Curriculum für das Masterstudium

Physics

Curriculum 2017 in der Version 2023

Dieses Curriculum wurde vom Senat der Karl-Franzens-Universität Graz in der Sitzung vom 17.05.2023 und vom Senat der Technischen Universität Graz in der Sitzung vom 22.05.2023 genehmigt.

Das Studium ist als gemeinsames Studium (§ 54e UG) der Karl-Franzens-Universität Graz (Uni Graz) und der Technischen Universität Graz (TU Graz) im Rahmen von „NAWI Graz" eingerichtet. Rechtsgrundlagen für dieses Studium sind das Universitätsgesetz (UG) sowie die Studienrechtlichen Bestimmungen der Satzungen der Uni Graz und der TU Graz in der jeweils geltenden Fassung.

Inhaltsverzeichnis:

I Allgemeines

§ 1. Gegenstand des Studiums und Qualifikationsprofil

Das naturwissenschaftliche Masterstudium Physics umfasst vier Semester. Der Gesamtumfang beträgt 120 ECTS-Anrechnungspunkte.

Das Masterstudium Physics wird als fremdsprachiges Studium in englischer Sprache durchgeführt.

Absolvent*innen dieses Studiums wird der akademische Grad „Master of Science“, abgekürzt „MSc“, verliehen.

(1) Gegenstand des Studiums

Das englischsprachige Masterstudium Physics an der Karl-Franzens-Universität Graz und der Technischen Universität Graz vermittelt eine naturwissenschaftliche Ausbildung im Fach Physik, welche eine besondere Breite des Fächerkanons anbietet, aus dem die Studierenden individuelle Schwerpunkte setzen können.

(2) Qualifikationsprofil und Kompetenzen

Das Ausbildungsziel des NAWI Graz Masterstudiums Physics (an der Karl-Franzens-Universität Graz und der Technischen Universität Graz) ist international wettbewerbsfähige Absolvent*innen heranzubilden, die befähigt sind, flexibel zukünftige Problemlösungen im physikalischen / naturwissenschaftlichen Bereich zu bewältigen. Dies wird durch eine Kombination aus fundierter allgemeiner Physikausbildung und Anwendungsnähe zusammen mit der Möglichkeit der individuellen Vertiefung erreicht. Dadurch können Absolvent*innen des Masterstudiums Physics in verschiedenen Berufsfeldern erfolgreich tätig werden und selbstverantwortlich wirken.

Die Studierenden des Masterstudiums Physics erhalten eine anspruchsvolle physikalisch-mathematische Ausbildung im Allgemeinen und können eine der folgenden fünf Vertiefungsrichtungen wählen: „Atmospheric Physics and Climate“, „Astrophysics“, „Experimental Physics”, “Space Physics and Aeronomy“, “Theoretical and Computational Physics“. Neben diesen vorgeschlagenen Vertiefungsrichtungen können die Studierenden flexibel ihre Module zusammenstellen und auf Wunsch individuelle Vertiefungsrichtungen genehmigt bekommen, um für zukünftige Anforderungen bestens vorbereitet zu sein.

Absolvent*innen dieses Studiums

- haben die im Bachelorstudium erworbenen Fähigkeiten vertieft und weiterentwickelt,
- sind mit Teilgebieten der aktuellen physikalischen Forschung vertraut und können diese reflektieren,
- können komplexe Problemstellungen durch Anwendung von physikalisch-mathematischen Methoden selbstständig bewältigen,
- weisen einen hohen Grad an analytischem Denkvermögen auf,
- besitzen ein hohes Maß an Teamfähigkeit, welches im Rahmen von Projektarbeiten vertieft geschult wurde,

- sind versiert im Umgang mit theoretischen, experimentellen bzw. computerbasierten Methoden zur Problemlösung,
- sind in der Lage die Ergebnisse ihrer Arbeit nach außen, sowohl an andere Experten als auch an Laien, zu kommunizieren,
- beherrschen die englische Fachsprache in einem sehr guten Ausmaß und sind zusammen mit dem international gebräuchlichen Titel „Master of Science" besonders wettbewerbsfähig im internationalen Kontext,
- qualifizieren sich für die selbstbestimmte und autonome Weiterführung ihrer Studien z.B. im Rahmen eines PhD/Doktoratstudiums.

(3) Bedarf und Relevanz des Studiums für die Wissenschaft und für den Arbeitsmarkt

Die Absolvent*innen mit einer einerseits breiten aber auch individuell vertieften Ausbildung, wie unter (2) angeführt, sind befähigt, in einer Reihe unterschiedlicher Berufsfelder im In- und Ausland tätig zu werden. Daher dienen sie im wissenschaftlichen, wirtschaftlichen und industriellen Bereich als hochqualifizierte Fachkräfte.

Die Absolvent*innen verfügen sowohl über ausgezeichnete Fachqualifikationen als auch über jene wertvolle häufig als „Physikalische Denkweise" bezeichnete personale Kernkompetenz, die sich aus einer Kombination von solidem naturwissenschaftlichen Wissen, Vertrautheit mit praktischen Methoden (experimentell, theoretisch und computerorientiert), hohem analytischen Denkvermögen und ausgeprägter Problemlösungsfähigkeit ergibt. Dadurch stellen die Absolvent*innen jene gesuchten Kräfte dar, welche flexibel und fachübergreifend für neu entstehende Aufgabenbereiche einsetzbar sind. Darüber hinaus findet physikalisches Arbeiten praktisch nur mehr in Arbeitsgruppen statt, wodurch die Teamfähigkeit besonders entwickelt wird. Durch dieses breite Kompetenzspektrum sind die Absolvent*innen vor allem für die nachstehend angeführten Berufsfelder im In- und Ausland bestens qualifiziert:

- Mitarbeit und Leitungsfunktion an öffentlichen/privaten Forschungs- und Bildungseinrichtungen im physikalisch-technischen Bereich
- Mitarbeit an großen internationalen Forschungskollaborationen
- Modellierung und Simulation im wissenschaftlichen, technischen und wirtschaftlichen Bereich
- Algorithmenentwicklung in diversen Fachgebieten
- Mitarbeit und Leitungspositionen in Forschungs- und Entwicklungsabteilungen diverser Industriebereiche, besonders der Hightech-Industrie
- Führungspositionen in der Verwaltung und Logistik
- Unternehmensberatung
- Tätigkeiten in der Qualitätskontrolle
- Beratungsorgan im naturwissenschaftlich-technischen Bereich

II Allgemeine Bestimmungen

§ 2. Zulassungsbedingungen:

(1) Das Masterstudium „Physics" baut auf dem im Rahmen von NAWI Graz angebotenen Bachelorstudium „Physik" auf. Dieses Studium erfüllt jedenfalls die Zulassungsvoraussetzungen für das Masterstudium „Physics". Zusätzlich dazu sind folgende Vorstudien fachlich in Frage kommend:

- Bachelorstudien der Physik und der Technischen Physik, welche an Universitäten aus einem der folgenden Länder absolviert wurden: Belgien, Bulgarien, Dänemark, Deutschland, Estland, Finnland, Frankreich, Griechenland, Irland, Italien, Island, Kroatien, Lettland, Lichtenstein, Litauen, Luxemburg, Malta, Niederlande, Norwegen, Österreich, Polen, Portugal, Rumänien, Schweden, Schweiz, Slowakei, Slowenien, Spanien, Tschechien, Ungarn, Vereinigtes Königreich und Zypern.

(2) Studien, die nicht unter Abs. 1 genannt werden, sind fachlich in Frage kommend, wenn aus den folgenden Fachbereichen insgesamt mindestens 105 ECTS-Anrechnungspunkte positiv absolviert wurden:

- 35 ECTS-Anrechnungspunkte aus Experimentelle Physik
- 30 ECTS-Anrechnungspunkte aus Theoretische Physik
- 35 ECTS-Anrechnungspunkte aus Mathematik
- 5 ECTS-Anrechnungspunkte aus Programmierung

(3) Studien, die nicht unter Abs. 1 oder Abs. 2 fallen, weisen wesentliche fachliche Unterschiede auf. Diese können durch Ergänzungsprüfungen ausgeglichen werden, wenn aus den in Abs. 2 genannten Fachbereichen mindestens 75 ECTS-Anrechnungspunkte absolviert wurden. Im Rahmen dieser Ergänzungsprüfungen können maximal 30 ECTS-Anrechnungspunkte vorgeschrieben werden.

(4) Bei Studien, die nicht unter Abs. 1 bis Abs. 3 fallen, bestehen wesentliche fachliche Unterschiede, die nicht ausgeglichen werden können. In diesem Fall ist die Zulassung zum Masterstudium „Physics" nicht möglich.

(5) Als Voraussetzung für die Zulassung zum Studium ist die für den erfolgreichen Studienfortgang erforderliche Kenntnis der englischen Sprache nachzuweisen. Die Form des Nachweises ist in einer Verordnung des Rektorats festgelegt.

§ 3. Zuteilung von ECTS-Anrechnungspunkten

Allen von den Studierenden zu erbringenden Leistungen werden ECTS-Anrechnungspunkte zugeteilt. Mit diesen ECTS-Anrechnungspunkten ist der relative Anteil des mit den einzelnen Studienleistungen verbundenen Arbeitspensums zu bestimmen, wobei das Arbeitspensum eines Jahres 1500 Echtstunden zu betragen hat und diesem Arbeitspensum 60 ECTS-Anrechnungspunkte zugeteilt werden (entsprechend einem Umfang von 25 Echtstunden je ECTS-Anrechnungspunkt). Das Arbeitspensum umfasst den Selbststudienanteil und die Semesterstunden. Eine Semesterstunde entspricht 45 Minuten pro Unterrichtswoche des Semesters.

§ 4. Gliederung des Studiums

Das Masterstudium Physics mit einem Arbeitsaufwand von 120 ECTS-Anrechnungspunkten umfasst vier Semester und ist wie folgt modular strukturiert:

	ECTS
Pflichtmodul G: General Physics	15
Pflichtmodul M: Preparation for the Master's Thesis	14
5 Vertiefungsmodule (je 9 ECTS-Anrechnungspunkte)	45
Elective Topics	9
Free Electives	6
Master's Thesis	30
Masterprüfung	1
Summe	120

§ 5. Lehrveranstaltungstypen

Lehrveranstaltungenstypen, die an der Uni Graz und an der TU Graz angeboten werden, sind den Satzungen der Universitäten geregelt.

§ 6. Gruppengrößen

Bei den nachfolgenden Lehrveranstaltungstypen werden folgende maximale Teilnehmendenzahlen (Gruppengrößen) festgelegt:

(1) Für Übungen (UE) und für Übungsanteile von Vorlesungen mit integrierten Übungen (VU) ist die maximale Gruppengröße 25. Entspricht der Übungsanteil der VU einer Laborübung, dann ist die maximale Gruppengröße für den Übungsanteil 6.

(2) Für Laborübungen (LU) und Privatissima (PV) ist die maximale Gruppengröße 6.

(3) Für Projekte (PT), Seminare (SE) und Exkursionen (EX) ist die maximale Gruppengröße 20.

§ 7. Richtlinien zur Vergabe von Plätzen für Lehrveranstaltungen

(1) Melden sich mehr Studierende zu einer Lehrveranstaltung an, als verfügbare Plätze vorhanden sind, dann erfolgt die Aufnahme der Studierenden nach dem folgenden Reihungsverfahren, wobei die einzelnen Kriterien in der angegebenen Reihenfolge anzuwenden sind:

a. Stellung der Lehrveranstaltung, im Curriculum (gem. §§ 8 und 9): Die Lehrveranstaltung ist im Curriculum, für das die Lehrveranstaltungsanmeldung erfolgt, in den Pflicht- oder Wahlmodulen vorgeschrieben. Diese Lehrveranstaltungen werden gleichrangig gereiht und jeweils gegenüber dem Freien Wahlfach bevorzugt.

b. Im Studium absolvierte/anerkannte ECTS-Anrechnungspunkte: Für die ECTS-Reihung werden alle Leistungen des Studiums, für das die Lehrveranstaltungsanmeldung erfolgt, herangezogen. Eine höhere Gesamtsumme wird bevorzugt gereiht.

c. Bisher benötigte Semesteranzahl im Studium: Reihung, nach der Anzahl der bisher benötigten Semester innerhalb des Studiums. Eine höhere Anzahl wird bevorzugt gereiht.

d. Losentscheid: Ist anhand der vorangehenden Kriterien keine Reihungsentscheidung möglich, entscheidet das Los.

(2) An Studierende, die im Rahmen von Mobilitätsprogrammen einen Teil ihres Studiums an den an NAWI Graz beteiligten Universitäten absolvieren, werden vorrangig bis zu 10% der vorhandenen Plätze vergeben.

III Studieninhalt und Studienablauf

§ 8. Module, Lehrveranstaltungen und Semesterzuordnung

Die einzelnen Lehrveranstaltungen dieses Masterstudiums und deren Gliederung in Pflicht- und Wahlmodule sind nachfolgend angeführt. Die in den Modulen zu vermittelnden Kenntnisse, Methoden oder Fertigkeiten werden in Anhang I näher beschrieben. Die Zuordnung der Lehrveranstaltungen zur Semesterfolge ist eine Empfehlung und stellt sicher, dass die Abfolge der Lehrveranstaltungen optimal auf Vorwissen aufbaut und das Arbeitspensum des Studienjahres 60 ECTS-Anrechnungspunkte nicht überschreitet. Die Zuordnung der Lehrveranstaltungen zu den beteiligten Universitäten erfolgt in Anhang II und § 9.

Masterstudium Physics							
Modul / **Lehrveranstaltung**	**SSt.**	**LV Typ**	**ECTS**	**Semester mit ECTS-Anrechnungspunkten**			
				I	**II**	**III**	**IV**
Pflichtmodul G: General Physics							
Statistical Physics[1]	2	VO	4	4			
Statistical Physics[1]	1	UE	2	2			
Advanced Quantum Mechanics[1]	2	VO	4	4			
Advanced Quantum Mechanics[1]	1	UE	2	2			
Introduction to General Relativity and Cosmology	2	VO	3	3			
Zwischensumme Pflichtmodul G	**8**		**15**	**15**			
Pflichtmodul M: Preparation for the Master's Thesis							
Zwischensumme Pflichtmodul M			14			12	2
Summe Pflichtmodule			**29**	**15**		**12**	**2**
5 Vertiefungsmodule (je 9 ECTS)			45	12	18	15	
Elective Topics			9		6	3	
Summe Wahlmodule lt. § 9			**54**	**12**	**24**	**18**	
Master's Thesis			**30**				30
Masterprüfung			**1**				1
Free Electives lt. § 10			**6**	3	3		
Summe Gesamt			**120**	**30**	**27**	**30**	**33**

[1]: gemeinsame Abhaltung mit Masterstudium „Technical Physics"

Modul M: Preparation for the Master's Thesis

Das Modul M dient der Vorbereitung der Master's Thesis und muss thematisch mit der Master's Thesis zusammenhängen. Es wird in der untenstehenden Tabelle definiert.

