**SILICON CARBIDE - THE PROBLEM WITH LABORATORY SPECTRA.** A. K. Speck[1], A. M. Hofmeister[2], & M. J. Barlow[1], [1]Department of Physics and Astronomy, University College London, Gower Street, London, WC1E 6BT, UK, (aks@star.ucl.ac.uk), [2]Department of Earth & Planetary Science, Washington University, St Louis, MO 63130, USA.

**Introduction:** Most of the solid material in the solar system is believed to have originated as small particles that condensed in outflows from evolved stars. However, most solar system solids (predominantly silicates) have been reprocessed and/or homogenized so extensively that even the most primitive meteorite silicate samples have lost the isotopic indicators of their presolar origins. But some types of dust particles in the solar system have not been reprocessed and can potentially be associated with their stellar origins. One such dust type, silicon carbide (SiC), has been found in primitive meteorites[1] and is believed to be a significant constituent of the dust around carbon-rich AGB stars[2],[3]. Silicon carbide grains can be divided into two basic groups: $\alpha$-SiC if the structure is one of the many hexagonal or rhombohedral polytypes and $\beta$-SiC if the structure is cubic[4]. Silicon carbide grains exhibit a strong mid-infrared feature between 10 and 12 $\mu$m, with the peak of the $\beta$-SiC feature occurring about 0.4 $\mu$m shortwards of that for $\alpha$-SiC. Until now, the observed peak wavelengths of the SiC feature in astronomical spectra have been interpreted as indicating $\alpha$-SiC to be the dominant type of SiC around carbon stars (e.g. [5],[6],[7],[8],[9]). In fact, [8],[9] found no evidence of $\beta$-SiC in these circumstellar environments. Silicon carbide grains found in meteorites have isotopic compositions which imply that most of these grains were formed around carbon stars, with small amounts forming around novae and supernovae (see [10],[11],[12] and references therein). With the exception of a few grains found in and amongst the meteoritic diamonds (and of unknown origin; [13]), to date, studies of meteoritic SiC grains have found them to be exclusively of the $\beta$-type[14]. $\beta$-SiC will transform into $\alpha$-SiC above 2100°C but the reverse process is thermodynamically unlikely. There is therefore an apparent discrepancy between the meteoritic and astronomical SiC-types, which has been discussed in detail by [8],[9].

This discrepancy is addressed by discussing the problems associated with previous interpretations of astronomical spectra that made use of laboratory infrared studies of terrestrial SiC. We have found that the problem in reconciling astronomical observations with meteoritic laboratory work has arisen from a misunderstanding and misinterpretation of laboratory spectra of SiC (and potentially other dust species). The results of fitting techniques used previously[5],[6],[7],[8],[9] are shown to be invalid due to the application of inappropriate matrix corrections to measured SiC optical properties. Furthermore, we show that IR spectra taken using the diamond anvil cell (DAC), thin film method provides data applicable to astronomical situations without further manipulation.

**Laboratory Techniques and Results:** New infrared (IR) absorption measurements of thin films of $\alpha$- and $\beta$-SiC created by compression in a diamond anvil cell will be presented. Unlike some other methods, a dispersive medium (such as potassium bromide; KBr) is not used. This relatively new approach is quantitative, if sufficient care is taken to produce an appropriately thin and uniform film, as shown by comparison of thin film spectra of various minerals to reflectivity data from the same samples[15],[16] and references therein. Moreover, thin film spectra of garnets are nearly identical to single-crystal absorption data acquired in a vacuum[15]: hence, thin film spectra can be applied to astronomical data without further manipulation. Our measurements strongly suggest, through comparison of the new thin film data with previous IR spectra collected for fine-grained KBr dispersions (in which the dust particles are dispersed in a KBr pellet), that the "matrix correction" wavelength shift, invoked by [17] and adopted by other authors (e.g. [18],[19]), should not be applied to laboratory spectra of

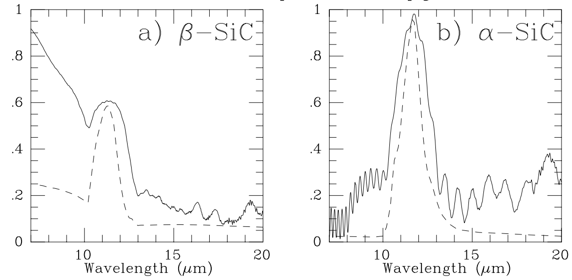


Figure 1: Thin film spectra (solid lines) and the uncorrected KBr dispersion data[19] (dashed lines).

sub-micron grain size dispersions of SiC. (See Fig.1).

