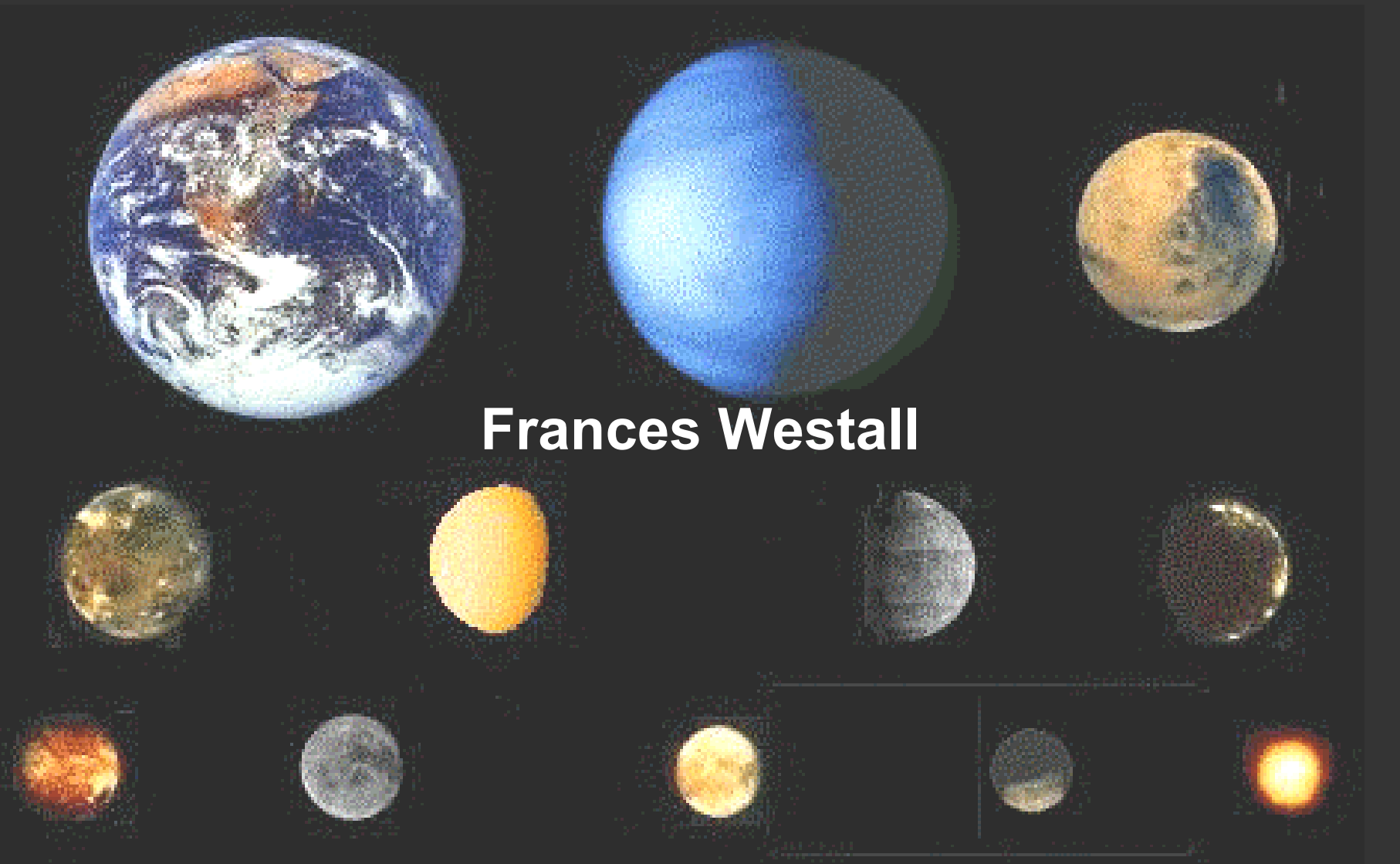
HABITABILITY IN THE SOLAR SYSTEM AND BEYON



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westall@cnrs-orleans.fr

→ WHAT IS HABITABILITY ?

→ EARTH

→ MARS

→ EUROPA

→ (VENUS?)

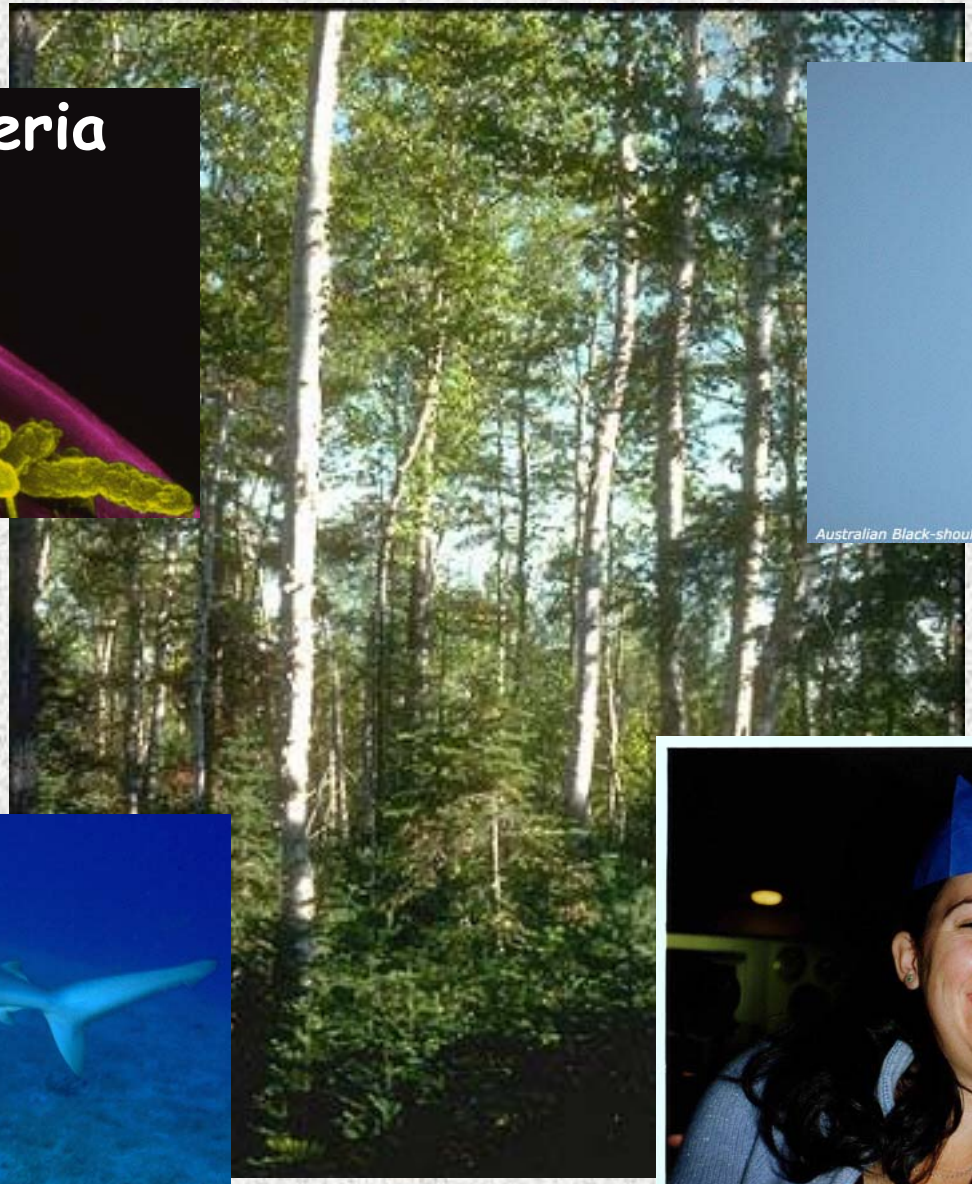
→ OTHER?

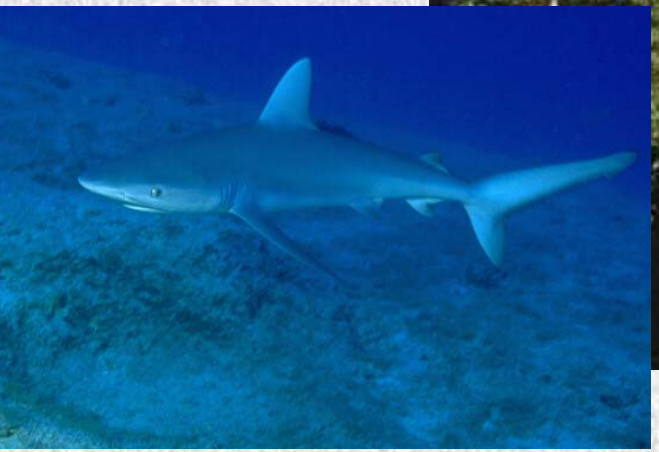
WHAT IS HABITABILITY?

Habitable = fit to be lived in

FOR WHAT KIND OF LIFE?

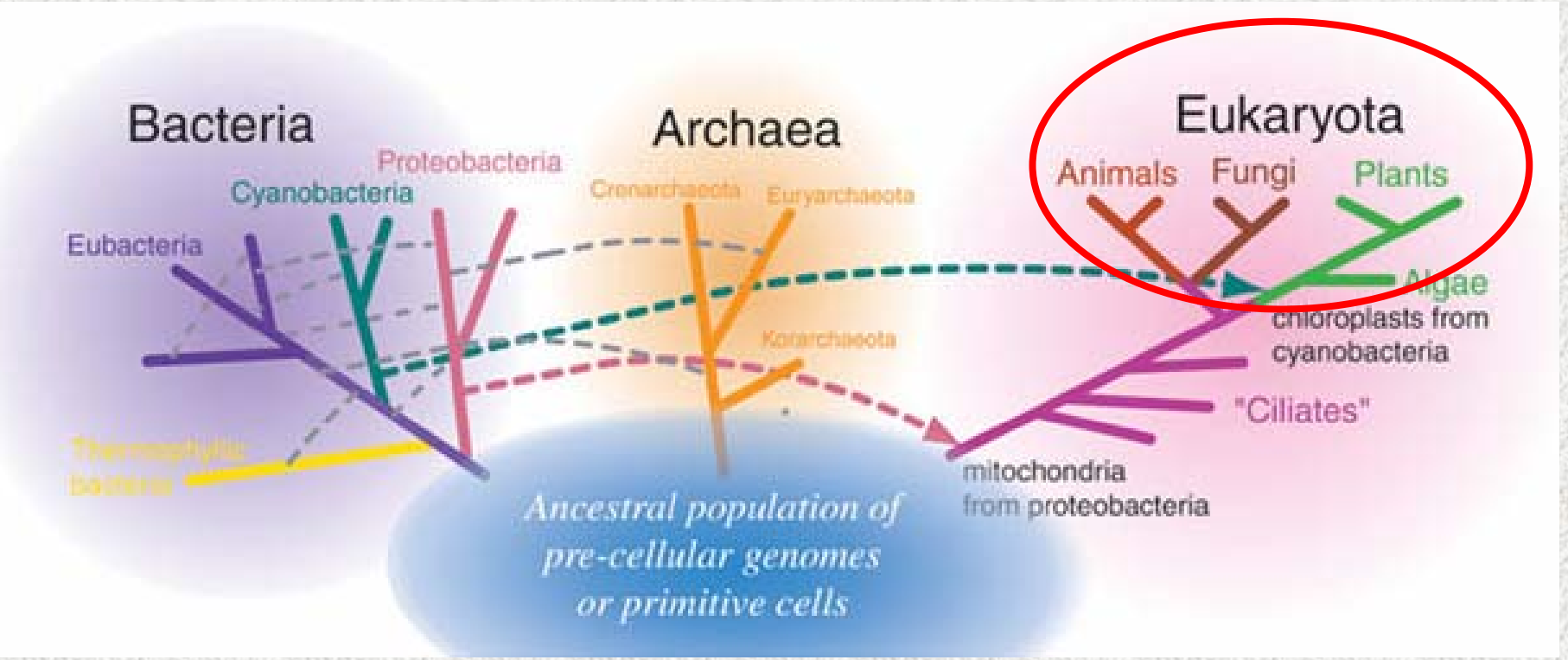
What kind of life?





