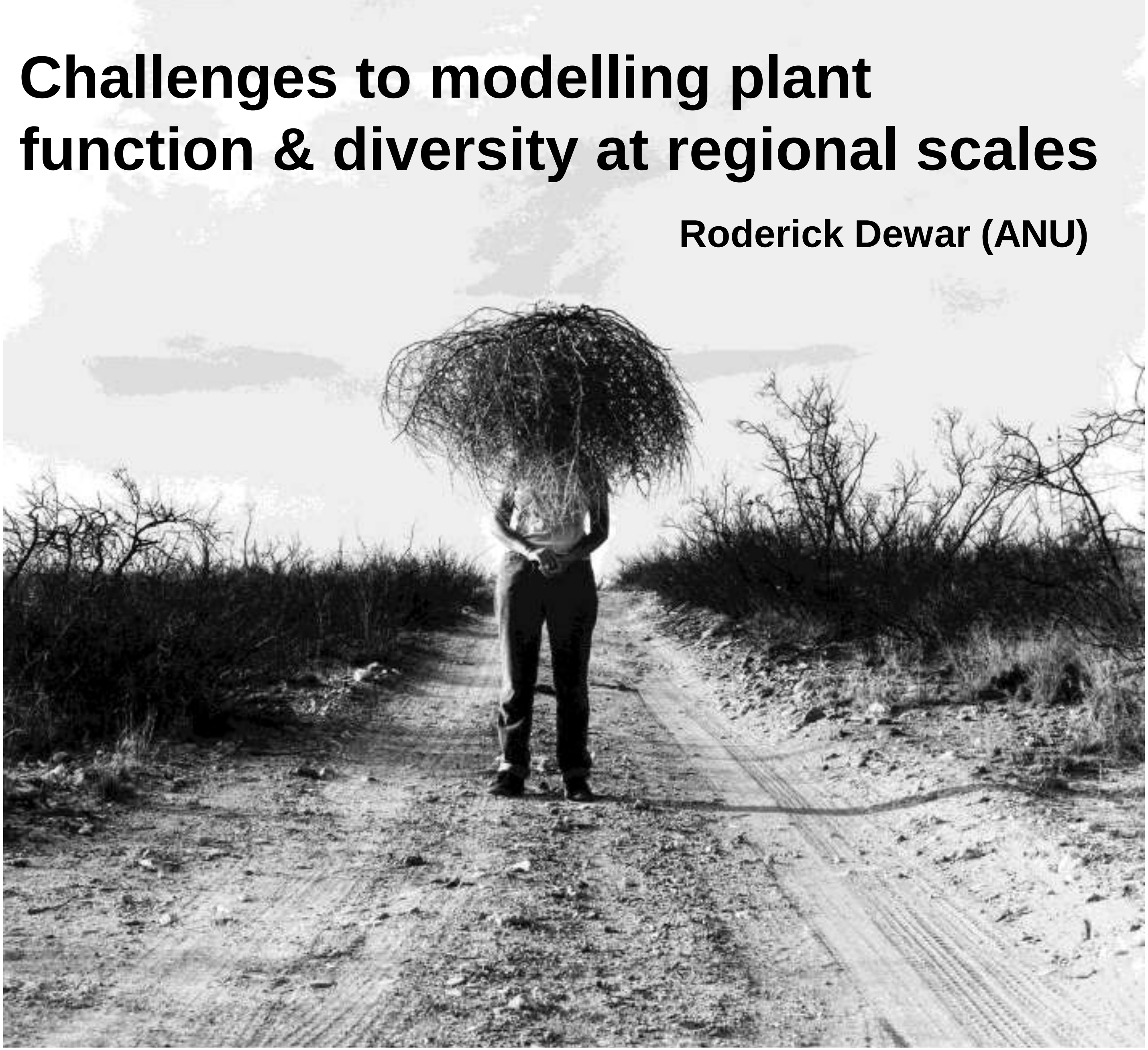
Challenges to modelling plant function & diversity at regional scales

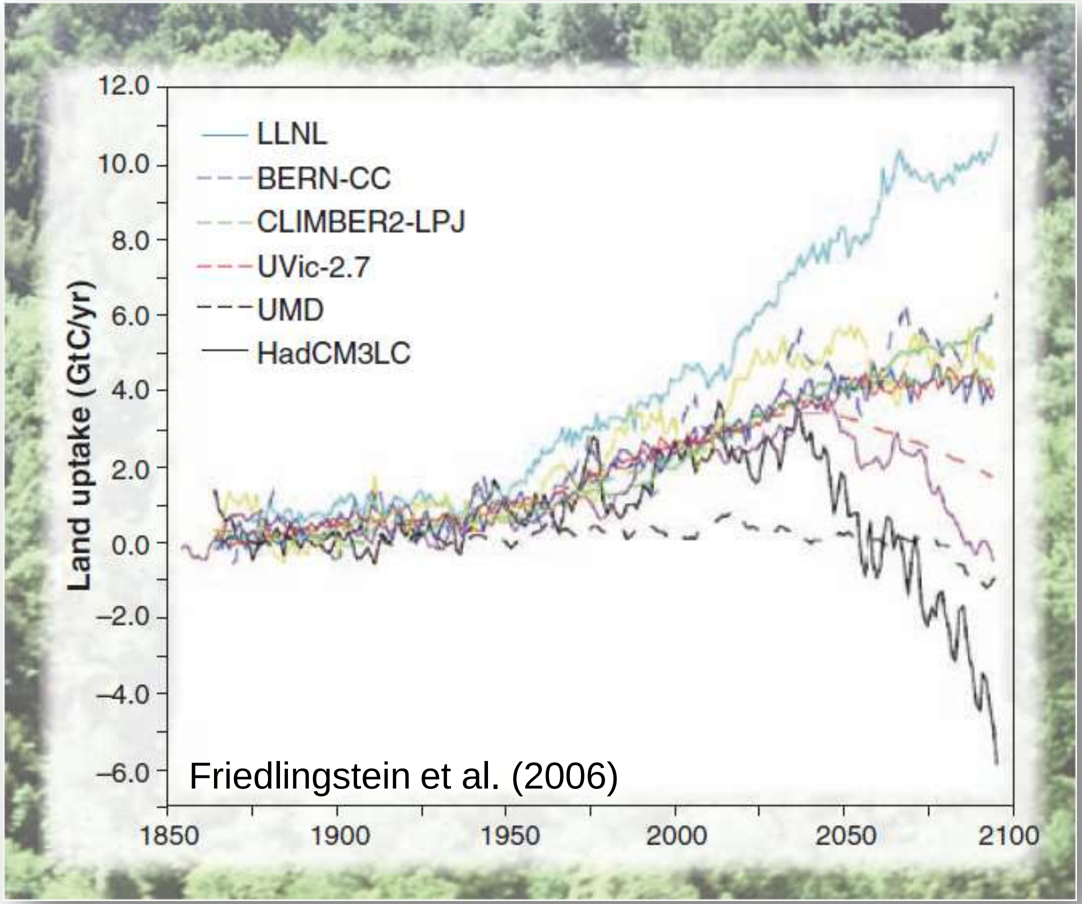
Roderick Dewar (ANU)



