



Mathematisch-Naturwissenschaftliche Fakultät



**Department of Mathematics** 

# Module Handbook Mathematical Physics Master of Science

Winter Semester 2024

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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	1	- <b>I</b>			
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
2-3	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
2-3	MAT-65-35	Quantum Shannon Theory and Beyond	L+ü	WPM		wr. o. or.	9
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

L=lecture, S=seminar, SL=seminar or lecture, E=exercise class, Pr=project work, C=colloquium, T=tutorial, IC=inverted classroom 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	27 CP			
2.	30	27 01	21 CP	30 CP	
3.	31			50 01	42 CP
4.	32				72 01

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)		
			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 ĆP)
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)		
			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 ĆP)
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	Scientif	ic Work
		Geometry in Physics (9 CP)				
1.	27	Mathematical Quantum Theory (9 CP)	Probability Theory (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. Probability Theory and Mathematical Statistics.

## 2.4 Overview by Study Progress and Credit Requirements

			Exam				Teaching				Те	2. 3.			
		Type of Exam	Duration (min)		Weight in the final grade	Course			Points (CP)	ECTS is a red Computare ma allocat to countion on	points to commen ulsory al arked as ion of Eu rses is fo ily. Cred ed upon	o semesi idation o locations such. T CTS poil or inform its are o	ters only. s he nts a- nly		
		be o	uratio	Grading	/eigh1	Type of	Status	SWS	ECTS	1.	2.	3.	4.		
		<u> </u>		G	3	ŕ	Ó	Ś		CP	CP	CP	CF		
	ndations of Mathematical Pl	hysics:							27						
	-65-11 Geometry in Physics	10/11	90–120					6	9						
1.		Wr. or	or	g	9		0	4		6					
2.	Exercises	Or.	20–30			E	0	2		3					
	-65-12 Mathematical Quantun	1						6	9						
1.		Wr. or	90–120 or	g	9		0	4		6					
2.	Exercises	Or.	20–30			E	0	2		3					
	-65-13 Mathematical Relativity	/ Wr.	00 120					6	9		0				
1.		or	90–120 or	g	9		0	4							
2.	Exercises	Or.	20–30			E	0	2	01		3				
	wledge Expansion:							<u> </u>	<b>21</b> 9						
1.	-40-31 Advanced Topics in Ma	Wr.	90–120				0	6 4	9	6					
1. 2.	Exercises	or	or	g	9	E	0	2		3					
	-40-32 Advanced Topics in Ph	Or.	20–30				0	6	9	5					
1.	Lecture	Wr.	90–120			L	o	4	5		6				
2.	Exercises	or	or	g	9	E	0	2			3				
	-40-33 Seminar	Or.	20–30				Ŭ	2	3						
1.	Seminar	Pres.	45–90	g	3	S	0	2	-			3			
	tive Specialisation:			3					30				I		
	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 Physics	s, can	n be ch	nosen. T	The choi	ces nee	d to		
MAT	-65-14 Mathematical Statistica	al Physi	cs					6	9						
1.	Lecture	Wr.	90–120 or	g	9	L	f	4			6				
2.	Exercises	or Or.	or 20–30	9		E	f	2			3				
MAT	-65-21 Advanced Topics in Ma	athemat	ical Quantu	um Th	eory			6	9						
	Lecture	Wr.	90–120			L	f	4			6				

			Exam				Teaching				Те	erm	
		Type of Exam	Duration (min)	D	Weight in the final grade	Type of Course			Points (CP)	ECTS is a re- Compl are ma allocat to coul- tion or	points to commen ulsory al arked as ion of Eu rses is fo ily. Cred ed upon	of exam o semest idation o locations such. T CTS poir or inform its are o complet	ters nly. S he nts a- nly
		Type o	Duratio	Grading	Weight	Type o	Status	SWS	ECTS	1. CP	2. CP	3. CP	4. CP
2.	Exercises					E	f	2			3		
MAT	-65-22 Advanced Topics in Ma	athemat	ical Quanti	um Th	eory	(short	version)	4	6		I		
1.	Lecture	Wr.	90–120	a	6	L	f	2			3		
2.	Exercises	or Or.	or 20–30	g	0	E	f	2			3		
MAT	-65-23 Advanced Topics in Ma	athemat	ical Relativ	rity				6	9				
1.	Lecture	Wr. or	90–120 or	g	9	L	f	2				3	
2.	Exercises	Or.	20–30	9		E	f	2				3	
MAT	-65-24 Advanced Topics in Ma	athemat	ical Relativ	rity (sł	nort ve	ersion	)	4	6		1		
1.	Lecture	Wr. or	90–120 or	g	6	L	f	2				3	
2.	Exercises	Or.	20–30	3		E	f	2				3	
Scie	entific Work							1	42				
MAT	-40-41 Scientific Project	1		1	1	1			9		1		
1.	Project	Proj.		ng	9		0					9	
MAT	-40-42 Mathematical Physics	Colloqu	ium	1	1		T		3		I		
1.	Colloquium			ng			0					1	2
MAT	-40-43 Master Thesis			1	1	1			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 cl f=fakultativ nours in cla	oral e ass, S e	S=sem	ninar, I	Proj.=proje	ect wo	ork, Ćo	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	Geometry in Physics     Compulsory Module       9									
Workload - Time in Class - Self-Study	270 h 90 h 180 h									
Duration										
Frequency	egularly in Winter Semester									
Term										
Language of Instruction	English	English								
Forms of Teaching and Learning	Lectures 4 SWS + Exercise	Lectures 4 SWS + Exercise Classes 2 SWS, Homework Assignements								
Content	relevance for physics. Partic and associated notions of c	cular topics are manifolds, diffe	ds of differential geometry and their erential forms, Riemannian metrics ry of submanifolds, real vector bun- hysics are discussed.							
Objectives	of differential geometry. The integral calculus and experie applied within physical theor and concepts from the lectur put it into a larger framework Through homework assignm and independent acquainta lectures. They learn how to to develop solution strategie	y develop, in particular, a deep ence through examples how the ies. Students are able to name re as well as to explain the con k. nents and exercise classes stu nce with the notions, stateme o transfer these methods to ne	nce with the use of the listed notions ber understanding of differential and a mathematical notions are naturally and prove the essential statements text developed in the lecture and to dents develop a confident, precise, nts, and methods explained in the ew problems, to analyse them and oup. They are able to present their cessary.							

