

Title: Life is What?

Speakers: Sara Walker

Series: Colloquium

Date: November 24, 2021 - 2:00 PM

URL: <https://pirsa.org/21110033>

Abstract: Currently, no general theory exists that explains what life is. While many definitions for life do exist, these are primarily descriptive, not predictive, and they have so far proved insufficient to explain the origins of life, or to provide rigorous constraints on what properties we might expect all examples of life to share (e.g., in our search for life in alien environments). In this talk I discuss new approaches to understanding what universal principles might explain the nature of life and elucidate the mechanisms of its origins, focusing on recent work in our group elucidating regularities and law-like behavior of biochemical networks on Earth from the scale of individual organisms to the planetary scale.

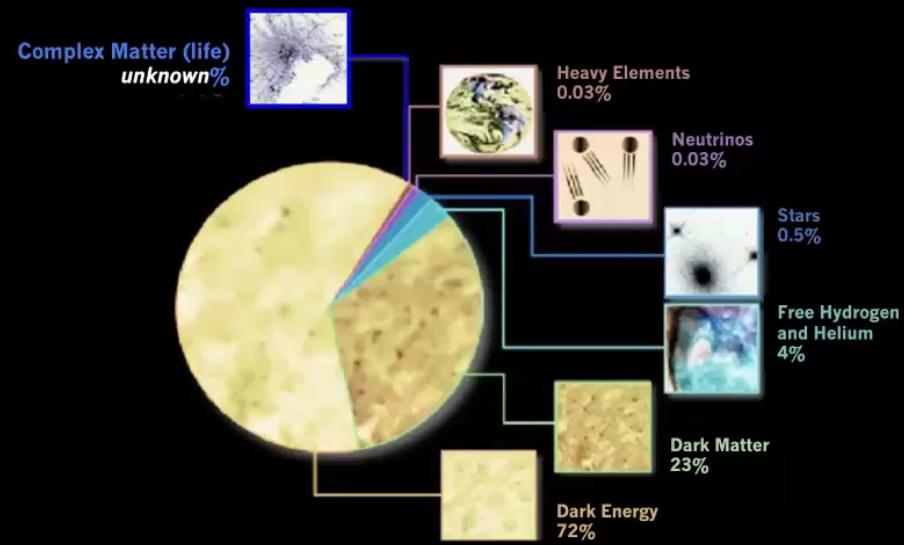
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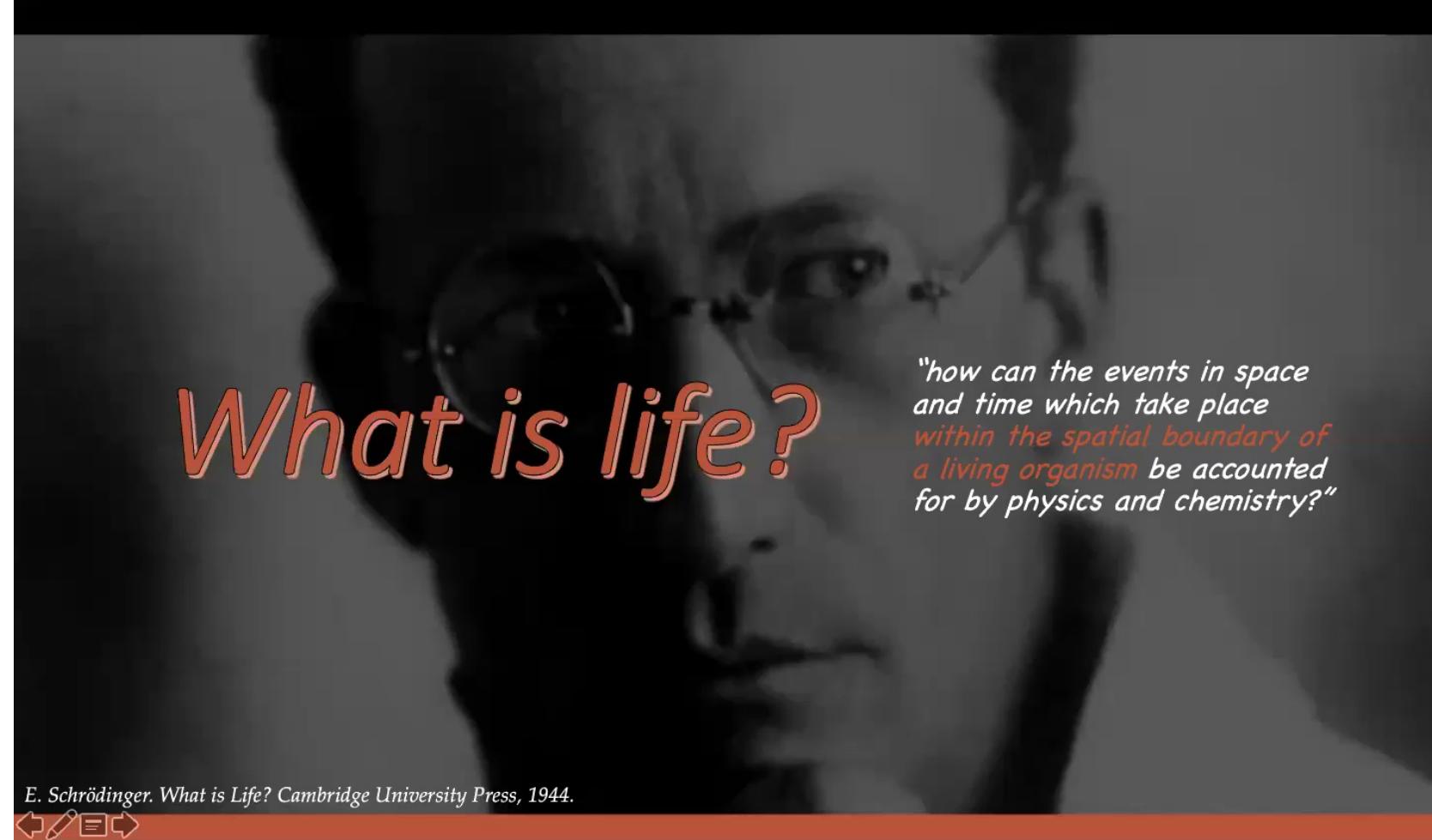


Sara Walker

Life is What?!

Sara Imari Walker, PhD
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Arizona State University
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 @Sara_Imari





What is life?

*"how can the events in space
and time which take place
within the spatial boundary of
a living organism be accounted
for by physics and chemistry?"*

E. Schrödinger. *What is Life?* Cambridge University Press, 1944.



Sara Walker



Defining “life”



