Milky Way

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The **Milky Way** is the galaxy[18][19][20][nb 1] that contains our Solar System.[21] The descriptive "milky" is derived from the appearance from Earth of the galaxy – a band of light seen in the night sky formed from stars that cannot be individually distinguished by the naked eye. The term "Milky Way" is a translation of the Latin *via lactea*, from the Greek γαλαξίας κύκλος (*galaxías kýklos*, "milky circle").[22][23][24] From Earth, the Milky Way appears as a band because its disk-shaped structure is viewed from within. Galileo Galilei first resolved the band of light into individual stars with his telescope in 1610. Until the early 1920s, most astronomers thought that the Milky Way contained all the stars in the Universe. Following the 1920 Great Debate between the astronomers Harlow Shapley and Heber Curtis,[25] observations by Edwin Hubble showed that the Milky Way is just one of many galaxies. Subsequent sensitive observations such as the Hubble telescope's Ultra Deep Field revealed a myriad of faint galaxies, which led to an estimate that the observable universe contained about 200 billion galaxies.[26][27] A 2016 study estimated that the observable universe contained ten times that number or 2 trillion galaxies.[28]

The Milky Way is a barred spiral galaxy that has a diameter usually considered to be about 100,000–120,000 light-years[29] but may be 150,000–180,000 light-years.[30] The Milky Way is estimated to contain 100–400 billion stars.[31][32] There are likely at least 100 billion planets in the Milky Way.[33][34] The Solar System is located within the disk, about 27,000 light-years from the Galactic Center, on the inner edge of one of the spiral-shaped concentrations of gas and dust called the Orion Arm. The stars in the inner ≈10,000 light-years form a bulge and one or more bars that radiate from the bulge. The very center is marked by an intense radio source, named Sagittarius A*, which is likely to be a supermassive black hole.

Stars and gases at a wide range of distances from the Galactic Center orbit at approximately 220 kilometers per second. The constant rotation speed contradicts the laws of Keplerian dynamics and suggests that much of the mass of the Milky Way does not emit or absorb electromagnetic radiation. This mass has been termed "dark matter".[35] The rotational period is about 240 million years at the position of the Sun.[15] The Milky Way as a whole is moving at a velocity of approximately 600 km per second with respect to extragalactic frames of reference. The oldest stars in the Milky Way are nearly as old as the Universe itself and thus likely formed shortly after the Dark Ages of the Big Bang.[9]

The Milky Way has several satellite galaxies and is part of the Local Group of galaxies, which is a component of the Virgo Supercluster, which is itself a component of the Laniakea Supercluster.[36][37]

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Appearance

The "Milky Way" can be seen as a hazy band of white light some 30 degrees wide arcing across the sky.[38] Although all the individual naked-eye stars in the entire sky are part of the Milky Way,[39][40] the light in this band originates from the accumulation of unresolved stars and other material located in the direction of the galactic plane. Dark regions within the band, such as the Great Rift and the Coalsack, are areas where light from distant stars is blocked by interstellar dust. The area of the sky obscured by the Milky Way is called the Zone of Avoidance.

Milky Way Galaxy

The Milky Way's Galactic Center in the night sky above Paranal Observatory (the laser creates a guide-star for the telescope).

Observation data

Type	Sb, Sbc, or SB(rs)bc[1][2] (barred spiral galaxy)
Diameter	100–180 kly (31–55 kpc)[3]
Thickness of thin stellar disk	≈2 kly (0.6 kpc)[4][5]
Number of stars	100–400 billion (2.5×10^{11} ±1.5×10^{11})[6][7][8]
Oldest known star	≥13.7 Gyr[9]
Mass	$0.8–1.5 \times 10^{12}$ $M_\odot$[10][11][12]
Angular momentum	≈1×10^{67} J s[13]
Sun's distance to Galactic Center	27.2 ± 1.1 kly (8.34 ± 0.34 kpc)[14]
Sun's Galactic rotation period	240 Myr[15]
Spiral pattern rotation period	220–360 Myr[16]
Bar pattern rotation period	100–120 Myr[16]
Speed relative to CMB rest frame	552 ± 6 km/s[17]
Escape velocity at Sun's position	550 km/s[12]
Dark matter density at Sun's position	$0.0088^{+0.0024}_{-0.0018}$ $M_\odot$pc^{-3} or $0.35^{+0.08}_{-0.07}$ GeV cm^{-3}[12]

See also: Galaxy, List of galaxies

The Milky Way has a relatively low surface brightness. Its visibility can be greatly reduced by background light such as light pollution or stray light from the Moon. The sky needs to be darker than about 20.2 magnitude per square arcsecond in order for the Milky Way to be seen.[41] It should be visible when the limiting magnitude is approximately +5.1 or better and shows a great deal of detail at +6.1. [42] This makes the Milky Way difficult to see from any brightly lit urban or suburban location, but very prominent when viewed from a rural area when the Moon is below the horizon.[nb 2] The new world atlas of artificial night sky brightness shows that more than one-third of Earth population cannot see the Milky Way from their homes due to light pollution.[43]

As viewed from Earth, the visible region of the Milky Way's Galactic plane occupies an area of the sky that includes 30 constellations. [44] The center of the Galaxy lies in the direction of the constellation Sagittarius; it is here that the Milky Way is brightest. From Sagittarius, the hazy band of white light appears to pass around to the Galactic anticenter in Auriga. The band then continues the rest of the way around the sky, back to Sagittarius. The band divides the night sky into two roughly equal hemispheres.

The Galactic plane is inclined by about 60 degrees to the ecliptic (the plane of Earth's orbit). Relative to the celestial equator, it passes as far north as the constellation of Cassiopeia and as far south as the constellation of Crux, indicating the high inclination of Earth's equatorial plane and the plane of the ecliptic, relative to the Galactic plane. The north Galactic pole is situated at right ascension 12^h 49^m, declination +27.4° (B1950) near β Comae Berenices, and the south Galactic pole is near α Sculptoris. Because of this high inclination, depending on the time of night and year, the arc of Milky Way may appear relatively low or relatively high in the sky. For observers from approximately 65 degrees north to 65 degrees south on Earth's surface, the Milky Way passes directly overhead twice a day.


A view of the Milky Way toward the constellation Sagittarius (including the Galactic Center) as seen from an area not polluted by light (the Black Rock Desert, Nevada). The bright object on the right is Jupiter, just above Antares.

The Milky Way arching at a high inclination across the night sky (*fish-eye mosaic shot at Paranal, Chile*). The bright object is Jupiter in the constellation Sagittarius. Galactic north is downwards.

This time-lapse video captures the Milky Way circling over ALMA.

