MODULE 3

LIFE AS THE NEXT FRONTIER IN PHYSICS

Exploring the New Science of Astrobiology

World Science Scholars

Sara Walker, PhD
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MODULE 3:

SIGNATURE OF LIFE

WHAT ARE THE SIGNATURES OF INFORMATION CONTROLLING MATTER?

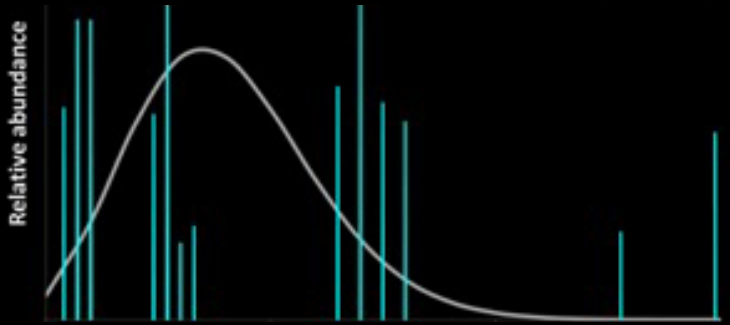


Figure courtesy of William Bains

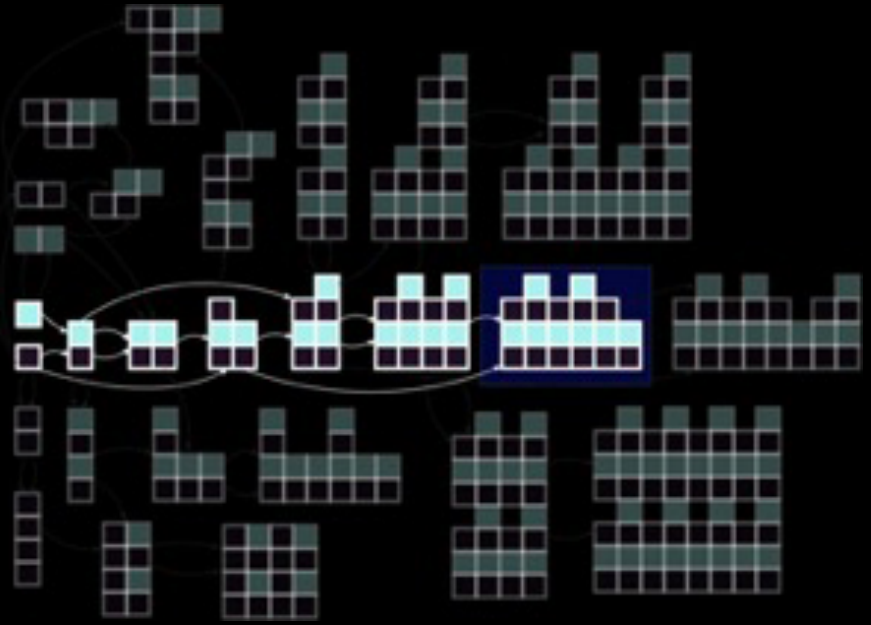
Abiotic (smooth curve) – high entropy

Biological (spikes) – low entropy, indicative of information control and evolutionary optimization (McKay, 2011)

Artificial life example: Dorn et al. (2011) in *Astrobiology*

Walker, Sara I., et al. "Exoplanet Biosignatures: Future Directions." *arXiv preprint arXiv:1705.08071* (2017).

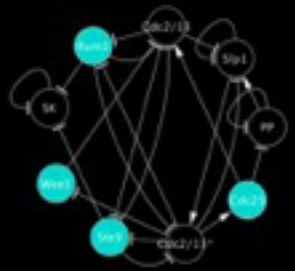
IMPROBABLE CHEMISTRY AS A BIOSIGNATURE



Some molecules or distributions of molecules may be so complex they require an algorithmic procedure to generate them, e.g., a living process

Marshall, Stuart M., Alastair RG Murray, and Leroy Cronin. “A probabilistic framework for identifying biosignatures using Pathway Complexity.” *Phil. Trans. R. Soc. A 375*, no. 2109 (2017): 20160342.

