PHYS 6381 - ASTR 3302
Fall 2021
Introduction to Astrophysics

Mario C. Díaz

Phone: (956) 8826690, E-Mail: mario.diaz@utrgv.edu, Office location: BINAB 2.126, Office hours: by appointment

> The following text is required by UTRGV authorities:
> COVID-19 RESOURCES: Required on all syllabi. Do not modify. Please visit the UTRGV COVID-19 protocols web page for the most up-to-date COVID-19 campus information and resources. The COVID-19 Frequently Asked Questions (FAQs) web page offers additional guidance to specific questions. To submit a question for the FAQ, please email WelcomeBack@utrgv.edu.
> UTRGV VACCINE PORTAL Required on all syllabi. Do not modify. UTRGV Students are eligible to receive the COVID-19 Vaccine. Students may access and complete their vaccine profile via the UTRGV Vaccine Portal. For additional information on the COVID-19 Vaccine, please visit the UTRGV Vaccine web page.

Course Description: This is an introduction to Modern Astrophysics at a graduate level (or advanced undergraduate level). It does require a familiarity with some astronomical concepts. For students who have never taken an astronomy class "An Introduction to Modern Astrophysics" by Carroll & Ostlie, 2nd Edition could work well as a reference.

1 Learning Objectives for this course

This is a course about the theoretical foundation of the physics of stars, galaxies and the universe. I will emphasize the rationale of astrophysical formulas as well as discuss their applications. Each item in each chapter of the layout presented below can be considered a topic knowledge that constitutes a major course requirement.

WARNING: the topics in the layout below are tentative. There is no guarantee that we will be able to cover all of them. I will prioritize in depth understanding by the majority of the students over amount of topics covered.

2 Course layout

2.1 STARS

1.1 Hydrostatic Equilibrium
Equilibrium equation - Central pressure - Gravitational binding energy - Virial theorem - Stability - Initial contraction - Kelvin time scale.

1.2 Radiative Energy Transport
Differential energy density - Transport term - Absorption term - Scattering term - Emission term - Equilibrium - Flux divergence - Momentum tensor divergence - Opacity - Rosseland mean - Radiative transport equations.

1.3 Radiative Models
Differential equations - Conditions at center - Conditions at nominal surface - True surface - Vogt–Russell theorem - Effective temperature - Color temperature - Hertzsprung–Russell relation - Eddington bound.

1.4 Opacity
Contributions to opacity - Stimulated emission - Thomson scattering - Free–free absorption - Kramers opacity - Bound–free absorption - Bound–bound

absorption.

1.5 Nuclear Energy Generation
Proton–proton chain - CNO cycle - Suppression factors - Coulomb barrier - Application to proton–proton chain - Solar neutrinos - Application to CNO cycle - Crossover - Beyond hydrogen burning - Carbon synthesis.

1.6 The Main Sequence
Temperature and density dependence of energy generation and opacity - Dimensional analysis - Gas pressure dominance: radius–mass relation, luminosity–mass relation, central temperature versus effective surface temperature, Hertzsprung–Russell slope - Hydrogen burning time - Radiation pressure dominance: radius–mass relation, luminosity–mass relation, Hertzsprung–Russell slope.

1.7 Convection
Stability against convection - Eddington discriminant - Mixing length theory - Efficient convection - Isentropic stars - The Sun - Variational principle.

1.8 Polytropes
Examples of polytropic stars - The Lane–Emden differential equation - Exact solutions - Numerical solutions.

1.9 Instability
Onset of instability: general theorem, with exceptions - Stars close to $\Gamma = 4/3$ - Expansion in $1/c^2$ - Appendix: Derivation of relativistic energy correction.

1.10 White Dwarfs and Neutron Stars
Equation of state for cold electrons - High-mass and low-mass white dwarfs - Neutronization - Relativistic instability - Equation of state for cold neutrons - Low-mass neutron stars - Landau–Oppenheimer–Volkoff limit - Neutron star spin - Pulsars.

1.11 Supermassive Stars
Gas/radiation pressure ratio - Equation of state - Mass - Stability - Evolution.

2.2 STAR BINARIES

2.1 Orbits
General orbits - Spectroscopic binaries - Energy and angular momentum - Relativistic corrections - Appendix: Calculation of time dilation in binary stars.

2.2 Close Binaries
Roche limit - Sirius A and B - Equipotential surfaces - Roche lobes - Mass transfer - Type 1a supernovae - Roche lobe volumes.