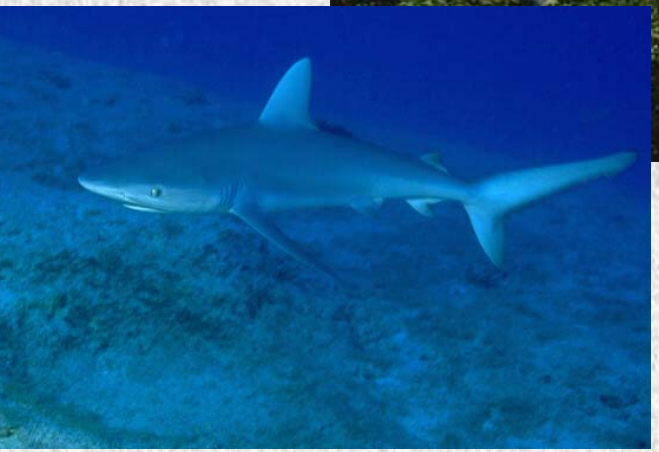
KINGDOMS OF LIFE

Most visible surface life



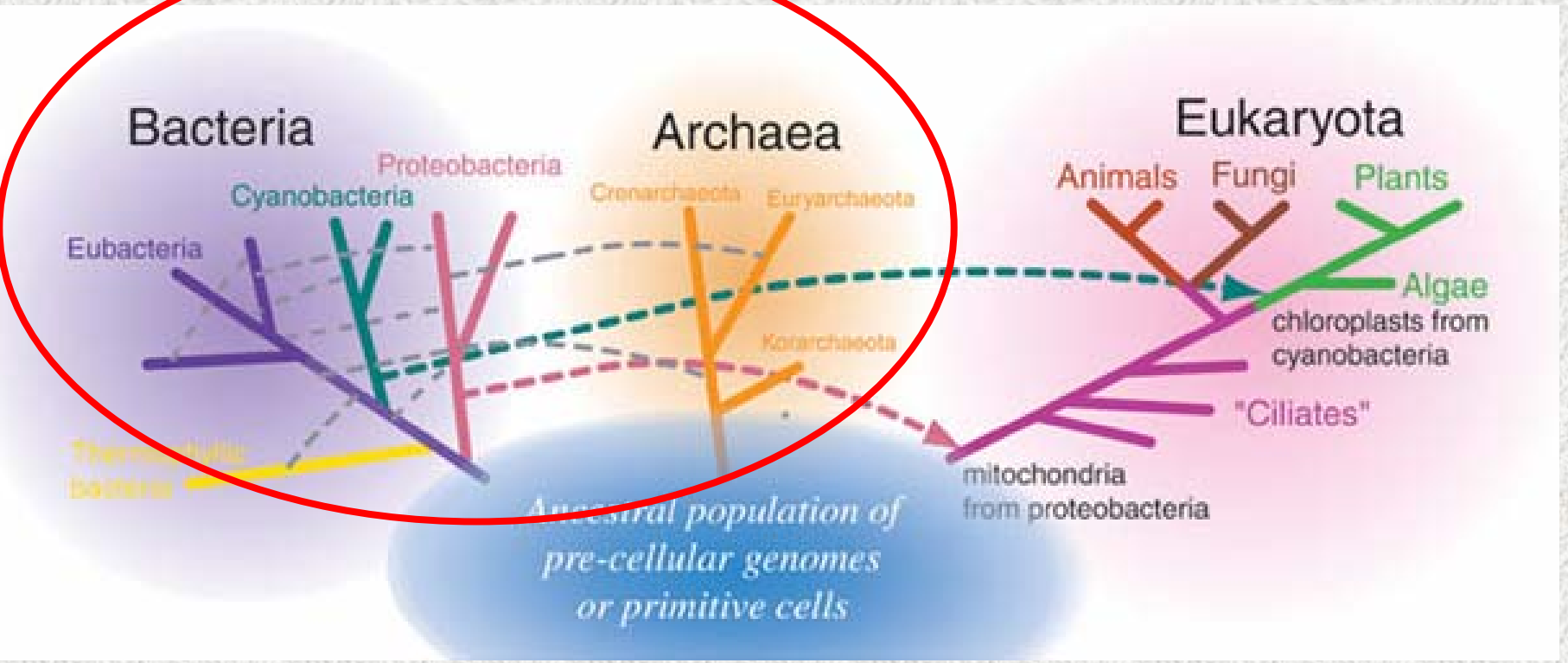
After Woese

Eucaryotes are the product of long co-evolution with a geologically active plane



KINGDOMS OF LIFE

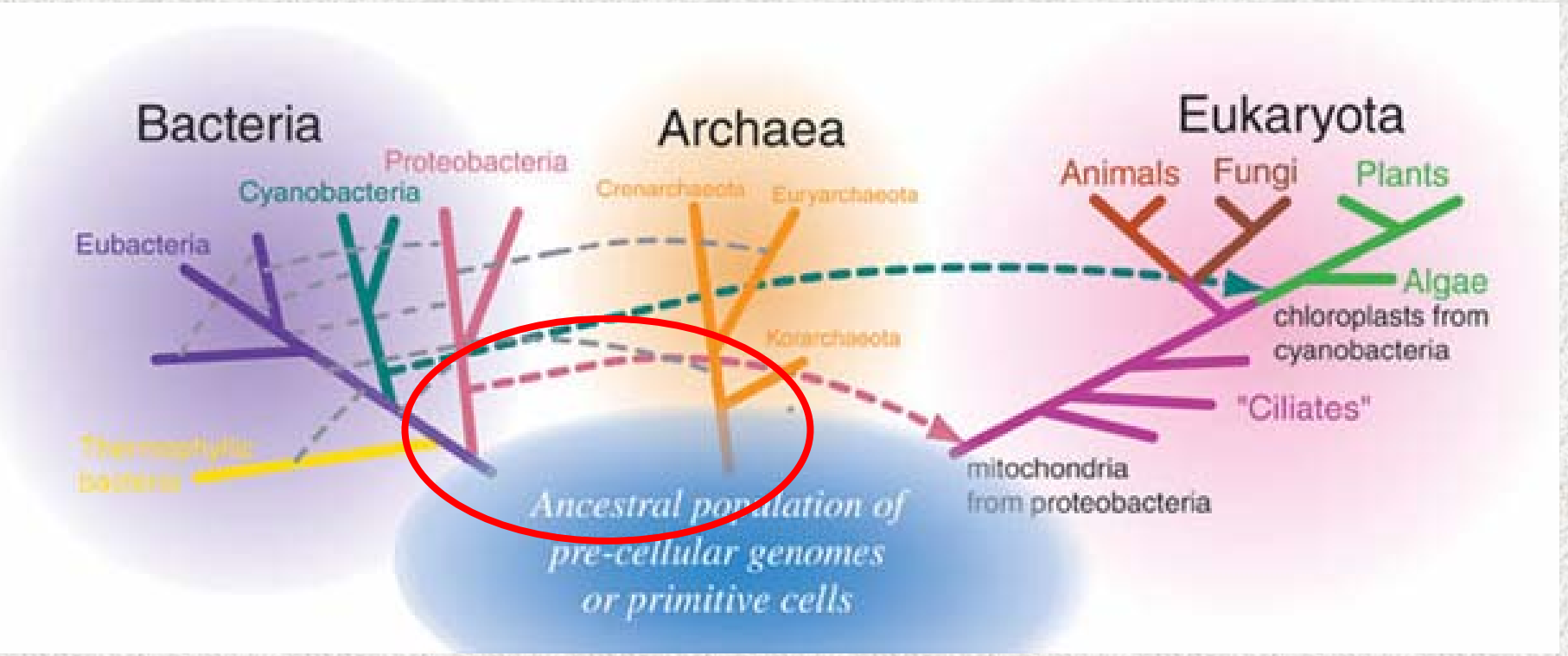
Largest biomass



After Woese

KINGDOMS OF LIFE

Earliest life and probable level of ET in the SS



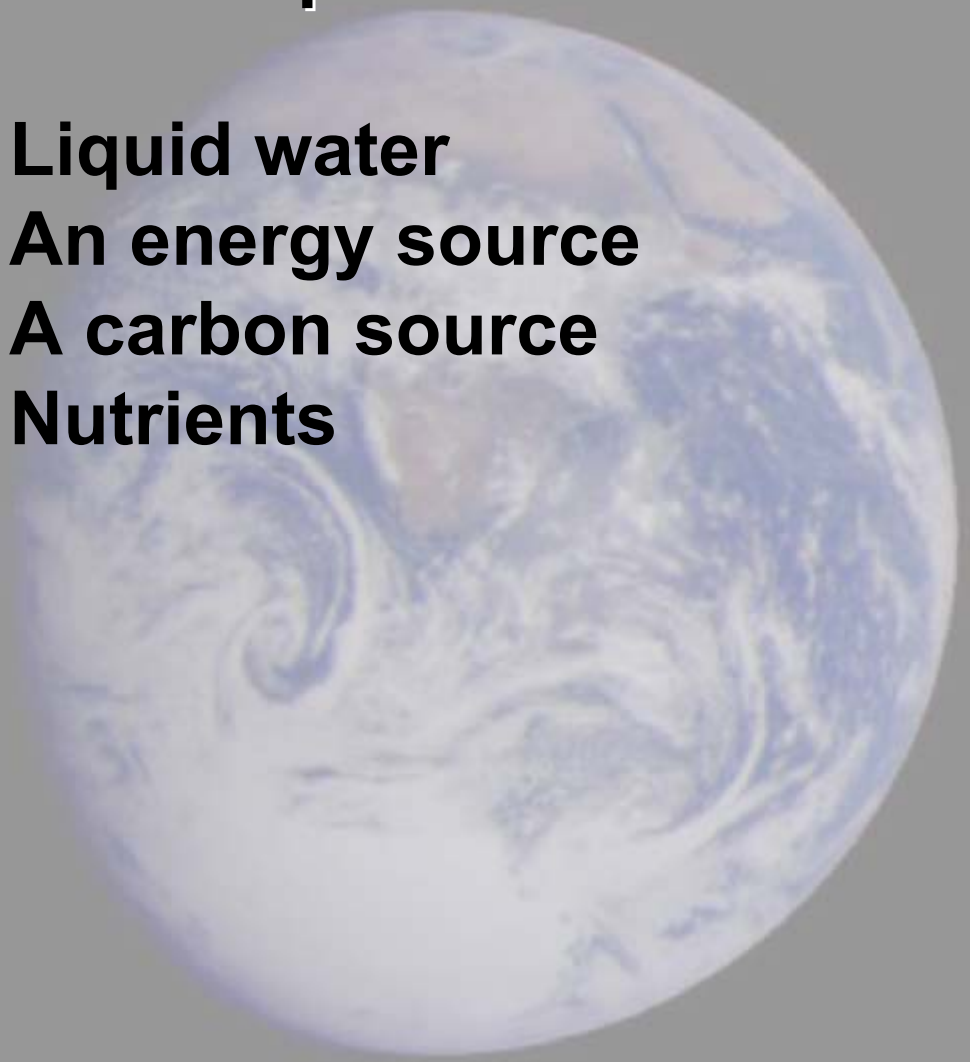
After Woese

Life needs :