Modul M: Preparation for the Master's Thesis							
Modul / Lehrveranstaltung	SSt.	LV Typ	ECTS	Semesterzuordnung WS	SS	Uni-Graz[1]	TU-Graz[1]
Modul M0: **Preparation for the Master's Thesis**							
Practical Training in the Area of the Master's Thesis[2]	4	LU/PT	10	X	X	X	
Tutorial in the Area of the Master's Thesis[2]	2	PV	2	X	X	X	
Master's Seminar in the Area of the Master's Thesis[2]	2	SE	2		X	X	

[1]: Zuordnung der Lehrveranstaltung zu den beteiligten Universitäten. Beide Universitäten sind genannt, wenn die Lehrveranstaltung von beiden Universitäten gemeinsam, parallel oder im Wechsel angeboten wird.

[2]: Diese Lehrveranstaltungen können auch mit einem Untertitel, der das Fachgebiet der Master's Thesis näher beschreibt, angeboten werden.

Wird die Master's Thesis in einem der Bereiche Astrophysics, Atmospheric Physics and Climate, oder Space Physics and Aeronomy verfasst, dann gilt abweichend folgende Festlegung für das Modul M:

Modul M: Preparation for the Master's Thesis in …							
Modul / Lehrveranstaltung	SSt.	LV Typ	ECTS	Semesterzuordnung WS	SS	Uni-Graz[1]	TU-Graz[1]
Modul M1: **Preparation for the Master's Thesis in Astrophysics**							
Data Analysis in Astrophysics[2]	3	VO	4	X		X	
Data Analysis in Astrophysics[2]	2	UE	3	X		X	
Selected Problems in Astrophysical Data Analysis[2]	2	SE	3		X	X	
Tutorial for Master's Students in Astrophysics	2	PV	2	X	X	X	
Master's Seminar in Astro- and Space Physics	2	SE	2		X	X	
Modul M2: **Preparation for the Master's Thesis in Atmospheric Physics and Climate**							
Field Course Atmospheric and Climate Physics[2]	3	PT	6		X	X	
Climate and Environmental Change – Current Research Topics	2	SE	3		X	X	
Selected Topics in Atmospheric and Climate Physics[2]	2	SE/VO	3		X	X	
Tutorial for Master's Students in Atmospheric Physics and Climate	2	PV	2	X	X	X	
Modul M3: **Preparation for the Master's Thesis in Space Physics and Aeronomy**							
Practical Training in Space Physics and Aeronomy[2]	3	PT	7	X		X	
Master's Seminar in Astro- and Space Physics	2	SE	2		X	X	
Selected Topics in Space Physics and Aeronomy	2	SE/VO	3		X	X	
Tutorial for Master's Students in Space Physics and Aeronomy	2	PV	2	X	X	X	

[1]: Zuordnung der Lehrveranstaltung zu den beteiligten Universitäten. Beide Universitäten sind genannt, wenn die Lehrveranstaltung von beiden Universitäten gemeinsam, parallel oder im Wechsel angeboten wird.

[2]: Diese Lehrveranstaltung wird im Zweijahresrhythmus angeboten.

§ 9. Wahlmodule

(1) Vertiefungsrichtungen

Auf Wunsch der/des Studierenden kann eine der unten aufgelisteten Vertiefungsrichtungen im Masterzeugnis ausgewiesen werden. Dazu müssen die Master’s Thesis und das Vorbereitungsmodul M fachlich dieser Vertiefungsrichtung entsprechen, sowie Vertiefungsmodule (siehe § 9 Abs. 3) entsprechend folgender Auflistung absolviert werden:

- **Astrophysics**: Module A1, A2, A3, A4, A5.
- **Atmospheric Physics and Climate:** Module C1, C2, C3, C4, C5.
- **Experimental Physics:** Mindestens 3 Module aus E1, E3, E4, E5, E7, wobei E4 und E5 nicht gemeinsam gewählt werden können.*
- **Space Physics and Aeronomy:** Module S1, S2, S3, S4, C2.
- **Theoretical and Computational Physics:** Module T1, T2, T3.

Eine andere als hier aufgelistete Vertiefungsrichtung kann vom studienrechtlichen Organ auf Antrag der/des Studierenden genehmigt werden, wobei eine entsprechende Liste an Vertiefungsmodulen festzulegen ist.

(2) Mentoring

Als Hilfestellung für die individuelle Zusammenstellung der Vertiefungsmodule wird den Studierenden empfohlen, mit einer zu wählenden Mentorin / einem zu wählenden Mentor im Laufe des ersten Semesters ein Gespräch abzuhalten. Dadurch soll ein optimaler Studienverlauf für die Studierenden gewährleistet werden. Eine Liste potentieller Mentorinnen und Mentoren aus dem Kreis der Lehrenden wird den Studierenden über die Webseiten der Physikinstitute bzw. der Studienvertretung zugänglich gemacht.

* Hiervon ausgenommen sind Studierende, die bei Inkrafttreten dieses Curriculums bereits Prüfungen zu diesen beiden Modulen erfolgreich abgelegt haben.

(3) Vertiefungsmodule

Es sind 5 Vertiefungsmodule zu je 9 ECTS-Anrechnungspunkten zu absolvieren. In jedem der gewählten Module sind die mit (♦) gekennzeichneten Lehrveranstaltungen verpflichtend zu absolvieren.

Vertiefungsmodule								
Modul / Lehrveranstaltung			LV		Semesterzuordnung		Uni-Graz[1]	TU-Graz[1]
		SSt.	Typ	ECTS	WS	SS		
Modul A1: **Stellar Astrophysics**								
♦	Stellar Structure and Evolution[2]	3	VO	4		X	X	
♦	Stellar Structure and Evolution[2]	1	UE	2		X	X	
♦	The Galaxy and Extragalactic System[2]	2	VO	3	X		X	
Modul A2: **Theoretical Astrophysics**								
♦	The Physics of Stellar Atmospheres[2]	3	VO	4	X		X	
♦	The Physics of Stellar Atmospheres[2]	1	UE	2	X		X	
♦	Magneto-hydrodynamics and Solar-terrestrial Modeling[2]	2	VO	3		X	X	
Modul A3: **Physics of the Solar System**								
♦	Introduction to Solar Physics[2]	2	VO	3		X	X	
♦	Introduction to Solar Physics[2]	1	UE	2		X	X	
♦	Solar Physics Lab Tour	1	EX	1		X	X	
♦	Introduction to Planetology[2]	2	VO	3	X		X	
Modul A4: **Observing Techniques in Astrophysics**								
♦	Instrumentation and Observing Techniques in Astrophysics[2]	2	VO	3	X		X	
♦	Astrophysics Lab	2	LU[4]	3	X		X	
♦	Astrophysical Seminar[2]	2	SE	3		X	X	
Modul A5: **Selected Topics in Astrophysics**								
	Exoplanets and Astrobiology[2]	2	VO	3		X	X	
	Introduction to Space Plasma Physics	2	VO	3	X		X	
	Astrophysics Lab 2[2]	2	LU[4]	3		X	X	
	Hydrodynamics[2]	2	VO	3		X	X	
	Sun and Space Weather[2]	2	VO	3	X		X	
	Advanced General Relativity and Quantum Gravity	2	VO	3		X	X	
	Astroparticle Physics[2]	2	VO	3		X	X	
	Further Lectures on Selected Astrophysical Topics[2]	2	VO/SE	3		X	X	
	Exoplanets and our place in the universe- an interdisciplinary approach	2	VO	3		X		X
Modul C1: **Principles of the Climate System**								
♦	Earth's Climate System and Climate Change	2	VO	3	X		X	
♦	Physical Oceanography, Hydrology and Climate[2]	2	VO	3		X	X	
♦	Paleoclimatology[2]	2	VO	3	X		X	

Vertiefungsmodule							
Modul / Lehrveranstaltung		LV		Semesterzu-ordnung		Uni-Graz[1]	TU-Graz[1]
	SSt.	Typ	ECTS	WS	SS		
Modul C2: **Data Analysis and Simulation**							
♦ Methods of Modeling and Simulation	4	VU	6	X		X	
♦ Time Series Analysis[2]	2	VO[8]	3		X	X	
Modul C3: **Atmospheric Physics**							
♦ Atmospheric Dynamics	2	VO[8]	3		X	X	
♦ Atmospheric Composition and Chem-istry	2	VO	3	X		X	
♦ Radiation and Energy Balance[2]	2	VO	3	X		X	
Modul C4: **Climate Physics**							
♦ Climate Modeling[2]	2	VO	3		X	X	
♦ Climate Dynamics[2]	2	VO[8]	3		X	X	
♦ Selected Topics in Climate Science	2	VO/SE	3	X		X	
Modul C5: **Atmosphere and Climate Measurement Methods**							
♦ Atmosphere and Climate Measure-ment Methods: Remote Sensing[2]	2	VO	3		X	X	
♦ Atmosphere and Climate Measure-ment Methods: in situ[2]	2	VO	3	X		X	
♦ Seminar on Atmosphere and Climate Measurement Methods[2]	2	SE	3		X	X	
Modul E1: **Surface Science: Basic Principles**							
♦ Research Laboratory Surface Science	2	LU[7]	3		X	X	X
Surface Science	2	VO	3	X		X	
Thin Film Science and Processing	2	VO	3		X		X
Modul E2: **Surface Science: Advanced Topics**							
Molecular Interfaces	2	VO	3		X	X	
Scanning Probe Techniques	2	VO	3		X	X	
Synchrotron Radiation Techniques	2	VO	3	X		X	
Surface Chemistry	2	VO	3		X		X
Vacuum Technology	2	VO	3	X		X	X
Special Topics in: „Surface Science“[2]	2	VO	3	X	X	X	
Modul E3: **Photon Science**							
♦ Research Laboratory Photon Science	2	LU[7]	3	X	X	X	X
Laser Spectroscopy	2	VO	3	X			X
Photonics: Light, Matter, and Time	2	VO	3		X		X
Structured Light and Nanoscale Wave Phenomena	2	VO	3	X		X	
Optical Waveguides, Photonic Cir-cuitry and Applications	2	VO	3		X	X	
Optical Measurement Techniques	2	VO	3	X			X
Modul E4: **Nano- and Laser-Optics** [5]							
♦ Optics - a Photonics Perspective	2	VO	3	X		X	
♦ Research Laboratory Nano and Laser Optics	2	LU[7]	3	X	X	X	X
Nano Optics	2	VO	3		X	X	
Laser Physics	2	VO	3	X		X	
Ultrafast Laser Physics	2	VO	3		X		X

Vertiefungsmodule							
Modul / Lehrveranstaltung		LV		Semesterzu-ordnung		Uni-Graz[1]	TU-Graz[1]
	SSt.	Typ	ECTS	WS	SS		
Modul E5: **Quantum Optics and Molecular Physics** [5]							
♦ Optics - a Spectroscopy Perspective	2	VO	3	X			X
♦ Research Laboratory Quantum Optics and Molecular Physics	2	LU[7]	3	X	X	X	X
Laser Physics	2	VO	3	X		X	
Ultrafast Laser Physics	2	VO	3		X		X
Quantum Optics	2	VO	3		X		X
Modelling of Molecular Systems	2	VO	3	X			X
Modul E6: **Nano and Quantum Matter**							
♦ Solid-State Physics: Size Effects and Quantum Phenomena	2	VO	3	X		X	
Modern Materials [2]	2	VO	3	X		X	
Theory of Superconductivity	2	VO	3	X			X
Phase Transitions and Critical Phe-nomena	2	VO	3	X			X
Theory of Magnetism and Collective Phenomena	2	VO	3	X			X
2D Materials	2	VO	3		X	X	
Modul E7: **Biological Applications**							
♦ Research Laboratory Biophysics	2	LU	3		X	X	
Molecular Biophysics 1	2	VO	3		X	X	
Molecular Biophysics 2	2	VO	3	X		X	
Biological and Biobased Materials	2	VO	3		X		X
Biophotonics	2	VO	3		X	X	
Theoretical Biophysics	2	VO	3	X			X
Soft Matter Physics	2	VO	3		X		X
Modul E8: **Industrial Applications**							
♦ Topics of Industrial Relevance	2	VO	3	X		X	
♦ Signal Theory and Signal Processing	2	VU[6]	3		X	X	X
Patent Law and Technology Transfer	2	VO	3		X	X	
Ultrasound Methods[2]	2	VO	3		X	X	
Thin Film Science and Processing	2	VO	3		X		X
Modelling and Simulations of Semi-conductors	2	VO	3		X		X
Modul S1: **Fundamentals of Space Physics and Aeronomy**							
♦ Introduction to Planetology[2]	2	VO	3	X		X	
♦ Introduction to Aeronomy[2]	2	VO	3	X		X	
♦ Introduction to Space Plasma Physics	2	VO	3	X		X	
Modul S2: **Solar and Heliospheric Physics**							
♦ Introduction to Solar Physics[2]	2	VO	3		X	X	
♦ Introduction to Solar Physics[2]	1	UE	2		X	X	
♦ Magneto-hydrodynamics and Solar-terrestrial Modeling[2]	2	VO	3		X	X	
♦ Solar Physics Lab Tour	1	EX	1		X	X	

