Astronomy

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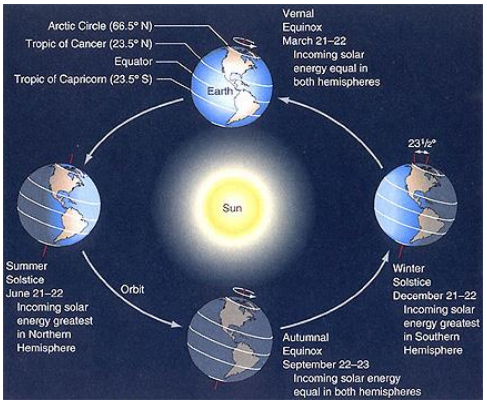
http://denisemeeks.com/science/notebooks/notebook_astronomy.pdf

Astronomy: Earth

mass (kg)	radius (km)	average density (gm/cm^3)	standard atmosphere (pascals)
5.97×10^{24}	6,378	5.514	101,325
mean distance from Sun (km = 1 AU)	**perihelion (km)**	**aphelion (km)**	**axial tilt**
1.496×10^{8}	1.471×10^{8}	1.521×10^{8}	23.45^{0}
gravity (m/s^2)	**average orbital speed (km/s)**	**escape velocity (km/s)**	**orbital eccentricity**
9.81	29.78	11.186	0.0167

Astronomy: Equinoxes and Solstices



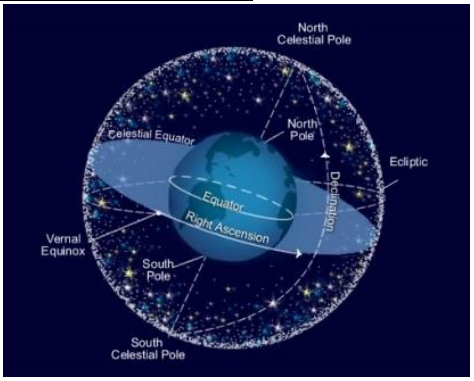
equinox: when the plane of Earth's equator passes through the center of the Sun, occurs around Mar. 20 and Sep. 23

solstice: when the Sun reaches its most northern or southern excursion relative to the celestial equator; occurs around Jun. 21 and Dec. 21

(Image source: https://cbsboston.files.wordpress.com/2015/09/sky.jpg)

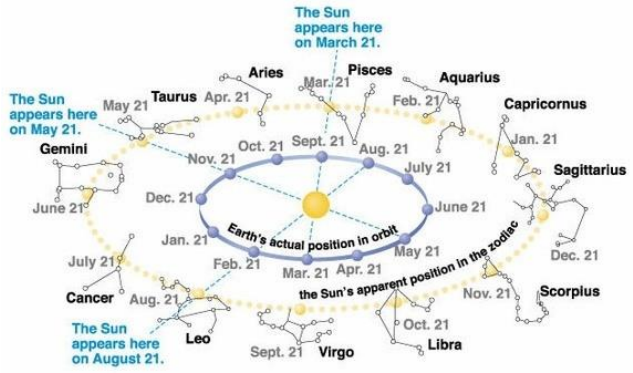
Astronomy: Celestial Sphere

celestial spere: an imaginary sphere of arbitrarily large radius, concentric with Earth; all objects in the observer's sky can be thought of as projected upon the inside surface of the celestial sphere



(Image source: https://en.wikipedia.org/wiki/Celestial_sphere; image source: Lunar and Planetary Institute)

Astronomy: Ecliptic



(Image source: https://www.quora.com/What-is-the-ecliptic)

Astronomy: Milankovitch Cycles (1)

Milankovitch cycles: describes the collective effects of changes in the Earth's movements on climate; theory that variations in eccentricity, axial tilt, and precession of Earth's orbit strongly influenced climatic patterns

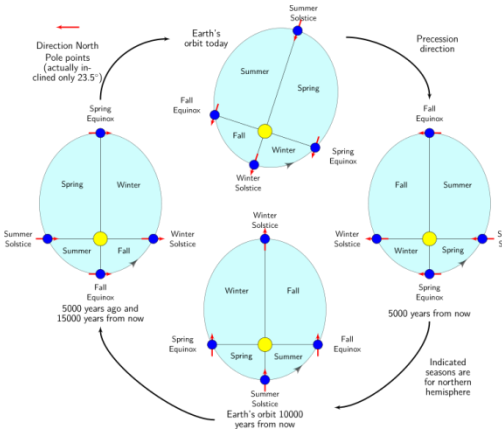
eccentricity: Earth's orbital eccentricity varies between nearly circular, with the lowest eccentricity of 0.000055, and mildly elliptical, highest eccentricity of 0.0679, with the mean eccentricity of 0.0019

axial tilt: varies with respect to the plane of Earth's orbit; slow 2.4° obliquity variations take approximately 41,000 years to shift between 22.1° and 24.5° and back again; when obliquity increases, amplitude of the seasonal cycle in insolation increases, summers in both hemispheres receive more radiative solar flux, and less in winters; when the obliquity decreases, summers receive less and winters receive more

precession: trend in direction of Earth's axis of rotation relative to fixed stars, period of about 26,000 years; gyroscopic motion is due to tidal forces exerted by the Sun and the Moon on Earth; both contribute equally to this effect.

Astronomy: Milankovitch Cycles (2)

(Source of (1): https://en.wikipedia.org/wiki/Milankovitch_cycles)



(Image source: https://en.wikipedia.org/wiki/Milankovitch_cycles#/media/File:Precession_and_seasons.svg, Krishnavedala, CC BY-SA 3.0)

Astronomy: Sidereal and Synodic Periods (1)

Earth		Moon	
sidereal rotation period in hours	sidereal orbital period in days	sidereal period in days	synodic period in days
23h 56m 4.099s	365.25636	27.32166	29.53059

sidereal period: amount of time that it takes an object to make a full orbit, relative to the stars; the sidereal day is 23h 56s
synodic period: amount of time that it takes for an object to reappear at the same point in relation to two or more other objects

synodic period between two bodies $\frac{1}{P_{syn}} = \frac{1}{P_1} + \frac{1}{P_2}$

P_1 and P_2 are the orbital periods of the two bodies

Astronomy: Sidereal and Synodic Periods (2)

prograde motion:

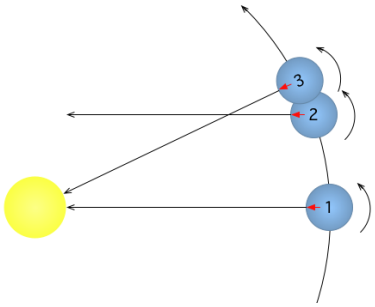
$$\text{length of solar day} = \frac{\text{length of sidereal day}}{1 - \frac{\text{length of sidereal day}}{\text{orbital period}}}$$

retrograde motion:

$$\text{length of solar day} = \frac{\text{length of sidereal day}}{1 + \frac{\text{length of sidereal day}}{\text{orbital period}}}$$

Astronomy: Sidereal and Synodic Periods (3)

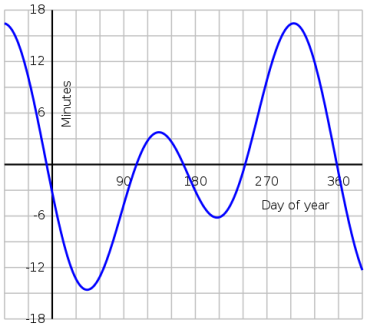
On a prograde planet like Earth, the stellar day is shorter than the solar day. At time 1, the Sun and a certain distant star are both overhead. At time 2, the planet has rotated 360° and the distant star is overhead again but the Sun is not (1→2 = one stellar day). It is not until a little later, at time 3, that the Sun is overhead again (1→3 = one solar day).



(Image source: https://en.wikipedia.org/wiki/Earth%27s_rotation#/media/File:Sidereal_day_(prograde).png, Gdr, CC BY-SA 3.0)

Astronomy: Equation of Time

apparent solar time: time indicated by a sundial
mean solar time: average as indicated by well-regulated clocks
equation of time: difference between apparent solar time and mean solar time
above the axis: sundial will appear fast relative to a clock; below the axis sundial will appear slow



(Image source: https://en.wikipedia.org/wiki/Equation_of_time#/media/File:Equation_of_time.svg, Drini, CC BY-SA 3.0)

Astronomy: Universal Time and Coordinated Universal Time

universal time: time standard based on Earth's rotation; modern continuation of Greenwich Mean Time (GMT), the mean solar time on the Prime Meridian at Greenwich, London, UK

Coordinated Universal Time (UTC): primary time standard by which the world regulates clocks and time; is within about 1 second of mean solar time at 0° longitude; does not observe daylight saving time

(Sources: https://en.wikipedia.org/wiki/Universal_Time, https://en.wikipedia.org/wiki/Coordinated_Universal_Time)

Astronomy: Julian Date and GMST

$$a = \text{floor}\left(\frac{14 - \text{month}}{12}\right) \quad y = \text{year} + 4800 - a \quad m = \text{month} + 12a - 3$$

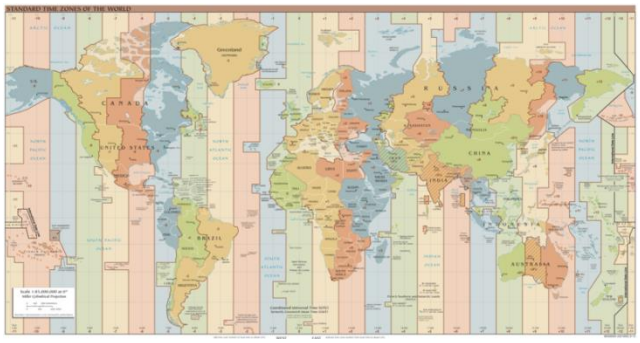
$$JDN = \text{day} + \text{floor}\left(\frac{153m + 2}{5}\right) + 365y + \text{floor}\left(\frac{y}{4}\right) - \text{floor}\left(\frac{y}{100}\right) + \text{floor}\left(\frac{y}{400}\right) - 32045$$

$$JD = JDN + \frac{\text{hour} - 12}{24} + \frac{\text{minute}}{1440} + \frac{\text{second}}{86{,}400}$$

$$D = JD - 2451545.0$$

$$GMST = 18.697374558 + 24.06570982441908 * D$$

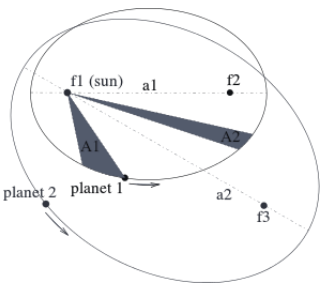
Astronomy: Time Zones



(Image source: https://en.wikipedia.org/wiki/Time_zone#/media/File:Standard_World_Time_Zones.png, TimeZonesBoy, CC BY-SA 4.0)

Astronomy: Kepler's Laws

1. The orbit of a planet is an ellipse with the Sun at one of the two foci.
2. A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time.
3. The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit. $P^2 = a^3$



(Image source: https://en.wikipedia.org/wiki/Kepler%27s_laws_of_planetary_motion#/media/File:Kepler_laws_diagram.svg, Hankwang, CC BY 2.5)

Astronomy: Orbits (1)

orbital speed $v = \sqrt{\frac{GM}{r}}$ escape speed $v = \sqrt{\frac{2GM}{r}}$

gravitational constant G = 6.67408 x 10^{-11} N m^2/kg^2

M = mass of body around which object is orbiting

r = distance of orbiting body from the center of mass M

gravitational potential energy $U = \frac{-GMm}{r}$

orbital period $T = \left(\frac{2\pi}{\sqrt{GM}}\right) r^{3/2}$ gravity $g = \frac{GM}{r^2}$

two massive bodies orbiting each other: $T = \left(\frac{2\pi}{\sqrt{G(M_1 + M_2)}}\right) r^{3/2}$

Astronomy: Orbits (2)

retrograde motion: motion backward from the norm

perigee: point in the orbit of the moon or a satellite at which it is nearest to Earth

apogee: point in the orbit of the moon or a satellite at which it is furthest from Earth

perihelion: point in the orbit of a planet, asteroid, or comet at which it is closest to the sun

aphelion: point in the orbit of a planet, asteroid, or comet at which it is furthest from the sun

periapsis: the point in the path of an orbiting body at which it is nearest to the body that it orbits

apoapsis: the point in the path of an orbiting body at which it is farthest from the body that it orbits

Astronomy: Orbit Classifications (1)

- altitude classifications
  - low Earth orbit (LEO): orbits ranging in altitude from 160 kilometers (100 statute miles) to 2,000 kilometers above mean sea level
  - medium Earth orbit (MEO): orbits with altitudes at apogee ranging between 2,000 kilometers and that of the geosynchronous orbit at 35,786 kilometers
  - geosynchronous orbit (GEO): circular orbit with an altitude of 35,786 kilometers; period equals one sidereal day, coinciding with the rotation period of the Earth
  - high Earth orbit (HEO): altitudes at apogee higher than that of the geosynchronous orbit

Astronomy: Orbit Classifications (2)

- eccentricity classifications
  - circular orbit: has an eccentricity of 0 and path traces a circle
  - elliptic orbit: eccentricity greater than 0 and less than 1 whose orbit traces the path of an ellipse
  - Hohmann transfer orbit: orbital maneuver that moves a spacecraft from one circular orbit to another using two engine impulses
  - geosynchronous transfer orbit: geocentric-elliptic orbit where perigee is at the altitude of a low Earth orbit (LEO) and apogee at altitude of a geosynchronous orbit
  - highly elliptical orbit (HEO):-geocentric orbit with apogee above 35,786 km and low perigee of about 1,000 km that result in long dwell times near apogee

(Source: https://en.wikipedia.org/wiki/Geocentric_orbit)

Astronomy: Orbital Elements (1)

- eccentricity (e): shape of the ellipse, describing how much it is elongated compared to a circle
- semimajor axis (a): sum of the periapsis and apoapsis distances divided by two
- inclination (i): vertical tilt of the ellipse with respect to the reference plane
- longitude of the ascending node (Ω): horizontally orients the ascending node of the ellipse with respect to the reference frame's vernal point
- argument of periapsis (ω): defines the orientation of the ellipse in the orbital plane, as an angle measured from the ascending node to the periapsis
- true anomaly (ν) at epoch(M_0): defines the position of the orbiting body along the ellipse at a specific time (the "epoch")

Astronomy: Orbital Elements (2)

$e = \frac{r_a - r_p}{r_a + r_p}$ r_p = perihelion distance r_a = aphelion distance

$a = \frac{r_p + r_a}{2}$ object circular velocity $v_c = \sqrt{\frac{GM}{a}}$

perihelion velocity $v_p = v_c\sqrt{\frac{1+e}{1-e}}$ aphelion velocity $v_a = v_c\sqrt{\frac{1-e}{1+e}}$

velocity at distance r $v_r = \sqrt{GM\left(\frac{2}{r} - \frac{1}{a}\right)}$

Astronomy: Celestial Coordinate Systems (1)

coordinate system	center point	fundamental plane (0° latitude)	poles	coordinates		primary direction (0° longitude)
				latitude	longitude	
horizontal (also called Alt-Az)	observer	horizon	zenith, nadir	altitude (*a*) or elevation	azimuth (A)	north or south point of horizon
equatorial	center of the Earth (geocentric)/center of the Sun (heliocentric)	celestial equator	celestial poles	declination (δ)	right ascension (α) or hour angle (h)	vernal equinox
ecliptic		ecliptic	ecliptic poles	ecliptic latitude (β)	ecliptic longitude (λ)	
galactic	center of the Sun	galactic plane	galactic poles	galactic latitude (b)	galactic longitude (l)	galactic center
supergalactic		supergalactic plane	supergalactic poles	supergalactic latitude (SGB)	supergalactic longitude (SGL)	intersection of supergalactic plane and galactic plane

(Source: https://en.wikipedia.org/wiki/Celestial_coordinate_system)

Astronomy: Celestial Coordinate Systems (2)

λ_0 = observer's longitude

φ_0 = observer's latitude

ε = obliquity of the ecliptic, 23.43707^0

θ_L = local sidereal time

θ_G = Greenwich sidereal time

hour angle ←→ right ascension

$$h = \theta_L - \alpha = \theta_G - \lambda_0 - \alpha$$

$$\alpha = \theta_L - h = \theta_G - \lambda_0 - h$$

Astronomy: Celestial Coordinate Systems (3)

equatorial ←→ ecliptic

$$\tan\lambda = \frac{\sin\alpha\cos\varepsilon + \tan\delta\sin\varepsilon}{\cos\alpha}$$

$$\sin\beta = \sin\delta\cos\varepsilon - \cos\delta\sin\varepsilon\sin\alpha$$

$$\tan\alpha = \frac{\sin\lambda\cos\varepsilon + \tan\beta\sin\varepsilon}{\cos\lambda}$$

$$\sin\delta = \sin\beta\cos\varepsilon + \cos\beta\sin\varepsilon\sin\lambda$$

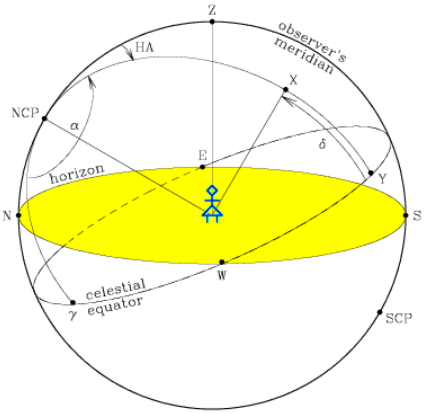
Astronomy: Right Ascension and Declination (1)

right ascension: abbreviated ra, celestial equivalent of terrestrial longitude; measured from the vernal equinox, or the First Point of Aries, which is the place on the celestial sphere where the Sun crosses the celestial equator from south to north at the March equinox, currently located in the constellation Pisces; measured in hours (h), minutes (m), and seconds (s), with 24h equivalent to a full circle

declination: abbreviated dec; symbol δ; one of the two angles that locate a point on the celestial sphere in the equatorial coordinate system; measured north or south of the celestial equator, along the hour circle passing through the point in question

hour angle: measures the angular distance of an object westward along the celestial equator from the observer's meridian to the hour circle passing through the object; always increasing with Earth's rotation; may be considered a means of measuring the time since an object crossed the meridian; aster on the observer's celestial meridian has a zero hour angle

Astronomy: Right Ascension and Declination (2)

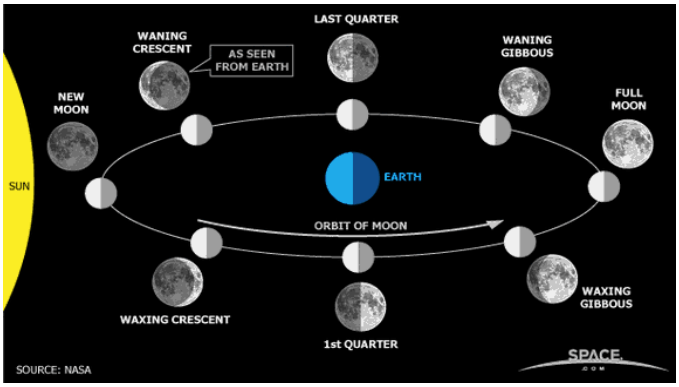


(Image source: http://astronomy.nmsu.edu/nicole/teaching/ASTR505/lectures/lecture08/slide05.html, M. Vogt, New Mexico State University)

Astronomy: Phases of the Moon (1)

phase	moonrise	overhead time	moonset
new	6 am	noon	6 pm
waxing crescent	9 am	3 pm	9 pm
first quarter	noon	6 pm	midnight
waxing gibbous	3 pm	9 pm	3 am
full	6 pm	midnight	6 am
waning gibbous	9 pm	3 am	9 am
third quarter	midnight	6 am	noon
waning crescent	3 am	9 am	3 pm

Astronomy: Phases of the Moon (2)



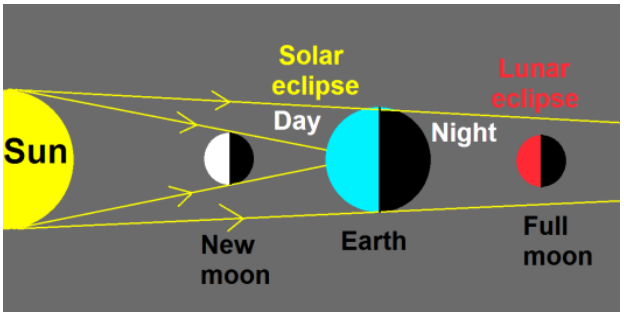
(Image source: NASA, public domain)

Astronomy: Lunar and Solar Eclipses (1)

lunar eclipse: occurs when the Moon passes directly behind the Earth into its umbra (shadow), can occur only when the sun, Earth, and moon are aligned ("syzygy"), with the Earth in the middle, a lunar eclipse can occur only the night of a full moon

solar eclipse: occurs when the Moon passes between the Sun and Earth, and the Moon fully or partially blocks ("occults") the Sun, can happen only at new moon when the Sun and the Moon are in conjunction as seen from Earth in an alignment ("syzygy"), in a total eclipse, the disk of the Sun is fully obscured by the Moon, in partial and annular eclipses, only part of the Sun is obscured

Astronomy: Lunar and Solar Eclipses (2)



(Image source: https://en.wikipedia.org/wiki/Lunar_eclipse#/media/File:Solar_lunar_eclipse_diagram.png, Tomruen, CC BY-SA 4.0)

Bortle Dark Sky Scale (1)

class	title	NELM	
1	excellent dark sky	7.6 - 8.0	• zodiacal light, gegenschein, zodiacal band, airglow readily visible • many constellations, particularly fainter ones, barely recognizable due to large number of stars • many Messier and globular clusters are naked-eye objects • M33 is a direct vision naked-eye object
2	typical truly dark sky	7.1 – 7.5	• zodiacal light is distinctly yellowish, bright enough to cast shadows at dusk and dawn • airglow may be weakly visible near horizon • summer Milky Way highly structured • many Messier objects and globular clusters are naked-eye objects • M33 is easily seen with naked eye

NELM – naked eye limiting magnitude

Bortle Dark Sky Scale (2)

class	title	NELM	
3	rural sky	6.6 – 7.0	• zodiacal light is striking in spring and autumn, and color is still visible • some light pollution evident at the horizon, dark above • nearer surroundings are vaguely visible • the summer Milky Way still appears complex • M15, M4, M5, and M22 are naked-eye objects • M33 is easily visible with averted vision
4	rural/ surban transition	6.1 – 6.5	• zodiacal light still visible • light pollution domes visible in several directions • clouds illuminated in the directions of the light sources, dark overhead • surroundings clearly visible, even at a distance • Milky Way well above the horizon but lacks detail • M33 difficult, averted vision object, visible when high

Bortle Dark Sky Scale (3)

class	title	NELM	
5	sub-urban sky	5.6 – 6.0	• only hints of zodiacal light are seen on the best nights in autumn and spring • light pollution is visible in most, if not all, directions • clouds are noticeably brighter than the sky • Milky Way very weak or invisible near the horizon, looks washed out overhead
6	bright sub-urban sky	5.1 – 5.5	• zodiacal light is invisible • light pollution makes the sky within 35° of horizon grayish white • clouds anywhere in the sky appear fairly bright • surroundings are easily visible • Milky Way is only visible near the zenith • M33 is not visible, M31 is modestly apparent

Bortle Dark Sky Scale (4)

class	title	NELM	
7	sub-urban/ urban transition	4.6 – 5.0	• light pollution makes the entire sky light gray • Milky Way invisible • M31 and M44 may be glimpsed, but with no detail • brightest Messier objects are dim
8	city sky	4.1 – 4.5	• sky is light gray or orange, one can easily read • stars forming familiar constellations weak or invisible • M31 and M44 barely glimpsed by experienced observer • only bright Messier objects detectable, with telescope
9	inner city sky	4.0	• sky is brilliantly lit • many constellations barely visible • aside from Pleiades, no Messier object naked eye visible • only observable objects are Moon, planets, a few bright star clusters

(Source: https://en.wikipedia.org/wiki/Bortle_scale)

Observational Astronomy (1)

radio astronomy: uses radiation outside the visible range with wavelengths greater than approximately one mm; different from most other forms of observational astronomy in that the observed radio waves can be treated as waves rather than discrete photons

infrared astronomy: founded on the detection and analysis of infrared radiation, wavelengths longer than red light and outside the range of our vision; useful for studying objects that are too cold to radiate visible light, such as planets, circumstellar disks or nebulae

optical astronomy: modern images are made using digital detectors, particularly using charge-coupled devices (CCDs) and recorded on modern medium; visible light itself extends from approximately 4000 Å to 7000 Å that same equipment can be used to observe some near-ultraviolet and near-infrared radiation

