

## RESEARCH NOTES FROM COLLABORATIONS

**Site survey for the Pierre Auger observatory**

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**Abstract**

Within the framework of the Pierre Auger project, it was necessary to identify suitable places for the observatory sites and to characterize them in order to make a final selection. ‘Pampa Amarilla’ in the province of Mendoza, Argentina and Millard County, State of Utah, USA have been chosen for the southern and northern sites, respectively. Atmospheric, meteorological, soil and topography studies were performed at those sites.

**1. Introduction**

The Pierre Auger project is designed to explore the cosmic ray energy spectrum and arrival direction distribution for energies above  $10^{19}$  eV and to statistically identify mass composition of the primary cosmic ray particles. Such data will shed light on the origin of these cosmic rays, their possible sources and on the magnetic fields between the sources and the Earth. Furthermore, for the subset of particles whose types have been identified, it may be possible to obtain information of relevance to particle physics at energies well beyond those attainable with the largest terrestrial accelerators.

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The project is building two similar observatories over an area of 3000 km<sup>2</sup> each (yielding a total acceptance for the two sites of 14 200 km<sup>2</sup> sr for zenith angles <60°) to study cosmic rays coming from outer space with the largest known energies in nature. There will be an observatory in each hemisphere in order to have an ample and isotropic sky coverage. The large area covered by each observatory is due to the extraordinarily low flux of cosmic rays above 10<sup>20</sup> eV. An estimate predicts that approximately 100 events/year with energies above 10<sup>20</sup> eV could be detected at each site, allowing studies of statistical significance [1]. Two experimental techniques will be used: surface detectors and fluorescence telescopes [2]. Such a hybrid approach will diminish systematic errors and will allow simultaneous measurements of both the lateral and longitudinal shower profiles.

The purpose of the site survey was to identify sites in the northern and southern hemispheres which might be suitable for construction of the Auger observatories and to characterize them as well as possible. Based on results of previous cosmic ray experiments [2] the Auger collaboration produced a number of criteria by which to select the sites. Apart from criteria of practical nature (a suitable infrastructure and a terrain that will not significantly impair either deployment or maintenance), the proposed sites were required to achieve the following conditions: (i) to cover an area of 3000 km<sup>2</sup>; (ii) to be placed at latitudes ranging from 30° to 45°, in order to have a uniform declination aperture; (iii) to be at an altitude between 500 and 1500 MASL (metres above sea level) so as to optimize the detection of showers at their maximum development, at the energies of interest; (iv) to have good weather conditions and atmospheric quality to minimize fluorescence light attenuation; (v) no nearby sources of light pollution which would increase the telescopes light background and (vi) a flat surface for good wireless communications from the surface detectors.

These criteria were circulated to interested parties in Argentina, Australia, China, Mexico, Russia, South Africa, Spain and the United States. They were asked to nominate candidate sites which were visited during 1995–1996. Whenever possible, a UBV photometry of selected stars was performed for a few days in candidate sites in order to study their atmospheric transparencies. These data, taken in drift-scan mode through a range of zenith angles, yield both the background sky brightness and the apparent magnitude of the star under observation. Given the limited time frame available for these observations, however, they did not provide final indications of the optical quality of the sites but they were the best available measure of the relative atmospheric clarity and background sky brightness levels at most of the sites investigated during the Auger site survey [2].

Taking these results into account, as well as the support of local scientists, civilians and governments and the criteria mentioned above, the Auger collaboration selected Pampa Amarilla, province of Mendoza, Argentina, as the site for the southern hemisphere observatory in November, 1995. In September 1996, Millard County, Utah in the USA, was selected as the northern site.

The following sections summarize the results of site visits in the southern and northern hemispheres and describe in some detail the character of both selected sites: Pampa Amarilla, where the first observatory is being constructed, and Millard County.

## **2. The southern hemisphere site**

### *2.1. Search*

Argentina, Australia and South Africa presented candidate sites for the southern Auger observatory. South Africa nominated Vaalputs (950 MASL), a repository for low level radioactive waste, located 300 km north of Cape Town and 120 km south of Springbok,

the nearest town. The site itself is rectangular,  $45 \times 85 \text{ km}^2$ , and has a network of well-maintained gravel roads and two power lines. The annual precipitation is less than 40 mm and summer time temperatures can exceed  $40^\circ\text{C}$ .