Vertiefungsmodule							
Modul / Lehrveranstaltung		LV		Semesterzuordnung		Uni-Graz[1]	TU-Graz[1]
	SSt.	Typ	ECTS	WS	SS		
Modul S3: **Physics of Planetary Atmospheres and Magnetospheres**							
♦ Physics of Planetary Atmospheres[2]	2	VO	3		X	X	
♦ Earth and Planetary Magnetic Fields[2]	2	VO	3		X	X	
♦ Planetary Magnetospheres[2]	2	VO	3		X	X	
Modul S4: **Measurement Methods and Observing Systems**							
♦ Measurement Methods in Space Physics[2]	2	VO	3		X	X	
♦ Space Missions and Experiments Design[2]	2	VO	3		X	X	
♦ Seminar on Measurement Methods in Space Physics[2]	2	SE	3		X	X	
Modul T1: **Advanced Theoretical Physics 1**							
♦ Advanced Mathematical Methods	3	VO	4,5	X		X	
♦ Quantum Field Theory	3	VO	4,5		X	X	
Modul T2: **Advanced Theoretical Physics 2**							
♦ Advanced Quantum Mechanics 2	2	VO	3		X	X	
♦ Advanced Statistical Physics	2	VO	3	X		X	X
♦ Basic Concepts of Solid-State Theory	2	VO	3		X	X	
Modul T3: **Computational Physics**							
♦ Numerical Methods in Linear Algebra	2	VU[3]	3		X	X	
♦ Monte-Carlo Methods	2	VU[3]	3	X		X	
Computational Methods in Nano Physics	2	VU[3]	3		X	X	
Computational Methods in Particle Physics	2	VU[3]	3		X	X	
Quantum Computing	2	VO	3		X	X	
Modul T4: **Theoretical Solid-State Physics** [5]							
♦ Quantum Theory of Many-Body Systems	2	VU[3]	3		X	X	X
Fundamentals of Electronic Structure Theory	2	VO	3	X		X	X
Theory of Magnetism and Collective Phenomena	2	VO	3	X			X
Theory of Superconductivity	2	VO	3	X			X
Phase Transitions and Critical Phenomena	2	VO	3	X			X
Special Topics in: Theoretical Solid-State Physics	2	VO	3		X	X	
Modul T5: **Theoretical Nano Physics**							
Theoretical Nano- and Quantum Optics	2	VO	3		X	X	
Fundamentals of Electronic Structure Theory	2	VO	3	X		X	X
Quantum Computing	2	VO	3		X	X	
Computational Methods in Nano Physics	2	VU[3]	3		X	X	

Vertiefungsmodule							
Modul / Lehrveranstaltung		LV		Semesterzu-ordnung		Uni-Graz[1]	TU-Graz[1]
	SSt.	**Typ**	**ECTS**	**WS**	**SS**		
Modul T6: **Modelling of Materials** [5]							
♦ Fundamentals of Electronic Structure Theory	2	VO	3	X		X	X
♦ Simulating Materials Properties from First Principles	2	UE	3		X	X	X
Applications of Electronic Structure Methods	2	VO	3		X		X
Ab-initio Methods for Correlated Materials	2	VO	3	X			X
Advanced Electronic Structure Theory	2	VO	3		X	X	X
Modelling of Molecular Systems	2	VO	3	X			X
Modul T7: **Foundations of Particle Physics**							
♦ Quantum Field Theory 2: Gauge Theories	4	VU[3]	6		X	X	
Lattice Field Theory[2]	2	VO	3		X	X	
Computational Methods in Particle Physics	2	VU[3]	3		X	X	
Special Topics in: “Particle Physics”	2	VO	3		X	X	
Advanced Mathematical Methods 2[2]	2	VO	3		X	X	
Modul T8: **Phenomenology of Particle Physics**							
Standard Model	3	VO	4,5	X		X	
Beyond the Standard Model	3	VO	4,5	X		X	
Advanced General Relativity and Quantum Gravity[2]	2	VO	3		X	X	
Astroparticle Physics[2]	2	VO	3		X	X	
Experimental particle physics[2]	2	VO	3	X		X	
Collider phenomenology[2]	2	VO	3	X		X	
Project in: “Particle Physics”	2	PT	3		X	X	

[1]: Zuordnung der Lehrveranstaltung zu den beteiligten Universitäten. Beide Universitäten sind genannt, wenn die Lehrveranstaltung von beiden Universitäten gemeinsam, parallel oder im Wechsel angeboten wird.
[2]: Diese Lehrveranstaltung wird im Zweijahresrhythmus angeboten. Hier ist es sichergestellt, dass das Studium trotzdem innerhalb von vier Semestern absolviert werden kann.
[3]: 2/3 SSt./Vorlesungsteil, 1/3 SSt./Übungsteil.
[4]: Für diese LU beträgt die Gruppengröße 10.
[5]: Gemeinsames Modul im gegenständlichen Masterstudium „Physics“ und im Masterstudium „Technical Physics“.
[6]: 2/3 SSt./Vorlesungsteil (VO), 1/3 SSt./Übungsteil. Der Übungsanteil entspricht einer Laborübung.
[7]: Für diese LU beträgt die Gruppengröße 3.
[8]: Diese Lehrveranstaltung kann nach Maßgabe der vorhandenen Ressourcen auch als VU mit 2/3 SSt./Vorlesungsteil und 1/3 SSt./Übungsteil angeboten werden.

(4) Elective Topics

Das Modul „Elective Topics“ umfasst Lehrveranstaltungen im Ausmaß von 9 ECTS-Anrechnungspunkten.

Für die Elective Topics können folgende Lehrveranstaltungen gewählt werden:

- Lehrveranstaltungen aus dem Katalog der o.g. Vertiefungsmodule (§ 9 Abs. 3), die nicht bereits in den gewählten Vertiefungsmodulen verwendet wurden.
- Pflicht- und Wahllehrveranstaltungen des NAWI Graz Masterstudiums „Technical Physics“ unter Berücksichtigung der jeweiligen Anmeldevoraussetzungen, wenn sie nicht bereits in den gewählten Vertiefungsmodulen verwendet wurden.
- Lehrveranstaltungen zur Vertiefung einer Fremdsprache (nur Englisch oder Deutsch, wenn diese Sprache nicht die Muttersprache ist) in einem Umfang von bis zu 3 ECTS-Anrechnungspunkten.
- Lehrveranstaltungen aus dem nachfolgenden Katalog „Weitere Elective Topics“.
- Deutschsprachige Lehrveranstaltungen aus dem nachfolgenden Katalog „Bachelor Physik“ des NAWI Graz Bachelorstudiums Physik.

Lehrveranstaltungskatalog: Weitere Elective Topics							
Lehrveranstaltung		LV		Semesterzuordnung		Uni-Graz[1]	TU-Graz[1]
	SSt.	Typ	ECTS	WS	SS		
Advanced Mathematical Methods	1	UE	1,5	X		X	
Quantum Field Theory	1	UE	1,5		X	X	
Halbleiterphysik und Mikroelektronik[4]	2	VO	4		X	X	
Digitalelektronik[4]	1	VU[3]	2	X		X	
Journal Club[4]	2	PV	3	X		X	
Mechanische Fertigungstechniken[4]	1	VU[3]	2	X		X	
Physics of Sustainable Energy	2	VO	3	X			X
Weltraumplasmaphysik[2,4]	1	VO	2		X		X
Fortgeschrittene Weltraumplasmaphysik[2,4]	1	VO	2		X		X
Aktive Plasmaexperimente im Weltraum[2,4]	1	VO	2		X		X

[1]: Zuordnung der Lehrveranstaltung zu den beteiligten Universitäten. Beide Universitäten sind genannt, wenn die Lehrveranstaltung von beiden Universitäten gemeinsam, parallel oder im Wechsel angeboten wird.

[2]: Lehrveranstaltung wird im Zweijahresrhythmus angeboten.

[3]: 1/4 SSt./Vorlesungsteil, 3/4 SSt./Übungsteil. Der Übungsanteil entspricht einer Laborübung.

[4]: Abhaltung in deutscher Sprache.

Lehrveranstaltungskatalog: Bachelor Physik							
Lehrveranstaltung		LV		Semesterzuordnung		Uni-Graz[1]	TU-Graz[1]
	SSt.	Typ	ECTS	WS	SS		
Moderne Kapitel der experimentellen Physik[2]	2	VO	3		X	X	
Moderne Kapitel der theoretischen Physik[2]	2	VO	3		X	X	
Physikalische Grundlagen der Materialkunde[2]	3	VO	4,5		X		X
Kontinuumsphysik[2]	2	VU[3]	3		X		X
Kryotechnik, Vakuumtechnik und Analysemethoden[2]	3	VO	4,5		X		X
Einführung in die Astrophysik[2]	2	VO	3	X		X	
Einführung in die Geophysik[2]	2	VO	3		X	X	
Einführung in die Meteorologie und Klimaphysik[2]	2	VO	3	X		X	

[1]: Zuordnung der Lehrveranstaltung zu den beteiligten Universitäten. Beide Universitäten sind genannt, wenn die Lehrveranstaltung von beiden Universitäten gemeinsam, parallel oder im Wechsel angeboten wird.

[2]: Abhaltung in deutscher Sprache. Empfohlen für Studierende, die Physik nicht im NAWI-Bachelorstudium Physik absolviert haben.

[3]: 2/3 SSt./Vorlesungsteil, 1/3 SSt./Übungsteil

§ 10. Free Electives

(1) Die im Rahmen der Free Electives im Masterstudium Physics zu absolvierenden Lehrveranstaltungen dienen der individuellen Schwerpunktsetzung und Weiterentwicklung der Studierenden und können frei aus dem Lehrveranstaltungsangebot aller anerkannten in- und ausländischen Universitäten sowie aller inländischen Fachhochschulen und pädagogischen Hochschulen gewählt werden. Anhang III enthält eine Empfehlung für diese frei wählbare Lehrveranstaltungen.

(2) Sofern einer frei zu wählenden Lehrveranstaltung keine ECTS-Anrechnungspunkte zugeordnet sind, wird jede Semesterstunde (SSt.) dieser Lehrveranstaltung mit einem ECTS-Anrechnungspunkt bewertet. Sind solche Lehrveranstaltungen jedoch vom Typ Vorlesung (VO), so werden ihnen 1,5 ECTS-Anrechnungspunkte pro SSt. zugeordnet.

(3) Weiters besteht gemäß § 13 die Möglichkeit, eine berufsorientierte Praxis oder kurze Studienaufenthalte im Ausland im Rahmen der Free Electives zu absolvieren.

§ 11. Master’s Thesis

(1) Die Master’s Thesis dient dem Nachweis der Befähigung, wissenschaftliche Themen selbstständig sowie inhaltlich und methodisch korrekt zu bearbeiten. Die Aufgabenstellung der Master’s Thesis ist so zu wählen, dass für die Studierende oder den Studierenden die Bearbeitung innerhalb von sechs Monaten möglich und zumutbar ist.

(2) Das Thema der Master’s Thesis ist aus einem der physikalischen Pflicht- oder Wahlmodule zu entnehmen. Über Ausnahmen entscheidet das zuständige studienrechtliche Organ.

(3) Die Master's Thesis ist vor Beginn der Bearbeitung über das zuständige Dekanat unter Einbindung des zuständigen studienrechtlichen Organs anzumelden. Zu erfassen sind dabei das Thema, das Fachgebiet, dem das Thema zugeordnet ist, sowie die Betreuerin bzw. der Betreuer mit Angabe des Instituts.

(4) Für die Master's Thesis werden 30 ECTS-Anrechnungspunkte festgelegt.

(5) Die Master's Thesis ist in elektronischer Form zur Beurteilung einzureichen.

§ 12. Anmeldevoraussetzungen für Lehrveranstaltungen/Prüfungen

(1) Die Zulassungsvoraussetzung zur kommissionellen Masterprüfung ist der Nachweis der positiven Beurteilung aller Prüfungsleistungen gemäß §§ 8 und 9 sowie die positiv beurteilte Master's Thesis.

(2) Studierende, die Ergänzungsprüfungen für die Zulassung zum Masterstudium Physics absolvieren müssen, müssen diese vor der Teilnahme an Laborübungen (LU) und an Vorlesungen mit Übungen (VU) mit Laborübungsanteil positiv absolviert haben.

§ 13. Auslandsaufenthalte und Praxis

(1) Empfohlene Auslandsstudien:

Studierenden wird empfohlen, in ihrem Studium ein Auslandssemester zu absolvieren. Dafür kommen in diesem Masterstudium insbesondere das zweite und dritte Semester in Frage. Während des Auslandsstudiums absolvierte Module bzw. Lehrveranstaltungen werden bei Gleichwertigkeit vom Studienrechtlichen Organ anerkannt. Zur Anerkennung von Prüfungen bei Auslandsstudien wird auf § 78 Abs. 5 UG verwiesen (Vorausbescheid).

Ferner können auf Antrag an das zuständige studienrechtliche Organ auch die erbrachten Leistungen von kürzeren Studienaufenthalten im Ausland, wie beispielsweise die aktive Teilnahme an internationalen Sommer- bzw. Winterschulen, im Rahmen der Free Electives anerkannt werden.

(2) Praxis:

Im Rahmen der Free Electives besteht die Möglichkeit, eine berufsorientierte Praxis zu absolvieren.

Dabei entsprechen jeder Arbeitswoche im Sinne der Vollbeschäftigung 1,5 ECTS-Anrechnungspunkten. Als Praxis gilt auch die aktive Teilnahme an einer wissenschaftlichen Veranstaltung. Diese Praxis ist von den zuständigen studienrechtlichen Organen zu genehmigen und hat in sinnvoller Ergänzung zum Studium zu stehen.

IV Prüfungsordnung und Studienabschluss

§ 14. Prüfungsordnung

Lehrveranstaltungen werden einzeln beurteilt.

(1) Über Lehrveranstaltungen, die in Form von Vorlesungen (VO) abgehalten werden, hat die Prüfung über den gesamten Inhalt der Lehrveranstaltung zu erfolgen. Prüfungen können ausschließlich mündlich, ausschließlich schriftlich oder kombiniert schriftlich und mündlich erfolgen.

(2) Über Lehrveranstaltungen, die in Form von Vorlesungen mit integrierten Übungen (VU), Übungen (UE), Laborübungen (LU), Projekten (PT), Seminaren (SE) und Exkursionen (EX) abgehalten werden, erfolgt die Beurteilung laufend auf Grund von Beiträgen, die von den Studierenden geleistet werden und/oder durch begleitende Tests. Jedenfalls hat die Beurteilung aus mindestens zwei Beurteilungen von Teilleistungen zu bestehen.

(3) Besteht ein Modul aus mehreren Lehrveranstaltungen, die Lehrveranstaltungen entsprechen, so ist die Modulnote zu ermitteln, indem

   a. die Note jeder dem Modul zugehörigen Lehrveranstaltung mit den ECTS-Anrechnungspunkten der entsprechenden Lehrveranstaltung multipliziert wird,
   b. die gemäß lit. a. errechneten Werte addiert werden,
   c. das Ergebnis der Addition durch die Summe der ECTS-Anrechnungspunkte der Lehrveranstaltungen dividiert wird und
   d. das Ergebnis der Division erforderlichenfalls auf eine ganzzahlige Note gerundet wird. Dabei ist bei Nachkommawerten, die größer als 0,5 sind aufzurunden, sonst abzurunden.
   e. Eine positive Modulnote kann nur erteilt werden, wenn jede einzelne Lehrveranstaltung positiv beurteilt wurde.
   f. Lehrveranstaltungen, deren Beurteilung ausschließlich die erfolgreiche bzw. nicht erfolgreiche Teilnahme bestätigt, sind in diese Berechnung laut lit. a. bis d. nicht einzubeziehen.

