Final Report

Funding Programme:	Helmholtz Young Investigators Groups
Project ID No.:	VH-NG-205
Project Title:	Multi-messenger studies of point sources of cosmic rays using data from IceCube
Group Leader:	Elisa Bernardini
Helmholtz Centre:	DESY
Participating University:	Humboldt
Report Period:	2006-2011

1) Summary (max. 1 DIN A4 page)

Please describe the main results and the progress achieved in comparison to the state of the art at the time of writing the application and give an outlook on possible future work and applications.

The objectives of the project were to contribute to the discovery of sources of high energy neutrinos and establish the multi-messenger approach. While no hints of cosmic neutrinos has been found so far by IceCube, the Young Investigator group provided substantial contributions to the field and gained considerable visibility in the experiments we participated to and in Germany (two theses received prestigious German awards). Moreover, we gained considerable additional knowledge as originary planned, by actively participating to the MAGIC Cherenkov Telescope. There we contributed to technical as well as scientific areas and gained boosted astrophysical background, thanks to the number of scientific successes of the experiments, to some of which we gave substantial contribution ourselves.
The main successes of the Young Investogator group are summarized here below.

- **Extension of the field of view of IceCube (and in general neutrino telescopes) to the full sky and to PeV energies:** we developed new data analysis concepts to reduce the otherwise overwhelming background of cosmic muons. For the first time we opened the field of view of a neutrino telescope to the entire sky (only half of the sky was previously accessible).
- **Advanced searches for neutrino flares**: we developed advanced data analysis concepts to study variable candidate sources of high energy neutrinos. On the one hand we developed dedicated searches, motivated by state of the art physics understanding. On the other we developed avanced statistical tests which improved the sensitivity to the expected weak signals.
- **Neutrino Triggered Target of Opportunity program:** we worked out phsyics concepts as well as technical solutions to coordinate quasi simultaneous observations of high energy neutrinos (by IceCube) and high energy gamma-rays. **We established the first coperation between a neutrino telescope (IceCube) and gamma-ray Cherenkov telescopes (MAGIC and VERITAS).**
- **We worked out catalogues of most probable neutrino source candidates,** based on state of the art theoretical predictions and electromagnetic information.
- **We developed a statistical approach to estimate the probability to observe enhanced states of high energy emission of selected astrophysical sources**.
- **We entered the field of high energy gamma-ray astronomy**, by actively participating to the MAGIC experiment. We contributed to both technical as well as scientific areas and had a leading position is a series of important publications. This was the first group at DESY participating in high energy gamma-rays strophysica, opening the way to subsequant participation in VERITAS, H.E.S.S. and the future CTA as well as HiSCORE.

2) Work and Results Report

a) Starting point (max. 1 DIN A4 page)

Please describe the point(s) at issue, the aims and the working hypotheses of the project.

The main objectives of the project were to contribute to the discovery of sources of high energy cosmic neutrinos and establish the so called “multi-messenger” method. The discovery of high energy neutrinos of cosmic origin aims at providing an unambiguous signature for acceleration of hadrons and this way address the question of the origin of cosmic rays. Due to the small cross section and low expected flux of neutrinos this is a difficult task and no indication of cosmic neutrino signals has been collected so far.
The IceCube neutrino telescope has been completed in the year 2010. This has represented a major milestone: **the minimum sensitivity to discover astrophysical neutrinos expected by favorable model predictions has been reached for the first time**. To establish a new observational window and discover cosmic neutrinos it is fundamental to push the potential of IceCube at the limit and, at the same time, develop advanced test hypotheses, exploiting the widest possible state of the art understanding of the physics problems addressed. Part of the planned activities were therefore devoted to **increasing the IceCube sensitivity to point sources of neutrinos. This we achieved in two ways: first of all we extended the energy range covered and, at the same time, the field of view**. For this, we improved the neutrino reconstruction and selection algorithms. In parallel, **new search strategies are were to be developed, aiming to increase the chance to discover comic neutrinos by looking for correlations with established signals** (e.g. flares in high-energy gamma-rays). In case of sources manifesting large time variations in the emitted radiation, the signal-to-noise-ratio can be increased by limiting the neutrino exposures to most favorable periods. The chance of discovery can be this way enhanced (the so-called multi-messenger approach). We also aimed at developing a **neutrino trigger for follow-up observations at relevant electromagnetic wavelengths**. Due to the limited theoretical understanding of the underlying phenomenology, **considerable work had to be dedicated to understanding which class of sources are the most suitable for this type of program and, in addition, which wavelength can be connected to the same mechanism responsible for high energy neutrinos**. Moreover, there was no established procedure to quickly analyze neutrino data in a way to generate prompt triggers (with maximum few hours delay with respect to data taking). To realize a trigger, it was necessary to **develop suitable (i.e. fast and well performing) algorithms** as well as **completely revolutionize the data analysis philosophy** (i.e. solve possible conflicts with the so called “blind analysis” principle). It was also necessary to establish the necessary synergies between independent experiments.

b) Description of the results (max. 4 DIN A4 pages)

Please describe the scientific and/or technical success of the group as well as secondary results achieved and essential experience gained. Please classify your own work within the national and international context.