Size and mass

The Milky Way is the second-largest galaxy in the Local Group, with its stellar disk approximately 100,000 ly (30 kpc) in diameter, and, on average, approximately 1,000 ly (0.3 kpc) thick.[4][5] As a guide to the relative physical scale of the Milky Way, if the Solar System out to Neptune were the size of a US quarter (24.3 mm (0.955 in)), the Milky Way would be approximately the size of the continental United States.[46] A ring-like filament of stars wrapping around the Milky Way may belong to the Milky Way itself, rippling above and below the relatively flat galactic plane.[30] If so, that would mean a diameter of 150,000–180,000 light-years (46 –55 kpc).[47]

A photograph of galaxy NGC 6744, which might resemble the Milky Way.[45]
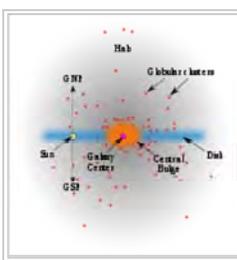
Schematic profile of the Milky Way.

Estimates of the mass of the Milky Way vary, depending upon the method and data used. At the low end of the estimate range, the mass of the Milky Way is 5.8×10^{11} solar masses ($M_\odot$), somewhat less than that of the Andromeda Galaxy.[48][49][50] Measurements using the Very Long Baseline Array in 2009 found velocities as large as 254 km/s (570,000 mph) for stars at the outer edge of the Milky Way.[51] Because the orbital velocity depends on the total mass inside the orbital radius, this suggests that the Milky Way is more massive, roughly equaling the mass of Andromeda Galaxy at 7×10^{11} $M_\odot$ within 160,000 ly (49 kpc) of its center.[52] In 2010, a measurement of the radial velocity of halo stars found that the mass enclosed within 80 kiloparsecs is 7×10^{11} $M_\odot$.[53] According to a study published in 2014, the mass of the entire Milky Way is estimated to be 8.5×10^{11} $M_\odot$,[54] which is about half the mass of the Andromeda Galaxy.[54]

Most of the mass of the Milky Way appears to be dark matter, an unknown and invisible form of matter that interacts gravitationally with ordinary matter. A dark matter halo is spread out relatively uniformly to a distance beyond one hundred kiloparsecs from the Galactic Center. Mathematical models of the Milky Way suggest that its total mass is $1-1.5 \times 10^{12}$ $M_\odot$.[10] Recent studies indicate a range in mass, as large as 4.5×10^{12} $M_\odot$[55] and as small as 0.8×10^{12} $M_\odot$.[56]

The total mass of all the stars in the Milky Way is estimated to be between 4.6×10^{10} $M_\odot$[57] and 6.43×10^{10} $M_\odot$.[10] In addition to the stars, there is also interstellar gas, comprising 90% hydrogen and 10% helium by mass,[58] with two thirds of the hydrogen found in the form of atomic form and the remaining one-third as molecular hydrogen. [59] The mass of this gas is equal to between 10%[59] and 15%[58] of the total mass of the galaxy's stars. Interstellar dust accounts for an additional 1% of the total mass of the gas.[58]

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The Milky Way contains between 200 and 400 billion stars[60][61] and at least 100 billion planets.[62] The exact figure depends on the number of very-low-mass stars, which are hard to detect, especially at distances of more than 300 ly (90 pc) from the Sun. As a comparison, the neighboring Andromeda Galaxy contains an estimated one trillion (10^{12}) stars.[63] Filling the space between the stars is a disk of gas and dust called the interstellar medium. This disk has at least a comparable extent in radius to the stars,[64] whereas the thickness of the gas layer ranges from hundreds of light years for the colder gas to thousands of light years for warmer gas.[65][66]

The disk of stars in the Milky Way does not have a sharp edge beyond which there are no stars. Rather, the concentration of stars decreases with distance from the center of the Milky Way. For reasons that are not understood, beyond a radius of roughly 40,000 ly (13 kpc) from the center, the number of stars per cubic parsec drops much faster with radius.[67] Surrounding the galactic disk is a spherical Galactic Halo of stars and globular clusters that extends further outward but is limited in size by the orbits of two Milky Way satellites, the Large and Small Magellanic Clouds, whose closest approach to the Galactic Center is about 180,000 ly (55 kpc).[68] At this distance or beyond, the orbits of most halo objects would be disrupted by the Magellanic Clouds. Hence, such objects would probably be ejected from the vicinity of the Milky Way. The integrated absolute visual magnitude of the Milky Way is estimated to be around −20.9.[69][70][a]

Both gravitational microlensing and planetary transit observations indicate that there may be at least as many planets bound to stars as there are stars in the Milky Way,[33][71] and microlensing measurements indicate that there are more rogue planets not bound to host stars than there are stars.[72][73] The Milky Way contains at least one planet per star, resulting in 100–400 billion planets, according to a January 2013 study of the five-planet star system Kepler-32 with the Kepler space observatory.[34] A different January 2013 analysis of Kepler data estimated that at least 17 billion Earth-sized exoplanets reside in the Milky Way.[74] On November 4, 2013, astronomers reported, based on *Kepler* space mission data, that there could be as many as 40 billion Earth-sized planets orbiting in the habitable zones of Sun-like stars and red dwarfs within the Milky Way. [75][76][77] 11 billion of these estimated planets may be orbiting Sun-like stars.[78] The nearest such planet may be 12 light-years away, according to scientists.[75][76] Such Earth-sized planets may be more numerous than gas giants.[33] Besides exoplanets, "exocomets", comets beyond the Solar System, have also been detected and may be common in the Milky Way.[79]

Structure

The Milky Way consists of a bar-shaped core region surrounded by a disk of gas, dust and stars. The mass distribution within the Milky Way closely resembles the type Sbc in the Hubble classification, which represents spiral galaxies with relatively loosely wound arms.[1] Astronomers began to suspect that the Milky Way is a barred spiral galaxy, rather than an ordinary spiral galaxy, in the 1990s. [82] Their suspicions were confirmed by the Spitzer Space Telescope observations in 2005[83] that showed the Milky Way's central bar to be larger than previously thought.

An artist's impression that shows how the Milky Way would look from very different perspectives than from Earth. From some angles, the central bulge shows up as a peanut-shaped glowing ball of stars, and from above, the central narrow bar appears clearly. The many spiral arms and their associated dust clouds are also clearly seen.

Galactic quadrants

A galactic quadrant, or quadrant of the Milky Way, refers to one of four circular sectors in the division of the Milky Way. In actual astronomical practice, the delineation of the galactic quadrants is based upon the galactic coordinate system, which places the Sun as the origin of the mapping system.[84]

Quadrants are described using ordinals—for example, "1st galactic quadrant",[85] "second galactic quadrant",[86] or "third quadrant of the Milky Way".[87] Viewing from the north galactic pole with 0 degrees (°) as the ray that runs starting from the Sun and through the Galactic Center, the quadrants are as follows:

- 1st galactic quadrant – $0° \leq$ longitude $(\ell) \leq 90°$[88]
- 2nd galactic quadrant – $90° \leq \ell \leq 180°$[86]
- 3rd galactic quadrant – $180° \leq \ell \leq 270°$[87]
- 4th galactic quadrant – $270° \leq \ell \leq 360° \ (0°)$[85]

