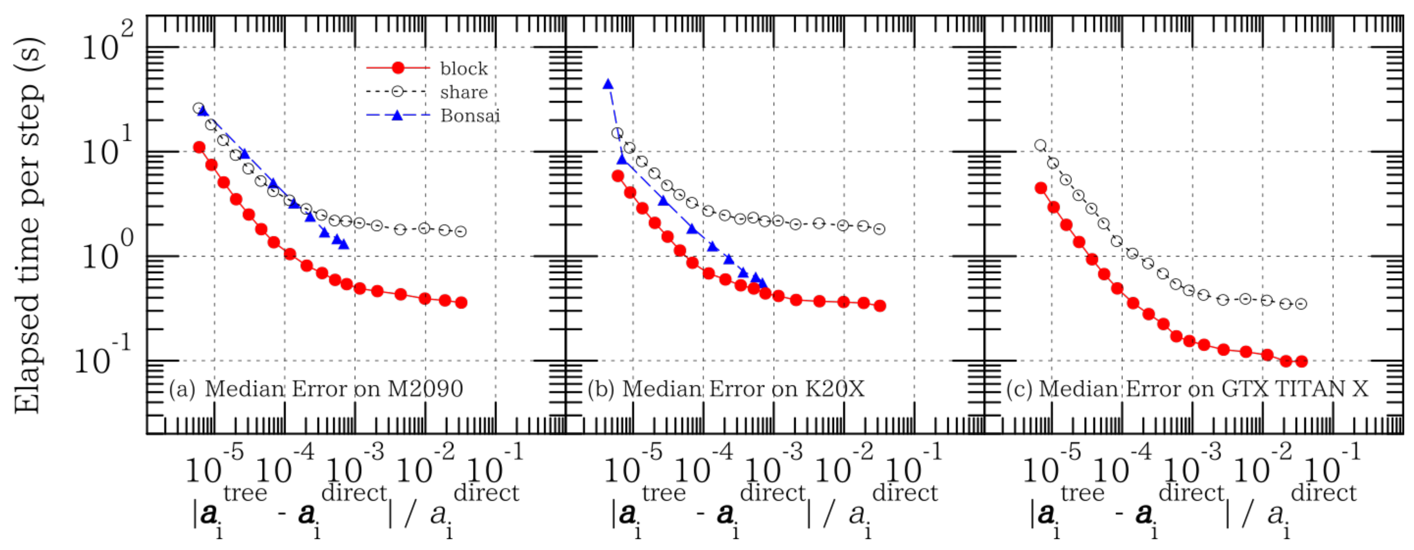
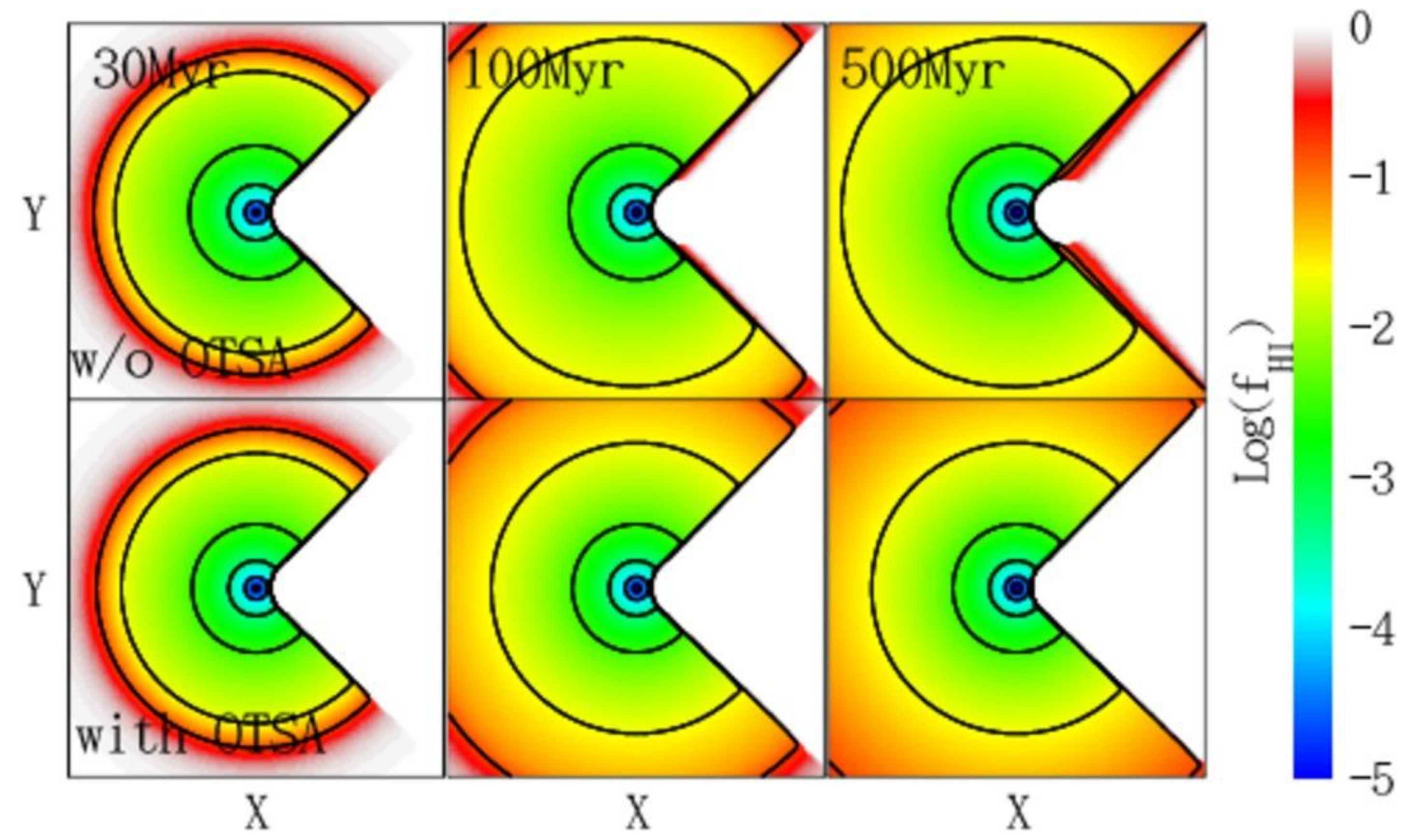
Solving the Mysteries of the Universe with Computational Astrophysics

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.



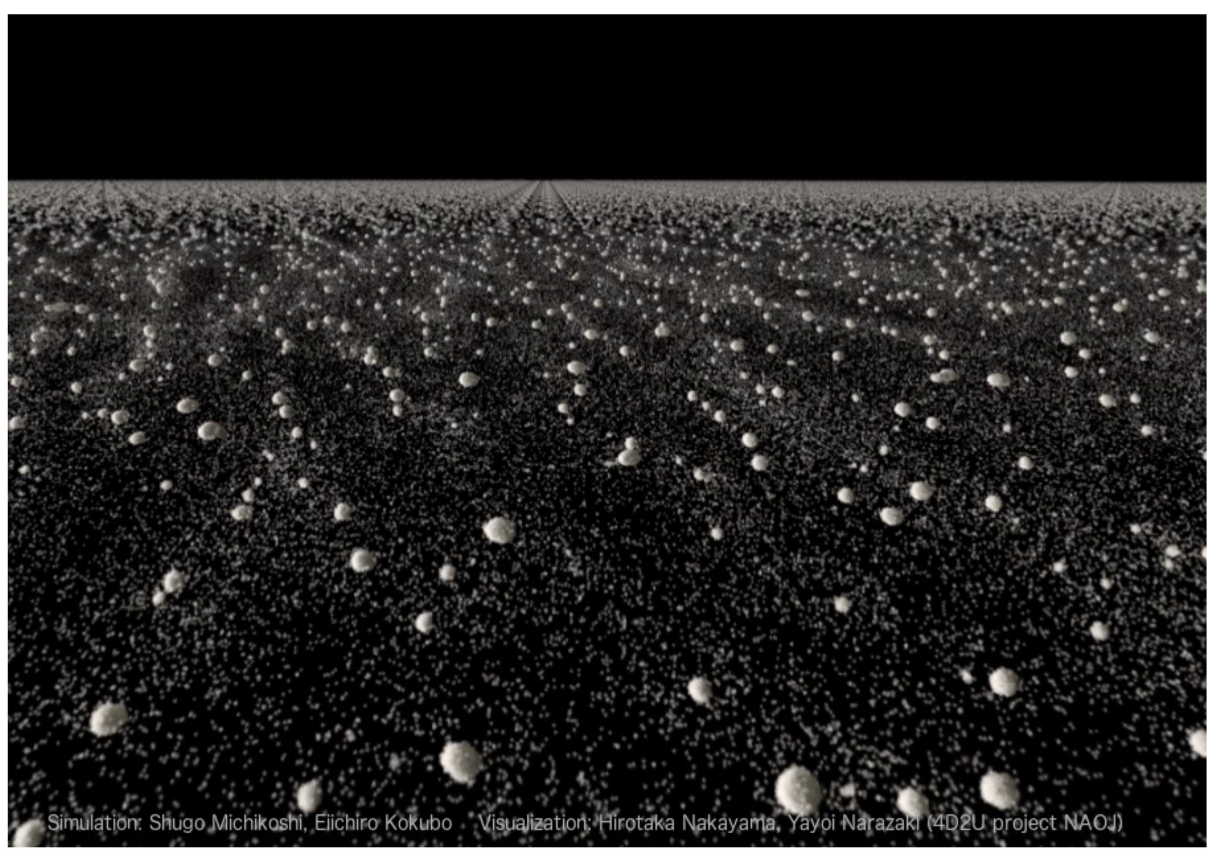
We developed an extremely efficient GPU-accelerated N-body code, named GOTHIC. The code brings together many of the most effective schemes including the tree method and block timestep (cf. shared timestep), and couples these with on-the-fly auto-tuning to minimize execution time. The code optimization and tests were done on Fermi, Kepler, and Maxwell generation GPUs with particle distributions representing the Andromeda galaxy using 8M particles. The calculations are faster than other leading codes, e.g. Bonsai, and exhibit accelerations up to 30% of the theoretical peak GPU performance in single precision.

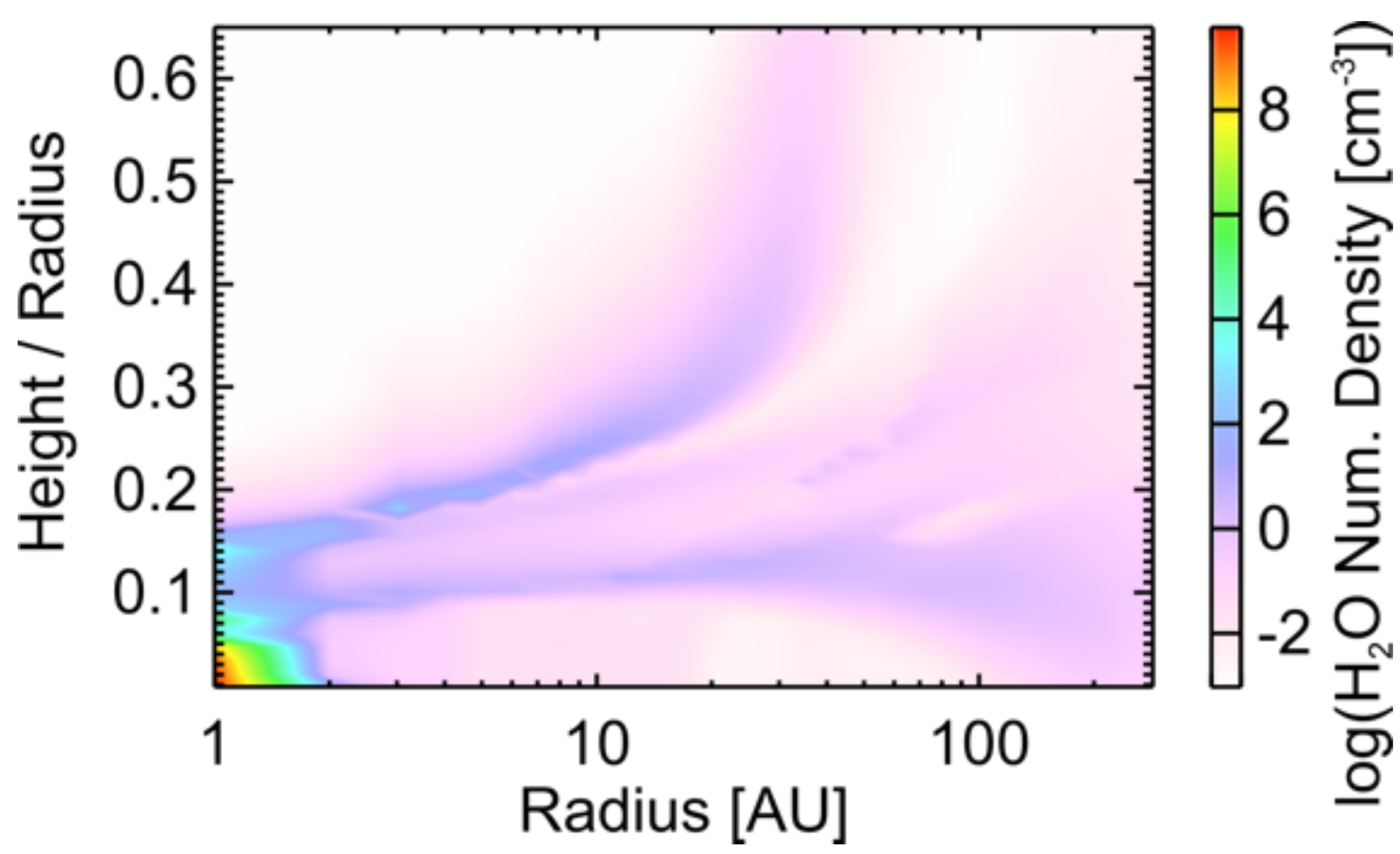


We developed a new GPU-accelerated code, which is capable of accurately computing the propagation of diffuse recombination photons in three dimensions. Diffuse photons affect the advance of ionization fronts and alter the ionization state in shadow regions. This effect can change the conditions of the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

Simulating protoplanetary disks and exploring the formation of planetary systems

Protoplanetary disks are rotating gas disks surrounding newly formed stars and contain micron-sized dust particles, covered by ice mantles. The dust particles coagulate to kilometer-sized planetesimals, which grow by mutual collisions and eventually turn into planets. The surface environments of planets are thought to be largely determined by gas and icy planetesimal accretion. Thus, the study of gas and ice chemical compositions in protoplanetary disks is important for understanding the beginning of life on planets.





Using the N-body simulations including the effects of inelastic collision and self-gravity, we investigated the dynamics of dust aggregates and the formation processes of planetesimals from dust aggregates in a protoplanetary disk. When a dust layer becomes sufficiently thin, the gravitational instability takes place and dense dust regions form. The dense dust regions facilitate dust growth and planetesimals form rapidly.

We simulated the distribution of water vapor in a protoplanetary disk around a typical T Tauri star. Various physical and chemical processes, e.g., gas-phase chemistry, grain surface chemistry, and chemistry induced by stellar ultraviolet photons and X-rays, are included. The simulations reveal where and how much water is present in the disk, and are useful for interpreting astrophysical observations of water in protoplanetary disks.

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