Time Dependence of Cosmic Ray Anisotropy

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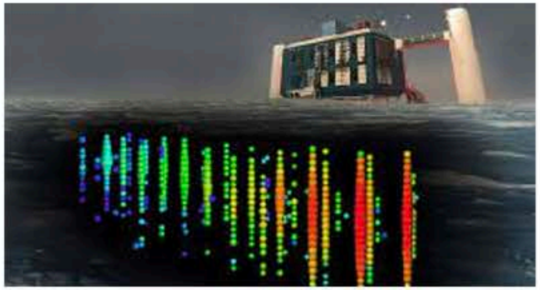
Background

IceCube is an in-ice Neutrino Observatory made of 5,160 Digital Optical Modules (DOMs) arranged in 86 strings buried a kilometer below the ice covering about a kilometer cube of space. The detector is designed to study cosmic ray neutrinos as they pass through Earth in an endeavor to better understand their sources. This is done by analyzing the size and shape of the events deposited in the detector.



Cosmic Ray Anisotropy and Time Dependence

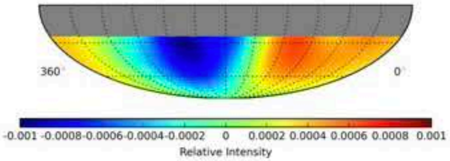
Anisotropy refers to the unequal distribution of high intensity events across the celestial sky meaning that some areas of the sky see more high energy events than others. The anisotropy is observed in sidereal time frame that is discussed below.

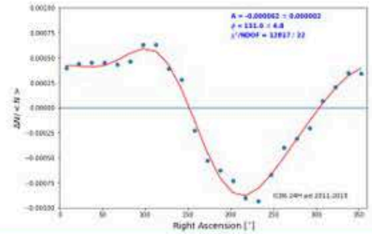
1D and 2D Projections

In order to study the time dependence of the cosmic ray anisotropy, we create 2D and 1D projections of the arrival direction (right ascension) and relative intensity. The 1D projection on the bottom is fitted to a third harmonic.

$$\sum_{n}^{3} A_n[\cos(n(\alpha - \varphi_n))]$$

The 2D and 1D sky maps show an increase in the relative intensity of events coming from lower right ascension angles. Together, these projections illustrate the anisotropy in the arrival direction of events around 14 TeV.

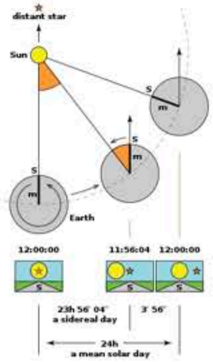




Time Frames

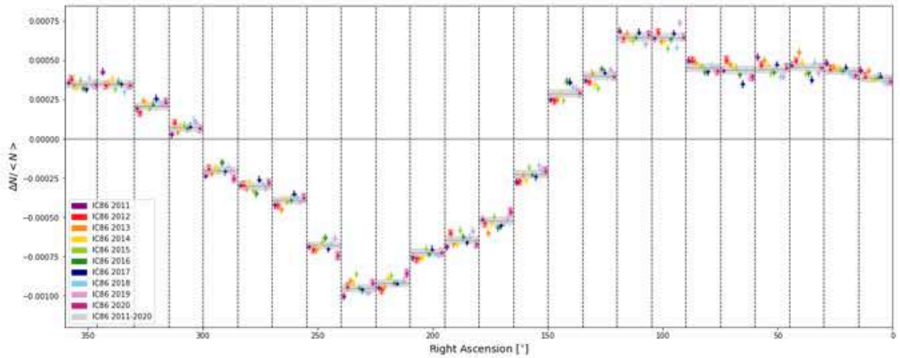
The Sidereal time frame is used to help quantify the time dependence of the anisotropy. Unlike the solar day which lasts 24 hours and uses the sun as a reference point, a sidereal day is shorter. It lasts 23 hours and 56 minutes and uses a distant star as a reference point.

In addition to the sidereal day, the anti-sidereal time frame is also used in anisotropy studies. An anti-sidereal day is longer than the solar day by the same amount that the sidereal day is shorter. This fictitious time frame is not meant to contain any real signal, so any signal collected in the anti-sidereal time frame is used as the systematic error.



Time Dependence

By combining the 1D projections using data from the 2011-2020, we can observe the trend of cosmic ray anisotropy for the past 9 years. Each year is broken down into 24 right ascension bins each represented by a dashed, vertical line. The shaded regions around each point are the systematic errors calculated using the anti-sidereal time frame. The solid horizontal line in each bin is the average value of the relative intensity for all years and the shaded vertical region represents the overall systematic error.



Conclusion

In our study of cosmic ray anisotropy, we have found that there is some time dependence. By looking at the 1D projections, we can see that some years trend above or below the average value for the relative intensity. Further study is required to better understand the observed time dependence.

ACKNOWLEDGMENTS: We would like to acknowledge our collaborators Mercer University, University of Wisconsin and the IceCube collaboration all funded by the NSF.

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