Credit, Grading, Weight if applicable	Title	Type of Course	Status	SWS	ECTS	Assignments	Type of Exam	Dur. of Exam	Grading	Weight for Grade		
	Geometry in Physics	L	0	4	6	yes	wr. o.	90-180	g	100		
_		Е	0	2	3	,	or.	o. 20-30	9			
	In this module students need t the exam. The type of examin							in order to	be adr	nitted to		
Literature	Exemplary Literature:											
	John Lee: Introduction	to sn	nooth	n mai	nifolc	ls. Spri	nger 2012.					
	• John Lee: Riemannian	mani	folds	: An	intro	ductio	n. Springer	1997.				
	Chris Isham: Modern d	iffere	ntial	geor	netry	/ for ph	ysicists. Wo	orld Scientifi	c 1999			
	• Mikio Nakahara: Geom	etry,	Торс	ology	and	Physic	s. IOP Publ	ishing 2003				
Transfer	Participation in the module is a ativity. Successful completion module Seminar Knowledge E Project.	י. ח of t	hen	nodu	le m	ay be	a prerequis	ite for partio	cipatio	n in the		
Prerequisites	-											
Responsible Persons	nristoph Bohle, Carla Cederbaum, Stefan Teufel											

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, IC=inverted classroom

Module Number: MAT-65-12	Module Title: Mathematical Quantum The	ory						f Module: Ilsory 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												
Content	The module provides an intr the formulation and analysis butions, Hilbert spaces, unit operators, spectral theorem, erators. In addition, basic ic perturbation theory, Hartree theory, adiabatic theory or s matical methods and areas examples from quantum the	of qua ary gro tensor deas fr resp. emicla are mo	intun oups om r Marti issica	n the and ducts nore ree-F al an	ories their , PO spec ock alysi	. Topic gener VMs, s cific me theory, s can b	s include th ators, spect pectral mea ethods such the Fock sp be discusse	e Fourier tra ral theory o sures, and as Rayleig bace formal d. The mer	ansforr f self-a trace c h-Sch sm, sc stioned	n, distri- adjacent lass op- rödinger attering mathe-			
Objectives	Students know and understa to analyse known and new of explain the statements and and their mathematical mode mathematical modelling and assignments and exercise of acquaintance with the notion how to transfer these methor strategies on their own and stand for them in a critical di	uestio proofs lelling l the r classes is, stat ods to within	ns fr of t and nathe stue emen new a gr	om q he le are a emat dents nts, a prol roup.	uant cture able ical i dev nd n olem The	um the e. Furt to que results velop a nethods s, to a ey are	ory. They a hermore, th stion the re derived fro confident, s explained nalyse ther	re able to u ley link phy- levance and m it. Throu precise, and in the lectur n and to de	ndersta sical p d adec ugh ho d inde es. Th evelop	and and roblems juacy of mework pendent ey learn solution			
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 Quantum Theory	L	0 0	4	6 3	yes	wr. o. or.	90-180 o. 20-30	g	100			
		In this module students need to successfully complete assignments in order to be admitted to the exam. The type of examination is set by the instructor.											
Transfer	Successful completion of mo ticipation in the module Adva pletion of one of the modules prerequisite for the participa	anced s Math	Topic emat	s in tical (	Math Quar	nematic ntum Th	al Quantum neory and M	ι Theory. Sι	iccess	ful com-			
Prerequisites	-												
Responsible Persons	Stefan Teufel												

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						<b>I</b>			
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 er th ieir c	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				

## Section 2: Knowledge Expansion

MAT-40-31	Module Title: Advanced Topics in Mathema	atics					of Module: ulsory Modul	e with	Choice
ECTS-Points	9								
Workload - Time in Class - Self-Study	Workload: 270 h	Time ir 90 h	n Class	:		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 (	Classes	2 SWS	S, Hor	meworl	< Assignem	ents		
Content	It is required to attend one of the correspondent SWS-cover mended subjects are for inst- tions, Harmonic analysis, Lie tic processes, Calculus of va geometry. Further details car	erage fro ance Pa groups, ariations	om the l artial dif , Nonlin s, Symp	Maste feren lear fi plectie	er's deq Itial equunctior c geon	gree progra uations, Nu al analysis netry, Algeb	m in Matherr merics of dif , Operator th praic topolog	iatics. ferenti eory, S y or A	Recom- al equa- Stochas- Igebraic
	Mathematics.							0	
Objectives	Mathematics. The students aquire deepend of physical applications. The the methods at hand to tack ticular the concrete content r of the chosen course in the n	d knowle / broade e mathe elated q	edge in en the t ematica qualifac	one basis I prot tion g	selecte of thei plems. goals, v	ed area of n r mathemat The further vill follow fr	nathematics ical knowled qualification om the mode	indepe ge and 1 goals	endently d extend s, in par-
Objectives Requirements for Obtaining Credit, Grading, Weight if applicable	The students aquire deepend of physical applications. The the methods at hand to tackli- ticular the concrete content r	d knowle / broade e mathe elated q nodule h	edge in en the t ematica qualifac	one basis I prot tion g	selecte of thei plems. goals, v	ed area of n r mathemat The further vill follow fr	nathematics ical knowled qualification om the mode	indepe ge and 1 goals	endently d extend s, in par-
Requirements for Obtaining Credit, Grading, Weight if	The students aquire deepend of physical applications. They the methods at hand to tackli- ticular the concrete content r of the chosen course in the n	d knowle y broade e mathe elated q nodule h C C C C C C C C C C C C C C C C C C C	edge in en the l ematica qualifac handbo	one pasis I prot tion g ok fo	selecte of thei olems. goals, v r the M	ed area of n r mathemat The further vill follow fr .Sc. Mathe	nathematics ical knowled qualification om the mode matics.	indepe ge and goals ule des	endently d extend s, in par- scription
Requirements for Obtaining Credit, Grading, Weight if	The students aquire deepend of physical applications. They the methods at hand to tackli- ticular the concrete content r of the chosen course in the n Title Advanced Topics in	d knowle y broade e mathe elated q hodule h estino O o ed L L E	edge in en the b ematica qualifac handbo 0 0 4 0 2 exessfully	one pasis I prot tion ( ok for SLO H 6 3 y com	selecte of thei plems. goals, v r the M stue units se yes yes	ed area of n r mathemat The further vill follow fr .Sc. Mathe Ex J o ed L wr. o. or. assignment	nathematics ical knowled qualificatior om the mode matics.	indepe ge and goals ule des built g	endently d extend s, in par- scription Parage Y 100
Requirements for Obtaining Credit, Grading, Weight if applicable	The students aquire deepend of physical applications. They the methods at hand to tackli- ticular the concrete content r of the chosen course in the n Title Advanced Topics in Mathematics	d knowle y broade e mathe elated q nodule h Sino O o ed. L L E to succe nation is	edge in en the b ematica qualifac handbo S S S O O A O O A O C S S S S S O O A O C S S S S S O O A O C S S S S S S S S S S S S S S S S S S	one pasis I prot tion ( ok for ok for U U U U U U U U U U U U U U U U U U U	selecte of thei plems. goals, v r the M stue ubiss V yes plete a nstruct	ed area of n r mathemat The further vill follow fr .Sc. Mathe Ex U to o o d L wr. o. or. assignment or.	nathematics ical knowled qualificatior om the mode matics.	indepe ge and goals ule des built g	endently d extend s, in par- scription Cuage N N N N N N N N N N N N N N N N N N N
Requirements for Obtaining Credit, Grading, Weight if	The students aquire deepend of physical applications. They the methods at hand to tackli- 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 exami	d knowle y broade e mathe elated q nodule h S D O O O O O O O O O O O O O O O O O O	edge in en the b ematica qualifac handbo snter S o 4 o 2 cessfully s set by or the m	one pasis I prot tion ( ok for ok for U U U U U G G 3 y com the i the i	selecte of thei plems. goals, v r the M stue ubisse yes plete a nstruct	ed area of n r mathemat The further vill follow fr .Sc. Mathe Ex U o o o c wr. o. or. assignment or.	nathematics ical knowled qualificatior om the mode matics.	indepe ge and goals ule des built g	endently d extend s, in par- scription Parage Y 100

