TESTING THE COSMIC ZOO HYPOTHESIS: HOW FREQUENT IS COMPLEX LIFE IN THE UNIVERSE? W: Bains[1] and D. Schulze-Makuch[2], [1]Department of Earth, Atmospheric and Planetary Science, MIT, 77 Mass. Ave., Cambridge, MA 02139, USA, bains@mit.edu, [2]Center of Astronomy and Astrophysics, Technical University Berlin, Hardenbergstr. 36, 10623 Berlin, Germany, dirksm@astro.physik.tu-berlin.de, dirksm@wsu.edu.

Introduction: Our recent categorization of the evolution of function in the history of life on Earth [1] concluded that complex life should evolve on any world on which life originates, and not be a rare phenomenon [2]. We referred to this as the Cosmic Zoo hypothesis. Here we discuss how the frequency of complex life in the Universe could be tested, given plausible advancements in remote sensing of exoplanets and site visits to planetary bodies in our own Solar System.

Testing with Remote Sensing: Current life detection is aimed at global planetary characteristics, such as the presence of biosignature gases or (possibly) of absorption features such as the vegetation 'red edge'[3]. However none of these distinguish complex from simple life. We argue, however, that complex life discrimination is possible if the spectral features can be spacially mapped. Technologies currently in the early planning stage, such as Starshade [4], provide the possibility to see star and planet as separate dots, and future development of this could allow large-scale mapping of spectral features on the planet. Even though the planet would still appear as a single dot, that dot would change brightness and color as it rotated and orbited its star. If conditions are favorable, this information could be used to get a crude map of the distribution of color on its surface.

However, if we can map an exoplanet, it would be in principle possible to determine the presence of complex life on that planet or moon if for example (1) the planet can be mapped remotely in a way that differences on its surface can be analyzed, (2) land can be distinguished from seas, or (3) a distinctive spectral feature attributed to life on the land can be mapped (and it can be ensured that strangely coloured rocks, dust clouds or other features are not detected instead, by mistake). We anticipate that future technology will make that possible within the next decades.

If we can distinguish land from ocean and the spectral characteristics of land from ocean on an exoplanet, then several potential tests for the presence of complex life become possible. We will discuss these, and the research that can be done in the near future to determine whether they are both possible and discriminatory.

Testing with Site Visits: There is only so much that can be achieved with remote sensing. Ultimately, confirmation that a planet hosts complex life, and indeed confirmation that it holds life at all, must come from close examination of the planet, including sampling its surface. Even that is challenging, as the Viking life detection experiments showed.

However, if we could find life on another body in our own Solar System, we can go there and analyze it. If such life existed, it would be a very strong argument that life on Earth was not an incredibly lucky event, but that life is common. The case of Europa is especially intriguing, because it might be the only place in our Solar System other than Earth to host complex life [5]. However, even with *in situ* sampling, detection of unambiguously complex life is challenging for environments less richly inhabited that Earth. We will discuss the issues with detecting complex life through *in situ* sampling.

The Cosmic Zoo hypothesis argues that complex life will develop readily if the environment is not too limited or transient. For this reason, searching for complex life as well as simple life on Solar System bodies is of pivotal importance, as finding either will place limits both on the abundance of life and place initial bounds on the environmental conditions needed for the development of complexity. We will conclude with a discussion of this, and how future missions can contribute to this agenda.

References: [1] Bains W. and Schulze-Makuch D. (2016) *Life*, 6, doi:10.3390/life6030025. [2] Ward P.. and Brownlee D. (2000) *Rare Earth; Why Complex Life is Uncommon in the Universe*, Copernicus. [3] Seager, S. et al (2005) *Astrobiology* 5, 372-390. [4] Turnbull, M. et al. (2012) *Publ. of the Astronomical Society of the Pacific*, 124, 418–447. [5] Irwin, L.N. and Schulze-Makuch, D. (2003) *Astrobiology*, 3, 813-821.