

COMPLEXITY IN SCIENCE

THERE IS AN INCREASING INTEREST IN THE
SCIENCE OF COMPLEX SYSTEMS

- "TACKLING COMPLEXITY IN SCIENCE"
EUROPEAN COMMISSION 2007

- "WHAT IS A COMPLEX SYSTEM"
LADYMAN, LAMBERG, WEISNER 2012

- "WHAT IS COMPLEXITY SCIENCE - REALLY?"
STEVEN E. PHELAN
EMERGENCE 3(1), 120-36 2001

WHAT IS A COMPLEX SYSTEM?

- MANY ELEMENTS INTERACTING IN MULTIPLE WAYS.
- NON-LINEAR EFFECTS.
- FEEDBACK IN INTERACTIONS.
- LACK OF A CENTRAL CONTROL MECHANISM.
- BOTTOM-UP INTERACTIONS - HIERARCHICAL STRUCTURE
- ROBUST EMERGENT PHENOMENA,
 ↑
 DON'T DEPEND ON DETAILS
 OF BOTTOM-UP INTERACTIONS

EXAMPLES OF COMPLEX SYSTEMS

- SOCIAL SYSTEMS — DEMOCRACY
- ECONOMICS
- BIOLOGICAL SYSTEMS
- EPIDEMICS
- CLIMATE
- ECOSYSTEMS
- CONSCIOUSNESS
- COMPUTER NETWORKS
- CELLULAR AUTOMATA NETWORKS
- ⋮
- THE UNIVERSE

FRANKLIN TAKES A SOMEWHAT DIFFERENT
VIEW POINT → HOW DOES COMPLEXITY OF
SYSTEMS MAKE KNOWLEDGE OF THEM
UNCERTAIN.

HE USES TWO EXAMPLES, WHICH ARE
CERTAINLY OF CURRENT INTEREST.

- HISTORY OF AN ECOSYSTEM → EVOLUTION
- THE EARTH'S CLIMATE

I THINK BOTH OF THEM SATISFY
MY CRITERIA FOR COMPLEX SYSTEMS.

EVOLUTION

AT FIRST GLANCE THIS SEEMS OBVIOUS
WE SEE ANIMALS PHYSICALLY ADAPT TO
THEIR ENVIRONMENT.

- DARWIN'S GALAPAGOS FINCHES
- SQUIRRELS IN TEXAS ARE LIGHT GOLDEN BROW - IN ONTARIO THEY ARE BLACK. FREQUENCY OF MELANISTIC PHASE INCREASES AS YOU GO NORTH
- GENERATIONS AFTER INDUSTRIALIZATION IN BRITAIN MOST MOTHS BLACK NOT WHITE.

