Chapter 6

Summary and discussion

Understanding of the origin of cosmic rays is still not clear despite of many efforts by people for a long time now. In current scenarios, high energy cosmic ray particles up to the second knee or even up to the ankle of the cosmic ray energy spectra are believed to be accelerated in galactic objects and above this energy cosmic ray particles are thought to be originated from extra-galactic sources. Supernova remnants appears the only viable class of galactic astrophysical objects which can accelerate cosmic rays up to the knee or even up to the ankle energy. But some important issues in SNR origin model of cosmic rays are not yet established, nor any cosmic ray source has been directly identified so far. As charged cosmic rays does not point back to the sites of its acceleration, detection of high energy gamma rays and neutrinos which may produce in the several astrophysical objects when accelerated cosmic ray particles interact with the ambient matter or radiation field of the source, are expected to provide strong evidence for identification of the acceleration sites of high-energy cosmic rays.

In the present thesis work we first examined critically the consequences of the maximum attainable energy of cosmic rays in SNR on the secondary gamma-ray spectrum of young supernova remnants. We investigated the implications of the acceleration of heavier nuclei in SNRs on energetic gamma rays produced in the hadronic interaction of cosmic rays with ambient matter. Our findings suggest that the energy conversion efficiency has to be nearly double ($\sim 20\%$) for the mixed cosmic ray composition compared to that of pure protons ($\sim 10\%$) to explain observations from individual SNRs. In this respect a conversion efficiency of the order of 20% is more demanding and also not unrealistic. Regarding the issue of the maximum energy of cosmic rays in SNRs, we compare two different scenarios: $Z \times 3$ PeV, which seems achievable under an amplified magnetic field situation and 200 TeV, which is the theoretical upper limit under a normal magnetic field picture. We find that both the scenarios can somewhat describe the observed gamma-ray spectra of all the SNRs considered except for SNR RX J1713.7-3946 in which the maximum cosmic ray energy appears to be much lower and energy conversion efficiency for mixed primary composition of cosmic rays need to be much higher. So the gamma-ray emission from RX J1713.7-3946 is likely to be leptonic in origin. We find that the two stated maximum energy scenarios give significantly different fluxes above a few tens of TeV, and therefore the experiment HAWC or upcoming experiments like CTA should be able to discriminate between the two maximum energy pictures and should provide experimental support in favor of this SNR paradigm of cosmic ray origin.

To test the SNR origin hypothesis of galactic cosmic rays, we also investigated the implication of such maximum energy scenarios on TeV gamma rays and neutrino fluxes from the four molecular clouds illuminated by SNR W28 emitted cosmic rays which is a better approach to probe the presence of hadronic cosmic ray in SNRs. Our results reconfirm that the observed GeV and TeV gamma rays from the stated molecular clouds can be explained in terms of interaction of W28 emitted hadronic cosmic rays with molecular clouds. It is found that the gamma ray flux above about 30 TeV corresponds to the maximum energy 3 PeV is significantly higher than that corresponds to the maximum energy 200 TeV. The corresponding flux levels is detectable by the upcoming CTA experiment with about 1000 hours exposure and by the planned LHAASO (KM2A) telescope with about 1 year exposure and it is expected that in near future TeV gamma ray observations will resolve the issue of maximum attainable energy of cosmic rays in SNR.

Under the SNR origin of cosmic rays framework, the mass composition of cosmic rays will be heavier beyond the knee if the knee is a proton knee. But despite of many efforts by different EAS experiments, mass composition of cosmic ray in PeV energy region is still not known conclusively. Here we proposed an alternate approach to establish the mass composition of primary cosmic rays above the knee of their energy spectrum through the study of high-energy gamma rays, muons, and neutrinos produced in the interactions of cosmic rays with solar ambient matter and radiation. It is found that the theoretical fluxes of TeV gamma rays, muons, and neutrinos from a region around 15^o of the Sun are sensitive to a mass composition of cosmic rays in the PeV energy range. Our findings suggest that with the correct model for density profile of the corona, the observed TeV and PeV gamma ray fluxes from corona can be utilized to distinguish a primary-cosmic-ray-composition scenario above the knee of the cosmic ray energy spectrum. When interactions of energetic cosmic rays with solar photons are considered, it is found that if cosmic rays are Fe nuclei above the second-knee energy, the TeV gamma ray flux would be substantially higher than that due to proton-dominated composition at the same energy region. we find that the chances of observation are better from within the solar corona than outside the corona. Our findings suggest that around 0.5 TeV and slightly below there should be a few tens of events per year in a square-kilometer gamma ray observatory from solar corona. So only a square-kilometer extension of a HAWC type of experiment should be able to detect cosmic ray induced TeV gamma rays from the solar corona and thereby may estimate the mass composition of cosmic rays above the knee.

Finally we demonstrated that High energy (TeV energies and above) neutrinos can also be originated from energetic electrons via electromagnetic interactions in different potential cosmic ray sources with flux levels comparable to the conventional hadronic originated neutrinos at high energies. So we may say that detection of neutrinos from an astrophysical source does not conclusively mean the presence of energetic hadrons in the source. But a notable signature of so produced leptonic neutrinos is the presence of a spectral break in the energy spectrum which can be utilized to discriminate between leptonic and hadronic originated neutrinos. Hence we find that an appropriate fluxes of gamma rays and neutrinos together over an energy range or even the nature of energy spectrum of detected neutrinos from a source over a wide energy range may allow clear identification of hadronic cosmic ray sources. A joint venture between upcoming high energy gamma ray telescopes such as CTA and the PINGU/Icecube thus may give conclusive evidence for sites of hadronic cosmic rays in near future. A detail Monte Carlo simulation will be done in near future to examine the detail energy spectrum and flux level (compared to hadronic originated neutrinos) of leptonic originated neutrinos.