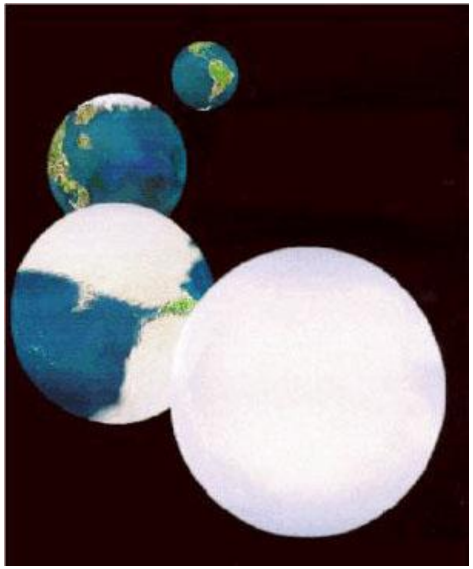
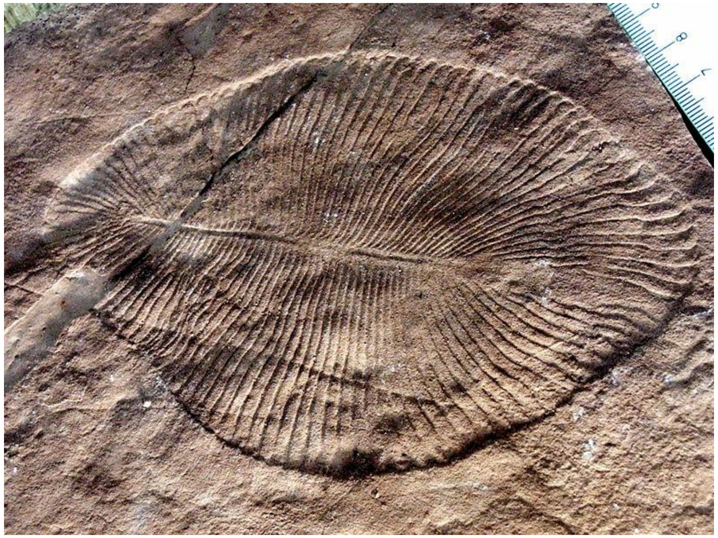
Snowball Earth, kin selection and the origin of animals





Richard Boyle
Postdoc, Earth system modelling group
LGMAC, UEA.
r.boyle@uea.ac.uk

Neoproterozoic geological record (1)Glaciers

Deposits derived from glacial action.

Two, arguably three distinct intervals

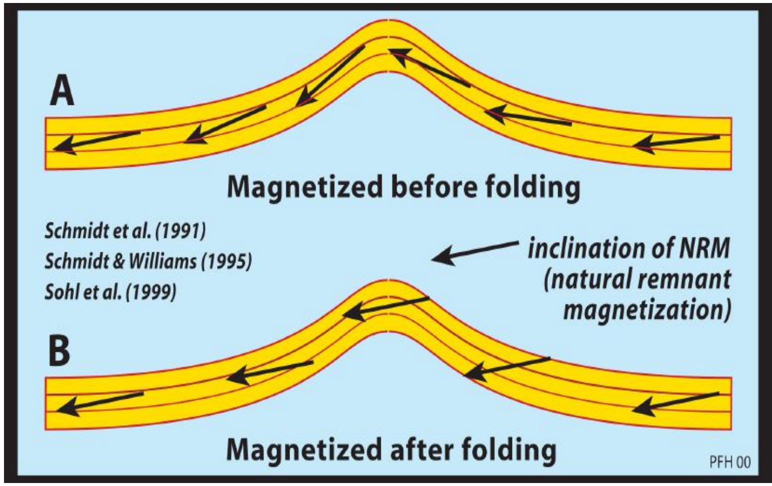
– (740-647 Ma, 660-635 Ma, and (arguably 580 Ma).

Primary equatorial remnant magnetism

Electron orientation relative to magnetic north retained in Fe atoms, (until extreme heating).

