Monitoring the Night Sky for IceACT

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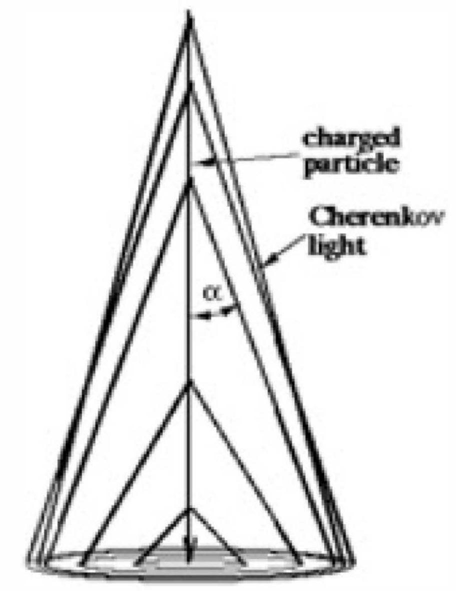
Abstract

The neutral subatomic neutrinos are astronomical messengers that can provide us information to investigate the most violent astrophysical sources: supernovas, gamma-ray bursts, and cataclysmic phenomena involving black holes and neutron stars. As these astrophysical neutrinos freely travel from their point of origin without being scattered by interstellar magnetic fields, we can analyze these particles by observing cosmic-ray air showers on the Earth's atmosphere. These are produced by the energetic neutrinos by interacting with the air particles that produce a wavefront of Cherenkov radiation. To better identify these background neutrinos, IceCube, the South Pole Neutrino Observatory, constructed an imaging air Cherenkov telescopes otherwise known as IceACT, that are located at the South Pole. These telescopes contain the resources to detect the atmospheric muons produced by the cosmic-ray air showers. Furthermore, IceACT can independently calibrate the angular reconstruction of IceCube to provide accurate results in future trials. Our objective is to further conclude that the data obtained by IceACT supports the readings by IceCube by providing an analysis that the Antarctic night sky interferes of detecting any possible indications of Cherenkov radiation. Through analyzing a sample size of 30 detected stars, we found that only about 60% of the photometric measurements are explained by a linear fit. Furthermore, calibrating the transparency of the atmosphere for IceACT measurements can be done to an uncertainty of approximately 0.5 magnitudes.

IceACT & Cherenkov Radiation

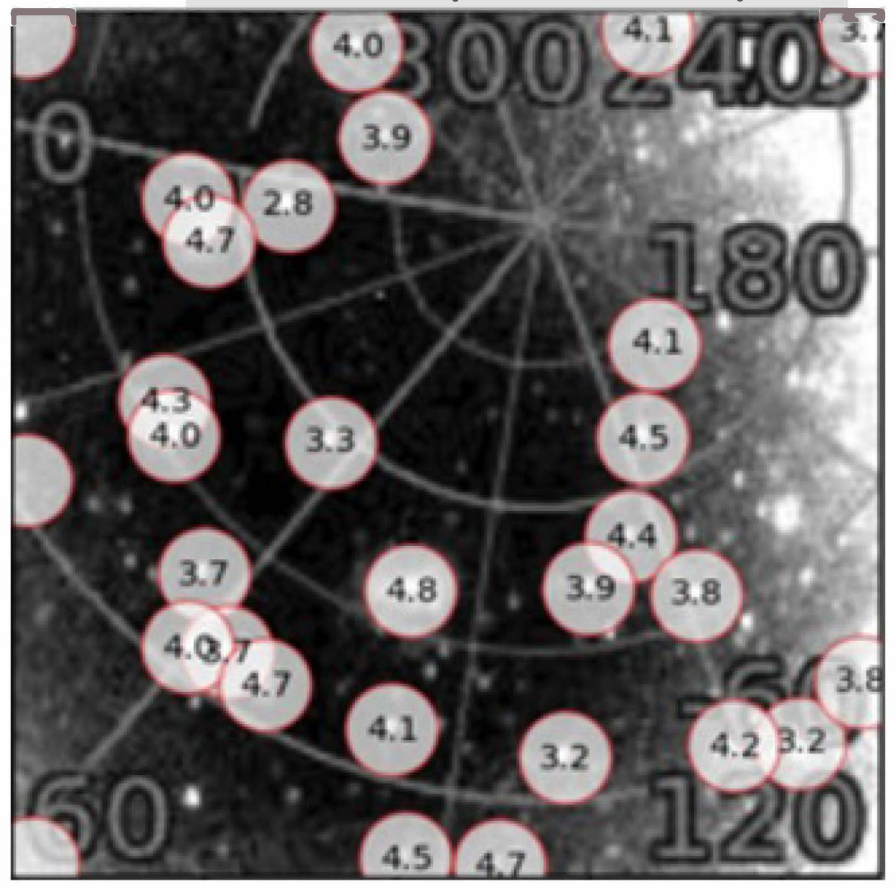
The main objectives of IceACT are to detect cosmic-ray muons and to study their composition between iron and proton cosmic ray showers. Since high-energy astrophysical neutrinos travel through cosmic rays towards Earth, they collide with particles in our atmosphere readily charging a fermion particle (i.e. an electron or muon). The fermion then travels faster than the phase velocity of light towards the Earth, and a portion of the particle energy is converted to a faint bluish light, known as Cherenkov radiation, that travels as a wave front traveling at a given angle. This angle is determined by the height of emission of the charged particle and the density of the air; at most the angle is measured to be less than 1.7 degrees. The photons from the Cherenkov radiation interact with other air particles, causing an air shower faster than the local speed of light.



