Updated Results on the UHECR Hotspot Observed by the Telescope Array Experiment

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The Telescope Array Experiment has observed an indication of intermediate-scale anisotropy in the UHECR arrival directions, called the Hotspot, with $E > 57$ EeV around the Ursa Major using the first 5-year data during a period between May 2008 and May 2013 collected by the TA surface detector array. The chance probability of this hotspot in an isotropic cosmic-ray sky was calculated to be 3.4σ (post trial). In this paper, we will report on an update of this result using the 11-year data collected by the TA surface detectors with more than doubled exposure since the first publication.

36th International Cosmic Ray Conference -ICRC2019-
July 24th - August 1st, 2019
Madison, WI, U.S.A.

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1. Introduction

The Telescope Array (TA) and the Pierre Auger Observatory (Auger) are the largest UHECR detectors in north and south hemispheres, respectively. They have both obtained some hints/evidence of anisotropy in the UHECR directions. Recent anisotropy measurements and the efforts to identify UHECR sources are summarized in Ref. [1]. The Auger group has claimed that the starburst model fits the observed UHECR distribution better than the hypothesis of isotropy with a statistical significance of 4.0σ [2]. They also has have claimed a dipole-like anisotropy with an amplitude of 6.5% for cosmic rays with energy greater than 8 EeV. The anisotropy has a statistical significance of 5σ [3].

The TA collaboration has first reported a hotspot of UHECRs, with $E > 57$ EeV, in the first 5-years observation period from 2008 May to 2013 May [4]. The "hotspot" is located near the direction of the Ursa Major cluster, and extends to $\sim20°$ angular scale. The chance probability of detecting this hotspot in an isotropic cosmic-ray sky was calculated to be 3.7×10^{-4} (3.4σ) assuming $15°$, $20°$, $25°$, $30°$, and $35°$ oversampling radius circles were searched. After the report of hotspot, the TA group found that the flux has a deficit in the energy range $10^{19.2} < E < 10^{19.75}$ eV and an excess in $E > 10^{19.75}$ eV (~57 EeV), respectively, compared with the average flux of the other sky using the 7-year data [5]. The post-trial probability of this spectral anisotropy appearing by chance from the isotropic distribution is estimated to be 9×10^{-5}, which corresponds to 3.74σ. Recent anisotropy studies by the TA are summarized in Ref. [6].

In this paper, we present the updated results on the TA hotspot with the latest 11-year data collected by the Telescope Array surface detector array.

2. Telescope Array Experiment

The Telescope Array (TA) is the largest cosmic-ray detector in the northern hemisphere. It consists of a surface detector (SD) array [7] and three fluorescence detector (FD) stations [8, 9]. The TA has been fully operational in Millard County, Utah, USA ($39.30°$N, $112.91°$W; about 1,400 m above sea level), since 2008. The TA SD array consists of 507 plastic scintillation detectors of 3 m^2 area located on a square grid with 1.2 km separation and makes measurements of the footprints of extensive air showers when they arrive at the Earth's surface. The SD array has an area of approximately 700 km^2. For more details, see Ref. [10]. The TA SD array observes cosmic rays from ~1 EeV to 100 EeV using the extensive-air-shower technique of a scintillation detector array with a duty cycle near 100% regardless of weather conditions, and with a wide field of view. These capabilities give us an unbiased survey of the northern sky. The telescope stations observe the sky over the SD array and make measurements of the longitudinal development of the air showers as they traverse the atmosphere.

