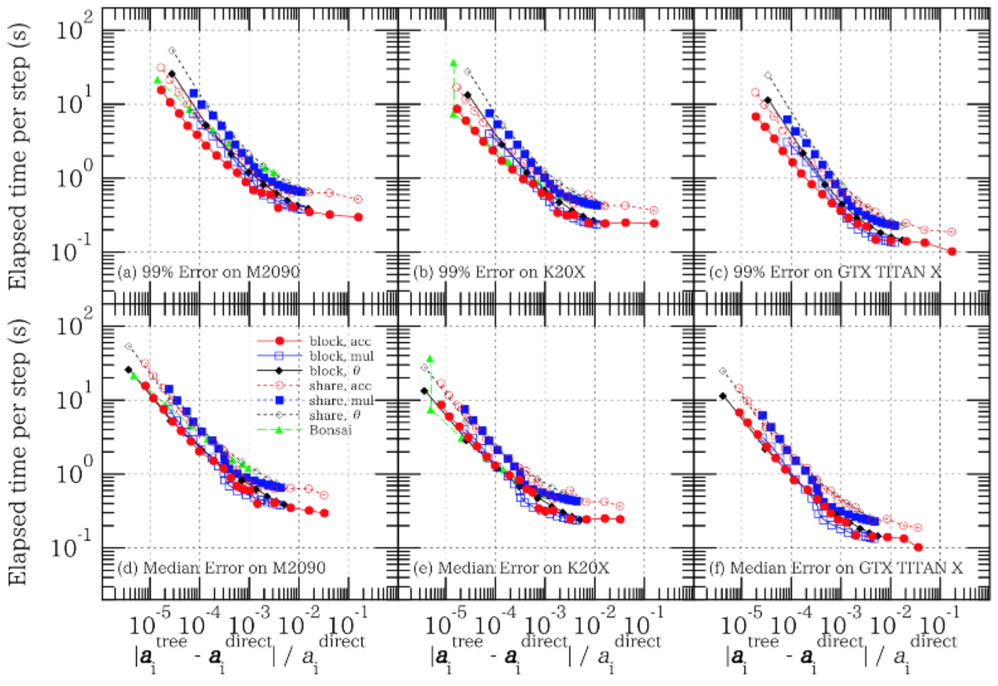
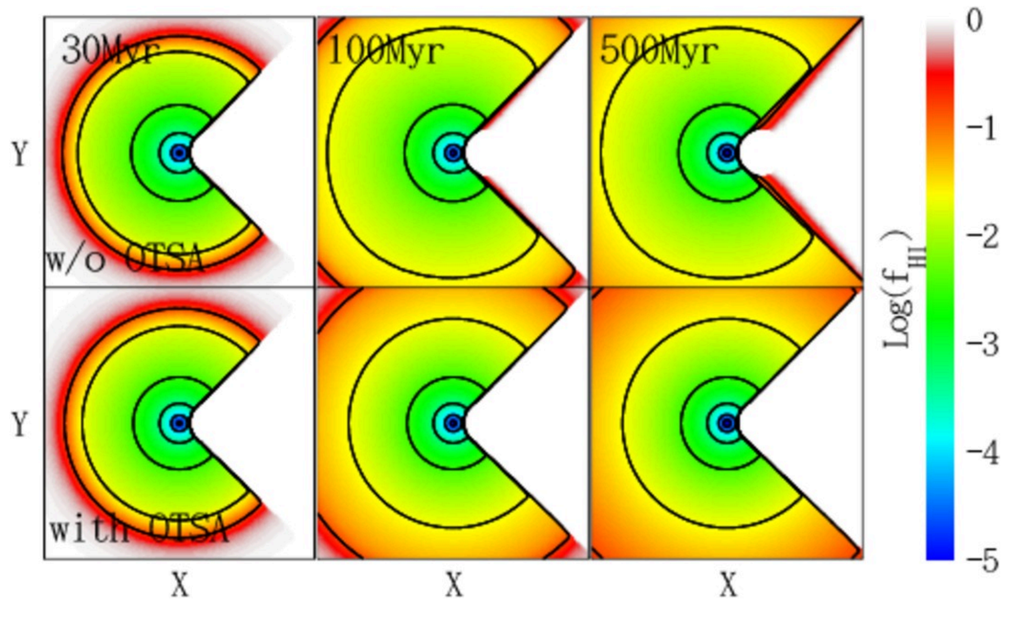
Solving the Mysteries of the Universe with Computational Astrophysics

GPU-accelerated high-fidelity gravity and radiation calculations

In the universe, gravity and radiation drive and regulate the formation of astrophysical objects such as galaxies, stars, planets, and black holes. The large dynamical range in density and thus gravitational force, and the short timescales involved in the propagation and interaction of radiation with interstellar matter pose great challenges for computational astrophysics. GPUs can provide substantial acceleration in N-body and radiative transfer calculations.



