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Terra Incognita I

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The topics discussed in the workshop session "Terra Incognita I" included a wide range of science. Central to the discussion however was the study of sub-leading neutrino oscillations driven by Θ_{13} and the possibility to observe CP-violation in the leptonic sector. Furthermore, the long-standing problem of sterile neutrinos was addressed, as well as the scenario that UHECR could be produced via so called Z-bursts. To employ neutrinos in the literal meaning of the workshop session title "Terra Incognita", namely to explore the unknown earth with neutrinos from geo-chemical origin, completed the session.

1. Introduction

Neutrino physics has recently gone through a phase of explosive development and matured into a dynamic research field where a number of breath-taking discoveries have been made. The discovery of neutrino masses and mixing – now already "Terra Cognita"– is the first solid evidence for the long-sought "physics beyond the standard model". In addition, there exist intriguing connections to several other physical sciences such as geo-physics or helio-seismology. Neutrinos are here in a two-fold way unique probes of new physics. First, they allow one to obtain information on fundamental properties as, for example, the values of neutrino masses and mixings, the Majorana nature of neutrinos and leptonic CP violation. These properties require theoretical explanations which go beyond the standard model of particle physics and they lead to consequences in the greater context of elementary particle physics. Leptonic CP violation, for example, is likely connected to the baryon asymmetry of the universe. The second lever arm on new physics provided by neutrinos is based on their extremely feeble interaction strength with ordinary matter that allows them to probe phenomena that are otherwise not accessible. Examples for that are the inner engines of core-collapse supernovae, gamma-ray bursts, active galactic nuclei, but also the interior of the Sun and the Earth. Neutrinos are messengers from the inner space of particle physics and the outer space of astrophysical phenomena and the universe.

Obviously not all of this topics could be covered in the workshop session "Terra Incognita I" and the interested reader is referred to the other sections of this conference proceedings. The focus of this session was in general on how neutrino physics may move on from what we know into less known territory. A key issue is here the detection of generic three flavour oscillation effects. Therefore emphasis was put on the investigation of the mixing angle Θ_{13} and CP-violating phases using new reactor and long-baseline accelerator experiments. The theoretical aspects of these topics were reviewed in the plenary session by J. Valle (Neutrinos and new physics) [1], by S. Petcov (Dirac and Majorana CP violation) [2], and the

experimental methods by M. Shaevitz (New reactor neutrino experiments) [3] and J.J. Gomez-Cadenas (Beta beams, superbeams and $\nu-$factories) [4]. Major part of the parallel session was related to detailed discussions of proposed new experiments, as for example proposed reactor oscillation experiments by G. Mention [5] and M. Goodman [6], or new accelerator projects as T2K by K. Kaneyuki [7] and NOνA by P. Litchfield [8]. Furthermore, the concepts of superbeams (M. Mezzetto) [9] and high energy beta beams (P. Migliozzi) [10] were discussed and compared with passion adequate for the southern location of the workshop. Parameter degeneracies encountered in future long baseline, how to resolve them, and the complementarity of accelerator and reactor and accelerator based experiments were illuminated in detail by S. Rigolin [11] and T. Schwetz [12]. Last but not least, the pending question of sterile neutrinos were discussed by M. Shaevitz [13], and G. Fiorentini [14] showed what we will learn about the interior of the Earth using geo-neutrinos. On the extremes of the energy scale D. Semikoz [15] discussed the concept and constrains of producing ultra high energy cosmic rays (UHECR) via Z-bursts, i.e. the resonant interaction of UHE cosmic neutrinos with relic neutrinos at the Z^0 resonance.
For an overview we list the talks of this workshop related to “Terra Incognita I” including the plenary and the parallel session in chronological order.