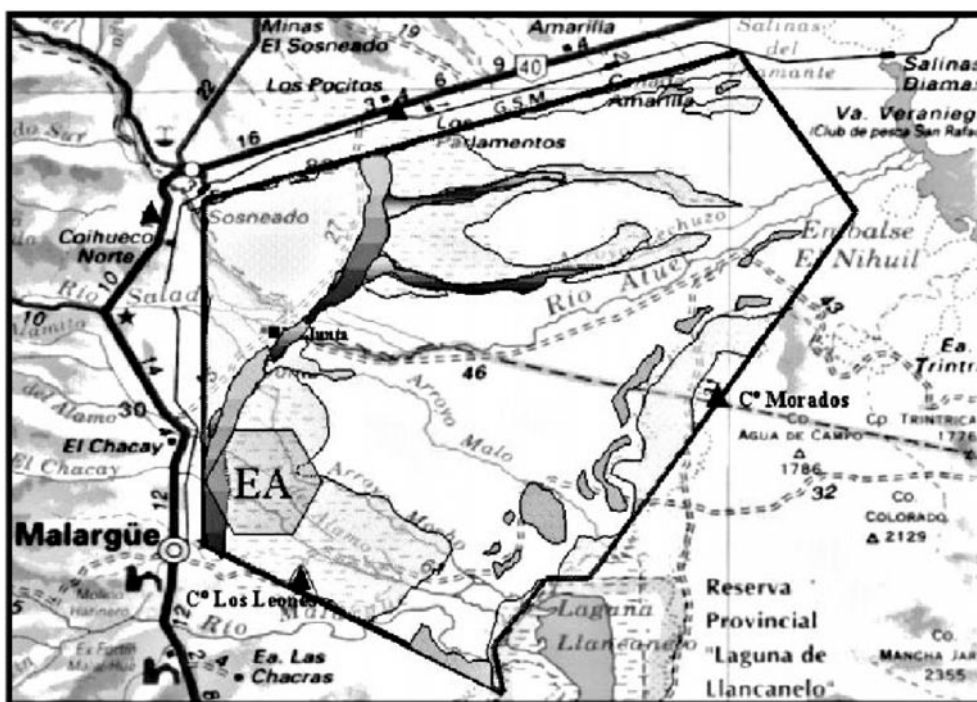
A south-east portion of the Woomera Protected Area (150 MASL), operated by the Australian Department of Defense, was proposed by this country for the southern site. Part of the land is used by the army for ammunition testing. Though for the most part flat, small pans and associated drainage are present within the site. Temperatures are moderate with a mean of  $21^\circ\text{C}$  and rainfall annually averages 140 mm. Woomera's infrastructure extends well into the site and electrical power, potable water and high-speed telecommunications links are present. Furthermore, the University of Adelaide and a number of Japanese institutions operate several atmospheric Cerenkov detectors at Woomera. In spite of all these features, the site did not fulfil the altitude requirement.

Several locations were identified within Argentina as possible candidate sites for the southern Auger observatory. After reviewing the available documentation, three were selected for more careful investigation: Laguna Blanca in Río Negro, La Humada in La Pampa and Monte Coman in Mendoza province. After site visits all three sites were found to be less than ideal. Laguna Blanca, while having extraordinarily clear and dark skies, was both too small and uneven. La Humada's size and topography were acceptable but the area lacked any significant infrastructure. Finally, Monte Coman, though otherwise satisfactory, was judged to be at an altitude too low (450 MASL) for optimal detector performance. Subsequently, two additional candidates were identified: Somuncura in Río Negro and Pampa Amarilla in Mendoza province. These sites were examined in a subsequent survey trip. Somuncura, the most southerly of the proposed southern hemisphere sites, has a number of attractive features, but poor access and lack of infrastructure resulted in the decision to drop it from further consideration. On the other hand, Pampa Amarilla combines nearly all the desirable characteristics found among the other sites in Argentina.

