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2M1207

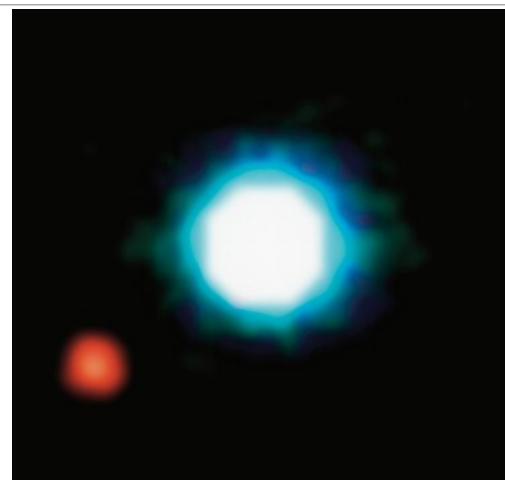
Coordinates: $12^h\ 07^m\ 33.47^s$, −39° 32′ 54.0″

2M1207, **2M1207A** or **2MASS J12073346−3932539** is a brown dwarf located in the constellation Centaurus; a companion object, 2M1207b, may be the first extrasolar planetary-mass companion to be directly imaged, and is the first discovered orbiting a brown dwarf.[5][6]

2M1207 was discovered during the course of the 2MASS infrared sky survey: hence the "2M" in its name, followed by its celestial coordinates. With a fairly early (for a brown dwarf) spectral type of M8,[1] it is very young, and probably a member of the TW Hydrae association. Its estimated mass is around 25 Jupiter masses.[4] The companion, 2M1207b, is estimated to have a mass of 5–6 Jupiter masses.[7] Still glowing red hot, it will shrink to a size slightly smaller than Jupiter as it cools over the next few billion years.

An initial photometric estimate for the distance to 2M1207 was 70 parsecs.[4] In December 2005, American astronomer Eric Mamajek reported a more accurate distance (53 ± 6 parsecs) to 2M1207 using the moving cluster method.[8] The new distance gives a fainter luminosity for 2M1207. Recent trigonometric parallax results have confirmed this moving cluster distance, leading to a distance estimate of 53 ± 1 parsec or 172 ± 3 light years.[4]

2M1207



European Southern Observatory infrared image of 2M1207 (bluish) and companion planet 2M1207b (reddish), taken in 2004.

Observation data	
Epoch J2000.0 Equinox J2000.0 (ICRS)	
Constellation	Centaurus
Right ascension	$12^h\ 07^m\ 33.47^s$[1]
Declination	−39° 32′ 54.0″[1]
Apparent magnitude (V)	20.15[2]
Characteristics	
Spectral type	M8IVe C[1]
V−R color index	+2.1[2]
R−I color index	+2.1[2]
Astrometry	
Proper motion (μ)	RA: −64.040 ± 0.087[3] mas/yr Dec.: −23.678 ± 0.072[3] mas/yr
Parallax (π)	15.4624 ± 0.1163 mas[3]
Distance	211 ± 2 ly (64.7 ± 0.5 pc)
Details	
Mass	~0.025[4] $M_\odot$

Planetary system

Like classical T Tauri stars, many brown dwarfs are surrounded by disks of gas and dust which accrete onto the brown dwarf.[9][10] 2M1207 was first suspected to have such a disk because of its broad H_α line.

This was later confirmed by ultraviolet spectroscopy.[10] The existence of a dust disk has also been confirmed by infrared observations[11] and with ALMA.[12] In general, accretion from disks are known to produce fast-moving jets, perpendicular to the disk, of ejected material.[13] This has also been observed for 2M1207; an April 2007 paper in the *Astrophysical Journal* reports that this brown dwarf is spouting jets of material from its poles.[14] The jets, which extend around 10^9 kilometers into space, were discovered using the Very Large Telescope (VLT) at the European Southern Observatory. Material in the jets streams into space at a few kilometers per second.[15]

Radius	~0.25[5] $R_\odot$
Luminosity	~0.002[5] $L_\odot$
Temperature	2550 ± 150[5] K
Age	$5 \cdot 10^6$ to $10 \cdot 10^6$[5] years
Other designations	
2MASSW J1207334−393254, 2MASS J12073346-3932539, TWA 27[1]	
Database references	
SIMBAD	data (https://simbad.cds.unistra.fr/simbad/sim-id?Ident=NAME+2M1207A)

The 2M1207A planetary system[7][12][16]

Companion (in order from star)	Mass	Semimajor axis (AU)	Orbital period (years)	Eccentricity	Inclination	Radius
circumstellar disk	9.4 ± 1.5 AU				35^{+20}_{-15}°	—
b	5–6 M_J	≥49.8 ± 1.1[17]	633-20046	0.02-0.98	13-150°	—

See also

- Lists of exoplanets
- Direct imaging of extrasolar planets

References

1. "TWA 27" (http://simbad.u-strasbg.fr/simbad/sim-basic?Ident=TWA+27). *SIMBAD*. Centre de données astronomiques de Strasbourg. Retrieved June 15, 2008.
2. An accurate distance to 2M1207Ab, C. Ducourant, R. Teixeira, G. Chauvin, G. Daigne, J.-F. Le Campion, Inseok Song, and B. Zuckerman, *Astronomy and Astrophysics* **477**, #1 (January 2008), pp. L1–L4. Bibcode:2008A&A...477L...1D (https://ui.adsabs.harvard.edu/abs/2008A&A...477L...1D/abstract) doi:10.1051/0004-6361:20078886 (https://doi.org/10.1051%2F0004-6361%3A20078886).
3. Brown, A. G. A.; et al. (Gaia collaboration) (2021). "Gaia Early Data Release 3: Summary of the contents and survey properties" (https://doi.org/10.1051%2F0004-6361%2F202039657). *Astronomy & Astrophysics*. **649**: A1. arXiv:2012.01533 (https://arxiv.org/abs/2012.01533). Bibcode:2021A&A...649A...1G (https://ui.adsabs.harvard.edu/abs/2021A&A...649A...1G). doi:10.1051/0004-6361/202039657 (https://doi.org/10.1051%2F0004-6361%2F202039657). S2CID 227254300 (https://api.semanticscholar.org/CorpusID:227254300). **(Erratum: doi:10.1051/0004-6361/202039657e (https://doi.org/10.1051%2F0004-6361%2F202039657e))**. Gaia EDR3 record for this source (http://vizier.u-strasbg.fr/viz-bin/VizieR-S?Gaia%20EDR3%203459372646830687104) at VizieR.

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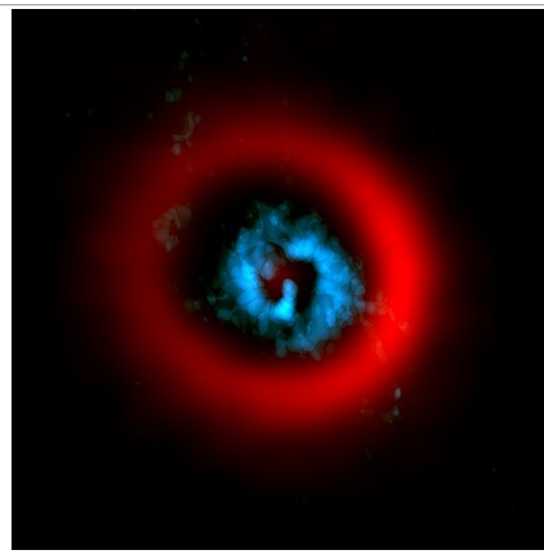
AB Aurigae

AB Aurigae is a young Herbig Ae star[3] in the Auriga constellation. It is located at a distance of approximately 531 light years from the Sun based on stellar parallax.[1] This pre-main-sequence star has a stellar classification of A0Ve,[4] matching an A-type main-sequence star with emission lines in the spectrum. It has 2.4 times the mass of the Sun and is radiating 38[8] times the Sun's luminosity from its photosphere at an effective temperature of 9,772 K.[10] The radio emission from the system suggests the presence of a thermal jet originating from the star with a velocity of 300 km s^{-1}. This is causing an estimated mass loss of $1.7 \times 10^{-8}\ M_\odot\ yr^{-1}$.[8]

This star is known for hosting a dust disk that may harbour a condensing planet or brown dwarf. The star could host a possible substellar companion in wide orbit. The star is part of the young Taurus-Auriga association,[4] which is located in the Taurus Molecular Cloud.[12] The star itself may recently have encountered a dense cloudlet, which disrupted its debris disk and produced an additional reflection nebula.[13]

AB Aurigae



ALMA image of the dust ring (red) and gaseous spirals (blue) of the circumstellar disk AB Aurigae reveal gaseous spiral arms inside a wide dust gap, providing a hint of planet formation. **Credit**: *ALMA (ESO/NAOJ/NRAO)/Tang et al.*

Observation data	
Epoch J2000	**Equinox J2000**
Constellation	Auriga
Right ascension	$04^h\ 55^m\ 45.84600^s$[1]
Declination	+30° 33′ 04.2933″[1]
Apparent magnitude (V)	7.05[2]
Characteristics	
Evolutionary stage	Pre-main-sequence[3]
Spectral type	A0Ve[4]
U−B color index	+0.04[5]
B−V color index	+0.11[5]
Variable type	INA (Herbig Ae)[3][6]
Astrometry	
Radial velocity (R_v)	+8.9 ±0.9[7] km/s
Proper motion (μ)	RA: +3.926[1] mas/yr Dec.: −24.112[1] mas/yr

Planetary system

In 2017 scientists used the Atacama Large Millimeter/submillimeter Array (ALMA) to take an image of the protoplanetary disk around AB Aurigae. The image showed a dusty disk which has a radius of about 120 astronomical units and a distinct "gap". Inside this gap gaseous spiral arms are detected in CO.[14][3]

Oppenheimer et al. (2008)[15] observed an annulus feature in AB Aurigae's dust disk between 43 and 302 AU from the star, a region never seen before. An azimuthal gap in an annulus of dust at a radius of 102 AU would suggest the formation of at least one small body at an orbital distance of nearly 100 AU. Such an object could turn out to be either a massive planetary companion or more likely a brown dwarf companion, in both cases located at nearly 100 AU from the bright star. So far the object is unconfirmed.

Observations with ALMA found two gaseous spiral arms inside the disk. These are best explained by an unseen planet with a semimajor axis of about 60–80 au. An additional planet with a semimajor axis of 30 au and with a large pitch angle compared to the disk (likely higher inclination) could explain the emptiness of the inner dusty disk.[3] The outer planet was still not detected as in 2022, putting an upper limit on is mass at 3–4 M_J, inconsistent with the spiral structures observed in the disk.[16] The planet-like clump observed in April 2022 at projected separation 93 AU from star, may be either an accretion disk around newly formed planet or the unstable disk region currently transforming into the planet.[17] The planet observation was confirmed in July 2022.[18]

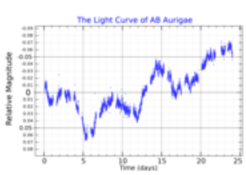
Parallax (π)	6.1400 ± 0.0571 mas[1]
Distance	531 ± 5 ly (163 ± 2 pc)
Details	
Mass	2.4 ±0.2[8] $M_\odot$
Radius	2.5[9] $R_\odot$
Luminosity	~38[8] $L_\odot$
Temperature	9,772[10] K
Age	4 ± 1[8] Myr
Other designations	
AB Aur, BD+30° 741, HD 31293, HIP 22910, SAO 57506[11]	
Database references	
SIMBAD	data (https://simbad.cds.unistra.fr/simbad/sim-id?Ident=HD+31293)

The AB Aurigae planetary system[15]

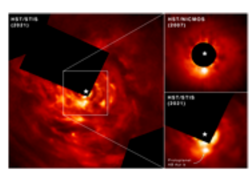
Companion (in order from star)	Mass	Semimajor axis (AU)	Orbital period (years)	Eccentricity	Inclination	Radius
protoplanetary disk	43–430[13] AU				—	—
b[17]	9–12[17] M_J	93[17]	?	0.19–0.60	27.1–58.2°	2.75 R_J

Gallery

AB Aurigae and its dust disk seen by Hubble



A light curve for AB Aurigae from *MOST* satellite data, adapted from Cody *et al.* (2013)[19]



Hubble Space Telescope images of protoplanet AB Aurigae b.

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Beta Pictoris

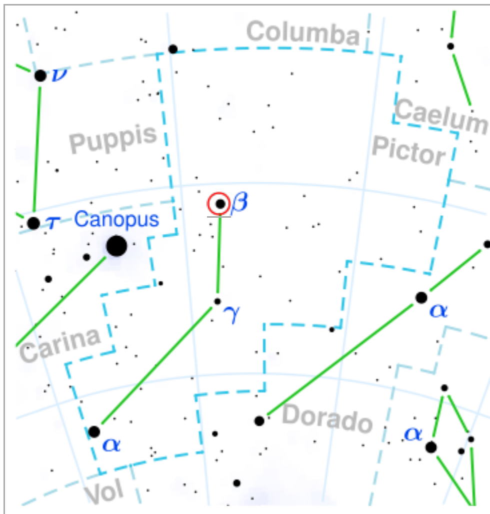
Beta Pictoris (abbreviated **β Pictoris** or **β Pic**) is the second brightest star in the constellation Pictor. It is located 63.4 light-years (19.4 pc) from the Solar System, and is 1.75 times as massive and 8.7 times as luminous as the Sun. The Beta Pictoris system is very young, only 20 to 26 million years old,[12] although it is already in the main sequence stage of its evolution.[8] Beta Pictoris is the title member of the Beta Pictoris moving group, an association of young stars which share the same motion through space and have the same age.[13]

The European Southern Observatory (ESO) has confirmed the presence of two planets, Beta Pictoris b,[14] and Beta Pictoris c,[15] through the use of direct imagery. Both planets are orbiting in the plane of the debris disk surrounding the star. Beta Pictoris c is currently the closest extrasolar planet to its star ever photographed: the observed separation is roughly the same as the distance between the asteroid belt and the Sun.[15]

Beta Pictoris shows an excess of infrared emission[16] compared to normal stars of its type, which is caused by large quantities of dust and gas (including carbon monoxide)[17][18] near the star. Detailed observations reveal a large disk of dust and gas orbiting the star, which was the first debris disk to be imaged around another star.[19] In addition to the presence of several planetesimal belts[20] and cometary activity,[21] there are indications that planets have formed within this disk and that the processes of planet formation may be ongoing.[22] Material from the Beta Pictoris debris disk is thought to be the dominant source of interstellar meteoroids in the Solar System.[23]

Location and visibility

β Pictoris



Location of β Pictoris (circled)

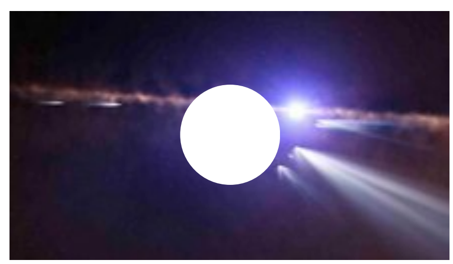
Observation data	
Epoch J2000	Equinox J2000
Constellation	Pictor
Right ascension	$05^h\ 47^m\ 17.1^s$[1]
Declination	−51° 03′ 59″[1]
Apparent magnitude (V)	3.861[1]
Characteristics	
Spectral type	A6V[2]
U−B color index	0.10[3]
B−V color index	0.17[3]
Variable type	Delta Scuti variable[4]
Astrometry	
Radial velocity (R_v)	+20.0 ± 0.7[5] km/s
Proper motion (μ)	RA: +4.65[6] mas/yr Dec.: +83.10[6] mas/yr
Parallax (π)	51.44 ± 0.12 mas[6]
Distance	63.4 ± 0.1 ly (19.44 ± 0.05 pc)
Absolute magnitude (M_V)	2.402[7]

Beta Pictoris is a star in the southern constellation of Pictor, the Easel, and is located to the west of the bright star Canopus.[24] It traditionally marked the sounding line of the ship Argo Navis, before the constellation was split.[25] The star has an apparent visual magnitude of 3.861,[1] so is visible to the naked eye under good conditions, though light pollution may result in stars dimmer than magnitude 3 being too dim to see. It is the second brightest in its constellation, exceeded only by Alpha Pictoris, which has an apparent magnitude of 3.30.[26]

Details	
Mass	1.75[8] $M_{\odot}$
Radius	1.8[9] $R_{\odot}$
Luminosity (bolometric)	8.7[8] $L_{\odot}$
Surface gravity (log *g*)	4.15[2] cgs
Temperature	8,052[2] K
Metallicity	+0.14[10]
Rotational velocity (*v* sin *i*)	130[11] km/s
Age	23 ± 3[12] Myr
Other designations	
GJ 219, HR 2020, CD −51°1620, HD 39060, GCTP 1339.00, SAO 234134, HIP 27321	
Database references	
SIMBAD	data (https://simbad.cds.unistra.fr/simbad/sim-id?Ident=bet+Pic)
ARICNS	data (https://wwwadd.zah.uni-heidelberg.de/datenbanken/aricns/cnspages/4c00467.htm)

The distance to Beta Pictoris and many other stars was measured by the Hipparcos satellite. This was done by measuring its trigonometric parallax: the slight displacement in its position observed as the Earth moves around the Sun. Beta Pictoris was found to exhibit a parallax of 51.87 milliarcseconds,[27] a value which was later revised to 51.44 milliarcseconds when the data was reanalyzed taking systematic errors more carefully into account.[6] The distance to Beta Pictoris is therefore 63.4 light years, with an uncertainty of 0.1 light years.[28][note 1]

The Hipparcos satellite also measured the proper motion of Beta Pictoris: it is traveling eastwards at a rate of 4.65 milliarcseconds per year, and northwards at a rate of 83.10 milliarcseconds per year.[6] Measurements of the Doppler shift of the star's spectrum reveals it is moving away from Earth at a rate of 20 km/s.[5] Several other stars share the same motion through space as Beta Pictoris and likely formed from the same gas cloud at roughly the same time: these comprise the Beta Pictoris moving group.[13]



This video sequence is based on an artist's impression of exocomets orbiting the star Beta Pictoris.

Physical properties

Spectrum, luminosity and variability

According to measurements made as part of the Nearby Stars Project, Beta Pictoris has a spectral type of A6V[2] and has an effective temperature of 8,052 K (7,779 °C; 14,034 °F),[2] which is hotter than the Sun's 5,778 K (5,505 °C; 9,941 °F).[29] Analysis of the spectrum reveals that the star contains a slightly higher ratio of heavy elements, which are termed metals in astronomy, to hydrogen than the Sun. This value is expressed as the quantity [M/H], the base-10 logarithm of the ratio of the star's metal fraction to that of the Sun. In the case of Beta Pictoris, the value of [M/H] is

0.05,[2] which means that the star's metal fraction is 12% greater than that of the Sun.[note 3]


Artist's impression of the planet Beta Pictoris b[note 2]

Analysis of the spectrum can also reveal the surface gravity of the star. This is usually expressed as log *g*, the base-10 logarithm of the gravitational acceleration given in CGS units, in this case, cm/s^2. Beta Pictoris has log *g*=4.15,[2] implying a surface gravity of 140 m/s^2, which is about half of the gravitational acceleration at the surface of the Sun (274 m/s^2).[29]

As an A-type main sequence star, Beta Pictoris is more luminous than the Sun: combining the apparent magnitude of 3.861 with the distance of 19.44 parsecs gives an absolute magnitude of 2.4,[7] as compared to the Sun, which has an absolute magnitude of 4.83.[29] This corresponds to a visual luminosity 9.2 times greater than that of the Sun.[note 4] When the entire spectrum of radiation from Beta Pictoris and the Sun is taken into account, Beta Pictoris is found to be 8.7 times more luminous than the Sun.[8][30]

Many main sequence stars of spectral type A fall into a region of the Hertzsprung–Russell diagram called the instability strip, which is occupied by pulsating variable stars. In 2003, photometric monitoring of the star revealed variations in brightness of around 1–2 millimagnitudes on frequencies between about 30 and 40 minutes.[4] Radial velocity studies of Beta Pictoris also reveal variability: there are pulsations at two frequencies, one at 30.4 minutes and one at 36.9 minutes.[31] As a result, the star is classified as a Delta Scuti variable.

Mass, radius and rotation

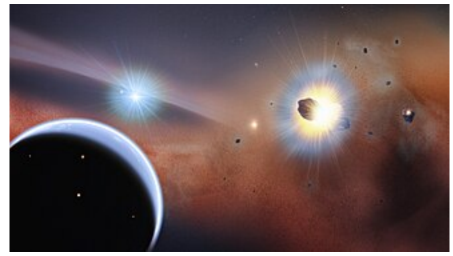
The mass of Beta Pictoris has been determined by using models of stellar evolution and fitting them to the star's observed properties. This method yields a stellar mass between 1.7 and 1.8 solar masses.[8] The star's angular diameter has been measured using interferometry with the Very Large Telescope and was found to be 0.84 milliarcseconds.[9] Combining this value with the distance of 63.4 light years gives a radius 1.8 times that of the Sun.[note 5]

The rotational velocity of Beta Pictoris has been measured to be at least 130 km/s.[11] Since this value is derived by measuring radial velocities, this is a lower limit on the true rotational velocity: the quantity measured is actually $v \sin(i)$, where i represents the inclination of the star's axis of rotation to the line-of-sight. If it is assumed that Beta Pictoris is viewed from Earth in its equatorial plane, a reasonable assumption since the circumstellar disk is seen edge-on, the rotation period can be calculated as approximately 16 hours, which is significantly shorter than that of the Sun (609.12 hours[29]).[note 6]

Age and formation

The presence of significant amounts of dust around the star[32] implies a young age of the system and led to debate about whether it had joined the main sequence or was still a pre–main sequence star[33] However, when the star's distance was measured by Hipparcos it was revealed that Beta Pictoris was located further away than previously thought and hence was more luminous than originally believed. Once the Hipparcos results were taken into account, it was found that Beta

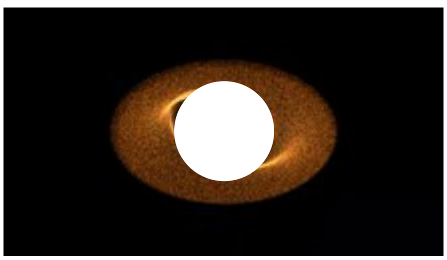
Pictoris was located close to the zero age main sequence and was not a pre–main sequence star after all.[8] Analysis of Beta Pictoris and other stars within the Beta Pictoris moving group suggested that they are around 12 million years old.[13] However more recent studies indicate that the age is roughly double this at 20 to 26 million years old.[34][12]



Artist's impression of Beta Pictoris[note 7]

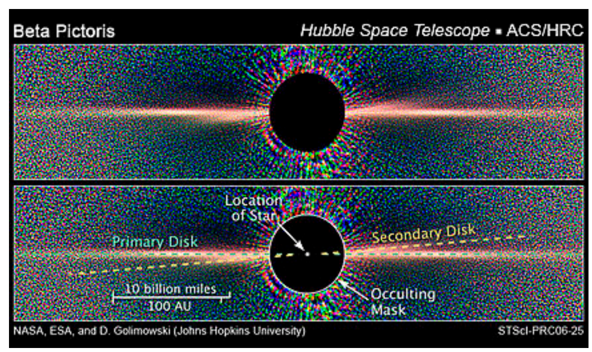
Beta Pictoris may have been formed near the Scorpius–Centaurus association.[35] The collapse of the gas cloud which resulted in the formation of Beta Pictoris may have been triggered by the shock wave from a supernova explosion: the star which went supernova may have been a former companion of HD 83058, which is now a runaway star. Tracing the path of HIP 46950 backwards suggests that it would have been in the vicinity of the Scorpius–Centaurus association about 13 million years ago.[35] However, HD 83058 has been found to be a spectroscopic binary and unlikely to have been ejected by the supernova explosion of a close companion, so the simple explanation for the origin of the Beta Pictoris cluster is in doubt.[36]

Circumstellar environment



Erika Nesvold and Marc Kuchner discuss their supercomputer simulation of how the Beta Pictoris b planet sculpts the Beta Pictoris debris disk into a warped spiral shape.