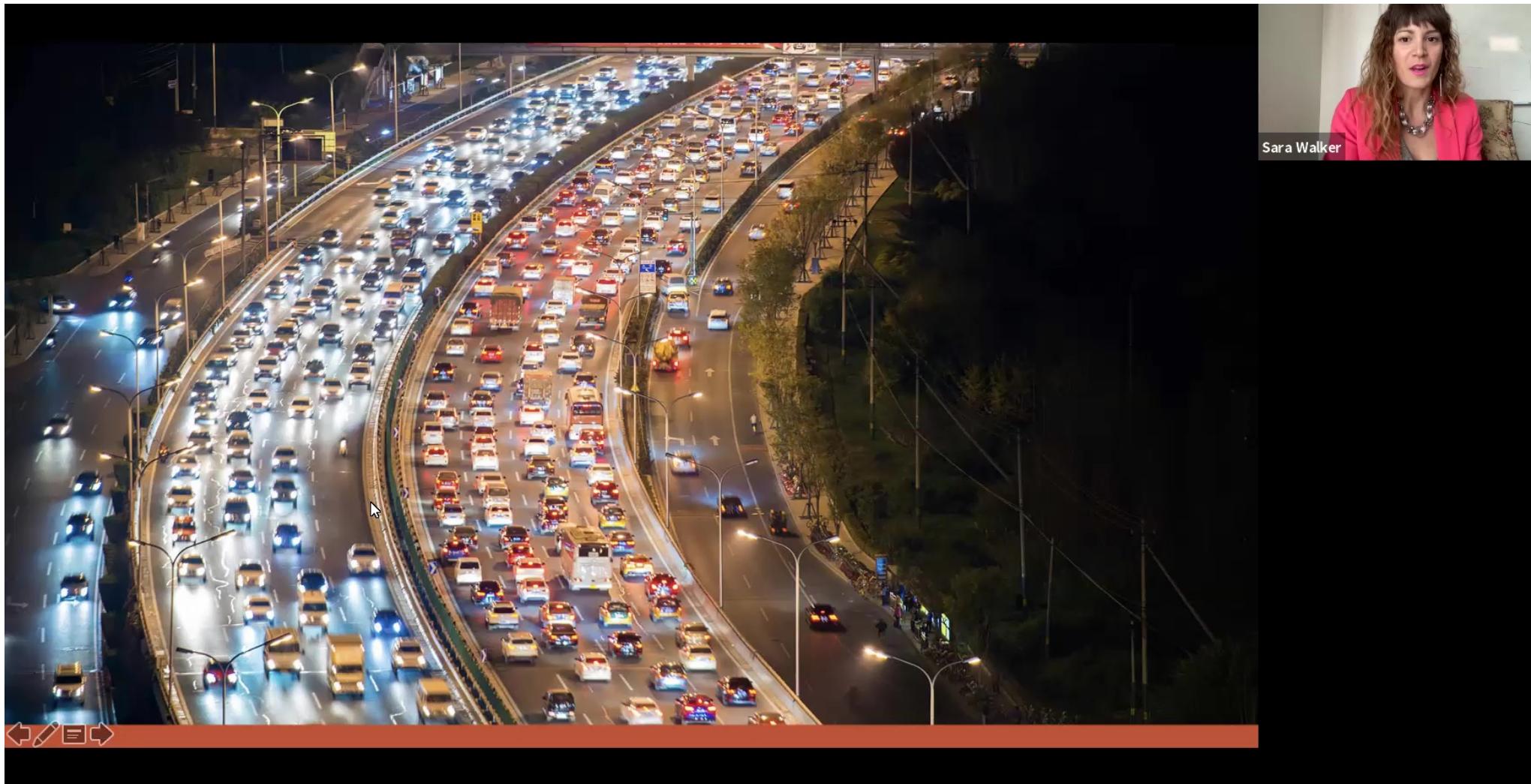
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Life [lahyf]:

“... any system capable of performing a number of such functions as eating, metabolizing, excreting, breathing, moving, growing, reproducing, and being responsive to external stimuli ...”



Sagan, Carl. "Definitions of life." *The Nature of Life: Classical and Contemporary Perspectives from Philosophy and Science* (2010): 303.



Sara Walker

There is no viable definition



Sara Walker

“ ... But many such properties are either present in machines that nobody is willing to call alive, or absent from organisms that everybody is willing to call alive.”

Sagan, Carl. "Definitions of life." *The Nature of Life: Classical and Contemporary Perspectives from Philosophy and Science* (2010): 303.



“Life does not exist.”

- Andrew Ellington
(American Chemical Society 2012)



Sara Walker

“as one focuses experimentally on any of the ‘defining’ properties of ‘life’, the sharp boundary seems to blur, splitting into finer and finer sub-divisions”

- Jack Szostak
(J. Biomolecular Struc. Dyn. 29.4 (2012): 599-600.)



Life is What?

“... living matter, while not eluding the “laws of physics” as established up to date, is likely to involve “other laws of physics” hitherto unknown”

E. Schrödinger. *What is Life?* Cambridge University Press, 1944.





“ ... the general laws on which the structure of theoretical physics is based claim to be valid for any natural phenomenon whatsoever. With them, it ought to be possible to arrive at the description, that is to say, the theory, of every natural process, including life, by means of pure deduction ...”



Albert Einstein, on the occasion of Max
Planck's 60th birthday
(emphasis added by me)



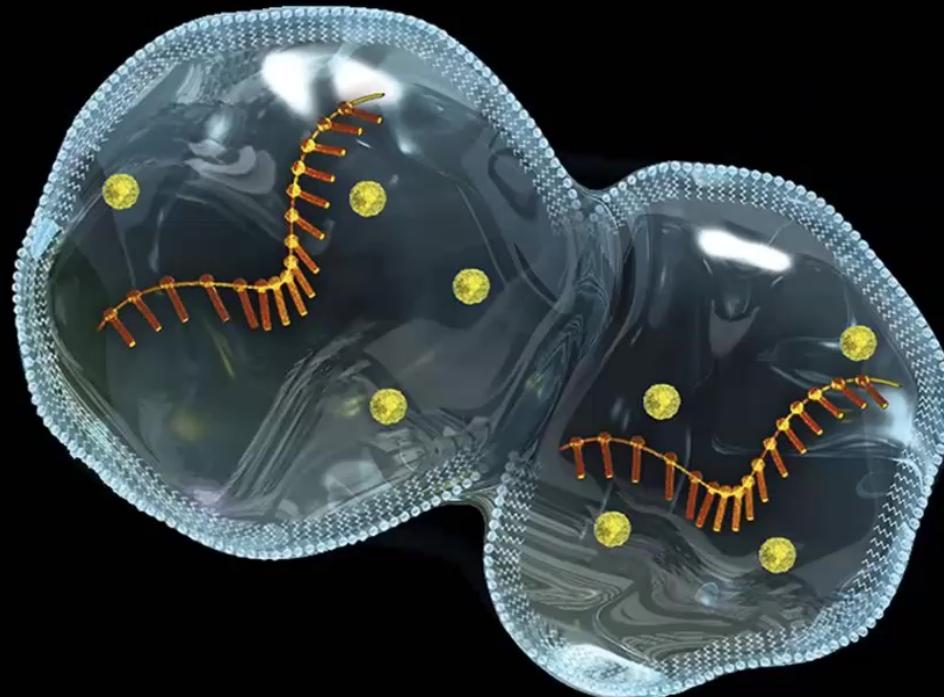
“There is a world beyond physics”

-Stuart Kauffman

(In “A World Beyond Physics”)



Sara Walker



Walker, Sara Imari. "The new physics needed to probe the origins of life." *Nature* 569.7754 (2019): 36-39.



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“The fundamental laws will no longer admit arbitrary initial conditions, and will not take the form of evolution equations”

-Frank Wilczek, Physics in 100 Years

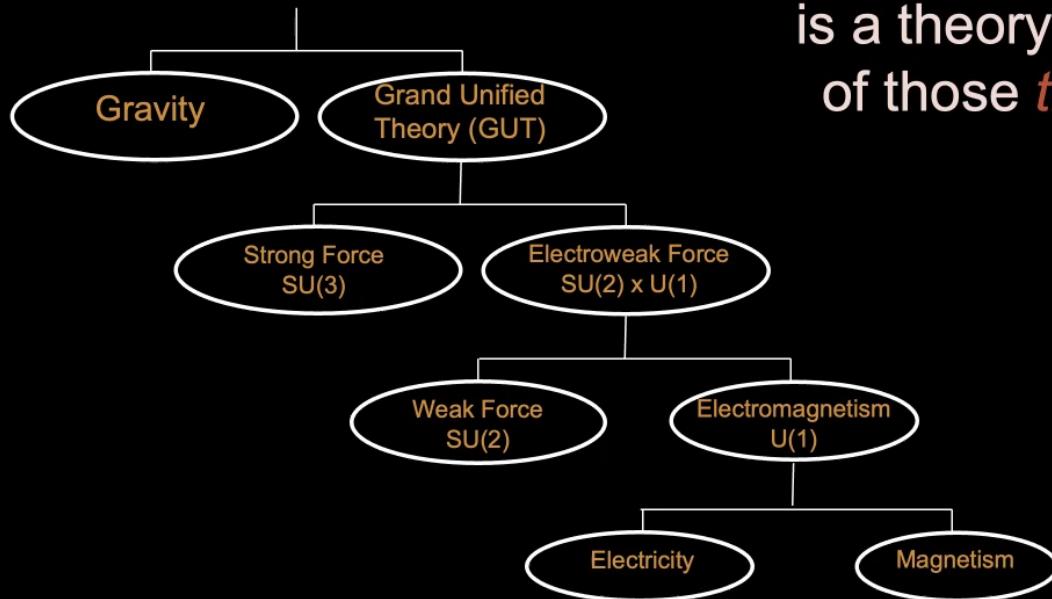




Sara Walker

Life does not violate any of the known laws of physics, but it is not explained by them either.

