	2
Credit points:	5	Independent study:	94 h	Number of semesters:	1
Compulsory form:	elective			Sem. hours / week:	4

Courses/Main topics:
Electrical properties of geological materials (L/E)
Numerical simulations in geophysics (L/E)

Attendance logic (if alternative selection, etc.):
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Lecturers:
Prof. Dr. Matthias Bücker
Dr. Christopher Virgil

Qualifications aims:
Electrical properties of geological materials
The students
- understand and are able to formulate the empirical and theoretical fundamentals of electrical conduction and polarisation processes in heterogeneous materials.
- apply there fundamentals to describe electrical properties of specific geological materials.
- are able to select suitable modelling approaches for a given problem.
- analyse the problems and trace them back to empirical and theoretical foundations.

Numerical simulations in geophysics
The students
- are able to plan numerical simulations and use them to solve geophysical problems.
- know different strategies for optimising finite-element meshes and are able to use them.
- are able to critically evaluate their simulation results.
- are able to present their simulation results visually.
- are able to document their approach and their results in a comprehensible way in a project report.

Contents:
Electrical properties of geological materials
- Fundamentals: petrophysics, microscopic heterogeneity of rocks, petrophysical modelling, conductivity and dielectric constant, complex conductivity, empirical models.
- Homogenisation: electrical properties of common rock constituents, electrolytic conductivity, Hittorf's, transfer numbers, simple averages, Reuss and Voigt bounds, geometric mean, effective-medium theory (EMT), Maxwell-Garnett equation, Hashkin and Shtrikman bounds, Bruggeman-Hanai-Sen equation, pore-network models, numerical modelling
- Electrical double layer: Helmholtz model, Gouy-Chapman model, Poisson-Boltzmann, Stern model
- Polarisation of the electrical double layer: derivation of Maxwell-Garnett equation, surface conductivity and polarisation, Stern-layer polarisation, diffuse-layer polarisation
- Membrane polarisation: model of Marshall and Madden, model of Bücker and Hördt
- Electrode polarisation: diffuse-layer charging, Wong model, reaction currents.
- Temperature effects: Temperature dependence above the freezing point of water, polarisation of ice.

Numerical simulations in geophysics
Basic use of the finite-element software Comsol Multiphysics: Generation of geometries, definition of physical problems, mesh generation, computation of a solution, visualisation of results, testing and validation of numerical solutions, strategies for mesh optimisation, adaptive mesh refinement, applications and simulations examples from the field of geomagnetic, implementation of physical problems using coefficient from PDEs, applications and simulation examples from the field of electrical rock properties, optimisation and sensitivity, parameter estimation and inversion, inversion of geomagnetic data.

Forms of Learning:
Lectures, exercises, for *Numerical simulations in geophysics* offered in the form of a 5-day block course during summer semester break

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: Creation and Documentation of a Computer or Software Programme

Turnus (beginning):
Summer semester

Responsible for the module: Bücker
Language: English
Media forms: Blackboard-, smartboard-, tablet lecture, projector, electronic handouts
Literature: Will be announced in the respective lecture at the beginning.
Explanatory comment: ---
Categories (module groups): Compulsory elective area Special Courses
Requirements for this module: ---
Degree programmes: Solar System Physics (BPO 2023) (Master)
Comment on allocation: ---

Module name: **Comets and TNOs**					Module number: **PHY-IGeP-40**
Institution: Institut für Geophysik und Extraterrestrische Physik					Module abbreviation: **WSC-CT**
Workload:	150 h	Attendance time:	42 h	Semester:	2
Credit points:	5	Independent study:	108 h	Number of semesters:	1
Compulsory form:	elective			Sem. hours / week:	3

Courses/Main topics:
Comets and TNOs (L)
Comets and TNOs (E)

Attendance logic (if alternative selection, etc.):
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Lecturers:
Prof. Dr. Jessica Agarwal

Qualifications aims:
The students
- can give an overview of the populations of TNOs and comets in the solar system and over past space missions to such objects.
- understand basic physical processes occurring in comets and TNOs
- can explain measurement methods relevant to cometary science and apply them in the approach
- can describe physical models currently used in commentary research and apply them in the approach.

