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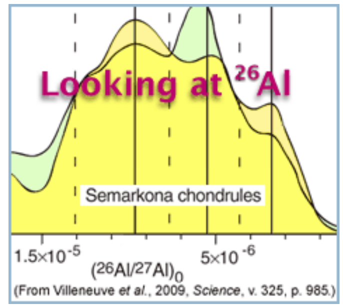

An Even More Precise View of Aluminum-26 in the Solar Nebula

--- New, precise analyses of the short-lived isotope aluminum-26 indicate it was distributed uniformly throughout the early solar system, an important clue to its origin.

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Aluminum-26, a short-lived isotope with a half-life of only 730,000 years, is a potentially valuable chronometer to use to date events as the Solar System was forming. To be useful as a dating tool however, it must be distributed uniformly throughout the Solar System. Johan Villeneuve, Marc Chaussidon, and Guy Libourel (Nancy Université, Nancy, France) have made high precision analyses of aluminum and magnesium isotopes using an ion microprobe. Consistent with previous results, they find that ^{26}Al was indeed distributed uniformly throughout at least the inner Solar System. Combining published and new data, they show that the rate at which chondrules formed might have varied.

Reference:

- Villeneuve, J., Chaussidon, M., and Libourel, G. (2009) Homogeneous distribution of ^{26}Al in the Solar System from the Mg Isotopic Composition of Chondrules. *Science,* v. 325, p. 985-988.

PSRDpresents: An Even More Precise View of Aluminum-26 in the Solar Nebula --Short Slide Summary (with accompanying notes).

Aluminum-26: An Informative Short-Lived Isotope

Solar System formation was a fast-paced business. The entire time from initial collapse of a cloud a light-year across to formation of millions of planetesimals was only a few million years. Determining what happened when requires a chronometer that can date events to an accuracy of about plus-or-minus about 100,000 years, on materials that formed more than 4.5 billion years ago. Aluminum-26 (^{26}Al) fills the bill. It has a half-life of 730,000 years. This means, of course, that this original ^{26}Al is gone now. A radioactive isotope decays to immeasurable amounts in about ten half-lives, or 7.3 million years for ^{26}Al. (Ten half-lives decreases the original amount by a factor of 2^{10}, about 1000.)

To be a useful chronometer, the ^{26}Al has to have been distributed uniformly throughout the Solar System. Then, by establishing the initial ratio of ^{26}Al to the stable isotope ^{27}Al, we can date lots of materials formed early in the history of the Solar System. The initial ^{26}Al /^{27}Al ratio appears to have been 5.2 x 10^{-5}, as determined from the ratio in the oldest components in chondritic meteorites, the calcium-aluminum-rich inclusions (CAIs).

NGC 2359 Nebula
with Wolf-Rayet star

© P. Berlind and P. Challis
Harvard-Smithsonian Center for Astrophysics
1.2-meter Telescope, Whipple Observatory

The utility of ^{26}Al does not stop with dating ancient events. The extent to which it is uniformly distributed allows cosmochemists to test models for how the ^{26}Al formed. Researchers have proposed two major mechanisms. One is injection of ^{26}Al (and some other short-lived isotopes) from an active star that spewed material into interstellar space. For example, formation of the Sun might have been preceded by formation and rapid life (only 4 million years) of a massive star, 20 times more massive than the Sun. Astronomical observations indicate that such stars pass through a stage in which they lose mass--up to an Earth mass per day!-- rapidly by blowing it into space at a couple of thousand kilometers per hour. These stellar winds contain ^{26}Al. One type of massive star is called a Wolf-Rayet star (named after the discoverers). In these large objects, elements formed inside by nuclear fusion, such as oxygen and aluminum, migrate toward the surface. This concentration of material begins to adsorb light from inside, eventually resulting in strong winds blowing off the surface and into interstellar space. The winds are shown in the left-hand image taken in the infrared. Astronomers believe that most massive stars (those >20 times the mass of the Sun) go through a Wolf-Rayet phase, which ends when they explode as supernova.

This telescopic image shows stellar winds blowing from a massive Wolf-Rayet star (brightest star near center). These winds contain ^{26}Al and other light isotopes. Astrophysicists believe that the ^{26}Al would have mixed thoroughly into the surrounding interstellar cloud, from which the Solar System formed. Image created by P. Berlind & P. Challis, Harvard-Smithsonian Center for Astrophysics.

