APPLICATION OF SYNCHROTRON-BASED X-RAY SCATTERING METHODOLOGIES TO METEORITE RESEARCH AT ADVANCED PHOTON SOURCE

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Introduction: The Structural Sciences (SRS) and Chemistry and Material Science (CMS) groups in the X-ray Science Division (XSD) of the APS operating several different X-ray beamlines. These facilities offer access to a range of important, non-destructive structural characterization techniques, such as High Resolution Power Diffraction (11-BM), Rapid Acquisition Powder Diffraction (17-BM), Pair Distribution Function (11-ID-B) and Small Angle Scattering (12-ID-B, C). The research performed at these beamlines includes (but is not limited to): energy systems and storage, catalysis, nano-scale materials, geologic studies, high-pressure, high-temperature, low temperature, *in situ* and *in operando* measurements. Our scientists and support staff have extensive expertise in non-ambient environments, which translates into real-world applications. In addition, high-throughput sample imaging and data processing capabilities are being developed. Most sample environments can generally be easily interchanged between the beamlines, which allows researchers to study the same sample *via* different techniques. Hence, these beamlines are ideally suited for the studies of meteorites and other planetary science objects under various conditions. During presentation, several applications of the different X-ray scattering techniques and corresponding beamlines will be discussed. For the case study analysis of we have chosen samples of two carbonaceous chondrites: Murchison (CM2) and Allende (CV3.2), and two iron meteorites: Canyon Diablo (IAB) and Bishop Canyon (IVA). All meteorite samples are on loan, courtesy of The Field Museum of Chicago.

Beamlines and Techniques: 11-BM is the high-resolution ($\Delta d/d \sim 1\text{-}2 \times 10^{-4}$) powder diffractometer. It operates with a slightly bent, double bounce Si(111) monochromator (normal operations in the range of 22-30 keV) with a vertical focusing mirror. Furthermore, it uses a bank of 12 point detectors, with Si(111) analyzer crystals, to obtain a low-background, high resolution signal. To date it is one of the highest resolution powder diffraction beamline in the world. Hence, this beamline is perfectly suited for bulk meteoritic sample analysis and will provide information about bulk crystalline mineralogical composition. Normal scan times on this instrument are 1 hour, with a minimum of 10 minutes.

17-BM is a rapid acquisition powder diffraction instrument, equipped with an extensive array of sample environments. This beamline would serve the planetary science community with fast and reliable data collection in various *in situ* processes. For example, it would allow to see the changes in the mineral composition of the sample upon heating or cooling. In fact, the beamline has been used for several years for various *in situ* powder diffraction studies, such as high pressure (diamond anvil cell), high temperature (furnace), low temperature (cryostream), controlled-atmosphere (flow cell), and high throughput (sample changer) measurements. In addition, ability to easily change the beam size (0.5-0.05mm) allows to perform 2D-scanning of the meteorite thin slices, which yield in the building of mineralogical 2D-maps. This is in particularly important for the analysis of the carbonaceous chondrites.

Pair Distribution Function (PDF) analysis has emerged as a versatile tool for materials characterization. It can be applied to a broad range of materials under a wide range of experimental conditions. It provides detailed structural insights into the local atomic arrangement of the sample, with crystallographic resolution, for a variety of materials, including those for which conventional crystallographic analysis fall short. This includes crystalline, nanoscale, amorphous, and disordered systems alike. This technique would provide invaluable insights into structural composition of the glass and amorphous components of meteorite samples. As a dedicated PDF instrument, 11-ID-B provides PDF data of the highest quality and supports a range of non-ambient environments.

12-ID-B,C beamlines are dedicated Small Angle X-ray Scattering (SAXS) beamlines. SAXS is a universal technique applicable to a broad range of particle sizes. With the brilliant synchrotron sources, and novel approaches to reconstruct 3D models, SAXS became a major tool to rapidly and comprehensively characterize nanostructured systems, which can be present inside the meteorites. At same time method yields not just information on the sizes and shapes of particles which can be present in the meteorites, but also on the internal structure of disordered and partially ordered systems.