Contents:
The topic of the lecture is mall bodies beyond the orbit of Neptune (Trans-Neptunian Objects, TNOs) and comets. The lecture will present what we have learned about the composition and interior structure of these objects from space missions and astronomical observations, how they evolve under the influence of solar irradiation, and which information they can give us about the early solar system and the process of planet formation.

Forms of learning:
Lectures, exercises

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: oral examination (20min) or written examination (60min)

Turnus (beginning):
Winter semester

Responsible for the module:
Agarwal

Language:
English

Media forms:
Blackboard-, smartboard-, tablet lecture, projector

Literature:
- Comets II, Eds. M. Festou, H.-U. Keller, H. A. Weaver, University of Arizona Press, 2004 (all files available online)
- Planetary Sciences, 2nd edition, I. de Pater & J. Lissauer, Cambridge University Press, 2015
- Encyclopedia of the Solar System, 2nd edition, eds. L.-A. McFadden, P. R. Weissman, T. V. Johnson, Elsevier Academic Press, 2007

Explanatory comment:

Categories (module groups):
Compulsory elective area Special Courses

Requirements for this module:
Module 1 or module 2

Degree programmes:
Solar System Physics (BPO 2023) (Master)

Comment on allocation:

Module name: **Asteroids**						Module number: **PHY-IGeP-41**	
Institution: Institut für Geophysik und Extraterrestrische Physik						Module abbreviation: **WSC-A**	
Workload:	150 h	Attendance time:	42 h	Semester:	2		
Credit points:	5	Independent study:	108 h	Number of semesters:	1		
Compulsory form:	elective			Sem. hours / week:	3		

Courses/Main topics:
Asteroids (L)
Asteroids (E)

Attendance logic (if alternative selection, etc.):
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Lecturers:
Prof. Dr. Jessica Agarwal

Qualifications aims:
The students
- recognise the different classes of asteroids and meteorites
- can describe the role of asteroids and meteorites in the wider context of the solar system
- understand and can describe the most relevant measurement methods used in asteroid research
- explain basic physical processing actin on asteroids

Contents:
The lecture deals with asteroids in our solar system. Three major methods of asteroid research will be presented: 1. meteorite research, 2. astronomical observations, 3. exploration with space probes. The lecture outlines the classification of asteroids and its connection with the composition of asteroids. Also physical processes driving asteroid evolution and their connection with the formation of the solar system will be discussed.

Forms of learning:
Lectures, exercises

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: oral examination (20min) or written examination (60min)

Turnus (beginning):
Summer semester

Responsible for the module:
Agarwal

Language:
English

Media forms:
Blackboard-, smartboard-, tablet lecture, projector

Literature:
- Burbine, T.H., 2017, Asteroids. Cambridge University Press.
- Michel, P., DeMeo, F., Bottke, W.F. (Hrsq.) 2015. Asteroids IV. The University of Arizona Press.
- Planetary Sciences, 2nd edition, I. de Pater & J. Lissauer, Cambridge University Press, 2015
- Encyclopedia of the Solar System, 2nd edition, eds. L.-A. McFadden, P. R. Weissman, T. V. Johnson, Elsevier Academic Press, 2007

Explanatory comment:

Categories (module groups):
Compulsory elective area Special Courses

Requirements for this module:
Module 1 or module 2

Degree programmes:
Solar System Physics (BPO 2023) (Master)

Comment on allocation:

Module name: **Space Technologies**						Module number: **PHY-IGeP-42**
Institution: Institut für Geophysik und Extraterrestrische Physik						Module abbreviation: **WSC-ST**
Workload: Credit points: Compulsory form:	150 h 5 elective	Attendance time: Independent study:	42 h 108 h	Semester: Number of semesters: Sem. hours / week:	2 1 3	

