

# Summary

In the beginning of the last century, several scientists discovered an ionising radiation that seemed to come from the sky. After experiments at high altitudes using balloons, it was found that charged particles coming from space were the cause of this radiation. These particles were called cosmic rays.

Since their discovery, scientists have tried to identify the sources of these cosmic rays. More specifically, the origin of the high energy cosmic rays is an enigma as one also needs to explain the mechanism behind their acceleration. Within our Galaxy, supernovae are believed to be responsible for the high energy cosmic rays.

However, at even higher energies, the sources of the so-called Ultra High Energy Cosmic Rays (UHECRs) are believed to be located outside our Galaxy. This is due to the fact that at a certain energy, the magnetic field of our Galaxy is not sufficient anymore to contain these particles.

The search for the sources of the UHECRs is thus focusing on the highest energetic phenomena outside our Galaxy. Since the most powerful objects known are Gamma Ray Bursts (GRBs) in which the energy of a supernova is released in just a few seconds, it is natural to associate these objects to the UHECRs.

Such an association implies the presence of protons (being the main component of the UHECRs) inside the GRBs. This is supported by the generally accepted GRB progenitor hypothesis. This hypothesis states that GRBs originate from the collapse of extremely massive stars or from the merger of compact binary systems like neutron stars and black holes. In both cases such a cataclysmic event would create a black hole generating the power required to accelerate the surrounding matter.

Following this scenario, the accelerated protons should interact with the ambient energetic photons to produce pions and subsequently high-energy neutrinos. Hence the detection of high-energy neutrinos from GRBs would provide an unique proof that the GRBs contain a hadronic component and that they are sources of UHECRs.

Since neutrinos are electrically neutral and interact only very weakly, they directly point back to their source and can reach the Earth unhindered. However, their detection requires a very large detector. Such a detector has been built at the South Pole where a cubic kilometer of ice has been instrumented with light detectors to form the IceCube observatory.

The analysis developed in the current thesis focuses on long duration GRBs (longer than 2

s) which are believed to originate from star collapses while the short duration GRBs (shorter than 2 s) are believed to originate from compact binary mergers. The selection of the events detected by the IceCube detector has been designed and optimised to search for a specific type of neutrino, the muon neutrino. The reason for this is that these neutrinos may produce a muon, which leaves a track like signature in the detector that allows to reconstruct the location of its origin.

Using a newly developed event selection, the background (mainly composed of muons produced in cosmic ray interactions in our atmosphere) could be dramatically reduced while allowing for a better signal acceptance than previous IceCube GRB analyses.

Once the background events were rejected and the neutrino induced events coming from the Northern Hemisphere (to use the Earth as a shield against the atmospheric muon background) were extracted from the data, a study of statistical methods was performed in order to define the most suitable method to search for neutrinos from long GRBs. This statistical method is required to state how significant our observations are. The newly designed statistical method allowed to improve the sensitivity of the analysis by a factor three with respect to previous analyses while extending the search time around the GRB to one hour, instead of the usual so-called prompt emission studies.

Unfortunately, no significant signal events in correlation with GRBs have been observed. This allowed to set upper-limits on the neutrino flux from GRBs. These limits rule out the model that predicts that the UHECRs originate from neutrons escaping the high intensity magnetic field surrounding GRBs. The model that predicts that a part of the protons accelerated by the GRBs do not interact with photons and form the UHECRs is not excluded but its parameter variations are constrained.

Furthermore, a limit on the fluence of neutrinos that could be emitted prior to the observed GRB when the environment is still opaque to photons has also been calculated. This limit as a function of the emission time prior to the GRB is the first one ever set by an (IceCube) analysis and represents thus a novel result. The previous limit by IceCube on such precursor neutrinos was calculated by assuming a specific model and only a time offset of about 100 s. The current analysis allowed to improve this previous limit by a factor 35.

The various models predicting neutrinos from GRBs are more and more constrained and if no signal neutrinos are found in the near future, GRBs will be definitely ruled out as main source of the UHECRs.