Plenary session:

- Neutrinos and new physics (J. Valle)
- Dirac and Majorana CP violation (S. Petcov)
- New reactor neutrino experiments (M. Shaevitz)
- Beta beams, superbeams and ν-factories (J.J. Gomez-Cadenas)

Parallel session:

- Neutrinos and Z-Bursts (D. Semikoz)
- Geo-neutrinos: A new probe of the Earth’s interior (G. Fiorentini)
- NOνA (P. Litchfield)
- T2K (K. Kaneyuki)
- Double-CHOOZ: A search for Θ_{13} (G. Mention)
- New reactor experiments beside Double-CHOOZ (M. Goodman)
- Combined potential of of future long baseline and reactor experiments (T. Schwetz)
- Superbeams (M. Mezzetto)
- Potential of (very) high γ β-beams (M. Migliozzi)
- Study of the eightfold degeneracy at a β-beam and super-beam facility (S. Rigolin)
- MiniBooNE and sterile neutrinos (M. Shaevitz)

2. Parallel session summary

2.1. From UHECR to the interior of the Earth

Nucleons can not be the origin of cosmic rays with energies above 10^{20} eV (UHECR), as the source of this radiation must be in the 'cosmological backyard of the Earth', i.e. at a distance not exceeding 50-100 Mpc because the path lengths is limited by the pion production with the cosmic micro wave background (Greisen-Zatsepin-Kuzmin, GZK [16]). However, no astrophysical objects are present in this vicinity which could accelerate protons to such energies. Many explanations have been put forward to explain UHECR's, one of which is the Z-burst mechanism [17,18] as discussed here by D. Semikoz [15]. Cosmic neutrinos of very high energies are not limited by the GZK cut-off, thus they could be the origin of the observed UHCER. Provided that the neutrino mass is below 1 eV, UHE cosmic neutrinos with energies $> 10^{21}$ eV can interact with relic neutrinos in our 'backyard' at the Z^0 resonance producing subsequently the UHCER shower observed on the surface of the Earth. Since Z-burst model predict large gamma-ray flux, conflicts with EGRET γ-ray data can be resolved only by postulating a local over density of relic neutrinos of at least a factor of 20 over 5 Mpc. It has been argued that one could derive a value for the neutrino mass assuming the correctness of the Z-burst models. Semikoz however pointed out that many free parameter allow to produce equally good fits for any given mass, thus the prediction power is limited. Z-burst models already are constrained by limits on UHE neutrino data from radio observation of the lunar surface (GLUE) and the Greenland ice (FORTE). Semikoz concluded that the upcoming ANITA experiment will have the sensitivity to unambiguously test the Z-burst model.

Literally more down to Earth, but not less puzzling, is the question addressed by G. Fiorentini [14] in his contribution concerning geo-ν's: What is the amount of uranium, thorium and potassium in the Earth, and what is the related radiogenic contribution to the terrestrial heat flow? Finding answers to these questions will test a fundamental geochemical paradigm: the bulk silicate Earth. With the new large scintillator detectors KamLAND and BOREXINO, the radiogenic heat will be directly measurable. Electron anti-neutrinos emitted in the beta decays in the Uranium and Thorium chain (alas not from ^{40}K) can be measured via inverse beta decay on protons. The current data from KamLAND 'provides a first glimpse', though backgrounds to the geo-ν signal from reactor neutrinos as well as from the (α,^{13}C) reaction, as first presented here at this workshop, need to be subtracted carefully. Fiorentini laid out the strategy how to derive the total mass of uranium/thorium of the Earth: in addition to the measured anti-neutrino flux at a given detector site, it is required to model with high accuracy the uranium/thorium content of the nearby (i.e. 200 km) vicinity. This nearby contribution from the Earth's crust can contribute up to 50% of the total neutrino signal. The difference to the total rate thus contains the information about the uranium/thorium contents of the mantle and core.