Simryn Gill

Water and carbon coupling at regional scales
CSIRO Canberra, 25-26 June 2012

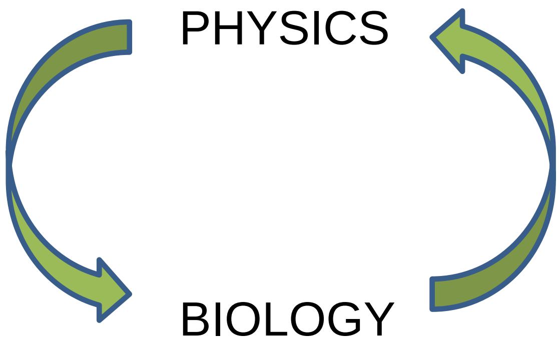
Projected global land C uptake



- different model structures
- empirical sub-models
- many tunable parameters

The challenge

Water-carbon coupling at regional scales ….



turbulent transport
climatology

plant adaptations
species changes

…. is there a unifying viewpoint?

plants, ecosystems, turbulent fluids, climate
=
complex, open, non-equilibrium systems

low-entropy
energy &
matter in

high-entropy
energy &
matter out

complex = many internal degrees of freedom

open = exchange energy & matter with their surroundings

non-equilibrium = dissipate free energy (produce entropy) maximum entropy

Research paper: Part of a special issue on canopy processes in a changing climate Tree Physiol. 31: 1007-1023 (2011)

Leaf-trait variation explained by the hypothesis that plants maximize their canopy carbon export over the lifespan of leaves

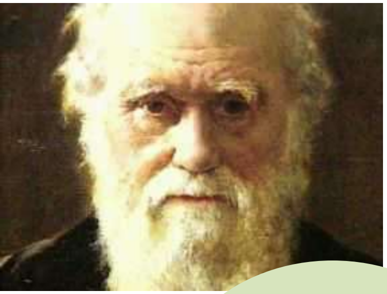
Ross E. McMurtrie[1,3] and Roderick C. Dewar[2]

plant optimization models

Research paper Tree Physiol. 32: 520-534 (2012)

Why does leaf nitrogen decline within tree canopies less rapidly than light? An explanation from optimization subject to a lower bound on leaf mass per area

Roderick C. Dewar[1,4], Lasse Tarvainen[2], Kathryn Parker[1], Göran Wallin[2] and Ross E. McMurtrie[3]



Ecology and Evolution 2: 1235-1250 (2012)

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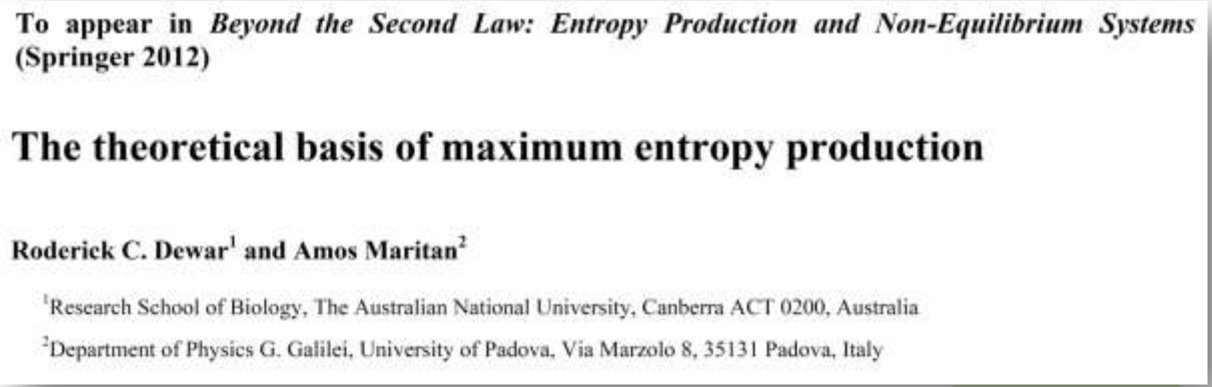
Plant root distributions and nitrogen uptake predicted by a hypothesis of optimal root foraging

Ross E. McMurtrie[1], Colleen M. Iversen[2], Roderick C. Dewar[3], Belinda E. Medlyn[4], Torgny Näsholm[5], David A. Pepper[1] & Richard J. Norby[2]

maximum fitness



To appear in *Beyond the Second Law: Entropy Production and Non-Equilibrium Systems* (Springer 2012)

The theoretical basis of maximum entropy production

Roderick C. Dewar[1] and Amos Maritan[2]

[1]Research School of Biology, The Australian National University, Canberra ACT 0200, Australia

[2]Department of Physics G. Galilei, University of Padova, Via Marzolo 8, 35131 Padova, Italy

