THE PRESENCE AND ABSENCE OF DIFFERENT ISOTOPICALLY ANOMALOUS PHASES IN THE PRIMITIVE INTERPLANETARY DUST PARTICLE TIBERIUS.

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Introduction: Interplanetary dust particles (IDPs) sample material preserved from the earliest formation of the solar system. Recent work shows the existence of a subgroup of IDPs characterized as isotopically primitive [1, 2]. These IDPs have anomalous bulk N isotopic compositions and contain abundant circumstellar and interstellar phases.

We have been examining one such IDP, nicknamed Tiberius (u44-m1-5), that was originally studied with the Washington University ims3f ion microprobe [3]. Those measurements showed Tiberius to be a fairly typical chondritic IDP with normal H and C isotopic compositions, and a bulk ^{15}N enrichment of 53 ± 6 ‰ [3, 4]. Significant portions of Tiberius were not consumed by the ims3f measurements, allowing NanoSIMS measurements to be made on this particle. Isotopic imaging of C and O led to the discovery of the first observed presolar grains of corundum and SiC in an IDP [4, 5]. Here we report on the results of additional C, N and O isotopic imaging measurements of this particle.

Presolar Phases in Tiberius: The NanoSIMS measurements were made in standard multi-collection imaging mode using a ~100 nm Cs^+ primary beam [5-7]. Three series of measurements were carried out: N and Si ($^{12}C^{14}N^-$, $^{12}C^{15}N^-$, $^{28}Si^-$, $^{29}Si^-$, $^{30}Si^-$), C and N ($^{12}C^-$, $^{13}C^-$, $^{12}C^{14}N^-$, $^{12}C^{15}N^-$, $^{28}Si^-$) and O ($^{16}O^-$, $^{17}O^-$, $^{18}O^-$, $^{28}Si^-$, $^{24}Mg^{16}O^-$).

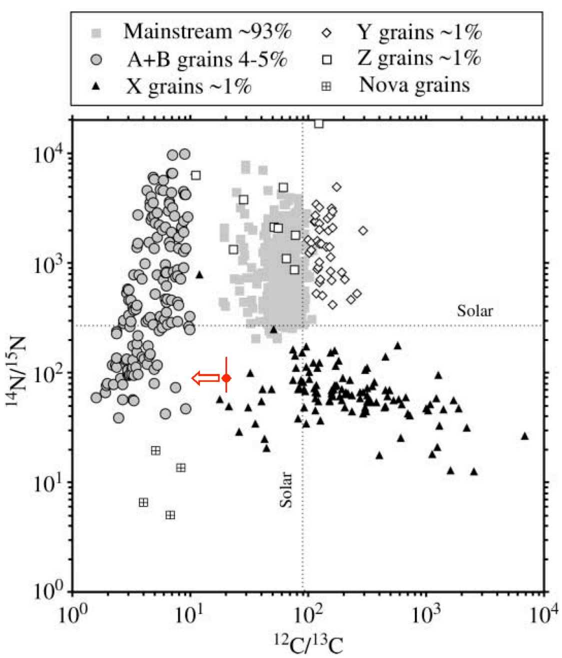

Figure 1. C and N isotopic composition of the SiC grain in Tiberius compared to established types of presolar SiC [8]. The grain is likely to be more ^{13}C-rich than actually measured (as indicated by the arrow), due to dilution with surrounding isotopically normal C.

SiC grain: a presolar grain identified as SiC was discovered through C and O isotopic imaging [4, 5]. The grain has a $^{12}C/^{13}C$ ratio of 20 ± 2 and low abundances of isotopically normal oxygen. N and Si isotope imaging shows that the grain has, within errors, a normal Si isotopic composition ($\delta^{29}Si$ = 90 ± 70 ‰, $\delta^{30}Si$ = 0 ± 80 ‰), but is enriched in ^{15}N (Fig. 1). Because of its small size (~150 nm diameter) and the fact that the surrounding material is also C-rich, the isotopic composition of the grain is probably diluted with isotopically normal C, and the $^{12}C/^{13}C$ ratio can be seen as an upper limit. In contrast, the area surrounding the grain is relatively N-poor and thus isotopic dilution probably did not significantly affect the N isotopic composition. Because the grain is likely to be more ^{13}C-rich than actually measured, and because it does not exhibit the ^{28}Si enrichment commonly seen in X-type SiC grains [8], we favor an identification of this grain as a type A+B SiC grain [5]. These grains make up about 4–5 % of all presolar SiC and probably come from J-type carbon stars [9].

^{15}N-rich hotspots: through N isotopic imaging, we were able to confirm the ^{15}N-enriched bulk composition of Tiberius; the NanoSIMS data show an average bulk ^{15}N enrichment of 77 ± 2 ‰. In addition, like other isotopically primitive IDPs [1, 2], Tiberius contains several ^{15}N-rich hotspots (Fig. 2). One hotspot was found during the N and Si imaging measurement and has a $\delta^{15}N$ of 1590 ± 160 ‰, but its C isotopic composition is unknown. The other two hotspots were observed during C and N isotopic imaging. One has normal C and a moderate ^{15}N enrichment ($\delta^{15}N$ = 360 ± 20 ‰), whereas the other is strongly enriched in ^{15}N ($\delta^{15}N$ = 1900 ± 210 ‰) and depleted in ^{13}C ($\delta^{13}C$ = -175 ± 10 ‰). All three hotspots are relatively large (between 400 and 800 nm in diameter) and are C-rich and depleted in Si. C isotopic anomalies are rare in IDPs and those found to date are all associated with large ^{15}N enrichments [1, 2, 10]. Most of the ^{15}N enrichments in IDPs are probably not carried by graphite [1], but we cannot rule out that a presolar graphite grain is the host phase of the C- and N-anomalous region in Tiberius. Subsequent O isotopic imaging shows that this region has a normal O isotopic composition.

