Oral Presentations

Radiative Feedback Effects of the First Objects in the Early Universe

Kyungjin Ahn, Paul R. Shapiro, Ilian T. Iliev, and Dongsu Ryu

The first astrophysical objects form at rare, high-density environment in the early universe. These objects deliver strong radiative, chemical and dynamical feedback effects onto their environments. We review our on-going attempts to calculate these feedback effects, focusing on (1) radiative feedback effects of the first Pop III stars, (2) 21-cm emission signal from high-redshift minihalos, and (3) simulations of cosmic reionization.

Radiation-SPH Simulation on the Radiative Feedback of POPIII Stars

Hajime Susa

We have been constructed a brand-new radiation hydrodynamics solver based upon SPH, which works on parallel computer system. The code is designed to investigate the formation and evolution of the first generation objects at $z > 10$, where the radiative feedback from various sources play important roles. We have applied the scheme on the POPIII star formation in the presence of nearby (POPIII) stars. The radiative feedback from latter stars play quite important roles through photoheating/photoionization and photodissociation of hydrogen molecules. We find that the photoheating/photoionization process cannot prevent the self-gravitating gas from collapsing if the density of the gas is sufficiently high. Moreover it helps the shielding of Lyman-Werner band radiation by creating H_2 shell just behind the ionization front.

Shock Waves and Cosmic Rays in the Large Scale Structure of the Universe

Dongsu Ryu and Hyesung Kang

In cosmological N-body/hydrodynamic simulations, shock waves form in the intergalactic space as a consequence of the large scale structure formation of the universe. Those cosmological shock waves, like most astrophysical shocks, are so-called collisionless shocks, where through dissipation process, a fraction of shock energy is converted into gas thermal energy as well as cosmic ray energy. In a previous work (Ryu et al. 2003), we showed that the cosmological shocks are abundant with the mean distance between shock surfaces of ~1 Mpc or so within nonlinear structures and that the energy of cosmic rays accelerated there could be as large as ~1/2 of the gas thermal energy in the present universe. In this talk, we present the preliminary results of an updated work where we consider the effects of other physical processes, such as radiative cooling/heating and feedbacks of galactic winds, on the statistics and energetics of the cosmological shock waves.

The Influence of Baryon on the Matter Distribution and Shape of Dark Matter Halos

Weipeng Lin, Y. P. Jing, S. Mao, L. Gao, and Mccarthy, I. G.

Using a set of high-resolution N-body/SPH cosmological simulations with identical initial conditions but run with different numerical setups, we investigate the influence of baryonic matter on the mass distribution of dark halos when radiative cooling is NOT included. We compare the concentration parameters of about 400 massive halos with virial mass from 10^{13} $M_{\odot}$ to 7.1×10^{14} $M_{\odot}$. We find that the concentration parameters for the total mass and dark matter distributions in non radiative simulations are on average larger by ~3% and 10% than those in a pure dark matter simulation. Our results indicate that the total mass density profile is little affected by a hot gas component in the simulations. After carefully excluding the effects of resolutions and spurious two-body heating between dark matter and gas particles, we conclude that the increase of the dark matter concentration parameters is due to interactions between baryons and dark matter. We demonstrate this with the aid of idealized simulations of two-body mergers. The results of individual halos simulated with different mass resolutions show that the gas profiles of densities, temperature and entropy are subjects of mass resolution of SPH particles. In particular, we find that in the inner parts of halos, as the SPH resolution increases the gas density becomes higher but both the entropy and temperature decrease. We also give results of simulations with star formation and SN feedback. As we have found, the inner slop of halos will be very steep because of gas cooling and steller components. In the simulation with star formation, the tri-axial halo shapes will become more spherical than those in DM-only simulation and simulations with nonradiative gas.

The Giant Arcs Statistics in the Three-year WMAP Cosmological Model

Guoliang Li, S. Mao, Y. P. Jing, H. J. Mo, L. Gao, and W. P. Lin

We use high-resolution N-body simulations to investigate the optical depth of giant arcs with length-to-width ratio larger than 7.5 and 10 in the "standard" Λ model with σ_8 = 0.9 and $\Omega_{m,0}$ = 0.3 and a model based on three-year Wilkinson Microwave Anisotropy Probe (WMAP) data. We find that, in dark-matter only simulations, the lensing probability in the three-year WMAP model (with σ_8 = 0.74 and $\Omega_{m,0}$ = 0.238) decreases by a factor of ~6 compared with that in the "standard" Λ model. The effects of baryonic cooling, star formation and feedbacks are uncertain, but we argue that baryons will only increase the lensing cross-section by a moderate factor, ~2. We conclude that the low central value of σ_8 and $\Omega_{m,0}$ preferred by the WMAP three-year data may be too low to be compatible with observations if conventional assumptions of the background source population are correct

Simulations of Gravitational Lensing on High-z Supernovae

Premana Premadi and Hugo Martel

We use a series of ray-tracing experiments to determine the magnification distribution of high-redshift sources by gravitational lensing. We determine empirically the relation between magnification and redshift, for various cosmological models. We then use this relation to estimate the effect of lensing on the determination of the cosmological parameters from observations of high-z supernovae. We found that, for supernovae at redshifts z < 1.8, the effect of lensing is negligible compared to the intrinsic uncertainty in the measurements.

Magnetohydrodynamic Simulations of the Formation of Loop Structures in our Galactic Center

Mami Machida, R. Matsumoto, S. Nozawa, K. Takahashi, and Y. Fukui

X-ray and radio observations of the Galactic center region revealed the existence of loop-like structures. Fukui et al. (2006) discovered 300pc scale loops of dense molecular gas anchored to the Galactic nuclear gas disk. The height, width, and line of sight velocity of molecular loops are about 100pc, 300pc, and 100km/s, respectively. These loops may be created by the Parker instability. We carried out magnetohydrodynamic (MHD) simulations of the galactic center gas disk. In this simulation, we adopt Miyamoto and Nagai (1975) gravitational potential. The initial disk is assumed to have weak toroidal magnetic fields. We assume that the gas sound speed is about 30km/s. As the magneto-rotational instability grows, the disk becomes turbulent. Magnetic fields are amplified up to 10 micro-Gauss. We found that loop like structures are created by bouyancy. The loop size is about 600pc width, and 100-200pc height. The speed of downflows along the loop exceeds the sound speed, and consistent with the observed line-of-sight velocities of molecular loops.

