Producing cosmic gamma rays in starburst regions

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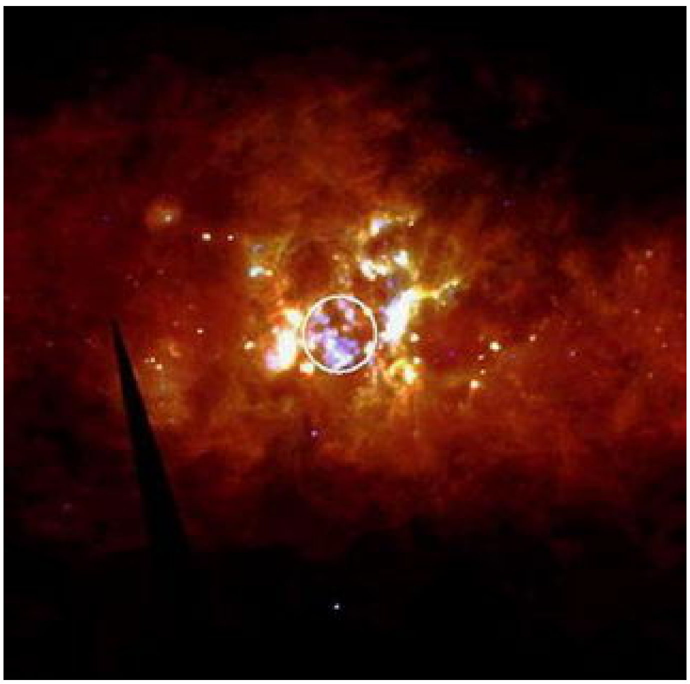

The starburst area in Cygnus OB2 is dominated by young, bright, hot stars and has been identified as a source of cosmic gamma rays. This is an infrared image of the area taken by the Infrared Astronomical Satellite. (Courtesy of J. Knoedlseder)

In 2002, when astronomers first detected cosmic gamma rays – the most energetic form of light known – coming from the constellation Cygnus they were surprised and perplexed. The region lacked the extreme electromagnetic fields that they thought were required to produce such energetic rays. But now a team of theoretical physicists propose a mechanism that can explain this mystery and may also help account for another type of cosmic ray, the high-energy nuclei that rain down on Earth in the billions.

The new mechanism is described in a *Physical Review Letters* paper published online on March 20. The theoretical study was headed by Thomas Weiler, professor of physics at Vanderbilt, working with Luis Anchordoqui at the University of Wisconsin-Milwaukee; John Beacom at Ohio State University; Haim Goldberg at Northeastern University; and Sergio Palomares-Ruiz at the University of Durham.

Existing methods for producing cosmic gamma rays require the ultra-strong electromagnetic fields found only in some of the most extreme conditions in the universe, such as stellar explosions and regions surrounding the massive black holes found at the core of many galaxies. So they couldn't explain how a "starburst" region in the Cygnus galaxy dominated by young, hot, bright stars could produce these energetic rays. The newly proposed mechanism, however, shows how two constituents present in such an area – fast-moving nuclei found in stellar winds and ultraviolet light – can interact to produce cosmic gamma rays.

Cosmic rays provide an invisible but important link between the Earth and the rest of the universe. They have a number of subtle effects on everyday life. They cause chemical changes in soil and rock and trigger lightning strikes, and some scientists have suggested that they may affect the climate by influencing the process of cloud formation. The circuitry in computer chips is now so small that individual cosmic rays can cause non-reproducible computer errors, and cosmic rays increase the risk of cancer among frequent airline passengers. There is also speculation that waves of cosmic rays streaming down the spiral arms of the galaxy could have contributed to past episodes of mass extinction on earth.

Since cosmic rays were discovered in 1912 in balloon experiments, scientists have marveled at the tremendous amount of energy that they carry and have speculated about their origins. Originally, about all researchers knew about them were that came from outer space. Today, scientists know that cosmic rays consist of a variety of different objects, including gamma rays, protons, electrons and the nuclei of a wide variety of different elements. They also know more about where cosmic rays come from. Most low-energy cosmic rays are produced by the sun. However, high-energy cosmic rays come from distant parts of the universe.

