STUDENTS TO STUDENTS

SPLIT SUMMER SCHOOL

Contents

2 Lecture Contents

2 Gravitation and Cosmology

2 Quantum Field Theory (QFT)

3 Strings and Conformal Field Theory

4 Mathematical Quantum Mechanics (MQM)

5 Guest Abstract

5 Daniel Denegri

5 Oscar Cata

6 Saša Krešić-Jurić

7 Important Events

7 Registration

7 Welcome Speech

7 City Tour

8 Dalmatian-Bavarian Breakfast

8 Closing Words

8 Quick Facts

9 Support

10 Meet your host city

Lecture Contents

Gravitation and Cosmology

This course will focus on understanding the conceptual and mathematical grounds of the theory of general relativity, which provides a classical description of gravity, and its applications. The series consists of three parts and contains a brief introduction of differential geometry focusing on its use throughout the physical application.
The first part deals with these basics of differential geometry, which is the mathematical language used by Einstein's gravity, and with this introduces the study of generalised spacetimes which - in contrast to Minkowski spacetime - are not necessarily flat. In this discussion we also will introduce the concept of Lie groups, forming an intersection between differential geometry and group theory, which is essential for many realms of modern physics.
In the second part of the lectures we are looking for the relativistic field equations for gravitation. We will begin with the simple model of a linear approximation of gravity. Since many results of experiments treating gravitation can be explained using such an approximation, this is a logical starting point. After finding the wanted linear equations we will move on to introduce curvature and analyze the Einstein-Hilbert equation.
In the last part we are going to present the Fierz-Pauli Lagrangian and investigate two of the main applications of general relativity: Black holes and Cosmology.

Quantum Field Theory (QFT)

This series will give some basic ideas of QFT. We will introduce the necessary tools for constructing QFT and obtaining consistent results from it. Formally, the course will be divided in 4 parts.
In the first part, the fundamental concepts of time-dependent perturbation expansion and renormalization will be introduced, using Quantum

Mechanics (QM) as an example. Following up, the motivation for using a Field Theory will be discussed in the second part, as well as some approaches to quantize it canonically. Afterwards, part three will motivate the path integral approach starting from its role in QM once again and generalising the concept to its application to QFT. At the end of this part the LSZ reduction formula will be shown as a fundamental result and tool for QFT. Equipped with the above methods and concepts, we will finalise the introductory series with postulating the Feynman rules and giving a simple example for the calculation of a cross section. Additionally the role of QFT in particle physics will be discussed.

Strings and Conformal Field Theory

In the two given lectures we will talk about the basic ideas of string theory, aiming for a first understanding of the central concepts and results.
The focus will be set on introducing the bosonic string and demonstrating fundamental outcomes and problems as well as first concrete results.
Although this theory mainly serves as toy model and preparatory theory for the advanced theories including fermionic strings and aiming for a description of fundamental physical phenomena, it is very useful in order to grasp some core concepts and the nature of string theories, which clearly differs from established fields in particle physics such as QFT.
We will quantize the bosonic string and investigate the properties of the spectrum, finding promising insights as well as profound problems of the model.
The requirement of self consistency will then take us to a fixed dimension, requiring us to introduce another important procedure of string theory called compactification. Although the treated theory will not be physical, resulting obstacles to develop a proper description of fundamental physics will become apparent and serve as a ground for conceptual and profound discussions.
The third lecture will treat conformal field theory (CFT) and is affiliated to the two above sessions as we will - after briefly introducing the main ideas - apply the mathematical basis to string theory. As we thus will see, CFT provides us with a nice example of the cooperation of mathematics and

theoretical physics. The mutual inspiration and stimulation of mathematics and string theory demonstrate the importance of interdisciplinary cooperation and communication.