Properties of the Structures formed by Parker-Jeans Instability

Young Min Seo, S. S. Hong, S. M. Lee, and J. Kim

We have modeled the Galactic ISM disk as a magnetized, isothermal, gaseous layer under simultaneous influences of the self and external gravities, and performed three dimensional MHD simulations of the Parker and Jeans instabilities in such layer. Perturbations of undular mode lead the ISM disk to bear out structures of two different scales. The Jeans gravitational instability is responsible for the larger one of the two, while the Parker is for the smaller one. Taking three combinations of self and external gravities, we have examined how the gravity combination would control physical properties of the resulting structures from the both instabilities. We have identified clumps from the simulation results and followed up their physical and geometrical properties as functions of time. Among the properties included are the mass, size, density, velocity dispersion, and various energetics of the clumps. These will be compared with the corresponding observational properties of interstellar clouds. The comparison will tell us how the giant molecular clouds and HI super-clouds have formed in the Galaxy. We will also discuss some problems stemming from the use of isothermal equation of state and the neglect of turbulence.

Instability of Self-gravitating Disks in Astrophysics

Chi Yuan and Hsiang-Hsu Wang

In galaxies or any disk systems in astrophysics, spirals commonly appear and may be identified as density waves. They can be created by internal or external disturbances, or by a self-induced mechanism. They are, however, not always stable, often developing into turbulence and chaos. The instability may be manifested as starburst rings or the chaotic sub-structure of spirals in observations. Shear instability (Rayleigh) and gravitational instability (Toomre), or a combination of both, are the two known instabilities happening in the astrophysical disk systems. Such instabilities also show up in the numerical simulations. Often they can be identified to be the two instabilities mentioned above. Sometime it is hard to tell. It is important to distinguish the real instability from the numerical ones in the numerical simulation of astrophysical disk problems. In this report, we will focus on this issue and present some of our thoughts and results.
The work is in parts supported by a grant from National Science Council, Taiwan NSC94-2752-M-001-002-PAE.

Gas Flow Induced by a Strong Bar Potential: Straight Dust Lanes Connecting to a Nuclear Starburst Ring

David Chien-Chang Yen, Lien-Hsuan Lin, and Chi Yuan

Galaxies with a major bar, such as NGC1300 and NGC1097, are characterized with a pair of straight dust lanes which connects to a central starburst ring. The flow field and the straight dust lanes can be reproduced by imposing a strong bar on a gaseous disk. In the simulation, we can see gas flow suddenly changes its direction upon entering the dust lanes, which are known as shocks, and continues to flow down the dust lanes along the leading edge of the bar. Results are sensitive to the strength of a bar potential and grid sizes. With proper choice of them, we can reproduce dust lanes, central starburst rings and outer spirals, exact as seen in the nearby barred galaxies. Strong bar potentials may lead to shear instability and develop chaotic sub-structures. It is another issue that we will discuss. In our numerical simulations, we use the Antares code which we have developed. It is a code which adopts Cartesian coordinates and uses the high-order Godunov scheme with unsplit flux calculated from the exact Riemann solver. It proves to be a better and effective tool for such problems. So far we have applied our numerical results to major-bar galaxies NGC1300 and the diamond-shaped double-ring galaxy NGC6782. Both are in excellent agreements with the observations.
The work is in parts supported by a grant from National Science Council, Taiwan, NSC95-2752-M-001-009-PAE.

Global SFR in Galactic Disks

Keiichi Wada and Colin Norman

The probability distribution functions (PDF) of density of the ISM in galactic disks and global star formation rate (SFR) are discussed. 3-D hydrodynamic simulations show that the PDFs in globally stable, inhomogeneous ISM in galactic disks are well fitted by a single log-normal function over a wide density range. Using the LN-PDF, we give SFR as a function of average gas density, a critical local density for star formation, and star formation efficiency. We find that the observed SFR in normal and starburst galaxies are well-fitted by the theoretical SFR in a wide range of the global gas density. Star formation efficiency for high density gas is 0.001-0.01 for normal spiral galaxies, and 0.01 - 0.1 for starburst galaxies. The LN-PDF and SFR proposed here could be applicable for modeling star formation on a kpc-scale in galaxies or numerical simulations of galaxy formation, in which the numerical resolution is not fine enough to describe the local star formation.

Global Simulations of Time Variabilities in Magnetized Accretion Disks

Ryoji Matsumoto and M. Machida

We carried out global three-dimensional magnetohydrodynamic (MHD) simulations of accretion disks. Numerical results indicate quasi-periodic reversals of mean azimuthal magnetic fields and sometimes show sawtooth-like oscillations of magnetic energy. The latter is correlated with the growth of one-armed (m=1) structure in accretion disks, which also generates high-frequency quasi-periodic oscillations (QPOs). We discuss the condition for the excitation of low-frequency QPOs and high frequency QPOs. We apply the numerical results to the galactic center black hole Sgr A*. We also present the results of numerical simulations including radiative cooling.

MHD Simulations of Flares and Jets in the Sun, Stars, and Accretion Disks

Kazunari Shibata

I would like to review MHD simulation studies in our group on flares and jets in the Sun, stars, and accretion disks, with emphasis on the role of magnetic reconnection.

The Evolution of Galaxies from Primeval Irregulars to Present-day Ellipticals

Masao Mori and Masayuki Umemura

Galaxy formation is believed to proceed in a bottom up manner, starting with the formation of small clumps of gas and stars that then merge hierarchically into giant systems. The baryonic gas loses thermal energy by radiative cooling and falls towards the centers of the new galaxies, while supernovae blow gas out. Any realistic model therefore requires a proper treatment of these processes, but hitherto this has been far from satisfactory. Here we report a simulation that follows evolution from the earliest stages of galaxy formation through the period of dynamical relaxation, at which point the resulting galaxy is in its final form. The bubble structures of gas revealed in our simulation (for times $<3 \times 10^8$ years) resemble closely high-redshift Lyman-α emitters. After 10^9 years, these bodies are dominated by stellar continuum radiation and then resemble the Lyman break galaxies, which are high-redshift star-forming galaxies. At this point, the abundance of heavy elements appears to be solar. After 1.3×10^{10} years, these galaxies resemble present-day ellipticals.

Formation of Galactic Warps in Triaxial Haloes

Sungsoo S. Kim, M. W. Jeon, and H. B. Ann

We investigate the formation of warps in triaxial haloes using N-body simulations. Triaxial haloes were represented by fixed external potentials in which self-gravitating discs were embedded. The density distributions of the haloes were modeled by triaxial modification of Hernquist models. We find that warps can develop in these models, and that the shape and persistence of warps depend sensitively on the halo triaxiality. Our simulation results are in agreement with those predicted by simple analytical models. We attribute the development of warps to the torque between a halo and a disc and that between the inner and outer regions of the disc.

