# Astro 6511/Phys 6525
# Physics of Compact Objects:
# (High Energy Astrophysics)

**Instructor**: Prof. Dong Lai
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• Office hours: After each class on Monday and Wednesday. For other time, please contact by email, usually answer within 24 hours.
**Time and Place**: M/W 9:40-10:55 am, Space Sciences Bldg. 622,
**Course website:** http://hosting.astro.cornell.edu/∼dong/a6511/a6511.html: See the website for a detailed log of each lecture, suggested readings, references, assignments, etc

Compact objects (neutron stars, black holes and white dwarfs) are the endpoints of stellar evolution. They are responsible for some of the most exotic phenomena in the universe: supernova explosion, radio pulsars, magnetars, bright X-ray sources, gamma-ray bursts, FRBs, etc. Supermassive black holes also lie at the heart of the violent processes in active galactic nuclei and quasars.

Compact objects are also important from a fundamental physics point of view. Their high densities and strong magnetic fields allow one to probe physics under extreme conditions. Their strong gravitational fields provide an arena for exploring the consequences of general relativity.

This is a one-semester lecture course on high energy astrophysics, with focus on compact stars and related subjects (including supermassive black holes). Comtemporary research problems will be discussed along the way. An important component of the course is to introduce/survey (generally in a quick and "low-brow" manner) the theoretical physics tools needed for understanding various astrophysical observations. As well as the "usual" physics such as E&M, Quantum, Statistical Mechanics, we will also touch upon various aspects of nuclear and particle physics, fluid mechanics, magnetohydrodynamics and general relativity.

A major topics to be covered is gravitational wave astrophysics (e.g. LIGO/LISA/PTA sources and related EM transients.)

The "bare minimum" prerequisites for this course are all of the physics at the upper division undergraduate level. (The more basic physics you have had at the graduate level, the easier the course will be for you.) Though helpful, no astronomy background is needed.

"General Relarivity" background: No prior knowledge of GR is required (Of course, you should be quite familiar with Special Relaivity). Practical GR (Astrophysical GR) will be introduced along the way during the semester, at the level of the Shapiro-Teukolsky book or the Thorne-Blandford book.

"Stellar Structure" background: Some people have already taken a course on stellar structure and evolution; this background is useful but not required. I will try to make the lecture self-contained, although those who have not studied stellar structure may want to do some extra reading.

"Radiative Processes" backgrond: High energy astrophysics necessarily involves study of various radiation processes. There is another graduate course, Astro 6530 ("Astrophysical Processes"), which will focus this. However, I will review/introduce material most relevant to high energy astrophysics as we go along.

### Tentative Syllabus

### Part I: Isolated (more or less) Compact Objects: Basics

• White dwarf: structure, formation and cooling.
• Neutron star: structure, EOS, mass limit, cooling, surface emission
• Pulsars: magnetosphere physics, B-field evolution, interior dynamics, radio wave propagation, PWN
• Core-collapse Supernova: hydrodynamics, shock waves, neutrinos, explosion in ISM, collapsar
• Black holes: introduction to GR, Schwarzschild and Kerr metric, motion of test mass, photon propagation, Penrose process

### Part II: Accretion Power in Astrophysics

• Accretion in binary systems: Roche lobe overflow, disk formation, wind accretion, effect on binary evolution
• Spherical Accretion: Bondi and Bondi-Hoyle, feeding of supermassive BHs
• Accretion disks: The origin of viscosity (MRI), time-scales and stability
• Accretion disks: thin/thick disks, radiatively inefficient accretion, disk dynamics, precession and warp
• Accretion onto Neutron Stars: X-ray pulsars, bursts, QPOs; pulsar recycling
• White dwarf accretion: CVs, Nova and Type Ia SN, AIC vs explosion, ultra compact binaries
• Supermassive BHs: introduction to AGN, radio sources, quasars, synchrotron radiation, minimum energy, supermassive binary BHs
• Jets: superluminal motions, launching mechanisms, Blandford-Znajek process

**Part III: Special Topics (Tentative, some will be integrated into Part I and II)**

• A major focus of this course is **Gravitational wave sources: NS/NS and NS/BH binaries, rotating collapse, LIGO, LISA and PTA sources**
• Gamma Ray Bursts: Simple fireball models, afterglows, relativistic shocks
• Magnetars, Fast radio bursts.
• Tidal disruption events
• Cosmic rays: EeV cosmic ray puzzles, particle acceleration, extremely high energy neutrinos (ICeCube)
• High-energy astrophysics of cluster of galaxies.

**Recommended Part-texts:**

There are no good textbooks available on the market which adequately cover all the topics for this course. The following books combined may cover some of the basics. (Cornell students have should free online access — see the class website for links).
• Shapiro and Teukolsky "Black Holes, White Dwarfs and Neutron Stars" (1983): covering equations of state, stucture, microphysics very well, but getting very dated in places (especially observations). It introduces many of the basic physics tools (GR, hydro, radiative transfer) in a simple, self-contained way. This is most useful for Part I and a bit of Part II..
• M. Longair "High Energy Astrophysics (3rd Ed)" (2011): broad coverage on general area of high energy astrophysics, but somewhat below the level of the course.
• Max Camenzind "Compact Objects in Astrophysics" (2007)
• Fulvio Melia "High-energy astrophysics" (2009): Cover general phenomenology and some theory topics very well.
• J. Frank, A. King and D. Raine "Accretion Power in Astrophysics" (3nd Ed, 2002): Good coverage of the title subject. This is most useful for Part II.
• T.J-L Courvoisier "High Energy Astrophysics"(2013)
• J.E. Horvath "High Energy Astrophysics: A Primer" (2022)
• W.H.G. Lewin, and M. van der Klis (eds) "Compact Stellar X-ray Sources" (2006). A nice collection of review articles on compact stars x-ray sources.
• J. Krolik "Active Galactic Nuclei" (1999): thorough coverage of AGNs
• G. Rybicki and A. Lightman "Radiative Processes in Astrophysics": This is the textbook we use for Astro 6530. I would recommend all astrophysics student to own this book.

**Other references:**

Since no book covers everything in the course, or covers the recent development in the best way, I will be providing links to recent papers/review papers. **Pay attention to the course website for detailed description of the content of each lecture and suggested readings.**

**Homeworks and Grade:**

Your final grade will be based on, roughly, 65% homework (which includes a final exam, which will be a long take-home homework) and 35% research project (detail later). There will be more regular homeworks (about one every 2 weeks) in the first half of the semester; they will be less frequent in the second half of the semester to allow time for the research project.