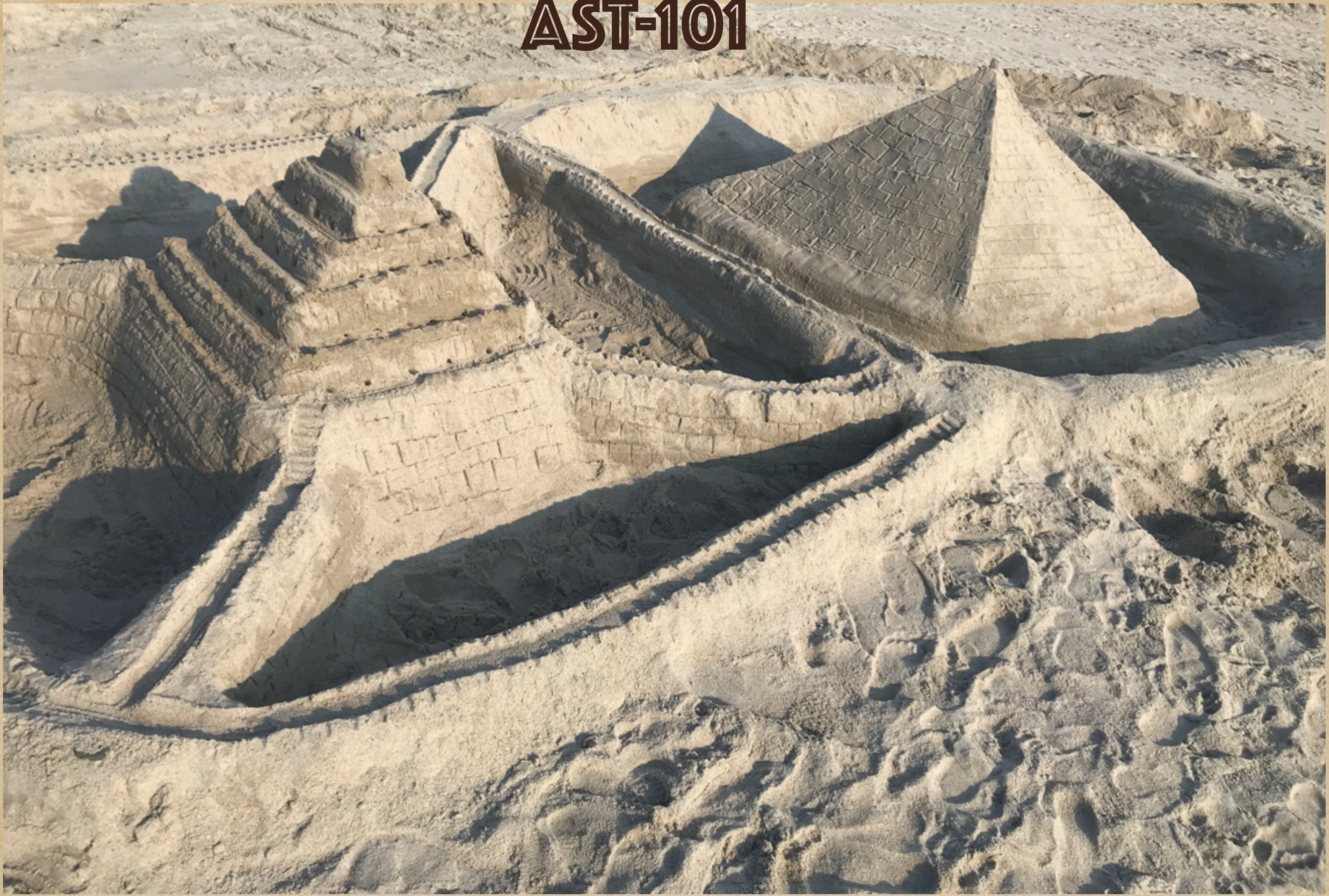
AST-101



Are we alone? Space colonization and the Fermi paradox

Luis Anchordoqui

On May 25, 1961 President Kennedy's announcement to put a man on the moon and bring him back safely before the end of the decade set the advent of human exploration of space for NASA, culminating to the landing on the Moon on July 16, 1969

It is difficult to believe that this is the only time such an event has ever happened in the history of the universe

The Fermi Paradox

Enrico Fermi:
Italian physicist
(1901-1954)

On the other hand

If intelligent life is common, where is everyone?

The Fermi Paradox

Discrepancy between strong likelihood of alien intelligent life (emerging under a wide variety of assumptions) and absence of any visible evidence for such emergence

The Fermi Paradox according to Sherlock Holmes

- Is there any point to which you wish to draw my attention?
- To the curious incident of the dog in the night-time
- The dog did nothing in the night time
- That was the curious incident, remarked Sherlock Holmes

Silver Blaze, A. Conan Doyle

Which of the following is not considered a potential solution to the question of why we lack any evidence of a galactic civilization?

A. there is no galactic civilization because we are the first species ever to achieve the ability to study the universe

B. the galactic civilization probably is undetectable because they operate under different laws of physics from the ones we know

C. the galactic civilization is deliberately avoiding contact with us

D. there is no galactic civilization because all civilizations destroy themselves before they achieve the ability to colonize the galaxy

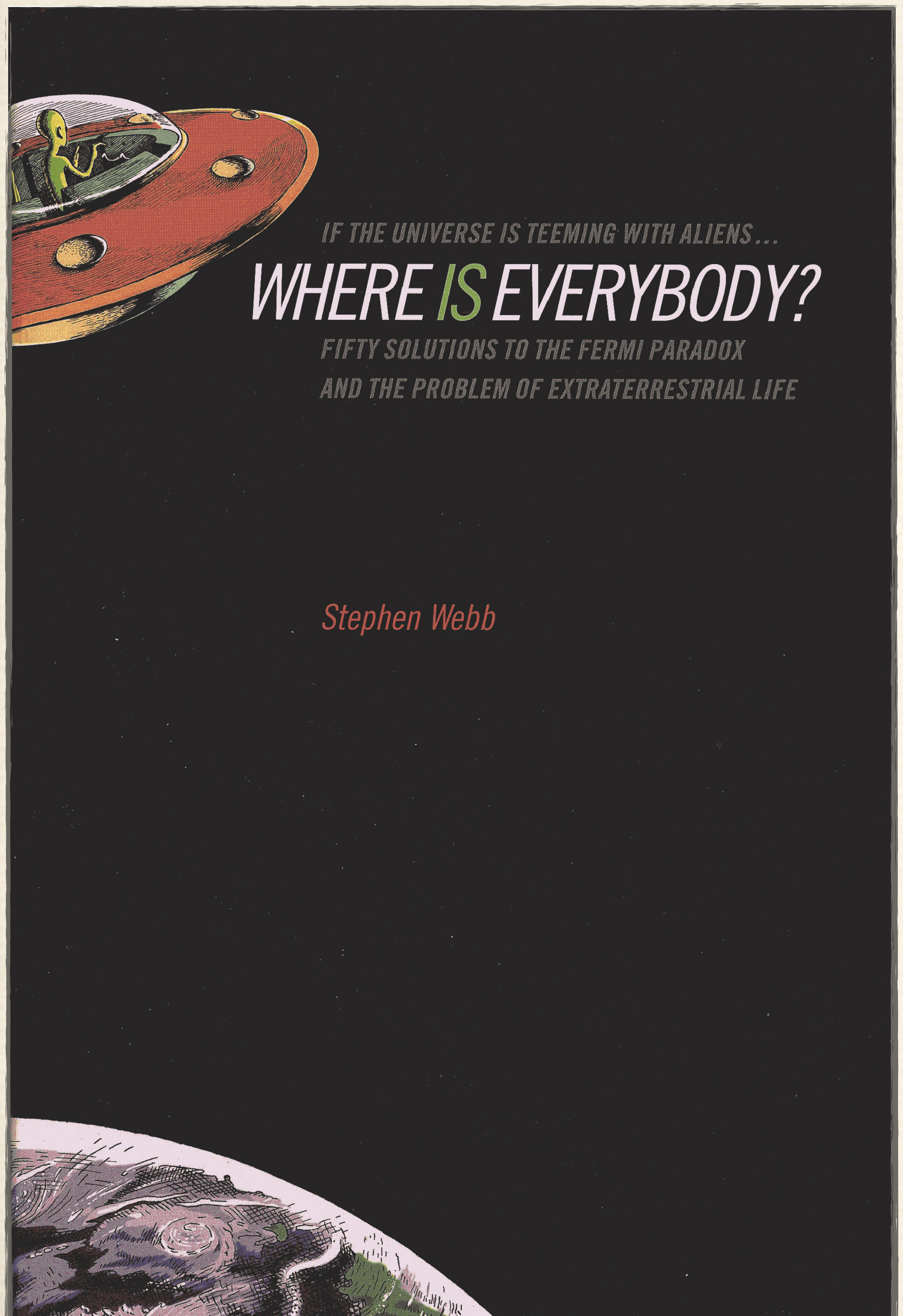
Which of the following is not considered a potential solution to the question of why we lack any evidence of a galactic civilization?

A. there is no galactic civilization because we are the first species ever to achieve the ability to study the universe

B. the galactic civilization probably is undetectable because they operate under different laws of physics from the ones we know

C. the galactic civilization is deliberately avoiding contact with us

D. there is no galactic civilization because all civilizations destroy themselves before they achieve the ability to colonize the galaxy



Types of answers:

1. They do not exist

2. They exist but have not yet communicated with us

3. They are here

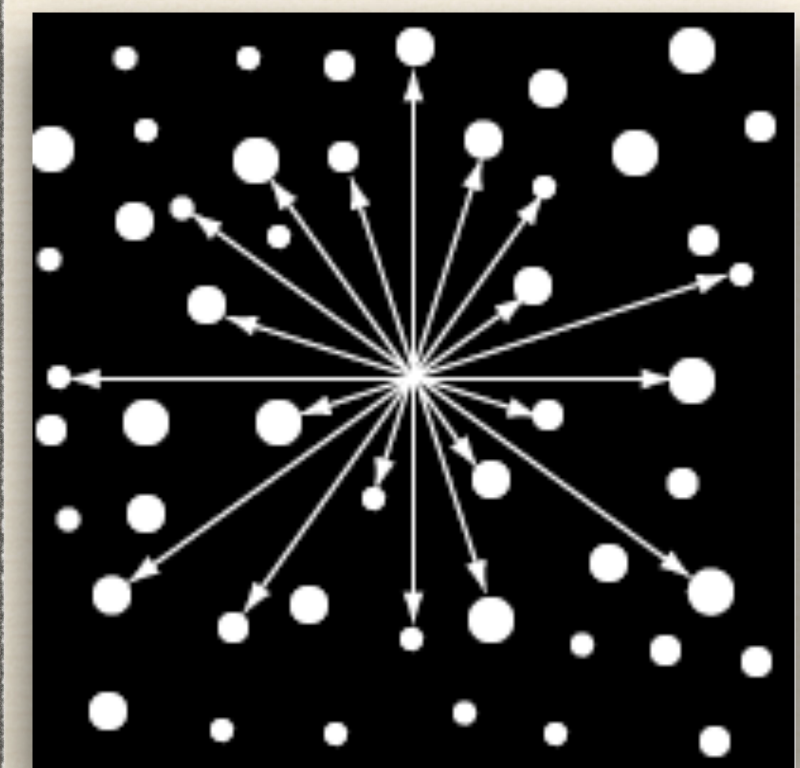
An Analogy

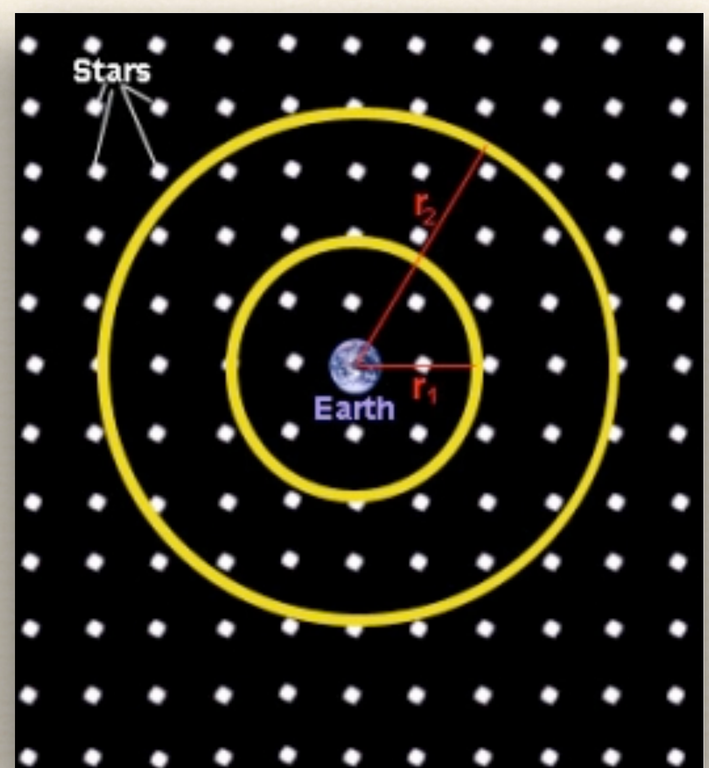
Recall Olbers' paradox:

An infinite universe that is infinitely old should be infinitely bright

So why is the night sky dark?

The night sky is dark because the universe is finite both spatially and temporally





Though the number of stars is huge, the universe is essentially sparse

The Fermi Paradox

- The FP may have a similar solution:
- "N" may be large (lots of civilizations) but the Galaxy is too large for the likelihood of one civilization encountering another
- ... yet
- The smaller N is, the more sparse the Galaxy

Whose paradox asks why the sky is not ablaze with starlight if the universe is infinite in extent and uniformly filled with stars?

A. Olber's

B. Fermi's

C. Schuller's

D. Miller's

Whose paradox asks why the sky is not ablaze with starlight if the universe is infinite in extent and uniformly filled with stars?

A. Olber's

B. Fermi's

C. Schuller's

D. Miller's


AD ASTRA
SPACE
EXPLORATION INNOVATION BROUGHT DOWN TO EARTH
sparks & honey

Purpose?

Although I could find more reasons, I think the best reason is, because we simply can!

Fly me to the Moon

Which unlucky Apollo lunar landing was canceled after an oxygen tank exploded?

A. Apollo 13

B. Apollo 11

C. Apollo 17

Which unlucky Apollo lunar landing was canceled after an oxygen tank exploded?

A. Apollo 13

B. Apollo 11

C. Apollo 17

Which was the first manned landing mission on the moon?

A. Apollo 13

B. Apollo 11

C. Apollo 17

Which was the first manned landing mission on the moon?

A. Apollo 13

B. Apollo 11

C. Apollo 17

In what year did Neil Armstrong make his historic walk on the Moon?

- **A.** 1959
- **B.** 1969
- **C.** 1979
- **D.** 1999

In what year did Neil Armstrong make his historic walk on the Moon?

A. 1959

B. 1969

C. 1979

D. 1999

How many people have set foot on the Moon?

A. 1

B. 0

C. 1000

D. 12

How many people have set foot on the Moon?

A. 1

B. 0

C. 1000

D. 12

How many manned moon landings have there been?

A. 1

B. 2

C. 3

D. 6

E. 10

F. 12

How many manned moon landings have there been?

