Progress Report February –June 2005

4 July 2005.

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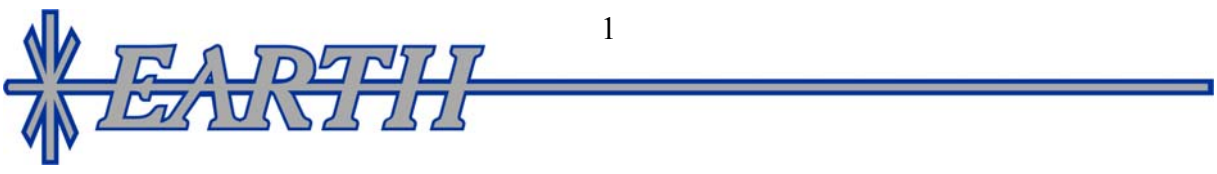

This document presents an overview of the essential events related to the Earth AntineutRino TomograpHy (EARTH) programme in the period February-June, 2005. This is the fourth progress report: the previous ones covered the period May-August 2004 and September-October 2004 and November 2004-January 2005.

General situation.

In the present period some important developments took place. On 21-23 March the Natural Sciences Cluster of the Faculty of Mathematics and Natural Sciences of the University of Groningen was evaluated by a Peer Review Committee. Although EARTH was only mentioned in the future outlook and not as a part of the evaluation, the project raised quite an intensive discussion. The final results of the evaluation are not available yet, but it tends to a recommendation for a review of EARTH by an expert committee on neutrino detection and geophysics.

In Groningen the Board of Advise of EARTH met for the first time on 11 April. The Board, chaired by Prof. Butcher of ASTRON, discussed the future structure of EARTH. It was generally agreed that EARTH is an ambitious programme with a wide scientific and technological scope. Only part of the scope, development of a directional sensitive antineutrino detector, fits in the mission of the KVI. It was therefore suggested and accepted that a foundation should be created with the goal "To support and maintain scientific and technological development, which may lead to a mapping of the radiogenic heat sources in the Earth's interior by detection of antineutrinos". The founders will be the University of Groningen, ASTRON and the Foundation JADE. After the foundation is created it will take over all general activities from the KVI. The role of the KVI will be that of one of the partners in detector development. In the meantime the foundation is not yet created, but the founding fathers have agreed on the text of the foundation act.

The Board of Advise concluded that EARTH was developing well and that a review committee for EARTH should take place as part of the go/nogo decision at the end of Phase I. On the detector development, especially on background reduction techniques, first some experimental work has to be done to make a relevant evaluation possible.

On 12 April it was officially announced that the KVI anticipates a close collaboration with Gesellschaft für Schwerionenforschung mbH in Darmstadt, Germany. On the one hand KVI has to curtail its non-mission activities, on the other hand the detection of low-energy neutrons (one of the key issues in the EARTH detector development) will be part of the mission activities under the anticipated KVI-GSI collaboration. As a consequence the KVI will pull out of the more geophysics oriented aspects of the EARTH programme.

The advertisement of a post-doc position led to 22 applicants from all over the world. Based on the information we selected two candidates for an interview at the end of March-beginning of April. After the interviews we were convinced that we had selected two top-quality candidates with complementary skills. Based on that conclusion we decided to search for an opportunity to attract both of them. Due to circumstances a position for a physicist became available at one of our main industrial partners. We are glad that we can announce that, depending on a work permit, dr. Matjaz Vencelj from Ljubljana, Slovenia will join Hi-Light Optics on 1 September. Since Hi-Light and EARTH have a similar goal in the photonics part of the detector development he will work part of his time on the EARTH detector.

For the second candidate we worked out a position such that he could work at detector development. The candidate, however, received a job-offer from two large and prestigious laboratories and projects. Our offer could not match at an offer from Princeton University that

the candidate could not refuse. He will be partly working in the underground laboratory of Gran Sasso and will hopefully stay in contact with us.

Funding

With the start-up funding by ASTRON and the matching in manpower by the KVI, the programme has been declared started on 1 September 2004. Several attempts to obtain a written confirmation from the South African National Research Foundation (NRF) have not yet been obtained, but in practice the people at iThemba LABS and the University of Cape Town (UCT) are working on the programme as agreed. On 22 February 2005 Ricky Smit (iThemba LABS) and Rob de Meijer visited the Director General of the South African Department of Science and Technology. In the meeting the DG expressed his interest in the programme EARTH and offered also support for an application in the EU programme New and Emerging Science and Technology (NEST). Moreover we discussed again the financial support for the South African contribution to EARTH. A budget has been supplied but no decision has been received yet.

