What the solar nebula was like

Two remarkable papers in this issue are a vivid pointer to the ways in which it may be possible to learn how the material from which the Solar System formed was itself produced.

WHAT is known about the solar nebula, the cloud of gas and dust from which the Solar System formed? And where did that come from? The two papers on pages 728 and 730 of this issue from Dr Edward Anders and his colleagues at the University of Chicago and Washington University, St Louis, are an intriguing pointer to how those legitimate questions may eventually be answered, but are also an illustration of how complicated the questions may prove to be.

The new development, ostensibly that of the discovery of silicon carbide in the Murray meteorite, is not in itself surprising. With the recognition that small crystals of diamond are to be found in meteorites, there are few who will be surprised to learn that there is silicon carbide as well.

In any case, as Anders and his colleagues say, silicon carbide has been recognised spectroscopically in the atmospheres of stars, so that the discoveries now reported are the first direct demonstration that the spectroscopic identifications are correct (as well as a vivid sign that the minerals carried by meteorites do indeed derive from stars). But it now also emerges that the occurrence of this material has a direct bearing on the chemical composition of the solar nebula or, more accurately and significantly, on the nature of at least one of the sources from which it was formed.

None of this should diminish wonder at the technical feat now reported, which is a breathtaking illustration of what microanalysis can now accomplish (see cover of this issue). Those concerned have been working with small grains, some just a few hundred Ångstroms in diameter, which have themselves been extracted from a sample of the Murray meteorite after treatment with strong acids and oxidizing agents to remove all but the most refractory of structures.

Even so, by the evidence of the two papers, it has been possible to identify some of these grains as sources of neon and xenon with anomalous isotope composition, a superbly delicate exercise in mass spectrometry. Telling that some of the grains consist of silicon carbide (most directly by Raman spectroscopy, most convincingly by electron diffraction) may be, by comparison, almost child's play. Even so, it is striking, and significant, that some of the crystals are found to be twinned, which fits in well with what emerges from the sequel, the suggestion that the silicon carbide grains were formed as such in the atmosphere of some star.

But what kind of star? This is the sense in which the mere presence of silicon carbide crystals is significant, by the test of what the chemistry textbooks call the principle of mass action. Atoms of silicon in a mixture of carbon and oxygen will preferentially be linked to oxygen rather than to carbon. For silicon carbide rather than silica crystals to be formed by condensation in the atmosphere of a star, carbon must be abundant relative to oxygen, which Anders and his colleagues say implies a star rich in carbon, presumably in the late stage of its evolution.

That is intriguing because it conflicts directly with the ratio of carbon to oxygen in the Solar System as it is, and where oxygen is half as abundant again as carbon. The implication is that the star or stars in whose atmosphere the grains of silicon carbide wëe formed were only minor contributors to the solar nebula. That, in itself, is no great surprise. The visible regions elsewhere in the Galaxy at which stars appear to be being formed are places where there is much more material than required for a single star, with the result that groups of stars formed at the same time. Why should not the Solar System also have been formed from a nebula to which several stars had independently contributed?

These are merely the straightforward implications of the presence of silicon carbide in the Murray meteorite. Anders and his colleagues are after much more specific information about the character of the stars that may have contributed material to the solar nebula, and which they hope to win from the evidence gathered by their microprobe analysis of the isotope composition of the silicon carbide. (Mass spectrometrists, used as they are to the manipulation of small samples, may well pause to note that Zinner, Tang and Anders laconically explain, on page 730, that their microprobe measurements have entailed the analysis of atoms thrown off a μm-sized patch on the surface of an aggregate with sensitivity good enough to discriminate between $^{13}C^{14}N^-$ and $^{12}C^{15}N^-$.)

It is important for the argument as so far advanced that the Murray meteorite has yielded two kinds of grains containing silicon carbide, in one of which it is associated with an amorphous compound of silicon and oxygen that may (this is surmise only) originally have been silicon nitride. That would have been oxidized by the hyperchromate treatment used to remove graphite and other materials containing organic carbon.

The most striking feature of the data now reported is that the isotope anomalies discovered by the microprobe analysis are, by the standards of terrestrial isotope analysis, huge — some samples yield an excess of ^{13}C measured by $\delta = +6{,}000$ ‰.

The conclusions should provide the astrophysicists who study nucleosynthesis with some tantalizing puzzles with which to grapple over the holidays ahead. First, there seem to be at least two sources of anomalously heavy carbon represented in the meteorite sample — one of them enriched in ^{13}C six times more than the other, but each of them associated with nitrogen deficient in the heavier isotope ^{15}N. Which of the anomalous noble gas materials is associated with which kind of anomalous silicon carbide is not unambiguously clear at this stage, although it appears that anomalous xenon (enriched in ^{130}Xe) is linked with the source of less markedly heavy carbon.

The silicon anomalies now reported will be even more taxing for the nucleogenesis community, which will have to account for at least three kinds of sources — producing silicon both enriched and depleted in ^{28}Si as well as silicon enriched in ^{29}Si. Anders and his colleagues explain that the two sets of anomalies are independent of each other — carbon and nitrogen anomalies must say something about the hydrogen-burning phase of a star's evolution and the silicon anomalies something about the later phases. But what?

Time will tell. This is not the first occasion when people have based inferences about the solar nebula on data gathered from materials at the surface of the Earth. The abundance of ^{26}Al has, for example, been regarded for more than a decade as an indicator of short-lived ^{26}Mg in the material of the solar nebula, suggesting a supernova explosion immediately preceding the Solar System.

The wealth of detail likely to emerge from the further research of Anders and his colleagues promises to specify the nature of the stars contributing material to the nebula, while the ^{26}Al evidence will suggest to some the event that swept this material into concentrations from which stars could form. **John Maddox**