Plane of electron orientation folds with plane of deposited rock – remnant magnetism primary, not artefactual.

Angle of orientation implies an equatorial latitude at deposition for the (!)glacial rock.



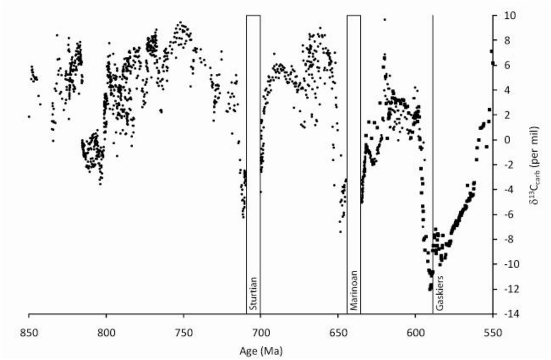
Neoproterozoic geological record

(2) Incompletely oxidised Iron rich marine sediments.

(Hoffman & Schrag, 2002)

(3) Inorganic carbon cycle

-Isotopic excursions (Hoffman et al, 1998)
-Loss of steady state inorganic carbon (Rothman, 1999)
-Massive carbonate deposition (Hoffman et al , 1998)



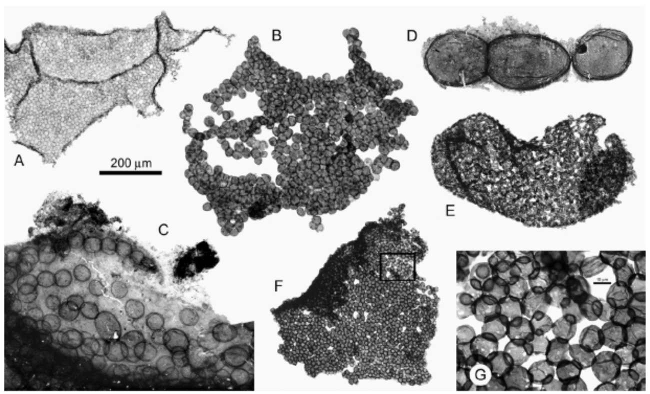
(4) Other geochemistry

-**Strontium isotopes invoke terrestrial runoff spike (Halverson, 2007)**
- Sulphur 34 invokes ocean anoxia (Canfield, 1998)
-**Oxygen 18 invokes cold temperatures (Zheng, 2004)**
- **Boron 11 invokes accumulation of ‘space dust’ on surface (Kaseman, 2005)**

