Evolution in the Extremes

How lichens evolutionary history and environmental context can inform astrobiological habitability

Murray Purkis

University of St Andrews

Background

Lichen have been found to survive in the most extreme regions of earth, but also to enter extreme hibernate, allowing for survival in space. Studying the evolution of the traits which allow them to do this, can help us to understand both life in extreme environments on earth, but also to further our knowledge of what regions could be considered habitable, and how we could detect life in these conditions.

This project examines whether these survival adaptations primarily arise from genetic history or local environmental pressures. In turn, this can inform our understanding of how life might adapt to extreme environments on other planets.

Methodology

I chose to study the genus '*Rhizocarpon*', which is distributed worldwide, and some of whose members have been found to survive in space-like conditions. For each species, I examined the following traits in relation to phylogeny and environment.

Secondary Acids – these produce chemical defences against UV and other environmental stresses. (Rhizocarpic, Psoromic, Stictic, Norstictic acids)

Water retention traits – adaptations which allow the lichen to survive without water for large amounts of time, allowing for dormancy of the lichen until rehydrated. (Kl Medulla test, Thalli thickness, Areola Thickness)

Pigmentation – Pigments present in the lichen filter for the types of energy absorbed, blocking dangerous radiation bands. They can also be used for remote sensing, on Earth or from space. (Thalli colour, Spore colour, P, C, K, KC tests)

Environment – Average latitude, elevation and UV index were found to test the influence of local environmental factors.

After doing this, I conducted multiple statistical analyses on these traits, including:

- Constructed a phylogenetic tree for Rhizocarpon species, using Bayesian inference to test which traits are phylogenetically conserved.
- Mann-Whitney U tests between all physiological/ chemical traits and environment data, with the distributions visualised by box and whisker plots.
- Mann-Whitney U tests between all physiological/ chemical traits, to test co-occurrence rates.
- Astrobiological modelling of lichen using Martian historical conditions to test the possibility of lithopanspermia (the theory that life on Earth was fertilised initially by comets from space).

Results

Phylogenetic

I found that we have one significant phylogenetic trait in the Kl Medulla spot test **(p=0.011)**, and we are approaching significance for the p test **(p=0.06).**