A. 1

B. 2

C. 3

D. 6

E. 10

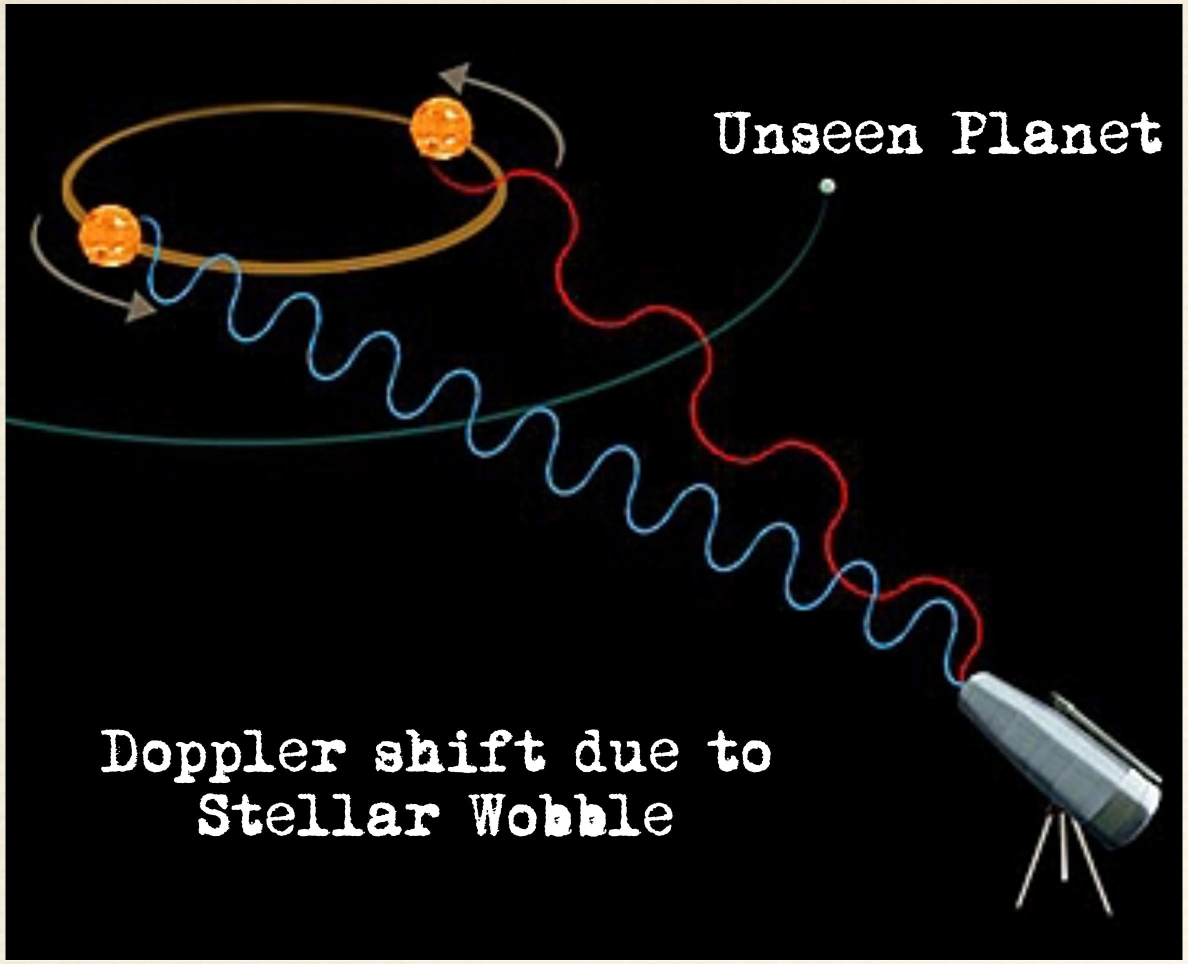
F. 12

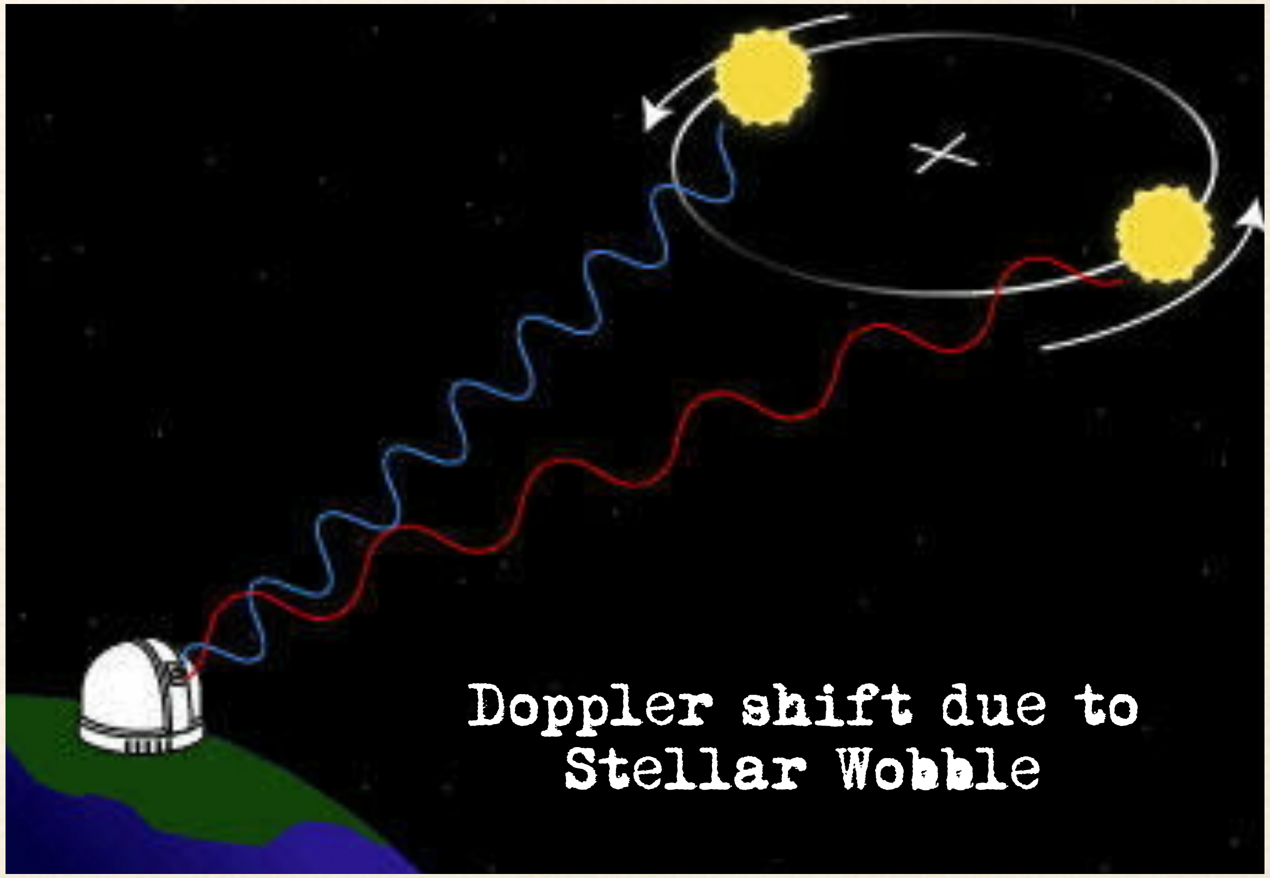
A home away from home

EXTRASOLAR HABITABILITY:

EARTH-LIKE PLANETS?

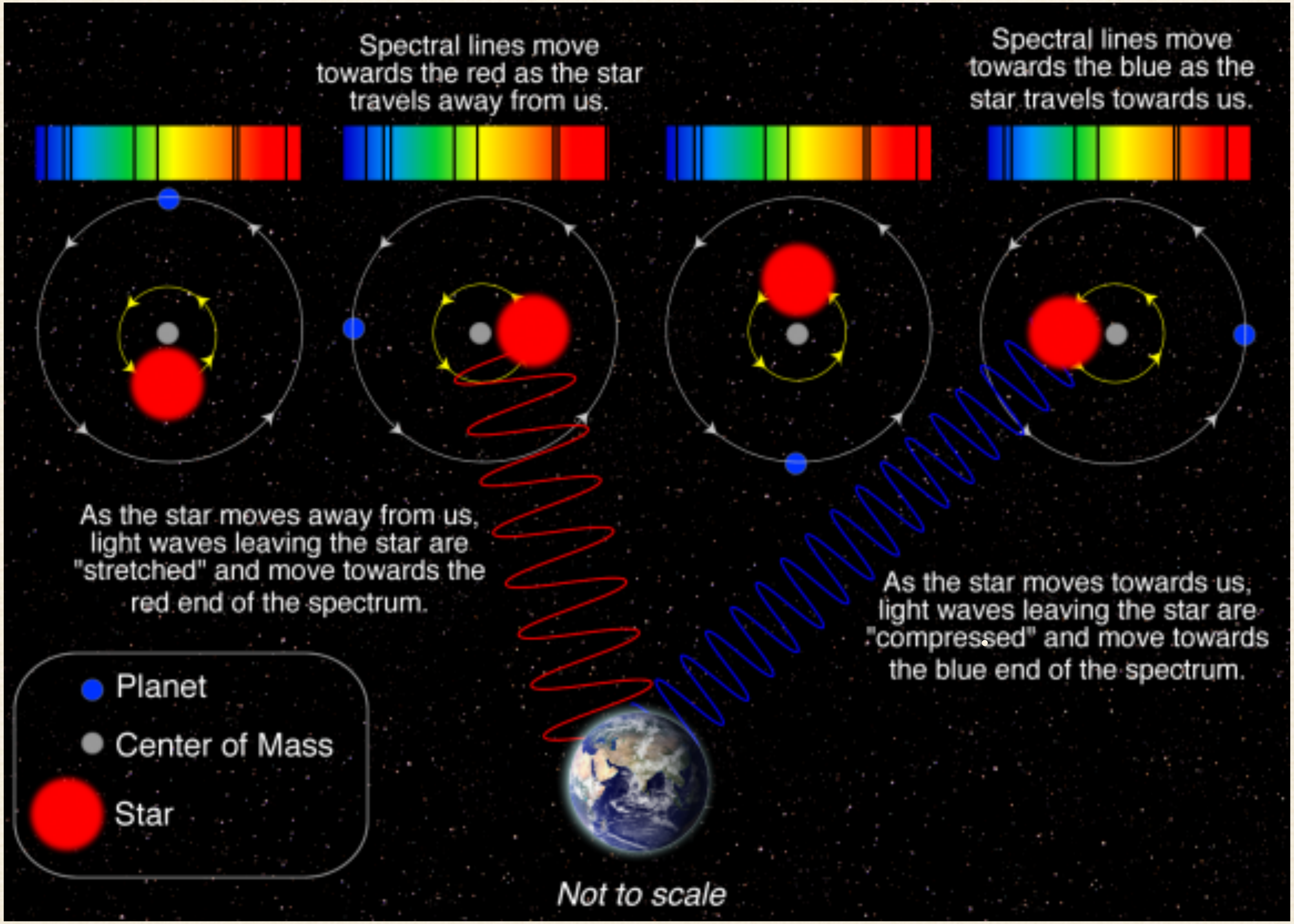
DETECTING EXOPLANETS WITH RADIAL VELOCITY MEASUREMENTS


Unseen Planet
Doppler shift due to
Stellar Wobble


Doppler shift due to
Stellar Wobble

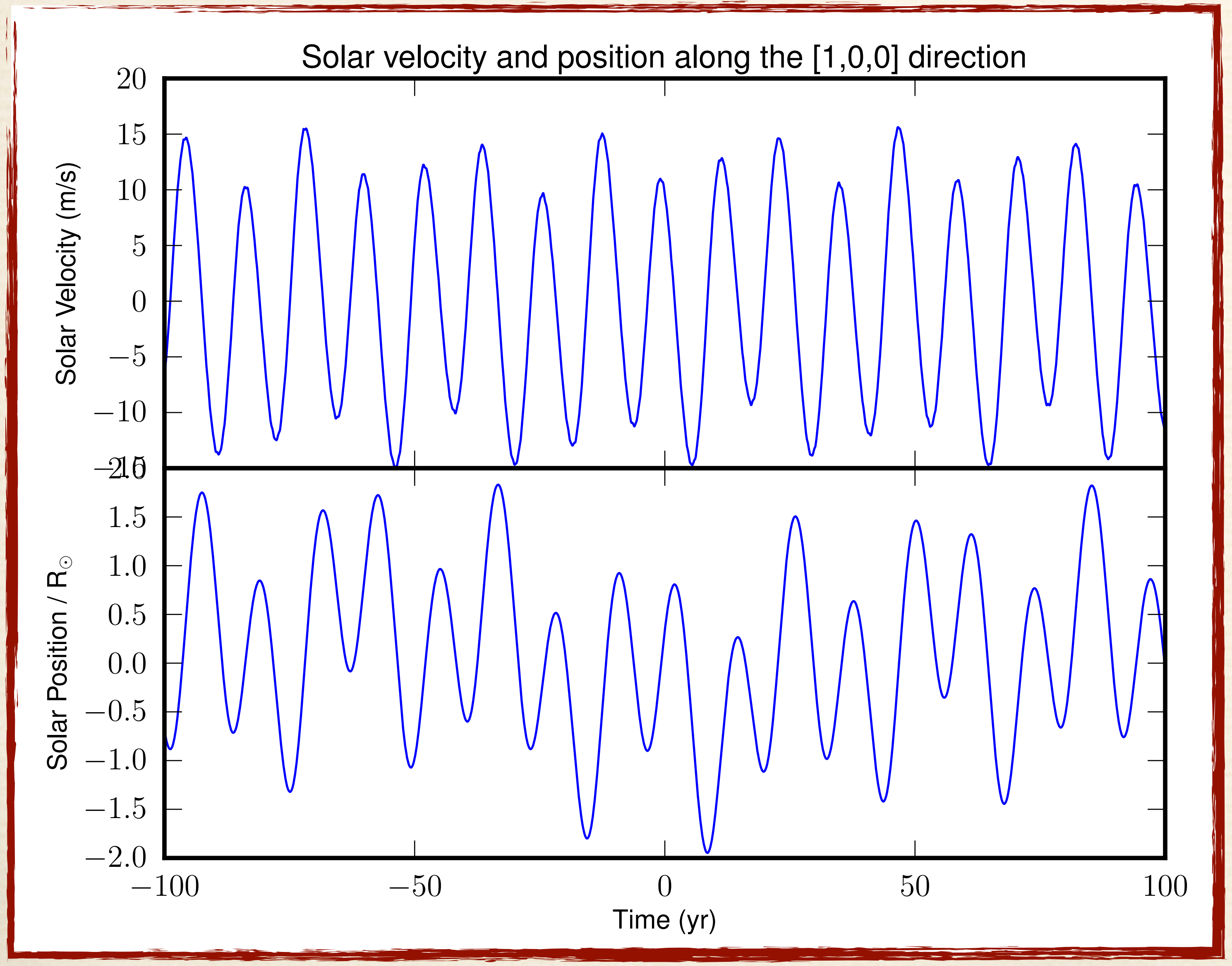
Radial velocity method

The star and planet orbit their common center of mass



If ETs were measuring the radial velocity of the Sun ...

All planets in the solar system contribute to the Sun's motion



This is the distance of the Sun from the solar system's barycenter in units of the Sun's radius

A Jupiter-mass companion to a solar-type star

Michel Mayor & Didier Queloz

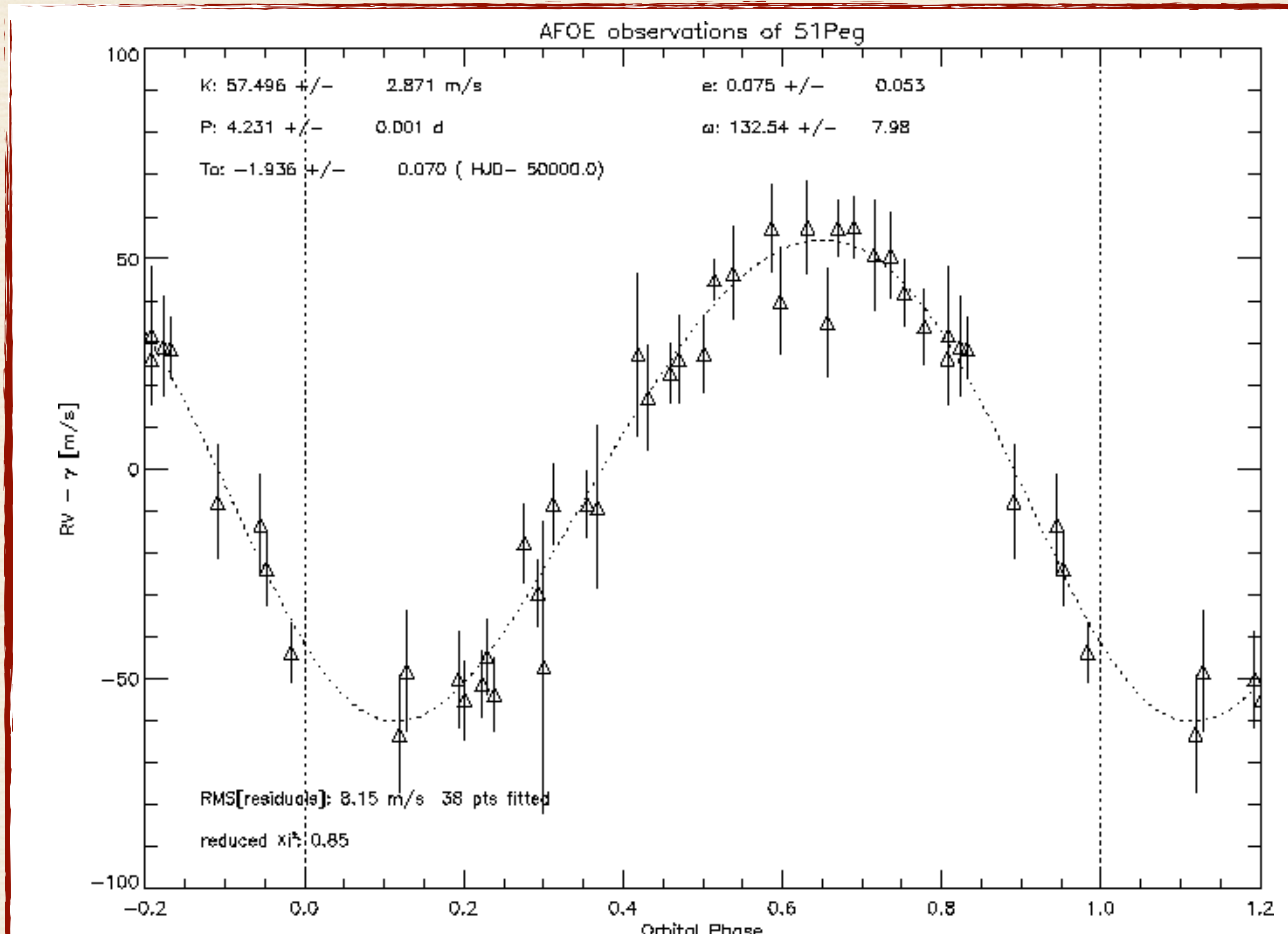
Geneva Observatory, 51 Chemin des Maillettes, CH-1290 Sauverny, Switzerland

The presence of a Jupiter-mass companion to the star 51 Pegasi is inferred from observations of periodic variations in the star's radial velocity. The companion lies only about eight million kilometres from the star, which would be well inside the orbit of Mercury in our Solar System. This object might be a gas-giant planet that has migrated to this location through orbital evolution, or from the radiative stripping of a brown dwarf.

