Statement of Purpose

The origin of the Universe as well as many other topics in contemporary astronomy, particle physics and cosmology may be elucidated with the developments taking place in the cross-disciplinary field of neutrino astrophysics. The reason for this can be found in the unique properties of neutrinos: they interact with the interstellar medium a lot less than photons or any other type of cosmic rays, their trajectories do not bend in the galactic electromagnetic fields and they propagate over a lot larger distances than photons or high-energy nuclei. They also serve as traces of hadronic processes in contrast to electromagnetic processes. By detecting high-energy neutrinos it would be possible to look into a lot deeper space than ever before. Four large under-water/ice neutrino detectors are presently at different stages of planning and operation. One of them was built in Lake Baikal in Russia, and it is one of the two currently operating neutrino telescopes. The purity of the water in the lake and the ease of access to it played major roles in choosing the location of the detector. The same can be said about the other currently operating neutrino telescope, called AMANDA, which is located at the Amundsen-Scott South Pole station. The unsurpassed purity and transparency of ice together with a well-developed infrastructure of the station made it an ideal choice for the location of the detector. The detector is built and operated by a collaboration of scientists from the USA, Germany, Sweden and Belgium. Berkeley is one of the founders of the experiment and plays a major role in it. The other two neutrino telescopes, to be located in the Mediterranean Sea, are only in the planning stages.

Last academic year (98/99) we had a visiting professor at Berkeley, Wolfgang Rhode from Wuppertal (Germany), who was invited to join the AMANDA collaboration. His goal was to transfer knowledge and experience acquired by AMANDA to the group of scientists in Wuppertal. We (he and I) have started working on a research project that will become my thesis. The aim of the project is to develop and implement a new scheme for generating a Monte Carlo signal for the existing and planned neutrino telescopes that will significantly improve the precision of the current routines, improve on the data analysis methods, and find possible new correlations between various data elements. This research will be used to estimate the efficiency of the AMANDA detector and to find new ways to increase it.

All of the currently realizable computer programs that generate this signal are based on Monte Carlo techniques. They propagate cosmic rays of known energy spectra through the Earth's atmosphere. Improving upon the air propagation scheme is the first part of my project, and I have already accomplished it. We have replaced the existing routines for the propagation of cosmic rays through air that are based on the Basiev simulation (Basiev) by the CORSIKA program. The former is a Russian-Zeuthen invention, preferred by several neutrino telescope groups for simulation of their data for some time now, primarily because of its computational speed advantage. The latter is a program written in Karlsruhe (Heck, et al., 1998) and used by hundreds of researchers around the world. It incorporates five hadronic interaction models, which have grown to become a standard in particle physics: GHEISHA, VENUS, QGSJET, DPMJET and SIBYLL. Questions have been raised about the accuracy that the Basiev code provides. There are several assumptions in it that are made in order to speed up the calculation. One of them is that the cosmic rays are 100% composed of hydrogen, whereas in fact this number is only about 60%, the remainder being helium and heavier elements. By using CORSIKA, we analyze not only proton but also many other contributions to the cosmic ray flux from all particles that are currently supported by the interaction models built into CORSIKA. This changes the spectra of the detectable particles at the ground level to a noticeable degree. In the Basiev-based simulations this discrepancy is overcome by changing the spectral index of the primary protons at the top of the atmosphere from the measured value. In our calculation we use the spectra measured at the top of the atmosphere and get results consistent with spectra from underground experiments at the bottom. The differences between the high-energy hadronic interaction models, built into CORSIKA, and the agreement with experiment as well as all other modifications and improvements we made are discussed in our paper (Chirkin & Rhode), accepted for presentation this August at the 26th International Cosmic Ray Conference, to be held in Salt Lake City, Utah. We have fully adapted our program for future integration into the full detector signal simulation. It gives the output in the standard form (adopted by several groups, working on neutrino detectors), and allows integration into the working chain of the detector signal simulation currently in use. We are running the program at this time at a computer facility consisting of 31 Pentium II processors at UC Berkeley. To this moment we have collected a large statistics (1.7 billion primaries analyzed).