The objectives of the project were to contribute to the discovery of sources of high energy neutrinos and establish the multi-messenger approach. While no hints of cosmic neutrinos has been found so far by IceCube, the Young Investigator group provided substantial contributions to the field and gained considerable visibility in the experiments we participated to and in Germany (two theses received prestigious German awards). Moreover, we gained considerable additional knowledge as originary planned, by actively participating to the MAGIC Cherenkov Telescope. There we contributed to technical as well as scientific areas and gained boosted astrophysical background, thanks to the number of scientific successes of the experiments, to some of which we gave substantial contribution ourselves.

The main successes of the Young Investogator group are summarized here below.

- **Extension of the field of view of IceCube (and in general neutrino telescopes) to**

the full sky and to PeV energies: we developed new data analysis concepts (from track reconstruction to the event selection) allowing to reduce the otherwise overwhelming background of cosmic muons from above the detector (i.e. the Southern sky for IceCube). This way it has become possible for the first time to search for cosmic neutrinos in the full sky [18, 35, 36, 37, 43]. With this approach, we also extended the sensitivity to multiple PeV energies, which were also previously non accessible to IceCube (and to neutrino telescopes in general). An illustration of this major result is given in Figure 1.

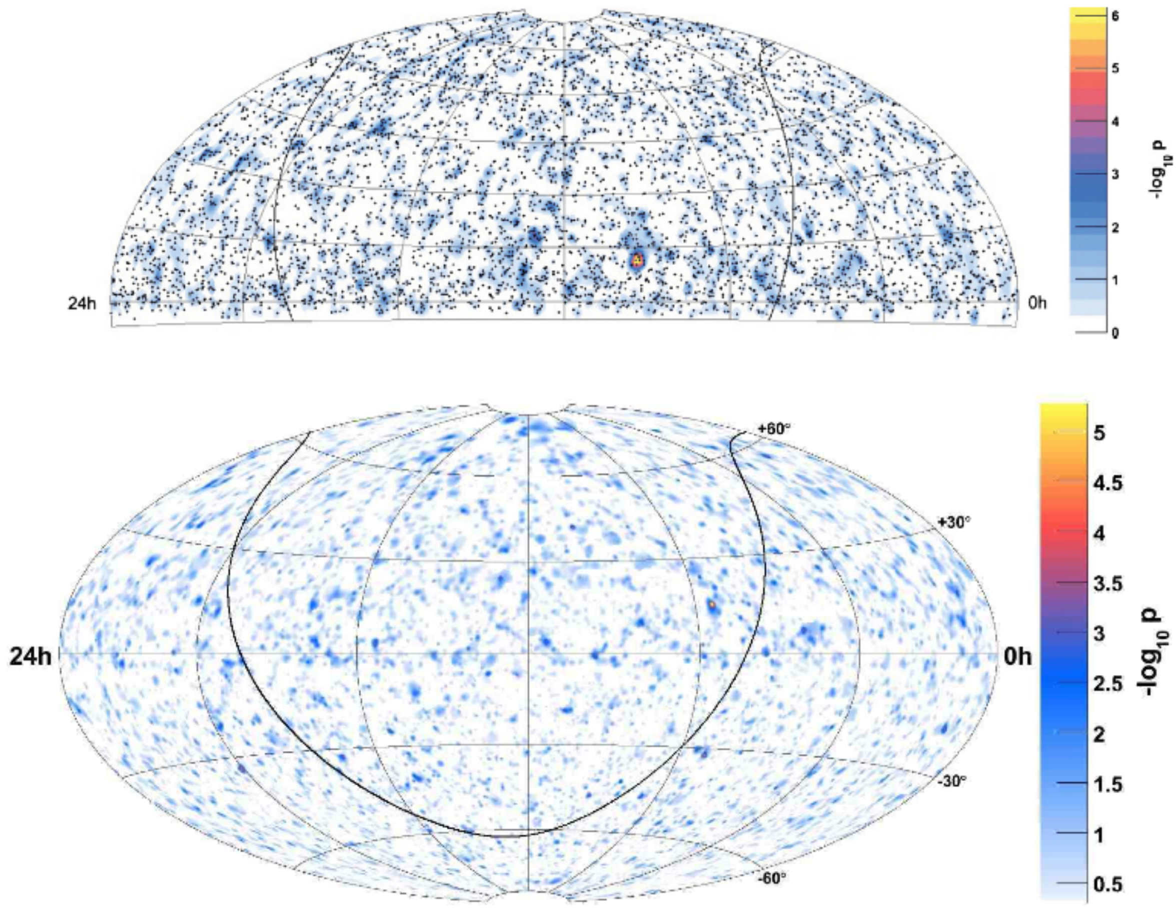

Figure 1: Extending the field of view of IceCube to the full sky: (top) a significance map before the implementation of the methods developed at DESY by the Young Investigator Group (figure from R. Abbasi et al. Astrophys.J.701, L47 (2009)); (bottom) a signficance map obtained after implementing the event selection concepts developed at DESY, to reduce the background of atmopsheric muons and allowing to test for csmic neutrinos in the entire sky (figure from R. Abbasi et al. Astrophys.J.732, 18 (2011)).

- **Development of advanced algorithms to search for neutrino flares**: we developed new data analysis concepts allowing to **search for flares of neutrinos in an untriggered manner** (i.e. the position and the length of the time window tested is not fixed a priopri e.g. based on external multi-wavelength data). This allows to enlarge the phase space tested, e.g. to cases in which there is no strict correlation of the neutrino emission with a given electromagnetic waveband and/or there is no available input electromagnetic data to identify a time window of enhanced high energy emission [e.g. 14, 38, 42, 44]. **We also developed new data analysis concepts allowing to identify** an overall occasional enhanced emission in the form of **a sequence of weak flares from a single source**, based on a “flare stacking approach” [1]. This hypothesis could not be tested with earlier methods used in neutrino telescopes.

