FIRST FE ISOTOPIC MEASUREMENT OF A HIGHLY ^{17}O-ENRICHED STARDUST SILICATE.

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Introduction: Stardust silicates are detected in primitive meteorites and interplanetary dust particles by highly anomalous isotopic signatures. Further chemical and isotopic investigations on these dust grains provide the possibility to test astrophysical constraints of evolved stars [e.g., 1]. One important discovery of these investigations is the fact that many of the stardust silicates found to date are characterized by a relatively high Fe content (~10 at.%), whereas equilibrium condensation should lead to more Mg-rich silicates (i.e., pure enstatite or forsterite). However, Mg-rich stardust silicates are very rare [2]. The origin of this Fe is a matter of intense research in the stardust silicate field, as it may be either a primary condensation or a secondary alteration feature [3-6]. It is also possible that both mechanisms lead to incorporation of Fe. In order to investigate these different effects and to decide between contrasting scenarios we performed Fe isotopic measurements on 13 stardust silicates from Acfer 094.

Experimental: Stardust silicates were located within the fine-grained meteorite matrix by a routine NanoSIMS setup at the Max Planck Institute for Chemistry in Mainz [6]. For the subsequent Fe isotopic measurements, we used the ~100 nm sized Cs$^+$ beam, as the spatial resolution of the O$^-$ beam is not sufficiently high enough. However, this only allowed the analysis of ^{54}Fe^{16}O and ^{56}Fe^{16}O as negative secondary ions. Measurements were done in combined analysis mode with three different magnetic fields: in a first field, only ^{16}O and ^{28}Si were measured as reference isotopes; in a second field, ^{52}Cr^{16}O was measured to correct for the ^{54}Cr^{16}O interference on ^{54}Fe^{16}O (between 1 and 5 %); in a third field, ^{17}O, ^{54}Fe^{16}O and ^{56}Fe^{16}O were measured. Stardust silicates were relocated by their anomalous ^{17}O/^{16}O ratio in the ion image. Only the innermost pixels of the dust grains were used for data reduction. Their ^{54}Fe^{16}O/^{56}Fe^{16}O ratios were normalized to surrounding matrix material in the ion image and expressed as δ-values. Measurement times of several hours until the grain was consumed resulted in relative errors between 2 and 8%.

Results and discussion: Thirteen stardust silicates in Acfer 094 with known O isotopic compositions already reported in [6] were measured for their ^{54}Fe^{16}O/^{56}Fe^{16}O ratios (Table 1 and Fig. 1). Among these, one is a Group IV silicate ("35_11") presumably of supernova origin, and one an "extreme" Group I silicate ("23_15") (^{17}O/^{16}O=3.85 ± 0.11 x 10^{-3}), whose

Si isotopic composition is known from a previous measurement [7] (δ^{29}Si=19±20, δ^{30}Si=71±26). This grain has a slightly irregular shape (Fig. 2) and might have a different origin than the majority of stardust silicate grains [7]. The remaining grains can be ascribed to Group I and come from low-mass asymptotic giant branch (AGB) stars of close-to-solar metallicity. In three cases, the ^{52}Cr^{16}O interference was not measured, the reported δ^{54}Fe values are therefore uncorrected (see Table 1).
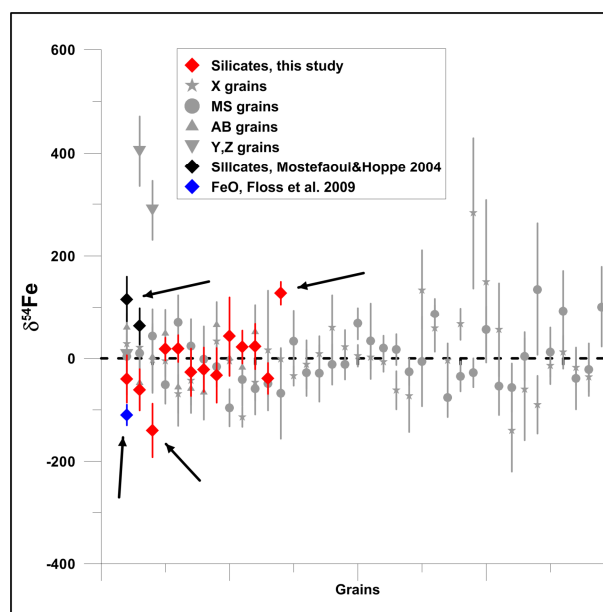

Figure 1. δ^{54}Fe values of all measured stardust silicates compared to SiC grains from [8] and three O-rich stardust grains [9,10]. O-rich stardust grains with significant anomalies in ^{54}Fe are marked by arrows.

