= Asteroid belt =

The asteroid belt is the circumstellar disc in the Solar System located roughly between the orbits of the planets Mars and Jupiter . It is occupied by numerous irregularly shaped bodies called asteroids or minor planets . The asteroid belt is also termed the main asteroid belt or main belt to distinguish it from other asteroid populations in the Solar System such as near @-@ Earth asteroids and trojan asteroids . About half the mass of the belt is contained in the four largest asteroids : Ceres , Vesta , Pallas , and Hygiea . The total mass of the asteroid belt is approximately 4 % that of the Moon , or 22 % that of Pluto , and roughly twice that of Pluto 's moon Charon (whose diameter is 1200 km) .

Ceres , the asteroid belt 's only dwarf planet , is about 950 km in diameter , whereas Vesta , Pallas , and Hygiea have mean diameters of less than 600 km . The remaining bodies range down to the size of a dust particle . The asteroid material is so thinly distributed that numerous unmanned spacecraft have traversed it without incident . Nonetheless , collisions between large asteroids do occur , and these can form an asteroid family whose members have similar orbital characteristics and compositions . Individual asteroids within the asteroid belt are categorized by their spectra , with most falling into three basic groups : carbonaceous (C @-@ type) , silicate (S @-@ type) , and metal @-@ rich (M @-@ type) .

The asteroid belt formed from the primordial solar nebula as a group of planetesimals . Planetesimals are the smaller precursors of the protoplanets . Between Mars and Jupiter , however , gravitational perturbations from Jupiter imbued the protoplanets with too much orbital energy for them to accrete into a planet . Collisions became too violent , and instead of fusing together , the planetesimals and most of the protoplanets shattered . As a result , 99 @.@ 9 % of the asteroid belt 's original mass was lost in the first 100 million years of the Solar System 's history . Some fragments eventually found their way into the inner Solar System , leading to meteorite impacts with the inner planets . Asteroid orbits continue to be appreciably perturbed whenever their period of revolution about the Sun forms an orbital resonance with Jupiter . At these orbital distances , a Kirkwood gap occurs as they are swept into other orbits .

Classes of small Solar System bodies in other regions are the near @-@ Earth objects , the centaurs , the Kuiper belt objects , the scattered disc objects , the sednoids , and the Oort cloud objects .

On 22 January 2014 , ESA scientists reported the detection , for the first definitive time , of water vapor on Ceres , the largest object in the asteroid belt . The detection was made by using the far @-@ infrared abilities of the Herschel Space Observatory . The finding was unexpected because comets , not asteroids , are typically considered to " sprout jets and plumes " . According to one of the scientists , " The lines are becoming more and more blurred between comets and asteroids . "

= = History of observation = =

In an anonymous footnote to his 1766 translation of Charles Bonnet 's Contemplation de la Nature , the astronomer Johann Daniel Titius of Wittenberg noted an apparent pattern in the layout of the planets . If one began a numerical sequence at 0 , then included 3 , 6 , 12 , 24 , 48 , etc . , doubling each time , and added four to each number and divided by 10 , this produced a remarkably close approximation to the radii of the orbits of the known planets as measured in astronomical units . This pattern , now known as the Titius ? Bode law , predicted the semi @-@ major axes of the six planets of the time (Mercury , Venus , Earth , Mars , Jupiter and Saturn) provided one allowed for a " gap " between the orbits of Mars and Jupiter . In his footnote Titius declared , " But should the Lord Architect have left that space empty ? Not at all . " In 1768 , the astronomer Johann Elert Bode made note of Titius 's relationship in his Anleitung zur Kenntniss des gestirnten Himmels (English : Instruction for the Knowledge of the Starry Heavens) but did not credit Titius until later editions . It became known as " Bode 's law " . When William Herschel discovered Uranus in 1781 , the planet 's orbit matched the law almost perfectly , leading astronomers to conclude that there had to be a planet between the orbits of Mars and Jupiter .

In 1800 the astronomer Baron Franz Xaver von Zach recruited 24 of his fellows into a club , the

Vereinigte Astronomische Gesellschaft (" United Astronomical Society ") which he informally dubbed the " Lilienthal Society " for its meetings in Lilienthal . Lilienthal is a town near Bremen , Germany that was home to a prominent telescope at the time . Determined to bring the Solar System to order , the group became known as the " Himmelspolizei " , or Celestial Police . Notable members included Herschel , the British astronomer royal , Nevil Maskelyne , Charles Messier , and Heinrich Olbers . The society assigned to each astronomer a 15 ° region of the zodiac to search for the missing planet .