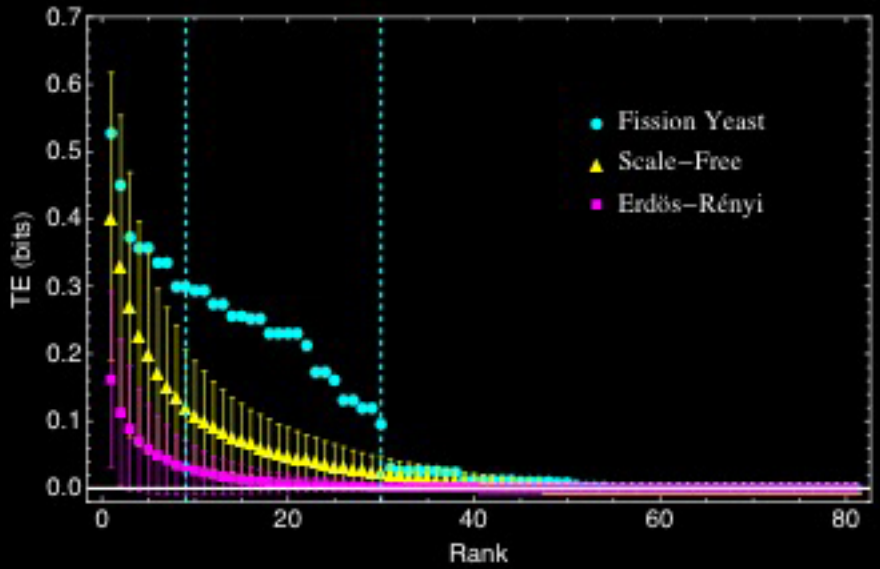
INFORMATIONAL STRUCTURE AS A BIOSIGNATURE



Biological

Random

Scale-free

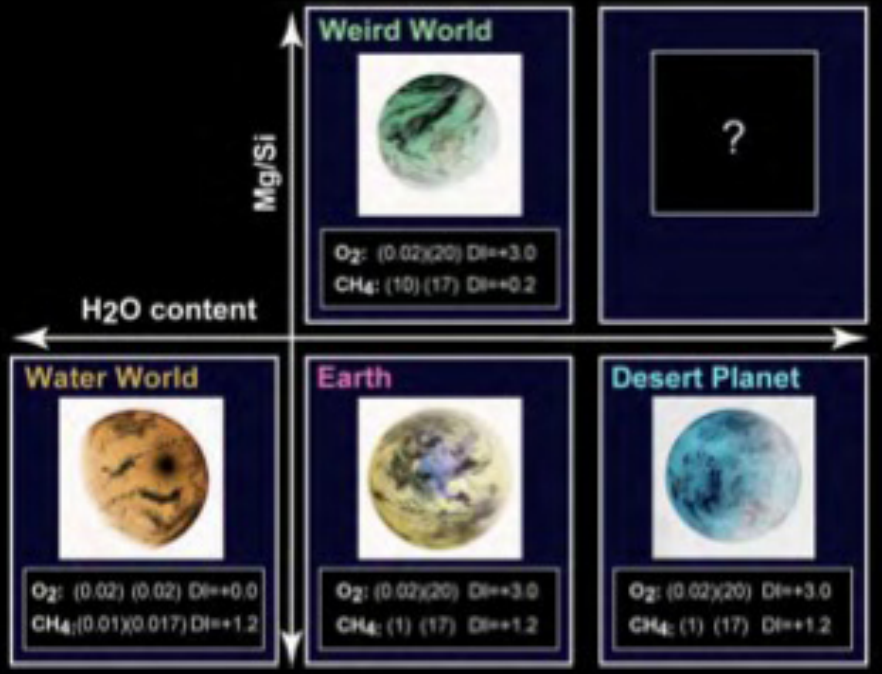


H. Kim, P.C.W. Davies and S.I. Walker (2015) New Scaling Relation for Information Transfer in Biological Networks. J. Roy. Soc. Interface 2015; Davies, P.C. and Walker, S.I., 2016. The hidden simplicity of biology. *Reports on Progress in Physics*, 79(10), p.102601.

