Characterization of Potential U.S. Sites for the Cherenkov Telescope Array

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Abstract: The Cherenkov Telescope Array (CTA) is a major ground-based observatory proposed for gamma-ray astronomy. CTA is envisioned to consist of two large arrays of atmospheric Cherenkov telescopes for the study of sources of high-energy gamma rays in the energy range of a few tens of GeV to beyond 100 TeV. One array would be located in the southern hemisphere and one in the northern hemisphere. After a detailed search, we have identified two potential sites in the USA for the northern array. Both sites are located in northern Arizona. Here we describe the two sites and the deployment of instrumentation to characterize them. The characteristics of the sites, in terms of their atmospheric and climatic properties, are described. We show recent data from the automated monitoring equipment at the sites and compare these data to a commercial simulation. Details regarding the facilities and infrastructure required for the sites are also presented.

Keywords: CTA, sites, atmospheric Cherenkov telescopes, VHE gamma-ray astronomy

1 Introduction

The Cherenkov Telescope Array (CTA) is an international consortium of 27 countries and approximately 1,000 scientists working to build the next generation gamma-ray observatory using the atmospheric Cherenkov technique and improving by a factor of ten the sensitivity of ground-based facilities for very high energy (VHE) gamma-ray astronomy. CTA will comprise two arrays, one in each hemisphere. Essential physical characteristics of the sites include 1 km$^2$ of relatively flat land (with < 8% grade across the entire area) and elevation > 1500 m. The standard CTA atmospheric monitoring station, the ATMOSCOPE, has been installed at each site since June, 2012.

The US team of CTA has identified two sites in Arizona as candidates for the northern hemisphere array. Land in Arizona has a variety of ownership types (private, State, US national forest, and Native American reservation). The proposed CTA sites are both on 1.6 km x 1.6 km square sections of privately owned land, which allows maximum ease and promptness of leasing and permitting. Figure 1 shows maps of the sites, illustrating the checkerboard pattern of land ownership prevalent in Arizona. White sections are privately owned.

2 The Arizona Sites

The Arizona East site is located 3 km from Meteor Crater and 65 km from the city of Flagstaff (pop. 65,500). The site is almost completely flat and treeless, and it lies at an elevation of 1,677 m. One of the US four-lane national highways, Interstate 40, is 6 km north and the main line of the Burlington Northern Santa Fe railroad is 1 km farther north of the proposed site.

The Arizona West site is located on the Yavapai Ranch, 25 km south of the town of Seligman, AZ (pop. 400), at an elevation of 1,670 m. Vegetation at the site is the low juniper pine and pinyon pine characteristic of this elevation in Arizona. This site is less flat than Arizona east but remains well within the CTA requirements.

The sites are reasonably close to Flagstaff, requiring either a 50-minute (Arizona East) or a 1 hour 45 minute (Arizona West) drive to reach. Lowell Observatory, which could serve as the local managing and scientific partner for the CTA, is sited in Flagstaff and permanent CTA employees would likely be based there.

3 Meteorological and Atmospheric Characteristics of the Sites

3.1 General Characteristics

Both sites have decades to over 100 years of meteorological records in place. All significant variables (temperature, humidity, wind, and natural hazards) in the historical record are within the CTA survivability requirements and within the operating requirements for a high fraction of the time. Data from the CTA ATMOSCOPEs also show no episodes of weather outside the requirements as well.
wind speeds. It was found that average wind speeds have a
higher during the day than at night. Figure 4 shows the av-
average wind speed versus hour of the day for both CTA can-
didate sites in Arizona.

While the ATMOSCOPEs have provided very detailed infor-
mation since their installation, estimating the suitabil-
ity of the sites for the 10+ years of the CTA experiment’s
presumed lifetime calls for an understanding of the longer-
term trends. In addition to the long-term weather records
mentioned previously, retrodictions of environmental con-
ditions at the CTA candidate sites have been obtained
from weather simulations carried out by a private company
(SENES) (see [1]). Correlation studies with simultaneous
ATMOSCOPE and weather simulation data have been per-
formed and the results from these studies give us a picture
of the long-term weather patterns.