## 2.2. Pampa Amarilla

*2.2.1. Site location and topography.* Pampa Amarilla ( $35.0^\circ$  to  $35.3^\circ$  S,  $68.9^\circ$  to  $69.4^\circ$  W, 1300–1500 MASL) lies in the southern portion of the province of Mendoza and extends over the Departments of San Rafael and Malargüe. The city of Malargüe (population 18 000) is located at the south-west border of the site (see figure 1). It lies 180 km south-west of San Rafael city and 420 km south of Mendoza, the province capital city. The site is polygonal, encompassing an area of  $3100 \text{ km}^2$ , and has a mean slope of less than 0.5%; there are no significant elevated points interior to the site though a few exist on its periphery. The Cordillera de los Andes and the dam Embalse El Nihuil bound the site to the west and east, respectively. The Salado and Atuel rivers enter the site from the west, join near its western edge, and cross from west to east. Laguna Llanquanelo, a wildlife wetland preserve, lies to the south-east (see figure 1).

Displayed in figure 1 is the location of the hills where the peripheral fluorescence detectors and the telecommunication towers [3] will be placed. The array border in the figure corresponds to the original baseline design (which has been replaced by a slightly different configuration) and indicates the region where the soil distribution study was made. Most of the array soil is composed of silt and clay, covered with low grass and small bushes, and is thus easy to cross during a large portion of the year, but not readily accessible after rain or snowfall. The alluvial cones of the Salado and Atuel rivers at the west and north-west of the site cover an area of approximately  $500 \text{ km}^2$  and have gravel soil, which is accessible all year long. However, in this region heavy thornbush has to be dealt with. There are two areas difficult to access



**Figure 1.** Map of the southern site. The bold line bounds indicate the region where the soil distribution study was made; it corresponds to the original baseline design, which has been replaced by a slightly different configuration. There will be three peripheral telescope systems at Cerro Los Leones, Cerro Morados and Cerro Coihueco (▲), plus a telescope system located either at the centre or at the north-eastern corner of the array. The site soils distributions are sketched: fine grained sand in the scattered closed loops along the east border, gravel and sand in the upper left corner and three different silt with clay soils in the rest. The hexagon labelled EA (engineering array) indicates the region initially foreseen for deployment of the first tanks. As a reference for the scale, the map covers 80 km from top to bottom, approximately.

for deployment of heavy components: the wet soil area next to the alluvial cones, with very dense pampa grass, and the very small shaded area close to the Llanquanelo wetlands, which are only accessible in summer time. Some sandy soils and isolated dunes are found scattered throughout the array, mainly in the eastern and south-eastern parts. At the juncture of the Atuel and Salado rivers, a delta with many small islands forms. This area will pose some difficulties for deployment, as it is hard to access and floods after heavy rain and snowfall.

Each tank deployed in the field is expected to be filled with 12 000 litres of ultra-pure water in one single step, in an effort to prevent bacteria and/or nutrients contamination. To prove the feasibility of such an operation, the transitability of a loaded truck along the site was tested. The vehicle employed was an 11-ton truck, 3 axes drive with 50 cm wide wheels. This truck was driven off-road through the regions of interest, where the soil was suspected to sink under its weight. The pulling of a 2-tonne trailer loaded with 12 tons was also tested satisfactorily. The use of a trailer has the advantage that the load is more evenly distributed over the truck and the trailer itself. In short, there appear to be no significant problems with deployment throughout most of the site, with the exceptions mentioned above.

The land is primarily used for grazing. Due to the sparse nature of the vegetation, individual land holdings are large and the number of landowners is 101 (26 in the Department

of San Rafael and 75 in the Department of Malargüe). Some land in the site belongs either to the province of Mendoza or to Natural Resources Administration. Legally binding contracts have already been signed by most of the landowners by which the Auger project gains access to the detectors over a period of 20 years, for deployment, commissioning and maintenance by paying a small annual rent per detector.