Statistical approaches to life detection

COMPOSITIONS OF EXOPLANETS WILL BE EVALUATED PROBABILISTICALLY

Biosignatures will also be evaluated probabilistically …



WHAT SHOULD BE OUR GOAL?

Evaluate the implications of the various parameters for exoplanetary ecosystem detectability in a *quantitative* framework.

BAYESIAN FRAMEWORK FOR LIFE DETECTION

PRIOR PROBABILITY OF LIFE

3.1 Habitability
6.1 Emergence of life
6.2 Biological innovations
8 Tuning search strategies

$$P(\text{life}|\text{data}) = \frac{P(\text{data}|\text{life})P(\text{life})}{P(\text{data}|\text{life})P(\text{life}) + P(\text{data}|\text{no life})(1 - P(\text{life}))}$$

POSTERIOR PROBABILITY OF LIFE

3 Detecting unknowing life
(see discussion on *detectability*)

7 Bayesian Example with O_2

8 Tuning search strategies

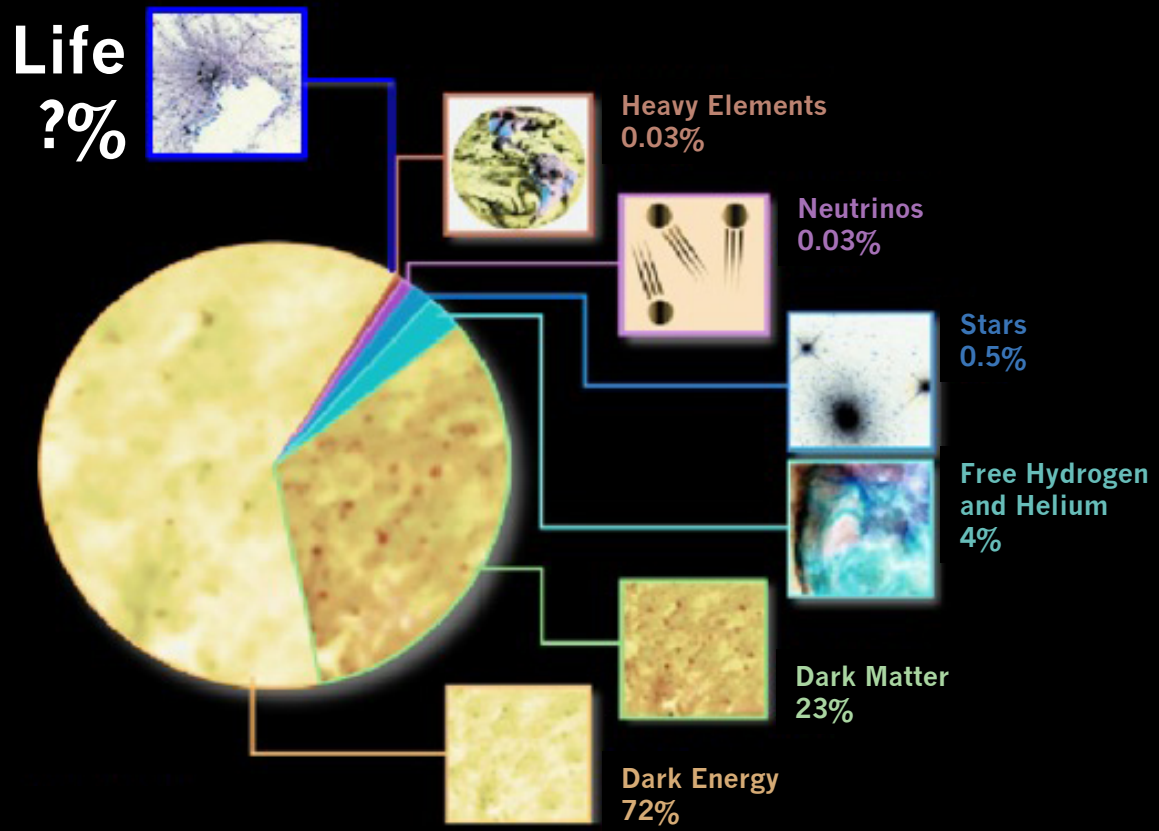
See also, Technology detection biases (Fuji et al, 2017, this issue)