A proposal was submitted to the Dutch Organisation for Physics Research FOM on 21 March. The funding is requested for developing, building and testing of a directional sensitive antineutrino detector. Funding would give us an opportunity to hire a graduate student and buy some equipment for an initial detector set-up. The final decision is expected soon.

On 11 March the outline proposal “Towards Earth Antineutrino Tomography” was submitted to the EU for the programme NEST/Adventure. This limited size proposal is due to be evaluated before a full scale proposal can be submitted. The requirements mention a highly ambitious, high risk programme in which Europe will be unique. The proposal is submitted together with the Physics Department University of Jyväskylä, Finland, Physics Department University of Debrecen, Hungary, and the Jozef Stefan Institute, Ljubljana, Slovenia as Physics partners and GeoForschungsZentrum Potsdam for the International Continental Scientific Drilling Programme, Applied Geophysics of the Aachen University of Technology and Nederlands Instituut voor Toegepaste Geologie-TNO as the Geophysics partners. No reply from the EU has yet been received.

To obtain funding for the ongoing and upcoming projects in the first phase a variety of funding possibilities have been explored. Since May 2004 we have worked with Technology Centre Northern-Netherlands (TCNN) on the preparation of two applications in the programme Innovatiesubsidie Samenwerkingsprojecten (IS) of the Dutch Ministry of Economic Affaires. One is focussing on the detector and electronics development, the other is aiming at investigating the feasibility of drilling for an EARTH antenna on Curaçao. In addition financial support for the antenna part is being sought from funds specially dedicated to collaborations with the Netherlands Antilles and in particular Curaçao. These possibilities were discussed with the authorities of the Antilles during the visit that Emiel van der Graaf and Rob de Meijer paid to Curaçao in the first week of January.

Due to the sudden change in mission of the KVI a proposal ready to be submitted for the detector development to IS, had to be postponed until its new deadline in September. On 12 May the international proposal for EARTH-DRILL (the antenna part) was submitted to SenterNovem as an application for IS-funding. In the proposal the three Geoscience partners of the NEST proposal, Focus Oil and Gas, TCNN, EARTH Foundation/ASTRON and

Aqualectra (Curacao) are partners. ASTRON has signed the funding request and will transfer its commitments to the Foundation after its initiation.

In the second half of June we started the preparation for the submission of the EARTH-SENSOR proposal. Soon an appointment will be made for a first round of discussions with SenterNovem.

Curaçao

An antenna on Curaçao will require well trained and educated people to operate it. As such training takes time we have to make high school students interested in science studies. During our visit to Curaçao we met with representatives of the UNA and some of the high schools at Curaçao and with the Stichting Studiefinanciering Curaçao. With the latter we discussed possibilities of stimulating high-school students to take up studying in a science direction. With the UNA we discussed their role in educating the science students and possibilities for collaboration with the University of Groningen. In addition the UNA has offered to take a coordinating role in a Hisparc project on Curaçao for high schools. Hisparc is a Dutch project (see www.hisparc.nl) in which pupils build a detector for high-energy cosmic rays and measure very-high energy cosmic events in coincidence measurements between signals occurring in detectors placed at some distance apart. We have established a contact between the Dean of the Technical Faculty of the UNA and the Dutch coordinator. The first contacts have been made.

The programme was discussed again during a visit of Mrs. Dr. G. Narain, Rector of the UNA to Groningen on 29 June. During a tour through the KVI, in addition to the cyclotron, the cold atom trap and various detector set-ups, a Hisparc detector was demonstrated to her. Dr. Narain stated that there is a visiting scientist, Dr. Albert Matis, who is enthusiastic to take the lead at the UNA for the HiSparc project. At the Schools the Dean of the Technical Faculty was met with quite some enthusiasm to participate, similar to our experience during the visit in January. The costs for one unit is about €5000, equivalent to more than ten PC's. The schools can not justify such an investment. Dr.Narain has proposed to extend the present "Scharnierproject" to HiSparc. In such a project pupils and teachers of the highest classes of the high schools work together at the UNA with students and teachers of UNA. If UNA could acquire a HiSparc unit, the schools could become involved in this way. Again the costs are imperative. The UNA does lack a budget and an attempt to obtain funds from outside has unfortunately failed. If about half of the budget could be found the project should be able to start at the UNA.

During her visit Dr. Narain expressed again the interest in the EARTH programme. Within the possibilities the UNA likes to participate after the project gets off the ground. The main contribution will be in the education and training programme. One possibility could be students that after the Bachelors education follow a master education at the RuG and follow the instrumentation speciality.

