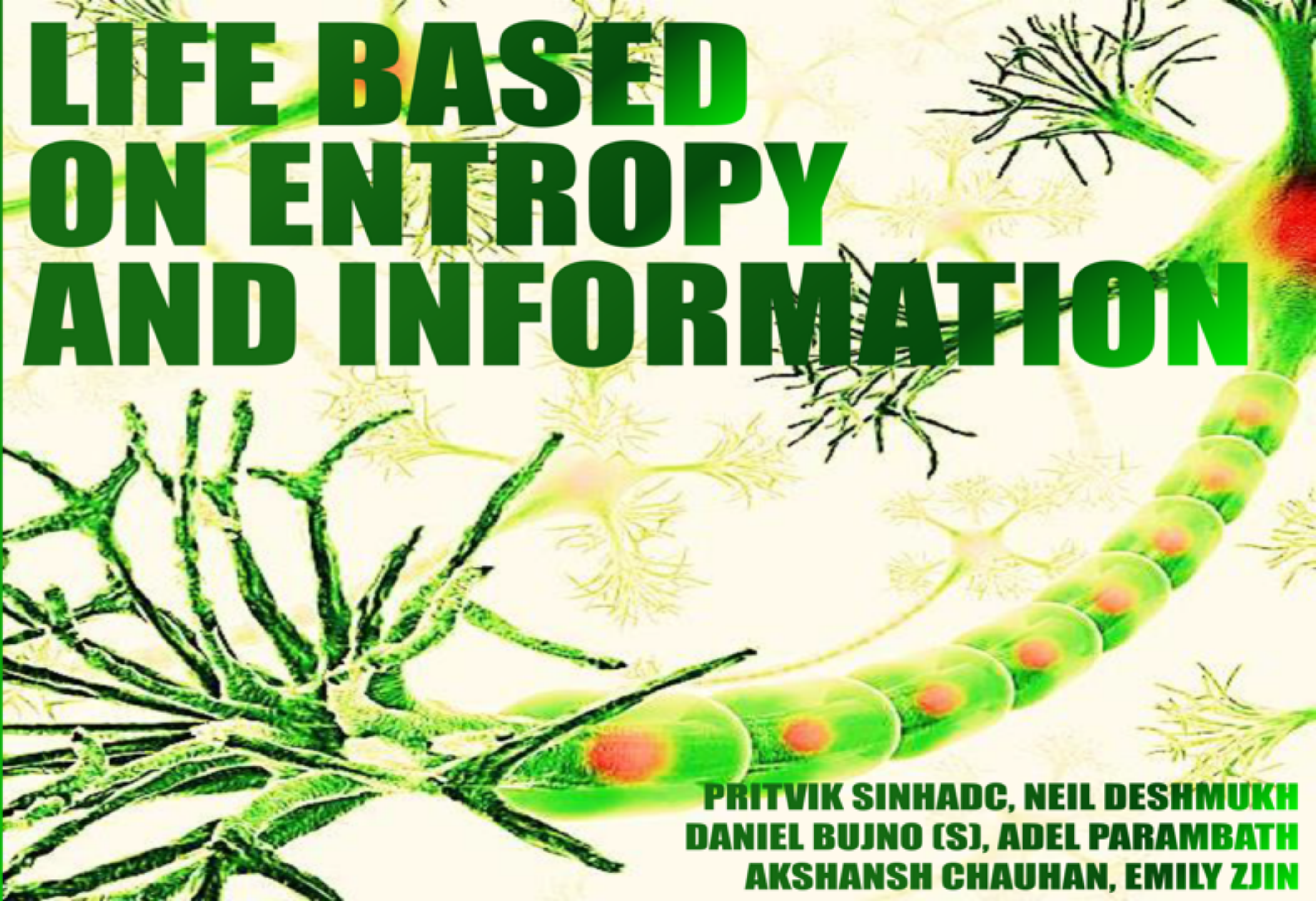
LIFE AS THE NEXT FRONTIER IN PHYSICS
PROFESSOR SARA WALKER'S PROJECT
FOR WORLD SCIENCE SCHOLARS

# LIFE BASED ON ENTROPY AND INFORMATION



PRITVIK SINHADC, NEIL DESHMUKH
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AKSHANSH CHAUHAN, EMILY ZJIN

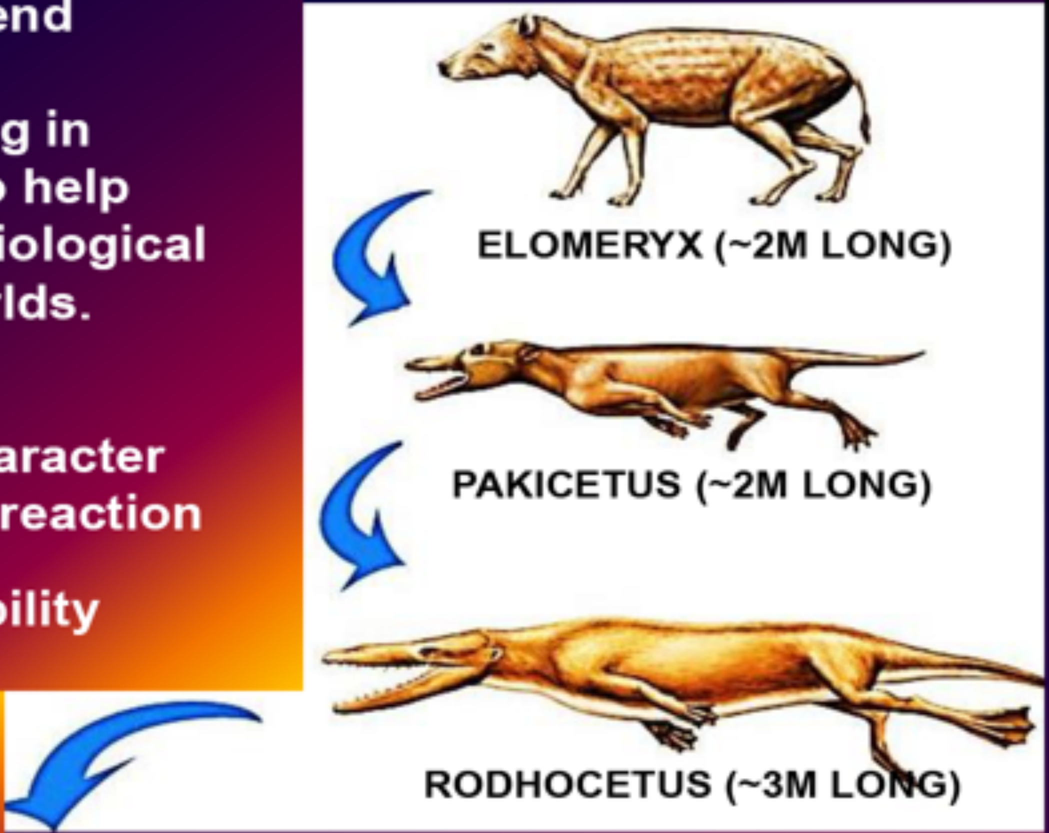
# GENERAL THEORY OF EVOLUTION

◆Attempts to extend and reformulate Darwinian thinking in chemical terms to help bridge between biological and chemical worlds.

◆ Based on the unique kinetic character of the replication reaction

◆ Identifies a stability kind associated solely with replicating entities

— dynamic kinetic stability



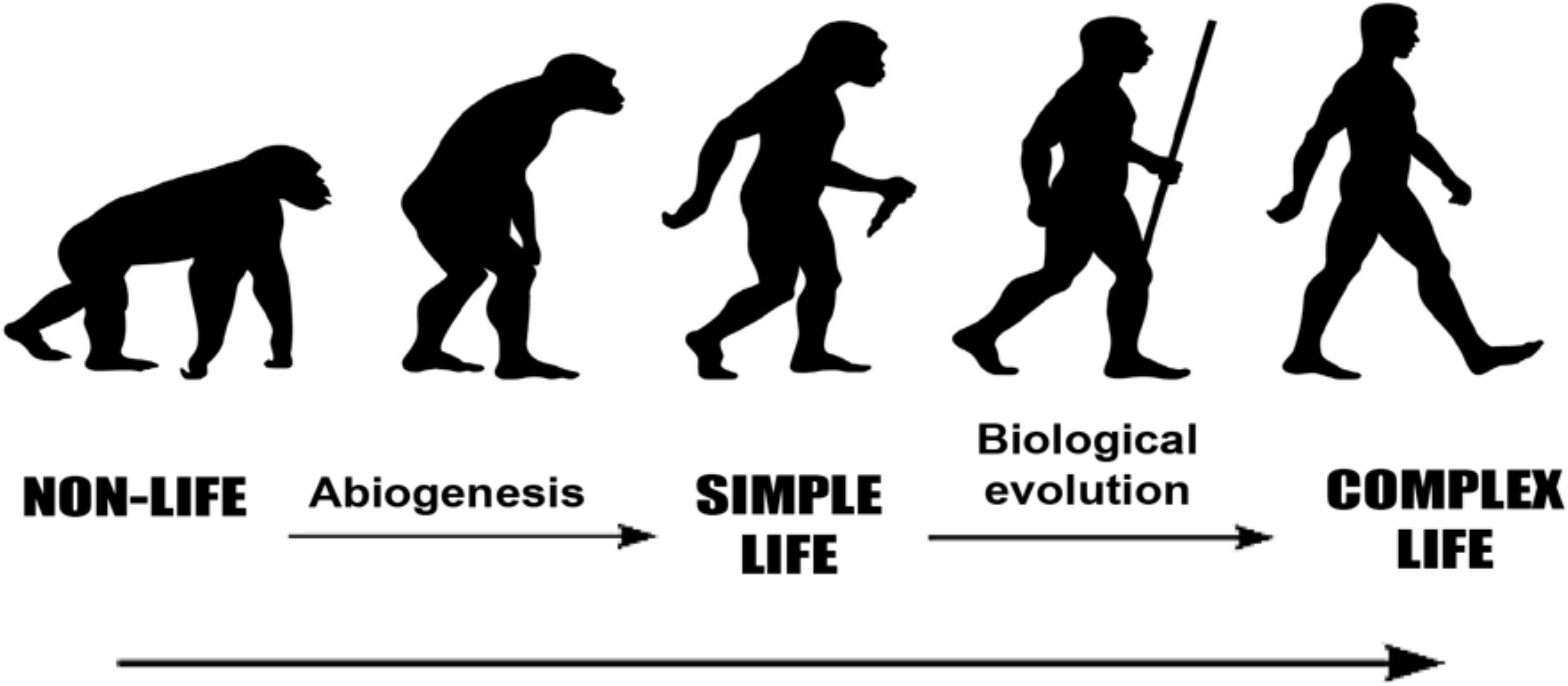


If we look at life from a physics point of view, we can see that all life shares two things in common:

◆ First, life resists entropy or decay, and, does so without aid unless nearing death

◆ Secondly, life can process or respond to information about its surroundings, such as how we notice when it is day or night (circadian rhythm) or how types of bacteria/ microbes/animals can react to droughts by entering into suspended animation (cryptobiosis). Those are, in our opinion, what defines life.