Courses/Main topics: Space Technologies (L) Space Technologies (E)
Attendance logic (if alternative selection, etc.): --
Lecturers: Prof. Dr. Joachim Block
Qualifications aims: The students - understand the historical development of space technology since the 1960s and can correlate the benchmarks of this technical development with the discrete steps of increasing knowledge about the planets, moons, and small bodies of the solar system (which was gained mission by mission). - are able to specify, estimate, and substantiate the basic requirements of orbit mechanics for the accessibility of different destinations in the solar system (e.g. Hohmann trajectories, gravity-assist manoeuvers, flight durations, etc.). - are able to specify the basic requirements for the design of an interplanetary spacecraft which shall be bound for a given destination (e.g.: When is it inevitable to base on-board power generation on RPGs instead of solar arrays? Which subsystems will need multiple redundancy?). - are able to select a suited effective combination of different types of PI instruments for the scientific payload of an envisaged interplanetary science mission bound for a given destination. - can compare any envisioned future mission scenarios with historical missions that have already been successfully performed.
Contents: All historically important science missions in the solar system which have been performed since the beginning of the space age (around ≈ 1960) are being thoroughly discussed. This includes both the technology of their on-board systems and of their PI instruments. It will be shown that the enormous increase of knowledge about the sun, the planets, moons, and small bodies of the solar system has been achieved in discrete steps which were coupled with the individual space missions and with the development status (or maturity) of their instruments. Based on this, the requirements for any future science missions will be discussed.
Forms of learning: Lectures, exercises
Examination modalities / Requirements for the award of credit points: (a) Study achievement: homework (b) Examination: oral examination (20min) or written examination (60min)
Turnus (beginning): Summer semester
Responsible for the module: Block
Language: English
Media forms: Blackboard-, smartboard-, tablet lecture, projector
Literature: A current selection of literature will be announced in good time before the start of the semester.
Explanatory comment: ---
Categories (module groups): Compulsory elective area Special Courses
Requirements for this module: Module 1 or module 2

Degree programmes: Solar System Physics (BPO 2023) (Master)
Comment on allocation: ---

Module name: **Space Missions and Project Management**						Module number: **PHY-IGeP-43**
Institution: Institut für Geophysik und Extraterrestrische Physik						Module abbreviation: **WSC-MPM**
Workload:	150 h	Attendance time:	42 h	Semester:	2	
Credit points:	5	Independent study:	108 h	Number of semesters:	1	
Compulsory form:	elective			Sem. hours / week:	3	

Courses/Main topics:
Space Missions and Project Management (L)
Space Missions and Project Management (E)

Attendance logic (if alternative selection, etc.):
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Lecturers:
Prof. Dr. Joachim Block

Qualifications aims:
The students
- understand how scientific space mission (in particular missions bound for destinations in the solar system) are structured in terms of project management, how their basic conception is - at first - being discussed within the scientific community, and how the projects are finally being selected and organized (in Europe mainly by ESA).
- understand the role and responsibility of the Principal Investigators (PI's) during and after the "Announcement of Opportunity" (AO).
- gain a thorough understanding of the importance of firm project phases with intermediate "Peer Reviews" and the corresponding management tools (RID's, NCR's, systematic project documentation, FMECA, risk analyses, "breadboard" and official qualification models, qualification and acceptance tests, etc.).
- are enabled to define the organisation of a fictional project review (e.g. a PDR) for a hypothetically envisaged science mission: Which qualification levels and documentation standards would be required, what kind of experts should be asked for participation as "peers", which kind of RID's would be "major"?
- are able to justify their proposals by examples and experiences from the real history of science missions in the solar system, as they will have been discussed in the preceding lectures.

Contents:
The whole course of project planning for scientific missions is being thoroughly discussed, from the first conceptional ideas and feasibility studies (phase A) via design and qualification of the spacecraft (phases B and C) and the construction of the flight model (phase D) until the launch campaign. Subsequently the typical course of a scientific mission (phase E) is taken into consideration. The discussions are geared towards outstanding examples of historical missions into the solar system.

Forms of learning:
Lectures, exercises

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: homework
(b) Examination: oral examination (20min) or written examination (60min)

Turnus (beginning):
Winter semester

Responsible for the module:
Block

Language:
English

Media forms:
Blackboard-, smartboard-, tablet lecture, projector

Literature:
A current selection of literature will be announced in good time before the start of the semester.

