SIZE-FREQUENCY DISTRIBUTIONS AND PHYSICAL PROPERTIES OF CHONDRULES FROM X-RAY MICROTOMOGRAPHY AND DIGITAL DATA EXTRACTION. J. M. Friedrich[1,2], S. A. Giordano[1], K. A. Tamucci[1], D. S. Ebel[2], M. L. Rivers[3], S. W. Wallace[2]. [1]Department of Chemistry, Fordham University, Bronx, NY 10458 USA (friedrich@fordham.edu), [2]Department of Earth and Planetary Sciences, American Museum of Natural History, New York, NY 10024 USA, [3]Consortium for Advanced Radiation Sources, University of Chicago, Argonne, IL 60439 USA.

Introduction: Accurate knowledge of the physical properties of chondrules is important for validating astrophysical theories concerning chondrule formation and their aggregation into the chondrites that contain them. The classification of chondrites into chemical groups also partially rests on chondrule dimensions since each chemical group possesses a distinct size-frequency distribution of chondrules.

Most chondrule size measurements have been made from the examination of two-dimensional (2D) petrographic thin sections (see [1] for a recent review) or from disaggregation of the chondrite and measurement of individual chondrules with a calibrated stereomicroscope [1 and references therein, 2, 3]. However, these methods have limitations. In the case of 2D measurements, stereological corrections are needed to obtain a valid three-dimensional (3D) size-frequency distribution. To obtain a valid chondrule size distribution with disaggregation-based chondrule studies, investigators must assume that all disaggregated chondrules are isolated, no chondrule breakage occurs, and fragments are not included in the investigation [3].

To overcome the challenges associated with other approaches, we have developed and employed methods [4] for the determination of chondrule size frequency distributions using a combination of the 3D technique x-ray microtomography (μCT) coupled with digital data extraction. With our methods, whole uncut chondrites can be imaged, eliminating any disaggregation bias or need for stereological correction. We demonstrate our methodology using four chondrites of different chemical classes. Our methodology also allows for the direct examination of other phenomena such as chondrule deformation, frequencies of compound chondrules, and the relationship between metal and chondrules in chondrites.

Methods: We use either synchrotron μCT at the GSECARS 13-BMD beamline located at the Advanced Photon Source of the Argonne National Laboratory or the GE phoenix v|tome|x s μCT system at the American Museum of Natural History to image small (~1-2 cm^3) chondrite chips using a resolutions of 5-10 μm/voxel. μCT produces a series of two-dimensional "slices" which, when stacked together, yield a 3D representation of the chondrite. Compositions of different minerals and chondrite components are depicted with varying greyscales and individual chondrules are visually identifiable within a chondrite [5,6].

The difficulty with computationally automating the task of isolating individual chondrules from a CT stack rests in their variable internal textures and the compositional variety among chondrules [4]. Since automatic identification of chondrules borders on difficult to impossible, a workable solution is manual identification of chondrules. To accomplish this task, we use one of two techniques: either the "crowdsourcing" initiative presented in [4] or individual efforts using the ImageJ plug-in TrakEM2 [7]. A combination of TrakEM2 and an interactive Wacom pen input display allows for quick and accurate chondrule marking. A depiction of the resulting digitally isolated chondrules is shown in Figure 1.

We have used the method presented in [4] to isolate chondrules from the Chainpur (LL3.4) and QUE 94594 (EL3) chondrites. Chondrules from the Sharps (H3.4) and Saratov (L4) were isolated using TrakEM2.

