

# PHY 090-011: From Black Holes to Strings: The Early Universe and the Nature of Space-Time

Lehigh University, Fall 2022

**Instructor:** Timm Wrase, Lewis Lab 418, see me in person or by email appointment [timm.wrase@lehigh.edu](mailto:timm.wrase@lehigh.edu) (email me any time with questions and feedback!)

**Office hours:** Monday 2-3pm or any other time by email appointment

**Class time and place:** Tuesday and Thursday 3:00-4:15pm in Lewis Lab 511

**Website:** <https://coursesite.lehigh.edu/>

**Overview:** In the early 20th century Einstein's theory of relativity drastically changed our understanding of gravity and the fabric of space-time. Despite its great successes, the theory of general relativity is incomplete. It does not take into account quantum mechanics and fails to describe fundamental properties of black holes and the very beginning of the universe. In this seminar we will explore the key developments in modern physics and the challenges of unifying all the fundamental forces. We will introduce the main ingredients of string theory, the most promising framework for a quantum description of gravity, and discuss its consequences for space-time at the smallest scales. As we will see, string theory has given us crucial insights into the structure of black holes and the early evolution of the universe. The format of the course will be discussion of weekly reading assignments, and a final paper.

## Required Textbooks:

- "The illustrated brief history of time" by Stephen Hawking (first half of semester)
- "The Hidden Reality" by Brian Greene (second half of semester)

## Additional references you might find useful or interesting

- "From Eternity to Here" by Sean Carroll
- "The First Three Minutes: A Modern View Of The Origin Of The Universe" by Steven Weinberg
- "The Inflationary Universe" by Alan Guth
- "Dark Matter and the Dinosaurs" by Lisa Randall
- "The Little Book of String Theory" by Steven Gubser
- "The Little Book of Black Holes" by Steven Gubser and Frans Pretorius

## General course requirements and assessment criteria:

- Weekly reading assignments and in-class discussions.
- Quizzes on the assigned readings.

- Final project: paper (10-15 pages) on a topic of your choice, related to issues discussed in class.
- Attend all classes.
- Complete all assignments on time.
- See me if you are having trouble or any questions, concerns or comments about the course!

**Grading:**

- Class participation and discussions based on weekly reading assignments: 40%
- Performance on quizzes: 20%
- Final Project: 40%

**Grading Scale:**

A = 88 – 100    B = 75 – 87    C = 60 – 74    D = 50 – 60

**Syllabus:**

- Space-time in special relativity
- Space-time curvature and general relativity
- The expanding universe
- The uncertainty principle and quantum mechanics
- Elementary particles and interactions in nature
- Black holes, singularities and Hawking radiation
- The evolution of the early universe
- The need for a theory of quantum gravity
- Strings, branes and extra dimensions
- Holography

**Initial Competencies:** No specific initial competences.

**Final Competencies:**

The students are expected to:

- Gain an appreciation for the major developments in particle physics, gravity and cosmology over the last century
- Learn the basic principles of special relativity, including concepts such as spacetime intervals, time dilation and length contraction.
- Develop intuition for the main principles of Einstein's theory of general relativity and properties of black holes, and an appreciation for the challenges of developing a theory of quantum gravity.
- Learn to perform literature searches and discuss science topics with a general audience, by preparing oral presentations and writing research-style papers.

**Accommodations for Students with Disabilities:** Lehigh University is committed to maintaining an equitable and inclusive community and welcomes students with disabilities into all of the University's educational programs. In order to receive consideration for reasonable accommodations, a student with a disability must contact Disability Support Services (DSS), provide documentation, and participate in an interactive review process. If the documentation supports a request for reasonable accommodations, DSS will provide students with a Letter of Accommodations. Students who are approved for accommodations at Lehigh should share this letter and discuss their accommodations and learning needs with instructors as early in the semester as possible. For more information or to request services, please contact Disability Support Services in person in Williams Hall, Suite 301, via phone at 610-758-4152, via email at [indss@lehigh.edu](mailto:indss@lehigh.edu), or online at <https://studentaffairs.lehigh.edu/disabilities>.

**The Principles of Our Equitable Community:** Lehigh University endorses [The Principles of Our Equitable Community](#). We expect each member of this class to acknowledge and practice these Principles. Respect for each other and for differing viewpoints is a vital component of the learning environment inside and outside the classroom.