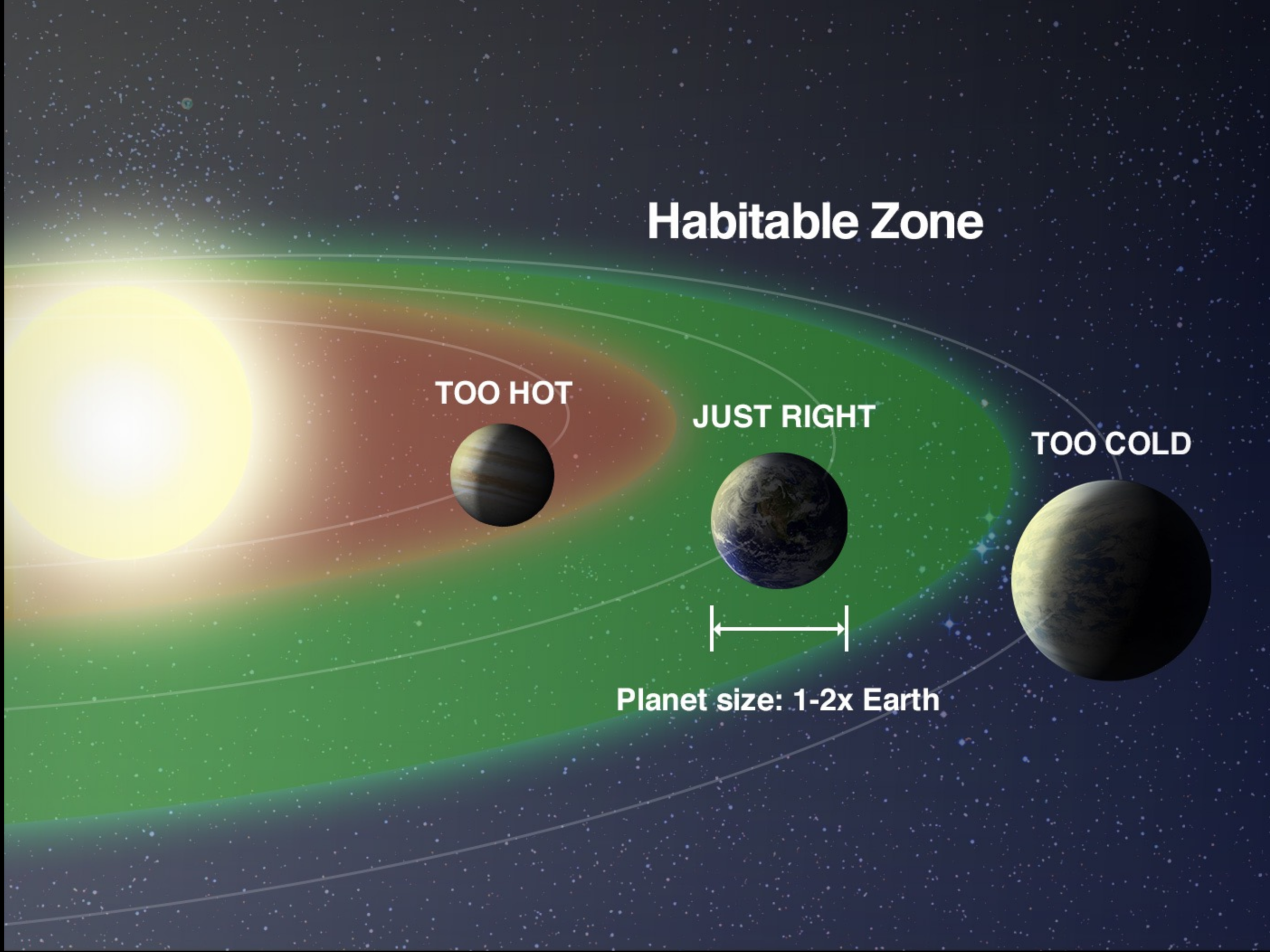
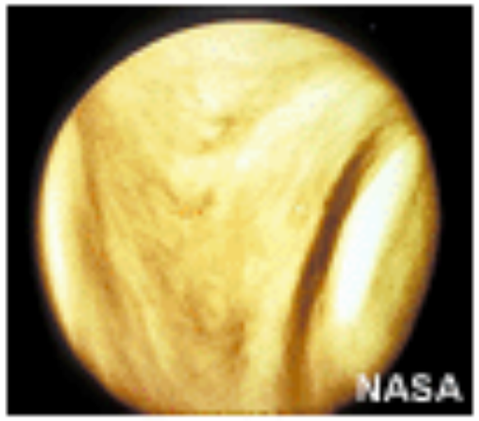
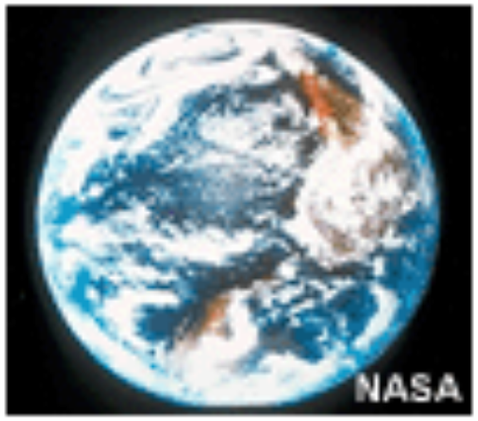
PALE DOTS

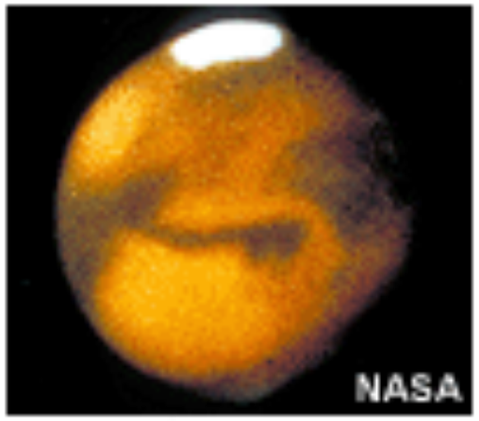
RAVI KOPPARAPU (NASA GODDARD)


Habitable Zone
TOO HOT
JUST RIGHT
TOO COLD
Planet size: 1-2x Earth

PLANETARY CLIMATES



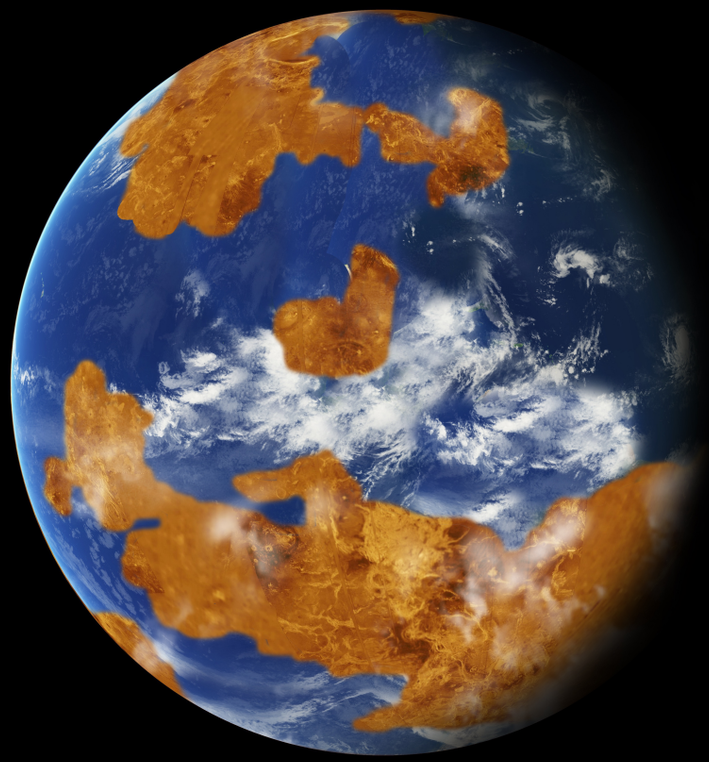




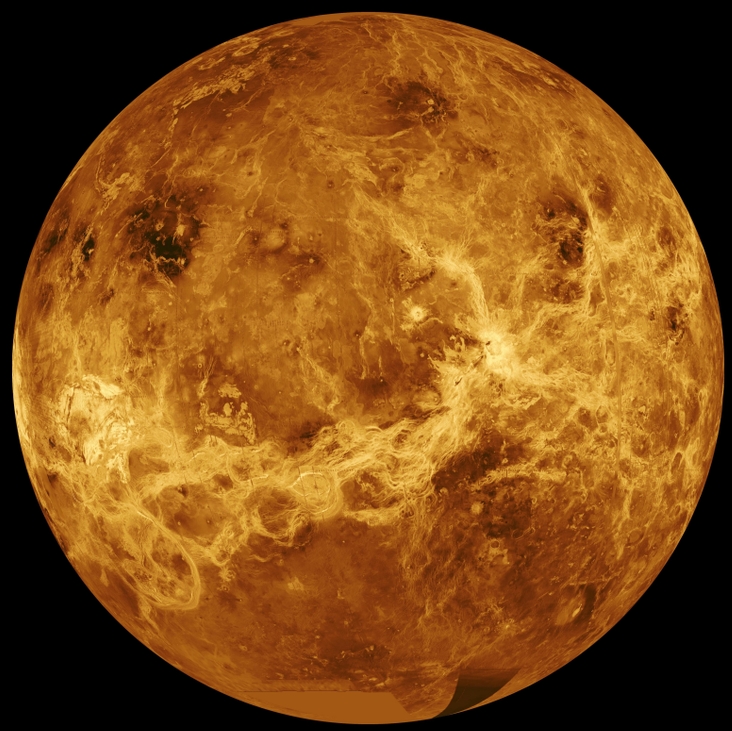
	Venus	Earth	Mars
Surface pressure relative to Earth (bars)	90	1	0.007
Major greenhouse gases (GHG)	CO_2	H_2O, CO_2	CO_2
Temperature if no GHG (°C)	-46	-18	-57
Actual temperature (°C)	477	15	-47
Temperature change due to GHG	+523	+33	+10

the three major terrestrial planets have vastly different tem

HABITABLE VENUS?