As an example, Figure 5 shows the correlation between
the temperature as recorded by the ATMOSCOPE and the
prediction of the simulation for the Arizona East site. The
data are essentially simultaneous (i.e. within one hour over-
lap, the time resolution for the SENES study). As can be
seen, the correlation is relatively good with a moderate
amount of spread. On the other hand, Figure 6 shows the
comparison for the wind speed at the same site. Here it is
clear that the the simulation overestimates the wind speed.
Thus a correction factor (that varies with wind speed) is
expected to be above the CTA operational requirement.

To quantify the darkness of the night sky at the can-
didate CTA sites, two devices are employed in the ATMOSCO-
COPE [2]. One is the Sky Quality Monitor (SQM) which
is a commercial device produced by Unihedron. It utilizes a TSL237 photodiode and a temperature sensor to provide a measure of the night sky brightness in mag/arcsec\(^2\). It has a claimed precision of ±10% (±0.10 mag/arcsec\(^2\)). The spectral responsivity of photodiode is quite broad, extending from 300 nm to 1100 nm with the peak responsivity at ~700 nm. This broad spectral response makes it a less-than-ideal instrument for measuring the night sky background relevant for atmospheric Cherenkov telescopes. The second device on the ATMOSCOPE used to measure the night sky background is the Light of Night Sky (LoNS) device. The key elements of the LoNS are a Hamamatsu 3584 PIN-photodiode and a filter wheel which includes a V-band filter and a custom “B” filter made from a combination of Schott BG25 and BG39 filters - meant to emulate the response of a photomultiplier tube. The data from the LoNS is the current measured from the photodiode (in pA).

In order to validate the night sky background measurements and to try to establish a conversion between LoNS photodiode current (in pA) and night sky background light (in mag/arcsec\(^2\)), the correlation between the LoNS “B”-filter photodiode current and the SQM measurement was investigated. This procedure was also used for the LoNS V-band filter. The correlation scatter plot (LoNS “B” vs. SQM) and unbinned fit are shown in Figure 7. Based on the definition of magnitude, one expects the correlation to follow the function \(\text{SQM} = a \log_{10} (\text{LoNS}) + b\) where \(a = -2.5\). Due to the difference in spectral response and fields of view (SQM FWHM ~ 20°, LoNS FWHM ~ 40°), the theoretical correlation is not seen in either the “B” or V-band LoNS filters. However, the relatively tight correlation does allow for a conversion from narrow-band LoNS current measurements to broadband measure of the night sky background in mag/arcsec\(^2\). We find that the ATMOSCOPE estimates for the night sky background levels at both sites agree with those determined by photometric techniques and carried out by the US National Park Service (see, e.g., Figure 3).

4 Facilities and Infrastructure

Both sites offer easy access and convenient infrastructure development. A modern, four-lane highway runs to within 7 km of AZ East and 25 km of AZ West, with either paved or good dirt roads coming to within a few kilometers of the sites. Electric substations operated by Arizona Public Service (APS) are nearby (within about 8 km for the East site). Wells are available at both sites for water, and internet connectivity up to 1 Gbps is available with high-speed microwave connections using either direct or 1-hop lines of sight to mountaintop towers near Flagstaff.

Nearby support facilities are excellent. Flagstaff has a modern airport with a 2,700 m runway and instrument landing system, and both Phoenix Sky Harbor International Airport and Las Vegas McCarran International Airport are 3-4 hour drives from the sites. Flagstaff Medical Center is a 267-bed, Level 1 Trauma Center facility equipped to handle any medical emergency and it is served by an air transport service that can reach the hospital from Arizona East in 15 minutes and from Arizona West in 35 minutes. Most permanent CTA personnel would likely be based in Flagstaff.

5 Conclusions

After a search of possible locations in the United States for the northern site of the Cherenkov Telescope Array, we have identified two sites in northern Arizona that fully satisfy all CTA requirements. Here we provide some of
the general characteristics for the sites, including typical meteorological conditions, night sky background levels, and available facilities and infrastructure. Results from the CTA ATMOSCOPE monitoring stations are shown, including initial comparisons between weather conditions measured by the ATMOSCOPE and those predicted by a commercial simulation. These comparisons give us some confidence in the ability of the simulation to estimate the weather conditions over a longer period of time.

Acknowledgment: We gratefully acknowledge support from the agencies and organizations listed in this page: http://www.cta-observatory.org/?q=node/22. This work was carried out, in part, with support from the US National Science Foundation and from the University of California.

References