Crystalline silicates in external galaxies

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Observational evidence has long supported that most of the interstellar silicates in galaxies are *amorphous*, meaning that while the basic silicate tetrahedra are present to give rise to the 9.7 and 18 μm Si-O stretching and O-Si-O bending modes, the lattice shows defects, and the chemical composition may be non-stoichiometric. While crystalline silicates may form around evolved stars at temperatures sufficiently high to allow for annealing, it is thought that the harsh interstellar environment quickly amorphitizes any crystalline silicates, most likely through bombardment by the heavy ions in cosmic rays (Demyk et al. 2001; Jäger et al. 2003; Brucato et al. 2004; Bringa et al. 2007; Szenes et al. 2010), and a firm upper limit of 2% on the crystalline fraction of silicates was derived based on the absence of substructure in the 9.7 μm feature (Kemper et al. 2004; Kemper et al. 2005).

Traditionally, silicates in the interstellar medium of external galaxies were also assumed to be completely amorphous. The first detection of crystalline silicates in external galaxies was reported by Spoon et al. (2006) in 12 out of a sample of 77 starbursting Ultraluminous Infrared Galaxies (ULIRGs), with Roussel et al. (2006) adding a 13^{th} galaxy, NGC 1377, to this sample. More recently, Willett et al. (2011) analysed mid-infrared spectra of 51 OH megamaser galaxies, finding that 19 of them show one or more of the crystalline silicate features between 11 and 28 μm in absorption, while Stierwalt et al. (2014) report the detection of crystalline silicates in 6% of the objects in a sample of 244 LIRG nuclei. The most spectacular detection is done by Aller et al. (2012), who report interstellar silicates with a crystallinity of ~95% in a foreground absorbing galaxy towards a quasar background source. The only other study quantifying the crystalline fraction is the aforementioned work by Spoon et al. (2006), who report a crystalline fraction of 6-13% in their interstellar silicates (when detected), using the definition for crystallinity by Kemper et al. (2004). A very simple model of the production of crystalline silicate dust by evolved stars, at a level of 10-20% of the total silicate dust production by these stars, is able to explain the observed crystallinities at about 30 Myr after the start of a starburst (Kemper et al. 2011). In general, the model can be used to estimate the transition time and interstellar conditions, such as cosmic ray fluence, based on observational constraints on the crystalline fraction.

However, the small number of known interstellar crystalline silicate fractions in star-forming galaxies limits the usefulness of such a model. We have devised a method to measure the crystalline fraction of silicates in a large number of galaxies quickly and easily. For this purpose, we are performing radiative transfer models of starburst galaxies, with varying crystalline fractions of their interstellar silicates using the SKIRT radiative transfer code (Camps & Baes 2015), and identified a method to determine the crystallinity of silicates in starburst galaxies directly from (archival) infrared spectroscopy.