Galactic Center

The Sun is 26,000–28,000 ly (8.0–8.6 kpc) from the Galactic Center. This value is estimated using geometric-based methods or by measuring selected astronomical objects that serve as standard candles, with different techniques yielding various values within this approximate range.[14][89][90][91][92] In the inner few kpc (around 10,000 light-years radius) is a dense concentration of mostly old stars in a roughly spheroidal shape called the bulge.[93] It has been proposed that the Milky Way lacks a bulge formed due to a collision and merger between previous galaxies and that instead has a *pseudobulge* formed by its central bar.[94]

The Galactic Center is marked by an intense radio source named Sagittarius A* (pronounced Sagittarius A-star). The motion of material around the center indicates that Sagittarius A* harbors a massive, compact object.[95] This concentration of mass is best explained as a supermassive black hole[nb 3][14][89] (SMBH) with an estimated mass of 4.1–4.5 million times the mass of the Sun.[89] The rate of accretion of the SMBH is consistent with an inactive galactic nucleus, being estimated at around $1 \times 10^{-5} \ M_\odot \ \text{y}^{-1}$.[96] Observations indicate that there are SMBH located near the center of most normal galaxies.[97][98]

The nature of the Milky Way's bar is actively debated, with estimates for its half-length and orientation spanning from 1 to 5 kpc (3,000–16,000 ly) and 10–50 degrees relative to the line of sight from Earth to the Galactic Center.[91][92][99] Certain authors advocate that the Milky Way features two distinct bars, one nestled within the other.[100] However, RR Lyr variables do not trace a prominent Galactic bar.[92][101][102] The bar may be surrounded by a ring called the "5-kpc ring" that contains a large fraction of the molecular hydrogen present in the Milky Way, as well as most of the Milky Way's star-formation activity. Viewed from the Andromeda Galaxy, it would be the brightest feature of the Milky Way.[103] X-ray emission from the core is aligned with the massive stars surrounding the central bar[96] and the Galactic ridge.[104]
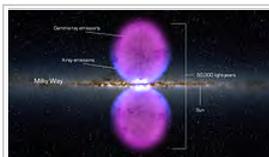
Illustration of the two gigantic X-ray/gamma-ray bubbles (blue-violet) of the Milky Way (center)

In 2010, two gigantic spherical bubbles of high energy emission were detected to the north and the south of the Milky Way core, using data from the Fermi Gamma-ray Space Telescope. The diameter of each of the bubbles is about 25,000 light-years (7.7 kpc); they stretch up to Grus and to Virgo on the night-sky of the southern hemisphere.[105][106] Subsequently, observations with the Parkes Telescope at radio frequencies identified polarized emission that is associated with the Fermi bubbles. These observations are best interpreted as a magnetized outflow driven by star formation in the central 640 ly (200 pc) of the Milky Way.[107]

Later, on January 5, 2015, NASA reported observing an X-ray flare 400 times brighter than usual, a record-breaker, from Sagittarius A*. The unusual event may have been caused by the breaking apart of an asteroid falling into the black hole or by the entanglement of magnetic field lines within gas flowing into Sagittarius A*, according to astronomers.[81]
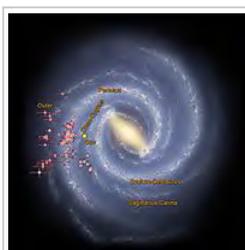
Spiral arms

Outside the gravitational influence of the Galactic bars, the structure of the interstellar medium and stars in the disk of the Milky Way is organized into four spiral arms.[108] Spiral arms typically contain a higher density of interstellar gas and dust than the Galactic average as well as a greater concentration of star formation, as traced by H II regions[109][110] and molecular clouds.[111]

The Milky Way's spiral structure is uncertain, and there is currently no consensus on the nature of the Milky Way's spiral arms.[80] Perfect logarithmic spiral patterns only crudely describe features near the Sun,[110][112] because galaxies commonly have arms that branch, merge, twist unexpectedly, and feature a degree of irregularity.[92][112][113] The possible scenario of the Sun within a spur / Local arm[110] emphasizes that point and indicates that such features are probably not unique, and exist elsewhere in the Milky Way. [112] Estimates of the pitch angle of the arms range from about 7° to 25°.[64][114] There are thought to be four spiral arms that all start near the Milky Way's center. These are named as follows, with the positions of the arms shown in the image at right:

Color	Arm(s)
cyan	3-kpc Arm (Near 3 kpc Arm and Far 3 kpc Arm) and Perseus Arm
purple	Norma and Outer arm (Along with extension discovered in 2004[115])
green	Scutum–Centaurus Arm
pink	Carina–Sagittarius Arm
There are at least two smaller arms or spurs, including:	
orange	Orion–Cygnus Arm (which contains the Sun and Solar System)

Two spiral arms, the Scutum–Centaurus arm and the Carina–Sagittarius arm, have tangent points inside the Sun's orbit about the center of the Milky Way. If these arms contain an overdensity of stars compared to the average density of stars in the Galactic disk, it would be detectable by counting the stars near the tangent point. Two surveys of near-infrared light, which is sensitive primarily to red giants and not affected by dust extinction, detected the predicted overabundance in the Scutum–Centaurus arm but not in the Carina–Sagittarius arm: the Scutum-Centaurus Arm contains approximately 30% more red giants than would be expected in the absence of a spiral arm.[114][116] This observation suggests that the Milky Way possesses only two major stellar arms: the Perseus arm and the Scutum–Centaurus arm. The rest of the arms contain excess gas but not excess old stars.[80] In December 2013, astronomers found that the distribution of young stars and star-forming regions matches the four-arm spiral description of the Milky Way.[117][118][119] Thus, the Milky Way appears to have two spiral arms as traced by old stars and four spiral arms as traced by gas and young stars. The explanation for this apparent discrepancy is unclear.[119]

Clusters detected by WISE used to trace the Milky Way's spiral arms

The Near 3 kpc Arm (also called Expanding 3 kpc Arm or simply 3 kpc Arm) was discovered in the 1950s by astronomer van Woerden and collaborators through 21-centimeter radio measurements of HI (atomic hydrogen).[120][121] It was found to be expanding away from the central bulge at more than 50 km/s. It is located in the fourth galactic quadrant at a distance of about 5.2 kpc from the Sun and 3.3 kpc from the Galactic Center. The Far 3 kpc Arm was discovered in 2008 by astronomer Tom Dame (Harvard-Smithsonian CfA). It is located in the first galactic quadrant at a distance of 3 kpc (about 10,000 ly) from the Galactic Center.[121][122]

A simulation published in 2011 suggested that the Milky Way may have obtained its spiral arm structure as a result of repeated collisions with the Sagittarius Dwarf Elliptical Galaxy.[123]

It has been suggested that the Milky Way contains two different spiral patterns: an inner one, formed by the Sagittarius arm, that rotates fast and an outer one, formed by the Carina and Perseus arms, whose rotation velocity is slower and whose arms are tightly wound. In this scenario, suggested by numerical simulations of the dynamics of the different spiral arms, the outer pattern would form an outer pseudoring,[124] and the two patterns would be connected by the Cygnus arm.[125]

Outside of the major spiral arms is the Monoceros Ring (or Outer Ring), a ring of gas and stars torn from other galaxies billions of years ago. However, several members of the scientific community recently restated their position affirming the Monoceros structure is nothing more than an over-density produced by the flared and warped thick disk of the Milky Way.[126]

Halo

Artist's conception of the spiral structure of the Milky Way with two major stellar arms and a bar[80]

Spitzer reveals what cannot be seen in visible light: cooler stars (blue), heated dust (reddish hue), and Sgr A* as bright white spot in the middle.