Module Number: MAT-40-32	Module Title: Advanced Topics in Theoret	cal Ph	ysics	;				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-Si 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	es 2 S	SWS	, Hor	neworl	k Assignem	ents		
Content	It is required to attend one physics as well as the resp from the Master's degree pr ticls Physics. Recommend physics, Theoretical astroph Advanced statistical physics tum optics, Quantum inform trophysics, Current topics in handbook of the correspond	ective ogram ed sub ysics, ysics, yang- ation t theore	exer in Pl jects Rela Mills heor	rcise nysic are tivist theo y, Co phy	clas s or for ic as ory, C osmo sics.	ses w the Ma instand trophys Conden logy, N Furth	ith the corr aster's degre ce Quantum sics, Many- nsed matter Jumerical m	espondent S ee program n field theor particle qua physics, The nethods in pl	SWS-c Astro a y and ntum s eoretic hysics	overage and Par- Particle systems al quan- and as-
Objectives	The students aquire deepe pendently of rigorous mather theoretical physics and exter qualification goals, in particu the module description of th the M.Sc. Astro and Particle	matica nd the lar the e chos	l forr meth conc en co	nalis ods crete	m. T at ha cont	hey br nd to t tent rel	oaden the l ackle proble ated qualifa	basis of thei ems in physic ction goals,	r know cs. The will foll	ledge ir e furthei ow from
		Θ						am (min)		Grade
Credit, Grading, Weight if	Title	Type of Course	Status	SWS	ECTS	Assignments	Type of Exam	Dur. of Exam	Grading	Weight for Gr
for Obtaining Credit, Grading,	Title Advanced Topics in Theoretical Physics	0	o o Status	SMS 4 2	د e ECTS	Assignments	of E	of Ex	ه Grading	L _
for Obtaining Credit, Grading, Weight if	Advanced Topics in	L L to suc	0 0 ccess	4 2 sfully	6 3 com	yes	W to add f wr. o. or. asssignments	ш то ЭО-180 о. 20-30	g	001 Weight for
for Obtaining Credit, Grading, Weight if applicable	Advanced Topics in Theoretical Physics In this module students need	U jo ed/L E to suc	0 0 ccess is se	4 2 sfully et by	6 3 com the i	yes nplete a nstruct	Wr. o. or. assignments tor.	ш то ЭО-180 о. 20-30	g	Weight for
for Obtaining Credit, Grading, Weight if	Advanced Topics in Theoretical Physics In this module students need the exam. The type of exam	d to suc	o o ccess is se for th	4 2 sfully et by	6 3 com the i aster	yes nplete a nstruct	Wr. o. or. assignments tor.	90-180 o. 20-30	g be adr	100 nitted to

Module Number: MAT-40-33	Module Title: Seminar Knowledge Extension	on						of Module: ulsory Modu	le with	Choice
ECTS-Points	3									
Workload - Time in Class - Self-Study	Workload: 90 h	Time 30 h	in C	lass	:		Self-S 60 h	tudy:		
Duration	1 Semester						I			
Frequency	Every Semester									
Term	2–3									
Language of Instruction	English or German									
Forms of Teaching and Learning	Seminar: Presentation, Disc	ussion	, Tea	mwc	ork, ⊦	landou	t			
Content	Various topics from various Physics.	area	s of	Mat	hem	atical I	Physics, M	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	hysic have	s by imp	app roveo	lying s d their s	cientific me skills in the	ethods and presentation	to pres n of ma	ent it in
								(uir		
Requirements for Obtaining Credit, Grading, Weight if applicable	Title	Type of Course	Status	SWS	P ECTS	Assignments	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
for Obtaining Credit, Grading, Weight if	Title Seminar	w Type of Course	o Status	SWS 2	ε ECTS	Assignments	Type of Exam	Dur. of Exam (n 45–90	ه Grading	Weight for Grade
for Obtaining Credit, Grading, Weight if		S	o	2	3	yes	Type of	Dur. of		-
for Obtaining Credit, Grading, Weight if applicable	Seminar	S uisite	o for th	2 ne ma	3 aster	yes thesis	- Type of	fo .ing 45–90	g	100

#### Section 3: Elective Specialisation

Within the study area Elective Specialisation 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	nester	
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 phenomena, renormalizatior	stical 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 acquaintal lectures. They learn how to to develop solution strategie	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 thents and exercise classes stu- nee with the notions, stateme transfer these methods to no	ted notions and methods and can titistical physics. They are able to librium, irreversability and entropy, and to question the relevance and ived from it. Thereby, they enhance out the first semester, in particular rove the essential statements and developed in the lecture and to put dents develop a confident, precise, nts, 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	,	or.	o. 20-30	9	
	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	participatio	n in the moo	dule Ac	lvanced
Prerequisites	-									
Responsible Persons	Roderich Tumulka									
Abbreviations:										

