Remote sensing of extraterrestrial life

Complexity
as the key characteristics of living systems

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Motivation

Goal

Origin/evolution of life from broadest possible perspective
with astrophysical means

Current starting points

Strongly influenced and guided by studies of life on our planet

Assumption:
Life is qualitatively different from inanimate/inert matter

Motivation

- NASA Astrobiology Roadmap (De Marais et al., 2008)
  - "How does life begin and evolve?"
  - "Does life exist elsewhere in the universe?"
  - "What is the future of life on Earth and beyond?" …

- Reference:

  ~~Definition of "Life"~~

  Physical and chemical conditions required by organisms on Earth
  (+ extremophiles; e.g., Seckbach 2006;
  + long-term evolution of terr. atm.; e.g., Kasting & Catling 2003)

Is it possible to achieve fundamental answers about life in the universe with this approach?

Analogy: Search for exoplanets – Search for life

- Detection of the first extrasolar planet (Mayor & Queloz, 1995):

  "Completion of the Copernican Revolution" (Black, 1995)

  Really?

  Proof of technological feasibility

  <u>Surprising</u> demonstration of the shortcomings of our understanding of possible planetary system architectures

- Real gain in knowledge:

  Possibility to put our solar system in context (e.g., Wang et al. 2015)

Analogy: Search for exoplanets – Search for life

- Life: Vastly more complex and less understood phenomenon

- Constraining search within the parameter space known for life on Earth:

  a. ET life similar to that on Earth:

     Limited conclusions about the likelihood
     of *existence* of *this* kind of life under different conditions

  a. More general understanding of the nature of life, its emergence, evolution, and possible manifestations: **By chance(!)**

Required: More general definition of the term “life”

Life: Minimum definition …

… for application in astrophysics

- No unique, generally accepted definition:

  Life: Complex phenomenon
  various characteristics, depending on the perspective

- Working definition **mandatory**
  - Preparation of observing/survey strategies
  - Potential development of required observing equipment
  - Analysis of observations: Evaluation: Life detection?

Concept: „Habitable Zone“

- Apparently safest (+ convenient + tempting) approach:

  Straight-forward definition of constraints for physical and chemical parameters within which known life forms *could survive* elsewhere

  – **Simple** quantitative criteria
    (e.g., existence of molecules; temperature/pressure range)

  – **Feasibility** to measure these parameters

Severe disadvantages

Concept: „Habitable Zone“

- Severe disadvantages
  - **Strong underlying assumption:**
    Emergence and evolution of live can be reduced to very limited number of basic key properties of the life-hosting celestial body
  - **Predictive Power?**
    Approach often used to derive predictions for the influence of the few individual parameters on the properties of the habitable zone
  - **Fundamental understanding of the general properties: By chance!**
    (if focused on the conditions relevant for life on Earth)
  - **Conditions under which life emerges: By chance!**
    (if focused on already existing terrestrial life)

Life: Towards a definition for the search for life

- "Life is a self-sustained chemical system capable of undergoing Darwinian evolution" (Joyce, 1995)
- "Autonomous agents capable of reproducing themselves, and of completing at least one thermodynamic work cycle" (Kauffman, 2004)

o.k.: in-situ studies (i.e., solar system)

Not applicable in ExoPlanetary Systems

Requirements

Probe existence of life remotely

Not in conflict with other definitions

Beyond geocentric perspective

Life: Minimum definition

Organization of matter in hierarchical manner:

Emergence of increasing complexity (in structure and functionality)

- Behavior of smallest units (on a given level):
  - Determines *their interplay* and *resulting response function* on next hierarchical level
  - Interplay: Amplification / Suppression of individual characteristics; Emergence of qualitatively new properties (responses)

- Living systems:

  Characterized by complex response function

  - including “internal biological functions” on various levels

Life: Minimum definition

(1)

Complexity: Key characteristics of living systems

(2)

Understanding the **Emergence of Life**

=

Understanding the **Emergence of highly complex structures**

Evaluation: Applicability of the definition

1. Expanding our view on possible life forms: Put life on Earth in context

- Definition covers a very basic property of all life forms on Earth
  + Any physical system potentially considered as life form

- No strict cut-off line between inanimate matter and organisms

- No assumption about the origin of life

Evaluation: Applicability of the definition

2. Beyond organisms

- View on individual organisms far too narrow
- Emergence of complexity reaches beyond organisms:

Organism ⟹ Population ⟹ Ecosystem ⟹ Biosphere

3. "Intelligent life"

- "Level" of intelligence:

  Degree of complexity of the response function

Evaluation: Applicability of the definition

4. Tracing complexity ("Biosignature")

- Increasing complexity of a physical system (organism, population, …): Potentially reflected by increasingly complex interaction with its **Environment**

  Special case:

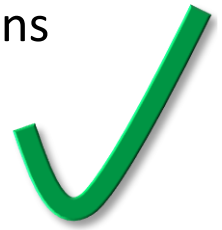
  Atmospheric states out-of-thermodynamical equilibrium
  (Lovelock 1965,1975)

  General case:

  Search for signatures which lack an explanation without the need of underlying complex processes

- Constraints? „Habitable Zone 2.0"

  Yes: Based on an improved understanding of the conditions under which complex structures emerge



In a nutshell …

Complexity: Key characteristics of living systems

- Provides basis to put life as we know it in context
- Can be traced without in-situ experiments

- Practical implementation:

  Step 1:

  – Search for signatures in observing data which lack an explanation without the need of complex processes
  – If target (e.g., exoplanet) fulfills this criterion Target marked as “showing potential signs of life”

  Step 2:

  – Dedicated follow-up studies to constrain and test hypotheses about the nature of the underlying complexity; Application of more specific definitions of life

- Useful (but not mandatory) “Homework” :

  Study the emergence of highly complex structures