8th Korean Astrophysics Workshop on

Astrophysics of High-Beta Plasma in the universe

November 10-13, 2014

ShineVille Resort, Jeju Island, Korea

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Scientific program

(40 min talk = 30 min of presentation + 10 min discussion)
(30 min talk = 25 min of presentation + 5 min discussion)
(20 min talk = 15 min of presentation + 5 min discussion)

November 10, 2014 (Monday)

8:30 – Registration
9:00 – 9:10 Opening

Morning Session: Observation of the intracluster medium – T. Kitayama

9:10 – 9:50 **Luigina Feretti**: Magnetic fields measurements and future (including review)
9:50 – 10:30 **Simona Giacintucci**: Statistics of radio minihalos and high-resolution SZ observations of cluster cool cores.

10:30 – 10:50 Coffee break

10:50 – 11:30 **Gabriele Giovannini**: Non Thermal Emission in Galaxy Clusters and Beyond
11:30 – 12:00 **Huub Rottgering**: Update of LOFAR observation of radio relics in clusters of galaxies

12:00 – 12:30 Discussion – **H. Rottgering**

12:30 – 2:00 Lunch break

Afternoon Session: Observation of the intracluster medium – L. Feretti

2:00 – 2:40 **Reinout J. van Weeren**: Particle acceleration at radio relics
2:40 – 3:20 **Maxim Markevitch**: X-ray constraints on microphysics of the intracluster plasma (including review)

3:20 – 4:00 Coffee break

4:00 – 4:40 **Hiroki Akamatsu**: Suzaku X-ray observations of radio relics in clusters of galaxies
4:40 – 5:20 **Daniel Wik**: The NuSTAR Galaxy Cluster Program: Latest Results

5:20 – 5:50 Discussion – **M. Markevitch**

November 11, 2014 (Tuesday)

Morning Session: Observation of the ICM – **R. van Weeren**

9:00 – 9:40 **Olaf Reimer**: Gamma-ray emission from galaxy clusters: Are we getting there soon? (including review)

9:40 – 10:20 **Tetsu Kitayama**: Prospects of galaxy cluster studies by ASTRO-H and ALMA

10:20 – 11:00 Coffee break

11:00 – 11:40 **Andra Stroe**: Challenging theory: low and high frequency radio spectral study of the Sausage cluster

11:40 – 12:10 Discussion – **O. Reimer**

12:00 – 2:00 Lunch break

Afternoon Session: Turbulence, waves, and shocks in the interplanetary medium – **M. Hoshino**

2:00 – 2:40 **T. W. Jones**: ICMs and the IPM: Birds of a Feather? (including review)

2:40 – 3:20 **Lynn B. Wilson**: Collisionless shocks in the interplanetary medium (lecture)

3:20 – 4:00 **Mitsuo Oka**: Electron acceleration at shocks in the interplanetary medium

4:00 – 4:30 Coffee break

4:30 – 5:10 **Peter Yoon**: Whistler waves and electron acceleration/heating in the planetary magnetospheres and interplanetary medium

5:10 – 5:50 **Lynn B. Wilson**: Wave-particle interactions at interplanetary shock waves

5:50 – 6:20 Discussion – **P. Yoon**

November 12, 2014 (Wednesday)

Morning Session: Turbulence, magnetic fields and particle transport- S. Oh

9:00 – 9:40 **Jungyeon Cho:** Magnetic fields in the large-scale structure of the universe: primordial or astrophysical?
9:40 – 10:00 **Hyunju Yoo**: Effects of Multiple-scale Driving on Turbulence Statistics
10:00 – 10:20 **Kiwan Park**: Influence of small scale magnetic energy and helicity on the growth of large scale magnetic field

10:20 – 10:40 Coffee break

10:40 – 11:20 **Peter Yoon**: Plasma turbulence and particle acceleration (lecture)
11:20 – 12:00 **Siming Liu**: Turbulence and stochastic particle acceleration in high-beta plasmas of SNRs