# GENERAL THEORY OF EVOLUTION




**SINGLE CONTINUOUS PROCESS GOVERNED BY DRIVE TOWARD GREATER DYNAMIC KINETIC STABILITY (DKS)**

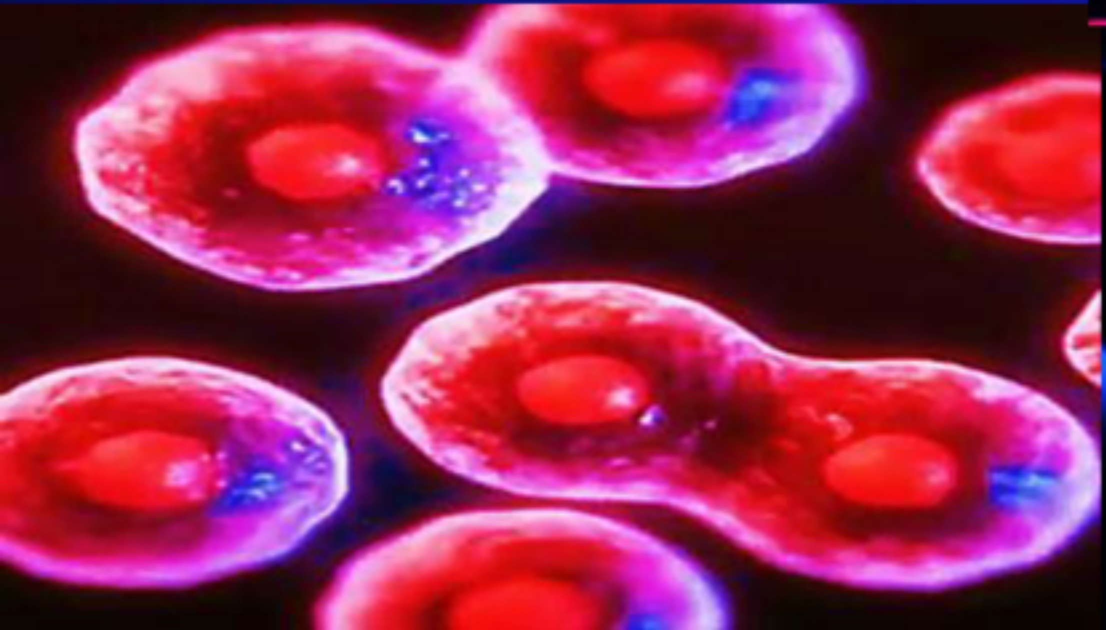
# LIFE MUST RESIST ENTROPY OR DECAY, AND DOES SO WITHOUT AID UNLESS NEARING DEATH

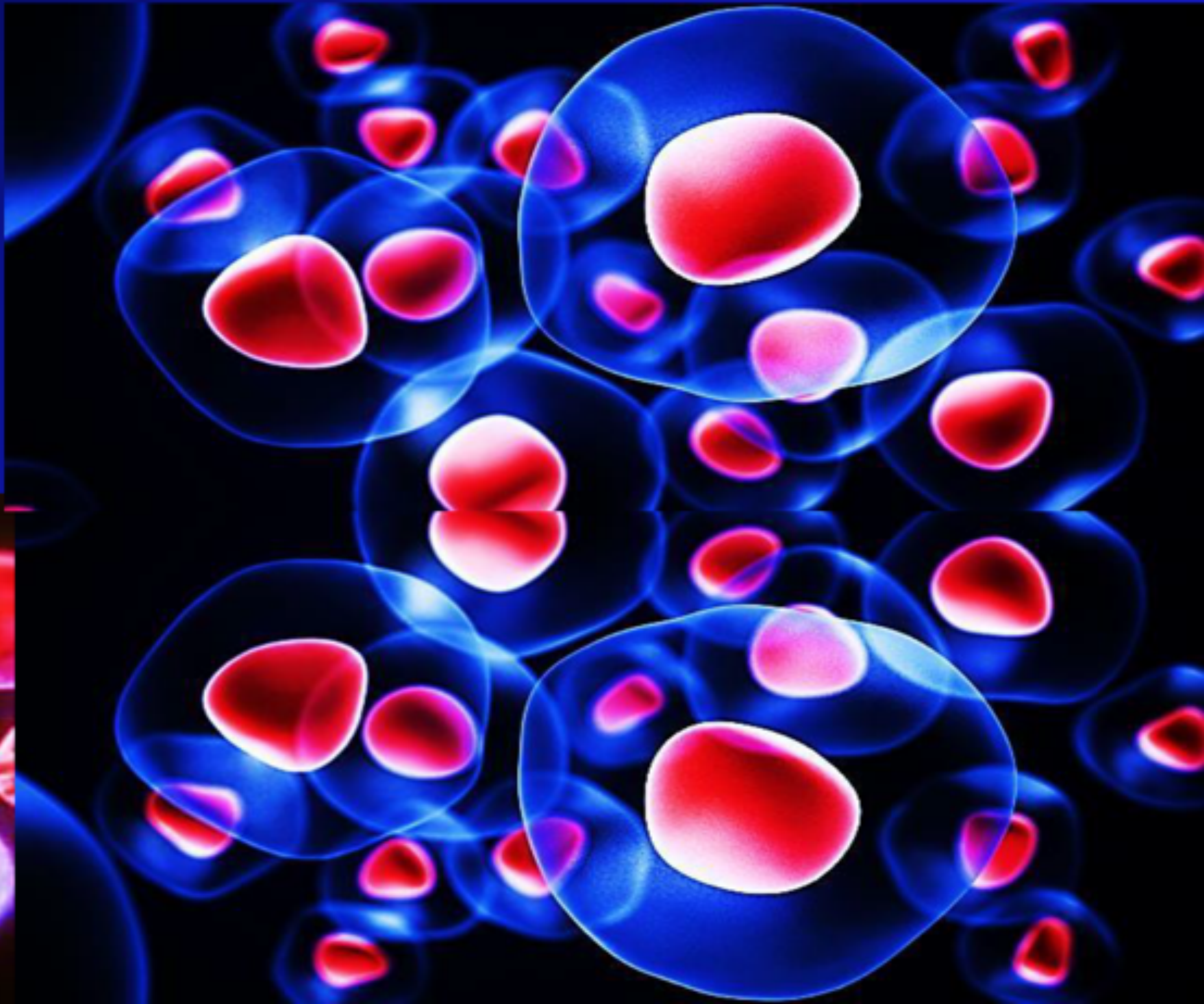
# WHAT IS ENTROPY?

Entropy is a measure of the orderliness of a physical system. States of low entropy are ‘highly ordered’ in something very like the everyday sense of the phrase. Picture a tidy desk, papers neatly stacked, pens in the pot. As order decreases and the desk gets messier, entropy increases. All living things are low-entropy and energy-consuming, so they are unstable in the thermodynamic sense. Nevertheless, they can still be remarkably stable in the sense of persisting over time.

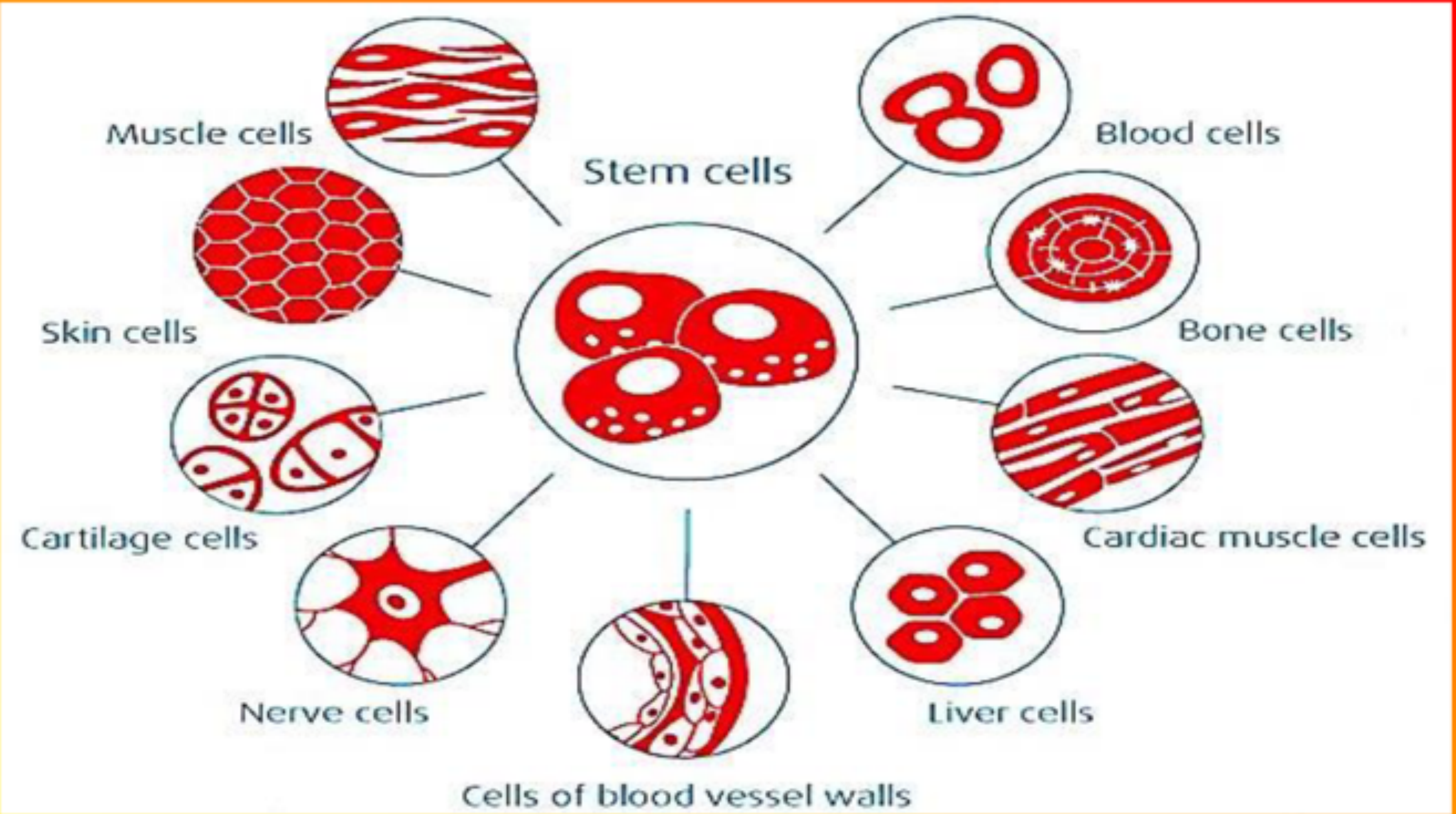
# DYNAMIC KINETIC STABILITY

Some replicating populations (certain bacterial strains, for example) have maintained themselves with little change over astonishing periods — millions, even a billion, years. They exhibit what we call dynamic kinetic stability (DKS). This dynamic kinetic stability is a property of all living organisms to a greater or lesser degree.