Explanatory comment:

Categories (module groups):
Compulsory elective area Special Courses

Requirements for this module:
Module 1 or module 2

Degree programmes:
Solar System Physics (BPO 2023) (Master)

Comment on allocation: ---

Module name: **Scientific Key Qualifications**						Module number: **PHY-IGeP-44**	
Institution: Institut für Geophysik und Extraterrestrische Physik						Module abbreviation: **FP-SKQ**	
Workload:	300 h	Attendance time:	84 h	Semester:	1		
Credit points:	10	Independent study:	216 h	Number of semesters:	2		
Compulsory form:	mandatory			Sem. hours / week:	6		

Courses/Main topics:
Scientific Programming
Scientific Communication

Attendance logic (if alternative selection, etc.):
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Lecturers:
Prof. Dr. Andreas Hördt
Prof. Dr. Ferdinand Plaschke
Prof. Dr. Jürgen Blum
Prof. Dr. Jessica Agarwal
N.N. (Theoretical Physics)
Prof. Dr. Matthias Bücker

Qualifications aims:
The students
- can solve numerical problems efficiently with the help of self-created programs.
- can analyse extensive data sets with the help of self-created programs.
- can visualise the results of their analyses and model calculations in an appealing way
- can carry out scientific searches
- can communicate specialised knowledge in writing.
- can communicate specialised knowledge in the form of lectures.
- can communicate in a team.

Contents:
Scientific programming and scientific communication are part of the scientific key qualifications. During the course “Scientific Programming” the students should learn modern simulations, modelling and data analysis techniques. The course “Scientific Communication” has two central aspects: 1. The communication of scientific content to the scientific community, e.g. writing of publication, presenting results, and communication within a team. 2. Communication of scientific content to the general public.

Forms of learning:
Lectures, exercises, internship, seminar

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: Creation and Documentation of a Computer or Software Programme
(b) Examination: oral presentation

Turnus (beginning):
Each semester

Responsible for the module:
Plaschke

Language:
English

Media forms:
Blackboard-, smartboard-, tablet lecture, projector, electronic handouts

Literature:

Explanatory comment:

Categories (module groups):
Research phase

Requirements for this module:

Degree programmes: Solar System Physics (BPO 2023) (Master)
Comment on allocation: ---

Module name: **Literature Research**					Module number: **PHY-IGeP-45**
Institution: Institut für Geophysik und Extraterrestrische Physik					Module abbreviation: **FP-LR**
Workload:	150 h	Attendance time:	28 h	Semester:	3
Credit points:	5	Independent study:	122 h	Number of semesters:	1
Compulsory form:	mandatory			Sem. hours / week:	2

Courses/Main topics:
Oberseminar Geo- und Astrophysik (OS)
Seminar Angewandte Geophysik (S)
Seminar Sonnensystemastronomie (S)
Seminar Planetenentstehung und kleine Körper (S)
Seminar Weltraumphysik und –sensorik (S)

Attendance logic (if alternative selection, etc.):

Lecturers:
Prof. Dr. Andreas Hördt
Prof. Dr. Ferdinand Plaschke
Prof. Dr. Jürgen Blum
Prof. Dr. Jessica Agarwal
N.N. (Theoretical Physics)
Prof. Dr. Matthias Bücker

Qualifications aims:
The students
- are able to assess the state of the art in a field of solar system research.
- can read scientific papers in a goal-oriented manner and reproduce the essential contents in their own words.
- are able to structure and organise their own research work.
- are able to present the results of their own work to an expert audience in written and oral form in a professional manner.

Contents:
The module encompasses various techniques to conduct literature research. These techniques involve utilising literature databases, managing literature references in conjunction with a word processing program, and the generation of comprehensive literature lists. In addition, current scientific research of the working groups of the participating institutes is presented and discussed in subject-specific seminars. In doing so, the students learn to follow the content of oral presentations and to discuss them critically. The students also learn how to create meaningful scientific illustrations, prepare and give their won presentations, and engage in critical discussions about their own results. Likewise, students learn to prepare their own technical and scientific activities and to place them in an overall scientific context.

Forms of learning:
Seminar

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: oral presentation

Turnus (beginning):
Each semester

Responsible for the module:
Hördt

Language:
English

Media forms:
Blackboard lecture, oral presentation

Literature:
Depending on the topic of the Master’s thesis.

Explanatory comments:

Categories (module groups):
Research phase

Requirements for this module:

Degree programmes: Solar System Physics (BPO 2023) (Master)
Comment on allocation: ---

Module name: **Research Internship**					Module number: **PHY-IGeP-46**
Institution: Institut für Geophysik und Extraterrestrische Physik					Module abbreviation: **FP-RI**
Workload:	450 h	Attendance time:	400 h	Semester:	3
Credit points:	15	Independent study:	50 h	Number of semesters:	2
Compulsory form:	mandatory			Sem. hours / week:	15

Courses/Main topics:
- Oberseminar Geo- und Astrophysik (OS)
- Seminar Angewandte Geophysik (S)
- Seminar Sonnensystemastronomie (S)
- Seminar Planetenentstehung und kleine Körper (S)
- Seminar Weltraumphysik und –sensorik (S)
- Forschungspraktikum (P)

Attendance logic (if alternative selection, etc.):
The research internship and one of the seminars offered are studied.