Mathematical Quantum Mechanics (MQM)

The aim of these lectures will be to get the participants acquainted with some basic topics in Mathematical Quantum Mechanics. After a small presentation of the subject and of the mathematical instruments needed in the following, self-adjoint operators will be introduced. Subsequently Stone's theorem will be proven in order to demonstrate the importance of self-adjointness. Afterwards, criteria for extensibility of operators will be discussed as well as its applications to physically relevant systems such as the hydrogen atom, the Chandrasekar operator and the Dirac operator. In the second pair of talks we want to show an alternative approach to quantum mechanics, which is based on C*-algebras. To this extent, we will start with some motivating thoughts and definitions of fundamental physical objects, such as observables and states, giving some examples. One of the advantages of adopting the algebraic approach is that there is no need to postulate Hilbert spaces: We show the Gelfand-Neimark-Seagal construction, which explains how they naturally arise in this context as *-representations of the algebra of the observables. We will then investigate the relation between the Hilbert spaces arising from different Gelfand-Neimark-Seagal constructions, relating it to the equivalence of *-representation. A final chapter will be devoted to an overview on composite systems including tensor products, pure and mixed states and entanglement.

Guest Abstract

We are happy to announce that in addition to the above lectures, three researchers and professors will present contents of their work and interests, connecting the introductory lectures with state-of-the-art research and results and providing with motivations to study the various fields shown throughout the conference.
Gladly we let you know that as guest lecturers we were able to win Saša Krešić-Jurić, Daniel Denegri and Oscar Cata.

Daniel Denegri

CEA-SACLAY AND CERN/PHYS. DEPT.

"From W, Z discoveries to the Higgs boson discovery"

The talk will briefly review the key steps that led to the establishment of the Standard Model of particle physics, in particular the discovery of the W and Z bosons in the UA1 experiment at CERN in 1982/83, then it will present the motivations and launching of the LHC project, and briefly mention the design and construction of the CMS detector in particular. We then discuss some of the main research topics at the LHC, the discovery of the Higgs boson and the present (2017) status of these studies, as well as studies with jets, top physics, supersymmetry searches. We finish with some expectations concerning the LHC over the next 10 to 15 years, as well as physics expectations for the near and middle-term future.

Oscar Cata

UNIVERSITÄT SIEGEN

"A Higgs or 'the' Higgs?"

The discovery of a scalar particle at CERN, with properties in agreement with theoretical expectations, is a strong indication that the Standard Model (SM) is the theory of the electroweak interactions, at least up to the energies which have been probed so far. However, validation of the SM from experimental data cannot be done unless a broader, more generic theoretical framework is employed. I will discuss the characteristics of this framework, which requires the use of effective field theories, and will comment on the different theoretical

possibilities (beyond the SM) that are still viable taking into account the current precision in Higgs physics at the LHC.

Saša Krešić-Jurić

FACULTY OF SCIENCE, UNIVERSITY OF SPLIT

"Integrable systems, geometry and group theory“

In this lecture we will discuss integrable systems and their relation with geometry and group theory. In particular, we will focus on finite and infinite dimensional Hamiltonian systems. In the first part of the lecture we will explain the role of Poisson geometry in the theory of finite dimensional Hamiltonian systems. We will then explain how this approach can be generalized to include infinite dimensional systems represented by partial differential equations (PDE's). In the second part of the lecture we will explore the role of loop groups in integration of such equations. We will explain how the Birkhoff factorization on loop groups is used in integration of nonlinear PDE's represented as the zero-curvature equation on loop algebras. Several examples with applications in physics will be presented, e.g. the Korteweg-de Vries equation, the nonlinear Schroedinger equation and the Heisenberg magnet equation.

Important events

Registration

The registration for the conference takes place on Sunday, September 17th, at 16:00h – 19:00h Here you will receive your welcome bag and important information regarding the conference. If you can not make it to the registration please contact us during the beginning of the school in order to register.

We are glad to announce that the lunch and coffee breaks are included in the conference participation. Lunch takes place daily between 12:45 pm and 2:15 pm at the restaurant of SC.

Welcome Speech

On Monday, we start at 8:45 am in the lecture hall (see quick facts) briefly welcoming you to the summer school and introducing to you the team and the schedule of the week.
Please take part in this event in order to receive latest updates and important information. We will then directly go over to the first lectures.

City Tour

On the first day there will be a tour around the city of Split, making you familiar with the most interesting and important locations and the other participants, of course. The meeting point for the tour is at 4:00 pm in front of the touristic palace at Lučka Kapetanija. We would be glad to see you all there in order to get to know you and explore the city.