Position and Brightness of Each Stars

The instrument we utilized to observe the Antarctic night sky is the AllSky 340 Camera that can view 130° of the night sky. This camera observes visible light and is equipped with a sensitive KAI 0340 Image Sensor that can read out the how much light is received in each image. The images are saved as FITS (Flexible Image Transport System) files that can contain multiple arrays of information and are widely used for astronomy research purposes. Each image taken by the AllSky 340 Camera has one minute of exposure time.

Stars detected by astrometry.net



By obtaining a FITS image by the AllSky 340 Camera, we used an astrometric calibration service website known as astrometry.net. where we uploaded it to. This website delivers information not just where each star is positioned, but as well as their photo-electron count, in other words, the amount of photons the camera received in a given image.

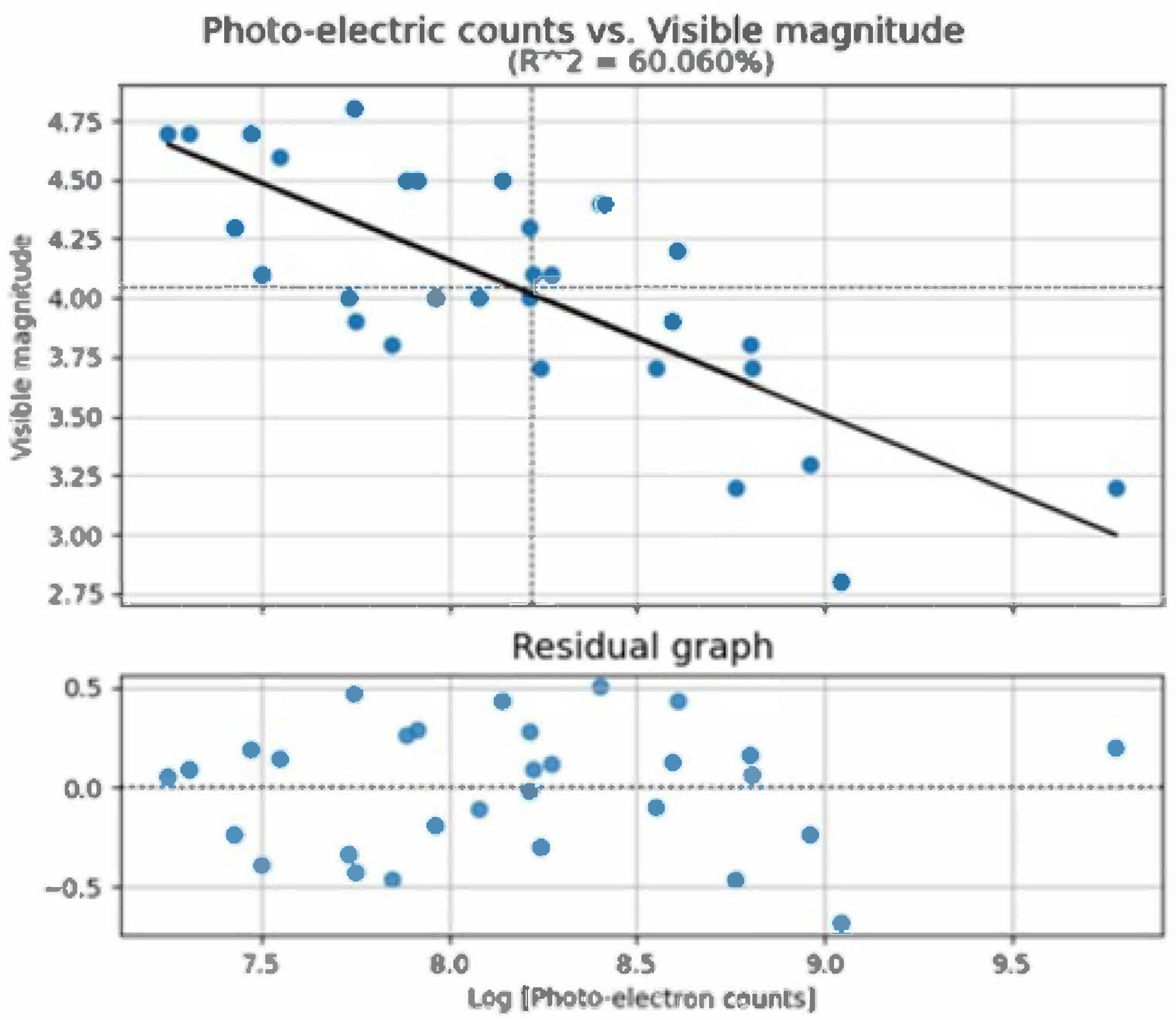
The image on the left displays the 30 stars detected by the astrometry.net along with a scalar value of their visual magnitude found by using Astropy, a Python core package that contains astronomy tools and astronomical catalogs.

