PHYS 514 GENERAL RELATIVITY AND COSMOLOGY 2018
Suggested Topics and References for the FINAL PAPER

Due: Monday, April 23, 2018 (by noon)

1. **Hamiltonian Formulation of Gravity**
   References:
   a) R. Wald, *General Relativity*, Chapter 10;
   b) C. Misner, K. Thorne and J. Wheeler, *Gravitation*, Chapter 21.

   The Hamiltonian formulation of gravity is the basis for any attempt to canonically quantize gravity. This is the topic for those of you wanting to learn something about one approach to quantum gravity.

2. **Rotating Black Holes**
   References:
   a) Textbook, Chapter 6, Sections 6.5 - 6.6
   b) S. Hawking and G. Ellis, *The Large Scale Structure of Space-Time*, Sections 5.5 & 5.6.

   In class I will only have time to discuss the most simple black hole solutions, namely the Schwarzschild and Reissner-Nordstrom black holes. Rotating black holes are of interest in astrophysics and cosmology and have some rather different properties.

3. **Double Pulsar PSR J1744-3922 as a Test of General Relativity**
   References:
   a) R. P. Breton, V. M. Kaspi, M. Kramer, 2, M. A. McLaughlin, M. Lyutikov, S. M. Ransom, I. H. Stairs and R. D. Ferdman *et al.*, "Relativistic Spin Precession in the Double Pulsar," Science **321**, 104 (2008) [arXiv:0807.2644 [astro-ph]].
   b) R. P. Breton, V. M. Kaspi, M. Kramer, 2, M. A. McLaughlin, M. Lyutikov, S. M. Ransom, I. H. Stairs and R. D. Ferdman *et al.*, "Using the double pulsar eclipses to probe fundamental physics," AIP Conf. Proc. **983**, 469 (2008).

   The double pulsar PSR J1744-3922 provides a new test of General Relativity. Explain the nature of the test.

4. **String Theory, Quantum Gravity and Early Universe Cosmology**
   References:
   a) B. Greene, *The Elegant Universe* (Part IV) (W. Norton, 1999).
   b) J. Schwarz, *Phys.Rept.* **315** (1999). 107-121.
   c) R. Brandenberger, *String Gas Cosmology: Progress and Problems*, *Classical and Quantum Gravity* **28** (2011) 204005.

   Explain why superstring theory might provide a quantum theory of gravity and a different view of early universe cosmology.

5. **Loop Quantum Gravity and Cosmology**
   References:
   a) M. Bojowald, "Loop Quantum Gravity and Cosmology: A dynamical introduction," arXiv:1101.5592 [gr-qc].

b) A. Ashtekar, “Introduction to loop quantum gravity and cosmology,” Lect. Notes Phys. **863**, 31 (2013).

Both Standard Big Bang cosmology and Inflationary cosmology suffer from an initial singularity. Loop quantum gravity is a proposal to quantize gravity using canonical methods. Applied to homogeneous and isotropic space-times, a cosmology emerges in which the initial singularity is replaced by a cosmological bounce. Your job is to critically review the foundations of loop quantum gravity and to show how a bouncing cosmology is argued to come about.

6. **Origin of Anisotropies in the Cosmic Microwave Background**
   References:

   a) D. Scott, J. Silk and M. White, *Science* **268**, 829 (1995).

   b) M. White, D. Scott and J. Silk, *Ann. Rev. Astron. Astrophys.* **32**, 319 (1994).

   c) W. Hu, Univ. of Chicago website http://background.uchicago.edu/ whu/ .

   d) D. Scott, Univ. of British Columbia website http://www.astro.ubc.ca/people/scott/cmb.html .

With the discovery of cosmic microwave anisotropies (CMB) in 1992, the high precision data from the WMAP satellite and the SPT and ACT experiments, and culminating with the March 21 2013 first data release from the Planck satellite, the CMB has become the best explored window to probe the early universe and to constrain the parameters which describe our universe on large scales. Give a description of how density perturbations lead to fluctuations in the temperature of the CMB and why one can learn about various parameters which describe the composition of the universe using the angular power spectrum of the CMB.

7. **Cosmic Strings as a Messenger of Particle Physics Beyond the Standard Model**
   References:

   a) R. Brandenberger, *Int. J. Mod. Phys.* **A9**, 2117 (1994).

   b) A. Vilenkin, “Cosmic strings: Progress and problems,” hep-th/0508135.

   c) R. Brandenberger, “Searching for Cosmic Strings in New Observational Windows,” arXiv:1301.2856 [astro-ph.CO].

Many particle physics models predict the existence of cosmic string defects. In models which admit cosmic strings, a network of such strings inevitably will form in the early universe and persist to the present time. Since these defects trap energy, the gravitational effects of this trapped energy density would yield specific signatures in new observational windows. Looking for these signals is hence a new way of probing particle physics beyond the Standard Model using cosmological observations. Provide a summary of the recent developments in this field.

8. **Modified Gravity and Dark Energy**
   References:

   a) S. M. Carroll, V. Duvvuri, M. Trodden and M. S. Turner, *Phys. Rev.* **D 70**, 043528 (2004) [arXiv:astro-ph/0306438].

   b) A. Silvestri and M. Trodden, *Rept. Prog. Phys.* **72**, 096901 (2009) [arXiv:0904.0024 [astro- ph.CO]].

Dark energy has emerged as one of the most pressing puzzles of fundamental physics. Is it due to a remnant cosmological constant, strange matter with an equation of state $p = -\rho$, or is it due to modified gravity? The topic of this essay will be to explore the third possibility. Specifically, consider the approach of replacing the gravitational Lagrangian R by $f(R)$, where f is some function.

You should write an essay of not more than 15 pages on one of the above topics. The level should be such that you would feel comfortable presenting the paper as an extra class in PH514. Try to focus on the main points. How does the topic fit into the field of general relativity and cosmology?. What are the main issues, the main results and the important techniques used?

I gave a range of topics ranging from more mathematical ones to those closely related to cosmology and astronomy. You are encouraged to pursue other topics. Consult with me in advance.