Final Exam Topics for PHY 490 – Black Holes **Spring 2021**

I. Kerr Metric
   a. Ring Singularity
   b. Event horizons
   c. Ergosurface, ergosphere
   d. Gravitational time dilation and redshift
   e. Particle and photon orbits
   f. Black hole shadow, Photon capture
   g. Circular orbits (photon, marginally stable, marginally bound)
   h. Penrose-Carter diagram
   i. Surface area
   j. Frame dragging (Lense-Thirring effect)
   k. Free fall
   l. Angular velocity at horizon
   m. ZAMOs
   n. Penrose process
   o. Black hole spin up
   p. Accretion, maximum *a*, maximum energy extraction

II. Black Hole Thermodynamics
   a. The laws of classical Thermodynamics, $dE = TdS - pdV$
   b. Carnot, Claussius, Maxwell, Boltzmann,
   c. Engines, Carnot cycle, reversible processes
   d. Entropy, $S = k \log W$, Forms of 2nd Law.
   e. Area theorem
   f. The laws of Black Hole Thermodynamics, $\delta m = \frac{\kappa}{8\pi}\delta A + \omega_+ \delta j$
   g. Entropy and temperature of a black hole
   h. Surface gravity
   i. Hawking radiation, black hole evaporation
   j. Planck units
   k. Penrose, Bekenstein, Hawking, Wheeler, Susskind, 't Hooft, Maldacena, and others
   l. Information paradox: AdS/CFT correspondence, Holographic principle, Entanglement

III. Wormholes
   a. Einstein-Rosen bridge
   b. Coined by Wheeler
   c. Embedding in cylindrical geometry
   d. Throat
   e. Traversable
   f. Exotic matter
   g. Time travel

IV. Einstein's Equation
   a. Einstein tensor
   b. Riemann curvature tensor
   c. Ricci tensor
   d. Curvature scalar
   e. Cosmological constant
   f. Stress-energy or energy-momentum tensor

V. Gravitational Waves – LIGO, TBA

VI. Other terms
   a. No hair theorem
   b. Cosmic censorship
   c. Singularity theorems
   d. Extremal black hole