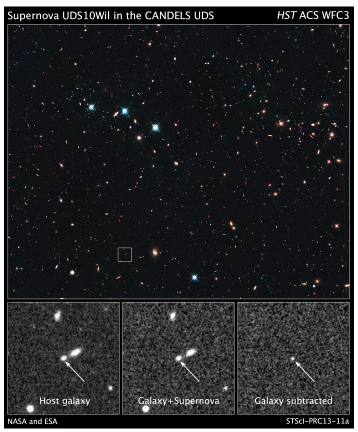
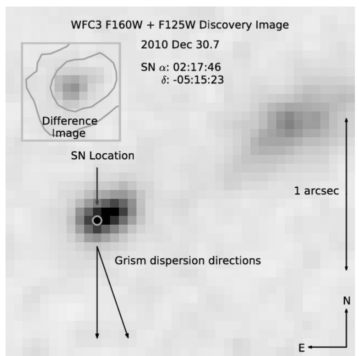
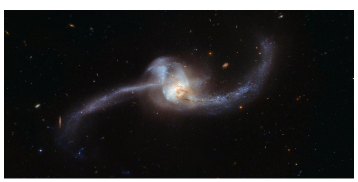
Stellar Objects

https://scioly.org/wiki/index.php/Astronomy

<table>
<tr><th rowspan="2">Name</th><th rowspan="2" colspan="2">Images</th><th rowspan="2">Constellation</th><th>Magnitude</th><th rowspan="2">Distance</th><th colspan="2">Coordinates</th><th>External Links</th></tr>
<tr><th>Apparent</th><th>Right Ascension</th><th>Declination</th><th></th></tr>
<tr><td rowspan="2">SN UDS10Wil</td><td rowspan="2">
</td><td rowspan="2">
</td><td>Cetus</td><td></td><td>10.5 Gly,
3.2 Gpc</td><td>02h 17m 46.3s</td><td>-05° 15′ 24.00″</td><td></td></tr>
<tr><td colspan="6">SN UDS10Wil is the furthest supernova so far of the type used to measure cosmic distances. It was discovered by the Hubble Space Telescope and was discovered as part of a three-year Hubble program that started in 2010 to survey faraway Type 1a supernovae known as the CANDELS survey.</td></tr>
<tr><td rowspan="2">NGC 2623</td><td rowspan="2"></td><td rowspan="2">[[]]</td><td>Cancer</td><td>13.36</td><td>250 Mly, 76.7 Mpc</td><td>08h 38m 24.1s</td><td>+25° 45′ 16.70″</td><td></td></tr>
<tr><td colspan="6">NGC 2623 is the result of a major collision and subsequent merger between two galaxies. The merger is going through late stages and is thought to eventually resemble what the Milky Way will look like when it collides with our neighboring galaxy, Andromeda in 4 billion years.</td></tr>
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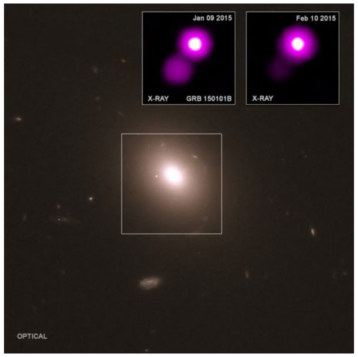
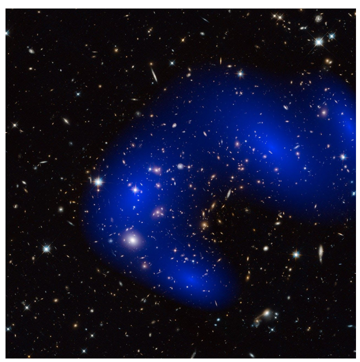
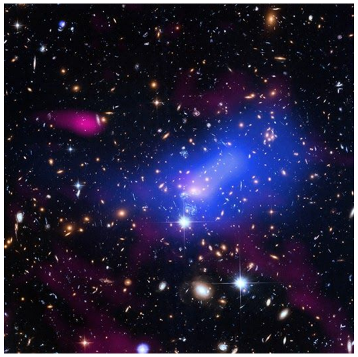
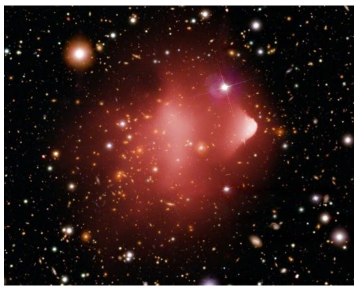
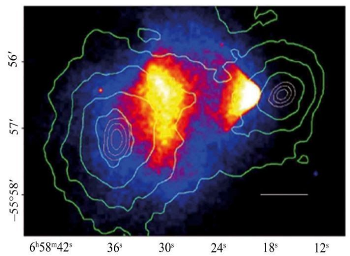
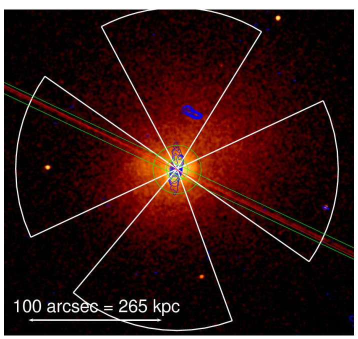
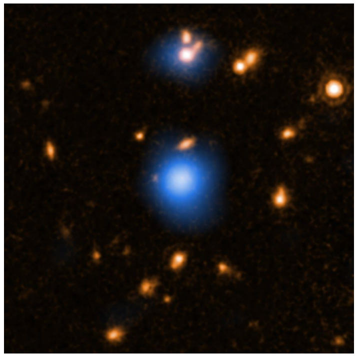
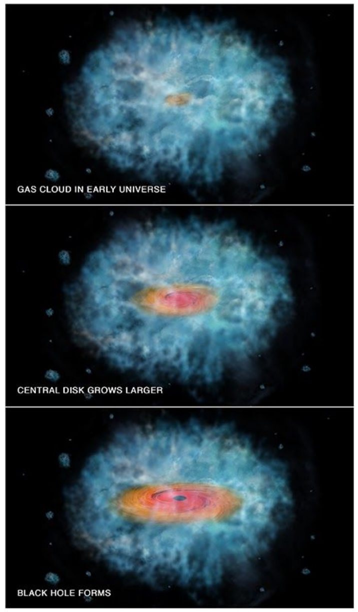
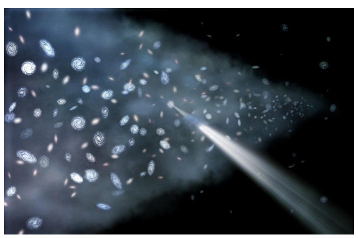
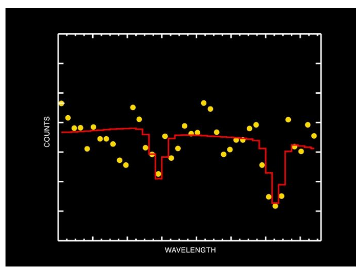
GRB 150101B		[[]]	Virgo		1.7 Gly, 0.52 Gpc	12h 32m 04.96s	−10° 56′ 00.7″	Chandra SIMBAD
JKCS 041		[[]]	Cetus		~9.9 Gly, ~ 3.04 Gpc	02h 26m 44s	−04° 41′ 37″	Chandra
MACS J0717.5+ 3745			Auriga		5.4 Gly, 1.7 Gpc	07h 17m 36.50s	+37° 45′ 23″	Chandra

MACS J1149.5+2223		[[]]	Leo		Approximately 5 billion light-years	11h 49m 36.3s	+22° 23′ 58.1″	Chandra Frontier Fields
Bullet Cluster (1E 0657-56)			Carina		3.7 billions light-years, 1.141 Gpc	06h 58m 37.9s	−55° 57′ 0″	
H1821+643		[[]]	Draco	14.24	3.4 Gly, 1.0 Gpc	18h 21m 57.24s	+64° 20′ 36.23″	Chandra SIMBAD

GOODS-S 29323			Fornax		13.2 Gly, 4.05 Gpc	03h 32m 28s	–27° 48′ 30″	Chandra
			The Chandra Deep Field Survey South is a photograph taken for over 8 million seconds exposure by the Chandra Deep Field Telescope. It contains at least 5,000 black holes, which makes it a topic of interest for astronomy.					
H2356-309			Sculptor		Approximately 2 billion light-years	23h 59m 07.9s	-30° 37′ 41.00″	Chandra SIMBAD

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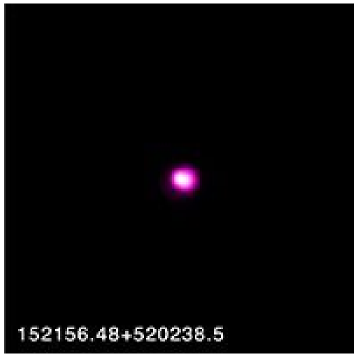
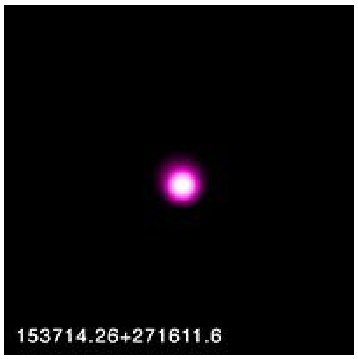
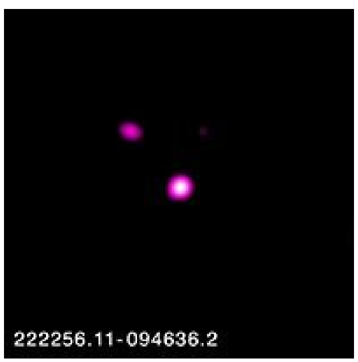
<tr><td>152156.48+520238.5</td><td></td><td>[[]]</td><td>Boötes</td><td></td><td>Approximately 10.75 billion light-years</td><td>15h 21m 56.5s</td><td>+52° 02′ 38.50″</td><td>Chandra</td></tr>
<tr><td>153714.26+271611.6</td><td></td><td>[[]]</td><td>Corona Borealis</td><td></td><td>Approximately 11.03 billion light-years</td><td>15h 37m 14.3s</td><td>+27° 16′ 11.6″</td><td>Chandra</td></tr>
<tr><td>222256.11-094636.2</td><td></td><td>[[]]</td><td>Aquarius</td><td></td><td>Approximately 11.48 billion light-years</td><td>22h 22m 56.10s</td><td>-09° 46′ 36.20″</td><td>Chandra</td></tr>
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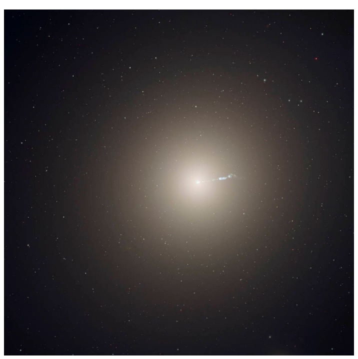
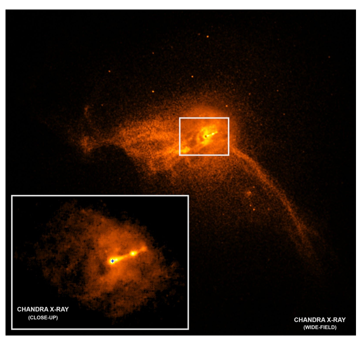
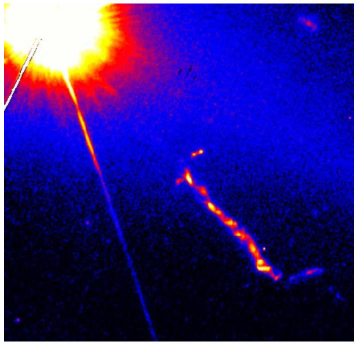
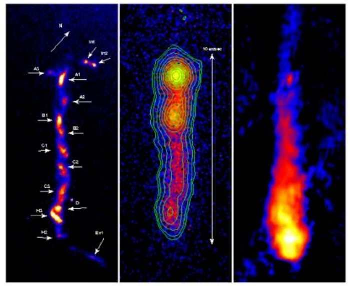
PSS 0133+0400	[[]]	[[]]	Pisces		Approximately 10.1 billion light-years	01h 31m 04.8s	+03° 45′ 37.8″	Chandra
PSS 0955+5940	[[]]	[[]]	Ursa Major		Approximately 10.2 billion light-years	09h 51m 37.4s	+59° 54′ 43.6″	Chandra
GW151226	[[]]	[[]]			Approximately 1.4 billion light-years	n/a	n/a	LIGO
			GW151226 was a Gravitational-Wave signal observed by the twin detectors of the Laser Interferometer Gravitational-Wave Observatory (LIGO) on December 26, 2015 at 03:38:53 UTC making it the second definitive observation of a merging binary black hole system detected by the LIGO Scientific Collaboration and Virgo Collaboration.					
M87			Virgo	7.19	53.5 ± 1.6 Mly, 16.4 ± 0.5 Mpc	12h 30m 49.42338s	+12° 23′ 28.0439″	Chandra

3C 273			Virgo	12.9	2.443 Gly, 749 Mpc	12h 29m 06.7s	+02° 03′ 09″	AAVSO Chandra
			3C 273 is the most optically bright quasar, and also one of the closest, in our night sky. Along with 3C 48, it was the first object to be identified as what we now know to be quasars.					

