Leiden-BNU Summer School for Astrophysics: Student Projects

Maxwell Xu Cai[1]

Project 1: Secular evolution of Planetary Systems

It is now clear that planets are common in the universe. Theoretically, it is predicted that planet formation is a byproduct of star formation, and therefore almost all stars have planets at least during their early stage. Observationally, around 4,000 planets are discovered as of May 2018[2].

Our Solar System, as the most well-known planetary system, has a history of ~ 5 Gyr. How stable is our Solar System? Will some planets collide with each other, or get ejected sometime in the future? What will the Solar System look like 10 million years from now? How about the dynamical stability of other planetary systems ?

Given the chaotic nature [see, e.g., Laskar, 1994] of planetary systems, resorting the stability using analytical approach is extremely difficult. Fortunately, we can now simulate the secular evolution of planetary systems thanks to the availability of state-of-the-art integration algorithms [e.g., Chambers, 1999; Rein and Liu, 2012].

In this project, students will construct the initial condition of the Solar System and other planetary systems, and use different integration algorithms to simulate them. The main objective of this project is to understand the orbital stability of the simulated planetary systems, as well as the efficiency of N-body integrators.

Project 2: Formation of Hot Jupiters

NASA's *Kepler* mission has revealed a large number of hot-Jupiters (HJs) [e.g., Winn *et al.*, 2010; Wang *et al.*, 2015a], which are Jupiter-mass gas giants orbiting closely to their host stars (orbital periods typically smaller than 10 days). These HJs typically have nearly circular orbits, usually tidally locked, and extreme and exotic atmospheres due to their short periods. There are two scenarios explaining the formation of hot-Jupiters: migration and *in-situ* formation. In this project, students will explore the possible mechanism of high-e migration through the Kozai-Lidov mechanism [cf. Lidov, 1962; Kozai, 1962; Naoz *et al.*, 2011].

Project 3: Dynamical Evolution of Star Clusters

It is now widely accepted that the star formation process takes place in star clusters and stellar associations [e.g., Lada and Lada, 2003]. The dynamical evolution of star clusters is driven by both internal processes (e.g., two-body relaxation, stellar evolution) and external processes (e.g., galaxy tidal field, interaction with giant molecular clouds) [see, e.g., Heggie and Hut, 2003; Cai *et al.*, 2016]. Most clusters (in particular low-mass open clusters) dissolve in due time, releasing their member stars as part of the galactic population. In this project, students will learn how to model star cluster evolution, carrying out simulations using GPU-accelerated codes (e.g., `NBODY6++GPU`, Spurzem [1999]; Aarseth [2003]; Wang *et al.* [2015b]) and interpret the simulation results to understand the structural evolution of star clusters.

Project 4: Dynamical modeling of the Milky Way-Andromeda Merger

Galaxy mergers are one of the most important dynamical processes in the dynamical history of galaxies. Depending on the speeds, impact angles, and mass ratio, galaxy mergers may produce irregular galaxies,

[1]Email: cai@strw.leidenuniv.nl
[2]http://exoplanet.eu/

lenticular galaxies, elliptical galaxies, or spiral galaxies. In the Local Group, the Andromeda galaxy (M31) is approaching the Milky Way galaxy at a speed of roughly 110 km/s [Sohn *et al.*, 2012]. It is predicted that the two galaxies will eventually collide in about 4.5 Gyr from now, merging into an elliptical galaxy, nicknamed Milkomeda or Milkdromeda [e.g., Cox and Loeb, 2008]. To study the merging process, the student is expected to model the velocity and impact angle of the two galaxies according to observational data, and then carry out the simulation using a GPU-accelerated tree-code (e.g., `Bonsai`, Bédorf *et al.* [2012]).

Project 5: Jupiter as a Shepherd of Asteroids

Jupiter is the most massive planet in the Solar System. Due to its strong gravitational field, it has played a major role in shaping the orbits of the asteroids nearby. In particular, a large number of asteroids [3] are locked at the L4 and L5 Lagrange points of Jupiter's orbit; millions of asteroids are confined in the Main Belt between the orbits of Mars and Jupiter.

In this project, students are expected to model the secular resonance between Jupiter and asteroids. The initial conditions can be derived from NASA's Minor Planet Center. The simulations will be carried out direct N-body codes, in which close encounters and collisions are properly taken into account. It is of particular interest to simulate the depletion of asteroids the Kirkwood gaps. Students will learn to monitor the relative energy error in a simulation, derive orbital elements from Cartesian coordinates, and perform simple stability analysis according to the simulation data.

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[3] See a full list from https://minorplanetcenter.net/iau/lists/t_jupitertrojans.html

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