Structured Red Giant Winds with Magnetized Hot Bubbles and the Dividing Line

Takeru K. Suzuki

By performing MHD simulations, we investigate mass loss of intermediate/low-mass main sequence and red giant stars. Alfven waves, which are excited by the photospheric perturbations due to the surface convections, travel outwardly and dissipate by nonlinear processes to accelerate and heat stellar winds. We dynamically treat these processes in open magnetic field regions from the photospheres to 25 stellar radii. When the star evolves to slightly blueward of the dividing line (Linsky & Haisch), the steady hot corona with temperature ~ 10^6 K, suddenly disappears. Instead, many hot (~ 10^6 K) and warm ($\gtrsim 10^5$ K) bubbles are formed in cool (T <~ 2 x 10^4 K) chromospheric winds because of thermal instability; the RGB star wind is not a steady stream but structured outflow. Mass loss rates of RGB stars largely vary in time because of many bubbles and blobs. The densities of the bubbles which are supported by the magnetic pressure can be kept low to reduce the radiative cooling so that the bubbles survive a long time. Even in the stars redward of the dividing line, hot bubbles intermittently exist, which can be sources of UV/X-ray emissions from hybrid stars.

Core Collapse And Supernova Explosion Of Massive Star Having Magnetic Field Inclined To The Rotation Axis

Hayato Mikami, Yuji Sato, Tomoyuki Hanawa, and Tomoaki Matsumoto

We show three-dimensional numerical simulations on the core collapse of a rotating massive star threaded by strong magnetic fields. The initial magnetic field is nearly uniform in the core and inclined by 60° with respect to the rotation axis. A typical model shows four outflows after the bounce. The first outflow is nearly spherical and is launched just after the core bounce. The last outflow is bipolar and parallel to the initial rotation axis. It is driven by the toroidal magnetic field induced by the rotation. Its launch is later when the initial magnetic field is weaker. The features of the outflow and remnant magnetic field depend on the inclination angle of the initial magnetic field.

The Virial Balance of Clumps and Cores in Molecular Clouds

Sami Dib, Jongsoo Kim, Andreas Burkert, Enrique Vazquez-Semadeni, Mohsen Shadmehri, and Thomas Henning

We study the virial balance of clumps and cores (CCs) in a set of three-dimensional numerical simulations of driven, MHD, isothermal molecular clouds (MCs). The simulations represent a range of magnetic field strengths in MCs from subcritical to non-magnetic regimes. We developed a clump-finding algorithm to identify CCs at different density threshold in the simulation box, and for each object, we calculate all the terms that enter the virial theorem in its Eulerian form. We also calculate, other quantities commonly used to indicate the state of gravitational boundedness of CCs such as the Jeans number J_c, the mass-to magnetic flux ratio μ_c, and the virial parameter a_{vir}. Our results suggest that: a) CCs are dynamical out-of-equilibrium structures. b) The surface energies are of the same order than their volume counterparts and thus are very important in determining the exact virial balance c) CCs can be either in the process of being compressed by the velocity field or of being dispersed. Yet, not all CCs that have a compressive velocity field at their boundaries are necessarily gravitationally bound. d) There is no one-to-one correspondence between the state of gravitational boundedness of a CC as described by the energy balance analysis (i.e., gravity versus other energies) or as implied by the classical indicators J_c, μ_c, and a_{vir}. In general, from the energy analysis, we observe that only the inner regions of the objects (i.e., the dense cores selected at high threshold levels) are gravitationally bound, whereas J_c and a_{vir} estimates tend to show that they are more gravitationally bound at the lowest threshold levels. g) We observe, in the non-magnetic simulation, the existence of a bound core with structural and dynamical properties that resemble those of the Bok globule Barnard 68 (B68). This suggests that B68 like cores can form in a larger molecular cloud and then be confined by the warm gas of a newly formed HII region, which can heat and rarefy the gas around the core, confine it, and extend its lifetime.

Dynamical Triggering of the Star / Molecular Cloud Formation around the Expanding HII Region and PDR

Takashi Hosokawa and Shu-ichiro Inutsuka

We probe the role of the expanding HII regions in various interstellar environments, focusing on the dynamical triggering of the star and molecular cloud formation. The dynamical evolution of the HII region, photodissociation region (PDR), and the swept-up shell has been analyzed by the numerical calculations of the radiation-hydrodynamics. Our calculations suggest that the expanding HII region is an efficient trigger of the star formation in the molecular cloud. The observational properties of some "collect and collapse" HII regions are successfully explained by our modeling. In the diffuse environment, on the other hand, the expanding HII region can compress the neutral medium to form the molecular clouds. We predict that the cold H_2 cloud without CO molecules will form in the shell, and have found the sign of this transitional gas phase in the recent observational data.

Fragmentation and Evolution of the First Core

Kohji Tomisaka and K. Saigo

We investigate the evolution of a rotating first core using three-dimensional hydro simulations. A barotropic equation of state is assumed to take account of the change in temperature during the evolution. Evolution of the first core is completely different depending on the rotation speed. The evolution is classified into three types with the rotation rate ω which is defined as the product of the angular rotation speed Ω and the free-fall time τ_{ff}. (1) When the rotation rate is about 10 times slower than that of the typical cloud cores ($\omega \lesssim 0.01$), the first core evolves similarly to a non-rotating cloud. The first core begins the second collapse after its mass exceeds 0.01-0.02 solar mass. The first core is short-lived as $\tau \sim 100$ years. (2) In the case of moderate rotation ($0.01 \lesssim \omega \lesssim 0.05$), the first core forms a centrifugally supported massive disk (about 0.1 solar mass). The first core is alive for several thousand years. Then, even after the second collapse, a remnant remains around a stellar core. (3) Assuming a rotation rate of $\omega \gtrsim 0.05$, which is often observed in NH3 and N2H+ cores, we found that the first core fragments into several pieces. In cases (2) and (3), a non-axisymmetric spiral mode grows after $T/|W|>0.27$. This spiral pattern extracts the angular momentum from the central part and induces further collapse. We will also discuss the observability of the rotating first core.

Driving Mechanism of the Outflow and Jet in the Star Formation Process

Masahiro Machida, S. Inutsuka, and R. Matsumoto

The stellar core formation and high-speed jets driven by the formed core are studied using three-dimensional resistive MHD nested grid simulations. Starting with a Bonnor-Ebert isothermal cloud rotating in a uniform magnetic field, we calculate the cloud evolution from the molecular cloud core to the stellar core. For comparison, we calculate two models: resistive and ideal MHD models. Both the resistive and ideal models have the same initial condition, but the former includes the dissipation process of magnetic field while the latter does not. The magnetic fluxes in the resistive MHD model are extracted from the first core during 10^{12} cm^{-3} < n < 10^{16} cm^{-3} by ohmic dissipation. Magnetic flux density of the formed stellar core in the resistive MHD model is 2 orders of magnitude smaller than that in ideal MHD model. Since magnetic braking is less effective in the resistive MHD model, a rapidly rotating stellar core (the second core) is formed. After stellar core formation, the magnetic field of the core is largely amplified, and high-speed (~ 45 km/s) jets are driven by the second core, which results in strong mass ejection. A cocoon-like structure around the second core also forms with clear bow shocks.