(4) Regelungen zur Wiederholung von Teilleistungen bei Lehrveranstaltungen mit immanentem Prüfungscharakter sind im Satzungsteil Studienrecht festgelegt.

(5) Die kommissionelle Masterprüfung besteht aus

   - Präsentation der Master's Thesis (maximal 20 Minuten),
   - Verteidigung der Master's Thesis (Prüfungsgespräch),
   - einer mündlichen Prüfung über Themen aus dem Modul, dem die Master's Thesis zugeordnet ist, sowie aus einem weiteren Modul gemäß §§ 8 und 9, das thematisch nicht dem Thema der Master's Thesis zugeordnet ist.

   Die Module werden vom zuständigen studienrechtlichen Organ der Universität der Zulassung auf Vorschlag des Kandidaten festgelegt. Die Gesamtzeit der kommissionellen Masterprüfung beträgt im Regelfall 60 Minuten und hat 75 Minuten nicht zu überschreiten.

(6) Der Prüfungskommission der Masterprüfung gehören die Betreuerin bzw. der Betreuer der Master's Thesis und zwei weitere Mitglieder an, die nach Anhörung des Kandidaten vom zuständigen studienrechtlichen Organ nominiert werden. Den Vorsitz führt ein Mitglied der Prüfungskommission, welches nicht Betreuerin/Betreuer der Master's Thesis ist.

(7) Die Note dieser kommissionellen Prüfung wird von der Prüfungskommission festgelegt.

§ 15. Studienabschluss

(1) Mit der positiven Beurteilung der Lehrveranstaltungen aller Pflicht- und Wahlmodule, der Free Electives, der Master's Thesis und der kommissionellen Masterprüfung wird das Masterstudium abgeschlossen.

(2) Über den erfolgreichen Abschluss des Studiums ist ein Abschlusszeugnis auszustellen. Das Abschlusszeugnis über das Masterstudium Physics enthält:
   a. eine Auflistung aller Module (Prüfungsfächer) gemäß § 4 (inklusive ECTS-Anrechnungspunkte) und deren Beurteilungen. Hierbei wird nur die englische Bezeichnung des Moduls angeführt ohne Angabe des Modulkennbuchstaben, also etwa „General Physics“ oder „Stellar Astrophysics“ usw.,
   b. Titel und Beurteilung der Master's Thesis,
   c. die Beurteilung der abschließenden kommissionellen Masterprüfung,
   d. den Gesamtumfang in ECTS-Anrechnungspunkten der Free Electives gemäß § 10,
   e. die Gesamtbeurteilung.

V In-Kraft-Treten und Übergangsbestimmungen

§ 16. In-Kraft-Treten

Dieses Curriculum 2017 in der Version 2023 (UNIGRAZonline Version 2023W, TUGRAZonline Version 2023W) tritt mit dem 1. Oktober 2023 in Kraft.

Curriculum	Version	UNIGRAZonline Version	TUGRAZonline Version	Veröffentlicht im Mitteilungsblatt Uni Graz	Veröffentlicht im MItteilungsblatt TU Graz
2017	2023	2023W	2023W	31.05.2023	31.05.2023

§ 17. Übergangsbestimmungen

Studierende des Masterstudiums Physics, die bei Inkrafttreten der Änderung des Curriculums am 1.10.2023 dem Curriculum in der Version 2017 unterstellt sind, werden mit 1.10.2023 dem Curriculum in der vorliegenden Version 2023 unterstellt.

Anhang zum Curriculum des Masterstudiums Physics

Anhang I.

Modulbeschreibungen der Pflichtmodule

Modul G	**General Physics**
ECTS credit points	15
Subject content	♦ Statistical Physics: Introduction; probability; classical statistical physics (microcanonical, canonical and grand canonical ensembles, ideal gas, etc.); quantum statistics (density operator, ensembles, Bose-Einstein and Fermi-Dirac statistics, ideal Bose gas, black-body radiation, etc.) ♦ Advanced Quantum Mechanics: Scattering theory; non-relativistic quantum field theory (second quantisation); many-particle quantum theory; coupling to electromagnetic field; gauge invariance; addition of angular momenta; Wigner-Eckart theorem ♦ Introduction to General Relativity and Cosmology: Manifolds and tensors, Einstein-Hilbert action and Einstein equation; linearised gravity and gravitational waves; homogenous and isotropic (Friedmann-Robertson Walker) cosmology; Schwarzschild metric; Kerr metric; numerical relativity and nonlinear gravitational waves
Learning outcomes	After having participated successfully in the module, students are able to • understand the basic principles of statistical physics and of general relativity and cosmology; • apply advanced methods in quantum theory, and • perform successful standard-type calculations in these fields. After having completed the module, students have gained profound knowledge of • classical statistical physics; • some aspects of quantum statistics, and • some of the more advanced techniques in quantum physics, and some basic understanding of the most prominent physical effects in general relativity.
Teaching and learning activities and methods	Lectures, exercise courses
Previous knowledge expected	Theory courses at bachelor's level
Frequency of offer	Every year

Modul M0	**Preparation for the Master's Thesis**
ECTS credit points	14
Subject content	♦ Practical Training in the Area of the Master's Thesis: Participation in current research topics related to the planned Master's Thesis; working and solving problems in teams; training in required theoretical and/or practical tools; presentation of the results in short talks ♦ Tutorial in the Area of the Master's Thesis: Students are introduced to the current literature and methods of their planned Master's Thesis project. Discussion and short presentations of physical knowledge required for the planned master's theses ♦ Master's Seminar in the Area of the Master's Thesis: Presentation of the ongoing (thesis) work of the participating advanced MSc students (and PhD students), complemented by recent and ongoing work of further presenters (e.g. of scientific guests)
Learning outcomes	After having participated successfully in the module, students are able to • solve problems in research-related topics; • present the results in short talks, and • discuss recent advances in the research field connected to the Master's Thesis.
Teaching and learning activities and methods	The module consists of a practical project, a tutorial and a seminar.
Previous knowledge expected	None
Frequency of offer	Every year

Modul M1	**Preparation for the Master's Thesis in Astrophysics**
ECTS credit points	14
Subject content	♦ Tutorial and Seminars for Master's Students in Astrophysics: Discussions and guidance for ongoing Master's Thesis projects of the participating MSc students; solar and stellar physics, stellar-planetary relations; observations and modelling; scientific writing; presentation skills; scientific ethics; preparation for the Master's Thesis defence; future perspectives in science with a focus on research frontiers in astrophysics ♦ Data Analysis and Selected Problems in Astrophysics: Data handling and scientific data reduction, data analysis and interpretation; space-borne and ground-based observations; numerical modelling; independent investigations in the framework of scientific projects; presentation of project results; group discussions; current understanding of fundamental physical processes in astrophysics; preparation of results in the form of figures and written text to be used for scientific publications
Learning outcomes	After having participated successfully in the module, students are able to • perform scientific projects on observational data analysis and numerical modelling on physical processes in astrophysics; • handle (large) astrophysical data sets and reduce them properly; • design observing campaigns; • analyse, interpret, and critically examine derived results; • contribute to the debate on astrophysical processes; • contribute to the debate on emerging topics in atmospheric physics; • plan and structure scientific work by themselves; • participate constructively in scientific discussions and discourse; • adequately document the results of scientific work in written form; • provide valuable contributions when working as a member of a scientific team, and • process results to be presented in scientific talks. After having completed the module, students have gained knowledge of • data analysis and interpretation; • numerical modelling of astrophysical processes; • the current understanding of astrophysics and major problems in astrophysics to be solved in future research; • the fundamentals of astrophysics and research frontiers in astrophysics, and • thesis design and good scientific practices.
Teaching and learning activities and methods	The module consists of one practical course, one lecture, two seminars and one tutorial.
Previous knowledge expected	None
Frequency of offer	At least every two years, tutorial and master's seminar at least every year

Modul M2	Preparation for the Master's Thesis in Atmospheric Physics and Climate
ECTS credit points	14
Subject content	♦ Tutorial for Master's Students in Atmospheric Physics and Climate: The earth's climate system; physical climate mechanisms and geobiochemical cycles; climate modelling and prediction; anthropogenic climate change, global warming and current research topics in climate and environmental change; guidance for ongoing thesis work of the participating MSc students ♦ Field Course Atmospheric and Climate Physics: Field measurements of meteorological parameters and climate variables; campaign design, instrument setup and calibration; data storage and data transfer; data analyses and interpretation ♦ Current Research Topics and Selected Topics: Understanding of fundamental physical processes in the atmosphere and climate system; current research frontiers in atmospheric and climate physics
Learning outcomes	After having participated successfully in the module, students are able to • perform meteorological measurements outside of laboratory environments; • calibrate meteorological instruments and facilitate data storage and transmission; • design and implement measurement campaigns; • analyse and interpret measurement records; • contribute to the debate on climate and environmental change on a global and regional scale; • contribute to the debate on emerging topics in atmospheric physics; • plan and structure scientific work by themselves; • participate constructively in scientific discussions and discourse; • adequately document the results of scientific work in written form, and • provide valuable contributions when working as a member of a scientific team. After having completed the module, students have gained knowledge of • instrument setup and calibration; • the design and implementation of meteorological field campaigns; • data analysis and interpretation; • the climate system, future projections of climate change and research frontiers in climate and environmental research; • the fundamentals of atmospheric and climate physics and research frontiers in atmospheric and climate physics, and • thesis design and good scientific practices.
Teaching and learning activities and methods	The module consists of one practical course, two seminars and one tutorial.
Previous knowledge expected	None
Frequency of offer	At least every two years, tutorial at least every year

Modul M3	Preparation for the Master's Thesis in Space Physics and Aeronomy
ECTS credit points	14
Subject content	♦ <u>Tutorial for Master's Students: Space Physics and Aeronomy</u>: For example, cosmic rays: historical development; V. F. Hess. Primary/secondary cosmic rays; (Fermi) acceleration mechanism; spallation; energy spectrum; Forbush decrease; geophysical effects; Stoermer trajectories; CRAND; Van Allen belts; air shower; particle detectors; cosmic ray observatories; Cerenkov radiation; CERN; interpretation of data. Discussion and support of the current level of knowledge in the field of the Master's Thesis; teamwork ♦ <u>Practical Training in Space Physics and Aeronomy</u>: Analysis of data obtained from in situ and remote measurements from ongoing space missions: in situ measurement of space plasma; data processing and analysis (calibration); single and multi-point measurements; comparison of observational results with models and theory. Remote measurement of planetary/solar radio waves; development of dynamic spectra. Analysis and interpretation of radio spectra; radio wave generation mechanism; source region; wave polarisation; propagation. Comparison with models and theory ♦ <u>Master's Seminar and Selected Topics</u>: Presentation of the ongoing (thesies) work of the participating advanced MSc students (and PhD students), complemented by recent and ongoing work of further presenters (e.g. of scientific guests)
Learning outcomes	After having participated successfully in the module, students understand • the fundamental physics principles of in situ and remote measurements; • the sequence of data acquisition, processing and analysis (calibration), modelling and simulation, and • the basics regarding selected topics in space physics and aeronomy. Students have gained • competence in space science through knowledge of experiment performance, data acquisition, physical processes interpretation, modelling and simulation; • profound knowledge of scientific literature search, oral presentations, writing scientific reports and papers, and • experience in various forms of scientific work (single, teamwork with different roles of responsibility).
Teaching and learning activities and methods	Practical training, seminar, teamwork, tutorial, lecture
Previous knowledge expected	Knowledge of astrophysics, astronomy, physics, geophysics, electromagnetism, hydrodynamics, electronics, plasma physics, elementary particle physics, waves theory at bachelor's level
Frequency of offer	At least every two years, tutorial at least every year

Modulbeschreibungen der Vertiefungsmodule

Modul A1	**Stellar Astrophysics**
ECTS credit points	9
Subject content	♦ Stellar Structure and Evolution: Basic equations of stellar structure; thermonuclear fusion in stars; protostars; main sequence stars; post-main sequence stellar evolution; final stages of stellar evolution; circumstellar disks and formation of planets ♦ Exercises in Stellar Structure and Evolution: Training in the methods introduced in the associated lecture by solving problems related to stellar properties and stellar evolution ♦ The Galaxy and Extragalactic System: Composition and structure of the galaxy and extragalactic systems; galaxy clusters; galactic distance indicators
Learning outcomes	After having participated successfully in the module, students are able to • understand the structure and evolution of stars with different masses; • understand basic stellar structure equations; • obtain physical stellar parameters from observations; • understand the basic structure of the universe, and • apply the knowledge obtained after having passed the mandatory exercises.
Teaching and learning activities and methods	The module consists of two mandatory courses in which the theoretical concepts are taught. In the mandatory exercises, students use practical examples to train and apply their knowledge.
Previous knowledge expected	None
Frequency of offer	At least every two years

Modul A2	Theoretical Astrophysics
ECTS credit points	9
Subject content	♦ The Physics of Stellar Atmospheres: Theory of stellar atmospheres; stellar spectra and spectral classification; qualitative and quantitative analysis of stellar spectra; theoretical description of spectral line profiles and comparison with observations; stellar model atmospheres ♦ Exercises in Stellar Atmospheres: Training in the methods introduced in the associated lecture by solving problems related to the analysis of stellar spectra ♦ Magnetohydrodynamics and Solar-terrestrial Modelling: Basic magnetohydrodynamics (MHD) equations; magnetic reconnection; interaction of the solar wind with planetary atmospheres; solar-terrestrial relations
Learning outcomes	After having completed the module successfully, students are able to • analyse and interpret stellar spectra; • understand stellar model atmospheres and the physics behind them; • compare theoretical models with other models and observations, and • understand the basic concepts of MHD and apply them to the solar-terrestrial interactions.
Teaching and learning activities and methods	The module consists of two mandatory lectures where the theoretical concepts are taught and their relation to observations is discussed. In the mandatory exercises, stellar spectra are classified, numerical methods and models to describe stellar atmospheres are discussed, and the models are compared with observations.
Previous knowledge expected	None
Frequency of offer	At least every two years