Observational Astronomy (2)

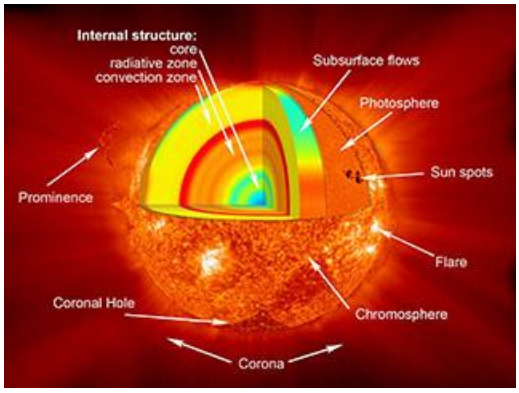
ultraviolet astronomy: employs UV wavelengths between 100 and 3200 Å; light at those wavelengths absorbed by the Earth's atmosphere, requiring observations to be performed from upper atmosphere or space; suited to study of thermal radiation and spectral emission lines from blue stars, planetary nebulae, supernova remnants, active galactic nuclei

X-ray astronomy: X-rays absorbed by Earth's atmosphere; all X-ray observations must be performed from high-altitude balloons, rockets, or X-ray astronomy satellites; X-ray sources include X-ray binaries, pulsars, supernova remnants, elliptical galaxies, clusters of galaxies, active galactic nuclei

gamma ray astronomy: satellites observes astronomical objects at shortest wavelengths; most gamma-ray emitting sources are actually gamma-ray bursts, objects which only produce gamma radiation for a few milliseconds to thousands of seconds before fading away

(Source: https://en.wikipedia.org/wiki/Astronomy)

Astronomy: Structure of the Sun (1)



(Image source: http://solarsystem.nasa.gov/planets/sun/indept, NASA, public domain)

Astronomy: Structure of the Sun (2)

layer	description
core	extends from center to about 20–25% of the solar radius; density of up to 150 g/cm^3, temperature close to 15.7 million K
radiative zone	thermal radiation primary means of energy transfer; temperature drops from approximately 7 million to 2 million K; transfer of energy by radiation; convection; density drops from 20 g/cm^3 to only 0.2 g/cm^3
tacholine	region where uniform rotation of radiative zone and differential rotation of the convection zone results in a large shear
convective zone	extends from 0.7 solar radii (200,000 km) to near the surface; temperature drops to 5,700 K and the density to only 0.2 g/m^3

Astronomy: Structure of the Sun (3)

layer	description
photosphere	visible surface of the Sun, is the layer below which the Sun becomes opaque to visible light; about 6000 K
chromosphere	layer about 2,000 km thick, dominated by a spectrum of emission and absorption lines
transition region	temperature rises rapidly from around 20,000 K in the upper chromosphere to coronal temperatures closer to 1,000,000 K
corona	has a particle density around 10^{15} m^{-3} to 10^{16} m^{-3}; the average temperature of the corona and solar wind is about 1,000,000–2,000,000 K; in the hottest regions it is 8,000,000–20,000,000 K
heliosphere	tenuous outermost atmosphere of the Sun, filled with the solar wind plasma

Astronomy: Sunspots, Solar Flares, and Coronal Mass Ejections

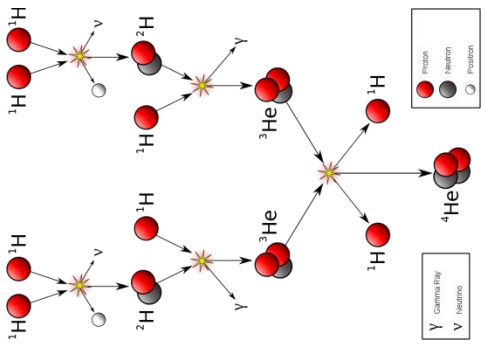
sunspot: temporary phenomena on solar photosphere; appear as dark spots; areas of reduced surface temperature caused by concentrations of magnetic field flux inhibiting convection; usually appear in pairs of opposite magnetic polarity; number varies according to approximately 11-year solar cycle

solar flare: sudden flash of brightness observed near the Sun's surface; involves a broad spectrum of emissions; energy release of typically 10^{20} joules of energy

coronal mass ejection: unusually large release of plasma and magnetic field from the solar corona; often follow solar flares and are normally present during a solar prominence eruption

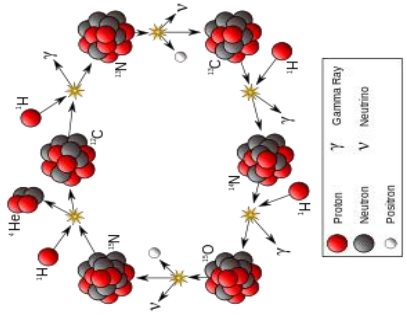
(Sources: https://en.wikipedia.org/wiki/Sunspot, https://en.wikipedia.org/wiki/Solar_flare, https://en.wikipedia.org/wiki/Coronal_mass_ejection)

Astronomy: Proton-Proton Chain



(Image source: https://en.wikipedia.org/wiki/Proton%E2%80%93proton_chain_reaction#/media/File:FusionintheSun.svg, Borb, CC BY-SA 3.0)

Astronomy: CNO Cycle



(Image source: https://en.wikipedia.org/wiki/CNO_cycle#/media/File:CNO_Cycle.svg, Borb, CC BY-SA 3.0)

Astronomy: Aurora Borealis and Aurora Australis (1)

aurora: natural light display in the sky, predominantly seen in the high latitude Arctic and Antarctic regions; produced when the magnetosphere is sufficiently disturbed by the solar wind that the trajectories of charged particles in both solar wind and magnetospheric plasma, mainly in the form of electrons and protons, precipitate them into the upper atmosphere (thermosphere/exosphere), where their energy is lost; the resulting ionization and excitation of atmospheric constituents emits light of various colors

Aurora Borealis: northern hemisphere aurora
Aurora Australis: southern hemisphere aurora

Astronomy: Aurora Borealis and Aurora Australis (2)

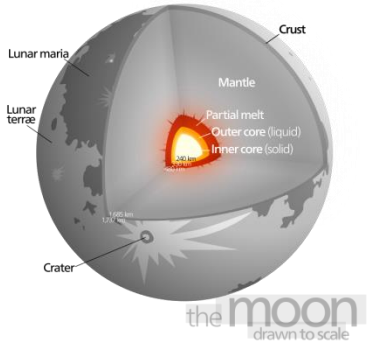
color	description
red	at highest altitudes, excited atomic oxygen emits at 630.0 nm; visible only under more intense solar activity; scarlet, crimson, and carmine are the most often-seen
green	at lower altitudes the 557.7 nm emission (green) dominates; most common color; from excited molecular nitrogen, which transfers energy by collision with oxygen atoms
blue	at lower altitudes, molecular nitrogen produces visible light in both red and blue parts of the spectrum, with 428 nm dominant
ultraviolet	has been observed; also seen on Mars, Jupiter and Saturn
infrared	part of many auroras
yellow, pink	mix of red, green, or blue; yellow-green common

(Source: https://en.wikipedia.org/wiki/Aurora)

Astronomy: Structure of the Moon (1)

The Moon is differentiated, with a geochemically distinct crust, mantle, and core. It has a solid iron-rich inner core with a radius of 240 km and fluid outer core made of liquid iron with a radius of roughly 300 km. Around the core is a partially molten boundary layer with a radius of about 500 km, thought to have developed through fractional crystallization of a global magma ocean shortly after formation 4.5 billion years ago. Crystallization of this magma ocean would have created a mafic mantle from the precipitation and sinking of the minerals olivine, clinopyroxene, and orthopyroxene; after about three-quarters of the magma ocean had crystallized, lower-density plagioclase minerals could form and float into a crust atop.
(Source: https://en.wikipedia.org/wiki/Moon)

Astronomy: Structure of the Moon (2)



(Image source: https://en.wikipedia.org/wiki/Moon#/media/File:Moon_diagram.svg, Kelvinsong, CC BY-3.0)

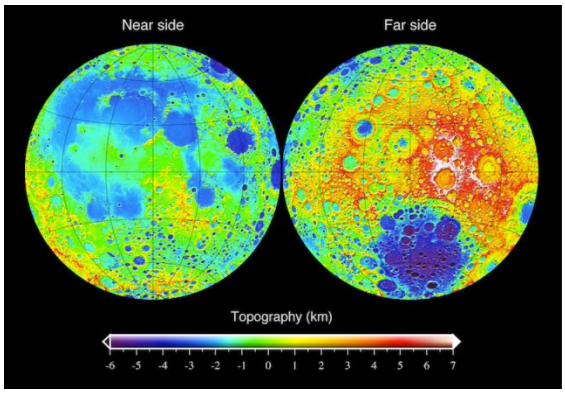
Astronomy: Saros Cycle and Metonic Cycle

saros cycle: period that can be used to predict eclipses of the Sun and Moon

metonic cycle: nearly a common multiple of the solar year and the synodic lunar month

saros cycle	metonic cycle
223 synodic months = 6,585.3211 days = 18 years, 11 days, 8 hours	6,940 days = 235 synodic months = 19 years

Astronomy: Lunar Topography



(Image source: https://en.wikipedia.org/wiki/Moon#/media/File:MoonTopoLOLA.png, Mark A. Wieczorek, CC BY 3.0)

Astronomy: Lunar Geology (1)

The prevailing hypothesis is that the Earth–Moon system formed as a result of the impact of a Mars-sized body, named Theia, with the proto-Earth (giant impact), that blasted material into orbit about the Earth that then accreted to form the present Earth-Moon system. The Moon's gravitational influence produces the ocean tides, body tides, and the slight lengthening of the day. Its current orbital distance is about thirty times Earth's diameter, with its apparent size in the sky almost the same as that of the Sun, resulting in the Moon covering the Sun nearly precisely in total solar eclipse.

Astronomy: Lunar Geology (2)

Its most visible feature is the giant far-side South Pole, Aitken basin, 2,240 km in diameter, the largest crater on the Moon the second-largest confirmed impact crater in the Solar System. It is 13 km deep, the lowest point on the surface of the Moon. The highest elevations are located directly to the northeast. It might have been thickened by the oblique formation impact of the South Pole Aitken basin. Other large impact basins, include Imbrium, Serenitatis, Crisium, Smythii, and Orientale, which have regionally low elevations and elevated rims. The far side of the lunar surface is on average about 1.9 km higher than that of the near side. The discovery of fault scarp cliffs implies that the Moon has shrunk within the past billion years, by about 90 meters.

Astronomy: Lunar Geology (3)

The dark and relatively featureless lunar plains are called maria (Latin for "seas"; singular mare), and were once believed to be filled with water. They are large solidified pools of ancient basaltic lava. Although similar to terrestrial basalts, lunar basalts have more iron and no minerals altered by water. Most of these lavas erupted or flowed into the depressions associated with impact basins. Several geologic provinces containing shield volcanoes and volcanic domes are found within the near side "maria." Almost all maria are on the near side of the Moon, and cover 31% of the surface of the near side, compared with 2% of the far side.

Astronomy: Lunar Geology (4)

There are estimated to be about 300,000 craters wider than 1 km on the near side. The lunar geologic timescale is based on the most prominent impact events, including Nectaris, Imbrium, and Orientale, characterized by rings of uplifted material, between hundreds and thousands of kilometers in diameter. The lack of an atmosphere, weather and recent geological processes mean that many of these craters are well-preserved. Because impact craters accumulate at a nearly constant rate, counting the number of craters per unit area can be used to estimate the age of the surface.

(Source: https://en.wikipedia.org/wiki/Moon)

Astronomy: Brief Lunar Exploration History 1959-1972 (1)

date	spacecraft	country	date	spacecraft	country
Jan 4, 1959	Luna 1	USSR	Aug 27, 1966	Luna 11	USSR
Mar 4, 1959	Pioneer 4	USA	Oct 22, 1966	Luna 12	USSR
Sep 14, 1959	Luna 2	USSR	Nov 10, 1966	Lunar Orbiter 2	USA
Oct 6, 1959	Luna 3	USSR	Dec 24, 1966	Luna 13	USSR
Jul 31, 1964	Ranger 7	USA	Feb 8, 1967	Lunar Orbiter 3	USA
Feb 20, 1964	Ranger 8	USA	Apr 20, 1967	Surveyor 3	USA
Jul 20, 1965	Zond 3	USSR	May 8, 1967	Lunar Orbiter 4	USA
Feb 3, 1966	Luna 9	USSR	Aug 5, 1967	Lunar Orbiter 5	USA
April 3, 1966	Luna 10	USSR	Sep 11, 1967	Surveyor 5	USA
Jun 2, 1966	Surveyor 1	USA	Nov 10, 1967	Surveyor 6	USA
Aug 14, 1966	Lunar Orbiter 1	USA	Apr 10, 1968	Luna 14	USSR

Astronomy: Brief Lunar Exploration History 1959-1972 (2)

date	spacecraft	country	date	spacecraft	country
Sep 18, 1968	Zond 5	USSR	Nov 17, 1970	Luna 17	USSR
Nov 14, 1968	Zond 6	USSR	Nov 17, 1970	Lunokhod 1	USSR
Dec 24, 1968	Apollo 8	USA	Feb 5, 1971	Apollo 14	USA
May 21, 1969	Apollo 10	USA	Jul 30, 1971	Apollo 15	USA
Jul 20, 1969	Apollo 11	USA	Aug 4, 1971	PFS-1	USA
Aug 11, 1969	Zond 7	USSR	Oct 3, 1971	Luna 19	USSR
Nov 19, 1969	Apollo 12	USA	Feb 21, 1972	Luna 20	USSR
Apr 14, 1970	S-IV	USA	Apr 21, 1972	Apollo 16	USA
Sep 20, 1970	Luna 16	USSR	Apr 24, 1972	PFS-2	USA
Oct 24, 1970	Zond 8	USSR	Dec 11, 1972	Apollo 17	USA

(Source: https://en.wikipedia.org/wiki/Exploration_of_the_Moon)

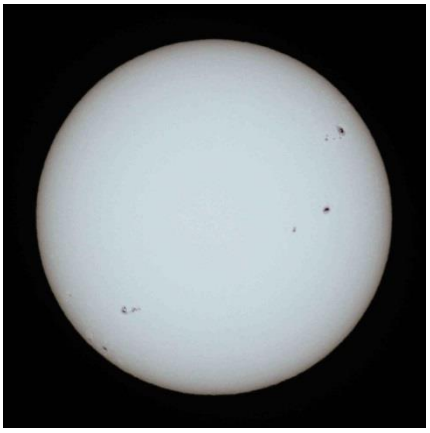
Astronomy: Sun (1)

Age:	4.6 billion years
Distance from galactic center:	26,000 ly
Orbital period:	225 – 250 million years around the center of the galaxy
Average orbital speed:	251 km/s around the center of the galaxy
Sidereal rotation period (solar day):	25.4 Earth days
Equatorial radius:	6.96×10^5 km (109 x Earth)
Surface area:	6.09×10^{12} km^2 (12,000 x Earth)
Volume:	1.41×10^{18} km^3 (1,300,000 x Earth)
Mass:	1.99×10^{30} kg (333,000 x Earth)
Mean density:	1.41 gm/cm^3 (0.26 x Earth)
Center density:	162.2 gm/cm^3 (29.4 x Earth)

Astronomy: Sun (2)

Surface gravity:	274 m/s^2 (27.9 x Earth)
Escape velocity:	617.7 km/s
Apparent magnitude:	-26.74
Angular diameter:	30’ (0.5 degrees)
Temperature:	5,778 K photosphere, 1.57×10^7 K in the core
Luminosity:	3.828×10^{26} W
Atmospheric composition:	73.5% hydrogen, 24.6% helium, trace amounts of oxygen, carbon, iron, neon, nitrogen, silicon, magnesium, and sulfur

Astronomy: Sun (3)



(Image source: https://en.wikipedia.org/wiki/Sun#/media/File:Sun_white.jpg, Geoff Elston, CC BY 4.0)

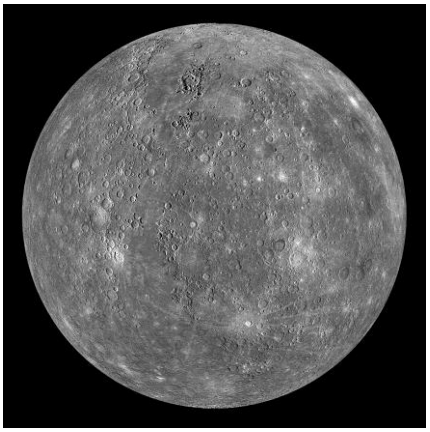
Astronomy: Planet Types

terrestrial: planet that is composed primarily of silicate rocks or metals, have a solid planetary surface, all terrestrial planets may have the same basic type of structure, such as a central metallic core, mostly iron, with a surrounding silicate mantle

jovian: usually primarily composed of low-boiling-point materials, rather than rock or other solid matter, but massive solid planets can also exist, sometimes known as gas giants or ice giants, depending on composition

dwarf: a planetary-mass object that is neither a planet nor a natural satellite, it is in direct orbit of the Sun, and is massive enough for its gravity to crush it into a hydrostatic equilibrium shape (usually a spheroid), but it has not cleared the neighborhood of other material around its orbit

Astronomy: Mercury (1)



(Image source: https://en.wikipedia.org/wiki/Mercury_(planet)#/media/File:Mercury_Globe-MESSENGER_mosaic_centered_at_0degN-0degE.jpg, NASA/APL, public domain)

Astronomy: Mercury (2)

- **smaller but more massive than Ganymede and Titan**
- **consists of ~70% metallic and 30% silicate material**
- **core occupies about 55% of its volume**
- **core has a higher iron content than that of any other major planet in the Solar System**
- **500-700 km silicate mantle**
- **crust estimated to be 35 km thick**
- **numerous narrow ridges, extending up to several hundred kilometers in length**
- **extensive mare-like plains and heavy cratering similar to those on the Moon, indicating geological inactivity for billions of years**

(Source: https://en.wikipedia.org/wiki/Mercury_(planet))

Astronomy: Mercury (3)

Discovery date:	ancient
Semimajor axis:	5.79×10^7 km (0.387 AU)
Orbital period:	0.24 years (88.0 days)
Synodic period:	0.32 years (115.9 days)
Average orbital speed:	47.4 km/s
Sidereal rotation period (Mercury day):	58.7 Earth days
Mean radius:	2,439.7 km (0.38 x Earth)
Surface area:	7.48×10^7 km^2 (0.15 x Earth)
Volume:	6.08×10^{10} km^3 (0.056 x Earth)
Mass:	3.30×10^{23} kg (0.055 x Earth)
Mean density:	5.43 gm/cm^3 (0.98 x Earth)

Astronomy: Mercury (4)

Surface gravity:	3.70 m/s^2 (0.38 x Earth)
Escape velocity:	4.25 km/s (0.38 x Earth)
Apparent magnitude:	+5.7 to -2.6
Angular diameter:	4.5” to 13”
Albedo:	0.12
Temperature:	340 K mean, 100 K minimum, 700 K maximum
Number of satellites:	0
Surface pressure:	trace
Atmospheric composition:	42% molecular oxygen, 29% sodium, 22% hydrogen, 6% helium, and traces of other elements

Astronomy: Venus (1)

(Image source: https://en.wikipedia.org/wiki/Venus#/media/File:Venus-real_color.jpg, NASA/Ricardo Nunes, public domain)

Astronomy: Venus (2)

- **has a core, mantle, and crust**
- **densest atmosphere of the four terrestrial planets, consisting of more than 96% carbon dioxide**
- **atmospheric pressure at the surface is 92 times that of Earth; by far hottest planet with a mean surface temperature of 735 K (462°C; 863°F); dense CO_2 clouds**
- **surface is isothermal**
- **clouds ma produce lightning**
- **has 167 large volcanoes over 100 km across**

(Source: https://en.wikipedia.org/wiki/Venus)

Astronomy: Venus (3)

Discovery date:	ancient
Semimajor axis:	1.08×10^8 km (0.723 AU)
Orbital period:	0.615 years (224.7 days, 1.92 Venus solar day)
Synodic period:	1.60 years (583.9 days)
Average orbital speed:	35.0 km/s
Sidereal rotation period (Venus day):	-243.0 Earth days (retrograde)
Mean radius:	6,051.8 km (0.95 x Earth)
Surface area:	4.60×10^8 km^2 (0.90 x Earth)
Volume:	9.28×10^{11} km³ (0.87 x Earth)
Mass:	4.87×10^{24} kg (0.82 x Earth)
Mean density:	5.24 gm/cm^3 (0.95 x Earth)

Astronomy: Venus (4)

Surface gravity:	8.87 m/s^2 (0.90 x Earth)
Escape velocity:	10.36 km/s (0.93 x Earth)
Apparent magnitude:	-4.9 to -3.8
Angular diameter:	9.7” to 66.0”
Albedo:	0.69
Temperature:	737 K
Number of satellites:	0
Surface pressure:	9.2 MPa (92 x Earth)
Atmospheric composition:	96.5% carbon dioxide, 3.5% nitrogen, 0.015% sulfur dioxide, 0.007% argon, 0.002% water vapor, 0.0017% carbon monoxide, 0.0012% helium, 0.0007% neon

Astronomy: Earth (1)

(Image source: https://en.wikipedia.org/wiki/Earth#/media/File:The_Earth_seen_from_Apollo_17.jpg, Harrison Schmitt, public domain)

Astronomy: Earth (2)

- **outer layer is chemically distinct silicate solid crust**
- **highly viscous solid mantle.**
- **crust is separated from mantle by Mohorovičić discontinuity**
- **crust thickness varies from about 6 km under oceans to 30–50 km for continents**
- **crust and cold, rigid, top of upper mantle known as lithosphere**
- **tectonic plates on lithosphere**
- **beneath lithosphere is asthenosphere, relatively low-viscosity layer on which lithosphere rides**
- **important changes in mantle crystal structure occur at 410 and 660 km below surface, spanning transition zone separating upper and lower mantle**
- **beneath the mantle, an extremely low viscosity liquid outer core outer lies above a solid inner core**

Source: https://en.wikipedia.org/wiki/Earth)

Astronomy: Earth (3)

Semimajor axis:	1.50×10^8 km (1.000 AU)
Orbital period:	1.000 year (365.26 days)
Average orbital speed:	29.8 km/s
Sidereal rotation period:	23 h 56 m 4.1 s (0.997 days)
Mean radius:	6,371.0 km
Surface area:	5.10×10^8 km^2 (1.49×10^8 km^2 land, 3.61×10^8 km^2 water)
Volume:	1.08×10^{12} km³
Mass:	5.97×10^{24} kg
Mean density:	5.51 gm/cm^3

Astronomy: Earth (4)

Surface gravity:	9.81 m/s^2
Escape velocity:	11.19 km/s
Albedo:	0.367
Temperature:	288 K mean, 184 K minimum, 330 K maximum
Number of satellites:	1
Surface pressure:	101.325 kPa
Atmospheric composition:	78.08% nitrogen, 20.95% oxygen, 0.930% argon, 0.0402% carbon dioxide, ~1% water vapor

Astronomy: Moon (1)

(Image source: https://en.wikipedia.org/wiki/Moon#/media/File:FullMoon2010.jpg, Gregory H. Revera, CC BY-SA 3.0)

Astronomy: Moon (2)

- **geochemically distinct crust, mantle, core**
- **solid iron-rich inner core with radius possibly as small as 240 km**
- **fluid outer core primarily made of liquid iron with radius about 300 km**
- **partially molten boundary layer around core with radius about 500 km**
- **structure thought to have developed through fractional crystallization of global magma ocean shortly after formation 4.5 billion years ago**
- **created mafic mantle from precipitation and sinking of minerals olivine, clinopyroxene, and orthopyroxene**
- **after about three-quarters of magma ocean had crystallised, lower-density plagioclase minerals formed and floated into crust atop**
- **geochemical suggests crust of mostly anorthosite**
- **mafic mantle composition, more iron-rich than Earth's**
- **crust about 50 km thick**

(Source: https://en.wikipedia.org/wiki/Moon)

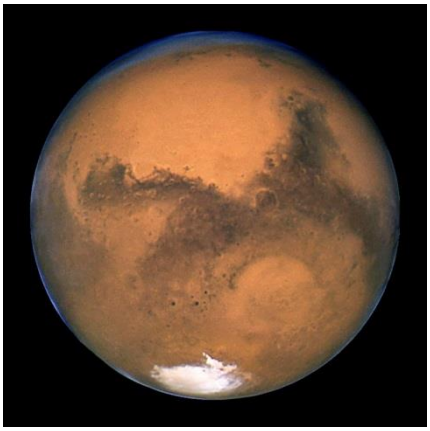
Astronomy: Moon (3)