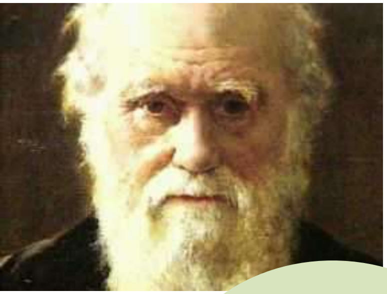
maximum entropy

maximum entropy production

PHYSICS

BIOLOGY

plant optimization models



maximum fitness

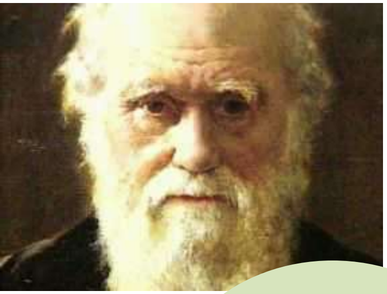
maximum entropy

PHYSICS

maximum entropy production

BIOLOGY

plant optimization models



maximum fitness

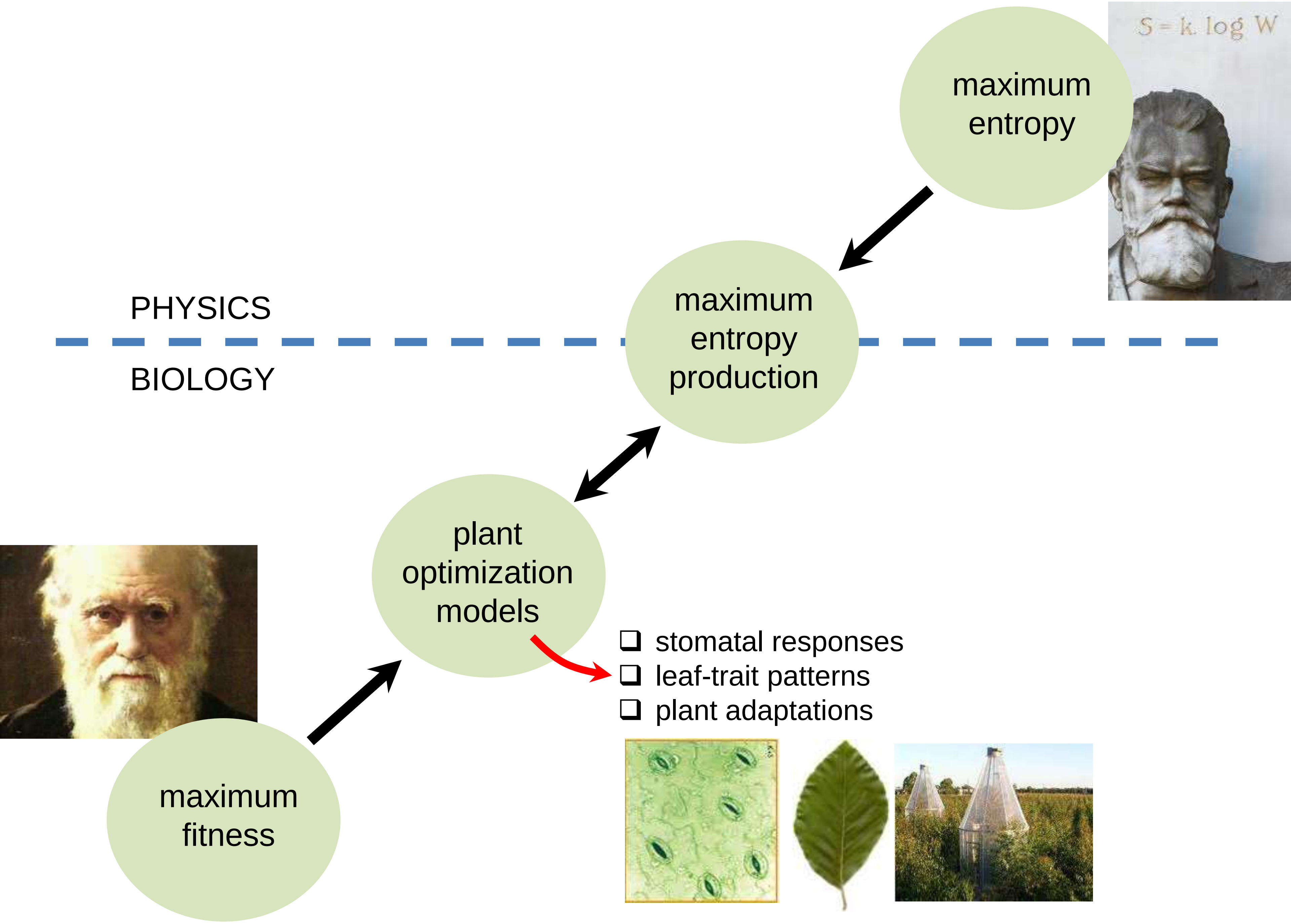
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

Phil. Trans. R. Soc. B (2010) **365**, 1429–1435
doi:10.1098/rstb.2009.0293

Maximum entropy production and plant optimization theories

Roderick C. Dewar*

Division of Plant Sciences, Research School of Biology, The Australian National University, Canberra ACT 0200, Australia


S = k. log W
maximum entropy
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maximum entropy production
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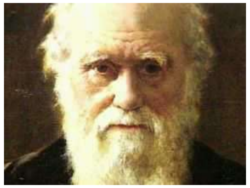
plant optimization models
❑ stomatal responses
❑ leaf-trait patterns
❑ plant adaptations
maximum fitness

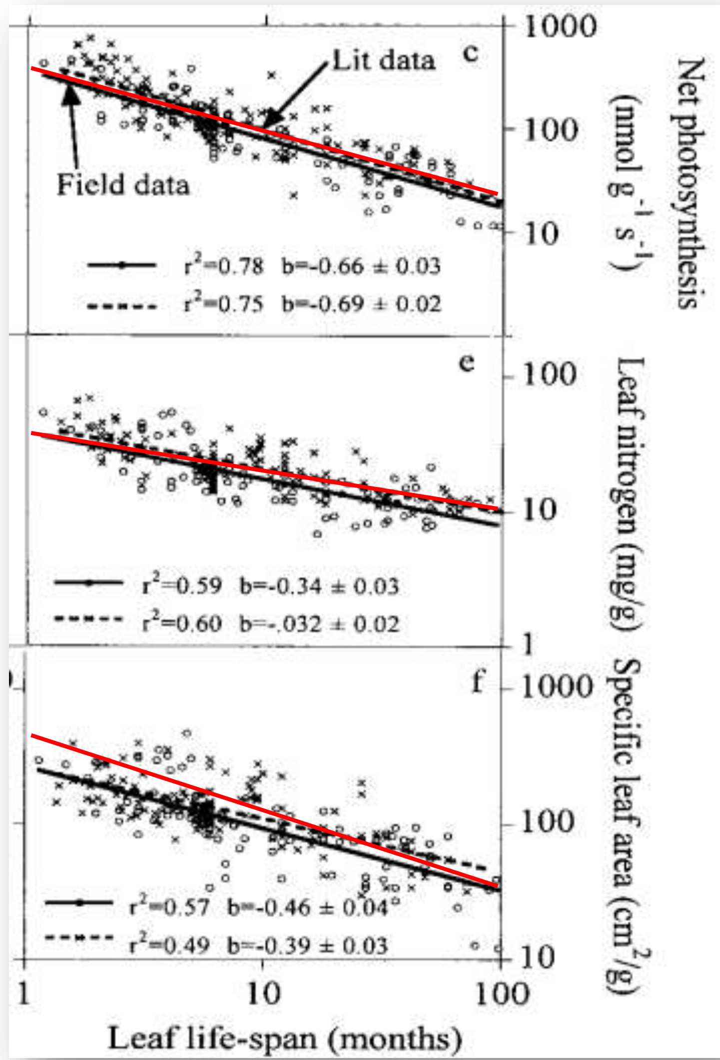


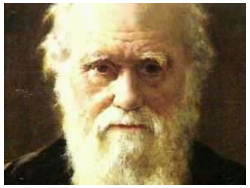
McMurtrie RE & Dewar RC (2011) Leaf-trait variation explained by the hypothesis that plants maximize their canopy carbon export over the lifespan of leaves.
Tree Physiology 31: 1007-1023

Plant optimization explains the global spectrum of leaf economics ….