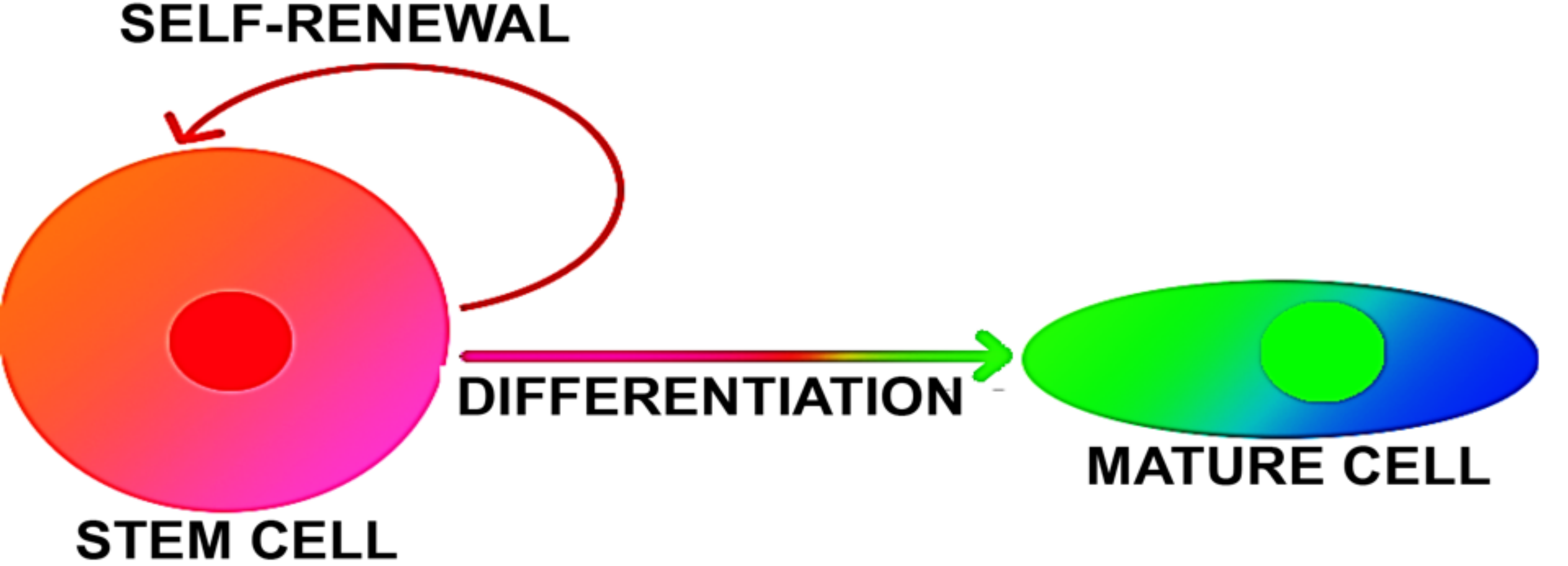


# BIOLOGICAL PROCESSES FOR RESISTING ENTROPY




Therefore, all living things are low entropy systems and most cellular processes seek to resist entropy. This is achieved via the various life processes that either repair cells (such as the proteins Rad50, Mre11 and NBS1) or the processes that produce more cells to replace dead cells (such as mitosis and meiosis). This means that a living system remains active and is able to move, convert energy, reproduce, etc.

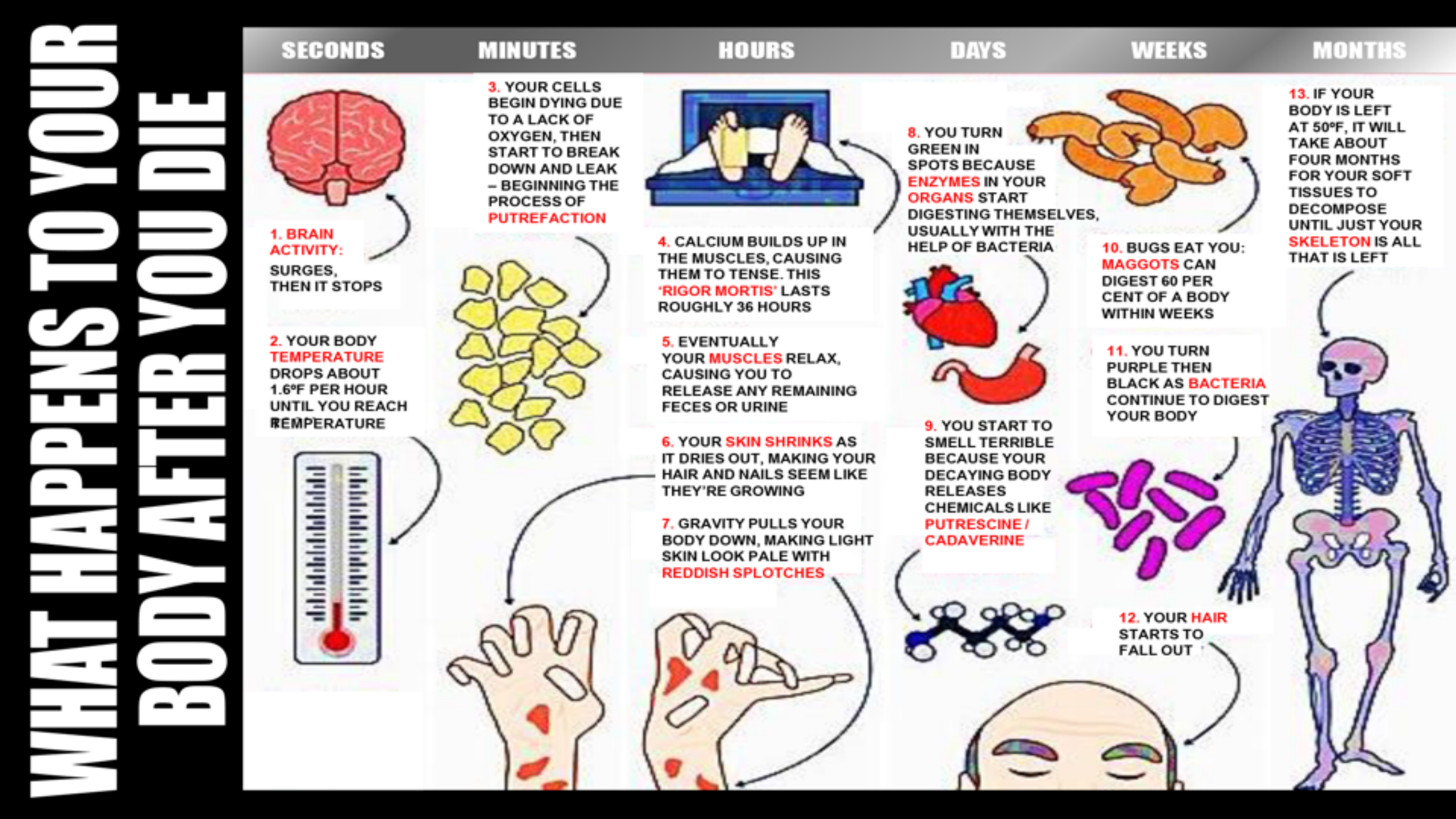
# STEM CELLS RESIST ENTROPY




Thus, all life resists entropy unless nearing death wherein these life processes cease, and many life forms can resist entropy over several generations via DKS.
In single cell lifeforms, those life processes are carried out by the organelles within the cell.

# DEATH AND ORGANISING LIFE ONTO A SPECTRUM

We can see that after an organism dies, those aforementioned life processes stop, and the body which may have lasted and functioned years or decades, decays in a matter of months to equilibrium. Thus, we can see a difference between 'living' and 'dead' things. We can also expand this into a spectrum. This definition exempts inanimate objects, fluids or fire, as these are unable to process information, and also exempts robots or computers as these require the aid of humans to be maintained and refuelled to resist entropy.



WHAT HAPPENS TO YOUR BODY AFTER YOU DIE
SECONDS
MINUTES
HOURS
DAYS
WEEKS
MONTHS
1. BRAIN ACTIVITY: SURGES, THEN IT STOPS
2. YOUR BODY TEMPERATURE DROPS ABOUT 1.6ºF PER HOUR UNTIL YOU REACH ROOM TEMPERATURE
3. YOUR CELLS BEGIN DYING DUE TO A LACK OF OXYGEN, THEN START TO BREAK DOWN AND LEAK – BEGINNING THE PROCESS OF PUTREFACTION
4. CALCIUM BUILDS UP IN THE MUSCLES, CAUSING THEM TO TENSE. THIS 'RIGOR MORTIS' LASTS ROUGHLY 36 HOURS
5. EVENTUALLY YOUR MUSCLES RELAX, CAUSING YOU TO RELEASE ANY REMAINING FECES OR URINE
6. YOUR SKIN SHRINKS AS IT DRIES OUT, MAKING YOUR HAIR AND NAILS SEEM LIKE THEY'RE GROWING
7. GRAVITY PULLS YOUR BODY DOWN, MAKING LIGHT SKIN LOOK PALE WITH REDDISH SPLOTCHES
8. YOU TURN GREEN IN SPOTS BECAUSE ENZYMES IN YOUR ORGANS START DIGESTING THEMSELVES, USUALLY WITH THE HELP OF BACTERIA
9. YOU START TO SMELL TERRIBLE BECAUSE YOUR DECAYING BODY RELEASES CHEMICALS LIKE PUTRESCINE / CADAVERINE
10. BUGS EAT YOU: MAGGOTS CAN DIGEST 60 PER CENT OF A BODY WITHIN WEEKS
11. YOU TURN PURPLE THEN BLACK AS BACTERIA CONTINUE TO DIGEST YOUR BODY
12. YOUR HAIR STARTS TO FALL OUT
13. IF YOUR BODY IS LEFT AT 50ºF, IT WILL TAKE ABOUT FOUR MONTHS FOR YOUR SOFT TISSUES TO DECOMPOSE UNTIL JUST YOUR SKELETON IS ALL THAT IS LEFT