FAMOUS EXAMPLE OF GIRAFFE'S NECK

USUAL EXPLANATION → RANDOM OCCURENCE
OF LONG NECK

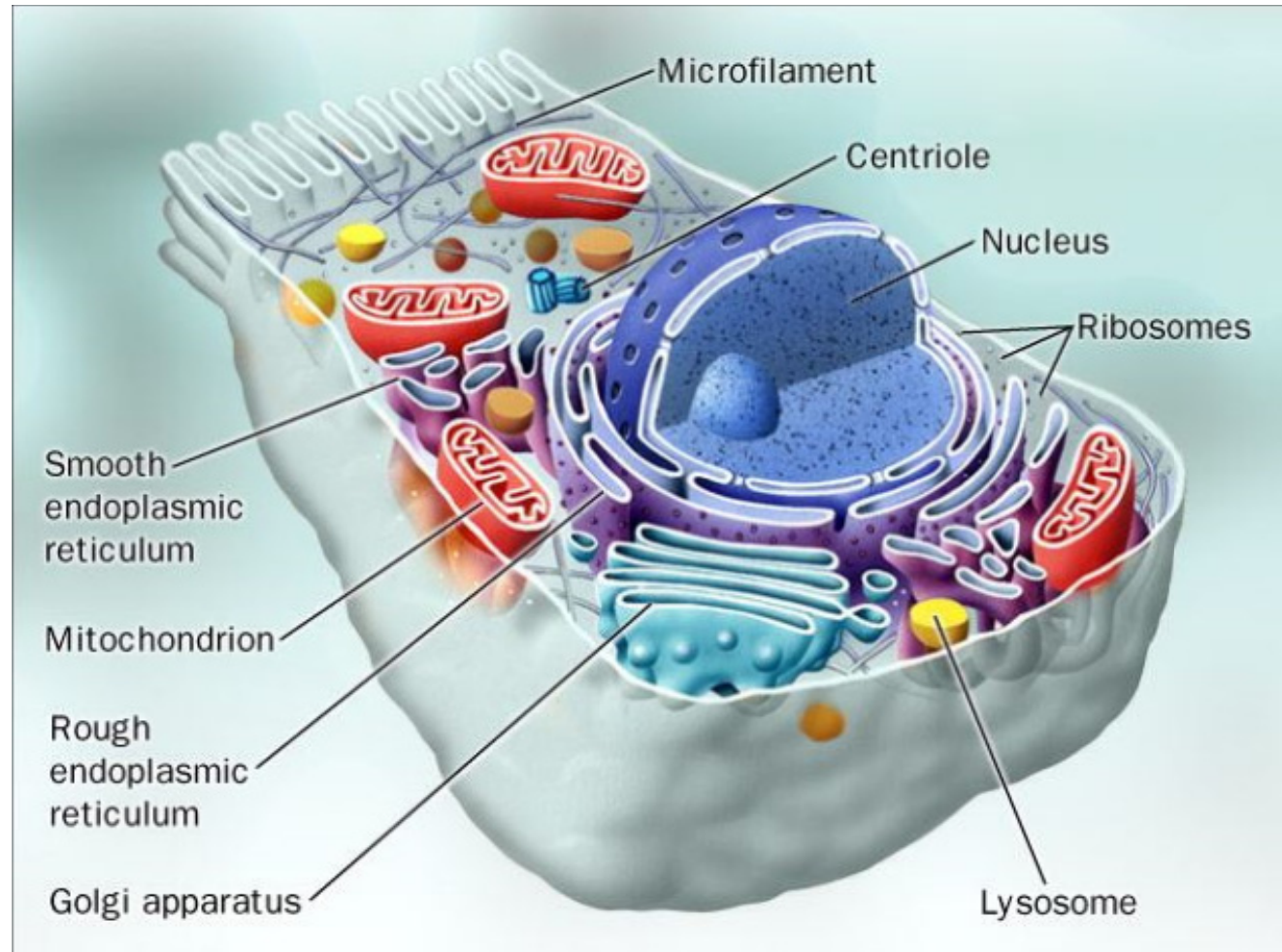
→ REACH FOOD THAT
OTHER'S CANNOT

50% OF TIME GIRAFFE'S FEED WITH NECK
HORIZONTAL

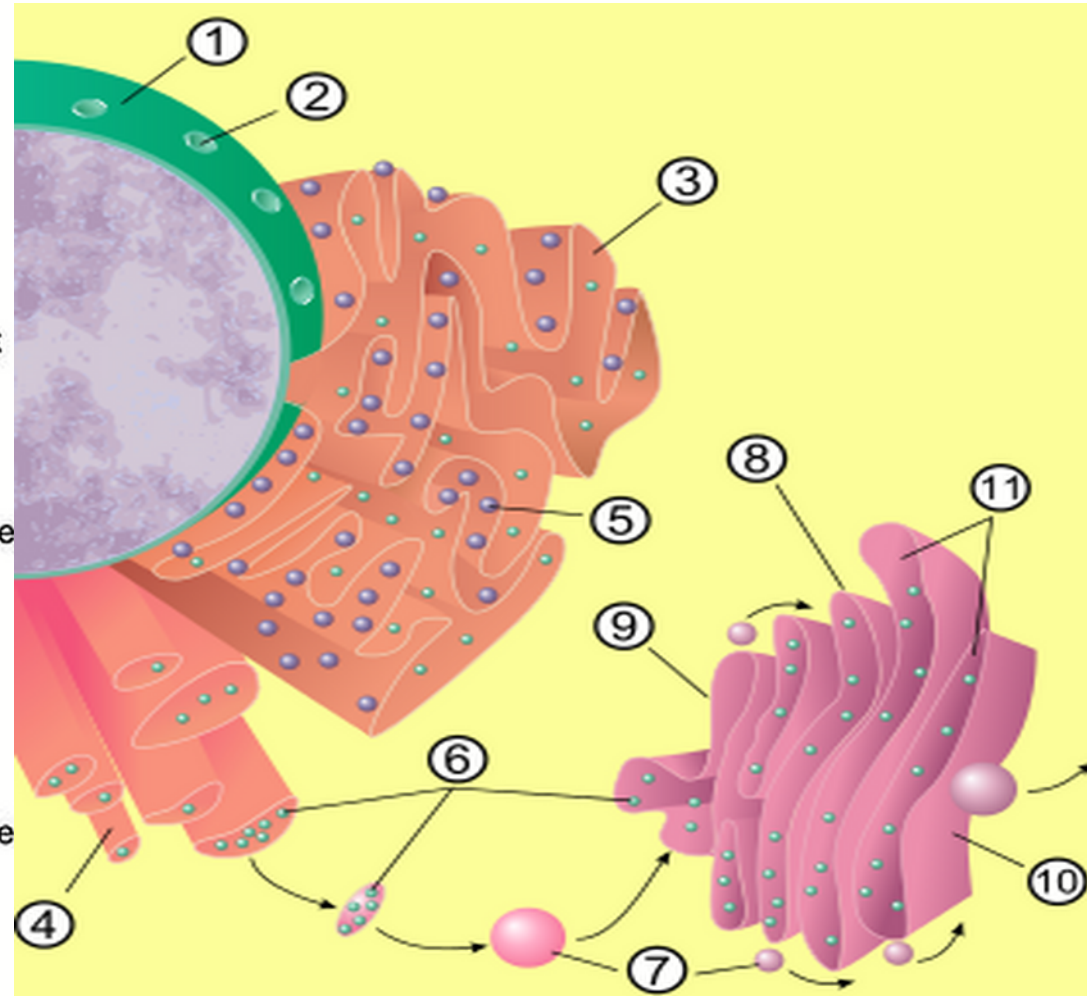
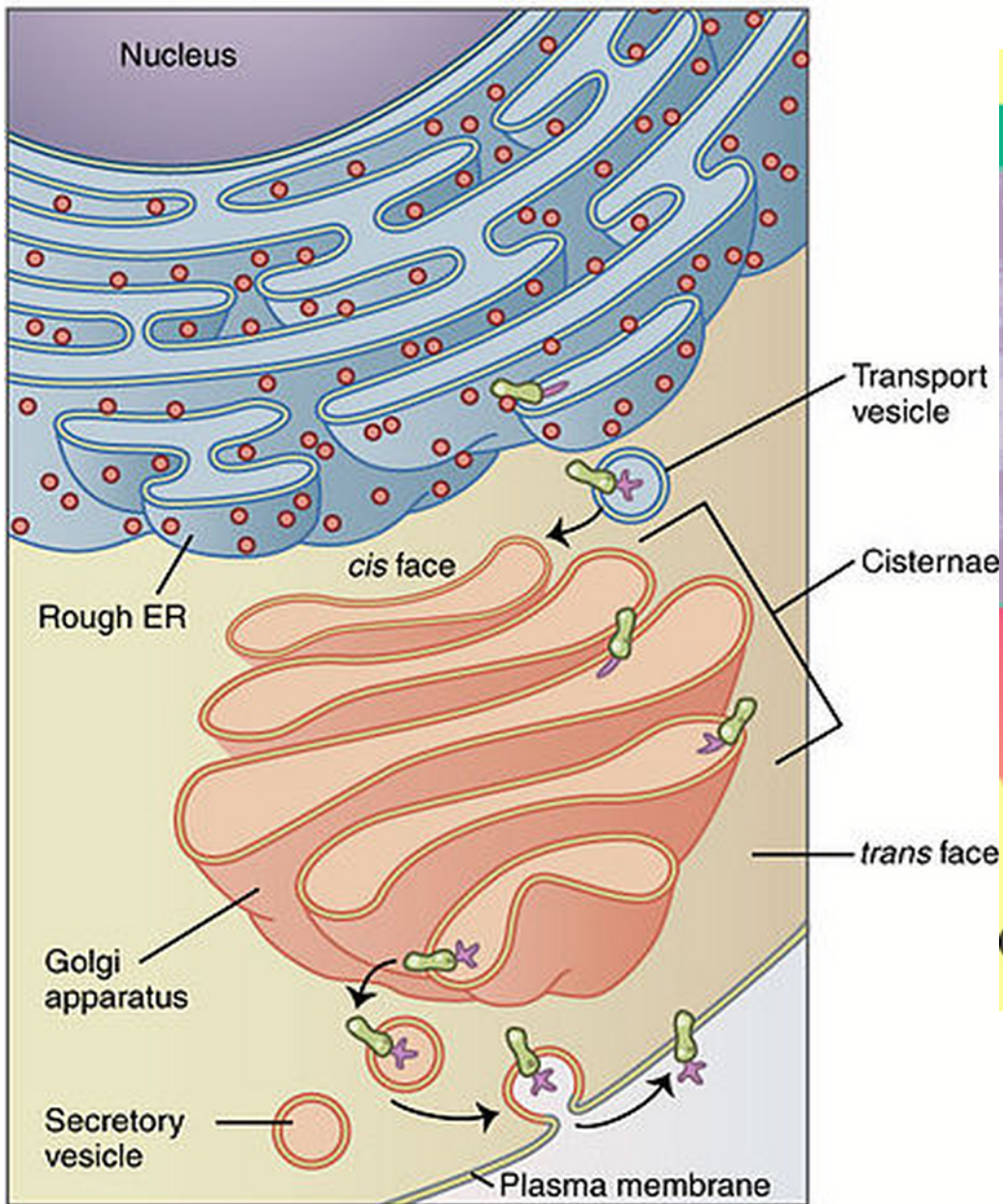
→ NECK LENGTH SELECTED BY
COMPETITION AMONG MALES
FOR MATES.

SO IT SEEMS OBVIOUS THAT GIVEN ENOUGH
TIME SIMPLE SYSTEMS WILL BE DRIVEN
BY SELECTION TO BECOME COMPLEX SYSTEMS.
WHEN YOU LOOK CLOSER — IT IS TRULY AMAZING
— THE ORIGIN OF LIVING THINGS

— THE ORIGIN OF
THE CELL
— AFTER THAT
IT WAS
SIMPLE?



GOLGI APPARATUS



FRANKLIN DISCUSSES SOME ISSUES IN
EVOLUTION — AS FAR AS I AM AWARE NO BIOLOGIST
REGARD ANY OF THESE ISSUES AS CASTING
DOUBT ON EVOLUTION PER SE

HE STATES THAT THE THEORY OF EVOLUTION
COMPRISES FOUR BASIC ESSENTIALLY
INDEPENDENT PROPOSITIONS.

↳ AS THEY ARE INDEPENDENT THEY
EACH NEED TO BE UNDERPINNED
BY THEIR OWN BODY OF EVIDENCE.

① PRESENT SPECIES HAVE DESCENDED

OVER A LONG PERIOD OF TIME FROM

"PRIMITIVE FORMS"

SAYS NOTHING ABOUT
MECHANISM OF EVOLUTION

↳ THIS IS NOT SO CLEAR TO ME

CLEARLY CYANOBACTERIA FROM THE
PRE-CAMBRIAN ARE MORE PRIMITIVE
THAN KANGEROOS

BUT DINOSAURS ARE NO MORE
PRIMITIVE THAN KANGEROOS (??)

SEE "WONDERFUL LIFE" S.J. GOULD

DOES EVOLUTION "IMPROVE" THINGS OR DOES
IT JUST FILL ECOLOGICAL NICHES?

② SPECIES CHANGE BY THE ACCUMULATION OF MANY SMALL CHANGES → AND THESE CHANGES ARE ENCODED IN THE ORGANISM SO THAT THEY CAN BE INHERITED.

↳ CENTRAL TO THIS IS WHAT IS MEANT BY "SMALL"

↳ I THINK YOU ALSO NEED TO INTRODUCE THE IDEA OF GROUPS BEING GEOGRAPHICALLY ISOLATED, FOR SPECIATION TO OCCUR.

③ THE CHANGES HAPPEN IN A RANDOM FASHION.

④ NATURAL SELECTION ACTS ON THESE SMALL CHANGES — SO THAT ADAPTATIONS ARE SELECTED SURVIVAL OF THE FITTEST

THIS SELECTION IS ALMOST THE SOLE DRIVER OF EVOLUTION.

