Chapter 7

Petaworld

1 000 000 000 000 000 (1.0 x 10^{15}) P

7.1 Petaworld Length

1 – 1000 Petameters (Pm) 1 x 10^{15} m

Distances to Nearby Stars

Star	**Distance**
Alpha Centauri	41 Pm
Barnard's Star	62 Pm
Sirius	81 Pm
61 Cygni	108 Pm
Vega	237 Pm
Capella	405 Pm
Algol	880 Pm
Polaris (North Star)	3 547 Pm
Betelgeuse	6 083 Pm
Rigel	8 136 Pm
Deneb	24 280 Pm

Table 7.1: Petameter Distant Stars

Stars only Petameters distant from Earth can be thought of as "nearby stars." Stars readily expressed in Exameters can be thought of as “far away stars.” In both cases, these stars are within our galaxy. Table 7.1 has a list of nearby stars. Light, and electromagnetic waves in general, travel at the speed of light. Light travels 9.461 Petameters in a year.* In the case of nearby stars, one can very roughly estimate how long it takes light to reach them by using one year per 10 Petameters (1 Year/10 Pm) as an approximation. In the case of Alpha Centauri, it’s about 4 years away when traveling at light-speed, Vega is 23 years, Polaris is 354 years, Rigel is 813 years, and Deneb is 2428 years.

Approximate Time For Light
To Traverse Metric Astronomy Boundaries

Distance	Light Time	Light Time
1000 Petameters	100 Years	1 Century
1000 Exameters	100 000 Years	100 Centuries
1000 Zettameters	100 000 000 Years	100 000 Centuries
1000 Yottameters	100 000 000 000 Years	100 000 000 Centuries

Table 7.2

Table 7.2 shows the approximate time it takes at light-speed to travel to each of the metric prefix boundaries. The light from nearby stars takes about 100 years.† The furthest light we see from a nearby star was generated just after the end of World War I. The light from a far away star, has taken up to 100 000 years to arrive. The light we see from the maximum distance of a far away star, is from a time when only about 200 000 humans populated the Earth. The distance across the Milky Way Galaxy is only about 1000 Em, so all the light we see from stars in our galaxy is from less than 100 000 years ago. The light generated by a star outside our galaxy, 1000 Zm distant, was radiated into space 98 million (Mega) years before humans appeared, and dinosaurs roamed the

*Voyager 1, at its current speed, will take 17 500 years to traverse 9.461 Pm, the distance light travels in a year.

†Exactly 105 years without approximation.

Earth. The age of the universe is only thought to be about 14 billion (Giga) years, which is a distance of about 130 Yottameters, and further than a realistic boundary for the stars we can possibly see.

The first six stars in Table 7.1, Alpha Centauri, Barnard's Star, Sirius, 61 Cygni, Vega, Capella, and Algol are all clearly categorized as nearby stars. Polaris is past the boundary, and would count as a far away star, as do Betelgeuse and Rigel. Deneb is clearly a far away star as it is 24.3 Exameters away.

The closest star, Alpha Centauri, is usually considered to be a star of the Southern Hemisphere, but occasionally it can just barely be seen in the southernmost parts of the United States. Alpha-Centauri is only visible below a latitude of 29 degrees north. Laredo, Texas is at 27.52 degrees north, and Key West Florida is at 24.54 degrees north, which means that in the 48 continuous states, Alpha-Centauri never edges above the horizon by more than a few degrees. In Hawaii, it can get about ten degrees above the horizon.

The first star whose distance was measured is 61 Cygni. German astronomer Friedrich Wilhelm Bessel (1784–1846) measured its distance in 1838. The method Bessel used to determine the distance of 61 Cygni utilizes the concept of parallax. Parallax assumes as the Earth orbits the Sun, far away stars will not shift with respect to other stars, but nearby ones will. This shift in the position of a nearby star with respect to far away stars is called *stellar parallax*. The Hubble Telescope can use stellar parallax to measure stars that are up to about 100 000 Petameters distant.

