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Interstellar 26Al and Excess 26Mg

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When groups in Australia and Caltech first showed that aluminum-rich minerals within the CaAl-rich inclusions from the Allende meteorite carried an excess of the heaviest isotope of magnesium, ^{26}Mg, it was concluded that a supernova explosion beside the forming solar system must have peppered the solar cloud with radioactive ^{26}Al. The inference was that later, after the solar system and the meteorites had assembled in much their present form, that ^{26}Al decayed to ^{26}Mg by nuclear beta decay within the Allende minerals. The highest concentrations observed suggested that 50 parts per million of aluminum was the radioactive mass-26 isotope, whose halflife for decay to ^{26}Mg is one milllion years. The believed requirement of a supernova accompanying the birth of the sun derived from the belief that the interstellar gas would not normally have nearly enough radioactive ^{26}Al within it, so that a synchronized thermonuclear explosion was accepted as the source of the cosmic radioactive "fallout" that the Allende minerals have recorded.

Now this situation has been vastly shaken by the actual detection of radioactive ^{26}Al in the interstellar medium today. The first detection, an historic first detection ever of interstellar radioactivity, was made by the HEAO 3 spacecraft [Mahoney et al. 1984, Astrophys. J., **286**, 578] which recorded a measurable flux of 1809 keV gamma rays striking the solar system. The 1809 keV gamma rays are a well known electromagnetic radiation given off following the beta decay of each ^{26}Al nucleus. The HEAO 3 spacecraft measured that about 480 such gamma rays impact a square meter every second, coming from the general direction of the center of our Galaxy, but at an unknown distance. Lingering doubts about the reality of this astonishing discovery have now been removed by a confirmation of its correctness. The Solar Maximum Mission that was so dramatically repaired by the Shuttle astronauts carried a gamma ray spectrometer that had since February 1980 taken unintentional periodic looks at our Galactic center. That spectrometer team (Share et al. 1985, submitted to Astrophys. J.) confirms about 400 gamma rays per square meter per second from the direction of the Galactic center, in direct agreement with the HEAO 3 measurement. It can now be asserted without reasonable doubt that some source of radioactive ^{26}Al lies in that general direction.

The analysis of the magnitude of this gamma ray flux and its implications for both the origin of the elements in explosions of stars and for the origin of the Allende minerals was undertaken by Clayton (1984, Astrophys. J., **280**, 144). He came to three startling conclusions: (1) if the ^{26}Al is spread uniformly throughout the interstellar gas, its concentration of about 10 parts per million of aluminum is rather close to the fossil evidence found in Allende minerals, suggesting that the requirement of a special supernova trigger to solar formation may have been unwarranted; (2) supernova explosions are not adequate to maintain this average level of interstellar radioactivity, so that nova explosions or gas streaming away from giant stars are the more likely origins of the radioactive aluminum. The ineffectiveness of supernovae in maintaining the observed concentration also argues against implicating a special supernova with the solar origin. These two conclusions, when added to other arguments that Clayton had advanced prior to the detection of ^{26}Al gamma rays, have almost eliminated that supernova-trigger concept. On the other hand, Clayton's third conclusion was that if the observed ^{26}Al is not assumed to be spread throughout the interstellar medium, it could in fact be local debris from a single supernova explosion that occurred very near the earth only abut 100,000 years ago, in which case it might give renewed emphasis to the concept of a similar explosion near the forming solar system 4.5 billion years ago. Other evidence bearing on the exciting possibility that Earth is now located in a supernova remnant is being analyzed by Clayton and his colleagues, who reported at the "Galaxy and Solar System" Meeting in Tucson in January possible evidences for this recent nearby supernova, primarily long standing puzzles in the cosmic radiation.