Protostellar Turbulence in Cluster Forming Regions

Fumitaka Nakamura and Zhi-Yun Li

Most, perhaps all, stars go through a phase of vigorous outflow during formation. We examine, through three-dimensional MHD simulation, the effects of protostellar outflows on cluster formation. We find that the initial turbulence in the cluster-forming region is quickly replaced by motions generated by outflows. The protostellar outflow-driven turbulence ("protostellar turbulence" for short) can keep the region close to a virial equilibrium long after the initial turbulence has decayed away. We argue that there exist two types of turbulence in star-forming clouds: a primordial (or "interstellar") turbulence and a protostellar turbulence, with the former transformed into the latter mostly in embedded clusters such as NGC 1333. Since the majority of stars are thought to form in clusters, an implication is that the stellar initial mass function is determined to a large extent by the stars themselves, through outflows that individually limit the mass accretion onto forming stars and collectively shape the environments (density structure and velocity field) in which most cluster members form.

Turbulence Driving and Cloud Formation in Galactic Spiral Arms

Woong-Tae Kim

We present dynamical evolution of gas flow across spiral arms in vertically stratified, self-gravitating, magnetized, galactic gas disks, using local numerical MHD simulations. The presence of a stellar spiral potential creates a spiral shock in the gas flow. Unlike in two-dimensional thin disks where spiral shocks are readily stationary, the shock fronts in vertically stratified disks never achieve a steady state, displaying large-amplitude flapping motions along the direction perpendicular to the shock. This shock flapping feed random gas motions that exceed a sonic value, suggesting that spiral shocks can be an important turbulence driver in disk galaxies. The non-steady flows associated with vertical spiral shocks appear to prevent coherent in-plane vortical structures from forming, suppressing the wiggle instability proposed for cloud formation in thin disks. On the other hand, spatially varying shear inside spiral arms still provides a favorable condition for magneto-Jeans instability to develop in a stratified disk. Consequently, spiral arms produce arm substructures including giant clouds and gaseous spurs, whose mean separations and masses are consistent with observations.

Dynamics of Multi-Phase Interstellar Medium

Shu-ichiro Inutsuka

Our understanding on the physical processes in the transition between warm neutral medium (WNM) and cold neutral medium (CNM) is dramatically increased in the last few years. In this talk we explain the basic property of thermal instability and the effect of magnetic field on it and analyze the propagation of a shock wave into WNM by taking into account radiative heating/cooling, thermal conduction, physical viscosity, and the magnetic field in one-, two-, and three-dimensional magnetohydrodynamical simulations. The results show that the thermal instability in the post-shock gas produces high-density cold cloudlets embedded in turbulent warm neutral medium. In the analysis of the complex dynamics of turbulent two-phase medium, we have found that the evaporating flow through the transition layer between cold and warm medium is unstable, which is analogous to the well-known Darrieus-Landau Instability of the flame front. We show our recent linear stability analysis of the transition layer, and discuss its role in the turbulence in two-phase medium. We also analyze the importance of ambipolar diffusion in producing moderately magnetized tiny cold cloudlets. The dynamical evolution driven by thermal instability in the post-shock layer is an important basic process for the transition from warm gases to cold gases, because the shock waves are frequently generated by supernovae in the Galaxy.

Statistical Properties of Density Fields in Isothermal Hydrodynamic Turbulent Flows

Jongsoo Kim and Dongsu Ryu

By performing numerical experiments for isothermal hydrodynamic turbulent flows, we study the statistical properties of density fields of them, such as power spectra, probability density functions, and core mass functions. The numerical resolution of the experiments goes up to 512^3 cells and the range of root-mean-square Mach numbers is from 1 to 10. As the Mach number increases, i) the slope of the density power spectrum becomes shallower, which is the consequence of the dominant filament and sheet structures in density fields of highly supersonic flows, and ii) the number of cores that are identified with a certain density threshold condition increases. We also find that the probability density function of isothermal gas densities in decay and driven turbulent flows is not necessary to follow a lognormal distribution. We will discuss the implications of our results on the observed spectral slopes of ionized and neutral gas components in the interstellar medium, and the theories of IMF and star formation.

MHD Turbulence and Particle Acceleration

Jungyeon Cho

Recently, there has been a significant breakthrough on the theory of magnetohydrodynamic (MHD) turbulence in a strongly magnetized medium. Perhaps the simplest form of turbulence in such a medium is Alfvenic MHD turbulence. In this talk I will focus on the physics of Alfvenic MHD turbulence. I will first review scaling relations of ordinary Alfvenic turbulence. Then I will talk about compressible MHD turbulence. Finally, I will discuss particle acceleration in MHD turbulence.

Self-Similar Evolution of Cosmic Ray Modified Shocks

Hyesung Kang

The evolution of cosmic ray (CR) modified shocks depends on complex interactions between the particles, magnetic field, and underlying plasma flow. In the kinetic equation approach to numerical study of CR acceleration at shocks, the diffusion-convection equation for the particle momentum distribution is solved along with suitably modified gasdynamic equations. It is required to follow a wide dynamic rang of length and time scales in such numerical simulations, since the diffusive shock acceleration (DSA) proceeds with diffusion length and time scales that increase with the particle momentum. The CR acceleration efficiency at such shocks can be obtained only through time-dependent integration from given initial states, because a CR modified shock is not a discontinuous structure and the CR acceleration is not instantaneous. We showed that the time dependent evolution of CR modified shocks becomes approximately self-similar, because the postshock variables including the CR pressure approach to time-asymptotic values and the shock structure stretches linearly with time. Based on the self-similarity, time asymptotic values of the CR acceleration efficiency are estimated as a function of shock Mach number from numerical simulation results of the DSA.

Particle Acceleration in Relativistic Shock Waves

Masahiro Hoshino

It is believed that the non-thermal particle acceleration as well as the plasma thermalization occurs in the neighborhood of collisionless shock front through the interaction of charged particles with the electrostatic and electromagnetic waves excited by a wide variety of plasma instabilities. The shock wave region is a rich repository of nonlinear plasma processes, and the simulation study by using particle-in-cell (PIC) code is now recognized to be useful for investigating plasma heating and particle acceleration seen in AGN jets, gamma-ray bursts, and pulsar wind nebula etc. We discuss the origin of high energy particles in the relativistic shocks by using PIC simulation. Specifically, we focus on several direct acceleration mechanisms such as surfing acceleration and wakefield acceleration.

General Relativistic MHD Simulations with Finite Conductivity

Shinji Koide, T. Kudoh, and K. Shibata

It is believed that relativistic jets from several kinds of objects in the universe are all formed by violent phenomena near the black holes. Among the proposed mechanisms, the magnetic mechanism of the jet formation becomes most promising because it may explain not only the acceleration but also the collimation of the jets. However, the distinct mechanism has not yet been shown. Here we report numerical results of jet formation enhanced by magnetic reconnection near a rapidly rotating black hole. To investigate the magnetic reconnection near the black hole, we have developed a general relativistic MHD simulation code including finite electric conductivity. The basic numerical method, tests, and preliminary results will be shown. We will also show a new result with appropriate equations of state covering the non-relativistic and relativistic regions.

