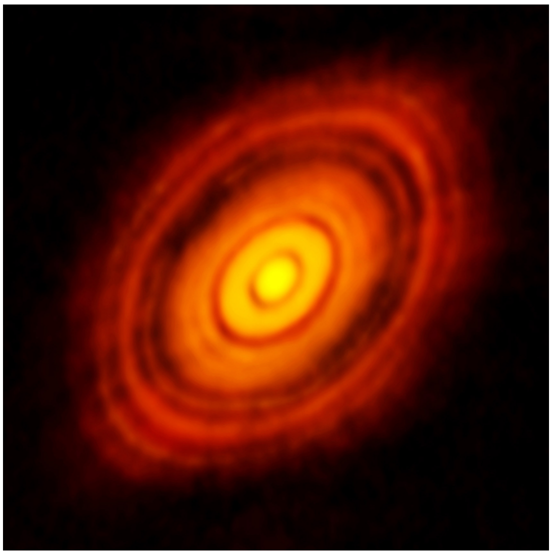
Planet-Disk-Interactions



SUMMARY.
Planets form in protoplanetary disks around young stars, like the one around HL-Tau imaged by ALMA shown on the adjacent picture. Such disks are mainly made of gas, with $\sim 1\%$ dust, from which planets grow. As a consequence, planets must interact with the gas while they form. Actually, the structures seen on the image may be due to planets in formation. In turn, the perturbed disk acts on the planets, which leads to a modification of their orbits : they migrate ! Migration is a key ingredient in planet formation, which shapes the final solar and extrasolar systems. In this METEOR, we will explore the theory and the various applications of planet-disk interactions.

OBJECTIVES

- Get a global picture of planetary formation, the physics of protoplanetary disks, the dynamics of planet-disk interactions (restricted three-body problem, notion of torque, pressure wave propagation).
- Use a complex hydrodynamics code. Run simulations on the observatory local cluster. Analyse the results of these simulations using `python` scripts that can be adapted. Develop a critical mind about these results to decide the set-up of the next simulations in the frame of the chosen project.

PREREQUISITES

- ☒ S1. Numerical methods
- ☒ S2. Dynamics & Planetology
- ☒ S2. General mechanics

Note: these lectures are not absolutely mandatory, but their good understanding would be of considerable help for this METEOR.

THEORY

by A. Crida

Physics of gas disks around stars: vertical hydrostatic equilibrium, equilibrium rotation velocity. Dust behaviour: sedimentation, radial drift. Planet formation: streaming instability, s$_{t}$one accretion, gaz accretion, formation of satellites. Planetary migration: Lindblad and corotation torques, gap opening. Applications to the solar system, and other systems.

by H. Méheut

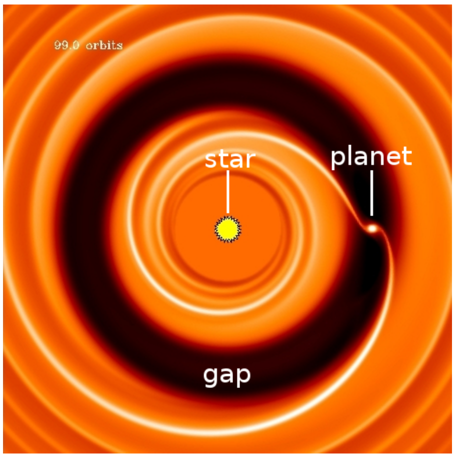
Fluid dynamics to model the gas of protoplanetary disks, Euler equations that will be solved by the code FARGOCA, perturbative approach and wave propagation in astrophysical disks.

by E. Lega

Calssical numerical methods for the integration of Navier-Stokes equations and for the N-body problem (finite difference, Runge-Kutta) and their use in the code FARGOCA. The code is specifically designed for the study of protoplanetary disks and for planets-disk interactions. Learn how to use the code and to run simulations on the local cluster.

APPLICATIONS

by A. Crida, E. Lega, H. Méheut



Gas density map from a numerical simulation with a giant planet on a fixed, circular orbit. A spiral wake (white) and a deep gap (black) are clearly visible, due to planet-disk interactions.

- **Common project:** Make a numerical simulation with our code FARGOCA, of a protoplanetary disk with an embedded terrestrial planet. Produce a gas density map and notice the spiral wake. Compare the numerical simulation with the theoretical spiral curve. Explore the parameter space to test the theory (or the code).
- **Personnal project:** Choose among the following possible personnal studies.
  - Mean motion resonance of several planets in convergent migration
  - Fourier decomposition of the spiral and link with mean motion resonances with the planet
  - (In)stability of a disk cavity and planet trap
  - Energy equation and role of the corotation torque
  - Effect of the indirect term on the stability of the disc and the dynamics of the planet

MAIN PROGRESSION STEPS

- **Weeks 1-2**: Theory lectures
- **Week 3**: Learn to use FARGOCA, study of the spiral wake + written exam
- **Weeks 4-7**: Personal projects
- **Week 7**: preparation of the defense

EVALUATION

- **Theory grade [30%]**
  - Production of the student's own lecture on Fluid mechanics with H. Méheut.
  - Written exam. Theoretical questions, exercices based on the examples seen in lectures by A. Crida and E. Lega.
- **Practice grade [30%]**
  Evaluation based on the students attitude and progresses during the practical work.

  Criteria are curiosity, autonomy, achievements, ease with the numerical tools, understanding of the physics and the numerics, general scientific attitude and critical mind.
- **Defense grade [40%]**
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Crida (2023)
- Baruteau et al. (2014) (video)

CONTACT

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