Title: Towards inclusion of biology in cosmology

Speakers: Marina Cortes

Collection: Emmy Noether Workshop: The Structure of Quantum Space Time

Date: November 22, 2019 - 2:00 PM

URL: http://pirsa.org/19110104

Abstract: Cosmologists wish to explain how our universe, in all its complexity, could ever have come about. For that, we assess the number degrees of freedom in our Universe now. This plays the role of entropy in thermodynamics of the Universe, and reveals the magnitude of the problem of initial conditions to be solved. In our budget, we account for gravity, thermal motions, and finally the vacuum energy whose entropy, given by the Bekenstein bound, dominates the entropy budget today.

There is however one number which we have not accounted for: the number of degrees of freedom in our complex biosphere. What is the entropy of life? Is it sizeable enough to need to be accounted for at the Big Bang, or negligible compared to vacuum entropy?

Towards the inclusion of biology in Cosmology

Marina Cortês

with Lee Smolin,

Andrew Liddle, Stuart Kauffman,

Carlo Rovelli, Jaron Lainier

Emmy Noether Workshop, November 22nd, 2019

Lee Smolin,
Andrew Liddle, Stuart Kauffman,
Carlo Rovelli, Jaron Lainier

• Indebted to my collaborators who are fearless. They do not fear asking questions and they do not fear the answers.

• Preempt: work in progress, lots of details to understand, lost of calculations left to do.

• Preempt: work in progress, lots of details to understand, lost of calculations left to do.

• I tried to make it accessible, but *ask* questions.

CORTÊS AND SMOLIN

ENERGETIC CAUSAL SETS

Emergence of space-time;

Time symmetric dynamics from time asymmetric laws;

Partial emergence of quantum mechanics

PHYS. REV. D 90, 084007 (2014)

PHYS. REV. D 90, 044035 (2014)

Correspondence of models with Spin Foam dynamics

with Wieland

PHYS. REV. D 97, 026004 (2018)

Time asymmetric extensions of General Relativity

with Gomes, Liddle

PHYS. REV. D 92, 043502 (2015)

PHYS. REV. D 94, 123514 (2016)

Correspondence of time asymmetry to Discrete Dynamical Systems

PHYS. REV. D 97, 026004 (2018)

arXiv:1902.05108

arXiv:1902.05082

PHYS. REV. D

Retrocausality and time asymmetry in quantum mechanics;

Avshalom Elitzur; Eliahu Cohen

Irreversibility

Irreversibility

If time is real (opposed to emergent) then it needs to have time's most stark property : IRREVERSIBILITY

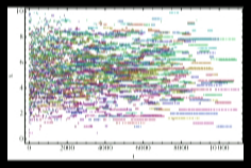
Irreversibility

If time is real (opposed to emergent) then it needs to have time's most stark property : IRREVERSIBILITY

Cortês and Smolin

The Universe as a Process of Unique Events

PHYS. REV. D 90, 084007 (2014)



Irreversibility onto quantum gravity

Seminal energetic causal sets

emergence of space-time from underlying time-asymmetry

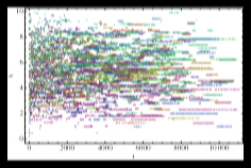
Irreversibility

If time is real (opposed to emergent) then it needs to have time's most stark property : IRREVERSIBILITY

CORTÊS AND SMOLIN

The Universe as a Process of Unique Events

PHYS. REV. D 90, 084007 (2014)



Irreversibility onto quantum gravity

Seminal energetic causal sets

emergence of space-time from underlying time-asymmetry

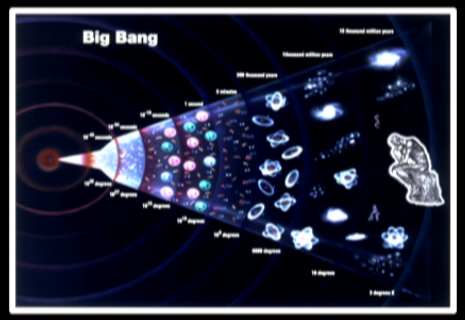
FIRST BUCHALTER COSMOLOGY PRIZE (2014)

Origins

In cosmology irreversibility is closely tied with initial conditions (origin of the arrows).