An environmental impact study has been made for the project by a private consultant and presented to the province. The Ministry for Environment and Public Works of Mendoza province ruled that an Environmental Impact Declaration is not required for the Auger project, although some recommendations were made concerning detector locations and deployment, in order to protect local fauna, vegetation and hydric resources.

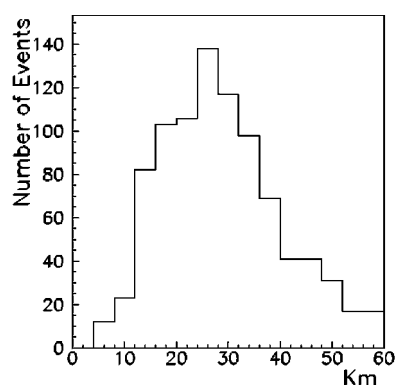
*2.2.2. Climate.* Pampa Amarilla lies in the rain shadow of the Andes and its climate is classified as arid. Historical meteorological data [4] for the Malargüe airport were obtained from the National Meteorological Service. Annual precipitation averaged 334 mm over 10 years (1981–1990) [4] and is nearly uniformly distributed throughout the year. Also, 13 months of data (1997–1998) were taken with a Davis Weather-Monitor II automatic station installed 12.5 km east of Los Pocitos. All parameters were recorded hourly and the accumulated data manually downloaded every 15–20 days [5]. This meteorological station observed an annual average of 626 mm, more than a half of it from November to December. This anomalous pattern of rainfall was probably a consequence of the ‘El Niño’ effect since it was observed in other regions of the country [6]. Data also show that typical rainfall occurred in short periods of time [5]: 63% of showers lasted less than one hour and 18% between one and two hours. Atmospheric mean pressure along the measured year was  $867.7 \text{ gr cm}^{-2}$  with an RMS of  $4.5 \text{ gr cm}^{-2}$ .

Study of winter temperatures from 20 years of Malargüe airport data shows that in some winters the mean daily temperature was below  $0 \text{ }^\circ\text{C}$  for a few days. Similar results were obtained from our 13 months of meteorological station data; the temperature was never below zero for a full day, it only remained in this condition for some hours per day during the winter season [5]. Several studies were performed in regards to freezing of the water inside the tanks. Full heat-exchange computer simulations [7] yielded that the ice layer might be in the range 0–20 cm, the variation being due to uncertainties in the simulation parameters (i.e. absorption and emission coefficients of the surface of the tank). Also, an experiment throughout 1999 was performed with a stainless steel full-size tank deployed at the site: it had a 1.5 cm thick ice layer formed for less than ten days. Based on these results, the tank baseline design does not include thermal insulation.

The site meteorological station showed that the wind is moderate and frequently from the north. Maximum wind gusts of about  $95 \text{ km h}^{-1}$  were measured on only two occasions, while the monthly average ranges from  $6\text{--}11 \text{ km h}^{-1}$  at night to  $7\text{--}18 \text{ km h}^{-1}$  during the day, depending on the season. Ten-year data from Malargüe airport show a median wind speed of  $6.0 \text{ km h}^{-1}$ , with a maximum gust velocity of  $174 \text{ km h}^{-1}$  (which occurred on June 26, 1990). The observatory and its components have been designed to withstand gusts of up to  $180 \text{ km h}^{-1}$ .

*2.2.3. Atmospheric clarity.* Regarding anthropogenic air/light pollution, the only town nearby is Malargüe, a small city with no significant industries. Some landowners burn vegetation in August–September which might introduce smoke in the site, this practice currently involves less than 5% of the site and it is declining.





**Figure 2.** Summary of the values obtained for the attenuation length centred at 440 nm during a total of 36 nights in the period July 7, 1998 to November 13, 1998. Data yield an average value of 31 km.

Several studies of the atmosphere at Pampa Amarilla were carried out. Air quality measurements, including an estimation of fog occurrence and determinations of aerosols contents and attenuation lengths, were performed.

