Galactic Dynamics in the Times of Gaia and other Great Surveys

Lecture & Exercise Program

Luis A. Aguilar (IAUNAM/México)

2 Lectures: Basic Galactic Dynamics in a rush.

I. Hamiltonian Dynamics
- Why Hamiltonian Dynamics?
- The starting point: The least Action Principle
- Hamilton's equations and phase space
- Canonical transformations and generating functions
- Hamilton-Jacobi and the search for a simpler picture
- The promised land: Action-angle space

II. Galactic Dynamics
- The collisionless Boltzmann equation: what it is and what it means
- Orbits as the fundamental building blocks of DF's
- Isolating integrals as shapers of orbits
- An interesting family tree: regular and irregular orbits
- The misfits: sensible dependence on initial conditions and chaos
- Putting everything together: Self-gravitational, relaxation and self-consistency
- What exactly does "relaxed" mean?
- Difference between test-particle and full *N*-body simulations.

Daniel Carpintero (La Plata/Argentina)

2 Lectures: Galactic Dynamics basic building bricks: Orbits

I. Regular and chaotic orbits
- Regular and chaotic orbits
- Poincare's sections
- Lyapunov exponents

II. Refining the orbital classification
- Other indicators of chaos: SALI, MEGNO, FLI, OFLI
- Regular families
- Classification of regular orbits: Spectral analysis

1 Exercise: Numerical laboratory for orbits.
- Poincare sections and Lyapunov exponents
- Chaos indicators and spectral analysis.

Francesca Figueras (U. de Barcelona/Spain)

3 Lectures:

I. Ingredients for a Galaxy model

How do we go about building a model of the galaxy

II. The Gaia mission

An in depth but quick introduction to the Gaia mission

III. The Gaia mock catalogues: GUMS and GOG
Description of two very powerful tools to immerse into the Gaia Universe.

2 Exercises:

I. How to install and use GOG
II. Derivation of the local force perpendicular to the galactic plane with a Gaia mock catalogue.

Daisuke Kawata (UCL/UK)

2 Lectures:

I. *N*-body/SPH simulations of our Galaxy
II. The Physics behind sub-grid modeling

1 Exercise:

I. Plugging N-body data into the Gaia universe: A barred galaxy simulation.

Paul McMillan (Oxford/UK)

3 Lectures: Actions, angles and approximations

I. Availability of exact actions for a limited set of potentials. Torus modeling: Key principles
II. Other approximations for actions
III. Use of angle-action approximations in Galactic modeling.

1 Exercise: Angles and actions in practice.

Bárbara Pichardo (UNAM/México)

3 Lectures: The influence of non-axisymmetric galactic structures: A Galaxy with spiral arms and a central bar.

I. Morphological description of spiral arms and bars in disk galaxies in general and in our Galaxy. First potential models for the Milky Way
II. More advanced models for the Galaxy. The dynamical effect of the non-axisymmetric structure
III. Stellar dynamics under the influence of the non-axisymmetric structure of the galaxy.

1 Exercise: A numerical laboratory to study the effect of non-axisymmetric structure on the orbital structure of our Galaxy.

Justin Read (U. of Surrey/UK)

3 Lectures: Dark matter in the Galaxy.

I. The local dark matter density
- Definition and some history
- Two approaches: rotation curve vs. local measurements
- Critique of both approaches. Power of combined approach
- Theoretical background: what to expect from Cosmology

II. Jeans vs. DF modeling
- Collisionless Boltzmann equation and its meaning
- Moments and derivation of Jeans' equations in cylindrical coords.
- Advantages and disadvantages of full Jeans vs. DF and mixed modeling
- Tests on mock *N*-body data

III. The latest results
- Application to real data: a census of results so far.
- The meaning of the results: spherical halo or dark disk?
- The future: Gaia and large surveys
- Remaining challenges and outlook

1 Exercise: Generate 1D mock data from Gaussian velocity distribution and recovery of original distribution using Markov Chain Monte Carlo.

Octavio Valenzuela (UNAM/México)

1 Lecture: *N*-body simulations of our Galaxy.

Notes: All lecture sessions are 45 minutes long.
There's always a 15 minute break after each lecture.
All exercise sessions are 1 hour and 45 minutes long.
There's always a 30 minute break between exercise sessions

Projects

- At the first project session (friday afternoon), some lecturers will present some possible projects for the students to develop.
- The students will then have 1 day to decide what project to work on, although students can propose projects of their own. It is strongly advised to set projects that use the concepts seen during the lectures and numerical tools used during the exercise sessions.
- The students will work in teams of 4 on their projects.
- They will have a total of 12 hours split in 4 sessions to work on their projects. On 2 of the sessions, the lecturers will be available to advise. On the remaining two, students will work on their own.
- On the last day of the school, we will switch to “symposium mode”. The students will present the results achieved on their projects as in a symposium. Lecturers will comment on the results and suggest possible continuations.

School Aims

The raison d’être for the school is the Gaia astrometric mission. The promise of the availability of positional, kinematic and even stellar atmospheric information for a significant fraction of stars in our Galaxy (~1%), at a level of precision never before attained in such a global scale, promises to be a major landmark in the characterization of our galaxy and the study of its evolution.

One of the disciplines that most likely will see a profound impact due to the Gaia database is Galactic Dynamics. The massive availability of data will allow us to use the traditional modeling procedures at an unprecedented degree of refinement. Even more exciting, new and powerful theoretical tools will be able to be applied for the first time.

The goal of the school is to introduce students to some of the modeling tools (old and new), that are likely to be relevant in the Gaia era.

Our aim has been understanding over formal lectures, and we recognize that practice is an important tool for understanding: from doing something is that familiarity arises. So, our school has been designed with a two pronged approach: lectures in the mornings and exercises in the afternoons.

The lecturers have taken the time to design exercise sessions that will introduce students to numerical tools, that they can use to work out concepts seen during the morning lectures.

In the second half of the school, students will work on some projects on their own, but with lecturer advise available. In these projects, students are expected to use the theoretical concepts and numerical tools covered before.

We do encourage all students to strongly interact with the lecturers, either during the lecture or exercise sessions, or during the recesses. Lecturers will be in the school room during most of the school, and not just for their participation. The reason is for them to be available to the students.

We do encourage you to feel at ease during the school and feel free to ask, or comment as much as you deem necessary.

“*The mind is not a vessel to be filled,*
but a fire to be kindled”
Plutarch

For the SOC,

Luis A. Aguilar