If you place your index finger in front of your nose, and between your eyes, and then alternate closing one eye, while leaving the other open, you will see your finger shift its position perhaps 50 millimeters or so. If you now extend your arm, you will see alternating which eye you use to view your index finger produces almost no shift in position.

The Moon has a parallax too. It's small, but is still large enough so ancient astronomers could measure it without telescopes. These astronomers were then able to estimate the distance to the Moon using this parallax value. Once the telescope was invented, it became possible to measure the parallax of Mars. This was used in turn to estimate the distance from the Earth to the Sun, and other Solar System distances.

The existence of stellar parallax was of considerable debate among astronomers for centuries. Bessel chose the rather dim star 61 Cygni, because its proper motion was the largest then known, which led him to think it was close to the Earth, despite its faint light. Bessel was the first to measure it, and computed the distance to 61 Cygni as 97.45 Petameters. Bessel published his results in 1838, and suddenly the size of the Universe expanded considerably in the mind of humans. For the first time, astronomers began to look beyond the solar system for new discoveries. The currently accepted distance to 61 Cygni is about 108 Petameters, which makes it a "nearby star" in terms of metric prefixes.

Scottish astronomer Thomas Henderson (1798–1844) chose Alpha Centauri as his candidate for the measurement of stellar parallax. Henderson finished taking his astronomical data before Bessel, but waited to analyze it, so Bessel became the first to detect stellar parallax. In 1839, Henderson published his results, showing Alpha Centauri has a larger stellar parallax than 61 Cygni, and is therefore closer. No other star has been observed to have a larger parallax, and so Alpha Centauri is the nearest star to us, although to be fair, it's a misnomer to call Alpha Centauri the nearest star because it is actually a binary system. There are two stars orbiting one another: Alpha Centauri A and Alpha Centauri B. The two stars each take turns being the nearest star to Earth as they orbit. The difference in distance is so minute, and the exchange so frequent, that in general the system is called Alpha Centauri.

For 75 years these two stars remained the closest known, until British astronomer Robert T. A. Innes (1861–1933) observed a dim star with a large stellar parallax in 1915. It turned out Alpha Centauri is actually a "ternary" star, or grouping of three stars. This new star was discovered to be a red dwarf about 1.6 Petameters from Alpha Centauri A and B. This distance is about

215 times the distance from our Sun to the Kuiper belt. Its orbital period is thought to be more than 500 000 years. Alpha Centauri C is sometimes called "Proxima Centauri" as it is the closest to us. Proxima is from a Latin word meaning "nearest."

Algol's distance is close to the boundary between nearby and far away stars at 880 Petameters. This star is the second brightest in the constellation Perseus. Every 69 hours, it dims and brightens very perceptively. Beta Persei, (Algol) quickly decreases a full magnitude in brightness over this short period, and then just as promptly regains its maximum luminance. Of all the variable stars, it is the most visible among the naked-eye stars. This variation might have alarmed people of this time. The star Algol is named after a creature from Arabic mythology, the "ghoul." This has been translated into English as "Demon Star." The Greeks constructed the constellation of Perseus around it, with Algol representing the head of the demon Medusa.

Dutch-English Astronomer John Goodricke (1764-1786), studied Algol without any supernatural predisposition. He showed the variations in magnitude were regular. In 1872, Goodricke suggested that an invisible companion star would periodically eclipse Algol, and decrease the amount of light observed. Goodricke's prediction was bold, and entirely correct. Stars of this type are now known as *eclipsing binaries.*

Over 4 000 planets external to our solar system have been cataloged. The first exoplanet to be discovered is thought to be HD 114762b in 1989, by a team led by David Latham. In the 1980s, the method used to search for exoplanets was to look for a star with a wobble that could reveal the existence of an orbiting planet. The measurement of this wobble was very difficult, and a number discoveries were announced and then retracted. Human and instrument errors produced an atmosphere of skepticism concerning announced discoveries of exoplanets.