Semimajor axis:	3.85 x 10^5 km (0.00257 AU)
Orbital period:	27 d 7 h 43 min 11.5 s (27.321 days)
Synodic period:	29 d 12 h 44 m 2.9 s (29.530 days)
Average orbital speed:	1.022 km/s
Sidereal rotation period (Moon day):	27.322 Earth days
Mean radius:	1,737.1 km (0.27 x Earth)
Surface area:	3.79 x 10^7 km^2 (0.074 x Earth)
Volume:	2.20 × 10^{10} km^3 (0.020 x Earth)
Mass:	7.34 x 10^{22} kg (0.012 x Earth)
Mean density:	3.34 gm/cm^3 (0.61 x Earth)

Astronomy: Moon (4)

Surface gravity:	1.62 m/s^2 (0.17 x Earth)
Escape velocity:	2.38 km/s (0.21 x Earth)
Apparent magnitude:	-2.5 to -12.9, -12.4 at full moon
Angular diameter:	29.3" to 34.1"
Albedo:	0.136
Temperature:	220 K mean, 100 K minimum, 390 K maximum
Surface pressure:	10^{-7} Pa day, 10^{-10} Pa night
Atmospheric composition:	trace

Astronomy: Mars (1)



(Image source: https://en.wikipedia.org/wiki/Mars#/media/File:Mars_23_aug_2003_hubble.jpg, Hubble Space Telescope, public domain)

Astronomy: Mars (2)

- **rotational period and seasonal cycles similar to Earth's**
- **site of Olympus Mons, the largest volcano and second-highest known mountain in the Solar System, and of Valles Marineris, one of largest solar system canyons**
- **moons, Phobos and Deimos, which may be captured asteroids**
- **dense metallic core overlaid by less dense materials**
- **core with radius of about 1,794 ± 65 km consisting primarily of iron and nickel with about 16–17% sulfur**
- **core surrounded by a silicate mantle that formed many tectonic and dormant volcanic features**
- **besides silicon and oxygen, most abundant elements in the crust are iron, magnesium, aluminum, calcium, and potassium; average thickness of the planet's crust about 50 km**

(Source: https://en.wikipedia.org/wiki/Mars)

Astronomy: Mars (3)

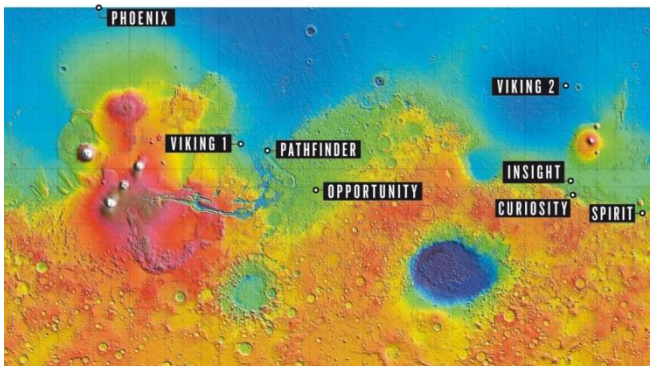
Discovery date:	ancient
Semimajor axis:	2.28 x 10^5 km (1.523 AU)
Orbital period:	1.88 years (686.7 days)
Synodic period:	2.13 years (778.0 days)
Average orbital speed:	24.1 km/s
Sidereal rotation period (Mars day):	1.03 Earth days
Mean radius:	3,389.5 km (0.53 x Earth)
Surface area:	1.45 x 10^8 km^2 (0.28 x Earth)
Volume:	1.63 × 10^{11} km^3 (0.15 x Earth)
Mass:	6.42 × 10^{23} kg (0.11 x Earth)
Mean density:	3.93 gm/cm^3 (0.71 x Earth)

Astronomy: Mars (4)

Surface gravity:	3.71 m/s^2 (0.38 x Earth)
Escape velocity:	5.03 km/s (0.45 x Earth)
Apparent magnitude:	+1.8 to -2.9
Angular diameter:	3.5" to 25.1"
Albedo:	0.17
Temperature:	210 K mean, 130 K minimum, 308 K maximum
Number of satellites:	2
Satellites:	Phobos, Deimos
Surface pressure:	0.636 kPa

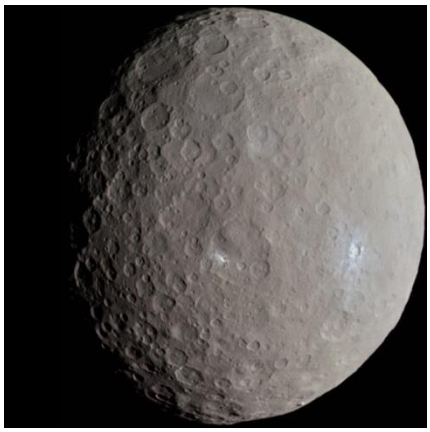
Atmospheric composition: 95.97% carbon dioxide, 1.93% argon, 1.89% nitrogen, 0.146% oxygen, 0.0577% carbon monoxide

Astronomy: Mars (5)



(Image source: http://www.nature.com/news/seven-days-6-12-september-2013-1.13715, NASA/JPL, public domain)

Astronomy: Ceres (1)



(Image source: https://en.wikipedia.org/wiki/Ceres_(dwarf_planet)#/media/File:Ceres_-_RC3_-_Haulani_Crater_(22381131691)_(cropped).jpg, Justin Cowart, CC BY 2.0)

Astronomy: Ceres (2)

Discovery date:	January 1, 1801 by Guiseppi Piazzi
Semimajor axis:	4.14×10^8 km (2.768 AU)
Orbital period:	4.60 years (1,680 days)
Synodic period:	1.23 years (449 days)
Average orbital speed:	17.905 km/s
Sidereal rotation period (Ceres day):	9.12 Earth hours
Mean radius:	473 km (0.0742 x Earth)
Surface area:	2.77×10^6 km^2 (0.0054 x Earth)
Volume:	8.26×10^8 km^3 (0.00076 x Earth)
Mass:	9.39×10^{20} kg (0.00016 x Earth)
Mean density:	2.16 gm/cm^3 (0.392 x Earth)

Astronomy: Ceres (3)

Surface gravity:	0.28 m/s^2 (0.0285 x Earth)
Escape velocity:	0.51 km/s
Apparent magnitude:	+6.7 to +9.3
Angular diameter:	0.84" to 0.33"
Albedo:	0.09
Temperature:	167 K
Number of satellites:	0

Astronomy: Largest Moons

	Ganymede	Titan	Callisto	Io	Moon	Europa	Triton
planet	Jupiter	Saturn	Jupiter	Jupiter	Earth	Jupiter	Neptune
radius (km)	2634	2576	2408	1818	1737	1561	1353
sem-major axis (km)	1,070,400	1,221,870	1,882,700	421,800	384,399	671,100	354,800
sidereal period (hr)	7.155	15.95	16.69	1.769	27.32	3.551	-5.877
discovery year	1610	1655	1610	1610	N/A	1610	1846
discovered	Galileo	Huygens	Galileo	Galileo	ancient	Galileo	Lassell

Astronomy: Jupiter (1)

(Image source: https://en.wikipedia.org/wiki/Jupiter#/media/File:Jupiter_and_its_shrunken_Great_Red_Spot.jpg, NASA/ESA and A. Simon, public domain)

Astronomy: Jupiter (2)

- **gas giant; mass 1/1,000th of the Sun, 2 ½ times that of all the other planets in Solar System combined**
- **primarily hydrogen and helium**
- **outer atmosphere segregated into several bands at different latitudes, resulting in turbulence and storms along their interacting boundaries**
- **prominent result is the Great Red Spot**
- **more than 60 moons**

(Source: https://en.wikipedia.org/wiki/Jupiter)

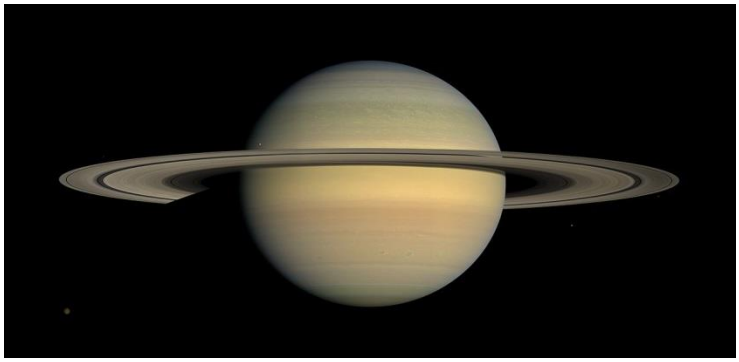
Astronomy: Jupiter (3)

Discovery date:	ancient
Semimajor axis:	7.78×10^8 km (5.202 AU)
Orbital period:	11.86 years (4,332 days)
Synodic period:	1.09 years (398.9 days)
Average orbital speed:	13.1 km/s
Sidereal rotation period (Jupiter day):	9.93 Earth hours
Mean radius:	69,911 km (10.97 x Earth)
Surface area:	6.14×10^{10} km^2 (121.9 x Earth)
Volume:	1.43×10^{15} km³ (1,321 x Earth)
Mass:	1.90×10^{27} kg (317.8 x Earth, 1/1047 of the Sun)
Mean density:	1.326 gm/cm^3 (0.24 x Earth)

Astronomy: Jupiter (4)

Surface gravity:	24.8 m/s² (2.53 x Earth)
Escape velocity:	59.5 km/s (5.31 x Earth)
Apparent magnitude:	-1.6 to -2.9
Angular diameter:	29.8" to 50.1"
Albedo:	0.34
Temperature:	165 K
Number of satellites:	at least 67
Large satellites:	Ganymede, Callisto, Io, Europa
Ring system:	faint, three main segments made of dust
Atmospheric composition:	89.8% hydrogen, 10.2% helium, ~0.3% methane, ~0.026% ammonia, ~0.003% hydrogen deuteride, 0.0006% ethane, 0.0004% water, ices

Astronomy: Saturn (1)



(Image source: https://en.wikipedia.org/wiki/Saturn#/media/File:Saturn_during_Equinox.jpg, NASA/JPL/Space Science Institute, public domain)

Astronomy: Saturn (2)

- **gas giant**
- **only 1/8th average density of Earth**
- **interior composed of core of iron–nickel and silicon and oxygen rocks**
- **core is surrounded by deep layer of metallic hydrogen, intermediate layer of liquid hydrogen and liquid helium**
- **prominent ring system of 9 continuous main rings**
- **more than 60 moons**

(Source: https://en.wikipedia.org/wiki/Saturn)

Astronomy: Saturn (3)

Discovery date:	ancient
Semimajor axis:	1.43×10^9 km (9.554 AU)
Orbital period:	29.46 years (10,759 days)
Synodic period:	1.04 years (378.1 days)
Average orbital speed:	9.69 km/s
Sidereal rotation period (Saturn day):	10.66 Earth hours
Mean radius:	58,232 km (9.14 x Earth)
Surface area:	4.27×10^{10} km^2 (83.7 x Earth)
Volume:	8.27×10^{14} km³ (764 x Earth)
Mass:	5.68×10^{26} kg (95.1 x Earth)
Mean density:	0.69 gm/cm^3 (0.13 x Earth)

Astronomy: Saturn (4)

Surface gravity:	8.96 m/s² (0.91 x Earth)
Escape velocity:	35.5 km/s (3.17 x Earth)
Apparent magnitude:	+1.2 to -0.24
Angular diameter:	14.5" to 20.1"
Albedo:	0.30
Temperature:	88 K to 151 K
Number of satellites:	at least 62 with regular orbits
Largest satellites:	Titan, Rhea, Iapetus, Dione, Tethys, Enceladus, Mimas
Ring system:	water ice, trace amounts of rock, particles from micrometer to meter sizes
Atmospheric composition:	~96% hydrogen, 3% helium, ~0.4% methane, ~0.01% ammonia, ices

Astronomy: Uranus (1)

(Image source: https://en.wikipedia.org/wiki/Uranus#/media/File:Uranus2.jpg, NASA/JPL/Cal Tech, public domain)

Astronomy: Uranus (2)

- **ice giant**
- **atmosphere primarily hydrogen and helium**
- **contains ices including water, ammonia, and methane, traces of other hydrocarbons**
- **coldest planetary atmosphere, minimum temperature of 49 K (−224.2°C)**
- **complex, layered cloud structure with water thought to make up the lowest clouds and methane the uppermost layer of clouds;**
- **interior is mainly composed of ices and rock**

(Sources: https://en.wikipedia.org/wiki/Uranus)

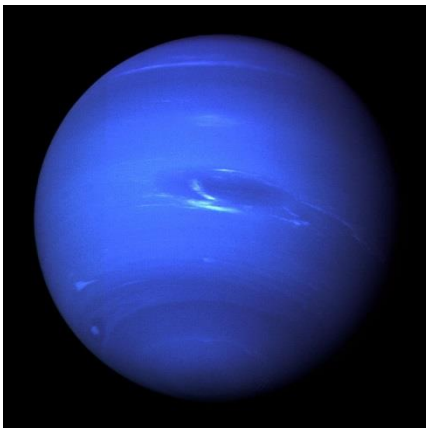
Astronomy: Uranus (3)

Discovery date:	March 13, 1781 by William Herschel
Semimajor axis:	2.88×10^9 km (19.218 AU)
Orbital period:	84.32 years (30,798 days)
Synodic period:	1.01 years (369.7 days)
Average orbital speed:	6.81 km/s
Sidereal rotation period (Uranus day):	-17.24 Earth hours (retrograde)
Mean radius:	25,362 km (3.98 x Earth)
Surface area:	8.12×10^9 km^2 (15.9 x Earth)
Volume:	6.83×10^{13} km³ (63 x Earth)
Mass:	8.68×10^{25} kg (14.8 x Earth)
Mean density:	1.27 gm/cm^3 (0.23 x Earth)

Astronomy: Uranus (4)

Surface gravity:	8.69 m/s² (0.89 x Earth)
Escape velocity:	21.3 km/s (1.90 x Earth)
Apparent magnitude:	+5.9 to +5.32
Angular diameter:	3.3” to 4.1”
Albedo:	0.30
Temperature:	53 K mean, 47 K minimum, 57 K maximum
Number of satellites:	at least 27, many named after Shakespearean characters
Largest satellites:	Miranda, Ariel, Umbriel, Titania, Oberon
Ring system:	thirteen narrow rings, may have been part of a moon
Atmospheric composition:	83% hydrogen, 15% helium, 2.3% methane, 0.009% hydrogen deuteride, ices

Astronomy: Neptune (1)



(Image source: https://en.wikipedia.org/wiki/Neptune#/media/File:Neptune_Full.jpg, NASA/JPL, public domain)

Astronomy: Neptune (2)

- **not visible to the unaided eye**
- **similar in composition to Uranus**
- **active, visible weather patterns**
- **strongest sustained winds of any planet in the Solar System, recorded speeds as high as 2,100 km per hour (580 m/s; 1,300 mph)**
- **temperatures at cloud tops near 55 K (−218°C)**
- **temperatures at center approximately 5,400 K (5,100°C)**
- **faint and fragmented ring system called “arcs"**

(Sources: https://en.wikipedia.org/wiki/Uranus)

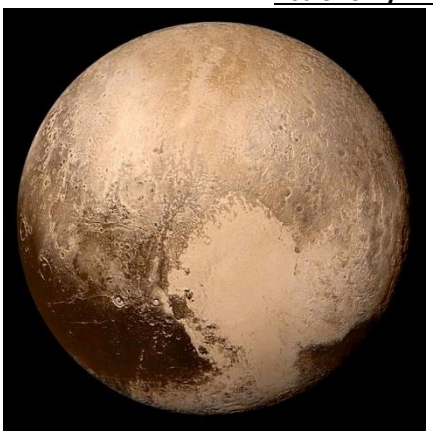
Astronomy: Neptune (3)

Discovery date:	September 23, 1846 by Le Verrier, Adams, and Couch
Semimajor axis:	4.50×10^9 km (30.110 AU)
Orbital period:	164.79 years (60,190 days)
Synodic period:	1.01 years (367.5 days)
Average orbital speed:	5.43 km/s
Sidereal rotation period (Neptune day):	16.1 Earth hours
Mean radius:	24,622 km (3.86 x Earth)
Surface area:	7.62×10^9 km^2 (14.9 x Earth)
Volume:	6.25×10^{13} km³ (58 x Earth)
Mass:	1.02×10^{26} kg (17.1 x Earth)
Mean density:	1.64 gm/cm^3 (0.30 x Earth)

Astronomy: Neptune (4)

Surface gravity:	11.15 m/s² (1.14 x Earth)
Escape velocity:	23.5 km/s (2.10 x Earth)
Apparent magnitude:	+8.0 to +7.78
Angular diameter:	2.2” to 2.4”
Albedo:	0.29
Temperature:	55 K – 72 K
Number of satellites:	14
Largest satellites:	Triton, Proteus, Nereid, Larissa, Galatea, Despina
Ring system:	three main, faint, fragmented ring arcs discovered in 1968
Atmospheric composition:	80% hydrogen, 19% helium, 1.5% methane, ~0.019% hydrogen deuteride, ices

Astronomy: Pluto (1)



(Image source: http://en.wikipedia.org/wiki/Pluto , NASA/Johns Hopkins/APL/Southwest Research Institute, public domain)

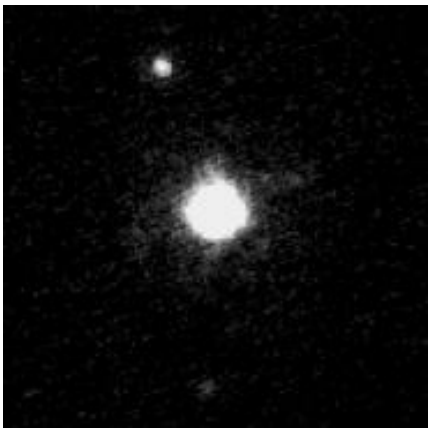
Astronomy: Pluto (2)

Surface gravity:	0.62 m/s² (0.063 x Earth)
Escape velocity:	1.21 km/s (0.11 x Earth)
Apparent magnitude:	+13.65
Angular diameter:	0.06” to 0.11”
Albedo:	0.49 to 0.66
Temperature:	44 K mean, 33 K minimum, 55 K maximum
Number of satellites:	5
Satellites:	Charon, Styx, Nix, Kerberos, Hydra
Surface pressure:	1.0 Pa
Atmospheric composition:	nitrogen, methane, carbon monoxide

Astronomy: Pluto (3)

Discovery date: February 18, 1930 by Clyde Tombaugh
Semimajor axis: 5.91×10^9 km (39.48 AU)
Orbital period: 248 years (90,560 days)
Synodic period: 1.004 years (366.7 days)
Average orbital speed: 4.67 km/s
Sidereal rotation period (Pluto day): -6.38 Earth days (retrograde)
Mean radius: 1,187 km (0.19 x Earth)
Surface area: 1.77×10^7 km^2 (0.034 x Earth)
Volume: 7.15×10^9 km^3 (0.007 x Earth)
Mass: 1.30×10^{22} kg (0.002 x Earth)
Mean density: 2.03 gm/cm^3 (0.39 x Earth)

Astronomy: Haumea (1)



(Image source: https://en.wikipedia.org/wiki/Haumea#/media/File:2003_EL61_Haumea,_with_moons.jpg, Mike Brown, Cal Tech, Keck Telescope, fair use)

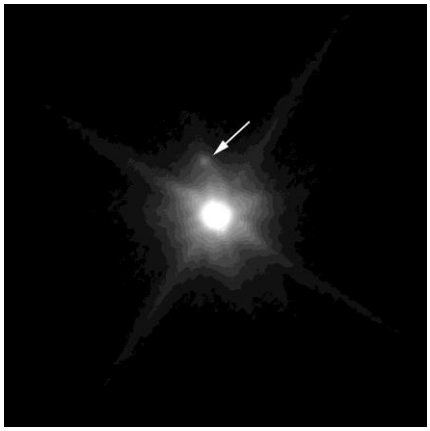
Astronomy: Haumea (1)

Discovery date: December 28, 2004 by Brown, Trujillo, and Rabinowitz
Semimajor axis: 6.47×10^9 km (43.35 AU)
Orbital period: 285 years (104,096 days)
Synodic period: 1.0035 years (366.5 days)
Average orbital speed: 4.53 km/s
Sidereal rotation period (Haumea day): 3.91 Earth days
Mean radius: 620 km
Surface area: 6.8×10^6 km^2 (0.013 x Earth)
Mass: 4.0×10^{21} kg (0.0007 x Earth)
Mean density: 2.6 – 3.3 gm/cm^3 (0.47 to 0.60 x Earth)

Astronomy: Haumea (2)

Surface gravity: 0.63 m/s^2 (0.064 x Earth)
Escape velocity: 0.91 km/s
Apparent magnitude: 17.3
Albedo: 0.80
Temperature: < 50K
Number of satellites: 2
Satellites: Hi'iaka, Namaka

Astronomy: Makemake (3)



(Image source: https://en.wikipedia.org/wiki/Makemake#/media/File:Makemake_moon_Hubble_image_with_legend_(cropped).jpg, NASA/ESA/A. Parker and M. Buie (Southwest Research Institute), W. Grundy (Lowell Observatory), and K. Noll (NASA GSFC), public domain)

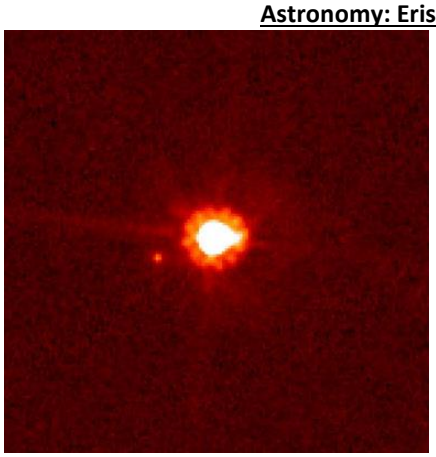
Astronomy: Makemake (2)

Discovery date: March 31, 2005 by Brown, Trujillo, and Rabinowitz
Semimajor axis: 6.84×10^9 km (45.72 AU)
Orbital period: 309 years (112,895 days)
Synodic period: 1.0032 years (366.4 days)
Average orbital speed: 4.42 km/s
Sidereal rotation period (Makemake day): 7.77 Earth hours
Mean radius: 715 km (0.11 x Earth)
Surface area: 6.90×10^6 km^2 (0.014 x Earth)
Volume: 1.70×10^9 km^3 (0.002 x Earth)
Mass: 44×10^{21} kg (0.0007 x Earth)
Mean density: 3.05 gm/cm^3 (0.55 x Earth)

Astronomy: Makemake (3)

Surface gravity: 0.47 m/s^2 (0.048 x Earth)
Escape velocity: 0.84 km/s (0.075 x Earth)
Apparent magnitude: 17.0
Albedo: 0.81
Temperature: 32 K – 44 K
Number of satellites: 1
Satellite: MK 2
Surface pressure: 4 – 12 nanobars
Atmosphere: proposed nitrogen, methane, and ethane

Astronomy: Eris (1)



(Image source: https://en.wikipedia.org/wiki/Eris_(dwarf_planet)#/media/File:Eris_and_dysnomia2.jpg, NASA/ESA and Mike Brown, public domain)

Astronomy: Eris (2)

Discovery date:	January 6, 2005 by Brown, Trujillo, and Rabinowitz
Semimajor axis:	1.02 x 10^{10} km (67.67 AU)
Orbital period:	558 years (203,810 days)
Synodic period:	1.0018 years (365.9 days)
Average orbital speed:	3.43 km/s
Sidereal rotation period (Eris day):	25.9 Earth hours
Mean radius:	1,163 km (0.18 x Earth)
Surface area:	1.70 x 10^{7} km^2 (0.033 x Earth)
Volume:	6.59 x 10^{9} km^3 (0.006 x Earth)
Mass:	1.66 x 10^{22} kg (0.0028 x Earth)
Mean density:	2.52 gm/cm^3 (0.46 x Earth)

Astronomy: Eris (2)

Surface gravity:	0.82 m/s^2 (0.084 of Earth)
Escape velocity:	1.38 km/s
Apparent magnitude:	18.7
Albedo:	0.96
Temperature:	42.5K, min 30K, max 55K
Number of satellites:	1
Satellite:	Dysnomia