Module Number:	Module Title:						Tuno o	fModulou		
MAT-65-15	Foundations of Quantum Me	chanic	s					f Module: 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	, Hoi	meworł	< Assigneme	ents		
Content	The module provides an intro ing its mathematical and phil Bohmian mechanics, many v sented and analysed mather berg's uncertainty principle, identical particles and theore	osoph vorlds natical the qu	ical a and t Ily ar antu	aspeo he co id ph m mo	ots. N ollap ysica easu	Various se of th ally. Oth	interpretati ne spontane her topics in t problem, E	ons such as ous wave fu clude Born'	Cope nction s rule,	nhagen, are pre- Heisen-
Objectives	Students know and can app understand several important matical knowledge relevant to mathematical treatment with surprising phenomena and controversial about the ortho debate on fundamental issue results of the lecture as well In the exercise classes they the terms, statements and m on new problems, to analyse They are able to present the	t theor o the a the p boaradc bdox in es. The as ass have a rethods them	ries c applic hysic oxes iterpi e stuc sessi acqu s of t and t	of how cation cal m of qu retati dents ng ar ired a he le o wo	w the n of t lantu on a s are nd ex a coure rk or	e quant hese ru ng. The um mee nd why capab cplainin nfident, e. They n solutio	um world w ules and the ey will famil chanics. Th , and will be le of naming g the prese precise an have learn on strategies	orks. They a cories and ca iarise thems ey will approve able to foll and provin nted connect d independe ed to transfe s on their ow	acquire an con selves reciate ow the g the e ctions. ent har er the r rn or in	mathe- nect the with the what is current ssential adling of nethods a team.
Requirements for Obtaining Credit, Grading, Weight if applicable	Title Foundations of Quantum Mechanics	T Type of Course	J Status	SMS 4	o ECTS	es Assignments	Type of Exam or. o.	Dur. of Exam (min) Dur. of Exam (min) 08-180 0. 20-30	ه Grading	Weight for Grade
		E	f	2	3			0. 20-30		
	The type of examination is s									
Transfer	The module belongs to the the chosen personal Study <i>Advanced Knowledge in Ma</i> strictive requirements of the	Specia thema	alisat a <i>tics</i>	ion, or <i>El</i>	it ca <i>lectiv</i>	ın be ir	ncluded in t	he sections	Study	' Focus,
Prerequisites	The basic modules on Analy	sis an	d Lin	ear A	lgeb	ora are	required.			
Responsible Persons	Roderich Tumulka									

Module Number: MAT-65-21	Module Title: Advanced Topics in Mathem	atical C	Quan	tum	Theo	ory		of Module: re Module		
ECTS-Points	9									
Workload - Time in Class - Self-Study	Workload: 270 h	Time 90 h	in C	lass:			Self-S <sup>-</sup> 180 h	tudy:		
Duration	1 Semester						,			
Frequency	not regularly									
Term	2-3									
Language of Instruction	English									
Forms of Teaching and Learning	Lectures 4 SWS + Exercise	Classe	es 2 S	SWS,	, Hor	neworl	k Assignem	ents		
Content	The module provides an intr like Hartree and Hartree-For mathematical models in qua tems. It will present both th particular area, as well as pr open problems.	ck the ntum f e fund	ory, field amei	BCS theoi ntal i	theo ry an math	ory, ad id tran: ematic	liabate theo sport in inte al results a	ory, renorma erdependent and physical	lisation fermin notior	n group non sys ns of th
0			-l						م ام م ما م	and ar
Objectives	Students obtain knowledge able to apply them in the and ematical Quantum Theory. S concepts from the lecture as it into a larger framework. T of research in the specific ar Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategie solutions and to stand for the	alysis o tudent well a ney are ea. ents a nce wit transf s on th	of kno is are is to e able nd ex th the fer th ieir o	own a e able expla e to c xercis e not ese wn a	and r to n in th desci se cla ions meth ind w	new pro name a e conte ribe an asses , staten nods to vithin a	bblems from nd prove th ext develop nd critically students de ments, and p new probl group. The	n the specific e essential s ed in the lec challenge th evelop a cont methods ex ems, to ana	c area stateme ture ar e curre fident, cplaine lyse th	of Math ents an nd to pu ent stat precise ed in th nem an
Objectives Requirements for Obtaining Credit, Grading, Weight if applicable	able to apply them in the ana ematical Quantum Theory. S concepts from the lecture as it into a larger framework. T of research in the specific ar Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategie solutions and to stand for the Title	alysis o tudent well a ney are ea. ents a nce wit transf s on th	of kno is are is to e able nd ex th the fer th ieir o	own a e able expla e to c xercis e not ese own a cal d	And r to n iin th desc iins meth isco w isco U	new pro name a e conte ribe an asses , staten nods to vithin a	bblems from nd prove th ext develop nd critically students de ments, and p new probl group. The	n the specific e essential s ed in the lec challenge th evelop a cont methods ex ems, to ana	c area stateme ture ar e curre fident, cplaine lyse th	of Math ents an nd to pu ent stat precise ed in th nem an
Requirements for Obtaining Credit, Grading, Weight if	able to apply them in the ana ematical Quantum Theory. S concepts from the lecture as it into a larger framework. T of research in the specific ar Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategie solutions and to stand for the	alysis of tudent well a ney are ea. ents a nee wit transf s on th em in a	of kno is are is to e able nd ex th the fer th fer th fer th fer th	own a e able expla e to o xercis e not ese wn a cal d	and r to n in th descr se cla ions meth ind w iscou	new pro aame a e conto ribe an asses , state nods to vithin a urse if	blems from nd prove th ext develop ad critically students de ments, and p new probl group. The necessary.	n 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 E E S U J	c area statemo ture ar e curre fident, cplaine lyse th o pres	of Mathents an and to puese to
Requirements for Obtaining Credit, Grading, Weight if	able to apply them in the ana ematical Quantum Theory. S concepts from the lecture as it into a larger framework. T of research in the specific ar Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategie solutions and to stand for the Title Advanced Topics in Mathematical Quantum	alysis o tudent well a ney are ea. ents a nce wit transf s on th em in a esunoO jo ed/ <u>i</u> L E	of knocks are s to e able able able a critic status o o o o ccess	own a able e able expla e to c esce won a ccal d o Mo c 4 2 sfully	And r r r r r r r r r r r r r r r r r r r	new pro name a e conto ribe an asses , state nods to vithin a urse if stue uuse stue uuse sy yes	blems from nd prove th ext develop nd critically students de ments, and o new probl group. The necessary.	n the specific e essential s ed in the lec challenge th evelop a com methods es ems, to ana ey are able t (L E E E S Q 90-180 o. 20-30	c area statemo ture ar e curre fident, cplaine lyse th o pres Dup g	of Mathents an and to puert stat precised in the ent the ent the ent the approximation Matheman ent the approximation Matheman ent stat precise ed in the approximation Matheman ent stat precise ed in the approximation Matheman ent stat at approximation Matheman ent stat at approximation At approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation appro
Requirements for Obtaining Credit, Grading, Weight if applicable	able to apply them in the ana ematical Quantum Theory. S concepts from the lecture as it into a larger framework. T of research in the specific ar Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategie solutions and to stand for the Title Advanced Topics in Mathematical Quantum Theory In this module students need	alysis o tudent well a ney are ea. ents a nce wit transf s on th em in a esino J o ed/I L E I to suc	of knocks are s to e able a de able ind exercises to e a critic sinter the ier	own a able e able expla e to c esce won a cal d o Mo 4 2 sfully	And r r r r r r r r r r r r r r r r r r r	new pro- name a e conto- ribe an asses , state nods to vithin a urse if stue ubiss V yes nplete a nstruct	blems from nd prove th ext develop nd critically students de ments, and o new probl group. The necessary.	n the specific e essential s ed in the lec challenge th evelop a com methods es ems, to ana ey are able t (L E E E S Q 90-180 o. 20-30	c area statemo ture ar e curre fident, cplaine lyse th o pres Dup g	of Mathents an and to puert stat precised in the ent the ent the approximation Matheman ent the approximation Mathematics Precise Mathematics Precise Mathematics Precise Mathematics Precise Mathematics Precise Mathematics Precise Mathematics Precise Mathematics Precise Mathematics Precise Mathematics Precise Mathematics Precise Mathematics Precise Precise Mathematics Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precise Precis Precise Precise Precis Precise Precise Precis
Requirements for Obtaining Credit, Grading, Weight if	able to apply them in the ana ematical Quantum Theory. S concepts from the lecture as it into a larger framework. T of research in the specific ar Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategie solutions and to stand for the Title Advanced Topics in Mathematical Quantum Theory In this module students need the exam. The type of exam	alysis o tudent well a ney are ea. ents a nce wit transf s on th em in a esino J o ed. L E I to suc nation quisite	of knoc s are s to e a able ind exercise the the erer the	own a able e able expla e to c esce won a cal d cal d d d 2 sfully et by ne ma	And r r r r r r r r r r r r r r r r r r r	new pro- name a e conto- ribe an asses , state nods to vithin a urse if stue ubiss V yes nplete a nstruct	blems from nd prove th ext develop nd critically students de ments, and o new proble group. The necessary.	n the specific e essential s ed in the lec challenge th evelop a com methods ex ems, to ana ey are able t ( ( E E E E 90-180 o. 20-30 s in order to	c area statemo ture ar e curre fident, cplaine lyse th o pres Dup g	of Mathents an and to puert stat precised in the ent the ent the ent the approximation Matheman ent the approximation Matheman ent stat precise ed in the approximation Matheman ent stat precise ed in the approximation Matheman ent stat at approximation Matheman ent stat at approximation At approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation approximation appro