Bright X-ray flares from Sagittarius A*, location of the supermassive black hole at the center of the Milky Way.[81]

Observed (normal lines) and extrapolated (dotted lines) structure of the spiral arms. The gray lines radiating from the Sun's position (upper center) list the three-letter abbreviations of the corresponding constellations.

The long filamentary molecular cloud dubbed "Nessie" likely forms a dense "spine" of the Scutum–Centarus Arm

The Galactic disk is surrounded by a spheroidal halo of old stars and globular clusters, of which 90% lie within 100,000 light-years (30 kpc) of the Galactic Center.[127] However, a few globular clusters have been found farther, such as PAL 4 and AM1 at more than 200,000 light-years from the Galactic Center. About 40% of the Milky Way's clusters are on retrograde orbits, which means they move in the opposite direction from the Milky Way rotation.[128] The globular clusters can follow rosette orbits about the Milky Way, in contrast to the elliptical orbit of a planet around a star.[129]

Although the disk contains dust that obscures the view in some wavelengths, the halo component does not. Active star formation takes place in the disk (especially in the spiral arms, which represent areas of high density), but does not take place in the halo, as there is little gas cool enough to collapse into stars.[15] Open clusters are also located primarily in the disk.[130]

Discoveries in the early 21st century have added dimension to the knowledge of the Milky Way's structure. With the discovery that the disk of the Andromeda Galaxy (M31) extends much further than previously thought,[131] the possibility of the disk of the Milky Way extending further is apparent, and this is supported by evidence from the discovery of the Outer Arm extension of the Cygnus Arm[115][132] and of a similar extension of the Scutum-Centaurus Arm.[133] With the discovery of the Sagittarius Dwarf Elliptical Galaxy came the discovery of a ribbon of galactic debris as the polar orbit of the dwarf and its interaction with the Milky Way tears it apart. Similarly, with the discovery of the Canis Major Dwarf Galaxy, it was found that a ring of galactic debris from its interaction with the Milky Way encircles the Galactic disk.

The Sloan Digital Sky Survey of the northern sky shows a huge and diffuse structure (spread out across an area around 5,000 times the size of a full moon) within the Milky Way that does not seem to fit within current models. The collection of stars rises close to perpendicular to the plane of the spiral arms of the Milky Way. The proposed likely interpretation is that a dwarf galaxy is merging with the Milky Way. This galaxy is tentatively named the Virgo Stellar Stream and is found in the direction of Virgo about 30,000 light-years (9 kpc) away.[134]
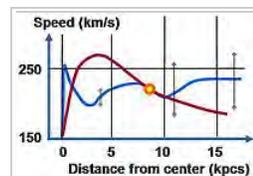
Gaseous halo

In addition to the stellar halo, the Chandra X-ray Observatory, XMM-Newton, and *Suzaku* have provided evidence that there is a gaseous halo with a large amount of hot gas. The halo extends for hundreds of thousand of light years, much further than the stellar halo and close to the distance of the Large and Small Magellanic Clouds. The mass of this hot halo is nearly equivalent to the mass of the Milky Way itself.[135][136][137] The temperature of this halo gas is between 1 and 2.5 million K (1.8 and 4.5 million °F).[138]

Observations of distant galaxies indicate that the Universe had about one-sixth as much baryonic (ordinary) matter as dark matter when it was just a few billion years old. However, only about half of those baryons are accounted for in the modern Universe based on observations of nearby galaxies like the Milky Way.[139] If the finding that the mass of the halo is comparable to the mass of the Milky Way is confirmed, it could be the identity of the missing baryons around the Milky Way.[139]

Sun's location and neighborhood

The Sun is near the inner rim of the Orion Arm, within the Local Fluff of the Local Bubble, and in the Gould Belt, at a distance of 8.33 ± 0.35 kiloparsecs (27,200 ± 1,100 ly) from the Galactic Center.[14][89][140] The Sun is currently 5–30 parsecs (16–98 ly) from the central plane of the Galactic disk.[141] The distance between the local arm and the next arm out, the Perseus Arm, is about 2,000 parsecs (6,500 ly).[142] The Sun, and thus the Solar System, is located in the Milky Way's galactic habitable zone.

Diagram of the Sun's location in the Milky Way. The angles represent longitudes in the galactic coordinate system.

Diagram of the stars in the Solar neighborhood

Galaxy rotation curve for the Milky Way. Vertical axis is speed of rotation about the Galactic Center. Horizontal axis is distance from the Galactic Center in kpcs. The Sun is marked with a yellow ball. The observed curve of speed of rotation is blue. The predicted curve based upon stellar mass and gas in the Milky Way is red. Scatter in observations roughly indicated by gray bars. The difference is due to dark matter. [35][143][144]

There are about 208 stars brighter than absolute magnitude 8.5 within a sphere with a radius of 15 parsecs (49 ly) from the Sun, giving a density of one star per 69 cubic parsecs, or one star per 2,360 cubic light-years (from List of nearest bright stars). On the other hand, there are 64 known stars (of any magnitude, not counting 4 brown dwarfs) within 5 parsecs (16 ly) of the Sun, giving a density of about one star per 8.2 cubic parsecs, or one per 284 cubic light-years (from List of nearest stars). This illustrates the fact that there are far more faint stars than bright stars: in the entire sky, there are about 500 stars brighter than apparent magnitude 4 but 15.5 million stars brighter than apparent magnitude 14.[145]

The apex of the Sun's way, or the solar apex, is the direction that the Sun travels through space in the Milky Way. The general direction of the Sun's Galactic motion is towards the star Vega near the constellation of Hercules, at an angle of roughly 60 sky degrees to the direction of the Galactic Center. The Sun's orbit about the Milky Way is expected to be roughly elliptical with the addition of perturbations due to the Galactic spiral arms and non-uniform mass distributions. In addition, the Sun oscillates up and down relative to the Galactic plane approximately 2.7 times per orbit. This is very similar to how a simple harmonic oscillator works with no drag force (damping) term. These oscillations were until recently thought to coincide with mass lifeform extinction periods on Earth.[146] However, a reanalysis of the effects of the Sun's transit through the spiral structure based on CO data has failed to find a correlation.[147]

It takes the Solar System about 240 million years to complete one orbit of the Milky Way (a galactic year),[15] so the Sun is thought to have completed 18–20 orbits during its lifetime and 1/1250 of a revolution since the origin of humans. The orbital speed of the Solar System about the center of the Milky Way is approximately 220 km/s (490,000 mph) or 0.073% of the speed of light. The Sun moves through the heliosphere at 84,000 km/h (52,000 mph). At this speed, it takes around 1,400 years for the Solar System to travel a distance of 1 light-year, or 8 days to travel 1 AU (astronomical unit).[148] The Solar System is headed in the direction of the zodiacal constellation Scorpius, which follows the ecliptic.[149]