How likely are the initial conditions that give rise to our universe?

What is the measure or volume of the initial conditions in the space of all configurations?



How to compute:

1. compute the entropy of the universe today.
2. get the corresponding number of degrees of freedom – proxy for configuration space today
3. Assume that the configuration space and physical laws remain constant throughout the universe's evolution.
4. Fundamental laws are deterministic

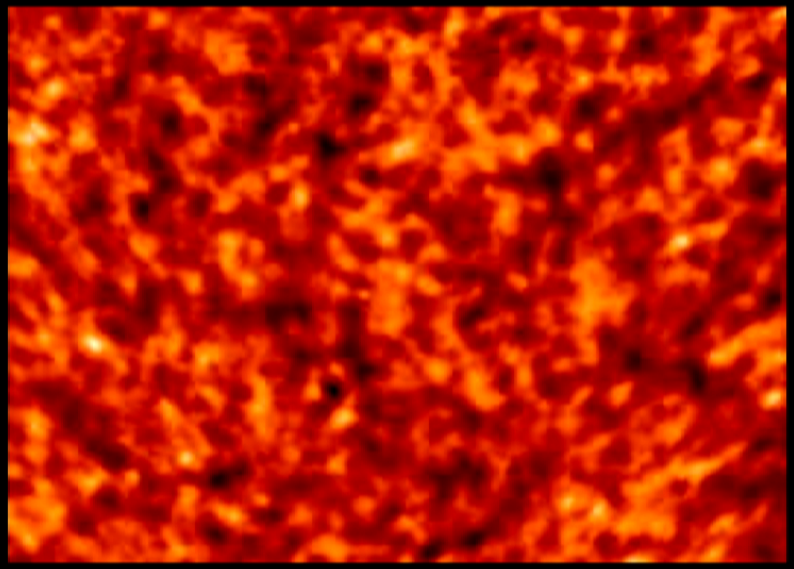
Calculating Early Universe Entropy:

traditional view

HOT PLASMA

$S = k \ln V = 10^{80} \times 10^{8}$ (natural units)

total number of degrees of freedom = $e^{10^{88}}$



Calculating Early Universe Entropy:

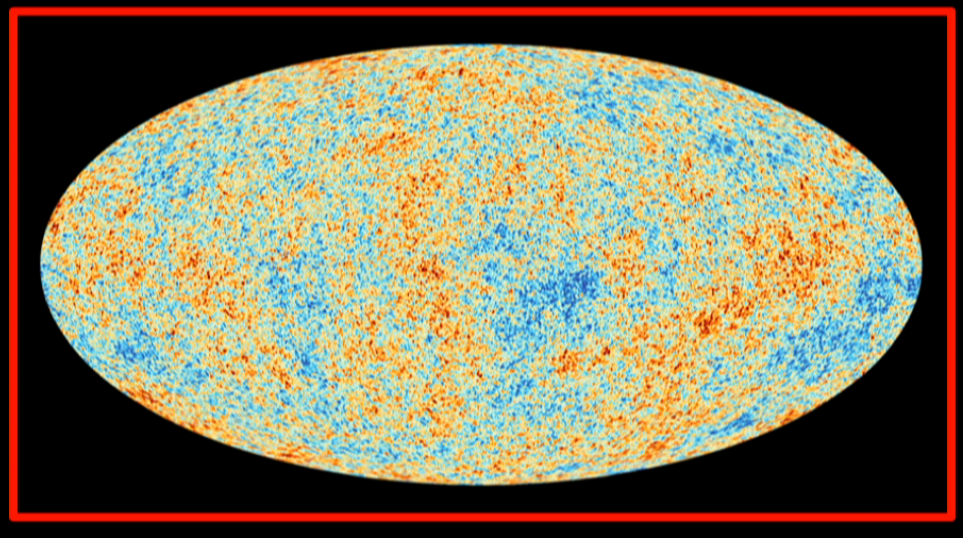
traditional view

HOT PLASMA

total number of degrees of freedom = $e^{10^{88}}$

if this was the total amount of degrees of freedom in the early universe today we would be a cold 3K plasma

like this



Calculating Early Universe Entropy:

HOT PLASMA

total number of degrees of freedom = $e^{10^{88}}$

Not like this

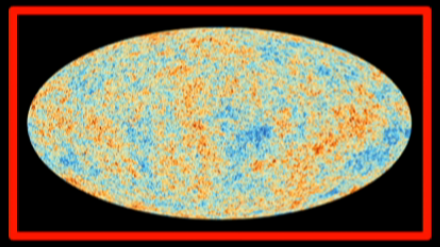
Illustris

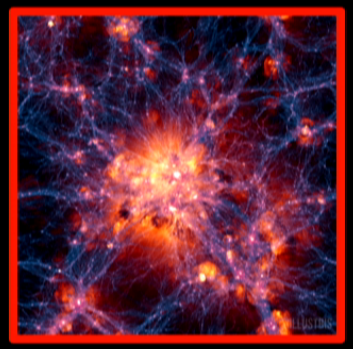
Calculating Early Universe Entropy:

HOT PLASMA

total number of degrees of freedom = $e^{10^{88}}$

Not like this





•Fortunately we'll want to explain how the galaxies got here (as well as the CMB) which wouldn't be true if weren't for gravity.

•So lets count the numbers of degrees of freedom in gravity.

•Nobody knows what is the number of degrees of freedom in gravity except for one case.

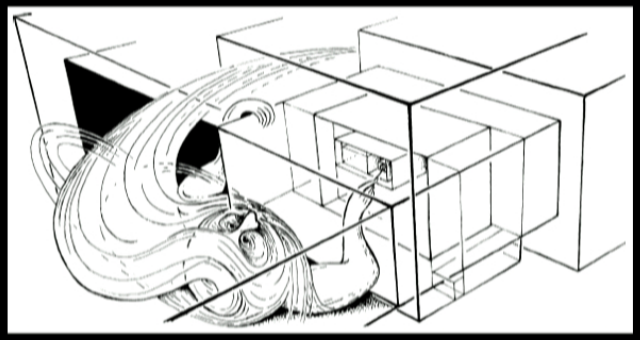
Early Universe Low Entropy: Bekenstein-Hawking

Number of gravitational degrees of freedom: 10^{21} per baryon (in a galaxy with 10^{10} solar masses and a Sagittarius A type black hole at the core with 10^{6} solar masses).

Number of baryons: 10^{80}

Entropy today is 10^{101}

We will eventually end up with entropy 10^{120} when all baryons collapse in super massive black hole.

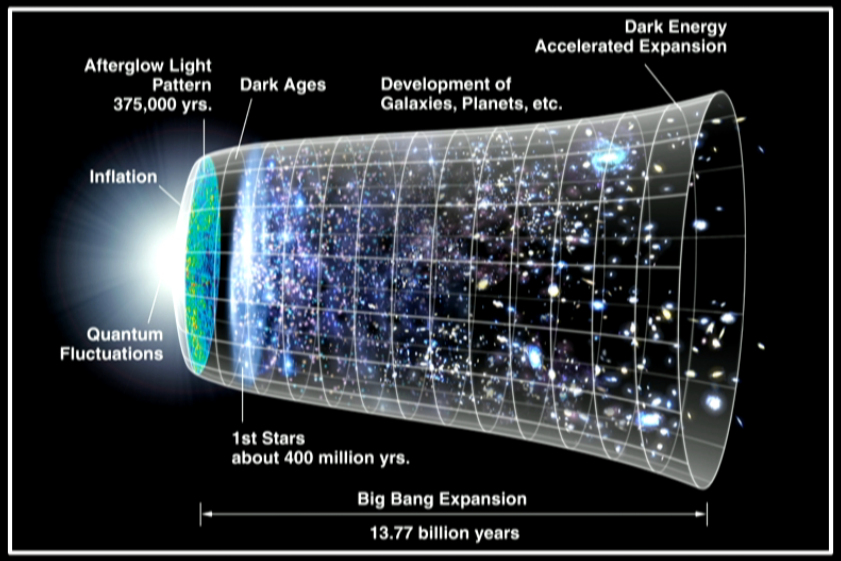


R.Penrose, *The Road to Reality*

Likelihood of the Big Bang: 1 in $e^{10^{101}}$

Are we done counting?

