Fall 2009 Phys 776. **Advanced Gravitation Theory:** Prof. B. L. Hu (*updated Oct 1*)
Field Theory Methods in Classical and Quantum Gravity

Classes meet Tu Th 11am-12:15pm in Room 4208 Toll (Physics) Bldg
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Preamble: Format, Goal, Emphasis

In view of the fact that the range of current research materials in black hole, early universe and gravitational wave physics is expanding while this is the only core course in gravitation / cosmology not even offered regularly every year I wish to try out a **new format** for this course for this semester. I will present the topics in a way intermediate between a traditional lecture style, with line by line derivation of formulas or detailed description, and that of a seminar where the key ideas, the methodology and the results are explained with more emphasis on understanding than plain derivations. In a way we will conduct the lectures like groups of mini-series of seminars for each of the four themes covered. This is doable because you are required to select a research topic from only one of the four themes to investigate further and make presentations on. The other themes you will gain some knowledge like from a seminar series but the one area you wish to specialize in you will gain some working knowledge from the beginning to the end of the semester, not unlike how a PhD student makes entry into research on his/her chosen subject. Though not required to do so, if you feel like trying to gain a better working knowledge on more than one theme, you can choose a topic between two themes, or even three. The preparation of research work and the final presentation of your fellow students into these other areas will provide the opportunity for you to witness the process and share their findings, thus expanding your horizon this way.

Thus the **goal** is to give students interested in entering research in gravitation theory some exposure to selected topics of current interest. The **emphasis** is to provide the students some first hand experience in carrying out research on some specialized area of a smaller scale but could have the potential to develop into a thesis topic itself.

Requirements: Students taking this course for credit are required to work on a small research project leading to a final presentation on a topic of current or fundamental interest within the general scope of the course content (see below) and submit a 10-15 page scholarly paper. I will assist you in choosing a topic, the selection of relevant literature to study and the preparation of your presentation and papers on an individual basis. One day at the end of the semester will be reserved for these presentations (~ 30 min) in lieu of the final examination. All registered students are required to attend this as it forms an integral part of the course. More details about this will be announced as the course progresses.

Note: The day of presentation is set on Dec. 4, from 12:30 – 5:30pm (6 talks @ 45min each). There is an obvious need for more time to cover the course materials outlined below, so after consultation with the attendees, we will add an extra *10 minutes in the class (till 12:25pm)* for approximately 20 lectures.

Course Contents: The approximate distribution of topics in this course is as follows:

1. Field theory methods in gravitational radiation and reaction (~8 lectures) Starting with the motion of relativistic particles in a gravitational field of a curved spacetime we aim to bring this subject to the level of current research. No prior knowledge of quantum field theory is required. (After all, this is a classical GR topic.) This part will be taught jointly with Dr. Chad Galley <crgalley@umd.edu>, who will give the first 4 lectures for the basics and a guest lecture at the end on his current research on effective field theory methods in gravitational radiation reaction. (Possible date: Dec. 8) We'll use the review of Eric Poisson, *The Motion of Point Particles in Curved Spacetime*[gr-qc/0306052] http://www.livingreviews.org/lrr-2004-6

2. Quantum Field theory in Curved Spacetime (~10 lectures) We begin with simple setups like Casimir effect to understand the behavior of quantum fluctuations and then discuss how vacua are defined in curved spacetimes. Particle creation in spacetimes with event horizons and in dynamical spacetimes will be discussed with applications to black hole and early universe quantum processes. We then discuss the stress energy tensor and renormalization schemes. We will use a standard textbook like Nicholas Birrell & Paul Davies, *Quantum Fields in Curved Spaces* (Cambridge University Press 1982). Professor Jacobson has kindly agreed to give a guest lecture on Hawking effect and black hole thermodynamics. (Possible Date: November 24 or Dec. 10)

3. Semiclassical Gravity (~5 lectures) Important developments in the 80s, centering on the so-called backreaction problem with the expectation value of a renormalized or regularized stress energy tensor as source of the semiclassical Einstein equation.

4. Stochastic Gravity (~6 lectures) An upgrade of semiclassical gravity theory developed in the 90's with fluctuations of quantum fields and metric fluctuations incorporated. The object of importance is the so-called noise kernel which is the expectation value of the correlation of the stress energy bi-tensor and the centerpiece is the Einstein-Langevin equation. This subject is the theoretical basis for applications to cosmological structure formation from quantum fluctuations, including the non-Gaussianity issue, black hole event horizon fluctuations, backreaction from Hawking radiation, metric fluctuations and spacetime foams. We'll use the *Living Reviews in Relativity* **11** (2008) 3 **Stochastic gravity: Theory and Applications**, by B. L. Hu and E. Verdaguer [arXiv:0802.0658]

Logbook of Lectures:

Week 1: Gravitational Radiation Reaction: Bi-Tensors
2: Gravitational Radiation Reaction: Green Functions
3: Gravitational Radiation Reaction: Coordinates
4: Motion of Charges and Masses in Curved Spacetimes
5. Quantum Fields in Curved Spacetimes Fundamentals: Vacuum State, Global Killing Vectors, Casimir Effect; Bogoliubov Transformation, Particle Creation.
6. Quantum Fields in Dynamical Spacetimes: Adiabatic Vacuum, Energy-Momentum Tensor, Adiabatic Regularization