Modul A3	Physics of the Solar System
ECTS credit points	9
Subject content	♦ <u>Introduction to Solar Physics</u>: The sun as a star; determination of basic physical parameters describing the sun and stars; solar interior structure; thermonuclear fusion in the solar core; solar neutrinos; helioseismology; solar atmosphere; phenomena of the quiet and the active sun; solar activity cycle; solar dynamo; solar wind; flares, coronal mass ejections; space weather ♦ <u>Exercises in Solar Physics</u>: Training in the methods introduced in the associated lecture by solving problems related to Solar Physics. ♦ <u>Solar Physics Lab Tour</u>: Excursion tour to Kanzelhöhe Observatory and practical to obtain an insight into state-of-the-art methods of ground-based observations of the sun ♦ <u>Introduction to Planetology</u>: Overview of the solar system (terrestrial planets, gas giants, moons, planetary ring systems, asteroids, and comets); structure and composition of planetary bodies (energy budget and dynamics); thermal models; tidal interactions; exploration of the solar system by satellite missions and ground-based observatories
Learning outcomes	After having participated successfully in the module, students are able to • understand the physics and structure of the sun and the solar system; • describe the most relevant phenomena of the quiet and the active sun; • understand the solar activity and its variability with the solar dynamo theory; • gain practical experience of how to obtain solar data with observations from ground-based and space-borne instruments; • describe the structure and composition of planetary bodies, and • understand the exploration of the solar system with in situ and remote sensing techniques.
Teaching and learning activities and methods	The module consists of two mandatory lectures that teach the basic theoretical concepts of the physics of the sun and the solar system. After having attended the two theoretical courses successfully, students improve their knowledge through practical exercises and observations in the Solar Physics Laboratory.
Previous knowledge expected	None
Frequency of offer	At least every two years

NAWI Graz Natural Sciences

Modul A4	Observation Techniques in Astrophysics
ECTS credit points	9
Subject content	♦ Instrumentation and Observing Techniques in Astrophysics: Introduction to classical and modern astrophysical techniques; observing electromagnetic radiation from radio to gamma rays; basics of optics; construction and operation of astronomical instruments; technology and application of detectors; telescopes; mountings; adaptive optics; interferometry; operation and usage of modern, large observatories; satellite observations; remote sensing and in situ instrument techniques; application to solar and stellar observations ♦ Astrophysics Lab: Planning and execution of practical observations at Lustbühel Observatory; practical methods for data reduction and data analysis ♦ Astrophysical Seminar: Platform for presenting and discussing selected topics in astrophysics using ground-based and space-based observations
Learning outcomes	After having participated successfully in the module, students are able to • understand modern telescopes and instruments and their fields of application; • understand astrophysical observing techniques (remote sensing and in situ); • plan own observations with telescopes and perform own photometric and spectroscopic measurements; • reduce observational data and present the results, and • obtain an overview of the modern topics in observational astrophysics.
Teaching and learning activities and methods	The module offers a lecture where the basics of modern astrophysical observing techniques are discussed. In the practical exercises, students have the possibility of carrying out their own observations with telescopes. The obtained data is analysed and discussed in the corresponding seminar. In the seminar, modern astrophysical topics are discussed.
Previous knowledge expected	None
Frequency of offer	At least every two years

Modul A5	Selected Topics in Astrophysics
ECTS credit points	9
Subject content	Students can make their own selection from a range of lectures. The goal is to specialise in specific fields of astrophysics by deepening knowledge. The topics include exoplanets and astrobiology; physics of space plasmas; an advanced observational laboratory; celestial mechanics; hydrodynamics; sun and space weather; advanced general relativity, and other topics (depending on topicality and possibilities).
Learning outcomes	• Students can specialise in theory and by practicing in specific topics and specific research fields of modern astrophysics.
Teaching and learning activities and methods	In the module, three lectures must be selected. These could be classical lectures, advanced laboratories or seminars. A total of 9 ECTS credit points is required.
Previous knowledge expected	None
Frequency of offer	At least every two years

Modul C1	Principles of the Climate System
ECTS credit points	9
Subject content	♦ The Earth's Climate System and Climate Change: The earth's climate system (terminology, subsystems, scales, balance principle, budgets and cycles); brief context of paleoclimate and history of climate; climate observations, climate elements, climate classification; physical climate mechanisms, water and energy cycles; the earth's radiation balance, and imbalances due to anthropogenic forcings and feedbacks; anthropogenic climate change; climate modelling, prediction, and projection; state-of-the-art physical climate change, adaptation, mitigation knowledge, IPCC and beyond ♦ Physical Oceanography, Hydrology and Climate: Descriptive oceanography, topography, plate tectonics; physical properties of water, chemistry of seawater; thermodynamics and hydrodynamics; equations of motion; waves, tides, and ocean circulation; sea ice and cryosphere; measurement techniques and instruments; oceans and climate ♦ Paleoclimatology: Climate change and environmental changes throughout the earth's history; physical mechanisms that caused these changes; scientific methods for the detection of past climate change and environmental changes
Learning outcomes	After having participated successfully in the module, students are able to • understand and critically appraise physical climate system and climate change knowledge; • adequately appreciate IPCC assessment report knowledge and conclusions; • apply the principles and methods of physical climatology, oceanography and hydrology; • contribute with expertise to the discourse on contemporary anthropogenic climate change and its consequences, in the proper context of paleoclimate and historical climate processes and dynamics; • describe the important processes influencing the oceans and the oceans' role in the climate system, and • provide an overview of the field of oceanography and discuss relevant current events (e.g. the increased melting of sea ice). After having completed the module, students have gained knowledge of • the earth's physical climate system and anthropogenic climate change; • key climate science methodologies including field modelling based on balance principles and state equations, network modelling based on budgets and cycles, climatic time series analysis from paleo-ages to the present; • physical oceanography and hydrology, and their relation to climate dynamics; • relations and interactions between the hydrosphere and the atmosphere, and • paleoclimatology and climate history of the Holocene and the previous millennia and centuries.
Teaching and learning activities and methods	The module consists of three lectures. The relevant theoretical concepts are taught in detail and illustrated with examples and applications.
Previous knowledge expected	None
Frequency of offer	At least every two years

Modul C2	Data Analysis and Simulation
ECTS credit points	9
Subject content	♦ <u>Methods of Modelling and Simulation</u>: Overview and basic methods of modelling and simulation of systems in atmospheric, climate and environmental sciences. Modelling and numerical simulation of deterministic, stochastic and dynamical systems. Mathematical and physical modelling/simulation via ordinary and partial differential equations, random processes, discrete automata. Basic numerical solution methods. Empirical modelling via linear and nonlinear regression methods. State estimation/measurement model estimation. Error analysis. Optimal estimation, inverse modelling and data inversion methods ♦ <u>Time Series Analysis</u>: Probability theory: random variables, distributions, statistical moments. Statistical inference: maximum likelihood estimation. Statistical modelling: linear, generalised and vector regression models. Stochastic processes: ARMA processes, Yule-Walker equations, simulation. Spectral analysis: spectrum, phase spectrum, cross spectrum, coherence, wavelet spectrum. Pattern methods: principal component analysis, canonical correlation analysis
Learning outcomes	After having participated successfully in the module, students are able to • understand the basic principles of system modelling/simulation and statistical time series analysis; • formulate and build mathematical/physical models; • apply suitable (numerical) methods for solving modelling problems; • apply suitable methods for the analysis of time series and data records, and • analyse and interpret model/simulation results. After having completed the module, students have gained • knowledge of different methods of modelling/simulation in atmosphere, climate and environmental sciences; • knowledge of fundamental concepts and different methods of time series analysis, and • problem solving skills for practical modelling/simulation and data analysis problems.
Teaching and learning activities and methods	The module consists of one lecture and one lecture with integrated exercise. In the lecture units, the material is presented theoretically and explained with selected examples. In the exercise units, practical training, mainly computer-based, is provided for the topics covered by the associated lectures, supported by adequate software. The training covers both independent problem solving (sup-ported by advice) and joint problem solving in a team.
Previous knowledge expected	Basic knowledge of a programming language at bachelor's level
Frequency of offer	Mandatory courses (♦) every year

Modul C3	Atmospheric Physics
ECTS credit points	9
Subject content	♦ <u>Atmospheric Dynamics</u>: Thermodynamics; equations of motion; balanced flow, scale analysis; circulation and vorticity; atmospheric waves; extra-tropical weather systems; general circulation; air masses and fronts; tropical and polar weather ♦ <u>Atmospheric Composition and Chemistry</u>: Development and evolution of planetary atmospheres; composition and vertical structure of the earth's atmosphere; fundamentals of stratospheric and tropospheric chemistry; chemical cycling; air pollution and air quality; photochemistry; gas-phase chemistry; aerosol nucleation and growth; aerosol-cloud chemistry; chemistry-climate connections; chemical geoengineering ♦ <u>Radiation and Energy Balance</u>: Radiative transfer in planetary atmospheres; radiative forcing; interaction of radiation (UV/VIS, IR) with gases and clouds; atmospheric energy budget
Learning outcomes	After having participated successfully in the module, students are able to • apply scale analysis to simplify the equations of motion; • apply perturbation analysis to study atmospheric waves; • solve chemical reaction equations; • contribute to the debate on stratospheric ozone depletion/recovery, degrading air quality and chemistry-climate connections, and • perform radiative transfer calculations. After having completed the module, students have gained knowledge of • the physical principles governing large-scale and mesoscale atmospheric flow and atmospheric thermodynamics; • the composition and evolution of planetary atmospheres and fundamental chemical cycles; • the principles of stratospheric and tropospheric chemistry and chemistry-climate connections, and • radiative forcing and transfer in planetary atmospheres, the earth's energy balance.
Teaching and learning activities and methods	The module consists of three lectures. The relevant theoretical concepts are taught in detail and illustrated with many examples and applications.
Previous knowledge expected	None
Frequency of offer	At least every two years

Modul C4	Climate Physics
ECTS credit points	9
Subject content	♦ Climate Modelling: Hierarchy of climate models; parameterisations; finite differencing; climate model experiments; uncertainties; skill of climate models; global climate projections; regional climate modelling ♦ Climate Dynamics: Geophysical fluid dynamics; energy balance models; climate equilibria and stability (warm and cold climates); large-scale atmospheric energy and momentum transport; air-sea fluxes; physics of large-scale climate modes (ENSO, NAO, PNA); inter-annual to centennial climate variability ♦ Selected Topics in Climate Science: Current status of climate observations and climate projections; current research frontiers in climate research
Learning outcomes	After having participated successfully in the module, students are able to • critically interpret the design of climate model experiments and future projections of global and regional climate change; • interpret fingerprints of large-scale climate modes; • apply fundamental geophysical fluid dynamics in process analyses, and • contribute to the debate on climate change on a global and regional scale. After having completed the module, students have gained knowledge of • the principles of climate modelling at an introductory level; • a wide range of possibilities of using climate models; • the benefits and limitations of climate models; • geophysical fluid dynamics and energy and momentum transport; • large-scale climate modes, their underlying drivers and their role in the climate system; • inter-annual to centennial climate variability, and • the current understanding of the climate system, future projections of climate change and research frontiers in climate research.
Teaching and learning activities and methods	The module consists of two lectures. The relevant theoretical concepts are taught in detail and illustrated with many examples and applications.
Previous knowledge expected	None
Frequency of offer	At least every two years

Modul C5	Atmosphere and Climate Measurement Methods
ECTS credit points	9
Subject content	♦ Atmosphere and Climate Measurement Methods: Remote Sensing: Introduction to and an overview of remote sensing of the atmosphere and climate. Types and classification of remote sensing systems, sensors, platforms, and basic measurement geometries. Physics of remote sensing. Relevant properties of electromagnetic radiation and interaction processes with matter, radiative transfer. Applications for remote sensing of thermodynamic variables, wind, and atmospheric composition ♦ Atmosphere and Climate Measurement Methods: In situ: Introduction to and an overview of in situ measurement methods for meteorological parameters, tropospheric trace gases, air pollutants, atmospheric properties and climate variables. Instrument types and underlying measurement/sampling/recording principles. Application of in situ measurements in atmospheric and climate research. Overview of global/regional in situ monitoring networks ♦ Seminar on Atmosphere and Climate Measurement Methods: Specific selected topics from the field of remote sensing and in situ atmospheric measurement methods for deepening knowledge of the topics in the associated lectures. Important measurement methods/techniques, instruments/sensors, data processing methods for atmospheric thermodynamic variables and atmospheric composition e.g. temperature, trace gas and wind sounding
Learning outcomes	After having participated successfully in the module, students are able to • name, classify, explain and distinguish important atmospheric measurement methods; • discuss advantages and disadvantages of individual methods; • select suitable observing systems for practical applications; • relate measurement principles to basic physical and chemical processes; • undertake literature research and cite scientific literature according to given standards; • prepare and summarise information on a scientific topic, and • present a scientific topic. After having completed the module, students have gained knowledge of • different atmospheric remote sensing measurement methods; • different atmospheric in situ measurement methods; • physical and chemical principles of individual measurement techniques, and • scientific presentation.
Teaching and learning activities and methods	The module consists of two lectures and an accompanying seminar. In the lectures, the material is presented theoretically. In the seminar, knowledge of the topics covered by the associated lectures is deepened. The seminar prepares students for independent work, and presentation and discussion of research-related topics on important or new atmospheric measurement methods.
Previous knowledge expected	None
Frequency of offer	At least every two years

Modul E1	Surface Science: Basic Principles
ECTS credit points	9
Subject content	♦ Surface Science: Geometric and electronic structure of surfaces (theory and methods); adsorption; (thermodynamics, growth processes) ♦ Experimental Methods in Surface Science: The focus is on understanding the principles of modern experimental surface science techniques and gaining direct hands-on experience with the techniques available at the surface science groups at Uni Graz and TU Graz. Introductory experiments (surface cleaning, structure and composition analysis, adsorption and desorption) are followed by a small research project on a specific instrument and topic. ♦ Thin Film Science and Processing: Principles of thin film growth; thermodynamics and kinetics; adsorption; desorption; diffusion; techniques (PVD, CVD, LB, spin coating); nanostructure fabrication (etching, etc.)
Learning outcomes	After having participated successfully in the module, students are able to • understand the fundamental (geometric and electronic) properties of surfaces as a representation of a truncated crystalline bulk material; • understand the principles of, operate, and interpret the results obtained with state-of-the-art ultra-high vacuum-based surface science methods and standard surface analytical methods for industry, and • understand the principles and methods of adsorption on surfaces, self-assembly, thin film growth and nanostructuring.
Teaching and learning activities and methods	Lectures, laboratory course
Previous knowledge expected	None
Frequency of offer	Every year