Galactic rotation

The stars and gas in the Milky Way rotate about its center differentially, meaning that the rotation period varies with location. As is typical for spiral galaxies, the orbital speed of most stars in the Milky Way does not depend strongly on their distance from the center. Away from the central bulge or outer rim, the typical stellar orbital speed is between 210 and 240 km/s (470,000 and 540,000 mph).[150] Hence the orbital period of the typical star is directly proportional only to the length of the path traveled. This is unlike the situation within the Solar System, where two-body gravitational dynamics dominate, and different orbits have significantly different velocities associated with them. The rotation curve (shown in the figure) describes this rotation. Toward the center of the Milky Way the orbit speeds are too low, whereas beyond 7 kpcs the speeds are too high to match what would be expected from the universal law of gravitation.
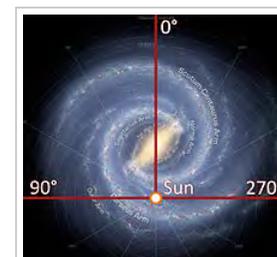
If the Milky Way contained only the mass observed in stars, gas, and other baryonic (ordinary) matter, the rotation speed would decrease with distance from the center. However, the observed curve is relatively flat, indicating that there is additional mass that cannot be detected directly with electromagnetic radiation. This inconsistency is attributed to dark matter.[35] The rotation curve of the Milky Way agrees with the universal rotation curve of spiral galaxies, the best evidence for the existence of dark matter in galaxies. Alternatively, a minority of astronomers propose that a modification of the law of gravity may explain the observed rotation curve.[151]

Formation

The Milky Way began as one or several small overdensities in the mass distribution in the Universe shortly after the Big Bang. Some of these overdensities were the seeds of globular clusters in which the oldest remaining stars in what is now the Milky Way formed. These stars and clusters now comprise the stellar halo of the Milky Way. Within a few billion years of the birth of the first stars, the mass of the Milky Way was large enough so that it was spinning relatively quickly. Due to conservation of angular momentum, this led the gaseous interstellar medium to collapse from a roughly spheroidal shape to a disk. Therefore, later generations of stars formed in this spiral disk. Most younger stars, including the Sun, are observed to be in the disk.[152][153]

Since the first stars began to form, the Milky Way has grown through both galaxy mergers (particularly early in the Milky Way's growth) and accretion of gas directly from the Galactic halo.[153] The Milky Way is currently accreting material from two of its nearest satellite galaxies, the Large and Small Magellanic Clouds, through the Magellanic Stream. Direct accretion of gas is observed in high-velocity clouds like the Smith Cloud.[154][155] However, properties of the Milky Way such as stellar mass, angular momentum, and metallicity in its outermost regions suggest it has undergone no mergers with large galaxies in the last 10 billion years. This lack of recent major mergers is unusual among similar spiral galaxies; its neighbour the Andromeda Galaxy appears to have a more typical history shaped by more recent mergers with relatively large galaxies.[156][157]

According to recent studies, the Milky Way as well as the Andromeda Galaxy lie in what in the galaxy color–magnitude diagram is known as the "green valley", a region populated by galaxies in transition from the "blue cloud" (galaxies actively forming new stars) to the "red sequence" (galaxies that lack star formation). Star-formation activity in green valley galaxies is slowing as they run out of star-forming gas in the interstellar medium. In simulated galaxies with similar properties, star formation will typically have been extinguished within about five billion years from now, even accounting for the expected, short-term increase in the rate of star formation due to the collision between both the Milky Way and the Andromeda Galaxy.[158] In fact, measurements of other galaxies similar to the Milky Way suggest it is among the reddest and brightest spiral galaxies that are still forming new stars and it is just slightly bluer than the bluest red sequence galaxies.[159]

Age and cosmological history

Night sky from a hypothetical planet within the Milky Way 10 billion years ago.[160]

Globular clusters are among the oldest objects in the Milky Way, which thus set a lower limit on the age of the Milky Way. The ages of individual stars in the Milky Way can be estimated by measuring the abundance of long-lived radioactive elements such as thorium-232 and uranium-238, then comparing the results to estimates of their original abundance, a technique called nucleocosmochronology. These yield values of about 12.5 ± 3 billion years for CS 31082-001[161] and 13.8 ± 4 billion years for BD +17° 3248.[162] Once a white dwarf is formed, it begins to undergo radiative cooling and the surface temperature steadily drops. By measuring the temperatures of the coolest of these white dwarfs and comparing them to their expected initial temperature, an age estimate can be made. With this technique, the age of the globular cluster M4 was estimated as 12.7 ± 0.7 billion years. Age estimates of the oldest of these clusters gives a best fit estimate of 12.6 billion years, and a 95% confidence upper limit of 16 billion years.[163]
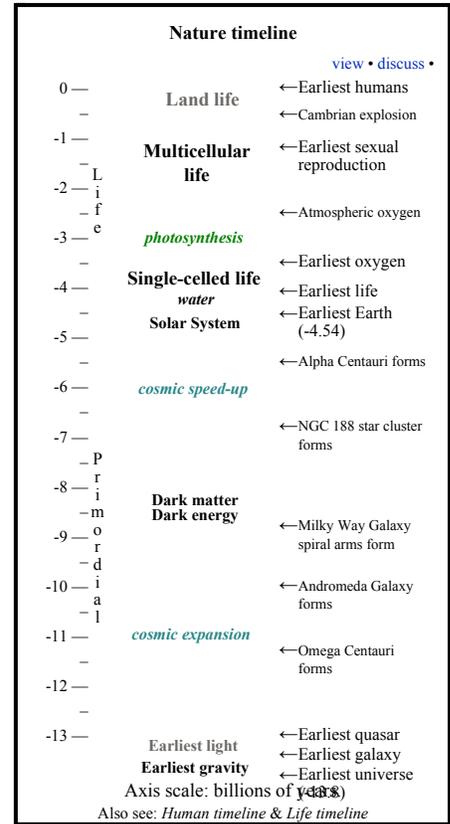
Several individual stars have been found in the Milky Way's halo with measured ages very close to the 13.80-billion-year age of the Universe. In 2007, a star in the galactic halo, HE 1523-0901, was estimated to be about 13.2 billion years old. As the oldest known object in the Milky Way at that time, this measurement placed a lower limit on the age of the Milky Way.[164] This estimate was made using the UV-Visual Echelle Spectrograph of the Very Large Telescope to measure the relative strengths of spectral lines caused by the presence of thorium and other elements created by the R-process. The line strengths yield abundances of different elemental isotopes, from which an estimate of the age of the star can be derived using nucleocosmochronology.[164] Another star, HD 140283, is 14.5 ± 0.7 billion years old and thus formed at least 13.8 billion years ago.[9][165]

