Syllabus for Physics 234B: String Theory II

This course will provide a systematic introduction into the nonperturbative structure of string theory and M-theory, with particular emphasis on the interplay between spacetime (super)gravity, black holes and branes, and the worldsheet formulation. Dualities of various sorts (such as the M-theory/string theory dualities, gauge-gravity dualities, and the AdS/CFT correspondence) play a prominent role.

Week-by-week outline of topics:

Week 1: Type II superstrings at strong coupling; $SL(2, \mathbf{Z})$ S-duality of Type IIB superstring theory; M-theory and supergravity in eleven dimensions.

Week 2: String-string dualities; Type I/heterotic $SO(32)$ duality; dualities upon compactification to lower dimensions.

Week 3: Heterotic M-theory as the strongly coupled limit of the $E_8 \times E_8$ heterotic string; compactifications of M-theory; enhanced gauge symmetries from branes; elements of M-theory phenomenology.

Week 4: Black branes in string theory; BPS limits; the NS5-brane; electric-magnetic duality and branes.

Week 5: Bekenstein-Hawking entropy of black holes and black branes; statistical interpretation of the thermodynamic BH entropy for D-brane systems; the holographic principle and entropy bounds.

Week 6: Supersymmetric D-branes and their worldvolume action: the Dirac-Born-Infeld action, Chern-Simons couplings to Ramond-Ramond fields, non-Abelian DBI; the Myers dielectric effect, giant gravitons.

Week 7: Unstable D-brane systems, Sen's conjectures, tachyon condensation on branes.

Week 8: Introduction to string field theory. Witten's open string field theory, closed string field theory and introduction to Berkovits' formalism; tachyon condensation and exact solutions of string field theory.

Week 9: Matrix models as a nonperturbative approach to strings in low dimensions; open-closed string duality and unstable D-branes.

Week 10: M(atrix) theory, as a nonperturbative definition of M-theory in light-cone frame, and as an example of gauge-gravity duality.

Week 11: Introduction to AdS/CFT correspondence: strings in the 't Hooft large N limit of QFT.

Week 12: AdS/CFT correspondence from the Maldacena limit of brane systems in string and M-theory; AdS/CFT as a holographic duality.

Week 13: Basics of the duality between Type IIB superstring on $\mathrm{AdS}_5 \times S^5$ and $\mathcal{N} = 4$ super Yang-Mills theory at large N; correlation functions, the Penrose limit and pp-waves, the BMN limit, giant gravitons on AdS.

Week 14: Gauge-gravity correspondence with various degrees of supersymmetry ($\mathcal{N} = 4, 2, 1$ and 0), and away from conformal invariance. Applications of AdS/CFT in nonperturbative quantum field theory.

Week 15: Selected topics from current research in string theory and quantum gravity.

Reading list:

[1] J. Polchinski, *String Theory, Vol. 1: An Introduction to the Bosonic String* (Cambridge University Press, 1998)

[2] J. Polchinski, *String Theory, Vol. 2 Superstring Theory and Beyond* (Cambridge University Press, 1998)

[3] K. Becker, M. Becker and J.H. Schwarz, *String Theory and M-Theory. A Modern Introduction* (Cambridge University Press, 2006)

[4] C.V. Johnson, *D-Branes* (Cambridge University Press, 2003)

[5] various review articles, such as: O. Aharony et al., *Large N Field Theories, String Theory and Gravity*, Phys. Reports **323** (2000) 183-386.

Course requirements:

Weekly homework assignments (40% of the grade), participation in weekly discussions (20% of the grade), final reading assignment and presentation or term paper (40% of the grade).

Course variations:

This course covers the modern areas of nonperturbative string theory and quantum gravity, a subject with many ramifications in various fields of physics and mathematics, and still under rapid development. The above syllabus represents only one example of how 234B may be taught in a given year. We anticipate a substantial variety from year to year depending on the instructor, both in the exact focus and variety of topics covered, and in the style of presentation and course requirements. It should be possible to take the course repeatedly for credit, based on the consent of the instructor who will ensure that this does not represent work repetition for the students.