Dalmatian-Bavarian Breakfast

At the end of the week, on Saturday morning, we will celebrate the Dalmatian-Bavarian cooperation with a culinary highlight, holding a breakfast with specialties of both, the Dalmatian and the Bavarian cuisine. We hope for an entertaining closing session of an interesting and insightful week with all of you, starting at 9:00 am at the atrium of Faculty of Science. The breakfast is included in the conference participation.

Closing word

After the breakfast, we will say farewell and goodbye in a last short meeting, closing the Students to Students Split Summer School 2017.

Quick facts

Lectures will take place at amphitheater: A1-1 at Faculty of Science (PMF). *Adress: Ul. Ruđera Boškovića 33, Split*

Lunch will take place every day from 18th to 22nd at the restaurant of SC. *Adress: Cvite Fiskovića 3, Split*

Accomodation for those who reserved it through us is located at student dorm *Dr. Franjo Tuđman.* You can register there at the reception. *Adress: Cvite Fiskovića 3, Split*

Contact e-mail: s2s4@pmfst.hr
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Pave Pilić (organizer): +385919483205 (pilicpave@gmail.com)

Support

We would like to thank the following sponsors which made it possible to hold S2S4 2017:

University of Split

Ludwig Maximilian University

Faculty of Science

Elite Master Course

Croatian Physical Association

Technical University Munchen

Splitska Banka

Pašike – Heritage Hotel & Restaurant

Catering SC

Mathematical Association Split

10 Meet your host city

11 Where am I?

11 Basic info's

12 Price list

12 Public tranport

13 Restaurants&fast-foods

13 Shopping&cinema

14 Nature and beaches

14 Park Forest Marjan

15 Bačvice Beach

15 Firule Beach

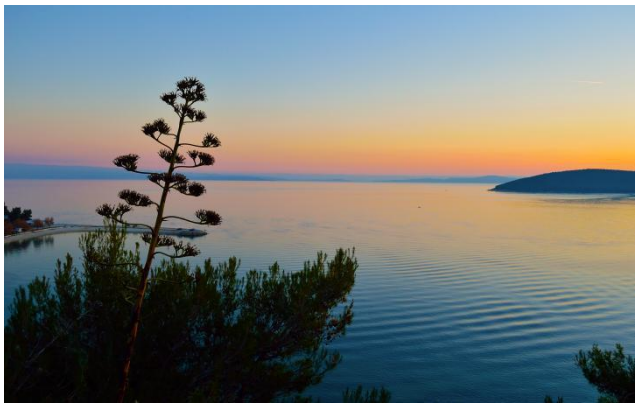
16 Frequently asked questions

17 Emergency telephone numbers

Where am I ?

This is the question you ask yourself only in two situations: after alcoholic coma and while visiting a country you have no idea about. For the first one you'll probably need a list of emergency telephone numbers too, which is on the last page. But first, here are some ..

Basic info's



Autumn in Split lasts from September to December, although not a favourite part of the year to some, in many ways it is the most beautiful time of the year to visit Split, especially at the end of September and in October. It is the time when the temperature of the sea is ideal, the summer heat is at its low, and the main season is still on.

Split is the largest city in Dalmatia, second largest city in Croatia and according to the latest census conducted in 2011 Split has almost 180 thousand inhabitants. Second largest Croatian cargo harbour, but also one of the largest passenger harbours on the Mediterranean. It is the administrative centre of the Split & Dalmatia County.

Split lies on the Adriatic coast, central Dalmatia, on the Split (Marjan) peninsula. Although surrounded by sea as a peninsula, Split also borders with surrounding mountains, Mosor on the northeast, Kozjak on the northwest, and Marjan hill as one of the most important symbols of the city, rising on the west side of the peninsula, in the immediate vicinity of the old city centre. Split is also surrounded by the islands Brač, Hvar, Šolta and Čiovo.

Price list

Everything has its price. Except winning an argument with your professor and taking a nap after exams – that's priceless. These informations will be very helpful and useful.

Public transport

Split has a very good public transport system which is run by the company Promet Split. The center itself is very well connected with the outer parts of the city. Local public bus transportation is in any case the cheapest mode of transport. A ticket for local city buses can be purchased directly from the driver or at most kiosks in Split (most kiosks of Tisak and Slobodna Dalmacija). If you buy a ticket at the kiosk, you have to show it to the driver who will annul it with a stamp.