- Liquid water
- An energy source
- A carbon source
- Nutrients

→ Conditions suitable for spontaneous generation and reproduction of life

An habitable planet should have :



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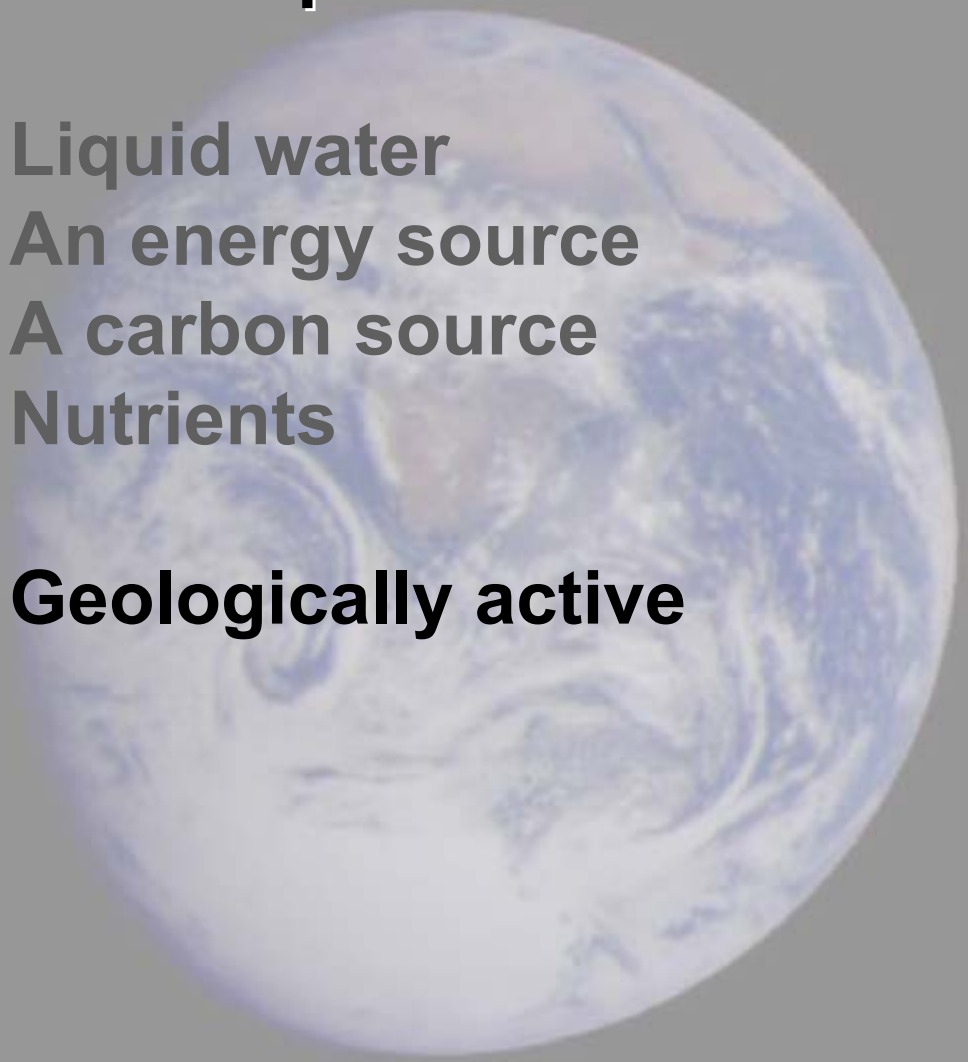


- Liquid water
- An energy source
- A carbon source
- Nutrients

- **Geologically active**

Survival conditions

Life can do without liquid water, energy and carbon for a certain period of time .....

HABITABILITY IN TIME

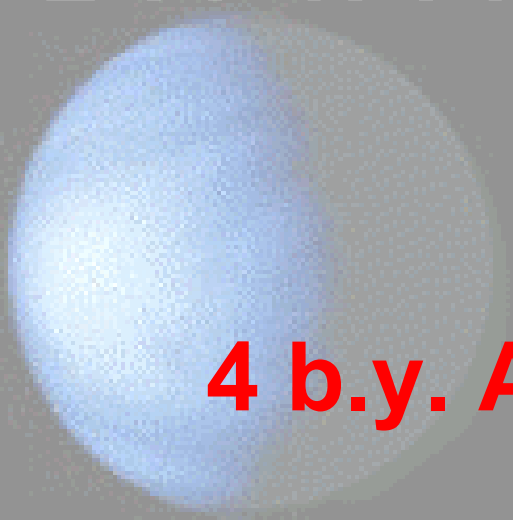
TODAY

EARTH
MARS ?
EUROPA ?

HABITABILITY IN TIME

TODAY

EARTH
MARS ?
EUROPA ?



4 b.y. AGO

EARTH
MARS ?
VENUS ?
EUROPA ?

THE HABITAT OF LIFE ON EARTH TODAY

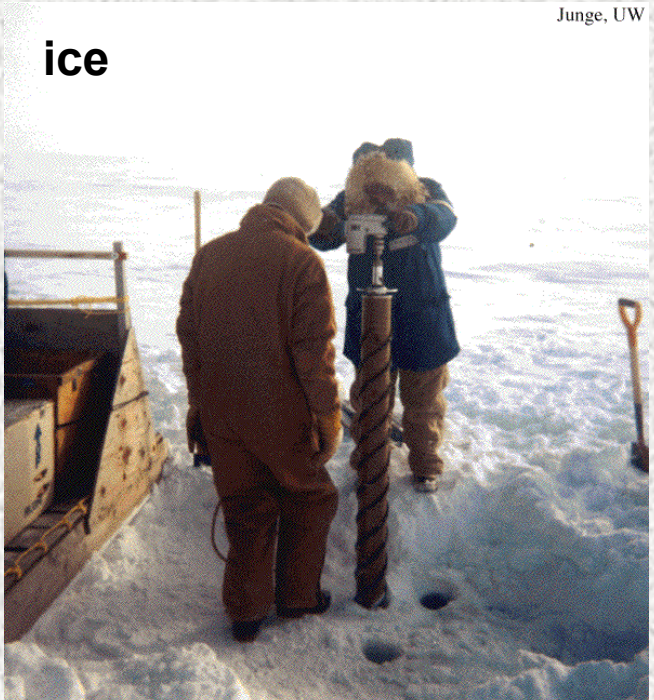
Average environmental conditions:

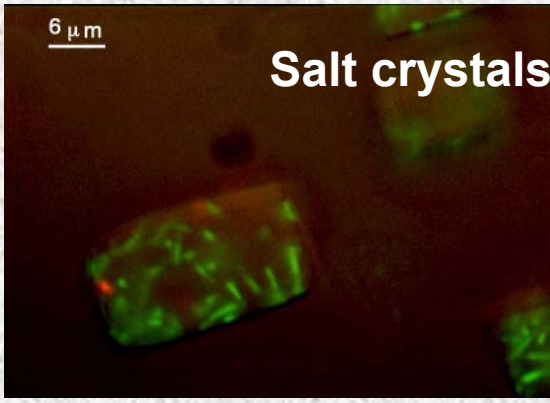
- **Temperature** **15°C**
- **pH** **7.2-7.4**
- **Atmosphere** **21% O_2**
- **Radiation** **1W/m2**
  (DNA-weighted UV)

LIFE ON EARTH TODAY

Life in extreme conditions

- Life can resist almost all extreme conditions
  - except high temperatures > ~120°C
  - not for very extended periods of time (> 10^6 y?).





Stan-Lotter

HABITABILITY AND LIFE ON EARTH TODAY

Life today is the result of co-evolution of the planet (geology) and biological evolution.

Earth today, with its oxygenic atmosphere and ozone layer, is the product of co-evolution of the planet and life

HABITABILITY AND LIFE ON EARTH TODAY

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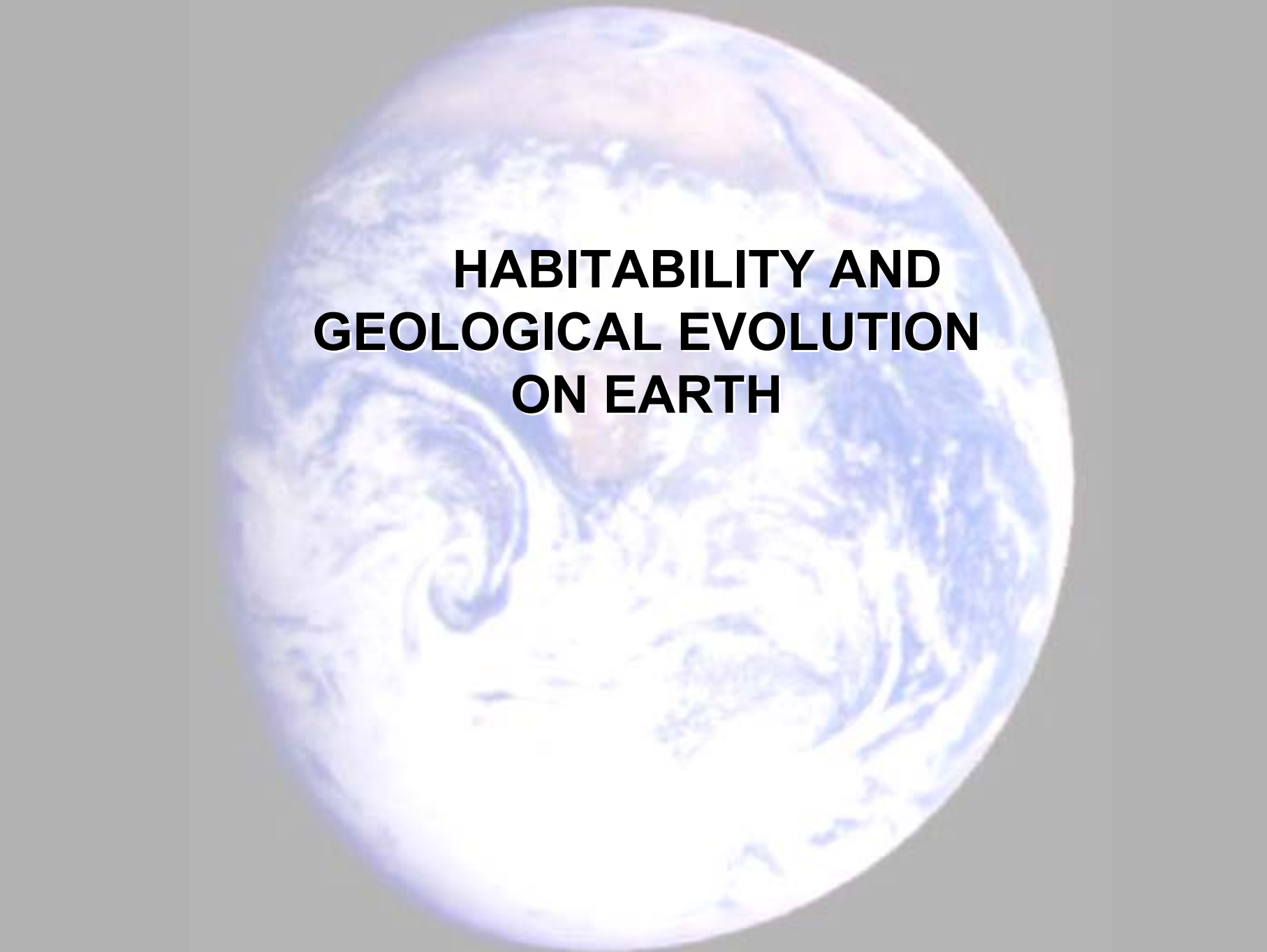
Understanding geological evolution is very important