Module Number: MAT-65-22	Module Title: Advanced Topics in Mathema version)	itical C	Quant	tum 1	Гheo	ry (sho		of Module: e Module			
ECTS-Points	6										
Workload - Time in Class - Self-Study	Workload: 180 h	Time 60 h	in C	lass:	:		Self-Si 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	neworł	k 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 he fur	ock ntum ndam	theor n field ienta	ry, B d the I mat	CS the ory and themat	ory, adiaba d transport i ical results	te theory, re n interdeper and physical	enorma ndent f I notior	alisation erminon 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 acquaintan lectures. They learn how to to develop solution strategies solutions and to stand for the	lysis of tudent well a ney are ne spe ents a ce 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 e to n uin th desc se cl tions meth und w	new pro name a e conte ribe ar asses , staten nods to vithin a	bblems from nd prove the ext develope id in parts a students de ments, and new proble group. The	n the specific e essential s ed in the lect also critically evelop a cont methods ex ems, to ana	area tateme ture ar challe fident, plaine lyse th	of Math- ents and d to put enge the precise, d in the em and	
Requirements for Obtaining Credit, Grading, Weight if applicable	Title Advanced Topics in Mathematical Quantum	T Type of Course	o Status	SWS 2	٤ ECTS	Assignments	Type of Exam o.	(uiu) Drit. of Exam 90-180 o. 20-30	ه Grading	Weight for Grade	
	Theory In this module students need the exam. The type of exami	E to such nation	o cces: is se	2 2 2 2 2 1 2	3 com the i	nplete a	or. assignments or.			nitted to	
Transfer	The module may be a prerec			-							
	, , , , , , , , , , , , , , , , , , , ,										
Prerequisites	Knowledge from the module	Knowledge from the module Mathematical Quantum Theory is assumed.         Stefan Teufel									