Model:

Data: Reich et al. (1997)



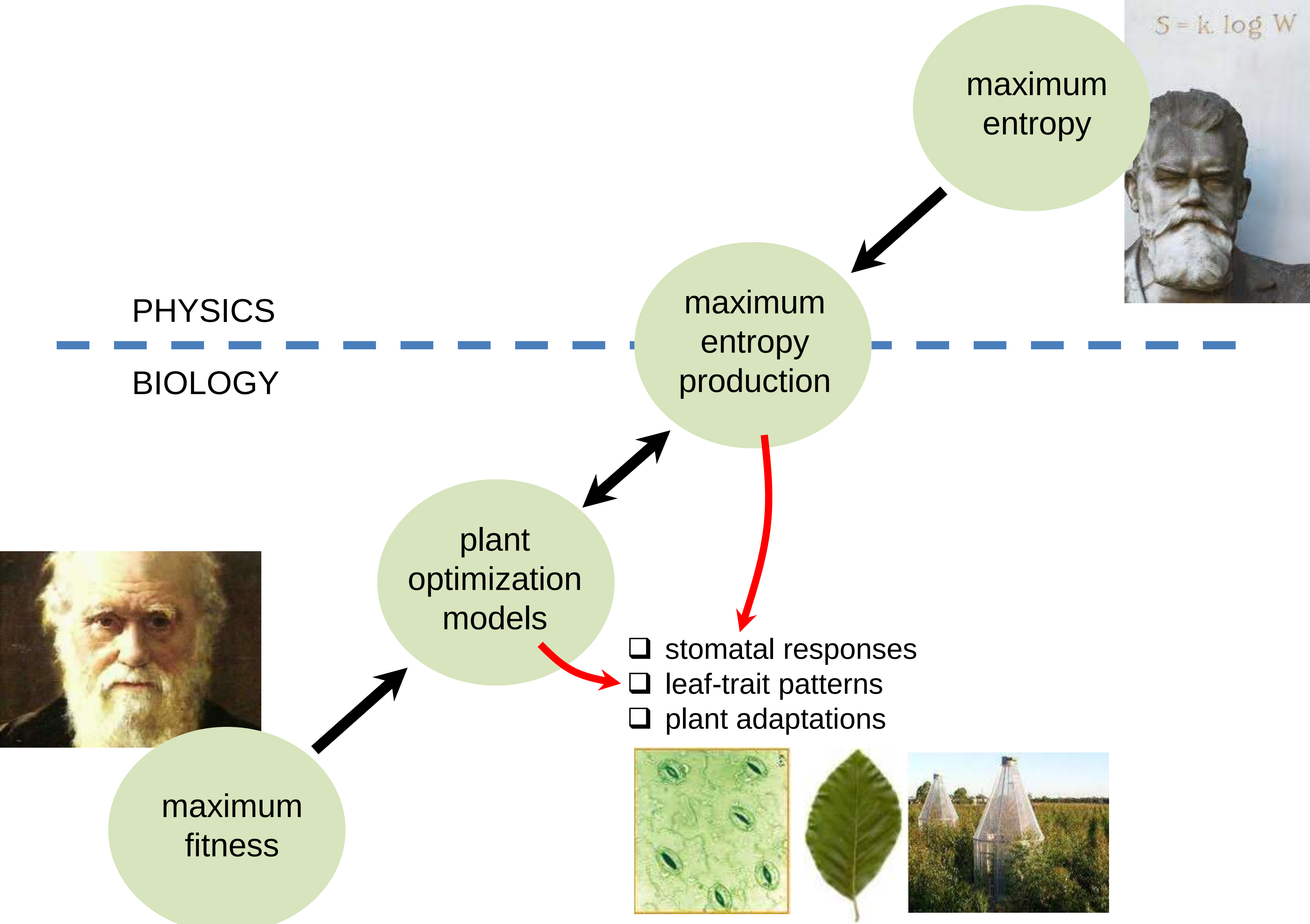


Dewar et al. (2012) Why does leaf nitrogen decline within tree canopies less rapidly than light? An explanation from optimization subject to a lower bound on leaf mass per area. *Tree Physiology* 32: 520-534

Plant optimization explains canopy traits ….

Foliage/canopy property	Measured	Predicted
Key traits used as model parameters		
Canopy light extinction coefficient, k_L (m^2 ground m^{-2} leaf)	0.43	-
Needle mass per unit area at bottom of canopy, m_a* (kg DM m^{-2} leaf)	0.181	-
Key traits predicted by MAXX	No parameter tuning!	
Canopy nitrogen extinction coefficient, k_N (m^2 ground m^{-2} leaf)	0.18	0.19
Canopy-average needle nitrogen concentration, N_f (%)	1.45	1.40
Total canopy nitrogen content, N_{tot} (g N m^{-2} ground)	21.3	21.6
Other traits		
Canopy leaf-area index, L_{tot} (m^2 leaf m^{-2} ground)	5.1±1.3[a]	5.05
Photosynthetic capacity at top of canopy, A_{sat} (μmol CO_2 m^{-2} leaf s^{-1})	12.3±1.9	13.4
Needle nitrogen content at top of canopy, N_a (g N m^{-2} leaf)	6.13	6.70

mature Norway spruce stand, Skogaryd, Sweden


S = k. log W
maximum entropy
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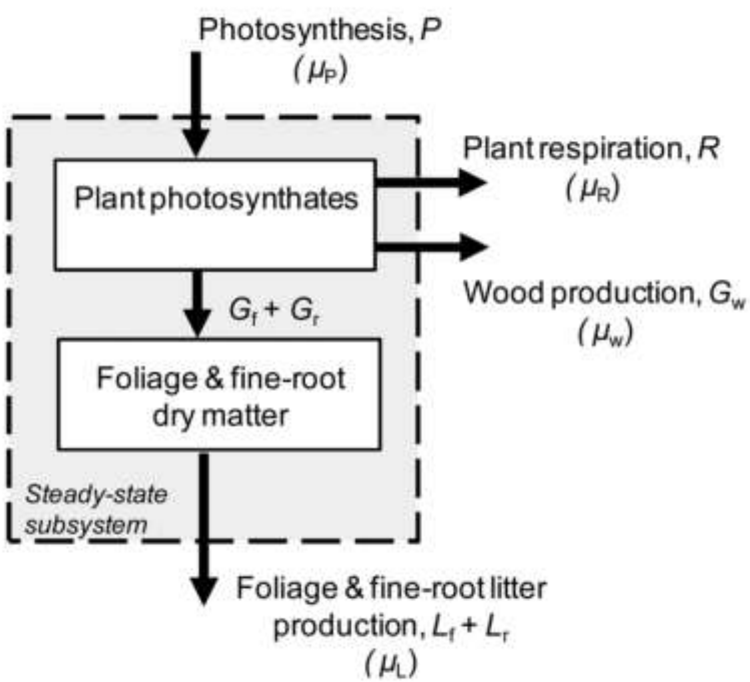
maximum entropy production
plant optimization models
maximum fitness
stomatal responses
leaf-trait patterns
plant adaptations

