

The Age of the Universe via Radioactive Decay Chronometers

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As the name implies, radioactive decay chronology uses the spontaneous decay of unstable isotopes as a way to estimate the age of stars and the Milky Way Galaxy, and thus t_0 .

Briefly, radioactive decay is the process by which “parent” isotopes spontaneously lose energy and turn into new “daughter” isotopes. The parent isotope’s half-life defines the rate at which this decay occurs. Some isotopes decay too quickly to be used as chronometers. Other isotopes decay more slowly, making them useful for estimating the age of very old objects. For example, ^{232}Th decays to ^{208}Pb with a half-life of approximately 14 Gyr, on the order of the age of the universe as estimated by other methods. Importantly, we can use changes in isotopic abundances in meteorites and stars to estimate the age of the Milky Way and constrain t_0 .

Radioactive decay chronology has been especially useful in determining the age of the solar system. In the 1950s, Claire Patterson and colleagues showed that iron meteorites contain information about the abundances of Pb isotopes at the time the solar system formed [De Laeter, 2006]. By comparing the ratios of $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ in a series of meteorites and ocean sediments, Patterson and his colleagues estimated the age of the Canyon Diablo meteorite: 4.55 ± 0.07 Gyr. Finally, Patterson and his colleagues showed that age of the Canyon Diablo meteorite is also a good estimate of the solar system’s age. This result continues to serve as an excellent estimate of the age of the solar system today.

Though radioactive decay chronology has been quite successful in determining the age of the solar system, there are a number of challenges to using this approach to estimate the age of the stars, the Milky Way, and the universe. In a meteorite, the presence of differentiated grains provides information about initial abundances of atoms. In stars, it is more difficult to determine the abundances of isotopes at the time the star formed, and how these abundances may have changed over time. Chronometers formed via r-processes and with long half-lives are the most useful for determining stellar and galactic ages.

In 1997, Cowan *et al.* used the ratio of Th/Eu in the sun and in the metal poor galactic halo star CS 22892-052 to estimate the age of the Milky Way. Cowan *et al.* assumed that the sun and CS 22892-052 formed with the same abundance of Th/Eu, and that this abundance changed over time only via radioactive decay of Th. Using current measurements of the Th/Eu ratio in the sun, as well as the known age of the sun and half-life of Th, Cowan *et al.* estimated the formation abundance of Th/Eu. They then estimated the age of CS 22892-052 using the observed Th/Eu ratio in the star and simple radioactive decay model. Their result of 15.2 ± 3.7 Gyr, sets a lower limit to the age of the Milky Way and thus the universe. Similarly, Dauphas (2005) used the U/Th ratio in meteorites and low-metallicity halo stars to estimate the age of the Milky Way. Dauphas’s results, which take into account the possibility of galactic chemical evolution, suggest that the Milky Way galaxy is $14.5 \pm^{2.8}_{2.2}$ Gyr old.

In a summary of radioactive decay chronology studies, Spergel *et al.* (2003) suggest that this approach yields a lower boundary to the age of the universe of 9.5 — 20 Gyr. These results can serve as part of a consistency check for cosmological models. However, the radioactive decay chronology approach is particularly limited by our understanding of the processes that produce isotopes, our models of how isotopic abundances change over time via galactic chemical evolution, and our ability to measure isotopic abundances of faint halo stars.

References

- Cowan *et al.* 1997, [ApJ](#), 480, 246
Dauphas N. 2005, *Nature*, 435, 1203
De Laeter, J.R. 2006, *Geol. Soc., London, Spec. Public.*, 256, 363
Spergel *et al.*, *ApJS* 148: 175-194, 2003
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