SN UDS10Wil

SN UDS10Wil (**SN Wilson**)[2] is a type Ia supernova, and as of April 2013, the farthest known.[3] It has a redshift of 1.914, which strongly implies that it exploded when the universe was about a third of its current size. It was discovered with the Hubble Space Telescope's Wide Field Camera 3.[1] The nickname SN Wilson is after the American President Woodrow Wilson.

NASA's Hubble Space Telescope has found the farthest supernova so far of the type used to measure cosmic distances. Supernova UDS10Wil, nicknamed SN Wilson after American President Woodrow Wilson, exploded more than 10 billion years ago.

SN Wilson belongs to a special class called Type Ia supernovae. These bright beacons are prized by astronomers because they provide a consistent level of brightness that can be used to measure the expansion of space. They also yield clues to the nature of dark energy, the mysterious force accelerating the rate of expansion.

"This new distance record holder opens a window into the early universe, offering important new insights into how these stars explode," said David O. Jones of Johns Hopkins University in Baltimore, Md., an astronomer and lead author on the paper detailing the discovery. "We can test theories about how reliable these detonations are for understanding the evolution of the universe and its expansion."

The discovery was part of a three-year Hubble program, begun in 2010, to survey faraway Type Ia supernovae and determine whether they have changed during the 13.8 billion years since the explosive birth of the universe. Astronomers took advantage of the sharpness and versatility of Hubble's Wide Field Camera 3 to search for supernovae in near-infrared light and verify their distance with spectroscopy. Leading the work is Adam Riess of the Space Telescope Science Institute in Baltimore, Md., and Johns Hopkins University.

Finding remote supernovae provides a powerful method to measure the universe's accelerating expansion. So far, Riess's team has uncovered more than 100 supernovae of all types and distances, looking back in time from 2.4 billion years to more than 10 billion years. Of those new discoveries, the team has identified eight Type Ia supernovae, including SN Wilson, that exploded more than 9 billion years ago.

"The Type Ia supernovae give us the most precise yardstick ever built, but we're not quite sure if it always measures exactly a yard," said team member Steve Rodney of Johns Hopkins University. "The more we understand these supernovae, the more precise our cosmic yardstick will become."

Although SN Wilson is only 4 percent more distant than the previous record holder, it pushes roughly 350 million years farther back in time. A separate team led by David Rubin of the U.S. Energy Department's Lawrence Berkeley National Laboratory in California announced the previous record just three months ago.

Astronomers still have much to learn about the nature of dark energy and how Type Ia supernovae explode.

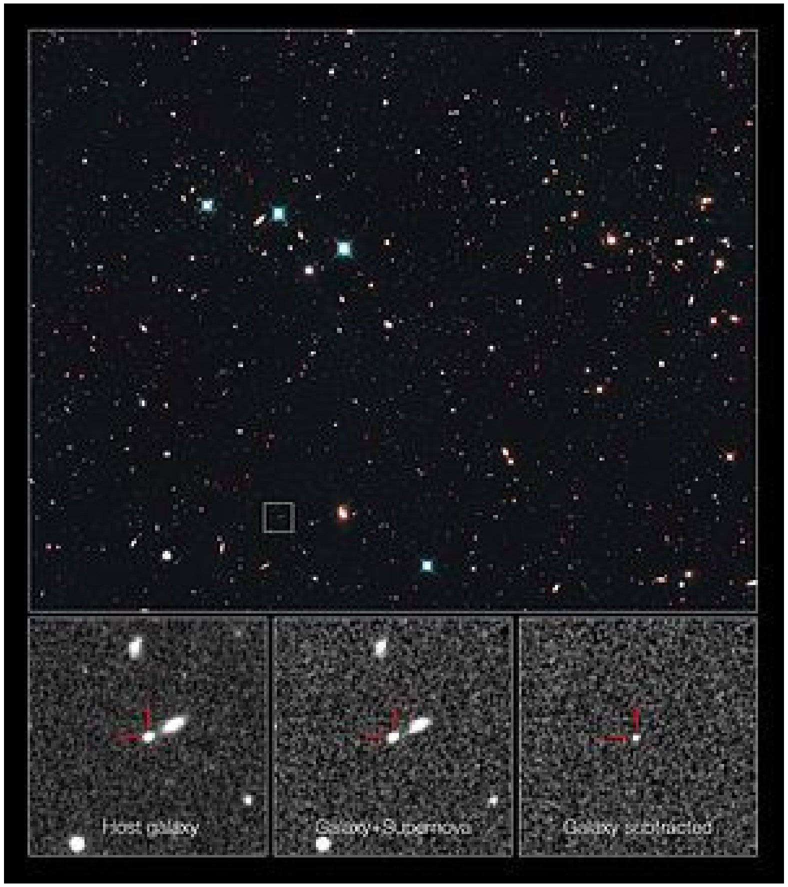
By finding Type Ia supernovae so early in the universe, astronomers can distinguish between two competing explosion models. In one model the explosion is caused by a merger between two white dwarfs. In another model, a white dwarf gradually feeds off its partner, a normal star, and explodes when it accretes too much mass.

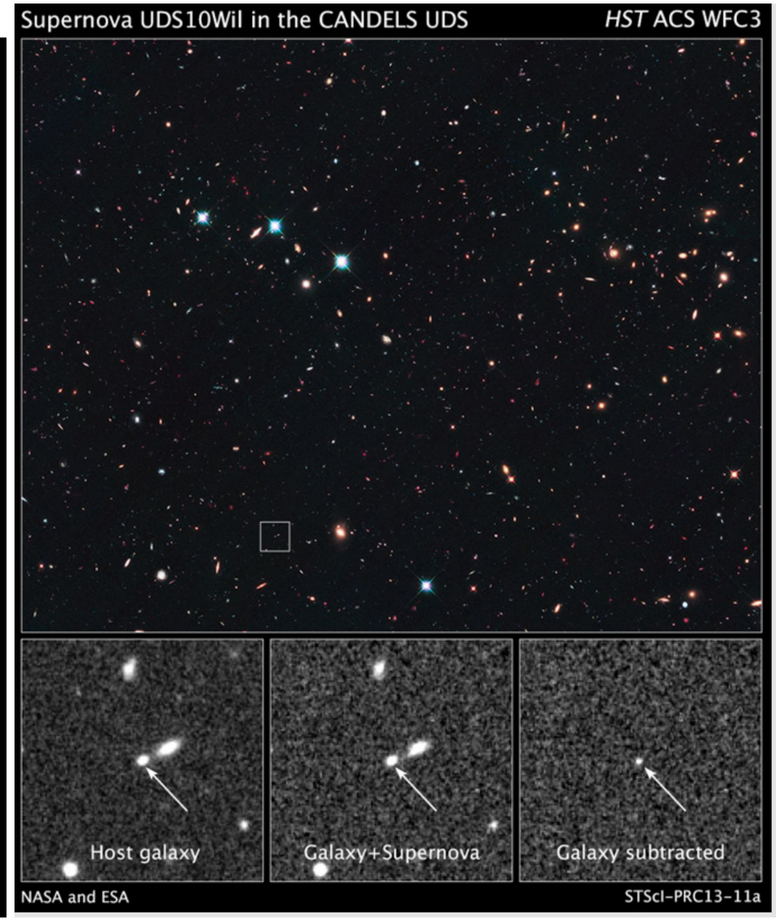
The team's preliminary evidence shows a sharp decline in the rate of Type Ia supernova blasts between roughly 7.5 billion years ago and more than 10 billion years ago. The steep drop-off favors the merger of two white dwarfs because it predicts that most stars in the early universe are too young to become Type Ia supernovae.

"If supernovae were popcorn, the question is how long before they start popping?" Riess said. "You may have different theories about what is going on in the kernel. If you see when the first kernels popped and how often they popped, it tells you something important about the process of popping corn."

Knowing the type of trigger for Type Ia supernovae also will show how quickly the universe enriched itself with heavier elements such as iron. These exploding stars produce about half of the iron in the universe, the raw material for building planets, and life.

The team's results have been accepted for publication in an upcoming issue of The Astrophysical Journal.





NGC 2623

NGC 2623/Arp 243 is an interacting galaxy located in the constellation Cancer. NGC 2623 is the result of two spiral galaxies that have merged together. Scientists believe that this situation is similar to what will occur to the Milky Way, which contains our solar system, and the neighboring galaxy, the Andromeda Galaxy in four billion years.[6] Studying this galaxy and its properties

have provided scientists with a better idea of the collision of the Milky Way and the Andromeda. Due to NGC 2623 being in the late stage of merging, the compression of the gas within the galaxy has led to a large amount of star formation, and to its unique structure of a bright core with two extending tidal tails.[6]
NGC 2623 is located in the constellation Cancer. Cancer is located 253 million light years away from the Earth, and it travels away from the Earth at a speed of approximately 5,500 kilometers per second.[7] Other galaxies that are also in the constellation Cancer like NGC 2623, are Messier 67(King Cobra Cluster), and Messier 44(Beehive Cluster), which also has the designation NGC 2632.[20]

The center of NGC 2623 is very bright and circular, and connected to it are two elongated tails, called tidal tails, of star clusters.[7] Because of how bright it is, it is classified as a super luminous galaxy.[9] The galaxy is very bright for both the radio waves and infrared waves it emits.[10] There are two very distinct features of the X-rays that NGC 2623 emits. One is the spectral hard and compact, nuclear feature, and the other one is a cool feature that is not located in the nucleus.[9] The cool feature of the X-rays is similar to X-ray outflows, that are observed around many other starburst galaxies, and this specific cool feature has a very diffuse structure is believed to be observed ejected gas, that comes from the inefficiency of star formation, as the process can't turn all matter into stars, therefore ejecting excess gas by supernova explosions, and stellar and galactic winds.[9]

Merging[edit]

NGC 2623 is in the late stage of merging, and is called a titanic galaxy merger.[7] The centers of the galaxies that have formed NGC 2623 have already collided, forming the bright and circular center of NGC 2623, which is very prominent. One true nucleus is believed to exist in this galaxy, and it is symmetric.[9] There have been inferences made that state that the merger should create a region of both compressed gas and dust, due to the observations that gas clouds are colliding within NGC 2623.[9]

Physical properties[edit]