- **Development of a neutrino alert system to trigger follow-up observations of potential neutrino flares**: we developed a system to promptly analyse data collected at the South Pole, from low level, to high level (neutrino events). The system constantly searches for enhancements in the neutrino flux from given directions of the sky, as well as the stability of the data records (through low level data quality selection). In cases of excesses of high energy neutrino events over time scales as long as three weeks an alert is set for a set of pre-selected directions (which are chosen in agreement with the cooperating partner experiments). For the time being, alerts are being sent to the Cherenkov telescopes MAGIC and VERITAS, which are ready to perform follow-up observations within the next available subsequent night. For this purpose, we worked out dedicated policies for the exchange of sensitive data between IceCube and the partner experiments and corresponding Memorandum of Understandings. We also regularly submitted observation proposals. We were granted several (<10) hours of observation time per cycle by MAGIC and VERITAS, which would suffice to guarantee suitable follow-up observations of the (expected) rare neutrino triggers. The alert system is active since March 2012. No alert has been sent to date of writing. **This work represents the first implementation of promt neutrino analysis** [34, 32, 35, 38] as well as **the first implementation of the so-called Neutrino Triggered Target of Opportunity program**.
- **We developed catalogues of most probable neutrino source candidates, based on state of the art theoretical predictions and electromagnetic information**. We performed extensive literature studies to review the state of the art theoretical understaning of the phenomenology connecting the emission of high energy neutrinos to electromagnetic wavelengths. We selected those models which are not being excluded by current observations. We selected a few wavelengths as indicators of possible flares of neutrinos associated to enhanced states of electromagnetic emission. We finally focused on a class of astrophysical sources (namely Blazars) and used state of the art experimental data at GeV energies from Fermi to select the possibly most luminous neutrino sources, based on the Proton Blazar Model by A. Reimer (2002) and the Neronov and Ribordy (2009) source selection (2009). We scan literature information for flares observed in optical, GeV and TeV energies to select periods of interest.
- **We developed a statistical approach to estimate the probability to observe enhanced states of high energy emission of selected astrophysical sources**. This is done by means of long-term gamma-ray light-curces obtained cross calibrating archival data of different instruments [2, 50] as well as promoting dedicated observation campaigns, see for example [9, 10, 26, 28, 29, 34]. Such a probabilty is of **extreme importance for the interpretation of any excess of neutrinos observed in coincidence with states of enhanced electromagnetic emission** (“multi-messenger correlations”). We created a public archive which is being used in many different research areas. An illustration of the data we collected is given in Figure 2, which is regularly being shown in many presentations at international conferences. We also created a public access data base [http://nuastro-zeuthen.desy.de/magic_experiment/projects/light_curve_archive/index_eng.html].