Theory of Everything



“The theory of everything
is a theory of everything except
of those *things that theorize.*”

—David Krakauer
Santa Fe Institute

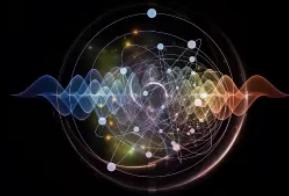


The laws we know and love



Sara Walker

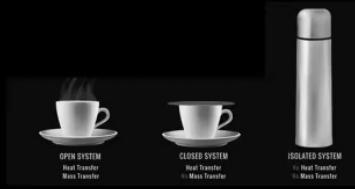
The laws of matter and light



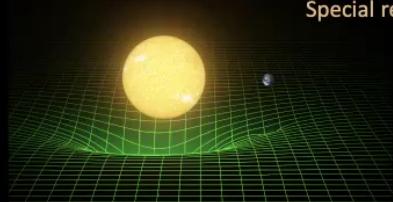
Quantum mechanics/quantum field theory/Standard Model

The laws of large numbers and observational uncertainty

Thermodynamics and statistical mechanics



The laws of space and simultaneity



Special relativity, general relativity

The laws of information/what is possible

The laws we know and love



Sara Walker

The laws of matter and light



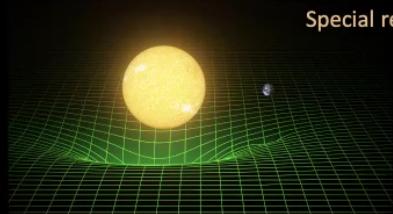
Quantum mechanics/quantum field theory/Standard Model

The laws of large numbers and observational uncertainty

Thermodynamics and statistical mechanics



The laws of space and simultaneity



Special relativity, general relativity

The laws of information/what is possible

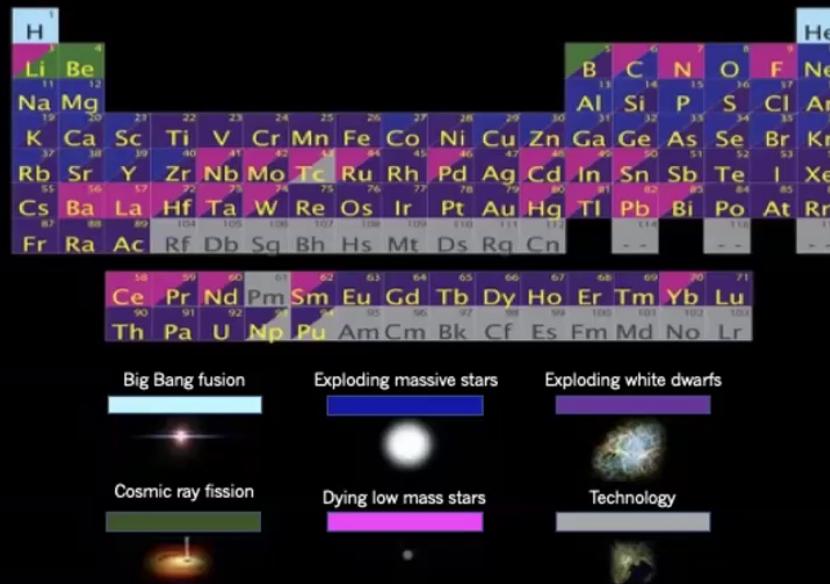
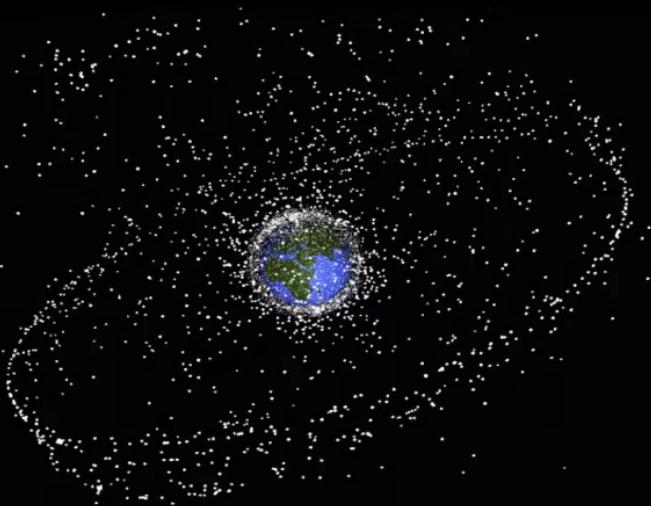
Assembly theory/casual set theory/constructor theory/Wolfram physics project/complexity science



"Information" and the physics of the possible



Sara Walker



Walker 2016 "The Descent of Math" In Trick of Truth: The Mysterious Connection Between Physics and Mathematics? A. Aguirre, B. Foster and Z. Merali (ed.) Springer.



“Base metals can be transmuted into gold by stars, and by intelligent beings who understand the processes that power stars, and **by nothing else in the universe**”

-David Deutsch

University of Oxford
“The Beginning of Infinity”



A History of Unifications – What's next?



Unification of algebra and geometry (Descartes)

Unification of terrestrial and celestial physics (Newton, Galileo)

Unification of mechanics and optics (Hamilton)

Unification of electricity, magnetism, and optics (Maxwell)

Unification of space and time (Einstein, Minkowski)

Unification of wave and particle (Einstein, de Broglie)

Unification of reasoning and calculation (Boole, Turing)

Unification of information/computation and matter (?)

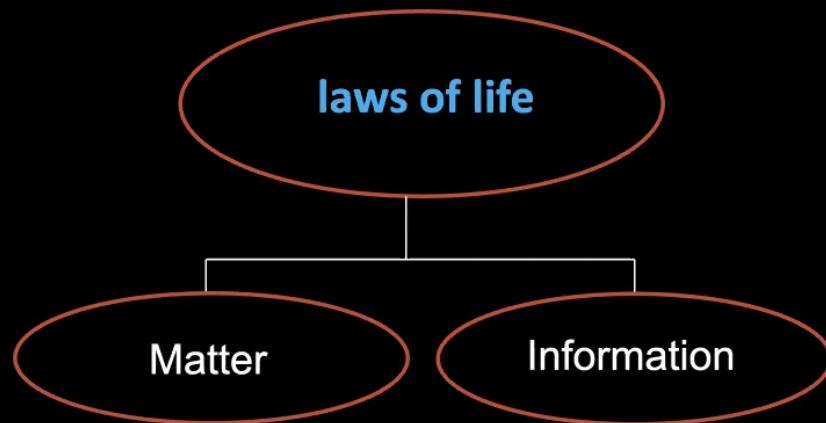
Wilczek, Frank. "Physics in 100 years." *arXiv preprint arXiv:1503.07735* (2015).

Unification at the Origin of Life



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The origin of life is problem of *unification*



Walker, Sara Imari. "Origins of life: a problem for physics, a key issues review." *Reports on Progress in Physics* 80.9 (2017): 092601.



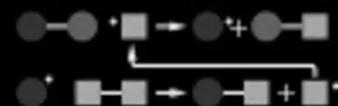
Bio from Bit

'Life' is where the physics of information is the dominant physics



Nonliving network

Radical chain reaction



Replication



Information propagation



Error correction



Evolution



Living network

DNA polymerase chain reaction



Image from: Cronin and Walker "Beyond prebiotic chemistry." *Science* 352, no. 6290 (2016): 1174-1175.