Debris disks

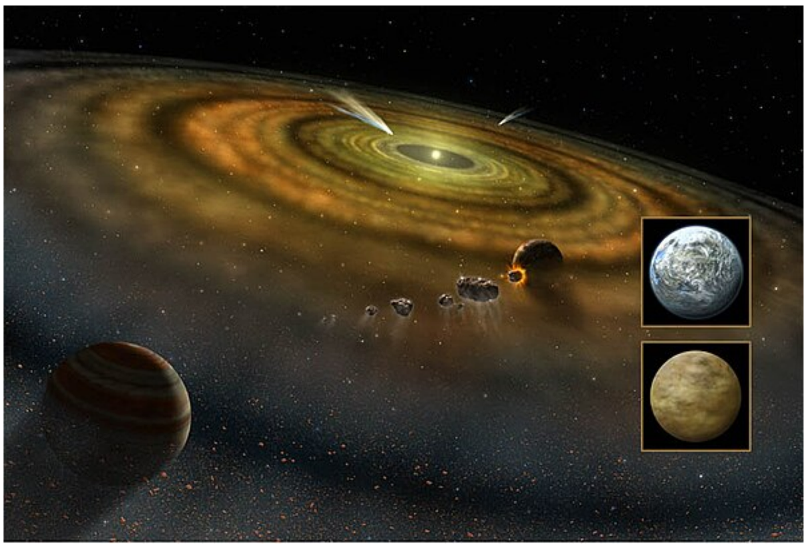


Hubble Space Telescope image of the main and secondary debris disks

Excess infrared radiation from Beta Pictoris was detected by the IRAS[37] spacecraft in 1983.[32] Along with Vega, Fomalhaut and Epsilon Eridani, it was one of the first four stars from which such an excess was detected: these stars are called "Vega-like" after the first such star discovered. Since A-type stars like Beta Pictoris tend to radiate most of their energy at the blue end of the spectrum,[note 8] this implied the presence of cool matter in orbit around the star, which would radiate at infrared wavelengths and produce the excess.[32] This hypothesis was verified in 1984 when Beta Pictoris became the first star to have its circumstellar disk imaged optically.[19] The IRAS data are (at the micron wavelengths): [12]=2.68, [25]=0.05, [60]=−2.74 and [100]=−3.41. The colour excesses are: E12=0.69, E25=3.35, E60=6.17 and E100=6.90.[16]

The debris disk around Beta Pictoris is seen edge-on by observers on Earth, and is orientated in a northeast-southwest direction. The disk is asymmetric: in the northeast direction it has been observed out to 1835 astronomical units from the star, while the southwest direction the extent is 1450 AU.[38] The disk is rotating: the part to the northeast of the star is moving away from Earth, while the part to the southwest of the disc is moving towards Earth.[39]

Several elliptical rings of material have been observed in the outer regions of the debris disk between 500 and 800 AU: these may have formed as a result of the system being disrupted by a passing star.[40] Astrometric data from the Hipparcos mission reveal that the red giant star Beta Columbae passed within 2 light years of Beta Pictoris about 110,000 years ago, but a larger perturbation would have been caused by Zeta Doradus, which passed at a distance of 3 light years about 350,000 years ago.[41] However computer simulations favor a lower encounter velocity than either of these two candidates, which suggest that the star responsible for the rings may have been a companion star of Beta Pictoris on an unstable orbit. The simulations suggest a perturbing star with a mass of 0.5 solar masses is likely to blame for the structures. Such a star would be a red dwarf of spectral type M0V.[38][42]



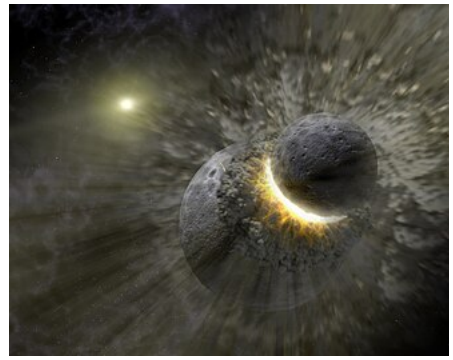
Various planet formation processes, including exocomets and other planetesimals, around *Beta Pictoris*, a very young type A V star (NASA artist's conception)

In 2006, imaging of the system with the Hubble Space Telescope's Advanced Camera for Surveys revealed the presence of a secondary dust disk inclined at an angle of about 5° to the main disk and extending at least 130 AU from the star.[43] The secondary disk is asymmetrical: the southwest extension is more curved and less inclined than the northeast. The imaging was not good enough to distinguish between the main and secondary disks within 80 AU of Beta Pictoris, however the northeast extension of the dust disk is predicted to intersect with the main disk at about 30 AU from the star.[43] The secondary disk may be produced by a massive planet in an inclined orbit removing matter from the primary disk and causing it to move in an orbit aligned with the planet.[44]

Studies made with the NASA Far Ultraviolet Spectroscopic Explorer have discovered that the disk around Beta Pictoris contains an extreme overabundance of carbon-rich gas.[45] This helps stabilize the disk against radiation pressure which would otherwise blow the material away into interstellar space.[45] Currently, there are two suggested explanations for the origin of the carbon overabundance. Beta Pictoris might be in the process of forming exotic carbon-rich planets, in contrast to the terrestrial planets in the Solar System, which are rich in oxygen instead of carbon.[46] Alternatively it may be passing through an unknown phase that might also have occurred early in the development of the Solar System: in the Solar System there are carbon-rich meteorites known as enstatite chondrites, which may have formed in a carbon-rich environment. It has also been proposed that Jupiter may have formed around a carbon-rich core.[46]

In 2011 the disk around Beta Pictoris became the first other planetary system to be photographed by an amateur astronomer. Rolf Olsen of New Zealand captured the disk with a 10-inch Newtonian reflector and a modified webcam.[47]

Planetesimal belts


The dust around Beta Pictoris may be produced by the collisions of large planetesimals.

In 2003, imaging of the inner region of the Beta Pictoris system with the Keck II telescope revealed the presence of several features which are interpreted as being belts or rings of material. Belts at approximately 14, 28, 52 and 82 astronomical units from the star were detected, which alternate in inclination with respect to the main disk.[20]

Observations in 2004 revealed the presence of an inner belt containing silicate material at a distance of 6.4 AU from the star. Silicate material was also detected at 16 and 30 AU from the star, with a lack of dust between 6.4 and 16 AU providing evidence that a massive planet may be orbiting in this region.[48][49] Magnesium-rich olivine has also been detected, strikingly similar to that found in the Solar System comets and different from the olivine found in Solar System asteroids.[50] Olivine crystals can only form closer than 10 AU from the star; therefore they have been transported to the belt after formation, probably by radial mixing.[50]

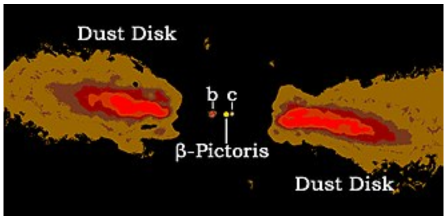
Modeling of the dust disk at 100 AU from the star suggests the dust in this region may have been produced by a series of collisions initiated by the destruction of planetesimals with radii of about 180 kilometers. After the initial collision, the debris undergoes further collisions in a process called a collisional cascade. Similar processes have been inferred in the debris disks around Fomalhaut and AU Microscopii.[51]

Falling evaporating bodies

The spectrum of Beta Pictoris shows strong short-term variability that was first noticed in the red-shifted part of various absorption lines, which was interpreted as being caused by material falling onto the star.[52] The source of this material was suggested to be small comet-like objects on orbits which take them close to the star where they begin to evaporate, termed the "falling evaporating bodies" model.[21] Transient blue-shifted absorption events were also detected, though less frequently: these may represent a second group of objects on a different set of orbits.[53] Detailed modeling indicates the falling evaporating bodies are unlikely to be mainly icy like comets, but instead are probably composed of a mixed dust and ice core with a crust of refractory material.[54] These objects may have been perturbed onto their star-grazing orbits by the gravitational influence of a planet in a mildly eccentric orbit around Beta Pictoris at a distance of roughly 10 AU from the star.[55] Falling evaporating bodies may also be responsible for the presence of gas located high above the plane of the main debris disk.[56] A study from 2019 reported transiting exocomets with TESS. The dips are asymmetric in nature and are consistent with models of evaporating comets crossing the disc of the star. The comets are in a highly eccentric orbit and are non-periodic.[57]

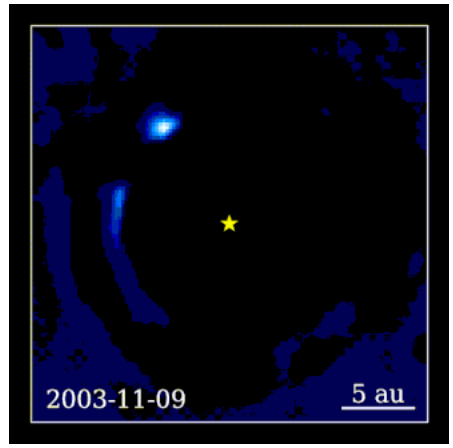
Planetary system

On November 21, 2008, it was announced that infrared observations made in 2003 with the Very Large Telescope had revealed a candidate planetary companion to the star.[58] In the autumn of



Artistic rendering of the Beta Pictoris system, showing accretion disk and Beta Pictoris b and Beta Pictoris c.

2009 the planet was successfully observed on the other side of the parent star, confirming the existence of the planet itself and earlier observations. It is believed that in 15 years (As of 2009) it will be possible to record the whole orbit of the planet.[14]



The motion of Beta Pictoris b. The orbital plane is viewed side-on; the planet is not moving towards the star.

The European Southern Observatory confirmed the presence of Beta Pictoris c, on 6 October 2020, through the use of direct imagery. Beta Pictoris c is orbiting in the plane of the debris disk surrounding the star. Beta Pictoris c is currently the closest extrasolar planet to its star ever photographed: the observed separation is roughly the same as the distance between the asteroid belt and the Sun.[15][59]

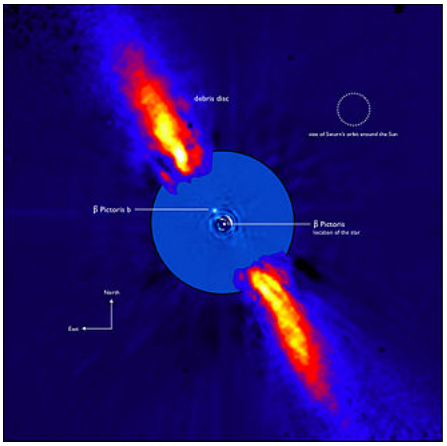
The Beta Pictoris planetary system[60][61]

Companion (in order from star)	Mass	Semimajor axis (AU)	Orbital period (years)	Eccentricity	Inclination	Radius
c	$10.139^{+1.175}_{-1.031}$ M_J	$2.680^{+0.016}_{-0.015}$	$3.266^{+0.015}_{-0.012}$	$0.314^{+0.024}_{-0.034}$	$88.947^{+0.083}_{-0.091}$°	—
Inner belt	6.4 AU				~89°	—
b	$11.729^{+2.337}_{-2.135}$ M_J	$10.018^{+0.082}_{-0.076}$	$23.593^{+0.248}_{-0.209}$	$0.106^{+0.007}_{-0.006}$	89.009 ± 0.012°	1.46 ± 0.01 R_J
secondary disk	130+ AU				89 ± 1°	—
main disk	16–1450/1835 AU				89 ± 1°	—

The radial velocity method is not well suited to study A-type stars like Beta Pictoris. The very young age of the star makes the noise even worse. Current limits derived from this method are enough to rule out hot Jupiter-type planets more massive than 2 Jupiter masses at a distance of less than 0.05 AU from the star. For planets orbiting at 1 AU, planets with less than 9 Jupiter masses would have evaded detection.[22][31] Therefore, to find planets in the Beta Pictoris system, astronomers look for the effects that the planet has on the circumstellar environment.

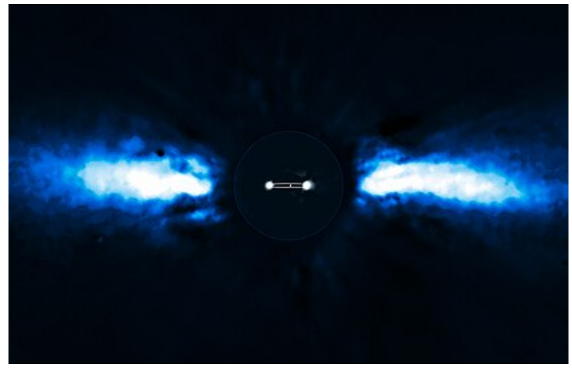
Multiple lines of evidence suggested the existence of a massive planet orbiting in the region around 10 AU from the star: the dust-free gap between the planetesimal belts at 6.4 AU and 16 AU suggest this region is being cleared out;[49] a planet at this distance would explain the origin of the falling evaporating bodies,[55] and the warps and inclined rings in the inner disk suggest a massive planet on an inclined orbit is disrupting the disk.[44][62]

The observed planet by itself cannot explain the structure of the planetesimal belts at 30 AU and 52 AU from the star. These belts might be associated with smaller planets at 25 and 44 AU, with around 0.5 and 0.1 Jupiter masses respectively.[22] Such a system of planets, if it exists, would be



ESO image of a planet near Beta Pictoris

close to a 1:3:7 orbital resonance. It may also be that the rings in the outer disc at 500–800 AU are indirectly caused by the influence of these planets.[22]


Beta Pictoris b in both elongations

The object was observed at an angular distance of 411 milliarcseconds from Beta Pictoris, which corresponds to a distance in the plane of the sky of 8 AU. For comparison, the orbital radii of the planets Jupiter and Saturn are 5.2 AU[63] and 9.5 AU[64] respectively. The separation in the radial direction is unknown, so this is a lower limit on the true separation. Estimates of its mass depend on theoretical models of planetary evolution, and predict the object has about 8 Jupiter masses and is still cooling, with a temperature ranging from 1400 to 1600 K. These figures come with the caveat that the models have not yet been tested against real data in the likely ranges of mass and age for the planet.

The semimajor axis is 8–9 AU and its orbital period is 17–21 years.[65] A "transit-like event" was observed in November 1981;[66][67] this is consistent with those estimates.[65] If this is confirmed as a true transit, the inferred radius of the transiting object is 2–4 Jupiter radii, which is larger than predicted by theoretical models. This may indicate that it is surrounded by a large ring system or a moon-forming disc.[67]

Confirmation of a second planet in the Beta Pictoris system was announced on 6 October 2020. The planet has a temperature of T = 1250 ± 50 K, a dynamical mass of M = 8.89 ± 0.75 MJup,[68] and an age of 18.5 ± 2.5 Myr.[15] It has an orbital period of about 1,200 days (3.3 years) and a semimajor axis of 2.7 AU, about 3.5 times closer to its parent star than Beta Pictoris b.[69][59] The orbit of Beta Pictoris c is moderately eccentric, with an eccentricity of 0.24.[69][59]

This planet presents data with conflict with current, as of 2020, models for planetary formation. β Pic c is at an age where planetary formations is predicted to occur via disk instability. However the planet orbits at a distance of 2.7 AU, which prediction says is too close for disk instability to occur. The low apparent magnitude, of MK = 14.3 ± 0.1, suggests that it formed via core accretion.[15]

Dust stream

In 2000, observations made with the Advanced Meteor Orbit Radar facility in New Zealand revealed the presence of a stream of particles coming from the direction of Beta Pictoris, which may be a dominant source of interstellar meteoroids in the Solar System.[23] The particles in the Beta Pictoris dust stream are relatively large, with radii exceeding 20 micrometers, and their velocities suggest that they must have left the Beta Pictoris system at roughly 25 km/s. These particles may have been ejected from the Beta Pictoris debris disk as a result of the migration of gas giant planets within the disk and may be an indication that the Beta Pictoris system is forming an

Oort cloud.[70] Numerical modeling of dust ejection indicates radiation pressure may also be responsible and suggests that planets further than about 1 AU from the star cannot directly cause the dust stream.[71]

See also

- 51 Ophiuchi

Notes

1. The parallax can be converted into distance using the equation: $\text{Distance in parsecs} = \frac{1}{\text{parallax in arcseconds}}$. See the article on propagation of uncertainty for information on how errors on derived values can be calculated.
2. For artist's impression of Beta Pictoris b, see:
   - "Length of Exoplanet Day Measured for First Time" (http://www.eso.org/public/news/eso1414/). *ESO Press Release*. Retrieved 2 May 2014.
3. Calculated from [M/H]: relative abundance = $10^{[M/H]}$
4. The visual luminosity can be calculated by: $\frac{L_{V*}}{L_{V\odot}} = 10^{0.4(M_{V\odot} - M_{V*})}$
5. The physical diameter can be found by multiplying the distance by the angular diameter in radians.
6. The rotation period can be calculated using the equations of circular motion: $P_{\text{rot}} = \frac{2\pi r}{v_{\text{rot}}}$
7. For artist's impression of Beta Pictoris, see:
   - "Crashing Comets Explain Surprise Gas Clump Around Young Star" (http://www.eso.org/public/news/eso1408/). *ESO*. Retrieved 12 March 2014.
8. From Wien's displacement law and a temperature of 8052 K the peak wavelength emission from Beta Pictoris would be around 360 nanometers which is in the near-ultraviolet region of the spectrum.

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2. Gray, R. O.; et al. (2006). "Contributions to the Nearby Stars (NStars) Project: Spectroscopy of Stars Earlier than M0 within 40 pc—The Southern Sample". *The Astronomical Journal*. **132** (1): 161–170. arXiv:astro-ph/0603770 (https://arxiv.org/abs/astro-ph/0603770). Bibcode:2006AJ....132..161G (https://ui.adsabs.harvard.edu/abs/2006AJ....132..161G). doi:10.1086/504637 (https://doi.org/10.1086%2F504637). S2CID 119476992 (https://api.semanticscholar.org/CorpusID:119476992).
3. Hoffleit D. & Warren Jr W.H. (1991). "HR 2020" (http://webviz.u-strasbg.fr/viz-bin/VizieR-5?-out.add=.&-source=V/50/catalog&recno=2020). *Bright Star Catalogue* (5th Revised ed.). Retrieved 2008-09-06.

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Carina Nebula

Coordinates: $10^h\ 45^m\ 08.5^s$, −59° 52′ 04″

The **Carina Nebula**[7] or **Eta Carinae Nebula**[8] (catalogued as **NGC 3372**; also known as the **Great Carina Nebula**[9]) is a large, complex area of bright and dark nebulosity in the constellation Carina, located in the Carina–Sagittarius Arm of the Milky Way galaxy. The nebula is approximately 8,500 light-years (2,600 pc) from Earth.[2]

Carina Nebula

Emission nebula

The Carina Nebula. Eta Carinae and the Keyhole Nebula are left of center, NGC 3324 is at upper right.

Observation data: J2000.0 epoch	
Right ascension	$10^h\ 45^m\ 08.5^s$[1]
Declination	−59° 52′ 04″[1]
Distance	~8,500 ly (~2,600[2] pc)
Apparent magnitude (V)	+1.0[3]
Apparent dimensions (V)	120 × 120 arcmins
Constellation	Carina
Physical characteristics	
Radius	~230[4] ly (~70 pc)

The nebula has within its boundaries the large Carina OB1 association and several related open clusters, including numerous O-type stars and several Wolf–Rayet stars. Carina OB1 encompasses the star clusters Trumpler 14 and Trumpler 16. Trumpler 14 is one of the youngest known star clusters at half a million years old. Trumpler 16 is the home of WR 25, currently the most luminous star known in our Milky Way galaxy, together with the less luminous but more massive and famous Eta Carinae star system and the O2 supergiant HD 93129A. Trumpler 15, Collinder 228, Collinder 232, NGC 3324, and NGC 3293 are also considered members of the association. NGC 3293 is the oldest and furthest from Trumpler 14, indicating sequential and ongoing star formation.

The nebula is one of the largest diffuse nebulae in our skies. Although it is four times as large as and even brighter than the famous Orion Nebula, the Carina Nebula is much less well known due to its location in the southern sky. It was discovered by Nicolas-Louis de Lacaille in 1752 from the Cape of Good Hope.

The Carina Nebula was selected as one of five cosmic objects observed by the James Webb Space Telescope, as part of the release of its first official science images. A detailed image was made of an early star-forming region of NGC 3324 known as the Cosmic Cliffs.[10]

Discovery and basic

information

Notable features	Eta Carinae Keyhole Nebula Many open clusters & dark nebulae
Designations	NGC 3372,[5] ESO 128-EN013,[1] GC 2197,[1] h 3295,[1] Caldwell 92[6]

Nicolas-Louis de Lacaille discovered the nebula on 25 January 1752.[3] Its dimensions are 120×120 arcminutes centered on the coordinates of right ascension 10^{h} 45^{m} 08.5^{s} and declination −59° 52′ 04″.[1] In modern times it is calculated to be around 8,500 light-years (2,600 pc) from Earth.[2]

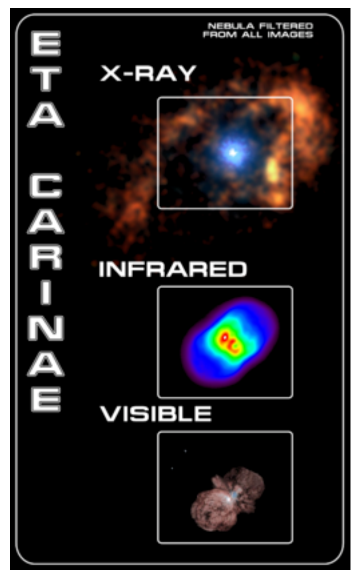
The Cosmic Cliffs at the edge of NGC 3324, one of the first images taken by the James Webb Space Telescope

Objects within the Carina Nebula

Eta Carinae

Eta Carinae is a highly luminous hypergiant star. Estimates of its mass range from 100 to 150 times the mass of the Sun, and its luminosity is about four million times that of the Sun.

This object is currently the most massive star that can be studied in great detail, because of its location and size. Several other known stars may be more luminous and more massive, but data on them is far less robust. (Caveat: Since examples such as the Pistol Star have been demoted by improved data, one should be skeptical of most available lists of "most massive stars". In 2006, Eta Carinae still had the highest *confirmed* luminosity, based on data across a broad range of wavelengths.) Stars with more than 80 times the mass of the Sun produce more than a million times as much light as the Sun. They are quite rare—only a few dozen in a galaxy as big as ours—and they flirt with disaster near the Eddington limit, i.e., the outward pressure of their radiation is almost strong enough to counteract gravity. Stars that are more than 120 solar masses exceed the theoretical Eddington limit, and their gravity is barely strong enough to hold in its radiation and gas, resulting in a possible supernova or hypernova in the near future.

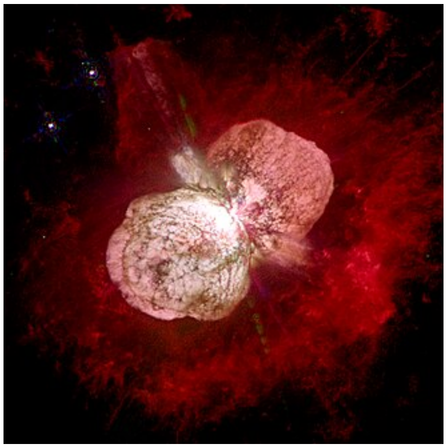


Eta Carinae observed in different wavelengths

Eta Carinae's effects on the nebula can be seen directly. Dark globules and some other less visible objects have tails pointing directly away from the massive star. The entire nebula would have looked very different before the Great Eruption in the 1840s surrounded Eta Carinae with dust, drastically reducing the amount of ultraviolet light it put into the nebula.

Homunculus Nebula

Within the large bright nebula is a much smaller feature, immediately surrounding Eta Carinae itself, known as the Homunculus Nebula (from Latin meaning *Little Man*). It is believed to have been ejected in an enormous outburst in 1841 which briefly made Eta Carinae the second-brightest star in the sky.



