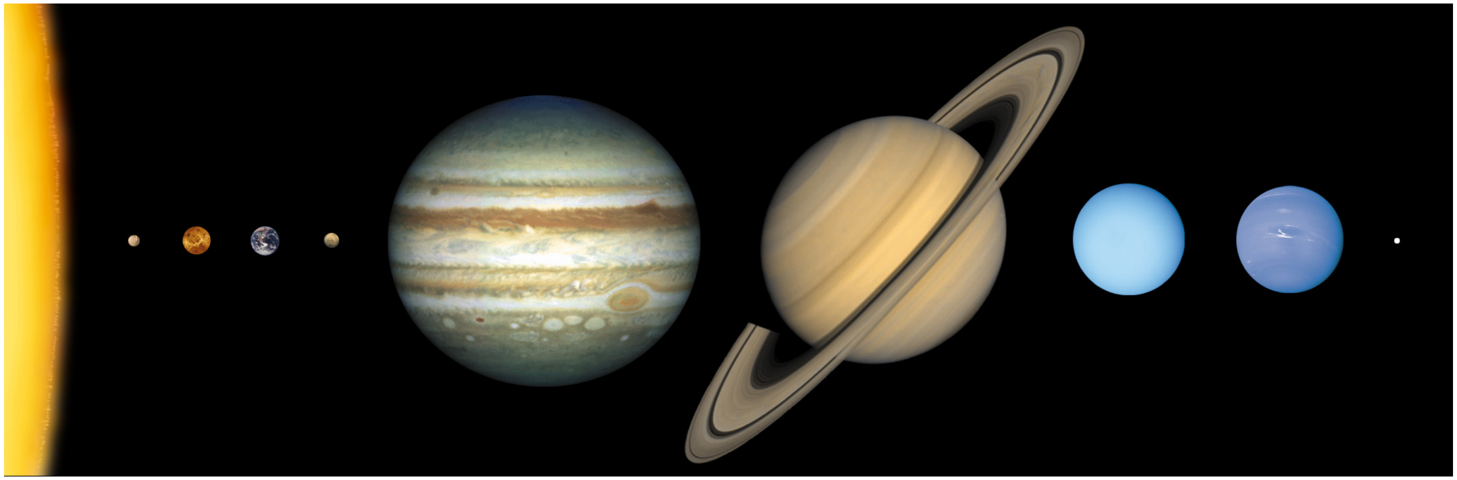
ASTRONOMY

Chapter 19 CELESTIAL DISTANCES

Chapter 20 BETWEEN THE STARS: GAS AND DUST IN SPACE

openstax™

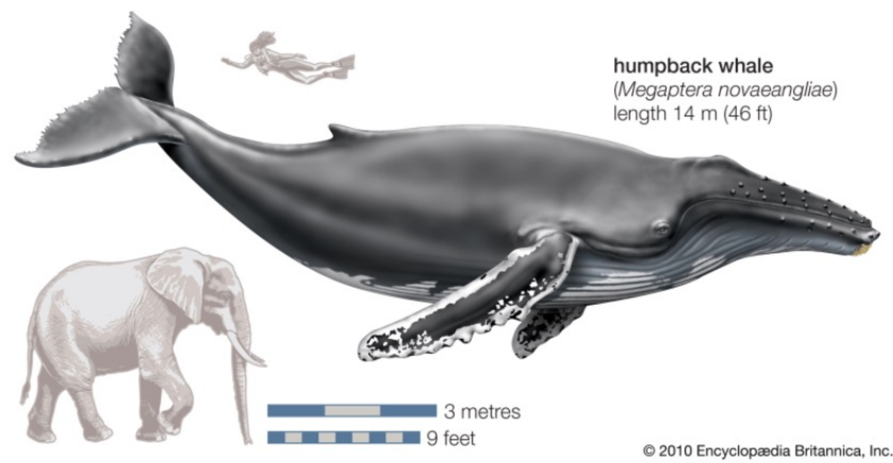
Scales of Things
(Not the kind you get weighed by standing on)



Credit: NASA.gov

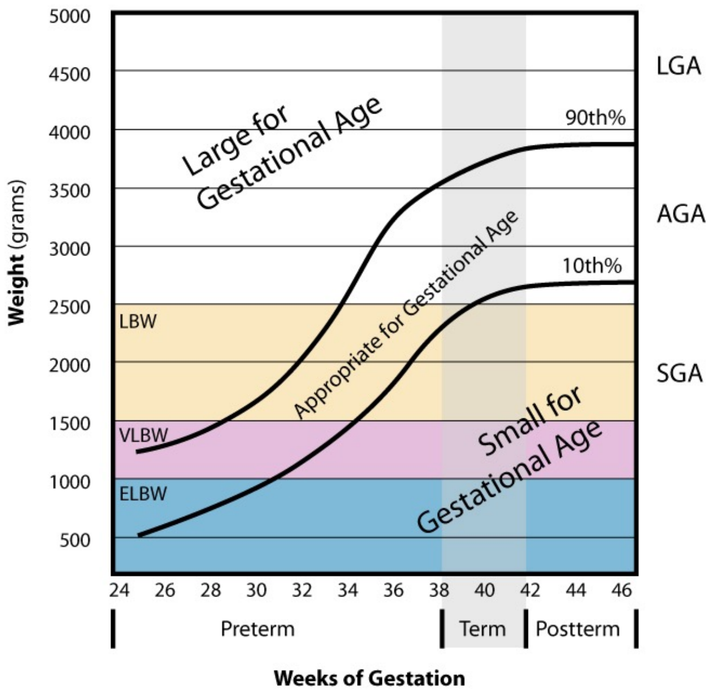
Orders of Magnitude

Number N	Expression in N=a×10b	Order of magnitude b
0.2	2×10^{-1}	−1
1	1×10^{0}	0
5	0.5×10^{1}	1
6	0.6×10^{1}	1
31	3.1×10^{1}	1
32	0.32×10^{2}	2
999	0.999×10^{3}	3
1000	1×10^{3}	3

