The Askar’yan Radio Array

Kael Hanson, for the ARA Collaboration

Université Libre de Bruxelles, Service de physique des particules élémentaires, Campus de la Plaine CP-230, Boulevard du Triomphe, B-1050 Bruxelles, Belgique
E-mail: khanson@ulb.ac.be

Abstract. We are developing an antenna array to be installed in boreholes extending 200 m below the ice surface at the geographic South Pole. ARA will cover a fiducial area of $150\,\text{km}^2$, chosen to ensure the detection of the flux of neutrinos guaranteed by observations of the GZK cutoff by HiRes and the Pierre Auger Observatory. The first components of ARA were installed during the austral summer of 2010-2011. After three years of operation, the full array sensitivity will exceed that of any other instrument in the 0.1-10 $\text{EeV}$ energy range by an order of magnitude. The primary goal of the ARA experiment is to establish the absolute cosmogenic neutrino flux through a modest number of events. This talk will describe the array, its science goals, and give the current status of the project.

1. Introduction
Measurements of cosmic rays have, since their discovery 100 years ago, have yielded an observed flux extending from $10^9$ eV to over $10^{20}$ eV that approximately obeys a broken power-law spectrum:

$$J(E) \propto E^{-\gamma}$$  \hspace{1cm} (1)

where the spectral index steepens from 2.7 to 3.0 around the “knee” at $E_{\text{CR}} \sim 10^{15}$ eV. The flux above $10^{18}$ eV manifests a cutoff beginning at about $3 \times 10^{19}$ eV, for CR proton primaries, due to the GZK effect [4, 5] wherein the pion production cross-section for UHECR is greatly enhanced by the $\Delta$ resonance channel, thus limiting the travel distance of cosmic rays at these extreme energies. This process produces UHE neutrinos which can travel cosmological distances. The fluxes [6] which result are detectable only by detectors of extremely large effective volumes. This effect is sensitive to the composition of the UHECR and as such measurement of the resulting neutrino signal could provide constraints on this still poorly measured quantity.

2. The ARA Radio Neutrino Detector at the South Pole
A collaboration has formed of researchers from the ANITA[1], IceCube[2], and RICE[3] experiments, which are either previously or currently engaged in searches for HE and UHE neutrinos, to construct such a detector. The detector has been named the Askar’yan Radio Array (ARA) in honor of Gurgen Askar’yan, the Soviet-Armenian physicist who first predicted that EM cascades produced by UHE neutrinos in radio transparent media would emit transient radiofrequency pulses that could be detected by radio antennas and sensitive electronics. The ARA antennas will be deployed in the ice at the South Pole where the 3 km-thick glacial ice sheet possesses characteristics very favorable to the detection of these signals.
2.1. Detector Geometry
The complete ARA array as it is currently envisioned will comprise 37 detector stations spaced in a hexagonal grid. Each station is 2 km from its neighbors. The station is a cluster of 8 horizontally and 8 vertically polarized receiver antennas buried on 4 strings sunk between 180 m and 200 m beneath the polar surface (Figure 1). It is necessary to sink the antennas to avoid raybending which occurs in the graded index medium called the firn where the snow deposited at the surface gradually transitions to bulk ice.

The geometry of ARA has been optimized to give maximal effective area over a broad range of GZK neutrino energies: at energies from $10^{17}$ eV, the effective triggering threshold of the detector, to $10^{18}$ eV each station is operating more or less independently as multi-station events are unlikely. Thus it must be possible to trigger and discriminate signal from background given triggered events from a single station. This drives the requirement of a waveform-capture-based data acquisition system described below. The predicted $V_{\text{eff}}(E_{\nu})$ is given in reference [7].

The ARA stations will be deployed over several seasons from 2012 to 2015 to eventually arrive at a total count of 592 receiver antennas on 148 strings within 37 stations. The nomenclature for this planned detector configuration is ARA-37.

2.2. Radiofrequency Detector
The antennas have been optimized, given the geometrical constraints of the 10" boreholes, for frequencies in the band of 150-1000 MHz (250-1000 MHz for the H-pol) where the Askar’yan EM pulse energies are concentrated and where the ice has long attenuation lengths ($O(1)$ km). Signals from the antennas are amplified with low-noise amps located at the antennas and then sent to the surface over RF optical links. At the surface the signals are split into trigger and digitizer paths. The trigger path includes a tunnel diode power detector which produces a pulse which is discriminated and used to trigger the acquisition electronics.

