Very High-Energy Gamma-Rays Observations of IC 443

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Abstract

IC 443 is a Type II supernova remnant about 5000 light-years away in the constellation Gemini that exploded with the energy of 5×10^{29} atomic bombs. It is one of the best-studied supernova remnants because of its interesting environment; the shockwave from the supernova is expanding into two molecular clouds of two densities, causing its interesting appearance. Taking data collected by the Very Energetic Radiation Imaging Telescope Array System (VERITAS), we analyzed the gamma-ray emission of IC 443 to learn more about this interesting system.

IC 443

IC 443 is a 10,000 year old supernova remnant that is 5,000 light-years away. The progenitor star fused hydrogen into helium, helium into carbon, all the way up to silicon into iron. Energy cannot be gained from the fusion of iron, so the gravity of the star took over. The core was compressed into a neutron star and the shockwave from the collapse carried stellar material away. The supernova that formed IC 443 exploded with the force of 5×10^{29} atomic bombs.

IC 443 is particularly interesting because the shockwave is interacting with the surrounding molecular cloud. Molecular clouds are star-forming regions. This particular cloud has different densities in different regions, though; in Figure 1, the two regions are seen in the lower-right and the upper-left.

Studying IC 443 helps us understand the method by which cosmic rays are created. Supernova remnants are believed to be the source of cosmic rays, and the gamma-ray spectrum of IC 443 will help us determine if this is true. Cosmic rays coming from supernovae would create pions when they go through the surrounding molecular cloud, and the neutral pions would decay into gamma-rays. Gamma-rays could instead be created through leptonic means, by low-energy photons inverse Compton scattering off electrons in the same molecular cloud. The spectral energy distribution from IC 443 will help us determine the model by which gamma-rays are created, and thus if cosmic rays are created by the supernova.

Gamma-Ray Astronomy

Gamma-ray astronomy operates in very different ways from traditional astronomy; since gamma-rays have such small wavelengths ($\leq 10^{-2}$ fm), we can't use mirrors or lenses to focus them. Instead, we can use methods from particle physics and examine the interaction of our particle (gamma rays) with some target material. Space-based telescopes can detect gamma-rays up to hundreds of GeVs: the Fermi LAT operates over a range of 50 MeV to 300 GeV. Above this, the number of gamma-rays from a source is so low that it isn't cost effective to observe them using space-based telescopes. Instead, we can observe the gamma-rays as they enter the atmosphere.

A gamma-ray entering the atmosphere creates an electromagnetic cascade, which is shown in Figure 2. The electrons and positrons created are going at virtually the speed of light, and are actually going faster than the local speed of light in air. The effect of this is similar to a sonic boom, but creates blue light called Cherenkov radiation. Gamma-ray observatories on the ground observe this Cherenkov radiation and can detect gamma-rays into TeV energies, above the range of space-based observatories.

The biggest difficulty in observing gamma-rays is the high background noise created by cosmic rays. A cosmic ray will also produce an electromagnetic cascade and Cherenkov radiation, just like a gamma-ray. Their cascade is more complex, however, and we can use the effects of that to reject data from cosmic rays during data analysis. Normally, there are between 1,000 and 10,000 cosmic rays for every gamma ray, but with data analysis we can reduce that to ratios as good as one cosmic ray for every two gamma-rays.