Only a few months later , a non @-@ member of the Celestial Police confirmed their expectations . On January 1 , 1801 , Giuseppe Piazzi , chair of astronomy at the University of Palermo , Sicily , found a tiny moving object in an orbit with exactly the radius predicted by the Titius ? Bode law . He dubbed it " Ceres " , after the Roman goddess of the harvest and patron of Sicily . Piazzi initially believed it to be a comet , but its lack of a coma suggested it was a planet . Fifteen months later , Olbers discovered a second object in the same region , Pallas . Unlike the other known planets , the objects remained points of light even under the highest telescope magnifications instead of resolving into discs . Apart from their rapid movement , they appeared indistinguishable from stars . Accordingly , in 1802 , William Herschel suggested they be placed into a separate category , named " asteroids " , after the Greek asteroeides , meaning " star @-@ like " . Upon completing a series of observations of Ceres and Pallas , he concluded ,

Neither the appellation of planets , nor that of comets , can with any propriety of language be given to these two stars ... They resemble small stars so much as hardly to be distinguished from them . From this , their asteroidal appearance , if I take my name , and call them Asteroids ; reserving for myself however the liberty of changing that name , if another , more expressive of their nature , should occur .

Despite Herschel 's coinage , for several decades it remained common practice to refer to these objects as planets . By 1807 , further investigation revealed two new objects in the region : 3 Juno and 4 Vesta . The burning of Lilienthal in the Napoleonic wars brought this first period of discovery to a close , and only in 1845 did astronomers detect another object (5 Astraea) . Shortly thereafter , new objects were found at an accelerating rate , and counting them among the planets became increasingly cumbersome . Eventually , they were dropped from the planet list as first suggested by Alexander von Humboldt in the early 1850s , and Herschel 's choice of nomenclature , " asteroids " , gradually came into common use .

The discovery of Neptune in 1846 led to the discrediting of the Titius ? Bode law in the eyes of scientists , because its orbit was nowhere near the predicted position . To date , there is no scientific explanation for the law , and astronomers ' consensus regards it as a coincidence .

The expression " asteroid belt " came into use in the very early 1850s , although it is hard to pinpoint who coined the term . The first English use seems to be in the 1850 translation (by E. C. Otté) of Alexander von Humboldt 's Cosmos : " [...] and the regular appearance , about the 13th of November and the 11th of August , of shooting stars , which probably form part of a belt of asteroids intersecting the Earth 's orbit and moving with planetary velocity " . Other early appearances occur in Robert James Mann 's A Guide to the Knowledge of the Heavens , " The orbits of the asteroids are placed in a wide belt of space , extending between the extremes of [...] " . The American astronomer Benjamin Peirce seems to have adopted that terminology and to have been one of its promoters . One hundred asteroids had been located by mid @-@ 1868 , and in 1891 the introduction of astrophotography by Max Wolf accelerated the rate of discovery still further . A total of 1 @,@ 000 asteroids had been found by 1921 , 10 @,@ 000 by 1981 , and 100 @,@ 000 by 2000 . Modern asteroid survey systems now use automated means to locate new minor planets in ever @-@ increasing quantities .

= = Origin = =

= = = Formation = = =

In 1802 , shortly after discovering Pallas , Olbers suggested to Herschel that Ceres and Pallas were fragments of a much larger planet that once occupied the Mars ? Jupiter region , this planet having suffered an internal explosion or a cometary impact many million years before . Over time , however , this hypothesis has fallen from favor . The large amount of energy required to destroy a planet , combined with the belt 's low combined mass , which is only about 4 % of the mass of the Moon , do not support the hypothesis . Further , the significant chemical differences between the asteroids become difficult to explain if they come from the same planet . Today , most scientists accept that , rather than fragmenting from a progenitor planet , the asteroids never formed a planet at all .

