X-RAY IMAGING WITH PHASE CONTRAST: AN APPROACH TO IN SITU MAPPING OF TEXTURES AND BIOSIGNATURES OF MARTIAN MATERIALS.

Z. W. Hu, XNano Sciences Inc., 8401 Whitesburg Drive # 12852, Huntsville, AL 35802 (zwhu@xnano.org).

Introduction: The highest priority science goal of Mars exploration in the next decade is to address the questions of habitability and the potential origin and evolution of life on Mars in detail through returning appropriate Mars samples to Earth for laboratory study [1-2]. Given the diversity of Mars and a lack of key flight ready instruments for astrobiological exploration, it is important to develop new in situ capabilities to image with high sensitivity the microscopic textures and morphologies of martian materials, and biosignatures (e.g., cellular structures, and sedimentary fabrics) in particular. In this presentation, an approach to in situ identification and selection of high-priority martian materials with X-ray phase contrast imaging will be explored, based on our experience in developing and applying coherence-based X-ray imaging methods to study interplanetary dust particles (IDPs) [3-4], low-density cellular materials [5], and biomacromolecular and oxide materials [6-7] as well as of involvement in Moon and Mars initiative.

Methods and Principles: X-ray phase contrast imaging, unlike the conventional imaging that relies on absorption, makes use of X-ray refraction or the phase shifts of the transmitted X-ray waves, which occur at regions with varying refractive indexes or electron density (like e.g. grain boundaries and interfaces), and translates the structure-induced phase modulations into intensity variations through wave interference. Exploiting phase contrast effects for X-ray imaging opens up a new way to study a wide range of materials or structures, particularly those of low density or light elements and similar density that are often difficult to resolve with absorption contrast alone.

Results and Discussions: With phase contrast imaging, even tiny drops of liquid water with negligible absorption contrast can be clearly visualized thanks to edge enhancement - a strong phase contrast effect taking place at the liquid-water boundary where the gradient of the refractive index is great. Combined with tomographic scans, we have been able to map the spatial distribution of liquid water trapped in ruptured cells of a cellular material in three-dimensional (3D) detail. Such imaging capability can be exploited to in situ examine potential evidence of water and liquid-water inclusions present in martian samples.

We have successfully exploited phase contrast effects to map porous structures in a detailed manner otherwise impossible in materials including IDPs [e.g., 3-4], ultralight foam [5], and carbon based material. In the cases of IDPs, phase contrast tomographic imaging enables open pores and textures as well as organics and minerals to be mapped in unprecedented 3D detail. This has provided a viable nondestructive way to examine, among others, processes IDPs and parent bodies have experienced during their formation and evolution, for example, aqueous alteration in hydrated chondritic smooth IDPs. The high sensitivity to textures, porous structures, and grain morphologies makes the phase imaging approach potentially well suited for in situ identifying signs of potential life on Mars, particularly biosignatures (including cellular structures, fossils, and laminations formed by biofilms) and evidence for liquid water and aqueous environments .

Conclusions: X-ray phase contrast imaging is intrinsically sensitive to microscopic textures and biosignatures of importance to assessing potential life on Mars and its past and present habitability. Developing a lightweight phase imaging instrument would be key to identifying and selecting high-priority materials for analysis. The in situ information to be nondestructively obtained would also serve as a reference for the preliminary assessment of returned samples on their integrity and signs of potential life using nondestructive screening tools such as CMT [8]. The new type of in situ instrument would probably be crucial to success of other sample return missions including cometary and lunar sample return missions. A conceived in situ instrument is modular, enabling multifunctional measurements if needed. This new effort would benefit the future human exploration of Mars by, for example, filling strategic knowledge gaps related to martian soil properties, dust effects, water resources, and human health risk mitigation, and would potentially result in a new generation of in situ CT for medical monitoring in future manned Mars mission.

References: [1] Vision and Voyages for Planetary Science for the Decade 2013-2022, NRC (2012). [2] Mars Science Goals, Objectives, Investigations, and Priorities, MEPAG (2010). [3] Hu Z. W. & Winarski R. (2011) LPS XXXXII, #2662. [4] Hu Z. W. & Winarski R. (2011) 74th Annual Meteoritical Soc. Meeting, #5288. [5] Hu Z. W. & De Carlo F. (2008) Scripta Mater. 59, 1127-1130. [6] Hu Z. W. et al. (2001) Phys. Rev. Lett. 87, 118101 1-4. [7] Hu Z. W. et al (1998) Nature 392, 690-693. [8] Flynn G. J. (2012) Life Detection in Extraterrestrial Samples, #6001.