THIS THEORY IS LOGICALLY COMPLEX

ALSO DISTANT FROM DIRECT OBSERVATION

— LARGE SCALE EVOLUTION TAKES PLACE ON A

TIME SCALE WHICH IS TOO LONG TO OBSERVE

DIRECTLY — MUST USE CIRCUMSTANTIAL EVIDENCE

→ FOSSIL RECORD

→ DNA ANALYSIS

FIRSTLY THERE IS SOME LEVEL OF INDEPENDENCE
BETWEEN THESE FOUR PLANKS OF THE THEORY

LAMARK (LYSENKO?) ACCEPTED ① & ②

BUT NOT ③ HE FAVOURED THE INHERITANCE
OF ACQUIRED CHARACTERISTICS

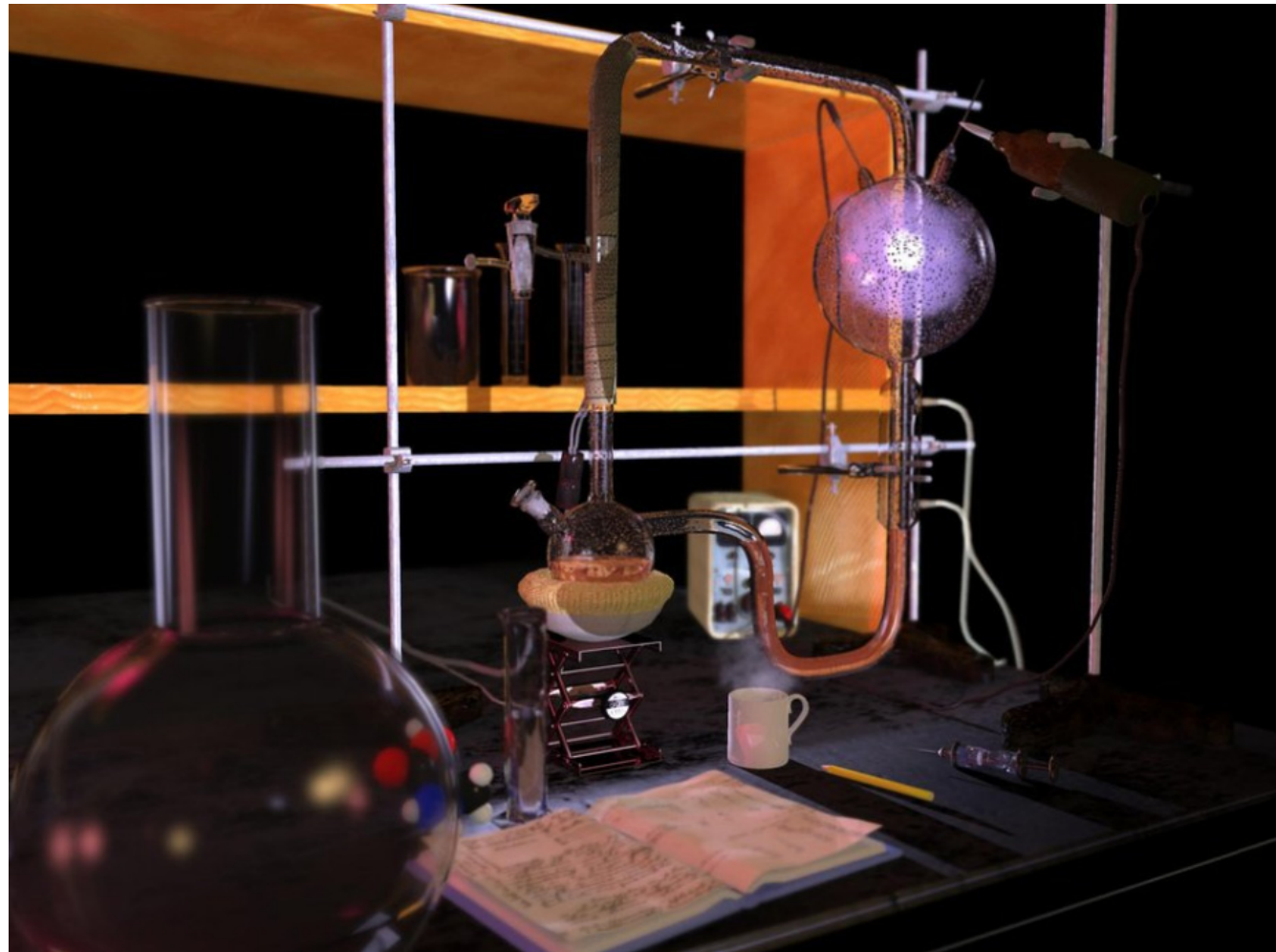
↳ SINCE ① → ④ ARE INDEPENDENT
WE NEED EVIDENCE FOR EACH
OF THEM.

SECONDLY EVOLUTION IS NOT A THEORY OF THE ORIGIN OF LIFE ON THIS PLANET

THERE HAVE BEEN SUGGESTIVE EXPERIMENTS THAT AMINO ACIDS ARE PRODUCED BY ELECTRIC DISCHARGES IN THE GASES WHICH CONSTITUTED

THE ATMOSPHERE OF THE EARLY EARTH

MILLER
UREY
EXPERIMENT



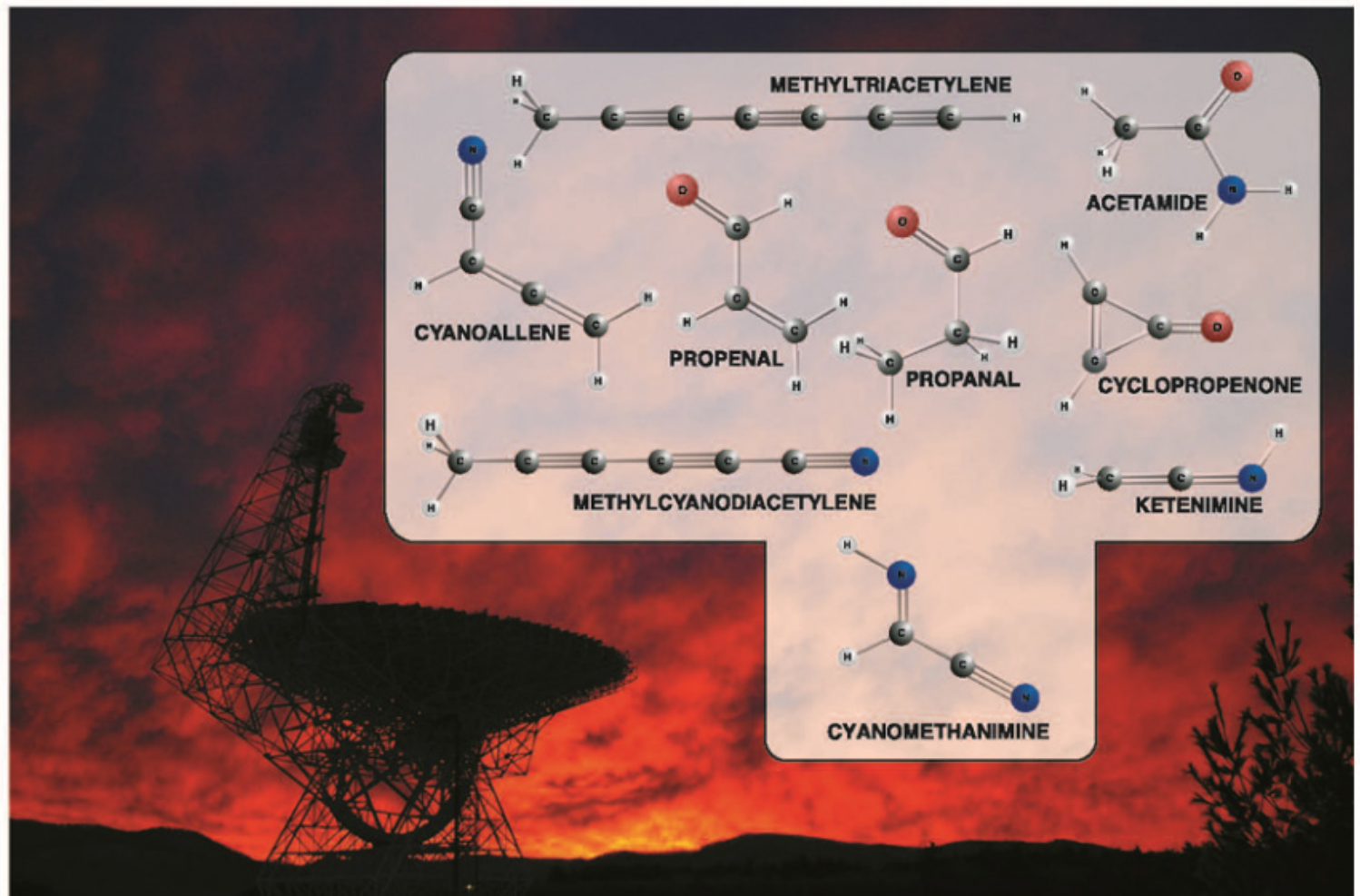
IN FACT WE ALSO SEE AMINO ACIDS IN SPACE

DID LIFE EVOLVE ON EARTH?

WAS IT SEEDED FROM SPACE? -WE HAVE NO IDEA

THE OBSERVATION OF EXTRATERRESTRIAL

LIFE WOULD
GIVE US
A CLUE.



FRANKLIN ALSO SAYS THAT THE IDEA THAT
EVOLUTION IS THE "FOUNDATION OF BIOLOGY" IS WRONG.