Eta Carinae, surrounded by the Homunculus Nebula

The Homunculus Nebula is a small H II region, with gas shocked into ionized and excited states.[11] It also absorbs much of the light from the extremely luminous central stellar system and re-radiates it as infrared (IR). It is the brightest object in the sky at mid-IR wavelengths.[12]:145–169

The distance to the Homunculus can be derived from its observed angular dimensions and calculated linear size, assuming it is axially symmetric. The most accurate distance obtained using this method is 7,660 ± 160 light-years (2,350 ± 50 pc). The largest radius of the bipolar lobes in this model is about 22,000 AU, and the axis is oriented 41° from the line of sight, or 49° relative to the plane of the sky, which means it is seen from Earth slightly more "end on" than "side on".[13]

Keyhole Nebula

The Keyhole Nebula is a dark nebulosity superimposed on the brightest part of the Carina Nebula.

The Keyhole, or Keyhole Nebula, is a small dark cloud of cold molecules and dust within the Carina Nebula, containing bright filaments of hot, fluorescing gas, silhouetted against the much brighter background nebula. John Herschel used the term "lemniscate-oval vacuity" when first describing it,[14] and subsequently referred to it simply as the "oval vacuity".[15] The term lemniscate continued to be used to describe this portion of the nebula[16] until popular astronomy writer Emma Converse described the shape of the nebula as "resembling a keyhole" in an 1873 *Appleton's Journal* article.[17] The name Keyhole Nebula then came into common use, sometimes for the Keyhole itself, sometimes to describe the whole of the Carina Nebula (signifying "the nebula that contains the Keyhole").[18][19]

The diameter of the Keyhole structure is approximately seven light-years (2.1 pc). Its appearance has changed significantly since it was first observed, possibly due to changes in the ionizing radiation from Eta Carinae.[20] The Keyhole does not have its own NGC designation. It is sometimes erroneously called NGC 3324,[21] but that catalogue designation refers to a reflection and emission nebula just northwest of the Carina Nebula (or to its embedded star cluster).[22][23][24]

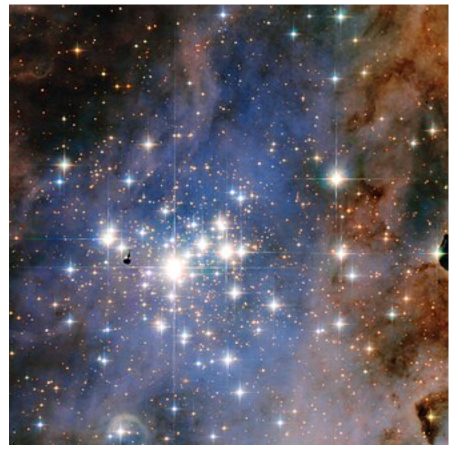
Defiant Finger

A small Bok globule in the Keyhole Nebula (at RA 10h 44m 30s, Dec −59° 40') has been photographed by the Hubble Space Telescope and is nicknamed the "Carina Defiant Finger" due to its shape.[25] In Hubble images, light can be seen radiating off the edges of the globule; this is especially visible in the southern tip, where the "finger" is. It is thought that the Defiant Finger is being ionized by the bright Wolf–Rayet star WR 25, and/or Trumpler 16-244, a bright blue supergiant. It has a mass of at least 6 $M_{\odot}$, and stars may be forming within it. Like other interstellar clouds under intense radiation, the Defiant Finger will eventually be completely evaporated; for this cloud the time frame is predicted to be 200,000 to 1,000,000 years.[26]


Hubble image of the Defiant Finger. North is down.

Trumpler 14

Trumpler 14 is an open cluster with a diameter of six light-years (1.8 pc), located within the inner regions of the Carina Nebula, approximately 8,000 light-years (2,500 pc) from Earth.[27] It is one of the main clusters of the Carina OB1 stellar association, which is the largest association in the Carina Nebula.[12] About 2,000 stars have been identified in Trumpler 14.[28] and the total mass of the cluster is estimated to be 4,300 $M_\odot$.[29]


Hubble image of the open cluster Trumpler 14

Trumpler 15

Trumpler 15 is a star cluster on the north-east edge of the Carina Nebula. Early studies disagreed about the distance, but astrometric measurements by the *Gaia* mission have confirmed that it is the same distance as the rest of Carina OB1.[2]

Trumpler 16

Trumpler 16 is one of the main clusters of the Carina OB1 stellar association, which is the largest association in the Carina Nebula, and it is bigger and more massive than Trumpler 14.[12] The star Eta Carinae is part of this cluster.

Mystic Mountain


Mystic Mountain

Mystic Mountain is the term for a dust–gas pillar in the Carina Nebula, a photo of which was taken by Hubble Space Telescope on its 20th anniversary. The area was observed by Hubble's Wide Field Camera 3 on 1–2 February 2010. The pillar measures three light-years (0.92 pc) in height; nascent stars inside the pillar fire off gas jets that stream from towering “peaks”.

WR 22

WR 22 is an eclipsing binary. The dynamical masses derived from orbital fitting vary from over 70 $M_\odot$ to less than 60 $M_\odot$ for the primary and about 21 to 27 $M_\odot$ for the secondary.[30] The spectroscopic mass of the primary has been calculated at 74 $M_\odot$[31] or 78.1 $M_\odot$.[32]

WR 25

WR 25 is a binary system in the central portion of the Carina Nebula, a member of the Trumpler 16 cluster. The primary is a Wolf–Rayet star, possibly the most luminous star in the galaxy. The secondary is hard to detect but thought to be a luminous OB star.

The brightest star is WR 25

HD 93129

HD 93129 is a triple star system of O-class stars in Carina. All three stars of HD 93129 are among the most luminous in the galaxy;[33] HD 93129 consists of two clearly resolved components, HD 93129 A and HD 93129 B, and HD 93129 A itself is made up of two much closer stars.

HD 93129 A has been resolved into two components. The spectrum is dominated by the brighter component, although the secondary is only 0.9 magnitudes fainter. HD 93129 Aa is an O2 supergiant and Ab is an O3.5 main sequence star.[34] Their separation has decreased from 55 milliarcseconds in 2004 to only 27 mas in 2013, but an accurate orbit is not available.[35]

HD 93129 B is an O3.5 main-sequence star 3 arcseconds away from the closer pair. It is about 1.5 magnitudes fainter than the combined HD 93129 A, and is approximately the same brightness as HD 93129 Ab.[36][37]

HD 93250

HD 93250 is one of the brightest stars in the region of the Carina Nebula. It is only 7.5 arcminutes from Eta Carinae,[38] and HD 93250 is considered to be a member of the same loose open cluster Trumpler 16, although it appears closer to the more compact Trumpler 14.[39]

HD 93250 is known to be a binary star, however, individual spectra of the two components have never been observed but are thought to be very similar. The spectral type of HD 93250 has variously been given as O5,[40] O6/7,[41] O4,[42] and O3.[43] It has sometimes been classified as a main sequence star and sometimes as a giant star.[42][43] The Galactic O-Star Spectroscopic Survey has used it as the standard star for the newly created O4 subgiant spectral type.[44]

HD 93205

HD 93205 is a binary system of two large stars.

The more massive member of the pair is an O3.5 main sequence star. The spectrum shows some ionized nitrogen and helium emission lines, indicating some mixing of fusion products to the surface and a strong stellar wind. The mass calculated from apsidal motion of the orbits is 40 to 60 $M_\odot$. This is somewhat lower than expected from evolutionary modelling of a star with its observed parameters.[45]

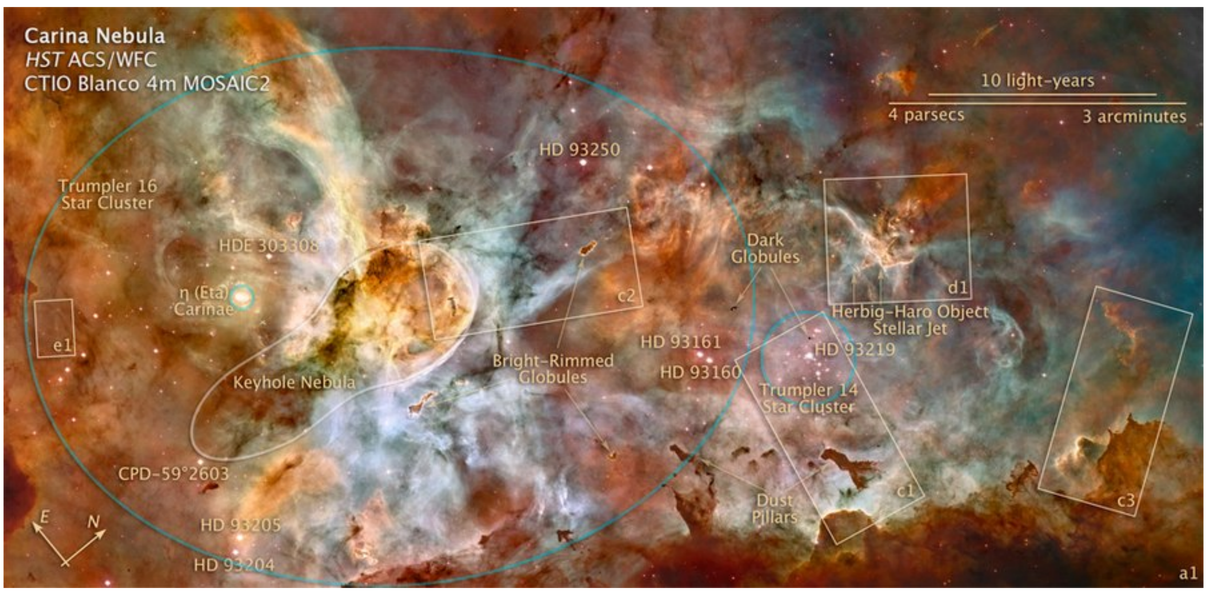
The less massive member is an O8 main sequence star of approximately 20 $M_\odot$.[46] It moves in its orbit at a speed of over 300 km/s (190 mi/s) and is considered to be a relativistic binary, which causes the apses of the orbit to change in a predictable way.[47]

Catalogued open clusters in Carina Nebula

As of 1998, there are eight known open clusters in the Carina Nebula:[3]

- Bochum 10 (Bo 10)
- Bochum 11 (Bo 11)
- Collinder 228 (Cr 228)[48]
- Collinder 232 (Cr 232)
- Collinder 234 (Cr 234)
- Trumpler 14 (Tr 14, Cr 230)
- Trumpler 15 (Tr 15, Cr 231)
- Trumpler 16 (Tr 16, Cr 233)

Annotated map

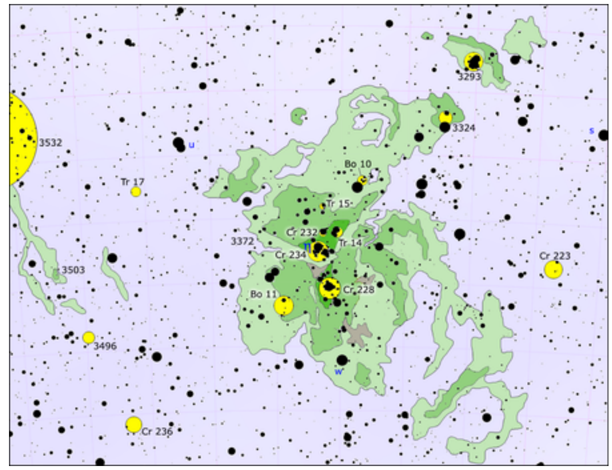


Annotated map of part of the Carina Nebula showing the location of various objects in the nebula. This view combines multiple ground and Hubble observatory images in a 50-light-year wide (15 pc) view.[49]

Gallery

Overview of the Carina Nebula. The Keyhole is superimposed on the bright area above center, and Eta Carinae is the bright star just to its left.

Carina Nebula in infrared light[50]



A celestial map of the nebula.

X-rays from stars and diffuse multimillion-Kelvin plasma light up the Carina Nebula in this Chandra X-ray Observatory image

Close-up of the Carina Nebula's central region

Wolf–Rayet star WR 22

Bok globule nicknamed "The Caterpillar"[51]

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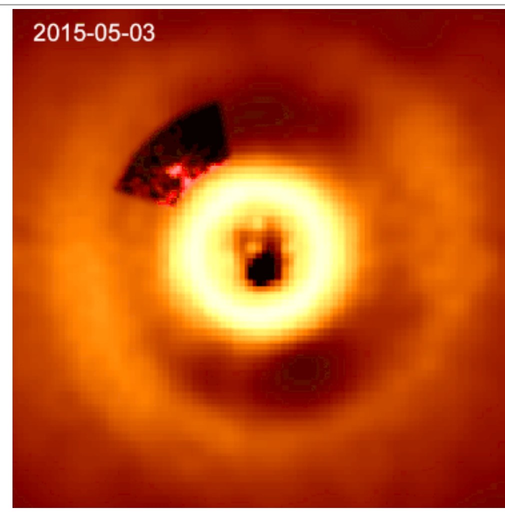
HD 169142

HD 169142 is a single Herbig Ae/Be star. Its surface temperature is 7650 ± 150 K. HD 169142 is depleted of heavy elements compared to the Sun, with a metallicity Fe/H index of −0.375 ± 0.125, but is much younger at an age of 7.5 ± 4.5 million years.[2] The star is rotating slowly and has relatively low stellar activity for a Herbig Ae/Be star.[3]

HD 169142



VLT/SPHERE image of the circumstellar disk and protoplanet candidate b around HD 169142. **Credit**: *ESO VLT/SPHERE - Monash University - Iain Hammond et al., adapted and mixed by Meli_thev*

Observation data	
Epoch J2000	**Equinox J2000**
Constellation	Sagittarius
Right ascension	18h 24m 29.7800s[1]
Declination	−29° 46′ 49.3286″[1]
Apparent magnitude (V)	8.16
Characteristics	
Evolutionary stage	Herbig Ae/Be star
Spectral type	A9III/IVe[2]
Astrometry	
Radial velocity (R_v)	−3 ± 2[3] km/s
Proper motion (μ)	RA: −2.335[4] mas/yr Dec.: −37.879[4] mas/yr
Parallax (π)	8.7053 ± 0.0268 mas[4]
Distance	375 ± 1 ly (114.9 ± 0.4 pc)
Details[2]	

Planetary system

The Disk

The star is surrounded by a complex, rapidly evolving protoplanetary disk with two gaps. In the 1995-2005 period the disk inner edge has moved inward by 0.3 AU.[5] The dust of the disk is rich in polycyclic aromatic hydrocarbons[6] and carbon monoxide.[7]

A study using ALMA data found that the water (H_2O) snow line is at around 20 astronomical units and the planet b is forming in beyond the water and carbon dioxide (CO_2) snow lines, but within the carbon monoxide (CO) snow line. The CO snow line lies at around 150 AU.[8]

The study also detected a range of molecules in the disk: diazenylium (N_2H^+), methanol (CH_3OH), [CI], deuterated hydrogen cyanide (DCN), carbon monosulfide (CS, $C^{34}S$, ^{13}CS), thioformaldehyde (H_2CS), formaldehyde (H_2CO), cyanoacetylene (HC_3N), cyclopropenylidene (c-C_3H_2), sulfur monoxide (SO, previously detected) and deuterated aldehyde (DCO, previously detected). The detection of methanol in this warm disk is interpreted as a leftover from a earlier and colder stage of the disk. The methanol is now sublimating in this warmer phase. This means that complex ices can survive the disk formation process.[8]

Mass	1.65 $M_\odot$
Radius	1.6 $R_\odot$
Luminosity	8.6 $L_\odot$
Surface gravity (log *g*)	4.05 ± 0.05 cgs
Temperature	7650 ± 150 K
Metallicity [Fe/H]	−0.375 ± 0.125 dex
Rotational velocity (*v* sin *i*)	55 ± 5 km/s
Age	7.5 ± 4.5 Myr
Other designations	
CD−29 14904, TYC 6856-876-1, GSC 06856-00876, 2MASS J18242978-2946492[1]	
Database references	
SIMBAD	data (https://simbad.cds.unistra.fr/simbad/sim-id?Ident=HD+169142)

The Planet

The annular gap and inner cavity observed in this protoplanetary disk both suggested the presence of embedded planets.[2] Several protoplanet candidates have been suggested in the literature starting from 2014.[9][10]

Nonetheless, a particular protoplanet candidate detected in 2015 and 2017 with the SPHERE instrument on the VLT appears to stand out, hereafter HD 169142 b.[11] A paper from 2023[12] confirmed that the motion of this protoplanet candidate was consistent with Keplerian motion. The object shifted with a change of the position angle of 10.2±2.8° between 2015 and 2019. The researchers point out three lines of evidence arguing in favour of this object being a protoplanet:

1. The object is found in annular gap separating the two bright rings of the disc, as predicted in theory
2. The protoplanet moved between 2015, 2017 and 2019 consistent with Keplerian motion of an object at a distance of about 37 astronomical units from its star.
3. A spiral-shaped signal consistent with the expected outer spiral wake triggered by a planet in the gap, based on simulations of the system.

The researchers also found the near-infrared colors of the object are consistent with starlight scattered by dust around the protoplanet. This dust could be a circumplanetary disk or a dusty envelope around the protoplanet.[12]

A study from June 2023, using archived ALMA data found sulfur monoxide and silicon monosulfide in the disk at the position of planet b. The paper also found compact ^{12}CO and ^{13}CO emission at the position of the planet. Carbon monoxide and sulfur monoxide were detected in other disks in the past and they are thought to be connected to protoplanets. Silicon monosulfide on the other hand was never before detected in any other disk and can only be detected if silicates are released from nearby dust grains in massive shock waves caused by gas travelling at high velocities. It is thought that planet b is driving an outflow causing these high velocities.[13][14] Outflows from proto-jovian planets were hypothesised since 1998.[15]

Outflows are known around isolated young proto-brown dwarfs,[16] but HD 169142 b could be the first confirmed protoplanet around a star showing clear evidence of an outflow. Evidence for inflow or outflows suspected to be caused by planets exist for other disks, such as a signature in the CI gas of HD 163296.[14]

The HD 169142 planetary system

Companion (in order from star)	Mass	Semimajor axis (AU)	Orbital period (days)	Eccentricity	Inclination	Radius
b	3 ± 2[12] M_J	37.2[12]	—	—	13[12]°	—
protoplanetary disk	20–250[2] AU				13[17]°	—

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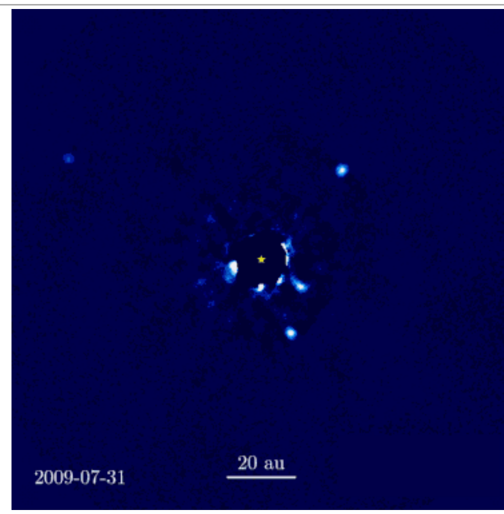
HR 8799

Coordinates: 23h 07m 28.7150s, +21° 08′ 03.302″

HR 8799 is a roughly 30 million-year-old main-sequence star located 133.3 light-years (40.9 parsecs) away from Earth in the constellation of Pegasus. It has roughly 1.5 times the Sun's mass and 4.9 times its luminosity. It is part of a system that also contains a debris disk and at least four massive planets. Those planets, along with Fomalhaut b, were the first exoplanets whose orbital motion was confirmed by direct imaging. The star is a Gamma Doradus variable: its luminosity changes because of non-radial pulsations of its surface. The star is also classified as a Lambda Boötis star, which means its surface layers are depleted in iron peak elements. It is the only known star which is simultaneously a Gamma Doradus variable, a Lambda Boötis type, and a Vega-like star (a star with excess infrared emission caused by a circumstellar disk).

HR 8799

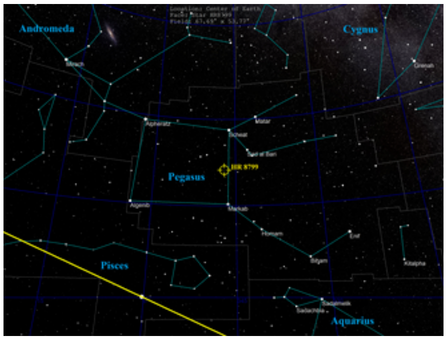


HR 8799 (center) with HR 8799 e (right), HR 8799 d (lower right), HR 8799 c (upper right), HR 8799 b (upper left) from W. M. Keck Observatory

Observation data	
Epoch J2000.0	Equinox J2000.0
Constellation	Pegasus
Right ascension	23^{h} 07^{m} 28.7157^{s}[1]
Declination	+21° 08′ 03.311″[1]
Apparent magnitude (V)	5.964[2]
Characteristics	
Spectral type	kA5 hF0 mA5 V; λ Boo[3][4]
U−B color index	−0.04[5]
B−V color index	0.234[2]
Variable type	Gamma Doradus variable[2]
Astrometry	
Radial velocity (R_v)	−11.5 ± 2[2] km/s
Proper motion (μ)	RA: 108.284 ± 0.056[1] mas/yr Dec.: −50.040 ± 0.059[1] mas/yr
Parallax (π)	24.4620 ± 0.0455 mas[1]

Location

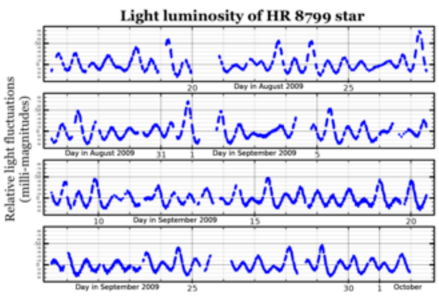
HR 8799 is a star that is visible to the naked eye. It has a magnitude 5.96 and it is located inside the western edge of the great square of Pegasus almost exactly halfway between Scheat and Markab. The star's name of *HR 8799* is its line number in the Bright Star Catalogue.