Astronomy: Asteroids

asteroid: shattered remnants of planetesimals, bodies within the young Sun's solar nebula that never grew large enough to become planets, contain amino acid compounds

diameter	number of	diameter	number of
100 m	~25,000,000	30 km	1,100
300 m	4,000,000	50 km	600
500 m	2,000,000	100 km	200
1 km	750,000	200 km	30
3 km	200,000	300 km	5
5 km	90,000	500 km	3
10 km	10,000	900 km	1

(Source: https://en.wikipedia.org/wiki/Asteroid#Asteroid_belt)

Astronomy: Five Largest Asteroids

	1 Ceres	4 Vesta	2 Pallas	10 Hygiea	704 Interamnia
dimensions (km)	965 x 962 x 891	573 x 557 x 446	550 x 516 x 476	530 x 407 x 370	350 x 304
mean distance from Sun (AU)	2.766	2.362	2.773	3.139	3.062
date discovered	Jan 1, 1801	March 29, 1807	March 28, 1802	April 12, 1849	October 2, 1910
discoverer	Piazzi	Olbers	Olbers	de Gasparis	Cerulli
class	G	V	B	C	F

(Source: https://en.wikipedia.org/wiki/Asteroid#Largest_asteroids)

Astronomy: Asteroid Types (1)

- C-group dark carbonaceous objects
  - B-type (2 Pallas), primitive, volatile-rich remnants, found in the outer asteroid belt
  - F-type (704 Interamnia), have spectra generally similar to those of the B-type asteroids, but lack the "water" absorption feature around 3 µm
  - G-type(1 Ceres), similar to the C-type objects, but contain a strong ultraviolet absorption feature below 0.5 µm
  - C-type (10 Hygiea), remaining majority of 'standard' C-type asteroids, form around 75% of known asteroids, distinguished by a very low albedo, include a large amount of carbon, in addition to rocks and minerals, occur most frequently at the outer edge of the asteroid belt

Astronomy: Asteroid Types (2)

- X-group
  - M-type (16 Psyche) metallic, moderately bright, likely pieces of the metallic core of differentiated, fragmented asteroids, may be source of iron meteorites, third most common type
  - E-type (44 Nysa, 55 Pandora) differ from M-type mostly by high albedo, may have enstatite ($MgSiO_3$) achondrite surfaces, large proportion of asteroids inside the asteroid belt, may have originated from reduced mantle of a differentiated asteroid
  - P-type (259 Aletheia, 190 Ismene; CP: 324 Bamberga) differ from M-type mostly by low albedo and featureless reddish spectrum, may be composed of organic rich silicates, carbon, anhydrous silicates, possibly with interior water ice interior, found in the outer asteroid belt and beyond

Astronomy: Asteroid Types (3)

- S-type (15 Eunomia, 3 Juno) silicaceous (or "stony") objects, silicaceous asteroids, second most common type at 17%
- small classes
  - A-type (246 Asporina), relatively uncommon inner-belt asteroids, have strong, broad 1 µm olivine feature, very reddish spectrum shortwards of 0.7 µm, may come from the completely differentiated mantle of an asteroid
  - D-type (624 Hektor), low albedo, featureless reddish spectrum, may be composed of organic-rich silicates, carbon, anhydrous silicates, interior water ice, found in the outer belt and beyond
  - T-type (96 Aegle), rare inner-belt asteroids, unknown composition, dark, featureless and moderately red spectra, and a moderate absorption feature shortwards of 0.85 µm

Astronomy: Asteroid Types (4)

- Q-type (1862 Apollo), relatively uncommon inner-belt asteroids, strong, broad 1 µm olivine and pyroxene feature, spectral slope indicates presence of metal, absorption features around 0.7 µm, spectrum generally intermediate between V and S-type
- R-type (349 Dembowska), moderately bright, relatively uncommon inner-belt asteroids, spectrally intermediate between V and A-type asteroids, spectrum shows olivine and pyroxene features at 1 and 2 µm, possibility plagioclase, around 0.7 µm the spectrum is very reddish
- V-type (4 Vesta), relatively bright, similar to more common S-type, also made up of stony irons, ordinary chondrites, with V-types containing more pyroxene than S-types

(Source: https://en.wikipedia.org/wiki/Asteroid_spectral_types)

Astronomy: Meteors, Meteoroids, Meteorites

meteor: the visible passage of a glowing meteoroid, micrometeoroid, comet or asteroid through Earth's atmosphere, after being heated to incandescence by collisions with air molecules in the upper atmosphere
meteoroid: small rocky or metallic body in outer space, meteoroids are significantly smaller than asteroids, and range in size from small grains to 1 meter-wide objects
meteorite: a solid piece of debris from an object, such as a comet, asteroid, or meteoroid, that originates in outer space, survives its passage through the Earth's atmosphere, and impacts Earth's surface or that of another planet

Astronomy: Kuiper Belt, Oort Cloud

Kuiper belt: a circumstellar disc beyond the planets, extending from the orbit of Neptune at 30 AU to approximately 50 AU from the Sun; 20 times as wide and 20 to 200 times as massive as the asteroid belt; consists mainly of small bodies and remnants from Solar System formation; most of its objects are composed largely of frozen volatiles, called "ices," including methane, ammonia and water
Oort cloud: a theoretical cloud of predominantly icy planetesimals believed to surround the Sun as far as somewhere between 50,000 and 200,000 AU;divided into a disc-shaped inner Oort cloud and a spherical outer Oort cloud

Astronomy: Meteor Showers (1)

shower	time	parent object
Quadrantids	early January	
Lyrids	late April	Comet Thatcher
Pi Puppids	late April	Comet 26P/Grigg--Skjellerup
Eta Aquariids	early May	Comet 1P/Halley
Arietids	mid-June	Comet 96P/Machholz
June Bootids	late June	Comet 7P/Pons-Winnecke
Southern Delta Aquariids	late July	Comet 96P/Machholz
Alpha Capricornids	late July	Comet 169P/NEAT
Perseids	mid-August	Comet 109P/Swift-Tuttle
Kappa Cygnids	mid-August	Minor planet 2008 ED69
Aurigids	early September	Comet C/1911 N1

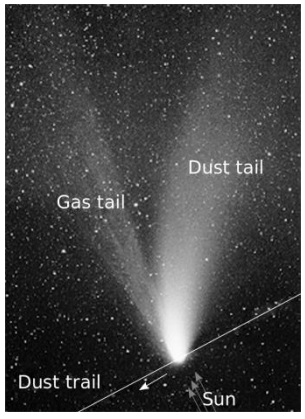
Astronomy: Meteor Showers (2)

shower	time	parent object
Draconids	early October	Comet 21P/Giacobini-Zinner
Orionids	late October	Comet 1P/Halley
Southern Taurids	early November	Comet 2P/Encke
Northern Taurids	mid-November	Minor planet 2004 TG_{10}
Andromedids	mid-November	Comet 3D/Bieta
Alpha Monocerotids	mid-November	unknown
Leonids	mid-November	Comet 55P/Tempel-Tuttle
Phoenicids	early December	Comet 289P/Blanpain
Geminids	mid-December	Minor planet 3200 Phaeton
Ursids	late December	Comet 8P/Tuttle

(Source: https://en.wikipedia.org/wiki/Meteor_shower)

Astronomy: Comets

comet: an icy small Solar System body that, when passing close to the Sun, warms and begins to evolve gasses, a process called outgassing, which produces a visible atmosphere or coma, and sometimes also a tail



(Image source: https://en.wikipedia.org/wiki/Comet#/media/File:Comet_Parts.svg, NASA Ames Research Center/K. Jobse, P. Jenniskens, public domain)

Astronomy: 10 Minor Planet Center Comets

comet designation	orbital period (years)	semi-major axis (a)	inclin-ation (i)	eccen-tricity (e)	total mag./ absolute mag.
1P/Halley	75.32	17.83414	162.2627	0.9671	5.5
2P/Encke	3.30	2.21473	11.7789	0.8482	14.1
3D/Biela	6.65	3.53466	13.2164	0.7513	7.1
4P/Faye	7.52	3.83746	9.05	0.5687	10.7
5D/Brorsen	5.46	3.10113	29.3821	0.8098	8.3
6P/d'Arrest	6.54	3.49537	19.4817	0.6128	14.2
7P/Pons–Winnecke	6.33	3.42249	22.3359	0.6374	15.1
8P/Tuttle	13.61	5.69986	54.9832	0.8198	9.8
9P/Tempel	5.56	3.13933	10.502	0.5119	13.1
10P/Tempel	5.37	3.06489	12.0292	0.5364	13.2

(Source: https://en.wikipedia.org/wiki/List_of_numbered_comets)

Astronomy: Interesting Exoplanets (1)

exoplanet	description
Kepler-186f	first rocky planet to be found within the habitable zone; very close in size to Earth
HD 209458 b (nickname "Osiris")	first planet to be seen in transit and first planet to have it light directly detected; showed that transit observations were feasible
Kepler-11 system	first compact solar system discovered by Kepler telescope; revealed that a system can be tightly packed, with at least five planets within the orbit of Mercury
Kepler-16b	real-life "Tatooine," Kepler telescope's first discovery of a planet that orbits two stars, known as a circumbinary planet
51 Pegasi b	giant planet, about half the mass of Jupiter; orbits its star every 4 days, first confirmed exoplanet around sun-like star
CoRoT 7b	first super-Earth identified as a rocky exoplanet

Astronomy: Interesting Exoplanets (2)

exoplanet	description
Kepler-22b	A planet in the habitable zone and a possible water-world planet unlike any seen in our solar system
Kepler-10b	Kepler telescope's first rocky planet discovery is a scorched, Earth-size world that scientists believe may have a lava ocean on its surface
Kepler-444 system	oldest known planetary system has five terrestrial-sized planets, all in orbital resonance
55 Cancri e	toasty world that rushes around its star every 18 hours. It orbits so closely, about 25 times closer than Mercury to our sun, that it is tidally locked with one face forever blisters under the heat of its sun
HD 189733 b	about the size of Jupiter, is one of the most studied exoplanets and is the first caught passing in front of its parent star in X-rays

Astronomy: Interesting Exoplanets (3)

PSR B1257+12 system	**smallest planetary bodies known to exist outside our solar system, they orbit a neutron star**
K2-3	**three super-Earths discovered by the K2 mission orbiting a nearby star; their mass and radius are already known and soon they may reveal their atmospheric composition**
HR 8799	**first directly imaged multi-exoplanet system. This system contains a debris disk and at least four massive planets**
Kepler-36 system	**two known planets in this system have the most closely spaced orbits ever confirmed; the neighboring duo comes within about 1.2 million miles of each other, only five times the Earth-Moon distance**
HD 114762 b	**discovered in 1989, three years prior to the pulsar planets and six years prior to 51 Peg b, it is HD the first discovered planet around a sun-like star; its mass is 11 times that of Jupiter and was found in an orbit of 84 days; it was initially assumed (incorrectly) to be a brown dwarf**

Astronomy: Interesting Exoplanets (4)

Kepler-452b	**the first Earth-sized planet found in the habitable zone of a sun-like star; it is 60 percent larger than Earth and 5 percent farther from its parent star than Earth is from the sun**
HD 80606 b	**this world has the most eccentric orbit, and as one scientist put it, "wears its heart on its sleeve," with storms, rotation, atmospheric heating, and a crazy orbit all plainly visible**
WASP-47	**part of a compact multi-planet system, it's the only known hot Jupiter with close planetary companions**
OGLE-2005-BLG-390	**considered to be the first cold super Earth, this exoplanet began to form a Jupiter-like core of rock and ice, but couldn't grow fast enough in size; its final mass is five times that of Earth; its nickname is Hoth, after a planet from Star Wars**

(Source: https://www.nasa.gov/feature/jpl/20-intriguing-exoplanets, NASA)

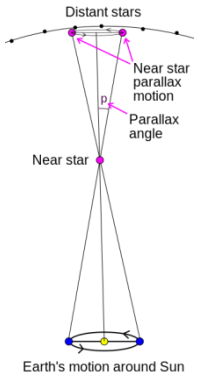
Astronomy: Stellar Parallax

distance in parsecs $d_{pc} = \frac{1}{p}$

p = parallax angle in arcseconds

1 parsec (pc) = 3.086 x 10^{16} meters

1 light year (ly) = 9.461 x 10^{15} meters



(Image source: https://commons.wikimedia.org/wiki/File:Stellarparallax_parsec1.svg, public domain)

Astronomy: Stefan-Boltzmann and Wein's Laws

Stefan-Boltzmann law: $P_{net} = e\sigma A(T^4 - T_s^4)$

σ = 5.67 x 10^{-8} W/m^2 K^4

P_{net} = net radiated power

e = emissivity A = area

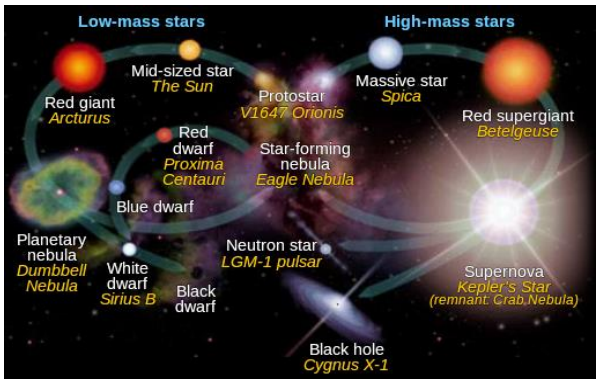
T = object temperature T_s = temperature of surroundings

Wein's law: $\lambda_{max} = \frac{b}{T}$

b = 2.89776829 nm K

temperatures in K

Astronomy: Stellar Evolution (1)



(Image source: http://scioly.org/wiki/index.php/Astronomy/Stellar_Evolution, cmglee, NASA Spaceflight Center, CC BY-SA 4.0)

Astronomy: Stellar Evolution (2)

- stellar nebula: cloud of gas, mostly hydrogen and helium, and dust in space, that is the birthplace of stars
- protostar: looks like a star but its core is not yet hot enough for fusion to take place; luminosity comes from the heating of the protostar as it contracts, usually surrounded by dust, which blocks light, difficult to observe in the visible spectrum
- T-Tauri star: very young, lightweight star, less than 10 million years old, that it still undergoing gravitational contraction; represents an intermediate stage between a protostar and a low-mass main sequence star like the Sun
- main sequence star: star that fuses hydrogen atoms to form helium atoms in their cores; 90 percent of stars are main sequence

Astronomy: Stellar Evolution (3)

- red giant: large bright star with a cool surface; formed during the later stages of the evolution as it runs out of hydrogen fuel at its center; have diameters between 10 and 100 times that of the Sun; very bright, with a surface temperature lower than that of the Sun; most common red giants are stars nearing the end but are still fusing hydrogen into helium in a shell surrounding a degenerate helium core
- planetary nebula: cloud of gas and dust; the outer layers of a star that are lost when the star changes from a red giant to a white dwarf

Astronomy: Stellar Evolution (4)

- supernova: explosive death of a star, and often results in the star obtaining the brightness of 100 million suns for a short time; extremely luminous burst of radiation expels much or all of a star's material at a great velocity, driving a shock wave into the surrounding interstellar medium; can be triggered by the sudden re-ignition of nuclear fusion in a degenerate star; or by the gravitational collapse of the core of a massive star
- nova: nuclear explosion of a white dwarf, causing sudden brightening; occurs on the surface of a white dwarf in a binary system; if the two stars of the system are sufficiently close material can be pulled from the companion star's surface onto the white dwarf; caused by the accretion of hydrogen onto the surface of the star, starting runaway fusion reaction

Astronomy: Stellar Evolution (5)

- white dwarf: very small, hot star, last stage in the life cycle of a star like the Sun; shrunken remains of normal stars, whose nuclear energy supplies have been used up; consist of degenerate matter with a very high density due to gravitational effects; one spoonful has a mass of several tons; gravity causes the star to collapse in on itself; great densities are only possible when electrons are displaced from their regular shells and pushed closer to the nucleus, allowing atoms to take up less space
- black dwarf: last stage of stellar evolution; is a white dwarf that has sufficiently cooled that it no longer emits significant heat or light.the time required for a white dwarf to reach this state is calculated to be longer than the current age of the universe (13.8 billion years), no black dwarfs are expected to exist yet

Astronomy: Stellar Evolution (6)

- brown dwarf: too large to be called a planet and too small to be a star; forms from a collapsing cloud of gas and dust, does not form an object which is dense enough at its core to trigger nuclear fusion; were first discovered in 1995
- neutron star: composed mainly of neutrons and produced after a supernova, forcing the protons and electrons to combine; typically have a mass of three times the Sun but a diameter of only 20 km
- black hole: form from massive stars at the end of their lifetimes; gravitational pull is so great that nothing can escape from it, not even light.; density inside it cannot be measured; distorts the space around it, and can often suck neighboring matter into them including stars

Astronomy: 25 Brightest Stars (1)

name	visual magnitude (m_V)	Bayer	distance (ly)	spectral class
Sirius	−1.46	α CMa	8.6	A1 V, DA2
Canopus	−0.74	α Car	310	A9 II
Rigil Kentaurus	−0.27 (0.01+1.33)	α Cen	4.4	G2 V, K1 V
Arcturus	−0.05	α Boo	37	K0 III
Vega	0.03 (−0.02-0.07var)	α Lyr	25	A0 Va
Capella	0.08 (0.03-0.16var)	α Aur	42	K0 III, G1 III
Rigel	0.13 (0.05-0.18var)	β Ori	860	B8 Ia
Procyon	0.34	α CMi	11	F5 IV-V
Achernar	0.46 (0.40-0.46var)	α Eri	140	B6 Vep
Betelgeuse	0.50 (0.2-1.2var)	α Ori	640	M2 Iab
Hadar	0.61	β Cen	350	B1 III
Altair	0.76	α Aql	17	A7 V
Acrux	0.76 (1.33+1.73)	α Cru	320	B0.5 IV, B1 V

Astronomy: 25 Brightest Stars (2)

name	visual magnitude (m_V)	Bayer	distance (ly)	spectral class
Aldebaran	0.86 (0.75-0.95var)	α Tau	65	K5 III
Antares	0.96 (0.6-1.6var)	α Sco	600	M1.5 Iab, B3 V
Spica	0.97 (0.97-1.04var)	α Vir	260	B1 III-IV, B2 V
Pollux	1.14	β Gem	34	K0 III
Fomalhaut	1.16	α PsA	25	A3 V
Deneb	1.25 (1.21-1.29var)	α Cyg	2,600	A2 Ia
Mimosa	1.25 (1.23-1.31var)	β Cru	350	B0.5 II, B2 V
Regulus	1.39	α Leo	77	B7 V
Adhara	1.50	ε CMa	430	B2 Iab:
Shaula	1.62	λ Sco	700	B2 IV
Castor	1.62 (1.98 + 2.97)	α Gem	52	Am, A1 V
Gacrux	1.64	γ Cru	88	M3.5 III

Astronomy: Binary Stars (1)

- visual binary: binary star for which the angular separation between the two components is great enough to permit them to be observed as a double star in a telescope or high-powered binoculars
- spectroscopic binary: the binary consists of a pair of stars where the spectral lines in the light emitted from each star shifts first towards the blue, then towards the red, as each moves first towards us, and then away from us, during its motion about their common center of mass, with the period of their common orbit; separation is very small
- eclipsing binary: binary star in which the orbit plane of the two stars lies so nearly in the line of sight of the observer that the components undergo mutual eclipses

Astronomy: Binary Stars (2)

- non-eclipsing binary: can be photometrically detected by observing how the stars affect each other; first is by observing extra light which the stars reflect from their companion; second by observing ellipsoidal light variations which are caused by deformation of the star's shape by their companions; third by looking at how relativistic beaming affects the apparent magnitude of the stars; detecting binaries with these methods requires accurate photometry
- astrometric binary: relatively nearby stars which can be seen to wobble around a point in space, with no visible companion; the visible star's position is detected to vary, due to the gravitational influence from its counterpart; the star's position is measured relative to more distant stars, and checked for periodic shifts

(Source: https://en.wikipedia.org/wiki/Binary_star#Methods_of_observation)

Astronomy: Supernovae

Type I no hydrogen	Type Ia presents a singly ionized silicon (Si II) line at 615.0 nm (nanometers), near peak light			thermal runaway
	Type Ib/c weak or no silicon absorption feature	Type Ib shows a non-ionized helium (He I) line at 587.6 nm		core collapse
		Type Ic weak or no helium		
Type II shows hydrogen	Type II-P/L/N Type II spectrum throughout	Type II-P/L no narrow lines	Type II-P reaches a "plateau" in its light curve	(Source: https://en.wikipedia.org/wiki/Supernova#Classification)
			Type II-L displays "linear" decrease in light curve	
		Type IIn some narrow lines		
	Type IIb spectrum changes to become like Type Ib			

Astronomy: Nebulae

molecular cloud: dense interstellar region with large quantity of molecular hydrogen
diffuse nebula: contain irregularly-shaped clouds of gas actively forming new stars; lack clearly defined boundaries
reflection nebula: when a star is surrounded by gas and dust, its light bounces around; blue light scatters more effectively, so they are usually blue
emission nebula: high energy radiation coming from new stars strips gas of its electrons; usually appear red
supernova remnant: gaseous envelope of an exploded star
planetary nebula: when medium mass stars explode, contract into white dwarves, leaving surrounding, glowing gas, can be many colors
dark nebula: created from huge quantities of gas and dust surrounding newly forming stars
Bok globule: contains lots of gas; among the coldest places in the universe, can span several light-years in diameter

Astronomy: Black Holes

class	mass (solar masses)	size
supermassive	~10^5–10^{10}	~0.001–400 AU
intermediate	~10^3	~10^3 km ≈R_{Earth}
stellar	~10	~30 km
micro	up to ~M_{Moon}	up to ~0.1 mm

black hole Schwarzschild radius $R = \frac{2MG}{c^2}$

Astronomy: Stellar Lifetime

mass of star	
less than 10 solar masses	10 or mor solar masses
lifetime = $\frac{1}{(number\ of\ solar\ masses)^3} x10^{10}$	lifetime = $\frac{1}{(number\ of\ solar\ masses)^2} x10^{10}$

Astronomy: Messier Objects (1)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M1	NGC 1952	Crab Nebula	supernova remnant	4.9–8.1	Taurus	8.4
M2	NGC 7089		cluster, globular	33	Aquarius	6.3
M3	NGC 5272		cluster, globular	33.9	Canes Venatici	6.2
M4	NGC 6121		cluster, globular	7.2	Scorpius	5.9
M5[J]	NGC 5904		cluster, globular	24.5	Serpens	6.7
M6	NGC 6405	Butterfly Cluster	cluster, open	1.6	Scorpius	4.2
M7	NGC 6475	Ptolemy Cluster	cluster, open	0.65–1.31	Scorpius	3.3
M8	NGC 6523	Lagoon Nebula	nebula with cluster	4.1	Sagittarius	6.0
M9	NGC 6333		cluster, globular	25.8	Ophiuchus	8.4
M10	NGC 6254		cluster, globular	14.3	Ophiuchus	6.4
M11	NGC 6705	Wild Duck Cluster	cluster, open	6.2	Scutum	6.3
M12	NGC 6218		cluster, globular	15.7	Ophiuchus	7.7

Astronomy: Messier Objects (2)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M13	NGC 6205	Great Globular	cluster, globular	22.2	Hercules	5.8
M14	NGC 6402		cluster, globular	30.3	Ophiuchus	8.3
M15	NGC 7078		cluster, globular	33	Pegasus	6.2
M16	NGC 6611	Eagle Nebula	nebula, H II region with cluster	7	Serpens	6.0
M17	NGC 6618	Omega, Swan, Horseshoe, or Lobster Nebula	nebula, H II region with cluster	5–6	Sagittarius	6.0
M18	NGC 6613		cluster, open	4.9	Sagittarius	7.5
M19	NGC 6273		cluster, globular	28.7	Ophiuchus	7.5
M20	NGC 6514	Trifid Nebula	nebula, H II region with cluster	5.2	Sagittarius	6.3

Astronomy: Messier Objects (3)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M22	NGC 6656	Sagittarius Cluster	cluster, globular	9.6–11.6	Sagittarius	5.1
M23	NGC 6494		cluster, open	2.15	Sagittarius	6.9
M24	IC 4715	Sagittarius Star Cloud	Milky Waystar cloud	~10	Sagittarius	4.6
M25	IC 4725		cluster, open	2.0	Sagittarius	4.6
M26	NGC 6694		cluster, open	5.0	Scutum	8.0
M27	NGC 6853	Dumbbell Nebula	nebula, planetary	1.148–1.52	Vulpecula	7.5
M28	NGC 6626		cluster, globular	17.9	Sagittarius	7.7
M29	NGC 6913		cluster, open	7.2	Cygnus	7.1
M30	NGC 7099		cluster, globular	27.8–31	Capricornus	7.7
M31	NGC 224	Andromeda Galaxy	galaxy, spiral	2,430–2,650	Andromeda	3.4
M32	NGC 221		galaxy, dwarf elliptical	2,410–2,570	Andromeda	8.1