At Lunar and Planetary Science 16, Clayton argued that the interpretation of the excess ^{26}Mg in Allende aluminum-rich minerals depends upon the correct interpretation of the ^{26}Al gamma-ray line. The correct interpretation of the gamma rays requires better information on their angular distribution. Because of their wide viewing angles and serendipitous measurements, the HEAO 3 and Solar Maximum Mission teams have been reluctant to be very precise about the angular distribution. Although they describe it as being "consistent with" radioactivity concentrated in the galactic plane having peak intensity near the Galactic center, they stop short of claiming that the data requires that interpretation. The single supernova neighbor could happen to be toward the general Galactic center, but it would occupy a large circular area on the sky, perhaps a 30° to 90° cone, and it would be most unlikely that the center of such a nearby distribution would happen to lie in the plane of the Galaxy. If the observing teams can successfully show that the latitude distribution is narrow and centered on the plane, Clayton said that we will be forced to accept the interpretation of the ^{26}Al concentration as a general feature of the gas as well as reaffirming te need of a nonsupernova source (e.g., novae) of the young ^{26}Al.

To aid this interpretation, Clayton presented theoretical angular distributions and isotopic concentrations that would be consistent with the observed gamma ray flux. He and Leising (1985, Astrophys. J., in press) made several different assumptions about the distribution of the production of ^{26}Al in the hopes that at least Gamma Ray Observatory, if not HEAO 3 or Solar Max, will be able to identify the actual angular distribution. The four cases they modelled assumed ^{26}Al production proportional to, respectively: (1) the mass distribution of cold molecular clouds; (2) the total mass distribution of interstellar matter; (3) the rate of optical emission from the surface of the disk; or (4) the distribution of Galactic novae. Their results offer good hope of recognizing the true situation. Easiest to recognize would be ^{26}Al production by novae because it would be much more strongly peaked toward the Galactic center than would the others. The corresponding Galactic concentration near the sun would be the lowest of those possibilities, however, only about 2 atoms of ^{26}Al per million Al atoms. The highest concentration, 10 ^{26}Al atoms per million Al atoms, exists in molecular clouds if the production occurs primarily within them, as it would if massive stars are its primary source.

Clayton emphasized that the isotopic concentration ^{26}Al/^{27}Al = 10 parts per million, which is consistent with the gamma-ray flux for the first three of these distributions, lies squarely between but distinct from the concentration 50 parts per million seen in some, but not all, aluminum-rich Allende minerals and the much smaller concentration less than 1 part per million that could be maintained there by supernova explosions. Thus the observed Allende concentrations of excess ^{26}Mg are still too large to be interpreted as being the average interstellar concentration, so that if the ^{26}Al was actually once alive in the Allende minerals seen today there must have been some source of ^{26}Al enhancement in the solar cloud as it was collapsing to form the solar system. Whether this contamination resulted from a nearby nova or red giant, its ejecta will have contained other nuclear clues that must be detailed and sought.

Clayton's final remarks reopened his assault [see for example Lunar Planet. Sci., 13, 115 (1982); Astrophys. J. 251, 374 (1981)] on the belief that the ^{26}Al was actually alive in the Allende minerals. He pointed out that whatever the source of the ^{26}Al observed by today's gamma radiation, those objects are necessarily ejecting 4 $M_\odot$ per million years into the interstellar medium. By contrast supernova eject 24 $M_\odot$ of new stable aluminum and stars reinject 60 $M_\odot$ of old stable aluminum over the same million years. Arguing that all of these ejecta condense into refractory aluminum-rich solids as they leave their respective sources, that the ^{26}Al decays to ^{26}Mg within the resulting mixture of well mixed dust grains, Clayton showed that the ratio $^{26}Mg/Al = 0.05$ results within the aluminum-rich dust, fully a thousand times greater than the correlation that later survives in the aluminum-rich minerals. This high interstellar correlation of excess ^{26}Mg with Al could not have been totally removed by evaporation, because the Allende minerals carry other isotopic anomalies that demonstrate that they were not evaporated totally at any stage prior to their assembly. Thus Clayton concludes that the ^{26}Mg-Al correlation observed in Allende minerals is a manifestation of a cosmic chemical memory. He laid down a challenge to mineral chemists to demonstrate how this memory survives the process of mineral formation and substantial extraction of magnesium from them.