From our set of meteorological data, fog was estimated to be present when the difference between air temperature and dew point was less than or equal to 0.9 °C. The value of 0.9 °C was chosen by reading of the station console while fog was observed to start vanishing. The results indicate that most of the fog occurrence corresponds to day or twilight times. If the phase of the Moon is included in the analysis, then the overlap of fluorescence detector observational conditions and fog times are reduced to 85 hours in 13 months, which should be compared to the expected 900 hours/year of fluorescence detector operation. Moreover, 85% of these situations occurred in the period February–May when the wind during foggy hours was weak (5–6 km h), allowing fog stratification at ground level [5].

The first dedicated experiment performed to determine the air transparency at Pampa Amarilla consisted of measuring the total vertical atmospheric opacity, by observing stars [8]. Luminosity of bright stars was measured for several elevations and three wavelengths (Johnson's system) for 22 nights from November 1997 to August 1998. Rather than using the drift-scan mode (which was used during the site survey in 1996), the telescope was set to follow the star. The total atmospheric opacity for the UV band (365 nm) had a range of 0.4–0.6 with an average value of 0.485 yielding an attenuation length of 2.06 air masses. A season modulation is observed in the results, showing less opacity during summer time. The value of 1.88 air masses measured during the site survey in the fall of 1996 [2] was found to be consistent with these results.

A second experiment was set up in 1997 in order to measure the horizontal attenuation length in the B band. The method used for measurements is based on the comparison of the intensities of light received by a CCD camera from two previously calibrated lamps installed at different distances [9]. The lamps were placed at the Picaso and Diamante peaks such that the distances and heights of the lamps with respect to the CCD were 14.79 km and 190 m for Picaso, and 43.94 km and 954 m for Diamante, respectively. The CCD camera (Olympus f/50 mm 1:1.8) was controlled by a laptop computer. A Kodak Wratten #47 filter, centred at 440 nm with a 380–520 nm range was used. Four measurement periods per night were scheduled using electronic timers to switch on and off the lamps. The results are displayed in the histogram of figure 2; they yield an average for the horizontal attenuation length

of 31 km with a wide dispersion, as shown in the figure. It should be noted that, although the atmosphere in the selected light-path is likely to be representative of the site's atmosphere, the fluctuations in transparency might be considerably bigger than those at the site [9]. Sudden increase in local cloudiness around the far lamp on the top of Diamante, an isolated tall peak at the periphery of the site, would reduce the value of the attenuation length. On the other hand, if the cloudiness is around the near lamp, the attenuation length would be enlarged, even beyond the value for air with no aerosol content (pure Rayleigh atmosphere), which is calculated to be 45 km.

Measurements were also performed to determine the aerosol contents of Pampa Amarilla by using a three-channel radiometer [10]. The three channels were centred at 380, 500 and 1000 nm with a FWHM of 10 nm each. These wavelengths were chosen since they are not absorbed by any common atmospheric gas, so the only dispersion or absorption of radiation in these bands is by aerosols. The attenuation coefficients were determined by measuring the sunlight over different sun angular positions. The values obtained indicate a 'clear' atmosphere and an attenuation length essentially independent of wavelength over the measured values, which suggests that the aerosols are relatively large particles ( $\approx 0.1 \mu\text{m}$ ).

**2.2.4. Infrastructure.** Pampa Amarilla is bounded to the north and west by Highway 40, an excellent paved road connecting San Rafael and Malargüe (see figure 1). High voltage transmission lines lie along the site's northern and western borders. A significant number of gravel and dirt roads exist within the site itself (most associated with a period of oil exploration in the area). Water is readily available from underground aquifers.

Malargüe supports the nearby winter resort of Las Leñas, as well as a small oil handling facility and several gypsum mines. While relatively small, Malargüe offers most of the goods and services required for day-to-day operation of the observatory. San Rafael (population 95 000) can provide significant light-industrial capacity as well as flight connections to Buenos Aires. The National Atomic Energy Commission of Argentina runs two facilities, the Sierra Pintada (170 km from Malargüe) and the Malargüe Mining Industrial Complexes, which are available for infrastructure support and managing activities at the site. There are also branches of the National Technological University at San Rafael and Mendoza City.

### 3. Northern hemisphere sites

#### 3.1. Search

There were a large number of candidate sites in the northern hemisphere extending from Kazakstan to the USA. In the end, only three were selected for closer examination: Tierra de Campos in Spain, El Barreal in northern Mexico and Millard County in the state of Utah in the United States.