**Results of fitting technique:** Having established that previous fits of laboratory spectra for SiC to astronomical spectra have been erroneous due to the unnecessary application of a KBr correction factor, we have refitted our own UKIRT CGS3 spectra of carbon stars[8],[9] without such a correction. We have used the same $\chi^2$–minimization routine[8] but the data, to which the KBr correction had previously been applied[8],[9], were used uncorrected this time. The results in Table 1 show that there is an obvious predominance of the $\beta$-SiC phase and that there is now no evidence for the $\alpha$-SiC phase at all.

Table 1: Results of the $\chi^2$-fitting of carbon star spectra

| Source | $T_{col}$ | SiC type | $T_{BB}$ | $T_{SiC}$ | $\tau_{SiC}$ | $\tau_{9.7}$ | $\chi^2_R$ |
|---|---|---|---|---|---|---|---|
| IRAS 21489+5301[2] | 455 | $\beta$-SiC | 449 | 293 | — | — | 0.515 |
| IRC+10216[2] | 520 | $\beta$-SiC | 511 | 230 | — | — | 1.260 |
| AFGL 5076[1] | 525 | $\beta$-SiC | 557 | 298 | 0.137 | — | 0.369 |
| AFGL 2494[1] | 525 | $\beta$-SiC | 516 | 383 | 0.167 | — | 0.306 |
| AFGL 3099[1] | 600 | $\beta$-SiC | 726 | 329 | 0.242 | — | 1.370 |
| AFGL 5102[1] | 600 | $\beta$-SiC | 650 | 355 | 0.161 | — | 0.345 |
| AFGL 2155[1] | 615 | $\beta$-SiC | 734 | 288 | 0.235 | — | 0.418 |
| IRAS 02152+2822[1] | 675 | $\beta$-SiC | 548 | 519 | 0.223 | — | 0.504 |
| IRC+40540[1] | 680 | $\beta$-SiC | 859 | 313 | 0.173 | — | 0.508 |
| AFGL 2368[1] | 800 | $\beta$-SiC | 727 | 321 | — | — | 1.772 |
| V Hya[1] | 865 | $\beta$-SiC | 1129 | 393 | 0.211 | — | 0.761 |
| IRC+00365[1] | 975 | $\beta$-SiC | 1788 | 215 | 0.114 | — | 2.316 |
| CIT 6[1] | 1100 | $\beta$-SiC | 960 | 363 | 0.217 | — | 1.294 |
| IRC+50096[2] | 1200 | $\beta$-SiC | 940 | 455 | — | — | 2.166 |
| R For[2] | 1400 | $\beta$-SiC | 906 | 800 | — | — | 1.237 |
| R Lep[2] | 1500 | $\beta$-SiC | 1284 | 573 | — | — | 5.267 |
| UU Aur[1] | 1500 | $\beta$-SiC | 2505 | 446 | 0.165 | — | 1.105 |
| V Cyg[1] | 1500 | $\beta$-SiC | 2556 | 568 | 0.139 | — | 1.014 |
| CS 776[2] | 1600 | $\beta$-SiC | 993 | 576 | — | — | 1.879 |
| V414 Per[1] | 1600 | $\beta$-SiC | 1102 | 920 | 0.177 | — | 0.579 |
| AFGL 3068[3] | 377 | $\beta$-SiC | 394 | 62 | 0.030 | — | 0.092 |
| IARS 02408+5458[3] | 320 | $\beta$-SiC | 388 | 96 | 0.152 | — | 1.686 |
| AFGL 2477*[3] | 340 | $\beta$-SiC | 377 | 114 | 0.073 | 0.104 | 0.419 |
| AFGL 5625†[3] | 333 | $\beta$-SiC | 358 | 185 | 0.097 | 0.113 | 0.306 |

1 Fits with self-absorbed emission
2 Fits with pure emission only
3 Fits with self-absorbed absorption
$\tau_{9.7}$ is the optical depth at 9.7 $\mu$m
* is fit with Trapezium interstellar silicate
† is fit with $\mu$ Cep interstellar silicate

**Conclusions**: There is now no astronomical evidence for the presence of $\alpha$-SiC in the circumstellar regions around carbon stars. While $\alpha$-SiC might exist in small quantities, all observations to date are consistent with the exclusive presence of $\beta$-SiC grains. This resolves the past discrepancy, reconciling astronomical observations and meteoritic samples of silicon carbide grains. Furthermore, we have shown that laboratory IR spectra applicable to astronomical environments can be produced using the DAC thin film method.

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