In general , in the Solar System , planetary formation is thought to have occurred via a process comparable to the long @-@ standing nebular hypothesis : a cloud of interstellar dust and gas collapsed under the influence of gravity to form a rotating disc of material that then further condensed to form the Sun and planets . During the first few million years of the Solar System 's history , an accretion process of sticky collisions caused the clumping of small particles , which gradually increased in size . Once the clumps reached sufficient mass , they could draw in other bodies through gravitational attraction and become planetesimals . This gravitational accretion led to the formation of the planets .

Planetesimals within the region which would become the asteroid belt were too strongly perturbed by Jupiter 's gravity to form a planet . Instead they continued to orbit the Sun as before , occasionally colliding . In regions where the average velocity of the collisions was too high , the shattering of planetesimals tended to dominate over accretion , preventing the formation of planet @-@ sized bodies . Orbital resonances occurred where the orbital period of an object in the belt formed an integer fraction of the orbital period of Jupiter , perturbing the object into a different orbit ; the region lying between the orbits of Mars and Jupiter contains many such orbital resonances . As Jupiter migrated inward following its formation , these resonances would have swept across the asteroid belt , dynamically exciting the region 's population and increasing their velocities relative to each other .

During the early history of the Solar System , the asteroids melted to some degree , allowing elements within them to be partially or completely differentiated by mass . Some of the progenitor bodies may even have undergone periods of explosive volcanism and formed magma oceans . However , because of the relatively small size of the bodies , the period of melting was necessarily brief (compared to the much larger planets) , and had generally ended about 4 @.@ 5 billion years ago , in the first tens of millions of years of formation . In August 2007 , a study of zircon crystals in an Antarctic meteorite believed to have originated from 4 Vesta suggested that it , and by extension the rest of the asteroid belt , had formed rather quickly , within ten million years of the Solar System 's origin .

= = = Evolution = = =

The asteroids are not samples of the primordial Solar System . They have undergone considerable evolution since their formation , including internal heating (in the first few tens of millions of years) , surface melting from impacts , space weathering from radiation , and bombardment by micrometeorites . Although some scientists refer to the asteroids as residual planetesimals , other scientists consider them distinct .

The current asteroid belt is believed to contain only a small fraction of the mass of the primordial belt . Computer simulations suggest that the original asteroid belt may have contained mass equivalent to the Earth . Primarily because of gravitational perturbations , most of the material was ejected from the belt within about a million years of formation , leaving behind less than 0 @.@ 1 % of the original mass . Since their formation , the size distribution of the asteroid belt has remained relatively stable : there has been no significant increase or decrease in the typical dimensions of the main @-@ belt asteroids .

The 4 : 1 orbital resonance with Jupiter , at a radius 2 @.@ 06 AU , can be considered the inner boundary of the asteroid belt . Perturbations by Jupiter send bodies straying there into unstable orbits . Most bodies formed inside the radius of this gap were swept up by Mars (which has an

aphelion at 1 @.@ 67 AU) or ejected by its gravitational perturbations in the early history of the Solar System . The Hungaria asteroids lie closer to the Sun than the 4 : 1 resonance , but are protected from disruption by their high inclination .

When the asteroid belt was first formed , the temperatures at a distance of 2 @.@ 7 AU from the Sun formed a " snow line " below the freezing point of water . Planetesimals formed beyond this radius were able to accumulate ice . In 2006 it was announced that a population of comets had been discovered within the asteroid belt beyond the snow line , which may have provided a source of water for Earth 's oceans . According to some models , there was insufficient outgassing of water during the Earth 's formative period to form the oceans , requiring an external source such as a cometary bombardment .

= = Characteristics = =

Contrary to popular imagery , the asteroid belt is mostly empty . The asteroids are spread over such a large volume that it would be improbable to reach an asteroid without aiming carefully . Nonetheless , hundreds of thousands of asteroids are currently known , and the total number ranges in the millions or more , depending on the lower size cutoff . Over 200 asteroids are known to be larger than 100 km , and a survey in the infrared wavelengths has shown that the asteroid belt has 0 @.@ 7 ? 1 @.@ 7 million asteroids with a diameter of 1 km or more . The apparent magnitudes of most of the known asteroids are 11 ? 19 , with the median at about 16 .

The total mass of the asteroid belt is estimated to be 2 @.@ 8 × 1021 to 3 @.@ 2 × 1021 kilograms , which is just 4 % of the mass of the Moon . The four largest objects , Ceres , 4 Vesta , 2 Pallas , and 10 Hygiea , account for half of the belt 's total mass , with almost one @-@ third accounted for by Ceres alone .

