



The Cosmos

Planets & Life



PHYS 214

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Please start all class related emails with “214:”

Note about assignments

- Assignment 1 marked – collect at the end of the lecture (will try and finish slightly early)
- Solutions available in the 3rd floor cabinets in Stirling Hall
 - Why not on the web? – Answer: answers passed around from year to year too easily
- Assignment 3 is posted

Today's Lecture

- Life: classification and the relevance of thermodynamics
 - Definitions of life
 - Recap of Laws of Thermodynamics
 - Entropy and life

Our progress thus far...

Of all the terms in the Drake equation, we've thus far focused on those that are solely astronomical in nature:

$$N = R^* p_p n_E p_l p_i p_c T$$

In the following weeks we'll discuss all the issues necessary to at least get some idea of what the values the remaining variables might take.

Things get much more speculative from now on!



"I THINK YOU SHOULD BE MORE
EXPLICIT HERE IN STEP TWO."

Appearance of life



- Perhaps understandably, early scientists believed life evolved spontaneously
 - Maggots “appear” to arise out of rotting meat
 - Lice out of sweat
 - And many other gruesome examples!
- While the idea was queried on occasion, a conclusive refutation of the idea was provided by Pasteur (in 1862) who showed proper sterilization and exclusion prevented the “spontaneous formation of life”
- Of course this opens another curious problem – life has to have evolved from non-living material at some point

What defines the “living state”?

- The idea of being “alive” or “living” is something that lay people believe they have a good understanding of
- Yet, to the biologist a precise definition is elusive
- More alarmingly, discussions about the definition have been going on for decades
- Many of you have, no doubt, had differing definitions in different courses (a molecular biologist's definition of life is very specific, for example)
- Neither is this discussion purely academic, it already has significant in the fields of artificial intelligence (where it is tied in intimately with the idea of consciousness)

According to Webster...

- Main Entry: life
- Pronunciation: 'lɪf
- Function: *noun*
- Inflected Form(s): *plural lives* /'lɪvz/
- Etymology: Middle English *lif*, from Old English *līf*; akin to Old English *libban* to live
- 1 ~~a : the quality that distinguishes a vital and functional being from a dead body~~ ~~b : a principle or force that is considered to underlie the distinctive quality of animate beings~~ **c : an organismic state characterized by capacity for metabolism, growth, reaction to stimuli, and reproduction**

Gilmour & Sefton

- Supposedly, most biologists identify two key phenomena that classify life
 - (1) The capacity for self replication
 - (2) The capacity to undergo Darwinian evolution
- This is a comparatively heuristic definition, so let's look at some of the implications briefly

Reproduction requirement

- This seems to be a fundamental requirement of Darwinian evolution
 - Preferable mutations, selected via some natural selection process, must be passed on to the general population
- Joyce of NASA proposed we adopt: “a self-sustaining chemical system capable of undergoing Darwinian evolution”
 - What about sterile offspring (e.g. mule), this is still alive in the sense we understand
 - Always going to be something we can't fit...