For more than ten years, several groups have been examining the radial velocities of dozens of stars, in an attempt to identify orbital motions induced by the presence of heavy planetary companions[1–5]. The precision of spectrographs optimized for Doppler studies and currently in use is limited to about 15 m s^{-1}. As the reflex motion of the Sun due to Jupiter is 13 m s^{-1}, all current searches are limited to the detection of objects with at least the mass of Jupiter (M_J). So far, all precise Doppler surveys have failed to detect any jovian planets or brown dwarfs.

Since April 1994 we have monitored the radial velocity of 142 G and K dwarf stars with a precision of 13 m s^{-1}. The stars in our survey are selected for their apparent constant radial velocity (at lower precision) from a larger sample of stars monitored for 15 years[6,7]. After 18 months of measurements, a small number of stars show significant velocity variations. Although most candidates require additional measurements, we report here the discovery of a companion with a minimum mass of 0.5 M_J, orbiting at 0.05 AU around the solar-type star 51 Peg. Constraints originating from the observed rotational velocity of 51 Peg and from its low chromospheric emission give an upper limit of 2 M_J for

51 Pegasi observations

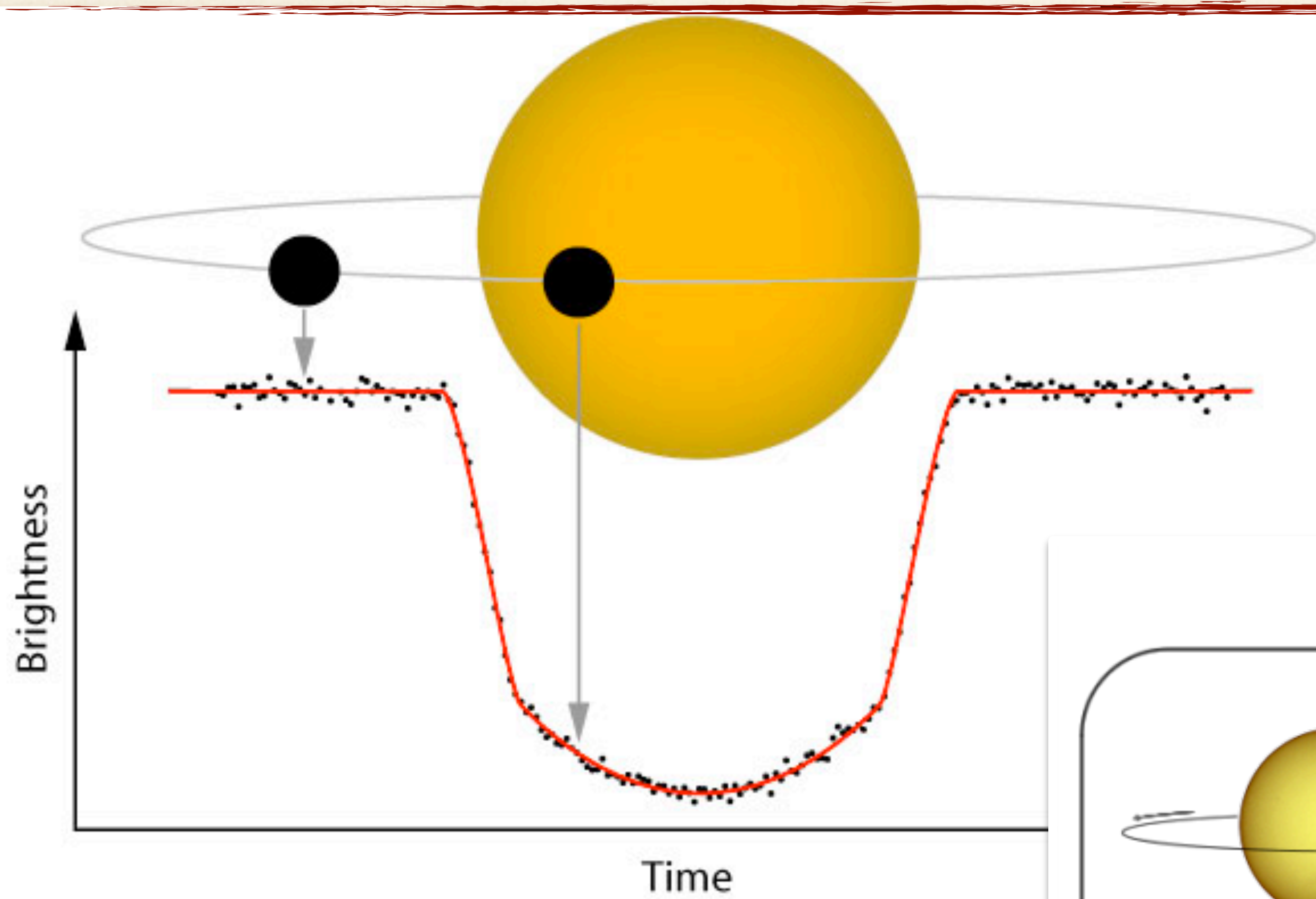


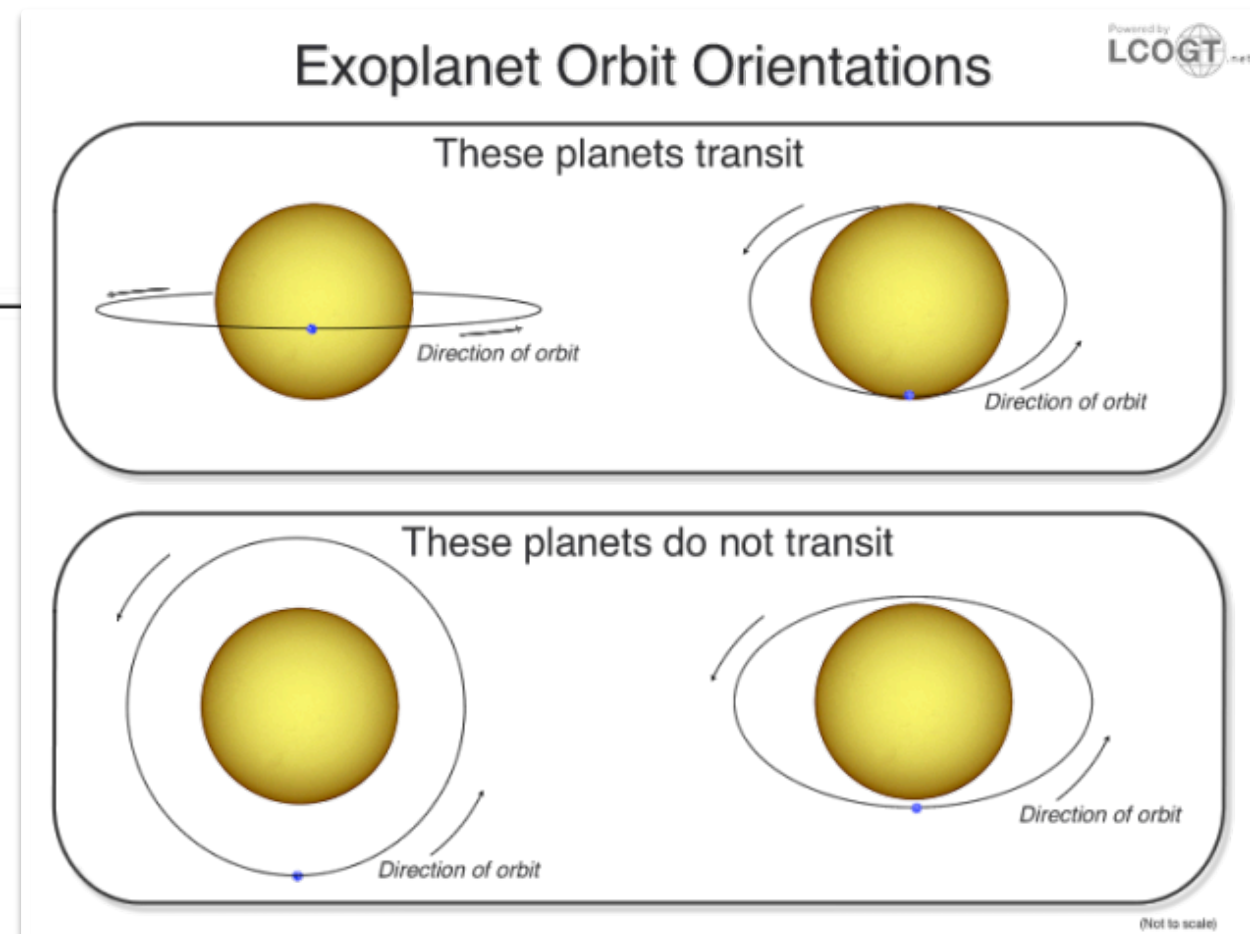
The Kepler mission

DETECTING EXOPLANETS

WITH PLANETARY TRANSITS

PLANETARY TRANSITS





Transit of Venus (2012)