= = = Composition = = =

The current belt consists primarily of three categories of asteroids : C @-@ type or carbonaceous asteroids , S @-@ type or silicate asteroids , and M @-@ type or metallic asteroids .

Carbonaceous asteroids , as their name suggests , are carbon @-@ rich . They dominate the asteroid belt 's outer regions . Together they comprise over 75 % of the visible asteroids . They are more red in hue than the other asteroids and have a very low albedo . Their surface composition is similar to carbonaceous chondrite meteorites . Chemically , their spectra match the primordial composition of the early Solar System , with only the lighter elements and volatiles removed .

S @-@ type (silicate @-@ rich) asteroids are more common toward the inner region of the belt , within 2 @.@ 5 AU of the Sun . The spectra of their surfaces reveal the presence of silicates and some metal , but no significant carbonaceous compounds . This indicates that their materials have been significantly modified from their primordial composition , probably through melting and reformation . They have a relatively high albedo , and form about 17 % of the total asteroid population .

M @-@ type (metal @-@ rich) asteroids form about 10 % of the total population ; their spectra resemble that of iron @-@ nickel . Some are believed to have formed from the metallic cores of differentiated progenitor bodies that were disrupted through collision . However , there are also some silicate compounds that can produce a similar appearance . For example , the large M @-@ type asteroid 22 Kalliope does not appear to be primarily composed of metal . Within the asteroid belt , the number distribution of M @-@ type asteroids peaks at a semi @-@ major axis of about 2 @.@ 7 AU . It is not yet clear whether all M @-@ types are compositionally similar , or whether it is a label for several varieties which do not fit neatly into the main C and S classes .

One mystery of the asteroid belt is the relative rarity of V @-@ type , or basaltic asteroids . Theories of asteroid formation predict that objects the size of Vesta or larger should form crusts and mantles , which would be composed mainly of basaltic rock , resulting in more than half of all asteroids being composed either of basalt or olivine . Observations , however , suggest that 99 percent of the predicted basaltic material is missing . Until 2001 , most basaltic bodies discovered in

the asteroid belt were believed to originate from the asteroid Vesta (hence their name V @-@ type) . However , the discovery of the asteroid 1459 Magnya revealed a slightly different chemical composition from the other basaltic asteroids discovered until then , suggesting a different origin . This hypothesis was reinforced by the further discovery in 2007 of two asteroids in the outer belt , 7472 Kumakiri and (10537) 1991 RY16 , with differing basaltic composition that could not have originated from Vesta . These latter two are the only V @-@ type asteroids discovered in the outer belt to date .

The temperature of the asteroid belt varies with the distance from the Sun . For dust particles within the belt , typical temperatures range from 200 K (? 73 ° C) at 2 @.@ 2 AU down to 165 K (? 108 ° C) at 3 @.@ 2 AU However , due to rotation , the surface temperature of an asteroid can vary considerably as the sides are alternately exposed to solar radiation and then to the stellar background .

= = = Main @-@ belt comets = = =

Several otherwise unremarkable bodies in the outer belt show cometary activity . Because their orbits cannot be explained through capture of classical comets , it is thought that many of the outer asteroids may be icy , with the ice occasionally exposed to sublimation through small impacts . Main @-@ belt comets may have been a major source of the Earth 's oceans , because the deuterium ? hydrogen ratio is too low for classical comets to have been the principal source .

= = = Orbits = = =

Most asteroids within the asteroid belt have orbital eccentricities of less than 0 @.@ 4 , and an inclination of less than 30 ° . The orbital distribution of the asteroids reaches a maximum at an eccentricity of around 0 @.@ 07 and an inclination below 4 ° . Thus although a typical asteroid has a relatively circular orbit and lies near the plane of the ecliptic , some asteroid orbits can be highly eccentric or travel well outside the ecliptic plane .

Sometimes , the term main belt is used to refer only to the more compact " core " region where the greatest concentration of bodies is found . This lies between the strong 4 : 1 and 2 : 1 Kirkwood gaps at 2 @.@ 06 and 3 @.@ 27 AU , and at orbital eccentricities less than roughly 0 @.@ 33 , along with orbital inclinations below about 20 ° . This " core " region contains approximately 93 @.@ 4 % of all numbered minor planets within the Solar System .