# LIFE MUST PROCESS AND RESPOND TO INFORMATION IN ITS SURROUNDINGS

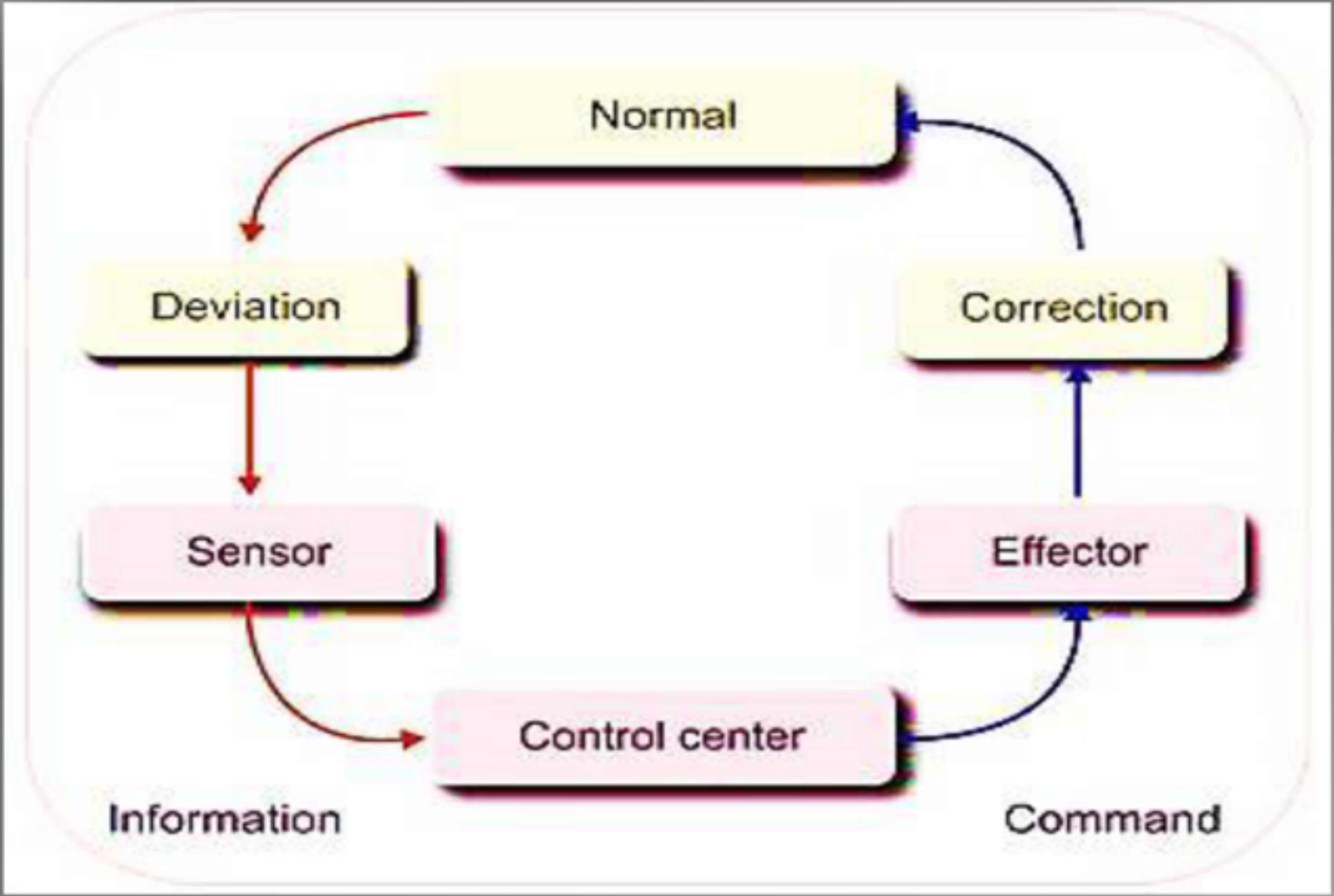
# BIOTIC AND ABIOTIC FACTORS

What we mean by process or respond to information is that the life form must be able to do this for multiple types of biotic and abiotic factors. These include, changes in water, atmosphere, temperature, lighting, nearby predators, harmful substances, etc. One cannot make a comprehensive list though. Therefore, viruses are not included as these do not respond to most abiotic factors and many viruses do not react to most biotic factors (bacteriophages only infect specific species of bacteria).

| BIOTIC FACTORS | ABIOTIC FACTORS |
| --- | --- |
| Biotic factors are the living or once-living components of an ecosystem, including animals, plants and microorganisms. | Abiotic factors are the non-living physical and chemical elements in the ecosystem. |
| Biotic components shape an ecosystem. | Abiotic resources are usually obtained from the lithosphere, atmosphere, and hydrosphere. |

**LIVING THINGS** **NON-LIVING THINGS**

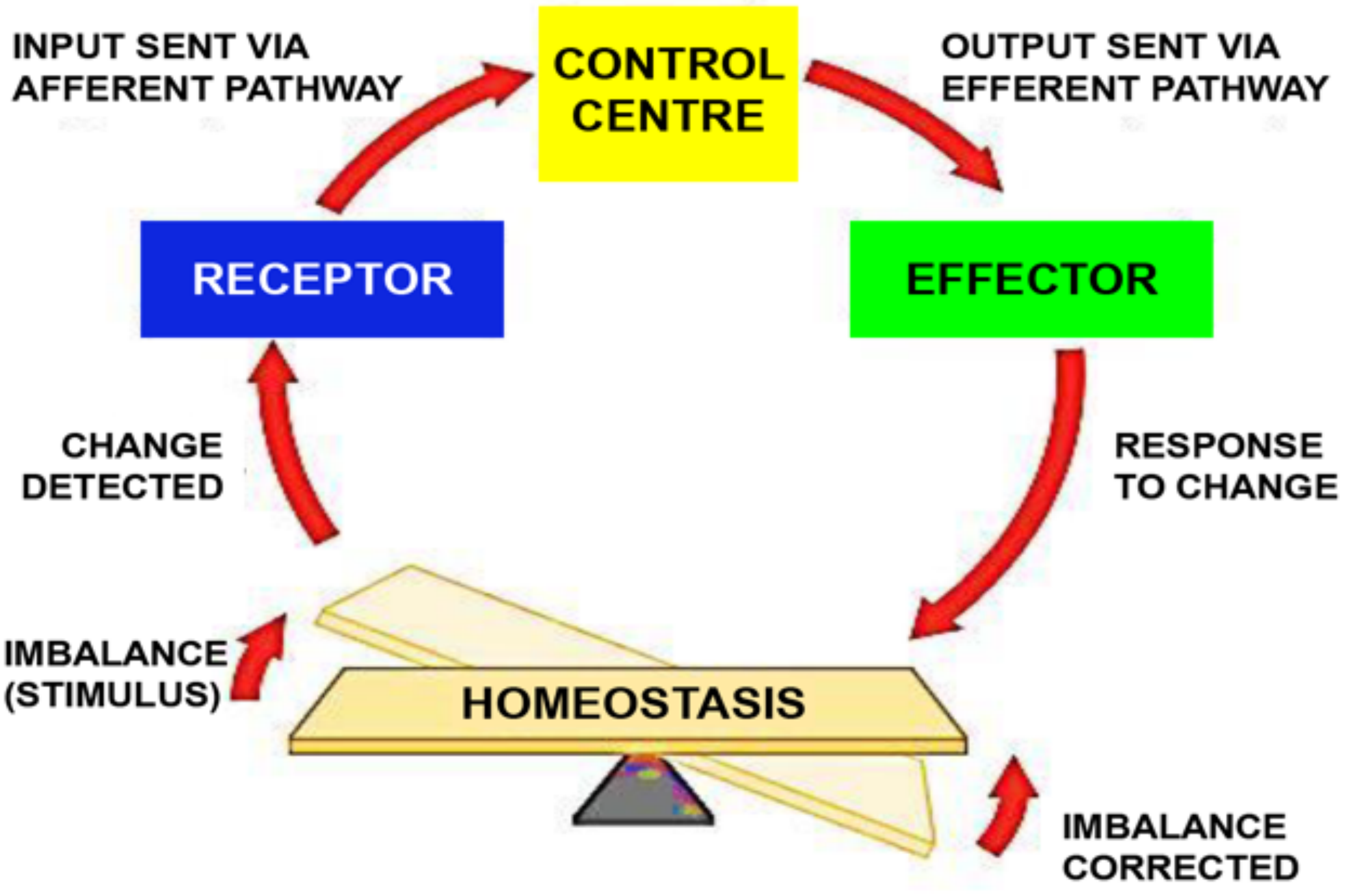
# HOMEOSTASIS



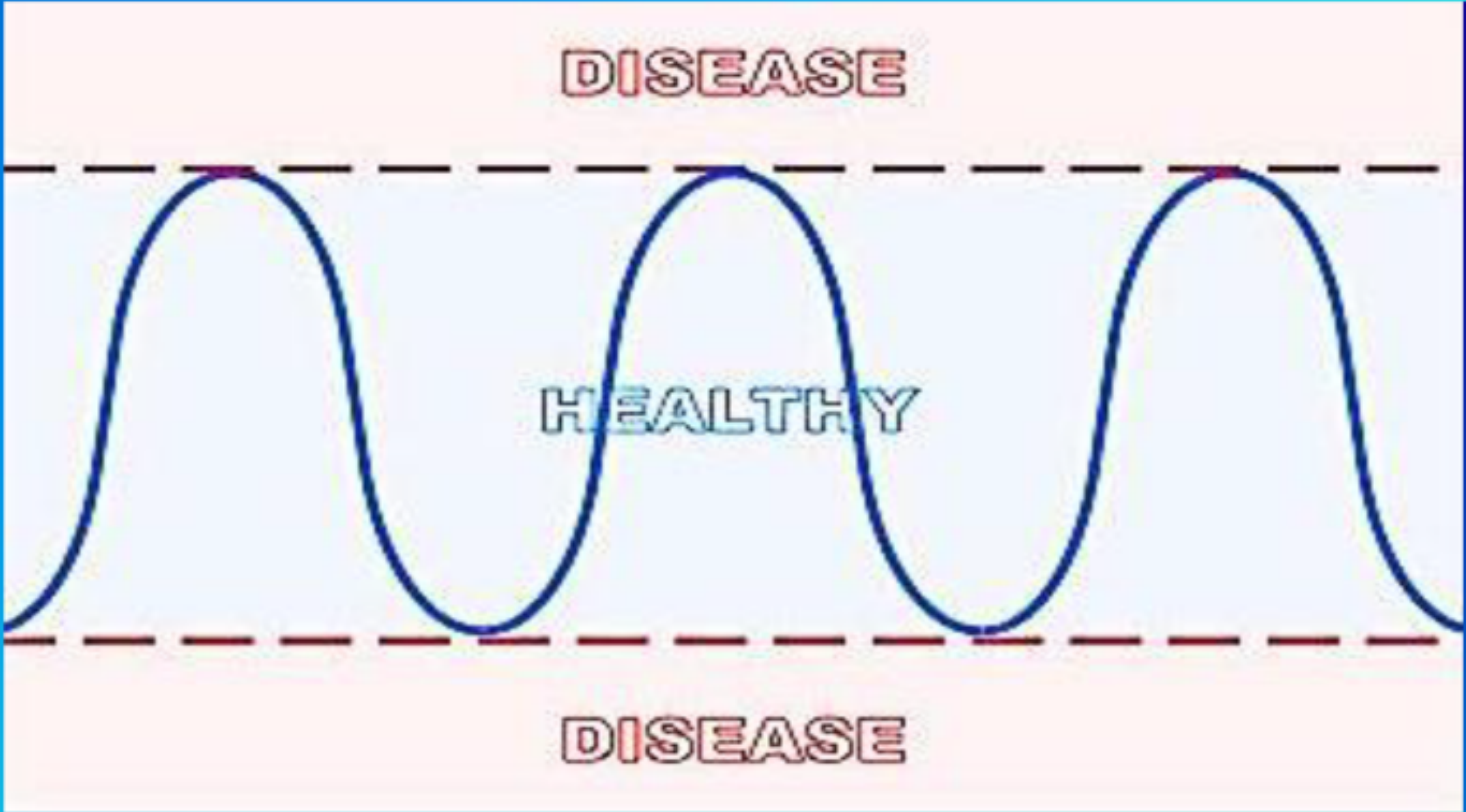

Just like all the changes that occur outside of our bodies (external environment), there are changes in our internal environment too. For instance, our bodies need to keep a constant body temperature, glucose level, water level and so on for the cells to function properly. Therefore, organisms must respond to changes in the external and internal environment. But conditions outside our bodies such as temperature, exercise, eating and so on, often affect our internal balance. The term used to describe the ability of an organism to maintain balance in its internal environment is called 'homeostasis'.