Astronomy: Messier Objects (4)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M33	NGC 598	Triangulum Galaxy	galaxy, spiral	2,380–3,070	Triangulum	5.7
M34	NGC 1039		cluster, open	1.5	Perseus	5.5
M35	NGC 2168		cluster, open	2.8	Gemini	5.3
M36	NGC 1960		cluster, open	4.1	Auriga	6.3
M37	NGC 2099		cluster, open	4.511	Auriga	6.2
M38	NGC 1912		cluster, open	4.2	Auriga	7.4
M39	NGC 7092		cluster, open	0.8244	Cygnus	5.5
M40		Winnecke 4	double star WNC4	0.51	Ursa Major	9.7
M41	NGC 2287		cluster, open	2.3	Canis Major	4.5
M42	NGC 1976	Orion Nebula	nebula, H II region	1.324–1.364	Orion	4.0
M43	NGC 1982	De Mairan's Nebula	nebula, H II region (part of Orion Nebula)	1.6	Orion	9.0

Astronomy: Messier Objects (5)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M44	NGC 2632	Beehive Cluster	cluster, open	0.577	Cancer	3.7
M45		Pleiades	cluster, open	0.39–0.46	Taurus	1.6
M46	NGC 2437		cluster, open	5.4	Puppis	6.1
M47	NGC 2422		cluster, open	1.6	Puppis	4.2
M48	NGC 2548		cluster, open	1.5	Hydra	5.5
M49	NGC 4472		galaxy, elliptical	53,600–58,200	Virgo	9.4
M50	NGC 2323		cluster, open	3.2	Monoceros	5.9
M51	NGC 5194, NGC 5195	Whirlpool Galaxy	galaxy, spiral	19,000–27,000	Canes Venatici	8.4
M52	NGC 7654		cluster, open	5.0	Cassiopeia	5.0
M53	NGC 5024		cluster, globular	58	Coma Berenices	8.3
M54	NGC 6715		cluster, globular	87.4	Sagittarius	8.4

Astronomy: Messier Objects (6)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M55	NGC 6809		cluster, globular	17.6	Sagittarius	7.4
M56	NGC 6779		cluster, globular	32.9	Lyra	8.3
M57	NGC 6720	Ring Nebula	nebula, planetary	1.6–3.8	Lyra	8.8
M58	NGC 4579		galaxy, barred spiral	~63,000	Virgo	10.5
M59	NGC 4621		galaxy, elliptical	55,000–65,000	Virgo	10.6
M60	NGC 4649		galaxy, elliptical	51,000–59,000	Virgo	9.8
M61	NGC 4303		galaxy, spiral	50,200–54,800	Virgo	10.2
M62	NGC 6266		cluster, globular	22.2	Ophiuchus	7.4
M63	NGC 5055	Sunflower Galaxy	galaxy, spiral	37,000	Canes Venatici	9.3
M64	NGC 4826	Black Eye Galaxy	galaxy, spiral	22,000–26,000	Coma Berenices	9.4
M65	NGC 3623	Leo Triplet	galaxy, barred spiral	41,000–42,000	Leo	10.3
M66	NGC 3627	Leo Triplet	galaxy, barred spiral	31,000–41,000	Leo	8.9

Astronomy: Messier Objects (7)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M67	NGC 2682		cluster, open	2.61–2.93	Cancer	6.1
M68	NGC 4590		cluster, globular	33.6	Hydra	9.7
M69	NGC 6637		cluster, globular	29.7	Sagittarius	8.3
M70	NGC 6681		cluster, globular	29.4	Sagittarius	9.1
M71	NGC 6838		cluster, globular	13.0	Sagitta	6.1
M72	NGC 6981		cluster, globular	53.40–55.74	Aquarius	9.4
M73	NGC 6994		asterism	~2.5	Aquarius	9.0
M74	NGC 628		galaxy, spiral	24,000–36,000	Pisces	10.0
M75	NGC 6864		cluster, globular	67.5	Sagittarius	9.2
M76	NGC 650/651	Little Dumbbell Nebula	nebula, planetary	2.5	Perseus	10.1
M77	NGC 1068	Cetus A	galaxy, spiral	47,000	Cetus	9.6
M78	NGC 2068		nebula, diffuse	1.6	Orion	8.3

Astronomy: Messier Objects (8)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M79	NGC 1904		cluster, globular	41	Lepus	8.6
M80	NGC 6093		cluster, globular	32.6	Scorpius	7.9
M81	NGC 3031	Bode's Galaxy	galaxy, spiral	11,400–12,200	Ursa Major	6.9
M82	NGC 3034	Cigar Galaxy	galaxy, starburst	10,700–12,300	Ursa Major	8.4
M83	NGC 5236	Southern Pinwheel Galaxy	galaxy, barred spiral	14,700	Hydra	7.5
M84	NGC 4374		galaxy, lenticular	57,000–63,000	Virgo	10.1
M85	NGC 4382		galaxy, lenticular	56,000–64,000	Coma Berenices	10.0
M86	NGC 4406		galaxy, lenticular	49,000–55,000	Virgo	9.8
M87	NGC 4486	Virgo A	galaxy, elliptical	51,870–55,130	Virgo	9.6
M88	NGC 4501		galaxy, spiral	39,000–56,000	Coma Berenices	10.4
M89	NGC 4552		galaxy, elliptical	47,000–53,000	Virgo	10.7

Astronomy: Messier Objects (9)

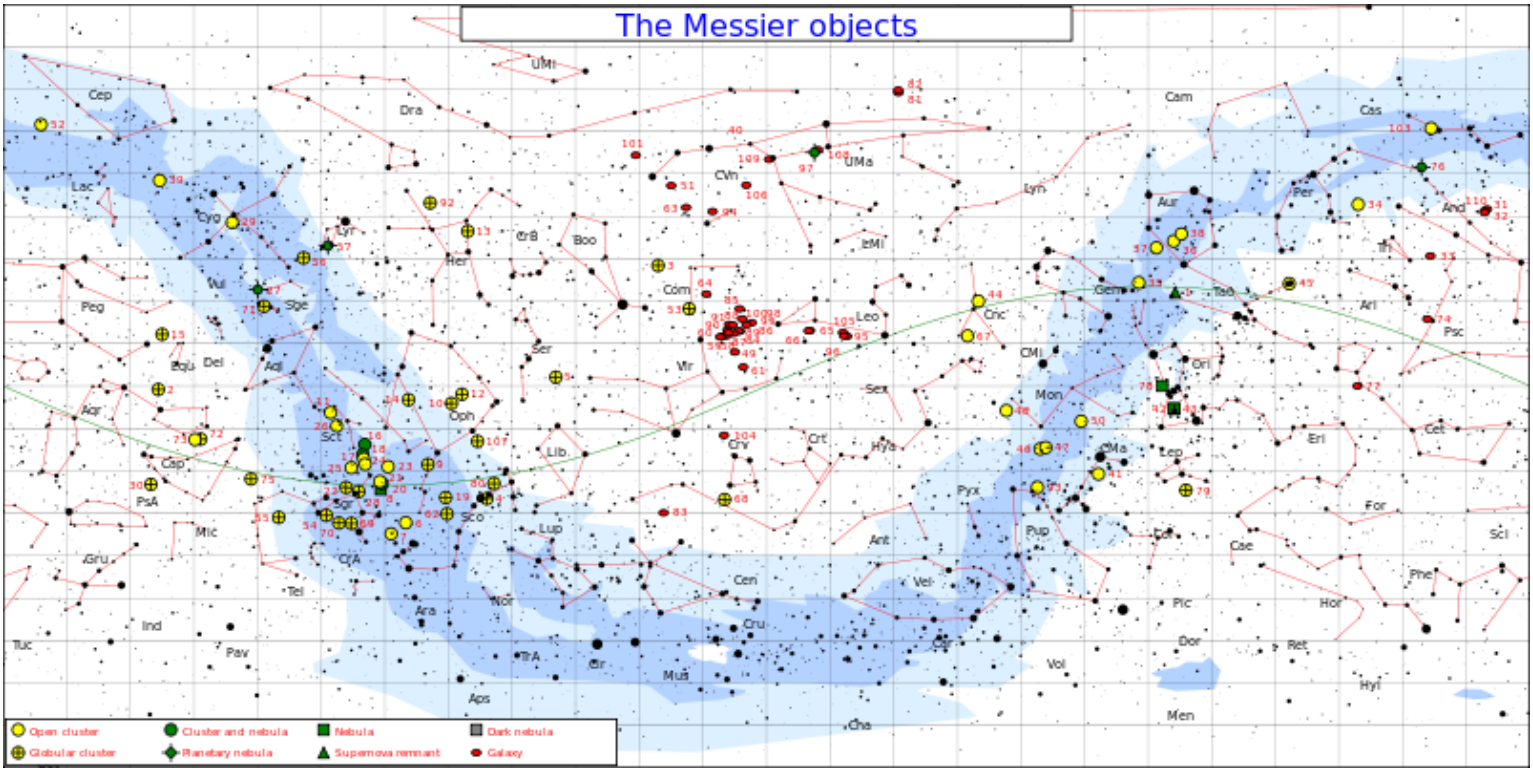
Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M90	NGC 4569		galaxy, spiral	55,900–61,500	Virgo	10.3
M91	NGC 4548		galaxy, barred spiral	47,000–79,000	Coma Berenices	11.0
M92	NGC 6341		cluster, globular	26.7	Hercules	6.3
M93	NGC 2447		cluster, open	3.6	Puppis	6.0
M94	NGC 4736		galaxy, spiral	14,700–17,300	Canes Venatici	9.0
M95	NGC 3351		galaxy, barred spiral	31,200–34,000	Leo	11.4
M96	NGC 3368		galaxy, spiral	28,000–34,000	Leo	10.1
M97	NGC 3587	Owl Nebula	nebula, planetary	2.03	Ursa Major	9.9
M98	NGC 4192		galaxy, spiral	44,400	Coma Berenices	11.0
M99	NGC 4254		galaxy, spiral	44,700–55,700	Coma Berenices	10.4
M100	NGC 4321		galaxy, spiral	55,000	Coma Berenices	10.1
M101	NGC 5457	Pinwheel Galaxy	galaxy, spiral	19,100–22,400	Ursa Major	7.9

Astronomy: Messier Objects (10)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M102	NGC 5866	Spindle Galaxy	galaxy, lenticular	50,000	Draco	10.7
M103	NGC 581		cluster, open	10	Cassiopeia	7.4
M104	NGC 4594	Sombrero Galaxy	galaxy, spiral	28,700–30,900	Virgo	9.0
M105	NGC 3379		galaxy, elliptical	30,400–33,600	Leo	10.2
M106	NGC 4258		galaxy, spiral	22,200–25,200	Canes Venatici	9.1
M107	NGC 6171		cluster, globular	20.9	Ophiuchus	8.9
M108	NGC 3556		galaxy, barred spiral	46,000	Ursa Major	10.7
M109	NGC 3992		galaxy, barred spiral	59,500–107,500	Ursa Major	10.6
M110	NGC 205		galaxy, dwarf elliptical	2,600–2,780	Andromeda	9.0

(Source: https://en.wikipedia.org/wiki/Messier_object)

Astronomy: Messier Objects (11)



(Image source: https://commons.wikimedia.org/wiki/File:MessierStarChart.svg, Jim Cornell, CC BY-SA 3.0)

Astronomy: Magnitude, Brightness and Luminosity (1)

apparent magnitude difference $m_2 - m_1 = -2.5\log\left(\frac{B_2}{B_1}\right)$

m_1 and m_2 = apparent magnitude B_1 and B_2 = brightness

$$\frac{B_{10}}{B_d} = \left(\frac{d}{10}\right)^2$$

B_{10} = brightness at a distance of 10 parsecs

B_d = brightness at a distance d parsecs

Astronomy: Magnitude, Brightness, and Luminosity (2)

absolute magnitude difference $M_2 - M_1 = -2.5\log\left(\frac{L_2}{L_1}\right)$

M_1 and M_2 = apparent magnitude L_1 and L_2 = brightness

absolute magnitude $M_V = m_V + 5 - 5\log d_{pc}$

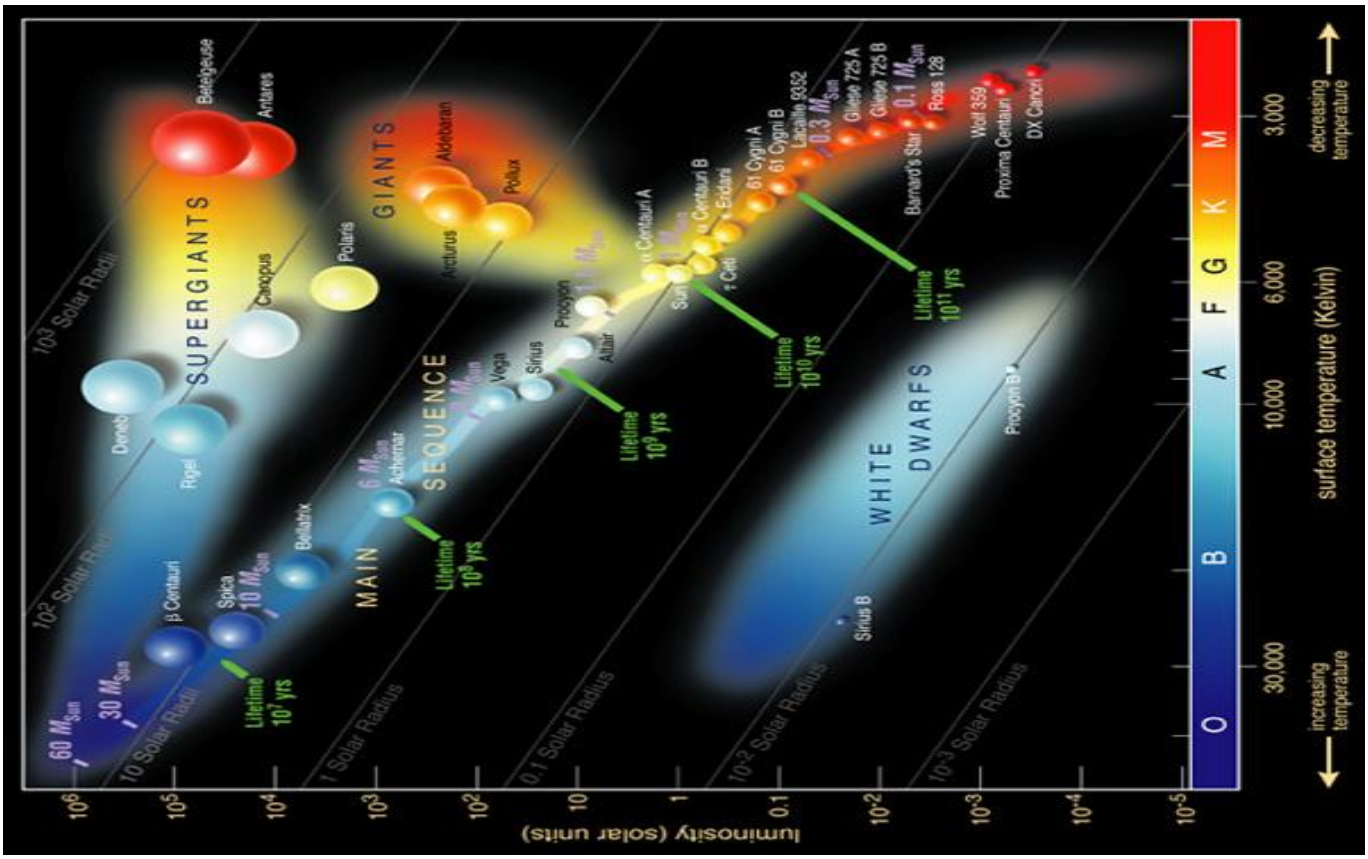
m_V = apparent magnitude d_{pc} = distance in parsecs

$d_{pc} = (10\,pc)(10^{(m_V - M_V)/5})$

$B = \frac{L}{4\pi d^2}$ L = luminosity in watts d = distance in meter

B = brightness in watts/meter^2

Hertzsprung-Russell Diagram (1)



(Image source: https://commons.wikimedia.org/wiki/File:Hertzsprung-Russel_StarData.png, ESO, CC BY-SA 4.0)

Astronomy: Hertzsprung-Russell Diagram (2)

class	temperature	Vega-relative "color label"	mass (solar masses)	radius (solar radii)	luminosity (solar luminosity; bolometric)	% of main-sequence stars
O	≥ 30,000 K	blue	≥ 16	≥ 6.6	≥ 30,000	~0.00003
B	10,000–30,000 K	blue white	2.1–16	1.8–6.6	25–30,000	0.13
A	7,500–10,000 K	white	1.4–2.1	1.4–1.8	5–25	0.6
F	6,000–7,500 K	yellow white	1.04–1.4	1.15–1.4	1.5–5	3%
G	5,200–6,000 K	yellow	0.8–1.04	0.96–1.15	0.6–1.5	7.6%
K	3,700–5,200 K	orange	0.45–0.8	0.7–0.96	0.08–0.6	12.1%
M	2,400–3,700 K	red	0.08–0.45	≤ 0.7	≤ 0.08	76.45%

(Source: https://en.wikipedia.org/wiki/Stellar_classification#cite_note-m.C3.B6re-6)

Astronomy: Constellations (1)

constellation	abbr	family	origin	meaning	brightest star
Andromeda	And	Perseus	ancient*	princess	Alpheratz
Antlia	Ant	La Caille	1763+*	air pump	α Antliae
Apus	Aps	Bayer	1603**	bird of paradise	α Apodis
Aquarius	Aqr	Zodiac	ancient*	water-bearer	Sadalsuud
Aquila	Aql	Hercules	ancient*	eagle	Altair
Ara	Ara	Hercules	ancient*	altar	β Arae
Aries	Ari	Zodiac	ancient*	ram	Hamal
Auriga	Aur	Perseus	ancient*	charioteer	Capella
Boötes	Boo	Ursa Major	ancient*	herdsman	Arcturus
Caelum	Cae	La Caille	1763+*	chisel	α Caeli
Camelopardalis	Cam	Ursa Major	1613++*	giraffe	β Camelopardalis
Cancer	Cnc	Zodiac	ancient*	crab	Tarf

Astronomy: Constellations (2)

constellation	abbr	family	origin	meaning	brightest star
Canes Venatici	CVn	Ursa Major	1690***	hunting dogs	Cor Caroli
Canis Major	CMa	Orion	ancient*	greater dog	Sirius
Canis Minor	CMi	Orion	ancient*	lesser dog	Procyon
Capricornus	Cap	Zodiac	ancient*	sea goat	Deneb Algiedi
Carina	Car	Heavenly Waters	1763+*	keel	Canopus
Cassiopeia	Cas	Perseus	ancient*	queen	Shedir
Centaurus	Cen	Hercules	ancient*	centaur	Alpha Centauri
Cepheus	Cep	Perseus	ancient*	king	Alderamin
Cetus	Cet	Perseus	ancient*	whale	Deneb Kaitos
Chamaeleon	Cha	Bayer	1603**	chameleon	α Chamaeleontis
Circinus	Cir	La Caille	1763+*	compasses	α Circini
Columba	Col	Heavenly Waters	1592++*	dove	Phact

Astronomy: Constellations (3)

constellation	abbr	family	origin	meaning	brightest star
Coma Berenices	Com	Ursa Major	1603**	Berenice's hair	β Comae Berenices
Corona Australis	CrA	Hercules	ancient*	southern crown	Alphekka Meridiana
Corona Borealis	CrB	Ursa Major	ancient*	northern crown	Alphecca
Corvus	Crv	Hercules	ancient*	crow	Gienah
Crater	Crt	Hercules	ancient*	cup	Labrum
Crux	Cru	Hercules	1603**	southern cross	Acrux
Cygnus	Cyg	Hercules	ancient*	swan	Deneb
Delphinus	Del	Heavenly Waters	ancient*	dolphin	Rotanev
Dorado	Dor	Bayer	1603**	dolphinfish	α Doradus
Draco	Dra	Ursa Major	ancient*	dragon	Etamin
Equuleus	Equ	Heavenly Waters	ancient*	pony	Kitalpha
Eridanus	Eri	Heavenly Waters	ancient*	river	Achernar

Astronomy: Constellations (4)

constellation	abbr	family	origin	meaning	brightest star
Fornax	For	La Caille	1763+*	chemical furnace	Fornacis
Gemini	Gem	Zodiac	ancient*	twins	Pollux
Grus	Gru	Bayer	1603**	crane	Alnair
Hercules	Her	Hercules	ancient*	strong man	Kornephoros
Horologium	Hor	La Caille	1763+*	pendulum clock	α Horologii
Hydra	Hya	Hercules	ancient*	monster	Alphard
Hydrus	Hyi	Bayer	1603**	lesser water snake	β Hydri
Indus	Ind	Bayer	1603**	Indian	The Persian
Lacerta	Lac	Perseus	1690***	lizard	α Lacertae
Leo	Leo	Zodiac	ancient*	lion	Regulus
Leo Minor	LMi	Ursa Major	1690***	lesser lion	Praecipua
Lepus	Lep	Orion	ancient*	hare	Arneb

Astronomy: Constellations (5)

constellation	abbr	family	origin	meaning	brightest star
Libra	Lib	Zodiac	ancient*	balance	Zubeneshamali
Lupus	Lup	Hercules	ancient*	wolf	Men
Lynx	Lyn	Ursa Major	1690***	lynx	Elvashak
Lyra	Lyr	Hercules	ancient*	lyre	Vega
Mensa	Men	La Caille	1763+*	Table Mountain	α Mensae
Microscopium	Mic	La Caille	1763+*	microscope	γ Microscopii
Monoceros	Mon	Orion	1613++*	unicorn	β Monocerotis
Musca	Mus	Bayer	1603**	fly	α Muscae
Norma	Nor	La Caille	1763+*	carpenter's level	γ_2 Normae
Octans	Oct	La Caille	1763+*	octant	ν Oct
Ophiuchus	Oph	Hercules	ancient*	serpent-bearer	Rasalhague
Orion	Ori	Orion	ancient*	hunter	Rigel

Astronomy: Constellations (6)

constellation	abbr	family	origin	meaning	brightest star
Pavo	Pav	Bayer	1603**	peacock	Peacock
Pegasus	Peg	Perseus	ancient*	winged horse	Enif
Perseus	Per	Perseus	ancient*	hero	Mirfak
Phoenix	Phe	Bayer	1603**	phoenix	Ankaa
Pictor	Pic	La Caille	1763+*	easel	α Pictoris
Pisces	Psc	Zodiac	ancient*	fishes	Alpherg
Piscis Austrinus	PsA	Heavenly Waters	ancient*	southern fish	Fomalhaut
Puppis	Pup	Heavenly Waters	1763+*	poop deck	Naos
Pyxis	Pyx	Heavenly Waters	1763+*	mariner's compass	α Pyxidis
Reticulum	Ret	La Caille	1763+*	eyepiece graticule	α Reticuli
Sagitta	Sge	Hercules	ancient*	arrow	γ Sagittae
Sagittarius	Sgr	Zodiac	ancient*	archer	Kaus Australis

Astronomy: Constellations (7)

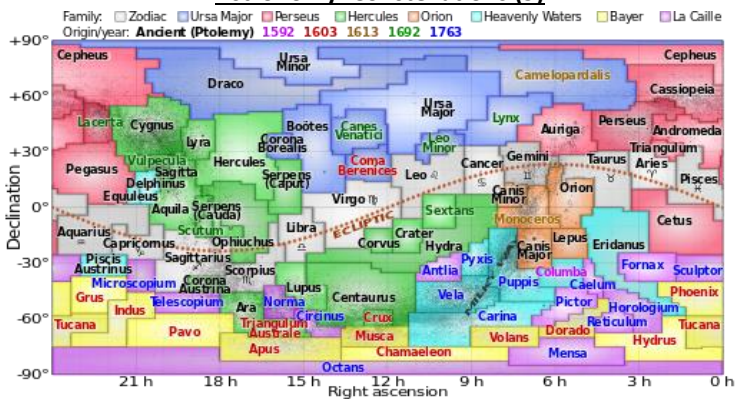
constellation	abbr	family	origin	meaning	brightest star
Scorpius	Sco	Zodiac	ancient*	scorpion	Antares
Sculptor	Scl	La Caille	1763+*	sculptor	α Sculptoris
Scutum	Sct	Hercules	1690***	shield	α Scuti
Serpens	Ser	Hercules	ancient*	snake	Unukalhai
Sextans	Sex	Hercules	1690***	sextant	α Sextantis
Taurus	Tau	Zodiac	ancient*	bull	Aldebaran
Telescopium	Tel	La Caille	1763+*	telescope	α Telescopii
Triangulum	Tri	Perseus	ancient*	triangle	β Trianguli
Triangulum Australe	TrA	Hercules	1603**	southern triangle	Atria
Tucana	Tuc	Bayer	1603**	toucan	α Tucanae
Ursa Major	UMa	Ursa Major	ancient*	great bear	Alioth
Ursa Minor	UMi	Ursa Major	ancient*	lesser bear	Polaris