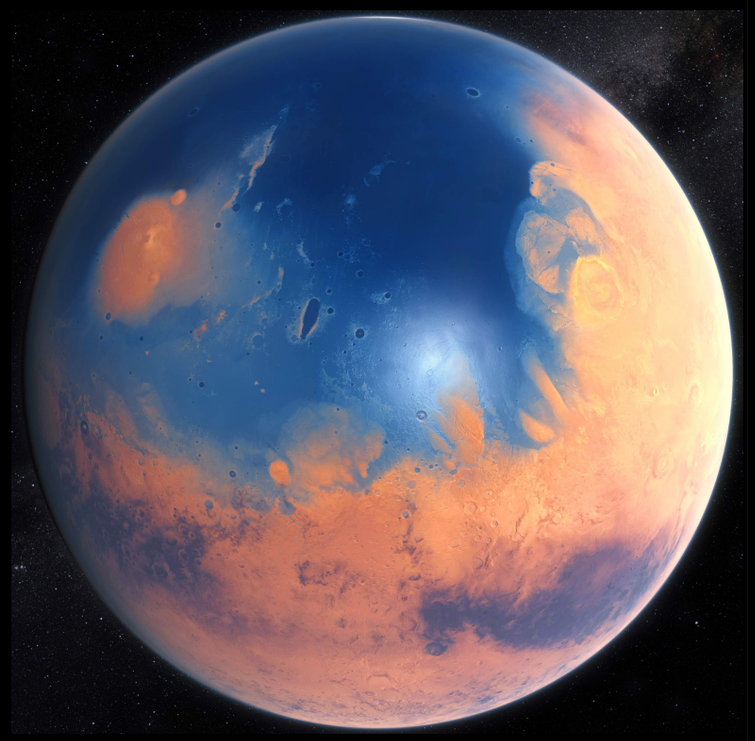
2.7 Billion years ago



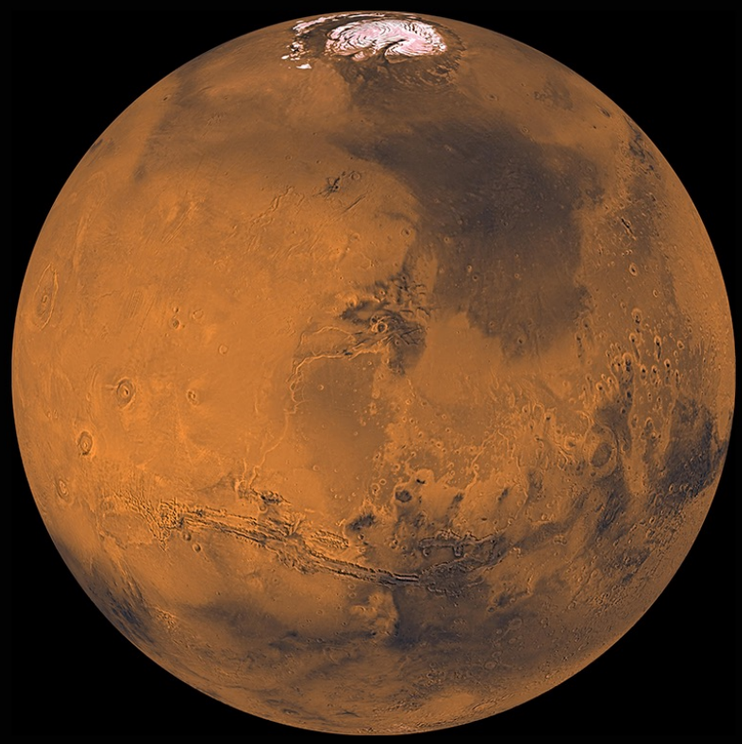
Present

d-water ocean and habitable surface temperatures for up t

HABITABLE MARS?



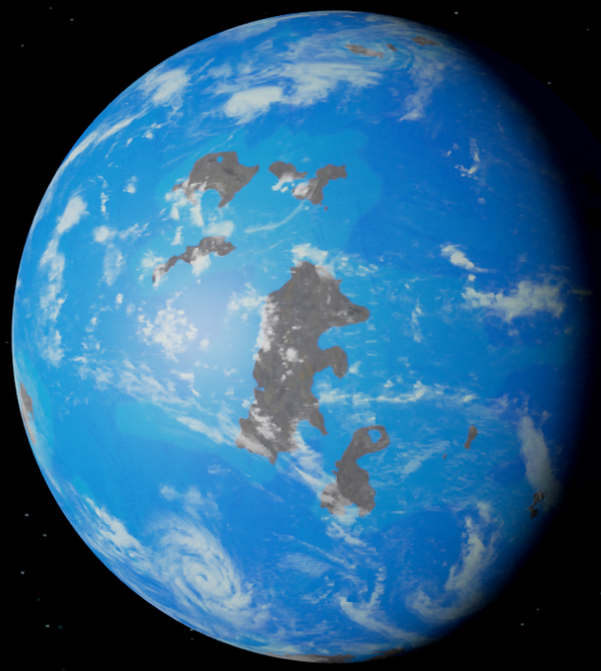
3.5 billion years ago



Present

r beds indicate presence of liquid water on the surface of a

HABITABLE EARTH

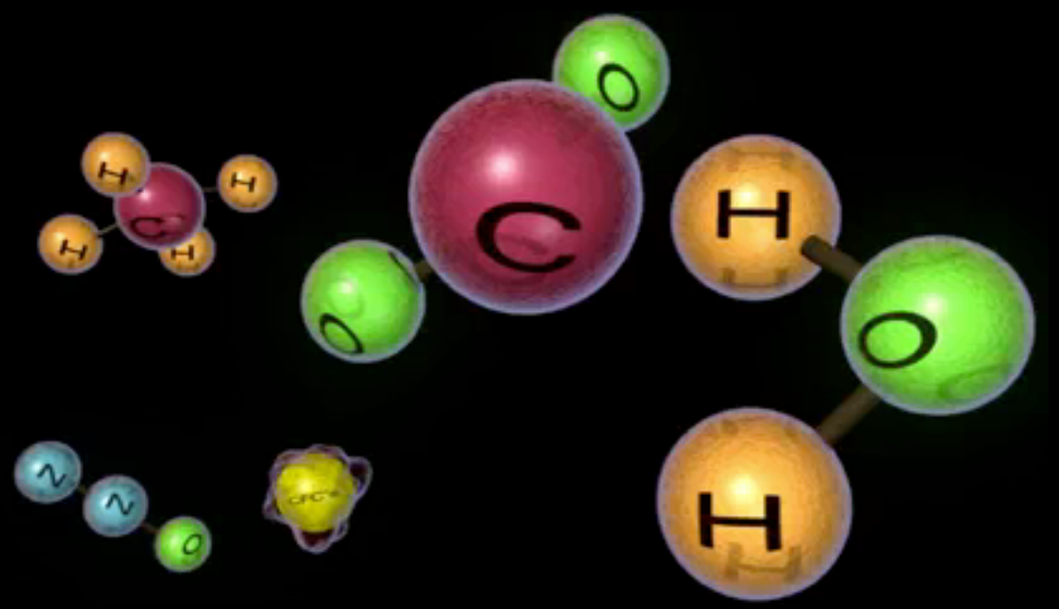


~3 billion years ago

Present

Earth was habitable at least ~3.5 billion years ago

SOME GASES CAUSE WARMING



National Aeronautics and Space Administration

earth's energy *budget*

The Earth's energy budget describes the various kinds and amounts of energy that enter and leave the Earth system. It includes both radiative components (light and heat), that can be measured by CERES, and other components like conduction, convection, and evaporation which also transport heat from Earth's surface. On average, and over the long term, there is a balance at the top of the atmosphere. The amount of energy coming in (from the sun) is the same as the amount going out (from reflection of sunlight and from emission of infrared radiation).

incoming solar radiation
340.4

reflected by clouds & atmosphere
77.0

total reflected solar radiation
99.9

reflected by surface
22.9

total outgoing infrared radiation
239.9

atmospheric window
40.1

emitted by atmosphere
169.9

emitted by clouds
29.9

absorbed by atmosphere
77.1

absorbed by atmosphere
358.2

greenhouse gases

latent heat
(change of state)

thermals
(conduction/ convection)

18.4

86.4

absorbed by surface
163.3

emitted by surface
398.2

back radiation
340.3

evapotranspiration

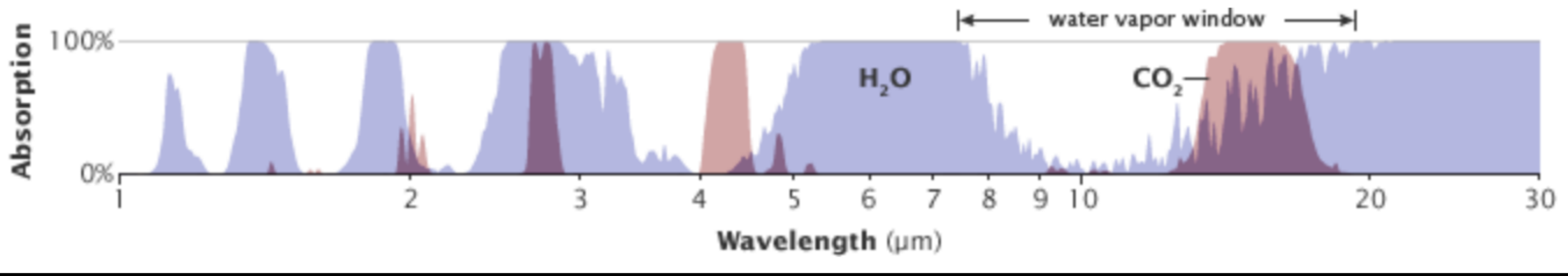
net absorbed
0.6

All values are fluxes in Wm^{-2} and are average values based on ten years of data

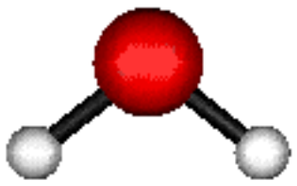
Loeb et al., J. Clim. 2009
Trenberth et al., BAMS, 2009

www.nasa.gov

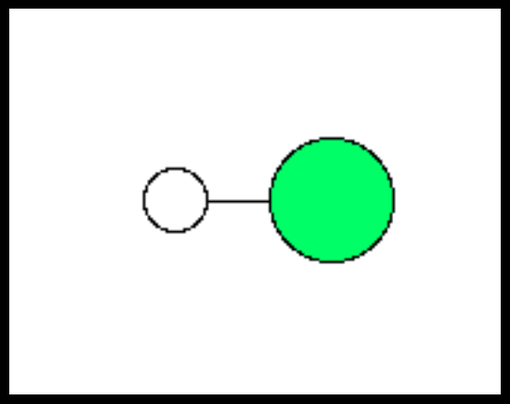
NP-2010-05-265-LaRC


water vapor window
100%
0%
Absorption
H_2O
CO_2
1
2
3
4
5
6
7
8
9
10
20
30
Wavelength (μm)