Two-fluid Dynamics in Extremely Strong Magnetic Field

Yasufumi Kojima

We present numerical simulation of cold plasma consisted of positive and negative charged particles moving in the magnetosphere of strongly magnetized stars, such as pulsars and magnetars. The fluid velocity is relativistic in general, and the motion is significantly influenced by the electro-magnetic field, whose energy density is larger than the fluid one. The fluid motions as well as time-dependent Maxwell's equations are consistently calculated, and some numerical results are shown.

Magnetohydrodynamic Simulations of Collapsars

Shin-ichiro Fujimoto, Kei Kotake, Shoichi Yamada, and Masa-aki Hashimoto

We perform long-term, two-dimensional, magnetohydrodynamic simulations of collapsars, or, rapidly rotating magnetized stars whose core collapse to a black hole, in light of the collapsar model of gamma-ray bursts. For assumed angular velocity distributions and the uniform vertical magnetic field of the star before the collapse, we have investigated the formation of an accretion disk around a black hole, the jet production near the hole, and long-term evolution of the disk. We found that a quasi-steady disk is formed inside a surface of weak shock and cools through a neutrino radiation chiefly, after material reaches to the black hole with high angular momentum. We also found that jets are magnetically driven near the black hole.

Simulation of Relativistic Outflows in Astrophysics

Indranil Chattopadhyay and Dongsu Ryu

In astrophysics, relativistic fluids are encountered in accretion discs, astrophysical jets, GRBs etc. In almost in all of these cases, there are regions of transition either (a) from non-relativistic to relativistic bulk velocities and/or (b) from non-relativistic to relativistic temperatures. It has been shown earlier that the equation state of the fluid with fixed adiabatic index (γ) may produce significant errors in calculating flow variables in these transitional domains of fluids. We compare relativistic outflows described by generalized equation of state with those by the fixed γ equation of state, and show that the internal structure of such flows are quite different. We also show that the adiabatic index of such flows depends on the interaction with ambient medium, and therefore has important observational consequences.

Gas-kinetic Schemes for Astrophysical Flow Simulations

Kun Xu

In the 1st part, I will introduce the gas-kinetic scheme for the numerical solution of Navier-Stokes equations, especially for the accurate computation of high speed compressible heat conducting flows. Then, the method about the implementation of the gravitational forcing term in the flux function will be presented. For the gas-kinetic scheme, it has been done mainly through the consideration of particle acceleration when passing through cell interfaces. Any scheme which ignores or implements inaccurately the gravitational forcing term in the Riemann solution cannot sustain long time integration due to the weakly non-conservativeness in the total energy. In the 2nd part, I will discuss the gas-kinetic scheme for MHD equations and the numerical examples from one to three dimensional simulations will be presented.

An Efficient High Resolution Shock-capturing Scheme for Multi-dimensional Astrophysical flows

Cong Yu

Many problems at the forefront of theoretical astrophysics require the treatment of dynamical fluid behavior. We present an efficient high resolution shock-capturing hydrodynamic scheme designed to study astrophysical dynamical phenomena. We have implemented weighted essentially non-oscillatory (WENO) scheme to gain fifth order accuracy in space. HLLE approximate Riemann solver is used for flux computation at cell interface, which does not require spectral decomposition into characteristic waves and computationally friendly. For time integration we apply a third order total variation diminishing (TVD) Runge-Kutta scheme. Extensive testing and comparison with schemes that require characteristic decomposition are performed demonstrating the ability of our scheme to address challenging open questions in astrophysics.

Minimum Numerical Viscosity to Care the Carbuncle Instability

Tomoyuki Hanawa, H. Mikami, and T. Matsumoto

We have developed an MHD solver by modifying the Roe-type approximate Riemann solver. The carbuncle instability is suppressed by adding numerical viscosity which is designed to work only near the shock front. Our new solver detects shock waves and evaluates their strength from the spatial variation of the characteristic speeds of MHD waves. The viscosity to care the carbuncle instability is added only in the region where an MHD wave converges. The amount of the numerical viscosity is proportional to the convergence rate of the MHD wave, $|d\lambda_i/dx|$, where λ_i denotes the characteristic speed of the i-th wave. We show some numerical examples and discuss reasonability of the numerical viscosity.

A New Fast Algorithm in Computational Cosmology

Longlong, Feng

Within the framework of Multi-Resolution Analysis (MRA), we describe a new fast algorithm in computational cosmology. Central to this algorithm is to make decomposition of cosmic fields and operators in the MRA, and realize their discrete representations. For a spatial point process, we show that it can be equivalently described by a operation of a Toeplitz matrix on a vector, which is accomplished by making use of fast Fourier transformation. Through numerical experiments, we demonstrate the algorithm with some cosmological applications including measuring correlation functions, power spectra, counts-in-cells in large data sets and also computing gravitational potential in a N-body system. The numerical tests indicate that the algorithm developed here provides a useful and effective tool for tackle large data sets in computational cosmology.

SFUMATO: Self-gravitational MHD AMR Code

Tomoaki Matsumoto

A new numerical code, called SFUMATO, for solving self-gravitational magnetohydrodynamics (MHD) problems using adaptive mesh refinement (AMR) is presented. A block-structured grid is adopted as the grid of the AMR hierarchy. The total variation diminishing (TVD) cell-centered scheme is adopted as the MHD solver, with hyperbolic cleaning of divergence error of the magnetic field also implemented. The self-gravity is solved by a multigrid method composed of (1) full multigrid (FMG)-cycle on the AMR hierarchical grids, (2) V-cycle on these grids, and (3) FMG-cycle on the base grid. The multigrid method exhibits spatial second-order accuracy, fast convergence, and scalability. The numerical fluxes are conserved by using a refluxing procedure in both the MHD solver and the multigrid method. The several tests are performed indicating that the solutions are consistent with previously published results.

FIRST Project: Ground Challenge for Radiation Hydrodynamic Simulations

Masayuki Umemura and FIRST Project Team

We report the FIRST project, where the final goal is the elucidation on the origin of first generation objects in the Universe through large-scale radiation hydrodynamic simulations. For the purpose, we are developing a new heterogeneous PC cluster system composed of 240 nodes, where a special-purpose processor (Blade-GRAPE) for gravity calculations is embedded in each node. The theoretical peak speed is 38 Tflops (35 Tflops in special processors and 3 Tflops in host nodes). The project issupported by a Specially Promoted Research in Grants-in-Aid for Scientific Research over four years (2004～2007) with the budget of 319.9 million yen (US $ 2.7 million), approved by The Ministry of Education, Culture, Sports, Science and Technology (MEXT) in Japan.