Module Number: MAT-65-23	Module Title: Advanced Topics in Mathem	atical F	Relativ	ity				Advanced Topics in Mathematical Relativity Elective Module								
ECTS-Points	9															
Workload - Time in Class - Self-Study	Workload: 270 h	Time 90 h	in Cla	ISS:		Self-St 180 h	udy:									
Duration	1 Semester					·										
Frequency	not regularly, in Winter Seme	ester														
Term	3															
Language of Instruction	English															
Forms of Teaching and Learning	Lectures 4 SWS + Exercise	Classe	es 2 SV	WS, Hoi	meworl	k Assignem	ents									
Content	The module provides an intro It will present both the fundar area, as well as provide an problems.	nental	mathe	ematica	l result	s and physic	cal notions o	f the p	articula							
Objectives	Students obtain deepend kr learn analytic and geometric															
	equations and to examine the mathematical solutions. Stu concepts from the lecture as it into a larger framework. The of research in the specific ar Through homework assignment and independent acquaintar lectures. They learn how to to develop solution strategies solutions and to stand for the	ese. N dents a well as ney are ea. ents an ce wit transf s on th	Aoreov are ab s to ex e able nd exe th the fer the neir ow	rer, they ole to na cplain th to desc ercise cl notions se meth rn and v	do une ame an ribe an asses , state nods to vithin a	derstand the d prove the ext develope d critically d students de ments, and new proble group. The	e physical re e essential s ed in the lect challenge the velop a conf methods ex ems, to anal	levano tateme ture ar e curre ident, plaine lyse th	ents and nd to pu ent state precise id in the nem and							
for Obtaining Credit, Grading, Weight if	equations and to examine th mathematical solutions. Stu concepts from the lecture as it into a larger framework. Th of research in the specific ar Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategies solutions and to stand for the Title Advanced Topics in	ese. N dents a well as ney are ea. ents an ce wit transfe s on th em in a esinoo jo ed/i L	Abreov are ab s to exe able nd exe th the fer	rer, they ole to na cplain th to desc ercise cl notions se meth rn and v	do une ame an ribe an asses , state nods to vithin a	derstand the d prove the ext developed d critically d students de ments, and new proble group. The necessary.	e physical re e essential s ed in the lect challenge the velop a conf methods ex ems, to anal ey are able to (IIIII) Ex U U U U U U U U U U U U U U U U U U	levano tateme ture ar e curre ident, plaine lyse th	ents and nd to pu ent state precise id in the nem and							
for Obtaining Credit, Grading, Weight if	equations and to examine th mathematical solutions. Stu concepts from the lecture as it into a larger framework. Th of research in the specific ar Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategies solutions and to stand for the Title	ese. N dents a well as ney arc ea. ents an ince wit transfi s on th em in a esunoO to ed/I L E	Aoreov are ab s to exe able nd exe th the ter ter ter ter ter ter ter ter ter ter	er, they le to na construction ercise cl notions se meth m and v al discort 4 6 2 3	do undame an he contu- ribe an lasses , state hods to vithin a urse if stue use if stue use yes	derstand the d prove the ext developed d critically of students de ments, and new proble group. The necessary.	e physical re e essential s ed in the leci challenge the velop a conf methods ex ems, to anal ey are able to ( L E E U U U O 90-180 o. 20-30	levano tateme ture ar e curre ident, cplaine yse th o pres	ents and nd to pu ent state precise d in the ent thei approve tub tub tub tub tub tub tub tub tub tub							
for Obtaining Credit, Grading, Weight if	equations and to examine th mathematical solutions. Stu concepts from the lecture as it into a larger framework. Th of research in the specific ar Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategies solutions and to stand for the Title Advanced Topics in Mathematical Relativity	ese. N dents a well as ney are ea. ents an ince wit transfi s on th em in a esunoO to ed/I L E	Aoreov are ab s to exe able nd exe th the ter ter ter ter ter ter ter ter ter ter	er, they le to na cplain th to desc ercise cl notions se meth m and v al discou 4 6 2 3 ully con	do una ame an he contu- ribe an lasses , state hods to vithin a urse if stue use if stue use yes	derstand the d prove the ext developed d critically of students de ments, and new proble group. The necessary.	e physical re e essential s ed in the leci challenge the velop a conf methods ex ems, to anal ey are able to ( L E E U U U O 90-180 o. 20-30	levano tateme ture ar e curre ident, cplaine yse th o pres	ents and nd to pue ent state precise d in the ent the ent the upper Upper Voi Upper Voi Upper Voi Upper Voi Voi Voi Voi Voi Voi Voi Voi Voi Voi							
for Obtaining Credit, Grading, Weight if applicable	equations and to examine th mathematical solutions. Stu concepts from the lecture as it into a larger framework. Th of research in the specific ar Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategies solutions and to stand for the Title Advanced Topics in Mathematical Relativity In this module students need	ese. N dents a well as ney are ea. ents an ce wit transfi s on th em in a es.noO to edA L E I to suc	Aoreov are ab s to ex- e able nd exe th the ter ter ter ter ter ter ter ter ter ter	er, they ble to na cplain th to desc ercise cl notions se meth n and v al discor 4 6 2 3 ully con by the i	do und ame an he contu- ribe an lasses , state hods to vithin a urse if stue use if stue use yes	derstand the d prove the ext developed d critically of students de ments, and new proble group. The necessary.	e physical re e essential s ed in the leci challenge the velop a conf methods ex ems, to anal ey are able to ( L E E U U U O 90-180 o. 20-30	levano tateme ture ar e curre ident, cplaine yse th o pres	ents an- nd to puert ent stat precise d in the ent the ent the ent the approximation N N 100							
Requirements for Obtaining Credit, Grading, Weight if applicable Transfer Prerequisites	equations and to examine th mathematical solutions. Stu concepts from the lecture as it into a larger framework. Th of research in the specific ar Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategies solutions and to stand for the Title Advanced Topics in Mathematical Relativity In this module students need the exam. The type of exami	ese. N dents a well as ney are ea. ents an ce wit transfi s on th em in a esino O to ed L E I to suc nation	Aoreov are ab s to ex- e able nd exe th the fer the er the er the er the a critica o o o ccessfu is set	er, they ble to na cplain th to desc ercise cl notions se meth n and v al discor 4 6 2 3 ully con by the i	do und ame an he contu- ribe an lasses , state hods to vithin a urse if vithin a vithin a v	derstand the d prove the ext developed d critically of students de ments, and new proble group. The necessary.	e physical re e essential s ed in the leci challenge the velop a conf methods ex ems, to anal ey are able to ( L E E U U U O 90-180 o. 20-30	levano tateme ture ar e curre ident, cplaine yse th o pres	ents and nd to pu ent state precise d in the ent thei approve tub tub tub tub tub tub tub tub tub tub							