12:00 – 12:30 Discussion – **T. W. Jones**

12:30 – 2:00 Lunch break

Afternoon Session: Turbulence, magnetic fields and particle transport – G. Giovannini

2:00 – 2:40 **Gianfranco Brunetti**: Turbulence and particle acceleration mechanisms in galaxy clusters (including review)
2:40 – 3:20 **Francesco Miniati**: Cosmological simulation of time dependent intracluster turbulence: insights on stochastic acceleration and the impact of microphysics
3:20 – 3:40 **Masahiro Hoshino**: Particle Acceleration and Angular Momentum Transport by Magneto-Rotational Instability in Kinetic Accretion Disks

3:40 – 4:10 Coffee break

4:10 – 4:50 **Christoph Pfrommer**: Cosmic ray feedback in galaxies and cool core clusters
4:50 – 5:30 **S. Peng Oh**: Cosmic Ray Transport and Heating in the Intracluster Medium

5:30 – 6:00 Discussion – **G. Brunetti**

6:30 – Banquet

November 13, 2014 (Thursday)

Morning Session: Shocks and particle acceleration – L. Wilson

9:00 – 9:40 **Dongsu Ryu**: Intracluster shock waves in simulations (including review)
9:40 – 10:20 **Sam Skillman**: Particle acceleration at structure formation shocks in the intracluster medium

10:20 – 10:50 Coffee break

10:50 – 11:30 **Anders Pinzke**: Reacceleration of Cosmic Rays in the Intra-Cluster Medium
11:30 – 12:00 **Hyesung Kang**: Radio Synchrotron Emission From Weak Spherical Shocks

11:00 – 12:30 Discussion **- D. Ryu**

12:30 – 2:00 Lunch break

Afternoon Session: Shocks and particle acceleration – H. Kang

2:00 – 2:40 **Anatoly Spitkovsky**: Particle acceleration and field generation in high-beta plasmas: PIC simulations (including review)
2:40 – 3:20 **Masahiro Hoshino**: Electron acceleration and reconnection at a high Mach number shock
3:20 – 4:00 **Tsunehiko Kato**: Particle Acceleration in Quasi-Parallel High-Mach-Number Shocks

4:00 – 4:30 Coffee break

4:30 – 5:10 **Damiano Caprioli**: Hybrid simulations of ion acceleration at shocks
5:10 – 5:40 **Xinyi Guo**: Non-Thermal Electron Acceleration in Low Mach Number Shocks
5:40 – 6:00 **Jaehong Park**: Diffusive shock acceleration of cosmic-ray ions and electrons in non-relativistic high Mach number quasi-parallel shocks

6:00 – 6:30 Discussion **- A. Spitkovsky**

6:30 - Closing

Nov. 10: Morning

Magnetic fields measurements and future

Luigina Feretti

INAF Istituto di Radioastronomia, Italy

The origin and evolution of magnetic fields in the Universe is one of the most fascinating and currently unsolved problems in astrophysics. The existence of large-scale fields, in particular, raises several problems because of the need of amplification mechanisms acting with large efficiency on large scales. Clusters of galaxies, being the largest systems in the Universe, represent an ideal laboratory to test theories for the origin of extragalactic magnetic fields. A significant breakthrough in the study of magnetic fields will be provided by the Square Kilometer Array, the major radio telescope in the 21st century. It will produce transformational science in many different fields of Astrophysics. I will review the current knowledge about cluster magnetic fields and the contribution from Square Kilometer Array to these studies.

Nov. 10: Morning

Statistics of radio minihalos and high-resolution SZ observations of cluster cool cores

Simona Giacintucci

University of Maryland, USA

Minihalos are rare diffuse radio sources found in some cluster cores. It has been proposed that gas sloshing may be responsible for the acceleration of the radio-emitting electrons. I will present results of a statistical study of the minihalo properties and their correlation with the X-ray properties of their cluster hosts. In particular, minihalos are found in almost all massive clusters with dense, sloshing cool cores. I will also present results of the first high angular resolution SZ observations of two extreme cool cores, RXCJ1504 and ZW1346, with CARMA. Unexpected SZ structure has been revealed in both cores.

