Course title:	Star Cluster Dynamics and Evolution
Lecturer:	dr Abbas Askar Affiliation: Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences (CAMK PAN)
Field, type and level of studies	Astronomy and Astrophysics: Masters and PhD Level Course on Stellar Dynamics and Star Cluster Evolution
Leading Institute	Astronomical Observatory, Faculty of Physics, University of Warsaw
Number of ECTS points:	
Course character:	Lecture
Language	English
Criteria to complete the course	- Successful completion and presentation of the results of the take-home exam conducted as group work - 80% course attendance
Number of hours	30
Short description (Skrócony opis przedmiotu)	Star clusters are important astrophysical laboratories for stellar evolution and dynamics. In this course, we will introduce the key concepts of stellar dynamics and will study the physical processes that drive the evolution of dense star clusters. We will discuss numerical modeling of star cluster evolution through simulations. The strengths and weaknesses of direct N-body and Monte Carlo methods will also be explained. Finally, we will cover how the interplay between dynamics and evolution can produce gravitational wave sources and stellar exotica in star clusters. The course will also introduce students to analyzing simulation data to infer meaningful information about present-day clusters and their evolutionary history.

Description (Pełny opis przedmiotu)	The following lecture outline presents the general structure of the course over 15 weeks. The exact content, order of topics, and level of detail may be adjusted during the semester depending on the background and interests of the students. Lecture 1. Introduction to star clusters and stellar dynamics: Overview of star clusters; types of star clusters; basics of stellar dynamics Lecture 2. Collisionless stellar dynamics: Phase-space description; distribution functions; virial theorem; equilibrium models. Lecture 3. Collisional stellar dynamics: Two-body relaxation; relaxation timescale; energy exchange; mass segregation. Lecture 4. Numerical methods for star cluster evolution: Direct N-body simulations; Monte Carlo methods; comparison of numerical approaches. Lecture 5. Thermodynamics of star clusters and simple cluster models: Gravothermal evolution; core collapse; post-core-collapse evolution; Plummer and King models. Lecture 6. Internal physical processes in star cluster evolution: Stellar and binary evolution; mass loss; formation of stellar remnants, role of binaries in energy generation and interaction Lecture 7. External physical processes in star cluster evolution: Galactic tidal fields; tidal truncation and evaporation; disk and bulge shocking. Lecture 8. Observations of star clusters: Structural and kinematic properties; surface brightness profiles; mass functions; binary fractions. Lecture 9. Astrophysical importance of star clusters: Star clusters as factories of stellar exotica Lecture 10. Black holes in star clusters: Formation and retention of black holes; dynamical interactions; intermediate-mass black hole formation Lecture 11. Formation of gravitational-wave sources in star clusters: Dynamical formation of compact object binaries that are gravitational wave sources Lecture 12. Summary and synthesis: Review of key concepts; open problems; introduction to the take-home exam and group

	assignment. Lectures 13–14: Group work on the take-home exam and preparation of results Lecture 15: Oral presentation of results (final exam)
Bibliography (Literatura)	• Hénon, M., *Collisional Dynamics of Spherical Stellar Systems* (Lecture notes) • Spitzer, L., *Dynamical Evolution of Globular Clusters* • Heggie, D. & Hut, P., *The Gravitational Million-Body Problem: A Multidisciplinary Approach to Star Cluster Dynamics* • Binney, J. & Tremaine, S., *Galactic Dynamics*, 2nd edition • *Rickman, H., Lecture Notes on Stellar Dynamics* Selected review articles and recent research papers will be provided during the course.
Learning outcomes (Efekty uczenia się)	**Knowledge (P8S_WG):** Students are able to understand the most important processes involved in the evolution of star clusters. They are able to distinguish between collisional and collisionless dynamical systems. They understand the numerical methods and techniques used in star cluster simulation codes. They are also able to understand the astrophysical importance of star clusters in producing gravitational wave sources and stellar exotica. **Practical Skills (P8S_UW, P8S_UK):** Students are able to analyze and draw meaningful astrophysical conclusions from simulation data. Are able to write simple scripts and tools to handle large data. The course will also require them to develop their presentation and writing skills. Students will be able to read and understand scientific papers on star cluster dynamics and evolution. **Social Skills (P8S_KK)**: Students are able to understand the astrophysical importance of studying star clusters and discuss topics in stellar dynamics with experts and colleagues. Students can critically evaluate arguments presented in scientific discussions and papers, work effectively in groups on joint projects, and collaboratively prepare and present scientific results.
Assessment methods and assessment criteria (Metody i kryteria oceniania)	The course is assessed through group work on a take-home exam and an oral presentation of the results. Assessment criteria include: 1) Correct understanding and application of concepts in stellar dynamics and star cluster evolution, 2) Quality of data analysis and interpretation of results, 3) Clarity, structure, and scientific quality of the presentation