Module Number: MAT-65-24	Module Title: Advanced Topics in Mather sion)	natical F	Relativit	y (shor	t ver-		f Module: e Module		
ECTS-Points	6								
Workload - Time in Class - Self-Study	Workload: 180 h	Time ii 60 h	in Class	:		Self-St 120 h	udy:		
Duration	1 Semester					1			
Frequency	not regularly, in Winter Seme	ester							
Term	3								
Language of Instruction	English								
Forms of Teaching and Learning	Lectures 2 SWS + Exercise	Classes	2 SWS	, Home	work A	ssigneme	ents		
Content	The module provides a sho relativity. It will present both particular area, as well as pr open problems.	the fund	lamenta	l mathe	matica	l results a	and physical	notior	ns of the
Objectives	Students obtain deepend kn learn analytic and geometric equations and to examine th mathematical solutions. Stu	c technic ese. Mo	ques in preover,	order to they do	o prove o under	e existend stand the	ce of solution physical re	ons of levanc	Einsteir e of the
	concepts from the lecture as it into a larger framework. T current state of research in t Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategie solutions and to stand for the	well as hey are he speci ents and nce with transfer s on the	to explate able to ific area d exercion the no or these eir own a	ain the c describ se class tions, s methoc and with	context ie and i ses stu tateme ds to ne nin a gr	develope in parts a dents dev nts, and ew proble oup. The	ed in the lect lso critically velop a conf methods ex ems, to ana	ture ar challe ident, plaine lyse th	nd to pu enge the precise d in the em and
for Obtaining Credit, Grading, Weight if	it into a larger framework. T current state of research in t Through homework assignm and independent acquaintar lectures. They learn how to	well as hey are a he speci- ents and nce with transfer s on the em in a c	to explate able to ific area d exercion the no or these eir own a	ain the c describ se class tions, s methoc and with liscours	context ie and i ses stu tateme ds to ne nin a gr	develope in parts a dents de nts, and ew proble oup. The cessary.	ed in the lect lso critically velop a conf methods ex ems, to ana	ture ar challe ident, plaine lyse th	nd to pur enge the precise d in the em and
Requirements for Obtaining Credit, Grading, Weight if applicable	it into a larger framework. T current state of research in t Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategie solutions and to stand for the	well as hey are he speci- ents and transfer s on the em in a c O O O O O O O O O O O O O O O O O O O	to expla able to ific area d exerci to the no r these bir own a critical o	ain the c describ se class tions, s methoc and with liscours	context e and i ses stu tateme ds to ne nin a gr se if nec	develope in parts a dents de nts, and ew proble oup. The cessary.	ed in the lect lso critically velop a conf methods ex ems, to anal y are able to ( ( E E E E E E E S U J o	ture ar challe ident, plaine lyse th p pres	nd to pur enge the precise d in the em and ent their
for Obtaining Credit, Grading, Weight if	it into a larger framework. T current state of research in t Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategie solutions and to stand for the Title Advanced Topics in	well as hey are ents and nce with transfer s on the em in a c b b o o o o o o d L E to succ ination is	to expla able to iffic area d exerci in the no or these irr own a critical of o 2 o 2 cessfully s set by	ain the c describ  se class tions, s methoc and with liscours S U U U U U U U U U U U U U U U U U U	ete ass tructor.	developed in parts a dents der nts, and ew proble oup. The cessary.	ed in the lect lso critically velop a conf methods ex ems, to anal y are able to (iii) ue y are able to 0 90-180 o. 20-30 a in order to eptional cas	ture ar challe ident, cplaine yse th o press g g be adr es the	nd to pu enge the precise d in the em and ent thei
for Obtaining Credit, Grading, Weight if applicable	it into a larger framework. T current state of research in t Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategie solutions and to stand for the Title Advanced Topics in Mathematical Relativity In this module students need the exam. The type of exam can be offered by the lecture	well as hey are ents and nce with transfer s on the em in a c s. D o o o d f L E to succ ination is r withou	to expla able to iffic area d exerci in the no er these air own a critical of o 2 o 2 cessfully s set by ut exerci	ain the c describ se class tions, s methoc and with liscours U U U 3 y comple the ins ses, in t	ete ass tructor. this cas	developed in parts a dents der nts, and ew proble oup. The cessary.	ed in the lect lso critically velop a conf methods ex ems, to anal y are able to (iii) ue y are able to 0 90-180 o. 20-30 a in order to eptional cas	ture ar challe ident, cplaine yse th o press g g be adr es the	nd to pue enge the precise d in the em and ent thei appendic to U U U U U U U U U U U U U U U U U U
for Obtaining Credit, Grading, Weight if	it into a larger framework. T current state of research in t Through homework assignm and independent acquaintar lectures. They learn how to to develop solution strategie solutions and to stand for the Solutions and to stand for the Advanced Topics in Mathematical Relativity In this module students need the exam. The type of exam can be offered by the lecture for the module instead of 6.	well as hey are ents and nce with transfer s on the em in a c b b b c c c c c c c c c c c c c c c c	to expla able to iffic area d exerci in the no er these air own a critical of o 2 o 2 cessfully s set by ut exerci or the m	ain the c describ se class tions, s methoc and with liscours Secure 3 y 3 y comple the ins ses, in t	ete ass tructor. this cas	develope in parts a dents de nts, and ew proble oup. The cessary. wr. o. or. ignments – In exce se, only 3	ed in the lect lso critically velop a conf methods ex ems, to anal y are able to (iii) ue y are able to 0 90-180 o. 20-30 a in order to eptional cas	ture ar challe ident, cplaine yse th o press g g be adr es the	nd to pu enge the precise d in the em and ent thei

Module Number: MAT-65-35	Module Title: Quantum Shannon Theory a	and Bey	/ond					of Module: e Module		
ECTS-Points	9									
Workload - Time in Class - Self-Study	Workload: 270 h	Time 90 h	in C	lass	:		Self-Si 180 h	udy:		
Duration	1 Semester	1								
Frequency	not regularly									
Term	2-3									
Language of Instruction	English									
Forms of Teaching and Learning	Lectures 4 SWS + exercise of	classes	s 2 S	WS,	hom	ework	assignmen	ts		
Content	Contents:									
	<ul> <li>Basic concepts about cuits, universality and</li> </ul>					tum co	mputer: qu	antum gates	s, quar	ntum cir-
	Quantum algorithms:	Deutso	ch-J	ozsa	, Shc	or and (	Grover.			
	Quantum communica coding. Quantum key				thec	orem, q	uantum tele	eportation ar	nd sup	erdense
	Physical realisations:	DiVinc	enzo	o crit	eria,	Cirac-2	Zoller quan	tum compute	er, circ	uit QED.
	Decoherence and ope	en quai	ntun	ı sys	tems	5.				
	Quantum error correct	tion. Fa	ault-	toler	ant q	uantur	n computinę	g.		
	Alternative models of	quantu	um c	omp	uting	: Adiat	patic quantu	im computat	ion.	
	<ul> <li>Introduction to the the entanglement, multipation</li> </ul>					ent: de	finition, crit	eria and me	easure	ment of
Objectives	In this course, the students quantum communication cha for several quantum informat timation and quantum hypoth essential results of the lectur In the exercise classes they the terms, statements and m on new problems, to analyse They are able to present the	annel. 1 ion pro nesis te e as we have a nethods them a	They esting ell as acqu s of t and t	kno sing f g. Th s ass ired he le o wo	w ho asks e stu essir a cor cture rk or	w to us s, such idents ng and nfident, e. They i solutio	e diverse q as quantum are capable explaining t precise an have learn on strategie	uantum entro tomograph of naming a he presente d independe ed to transfe s on their ow	opic m y, quar Ind pro d conr ent har er the r n or in	easures ntum es- oving the nections. ndling of methods a team.
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
	Quantum Shannon Theory and Beyond	L	f f	4	6 3	yes	wr. o. or.	90-180 o. 20-30	g	100
	In this module an exercise of examination the coursework oral is decided by the instruc	must h	nave	bee	n acc	uired.	Whether th	e examinatio		