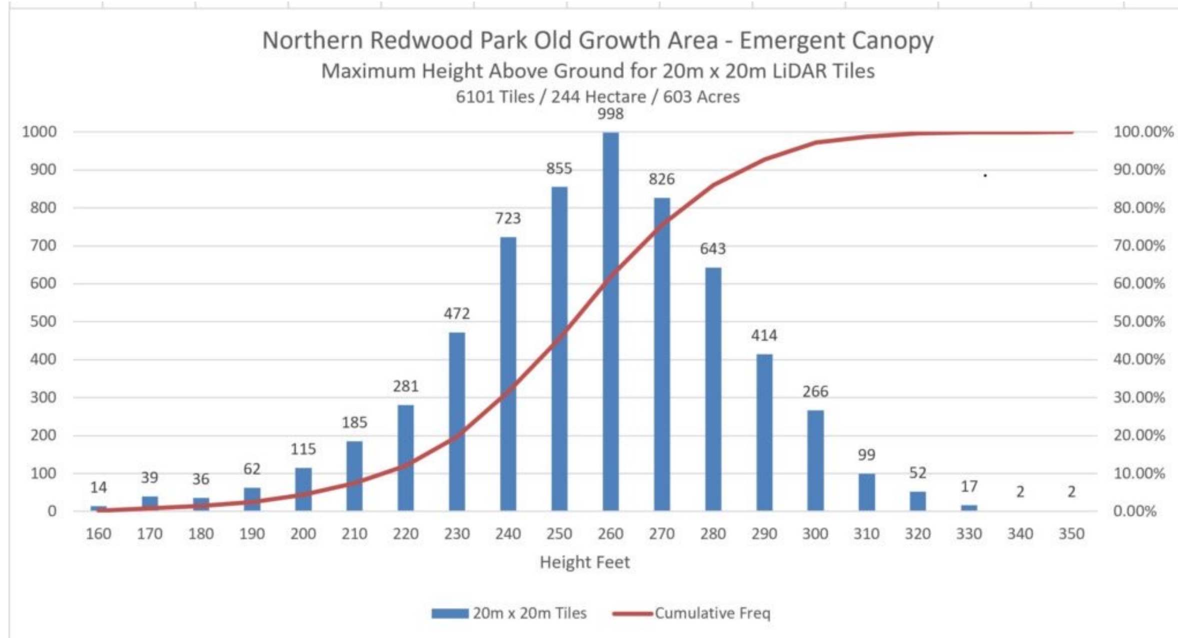


Credit: https://twitter.com/MCERCMarineEco

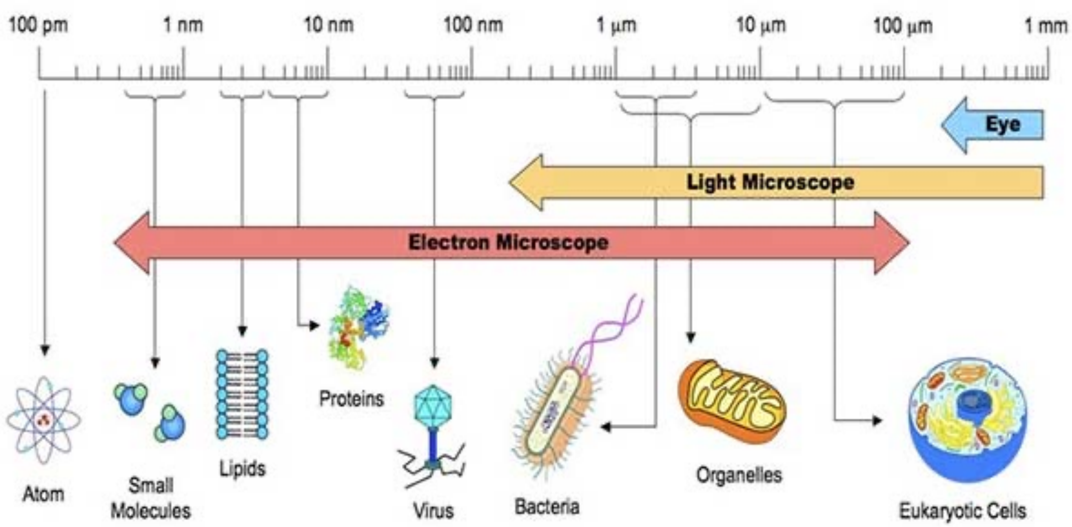
Orders of Magnitude



Credit: Wikipedia

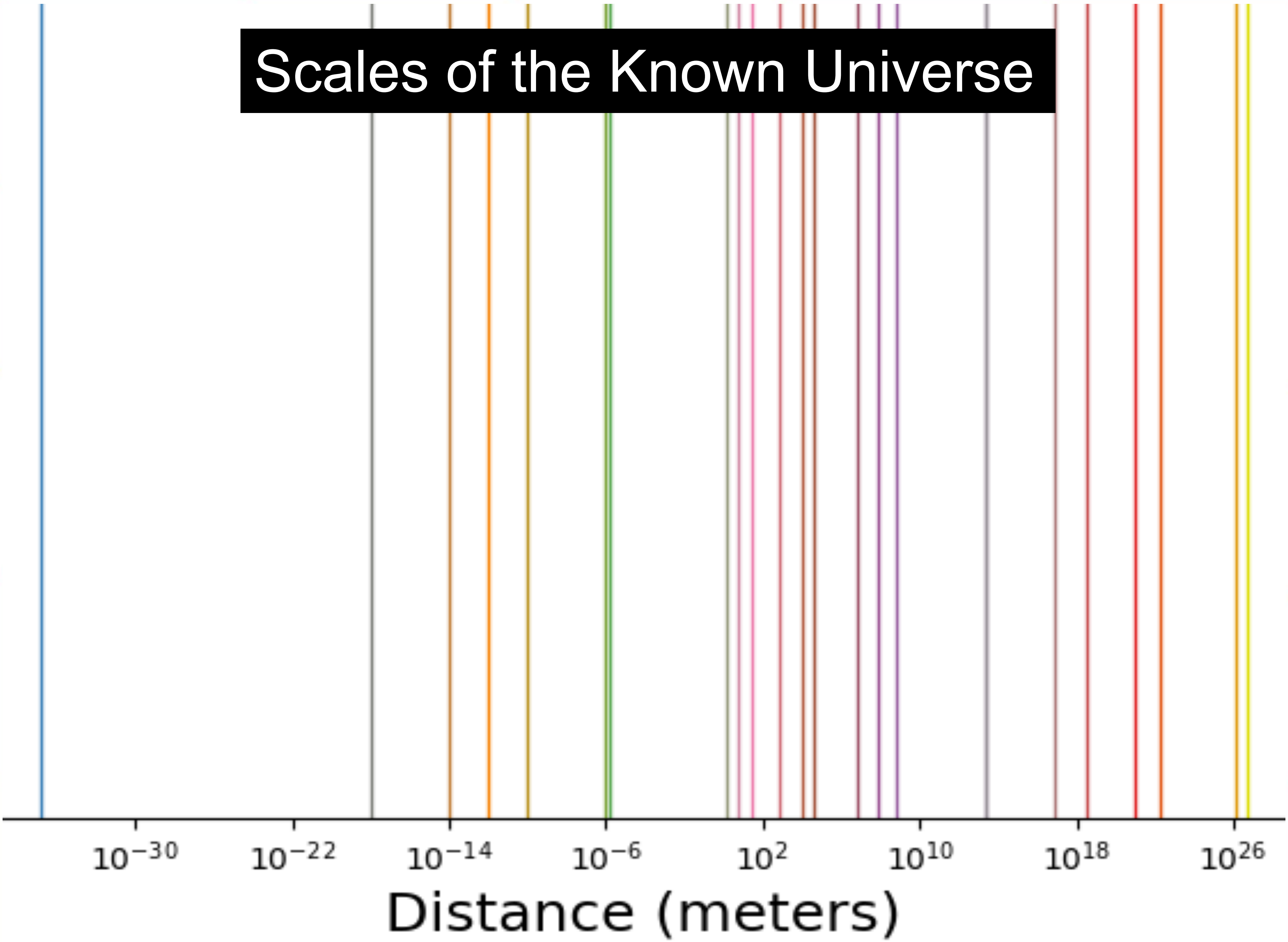


Credit: Verylargeandtallredwoods.com

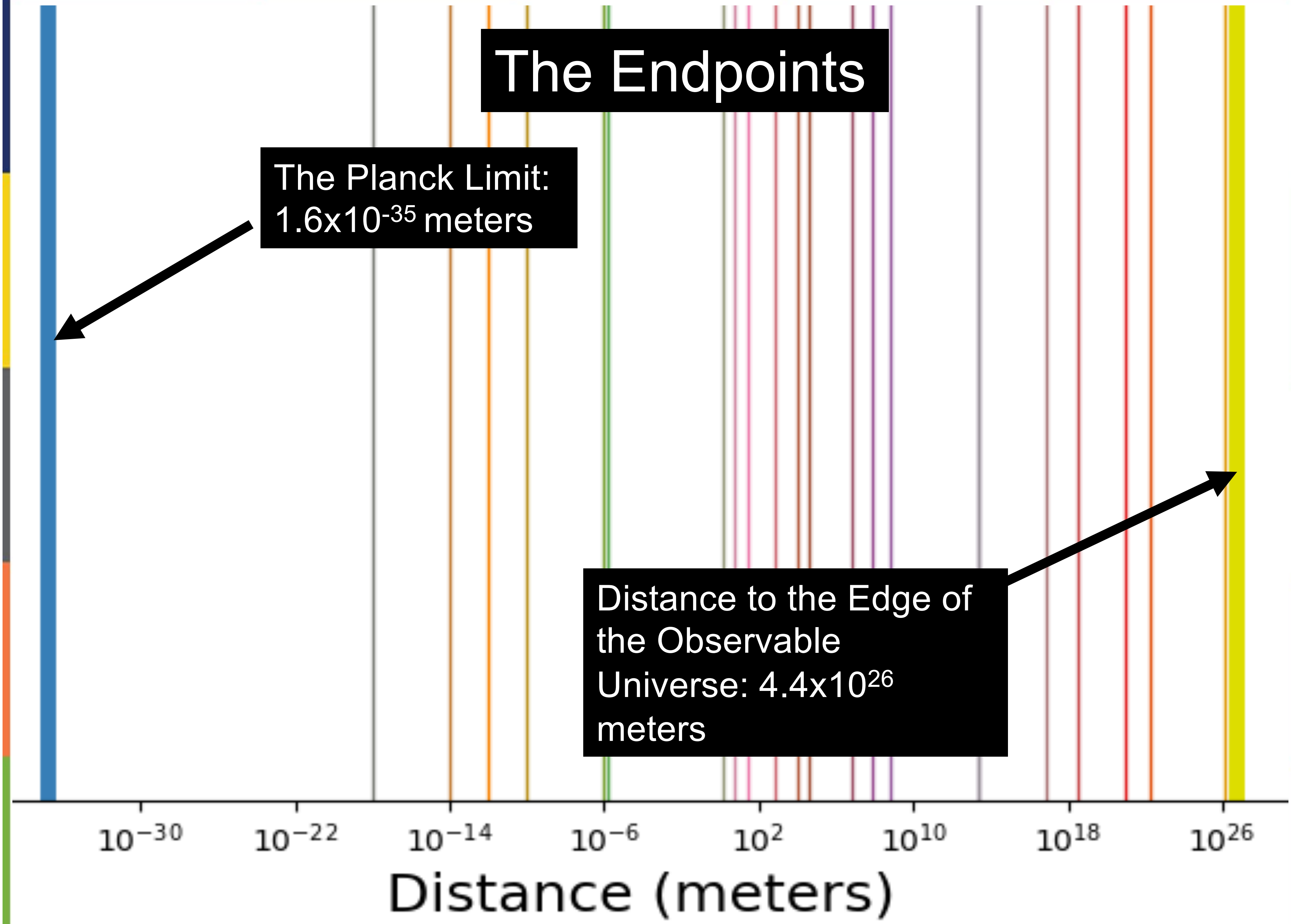


Credit: microbiologyinfo.com

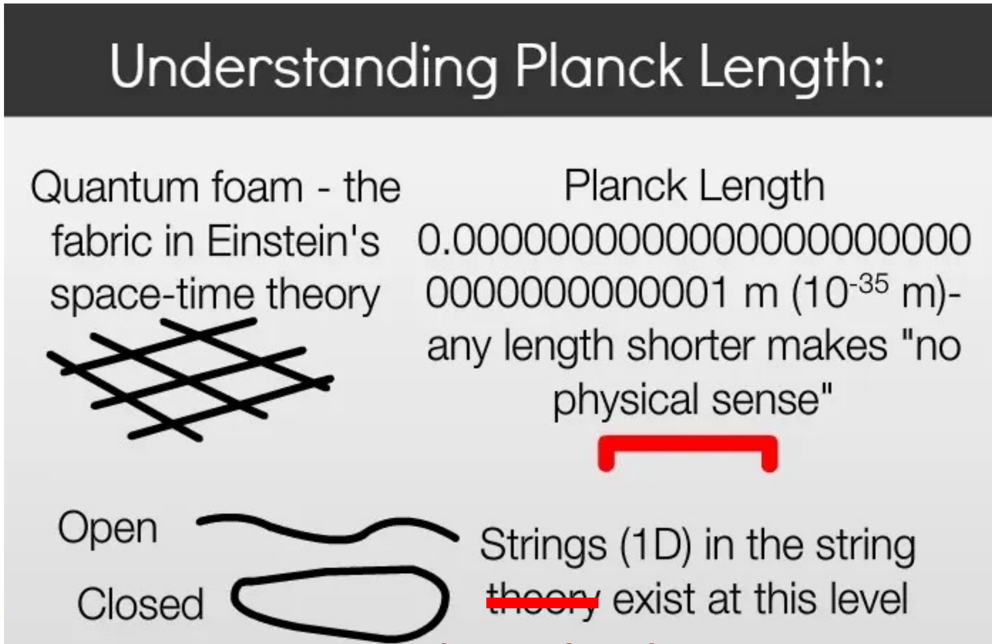
Scales of the Known Universe



The Endpoints



The Endpoints

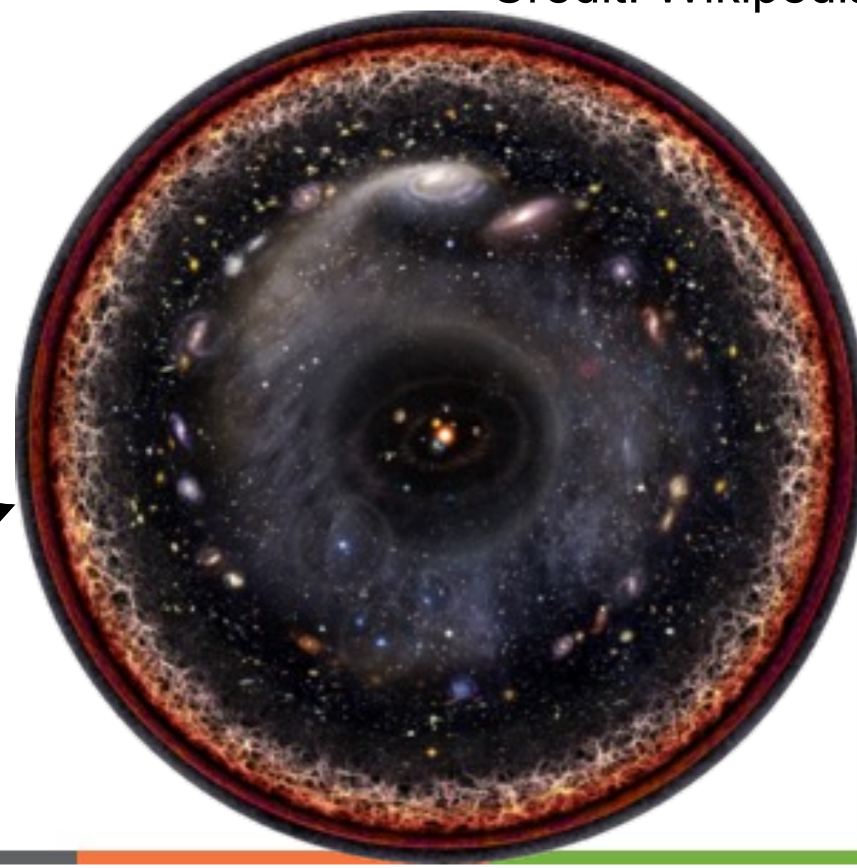


hypothesis

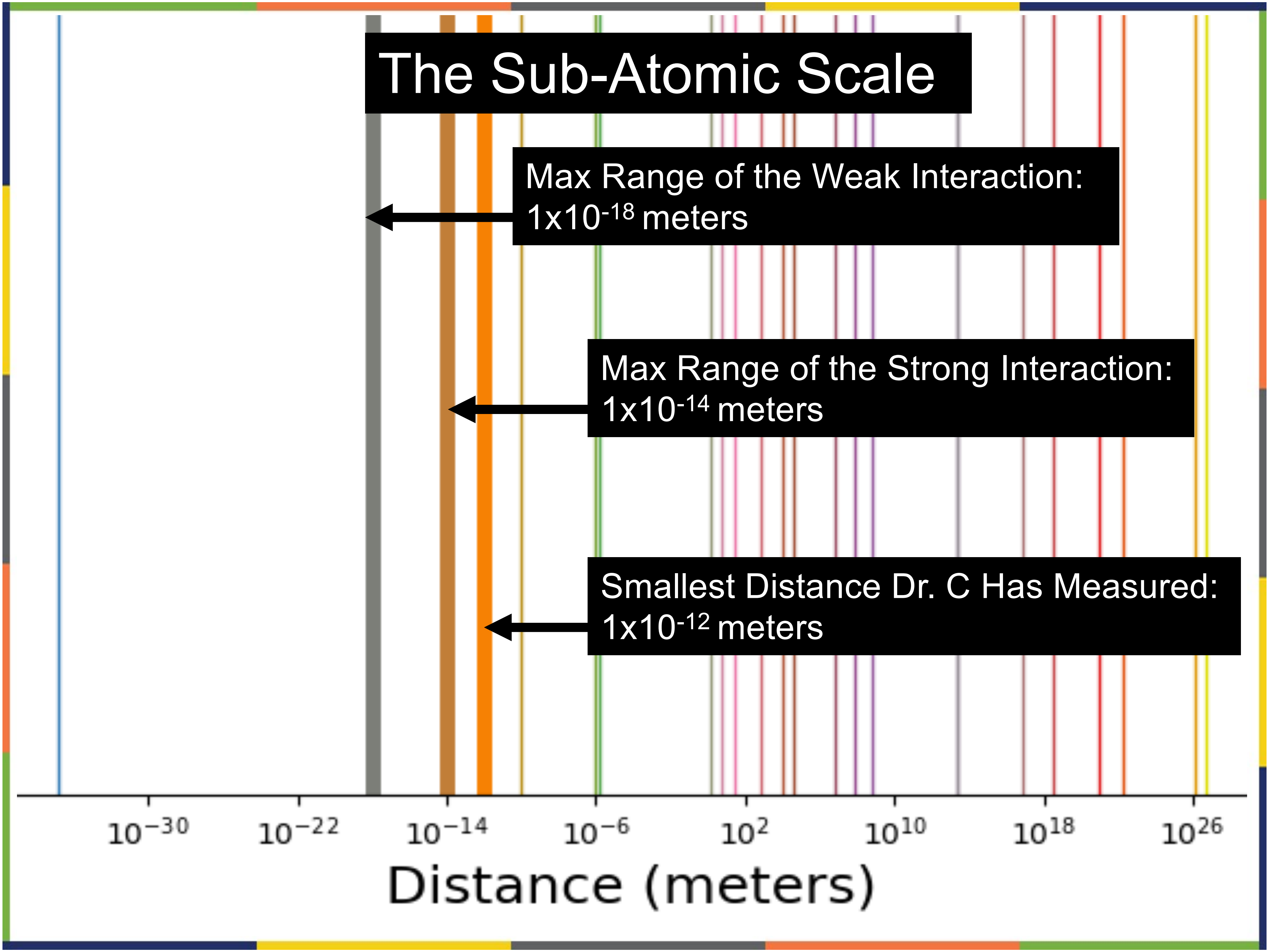
Credit: NASA.gov

The Planck Limit: 1.6×10^{-35}

Credit: Wikipedia

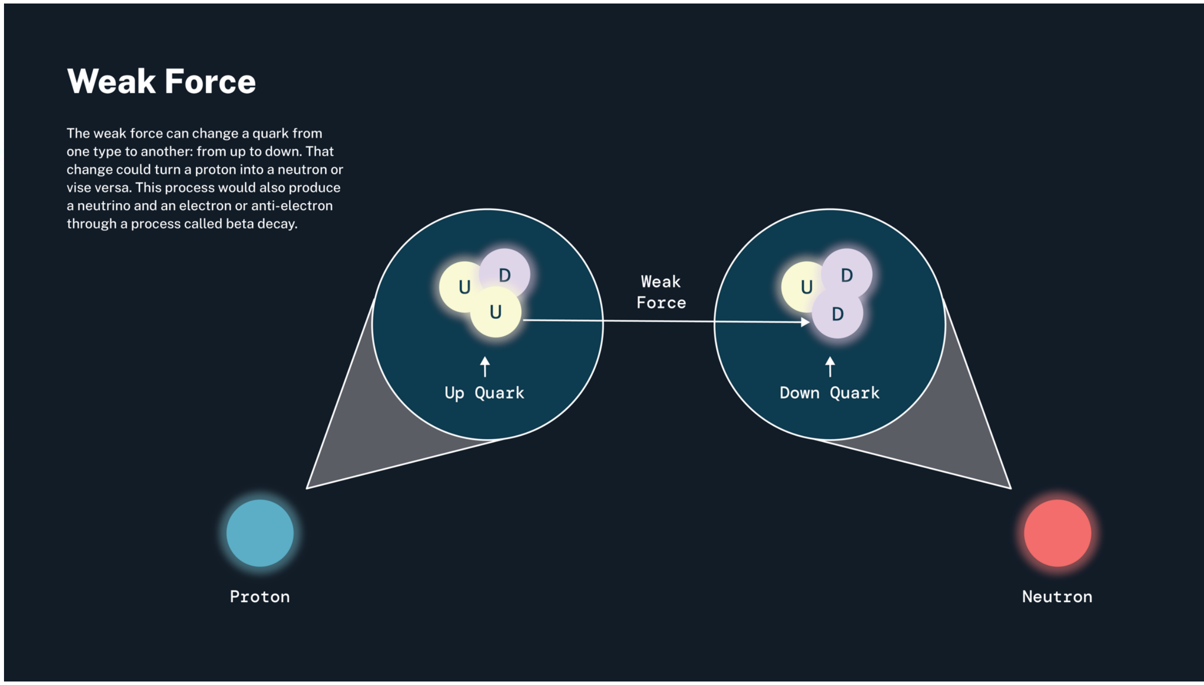


Distance to the Edge of the Observable Universe: 4.4×10^{26} meters



The Sub-Atomic Scale
Max Range of the Weak Interaction:
1x10-18 meters
Max Range of the Strong Interaction:
1x10-14 meters
Smallest Distance Dr. C Has Measured:
1x10-12 meters
10−30
10−22
10−14
10−6
10^2
10^10
10^18
10^26
Distance (meters)

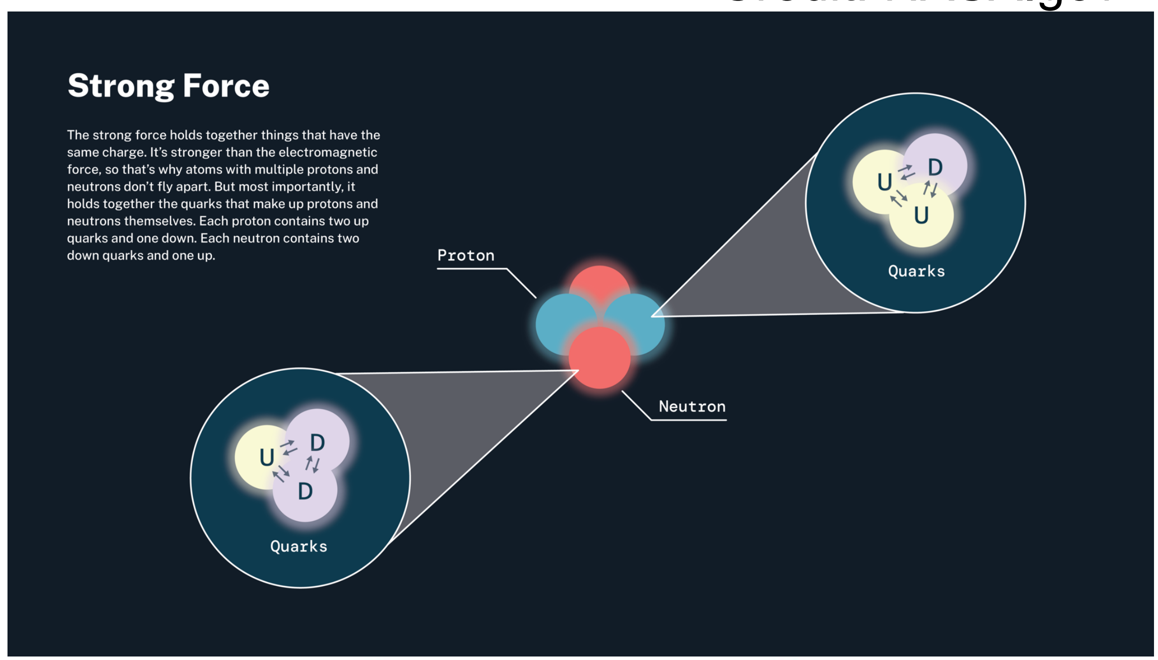
The Sub-Atomic Scale



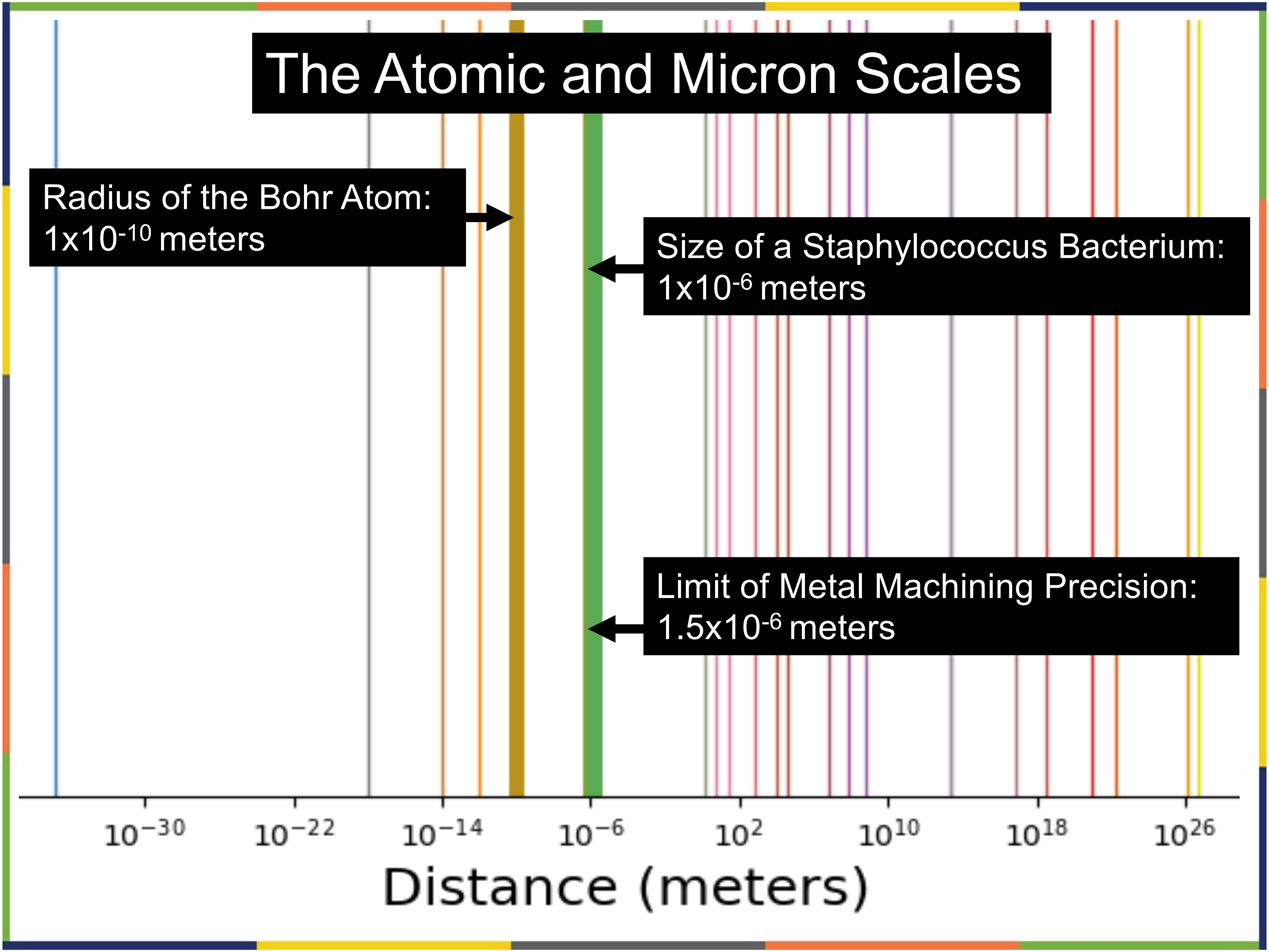
Max Range of the Weak Interaction: 1×10^{-18} meters

Credit: NASA.gov

Credit: NASA.gov

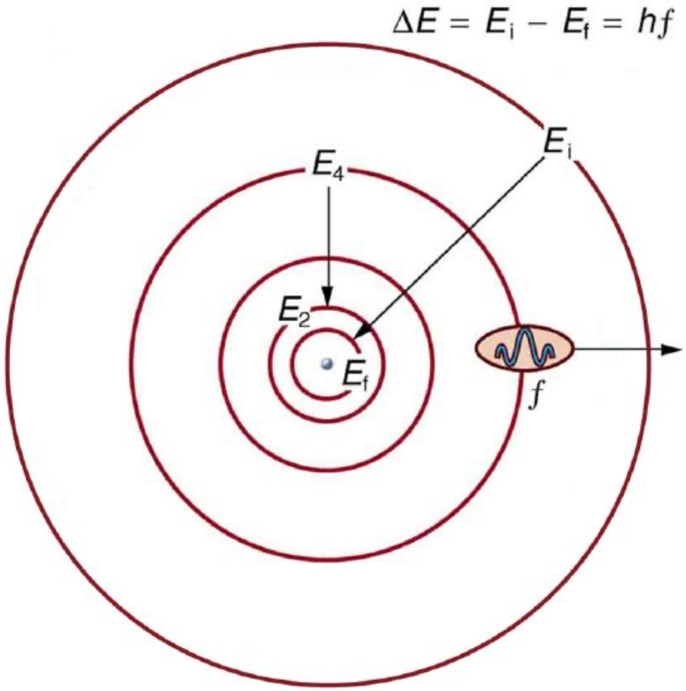


Max Range of the Strong Interaction: 1×10^{-14} meters



The Atomic and Micron Scales
Radius of the Bohr Atom: 1x10-10 meters
Size of a Staphylococcus Bacterium: 1x10-6 meters
Limit of Metal Machining Precision: 1.5x10-6 meters
10−30
10−22
10−14
10−6
102
1010
1018
1026
Distance (meters)

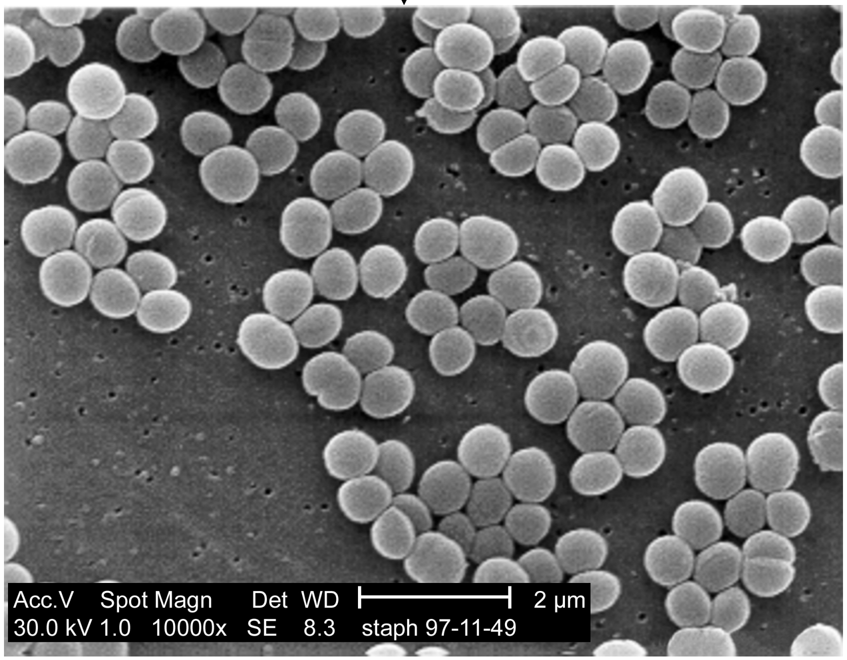
The Atomic and Micron Scales



Credit: Wikipedia

Radius of the Bohr Atom:
1×10^{-10} meters

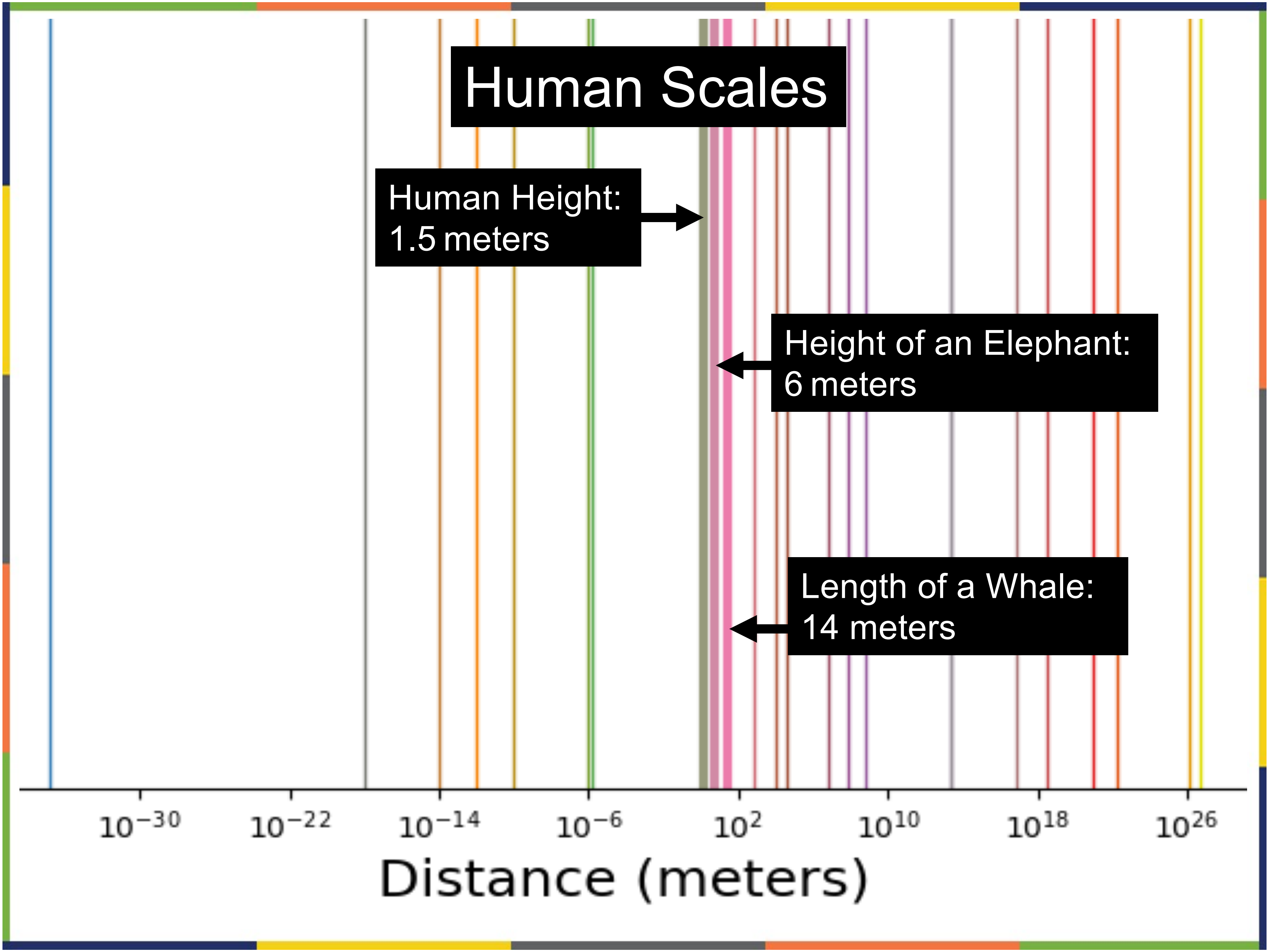
Size of a Staphylococcus Bacterium:
1×10^{-6} meters



Credit: Wikipedia

Credit: Cole-Palmer

Limit of Metal Machining Precision:
1.5×10^{-6} meters

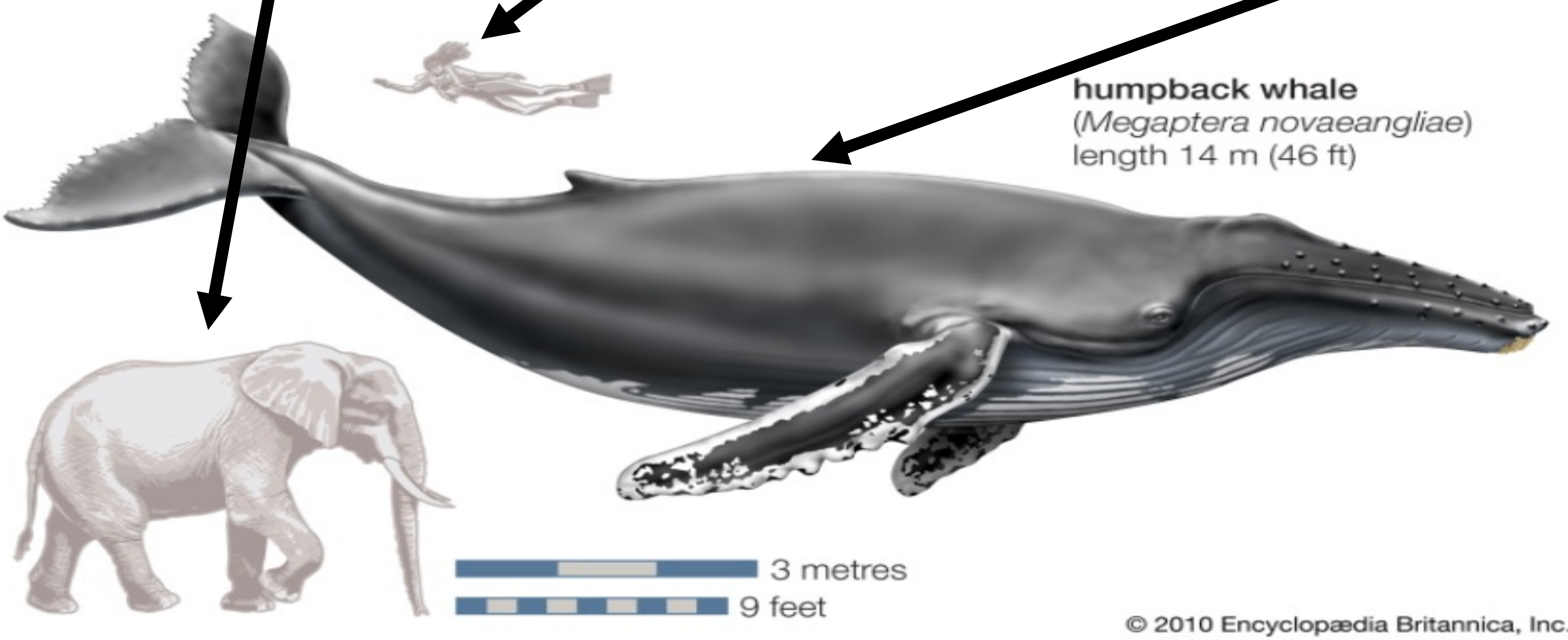

Human Scales
Human Height:
1.5 meters
Height of an Elephant:
6 meters
Length of a Whale:
14 meters
10^{-30}
10^{-22}
10^{-14}
10^{-6}
10^{2}
10^{10}
10^{18}
10^{26}
Distance (meters)