I DISAGREE. IT IS TRUE THAT BIOLOGY IS ABOUT
CURRENTLY EXISTING LIFE

OUR UNDERSTANDING MANY ASPECTS OF
BIOLOGY IS SURELY BASED ON UNITY OF LIFE

IT WOULD BE DIFFICULT TO UNDERSTAND

THE PROCESS OF PHOTOSYNTHESIS IF EVERY
PLANT USED A DIFFERENT CHEMICAL

ONE CAN ALSO OVERUSE THE IDEA OF EVOLUTION

→ SOCIOBIOLOGY IS A CASE IN POINT

EVIDENCE FOR EVOLUTION

- FOSSIL RECORD
- GEOGRAPHICAL DISTRIBUTION OF SPECIES
- PENTADACTYL LIMBS
- VESTIGIAL FORMS GILL SLITS IN HUMAN EMBRYOS

REASONABLE AGREEMENT BETWEEN

CLAD DIAGRAMS DERIVED FROM HOMOLOGIES
AND FROM BLOOD CHEMISTRY

THESE ARE ALL GOOD EVIDENCE FOR EVOLUTION
IN THAT THEY CAN EASILY BE DESCRIBED
BY COMMON DESCENT.

EVOLUTION ALSO MAKES USEFUL PREDICTIONS

— NO RABBITS IN JURASSIC STRATA

— NONE FOUND ✓

BUT IF WE FOUND ONE — I SUSPECT WE
COULD FIND GEOLOGICAL REASONS TO DISMISS

ASPECTS OF HOMOLGY EVIDENCE

PENTADACTYL LIMB — 5 IS A RANDOM #
∴ COMMON DESCENT?

WHAT ABOUT EYES? — SPIDERS 8, 6, 4, 2

BURGESS SHALE 3

"WHY" DO FORE & HIND LIMBS HAVE 5 DIGITS

↳ PROBABLY EXAMPLE OF COMPLEXITY

↳ WE WILL NEVER KNOW

BY & LARGE EVIDENCE FOR COMMON DESCENT — STRONG

WHAT ABOUT REMAINING THREE THESES?

② EVIDENCE THAT EVOLUTIONARY CHANGES ARE
GENERALLY SMALL — GENETIC EXPERIMENTS
— SELECTIVE BREEDING

DARWIN'S VIEW OF CONTINUOUS VARIATION
MODIFIED BY KNOWLEDGE OF DISCRETE DNA

— LARGE MORPHOLOGICAL "JUMPS" POSSIBLE

— ABSORPTION OF MITOCHONDRIA
INTO CELL ONE SHOT PROCESS

THE IDEA OF CONTINUOUS MODIFICATION IS IMPORTANT.

IF ONE WANTS TO EXPLAIN GAPS IN FOSSIL RECORD BY EVOLUTIONARY JUMPS HAVE TO AVOID ENDING UP WITH DISSOCIATION OF EVIDENCE & THEORY

JUMPS IMPROBABLE & UNEXPLAINED.

ONE EXPLANATION OF GAPS IN FOSSIL RECORD

PUNCTUATED EQUILIBRIA

SPECIES UNCHANGED FOR LONG PERIODS

THEN CHANGE RAPIDLY — PROBABILITY OF

FOSSILS OF INTERMEDIATES SMALL

COMPLEXITY MAKES KNOWLEDGE DIFFICULT

③ EVIDENCE THAT GENETIC CHANGE IS RANDOM

→ NO EXAMPLE OF INHERITANCE OF ACQUIRED CHARACTERISTICS HAS BEEN FOUND KAMMERER FAKES

OBSERVED RATES OF SPONTANEOUS MUTATIONS AND RADIATION INDUCED MUTATIONS SUGGEST THAT CHANGES ARE RANDOM

SO — COMMON DESCENT
GRADUAL CHANGE
RANDOM VARIATION } ON SOLID GROUND

WHAT ABOUT NATURAL SELECTION?

NATURAL SELECTION SEEMS SO SIMPLE

→ "MUST" BE TRUE

ILLUSION OF CERTAINTY

→ WE KNOW THAT WE CAN BREED
A BIGGER POTATO BY SELECTING
ON VARIATIONS IN THE POTATO
GENE POOL

→ SAYS NOTHING, A PRIORI, ABOUT
SPECIATION → HOW A POPULATION
OF POTATOES EVOLVES INTO
A POPULATION OF YAMS

COULD BE A COMPLETELY
DIFFERENT MECHANISM.

NATURAL SELECTION

SEEMS OBVIOUS AT FIRST SIGHT.

T. H. HUXLEY " HOW EXTREMELY STUPID NOT
TO HAVE THOUGHT OF THAT "

THAT IT MUST BE TRUE AT SOME LEVEL
CREATES AN ILLUSION OF CERTAINTY

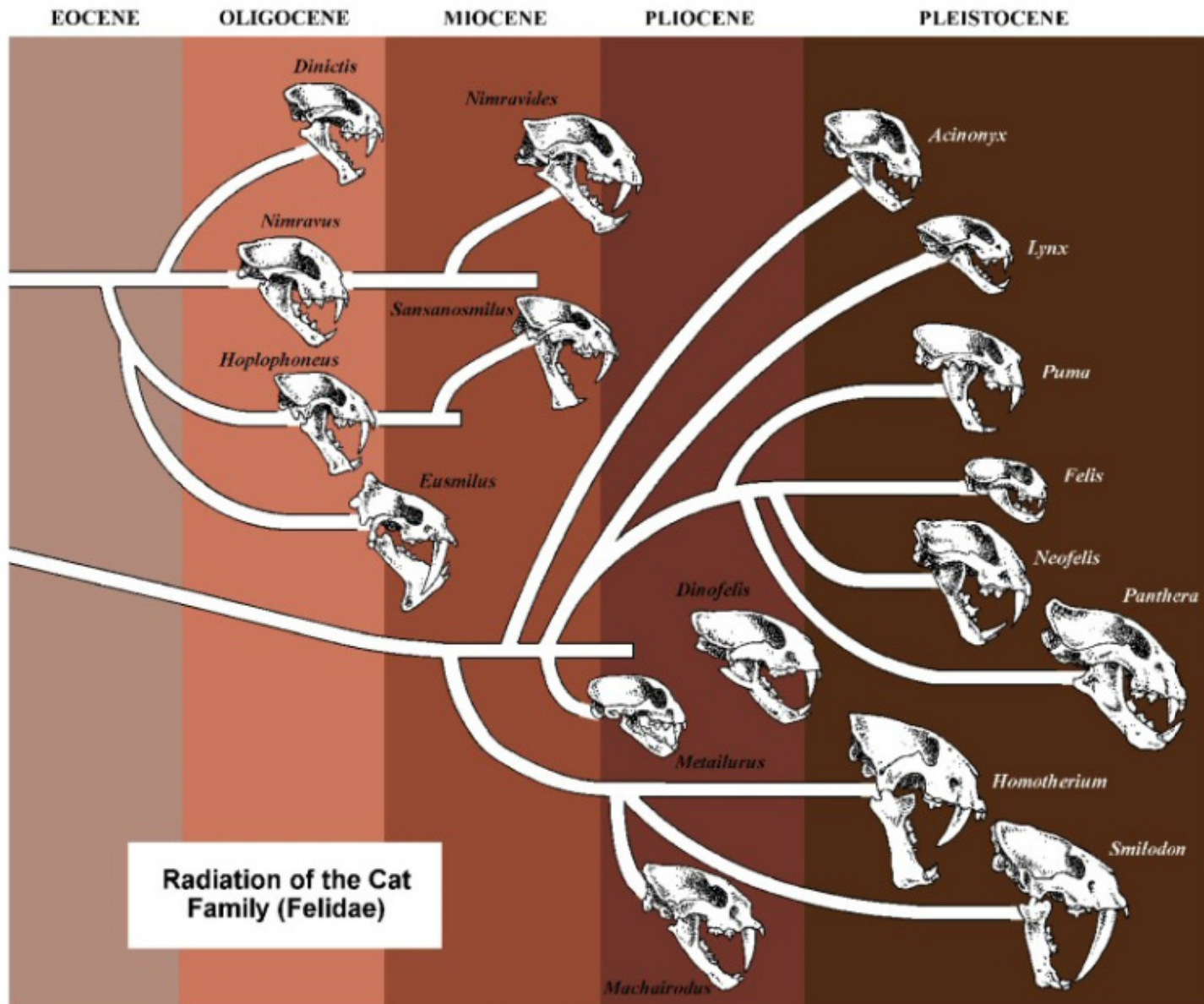
THERE MUST BE EVOLUTION + NATURAL
SELECTION - BUT HOW LARGE ARE EFFECTS
AND HOW QUICKLY DO THEY ACT

AGAIN THIS IS A CASE OF COMPLEXITY
MAKING IT DIFFICULT OR IMPOSSIBLE
TO HAVE COMPLETE KNOWLEDGE

EASY TO BREED CATS OF DIFFERENT
COLOURS → DUE TO NATURAL GENETIC VARIATION



FAR FROM OBVIOUS HOW NATURAL SELECTION
PRODUCES A MODERN CAT FROM AN
EOCENE PRE CURSOR



DARWIN WAS AWARE OF PROBLEM OF SPECIATION

THE MAIN PROBLEM IS THAT WE ARE FORCED
TO MAKE AN ENORMOUS EXTRAPOLATION TO
LARGE TIME SCALES FROM WHAT WE SEE ON
SHORT TIME SCALES

THERE ARE SEVERAL MODERN IDEAS
ON SPECIATION

ALLOPATRIC → GROUPS BECOME SEPARATED
EVOLVE IN ISOLATION

PERIPATRIC → RANDOM VARIATIONS ON
THE PERIPHERY OF A
POPULATION

- PARAPATRIC → TWO POPULATIONS PARTIALLY SEPARATED
- INTERBREED AT CONTACT POINT
 - PRODUCES LESS WELL ADAPTED INDIVIDUALS
 - POPULATIONS GENETICALLY DRIFT APART

I SUSPECT THAT THERE WILL BE NO FINAL RESOLUTION — THESE PROCESSES EXTREMELY COMPLEX — PROBABLY CONTINGENT.