A Planet that transits ☛ Unique opportunity to observe an exoplanet's

radius

+

orbit

+

mass

+

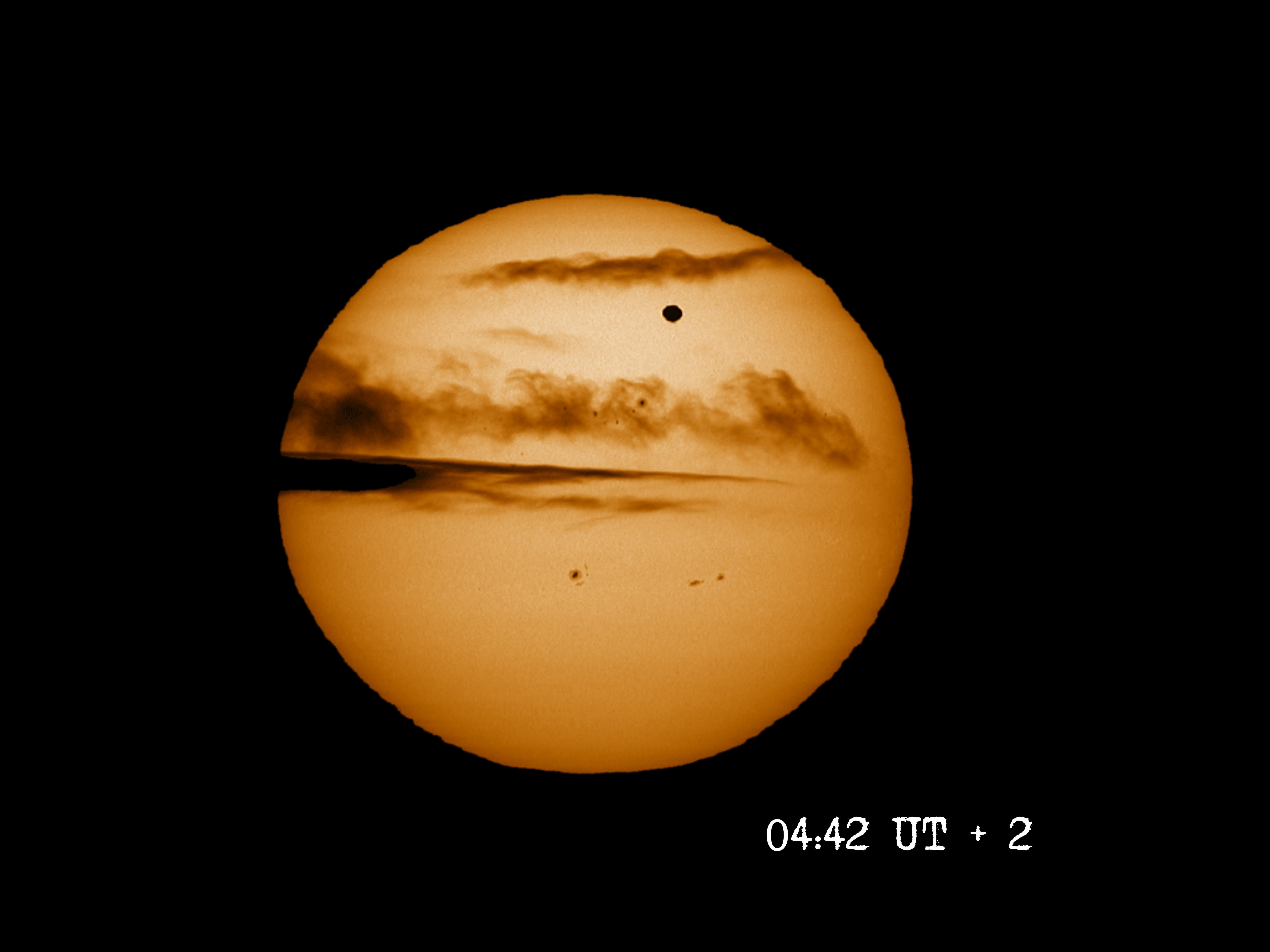
atmosphere

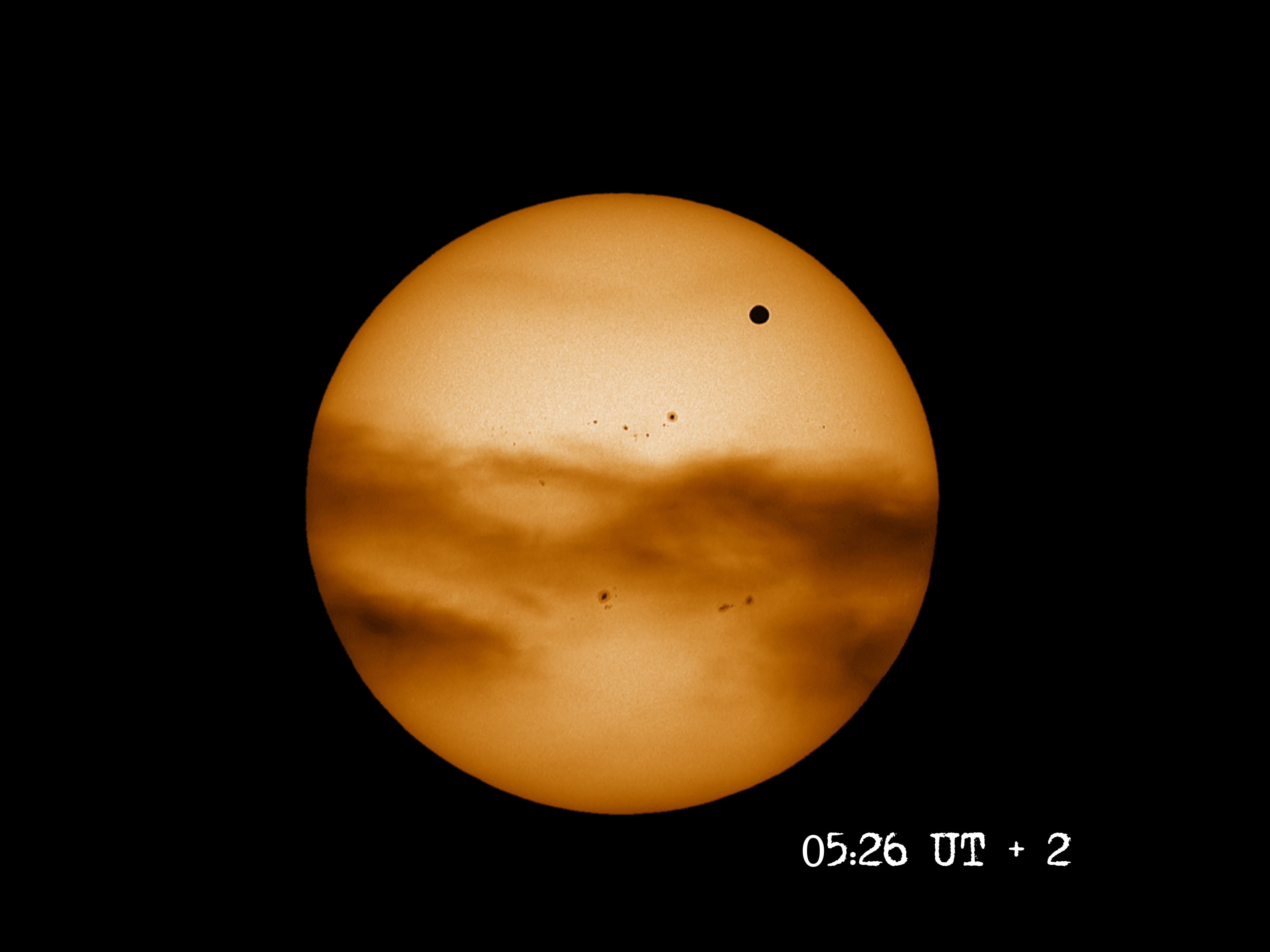
↓

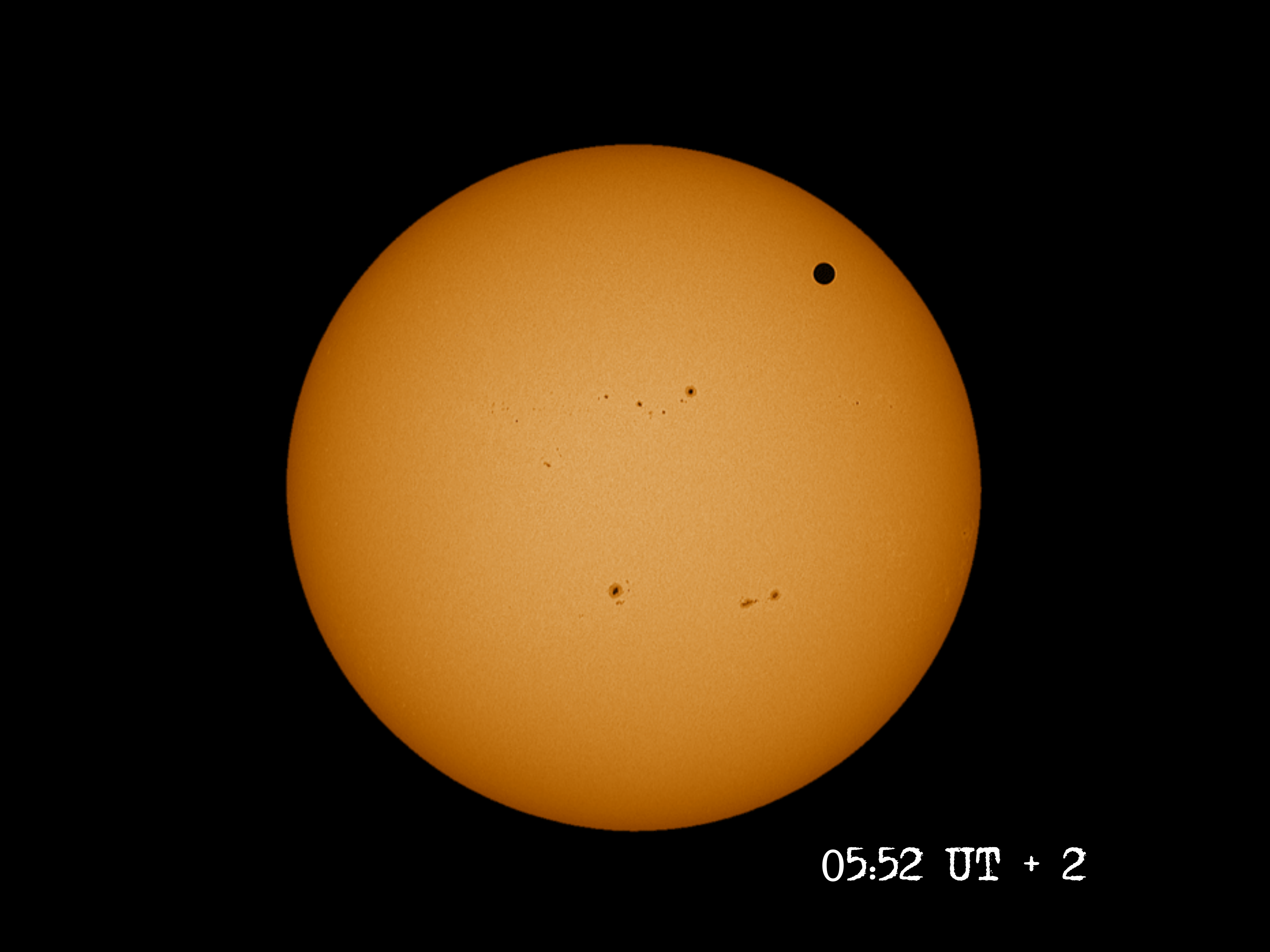
Is it like Earth?

Is it habitable?

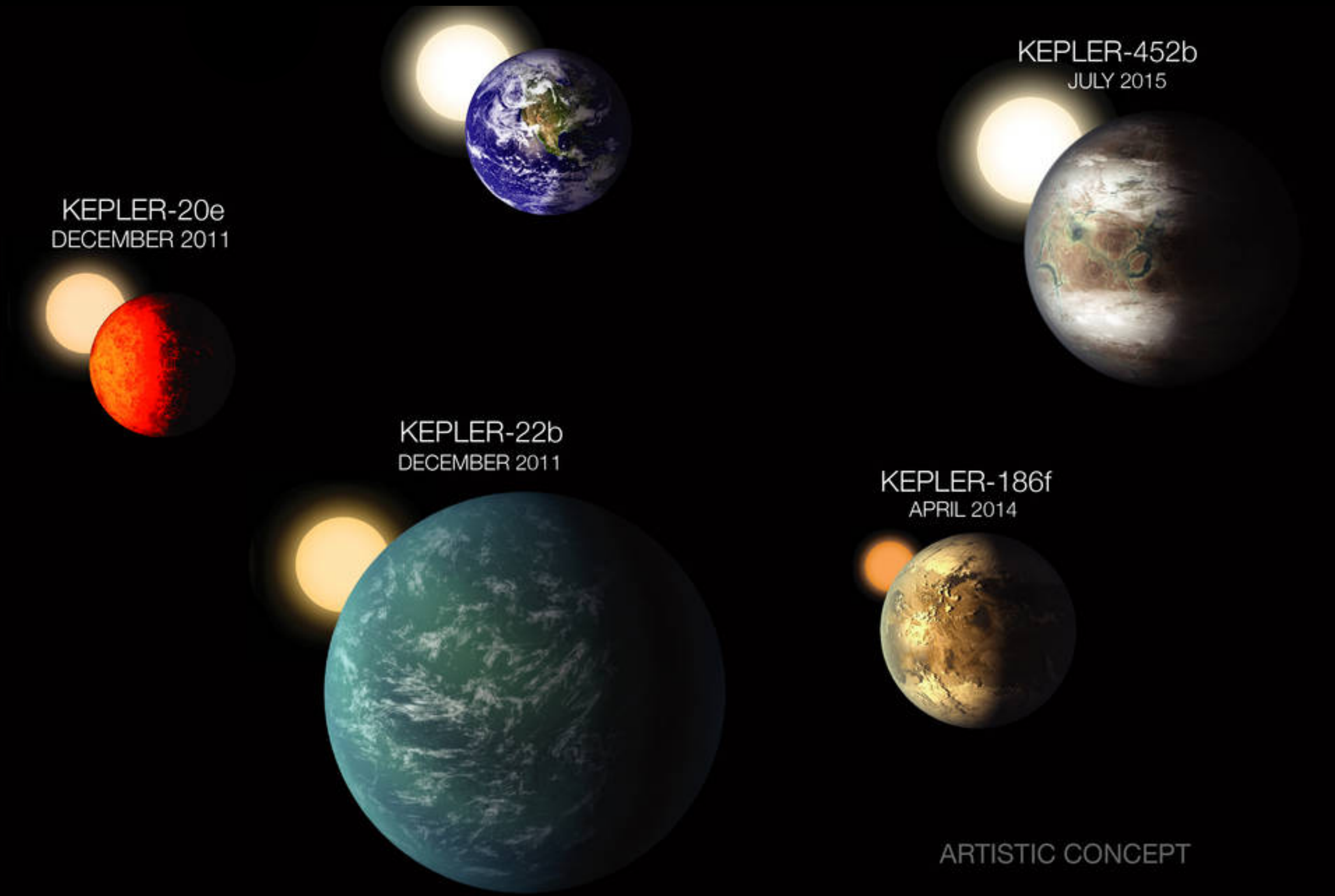
Is it inhabited?


04:42 UT + 2

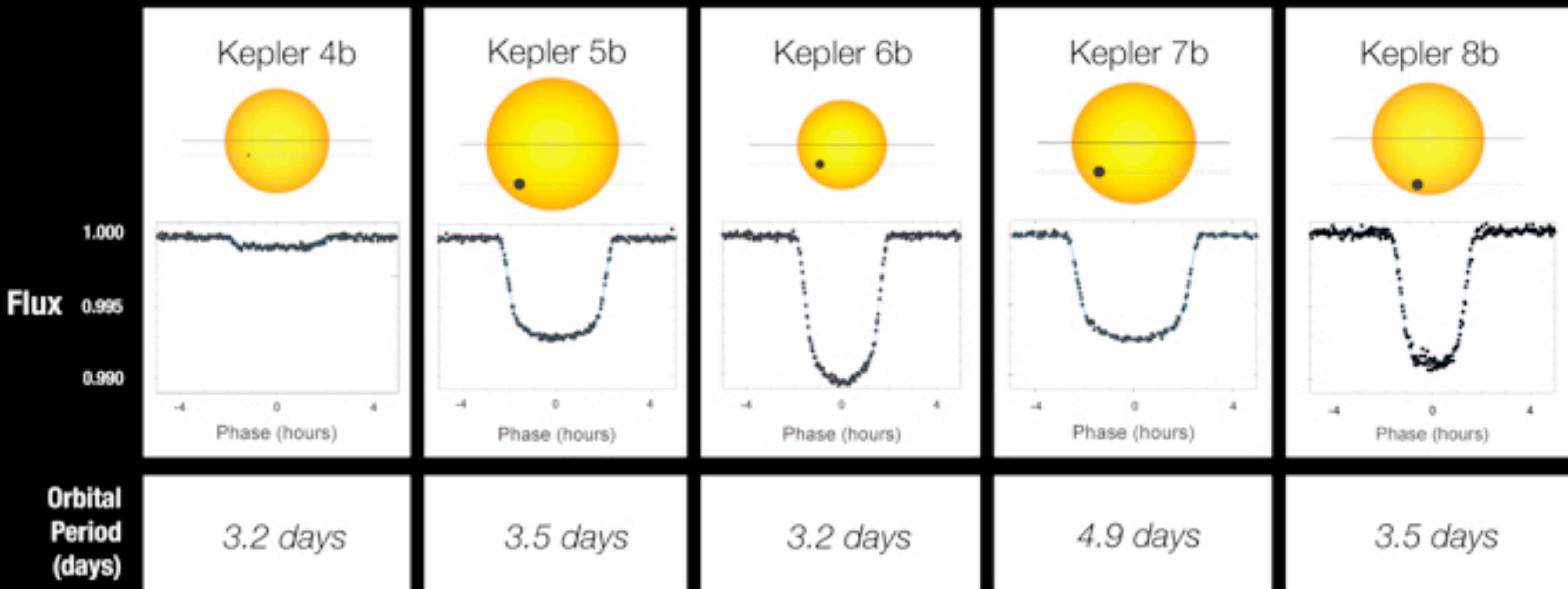

05:26 UT + 2


05:52 UT + 2

Searching for habitable Worlds



Transit light curves



Planet habitability

- Potential of a planet to develop and sustian life
- Largely agreed on an extrapolation of Earth's and Sun's characteristics

Extended regions of water

NASA

Favourable conditions for the assembly of complex organic molecules

Energy sources

HZ: habitable zone

- All organisms living on Earth require C-based chemistry in liquid water

- According to hot Big Bang model ☛ life (as we know it) could not have appeared earlier than $t \sim 10$ Myr after the Bang 'cause Universe was bathed in thermal radiation background above boiling temperature of liquid water

- After $10 \lesssim t/\text{Myr} \lesssim 17$ Universe cooled down to habitable comfortable temperatures ☛ $273 \lesssim T/\text{K} \lesssim 373$

- Each star is surrounded by an habitable zone defined as the orbital range around star within which surface liquid water could be sustained

- Since water is essential for life as we know it search for biosignature gases naturally focuses on planets located in habitable zone of their host stars

➢ Total energy flux F (energy per unit area per unit time) passing through a region can be related to effective temperature T

$$\mathscr{F} = \sigma_{SB}\, T^4$$

Stefan-Boltzmann constant ☛ $\sigma_{SB} \approx 5.67 \times 10^{-8}\ \mathrm{W m^{-2}\ {}^\circ K^{-4}}$

➢ Luminosity (energy per unit time) of star is L and flux at distance r from the star are related by

$$\mathscr{F} = \frac{L}{4\pi r^2}$$

because area of sphere of radius r is $A = 4\pi\, r^2$ and flux is luminosity divided by area

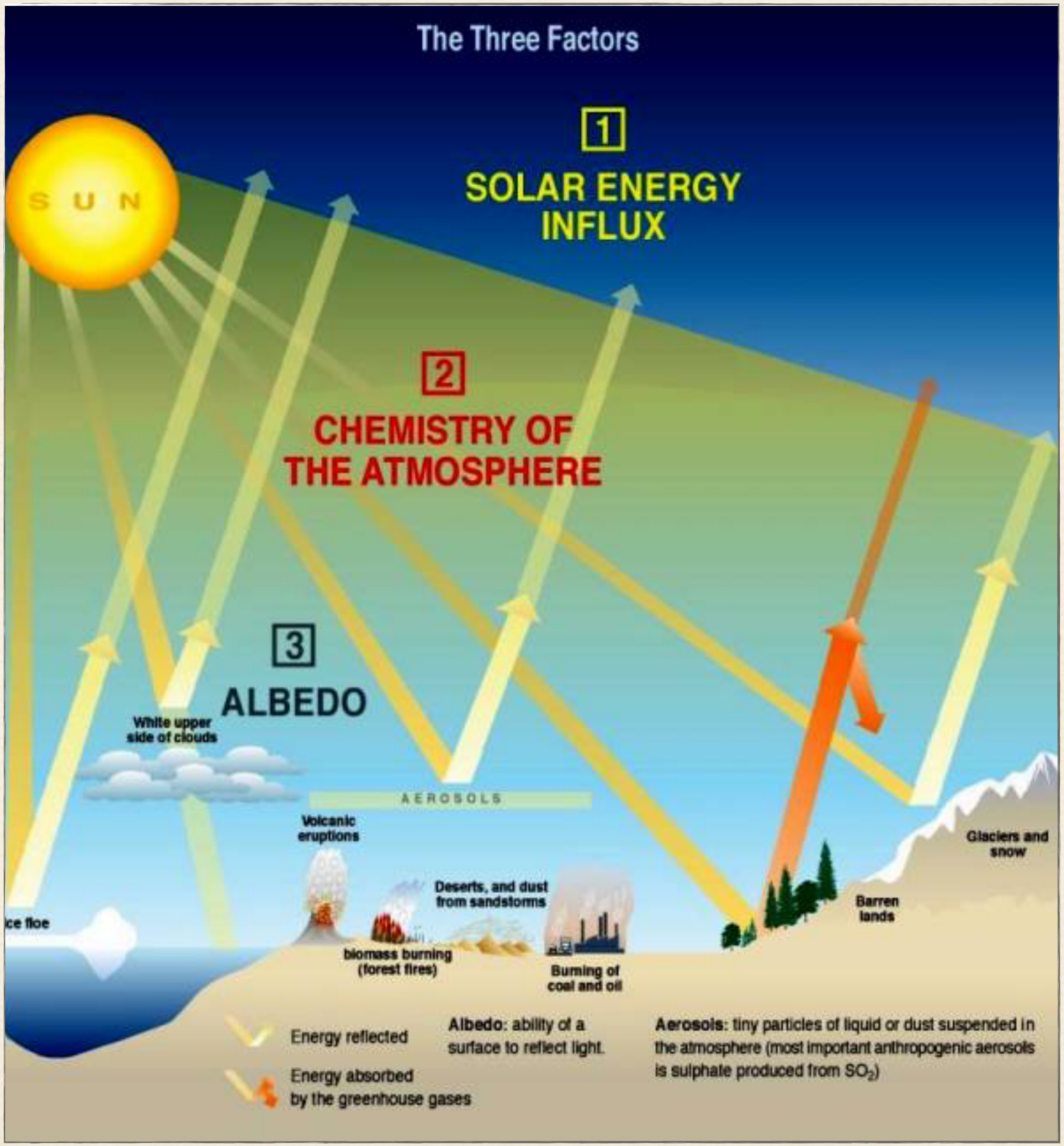
➢ Quick estimate of T at given r from

$$\sigma_{SB}\, T^4 = \mathscr{F} = \frac{L}{4\pi r^2}$$

For solar system ☛ σ_{SB}, 4π, $L_\odot$ are constants

$$T^4 \propto \frac{1}{r^2} \Rightarrow T \propto r^{-1/2}$$

Albedo



The Three Factors
SUN
1
SOLAR ENERGY INFLUX
2
CHEMISTRY OF THE ATMOSPHERE
3
ALBEDO
White upper side of clouds
AEROSOLS
Volcanic eruptions
Deserts, and dust from sandstorms
ice floe
biomass burning (forest fires)
Burning of coal and oil
Barren lands
Glaciers and snow
Energy reflected
Energy absorbed by the greenhouse gases
Albedo: ability of a surface to reflect light.
Aerosols: tiny particles of liquid or dust suspended in the atmosphere (most important anthropogenic aerosols is sulphate produced from SO_2)

The word Albedo refers to which of the following?