Human Scales

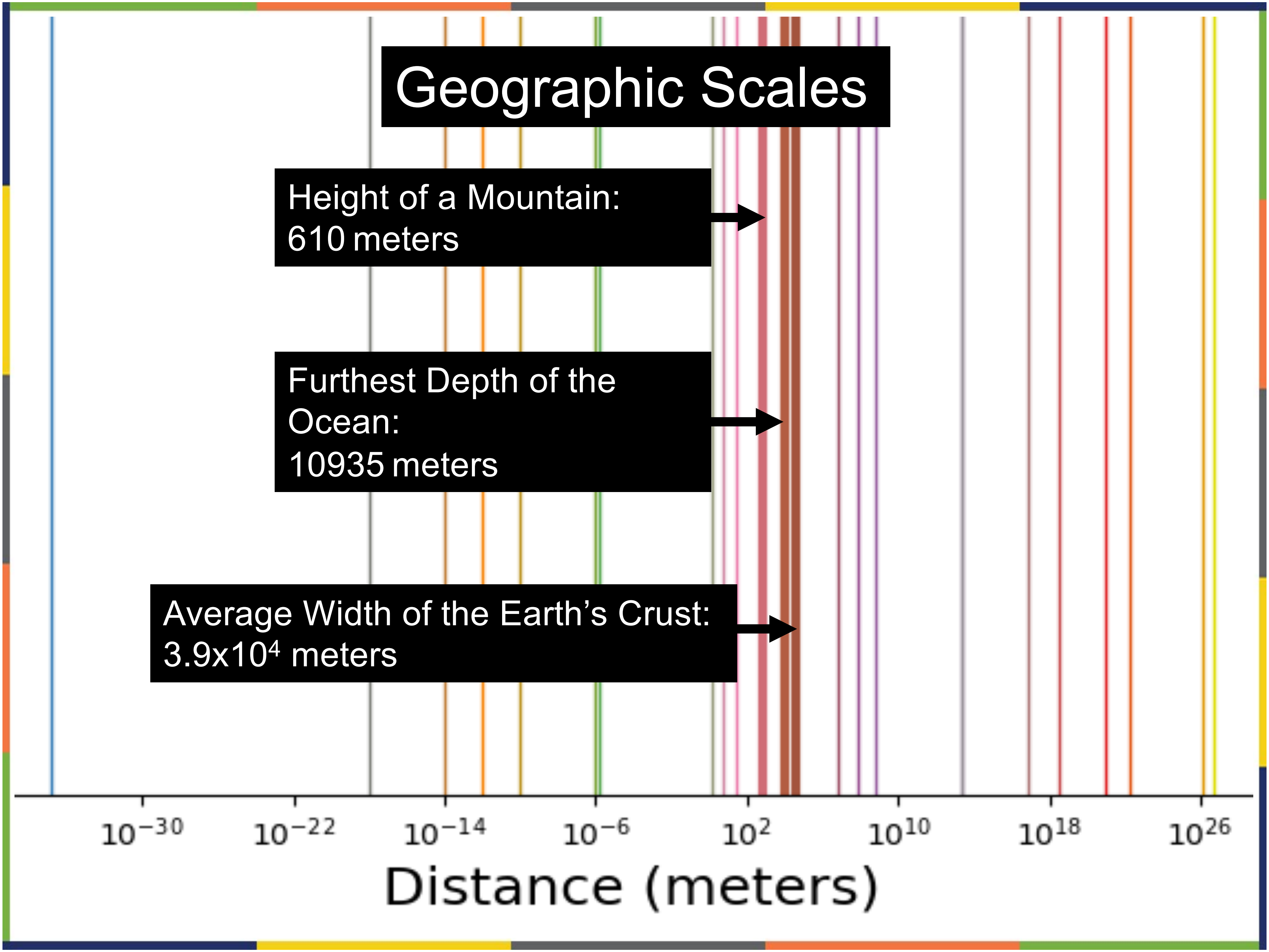
Height of an Elephant:
6 meters

Human Height:
1.5 meters

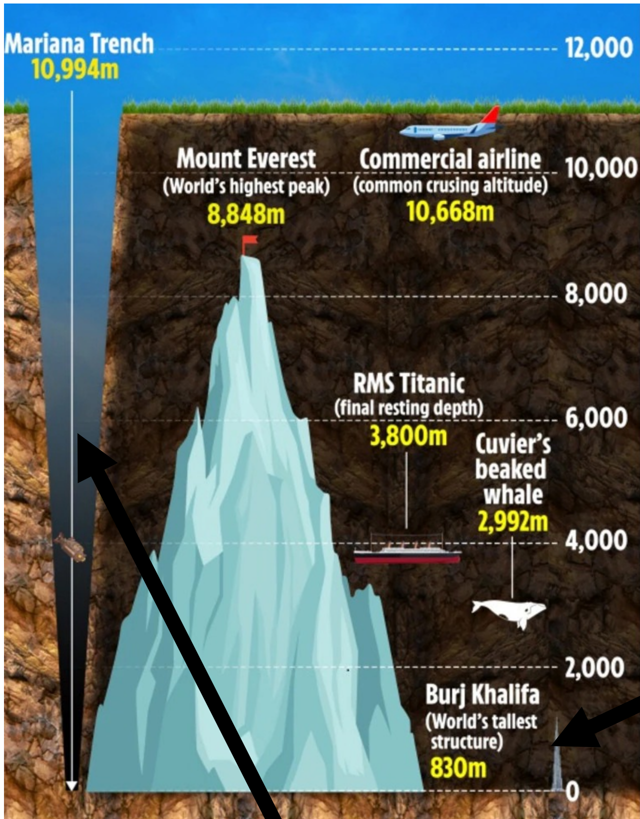
Length of a Whale:
14 meters



Credit: https://twitter.com/MCERCMarineEco


Geographic Scales
Height of a Mountain:
610 meters
Furthest Depth of the Ocean:
10935 meters
Average Width of the Earth's Crust:
3.9x10^4 meters
10^−30
10^−22
10^−14
10^−6
10^2
10^10
10^18
10^26
Distance (meters)

Geographic Scales

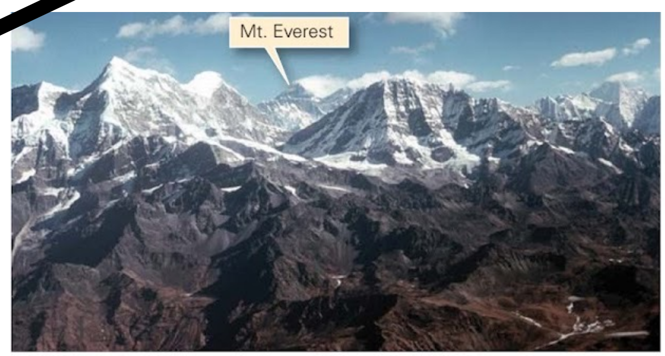


Credit: learngeology.blogspot.com

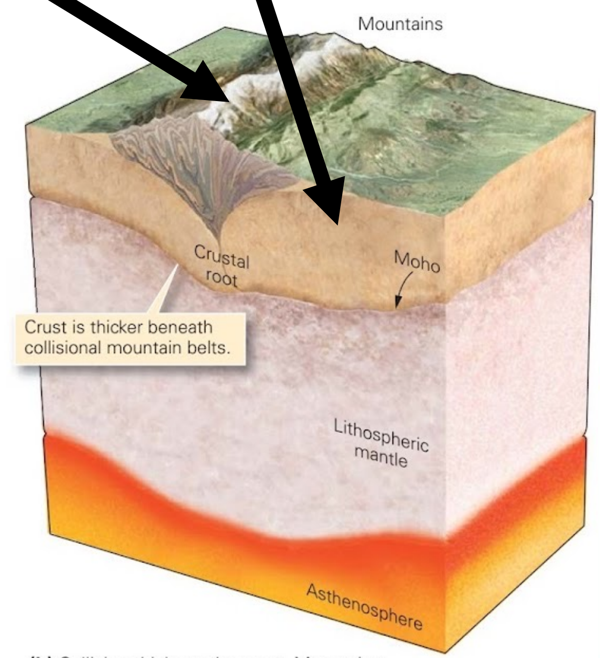
Average Width of the Earth's Crust:
3.9×10^4 meters

Height of a Average Mountain:
610 meters

Credit: learngeology.blogspot.com

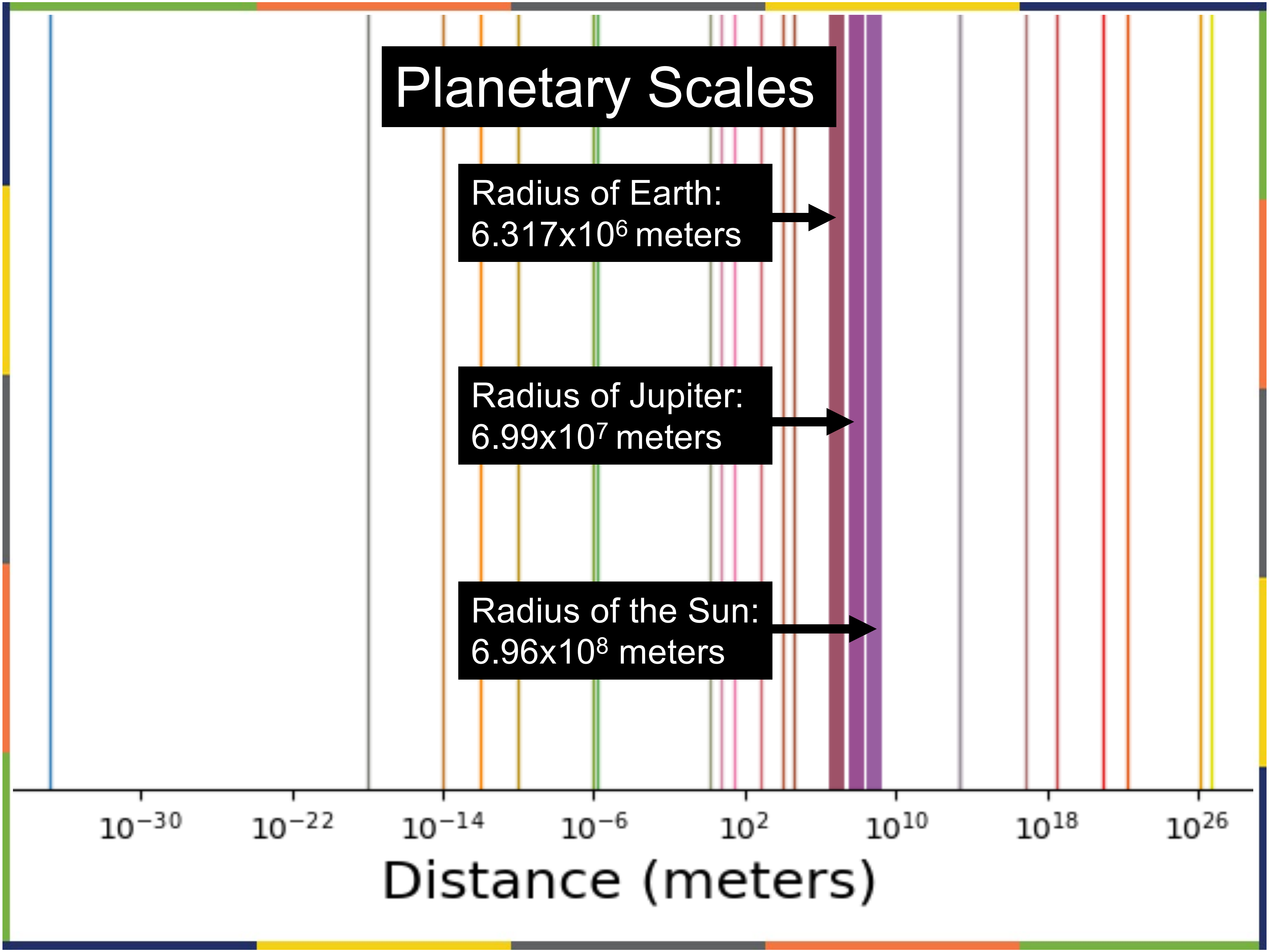


(a) The Himalayas are the world's highest mountain range. The crust beneath them is almost twice the normal thickness.



(b) Collision thickens the crust. Mountains

Furthest Depth of the Ocean:
10935 meters



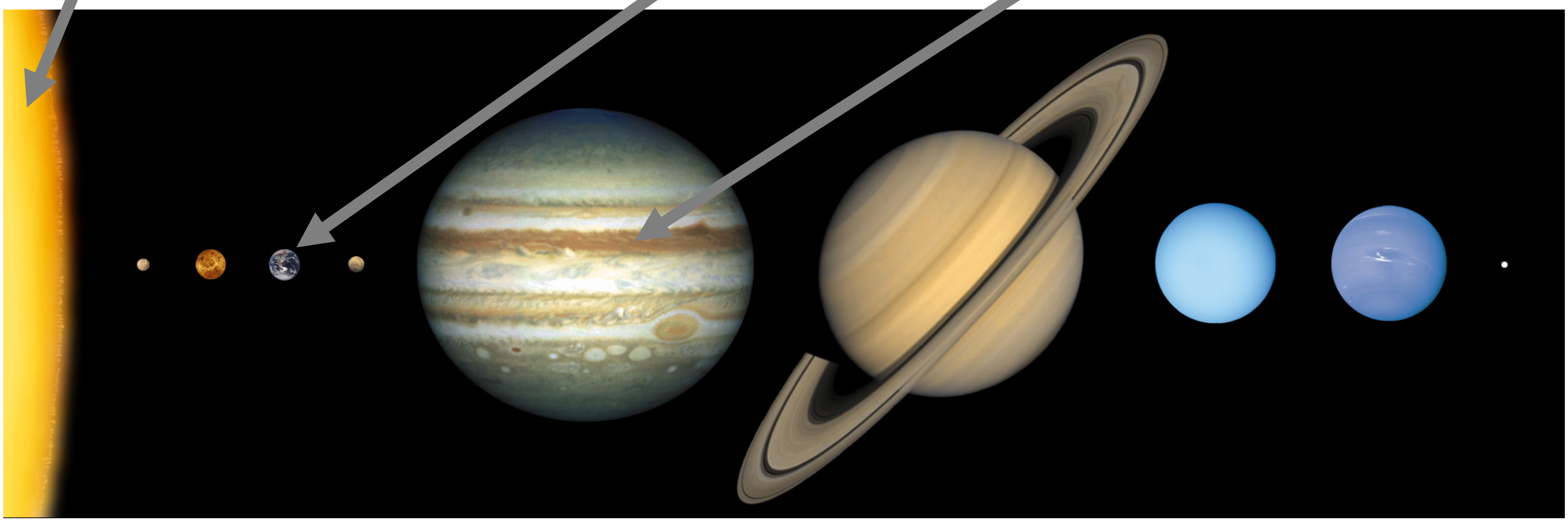
Planetary Scales
Radius of Earth:
6.317x10^6 meters
Radius of Jupiter:
6.99x10^7 meters
Radius of the Sun:
6.96x10^8 meters
10^−30
10^−22
10^−14
10^−6
10^2
10^10
10^18
10^26
Distance (meters)

Planetary Scales

Radius of the Sun: 6.96×10^8 meters

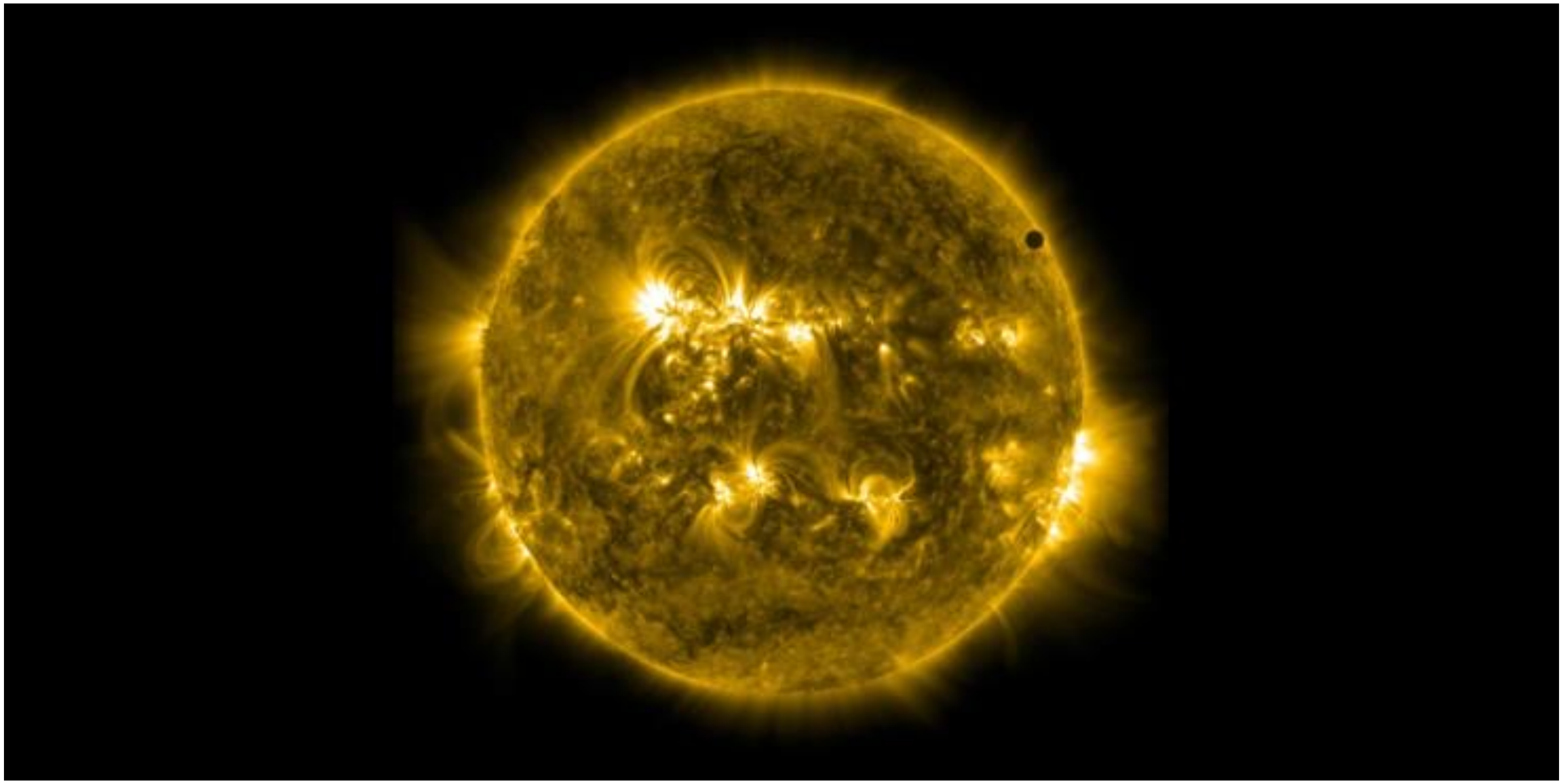
Radius of Earth: 6.317×10^6 meters

Radius of Jupiter: 6.99×10^7 meters



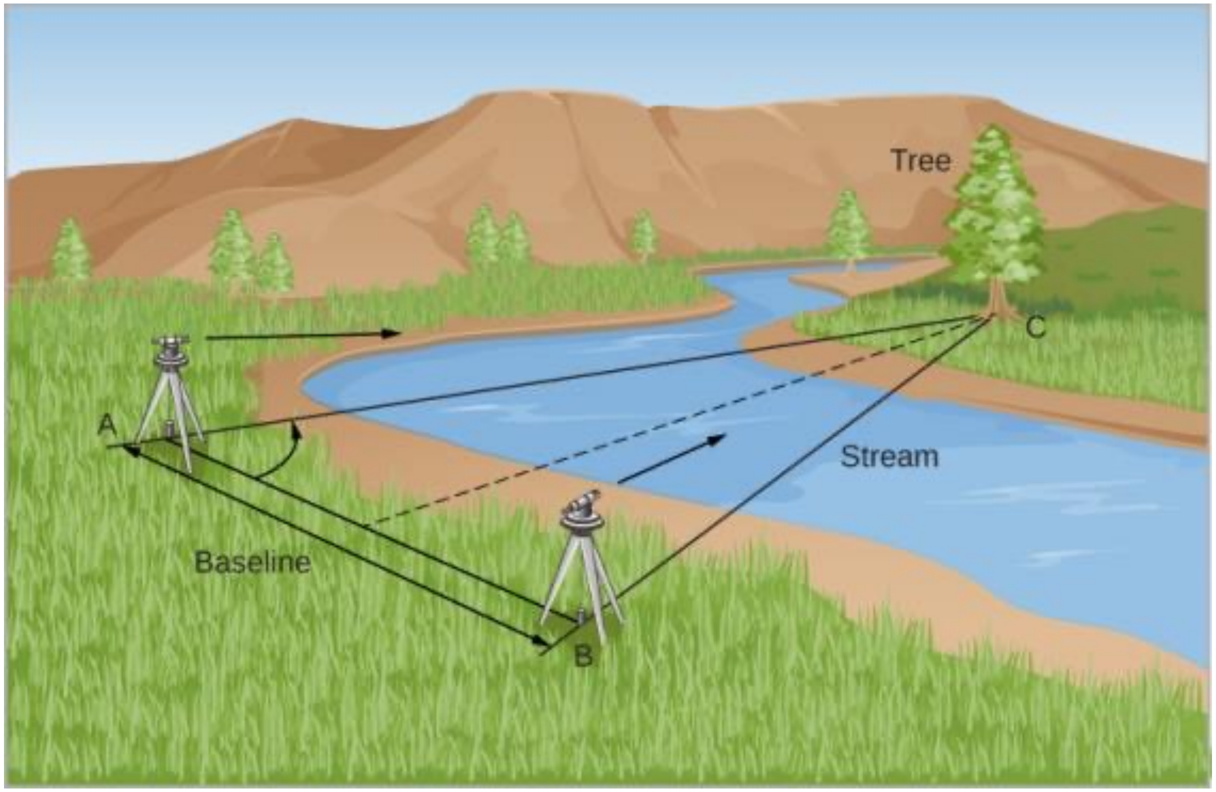
Credit: NASA.gov

FIGURE 19.2



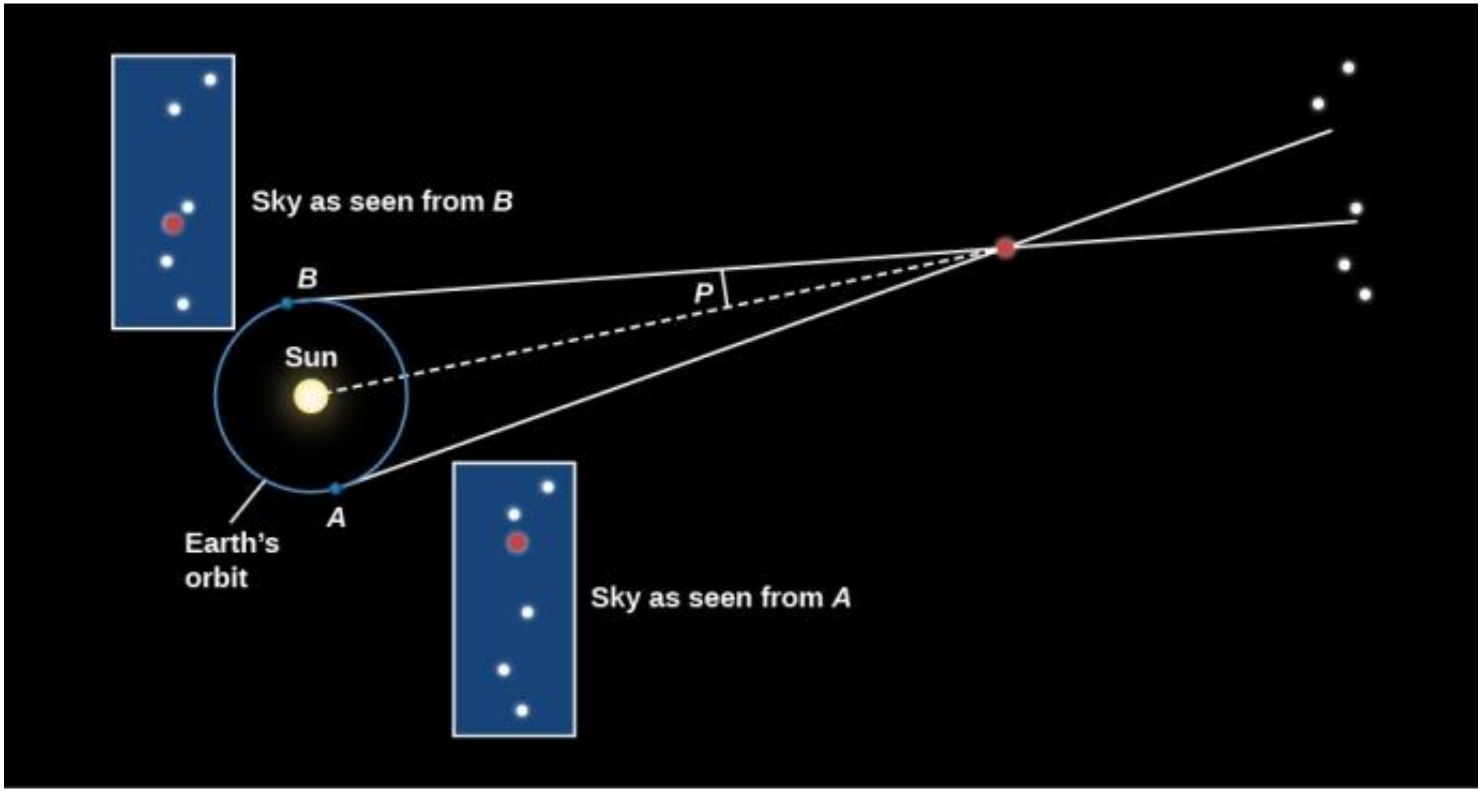
Venus Transits the Sun, 2012. This striking “picture” of Venus crossing the face of the Sun (it’s the black dot at about 2 o’clock) is more than just an impressive image. Taken with the Solar Dynamics Observatory spacecraft and special filters, it shows a modern transit of Venus. Such events allowed astronomers in the 1800s to estimate the distance to Venus. They measured the time it took Venus to cross the face of the Sun from different latitudes on Earth. The differences in times can be used to estimate the distance to the planet. Today, radar is used for much more precise distance estimates. (credit: modification of work by NASA/SDO, AIA)

FIGURE 19.4



Triangulation. Triangulation allows us to measure distances to inaccessible objects. By getting the angle to a tree from two different vantage points, we can calculate the properties of the triangle they make and thus the distance to the tree.

