Introduction to VHE Gamma-Ray Astrophysics

For most of history, the field of astronomy was limited to viewing the Universe with telescopes sensitive only to visible light. More recently, technological advances have opened “new windows” allowing astronomers to study the Universe in nearly all wavelengths of light, from the longest wavelengths (radio waves) to the shortest (gamma-rays). Every time a new window is opened, astronomers learn something new about the Universe and the astrophysical phenomena within it. Very-high-energy astronomy is a relatively new window in astronomy which allows astronomers to gain insight into the most extreme astrophysical processes in our Universe through the observation of very-high-energy gamma-rays. These very-high-energy (VHE) photons have energies between 100 GeV and 10 TeV and are produced by extraordinary astrophysical processes or by particles or forces beyond the standard model.

There have been more than 100 sources detected in the VHE regime (http://tevcat.uchicago.edu/). These detections include the very-high-energy standard candle: the Crab Nebula, the supernova remnant resulting from a supernova explosion nearly 1000 years ago on July 4th, 1054 A.D.. This Nebula was first detected in the VHE regime in 1989 by T. C. Weekes et al. with the Whipple Telescope[1]. Since that time, there have been other Galactic detections of supernova remnants, pulsars and binaries and a few sources with undetermined classification. The most common VHE detected source class is that of blazars. These objects are a type of active galaxy, thought to be powered by a supermassive black hole, which have a relativistic jet closely oriented toward Earth [a]. There are also extragalactic VHE detections of two starburst galaxies [2,3] and two radio galaxies [4,b].

Objects like stars emit light because they have very high temperatures. The spectrum of thermal radiation emitted by hot objects is determined entirely by their temperature. Hotter objects emit more photons with higher energies than cooler objects, but no matter how hot an object is, it will never produce a large number of gamma rays. A substantial flux of gamma rays can only be produced via non-thermal processes such as in the acceleration of relativistic charged particles, for example by a magnetic field or a plasma shock. VERITAS observations of these relativistic processes are used to view the highest energy cosmic accelerators in the Universe, at energies far higher than the capability of terrestrial accelerators. A major open question within the astroparticle physics community is whether VHE gamma-ray emission results from processes involving acceleration of electrons or protons. We can use VHE observations of previously detected TeV sources to investigate the nature of the very-high-energy objects’ power sources and of the particle population of these high energy mechanisms. New VHE detections can be used in the investigation of more mysterious phenomena taking place in these extraordinary astrophysical environments which are of interest to the fields of cosmology and particle physics.
In observational cosmology a large amount of our knowledge is based on the diffuse background radiation fields that surround us. A prominent example of such a radiation field is the 2.7 K thermal afterglow of the Big Bang, the cosmic microwave background (CMB). At shorter wavelengths, between the ultraviolet and the far-infrared, the extragalactic radiation field consists of the accumulated and reprocessed radiation of all starlight produced thus far. This extragalactic background light (EBL) encodes the integrated history of structure formation and the evolution of stars in the Universe. Understanding these characteristics requires detailed theoretical modeling of all the processes that contribute, e.g. structure formation and stellar evolution (e.g. [5, 6, 7, 8, 9, 10]). Very-high-energy observations of blazars can be used to indirectly constrain these models.

Direct measurements of the EBL are difficult because of strong foreground sources in our solar system (zodiacal light) and the Galaxy (e.g. [11]). Moreover, a direct measurement would only reflect the current integrated state, which leaves the challenging task of devolving the EBL in time. These caveats can be avoided when VHE gamma-rays are used to probe the EBL through gamma-ray absorption. VHE gamma-rays that propagate through the intergalactic medium are absorbed by low energy EBL-photons via pair production, $\gamma + \gamma \rightarrow e^+ + e^-$ [12, 13]. There exists a strong correlation in energy between the interacting VHE gamma-rays and EBL photons, such that for each energy band of low energy EBL photons, a band of VHE gamma-rays has the highest probability for interaction. The absorption process deforms the intrinsic VHE gamma-ray spectra emitted by extragalactic objects, this deformation can be used to estimate the properties of the EBL [14, 15, 16, 17].

One of the greatest challenges associated with modeling the formation history of the Universe is the general lack of knowledge regarding the nature of Dark Matter. The existence of astrophysical non-baryonic matter has been established by the gravitational effects that can be seen on various scales, including star orbital velocities and galaxy-galaxy collisions. Indirect dark matter searches with ground based gamma-ray observatories provide an alternative for identifying the particle nature of dark matter that is complementary to that of direct searches or accelerator production experiments such as the LHC. The best laboratory for constraining the nature of the dark matter particles is through observations of nearby dwarf spheroidal galaxies, which are dark-matter-dominated objects which have well-measured dark matter density profiles (through stellar velocity measurements). VERITAS focuses on the indirect search for very-high-energy gamma rays through observation of these dwarf galaxies which would result from the interaction or decay of Dark Matter particles, as determined by certain Dark Matter models. Non-detection of these gamma-rays from dwarf galaxies are then translated into cross-section limits which in turn constrain the available parameter space for Dark Matter models.

References:

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