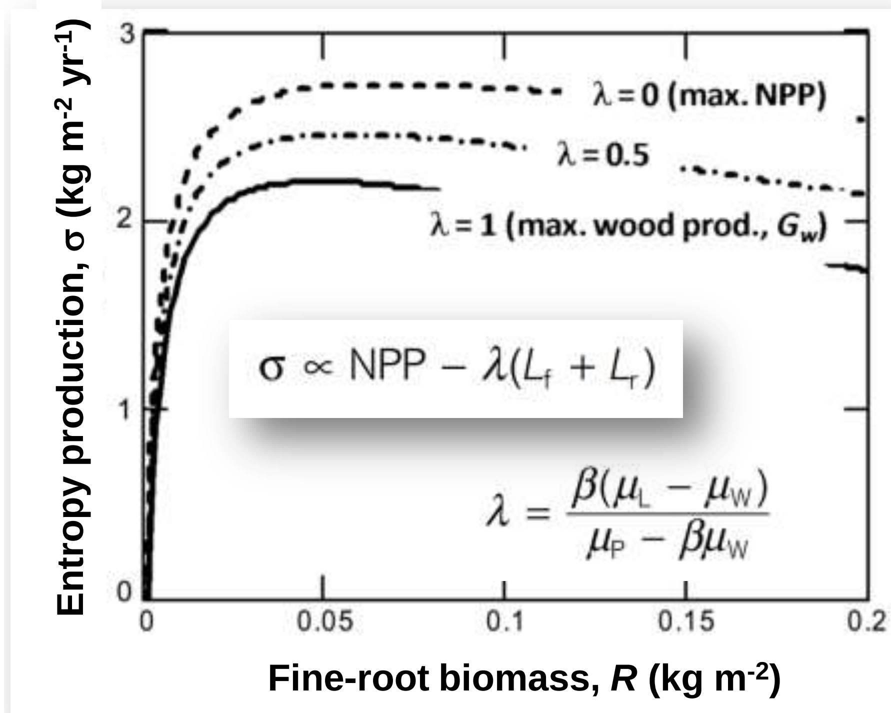
Invited review Tree Physiol. doi:10.1093/treephys/tpr138 (2012)

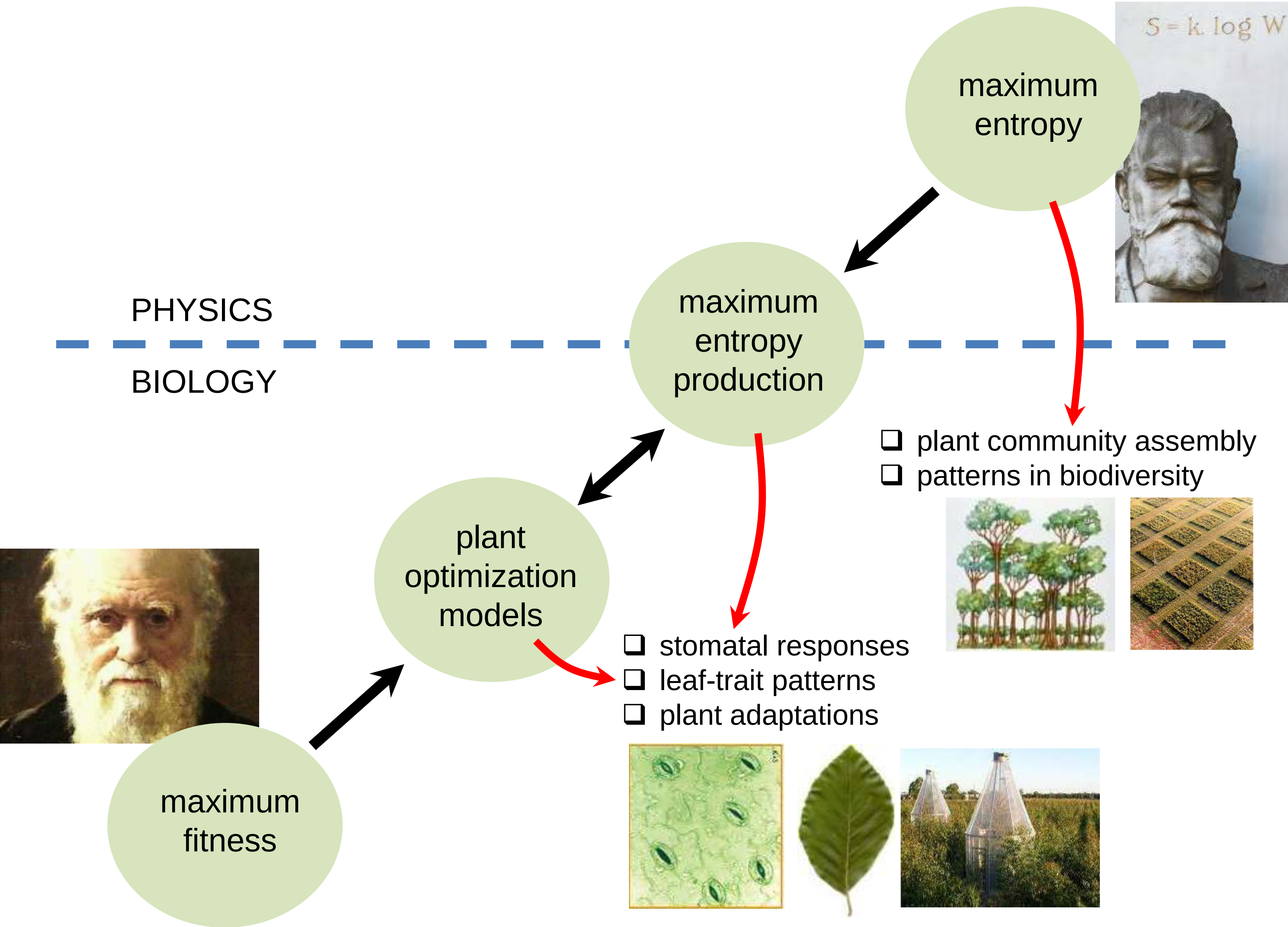
Modeling carbon allocation in trees: a search for principles

Oskar Franklin[1,7], Jacob Johansson[1,2], Roderick C. Dewar[3], Ulf Dieckmann[1], Ross E. McMurtrie[4], Åke Brännström[1,6] and Ray Dybzinski[5]

Maximum entropy production is consistent with plant optimization ....







maximum entropy
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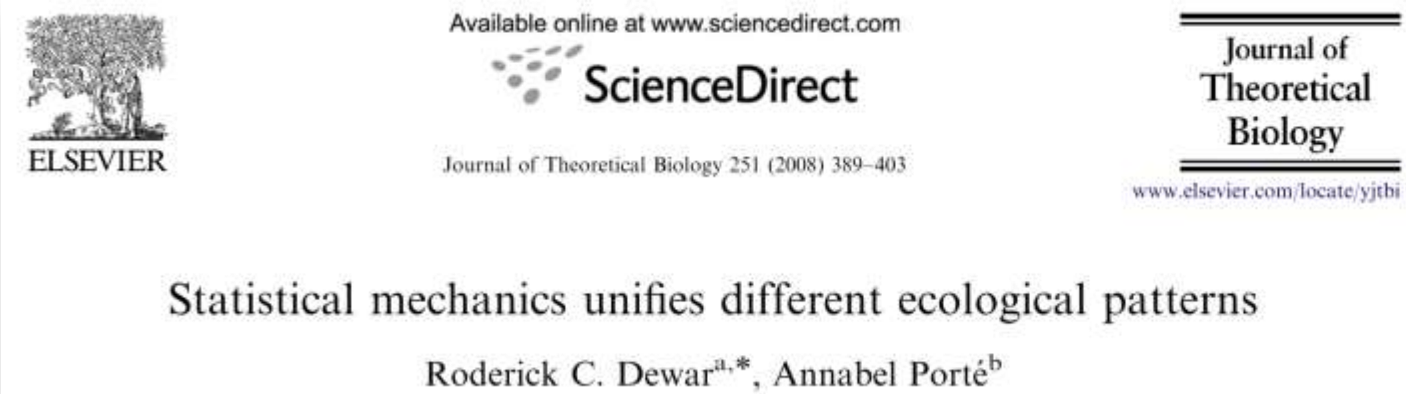