# HOMEOSTASIS AS AN EXAMPLE

Homeostasis is achieved by a mechanism involving three components: The Receptor (or sensor), Control Center (or processor) and the Effector.
Here is an example:
THE SENSOR: Sensors on your skin can detect when the temperature outside increases.
THE CONTROL CENTRE: The brain receives the signal from the sensor and processes it (finds a solution).
THE EFFECTOR: Sweat glands get to work, and blood flow increases to produce sweat, which cools the organism down. This way, the organism's original balance is restored.



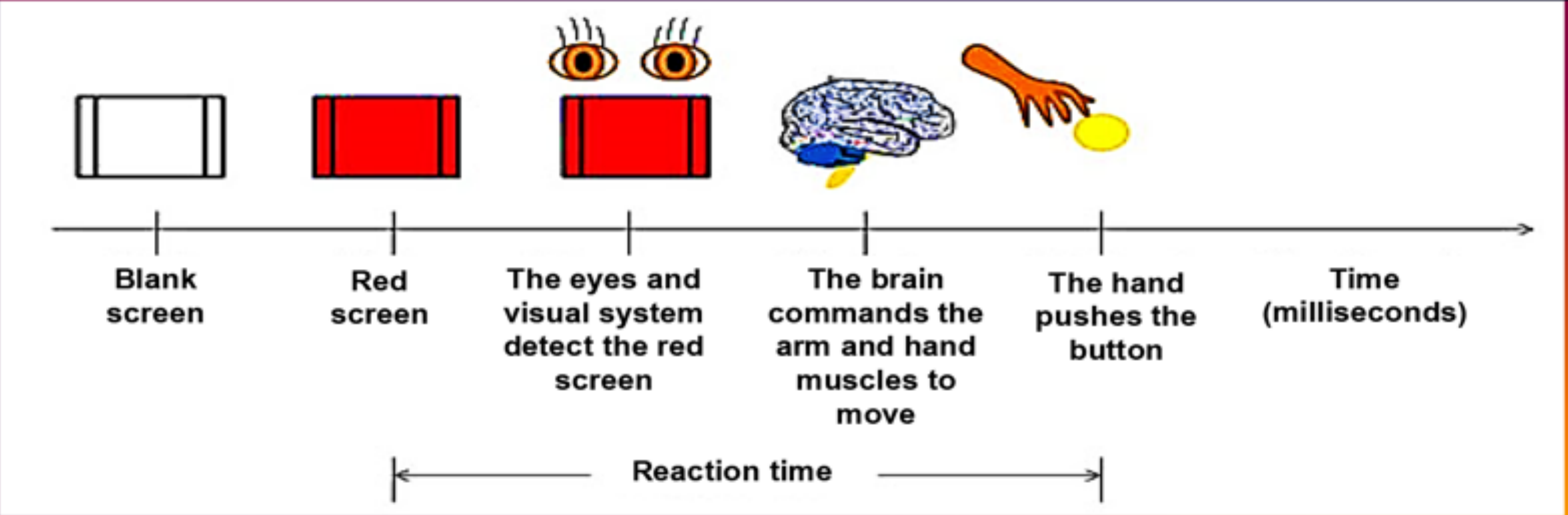
# COMPONENTS OF SENSORY RESPONSE




Organisms must have these three components for responding to their environment:
Some kind of sensor, some kind of control centre, and some kind of effector to respond to any environmental change. Homeostasis does not involve keeping conditions static.
It involves keeping conditions within tightly regulated physiological tolerance limits.

# TIME LIMIT FOR REACTION

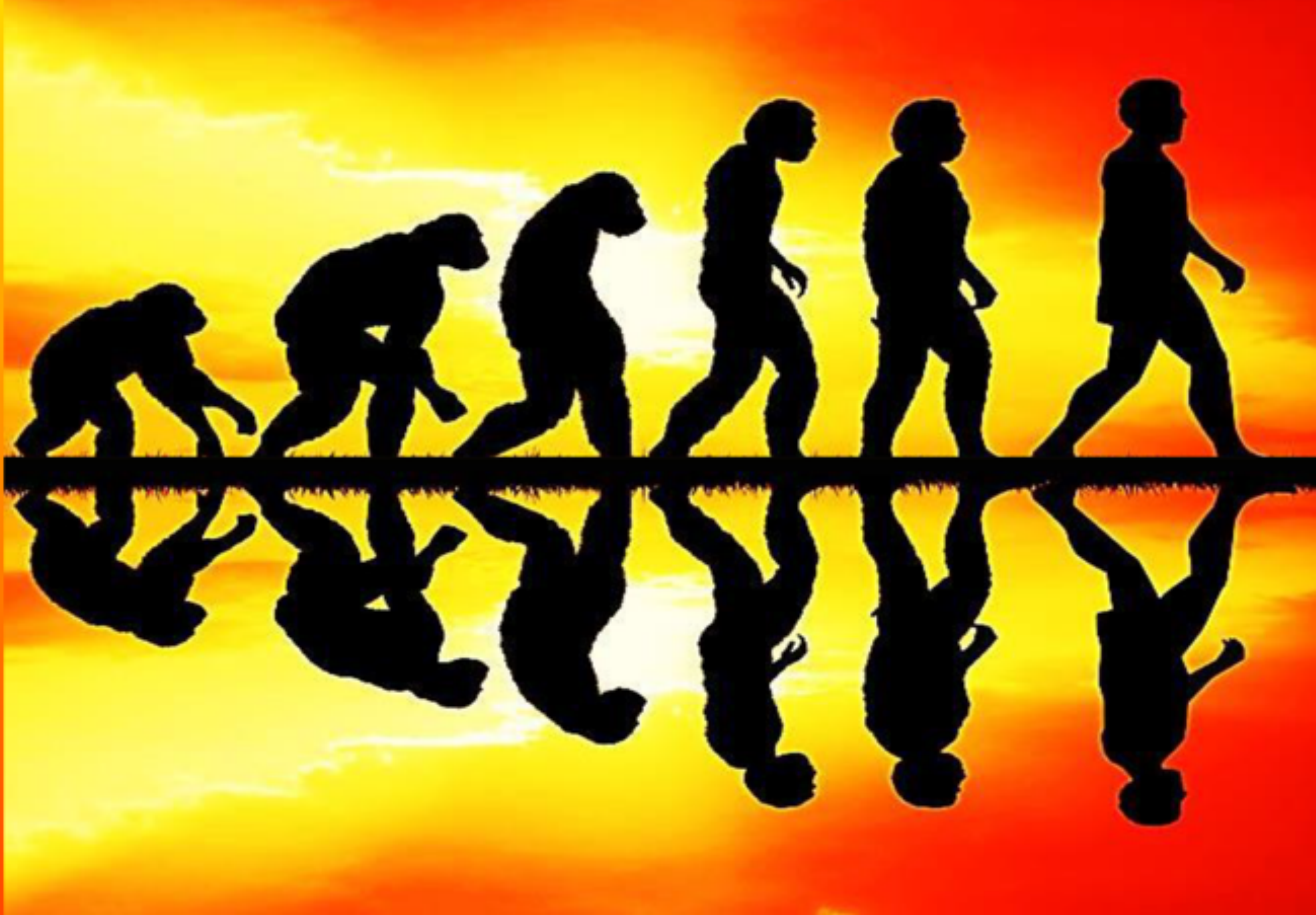
Reaction time is very important for any species to survive and evolve. With the three components used for responding to their environment, organisms must do so within a certain time based on the stimuli that they are presented with. Adapting and reacting to an organism's stimuli can happen within the a few milliseconds, or over the span of days. This depends on the stimuli that is presented to the organism. If a small insect sees that a predator approaches, it must act quickly as to not get eaten. Reaction time must also evolve, change, and have limits as stimuli in the world is ever changing and can be different at any given moment. Stimuli can vary in any situation that the organism is in, and limits must be put in place to ensure the safety of that organism
It involves keeping conditions within tightly regulated physiological tolerance limits.



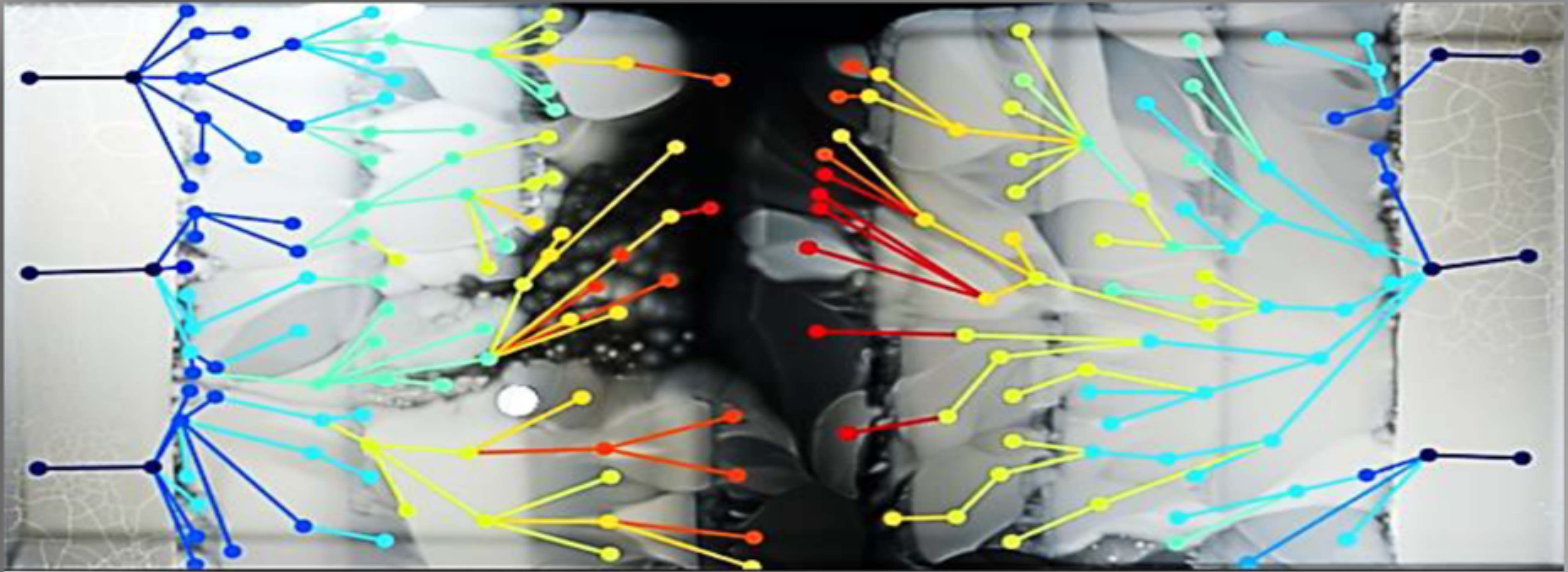
# LIFE MUST EVOLVE OVER TIME

# EVOLVING OVER TIME

The final rule is that the organism/species must be capable of evolving over time. Some may propose that a species at a Hardy Weinberg Equilibrium is not currently capable of this so would be excluded from this theory. The main point is that, even if a species is at such an equilibrium, its ancestors were not. How else would the current species come into being? Thus, the organism and all other members of its species are alive. The fact that its ancestors evolved over time is proof that the current species can do the same.