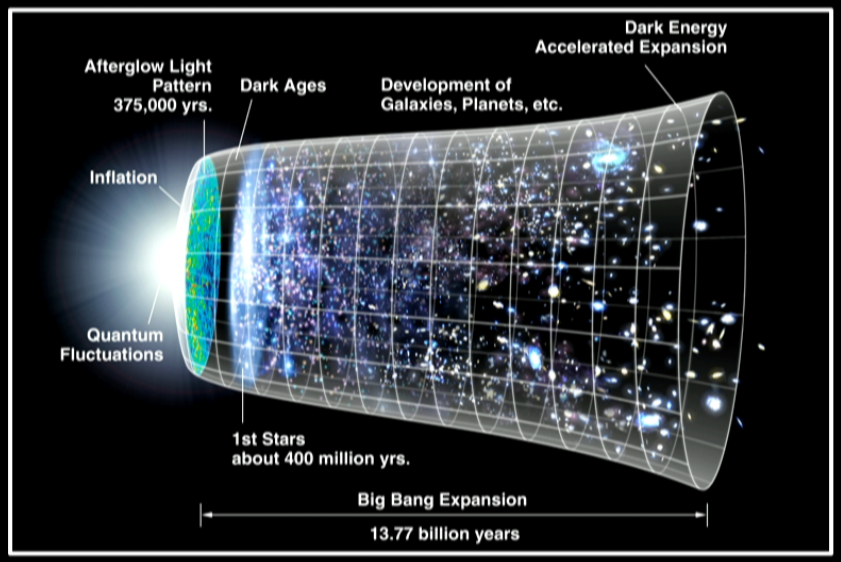
No. We haven't accounted for the gentle outwards curve in the late universe.

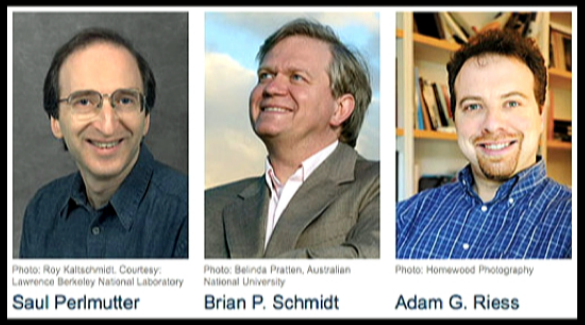


Early Universe Low Entropy

That's also not how the universe looks like today. There is dark energy.

The entropy of the vacuum is given by the Bekenstein bound.





Likelihood of the Big Bang: 1 in $e^{10^{120}}$

$e^{10^{120}}$

You know you're in trouble when you need an exponential
to represent the exponent of your number

Accounting for different contributions to today's entropy

•Are we done counting degrees of freedom in the universe today? Or is there is anything we're (still) overlooking.

What is your ambition for cosmology?

• What parts of the universe do you want to include in your cosmology. What are the seeds you want to include in initial conditions?

• Conventional: theoretical model where galaxies can be treated as points in the homogeneous isotropic fluid. Study and explain origin of inhomogenities that seed formation of structure.

What is your ambition for cosmology?

Cosmos is all there is, all there was, and all there will be.

Carl Sagan, *Cosmos*

What is your ambition for cosmology?

