

The background features a dark blue space filled with white stars. Overlaid on this are several white astronomical diagrams. On the left, there is a large circular diagram with concentric circles and radial lines, resembling a celestial sphere or a coordinate system. To its right, there are smaller circular diagrams, some with arrows indicating rotation or movement. The overall aesthetic is scientific and futuristic.

# ASTRO 5: LIFE IN THE UNIVERSE:

## LECTURE #1: WHAT IS LIFE?

**BEFORE WE CAN SEARCH FOR IT, AND  
ASSESS ITS PROBABILITIES ELSEWHERE IN  
THE GALAXY, WE NEED TO DEFINE WHAT  
WE'RE LOOKING FOR**

# WHAT CRITERIA MUST SOMETHING HAVE BEFORE YOU WOULD CALL IT “ALIVE”?

- A biologist considers... “What is Life?”. It’s not an easy question...

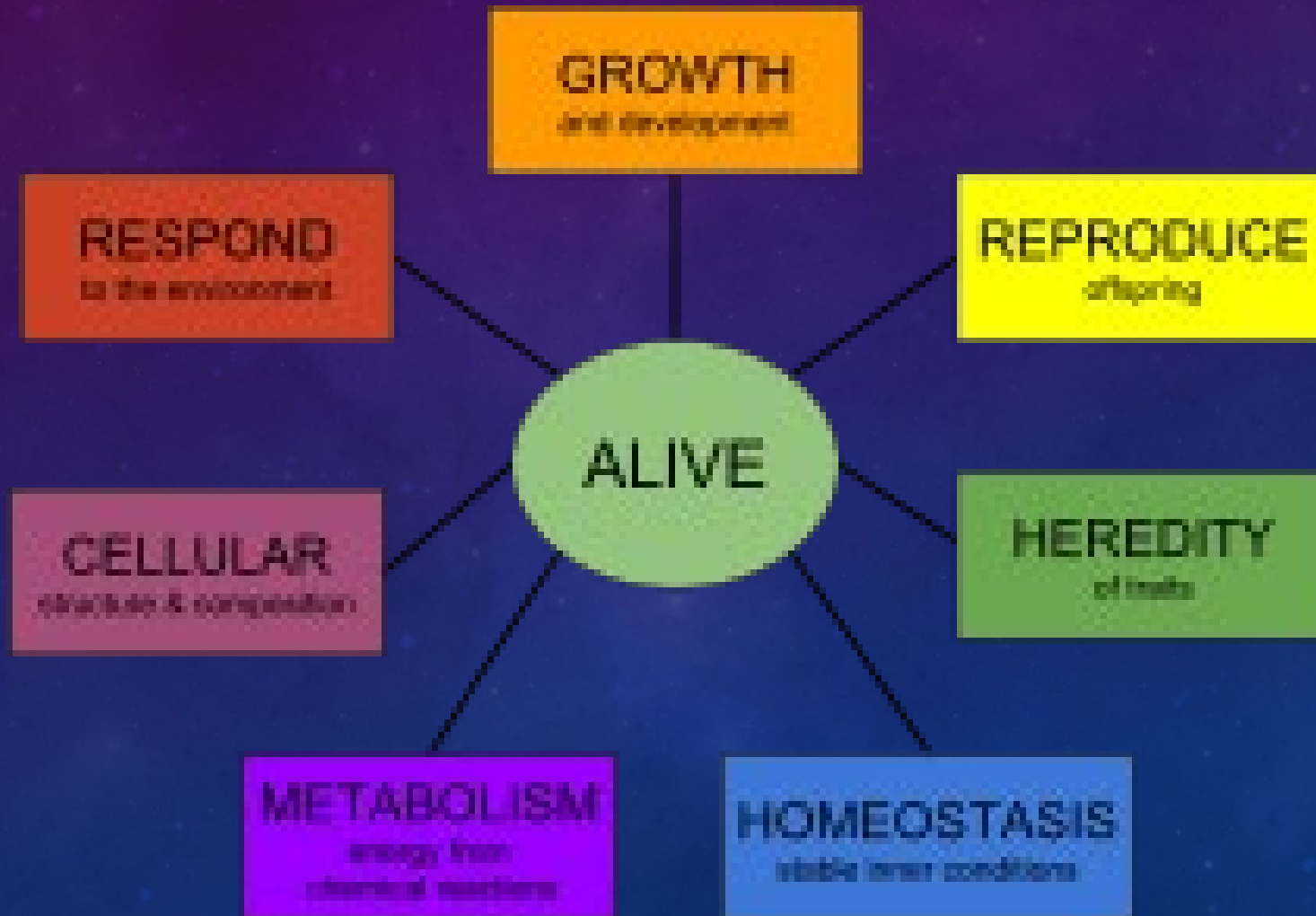
YOU CAN FIND DISAGREEMENT AMONG BIOLOGISTS WITH THE DEFINING CHARACTERISTICS OF LIFE, EVEN JUST DEFINING LIFE AS WE KNOW IT ON EARTH... HERE'S ONE SET:

## Definition of Life

**The Definition of Life: A being exhibiting all 7 criteria;**

1. Homeostasis
2. Organization
3. Metabolism
4. Growth
5. Adaptation
6. Response to Stimuli
7. Reproduction

# HERE'S ANOTHER, NOW INCLUDING THE NEED TO HAVE CELLS



# ANOTHER LIFE DEFINITION SET ... “ALL LIVING THINGS HAVE...”

## • Needs:

- Water
- Energy
- Exchange gas with surroundings
- Eliminate Waste

## • Functions and Structure:

- Respond to the Environment
- Reproduce
- Have growth as a prime goal
- Have cellular structure

HERE'S ANOTHER RATHER DEFINITELY STATED SET: "IN ORDER FOR AN ORGANISM TO BE CONSIDERED LIVING IT *MUST* SATISFY ALL 8 CRITERIA..."

- Be made of cells (at least 1)
- Take in and use energy (have metabolism)
- Respond to their environment
- Grow, develop, and die
- Be highly organized
- Maintain homeostasis
- Contain DNA to reproduce more cells and organisms
- Contain DNA so as to be able to evolve

# DNA? AGREED WE NEED REPLICATION TO REPAIR DAMAGE, HENCE GROWTH... BUT

- DNA coding is needed to create DNA
- So where did DNA first come from?
- Many biologists find a good hypothesis is that it arose from more primitive life based on RNA
- So is RNA-based life, not life? Is it not possible that RNA-based life could bypass the DNA breakthrough and yet remain RNA life, and still handle existence? Or TNA?

# DNA VS. RNA

The diagram illustrates the structural and chemical differences between DNA and RNA. On the left, the DNA structure is shown as a double helix with a central axis of sugar-phosphates and two strands of base pairs. On the right, the RNA structure is shown as a single helix with a central axis of sugar-phosphates and one strand of nucleobases. The chemical structures of the nucleobases are shown below each structure, with their corresponding colors and names.

**Nucleobases of DNA:**

- Thymine:** CC1=CNC(=O)NC1=O (Red)
- Cytosine:** NC1=NC(=O)NC(=O)N1 (Blue)
- Adenine:** NC1=NC=NC2=C1N=CN2 (Yellow)
- Guanine:** NC1=NC2=C(N=CN2)C(=O)N1 (Green)

**Nucleobases of RNA:**

- Uracil:** O=C1NC=CC(=O)N1 (Orange)
- Cytosine:** NC1=NC(=O)NC(=O)N1 (Blue)
- Adenine:** NC1=NC=NC2=C1N=CN2 (Yellow)
- Guanine:** NC1=NC2=C(N=CN2)C(=O)N1 (Green)

**DNA:** Deoxyribonucleic Acid

**RNA:** Ribonucleic Acid



# NEW RESEARCH SUGGESTS A MOLECULE THAT IS A MIXTURE OF RNA, DNA AND TNA COULD HAVE BEEN A THERMODYNAMICALLY FAVORABLE PATH TO LIFE

- *“Krishnamurthy now has experimental evidence to demonstrate that life's process on Earth could have actually started with molecules that looked like a mixture of RNA and DNA. In the latest issue of Nature Chemistry, he and the study's first author, Subhendu Bhowmik, PhD, also of Scripps Research, report that these mixed molecules form unstable duplexes and have lesser affinity for themselves.*
- *Surprisingly, these ‘chimeras’ have stronger affinity for RNA and DNA, which allows them to act as templates for making RNA or DNA.*
- *By mixing RNA-DNA, the researchers showed that it could have been possible to form a mixed molecule that could work as templates for RNA and DNA. This mixed molecule is also a high-energy system in the sense that it forms unstable duplexes.*
- *TNA – a proposed ancestor of RNA, could work, as it cross-pairs with both RNA and DNA*
- *The new research shows that these unstable duplexes (higher energy systems) are capable of giving rise to RNA and DNA, which form more stable duplexes (lower energy systems). Thus, there is a thermodynamically favorable movement from chimeric systems (less-stable, higher-energy) to homogeneous systems (more-stable, lower-energy).”*

# BUT ARE WE GETTING TOO NARROW IN DEMANDING LIFE HAVE CELLS?

- What are cells good for? Why did they come into being on our planet?
- Cells – defined by cell walls, separating them from what is outside
- Why are the walls needed? Because oxygen is so reactive, that it's a “wild bull” in the chemical machinery needed to keep the cell alive and thriving. You've heard of the importance of “anti-oxidants” in your diet? It's like that
- Well, must all life be oxygen using? We're not sure about that. All complex life on Earth is, but...