2.3. Signal Digitization and Data Acquisition
Full-speed (3.2 GSPS) digitization is performed by a custom ASIC developed by the University of Hawaii IDL called the IRS. It is a switched-capacitor array digitizer based on earlier designs including the BLAB and LABRADOR chips. Unlike its predecessors, the IRS contains a massive amount of analog storage cells: 32k per channel over 8 sampling channels, thus over 262k cells. The 32k cells are organized into 512 pages of 64 samples. Each page may be written to and
digitized independently of all others. Logic in an FPGA which controls the operation of the IRS
is used to trigger and set aside the IRS pages which correspond to the digital waveform samples
around the trigger so that they are not overwritten by the IRS which is continuously sampling
the RF inputs onto the capacitors. As long as there are free pages for writing the IRS achieves
100% deadtime-free operation. Throughput is limited by the 12-bit parallel Wilkinson digitizers
and readout of the device which requires 15 μs per block of 64 samples. Triggers in ARA will
readout 20 blocks thus the maximum trigger rate supported in ARA is 3.3 kHz.

Triggers and the associated digitized waveforms are passed to a low-power embedded Linux
system located on the ice surface at the nexus of the antenna boreholes. Data is transmitted
to a central processing facility located in the IceCube counting house (ICL) over a conventional
IP-based Ethernet network. During the 2-3 years of ARA station deployment, the network is
physically carried by fiber optic cables deployed between the ICL and the remote stations. In
the years following, cabling will not be supported and these stations must transmit data using
wireless networks. Test deployments of 802.11 WiFi-based technologies are scheduled for the
2011-12 season.

In addition, the lack of cables implies that the power infrastructure must be furnished by
electrical generators in the field. Wind and solar power generation facilities are being developed
to fulfill this need.

3. ARA Performance

3.1. ARA Testbed

The first ARA station is expected to be deployed during the South Pole 2011-12 season. Thus,
actual performance data of the instrument is not available at this time. The ARA collaboration
deployed the ARA testbed during the prior austral summer. The mission goals for this
instrument were to establish the feasibility of operating ARA at the South Pole including
surveying the EMI environment, the RF properties of the ice, and the operation of the sensitive
electronics in the extreme cold. Data from this station was recorded and analyzed and the
results were published [7]. Some highlights are summarized here:

- With exception of a few periods each day the South Pole EMI environment is exceptionally
  quiet and compatible with operating the ARA antennas at near-thermal noise sensitivity.
The episodic noise has been traced to weather balloon telemetry at South Pole station and
in the worst case would incur a 3% downtime each day.

- The attenuation length of RF in the ice, as measured by the ARA testbed receiving pulses
  from a pulser deployed at the bottom of one of the last IceCube strings, is slightly better
  than expected: the average attenuation at 300 MHz is $1660^{+225}_{-120}$ m in the top 1.5 km of ice.

- The testbed electronics are functioning well in the field. Time resolution of incident waves
  using cross-correlation techniques is approaching 100 ps with improvements expected in the
  ARA electronics.

3.2. Monte Carlo Studies of ARA-37

The ARA-37 array response has been simulated with various input fluxes from current models
of GZK neutrino production as described in the report [7]. After 3 years of operation the
expected event count could be as low as 1.5 or as high as several hundred events given the
current band of uncertainty in the theoretical predictions. However, ARA-37 will be the most
sensitive instrument for this measurement. It’s performance alongside IceCube, ANITA, Auger,
and RICE is given in Figure 2.
4. ARA Future
The ARA instrument represents a transitional stage towards the realization of extremely large volume neutrino telescopes capable of neutrino astronomy at GZK scale energies. Technology development with the aim of producing such an instrument is a necessary secondary but parallel goal of the collaboration. Advances in data acquisition are currently being pursued to reduce power and cost of optical down-hole signal transmission [8]. Trigger development is essential to push the antenna sensitivities down as close to thermal as is possible to reduce the energy thresholds: a factor of 30% reduction in the threshold doubles the event rate at $10^{18}$ eV. And finally, development of robust infrastructures for power generation and wireless communications over 100’s of km$^2$ of the remote polar plateau is an absolute necessity in order to make these super-arrays practically possible.

References
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