(	
Literature	Exemplary Literature:
	<ul> <li>Michael A. Nielsen, Isaac L. Chuang: Quantum Computation and Quantum Informa- tion. CUP 2010.</li> </ul>
	Mark M. Wilde: From Classical to Quantum Shannon Theory. arXiv 2019.
	<ul> <li>John Watrous: The theory of quantum information. CUP 2018.</li> </ul>
	Eric A. Carlen: Trace inequalities and quantum entropy. Rutgers 2009.
	Michael A. Wolf: Quantum Channels and Operations Guided Tour. Lecture Notes 2012.
Transfer	The module belongs to the <i>Study Specialisation Mathematical Physics</i> . Taking into account the chosen personal Study Specialisation, it can be included in the sections <i>Study Focus</i> , <i>Advanced Knowledge in Mathematics</i> or <i>Elective Specialisation</i> , in accordance with the restrictive requirements of the respective section.
Prerequisites	The basic modules on Analysis and Linear Algebra are required.
Responsible Persons	Angela Capel Cuevas
Abbreviations:	ad h-hour wr-written exam MT-master thesis or-oral exam ng-not graded

## 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-Study: 255 h				
Duration	1 Semester											
Frequency	Every Semester											
Term	3											
Language of Instruction	English											
Forms of Teaching and Learning	Individual supervision by a mentor, study of scientific works.											
Content	<ul> <li>Content:</li> <li>Definition of an advanced scientific project in coordination with the mentor.</li> <li>Independent search and study of the relevant scientific literature.</li> <li>Formulation of specific problems and methodical approach to their solution.</li> <li>Written presentation of the project in conext of current state of research on 5-10 pages</li> <li>This module serves generally as a preparation for the Master Thesis</li> </ul>							) pages.				
Objectives	<ul> <li>Students</li> <li>develop skills to systematically familiarize themselves with a new subject,</li> <li>learn to work critically and to form a substantiated, professional and interdisciplinary judgement,</li> <li>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.</li> </ul>											
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)	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 Vogelsang.											

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-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 of the involved departments, guest scientists and master's students, who present the results of their Master Thesis.									
	Students gain an insight into the current development of mathematical physics beyond the area of their own specialization. They develop the ability to follow scientific presentations and to discuss and challenge them within a larger group of scholars. They therefore also obtain interdisciplinary and intercultural competencies through regular cooperation and discussion in mixed groups.									
Objectives	area of their own specialization to discuss and challenge the	on. They d m within a	levelc a larg	op the er gr	e ability oup of	y to follow s scholars.	cientific pr They there	esentati fore als	ons an o obtai	
Requirements for Obtaining Credit, Grading, Weight if	area of their own specialization to discuss and challenge the interdisciplinary and interculto	on. They d m within a	levelc a larg	op the er gr	e ability oup of	y to follow s scholars.	cientific pr They there	esentati fore als	ons an o obtai	
Requirements for Obtaining Credit, Grading, Weight if	area of their own specialization to discuss and challenge the interdisciplinary and intercultor mixed groups.	on. They c m within a iral compe	levelc a large etenci	op the er gr ies th	e ability oup of prough	y to follow s scholars. regular coo	cientific pr They there peration a ( <u>د</u> <u>ال</u> س س س	esentati fore als nd discu	ons an o obtai Ission i	
Requirements for Obtaining Credit, Grading, Weight if	area of their own specialization to discuss and challenge the interdisciplinary and intercultur mixed groups. Title Colloquium Winter	on. They c m within a iral compe Status Status	s S S S S S S S S S S S S S S S S S S S	SLO	e abilit oup of nrough stuemuts V	y to follow s scholars. regular coo	cientific pr They there peration a ( <u>د</u> <u>ال</u> س س س	Besentati	ons an o obtai Ission i	
Requirements for Obtaining Credit, Grading, Weight if applicable	area of their own specialization to discuss and challenge the interdisciplinary and intercultur mixed groups. Title Colloquium Winter Semester Colloquium Summer	on. They c m within a iral compe Statras C o C o	levelc a large etenci S S 2	SLO3 1	e abilit roup of nrough Assiduments no	y to follow s scholars. regular coo	cientific pr They there peration a ( <u>د</u> <u>ال</u> س س س	esentati fore als nd discu	ons an o obtai Ission i	
Objectives Requirements for Obtaining Credit, Grading, Weight if applicable Transfer Prerequisites	area of their own specialization to discuss and challenge the interdisciplinary and intercultur mixed groups. Title Colloquium Winter Semester Colloquium Summer	on. They c m within a iral compe Statras C o C o	levelc a large etenci S S 2	SLO3 1	e abilit roup of nrough Assiduments no	y to follow s scholars. regular coo	cientific pr They there peration a ( <u>د</u> <u>ال</u> س س س	esentati fore als nd discu	ons an o obtai Ission i	

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

Prerequisites	<ul> <li>27 CP from the compulsory elective section Foundations of Mathematical Physics,</li> <li>a total of 18 CP from the sections Knowledge Expansion and Elective Specialisation,</li> <li>Successful completion of module Scientific Project.</li> </ul>
Responsible Persons	Stefan Teufel, Werner Vogelsang.
Abbreviations:	d h-hour wr-written evam MT-master thesis or-oral evam ng-not graded