FIȘA DISCIPLINEI

1. Date despre program

1.1 Instituția de învățământ superior	Universitatea de Vest din Timișoara
1.2 Facultatea / Departamentul	Facultatea de Fizică
1.3 Departamentul	Physics
1.4 Domeniul de studii	Physics
1.5 Ciclul de studii	Master
1.6 Programul de studii / Calificarea	Advanced research methods in physics

2. Date despre disciplină

2.1 Denumirea disciplinei	**Numerical Relativity ARMP 2407**						
2.2 Titularul activităților de curs	Daniela Delia Alic						
2.3 Titularul activităților de seminar	Daniela Delia Alic						
2.4 Anul de studiu	2	2.5 Semestrul	1	2.6 Tipul de evaluare	E[1]	2.7 Regimul disciplinei	DS/ DFA C

3. Timpul total estimat (ore pe semestru al activităților didactice)

3.1 Număr de ore pe săptămână	4	din care: 3.2 curs	2	3.3 seminar/laborator	2
3.4 Total ore din planul de învățământ	56	din care: 3.5 curs	28	3.6 seminar/laborator	28
Distribuția fondului de timp:					ore
Studiul după manual, suport de curs, bibliografie și notițe					28
Documentare suplimentară în bibliotecă, pe platformele electronice de specialitate / pe teren					20
Pregătire seminare / laboratoare, teme, referate, portofolii și eseuri					28
Tutorat					14
Examinări					4
Alte activități					

3.7 Total ore studiu individual	**94**
3.8 Total ore pe semestru	**150**
3.9 Numărul de credite	**6**

4. Precondiții (acolo unde este cazul)

4.1 de curriculum	• Gravitation and cosmology
4.2 de competențe	• General knowledge of programming, physics, mathematics, and the theory of relativity • Ability to work individually and in a team

[1] Conform articolului 37, alineatul (1) din Legea învățământului superior nr. 199/2023, cu modificările și completările ulterioare, *„succesul academic al unui student pe parcursul unui program de studii este determinat prin* ***verificarea dobândirii rezultatelor așteptate ale învățării prin evaluări de tip examen și prin evaluarea pe parcurs****”*.

5. Condiții (acolo unde este cazul)

5.1 de desfășurare a cursului	• Lecture hall/amphitheatre with video projector system and whiteboard; computer - workstation/laptop and internet connection
5.2 de desfășurare a seminarului / laboratorului	• Seminar room with computers - workstation/laptop with internet connection; video projection system, whiteboard

6. Obiectivele disciplinei - rezultate așteptate ale învățării la formarea cărora contribuie parcurgerea și promovarea disciplinei

Cunoștințe	• to know the advanced notions in the field of Physics, which involves a critical understanding of theories and principles • to know the working formulas for calculations with physical quantities using properly the principles and laws of physics • to know the language specific to the field
Abilități	• To describe physical systems using specific theories and tools (experimental and theoretical models, algorithms, schemes, etc.) • to apply the principles and laws of physics in solving theoretical or practical problems, under conditions of qualified assistance • to use the computer and calculation programs for the numerical simulation of the physical processes • To describe and explain the fundamental principles of physics, including those of: Relativity and Quantum Mechanics, Standard Model, Quantum fields and particles, Cosmology
Responsabilitate și autonomie	• to critically analyze a specialized report, scientific communication with a medium degree of difficulty in the field of physics • to autonomously use information sources and resources for communication and assisted professional training (Internet portals, specialized software applications, databases, online courses, etc.) both in Romanian and in a language of international circulation

7. Conținuturi

7.1 Curs	Metode de predare	Observații
Chap.1. General Relativity prerequisites synthesis (2 hours) • The Einstein Equations in 4D spacetime	The presentations use multimedia tools and are accompanied by discussions and explanations on the	

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Exact solutions
Analytical and numerical approximations
Chap.2. The 3+1 decomposition of Einstein’s equations – numerical view – evolving black hole spacetimes (10 hours)
The constraint and evolution equations – ADM formalism
Conformal transformations – puncture technique
Psedo-hyperbolic systems - the BSSN and Z3 formulations
Conformal and covariant Z4 formulation – constraint damping
Gauge conditions (singularity avoiding lapse and symmetry-seeking shift evolution)
Chap. 3. Matter sources in General Relativity (6 hours)
GR Hydrodynamics - neutron stars
GR Magnetohydrodynamics – the ideal MHD evolution equations and the Force-Free limit
GR resistive magnetohydrodynamics – formulation and tests
GR fermion-boson stars
Scalar fields as dark matter halos
Chap. 4. Numerical methods (4 hours)
Finite difference methods
Kreiss-Oliger dissipation
</td>
<td>application of the principles of the Theory of Relativity.