MOLECULES AND RADIATION

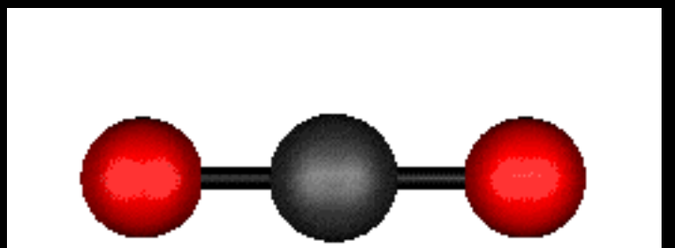


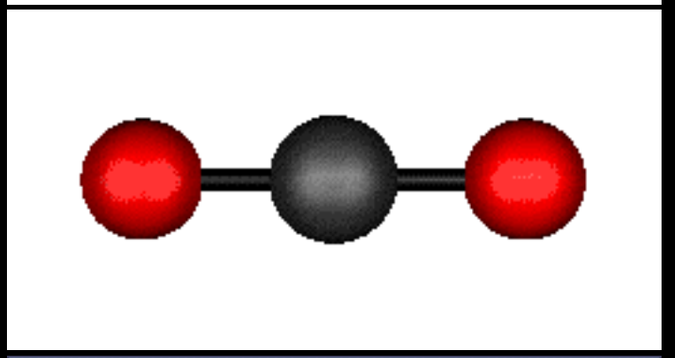
H2O

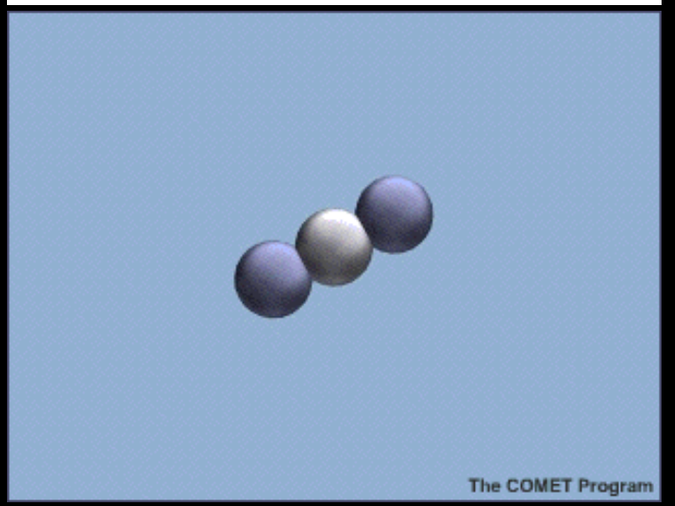


Any two atom molecule

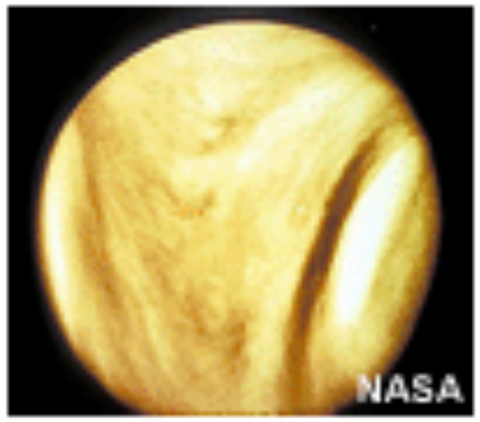
CO2

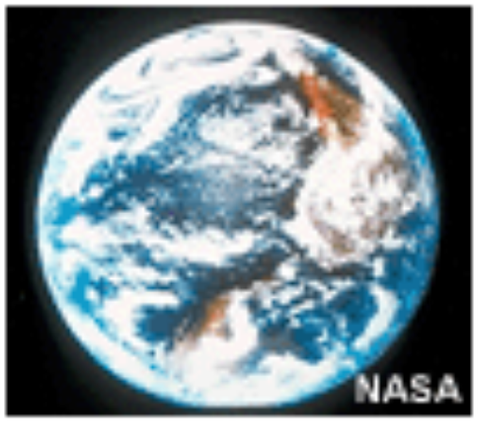


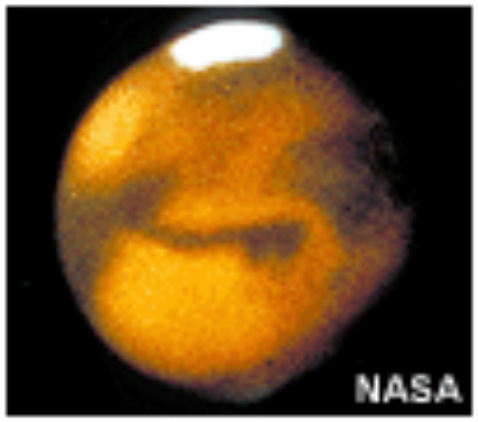




PLANETARY CLIMATES







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Greenhouse warming is not unique to Earth.

are about our opinions, news or debates. They only care ab

FAINT YOUNG SUN

Our Sun was ~30% less bright 3 billion years ago. But Earth (and possibly Venus and Mars) likely maintained habitable conditions

Earth's Atmosphere Through Time

Escape to space

Water, H_2, CO

Steam Atm.

Abundance

?

Temperature

Ice Ages

CO_2

O_2

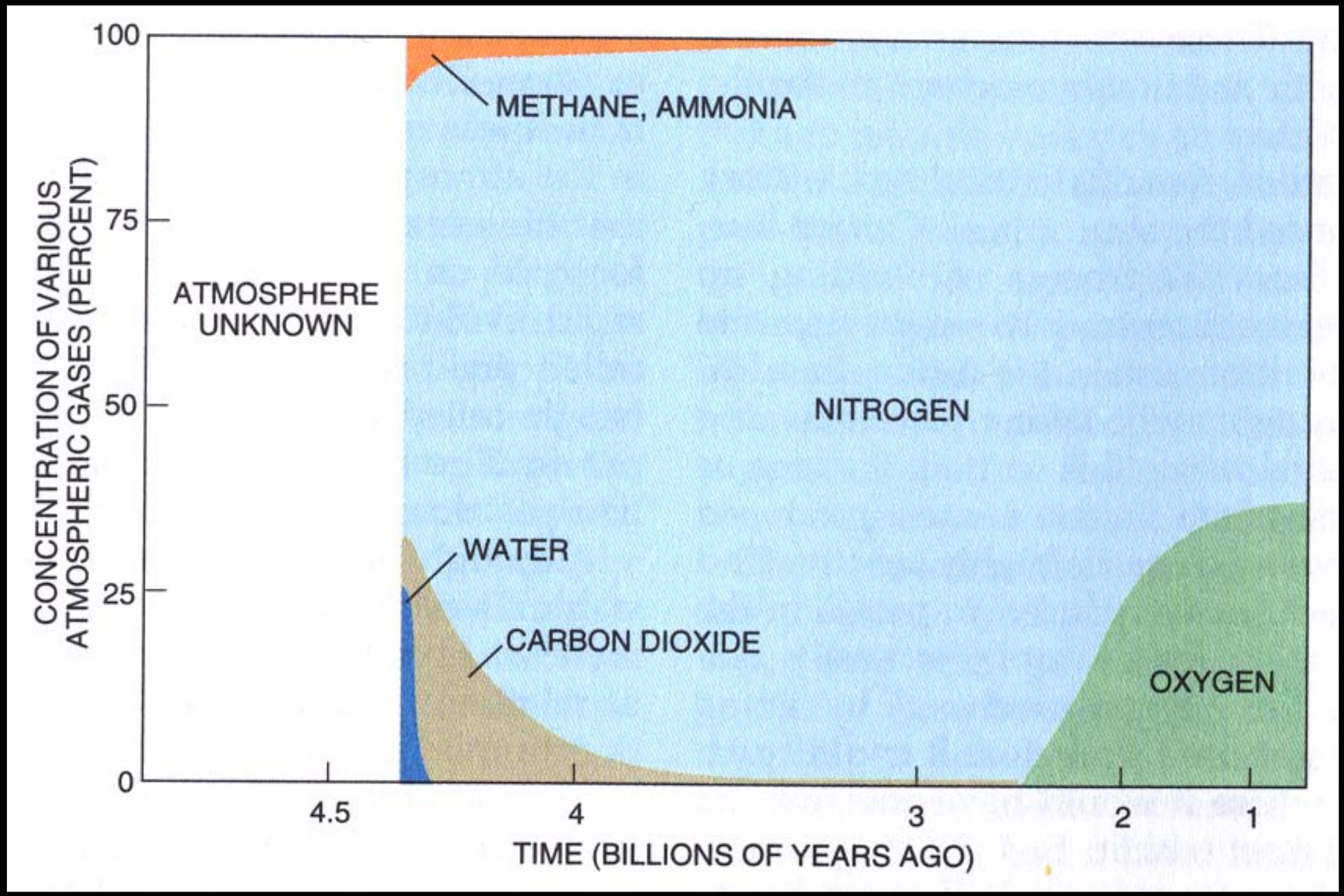
Impacts ?

CH_4

+ other reduced gases

4.56 4.46 4.44 4.2 3.8 3.5 2.2 0.6 Today

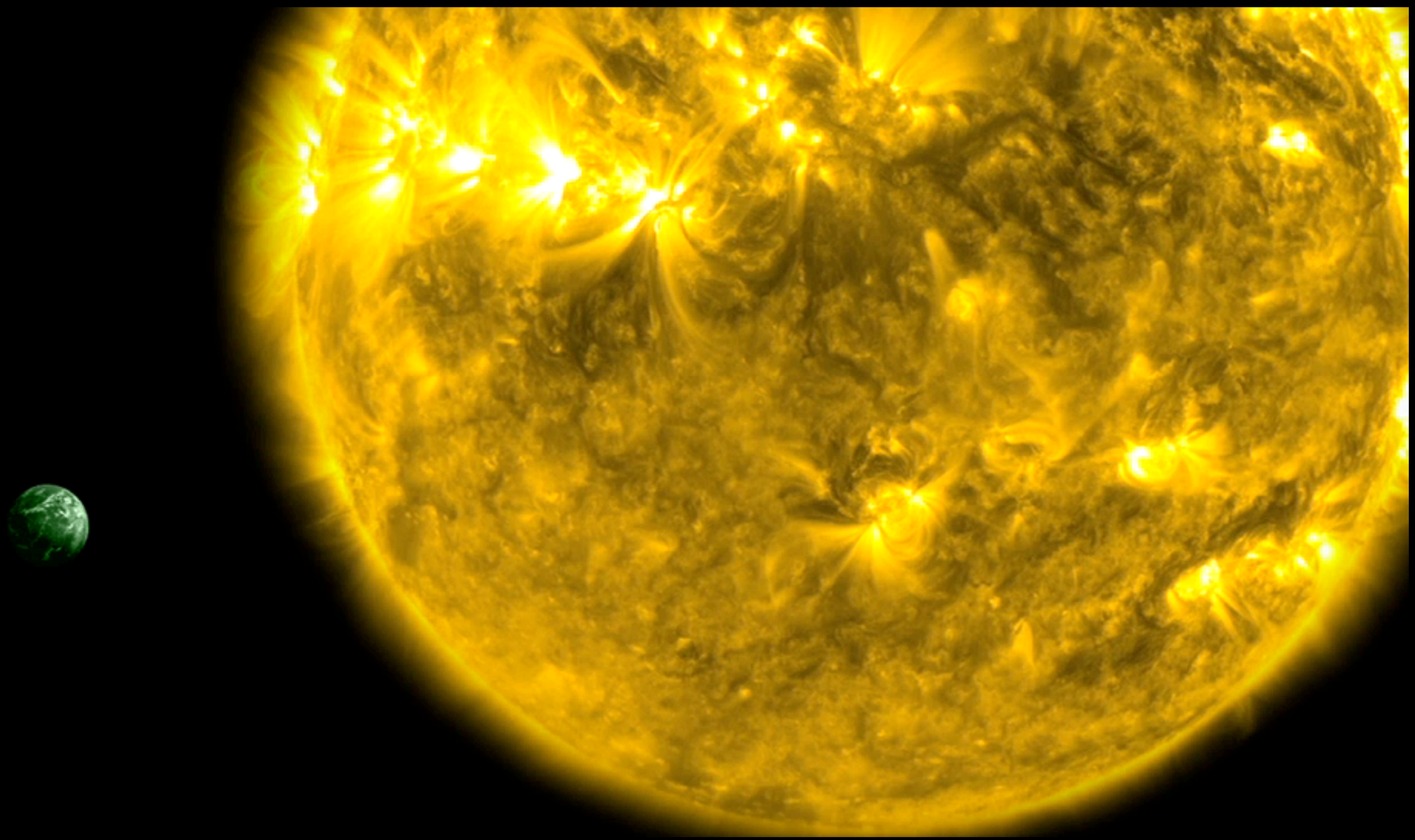
Time before present, billions of years


100
75
50
25
0
CONCENTRATION OF VARIOUS ATMOSPHERIC GASES (PERCENT)
ATMOSPHERE UNKNOWN
METHANE, AMMONIA
NITROGEN
WATER
CARBON DIOXIDE
OXYGEN
4.5
4
3
2
1
TIME (BILLIONS OF YEARS AGO)

