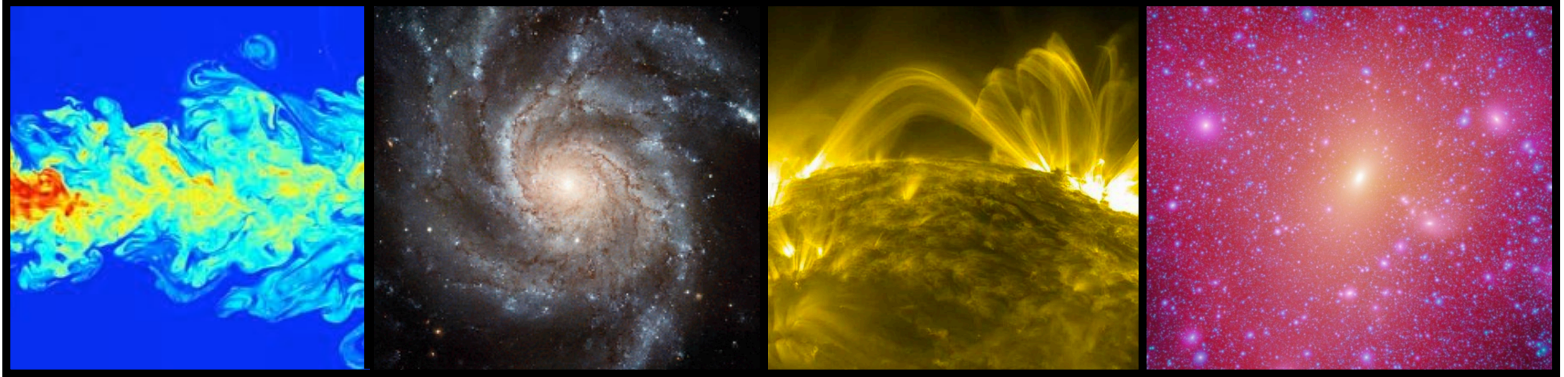# ASTR 501
Dynamics of Astrophysical Many-Body Systems

Course Description

This course presents an in-depth treatment of the dynamics of astrophysical systems, including gases, plasmas, and stellar systems. The course starts with a detailed formulation of the theoretical foundations, using kinetic theory and statistical physics to describe the dynamics of many-body systems. Special emphasis will be given to collisional processes in various astrophysical systems. Next, after deriving the relevant moment equations, we focus on specific topics related to (i) stellar dynamics, (ii) hydrodynamics, and (iii) plasma physics. Related to stellar dynamics we cover potential theory, orbit theory, Jeans modeling, gravitational encounters and secular evolution (bars and spiral structure). In the field of (non-radiative) hydro-dynamics we study, among others, the Navier-Stokes equation, vorticity, transport coefficients, accretion flow, turbulence, fluid instabilities, and shocks. We end with a cursory overview of plasma physics, including the Vlasov equation and the two-fluid model, Langmuir waves, Alfvén waves, Landau damping, ideal vs. resistive magneto-hydrodynamics (MHD), and dynamos. Throughout the course we shall focus on specific astrophysical applications.

Instructor : Prof. Frank van den Bosch (KT, Office: 649)
e-mail: frank.vandenbosch@yale.edu

Course Website : https://campuspress.yale.edu/astro501/

Lecture Hours : TTh 9.00-10.15am   **Location** TBD

Office Hours : TBD   **Location** KT#649

Grading : 35% Final Exam + 35% Problem Sets + 30% MidTerm Exam

Course Format : Blackboard presentations & in-class discussion

Course Outline

PART I: Theoretical Foundations   [Lectures 1-5]

❖ **Time and length scales of astro-physical many-body systems**

❖ **Review of Classical Dynamics**
Lagrangian & Hamiltonian formalism, Poisson brackets, canonical transformations

❖ **Kinetic Theory:**
Liouville theorem, BBGKY hierarchy, Boltzmann and Vlasov equations

❖ **Collisional Dynamics:**
Langevin equation, fluctuation-dissipation theorem, relaxation time, Lenard-Balescu equation, diffusion coefficients, Fokker-Planck equation, Maxwell-Boltzmann distribution

PART II: Stellar Dynamics   [Lectures 6-12]

❖ **Potential Theory**
Poisson equation, spherical systems, ellipsoidal systems, multipole expansion, disk potentials

❖ **Orbit Theory**
integrals of motion, action-angle variables, KAM theorem, surfaces of section, resonances