Initially, three sites were under consideration in Spain: Tierra de Campos in Castilla and León, La Mancha in Castilla, north-west of Albacete and Los Monegros east of Zaragoza. All of them are located approximately 250 km from Madrid. All three sites are very well endowed with infrastructure including roads, electrical power and communications links. In the end, however, only Tierra de Campos was selected for further consideration. Both La Mancha, a heavily cultivated and somewhat irregular region, and Los Monegros, an area of significant vertical relief, were judged to be unsuitable. Tierra de Campos (780 MASL) is 40 km north of Valladolid. The terrain is broadly flat with a mean slope from north to south of 0.65%. The climate is classified as 'semi-arid' with a mean annual precipitation of 450 mm. Mean

maximum and minimum temperatures are 28 °C and 0.5 °C respectively. The area is fairly populated with more than 1000 landowners in the prospect site.

In consultation with a group of geologists with extensive experience in the area, a candidate site was identified at El Barreal (1200 MASL), Mexico, just south of the international border with the United States. The proposed site is approximately 100 km south-west of Ciudad Juarez/El Paso. The area is best described as 'semi-desert'. The mean extreme temperatures are 35 °C and -1 °C, with an annual precipitation of 220 mm which falls primarily in the summer months. Infrastructure at El Barreal is somewhat limited. Electrical power is available along the western edge of El Barreal.

More than a dozen sites in the south-western United States were considered for the northern Auger observatory. Among these, four were selected for detailed investigation: a 'Grand Canyon' site, just north of Flagstaff, Arizona; Lamar, Colorado; Millard County, Utah and Engle, New Mexico. Climatological data for the Grand Canyon, Engle and Millard County sites suggest that they enjoy particularly clear atmospheric conditions; Lamar and Millard County benefit from well-developed infrastructure. Following a careful review of the available data (e.g., climatological, topographic), Millard County was selected as the preferred US candidate for the location of the northern Auger observatory.

### 3.2. Millard County

*3.2.1. Site location and topography.* The site is located within a large, flat region of the Great Basin in Millard County, Utah, 150 km south-west of Salt Lake City (39.1° N, 112.6° W, 1400 MASL). The town of Delta (population 3000) lies just outside the array's northern boundary, and Fillmore (population 2000), the county seat, lies just outside the perimeter to the east.

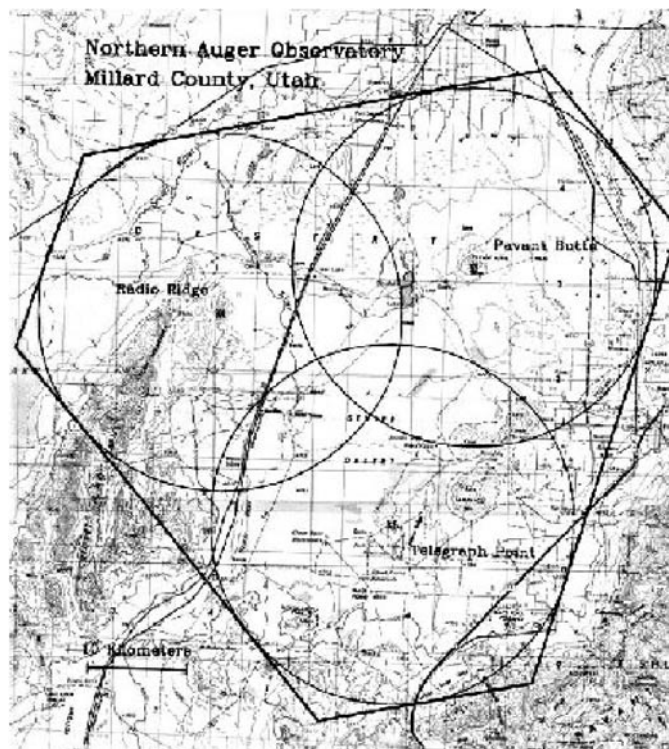
The site is bounded to the east by the Pavant Mountain range and to the west by the Cricket Mountains (see figure 3). A number of peaks and ridges exist within its boundaries including: the northern portion of the Cricket Mountains, Pavant Butte, Beaver Ridge (Telegraph Point) and Black Rock Mesa. These isolated and advantageously located features rise above a generally flat expanse of grass land and mud flats, which allow for a near optimum geometry for the fluorescence detector. Volcanic outflows cover a small area (50–60 km<sup>2</sup>) of the eastern portion of the site. There are some permanent wetlands (10–20 km<sup>2</sup>) in the centre and extreme north-eastern portion of the site.