HABITABILITY AND GEOLOGICAL EVOLUTION ON EARTH

HABITABILITY AND LIFE ON EARTH 3.5 GA

Only 2 areas in the world that contain ancient, well-preserved rocks:

Barberton, South Africa
The Pilbara, Australia

→ Problem of lack of data points

HABITABILITY AND LIFE ON EARTH 3.5 GA

verage environmental conditions:

	3.5 Ga	TODAY
Temperature	> 50°C	15°C
pH	5-6	7.2-7.4
Atmosphere	<0.2% O_2	21% O_2
Radiation	54 W/m^2 (DNA-weighted UV)	1W/m^2

HABITABILITY AND LIFE ON EARTH 3.5 GA

Signatures of life ?

- **Extant – extinct**

- **Structural**
- **Biogeochemical**

HABITABILITY AND LIFE ON EARTH 3.5 GA

Abundance of life:

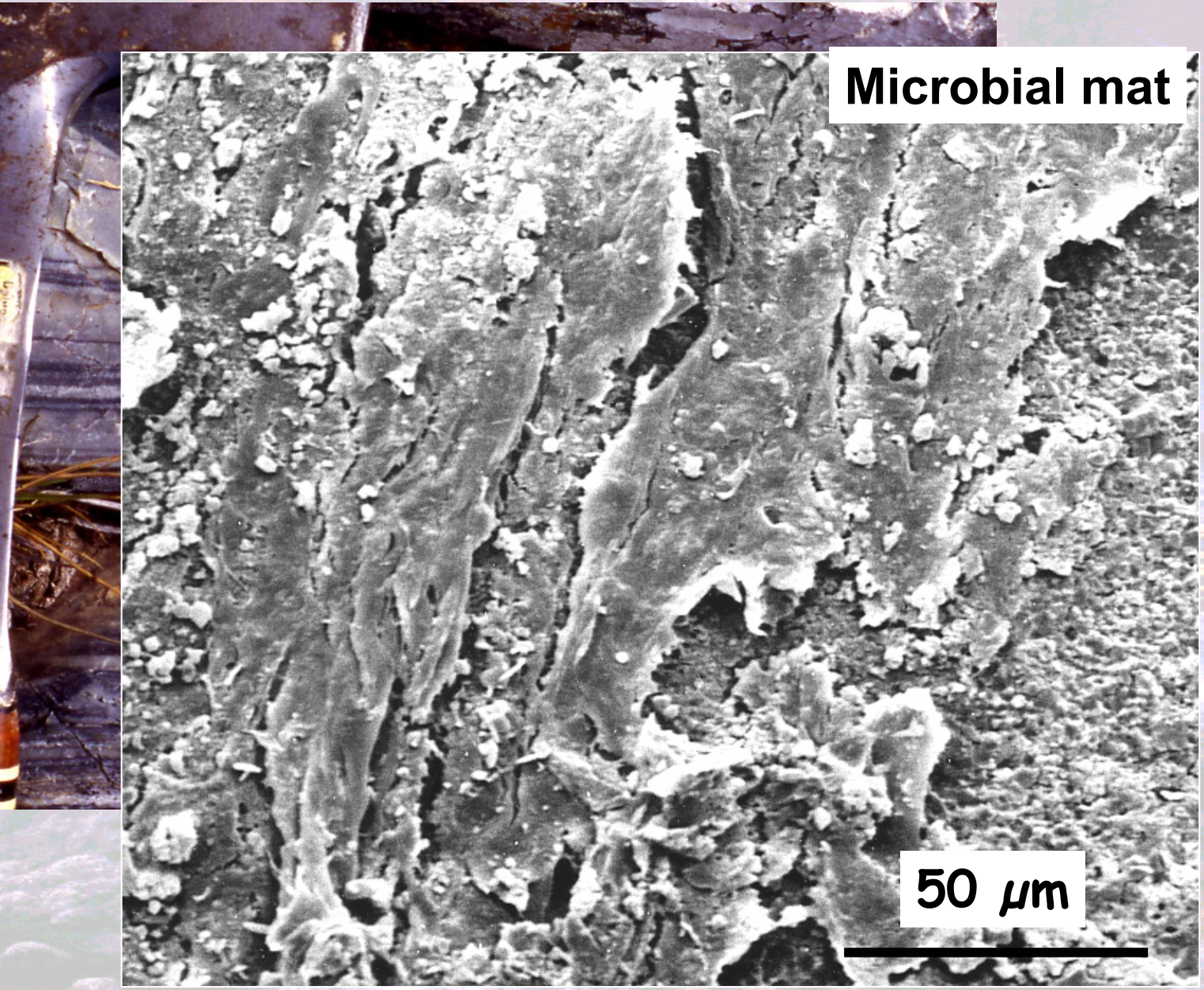
- Far lower biomass than on present Earth

  (more primitive type of metabolism)

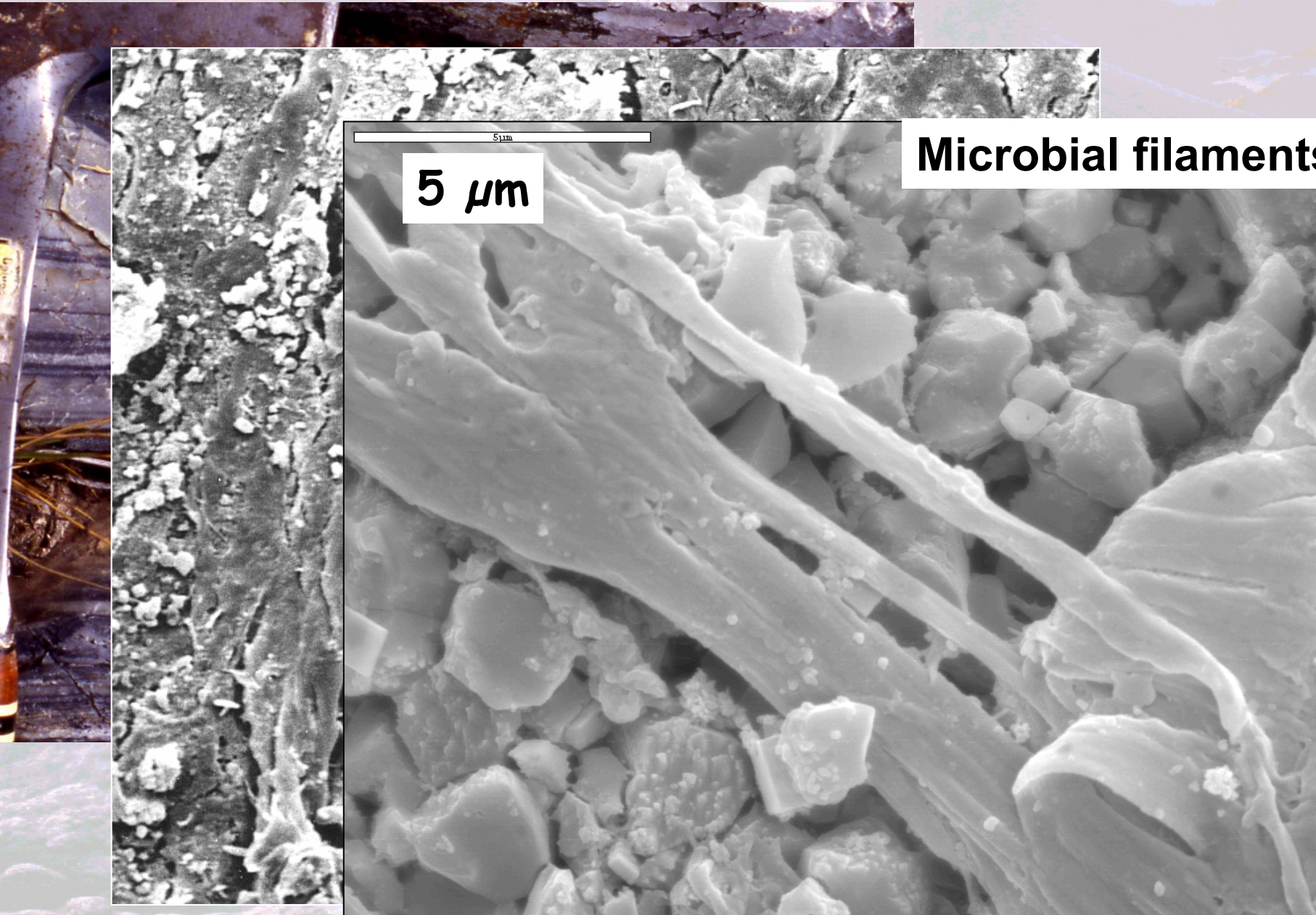
→Manifestations of life far fewer and more subtle