Neoproterozoic geological record

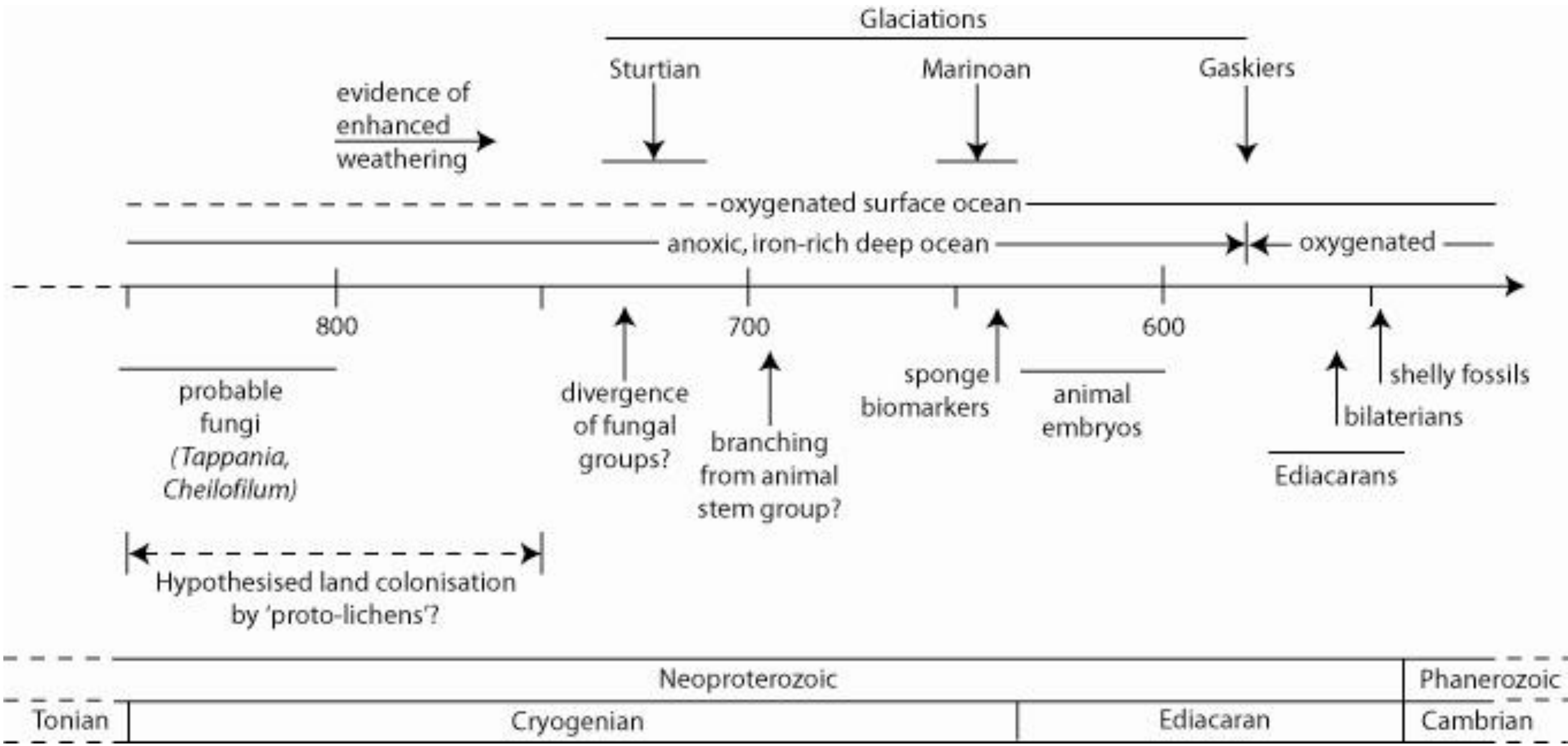
(5) First heterotrophic macrobiota with organ-grade differentiation, probably including direct ancestors of Cambrian Eumetazoa.

(First "animals"). In immediate aftermath of glaciation….



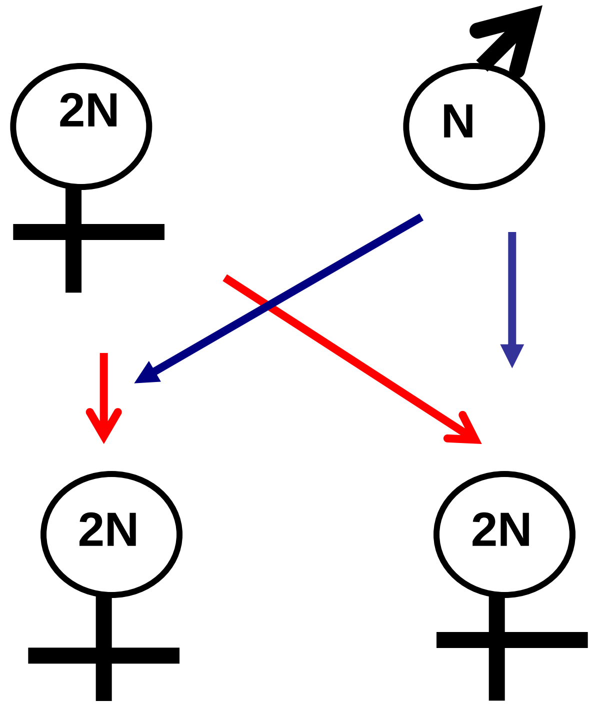
-Epithelial differentiation by 635Ma
- Bilateral symetry and mobility by 560 Ma
-Biomineralisation and predation by 545 Ma

“Testing the limits of global change” (Hoffman & Schrag, 2002)



Altruism

" I will confine myself to one special difficulty, that at first appeared insuperable, and actually fatal to my theory. I allude to the neuters or sterile females in insect communities…." Charles Darwin, 1859.