Modul E2	Surface Science: Advanced Topics
ECTS credit points	9
Subject content	Molecular Interfaces: Bonding; orbitals; band structure; interfaces; angle-resolved UPS; orbital tomography Scanning Probe Techniques: Scanning tunnelling microscopy (theory; operation; measurement modes; spectroscopy; applications; spin-polarised STM; inelastic STM/STS; manipulation). Atomic force microscopy (theory; interaction forces; modes (static, dynamic); force-distance curves; Kelvin probe; magnetic force spectromicroscopy: PEEM; LEEM; µ-XPS Synchrotron Radiation Techniques: Synchrotron light generation (history, accelerators, etc.); synchrotron XPS (time-resolved; data analysis; line shapes; curve fitting, etc.); X-ray absorption spectroscopy (EXAFS, XANES) Surface Chemistry: Chemical reactions on surfaces (heterogeneous catalysis; photocatalysis; electrochemistry) Vacuum Technology: Gas kinetics; pumps; pressure measurements; vacuum chambers; safety
Learning outcomes	These advanced courses are partly intended as preparation for and as accompanying lectures during the master's research project. They provide students with deeper knowledge of the systems and techniques of surface physics and surface chemistry.
Teaching and learning activities and methods	Lectures
Previous knowledge expected	None
Frequency of offer	Every year

Modul E3	**Photon Science**
ECTS credit points	9
Subject content	Laser Spectroscopy: Laser spectroscopy techniques for atomic and molecular gasses, liquids, and solids; overview on optical spectroscopic diagnostic in strumentation; high-frequency and time-resolved spectroscopy and related diagnostic methods including most recent developments in optical spectroscopy, ranging from the x-ray to the infrared spectral region Structured Light and Nanoscale Wave Phenomena: Introduction to the fascinating structure of light – from tall to small; discussion of various types of structured electromagnetic fields, generation methods and inherent properties; evanescent and propagating fields, polarization, angular momenta of light fields, optics of dielectric and metallic nanostructures, light-matter interactions at the nanoscale; exotic phenomena and intriguing effects in nanostructured fields; modern applications in nano-metrology, sensing, imaging, spectroscopy, polarimetry, photonic nanocircuitry, etc. Photonics: Light, Matter, and Time: Ultrafast time-domain perspective on optical properties of atoms and solids, dynamics of energy exchange between electric field and matter; refractive index and transition rates from quantum mechanical principles, optical control of charge and spin Optical Waveguides, Photonic Circuitry and Applications: Introduction to various kinds of optical waveguides (integrated, dielectric, plasmonic, photonic crystal waveguides and fibers); discussion of photonic integrated circuits, corresponding components, and fascinating applications as well as recent developments Optical Measurement Techniques: Introduction to optical spectroscopy methods for physics, chemistry and biological sciences with focus on providing knowledge for estimating applicability ranges of various methods, and on basics of spectroscopy instruments. Research Laboratory Photon Science: Practical training in advanced experimental optical techniques with a selection of intriguing topics related to photon sciences to be chosen in accordance with interests and lectures attended
Learning outcomes	This module is designed to provide • a concise theoretical knowledge base in photon science and related areas of physics (Optics, Electrodynamics, Quantum Mechanics, Physics of Semiconductors) • understanding of fundamental laws of physics driving modern engineering areas including telecommunications, optoelectronics, photonics, nano and microfabrication • essential laboratory skills including experimental design, assembly of optical equipment, data acquisition and analysis • training to communicate scientific and engineering ideas both orally and in written form.
Teaching and learning activities and methods	Lectures, laboratory course
Previous knowledge expected	Fundamentals of electrodynamics and optics as well as corresponding mathematical concepts (Bachelor's level)
Frequency of offer	every year

Modul E4	**Nano and Laser-Optics**
ECTS credit points	9
Subject content	♦ Optics - a Photonics Perspective: Light and matter; interference and diffraction; beam and pulse propagation; layered media and waveguides; microscopy; sources and detectors ♦ Research Laboratory Nano-optics and Laser Optics: Practical training in advanced experimental techniques with the opportunity to choose topics according to interests and lectures attended Nano-optics: Super-resolution microscopy; near-field microscopy; quantum emitters; photonic crystals; plasmonics; metamaterials Laser Physics: Emission and absorption; Einstein coefficients; laser theory and rate equations; optical resonators and modes; laser pulses; laser types; laser safety Ultrafast Laser Physics: Introduction to the state-of-the-art research field of femtosecond time-resolved molecular spectroscopy: generation and amplification of femtosecond laser pulses; pulse propagation in media, dispersion compensation; pulse characterisation; methods and examples of femtosecond time-resolved spectroscopy; strong field effects; applications
Learning outcomes	After having participated successfully in the module, students are able to • understand and apply the concepts of ray and wave optics; • understand and apply the concepts of optical material properties and light-matter interaction at all length scales, and • understand and apply the physical and technical principles of (ultrafast) lasers. After having completed the module, students have acquired • the ability to design optical and laser setups, and • the basis for the Master's Thesis in a research laboratory in the fields of modern optics and photonics.
Teaching and learning activities and methods	Lectures, laboratory course
Previous knowledge expected	Experimental physics, quantum mechanics, electrodynamics and mathematical concepts at bachelor's level
Frequency of offer	Every year

Modul E5	Quantum Optics and Molecular Physics
ECTS credit points	9
Subject content	Concepts of light-matter interaction are introduced and described with semiclassical and quantum physics. Topics ranging from light propagation in solids to the investigation of processes in isolated molecules with femtosecond laser pulses and their modelling are covered. ♦ Optics - a Spectroscopy Perspective: Basics of optics for research and industrial applications: light propagation in isotropic materials; conducting media and birefringent crystals; polarisation optics; nonlinear optics; Fraunhofer and Fresnel diffraction; Fresnel zone plates; coherence and interference; holography; Fourier optics ♦ Research Laboratory Quantum Optics and Molecular Physics: Practical training in advanced experimental techniques with the opportunity to choose topics according to interests and lectures attended. Students also participate in one of the research experiments. Ultrafast Laser Physics: Introduction to the state-of-the-art research field of femtosecond time-resolved molecular spectroscopy: generation and amplification of femtosecond laser pulses; pulse propagation in media, dispersion compensation; pulse characterisation; methods and examples of femtosecond time-resolved spectroscopy; strong field effects; applications Laser Physics: Emission and absorption; Einstein coefficients; laser theory and rate equations; optical resonators and modes; laser pulses and types; laser safety Quantum Optics: Correlated photons; theory of light-pressure force; laser cooling and trapped atomic ensembles; atom interferometry; quantum interference; foundations and theory of atomic clocks and optical magnetometers Modelling of Molecular Systems: Non-Born-Oppenheimer effects; rovibronic interactions; group theory; excited states; post-Hartree-Fock techniques; solvation, QM/MM embedding; reaction dynamics and transition state theory
Learning outcomes	After having participated successfully in the module, students are able to • solve optics-related tasks in research and industry, equipped with a substantial fundamental and practical basis; • understand light-induced molecular processes, their investigation with (femtosecond) laser radiation, as well as their modelling; • design and construct optical setups for laser applications, and • carry out a Master's Thesis in a research laboratory in the field of modern optics or laser spectroscopy.
Teaching and learning activities and methods	Lectures, laboratory course
Previous knowledge expected	Experimental physics, quantum mechanics, electrodynamics and mathematical concepts at bachelor's level
Frequency of offer	Every year

Modul E6	Nano and Quantum Matter
ECTS credit points	9
Subject content	♦ Solid-State Physics: Size Effects and Quantum Phenomena: Building crystals from atoms; chemical bond; translational symmetry; zone mapping; phonons; band structure; magnetism; surface and interfaces; heterojunctions; low-dimensional systems; confined states in, exotic quantum effects in nanostructures; spin transport and magnetisation switching; dimensionality; periodic boundary conditions at finite size; development of Bloch states; oligomers-polymers; carbon nanophases; quantum dots; Born-Oppenheimer; Hückel; tight-binding; Hubbard; Heisenberg; magnons; quantum Hall; topological insulators; superconductivity and superfluidity; polaritons; plasmons; mass of photons; soft modes; phase transitions Modern Materials: Shape-dependent and size-dependent properties; nanoanalytic; nanostructures; quantisation effects; single-electron effects; molecular electronics; nanoparticles; polymers and biological materials; smart materials Theory of Superconductivity: Phenomenology of superconductors; the Meissner effect; London equations. Microscopic theory: BCS theory at zero and finite temperatures; introduction to strong-coupling Migdal-Eliashberg theory Phase Transitions and Critical Phenomena: Lattice models and applications of statistical physics. Mean field; perturbation series; transfer matrix; renormalisation group; mapping between representations. Simulation techniques and practical examples, including cluster Monte Carlo and Kosterlitz-Thouless transition Theory of Magnetism and Collective Phenomena: Magnetic exchange mechanisms; models for magnetic materials; response functions and phase transitions; Brown theory of micromagnetism; magnetic domains 2D Materials: Monoelemental (Xenes) and compound (MXenes, oxides, alloys) two-dimensional materials; freestanding, supported and stacked layers; physical, electrical, magnetic, chemical properties; characterization and applications.
Learning outcomes	After having participated successfully in the module, students • understand modern physics based on size effects, dimensionality and quantum phenomena; • have gained an experimental and theoretical insight into methods of modern physics, and • have acquired knowledge and an understanding of the principles of modern materials and their use in new products.
Teaching and learning activities and methods	Lectures
Previous knowledge expected	Knowledge of Solid-State physics, quantum mechanics, experimental and computational techniques at bachelor's level
Frequency of offer	Mandatory courses (♦) every year; others at least every two years

Modul E7	Biological Applications
ECTS credit points	9
Subject content	Molecular Biophysics 1: Origin, evolution and building elements of life; structure of cells and biological materials; intermolecular forces and interactions; diffusion and dynamics; molecular interplay in cellular processes Molecular Biophysics 2: Selected topics in molecular biophysics, including protein conformation, lipid membranes, lipid/protein interactions, motor proteins, cytoskeleton/membrane interactions, membrane processes Biophotonics: Interaction of light with biological tissue, including models of light transport; therapeutic effects of light and optical imaging methods in biology and medicine, including special microscopy techniques, optical coherence tomography and photoacoustic imaging Theoretical Biophysics: Theory of soft and biological matter, focussing on the thermodynamics and kinetics of water, electrolytes, lipids, proteins and DNA. The course covers atomistic models as well as continuum and mean-field theory, spanning length scales from single atoms to membranes and vesicles. Soft Matter Physics: Structural, mechanical and optical properties of soft matter, such as colloids, gels, liquid crystals, polymers and biological systems; hierarchical structures; self-assembly; internal surfaces; metastable states and phase separation Biological and Biobased Materials: Mutual dependencies of physicochemical properties and function of biological materials; hierarchical construction and the resulting material properties both on the molecular and the macroscopic levels; applications in the form of biosensors or synthetic fibres ♦ Research Laboratory Biophysics: Practical training in advanced experimental techniques, including photoacoustic spectroscopy and imaging, small angle X-ray diffraction, X-ray reflectivity, with the opportunity to choose topics according to interests and lectures attended
Learning outcomes	After having participated successfully in the module, students are able to • understand the hierarchical structure of biological systems; • specify methods for determining physical properties of biological materials, and • use selected experimental methods for the characterisation of biological materials.
Teaching and learning activities and methods	Lectures, laboratory course
Previous knowledge expected	None
Frequency of offer	Mandatory course (♦) every year; others at least every two years

Modul E8	Industrial Applications
ECTS credit points	9
Subject content	♦ Topics of Industrial Relevance: External lecturers present a course on technological and analytic methods and current innovative developments of industrial relevance challenging physicists. The main aspect is the perspective from outside the university on research and development and the specific expectations of physicist graduates. Specific topics from various fields of industrial relevance are offered on an annual basis. ♦ Signal Theory and Signal Processing: Introduction to the fundamentals of signal theory, digital filters, spectral analysis (FFT, wavelets, Hilbert transform), noise measurements and correlation techniques, embedding software in hardware solutions Patent Law and Technology Transfer: Basics of intellectual property rights (IPRs) with a special focus on patents; (rough) overview of patent systems (esp. USA and Europe); search for patent literature; tools for technology transfer, licensing contracts and case study Ultrasound Methods: Theory of ultrasound in fluids and solids, ultrasonic waves in bulk, at surfaces and interfaces; ultrasound generation and measurement techniques; ultrasound applications: non-destructive evaluation of materials, acoustic microscopy, biomedical imaging, photoacoustic imaging Thin Film Science and Processing: Principles of thin film growth, thermodynamics and kinetics, adsorption, desorption, diffusion, techniques (PVD, CVD, LB, spin coating), nanostructure fabrication (etching, etc.) Modelling and Simulation of Semiconductors: Introduction to the electronic structure of semiconductors; scattering mechanisms for electrons; transport modelling techniques (drift diffusion, Monte Carlo, Boltzmann equation); organic and nanotube field-effect transistors Excursion: An excursion to companies or external laboratory courses.
Learning outcomes	After having participated successfully in the module, students • have gained suitable knowledge of the concepts of how physical research is transferred to industrial applications and methods; • have acquired some specific professional skills in management and legal aspects (protection of intellectual property rights, patent law), and • are able to use modern experimental equipment and methods in industry. After having completed the module, students • have gained experience to use basic physical knowledge in industry; • are familiar with industrial practice to assess industrial projects, and • possess competence in the specialised elective courses.
Teaching and learning activities and methods	Lectures, laboratory courses at the university or (externally) in industry, excursion to specific companies
Previous knowledge expected	Knowledge of Solid-State physics, quantum mechanics, experimental and computational techniques at bachelor’s level
Frequency of offer	Mandatory courses (♦) every year; others at least every two years