A RELATED QUESTION IS WHY ARE THERE SPECIES AT ALL?

— SPLITTING LEADS TO GROUPS WHICH ARE MORE ADAPTED TO LOCAL ENVIRONMENT

— SPLITTING STOPS WHEN SUB-SPECIES CANNOT COMPETE WITH SPECIES

AGAIN COMPLEXITY HIDES KNOWLEDGE

↳ RECOURSE TO MODELING

A REAL PROBLEM IS SUFFICIENT TIME?

- IT HAPPENED SO THERE MUST HAVE BEEN TIME

BIOLOGICAL COMPLEXITY MAKES IT IMPOSSIBLE
TO "PROVE"

A FINAL COMPLEX DIFFICULTY IS THAT
HOW DNA PRODUCES AN ORGANISM AND
HOW THE ENVIRONMENT INTERACTS
WITH DNA IS COMPLEX & NOT
COMPLETELY UNDERSTOOD

THERE SEEMS TO BE MORE INFORMATION
IN AN ORGANISM THAN IN DNA

HUMAN GENOME HAS 3×10^9 BASE PAIRS
 $\sim 6 \times 10^9$ BITS

BRAIN HAS 10^{10} NEURONS EACH WITH 10^4
CONNECTIONS

DNA MUST CODE FOR GROWTH OF NEURONS
→ NOT COMPLETE BRAIN
STRUCTURE?

AN ORGANISM IS THE INTERACTION
OF MANY STRUCTURES — COMPLEX
EMERGENT

- RELATIONSHIP BETWEEN GENETIC MATERIAL
AND EXPRESSED CHARACTERISTICS IS
NOT ONE-TO-ONE

- DNA NOT A LIST OF INSTRUCTIONS TO
BUILD AN ORGANISM

- DNA → CODES FOR PROTEINS

ACTION OF PROTEINS INHERENT
IN THE STRUCTURES THEY FOLD
INTO → NOT CODED IN DNA

→ IS THAT TRUE

- MORE ALIKE TO THE RULES
OF CHESS.

INTELLIGENT DESIGN

IT'S USUALLY A MISTAKE TO DISMISS PEOPLE
YOU DISAGREE WITH AS "JUST STUPID"

INTELLIGENT DESIGN PROponents OFTEN
RAISE ISSUE OF INTERMEDIATE STRUCTURES

EVOLUTION OF COMPLEX STRUCTURE

LIKE AN EYE.

IRREDUCIBLE

COMPLEXITY

RESPONSE

— EYES EVOLVED INDEPENDENTLY

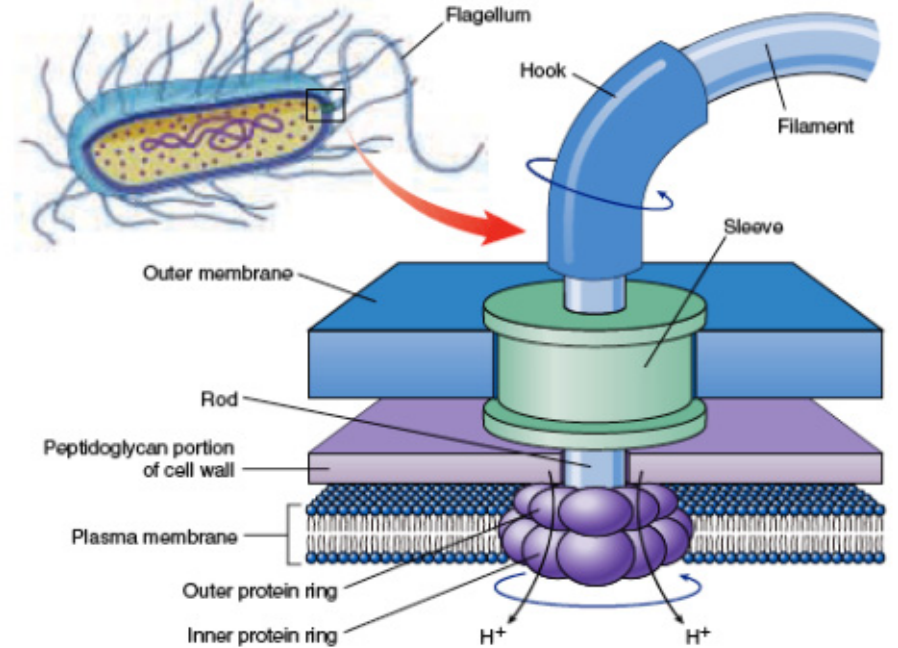
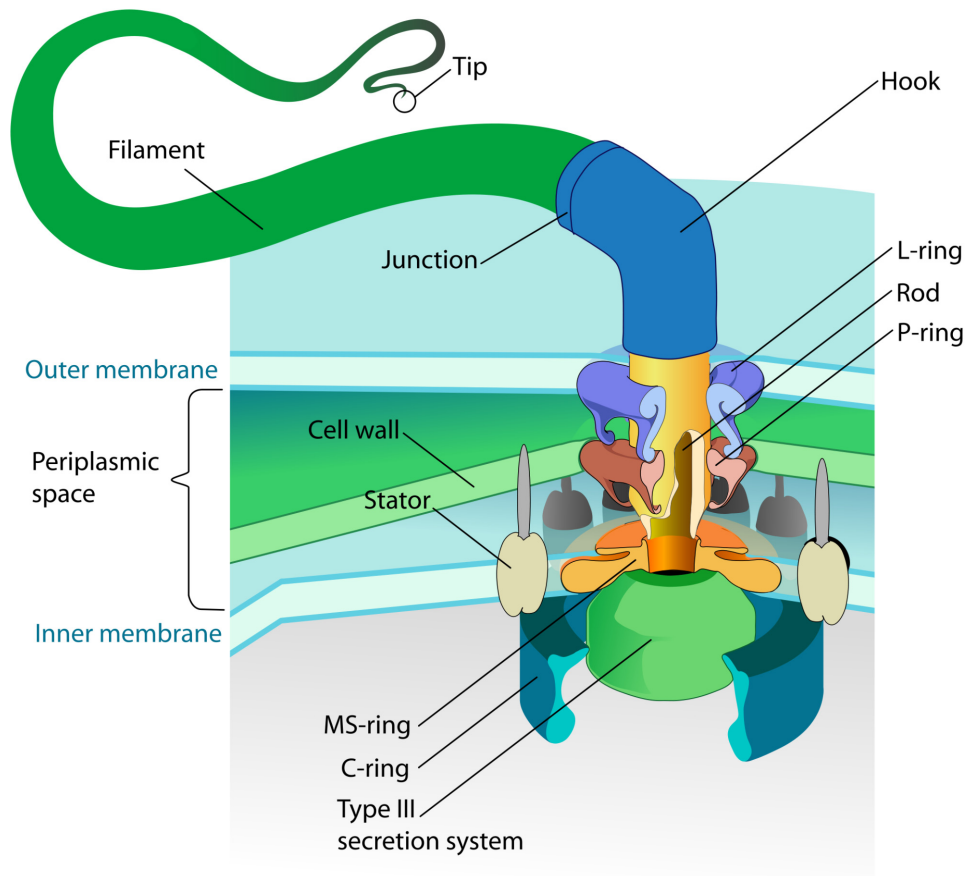
SEVERAL TIMES

— ANY LIGHT SENSITIVE STRUCTURE

IS OF UTILITY.

