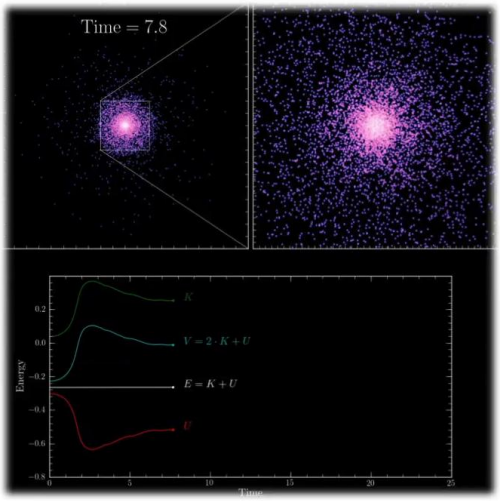
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

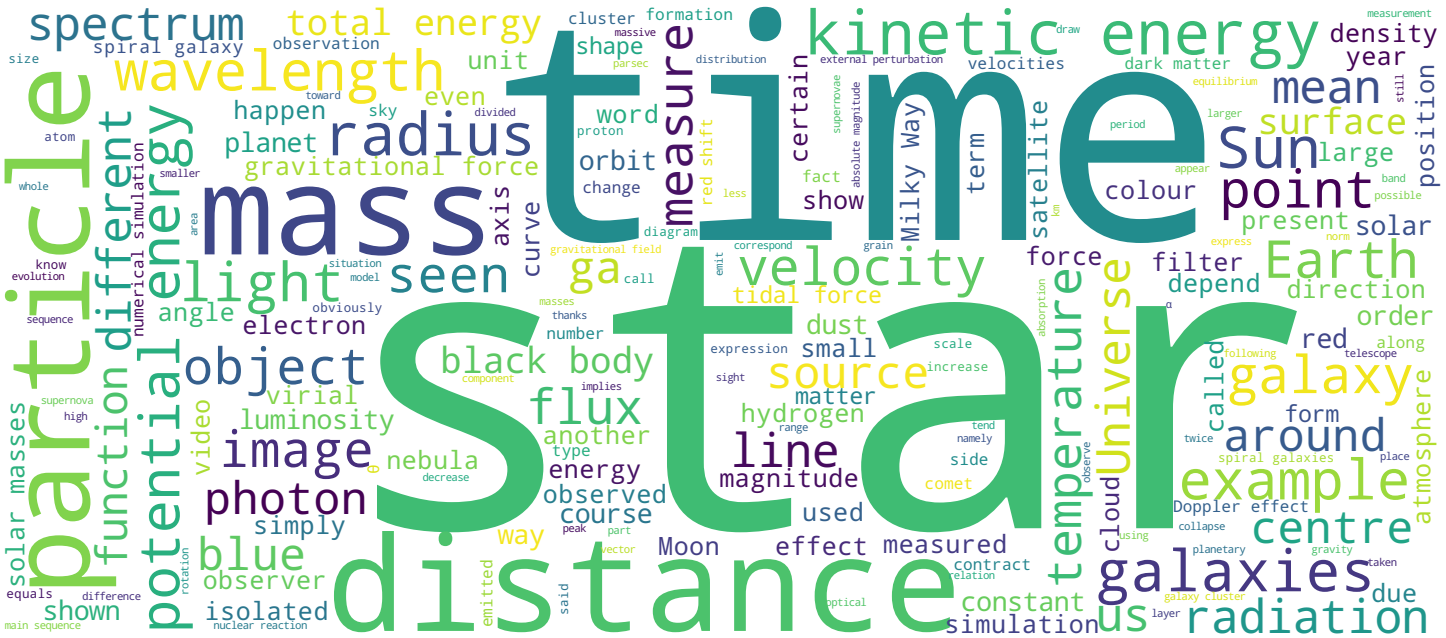
Virial Theorem: Numerical Illustrations

Introduction to Astrophysics; Chapter 1.4

Frédéric Courbin



Self-graviting system (Yves Revaz, EPFL)



