Rings of Neptune

The rings of Neptune consist primarily of five principal rings and were first discovered (as " arcs ") in 1984 in Chile by Patrice Bouchet , Reinhold Häfner and Jean Manfroid at La Silla Observatory (ESO) during an observing program proposed by André Brahic and Bruno Sicardy from Paris Observatory , and at Cerro Tololo Interamerican Observatory by F. Vilas and L.-R. Elicer for a program led by William Hubbard . They were eventually imaged in 1989 by the Voyager 2 spacecraft . At their densest , they are comparable to the less dense portions of Saturn 's main rings such as the C ring and the Cassini Division , but much of Neptune 's ring system is quite tenuous , faint and dusty , more closely resembling the rings of Jupiter . Neptune 's rings are named after astronomers who contributed important work on the planet : Galle , Le Verrier , Lassell , Arago , and Adams . Neptune also has a faint unnamed ring coincident with the orbit of the moon Galatea . Three other moons orbit between the rings : Naiad , Thalassa and Despina .

The rings of Neptune are made of extremely dark material , likely organic compounds processed by radiation , similar to that found in the rings of Uranus . The proportion of dust in the rings (between 20 % and 70 %) is high , while their optical depth is low to moderate , at less than 0 @.@ 1 . Uniquely , the Adams ring includes five distinct arcs , named Fraternité , Égalité 1 and 2 , Liberté , and Courage . The arcs occupy a narrow range of orbital longitudes and are remarkably stable , having changed only slightly since their initial detection in 1980 . How the arcs are stabilized is still under debate . However , their stability is probably related to the resonant interaction between the Adams ring and its inner shepherd moon , Galatea .

= = Discovery and observations = =

The first mention of rings around Neptune dates back to 1846 when William Lassell , the discoverer of Neptune 's largest moon Triton , thought he had seen a ring around the planet . However , his claim was never confirmed and it is likely that it was an observational artifact . The first reliable detection of a ring was made in 1968 by stellar occultation , although that result would go unnoticed until 1977 when the rings of Uranus were discovered . Soon after the Uranus discovery , a team from Villanova University led by Harold J. Reitsema began searching for rings around Neptune . On 24 May 1981 , they detected a dip in a star 's brightness during one occultation ; however , the manner in which the star dimmed did not suggest a ring . Later , after the Voyager fly @-@ by , it was found that the occultation was due to the small Neptunian moon Larissa , a highly unusual event .

In the 1980s , significant occultations were much rarer for Neptune than for Uranus , which lay near the Milky Way at the time and was thus moving against a denser field of stars . Neptune 's next occultation , on 12 September 1983 , resulted in a possible detection of a ring . However , ground @-@ based results were inconclusive . Over the next six years , approximately 50 other occultations were observed with only about one @-@ third of them yielding positive results . Something (probably incomplete arcs) definitely existed around Neptune , but the features of the ring system remained a mystery . The Voyager 2 spacecraft made the definitive discovery of the Neptunian rings during its fly @-@ by of Neptune in 1989 , passing by as close as 4 @,@ 950 km (3 @,@ 080 mi) above the planet 's atmosphere on 25 August . It confirmed that occasional occultation events observed before were indeed caused by the arcs within the Adams ring (see below) . After the Voyager fly @-@ by the previous terrestrial occultation observations were reanalyzed yielding features of the ring 's arcs as they were in 1980s , which matched those found by Voyager almost perfectly .

Since Voyager 's fly @-@ by , the brightest rings (Adams and Le Verrier) have been imaged with the Hubble Space Telescope and Earth @-@ based telescopes , owing to advances in resolution and light @-@ gathering power . They are visible , slightly above background noise levels , at methane @-@ absorbed wavelengths in which the glare from Neptune is significantly reduced . The fainter rings are still far below the visibility threshold .