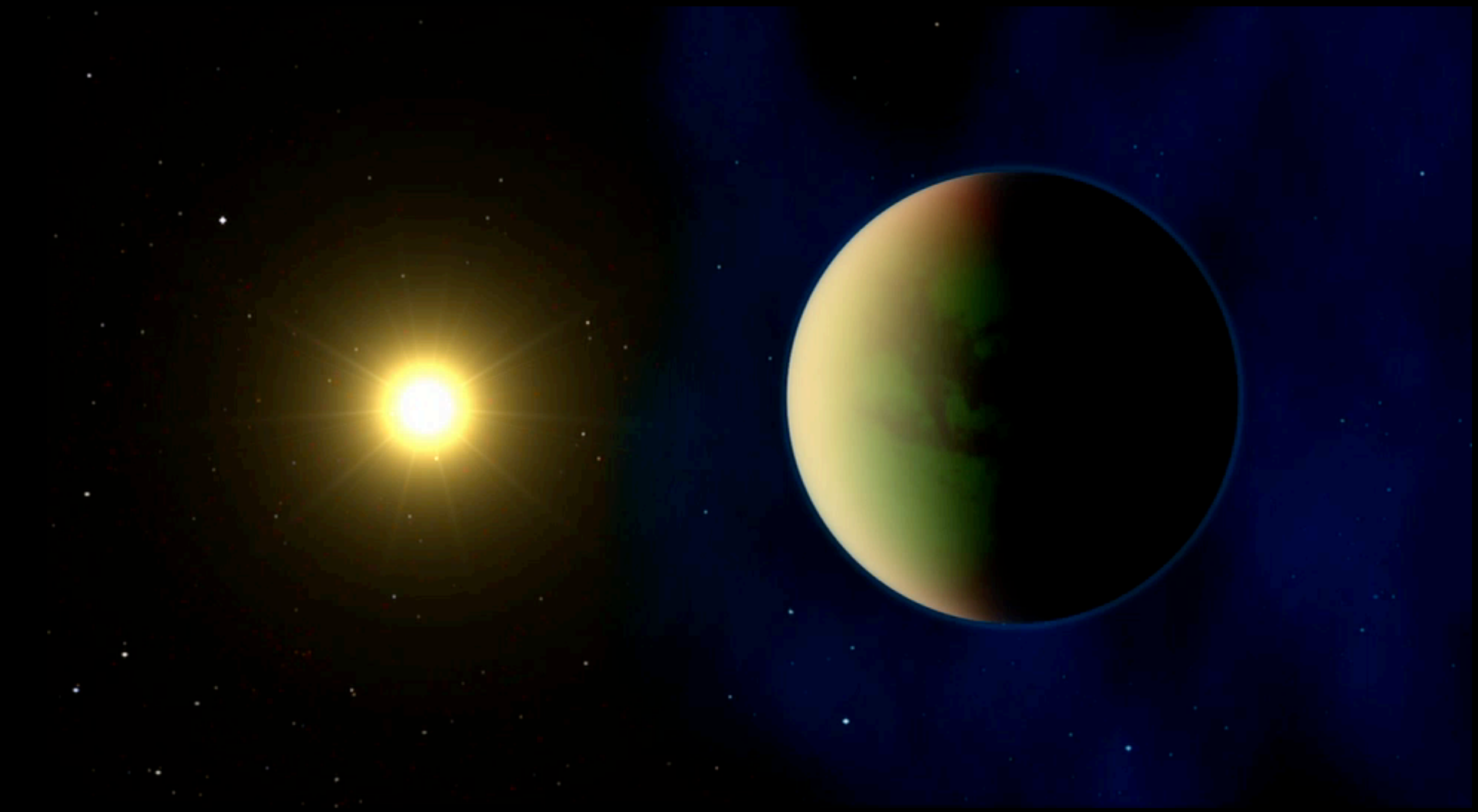
LAWS OF PHYSICS ARE SAME EVERYWHERE

Exoplanets may also have similar composition

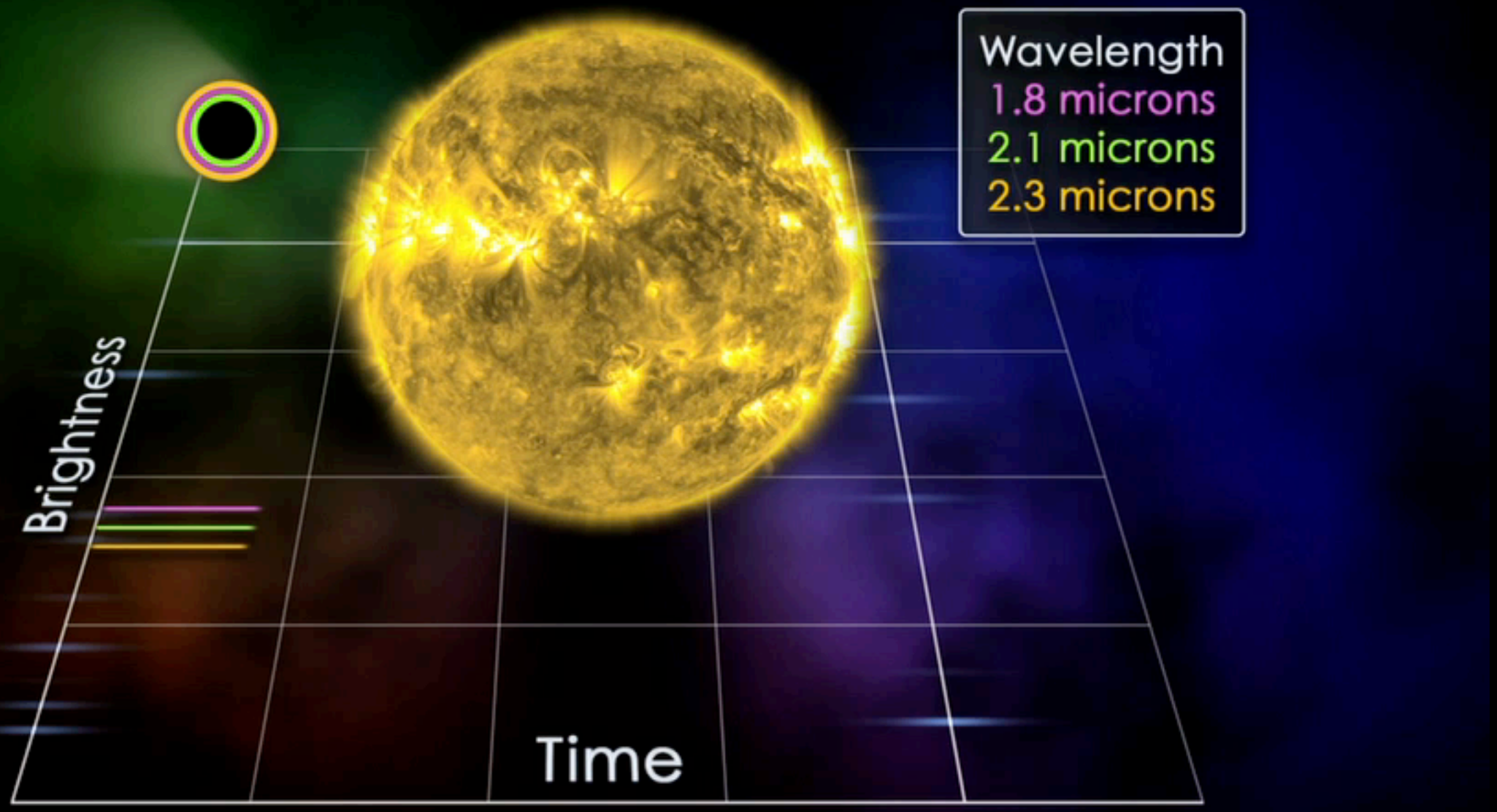
EXOPLANET ATMOSPHERES



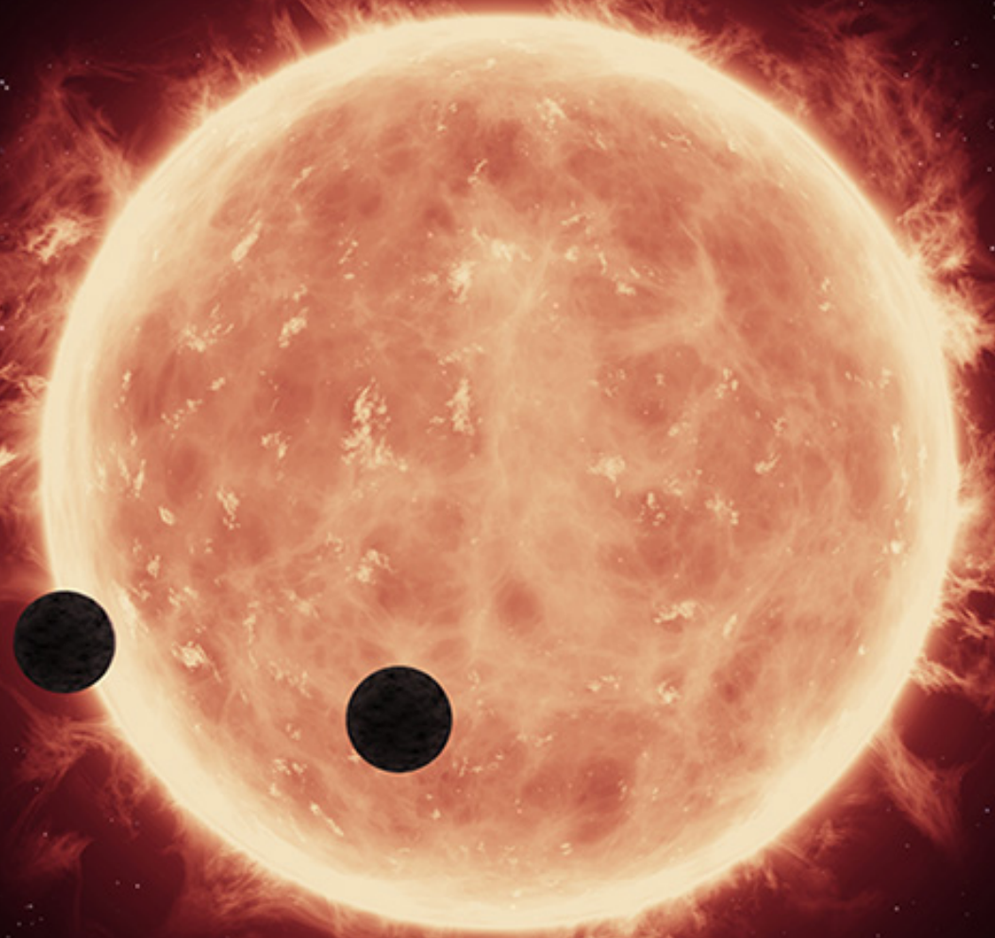
EXOPLANET ATMOSPHERES



DETECTING EXOPLANET ATMOSPHERES

