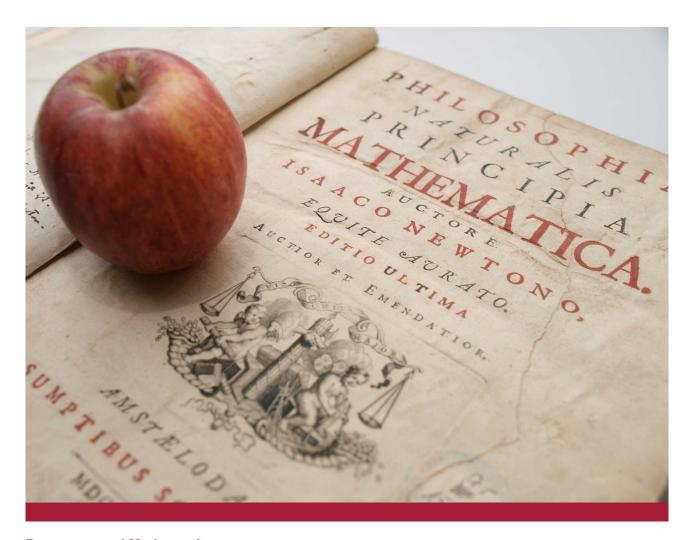
EBERHARD KARLS UNIVERSITÄT TÜBINGEN



Mathematisch-Naturwissenschaftliche Fakultät



Department of Mathematics

Module Handbook Mathematical Physics Master of Science

Summer Semester 2020

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1 Program description

1.1 Study Concept

The Master of Science Mathematical Physics is an international research-oriented two year master's program offered jointly by the departments of Mathematics and Physics within the Faculty of Science of the University of Tübingen starting every year in the winter semester. It is geared towards students with a solid background in Mathematics as well as in Physics, and it requires a bachelor's degree in physics or mathematics or an equivalent degree. The scientific discipline "Mathematical Physics" is concerned with the mathematically rigorous formulation and analysis of physical theories and models. In this master's program students will thus deepen and broaden their knowledge of Mathematics and Physics in interdisciplinary courses in Mathematical Physics as well as in disciplinary courses in Mathematics and Theoretical Physics. At the end of the program they are particularly well prepared for jobs where the typical competences of mathematicians are needed in combination with applications of physics. The program is international and cannot be pursued without a solid knowledge of the English language. Language skill on the level of B2 according to the European Framework of Reference for Languages are therefore required. All mandatory modules and a large number of facultative modules are offered only in English. Some facultative modules may sometimes be offered only in German.

1.2 Qualification Goals

Students deepen and broaden their theoretical knowledge of different areas of mathematical physics, mathematics and theoretical physics. They become proficient in general and specific methods and principles in these areas. They can connect problems and questions from physics with their counterparts in mathematical models and are able to judge and critically question the relevance and adequacy of mathematical models and the derived consequences. They are able to report on and scrutinize the current state of research in the area of their specialisation. Graduates can apply their expanded knowledge in order to develop and successfully handle their own research projects. They are able to present, discuss, and defend the results of their research in writing and orally in front of a scientific audience. In the course of the Mathematical Physics Colloquium students practice scientific collaboration and discourse in interdisciplinary and internationally mixed groups.

Their education enables graduates in mathematical physics to successfully and professionally tackle complex mathematical modelling problems in physics and, after an appropriate familiarization with the subject, also in other areas of technology, finance or economics. They are moreover well prepared for interdisciplinary and international collaborations in mixed teams of different specialists from different cultural backgrounds, as are common nowadays in all areas of research and development.

1.3 Program Structure

The Master's Program is a two year (four terms) consecutive study program with a modular structure. Based on the foundational modules "Geometry in Physics", "Functional Analysis in Geometry", "Mathematical Quantum Theory", and "Mathematical Relativity", to be attended during the first year, students can specialise rather freely according to their personal preferences in one or more areas of Mathematical Physics, Mathematics and/or Theoretical Physics. The few restrictions are that every student must take at least one module from the Mathematics master's program and one module from the Theoretical Physics master's program, as well as a seminar. As a consequence, all graduates of the Master's Program have proven their ability to successfully conduct mathematical studies and theoretical physics studies at the master's level. A Scientific Project in the third term typically serves as a preparation for the Master Thesis (M.Sc. Thesis, 30 ECTS-points) written during the final term. During the second year students are also required to attend the Mathematical Physics Colloquium. This is a weekly colloquium where specialists lecture about recent developments in Mathematical Physics, and students have the opportunity to meet and discuss with international guest scientists and local researchers about current topics. The prescribed period of study is two years corresponding to a total of 120 ECTS points.

1.4 Mentoring

At the start of the program every student will be assigned to a mentor from the group of professors involved in the master's program for the whole duration of his/her studies. Students meet their mentor at the beginning and later at least once per term in order to plan and discuss the progress of their studies. In particular, at these meetings the study and examination plan in compliance with the examination regulations is discussed. The module selection is documented and passed on to the head of the examinations board for approval. During the first meeting possible gaps in the knowledge should be discussed in order to fill them by taking appropriate courses within the area of elective specialisation. The study and examination plan is then updated every semester during the meetings with the mentor. The mandatory mentoring program assures that students specialise in a purposeful way and select accordingly goal-oriented combinations of modules from mathematics and physics.

During the meetings with the mentor also possible time slots for a study period at a university abroad can be discussed. In principle, every semester is suitable, depending on the study progress of the student and the courses available at the other institution. It is also possible to write the master's thesis during a stay abroad under the cosupervision of a scientist there.

1.5 Information for students with a bachelor's degree in Physics at the University of Tübingen

Graduates of the 4-year degree program Bachelor of Science in Physics at the University of Tübingen can already gain up to 60 credit points for the degree program Master of Science in Mathematical Physics during their bachelor studies.

In particular,

• the module BMTPKFT Klassische Feldtheorie from the bachelor's program can be credited with

9 credit points for the module MAT-40-32 Advanced Topics in Theoretical Physics in the master's program, and

• up to 21 credit points in the section Vertiefungsfach in the bachelor's program can be credited in the section Elective Studies, provided the choice is suitable.

Moreover,

- up to 27 credit points in the section Ergänzungsmodule in the bachelor's program can be gained via the modules MAT-65-11 Geometry in Physics, MAT-65-12 Mathematical Quantum Theory, MAT-65-13 Mathematical Relativity or MAT-65-14 Mathematical Statistical Physics from the master's program, and
- the bachelor's thesis can be credited with 9 credit points in the module Scientific Project.

In order to finish the Master of Science in Mathematical Physics subsequently to the bachelor's degree in Physics at the University of Tübingen it is recommended to choose in the section Vertiefungsfach in the bachelor's program courses in theoretical physics, which can be credited in the section Elective Studies in the master's program in Mathematical Physics. Moreover, it is recommended to choose in the section Ergänzungsmodule in the bachelor's program at least two of the modules MAT-65-11, MAT-65-12, MAT-65-13 or MAT-65-14 from the master's program in Mathematical Physics. Good choices would be the combinations MAT-65-11 + MAT-65-13 and MAT-65-12 + MAT-65-14. Also the combination MAT-65-11 and MAT-65-12 would be suitable.

2 Study Plans

2.1 Overview by Modules

We provide here an overview of the study plan as a table showing the modules to be taken.

Suggested Term	Module Number	Module Title	Type of Course	Type of Module	Assign- ments	Type of Exam	ECTS- Points
Section 1: I	oundations						
1	MAT-65-11	Geometry in Physics	L+E	PM	HA	wr. o. or.	9
1	MAT-65-12	Mathematical Quantum The- ory	L+E	PM	HA	wr. o. or.	9
2	MAT-65-13	Mathematical Relativity	L+E	PM	HA	wr. o. or.	9
Section 2: I	Knowledge E	xpansion					
1–3	MAT-40-31	Advanced Topics in Mathe- matics	L+E	PMW	HA	wr. o. or.	9
1–3	MAT-40-32	Advanced Topics in Theoreti- cal Physics	L+E	PMW	HA	wr. o. or.	9
2–3	MAT-40-33	Seminar Knowledge Exten- sion	S	PMW	s.M.	Р	3
Section 3: I	Elective Spec	ialisation		_			
2-3	MAT-65-14	Mathematical Statistical Physics	L+E	WPM	HA	wr. o. or.	9
2-3	MAT-65-15	Foundations of Quantum Mechanics	L+E	WPM	HA	wr. o. or.	9
2	MAT-65-21	Advanced Topics in Mathe- matical Quantum Theory	L+E	WPM	HA	wr. o. or.	9
2	MAT-65-22	Advanced Topics in Math- ematical Quantum Theory (short version)	L+E	WPM	HA	wr. o. or.	6
3	MAT-65-23	Advanced Topics in Mathe- matical Relativity	L+E	WPM	HA	wr. o. or.	9
3	MAT-65-24	Advanced Topics in Math- ematical Relativity (short version)	L+E	WPM	HA	wr. o. or.	6
Section 4: S	Scientific Wo	rk					
3	MAT-40-41	Scientific Project	Р	PM	s.M.	-	9
3–4	MAT-40-42	Mathematical Physics Collo- quium	C+C	PM	-	-	3
4	MAT-40-43	Master Thesis M.Sc. Mathe- matical Physics	MT	PM	s.M.	MT	30

Abbreviations:

L=lecture, S=seminar, SL=seminar or lecture, E=exercise class, Pr=project work, C=colloquium, T=tutorial PM=compulsory module, PMW=compulsory module with choice, WPM=elective module HA=homework assignment, MT=master thesis, or.=oral exam, wr.=written exam, o.=or, P=presentation s.M. = see module description

Within the area "Elective Specialization", the listed modules from the Mathematical Physics program can be chosen as well as a large number of advanced modules from the master's degree programs Mathematics, Physics, or Astro and Particle Physics, cf. Section 3.