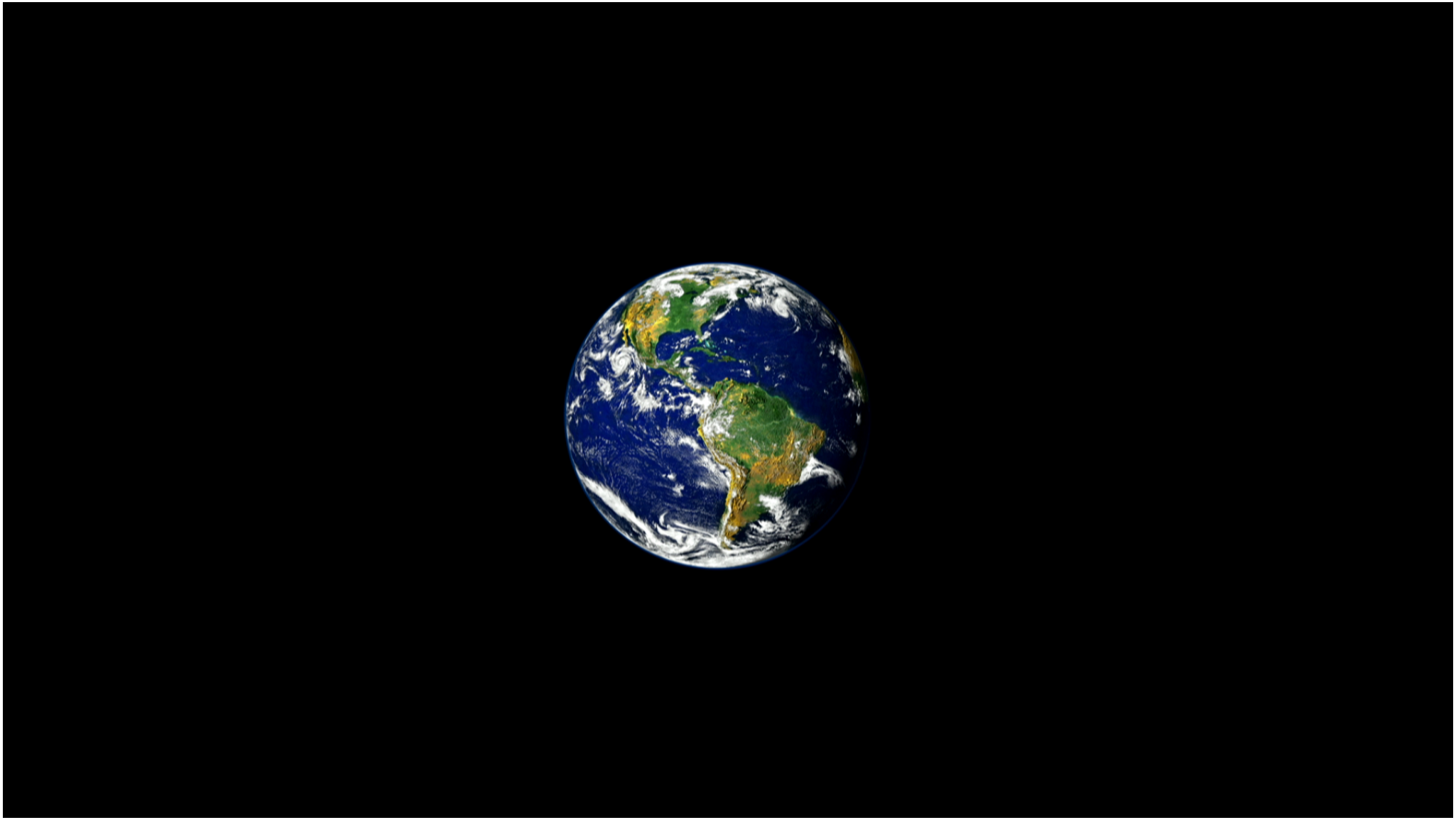
Cosmos is all there is, all there was, and all there will be.

Carl Sagan, *Cosmos*

My ambition for cosmology is that it (ultimately) will explain *everything* we see.

What is your ambition for cosmology?

There is one number we have not included in our entropy budget.



What is the configuration space of the biosphere?

What is your ambition for cosmology?

- What is the entropy of life?
- Is it sizable and to be accounted for at the big bang, or is it negligible compared to the entropy of Lambda?
- If we give life an equal status in physics, if we democratically attribute biological systems on earth with their own configuration space, and their own volume of microphysical degrees of freedom, what number will we find?
- How does that number compare with the number of d.o.f in the area of black holes? Can we ignore it altogether or will we find something altogether new?

