FRIEDRICH-SCHILLER-UNIVERSITÄT JENA

Faculty of Physics and Astronomy

Working Group Teaching Methodology in Physics and Astronomy

ASTRONOMY FROM MULTIPLE PERSPECTIVES – COMPACT OBJECTS

Wilhelm and Else Heraeus Summer School

2nd Sept.— 6th Sept. 2024 | Jena, Germany

Monday | 2nd Sept.

9:00 am	**Registration opens**
10:00 am	**Introduction**
10:30 am	Coffee break
11:00 am	**From Counterintuitive Properties of Accelerated Motion to Compact Objects in General Relativity** *Markus Pössel (Haus der Astronomie, Heidelberg)*
12:30 pm	Lunch break
2:00 pm	**Testing General Relativity with the Massive Black Hole in the Galactic Center** *Stefan Gillessen (Max Planck Institute for Extraterrestrial Physics)*
3:30 pm	Coffee break
4:00 pm - 6:00 pm	**Group Tutorial** *Padova*

Tuesday | 3rd Sept.

9:00 am	**Black Holes in General Relativity** *Reinhard Meinel (Friedrich Schiller University Jena)*
10:30 am	Coffee break
11:00 am	**The Hawking Effect and Related Quantum Effects at the Event Horizon** *Sebastian Ulbricht (Physikalisch-Technische Bundesanstalt PTB, TU Braunschweig)*
12:30 pm	Lunch break
2:00 pm	**Group Tutorial** *Heidelberg*
4:00 pm	Coffee break
4:30 pm - 6:00 pm	**Across the Horizon into a Black Hole** *Plenary Tutorial* *Ute Kraus (University of Hildesheim)*

Wednesday | 4th Sept.

Excursion day

9:30 am	**Meeting point:** *at the conference venue (Faculty of Physics and Astronomy, Max-Wien-Platz 1, 07743 Jena)*
	Visits at: The Wartburg *(a castle originally built in the Middle Ages around 1067 where Martin Luther translated the New Testament into German)*
	University Observatory Großschwabhausen
~ 5:30 pm	Arrival back in Jena

Information:

We will travel all routes by tour bus.

Please take enough drinks with you for the day.

At Wartburg Castle there are cafés and food stands where you can get a small lunch, e.g. a real Thuringian bratwurst.

Thursday | 5th Sept.

9:00 am	**Studying Binary Neutron Stars through Nuclear Physics and Multi-Messenger Observations** *Tim Dietrich (Max Planck Institute for Gravitational Physics)*
10:30 am	**Coffee break**
11:00 am	**Gravitational Waves from Compact Objects** *Sebastiano Bernuzzi (Friedrich Schiller University Jena)*
12:30 pm	**Lunch break**
2:00 pm	**Gravity Experiments with Radio Pulsars — 50 Years after the Discovery of the Hulse-Taylor Pulsar** *Norbert Wex (Max Planck Institute for Radio Astronomy)*
3:30 pm	**Coffee break**
4:00 pm - 6:00 pm	**Group Tutorial** *Jena*

Friday | 6th Sept.

9:00 am	**The Puzzling Tale of Compact Object Populations** *Erika Korb (University of Padua)*
10:30 am	**Coffee break**
11:00 am	**A Mysterious Missing Link: Formation and Evolution of Intermediate-Mass Black Holes in Dense Stellar Environments** *Manuel Arca Sedda (Gran Sasso Science Institute)* *via video broadcast*
12:30 pm	**Lunch break**
2:00 pm - 4:00 pm	**Group Tutorial** *Milano*
7:00 pm	**Conference dinner** *Venue: Landgrafen Jena* *(Landgrafenstieg 25, 07743 Jena)*

Information

Conference venue:
Faculty of Physics and Astronomy
Lecture hall 1 (HS 1)
Max-Wien-Platz 1
07743 Jena

Hotel:
Best Western Hotel
Rudolstädter Str. 82
07745 Jena

How to get from the hotel to the conference venue :
By tram (~35 min):

