MEASURING THE BULK DENSITY OF METEORITES AND ROCK SAMPLES NON-DESTRUCTIVELY USING 3D LASER IMAGING. D. L. Smith[1], C. Samson[1], R. Herd[1, 2], I. Christie[3], J-E Sink[3], A. DesLauriers[3] and R. E. Ernst[1, 2] , [1]Department of Earth Sciences, Carleton University, Ottawa, ON, K1S 5B6, Canada, smitdarr@hotmail.com, csamson@ccs.carleton.ca, [2]Geological Survey of Canada, Natural Resources Canada, 601 Booth St., Ottawa, ON, K1A 0E8, Canada, rernst@NRCan.gc.ca, herd@NRCan.gc.ca. [3]Neptec Design Group, 302 Legget Dr. Ottawa, ON, K2K 1Y5, Canada, ichristie@neptec.com, JESink@neptec.com, adeslauriers@neptec.com.

Introduction: A rapidly expanding inventory of meteorite specimens worldwide (mainly from Antarctica and deserts in Asia and Africa) has resulted in a backlog of unclassified samples. Some of these specimens are small and/or fragile, and preservation of all of them is a priority. There has therefore been growing interest in rapid non-destructive characterization of meteorites using petrophysical properties including magnetic susceptibility (MS), anisotropy of magnetic susceptibility (AMS), porosity and bulk density [e.g. 1, 2, 3].

Bulk density is a physical parameter that varies among rock types and can provide insight into the origin of rock material. Current measurement techniques, however, are destructive and suffer from various degrees of inaccuracy and precision. Soaking the sample in a fluid and employing Archimedes' Principle is the most utilized technique, although errors can be introduced by fluid entering the pore spaces and irreversible damage to the specimen can occur. An alternative method uses the displacement of tiny glass beads to imitate the fluid in Archimedes' Principle. Although the technique is non-destructive, it suffers from shaking and compaction of the beads and several other forms of error [4].

We present initial results of a new non-destructive technique for determining the bulk density of meteorites and other solid objects using the Laser Camera System (LCS), an auto-synchronous laser scanner developed by Neptec Design Group of Ottawa, Canada, and demonstrated during Mission STS-105 of space shuttle Discovery [5, 6, 7] [Figure 1]. Eleven chondrites and achondrites which vary in shape, size, surface roughness and reflectance were imaged and their densities computed [Table 1]. Combined with other physical properties, such as MS and AMS, density can characterize each meteorite class and thus provide a robust method of rapid classification. In addition, this approach provides insight into the origin and formation of meteorites, and can be applied to asteroidal studies.

All the meteorites measured are from the National Meteorite Collection of Canada of the Geological Survey of Canada (GSC), Natural Resources Canada.

Methodology: The LCS was mounted on a standing tripod, approximately 1.2 m in front of a pedestal where a meteorite was presented. A raster scan was performed in a systematic 1000x1000 voxel grid pattern until the surface features within the field of view had been imaged. The meteorite was then rotated, without contact, approximately 45 degrees by means of a turntable and a new scan was then performed. This process was repeated six times. Finally, the meteorite was physically reoriented in order to image the top and bottom surfaces. Any sharp edges present were also imaged to ensure complete surface coverage. A total of nine to twelve scans were required to cover the entire surface area of each meteorite. Less were required for smaller meteorites as there is less surface area to image. Minimal handling of the meteorite was required during the imaging process.

The acquired LCS point cloud data (3 spatial coordinates and reflection intensity per voxel) were imported into Polyworks Modeler 3D visualization software developed by InnovMetric [8]. Polyworks was used to assemble the individual images into a detailed 3D closed model whose volume was then automatically calculated [Figures 2, 3]. Polyworks divides the modeled surface into triangles of varying size depending on roughness: the rougher the surface the more triangles present. The mass of the specimen being known, its bulk density can be easily determined, with minimum contact or degradation of the sample, and the images can be stored for future investigations.

Imaging takes approximately 20-30 minutes to complete depending on the size of the meteorite being imaged and the resolution desired. Assembling the images using Polyworks takes approximately 45-60 minutes per meteorite and requires a user with proficient skill and knowledge of the program. Thus within 90 minutes the bulk density of any fragile, soluble or porous object can be determined without contaminating it.

In four cases, two fragments of the same meteorite of different size and shape were imaged in order to determine the precision of the approach as the densities should be the same assuming no veining or heterogeneities between fragments.

Results: Bulk density values of eleven chondrites and achondrites are listed in Table 1. The densities determined using 3D laser imaging compare very well with published data [9]. Deviations between the two data sets are as follows: Allende +3.1 and +4.1 %, Blithfield N/A, Bruderheim +2.7 and +3.5%, Millbillillie -1.3%, Mocs +3.7 and +5.2%, Norton County -3.3% and Pultusk +3.0 and +3.7% (+ is LCS > published, - is LCS < published). The average difference is 3.4%.