Nov. 10: Morning

Non Thermal Emission in Galaxy Clusters and Beyond

Gabriele Giovannini

University of Bologna & INAF Istituto di Radioastronomia, Italy

I will present and discuss observational evidences on the presence of non-thermal diffuse emission in low mass clusters and in regions beyond galaxy clusters. The presence of radio emission on such a large scale allows to expand our knowledge of magnetic fields from clusters to filaments. This will be a fundamental step to understand the origin and properties of cosmological scale magnetic fields. In more detail I would like to discuss the peculiar diffuse radio source 0917+75 identified with a galaxy filament with no detected X-ray emission.

Nov. 10: Morning

Update of LOFAR observation of radio relics in clusters of galaxies

Huub Rottgering

Leiden Observatory, Netherlands

Nov. 10: Afternoon

Particle acceleration at radio relics

Reinout J. van Weeren

Harvard-Smithsonian Center for Astrophysics, USA

In the outskirts of some merging galaxy clusters elongated Mpc-size radio sources are found, so-called radio relics. The observed synchrotron radiation from these relics directly shows that magnetic fields and relativistic particles must be present in the ICM. The main scenario is that shocks, generated by merger events, accelerate particles to relativistic energies via the DSA mechanism. Some radio and X-ray observations provide support for this scenario. However, the Mach numbers of these cluster merger shocks are low and DSA is believed to be very inefficient in this case. The presence of bright radio relics is therefore puzzling. This could indicate that some other form of acceleration, or re-acceleration takes place. Another possibility is that the DSA mechanism is not well enough understood at low Mach number shocks. In this talk I will present results from radio and X-ray observations that show some unusual properties of relics, suggesting that the origin of relics is probably more complex than initially thought.

Nov. 10: Afternoon

X-ray constraints on microphysics of the intracluster plasma

Maxim Markevitch

NASA Goddard Space Flight Center, USA

Nov. 10: Afternoon

Suzaku X-ray observations of radio relics in clusters of galaxies

Hiroki Akamatsu

SRON, Netherlands

Based on the framework of the hierarchical structure formation theory, clusters of galaxies grow though merging event with smaller objects and accretion flows from large scale structure filaments. The thermalisation history of the ICM contains instructional information of the comic baryons. In particular, merging event between massive clusters of galaxies is one of an energetic event in the Universe since the Big Bang, which release an enormous energy. These gravitational energy convert into a heating of Intra- Cluster Matter (ICM) and particle acceleration by shocks and via the mechanism of diffusive shock acceleration. We performed systematic X-ray studies of 7 radio relic region in 5 merging clusters (e.g., Akamatsu & Kawahara 2013, Akamatsu et al. 2013). In the 5 radio relics, we confirmed significant temperature drop across the relic. It strongly indicates that presence of a shock front at radio relic. The Mach number from the measured temperature drop spans M=1.5-3. These values are almost consistent with the Mach number from Radio observations. We will also report recent our activities.

Nov. 10: Afternoon

The NuSTAR Galaxy Cluster Program: Latest Results

Daniel Wik

NASA Goddard Space Flight Center & Johns Hopkins University, USA

Efforts to characterize the hard (>10 keV) X-ray emission from galaxy clusters have historically been hampered by a lack of observatories with imaging capabilities. As the first orbiting observatory with mirrors able to focus >10 keV X-rays, NuSTAR makes possible the most sensitive searches yet for inverse Compton emission associated with radio halos and relics and tight constraints on the temperatures of shocked regions. I will review the current status of NuSTAR's Cluster Working Group effort to analyze extensive observations of the Bullet Cluster, the Coma Cluster, and Abell 2256 and summarize the physical implications for state of the intracluster medium in merging galaxy clusters.

Nov. 11: Morning

Gamma-ray emission from galaxy clusters: Are we getting there soon?