FLAGELLUM - IRREDUCIBLE COMPLEXITY

BASIC INTELLIGENT DESIGN IDEA IS TO LOOK FOR
STRUCTURE TOO COMPLEX TO EVOLVE FROM
SOMETHING USEFUL AND SIMPLER



CHEMICAL PUMP ROTATES
FLAGELLUM 0 - 1000 RPM

→ TOO COMPLEX TO EVER REPRODUCE
EVOLUTIONARY SEQUENCE

ON THE OTHER HAND

IMPOSSIBLE TO SHOW THAT IT COULD
NOT HAVE EVOLVED

MAYBE STRUCTURE IS DERIVED FROM ONE
USED TO INJECT TOXINS IN CELLS

EXAPTATION → "REUSE" OF STRUCTURE
WHICH EVOLVED IN
A DIFFERENT ROLE

GLOBAL WARMING

THIS IS ANOTHER CONTENTIOUS CONTEMPORARY ISSUE

THIS IS SIMILAR TO EVOLUTION

↳ TOO OBVIOUS TO BE WRONG

- INDUSTRIAL CIVILIZATION PUMPS CO_2
INTO THE ATMOSPHERE

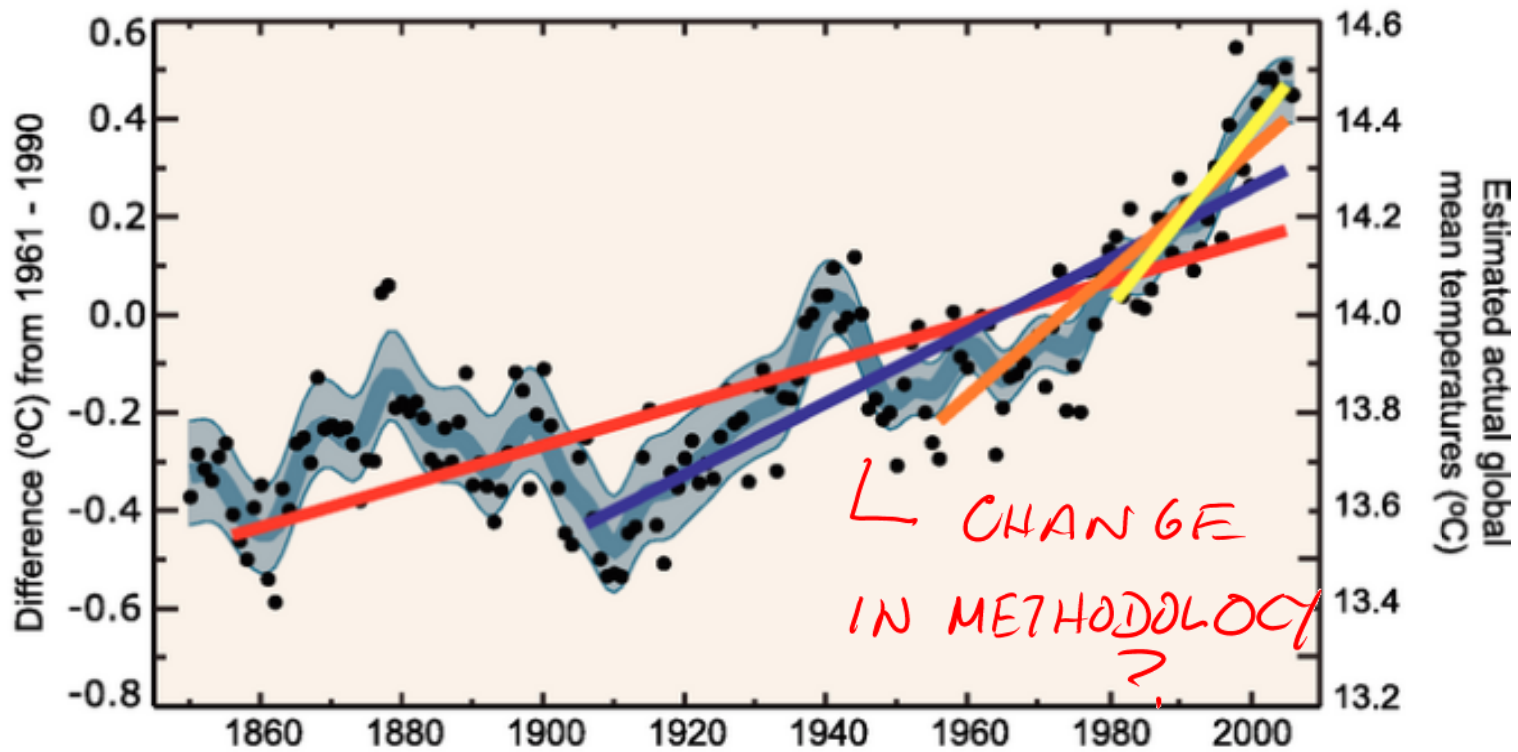
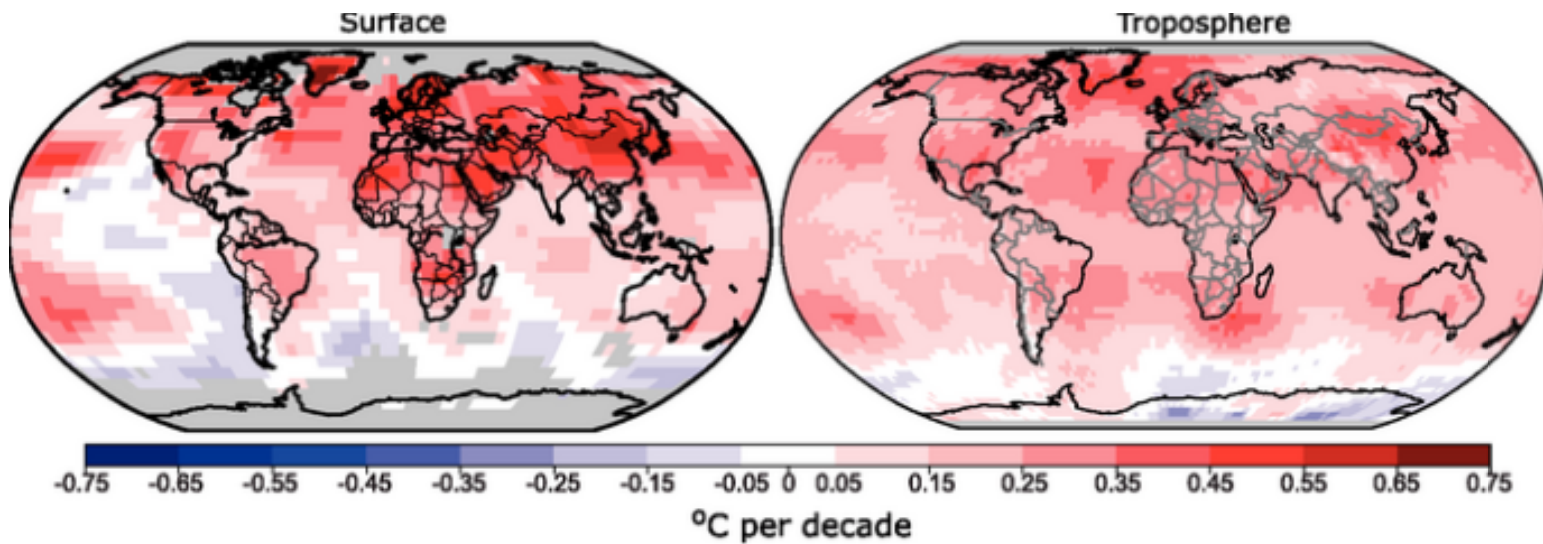
- THINGS WILL HEAT UP

BUT THE ATMOSPHERE IS COMPLEX

MANY SYSTEMS WITH MULTIPLE INTERACTIONS

GLOBAL WARMING HYPOTHESIS DEPENDS ON SEVERAL INDEPENDENT THESES - EACH OF WHICH NEEDS ITS OWN EVIDENTIAL SUPPORT

- ① THE GLOBE HAS BEEN WARMING UNUSUALLY SINCE THE START OF LARGE SCALE INDUSTRIAL CIVILIZATION.
- ② THERE ARE NO KNOWN NATURAL CAUSES OF THIS WARMING.
- ③ BURNING FOSSIL FUELS IS A NECESSARY AND SUFFICIENT CAUSE OF THIS WARMING.



Period	Rate
Years	°C per decade
25	0.177±0.052
50	0.128±0.026
100	0.074±0.018
150	0.045±0.012

- Annual mean
- Smoothed series
- 5-95% decadal error bars

① SEEMS PRETTY WELL ESTABLISHED

THERE DOES SEEM TO BE WARMING OVER
THE LAST FEW DECADES

HOWEVER THERE IS NOT A MONOTONIC INCREASE

ARE THE VARIOUS STRUCTURES ATMOSPHERIC
EFFECTS — OR INTER-NORMALIZATION ERRORS?