Location of HR 8799

Distance	133.3 ± 0.2 ly (40.88 ± 0.08 pc)
Absolute magnitude (M_V)	2.98 ± 0.08[3]
Details	
Mass	$1.43\ ^{+0.06}_{-0.07}$[6] $M_\odot$
Radius	1.34 ± 0.05[3] $R_\odot$
Luminosity (bolometric)	4.92 ± 0.41[3] $L_\odot$
Surface gravity (log *g*)	4.35 ± 0.05[3] cgs
Temperature	7430 ± 75[3] K
Metallicity [Fe/H]	−0.52 ± 0.08[7][a] dex
Rotational velocity (*v* sin *i*)	37.5 ± 2[3] km/s
Age	$30\ ^{+20}_{-10}$[8] Myr
Other designations	
V342 Pegasi, BD+20 5278, FK5 3850, GC 32209, HD 218396, HIP 114189, PPM 115157, SAO 91022, TYC 1718-2350-1.[2]	
Database references	
SIMBAD	data (https://simbad.cds.unistra.fr/simbad/sim-id?Ident=HR+8799)
Exoplanet Archive	data (https://exoplanetarchive.ipac.caltech.edu/cgi-bin/DisplayOverview/nph-DisplayOverview?objname=HR+8799)
Extrasolar Planets Encyclopaedia	data (http://exoplanet.eu/star.php?st=HR+8799)

Stellar properties



A broadband optical light curve for V342 Pegasi (HR 8799), adapted from Sódor *et al.* (2014)[9]

The star HR 8799 is a member of the Lambda Boötis (λ Boo) class, a group of peculiar stars with an unusual lack of "metals" (elements heavier than hydrogen and helium) in their upper atmosphere. Because of this special status, stars like HR 8799 have a very complex spectral type. The luminosity profile of the Balmer lines in the star's spectrum, as well as the star's effective temperature, best match the typical properties of an F0 V star. However, the strength of the calcium II K absorption line and the other metallic lines are more like those of an A5 V star. The star's spectral type is therefore written as kA5 hF0 mA5 V; λ Boo.[3][4]

Age determination of this star shows some variation based on the method used. Statistically, for stars hosting a debris disk, the luminosity of this star suggests an age of about 20–150 million years. Comparison with stars having similar motion through space gives an age in the range 30–160 million years. Given the star's position on the Hertzsprung–Russell diagram of luminosity versus temperature, it has an estimated age in the range of 30–1,128 million years. λ Boötis stars like this are generally young, with a mean age of a billion years. More accurately, asteroseismology also suggests an age of approximately a billion years.[10] However, this is disputed because it would make the planets become brown dwarfs to fit into the cooling models. Brown dwarfs would not be stable in such a configuration. The best accepted value for an age of HR 8799 is 30 million years, consistent with being a member of the Columba association co-moving group of stars.[11]

Earlier analysis of the star's spectrum reveals that it has a slight overabundance of carbon and oxygen compared to the Sun (by approximately 30% and 10% respectively). While some Lambda Boötis stars have sulfur abundances similar to that of the Sun, this is not the case for HR 8799; the sulfur abundance is only around 35% of the solar level. The star is also poor in elements heavier than sodium: for example, the iron abundance is only 28% of the solar iron abundance.[12] Asteroseismic observations of other pulsating Lambda Boötis stars suggest that the peculiar abundance patterns of these stars are confined to the surface only: the bulk composition is likely more normal. This may indicate that the observed element abundances are the result of the accretion of metal-poor gas from the environment around the star.[13]

In 2020, spectral analysis utilizing multiple data sources have detected an inconsistency in prior data and concluded the star carbon and oxygen abundances are the same or slightly higher than solar. The iron abundance was updated to 30^{+6}_{-5}% of solar value.[7]

Astroseismic analysis using spectroscopic data indicates that the rotational inclination of the star is constrained to be greater than or approximately equal to 40°. This contrasts with the planets' orbital inclinations, which are in roughly the same plane at an angle of about 20° ± 10°. Hence, there may be an unexplained misalignment between the rotation of the star and the orbits of its planets.[14] Observation of this star with the Chandra X-ray Observatory indicates that it has a weak level of magnetic activity, but the X-ray activity is much higher than that of an A-type star like Altair. This suggests that the internal structure of the star more closely resembles that of an F0 star. The temperature of the stellar corona is about 3.0 million K.[15]

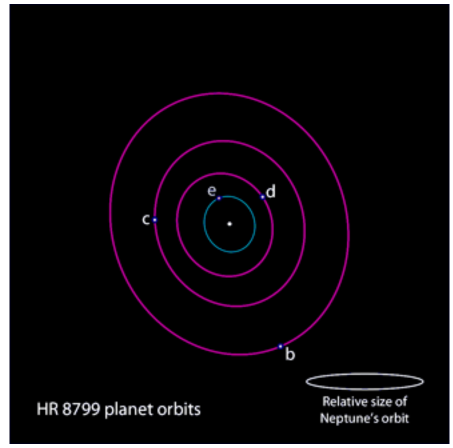
Planetary system

The HR 8799 planetary system[8][16][17][18]

Companion (in order from star)	Mass	Semimajor axis (AU)	Orbital period (years)	Eccentricity	Inclination	Radius
e	7.4 ±0.6 M_J	16.25 ±0.04	~45	0.1445 ±0.0013	25 ± 8°	$1.17^{+0.13}_{-0.11}$ R_J
d	9.1 ±0.2 M_J	26.67 ±0.08	~100	0.1134 ±0.0011	28°	$1.2^{+0.1}_{-0}$ R_J
c	7.8 ±0.5 M_J	41.39 ±0.11	~190	0.0519 ±0.0022	28°	$1.2^{+0.1}_{-0}$ R_J
b	5.7 ±0.4 M_J	71.6 ±0.2	~460	0.016 ±0.001	28°	$1.2^{+0.1}_{-0.1}$ R_J
Dust disk	135–360[19] AU				—	—

On 13 November 2008, Christian Marois of the National Research Council of Canada's Herzberg Institute of Astrophysics and his team announced they had directly observed three planets orbiting the star with the Keck and Gemini telescopes in Hawaii,[20][21][22][23] in both cases employing adaptive optics to make observations in the infrared.[b] A precovery observation of the outer 3 planets was later found in infrared images obtained in 1998 by the Hubble Space Telescope's NICMOS instrument, after a newly developed image-processing technique was applied.[24] Further

observations in 2009–2010 revealed the fourth giant planet orbiting inside the first three planets at a projected separation just less than 15 AU,[8][25] which has been confirmed by multiple studies.[26]



Orbit diagram of the HR 8799 planetary system

The outer planet orbits inside a dusty disk like the Solar Kuiper belt. It is one of the most massive disks known around any star within 300 light years of Earth, and there is room in the inner system for terrestrial planets.[22] There is an additional debris disk just inside the orbit of the innermost planet.[8]

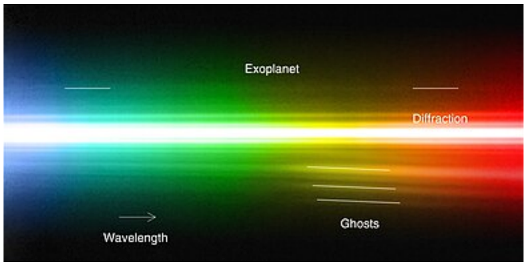
The orbital radii of planets e, d, c, and b are 2–3 times those of Jupiter, Saturn, Uranus, and Neptune's orbits, respectively. Because of the inverse square law relating radiation intensity to distance from the source, comparable radiation intensities are present at distances $\sqrt{4.9} \approx 2.2$ times farther from HR 8799 than from the Sun, the upshot being that corresponding planets in the solar and HR 8799 systems receive similar amounts of stellar radiation.[8]

These objects are near the upper mass limit for classification as planets; if they exceeded 13 Jupiter masses, they would be capable of deuterium fusion in their interiors and thus qualify as brown dwarfs under the definition of these terms used by the IAU's Working Group on Extrasolar Planets.[27] If the mass estimates are correct, the HR 8799 system is the first multiple-planet extrasolar system to be directly imaged.[21] The orbital motion of the planets is in an anticlockwise direction and was confirmed via multiple observations dating back to 1998.[20] The system is more likely to be stable if the planets e, d, and c are in a 4:2:1 resonance, which would imply that the orbit of the planet d has an eccentricity exceeding 0.04 in order to match the observational constraints. Planetary systems with the best-fit masses from evolutionary models would be stable if the outer three planets are in a 1:2:4 orbital resonance (similar to the Laplace resonance between Jupiter's inner three Galilean satellites: Io, Europa, and Ganymede as well as three of the planets in the Gliese 876 system).[8] However, it is disputed if planet b is in resonance with the other 3 planets. According to dynamical simulations, the HR 8799 planetary system may be even an extrasolar system with multiple resonance 1:2:4:8.[18] The 4 young planets are still glowing red hot from the heat of their formation, and are larger than Jupiter and over time they will cool and shrink to the sizes of 0.8–1.0 Jupiter radii.

The broadband photometry of planets b, c and d has shown that there may be significant clouds in their atmospheres,[25] while the infrared spectroscopy of planets b and c points to non-equilibrium CO / CH_4 chemistry.[8] Near-infrared observations with the Project 1640 integral field spectrograph on the Palomar Observatory have shown that compositions between the four planets vary significantly. This is a surprise since the planets presumably formed in the same way from the same disk and have similar luminosities.[28]

Planet spectra

A number of studies have used the spectra of HR 8799's planets to determine their chemical compositions and constrain their formation scenarios. The first spectroscopic study of planet b (performed at near-infrared wavelengths) detected strong water absorption and hints of methane



The spectrum is that of a giant exoplanet, orbiting around the bright and very young star HR 8799, about 130 light-years away. This spectrum of the star and the planet was obtained with the NACO adaptive optics instrument on ESO's Very Large Telescope.

absorption.[29] Subsequently, weak methane and carbon monoxide absorption in this planet's atmosphere was also detected, indicating efficient vertical mixing of the atmosphere and a disequilibrium CO / CH_4 ratio at the photosphere. Compared to models of planetary atmospheres, this first spectrum of planet b is best matched by a model of enhanced metallicity (about 10 times the metallicity of the Sun), which may support the notion that this planet formed through core-accretion.[30]

The first simultaneous spectra of all four known planets in the HR 8799 system were obtained in 2012 using the Project 1640 instrument at Palomar Observatory. The near-infrared spectra from this instrument confirmed the red colors of all four planets and are best matched by models of planetary atmospheres that include clouds. Though these spectra do not directly correspond to any known astrophysical objects, some of the planet spectra demonstrate similarities with L- and T-type brown dwarfs and the night-side spectrum of Saturn. The implications of the simultaneous spectra of all four planets obtained with Project 1640 are summarized as follows: Planet b contains ammonia and/or acetylene as well as carbon dioxide, but has little methane; planet c contains ammonia, perhaps some acetylene but neither carbon dioxide nor substantial methane; planet d contains acetylene, methane, and carbon dioxide but ammonia is not definitively detected; planet e contains methane and acetylene but no ammonia or carbon dioxide. The spectrum of planet e is similar to a reddened spectrum of Saturn.[28]

Moderate-resolution near-infrared spectroscopy, obtained with the Keck telescope, definitively detected carbon monoxide and water absorption lines in the atmosphere of planet c. The carbon-to-oxygen ratio, which is thought to be a good indicator of the formation history for giant planets, for planet c was measured to be slightly greater than that of the host star HR 8799. The enhanced carbon-to-oxygen ratio and depleted levels of carbon and oxygen in planet c favor a history in which the planet formed through core accretion.[31] However, it is important to note that conclusions about the formation history of a planet based solely on its composition may be inaccurate if the planet has undergone significant migration, chemical evolution, or core dredging. Later, in November 2018, researchers confirmed the existence of water and the absence of methane in the atmosphere of HR 8799 c using high-resolution spectroscopy and near-infrared adaptive optics (NIRSPAO) at the Keck Observatory.[32][33]

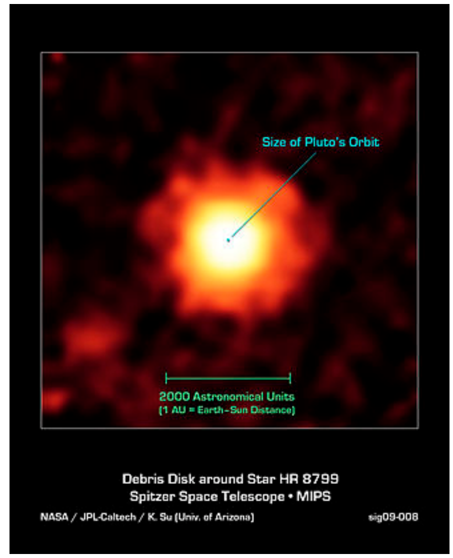
The red colors of the planets may be explained by the presence of iron and silicate atmospheric clouds, while their low surface gravities might explain the strong disequilibrium concentrations of carbon monoxide and the lack of strong methane absorption.[31]

Debris disk

In January 2009 the Spitzer Space Telescope obtained images of the debris disk around HR 8799. Three components of the debris disk were distinguished:

1. Warm dust ($T \approx 150$ K) orbiting within the innermost planet (e). The inner and outer edges of this belt are close to 4:1 and 2:1 resonances with the planet.[8]

2. A broad zone of cold dust ($T \approx 45$ K) with a sharp inner edge orbiting just outside the outermost planet (b). The inner edge of this belt is approximately in 3:2 resonance with said planet, similar to Neptune and the Kuiper belt.[8]
3. A dramatic halo of small grains originating in the cold dust component.



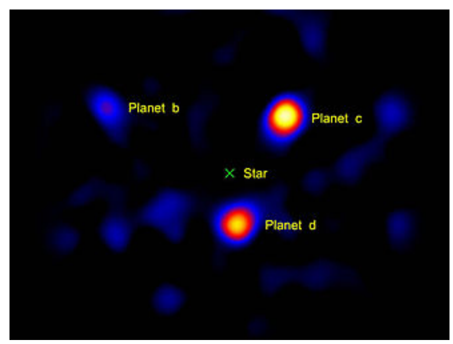
Spitzer infrared image of HR 8799's debris disk, January 2009. The small dot in the centre is the size of Pluto's orbit.

The halo is unusual and implies a high level of dynamic activity which is likely due to gravitational stirring by the massive planets.[34] The Spitzer team says that collisions are likely occurring among bodies similar to those in the Kuiper Belt and that the three large planets may not yet have settled into their final, stable orbits.[35]

In the photo, the bright, yellow-white portions of the dust cloud come from the outer cold disk. The huge extended dust halo, seen in orange-red, has a diameter of ≈ 2,000 AU. The diameter of Pluto's orbit (≈ 80 AU) is shown for reference as a dot in the centre.[36]

This disk is so thick that it threatens the young system's stability.[37]

Vortex Coronagraph: Testbed for high-contrast imaging technology



Direct image of exoplanets around the star HR 8799 using a vortex coronagraph on a 1.5 m portion of the Hale Telescope

Up until the year 2010, telescopes could only directly image exoplanets under exceptional circumstances. Specifically, it is easier to obtain images when the planet is especially large (considerably larger than Jupiter), widely separated from its parent star, and hot so that it emits intense infrared radiation. However, in 2010 a team from NASAs Jet Propulsion Laboratory demonstrated that a vortex coronagraph could enable small telescopes to directly image planets.[38] They did this by imaging the previously imaged HR 8799 planets using just a 1.5 m portion of the Hale Telescope.

NICMOS images

In 2009, an old NICMOS image was processed to show a predicted exoplanet around HR 8799.[39] In 2011, three further exoplanets were rendered viewable in a NICMOS image taken in 1998, using advanced data processing.[39] The image allows the planets' orbits to be better characterised, since they take many decades to orbit their host star.[39]

Search for radio emissions

Starting in 2010, astronomers searched for radio emissions from the exoplanets orbiting HR 8799 using the radio telescope at Arecibo Observatory. Despite the large masses, warm temperatures, and brown dwarf-like luminosities, they failed to detect any emissions at 5 GHz down to a flux density detection threshold of 1.0 mJy.[40]

See also

- List of exoplanets
- Direct imaging of extrasolar planets

Notes

a. The star is a member of the Lambda Boötis class of peculiar stars, thus the observed abundance may not reflect the abundances of the star as a whole.
b. The planets are young and therefore they are still hot and bright in the near-infrared part of the spectrum.

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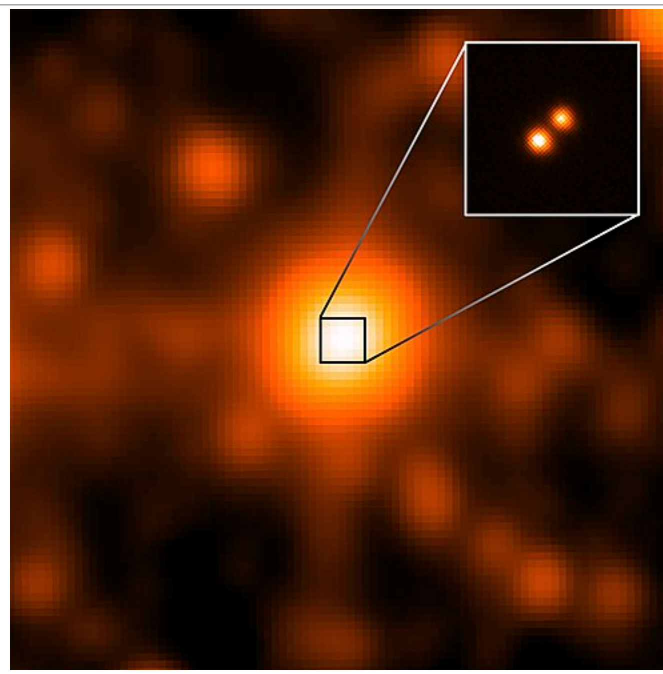
Luhman 16

Coordinates: 10h 49m 18.723s, −53° 19′ 09.86″

Luhman 16 (also designated **WISE 1049−5319** or **WISE J104915.57−531906.1**) is a binary brown-dwarf system in the southern constellation Vela at a distance of approximately 6.5 light-years (2.0 parsecs) from the Sun. These are the closest-known brown dwarfs and the closest system found since the measurement of the proper motion of Barnard's Star in 1916,[11][12] and the third-closest-known system to the Sun (after the Alpha Centauri system and Barnard's Star). The primary is of spectral type L7.5 and the secondary of type T0.5 ± 1 (and is hence near the L–T transition).[13] The masses of Luhman 16 A and B are 33.5 and 28.6 Jupiter masses, respectively, and their ages are estimated to be 600–800 million years.[5] Luhman 16 A and B orbit each other at a distance of about 3.5 astronomical units[4] with an orbital period of approximately 27 years.[5]

Luhman 16



WISE image of Luhman 16. In the GMOS image in the inset, it is resolved into a pair.

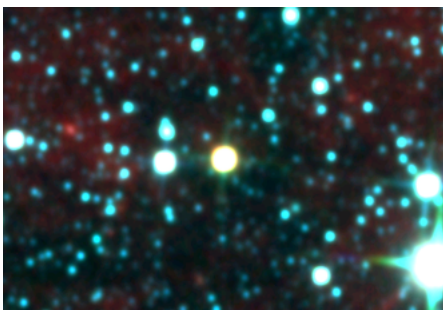
Observation data	
Epoch J2000[1]	Equinox J2000[1]
Constellation	Vela
Right ascension	$10^h\ 49^m\ 18.723^s$[1]
Declination	−53° 19′ 09.86″[1]
Apparent magnitude (V)	16.20[2]
Characteristics	
Spectral type	A: L7.5[3] B: T0.5 ± 1[3]
Apparent magnitude (i (DENIS filter system))	14.94 ± 0.03[4]
Apparent magnitude (J (2MASS filter system))	10.73 ± 0.03[4]
Apparent magnitude (J (DENIS filter system))	10.68 ± 0.05[4]

Discovery

This system was discovered by Kevin Luhman, astronomer from Pennsylvania State University and a researcher at Penn State's Center for Exoplanets and Habitable Worlds,[11] from images made by the Wide-field Infrared Survey Explorer (WISE) Earth-orbiting satellite—NASA infrared-wavelength 40 cm (16 in) space telescope, a mission that lasted from December 2009 to February 2011; the discovery images were taken from January 2010 to January 2011, and the discovery was announced in 2013 (the pair are the only two objects announced in the discovery paper). The system was found by comparing WISE images at different epochs to reveal objects that have high proper motions.[11][4]

Luhman 16 appears in the sky close to the galactic plane, which is densely populated by stars; the abundance of light sources makes it difficult to spot faint objects. This explains why an object so near to the Sun was not discovered in earlier searches.[4]

Discovery of companion



Luhman 16 is the yellow disc at the center of this WISE image. The individual brown dwarfs are not resolved.

The second component of the system was also discovered by Luhman in 2013, and was announced in the same article as the primary. Its discovery image in the *i*-band was taken on the night of 23 February 2013 with the Gemini Multi-Object Spectrograph (GMOS) at the Gemini South telescope, Chile. The components of the system were resolved with an angular distance of 1.5 arcseconds, corresponding to a projected separation of 3 AU, and a magnitude difference of 0.45 mag.[4]

Precovery

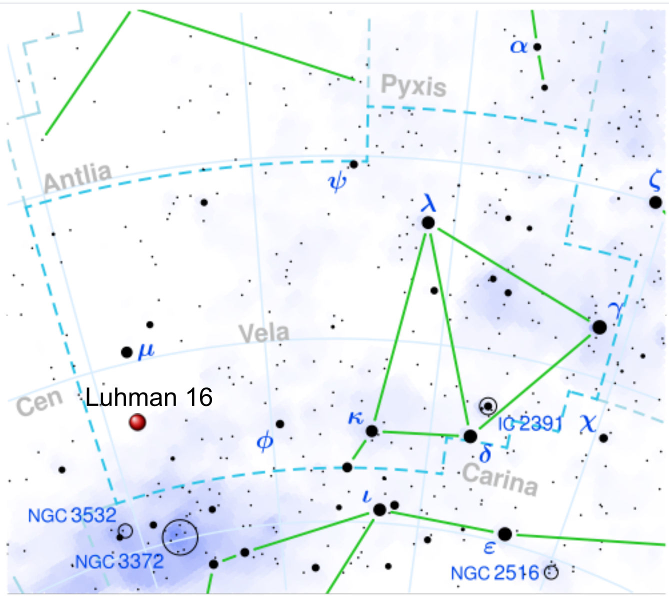
Although the system was first found on images taken by WISE in 2010–2011,

Apparent magnitude (H (2MASS filter system))	9.56 ± 0.03[4]
Apparent magnitude (K_S (2MASS filter system))	8.84 ± 0.02[4]
Apparent magnitude (K_S (DENIS filter system))	8.87 ± 0.08[4]
Astrometry	
Proper motion (μ)	RA: −2 762.16 ± 2.43[5] mas/yr Dec.: 357.79 ± 3.44[5] mas/yr
Parallax (π)	501.557 ± 0.082 mas[6]
Distance	6.503 ± 0.001 ly (1.9938 ± 0.0003 pc)
Orbit[6]	
Period (P)	$27.54^{+0.39}_{-0.43}$ yr
Semi-major axis (a)	$3.557^{+0.026}_{-0.023}$ AU
Eccentricity (e)	0.343 ± 0.005
Inclination (i)	100.26 ± 0.05°
Longitude of the node (Ω)	139.67 ± 0.05°
Periastron epoch (T)	2 017.78 ± 0.05
Argument of periastron (ω) (secondary)	128.1 ± 1.5°
Details[7][8][5]	
Luhman 16A	
Mass	0.032 $M_\odot$
Mass	33.5 ± 0.3[6] M_{Jup}
Radius	~0.85[note 1] R_{Jup}
Luminosity	0.000 0219[5] $L_\odot$
Temperature	1350 K
Luhman 16B	
Mass	0.027 $M_\odot$
Mass	28.6 ± 0.3[6] M_{Jup}
Radius	~1.04[note 1] R_{Jup}
Luminosity	0.000 0209[5] $L_\odot$
Temperature	1210 K
Position (relative to A)[4]	
Component	B
Angular distance	1.5″

afterwards it was precovered from the Digitized Sky Survey (DSS, 1978 (IR) & 1992 (red)),[4] Infrared Astronomical Satellite (IRAS, 1983),[1] ESO Schmidt telescope (1984 (red)),[1] Guide Star Catalog (GSC, 1995),[1] Deep Near Infrared Survey of the Southern Sky (DENIS, 1999),[4] Two Micron All-Sky Survey (2MASS, 1999),[4] and the AKARI satellite (2007).[1]

On the ESO Schmidt telescope image, taken in 1984, the source looks elongated with a position angle of 138°.[1] The similarity of this position angle with that of the resolved pair in the GMOS image (epoch 2013) in Fig. 1 of Luhman (2013) suggests that the time period between 1984 and 2013 may be close to the orbital period of the system (not far from original orbital period estimate by Luhman (2013)[4]).[1]

Observed separation (projected)	3 AU
Other designations	
LUH 16,[1] Luhman–WISE 1,[1] WISE J104915.57−531906.1,[4] DENIS-P J104919.0−531910,[9] 2MASS J10491891−5319100,[9] IRAS Z10473-5303,[1] AKARI J1049166−531907,[1] GSC2.2 S11132026703,[1] GSC2.3 S4BM006703,[1] TIC 119862115,[9] GJ 11551[10]	
Database references	
SIMBAD	The system (https://simbad.cds.unistra.fr/simbad/sim-id?Ident=WISE+J104915.57-531906.1)
	A (https://simbad.cds.unistra.fr/simbad/sim-id?Ident=NAME+WISE+J1049-5319A)
	B (https://simbad.cds.unistra.fr/simbad/sim-id?Ident=NAME+WISE+J1049-5319B)



Location of Luhman 16 in the constellation Vela

Name

Eric E. Mamajek proposed the name Luhman 16 for the system, with the components called Luhman 16A and Luhman 16B. The name originates from the frequently updated Washington Double Star Catalog (WDS). Kevin Luhman had already published several new discoveries of binary stars that have been compiled in the WDS with discovery identifier "LUH". The WDS catalog now lists this system with the identifier 10493−5319 and discoverer designation LUH 16.[14]

The rationale is that Luhman 16 is easier to remember than WISE J104915.57−531906.1 and that "it seems silly to call this object by a 24-character name (space included)".[1][15][note 2] The "phone number names" also include WISE J1049−5319 and WISE 1049−5319. Luhman–WISE 1 was proposed as another alternative.[1]

As a binary object it is also called Luhman 16AB.