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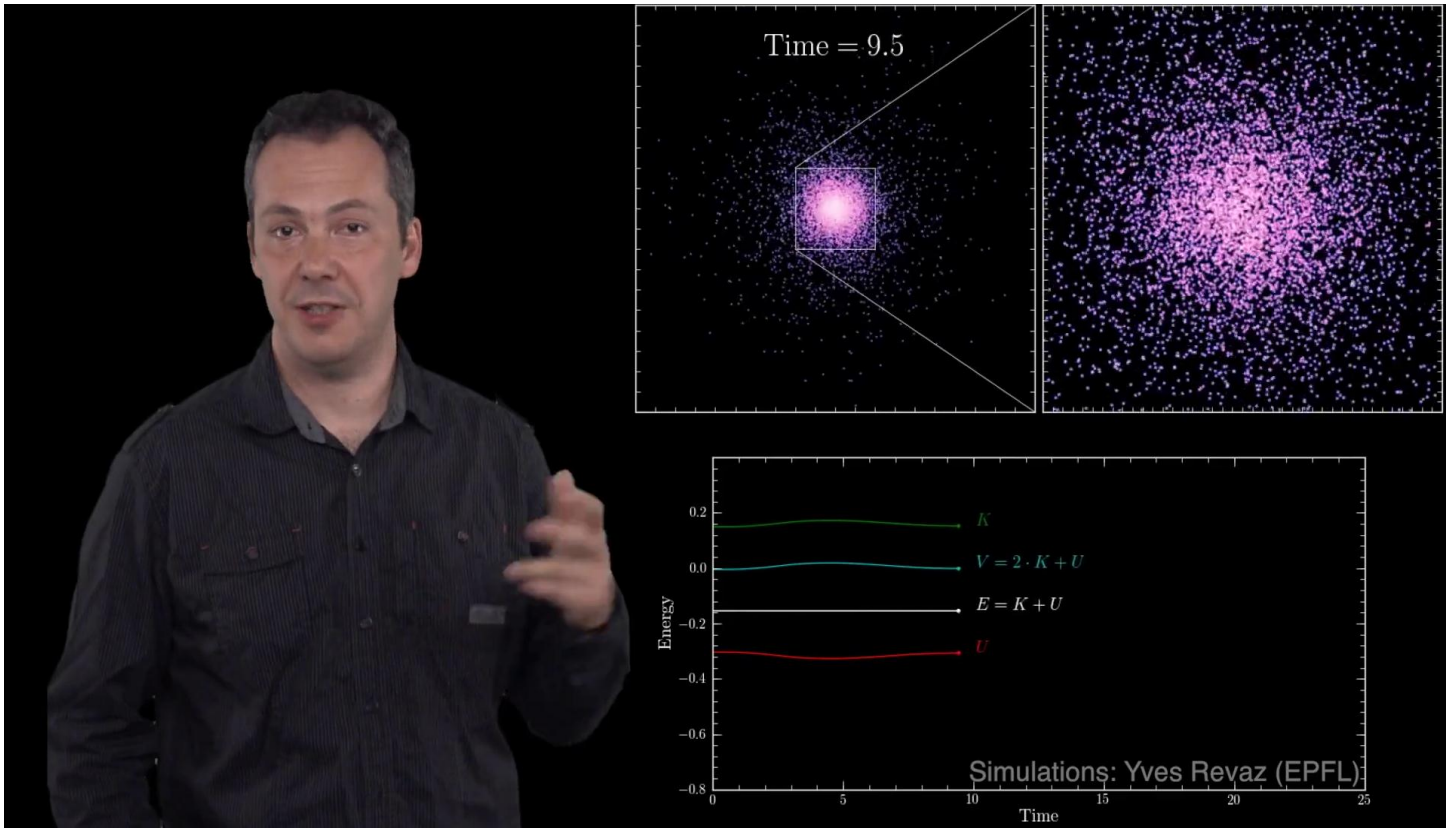
Video