= = General properties = =

 Neptune possesses five distinct rings named , in order of increasing distance from the planet , Galle , Le Verrier , Lassell , Arago and Adams . In addition to these well @-@ defined rings , Neptune may also possess an extremely faint sheet of material stretching inward from the Le Verrier to the Galle ring , and possibly farther in toward the planet . Three of the Neptunian rings are narrow , with widths of about 100 km or less ; in contrast , the Galle and Lassell rings are broad ? their widths are between 2 @,@ 000 and 5 @,@ 000 km . The Adams ring consists of five bright arcs embedded in a fainter continuous ring . Proceeding counterclockwise , the arcs are : Fraternité , Égalité 1 and 2 , Liberté , and Courage . The first three names come from " liberty , equality , fraternity " , the motto of the French Revolution and Republic . The terminology was suggested by their original discoverers , who had found them during stellar occultations in 1984 and 1985 . Four small Neptunian moons have orbits inside the ring system : Naiad and Thalassa orbit in the gap between the Galle and Le Verrier rings ; Despina is just inward of the Le Verrier ring ; and Galatea lies slightly inward of the Adams ring , embedded in an unnamed faint , narrow ringlet .
 The Neptunian rings contain a large quantity of micrometer @-@ sized dust : the dust fraction by cross @-@ section area is between 20 % and 70 % . In this respect they are similar to the rings of Jupiter , in which the dust fraction is 50 % ? 100 % , and are very different from the rings of Saturn and Uranus , which contain little dust (less than 0 @.@ 1 %) . The particles in Neptune 's rings are made from a dark material ; probably a mixture of ice with radiation @-@ processed organics . The rings are reddish in color , and their geometrical (0 @.@ 05) and Bond (0 @.@ 01 ? 0 @.@ 02) albedos are similar to those of the Uranian rings ' particles and the inner Neptunian moons . The rings are generally optically thin (transparent) ; their normal optical depths do not exceed 0 @.@ 1 . As a whole , the Neptunian rings resemble those of Jupiter ; both systems consist of faint , narrow , dusty ringlets and even fainter broad dusty rings .
 The rings of Neptune , like those of Uranus , are thought to be relatively young ; their age is probably significantly less than that of the Solar System . Also , like those of Uranus , Neptune 's rings probably resulted from the collisional fragmentation of onetime inner moons . Such events create moonlet belts , which act as the sources of dust for the rings . In this respect the rings of Neptune are similar to faint dusty bands observed by Voyager 2 between the main rings of Uranus .

= = Inner rings = =

 The innermost ring of Neptune is called the Galle ring after Johann Gottfried Galle , the first person to see Neptune through a telescope (1846) . It is about 2 @,@ 000 km wide and orbits 41 @,@ 000 ? 43 @,@ 000 km from the planet . It is a faint ring with an average normal optical depth of around 10 ? 4 , and with an equivalent depth of 0 @.@ 15 km . The fraction of dust in this ring is estimated from 40 % to 70 % .
 The next ring is named the Le Verrier ring after Urbain Le Verrier , who predicted Neptune 's position in 1846 . With an orbital radius of about 53 @,@ 200 km , it is narrow , with a width of about 113 km . Its normal optical depth is 0 @.@ 0062 ± 0 @.@ 0015 , which corresponds to an equivalent depth of 0 @.@ 7 ± 0 @.@ 2 km . The dust fraction in the Le Verrier ring ranges from 40 % to 70 % . The small moon Despina , which orbits just inside of it at 52 @,@ 526 km , may play a role in the ring 's confinement by acting as a shepherd .
 The Lassell ring , also known as the plateau , is the broadest ring in the Neptunian system . It is the namesake of William Lassell , the English astronomer who discovered Neptune 's largest moon , Triton . This ring is a faint sheet of material occupying the space between the Le Verrier ring at about 53 @,@ 200 km and the Arago ring at 57 @,@ 200 km . Its average normal optical depth is around 10 ? 4 , which corresponds to an equivalent depth of 0 @.@ 4 km . The ring 's dust fraction is in the range from 20 % to 40 % .
 There is a small peak of brightness near the outer edge of the Lassell ring , located at 57 @,@ 200 km from Neptune and less than 100 km wide , which some planetary scientists call the Arago ring after François Arago , a French mathematician , physicist , astronomer and politician . However ,

many publications do not mention the Arago ring at all .

Adams ring

The outer Adams ring , with an orbital radius of about 63 @,@ 930 km , is the best studied of Neptune 's rings . It is named after John Couch Adams , who predicted the position of Neptune independently of Le Verrier . This ring is narrow , slightly eccentric and inclined , with total width of about 35 km (15 ? 50 km) , and its normal optical depth is around 0 @.@ 011 ± 0 @.@ 003 outside the arcs , which corresponds to the equivalent depth of about 0 @.@ 4 km . The fraction of dust in this ring is from 20 % to 40 % ? lower than in other narrow rings . Neptune 's small moon Galatea , which orbits just inside of the Adams ring at 61 @,@ 953 km , acts like a shepherd , keeping ring particles inside a narrow range of orbital radii through a 42 : 43 outer Lindblad resonance . Galatea 's gravitational influence creates 42 radial wiggles in the Adams ring with an amplitude of about 30 km , which have been used to infer Galatea 's mass .

