Meteoritic Constraints on the Origins of our Solar System

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Introduction: The abundance of ^{26}Al ($t_{1/2}$=0.7 Myr) as inferred in meteorites is ~17 times larger than the average ISM abundance at solar system birth from gamma-ray astronomy [1,2,3,6], which is too high [4,5,6] to be accounted for by long-term Galactic chemical evolution [4,7,8] or early solar system particle irradiation [9, 10].

This led to suggestions starting 40 years ago [11] that a nearby supernova (SN) explosion triggered the collapse of a molecular cloud and the formation of the solar system. ^{26}Al was created via stellar and SN nucleosynthesis, and injected into the protostellar cloud by the shock wave. This suggestion has been followed up by several authors [7,12, 13]. If correct, one would expect this to be accompanied by a high abundance of ^{60}Fe ($t_{1/2}$=2.6 Myr) which is produced in SN explosions. Recent work instead found that the ^{60}Fe/^{56}Fe ratio at solar system formation is about an order of magnitude lower that the average ISM value, inconsistent with direct injection from a nearby SN [6, 14].

Any potential model of solar system formation thus needs to explain both high ^{26}Al/^{27}Al and low ^{60}Fe/^{56}Fe ratios. The distribution of ^{26}Al in the Galaxy closely traces the distribution of very massive stars, making Wolf-Rayet (W-R) stars and core-collapse SNe the primary candidates for ^{26}Al production [20]. The former are stars with initial mass ≥ 25, which have lost their H and possibly He envelopes. Many authors have suggested that stellar winds from massive stars, could be the source of ^{26}Al in the early solar system [5, 14, 15, 16, 17, 18].

Using a combination of semi-analytic calculations, astronomical observations, and numerical modeling, in this presentation we advance the idea that ***our solar system was formed by triggered star formation in the dense shell of a Wolf-Rayet wind bubble****, which can simultaneously explain both the high ^{26}Al and low ^{60}Fe abundance.*

^{26}Al Yields from massive stars: A single massive star above 50 $M_\odot$ generally provides sufficient ^{26}Al to account for the early solar system budget. In some scenarios lower mass W-R stars may suffice. The ^{60}Fe yield from the wind is negligible - ^{60}Fe in the proto-solar nebula arises from the swept-up material

Wolf-Rayet Bubbles: W-R stars are post-main-sequence, hot massive stars which have strong winds with terminal velocities of 1000-2000 km s^{-1} [19]. The combined action of the supersonic winds and ionizing radiation results in the formation of photo-ionized wind-blown bubbles around the stars, consisting of a low-density interior surrounded by a high-density shell. Most of the volume is occupied by a low-density high-temperature plasma. Star formation has been seen at the boundaries of wind-bubbles around O, B and WR stars [20,21,22,23,24].

Injection of ^{26}Al from the Wind to the Solar System: We suggest that ^{26}Al condenses onto, and is injected mainly via dust grains (see also [25,26]). Dust forms close in to WC stars [27,28], with grains ~ 1μm in size [29]. The stopping distance of 1μm size grains in bubbles is several parsecs, exceeding the bubble size. The grains can survive passage through the reverse shock and the low density shocked wind, and reach the outer dense shell. They would then be injected into the high density cores, penetrating depths of 1 to several hundred AU.

Finally, the massive star will explode as a SN of Type Ib/c. We have explored why the material ejected in the explosion, which contains both ^{26}Al and ^{60}Fe, may not be able to contaminate the early solar system.

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