The Maximum Growth Rate for Life on Earth. R. Corkrey[1], T. A. McMeekin[1], J. P. Bowman[1], J. Olley[1], D. Ratkowsky[1], C. Macdonald[1], T. Ross[1],
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Introduction: Life on Earth exhibits growth rates that are temperature-dependent. While it is well known that growth rates of individual strains and species are temperature-dependent, we have recently shown that the statistical distribution of specific growth rates of microbes and multicellular organisms from all three domains of life are also a function of temperature [1]. We term this distribution of growth rates the Biokinetic Spectrum for Temperature (BKST). From this, we have concluded that the maximum rate of growth of all life when grown under optimal conditions forms a distinct limit that varies predictably and continuously with temperature [2].

Methods: We collated a total of 10956 growth rates from peer-reviewed papers representing 1627 species and strains from Archaea, Bacteria and Eukarya. We described the BKST using Bayesian quantile regression to obtain quantile curves of growth by temperature. We then developed a method to extrapolate the quantile curves to obtain the predicted maximum rate of growth versus temperature for any life on Earth.

Results: The BKST was first described by us [1]. The most striking feature of the BKST was the triangular distribution manifested by the set of points representing the highest growth rate at each temperature, below which are strains growing at varying, but slower, rates (Fig. 1). We find that the predicted maximum growth rate occurs at 45.8ºC with an estimated minimum generation time of 5.16 minutes [2]. At slightly higher temperatures growth rates are attenuated. We previously termed this the mesophile-thermophile gap [1] and it remains unexplained. We estimate that minimum of the gap occurs at around 56ºC [2]. The maximum predicted rate curve conforms to the observed data except below 0ºC and at high temperatures (above about 100ºC). Outside these limits the predicted rate curve is higher than the observed data. We also describe interactive effects on the BKST due to water activity and pH.

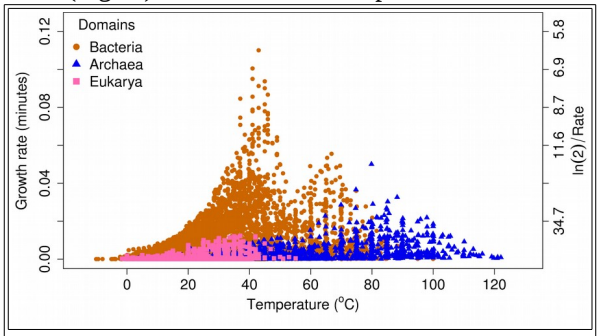

Figure 1: Specific growth rate versus temperature by domain.

Discussion: The BKST possibly arises from a trade-off between activity and stability of enzymes involved in a rate-limiting Master Reaction within the cell [1]. This accounts for the larger portion of the BKST. The deviation of the predicted maximum rate curve below 0ºC may arise from changing bulk properties of water, such as diffusion and water activity. At high temperatures the deviation may be due to an increasing degree of denaturation and degradation of biomolecules.

The BKST has potential application in astrobiology by providing an estimate of the maximum possible growth rate attainable by terrestrial life and perhaps life elsewhere. The area under the maximum growth rate curve and the peak rate can serve a complementary role to cardinal temperatures (e.g. T_{min} and T_{max}) when considering habitability. Rates occurring in the heavy green shaded region of Fig. 2 have not been observed on Earth, whereas observations in the orange checked area are feasible though unlikely. This approach provides a diagnostic for unusual life, such as second biogenesis or non-terrestrial life, and which does not require knowledge of the biochemistry of the life involved.

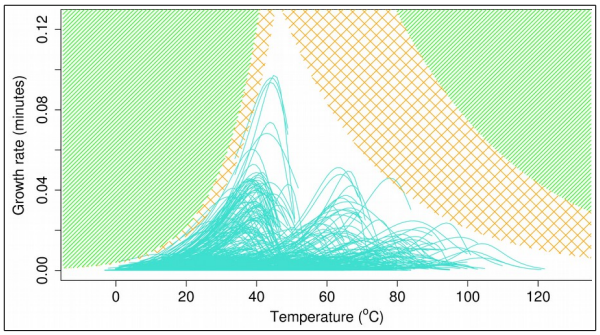

Figure 2: The upper 99% credible band for the predicted maximum growth rate curve is shown with hatching and higher rates with heavy green shading. Also shown are estimated growth curves for individual strains.

References: [1] Corkrey, R. et al. *The Biokinetic Spectrum for Temperature*, PLOS ONE 11 : e0153343. [2] Corkrey, R. et al. (In press). *The maximum growth rate of life on Earth*, International Journal of Astrobiology.