Modul S1	Fundamentals of Space Physics and Aeronomy
ECTS credit points	9
Subject content	♦ Introduction to Planetology: Overview of the solar system (terrestrial planets, gas giants, moons, planetary ring systems, asteroids and comets); structure and composition of planetary bodies (energy budget and dynamics); thermal models; tidal interactions ♦ Introduction to Aeronomy: Basis of atmospheric physics in general (composition and structure, transport processes, radiation, chemistry); special situation of upper atmospheres; examples; overview of experimental methods; overview of models; review: ionospheres ♦ Introduction to Space Plasma Physics: Fundamentals of the motion of charged particles in electric and magnetic fields; magnetohydrodynamic equations; elementary wave phenomena in plasmas; magnetohydrodynamic and electrodynamic waves in plasmas; magnetoplasmas in planetary magnetospheres
Learning outcomes	After having participated successfully in the module, students are able to • give an overview of the physical properties of the bodies in our planetary system; • explain the differences and commonalities of the planets and their physical causes; • describe the basic physical processes governing planetary atmospheres – with a focus on the upper atmosphere; • give an overview of the basic physical processes in planetary ionospheres, and • explain the fundamentals of magnetohydrodynamics and electrodynamic waves in plasmas. After having completed the module, students have gained knowledge of • terrestrial planets, gas giants, moons, planetary ring systems, asteroids, and comets; • the energy budget and dynamics of planets and tidal interactions; • methods and research systems in the aeronomy of the upper atmospheres of the earth and the planets with an emphasis on the neutral gas part; • the fundamentals of the motion of charged particles in electric and magnetic fields, and • the behaviour of space plasmas and wave phenomena in magnetoplasma.
Teaching and learning activities and methods	The module consists of three lectures. The relevant theoretical concepts are taught in detail and illustrated with examples and applications.
Previous knowledge expected	None
Frequency of offer	At least every two years

Modul S2	Solar and Heliospheric Physics
ECTS credit points	9
Subject content	♦ Introduction to Solar Physics: The sun as a star; determination of basic physical parameters describing the sun and stars; solar interior structure; thermonuclear fusion in the solar core; solar neutrinos; helioseismology; solar atmosphere; phenomena of the quiet and the active sun; solar activity cycle; solar dynamo; solar wind; flares, coronal mass ejections and space weather ♦ Magnetohydrodynamics and Solar-terrestrial Modelling: Basic magnetohydrodynamics (MHD) equations; magnetic reconnection; interaction of the solar wind with planetary atmospheres; solar-terrestrial relations ♦ Exercises in Introduction to Solar Physics: Training in the methods introduced in the associated lecture by solving problems related to Solar Physics. ♦ Solar Physics Lab Tour: Excursion tour to Kanzelhöhe Observatory and practical to obtain an insight into state-of-the-art methods of ground-based observations of the sun
Learning outcomes	After having participated successfully in the module, students are able to • understand the physics and structure of the sun and the solar system; • describe the most relevant phenomena of the quiet and the active sun; • understand solar activity and its variability with the solar dynamo theory; • understand the basic concepts of MHD and apply them to the solar-terrestrial interactions, and • give an overview of plasma physical phenomena and their applications in the solar system and astrophysical systems. After having completed the module, students have gained knowledge of • the solar interior structure and helioseismology; • solar wind, flares, coronal mass ejections, and space weather; • basic magnetohydrodynamics; • magnetic reconnection and interaction of the solar wind with planetary atmospheres; • practical analysis methods for space plasmas (waves, shock waves, turbulence, reconnection), and • the plasma physical picture of the solar system.
Teaching and learning activities and methods	The module consists of three lectures. The relevant theoretical concepts are taught in detail and illustrated with examples and applications.
Previous knowledge expected	None
Frequency of offer	At least every two years

Modul S3	Physics of Planetary Atmospheres and Magnetospheres
ECTS credit points	9
Subject content	♦ Physics of Planetary Atmospheres: Overview of the origin and evolution of planetary atmospheres. Solar system planets versus exoplanets. Atmosphere structure and escape. Sources of initial atmospheres and water inventories of terrestrial planets. Formation of mineralogical (silicate) atmospheres and exospheres. The role of impacts by comets and asteroids. Spacecraft techniques for atmosphere detection on planets beyond the earth ♦ Earth's and Planetary Magnetic Fields: Concept of magnetic fields. Planetary core dynamics of electrically conducting fluids. Elements of magnetohydrodynamics. Dynamo mechanisms (twisting and stretching effects). Potential field description using spherical harmonic analysis. Surface remanent magnetisation. Paleomagnetism. Ionospheric and magnetospheric sources. Time variation of magnetic fields. Magnetic fields of solar system bodies. Measurement techniques ♦ Planetary Magnetospheres: Physics of interaction between the solar wind plasma and planetary magnetic fields. Magnetospheric structures and internal processes of magnetised solar system planets: electric fields, charged particle motion, Van Allen belts. Auroral processes, planetary non-thermal radio emission. Specifics of giant planets magnetospheres (Jupiter-Io interaction, Saturn microsignatures, magnetospheric structure changes of oblique rotators). Magnetic indices
Learning outcomes	After having participated successfully in the module, students understand • the fundamental physics principles of planetary atmospheres; • the concept of magnetic fields and their origin, and • the basic plasma physics involved in particle and field interactions. Students have gained • an insight into complex interconnected areas of aeronomy and habitability; • competence in space science through magnetic fields, and • profound knowledge of solar system plasma physics.
Teaching and learning activities and methods	Lectures
Previous knowledge expected	Knowledge of astrophysics, astronomy, geophysics (earth's interior structure), chemistry, electromagnetism, hydrodynamics, plasma physics, electromagnetic and plasma waves at bachelor's level
Frequency of offer	At least every two years

Modul S4	Measurement Methods and Observing Systems
ECTS credit points	9
Subject content	♦ Measurement Methods in Space Physics: Plasma, fields and waves as measurement parameters in a near-planetary environment, interplanetary space and from the ground. Remote and in situ measurements by satellites, spacecraft and telescopes. Fundamental measurement methods and techniques by single/multiple (simultaneous) experiments. Data acquisition and analysis of significance, error, and interpretation. Connection between experiment reliability and data quality ♦ Space Missions and Experiments Design: Physics objectives of space target and corresponding space mission development. Concept of spacecraft/satellite construction and science payload. Experiments design, power, data storage, communication and housekeeping systems. Interconnectivity and complementarity of experiments, issues of experiment and data calibration. Optimisation of choice of spacecraft/satellite trajectory and sequence of experiment operations ♦ Seminar on Measurement Methods in Space Physics: The content of the lecture Measurement Methods in Space Physics is treated interactively and enforced by students' presentations, discussions and teamwork. Additional related issues and objectives have to be identified, analysed, interpreted and presented by students' literature and media search.
Learning outcomes	After having participated successfully in the module, students understand • the fundamental physics principles of remote and in situ measurement methods; • the concept of space mission development, experiment performance, observation, and data acquisition, and • the basics regarding data quality, significance and error analysis. Students have gained • an insight into the complex interconnection of experiment and observational data; • competence in space science through knowledge of experiment performance, data acquisition and physical process interpretation, and • profound knowledge of measurement methods and techniques.
Teaching and learning activities and methods	Lectures and seminar
Previous knowledge expected	Knowledge of astrophysics, astronomy, physics, geophysics, electromagnetism, hydrodynamics, electronics, plasma physics and waves theory at bachelor's level
Frequency of offer	At least every two years

Modul T1	Advanced Theoretical Physics 1
ECTS credit points	9
Subject content	♦ Advanced Mathematical Methods: Group theory (discrete groups, Lie algebras and Lie groups); complex analysis (Cauchy's integral theorem, residue theorem, conformal maps, etc.), basic elements of geometry and topology (manifolds, homotopy groups) ♦ Quantum Field Theory: Klein-Gordon, Dirac and Maxwell fields; canonical formalism, functional integrals, Feynman rules, renormalisation, leading order QED processes
Learning outcomes	After having participated successfully in the module, students are able to • perform successful standard-type calculations involving group representations and algebras, with complex functions and distributions, and with elementary topological quantities; • understand the basic principles of quantum field theory; • apply basic methods in quantum field theory, and • perform successful standard-type calculations in quantum field theory. After having completed the module, students have gained • profound knowledge of group theory, complex analysis and the basics of quantum field theory.
Teaching and learning activities and methods	Lectures, exercise-based courses
Previous knowledge expected	Theory courses at bachelor's level and General Physics module
Frequency of offer	Every year

Modul T2	Advanced Theoretical Physics 2
ECTS credit points	9
Subject content	♦ Advanced Statistical Physics: Phase transitions; renormalisation group; Bose-Einstein condensates; spontaneous symmetry breaking and Goldstone theorem ♦ Advanced Quantum Mechanics 2: Scattering theory (continued); open quantum systems; density operator; quantum measurement; quantum information; quantum optics ♦ Basic Concepts in Solid-State Theory: Electron gas; Bloch theorem and Bloch waves; spin-orbit coupling; ion lattices and phonons; electron-phonon interaction and (conventional) superconductivity; Hartree-Fock approximation; screening
Learning outcomes	After having participated successfully in the module, students are able to • understand properties of physical systems from the thermodynamic limit in statistical physics; • apply further advanced methods in quantum theory, and • perform successful standard-type calculations in these fields. After having completed the module, students have gained • profound knowledge of phase transitions, properties of systems with spontaneously broken symmetries and exotic types of quantum matter as well as modern developments in quantum theory, and • basic knowledge of the underlying principles of Solid-State theory.
Teaching and learning activities and methods	Lectures
Previous knowledge expected	Theory courses at bachelor's level and General Physics module
Frequency of offer	Every year

Modul T3	Computational Physics
ECTS credit points	9
Subject content	♦ Numerical Methods in Linear Algebra: Numerical methods of linear algebra and partial differential equations; direct and iterative methods for solving linear systems of equations and eigenvalue problems; finite difference approach to partial differential equations; von Neumann stability ♦ Monte Carlo Methods: Random numbers; random walks; importance sampling; Metropolis algorithm; cluster and worm algorithms; data analysis. Applications: spin systems, lattice field theories Computational Methods in Nano Physics: Computational approaches in Solid-State physics, with an emphasis on dynamic processes e.g. spontaneous magnetisation and self-consistency; quantum interference effects in qubit control; spin-selective transport in semiconductor heterostructures; Andreev reflection, etc. Computational Methods in Particle Physics: Numerical solution of functional equations, e.g. exact renormalisation group equations, Dyson-Schwinger equations and Bethe-Salpeter equations Quantum Computing: Qubit, Density matrix, quantum gates, quantum entanglement, teleportation and algorithms, Schor algorithm and RSA, Error correction, Quantum Cryptography, Simulation methods, Hardware implementations
Learning outcomes	After having completed the module, students are able to • apply direct and iterative methods for the numerical solution of linear systems of equations; • characterise and analyse finite difference approximations of partial differential equations by a von Neumann stability analysis and compute their solution; • classify various Monte Carlo methods; • apply Monte Carlo methods to physical problems, and • convert physical problems of Solid-State physics or elementary particle physics into numerical algorithms and obtain their numerical solutions.
Teaching and learning activities and methods	The module consists of two compulsory lectures teaching the theoretical basis of the numerical algorithms, knowledge of which is deepened by solving problems by writing computer programs. In a further lecture, either numerical methods specific to problems of Solid-State theory or particle physics are treated.
Previous knowledge expected	None
Frequency of offer	Every year

Modul T4	Theoretical Solid-State Physics
ECTS credit points	9
Subject content	♦ Quantum Theory of Many-Body Systems: Correlation functions and linear response, Fermionic and Bosonic single-particle Green's functions, Perturbation theory and Feynman diagrams, Simple approximations: Hartree-Fock, Random Phase Approximation, Screening Fundamentals of Electronic Structure Theory: Electronic band structure; free-electron bands and tight-binding approximation. Self-consistent field approximation; density functional theory; basis functions; full-potential and pseudopotential methods; advanced topics Theory of Magnetism and Collective Phenomena: Magnetic exchange mechanisms; models for magnetic materials; response functions and phase transitions; Brown theory of micromagnetism; magnetic domains Theory of Superconductivity: Phenomenology of superconductors; the Meissner effect; London equations. Microscopic theory: BCS theory at zero and finite temperatures; introduction to strong-coupling Migdal-Eliashberg theory Phase Transitions and Critical Phenomena: Lattice models and applications of statistical physics. Mean field; perturbation series; transfer matrix; renormalisation group; mapping between representations. Simulation techniques and practical examples, including cluster Monte Carlo and Kosterlitz-Thouless transition
Learning outcomes	After having participated successfully in the module, students have a clear overview of the fundamental methods and open problems of modern theoretical Solid-State physics. After having completed the module, students have acquired the basic skills to solve related problems at the level of a Master's Thesis.
Teaching and learning activities and methods	Lectures with multimedia material
Previous knowledge expected	Knowledge of Solid-State physics, quantum mechanics and statistical physics at master's level
Frequency of offer	Mandatory courses (♦) every year; others at least every two years

Modul T5	Theoretical Nano Physics
ECTS credit points	9
Subject content	Theoretical Nano- and Quantum Optics: Quantisation of the electromagnetic field; basic concepts of quantum optics; Green's function; optical near fields; surface plasmons Quantum Computing: Qubit, Density matrix, quantum gates, quantum entanglement, teleportation and algorithms, Schor algorithm and RSA, Error correction, Quantum Cryptography, Simulation methods, Hardware implementations Fundamentals of Electronic Structure Theory: Electronic band structure; construction of free-electron bands and tight-binding approximation. Self-consistent field approximation; density functional theory; basis functions; full-potential and pseudopotential methods; advanced topics Computational Methods in Nano Physics: Computational approaches in Solid-State physics, with an emphasis on dynamic processes e.g. spontaneous magnetisation and self-consistency; quantum interference effects in qubit control; spin-selective transport in semiconductor heterostructures; Andreev reflection, etc.
Learning outcomes	After having completed the module, students are able to • understand and apply concepts of quantum optics; • comprehend the foundations and applications of plasmonics; • classify and apply quantum and semiclassical approaches of transport theory; • explain the foundations of density functional theory and interpret typical results of DFT calculations, and • classify various quantum states of modern Solid-State physics.
Teaching and learning activities and methods	Lectures
Previous knowledge expected	Knowledge of Solid-State physics, quantum mechanics and statistical physics at master's level
Frequency of offer	Mandatory courses (♦) every year; others at least every two years

