RESOLVING THE CONTRADICTORY RESULTS FOR CHONDRULE SIZE DISTRIBUTIONS WHEN THESE ARE EMPIRICALLY DETERMINED OR THEORETICALLY CONSIDERED.

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Introduction: Determining true (3D) chondrule size distributions is a long-standing problem, since the physical separation of representative sets of chondrules from their host meteorites is only rarely possible (e.g., 1). Determining chondrule size distributions from 3D tomography, the preferable method of investigation [e.g., 2-4], is tedious and time consuming and has so far only been done for a limited set of chondrites [e.g., 5]. Therefore, chondrule size distributions are often determined in 2D sections [6, and references therein], from so-called "apparent chondrule sizes". This is, of course, accompanied by sectioning effects, which have been studied over the decades by several authors. Two main effects are: (i) larger chondrules are sectioned more often than smaller chondrules, biasing the result towards larger chondrule sections, and (ii) non-equatorial sections are overwhelmingly more frequent, biasing the result towards smaller chondrule sections [7]. The theoretical studies by [7] and [8] conclude that 2D studies overestimate large chondrules, i.e., a determined 2D chondrule size distribution should be shifted to larger chondrule sizes than the real 3D chondrule size distribution. This prediction is, however, contradicted by empirical studies of [1,5,9], who found the opposite: the 2D size distribution is shifted to smaller chondrule sizes compared to the determined 3D data. Also, an attempt to apply the 2D-3D conversion of [7] to measured 2D size distributions failed [10].

Chondrules typically do not range from size 0 all the way up to a maximum chondrules size. There appears to be a group-specific minimum chondrules size [1,5], and this also appears to be critical when studying chondrule size distributions.

Here, we use a new model approach in an attempt to resolve the contradictory reports described above.

Method: We use a mathematical model that mimics the 2D size distribution in a chondrite section. The model is set-up as illustrated in Fig. 1: we randomly place thousands of chondrules (= spheres) with a given size distribution – the true 3D chondrule distribution – inside a cube. This cube and its chondrules are sectioned multiple times at equidistant intervals. The size (= diameter) of the 2D sections of all chondrules in all sections, i.e., their apparent sizes, are determined. The 2D chondrule size distribution of these sections are then compared to the given true 3D chondrule size distribution. This given distribution requires a number of parameters, which are subsequently varied, e.g.: (i) The distribution type– we used: normal, log-normal, Weibull, and Poisson. (ii) The parameter(s) for the chosen size distribution – e.g., mean (μ) and/or width (σ,α). (iii) A minimum chondrule size. (iv) A maximum chondrule size. (v) The distance between the equidistant sections through the cube.

The chondrule density has no influence on the result, as chondrules are not allowed to overlap. A number of sections at the top and bottom of the cube are ignored to avoid certain artifacts, which are not further detailed here. The model has been realised with the *Mathematica* software package.

Results: The distribution parameters and size factors for the given chondrule size distribution were chosen to resemble typical chondrule size ranges, i.e., between roughly 200 and 2000 µm. Minimum chondrule sizes were varied between 0 and 400 µm. Equidistances of 100 µm between sections have been proven to be sufficient. We placed 5000 chondrules in a cube with an edge length of 50,000 µm. This typically led to approx. 80 to 200 chondrules cut per section, i.e., a total of a couple of ten thousand cut chondrules (cuts per section times the number of sections), from which the 2D distributions were produced.

The result we are interested in is, whether the size distribution of the 2D chondrule cut faces is shifted to lower or higher values compared to the given true size

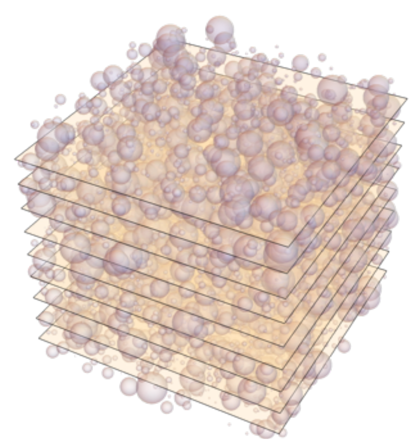

Fig. 1: Cube with thousands of non-overlapping spheres having a log-normal size distribution. Yellow planes illustrate 2D sections through the cube and spheres.