2.2 Overview by the Course of Studies

We first provide a general study plan showing the distribution of credit points over the different areas and the general time line. On the following pages example study plans for different types of specialisation are provided, where possible courses are assigned to the modules MAT-40-31 and MAT-40-32 as well as the modules from the area of Elective Specialisation.

Term	СР	Foundations of Mathematical Physics	Knowledge Expansion	Elective Specialisation	Scientific Work
1.	27	07.00			
2.	30	27 CP	21 CP		
3.	31			30 CP	
4.	32				42 CP

Figure 2.1: General Study Plan

2.3 Example Study Plans

The example study plans shown below shall give an idea how the individual study in the different specialisations could look like. They are not meant as a recommendation, and it is neither guaranteed that the courses listed will be offered each year, nor that they all will be given in English.

Example Study Plan without Specialisation

Term	СР	Foundations of Mathematical Physics	Knowledge Expansion	Elective Specialisation	Scientif	ic Work
		Geometry in Physics (9 CP)	Linear Partial			
1.	27	Mathematical Quantum Theory (9 CP)	Differential Equations (9 CP)			
		Mathematical		Advanced Topics in Mathematical Quantum Theory (9 CP)		
2.	30	Relativity (9 CP)	Seminar(3 CP)	Mathematical Statistical Physics (9 CP)		
			Quantum Field	Advanced Topics in Mathematical Relativity (6 CP)		
3.	31		Theory and Particle Physics (9CP)	Advanced Topics in Mathematical Statistical Physics (6 CP)	Mathe- matical Physics	Scientific Project (9 CP)
4.	32				Colloquium (3 CP)	Master Thesis (30 CP)

Figure 2.2: The program Mathematical Physics can be completed to a large extent also without choosing a particular specialisation. In this case we recommend taking all four foundational modules and also all advanced courses offered. The modules from the area Knowledge Expansion should then be chosen in accordance with the planned specialisation in the Scientific Project and the Master Thesis, cf. e.g. the following study plans.

Example Study Plan Quantum Theory

Term	СР	Foundations of Mathematical Physics	Knowledge Expansion	Elective Specialisation	Scientif	ic Work
		Geometry in Physics (9 CP)				
1.	27	Mathematical Quantum Theory (9 CP)	Operator Theory (9 CP)			
2.	30	Mathematical Relativity (9 CP)	Quantum Field Theory and Particle Physics (9 CP)	Functional Analysis (9 CP)		
۷.	50		Seminar(3 CP)			
				Advanced Topics in Mathematical Quantum Theory (9 CP)		
3.	31			Computational Methods in Physics / Astrophysics (6 CP)	Mathe-	Scientific Project
				Theoretical Condensed Matter Physics (6 CP)	matical Physics Colloquium (3 CP)	(9 ČP)
4.	32					Master Thesis (30 CP)

Figure 2.3: The mathematical foundations of quantum theory are predominantly allocated to areas of analysis. Thus we recommend that those specialising in one of the areas Mathematical Quantum Theory, Quantum Field Theory, Condensed Matter, Many-Body Quantum Systems, or Quantum Information attend mathematical courses from analysis, e.g. Operator Theory, Partial Differential Equations, Calculus of Variations, and Numerical Analysis.

Example Study Plan Relativity

Term	СР	Foundations of Mathematical Physics	Knowledge Expansion	Elective Specialisation	Scientif	ic Work
		Geometry in Physics (9 CP)	Astronomy and			
1.	27	Mathematical Quantum Theory (9 CP)	Astrophysics (9 CP)			
2.	30	Mathematical Relativity (9 CP)	Introduction to Partial Differential Equations (9 CP)	Riemannian Geometry (9 CP)		
۷.	30		Seminar(3 CP)			
				Advanced Topics in Mathematical Relativity (9 CP)		
3.	31			Theoretical Astrophysics (6 CP)	Mathe-	Scientific Project
				Computational methods in Physics / Astrophysics (6 CP)	matical Physics Colloquium (3 CP)	(9 CP)
4.	32					Master Thesis (30 CP)

Figure 2.4: The mathematical foundations of relativity are predominantly allocated to areas of geometry and analysis. Thus we recommend that those specialising in one of the areas Mathematical Relativity, Astronomy, Cosmology, or Astro Physics attend mathematical courses from geometry, e.g. Riemannian Geometry and Lorentz Geometry, and from analysis, e.g. Partial Differential Equations, Calculus of Variations, and Numerical Analysis.

Example Study Plan Statistical Physics

Term	СР	Foundations of Mathematical Physics	Knowledge Expansion	Elective Specialisation	Scientific Work		
		Geometry in Physics (9 CP)					
1.	27	Mathematical Quantum Theory (9 CP)	Stochastic Processes (9 CP)				
		Mathematical	Advanced Statistical	Mathematical Statistical Physics (9 CP)			
2.	30	Relativity (9 CP)	Physics (9 CP)	Density Functional Theory (6 CP)			
				Advanced Topics in Mathematical Statistical Physics (6 CP)		Scientific	
3.	31		Seminar (3CP)	Mathematical Statistics (9 CP)	Mathe- matical Physics	Project (9 CP)	
4.	32				Colloquium (3 CP)	Master Thesis (30 CP)	

Figure 2.5: The mathematical foundations of statistical physics are predominantly allocated to areas of probability. Thus we recommend that those specialising in one of the areas Mathematical Statistical Physics, Soft Matter, or Density Functional Theory attend mathematical courses from probability, e.g. Stochastic Processes and Mathematical Statistics.

2.4 Overview by Study Progress and Credit Requirements

	rview by Study Progress an		-						1				
			Exam				Teaching				Те	erm	
		f Exam	Duration (min)	D	Weight in the final grade	f Course			Points (CP)	ECTS is a red Comple are ma allocat to coult tion on	points to commenulsory all arked as ion of Eu rses is fo ily. Cred ed upon	of exam o semest idation o locations such. T CTS poin or inform its are o complet	ters nly. S he nts a- nly
		Type of E	uratio	Grading	eighi	Type of	Status	SWS	ECTS	1.	2.	3.	4.
				Ū	3	È	5 V	S	ш	СР	CP	СР	CP
Fou	ndations of Mathematical Pl	nysics:							27				
MAT	-65-11 Geometry in Physics					1	[6	9		[[
1.	Lecture	Wr. or	90–120 or	g	9	L	0	4		6			
2.	Exercises	Or.	20–30			E	0	2		3			
MAT	-65-12 Mathematical Quantun	n Theor	у		1	1		6	9				
1.	Lecture	Wr. or	90–120 or	g	9	L	0	4		6			
2.	Exercises	Or.	20–30			E	0	2		3			
MAT	-65-13 Mathematical Relativity	/			1		Γ	6	9		1		
1.	Lecture	Wr. or	90–120 or	g	9	L	0	4			6		
2.	Exercises	Or.	20–30			E	0	2			3		
Kno	wledge Expansion:							1	21				
MAT	-40-31 Advanced Topics in Ma	athemat	ics	I	1	1	T	6	9				
1.	Lecture	Wr. or	90–120 or	g	9	L	0	4		6			
2.	Exercises	Or.	20–30			E	0	2		3			
MAT	-40-32 Advanced Topics in Ph	ysics		I	1		Γ	6	9				
1.	Lecture	Wr. or	90–120 or	g	9	L	0	4			6		
2.	Exercises	Or.	20–30	3		E	0	2			3		
MAT	-40-33 Seminar							2	3				
1.	Seminar	Pres.	45–90	g	3	S	0	2				3	
Elec	ctive Specialisation:								30				
l	Here the modules MAT-65-15 Master's Programs in Mathem be discussed and agreed upor board.	atics, P	hysics, and	d Astro	o and	Partic	cle Physic	s, can	i be cl	nosen. 1	The choi	ces need	d to
MAT	-65-14 Mathematical Statistica	al Physi	CS					6	9				
1.	Lecture	Wr.	90–120	a	9	L	f	4			6		
2.	Exercises	or Or.	or 20–30	g	9	E	f	2			3		