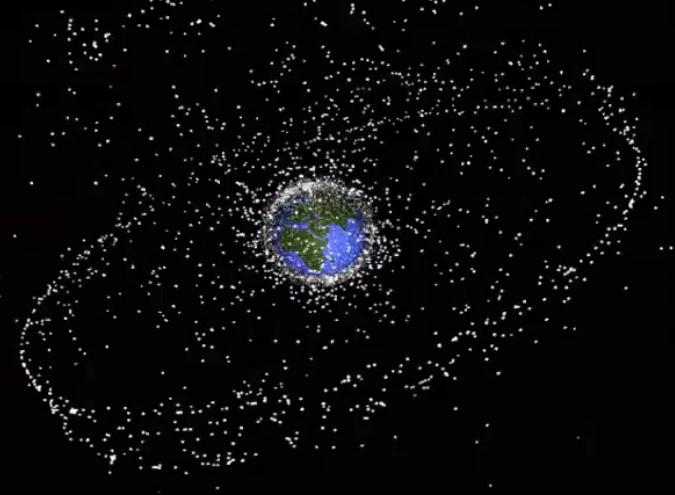
Life ≠ Alive



(w/ Michael Lachmann, Aeon magazine 2019)



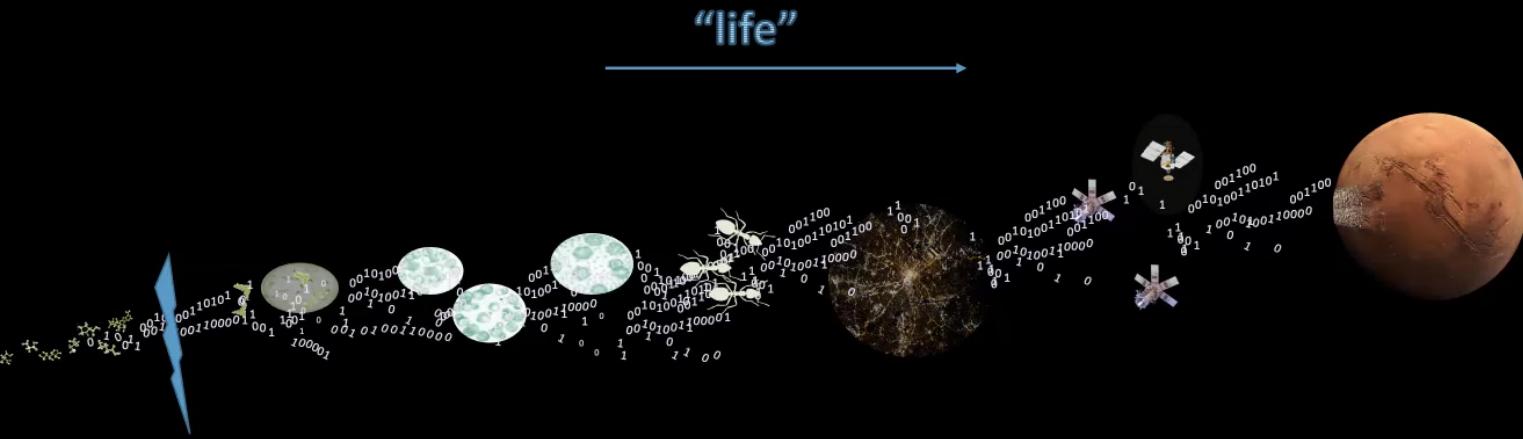
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The Origin of Life: Finding the transition from non-living to living physics



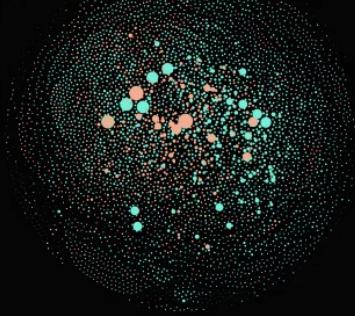
Abiotic

Biological

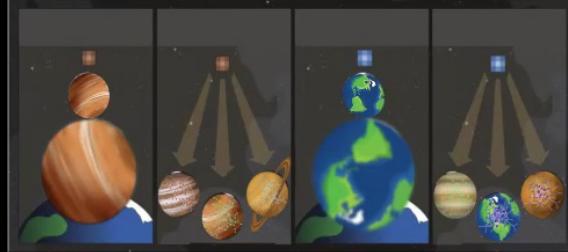
Technological



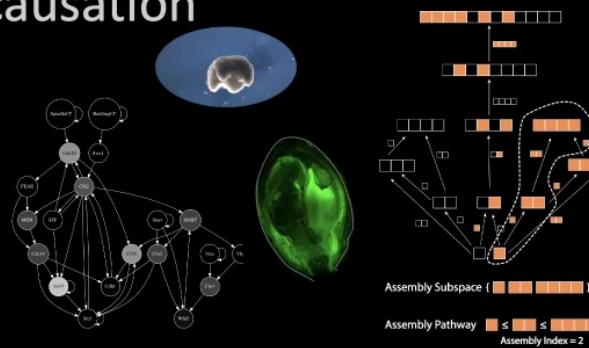
Statistical approaches to characterizing life's chemistry



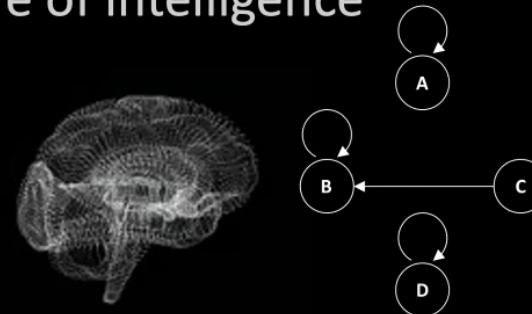
Universal Signatures of Life



Life as the physics of information & causation



The nature of intelligence





Assembly Theory



Sara Walker

“One can best feel in dealing with living systems how primitive physics still is.”
– *Albert Einstein*

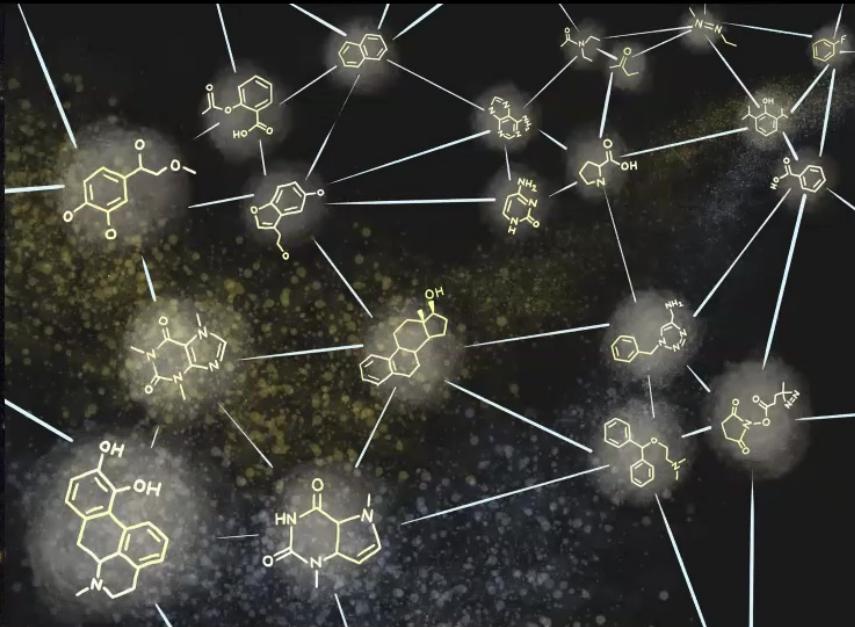
The Problem of What Exists



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Hubble Image

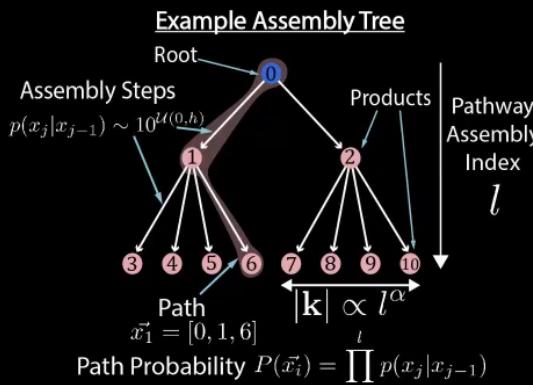


Naomi Johnson, Lee Cronin @croninlab

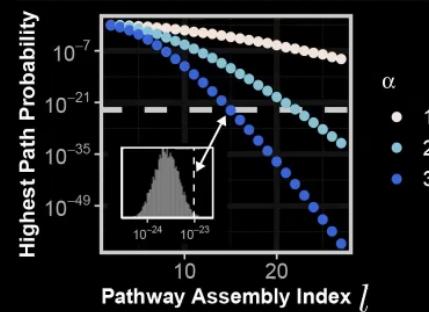
Combinatorial Space is HUGE – what principles explain why some things exist and not others?