FIGURE 19.6

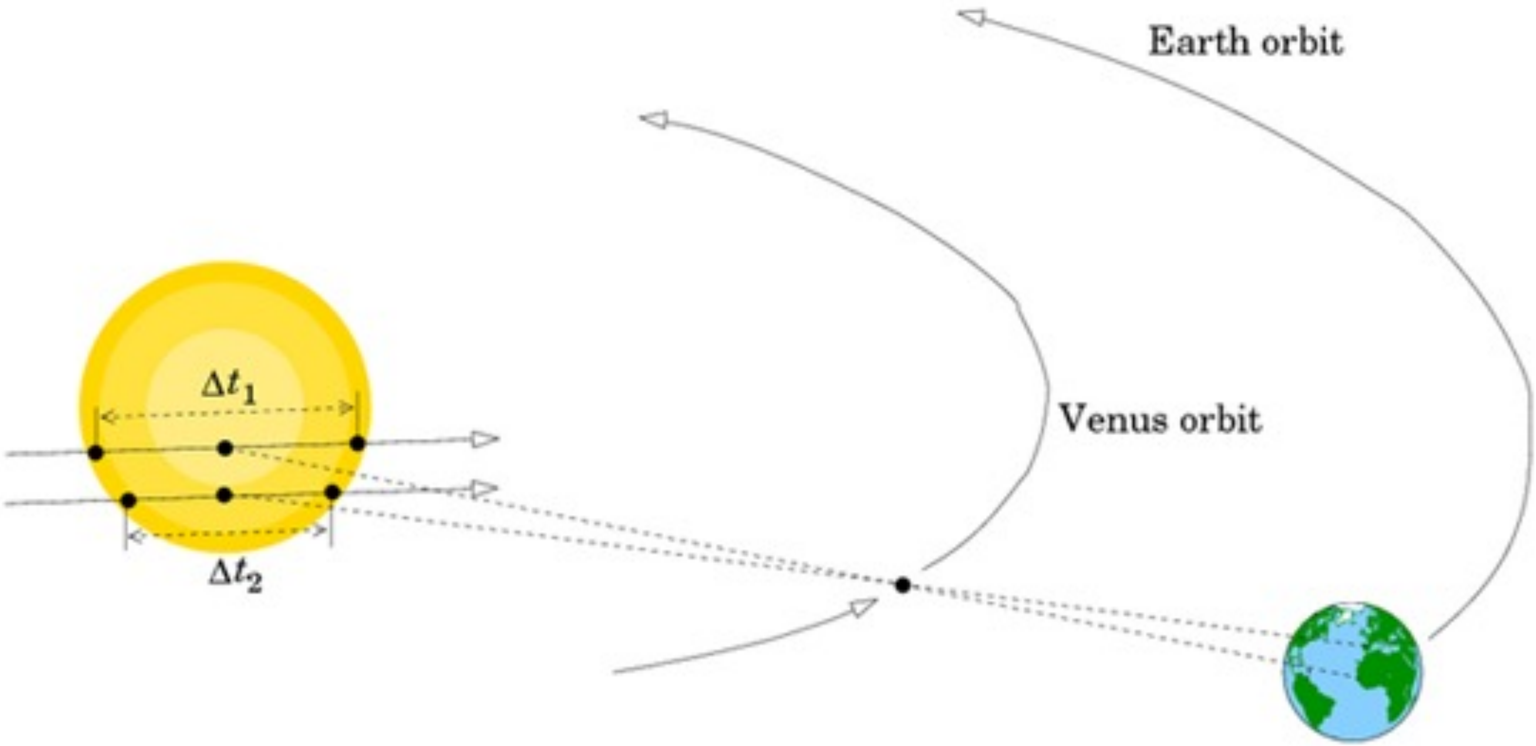


Parallax. As Earth revolves around the Sun, the direction in which we see a nearby star varies with respect to distant stars. We define the parallax of the nearby star to be one half of the total change in direction, and we usually measure it in arcseconds.

FIGURE 19.3

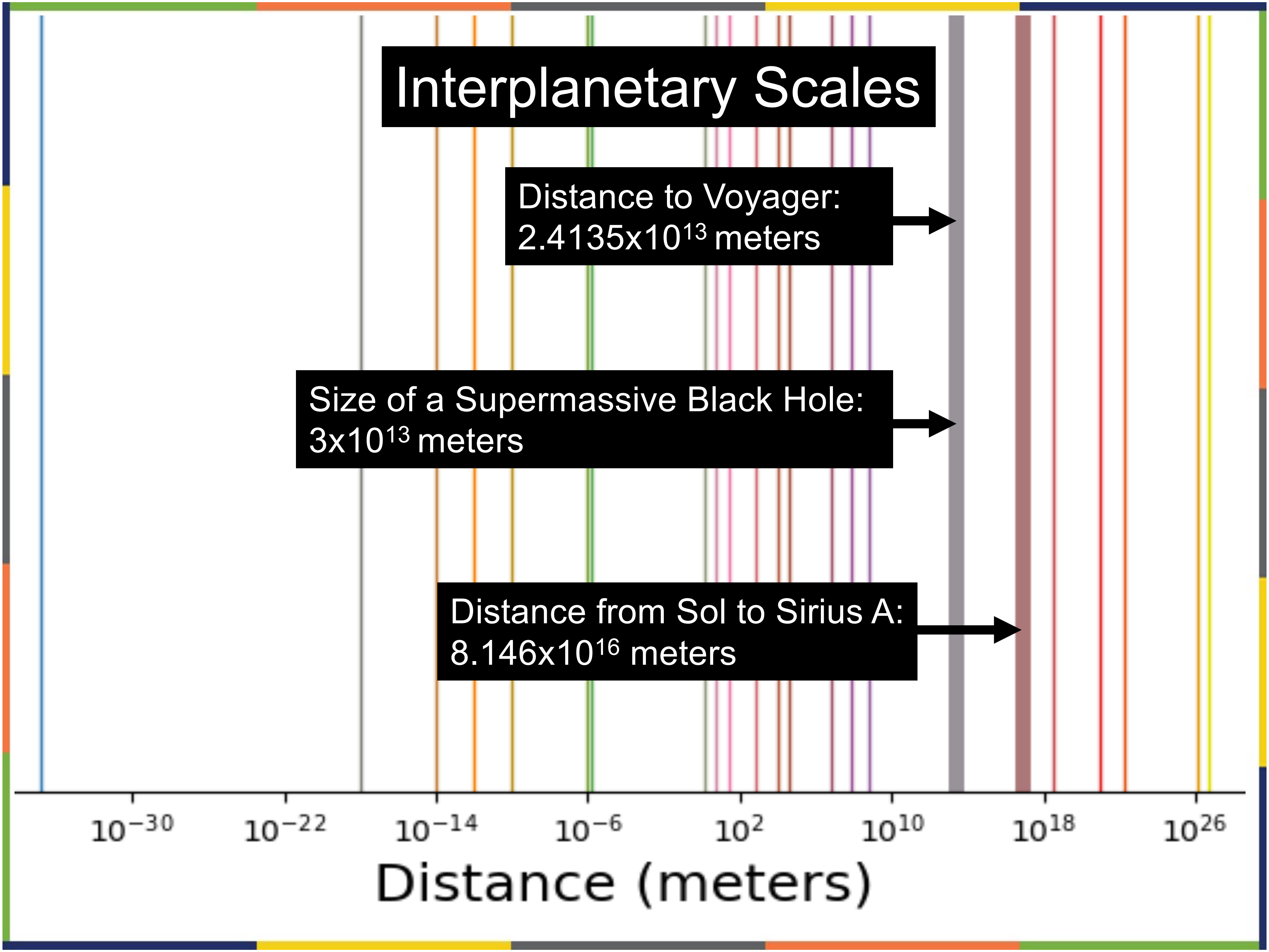
Radar Telescope. This dish-shaped antenna, part of the NASA Deep Space Network in California’s Mojave Desert, is 70 meters wide. Nicknamed the “Mars antenna,” this radar telescope can send and receive radar waves, and thus measure the distances to planets, satellites, and asteroids. (credit: NASA/JPL-Caltech)

EDMOND HALLEY'S PROPOSAL, 1716



all that is needed are "common telescopes and clocks, only good of their kind; and in the observers, nothing more is needful than fidelity, diligence, and a moderate skill in Astronomy."

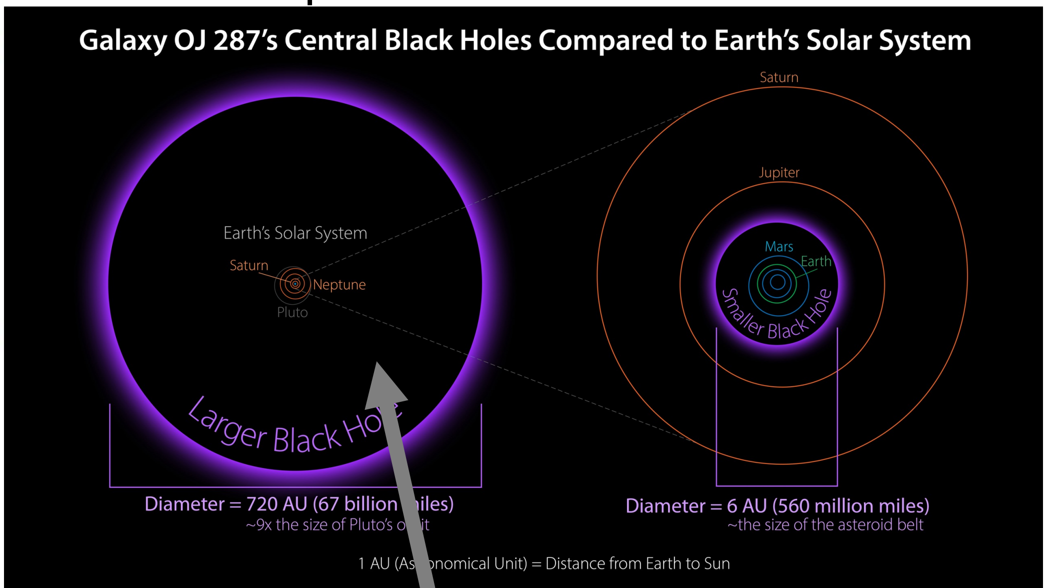
http://transitofvenus.nl/wp/getting-involved/measure-the-suns-distance/



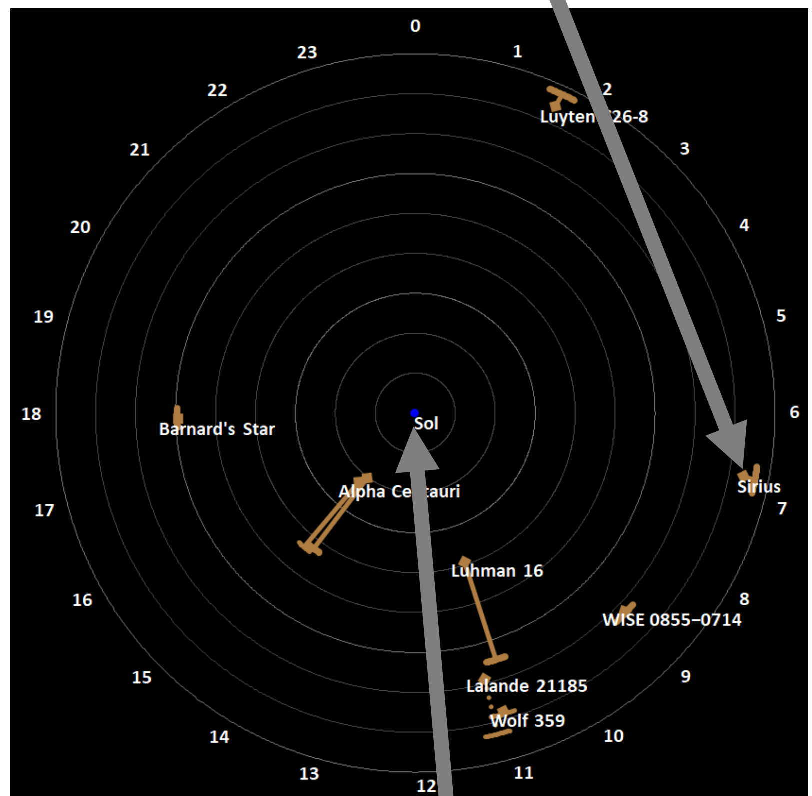
Interplanetary Scales
Distance to Voyager: 2.4135x10^13 meters
Size of a Supermassive Black Hole: 3x10^13 meters
Distance from Sol to Sirius A: 8.146x10^16 meters
10^−30
10^−22
10^−14
10^−6
10^2
10^10
10^18
10^26
Distance (meters)

Interplanetary Scales

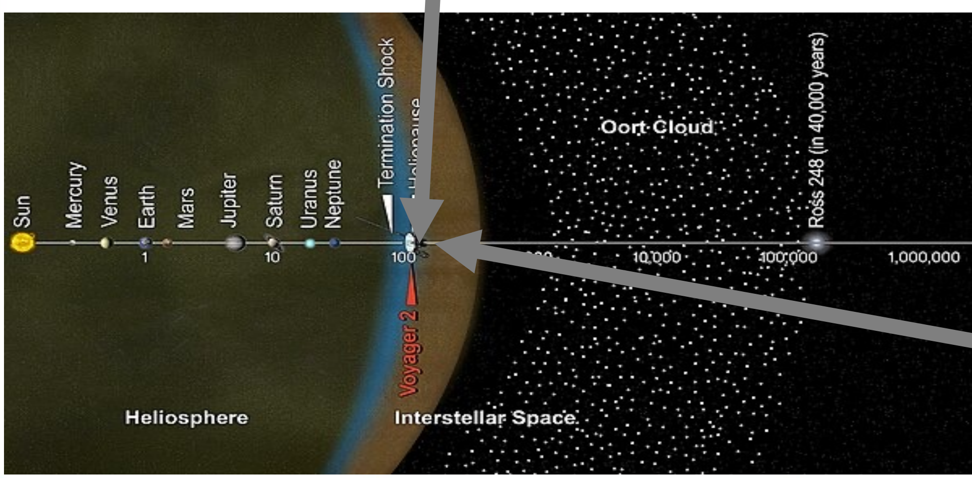
Credit: Wikipedia



Distance from Sol to Sirius A: 8.146×10^{16} meters



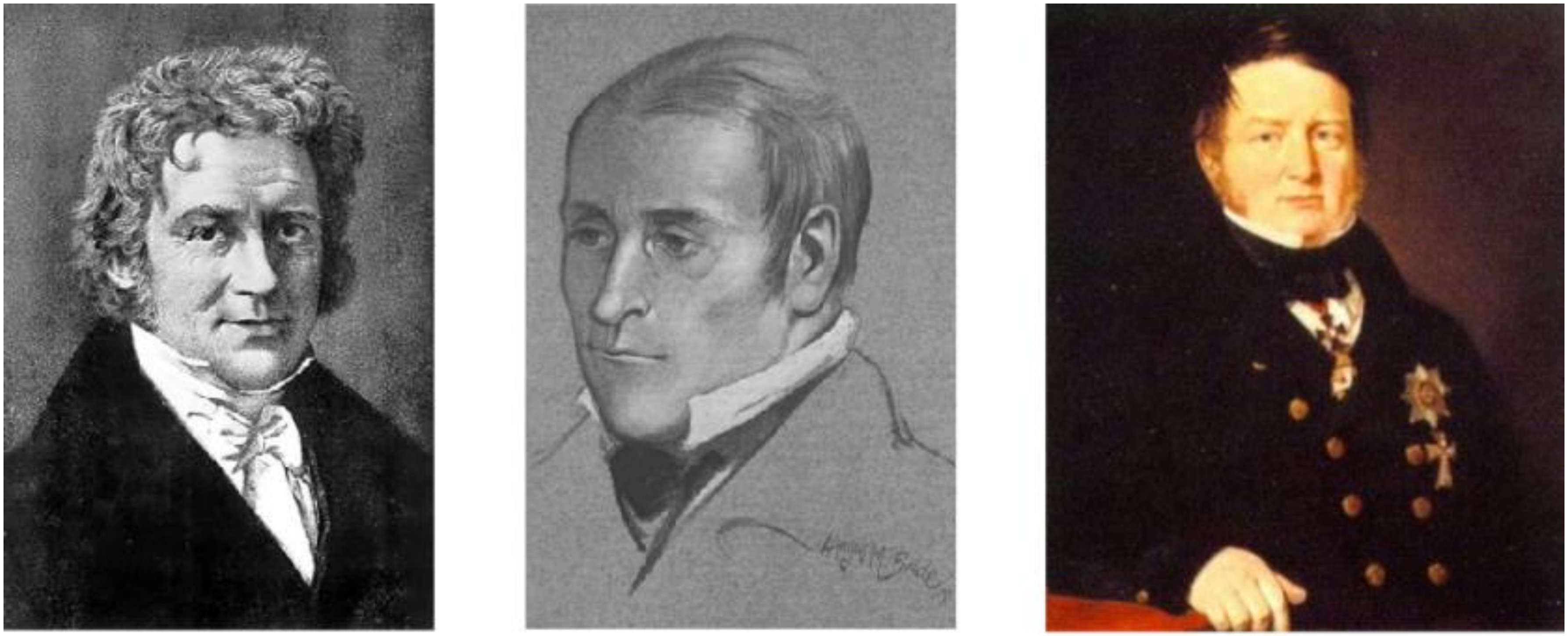
Size of a Supermassive Black Hole: 2.4135×10^{13} meters



Credit: Wikipedia

Distance to Voyager: 2.4135×10^{13} meters

FIGURE 19.5



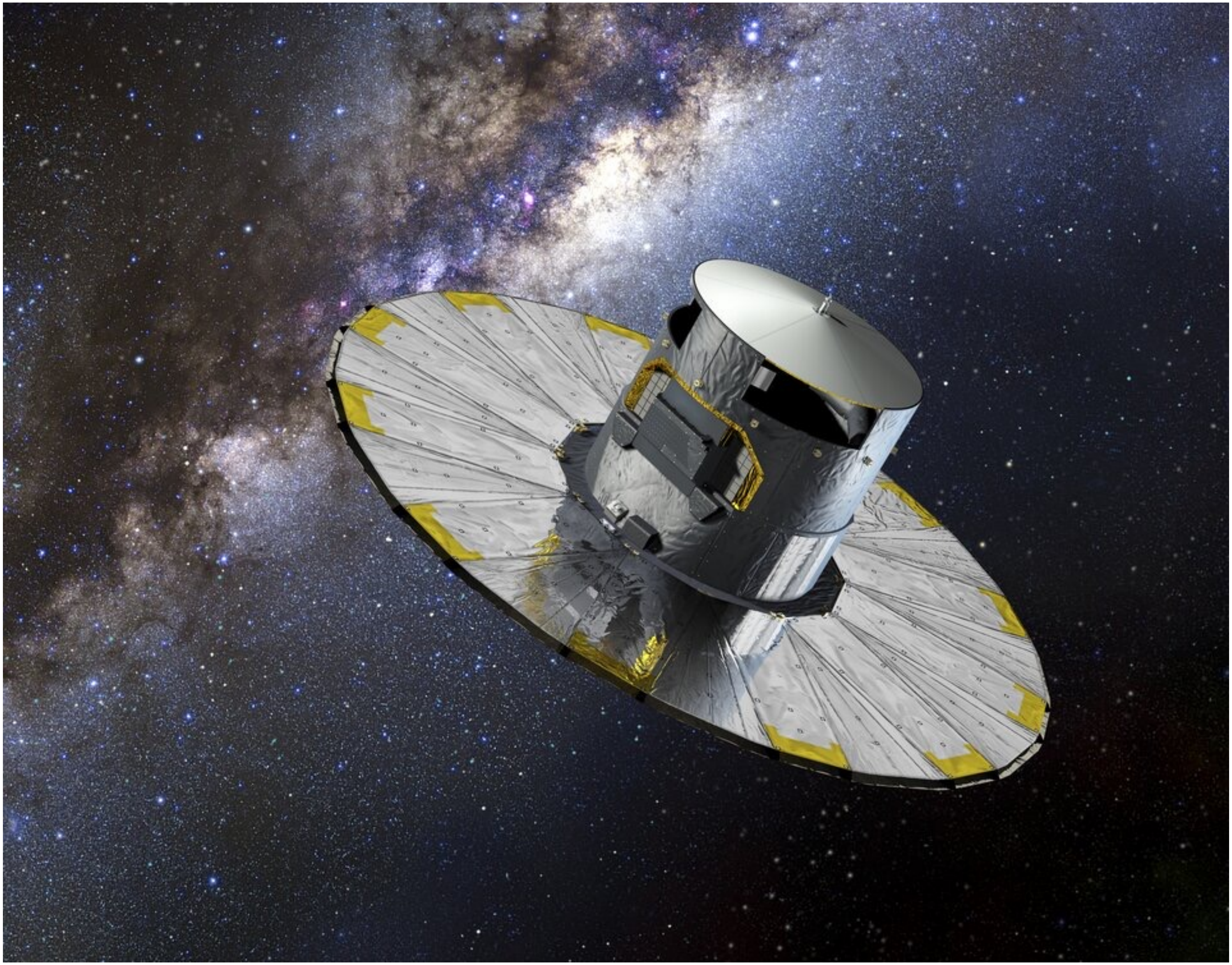
(a) (b) (c)

Friedrich Wilhelm Bessel (1784–1846), Thomas J. Henderson (1798–1844), and Friedrich Struve (1793–1864). (a) Bessel made the first authenticated measurement of the distance to a star (61 Cygni) in 1838, a feat that had eluded many dedicated astronomers for almost a century. But two others, (b) Scottish astronomer Thomas J. Henderson and (c) Friedrich Struve, in Russia, were close on his heels.