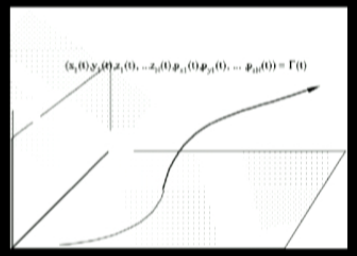
Can we aspire to take the first small steps towards the inclusion of biology in our cosmology?

What is the configuration space of the biosphere?

- There are less particles on earth than in universe. It's ridiculous that it can contain more degrees of freedom than vacuum energy.
- If we do permutations of particles on the planet across (physical) configuration space we'll get a number vastly smaller than $e^{10^{120}}$
- Physical c.s. does not account for formation of complex structures.
- There are new degrees of freedom in dynamics of complex systems in general, and biological systems in particular, that are not captured in combinatorial position-momentum permutations of configuration space.

Newtonian Paradigm

- Configuration space or phase space - one of the most important and prevalent tools in (classical) physics.
- 6N dimensional – 6 position, momentum variable per particle
- Together with specification of,
  - deterministic laws
  - initial conditions or boundary conditions



this forms the Newtonian paradigm or Newtonian methodology for studying physical systems

- View that has prevailed in physics for 200-300 years.
- Valid for systems where configuration space is constant in time and physical laws are deterministic (in Bigbang initial conditions case.

Time in Cosmology

Perimeter Institute for Theoretical Physics -June 2016

Organizers: Marina Cortês, Lee Smolin

Participants: George Ellis, Neil Turok, Sean Carroll, Jim Bardeen, Andrew Liddle, Andy Albrecht, Abhay Ashtekar, João Magueijo, Carlo Rovelli, Barbara Drossel, Brian Keating, Fay Dowker,…

All discussions available at

PIRSA

Irreversibility – formation of complex structure

• Stuart Kauffman, Barbara Drossel, George Ellis

• Formation of structure, complexity, and top-down causation, in statistical physics, many body physics (condensed matter and quantum systems), and biology.

• They argued that there are limitations of the Newtonian paradigm in applications of complex structures.

Adjacent possible

Kauffman, *At Home in the Universe* (1995)

- There is no initial configuration space from which the biosphere can be derivable.
- Write down the configuration at the onset of life 3.5 billion years ago.
- Write down all possible states of the biosphere from 3.5 billion years ago until now.
- Theory of the adjacent possible
- In the biosphere the configuration space is ever expanding.
- The universe is highly non ergodic. Exploration of today's configuration space at a rate of microsecond per state would take several times the Hubble time.

Adjacent possible

• Configuration space of life cannot be pre-stated.

• The configuration space of life cannot be pre-specified for the Newtonian paradigm to be used.

• It is ever increasing, constituents in a given space combine to form novel, more complex structures, which could not have been derived *a priori*.

• The biosphere (econosphere) have exploded in diversity, exploding into their adjacent possibles. Both create their new configuration space at each moment in evolution.