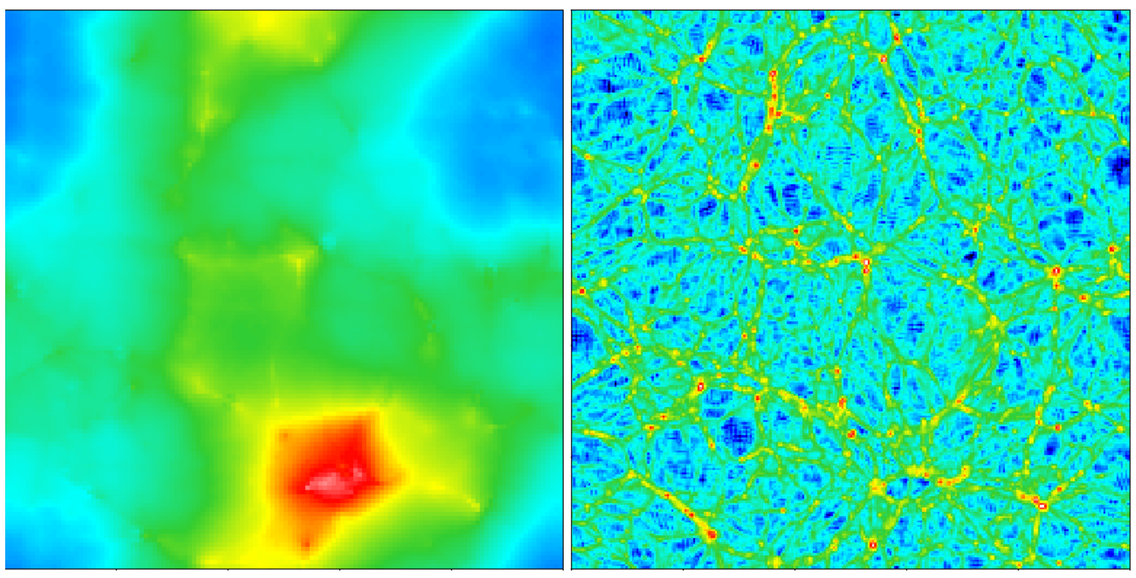
We developed an extremely efficient GPU-accelerated N-body code, named GOTHIC. The code brings together many of the most effective schemes including the tree method and hierarchical time-step, and couples these with on-the-fly auto-tuning to minimize execution time. The calculations are accelerated to 30% of the theoretical peak GPU performance.



We developed a new GPU-accelerated code, which is capable of accurately computing the propagation of diffuse recombination photons in three dimensions. Diffuse photons affect the advance of ionization fronts and alter the ionization state in shadow regions. This effect can change the conditions of the interstellar medium and star-formation in the early universe.

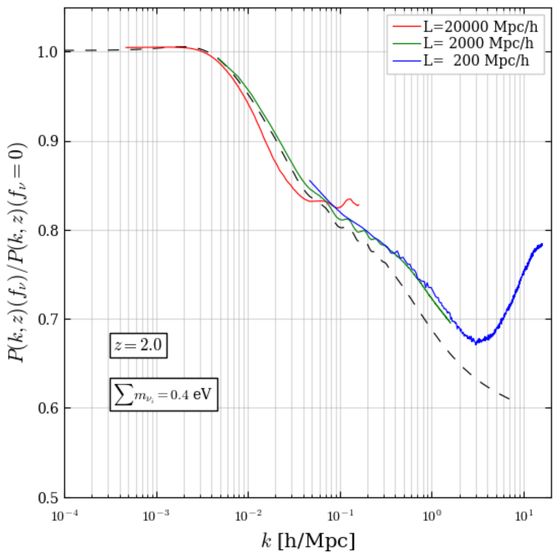
Simulating the dynamical effect of neutrinos on the large-scale structure of the universe

Neutrinos are electrically neutral elementary particles and had been thought to be massless in the standard model of elementary particle physics. Recently it turns out that neutrinos have non-zero mass, although their absolute mass is still unknown (though estimated to be less than 1eV), through the experimental discovery of a quantum phenomenon of neutrinos called “neutrinos oscillation”. Since there exist a huge number of neutrinos in the universe, they can affect the dynamics of the large-scale structure (LSS) of the universe through the gravitational interaction.



Distribution of cold dark matter (right panel) and neutrino (left panel) in the LSS of the universe (colors indicate mass density of each component). Due to its very large velocity dispersion, neutrinos have much more diffuse distribution than cold dark matter.

We perform numerical simulations of the LSS of the universe composed of cold dark matter and neutrinos, in which the dynamics of cold dark matter is simulated with a N-body simulation, and that of neutrinos are simulated by solving the Vlasov-Poisson equations (aka the collisionless Boltzmann equation) in the six-dimensional phase space volume.



Ratio of density power spectra with and without neutrino mass. Presence of massive neutrinos dynamically suppress the growth of power spectrum, and the extent of the suppression is a measure of neutrino mass.