FIGURE 19.1

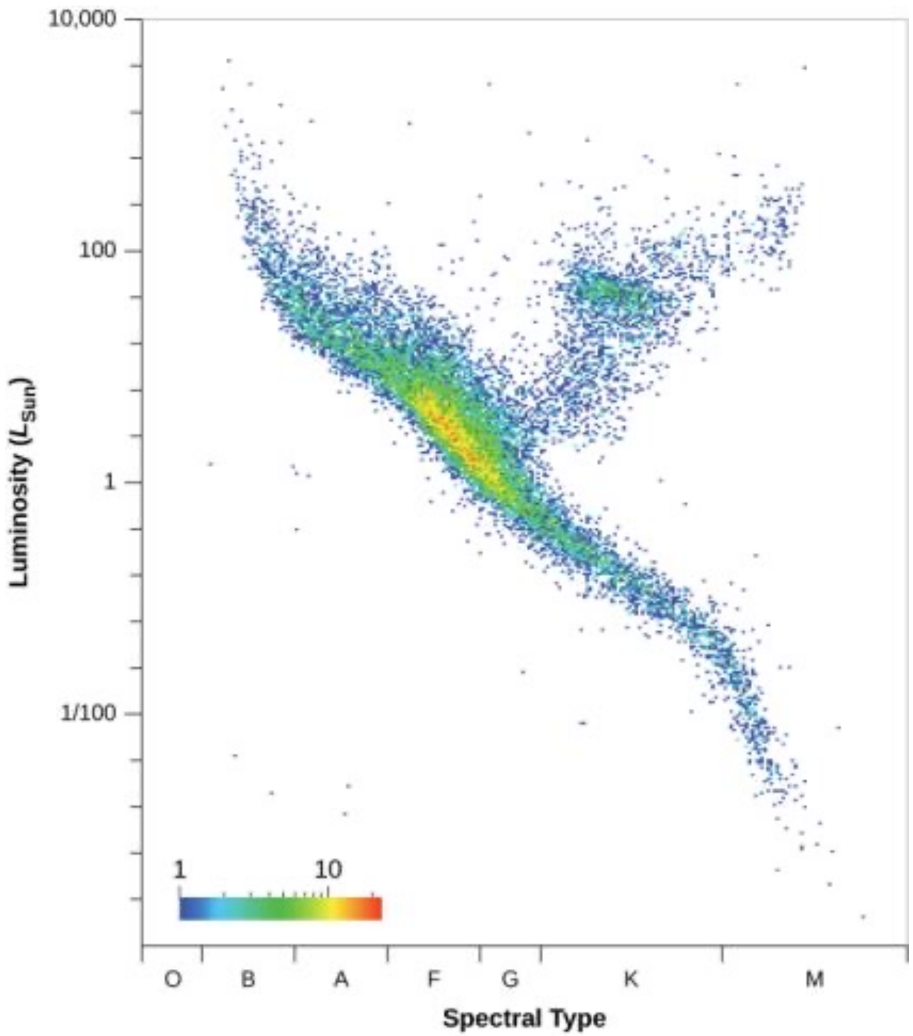
Globular Cluster M80. This beautiful image shows a giant cluster of stars called Messier 80, located about 28,000 light-years from Earth. Such crowded groups, which astronomers call globular clusters, contain hundreds of thousands of stars, including some of the RR Lyrae variables discussed in this chapter. Especially obvious in this picture are the bright red giants, which are stars similar to the Sun in mass that are nearing the ends of their lives. (credit: modification of work by The Hubble Heritage Team (AURA/ STScI/NASA))

EUROPEAN SPACE AGENCY'S 'GAIA' SATELLITE

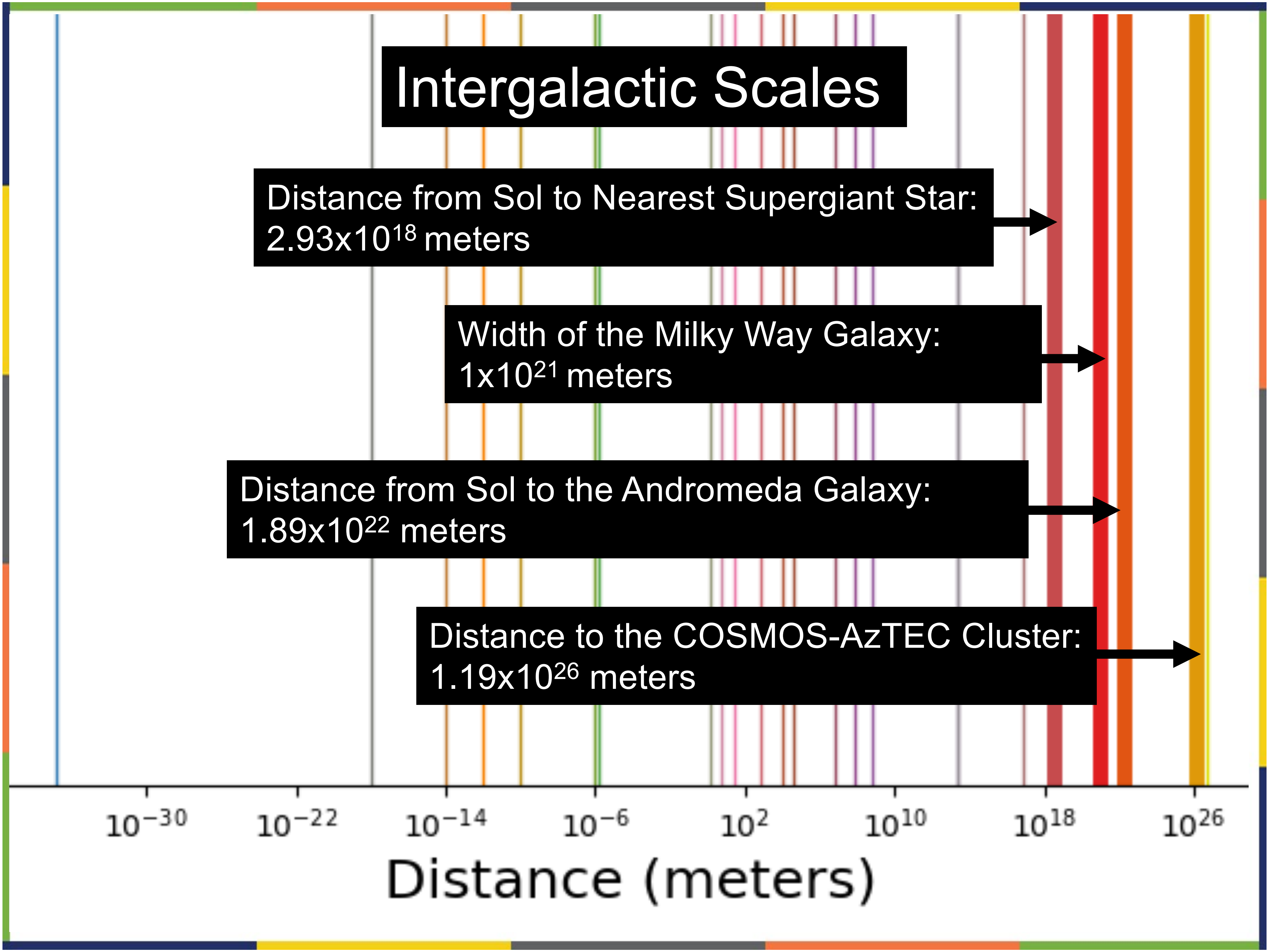


Credit: European Space Agency

FIGURE 19.8



H–R Diagram of Stars Measured by Gaia and Hipparcos. This plot includes 16,631 stars for which the parallaxes have an accuracy of 10% or better. The colors indicate the numbers of stars at each point of the diagram, with red corresponding to the largest number and blue to the lowest. Luminosity is plotted along the vertical axis, with luminosity increasing upward. An infrared color is plotted as a proxy for temperature, with temperature decreasing to the right. Most of the data points are distributed along the diagonal running from the top left corner (high luminosity, high temperature) to the bottom right (low temperature, low luminosity). These are main sequence stars. The large clump of data points above the main sequence on the right side of the diagram is composed of red giant stars. (credit: modification of work by the European Space Agency)

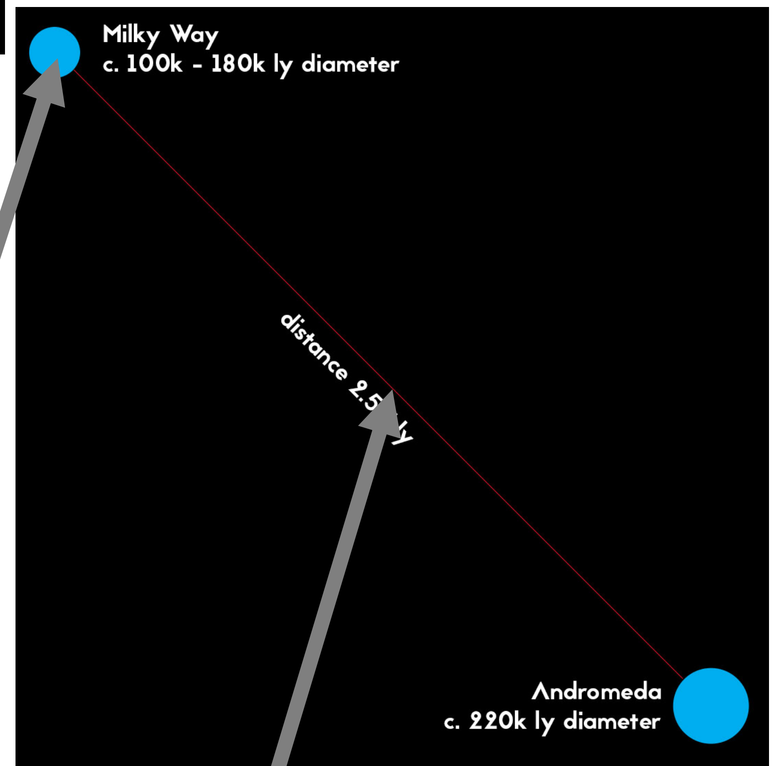

Intergalactic Scales
Distance from Sol to Nearest Supergiant Star:
2.93x10¹⁸ meters
Width of the Milky Way Galaxy:
1x10²¹ meters
Distance from Sol to the Andromeda Galaxy:
1.89x10²² meters
Distance to the COSMOS-AzTEC Cluster:
1.19x10²⁶ meters
10⁻³⁰
10⁻²²
10⁻¹⁴
10⁻⁶
10²
10¹⁰
10¹⁸
10²⁶
Distance (meters)

Intergalactic Scales

Distance from Sol to Nearest Supergiant Star:
2.93×10^{18} meters

Credit: Wikipedia

Credit: Wikipedia



Width of the Milky Way Galaxy:
1×10^{21} meters

Credit: Smithsonian Magazine

Distance from Sol to the Andromeda Galaxy:
1.89×10^{22} meters

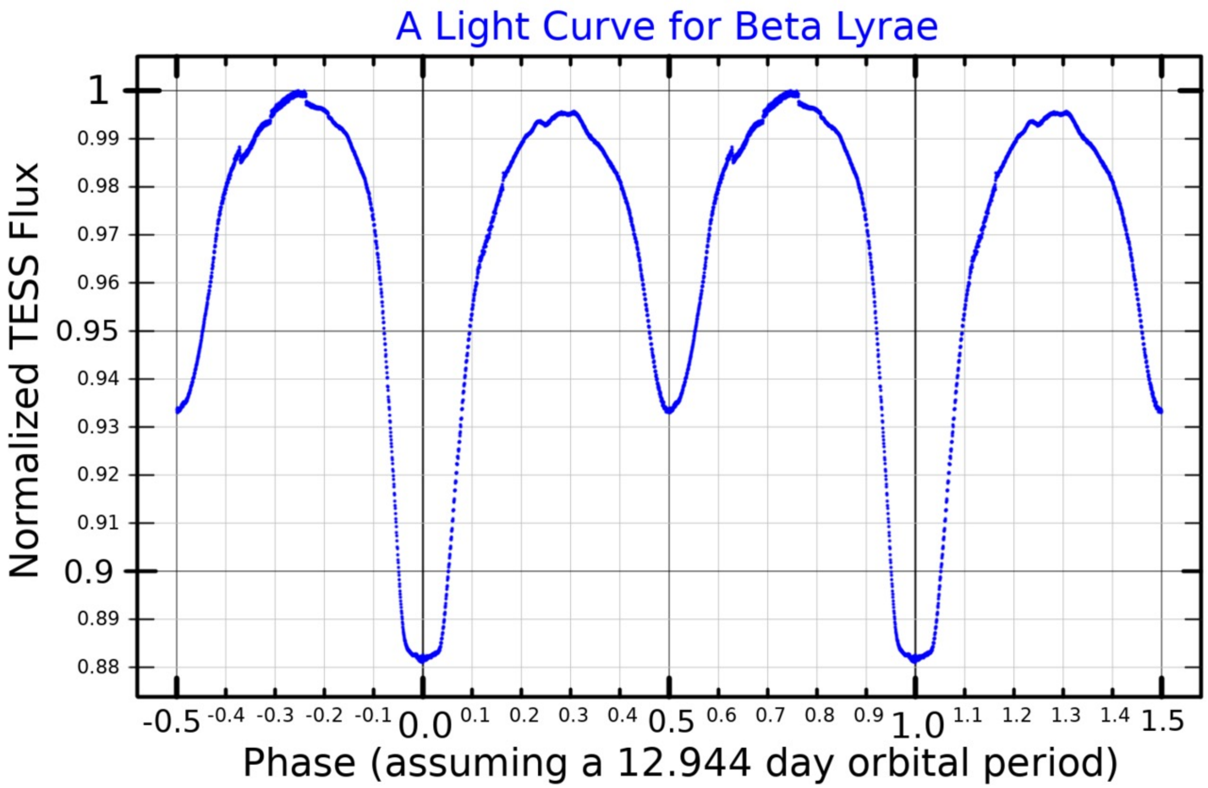
Distance to the COSMOS-AzTEC Cluster:
1.19×10^{26} meters

Measuring Distance on Galactic Scales

John Goodricke (1764–1786). This portrait of Goodricke by artist J. Scouler hangs in the Royal Astronomical Society

Henrietta Swan Leavitt (1868–1921). Leavitt worked as an astronomer at the Harvard College Observatory. While studying photographs of the Magellanic Clouds, she found over 1700 variable stars, including 20 cepheids. Since all the cepheids in these systems were at roughly the same distance, she was able to compare their luminosities and periods of variation. She thus discovered a fundamental relationship between these characteristics that led to a new and much better way of estimating cosmic distances. (credit: modification of work by AIP)

Measuring Distance on Galactic Scales



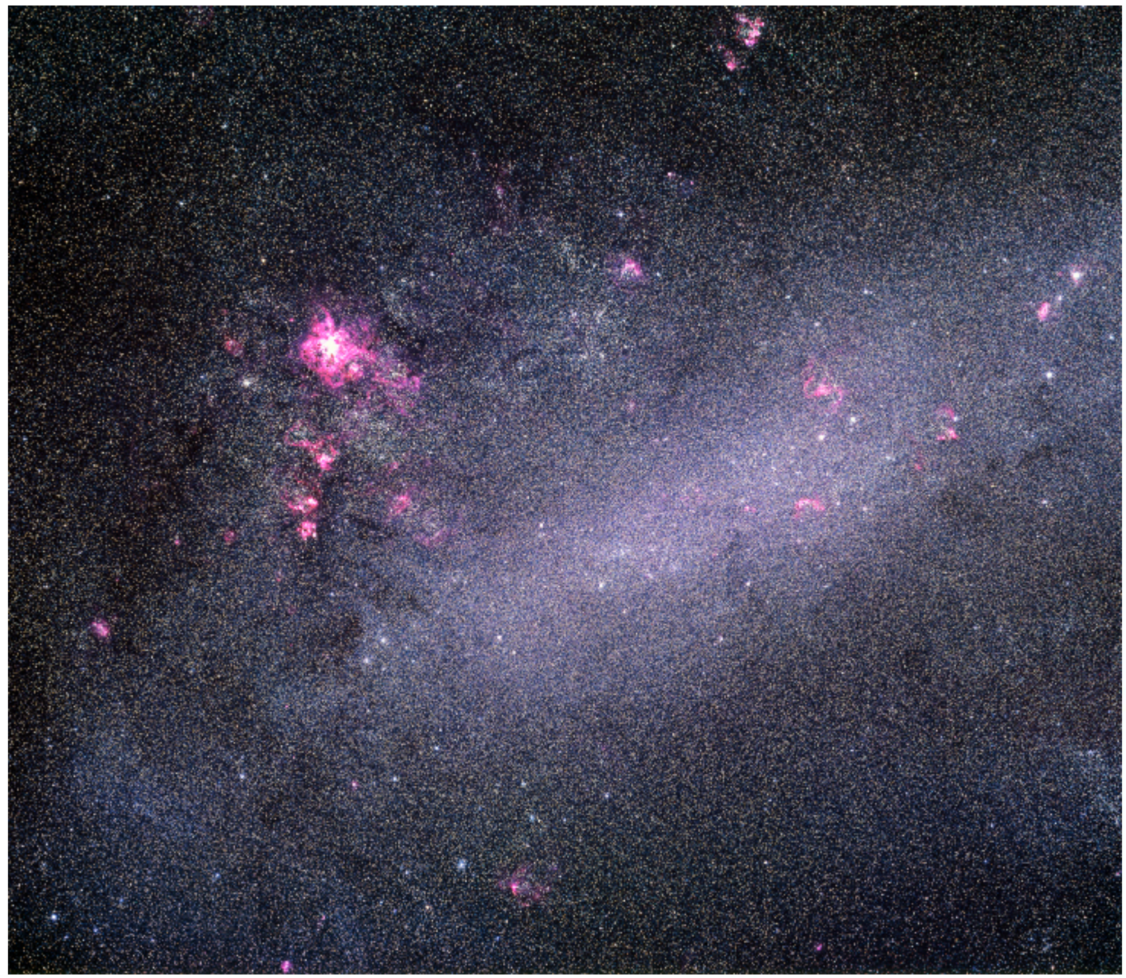
Credit: Wikipedia

Cepheid Light Curve. Goodricke was the first to discover that Beta Lyrae and Delta Cephei was a variable star. The cephelids are named after Delta Cephei.

Credit: Wikipedia

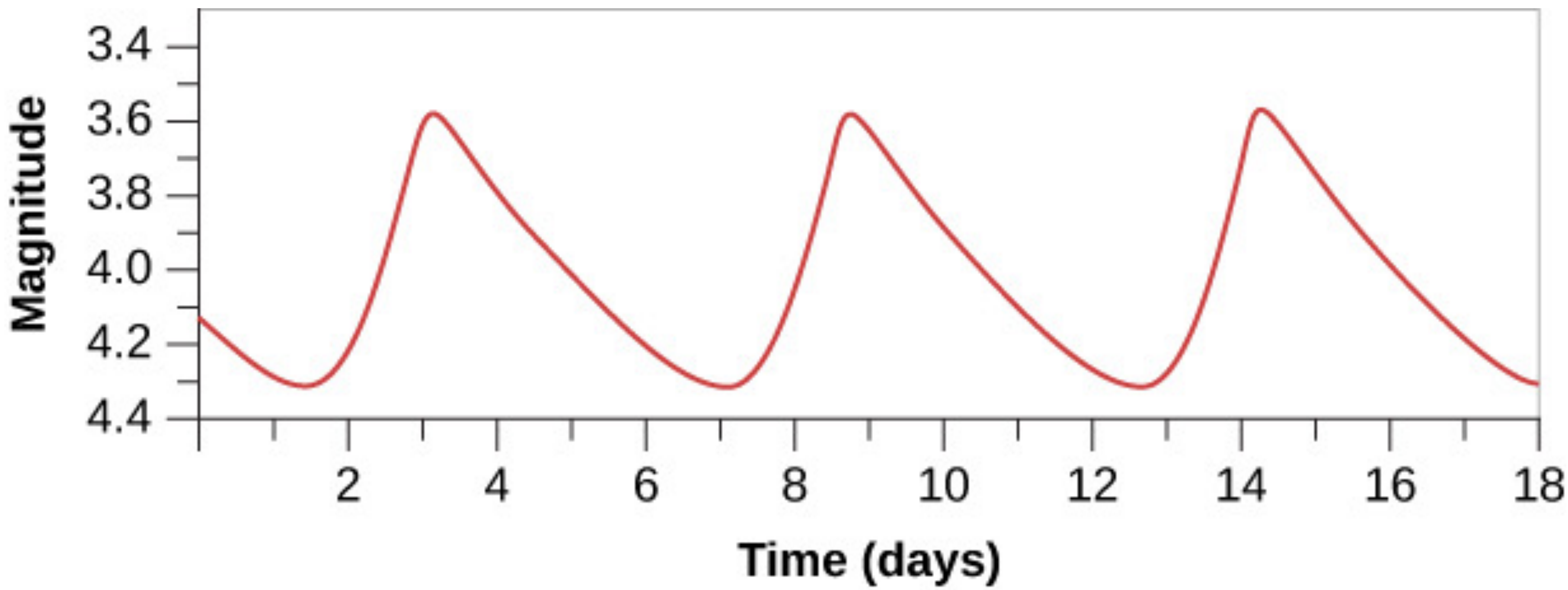
Measuring Distance on Galactic Scales

Leavitt found the period-luminosity relationship of cephelids by examing stars in the Large Magellanic Cloud.

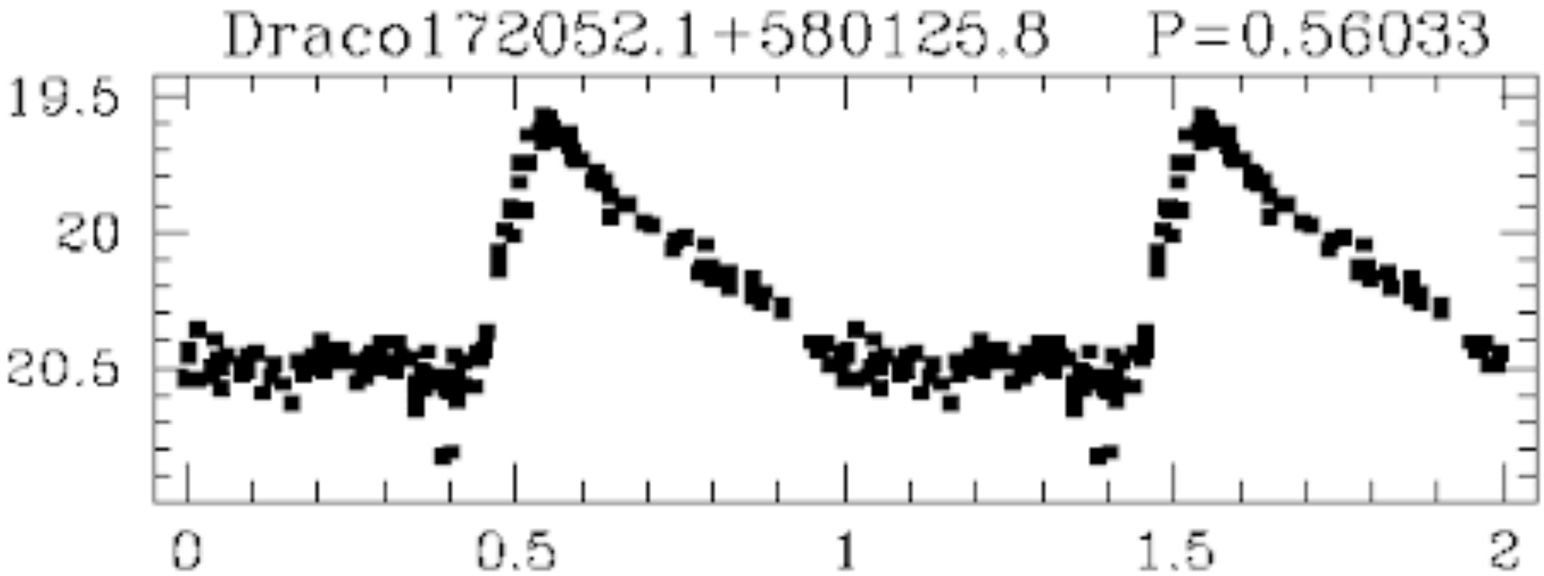


Large Magellanic Cloud. The Large Magellanic Cloud (so named because Magellan's crew were the first Europeans to record it) is a small, irregularly shaped galaxy near our own Milky Way. It was in this galaxy that Henrietta Leavitt discovered the cepheid period-luminosity relation. (credit: ESO)

FIGURE 19.9

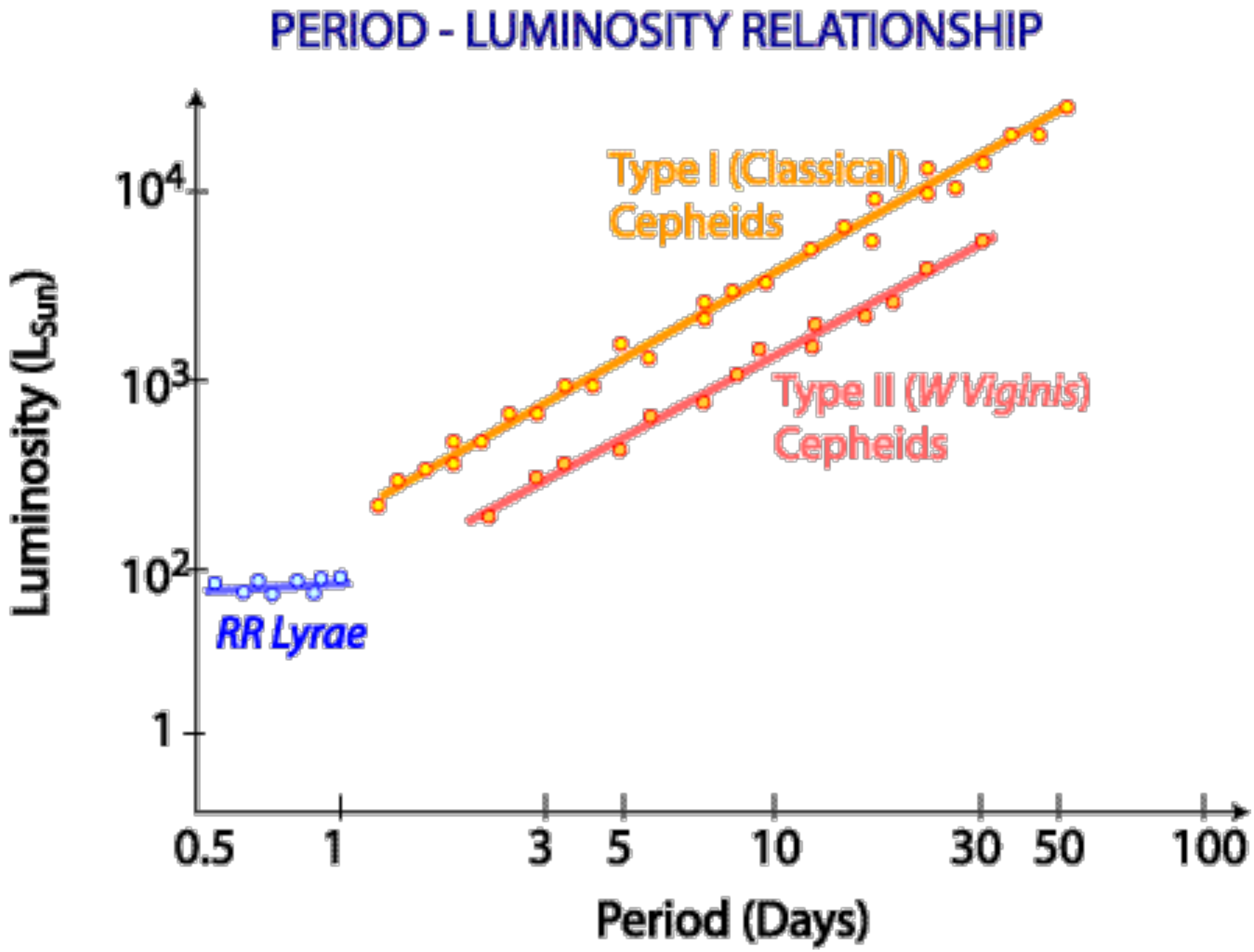


Cepheid Light Curve. This light curve shows how the brightness changes with time for a typical cepheid variable, with a period of about 6 days.