The age of stars in the galactic thin disk has also been estimated using nucleocosmochronology. Measurements of thin disk stars yield an estimate that the thin disk formed 8.8 ± 1.7 billion years ago. These measurements suggest there was a hiatus of almost 5 billion years between the formation of the galactic halo and the thin disk.[166] Recent analysis of the chemical signatures of thousands of stars suggests that stellar formation might have dropped by an order of magnitude at the time of disk formation, 10 to 8 billion years ago, when interstellar gas was too hot to form new stars at the same rate as before.[167]

The satellite galaxies surrounding the Milky way are not randomly distributed, but seemed to be the result of a break-up of some larger system producing a ring structure 500,000 light years in diameter and 50,000 light years wide.[168] Close encounters between galaxies, like that expected in 4 billion years with the Andromeda Galaxy rips off huge tails of gas, which, over time can coalesce to form dwarf galaxies in a ring at right angles to the main disc.[169]

Environment

The Milky Way and the Andromeda Galaxy are a binary system of giant spiral galaxies belonging to a group of 50 closely bound galaxies known as the Local Group, surrounded by a Local Void, itself being part of the Virgo Supercluster. Surrounding the Virgo Supercluster are a number of voids, devoid of many galaxies, the Microscopium Void to the "north", the Sculptor Void to the "left", the Bootes Void to the "right" and the Canes-Major Void to the South. These voids change shape over time creating filamentous structures of galaxies. The Virgo Supercluster for instance is being drawn towards the Great Attractor,[170] which in turn forms part of a greater structure, called Laniakea.[171]

Nature timeline

view • discuss •

0 —	Land life	←Earliest humans
–		←Cambrian explosion
-1 —	Multicellular life	←Earliest sexual reproduction
– L i		
-2 — f e		←Atmospheric oxygen
–	*photosynthesis*	
-3 —		←Earliest oxygen
–	Single-celled life	←Earliest life
-4 —	*water*	←Earliest Earth (-4.54)
–	Solar System	
-5 —		←Alpha Centauri forms
–		
-6 —	*cosmic speed-up*	
–		←NGC 188 star cluster forms
-7 — P		
– r i		
-8 — m o	Dark matter Dark energy	
-9 — r d		←Milky Way Galaxy spiral arms form
– i a		
-10 — l		←Andromeda Galaxy forms
-11 —	*cosmic expansion*	←Omega Centauri forms
–		
-12 —		
–		
-13 —	Earliest light	←Earliest quasar ←Earliest galaxy
	Earliest gravity	←Earliest universe

Axis scale: billions of years)
Also see: *Human timeline* & *Life timeline*

Two smaller galaxies and a number of dwarf galaxies in the Local Group orbit the Milky Way. The largest of these is the Large Magellanic Cloud with a diameter of 14,000 light-years. It has a close companion, the Small Magellanic Cloud. The Magellanic Stream is a stream of neutral hydrogen gas extending from these two small galaxies across 100° of the sky. The stream is thought to have been dragged from the Magellanic Clouds in tidal interactions with the Milky Way.[172] Some of the dwarf galaxies orbiting the Milky Way are Canis Major Dwarf (the closest), Sagittarius Dwarf Elliptical Galaxy, Ursa Minor Dwarf, Sculptor Dwarf, Sextans Dwarf, Fornax Dwarf, and Leo I Dwarf. The smallest dwarf galaxies of the Milky Way are only 500 light-years in diameter. These include Carina Dwarf, Draco Dwarf, and Leo II Dwarf. There may still be undetected dwarf galaxies that are dynamically bound to the Milky Way, which is supported by the detection of nine new satellites of the Milky Way in a relatively small patch of the night sky in 2015.[173] There are also some dwarf galaxies that have already been absorbed by the Milky Way, such as Omega Centauri.[174]

Diagram of the galaxies in the Local Group relative to the Milky Way

In 2014 researchers reported that most satellite galaxies of the Milky Way actually lie in a huge disk, with almost all satellite galaxies moving in the same direction within this disk.[175] This came as a surprise: according to standard cosmology, the galaxies should form in halos of dark matter, be widely distributed and should move in random directions. This discrepancy is still not fully explained.[176]

In January 2006, researchers reported that the heretofore unexplained warp in the disk of the Milky Way has now been mapped and found to be a ripple or vibration set up by the Large and Small Magellanic Clouds as they orbit the Milky Way, causing vibrations when they pass through its edges. Previously, these two galaxies, at around 2% of the mass of the Milky Way, were considered too small to influence the Milky Way. However, in a computer model, the movement of these two galaxies creates a dark matter wake that amplifies their influence on the larger Milky Way.[177]

The position of the Local Group within the Virgo Supercluster

Current measurements suggest the Andromeda Galaxy is approaching us at 100 to 140 km/s (220,000 to 310,000 mph). In 3 to 4 billion years, there may be an Andromeda–Milky Way collision, depending on the importance of unknown lateral components to the galaxies' relative motion. If they collide, the chance of individual stars colliding with each other is extremely low, but instead the two galaxies will merge to form a single elliptical galaxy or perhaps a large disk galaxy[178] over the course of about a billion years.[179]

Velocity

Although special relativity states that there is no "preferred" inertial frame of reference in space with which to compare the Milky Way, the Milky Way does have a velocity with respect to cosmological frames of reference.

One such frame of reference is the Hubble flow, the apparent motions of galaxy clusters due to the expansion of space. Individual galaxies, including the Milky Way, have peculiar velocities relative to the average flow. Thus, to compare the Milky Way to the Hubble flow, one must consider a volume large enough so that the expansion of the Universe dominates over local, random motions. A large enough volume means that the mean motion of galaxies within this volume is equal to the Hubble flow. Astronomers believe the Milky Way is moving at approximately 630 km/s (1,400,000 mph) with respect to this local co-moving frame of reference.[180] The Milky Way is moving in the general direction of the Great Attractor and other galaxy clusters, including the Shapley supercluster, behind it.[181] The Local Group (a cluster of gravitationally bound galaxies containing, among others, the Milky Way and the Andromeda Galaxy) is part of a supercluster called the Local Supercluster, centered near the Virgo Cluster: although they are moving away from each other at 967 km/s (2,160,000 mph) as part of the Hubble flow, this velocity is less than would be expected given the 16.8 million pc distance due to the gravitational attraction between the Local Group and the Virgo Cluster.[182]

Another reference frame is provided by the cosmic microwave background (CMB). The Milky Way is moving at 552 ± 6 km/s (1,235,000 ± 13,000 mph)[17] with respect to the photons of the CMB, toward 10.5 right ascension, −24° declination (J2000 epoch, near the center of Hydra). This motion is observed by satellites such as the Cosmic Background Explorer (COBE) and the Wilkinson Microwave Anisotropy Probe (WMAP) as a dipole contribution to the CMB, as photons in equilibrium in the CMB frame get blue-shifted in the direction of the motion and red-shifted in the opposite direction.[17]

Etymology and mythology

In Babylonia, the Milky Way was said to be the tail of Tiamat, set in the sky by Marduk after he had slain the salt water goddess. It is believed this account, from the Enuma Elish had Marduk replace an earlier Sumerian story when Enlil of Nippur had slain the goddess.