Despite the years of study, cosmic rays have managed to keep a number of secrets. For example, the most energetic proton-cosmic rays – nicknamed "Oh-my-God-particles" – pack a punch equivalent to that of a fast-pitch baseball. In the baseball, billions upon billions of nuclear particles share this energy. These energetic cosmic rays demonstrate that there are ways to pack the same amount of energy into a single particle, but, despite their continuing efforts, scientists have not yet found an acceptable mechanism for doing so.

Another outstanding question is the origin of the most energetic gamma rays. They carry a trillion times more energy than photons in the visible range, making them the most energetic form of light known. (Atomic particles like protons and electrons gain and lose energy by speeding up and slowing down. Light particles, called photons, always travel at the same speed and gain energy by oscillating faster at shorter wavelengths and lose energy by oscillating more slowly at longer wavelengths.) Physicists measure the energy in photons in electron-volts: the amount of energy a single electron gains when it passes through a potential difference of one volt. Cosmic gamma rays contain tens of trillions of electron volts. Such TeV gamma rays are relatively rare: one falls on a square kilometer of earth per second on average. Virtually all of them collide with air molecules and produce a cascade of energetic particles in the upper atmosphere.

Scientists have come up with several mechanisms that can explain how photons can gain so much energy. They do a good job of explaining how TeV gamma rays can be created by the ultra-strong electrical and magnetic fields that occur when stars explode and that are associated with the super-massive black holes found in many galaxies.

One of the generally accepted mechanisms begins with electrons that have been accelerated to extremely high energies. When such an electron runs head on into a microwave photon, it can transfer much of its energy into the photon by a process called Compton back scattering. In the process, the microwave photon is transformed into a TeV gamma ray. A variation on the theme involves the interaction of a fast-moving electron with an extremely strong magnetic field. The magnetic field throws the electron into a curve. If the curve is sharp enough, the electron will lose energy by emitting high-energy gamma rays: a phenomenon called bremsstahlung.

The second mechanism involves collisions between highly accelerated protons and a photon. In this case, the proton first absorbs the photon. This makes the proton unstable, so it decays into a short-lived subatomic particle called a pion, which, in turn, decays into a pair of cosmic gamma rays.

"There is a region in Cygnus, called Cygnus OB2, where there have been unexplained observations of TeV gamma rays: That is where we jumped in," says Weiler.

The new mechanism he and his colleagues have worked out uses the strong ultraviolet light produced by young, hot, stars and the nuclei of iron and silicon, which should be present in the stellar winds in starburst regions. Both nuclei carry strong positive electric charges, so they can be accelerated to extremely high velocities by moderate electromagnetic fields. The scientists calculate that when one of these nuclei collides with a photon of ultraviolet starlight, it will frequently disintegrate into a nuclear fragment and some TeV gamma rays.

"Each of these three mechanisms – electron versus proton versus nucleus as accelerated beam – has a characteristic signature in the gamma ray spectrum. Our nuclear mechanism fits the observations from Cygnus OB2 much better than the others," says Weiler.

The heavy nuclei required in this process are produced in supernovas and there are no known exploded stars in the region. This the model assumes that these nuclei, which are spread throughout space, are trapped in starburst regions. "This is one of the weakest parts of our model, so I don't want to push it," says Weiler. However, if it is correct then these regions may be an important source of the nuclei fraction of the cosmic rays that fall on Earth. The nuclei that produce the cosmic gamma rays should also stream out into the galaxy and some eventually should reach Earth as cosmic rays. Unlike gamma rays, which can be tracked back to their sources, the paths of electrically charged nuclei are altered by the magnetic fields that they pass through so it is not possible to determine their origins directly.

Source: Vanderbilt University

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