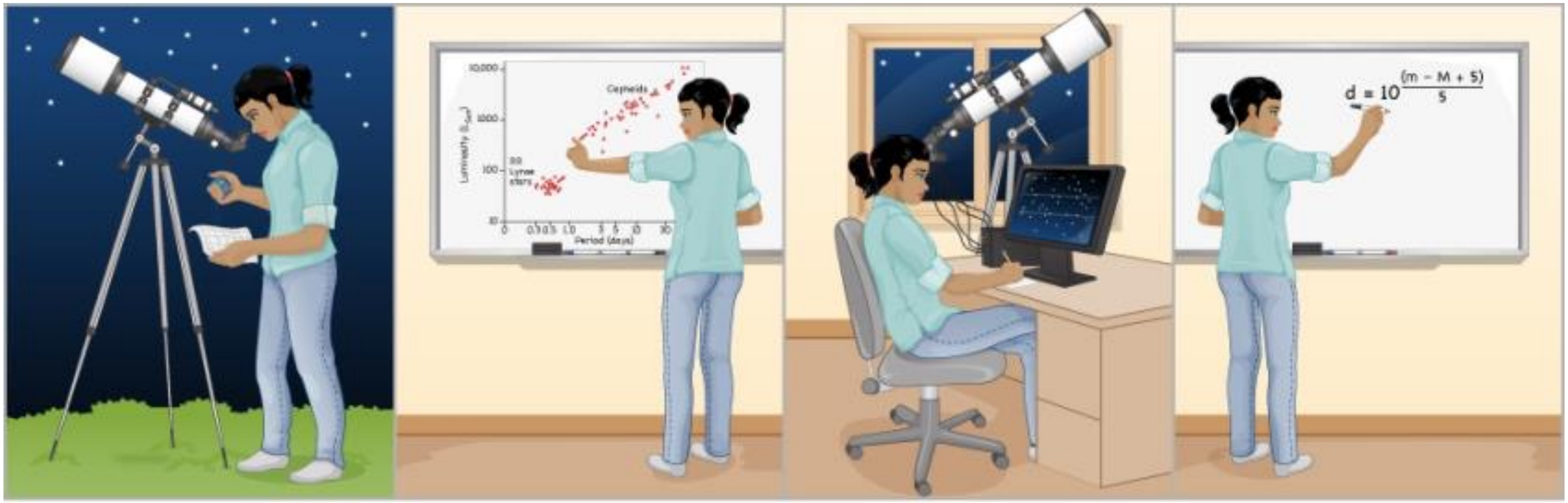
RR Lyrae Light Curve. This light curve shows how the brightness changes with time for a typical RR Lyrae variable, with a period of about 1 day.

Credit: spiff.rit.edu



Credit: The Australian Telescope National Facility

FIGURE 19.12



(a) (b) (c) (d)

How to Use a Cepheid to Measure Distance.

(a) Find a cepheid variable star and measure its period.

(b) Use the period-luminosity relation to calculate the star's luminosity.

(c) Measure the star's apparent brightness.

(d) Compare the luminosity with the apparent brightness to calculate the distance.

$$Apparent\ Brightness = \frac{Luminosity}{4\pi r^2}$$

DISTANCES FROM SPECTRAL TYPES

As satisfying and productive as variable stars have been for distance measurement, these stars are rare and are not found near all the objects to which we wish to measure distances.

Suppose, for example, we need the distance to a star that is not varying, or to a group of stars, none of which is a variable.

In this case, it turns out the H–R diagram can come to our rescue.

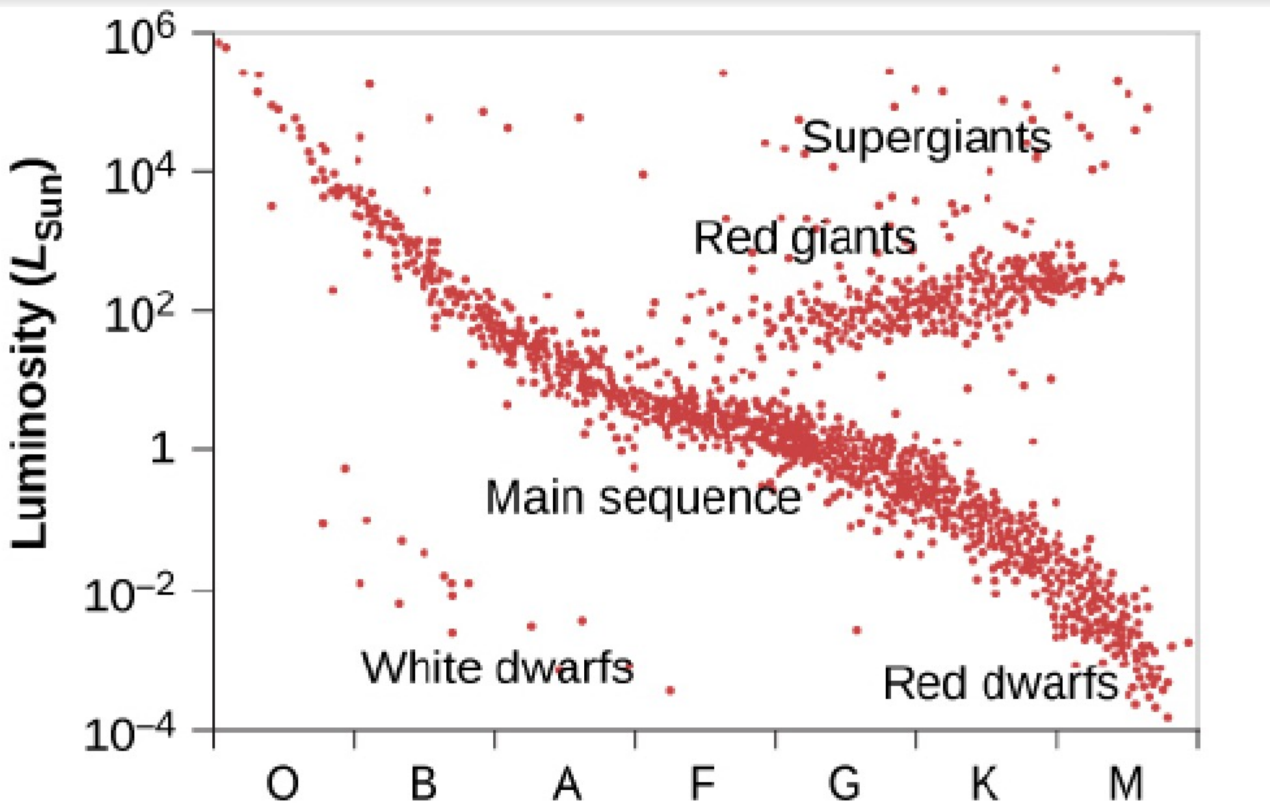
DISTANCES FROM SPECTRAL TYPES

If we can observe the spectrum of a star, we can estimate its distance from our understanding of the H–R diagram.

If there were only main sequence stars, then spectral type alone would place the star at a unique place on the HR diagram, from which we could read off the luminosity,

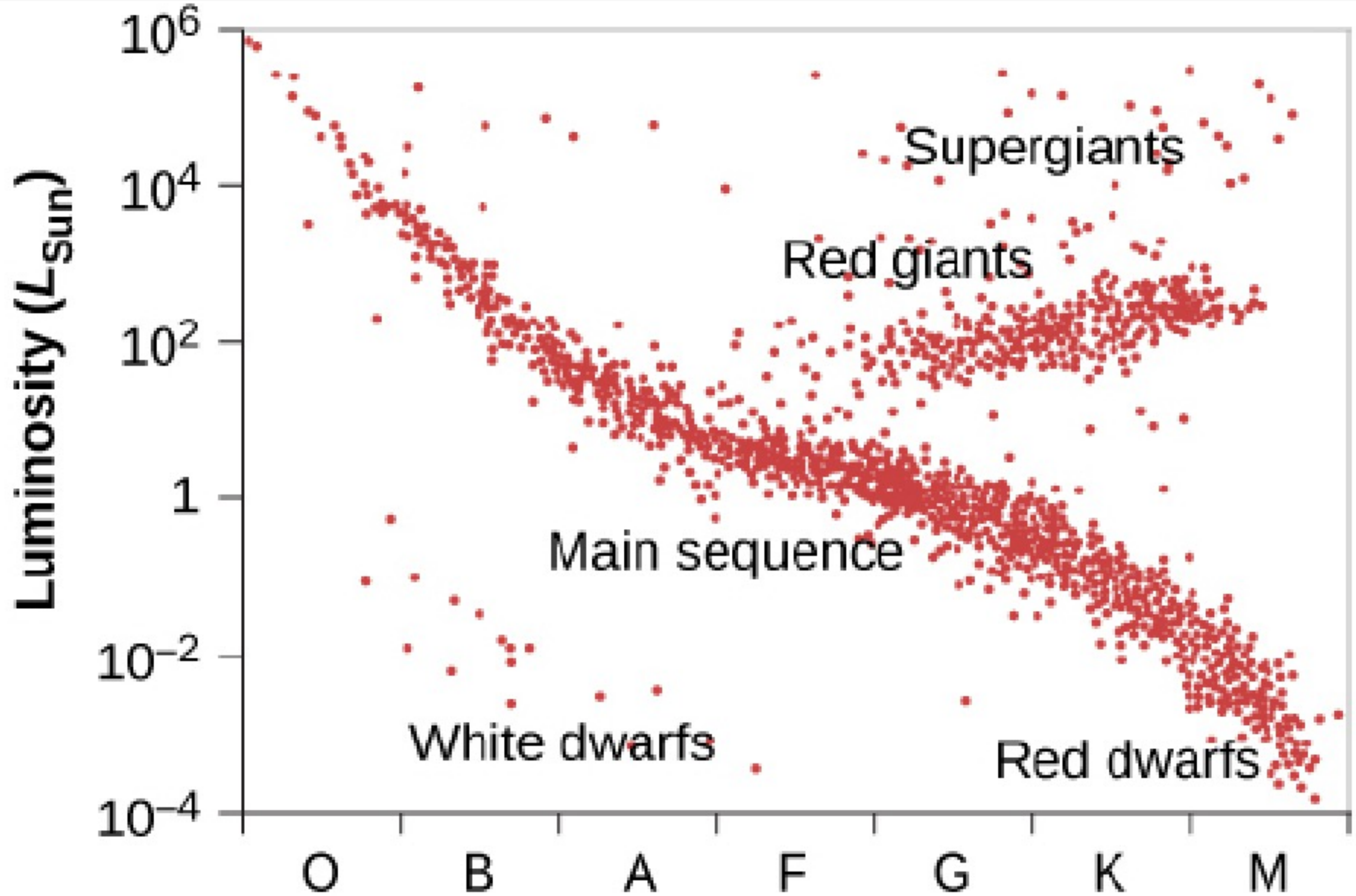
And from the brightness vs luminosity, get the distance.

BUT…



DISTANCES FROM SPECTRAL TYPES

We need to distinguish between dwarfs, giants, and supergiants:



LUMINOSITY CLASSES

We can learn more from a star's spectrum, however, than just its temperature.

We can detect pressure differences in stars from the details of the spectrum.

This knowledge is very useful because giant stars are larger (and have lower pressures) than main-sequence stars, and supergiants are still larger than giants.

If we look in detail at the spectrum of a star, we can determine whether it is a main-sequence star, a giant, or a supergiant.

MEASUREMENT OF LUMINOSITY CLASSES

We can detect pressure differences in stars from the details of the spectrum.

Absorption lines are pressure sensitive.

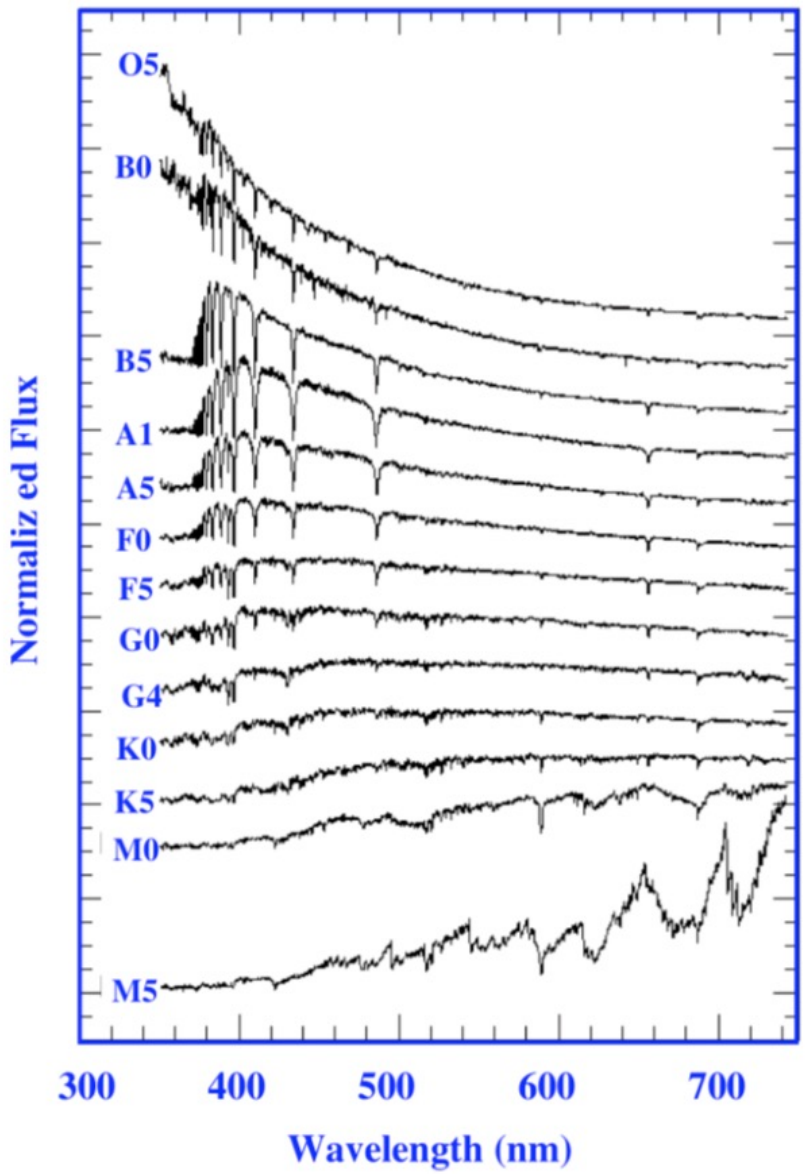
Lines get broader as pressure increases.

Larger stars are puffier, which means lower pressure, so that:

Larger Stars have Narrower Lines

If we look in detail at the spectrum of a star, we can determine whether it is a main-sequence star, a giant, or a supergiant.

SPECTRA OF DWARF (CLASS V) STARS



http://www.astronomy.ohio-state.edu/~jaj/Ast162/lectures/notesWL9.pdf

LUMINOSITY CLASSES

The luminosity classes are denoted by Roman numbers as follows:

- Ia: Brightest supergiants
- Ib: Less luminous supergiants
- II: Bright giants
- III: Giants
- IV: Subgiants (intermediate between giants and main-sequence stars)
- V: Main-sequence stars

LUMINOSITY CLASSES

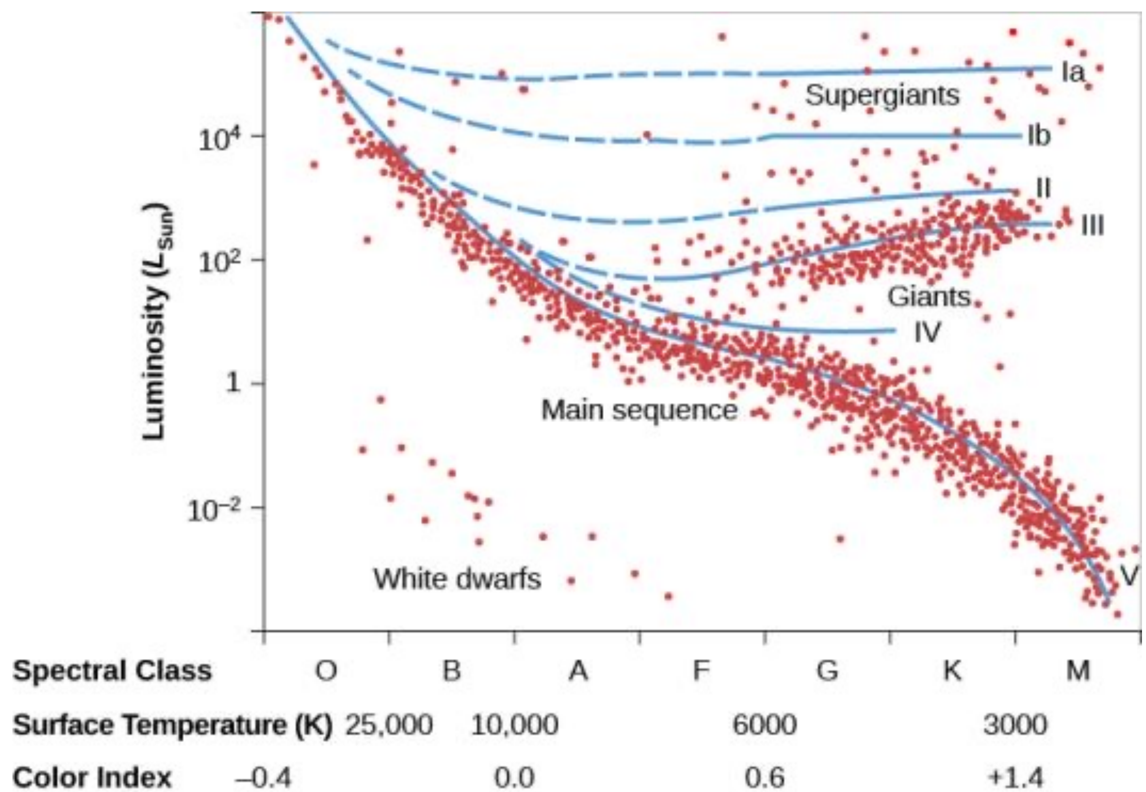
The full spectral specification of a star includes its luminosity class.

For example:

a main-sequence star with spectral class F3 is written as F3 V.

The specification for an M2 giant is M2 III.

FIGURE 19.15



Luminosity Classes. Stars of the same temperature (or spectral class) can fall into different luminosity classes on the Hertzsprung-Russell diagram. By studying details of the spectrum for each star, astronomers can determine which luminosity class they fall in (whether they are main-sequence stars, giant stars, or supergiant stars).

THE COSMIC DISTANCE LADDER

This chain of methods allows astronomers to push the limits when looking for even more distant stars.

Recent work, for example, has used RR Lyrae stars to identify dim companion galaxies to our own Milky Way out at distances of 300,000 light-years.

The H–R diagram method was recently used to identify the two most distant stars in the Galaxy: red giant stars way out in the halo of the Milky Way with distances of almost 1 million light years.

Distance Range of Celestial Measurement Methods

Method	Distance Range
Trigonometric parallax	4–30,000 light-years when the Gaia mission is complete
RR Lyrae stars	Out to 300,000 light-years
H–R diagram and spectroscopic distances	Out to 1,200,000 light-years
Cepheid stars	Out to 60,000,000 light-years

ASTRONOMY

Chapter 19 CELESTIAL DISTANCES

Chapter 20 BETWEEN THE STARS: GAS AND DUST IN SPACE

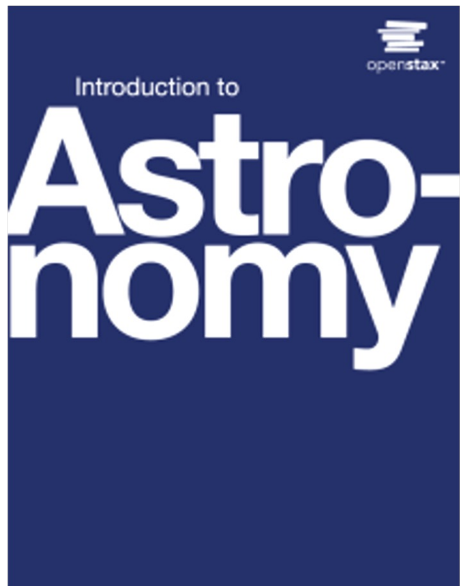


FIGURE 20.9

Barnard 68. This object, first catalogued by E. E. Barnard, is a dark interstellar cloud. Its striking appearance is due to the fact that, since it is relatively close to Earth, there are no bright stars between us and it, and its dust obscures the light from the stars behind it. (It looks a little bit like a sideways heart; one astronomers sent a photo of this object to his sweetheart as a valentine.) (credit: modification of work by ESO)

FIGURE 20.2

Various Types of Interstellar Matter. The reddish nebulae in this spectacular photograph glow with light emitted by hydrogen atoms. The darkest areas are clouds of dust that block the light from stars behind them. The upper part of the picture is filled with the bluish glow of light reflected from hot stars embedded in the outskirts of a huge, cool cloud of dust and gas. The cool supergiant star Antares can be seen as a big, reddish patch in the lower-left part of the picture. The star is shedding some of its outer atmosphere and is surrounded by a cloud of its own making that reflects the red light of the star. The red nebula in the middle right partially surrounds the star Sigma Scorpii. (To the right of Antares, you can see M4, a much more distant cluster of extremely old stars.) (credit: modification of work by ESO/Digitized Sky Survey 2)

THE STAR-GAS-STAR CYCLE

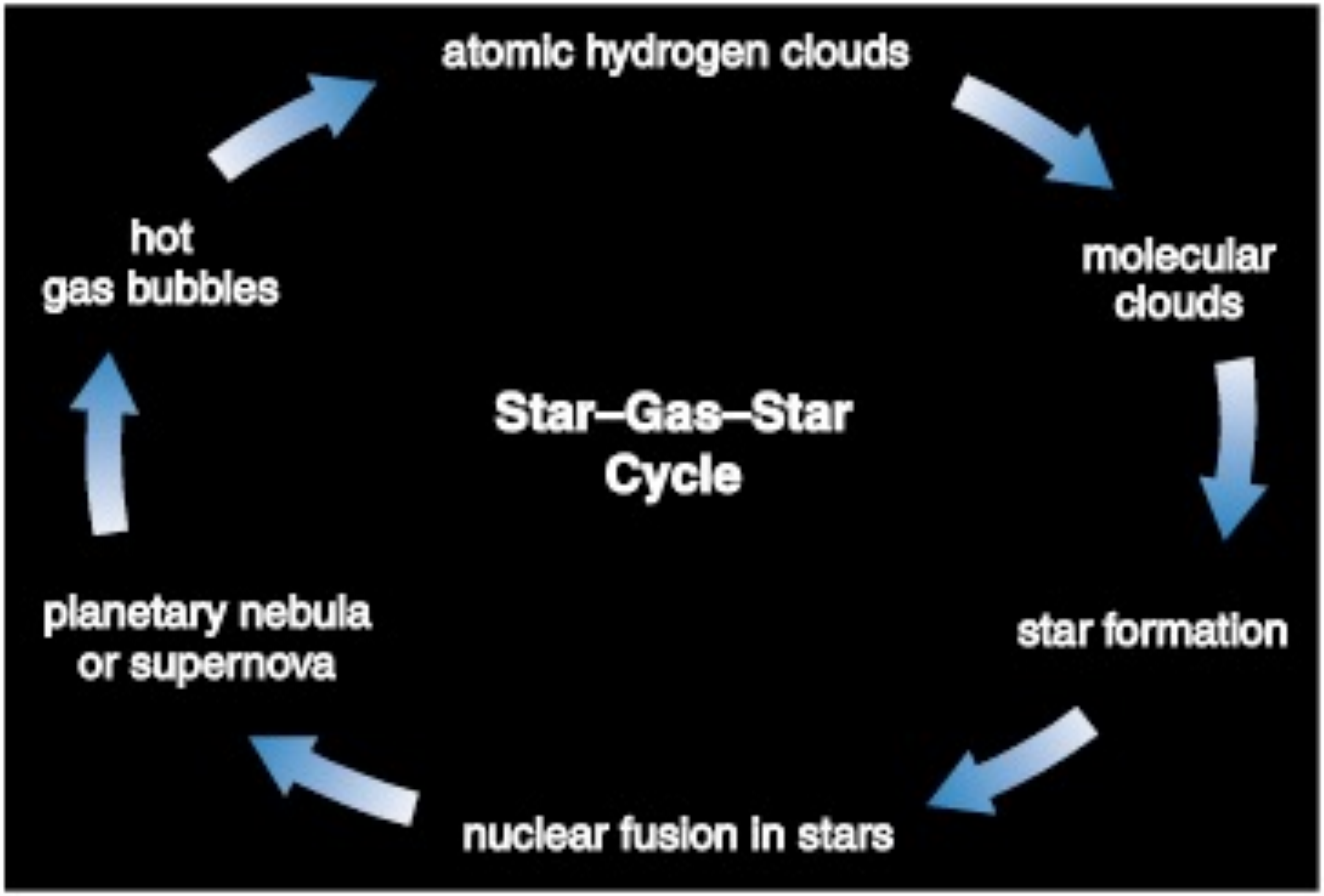


Figure 11.4 | The star–gas–star cycle.