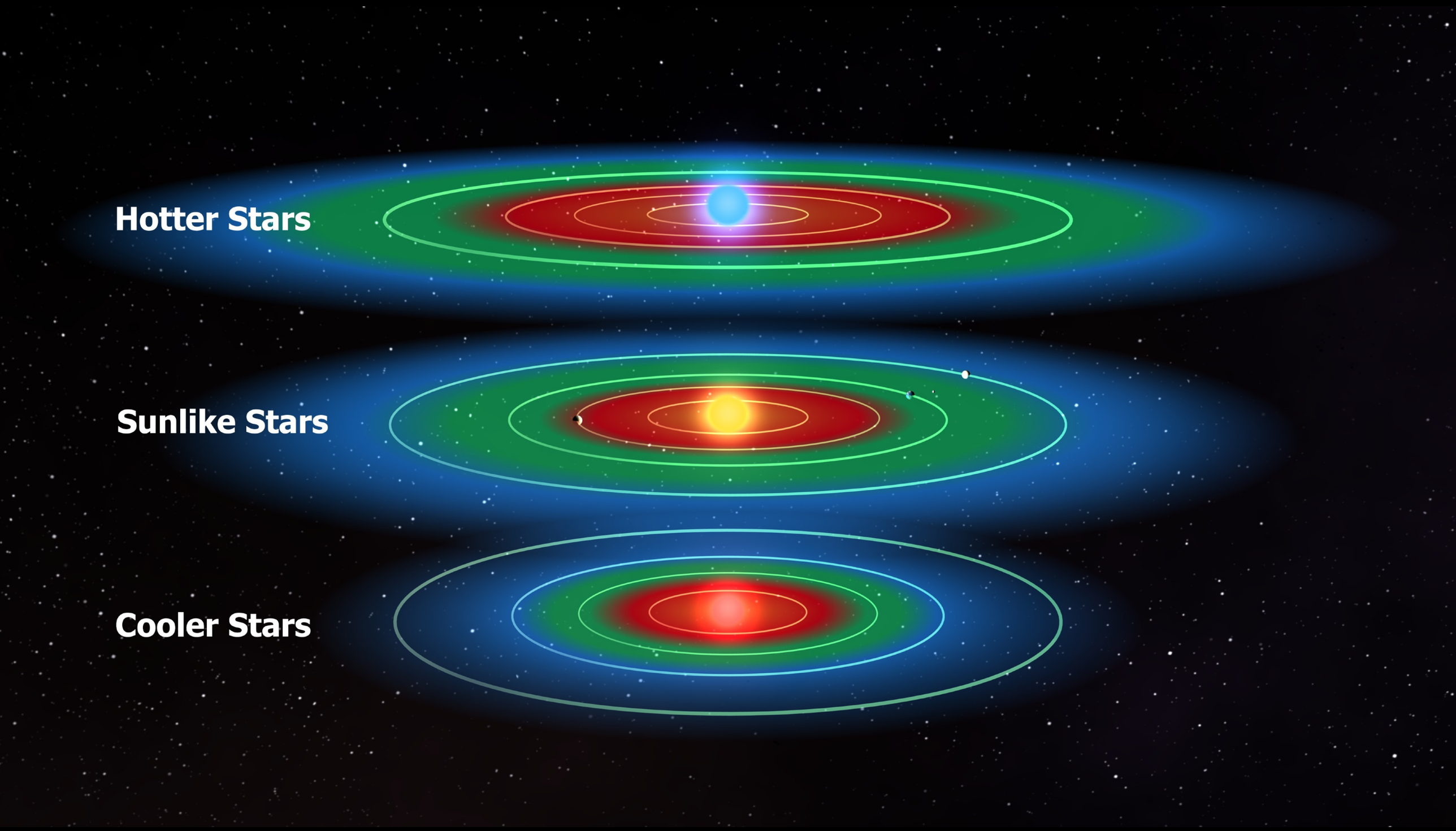


HABITABLE PLANETS?



Where to find them?

HABITABLE ZONE



NASA/Kepler Mission/Dana Berry

POTENTIAL HABITABLE PLANETS

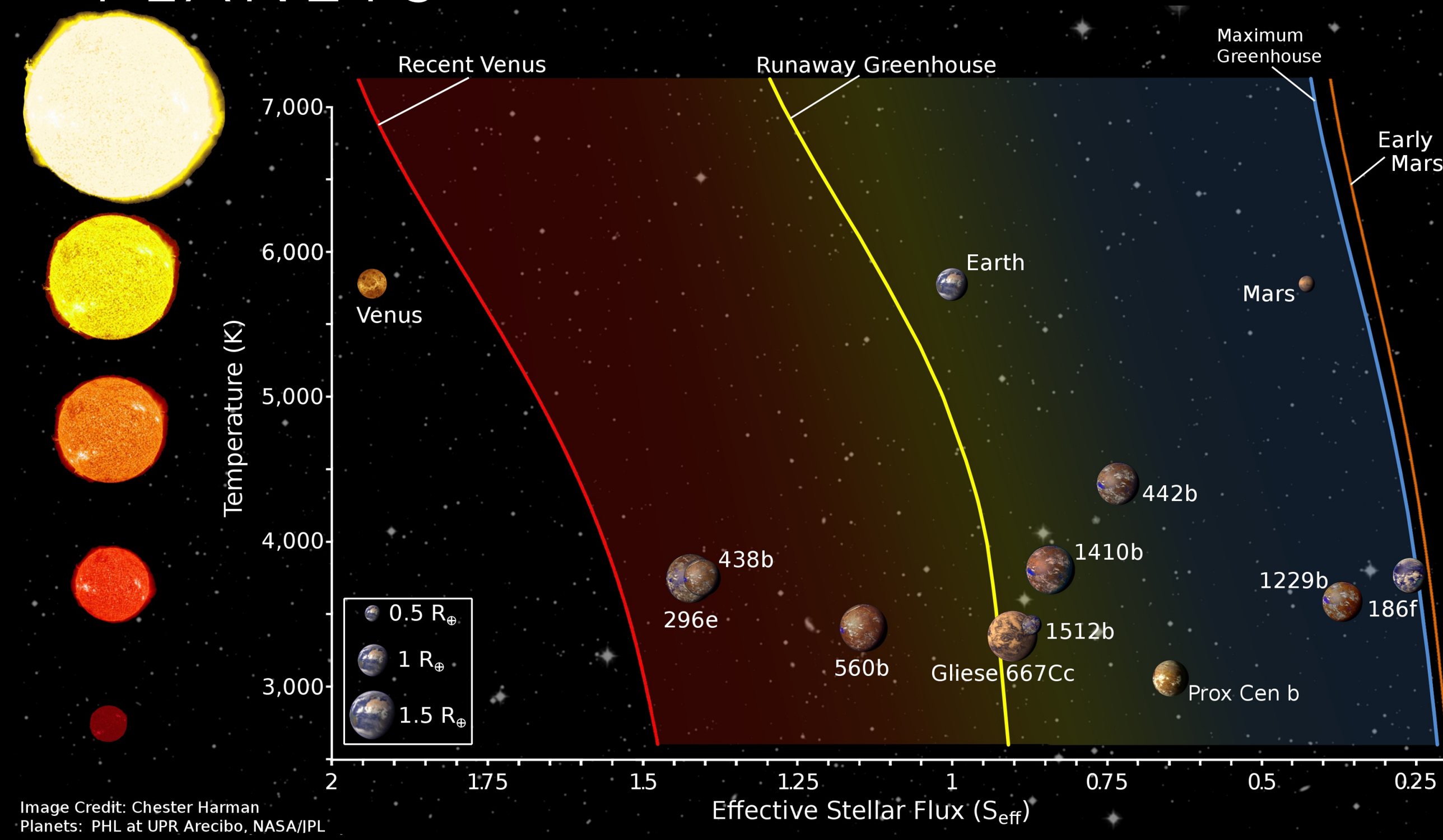
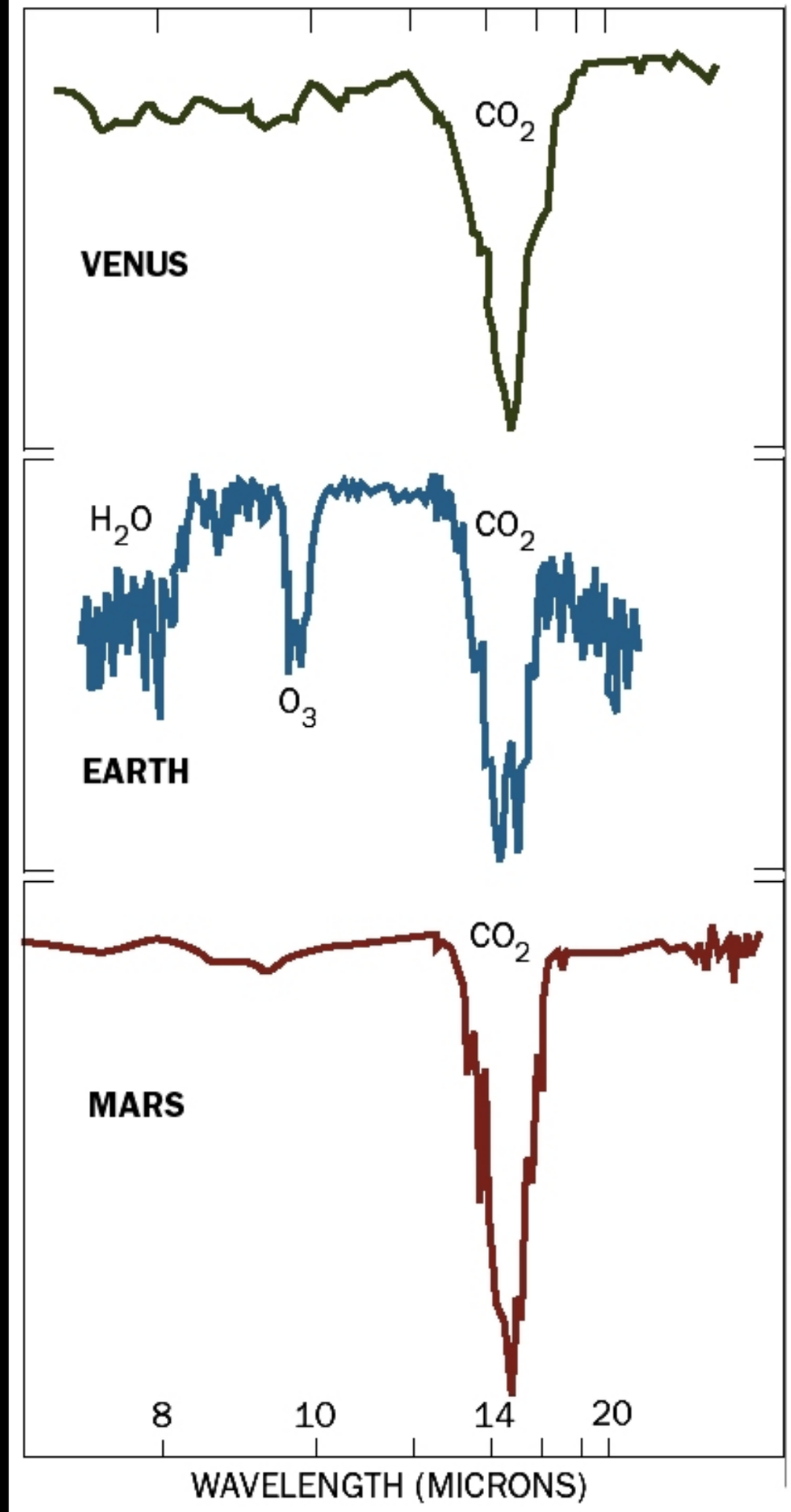
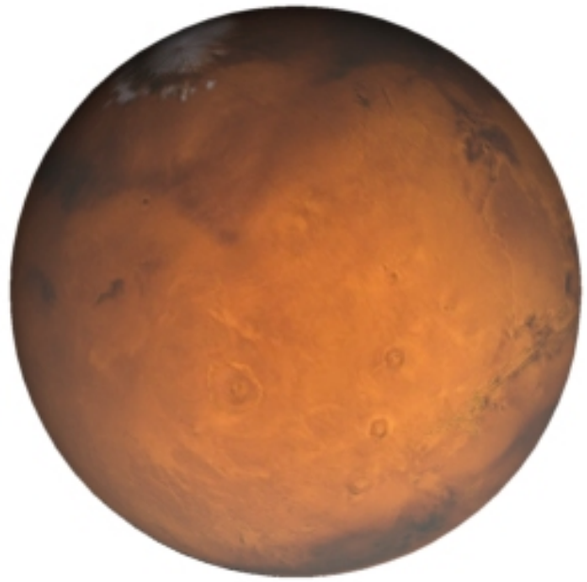