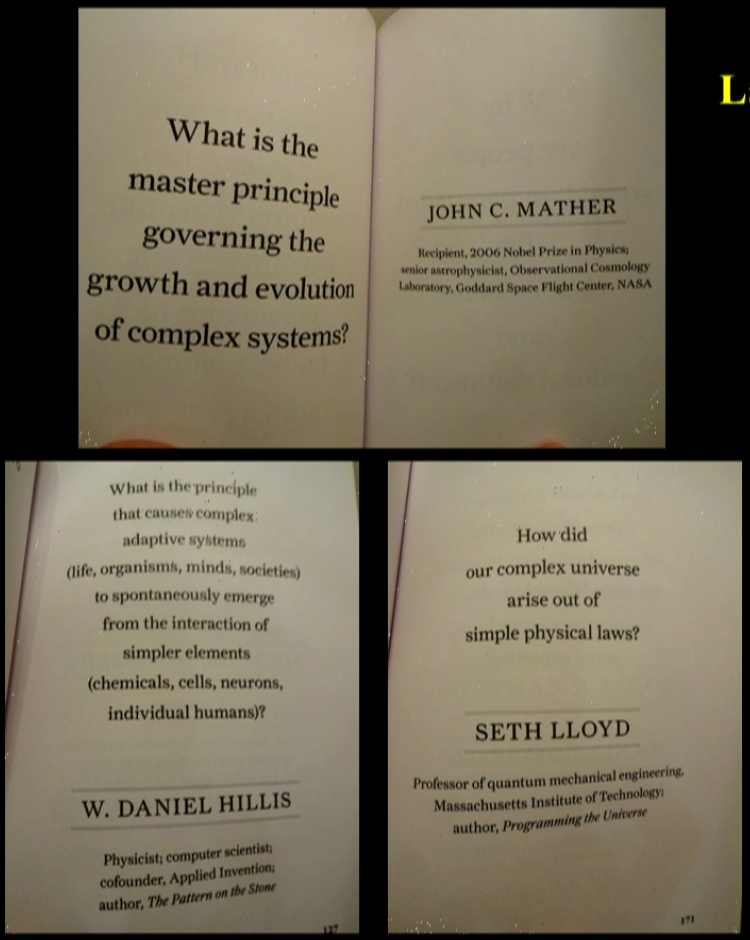
• We cannot write laws in differential form to predict what the next "fittest" organism will be.

Adjacent possible

We cannot integrate the equations of motion to predict what a person will decide or what an organism will do.

Biologists seem to be ok with impossibility of knowing, but physicists have a little more trouble…

What are the last questions?



Last 'Edge' essay collection (2018)

Edge.org

John Brockman, Brockman Inc.

The name of the game is *getting to exist.*

What is the number of possible states in the biosphere? Is it countable?

•What is the number of uses for a screwdriver?

•It cannot be predicted that a bacteria will jump on the back of another bacteria and find competitive advantage.

•It cannot be predicted that when fish developed a swim bladder there happened to swim a bacteria nearby who found it a hospitable environment to live.

• We can't count number of possible functions of elements in biological systems. There is no one function that you can prove to be outside the set of possibilities.

•By induction show that it is divergent.

What is the number of possible states in the biosphere? Is it countable?

- If it's unbounded then we in physics have experience in regulating infinities.
- We can make an approximation that will bring the value down to finiteness.
- Then the question is: is that number larger than the entropy of the vacuum? $e^{10^{120}}$

- Captured in the equation for the adjacent possible.

What is the number of possible states in the biosphere? Is it countable?

- If it's unbounded then we in physics have experience in regulating infinities.
- We can make an approximation that will bring the value down to finiteness.
- Then the question is: is that number larger than the entropy of the vacuum?

$e^{10^{120}}$

This is the project.

What is the number of possible states in the biosphere?

1. Theory of the Adjacent possible
2. Mutual information, criticality, and edge of chaos
   - Genetic Regulatory random Boolean networks

Theory of the adjacent possible

Combinatorial Innovation

A feature of biological systems (human creativity/number of patents) is the ability to take a subset of existing items (living cells/objects/ideas/ techniques) and combine them in various ways to give rise to new items which in turn fuel further growth.

TAP equation represents the time evolution of the diversity (of life).

$$M_{t+1} = M_t + \sum_{i=1}^{M_t} \alpha_i \binom{M_t}{i}$$

Koppl et al (2018);

Steel, Hordijk, Kauffman (2019)

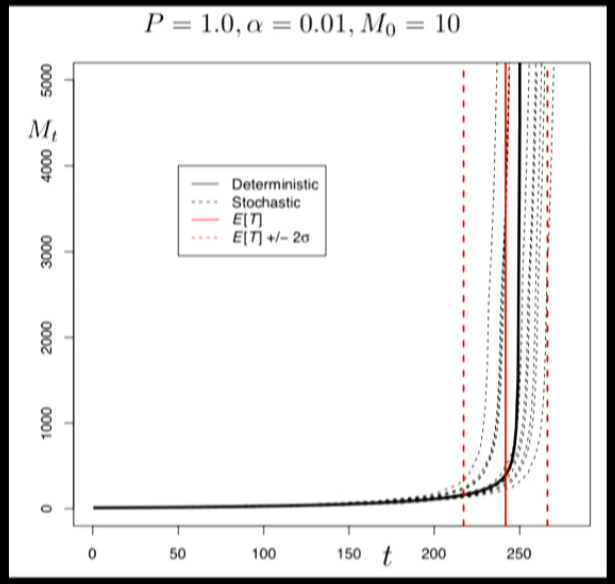
M - number of elements in the system at time t