A. the wobbling motion of a planet

B. the amount of light a planet reflects

C. the phase changes of a planet

D. the brightness of a star

The word Albedo refers to which of the following?

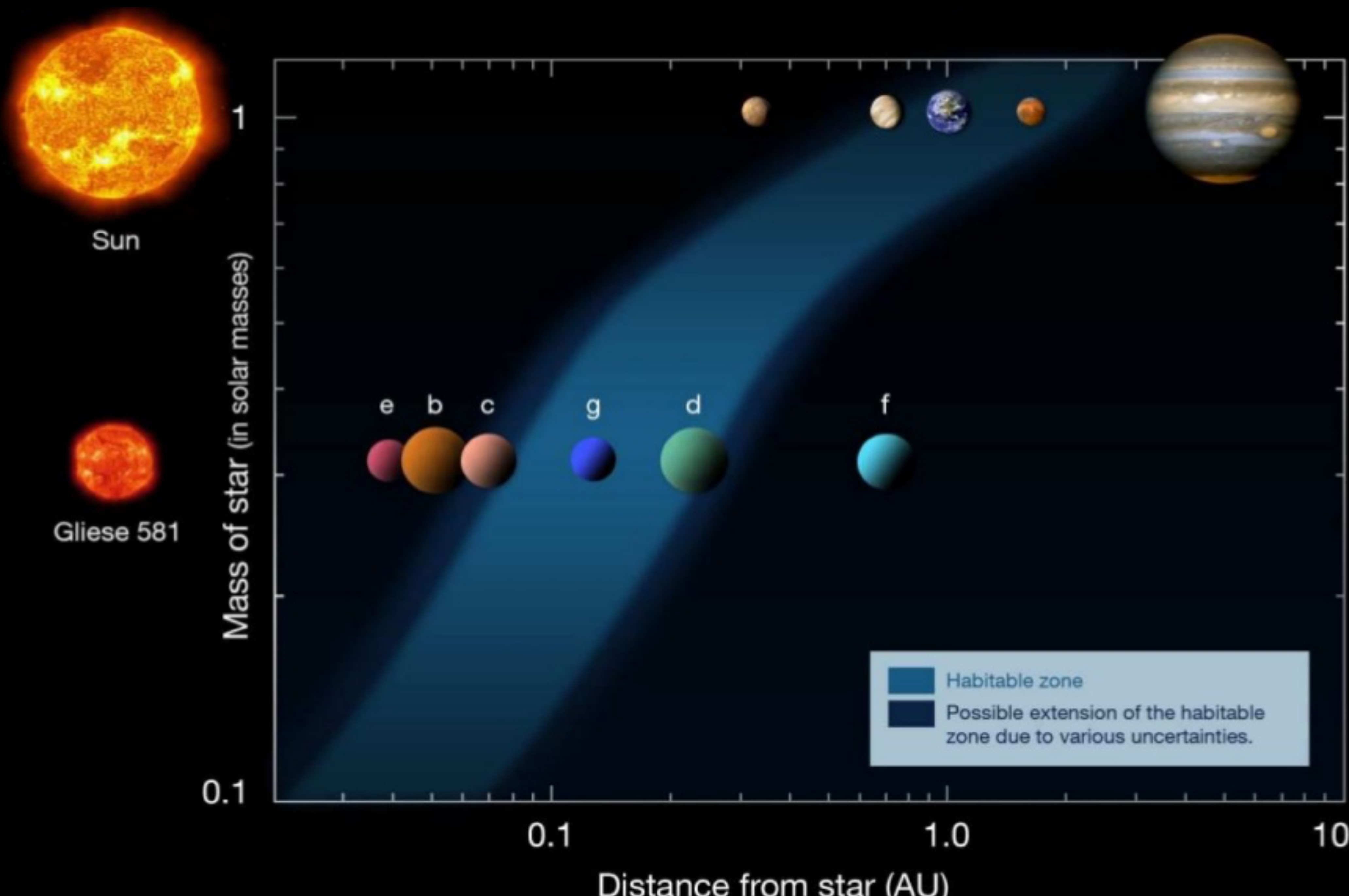
A. the wobbling motion of a planet

B. the amount of light a planet reflects

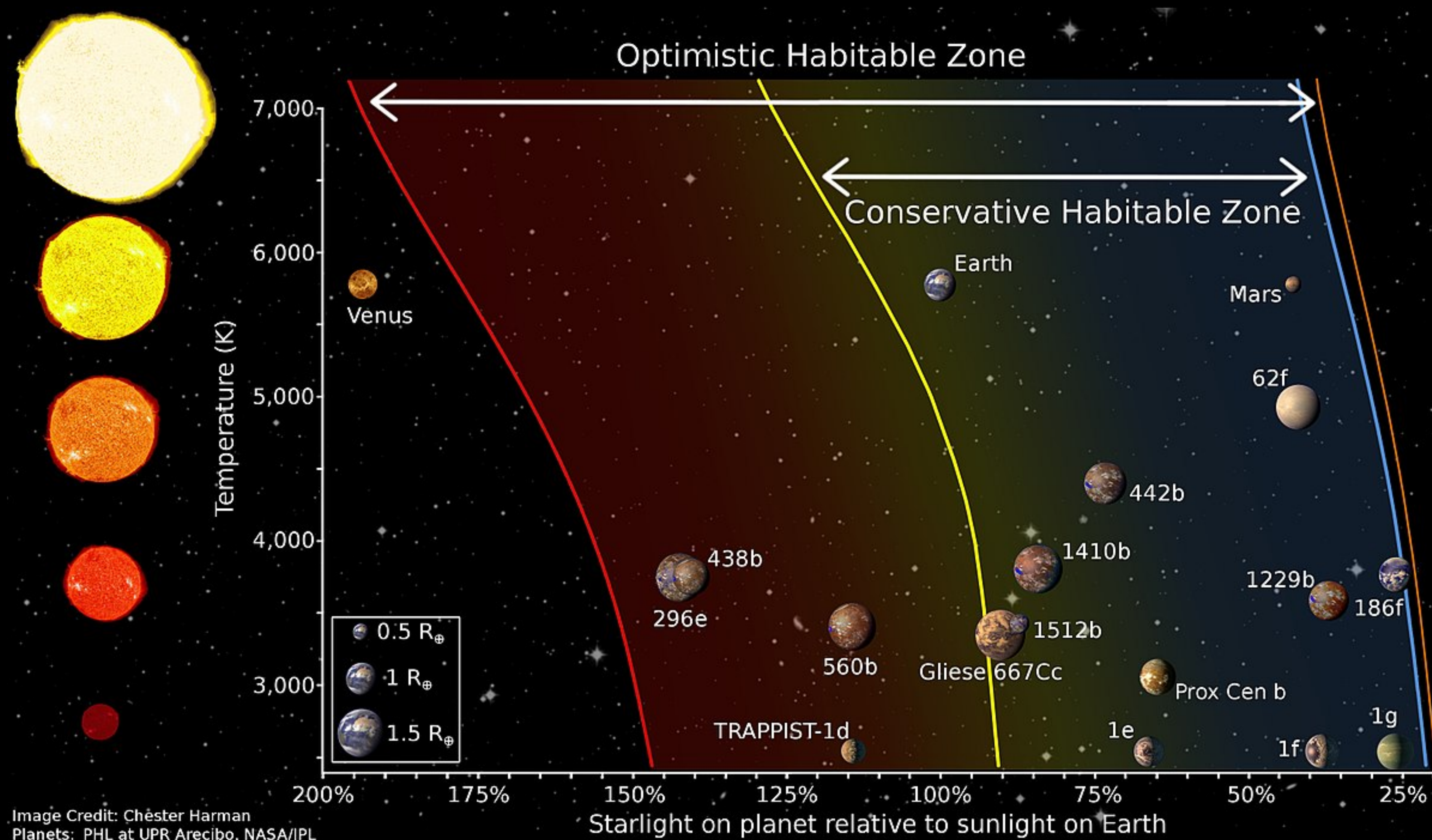
C. the phase changes of a planet

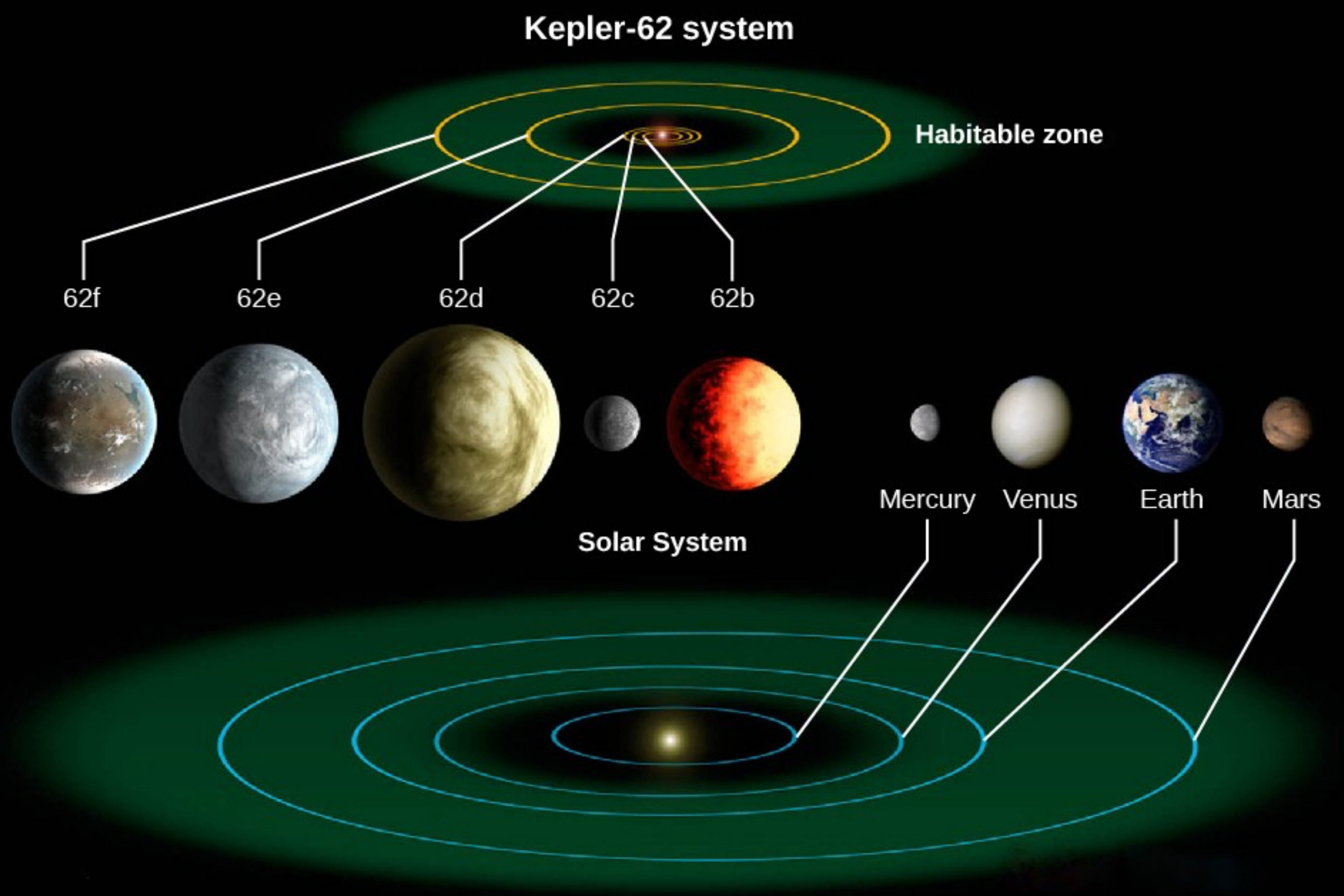
D. the brightness of a star

Goldilock's zone



Habitable zone regions




Kepler-62 system
Habitable zone
62f
62e
62d
62c
62b
Mercury
Venus
Earth
Mars
Solar System

What defines the habitable zone around a star?

A. the region around a star where rocky planets form

B. the region around a star where humans can survive

C. the region around a star where liquid water can potentially exist on planetary surfaces

D. the region around a star where the ultraviolet radiation does not destroy organisms on a planetary surface

E. the region around a star where life exists

What defines the habitable zone around a star?

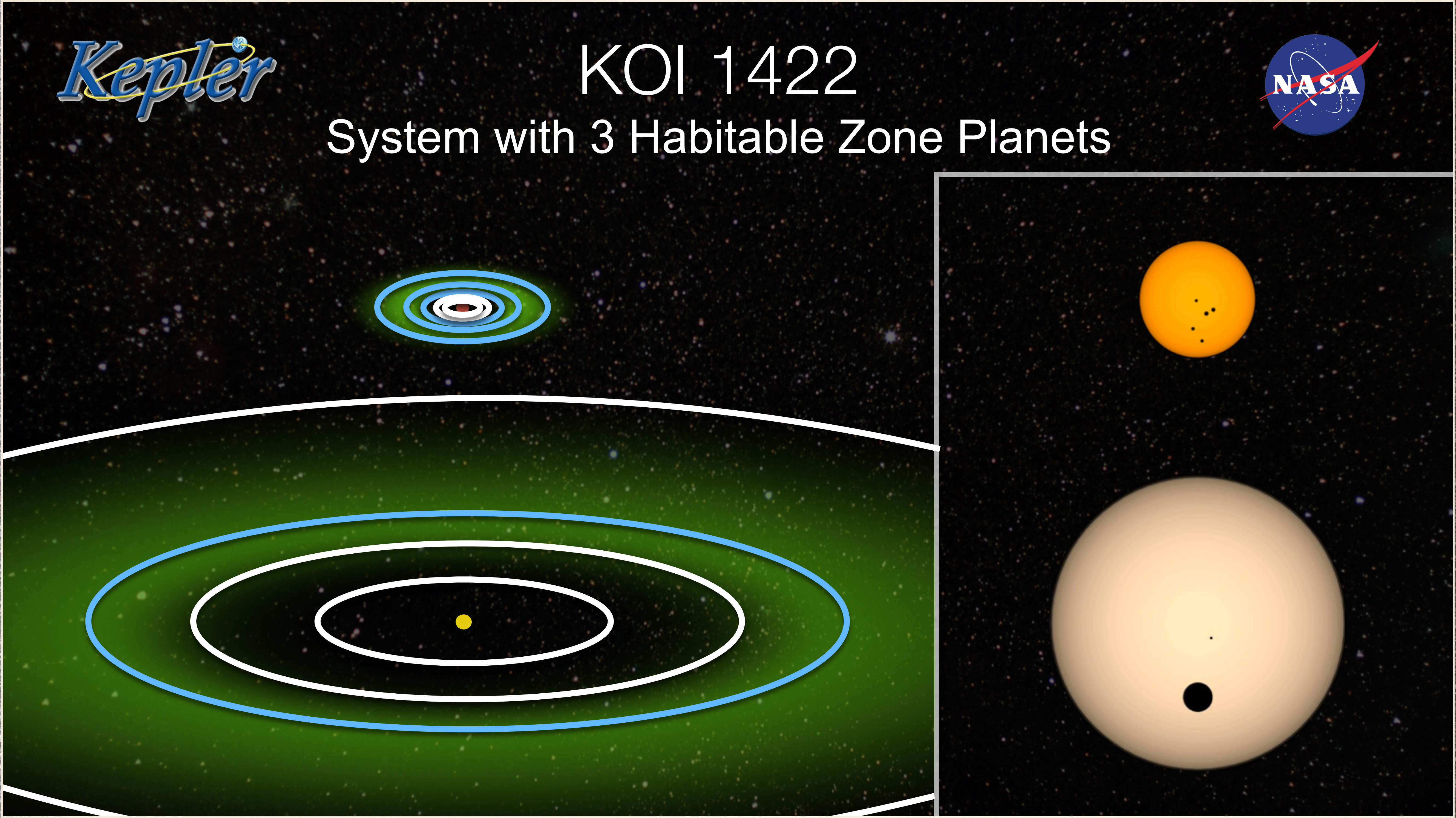
A. the region around a star where rocky planets form