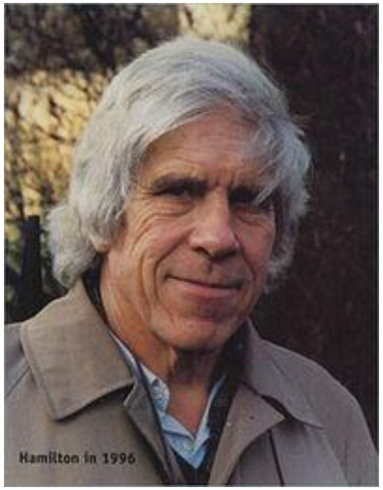
Parent-Offspring relatedness Equals 0.5

Parent-Offspring relatedness equals 1.0

Worker females related to one another by ¾, but to their own potential offspring by only ½ . RELATEDNESS AND COOPERATION CORRELATE.

Kin selection

A gene causes a property disadvantageous to the (“altruist”) organism with the gene, but beneficial to another (“recipient”) organism. The gene becomes more frequent when it causes benefit to a copy of itself residing in another organism.



W.D. Hamilton FRS
1936-2000

R*B>C

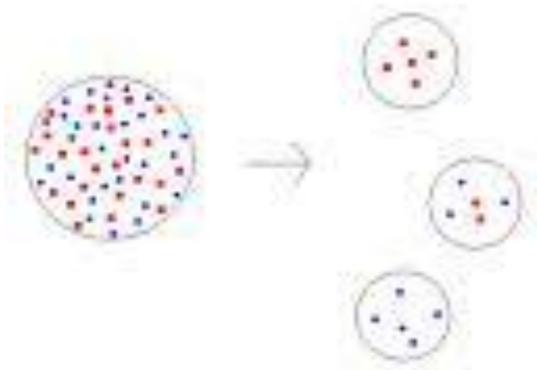
Altruist to recipient relatedness=R
Benefit to recipient =B
Cost to altruist =C

“Neoproterozoic “Snowball Earth” glaciations and the evolution of altruism”

Boyle, R.A., Lenton, T.M. & Williams, H.T.P. 2007. Geobiology 10.1111/j.1472-4669

You can’t take a cutting from an animal….

Freeze thaw cycles, population crashes/isolation events, repeated over millenial timescales.



