The monitoring of weather and atmospheric condition of LHAASO site

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Abstract: The Large High Altitude Air Shower Observatory (LHAASO) project is proposed to study high energy gamma ray astronomy and cosmic ray physics. As a component of the project, the wide field of view Cherenkov telescope array is designed to study the spectrum and compositions of cosmic rays. Two prototype telescopes have been operated since 2008. The weather condition and the air quality are very crucial to the energy reconstruction and spectrum calculation. So in order to calibrate the weather and air condition, the UV bright stars are used, as a cross check, and the infrared data are also analyzed.

Keywords: LHAASO, calibration, UV star

1 Introduction

The Large High Altitude Air Shower Observatory (LHAASO) project [1] aims to study 40 GeV-1 PeV γ ray astronomy and 20 TeV - 1 EeV cosmic ray physics at Yangbajing (4300m a.s.l), Tibet, China, near the AS, and ARGO-YBJ experiments. As a component of the LHAASO project, the Wide Field of View (FOV) Cherenkov Telescope Array (WFCTA) is designed to study cosmic ray energy spectrum species by species by measuring the energy and $X_{\text{max}}$ depth of each air shower.

Two WFCTA prototype telescopes have been constructed and placed near the ARGO-YBJ Experimental Hall. The two telescopes can be operated in both monocular and stereo modes, and the coincident observation with the ARGO-YBJ detector is achieved off-line. Each telescope is made up of two main parts, the reflector and the camera. The reflector consists of 20 spherical mirrors with a radius curvature $R$ of $4730 \pm 20\text{mm}$, corresponding to a total area of $4.7\text{m}^2$. The reflecting efficiency of the mirrors is about 82% for light with wavelength larger than 300nm. A camera is placed at the focal plane which is $2305\text{mm}$ away from the reflector center to optimize the spot shape of a point-like object. The camera is composed of 256 flat hexagonal photomultipliers tubes (PMTs) each of which has a diameter of $40\text{mm}$, corresponding to a FOV of about $1^\circ \times 1^\circ$. The PMTs are arranged in 16 columns and 16 rows forming a total FOV of $14^\circ \times 16^\circ$[2]. The maximum quantum efficiency of PMTs can reach 30% at 420nm. The signals of the PMTs are digitized by $50\text{MHz}$ Flash Analog to Digital Converters (FADCs)[1]. The gain and variance between PMTs are calibrated by the led which is installed in the front of the camera[3]. The whole system is hosted in a shipping container with a dimension of $2.5\text{m} \times 2.3\text{m} \times 3\text{m}$. The container is mounted on a standard dump-truck frame with a hydraulic lift, which makes the container be tilted in any elevation angles from 0 to 60 degrees. The pointing direction of the telescope can be easily changed by the container. The pointing directions can be calibrated by the bright stars observed by the telescopes and the accuracy of the calibration can reach up to $0.1^\circ$[4].

Cherenkov photons emitted in the air shower suffer Raleigh and aerosol scattering during their propagation to the telescope. The Raleigh scattering is caused by molecules in the atmosphere and changed according to the air pressure. The aerosol scattering is caused by the dust in the atmosphere. The scattering will become more seriously under the bad weather condition. So the Cherenkov photons recorded by the telescope vary with different weather conditions. However, energy reconstruction relies on the number of the recorded Cherenkov photons, so some bias during the energy reconstruction would be introduced for the events observed in the bad weather and atmospheric conditions. In addition, the aperture would become shorter in the bad weather and atmospheric conditions, which will effect the estimation of the energy spectrum. In order to estimate the energy spectrum correctly, the weather and atmospheric conditions should be studied very carefully.

Several methods are introduced to calibrate the weather and atmospheric conditions in the air fluorescence and Cherenkov telescopes. For example, the YAG laser and the infrared detector are used to calibrate the atmospheric condition and clouds in HiRes experiments.
However, the installation of the laser has not been setup until 2011, in order to calibrate the weather and atmospheric conditions before 2011, a new method is introduced. In this paper, the method of calibrating the weather conditions by bright stars will be described. The method is used to analyze the data of Nov. and Dec. 2009, totally 39 days. Finally, the infrared data offered by IAP are used to test the validity of the method.

2 Star light

The night sky background (NSB) contains two components, one is the diffuse lamplight from the town of Yangbajing, the other one with well known directions and stable fluxes is from the bright stars appearing in the FOV of the telescope. The changes of the NSB reflect the weather and atmosphere conditions.

In addition to recording the Cherenkov light from air showers, the camera can also record the NSB during the observation. For each air shower event, the signal of Cherenkov light can only last a few nanoseconds, while the trigger window lasts \(18 \mu s\), thus telescopes record NSB in most of the trigger window. In order to avoid the Cherenkov signal, only the average value in the last \(2 \mu s\) of the trigger window recorded by the telescope is used as the relative strength of the NSB. In order to reduce the fluctuations, the value of the recorded NSB is averaged every 10s.

After subtracting the diffuse NSB, the component of the star can be seen clearly. Figure 1 shows the changes of the total flux of stars recorded by the telescope in an observation night with a very clear weather condition. The bump in the figure 1 is caused by the Galactic plane, which is rich in bright stars.