Olaf Reimer

University of Innsbruck, Austria

Nov. 11: Morning

Prospects of galaxy cluster studies by ASTRO-H and ALMA

Tetsu Kitayama

Toho University, Japan

The ASTRO-H observatory will achieve the X-ray spectral resolution better than 7eV required to measure velocities of intracluster plasma, whereas ALMA will resolve the thermal Sunyaev-Zel'dovitch effect from the same plasma with an angular resolution of 5 arcsec, both for the first time. I will discuss prospects of studying dynamics of galaxy clusters by these instruments based on detailed feasibility studies.

Nov. 11: Morning

Challenging theory: low and high frequency radio spectral study of the Sausage cluster

Andra Stroe

Leiden Observatory, Netherlands

The most extreme clusters mergers can produce massive travelling. Giant radio relics form at these shock fronts, where accelerated electrons emit synchrotron radiation. The Sausage cluster hosts an extraordinary Mpc-wide, narrow radio relic with undisturbed morphology tracing a 4.6 Mach number shock. In order to fully explore such a unique laboratory, we carried out the widest radio frequency analysis of the Sausage radio relic, spanning from 150 MHz to 16 GHz with GMRT, WSRT and AMI. We present index and curvature maps pinpointing spectral trends conclusive for diffusive shock acceleration of relativistic particles and test injection models such as the Jaffe-Perola, Kardashev-Pacholczyk and Tribble. However, our recent 16 GHz AMI observation challenge the simple picture of electrons ageing in a uniform magnetic field behind a simple shock front: the low-frequency (<2 GHz) spectrum of the relic is well represented by a power-law, but it clearly steepens towards 16 GHz. This surprising high-frequency spectral steepening suggests that the continuous injection relic formation model, which has been widely used in the literature to explain the formation of radio relics, needs to be revisited.

Nov. 11: Afternoon

ICMs and the IPM: Birds of a Feather?

T. W. Jones

University of Minnesota, USA

Intracluster media (ICMs) and the interplanetary medium (IPM) are fully ionized, weakly collisional plasmas. Both are moderately turbulent, possess magnetic fields of roughly comparable strength, contain weak-to-moderate strength shocks and accelerate super-thermal particles. At the same time, their physical length scales, temperatures, densities and pressures differ by substantial factors. It is an important question whether their similarities are sufficient that insights obtained from one can help understand the other. In particular, the IPM is available for detailed in situ, time dependent studies, while ICMs are very remote, stationary on human time scales and generally difficult to study. In this talk I will lay out the case that the IPM can offer lessons of value to the study of ICMs.

Nov. 11: Afternoon

Collisionless shocks in the interplanetary medium

Lynn B. Wilson

NASA Goddard Space Flight Center, USA

Nov. 11: Afternoon

Electron acceleration at shocks in the interplanetary medium

Mitsuo Oka

UC Berkeley, USA

Nov. 11: Afternoon

Whistler waves and electron acceleration/heating in the planetary magnetospheres and interplanetary medium

Peter Yoon
University of Maryland, USA

Among the first discoveries of the near-Earth space environment at the dawn of the space exploration in the 1960s was the radiation (or Van Allen) belt. Most recent observations by NASA's Van Allen probes, which were launched recently to re-investigate the Earth's radiation belt, are showing oblique whistlers with amplitudes of the order of 10% to the background magnetic field. Recent works by the present author showed that coherent oblique whistlers of such amplitudes lead to efficient acceleration and heating of electrons to relativistic energies. In the interplanetary medium it is well known that the electrons of solar origin feature non-thermal velocity distribution. The plasma environment in the interplanetary medium is also replete with large-amplitude electromagnetic turbulence, which includes intermediate-frequency whistler turbulence. The author's recent work demonstrates that these incoherent whistler waves are capable of generating the observed non-thermal electron velocity distribution function. This talk will review the wave-particle interaction of both types of coherent and incoherent whistler waves with relativistic electrons in both the magnetospheric environment and interplanetary medium.

