PRESOLAR GALACTIC MERGER SPAWNED SiC GRAIN MAINSTREAM.

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Introduction: The mainstream SiC grains have presented unsolved puzzles. Whereas their origin in AGB carbon stars seems correct, based on C isotopes and s-process trace elements, the Si isotopes present two dominating puzzles that are quite extreme in the picture [1,2] that chemical evolution of the Galaxy has generated the SiC mainstream correlation line. The first is that most of the donor AGB stars appear to have evolved in higher-metallicity regions of the Galaxy than has the sun [1,3]; and the second is that the correlation line $\delta(29)$ vs. $\delta(30)$ has slope $m= 4/3$ rather than unity, the slope expected if the solar Si composition reflects that of the local interstellar medium when the sun was born [1,3]. In this work I present a new dynamics-based interpretation of these puzzles and discuss associated features that are thrown into a new light by it.

Mergers: It is widely believed now that galactic mergers played a large role in the growth of the total mass of the Galaxy. I propose that the Si-isotope correlation line is but a two-component mixing line between galactic-disk gas and a satellite galaxy that was cannibalized by the Galaxy about 6.5 Gyr ago. I stress that this is not improbable, but is rather the current view of how much of the Galaxy grew. This mixing occurred along a hydrodynamic stream generated by the gaseous collision of these two earlier galaxies. Fig. 1 illustrates the idea succinctly. I take the upper end of the mixing line in the Si three-isotope plot to be G, the Milky Way disk near the solar birth radius at the time of the merger. The lower end of the mixing line, S, represents the Si composition of the cannabilized dwarf-galaxy companion diluted by that of the Galaxy. That companion may have been similar, but nearer, than the familiar clouds of Magellan. The endmembers of the mixing line can lie anywhere beyond the extremities of the SiC grains. I argue that the Galaxy lay at the upper end of the mainstream in the Si three-isotope plot, whereas the satellite S may have lain well below the mainstream's lower end. The sun is shown as a large circle. As this merger occurred, vigorous star formation was induced by the hydrodynamic shock waves set up by the gaseous collisions. Turbulence along those collision fronts mixed the gases of the two systems to variable degrees, so that new stars formed from linear admixtures of the two end points. Many of these stars evolved to AGB stars about 1.5-2.0 Gyr later, at which time many donated their SiC particles to the interstellar medium at the solar radius of the Galaxy. Shortly thereafter, the sun formed from a similar mixture of the two gases, but which by then had been enriched to only slight degree by stellar nucleosynthesis during the roughly 2 Gyr prior to the sun's birth.

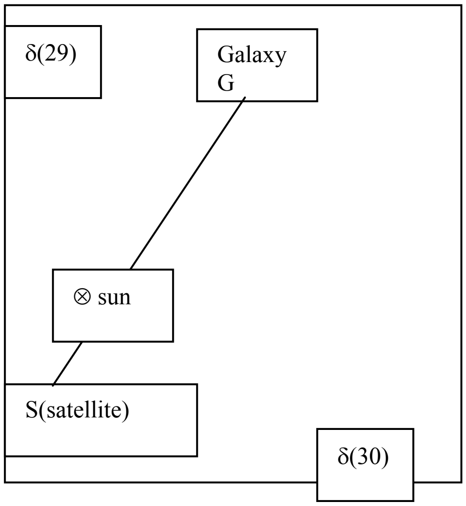

Fig 1. Three-isotope Si plot of mainstream SiC. The correlation line has slope $m=4/3$. The mainstream line is about $\delta(30)= 20$ ppm right of the sun.

Consequences: Important aspects of the merger model touch much of astrophysics, giving breathtaking sweep to the study of meteorite materials. *Stimulated star formation*. Star formation stimulated by gaseous shocks is well recognized in astronomy. The high pressures caused by the merging and mixing of gases along the interface of satellite stream (S) with galactic stream (G) stimulated abundant formation of AGB stars.

Metallicity. The accreted satellite was a low-metallicity dwarf galaxy whose nucleosynthesis had been of the starburst type; viz., more dominated by low Z Type II supernovae than the steady-state blend of our Galaxy's disk. Owing to its lower metallicity the Si isotopes (S) of the satellite were lighter [1,3] than those (G) in the more mature Galaxy. If the gas from which the sun formed (about 2Gyr after the merger) was more rich than average in the acceted gas S of the satellite, the puzzling heaviness of the SiC grains in comparison with solar Si is explained. Si isotopes of the undiluted Galaxy are identified as the top of the SiC correlation line, modified slightly by s process in the AGBs. The lack of clustering at the upper end suggests that most presolar AGB stars in the solar neighborhood contained some admixture of S. The expectation that a smaller number of pure G AGB stars must also have existed suggests that the upper end of the mainstream is the endmember G. The lower endmember S, on the other hand, may lie well below the lower end of the mainstream. The ^{29}Si/^{28}Si ratios in mainstream grains range roughly from 95% to +116% of the solar ratio; but the satellite S may have contained ratios as small as 10% of the solar ratio or as large as 95% of solar. Taking as an example S to be Magellanic-cloud-like (1/2 solar metallicity), the sun would contain 24% S gas and the lower end of the mainstream would contain 32% S gas if the upper end of the SiC line contains no S gas.