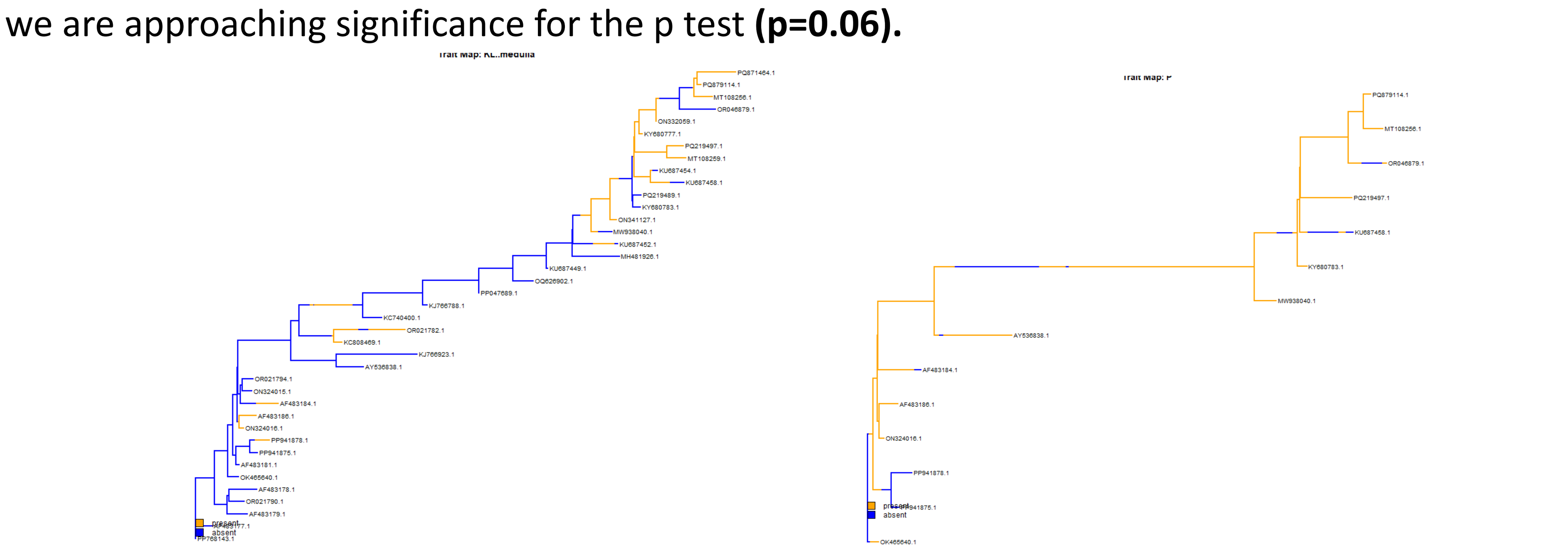

Figure 1, this shows the traits Kl Medulla, and P test mapped onto the phylogenetic tree constructed through RevBayes. For both we can visually see certain traits to appear down individual clades, and the Kl Medulla is significant for this.

Environmental

Both Rhizocarpic acid and Psoromic acid are significantly related to elevation **(p = 0.027, 0.014)**, while latitude appears to correlate with thallus colour and is significantly correlated with spore colour **(p =0.0495).**

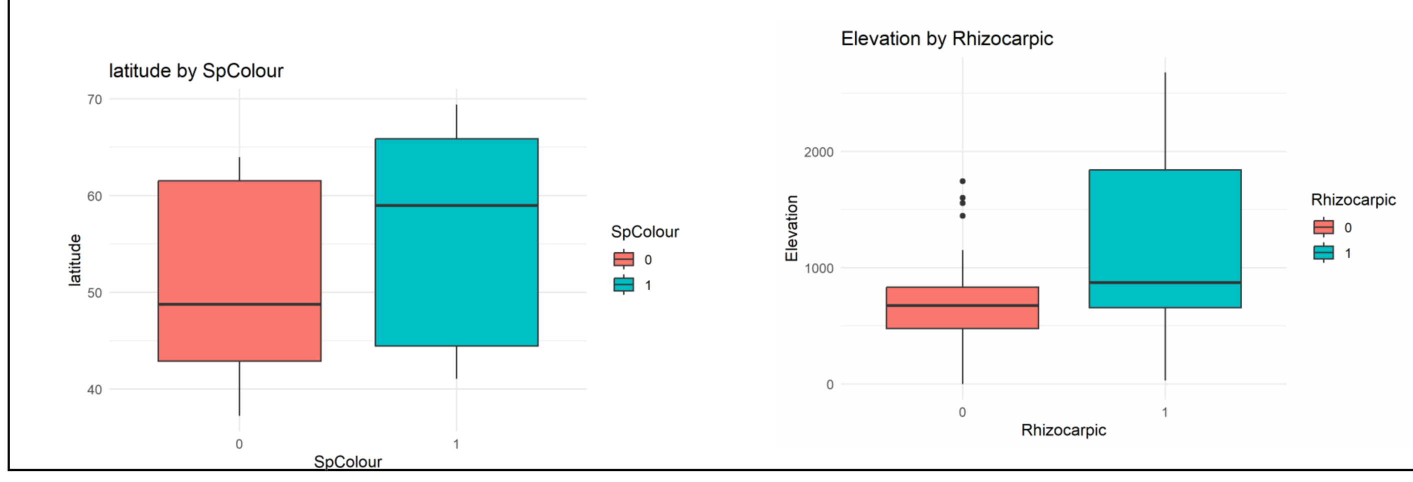

Figure 2, box and whisker plots showing the latitude of lichen against their spore colour, and the elevation vs the presence of Rhizocarpic acid

Co-occurrence

Several traits show significant correlations:

Secondary acids tend to occur in pairs rhizocarpic with psoromic, and norstictic with stictic.

The **Kl medulla test** is positively associated with both rhizocarpic and psoromic acids.

Thallus colour also correlates: species with rhizocarpic/psoromic are generally lighter, while those with norstictic are darker.