			Exam				Teaching	J			Те	rm	
		Type of Exam	Duration (min)		Weight in the final grade	Course			Points (CP)	ECTS is a red Compl are ma allocat to coun tion on	points to commen ulsory al arked as ion of E0 rses is fo ly. Cred ed upon	of exame o semest dation o locations such. Ti CTS poir or inform its are of complet	ters nly. S he nts a- nly
		e of	atio	Grading	ight	Type of (Status	S	ECTSF	1.	2.	3.	4.
		Typ	Du	Ū	We	Typ	Sta	SWS	ШC	СР	СР	СР	СР
MAT	-65-21 Advanced Topics in Ma	athemat	ical Quantu	um Th	eory	1	I	6	9				
1.	Lecture	Wr.	90–120 or	g	9	L	f	4			6		
2.	Exercises	or Or.	or 20–30	g	5	E	f	2			3		
MAT	-65-22 Advanced Topics in Ma	athemat	ical Quantı	um Th	eory	(short	version)	4	6				
1.	Lecture	Wr. or	90–120 or	a	6	L	f	2			3		<u> </u>
2.	Exercises	Or.	20–30	9	g 6 E f 2 3								
MAT	-65-23 Advanced Topics in Ma	athemat	ical Relativ	ity			ſ	6	9				
1.	Lecture	Wr. or	90–120 or	g	9	L	f	2				3	
2.	Exercises	Or.	20–30			E	f	2				3	
MAT	-65-24 Advanced Topics in Ma	athemat	ical Relativ	ity (sł	nort ve	ersion)	4	6				
1.	Lecture	Wr. or	90–120 or	g	6	L	f	2				3	
2.	Exercises	Or.	20–30			E	f	2				3	
Scie	entific Work							1	42				
MAT	-40-41 Scientific Project			1	1	1	I		9				
1.	Project	Proj.		ng	9		0					9	
MAT	-40-42 Mathematical Physics	Colloqu	ium	I	1	T	1		3				
1.	Colloquium			ng			0					1	2
MAT	-40-43 Master Thesis				1	1	I		30				
1.	Thesis	Thes.		g	30		0						30
	Form of examination : MA=N Form of teaching : L=lect Status : o=obli	laster T ure, E= gatory,	=non grade hesis, Or.= exercise cla f=fakultativ nours in cla	oral e ass, S e	S=sem	iinar, I	⊃roj.=proj	ect wo	ork, Čo	oll.=collo			

3 Module Descriptions

Section 1: Foundations

In the case that some of the mandatory modules in this section or modules, which are essentially identical as far as the contents and competences are concerned, have been part of the Bachelor studies, which are the prerequisite for this Master's Degree Program, according to the examination regulations these modules cannot be taken in the Master's Degree Program any more. They have to be replaced by other suitable modules in the framework of the studies and examination plan.

Module Number: MAT-65-11	Module Title: Geometry in Physics		Type of Module: Compulsory Module							
ECTS-Points	9									
Workload - Time in Class - Self-Study	Workload:Time in Class:Self-Study:270 h90 h180 h									
Duration	1 Semester									
Frequency	regularly in Winter Semester									
Term	1									
Language of Instruction	ts 9 lass Workload: 270 h Time in Class: 90 h Self-Study: 180 h 1 Semester 180 h 1 Semester 1 regularly in Winter Semester 1 1 Image: Classes 2 SWS, Homework Assignements eaching ng Lectures 4 SWS + Exercise Classes 2 SWS, Homework Assignements The module provides an introduction to fundamental methods of differential geometry and the relevance for physics. Particular topics are manifolds, differential forms, Riemannian metric and associated notions of curvature, Riemannian geometry of submanifolds, real vector bur dles, and connections. Applications of these concepts in Physics are discussed. Students obtain knowledge, understanding, and acquaintance with the use of the listed notions of differential ageometry. They develop, in particular, a deeper understanding of differential ageometry. They develop, in particular, a deeper understanding of differential geometry. They develop, in particular, a deeper understanding of differential ageometry. They develop, in particular, a deeper understanding of differential and integral calculus and experience through examples how the mathematical notion are naturally applied within physical theories. Students obtain knowledge, understanding of differential geometry. They develop, in particular, a deeper understanding of differential and integral calculus and experience through examples how the mathematical notion are naturally applied within physical theories. Students obtain knowledge, understanding of differential and integral calculus and experience through examples how the mathematical notions are naturally app									
Forms of Teaching and Learning	270 h 90 h 180 h 1 Semester regularly in Winter Semester 1 1 English Image: Semester Semester 1 English Image: Semester Semestring and Semester Semester Semester Semestris Semester Semesenda									
Content										
Objectives	Geometry in Physics Compulsory Module 9 Vorkload: Time in Class: Self-Study: 270 h 90 h 180 h 1 Semester regularly in Winter Semester 1 1 English Image: Self-Study: Self	, a deeper understanding of differ- ples how the mathematical notions ain knowledge, understanding, and ial geometry. They develop, in par- al calculus and experience through plied within physical theories. Stu- ts and concepts from the lecture as to put it into a larger framework. Idents develop a confident, precise, ints, and methods explained in the ew problems, to analyse them and oup. They are able to present their								

Requirements for Obtaining Credit, Grading, Weight if applicable	Title	Type of Course	Status	SWS	ECTS	Assignments	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade	
	Geometry in Physics	L	0	4	6	yes	wr. o.	90-180	g	100	
		E	o	2	3		or.	o. 20-30			
	In this module students need the exam. The type of examin							in order to	be adr	nitted to	
Literature	Exemplary Literature:										
	John Lee: Introduction	to sn	nootł	n ma	nifolo	ds. Spr	inger 2012.				
	John Lee: Riemannian	man	ifolds	s: An	intro	oductio	n. Springer	1997.			
	Chris Isham: Modern of the second secon	differe	ntial	geo	metry	y for ph	iysicists. Wo	orld Scientifi	c 1999).	
	Mikio Nakahara: Geon	netry,	Торс	ology	and	Physic	s. IOP Pub	lishing 2003			
Transfer	Participation in the module is ativity. Successful completio module Seminar Knowledge Project.	n of t	the r	nodu	ile m	ay be	a prerequis	ite for parti	cipatio	n in the	
Prerequisites	-	hristoph Bohle, Carla Cederbaum, Stefan Teufel									
Responsible Persons	Christoph Bohle, Carla Ceder										
	ed, h=hour, wr.=written exam, =presentation, S=seminar, SL=										

o=obligatory, o.=or, P=presentation, S E=exercise class, L=lecture, T=tutorial

Module Number: MAT-65-12	Module Title:	r\/						of Module: ulsory Modul					
	Mathematical Quantum Theo	ry					Compl	lisory Modu	le				
ECTS-Points	9												
Workload - Time in Class - Self-Study	Workload: 270 h	Time 90 h	in C	lass	:		Self-St 180 h	udy:					
Duration	1 Semester												
Frequency	regularly in Winter Semester												
Term	1												
Language of Instruction	English												
Forms of Teaching and Learning	Lectures 4 SWS + Exercise 0	ectures 4 SWS + Exercise Classes 2 SWS, Homework Assignements											
Content	stationary and time-dependen Rayleigh-Schrödinger perturn space formalism, and elemer	he module provides an introduction to mathematical quantum theory. Particular topics are the tationary and time-dependent Schrödinger equation, fundamental approximation methods as tayleigh-Schrödinger perturbation theory and Hartree- resp. Hartree-Fock theory, the Fock pace formalism, and elements of scattering theory. Optionally, other topics such as adiabatic neory and semiclassical approximations can be discussed.											
Objectives	Students obtain knowledge a them to analyse known and r physical problems in atom, s spectral and interference there the mathematical model and amples how the mathematica they enhance their knowledg derstanding of the listed notion problems from quantum theore state and particle pysics and retical methods and to quest of the results derived from it, notions are naturally applied on methods and subjects. Str concepts from the lecture as it into a larger framework. Through homework assignment and independent acquaintant lectures. They learn how to to develop solution strategies solutions and to stand for the	new provide state of the contract of the contr	roble ate a al mee e res pons a metho mat e rele ents s are s to e nd e: h the er th eir o	ms f fand particular for the fand particular for the factor of the facto	rom partic s an deriv atura and s ds au ds au ds au erien theo to n theo to n theo theo theo theo theo theo theo theo	quantucle pysi d to qui ed fror ally app subjects nd can o interr I mode nd ade nce thro ries. T aame al e conto asses , state nods to vithin a	Im theory. T cs and thei lestion the r n it. Studer lied within p s. Students use them t elate physic els via spec quacy of the bugh examp hereby, they nd prove the ext develope students de ments, and o new proble group. The	They are able r mathemati- elevance an its experience obtain know o analyse ki cal problems tral and inte e mathemati- oles how the y enhance the e essential s ed in the lect welop a cont methods ex- ems, to ana ey are able to	e to inf cal mo d adec ce thro pries. T /ledge nown a in ato rference cal mo tateme ture ar fident, cplaine lyse th	errelate dels via quacy of ough ex- Thereby, and un- and new m, solid ce theo- odel and ematical owledge ents and d to put precise, d in the em and			
Requirements for Obtaining Credit, Grading, Weight if applicable	Title	pe of Course atus MS CTS CTS Ssignments ssignments pe of Exam (min) ur. of Exam (min) ur. of Exam (min)											
	Mathematical Quantum	L	0	4	6	yes	wr. o.	90-180	g	100			
	Theory In this module students need					nplete a		o. 20-30 s in order to		nitted to			
		the exam. The type of examination is set by the instructor.											
Transfer	ticipation in the module Adva pletion of one of the modules	Successful completion of module Mathematical Quantum Theory is a prerequisite for the par- ticipation in the module Advanced Topics in Mathematical Quantum Theory. Successful com- pletion of one of the modules Mathematical Quantum Theory and Mathematical Relativity is a prerequisite for the participation in the module Scientific Project.											