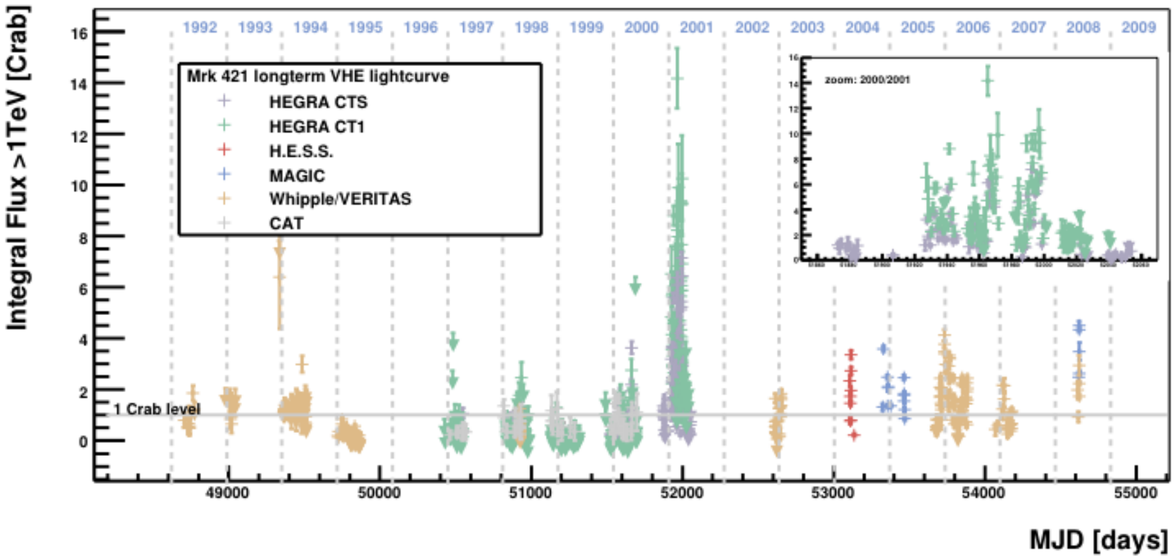

Figure 2: Long term gamma-ray light-curve of the source Markarian 421, spanning 17 years of observations. This is the most impressive coverage ever reached in gamma-rays for any astrophysical source. From K. Satalecka, Humboldt University (2010).

- **We entered the field of high energy gamma-ray astronomy**, by actively participating to the MAGIC experiment. We contributed to both technical (e.g. validation of reconstruction software, Monte Carlo simulation production, commissioning of the second MAGIC telescope) as well as scientific areas (e.g. monitoring of known Blazars, discovery of Flat Spectrum Radio Quasars (like 3C279), coordination of multi-wavelength campaigns and promotion of successful observation proposals for Blazars (LBLs, and FSRQs) and had a substantial contribution to a series of important publications [3-13]. One of the most recent results was achieved in the study of the broadband emission of Supernova remnants. **At DESY we developed a set of tools to interpret the high energy emission of the object W51C.** It was found that hadronic models best described the broadband emission of the object, contrary to leptonic models, **making this source a prime candidate for cosmic ray acceleration on the Galaxy** [3]. We finally **contributed to the instrumentation of the camera of the second MAGIC telescope with high quantum efficiency PMTs and also contributed to the first large scale file test of Hybrid Photodetectors** [24, 25]. This was the first group at DESY participating in high energy gamma-ray astrophysics, later followed by participation in VERITAS, H.E.S.S. and the future CTA as well as HiSCORE.

c) Outlook on future work, sustainability (max. 2 DIN A4 pages)

Did you encounter unexpected effects or questions during the funding period? Do you see the need for further research in this respect? Please describe planned activities to further develop this work, also if to be carried out elsewhere or in a different constellation.

…

No indication of cosmic neutrinos has been found so far by IceCube. The next two-to-three years are the most important to ultimately clarify the scientific yield of state-of-the-art neutrino astronomy. It is therefore important to keep a certain involvement in the IceCube experiment and contribute to the search for point sources of neutrinos. I will work on topics connected to the multi-messenger approach, which has been clearly distinguishing my contributions in the last few years, as well as on technical improvements of the observation technique. In particular I will further pursue the Neutrino-triggered Target of Opportunity program with IceCube and MAGIC (and, more recently, VERITAS) and work towards the development of this approach into a tool for realtime astronomy. The necessary resources (personnel as well maintenance and operation) are available within the budget of the DESY astroparticle group.