The size of NGC 2623 spans 50 thousand light years across.[7] In comparison, the Milky Way, the galaxy that our solar system is located in and also a spiral galaxy, has a diameter of approximately 150 thousand to 200 thousand light years across.[11]

The infrared luminosity of this galaxy is 3.3*1011 L☉ (solar luminosity).[12] Luminosity is a space objects measure for brightness. Only some galaxies can emit energy that has infrared wavelengths, as most only emit radio wavelengths. This type of emission is seen in Seyfert Galaxies, since their cores are especially bright.[13]

The distance modulus, which is the absolute magnitude subtracted from the apparent magnitude of an object in space is 34.50.[14][15] This value has come from distances that have been acquired from recession velocities that are relative to the local groups.[16]

Classification[edit]

The nucleus of this galaxy is filled with many young stars, due to the star formation that takes place. Because there is a such a large amount, NGC 2623 is classified as a Seyfert Galaxy.[7] Seyfert Galaxies have very bright cores and similar properties as quasars.[17] Quasars are nuclei of galaxies that contain super massive black holes and emit a massive amount of energy. While both types of galaxies contain supermassive black holes at their centers, Seyfert Galaxies, such as NGC 2623, tend to emit a much lower amount of visible light. Seyfert galaxies are still very uncommon as only 10 percent of spiral galaxies fall under this classification.[18]

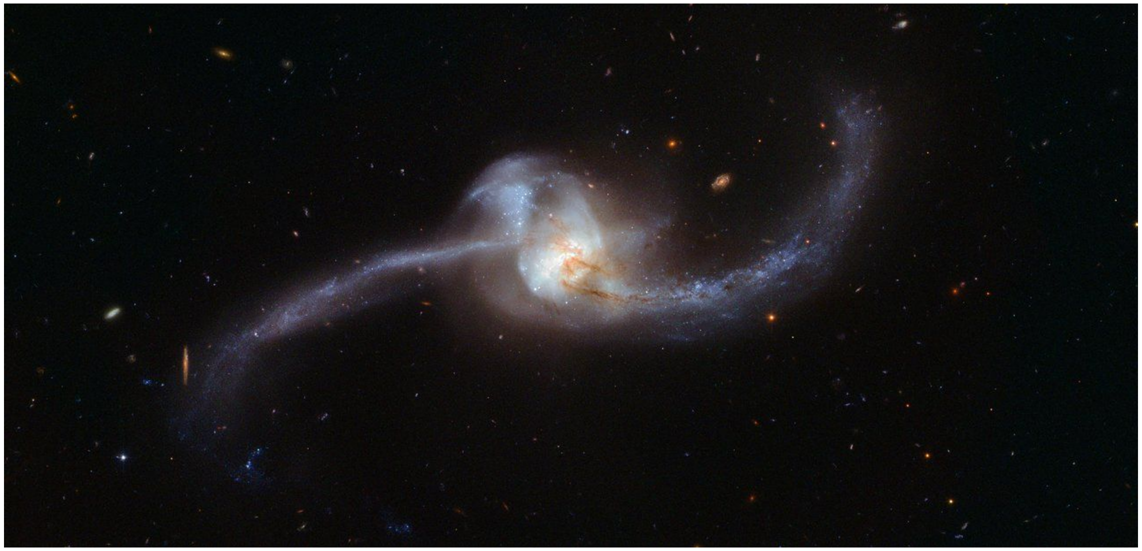
Star formation[edit]

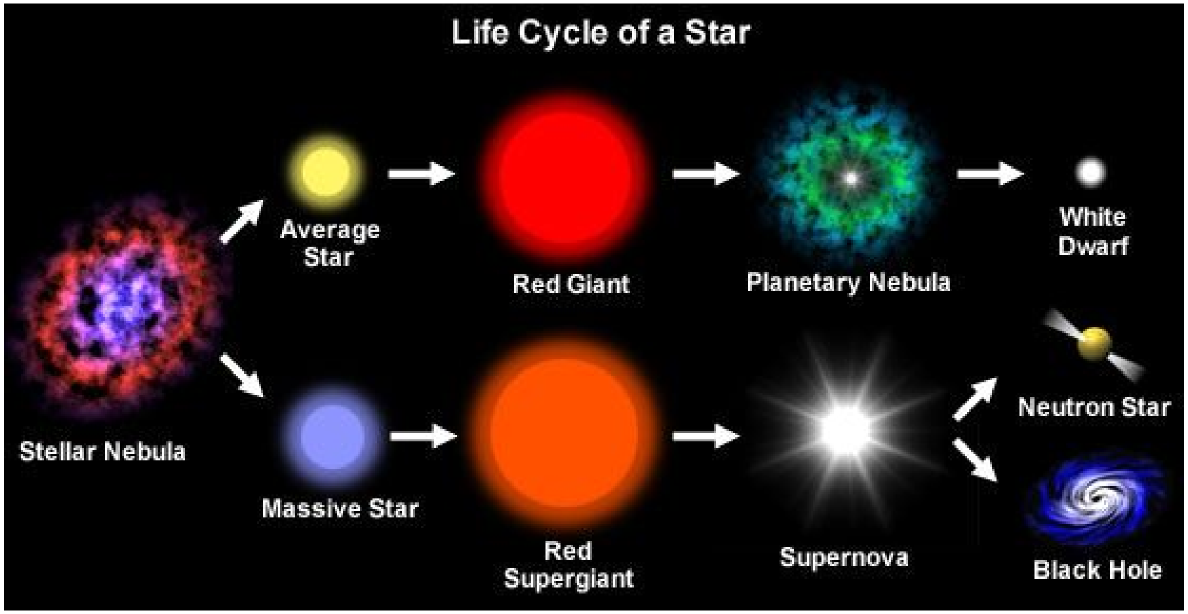
Hubble Image

In NGC 2623 there are bright star clusters in the tails of the galaxy, and many of them are situated in the upper tail. There are at least 170 star clusters within the galaxy.[19] In addition to this both tails contain many young stars in their respective early stages in evolution.[7] The most active part of the galaxy in regards to star formation is the upper and more prominent tail. Through HST and GALEX, which are two space telescopes, images it is evident that recent star formation has occurred within the galaxy.[12] Though there are many star clusters in the tails of NGC 2623, the nucleus, or center of the galaxy still is responsible for more than 99 percent of the star formation occurring.[12]

Tidal tails[edit]

The large trails of gas on each end of NGC 2623 are known as tidal tails. Tidal tails are long strips of bright star clusters that occur due to the interactions between different galaxies. In the case of this galaxy, the tidal tails are formed due to the merging of the galaxies that formed NGC 2623.[15] Tidal tails are very strong indicators of whether a galaxy has been formed due to the merging of multiple other galaxies. Tidal tails can also be seen in the Antennae galaxy, as they were also formed by the merging of galaxies, similar to how NGC 2623 was formed. Tidal tails are helpful to astronomers as they can indicate the formation and evolution of a galaxy.





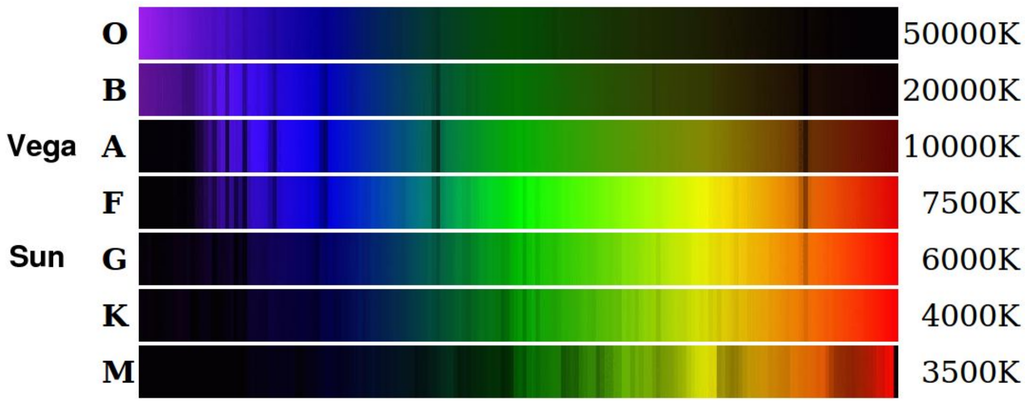
Standard Astronomical Units:

- solar mass ($M_{\odot}$) = 2×10^{30} kg.
- Jupiter Mass (M_J or M_{JUP}) = 1.898×10^{27}
- Earth mass ($M_{\oplus}$) = 5.9742×10^{24}
- Speed of Light © = 299 792 458 m / s

Units of Distance:

- Astronomical Unit = 1.496e11 m
- Light Year = 9.461e15 m, 63,240 au
- Parsec = 3.086e16 m, 3.261 ly, 206,265 au

Type	Color	Approximate Surface Temperature	Main Characteristics	Examples
O	Blue	> 25,000 K	Singly ionized helium lines either in emission or absorption. Strong ultraviolet continuum.	10 Lacertra
B	Blue	11,000 - 25,000	Neutral helium lines in absorption.	Rigel Spica
A	Blue	7,500 - 11,000	Hydrogen lines at maximum strength for A0 stars, decreasing thereafter.	Sirius Vega
F	Blue to White	6,000 - 7,500	Metallic lines become noticeable.	Canopus Procyon
G	White to Yello w	5,000 - 6,000	Solar-type spectra. Absorption lines of neutral metallic atoms and ions (e.g. once-ionized calcium) grow in strength.	Sun Capella
K	Oran ge to Red	3,500 - 5,000	Metallic lines dominate. Weak blue continuum.	Arcturus Aldebaran
M	Red	< 3,500	Molecular bands of titanium oxide noticeable.	Betelgeuse Antares



Spectral Class Properties

Type	Temperature (Kelvin)	Color	Hydrogen
O	30,000-60,000	Blue	Weak
B	10,000-30,000	Blue-White	Medium
A	7,500-10,000	White	Strong
F	6,000-7,500	White	Medium
G	5,000-6,000	Yellow	Weak
K	3,500-5,000	Yellow-Orange	Very Weak
M	2,000-3,500	Red	Very Weak

Hertzberg Russell Notes

Balmer lines (lines from the first excited state of hydrogen atoms) are strong in A stars. O stars are too hot -- all the hydrogen is ionized. G stars are too cool -- all the hydrogen atoms are in the ground state.

Type Ia supernovae

Type Ia supernovae are caused not by high-mass stars reaching the end of their lives, but by white dwarves that gain too much mass. They generally occur in binary systems in which a white dwarf pulls enough mass off of its companion to go supernova. This limit is 1.4 solar masses. When the white dwarf exceeds this limit, it blows itself up in a supernova that is significantly brighter than a Type II supernova. All Type Ia supernovae are of the same brightness, and this fact can be used to determine intergalactic distances.