❖ **Jeans Theorem & Jeans Modeling**
Jeans equations of spherical, axisymmetric & triaxial systems, mass-anisotropy degeneracy kinematics, Schwarzschild modeling

❖ **Gravitational Encounters & Relaxation**
impulse approximation, dynamical friction, orbital decay, phase mixing, violent relaxation

❖ **Secular Evolution**
bars and spirals, swing amplification, radial migration, Toomre criterion, gravothermal catastrophe

PART III: Hydro Dynamics   [Lectures 13-20]

❖ **Equations of HydroDynamics**
  continuity, momentum and energy equations, closure relations (equations of state)

❖ **Vorticity & Circulation**
  vortex tubes, vorticity equation, baroclinicity, Helmholtz theorems, turbulence

❖ **Transport Coefficients**
  Chapman-Enskog expansion, diffusion, viscosity & thermal conductivity, stress tensor

❖ **Navier-Stokes**
  viscous flow, accretion flow,

❖ **Fluid Instabilities**
  Klevin-Helmholtz, Rayleigh Taylor, thermal instability, Jeans criterion

❖ **Sound waves & Shocks**
  linear perturbation theory, sound speed, Rankine-Hugoniot jump conditions

PART IV: Plasma Physics   [Lectures 21-24]

❖ **Introduction to Plasmas**
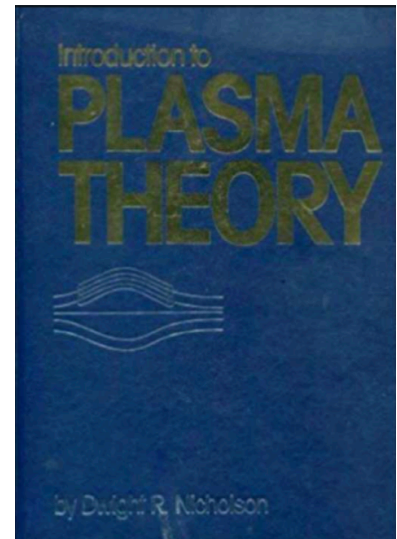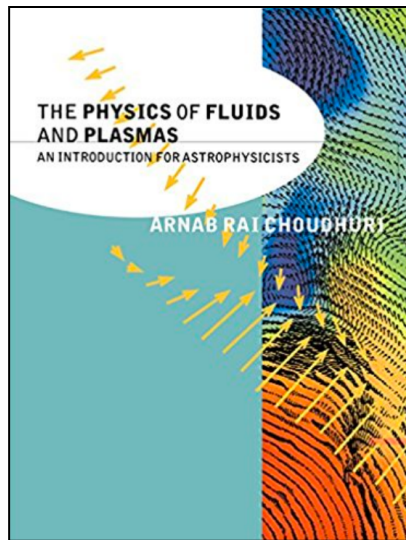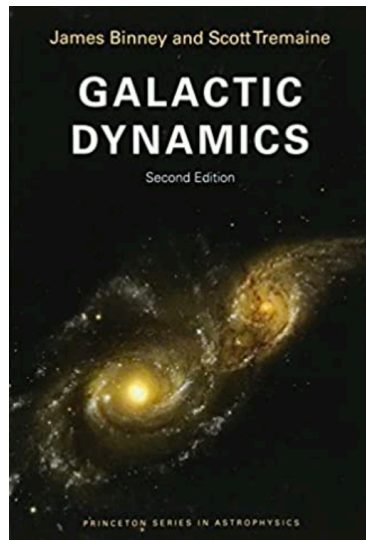 *length scales, Debye length, plasma frequency, plasma parameter, collision frequency*

❖ **Collisionless Plasmas**
  Vlasov equation, Langmuir waves, Landau damping, two-fluid model

❖ **MagnetoHydroDynamics (MHD)**
  resistive vs. ideal MHD, Ohms' law, induction equation, dynamos

Recommended Textbooks

❖ **Galactic Dynamics (second edition)**
   Author: *James Binney & Scott Tremaine*   *(ISBN-978-0-691-15902-7)*

❖ **The physics of fluids and plasmas: an introduction for astrophysicists**
   Author: *Arnab Rai Choudhuri*   *(ISBN-0-521-55543)*

❖ **Introduction to Plasma Theory**
   Author: *Dwight R. Nicholson*   *(ISBN-978-0-894-6467705)*

Recommended Clothing