EPFL

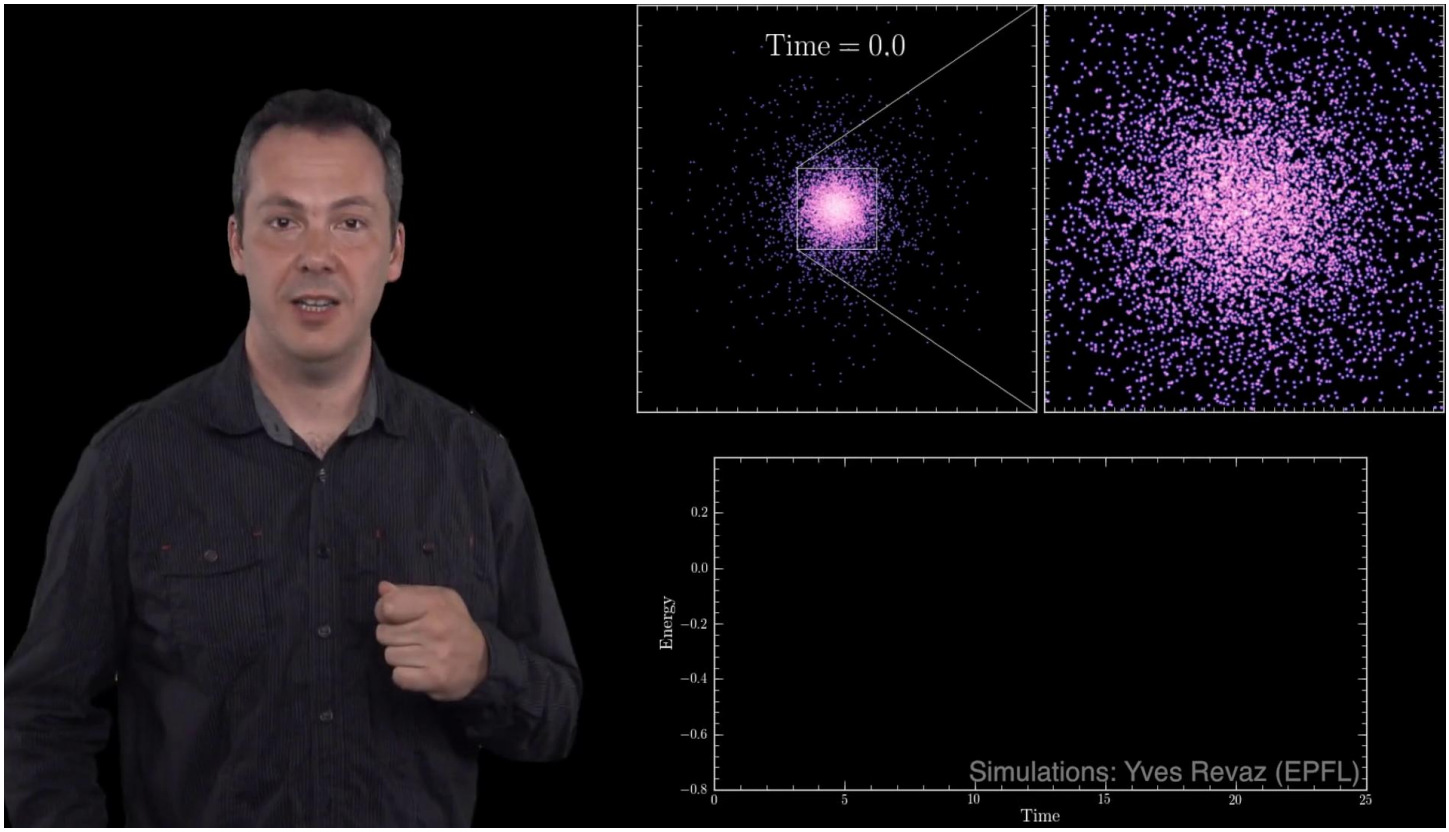


We present here four videos with numerical simulations illustrating the time evolution of an isolated self-gravitating system of particles, in other words only influenced by its own gravitational force. In the following simulations we used a limited number of particles : 8000 particles, shown in the upper part of the simulation, with an enlargement in the right part of the simulation. At each instant between each video frame, all the gravitational forces between the particles are computed in order to predict at each time the position and the velocity of each particle and to let evolve with time several quantities such as the virial, the kinetic energy, the potential energy and the total energy. Lets evolve the system over time. In each following footage, the initial positions of all the particles are strictly the sames. Only the velocities, that is the kinetic energy, changes. In each simulation we show in the bottom part of the video the kinetic energy in green, the potential energy in red and their sum, the total energy in white. As for the virial, i.e., twice the kinetic energy plus the potential energy, it is shown in blue.