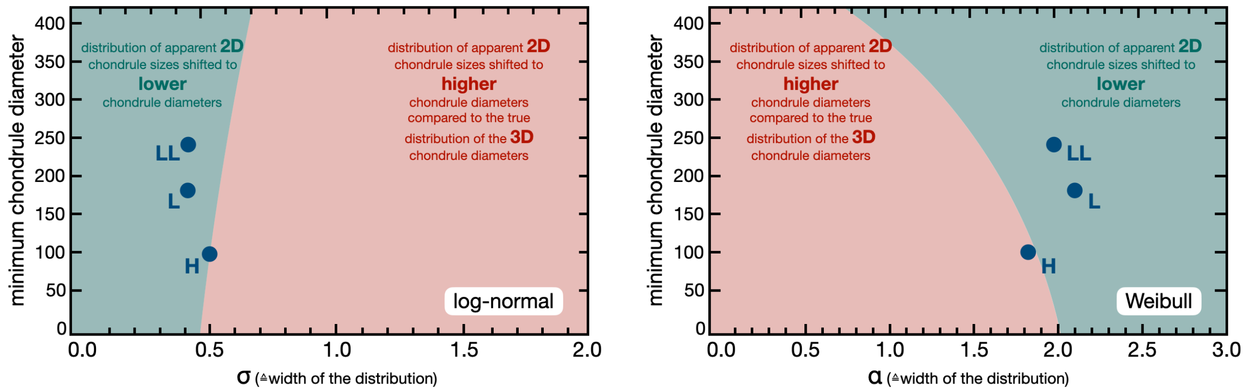

Fig. 2: The distribution of apparent 2D chondrule sizes can be shifted to lower or higher values than the given, true 3D chondrule distribution, depending on the distribution type and its defining parameter(s). Distribution parameters from empirical chondrules sizes distributions are plotted in blue [1]. Log-normal distributions provide better fits than Weibull distributions.

distribution of the 3D chondrules. Interestingly, the answer to this question is equivocal and depends on the parameters for the given, true 3D chondrule size distribution. This means, the size distribution of the 2D cut faces can be shifted to lower or higher values compared to the 3D distribution. Two parameters largely decide which way the 2D size distribution will be shifted. These are (i) the parameter for the variance of the distribution (e.g., σ, α) and (ii) the minimum chondrule size.

In Fig. 2, the colours indicate whether the size distribution of the 2D apparent chondrule sizes is shifted to lower (teal) or higher (rose) values, depending on the combination of σ or α and the minimum chondrule size.

The left plate shows the result when the given 3D chondrule size distribution is log-normal. Distributions of 2D apparent chondrule sizes are shifted to smaller diameters compared to the true 3D chondrule size distributions when σ and minimum chondrule sizes are small. This is reversed when σ becomes larger than at least about 0.5, depending on the minimum chondrule size of the true 3D chondrules.

The right plate shows the result when the given size distribution is a Weibull distribution. The 2D distributions are shifted to larger chondrule sizes compared to the true 3D distributions, when α is smaller than 2, but this values strongly depends on the minimum chondrule size of the true 3D chondrules. This seems contradictory to the results when the 3D chondrule size distributions are log-normal. This is, however, not really the case, as Weibull-fits of empirically determined chondrule size distributions have α-values around 2.

In case a given 3D chondrule size distribution were normal (not shown), the 2D distribution would always be shifted to smaller chondrule sizes.

Discussion: Log-normal distributions provide good fits to empirical data [1] and are therefore the ones discussed in more detail here:

The parameter σ represents the width of the log-normal distribution. At small σ (< ~0.5-0.7), chondrule sizes are rather similar. In these cases, random sections through the spheres would mostly be smaller than the true 3D chondrule sizes, and the size distribution of apparent 2D chondrule sizes would be shifted to smaller sizes. With increasing σ, larger chondrules are sectioned more often than smaller chondrules. This produces an overabundance of large chondrule sections in the distributions of the apparent 2D chondrules, which are then shifted to larger sizes compared to the true distribution of the 3D chondrule sizes.

Conclusions: We suggest that the reported contradictions between theoretical considerations and empirical data are related to the parameters used for model distributions of chondrule sizes. It is observed that the distributions of the apparent 2D chondrule sizes in thin sections are shifted to smaller sizes compared to the distributions of true the true 3D size distributions obtained by chondrule separation and µ-CT measurements [1,5,9]. These findings are confirmed by the presented theoretical considerations (Fig. 2), using realistic parameters for σ (0.45-0.5) and minimum chondrule sizes from ordinary chondrites (90-240 µm; [1]). The contradictory calculations and models [7,8] which predict the opposite likely assumed too large e.g., σ. These were so far not found in the – unfortunately – very few chondrites from which we currently have reliable chondrule size data.

References: [1] Metzler K (2018), *MAPS,* 53, 1489. [2] Ebel et al. (2009), *LPSC* #2065. [3] Hezel D.C. et al. (2013) *GCA,116*, 33. [4] Hanna R.D. and Ketcham R.A. (2017) *CdE – Geochemistry, 77*, 547. [5] Metzler et al. (2019), *ApJ,* 887, 230. [6] Friedrich J.M. et al. (2014) CdE – Geochemistry, 75, 419. [7] Eisenhour D. (1996) *MAPS, 31*, 243. [8] Cuzzi, J.N. and Olson, D.M. (2017), *MAPS, 52*, 532. [9] Hughes D.W. (1978), *EPSL*, 38, 391. [10] O´Hara and Dunn (2017), *GSA*, 49, 177.