Efficient Monte Carlo Radiative Transfer with SKIRT

Maarten Baes

I will present SKIRT, a fully 3D Monte Carlo code developed to study a dust radiative transfer in a variety of astrophysical environments. I shall discuss the basic ingredients of Monte Carlo radiative transfer and highlight the main advantages and disadvantages. Using the SKIRT code, I shall demonstrate how these disadvantages can be avoided nowadays by applying optimization techniques, such that Monte Carlo radiative transfer codes can be accurate, flexible, efficient and fast. I discuss some applications of SKIRT, ranging from circumstellar discs to dusty galaxies. In particular, I will discuss the effect of dust on the observed kinematics of dusty galaxies and present our new atlas of dusty spiral galaxy models that can be used as a tool to interpret images, FIR fluxes and SEDs of normal galaxies in the Local Universe.

A New Method for Treating the Energy Equation in SPH

Dimitris Stamatellos and A. P. Whitworth

We will present a new method to include the effects on radiative transfer in SPH hydrodynamic simulations (Stamatellos & Whitworth, in preparation). The method uses the density and gravitational potential of each particle to get an estimate of the local optical depth, which in turns regulates the heating and cooling timescale for each particle. The effects of H_2 dissociation, H ionisation, and opacity changes due to e.g. the sublimation of dust, plus the thermal inertia effects can all be captured at minimal computational cost. The SPH-RT implementation is only slightly slower than a traditional SPH method without radiative transfer, thus it is very efficient.

The SZ-Galaxy Relation

Jiawei Shao, Pengjie Zhang, Weipeng Lin, and Yipeng Jing

The thermal Sunyaev-Zel'dovich (SZ) effect directly measures the integrated thermal pressure of free electrons along the line of sight and thus contains invaluable information on the thermal state of the intergalactic medium (IGM) and intra-cluster medium (ICM). However, the redshift information is entangled in the projection along the line of sight. This deficit will severely degrade the power of the SZ effect to probe the thermal history of IGM and ICM. Fortunately, the SZ effect, as a tracer of the large scale structure, is correlated with distribution of galaxies, whose redshifts can be measured. By cross correlating the SZ effect with galaxies, the redshift information of the SZ effect and thus the thermal history of the IGM and ICM can be recovered. For this purpose, we will investigate the 3D thermal pressure-galaxy cross correlation, instead of the 2D SZ-galaxy cross correlation. We use a series of hydro simulations to calculate the SZ effect and the thermal pressure-mass cross correlation. We will populate the same simulations with galaxies using semi-analytical models and quantify the cross correlation between galaxies and the SZ effect. We show some very preliminary results.

The Dynamics of Galactic Globular Cluster NGC 6656

Chen Ding, Wang Jiaji, and Chen Li

Using three epoch HST WFPC2 images, we measured the relative proper motion of NGC 6656 with respect to the bulge and the internal velocity dispersion of the cluster. Combining the result of proper motion with the motion of the Sun, rotation of the Local Standard of Rest and radial velocity of the cluster, we derived the 3-dimensional motion of the cluster. Given the gravitational potential function of our Galaxy, the orbit of the cluster during the past 10 Gyr was calculated. From the results we found, NGC 6656 has a moderate eccentricity and relatively lower obliquity orbit and is near its perigalacticon now. Our work on the cluster stars suggests that the velocity dispersion in the core radius is larger than the dispersion measured earlier along the line of sight. Adopting the new fundamental parameters of the cluster, we calculate the M/L ratio of the cluster and found the value about 3.3 which is higher than the previous work. We adopt our result to test the FP relation of the globular clusters. A little deviation is found. More observations are needed to confirm the results presented here: longer time baseline can further improve the precision of the proper motion; a larger field will contain more cluster and field stars to give a more distinct separation.

Formation of Globurar Clusters under the influence of UV Radiation

Kenji Hasegawa and Masayuki Umemura

We explore the possibility that globular clusters (GCs) form within UV radiation fields. Since GCs consist of Pop II stars, it is expected that the formation of GCs are affected by Pop III stars. Also, the age distribution of GCs shows that a large portion of GCs formed after the cosmic reionization. Thus, it is likely that a lot of GCs formed under the UV background radiation field. To simulate the formation of GCs with UV radiation, we solve gas and dark matter dynamics in spherical symmetry, consistently incorporating the radiative transfer of UV photons and non-equilibrium chemical reactions regarding hydrogen molecules (H_2). In addition, the star formation from cooled gas component is included. As a result, it turns out that a gas cloud with infall velocity exceeding the sound speed keeps contracting even if the cloud is fully ionized. This contracting cloud is finally shielded against UV radiation and cools via H_2 cooling. In this case, the energy dissipation is considerably strong and eventually a compact star cluster forms at the center of diffuse dark matter halo. On the other hand, if there is no UV or very weak UV, a more diffuse star cluster forms since stars are born in earlier dynamical stage. We also simulate the long-term dynamical evolution of star clusters in the tidal field of host galaxy, using N-body technique. As a result, we find that in the former case, the diffuse dark matter halo is stripped away by tidal interaction with host galaxy, and a star cluster with a small amount of dark matter survives. The latter case leads to the formation of small galaxies like dwarf spheroidals. We find that star clusters formed in UV radiation are well consistent with the observed correlation between velocity dispersion and cluster mass.

The Response of Galactic Gas Disks to A Spiral Density-wave Potential

Hsiang Hsu Wang, C. Yuan, and David C. C. Yen

We revisit the classic problem of the response of the gas in a galactic disk to an imposed spiral density-wave potential of stellar origin. The results show the distinct difference between waves generated by resonance excitation and forced oscillation. To avoid the confusion of mixing these two types of waves, we systematically reduce the strength of the spiral potential or the force near the primary Lindblad resonances. So we can study the original problem of shock formation and star formation problem formulated by Roberts (1969). For the cases without self-gravitation of the gas disk, in addition to the primary doubly periodic shocks, the presence of the branch-like structures which correspond to the ultra-harmonic resonances is pronounced. On the other hand, once the self-gravitation is included, unlike the work of Chakrabarti et al. (2003), the sub-structures associated with the ultra-harmonics are not necessarily enhanced by the self-gravity. Their growth may be deteriorated by the growth of the primary shocks. Sub-structures other than those identified with the ultra-harmonics may result from shear instability of Rayleigh's kind or gravitational instability of Toomre's kind. They are responsible for the branches, feathers or chaotic sub-structures observed in nearby galaxies in far infra-red.
The work is in parts supported by a grant from National Science Council, Taiwan NSC95-2752-M-001-009-PAE.