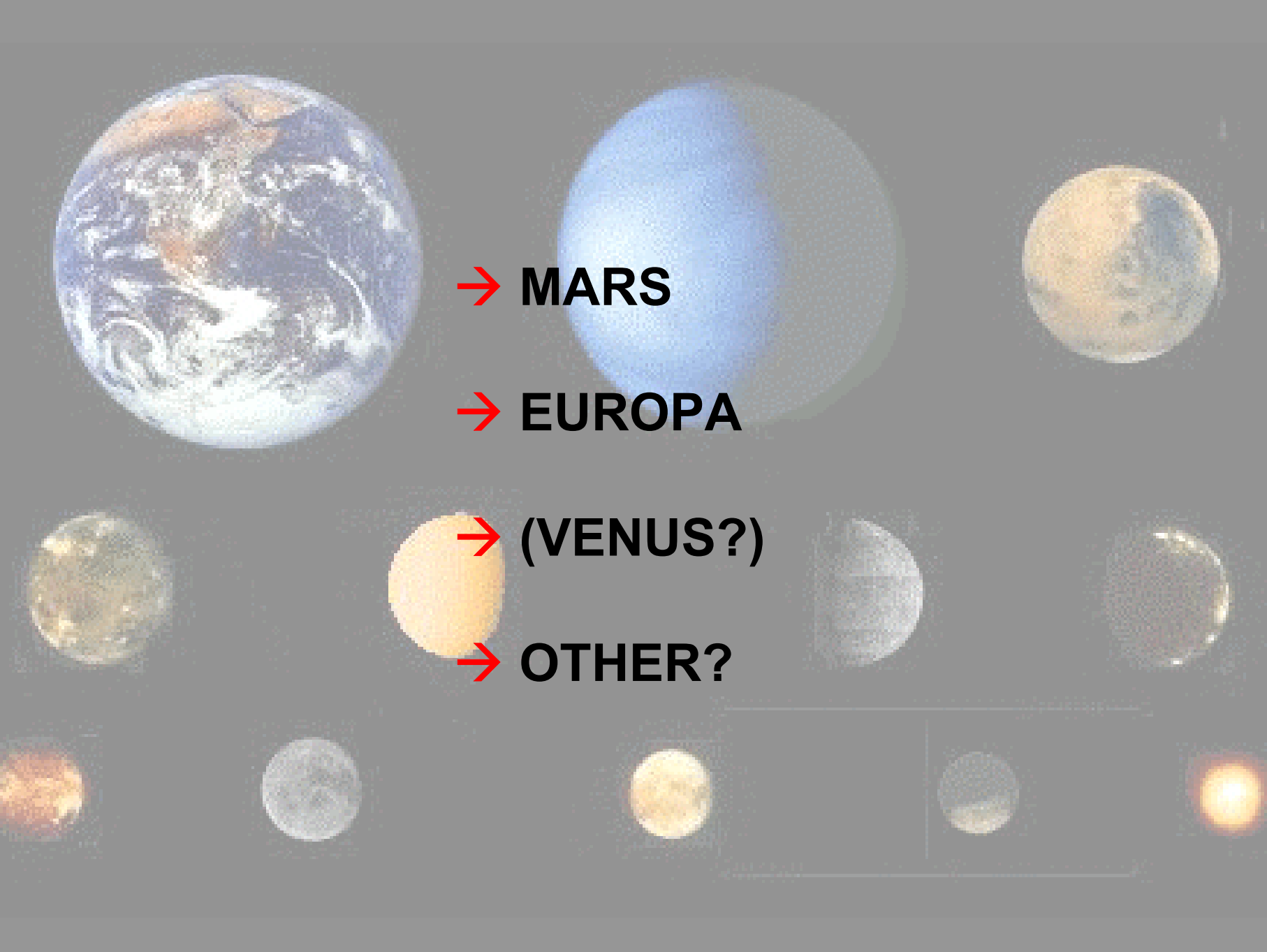
HABITABILITY AND LIFE ON EARTH 3.5 GA

HABITABILITY AND LIFE ON EARTH 3.5 GA



HABITABILITY AND LIFE ON EARTH 3.5 GA



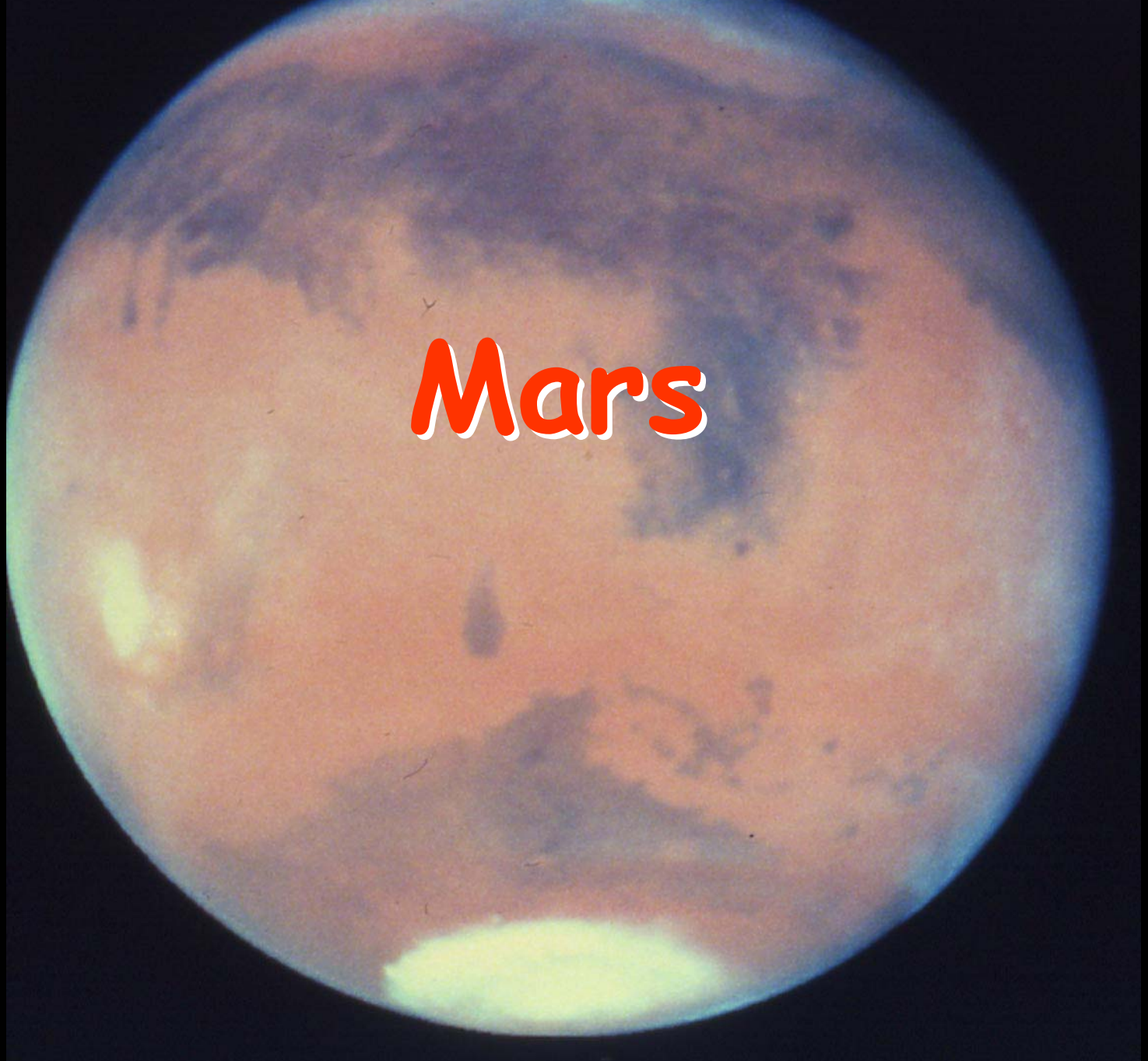


→ MARS

→ EUROPA

→ (VENUS?)

→ OTHER?


Mars

HABITABILITY OF A PLANET PAST AND PRESENT?

1. The geological characteristics of the planet (structure, dynamics, composition) throughout its history

2. History of changing environmental conditions

3. Was there/is there life on the planet (spontaneous generation or transported from elsewhere)?

HABITABILITY OF MARS PAST AND PRESENT?

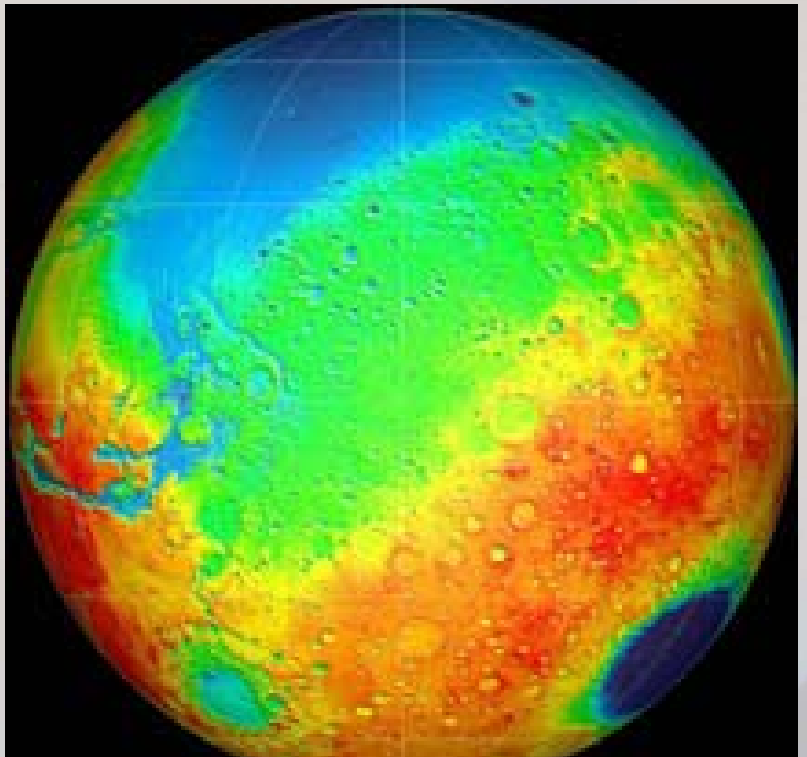
1. STRUCTURE

- Core, mantle, crust structure
- One plate planet

HABITABILITY OF MARS PAST AND PRESENT?

1. STRUCTURE

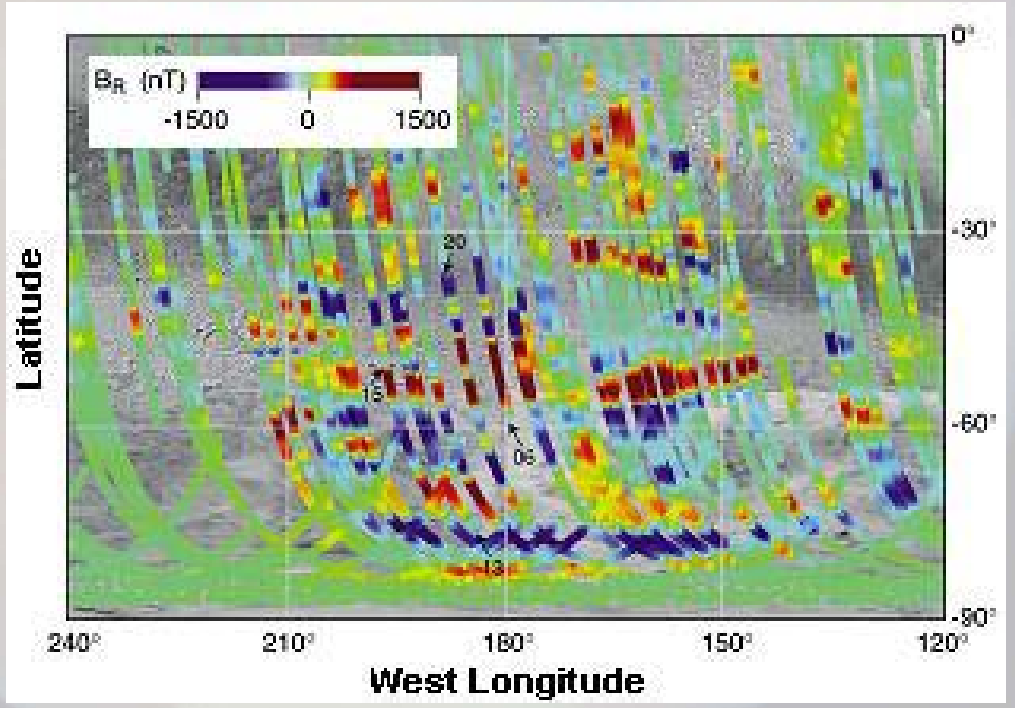
- N/S crustal dichotomy



HABITABILITY OF MARS PAST AND PRESENT?