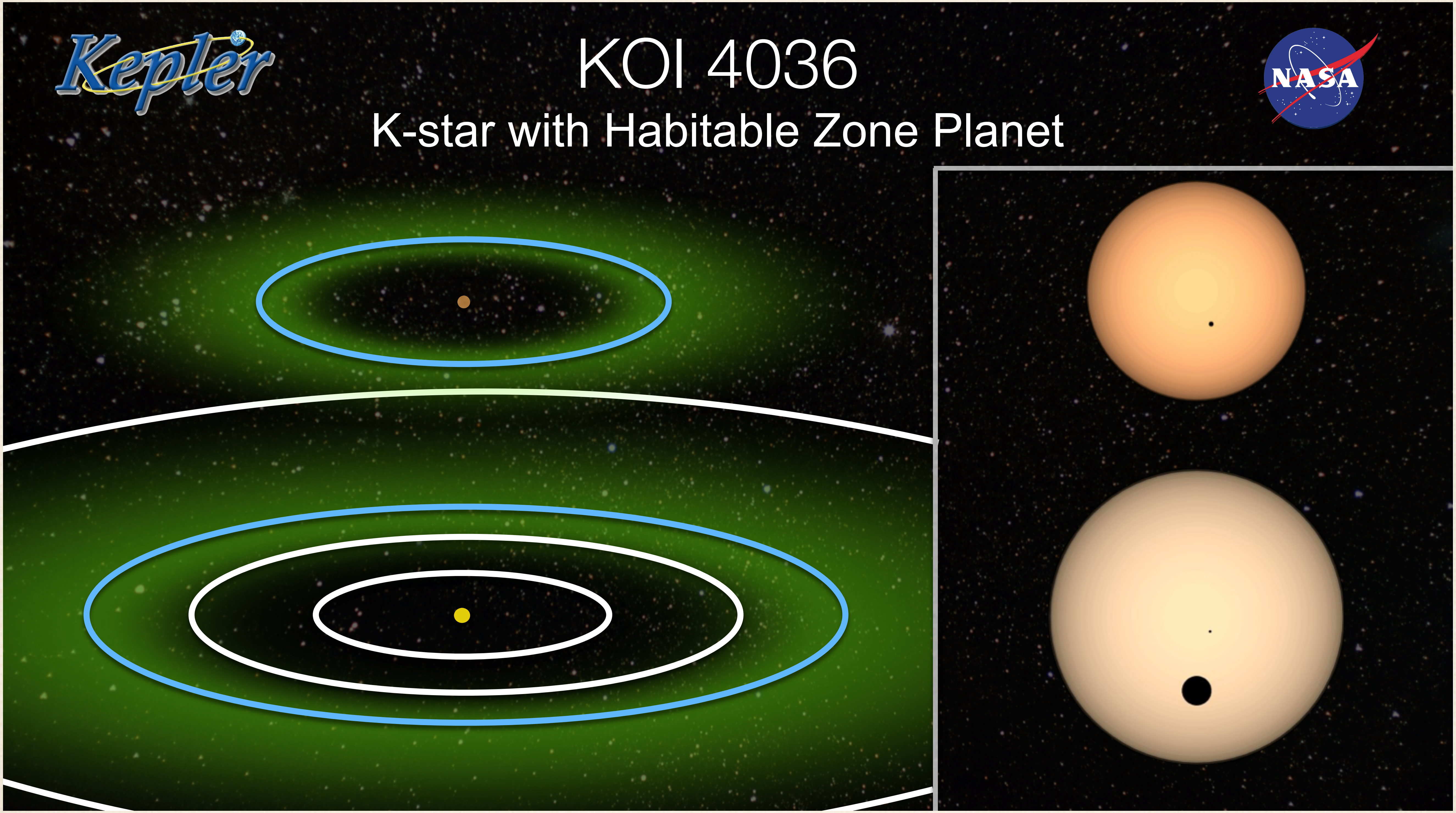
B. the region around a star where humans can survive

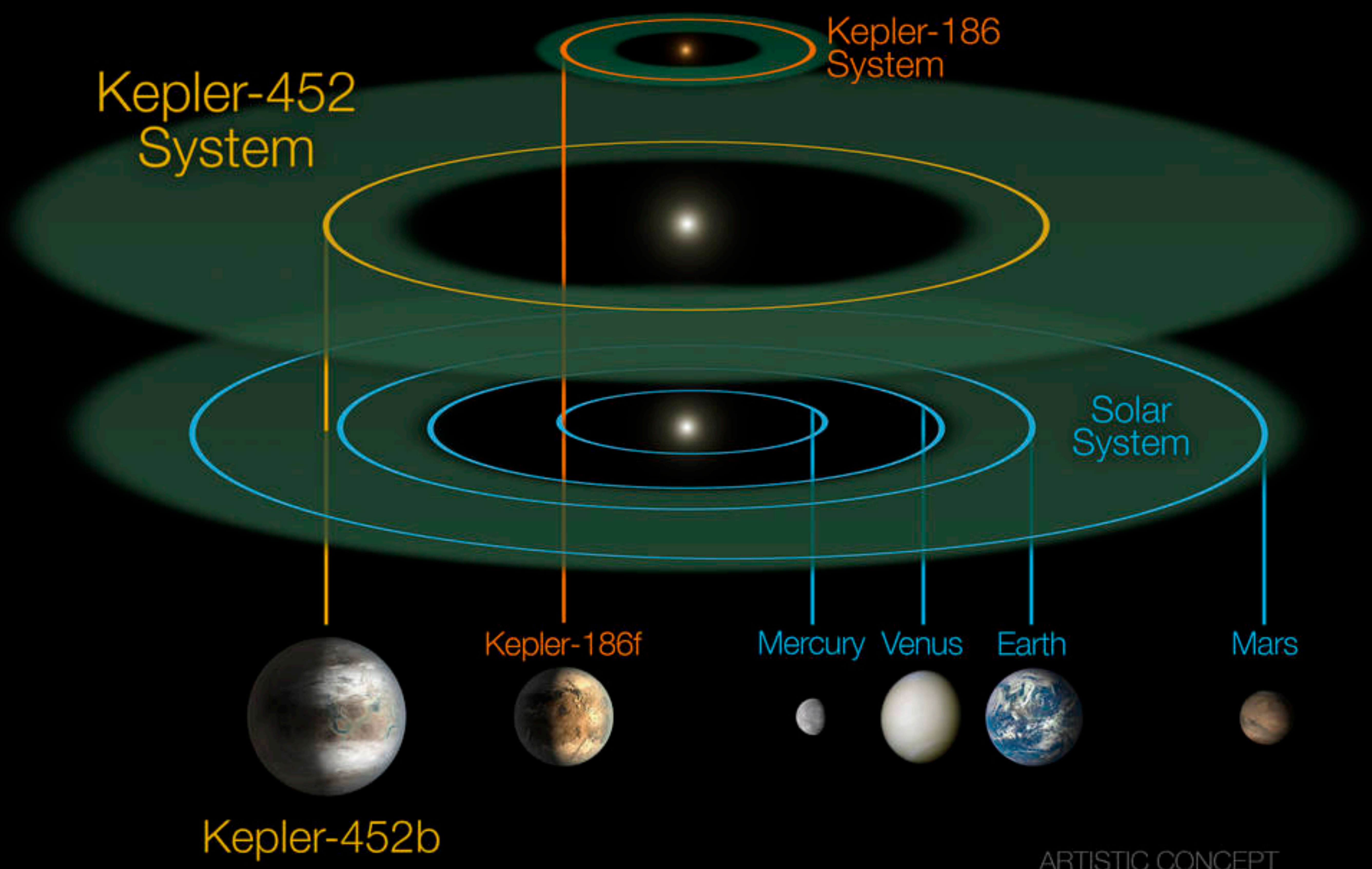
C. the region around a star where liquid water can potentially exist on planetary surfaces

D. the region around a star where the ultraviolet radiation does not destroy organisms on a planetary surface

E. the region around a star where life exists


Kepler
KOI 1422
System with 3 Habitable Zone Planets
NASA

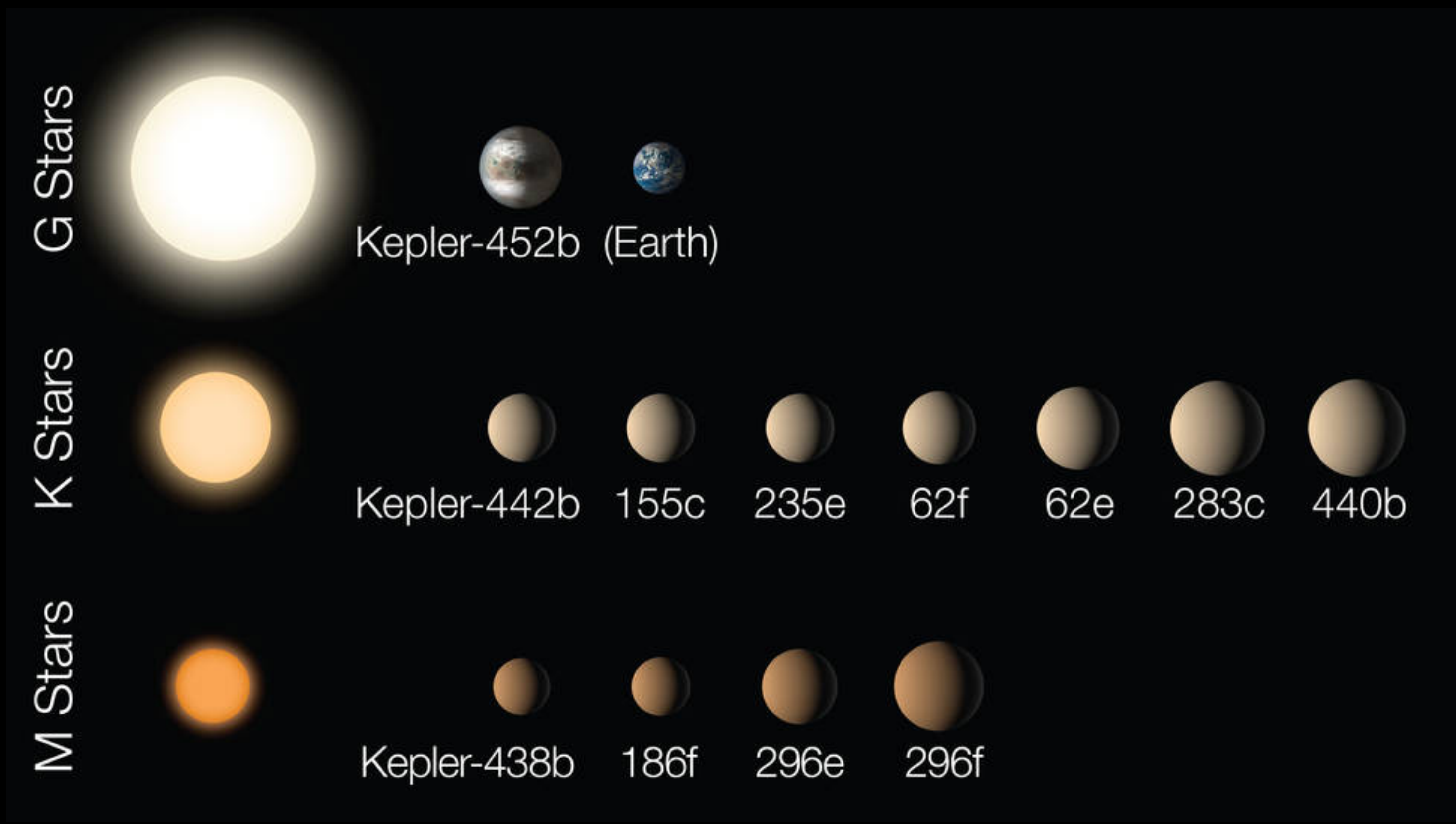

Kepler
KOI 4036
K-star with Habitable Zone Planet
NASA


Kepler-186
System
Kepler-452
System
Solar
System
Kepler-186f
Mercury
Venus
Earth
Mars
Kepler-452b
ARTISTIC CONCEPT

Kepler's small habitable zone planets

As of July 2015

Planets enlarged 25x compared to stars



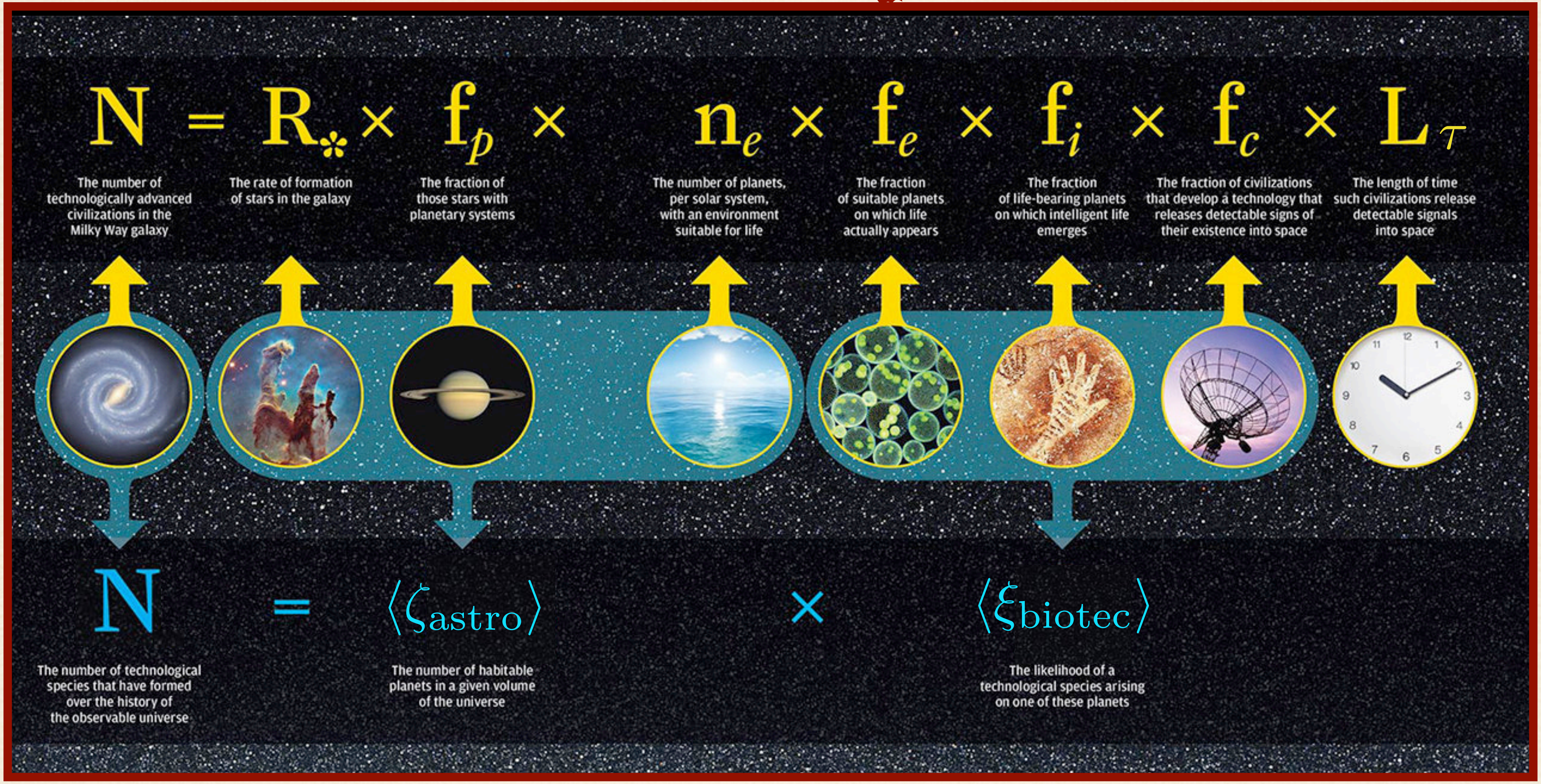
Why search? Assessing the Odds

- The astrophysical case:
  p (habitable planets | Galaxy)

- The biological case:
  p (life | habitable planets)

- Complexity:
  p (technology | life)
  p (extroversion | technology)

Drake's equation



- $\langle \zeta_{astro} \rangle \sim 0.002\ \mathrm{yr}^{-1}$ and $\xi_{biotec} \leq 1$
- If the communicative pase is smaller than 500 years there would be no paradox

How many Planets are in the Galaxy?

- There are approximately 100 billion F,G,K stars

  About 2/3 of these are in binaries with other stellar companions (not ideal for planets - but see Kepler results)

- Most of the ~30 billion isolated stars likely have planetary systems (and so do some binary systems)

- If 1% of these have planets that are habitable and on which life has formed there could be N_p= 300 million planets with the potential of harboring life

- With these numbers, the nearest life-bearing planet could be <10 pc away. (cf. Kepler numbers discussed earlier)

Which of the following parameters in the Drake Equation do we have sufficient data on such that the value we might assign when calculating the Drake equation goes beyond pure speculation?

A. the number of habitable planets per planetary system

B. the fraction of habitable planets on which life arises

C. the rate of star formation

D. the average lifetime of a technological civilization

E. the fraction of life-bearing planets on which intelligence arises

Which of the following parameters in the Drake Equation do we have sufficient data on such that the value we might assign when calculating the Drake equation goes beyond pure speculation?