Nov. 11: Afternoon

Wave-particle interactions at interplanetary shock waves

Lynn B. Wilson
NASA Goddard Space Flight Center, USA

Collisionless shock waves are a topic of great interest in multiple fields of study from lab plasmas to astrophysics. Shock waves are arise when a nonlinearly steepening wave manages to form a stable discontinuity through the irreversible transformation of the free energy, or energy dissipation, available in the change in bulk flow kinetic energy across the shock to some other form (e.g., heat). In a regular fluid (e.g., Earth's atmosphere), shock initiation can occur because binary particle collisions provide sufficient energy dissipation to balance nonlinear wave steepening. Every since the prediction of collisionless shocks nearly 60 years ago, the debate surrounding possible energy dissipation mechanisms has been a subject of great debate. The energy dissipation mechanisms proposed are: (1) quasi-static field effects [e.g., cross-shock potential]; (2) particle reflection; (3) dispersive radiation; and (4) wave-particle interactions. However, recent results show that the first three mechanisms are all part of pathways that ultimately end with this "black box" mechanism I refer to as "wave-particle interactions." Therefore, in this talk I will focus on wave-particle interactions and present recent results showing that they are capable to regulating the macroscopic structure of collisionless shock waves.

Nov. 12: Morning

Magnetic fields in the large-scale structure of the universe: primordial or astrophysical?

Jungyeon Cho

Chungnam National University, Korea

In usual astrophysical circumstances, magnetic diffusivity is very low and, as a result, magnetic fields lines are tied to fluid elements. Therefore random turbulence motions can efficiently stretch magnetic field lines, which results in amplification of magnetic field. This turbulence dynamo is believed to play important roles in the origin of cosmic magnetism. For turbulence dynamo, a weak seed magnetic field is required. If the seed field has a cosmological origin, it could be regarded as uniform (or homogeneous) at the scale of galaxy clusters. On the other hand, if the seed field is ejected from an astrophysical body, it could be highly localized in space at the beginning. In this talk I'll discuss growth of uniform and localized seed magnetic fields in turbulence. I will demonstrate that growth of both uniform and localized seed magnetic fields in clusters of galaxies is very similar. Therefore, it is difficult to tell whether or not the seed magnetic field has a cosmological or an astrophysical origin in clusters of galaxies. However, I'll show that it is possible to tell the difference in filaments. I'll also claim that turbulence dynamo models favor an astrophysical origin of cosmic magnetism, rather than a primordial origin.

Nov. 12: Morning

Effects of Multiple-scale Driving on Turbulence Statistics

Hyunju Yoo

Chungnam National University, Korea

Turbulence is ubiquitous in astrophysical fluids such as the interstellar medium and the intracluster medium. In turbulence studies, it is customary to assume that fluid is driven on a single scale. However, in astrophysical fluids there can be many different driving mechanisms that act on different scales. If there are multiple energy-injection scales, the process of energy cascade and turbulence dynamo will be different compared with the case of the single energy-injection scale. In this work, we perform three-dimensional incompressible/compressible magnetohydrodynamic turbulence simulations. We drive turbulence in Fourier space in two wavenumber ranges, $2 \le k \le \sqrt{12}$ (large scale) and $15 \le k \le 26$ (small scale). We inject different amount of energy in each range by changing the amplitude of forcing in the range. We show how kinetic, magnetic, and density spectra are affected by the two-scale energy injections and we discuss the behavior of turbulence dynamo and the observational implications in the presence of energy injections at two scales. Especially, we show turbulence models correspond to ICM turbulence and discuss the different results depending on contribution of the each of the energy injections.