Astrometry

Position in the sky

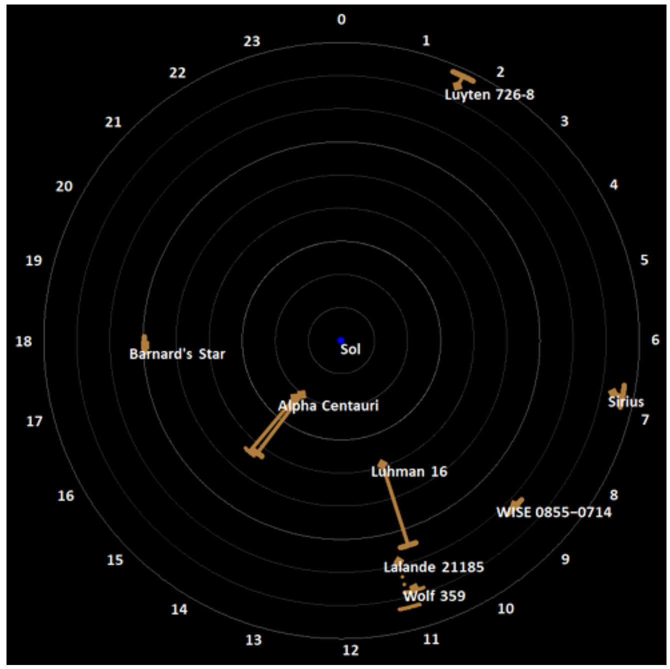
Luhman 16 is located in the southern celestial hemisphere in the constellation Vela. As of July 2015, its components are the nearest-known celestial objects in this constellation outside the Solar System. Its celestial coordinates: RA = $10^h\ 49^m\ 18.723^s$, Dec = −53° 19′ 09.86″.[1]

Distance

The trigonometric parallax of Luhman 16 as published by Sahlmann & Lazorenko (2015) is 0.500 51 ± 0.000 11 arcsec, corresponding to a distance of 6.5166 ± 0.0013 light-years (1.998 ± 0.0004 parsecs).[13]

Proximity to the Solar System

Currently Luhman 16 is the third-closest-known star/brown-dwarf system to the Sun after the triple Alpha Centauri system (4.37 ly) and Barnard's Star (5.98 ly), pushing Wolf 359 (7.78 ly) to the fifth place, along with the discovery of WISE 0855−0714. It also holds several records: the nearest brown dwarf, the nearest L-type dwarf, and possibly the nearest T-type dwarf (if component B is of T-type).



The position of Luhman 16 on a radar map among all stellar objects or stellar systems within 9 light years (ly) from the map's center, the Sun (Sol). The diamond-shapes are their positions entered according to right ascension in hours angle (indicated at the edge of the map's reference disc), and according to their declination. The second mark shows each's distance from Sol, with the concentric circles indicating the distance in steps of one ly.

Proximity to Alpha Centauri

Luhman 16 is the nearest-known star/brown-dwarf system to Alpha Centauri, located 3.577 ly (1.097 pc) from Alpha Centauri AB, and 3.520 ly (1.079 pc) from Proxima Centauri.[note 3] Both systems are located in neighboring constellations, in the same part of the sky as seen from Earth, but Luhman 16 is a bit farther away. Before the discovery of Luhman 16, the Solar System was the nearest-known system to Alpha Centauri.

Luhman 16 is closer to Proxima Centauri than to Alpha Centauri AB, just like Earth, even though Luhman 16 is further from Earth than Alpha Centauri system. Therefore Luhman 16 has smaller angular distance to Proxima Centauri than to Alpha Centauri AB in Earth's sky, and this makes more contribution to the distance difference from Luhman 16 to Alpha Centauri than to the distance difference between them and Earth.

Proper motion

Luhman 16A and B orbit each other at a distance of only 3.5 AU.[16]

The proper motion of Luhman 16 as published by Garcia *et al.* (2017), is about 2.79″/year, which is relatively large due to the proximity of Luhman 16.[5]

Radial velocity

The radial velocity of component A is 23.1 ± 1.1 km/s (14.35 ± 0.68 mi/s), and the radial velocity of component B is 19.5 ± 1.2 km/s (12.12 ± 0.75 mi/s).[8] Since values of the radial velocity are positive, the system currently is moving away from the Solar System.

Assuming these values for the components, and a mass ratio of Luhman 16 from Sahlmann & Lazorenko (2015) of 0.78,[13] the system's barycentre radial velocity is about 21.5 km/s (13.4 mi/s).[note 4] This implies that Luhman 16 passed by the Solar System around 36,000 years ago at a minimal distance of about 5.05 ly (1.55 pc).

Orbit and masses

In Luhman 16's original discovery paper, Luhman *et al.* (2013) estimated the orbital period of its components to be about 25 years.[4]

Garcia *et al.* (2017), using archival observations extending over 31 years, found an orbital period of 27.4 years with a semi-major axis of 3.54 AU. This orbit has an eccentricity of 0.35 and an inclination of 79.5°. The masses of the components were found to be $34.2^{+1.3}_{-1.2}\ M_{\mathrm{Jup}}$ and $27.9^{+1.1}_{-1.0}\ M_{\mathrm{Jup}}$, respectively, with their mass ratio being about 0.82.[5]

With the data from *Gaia* DR2 in 2018, their orbit was refined to a period of 27.5 ± 0.4 years, with a semi-major axis of 3.56 ± 0.025 AU, an eccentricity of 0.343 ± 0.005, and an inclination of 100.26° ± 0.05° (facing the opposite direction as the 2017 study found). Their masses were additionally refined to $33.51^{+0.31}_{-0.29}\ M_{\mathrm{Jup}}$ and $28.55^{+0.26}_{-0.25}\ M_{\mathrm{Jup}}$.[6]

These results are consistent with all previous estimates of the orbit and component masses.[5][1][3][13]

By comparing the rotation periods of the brown dwarfs with the projected rotational velocities, it appears that both brown dwarfs are viewed roughly equator-on, and they are aligned well to their orbits.[17]

Age

A 2013 paper, published shortly after Luhman 16 was discovered, concluded that the brown dwarf belongs to the thin disk of the Milky Way with 96% probability, and therefore does not belong to a young moving group.[1] Based on lithium absorption lines the system has a maximum age of about

3–4.5 Gyr.[18][19] Observations with the VLT showed that the system is older than 120 Myr.[20]

However, in 2022, Luhman 16 was found to be a member of the newly discovered Oceanus moving group, which has an age of 510 ± 95 Myr.[21]

Search for planets

In December 2013, perturbations of the orbital motions in the system were reported, suggesting a third body in the system. The period of this possible companion was a few months, suggesting an orbit around one of the brown dwarfs. Any companion would need to be below the brown-dwarf mass limit, because it would otherwise have been detected through direct imaging. Researchers estimated the odds of a false positive as 0.002%, assuming the measurements had not been made in error. If confirmed, this would have been the first exoplanet discovered astrometrically. They estimate the planet to likely have a mass between "a few" and 30 M_{Jup}, although they mention that a more massive planet would be brighter and therefore would affect the "photocenter" or measured position of the star. This would make it difficult to measure the astrometric movement of an exoplanet around it.[7]

Subsequent astrometric monitoring of Luhman 16 with the Very Large Telescope has excluded the presence of any third object with a mass greater than 2 M_{Jup} orbiting around either brown dwarf with a period between 20 and 300 days. Luhman 16 does not contain any close-in giant planets.[13]

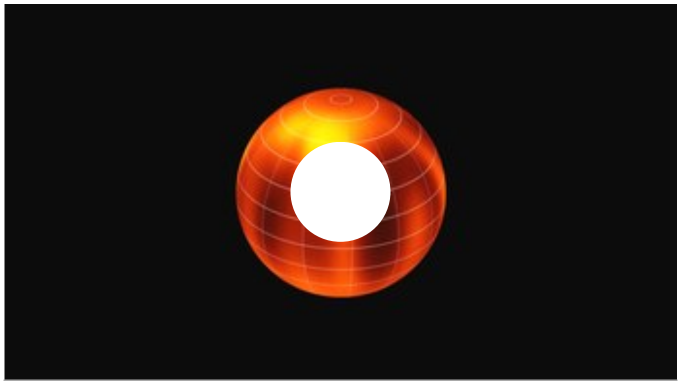
Observations with the *Hubble Space Telescope* in 2014–2016 confirmed the nonexistence of any additional brown dwarfs in the system. It additionally ruled out any Neptune mass (17 M_{Earth}) objects with an orbital period of one to two years.[22] This makes the existence of the previously found exoplanet candidate highly unlikely.

Atmosphere

A study by Gillon *et al.* (2013) found that Luhman 16B exhibited uneven surface illumination during its rotation.[23] On 5 May 2013, Crossfield *et al.* (2014) used the European Southern Observatory's Very Large Telescope (VLT) to directly observe the Luhman 16 system for five hours, the equivalent of a full rotation of Luhman 16B.[24][25] Their research confirmed Gillon *et al.*'s observation, finding a large, dark region at the middle latitudes, a bright area near its upper pole, and mottled illumination elsewhere. They suggest this variant illumination indicates "patchy global clouds", where darker areas represent thick clouds and brighter areas are holes in the cloud layer permitting light from the interior.[24][25] Luhman 16B's illumination patterns change rapidly, on a day-to-day basis.[23][17] Luhman 16B is one of the most photometrically variable brown dwarfs known, sometimes varying with an amplitude of over 20%.[26] Only 2MASS J21392676+0220226 is known to be more variable.[26]

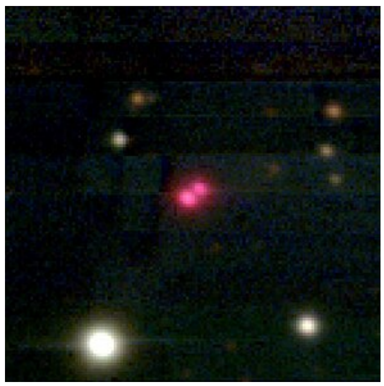
Heinze *et al.* (2021) observed variability in spectral lines of alkali metals such as potassium and sodium; they suggested that the variations were caused by changes in cloud cover, which changed the local chemical equilibrium with chlorides. Lightning or aurorae were deemed possible, but less likely.[26]

Luhman 16B's lightcurve shows evidence of differential rotation. There is evidence of equatorial regions and mid-latitude regions with different rotation periods. The main period is 5.28 hours, corresponding to the rotation period of the equatorial region.[17] Meanwhile, the rotation period of Luhman 16A is likely 6.94 hours.[17]



Surface map of Luhman 16B recreated from VLT observations

Artist's impression of Luhman 16B based on the VLT observations



Luhman 16 with VLT's MUSE instrument in visible light.

Radio and X-ray activity

In a study by Osten *et al.* (2015), Luhman 16 was observed with the Australia Telescope Compact Array in radio waves and with the Chandra X-ray Observatory in X-rays. No radio or X-ray activity was found at Luhman 16 AB, and constraints on radio and X-ray activity were presented, which are "the strongest constraints obtained so far for the radio and X-ray luminosity of any ultracool dwarf".[27]

See also

- Substellar object

Notes

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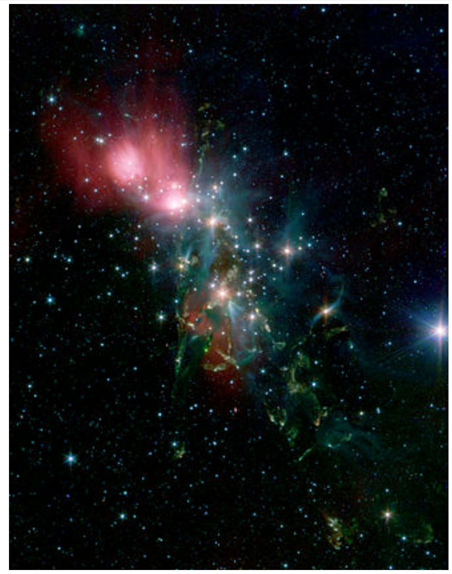
NGC 1333

NGC 1333 is a reflection nebula located in the northern constellation Perseus, positioned next to the southern constellation border with Taurus and Aries.[3] It was first discovered by German astronomer Eduard Schönfeld in 1855.[4] The nebula is visible as a hazy patch in a small telescope, while a larger aperture will show a pair of dark nebulae designated Barnard 1 and Barnard 2.[5] It is associated with a dark cloud L1450 (Barnard 205). Estimates of the distance to this nebula range from 980–1,140 ly (300–350 pc).[4]

NGC 1333	
Reflection nebula	



An infrared image of NGC 1333 by the Spitzer Space Telescope

Observation data: J2000.0 epoch	
Right ascension	$03^h\ 29^m\ 11.3^s$[1]
Declination	+31° 18′ 36″[1]
Distance	967 ly (296.5 pc)[1] ly
Apparent magnitude (V)	5.6
Apparent dimensions (V)	6′ x 3′
Constellation	Perseus
Designations	Ced 16, GN 03.26.1, LBN 741[2]

This nebula is in the western part[4] of the Perseus molecular cloud and is a young region of very active star formation,[6] being one of the best-studied objects of its type.[4] It contains a fairly typical hierarchy of star clusters that are still embedded in the molecular cloud in which they formed,[7] which are split into two main sub-groups to the north and south. Most of the infrared emission is happening in the southern part of the nebula. A significant portion of the stars seen in the infrared are in the pre-main sequence stage of their evolution.[6]

The nebula region has a combined mass of approximately 450 $M_\odot$,[4] while the cluster contains around 150 stars with a median age of a million years and a combined mass of 100 $M_\odot$. The average star formation rate is $1 \times 10^{-4}\ M_\odot\ \mathrm{yr}^{-1}$.[4] Within the nebula are 20 young stellar objects producing outflows, including Herbig–Haro objects, and a total of 95 X-ray sources that are associated with known members of embedded star clusters.[6] In 2011 researchers reported finding 30 to 40 brown dwarf objects in the cloud and in the Rho Ophiuchi cloud complex.[8]

15 objects with a spectral type of M9 or later were discovered in NGC 1333. This spectral type corresponds to a mass of a planetar-mass object (PMO) at the age of NGC 1333. About 42% of the PMO are surrounded by a circumstellar disk, but only one out of six objects with a spectral type of L0 (about 10 M_J) or later has a disk. Scholz et al. argues that this indicates that very low mass PMOs form like planets (aka ejected planets) and not like stars (also called sub-brown dwarfs).[9] Parker & Alves de Oliveira on the other hand argue that the distribution of PMOs in NGC 1333 follows N-body simulations of objects that form like stars and that none of the PMOs has a peculiar motion, which is predicted for ejected planets. They also note that ejected planets are hiding in this and star-forming regions.[10]

Gallery

A small region of NGC 1333 taken by Hubble Space Telescope.[11]

There are 5 Herbig–Haro objects (numbered 7 to 11) in NGC 1333.[12]

NGC 1333 by the Mount Lemmon Sky Center

The region south of NGC 1333 in infrared. It shows the dark clouds Barnard 203 and 204

Perseus giant molecular cloud with star nurseries IC348 and NGC1333

References

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2. "NGC 1333" (http://simbad.u-strasbg.fr/simbad/sim-basic?Ident=NGC+1333). *SIMBAD*. Centre de données astronomiques de Strasbourg. Retrieved 2020-08-15.
3. Sinnott, Roger W.; Perryman, Michael A. C. (1997). *Millennium Star Atlas*. Vol. 1. Sky Publishing Corporation and the European Space Agency. ISBN 0-933346-84-0.
4. Walawender, J.; et al. (December 2008). Reipurth, Bo (ed.). *NGC 1333: A Nearby Burst of Star Formation* (http://www.ifa.hawaii.edu/publications/preprints/08preprints/Walawender_08-206.pdf) (PDF). p. 346. Bibcode:2008hsf1.book..346W (https://ui.adsabs.harvard.edu/abs/2008hsf1.book..346W). Retrieved 2020-08-15. {{cite book}}: |work= ignored (help)

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TRAPPIST-1

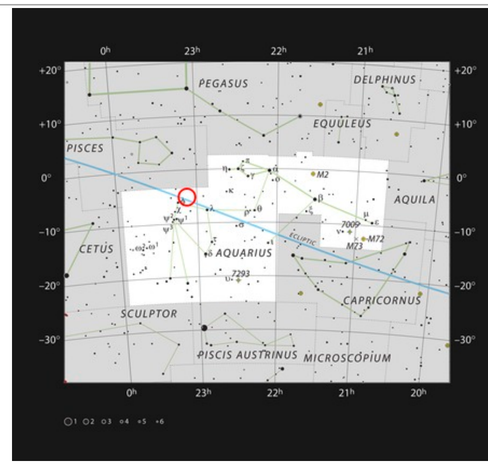
Coordinates: 23h 06m 29.383s, −05° 02′ 28.59″

TRAPPIST-1 is a cool red dwarf star[b] with seven known exoplanets. It lies in the constellation Aquarius about 40.66 light-years away from Earth, and has a surface temperature of about 2,566 kelvins (2,290 degrees Celsius; 4,160 degrees Fahrenheit). Its radius is slightly larger than Jupiter and it has a mass of about 9% of the Sun. It is estimated to be 7.6 billion years old, making it older than the Solar System. The discovery of the star was first published in 2000.

Observations in 2016 from the Transiting Planets and Planetesimals Small Telescope (TRAPPIST) at La Silla Observatory in Chile and other telescopes led to the discovery of two terrestrial planets in orbit around TRAPPIST-1. In 2017, further analysis of the original observations identified five more planets, of unknown types. It takes the seven planets between about 1.5 and 19 days to orbit around the star in circular orbits. They are likely tidally locked to TRAPPIST-1, such that one side of each planet always faces the star, leading to permanent day on one side and permanent night on the other. Their masses are comparable to that of Earth and they all lie in the same plane; from Earth they seem to move past the disk of the star.

Up to four of the planets – designated *d*, *e*, *f* and *g* – orbit at distances where temperatures are suitable for the existence of liquid water, and are thus potentially hospitable to life. There is no evidence of an atmosphere on any of the planets. It is unclear whether radiation emissions from TRAPPIST-1 would allow for such atmospheres. The planets have low densities; they may consist of large amounts of volatile materials. Due to the possibility of several of the planets being habitable, the system has drawn interest from researchers and has appeared in popular culture.

TRAPPIST-1



TRAPPIST-1 is within the red circle in the constellation Aquarius.

Observation data	
Epoch J2000	Equinox J2000
Constellation	Aquarius
Right ascension	23h 06m 29.368s[1]
Declination	−05° 02′ 29.04″[1]
Apparent magnitude (V)	18.798 ± 0.082[2]
Characteristics	
Evolutionary stage	Main sequence
Spectral type	M8V[3]
Apparent magnitude (R)	16.466 ± 0.065[2]
Apparent magnitude (I)	14.024 ± 0.115[2]
Apparent magnitude (J)	11.354 ± 0.022[4]
Apparent magnitude (H)	10.718 ± 0.021[4]
Apparent magnitude (K)	10.296 ± 0.023[4]
V−R color index	2.332
R−I color index	2.442
J−H color index	0.636
J−K color index	1.058
Astrometry	
Proper motion (μ)	RA: 930.788[1] mas/yr Dec.: −479.038[1] mas/yr
Parallax (π)	80.2123 ± 0.0716 mas[1]
Distance	40.66 ± 0.04 ly (12.47 ± 0.01 pc)
Details	

Discovery

The star now known as TRAPPIST-1 was discovered in 1999 by astronomer John Gizis and colleagues[16] during a survey of close-by ultra-cool dwarf stars.[17][18] It appeared in sample C[16][17] of the surveyed stars, which was obtained in June 1999. Publication of the discovery took place in 2000.[19] The name is a reference to the TRansiting Planets and PlanetesImals Small Telescope (TRAPPIST)[11][c] project that discovered the first two exoplanets around the star.[23]

Its planetary system was discovered by a team led by Michaël Gillon, a Belgian astronomer[24] at the University of Liege,[25] in 2016[26] during observations made at the La Silla Observatory, Chile,[27][28] using the TRAPPIST telescope. The discovery was based on anomalies in the light curves[d] measured by the telescope in 2015. These were initially interpreted as indicating the existence of three planets. In 2016, separate discoveries revealed that the third planet was in fact multiple planets. The telescopes and observatories involved were[11] the Spitzer Space Telescope; the ground-based TRAPPIST and TRAPPIST-North in Oukaïmeden Observatory, Morocco; the South African Astronomical

Observatory; and the Liverpool Telescopes and William Herschel Telescopes in Spain.[30]

The observations of TRAPPIST-1 are considered among the most important research findings of the Spitzer Space Telescope.[31] Complementing the findings were observations by the Himalayan Chandra Telescope, the United Kingdom Infrared Telescope, and the Very Large Telescope.[32] Since then, research has confirmed the existence of at least seven planets in the system,[33] the orbits of which have been calculated using measurements from the Spitzer and Kepler telescopes.[34] Some news reports incorrectly attributed the discovery of the TRAPPIST-1 planets to NASA; in fact the TRAPPIST project that led to their discovery received funding from both NASA and the European Research Council of the European Union (EU).[35]

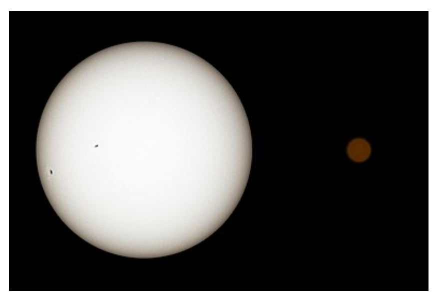
Mass	0.0898 ± 0.0023[5] $M_\odot$
Radius	0.1192 ± 0.0013[5] $R_\odot$
Luminosity (bolometric)	0.000553 ± 0.000018[5] $L_\odot$
Surface gravity (log *g*)	$5.2396^{+0.0056}_{-0.0073}$[a][5] cgs
Temperature	2,566 ± 26[5] K
Metallicity [Fe/H]	0.04 ± 0.08[6] dex
Rotation	3.295 ± 0.003 days[7]
Rotational velocity (*v* sin *i*)	6[8] km/s
Age	7.6 ± 2.2[9] Gyr
Other designations	
2MUDC 12171,[10] 2MASS J23062928–0502285, EPIC 246199087,[11] K2-112,[12] SPECULOOS-1, an internal name of the star used by the SPECULOOS project, as this star was its first discovery,[13] and TRAPPIST-1a.[14]	
Database references	
SIMBAD	data (https://simbad.cds.unistra.fr/simbad/sim-id?Ident=2MASS+J23062928-0502285)
Exoplanet Archive	data (https://exoplanetarchive.ipac.caltech.edu/cgi-bin/DisplayOverview/nph-DisplayOverview?objname=TRAPPIST-1)
Extrasolar Planets Encyclopaedia	data (http://exoplanet.eu/star.php?st=TRAPPIST-1)

Description

TRAPPIST-1 is in the constellation Aquarius,[25] five degrees south of the celestial equator.[e][1][37] It is a relatively close star[38] located 40.66 ± 0.04 light-years from Earth,[f][1] with a large proper motion[g][38] and no companion stars.[41]

It is a red dwarf of spectral class M8.0 ± 0.5,[h][32][44] meaning it is relatively small and cold.[45] With a radius 12% of that of the Sun, TRAPPIST-1 is only slightly larger than the planet Jupiter (though much more massive).[32] Its mass is approximately 9% of that of the Sun,[45] being just sufficient to allow nuclear fusion to take place.[46][47] TRAPPIST-1's density is unusually low for a red dwarf.[48] It has a low effective temperature[i] of 2,566 K (2,293 °C) making it, as of 2022, the coldest-known star to host planets.[50] TRAPPIST-1 is cold enough for condensates to form in its photosphere;[j] these have been detected through the polarisation they induce in its radiation during transits of its planets.[52]

There is no evidence that it has a stellar cycle.[k][54] Its luminosity, emitted mostly as infrared radiation, is about 0.055% that of the Sun.[45][55] Low precision[56] measurements from the XMM-Newton satellite[57] and other facilities[58] show that the star emits faint radiation at short wavelengths such as x-rays and UV radiation.[l][57] There are no detectable radio wave emissions.[60]



True-colour illustration of the Sun *(left)* next to TRAPPIST-1 *(right)*. TRAPPIST-1 is darker, redder, and smaller than the Sun.