Significance Matrix (p-values < 0.05 highlighted)

	Rhizocarpic	Psoromic	Stictic	Norstictic	ThColour	KL	SpColour
Rhizocarpic		5.81E-07	6.78E-01	6.28E-01	2.44E-02	1.16E-02	2.79E-01
Psoromic	5.81E-07		4.39E-02	6.06E-02	7.54E-04	3.46E-02	9.41E-01
Stictic	6.78E-01	4.39E-02		2.13E-03	3.73E-01	1.00E+00	6.59E-01
Norstictic	6.28E-01	6.06E-02	2.13E-03		1.50E-02	1.68E-01	1.28E-01
ThColour	2.44E-02	7.54E-04	3.73E-01	1.50E-02		5.17E-01	1.50E-01
KL	1.16E-02	3.46E-02	1.00E+00	1.68E-01	5.17E-01		1.61E-01
SpColour	2.79E-01	9.41E-01	6.59E-01	1.28E-01	1.50E-01	1.61E-01	

Figure 3: A table of the p-value results from Mann-Whitney U tests between traits

Astrobiological

By running ROCKE-3D tests against the lichen's habitability information, and environmental adaptation data that we found, I can simulate what relative conditions we could expect it to be able to survive in, and to be able to completely hibernate its metabolic processes. Running this against historical Martian conditions I found that there were likely brief temporal and spatial windows for habitability of earth-like lichen, which supports a potential mechanism for lithopanspermia.

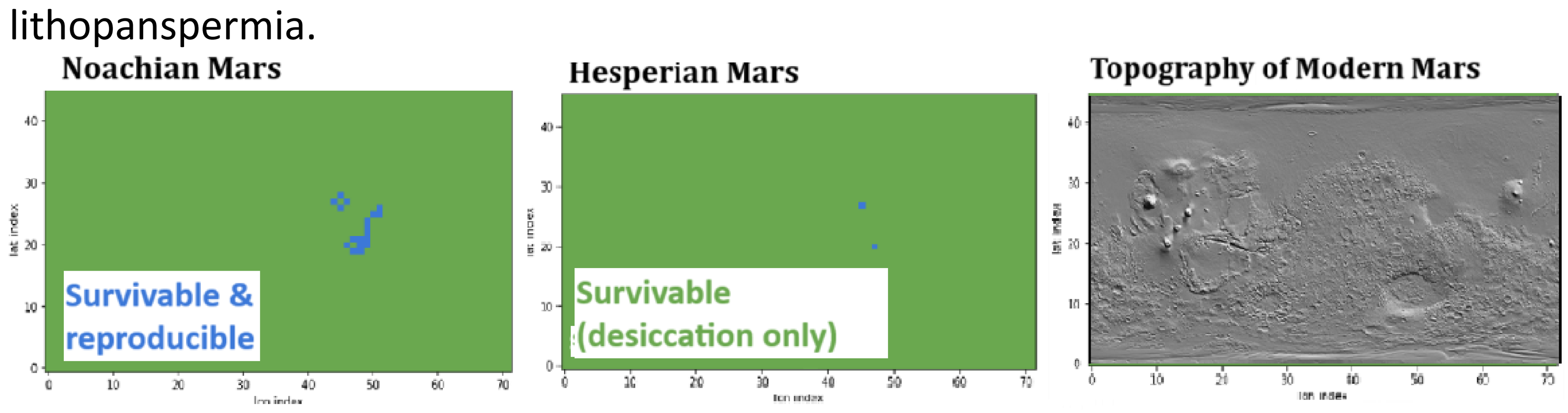

Figure 4, a model of historical Mars and regions which could hypothetically support lichen.

Acknowledgments

I would like to thank Lord Laidlaw and the Laidlaw foundation for this wonderful opportunity, and my wonderful supervisor Dr Carolin Kosiol for being so incredibly supportive.

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Discussion

In conclusion Rhizocarpon possess some of their survival traits due to phylogenetic evolution such as with water desiccation, while some such as pigmentation and UV resistance exist in part due to adaptation to localised conditions. Rhizocarpon also utilise various chemical and physiological traits simultaneously to allow for survival in extreme environments. By feeding this information through to astrophysical software we can improve our understanding of how life can survive in extreme conditions, and also further test the origins of life on earth.