Detector development

In the last two progress report the first measurements on a test cell at iThemba LABS, South Africa were described. These measurements simulated the basic principle for antineutrino detection, namely the delayed coincidence method, with the use of a neutron source and a ^{10}B-loaded scintillator. Moreover the data showed that signals produced by γ-radiation and neutrons can be distinguished by analysing the pulse shapes of the digitized pulses. Moreover

simulation calculations were made to investigate the dependence of the directionality on the diameter of the detector cells. The simulations stress the importance of ^{10}B (boron-10) being present in the detector material. This addition leads to a capture of the neutron by boron, followed by the emission of an α-particle. The properties of boron lead to an early capture of the neutron, such that it has not lost too much of its original direction. The α-particle is stopped instantly and its signal therefore indicates the stopping location of the neutron. Another result of the simulations is that one can estimate the degree of direction sensitivity as function of the diameter of the detector.

At iThemba LABS and the University of Cape Town tests have been continued to determine the feasibility of using a ^{10}B-loaded liquid organic scintillator to detect double pulse events from inverse beta decay of the neutron. The ultimate objective is to develop an electron-antineutrino detector based on this method. Test measurements are carried out using double pulse events generated by neutrons from a ^{252}Cf source. The first pulse is due to the recoil proton produced when the neutron initially scatters off a hydrogen nucleus in the scintillator. The second pulse is produced by the alpha particle and ^{7}Li recoil that are emitted after the neutron is moderated and eventually captured by a ^{10}B nucleus. In the antineutrino detector that is ultimately envisaged the first pulse will be produced by the positron emitted following antineutrino capture by a proton. Scintillation pulse shape discrimination will then be used to *reject* background due to neutron double-pulse events like those being studied in the test measurements.

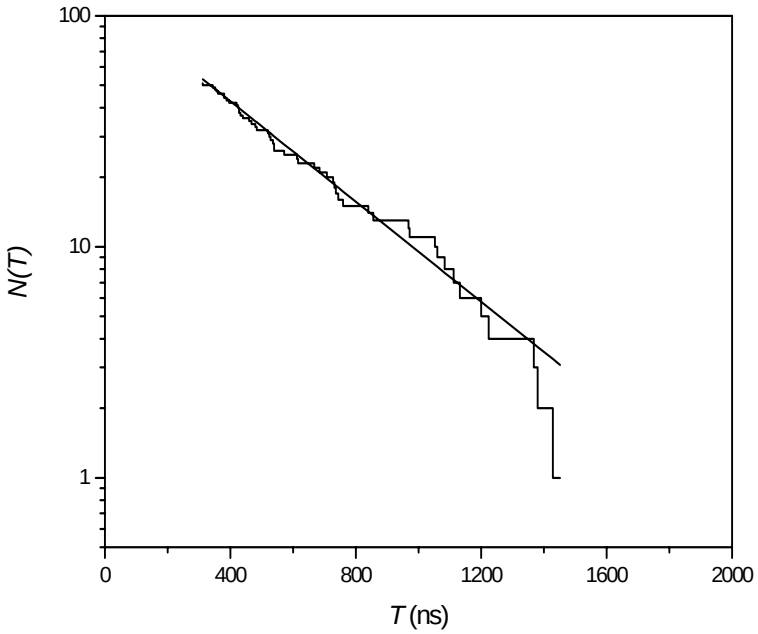

Figure 1: Plot of *N(T)*, the number of events for which the time delay between first and second pulses is ≥ *T*, versus *T*. The histogram shows experimental data obtained using neutrons from a ^{252}Cf spontaneous fission source. The line shows the fitted function $N(T) = 116 \exp(-T/T_0)$ for $T_0 = 400$ ns.

The test measurements have included investigations of spurious double pulse events that arise, under certain conditions, from double pulsing (after-pulsing) by the phototube. This effect is attributed to ion and/or optical feedback inside the phototube. It occurs at a characteristic time after the initial pulse, depending on the operating conditions. Procedures have been developed to minimize this background and to distinguish it from the events of interest.

Figure 1 shows the distribution of number of events as a function of the time T between first and second pulses, for neutron double pulse events produced by the ^{252}Cf source. From simple considerations this distribution is expected to drop off exponentially with a decay time T_0 that depends on the concentration of ^{10}B in the liquid scintillator, the detector geometry and perhaps other factors too. Monte-Carlo simulations are in progress to determine T_0 for comparison with the experimental measurements.