Rotation period and age

Measurements of TRAPPIST-1's rotation have yielded a period of 3.3 days; earlier measurements of 1.4 days appear to have been caused by changes in the distribution of its starspots.[61] Its rotational axis may be slightly offset from that of its planets.[62]

Using a combination of techniques, the age of TRAPPIST-1 has been estimated at about 7.6 ± 2.2 billion years,[63] making it older than the Solar System, which is about 4.5 billion years old.[64] It is expected to shine for ten trillion years – about 700 times[65] longer than the present age of the Universe[66] – whereas the Sun will run out of hydrogen and leave the main sequence[m] in a few billion years.[65]

Activity

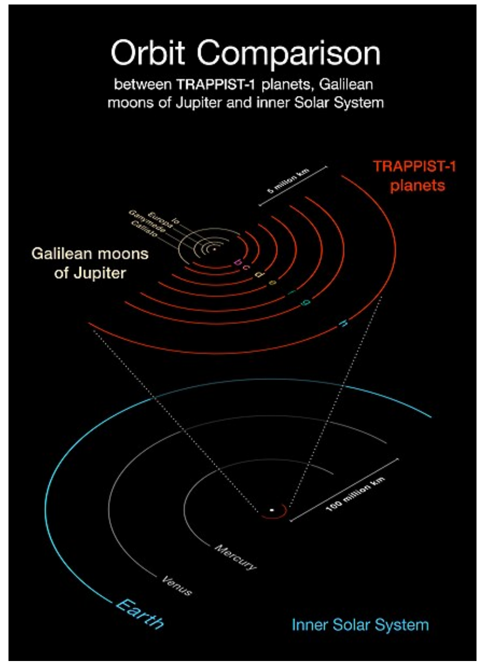
Photospheric features have been detected on TRAPPIST-1.[68] The Kepler and Spitzer Space Telescopes have observed possible bright spots, which may be faculae,[n][70][71] although some of these may be too large to qualify as such.[72] Bright spots are correlated to the occurrence of some stellar flares.[o][73]

The star has a strong magnetic field[74] with a mean intensity of about 600 gauss.[p][76] The magnetic field drives high chromospheric[q][74] activity, and may be capable of trapping coronal mass ejections.[r][69][77]

According to Garraffo *et al.* (2017), TRAPPIST-1 loses about 3×10^{-14} solar masses per year[78] to the stellar wind, a rate which is about 1.5 times that of the Sun. [79] Dong *et al.* (2018) simulated the observed properties of TRAPPIST-1 with a mass loss of 4.1×10^{-15} solar masses per year.[78] Simulations to estimate mass loss are complicated because, as of 2019, most of the parameters that govern TRAPPIST-1's stellar wind are not known from direct observation.[80]

Planetary system

TRAPPIST-1 is orbited by seven planets, designated TRAPPIST-1b, 1c, 1d, 1e, 1f, 1g, and 1h[81] in alphabetic order going out from the star.[s][84] These planets have orbital periods ranging from 1.5–19 days,[85][86][6] at distances of 0.011–0.059 astronomical units[t] (1,700,000–8,900,000 km).[88]



Comparison of the orbits of the TRAPPIST-1 planets with the Solar System and Jupiter's moons

All the planets are much closer to their star than Mercury is to the Sun,[26] making the TRAPPIST-1 system very compact.[89] Kral *et al.* (2018) did not detect any comets around TRAPPIST-1,[90] and Marino *et al.* (2020) found no evidence of a Kuiper belt,[91] although it is uncertain whether a Solar System-like belt around TRAPPIST-1 would be observable from Earth.[92] Observations with the Atacama Large Millimeter Array found no evidence of a circumstellar dust disk.[93]

The inclinations of planetary orbits relative to the system's ecliptic are less than 0.1 degrees[u],[95] making TRAPPIST-1 the flattest planetary system in the NASA Exoplanet Archive.[96] The orbits are highly circular, with minimal eccentricities[v][89] and are well-aligned with the spin axis of TRAPPIST-1.[98] The planets orbit in the same plane and, from the perspective of the Solar System, transit TRAPPIST-1 during their orbit[99] and frequently pass in front of each other.[100]

Size and composition

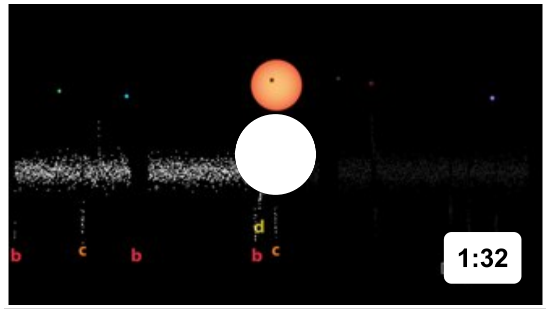
The radii of the planets are estimated to range between $77.5^{+1.4}_{-1.4}$ and $112.9^{+1.5}_{-1.3}$% of Earth's radius.[101] The planets:star mass ratio of the TRAPPIST-1 system resembles that of the moons:planet ratio of the Solar System's gas giants.[102]

The TRAPPIST-1 planets are expected to have compositions that resemble each other[103] as well as that of Earth.[104] The estimated densities of the planets are lower than Earth's[34] which may imply that they have large amounts of volatile chemicals.[w] Alternatively, their cores may be smaller than that of Earth;[106] or include large amounts of elements other than iron;[107] or their iron may exist in an oxidised form rather than as a core;[106] or they may be rocky planets with less iron than that of Earth.[108] Their densities are too low for a pure magnesium silicate composition,[x] requiring the presence of lower-density compounds such as water.[110][111] Planets b, d, f, g and h are expected to contain large quantities of volatile chemicals.[112] The planets may have deep atmospheres and oceans, and contain vast amounts of ice.[113] Several compositions are possible considering the large uncertainties in their densities.[114] The photospheric features of the star may introduce inaccuracies in measurements of the properties of TRAPPIST-1's planets,[68] including their densities being underestimated by 8^{+20}_{-7} percent,[115] and incorrect estimates of their water content.[116]

Resonance and tides

The planets are in orbital resonances.[117] The durations of their orbits have ratios of 8:5, 5:3, 3:2, 3:2, 4:3 and 3:2 between neighbouring planet pairs,[118] and each set of three is in a Laplace resonance.[y][89] Simulations have shown such resonances can remain stable over billions of years but that their stability is strongly dependent on initial conditions. Many configurations become unstable after less than a million years. The resonances enhance the exchange of angular momentum between the planets, resulting in measurable variations – earlier or later – in their transit times in front of

TRAPPIST-1. These variations yield information on the planetary system,[120] such as the masses of the planets, when other techniques are not available.[121] The resonances and the proximity to the host star have led to comparisons between the TRAPPIST-1 system and the Galilean moons of Jupiter.[99] Kepler-223 is another exoplanet system with a TRAPPIST-1-like long resonance.[122]



Animation of TRAPPIST-1 exoplanets transiting their host star, with effects on the star's light curve.

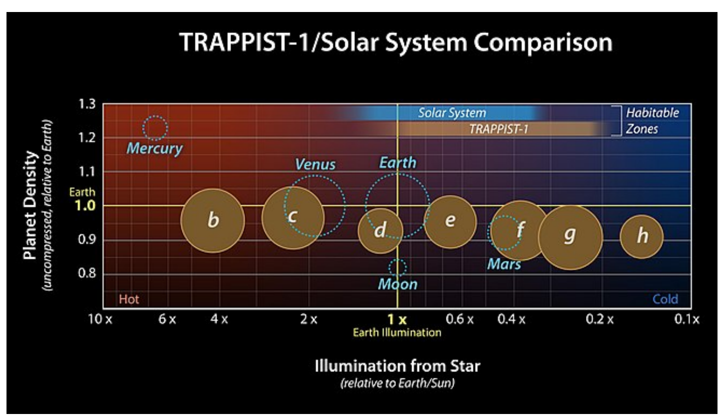
The mutual interactions of the planets could prevent them from reaching full synchronisation, which would have important implications for the planets' climates. These interactions could force periodic or episodic full rotations of the planets' surfaces with respect to the star on timescales of several Earth years.[123] Vinson, Tamayo and Hansen (2019) found the planets TRAPPIST-1d, e and f likely have chaotic rotations due to mutual interactions, preventing them from becoming synchronised to their star. Lack of synchronisation potentially makes the planets more habitable.[124] Other processes that can prevent synchronous rotation are torques induced by stable triaxial deformation of the planets,[z] which would allow them to enter 3:2 resonances.[126]

The closeness of the planets to TRAPPIST-1 results in tidal interactions[127] stronger than those on Earth.[128] All the planets have reached an equilibrium with slow planetary rotations and tidal locking,[127] which can lead to the synchronisation of a planet's rotation to its revolution around its star.[aa][130]

The planets are likely to undergo substantial tidal heating[131] due to deformations arising from their orbital eccentricities and gravitational interactions with one another.[132] Such heating would facilitate volcanism and degassing[ab] especially on the innermost planets, with degassing facilitating the establishment of atmospheres.[134] According to Luger *et al.* (2017), tidal heating of the four innermost planets is expected to be greater than Earth's inner heat flux.[135] For the outer planets Quick *et al.* (2020) noted that their tidal heating could be comparable to that in the Solar System bodies Europa, Enceladus, and Triton.[136]

Tidal heating could influence temperatures of the night sides and cold areas where volatiles may be trapped, and gases are expected to accumulate; it would also influence the properties of any subsurface oceans[137] where volcanism and hydrothermal venting[ac] could occur.[139] It may further be sufficient to melt the mantles of the four innermost planets, in whole or in part,[140] potentially forming subsurface magma oceans.[141] This heat source is likely dominant over radioactive decay, both of which have substantial uncertainties and are considerably less than the stellar radiation received.[142] Intense tides could fracture the planets' crusts even if they are not sufficiently strong to trigger the onset of plate tectonics.[143] Tides can also occur in the planetary atmospheres.[144]

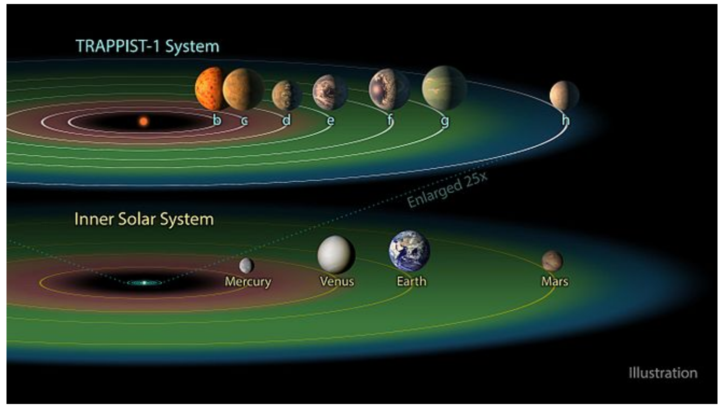
Skies and impact of stellar light



Relative sizes, densities,[ad] and illumination of the TRAPPIST-1 system compared to the inner planets of the Solar System

Because most of TRAPPIST-1's radiation is in the infrared region, there may be very little visible light on the planets' surfaces; Amaury Triaud, one of the system's co-discoverers, said the skies would never be brighter than Earth's sky at sunset[146] and only a little brighter than a night with a full moon. Ignoring atmospheric effects, illumination would be orange-red.[147] All of the planets would be visible from each other and would, in many cases, appear larger than Earth's Moon in the sky of Earth;[26] observers on TRAPPIST-1e, f and g, however, could never experience a total stellar eclipse.[ae][84] Assuming the existence of atmospheres, the star's long-wavelength radiation would be absorbed to a greater degree by water and carbon dioxide than sunlight on Earth; it would also be scattered less by the atmosphere[148] and less reflected by ice,[149] although the development of highly reflective hydrohalite ice may negate this effect.[150] The same amount of radiation results in a warmer planet compared to Sun-like irradiation;[148] more radiation would be absorbed by the planets' upper atmosphere than by the lower layers, making the atmosphere more stable and less prone to convection.[151]

Habitable zone



Habitable zones of TRAPPIST-1 and the Solar System. The displayed planetary surfaces are speculative.

For a dim star like TRAPPIST-1, the habitable zone[af] is located closer to the star than for the Sun.[152] Three or four[57] planets might be located in the habitable zone; these include *e*, *f*, and *g*;[152] or *d*, *e*, and *f*.[74] As of 2017, this is the largest-known number of planets within the habitable zone of any known star or star system.[153] The presence of liquid water on any of the planets depends on several other factors, such as albedo (reflectivity),[154] the presence of an atmosphere[155] and any greenhouse effect.[156] Surface conditions are difficult to constrain without better knowledge of the planets' atmospheres.[155] A synchronously rotating planet might not entirely freeze over if it receives too little radiation from its star because the day-side could be sufficiently heated to halt the progress of glaciation.[157] Other factors for the occurrence of liquid water include the presence of oceans and vegetation;[158] the reflective properties of the land surface; the configuration of continents and oceans;[159] the presence of clouds;[160] and sea ice dynamics.[161] The effects of volcanic activity may extend the system's habitable zone to TRAPPIST-1h.[162]

Intense extreme ultraviolet (XUV) and X-ray radiation[163] can split water into its component parts of hydrogen and oxygen, and heat the upper atmosphere until they escape from the planet. This was thought to have been particularly important early in the star's history, when radiation was more intense and could have heated every planet's water to its boiling point.[149] This process is believed to have removed water from Venus.[164] In the case of TRAPPIST-1, different studies with different assumptions on the kinetics, energetics, and XUV emissions have come to different conclusions on whether any TRAPPIST-1 planet may retain substantial amounts of water. Because the planets are most likely synchronised to their host star, any water present could become trapped on the planets' night sides and would be unavailable to support life unless heat transport by the atmosphere[165] or tidal heating are intense enough to melt ice.[166]

Moons

No moons with a size comparable to Earth's have been detected in the TRAPPIST-1 system,[167] and they are unlikely in such a densely packed planetary system. This is because moons would likely be either destroyed by their planet's gravity after entering its Roche limit[ag] or stripped from the planet by leaving its Hill radius[ah][170] Although the TRAPPIST-1 planets appear in an analysis of potential exomoon hosts, they do not appear in the list of habitable-zone exoplanets that could host a moon for at least one Hubble time,[171] a timeframe slightly longer than the current age of the Universe.[172] Despite these factors, it is possible the planets could host moons.[173]

Magnetic effects

The TRAPPIST-1 planets are expected to be within the Alfvén surface of their host star,[174] the area around the star within which any planet would directly magnetically interact with the corona of the star, possibly destabilising any atmosphere the planet has.[175] Stellar energetic particles would not create a substantial radiation hazard for organisms on TRAPPIST-1 planets if atmospheres reached pressures of about 1 bar.[176] Estimates of radiation fluxes have considerable uncertainties due to the lack of knowledge about the structure of TRAPPIST-1's magnetic field.[177] Induction heating from the star's time-varying electrical and magnetic fields[140][178] may occur on its planets[179] but this would make no substantial contribution to their energy balance[142] and is vastly exceeded by tidal heating.[136]

Formation history

The TRAPPIST-1 planets most likely formed further from the star and migrated inwards,[180] although it is possible they formed in their current locations.[181] According to Ormel *et al.* (2017), the planets formed when a streaming instability[ai] at the water-ice line gave rise to precursor bodies, which accumulated additional fragments and migrated inwards, eventually giving rise to planets.[183] The migration may initially have been fast and later slowed,[184] and tidal effects may have further influenced the formation processes.[185] The distribution of the fragments would have controlled the final mass of the planets, which would consist of approximately 10% water consistent with observational inference.[183] Resonant chains of planets like those of TRAPPIST-1 usually become unstable when the gas disk that gave rise to them dissipates, but in this case, the planets remained in resonance.[186] The resonance may have been either present from the system's formation and was preserved when the planets simultaneously moved inwards,[187] or it might have formed later when inward-migrating planets accumulated at the outer edge of the gas disk and interacted with each other.[181] Inward-migrating planets would contain substantial amounts of water – too much for it to entirely escape – whereas planets that formed in their current location would most likely lose all water.[188][189] According to Flock *et al.* (2019), the orbital distance of the innermost planet TRAPPIST-1b is consistent with the expected radius of an inward-moving planet around a star that was one order of magnitude brighter in the past,[190] and with the cavity in the protoplanetary disc created by TRAPPIST-1's magnetic field.[191] Alternatively, TRAPPIST-1h may have formed in or close to its current location.[192]

The presence of other bodies and planetesimals early in the system's history would have destabilised the TRAPPIST-1 planets' resonance if the bodies were massive enough.[193] Raymond *et al.* (2021) concluded the TRAPPIST-1 planets assembled in 1–2 million years, after which time little additional mass was accreted.[194] This would limit any late delivery of water to the planets[195] and also implies the planets cleared the neighbourhood[aj] of any additional material.[196] The lack of giant impact events (the rapid formation of the planets would have quickly exhausted pre-planetary material) would help the planets preserve their volatile materials.[197]

Due to a combination of high insolation, the greenhouse effect of water vapour atmospheres and remnant heat from the process of planet assembly, the TRAPPIST-1 planets would likely have initially had molten surfaces. Eventually the surfaces would cool until the magma oceans solidified, which in the case of TRAPPIST-1b may have taken between a few billions of years, or a few millions of years. The outer planets would then have become cold enough for water vapour to condense.[198]

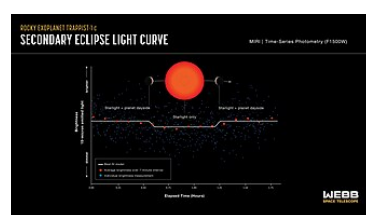
List of planets

The TRAPPIST-1 system with distances to scale, compared with the Moon-Earth distance

TRAPPIST-1b

TRAPPIST-1b has a semi-major axis of 0.0115 astronomical units (1,720,000 km)[199] and an orbital period of 1.51 Earth days. It is expected to be tidally locked to its star. The planet is outside the habitable zone;[200] its expected irradiation is more than four times that of Earth.[200] TRAPPIST-1b has a slightly larger measured radius and mass than Earth but estimates of its density imply it does not exclusively consist of rock.[201] Owing to its black-body temperature of 124 °C (397 K), TRAPPIST-1b may have had a runaway greenhouse effect similar to that of Venus;[74] its atmosphere, if present, may be similarly deep, dense, and hot.[202] Based on several climate models, the planet would have been desiccated by TRAPPIST-1's stellar wind and radiation;[203][204] it could be quickly losing hydrogen and therefore any hydrogen-dominated atmosphere.[ak] Water, if any exists, could persist only in specific settings on the planet,[206] whose surface temperature could be as high as 1,200 °C (1,470 K), making TRAPPIST-1b a candidate magma ocean planet.[207]

TRAPPIST-1c



Infrared measurements by the NASA / ESA / Canadian Space Agency / James Webb Space Telescope of TRAPPIST-1 c indicate that it is likely not as Venus-like as once imagined.

TRAPPIST-1c has a semi-major axis of 0.0158 AU (2,360,000 km)[199] and orbits its star every 2.42 Earth days. It is close enough to TRAPPIST-1 to be tidally locked.[200] Its atmosphere could either be absent or thick like that of Venus.[202] TRAPPIST-1c is outside the habitable zone[200] as it receives about twice as much stellar irradiation as Earth[208] and thus either is or has been a runaway greenhouse.[74] Based on several climate models, the planet would have been desiccated by TRAPPIST-1's stellar wind and radiation.[203] TRAPPIST-1c could harbour water only in specific settings on its surface.[206] Observations in 2017 showed no escaping hydrogen,[58] but observations by the Hubble Space Telescope (HST) in 2020 indicated that hydrogen may be escaping at a rate of 1.4×10^7 g/s.[205]

TRAPPIST-1d

TRAPPIST-1d has a semi-major axis of 0.022 AU (3,300,000 km) and an orbital period of 4.05 Earth days. It is more massive but less dense than Mars.[209] Based on fluid dynamical arguments, TRAPPIST-1d is expected to have weak temperature gradients on its surface if it is tidally locked,[210] and may have significantly different stratospheric dynamics than that of Earth.[211] Several climate models suggest that the planet may[203] or may not have been desiccated by TRAPPIST-1's stellar wind and radiation;[203] density estimates, if confirmed, indicate it is not dense enough to consist solely of rock.[201] The current state of TRAPPIST-1d depends on its rotation and climatic factors like cloud feedback;[al][202] it is close to the inner edge of the habitable zone, but the existence of either liquid water or alternatively a runaway greenhouse effect (that would render it uninhabitable) are dependent on detailed atmospheric conditions.[213] Water could persist in specific settings on the planet.[206]

TRAPPIST-1e

TRAPPIST-1e has a semi-major axis of 0.029 AU (4,300,000 km)[199] and orbits its star every 6.10 Earth days.[214] It has density similar that of Earth.[215] Based on several climate models, the planet is the most likely of the system to have retained its water,[203] and the most likely to have liquid water for many climate states. A dedicated climate model project called TRAPPIST-1 Habitable Atmosphere Intercomparison (THAI) has been launched to study its potential climate states.[216] Based on observations of its Lyman-alpha radiation emissions, TRAPPIST-1e may be losing hydrogen at a rate of 0.6×10^7 g/s.[205]

TRAPPIST-1e is in a comparable position within the habitable zone to that of Proxima Centauri b,[am][218][219] which also has an Earth-like density.[215] TRAPPIST-1e could have retained masses of water equivalent to several of Earth's oceans.[74] Moderate quantities of carbon dioxide could warm TRAPPIST-1e to temperatures suitable for the presence of liquid water.[204]

TRAPPIST-1f

TRAPPIST-1f has a semi-major axis of 0.038 AU (5,700,000 km)[199] and orbits its star every 9.21 Earth days.[214] It is likely too distant from its host star to sustain liquid water, being instead an entirely glaciated snowball planet.[203] Moderate quantities of CO_2 could warm TRAPPIST-1f to temperatures suitable for the presence of liquid water.[206] TRAPPIST-1f may have retained masses of water equivalent to several of Earth's oceans[74] and which could comprise up to half of the planet's mass;[220] it could thus be an ocean planet.[an][222]

TRAPPIST-1g

TRAPPIST-1g has a semi-major axis of 0.047 AU (7,000,000 km)[199] and orbits its star every 12.4 Earth days.[214] It is likely too distant from its host star to sustain liquid water, being instead a snowball planet.[203] Moderate quantities of CO_2[206] or internal heat from radioactive decay and tidal heating may warm its surface to above the melting point of water.[223] TRAPPIST-1g may have retained masses of water equivalent to several of Earth's oceans;[74] density estimates of the planet, if confirmed, indicate it is not dense enough to consist solely of rock.[201] Up to half of its mass may be water.[220]

TRAPPIST-1h

TRAPPIST-1h has a semi-major axis of 0.062 astronomical units (9,300,000 km); it is the system's least massive known planet[199] and orbits its star every 18.9 Earth days.[214] It is likely too distant from its host star to sustain liquid water and may be a snowball planet,[203] or have a methane/nitrogen atmosphere resembling that of Titan.[224] Large quantities of CO_2, hydrogen or methane,[225] or internal heat from radioactive decay and tidal heating,[223] would be needed to warm TRAPPIST-1h to the point where liquid water could exist.[225] TRAPPIST-1h could have retained masses of water equivalent to several of Earth's oceans.[74]

Data table

TRAPPIST-1 planets data table[226][86][6]