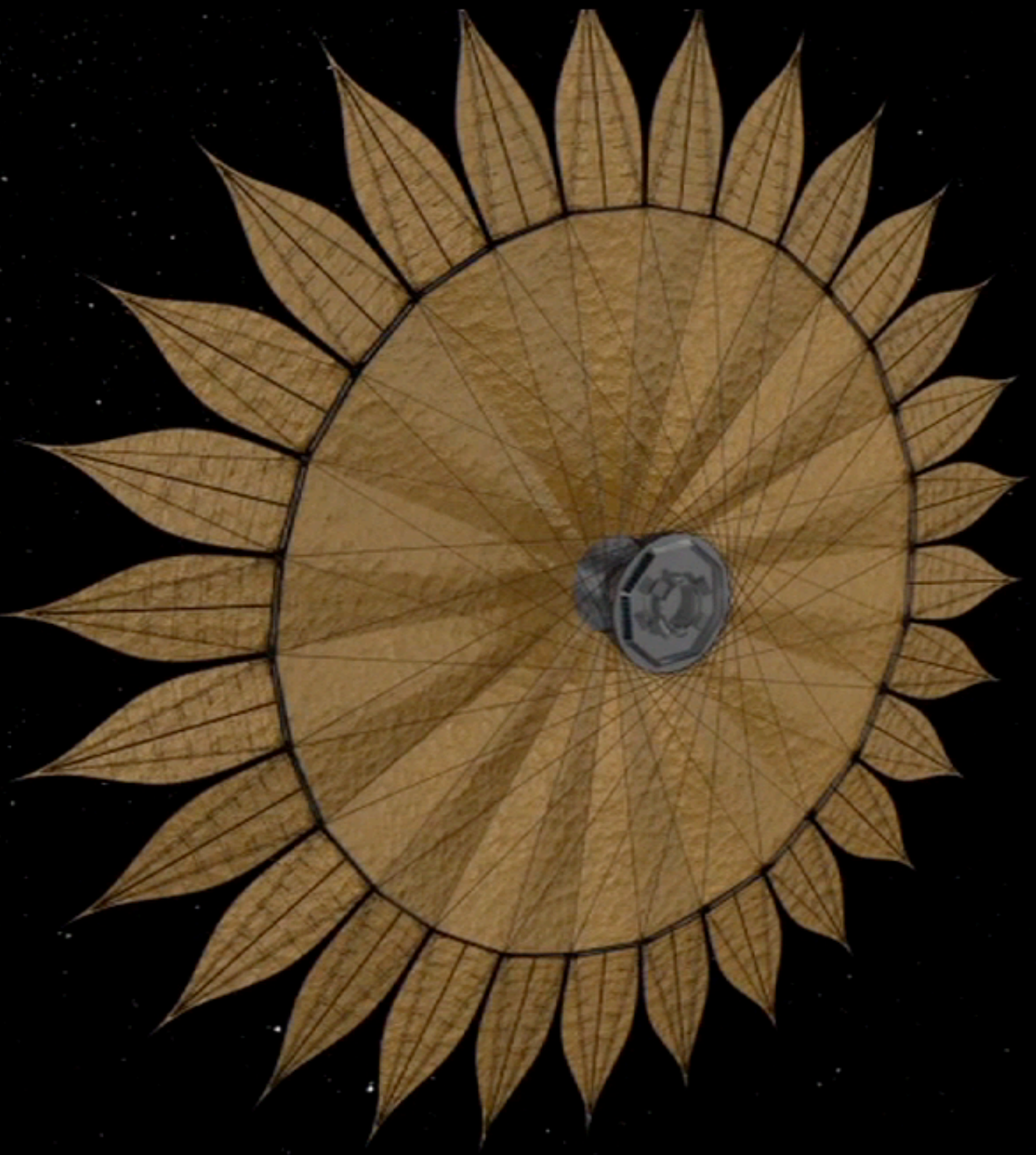
Image Credit: Chester Harman
Planets: PHL at UPR Arecibo, NASA/JPL

http://www3.geosc.psu.edu/~ruk15/planets/Seff_HZ_sci_09012016.jpg

- How do we identify habitable planets?
- By finding ‘bio-signatures’





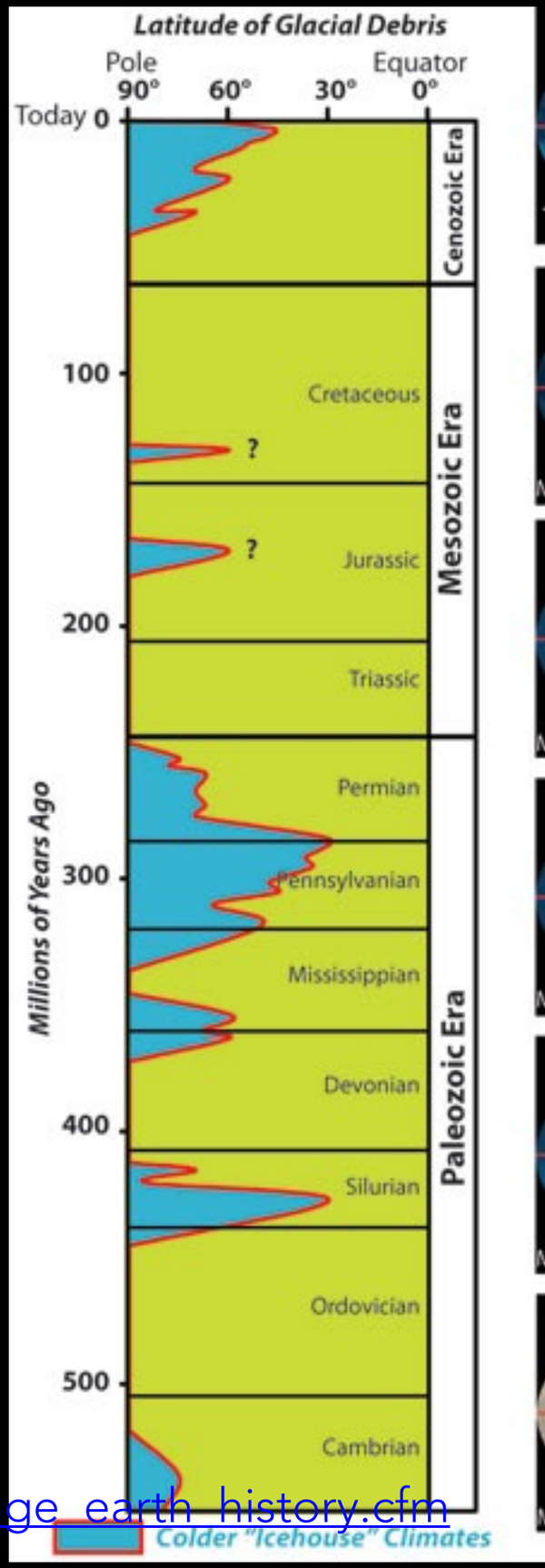


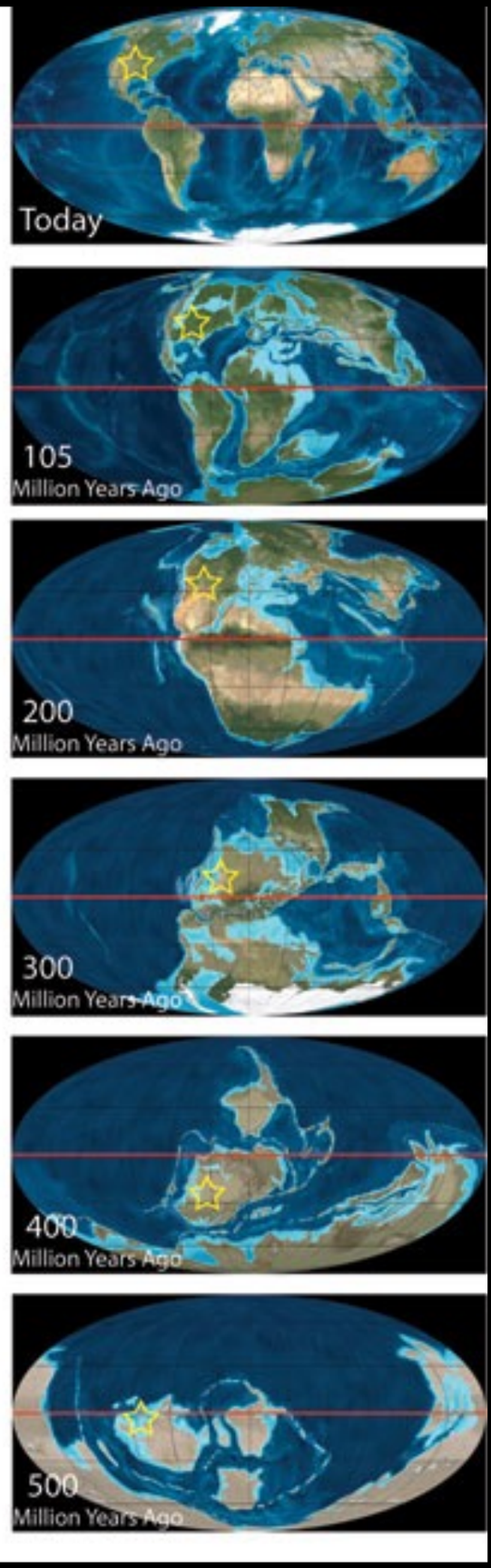
Studying Other Worlds with the Help of a Starshade

CLIMATE CHANGE OVER TIME

- Earth underwent intense climate change over its history. So what is new about current climate change?

- 1. Modern humans existed only in the last ~200,000 years or so. Eco-system was different when hot temperatures persisted.