ATMOSPHERIC EFFECTS

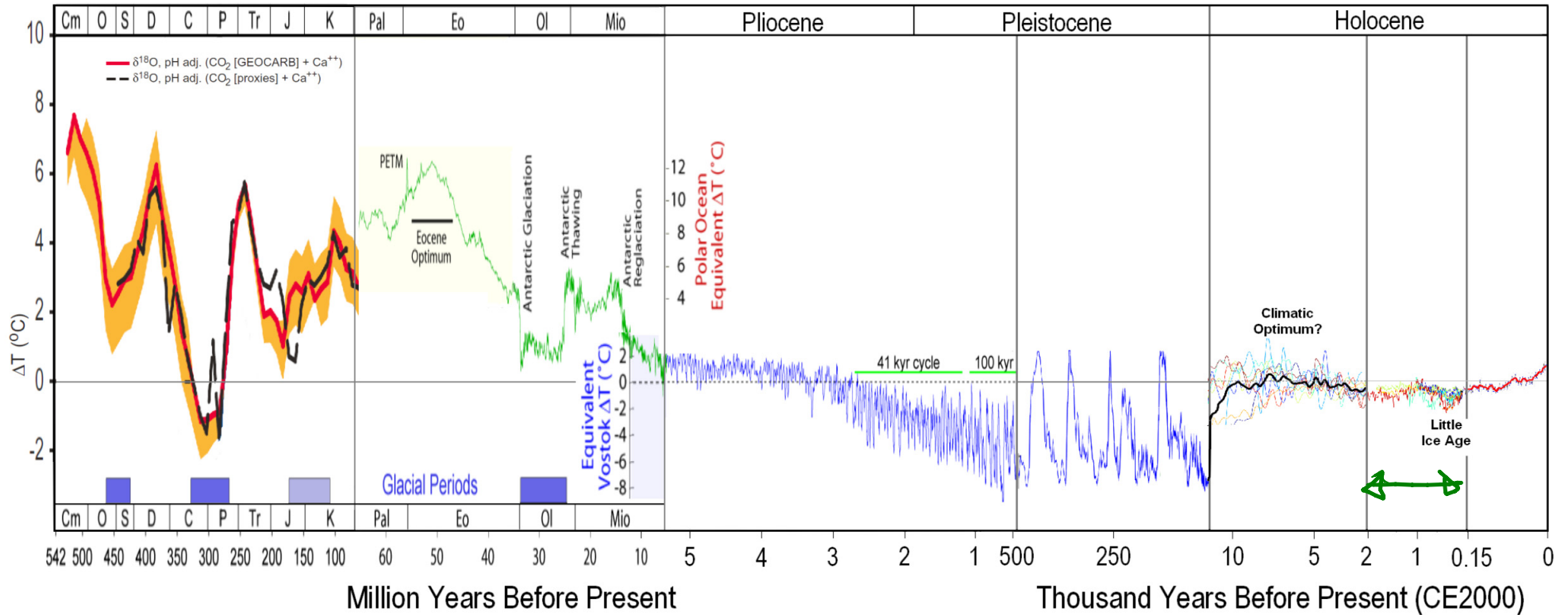
1940 - 1970 DUE TO AERSOLS?

~ 1990 - 2010 DUE TO OCEANS
ABSORBING HEAT.

KNOWN NORMALIZATION PROBLEM IN 1945

→ BUT IT WAS COLD

Temperature of Planet Earth



PALEOCLIMATE IS IMPORTANT TO UNDERSTAND
IF WE ARE TO BE CONFIDENT THAT WE
UNDERSTAND PRESENT PATTERNS
GOING BACK 2000 YEARS VARIATIONS SEEM LESS
THAN PRESENT.
GOING BACK FURTHER?

TO PRODUCE THIS PALEOTEMPERATURE RECORD
DEPENDS ON MANY COMPLEX MEASUREMENTS
TO FURTHER UNDERSTAND IT IS A
EXCELLENT EXAMPLE OF TRYING TO
UNDERSTAND A COMPLEX SYSTEM