Latham and his colleagues needed a stationary, non-wobbling star to use as a calibration standard. They used HD 114762, which is about 1200 Petameters distant, just slightly past the

Exoplanet Distances from the Sun

Exoplanet	Distance	
Proxima Centauri B	40 Pm	Closest known exoplanet
K2-A18b	117 Pm	Habitable with atmospheric water
TRAPPIST-1b	370 Pm	Largest number of habitable planets
TRAPPIST-1c	370 Pm	Largest number of habitable planets
TRAPPIST-1d	370 Pm	Largest number of habitable planets
2MASS J21268140	828 Pm	Largest exoplanet orbit
Latham's Planet	1 192 Pm	First exoplanet discovered
HR 8799b	1 220 Pm	First set of directly imaged exoplanets
HR 8799c	1 220 Pm	First set of directly imaged exoplanets
HR 8799d	1 220 Pm	First set of directly imaged exoplanets
2M1207b	1 608 Pm	First directly imaged exoplanet
Kepler-186f	5 506 Pm	First Earth-like Goldilocks exoplanet
SWEEPS-11,4	262 137 Pm	Farthest known exoplanets

Table 7.3: Petameter Distant Exoplanets

metric boundary for a "far away" star. On April Fool's day of 1988, the group observed a possible wobble in the star chosen as a non-wobbling standard. Seven years of recorded data were scrutinized, and it was confirmed the tiny variation was consistent with something orbiting HD 114762, which was designated HD 114762b following common convention.

The orbital period of the object was only 84 days, which struck the astronomers of the time as extraordinary. It also took an extremely elliptical path along its orbit, unlike the more circular orbits of our solar system. The object was only 53 Gigameters from HD 114762. The planet Mercury orbits at a distance of 58 Gm from our sun, and has an orbital period of 88 days. Unlike Mercury, it is a giant. It is somewhere between 10-60 times as massive as Jupiter!—yet orbiting very close to its star.

Given this information, the cautious conclusion was that the object orbiting HD 114762 was a star which forms a binary star pair. Binary stars are quite common, and it would be a probable explanation for the object, but it was way too small for nuclear fusion to occur. It could be a brown dwarf, a gaseous object around 13 to 80 times the mass of Jupiter, which are not able to make the stellar threshold. The problem for the researchers was they could not accurately determine the mass of the orbiting object. With the uncertainties about the discovery, and after considerable debate, the group classified it as a brown dwarf, but also indicated it could well be a planet. It is now generally accepted as the first discovered exoplanet, but future measurements are expected to remove all doubt. The planet is now unofficially called Latham's Planet.

The closest exoplanet is only 40 Petameters away, and orbits our nearest star Proxima Centauri. Appropriately, Proxima Centauri is Latin for "nearest [star] of Centaurus." Proxima Centauri is a red dwarf star. Proxima Centauri b, is an exoplanet that orbits at a distance of only about 7.5 Gigameters. The exoplanet's close proximity to its red dwarf sun produces temperatures that are in the habitable zone, where liquid water can exist. It has a mass about 1.3 times that of Earth, but orbits its sun every 11.2 (Earth) days with a rotation period of about 83 days. Its large stellar wind pressure, which would whisk away any atmosphere, and periodic flaring, make it unlikely to be habitable without a large magnetic field. The amount of visible light spectrum Proxima Centauri b receives is so low, that from a human perspective, one would experience at its surface a maximum brightness similar to twilight on Earth.

Exoplanet K2-18b, which orbits K2-18, a red dwarf star in the constellation Leo, is a mere 117 Petameters from Earth. K2-18b is also the first exoplanet discovered which is in the habitable zone, where water has been detected in its atmosphere, and conditions are such that liquid water could exist. The planet is more like Neptune than Earth, but might have a rocky core. It has a mass about eight times that of Earth, and orbits at a distance of only 22 Gm from K2-18, which is less than half the distance of Mercury to our Sun. It orbits around K2-18 in only 33 days, for a year that is 11 times shorter than the Earth's.

