

# INTERSTELLAR GRAINS WITHIN INTERSTELLAR GRAINS; Thomas J.

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C $\alpha$ , the carrier of Ne-E(L), consists of round graphitic spherules (1-6 $\mu$ m) that have extremely anomalous C isotopic compositions and large excesses of fossil <sup>26</sup>Mg from the decay of <sup>26</sup>Al [1,2]. Here we report the results of ion microprobe and transmission electron microscope (TEM) studies of 5 interstellar graphitic spherules extracted from a C $\alpha$  separate (LFC1) of the carbonaceous chondrite Murchison. Details of the preparation procedure for this residue have been described previously [1]. Carbonaceous particles were deposited from suspension on a gold foil, characterized for major elements and external morphology in the scanning electron microscope, and then analyzed for C and N isotopic compositions and H, C, N, O and Si concentrations in the ion microprobe (Table 1). Three of the particles (#5, #56 and #63) were subsequently analyzed on the gold foil for degree of graphite crystallinity by laser Raman microprobe [3]. After these analyses the particles were dismounted from the gold foil, imbedded in resin, and sliced into 70nm sections with an ultramicrotome equipped with a diamond knife. The sections were retrieved on Cu TEM grids covered with holey C films, and were examined for composition and structure in a JEOL-2000FX TEM equipped with a Gatan 607 electron energy loss spectrometer (EELS) and a Tracor Northern energy dispersive X-ray detector (EDS) with a Be window.

The graphitic spherules have <sup>12</sup>C/<sup>13</sup>C ratios between 7 and 1330 that are dramatically different from the solar value of 89, and concentrations of H, N, O and Si that appear to increase with decreasing <sup>12</sup>C/<sup>13</sup>C ratio (Table 1). Two morphological types of spherules were observed: three of the spherules (#5, #56, #63) consist of concentric shells of fairly well graphitized carbon, while the other two (#4, #84) consist of concentrically arranged discontinuous scales of poorly graphitized carbon. In one of the spherules (#84) we observed numerous (an average of 6 per 70 nm section) small (10-20nm) euhedral crystals of a phase which gave only a Ti signal in EDS. Electron diffraction patterns of these crystals gave d-spacings commensurate with the (111), (220) and (311) spacings for cubic TiC (0.250nm, 0.153nm and 0.131nm, respectively). The only other candidate mineral species, cubic TiN, could be safely excluded because it has a unit cell 2.5% smaller than TiC, and because only Ti and C were detected in EELS, but not N. The TiC is present in very low abundance: it constitutes only about 25 ppm of spherule #84. The random distribution of the TiC crystals and their lack of orientational conformity with the graphitic layers suggests that they did not form *in situ*, but nucleated elsewhere and were entrained by the growing spherule. Direct observation shows that there is no other mineral phase in the core of #84 which could have served as a deposition nucleus, and evidently the spherule nucleated as graphite. *Because the C isotopic ratio of spherule #84 is demonstrably non-solar (Table 1), the included TiC crystals must similarly be stellar condensates, but they are also unique in that they have been protected inside the graphitic spherule since they were accreted onto its growing surface. They thus represent the first unambiguous examples of stellar condensates preserved in pristine form and unaltered by processing in the interstellar medium.* Because of its very low abundance, it appears unlikely that TiC would be astronomically observable. This is the first report of TiC in meteorites, although an occurrence of a much larger (several  $\mu$ m) TiC in an Antarctic ice particle has previously been reported [4].

Equilibrium condensation calculations [5] show that C and TiC are the first phases to condense in a gas of solar composition (except for C and O) over a wide range of pressures when  $C/O > 1$ . The observed phase assemblage for spherule #84 is consistent with formation in the atmosphere of a carbon-rich star at temperatures ranging from roughly 1500-2000K. Barring compositional changes in the gas phase which inhibited further precipitation of C, the absence of other phases (except for the observation of a single occurrence of SiC) and the small size of the included TiC crystals suggest that the growth of spherule #84 was quenched early in the condensation sequence, possibly by expulsion of the grain into lower pressure regions of the stellar atmosphere. Also, a relatively short spherule formation time is suggested by the observed poor degree of graphitization. The lack of internal crystals in the other spherules studied, regardless of degree of graphitization, implies compositional differences and/or differences in the details of spherule growth history in the various stellar sources responsible for these grains.

**REFERENCES:** [1] Amari S. *et al.* (1990) *Nature* **345**, 238; [2] Zinner E. *et al.* (1991), *Nature*, in press. [3] Zinner E. *et al.* (1990), *Lunar Planet. Sci. XXI*, 1379; [4] Zolensky *et al.* (1989), *Proc. 19th Lunar Planet. Sci. Conf.*, 505; [5] Lattimer *et al.* (1978) *Ap. J.* **219**, 230.

**Table 1: Isotopic, elemental and structural data for interstellar graphite spherules<sup>a</sup>**

Particle #	Size (μm)	Internal Morphology <sup>b</sup>	Internal Grains	$^{12}\text{C}/^{13}\text{C}^c$	$^{14}\text{N}/^{15}\text{N}^d$	H <sup>-</sup> /C <sup>-</sup>	O <sup>-</sup> /C <sup>-</sup>	CN <sup>-</sup> /C <sup>-</sup>	Si <sup>-</sup> /C <sup>-</sup> (10 <sup>-5</sup> )
63	5.5	platy	no	81.8	277	.0134	.050	.0102	10.3
56	4	platy	no	1330	380	.0083	.043	.0056	4.9
4	4.5	scaly	no	18.1	253	.046	.306	.142	165
5	8	platy	no	6.99	241	.086	.233	.218	56
84	5.5	scaly	yes	62.0	193	.057	.135	.124	168

a) From Murchison carbonaceous meteorite dissolution residue LFC1 [1]. Tabulated elemental and isotopic ratios are from ion microprobe measurements.

b) platy = continuous concentric graphitic sheets with moderately long-range order; scaly = short discontinuous concentric scales, poorly graphitized.

c) solar ratio = 89

d) solar ratio = 273