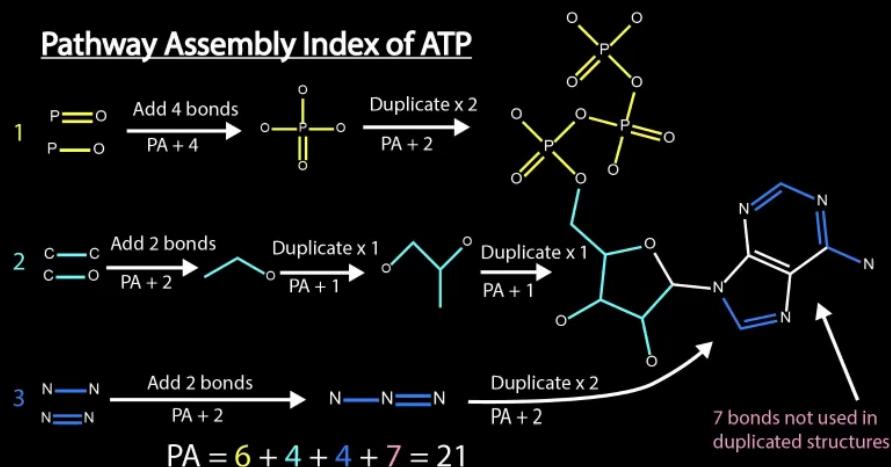
Assembly Theory



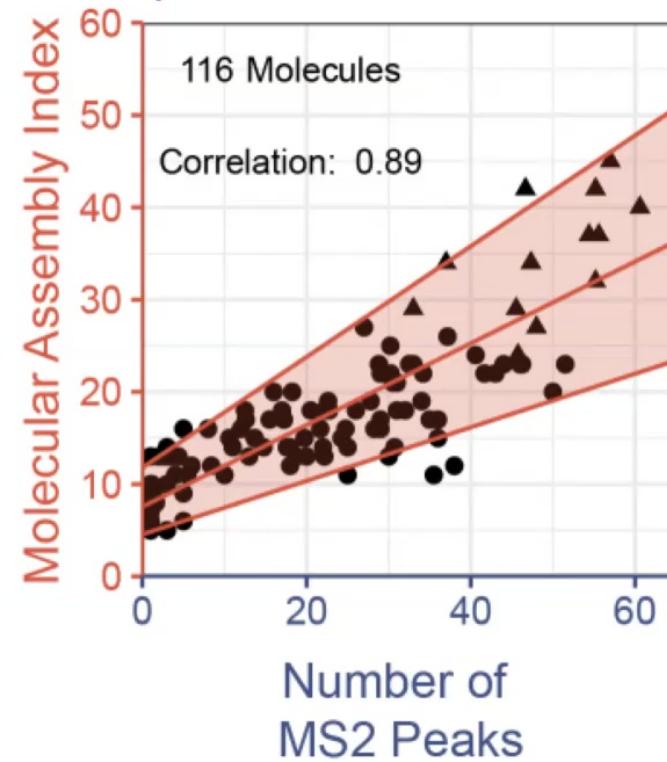
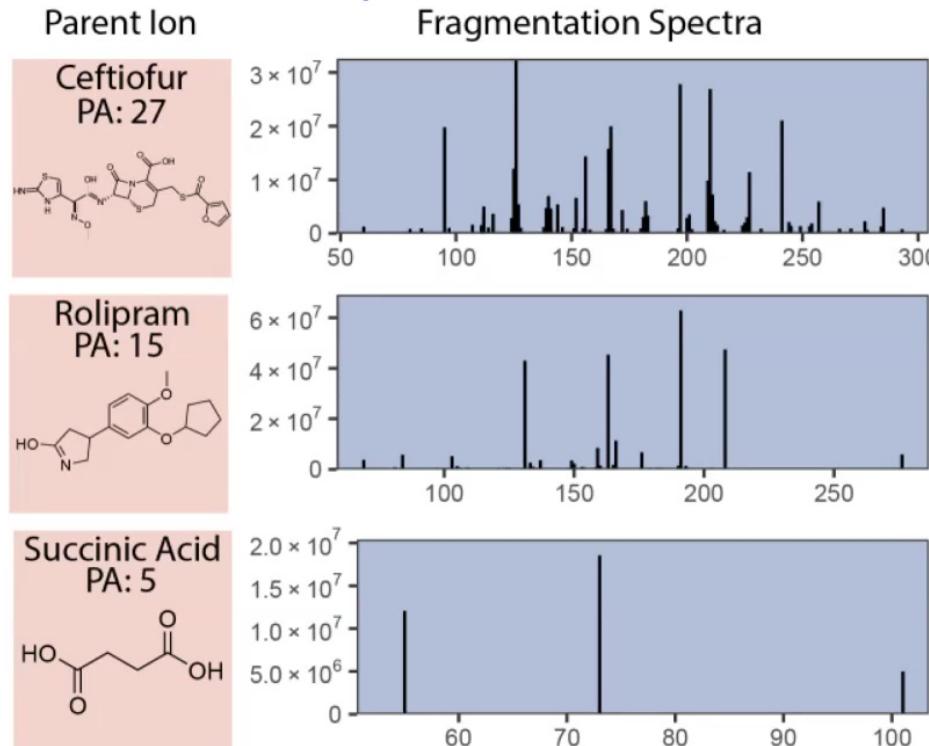
Statistics from 3,000,000 Random Trees



Pathway Assembly Index of ATP



Assembly Measurement System



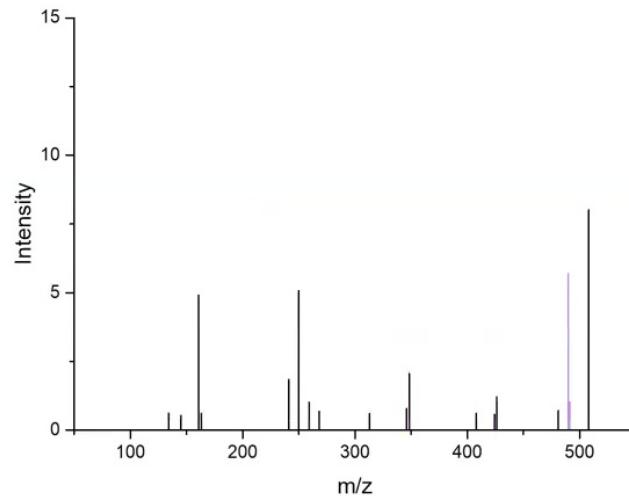
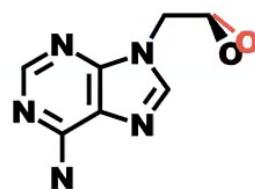
Assembly Measurement System



Sara Walker

Molecular Assembly Index (MA)

MA: 13

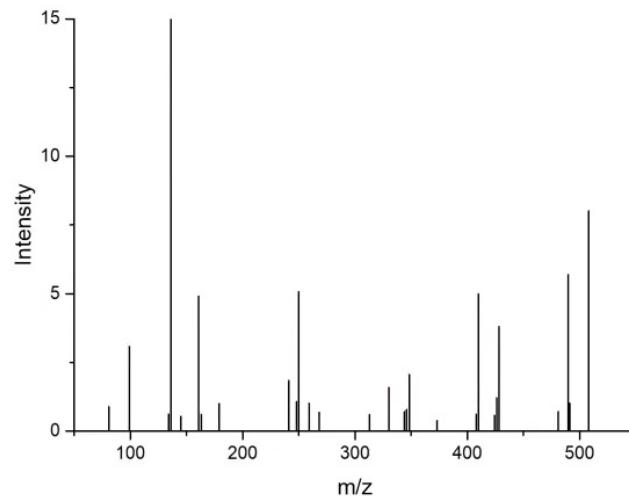
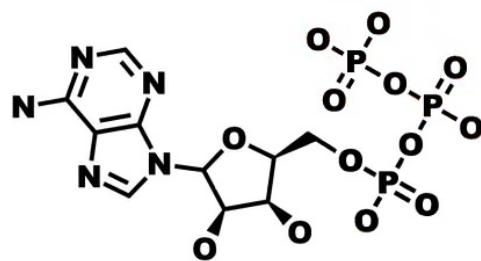


Assembly Measurement System



Molecular Assembly Index (MA)