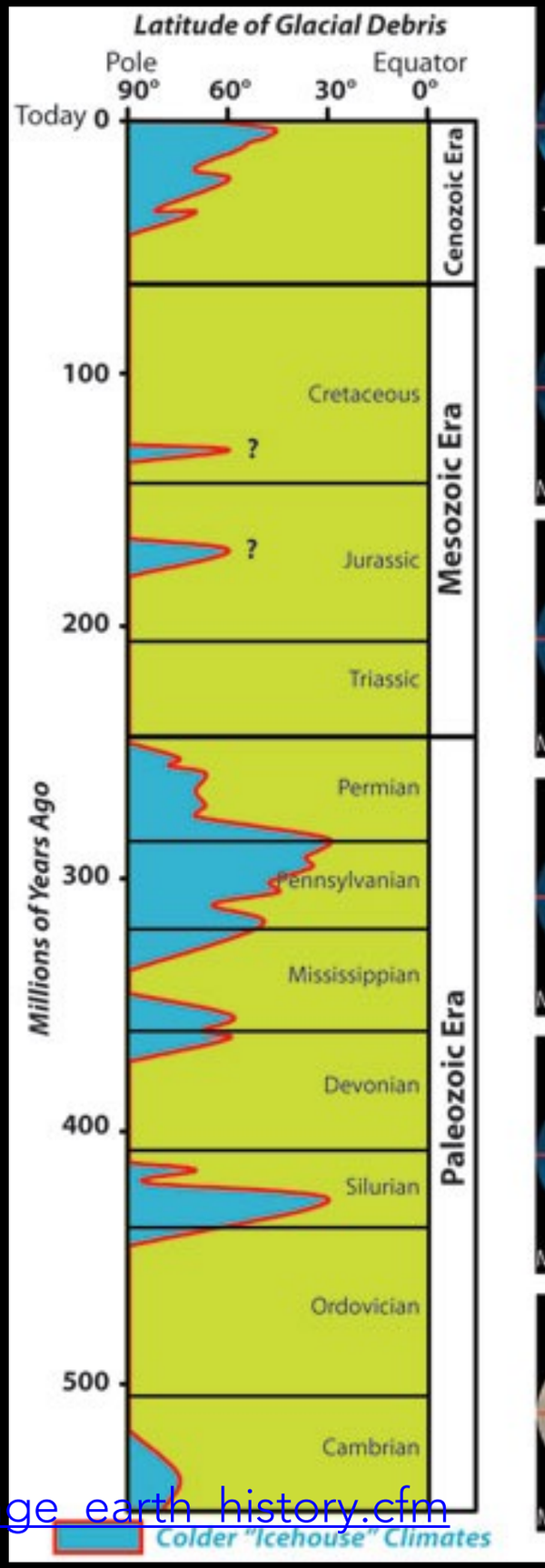


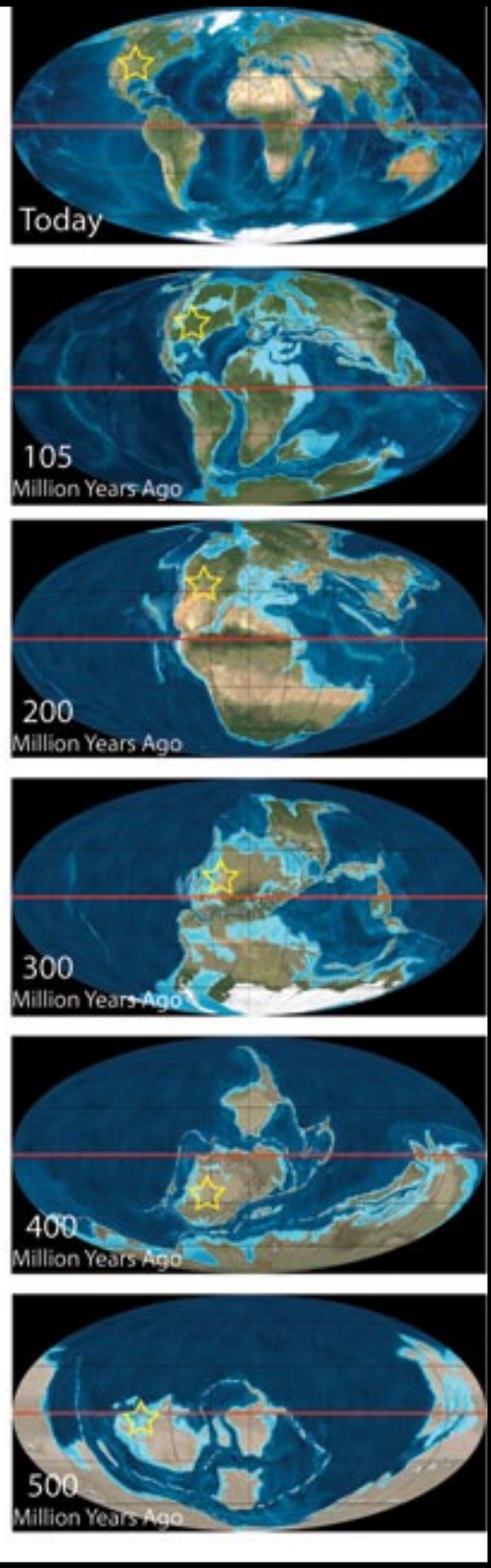
http://nature.nps.gov/geology/nationalfossilday/climate_change_earth_history.cfm

CLIMATE CHANGE OVER TIME

- Earth underwent intense climate change over its history. So what is new about current climate change?

- 2. Those changes took thousands or millions of years. We are experiencing the same change in decades.



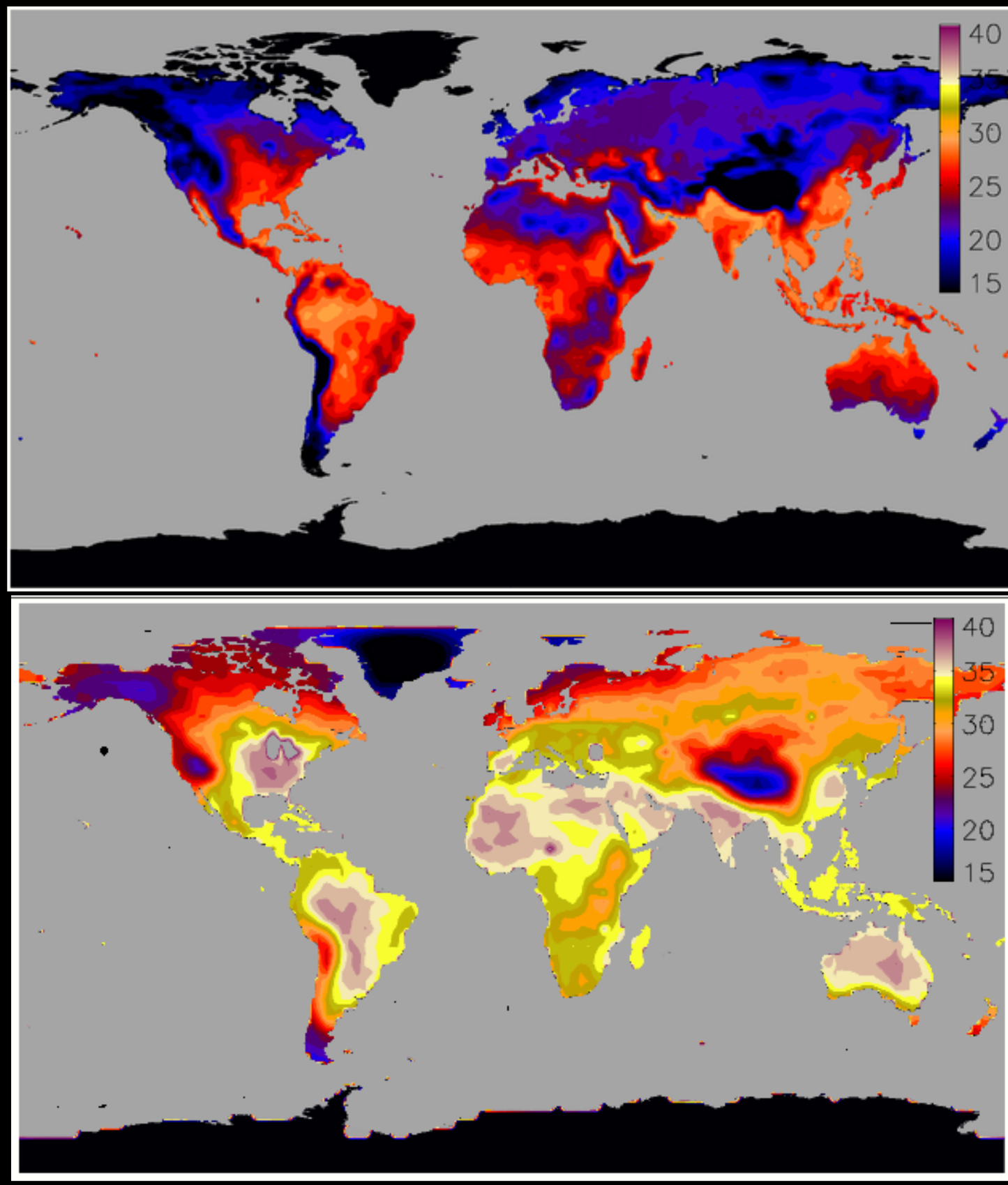


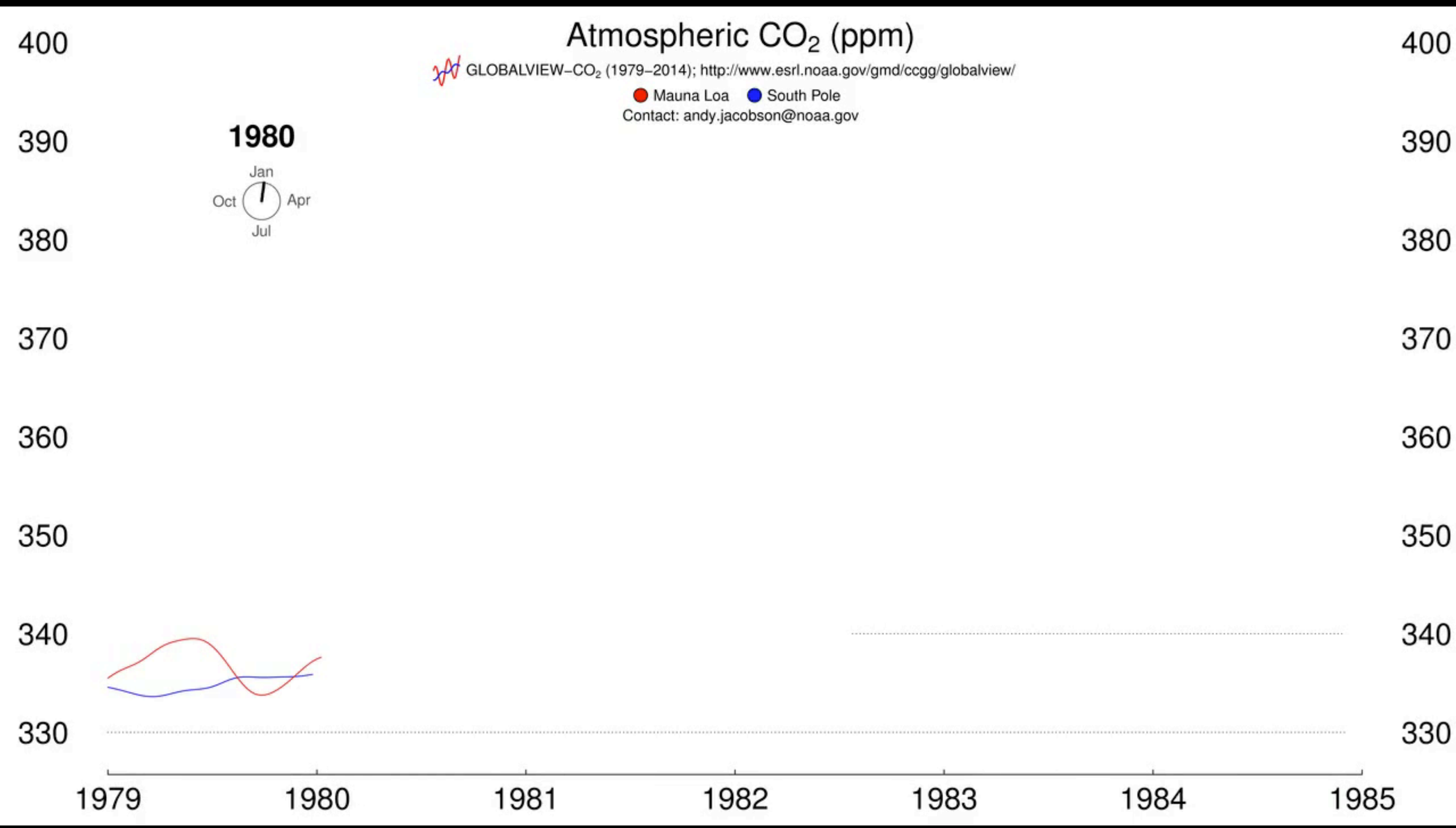
http://nature.nps.gov/geology/nationalfossilday/climate_change_earth_history.cfm

HEAT STRESS

- It doesn't take that many degrees of global warming to allow peak heat summertime heat stress to (occasionally) become unsurvivable, in many parts of the world that are currently highly populated.