Available online at www.sciencedirect.com
ScienceDirect
Journal of Theoretical Biology 251 (2008) 389–403
ELSEVIER
Journal of Theoretical Biology
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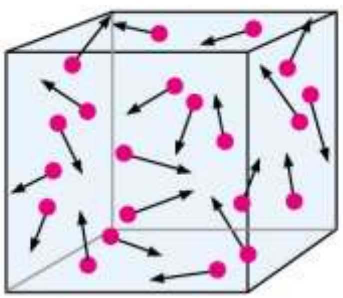
Statistical mechanics unifies different ecological patterns

Roderick C. Dewar[a,*], Annabel Porté[b]

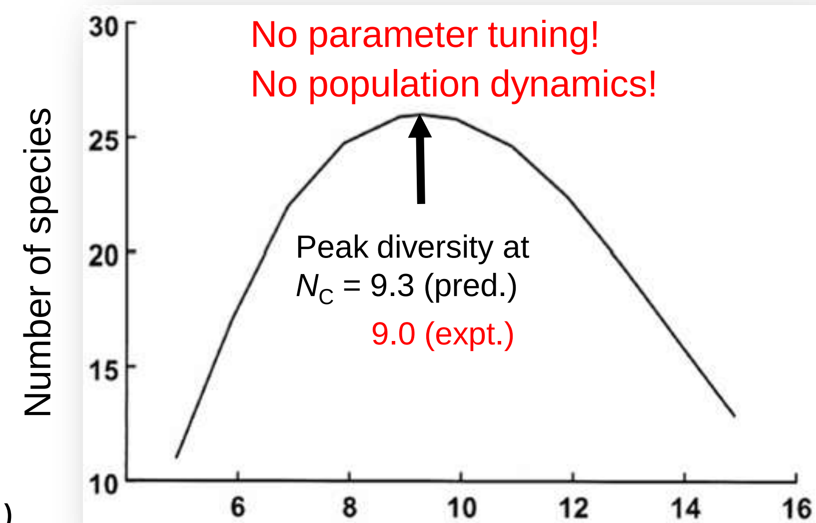
Boltzmann's maximum entropy explains patterns in plant diversity …..

statistical physics ↔ community ecology



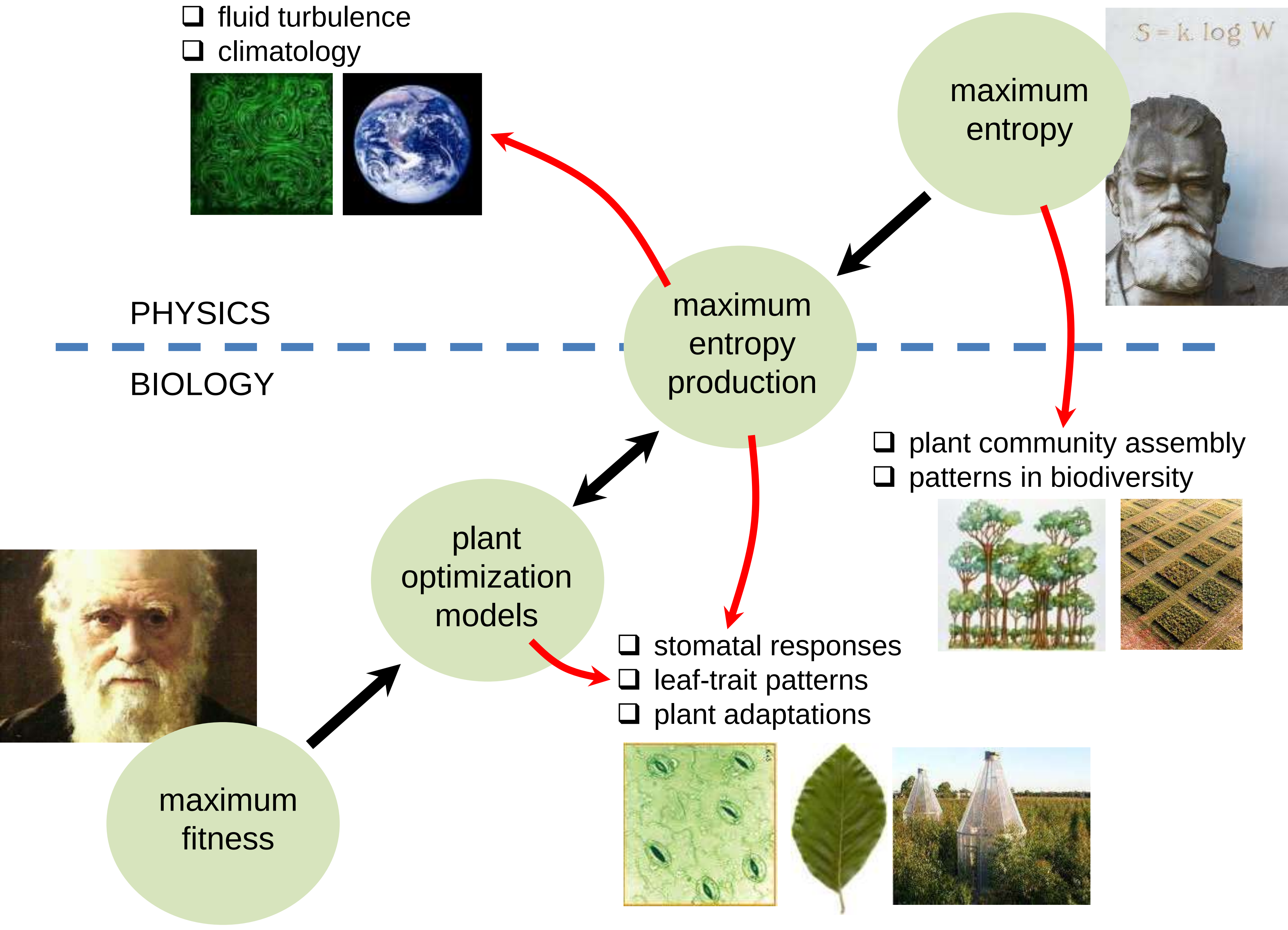
molecules of a gas ↔ *individuals of a community*
constraints V, U ↔ *resource constraints (e.g.* N_C*)*
macroscopic laws ↔ *macro-ecological patterns*

N-limited grassland (Cedar Creek):



Community nitrogen use, N_C (g N m^{-2} yr^{-1})