Generally exoplanets are discovered using indirect techniques, such as star wobble, or transit, where the amount of light from a star is decreased as the planet orbits between its star and Earth. In rare instances, such as 2M1207b, it is possible to image a planet directly. Its brown dwarf parent star, 2M1207, is the first discovered to have an orbiting planet. 2M1207 is 1608 Petameters from Earth.

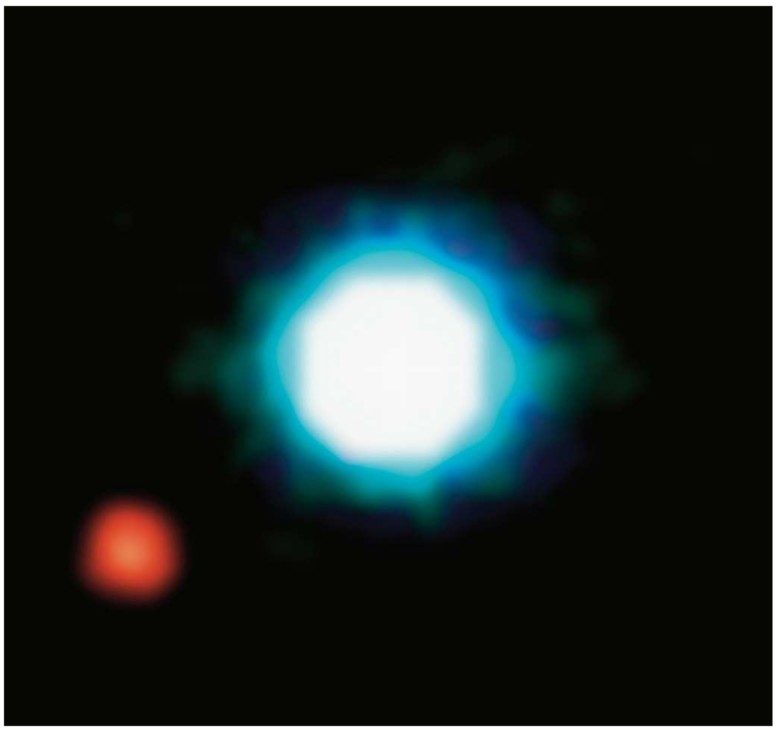

Figure 7.1: First image of an exoplanet. Red image to the lower left is exoplanet 2M1207b. – European Southern Observatory (ESO) Creative Commons

The first direct image of an exoplanet, captured in infrared light, is shown in Figure 7.1. The red image to the lower left is the orbiting planet. 2M1207b is a gas giant with a mass about four times that of Jupiter's. It orbits at a distance of 6 000 Gigameters from 2M1207, which is about the same as Pluto is from our sun.

The farthest exoplanets discovered thus far are SWEEPS-4 and SWEEPS-11, which are 262 137 Petameters (262 Exameters) distant. These planets orbit a "far away star."

The star which holds the record for the largest number of habitable planets is TRAPPIST-1 with three. It also holds the record for largest number of terrestrial planets at seven. TRAPPIST-1 is an ultra-cool red dwarf star, which is a bit larger than Jupiter, but is much more dense, with around 84 times its mass. All of the TRAPPIST planets orbit at a distance inside the separation from Mercury to our sun. TRAPPIST-1b, 1c, and 1d orbit at 1.7 Gm, 2.3 Gm, and 3.3 Gm respectively, whereas Mercury orbits at a distance of 58 Gm. The planets are so close together that one expects on any of the planets, the others would appear enormous. They all have radii between that of Earth and Mars.

The planetary system with the largest orbital distance from its host star, TYC 9486-927-1, is 2MASS J21268140 at an astonishing 1 032 230 Gigameters! Or 1.032 Petameters! When astronomers first noticed this exoplanet, they were stunned that it did not appear to have a host star. When the star was finally located, it was determined the exoplanet was almost 175 times the distance that Pluto is from our sun. This is without question the largest planetary system ever discovered.