Astronomy: Constellations (8)

constellation	abbr	family	origin	meaning	brightest star
Vela	Vel	Heavenly Waters	1763+*	sails	Regor
Virgo	Vir	Zodiac	ancient*	maiden	Spica
Volans	Vol	Bayer	1603**	flying fish	β Volantis
Vulpecula	Vul	Hercules	1690***	fox	Anser

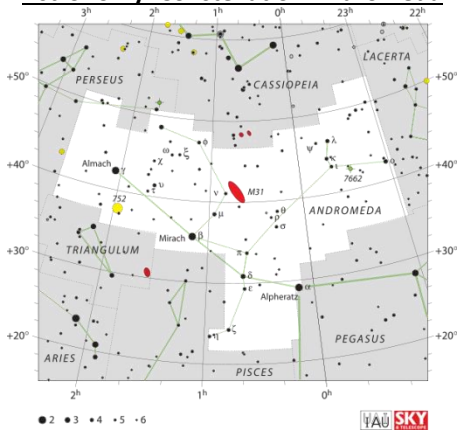
*Ptolemy
**_Uranometria_, created by Keyser and de Houtman
***_Firmamentum Sobiescianum_, Hevelius
+*Lacaille
++*Plancius

Astronomy: Constellations (9)

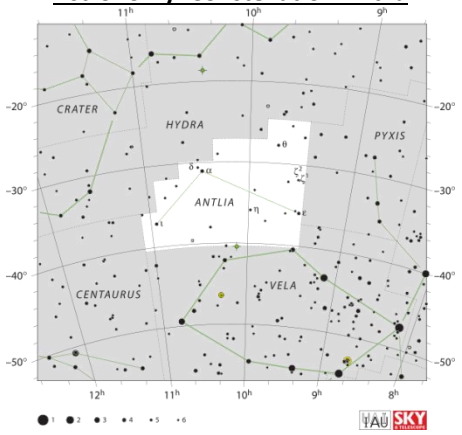


(Image source: https://en.wikipedia.org/wiki/88_modern_constellations#/media/File:Constellations_ecliptic_equirectangular_plot.svg, Cmglee, Timwe, NASA, public domain)

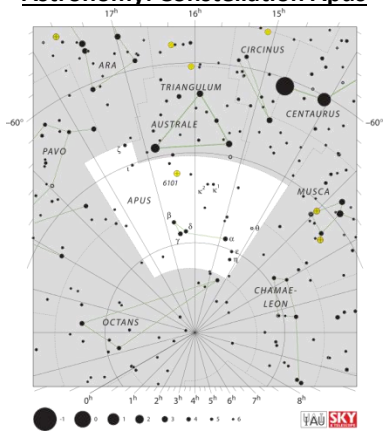
Astronomy: Constellation Andromeda



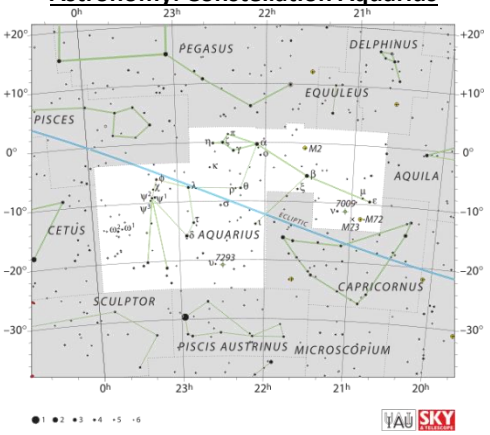
Astronomy: Constellation Antlia



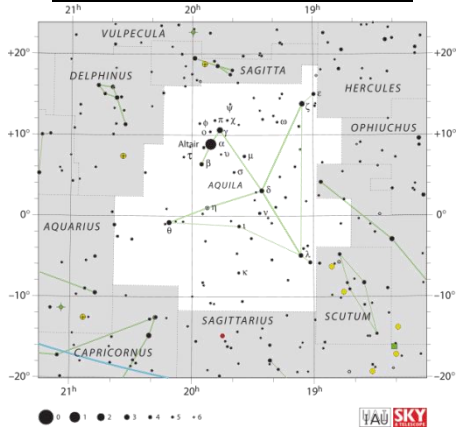
Astronomy: Constellation Apus



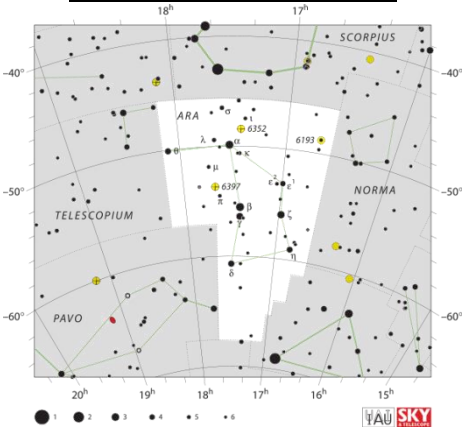
Astronomy: Constellation Aquarius



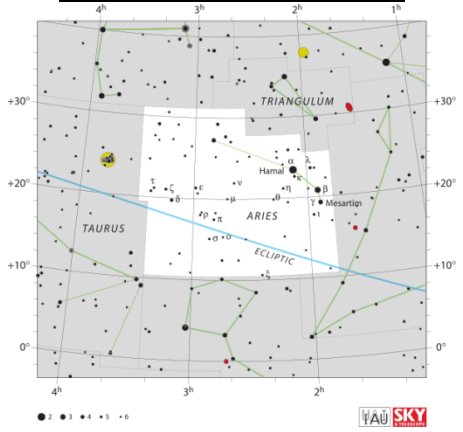
Astronomy: Constellation Aquila



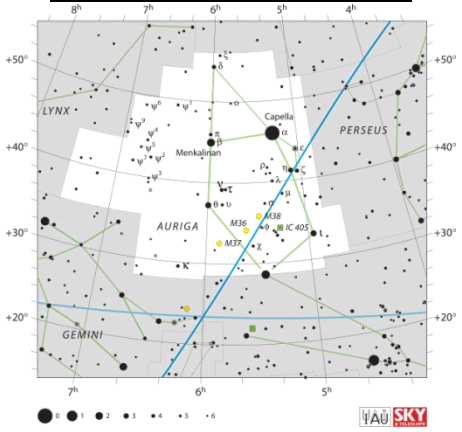
Astronomy: Constellation Ara



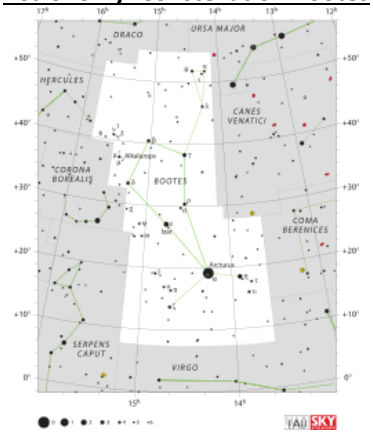
Astronomy: Constellation Aries



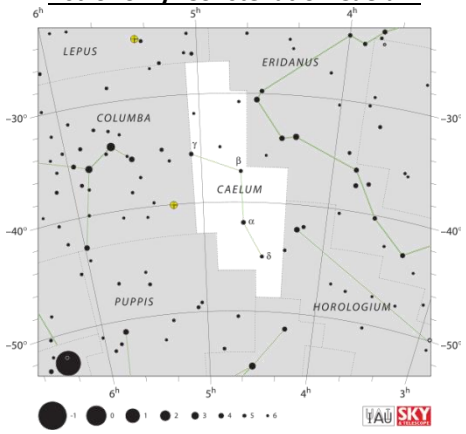
Astronomy: Constellation Auriga



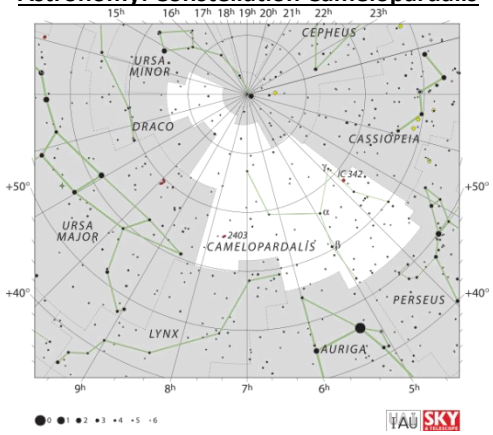
Astronomy: Constellation Boötes



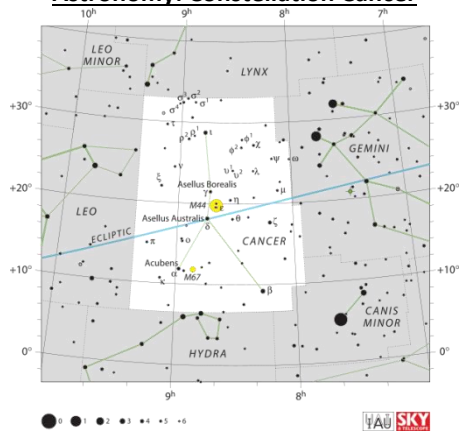
Astronomy: Constellation Caelum



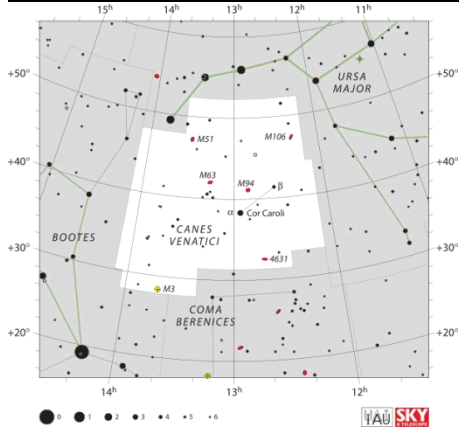
Astronomy: Constellation Camelopardalis



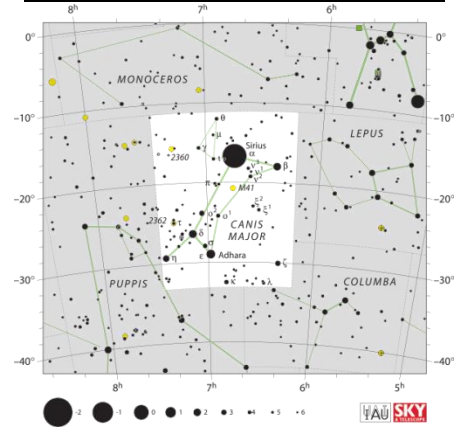
Astronomy: Constellation Cancer



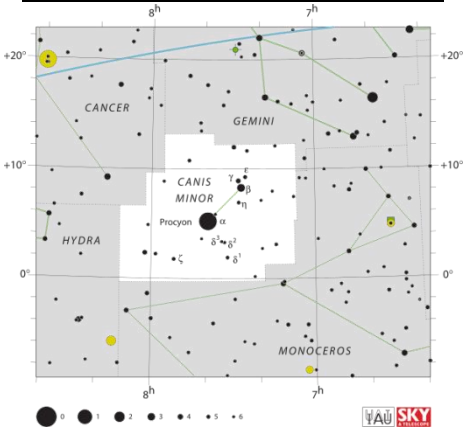
Astronomy: Constellation Canes Venatici



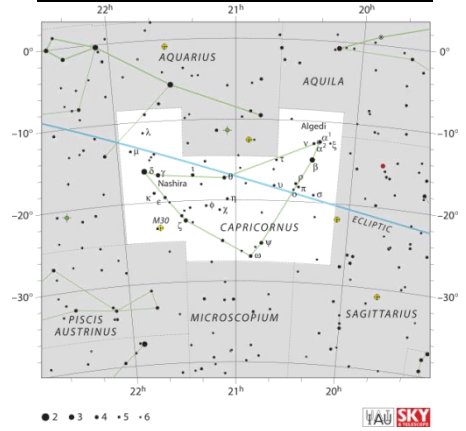
Astronomy: Constellation Canis Major



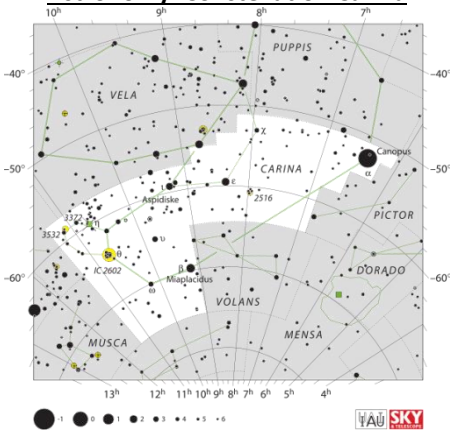
Astronomy: Constellation Canis Minor



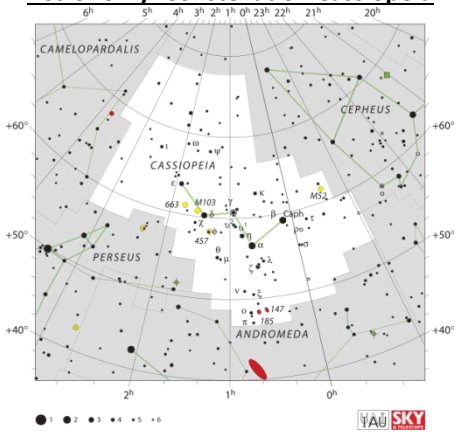
Astronomy: Constellation Capricorn



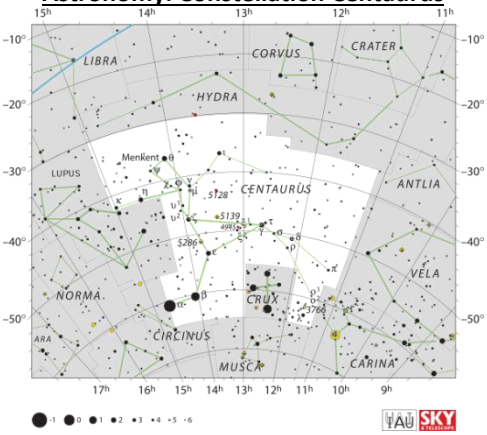
Astronomy: Constellation Carina



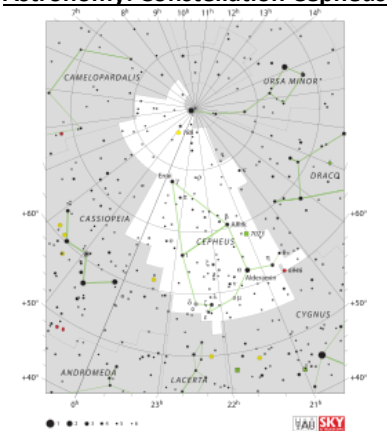
Astronomy: Constellation Cassiopeia



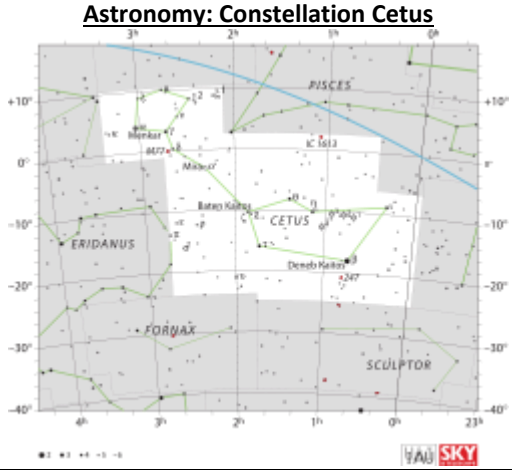
Astronomy: Constellation Centaurus



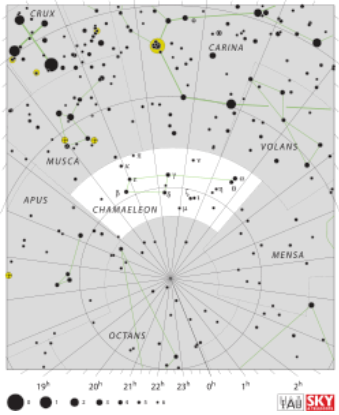
Astronomy: Constellation Cepheus



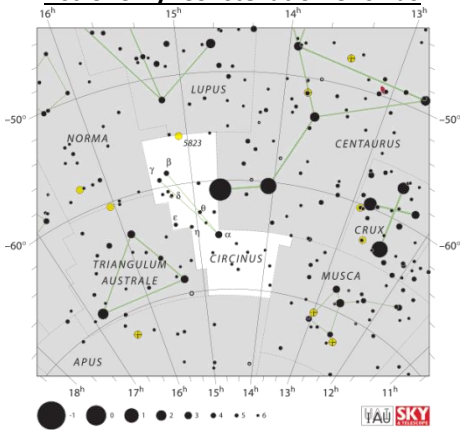
Astronomy: Constellation Cetus



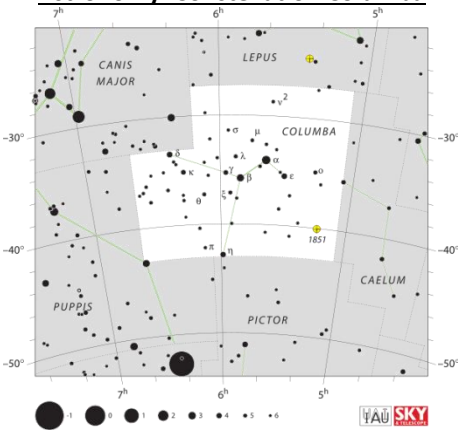
Astronomy: Constellation Chamaeleon



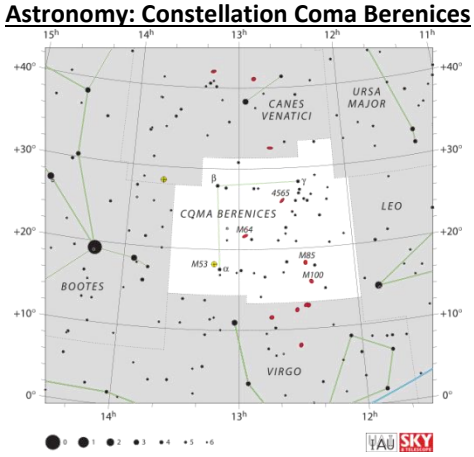
Astronomy: Constellation Circinus



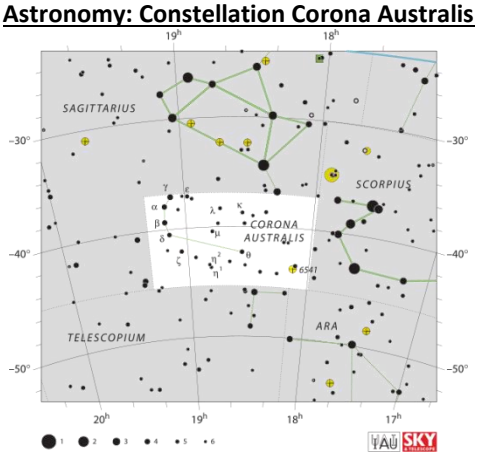
Astronomy: Constellation Columba



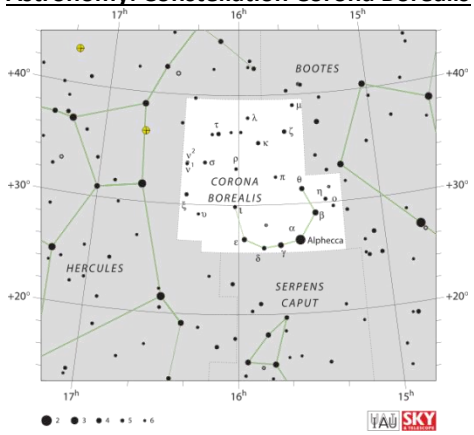
Astronomy: Constellation Coma Berenices



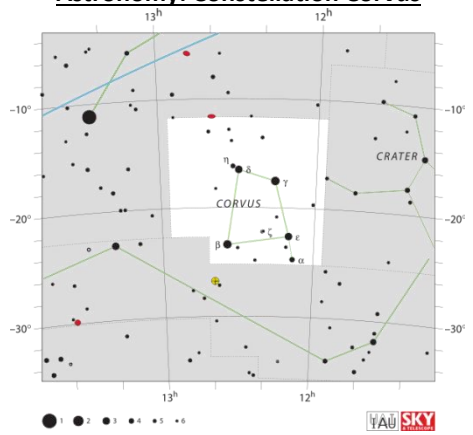
Astronomy: Constellation Corona Australis



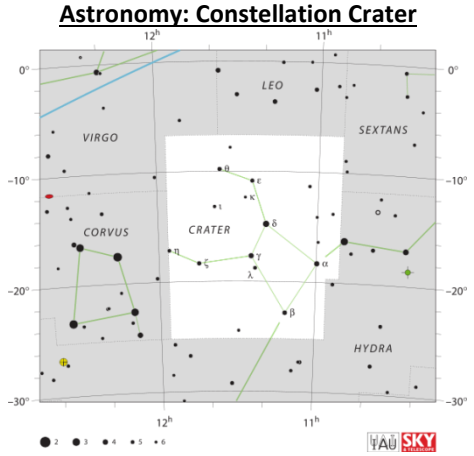
Astronomy: Constellation Corona Borealis