Prerequisites	-
Responsible Persons	Christian Hainzl, Stefan Teufel
Abbreviations:	

Module Number: MAT-65-13	Module Title: Mathematical Relativity							of Module:	le	
ECTS-Points	9						· ·			
Workload - Time in Class - Self-Study	Workload: 270 h	Time 90 h	in C	lass	:		Self-St 180 h	udy:		
Duration	1 Semester						I			
Frequency	regularly in Summer Semeste	ər								
Term	2									
Language of Instruction	English									
Forms of Teaching and Learning	Lectures 4 SWS + Exercise C	Classe	es 2 S	SWS	, Hor	meworl	k Assignem	ents		
Content	The module provides an intro ics are Newton's theory of g equation, Schwarzschild mod ter models, black holes, Cau gravitational waves can be dis	pravity del. C uchy p	, spe ptior proble	ecial nally,	theo othe	ory of r er topic	elativity, rel s such as c	ativistic effe cosmologica	cts, E I mode	instein's els, mat-
Objectives	Students obtain knowledge a use them to analyse known a interrelate physical problems through methods from different mathematical model and of th on methods and subjects ga 65-11. Students are able to r lecture as well as to explain framework. Through homework assignment and independent acquaintan lectures. They learn how to to develop solution strategies solutions and to stand for the	and no in co ntial g ie resi ined t name the c ents a ce wit transf on th	ew p smol eomo ults c hrou and i onte nd e th the fer the	roble ogy etry a lerive ghou prove xt de xerci e not ese wn a	ms f and to and to ed fro to the the evelop se cl tions meth and w	rom the astroph o quest om it. T e first s essen ped in asses , state nods to vithin a	e theory of hysics and t ion the rele hereby, the emester, in tial stateme the lecture students de ments, and new proble group. The	relativity. The cheir mather vance and a y enhance the particular in nts and con and to put velop a content methods exerts, to ana	ney are natical dequa neir kno n modu cepts it into fident, cplaine lyse th	e able to models cy of the owledge ule MAT- from the a larger precise, d in the mem and
Requirements for Obtaining Credit, Grading, Weight if applicable	Title Mathematical Relativity	T Type of Course	o Status	SMS 4	9 ECTS	ak Assignments	Type of Exam o.	Dur. of Exam (min) 081-06	ه Grading	00 Weight for Grade
		Е	0	2	3		or.	o. 20-30		
	In this module students need the exam. The type of examine							s in order to	be adr	nitted to
Transfer	Successful completion of mod in the module Advanced Top the modules Mathematical R the participation in the modul	ics in Ielativ	Mat ity o	hema r Ma	atical them	l Relati	vity. Succe	ssful comple	etion o	f one of
Prerequisites	Participation in the module G	eome	try ir	l Phy	sics	is a pro	erequisite.			
Responsible Persons	Carla Cederbaum, Gerhard H	luiske	n, Fr	ank	Loos	e				

Abbreviations:

Section 2: Knowledge Expansion

MAT-40-31	Module Title: Advanced Topics in Mathema	atics						of Module: ulsory Modu	le with	Choice
ECTS-Points	9									
Workload - Time in Class - Self-Study	Workload: 270 h	Time 90 h	in C	lass	:		Self-S 180 h	tudy:		
Duration	1 Semester						·			
Frequency	Every Semester									
Term	1–3									
Language of Instruction	English or German									
Forms of Teaching and Learning	Lectures 4 SWS + Exercise (Classe	s 2 S	SWS	, Hoi	meworl	k Assignem	ents		
Content	It is required to attend one of the correspondent SWS-cover mended subjects are for insta- tions, Harmonic analysis, Lie tic processes, Calculus of va- geometry. Further details car Mathematics.	erage f ance F group ariation	rom Partia s, No ns, S	the N al difi onlin Symp	Maste feren ear fi olectie	er's deq Itial equunctior c geon	gree progra uations, Nu nal analysis netry, Algeb	m in Mathem merics of dif , Operator th praic topolog	natics. ferenti eory, S y or A	Recom- al equa- Stochas- Igebraic
Objectives	The students aquire deepend of physical applications. They the methods at hand to tackle	/ broa e math	den i nema	the b atical	asis prot	of thei olems.	r mathemat The further	ical knowled	ge and	dextend
	ticular the concrete content r of the chosen course in the n									
Requirements for Obtaining Credit, Grading, Weight if applicable	ticular the concrete content r									
for Obtaining Credit, Grading, Weight if	ticular the concrete content r of the chosen course in the n	nodule	han	dboo	ok fo	r the M	.Sc. Mathe	matics.	ule des	scription
for Obtaining Credit, Grading, Weight if	ticular the concrete content r of the chosen course in the n Title Advanced Topics in	L L E to suc	o Status	SMS 4 2 sfully	SLOJ 6 3 7 com	r the M stue yes pplete a	Sc. Mathe	matics. (iiii) Dr. of Dr. of 90-180 o. 20-30	g g	Meight for Grade
for Obtaining Credit, Grading, Weight if	ticular the concrete content r of the chosen course in the n Title Advanced Topics in Mathematics In this module students need	L L L L L L L L L L L L	e han Statns 0 0 0 0 0 0	on Mon Mon Mon Mon Mon Mon Mon Mon Mon Mon	SLOU 6 3 7 conr the i	r the M stue Wubisse yes pplete a nstruct	Sc. Mathe	matics. (iiii) Dr. of Dr. of 90-180 o. 20-30	g g	Meight for Grade
for Obtaining Credit, Grading, Weight if applicable	ticular the concrete content r of the chosen course in the n Title Advanced Topics in Mathematics In this module students need the exam. The type of examin	L L L uisite	e han shan o ccess is se for th	sfully ne m	SLO U G G G G G G S C C M C C M C C M C C M C C M C C M C	r the M stue Ubisse yes nplete a nstruct	Sc. Mathe	matics. (iiii) Dr. of Dr. of 90-180 o. 20-30	g g	Meight for Grade