The first directly imaged set of multiple planets orbiting a star are HR 8799b, HR 8799c, and HR 8799d, shown in Figure 7.2. The orbital motion of these planets has also been directly imaged. Their host star HR 8799 is a main-sequence star with about 1.5 times the Sun's mass, and 4.9 times its luminosity. The imaged planets, b, c and d are all about 1.2 times the radius of Jupiter, 86 Megameters, and 5-7 times its mass. Four planets total have been verified to orbit HR 8799, with orbital distances from 6 732 Gm (e) to 10 173 Gm (b). The innermost planet, HR 8799e has an orbit comparable in distance to Pluto, and the outermost similar to Eris.

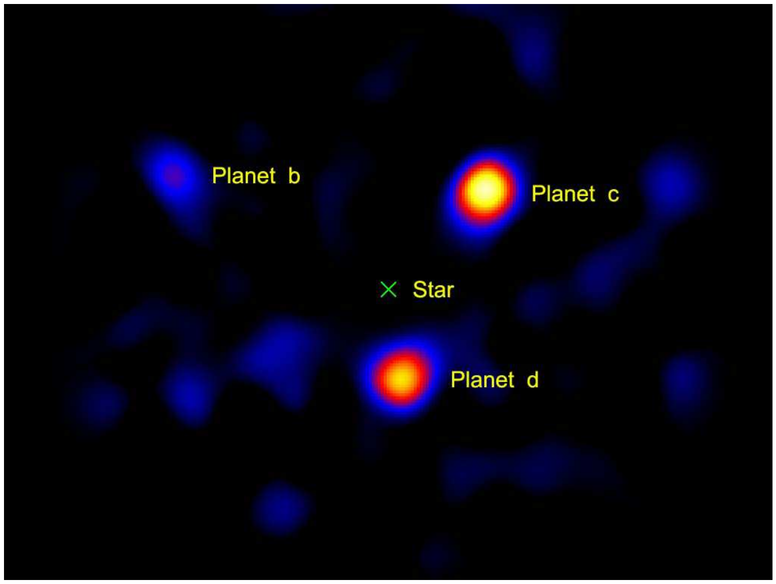

Figure 7.2: Direct image of Jupiter sized exoplanets HR 8799b,c,d – By NASA/JPL-Caltech/Palomar Observatory

Kepler-186f orbits a red dwarf star, it is similar to Earth in radius, and orbits in the habitable zone every 129.9 days. Four other planets similar to Earth in size revolve in closer orbits around Kepler-186. Kepler-186f was the first Earth-like planet discovered in the "Goldilocks zone." This is is also called the habitable zone, where temperatures are such that water will remain liquid. The planet is at a distance of 5 506 Pm (5.5 Em) from us, and therefore orbits a "far away star." This makes it difficult to study with current technology.

7.2 Petaworld Area

1 – 1 000 000 Square Petameters (Pm^2) 1 x 10^{30} m^2

The world of square Petameters is a sparse one. The Dutch-American astronomer Bart Bok (1906-1983) was the first to iden-

Figure 7.3: Bubble Nebula, NGC 7635 – Hubble Space Telescope NASA ESA

tify dense clouds of dust and interstellar gas, which are hypothesized to be star formation structures. These structures are thought to condense and create stars and star clusters. These clouds became known as *Bok globules*. They are thought to have masses ranging from two to fifty times the mass of the Sun, and are estimated to be about 9.5 Petameters in extent. Their surface area is around 300 square Petameters.

The surface area of The Bubble nebula, first discovered by William Herschel in 1787, is about 30 000 square Petameters (Figure 7.3). The word *nebula* comes from the Greek word for cloud. The Bubble nebula has a diameter of around 95 Petameters. The central star, SAO 20575, that "blew the bubble," has a radius about 15 times that of the Sun, or approximately 10 Gigameters. SAO 20575 is expected to end its life exploding as a supernova, after expelling up to 65% of it's mass before doing so.

