Accounting for SLRs in the Early Solar System with a Triggered Star Formation Model for the Solar System

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Introduction: The early Solar System (ESS) was characterized by a value of ^{26}Al that exceeded the Galactic average [1,2,3,4], while ^{60}Fe in the ESS was about an order of magnitude less than the Galactic value [4,5]. These results disputed the existence of a supernova near the solar system at the time of formation. An alternative source of ^{26}Al is Wolf-Rayet (W-R) stars [5,6,7,8,9,10,11]. Aluminium-26 is carried out in the winds of these stars. No ^{60}Fe is ejected in the wind. [12] showed that a single W-R star above about 50 $M_\odot$ could be sufficient to provide the measured amount of ^{26}Al in the ESS. W-R stars have strong winds that sweep up the surrounding medium to form wind bubbles bordered by a dense shell. The ^{26}Al is carried out by dust grains in the wind from the star to the dense shell, where it is released. The solar system could be formed by triggered star formation in the dense shell.

Besides ^{26}Al and ^{60}Fe, many other short-lived radionuclides (SLRs) were present in the ESS [13,14]. We investigate whether the triggered star-formation model can account for the abundance of these SLRs, which could be (1) emitted by the star, carried out in the wind (via dust grains in this model) and injected into the dense shell, (2) be already prevalent in the local interstellar medium that was swept-up to form the dense shell or (3) be due to irradiation, from the SN following the W-R star if a SN explosion occurs, or from the early Sun.

Short-lived radionuclides: *^{10}Be* The abundance of this SLR is found to have a large range of values in meteorites. It does not correlate with ^{26}Al, which suggests a different source. It is most likely due to cosmic ray irradiation.

^{26}Al As was shown in [12], most stars above 50 $M_\odot$ can provide the level of ^{26}Al seen in the ESS, even accounting for the fact that only 10% of the ^{26}Al may eventually reach the dense shell.

^{36}Cl has a half-life of 0.3 Myr. The ESS ratio of ^{36}Cl/^{35}Cl was 1.7–3 × 10^{-5} [15]. A single W-R star above 50 $M_\odot$ can account for the initial ESS ratio, according to stellar models [16]. Given the short half-life, this depends on when the ^{36}Cl is emitted. Being volatile, it is unlikely to be transported by dust grains, which makes a stellar origin difficult in this model. It can be formed by irradiation, which could be sufficient to explain its ESS abundance.

^{41}Ca has a half-life of 100,000 yr. [17] determined the value of ^{41}Ca/^{40}Ca in the ESS to be 4.2 × 10^{-9}. In principle the models of [16] suggest that W-R stars above 50 $M_\odot$ could easily provide the requisite amount of ^{41}Ca in the ESS. Due to the short half-life, one must account for exactly when in the evolution of the star the ^{41}Ca is emitted.

^{53}Mn has a large half-life whose exact value is still debated. It may be overproduced in massive stars that collapse to a supernova [18]. However a negligible amount is emitted in the winds of massive stars [16]. In our model we expect that the observed ^{53}Mn in the ESS would arise from the Galactic background, and be in the swept-up dense shell, part of which collapses to form the solar system. It could also be due to irradiation, as shown by [19].

^{60}Fe The ^{60}Fe in this model arises primarily from the Galactic background, similar to ^{53}Mn, and is present in the swept-up dense shell. With a half-life of 2.6 Myr, the ^{60}Fe will have time to decay, since the shell is swept up mainly in the main-sequence phase, and will therefore have a value equal to or less than the Galactic value.

^{107}Pd is produced by neutron capture on to ^{106}Pd. It can have contributions from both the *s* and *r* processes [14]. A recent investigation of the Muonionalusta meteorite quoted a value of ^{107}Pd/^{108}Pd in the ESS of 3.5–6.6 × 10^{-5} [20]. [7] have shown that this required amount of ^{107}Pd can be produced in W-R stars.

^{129}I is exclusively produced by the *r*-process [22], but could include contributions from shell nucleosynthesis in massive stars [21]. Irrespective, ^{129}I in this model already existed in the Galaxy and was swept-up in the dense shell.

^{182}Hf This radionuclide can have both *r* and *s* process contributions, the latter primarily from AGB stars [22]. It is swept-up by the wind and is a part of the dense shell that ultimately collapses to form the solar system.

Summary: Triggered star formation in the shell of a W-R star can explain abundances of most SLRs. ^{41}Ca and ^{107}Pd, being refractory elements, would condense into dust grains and be transported similarly to ^{26}Al in our model.

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