MAT-40-32	Module Title: Advanced Topics in Theoretic	al Phys	sics				of Module: ulsory Modul	le with	Choice
ECTS-Points	9								
Workload - Time in Class - Self-Study	Workload: 270 h	Time ii 90 h	n Clas	s:		Self-St 180 h	udy:		
Duration	1 Semester								
Frequency	Every Semester								
Term	1–3								
Language of Instruction	English or German								
Forms of Teaching and Learning	Lectures 4 SWS + Exercise 0	Classes	2 SW	S, Hor	meworl	k Assignem	ents		
Content	It is required to attend one physics as well as the response from the Master's degree pro- ticls Physics. Recommende physics, Theoretical astrophy Advanced statistical physics, tum optics, Quantum informat trophysics, Current topics in handbook of the corresponding	ective e gram in d subje rsics, Re rsics, Re r	exercise n Physi ects ar elativis fills the eory, C ical ph	e clas ics or e for stic as eory, C cosmo ysics.	ses wi the Ma instanc trophys Conden logy, N Furth	ith the corre aster's degre ce Quantum sics, Many- used matter Jumerical m	espondent S ee program i field theor particle qua physics, The ethods in pl	SWS-c Astro a y and ntum s eoretic hysics	overage and Par- Particle systems al quan- and as-
		ig degr	ree pro	grams	5.				
Objectives	The students aquire deepen pendently of rigorous mather theoretical physics and exten qualification goals, in particul the module description of the the M.Sc. Astro and Particle	d know natical f d the m ar the c choser	/ledge formali iethods concret	in on ism. T s at ha e cont	e selec They br and to ta tent rela	oaden the t ackle proble ated qualifa	basis of their ms in physic ction goals,	r know cs. The will foll	ledge ir e furthei low from
Objectives Requirements for Obtaining Credit, Grading, Weight if applicable	The students aquire deepen pendently of rigorous mather theoretical physics and exten qualification goals, in particul the module description of the the M.Sc. Astro and Particle	d know natical f d the m ar the c choser Physics	vledge formali aethods concret n cours s.	in on ism. T s at ha e cont se in t	e selec They br and to ta tent rela	ackle proble ackle proble ated qualifa dule handbo mex H b o e d L	Dasis of their ems in physic ction goals, bok for the N ((r know cs. The will foll	ledge in e further ow from
Requirements for Obtaining Credit, Grading, Weight if	The students aquire deepen pendently of rigorous mather theoretical physics and exten qualification goals, in particul the module description of the the M.Sc. Astro and Particle	d know natical 1 d the m ar the c choser Physics O S O O O O O O O O O O O O O O O O O	/ledge formali iethods concret n cours s.	in on ism. T s at ha e cont se in t	e selec They br and to ta tent rela he moo	Exactle proble ackle proble ated qualifa dule handbo	Example of the series of the s	r know cs. The will foll 1.Sc. P	e further ow from Pysics or ov
Requirements for Obtaining Credit, Grading, Weight if	The students aquire deepen pendently of rigorous mather theoretical physics and exten qualification goals, in particul the module description of the the M.Sc. Astro and Particle Title Advanced Topics in	d know natical 1 d the m ar the cc choser Physics O to succ L E to succ	vledge formali eethods oncretin n cours s. sntet S. 0 4 0 2 cessful	in on ism. T s at ha e cont se in t U U U U U U U	e selec They br and to t tent rela he mod stue uses Se yes	wr. o. or. assignments	90-180 o. 20-30	r know cs. The will foll 1.Sc. P built bui	ledge ir e further low from Pysics of egg tub S S S S S S S S S S S S S S S S S S S
Requirements for Obtaining Credit, Grading, Weight if applicable	The students aquire deepen pendently of rigorous mather theoretical physics and exten qualification goals, in particul the module description of the the M.Sc. Astro and Particle Title Advanced Topics in Theoretical Physics In this module students need	d know natical f d the m ar the cc choser Physics O to ega O to ega C to E to succ nation is	vledge formali eethods oncretin n cours s. sntet S o 4 o 2 cessfull s set by	in on ism. T s at ha e cont se in t U U U U U U U U U U U U U U U U U U U	e selec They br and to t tent rela he mod stue Ubiss V yes nplete a nstruct	wr. o. or. or.	90-180 o. 20-30	r know cs. The will foll 1.Sc. P built bui	ledge ir e furthe low from Pysics o egg tug tug Sub tug Sub tug Sub tug Sub tug Sub tug Sub tug Sub tug Sub tug Sub tug Sub tug Sub tug Sub tug Sub tug Sub tug Sub tug Sub Sub Sub Sub Sub Sub Sub Sub Sub Sub
Requirements for Obtaining Credit, Grading, Weight if	The students aquire deepen pendently of rigorous mather theoretical physics and exten qualification goals, in particul the module description of the the M.Sc. Astro and Particle Title Advanced Topics in Theoretical Physics In this module students need the exam. The type of examin	d know natical f d the m ar the cc choser Physics O to ega O to ega C to E to succ nation is uisite fo	vledge formali eethods oncretin n cours s. oncretin n cours s. oncretin n cours s. oncretin n cours s. oncretin n cours s. oncretin n cours s. oncretin n cours s. oncretin n cours s. oncretin n cours s.	in on ism. T s at ha e cont se in t b U u d 6 3 ly com y the i naster	e selec They br and to t tent rela he mod stue Ubiss V yes nplete a nstruct	wr. o. or. or. or.	asis of their ems in physic ction goals, bok for the M (IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII	r know cs. The will foll 1.Sc. P buipper g g be adr	ledge ir e furthe low from Pysics o eperge Lor Hole No 100 nitted to

Module Number: MAT-40-33	Module Title: Seminar Knowledge Extension	on						f Module: Ilsory Modu	le with	Choice
ECTS-Points	3						·			
Workload - Time in Class - Self-Study	Workload: 90 h	Time 30 h	in C	lass:			Self-St 60 h	udy:		
Duration	1 Semester									
Frequency	Every Semester									
Term	2–3									
Language of Instruction	English or German									
Forms of Teaching and Learning	Seminar: Presentation, Disc	ussion	, Tea	mwo	ork, ⊢	landou	t			
Content	Various topics from various Physics.	area	s of	Mat	hema	atical F	Physics, Ma	athematics	or The	eoretical
Objectives	The students have learnt to vanced topic in Mathematics form of an oral presentation. ical or physical results and a	s or Pl They l	hysic have	s by impr	app rovec	lying s I their s	cientific me skills in the p	thods and to presentation	o pres o of ma	ent it in
Objectives Requirements for Obtaining Credit, Grading, Weight if applicable	vanced topic in Mathematics form of an oral presentation.	s or Pl They l	hysic have	s by impr	app rovec	lying s I their s	cientific me skills in the p	thods and to presentation	o pres o of ma	ent it in
Requirements for Obtaining Credit, Grading, Weight if	vanced topic in Mathematics form of an oral presentation. ical or physical results and a	s or Pl They re able	hysic have to a	s by impr rgue	app rovec for t	lying s I their s hese re	cientific me skills in the p esults in crit	thods and to presentation ical discuss	o pres o of ma ions.	ent it in themat-
Requirements for Obtaining Credit, Grading, Weight if	vanced topic in Mathematics form of an oral presentation. ical or physical results and a	s or Pl They f re able esuno S	hysic have to a Statns o	s by impr rgue SMS 2	app rovec for t SLOJ 3	lying s I their s hese re Suments yes	Listentific me skills in the p esults in crit Exam Exam Exam Exam Exam Exam P	thods and to presentation ical discuss (U E M B C C C C C C C C C C C C C C C C C C	o pres of ma ions.	ent it in themat- Crade
Requirements for Obtaining Credit, Grading, Weight if applicable	vanced topic in Mathematics form of an oral presentation. ical or physical results and a Title Seminar	s or Pl They l re able S L uuisite	hysic have to a Status 0 for th	s by impr rgue SMS 2 ne ma	app rovec for t SLO 3 aster	lying s I their s hese re stue Wubisse yes thesis	cientific me skills in the p esults in crit T D e of E X T P	thods and to presentation ical discuss (()))))))))))))))))	o pres o of ma ions. Dupper g	ent it in themat- Meight for Grade 100

Section 3: Elective Specialisation

Within the study area Elective Specialization students can choose modules from the Master Programs Mathematical Physics, Mathematics, Physics, and Astro and Particle Physics according to their individual interests. In particular, courses listed in the module descriptions MAT-40-31 and MAT-40-32 but not chosen there, the module MAT-65-13 respectively MAT-65-14 not yet chosen in the area Foundations, the modules MAT-65-15 and MAT-65-21 to MAT-65-24, as well as other appropriate advanced modules from the programs Mathematical Physics, Mathematics, Physics, and Astro and Particle Physics are available. Note that not all modules can be offered every year, but there is always a broad choice. Also note that some modules from other programs might be offered only in german, but also here a choice of english courses is ensured. The selection of modules within the area Elective Specialisation must be discussed and decided together with the mentor. Each module can be selected only once. In agreement with the mentor and upon request at the examinations board, 9 ECTS points within the area of Elective Specialisation can be allocated for modules that serve to close knowledge gaps either in mathematics or physics.

Within the area of Elective Specialisation students obtain relevant skills. They learn to independently judge which additional qualifications and competences are relevant to their studies and to select courses accordingly. They are able to acquire specific knowledge also beyond the mandatory parts of the study program. Within the area of their specialisation they can report on and scrutinize the current state of research. In the exercise classes students learn to work confidently, precisely and independently with the notions, statements and methods presented during the lectures. They also learn how to apply methods to new problems and to analyse and solve them alone or in groups.

Module Number: MAT-65-14	Module Title: Mathematical Statistical Phy	sics	Type of Module: Elective Module
ECTS-Points	9		
Workload - Time in Class - Self-Study	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Duration	1 Semester		
Frequency	not regularly, in Summer Sei	mester	
Term	2-3		
Language of Instruction	English		
Forms of Teaching and Learning	Lectures 4 SWS + Exercise	Classes 2 SWS, Homework A	ssignements
Content	concepts of probability theor bles, thermal equilibrium, E cesses, Wiener process), la phase transitions), statistica tion to thermal equilibrium, E	y, classical statistical mechani oltzmann equation, entropy), ttice models (Ising model, Gil Il quantum mechanics (quant Bose-Einstein condensate). O t phenomena, renormalizatior	istical physics. Particular topics are cs of gases (equivalence of ensem- Brownian motion (stochastic pro- obs measure, thermodynamic limit, um mechanical ensembles, transi- ptionally, other topics such as open a group theory and the fluctuation-
Objectives	use them to analyse known interrelate fundamental phy and their mathematical mod adequacy of the mathematic their knowledge on methods on probability theory. Stude concepts from the lecture as it into a larger framework. Through homework assignm and independent acquaintan lectures. They learn how to to develop solution strategie	n and new problems from sta sical concepts, such as equi lels vie probabilistic methods al model and of the results der s and subjects gained through ents are able to name and p well as to explain the context nents and exercise classes stu- nce with the notions, statement of transfer these methods to not	ted notions and methods and can atistical physics. They are able to librium, irreversability and entropy, and to question the relevance and rived from it. Thereby, they enhance nout the first semester, in particular rove the essential statements and developed in the lecture and to put idents develop a confident, precise, ents, and methods explained in the ew problems, to analyse them and oup. They are able to present their cessary.