Public city bus system of the city of Split is divided into four (4) zones:

Zone 1: The city of Split

- one way ticket: 11kn

Be smart, cheat the sistem. Buy round-trip ticket for 1st zone on kiosk: 18kn.

Zone 2: Solin, Stobreč, Podstrana and Klis

- one way ticket: 13kn

Again. Be smart. Round-trip ticket is 22kn.

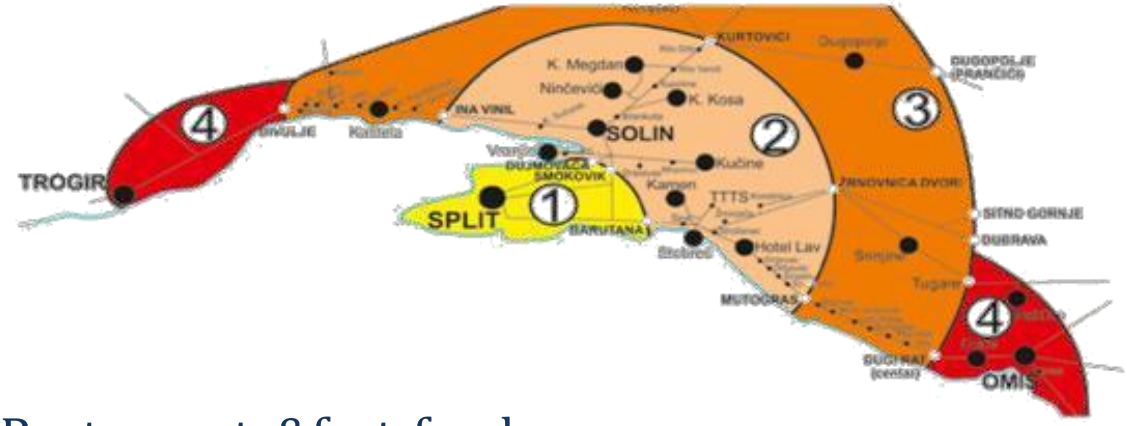
Zone 3: Kaštela, Dugopolje, Dugi Rat

- one way ticket: 17kn (round-trip ticket:

27kn) Zone 4: Trogir, Omiš

- one way ticket: 21kn (round-trip ticket: 33kn)

Keep in your mind: there are no night bus lines during work days. Only Friday and weekend. If you like night walking tours here's a chance for you.



Restaurants&fast-foods

Split restaurants tend to stick to tried & true favourites to please their local customers and the locals love local Dalmatian dishes. A few exotic restaurants do exist but grilled **fresh fish**, **stewed meat**, **homemade pasta** and fluffy **pizza** are the local favorites that you'll find on menus throughout town. Split's growing crowd of international visitors have added more vegetarian and vegan options to local menus even though the traditional diet leans toward fish and seafood.

As everywhere in Croatia, prices are marching ever upward in Split. Before getting in a lather about it, take a look at the prices in a local supermarket. They're the same as most other European destinations. That is, you can't expect restauranteurs to give a break to their customers when they're paying through the nose. Still, you can get good value if you sniff around. Prices can be affordable if you choose carefully.

The most of restaurants are located in the old centre of Split.

- pizza or pasta: 34-70kn
- lunch and dinner in local restaurants: 70-150kn
- meal in top restaurants: 150-300kn

Splits fast food service is the best in Croatia so if you're not the restaurant fan everything is affordable for very low prices: 10-30kn.

Shopping&cinema

There are three shopping centres in Split:

- Joker (bus lines: 1,2,3,9,10,16,17,22)
- City Center One (6,18)
- Mall of Split (6,18)

Nature&beaches

Yes. The second largest **city** in Croatia is famous for its beaches and forests. Admit it, this is at least 50% of reasons why you actually came here.

Park forest Marjan - the hill that overlooks the city has always been the most impressive part of Split imagery. Such a harmony between natural and urban is rarely found; on one side the densely populated city in all of its glory and on the other a peninsula of almost pristine nature.
Holy hill, as it is often called, harbors many monuments of sacred and secular architecture which are combined with this green oasis in such a way that they inspire a sense or awe an admiration even in a passer-by. We'll have a special tour around this forest.