A. the number of habitable planets per planetary system

B. the fraction of habitable planets on which life arises

C. the rate of star formation

D. the average lifetime of a technological civilization

E. the fraction of life-bearing planets on which intelligence arises

One reason that might be valid for not expecting life on a planet orbiting a very high-mass (blue, spectral type O) star is

A. no habitable zone possible—star is too hot

B. habitable zone too far from the star

C. the lifetime of the star is probably too short for life to begin

D. too much ultraviolet radiation

E. no habitable zone possible—star is too luminous

One reason that might be valid for not expecting life on a planet orbiting a very high-mass (blue, spectral type O) star is

A. no habitable zone possible—star is too hot

B. habitable zone too far from the star

C. the lifetime of the star is probably too short for life to begin

D. too much ultraviolet radiation

E. no habitable zone possible—star is too luminous

Which of the following statements best reflects our current knowledge about the term f_{life} in the equation

Number of Civilizations = N_p x f_{life} x $f_{civilization}$ x f_{now}?

A. the value of f_{life} must be either 0 percent or 100 percent

B. the value of f_{life} is between 0 percent and 100 percent

C. the value of f_{life} is between 0 percent and 1 percent

D. the value of f_{life} is roughly 50 percent

E. the value of f_{life} is presently unknown but should be well known within just a few years

Which of the following statements best reflects our current knowledge about the term f_{life} in the equation

Number of Civilizations = $N_p \times f_{life} \times f_{civilization} \times f_{now}$?

A. the value of f_{life} must be either 0 percent or 100 percent

B. the value of f_{life} is between 0 percent and 100 percent

C. the value of f_{life} is between 0 percent and 1 percent

D. the value of f_{life} is roughly 50 percent

E. the value of f_{life} is presently unknown but should be well known within just a few years

Are we alone?

Now is the time to find out

Is there anybody out there?

What do we look for?
Reciprocity: what do we radiate?

Transmission from Arecibo (1974), beamed once towards M13 (8 kpc) at 2.4 GHz

1679 bits = 23 × 73 grid

Can you decode it?

The message consists of seven parts that encode the following (from the top down):

The numbers one (1) to ten (10) (white)

The atomic numbers of the elements hydrogen, carbon, nitrogen, oxygen, and phosphorus, which make up deoxyribonucleic acid (DNA) (purple)

The formulas for the sugars and bases in the nucleotides of DNA (green)

The number of nucleotides in DNA, and a graphic of the double helix structure of DNA (white & blue)

A graphic figure of a human, the dimension (physical height) of an average man, and the human population of Earth (red, blue/white, & white respectively)

A graphic of the Solar System indicating which of the planets the message is coming from (yellow)

A graphic of the Arecibo radio telescope and the dimension (the physical diameter) of the transmitting antenna dish (purple, white, and blue)

In 1974, a radio message was sent out from the Arecibo observatory in Puerto Rico
How far has it gotten, approximately?

A. just beyond our Solar System

B. not even to the nearest stars

C. just a miniscule fraction of the distance across the Milky Way

D. almost to the center of the Milky Way

E. beyond the Milky Way, to the Andromeda galaxy

In 1974, a radio message was sent out from the Arecibo observatory in Puerto Rico
How far has it gotten, approximately?

A. just beyond our Solar System

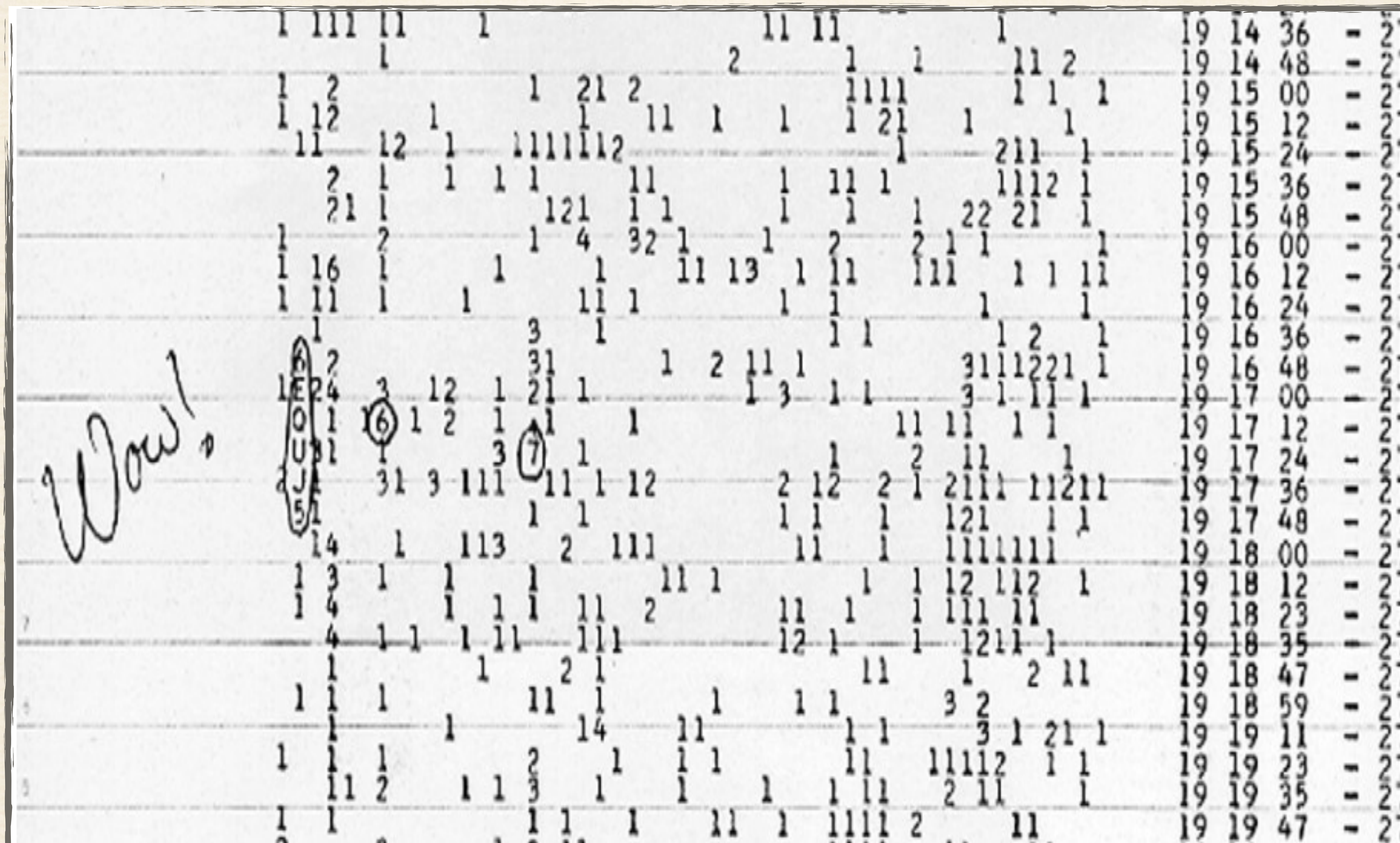
B. not even to the nearest stars

C. just a miniscule fraction of the distance across the Milky Way

D. almost to the center of the Milky Way

E. beyond the Milky Way, to the Andromeda galaxy

A Famous SETI False Alarm (?)



The "Wow!" signal,
Jerry Ehman, Big Ear radio telescope, Ohio State 1977.

At present, what is the primary way that the search for extraterrestrial intelligence (SETI) is carried out?

A. by searching for planets around distant stars

B. by using large X-ray telescopes to search for signals from extraterrestrial civilizations

C. by using radio telescopes to search for signals from extraterrestrial civilizations

D. by analyzing high-resolution images of nearby stars in search of evidence of structures that could not have developed naturally

E. by seeking access to the secret records and alien corpses kept at Area 51

At present, what is the primary way that the search for extraterrestrial intelligence (SETI) is carried out?

A. by searching for planets around distant stars

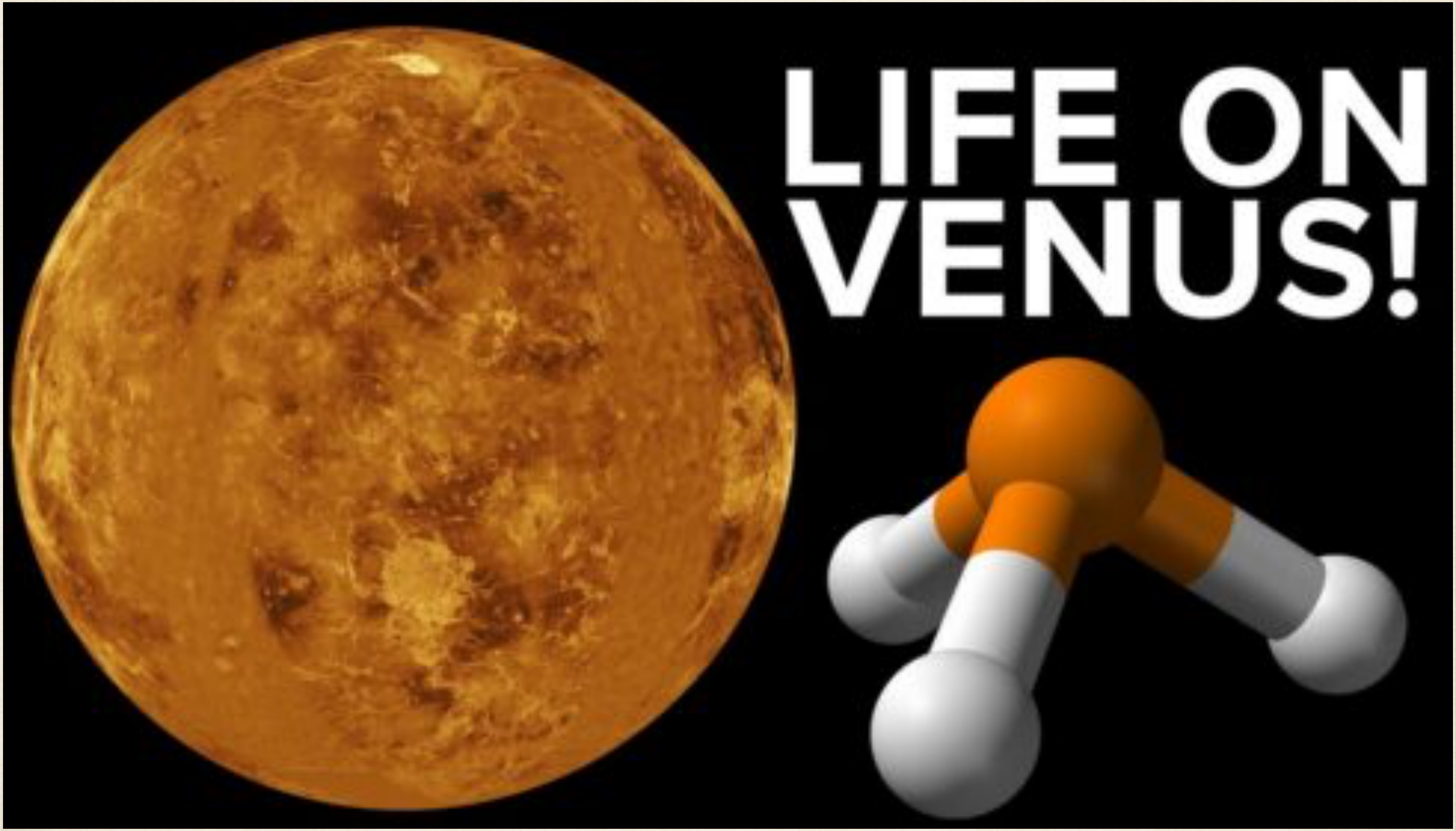
B. by using large X-ray telescopes to search for signals from extraterrestrial civilizations

C. by using radio telescopes to search for signals from extraterrestrial civilizations

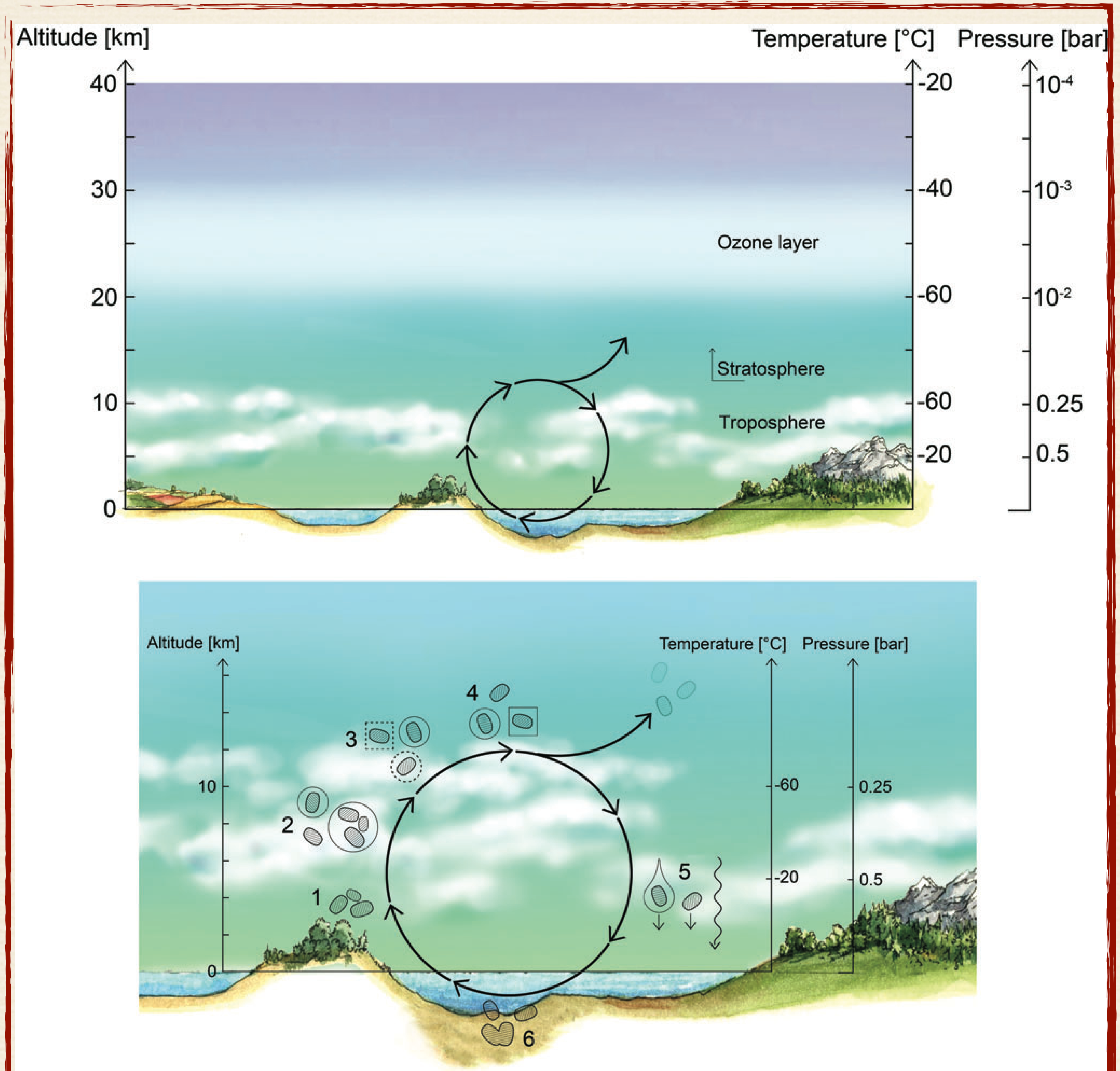
D. by analyzing high-resolution images of nearby stars in search of evidence of structures that could not have developed naturally

E. by seeking access to the secret records and alien corpses kept at Area 51

Detection of PH_3 ☛ life biomarker



Life cycle of Earth's aerial biosphere



Life cycle of Earth's aerial biosphere

(1) Updraft of metabolically active microorganisms (dashed blobs) from the surface

(2) Microbial cells are metabolically active both within water cloud droplets (solid circles) and in the free-floating form