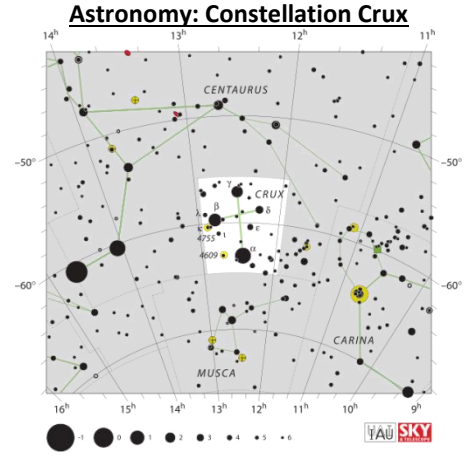
Astronomy: Constellation Corvus



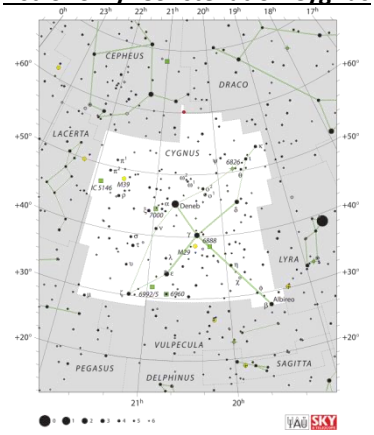
Astronomy: Constellation Crater



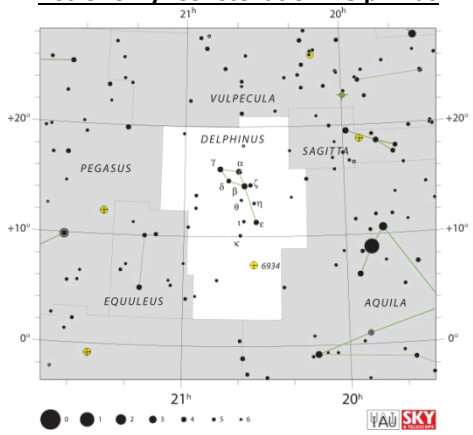
Astronomy: Constellation Crux



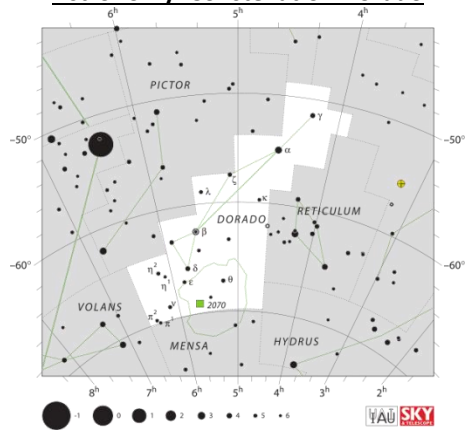
Astronomy: Constellation Cygnus



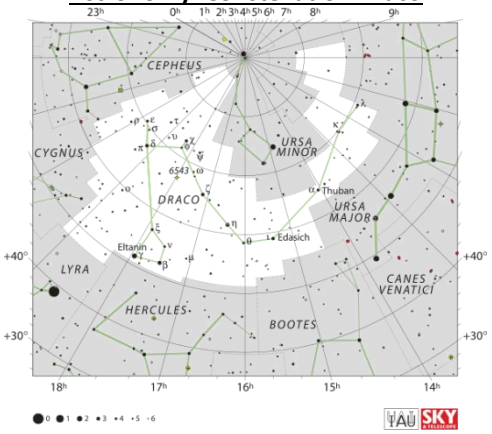
Astronomy: Constellation Delphinus



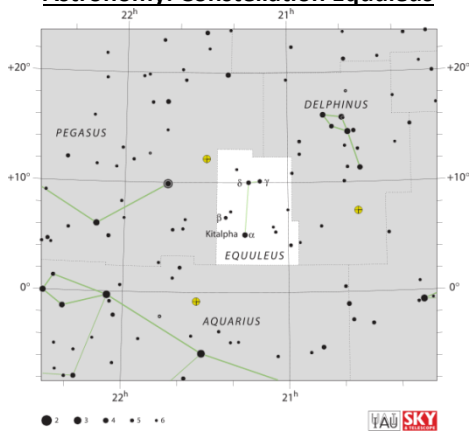
Astronomy: Constellation Dorado



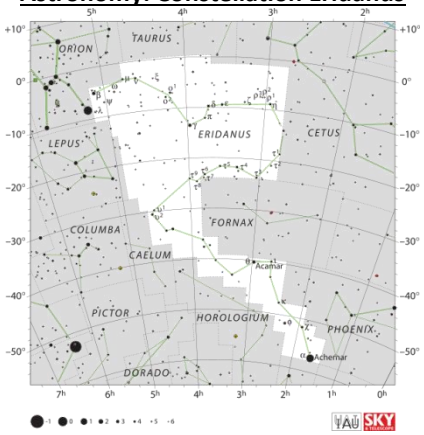
Astronomy: Constellation Draco



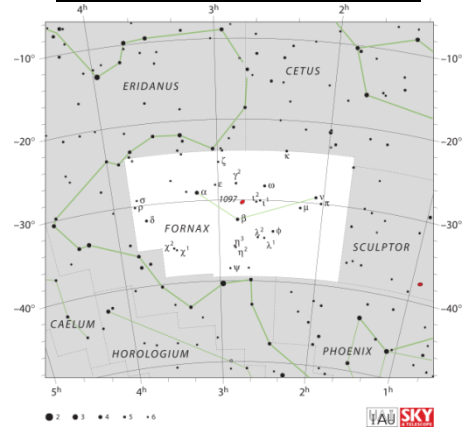
Astronomy: Constellation Equuleus



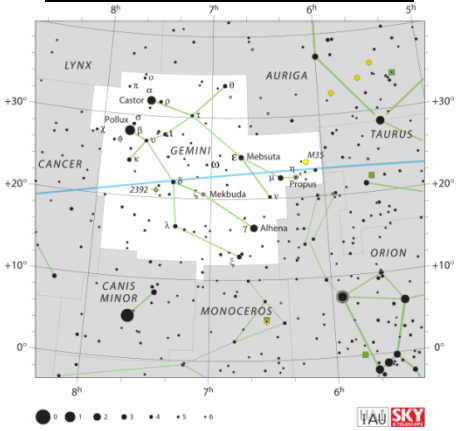
Astronomy: Constellation Eridanus



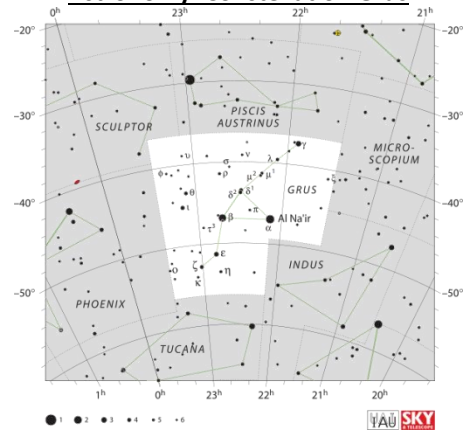
Astronomy: Constellation Fornax



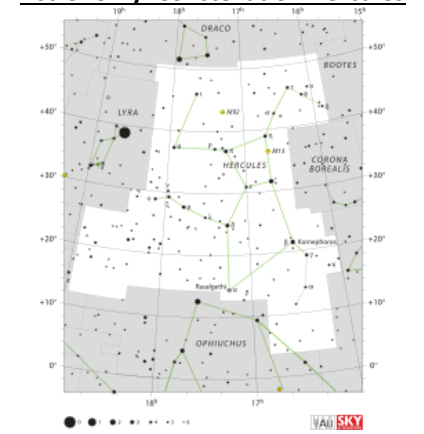
Astronomy: Constellation Gemini



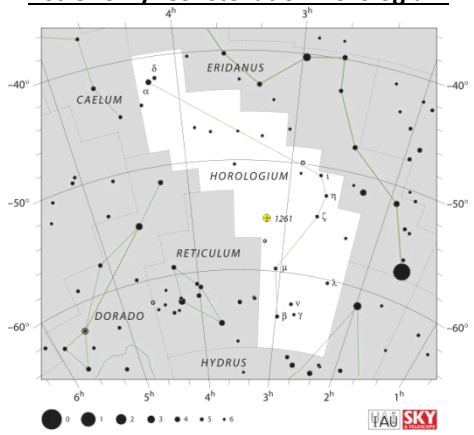
Astronomy: Constellation Grus



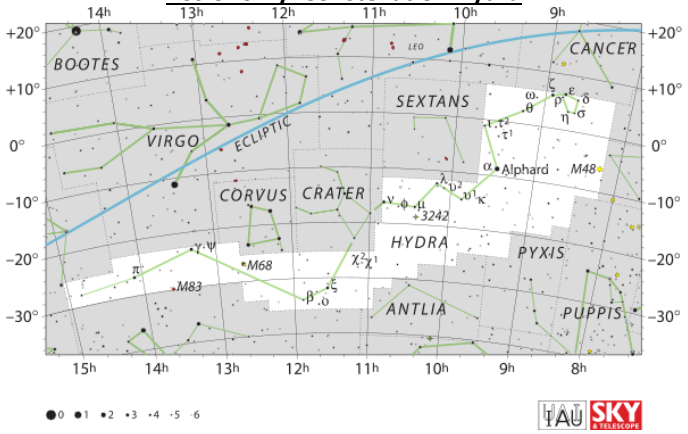
Astronomy: Constellation Hercules



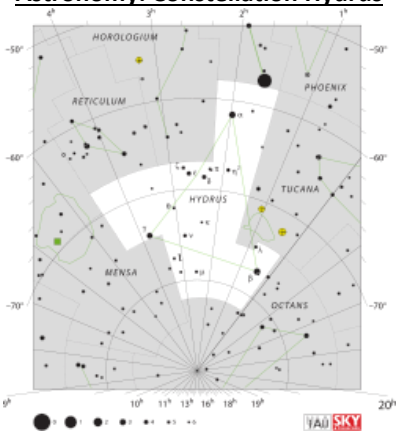
Astronomy: Constellation Horologium



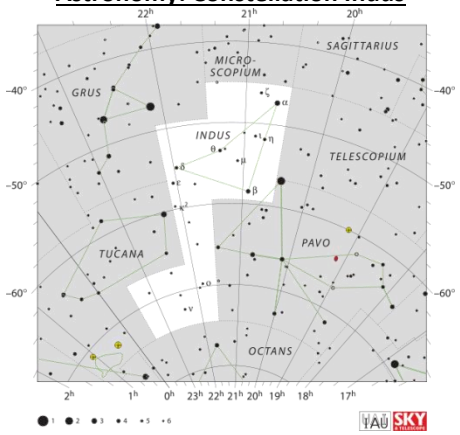
Astronomy: Constellation Hydra



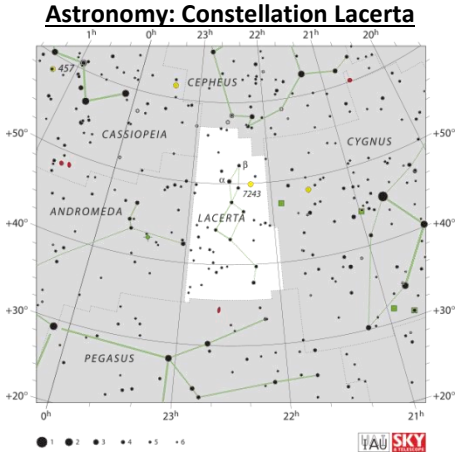
Astronomy: Constellation Hydrus



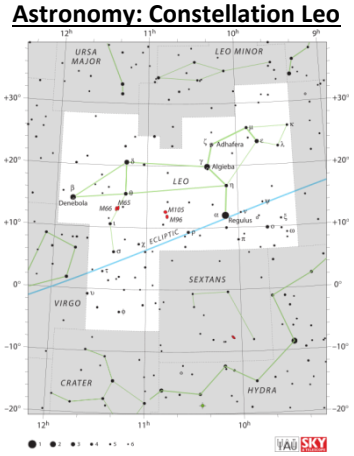
Astronomy: Constellation Indus



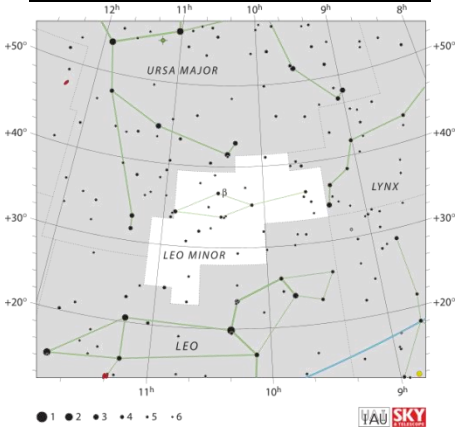
Astronomy: Constellation Lacerta



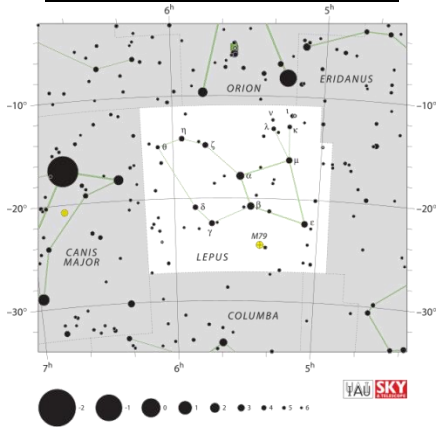
Astronomy: Constellation Leo



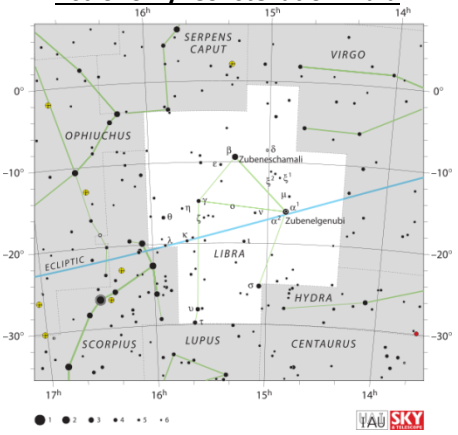
Astronomy: Constellation Leo Minor



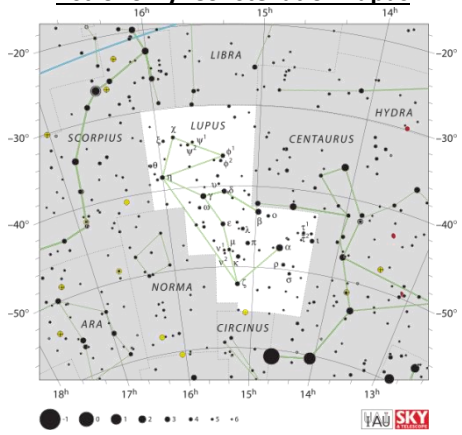
Astronomy: Constellation Lepus



Astronomy: Constellation Libra



Astronomy: Constellation Lupus



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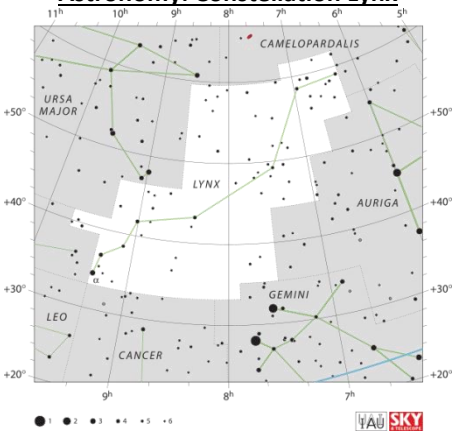
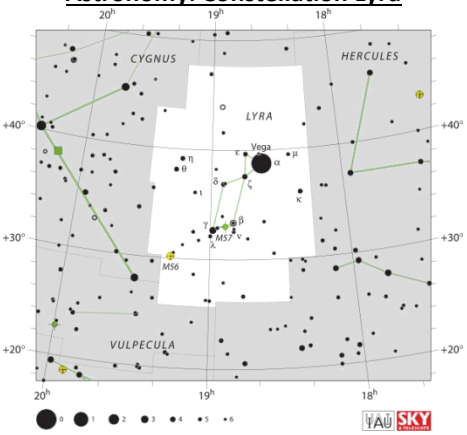


Astronomy: Constellation Lyra



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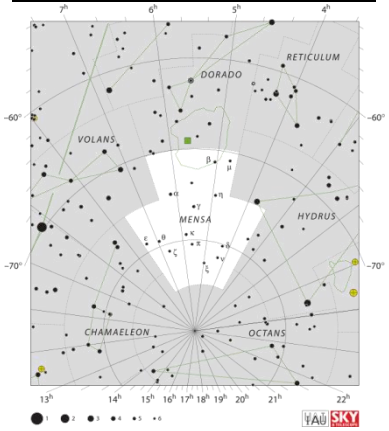
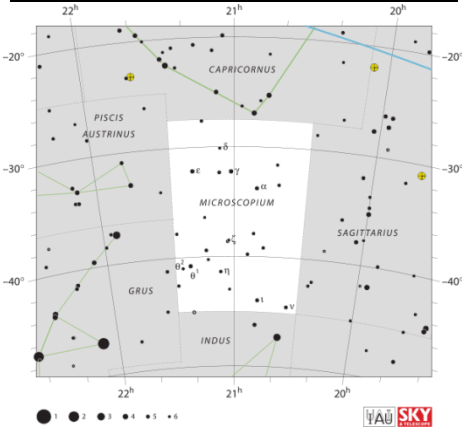
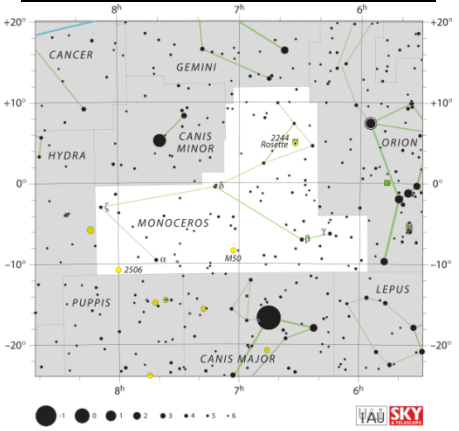


Astronomy: Constellation Microscopium



Astronomy: Constellation Monoceros



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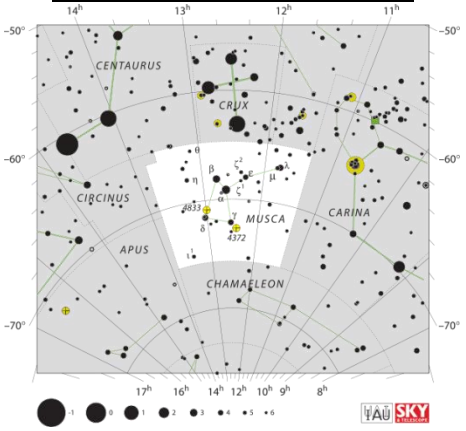
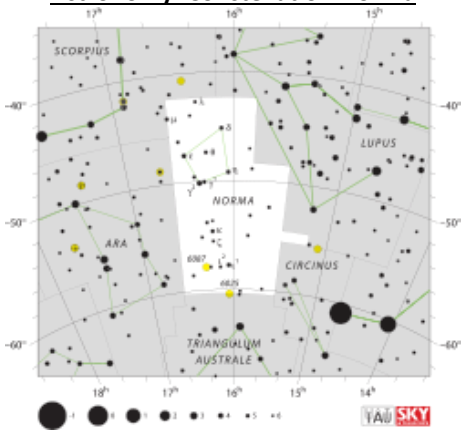
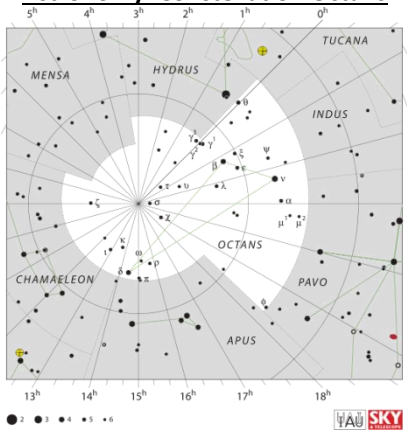


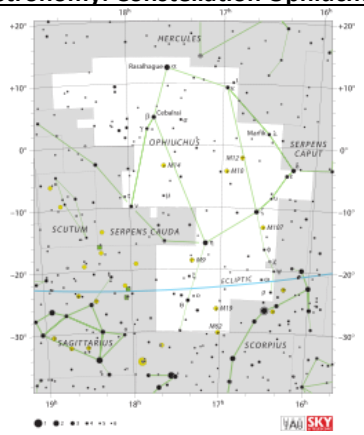
Astronomy: Constellation Norma



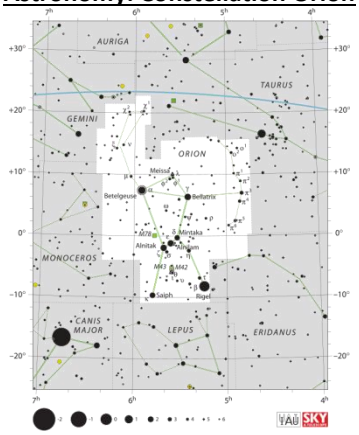
Astronomy: Constellation Octans



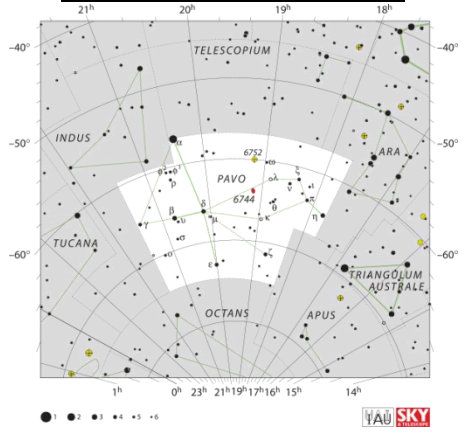
Astronomy: Constellation Ophiuchus



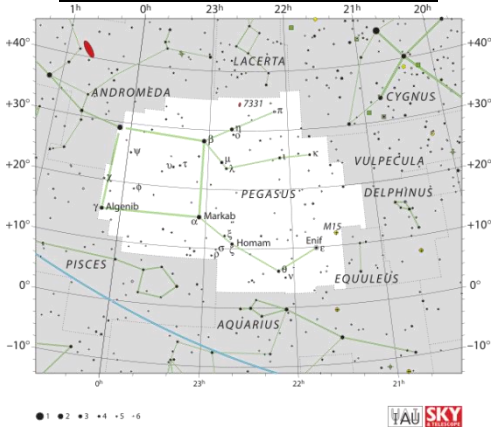
Astronomy: Constellation Orion



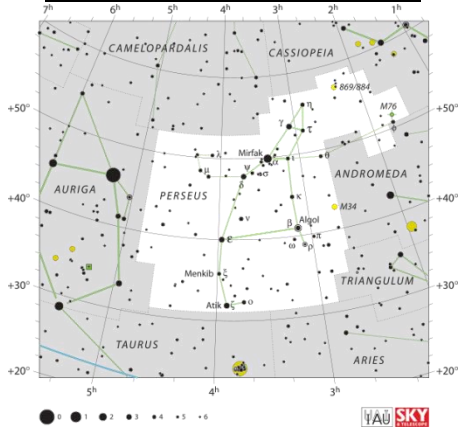
Astronomy: Constellation Pavo



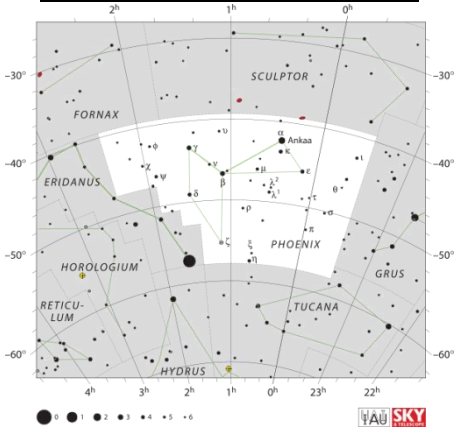
Astronomy: Constellation Pegasus



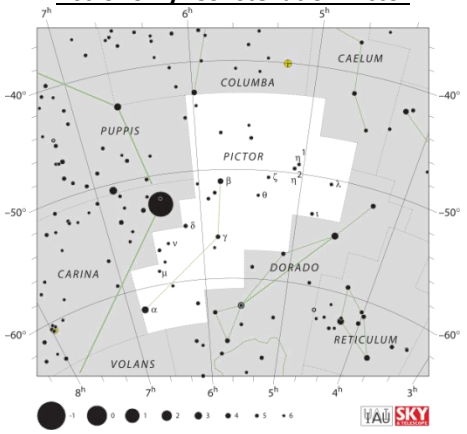
Astronomy: Constellation Perseus



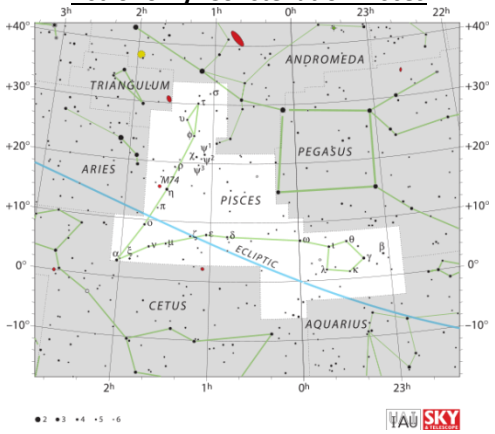
Astronomy: Constellation Phoenix



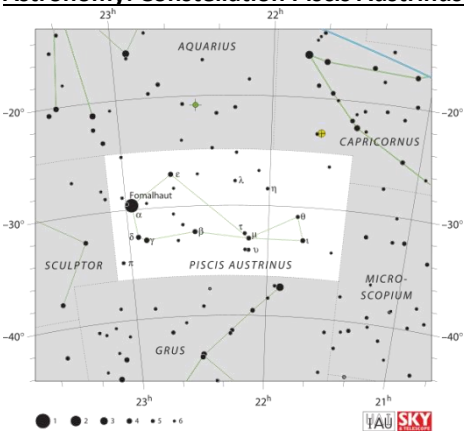
Astronomy: Constellation Pictor



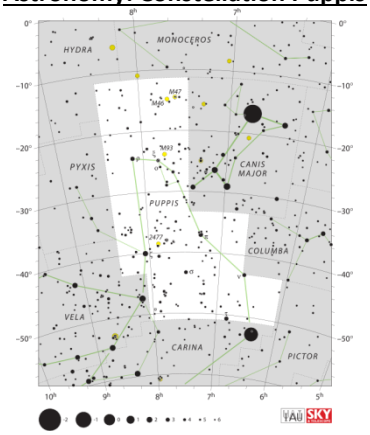
Astronomy: Constellation Pisces



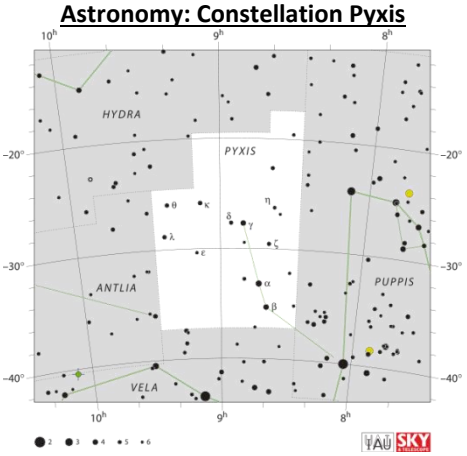
Astronomy: Constellation Piscis Austrinus