Data have till now been recorded by employing a fast digital oscilloscope to digitize phototube output pulse shapes and using LABVIEW software for data transfer to a PC. Files generated in this way are very large which in turn places limitations on the amount of data that can be collected. A more efficient way of recording pulse shape information will be investigated next. Progress is also being made with calculations to simulate, with MCNP, the neutron interaction in a boron-loaded scintillator.

At the KVI a test box has been designed to test detectors under various controlled conditions. The box is presently under construction.

Scientific contacts

Through the contacts with RWTH-University in Aachen the German Geological Research Centre, GFZ, in Potsdam, approached us on 31 January. GFZ is involved in the International Continental Scientific Drilling Programme (ICDP). Subsequently we approached ICDP with the request for EARTH to be considered by their Scientific Panel for support by ICDP technical groups. Initially this support could be travel and meeting money to consult with their technicians, engineers and scientists. At a later stage it could lead to funding part of the drilling and assistance in the geophysical measurements in the borehole.

In Germany the German Research Community (DFG) has a priority programme “ICDP” to fund the German participation in the International ICDP. This programme finances the scientific participation by German labs for e.g. interpretation of down-hole logging data, temperature measurements, etc. Logging itself could be funded through the international ICDP. EARTH will have to submit a proposal for operational support to ICDP, which could finance the drilling and onsite actions. The science part, for the German partners, could be financed by the DFG priority programme.

In the beginning of March the Scientific Advisory Group (SAG) of ICDP met in Vienna and informally discussed the EARTH programme. The panel strongly recommended to GFZ to co-operate with EARTH and expressed that EARTH is very interesting and EARTH needs geoscience and drilling engineering input to better address these topics and to broaden the support through the geoscience community.

On March 22nd Mrs. Kathrin Hochmuth, Technical University München (TUM), gave a presentation on the angular distribution of geoneutrinos and their detection with LENA. Her presented work was partly carried out during a stay with Dr. Brian Fields of the University of Illinois and is part of her “Diplomarbeit” at the TUM. After her presentation various aspects of background reduction techniques with the LENA and the EARTH detector were discussed. The discussion strengthened us that the modular approach as proposed for EARTH, which deviates strongly from monolithic detectors like LENA, provides new ways to reduce background..

On 12 April Dr. H. de Kerret, College de France, Paris, gave a seminar at the KVI on the experiments at Bugey and Chooz. Also with him we discussed our detector proposal. At the earlier experiments at Bugey modular detectors were used with a diameter of about 8cm. These detectors were filled with liquid scintillator. After the discussion Dr. de Kerret indicated that at that time (10-15 years ago) directional sensitivity was not so much of an issue since they knew where the source of antineutrinos (the reactor) was located. At that time they used large diameter detectors, since they expected an easier way of background reduction. Going to smaller diameter detector was not considered. He agreed that with the new materials and technologies it is worthwhile to investigate the EARTH-type of detectors. He stated that if we would not do the development, it will be very likely that somebody else would pick up the idea.

Seminars and presentations.
22 February 2005, *Earth Antineutrino Tomography*, R.J. de Meijer, Presentation Department of Science and Technology, Pretoria, South Africa.
14 March 2005, *Earth Antineutrino Tomography*, R.J. de Meijer, Presentation Board of Advise EARTH, Groningen.
2 and 3 June, *Het radioactieve hart van Moeder Aarde*, R.J. de Meijer, Presentations to the Public as part of the World Year of Physics activities, Groningen
8 June, *Earth Antineutrino Tomography*, R.J. de Meijer and H.J. Wörtche, Seminar Physics Department, Technical University München, Germany.

Publications and publicity.

- Popular scientific journals and newspapers

Natuurwetenschap & Techniek: M.Crok,

- Travel reports

EARTH REP-005: *Report meeting with SA-Department of Science and Technology on 22 February 2005, Oranje Nassau Building, Pretoria and on 4 March 2005 at iThemba LABS, Faure.*
EARTH REP-007: *Report on a visit to deep drill holes at Windischeschenbach and the Technical University München, 6-8 June 2005*

Website and ppt-mastersheets.
A beginning is made to have a web site. Initially it will be part of the KVI website: www.kvi.nl/~earth/main.htm. The website contains a number of reports and a programme description.

For Power Point presentations a background sheet is available for members of the consortium.

EARTH Team.

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Industrial Partners

The Netherlands

Focus Oil and Gas, Beverwijk.
Hi-Light Opto Electronics, Tolbert.
Lambert Instruments, Leutingewolde.
Schramifa, Stadskanaal.
Scionix, Bunnik.
Technologie Centrum Noord Nederland (TCNN), Groningen.
Variass Electronics B.V. Veendam.

Curaçao

Aqualectra.