Amorphous Silicates as Precursors for Cosmic Carbonates. Sarah J. Day¹,², Stephen P. Thompson, A. Evans¹, and Julia E. Parker²
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Context
Silicates are one of the most primitive, refractory dust species known to have been present within the pre-solar nebula. Calcic pyroxenes ((Ca,Mg)Si₂O₆) and forsteritic olivines (MgSiO₄) are found within meteorites as characteristic mineral components of Calcium Aluminium Inclusions (CAIs) [1]. The chemical structure of such materials is directly related to their formation history and subsequent evolution, therefore studying the physical properties of these minerals can provide a diagnostic with which to gain valuable information about the environmental conditions within the early solar nebula, and the processes leading to their formation.

Through the use of laboratory analogues the effect on chemical structure as a function of thermal processing can be quantified. Using a combination of synchrotron X-ray powder diffraction (SXPD) and Fourier transform infrared spectroscopy (FTIR) the presence of certain spectral features can be directly related to changes in the physical structure of the grain material. Understanding the relationship between spectral features and the structural evolution of grains is extremely important, making astronomical spectra a useful tool in our understanding of solar system and planetary formation.

Experimental
Amorphous cosmic silicate analogues have been produced through vacuum ageing of Sol Gels [2]. This produces disordered, fine grained, amorphous powders of composition MgₓCa₍1−x₎SiO₃, where 0 < x < 1, analogous to silicates present within the interstellar and proto-solar medium [3, 4].

Using SXPD, on beamline I11 at Diamond Light Source [5], the structure of these analogues is monitored as the samples are exposed to gaseous CO₂ under non-ambient thermal conditions. This is performed in-situ using a gas cell, with a CO₂ pressure of 1 bar. Scans are performed using a position sensitive detector (PSD) [6], specially designed for fast X-ray diffraction measurements. This enables details of the kinematics and structural mechanisms governing the transition from amorphous to crystalline during thermal annealing to be established.

SEM imaging and Raman spectroscopy were also used to complement these measurements and to provide further characterisation of the samples.

Preliminary Results
Fig. 1 shows the fine grained, porous nature of the vacuum-dried analogues. No isolated grains can be observed, even at a resolution of ~5µm, instead the powder forms a network of branch-like structures.

Figure 1: SEM image of vacuum-dried powder, no isolated grains can be distinguished even at a resolution of ~5µm.

FTIR spectra of five analogues of different composition are shown in Fig. 2. The spectra confirm the similarity of the analogues to astronomical silicates, exhibiting the broad feature at 10µm characteristic of amorphous silicates observed in a wide variety of astronomical environments, including the interstellar medium [7], circumstellar regions around both young stellar objects and asymptotic giant branch stars [8], and in planetary systems [9]. There are also a number of interesting features, including a shoulder at 11.3µm and two broad features at 7µm and 16.2µm that vary with composition, strengthening with increasing calcium content.

Fig. 3 shows real time PSD scans taken as a sample was heated in-situ from 296K (room temperature) to 1250K, using a Cyberstar hot air blower, whilst being exposed to CO₂. This lead to full crystallisation of the samples at temperatures above 1050K.

The importance of this is to gain a detailed understanding of the physical properties of amorphous silicates in vacuum, in order to determine the processes...
The results of this research will be presented, focussing on the structural mechanisms involved with the thermal evolution of silicates in order to place physical constraints on the environments and the possible formation routes of astrophysical carbonates.

References