# RANDOM MUTATIONS



Moreover, if the organism has genetic material that can undergo the random mutations critical to evolution (all organisms have either DNA or RNA, both experience random mutations), it proves that this species is capable of evolving as long as it is not at an equilibrium and there is no change to the environment.

# ENVIRONMENTAL CONDITIONS

Moreover, we have not found any evidence that organisms can remain at a Hardy-Weinberg equilibrium indefinitely. Even in the case of living fossils such as the coelacanth, there is a clear evolution shown over generations in all living fossils. For example, coelacanth size has reduced by a factor of three over 100 million years, due to mass extinctions and lack of resources. Since climate change will always bring about a migration or mixing of genes within a species, and thus produce variation, organisms must evolve over time due to a constant change in environmental conditions. Therefore, it is impossible that any organism can remain at a Hardy-Weinberg equilibrium indefinitely.

# CONDITIONS FOR HARDY-WEINBERG EQUILIBRIUM

- The Hardy-Weinberg theorem describes a hypothetical population that is not evolving
- It is a model which has assumptions
  - No mutations, or mutational equilibrium
  - Random mating, that is organisms with one genotype do not prefer to mate with organisms with a certain genotype
  - No natural selection, or no genotype is more likely to survive than another
  - Extremely large population size to ensure no statistical flukes
  - No gene flow, no migration between populations, that is the population remains static
- If the population is not in H-W equilibrium, then one of the assumptions has been violated

# LIFE AS A SPECTRUM

A black and white approach to defining life, where something is either definitely alive or not, almost always results in objects that are neither alive or non-living, making it impossible to classify them (viruses). A spectrum for life, where a creature's position on it defines how 'alive' it is, eliminates many of the problems with a black and white approach to life. The factors defining how alive something is are related to the second criteria of life and are as stated:

1. The number of types of stimuli a creature can react to and the number of responses. The greater the number, the more alive. For example, a ocean sponge can react to its environment, but it has less distinct reactions than a human, which can respond to many stimuli.
2. Reaction speed of a creature compared to its life span. The faster the reactions, the more alive.

LESS ALIVE

MORE ALIVE

Rock: Does not resist entropy or undergo evolution. Not capable of responding to stimuli to benefit itself.

Viruses: Capable of few responses to stimuli. Undergo evolution and resist decay.

Humans: Capable of many responses to stimuli. Undergo evolution and resist decay.

# FALLACIES IN THIS CRITERION

- The first criterion is an excellent indicator of life alone, though it has its flaws. All species rely on external non-living aid to survive such as habitats or sunlight. In addition requiring that living organisms need not to rely on other living organisms is a circular definition in itself.
- Many species need to rely on other living organisms at birth and sometimes throughout their lives. Human children need external aid to survive their first few years of life. Other species live in symbiotic relationships and might not be able to live without it.
- Such examples include the mutualistic relationship of clown fish and anemone, the commensalistic relationship of remora fish and whales, and the parasitic relationship of ticks and deer. The four species, the clown fish, anemone, remora, and ticks, rely on another species to survive, an external aid.

# LAYERS OF LIFE

◆ Many living systems work in tandem to form another layer of 'life.' Often each individual system specializes to further help the collective whole.

◆ Multi-cellular organisms are made up of many trillions of cells. Each cell is alive on its own, however the collective works together to make a second layer of life.

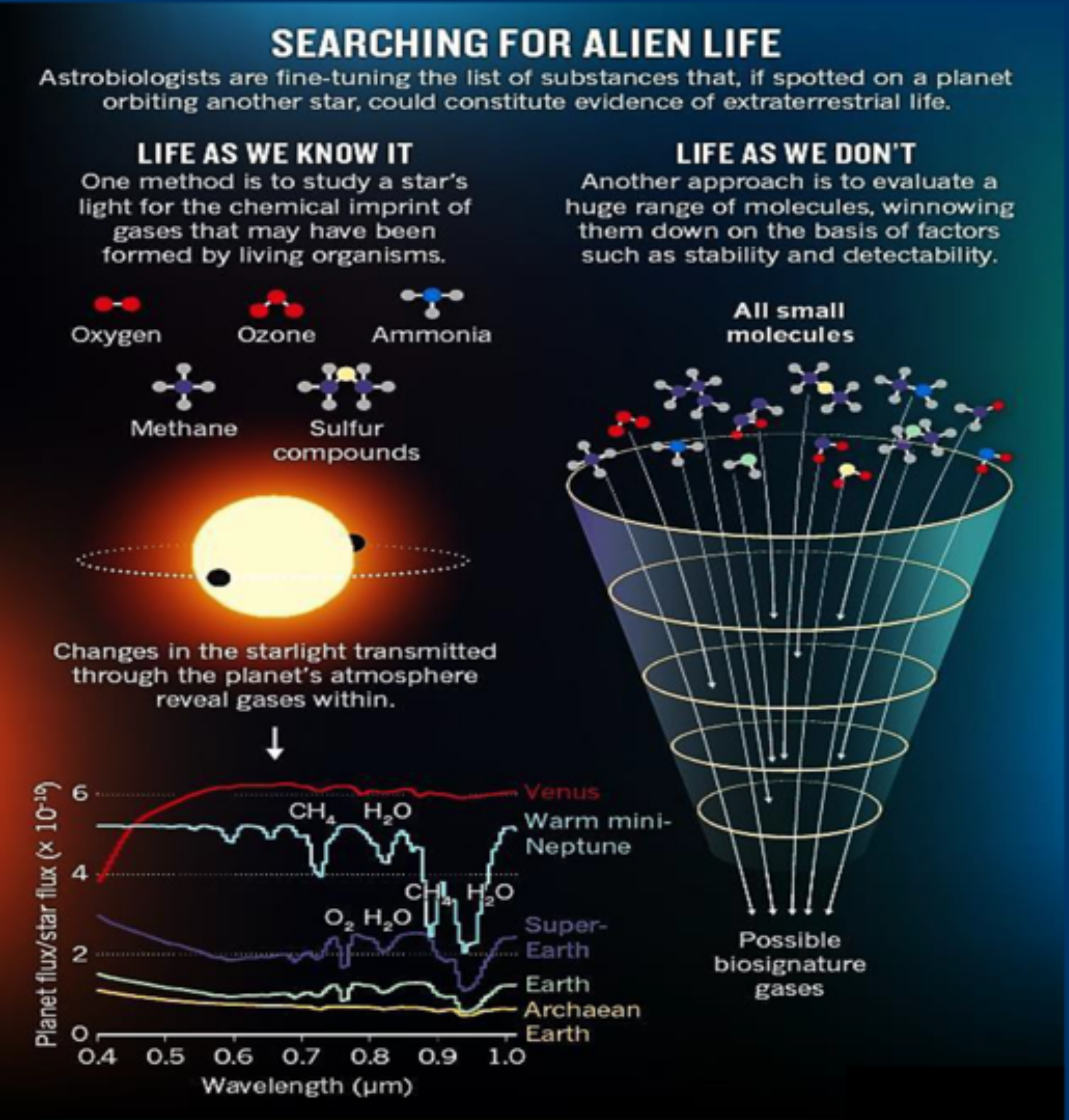
◆ Multi-cellular organisms can come together to form it's own life as well. An example is an ant colony or a corporation.

◆ Both ant colonies and corporations resist entropy, respond to stimuli such as weather or market changes, and evolve and adapt over time. In addition, both can die in similar ways as multi-cellular organisms do.