LIKELIHOOD OF OBSERVATIONS ON NON-LIVING WORLDS

4.1 Stellar environment
4.2 Climate and Geophysics
4.3 Geochemical Environment

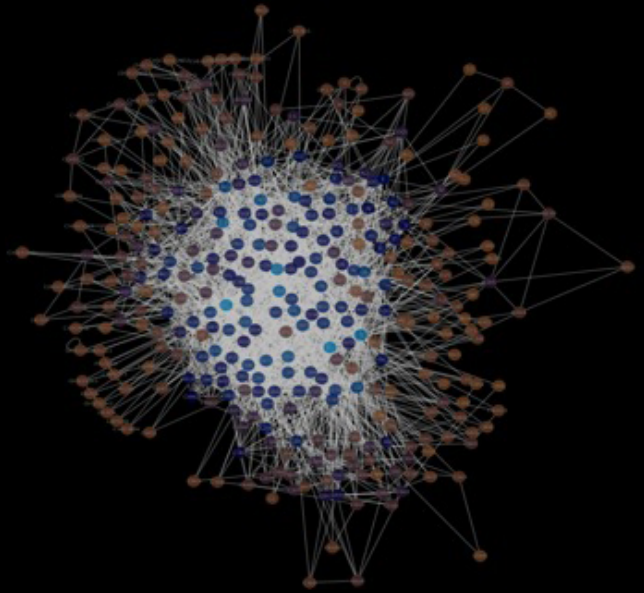
LIKELIHOOD OF OBSERVATIONS ON LIVING WORLDS

5.1 Black Box Approaches to Living processes
5.2 Life as Improbable Chemistry
5.3 Life as an evolutionary process
5.4 Insights from Universal Biology


Life
?%
Heavy Elements
0.03%
Neutrinos
0.03%
Stars
0.5%
Free Hydrogen
and Helium
4%
Dark Matter
23%
Dark Energy
72%