The majority of the land in the region is unoccupied and unimproved. The regions immediately bordering the towns of Delta and Fillmore are cultivated.

*3.2.2. Land ownership and permission.* Most of the site (75%) is on federally owned public land managed by the US Bureau of Land Management (BLM). Permission to use this land is obtained by establishing, to the satisfaction of the local BLM office, that the project is in compliance with National Environmental Protection Agency (NEPA) regulations. An environmental assessment must be undertaken in which the effects of the project on threatened or endangered species, sensitive plants, cultural resources or riparian systems are studied. This assessment must be performed not only for the actual tank sites but also for the probable installation and access paths from the nearest roadway.

Approximately 5% of the site is owned by the State of Utah and is managed by the State Trust Lands Administration. This land must be leased. Annual site rental is assigned at the prime interest rate times its fair market value. This type of land occurs in one square mile tracts randomly located throughout the BLM property. The remaining 20% of the site land is privately owned. This land consists of farms in the north near Delta and in the east near





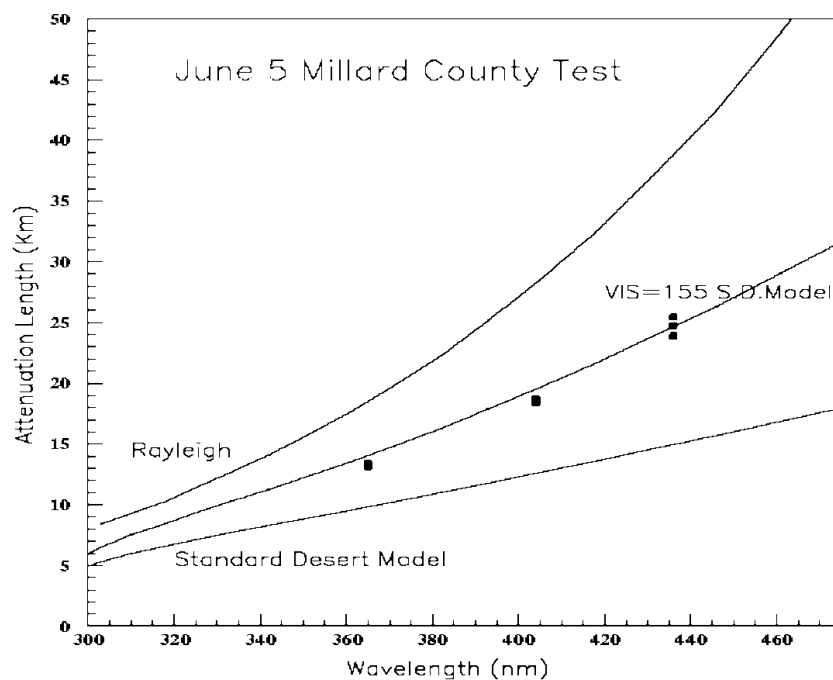
**Figure 3.** Northern site map. The array bounds are displayed in bold lines. There will be three telescope systems at Radio Ridge, Pavant Butte and Telegraph Point. The circles guide the eye as to the coverage of each telescope.

Fillmore. The project must gain the cooperation of 200–300 farmers in order to use the land. The local farm bureau has endorsed the project and has agreed to facilitate negotiations with its membership for individual land access.

