New cosmic ray theory sheds light on galactic evolution mystery

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Media Contacts: Warren R. Froelich, UCSD, (619) 534-8564, wfroelic@ucsd.edu

Bill Steigerwald, NASA, (310) 286-5017, wsteiger@pop100.gsfc.nasa.gov

NEW COSMIC RAY THEORY SHEDS LIGHT ON GALACTIC EVOLUTION MYSTERY

SAN DIEGO, CALIF. --A team of astrophysicists announced today the development of a new theory to account for the source of heavy elements in cosmic rays, high-energy celestial particles that bombard the Earth at velocities near the speed of light.

The team--Richard Lingenfelter of the University of California San Diego, La Jolla, Calif.; Reuven Ramaty of NASA's Goddard Space Flight Center in Greenbelt, Md.; and Benzion Kozlovsky of Tel Aviv University, Ramat Aviv, Israel--proposes that nuclei broken off from high velocity dust freshly formed in exploding stars, called supernovae, are accelerated by shock waves of the blast to become cosmic rays.

Such a cosmic ray origin can account for the mysterious abundance of the element beryllium in ancient stars within our Galaxy. Of all elements in nature, beryllium is unique in that it can only be produced by cosmic rays.

The new theory will be presented at a press conference scheduled for 8:30 a.m. PDT, Thursday, June 11, 1998, during the 192nd national meeting here of the American Astronomical Society.

Since their discovery earlier this century, the origin of cosmic rays has remained something of a mystery. In particular, the source of the energy is thought to be supernova shock waves, but the source of the particles that are accelerated to cosmic ray energies is not known.

"Previous theories suggested that cosmic rays are produced when a supernova shock wave hits particles already present in the interstellar medium (very low density gas and dust between the stars). We suggest that cosmic rays are accelerated by the supernova shock directly from the material ejected by the supernova," said Lingenfelter.

"Our new theory was motivated by a mystery in Galactic evolution, the high abundance of beryllium in old stars born soon after the formation of the Galaxy," said Ramaty.

Shortly after the "Big Bang," the primordial explosion believed to have created the universe, the first generation of stars in the Galaxy formed from collapsing clouds of gas of almost pure hydrogen and helium, because the big bang fireball cooled before heavier elements could be synthesized. The most massive of these stars exploded as supernovae after relatively short lifetimes (tens of millions of years) ejecting heavier elements, created by nuclear fusion, which then enriched the interstellar medium from which subsequent generations of stars were born.

In recent years, astronomers conducted extensive studies with powerful ground- and space-based telescopes of the old halo stars surrounding the Milky Way. Some of these stars, with ages of 10 billion years and more, are among the oldest in our Galaxy.

These very old stars are made up of mostly hydrogen and helium, with only traces of heavy elements such as oxygen and iron. But in these stars there is a surprisingly high abundance of beryllium, relative to iron. For unlike iron and most other elements in nature, beryllium is not synthesized by stellar nuclear fusion. It is made instead by the breakup of carbon and oxygen nuclei in collisions between high-velocity (cosmic ray) particles and interstellar matter.

The high and nearly constant beryllium abundances found in stars of all ages, led to the conclusion that the amount of beryllium produced by cosmic rays from each supernova explosion has remained roughly constant over time, from the Galaxy's early years to recent times.

"This result rules out the acceleration of cosmic rays out of the interstellar medium, because in that case the composition of the cosmic rays would evolve in proportion to that of the interstellar medium. And the beryllium yield per supernova would increase as the interstellar abundances of carbon and oxygen increase, contrary to observations. We had to develop new theory of cosmic ray origin to resolve this contradiction," the researchers said.

During the dying moments of a star when, under the force of gravity and internal radiation, the core contracts and is heated, resulting in a tremendous explosion rivaling the combined output of all the rest of the stars in the galaxy. A supernova is born.

Powered by this explosion, vast quantities of plasma (ionized gas) are ejected at thousands of miles per second into surrounding space. As this material moves at superAlfvenic speeds (the plasma equivalent of supersonic speeds), a shock wave is formed. It is this shock that is thought to accelerate the cosmic rays.

"We are confident that shock waves in astronomical plasmas can accelerate particles to cosmic ray velocities, because we have observed this happening in our own solar system," said Lingenfelter. "Shock waves form in the solar wind plasma under a variety of circumstances. Both the shocks and the particles that they accelerate have been directly observed with instruments on several NASA Space Physics missions," said Ramaty.

"Behind the supernova shock the ejecta is highly enriched in carbon, oxygen, magnesium, aluminum, silicon, calcium, iron and nickel, synthesized under the tremendous heat and pressure during the star's last years and final death throes.

"As the plasma expands and cools, these nucleosynthetic products condense as dust grains of graphite and metallic oxides, that, under the force of the explosion are shot into the cosmos like tiny bullets. Indeed, as the shock plows into the interstellar medium and slows down, the grains continue moving at more than 1,500 miles per second, passing through the slowing plasma and catching up with the shock wave.

As this dust passes through the plasma, atoms torn from the grains become electrically charged, and those shed in the vicinity of the shock are accelerated to cosmic ray velocities. The fast carbon and oxygen nuclei from the graphite and oxide grains, provide the cosmic rays needed to produce the beryllium."

Evidence for the formation of massive amounts of high velocity dust in supernova ejecta came from observations of the optical absorption and infrared re-emission of light from the Supernova 1987a. Further evidence for the high speed ejection of supernova grains came in 1996 when researchers from NASA's Goddard Space Flight Center and the University of Maryland, using gamma-ray spectrometers mounted on high-flying balloons, detected clouds of radioactive aluminum throughout the Galaxy moving at unexpectedly high speeds. This aluminum is thought to be in the dust grains shot out from supernovae.

"We are currently testing our theory with measurements by cosmic ray detectors on board NASA's recently launched Advanced Composition Explorer (ACE) spacecraft," emphasized both Lingenfelter and Ramaty.

Details of this new theory will appear in the June 20, 1998 issue of The Astrophysical Journal Letters, (volume 500, number 2), and the authors review the implications of the early Galactic beryllium observations in the April 1998 issue of Physics Today, (volume 51, number 4).

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