Nov. 12: Morning

Influence of small scale magnetic energy and helicity on the growth of large scale magnetic field

Kiwan Park

UNIST, Korea

We investigated the influence of small scale magnetic energy (EM) and magnetic helicity (HM) on the growth rate (γ) of B field (large scale magnetic field). HM that plays a key role in MHD dynamo is a topological concept describing the structural properties of magnetic fields. Since EM is a prerequisite of HM, it is not easy to differentiate the intrinsic properties of HM from the influence of EM. However, to understand MHD dynamo the features of helical and nonhelical magnetic field should be made clear. For this, we made a detour: we gave each simulation set its own initial condition (IC, same EM(0) and specific HM(0) at the forced wave number kf = 5), and then drove the system with positive helical kinetic energy(kf = 5). According to the simulation results, EM(0), whether or not helical, increases the growth rate of B. The positive HM(0) boosts the increased growth rate, but the negative HM(0) decreases it. To explain these results two coupled equations of HM and EM were derived and solved using a simple approximate method. The equations imply that helical magnetic field evolves into the total (helical and nonhelical) magnetic field but quenches itself. Nonhelical magnetic field also evolves into the total magnetic field but quenches itself. The initially given EM(0) modifies the electromotive force (〈u×b〉, EMF) and generates new terms. The effects of these terms depend on the magnetic diffusivity η, position of initial conditions kf , and magnetic diffusion time. But the influence disappears exponentially as time passes, so the saturated magnetic fields are eventually independent of the pre-existing initial conditions.

Nov. 12: Morning

Plasma turbulence and particle acceleration

Peter Yoon

University of Maryland, USA

Nov. 12: Morning

Turbulence and stochastic particle acceleration in high-beta plasmas of SNRs

Siming Liu

Purple Mountain Observatory, China

With advances in gamma-ray astronomy during the past decade, significant insights on particle acceleration processes in shocks of supernova remnants have been obtained. In particular, these observations have uncovered a class of TeV bright shell-type supernova remnants (SNRs) with emission from radio to gamma-ray completely dominated by high-energy electrons, implying efficient electron acceleration in high-beta plasmas. Although there is no direct observational evidence of efficient ion acceleration in such kind of SNRs due to the low density of the background plasma, considering the gamma-ray emission characteristics of relatively older remnants and the SNRs origin of the Galactic cosmic rays, it is likely that the ion acceleration in SNRs is much more efficient than the electron acceleration. A unified model for particle acceleration in SNRs is emerging and may find applications in high-beta plasmas of other astrophysical systems.

Nov. 12: Afternoon

Turbulence and particle acceleration mechanisms in galaxy clusters

Gianfranco Brunetti

INAF Istituto di Radioastronomia, Italy

Nov. 12: Afternoon

Cosmological simulation of time dependent intracluster turbulence: insights on stochastic acceleration and the impact of microphysics

Francesco Miniati

ETH Zurich, Swiss

I use the Matryoshka run (Miniati 2014a,b) to study the time dependent statistics of structure-formation driven turbulence in the intracluster medium of a 1015 Msun galaxy cluster. The simulation is characterized by an unprecedented resolution of 7 h-1 kpc throughout the cluster virial volume, which is sufficient to capture the inertial range of the turbulence cascade over at least a decade of special scales. I use the statistical properties of the turbulence in the inner Mpc, particular the outer scale, velocity dispesion and cascade slope, as a function of time (i.e., redshift) to test models of stochastic particle acceleration by compressional modes for the origin of diffuse radio halo emission in galaxy clusters. The simulated cluster is particularly interesting as a major merger occurs around redshift z~0, which is thought to trigger radio halo emission. The turbulence simulation model constrains an important unknown of this complex problem and brings forth its dependence on the elusive micro-physics of the intra-cluster plasma. In particular, the specifics of the plasma collisionality and the dissipation physics of weak shocks affect the cascade of compressional modes with strong impact on the acceleration rates. In this context radio halos emerge as complex phenomena in which a hierarchy of processes acting on progressively smaller scales are at work.

Nov. 12: Afternoon

Particle Acceleration and Angular Momentum Transport by Magneto-Rotational Instability in Kinetic Accretion Disks

Masahiro Hoshino

University of Tokyo, Japan

Particle acceleration and angular momentum transport during the magneto-rotational instability (MRI) in a collisionless accretion disk was investigated by using 3d PIC simulation. We discuss that anisotropic plasma pressure induced during the time evolution of MRI leads to violent magnetic reconnection, resulting in the rapid generation of the nonthermal particles and the efficient angular momentum transport. The collisionless accretion disk may be a possible model to explain the origin of high energy particle observed around massive black holes.

