SWANSONG BIOSPHERES: CAN WE DETECT LIFE ON A PLANET NEARING THE END OF ITS HABITABLE LIFETIME? J. T. O'Malley-James[1], J. S. Greaves[2], C. S. Cockell[3], J. A. Raven[4], [1]Institute for Pale Blue Dots, Astronomy, Cornell University (616A Space Science Building, Cornell University, Ithaca, NY, 14853, jto5@st-andrews.ac.uk), [2]University of St Andrews (School of Physics & Astronomy, St Andrews, Fife, KY16 9SS, UK, jsg5@st-andrews.ac.uk), [3]UK Centre for Astrobiology, University of Edinburgh (School of Physics and Astronomy, University of Edinburgh, Edinburgh, UK, c.s.cockell@ed.ac.uk), [4]The James Hutton Institute, University of Dundee (Division of Plant Sciences, University of Dundee at TJHI, The James Hutton Institute, Invergowrie, Dundee, UK, j.a.raven@dundee.ac.uk).

Introduction: Earth will become uninhabitable within the next 1-3 billion years as a result of the moving boundaries of the habitable zone caused by the increasing luminosity of the Sun [1,2]. During this time, environmental conditions on Earth will become increasingly extreme. Hence, the forms of life that can live on the planet will change. Conditions increasingly favor a unicellular microbial biosphere, until rising temperatures make the planet uninhabitable for even the most extremophilic organisms. These changes to the biosphere change the planet's biosignatures. Therefore, if an older Earth analog was discovered, it would probably exhibit different biosignatures to the present-day Earth. Here we present predictions for these future biosignatures. The results of a latitude-based climate model were used to predict future climates on Earth and the types of life that could live there. This then enabled the expected changes in Earth's remotely detectable biosignatures to be modeled and their detectability assessed.

Stages of Biosphere Death: The increasing luminosity of the Sun as it ages increases mean surface temperatures on Earth. This causes an increase in atmospheric water vapor, leading to an increase in silicate weathering, which draws down CO_2 from the atmosphere. Water vapor is a potent greenhouse gas, hence its presence in the atmosphere raises temperatures further, facilitating increased CO_2 draw-down. Decreasing CO_2 levels result in the gradual decline of plant species [2][3]. Animal species dependent on plant species for food and oxygen become extinct during the same time-frame [1]. This leaves behind a microbial biosphere, which declines until the planet is no longer habitable.

The surface temperature model described in [1] is driven by the Sun's predicted luminosity evolution and incorporates eccentricity and obliquity variations and greenhouse gas fluxes to predict mean surface temperature evolution at different latitudes on the planet. By running this model for 3 Gyr into the future, time-frames were placed on each stage of biosphere decline. Plant and animal species could exist for up to 1 Gyr from present, while a microbial biosphere could persist for up to 2.8 Gyr in some refuges [1].

Detectability: The surface temperature model was also used to predict the size of this future microbial biosphere over time, as illustrated in Fig. 1. This information was then used to drive an atmosphere-biosphere gas exchange model, enabling biosignature predictions to be made. Atmospheric CH_4 produced by anaerobic organisms reached detectable levels in the model, making this a good candidate signature [3].

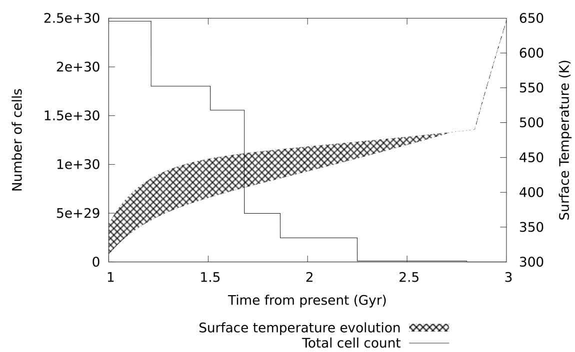

Figure 1. Microbial abundance change with time. The surface temperature range over latitude is illustrated by the shaded curve [3].

Prospects: Testing these predictions is a difficult challenge. The discovery of a planet that is a near analog to the future Earth could provide the means to do so. It could also help to tackle uncertainties about the connection between temperature and silicate weathering rates and the fate of the oceans. However, analogs of the future Earth could be rare; planet formation studies suggest only 10^3 exist within the galaxy, lowering the chances of finding one close enough to Earth to characterize its atmosphere [4].

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