Figure 11.4. Page 181. *The Cosmic Perspective Fundamentals*. Publisher: Addison-Wesley. © 2010

THE STAR–GAS–STAR CYCLE

In the Milky Way's disk, stars are continually forming and dying within it through a process we will call the star–gas–star cycle (Figure 11.4).

Several of the steps in this cycle are already familiar:

- Stars are born when gravity causes the collapse of molecular clouds within the interstellar medium.
- They shine for millions or billions of years with energy produced by nuclear fusion, dying only when they've exhausted their fuel for fusion.
- As they die, they return much of their material back to the interstellar medium—through a planetary nebula in the case of a low-mass star or through a supernova in the case of a high-mass star.

GAS IN THE INTERSTELLAR MEDIUM

The remaining stages of the star–gas–star cycle take place in the interstellar medium. Gas ejected by stars, particularly the gas from supernova explosions, often enters the interstellar medium in the form of a hot bubble.

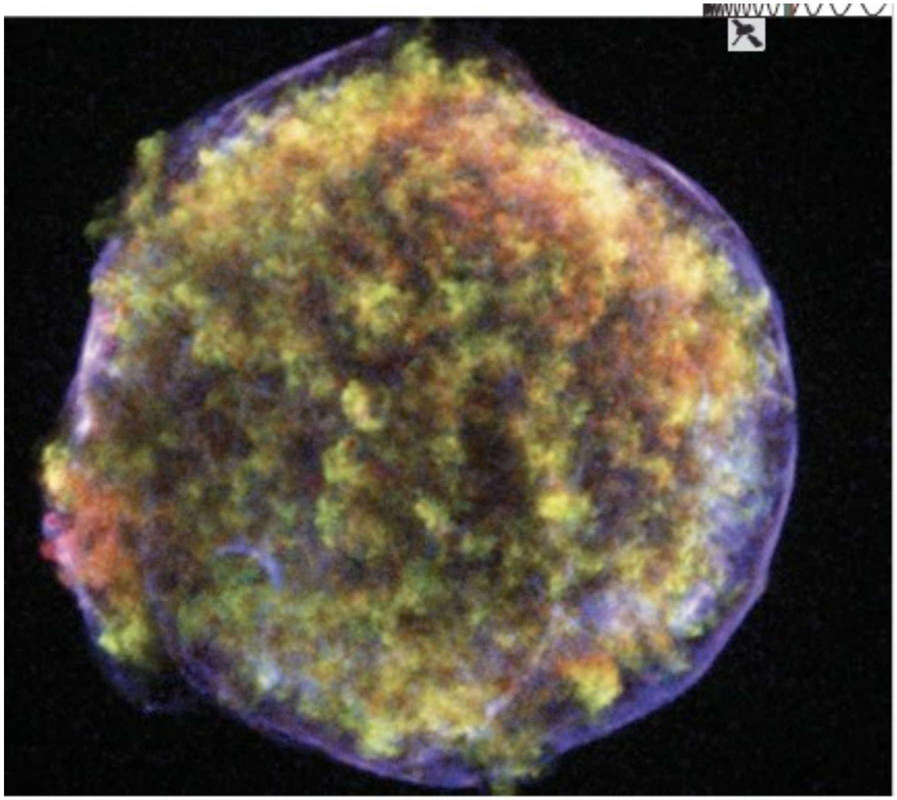


Figure to Left. The bubble produced by a 400-year-old supernova explosion, which contains ionized gas hot enough to emit X rays. This million-degree gas takes many thousands of years to cool, but eventually reaches a temperature of around 10^4 K, which is still quite warm but cool enough for hydrogen atoms to remain neutral rather than being ionized.

SLOW COOLING OF THE INTERSTELLAR MEDIUM

Matter remains in the warm atomic hydrogen stage for millions of years, and during this time gravity slowly draws blobs of atomic gas together into tighter clumps, which radiate energy and cool more efficiently as they grow denser.

Even so, the interstellar medium remains a nearly perfect vacuum by earthly standards: On average, each cubic centimeter contains only one hydrogen atom.

The temperature of these gas clumps eventually drops well below 100 K, allowing the hydrogen atoms to pair up into hydrogen molecules. The cool, dense clumps then become molecular clouds which go on to form stars, thereby completing the star–gas–star cycle.

HEAVY ELEMENTS

In addition to making new generations of stars possible, this galactic recycling process gradually changes the chemical composition of the interstellar medium.

Recall that the early universe contained only the chemical elements hydrogen and helium; all heavier elements have been produced by stars. The newly created elements mix with other interstellar gas and become incorporated into new generations of stars.

That is how our solar system came to have the elements from which our planet was made. Today, thanks to more than 10 billion years of galactic recycling, elements heavier than helium constitute about 2% of the galaxy’s gaseous content by mass.The remaining 98% consists of hydrogen (about 70%) and helium (about 28%).

STAR-FORMING REGIONS

The star–gas–star cycle has operated continuously since the Milky Way's birth, yet new stars are not spread evenly across the galaxy. Some regions seem much more fertile than others. Galactic environments rich in molecular clouds tend to spawn new stars easily, while gas-poor environments do not. However, molecular clouds are dark and hard to see, so we often have to look for other signs of star formation.

Wherever we see hot, massive stars, we know that we have spotted a region of active star formation. Because these stars live fast and die young, they never get a chance to move very far from their birth mates. They therefore signal the presence of star clusters in which many of their lower-mass companions are still forming.

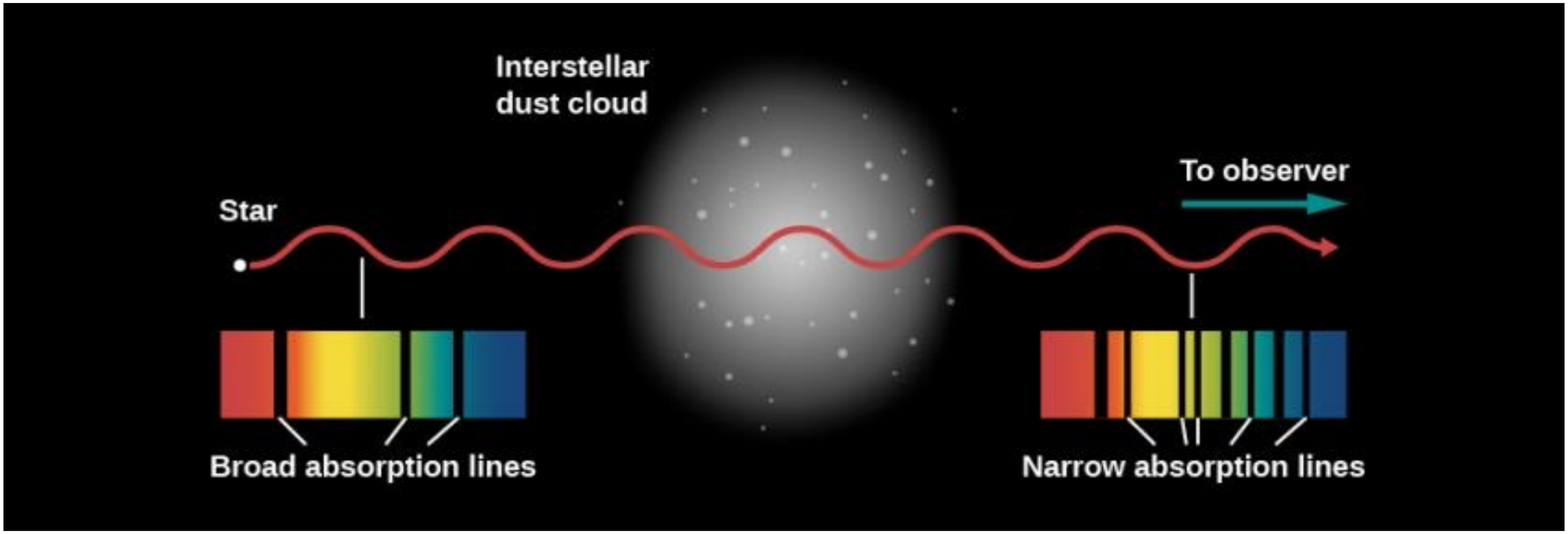
FIGURE 20.1

NGC 3603 and Its Parent Cloud. This image, taken by the Hubble Space Telescope, shows the young star cluster NGC 3603 interacting with the cloud of gas from which it recently formed. The bright blue stars of the cluster have blown a bubble in the gas cloud. The remains of this cloud can be seen in the lower right part of the frame, glowing in response to the starlight illuminating it. In its darker parts, shielded from the harsh light of NGC 3603, new stars continue to form. Although the stars of NGC 3603 formed only recently, the most massive of them are already dying and ejecting their mass, producing the blue ring and streak features visible in the upper left part of the image. Thus, this image shows the full life cycle of stars, from formation out of interstellar gas, through life on the main sequence, to death and the return of stellar matter to interstellar space. (credit: modification of work by NASA, Wolfgang Brandner (JPL/IPAC), Eva K. Grebel (University of Washington), You-Hua Chu (University of Illinois Urbana-Champaign))

FIGURE 20.3

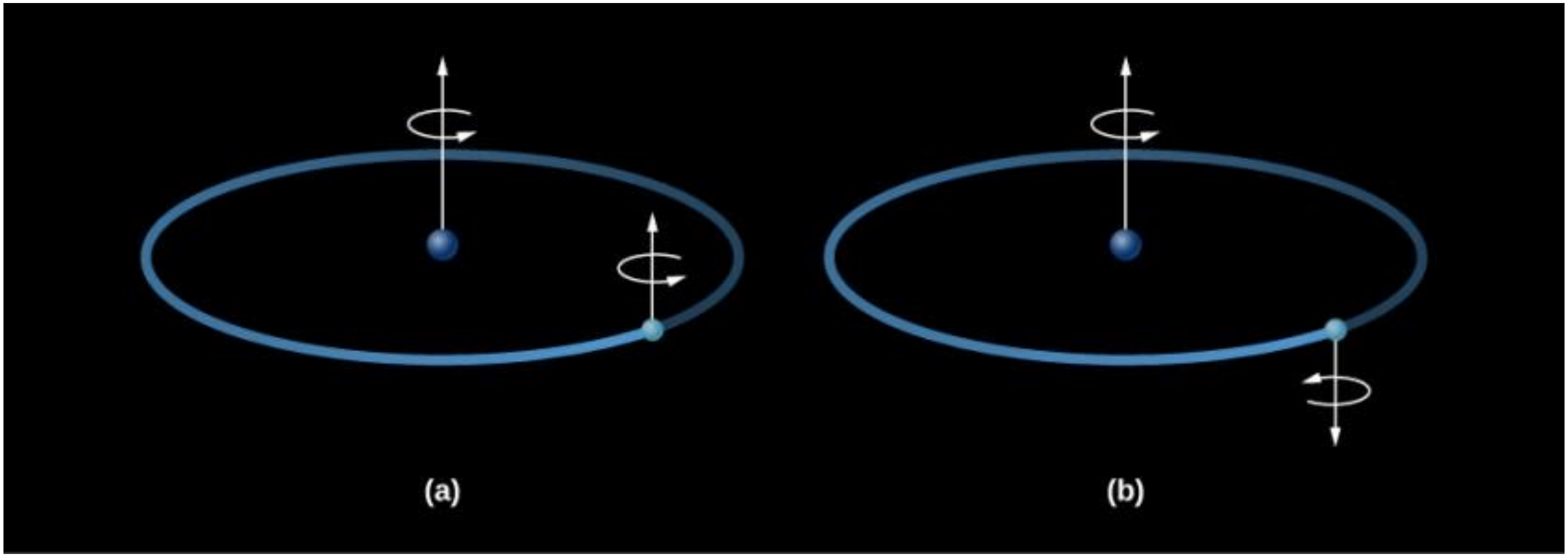
Orion Nebula. The red glow that pervades the great Orion Nebula is produced by the first line in the Balmer series of hydrogen. Hydrogen emission indicates that there are hot young stars nearby that ionize these clouds of gas. When electrons then recombine with protons and move back down into lower energy orbits, emission lines are produced. The blue color seen at the edges of some of the clouds is produced by small particles of dust that scatter the light from the hot stars. Dust can also be seen silhouetted against the glowing gas. (credit: NASA,ESA, M. Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Project Team)

FIGURE 20.4



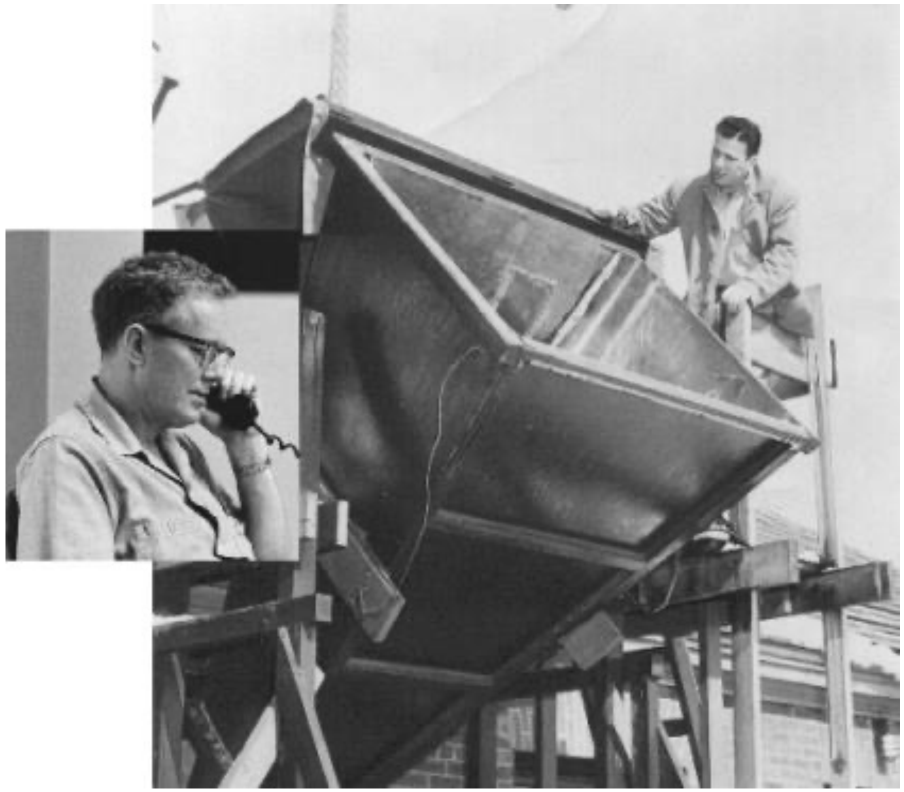
Absorption Lines though an Interstellar Dust Cloud. When there is a significant amount of cool interstellar matter between us and a star, we can see the absorption lines of the gas in the star's spectrum. We can distinguish the two kinds of lines because, whereas the star's lines are broad, the lines from the gas are narrower.

FIGURE 20.5



Formation of the 21-Centimeter Line. When the electron in a hydrogen atom is in the orbit closest to the nucleus, the proton and the electron may be spinning either (a) in the same direction or (b) in opposite directions. When the electron flips over, the atom gains or loses a tiny bit of energy by either absorbing or emitting electromagnetic energy with a wavelength of 21 centimeters.

FIGURE 20.6

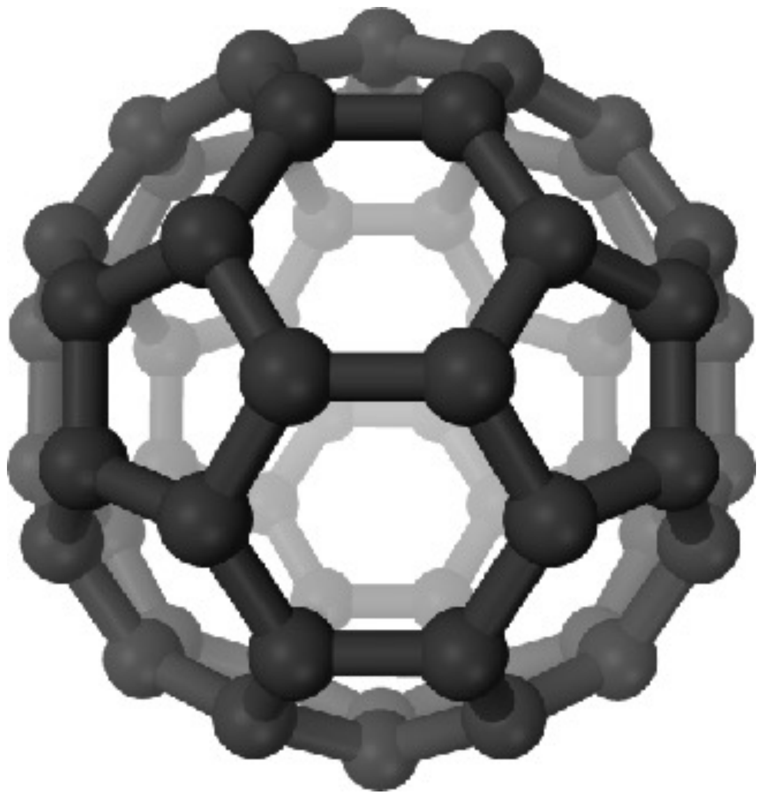


Harold Ewen (1922–2015) and Edward Purcell (1912–1997). We see Harold Ewen in 1952 working with the horn antenna (atop the physics laboratory at Harvard) that made the first detection of interstellar 21-cm radiation. The inset shows Edward Purcell, the winner of the 1952 Nobel Prize in physics, a few years later. (credit: modification of work by NRAO)

FIGURE 20.7

Vela Supernova Remnant. About 11,000 years ago, a dying star in the constellation of Vela exploded, becoming as bright as the full moon in Earth's skies. You can see the faint rounded filaments from that explosion in the center of this colorful image. The edges of the remnant are colliding with the interstellar medium, heating the gas they plow through to temperatures of millions of K. Telescopes in space also reveal a glowing sphere of X-ray radiation from the remnant. (credit: Digitized Sky Survey, ESA/ESO/NASA FITS Liberator, Davide De Martin)

FIGURE 20.8



Fullerene C60. This three-dimensional perspective shows the characteristic cage-like arrangement of the 60 carbon atoms in a molecule of fullerene C60. Fullerene C60 is also known as a “buckyball,” or as its full name, buckminsterfullerene, because of its similarity to the multisided architectural domes designed by American inventor R. Buckminster Fuller.