In western culture the name "Milky Way" is derived from its appearance as a dim un-resolved "milky" glowing band arching across the night sky. The term is a translation of the Classical Latin *via lactea*, in turn derived from the Hellenistic Greek γαλαξίας, short for γαλαξίας κύκλος (*galaxías kýklos*, "milky circle"). The Ancient Greek γαλαξίας (*galaxias*) – from root γαλακτ-, γάλα ("milk") + -ίας (forming adjectives) – is also the root of "galaxy", the name for our, and later all such, collections of stars.[22][183][184][185] In Greek mythology it was supposedly made from the forceful suckling of Heracles, when Hera acted as a wetnurse for the hero.

The Milky Way, or "milk circle", was just one of 11 "circles" the Greeks identified in the sky, others being the zodiac, the meridian, the horizon, the equator, the tropics of Cancer and Capricorn, Arctic and Antarctic circles, and two colure circles passing through both poles.[186]
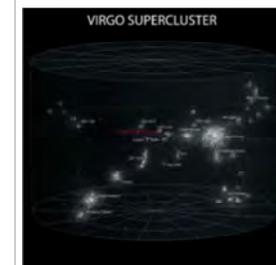
Astronomical history

In *Meteorologica* (DK 59 A80), Aristotle (384–322 BC) wrote that the Greek philosophers Anaxagoras (c. 500–428 BC) and Democritus (460–370 BC) proposed that the Milky Way might consist of distant stars.[187] However, Aristotle himself believed the Milky Way to be caused by "the ignition of the fiery exhalation of some stars which were large, numerous and close together"[188] and that the "ignition takes place in the upper part of the atmosphere, in the region of the world which is continuous with the heavenly motions."[189][190] The Neoplatonist philosopher Olympiodorus the Younger (c. 495–570 A.D.) criticized this view, arguing that if the Milky Way were sublunary, it should appear different at different times and places on Earth, and that it should have parallax, which it does not. In his view, the Milky Way is celestial. This idea would be influential later in the Islamic world.[191]

The shape of the Milky Way as deduced from star counts by William Herschel in 1785; the Solar System was assumed near center

The Persian astronomer Abū Rayhān al-Bīrūnī (973–1048) proposed that the Milky Way is "a collection of countless fragments of the nature of nebulous stars".[192] The Andalusian astronomer Avempace (d 1138) proposed the Milky Way to be made up of many stars but appears to be a continuous image due to the effect of refraction in Earth's atmosphere, citing his observation of a conjunction of Jupiter and Mars in 1106 or 1107 as evidence.[190] Ibn Qayyim Al-Jawziyya (1292–1350) proposed that the Milky Way is "a myriad of tiny stars packed together in the sphere of the fixed stars" and that these stars are larger than planets.[193]

According to Jamil Ragep, the Persian astronomer Naṣīr al-Dīn al-Ṭūsī (1201–1274) in his *Tadhkira* writes: "The Milky Way, i.e. the Galaxy, is made up of a very large number of small, tightly clustered stars, which, on account of their concentration and smallness, seem to be cloudy patches. Because of this, it was likened to milk in color."[194]

Actual proof of the Milky Way consisting of many stars came in 1610 when Galileo Galilei used a telescope to study the Milky Way and discovered that it is composed of a huge number of faint stars.[195][196] In a treatise in 1755, Immanuel Kant, drawing on earlier work by Thomas Wright,[197] speculated (correctly) that the Milky Way might be a rotating body of a huge number of stars, held together by gravitational forces akin to the Solar System but on much larger scales.[198] The resulting disk of stars would be seen as a band on the sky from our perspective inside the disk. Kant also conjectured that some of the nebulae visible in the night sky might be separate "galaxies" themselves, similar to our own. Kant referred to both the Milky Way and the "extragalactic nebulae" as "island universes", a term still current up to the 1930s.[199][200][201]

The first attempt to describe the shape of the Milky Way and the position of the Sun within it was carried out by William Herschel in 1785 by carefully counting the number of stars in different regions of the visible sky. He produced a diagram of the shape of the Milky Way with the Solar System close to the center.[202]

In 1845, Lord Rosse constructed a new telescope and was able to distinguish between elliptical and spiral-shaped nebulae. He also managed to make out individual point sources in some of these nebulae, lending credence to Kant's earlier conjecture.[203]

In 1917, Heber Curtis had observed the nova S Andromedae within the Great Andromeda Nebula (Messier object 31). Searching the photographic record, he found 11 more novae. Curtis noticed that these novae were, on average, 10 magnitudes fainter than those that occurred within the Milky Way. As a result, he was able to come up with a distance estimate of 150,000 parsecs. He became a proponent of the "island universes" hypothesis, which held that the spiral nebulae were actually independent galaxies.[204] In 1920 the Great Debate took place between Harlow Shapley and Heber Curtis, concerning the nature of the Milky Way, spiral nebulae, and the dimensions of the Universe. To support his claim that the Great Andromeda Nebula is an external galaxy, Curtis noted the appearance of dark lanes resembling the dust clouds in the Milky Way, as well as the significant Doppler shift.[205]

Photograph of the "Great Andromeda Nebula" from 1899, later identified as the Andromeda Galaxy

The controversy was conclusively settled by Edwin Hubble in the early 1920s using the Mount Wilson observatory 2.5 m (100 in) Hooker telescope. With the light-gathering power of this new telescope, he was able to produce astronomical photographs that resolved the outer parts of some spiral nebulae as collections of individual stars. He was also able to identify some Cepheid variables that he could use as a benchmark to estimate the distance to the nebulae. He found that the Andromeda Nebula is 275,000 parsecs from the Sun, far too distant to be part of the Milky Way.[26][206]

Mapping

The satellite Gaia is mapping the Milky Way with five planned releases of the maps to the year 2022.[207][208]

See also

- Baade's Window
- Oort constants
- List of galaxies

Notes

1. Jay M. Pasachoff in his textbook *Astronomy: From the Earth to the Universe* states the term *Milky Way* should refer exclusively to the band of light that the galaxy forms in the night sky, while the galaxy should receive the full name *Milky Way Galaxy*. See:
   - Pasachoff, Jay M. (1994). *Astronomy: From the Earth to the Universe*. Harcourt School. p. 500. ISBN 0-03-001667-3.

2. See also Bortle Dark-Sky Scale.
3. For a photo see: "Sagittarius A*: Milky Way monster stars in cosmic reality show". *Chandra X-ray Observatory*. Harvard-Smithsonian Center for Astrophysics. January 6, 2003. Retrieved May 20, 2012.

a. Karachentsev et al. give a *blue* absolute magnitude of −20.8. Combined with a color index of 0.55 estimated here (http://adsabs.harvard.edu/abs/2014MNRAS.440..405M), an absolute visual magnitude of −21.35 (−20.8 − 0.55 = −21.35) is obtained. Note that determining the absolute magnitude of the Milky Way is very difficult, because Earth is inside it.