α - decreasing sequence of numbers reflecting decreasing ease in finding and testing new combinations

Explosive growth at finite time to infinity

Theory of the adjacent possible

Combinatorial Innovation



Steel, Hordijk, Kauffman (2019)

Explosive growth at finite time to infinity. Even when truncated at combinations of 2 elements.

Patents explore and create the unprintable adjacent possible.

Theory of the adjacent possible

Combinatorial Innovation

A feature of biological systems (human creativity/number of patents) is the ability to take a subset of existing items (living cells/objects/ideas/ techniques) and combine them in various ways to give rise to new items which in turn fuel further growth.

TAP equation represents the time evolution of the diversity (of life).

$$M_{t+1} = M_t + \sum_{i=1}^{M_t} \alpha_i \binom{M_t}{i}$$

- deterministic
- no extinction

M - number of elements in the system at time t

α - decreasing sequence of numbers reflecting decreasing ease in finding and testing new combinations

Explosive growth at finite time to infinity

Application of Adjacent possible (Kauffman)

- 10^5 variables in one organism at any one time.
- 100 billion species and correlations between subsets in the past 3.7 billion years.
- Typical population size in one species 100,000.
- Number of possible states by TAP equation is $e^{10^{43}}$

- That's large but not Lambda.
- Organisms have more than 10^5 variables.
- Humans have a trillion cells.

Conclusions

- First steps towards inclusion of biology into cosmology
- First computation of degrees of freedom in biosphere from physics point of view.
- Starting of a brand new field: Bio-cosmology.
- Assessment of the precise cosmic placement, in the information content of the universe, of our biosphere, and all living beings on the planet.
- And to finish I'll reveal the real underlying interest behind this programme…

Mutual Information
Genetic Regulatory Networks
Criticality in random Boolean networks

- Measure zero. The number of boolean networks which are critical has measure zero. (Chaotic/Ordered)
- Because of this we call them the edge of chaos.
- It appears that life explores the measure zero set of networks which are critical. MI is maximized at dynamical criticality.
- Systems with multi-stability and multiple attractors.

Life maximizes mutual information

- MI is another proposal for counting d.o.f. in the biosphere.

Conclusions

- First steps towards inclusion of biology into cosmology
- First computation of degrees of freedom in biosphere from physics point of view.
- Starting of a brand new field: Bio-cosmology.
- Assessment of the precise cosmic placement, in the information content of the universe, of our biosphere, and all living beings on the planet.
- And to finish I'll reveal the real underlying interest behind this programme…

Cosmology for climate change

• Climatologists have seen their reputation systematically undermined by Big Oil and corporate political interests.

• It's hard to convey the specialness and richness of life in our planet in a way that's unmistakeable (not qualitative).

• By producing a number, computed by (non climatologist) physicists, that expresses and quantifies the exceptional uniqueness of the planet.

• There's the possibility that it can be more compelling to some minds than qualitative statements.

• We cosmologists are still listened to. Maybe we have a role to play.

Cosmology for climate change

• Climatologists have seen their reputation systematically undermined by Big Oil and corporate political interests.

• It's hard to convey the specialness and richness of life in our planet in a way that's unmistakeable (not qualitative).

• By producing a number, computed by (non climatologist) physicists, that expresses and quantifies the exceptional uniqueness of the planet.

• There's the possibility that it can be more compelling to some minds than qualitative statements.

• We cosmologists are still listened to. Maybe we have a role to play.

'Cosmologists find there is more information in life on our planet than in the remainder of the universe'

Be the kind of woman who, when her feet hit the ground every morning, the devil goes 'Damn, she's up!'