Notes

Summary

0m 04s

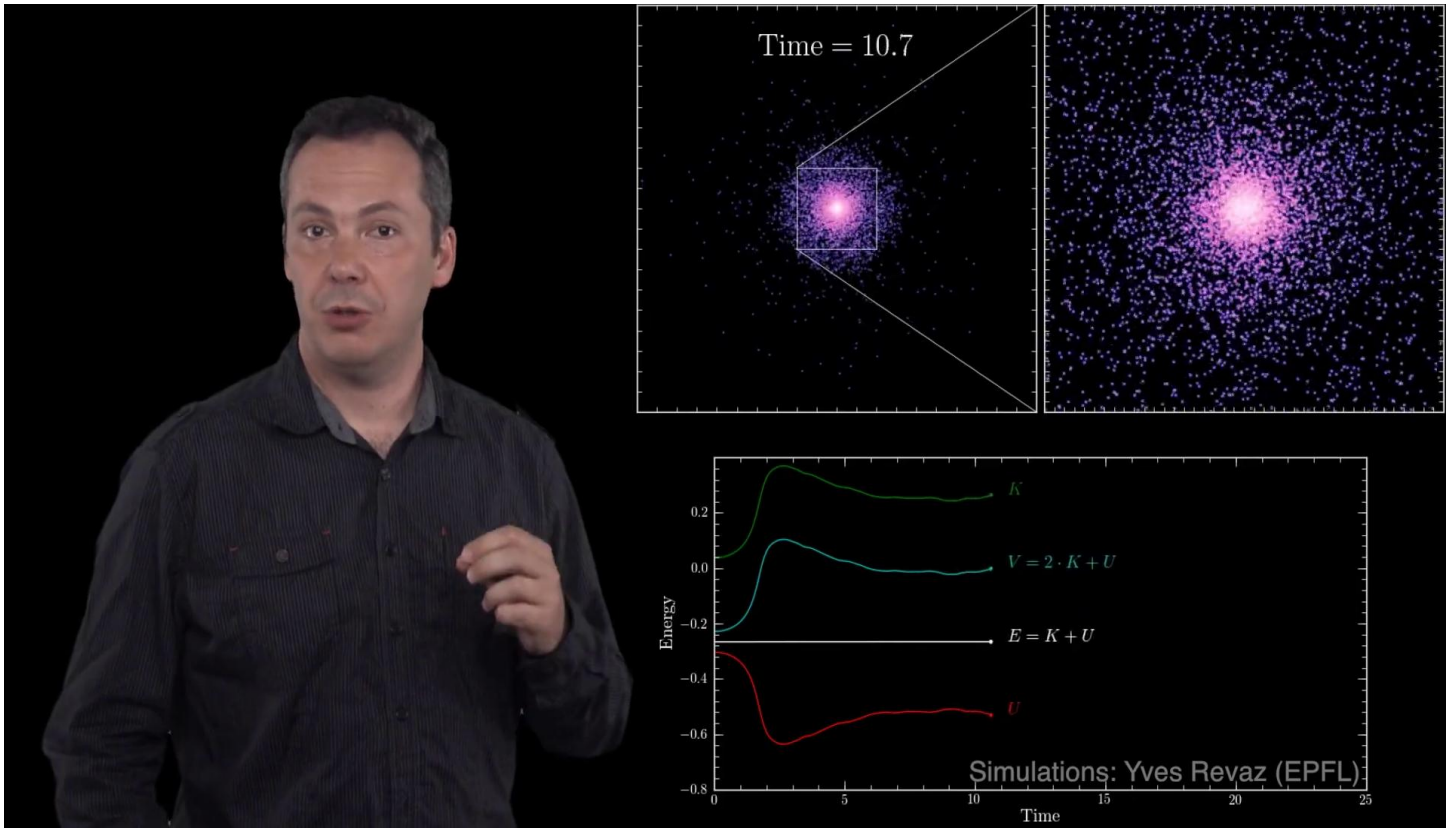


We first see that in such a system, completely isolated, that the total energy is always exactly conserved up to numerical errors, up to the accuracy of the simulation. The potential energy plus twice the kinetic energy, namely the virial, oscillates indeed around 0 over time. Lets see what happens now if the system is not isolated anymore ? We introduce an external perturbation to the system which affects the shape of the self-gravitating system, which actually isn't self-graviting anymore, and affects the physical quantities we measure. The physical quantities are in the lower part and the system still in the upper part. We see that under the effect of an external perturbation the system deforms over time and we also see that the total energy increases. The virial does not oscillate around zero anymore but also tends to increase. In this specific case we tend to add up kinetic energy to the system through the external perturbation. Now let us go back to an isolated system, that is without external gravitational field anymore. We will set initial conditions such that the kinetic energy is too low to counterbalance the potential energy.

Notes

Summary

1m 22s



In such a case, the total energy is of course conserved over time since the system is isolated. What happens is that the system has to contract to make a sudden increase of the kinetic energy at the beginning of the simulation. In order to gain kinetic energy, we lose potential energy, and to lose potential energy the system contracts until reaching an equilibrium after a some time where the virial oscillates around zero. The system was initially too big for its kinetic energy and as such contracted itself to reach a new equilibrium. In a similar way, if we take an isolated system but this time with too much kinetic energy in regards to potential energy then the kinetic and potential energies will balance each other as seen here. The kinetic energy decreases over time, the potential energy increases over time, the total energy is conserved since the system is isolated and the virial will naturally converge to a mean value of zero after a some time. As opposed to the previous simulation, the system will grow in size contrary to the contraction observed previously. The numerical simulations shown here only use a limited number of particles yet enough to illustrate the time evolution of a self-graviting system. However, they only take into account the gravitational forces between the particles.

Notes

Summary

2m 44s

Other numerical simulations can be used to understand the formation and evolution of galaxies. They can include up to hundreds of billions of particles as well as the physics of gas surrounding the particles and the explosion of supernovae. In the simulation you see behind me, we used ten million particles to model the evolution of a spiral galaxy over several hundreds of millions of years.

Notes

Summary

4m 11s