Requirements for Obtaining Credit, Grading, Weight if applicable	Title	Type of Course	Status	SWS	ECTS	Assignments	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
	Mathematical Statistical	L	f	4	6	yes	wr. o.	90-180	g	100
	Physics	Е	f	2	3	,63	or.	o. 20-30	9	100
	In this module students need the exam. The type of examin							in order to	be adn	nitted to
Transfer	Successful completion of mod Topics in Mathematical Statist				uisite	e for the	e participatic	on in the moo	dule Ac	lvanced
Prerequisites	-									
Responsible Persons	Marcello Porta, Roderich Turr	iulka								
Abbreviations:	nd h-hour wr-written exam	MT-	maet	tor th	nocie	or –c	oral evam	na-not araa	had	

Module Number:	Module Title:						Type o	of Module:		
MAT-65-15	Foundations of Quantum Me	chanic	cs					e Module		
ECTS-Points	9									
Workload - Time in Class - Self-Study	Workload: 270 h	Time 90 h	e in C	lass	:		Self-St 180 h	udy:		
Duration	1 Semester									
Frequency	regularly every two years									
Term	2-3									
Language of Instruction	English									
Forms of Teaching and Learning	Lectures 4 SWS + Exercise (Classe	es 2 \$	SWS	, Hor	neworł	k Assigneme	ents		
Content	The module provides an intro ing their mathematical and p hagen, Bohmian mechanics, troduced and analysed math Heisenberg's uncertainty rela orem, identical particles, and	ohiloso many emati ation, t	ophic / wor cally he q	al as rlds, and uant	spect and phys um m	s. Diff sponta sically. neasure	erent interp neous wave Further top ement proble	pretations su e function c bics include	ich as ollapse the Bo	Copen- e are in- orn rule,
Objectives	Students know and can app understand several importan ematical knowledge relevant matical treatment to the phy phenomena and paradoxes about the orthodox interpret foundational issues. Student cepts from the lecture as we into a larger framework. Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategies solutions and to stand for the	t theo to us sical r of qua ation s are ation s are ation s are s are transf s on th	ries of ing t mear antur and able o exp nd e for th fer th neir of	of ho hese ning. m me why, to na blain xerci e no iese wm a	w the rule The echai and the c se cl tions meth and w	e quan s and y fami nics. T are at and pro context asses , staten nods to vithin a	tum world w theories and liarise them They apprecedule to follow ove the essed developed students de ments, and new proble group. The	vorks. They d can conne selves with ciate what is contempor ential statem in the lectur velop a cont methods ex ems, to ana ey are able t	acquir ect the the su s contr ary de nents a re and fident, cplaine lyse th	e math- mathe- rrprising oversial bate on nd con- to put it precise, d in the em and
Requirements for Obtaining Credit, Grading, Weight if applicable	Title	Type of Course	Status	SWS	ECTS	Assignments	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
	Foundations of Quantum Mechanics	L	f f	4 2	6 3	yes	wr. o. or.	90-180 o. 20-30	g	100
	In this module students need the exam. The type of exami							s in order to	be adr	nitted to
Transfer	-									
Prerequisites	The basic modules on Analy	sis an	d Lin	ear A	Algeb	ora are	required.			
Responsible Persons	Roderich Tumulka									

Abbreviations:

Module Number: MAT-65-21	Module Title: Advanced Topics in Mathem	atical C	Quant	tum The	eory		of Module: re Module		
ECTS-Points	9								
Workload - Time in Class - Self-Study	Workload: 270 h	Time 90 h	in Cla	ass:		Self-Si 180 h	tudy:		
Duration	1 Semester					·			
Frequency	not regularly, in Summer Se	mester							
Term	2								
Language of Instruction	English								
Forms of Teaching and Learning	Lectures 4 SWS + Exercise	Classe	s 2 S	WS, Ho	mewor	k Assignem	ents		
Content	The module provides an int like Hartree and Hartree-For mathematical models in qua tems. It will present both th particular area, as well as propen problems.	ock theo antum fi e funda	ory, E ield tl amen	BCS the heory a ntal mat	eory, ac and tran hematic	liabate theo sport in inte cal results a	ory, renorma erdependent and physical	lisatior fermir notion	n group non sys ns of the
Objectives			بالم الم	ondina	of the c	oquirad pat		thode	and are
Objectives	Students obtain knowledge able to apply them in the an- ematical Quantum Theory. S concepts from the lecture as it into a larger framework. T of research in the specific an Through homework assignm and independent acquainta lectures. They learn how to to develop solution strategie solutions and to stand for th	alysis o Students well as hey are rea. nents ar nce with transfe s on the	If know s are s to e able nd ex h the er the eir ov	wn and able to explain t to des ercise o e notion ese me wn and	new pr name a he cont cribe ar classes s, state thods to within a	oblems from and prove the ext developed and critically of students de ments, and ponew problect group. The	n the specific e essential s ed in the lec challenge th evelop a cont methods ex ems, to ana	c area (tateme ture ar e curre fident, (plaine lyse th	of Math ents and nd to pu ent state precise d in the nem and
Objectives Requirements for Obtaining Credit, Grading, Weight if applicable	able to apply them in the an ematical Quantum Theory. S concepts from the lecture as it into a larger framework. T of research in the specific at Through homework assignm and independent acquainta lectures. They learn how to to develop solution strategies solutions and to stand for th Title Advanced Topics in Mathematical Quantum Theory	alysis o Students well as hey are ea. hents ar noce with transfe s on the em in a support of the example of transfe s on the example of transfe transf	o o	wn and able to explain t e to des ercise o e notion ese me wn and cal disco S S S S L U U U U U U U U U U U U U U U	new pr name a he cont cribe ar classes s, state thods to within a ourse if stue uu S s v yes	blems from and prove the ext developed a critically of students de ments, and o new problect group. The necessary.	the specific e essential s ed in the lec challenge th evelop a cont methods ex ems, to ana ey are able t ((E E E S U Jo - S 0 - 180 o. 20-30	c area o tateme ture ar e curre fident, cplaine lyse th o prese D g	of Mathents and to purents and to purent state precise ad in the nem and ent their build b
Requirements for Obtaining Credit, Grading, Weight if	able to apply them in the an ematical Quantum Theory. S concepts from the lecture as it into a larger framework. T of research in the specific an Through homework assignm and independent acquainta lectures. They learn how to to develop solution strategies solutions and to stand for th Title Advanced Topics in Mathematical Quantum	alysis o Students well as hey are ea. lents ar nce wit transfe s on the em in a es. Jo ed/I L E	o o ccessi	wn and able to explain t to des ercise of a notion ese me wn and cal disco <u>A</u> <u>A</u> <u>A</u> <u>A</u> <u>A</u> <u>A</u> <u>A</u> <u>A</u> <u>A</u> <u>A</u>	new pr name a he cont cribe ar classes s, state thods to within a purse if stue unse stue unse stue yes yes	wr. o. or. assignments	the specific e essential s ed in the lec challenge th evelop a cont methods ex ems, to ana ey are able t ((E E E S U Jo - S 0 - 180 o. 20-30	c area o tateme ture ar e curre fident, cplaine lyse th o prese D g	of Mathents and to purents and to purent state precise ad in the nem and ent their build b
Requirements for Obtaining Credit, Grading, Weight if applicable	able to apply them in the an ematical Quantum Theory. S concepts from the lecture as it into a larger framework. T of research in the specific an Through homework assignm and independent acquainta lectures. They learn how to to develop solution strategies solutions and to stand for th Title Advanced Topics in Mathematical Quantum Theory In this module students need	alysis o Students well as hey are ea. lents ar nce witi transfe s on the em in a sunco to ed L E	o o o ccessi is set	wn and able to explain t to des ercise of a notion ese me wn and cal disco 4 6 2 3 fully co t by the	new pr name a he cont cribe ar classes s, state thods to within a burse if stue ubiss V yes mplete a instruc	wr. o. or. assignments	the specific e essential s ed in the lec challenge th evelop a cont methods ex ems, to ana ey are able t ((E E E S U Jo - S 0 - 180 o. 20-30	c area o tateme ture ar e curre fident, cplaine lyse th o prese D g	of Math ents and to pue ent state precise d in the ent their so up to to to to to to to to to to to to to
Requirements for Obtaining Credit, Grading, Weight if	able to apply them in the an ematical Quantum Theory. S concepts from the lecture as it into a larger framework. T of research in the specific an Through homework assignm and independent acquainta lectures. They learn how to to develop solution strategies solutions and to stand for th Title Advanced Topics in Mathematical Quantum Theory In this module students need the exam. The type of exam	alysis o Students well as hey are ea. hents ar nce with transfe s on the em in a <u>sumo</u> to <u>so</u> <u>to</u> <u>ed</u> <u>L</u> <u>E</u> d to suc ination	o o o o o o o o o o o o o o o o o o o	wn and able to explain t to des ercise of a notion ese me wn and cal disco 4 6 2 3 fully co t by the	new pr name a he cont cribe ar classes s, state thods to within a burse if stue ubiss V yes mplete a instruc	wr. o. or. assignments	the specific e essential s ed in the lec challenge th evelop a cont methods ex ems, to ana ey are able t ((E E E S U Jo - S 0 - 180 o. 20-30	c area o tateme ture ar e curre fident, cplaine lyse th o prese D g	of Math ents and to pue ent state precise d in the ent thei operation the set of the period to to to to to to to to to to to to to