Planet Migration in a Proto-planetary Disk

Hui Zhang, Chi Yuan, and Chien-Chang Yen

We present the results of numerical simulations of the migration of a Jovian planet embedded in a self-gravitating proto-planetary disk. The Antares code we have developed is adopted in the calculations. It is a 2-D Godunov code based on the exact Reimann solution for isothermal or polytropic gas, featured with non-reflecting boundary conditions and Poisson solver for non-periodic boundary conditions. We use the Cartesian coordinate version of the code to avoid the well-known problem of the inner boundary. To carry out the calculation, however, a softening length is assigned to the central star. Normally the planet would migrate through all three types of migration phases, from Type I (embedded) to Type III (presence of horseshoe configuration) to Type II (forming a clear gap). Sometime Type III will re-appear after Type II phase. We find that the rapid migration in Type I and Type III is associated with the net negative torque within the Roche lobe of the planet, which accounts for more than 60% of the total torques the planet experiences. When the gap forms (Type II), hence matter in the lobe is drastically depleted, the planet will migrate slowly. We also notice that the self-gravity of the disk will change planet's migration rate and enhance its eccentricity. These effects are more pronounced after the gap is well formed.
The work is in parts supported by a grant from National Science Council, Taiwan NSC94-2752-M-001-002-PAE.

The Structure of Accretion Disks Formed by Merging of White Dwarfs

Toshinao Shioya, T. Sano, T. Tsuribe, and H. Takabe

The coalescence of two white dwarfs in a close binary system is investigated using hydrodynamical simulations. The Godunov Smoothed Particle Hydrodynamics method is adopted for the calculations. We perform various models of binary systems with different masses and mass ratios of the white dwarfs. As a result of the coalescence, an accretion disk is formed around the primary star. The characteristic quantities of the disks, such as the temperature and rotation profile, are found to be independent of the initial binary parameters. We also discuss the subsequent evolution of the accretion disk and the possibility of Type Ia supernova explosion from merging of two white dwarfs.

Long Term Simulations Of Astrophsical Jets; Energy Structure and Quasi-Periodic Ejection

Ahmed Ibrahim and Kazunari Shibata

We have performed self-consistent 2.5-dimensional nonsteady MHD numerical simulations of jet formation as long as possible, including the dynamics of accretion disks. Although the previous nonsteady MHD simulations for astrophysical jets revealed that the characteristics of nonsteady jets are similar to those of steady jets, the calculation time of these simulations is very short compared with the time scale of observed jets. Thus we have investigated long term evolutions of mass jet velocity, mass accretion rate, mass outflow rate, and various energy flux. We found that average Poynting flux is dominant over both kinetic energy flux and enthalpy flux especially when initial magnetic field is strong. The radial dependences of different energies reveal that the main source of collimation comes from the pinching by toroidal field. The ejection of jet is quasi-periodic and the periodicity of the jet can be related to the time needed for the initial magnetic field to be twisted to generate toroidal filed. We compare our results with both the steady state theory and previous 2.5-dimensinal nonsteady MHD simulations. Then time averaged velocity of jets $V_{\rm ave}$ are 0.1 V_k and 0.1 $V_{z\ \rm max}$, where V_k is the Keplerian velocity at $(r, z) = (1, 0)$ and $V_{z\ \rm max}$ is the maximum velocity of jet. Nevertheless, the characteristics of our simulations are consistent with those of steady solution and previous short term simulations in that the dependences of the time averaged velocity $V_{z\ \rm ave}$ and mass outflow rate $dM_{\rm ave}$ on the initial magnetic field strength are approximately $dM_{\rm ave} \sim B_0$ and V_z ave $\sim B_0^{1/3}$.

Evidence for Episodic Particle Acceleration in M87 Jet

Chun-Cheng Wang and Yao-Quan Chu

We present numerical analysis of the multi-waveband Spectral Energy Distribution (SED) of M87 jet. The results in the jet nucleus and 8 kpc scale knots suggest there is systematic deviation off standard synchrotron spectrum models, i.e. KP and CI models. This provides evidence of episodic particle acceleration in large-scale jet of M87. Our results are supported by latest X-ray observations of a large sample of BL Lac objects, which are argued to be the same nature as FR I radio galaxies (e.g. M87) within the unified scheme of radio-loud AGNs.

Numerical Simulations on the Dynamical Evolutions of the Supernova Remnants near the Edges of the Molecular Clouds

WanKee Cho, Jongsoo Kim and Bon-Chul Koo

We have carried out 3-D numerical simulations on the dynamical evolution of supernova remnants near the edges of large dense clouds to understand the break-out morphology SNRs. We vary the depth of SN explosion within the cloud and also the density contrast between the cloud and the intercloud medium which are in the pressure equilibrium. We find a power-law relationship between the SNR radius and the age. The closer to the edge of the cloud the SN explodes and the bigger the density contrast is, the exponent converges to 3/4 toward the intercloud medium and to 3/5 in the opposite limit. We carry out a higher (1024^3) resolution simulation for the case when the SN explodes at 2.5 pc from the cloud edge. We find a clumpy structure in the shell and colliminated gas flow toward the intercloud medium. We explore the origin of these structures.

Three-dimensional MHD Simulations of Magnetized Molecular Cloud Fragmentation with Turbulence and Ion-neutral Friction

Takahiro Kudoh and Shantanu Basu

We perform a 3D-MHD simulation of a self-gravitating isothermal gas layer that is initially penetrated by a uniform magnetic field. The strength of the initial magnetic field is such that the cloud is slightly sub-critical. In this system, we input random super-sonic turbulence initially. Ion-neutral friction is also introduced in the magnetized gas so that the magnetic diffusion allows gas to go across the magnetic field and form self-gravitating cores. We found that the time scale of core formation is on the order of the 10^6 years, which is faster than the usual magnetic diffusion time (10^7 years) estimated from the initial condition. Our result is consistent with the results of 2D-MHD simulations by Li & Nakamura (2004).

Interstellar Turbulence Driving by Galactic Spiral Shocks

Chang-Goo Kim, Woong-Tae Kim, and Eve C. Ostriker

Spiral shocks are potentially a major source of turbulence in the interstellar medium. To address this problem quantitatively, we use numerical simulations to investigate gas flow across spiral arms in vertically stratified, self-gravitating, magnetized models of galactic disks. Our models are isothermal, quasi-axisymmetric, and local in the quasi-radial direction while global in the vertical direction. We find that a stellar spiral potential perturbation promptly induces a spiral shock in the gas flow. For vertically stratified gas disks, the shock front in the radial-vertical plane is in general curved, and never achieves a steady state. This behavior is in sharp contrast to spiral shocks in two-dimensional(thin) disks, which are generally stationary. The non-steady motions in our models include large-amplitude quasi-radial flapping of the shock front. This flapping feeds random gas motions on the scale of the vertical disk thickness, which then cascades to smaller scales. The induced gas velocity dispersion in quasi-steady state exceeds the sonic value for a range of shock strengths, suggesting that spiral shocks are indeed an important generator of turbulence in disk galaxies.