The major unexpected effect encountered during the entire project was an active participation of the Young Investigator group of DESY to the MAGIC experiment. I aimed at an active contribution to the analysis of data from TeV gamma-ray experiments at the Humboldt University, to have access to data which is often not been published (e.g. monitoring data of known sources). Another goal, was to obtain deeper understanding of such data, for a better exploitation in correlation studies with neutrinos. Since TeV Cherenkov Telescopes do not grant public access to data, it became clear that to achieve such a goal it was necessary to become member of one of such experiments. In 2007 I was granted a special funding by the Helhmoltz Association, to contribute to the intrumentation of the camera of the second MAGIC telescope and increase the sensitivity at low energies (which is a fundamental feature to be able to detect an important class of high energy gamma-ray sources which are also primary candidate for high energy neutrinos, namely Flat Spectrum Radio Quasars, hereafter FSRQs). With this funding it became possible to enter the MAGIC experiments as full members. We contributed in several scientific and technological areas and opened the way to the participation of DESY (and the Helmholtz Association) to the future Cherenkov telescope CTA.

Today I am leading a very small but recognized MAGIC group at DESY (one PhD student and one post-doc), based on the resources of the Helmholtz YIG grant. The small group currently works on the analysis of data as well as the interpretation of the observed emission of Active Galactic Nuclei (hereafter AGNs) and Supernova Remnants. In the future, I aim at a strengthening of both the DESY involvement in MAGIC and CTA (making DESY the only place in the world housing involvement in all key IACT experiments which are paving the way to CTA), as well as of the astroparticle group at the Humboldt University as a whole and of its participation in CTA. This perfectly fits in the overall scientific plan of both DESY and the Helmholtz Association, as well as of the Humboldt University. Three working packages are planned to be covered with the additional resources granted by the Helmholtz Association to newly created W2 positions if the negotiation fort he W2 position at Humboldt turn successful in fall 2012:

1) Hadronic models of opaque sources like Flat Spectrum Radio Quasars (hereafter FSRQs). These sources are very interesting for gamma-ray astrophysics, both being among the most distant observable objects (and as such potentially providing a laboratory for cosmological studies) and so far the least understood in terms of a plausible emission mechanism. In particular, they are promising candidate sites for hadron acceleration, making them interesting also in the context of cosmic ray physics as well as neutrino astronomy.

The goal of this working package is to develop semi-analytical hadronic models to fit the multiwavelength spectral energy distributions and extract astrophysical information (i.e. energy density of accelerated particles, magnetic field strength etc.) of FSRQs as well as other (simpler from the astroparticle modeling perspective) AGNs. This activity will be quite original and unique in the field. In fact, while there are publicly available similar parametrizations based on electromagnetic fits, there are very few theorists currently capable of explaining the high energy emission in the context of hadronic models (i.e. assuming a certain contribution of accelerated protons, more complex from the particle physics point of view).

2) Improved hadron background rejection with IACT. Among all the IACT installations MAGIC is currently offering the lowest energy threshold. The scientific harvest offered by this feature is spectacular and recently ensured the discovery of pulsed emission at very high energies from the Crab Nebula as well as a set of most distant objects in the Universe (for which high energy photons are suppressed due to interactions with the extragalactic background light and detection is only possible at low energies and with large effective areas). Still, the full potential (which may yield in the future results also in the study of Dark Matter and well as in the physics of Gamma Ray Bursts) needs to be explored, the main limit currently being the still dominant hadron background and the somewhat larger systematic uncertainty. To boost the physics

potential of future installations like CTA these aspects need to be more comprehensively addressed. MAGIC is currently the best suited experiment to explore this sector. This work will be done within the framework of two analysis working groups in MAGIC and in cooperation with the software board. It could progressively use CTA software for analysis and simulation. This last aspect would offer the ideal ground for concrete cooperation with the DESY groups working on the other IACT installations (VERITAS and H.E.S.S.).

3) Measurement of the electron spectrum with MAGIC. Measurements by the ATIC and PAMELA collaborations point towards a relatively local source of positrons and electrons. The main candidates for such a source are either pulsars or Dark Matter annihilation, besides Supernova explosions and the interactions of cosmic rays with the interstellar matter. One marker to distinguish the two first cases is the spectral shape (the Dark Matter spectrum exhibiting a sudden drop at an energy corresponding to the Dark Matter particle mass, contrary to the smoothly decreasing pulsar spectrum). MAGIC is an ideal instrument to contribute to this measurement, due to its low energy threshold, compared to other Cherenkov telescope installations. The wide energy range that can be covered offers a very good overlap at low energies with Fermi and at high energies with H.E.S.S., therefore allowing a good cross calibration of independent techniques over roughly two energy decades. This work will be conducted in collaboration with other MAGIC groups as well as in cooperation with the DESY groups involved in Dark Matter related searches at DESY, i.e. the VERITAS and the theory group in the framework of the Helmholtz Allianz for Cosmic Particles) and the H.E.S.S. group at the Humboldt University. Moreover, Dark Matter related searches are a key topic of the above mentioned Graduate School "Mass, Spectrum, Symmetry (GK 1504)" and this activity well fits its programmatic plan.