The next part of my project will be to propagate the particles taken at the ground level through the ice or water to the underground detector. That will require some improvement of the precision of the muon propagation routines. All neutrino detectors currently being utilized or built are looking for Cherenkov photons emanating from upgoing muons created by interactions of cosmic neutrinos with the detector medium. There is also a background of downgoing muons created by air showers generated by cosmic rays that is about six orders of magnitude greater than the signal, and of muons created by neutrinos of similar origin that is about two orders of magnitude greater than the signal. To show that the operation of a neutrino telescope is possible, we need to show that it is possible to separate the signal from such a large background of noise. That is why it is imperative that we supply high precision algorithms at each step of the calculation. It is especially true for the muon propagation step. A muon may interact several thousands or even tens of thousands of times before it produces a

Cherenkov photon that hits an optical module in the detector. Each time it interacts, it loses energy or bends its trajectory. A typical error of 1% is introduced at each step by simulations currently in use (MUDEDX, NUTOMU, GEANT, MUSIC and AMASIM). This may lead to cumulative errors of several hundred to a thousand percent, which places the whole muon propagation scheme, currently used, in doubt. It is clear that the precision of this step of the calculation must be improved. With the introduction of even faster computers this may not seem like a major problem. One may adapt existing programs for faster computer resources and get a better accuracy. With a quickly increasing number of cross sections to evaluate as the precision increases it is doubtful, however, that the required accuracy can be achieved on any stand-alone computer system to be built within the next few years. Therefore, a cluster of computers should be used. One may write a Perl script to manage the calculation, and since it is a Monte Carlo calculation, it is very easy to define separate independent tasks to be distributed among the computers. It is not going to be the most efficient use of the resources though. The number of computers will be very limited - here, at Berkeley, I do not have easy access to more than 20 computers. And, in many cases, if we decide to use more than 20 computers, they are going to be not only PCs running Linux, but also PCs running Windows, SUNs running Solaris, DEC workstations running Digital UNIX, and perhaps even MACs running MacOS. Writing a script that would manage a big number of computers so different and even compiling the program for more than one OS would be a complicated task.

A novel and, as we think, better approach would be based on a program that is written in a platform-independent language. The programming language that we have in mind is Java. It is supported on most computer platforms available today, and it is very portable on them. The program that would manage the execution of our code is SYMPHONY (Symphony). It is currently under development, but has already been successfully tested on a number (up to 100) of computers in student facilities at the University of Freiburg. The client program being written in Java, the ease of installation may bring a number of computers available to a level well beyond expected. My primary goal to be completed in Germany will be to write a complete muon-through-ice propagation code in Java, incorporating all cross sections and energy losses required for the precision we are looking for, as well as tailoring it to work as part of the detector simulation.

This summer, aside from studying German, I am working on a project designed to model the properties of ice measured at the South Pole. The levels of impurities are inferred from the scattering and absorption coefficients drawn from AMANDA-B calibration data as well as from more direct ice core measurements. The results from this research will be used in writing the muon propagation code. To test this code, as well as the air propagation simulation, I will need to compare the outcome with the measurements of the underground experiments.

The main source of these is the results published by the Frejus collaboration (Frejus). Once in Germany, I will have access to the Frejus data, which will give me an opportunity to improve the simulation. I will also be able to interact with DESY researchers from Zeuthen, who have written large parts of the data analysis code used by the AMANDA collaboration, and the research group in Mainz which recently joined the AMANDA collaboration.

Germany is moving into a role of international leadership in neutrino astrophysics, especially its computational aspects. The experience I acquire while in Germany will clearly be valuable to the group in Berkeley. Personally, I am looking forward to going to Germany, because it will allow me to complete an important step on the way to my degree by giving me a chance to interact more closely with my research advisor, who is a world authority in the field of muon propagation, and giving me access to the resources I need. It will allow me to take my qualifying examination by the time I return to USA. It will also give me an excellent chance to practice my German.

References

Basiev: http://www.ifh.de/baikal/software/siegmund/gen_3.html
Heck, D., et al. 1998, Report FZKA 6019, Forschungszentrum Karlsruhe
Chirkin, D. and Wolfgang, R., Proc. 26th ICRC (Salt Lake City, 1999)
Symphony: http://vowi.ruf.uni-freiburg.de/Test/Symphony
Daum, K. et al., Frejus Coll. 1995, Z. Phys. C 66, 417