2.2. Next generation reactor experiments

The latest reactor neutrino experiment KamLAND has shown the discovery potential of oscillation search with electron-antineutrinos from nuclear reactors. The oscillation parameters investigated with a baseline of 160 km in this experiment are Δm_{sol} and Θ_{12}. The next generation of reactor experiment will be optimized to probe Θ_{13} in a disappearance mode with a baseline of about 1 km between reactor and detector. The experimental scheme relies on a two-detector concept: a near-detector serves as a neutrino flux monitor close to the neutrino source while the far detector gives the deviation from the $1/r^2$ flux due to oscillations. Moreover, the deformation of the spectral shape complements the rate information. G. Mention [5] discussed the status of the Double-CHOOZ project [19], which is most advanced amongst the various proposals. The Double-CHOOZ collaboration expects to achieve a sensitivity $\sin^2 2\Theta_{13} < 0.02$ after three years of data taking starting in 2008.

M. Goodman [6] summarized the status of the other new reactor projects pursued [20]. This included the original two-detector Θ_{13} proposal, ie. the Russian K2DET scheme in Krasnoyarsk, as well as more recent Japanese KASKA project, the US Diablo Canyon and Braidwood sites, the Chinese Daya Bay and the Brazilian Angra proposals. Which of the projects will be realized and which sensitivity can actually be achieved will be seen within the near future. Latest results for Δm^2_{23} of the K2K experiment which actually is decisive for the optimal reactor–detector distance indicates that the relative short baseline of the Double-CHOOZ experiment is not of disadvantage. All projects aim to become operational during 2008 thus to acquire data simultaneously with the T2K experiment as described below.

2.3. Next generation accelerator experiments

Atmospheric and solar/reactor neutrino oscillations led to a first rough determination of the quadratic mass splittings Δm^2_{atm} and Δm^2_{sol}, respectively. This determines for a given energy E the baseline L where the first oscillation maximum occurs. For Δm^2_{atm} and energies in the range of a few GeV one finds interestingly baselines of hundreds of kilometers allowing long baseline experiments with artificial neutrino beams. The K2K experiment has confirmed in this way atmospheric neutrino oscillations at a baseline of $L = 250$ km. The MINOS experiment, which has just started and which has a baseline of 730 km, will measure the leading 2x2 oscillation parameters much better. OPERA and ICARUS will start a bit later at CNGS and they will contribute to an even better measurement of the leading oscillation parameters in the next years. The combination of MINOS, OPERA and ICARUS will determine the leading oscillation parameters at $\mathcal{O}(10\%)$ and it may even be able to improve the limit on Θ_{13} somewhat [21]. Establishing a finite value of Θ_{13} is of course the key to generic three flavour oscillation effects and to leptonic CP violation where the subsequent generation of experiments will therefore be crucial. New reactor experiments like Double-CHOOZ [5] and other, more advanced setups [3,6], will contribute here, but the next generation of long baseline experiments T2K [7] and eventually NOνA [8] will lead to a significant progress. The status of the most advanced (and approved) next generation long baseline oscillation experiment, the Tokai to Kamioka (T2K) project, was presented by K. Kaneyuki [7]. According to the Japanese time schedule, first events from the "off-axis" muon neutrino beam will arrive at Kamioka in 2009. The mean beam energy is 1 GeV and the distance from the source to the detector 295 km. The proton beam will initially have a power of 0.75 MW and will be the first of the so called "super-beams". The long term plans are to increase the power to 4 MW and shift from the 22.5 kt Super-Kamiokande detector to a megaton Hyper-Kamiokande detector. In addition to the far detector, the T2K project will include two near-detectors at 280 m and 2 km in order to get handle on the neutrino beam. The physics goals are to perform precision measurements aiming at an accuracy of 10^{-4} eV^2 for $\delta(\Delta m^2_{23})$ and 10^{-2} for $\delta(\Theta_{23})$. The main objective of T2K will be the study of Θ_{13} via $\nu_\mu \to \nu_e$ appearance search. The status of NOνA was subsequently discussed by P. Litchfield [8]. NOνA would operate at L =800 km at about 10 km off-axis the NuMI beam. Compare to T2K, NOνA has a higher energy and different suitable detector concepts are therefore studied. The higher energy implies also a longer baseline for the first oscillation maximum. This longer baseline leads to a sensitivity to matter effects, such that NOνA is complementary to T2K, where matter effects are irrelevant. The combination of T2K, NOνA and new reactor experiments has altogether a remarkable power [21], e.g. for the determination of Θ_{13}. Beyond that there exist even more powerful instruments like advanced super-beams, β-beams and neutrino factories, where J.J. Gomez-Cadenas [4] gave in a plenary talk an overview comparing the different options. M. Mezzetto [9] discussed in more detail in the parallel session the European ideas in superbeams and beta-beams, while M. Migliozzi [10] emphasized the potential of very high γ β-beams. These long term machines have a remarkable potential, but they certainly require further R& D on a number of technological issues. However, it is encouraging that a path to precision measurements exists which may eventually establish leptonic CP violation.

