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Erratum

The shape and composition of interstellar silicate grains

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The paper "The shape and composition of interstellar silicate grains" by Min et al. (2007) discusses the composition, shape distribution, and the magnesium and iron content of interstellar silicate grains. These properties of the interstellar grains were derived from infrared spectral observations of absorption by interstellar dust. In Sects. 4 and 5, the implications of the findings of this study are discussed with respect to processing in various environments. In particular the relation with glass with embedded metal and sulfides (GEMS) is discussed. Our survey of the relevant literature on GEMS grains was incomplete and overlooked some important observations that we clarify in detail below. Despite these changes, we would like to stress that the results for the composition, magnesium and iron content, and the shape distribution of interstellar silicates remain correct. As a result, the conclusions unrelated to the GEMS grains remain unaltered.

In addition to the corrections for Sect. 4.3, we would like to point out that the SiC found by Bernatowicz et al. (1987) was not detected in an IDP, as we suggested, but in the Murray carbonaceous chondrite.

We first outline the shortcomings in the discussion in that paper. Second, we discuss the implications of these corrections and clarifications for the conclusions we draw concerning the nature of GEMS.

Corrections and clarifications for Sect. 4.3

- Bradley et al. (1999b) do not claim that GEMS might be *unprocessed* leftovers from the interstellar medium. They show that there are similarities and suggest that GEMS might be remnants from the ISM which could have been processed to a certain extent.
- "Preliminary observations indicate that the iron sulfide inclusions in GEMS are located preferably at the edge of the grains." (Min et al. 2007). Although, in our opinion, current evidence points towards this conclusion, we also have to note that observations are reported in the literature where FeS inclusions are claimed to be seen distributed homogeneously or even located primarily in the center (e.g., Bradley 1994; Westphal & Bradley 2004). We conclude that the location of the FeS inclusions in GEMS is currently an open question.
- The O/Si ratio as reported in that discussion was based on the stoichiometry of the silicate glass. However, in general, stoichiometry cannot be assumed for amorphous silicates. In particular, GEMS are enriched in oxygen. The measured average O/Si ratio in GEMS as reported in the literature ranges from 3.6 to 4.0, although a much wider range can be found for individual GEMS grains.
- The reported spectral position of the GEMS absorption feature is incomplete. We report a wavelength of the maximum feature around 9.3 micron. However, measurements have been reported ranging from 9.2 to 10.4 μm (Bradley et al. 1999a,b). Although the average absorption feature as reported in Bradley et al. (1999a) indeed has a maximum around 9.3 μm, we now believe that there is not enough data at the moment to really constrain the spectral shape of the GEMS absorption profile with any significance. Any comparison claiming differences or similarities in the spectral profiles of GEMS and ISM silicates is thus premature at this point.
- We would like to clarify one point that was not properly explained in the text. It was unclear in the text where the (Mg+Fe)/Si of ≈0.7 of the silicate glass in GEMS comes from. This ratio is derived from two different observations: i) the Mg/Si in GEMS grains is ≈0.7; ii) the silicate glass in GEMS contains only a very insignificant fraction of Fe. This taken together leads to (Mg+Fe)/Si ≈ Mg/Si ≈ 0.7.

The nature of GEMS

We now evaluate the conclusions drawn by Min et al. (2007) concerning the nature of GEMS taking the above corrections to the GEMS data into account. As we already pointed out in the original paper, GEMS with anomalous oxygen isotopes have been reported. This indicates that these GEMS originate in the outflows of AGB stars and red giants. Therefore, they must have

travelled through the ISM from their formation region to the molecular cloud from which the Solar System formed. Thus, at some point they have been part of the interstellar dust population. However, they are only a small fraction of the total GEMS population.

Several differences between the grains in the diffuse ISM and GEMS can be pointed out:

- In the diffuse interstellar gas the sulfur abundance is approximately solar (Sofia 2004). This implies that dust grains in the diffuse ISM are very sulfur poor; however, GEMS grains contain a significant amount of sulfur. On average the S/Si ratio in GEMS grains is ~60% of the solar value (Keller et al. 2005). The measurements of sulfur depletion in the ISM show that for the diffuse ISM grains S/Si < 23% of the solar value (Sofia 2004).
- Our analysis indicates that the diffuse ISM silicates have (Mg+Fe)/Si $\approx$ 1.5. The silicate glass in individual GEMS grains span a wide range in this ratio. On average the value is (Mg+Fe)/Si $\approx$ 0.7.

On the other hand, similarities between GEMS grains and the diffuse ISM dust grains can be reported:

- both the ISM silicates and the glass in the GEMS are very Mg rich. Our analysis of the ISM grains indicate that Mg/(Mg+Fe) $\approx$ 0.9, consistent with the glassy silicates in GEMS;
- the bulk O/Si ratio in GEMS and ISM silicates is $\approx$3.5.

We note that, though the *bulk* O/Si ratio in GEMS and ISM silicates is similar, our analysis shows that the ISM grains are consistent with stoichiometric silicates, while GEMS grains are, on average, not stoichiometric; instead they are enriched in oxygen (see Ishii et al. 2008; and the comment to Min et al. 2007, by Bradley & Ishii). Currently there are no laboratory spectra available for oxygen-enriched amorphous silicates, so a comparison cannot be made. We thus conclude that a direct comparison between the *bulk* O/Si in GEMS grains and ISM silicates is, at this point, ambiguous.

These arguments taken together suggest that, although there are interesting similarities between the composition of GEMS and those of the silicates in the diffuse ISM, the overall properties of GEMS are not similar to the bulk grain properties in the diffuse ISM. Though it is clear that the GEMS with anomalous oxygen isotopes have resided in the ISM, therefore have been part of the population of ISM grains, the origin of isotopically solar GEMS remains an open question. We would like to point out that no significant difference is found between the isotopically solar and the anomalous GEMS grains, suggesting a similar formation mechanism, and possibly a similar origin. Our results, on the other hand, suggest that GEMS, with the composition as found in our Solar System, are inconsistent with the bulk composition of the grains in the diffuse ISM. This indicates that diffuse interstellar silicates are not predominantly GEMS. However, we would like to stress that we cannot turn the argument around so that, from our results, we cannot exclude the possibility that a significant fraction of GEMS grains have an interstellar origin, as long as they do not dominate the silicate grain population. They may either be of circumstellar origin, but having resided in the ISM for a long period ($\sim 10^8$ yr), or they may have formed in the collapsing solar molecular cloud. In addition, recent work by Keller et al. (2005) and Keller & Messenger (2007) on GEMS grains suggests that most are products of the early solar system.

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