FOUNDER EFFECTS**

HIGH LOCAL RELATEDNESS

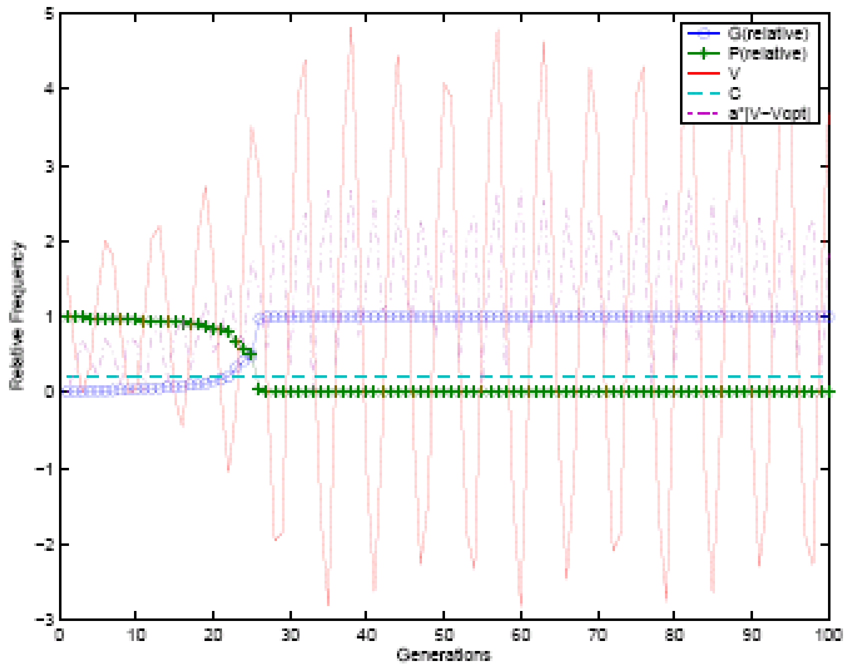
STRONG KIN SELECTION FOR ALTRUISM OF UNPRECENTED DURATION

$$\prod_{t=1}^{t_{crit}} \frac{1}{2}\left(1 + \frac{\int_0^t \frac{\partial E}{\partial t}\left(\frac{\partial}{\partial E}(rb - c)\right)\partial t}{\left|\int_0^t \frac{\partial E}{\partial t}\left(\frac{\partial}{\partial E}(rb - c)\right)\partial t\right|}\right) > 0$$

Cohen, D. & Eshel, I., 1975 Theoretical Population Biology 10(3). 1976.

LOW PRODUCTIVITY
EXTREME ENVIRONMENTAL
FLUCTUATION

GROUP VIABILITY SELECTION
FOR PHYSIOLOGICAL BUFFERING



Boyle, R.A. & Lenton, T.M. 2006. “Fluctuation in the physical environment as a Mechanism for reinforcing evolutionary transitions” JTB 242, 832-843.

$$\alpha \cdot \left|V - V_{opt}\right| > C$$

Illustrative model:
- 101 GROUPS, EACH WITH TWO NEIGHBOURS
- LOCAL FITNESS OF ALL PROPORTIONAL TO ALTRUIST FREQUENCY, ALTRUISTS REQUIRED FOR GROUP SURVIVAL
- DIFFUSSIVE MIXING BETWEEN GROUPS