**3.2.3. Infrastructure.** The Millard County site was chosen primarily for its unusually extensive infrastructure and accessibility. It lies 2.5 hours, by automobile, from Salt Lake City and 3.5 hours from Las Vegas. Interstate highway I-15 bounds the east and south-east edges of the site. The north is bounded by US highway 50. Highway 257 bisects the site from north to south. Numerous gravel roads cross the area and the high ground of the Cricket Mountains, Pavant Butte and Black Rock are all accessible via gravel road. Approximately 90% of the land area of the site can be accessed by less than 2.5 km of off-road travel. There is a rail-line with numerous sidings, which runs north-south through the centre of the site. There are many power lines crossing the site. A power line crosses Beaver Ridge in the south and a high voltage transmission line passes east-west just north of Pavant Butte. Another power line supplies power to the radio towers and facilities in the Cricket Mountain foothills.

The site enjoys an extensive phone and communications network. High speed data links service the schools in Delta and Fillmore. There is an optical fibre switching station near the northern edge of the site. High speed optical fibre links run along I-15 in the east and highway 257 near the centre of the site.

Abundant pure water is readily available at the site. The Intermountain Power Project (IPP), 16 km to the north of Delta produces large amounts of de-ionized water for its steam



**Figure 4.** Measured horizontal attenuation lengths versus wavelength. The top curve represents a pure Rayleigh atmosphere. The bottom curve represents a standard desert atmospheric model in which the total visibility is fixed at 155 km.

turbines. A fraction of this water has been made available for the Auger project at a small cost.

**3.2.4. Climate.** Millard County is situated in a dry desert region of the Western United States. Between 1938 and 1999 the mean annual precipitation at Delta, Utah, was 211 mm. The average snow depth for the month of January, the statistically snowiest month, is 46 mm. The region is characterized by extremes in temperature. The average temperatures for the months of December ( $-7-0^{\circ}\text{C}$ ) and January ( $-4-0^{\circ}\text{C}$ ) are below the freezing point of water. Without insulation the water Cherenkov tanks would have a tendency to freeze during these months.

**3.2.5. Atmospheric clarity.** The Millard County site is in the Great Basin region of the United States which is renowned for its clear air. It is just 100 km south from Dugway, where atmospheric conditions have been proven to be very suitable for air fluorescence cosmic ray detectors. The University of Utah's Fly's Eye and HiRes cosmic ray experiments have been operating successfully there for several decades. The atmospheric attenuation length for UV light at Millard County is expected to vary in the same range as at Dugway. The IPP exhaust stack, which is 16 km north of the proposed array perimeter, is a possible local source of air pollution. Its potential is not great, however, since the IPP thoroughly scrubs any particulate and sulfur compounds which it produces leaving only water vapour and nitrous oxides as effluents. The air masses in the area provide additional suppression by moving from west to east, sweeping any pollution products to the east and away from the detector volume. Aerosols from the IPP rarely invade the space over the array.

Direct measurements of the horizontal attenuation length have been performed at the site. During a one night test, a calibrated mercury vapour light source was placed on Cedar Mountain near Fillmore and observed with a CCD camera located on the Cricket Mountains. The test sampled a 50 km horizontal column of air stretching nearly through the centre of the array from east to west. Receiver and light source were situated approximately 100 m above the intervening plane.

Photometric measurements were taken through narrow band interference filters at three wavelengths: 365, 404 and 436 nm. The results are shown in figure 4. The attenuation lengths measured on the night of the test were  $13.27 \pm 0.2$  km,  $18.10 \pm 0.3$  km and  $24.8 \pm 0.7$  km at the three respective wavelengths. The measurements fall fairly close to predictions based on a standard desert aerosol composition with average density adjusted to give a total visibility of 155 km. It is apparent that the air clarity for the night of the test was significantly better than the zero wind velocity standard desert atmosphere shown in the lowest curve in figure 4. This is consistent with the experience of the Utah HiRes experiment at Dugway. The average atmosphere for that experiment was clearer than the standard desert atmosphere predictions.

#### 4. Conclusions

The two Pierre Auger observatory sites were selected. A comprehensive study in order to characterize the sites (atmospheric attenuation lengths, wind speed, temperature control and freezing computer simulations, soils and tank deployment studies, telecommunications) was undertaken. Land access has been guaranteed and deployment has begun in the south.

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