d) Potential for application/exploitation (max. 2 DIN A4 pages)

How do you yourself assess the potential for application or exploitation of the results? Where do you see future possibilities? Please describe realized or planned measures for applying the results. Please also include information on patents, licences, co-operations with industry, etc.

- **Extension of the field of view of IceCube (and in general neutrino telescopes) to the full sky and to PeV energies:** The concepts we developed have become a standard for IceCube (and Antares), see for example [17]. A complete list of publications exploiting this method could be provided under request.
- **Development of advanced algorithms to search for neutrino flares**: the methods developed were applied to IceCube data [14, 35, 38, 39, 41, 42, 44] and are currently further extended to multiple sources, based on a "source stacking approach".
- **Development of a neutrino alert system to trigger follow-up observations of potential neutrino flares**: **this work represent the first implementation of promt neutrino analysis**, with benefits in many other areas of IceCube data analysis, allowing for the first time promt follow-up analysis of interesting events, like the unexpected gamma-ray flare of the Crab Nebula, see [Science 11, February 2011]. **This lead to the first promt neutrino analysis** [16]. The data processing scheme developed was also extended for a similar program which took inspeiration from this work and was extended to optical wavelengths in the search for neutrinos associated with Supernovae and Gamma Ray Burst [15]. The system developed will be further extended in the future to the full sky (i.e. additing the Southern Sky) and to an unbiased set of sources (i.e. any possible direction of the sky). I also plan to extend the system including more advanced stastical techniques (based on a maximum likelihood approach as opposed to the current binned method, see also point 2 of this report).
- **We developed catalogues of most probable neutrino source candidates, based on state of the art theoretical predictions and electromagnetic information**. These catalogues are used in several IceCube analyses (e.g. a dedicated analysis for neutrino flares from 3C279 in [18], time variable searches in IceCube [14]).
- **Assessment of the probability to observe states of enhanced emission of known objects**: we could access this parameter for a limited set of sources, for which sufficient

high energy gamma-ray data is available. Further progress will be achieved in the future with increasing exposures to other objects. **The probability we have derived is a fundamental (and essential) parameter to interpret any correlation studies to neutrinos** [e.g. 41]. Due to the limited discovery potential of neutrinos alone (because of the low expected neutrino fluxes) the observation of excesses of neutrinos in coincidence with states of enhanced emission at other wavelengths, where signals can be detected with much higher significance, is most likely a key approach to establish neutrino astronomy. To be able to disentangle statistical fluctuations to real discoveries, the above mentioned probability would then be a fundamental ingredient.

- **Modeling the broadband emission of Supernova remnants**: besides the results shown in [3], the set of tools we develoepd at DESY is general and is currently being applied to a series of other sources. It also allows a motivated prediction of the probabilty to discover new very high energy emitters to be observed with MAGIC and is therefore being used to optimize obervation proposals.

Patents, licences, co-operations with industry do not apply to this project.

3) Qualification of Junior Researchers (max. 2 DIN A4 pages)

Please describe the structure of the Young Investigators Group in the course of the funding period and the main achievements regarding personal qualifications (including your own): Diploma degrees, conferring of doctorates, "Habilitations", appointments/junior professorships, tenure track, awards, etc. Please also describe any particularities as well as your work-related plans after the end of the funding period.

During the course of the funding period the group was each year composed of myself (leader), one post-doc, up to 4 PhD student and, occasionally, one diploma, one bachleor and few summer students.
Altogether, not accounting short post-doc contract periods for the students that graduated with me, I have been working together with four post-doc, nine PhD students and four diploma (master) students.
After the funding period, I am still leading a group composed of one post-doc and five PhD students. Some of the members work in the IceCube experiments and other in the MAGIC experiments. I was positively reviewed for the W2/W3 funding program of the Helmholtz Association of excellent female scientists. The negotiations for a W2 position at the Humboldt University are in progress.
A detailed list of diploma or doctoral degrees conferred during the Young Investigator funding period, as well as awards, is given below.