# THE EVIDENCE SUGGESTS EARTH LIFE DEVELOPED CELLS AS A DEFENSE AGAINST THE HIGHLY REACTIVE AND DANGEROUS – TO – CONTROL CHEMICAL CALLED OXYGEN

- Is cellular life really the only conceivable life?
- Oxygen is a great source of energy because it has such strong bonds
- But it is highly toxic to organisms unless carefully controlled. It was certainly toxic to anaerobic early life.
- If you think of life this way - *“Well, I’ll know it when I see it”*, isn’t life defined more by what it DOES, and not the particular structures in which that was enabled in our particular planet? **I think “yes”**.
- What do you think? Let’s kick it around.

# THE ABILITY TO REPRODUCE SEEMS FUNDAMENTAL TO ALL THESE LISTS OF CRITERIA... YET:



- Mules are created as offspring from such dissimilar species that they are sterile and cannot reproduce.
- Does that mean they are not life? Try telling the mule that, and see how he reacts (first, stand back and clear of back hoofs!)

# ABILITY TO EVOLVE BY NATURAL SELECTION?

- In the early 1990s, an advisory panel to NASA's astrobiology program, which included biochemist Gerald Joyce, came up with a working definition: *Life is a self-sustaining chemical system capable of Darwinian evolution.*
- So now, evolution is necessary to be alive? Does that sound fair?

# HERE'S MY MORE FOCUSED SET OF CRITERIA, HOPEFULLY TO BETTER INCLUDE POSSIBILITIES FOR BIZARRE ALIEN LIFE

- Must reproduce itself (No need to specify how!) – this is probably the most defining characteristic
- Must take in nutrients and energy from environment to accomplish its goals
- Must be able to fight for an ecological niche by out-competing other life wanting those resources
- \*Must be capable of evolving, in order to keep its competitive edge in an environment that changes (but, let's kick this around... does this really define all things you could consider "alive"?)

# THESE ACTIONS ARE COMPLICATED

- They require a large number of “degrees of freedom” in the entity doing them, in the jargon of Information Theory
- In plain English – *Life is Complex*
- There are 92 chemical elements allowed by the laws of physics in this Universe... proton number from 1 to 92. (Higher numbered elements are created artificially in particle accelerators, but they radioactively decay to simpler elements rapidly).
- ...And those laws are exquisitely verified to be the same laws obeyed at all places and all times in our universe (never mind the multi-verse here, that’s a very different answer)

# THERE IS ONLY ONE CHEMICAL ELEMENT WHICH IS CAPABLE OF MAKING COMPLEX MOLECULES NATURALLY— CARBON

- Carbon has 4 bonds and they are of the right strength to make molecules with the right flexibility to make structures of many atoms of great complexity and shape. No other atom has this property.
- We see no way that any conceivable naturally created life in our universe could be based on any other chemistry than carbon.
- It doesn't look like a limitation in our imagination, it seems dictated by our laws of physics.
- Life in our Universe, it seems, is all Carbon-based.
- Finding natural life elsewhere in our universe means finding environments where carbon can assemble complex molecules — organic molecules



# WHY CAN'T COMPLEX LIFE BE BASED NATURALLY ON SILICON?

- Bonds between Si and Si or between Si and H are not as stable as the bond between Si and O, so silicates (Si+O) are what predominate, not chains and structures of Si-Si-Si- as you can have in C-C-C....
- Molecules based on Si and H are unstable in presence of water, carbohydrates are more stable in the presence of water.
- The energy contained in carbon molecules is stored in their “handedness” or “chirality”, so that compatible molecules can fit together like lock and key. Carbon has a large range of such possibilities, **Silicon does not.**
- Could Silicon be the basis for alien life forms, like Carbon is on Earth?  
– Dessy 1998 in Scientific American

# “NATURAL” LIFE? YES, I’M SKIRTING A COMPLICATION HERE...

- MIT Professor Max Tegmark thinks that, at least for conscious life, we are exhibiting “carbon chauvinism” if we dismiss the possibility of consciousness in Artificial Intelligence (A.I.)
- I’ll leave aside A.I. for now.
- Consciousness might only exist in advanced life
- I’m interested in finding just life of any kind, any life.
- Silicon life almost certainly can’t arise naturally.
- It must be created. Only then... maybe dominate!



*"I HOPE WE'RE NOT JUST THE BIOLOGICAL BOOT-LOADER FOR DIGITAL SUPER-INTELLIGENCE. UNFORTUNATELY THIS IS INCREASINGLY PROBABLE" — ELON MUSK*



# CONSIDER THIS INTRIGUING DISCUSSION BETWEEN SCIENTISTS, ANALYZING THE QUESTION:

- Alien life: Will we know it when we see it?
- Features planetary astronomer Sara Seager, physicist Paul Davies, among other good scientists.
- Please listen and watch this 1hr 33min YouTube video linked above and we will discuss it next week.