- *walk to tram stop „Winzerla"*
- *take the tram line 2 towards „Jena-Ost"*
- *exit at „Stadtzentrum, Löbdergraben" (city center)*
- *you can either walk from there (15 min) OR*
- *take the tram line 1 or 4 towards „Zwätzen" (from the same platform you just arrived on)*
- *exit at „Spittelplatz", walk from there (9 min)*

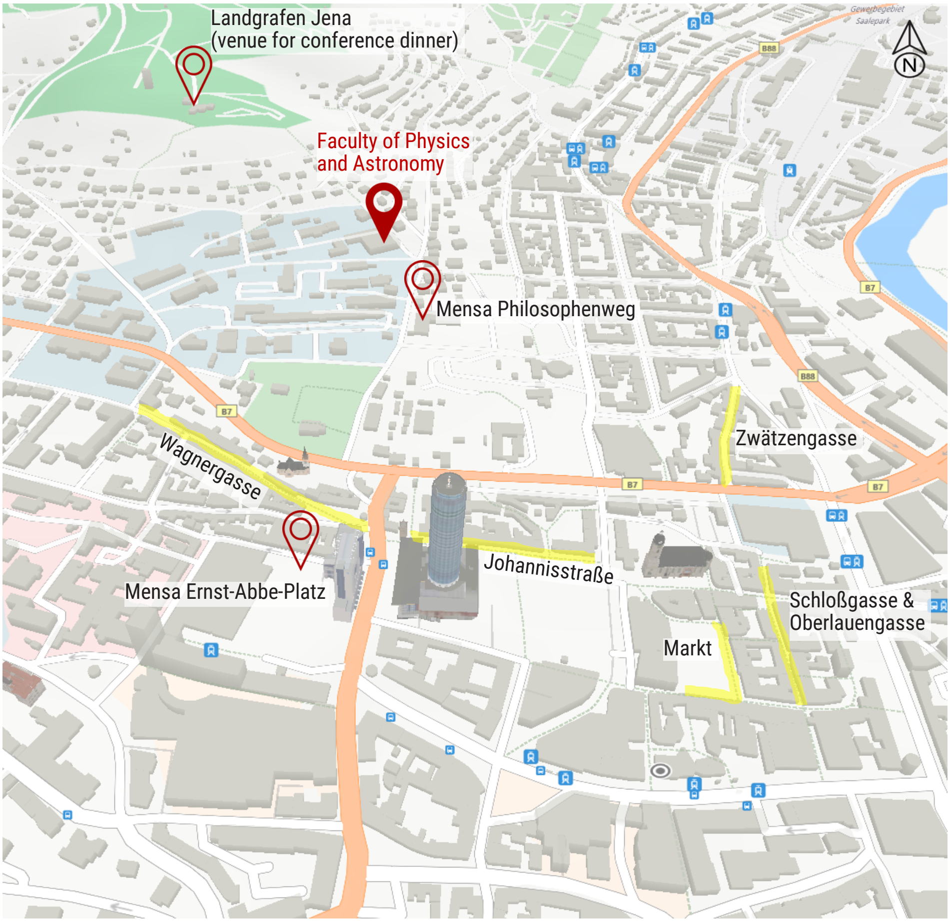
By bus (~45 min):

- *walk to bus stop „Winzergasse"*
- *take the bus line 12 towards „Stadtzentrum, Teichgraben"*
- *exit at „Stadtzentrum, Teichgraben" (city center)*

Lunch & Dinner

You can go to a university canteen („Mensa“) or you will find plenty of restaurants at various prices throughout the city center.

The streets with a particularly high concentration of restaurants are highlighted in yellow.



Windows Maps App, edited

Wi-Fi Access

Option 1

When you have eduroam-Wi-Fi at your home institution, you can also use the eduroam-Wi-Fi here.

Option 2

Use our free Wi-Fi:

- during the conference
- available in all buildings of the Jena University

Wi-Fi name (SSID):	guests.uni-jena.de
username: (Benutzername)	Astronomy
password:	Jena2024

If you encounter difficulties when connecting to the login page (e.g. certificate error messages):
http://detectportal.firefox.com
Or feel free to ask us.