2.3 Gravitational Wave Emission: Binary Pulsars
The Hulse–Taylor pulsar - Quadrupole approximation for emitted power - Decrease in period - Decrease in eccentricity - Time to coalescence - Gamma ray bursts and kilonovae - Total radiated energy - More binary pulsars.

2.4 GW Detection: Coalescing Binaries
Weber bars - Interferometers - Sources - Black holes versus neutron stars - Chirps - Description of LIGO - Transformation to transverse-traceless gauge - Response of LIGO to gravitational waves - Shot noise and seismic noise - Sensitivity - 2015 detection of gravitational waves - Diagnosis of source: chirp mass, relativistic corrections - Estimate of distance - More coalescing black-hole binaries - A coalescing neutron star binary - Blind spots.

2.3 THE INTERSTELLAR MEDIUM

3.1 Spectral Lines
General transport equation - Optical depth - Solution for homogeneous emission/absorption ratio - Doppler broadening - Einstein A and B coefficients - Emission lines from clouds in thermal equilibrium - Emission lines from non-equilibrium regions - Absorption lines - 21 cm lines - CN absorption lines.

3.2 HII Regions
Strömgren spheres - Differential equation for ionization - Interior of the sphere - Surface of the sphere - Recombination lines - Heating.

3.3 Cooling
Cooling function - Prompt radiation case - Excitation by electrons - Hydrogen atoms - Russell–Saunders classification of atom and ion states - CII - OIII - OII - Cooling in HII regions - Delayed radiation case - H2 and CO molecules - Bremsstrahlung cooling.

3.4 Star Formation
Virial estimates - Jeans radius and mass - Molecular clouds - Dispersion relation for gravitational perturbations - Transition to instability - Collapse time.

3.5 Accretion Disks
Exceeding the Eddington limit - Role of viscosity - Differential equations for surface density - Mass and angular-momentum flow - Steady disks - Viscous heating - Spectral distribution - Thickness of disk - Decaying disks - Bessel function solution for constant viscosity - Expansion of disk - Accretion disks in binaries - Cataclysmic variables.

3.6 Accretion Spheres
Bondi accretion - Conservation laws - The wind equation - Transonic solutions - Mass accretion rate - M31.

3.7 Soft Bremsstrahlung
Emissivity and Gaunt factor - Born approximation - A misleading formula - Low-energy theorem - Debye

screening.

2.4 GALAXIES

4.1 Collisionless Dynamics
Collisionless Boltzmann equation - Surface density from velocity dispersion - Moment equations - Solutions to Boltzmann equation - Eddington theorem.

4.2 Polytropes and Isothermals - Polytrope solutions of Boltzmann equation - Isothermal solutions of Boltzmann equation - Galaxy clusters - Dark matter - Missing baryons? - NFW distribution.

4.3 Galactic Disks
- Rotation curves - Bulge dominance - Disk dominance - Halo dominance.

4.4 Spiral Arms
Trailing and leading spirals - Differential equations for surface density - Lin–Shu density waves - Winding from differential rotation - Pitch angle and winding problem - Epicyclic frequency - Pattern frequency - Crowding - Lindblad resonances.

4.5 Quasars
Quasi-stellar objects and sources - Accretion on black holes - Heating of accretion disks.

3 Evaluation

Evaluation will be through homework assigned (50%) and three exams (first one 15%, second one 15%, final 20%).
The main difference between PHYS 6381 and ASTR 3301 will be in the depth of the understanding and knowledge required as outcomes in the class. Consequently exams and HW will be different for each of these courses.

4 Bibliography

I will be following closely **Lectures on Astrophysics** by Steven Weinberg (Cambridge).
It is not necessary to buy the book, but if you want to buy one I definitely recommend it. I will be providing notes which will be following the book format but also elaborating more on certain topics and presenting others that not every student could have necessarily been exposed to.
An excellent book, after 80 years!, is S. Chandrasekhar's "An Introduction to the study of Stellar Structure" published by Dover in 1965 (the original book is from 1939). A good book as a resource, but lacking the depth and rigor of Weinberg's is **An Introduction to Modern Astrophysics** by Carroll & Ostie (Pearson Addison Wesley). Another good and usseful book, but also lacking the depth and rigor of Weinberg's is **Astrophysics for Physicists** by Arnab Rai Choudhuri (Cambridge). Finally a very thorough and more encyclopedic resource are the three volumes of **Theoretical Astrophysics** by T. Padmanabhan (also Cambridge).