Modul T6	Modelling of Materials
ECTS credit points	9
Subject content	Students are introduced to modern simulation techniques for electronic and nuclear motion in atoms, molecules and bulk structures. They are taught topical problems inspired by current research and industrial needs. ♦ Fundamentals of Electronic Structure Theory: Electronic band structure; free-electron bands and tight-binding approximation. SCF approximation; density functional theory (DFT); basis functions; full-potential and pseudo-potential approximations; advanced topics ♦ Simulating Materials Properties from First Principles: Tutorial and scientific exercise. Molecular properties; excitations; vibrations; visualisation; bandstructure calculations; ab initio MD; interaction driven Mott transition Advanced Electronic Structure Theory: Advanced Electronic Structure Theory: Ab-initio electronic structure methods beyond ground state density functional theory; density functional perturbation theory for the calculation of phonon spectra; time-dependent density functional theory; quasi-particles within many-body perturbation theory Modelling of Molecular Systems: Non-Born-Oppenheimer effects; rovibronic interactions; group theory; excited states; post-Hartree-Fock techniques; solvation, QM/MM embedding; reaction dynamics and transition state theory Applications of Electronic Structure Methods: Interpretation of electronic structure calculations; global structure determination; ab initio thermodynamics, vibrations, phonon bands and heat transport; optical and core-level excitations; scanning probe experiments Ab Initio Methods for Correlated Materials: Introduction to correlated materials; localised basis sets; Hubbard model and calculation of interaction parameters; (non-)Fermi liquids; dynamical mean field theory; Mott-Hubbard transition
Learning outcomes	The module offers a solid methodical and computational background as well as practical knowledge regarding program packages and libraries at the edge of current research. Participants are equipped with substantial knowledge in the field of materials modelling and electronic structure theory, which makes them valuable job candidates at materials research facilities.
Teaching and learning activities and methods	Lectures, laboratory course
Previous knowledge expected	Quantum mechanics, electrodynamics, advanced quantum mechanics
Frequency of offer	Every year

Modul T7	Foundations of Particle Physics
ECTS credit points	9
Subject content	♦ <u>Quantum Field Theory 2: Gauge Theories</u>: Classical non-Abelian gauge theories, instantons and topological field configurations; perturbative quantization; BRST and anti-field formalism; Slavnov-Taylor identities; perturbative calculation at loop level and renormalization; matter in gauge theories; global and local anomalies; quantization beyond perturbation theory; composite states; symmetries and symmetry breaking <u>Lattice Field theory:</u> Regularization of non-gauge and gauge theories on the lattice; scale setting and continuum limits; fermions and chiral symmetry; Markov chain and Monte Carlo; numerical algorithms (Metropolis, heatbath, fermion algorithms); transfer matrix; lattice perturbation theory; finite temperature and density; spectroscopy of bound states and resonances <u>Computational Methods in Particle:</u> Numerical approaches to integrals; functional equations;(differntio-)integral equations; renormalization; manipulation of large matrices; Monte Carlo methods; efficient numerical algorithms for linear algebra; machine learning <u>Special topics in: Particle Physics:</u> Selected topics of current or emerging interest, which are not covered in other parts of T7 or T8 <u>Advanced Mathematical Methods 2:</u> Topology; differential geometry; category theory; operator algebras; integral equations
Learning outcomes	After having participated successfully in the module, students are able to • understanding of fundamental properties of gauge theories • skills and understanding of tools required to do research in particle physics in the context of a master thesis
Teaching and learning activities and methods	Lectures, exercises and project
Previous knowledge expected	Theory courses at bachelor's level, General Physics module as well as module T1
Frequency of offer	Lecture Quantum Field Theory II and project every year; other lectures and exercises every second year

Modul T8	Phenomenology of Particle Physics
ECTS credit points	9
Subject content	♦ Standard Model: QCD; hadrons; chiral symmetry breaking; PDFs and fragmentation; QED; electroweak physics and the Brout-Englert-Higgs effect; CKM and PMNS matrices and oscillation; precision tests; flavor physics; QCD and - electroweak phase diagram Beyond the Standard Model: Limits of the standard model; supersymmetry; composite Higgs; multi-Higgs models; grand-unified theories; supergravity; string theory; axions; other extensions of the SM; simplified models Advanced General Relativity and Quantum Gravity: General relativity as a gauge theory; torsion; initial-value problem; black holes; cosmology; gravitational waves; foliation and Hamiltonian formulation; canonical quantum gravity; asymptotic Safety; dynamical triangulation; loop quantum gravity; string theory; other quantum and non-quantum theories of gravity Astroparticle Physics: Astrophysical observations; cosmology and inflation; baryo-, lepto-, and nucleogenesis; dark matter indications and dark matter models; relic density and thermal history of the universe; dark energy; cosmic ray propagation and interactions; neutrinos in the cosmos; compact stellar objects Experimental particle physics: Accelerators and enabling technologies; collisions and their interplay in understanding the shortest length scales; interaction of particles - with matter; detector technologies: gaseous detectors, silicon detectors, calorimetry, particle ID, rvent reconstruction; trigger; principles of data analyses, and their statistical description Collider phenomenology: Fixed-order calculation of amplitudes and cross sections; PDFs and fragmentation functions; (QCD) coherence; jet cross sections; event shapes and resummation; Monte Carlo event generators and phenomenological models; specific collider reactions with leptons, hadrons and heavy ions Project in: "Particle Physics": Small analytical or numerical projects motivated by current research; can be done in connection with a master thesis
Learning outcomes	After having participated successfully in the module, students are able to • knowledge of several contemporary areas of particle physics • Overview of particle physics in general and connection to neighboring fields • Basic knowledge about phenomenology to do research in particle physics in the context of a master thesis
Teaching and learning activities and methods	Lectures and project
Previous knowledge expected	Theory courses at bachelor's level, General Physics module as well as module T1
Frequency of offer	Lecture Hadron Physics and project every year; other lectures and exercises every second year

Anhang II

Studienablauf

1. Semester	SSt.	Typ	ECTS	Uni Graz[1]	TU Graz[1]
Statistical Physics (Modul G)	2	VO	4	X	X
Statistical Physics (Modul G)	1	UE	2	X	X
Advanced Quantum Mechanics (Modul G)	2	VO	4	X	X
Advanced Quantum Mechanics (Modul G)	1	UE	2	X	X
Introduction to General Relativity and Cosmology (Modul G)	2	VO	3	X	
Vertiefungsmodule	8		12	X	X
Free Electives	2		3	X	X
1. Semester Summe	18		30		
2. Semester					
Vertiefungsmodule	14		21	X	X
Elective Topics	4		6	X	X
Free Electives	2		3	X	X
2. Semester Summe	20		30		
3. Semester					
Vertiefungsmodule	8		12	X	X
Practical Training in the Area of the Master's Thesis (Modul M0)	4	LU/PT	10	X	
Tutorial for Master's Students in the Area of the Master's Thesis (Modul M0)	2	PV	2	X	
Elective Topics	2		3	X	X
3. Semester Summe	16		27		
4. Semester					
Master's Seminar in the Area of the Master's Thesis (Modul M0)	2	SE	2	X	
Master's Thesis			30	X	
Masterprüfung			1		
4. Semester Summe	2		33		
Summe ECTS gesamt			120		

[1]: Zuordnung der Lehrveranstaltung zu den beteiligten Universitäten. Beide Universitäten sind genannt, wenn die Lehrveranstaltung von beiden Universitäten gemeinsam, parallel oder im Wechsel angeboten werden.

Anhang III

Empfohlene Lehrveranstaltungen für die Free Electives

Frei zu wählende Lehrveranstaltungen können laut § 10 dieses Curriculums frei aus dem Lehrveranstaltungsangebot aller anerkannten in- und ausländischen Universitäten sowie aller inländischen Fachhochschulen und pädagogischen Hochschulen gewählt werden.

Im Sinne einer Verbreiterung der Wissensbasis im Bereich der Module dieses Studiums werden Lehrveranstaltungen aus den Gebieten Fremdsprachen, soziale Kompetenz, Technikfolgenabschätzung sowie Frauen- und Geschlechterforschung (hier besonders die Veranstaltung „Ein Doktoratsstudium an der Fakultät für Mathematik, Physik und Geodäsie- Informationsveranstaltung für Masterstudentinnen") empfohlen. Weiters wird auf das Angebot der Serviceeinrichtung Sprachen, Schlüsselkompetenzen und Interne Weiterbildung der TU Graz bzw. Treffpunkt Sprachen der Universität Graz, des Zentrums für Soziale Kompetenz der Universität Graz sowie des Interuniversitären Forschungszentrums für Technik, Arbeit und Kultur hingewiesen. Zusätzlich werden die überfakultären Mastermodule „Masterstudium Plus" der Universität Graz empfohlen.

Im Sinne der Qualifizierung für zukünftige Leitungs- und Führungspositionen wird auch auf das Angebot der „Transferinitiative für Management- und Entrepreneurship-Grundlagen, Awareness, Training und Employability" (kurz: TIMEGATE) der Universität Graz verwiesen.

Weitere empfohlene Lehrveranstaltungen für die Free Electives:							
Lehrveranstaltung		LV		Semesterzuordnung		Uni-Graz[1]	TU-Graz[1]
	SSt.	**Typ**	**ECTS**	**WS**	**SS**		
Praxiseinblick: Human Ressource Management[1]	1	KS	1	X	X	X	

[1]: Abhaltung in deutscher Sprache.

Anhang IV

Äquivalenzliste

Für Lehrveranstaltungen, deren Äquivalenz bzw. Anerkennung in diesem Teil des Anhangs zum Curriculum definiert ist, ist keine gesonderte Anerkennung durch das für studienrechtliche Angelegenheiten zuständige Organ mehr erforderlich. Auf die Möglichkeit einer individuellen Anerkennung nach § 78 UG per Bescheid durch das für studienrechtliche Angelegenheiten zuständige Organ wird hingewiesen.
Eine Äquivalenzliste definiert die Gleichwertigkeit von positiv absolvierten Lehrveranstaltungen dieses vorliegenden Curriculums und des vorhergehenden Curriculums. Diese Äquivalenz gilt in beide Richtungen, d.h. dass positiv absolvierte Lehrveranstaltungen des vorhergehenden Curriculums zur Anrechnung im vorliegenden Curriculum heranzuziehen sind, und positiv absolvierte Lehrveranstaltungen des vorliegenden Curriculums zur Anrechnung im vorhergehenden Curriculum.
Lehrveranstaltungen, die bezüglich Titel und Typ sowie Anzahl der ECTS-Anrechnungspunkte oder Semesterstundenanzahl übereinstimmen, sind äquivalent und werden deshalb nicht in der Äquivalenzliste angeführt.

Lehrveranstaltung aus dem auslaufendem Curriculum 2017 (2017W)				**Lehrveranstaltung aus dem vorliegenden Curriculum 2023 (2023W)**			
Lehrveranstaltung	**LV-Typ**	**SSt.**	**ECTS**	**Lehrveranstaltung**	**LV-Typ**	**SSt.**	**ECTS**
Pflichtmodul M							
Master`s Seminar in Astrophysics	SE	2	2	Master`s Seminar in Astro- and Space Physics	SE	2	2
Practical Training in Space Physics and Aeronomy	PT	3	6	Practical Training in Space Physics and Aeronomy	PT	3	7
Master`s Seminar in Space Physics and Aeronomy	SE	2	3	Master`s Seminar in Astro- and Space Physics	SE	2	2
Schwerpunktfach Astrophysics							
Solar Physics Lab	PT	1	1	Solar Physics Lab Tour	EX	1	1
Astrophysics Lab	PT	2	3	Astrophysics Lab	LU	2	3
Astrophysics Lab 2	PT	2	3	Astrophysics Lab 2	LU	2	3
Schwerpunktfach Experimental Physics							
Experimental Methods in Surface Science	VU	2	3	Research Laboratory Surface Science	LU	2	3
Research Laboratory Spectroscopy	LU	2	3	Research Laboratory Photon Science	LU	2	3
Spectroscopy	VO	2	3	Laser Spectroscopy	VO	2	3
Advanced Optics	VO	2	3	Optics – A Photonics Perspective	VO	2	3
Fundamental Optics	VO	2	3	Optics – A Spectroscopy Perspective	VO	2	3
Biomagnetism	VO	2	3	Theoretical Biophysics	VO	2	3

Lehrveranstaltung aus dem auslaufendem Curriculum 2017 (2017W)				Lehrveranstaltung aus dem vorliegenden Curriculum 2023 (2023W)			
Lehrveranstaltung	**LV-Typ**	**SSt.**	**ECTS**	**Lehrveranstaltung**	**LV-Typ**	**SSt.**	**ECTS**
Schwerpunktfach Atmospheric Physics and Climate							
Methods of Modeling and Simulation *und* Methods of Modeling and Simulation	VO *und* UE	2 *und* 2	3 *und* 3	Methods of Modeling and Simulation	VU	4	6
Atmospheric Measurement Methods: Remote Sensing	VO	2	3	Atmosphere and Climate Measurement Methods: Remote Sensing	VO	2	3
Atmospheric Measurement Methods: in situ	VO	2	3	Atmosphere and Climate Measurement Methods: in situ	VO	2	3
Seminar on Measurement Methods in Atmospheric Physics	SE	2	3	Seminar on Atmosphere and Climate Measurement Methods	SE	2	3
Schwerpunktfach Space Physics and Aeronomy							
Solar Physics Lab	PT	1	1	Solar Physics Lab Tuor	EX	1	1
Schwerpunktfach Theoretical and Computational Physics							
Green's Function for Solid-State Physics	VU	2	3	Quantum Theory of Many-Body Systems	VU	2	3
Computational Methods in Solid-State Physics	VU	2	3	Computational Methods in Nano Physics	VU	2	3
Theoretical Nano- and Quantum Physics	VO	2	3	Theoretical Nano- and Quantum Optics	VO	2	3
Advanced Ab-Initio Techniques	VO	2	3	Advanced Electronic Structure Theory	VO	2	3
Special Topics in: Foundations of Particle Physics	VO	2	3	Special Topics in: Particle Physics	VO	2	3
Physics Beyond the Standard Model	VO	2	3	Beyond the Standard Model	VO	3	4,5

Lehrveranstaltungen des vorherigen Curriculums, die bereits absolviert wurden, die aber im neuen Curriculum weder in einem Modul noch in der Äquivalenzliste vorkommen, können weiterhin in dem Modul, in dem sie ursprünglich vorkamen, angerechnet werden.

Wer „Synchrotron Radiation Techniques" bereits absolviert hat, kann sich das nach wie vor auch für Modul E3 anrechnen lassen. Wer „Computational Methods in Solid-State Physics" bereits absolviert hat, kann es sich entweder nach wie vor für Module T4 oder als „Computational Methods in Nanophysics" in T5 anrechnen lassen.

Anhang V

Glossar

Glossar der verwendeten Bezeichnungen, welche in den Satzungen und Richtlinien der beiden Universitäten unterschiedlich benannt sind.

Bezeichnung in diesem Curriculum (NAWI Graz)	**Bezeichnung Uni Graz**	**Bezeichnung TU Graz**
SSt.	KStd.	SSt.
Elective Topics		Wahlfach
Free Electives	Freie Wahlfächer	Freie wählbare Lehrveranstaltung