MA: 21

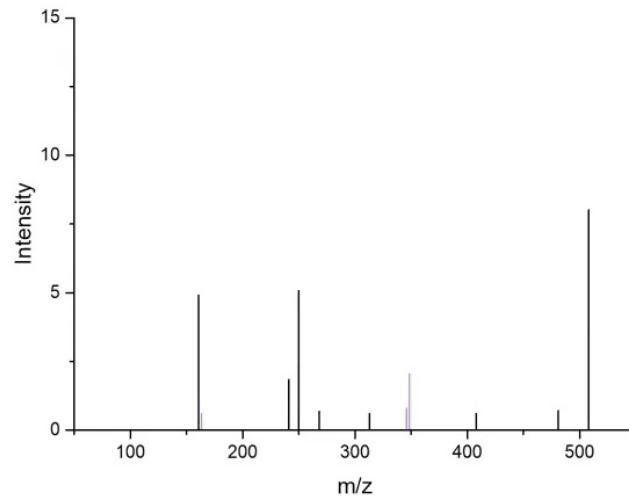
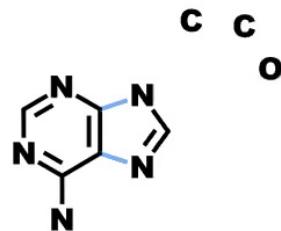


Assembly Measurement System



Molecular Assembly Index (MA)

MA: 9



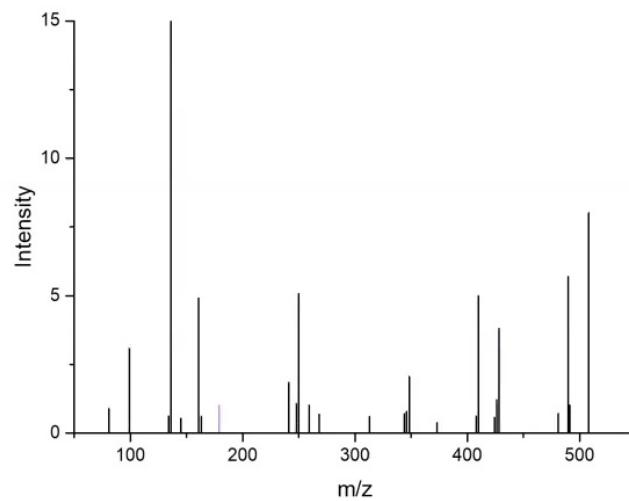
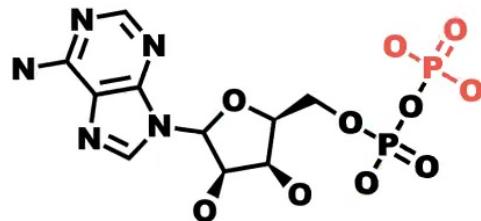
Assembly Measurement System



Sara Walker

Molecular Assembly Index (MA)

MA: 20

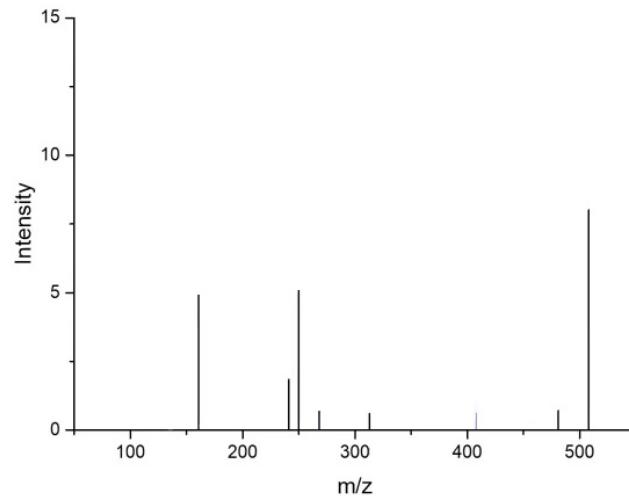
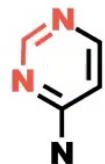


Assembly Measurement System



Molecular Assembly Index (MA)

MA: 7



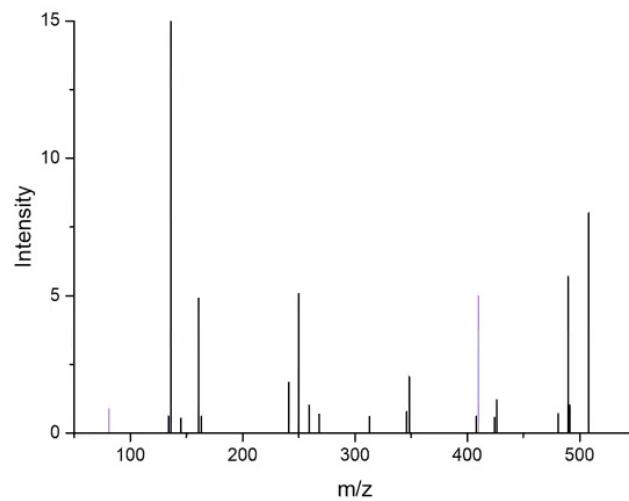
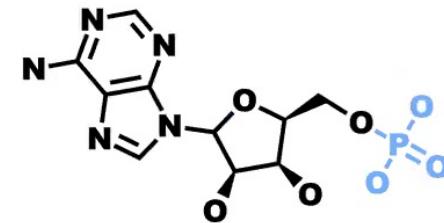
Assembly Measurement System



Molecular Assembly Index (MA)

MA: 15

New Bond
Formation
⁺⁴

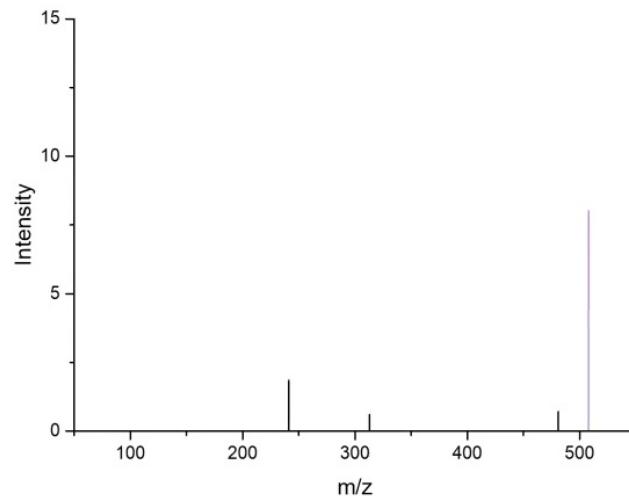
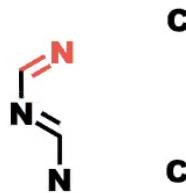


Assembly Measurement System



Molecular Assembly Index (MA)

MA: 3

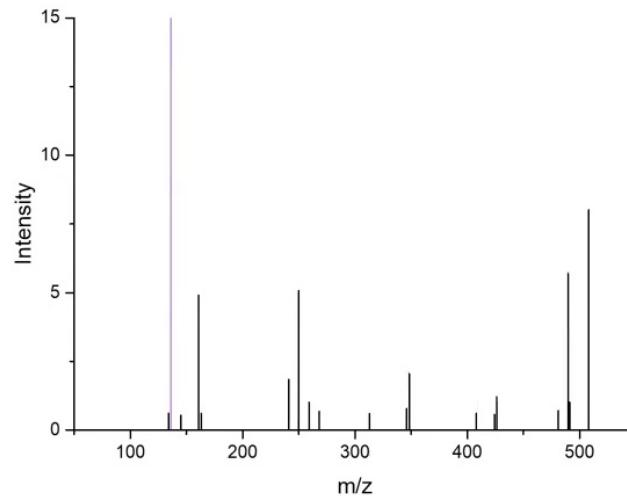
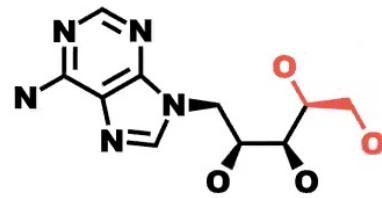


Assembly Measurement System



Molecular Assembly Index (MA)

