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A Picture of Radioactivity from the Inner Part of Our Galaxy

Max Planck astronomers, using INTEGRAL, identify regions of new atomic-nuclei production

Our environment is composed of "stardust", the chemical elements formed long ago in stellar interiors and supernovae. This process of nuclear fusion leads to the emission of gamma rays, which easily reach us from all regions of the Milky Way Galaxy. An international team of researchers led by Roland Diehl of the Max Planck Institute for Extraterrestrial Physics in Garching, Germany now has been using ESA's INTEGRAL satellite to determine that gamma rays from radioactive aluminium (26Al) originate from the central regions of the Galaxy. This implies that production of new atomic nuclei is an on-going process and occurs in star forming regions galaxy-wide. From those new observations, the astronomers estimate that the total amount of radioactive 26Al in the Galaxy is equivalent to three solar masses. This amount of production corresponds to a galactic rate of supernovae from gravitational collapse of about one every 50 years (Nature, 5 January 2005).

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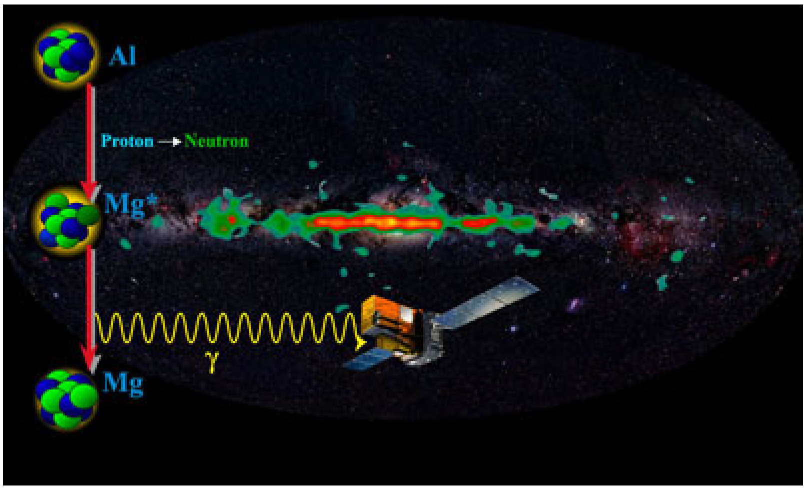

Image 1: *Radioactive decay of unstable isotopes leads to emission of gamma rays with a characteristic energy (coloured) being determined by properties of the atomic nucleus. ESA's INTEGRAL satellite observatory has been measuring such gamma rays since October 2002.*

Radioactive isotopes are by-products of nuclear fusion reactions, which produce new atomic nuclei in stellar interiors and in supernovae. In the gamma ray light of 26Al isotopes, which decay after about a million years to magnesium, one sees the radioactive glow of regions of the Galaxy with recent production of new nuclei. Visible light, on the other hand, often cannot reach us from stars in those regions, due to occulting interstellar gas clouds.

Image: Max Planck Institute for Extraterrestrial Physics

We are familiar with radioactive isotopes from medical radiology tests and treatments. Astrophysicists use penetrating gamma rays emitted during radioactive decay to obtain direct messages from cosmic nuclear fusion reactions, through special telescopes operated in near-Earth space. Gamma-rays from decaying ^{26}Al were detected in 1978, and because of its known half life of 720, 000 years, this provided direct proof of currently-ongoing nucleosynthesis. Supernova 1987 in the Large Magellanic Cloud galaxy was then observed through short-lived radioactive gamma rays. This led scientists to believe that these nuclei had been produced within this supernova event.

Astrophysicists from the Max Planck Institute for Extraterrestrial Physics in Garching were part of the pioneering sky study on such radioactive gamma rays. Roland Diehl and his MPE colleagues were able to show in the mid-1990s that this relatively long-lived radioactivity is present over large regions along the plane of the Galaxy. Hence, production of new atomic nuclei is common in the Galaxy. This was a scientific surprise, because at the end of the 1970s,traces of ^{26}Al decay had been found in meteorite samples originating from the early solar system. This finding had been interpreted as evidence that the ^{26}Al radioactivity was a key ingredient in the formation of planetary bodies of the solar system; radioactive heat is a necessary ingredient to melt cometary material to form rocks. Therefore it was commonly believed at that time that ^{26}Al radioactivity was intimately related to the early solar system; now, however, we have signals of currently-decaying ^{26}Al all over the Galaxy. A unifying picture emerged from nucleosynthesis theories of the 1950s, which claimed that all nuclear species were produced inside stars, novae, and supernovae. ^{26}Al could be the result of such stellar processing, occurring, with some enhancement, near the formation site of the solar system 4.5 billion years ago. Alternatively, special conditions during the formation of the solar system were thought to cause high-energy particle collisions, which could produce ^{26}Al locally. These two competing scenarios are still debated and remain an unsolved puzzle. Although gamma rays clearly show widespread cosmic nucleosynthesis, it remains to be understood if only this, or additional local high-energy reactions, has produced the amount of ^{26}Al inferred for the early solar system. One key to answering this question is the determination of the total ^{26}Al content of the Galaxy.

Gamma-Ray Spectroscopy with INTEGRAL

The new observational capabilities of ESA's INTEGRAL satellite now provide fresh insights. INTEGRAL carries a spectrometer for gamma rays, which is capable of recording the energy of gamma ray photons with unprecedented precision. This is because its camera is composed of Ge semiconductor detectors, similar to the ones which have been used in terrestrial nuclear laboratories and are operated at temperatures below 90K (corresponding to -183°C) to reduce noise from thermal motions of atoms. The SPI satellite telescope using this camera has been operated aboard INTEGRAL since October 2002 in space at altitudes up to 150, 000 kilometres above Earth.