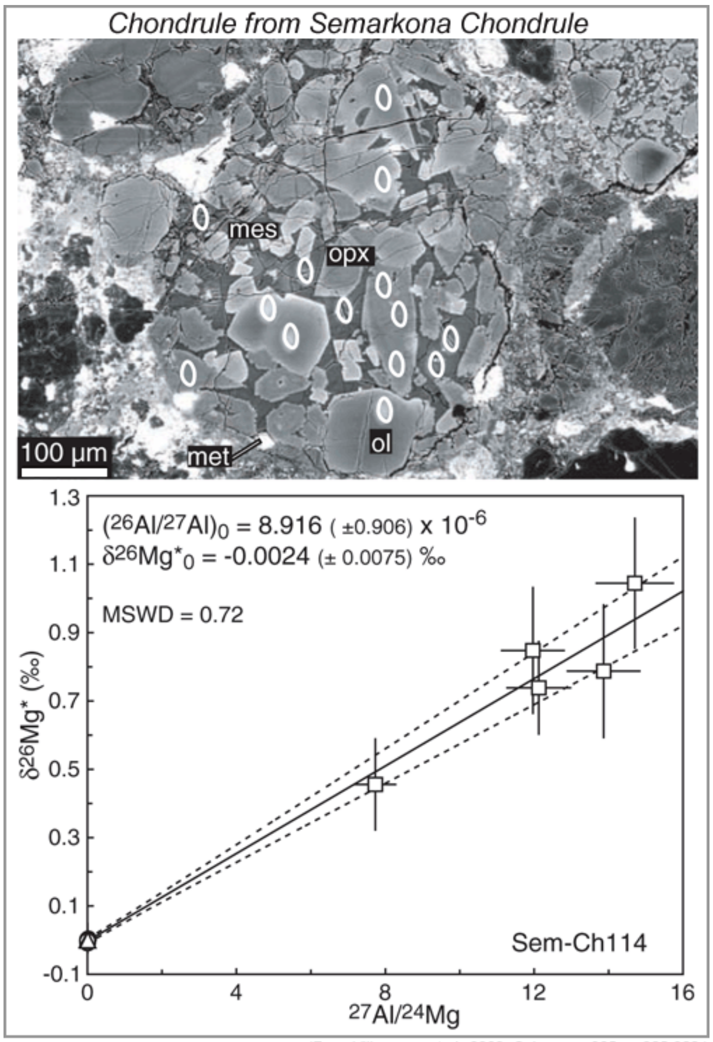
The other mechanism proposed for making ^{26}Al is irradiation of dust and gas within the Solar System. This would take place near the early, active Sun. There is some question that these isotopes made near the Sun would be thoroughly mixed throughout the disk surrounding it.

But was ^{26}Al distributed uniformly in the Solar System? There is good evidence that it was [see **PSRD** article: Using Aluminum-26 as a Clock for Early Solar System Events]. Using even more precise analytical techniques, Villeneuve and his colleagues took another look at the problem.

Precise Measurements

Villeneuve and colleagues used an ion microprobe at the Centre de Recherches Petrographiques et Geochimiques at Nancy Université, Nancy, France, in association with the Centre National de la Recherche Scientifique (CNRS). They made high-precision analyses of aluminum and magnesium isotopes, essential because ^{26}Al decays to ^{26}Mg, requiring measurement of ^{27}Al, ^{24}Mg, ^{25}Mg, and ^{26}Mg). They measured all four isotopes simultaneously and paid particular attention to determining the backgrounds on each detector and corrected for isotopes that have almost the same atomic weights as the ones they wanted to measure. As a result of these efforts, the data are precise to plus or minus 5 parts per million--pretty amazing for ion microprobe spots only 20 micrometers across.