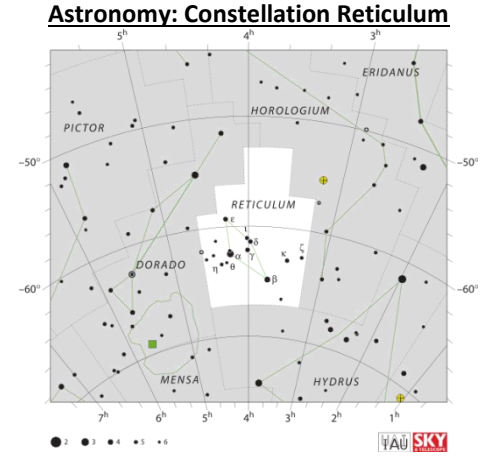
Astronomy: Constellation Puppis



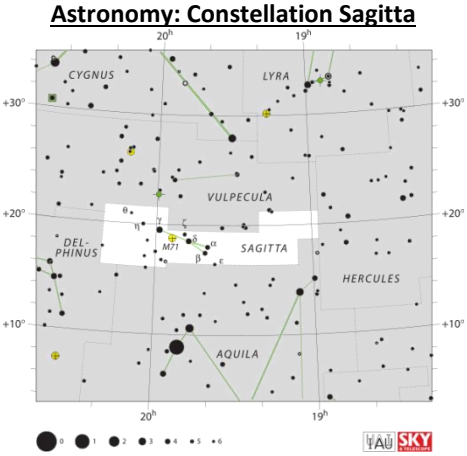
Astronomy: Constellation Pyxis



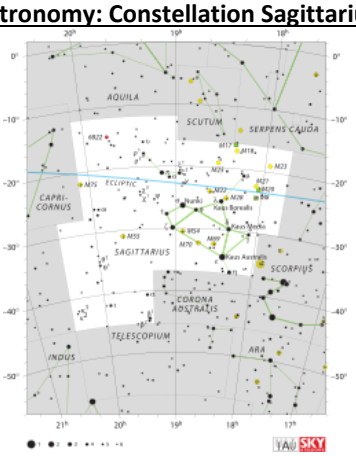
Astronomy: Constellation Reticulum



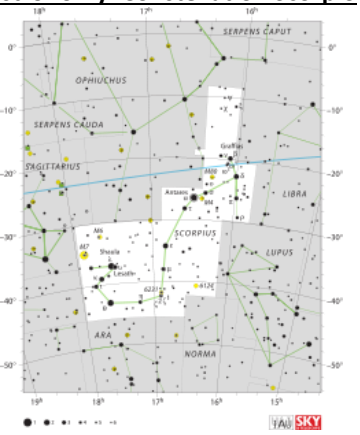
Astronomy: Constellation Sagitta



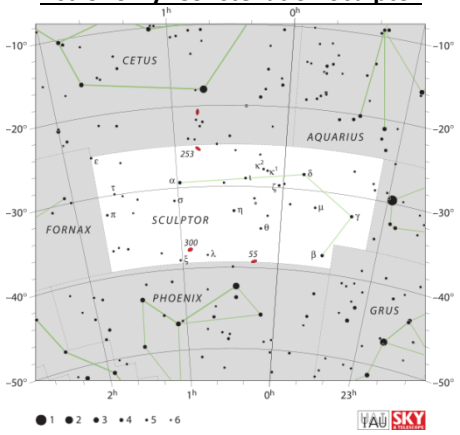
Astronomy: Constellation Sagittarius



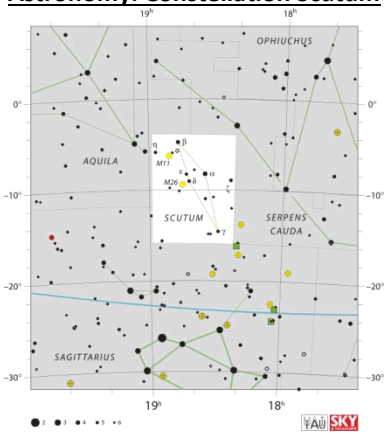
Astronomy: Constellation Scorpio



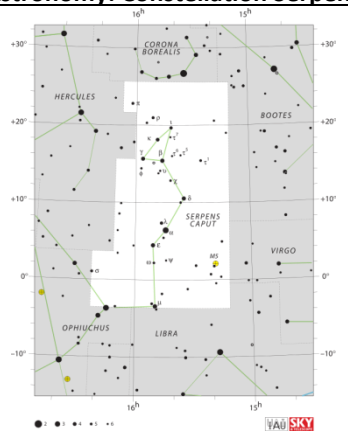
Astronomy: Constellation Sculptor



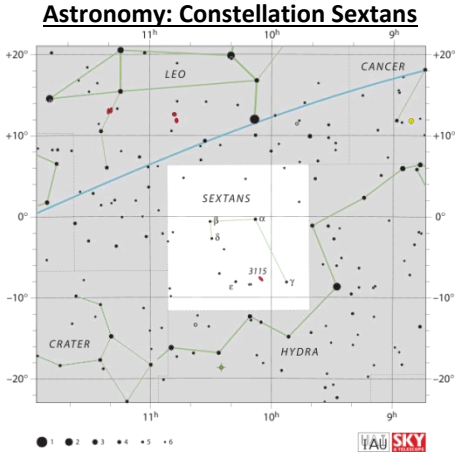
Astronomy: Constellation Scutum



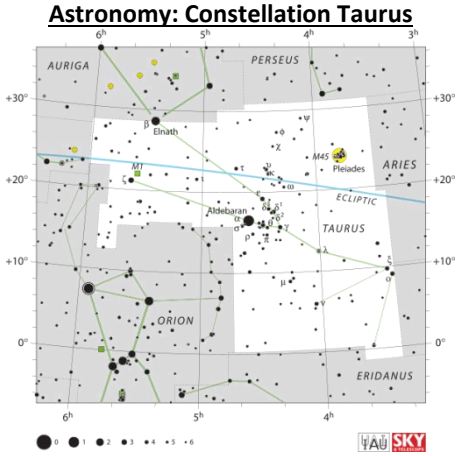
Astronomy: Constellation Serpens



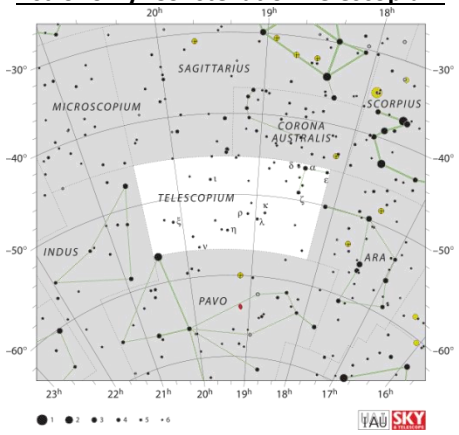
Astronomy: Constellation Sextans



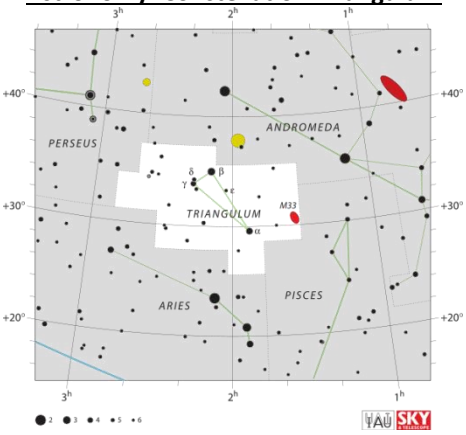
Astronomy: Constellation Taurus



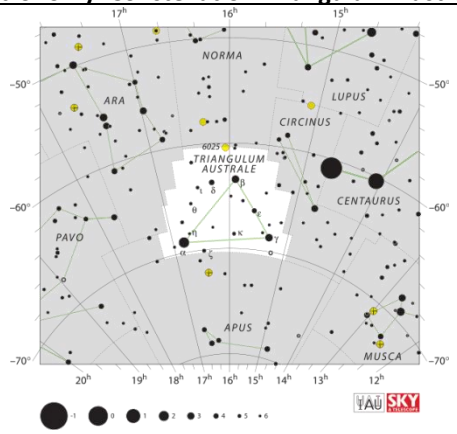
Astronomy: Constellation Telescopium



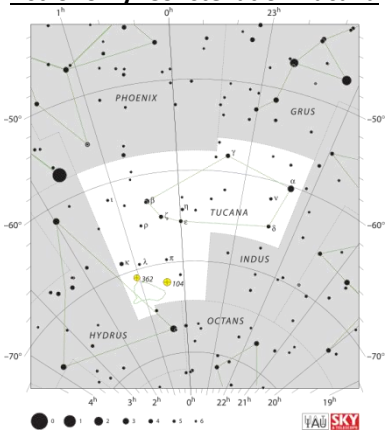
Astronomy: Constellation Triangulum



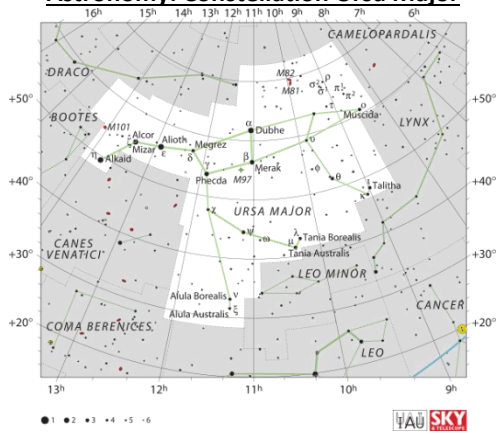
Astronomy: Constellation Triangulum Australe



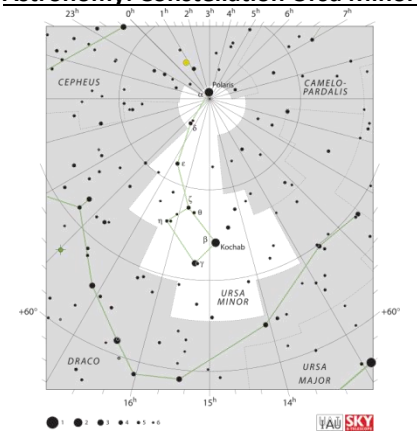
Astronomy: Constellation Tucana



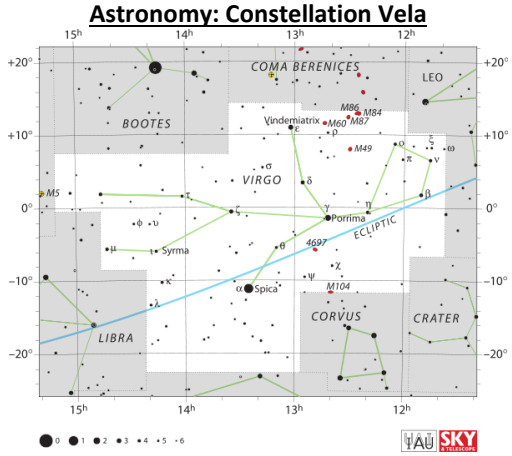
Astronomy: Constellation Ursa Major



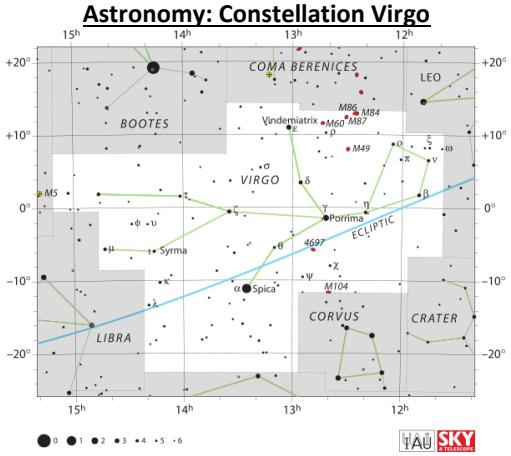
Astronomy: Constellation Ursa Minor



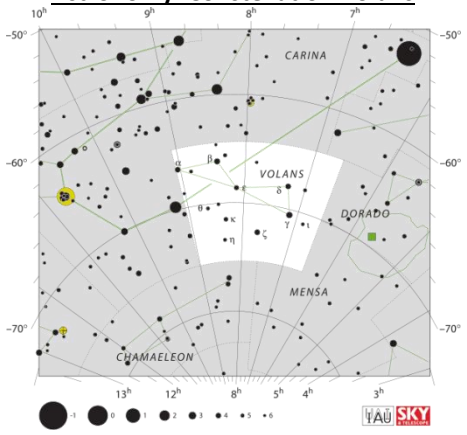
Astronomy: Constellation Vela



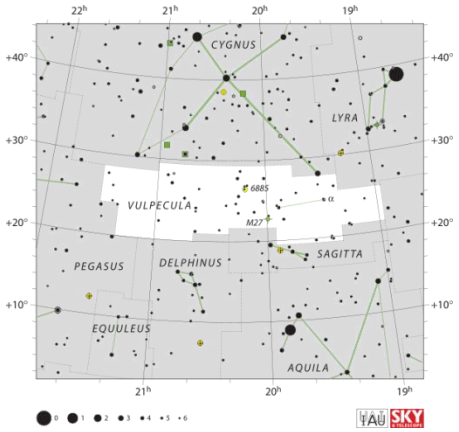
Astronomy: Constellation Virgo



Astronomy: Constellation Volans



Astronomy: Constellation Vulpecula



(Constellation images source: http://www.iau.org/public/themes/constellations/, IAU, CC BY 3.0)

Astronomy: Milky Way Galaxy (1)

Milky Way: barred spiral galaxy, diameter about 100,000–120,000 light-years, containing about 100–400 billion stars, more than 100 billion planets

solar System location: about 27,000 light-years from the galactic center, on the inner edge of the Orion Arm

center: marked by an intense radio source, Sagittarius A*, likely a supermassive black hole

orbits: stars and gases orbit at approximately 220 km/s; constant rotation suggests that much mass of the Milky Way does not emit or absorb electromagnetic radiation; mass termed "dark matter"

Astronomy: Milky Way Galaxy (2)

rotational period: about 240 million years at the position of the Sun, galaxy is moving at approximately 600 km/s with respect to extragalactic frames of reference.

oldest stars: nearly as old as the Universe itself and thus likely formed shortly after the Big Bang.

related galaxies: satellite galaxies and part of the Local Group of galaxies, a component of the Virgo Supercluster, which is itself a component of the Laniakea Supercluster

(Source: https://en.wikipedia.org/wiki/Milky_Way)

Astronomy: Galaxy Classification (1)

- elliptical galaxies: smooth, featureless light distributions and appear as ellipses in images, designated "E", followed by an integer n representing degree of ellipticity on the sky
- spiral galaxies: consist of a flattened disk, with stars forming a (usually two-armed) spiral structure, and a central concentration of stars known as the bulge, similar in appearance to an elliptical galaxy, designated "S," roughly half of all spirals are also observed to have a bar-like structure, extending from the central bulge, designated "SB"
- lenticular galaxies: designated S0, consist of a bright central bulge surrounded by an extended, disk-like structure, the disks of lenticular galaxies have no visible spiral structure and are not actively forming stars in any significant quantity

Astronomy: Galaxy Classification (2)

- bars: SA designates spiral galaxies without bars, SAB denotes weakly barred spirals, lenticular galaxies classified as unbarred (SA0) or barred (SB0), with notation S0 reserved for galaxies for which it is impossible to tell if a bar is present or not
- rings: those possessing ring-like structures (denoted '(r)') and those without rings (denoted '(s)'), "transition" galaxies designated by (rs)
- spiral arms: spiral galaxies are assigned to a class based primarily on the tightness of their spiral arms
  - Sd (SBd): diffuse, broken arms made up of individual stellar clusters and nebulae; very faint central bulge
  - Sm (SBm): irregular in appearance; no bulge component
  - Im: highly irregular galaxy

(Source: https://en.wikipedia.org/wiki/Galaxy_morphological_classification)

Astronomy: Hubble's Law (1)

Hubble's law:

1. Objects more than 10 megaparsecs have a Doppler shift as relative velocity away from Earth;
2. This Doppler-shift-measured velocity is approximately proportional to their distance from the Earth for galaxies up to a few hundred megaparsecs away.

(Source: https://en.wikipedia.org/wiki/Hubble%27s_law)

Astronomy: Hubble's Law (2)

redshift $z = \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}}$

λ_{obs} = wavelength, due to movement, of a line in the object's spectrum

λ_{rest} = wavelength of the same line if the object were not moving

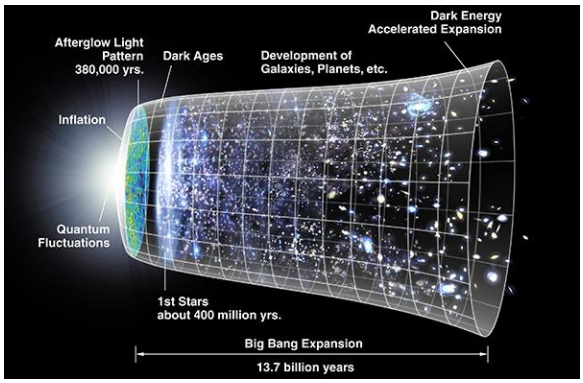
lookback time $T_{LB} = \frac{z}{H_0(1+z)}$

Hubble constant H_0 = 67.6 kilometers/second/megaparsec

(Source: https://en.wikipedia.org/wiki/Hubble%27s_law)

Astronomy: Cosmology

cosmology: study of the origin, evolution, and eventual fate of the universe



(Image source: https://astrosociety.org/wp-content/uploads/2012/10/1-CMB_Timeline300_no_WMAP.jpg, Astronomical Society of the Pacific)

Astonomy: Chemical Abundance of the Universe

Atomic number	Element	Mass fraction ppm
1	hydrogen	739,000
2	helium	240,000
8	oxygen	10,400
6	carbon	4,600
10	neon	1,340
26	iron	1,090
7	nitrogen	960
14	silicon	650
12	magnesium	580
16	sulfur	440

Astronomy: History of the Universe (1)

epoch/era	time	redshift	temperature	description
Planck	$<10^{-43}$ s		$>10^{32}$ K 10^{19} GeV	quantum effects dominate
Grand unification	$<10^{-36}$ s		10^{16} GeV	3 forces of standard model unified
Inflation/ electroweak			10^{28} K - 10^{22} K	cosmic inflation expands space
Quark	$>10^{12}$ s		10^{12} K	forces of standard model have separated
Hadron	10^{-6} - 1 s		10^{10} K – 10^{9} K	quarks bound to hadrons
Lepton	1 s - 10 s		10^{9} K	neutrino decoupling

Astronomy: History of the Universe (2)

epoch/era	time	redshift	temperature	description
Photon	10 s - 10^{13} s		10^{9} K – 10^{3} K	universe consists of plasma of nuclei, electrons, and photons
Big Bang nucleo-synthesis	10 s – 10^{3} s		10 MeV – 100 KeV 10^{11} K – 10^{9} K	protons and neutrons bound
Matter-dominated era	47 ka – 10 Ga	3600 – 0.4	10^{4} K – 4 K	decelerated expansion of space

Astronomy: History of the Universe (3)

epoch/era	time	redshift	temperature	description
Recombination	380 ka	1100	4000 K	electrons and atomic nuclei form neutral atoms
Dark Ages	380 ka - 150 Ma	1100 - 20	4000 K – 60 K	formation of first stars
Stelliferous	150 Ma – 100 Ga	20 - -0.99	60 K – 0.03 K	first formation of Population III stars
Reionization	150 Ma – 1 Ga	20 - 6	60 K – 19 K	most distant astronomical objects date to this period

Astronomy: History of the Universe (4)

epoch/era	time	redshift	temperature	description
Galaxy formation and evolution	1 Ga – 10 Ga	6 – 0.4	19 K – 4 K	galaxy clusters form
Dark-energy dominated	>10 Ga	< 0.4	< 4 K	matter density falls below dark energy density
Present	13.8 Ga	0	2.7 K	
Far future	>100 Ga	< -0.99	< 0.1 K	may become Dark Era, Big Crunch, or Big Rip

(Source: https://en.wikipedia.org/wiki/Chronology_of_the_universe)

Astronomy: Drake Equation

Drake equation: argument used to arrive at an estimate of the number of active, communicative extraterrestrial civilizations, N, in the Milky Way

$$N = R^* * f_p * n_e * f_\lambda * f_i * f_c * L$$

R^* = average rate of star formation in our galaxy

f_P = fraction of formed stars that have planets

n_e = average number of planets per star that can potentially support life

f_λ = fraction of those planets that actually develop life

f_i = fraction of planets bearing life on which intelligent, civilized life has developed

f_c = fraction of civilizations that have developed communications

L = length of time over which such civilizations release detectable signals

Astronomy: Fermi Paradox

Fermi paradox: apparent contradiction between lack of evidence and high probability estimates by Drake equation for existence of extraterrestrial civilizations; basic points of the argument are:

- billions of stars in the galaxy similar to the Sun, many of which are billions of years older than Earth;
- with high probability, some of them will have Earth-like planets, and if the Earth is typical, some might develop intelligent life;
- some of these civilizations might develop interstellar travel;
- even at the slow pace of currently envisioned interstellar travel, the Milky Way galaxy could be completely traversed in a few million years.

Fermi asked "Where is everybody?" Attempts to explain Fermi paradox suggest intelligent extraterrestrial life is extremely rare, or propose such civilizations have not contacted or visited Earth.

(Source: https://en.wikipedia.org/wiki/Fermi_paradox)

Astronomy: Kardashev Scale

Type I Plantetary Society: able to harness all their planet's energy; control natural forces; able to gather and store energy from their star

Type II Interplanetary Society: can harness the power of entire star; mastered fusion; ability to occupy several planets; virtually immune to extinction

Type III Interstellar Society: galactic travelers; move from star to star, colonizing planets; likely that cyborgs are the most advanced beings; humans become a sub-species

Type IV Intergalactic Society: able to harness energy of entire universe; could live inside supermassive black holes; could potentially change the strucutre of space-time or slow entropy

Type V Universe Society: can control power output of a collection of universes, jump between multiverses, manipulate the universe at will

(Source: http://www.disclose.tv/news/did_you_know_about_the_kardashev_scale__type_i_ii_iii_iv_v_alien_civilizations/125839)

Astronomy: Rocket Equation

change in velocity Δv is a measure of the impulse that is needed to perform a maneuver such as launch from, or landing on a planet or moon, or in-space orbital maneuver; it is a scalar with the units of speed

$$\Delta v = I_{sp} g_0 \ln \frac{m_0}{m_f}$$

I_{sp} = specific impulse in seconds

g_0 = 9.81 m/s^2

m_0 = initial mass

m_f = final mass

Astronomy: Special Relativity (1)

Special relativity is based on:

1. The laws of physics are invariant (i.e. identical) in all inertial systems (non-accelerating frames of reference).
2. The speed of light in a vacuum is the same for all observers, regardless of the motion of the light source.

Originally proposed in 1905 by Albert Einstein in the paper "On the Electrodynamics of Moving Bodies,." it explains length contraction, time dilation, relativistic mass, a universal speed limit and relativity of simultaneity, and mass-energy equivalence, $E = mc^2$, where c is the speed of light, m is mass, and E is energy.

(Source: https://en.wikipedia.org/wiki/Special_relativity)

Astronomy: Special Relativity (2)

time dilation $\frac{t'}{t} = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$

length contraction $\frac{l'}{l} = \sqrt{1-\frac{v^2}{c^2}}$

mass increase $\frac{m'}{m} = \sqrt{1-\frac{v^2}{c^2}}$

t' = time measured by moving object

t = time measured by objects at rest compared to moving object

l' = length of moving object

l = length of object at rest

m' = mass of moving object

m = mass of object at rest

v = velocity of moving object in units of c

c = velocity of light

Astronomy: Special Relativity (3)

relativistic velocity addition $v_{12} = \frac{v_1 + v_2}{1 + \frac{v_1 v_2}{c^2}}$

v_1 = velocity of object 1

v_2 = velocity of object 2

v_{12} = relative velocity of objects 1 and 2 moving toward each other

speed of light c = 299,792,458 meters/second (approximately 3.00×10^8 meters/second = 186,282 miles/second)

Astronomy: General Relativity

General relativity is the geometric theory of gravitation published by Albert Einstein in 1915. It generalizes special relativity and Newton's law of universal gravitation, providing a unified description of gravity as a geometric property of spacetime. Some predictions include gravitational time dilation, gravitational lensing, the gravitational redshift of light, and gravitational time delay. The theory implies the existence of black holes, supported by observations of intense radiation emitted by microquasars and active galactic nuclei.

(Source: https://en.wikipedia.org/wiki/General_relativity)