3. Results and Discussions

The updated results on the TA hotspot were reported at the previous conferences using the 7-year [11] and 9-year data [12], respectively. In this work we test this result using the 11-year data collected by the TA SD array. We have observed 168 events with $E > 57$ EeV in 11 years, which is
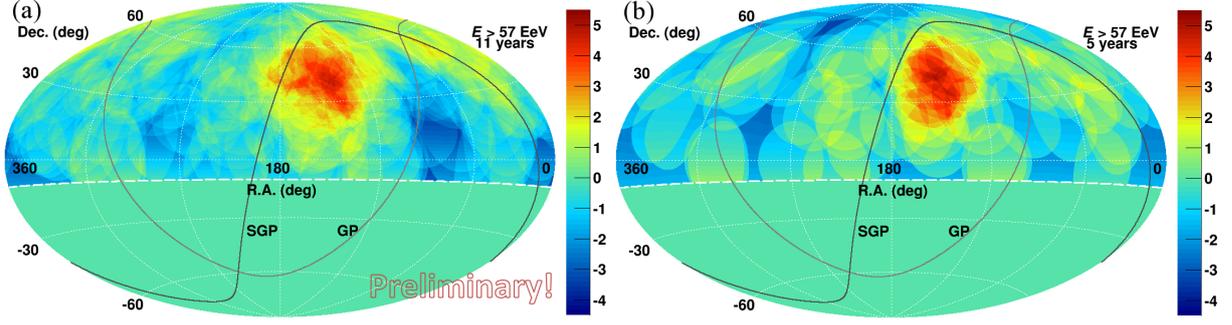
Figure 1: (a) A significance map of the UHECR events with $E > 57$ EeV for 11 years of TA data (May 2008 - May 2019) in the equatorial coordinates. Events are smoothed by $25°$ oversampling radius circle, which is defined in this paper. (b) A significance map of the UHECR events with $E > 57$ EeV for events observed in the 1st 5 years of TA data (May 2008 - May 2013). Events are smoothed by $20°$ oversampling radius circle according to our original paper [4]. The solid curves indicate supergalactic plane (SGP) and the galactic plane (GP).
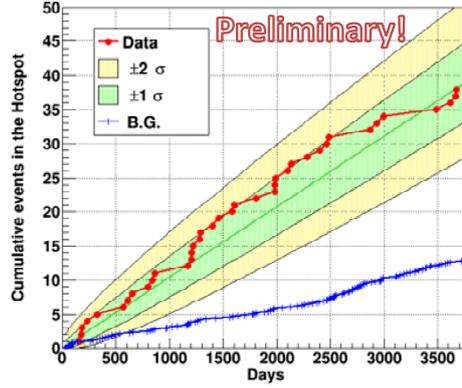
Figure 2: Number of cumulative events of the hotspot region (Red curve), and cumulative background events (Blue curve), respectively, above 57 EeV. The green and yellow shaded areas show $\pm 1\sigma$ and $\pm 2\sigma$ deviations from the rate of data observation respectively, assuming a linear increase in rate.

approximately double statistics of the first 5-year observation. These events are summed over different five oversampling radius circles, $15°$, $20°$, $25°$, $30°$, and $35°$. The centers of tested directions are on a $0.1° \times 0.1°$ grid in the equatorial coordinates. We then search for the maximum significance over all grid points and five oversampling radius circles. We found the maximum significance of 5.1σ at a position R.A.=$144.3°$, and Dec.=$40.3°$ with $25°$ oversampling radius circle. The chance probability of the 11-year hotspot in an isotropic sky is estimated to be 2.1×10^{-3} (2.9σ). Figure 1 (a) shows the significance maps of the UHECR events with $E > 57$ EeV for 11 years with $25°$ radius circle, compared with our previous result for the 1st 5 years of data with $20°$ shown in Fig.1 (b) [4]. The 11-year hotspot looks larger size than the 5-year hotspot (the number of background events in $25°$ radius circle is 50% higher than that of $20°$ radius circle). It has extended all the way to the supergalactic plane (SGP), and is irregular in shape. Therefore a circular oversampling shape is not really appropriate. In that case, the significance of such an excess might be underestimated.

In Fig.1 (a), a marginal excess is seen along the SGP (around the Perseus-Pisces Supercluster) at the local significance of $\sim 3\sigma$.

We divided the 11-year data into the first 5 years and the second 6 years. The significance at the hotspot position is 5.0σ for the first 5 years and 2.2σ for the second 6 years, respectively, with $25°$ radius circle. Figure 2 shows the cumulative events inside the hotspot circle defined by the 11-year dataset to check a deviation from the linear increase. The green and yellow bands in this figure represent the $\pm 1\sigma$ and $\pm 2\sigma$ allowed regions, respectively. The increase rate of the events inside the hotspot circle is consistent with a constant within $\pm 1\sigma$ fluctuation.

4. Summary

In this paper, the TA hotspot analysis was updated using the 11-year observation. We found the local significance of 5.1σ at a position R.A.=144.3°, and Dec.=40.3° with $25°$ oversampling radius circle. The chance probability of the 11-year hotspot in an isotropic sky is estimated to be 2.1×10^{-3} (2.9σ). The TA will continuously observe to verify our current results. In addition, the TA×4 experiment has partly started its data taking in 2019 [13], which will extend the size of the TA SD by a factor of 4 in near future to collect data at a faster rate.

Acknowledgments

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