MA: 14



Assembly Measurement System

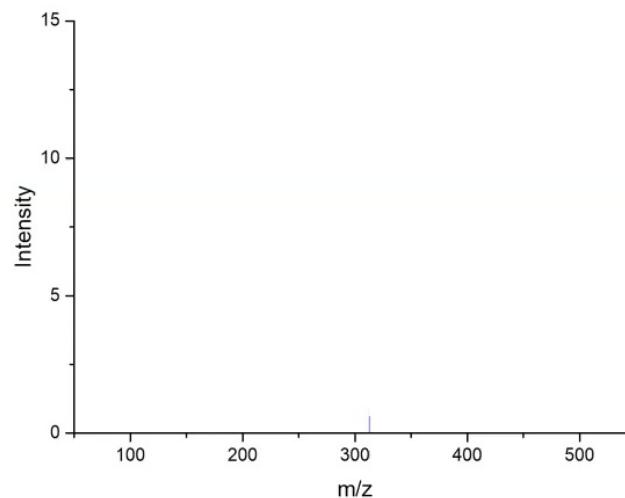


Molecular Assembly Index (MA)

MA: 1

+1

New Bond
Formation



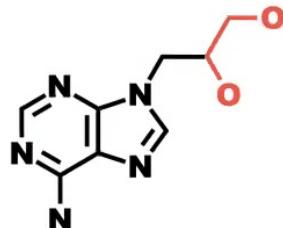
Assembly Measurement System



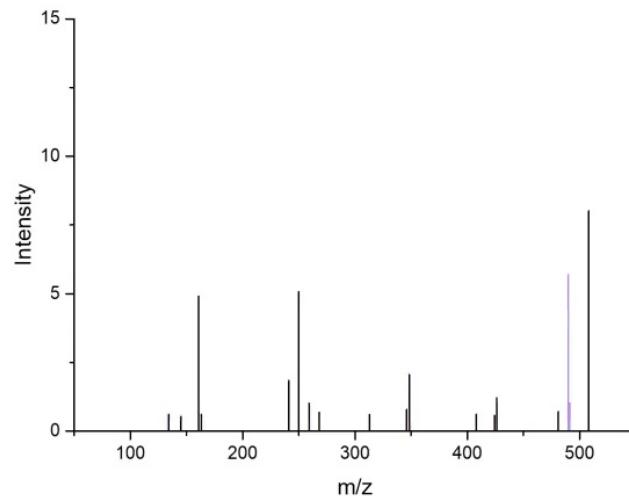
Molecular Assembly Index (MA)

MA: 13

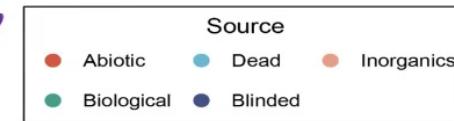
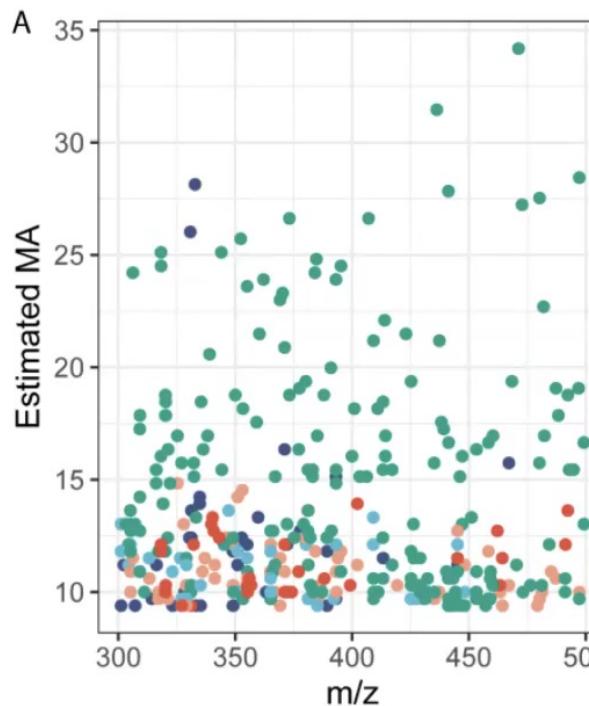
Duplicate Substructure +1



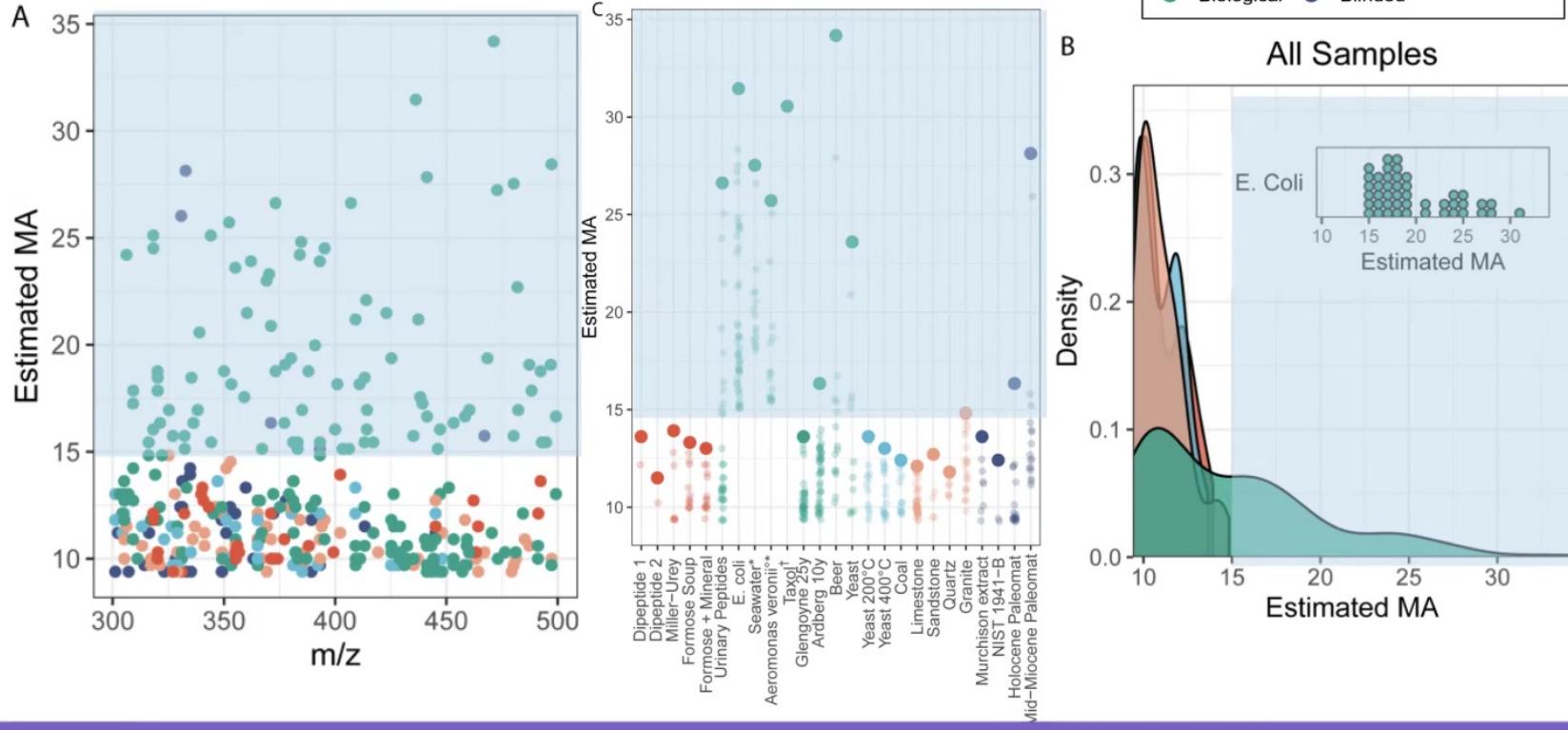
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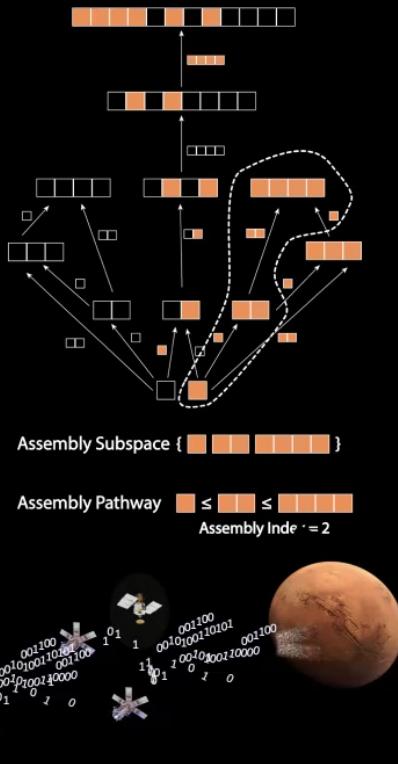
Assembly Measures 'Living Physics'