**COLONIES → LEVEL 3**

**MULTI-CELLULAR ORGANISMS → LEVEL 2**

**SINGLE-CELLULAR ORGANISMS → LEVEL 1**

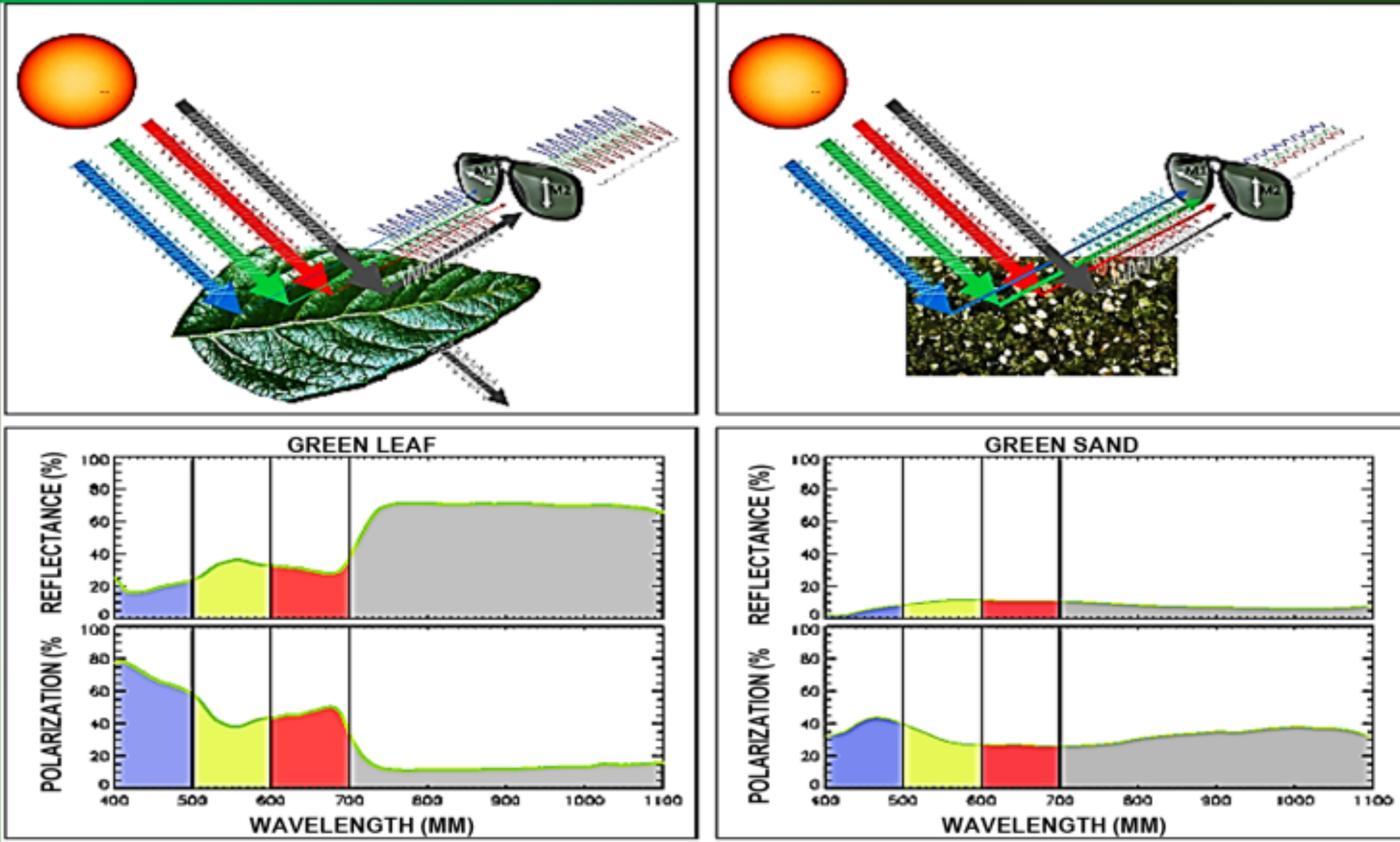



# HOW TO DETECT LIFE

Finally, on the question of how to detect life, there are a few methods. One is a direct spectroscopic analysis of the planet's atmosphere. This would use foldable shields to block out excess starlight and a spectrometer to observe the tell-tale spectral lines that indicate the abundant presence of compounds or molecules caused by the presence of life. For example, the abundance of oxygen in the atmosphere could indicate life's presence (oxygen is primarily created via photosynthesis on Earth). Other elements may also be analysed (carbon dioxide) or the probabilities could be considered (Bayesian framework). Or we could directly analyse the distribution of the molecules on the planet that shows high entropy would be abiotic and low entropy would be biotic.

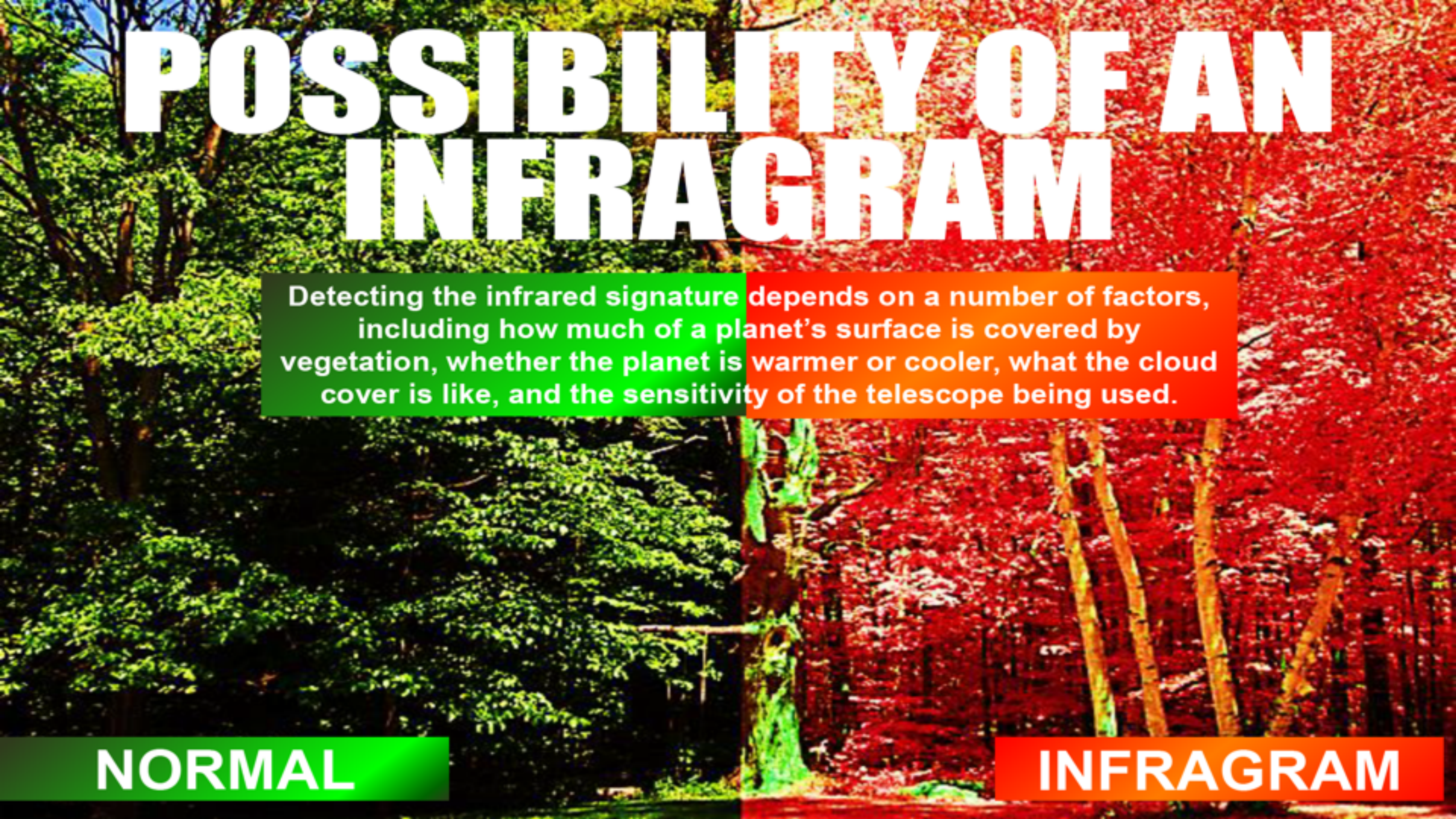
# INFRARED SIGNATURE

For reasons that aren't exactly clear, photosynthetic plants reflect specific wavelengths of infrared light, with some plants being more reflective than others. Called the vegetation red edge, this pattern is visible in near-infrared wavelengths, which are a bit longer than the colours our eyes perceive yet are easily detected by the right kind of telescope.

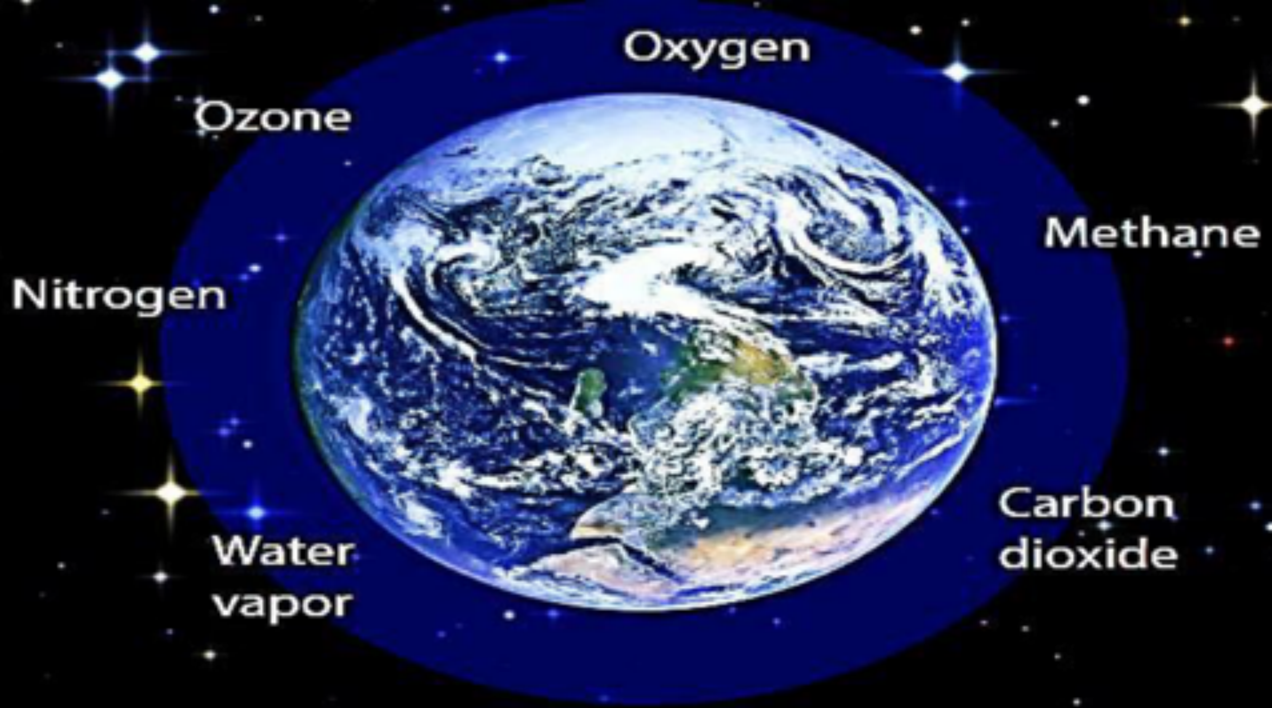


# POSSIBILITY OF AN INFRAGRAM

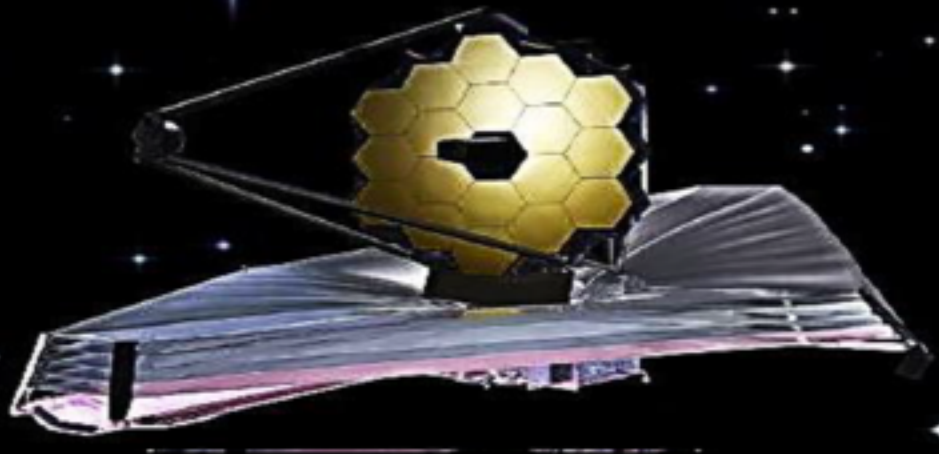
Detecting the infrared signature depends on a number of factors, including how much of a planet's surface is covered by vegetation, whether the planet is warmer or cooler, what the cloud cover is like, and the sensitivity of the telescope being used.

