

## Mid Term Report

<b>Type of project:</b> Helmholtz-University Young Investigator group	
support-Nr.: VH NG 205	Name of project: Multi-messenger studies of point sources of cosmic rays including data from IceCube
Scientist in charge: Elisa Bernardini	
reference period: 03/2006	until: 02/2011

The main focus of this group is the search for point sources of neutrinos with IceCube and the development of the multi-messenger approach [1]. The activities are organized in three working packages (cfr. Proposal for VH-NG-205, approved Nov. 2005):

- A. *Optimization of event reconstruction and selection algorithms for the best sensitivity to point sources of neutrinos;*
- B. *Enhancement of the signal-to-noise ratio by using observations made with electromagnetic waves;*
- C. *Development of multi-messenger astronomy with neutrinos.*

The main achievements reached in 2007 for each working package is summarized in what follows.

### Progress of the working plan mentioned in the proposal and achieved milestones

#### Optimization of event reconstruction and selection algorithms for the best sensitivity to point sources of neutrinos

1. *Development of a novel concept in the search for point sources of neutrinos extending the sensitivity to multi-PeV energies:* we developed a prototype analysis using data from AMANDA, with very encouraging results that will allow to test possible correlations with the highest energy cosmic rays events recently reported by Auger (Science 2007). A parallel extension of this concept to IceCube was also started. Results have been reported in [2]-[4].

#### Enhancement of the signal-to-noise ratio based on electromagnetic signals

1. *Long-term  $\gamma$ -ray light curves compilation:* we created and maintain a public archive collecting historical  $\gamma$ -ray data [5] and developed concepts for the cross-calibration of the independent data records to create combined light curves.
2. *Characterization of the states of high-energy  $\gamma$ -ray emission:* based on the combined light-curves, we developed a method to estimate the frequency of states of enhanced emission for a sample of Active Galactic Nuclei. Results were presented in [6].
3. *Un-biased search for time clusters of neutrinos and search for neutrinos in coincidence with states of enhanced  $\gamma$ -ray emission:* we selected targets based on their properties in the high-energy  $\gamma$ -ray emission, and searched for neutrino clumps as well as neutrinos in coincidence with periods of enhanced  $\gamma$ -ray emission. For this purpose we developed an advanced background estimation method as well as an entirely new approach to look for neutrinos flares. Results were presented in [8]-[9].

#### Development of multi-messenger astronomy with neutrinos

- A. *Development of a neutrino-triggered Target of Opportunity strategy:* in 2006 we realized the first collaboration between a neutrino telescope and a  $\gamma$ -ray telescope, performing coordinated measurements with AMANDA and MAGIC and developed an entirely new concept to study possible correlations between different messengers, in which neutrino alerts are sent to a telescope that can monitor the state of

electromagnetic emission of the target objects. In 2007 we completed the analysis of the data records collected and started the development of a neutrino alert system for IceCube, by working on the on-line filtering of the events for the configuration of 2008 (40 strings) and on the development of a system to monitor the detector stability over short time scales.

- B. *Analysis of un-biased  $\gamma$ -ray observations*: to address the issue of trigger biases affecting historical  $\gamma$ -ray data and enhance the fraction of records on exceptional states of electromagnetic emission, we contributed to the promotion of long-term monitoring programs with MAGIC and started the analysis of the observations performed in 2006 and 2007. These data records are often non-standard (e.g. taken under conditions of higher background from the light of the night sky) and dedicated Monte Carlo studies are required. We therefore also started the production of the required simulation data.

All activities are being carried out in agreement with the time planning of the proposal. In addition to the activities planned in the Proposal for VH-NG-205, part of the group joined the MAGIC collaboration and is involved in the analysis of  $\gamma$ -ray data of Cherenkov telescopes. This is significantly strengthening our potential in realizing multi-messenger studies (see last point in the list above).

#### Participation to MAGIC

We aim at enlarging the available statistics of  $\gamma$ -ray time series. Besides combining existing data, we are working on the analysis of new records collected with the MAGIC telescope during the AGN monitoring program of 2007. To optimize the observation time, part of the monitoring observations are carried out in conditions of increased background from the light of the night sky (e.g. with Moon or twilight). We therefore started the production of dedicated Monte Carlo. We also participate to a large-scale field test of advanced photo-detector (UBAs and HPDs), expected to provide an improved quantum efficiency (peak efficiency larger than 50%). This is expected to lower the energy threshold of the detector and enhance the capability to detect, among others, very distant AGNs. This work is supported by an extra Helmholtz grant (SO-NG-063). E. Bernardini also successfully applied for an associate MAGIC membership of part of the group (leader, post-doc and one PhD student). The application for full membership has been accepted in April 2008.