The Fe isotopic compositions of the majority of measured silicates are solar within errors (Fig. 1). At first glance, this seems to support the scenario that measured high Fe contents of stardust silicates are of secondary, i.e., solar origin. However, the large majority of measured SiC grains also exhibit close-to-solar ^{54}Fe/^{56}Fe ratios [8], which therefore do not seem to be diagnostic to distinguish between different scenarios. Typically, in low-mass AGB stars, the initial ^{54}Fe/^{56}Fe ratio of the parent star is not changed substantially during stellar evolution. The measured ^{54}Fe/^{56}Fe ratios should therefore represent largely initial stellar compositions inherited from the local interstellar medium. As can be seen from the ^{54}Fe/^{56}Fe ratios of mainstream SiC grains, the parent AGB stars

had close-to-solar ^{54}Fe/^{56}Fe ratios. It is therefore difficult, if not impossible, from the present data set to distinguish a presolar from a solar Fe component in solar-metallicity AGB star silicates.
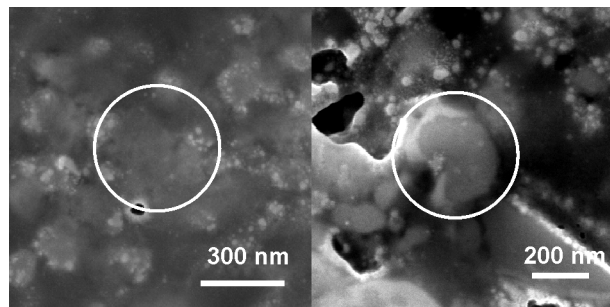

Figure 2. Example SE images of measured stardust silicates. *Left*: the highly ^{17}O-enriched grain 23_15 before the Fe isotopic analysis. *Right*: grain 27_02 with a small rim of presumably secondary Fe-rich material.

Previous measurements revealed a few grains with anomalous ^{54}Fe/^{56}Fe ratios: First, the stardust silicate measured by [9] and the stardust FeO grain from [10], both of Group IV, are enriched and depleted, respectively, in ^{54}Fe relative to solar. Group IV grains are likely to be from type II supernovae (SNe) [7,11]. If those grains contain material from inner SN zones, we would also expect higher-than-solar ^{54}Fe/^{56}Fe ratios as those zones are enriched in ^{54}Fe. Only one SiC SN grain in the study of [8] exhibits a significant ^{54}Fe/^{56}Fe anomaly, but it is a depletion in ^{54}Fe of about 10%. It is therefore apparent, that the ^{54}Fe/^{56}Fe ratios of SN grains are still not understood [8]. Second, one SiC Y and one SiC Z grain show excesses in ^{54}Fe, which is puzzling as well, as these grains are believed to come from AGB stars of lower-than-solar metallicity and should therefore exhibit ^{54}Fe deficits [8].

Third, the "extreme" grain 23_15 from this study, whose O and Si isotopic compositions have been explained either by an origin around a binary star or an intermediate-mass (~3.5-4 $M_\odot$) AGB star [7], exhibits a deficit in ^{54}Fe. For the latter scenario this is in conflict with predictions from current AGB star models [8], but it will be interesting to see whether future models of intermediate-mass stars might be able to account for larger ^{54}Fe depletions than currently predicted. Alternatively, the ^{54}Fe depletion might be largely the fingerprint of Galactic chemical evolution (GCE), i.e., the grain derives from an AGB star of lower-than-solar metallicity. However, this is in contrast to the close-to-solar ^{18}O/^{16}O ratio of this grain. If the proposed binary star scenario for highly ^{17}O-enriched stardust oxides and silicates [7,11] is true, it remains to be seen what stellar source provided the