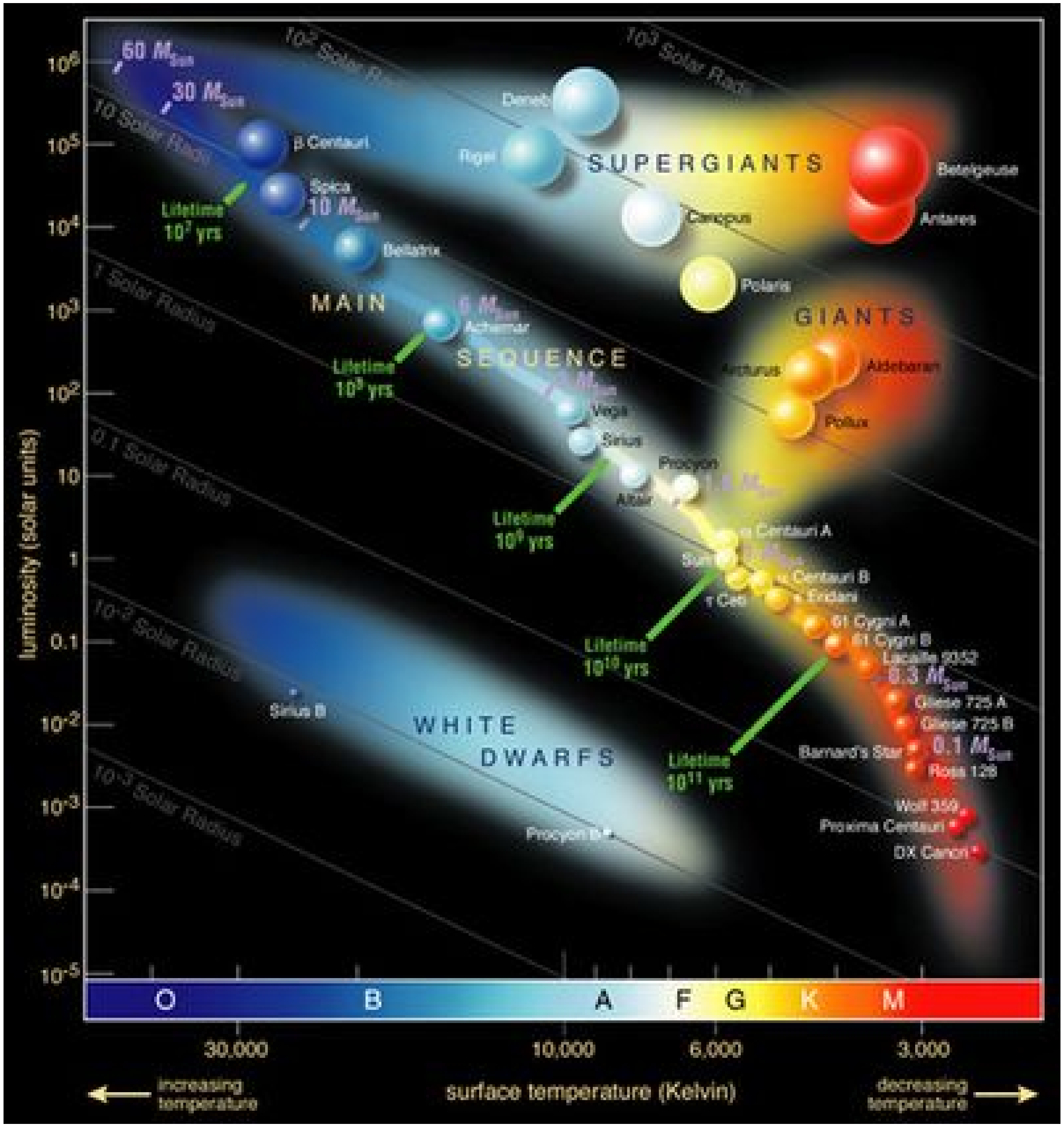
Type II supernovae

A **Type II supernova** is where a star of at least eight solar masses cannot fuse any more elements together to create energy. This happens when iron is created; no nuclear energy can be made from iron with fusion or fission. When this happens, the star blows itself apart. Heavy elements - elements with atomic numbers greater than 26 - are created in these supernovae. If the star's core has a mass of 1.4 to 3.2 solar masses, a **neutron star** is formed. Neutron stars are incredibly dense - a neutron star with a diameter of about 12 km has the same mass as the Sun. Some neutron stars rotate quickly enough to emit beams of radiation at the magnetic poles; these are called **pulsars**, as the beams appear to "pulse" at a constant rate. However, if the core has a mass greater than 3.2 solar masses, a **black hole** is formed. These are made of degenerate elementary particles and have infinite density. Their gravity is so great that at a certain distance, called the **event horizon**, not even light can escape. This is where they get the name "black" holes.

Intrinsic Variable Stars

These variables vary in brightness due to changes in the properties of the star itself. For example, pulsating variable stars expand and contract, increasing their radius and changing their luminosity. The most well known type of variables stars are:

- **Cepheid Variables** are stars that lie on the instability strip and have a fixed period-luminosity relationship. This relationship allows for the determining of distances to objects and galaxies. Additionally, Cepheid variables pulsate via the k-mechanism, where if the opacity of a star increases with temperature, more heat is trapped, causing the star to expand. However, as it expands, it becomes more transparent, releasing that heat, and decreasing in size once again.



- **RR Lyrae Variables** are stars that are similar to Cepheid variables, but are older and have shorter periods than

Cepheids.

- **Mira Variables** are asymptotic giant branch red giants that have luminosity amplitudes of 2 to 11 magnitudes. The prototype of this type of star was Omicron Ceti, also known as Mira. The entirety of the star is expanding and contracting, causing the fluctuations in luminosity.

Extrinsic Variable Stars

Extrinsic variable stars change in luminosity as a result of external changes.

- **Rotating variable stars** vary in brightness due to its rotation, potentially causing sunspots to appear into view. These darker regions on the star reduce the luminosity, and thus appear to have variable luminosity.
- **Eclipsing variable stars** are stars that vary in brightness due to our view being obscured by another object. Just as astronomers can detect the minute difference in brightness of exoplanet transits in transit photometry, they can detect the variations in brightness. As the secondary star travels around the primary, the primary star's brightness appears to dim, even though the star itself may not be undergoing any changes to its properties.

Stellar Populations

Populations of stars are classified by their metallicity, or by how much heavy metals a star has.

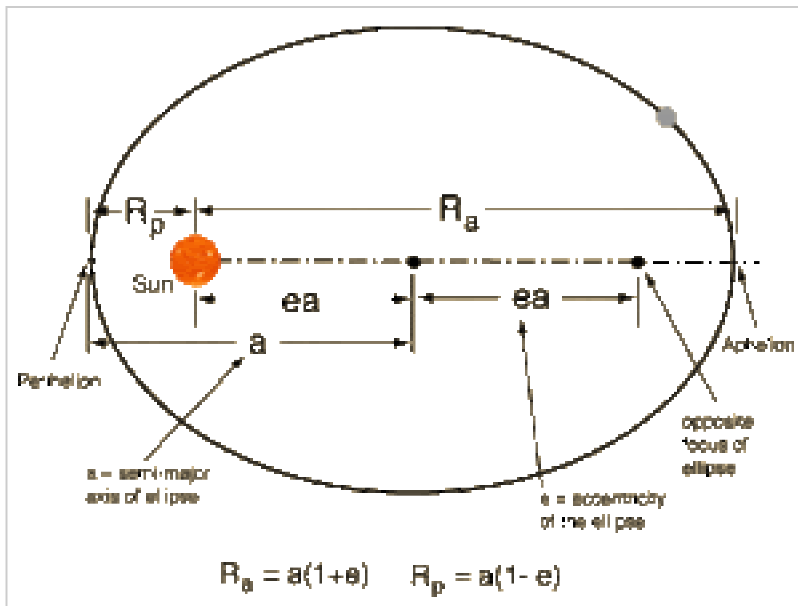
- **Population I** has the greatest concentration of metals, and most of them are relatively new stars that have taken metals expelled from other stars. The Sun is included within this group, as are many stars in the outer reaches of our galaxy. These make up the majority of stars in spiral and irregular galaxies. Open clusters, which are mostly located in the spiral arms of a galaxy contain mostly Population I stars.
- **Population II** has some heavy metals, but not as much as Population I, as they are older and did not benefit from as much metal dust as newer stars did. Stars in globular clusters and near the core of our galaxy belong to this population. Smaller galaxies also have more stars in this population. Population II stars also make up the majority of stars in elliptical galaxies. There is also a hypothetical
- *Population III* consisting of the very first stars with little to no metal content, as they did not exist near the beginning of the universe. They did not last very long, but helped the metals to form for the later populations.

Kepler's Laws

Kepler's Laws govern the orbits of satellites. They were originally formed with respect to planetary motion around the sun, but they apply to other elliptical orbits as well.

Kepler's First Law

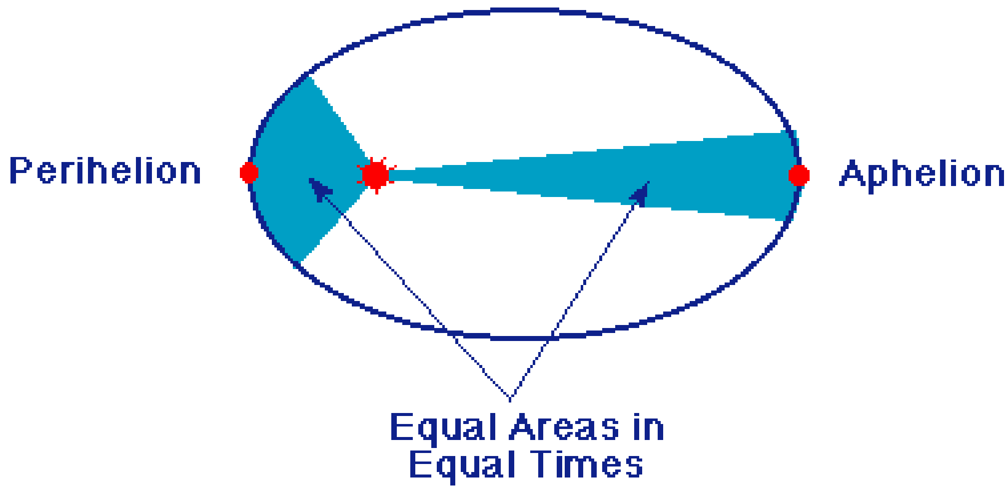
The first law says that **all of the orbits of the planets are elliptical with the Sun at one focus.** In terms of ellipses, the foci are two points along the *semi-major axis* (a in the diagram) of the ellipse around which the planet orbits. At any given point in time, the sum of the planet's distances to both foci is constant, giving it is slightly flattened shape. In the case of a circle, both foci are at the same point. The diagram below illustrates this point.

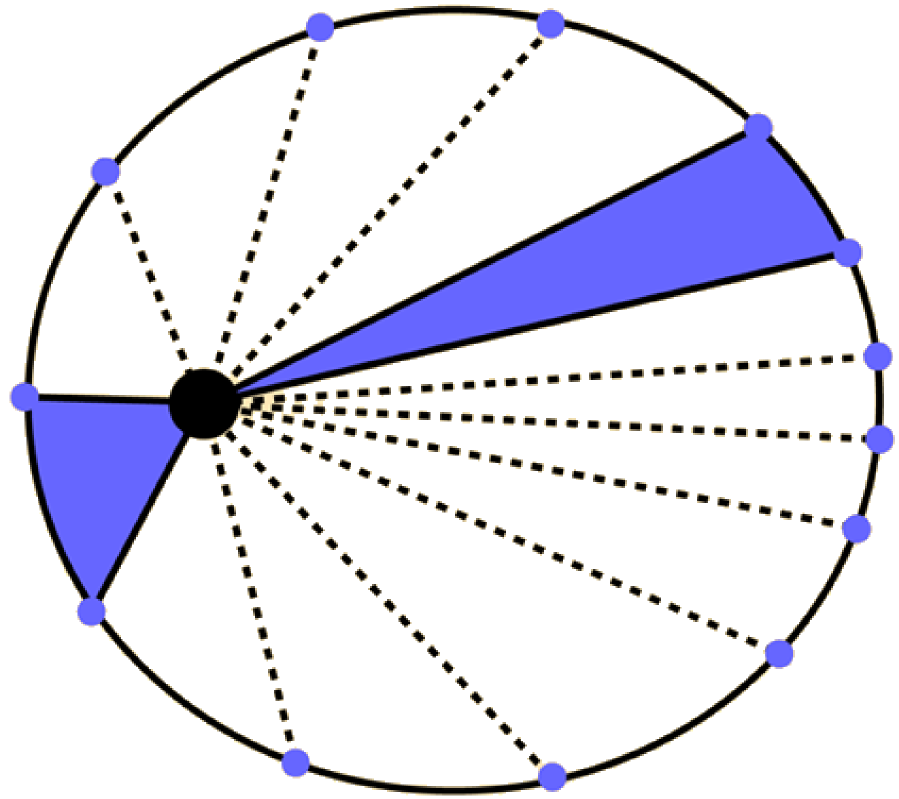


A diagram demonstrating Kepler's First Law. For a more basic diagram, see the Solar System page.