= = = = Kirkwood gaps = = = =

The semi @-@ major axis of an asteroid is used to describe the dimensions of its orbit around the Sun , and its value determines the minor planet 's orbital period . In 1866 , Daniel Kirkwood announced the discovery of gaps in the distances of these bodies ' orbits from the Sun . They were located at positions where their period of revolution about the Sun was an integer fraction of Jupiter 's orbital period . Kirkwood proposed that the gravitational perturbations of the planet led to the removal of asteroids from these orbits .

When the mean orbital period of an asteroid is an integer fraction of the orbital period of Jupiter , a mean @-@ motion resonance with the gas giant is created that is sufficient to perturb an asteroid to new orbital elements . Asteroids that become located in the gap orbits (either primordially because of the migration of Jupiter 's orbit , or due to prior perturbations or collisions) are gradually nudged into different , random orbits with a larger or smaller semi @-@ major axis .

The gaps are not seen in a simple snapshot of the locations of the asteroids at any one time because asteroid orbits are elliptical , and many asteroids still cross through the radii corresponding to the gaps . The actual spatial density of asteroids in these gaps does not differ significantly from the neighboring regions .

The main gaps occur at the 3 : 1 , 5 : 2 , 7 : 3 , and 2 : 1 mean @-@ motion resonances with Jupiter . An asteroid in the 3 : 1 Kirkwood gap would orbit the Sun three times for each Jovian orbit , for

instance . Weaker resonances occur at other semi @-@ major axis values , with fewer asteroids found than nearby . (For example , an 8 : 3 resonance for asteroids with a semi @-@ major axis of 2 @.@ 71 AU .)

The main or core population of the asteroid belt is sometimes divided into three zones , based on the most prominent Kirkwood gaps . Zone I lies between the 4 : 1 resonance (2 @.@ 06 AU) and 3 : 1 resonance (2 @.@ 5 AU) Kirkwood gaps . Zone II continues from the end of Zone I out to the 5 : 2 resonance gap (2 @.@ 82 AU) . Zone III extends from the outer edge of Zone II to the 2 : 1 resonance gap (3 @.@ 28 AU) .

The asteroid belt may also be divided into the inner and outer belts , with the inner belt formed by asteroids orbiting nearer to Mars than the 3 : 1 Kirkwood gap (2 @.@ 5 AU) , and the outer belt formed by those asteroids closer to Jupiter 's orbit . (Some authors subdivide the inner and outer belts at the 2 : 1 resonance gap (3 @.@ 3 AU) , whereas others suggest inner , middle , and outer belts .)

= = Collisions = =

The high population of the asteroid belt makes for a very active environment , where collisions between asteroids occur frequently (on astronomical time scales) . Collisions between main @-@ belt bodies with a mean radius of 10 km are expected to occur about once every 10 million years . A collision may fragment an asteroid into numerous smaller pieces (leading to the formation of a new asteroid family) . Conversely , collisions that occur at low relative speeds may also join two asteroids . After more than 4 billion years of such processes , the members of the asteroid belt now bear little resemblance to the original population .

Along with the asteroid bodies , the asteroid belt also contains bands of dust with particle radii of up to a few hundred micrometres . This fine material is produced , at least in part , from collisions between asteroids , and by the impact of micrometeorites upon the asteroids . Due to the Poynting ? Robertson effect , the pressure of solar radiation causes this dust to slowly spiral inward toward the Sun .

The combination of this fine asteroid dust , as well as ejected cometary material , produces the zodiacal light . This faint auroral glow can be viewed at night extending from the direction of the Sun along the plane of the ecliptic . Asteroid particles that produce the visible zodiacal light average about 40 ?m in radius . The typical lifetimes of main @-@ belt zodiacal cloud particles are about 700 @,@ 000 years . Thus , to maintain the bands of dust , new particles must be steadily produced within the asteroid belt . It was once thought that collisions of asteroids form a major component of the zodiacal light . However , computer simulations by Nesvorný and colleagues attributed 85 percent of the zodiacal @-@ light dust to fragmentations of Jupiter @-@ family comets , rather than to comets and collisions between asteroids in the asteroid belt . At most 10 percent of the dust is attributed to the asteroid belt .