Module Number: MAT-65-22	Module Title: Advanced Topics in Mathema version)	itical C	Quant	tum 1	Гheo	ry (sho		of Module: ve Module		
ECTS-Points	6									
Workload - Time in Class - Self-Study	Workload: 180 h	Time 60 h	in C	lass:			Self-S 120 h	tudy:		
Duration	1 Semester									
Frequency	not regularly, in Summer Ser	nester								
Term	2									
Language of Instruction	English									
Forms of Teaching and Learning	Lectures 2 SWS + Exercise (Classe	es 2 S	SWS	, Hor	neworl	< Assignem	ents		
Content	The module provides a sho theory, like Hartree and Har group, mathematical models systems. It will present both particular area, as well as pro open problems.	tree-F in qua the fur	ock ntum ndam	theor n field ienta	ry, B d the I mat	CS the ory and themat	eory, adiaba d transport ical results	ate theory, r in interdeper and physica	enorm ndent f I notior	alisatior erminor ns of the
Objectives	Students obtain knowledge a able to apply them in the ana ematical Quantum Theory. S concepts from the lecture as it into a larger framework. Th current state of research in th Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategies solutions and to stand for the	lysis c tudent well a ney are ne spe ents a ice wit transf s on th	of kno s are s to o e able cific nd e th tho fer th neir o	own a e able expla e to e area area xerci: e not ese wn a	and r to n in th desc se cl ions ions meth und w	new pro name a e conte ribe ar asses , staten nods to vithin a	bblems fron nd prove th ext develop nd in parts a students de ments, and new probl group. The	n the specific e essential s ed in the lec also critically evelop a com methods ex ems, to ana	c area stateme ture ar challe fident, cplaine lyse th	of Mathents and and to purenge the precise of in the nem and
Requirements for Obtaining Credit, Grading, Weight if applicable	Title Advanced Topics in	- Type of Course	Status	SWS	ECTS	Assignments	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
	Mathematical Quantum Theory	E	0	2 2	3 3	yes	wr. o. or.	90-180 o. 20-30	g	100
	In this module students need the exam. The type of exami							s in order to	be adr	nitted to
Transfer	The module may be a prerec	luisite	for th	ne ma	aster	thesis				
Prerequisites	Module Mathematical Quant	um Th	eory.							
	Christian Hainzl, Stefan Teuf									

Module Number: MAT-65-23	Module Title: Advanced Topics in Mathem	atical F	Relati	vity				of Module: ve Module		
ECTS-Points	9									
Workload - Time in Class - Self-Study	Workload: 270 h	Time 90 h	in C	lass:			Self-S 180 h	tudy:		
Duration	1 Semester	•								
Frequency	not regularly, in Winter Sem	ester								
Term	3									
Language of Instruction	English									
Forms of Teaching and Learning	Lectures 4 SWS + Exercise	Classe	es 2 S	SWS,	Hor	neworł	< Assignem	ents		
Content	The module provides an intr It will present both the funda area, as well as provide an problems.	mental	math	nema	tical	result	s and physi	cal notions o	f the p	articula
Objectives	Students obtain deepend ku learn analytic and geometri equations and to examine the mathematical solutions. Stu	c techr iese. N idents	nique: /loreo are a	s in c ver, t	orde they o na	r to pro do uno ime an	ove existen derstand th d prove the	ice of solutic e physical re	ons of elevanc	Einsteir ce of the
	concepts from the lecture as it into a larger framework. T of research in the specific an Through homework assignm and independent acquainta lectures. They learn how to to develop solution strategies solutions and to stand for th	hey are rea. nents a nce wit o transf s on th	e able nd ex th the fer the neir ov	e to d cercis e noti ese r wn ar	lesci se cla ions, neth nd w	ribe an asses : , stater nods to <i>v</i> ithin a	to critically students de ments, and new probl group. The	challenge the evelop a cont methods ex ems, to ana	e curre fident, cplaine lyse th	nd to pur ent state precise ed in the nem and
for Obtaining Credit, Grading, Weight if	it into a larger framework. T of research in the specific al Through homework assignn and independent acquainta lectures. They learn how to to develop solution strategie	hey are rea. nents a nce wit o transf s on th	e able nd ex th the fer the neir ov	e to d ærcis e noti ese r wn ar cal di	lesci se cla ions, neth nd w	ribe an asses : , stater nods to <i>v</i> ithin a	to critically students de ments, and new probl group. The	challenge the evelop a cont methods ex ems, to ana	e curre fident, cplaine lyse th	nd to put ent state precise d in the nem and
Requirements for Obtaining Credit, Grading, Weight if applicable	it into a larger framework. T of research in the specific an Through homework assignn and independent acquainta lectures. They learn how to to develop solution strategies solutions and to stand for th	hey are rea. hents a nce with transf s on th em in a	e able nd ex th the fer the neir ov a critic	e to d ærcis e noti ese r wn ar cal di	lesci ions neth nd w scou	ribe an asses : , staten nods to vithin a urse if i	d critically students de ments, and new probl group. The necessary.	challenge the evelop a cont methods ex- ems, to ana ey are able to (e curre fident, plaine lyse th o pres	nd to purient state precise d in the nem and ent their
for Obtaining Credit, Grading, Weight if	it into a larger framework. T of research in the specific al Through homework assignn and independent acquainta lectures. They learn how to to develop solution strategie solutions and to stand for th Title Advanced Topics in	hey are rea. hents a nce wit transf s on th em in a sunoO to ed/I L E	e able nd ex th the fer th eer o a critic o o o ccess	xercis e noti ese r wn ar cal dia x x x x x x x x x x x x x x x x x x	lesci se cl: ions meth nd w scou 6 3 com	ribe an asses ; , staten nods to vithin a urse if n stue ubiss V yes	d critically students dements, and new probl group. The necessary.	challenge the evelop a cont methods ex- ems, to ana ey are able to 	e curre fident, cplaine lyse th o pres buipe g	nd to pu ent state precise d in the eent thei
for Obtaining Credit, Grading, Weight if applicable	it into a larger framework. T of research in the specific a Through homework assignn and independent acquainta lectures. They learn how to to develop solution strategie solutions and to stand for th Title Advanced Topics in Mathematical Relativity In this module students need	hey are rea. neents a nce wit transf s on th em in a sunoO to edA L E d to suc ination	e able nd ex th the fer th eer o a critic statrs o o o ccesss is se	on the second se	Iesci ions, meth nd w scou 6 3 com the i	ribe an asses ; , staten nods to vithin a urse if n stue ub iss V yes nplete a nstruct	d critically students dements, and new probl group. The necessary.	challenge the evelop a cont methods ex- ems, to ana ey are able to 	e curre fident, cplaine lyse th o pres buipe g	nd to puper state precise d in the ent thei approve tub tub set approve tub tub tub tub tub tub tub tub tub tub
for Obtaining Credit, Grading, Weight if	it into a larger framework. T of research in the specific a Through homework assignn and independent acquainta lectures. They learn how to to develop solution strategie solutions and to stand for th Title Advanced Topics in Mathematical Relativity In this module students need the exam. The type of exam	hey are rea. neents a nce wit transf s on th em in a sunoO to edA L E d to suc ination quisite	e able nd ex th the fer th eer o a critic statrs o o o ccesss is se	on the second se	Iesci ions, meth nd w scou 6 3 com the i	ribe an asses ; , staten nods to vithin a urse if n stue ub iss V yes nplete a nstruct	d critically students dements, and new probl group. The necessary.	challenge the evelop a cont methods ex- ems, to ana ey are able to 	e curre fident, cplaine lyse th o pres buipe g	nd to pu ent state precise d in the ent thei ent thei S 100