Nov. 12: Afternoon

Cosmic ray feedback in galaxies and cool core clusters

Christoph Pfrommer:

Heidelberg Institute for Theoretical Studies, Germany

I will show how cosmic ray feedback is able to drive galactic winds in low-mass galaxies. Simultaneously, cosmic-ray heatiang can balance radiative cooling of the low-entropy gas at the centers of galaxy clusters and in mitigating the star formation of the brightest cluster galaxies.

Nov. 12: Afternoon

Cosmic Ray Transport and Heating in the Intracluster Medium

S. Peng Oh

UC Santa Barbara, USA

Although cosmic rays only constitute a small fraction of the energy density of the intra-cluster medium, their influence can be profound. They potentially provide pressure support and heating (both collisionally and MHD wave heating), and due to long lifetimes, contain archaeological information about cosmological shocks and AGN activity, which can be mined in radio and gamma-ray data. Their transport properties in the ICM can potentially be very different from what we are accustomed to in the ISM; in particular, super-Alfvenic streaming may be possible. I review recent work on this topic, and prospects for the future.

Nov. 13: Morning

Intracluster shock waves in simulations

Dongsu Ryu

UNIST, Korea

Nov. 13: Morning

Particle acceleration at structure formation shocks in the intracluster medium

Sam Skillman

Stanford University, USA

I will discuss recent advances in our understanding of how, where, and when structure formation shocks occur in the intracluster medium, with particular focus on how they may impact the relativistic particle population that is observed in radio wavelengths. By using cosmological simulations that follow the acceleration, advection, and cooling of a non-thermal population of cosmic rays, we can produce synthetic observations for upcoming radio surveys, and their correlation with observations in the X-ray, optical, and SZ.

Nov. 13: Morning

Reacceleration of Cosmic Rays in the Intra-Cluster Medium

Anders Pinzke

Dark Cosmology Centre, University of Copenhagen, Denmark

Observations of giant radio halos and radio relics in galaxy clusters demonstrate the presence of synchrotron emitting electrons with GeV energies in more than 50 clusters. The precise origin of these radio emitting electrons is, however, still unclear. In this talk I discuss how Fermi I and II reacceleration impact both the spectral and spatial distributions of cosmic rays in the intra-cluster medium as well as the associated radio emission in both halos and relics.

Nov. 13: Morning

Radio Synchrotron Emission From Weak Spherical Shocks

Hyesung Kang

Pusan National University, Korea

We study the evolution of the energy spectrum of cosmic-ray electrons accelerated at spherically expanding shocks with low Mach numbers and the ensuing spectral signatures imprinted in radio synchrotron emission. Time-dependent simulations of diffusive shock acceleration (DSA) of electrons in the test-particle limit have been performed for spherical shocks with the parameters relevant for typical shocks in the intracluster medium. The electron and radiation spectra at the shock location can be described properly by the test-particle DSA predictions with the instantaneous shock parameters. However, the volume integrated spectra of both electrons and radiation deviate significantly from the test-particle power-laws, because the shock compression ratio and the flux of injected electrons at the shock gradually decrease as the shock slows down in time. So one needs to be cautious about interpreting observed radio spectra of evolving shocks by simple DSA models in the test-particle regime.

Nov. 13: Afternoon

Particle acceleration and field generation in high-beta plasmas: PIC simulations

Anatoly Spitkovsky

Princeton University, USA

I will review the progress in modeling shock structure and particle acceleration using kinetic simulations, and underline the outstanding issues in understanding field amplificaiton, angle dependence of particle injection and acceleration and explaining the electron to ion ratio in Fermi process. I will also describe new scenarios of generation of first magnetic fields during structure formation which can be relevant for the magnetization of intercluster plasma.