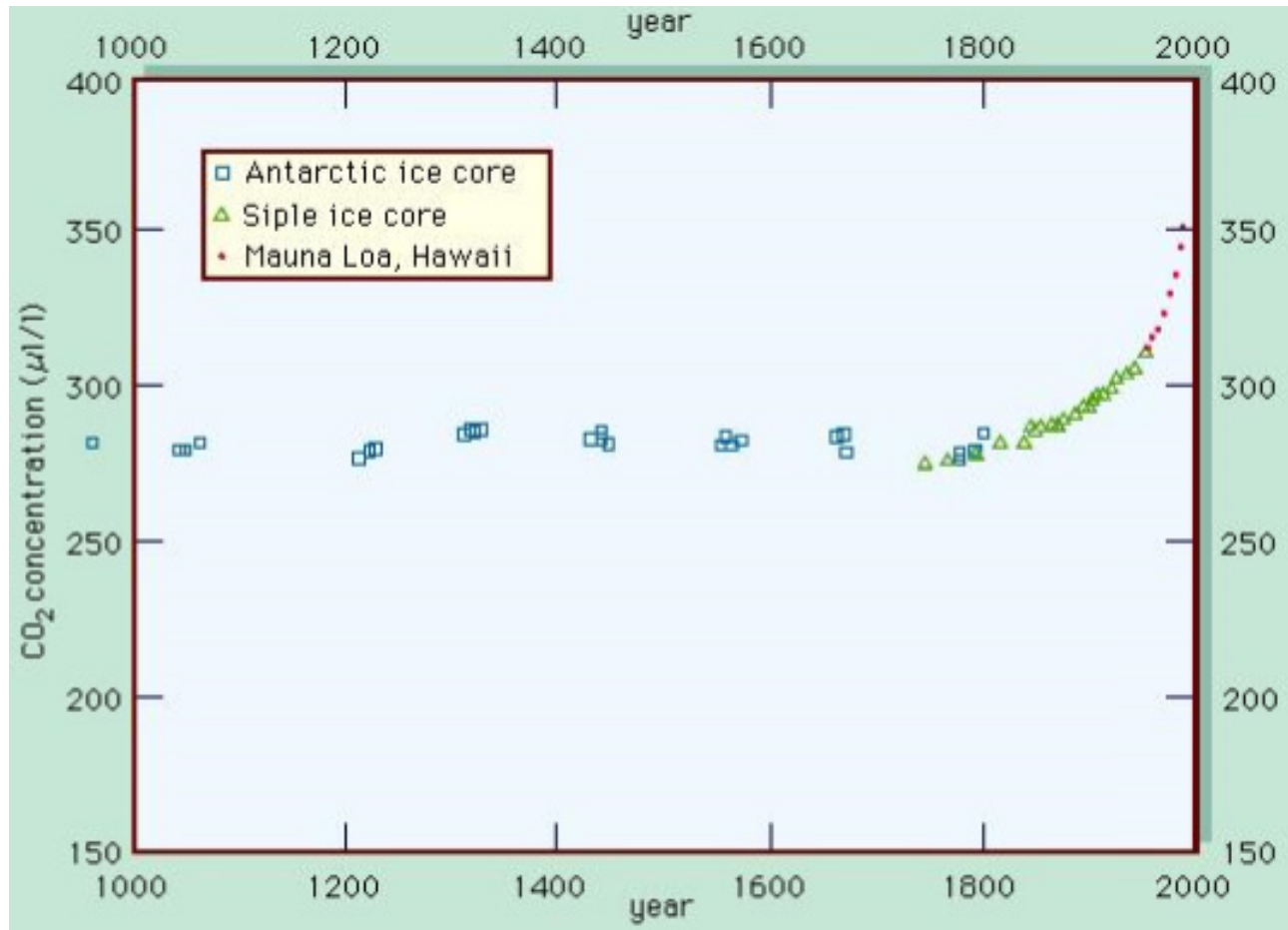
ONE CAN ONLY DO THIS THROUGH

MODELING



COMMONALITY OF COMPLEX SYSTEMS
INVESTIGATED BY SCIENCE

IF WARMING IS ESTABLISHED WE HAVE
TO DEMONSTRATE THAT THIS IS CAUSED
BY BURNING FOSSIL FUELS



THE RECORDS SHOW A CLEAR RISE
IN CO₂ FROM 1800, FASTER SINCE 1950

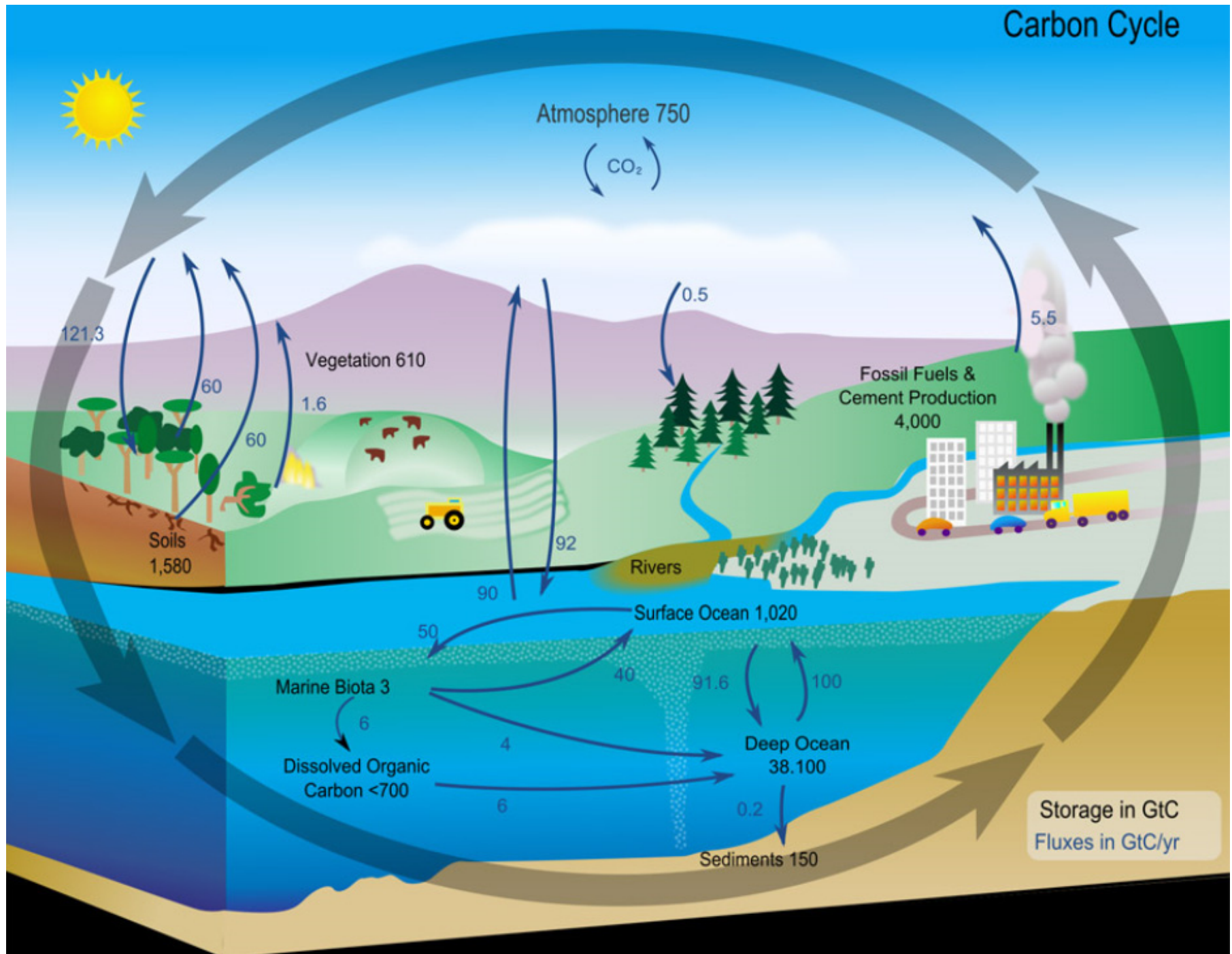
ONE MIGHT THINK IT SHOULD BE SIMPLE
TO CORRELATE $\text{CO}_2 \leftrightarrow$ TEMPERATURE

→ THIS CAN ONLY BE DONE VIA MODELING

INTERACTION OF

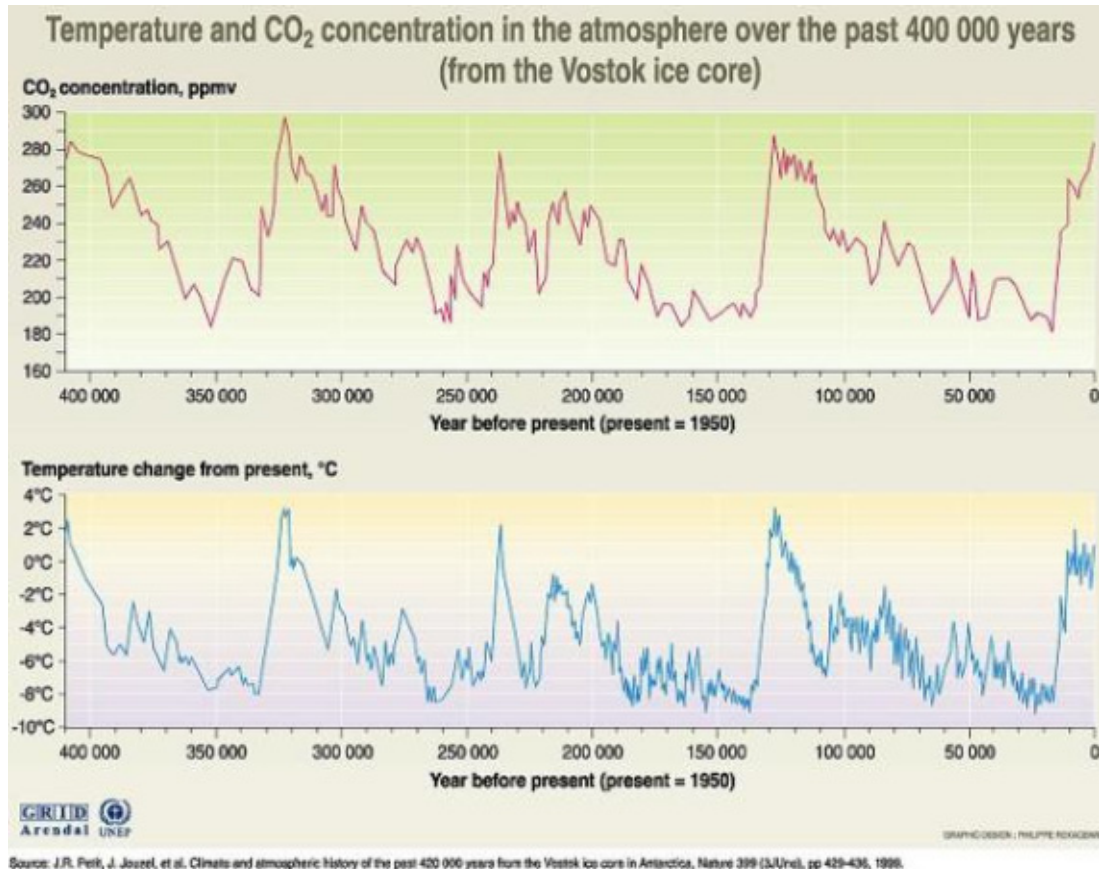
- CO_2
- TEMPERATURE
- WATER VAPOUR
- CLOUD FORMATION
- AERO SOLS
- GLOBAL HEAT TRANSPORT
- HEAT TRAPPING
- REFLECTION OF SOLAR
RADIATION

THIS GIVES SOME IDEA OF COMPLEXITY



- THE AMOUNT OF CO_2 RELEASED INTO THE ATMOSPHERE BY BURNING FOSSIL FUELS IS LARGE COMPARED TO NATURAL COMPOSITION IN THIS EPOCH
- THE ATMOSPHERE DOES NOT CONTAIN A LOT OF MATTER. SO LARGE INFLUXES COULD BE DANGEROUS.
- BUT AMOUNT OF CO_2 RELEASED IS NOT LARGE COMPARED TO AMOUNT CYCLED IN/OUT OF VEGETATION, SOILS, OCEANS
- UNCERTAINTY IN EACH COMPLEX INTERACTION VERTEX MAKES GOOD PREDICTIONS HARD

IMPORTANT TO UNDERSTAND $CO_2 \leftrightarrow$ TEMP IN THE PALEOCLIMATE VOSTOK ICE CORES - ANTARCTICA



Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3/June), pp 429-436, 1996.

CLEARLY CO_2 AND TEMPERATURE ARE STRONGLY CORRELATED

J. R. PETIT et al NATURE
399 (1999) 429-436
CLAIM THAT WARMING
PRECEEDS CO_2 RISE
BY ~ 800 YEARS

THIS WAS DURING AN ICE AGE

MAY HAVE NO RELEVANCE TO PRESENT EPOCH

OTHER EFFECTS?

- SUNS RADIANCE
- SUN SPOT CYCLE
- COSMIC RADIATION & CLOUD FORMATION
(COULD EXPERIMENT - CERN)
- INTERACTIONS WITH EARTH / SOLAR / GALACTIC MAGNETIC FIELDS

MY SENSE IS THAT THE LITERATURE DOES NOT FAVOUR ANY OF THESE

MANY INTERESTING PHENOMENA

(PERHAPS THE MOST INTERESTING)

ARE ASSOCIATED WITH COMPLEX SYSTEMS

→ MANY SUBSYSTEMS WITH MULTIPLE
INTERACTIONS INVOLVING FEEDBACK &
PERHAPS NON-LINEARITY.

→ COMPLEXITY HIDES KNOWLEDGE

→ COMPUTER MODELING / SIMULATION

GARBAGE IN → GARBAGE OUT.

CLIMATE VARIATION ON MARS

POSITED AS TEST CASE → NO FOSSIL FUEL
BURNING ON MARS

? SAME INFLUENCE OF SOLAR RADIATION
AS EARTH?

UNLIKELY → NO OCEANS ON MARS