Kepler's Second Law

The second law is slightly more complex. This law says that **a planet traces out equal areas in equal time**. Since the satellite does not trace out as much area when it is closer to the Sun, it has to move faster in order for this law to be true, so this law basically proves that objects move faster the closer they are to the central object. This law is more easily explained with a diagram.





Kepler's Third Law

All of these laws are important for a basic knowledge of astrophysics, but Kepler's Third Law is the one of most relevance to the Astronomy event. According to this law, **the square of the satellite's period is directly proportional to the cube of the length of its semi-major axis.** This law can be presented symbolically as

$P_2 \propto a_3$

$$z = \frac{\Delta\lambda}{\lambda} = \sqrt{\frac{1 + v/c}{1 - v/c}} - 1$$

$1 + z = l_{observed} / l_{rest}$

$G = 6.67408 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$

$$T^2 = \frac{4\pi^2}{GM} a^3$$

can be expressed as simply

$$T^2 = a^3$$

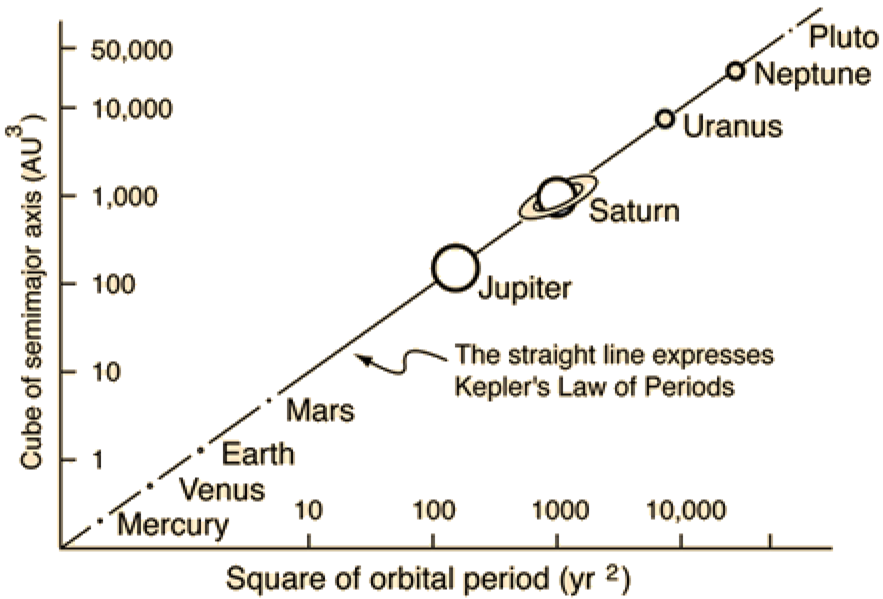
If expressed in the following units:

T Earth years

a Astronomical units AU (a = 1 AU for Earth)

M Solar masses $M_{\odot}$

Then $\frac{4\pi^2}{G} = 1$



Starburst Galaxies

A starburst galaxy is a term used to refer to any galaxy with a star formation rate up to 100 times greater than a normal galaxy. This rate is high enough that if this rate were to persist in the long-term, the star's reserves of gas would deplete in a small fraction of the galaxy's lifetime. For this reason, most starburst galaxies only stay that way for a short period of time. Starburst activity frequently arises when two or more galaxies interact with each other. Starburst galaxies are responsible for a sizable fraction of the universe's star formation.

The high activity areas can be spread throughout the galaxy, or concentrated in a small area. Typically, starbursts are observed around the nucleus of a galaxy.

Determining Distances

Cepheids and RR Lyrae

A period-luminosity graph

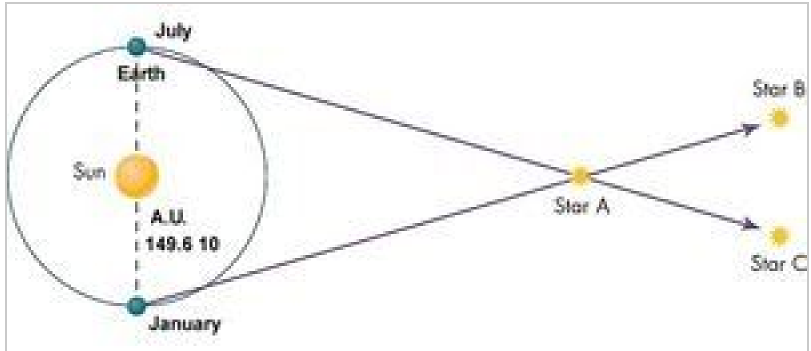
This section deals with the uses of Cepheids and RR Lyrae in determining distances. For information about their physical properties, please see Astronomy/Variable Stars

Cepheids and RR Lyrae are two types of variable stars that are especially good for finding distances to galaxies or other groups of stars because they have direct correlations between luminosity and period. In both Cepheids and RR Lyrae, the longer the period, the higher the luminosity. Cepheids typically have periods of about 1 to 50 days. **Type I Cepheids**, or Classical Cepheids, are brighter, newer Population I stars (see section about stellar populations below for an explanation). **Type II Cepheids** are similar to Type I in terms of the relationship, but they are smaller, dimmer Population II stars. These are also called *W Virginis* stars.

RR Lyrae are different from Cepheids in that they are older and fainter than Cepheids. RR Lyrae stars typically have shorter periods than Cepheids - usually less than one day. They have masses about half that of our Sun, and are Population II stars. Also, the luminosity does not increase as much to a change in period, as **most RR Lyrae have absolute magnitudes close to 0.75**. Therefore, they are only useful in our galaxy and the one closest to us, Andromeda. However, this makes them very useful in determining distance, because once an RR Lyrae star has been found, one only needs to know the apparent magnitude in order to put it into the distance modulus equation and find distance. RR Lyrae have been linked to globular clusters, since most variable stars in globular clusters are RR Lyrae. They are named after the original RR Lyrae in the constellation Lyra.

These variable stars are useful in calculations because once the period is found, the luminosity can be calculated or determined through the use of a period-luminosity graph. Then, through other formulas, the distance can also be determined. This gives them the use as "standard candles" in galaxies relatively close to ours in our universe. NGC 4603, one of the listed DSO's, is the furthest galaxy that a Cepheid has been used to calculate distance at 108 million light years away.

Distance Equations



A diagram of parallax showing how the apparent position of Star A changes from January to July. Over this time span, the Earth travels 2 AU, so half of the total change is used as the value for parallax, in arcseconds. This value can then be used to determine distance in parsecs using 1/parallax.

There are many equations that are used to find distances to objects in space. Several of these equations can be found in the [Astronomy formula sheet].

Triangulation/Parallax

Triangulation is often used to determine distances. This method is based on parallax shifts, apparent changes in a star's location when viewed from different locations. The *parallax* of a star is one-half of the angular shift seen of an object produced over six months, which corresponds to a distance of 2 AU. In other words, it is the angle subtended by a star as the Earth moves by 1 AU. The parallax decreases as distance increases. The equation for parallax is:

$D=1p$ $D=1p$

Thus, a parsec is defined as the distance to a star that has a parallax of one arcsecond. Parallax is only useful to measure stars up to 1000 parsecs away, since past that the parallax is so small that it is not accurate.

Hubble's Law

Hubble's Law uses the fact that objects in space are receding from us to determine distance. Edwin Hubble found that the recessional velocity is proportional to the distance away an object is and created an equation,

$v=H_0D$v=HoD

, where v is the recessional velocity,

H_0Ho

is Hubble's constant, and D is the distance. The exact value of Hubble's constant is disputed, but most values are about 70.

The value of v is found by looking at an object's spectrum. The recessional velocity is the redshift multiplied by the speed of light, and in order to find redshift, a spectrum must be used. Redshift is how much a spectrum shifts toward the red side of the spectrum due to recession. Redshift, or Z, is found by dividing the change in wavelength of the spectrum by the wavelength the object was expected to have.

Distance Modulus

The distance modulus equation is also very important. It relates an object's distance with the difference between the apparent magnitude (m) with the absolute magnitude (M). This difference is known as the *distance modulus*.

$5\ (\log_{10}(d)-1)=m-M$5 (log10(d)−1)=m−M

where d is in parsecs, and m,M are apparent and absolute magnitudes respectively.

This equation can be written in many different ways so that different values can be found, but the essential purpose of the formula remains the same. A good way to practice using this equation before the competition is to take the apparent magnitude and approximate distance to a DSO and use them to find the absolute magnitude. This experience will be a time-saver if you have to use it during the test.

Radiation Laws

The radiation laws show relationships between stellar temperature, radius, and luminosity. Both Wien's Law and Stefan's Law are proportionality statements that can be turned into equations by introducing a proportionality constant. In this event, math questions will typically approximate a star or other luminous object with a blackbody.

Wien's Law: Wien's displacement law states that the wavelength where a blackbody emits most of its radiation is inversely proportional to the temperature. In equations,

Radiation Laws

(mathematical formulas for describing blackbody spectra)

- Wien's Law – relates the temperature T of an object to the wavelength λ_{max} at which it emits the most radiation.

$$\lambda_{\max} = \frac{0.29\ cm}{T}$$

the hotter the object, the bluer the radiation

- Stefan's Law – the total energy radiation per unit time is proportional to the fourth power of the object's temperature.

$$F = \sigma T^4$$

$$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 \cdot K^4}$$

as the temperature of an object increases, the total amount of radiation increases rapidly

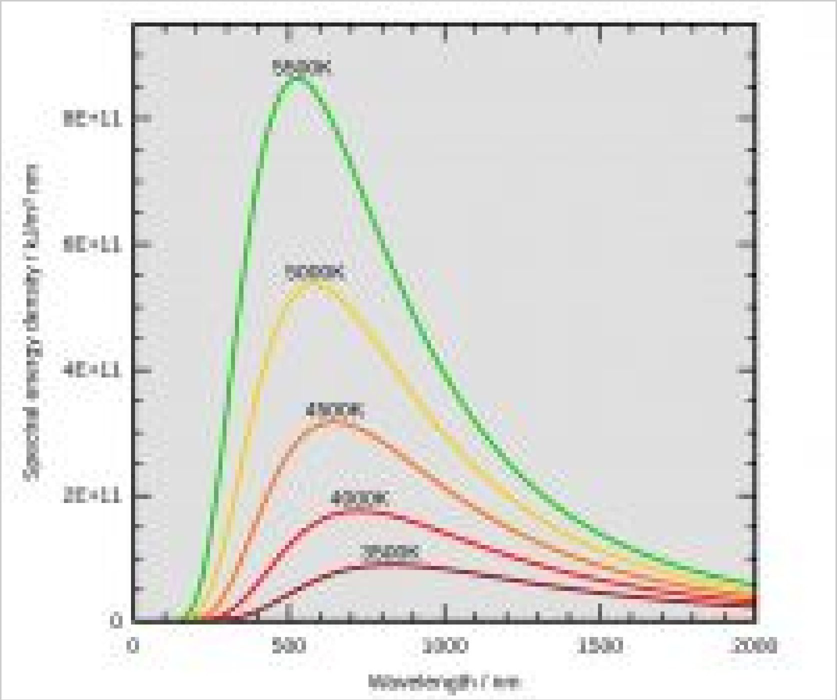
P = net radiated power	e = emissivity (=1 for ideal radiator)
A = radiating area	T = temperature of radiator
σ = Stefan's constant	T_C = temperature of surroundings

$$\sigma = 5.6703x10^{-8}\, watt / m^2 K^4$$

$$\frac{P}{A} = \sigma T^4 \; j / m^2 s$$ Stefan-Boltzmann Law

$$\sigma = 5.6703x10^{-8}\, watt / m^2 K^4$$

Planck's Law: Planck's Law states that a hotter blackbody emits more energy at every frequency than a cooler blackbody. The equation form of the law is complicated, but on a radiance vs. temperature graph the curve for a hotter blackbody never dips below that of a cooler one.