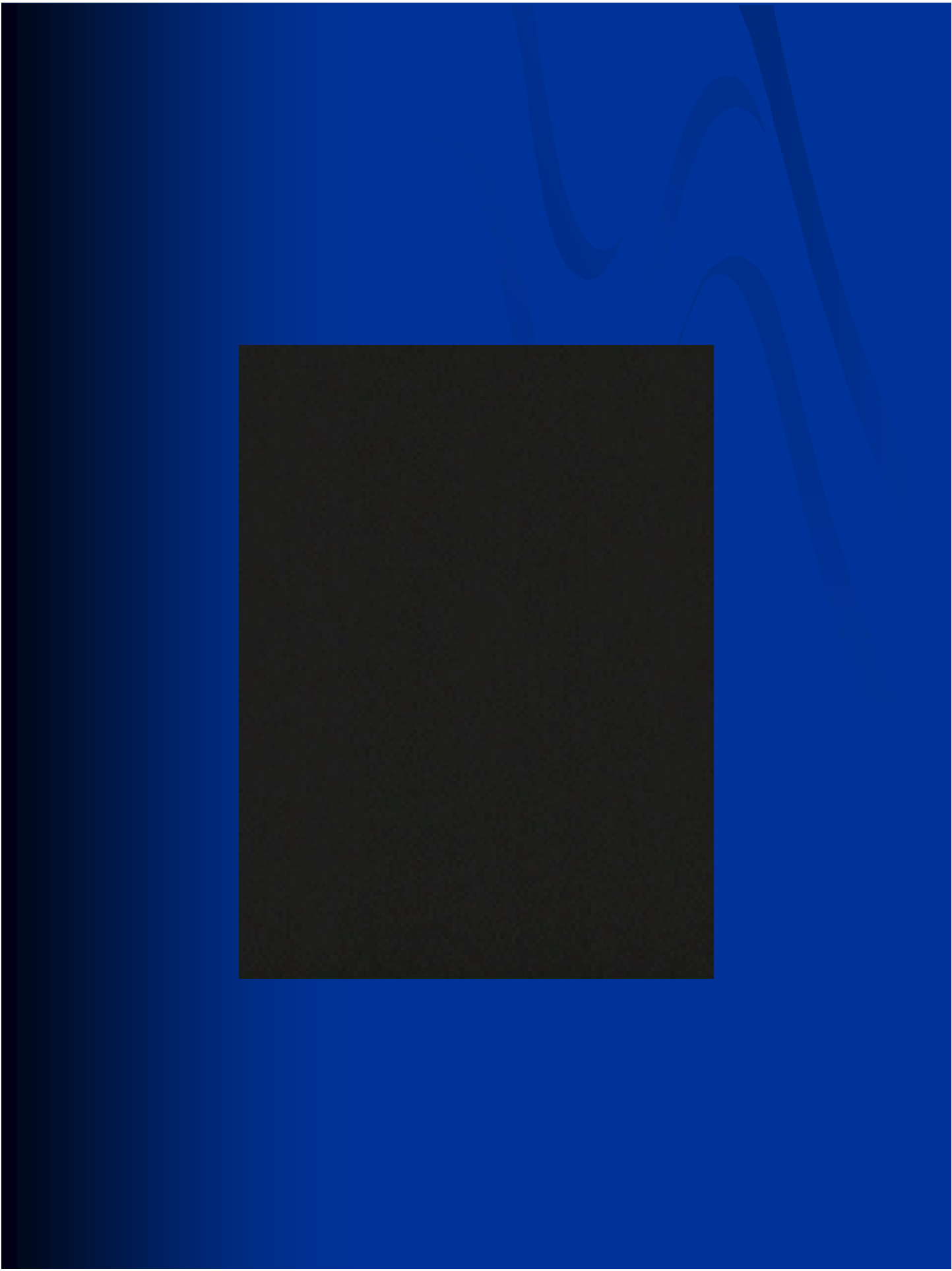
Evolution (recap of salient issues)

- Change in a *populations* inherited characteristics or traits, from one generation to the next
- Evolution occurs when traits become more common or rare in a population
- This can occur randomly (genetic drift) or through traits having a higher reproductive value through *natural selection*

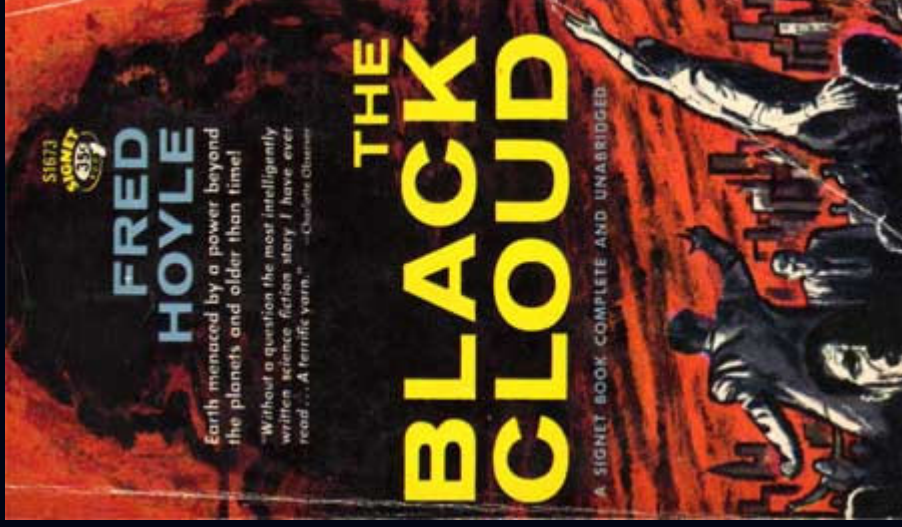
What if we remove evolution?