7.3 Petaworld Volume

1 – 1 000 000 000 Cubic Petameters (Pm^3) 1 x 10^{45} m^3

Petaliter Examples

Item	Volume
Ice on Planet Mercury	1 PL
Lake Superior	12 PL
Water in The Earth's Atmosphere	20 PL
Total Water in The Great Lakes	23 PL
Lake Baikal	24 PL
Total Fresh Water on Earth	109 PL

Table 7.4

The planet Mercury has a surface temperature which ranges from -173 °C to 427 °C. Mercury has a very small axis tilt of about $\frac{1}{30}$ of a degree. Because of this, Mercury does not experience seasons like other planets in the Solar System, and its polar regions are perennially below -93 °C. Radar measurements strongly indicate ice (frozen water) exists in the bottom of its polar craters. Craters with sufficient depth are shaded from direct sunlight, and retain temperatures below -171 °C. It is estimated up to 1 Petaliter of water may be contained within these craters.

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The volume of water in Lake Superior is 12 Petaliters. The amount of water in the Earth's atmosphere, for comparison, is approximately 20 Petaliters. Lake Baikal in southern Siberia is the largest freshwater lake on Earth, and also the deepest, with a maximum depth of 1642 meters. The lake is thought to be 25 million years old, which would also make it the oldest lake on our planet. Lake Baikal contains 23.6 Petaliters of water. This is slightly larger than the volume of all the Great Lakes combined at 22.7 Petaliters. The total amount of fresh water on Earth is about 109 Petaliters.

$\mathrm{Pm}^3 \bullet\bullet\bullet \mathrm{Pm}^3$

A typical Bok globule has a volume of around 450 cubic Petameters.

Cubic Petameter Examples

Item	**Volume**
Bok Globule	450 Pm^3
Oort Cloud Volume	28 370 Pm^3
Sphere Enclosing Alpha Centauri	295 942 Pm^3
Sphere Enclosing Sirius	2 255 580 Pm^3
M71 (Globular Cluster)	8 725 000 Pm^3
47 Tucanae (NGC 104)	766 000 000 Pm^3

Table 7.5

The enclosed volume of the Oort Cloud sphere is about 28 370 cubic Petameters. The Oort cloud is so large it extends to almost one-half the distance to our nearest stellar neighbor, Alpha Centauri. Alpha Centauri is 41 Petameters from the Sun. A sphere centered on us, but also big enough to enclose it, would have a volume of 295 942 cubic Petameters.

Sirius is the brightest star in the night sky and about 81 Petameters from Earth. It is also known as the Dog Star because it's in the constellation Canis Major, or "Great Dog," often pictured as a hunting dog for the nearby constellation Orion, "The Hunter." In ancient times, the appearance of Sirius in the summer sky was thought to be responsible for oppressive heat, or the "dog days" of summer. The name Sirius is derived from an ancient Greek word which means "scorcher." In Vergil's *Aeneid*, an epic Latin poem from about 19 BC, we find the passage:

. . . the Dog Star burned
Our green plantations barren, and our grassland
Withered; sickly stalks denied us food.[1]

A sphere centered on us and enclosing the Sirius binary star system has a volume of about 2 255 580 cubic Petameters.

A globular cluster is a spherical distribution of stars all orbiting about the central core of a galaxy as a set of collective satellites. M71 is one such globular cluster in the constellation Sagitta. It was first identified in 1746 by Swiss astronomer Jean-Philippe Loys de Chéseaux (1718–1751). M71 is about 113.5 Exameters from Earth, with a diameter of 255 Petameters. This cluster is roughly spherical, and has a volume of about 8 725 000 cubic Petameters.

Globular clusters are not thought to be promising locations for the development of planetary systems. On average, the separation of stars in a globular cluster is on the order of 10 Petameters, but near the core, the separation can be a mere 10 Terameters (similar to the maximum extent of our solar system). A planet located near the center of a globular cluster would experience a sky perpetually filled with intense light, and never darkness.

47 Tucanae (NGC 104) is a globular cluster about 158 Exameters distant. It has a diameter of about 1135 Petameters and occupies a volume of nearly 766 000 000 cubic Petameters.