The actual equation for Planck's law, known as the Planck function, is rarely used in calculation - it is usually only used in questions conceptually. It is a multivariable function that describes the radiance of a blackbody at different temperatures and wavelengths of light.

Period-Luminosity Relationship

Period-luminosity relations are known for several types of pulsating variable star: type I Cepheids; type II Cepheids; RR Lyrae variables; Mira variables; and other lo

Classical Cepheids [edit]

The Classical Cepheid period-luminosity relation has been calibrated by many astronomers throughout the twentieth century, beginning with Hertzsprung.[14] Calibra calibration was established by Benedict et al. 2007 using precise HST parallaxes for 10 nearby classical Cepheids.[15] Also, in 2008, ESO astronomers estimated wi nebula in which it is embedded.[16] However, that latter finding has been actively debated in the literature.[17]

The following relationship between a Population I Cepheid's period P and its mean absolute magnitude M_v was established from Hubble Space Telescope trigonom

$$M_{\mathrm{v}} = (-2.43 \pm 0.12)\,(\log_{10} P - 1) - (4.05 \pm 0.02)$$

with P measured in days. [18][15] The following relations can also be used to calculate the distance d to classical Cepheids:

$$5\log_{10} d = V + 3.34\log_{10} P - 2.45(V - I) + 7.52\,. \text{ [15]}$$

or

$$5\log_{10} d = V + 3.37\log_{10} P - 2.55(V - I) + 7.48\,.\text{[19]}$$

I and V represent near infrared and visual apparent mean magnitudes, respectively.

Laws and Constants

ADVANCED PLACEMENT PHYSICS 1 EQUATIONS, EFFECTIVE 2015

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	Coulomb's law constant, $k = 1/4\pi\varepsilon_0 = 9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Universal gravitational constant, $G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Speed of light, $c = 3.00 \times 10^8$ m/s	Acceleration due to gravity at Earth's surface, $g = 9.8\ \text{m/s}^2$

UNIT SYMBOLS	meter,	m	kelvin,	K	watt,	W	degree Celsius,	°C
	kilogram,	kg	hertz,	Hz	coulomb,	C		
	second,	s	newton,	N	volt,	V		
	ampere,	A	joule,	J	ohm,	Ω		

PREFIXES		
Factor	**Prefix**	**Symbol**
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. Assume air resistance is negligible unless otherwise stated.
III. In all situations, positive work is defined as work done <u>on</u> a system.
IV. The direction of current is conventional current: the direction in which positive charge would drift.
V. Assume all batteries and meters are ideal unless otherwise stated.

Intensity Ratio:	$\frac{I_A}{I_B} = 2.512^{M^B - M^A}$	
Magnitude Difference:	$M_A - M_B = 2.5 \log \frac{I_A}{I_B}$	
Small Angle Formula:	$\frac{angular\ diameter - arcseconds}{206265} = \frac{linear\ diameter}{distance}$	
Circular Velocity:	$V_C = \sqrt{\frac{GM}{r - meters}}$	M = mass of central body (kg) G = 6.67 × 10^{-11} m^3/s^2kg * Answer in m/s
Compare LGP:	$\frac{LGP_A}{LGP_B} = \left(\frac{D_A}{D_B}\right)^2$	D = diameter * Answer in times (×)
Resolving Power:	$\alpha = \frac{11.6}{D(cm)}$	D = diameter (cm) * Answer in arcseconds
Magnification:	$M = \frac{F_O}{F_E}$	F_O = focal length of objective F_e = focal length of eyepiece
Wien's Law:	$\lambda_{max} = \frac{3{,}000{,}000}{T - degrees\ Kelvin}$	* Answer in nm
	$\lambda_{max} = \frac{.2987}{T} \times 10^8 \text{Å}$	
	$T = \frac{2.9 \times 10^8 \text{Å}}{peak\ \lambda}$	
Stefan-Boltzmann Law:	$E = \sigma T^4 (J/s/m^2)$	T = K σ = 5.67 ×10^{-8}J/m^2s degree^4 * Answer in J
Doppler Formula:	$\frac{V_r}{c} = \frac{\Delta_\lambda}{\lambda_o}$	V_r = radial velocity c = 300,000 km/s Δ_λ = change in λ λ_o = observed λ
Fusion Explained:	$E = mc^2$	m = kg c = 3×10^8m/s * Answer in Joules

Distance to Star: $d = \frac{206{,}265}{p\text{−}arcseconds}$ p = parallax * Answer in AU

F Ratio: $\frac{focal\ length(mm)}{objective\ diameter\ (mm)}$

Distance Modulus:	$m_v - M_v = -5 + 5\log d \quad d = 10^{\frac{m_V - M_v + 5}{5}} = pc$	
Luminosity of Star:	$\frac{L}{L_\odot} = \left(\frac{R}{R_\odot}\right)\left(\frac{T}{T_\odot}\right)$	* Answer in times (×)
Mass of Binary System:	$M_A + M_B = \frac{a^3}{p^2}$	M = solar masses p = orbital period (yrs) a = AU
Kepler's 3rd Law:	$p^2 = a^3$	p = orbital period (yrs) a = distance (AU)
Mass-Luminosity Relation:	$L = M^{3.5}$	M = star mass in M_O * Answer in times (×)
Life Expectancy:	$T = \frac{1}{M^{2.5}}$	M = star mass in M_O * Answer in O lifetimes × 10 billion = years
Schwarzschild Radius:	$R_S = \frac{2GM}{c^2}$	G = 6.67 × 10^{-11} m^3/s^2kg M = mass (kg) C = 3× 10^8 m/s * Answer in m
Hubble Law:	$V_r = \mathrm{Hd}$	V_r = velocity of recession of galaxy (km/s) H = 20km/s/Mpc d = distance (Mpc)
Redshift:	$Z = \frac{\Delta\lambda}{\lambda_O}$	$\Delta\lambda$ = change in λ λ_O = unshifted λ
Age of Universe:	$T_U = \frac{1}{H} \times 10^{12} years$	H = 70 km/s/Mpc * Answer in years
Distance-Rate-Time:	$d = rt$ $r = \frac{d}{t}$ $t = \frac{d}{r}$	
Newton's Law of Gravity:	$F = G\frac{m_1 m_2}{r^2}$	G = 6.67 × 10^{-11} m^3/s^2kg $m_1 m_2$ = masses of objects in kg r = distance between the two masses (m) F = the strength of the gravitational force (N)

Flux: $\frac{1}{d^2}$

$$L(M_V) = r^2$$

$$\frac{distance\ to\ star}{diameter\ of\ earth's\ orbit} = \frac{focal\ length\ of\ scope\ (mm)}{parallax\ shift}$$

Diameter of orbit: 300,000 km
* Answer in km

Dispersion Distance: $D = \frac{T_2 - T_1}{124.5\left(\left(\frac{1}{f_2}\right)^2 - \left(\frac{1}{f_1}\right)^2\right)}$

$$\left(\frac{1}{400}\right)^2 - \left(\frac{1}{600}\right)^2 = 3.472 \times 10^{-6}$$

$$\left(\frac{1}{400}\right)^2 - \left(\frac{1}{800}\right)^2 = 4.688 \times 10^{-6}$$

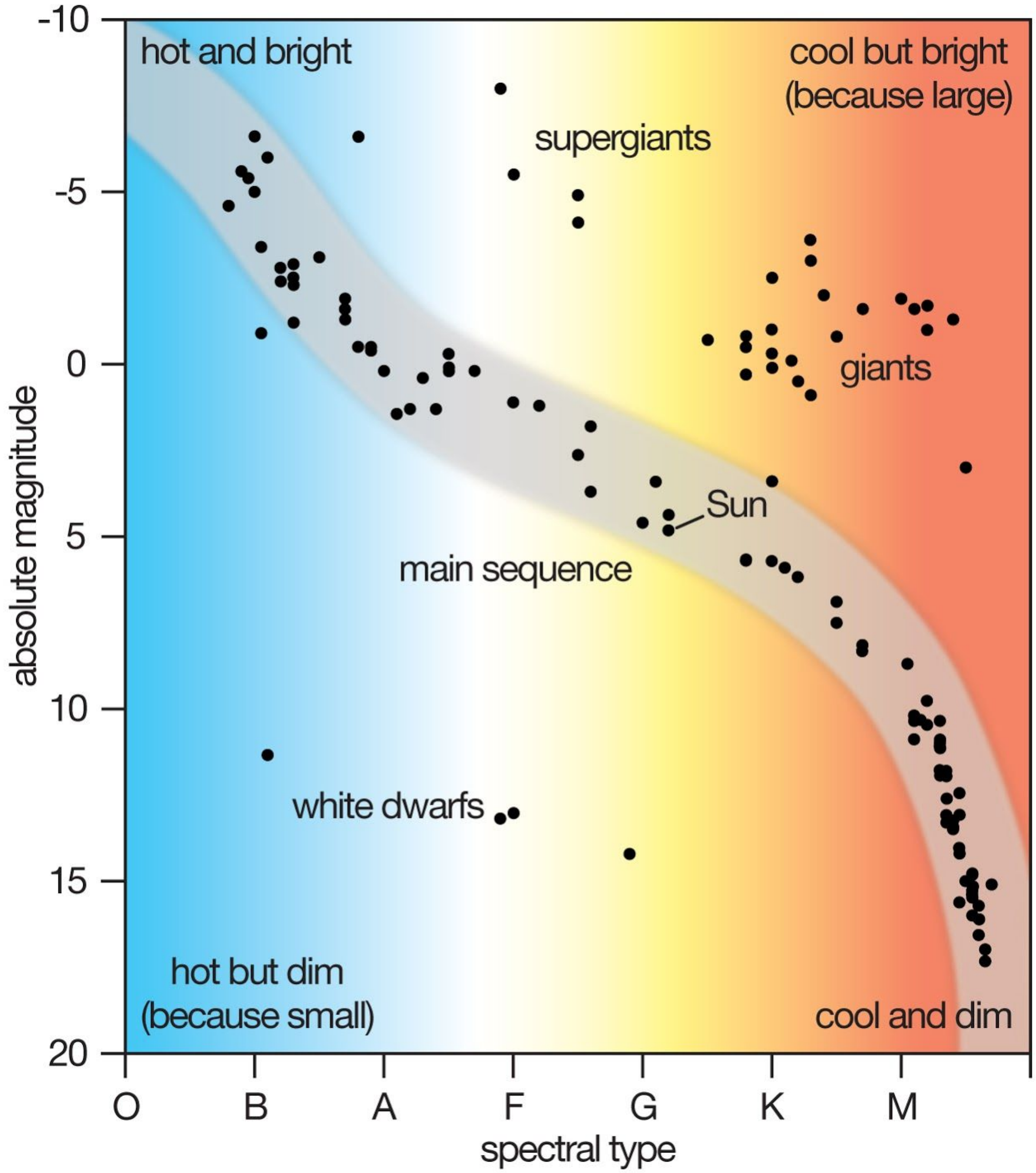
$$\left(\frac{1}{600}\right)^2 - \left(\frac{1}{800}\right)^2 = 1.215 \times 10^{-6}$$

