

Astrowatch

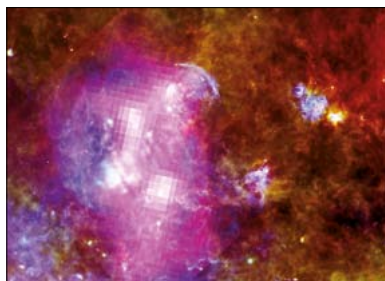
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Supernova remnants accelerate cosmic rays

A century after the discovery of cosmic rays, NASA's Fermi Gamma-ray Space Telescope has gathered strong evidence that protons are, indeed, accelerated to high-energies by supernova remnants (SNRs). The "smoking gun" is the production of neutral pions in proton-proton collisions and their subsequent decay, revealed by the shape of the gamma-ray spectrum measured in two SNRs.

Cosmic rays are high-energy charged particles (mostly protons) interacting in the Earth's atmosphere. Except for the low-energy component in the solar wind, they hit the Earth from all directions because the interstellar magnetic field deflects them randomly. This means that cosmic rays cannot be traced to their sources – so their origin has remained a mystery since their discovery by Victor Hess in 1912 (*CERN Courier* July/August 2012 p14).

Based on the pioneering work of Enrico Fermi in 1949, researchers have suspected that SNRs are capable of accelerating particles to cosmic-ray energies according to the following scenario. A massive star exploding as a supernova will produce an expanding shock wave in the interstellar medium. A particle crossing the shock front gains an increase in speed of about 1%. This is not much but it can become important for multiple crossings that can be induced when a turbulent magnetic field deflects a charged particle in a random walk process. A particle that crosses the shock discontinuity many times can gain enough energy to break free and escape into the Galaxy – becoming a cosmic ray.



This image combines data from ESA's Herschel Space Observatory with Fermi's gamma-ray observations (magenta) of supernova remnant W44. (Image credit: NASA/DOE/Fermi LAT collaboration and ESA/Herschel.)

The detection of high-energy gamma rays emitted by SNRs provided the first observational evidence for such a mechanism (*CERN Courier* January/February 2005 p30). This was corroborated by the detection with Cherenkov telescope arrays of the nearby starburst galaxies M82 and NGC 253 (*CERN Courier* December 2009 p11). However, it was still possible that the gamma-ray radiation could be induced by bremsstrahlung or inverse-Compton radiation from electrons, rather than by cosmic-ray protons.

An opportunity to disentangle the two processes by studying lower-energy gamma-rays at energies of MeV to GeV came with the launch of the Fermi satellite in 2008 (*CERN Courier* November 2008 p13).

To prove that SNRs produce cosmic rays, the Fermi collaboration has focused on two particular objects, known as IC 443 and W44. Not too distant in the Galaxy, these have the advantage that they are expanding into cold, dense clouds of interstellar gas. These clouds emit gamma rays when struck by high-speed particles escaping the remnants. If these particles are protons, then they can produce neutral pions when colliding with ambient nuclei in the gas clouds. The pions then instantly decay into pairs of gamma rays with an energy of half of the pion rest mass, 135 MeV, in the rest frame of the particle. While the photon number spectrum is thus centred at 67.5 MeV, the usual representation of the gamma-ray spectrum – the photon number spectrum multiplied by the square of the photon energy – rises steeply below around 200 MeV.

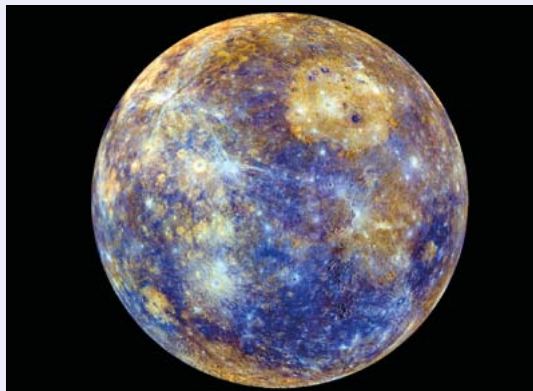
Thanks to improved calibrations at low energies, the Fermi spectra of IC 443 and W44 can now show the presence of the low-energy spectral cut-off expected from pion decay. The study published in *Science* by the Fermi collaboration shows that the gamma-ray spectra of both sources are better reproduced by pion decay rather than by bremsstrahlung radiation from electrons. This observational proof of proton acceleration in SNRs was one of the key objectives of the Fermi mission and confirms the basic principle of particle acceleration suggested by Enrico Fermi some 60 years ago.

● Further reading

M Ackermann *et al.* 2013 *Science* **339** 807.

Picture of the month

This colourful view of Mercury was produced by assembling thousands of images of its surface taken by NASA's MErcury Surface, Space ENvironment, GEOchemistry, and Ranging (MESSENGER) spacecraft, which has been in orbit round the planet for two years (*CERN Courier* April 2012 p15). Before MESSENGER, more than half of the planet was a complete mystery. This image (and the one of the opposite side) completes the 100% coverage of the planet. The colours are not what Mercury would look like to the human eye but enhance the chemical, mineralogical and physical differences between the rocks that make up its surface. The giant Caloris basin is the large circular, tan-coloured feature to the upper right. Created by the impact of a comet or asteroid during the Solar System's early years, it was subsequently flooded with lava from volcanic activity. Younger impact craters are surrounded by rays of ejected material appearing light blue or white. (Image credit: NASA/JHU Applied Physics Lab/Carnegie Inst. Washington.)



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