Astrometry.net   The Astropy Project

Photometric Analysis

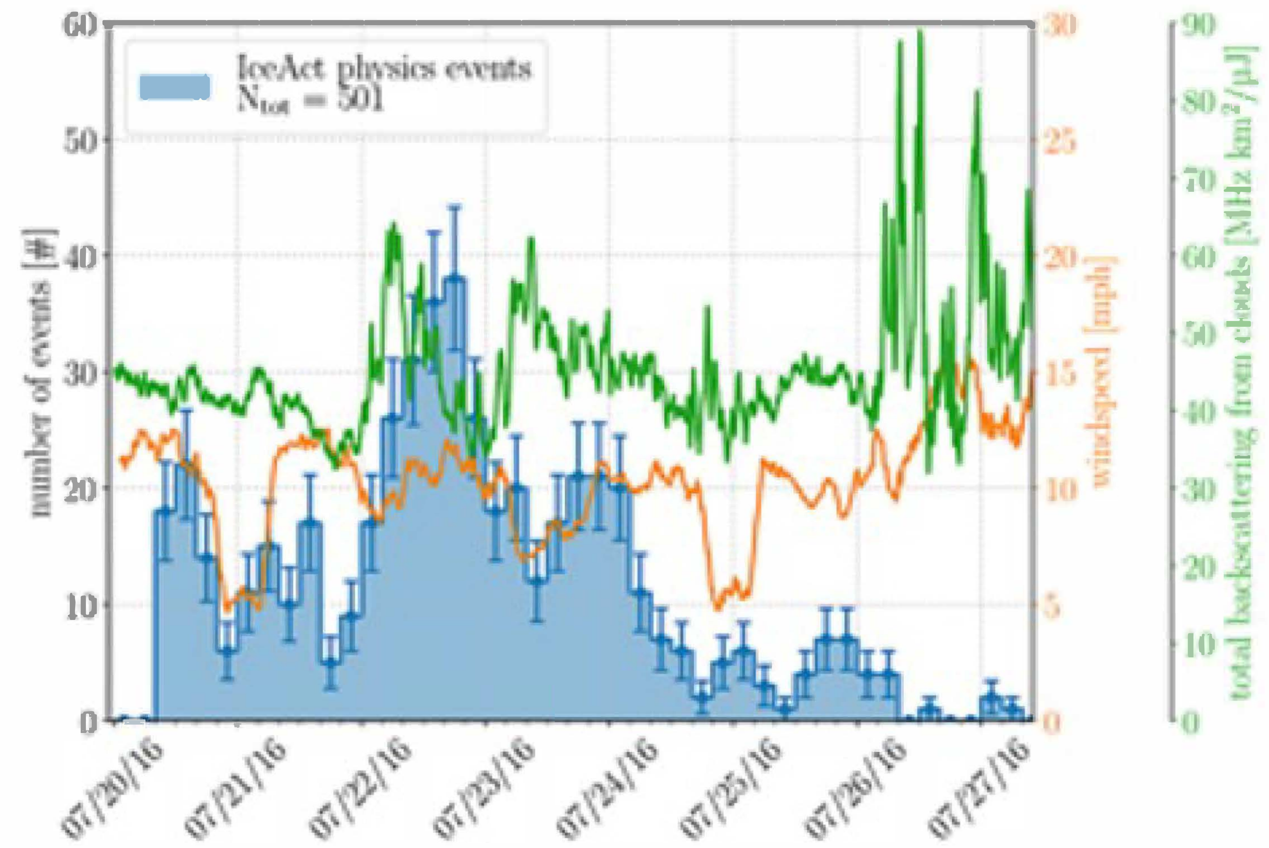
Based on the photo-electron and the visual magnitude datasets we received by astrometry.net and Astropy, we observed that they are both normally distributed. By taking the logarithm of the photo-electron counts, this dataset is centered at 8.217 with a low spread of 0.687 that is slightly skewed right. For the visual magnitude dataset, it is centered at 4.05 with similar spread of 0.488 that is slightly skewed left. In either dataset, no outliers were detected.

Log [Photo-electron counts]	Visible Magnitude
$\mu = 8.217$	$\mu = 4.05$
$\sigma = 0.687$	$\sigma = 0.488$



To determine if the photo-electron count received by our sample stars is due to the visual flux of those stars, a correlation plot shown on the right was made. We can see that there exists a negative association and based on the residual plot below the datapoints signify that the data is linear with an approximate error of 0.5. Additionally, we can see that the limiting magnitude, the dimmest star our camera can detect through visual is estimated to be 4.8.

As there exists a moderate relationship, $R^2 = 60.06\%$, between the photo-electric counts and the visual magnitude, we conclude that visual brightness of the stars seen at the Antarctic night sky do adequately contribute in the number of photons detected by the AllSky 340 camera.



To conclude whether the number of incidents are due to cosmic air showers or stellar light, we observe the figure on the left. The relationship that we observed is between the number of physics events (cosmic ray air showers) shown in blue. Each physics event is a flash of Cherenkov radiation that observed by the operated IceACT instrument. These flashes are near-instantaneous unlike the persistent stellar light that is emitted by the entire night sky; however, it's important to note that there potentially lies a type II error where signs of a cosmic ray air shower could be outshined by the sky's background radiation.

Conclusions

Based on the 30 stars detected of our FITS image, we observed that there is a moderate, linear correlation between the number of photons received by the camera and the visual brightness of each star, such that $R^2 = 60.06\%$. Additionally, as the number of physics events detected by IceACT are due to the flashes of light caused by the cosmic ray air showers, we conclude that there lies a potential type II error where stellar light surpasses the irradiance of Cherenkov light received by the telescope.

***More than 20 researchers contributed to IceACT from RWTH Aachen University, Marquette University, Friedrich Alexander University Erlangen, Michigan State University, Technical University of Dortmund, University of Canterbury and the University of Wisconsin, Madison.**