It is not inconceivable that systems could be created that both exhibit the capability to reproduce and adapt. Assuming a definition that includes evolution disbars us from considering these objects as life, while many of us probably would consider them alive... (What about the chemical issue?)



Physics motivated alternative life-forms



- Interstellar dust grains interacting magnetically – carries “messages” the same way as a nervous system
- Would actually have to process information very slowly
- Nice piece of science fiction
- Actually partially motivated the physicist Freeman Dyson to consider the extremely long term evolution of life

Information in living systems

- Living beings must have (a) an information carrier that describes their properties and (b) a mechanism to carry out this information
 - These are called gene's and (loosely) metabolism
- From an information theoretic standpoint we can write computer codes that employ this behaviour
 - We have already created examples of computer codes that go beyond being mere viruses
 - they can evolve, have selection criteria and show many properties of biological systems
 - This is the field of artificial life and is closely related to genetic algorithms and evolutionary programming
 - Check out <http://www.his.atr.jp/~ray/tierra>

Information content of living systems



- If we total up all the “useful” information in our genes it probably comes out to around 100×10^6 bits of information
 - 1 byte = 8 bits of information, and you hard drive is several gigabytes in size
- A pulp fiction novel probably contains on average around 2×10^6 bits of information
 - We are each equivalent to about 50 bad romance novels!
- The university libraries easily contain ten trillion bits of information
 - The amount of information handed down through books actually far exceeds that of DNA...

These two overheads motivated by a Scientific American article by Stephen Hawking

Evolution as a rate of transfer of information

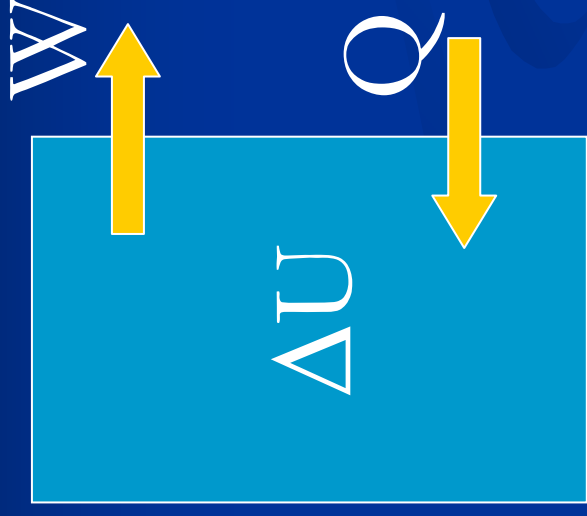
- For 3 ½ billion years information was passed from generation to generation via genetic code
 - admittedly some capacity for learned behaviours
- In the last 10,000 years the development of language has changed the primary mode of information transfer from genetic to external mechanisms
 - We now mostly embody this information in books, although digital storage is taking over rapidly
- It seems inevitable (someone, somewhere...) that this will eventually lead to our being able to manipulate and “improve” our DNA
- Once we achieve this point will superhumans become the eventual by product?
 - At which point “evolution” is now being directly determined by external influences - more so than genetic information carried in genes
- This is not mere speculation...

Life from a physics perspective

- Replication requires both matter and energy
 - Presumably these must come from the environment in which life is based
- However, perhaps the most key issue is entropy
 - Thermodynamics gives us key insights into understanding how chemical-based life can evolve
 - Useful to quickly review the 1st & 2nd Laws of Thermodynamics

1st Law of Thermodynamics

- “In energy process, energy can neither be created or destroyed, so that the total energy of the Universe remains constant”
- For a system a system with internal energy U , doing work W , and adding heat Q to the system



$$\Delta U = Q - W$$

Consider gas expanding: work is done against the surroundings, so internal energy must go down. If we add heat to the system we expect the temperature to go up.