Lecturers:
Prof. Dr. Andreas Hördt
Prof. Dr. Ferdinand Plaschke
Prof. Dr. Jürgen Blum
Prof. Dr. Jessica Agarwal
N.N. (Theoretische Physik)
Prof. Dr. Matthias Bücker

Qualifications aims:
The students acquire experimental and theoretical skills to carry out research. In close contact with the chosen research group, the students lay the technical and experimental foundations for their future master projects. They acquire the skills to independently carry out experiments or theoretical investigations that are relevant for the thesis project. They acquire the skills to professionally present their own work and results in a scientific context.

Contents:
10-week internship on a research topic in solar system physics [in mutual understanding with the master thesis advisor] to familiarise themselves with the theoretical and experimental methods required to carry out the thesis project. For experimental work this includes mainly pre-experiments in the context of the future thesis project, design of components for the experiments, construction of experimental set-ups, ordering of hardware components, and shadowing visits to on-going experiments in the research group. For a theory-based project, students will familiarise themselves with relevant software packages, the development of small pieces of software, test calculations and shadowing visits to the on-going work in the research group. Also attendance of so-called summer- or winter-schools (e.g., the ESA academy) and studies abroad can become part of this module.

Forms of learning:
Project work

Examination modalities / Requirements for the award of credit points:
(a) Study achievement: successful execution of the research internship
(b) Examination: oral presentation on the contents and objectives of the Master's thesis

Turnus (beginning):
Each semester

Responsible for the module:
Agarwal

Language:
English

Media forms:

Literature:
The required literature is specified by the supervisor.

Explanatory comment:

Categories (module groups):
Research phase

Requirements for this module: ---
Degree programmes: Solar System Physics (BPO 2023) (Master)
Comment on allocation: ---

Module name: **Master Thesis**					Module number: **PHY-IGeP-47**
Institution: Studiendekanat Physik					Module abbreviation: **FP-MT**
Workload:	900 h	Attendance time:	30 h	Semester:	3
Credit points:	30	Independent study:	870 h	Number of semesters:	2
Compulsory form:	mandatory			Sem. hours / week:	0

Courses/Main topics:
- Betreuung von Masterarbeiten - Agarwal
- Betreuung von Masterarbeiten - Blum
- Betreuung von Masterarbeiten - Bücker
- Betreuung von Masterarbeiten - Hördt
- Betreuung von Masterarbeiten - Plaschke
- Betreuung von Masterarbeiten – N.N. (Theoretical Physics)

Attendance logic (if alternative selection, etc.):
It is recommended to start the Master's thesis only after completion of the other course belonging to the Master's programme.

Lecturers:
Lecturers of the Physics department

Qualifications aims:
The students are able to work on a topic in the field of solar system physics under guidance using scientific methods within a given time limit. In doing so, they show that they understand technical correlations and can expand scientific knowledge boundaries. They can present and assess the procedure and results in the form of a paper. The students can organise their own scientific project.

Contents:
Independent work (under supervision) on a topic from the field of solar system physics using scientific methods and writing of a scientific thesis within a given deadline. The contents depend on the topic of the thesis and lie in the field of experimental and theoretical solar system physics.

Forms of learning:
Independent but supervised academic work; structured supervision meetings

Examination modalities / Requirements for the award of credit points:
Examination: Master Thesis

Turnus (beginning):
Each semester

Responsible for the module:
Office of the Dean of Studies in Physics

Language:
English

Media forms:

Literature:
To be determined individually with the supervisor of the Master's thesis.

Explanatory comment:
The Master's thesis includes working independently on a scientific topic and writing a scientific paper on the results within a period of eight months. The period is calculated from the issue of the topic the submission of the thesis. The Master' thesis must be written in English; other languages may be approved by the examination board upon application.

Categories (module groups):
Research phase

Requirements for this module:

Degree programmes:
Solar System Physics (BPO 2023) (Master)

Comment on allocation:
