Division of Astrophysics

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We apply fundamental physics to investigate a wide variety of astrophysical phenomena, including the birth and evolution of the first stars and galaxies in the universe, the characteristics of the light they emit, the formation and evolution of galaxies, galaxy clusters, and other large-scale structures, the formation and evolution of black holes and their jets and radiation, the formation of planets, and the origin of life in the universe. We are also researching how technology developed in this field may find applications in medicine.

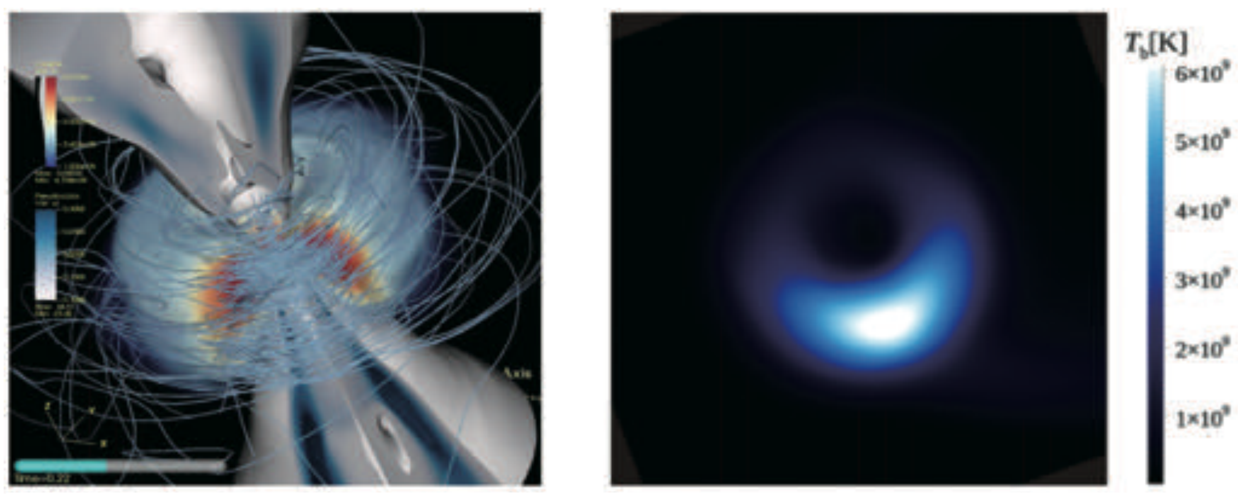


Fig.1
Left: Black hole accretion disks and jets in general relativistic radiative magnetohydrodynamic simulations.
Right: Black hole shadow reproduced by general relativistic radiative transfer calculations

Black-hole physics

In the accretion disk, where matter accumulates owing to the strong gravity of the black hole, powerful radiation and jets are generated through the release of gravitational energy. We are investigating high-energy astrophysical phenomena around black holes and the radiation from black-hole phenomena through general-relativistic radiation-magnetohydrodynamic simulations.

Supermassive black holes and galaxy evolution

Every galaxy harbors a supermassive black hole at its center that grows by swallowing stars and interstellar matter and simultaneously launches powerful jets into the galaxy that blow away interstellar gas and regulates star formation and black hole growth. We are investigating these complex cycles in galaxy evolution through relativistic magnetohydrodynamic simulations.

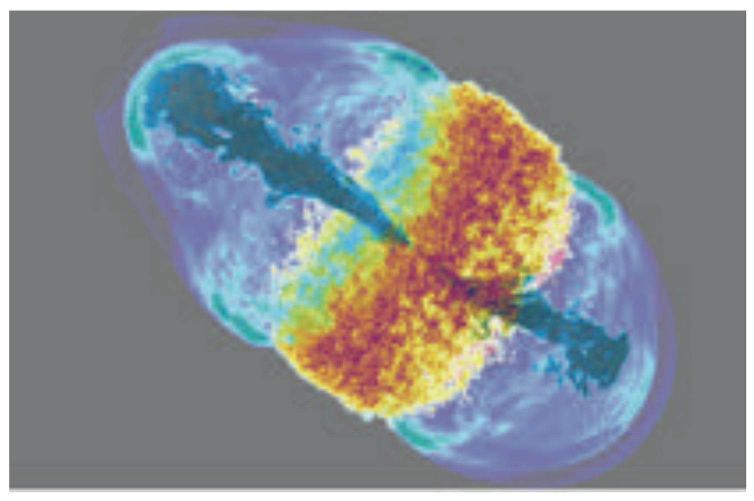
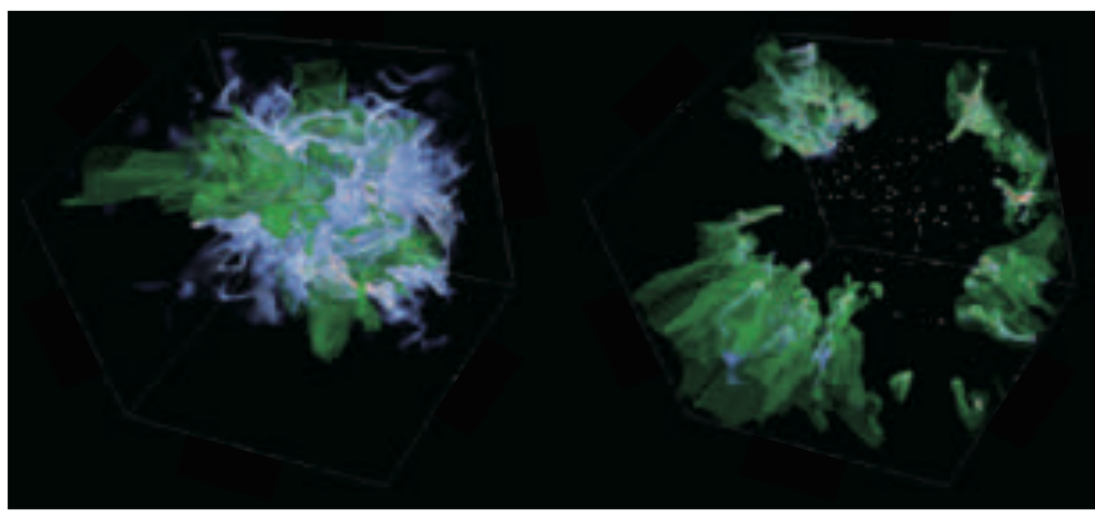


Fig. 3 Interaction between interstellar gas and jets



Star cluster formation

Most stars are born as members of star clusters in the Universe. The physical processes in star-cluster formation determine the properties of the stars. We are studying star-cluster formation and cloud dispersal by radiative feedback using radiation hydrodynamics simulations.

Fig. 2 Cloud dispersal by radiative feedback in star cluster formation

Galaxy evolution and dark matter

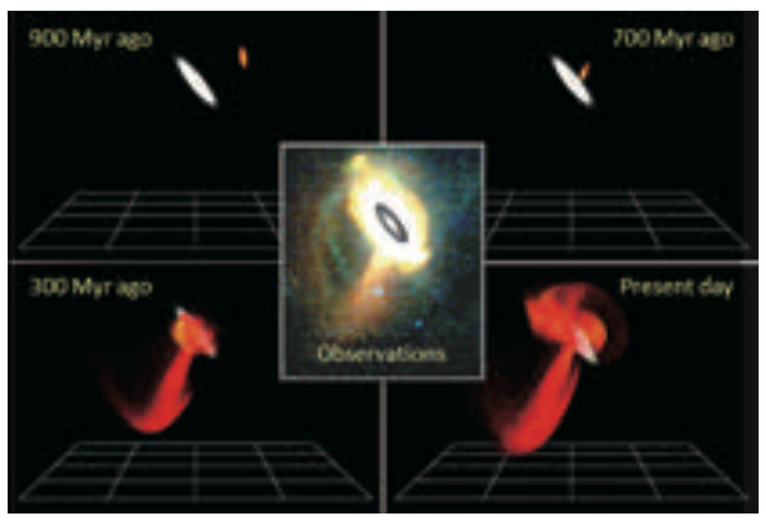


Fig. 4 A galaxy collision that occurred in the Andromeda Galaxy approximately 1 billion years ago

Dark matter is known to play an important role in the evolution of galaxies, but its nature remains shrouded in mystery, and many contradictions within existing theories persist. We are investigating the nature of dark matter haloes by studying galaxy collisions.

Galaxy formation

In the early universe, massive galaxies and supermassive black holes may have formed through frequent merging of galaxies and rapid gas accretion in primordial galaxy clusters. We are studying physical phenomena occurring in primordial galaxy clusters through cosmological radiation-hydrodynamic simulations.

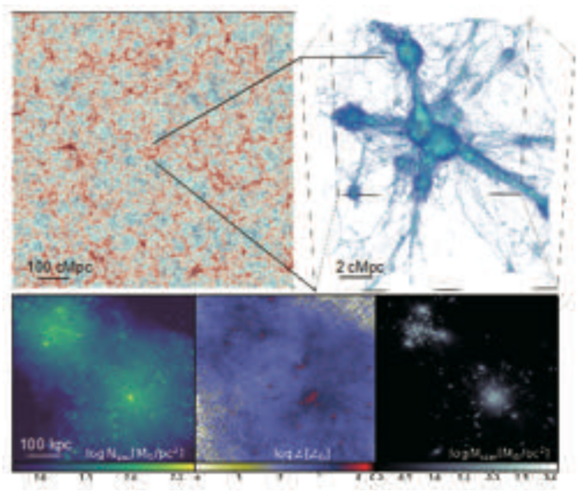
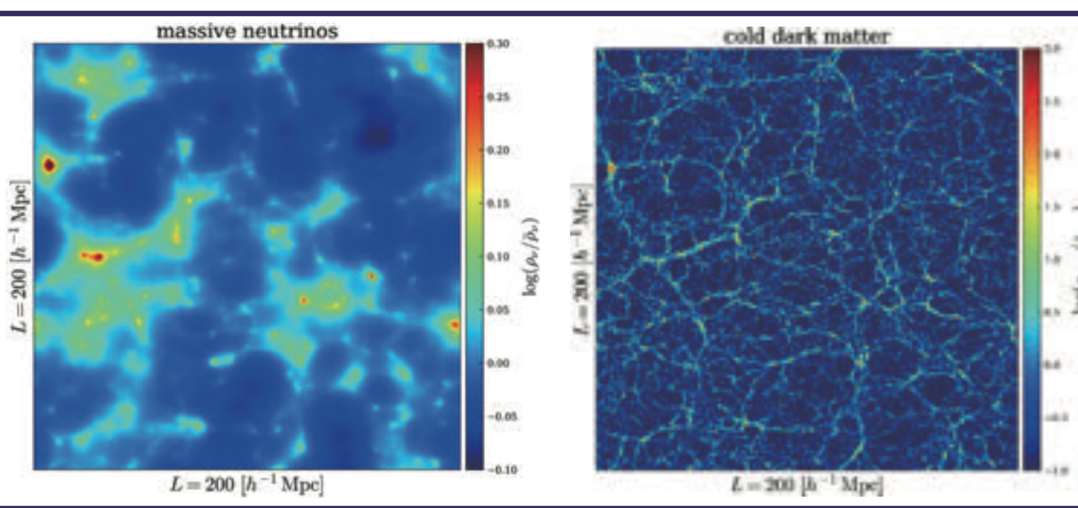


Fig.5 Upper left: Large-scale matter distribution in the universe.
Upper right: Structure of gas near the central galaxy in a proto-galaxy cluster.
Bottom: From left to right, galactic gas, heavy elements, and stellar surface density.

Neutrinos and the formation of large-scale structures in the universe



We have conducted the world' s first high-precision Vlasov simulations of the large-scale structure in the universe that include neutrinos and that outperform conventional N-body simulation. The simulations can be used in conjunction with future observational projects of large-scale galaxy survey to constrain the neutrino mass.

Fig. 6 Left: Large-scale structure with neutrinos.
Right: Large-scale structure without neutrinos.

Applications of astrophysical techniques in medicine

Diffuse optical tomography (DOT) using near-infrared light in the wavelength range of 700-1000 nm has been garnering attention as a new medical diagnostic method because it is non-invasive and does not expose the patient to radiation. We are studying light propagation in living organisms by applying high-precision techniques for radiative transfer calculation developed in astrophysics to DOT.

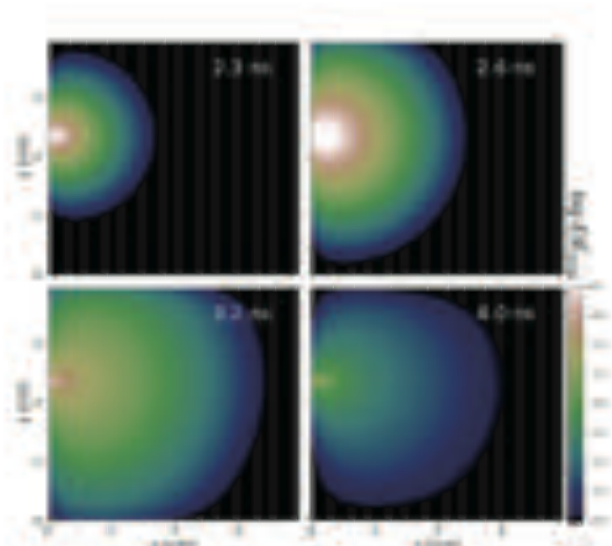


Fig. 7 Radiative transfer in live tissue irradiated by pulsed light