Theses supervised (or still in progress)

- Rafael Lang, Diploma, Faculty of Sciences, Universität Ulm, 2005, title: Search for Point Sources of High-Energy Neutrinos with the AMANDA Detector. Afterwards appointed for a PhD at the Max Planck Institute in Munich.
- Markus Ackermann, PhD, Humboldt-Universität zu Berlin, 2006, title: A search for neutrinos of cosmic origin with the AMANDA-II detector. Afterwards appointed for a post-dco position at SLAC (USA). Today staff scientist at DESY.
- Robert Franke, Diploma, Humboldt-Universität zu Berlin, 2007, title: A new Approach to the Search for Point-like Sources of Cosmic Neutrinos at PeV Energies with AMANDA-II. Afterwards appointed for a PhD at DESY.
- Sirin Odrowski, Diploma, Leibniz Universität Hannover, 2008, title: Neutrino triggered Target of Opportunity (NToO) gamma-ray observations triggered by IceCube: Development of the alert trigger. Afterwards appointed for a PhD at the Max Planck Institute in Heidelberg.
- Robert Lauer, PhD, Humboldt-Universität zu Berlin, 2010, title: Extending the search for cosmic point sources of neutrinos with IceCube beyond PeV energies and above the horizon. Afterwards appointed for a post-doc at the Department of Physics and Astronomy at the University of New Mexico (USA).
- Konstancja Satalecka, PhD, Humboldt-Universität zu Berlin, 2010, title: Multimessenger

studies of point-sources using the IceCube neutrino telescope and the MAGIC gamma-ray telescope. Afterwards appointed for a psot-doc at the Computaitonal University of Madrid (Spain).

- José Luis Bazo Alba, Humboldt-Universität zu Berlin, 2010, title: Search for steady and flaring astrophysical neutrino point sources with the IceCube detector. Afterwards appointed for a post-doc at INFN in Perugia (Italy).
- Fabian Jankowski, Diploma Humboldt-Universität zu Berlin, 2012, title: Modeling the multi-wavelength emission of Supernova Remnants: spectral properties of W51C as observed with MAGIC. Applying for a PhD position.
- Robert Franke, PhD, Humboldt-Universität zu Berlin, expected 2012.
- Gessica de Caneva, PhD, Humboldt-Universität zu Berlin, expected 2013.
- Angel Humberto Cruz Silva, PhD, Humboldt-Universität zu Berlin, expected 2013.
- Kathrin Mallot, PhD, Humboldt-Universität zu Berlin, expected 2013/2014.
- Meike de Width, PhD, Humboldt-Universität zu Berlin, expected 2014/2015.

Awards

- Markus Ackermann, PhD Humboldt University in Berlin (2006): DESY Physics Review
- Committee prize in 2007.
- Robert Franke, Master Humboldt University in Berlin (2008): Heraeus Fundation prize in 2008.

4) Public relations

By which means did you gain publicity (e.g. reporting in media, own website)?

Although I have a own web site and a group web sitye through the DESY server, I believe that the best mean to gain publicity has been participation to conferences. I was invited to give a series of well prestigious talks (among which a review on Gamma-rays and Neutrinos at the Europhysics Conference on High Energy Physics in Manchester (England), in 2007 and a review on Neutrino Astrophysics at the meeting of the German Physics Society in Bonn in 2010).
I have been invited to organize a series of international conferences (e.g. *II MAGIC Stereo Analysis Workshop* in DESY Zeuthen (2011), *Particle Astrophysics with Atmospheric Cherenkov Telescopes* (parallel session convener) at the TeVPa09 Conference SLAC/USA (2009), *High Energy Neutrino* (parallel session convener) at the TeVPa08 Conference Beijing/China (2008) and most recently the Neutrino Oscillation Workshop in Conca Specchiulla (Italy) and the International Symposium on Very High Energy Cosmic Ray Interactions (ISVHECRI), both in 2012).
I was invited to write a review book on Neutrino Astrophysis by Whiley.
I am regularly serving as referee for journal publications (among other Science) and I was invited to write a **perspective article on Science**.

5) Networking

What co-operation and communication structures (centre/university if applicable) have been developed during the course of the funding? How satisfied are you with the co-operation with the Helmholtz-Centre / university?