Planet	M	SX	OP	E	I	R	RX	T	G	ORb	ORi
b	1.374 ±0.069	0.01154 ±0.0001	1.510826 ±0.000006	0.00622 ±0.00304	89.728 ±0.165°	1.116 $^{+0.014}_{-0.012}$	4.153 ±0.160	397.6 ±3.8K (124.5 ± 3.8 °C; 256.0 ± 6.8 °F)[ao]	1.102 ±0.052	—	—
c	1.308 ±0.056	0.01580 ±0.00013	2.421937 ±0.000018	0.00654 ±0.00188	89.778 ±0.118°	1.097 $^{+0.014}_{-0.012}$	2.214 ±0.085	339.7 ±3.3K (66.6 ± 3.3 °C; 151.8 ± 5.9 °F)	1.086 ±0.043	5:8	5:8
d	0.388 ±0.012	0.02227 ±0.00019	4.049219 ±0.000026	0.00837 ±0.00093	89.896 ±0.077°	0.770 $^{+0.011}_{-0.010}$	1.115 ±0.04	286.2 ±2.8K (13.1 ± 2.8 °C; 55.5 ± 5.0 °F)	0.624 ±0.019	3:8	3:5
e	0.692 ±0.022	0.02925 ±0.00025	6.101013 ±0.000035	0.00510 ±0.00058	89.793 ±0.048°	0.920 $^{+0.013}_{-0.012}$	0.646 ±0.025	249.7 ±2.4K (−23.5 ± 2.4 °C; −10.2 ± 4.3 °F)	0.817 ±0.024	1:4	2:3
f	1.039 ±0.031	0.03849 ±0.00033	9.207540 ±0.000032	0.01007 ±0.00068	89.740 ±0.019°	1.045 $^{+0.013}_{-0.012}$	0.373 ±0.014	217.7 ±2.1K (−55.5 ± 2.1 °C; −67.8 ± 3.8 °F)	0.951 ±0.024	1:6	2:3
g	1.321 ±0.038	0.04683 ±0.0004	12.352446 ±0.000054	0.00208 ±0.00058	89.742 ±0.012°	1.129 $^{+0.015}_{-0.013}$	0.252 ±0.010	197.3 ±1.9K (−75.8 ± 1.9 °C; −104.5 ± 3.4 °F)	1.035 ±0.026	1:8	3:4
h	0.326 ±0.020	0.06189 ±0.00053	18.772866 ±0.000214	0.00567 ±0.00121	89.805 ±0.013°	0.775 $^{+0.014}_{-0.014}$	0.144 ±0.006	171.7 ±1.7K (−101.5 ± 1.7 °C; −150.6 ± 3.1 °F)	0.570 ±0.038	1:12	2:3

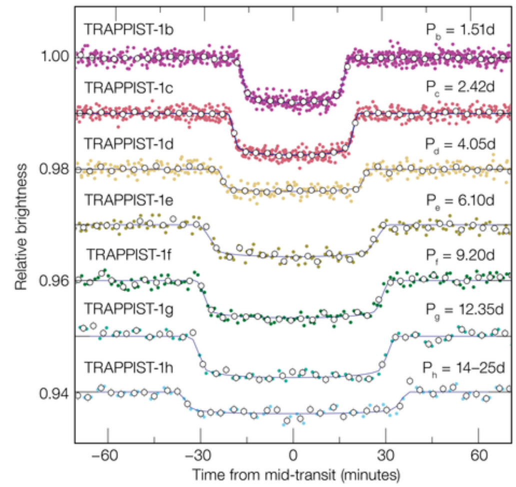
M mass (Earth masses) · **OP** orbital period (days) · **E** eccentricity[86] · **I** inclination[85] · **R** radius (Earth radii) · **RX** radiation flux (Earth units)[85] · **T** temperature[86] (equilibrium, assumes null Bond albedo) · **G** gravity (Earth units)[85] · **ORb** approximate orbital resonance with TRAPPIST-1b · **ORi** approximate orbital resonance with inward planet

Potential planetary atmospheres

As of 2020, there is no definitive evidence that any of the TRAPPIST-1 planets have an atmosphere,[ap][228] but atmospheres could be detected in the future.[229] The outer planets are more likely to have atmospheres than the inner planets.[180] Several studies have simulated how different atmospheric scenarios would look to observers, and the chemical processes underpinning these atmospheric compositions.[230] The visibility of an exoplanet and of its atmosphere scale with the inverse square of the radius of its host star.[229] Detection of individual components of the atmospheres – in particular CO_2, ozone, and water[231] – would also be possible, although different components would require different conditions and different numbers of transits.[232] A contamination of the atmospheric signals through patterns in the stellar photosphere is a further impediment to detection.[233]

The existence of atmospheres around TRAPPIST-1's planets depends on the balance between the amount of atmosphere initially present, its rate of evaporation, and the rate at which it is built back up by meteorite impacts,[89] incoming material from a protoplanetary disk[aq],[235] and outgassing and volcanic activity.[236] Impact events may be particularly important in the outer planets because they can both add and remove volatiles; addition is likely dominant in the outermost planets where impact velocities are slower.[237][238] Although the properties of TRAPPIST-1 are unfavourable to the continued existence of atmospheres around its planets,[239] the formation conditions of the planets would give them large initial quantities of volatile materials,[180] including oceans over 100 times larger than those of Earth.[240]

If the planets are tidally locked to TRAPPIST-1, surfaces that permanently face away from the star can cool sufficiently for any atmosphere to freeze out on the night side.[241] This frozen-out atmosphere could be recycled through glacier-like flows to the day side with assistance from tidal or geothermal heating from below, or could be stirred by impact events. These processes could allow an atmosphere to persist.[242] In a carbon dioxide (CO_2) atmosphere, carbon-dioxide ice is denser than water ice, under which it tends to be buried. CO_2-water compounds named clathrates[ar] can form. Further complications are a potential runaway feedback loop between melting ice and evaporation, and the greenhouse effect.[244]



Graph showing dips in brightness in TRAPPIST-1 star by the planet's transits or obstruction of starlight. Larger planets create deeper dips and further planets create longer dips.

Numerical modelling and observations constrain the properties of hypothetical atmospheres around TRAPPIST-1 planets:[180]

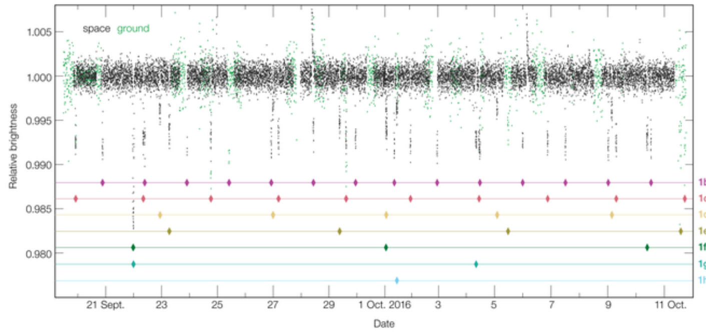
- Theoretical calculations[245] and observations have ruled out the possibility the TRAPPIST-1 planets have hydrogen-rich[222][246] or helium-rich atmospheres.[247] Hydrogen-rich exospheres[as] may be detectable[249] but have not been reliably detected,[250] except perhaps for TRAPPIST-1b and 1c by Bourrier *et al.* (2017).[192][14]
- Water-dominated atmospheres, though suggested by some density estimates, are improbable for the planets because they are expected to be unstable under the conditions around TRAPPIST-1, especially early in the star's life.[201] The spectral properties of the planets imply they do not have a cloud-free, water-rich atmosphere.[251]
- Oxygen-dominated atmospheres can form when radiation splits water into hydrogen and oxygen, and the hydrogen escapes due to its lighter mass. The existence of such an atmosphere and its mass depends on the initial water mass, on whether the oxygen is dragged out of the atmosphere by escaping hydrogen and of the state of the planet's surface; a partially molten surface could absorb sufficient quantities of oxygen to remove an atmosphere.[252]
- Atmospheres formed by ammonia and/or methane near TRAPPIST-1 would be destroyed by the star's radiation at a sufficient rate to quickly remove an atmosphere. The rate at which ammonia or methane are produced, possibly by organisms, would have to be considerably larger than that on Earth to sustain such an atmosphere. It is possible the development of organic hazes from ammonia or methane photolysis could shield the remaining molecules from degradation caused by radiation.[253] Ducrot *et al.* (2020) interpreted observational data as implying methane-dominated atmospheres are unlikely around TRAPPIST-1 planets.[254]
- Nitrogen-dominated atmospheres are particularly unstable with respect to atmospheric escape, especially on the innermost planets, although the presence of CO_2 may slow evaporation.[255] Unless the TRAPPIST-1 planets initially contained far more nitrogen than Earth, they are unlikely to have retained such atmospheres.[256]
- CO_2-dominated atmospheres escape slowly because CO_2 effectively radiates away energy and thus does not readily reach escape velocity; on a synchronously rotating planet, however, CO_2 can freeze out on the night side, especially if there are no other gases in the atmosphere. The decomposition of CO_2 caused by radiation could yield substantial amounts of oxygen, carbon monoxide (CO),[204] and ozone.[257]

Theoretical modelling by Krissansen-Totton and Fortney (2022) suggests the inner planets most likely have oxygen-and-CO_2-rich atmospheres, if any.[258] If the planets have an atmosphere, the amount of precipitation, its form and location would be determined by the presence and position of mountains and oceans, and the rotation period.[259] Planets in the habitable zone are expected to have an atmospheric circulation regime resembling Earth's tropical regions with largely uniform temperatures.[260] Whether greenhouse gases can accumulate on the outer TRAPPIST-1 planets in sufficient quantities to warm them to the melting point of water is controversial; on a synchronously rotating planet, CO_2 could freeze and precipitate on the night side, and ammonia and methane would be destroyed by XUV radiation from TRAPPIST-1.[74] Carbon dioxide freezing-out can occur only on the outermost planets unless special conditions are met, and other volatiles do not freeze out.[261]

Stability

The emission of extreme ultraviolet (XUV) radiation by a star has an important influence on the stability of its planets' atmospheres, their composition and the habitability of their surfaces.[261] It can cause the ongoing removal of atmospheres from planets.[89] XUV radiation-induced atmospheric escape has been observed on gas giants.[262] M dwarfs emit large amounts of XUV radiation;[261] TRAPPIST-1 and the Sun emit about the same amount of XUV radiation[at] and because TRAPPIST-1's planets are much closer to the star than the Sun's, they receive much more intense irradiation.[55] TRAPPIST-1 has been emitting radiation for much longer than the Sun.[264] The process of atmospheric escape has been modelled mainly in the context of hydrogen-rich atmospheres and little quantitative research has been done on those of other compositions such as water and CO_2.[246]

TRAPPIST-1 has moderate to high stellar activity[au],[32] and this may be another difficulty for the persistence of atmospheres and water on the planets:[27]



Observed brightness of the TRAPPIST-1 star, showing large variation in brightness. The graph displays dips, indicating the transit of exoplanets. The planet corresponding to the dips in brightness are plotted below with diamond markers.

- Dwarfs of the spectral class M have intense flares;[261] TRAPPIST-1 averages about 0.38 flares per day[74] and four to six superflares[av] per year.[267] Such flares would have only small impacts on atmospheric temperatures but would substantially affect the stability and chemistry of atmospheres.[89] According to Samara, Patsourakos and Georgoulis (2021), the TRAPPIST-1 planets are unlikely to be able to retain atmospheres against coronal mass ejections.[268]
- The stellar wind from TRAPPIST-1 may have a pressure 1,000 times larger than that of the Sun at Earth's orbit, which could destabilise atmospheres of the star's planets[269] up to planet f. The pressure would push the wind deep into the atmospheres,[203] facilitating loss of water and evaporation of the atmospheres.[89][224] Stellar wind-driven escape in the Solar System is largely independent from planetary properties such as mass;[270] stellar wind from TRAPPIST-1 could remove the atmospheres of its planets on a timescale of 100 million to 10 billion years.[271]
- Ohmic heating[aw] of the atmosphere of TRAPPIST-1e, f, and g amounts to 5–15 times the heating from XUV radiation; if the heat is effectively absorbed, it could destabilise the atmospheres.[273]

The star's history also influences the atmospheres of its planets.[274] Immediately after its formation, TRAPPIST-1 would have been in a pre-main-sequence state, which may have lasted between hundreds of millions[261] and two billion years.[233] While in this state, it would have been considerably brighter than it is today and the star's intense irradiation would have impacted the atmospheres of surrounding planets, vaporising all common volatiles such as ammonia, CO_2, sulfur dioxide, and water.[275] Thus, all of the system's planets would have been heated to a runaway greenhouse[ax] for at least part of their existence.[261] The XUV radiation would have been even higher during the pre-main-sequence stage.[89]

Possible life

Life may be possible in the TRAPPIST-1 system, and some of the star's planets are considered promising targets for its detection.[27] On the basis of atmospheric stability, TRAPPIST-1e is theoretically the planet most likely to harbour life; the probability that it does is considerably less than that of Earth. There are an array of factors at play:[276][277]

- Due to multiple interactions, TRAPPIST-1 planets are expected to have intense tides.[278] If oceans are present,[ay] the tides could: lead to alternate flooding and drying of coastal landscapes triggering chemical reactions conducive to the development of life;[280] favour the evolution of biological rhythms such as the day-night cycle that otherwise would not develop in a synchronously rotating planet;[281] mix oceans, thus supplying and redistributing nutrients;[282] and stimulate periodic expansions of marine organisms similar to red tides on Earth.[283]
- TRAPPIST-1 may not produce sufficient quantities of radiation for photosynthesis to support an Earth-like biosphere.[284][285][286] Mullan and Bais (2018) speculated that radiation from flares may increase the photosynthetic potential of TRAPPIST-1,[287] but according to Lingam and Loeb (2019), the potential would still be small.[288]
- Due to the proximity of the TRAPPIST-1 planets, it is possible rock-encased microorganisms ripped[az] from one planet may arrive at another planet while still viable inside the rock, allowing life to spread between the planets if it originates on one.[289]
- Too much UV radiation from a star can sterilise the surface of a planet[111][152] but too little may not allow the formation of chemical compounds that give rise to life.[14][290] Inadequate production of hydroxyl radicals by low stellar-UV emission may allow gases such as carbon monoxide that are toxic to higher life to accumulate in the planets' atmospheres.[291] The possibilities range from UV fluxes from TRAPPIST-1 being unlikely to be much larger than these of early Earth – even in the event that TRAPPIST-1's emissions of UV radiation are high[292] – to being sufficient to sterilise the planets if they do not have protective atmospheres.[293] As of 2020 it is unclear which effect would predominate around TRAPPIST-1,[233] although observations with the Kepler Space Telescope and the Evryscope telescopes indicate the UV flux may be insufficient for the formation of life or its sterilisation. [267]
- The outer planets in the TRAPPIST-1 system could host subsurface oceans similar to those of Enceladus and Europa

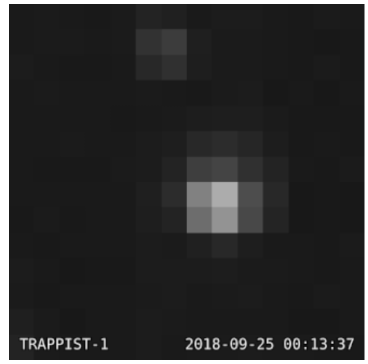
in the Solar System.[294] Chemolithotrophy, the growth of organisms based on non-organic reduced compounds,[295] could sustain life in such oceans.[139] Very deep oceans may be inimical to the development of life.[296]

- Some planets of the TRAPPIST-1 system may have enough water to completely submerge their surfaces.[297] If so, this would have important effects on the possibility of life developing on the planets, and on their climates,[298] as weathering would decrease, starving the oceans of nutrients like phosphorus as well as potentially leading to the accumulation of carbon dioxide in their atmospheres.[299]

In 2017, a search for technosignatures that would indicate the existence of past or present technology in the TRAPPIST-1 system found only signals coming from Earth.[300] In less than two millennia, Earth will be transiting in front of the Sun from the viewpoint of TRAPPIST-1, making the detection of life on Earth from TRAPPIST-1 possible.[301]

Reception and scientific importance

Public reaction and cultural impact



Kepler image of TRAPPIST-1

The discovery of the TRAPPIST-1 planets drew widespread attention in major world newspapers, social media, streaming television and websites.[302][303] As of 2017, the discovery of TRAPPIST-1 led to the largest single-day web traffic to the NASA website.[304] NASA started a public campaign on Twitter to find names for the planets, which drew responses of varying seriousness, although the names of the planets will be decided by the International Astronomical Union.[305] The dynamics of the TRAPPIST-1 planetary system have been represented as music, such as Tim Pyle's *Trappist Transits*,[306] in Isolation's single *Trappist-1 (A Space Anthem)*[307] and Leah Asher's piano work *TRAPPIST-1*.[308] The alleged discovery of an SOS signal from TRAPPIST-1 was an April Fools prank by researchers at the High Energy Stereoscopic System in Namibia.[309] In 2018, Aldo Spadon created a giclée (digital artwork) named "TRAPPIST-1 Planetary System as seen from Space".[310] A website was dedicated to the TRAPPIST-1 system.[311]

Fictional TRAPPIST-1e tourism poster made by NASA

Exoplanets are often featured in science-fiction works; books, comics and video games have featured the TRAPPIST-1 system, the earliest being *The Terminator*, a short story by Swiss author Laurence Suhner published in the academic journal that announced the system's discovery.[312] At least one conference was organised to recognise works of fiction featuring TRAPPIST-1.[313] The planets have been used as the basis of science education competitions[314] and school projects.[315][316] Websites offering TRAPPIST-1-like planets as settings of virtual reality simulations exist,[317] such as the "Exoplanet Travel Bureau"[318] and the "Exoplanets Excursion" – both by NASA.[319] Scientific accuracy has been a point of discussion for such cultural depictions of TRAPPIST-1 planets.[320]

Scientific importance

TRAPPIST-1 has drawn intense scientific interest.[228] Its planets are the most easily studied exoplanets within their star's habitable zone owing to their relative closeness, the small size of their host star, and because from Earth's perspective they frequently pass in front of their host star.[33] Future observations with space-based observatories and ground-based facilities may allow further insights into their properties such as density, atmospheres, and biosignatures.[ba] TRAPPIST-1 planets[322][323] are considered an important observation target for the James Webb Space Telescope (JWST)[bb][228] and other telescopes under construction.[158] Together with the discovery of Proxima Centauri b, the discovery of the TRAPPIST-1 planets and the fact that three of the planets are within the habitable zone has led to an increase in studies on planetary habitability.[326] The planets are considered prototypical for the research on habitability of M dwarfs.[327] The star has been the subject of detailed studies[104] of its various aspects[328] including the possible effects of vegetation on its planets; the possibility of detecting oceans on its planets using starlight reflected off their surfaces;[329] possible efforts to terraform its planets;[330] and difficulties any inhabitants of the planets would encounter with discovering the law of gravitation[331] and with interstellar travel.[332]

The role EU funding played in the discovery of TRAPPIST-1 has been cited as an example of the importance of EU projects,[35] and the involvement of a Moroccan observatory as an indication of the Arab world's role in science. The original discoverers were affiliated with universities spanning Africa, Europe, and North America,[333] and the discovery of TRAPPIST-1 is considered to be an example of the importance of co-operation between observatories.[334] It is also one of the major astronomical discoveries from Chilean observatories.[335]

Exploration

TRAPPIST-1 is too distant from Earth to be reached by humans with current or expected technology.[336] Spacecraft mission designs using present-day rockets and gravity assists would need hundreds of millennia to reach TRAPPIST-1; even a theoretical interstellar probe travelling at the speed of light would need decades to reach the star. The speculative Breakthrough Starshot proposal for sending small, laser-accelerated, uncrewed probes would require around two centuries to reach TRAPPIST-1.[337]

See also

- HD 10180, a star with at least six known planets, and three more exoplanet candidates
- Tabby's Star, another star with notable transit data
- LHS 1140, another star with a planetary system suitable for atmospheric studies
- LP 890-9, the second-coolest star found to host a planetary system, after TRAPPIST-1.
- List of potentially habitable exoplanets

Notes

a. A log(*g*) of 2.992 for the Earth indicates that TRAPPIST-1 has a surface gravity approximately 177 times stronger than Earth's.
b. A red dwarf is a very small and cold star. They are the most common type of star in the Milky Way.[15]
c. TRAPPIST is a 60-centimetre (24 in) telescope[11] intended to be a prototype for the "Search for habitable Planets EClipsing ULtra-cOOl Stars" project (SPECULOOS), which aims to identify planets around close, cold stars.[20][21] TRAPPIST is used to find exoplanets, and is preferentially employed on stars colder than 3,000 K (2,730 °C; 4,940 °F).[22]
d. When a planet moves in front of its star, it absorbs part of the star's radiation, which may be observed via telescopes.[29]
e. The celestial equator is the equator's projection into the sky.[36]
f. Based on parallax measurements;[1] the parallax is the position of a celestial object with respect to other celestial objects for a given position of Earth. It can be used to infer the distance of the object from Earth.[39]
g. The movement of the star in the sky, relative to background stars.[40]
h. Red dwarfs include the spectral type M and K.[42] Spectral types are used to categorise stars by their temperature.[43]
i. The effective temperature is the temperature a black body that emits the same amount of radiation would have.[49]
j. The photosphere is a thin layer at the surface of a star, where most of its light is produced.[51]
k. The solar cycle is the Sun's 11-year long period, during which solar output varies by about 0.1%.[53]
l. Including Lyman-alpha radiation[59]
m. The main sequence is the longest stage of a star's lifespan, when it is fusing hydrogen.[67]
n. Faculae are bright spots on the photosphere.[69]
o. Flares are presumably magnetic phenomena lasting for minutes or hours during which parts of the star emit more radiation than usual.[69]
p. For comparison, a strong fridge magnet has a strength of about 100 gauss and Earth's magnetic field about 0.5 gauss.[75]
q. The chromosphere is an outer layer of a star.[69]
r. A coronal mass ejection is an eruption of coronal material to the outside of a star.[69][77]
s. Exoplanets are named in order of discovery as "b", "c" and so on; if multiple planets are discovered at once they are named in order of increasing orbital period.[82] The term "TRAPPIST-1a" is used to refer to the star itself.[83]
t. One astronomical unit (AU) is the mean distance between the Earth and the Sun.[87]
u. For comparison, Earth's orbit around the Sun is inclined by about 1.578 degrees.[94]
v. The inner two planets' orbits may be circular; the others could have a small eccentricity.[97]

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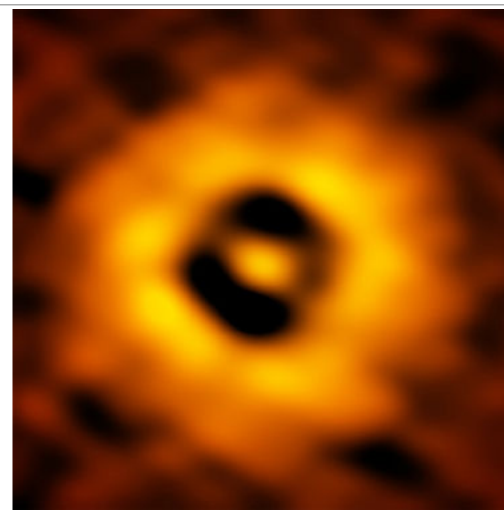
TW Hydrae

TW Hydrae is a T Tauri star approximately 196 light-years away[1] in the constellation of Hydra (the Sea Serpent). TW Hydrae is about 80% of the mass of the Sun, but is only about 5-10 million years old. The star appears to be accreting from a face-on protoplanetary disk of dust and gas, which has been resolved in images from the ALMA observatory. TW Hydrae is accompanied by about twenty other low-mass stars with similar ages and spatial motions, comprising the "TW Hydrae association" or TWA, one of the closest regions of recent "fossil" star-formation to the Sun.

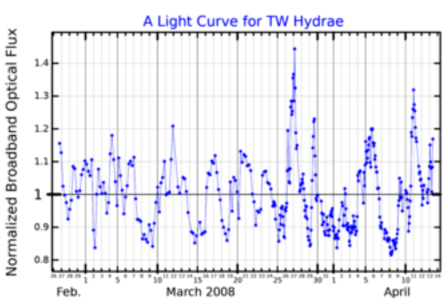
TW Hydrae



Inner region of TW Hydrae protoplanetary disc
Credit: *S. Andrews, B. Saxton, ALMA (see description)*

Observation data	
Epoch J2000.0	**Equinox J2000.0**
Constellation	Hydra
Right ascension	$11^h\ 01^m\ 51.9054^s$[1]
Declination	−34° 42′ 17.0316″[1]>
Apparent magnitude (V)	11.27 ± 0.09[2]
Characteristics	
Evolutionary stage	Pre-main-sequence
Spectral type	K6[2]
U−B color index	-0.33[3]
B−V color index	0.67[2]
J−H color index	0.659[2]
J−K color index	0.92[2]
Variable type	T Tauri
Astrometry	
Radial velocity (R_v)	13.40 ± 0.8[2] km/s
Proper motion (μ)	RA: −68.389 ± 0.054[1] mas/yr Dec.: −14.016 ±

Stellar characteristics



A broadband optical light curve plotted from *MOST* microsatellite data published by Rucinski *et al.* (2008)[6]

TW Hydrae is a pre-main-sequence star that is approximately 80% the mass of and 111% the radius of the Sun. It has a temperature of 4000 K and is about 8 million years old. In comparison, the Sun is about 4.6 billion years old[7] and has a temperature of 5778 K.[8] The star's luminosity is 28% (0.28x) that of the Sun, equivalent to that of a main-sequence star of spectral type ~K2. However, the spectral class is K6.