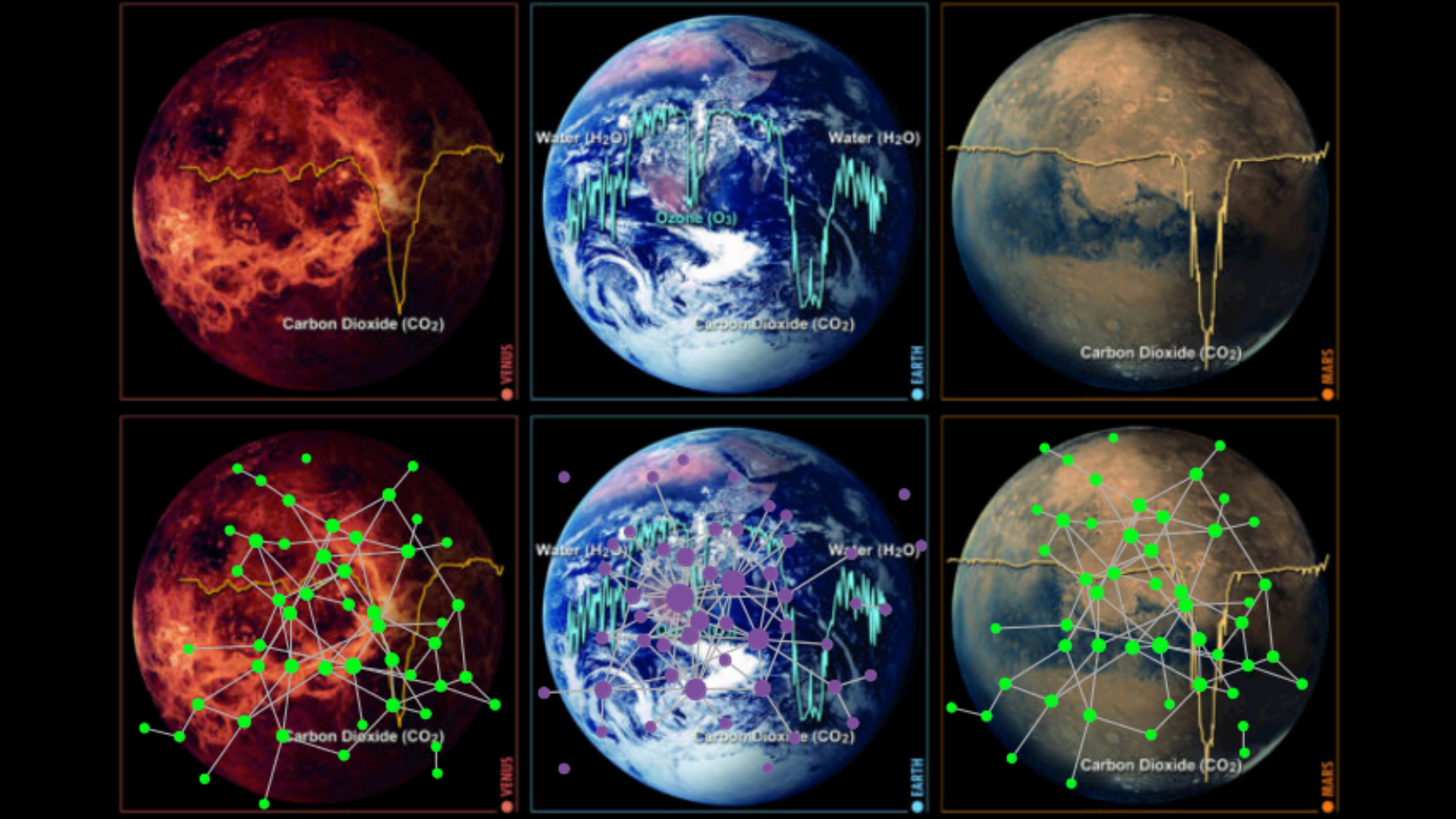
NASA Figure

NETWORK BIOSIGNATURES FOR PLANETARY ATMOSPHERES



Chemistry in Earth's stratosphere represented as a network

DeMore, W.B., Sander, S.P., Golden, D.M., Hampson, R.F., Kurylo, M.J., Howard, C.J., *et al*. (1997). Chemical kinetics and photochemical data for use in stratospheric modeling. Evaluation Number 12. JPL Publication 97-4.


Carbon Dioxide (CO_2)
VENUS
Water (H_2O)
Water (H_2O)
Ozone (O_3)
Carbon Dioxide (CO_2)
EARTH
Carbon Dioxide (CO_2)
MARS
Carbon Dioxide (CO_2)
VENUS
Water (H_2O)
Water (H_2O)
Carbon Dioxide (CO_2)
EARTH
Carbon Dioxide (CO_2)
MARS

EXAMPLES TO QUANTIFY LIFE

- Planetary atmospheres
- Oil droplets
- Planaria
- Gene regulatory networks

SUMMARY

- Planetary atmospheres
- Oil droplets
- Planaria
- Gene regulatory networks

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