During the course of funding I received positive support by the Humboldt University of Berlin. In 2007 I was Acknowledged the right of independent performance of research and teaching duties (“Selbständige Wahrnehmung von Aufgaben in Forschung und Lehre”) as well as supervision of doctoral projects and evaluation of doctoral theses (“Recht Promotionsvorhaben zu beteuen und die Dissertation zu begutachten, sihe hierzu § 4 Abs. 2 der PromO vom 01.10.2002”) at the Humboldt University of `Berlin.
I contributed to the application to the Deutsche Forschungsgemeinschaft for a research training school and since 2009 I am Faculty member of the *Mass, Spectrum, Symmetry Graduiertenkolleg* (Research Training Group GK 1504) at DESY in Zeuthen/Germany, Humboldt University of Berlin/Germany and Technical University of Dresden/Germany. I also serve as member of its selection committee.

6) List of Publications

Articles in scientific journals, written contributions to scientific meetings, contributions to books, study or Diploma theses, dissertations, "Habilitations", reports and other publications.

It follows a list of journal publications with either exclusive or fundamental contribution from the Young Investigator Group.

Refereed journal publications (Few authors)

[1] A method for untriggered time-dependent searches for multiple flares from neutrino point sources, D. Gora, E. Bernardini and A.H. Cruz Silva, accepted for publication to Astroparticle Physics.

[2] Long-term lightcurves from combined unified very high energy gamma-ray data, M. Tluczykont, E. Bernardini, K. Satalecka, R. Clavero, M. Shayduk, and O. Kalekin, A&A 524, A48 (2010).

Refereed journal publications (MAGIC)

[3] Morphological and spectral properties of the W51 region measured with the MAGIC telescopes, MAGIC Collaboration (J. Aleksić et al.), accepted for publication to Astron. Astrophys.

[4] Mrk 421 active state in 2008: the MAGIC view, simultaneous multi-wavelength observations and SSC model constrained, MAGIC Collaboration (J. Aleksic et al.), submitted for publication to Astron. Astrophys.

[5] Fermi large area telescope observations of Markarian 421: The missing piece of its spectral energy distribution, Fermi and MAGIC Collaboration (A.A. Abdo et al.), Astrophys. J. 736, 131 (2011).

[6] MAGIC discovery of VHE Emission from the FSRQ PKS 1222+21, MAGIC Collaboration (J. Aleksić et al.), Astrophys. J. Letters 730, L8 (2011).

[7] MAGIC observations and multiwavelength properties of the quasar 3C279 in 2007 and 2009, MAGIC Collaboration (J. Aleksić et al.), Astron. Astrophys. 530, A4 (2011).

[8] Spectral Energy Distribution of Markarian 501: Quiescent State vs. Extreme Outburst, VERITAS and MAGIC Collaborations (V.A.Acciari et al.), Astrophys. J. 729, 2 (2010).

[9] Insights Into the High-Energy Gamma-ray Emission of Markarian 501 from Extensive Multifrequency Observations in the Fermi Era FERMI, MAGIC and VERITAS Collaborations, accepted for publication Astrophys. J. 2010 October.

[10] MAGIC TeV Gamma-Ray Observations of Markarian 421 during Multiwavelength Campaigns in 2006, MAGIC Collaboration (J. Aleksić et al.), Astron. Astrophys. 519, A32 (2010).

[11] Simultaneous Multiwavelength Observation of Mkn501 in a Low State in 2006, MAGIC Collaboration (H. Anderhub et al.), Astrophys. J. 705 (2009) 1624.

[12] THE JUNE 2008 FLARE OF MARKARIAN 421 FROM OPTICAL TO TEV ENERGIES, AGILE, GASPWEBT, MAGIC,VERITAS Collaborations, (I. Donnarumma et al.), Astrophys. J. Lett. 691, L13 (2009).

[13] MAGIC upper limits to the VHE gamma-ray flux of 3C454.3 in high emission state, MAGIC Collaboration (H. Anderhub et al.), Astron. Astrophys. 498, 83 (2009).

Refereed journal publications (AMANDA/IceCube)

[14] Time-Dependent Searches for Point Sources of Neutrinos with the 40-String and 22-String Configurations of IceCube, IceCube Collaboration (R. Abbasi et al.), Astrophys. J. 744, 1 (2012).

[15] Searching for soft relativistic jets in Core-collapse Supernovae with the IceCube Optical Follow-up Program, The IceCube and The ROTSE Collaborations (R. Abbasi et al.), Astron. Astrophys.

[16] Neutrino analysis of the September 2010 Crab Nebula flare and time-integrated constraints on neutrino emission from the Crab using IceCube, IceCube Collaboration (R. Abbasi et

al.), Astrophys. J. 745, 45 (2012).
[17] Time-Integrated Searches for Point-like Sources of Neutrinos with the 40-String IceCube Detector, IceCube Collaboration (R. Abbasi et al.), Astrophys. J. 732 , 18 (2011).
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