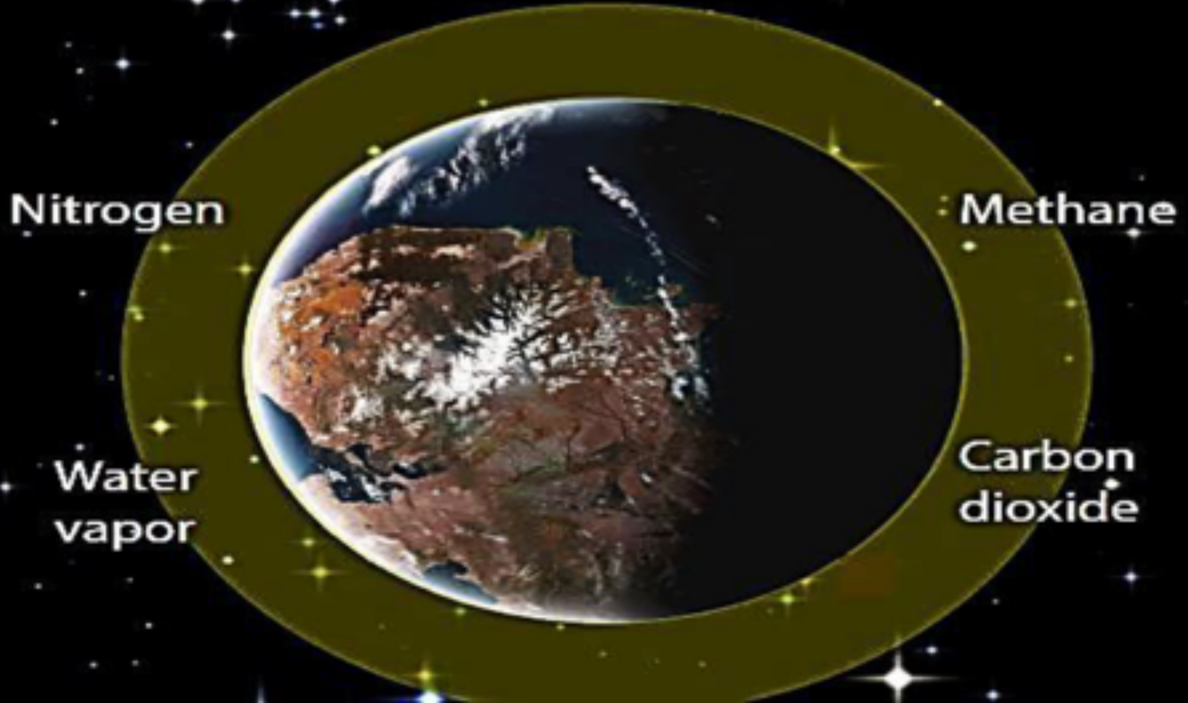


# BIO MARKERS



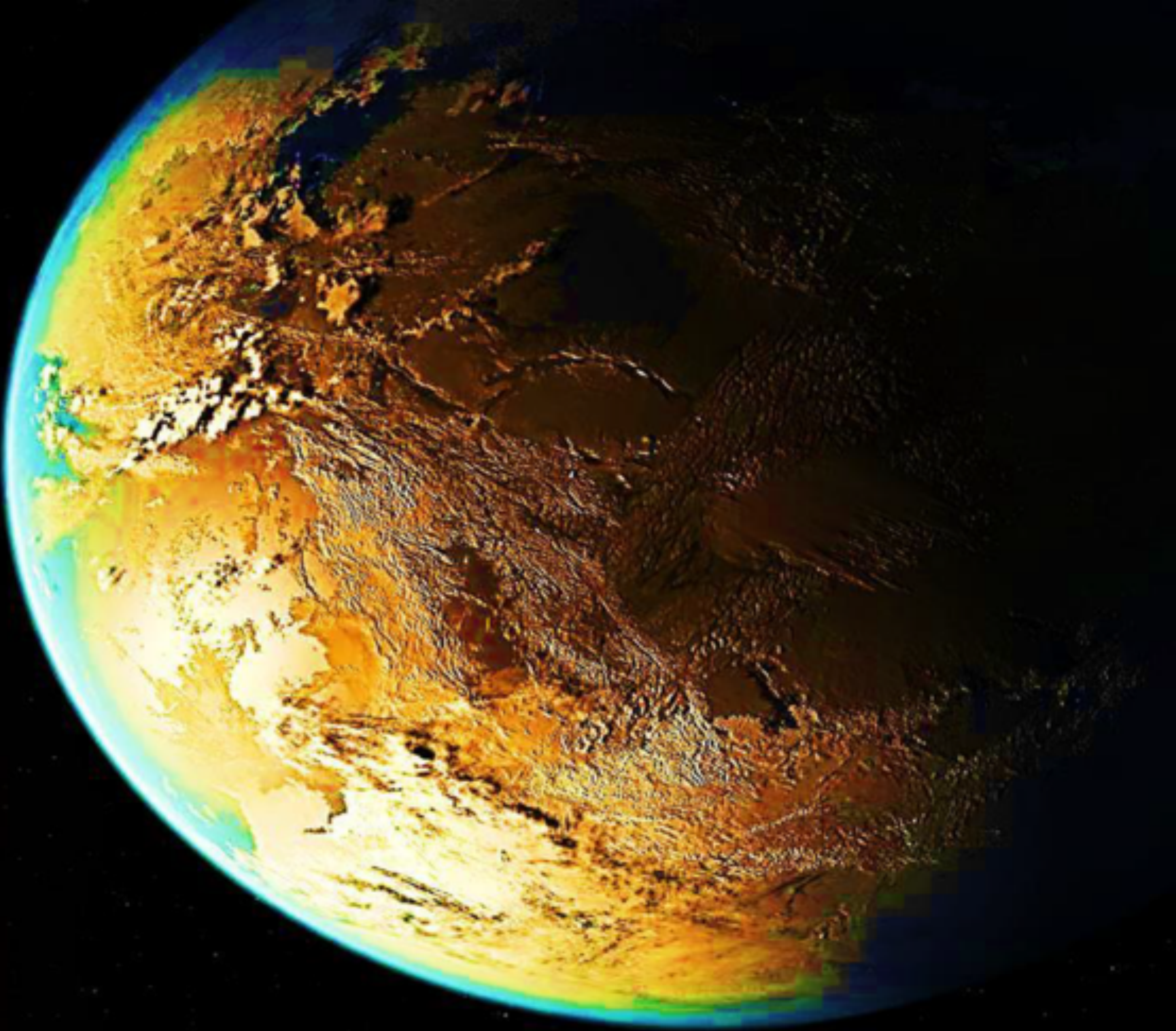

These are all bio markers, gases in the atmosphere such as water, oxygen, carbon dioxide that are all indicative of life's presence could give us hints that certain planets might be filled with life.






Until the James Webb infrared telescope is launched in a few years we don't even have any technology capable of detecting bio markers in the atmosphere of an exoplanet. However, an infra-red spectrum will tell us if there is water, oxygen, ozone, methane, carbon dioxide all of which are possible clues to the presence of life.

# THANK YOU



**PICTURE COURTESY:**

SLIDE 3: GENERAL THEORY OF EVOLUTION

http://blogs.discovermagazine.com/d-brief/files/2018/08/shutterstock_550488199.jpg

SLIDE 5: WHAT IS ENTROPY?

https://s3.ap-south-1.amazonaws.com/m3india-app-dev/ckeditor/content/cell-1529565353.jpg

SLIDE 6:DYNAMIC KINETIC STABILITY

https://www.engineering.com/Portals/0/BlogFiles/tomspendlove/fat%20cells.JPG

https://med.news.am/static/news/b/2016/04/10072.jpg

SLIDE 7:BIOLOGICAL PROCESSES FOR RESISTING ENTROPY

https://www.vita34.com/wp-content/uploads/stem-cells-differrentiation.jpg

SLIDE 8:STEM CELLS RESIST ENTROPY

https://www.sott.net/image/s19/399795/full/StemCell.png

SLIDE 9: DEATH AND ORGANISING LIFE ONTO A SPECTRUM

https://i2-prod.mirror.co.uk/incoming/article11135689.ece/ALTERNATES/s615b/PROD-Male-cardiovascular-system-artwork.jpg

SLIDE 10: WHAT HAPPENS TO YOUR BODY AFTER YOU DIE

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SLIDE 12: BIOTIC AND ABIOTIC FACTORS

https://d2jmvrsizmvf4x.cloudfront.net/CcxgSYzTFGHWYUJ1VWCg_abiotic.jpg

SLIDE 13: HOMEOSTASIS

https://www.earthslab.com/wp-content/uploads/2017/01/011417_1602_Homeostasis1.jpg

SLIDES 14 and 15: HOMEOSTASIS AS AN EXAMPLE and COMPONENTS OF SENSORY RESPONSE

http://ib.bioninja.com.au/_Media/homeostasis_med.jpeg

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SLIDE 18: EVOLVING OVER TIME

https://www.psypost.org/2018/04/scientific-reasoning-ability-not-predict-acceptance-evolution-among-religious-individuals-study-finds-51082#prettyPhoto/0/

SLIDE 19: RANDOM MUTATIONS

http://www.visualisingdata.com/wp-content/uploads/2016/12/10Sig-Evolution.png

SLIDE 20: ENVIRONMENTAL CONDITIONS

https://outreach-international.org/3-extreme-weather-conditions-worldwide/

SLIDE 21: CONDITIONS FOR HARDY-WEINBERG EQUILIBRIUM

http://www.nature.com/scitable/content/ne0000/ne0000/ne0000/ne0000/13295783/andrews_banner_ksm.jpg:

SLIDE 23: HOW TO DETECT LIFE

https://www.nature.com/polopoly_fs/7.38071.1469708499!/image/Exoplanet_biosignatures_graphic_NEWS_WEBNEW.jpg_gen/derivatives/landscape_630/Exoplanet_biosignatures_graphic_NEWS_WEBNEW.jpg

SLIDE 24: INFRARED SIGNATURE

http://the-colossus.com/images/biosignatures_photosynthesis.png

SLIDE 25: POSSIBILITY OF AN INFRAGRAM

https://petapixel.com/assets/uploads/2013/06/infragram1.png

SLIDE 26: BIO MARKERS

https://scitechdaily.com/images/Disequilibrium-Biosignatures-Will-Help-Astronomers-Detect-Life-on-Exoplanets.jpg

SLIDE 27:THANK YOU

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