Arcs

The brightest parts of the Adams ring , the ring arcs , were the first elements of Neptune 's ring system to be discovered . The arcs are discrete regions within the ring in which the particles that it comprises are mysteriously clustered together . The Adams ring is known to comprise five short arcs , which occupy a relatively narrow range of longitudes from 247 ° to 294 ° . In 1986 they were located between longitudes of :
247 ? 257 ° (Fraternité) ,
261 ? 264 ° (Égalité 1) ,
265 ? 266 ° (Égalité 2) ,
276 ? 280 ° (Liberté) ,
284 @.@ 5 ? 285 @.@ 5 ° (Courage) .
The brightest and longest arc was Fraternité ; the faintest was Courage . The normal optical depths of the arcs are estimated to lie in the range 0 @.@ 03 ? 0 @.@ 09 (0 @.@ 034 ± 0 @.@ 005 for the leading edge of Liberté arc as measured by stellar occultation) ; the radial widths are approximately the same as those of the continuous ring ? about 30 km . The equivalent depths of arcs vary in the range 1 @.@ 25 ? 2 @.@ 15 km (0 @.@ 77 ± 0 @.@ 13 km for the leading edge of Liberté arc) . The fraction of dust in the arcs is from 40 % to 70 % . The arcs in the Adams ring are somewhat similar to the arc in Saturn 's G ring .
The highest resolution Voyager 2 images revealed a pronounced clumpiness in the arcs , with a typical separation between visible clumps of 0 @.@ 1 ° to 0 @.@ 2 ° , which corresponds to 100 ? 200 km along the ring . Because the clumps were not resolved , they may or may not include larger bodies , but are certainly associated with concentrations of microscopic dust as evidenced by their enhanced brightness when backlit by the Sun .
The arcs are quite stable structures . They were detected by ground @-@ based stellar occultations in the 1980s , by Voyager 2 in 1989 and by Hubble Space Telescope and ground @-@ based telescopes in 1997 ? 2005 and remained at approximately the same orbital longitudes . However some changes have been noticed . The overall brightness of arcs decreased since 1986 . The Courage arc jumped forward by 8 ° to 294 ° (it probably jumped over to the next stable co @-@ rotation resonance position) while the Liberté arc had almost disappeared by 2003 . The Fraternité and Égalité (1 and 2) arcs have demonstrated irregular variations in their relative brightness . Their observed dynamics is probably related to the exchange of dust between them . Courage , a very faint arc found during the Voyager flyby , was seen to flare in brightness in 1998 ; it was back to its usual dimness by June 2005 . Visible light observations show that the total amount of material in the arcs has remained approximately constant , but they are dimmer in the infrared light wavelengths where previous observations were taken .

Confinement

The arcs in the Adams ring remain unexplained . Their existence is a puzzle because basic orbital dynamics imply that they should spread out into a uniform ring over a matter of years . Several theories about the arcs ' confinement have been suggested , the most widely publicized of which holds that Galatea confines the arcs via its 42 : 43 co @-@ rotational inclination resonance (CIR) . The resonance creates 84 stable sites along the ring 's orbit , each 4 ° long , with arcs residing in the adjacent sites . However measurements of the rings ' mean motion with Hubble and Keck telescopes in 1998 led to the conclusion that the rings are not in CIR with Galatea .

A later model suggested that confinement resulted from a co @-@ rotational eccentricity resonance (CER) . The model takes into account the finite mass of the Adams ring , which is necessary to move the resonance closer to the ring . A byproduct of this theory is a mass estimate for the Adams ring ? about 0 @.@ 002 of the mass of Galatea . A third theory proposed in 1986 requires an additional moon orbiting inside the ring ; the arcs in this case are trapped in its stable Lagrangian points . However Voyager 2 's observations placed strict constraints on the size and mass of any undiscovered moons , making such a theory unlikely . Some other more complicated theories hold that a number of moonlets are trapped in co @-@ rotational resonances with Galatea , providing confinement of the arcs and simultaneously serving as sources of the dust .

= = Exploration = =

The rings were investigated in detail during the Voyager 2 spacecraft 's flyby of Neptune in August 1989 . They were studied with optical imaging , and through observations of occultations in ultraviolet and visible light . The spaceprobe observed the rings in different geometries relative to the Sun , producing images of back @-@ scattered , forward @-@ scattered and side @-@ scattered light . Analysis of these images allowed derivation of the phase function (dependence of the ring 's reflectivity on the angle between the observer and Sun) , and geometrical and Bond albedo of ring particles . Analysis of Voyager 's images also led to discovery of six inner moons of Neptune , including the Adams ring shepherd Galatea .

= = Properties = =

* A question mark means that the parameter is not known .