The star's apparent magnitude, or how bright it appears from Earth's perspective, is 11.27. It is too dim to be seen with the naked eye.

Planetary system

	0.059[1] mas/yr
Parallax (π)	16.6428 ± 0.0416 mas[1]
Distance	196.0 ± 0.5 ly (60.1 ± 0.2 pc)
Details	
Mass	0.8[4] $M_\odot$
Radius	1.11[5] $R_\odot$
Luminosity (bolometric)	0.28[note 1] $L_\odot$
Temperature	4,000[5] K
Age	8[5] Myr
Other designations	
TWA 1, TW Hya, CD−34° 7151, HIP 53911	
Database references	
SIMBAD	data (https://simbad.cds.unistra.fr/simbad/sim-id?Ident=TW+Hya)

The TW Hydrae planetary system[9]

Companion (in order from star)	Mass	Semimajor axis (AU)	Orbital period (days)	Eccentricity	Inclination	Radius
b (unconfirmed)	23.72 $M_\oplus$	22	—	—	—	~4.25 $R_\oplus$
Protoplanetary disk	1–30? AU				—	—

The star is known to host one likely exoplanet, TW Hydrae b.

Protoplanetary disk

Previously disproven protoplanet

In December 2007, a team led by Johny Setiawan of the Max Planck Institute for Astronomy in Heidelberg, Germany announced discovery of a planet orbiting TW Hydrae, dubbed "TW Hydrae b" with a minimum mass around 1.2 Jupiter masses, a period of 3.56 days, and an orbital radius of 0.04 astronomical units (inside the inner rim of the protoplanetary disk). Assuming it orbits in the same plane as the outer part of the dust disk (inclination 7±1°[10]), it has a true mass of 9.8±3.3 Jupiter masses.[10][11] However, if the inclination is similar to the inner part of the dust disk (4.3±1.0°[12]), the mass would be 16^{+5}_{-3} Jupiter masses, making it a brown dwarf.[12] Since the star itself is so young, it was presumed this is the youngest extrasolar planet yet discovered, and essentially still in formation.[13]

In 2008 a team of Spanish researchers concluded that the planet does not exist: the radial velocity variations were not consistent when observed at different wavelengths, which would not occur if the origin of the radial velocity variations was caused by an orbiting planet. Instead, the data was better modelled by starspots on TW Hydrae's surface passing in and out of view as the star rotates. "Results support the spot scenario rather than the presence of a hot Jupiter around TW Hya".[14] Similar wavelength-dependent radial velocity variations, also caused by starspots, have been detected on other T Tauri stars.[15]

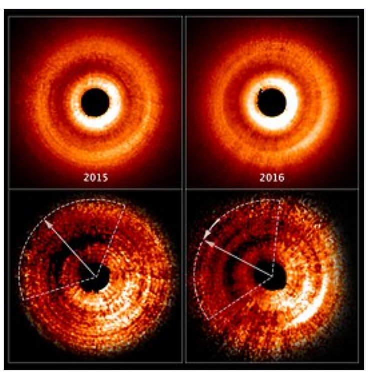
New study of more distant planet

In 2016, ALMA found evidence that a possible Neptune-like planet was forming in its disk, at a distance of around 22 AU.[16]

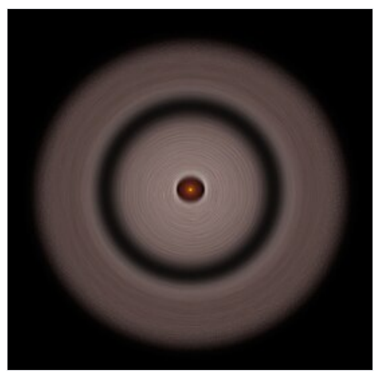
Detection of methanol

In 2016, methanol, one of the building blocks for life, was detected in the star's protoplanetary disk.[17][18][19][20][21][22][23][24]

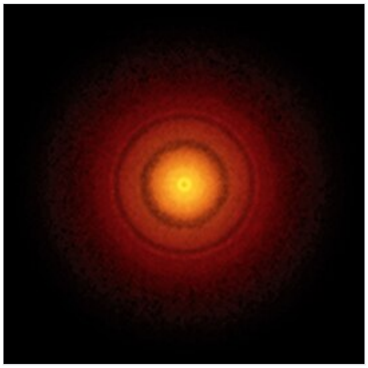
Gallery



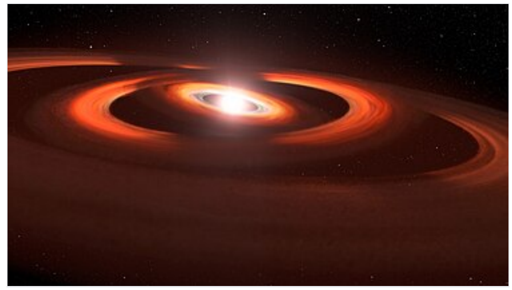
Shadow moving counterclockwise around a gas and dust disc.[25]



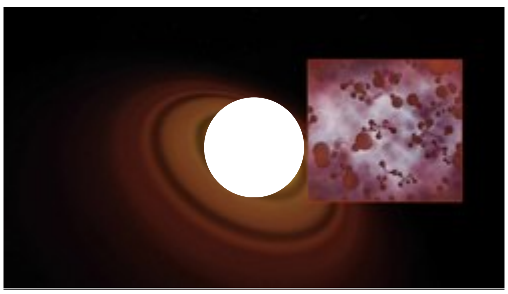
Simulation based on Hubble observations.



TW Hydrae protoplanetary disc.



This illustration is based on NASA/ESA Hubble Space Telescope images of a gas and dust discs encircling the young star TW Hydrae.



This artist's impression video shows the protoplanetary disc around TW Hydrae. The organic molecule methyl alcohol (methanol) has been found in this disc.

Notes

1. From $L=4\pi R^2\sigma T_{\rm eff}^4$, where L is the luminosity, R is the radius, $T_{\rm eff}$ is the effective surface temperature and σ is the Stefan–Boltzmann constant.

References

1. Brown, A. G. A.; et al. (Gaia collaboration) (August 2018). "*Gaia* Data Release 2: Summary of the contents and survey properties" (https://doi.org/10.1051%2F0004-6361%2F201833051). *Astronomy & Astrophysics*. **616**. A1. arXiv:1804.09365 (https://arxiv.org/abs/1804.09365). Bibcode:2018A&A...616A...1G (https://ui.adsabs.harvard.edu/abs/2018A&A...616A...1G). doi:10.1051/0004-6361/201833051 (https://doi.org/10.1051%2F0004-6361%2F201833051). Gaia DR2 record for this source (http://vizier.u-strasbg.fr/viz-bin/VizieR-S?Gaia%20DR2%2054017956625605003522) at VizieR.
2. "V* TW Hya" (http://simbad.u-strasbg.fr/simbad/sim-basic?Ident=V%2A+TW+Hya). *SIMBAD*. Centre de données astronomiques de Strasbourg. Retrieved 2014-01-02.

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WASP-18b

Coordinates: 01h 37m 25s, −45° 40′ 41″

WASP-18b is an exoplanet that is notable for having an orbital period of less than one day. It has a mass equal to 10 Jupiter masses,[1] just below the boundary line between planets and brown dwarfs (about 13 Jupiter masses). Due to tidal deceleration, it is expected to spiral toward and eventually merge with its host star, WASP-18, in less than a million years.[1] The planet is approximately 3.1 million km (1.9 million mi; 0.021 AU) from its star, which is about 400 light-years (120 parsecs) from Earth. A team led by Coel Hellier, a professor of astrophysics at Keele University in England, discovered the exoplanet in 2009.[1]

Scientists at Keele and at the University of Maryland are working to understand whether the discovery of this planet so shortly before its expected demise (with less than 0.1% of its lifetime remaining) was fortuitous, or whether tidal dissipation by WASP-18 is actually much less efficient than astrophysicists typically assume.[1][5] Observations made over the next decade should yield a measurement of the rate at which WASP-18b's orbit is decaying.[6]

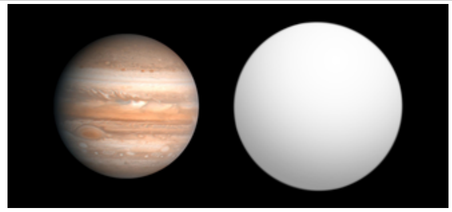
The closest example of a similar situation in the Solar System is Mars' moon Phobos. Phobos orbits Mars at a distance of only about 9,000 km (5,600 mi), 40 times closer than the Moon is to the Earth[7] and is expected to be destroyed in about eleven million years.[8]

The planet's dayside temperature, as measured in 2020, is 3,029 ± 50 K (2,755.8 ± 50.0 °C; 4,992.5 ± 90.0 °F).[3] A 2023 study found an average dayside temperature of $2{,}781\,^{+25}_{-13}$ K (2,508 °C; 4,546 °F).[4]

A study in 2012, utilizing the Rossiter–McLaughlin effect, determined that the planetary orbit is well aligned with the equatorial plane of the star, with a misalignment equal to 13 ± 7°.[9]

A 2017 study detected carbon monoxide in the planet's atmosphere, without signs of water vapor.[10][11] However, in 2023, the James Webb Space Telescope

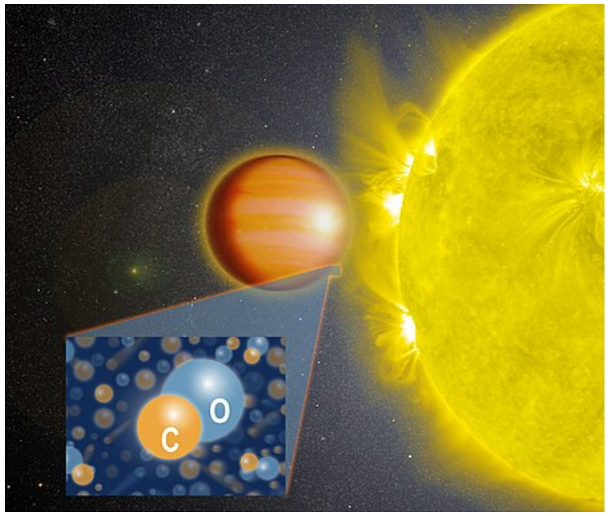
WASP-18b



Size comparison of WASP-18b with Jupiter.

Discovery[1]	
Discovered by	Hellier et al. (SuperWASP)
Discovery date	August 27, 2009
Detection method	Transit (including secondary eclipses)
Orbital characteristics[2]	
Semi-major axis	0.02024 ± 0.00030 AU (3,028,000 ± 45,000 km)
Eccentricity	$0.0051\,^{+0.0070}_{-0.0037}$
Orbital period (sidereal)	0.941 452 23(24) d 22.59485352 h
Inclination	$83.5°\,^{+2.0°}_{-1.6°}$
Argument of periastron	$-85°\,^{+72°}_{-96°}$
Semi-amplitude	$1814\,^{+23}_{-24}$ m/s
Star	WASP-18
Physical characteristics[2]	
Mean radius	1.240 ± 0.079 R_J
Mass	10.20 ± 0.35 M_J
Mean density	$6.6\,^{+1.2}_{-1.1}$ g/cm^3
Temperature	3,029 ± 50 K (2,756 °C; 4,993 °F)[3] $2{,}781\,^{+25}_{-13}$ K (2,508 °C; 4,546 °F)[4]

detected water vapor in the planet's atmosphere.[4][12]



Exoplanet WASP-18b − high carbon monoxide levels detected in stratosphere (artist concept)[11]

See also

- SuperWASP

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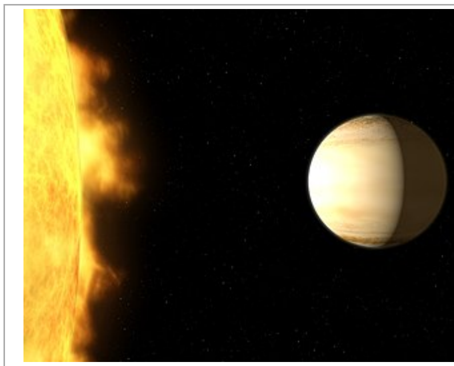
WASP-39b

Coordinates: 14h 29m 18.0s, −03° 26′ 40″

WASP-39b, officially named **Bocaprins**, is a "hot Jupiter" extrasolar planet discovered in February 2011[3] by the WASP project, notable for containing a substantial amount of water in its atmosphere.[1][4][5] In addition WASP-39b was the first exoplanet found to contain carbon dioxide in its atmosphere,[6][7] and likewise for sulfur dioxide.

WASP-39b is in the constellation Virgo, and is about 700 light-years from Earth.[1] As part of the NameExoWorlds campaigns at the 100th anniversary of the IAU, the planet was named Bocaprins, after the beach Boca Prins in the Arikok National Park of Aruba.

WASP-39b / Bocaprins



Exoplanet WASP-39b artist's concept[1]

Discovery	
Discovery site	WASP[2]
Discovery date	2011[2]
Detection method	Primary transit[2]
Orbital characteristics	
Semi-major axis	0.0486 ± 0.0005 AU, (7.27 ± 0.1) × 10^6 km
Eccentricity	0[2]
Orbital period (sidereal)	4.055 26[2] d
Inclination	87.83 ± 0.25[2]
Star	WASP-39[2]
Physical characteristics	
Mean radius	1.27 ± 0.04[2] R_J, (91 ± 3) × 10^3 km
Mass	0.28 ± 0.03[2] M_J
Mean density	180 ± 40 kg m^{-3}

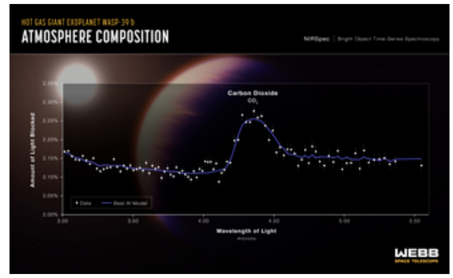
Characteristics

Comparison of "hot Jupiter" exoplanets, including WASP-39b (top row; 4th from left) (artist's concept).
From top left to lower right: WASP-12b, WASP-6b, WASP-31b, WASP-39b, HD 189733b, HAT-P-12b, WASP-17b, WASP-19b, HAT-P-1b and HD 209458b.

WASP-39b has a mass of about 0.28 times that of Jupiter and a radius about 1.27 times that of Jupiter (91,000 km).[2] It is a hot gas giant planet with a high temperature of 900 °C.[6] The exoplanet orbits very close (7 million km) to WASP-39, its host star, every 4 days.[1]

WASP-39b is also notable for having an extremely low density, near that of WASP-17b. While WASP-17b has a density of 0.13 ± 0.06 g/cm^3, WASP-39b has a slightly higher density of 0.18 ± 0.04 g/cm^3.

Atmospheric composition



WASP-39b's atmospheric transmission spectrum captured by Webb’s Near-Infrared Spectrograph (NIRSpec) reveals first clear evidence for carbon dioxide in a planet outside the Solar System.[6]

Hot water molecules were found in the atmosphere of WASP-39b in a 2018 study.[1] The atmospheric transmission spectra, taken by different instruments, were inconsistent as in 2021, possibly indicating a disequilibrium atmospheric chemistry.[8] High-fidelity spectra obtained by the James Webb Space Telescope in 2022 did not confirm a disequilibrium chemistry.

WASP-39b is one of the James Webb Space Telescope's early release science targets. Sulfur dioxide was observed in this planet's atmosphere for the first time, or indeed of any planet outside of the Solar System, indicating the existence of photochemical processes in the atmosphere.[9] WASP-39b is the first exoplanet in which carbon dioxide has been detected.[6][10][7]

Planetary transmission spectra taken in 2022 has indicated the atmosphere of WASP-39b is partially cloudy, and planet C/O ratio appears to be subsolar.[11] The spectral signature of water, carbon dioxide, sodium[12] and sulfur dioxide were also detected.[13]

WASP-39 (star)

The parent star **WASP-39** is of spectral class G and is slightly smaller than the Sun. It lies in the Virgo constellation, 698 light-years from Earth.[1] The star WASP-39 was named Malmok.[14][15]

Malmok

Observation data	
Epoch J2000.0	**Equinox J2000.0 (ICRS)**
Constellation	Virgo
Right ascension	$14^h\ 29^m\ 18.4151689656^s$
Declination	−03° 26′ 40.204480380″
Apparent magnitude (V)	12.09
Distance	702 ± 2 ly (215.4 ± 0.7 pc)
Other designations	
2MASS J14291840-0326403, Gaia DR2 3643098875168270592, Gaia EDR3 3643098875168270592	
Database references	

See also

- WASP-6b
- WASP-17b
- WASP-19b
- WASP-31b
- WASP-121b
- List of proper names of exoplanets (see section Sources in References)
- List of transiting exoplanets
- List of exoplanets discovered in 2011

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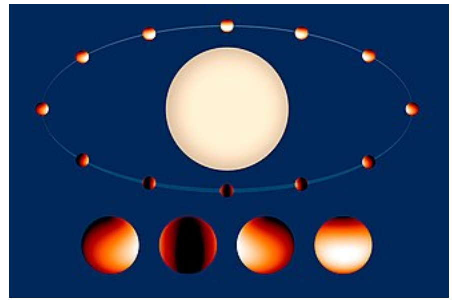
WASP-43b

WASP-43b, formally named **Astrolábos**,[3] is a transiting planet in orbit around the young, active, and low-mass star WASP-43 in the constellation Sextans. The planet is a hot Jupiter with a mass twice that of Jupiter, but with a roughly equal radius. WASP-43b was flagged as a candidate by the SuperWASP program, before they conducted follow-ups using instruments at La Silla Observatory in Chile, which confirmed its existence and provided orbital and physical characteristics. The planet's discovery was published on April 14, 2011.[2]

At the time of its discovery, WASP-43b had an orbital period of approximately 0.8 days (19.2 hours), the second-shortest orbit ever detected, surpassed only by WASP-19b.[2] In addition, at the time of discovery, WASP-43b was the most closely orbiting hot Jupiter known,[2] a phenomenon that can most likely be explained by its host star's low mass.

WASP-43b / Astrolábos



Exoplanet WASP-43b orbits its parent star.[1]

Discovery[2]	
Discovered by	Coel Hellier *et al.*
Discovery site	La Silla Observatory / South African Astronomical Observatory
Discovery date	Published April 15, 2011
Detection method	transit method (secondary occultation detected later)
Designations	
Alternative names	Astrolábos[3]
Orbital characteristics	
Semi-major axis	0.01526 (± 0.00018)[4] AU
Eccentricity	< 0.0298 [4]
Orbital period (sidereal)	0.81347753 (± 0.00000071)[4] d
Inclination	82.33 (± 0.20) [4]
Star	WASP-43

Nomenclature

In August 2022, this planet and its host star were included among 20 systems to be named by the third NameExoWorlds project.[7] The approved names, proposed by a team from Romania, were announced in June 2023. WASP-43b is named **Astrolábos** and its host star is named **Gnomon**, after the gnomon and the Greek word for the astrolabe.[3]

Observational history

WASP-43 was first flagged as host to a potential transiting event (when a body crosses in front of and dims its host star) by data collected by SuperWASP, a British organization working to discover transiting planets across the entirety of the sky. In particular, WASP-43 was observed first by the leg of WASP-South at the South African Astronomical Observatory between January and May 2009.[2]

Later observation by both SuperWASPs in the Northern and Southern Hemispheres led to the collection of 13,768 data points between January and May 2010 and to the use of the CORALIE spectrograph at La Silla Observatory in Chile.

Fourteen measurements using the radial velocity method confirmed WASP-43b as a planet, revealing its mass in the process. The use of La Silla's TRAPPIST telescope helped the science team working on the planet to create a light curve of the planet's transit in December 2010.[2]

The planet's discovery was published in the journal *Astronomy and Astrophysics* on April 14, 2011.[2]

Physical characteristics	
Mean radius	$1.04^{+0.07}_{-0.09}$[5] R_J
Mass	2.03 (± 0.1)[5] M_J
Albedo	<0.06[6]
Temperature	1666 ± 48 K

In 2014, a secondary transit of the planet was reported.[8] Full observation of phases of the planet was reported in September 2014.[9]

Host star

WASP-43 is a K-type star in the Sextans constellation that is about 80 parsecs (261 light years) away.[2] The star has a mass 0.58 times that of the Sun, but is more diffuse, with a radius 0.93 times that of the Sun. The star's effective temperature is 4,400 K, making the star cooler than the Sun, and is metal-poor with regards to the Sun because it has a metallicity of [Fe/H] = −0.05 (89% the amount of iron in the Sun).[5] The star is young, and is estimated to be 598 million years old (as compared to the Sun's 4.6 billion years).[5] Analysis of emission lines indicate that WASP-43 is an active star.[2]

WASP-43 has one detected planet in its orbit, WASP-43b. The star has an apparent magnitude of 12.4, and thus is too faint to be seen with the unaided eye from Earth.[5]

Characteristics

WASP-43b is a dense hot Jupiter with a mass 2.05 times the mass of Jupiter, but a radius 1.036 times that of Jupiter's. The planet orbits its host star at a mean distance of 0.01526 AU every 0.813478 days (19.5235 hours);[5] this orbital period, at the time of WASP-43b's discovery, was the second-shortest orbit yet detected, surpassed only by WASP-19b. In comparison, Mercury has an orbital period of 87.97 days and lies at a mean distance of 0.387 AU from the Sun.[10] In addition, WASP-43b had the closest orbit to its host star (among hot Jupiters) at the time of its discovery, comparable only to the super-Earth planet GJ 1214 b and to the planetary candidate orbiting KOI-961 (confirmed a year later as Kepler-42). While hot Jupiters are known to have small orbital periods, planets with *exceptionally* small periods below three or four days are extremely rare; however, in the case of WASP-43b, the planet's proximity can be explained because its host star has a very low mass. The rarity of systems like that of WASP-43 and its planet suggest that hot Jupiters do not usually occur around low-mass stars, or that such planets cannot maintain stable orbits around such stars.[2]

WASP-43b, along with the planets WASP-19b and WASP-18b, conflicted with currently accepted models of tidal movements derived from observations of the orbits of binary star systems. Revisions to the model with regard to planets were proposed to help the models conform to the orbital parameters of these planets.[2] No orbital decay driven by tidal dissipation was detected in 2016, placing a lower limit of 10 million years on the remaining planetary lifetime.[11] Updated orbital period measurements have failed to detect orbital decay as of 2021.[12][13]

Atmosphere

In 2019, the spectrum of WASP-43b was taken, with the best fit being water-containing clouds without significant amounts of alkali metals.[14] In 2020, further analysis of the spectra revealed the presence of bivalent aluminum oxide (AlO) and water in the atmosphere,[15] while carbon monoxide, carbon dioxide and methane were not detected. Climate modelling suggests the carbon monoxide concentration may be variable, while the atmospheric spectrum of WASP-43b is dominated by clouds made of refractory mineral particles, with a small contribution from hydrocarbon haze.[16] Carbon to oxygen ratio in the planet (0.75 ± 0.15) is elevated compared to the Solar ratio of 0.55.[17] The planet is very dark overall, with no clouds on the dayside[18] and an albedo below 0.06.[6]

There is a large difference in temperature between dayside (1479 ± 13 K) and nightside (755 ± 46 K).[18]

External links

- "WASP-43b" (http://simbad.u-strasbg.fr/simbad/sim-basic?Ident=WASP-43b). *SIMBAD*. Centre de données astronomiques de Strasbourg.
- WASP Planets (http://wasp-planets.net/wasp-planets/)
- "Hubble Hangout on planet WASP-43b" (https://www.youtube.com/watch?v=n-oDqYCf3XY). *YouTube*. 2014. Retrieved 7 Nov 2014.

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