2. DYNAMICS

- Pre 4 Ga magnetic field



HABITABILITY OF MARS PAST AND PRESENT?

2. DYNAMICS

- No lateral plate tectonics
- Volcanism (up to recent)

HABITABILITY OF MARS PAST AND PRESENT?

3. COMPOSITION

- Fe-rich mantle
- Basaltic crustal rocks

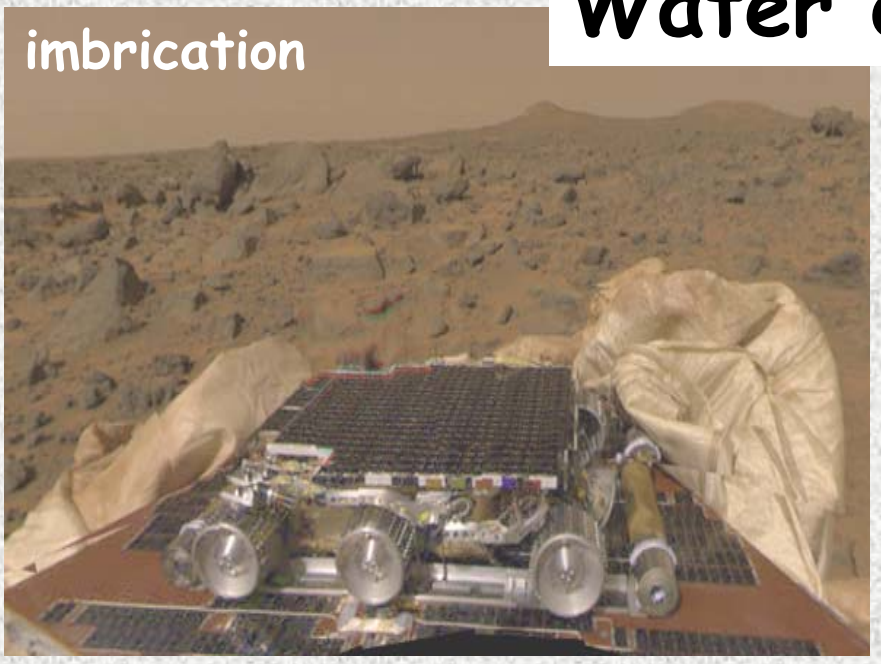
HABITABILITY OF MARS PAST AND PRESENT?

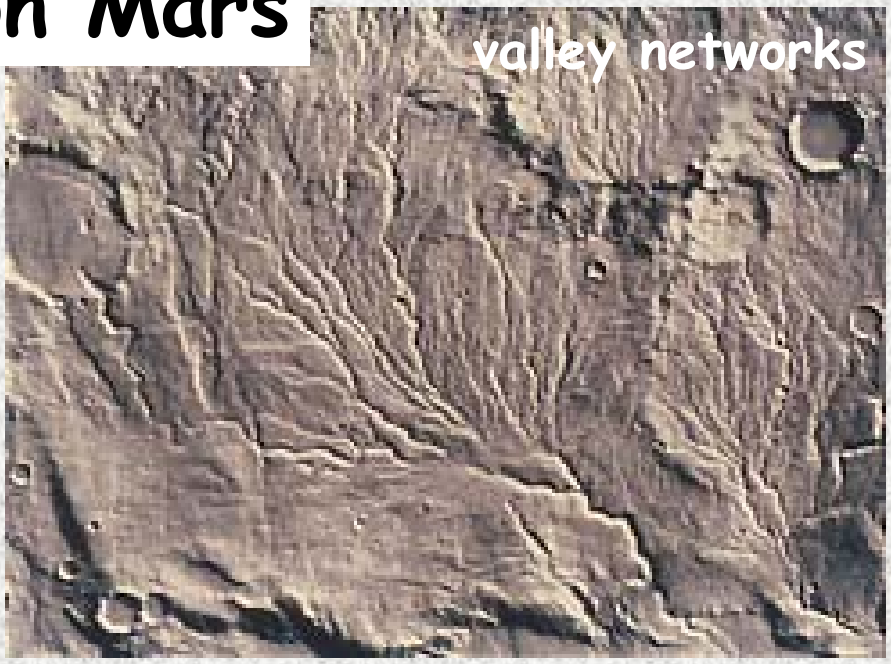
ENVIRONMENTAL CONDITIONS

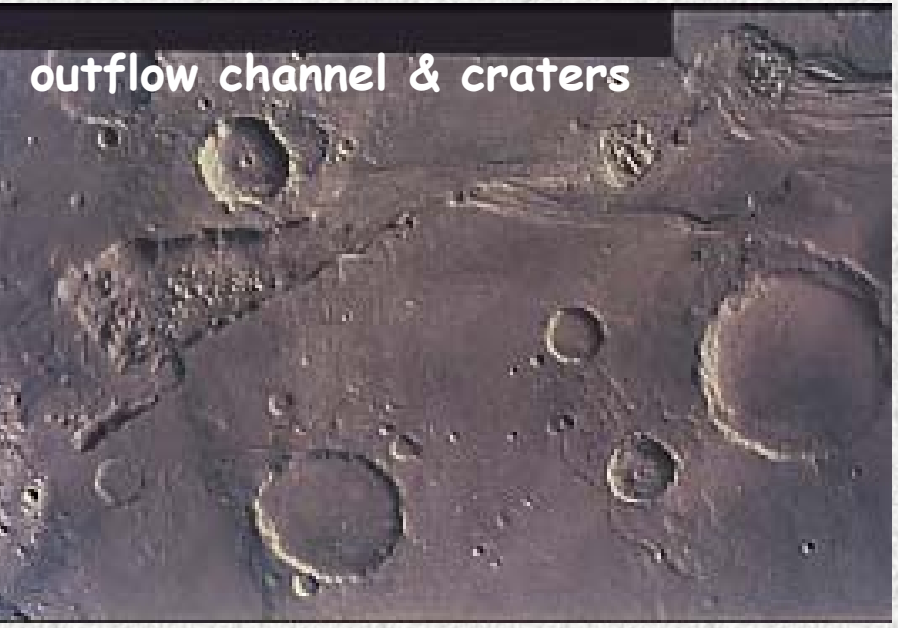
- Early Mars was water-rich
- Carbon
- Energy sources
  (geochemical, hydrothermal, solar)
- Nutrients

(radiation ~54W/m^2)

Water on Mars







HABITABILITY OF MARS PAST AND PRESENT?

EARLY MARS WAS HABITABLE

HABITABILITY OF MARS PAST AND PRESENT?

EARLY MARS WAS HABITABLE

- **On the surface and subsurface**
- **By primitive microorganisms**

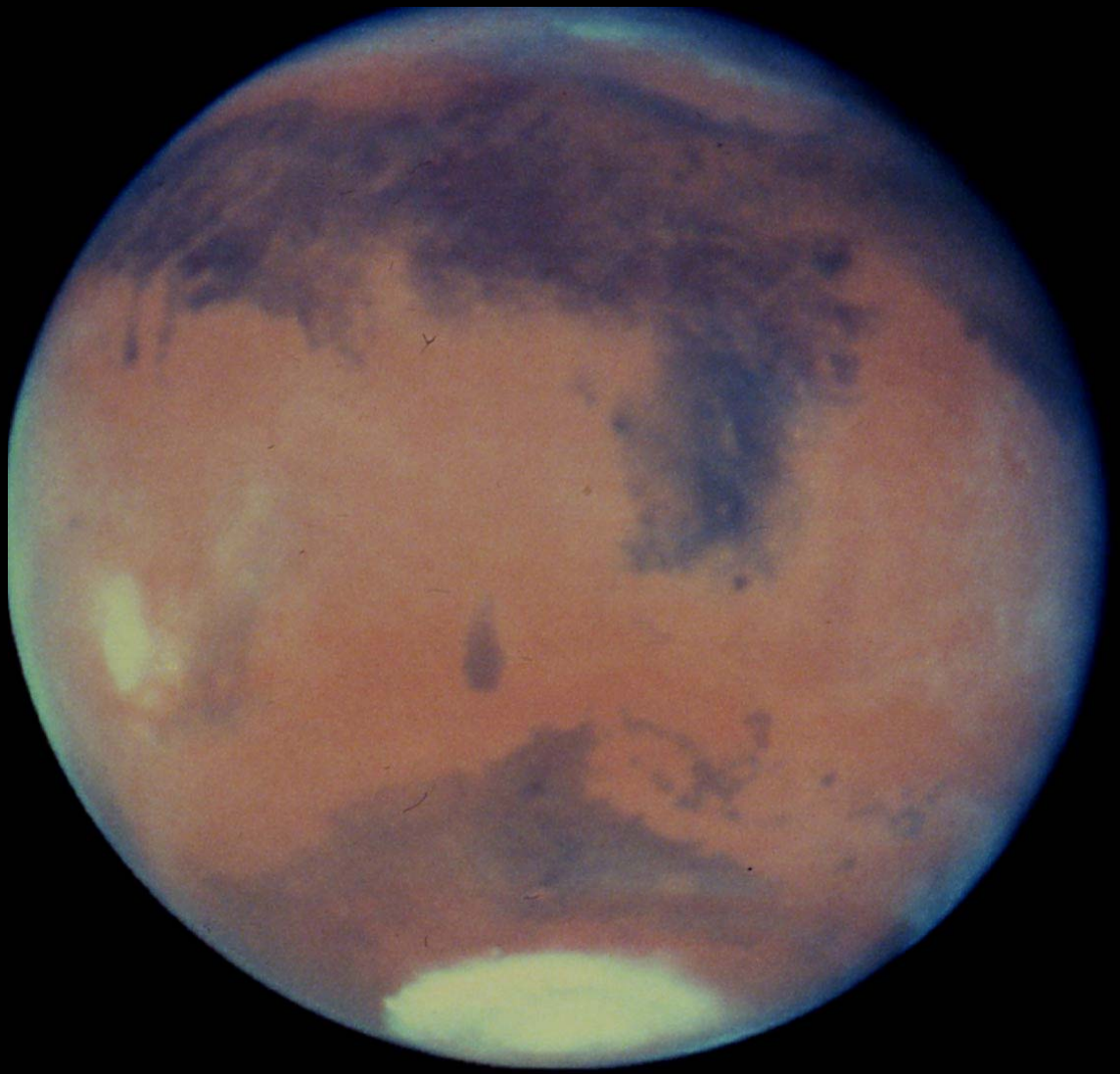
→ **Signatures of life will be subtle**

CHANGING ENVIRONMENTAL CONDITIONS

- **Loss of surface volatiles ~3.8 Ga**

→ Freezing and drying of planet
→ Cryosphere formation

HABITABILITY OF MARS TODAY?



HABITABILITY OF MARS TODAY?