Jason Bertram → savannas → *prob*(tree cover fraction | MAP)



fluid turbulence
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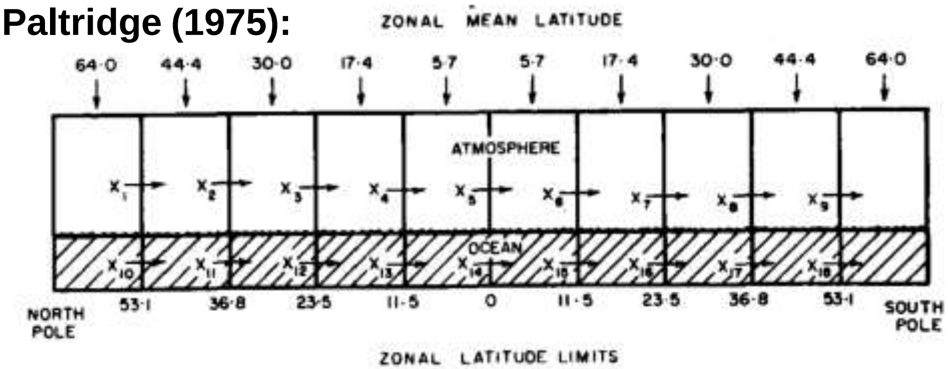
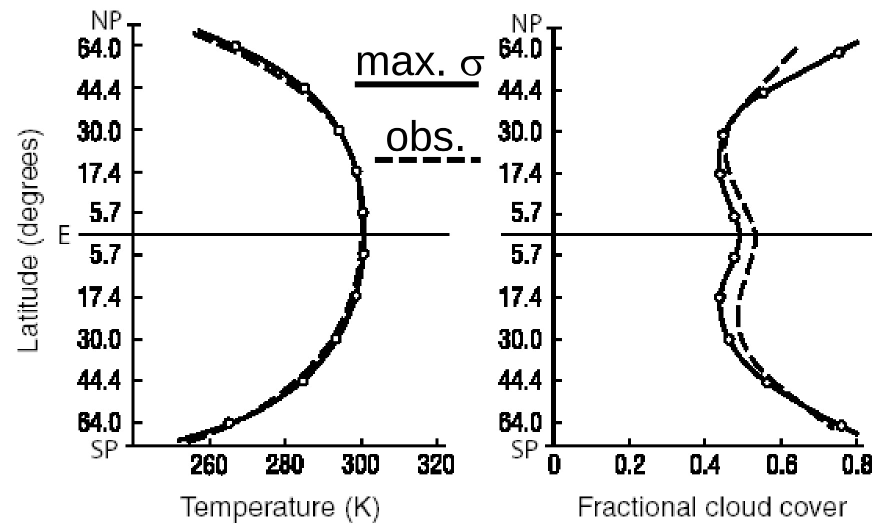
Max. entropy production reproduces large-scale climate features ….

Paltridge (1975):





σ = thermal dissipation by turbulent heat fluxes

$$= \sum_{i=1}^{9} X_i \left(\frac{1}{T_{i+1}} - \frac{1}{T_i} \right)$$

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Dewar & Maritan (2012): Boltzmann's max. entropy → max. entropy production → max. σ

Max. entropy production explains mean turbulent velocity profiles ….

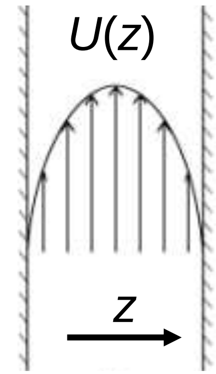
J. Fluid Mech. (2003), vol. 489, pp. 185–198. © 2003 Cambridge University Press 185
DOI: 10.1017/S0022112003004907 Printed in the United Kingdom

Borders of disorder: in turbulent channel flow

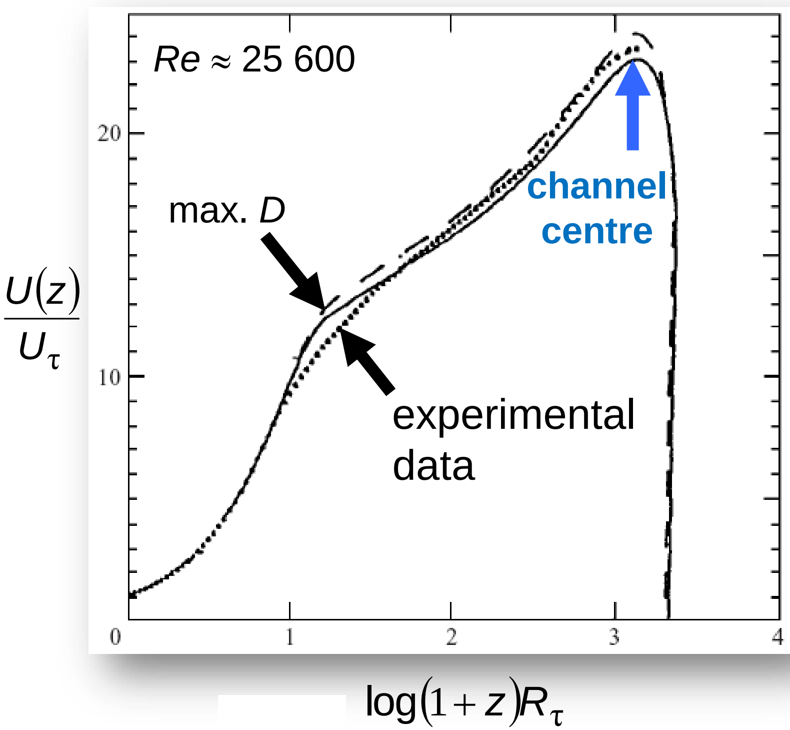
By WILLEM V. R. MALKUS
Massachusetts Institute of Technology, Department of Mathematics, Cambridge, MA 02139, USA

(Received 10 June 2002 and in revised form 6 February 2003)