Cosmic radiation bombarding the telescope in space, however, leads to destruction of the camera crystals. French team colleagues from CESR Toulouse, who have been developing this instrument together with several other European institutes, counteract the problem using a special trick. Periodically, the camera is heated to ~100°C for a few days, which repairs crystal damage and maintains the precision of the spectrometer over the years. This is important because celestial ^{26}Al gamma rays arrive at the instrument at a rate of one every few minutes. Thus many months of operation are required to make a precise spectral recording.

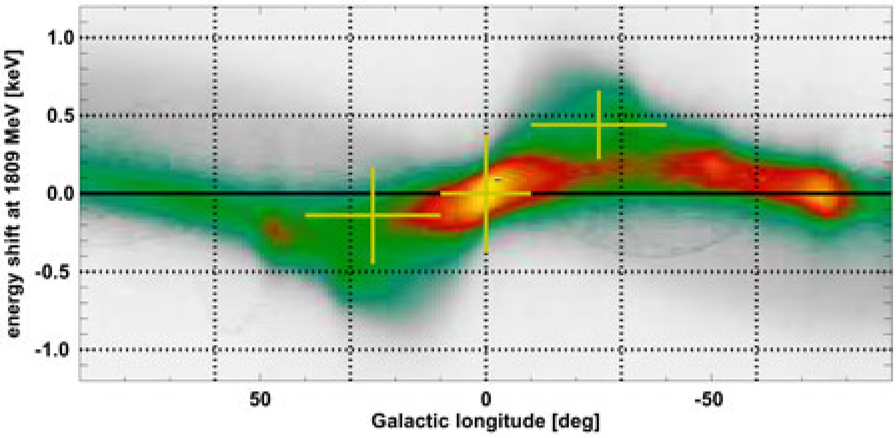

Image 2: *Expected line shifts from the Doppler effect along the plane of the Galaxy, as they result from galactic rotation. The modelled distribution of sources (coloured) agree with the measured line position changes from INTEGRAL (crosses).*

Image: Max Planck Institute for Extraterrestrial Physics

Roland Diehl and his colleagues were able to measure the recorded ^{26}Al gamma ray line energies along the plane of the inner Galaxy. They searched for variations in the line energy, which could provide hints for the location of the sources within the plane of the Galaxy. The disc of the Galaxy rotates about its central axis, but not like a rotating wheel does. Rather, inner regions move faster, to counteract gravitational pull from the central gravity by increased centrifugal forces. Therefore, if we look into the central regions, parts of the Galaxy have rather large relative motions, compared to the sun on its path around the galactic centre. Nuclear physics specifies that ^{26}Al decay gamma rays have an intrinsic energy value of 1808.65 kilo electron volts. They are moderated by the Doppler effect in a characteristic way, if sources of ^{26}Al gamma rays are observed from inner regions of the Galaxy. This characteristic pattern is what the researchers in Garching now found in their INTEGRAL data.

We learn from this measurement that indeed ^{26}Al decay gamma rays reach us from the inner regions of the Galaxy, rather than from foreground regions along the same line of sight, which might have locally-enhanced ^{26}Al production. Foreground regions would not have the observed high relative velocity. This leads us to conclude that observed ^{26}Al gamma rays can be attributed to Galaxy-wide regions of nucleosynthesis, and a geometrical model of the Galaxy can be used to translate the observed intensity into an amount of ^{26}Al for the entire Galaxy.

The Garching team estimates that the Galaxy contains a radioactive ^{26}Al mass of about three solar masses. This is a lot, given that ^{26}Al is an extremely rare isotope; the fraction estimated for the early solar system is 5/100,000 of ^{26}Al , in proportion to its stable aluminium isotope (^{27}Al). From the observed distribution of ^{26}Al gamma ray emission along the plane of the Galaxy, astrophysicists had inferred that the likely sources are mainly massive stars. Because massive stars terminate their evolution in a supernova, the researchers could estimate the rate of such supernova events, which correspond, on average, to the production of the observed amount of ^{26}Al . They obtained a rate of two supernovae per century. This number is consistent with what indirectly had been inferred from observations of other galaxies and their comparison to the Milky Way. Thus, the new INTEGRAL results confirm both the production of ^{26}Al in massive stars and supernovae as well as the rate of supernovae, which is one of the key parameters of our own Galaxy.

The INTEGRAL spectrometer for gamma rays will continue to operate for several more years. Astrophysicists thus hope even to increase the precision of such measurements. Project leader Roland Diehl explains, ‘these gamma ray observations provide insights about our home galaxy, which are difficult to obtain at other wavelengths due to interstellar absorption.’

These INTEGRAL based studies involve research by the Max Planck Institute for Extraterrestrial Physics; the Centre d'Etude Spatiale des Rayonnements and Université Paul Sabatier, Toulouse,France; the DSM/DAPNIA/Service d'Astrophysique, CEA Saclay, Gif-Sur-Yvette,France; Clemson University, Clemson,USA; ESA/ESTEC, Noordwijk, the Netherlands; and the Space Sciences Laboratory, Berkeley,USA.

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Related Links:

[1] Further information about INTEGRAL

[2] MPG Annual Report 2005 "More than hot: Sources of Cosmic Gamma-Rays" (in German)

[3] Additional informations and images

Original work:

Roland Diehl, Hubert Halloin, Karsten Kretschmer, Giselher G. Lichti, Volker Schönfelder, Andrew W.Strong, Andreas von Kienlin, Wei Wang, Pierre Jean, Jürgen Knödlseder, Jean-Pierre Roques, Georg Weidenspointner, Stephane Schanne, Dieter H. Hartmann, Christoph Winkler, and Cornelia Wunderer
Radioactive 26Al and massive stars
Nature, 5 January 2005

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