Numerical Simulations of Relativistic Expansion of Magnetic Arcades in Magnetars

Eiji Asano, H. Takahashi, and R. Matsumoto

According to a model of SGR outbursts proposed by Thompson and Duncan (2001), we simulated the relativistic expansion of magnetic arcades anchored to the surface of a magnetar. We assumed axial symmetry and applied relativistic MHD code and relativistic force-free code based on the HLL scheme. The force-free code is suitable for studying magnetically dominated relativistic plasma. When the footpoints of the magnetic arcade are twisted by the shear motion, magnetic loops expand in radial direction. Magnetic reconnection taking place in the expanding arcade creates relativistically moving plasmoids. We also discuss the particle acceleration due to magnetic reconnection and due to shock waves generated ahead of the expanding magnetic arcades.

Particle Acceleration by Relativistic Expansion of Magneitc Arcades

Hiroyuki Takahashi, E. Asano, and R. Matsumoto

As a model of SGR outbursts, Thompson & Duncan(2001) proposed a magnetic arcade model. Like a solar flares, Magnetic arcades expand and its energy is converted into plasmas. Asao et al. carried out 2.5 dimensional relativistic force free simulation and confirmed that current sheets are formed inside the arcades. We concentrated on this current sheets and carried out 2.5 dimensional relativistic particle simulation(PIC). We report the result and discuss how much energy of shear motion is converted into particle energy.

Behaviour of Dissipative Accretion Flows around Black Holes

Santabrata Das

We investigate the behaviour of dissipative accreting matter close to a black hole as it provides the important observational features of galactic and extra-galactic black holes candidates. We find the complete set of global solutions in presence of viscosity and synchrotron cooling. We show that advective accretion flow can have standing shock wave and the dynamics of the shock is controlled by the dissipation parameters (both viscosity and cooling). We study the effective region of the parameter space for standing as well as oscillating shock. We find that shock front always moves towards the black hole as the dissipation parameters are increased. However, viscosity and cooling have opposite effects in deciding the solution topologies. We obtain two critical cooling parameters that separate the nature of accretion solution.

Optimization of SPH for Numerical Simulation of Subcluster Acquisition in Formation of Galaxy Clusters

Takuya Akahori

We have investigated thermal evolutions of intracluster hot gas from a view point of the core size. In the observed core-size distribution there exist huge-core clusters which deviate strongly from the self-similar relation. A possible origin of such huge cores may be acquisitions of sub-group of galaxies (or subcluster mergers). In order to clarify the effects of these drastic events on core sizes, we are preparing a combined SPH + N-body code for hydrodynamical simulations. Critical physical processes of interest are the propagation of shock and its dissipation. Thus, first of all, we examine the detailed behavior of numerical viscosity in SPH, and optimize our code. We considered the propagation of spherical Taylor-Sedov blast waves and the acquisition of subclusters. We confirmed that the standard Monaghan-Gingold viscosity tends to exaggerate the viscous heating, while the signal viscosity provides relatively reasonable results. The viscous limiter do not always improve the numerical viscosity, especially for limited particle simulations.

P3MSPH-GRAPE Simulations with FIRST Cluster

Tamon Suwa, Masayuki Umemura, and FIRST Project Team

In order to simulate self-gravitating systems with high performance, we are developing a cluster system "FIRST" in the University of Tsukuba. FIRST consists of 240 node computers and each node has 2 CPUs and 1 special purpose board called "Blade-GRAPE". Blade-GRAPEs are designed to calculate gravitational interactions directly and the peak speed of one Blade-GRAPE is 136.8 GFLOPS. FIRST is very suitable for astrophysical simulations, since Blade-GRAPE accelerate the calculation of gravitational force, which is very heavy part of simulations in many cases. To perform large-scale simulations on cosmological structure formation with FIRST, we have developed a parallel P3MSPH-GRAPE code. Using this code we measure the performance of FIRST system and report the results, e.g. speedup of gravity calculation by Blade-GRAPE, parallel efficiency, and communication overhead. We also present some scientific results.

Development of MHD-GRAPE Code for FIRST Simulator

Yoshiaki Kato and Masayuki Umemura

We present our recent development of magnetohydrodynamics (MHD) code with self-gravity for FIRST simulator, which is HMCS-E (Heterogeneous MultiComputer System-Embedded) cluster system with GRAPE located in center for compuational sciences at University of Tsukuba. MHD solver is based on Modified Lax-Wendroff scheme and the self-gravitational force of fluid is solved by direct summation (GRAPE). Our code can be applicable to a variety of self-gravitating MHD system such as interstellar mediums, star forming regions, and massive accretion disks. By using FIRST simulator, our purpose is to elucidate the evolution of cosmic magnetism.

Hydrodynamics of Molten Droplet in Millimeter Scale

Hitoshi Miura, Taishi Nakamoto, and Masao Doi

Millimeter-sized, spherical silicate grains abundant in chondritic meteorites, which are called as chondrules, are considered to be a strong evidence of the melting event of silicate dust particles in the proto-planetary disk. One of the most plausible scenarios is that the chondrule precursor dust particles are heated and melt in the high-velocity rarefied gas flow (shock-wave heating model). The hydrodynamics of the molten silicate dust particles in the gas flow is very attractive issues: the internal flow tends to homogenize the chemical/isotopic abundances in the droplet, the surface deformation would relate to the external shapes of chondrules, the fragmentation by the gas drag force might determine the maximum sizes of chondrules, and so forth. The notable feature that is not seen in general astrophysical hydrodynamics is the incompressibility of the molten droplet. Therefore, we have to consider the multi-phase fluids (incompressible droplet and compressible ambient region). We developed the three-dimensional hydrodynamic code and simulated the hydrodynamics of millimeter-sized and incompressible molten silicate dust particles in the rarefied nebula gas flow. In the meeting, we plan to introduce the shock-wave heating scenario for chondrule formation and how interest the molten droplet hydrodynamics is.

Dynamical Transport of Asteroid Fragments from the nu6 Resonance

Takashi Ito and Renu Malhotra

A large disruption in the main asteroid belt can cause a large flux, an "asteroid shower", on the terrestrial planets. We quantitatively examine the hypothesis that such an event was the cause of the lunar late heavy bombardment. We performed numerical integrations of many test particles starting in the vicinity of the nu6 secular resonance in the main asteroid belt. The purpose of these integrations is to calculate, for each of the terrestrial planets, the collision probability of asteroids coming from an asteroid break-up event in the inner part of the main belt. Compared with previous studies, we simulate nearly two orders of magnitude larger number of particles, and we include the orbital effects of all the eight major planets. We also numerically examined in detail the orbital evolution of asteroid fragments once they enter the Earth's activity sphere, including the effect of the Earth-Moon orbit. We obtained the collision probability, the distributions of impact velocities, impact positions, and impact angles of asteroid fragments on the Moon.

Application of Picard-Chebyshev Method to Orbital Dynamics

Hideyoshi Arakida, T. Ito, and T. Fukushima

We apply Picard-Chebyshev method to the orbital motion. First, we deal with Kepler motion and examine the efficiency of this method. And then, we show the results of integration of three body problem. We also investigate the vectorization/parallelization of this method.