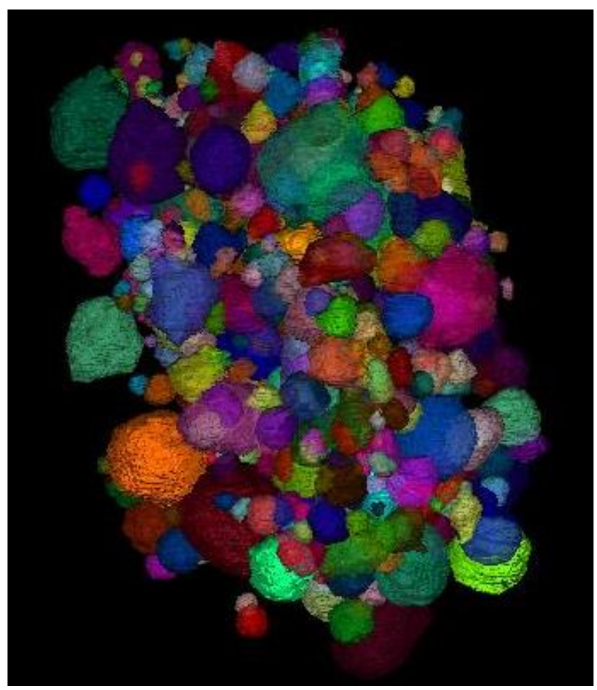
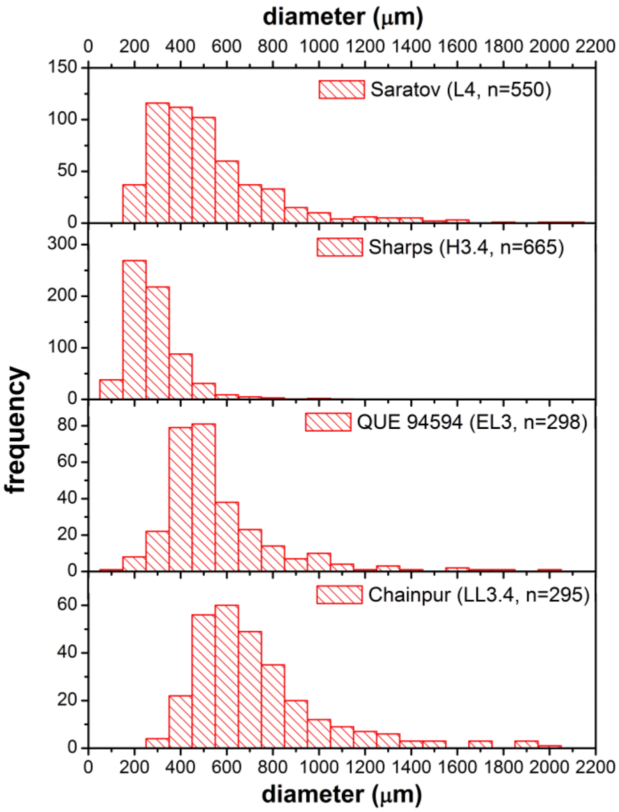


Figure 1. 3D representation of 550 individual digitally isolated chondrules in the Saratov L4 chondrite. The volume of the chondrite investigated comprises ~0.5 cm^3.

Figure 2. Histograms of populations of whole chondrules from four chondrites. Diameters were determined by digital isolation of individual chondrules within a µCT volume. Our methods yield a true 3D-based chondrule size-frequency distribution without the need for 2D → 3D stereological correction.



Results and Discussion: With the individual chondrules digitally marked and their positions registered, we can calculate the volume of each chondrule. We used their volumes to determine the sphere-equivalent diameter of each chondrule and generate a size-frequency distribution. Resulting histograms are shown in Figure 2.

Although in the past, some have assumed that chondrule size frequencies follow either normal, log-normal, Weibull, or other statistical distributions [1], the true statistical distribution function of chondrule size frequencies is unknown [3]. Nevertheless, it can be informative to calculate descriptive statistics for our data assuming simple and familiar normal and log-normal distributions for comparison with previous results [see 1 for a compilation].

We have data for only one specimen of each of the ordinary chondrites and the L chondrite is of higher petrographic type than the H or LL chondrites. Our mean chondrule size does increase as expected [1] with H<L<LL and the EL chondrite has an approximate mean and distribution consistent with previous determinations of EL chondrule properties [1,8,9]. Our histograms also follow trends seen in previous data: the LL chondrite size distribution seems skewed towards larger sizes when compared with the L chondrites.

Table 1. Statistical descriptions of chondrule dimensions in four chondrites.

chondrite	n	distribution, $\overline{x} \pm 1\sigma$ (µm) normal	log-normal
Saratov (L4)	550	520 ± 280	$470\,^{+270}_{-170}$
Sharps (H3.4)	665	280 ± 123	$260\,^{+120}_{-80}$
QUE 94594 (EL3)	298	570 ± 300	$510\,^{+270}_{-180}$
Chainpur (LL3.4)	295	740 ± 330	$690\,^{+310}_{-210}$

Summary and Future Directions: We have successfully used µCT and digital data extraction to digitally isolate chondrules in four chondrite volumes. Our resulting size-frequency distributions do not need complicated 2D → 3D stereological corrections or rely on disaggregation techniques, which can lead to a bias toward larger chondrule sizes. We hope to thoroughly examine chondrule size distributions between and among different chondrite chemical types.

Our unique 3D data also offer opportunities to examine the frequency and types of compound chondrules. To date, binary, ternary, and quaternary compound chondrules have been observed within our datasets. Other phenomena such as chondrule deformation and the relationship between metal and chondrules in chondrites can be readily investigated.

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Acknowledgments: JMF recognizes the Camille and Henry Dreyfus Special Grant Program in the Chemical Sciences and a Theodore Dunham, Jr. Grant of the Fund for Astrophysical Research. Each has provided vital material support. SAG was supported by a Clare Boothe Luce Summer Research Scholarship. KAT was supported by a Fordham University Undergraduate Summer Research Grant.