ENVIRONMENTAL CONDITIONS

- Some water (mostly frozen)
- Carbon
- Energy sources (geochemical, hydrothermal, solar)
- Radiation ~54W/m^2
- Limited geological renewal of nutrients

HABITABILITY OF MARS PAST AND PRESENT?

MARS IS HABITABLE

- In melt pockets in the subsurface cryosphere
- Organisms using a very primitive metabolism

ASSESSING THE HABITABILITY OF MARS PAST AND PRESENT?

- **Understand the workings of the planet (life cannot last long on a dead planet)**

- **Much more information about the geological/ environmental history of the planet**
  - Impact history
  - Volcanic/hydrothermal activity
  - Sedimentological environment
  - Volatile inventory

ASSESSING THE HABITABILITY OF MARS PAST AND PRESENT?

- Did life appear on Mars? What was its fate?

  → search for biosignatures (structural, biogeochemical)

- What was/is the nature of martian life? (similar to terrestrial life or different e.g. different chirality, biomolecules?)

- Distribution of life, past and present?

ASSESSING THE HABITABILITY OF MARS PAST AND PRESENT?

Major requirements:

Orbital mapping	- morphology - mineralogy - water (H, liquid/ice H2O) - location of hot spots (present volcanic activity) - CH4

ASSESSING THE HABITABILITY OF MARS PAST AND PRESENT?

Major requirements:

***In situ* studies**

- global seismic structure
- geomorphology

RETURN SAMPLES

- mineralogy
- petrography
- chemistry
- biochemistry
- micropalaeontology

} surface/ subsurface

- dating

- local weather
- local atmosphere
- radiation levels

} Human exploration

ASSESSING THE HABITABILITY OF MARS PAST AND PRESENT?

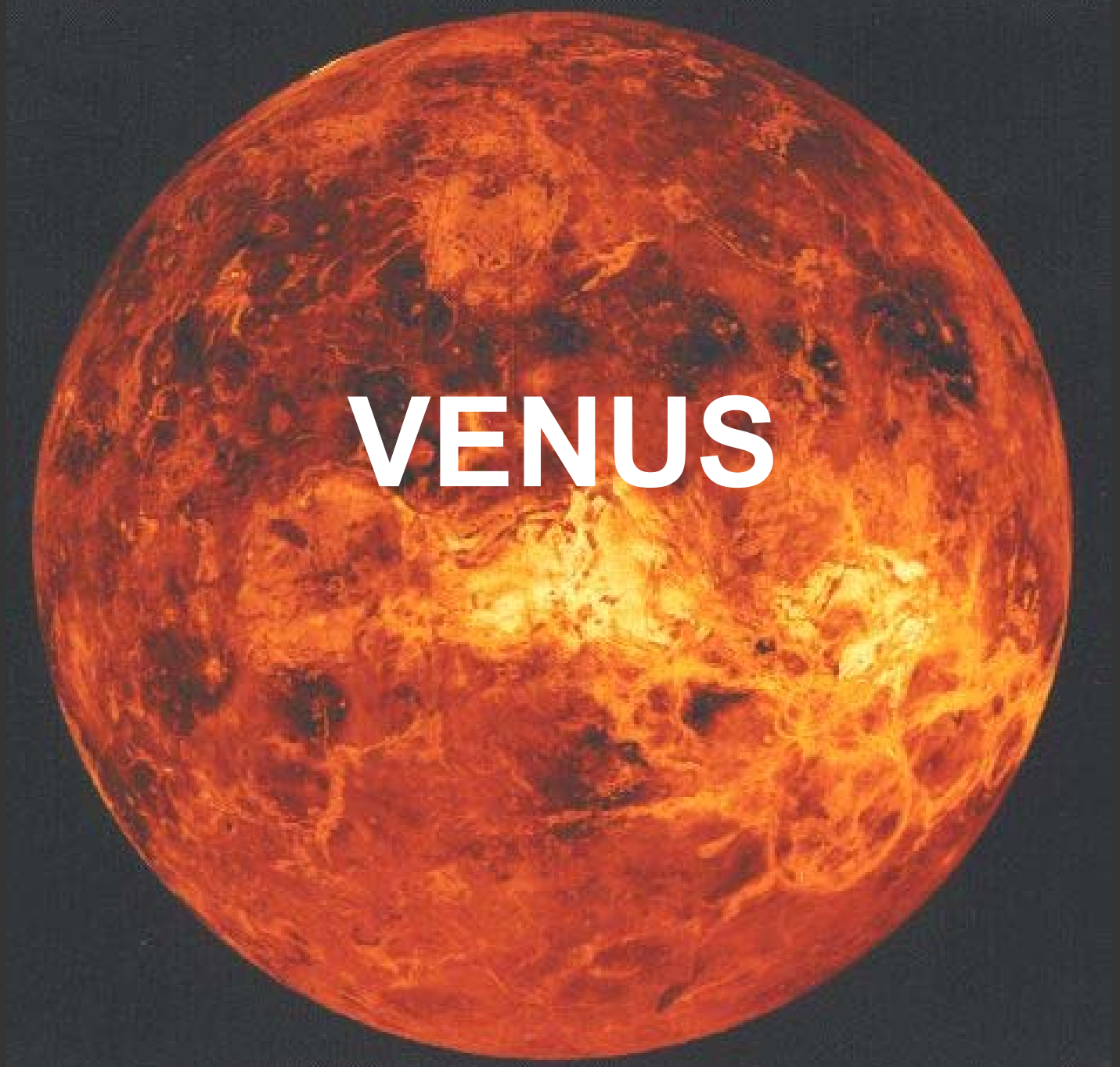
- *All require dated rocks (in situ methods or sample return)*
- *Instruments have to be able to travel*
- *Context is of paramount importance - difficult in subsurface*

ASSESSING THE HABITABILITY OF MARS PAST AND PRESENT?

- Mars can give us information about the geological and environmental conditions during the earliest evolution of the terrestrial planets

- Mars has rocks old enough to contain evidence of the origin and earliest evolution of life

  - distinction between inert/living
  - testing panspermia


VENUS

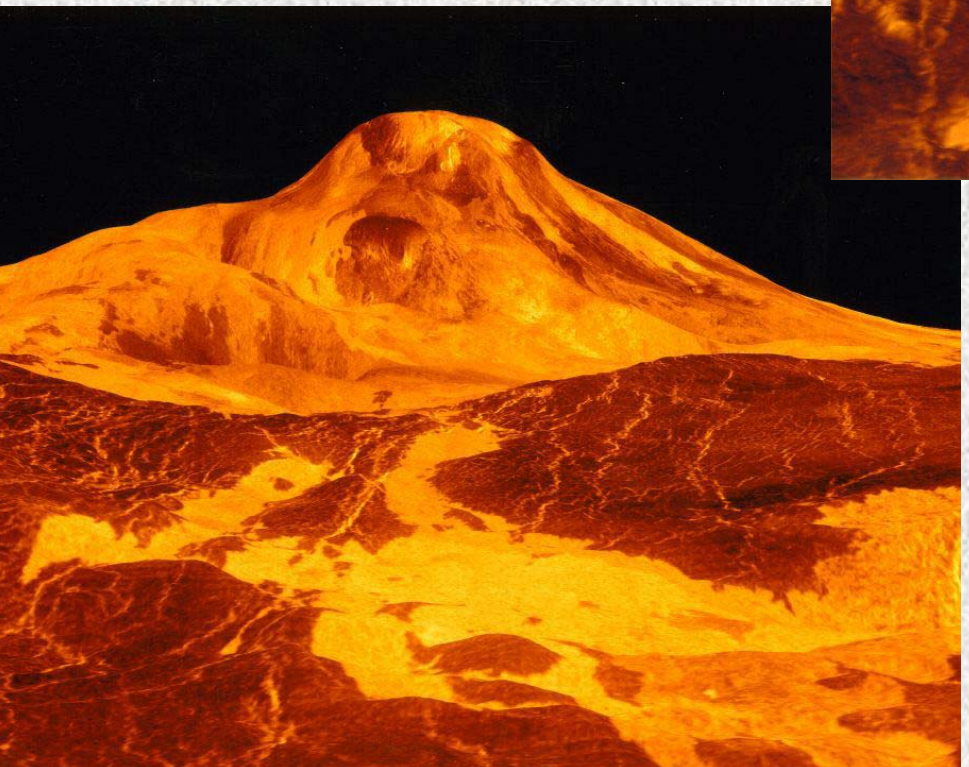
VENUS

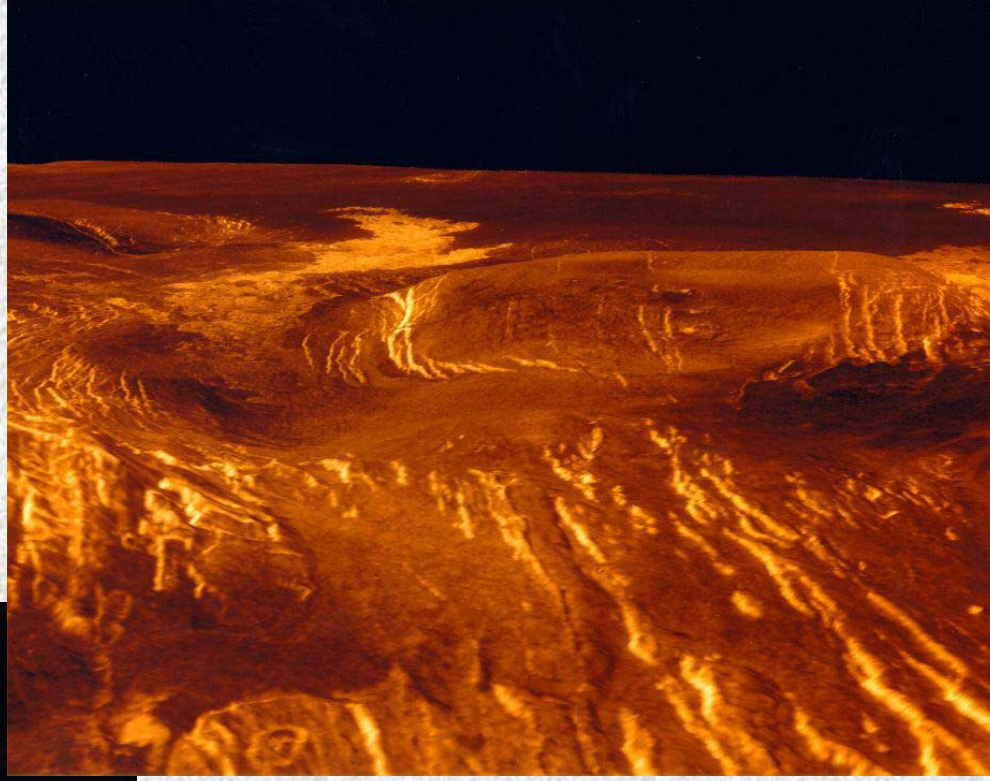
- Terrestrial planet
- Had an early geological/environmental evolution similar to the Earth
- Had water, organics, energy
- Was an HABITABLE planet
- May have been able to support life