Sherwood & Huber 2010



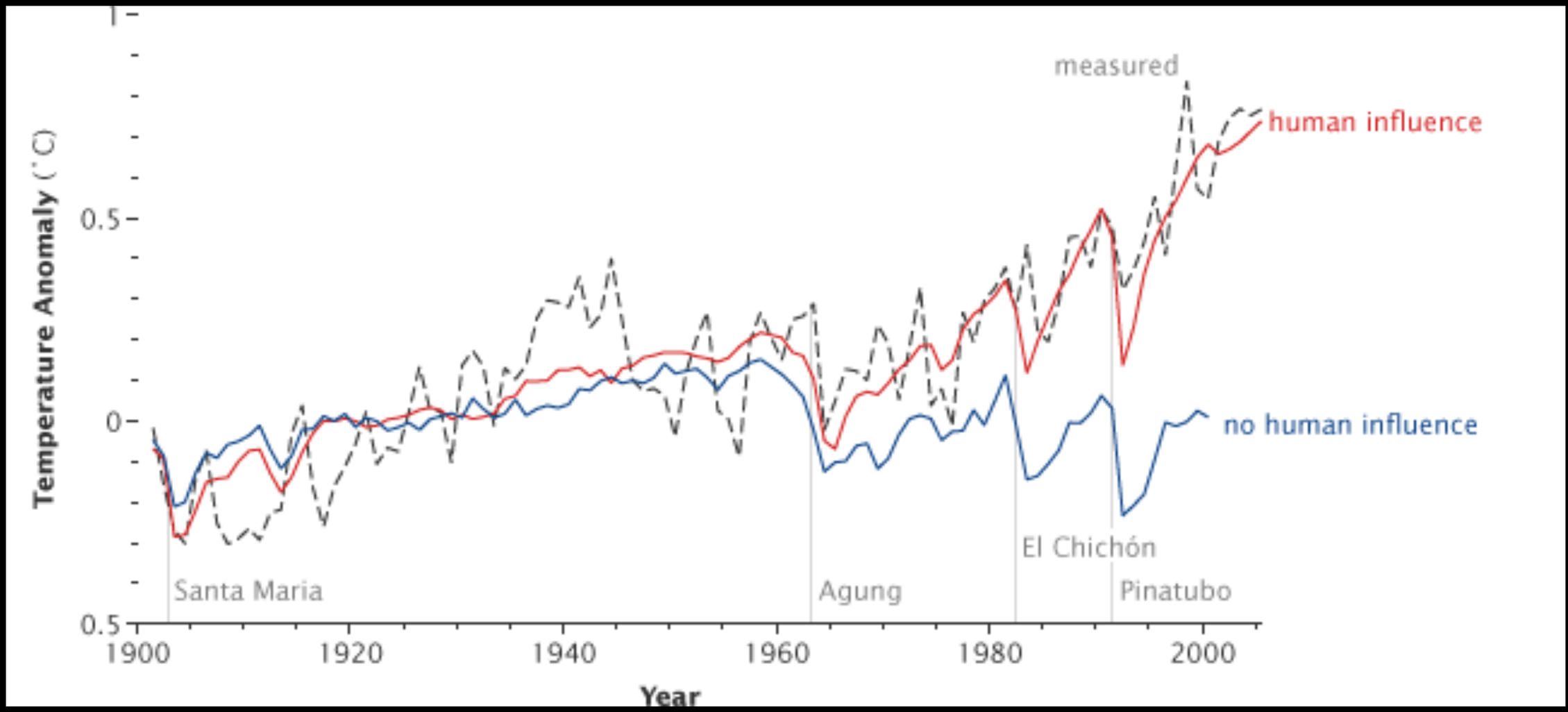


NOAA: https://www.youtube.com/watch?v=UatUDnFmNTY

PERSPECTIVE

PERSPECTIVE

BUT HOW DO YOU KNOW IT IS CAUSED BY HUMANS?

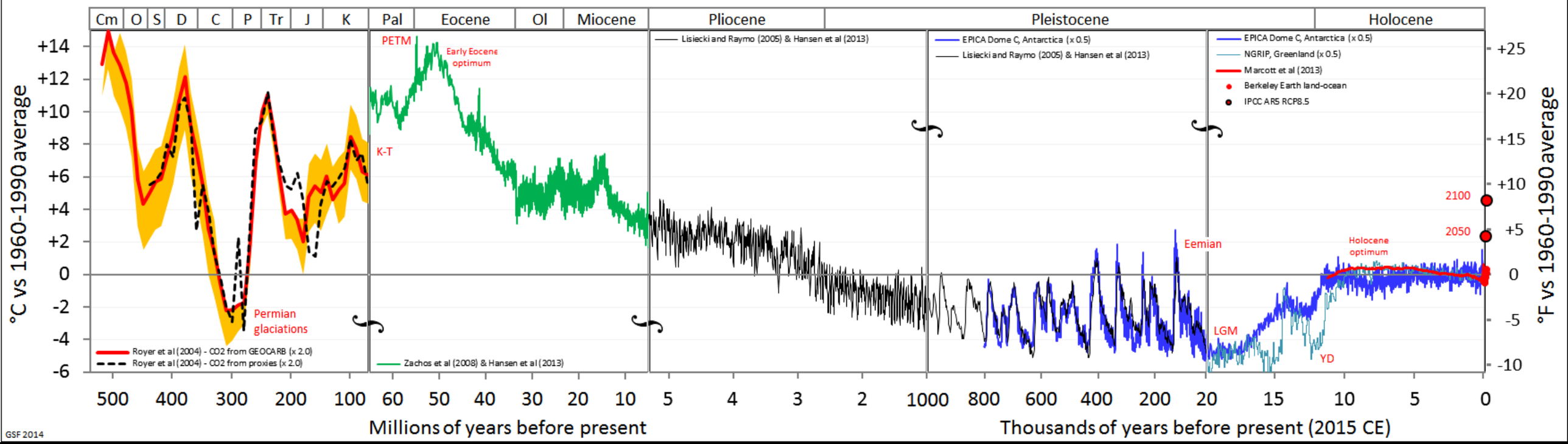


http://earthobservatory.nasa.gov/blogs/climateqa/if-earth-has-warmed-and-cooled-throughout-history-what-makes-that-humans-are-causing-global-warming-now/

CLIMATE AND WEATHER

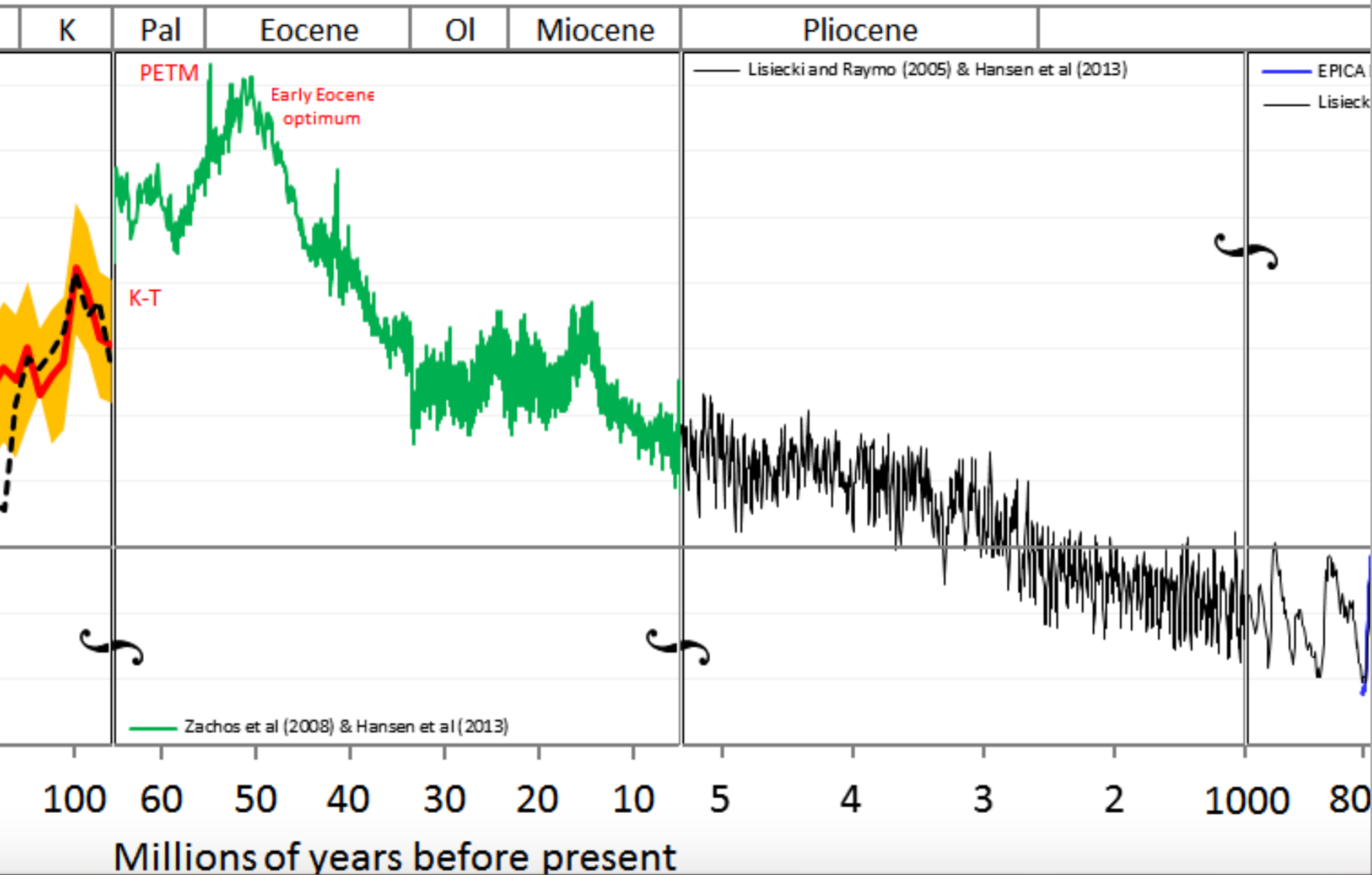
- "It's cold outside my house and/or I see snow. This is an indication global warming is not real"
  - 1. Your house/town/city/state/U.S is not the world. It is called "global" warming.
  - 2. Climate and weather are different. What you are talking about is weather. We are talking about "climate" change.
  - 3. "Global climate" change is the long-term change in the *Earth's climate*
  - 4. Living in non-coastal part of the U.S shouldn't make us indifferent to the effects of climate change on people living in coastal areas (including U.S)

Temperature of Planet Earth



GSF 2014

Temperature of Planet Earth



CONTACT

Ravi Kopparapu
Ph: 225-678-0058
email: ravikumar.kopparapu@nasa.gov
webpage: http://www3.geosc.psu.edu/~ruk15/

PROJECTS/IDEAS/

MCN

- Climate change does not care about the law of the land in the U.S. It cares about the laws of physics.