The real fluxes of the stars can be obtained from the star catalog. In our analysis, the TD1 catalog is used, which has four different wavelength bands, 1565, 1965, 2365 and 2740 Å, respectively [5]. The WFCTA telescopes are sensitive in the near UV band, so the last wavelength band of TD1 is used. At a clear night, a clear correlation between the fluxes of the stars which are in the FOV of the telescope and the observed one can be seen as shown in figure 2.

3 Weather condition selection

3.1 The whole night selection

As shown in figure 2, a clear correlation between the total star fluxes and the recorded FADC counts at a clear night can be seen, and the correlation coefficient can reach 0.95. When the cloud increases, the absorption and the reflection to the star photons increase. And at the same time, the cloud can reflect more photons which come from the ground, therefore, the total intensity of NSB is increased, the correlation between the fluxes of stars and the FADC counts become weaker or even disappeared. So the correlation coefficient is introduced to judge the weather condition.

The data of Nov. and Dec. 2009 total 39 days is analysed. The distribution of the correlation coefficient is shown in figure 3. The weather with correlation coefficient better than 0.8 is defined as good weather. Only the data obtained under the defined weather condition should be used in the energy spectrum calculation. From figure 3, there are 22 days with good weather condition out of the 39 days.
3.2 The selection on hour scale

If the weather changes during one night as shown in figure 4, it is necessity to select the bad weather. In order to study the weather changes of the nights selected by the correlation coefficient in detail, an analysis on hour scale is used.

The FADC counts recorded by the telescope and the total fluxes of stars are fitted by two linear functions which is shown in figure 2. The range with higher star fluxes is corresponding the Galactic plane which is rich in stars. So the total background is higher than other time and more FADC counts are recorded. So the fit is divided into two ranges, with Galactic plane and without Galactic plane respectively.

If the differences between the FADC counts and the fitted value are larger than 4RMS, the points are subtracted as bad weather conditions.

4 The calibration of the transparency

The correlation coefficient can only define the weather qualitatively, however, the differences among the selected 22 days with good weather defined by the correlation coefficient can not be shown by the parameter.

If a night has a very good transparency of the atmosphere, the photons from stars have more possibility to penetrate the atmosphere, therefore, the telescope has a better response to the photons than the night with a worse transparency.

In order to calibrate the weather in detail, the slope fitted by the linearity function is used to indicate the transparency of the atmosphere.

The fit parameters (slope $k$ and intercept $b$) of the linearity function as shown in figure 2 are shown in figure 5. As can be seen from figure 5, the two parameters are correlated which are caused by the diffuse background subtraction. So the FADC counts and the total star fluxes are fitted by linear function with the slope $k$ as a function of intercept $b$ ($k = 7.4 \times 10^5 \cdot b - 4882$). Here, the parameter $b$ is defined as the transparency of the atmosphere. The distributions of the transparency is shown in figure 6. The larger the value in the figure 6 is, the better transparency of the atmosphere is expected.

5 The test of the transparency

The star light is the first used to select the weather and to calibrate the transparency of the atmosphere, so the reliability of the method has to be tested by other method and data.

First, the method is tested by the infrared data. An infrared detector was installed in Yangbajing to detect the thickness of the cloud. The infrared temperature increases as the thickness of the cloud increases. The distribution of the infrared temperature is shown in figure 7. The fist bump is corresponding to the weather with cloudless, while the seconded one indicates the weather with cloudiness. If the infrared temperature is higher than 0.8, the corresponding weather is considered as cloudiness.

The correlation between the infrared temperature and the transparency of atmosphere obtained by the star light is shown in figure 8. As shown in figure 8, when the infrared
temperature increases, the transparency of the atmosphere is decreased. The correlation is consistent with the expectation.

Another test can be done by the image size of the Cherenkov light emitted by the particles in the EAS. When the transparency of the atmosphere decreases, the absorption and scattering of the atmosphere to the Cherenkov photons are increases, therefore, the average image size of the Cherenkov photons decreases. The correlations between the two parameters can be seen in figure 9. Because the effect is only obvious to the low energy events, only events with \( n_{\text{hit}} \) lower than 1000 are used. From figure 9, the correlation between the transparency and the average images size is consistent with the expectation.

By the tests of the new method, the results obtained by the method is correct and reliable.

6 Conclusion

The two prototypes of WFCTA have been operated in Yangbajing till now. The weather condition is very important for the energy spectrum calculation. In order to study the weather and atmosphere condition of the town of Yangbajing a new method is introduced.

The correlation coefficient between the total fluxes of bright stars in the FOV of the telescopes and the FADC counts recorded by the telescope is used to select the clear nights. If the correlation coefficient is better than 0.8, the weather is considered as a good weather. At the same time, the weather is selected on hour scale by the differences between the FADC counts and the fitted value.

In order to study the weather and atmosphere condition in detail, the transparency of the atmosphere is introduced, and the results are tested by the infrared temperature and the average image size. The tested results are consistent with each other.

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