2.4. Parameter degeneracies and the power of combined analysis

Generic three flavour oscillations in matter are in general quite complicated compared to the simple textbook two neutrino case. A systematically simplified approach is given by an expansion in the small quantities $\alpha = \Delta m^2_{sol}/\Delta m^2_{atm}$ [22]. All oscillation channels have a limit which is effectively described by the simple two neutrino formulae, but at a certain level of precision all oscillation formulae depend on all oscillation parameters. This leads to a complicated parameter dependence with degeneracies and correlations which must be disentangled. This is not easy and it takes good strategies which optimally use the available experimental information. T. Schwetz [12] discussed how the combination of future long baseline and reactor experiments will be able to disentangle the parameter correlations. S. Rigolin [11] showed how this might be improved in the long run with β-beams and superbeams.

2.5. Sterile neutrinos

Among the features which are so far not understood is why different generations exist and why there are three of them. Therefore we should not simply assume in the case of right-handed neutrinos that three copies exist and that the standard see-saw produces three light Majorana neutrinos along with three heavy Majorana states. In fact, there is the long standing LSND result which points towards a third mass splitting between neutrino states, which is not possible if only three light neutrinos exist. However, it is important to keep in mind that by introducing more than three right-handed neutrinos or by a singular see-saw mechanism, it is quite natural possible to have additional light sterile neutrinos. This is disfavored by cosmological arguments based on structure formation and on big bang nucleosynthesis, but it could turn out that the systematical uncertainties are in these cases somewhat bigger than anticipated. M. Shaevitz [13] reminded the audience in his talk that it is quite conceivable that the on-going MiniBooNE experiment confirms LSND. This would certainly lead to another neutrino revolution, since the consequence would be that many interesting effects could be observed, including much stronger leptonic CP violation. On the theoretical side it would lead to many new ideas and questions.

3. Outlook

The complicated initial landscape of oscillation islands has been replaced by two well identified solar and atmospheric solutions and the leading oscillation parameters are quite well known. The talks related to this session clearly show that oscillation physics will move on into a precision era with measurements at the percent level or below. This will generally be very useful for models of neutrino masses, since it will not be easy to explain all the precise leading oscillation parameters and a small Θ_{13} in a certain model. Even more, the experiments which are on-going or in the planing phase, will lead to a precision which tests generic three flavour effects and which will significantly improve our knowledge on Θ_{13}. Even though any value of Θ_{13} could in principle exist, most models tend to predict values in the range that will become accessible. This can be understood from a general perspective, since a small value of Θ_{13} may be a numerical coincidence, while a tiny value needs a symmetry or another mechanism able to explain such a tiny value. One could therefore claim that even a null measurement of future searches for Θ_{13} would be interesting, since it would point to another unexpected flavour feature in the neutrino sector, just as the two large mixing angles where a complete surprise. Whatever the coming precision oscillation experiments will bring, their results have the potential to be in the long run the most precise information on flavour. This may help to finally understand the origin of flavour and it should help to further understand the role of leptonic CP violation in the generation of the baryon asymmetry of the universe. However, neutrinos will also continue to play an important role as probes into otherwise inaccessible systems, as it was shown in the talks about UHE neutrinos and geo neutrinos. The Terra Incognita of neutrino physics looks altogether very promising and we can be sure that this field will stay exciting in the years to come.

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