Presolar silicates and oxides: a presolar grain of corundum was found in Tiberius during the original

C and O isotopic imaging measurements [4, 5]. This grain has a composition similar to group 1 oxide grains thought to be of red giant or AGB origin [11] and also contains excess ^{26}Mg from the decay of extinct ^{26}Al [5]. However, the areas analyzed did not contain any presolar silicate grains. IDPs contain higher abundances of presolar silicates than most primitive meteorites [12, 13] and the most recent estimate for isotopically primitive IDPs is ~375 ppm

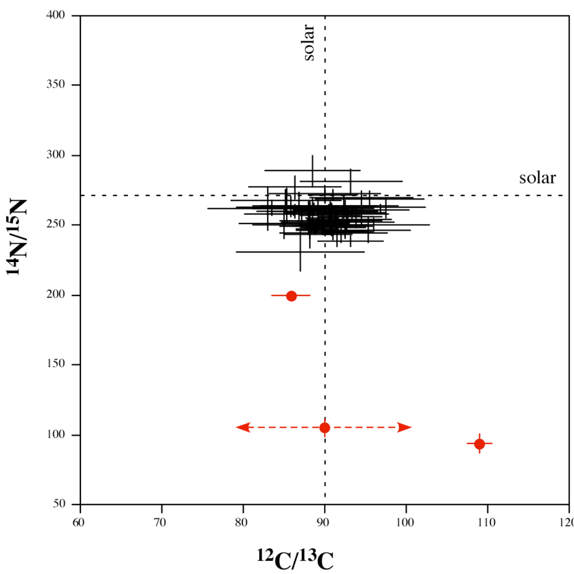

Figure 2. C and N isotopic compositions (1σ errors) of three ^{15}N-rich hotspots in Tiberius compared with similarly-sized sub-regions of the particle. The C isotopic composition of one grain was not measured and is arbitrarily placed at the solar value. Note that the bulk composition of Tiberius is enriched in ^{15}N.

[1]; thus, one might expect this IDP to contain presolar silicate grains. We made further O isotopic measurements of Tiberius after the C and N measurements, but again did not find any O-anomalous silicate (or additional oxide) grains.

Discussion: The discovery of presolar corundum and SiC in IDPs is consistent with our understanding that presolar grains were part of a widespread reservoir that was incorporated into all solar system bodies and that differences in abundances in different materials reflect different degrees of solar system processing. Isotopically primitive IDPs appear to have undergone the least solar system processing, as indicated by their N isotopic systematics and high presolar silicate concentrations [1]; Tiberius, with its variety of presolar phases and bulk ^{15}N enrichment, seems to be similar to other isotopically primitive IDPs. However, notably absent from the presolar grain inventory of Tiberius are circumstellar silicates.

One possibility is that this is only a random statistical effect. Based on the abundance of presolar silicates in primitive IDPs and the area of Tiberius originally analyzed, the chance of finding a presolar silicate was estimated to be about 60% [5]. With the additional areas analyzed here, that probability rises to ~70–80% (because the same regions were analyzed in both sets of measurements, some of the same material may have been analyzed twice; however, the intervening C and N measurements sputtered some material away, so we estimate the duplication to be less than 50%). Although the chances of not finding a presolar silicate in Tiberius are still statistically within expectations, we also consider another possibility below.

During the initial characterization of Tiberius, a fragment of this particle was mounted on KBr for IR measurements [3]. The IR spectrum hinted at the presence of layer lattice silicates, although the classification was not conclusive [3, 4]. In an attempt to better constrain the mineralogy of Tiberius, we carried out Raman spectroscopy on the two fragments remaining from the NanoSIMS measurements. Characteristic peaks for minerals with orthosilicate and chain silicate structures were not observed, ruling out the presence of olivine and pyroxene. Rather, the Raman spectrum suggests the presence of layer lattice silicates, together with highly disordered carbonaceous matter. Although no O–H peaks were observed, the Si–O peaks below 1000 Δcm^{-1} are consistent with a tri-octahedral sheet silicate structure. Heating of the IDP (possibly during atmospheric entry) may have caused dehydration.

If the phyllosilicates in Tiberius originally were hydrated, aqueous alteration could account for the apparent absence of presolar silicates. Aqueous alteration is more likely to affect presolar silicates than other more refractory presolar phases, either by destroying them or re-equilibrating their oxygen isotopes. This has been observed, for example, in the CR chondrite Renazzo, which contains abundant SiC and matrix material with N isotopic systematics similar to those observed in isotopically primitive IDPs, but does not appear to contain presolar silicates [14]. The similarities with Renazzo may indicate a link between Tiberius and primitive meteorites like the CR chondrites.

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