2nd Law of Thermodynamics

- The second law has many different definitions, but the best way to think about it is that entropy, S , describes the way energy flows in a system

$$\Delta S = \frac{Q}{T}$$

- Where Q is the heat given to the system by the surroundings which are at an infinitesimally higher temperature, T , than the system

But isn't entropy “disorder”?

- This is a common interpretation that is really very misleading – fortunately most new textbooks no longer have this definition
 - It stems from definitions dating back to the late 1800s
 - Exactly what units does “disorder” have? The definition of the change in entropy I have given means S has units of Joules per Kelvin
 - We should really think about it in terms of the available states of a system, not what particular state it is in
- Really the best way to think of entropy is that energy always wants to disperse whenever possible
 - Resists staying localized
 - We then quantify this effect precisely using the 2nd Law of Thermodynamics

Entropy is not an easy concept

- While we can easily form coherent questions about pressures of gas, volumes, temperature changes *etc.* applying to life is harder
 - You always have to make sure the equations contain all of the pieces involved in the system you are modelling
- If you're interested just take a look at the amount of material on the web about the 2nd Law and evolution
 - There's a lot of gibberish out there!
- This comes back to the pseudoscience caveat I gave in the first lecture – just because it looks sensible, doesn't mean it is

Fallacy of the entropy argument against evolution

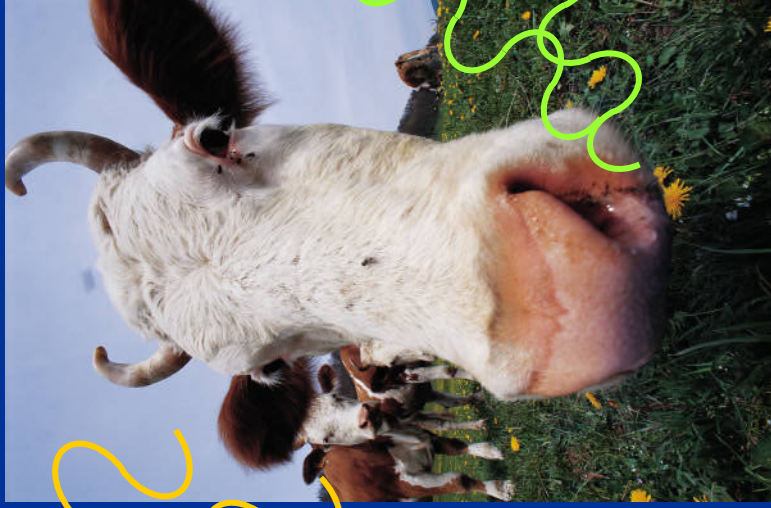
- “The 2nd Law of Thermodynamics implies *ordered* systems cannot be formed because *disorder* must increase”
 - Such an argument assumes there is a special meaning behind order
 - Example: many crystals systems form apparently ordered patterns because they are energetically favourable
 - Neither is the Earth a closed system, we are constantly being supplied with new, low entropy energy to distribute, and/or use to locally drive systems into a low entropy state
- Besides, this issue is probably much better addressed using the “Gibbs Free Energy” *e.g.* see Lehninger “Principles of Biochemistry”

Entropy for living systems in their environment

HEAT

Animals are constantly using energy to keep their bodies in a low entropy state. The energy used to produce this lowering of entropy ends up increasing the entropy of the surroundings greatly.

$$\Delta S_{\text{system}} = \Delta S_{\text{cov}} + \Delta S_{\text{surr}} > 0$$



Summary of lecture 16

- An exact classification of life remains elusive
- Under simpler, non-chemical definitions of life, we have already succeeded in simulating evolutionary systems
- From the information theoretic perspective, the use of books far exceeds the passing on of information via genetic material
- Despite arguments to the contrary, evolution is not at odds with the 2nd Law of Thermodynamics
 - In a combined system, pieces of the total system may indeed reach lower entropy states while the total system entropy increases

Next lecture

- Biochemistry and DNA
- Guest lecture next Friday (8th March) by Dr Virginia Walker (Biology) on extremeophiles