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Summary of Joint Discussion 1

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Abstract. We review the main ideas discussed during the meeting and propose methods for a new generation of space accelerators

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Overall theories of particle acceleration were divided into three broad classes: (1) DC E-fields (double layers, thin current sheets), (2) stochastic acceleration in turbulent electromagnetic and electrostatic fields (Fermi acceleration or wave-particle interaction), and (3) shock waves. Blandford called these three processes (1) Direct or coherent, (2) stochastic (Markovian), and (3) systematic (Non-Markovian), while Melrose argued that ultimately all must involve induced rather than electrostatic E-fields. As we will show, all acceleration process discussed up to now fall into one of these classes. Let us call these three fundamental mechanisms, cosmic accelerators (CA).

The next important aspect in analysis of cosmic particle acceleration is the relation of the CA(s) to the host environment in which they operate, e.g., solar active regions host transient explosions, like Coronal Mass Ejections (CMEs) and flares); shell-type SNR host spherical shocks; extragalactic jets and AGNs host turbulent relativistic flows and shocks; and clusters of galaxies host MHD turbulence.

Finally we have to adopt an analytic or a computational method for analysis of the interaction of the CA with the particles. It is well known (e.g., Melrose) that at least two spatio-temporal scales are involved : (1) that of the macroscopic evolution of the environment hosting the CA; and (2) that of the microscopic interaction of particles with the CA. We usually try to split the analysis of the problem in two steps: (1) use the MHD equations to derive the electric and magnetic fields structure/spectrum of MHD waves, shock(s,) or current sheets; and (2) use these 'slowly' changing fields to study the fast evolution of particles by solving the diffusion equation, or following numerically test particles, in prescribed fields. Both methods lack self-consistency and, since efficient acceleration means fast transfer of energy from the CA to the particles, this approach will eventually break down.

During the meeting we had a series of interesting presentations on the topics mentioned above. Lin presented a full account of energetic particles in the heliosphere and touched on many unsolved issues. He stressed that the Earth is a strong γ-ray source, referring to terrestrial γ-ray flashes which are closely correlated with lightning strokes. The acceleration of particles is extremely fast and reaches very high energies (a few MeV). Is this a clear example of Direct acceleration? Other places where particles are efficiently accelerated are : (1) terrestrial radiation belts; (2) solar flares and CMEs; and (3) planetary magnetospheres/tails, and interplanetary space. A key point in Lin's talk was that heliospheric physics still has many unsolved problems so cannot be seen as the paradigm for the rest of CAs. These problem areas includes shock wave acceleration which is so popular in astrophysics. Kahler reported a search for evidence of non-relativistic and relativistic particles during CMEs, hoping to discover whether these particles are accelerated in the vicinity of an associated flare or are clearly associated with the CME shock. He had a hard time deciding from the available data the relative contributions of these two accelerators. The best he can say at the moment is that relativistic SEP particles seem to show better correlation with the CME than do the non-relativistic particles. In my view, the truth of the matter is that shock acceleration has not been unanimously accepted as an efficient accelerator for very high energy particles in the heliosphere.

Benz *et al.* analyzed the hard X-ray spectral evolution of coronal sources and tried to explain the often observed Soft-Hard-Soft spectral behavior of the radiation in the course of each Hard X-ray peak. They invoked the turbulence excited by reconnection as their CA mechanism and found that they cannot model the observations without additional transport effects (return current, high wave density, etc). The main issue for turbulent acceleration of particles during solar flares is the fact that the correlation of magnetic reconnection with the MHD waves assumed in this study remains conjectural.

Magnetic reconnection was analyzed in three separate contributions presented by Kraus-Verban and Welsch, by Bárta and Karlický, and by Dalla and Browning. Using a hybrid code (fluid electrons and kinetic ions) Kraus-Verban and Welsch proved that half of the available magnetic energy in low-β Petschek reconnection will go to ion heating. Within msecs a beam of MeV ions is created which can drive fast magnetosonic waves and, as Benz et all suggested, these waves may accelerate the particles. All these multi-level mechanisms (reconnection-MHD waves-particles) are of low efficiency. Observations, on the other hand, suggest very efficient transfer of magnetic energy to energetic particles (Lin) during solar flares.

Bárta and Karlický, using a 2.5D MHD code, created a flaring environment and then followed test particles to study its influence on the particles. They studied the combined action of pinch effects (betatron action) on electrons trapped in non-equilibrium plasmoids and collapsing magnetic traps. Dalla and Browning set up a 3D magnetic structure (magnetic null) which is known to host a magnetic reconnection environment, and followed test particles to study the efficiency of energy dissipation. The test particles were injected in random places inside the 3D structure. In 60 msecs the initial Maxwellian distribution has absorbed a considerable fraction of the available magnetic energy in the simulation box and developed a tail with spectral index -1. All such test particle codes are again lacking in self consistency in the sense of particle feedback on the CA mechanism. For efficient particle accelerators, as data indicate for e.g. magnetic reconnection, this is not a fully adequate method for analysis. A full 3D particle code is needed.

Medvedev presented extensive evidence suggesting that many well known applications of Fermi acceleration in relativistic shocks are problematic. His suggestion is that shock acceleration of electrons may be the effect of micro-physics on collisionless processes. 3D kinetic aspects of shock acceleration are currently a very active research topic (Gabici). However, shock acceleration is still the main candidate for acceleration of Galactic cosmic rays in shell-type SNRs. Gallant presented evidence for particle acceleration in blast waves (see also Asvarov).

Stochastic acceleration in shear flows was proposed by Rieger and Duffy as the acceleration mechanism in AGNs and GRBs. Brunetti and Lazarian used stochastic acceleration to explain the non-thermal emission in galaxy clusters. Obviously in both studies the MHD waves are put there by hand, rather than arising from basic physics, but the results agree with the observations using reasonable spectra and amplitudes for the MHD waves.

Based on these many fascinating contributons, I would like to close the summary with a few personal thoughts.

(*a*) So far ‘turbulence’ has meant ‘particle scattering by a spectrum of **low amplitude** waves’. However ‘Strong MHD turbulence’ is a much wider ranging topic which may unite many of the CAs mentioned above. Increasing the amplitude of MHD waves to reach $\delta B/B \sim 1$ leads shocks and magnetic reconnection seemingly to co-exist and provide a new meaning for the concept of stochastic acceleration.

(*b*) The sharp separation of the three classes of CA, presented at the beginning of this summary, loses its meaning inside a major cosmic explosion. We may start with a large 3D current sheet which soon collapses to a “turbulent structure with many short lived current sheets, flows and shocks” or a large scale 3D shock may lose its character inside a strong turbulent flow. The mixing of acceleration mechanisms is a new concept and has not yet been discussed in depth.

(*c*) So far MHD codes have been used extensively for providing the environment in which kinetic aspects of particle accretion were investigated. This approach is possible when the non-linear structures are isolated in a single shock (CME, Shell-type SNRs) or one large scale 3D current sheet and stable for a long time. Our studies so far show that, inside the non linear structures (current sheets, shocks), acceleration is extremely efficient and requires a fully kinetic treatment. The problem becomes almost impossible to handle when the environment follows the ideal MHD equations and, at specific isolated short lived points, randomly appearing inside the large scale structure, the energy is dissipated kinetically. The communication between the large scale MHD code and short lived nonlinear dissipation structures remain a major unsolved problem.

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