applied pressure gradient

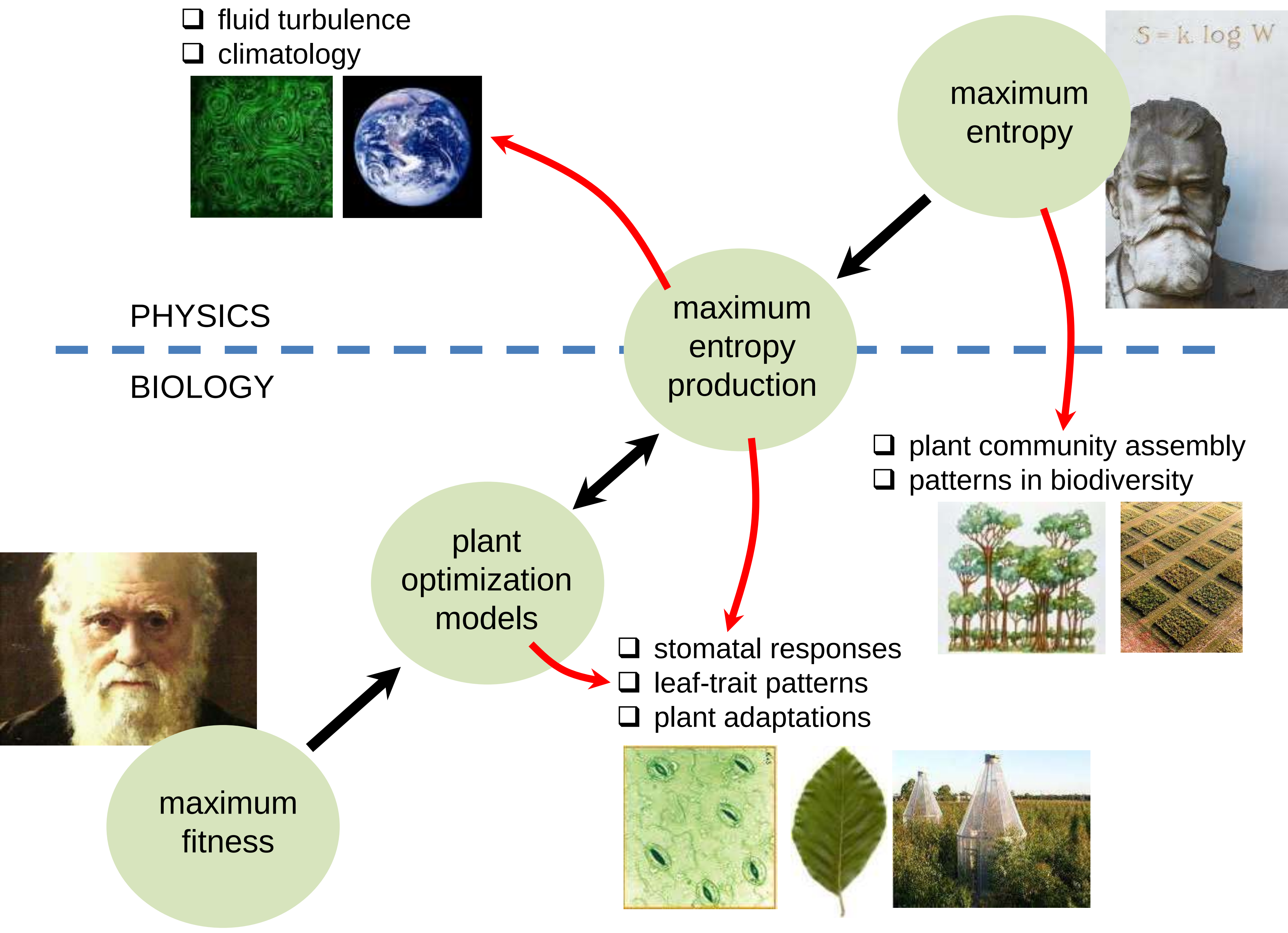


D = rate of dissipation by mean flow $U(z) = \int U'(z)^2\,\mathrm{d}z$



Dewar & Maritan (2012):

Max. entropy → max. entropy production → max. D



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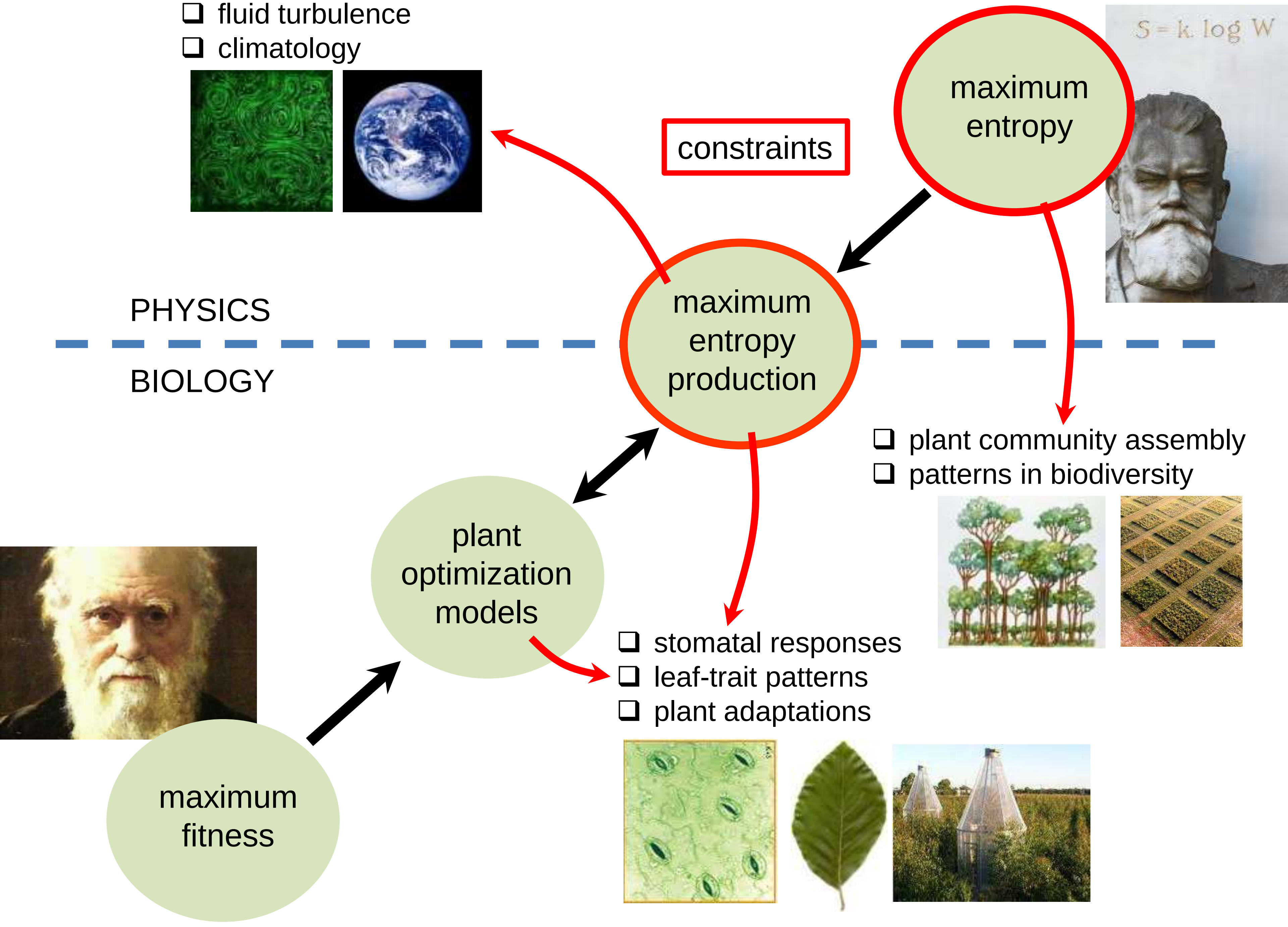

fluid turbulence
climatology
constraints
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Conclusion:
Use maximum entropy to tame complexity in biology and physics …

Simryn Gill

… realistic predictions from just a few key constraints