Assembly Measures 'Living Physics'



Assembly Theory and Causal Histories

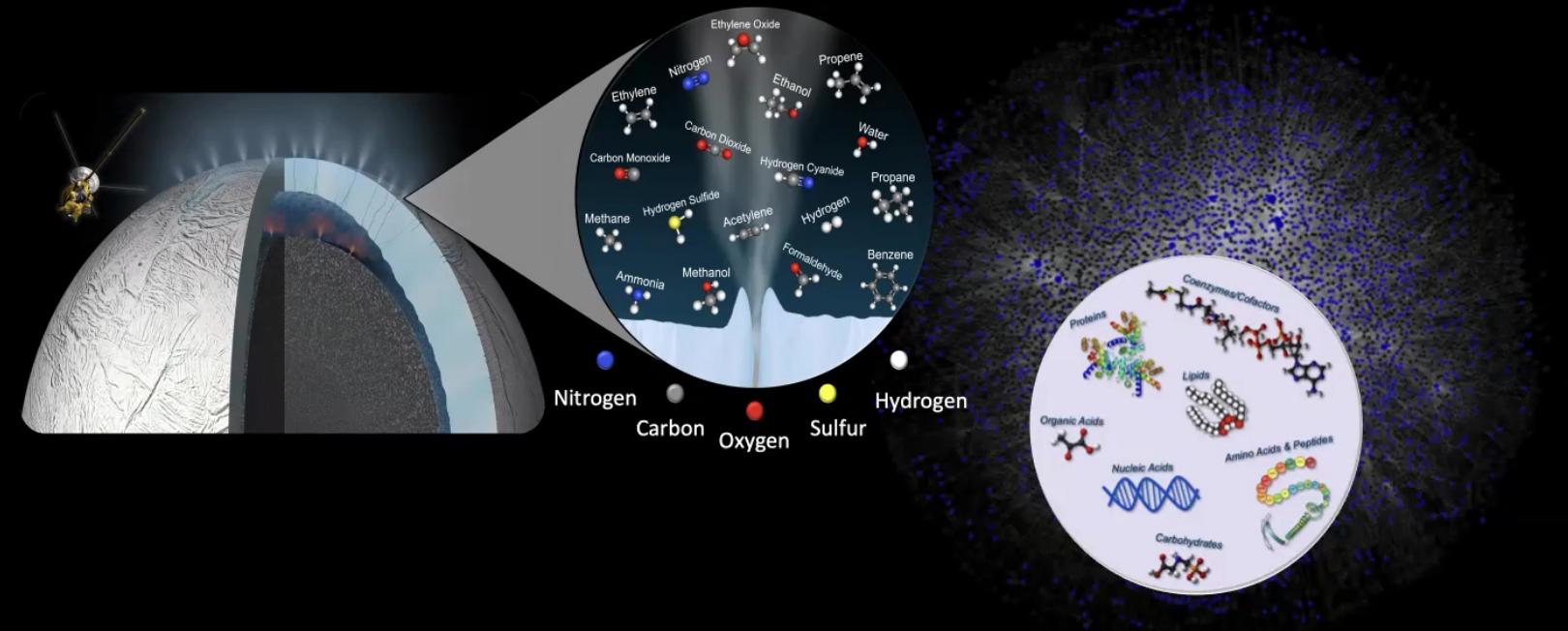


Marshall, S.M., Moore, D., Murray, A.R., Walker, S.I. and Cronin, L., 2019. Quantifying the pathways to life using assembly spaces. *arXiv preprint arXiv:1907.04649*.

Looking for Life in Molecular Assembly on Other Worlds



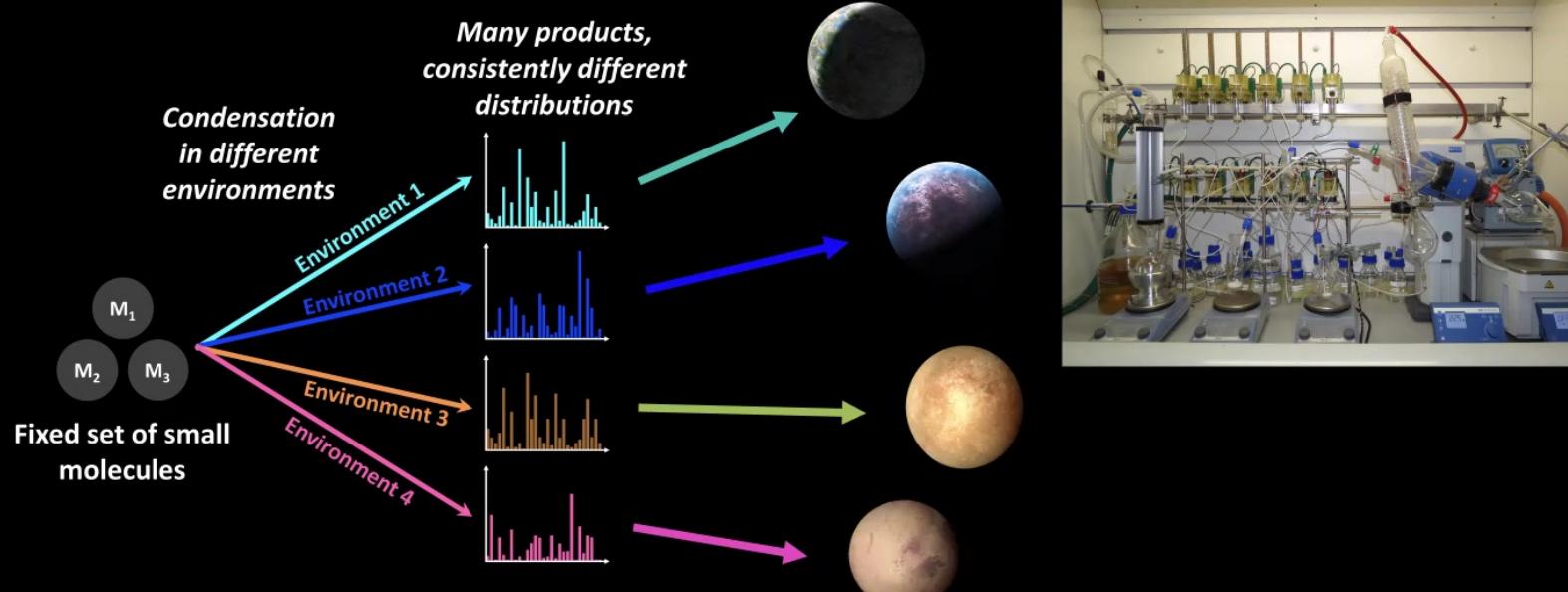
Sara Walker



Statistically exploring the origins of life and the role of planetary context



Sara Walker



Surman, Andrew J., Marc Rodriguez-Garcia, Yousef M. Abul-Haija, Geoffrey JT Cooper, Piotr S. Gromski, Rebecca Turk-MacLeod, Margaret Mullin, Cole Mathis, Sara I. Walker, and Leroy Cronin. (2019) "Environmental control programs the emergence of distinct functional ensembles from unconstrained chemical reactions." *Proceedings of the National Academy of Sciences* 116 (12) : 5387-5392. Shipp JA, Gould IR, Shock EL, Williams LB, Hartnett HE. Spahlerite is a geochemical catalyst for carbon– hydrogen bond activation. *Proceedings of the National Academy of Sciences*. 2014 Aug 12;111(32):11642-5.



Thank you

Lab Members working on projects presented:

Hyunju Kim
Doug Moore
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Dylan Gagler
Bradley Karas
John Malloy
Camerian Millsaps
Pilar Vergeli
Veronica Mierzejewski
Cole Mathis (now NASA Postdoc Fellow)
Harrison Smith (now at ELSI @ Tokyo Tech)

Collaborators on projects/ideas discussed:

Lee Cronin (Glasgow)
Aaron Goldman (Oberlin)
Chris Kempes (SFI)
Michael Lachmann (SFI)
Paul Davies (ASU)



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