Active and Collaborative Learning
The course provides students with teaching materials and pedagogical resources in electronic format, including numerical models and dedicated software.

Discussions are initiated and explanations on the topic are provided, supported by specific case studies. After the presentation of theoretical aspects, concrete applications and case studies are introduced.</td>
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• High-Resolution-Shock-Capturing methods • Method of lines • Runge-Kutta Implicit-Explicit schemes • Convergence testing **Chap. 5. Challenges in numerical evolution (6 hours)** • Standard testbeds in Numerical Relativity • Spacetimes in spherical symmetry (black holes, stars) • Binary black-holes • Binary neutron stars • Gravitational wave extraction • Electromagnetic signal		

Bibliografie:
1. Thomas W. Baumgarte, Stuart L. Shapiro, Numerical Relativity (Cambridge University Press, 2010). ISBN: 978-0-511-72937-9.
2. Miguel Alcubierre, Introduction to 3+1 Numerical Relativity (Oxford University Press, 2008). ISBN: 978-0-19-920567-7.
3. C. Bona, C. Palenzuela-Luque, C. Bona-Casas, Elements of Numerical Relativity and Relativistic Hydrodynamics (Springer, 2009). ISBN: 978-3-642-01164-1.
4. Luciano Rezzolla, Olindo Zanotti, Relativistic Hydrodynamics (Oxford University Press, 2013). ISBN: 978-0-19-852890-6

7.2 Seminar / laborator	Metode de predare	Observații
Chap.1. Standard numerical relativity tests (4 hours) • Robust stability test • Linearized wave test • Gauge wave test **Chap.2. Spacetime evolution in spherical symmetry (4 hours)** • Schwarzschild black hole with different gauge conditions **Chap. 3. Matter evolution in spherical symmetry (4 hours)**	Explanation, demonstration, and case studies (including multimedia), along with individual and team applications (in pairs), using specialized software such as the Einstein Toolkit, conducted in the seminar room. Active and collaborative learning methods are applied.	

• Fermion-boson star with different boundary conditions **Chap. 4. Numerical methods (6 hours)** • Numerical implementation and evolution of GRMHD using HRSC methods • Numerical implementation and evolution of GRMHD systems with stiff terms using RKIMEX **Chap. 5. Einstein Toolkit applications (10 hours)** • Puncture black hole evolution • Equal and un-equal mass binary black-holes in vacuum • Equal and un-equal mass binary black-holes in electro-magnetic fields – jet structure formation • Binary neutron stars • Gravitational waves extraction		
Bibliografie: https://einsteintoolkit.org/documentation.html		

8. Coroborarea conținuturilor disciplinei cu așteptările reprezentanților comunității epistemice, asociațiilor profesionale și angajatori reprezentativi din domeniul aferent programului

Understanding and applying specific formulations of the Einstein equations, along with the analytical and numerical techniques covered in this course, are essential for developing practical skills in coding, simulation, and interpretation of results. The course also emphasizes teamwork, project planning and execution, and cultivating a scientific environment grounded in values and professional ethics. In terms of content, the course explores modern aspects of black hole and stellar physics, including numerical simulations of extremely compact objects, within the framework of gravitational wave astronomy. Graduates will acquire knowledge of contemporary research areas and ongoing efforts

related to detecting and interpreting gravitational waves, using ground-based detectors such as Advanced LIGO, VIRGO, and KAGRA. Looking ahead, future space-based detectors like LISA, as well as next-generation ground-based detectors such as the Einstein Telescope and Cosmic Explorer—with improved sensitivity at lower frequencies—are expected to provide deeper insights into fundamental questions about the universe.

9. Evaluare

Tip activitate	9.1 Criterii de evaluare	9.2 Metode de evaluare	9.3 Pondere din nota finală
9.4 Curs	For 50% score: fundamental notions in this field. For 100% score: advanced notions in this field.	Written assessment: multiple choice questions. Oral exam: a) basic topics; b) advanced topics.	25% 25%
9.5 Seminar / laborator	For 50% score: fundamental notions in this field. For 100% score: advanced notions in this field.	Written assessment: Problem solving using computer simulations.	50%
9.6 Standard minim de performanță			
• 50% score for the multiple choice test; • 50% score for the test question; • Oral exam on elementary topics. • Alternatively: • 50% score for the multiple choice test; • Written project on one of the course topics.			

Data completării

17.09.2025

[redacted]

Titular de disciplină
Dr. Alic Daniela

Data avizării în departament

Director de departament
Conf. Dr. Nicoleta STEFU