Consistency between meteorite pairs of different size and shape is displayed. The density of the Mocs meteorites show the largest standard deviation. This may be attributed to the presence of veins introducing heterogeneities in the samples. Pultusk is a veined breccia. The densities of the two Pultusk specimens, however, are very close suggesting minimal or consistent veining for the two fragments measured.

Meteorite size did not appear to pose a problem during the imaging process nor during density calculations as seen by the high accuracy of the smaller Millbillillie, Norton County and one Mocs meteorites.

Conclusions: The LCS is a very effective tool for determining the bulk density of meteorites of various shapes, sizes and surface characteristics. Applications of the technique could readily be extended to any rock sample identified by the LCS mounted on a roving robot while it is exploring its geological environment. The LCS is also a useful tool for many man-made or natural samples (e.g. archaeological, anthropological, geological, biological) which may need to be documented with minimal handling or processing. 3D laser imaging, especially when used in combination with other techniques such as rock magnetic measurements, is a rapid and non-destructive tool for documenting and classifying both terrestrial and extraterrestrial material.

References: [1] Smith D. L. et al. (2004) *Joint Assembly,* Abstract #1243. [2] Rochette P. et al. (2001) *Quaderni di Geofisica*, 18: 30 p. [3] Pesonen L. J. et al., (1993) *Proc. NIPR Symp. Ant. Met.* 6, 401-416. [4] Wilkison S. L. and Robinson M. S. (2000) LPSC XXXI, Abstract #1939. [5] Samson, C. et al. (2002) *SPIE,* 4714, p.87-96. [6] Samson, C. et. al. (2004) *Can Aero. Space Jour.* 50(2), 115-123. [7] Herd R. et al. (2003) LPSC XXXIV, Abstract #1718. [8] http://www.innovmetric.com [9] Brit D. T. and Consolmagno G. J. (2003) *Met. Planet. Sci.* 38, no. 8, 1161-1180.

Table 1: Bulk densities of meteorites from this study

Meteorite	Class	Mass (g)	Bulk Density (g/cm^3)	Published Densities [9] (g/cm^3)
Allende	CV3.2	754	2.970	2.88±0.05
Allende	CV3.2	492	2.997	2.88±0.05
Blithfield	EL6	625.6	3.927	NA
Bruderheim	L6	277	3.431	3.34±0.04
Bruderheim	L6	123	3.456	3.34±0.04
Millbillillie	EUC	55.98	2.822	2.86
Mocs	L6	29.87	3.297	3.18±0.08
Mocs	L6	151	3.345	3.18±0.08
Norton County	AUB	32.38	2.872	2.97±0.12
Pultusk	H5	276	3.574	3.47±0.05
Pultusk	H5	45.36	3.597	3.47±0.05

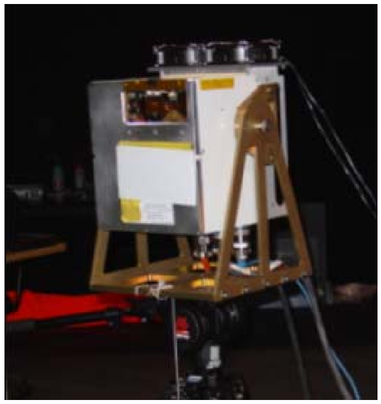

Figure 1
Laser Camera System
($18.8 \times 25.4 \times 27.9\ cm^3$)

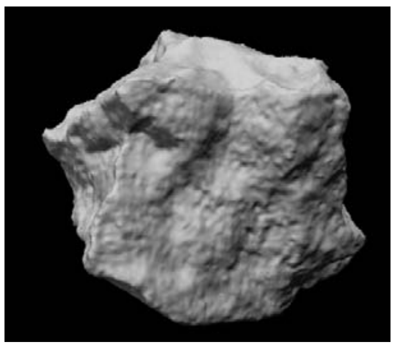

Figure 2
Blithfield: solid smooth model

~ 1cm

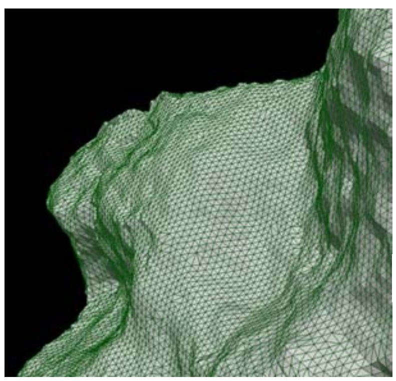

Figure 3
Blithfield: wireframe model (detail)

~ 2mm