The Imaging Cherenkov Technique

When VHE gamma rays arrive at the top of the atmosphere, they quickly collide with an air molecule, producing a few energetic charged particles which, in turn, interact with other molecules, deeper in the atmosphere, producing more particles. This process repeats itself in a cascade resulting in an extensive air shower (Figure 5) which develops until the total energy of the initial gamma ray is dissipated in the atmosphere. Particles in air showers are so energetic that they go faster than the speed of light in the air, thus producing a faint blue glow called Cherenkov light. When it reaches the ground, the Cherenkov light produced by one extensive air shower is spread over an area of twenty to forty acres. The Cherenkov light is very faint, just a few photons of visible light per square yard; the Cherenkov flash is also very brief; it lasts less than ten billions of a second.

Figure 5: The Cherenkov light from an atmospheric shower can be collected by several telescopes (center), each producing an image of the shower. Stacking all the images together provides the direction of the primary gamma ray (left). Projecting the images on the ground allows to reconstruct where the gamma ray would have arrived if it had not interacted in the atmosphere (right).

Large light collectors, like the StarBase telescopes, equipped with fast photo-detectors and electronics can record these flashes of light and produce an image of the extensive atmospheric shower. The shower points back to the direction of the astrophysical object that emitted the primary gamma ray. When an atmospheric shower is imaged from different view points with different telescopes, the images can be combined to reconstruct the direction of the gamma ray source (Figure 6).

The night sky around SeaBase, 40 miles from Salt Lake City, is sufficiently dark for the faint Cherenkov light to be detected. The StarBase telescopes have been installed under the clear Utah skies to test various photo-detectors that will soon be used in future giant gamma ray observatories.

Very High Energy Gamma Ray Astronomy

Very High Energy (VHE) gamma rays are quanta of electromagnetic radiation (photons), but with from a hundred million to a hundred trillion times more energy than visible light. VHE gamma rays are copiously produced in astrophysical objects powered by the most violent phenomenon in the universe. The Earth is very far away from these objects, in a safe region where VHE gamma rays are very rare. Because VHE gamma rays are so energetic and so rare, astronomers would have to use huge orbiting satellites to study these messengers of the universe. Astrophysicists realized that instead of building such huge instruments, they could simply use the Earth’s atmosphere as a VHE gamma ray detector with a method known as the Imaging Air Cherenkov Technique.

Figure 6: The Crab Nebula (left) is the remnant from a Super Nova observed in 1054 by Anasazi people who depicted their observations on a petroglyph in Chaco canyon (center). The Crab Nebula was the first discovered astrophysical source of gamma rays. Here is a gamma ray sky map of the region of the Crab Nebula obtained with VERITAS (http://veritas.sao.arizona.edu) in southern Arizona (right).

The first VHE gamma ray source to be discovered was the Crab Nebula (Figure 6), the remnant of a supernova that was observed in 1054 by the Ancestral Anasazi of Chaco Canyon (Figure 5). At the center of the Crab Nebula is a spinning neutron star with a strong magnetic field that acts as a dynamo, accelerating electrically charged particles to such high energies they produce VHE gamma rays. Even though the Crab Nebula is 6000 light years away, it can be considered to be in our neighborhood, well within our own galaxy.

Astronomers also use atmospheric Cherenkov telescopes to study active galaxies, hundreds of millions of light years away. These objects are so distant, the gamma rays we detect today started their journey toward our telescopes even before dinosaurs were roaming the Earth. The centers of active galaxies are ruled by giant black holes that can be from millions to billions of times more massive than our gentle Sun. The black hole consumes stars and surrounding gases, compressing and heating them to temperatures of millions of degrees before swallowing them. The magnetic fields produced in the swirl form a jet of material ejected along an axis with huge velocities of 99.9% of the speed of light. These jets seem to be responsible for the VHE gamma ray emission observed in more than a dozen of active galaxies.

VHE gamma ray observations allow the probing of the close vicinity of supernovae, neutron stars and huge black holes from thousands to millions of light years away. By testing and developing new photo-detectors, here at StarBase, we are contributing to the future observations of our fascinating universe.