FIGURE 20.10

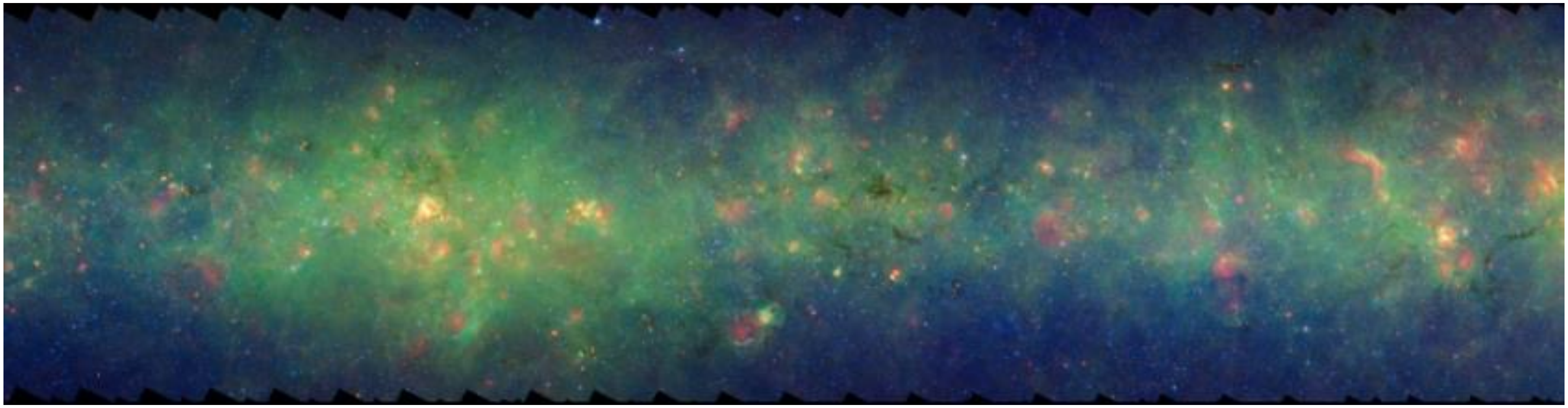
Edward Emerson Barnard (1857–1923). Barnard's observations provided information that furthered many astronomical explorations. (credit: The Lick Observatory)

FIGURE 20.11

(a) (b)

Visible and Infrared Images of the Horsehead Nebula in Orion. This dark cloud is one of the best-known images in astronomy, probably because it really does resemble a horse's head. The horse-head shape is an extension of a large cloud of dust that fills the lower part of the picture. (a) Seen in visible light, the dust clouds are especially easy to see against the bright background. (b) This infrared radiation image from the region of the horse head was recorded by NASA's Wide-Field Infrared Survey Explorer. Note how the regions that appear dark in visible light appear bright in the infrared. The dust is heated by nearby stars and re-radiates this heat in the infrared. Only the top of the horse's head is visible in the infrared image. Bright dots seen in the nebula below and to the left and at the top of the horse head are young, newly formed stars. The insets show the horse head and the bright nebula in more detail. (credit a: modification of work by ESO and Digitized Sky Survey; credit b: modification of work by NASA/JPL-Caltech)

FIGURE 20.12

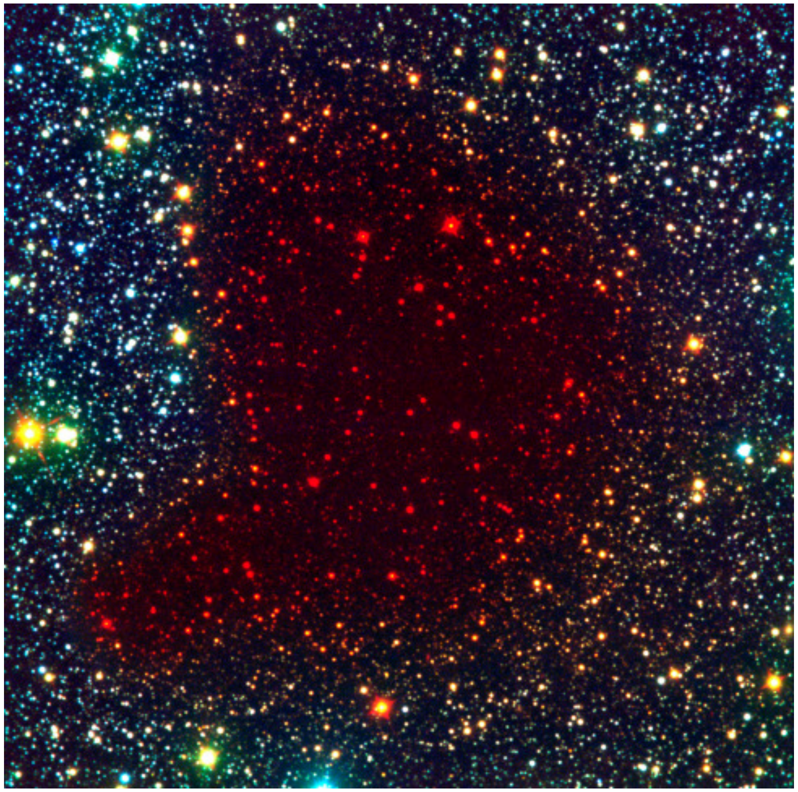


Infrared Emission from the Plane of the Milky Way. This infrared image taken by the Spitzer Space Telescope shows a field in the plane of the Milky Way Galaxy. (Our Galaxy is in the shape of a frisbee; the plane of the Milky Way is the flat disk of that frisbee. Since the Sun, Earth, and solar system are located in the plane of the Milky Way and at a large distance from its center, we view the Galaxy edge on, much as we might look at a glass plate from its edge.) This emission is produced by tiny dust grains, which emit at 3.6 microns (blue in this image), 8.0 microns (green), and 24 microns (red). The densest regions of dust are so cold and opaque that they appear as dark clouds even at these infrared wavelengths. The red bubbles visible throughout indicate regions where the dust has been warmed up by young stars. This heating increases the emission at 24 microns, leading to the redder color in this image. (credit: modification of work by NASA/JPL-Caltech/University of Wisconsin)

FIGURE 20.13

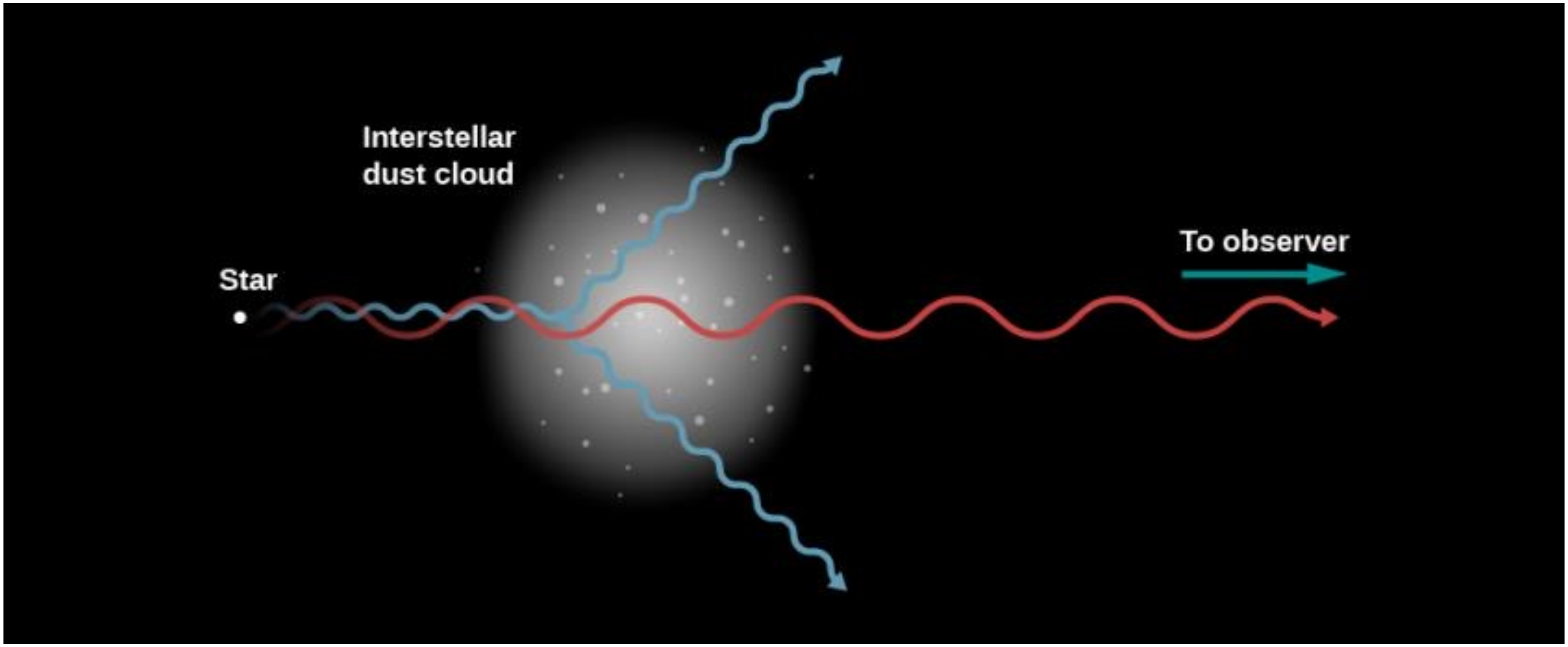
Pleiades Star Cluster. The bluish light surrounding the stars in this image is an example of a reflection nebula. Like fog around a street lamp, a reflection nebula shines only because the dust within it scatters light from a nearby bright source. The Pleiades cluster is currently passing through an interstellar cloud that contains dust grains, which scatter the light from the hot blue stars in the cluster. The Pleiades cluster is about 400 light-years from the Sun. (credit: NASA, ESA and AURA/Caltech)

FIGURE 20.14



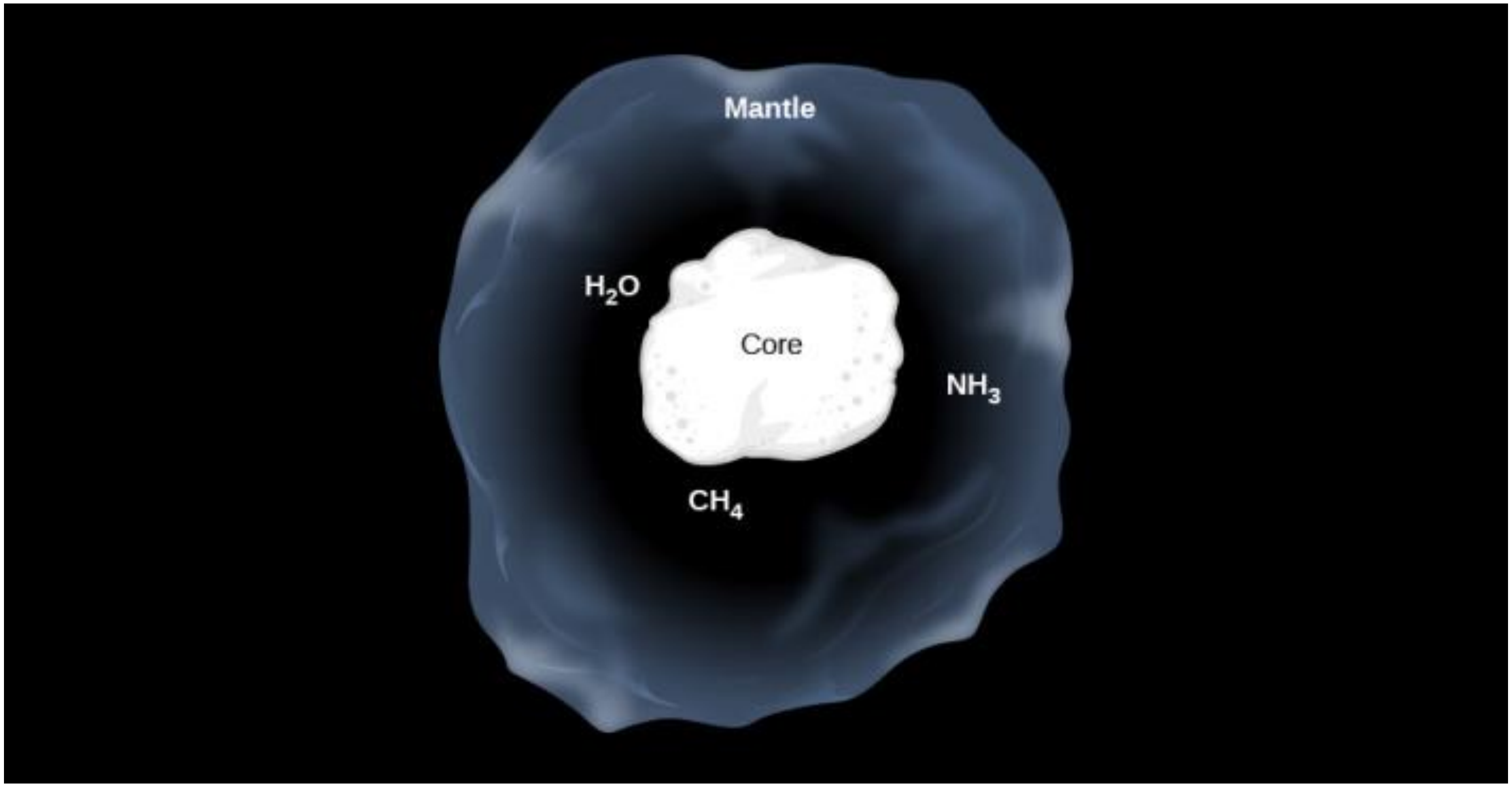
Barnard 68 in Infrared. In this image, we see Barnard 68, the same object shown in Figure 20.9. The difference is that, in the previous image, the blue, green, and red channels showed light in the visible (or very nearly visible) part of the spectrum. In this image, the red color shows radiation emitted in the infrared at a wavelength of 2.2 microns. Interstellar extinction is much smaller at infrared than at visible wavelengths, so the stars behind the cloud become visible in the infrared channel. (credit: ESO)

FIGURE 20.15



Scattering of Light by Dust. Interstellar dust scatters blue light more efficiently than red light, thereby making distant stars appear redder and giving clouds of dust near stars a bluish hue. Here, a red ray of light from a star comes straight through to the observer, whereas a blue ray is shown scattering. A similar scattering process makes Earth's sky look blue.

FIGURE 20.16

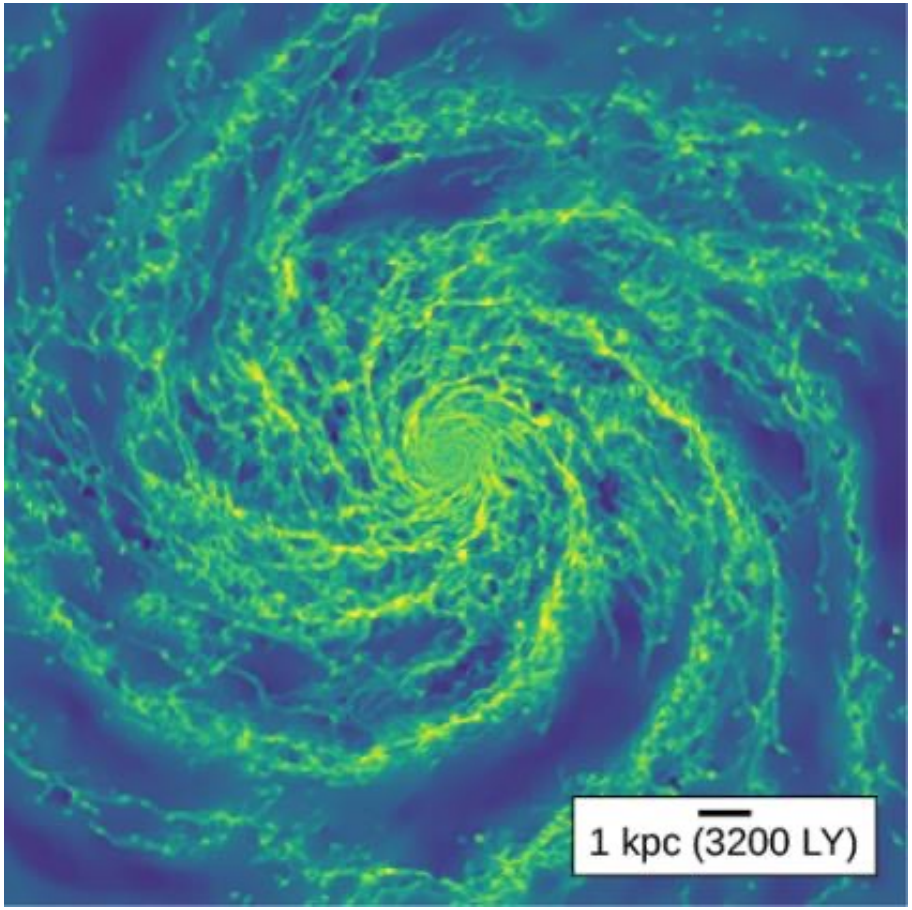


Model of an Interstellar Dust Grain. A typical interstellar grain is thought to consist of a core of rocky material (silicates) or graphite, surrounded by a mantle of ices. Typical grain sizes are 10^{-8} to 10^{-7} meters. (This is from 1/100 to 1/10 of a micron; by contrast, human hair is about 10–200 microns wide.)

FIGURE 20.17

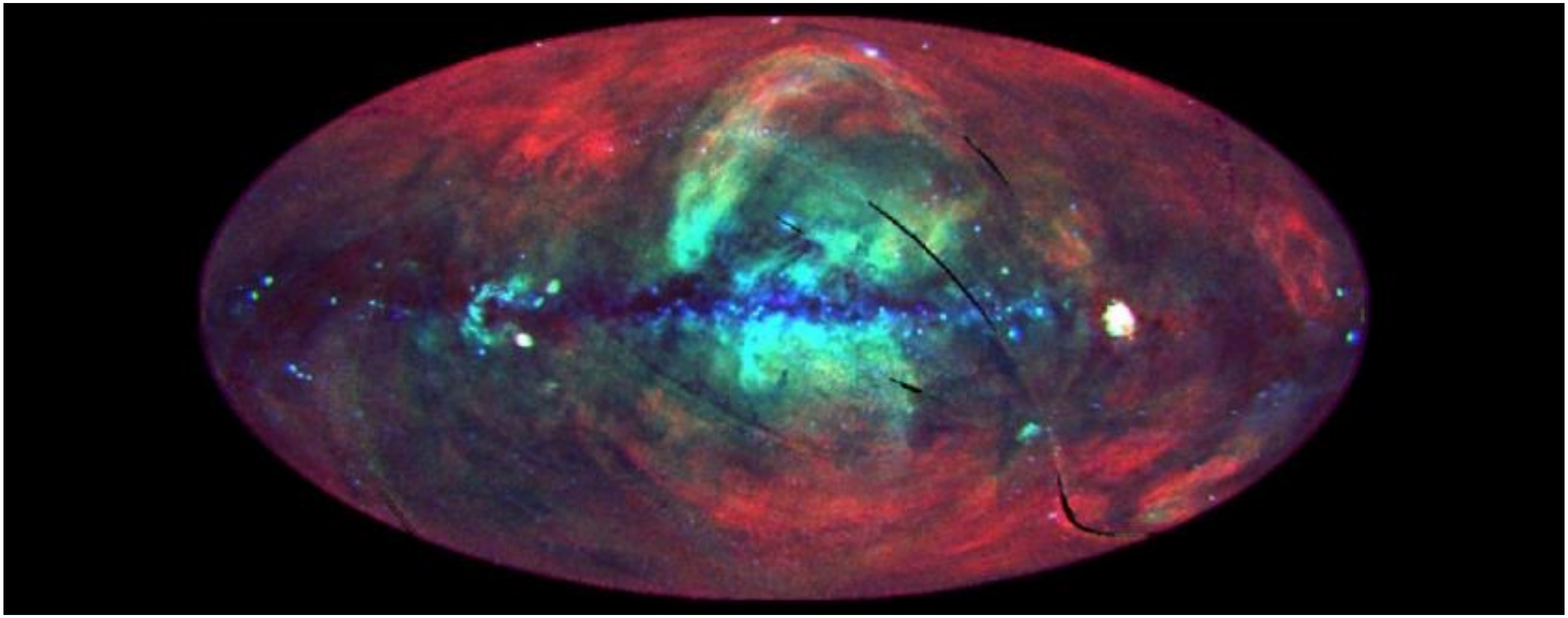
Victor Hess (1883–1964). Cosmic-ray pioneer Victor Hess returns from a 1912 balloon flight that reached an altitude of 5.3 kilometers. It was on such balloon flights that Hess discovered cosmic rays.

FIGURE 20.18



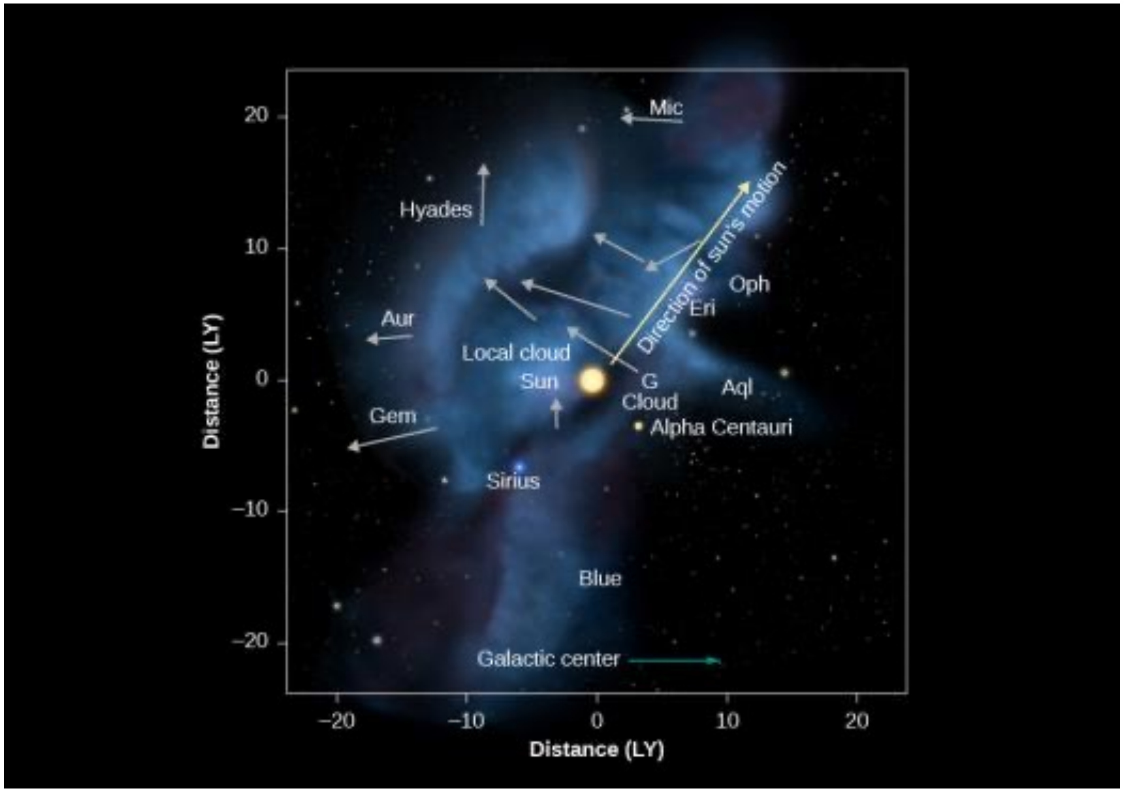
Large-Scale Distribution of Interstellar Matter. This image is from a computer simulation of the Milky Way Galaxy's interstellar medium as a whole. The majority of gas, visible in greenish colors, is neutral hydrogen. In the densest regions in the spiral arms, shown in yellow, the gas is collected into giant molecular clouds. Low-density holes in the spiral arms, shown in blue, are the result of supernova explosions. (credit: modification of work by Mark Krumholz)

FIGURE 20.19



Sky in X-Rays. This image, made by the ROSAT satellite, shows the whole sky in X-rays as seen from Earth. Different colors indicate different X-ray energies: red is 0.25 kiloelectron volts, green is 0.75 kiloelectron volts, and blue is 1.5 kiloelectron volts. The image is oriented so the plane of the Galaxy runs across the middle of the image. The ubiquitous red color, which does not disappear completely even in the galactic plane, is evidence for a source of X-rays all around the Sun. (credit: modification of work by NASA)

FIGURE 20.20



Local Fluff. The Sun and planets are currently moving through the Local Interstellar Cloud, which is also called the Local Fluff. Fluff is an appropriate description because the density of this cloud is only about 0.3 atom per cm3. In comparison, Earth's atmosphere at the edge of space has around 1.2 × 1013 molecules per cm3. This image shows the patches of interstellar matter (mostly hydrogen gas) within about 20 light-years of the Sun. The temperature of the Local Interstellar Cloud is about 7,000 K. The arrows point toward the directions that different parts of the cloud are moving. The names associated with each arrow indicate the constellations located on the sky toward which the parts of the cloud are headed. The solar system is thought to have entered the Local Interstellar Cloud, which is a small cloud located within a much larger superbubble that is expanding outward from the Scorpius-Centaurus region of the sky, at some point between 44,000 and 150,000 years ago and is expected to remain within it for another 10,000 to 20,000 years. (credit: modification of work by NASA/Goddard/Adler/ University Chicago/Wesleyan)

SUMMARY

- Distance Measurements
  a) Parallax
  b) Cepheid Variables
- Stellar Luminosity Classes
- Interstellar Matter
- The Star-Gas-Star Cycle

READ CHAPTER 19

READ CHAPTER 20

Homework Problems on Canvas

Due by Sunday night

No Late Submissions

QUESTION ABOUT SOLAR ENERGY GENERATION

Today we realize that the source of energy for the Sun is a process called

a. nuclear fusion

b. Kelvin-Helmholtz contraction

c. mechanical to thermal energy conversion

d. radioactivity

e. dilithium crystal moderation

QUESTION ABOUT SOLAR ENERGY GENERATION

Where in the Sun does fusion of hydrogen occur?

a. only in the core

b. only near the photosphere (its visible surface layer)

c. pretty much throughout the entire body of the Sun

d. only in the layer where there is a lot of convection going on

e. nowhere

QUESTION ABOUT THE SUN

Which of the following, produced at the core of the Sun, will take the shortest time to emerge from the Sun's photosphere (surface)?

a. a photon (wave) of gamma-rays

b. a positron

c. a neutrino

d. a deuteron

e. an x-ray produced after radiation has interacted with matter in the core

QUESTION ABOUT STARS

Since all stars begin their lives with the same basic composition, what characteristic most determines how they will differ?

(a) location where they are born

(b) time they are born

(c) luminosity they are born with

(d) mass they are born with

(e) color they are born with

QUESTION ABOUT TYPES OF STARS: OBAFGKM

Which of these stars has the coolest surface temperature?

- (a) an A star
- (b) an F star
- (c) a K star

QUESTION ABOUT TYPES OF STARS: OBAFGKM

Which of these stars is the most massive?

- (a) a main-sequence A star
- (b) a main-sequence G star
- (c) a main-sequence M star