Module Number: MAT-65-24	Module Title: Advanced Topics in Mather sion)	natical	Rela	itivity	(sh	iort ve		f Module: e Module		
ECTS-Points	6									
Workload - Time in Class - Self-Study	Workload: 180 h	Time 60 h	in Cl	ass:			Self-St 120 h	udy:		
Duration	1 Semester									
Frequency	not regularly, in Winter Seme	ester								
Term	3									
Language of Instruction	English									
Forms of Teaching and Learning	Lectures 2 SWS + Exercise	Classe	s 2 S	WS,	Hon	neworł	< Assigneme	ents		
Content	The module provides a sho relativity. It will present both particular area, as well as pr open problems.	the fun	Idame	ental	mat	hemati	ical results a	and physica	l notior	ns of the
Objectives	Students obtain deepend kr learn analytic and geometric equations and to examine th mathematical solutions. Stu concepts from the lecture as it into a larger framework. T current state of research in t Through homework assignm and independent acquaintal lectures. They learn how to to develop solution strategie solutions and to stand for the	c techni dents a well as hey are he spe nce wit transf s on th	niques Aoreov are al s to e e able cific a nd ex h the er the eir ov	s in c ver, t ble tc xplai e to d area. ercis notio ese n vn ar	order hey o na n the escr e cla ons, neth nd w	r to pro do uno me an e conte ribe an asses : stater ods to rithin a	ove existend derstand the d prove the ext develope id in parts a students de ments, and new proble group. The	ce of solutic e physical re essential s ed in the lec lso critically velop a cont methods ex ems, to ana	ons of elevanc tateme ture ar challe fident, cplaine lyse th	Einstein ce of the ents and to pur enge the precise d in the iem and
		em in a	Critic	ai dis	5000		necessary.			
Requirements for Obtaining Credit, Grading, Weight if applicable	Title Advanced Topics in Mathematical Relativity	Type of Course	0		s ECTS	Assignments	necessary. Шах Jo ed L wr. o. or.	Dur. of Exam (min) 00-180 0. 20-30	ه Grading	Weight for Grade
for Obtaining Credit, Grading, Weight if	Title Advanced Topics in	L L L L L L L L	o O Status	SMS 2 2 fully 0	com	yes plete	wr. o. or. wr. os.	Dri. of Exam 90-180 0. 20-30	g	Weight for Grade
for Obtaining Credit, Grading, Weight if applicable	Title Advanced Topics in Mathematical Relativity In this module students need	L L d to suc	o O Status	SMS 2 2 fully of t by th	S ECTS 3 3 com he ir	yes plete a nstruct	wr. o. or. wr. or. assignments or.	Dri. of Exam 90-180 0. 20-30	g	Weight for Grade
for Obtaining Credit, Grading, Weight if	Title Advanced Topics in Mathematical Relativity In this module students need the exam. The type of exam	L L d to suc ination	o O Status	SMS 2 2 fully of t by th	S ECTS 3 3 com he ir	yes plete a nstruct	wr. o. or. wr. or. assignments or.	Dri. of Exam 90-180 0. 20-30	g	Weight for Grade

Section 4: Scientific Work

Module Number: MAT-40-41	Module Title: Scientific Project							Type of Module: Compulsory Module			
ECTS-Points	9										
Workload - Time in Class - Self-Study	Workload:Time in Class:270 h15 h						Self-S 255 h	Self-Study: 255 h			
Duration	1 Semester										
Frequency	Every Semester										
Term	3										
Language of Instruction	English										
Forms of Teaching and Learning	Individual supervision by a m	entor	, stuc	ly of	sciei	ntific w	orks.				
Content	Content: Definition of an advant Independent search at Formulation of specifit Written presentation of This module serves generally	nd stu c prob f the p	idy o Iems proje	f the and ct in	relev met cone	vant sc hodical xt of cu	ientific liter I approach urrent state	ature. to their solu of research	ition.) pages.	
Objectives	 Students develop skills to systematically familiarize themselves with a new subject, learn to work critically and to form a substantiated, professional and interdisciplinary judgement, acquire qualifications in such areas as literature research, identification of relevant problems and appropriate methods, as well as in the written presentation of a research proposal. 										
Requirements for Obtaining Credit, Grading, Weight if applicable	Title Scientific Project	Type of Course	o Status	SMS 1	ω ECTS	Assignments	Type of Exam	Dur. of Exam (min)	gu Grading	Weight for Grade	
Transfer	Successful completion of this module is a prerequisite for participation in module Master The- sis.										
Prerequisites	Successful completion of module Geometry in Physics and of one of the modules Mathemati- cal Quantum Theory or Mathematical Relativity.										
Responsible Persons	Stefan Teufel, Werner Vogels	ang.									

Abbreviations:

Module Number: MAT-40-42	Module Title: Mathematical Physics Colloquium						Type of Module: Compulsory Module			
ECTS-Points	3									
Workload - Time in Class - Self-Study	Workload:Time in Class:90 h60 h					Self-S 30 h	Self-Study: 30 h			
Duration	2 Semester									
Frequency	Every Semester									
Term	3–4									
Language of Instruction	English									
Forms of Teaching and Learning	Presentations, discussions. Specific form of study: during the final semester students present their Master thesis.									
Content	During each semester on 15 appointed dates (2 h each) there will take place presentations and discussions on current topics in mathematical physics. Speakers are the researchers o the involved departments, guest scientists and master's students, who present the results o their Master Thesis.									
	their Master Thesis.									
Objectives	Students gain an insight into area of their own specializatio to discuss and challenge the interdisciplinary and intercultu mixed groups.	on. They m within	devel a larg	op th jer gi	e abilit roup of	y to follow f scholars.	scientific p They ther	resentati efore als	ons an o obtai	
Requirements for Obtaining Credit, Grading, Weight if	Students gain an insight into area of their own specializatio to discuss and challenge the interdisciplinary and intercultu	on. They m within	devel a larg etenc	op th jer gi	e abilit roup of	y to follow f scholars.	scientific p They ther	resentati efore als	ons an o obtai	
Objectives Requirements for Obtaining Credit, Grading, Weight if applicable	Students gain an insight into area of their own specializatio to discuss and challenge the interdisciplinary and intercultu mixed groups.	on. They on m within Iral comp		op th jer gr ies th	e abilit roup of nrough	y to follow f scholars. regular co	Scientific p They ther operation	resentati efore als and discu	ons an o obtai ussion i	
Requirements for Obtaining Credit, Grading, Weight if	Students gain an insight into area of their own specializatio to discuss and challenge the interdisciplinary and intercultu mixed groups.	Type of Course Course Status	a largetend	op thi jer gr ies the SLO	e abilit roup of nrough stuemus ssg	y to follow f scholars. regular co	Scientific p They ther operation	resentati efore als and discu	ons an o obtai ussion i	
Requirements for Obtaining Credit, Grading, Weight if applicable	Students gain an insight into area of their own specializatio to discuss and challenge the interdisciplinary and intercultu mixed groups. Title Colloquium Winter Semester Colloquium Summer	on. They m within iral comp Statns C o	a largetend	op thiger gristics the state of	e abilit roup of nrough Siguest Siguest No	y to follow f scholars. regular co	Scientific p They ther operation	resentati efore als and discu bupper b bup bup bup bup bup bup bup bup bup b	ons an o obtai ussion i	
Requirements for Obtaining Credit, Grading, Weight if	Students gain an insight into area of their own specializatio to discuss and challenge the interdisciplinary and intercultu mixed groups. Title Colloquium Winter Semester Colloquium Summer	on. They m within iral comp Statns C o	a largetend	op thiger gristics the state of	e abilit roup of nrough Siguest Siguest No	y to follow f scholars. regular co	Scientific p They ther operation	resentati efore als and discu bupper b bup bup bup bup bup bup bup bup bup b	ons an o obtai ussion i	

o=obligatory, o.=or, P=presentation, S=seminar, SL=seminar or lecture, SWS=hours per week in class, E=exercise class, L=lecture, T=tutorial

Module Number:	Module Title:							Type of Module:				
MAT-40-43	Master Thesis M.Sc. Mathematical Physics Compulsory Module											
ECTS-Points	30											
Workload - Time in Class - Self-Study	Workload: 900 h	Time 0 h	in C	lass	:		Self-St 900 h	udy:				
Duration	1 Semester											
Frequency	Every Semester											
Term	4											
Language of Instruction	English or German											
Forms of Teaching and Learning	Master thesis											
Content	 Students are assigned to workgroups and participate in seminars of the group. Under the supervision of the mentor students have to handle a concrete problem from mathematical physics by applying scientific methods and present it in written form in English or German. In particular this includes: Definition of an advanced scientific task in coordination with the mentor; Independent search and study of the relevant scientific literature; Formulation of appropriate questions and methodical approach to their answers; Independent execution and written presention of the project and the results in the context of the current state of research; Presentation of the results in English in Mathematical Physics Colloquium. 					ematical man. In s;						
Objectives	 Students are able to develop acquaintance with a new problem within a given period of time and treat it with increasing independence by applying scientific methods; develop acquaintance with scientific literature on a new topic; critically interpret scientific results and integrate them into their state of knowledge; present their results in written form based on principles of Good Scientific Practice; present their work in an international scientific environment. 						dge;					
Requirements for Obtaining Credit, Grading, Weight if applicable	Title Master Thesis	Type of Course	o Status	- SWS	ECTS 00	a Assignments	Type of Exam	Dur. of Exam (min)	ه Grading	Weight for Grade		
Transfer												

Prerequisites	 27 CP from the compulsory elective section Foundations of Mathematical Physics, a total of 18 CP from the sections Knowledge Expansion and Elective Specialisation, Successful completion of module Scientific Project.
Responsible Persons	Stefan Teufel, Werner Vogelsang.
Abbreviations:	