Villeneuve used the cosmochemist's favorite primitive ordinary chondrite, Semarkona, which experienced little thermal or aqueous alteration on its parent asteroid. They analyzed the four isotopes in crystals and the glassy residue between crystals in 15 chondrules in Semarkona. A typical result is shown in the plot below. The initial $^{26}Al/^{27}Al$, hence the age since formation of the first solids in the Solar System, is determined from the slope of the line. (The y-axis is essentially the ratio of $^{26}Mg/^{24}Mg$, which is equivalent to $^{26}Al/^{24}Mg$ if the initial $^{26}Mg/^{24}Mg$ is small [as it is--see the intercept value, in this case -0.0024]. The slope is y/x, hence $^{26}Al/^{27}Al$.)

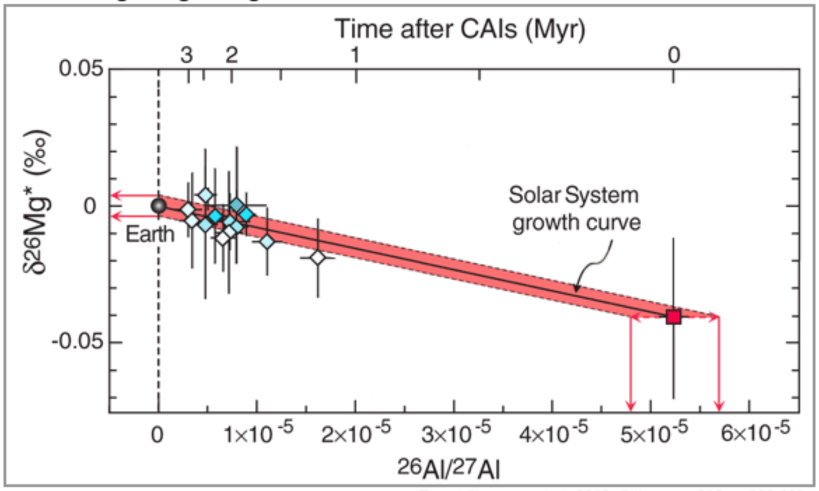


(From Villeneuve *et al.*, 2009, *Science*, v. 325, p. 985-988.)

[Top] Backscattered electron image made in a scanning electron microscope of a chondrule in the Semarkona chondrite. The white ovals show the locations of ion microprobe analyses. Abbreviations are opx for orthopyroxene; ol for olivine; and mes for mesostasis, which is the left over material and is largely glass. [Bottom] Isotopic abundances for each ion microprobe analysis in the chondrule. The error bars correspond to two standard deviations. The square symbols are for the mesostasis points. Olivine and orthopyroxene plot near the y-axis because they contain only small amounts of aluminum.

The 15 chondrules vary in the $^{26}Al/^{27}Al$ ratio, implying different formation ages. Of course, the different ratios might also mean that ^{26}Al was not distributed uniformly. Villeneuve and coworkers show that the range in $^{26}Al/^{27}Al$ is most likely due to differences in ages and that the ratio is consistent with that found in CAIs. They calculated how $^{26}Mg/^{24}Mg$ would increase with time (see graph below) by assuming an initial ratio the same as in CAIs (5.2×10^{-5}). The ratio is anchored on the right by CAIs (red square) and the growth is shown by the dark line. Note that the chondrule data all lie along the line. The array defines an uncertainly given by the red band around the dark line. If $^{26}Al/^{27}Al$ was not distributed uniformly throughout the Solar System, the chondrules should not plot along a single line.

Increasing $^{26}Mg/^{24}Mg$ with Time based on Semarkona Chondrules



(From Villeneuve *et al.*, 2009, *Science*, v. 325, p. 985-988.)