Slope m=4/3. To explain the correlation slope in this picture the Galaxy G locally contained isotopes characterized by 30% greater ^{29}Si/^{30}Si ratio than that of the accreted gas S. This happens plausibly if low-metallicity Type II supernovae in the satellite had produced a slightly smaller ratio than had the higher metallicity Type IIs of the Galaxy disk. By contrast, interpreting m=4/3 as but an unusual solar composition in Galactic gas [5] would require more extreme s-process nucleosynthesis in AGB stars than is standard.

Sun leftward of the SiC line. The sun would lie on the SiC mixing line but for two things. The s process nucleosynthesis in the AGB stars generated by intermediate mass stars that did form on the mixing line shifted all ^{30}Si compositions to the right (say by δ= 20 ppm). Thus the sun must sit left of the mixing line. Additionally, the eventual solar gas has nucleosynthesis input during the 2 Gyr between the merger epoch and the epoch of solar birth, most likely from the Type II supernovae spawned by the merger itself. Extinct radioactivity attests to them [6]. Their ejecta may have displaced solar Si isotopes from the mixing line.

Carbon isotopes. The puzzlingly large solar ^{12}C/^{13}C ratio reflects mixing with the S gas, which would be ^{12}C-rich in a starburst galactic satellite. AGB-star production of ^{13}C had been less significant in the satellite than in the more mature Galaxy, for which low-mass stars had more time to contribute. Post-merger supernovae augmented solar ^{12}C.

Secondary oxygen isotopes. Because both heavy O isotopes must also be more abundant in G gas than in S gas owing to galactic chemical evolution [1], the heavy O isotopes in mainstream SiC grains should in this picture correlate with the grain's heaviness of Si. Detecting this may be difficult in mainstream SiC grains owing to their small O concentrations. Moreover, the deep burning in the stellar envelopes so greatly depletes ^{18}O that the measurement will suffer from the ambiguity of burning in the AGBs.

The ^{18}O/^{17}O puzzle. No explanation exists for the puzzling fact that solar ^{18}O/^{17}O=5.3 is 65% greater than galactic measurements ^{18}O/^{17}O=3.2 [4]. This work attributes that fact primarily to extra ^{17}O deficiency in satellite S gas. The extra ^{17}O deficiency in the low-metallicity satellite galaxy resulted from its starburst metallicity pattern, in which nucleosynthesis was dominated by low-Z supernovae, which are very small ^{17}O producers . The more mature Galaxy had benefited more from low-mass stellar production of ^{17}O. Also, or alternatively, the burst of post-merger supernovae caused by the merger may have enriched solar gas preferentially in ^{18}O prior to solar birth.

Titanium isotopes. Excesses of ^{46}Ti and ^{47}Ti in mainstream grains correlate [2] with δ(^{29}Si) along the SiC line. I interpret that as the greater chemical evolution of the more mature Galaxy disk having resulted in larger ^{46}Ti/^{48}Ti and ^{47}Ti/^{48}Ti at G than had the low-metallicity supernovae of the accreted satellite on S. This correlation becomes thereby a corollary of this picture. Heavier isotopes, ^{49}Ti and ^{50}Ti, do not correlate as well owing to strong AGB s process.

Cosmoradiogenic chronology. Because the starburst satellite supernovae may have been more recent than those of the Galaxy, cosmoradiogenic ^{206}Pb/^{207}Pb [7] and ^{235}U/^{238}U ratios, and others, may greatly differ between S and G, yielding correlation lines in SiC grains. Unfortunately, counting efficiency is not yet great enough for experimental results. Moreover, G Pb contains much more s-process Pb than is expected in the satellite, giving added slopes to correlation lines.

Alternative Mixing: Alternative reasons for large-scale gaseous mixing exist. Differing radial galactic gas zones of differing ^{29}Si/^{28}Si ratios may have suffered induced mixing, perhaps also by a merger. These might account for the puzzles of the mainstream correlation line in an analogous way to the details proposed here. The end members will then be isotopically nearer. The slope 4/3 then will require more detailed explanation.

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References: [1] Clayton D.D. (1988) *ApJ*, **334**, 191; [2] Hoppe P. and Ott U. (1997) in *Astrophys. Implications of Lab. Study of Presolar Materials* , eds. Bernatowicz T. & Zinner E. (AIP:New York) p. 27; [3] Timmes F.X. & Clayton D.D. (1996) *ApJ*, **472**, 723; [4] Bieging J.H. (1997) in *Astrophys. Implications of Lab. Study of Presolar Materials* , eds. Bernatowicz T. & Zinner E. (AIP:New York) p. 265 ; [5] Clayton D. D. and Timmes, F. (1997) *ApJ*, **483**, 220; [6] Meyer B. S. and Clayton D. D. (2000) *Space Sci. Revs*. **92**, 133; [7] Clayton D. D. (1964) *ApJ* **139**, 637