VENUS

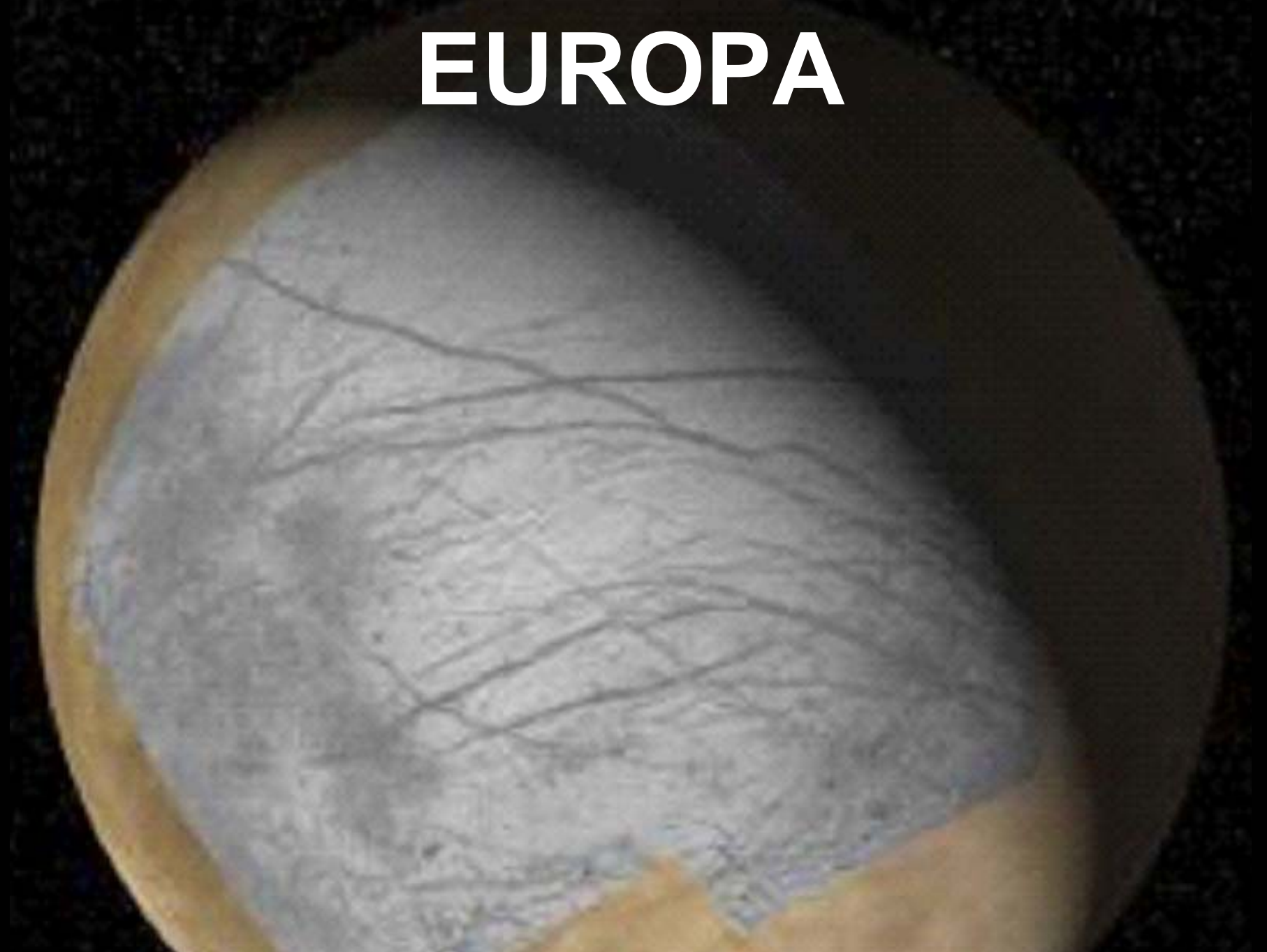
- Runaway greenhouse effect → surface temperatures > 480°C
- No liquid water nor usable organics (at surface)
- Is not an HABITABLE planet now (surface)
- Volcanically active planet
- Coronae structures (c.f. early Earth?)

Maat Mons volcano



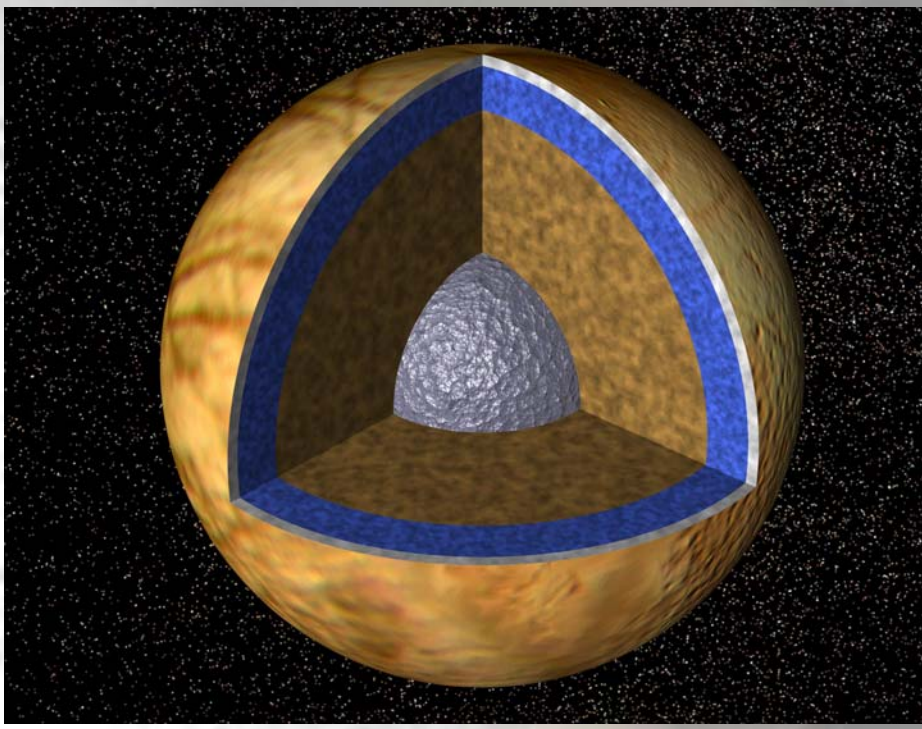


Corona structure


EUROPA

EUROPA

- Core (Fe rich)
- Silicate mantle
- Subsurface ocean
- 100-150 km ice crust
- Gravity field



EUROPA – PAST AND PRESENT HABITABILITY ?

2. Icy surface
   - Structurally complex – cryovolcanism
   - Dark patches = sulphate salt deposits on surface

3. Geological evolution

   - Cooling down of planet
   - Internal heat source
     (radioative decay or heat provided by flexing caused by Jupiter?)

EUROPA – PAST AND PRESENT HABITABILITY ?

- Liquid water
- Organics
- Energy (thermal, geochemical)
- Nutrients

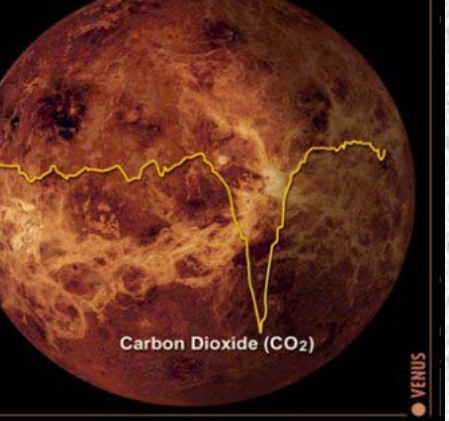
Europa was/is potentially habitable

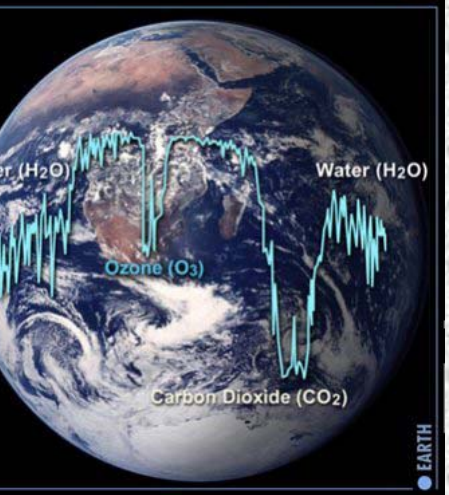
OTHER BODIES

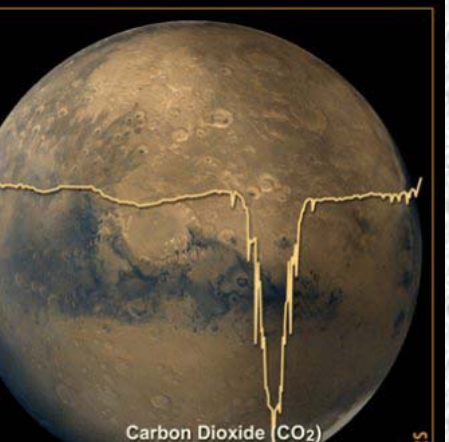
Prebiotic molecules
- building bricks of life

Panspermia ?

Detection and characterisation of exoplanets





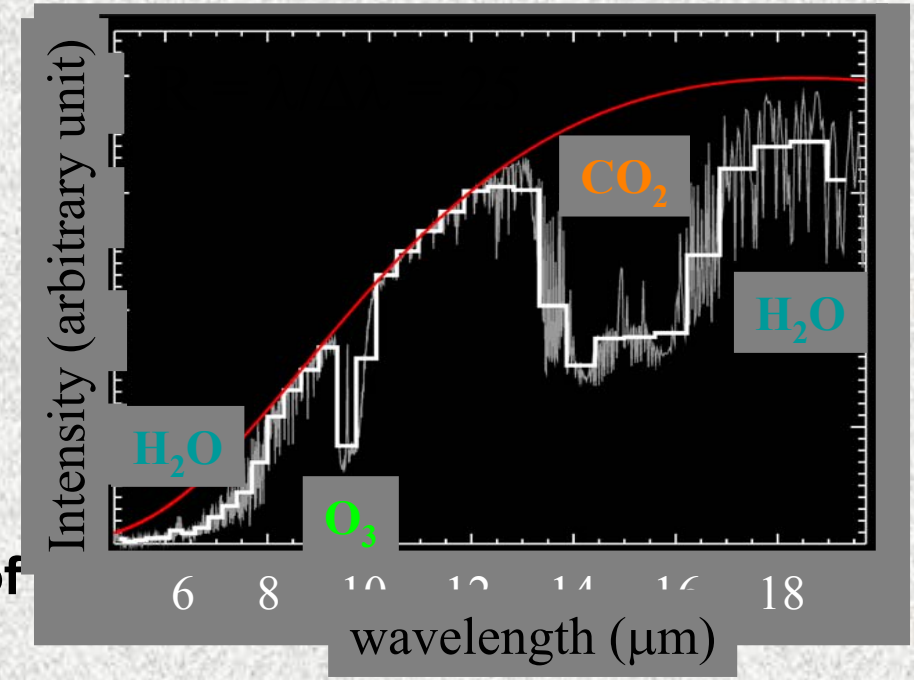


$$\{CO_2 + H_2O + O_3\}$$

Analysing the light from the planet

with a spectrograph

allows identification of key gases



THANK YOU TO:

Alain Léger
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Helga Stan-Lotta