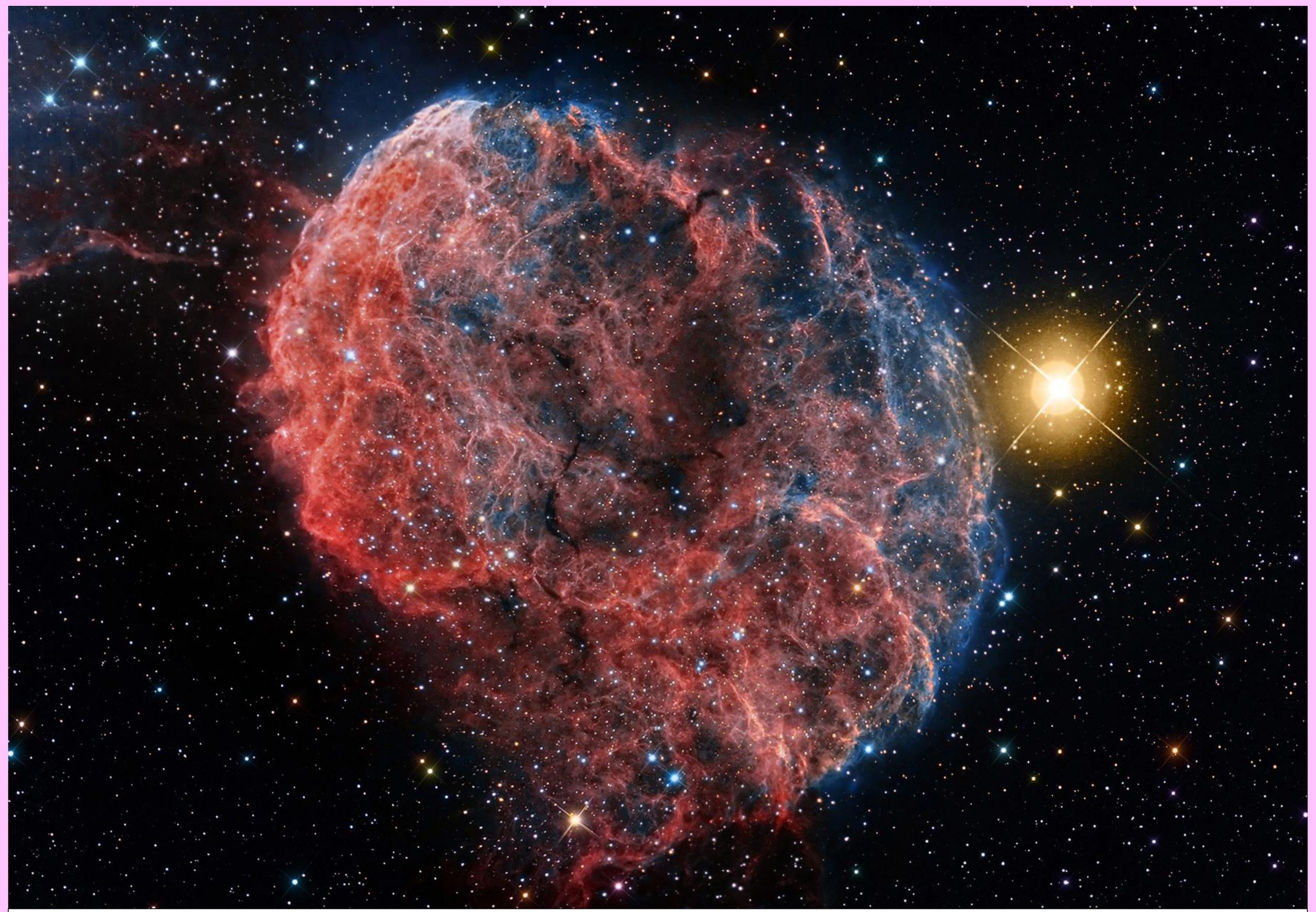

Figure 1: An image of the supernova remnant IC 443. The bright star on the right is η Geminorum. The lower-right is less dense than the upper left, so the supernova shockwave is interacting with the two regions in different ways.

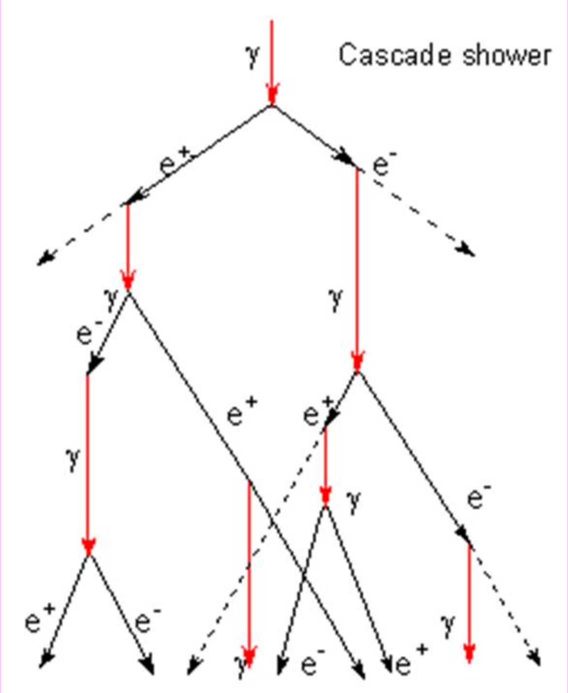

Figure 2: An incoming gamma-ray creates electrons and positrons by pair-production, which create more gamma-rays through Bremsstrahlung. The electrons and positrons produce Cherenkov radiation

Figure 3: One of the telescopes of VERITAS. For scale, the white box at the bottom is a truck trailer which houses the electronics for the telescope. Each mirror is about half a meter in diameter. The receiver box for the dish contains a 499 pixel camera.

Figure 5: The full VERITAS array. Each telescope is identical to the one shown in Figure 3. VERITAS is located on Mount Hopkins which is south of Tucson, Arizona.

VERITAS

VERITAS (Very Energetic Radiation Imaging Telescope Array System) is an array of Imaging Atmospheric Cherenkov Telescopes, which observes the Cherenkov radiation created by gamma-rays entering our atmosphere. It operates with four 12 m reflectors like the one shown in Figure 3 and can detect gamma-rays from 100 GeV to 30 TeV. VERITAS is located in southern Arizona at the Fred Lawrence Whipple Observatory. It was first proposed in 1996 but didn't have First Light until 2007, more than ten years later.

The whole array can be seen in Figure 5. The array was upgraded in 2009 when one of the telescopes was moved to allow for better resolution; Figure 5 shows the current arrangement. The array was upgraded again in 2012 – the phototubes on the cameras were all upgraded for better performance. With its current setup, VERITAS will likely operate through 2017.