7.4 Petaworld Mass

1 – 1000 Petagrams (Pg) 1 x 10^{15} g

The Great Wall of China, on the order of 6.3 Megameters long, 9 meters in height, and about 10 meters thick, has an estimated mass of 1.5 Petagrams. The Great Pyramid of Giza is a mere 0.006 Petagrams (5.9 Teragrams) by comparison. The largest single work of civil engineering by a pre-industrial people, The Great Wall of China, just edges into the Petagram realm.

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Items with Petagram Mass

Item	Mass
1 mL of Matter in a Neutron Star	1.1 Pg
The Great Wall of China	1.5 Pg
World Crude Oil Production (2009)	4 Pg
Total Bacterial Biomass in the Oceans	11 Pg
Global Human Carbon Dioxide Emission	40 Pg
Human Released Atmospheric Carbon Since 1750	300 Pg
Total Carbon Stored in Earth's Atmosphere	720 Pg
Total Carbon in Coal Deposits Worldwide	3500 Pg

Table 7.6: Petagram Examples

A single milliliter of matter from a neutron star has a mass of 1.1 Petagrams, or nearly the mass of the entire Great Wall of China, but compressed into a cube with 10 mm sides.

Neutron stars are formed during a supernova explosion. The exploding star's core has run out of fuel, and ceases production of energy. Until this point, the outward pressure from the production of energy had balanced the inward pressure of gravity. Gravity almost instantaneously collapses the matter inside, which is mostly iron, compressing it with such violence that it crushes the atoms, pressing the outer electrons into the protons at the nucleus forming neutrons. The outer layers of the star are blown away as this occurs. Neutron stars are probably not entirely made of neutrons however, internal nuclear processes can eject neutrinos, leaving somewhere around 10 % of the star existing as protons, and as neutrino energy leaves, the star is cooled.

The atoms go from about 100 picometers across, to a glob of neutrons only a few femtometers wide. If the Earth were compressed by this amount, it would reduce it from a ball about 12 800 Kilometers in diameter, to one that is about 128 meters, a bit longer than the length of a 100 meter dash. When the limit of compression is reached, there are about 20 neutrons for each proton left behind. Much of the star is thought to essentially be one giant atomic nucleus, held together by gravity. The interior details of neutron stars is the subject of considerable speculation and contemporary research.

On August 17, 2017, gravitational waves from the merger of two neutron stars were detected in the US and Europe simultaneously. This was the first time gravitational waves produced only by neutron stars were detected, previously only pairs of black holes merging were received. Optical telescopes, for the first time, observed light from the location of the merger. For the first time, information from electromagnetic waves and gravitational waves could be studied together. The star pair merged about 1.22 Yottameters from our solar system. The diameter of the observable universe is around 880 Ym.

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The total bacterial biomass found in the oceans is approximately 11 Petagrams. If each of these microbes reproduced weekly, they would generate progeny at a rate of about 11 Teragrams every minute. Humans extract about 99 Teragrams of seafood from the oceans annually. This is approximately equivalent to the amount of organic biomass generated by bacteria in the oceans in about 90 minutes.[2] If this reproduction continued without bound, the oceans would quickly transform from water to bacteria. Fortunately, there are organisms which consume these bacteria as prodigious enough rate to act as a check.

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The industrial world is currently extracting about four Petagrams of crude oil from the planet each year. It is estimated humans have released at least 300 Petagrams of carbon into the atmosphere since 1750. The total carbon in the Earth's atmosphere is 720 Petagrams. The amount of human-released carbon is thus about 42 % of the total carbon in the atmosphere. Seven hundred twenty Petagrams is about one fifth the estimated amount of coal deposits worldwide. When expressed in Petagrams, it is clear the amount of carbon emissions each year is significant when compared with the total carbon present in the Earth's atmosphere.

References

[1] Robert Fitzgerald *The Aeneid*, Random House, 1983, Page 70

[2] Palumbi, S., and Palumbi A., *The Extreme Life of the Sea* Princeton University Press, 2014 pg 40