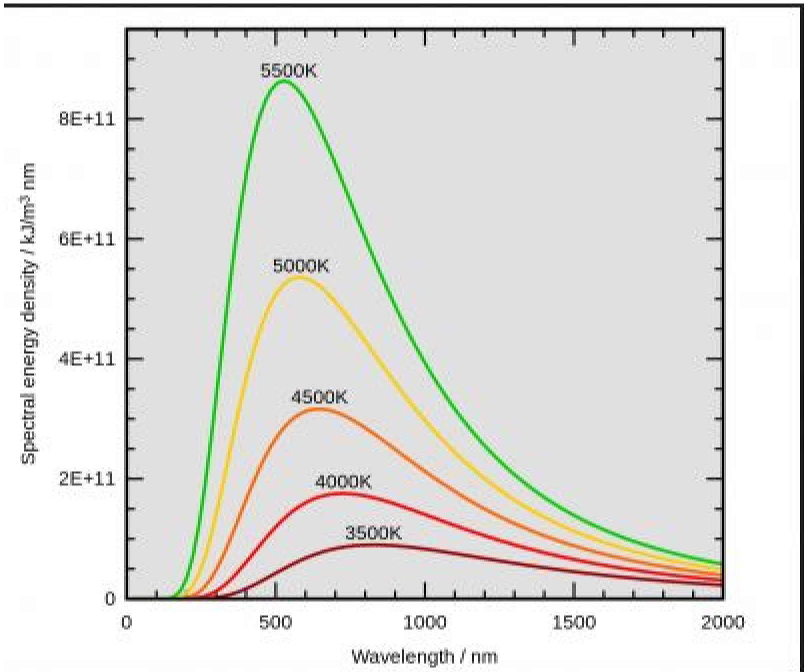
Kepler's 1st Law (Eccentricity): $e = \frac{c}{a}$

Ratio: $\frac{distance}{size/separation}$

Frequency: $v = \frac{c}{\lambda}$

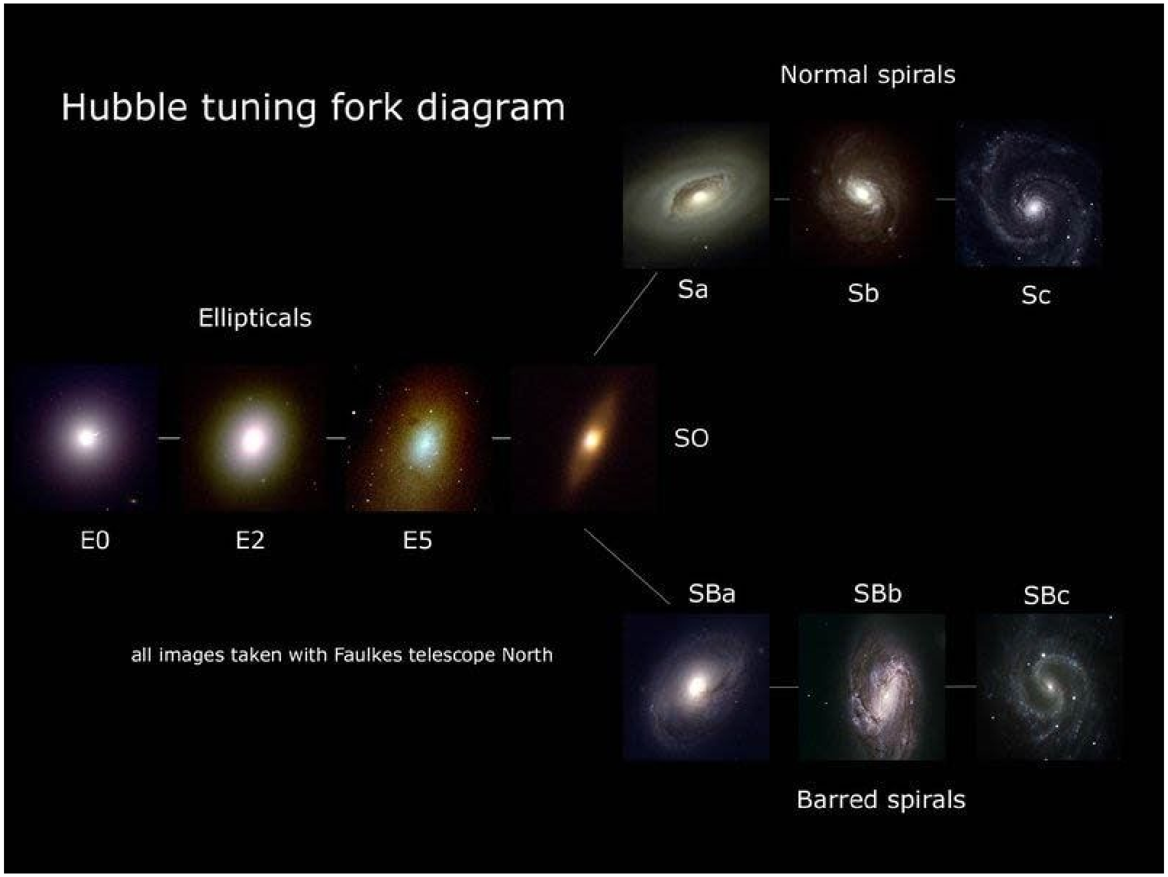
Hertzsprung-Russell diagram





5500K
5000K
4500K
4000K
3500K
8E+11
6E+11
4E+11
2E+11
0
0
500
1000
1500
2000
Wavelength / nm
Spectral energy density / kJ/m³ nm

Hubble Types



Most disc galaxies (Sa, Sb, Sc above) also have spiral arms and are called spiral galaxies. About half also have well-defined 'bars' near the center, and these are called barred spirals (SBa, SBb, SBc above).

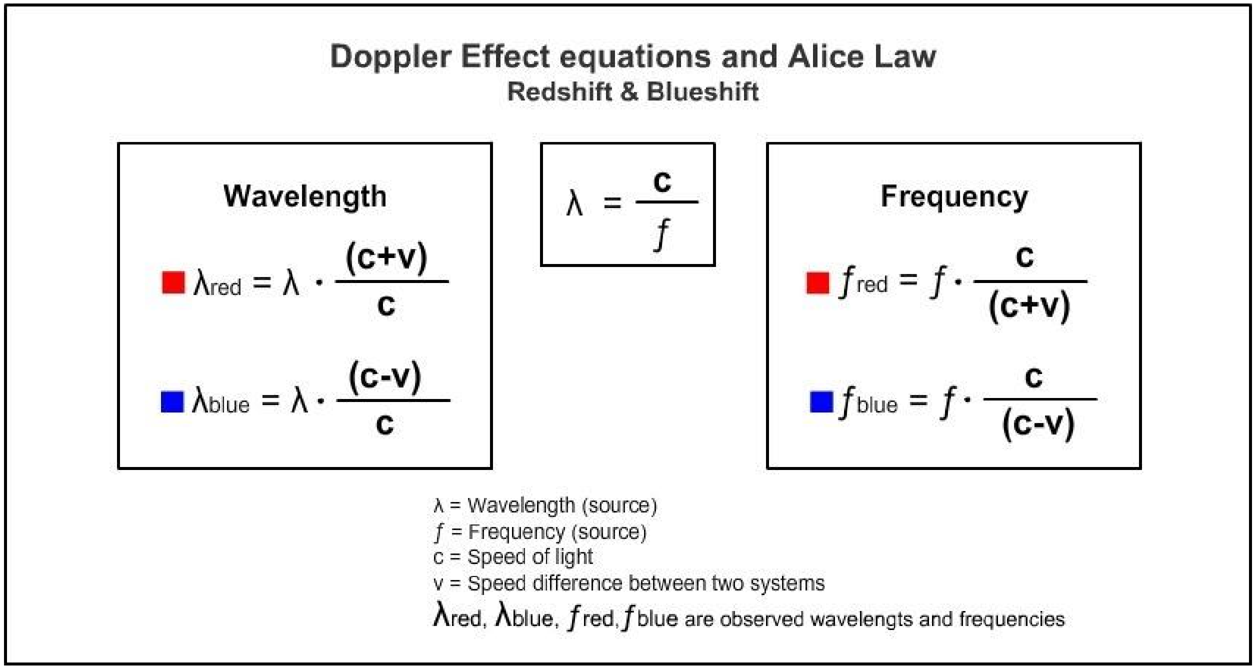
A few disc galaxies (S0, SB0) do not have any spiral arms and these are called lenticular (or 'lens shaped') galaxies. They consist of a disc and a smaller bulge of variable size. The S0 and SB0 diagrams above are just diagrammatic representations - in practice it is hard to tell lenticular galaxies at various viewing angles from elliptical galaxies (because a face-on lenticular would look like an E0 elliptical, while one inclined at 66 degrees would appear like an E6, for example).

Very few galaxies show no obvious symmetry and do not fall into any of these categories. We will simply call all of these irregular galaxies (Irr), although astronomers have identified many different types which have been given different names.

Notable Galaxies

- Milky Way - hubble type SBb
- Andromeda (M31) - hubble type Sb
- Whirlpool (M51) - hubble type Sb

Class	Absolute magnitude (B-band)	Mass (solar masses)	Diameter (kiloparsec)
Ellipticals	-8 to -23	10^7 to 10^{12}	~0.3 to 100s
Spirals	-16 to -23	10^9 to 10^{12}	5 to 100
Irregulars	-13 to -20	10^8 to 10^{10}	1 to 10



Quantity	Symbol	Value	Relative uncertainty	Ref.
Defining constants				
Gaussian gravitational constant	*k*	$0.017\ 202\ 098\ 95\ A^{3/2}\ S^{-1/2}\ D^{-1}$	defined	[2]
Speed of light	*c*	$299\ 792\ 458\ \mathrm{m\ s^{-1}}$	defined	[7]

Mean ratio of the TT second to the TCG second	$1 - L_G$	$1 - 6.969\ 290\ 134 \times 10^{-10}$	defined	[8]
Mean ratio of the TCB second to the TDB second	$1 - L_B$	$1 - 1.550\ 519\ 767\ 72 \times 10^{-8}$	defined	[9]
Primary constants				
Mean ratio of the TCB second to the TCG second	$1 - L_C$	$1 - 1.480\ 826\ 867\ 41 \times 10^{-8}$	1.4×10^{-9}	[8]
Light-time for unit distance	τ_A	499.004 786 3852 s	4.0×10^{-11}	[10][11]
Equatorial radius for Earth	a_e	$6.378\ 1366 \times 10^{6}$ m	1.6×10^{-8}	[11]
Potential of the geoid	W_0	$6.263\ 685\ 60 \times 10^{7}\ m^2\ s^{-2}$	8.0×10^{-9}	[11]
Dynamical form-factor for Earth	J_2	0.001 082 6359	9.2×10^{-8}	[11]
Flattening factor for Earth	$1/f$	0.003 352 8197 = 1/298.256 42	3.4×10^{-8}	[11]
Geocentric gravitational constant	GE	$3.986\ 004\ 391 \times 10^{14}\ m^3\ s^{-2}$	2.0×10^{-9}	[10]
Constant of gravitation	G	$6.674\ 28 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$	1.0×10^{-4}	[12]
Ratio of mass of Moon to mass of Earth	μ	0.012 300 0383 = 1/81.300 56	4.0×10^{-8}	[10][11]

General precession in longitude, per Julian century, at standard epoch 2000	ρ	5028.796 195″	*	[13]
Obliquity of the ecliptic, at standard epoch 2000	ε	23° 26′ 21.406″	*	[13]
Derived constants				
Constant of nutation, at standard epoch 2000	N	9.205 2331″	*	[14]
Unit distance = $c\tau_A$	A	149 597 870 691 m	4.0×10^{-11}	[10][11]
Solar parallax = $\arcsin(a_e/A)$	$\pi_\odot$	8.794 1433″	1.6×10^{-8}	[2]†
Constant of aberration, at standard epoch 2000	κ	20.495 52″		[2]
Heliocentric gravitational constant = A^3k^2/D^2	GS	$1.327\ 2440\times10^{20}$ m^3 s^{-2}	3.8×10^{-10}	[11]
Ratio of mass of Sun to mass of Earth = $(GS)/(GE)$	S/E	332 946.050 895		[10]
Ratio of mass of Sun to mass of (Earth + Moon)	(S/E) $(1+\mu)$	328 900.561 400		[10]
Mass of Sun = $(GS)/G$	S	1.98855×10^{30} kg	1.0×10^{-4}	[2]†
System of planetary masses: Ratios of mass of Sun to mass of planet[10]				