Results

Using VEGAS, one of two standard VERITAS analysis packages, we analyzed 41.7 hours of data taken by VERITAS between 2009 and 2014. We found a maximum significance of 9.93 located at a Right Ascension of 94.1096° and a Declination of 22.5794°. This is consistent with a previous analysis of data taken from 2007 to 2009 in which the TeV gamma ray emission was found to be located near where the shockwave from the supernova is interacting with a dense part of the molecular cloud.

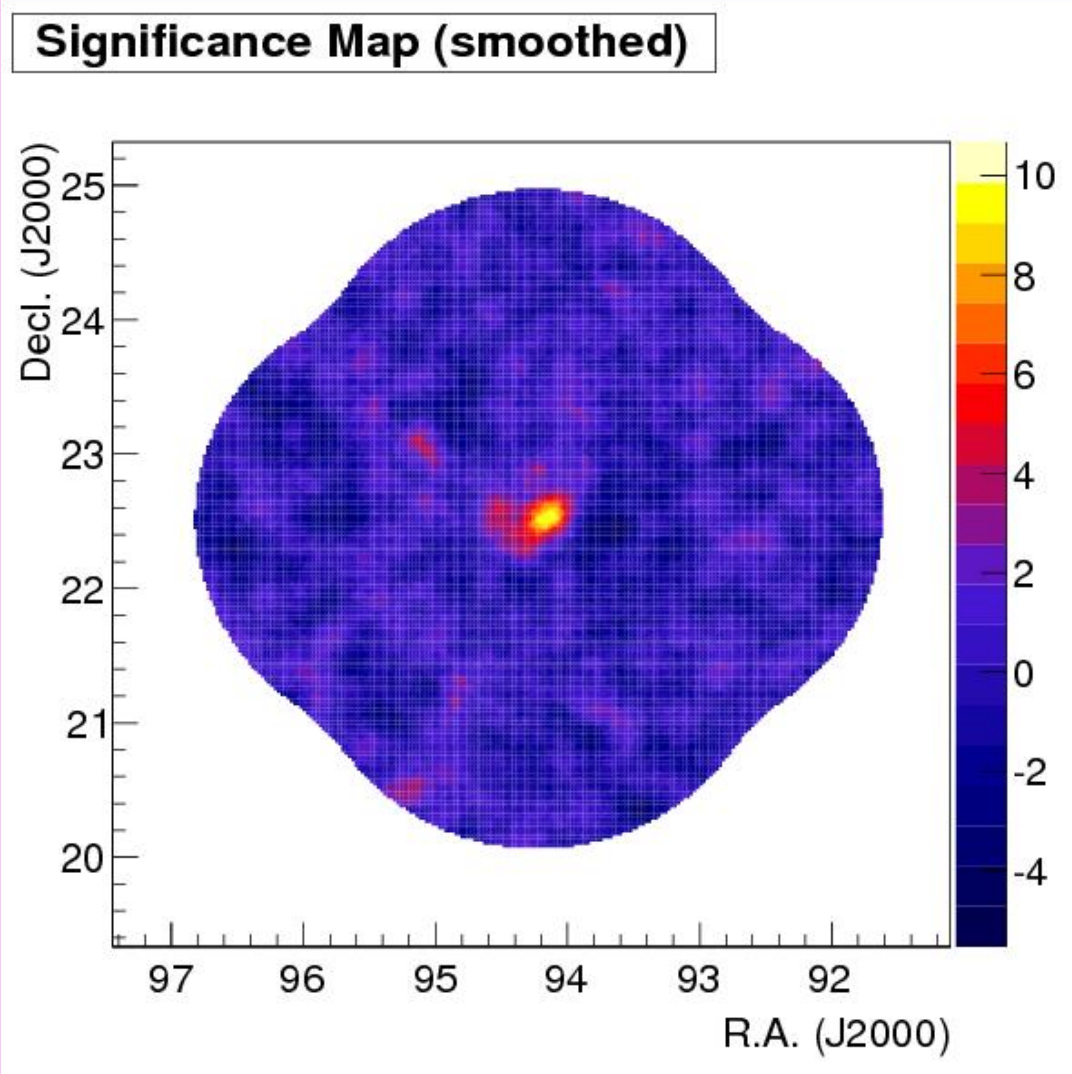

Figure 4: This is a significance map from our analysis of 41.7 hours IC 443. As seen in the scale on the right, the more yellow, the higher the significance. According to our analysis, the maximum significance of 9.93 is located at a Right Ascension of 94.1096° and a Declination of 22.5794°.

Future

We are currently still in the process of analyzing IC 443. This is only a preliminary results to show that our analysis works. There are several things we can to do make our results better and more meaningful. In order to distinguish between models of hadronic or leptonic origin of the TeV gamma rays, we need to determine the energy spectrum of the gamma-rays. To do this, we need to apply an effective area table to our data. This is based on simulations of gamma-ray showers and will allow VEGAS to create an energy spectrum. Finally, the analysis algorithm we used is most sensitive to point sources, but there are indications that the TeV emission from IC443 is extended. We need to apply the extended source algorithms to this data set.

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