Split has 14km of beaches. All of them have blue flag – the symbol of top quality sea water. Here are the most popular:

Bačvice beach

Bacvice beach is a natural phenomenon in the heart of the city and also the most popular sandy beach in the center. The beach is only 1 km away from the center of Split. You can reach it on foot in just 10 minutes by heading in the direction of the main bus station and the ferry port. Just cross the bridge and you will already see the sandy bay. During the day Bacvice is a promenade all ages enjoy, as well as a place where local and foreign swimmers come to chill out, while at night the resort “transforms” into the center of entertainment for young people.

After closing the bars in town, go to Bacvice beach to enjoy the nightlife under the stars. The best place in Split to finish your nightlife adventure.

Firule beach

Few minutes by foot from Bacvice you'll find much smaller and less crowded sandy bay where is located one of the oldest nightclubs in Split – Zenta. It’s a popular venue for rock gigs as well as weekend DJ sessions, and

you'll frequently see Zenta posters plastered around town on the eve of big events. Two floors, a summer terrace and outside bar allow plenty of space to dance or relax.

FREQENTLY ASKED QUESTIONS

1) Are there any dangerous neigbourhoods in Split?

No. The only danger might be weather. Follow it: http://meteo.hr/

2) One croatian kuna is...?

Enough to sit and cry. 1HRK~0.13EUR~0.16USD

3) **Where can I find a list of all bus lines?** http://

www.promet-split.hr/images/VOZNI_RED/vozni_red.pdf

4) Clubs, music and prices?

Club	Music	Location	Bus	Entrance
Central Club	Disco hits, R'N'B, hip-hop, jazz, evergreen music, house groove, dance	Trg Gaje Bulata (centre of Split)	1, 5, 5a, 6, 11, 14, 16, 18, 22, 23(night line)	~50kn
Tropic Club	Disco hits, croatian hits, turbofolk	Bačvice Beach	3, 5, 5a, 8, 11, 14, 17, 39(night line)	Free, 60kn(concerts)
Zenta Club	Disco hits, ROCK, exYu rock, pop, techno, R'N'B, rap, house, croatian hits, trash, 70s, 80s, 90s	Firule Beach	3, 5, 5a, 8, 11, 17, 39(night line)	Free – 20kn, 50-100kn (concerts)
Bačvice Club	Disco hits, pop, techno, house, rap, dance	Bačvice Beach	same as Tropic Club	Free
Vanilla Club	Croatian hits, turbofolk, Balkan hits, pop, techno, rock, trash	Poljud stadium	7, 17, 39(night line)	0 – 20kn

5) Are there any dangerous animals in sea?

Yes. People on jet-ski who don't follow the rules (<300m away from the coast). If you rent one, don't be one of them.

6) In the middle of day, on 30°C, I went on wild terrain wearing flip-flops and without a bottle of water, then I realized that's a stupid idea. What now?

Call Croatian Mountain Rescue Service (HGSS) – phone: 112. The service is free, but doesn't mean you can call them for pizza delivery or when you get tired.

7) Drinking and smoking?

Is allowed. Everywhere in public. But not a smart idea if you find yourself in situation like question 6. Do not drink&swim, drink&drive or drink&(anything that includes physical work). Smoking is prohibited in Park Forest Marjan and some restaurants. Grilling is also prohibited in Park Forest Marjan because you might grill entire city instead.

8) Cinema and theatre?

Croatian National Theatre: http://www.hnk-split.hr/en/

Cineplexx Cinema: http://www.cineplexx.hr/center/cineplexx-city-center-one-split/

Cinestar Cinema: http://www.blitz-cinestar.hr/cinestar-split

EMERGENCY TELEPHONE NUMBERS

National Protection and Rescue Directorate	**112**	**Hospital 'Firule'**	**556-111**
Police	**92**	**Hospital 'Križine'**	**557-111**
Firefighters	**93**	**Pharmacy 'Dobri'**	**348-074**
Ambulance	**94**	**Pharmacy 'Lučac'**	**533-188**
Sea Help service	**9155**	**Autoclub**	**1987**

Tourist information centre: 345-606

+385 (Croatia) || 021(Split)