#### Teaching

- "Introduction to Astroparticle Physics" at the Humboldt University in Berlin, by E. Bernardini (tutorial by K. Satalecka), Winter Semester 2007/2008.
- "Neutrino Sector" (6 hours) at the Joint Belgian-Dutch-German School (SPA, Belgium) by E. Bernardini, Summer 2007.

#### Milestones

- Development of a novel analysis concept extending the sensitivity to multi-PeV neutrino sources and analysis of AMANDA and IceCube data;
- Creation of a public archive of historical gamma-ray data and development of criteria for the cross calibration of independent records;
- Analysis of all available AMANDA data to search for neutrino flares, both un-biased and in correlation with periods of enhanced g-ray emission, with an advanced background estimation methodology.
- Completion of analysis of data from a prototype Neutrino-Triggered Target of Opportunity (NToO) system to trigger gamma-ray follow-up observations;
- Development of concepts for the on-line selection of IceCube events in view of an implementation of the NToO with IceCube;
- Development of a data stability monitoring and successful test of its performance of IceCube 22 data.

## Adherence to time and financial plan

The progress of the activities is in agreement with the proposed time-plan. Additional activities are also being carried out, including an active participation to the MAGIC Cherenkov telescope.

The financial status is following the plans. The multi-messenger group grew in 2007, with the employment of a new PhD student, of a scientific assistant (three months) and the engagement of a new diploma student.

### Publications

- [1] Cosmic ray Physics: Gamma-rays and Neutrinos, E. Bernardini, invited talk at HEP 2007, Europhysics Conference on High Energy Physics, July 2007, Manchester (England). Proceedings to appear in *LoP Journals*.
- [2] R. Franke, "A new approach to the Search for Point-like Sources of Cosmic Neutrinos at PeV Energies with AMANDA-II", Diploma Thesis, Humboldt Uni. (2007).
- [3] Point source analysis for cosmic neutrinos beyond PeV energies with AMANDA and IceCube, E. Bernardini, R. Franke, R. Lauer et al., for the IceCube Collaboration, 30th International Cosmic Ray Conference (ICRC 2007), Merida, Yucatan, Mexico, 3-11 Jul 2007, e-Print Archive: arXiv:0711.0353, pages 103-106.
- [4] Searches for point-like sources of cosmic neutrinos with IceCube, E. Bernardini, R. Lauer, R. Franke et al., for the IceCube Collaboration, Cosmic Matter, Wuerzburg (Germany), 24-29 September 2007.
- [5] <http://www-zeuthen.desy.de/multi-messenger/GammaRayData/index.html>
- [6] Long-term  $\gamma$ -ray lightcurves and high state probabilities of Active Galactic Nuclei, E. Bernardini, M. Tluczykont et al., *J. Phys. Conf. Ser.* 60, 318 (2007).
- [7] A. Achterberg et al, (IceCube Collaboration), *Phys. Rev. D* 75 (2007) 102001.
- [8] Cluster search for neutrino flares from pre-defined directions, E. Bernardini, K. Satalecka et al., for the IceCube Collaboration, 30th International Cosmic Ray Conference (ICRC 2007), Merida, Yucatan, Mexico, 3-11 Jul 2007, e-Print Archive: arXiv:0711.0353, pages 115-118.
- [9] Search for Transient Emission of Neutrinos in IceCube, E. Bernardini, K. Satalecka, Y. Sestayo et al., for the IceCube Collaboration, Cosmic Matter, Wuerzburg (Germany), 24-29 September 2007.
- [10] Neutrino Triggered Target of Opportunity (NTOO) test run with AMANDA and MAGIC, 30th ICRC, International Cosmic Ray Conference, July 2007, Merida (Mexico), e-Print Archive: arXiv:0709.2640.
- [11] The MAGIC/IceCube Target of Opportunity Program test run, M. Ackermann, E. Bernardini, N. Galante, F. Goebel, M. Tluczykont, R. Wagner et al., for the IceCube and MAGIC Collaborations, Cosmic Matter, Wuerzburg (Germany), 24-29 September 2007.
- [12] Extension of IceCube at Lower Energy: the Use of AMANDA as Nested Array and the Future Perspectives, J. Becker, E. Bernardini, E. Resconi et al., for the IceCube Collaboration, Cosmic Matter, Wuerzburg (Germany), 24-29 September 2007.