From Counterintuitive Properties of Accelerated Motion to Compact Objects in General Relativity

Dr. Markus Pössel (Haus der Astronomie, Heidelberg)

Special relativity introduces several notions that run counter to classical intuition, notably the relativity of simultaneity, and effects like time dilation and length contraction.

In this talk, I present some additional counterintuitive properties, which have their root in classical physics, but come to the fore in relativity. These properties are linked to certain types of accelerated motion. They have direct relevance for our understanding of static gravitational fields, and thus for the simplest description of compact objects in general relativity, including black holes, and they show a deep connection between what is usually called the gravitational redshift on the one hand and the Doppler effect on the other.

Testing General Relativity with the Massive Black Hole in the Galactic Center

Dr. Stefan Gillessen (Max Planck Institute for extraterrestrial physics)

Black holes have become reality. Astronomical measurements give clear evidence of the existence of such dark gravity monsters. By far the most convincing case is the massive black hole in the Galactic Center, honoured with the 2020 Nobel prize in physics.

With modern instrumentation, individual stellar orbits around a compact, 4-million-solar mass object can be traced, leaving no doubt on the nature of the central object. Nowadays, the black hole can be used to test the underlying theory, general relativity. The motions of the stars are showing — once again — that Einstein was right.

Black Holes in General Relativity

Prof. Dr. Reinhard Meinel (Friedrich Schiller University Jena)

After a short historical introduction I shall discuss the basic properties of stationary black holes in general relativity. In particular, this includes the event horizon. The formation of black holes via gravitational collapse, properties of rotating black holes, black hole uniqueness, and the possibility of quasi-stationary routes to black holes will also be covered.

The Hawking Effect and Related Quantum Effects at the Event Horizon

Dr. Sebastian Ulbricht (Physikalisch-Technische Bundesanstalt PTB, TU Braunschweig)

The effects of gravity and quantum physics, predicted by the theories of general relativity and quantum field theory, are well understood in their respective regimes. However, a combined theory of both, explaining their interrelation at all scales, is still not found. A famous example, in which both are relevant, is the Hawking effect, considered in this lecture:

In classical general relativity, a black hole only can absorb matter and is therefore ever growing. In 1974, Steven Hawking studied quantum fields in the background of a classical black hole. He found that it must emit particles with a thermal spectrum of temperature $T \sim 1/M$ indirectly proportional to the black hole's mass. This gives rise to the conclusion, that a black hole in the presence of a quantum field is allowed to shrink and ultimately to even evaporate in contradiction with its purely classical description.

We give a brief glimpse on the topic of quantum physics in curved spacetime and motivate the emergence of Hawking radiation in the vicinity of a black hole from the related but purely kinematic effect of particle creation in the frame of an accelerated observer (Unruh effect).

Across the Horizon into a Black Hole

Prof. Dr. Ute Kraus (University of Hildesheim)

In this workshop we explore the horizon and the interior of a Schwarzschild black hole.

We will look at probes falling into the black hole and study their communication with a stationary space station and with each other.

For this exploration, we will use a sector model of the black hole spacetime. This model represents the curved spacetime and lets us construct light signals with pencil and ruler.

Studying Binary Neutron Stars through Nuclear Physics and Multi-Messenger Observations

Prof. Dr. Tim Dietrich (Max Planck Institute for Gravitational Physics)

Neutron stars are astrophysical laboratories, enabling the exploration of matter at the highest densities known in our Universe, right on the edge of black hole formation. Despite their importance, our understanding of the dense matter within neutron star cores remains limited. However, recent advancements in multi-messenger astronomy — particularly the detection of gravitational waves and electromagnetic counterparts from neutron star mergers — have opened new avenues for probing this extreme matter. Essential for an accurate interpretation of binary neutron star mergers are reliable models describing the last stages of their coalescence, e.g., through complex numerical-relativity simulations.