Mercury		6 023 600		
Venus		408 523.71		
Earth + Moon		328 900.561 400		
Mars		3 098 708		
Jupiter		1047.3486		
Saturn		3497.898		
Uranus		22 902.98		
Neptune		19 412.24		
Pluto		135 200 000		
Other constants (outside the formal IAU System)				
Parsec = *A*/tan(1")	pc	$3.085\ 677\ 581\ 28\times10^{16}$ m	4.0×10^{-11}	[15]†
Light-year = 365.25*cD*	ly	$9.460\ 730\ 472\ 5808\times10^{15}$ m	defined	[15]†
Hubble constant	H_0	70.1 km s^{-1} Mpc^{-1}	0.019	[16]
Solar luminosity	$L_\odot$	3.939×10^{26} W	variable,	[17]

		$= 2.107\times10^{-15}\ S\ D^{-1}$	±0.1%	

Quantity	Value[23]	Relative standard uncertainty
Avogadro constant	$6.02214076\times10^{23}\ \mathrm{mol}^{-1}$[24]	0
Boltzmann constant	$1.380649\times10^{-23}\ \mathrm{J\cdot K^{-1}}$[25]	0
elementary charge	$1.602176634\times10^{-19}\ \mathrm{C}$[26]	0
Newtonian constant of gravitation	$6.67430(15)\times10^{-11}\ \mathrm{m^3\cdot kg^{-1}\cdot s^{-2}}$[27]	2.2×10^{-5}
Planck constant	$6.62607015\times10^{-34}\ \mathrm{J\cdot s}$[28]	0
speed of light in vacuum	299792458 m/s[9]	0
vacuum electric permittivity	$8.8541878128(13)\times10^{-12}\ \mathrm{F\cdot m^{-1}}$[7]	1.5×10^{-10}
vacuum magnetic permeability	$1.25663706212(19)\times10^{-6}\ \mathrm{N\cdot A^{-2}}$[29]	1.5×10^{-10}
electron mass	$9.1093837015(28)\times10^{-31}\ \mathrm{kg}$[30]	3.0×10^{-10}

proton mass	$1.67262192369(51)\times10^{-27}$ kg[31]	3.1×10^{-10}
fine-structure constant	$7.2973525693(11)\times10^{-3}$[32]	1.5×10^{-10}
Josephson constant	$483597.8484...\times10^{9}$ $\mathrm{Hz\cdot V^{-1}}$[33]	0
molar gas constant	8.314462618... $\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$[34]	0
Rydberg constant	10973731.568160(21) $\mathrm{m^{-1}}$[35]	1.9×10^{-12}
von Klitzing constant	25812.80745... Ω[36]	0

Name	Quantity	Dimension symbol	Value (SI units)
Planck length	Length	L	$1.616255(18)\times10^{-35}$ m[4]
Planck mass	Mass	M	$2.176435(24)\times10^{-8}$ kg[5]
Planck time	Time	T	$5.391247(60)\times10^{-44}$ s[6]
Planck charge	Electric charge	Q	$1.87554603778(14)\times10^{-18}$ C[7][8][9]
Planck temperature	Temperature	Θ	$1.416785(16)\times10^{32}$ K[10]

Chronology of Universe

Epoch	Time	Redshift	Radiation temperature (Energy) [verification needed]	Description
Planck epoch	$<10^{-43}$ s		$>10^{32}$ K ($>10^{19}$ GeV)	The Planck scale is the physical scale beyond which current physical theories may not apply, and cannot be used to calculate what happened. During the Planck epoch, cosmology and physics are assumed to have been dominated by the quantum effects of gravity.
Grand unification epoch	$<10^{-36}$ s		$>10^{29}$ K ($>10^{16}$ GeV)	The three forces of the Standard Model are unified (assuming that nature is described by a Grand Unified Theory).

Inflationary epoch, Electroweak epoch	$<10^{-32}$ s		10^{28} K ~ 10^{22} K (10^{15} ~ 10^{9} GeV)	Cosmic inflation expands space by a factor of the order of 10^{26} over a time of the order of 10^{-33} to 10^{-32} seconds. The universe is supercooled from about 10^{27} down to 10^{22} kelvins.[8] The strong interaction becomes distinct from the electroweak interaction.
Quark epoch	10^{-12} s ~ 10^{-6} s		$>10^{12}$ K (>100 MeV)	The forces of the Standard Model have separated, but energies are too high for quarks to coalesce into hadrons, instead forming a quark–gluon plasma. These are the highest energies directly observable in the Large Hadron Collider.
Hadron epoch	10^{-6} s ~ 1 s		$>10^{10}$ K (>1 MeV)	Quarks are bound into hadrons. A slight matter-antimatter-asymmetry from the earlier phases (baryon asymmetry) results in an elimination of anti-hadrons.
Neutrino decoupling	1 s		10^{10} K (1 MeV)	Neutrinos cease interacting with baryonic matter. The sphere of space that will become the observable universe is approximately 10 light-years in radius at this time.
Lepton epoch	1 s ~ 10 s		10^{10} K ~ 10^{9} K (1 MeV ~ 100 keV)	Leptons and antileptons remain in thermal equilibrium.

Big Bang nucleosynthesis	10 s ~ 10^3 s		10^9 K ~ 10^7 K (100 keV ~ 1 keV)	Protons and neutrons are bound into primordial atomic nuclei, hydrogen and helium-4. Small amounts of deuterium, helium-3, and lithium-7 are also synthesized. At the end of this epoch, the spherical volume of space which will become the observable universe is about 300 light-years in radius, baryonic matter density is on the order of 4 grams per m^3 (about 0.3% of sea level air density)—however, most energy at this time is in electromagnetic radiation.
Photon epoch	10 s ~ $1.168 \cdot 10^{13}$ s (370 ka)		10^9 K ~ 4000 K (100 keV ~ 0.4 eV)	The universe consists of a plasma of nuclei, electrons and photons; temperatures remain too high for the binding of electrons to nuclei.

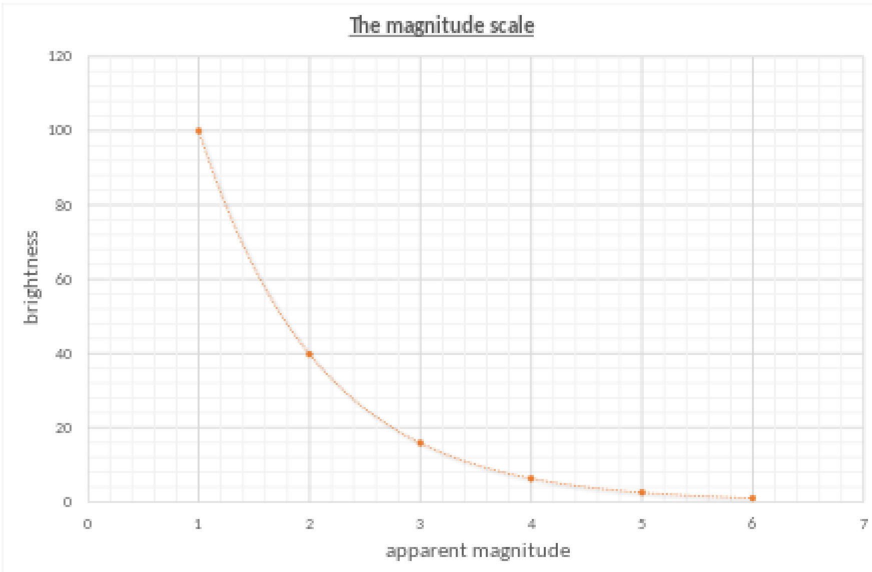
Recombination	370 ka	1100	4000 K (0.4 eV)	Electrons and atomic nuclei first become bound to form neutral atoms. Photons are no longer in thermal equilibrium with matter and the universe first becomes transparent. Recombination lasts for about 100 ka, during which universe is becoming more and more transparent to photons. The photons of the cosmic microwave background radiation originate at this time. The spherical volume of space which will become the observable universe is 42 million light-years in radius at this time. The baryonic matter density at this time is about 500 million hydrogen and helium atoms per m^3, approximately a billion times higher than today. This density corresponds to pressure on the order of 10^{-17} atm.
Dark Ages	370 ka ~? 150 Ma (Only fully ends by about 1 Ga)	1100 ~ 20	4000 K ~ 60 K	The time between recombination and the formation of the first stars. During this time, the only source of photons was hydrogen emitting radio waves at hydrogen line. Freely propagating CMB photons quickly (within about 3 million years) red-shifted to infrared, and universe was devoid of visible light.

Star and galaxy formation and evolution	Earliest galaxies: from about ?300-400 Ma (first stars: similar or earlier) Modern galaxies: 1 Ga ~ 10 Ga (Exact timings being researched)	From about 20	From about 60 K	The earliest known galaxies existed by about 380 Ma. Galaxies coalesce into "proto-clusters" from about 1 Ga (redshift $z = 6$) and into galaxy clusters beginning at 3 Ga ($z = 2.1$), and into superclusters from about 5 Ga ($z = 1.2$). See: list of galaxy groups and clusters, list of superclusters.
Reionization	Onset 250 Ma ~ 500 Ma Complete: 700 Ma ~ 900 Ma Ends: 1 Ga (All timings approximate)	20 ~ 6	60 K ~ 19 K	The most distant astronomical objects observable with telescopes date to this period; as of 2016, the most remote galaxy observed is GN-z11, at a redshift of 11.09. The earliest "modern" Population III stars stars are formed in this period.
Present time	13.8 Ga	0	2.7 K	Farthest observable photons at this moment are CMB photons. They arrive from a sphere with the radius of 46 billion light-years. The spherical volume inside it is commonly referred to as the observable universe.
Alternative subdivisions of the chronology (overlapping several of the above periods)				

Radiation-dominated era	From inflation (~ 10^{-32} sec) ~ 47 ka	>3600	>10^4 K	During this time, the energy density of massless and near-massless relativistic components such as photons and neutrinos, which move at or close to the speed of light, dominates both matter density and dark energy.
Matter-dominated era	47 ka ~ 9.8 Ga[2]	3600 ~ 0.4	10^4 K ~ 4 K	During this time, the energy density of matter dominates both radiation density and dark energy, resulting in a decelerated metric expansion of space.
Dark-energy-dominated era	>9.8 Ga[7]	<0.4	<4 K	Matter density falls below dark energy density (vacuum energy), and expansion of space begins to accelerate. This time happens to correspond roughly to the time of the formation of the Solar System and the evolutionary history of life.
Stelliferous Era	150 Ma ~ 100 Ga	20 ~ −0.99	60 K ~ 0.03 K	The time between the first formation of Population III stars until the cessation of star formation, leaving all stars in the form of degenerate remnants.

Far future	>100 Ga	<−0.99	<0.1 K	The Stelliferous Era will end as stars eventually die and fewer are born to replace them, leading to a darkening universe. Various theories suggest a number of subsequent possibilities. Assuming proton decay, matter may eventually evaporate into a Dark Era (heat death). Alternatively the universe may collapse in a Big Crunch. Alternative suggestions include a false vacuum catastrophe or a Big Rip as possible ends to the universe.

Magnitude:



The magnitude scale
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100
80
60
40
20
0
0
1
2
3
4
5
6
7
apparent magnitude