ABSTRACT

The origin of cosmic rays is regarded as one of the fundamental open questions of modern physics. To inquire more clearly the astrophysical environments and the viable mechanisms which sustain the huge power for their acceleration, it is imperative to investigate the fluxes of multi-messenger particles reaching the Earth. In this context, the discovery of diffuse flux of astrophysical neutrinos in 2013 by IceCube added an important class of multi-messenger particles into the field. The aim of the work performed by the author (in collaboration with a few others) in this thesis is basically related to a theoretical estimation of the TeV−PeV energy fluxes of these neutrinos and/or accompanying gamma rays from some plausible astrophysical sources (point-like and diffuse sources). The main objectives of the thesis are

[i] to probe the origin of cosmic rays through TeV−PeV energy multi-messengers namely neutrinos and gamma rays,

[ii] to estimate theoretically the TeV−PeV energy neutrino and/or gamma-ray fluxes at Earth primarily from the aftermath processes of the acceleration era of VHE−UHE protons and nuclei or electrons on the ambient matter and/or radiative background at the source environment or ISM,

[iii] to apply the above methodology to estimate diffuse fluxes of TeV−PeV energy astrophysical neutrinos coming from all directions in the sky contributed by three source classes: (i) extragalactic milli-second pulsars; (ii) AGN and (iii) an extended source - Galactic center. Moreover, we estimate astrophysical neutrino fluxes from some predefined point-like galactic source classes by IceCube: (i) pulsars and nebulae, and (ii) magnetars. We also estimated the TeV−PeV energy flux of gamma rays produced concurrently with neutrinos in those astrophysical sources,

[iv] to understand the astrophysical origin of IceCube (diffuse neutrino flux) and also the Antarctic Muon and Neutrino Detector Array - AMANDA-II (directed neutrino flux) detected TeV−PeV energy neutrinos by analyzing the theoretically predicted fluxes of neutrinos. This study is closely linked with the origin of cosmic rays. The thesis emphasizes to enlighten this area primarily,

and

[v] to understand the observed data on gamma-ray fluxes obtained from experiments *viz.* High Altitude Water Cherenkov (HAWC) and LHAASO by analyzing the predicted fluxes of accompanying gamma rays.

The **first chapter** of this thesis has given an overview of the multi-messenger astronomy, aimed at exploring the cosmos by blending two important windows of astrophysics with the use of cosmic messengers: TeV−PeV energy neutrinos and gamma rays.

A synopsis of the present status of the gamma-ray and neutrino astronomy from both theoretical and experimental standpoints concerning cosmic-ray origin is given in the **second chapter**. In this context, it also reviews the theoretical basis of adopted particle acceleration models and photon-splitting process, a QED process that takes place in presence of strong magnetic fields.

The **third to sixth chapters** are focused on the author's original research works on the origin of cosmic rays through the study of TeV−PeV energy neutrinos and gamma rays.

The **third chapter** is divided into two main parts: in **part A**, an estimation of the fluxes of TeV neutrinos and gamma rays to be observed at Earth from pulsars polar caps via interaction of polar cap accelerated protons with radiative background is presented; **part B** deals with the estimation of PeV neutrino and gamma-ray fluxes from magnetar polar caps, considering that protons are accelerated in polar cap regions, and interact with background photon fields (ultraviolet A and B type soft photons). In this context, the observational situation of neutrino and gamma ray detections by the current and possible future experiments are discussed.

The **fourth chapter** goes into detail about the methodology of revised estimation of the diffuse flux of PeV neutrinos produced in the accretion disk region of active galactic nuclei (AGN) by centrifugally accelerated protons on the soft photon targets based on the latest cosmological framework with a view to predicting the observed diffuse flux of PeV neutrinos by IceCube. The diffuse PeV gamma rays produced together with neutrinos, and their possibilities to be detected at Earth are also discussed.

The **fifth chapter** describes the hadronic emission scenario in the extended source Sagittarius $A^\star$ with energies ~ 100 PeV or more, followed by an estimation of the diffuse

fluxes of PeV neutrinos and gamma rays produced via cosmic rays-gas/ISM (pp) interactions. The chapter ends with a concise discussion on the detection feasibility of the predicted low fluxes of galactic PeV neutrinos and gamma rays at Earth by the current and future generations of neutrino and gamma-ray observatories.

Hadronic scenarios are widely accepted for the production of high-energy neutrinos. Most of the models proposed in earlier studies took $p\gamma$ and/or pp interactions for the production of UHE neutrinos in different sources. But, the **sixth chapter** focuses on the estimation of diffuse flux of PeV neutrinos contributed by the process of purely leptonic origin, particularly, via the e^-e^+ interaction in new-born milli second pulsars in the universe at redshifts in the range $0.002 - 5$. The chapter also derives the high-energy diffuse gamma-ray flux for a relevant $e^-\gamma_{low}$ interaction, in softer radiation field zones in pulsar's environment. The chapter ends with a discussion on the possibility of leptonic originated diffuse neutrinos to be detected by IceCube.

A summary of the presented research work with a brief discussion is presented finally in **seventh chapter**.

The results reported in this thesis have been published in peer-reviewed journal papers, and in proceedings/book chapters. A list of these papers is provided in the **Preface** of the thesis.