In addition, studies of binary neutron stars can be complemented by other astrophysical observations of neutron stars, as well as by nuclear physics research, such as new theoretical computations or heavy-ion collision experiments. We outline how the combination of current theoretical knowledge, astrophysical observatories, and experimental facilities helps us to improve our knowledge about the equation of state within the cores of neutron stars.

Gravitational Waves from Compact Objects

Prof. Dr. Sebastiano Bernuzzi (Friedrich Schiller University Jena)

Compact objects, like white dwarfs, black holes and neutron stars, are stellar-remnants characterized by extreme gravity and matter densities. They are sources of (or involved in) some of the most luminous astrophysical emissions in the Universe, including gravitational waves.

Predicted by Einstein soon after the formulation of general relativity, gravitational waves are spacetime perturbations generated by compact sources with a time-varying quadrupole moment. Gravitational wave has been inferred from pulsars (radio) observations and, more recently, directly detected from binary systems made of black holes and neutron stars. Their observation helps us to understand fundamental physics and the engines behind high-energy astrophysical emissions.

The first part of the lecture introduces compact objects in General Relativity and astrophysics. The second part of the lecture focuses on gravitational-waves, covering both basic concepts and modern multi-messeneger observations of compact binaries.

Gravity Experiments with Radio Pulsars – 50 Years after the Discovery of the Hulse-Taylor Pulsar

Dr. Norbert Wex (Max Planck Institute for Radio Astronomy)

This year marks the 50th anniversary of the discovery of the first pulsar in a binary star system by Russell Hulse and Joseph Taylor. Previously, precision gravity tests were essentially limited to the weak-field, slow-motion region of the Solar System. The discovery and continued observations of the Hulse-Taylor pulsar made it possible for the first time to investigate the gravitational interaction of strongly self-gravitating bodies, in particular two neutron stars. Above all, these observations have also led to the confirmation of the existence of gravitational waves.

Meanwhile, several pulsars have been discovered which provide unique test-beds for general relativity. They allow us to study different aspects of relativistic gravity, depending on their orbital characteristics and the properties of their companions. One system that deserves special mention is the “Double Pulsar", which has far exceeded our original expectations. In many ways, pulsar experiments are a valuable complement to other modern gravity tests.

In my talk I will give an introduction to gravity tests with radio pulsars, highlight some of the major results, and give a brief outlook on the future of this exciting field of experimental gravity.

The Puzzling Tale of Compact Object Populations

Erika Korb (University of Padua)

Compact objects can be found in different flavours in the universe. They differ in mass, size, and location. Some of them reside in the center of galaxies, some hide in stellar clusters, and some just wander across the stars, alone or in binaries.

For decades, electromagnetic observations have been used to discover and characterize any type of compact object, except binary black holes. Their existence was confirmed only in 2015, with the first detection of a binary compact object that merged via gravitational wave emission. Since then, about 100 mergers were observed with gravitational wave detectors, providing an unique opportunity to investigate the formation channels of compact object binaries. The next generation of gravitational wave detectors is expected to probe a larger portion of the universe, increasing the observed population of compact objects and shedding new light on their evolution across cosmic time.

A Mysterious Missing Link: Formation and Evolution of Intermediate-Mass Black Holes in Dense Stellar Environments

Prof. Manuel Arca Sedda (Gran Sasso Science Institute)

Intermediate-mass black holes (IMBHs), with masses in the range 100 - 100,000 solar masses, are thought to bridge the gap between stellar mass black holes, formed from the death of massive stars, and supermassive black holes, now routinely found in the centre of galaxies. From the observational perspective, however, little is known about IMBHs. Despite a few observations of low-mass IMBHs performed by gravitational-wave (GW) detectors, and observations of high-mass IMBHs in the nuclei of dwarf galaxies, currently there is no smoking-gun observation of an IMBH with a mass in the range 1,000 - 10,000 solar masses, making it hard to asses the nature of IMBHs. Are they a real missing link? Or, rather, they just represent the endpoint of stellar and supermassive black hole populations?

In this talk, we will try to understand how far we are from a definitive answer to this question, and how future detectors and models can help us unravelling the true nature of IMBHs.

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