Book Review

Neutrino Astronomy: Current Status, Future Prospects by Thomas Gaisser and Albrecht Karle (World Scientific Publishing Company, Singapore, 2017)

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The seminal report in 2014 on high energy neutrino signals observed with the IceCube detector located near the South Pole has been the starting point of an incredible widening of our perspectives to *observe* the creation and the development of our universe, much deeper and much further back in time as when resting on the so far existing — surely highly advanced — modern astrophysical observational techniques.

The intrinsic reason for these overwhelming possibilities of HE neutrino astrophysics rests in the neutrino properties themselves: If energetic enough, they are messenger particles reporting about very violent early happenings that occur(ed) in the evolution of the universe. What makes HENs unique is their penetration power, going through virtually anything.

The incredibly low interaction cross-sections of the exclusively weakly interacting neutrinos with any potential detector has been the nightmare of early (low energy, O(MeV)) neutrino experiments, such as, e.g. solar neutrino detection. However, considering high energy ($> \text{GeV}$, up to TeV, PeV, even EeV) neutrinos and the potential availability of very large target sizes of water, ice, air, even planetary bodies (e.g. Earth, moon, and other moons) for exploration, provided they can be sufficiently densely instrumented with high-precision and sensitive instruments for signal recovery and protected (or discriminated by anticoincidence vetoes) from disturbing background, turns the almost unlimited attenuation length of the neutrinos into an advantage: little disturbance (leave alone absorption) on the way from where they come from

up to the detector. All that happens to them are flavor oscillations (ν_μ , ν_e , ν_τ). This may be welcoming to explore fundamental particle physics issues; in the astrophysical context, at high energies ‘flavor-democracy’ prevails, 1/3 for each flavor.

The present volume is a collection of 15 independent chapters written by competent performers in their respective fields of high energy astronomy, invited review by the two Editors (10 single authored, 5 double authored). It is definitely *not* a monograph on a research topic. It resembles more of a proceedings volume of a topical conference.

Chapters 1–4, 10 and 11 of the collection describe (in this order) the mechanisms and the potential possibilities to observe the prime candidate processes for the production of HE neutrinos: gamma ray bursts (GRB), active galactic nuclei (AGN), HE cosmic ray related HE neutrinos (through decay of charged pions), ‘nearby’ galactic neutrinos, supernova core collapse neutrinos and dark matter annihilation. In all these cases, the interaction of primary HE neutrinos within or near the instrumented target produces secondaries that emit Cherenkov light, normally detected by PMT’s.

Chapter 5 summarizes the existing data status of astrophysical high energy neutrino observations from all detectors that are already taking data, with deserved emphasis on IceCube.

Chapters 6–8 are devoted to the full descriptions of these experimental projects: IceCube (Chapter 6: Antarctic Ice Shield near the South Pole); ANTARES (Chapter 7: Deep salt water near the Mediterranean Sea Shore of France and Italy); BAIKAL (Chapter 8: Deep water in Lake Baikal).

The early success of the latter detectors (O(100) PeV-events) but their failure to record locally identified point sources led — as natural in such cases of principally low event rate experiments — to the desire to *upscale*. This approach is not extremely intelligent, but admittedly it seems to be the fastest (only?) way to make progress. The limitation then comes from two sites:

- (1) What the world in which we live has to offer as suitable extended targets (even the Antarctic ice sheet is not 100 km thick), and the Lunar Regolith cover may be wide, but hardly deeper than O (10 m). Bioluminescence in deep waters cannot be turned off.
- (2) The scaling of event rates with €/\$. And how much is society willing to devote for mankind to understand our universe? More than the present military budgets? We get in this order of magnitude with our un-reflected dreams. Before this could happen, we would first have to organize a humanistic society without starvation of children anywhere: Science should become less demanding.

Upscaling-projects still in the range of present practicability are underway for IceCube in the form of Ice Cube Gen (Chapter 13) and for ANTARES in the form of Km3NeT (Chapter 12). While in the TeV-PeV neutrino Energy range spectacular astrophysical extragalactic observations are in the center of interest, these detectors produce, as a by-product, a wealth of information from fighting against the atmospheric GeV neutrino background. This offers the chance for particle physics to get its share from large-scale astrophysics experiments. Large datasets become available to study neutrino flavor physics via long baseline oscillations. The ICE Cube Gen2 Project at the South Pole devotes this aspect to its sub-project PINGU, the analogous ORCA project is planned by the Km3NeT (Antares) collaboration. The present and future efforts in this respect are covered in Chapter 14.

The final chapter (Chapter 15) describes the quest for detection of ultra-high energy — O(EeV) — neutrinos that stem from the interaction of >100 EeV Cosmic Ray particles with the cosmic microwave background (GZK-neutrinos). In truly huge volumes of dielectric target material, coherent electromagnetic radiation may be observed using microwave horn Antennas. Feasibility tests have started in ground-based Askaryan Radio Array

(ARA) and stationary NASA Balloon experiments (ANITA: Antarctic Impulsive Transient Antenna).

The scientific authority of the individual chapters is beyond any doubt. In most chapters, the description of the issues and perspectives is pleasantly objective. This having been said, some critical remarks may be in order:

Little editorial amalgamation can be noticed. 15 players are not an orchestra. The ratio of general context to practical details differs widely from article to article. Some take a pedagogical attitude for the benefit of the interested non-expert, others tell only their direct colleagues what they surely know already, but this is less useful for the interested non-specialist. It is ambivalent what audience the editors have in mind.

The title of the book is *unacceptable*, it should read: ‘High Energy Neutrino Astronomy’. Neutrino astronomy started with the Sun (and, later SN1987A). To my knowledge, the Sun is a prime object of astronomy since ancient times. A short note on these ‘early years’ of solar neutrino research would be appropriate in any case. If it is felt too far away from the present topic, then at least the ‘High Energy’-Prefix would have been *mandatory*.

Whereas the reference lists of the individual chapters are nearly complete and therefore very useful for active researchers in the field, the Index of the volume is (at best) a joke. 2 Pages! Even a minimum editorial effort using a standard software could have produced a useful guide for the non-specialist, the effort would have been less than one working day.

Educationally, the highlight of the book is clearly Chapter 9 “The Dawn of Multi-Messenger Astronomy” by Marcos Santander. And this is not only because of the spectacular LIGO/VIRGO event of 2017 August 17, in which gravitational waves, gamma rays and electromagnetic emissions in the whole spectrum from IR through visible to UV have been jointly observed and localized in the sky. Even though no HE neutrino Pulse was observed in this specific case (the merger of two neutron stars) it constitutes the first definitely localized VHE point source event. It raises optimistic anticipations that Multi-Messenger-Astronomy may become the standard approach for exploring the depth of the universe in the years to come. Unfortunately, the event came a few months too late to be covered in the present volume.

The book is useful because the topic is so exciting. Regrettably, it does not send out this earthshaking message to a general audience, as it should. The compilation of competent articles cannot replace a single authored authoritative monograph that combines competence at the format of e.g. Annual Reports of ... or *Rev. Mod. Phys.*, with the clear message digressive to a wide audience of scientists (and even educated non-scientists): that

we have the privilege to witness the dawn of a new Era of understanding the physical world.

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