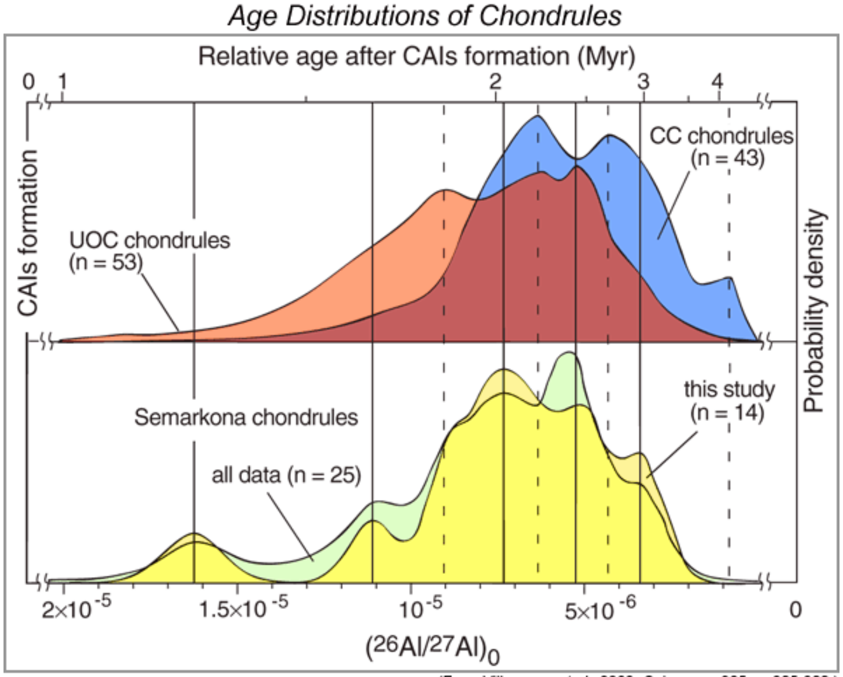
The line within the shaded red band is the growth curve for decay of ^{26}Al starting with an initial $^{26}Al/^{27}Al$ like that in calcium-aluminum-rich inclusions (CAIs), indicated by the red square. Ages relative to CAIs are show at the top of the plot. The red band and red arrows show the error envelope and are defined by the small scatter in the chondrule data (symbols with analytical uncertainties shown). To simplify the diagram, we omitted data for one chondrule exceptionally rich in aluminum.

Using the Uniformity in Aluminum-26: Chondrule Formation Events

To show how useful ^{26}Al is as a chronometer, Villeneuve and coworkers discuss the timing of chondrule formation. One important note they make is that the Semarkona chondrules they dated have ages that span a range of about 3 million years. Thus, their one small sample of the meteorite, which has a volume of only a few cubic centimeters, contains the products of heating events in the solar nebula that occurred over a long period.

The authors also combined their data with previously-published data to assess the timing of chondrules formation in general. Those results are shown in the graph below. The curves are basically histograms with each entry given a probability based on its analytical uncertainty. The distributions for Semarkona only and for chondrules in other unequilibrated ordinary chondrites (UCO) and carbonaceous chondrites (CC) show distinctive peaks. These may represent the intensity of chondrule forming events, or they might reflect the efficiency of chondrule preservation (many chondrules appear to contain recycled bits of pre-existing chondrules). Whichever is correct, the precise dating techniques require that ^{26}Al to have uniformly distributed in the early Solar System and this seems to be the case.

Age Distributions of Chondrules



(From Villeneuve *et al.*, 2009, *Science*, v. 325, p. 985-988.)

Initial $^{26}Al/^{27}Al$ and its corresponding relative age (top axis) for Semarkona chondrules (bottom) and chondrules in other unequilibrated ordinary chondrites (UOC) and carbonaceous chondrites (CC). The vertical solid lines represent peaks in the Semarkona distributions; dashed lines represent peaks in the UOC and CC distribution. Each peak might represent an up tick in chondrule production, or the peaks might reflect the efficiency of chondrules preservation.

Villeneuve and colleagues conclude that ^{26}Al was distributed uniformly (within about 10%) throughout the inner Solar System. This does not rule out some contribution to the ^{26}Al inventory from solar radiation, and it is possible that other short-lived isotopes might be produced by that mechanism. This is an active field of research with continuous improvements in analytical techniques and understanding of stellar processes. This is not likely to be the last word on ^{26}Al!

Additional Resources

LINKS OPEN IN A NEW WINDOW.

- **PSRDpresents:** An Even More Precise View of Aluminum-26 in the Solar Nebula --Short Slide Summary (with accompanying notes).

- Villeneuve, J., Chaussidon, M., and Libourel, G. (2009) Homogeneous distribution of ^{26}Al in the Solar System from the Mg Isotopic Composition of Chondrules. *Science*, v. 325, p. 985-988.
- Zinner, E. (2002) Using Aluminum-26 as a Clock for Early Solar System Events. *Planetary Science Research Discoveries.* http://www.psrd.hawaii.edu/Sept02/Al26clock.html

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