^{54}Fe deficit or ^{56}Fe excess we see in this grain. If the companion star that contaminated the grain-producing AGB star is a nova [7,11], it is currently not known whether dredged-up nova material could account for Fe isotope anomalies as observed in 23_15. The standard nucleosynthetic endpoint for nova nucleosynthesis is Ca. However, a more violent outburst might also effect the isotopic compositions of elements beyond Ca [12], but predictions for ^{54}Fe/^{56}Fe are not available yet. Further work on stellar model predictions and on the GCE of the Fe isotopes is clearly necessary to find a satisfactory explanation of the anomaly in grain 23_15.

One of our common Group I grains exhibits a higher-than-solar ^{54}Fe/^{56}Fe ratio (Fig. 1). However, no ^{54}Cr interference correction could be made in this case and it is well conceivable that much of the apparent ^{54}Fe excess is due to unresolved ^{54}Cr.

Grain	Fe cont. (at.%)	^{17}O/^{16}O (x10^{-4})	^{18}O/^{16}O (x10^{-3})	δ^{54}Fe (‰)	^{52}Cr^{16}O corr(%)
12_02	13.6 ± 1.5	7.36 ± 0.50	1.61 ± 0.07	-40 ± 46	1.6
16_08	7.2 ± 0.8	7.41 ± 0.70	1.49 ± 0.10	-61 ± 40	2.0
23_15	-	38.49 ± 1.06	2.04 ± 0.08	-140 ± 52	2.3
24_04	-	5.93 ± 0.41	2.03 ± 0.07	18 ± 22	2.2
24_08	-	6.89 ± 0.41	1.92 ± 0.07	19 ± 26	2.6
26_12	6.0 ± 0.7	6.32 ± 0.40	1.93 ± 0.07	-27 ± 46	4.5
27_02	7.7 ± 0.9	6.23 ± 0.50	2.05 ± 0.08	-22 ± 43	2.8
27_07	11.6 ± 1.3	6.12 ± 0.42	1.64 ± 0.07	-33 ± 53	-
31_09a	2.7 ± 0.3	9.66 ± 0.54	2.04 ± 0.08	43 ± 77	4.2
31_09b	3.8 ± 0.4	7.84 ± 0.52	1.73 ± 0.07	22 ± 32	1.1
34_15	4.2 ± 0.5	5.88 ± 0.43	1.44 ± 0.07	23 ± 44	2.0
35_11	8.2 ± 0.9	4.31 ± 0.44	3.00 ± 0.11	-39 ± 30	-
35_19	15.9 ± 1.8	6.04 ± 0.35	1.59 ± 0.06	128 ± 22	-

Table 1. Fe contents from Auger analyses [6] and O and Fe isotopic data of measured silicates. Correction of the ^{54}Cr^{16}O interference to ^{54}Fe^{16}O was made under the assumption of a solar ^{54}Cr/^{52}Cr ratio and is expressed as percent of the ^{54}Fe^{16}O signal.

References: [1] Hoppe P. & Vollmer C. (2008), *AIP Conference Proceedings* 1001 (eds. R. Guandalini, S. Palmerini and M. Busso), 254-261. [2] Vollmer C. et al. (2009), *ApJ,* 700, 774-782. [3] Nguyen A.N. & Zinner E. (2004), *Science,* 303, 1496-1499. [4] Bose M. et al. (2008), *Meteorit. Planet. Sci.,* 71, #5094. [5] Floss C. & Stadermann F. J. (2009), *GCA,* 73, 2415-2440. [6] Vollmer C. et al. (2009), *GCA,* 73, 7127-7149. [7] Vollmer C. et al. (2008), *ApJ,* 684, 611-617. [8] Marhas K.K. et al. (2008), *ApJ,* 689, 622-645. [9] Mostefaoui S. & Hoppe P. (2004), *ApJ,* 613, L149-L152. [10] Floss C. et al. (2008), *ApJ,* 672, 1266-1271. [11] Nittler L. R. et al. (2008), *ApJ,* 682, 1450-1478. [12] José J. et al. (2007), *Meteorit. Planet. Sci.*, 42, 1135-1143.