Nov. 13: Afternoon

Electron acceleration and reconnection at a high Mach number shock

Masahiro Hoshino

University of Tokyo, Japan

Nov. 13: Afternoon

Particle Acceleration in Quasi-Parallel High-Mach-Number Shocks

Tsunehiko Kato
National Astronomical Observatory of Japan, Japan

We investigate shock formation and particle acceleration processes for both protons and electrons in a quasi-parallel high-Mach-number collisionless shock through a long-term, large-scale particle-in-cell simulation. We show that both protons and electrons are accelerated in the shock and that these accelerated particles generate large-amplitude Alfvénic waves in the upstream region of the shock. A fraction of protons are accelerated in the shock with a power-law-like energy distribution. The rate of proton injection to the acceleration process is approximately constant. The dominant acceleration process is a Fermi-like process through repeated shock crossings of the protons. This process is a `fast' process in the sense that the time required for most of the accelerated protons to complete one cycle of the acceleration process is much shorter than the diffusion time. A fraction of the electrons is also accelerated by the same mechanism, and have a power-law-like energy distribution. However, the injection does not enter a steady state during the simulation, which may be related to the intermittent activity of the upstream waves. Upstream of the shock, a fraction of the electrons is pre-accelerated before reaching the shock, which may contribute to steady electron injection at a later time. I will talk about these results.

Nov. 13: Afternoon

Hybrid simulations of ion acceleration at shocks

Damiano Caprioli
Princeton University, USA

Hybrid particle in cell simulations (with kinetic protons and fluid electrons) are providing us with unprecedented insights into the microphysics of collisionless shocks, also attesting to their ability to accelerate particles and to generate magnetic fields. I present state-of-the-art 2D and 3D simulations of non-relativistic shocks, discussing under which conditions (shock strength and inclination) ions are injected and energized via diffusive shock acceleration. I also show how resonant and non-resonant instability generate magnetic turbulence, and illustrate the energy spectrum of the self-generated turbulence. Finally, I outline the relevance of these findings for cosmic ray acceleration in supernova remnants and in galaxy clusters.

Nov. 13: Afternoon

Non-Thermal Electron Acceleration in Low Mach Number Shocks

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Electron acceleration to non-thermal energies is known to occur in low Mach number (M<5) high plasma beta shocks in galaxy clusters and solar flares, but the acceleration mechanism remains poorly understood. Using two and three dimensional particle-in-cell plasma simulations, we find that electrons are efficiently accelerated in low Mach number quasi-perpendicular shocks via a Fermi-like process, by bouncing between the upstream region and the shock front. Each reflection by the shock results in energy gain via shock drift acceleration. The upstream scattering is provided by oblique magnetic waves, which are self-generated by the electrons escaping ahead of the shock via the electron firehose instability. We find that our mechanism works for shocks with plasma beta ranging from 20 to 200 at nearly all magnetic field obliquities, and for electron temperatures in the range relevant for galaxy clusters. Our findings offer a natural solution to the conflict between the bright radio synchrotron emission observed from the outskirts of galaxy clusters and the low electron acceleration efficiency usually expected in low Mach number shocks.

Nov. 13: Afternoon

Diffusive shock acceleration of cosmic-ray ions and electrons in non-relativistic high Mach number quasi-parallel shocks

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Diffusive shock acceleration(DSA) for both the ions and the electrons is studied in non-relativistic high Mach number quasi-parallel shocks using 1D particle-in-cell simulations. Both the species in the downstream develop power-law distributions with the spectral index 4 in the momentum space, in agreement to the prediction of DSA. The right-handed circularly polarized waves excited by the non-resonant hybrid instability(or the Bell instability) are observed in the upstream. The ions get injected into DSA after a few gyro-cycles via shock drift acceleration(SDA). The electrons are energized via SDA first and then re-energized via "multi-SDA cycles" mediated by the interaction with the Bell modes. Finally the electrons get injected into DSA and the "electron injection problem" is resolved.