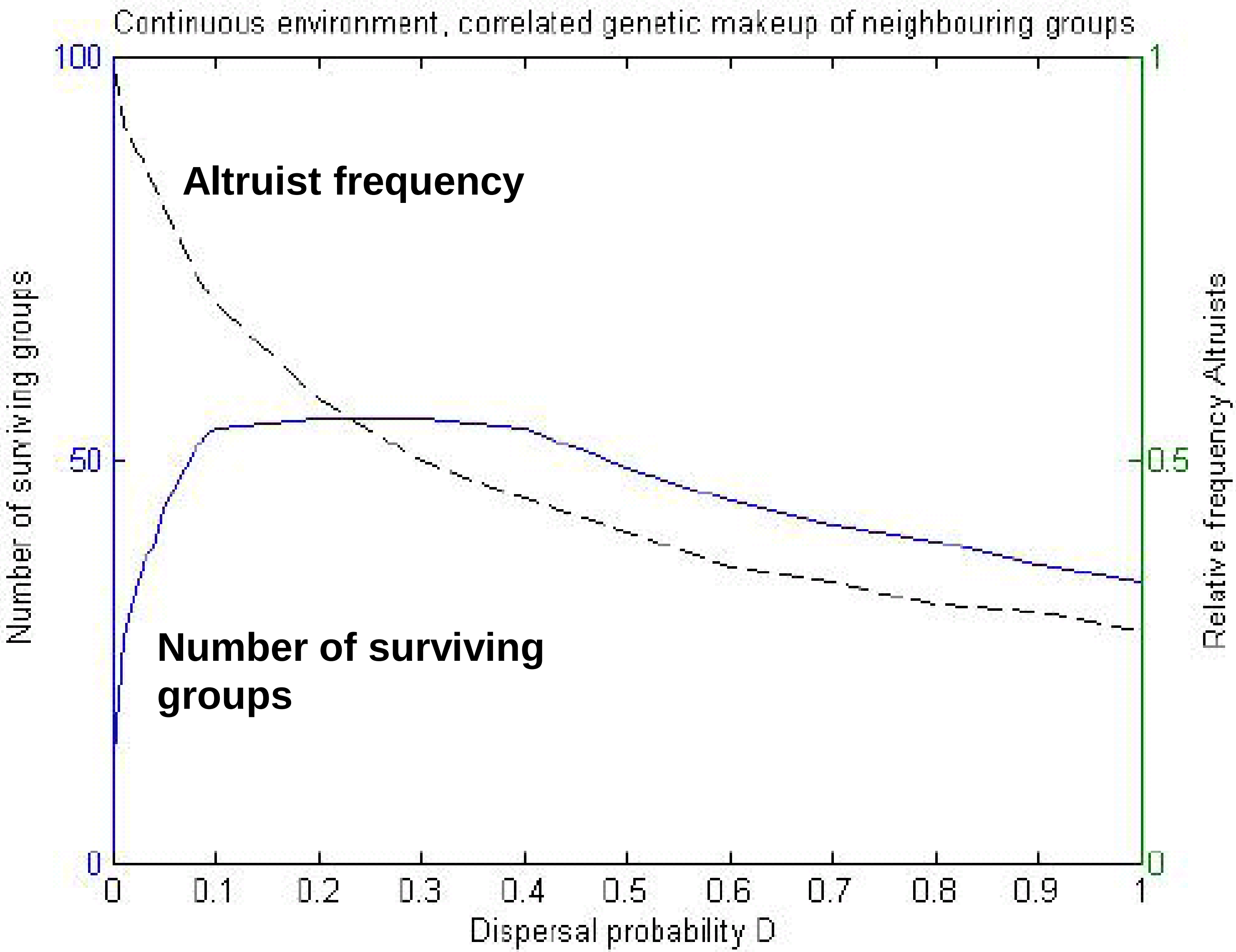
$$F_A = (\frac{N_A}{N_A + N_S})b - c$$

$$F_S = (\frac{N_A}{N_A + N_S})b$$

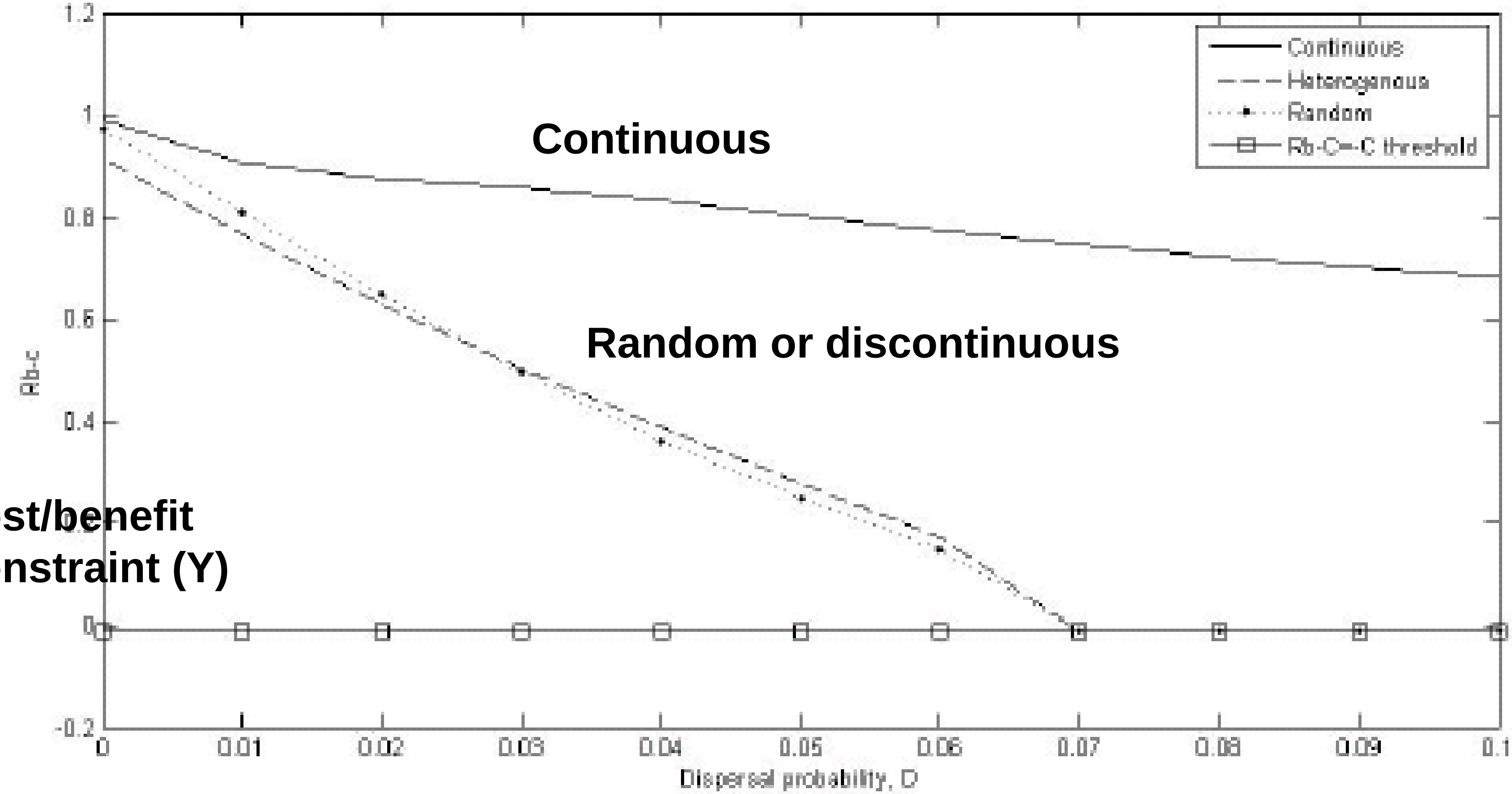
$$N_{A_{t,G}} = [(\frac{N_{A_{t-1,G}}}{N_{A_{t-1,G}} + N_{S_{t-1,G}}})b - c] \cdot [N_{A_{t-1,G}} + D \cdot (N_{A_{t-1,G+1}} + N_{A_{t-1,G-1}})]$$

$$N_{S_{t,G}} = [(\frac{N_{A_{t-1,G}}}{N_{A_{t-1,G}} + N_{S_{t-1,G}}})b] \cdot [N_{S_{t-1,G}} + D \cdot (N_{S_{t-1,G+1}} + N_{S_{t-1,G-1}})]$$

LOWER INTER-GROUP DISPERSAL FAVOURS ALTRUISM



FREQUENCY INITIALISATIONS INVOLVING LOCAL DISCONTINUITIES FAVOUR CHEATERS, CONTINUOUS CHANGE IN INITIAL FREQUENCIES FAVOUR ALTRUISTS…



Continuous

Random or discontinuous

Cost/benefit Constraint (Y)

Dispersal (X)

Proposition: Snowball Earth directly triggered the evolution of animals

1) **High relatedness = strong kin selection = release of altruism constraint on germline-soma terminal differentiation.**

2) **Group level differentiated physiology, including organ-grade form, was better disposed to tolerate extreme environments.**

3) **Discontinuous initial frequencies, in conjunction with low dispersal and group viability selection, favour altruism globally.**

Future higher resolution agent-based modelling of this hypothesis…..

Corollary (?):
Laws of form are constant. But when a type of form has short term low fitness, a special environment must drive its initial emergence….

$$\frac{\partial}{\partial t}(rb - c) = \frac{\partial}{\partial E}(rb - c)\frac{\partial E}{\partial t}$$

To find "complex" life elsewhere, we must find planets with evidence of an equally "complex", probably stepwise, climatic history.

Acknowledgements

Tim Lenton
Hywel Williams
Andy Watson
Nick Butterfield

The Leverhulme Trust