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197. Thomas Wright, *An Original Theory or New Hypothesis of the Universe* … (London, England: H. Chapelle, 1750).
   - On page 57 (https://books.google.com/books?id=80VZAAAAcAAJ&pg=PA57#v=onepage&q&f=false), Wright stated that despite their mutual gravitational attraction, the stars in the constellations don't collide because they are in orbit, so centrifugal force keeps them separated: " … centrifugal force, which not only preserves them in their orbits, but prevents them from rushing all together, by the common universal law of gravity, … "
   - On page 48 (https://books.google.com/books?id=80VZAAAAcAAJ&pg=PA48#v=onepage&q&f=false), Wright stated that the form of the Milky Way is a ring: " … the stars are not infinitely dispersed and distributed in a promiscuous manner throughout all the mundane space, without order or design, … this phænomenon [is] no other than a certain effect arising from the observer's situation, … To a spectator placed in an indefinite space, … it [i.e. the Milky Way (*Via Lactea*)] [is] a vast ring of stars … "
   - On page 65 (https://books.google.com/books?id=80VZAAAAcAAJ&pg=PA65#v=onepage&q&f=false), Wright speculated that the central body of the Milky Way, around which the rest of the galaxy revolves, might not be visible to us: " ... the central body A, being supposed as *incognitum* [i.e. an unknown], without [i.e. outside of] the finite view; ... "
   - On page 73 (https://books.google.com/books?id=80VZAAAAcAAJ&pg=PA73#v=onepage&q&f=false), Wright called the Milky Way the *Vortex Magnus* (the great whirlpool) and estimated its diameter to be 8.64×10^{12} miles (13.9×10^{12} km).
   - On page 33 (https://books.google.com/books?id=80VZAAAAcAAJ&pg=PA33#v=onepage&q&f=false), Wright speculated that there are a vast number of inhabited planets in the galaxy: " … ; therefore we may justly suppose, that so many radiant bodies [i.e. stars] were not created barely to enlighten an infinite void, but to … display an infinite shapeless universe, crowded with myriads of glorious worlds, all variously revolving round them; and … with an inconceivable variety of beings and states, animate … "

198. Immanuel Kant, *Allgemeine Naturgeschichte und Theorie des Himmels* … (https://books.google.com/books?id=nCcaAQAAMAAJ&pg=PP9#v=onepage&q&f=false) [Universal Natural History and Theory of Heaven …], (Koenigsberg and Leipzig, (Germany): Johann Friederich Petersen, 1755). On pages 2–3, Kant acknowledged his debt to Thomas Wright: *"Dem Herrn Wright von Durham, einen Engeländer, war es vorbehalten, einen glücklichen Schritt zu einer Bemerkung zu thun, welche von ihm selber zu keiner gar zu tüchtigen Absicht gebraucht zu seyn scheinet, und deren nützliche Anwendung er nicht genugsam beobachtet hat. Er betrachtete die Fixsterne nicht als ein ungeordnetes und ohne Absicht zerstreutes Gewimmel, sondern er fand eine systematische Verfassung im Ganzen, und eine allgemeine Beziehung dieser Gestirne gegen einen Hauptplan der Raume, die sie einnehmen."* (To Mr. Wright of Durham, an Englishman, it was reserved

to take a happy step towards an observation, which seemed, to him and to no one else, to be needed for a clever idea, the exploitation of which he hasn't studied sufficiently. He regarded the fixed stars not as a disorganized swarm that was scattered without a design; rather, he found a systematic shape in the whole, and a general relation between these stars and the principal plane of the space that they occupy.)

199. Kant (1755), pages xxxiii–xxxvi of the Preface (Vorrede): (https://books.google.com/books?id=nCcaAQAAMAAJ&pg=PP49#v=onepage&q&f=false) *"Ich betrachtete die Art neblichter Sterne, deren Herr von Maupertuis in der Abhandlung von der Figur der Gestirne gedenket, und die die Figur von mehr oder weniger offenen Ellipsen vorstellen, und versicherte mich leicht, daß sie nichts anders als eine Häufung vieler Fixsterne seyn können. Die jederzeit abgemessene Rundung dieser Figuren belehrte mich, daß hier ein unbegreiflich zahlreiches Sternenheer, und zwar um einen gemeinschaftlichen Mittelpunkt, müste geordnet seyn, weil sonst ihre freye Stellungen gegen einander, wohl irreguläre Gestalten, aber nicht abgemessene Figuren vorstellen würden. Ich sahe auch ein: daß sie in dem System, darinn sie sich vereinigt befinden, vornemlich auf eine Fläche beschränkt seyn müßten, weil sie nicht zirkelrunde, sondern elliptische Figuren abbilden, und daß sie wegen ihres blassen Lichts unbegreiflich weit von uns abstehen."* (I considered the type of nebulous stars, which Mr. de Maupertuis considered in his treatise on the shape of stars, and which present the figures of more or less open ellipses, and I readily assured myself, that they could be nothing else than a cluster of fixed stars. That these figures always measured round informed me that here an inconceivably numerous host of stars, [which were clustered] around a common center, must be orderly, because otherwise their free positions among each other would likely present irregular forms, not measurable figures. I also realized: that in the system in which they find themselves bound, they must be restricted primarily to a plane, because they display not circular, but elliptical figures, and that on account of their faint light, they are located inconceivably far from us.)

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Further reading

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- Cristina Chiappini, The Formation and Evolution of the Milky Way, American Scientist, November/December 2001, pp. 506–515 (http://www.astro.caltech.edu/~george/ay20/Chiappini-MilkyWay.pdf)

External links

- Milky Way – 3D Map (http://www.3dgalaxymap.com/#/GalaxyMap)
- Milky Way – Basic plan map (http://galaxymap.org/drupal/node/171) – Includes spiral arms and Orion spur
- Milky Way – IRAS (infrared) survey (http://www.sky-map.org/?

ra=12.0593794293245&de=-20.27239516216098&zoom=0&show_grid=1&show_constellation_lines=1&show_constellation_boundaries=1&show_const_names=0&sh – wikisky.org
- Milky Way – H-Alpha survey (http://www.sky-map.org/?ra=12.0593794293245&de=-20.27239516216098&zoom=0&show_grid=1&show_constellation_lines=1&show_constellation_boundaries=1&show_const_names=0&sh – wikisky.org
- Milky Way – MultiWavelength (http://mwmw.gsfc.nasa.gov/) – Images and VRML models (NASA)
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- Milky Way (http://messier.seds.org/more/mw.html) – SEDS Messier website
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- Milky Way Video (02:37) – VISTA IR Telescope Image (October 24, 2012) (https://www.youtube.com/watch?v=8o8rNBtaI_4)
- Milky Way Video (06:37) – in RealTime (Oregon; September 17, 2016) (http://cosmicpursuits.com/1262/real-time-view-milky-way)
- All-Sky Map (http://sci.esa.int/science-e-media/img/ec/PLANCK_FSM_03_Black_Regions_v02_extragalactic_frame_orig.jpg) – CMB radiation (Planck; one-year survey)

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