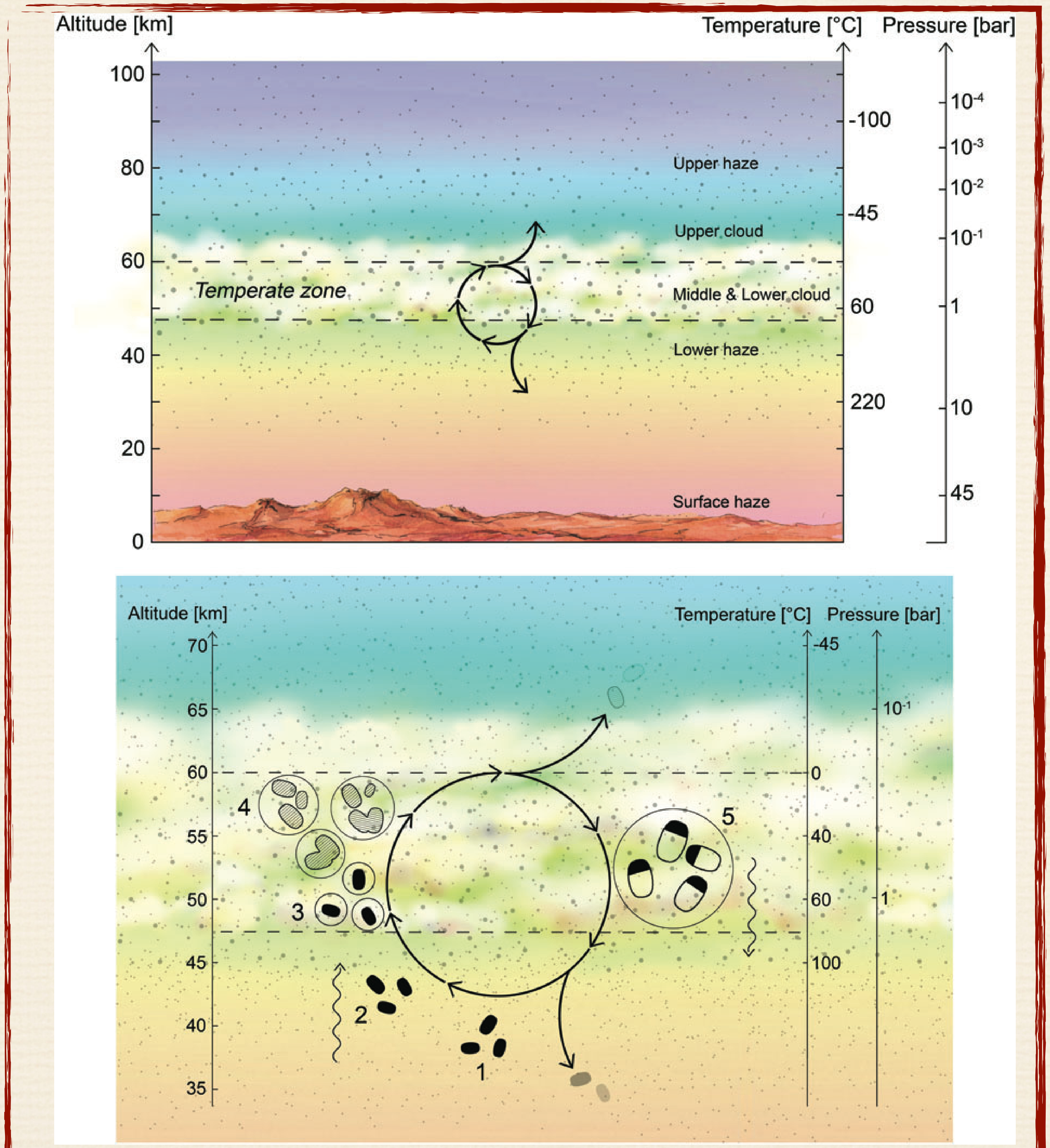
(3) Cells likely act as cloud condensation nuclei dashed circle) and promote ice nuclei (dashed square) in the atmosphere, promoting droplet formation

(4) Metabolically active cells transiently persist in the atmosphere, are transported over long distances until

(5) deposition onto the surface by precipitation or downdraft

(6) On colonization of the new surface habitat, active cell division commences

Life cycle of Venus' aerial biosphere



(1) Desiccated spores (black blobs) persist in the lower haze

(2) Updraft of spores transports them up to the habitable layer

(3) Spores act as cloud condensation nuclei, and once surrounded by liquid (with necessary chemicals dissolved) germinate and become metabolically active

(4) Metabolically active microbes (dashed blobs) grow and divide within liquid droplets (solid circles)

The liquid droplets grow by coagulation

(5) The droplets reach a size large enough to gravitationally settle down out of the atmosphere; higher temperatures and droplet evaporation trigger cell division and sporulation

The spores are small enough to withstand further downward sedimentation, remaining suspended in the lower haze layer "depot."

read more ☛ arXiv:2404.05356

Principles and Paradox

Copernican principle

- We find ourselves on an ordinary planet around an ordinary star in an ordinary galaxy
- AKA the assumption of mediocrity (we're mediocre & there must be lots more like us)

Anthropic principle

- The universe necessarily has properties that allow complex beings like ourselves and life generally to have evolved
- Is the universe ordinary?

Fermi Paradox

- Given CP + AP, if N is large, where is everybody?

The only place outside of Earth where there is irrefutable evidence for (ancient, microbial) life is

A. the Moon

B. Mars

C. Pluto

D. Venus

E. None of the above-there is no irrefutable evidence for life beyond Earth

The only place outside of Earth where there is irrefutable evidence for (ancient, microbial) life is

A. the Moon

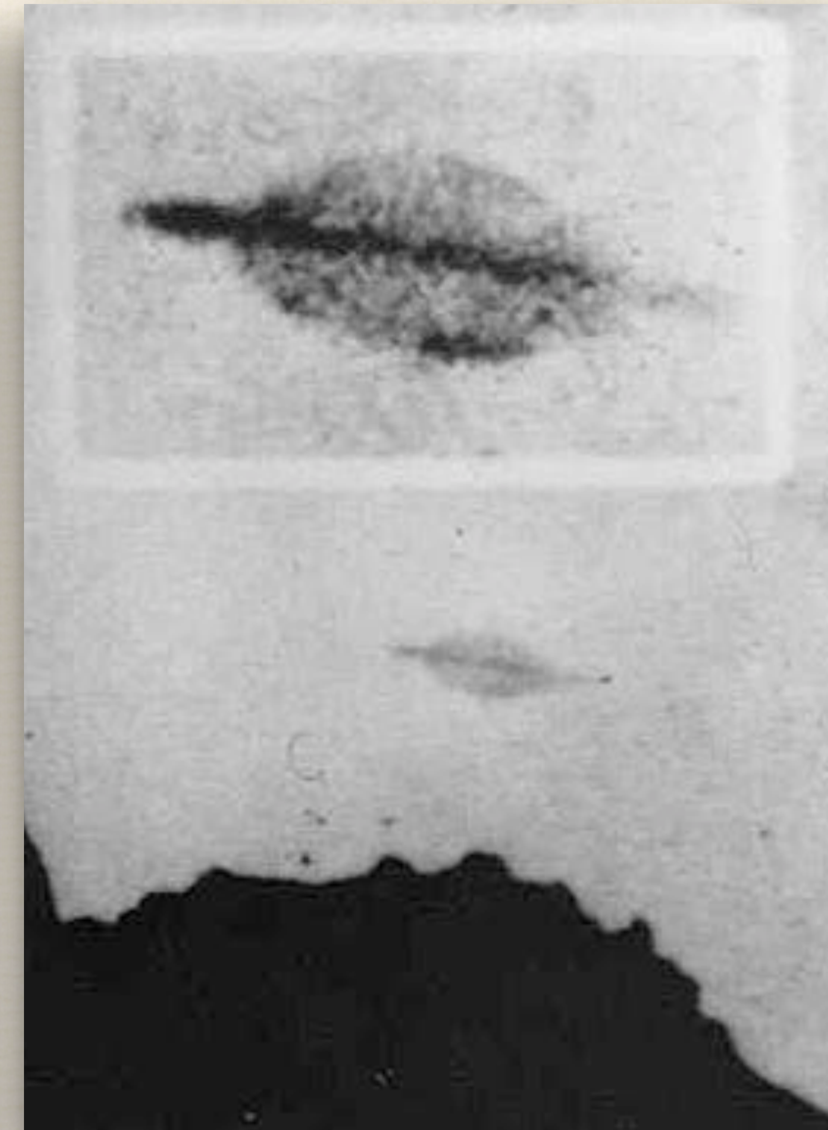
B. Mars

C. Pluto

D. Venus

E. None of the above-there is no irrefutable evidence for life beyond Earth

What about UFOs?



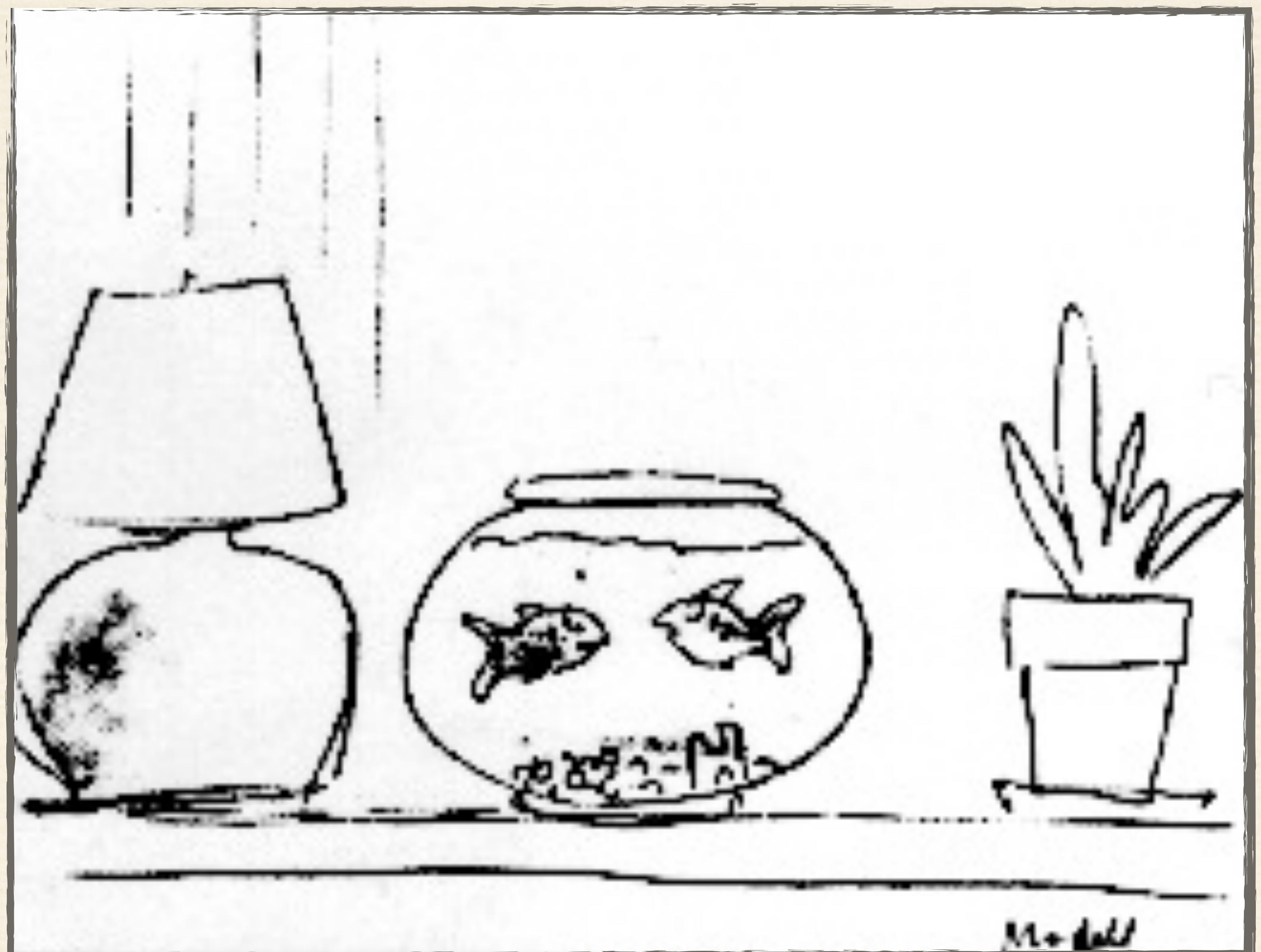
?

What about UFOs?

- Smartphones are common today - photo + video recording at fingertips
- "Dashcams" capture continuous footage: e.g. Chelyabinsk meteor, 2013
- Robotic survey telescopes continuously monitor night sky

... Did UFOs become shy just as our ability to record them became commonplace?

Given rates implied by UFO sighting claims in the past, we should have high quality photo / audio / video recordings routinely today → Not plausible



——————— I'll tell you something else I think. I think there are other bowls somewhere out there with intelligent life just like ours.

QUERY 32

Is it your opinion that manned space travel is possible with present technology?
Mention at least two of the problems that interstellar travelers would face, and briefly discuss how they could be resolved

QUERY 32

My opinion, which may differ from yours, is that manned interstellar travel is not presently feasible. One problem, if we launched a rocket that traveled at the speed of Voyager 1, is that the travel time to even the nearest star would be a thousand times longer than the average lifetime of a human being. This would require putting the astronauts in suspended animation (something that hasn't been successfully done with humans), or sending out a colony ship, in which a few thousand generations of people would live and die before reaching the target star. Since packing 74,000 years of box lunches would not be practical (far too massive), the colony ship would have to be a selfsustaining ecosystem.

QUERY 32

Previous attempts to set up enclosed ecosystems have revealed the difficulty of keeping such a system from "crashing" within a few years. We have to understand the biosphere here on Earth much better if we are to recreate a mini-Earth within a spacecraft. We might try to decrease the travel time by accelerating our interstellar spacecraft to speeds much higher than that of Voyager 1. The problem with this approach is that it requires very large amounts of energy. Moreover, even if you increased the spacecraft's speed by a factor of 100 over that of Voyager 1, it would still take 740 years to reach Proxima Centauri.

QUERY 32

Our society is evolving rapidly; are we willing to trust that future generations on the spaceship are still interested in traveling to Proxima Centauri and that future generations on Earth will still be interested in the news from Proxima Centauri

QUERY 33

The star Phi Orionis, like the Sun, is powered by the fusion of hydrogen to helium. The mass of Phi Orionis is $M_\varphi = 18M_\odot$. The luminosity of Phi Orionis is $L_\varphi = 20{,}000L_\odot$. Discuss the likelihood of intelligent life existing on a planet orbiting the star Phi Orionis. [Questions you might want to consider: What is the lifespan of Phi Orionis? How long did it take intelligent life to develop on Earth? How far would you have to be from Phi Orionis to receive the same flux of light that we receive here on Earth from the Sun?

QUERY 33

It is unlikely, in my opinion, that intelligent life has developed from scratch on a planet orbiting Phi Orionis. First, given the mass and luminosity of Phi Orionis, its expected lifespan is

$$t_\Phi = t_\odot \frac{M_\Phi}{M_\odot}\frac{L_\odot}{L_\Phi} = 10 \text{ billionyears} \times 18 \times \frac{1}{20,000} = 9 \text{ millionyears}$$

Since it has taken over 4.5 billion years for (more-or-less) intelligent life to develop on Earth, having it evolve in a time of less than 9 million years implies an extraordinarily rapid rate of evolution.

QUERY 33

Second, since the luminosity of Phi Orionis is 20,000 times that of the Sun, planets close to Phi Orionis would be badly scorched. For a planet to receive the same flux of light from Phi Orionis that we receive 1 AU from the Sun, its distance from Phi Orionis would have to be ☛ $\sqrt{20,000}$ AU $= 141$ AU

This is far larger than the orbit of Neptune, in a region where the Solar System has no planets at all

QUERY 34

At a pressure of 1 atmosphere, water freezes at 273 K and boils at 373 K. We say that a planet is in the habitable zone if its equilibrium temperature is within the range allowing liquid water. Assume that the planet has an albedo similar to that of Earth. The equilibrium temperature of the Earth (at 1 AU from a solar type star and with Earth's albedo) is 263 K. How does the equilibrium temperature of a planet depend upon the planet's distance from the star R and the luminosity of the star, L? Write your answer in the following form:

$$T_{\text{eq}} = X(\text{in Kelvin}) \left(\frac{L}{L_\odot}\right)^{\alpha} \left(\frac{r}{\text{AU}}\right)^{\beta}$$

and find the exponents α and β, as well as the constant X

QUERY 34

The amount of light emitted is equal to that absorbed so

$$\sigma T^4 \sim \frac{(1-\alpha)L}{r^2}$$

We find that $T \propto L^{1/4}\, r^{-1/2}$ we rewrite this as

$$T_{\rm eq} = 263\ {\rm K} \left(\frac{L}{L_\odot}\right)^{1/4} \left(\frac{r}{\rm AU}\right)^{-1/2}$$

QUERY 35

What are the inner and outer radii (in AU from the star) of the habitable zone near a star that is 100 times as luminous as the Sun (such as a red giant)? The Sun will become a red giant in a few billion years. Speculate on which moons and satellites in our solar system might become nice places to live during this time

QUERY 35

We need to solve two equations

$$T_{\rm boil} = 373 \text{ K} = 263 \text{ K} \left(\frac{L}{L_\odot}\right)^{1/4} \left(\frac{r}{\rm AU}\right)^{-1/2}$$

and a similar equation for freezing. We find

$$r(\text{inner}) = \left(\frac{100 L_\odot}{L_\odot}\right)^{1/2} \left(\frac{273}{263}\right)^2 \text{ AU} = 10.8 \text{ AU}$$

and

$$r(\text{outer}) = \left(\frac{100 L_\odot}{L_\odot}\right)^{1/2} \left(\frac{373}{263}\right)^2 \text{ AU} = 20.1 \text{ AU}$$

When the Sun becomes a red giant the moons of Saturn and Uranus might become nice places to live

That's all folks