ASTRONOMY 506 Spring 2012 Instructor: Anatoly Klypin

Part I : STELLAR DYNAMICS
Part II: HYDRODYNAMICS

Midterm: 12 March. It is a written exam: two questions and two problems to solve
Final : 2 May. It will be an a written exam: short questions and two problems to solve

Project: Study dynamical evolution of a gravitational system of thousands of particles using N-body code written by yourself. The code must be parallelized using OpenMP. Chose one of the following projects:

(1) Dynamical friction: Motion of a massive "satellite" in a halo. Study changes of the orbit (radius, angular momentum, eccentricity) of a massive particle moving in the halo made of 50,000 small particles. Compare results with theoretical predictions. What happens to the halo when the satellites sinks to the center of the system? Where the angular momentum of the satellite is deposited? How energy of halo particles changes? The halo ("galaxy") is a spherically symmetric non-rotating object in equilibrium. Run two models with different initial eccentricities.

(2) Tidal stripping of a satellite of the Milky Way. Study properties of a dwarf spheroidal galaxy orbiting our Milky Way galaxy. The satellite should be modeled with 30,000 particles set in equilibrium. Add gravitational potential of our Galaxy. This can be modeled as a sum of an NFW dark-matter halo and a stellar disk. How parameters of the satellite change when it moves around our Milky Way? How its density and circular velocity profile evolve with time? What fraction of mass is lost due to stripping? How do results depend on orbit of the satellite?

(3) Collision and merging of two "elliptical galaxies". Prepare two equilibrium systems of 20,000 particles each. Put them in an orbit. Study the merging process. What is the density profile of the final system? How much does it change as compared with the initial profile? What happens with the angular momentum of the system? What fraction of particles and angular momentum escapes? What is the distribution of the angular momentum of the final configuration? Run two models with different orbit parameters.

(4) Testing monolithic collapse scenario. This used to be one of the main scenario for formation of galaxies. According to this scenario bulges and elliptical galaxies were formed in short initial stage when galaxy collapsed from a large quasi-homogeneous initial cloud. Let's test it using n-body simulations. We know how an elliptical galaxy should look like. It should have a mass of about $10^{12}M_{\odot}$. The central velocity dispersion should be about 200 km/s (give an take few dozen km/s). The central region of the galaxy should be relatively compact (2-5kpc) followed by halo where density declines as $\propto r^{-4}$. In the central region the density increased with declining radius as $\propto r^{-1}$. Set initial conditions for 30,000 particles in a homogeneous sphere.

Initial velocities of particles are very small. Let the system evolve and relax. Study the density and rms velocity profile of the relaxed system. Try to find whether there is a way to scale the system so that it matches properties of elliptical galaxies.

(5) Use your n-body code to study evolution of a simplified model of proto-Solar system: 30,000 objects orbiting a massive central object. How orbital parameters of particles change? What are the effects of placing relatively massive objects ("Jupiters") in the system? How orbit of "Jupiter" evolves when placed in relatively massive disk?

(6) Resonances in trans-neptunian objects. It is known that Pluto and a whole family of Kuiper-belt objects are in the resonance with Neptune. How this happens and what is the role of those resonances is the subject of this project. In this case only the large planets of the solar system are important as perturbers. We start by placing the large planets in circular orbits around the Sun. We also place a large number (hundreds) of Kuiper-belt objects outside of the Neptune orbit. Try first with placing the objects on (initial) circle orbits. Note that masses and interactions between the Kuiper-belt objects are negligible. Do not include those into calculations of forces. What will happen with the objects after a long period of time? Will some of the them be ejected? How orbital frequencies of the objects evolve? Accuracy of integration is very important for this project. Energy should be preserved with many digits.

You should use Fortran, C, or C++

The project should be written as an article:

- Abstract
- Introduction
- Method and tests
- Analytical estimates
- Results
- Conclusions

You should use TEX or LATEX to format the text. Use supermongo or IDL to make plots.

First part of the Project (50% of the grades for the project) is due 30 March.

Students should finish simulations and present first results: plots with written figure captions, short description of project and setup of simulations. They have two weeks to respond to my comments.

Final Project is due 13 April.

Homeworks will be given regularly.

Books: Handouts, lecture notes, and

Binney & Tremain "Galactic Dynamics"

Pringle & King "Astrophysical Flows

Landau & Lifshitz "Hydrodynamics"

Grading: for AST506

25% for Homework	25% for Midterm	5% for class activity
25% for Project	25% for Final	

Grading: for AST406

33% for Homework	33% for Midterm	5% for class activity
33% for Final	20% extra credit for a simplified project.	

Part I: STELLAR DYNAMICS

(1) Programming.
(2) N-body problem: numerical methods.
(3) Gravitational potential. General results.
(4) Potentials of spherically symmetric systems.
(5) Potentials of non-spherically systems : general trends and general results.
(6) Motion of particles in a central force: basic equations and properties.
(7) Orbits of stars. Epicycle approximation.
(8) Virial theorem: derivation and limits of application
(9) Two-body relaxation: mechanism, different effects, time-scales.
(10) Two-body relaxation: more formal approach.
(11) Dynamical Friction: basic results and assumptions.
(12) Violent relaxation: basic ideas. Discussion
(13) Boltzman equation: distribution function, phase-space, mean velocity and "pressure".
(14) Boltzman equation: derivation and basic properties.

(15) Midterm
(16) Jeans equations.
(17) Jeans Instability. Toomre instability.

Part II: HYDRODYNAMICS

(1) Elements of Thermodynamics, gas cooling rates.
(2) Hydrodynamics: introduction. Continuity and Euler eqs.
(3) Energy equation.
(4) Lagrangian approach: simple solution for cold flow of gas.
(5) Bernoulli equation. Kelvin theorem.
(6) Propagation of waves: Jeans instability, sound.
(7) Shock waves I.
(8) Shock waves II.
(9) Instabilities
(10) Bondi flow
(11) Discussion