= = = Meteorites = = =

Some of the debris from collisions can form meteoroids that enter the Earth 's atmosphere . Of the 50 @,@ 000 meteorites found on Earth to date , 99 @.@ 8 percent are believed to have originated in the asteroid belt .

= = Families and groups = =

In 1918 , the Japanese astronomer Kiyotsugu Hirayama noticed that the orbits of some of the asteroids had similar parameters , forming families or groups .

Approximately one @-@ third of the asteroids in the asteroid belt are members of an asteroid family . These share similar orbital elements , such as semi @-@ major axis , eccentricity , and orbital inclination as well as similar spectral features , all of which indicate a common origin in the breakup of a larger body . Graphical displays of these elements , for members of the asteroid belt , show

concentrations indicating the presence of an asteroid family . There are about 20 ? 30 associations that are almost certainly asteroid families . Additional groupings have been found that are less certain . Asteroid families can be confirmed when the members display common spectral features . Smaller associations of asteroids are called groups or clusters .

Some of the most prominent families in the asteroid belt (in order of increasing semi @-@ major axes) are the Flora , Eunoma , Koronis , Eos , and Themis families . The Flora family , one of the largest with more than 800 known members , may have formed from a collision less than a billion years ago . The largest asteroid to be a true member of a family (as opposed to an interloper in the case of Ceres with the Gefion family) is 4 Vesta . The Vesta family is believed to have formed as the result of a crater @-@ forming impact on Vesta . Likewise , the HED meteorites may also have originated from Vesta as a result of this collision .

Three prominent bands of dust have been found within the asteroid belt . These have similar orbital inclinations as the Eos , Koronis , and Themis asteroid families , and so are possibly associated with those groupings .

= = = Periphery = = =

Skirting the inner edge of the belt (ranging between 1 @.@ 78 and 2 @.@ 0 AU , with a mean semi @-@ major axis of 1 @.@ 9 AU) is the Hungaria family of minor planets . They are named after the main member , 434 Hungaria ; the group contains at least 52 named asteroids . The Hungaria group is separated from the main body by the 4 : 1 Kirkwood gap and their orbits have a high inclination . Some members belong to the Mars @-@ crossing category of asteroids , and gravitational perturbations by Mars are likely a factor in reducing the total population of this group .

Another high @-@ inclination group in the inner part of the asteroid belt is the Phocaea family . These are composed primarily of S @-@ type asteroids , whereas the neighboring Hungaria family includes some E @-@ types . The Phocaea family orbit between 2 @.@ 25 and 2 @.@ 5 AU from the Sun .

Skirting the outer edge of the asteroid belt is the Cybele group , orbiting between 3 @.@ 3 and 3 @.@ 5 AU . These have a 7 : 4 orbital resonance with Jupiter . The Hilda family orbit between 3 @.@ 5 and 4 @.@ 2 AU , and have relatively circular orbits and a stable 3 : 2 orbital resonance with Jupiter . There are few asteroids beyond 4 @.@ 2 AU , until Jupiter 's orbit . Here the two families of Trojan asteroids can be found , which , at least for objects larger than 1 km , are approximately as numerous as the asteroids of the asteroid belt .

= = = New families = = =

Some asteroid families have formed recently , in astronomical terms . The Karin Cluster apparently formed about 5 @.@ 7 million years ago from a collision with a progenitor asteroid 33 km in radius . The Veritas family formed about 8 @.@ 3 million years ago ; evidence includes interplanetary dust recovered from ocean sediment .

More recently , the Datura cluster appears to have formed about 450 thousand years ago from a collision with a main @-@ belt asteroid . The age estimate is based on the probability of the members having their current orbits , rather than from any physical evidence . However , this cluster may have been a source for some zodiacal dust material . Other recent cluster formations , such as the Iannini cluster (circa 1 ? 5 million years ago) , may have provided additional sources of this asteroid dust .

= = Exploration = =

The first spacecraft to traverse the asteroid belt was Pioneer 10 , which entered the region on 16 July 1972 . At the time there was some concern that the debris in the belt would pose a hazard to the spacecraft , but it has since been safely traversed by 12 spacecraft without incident . Pioneer 11 , Voyagers 1 and 2 and Ulysses passed through the belt without imaging any asteroids . Galileo

imaged 951 Gaspra in 1991 and 243 Ida in 1993 , NEAR imaged 253 Mathilde in 1997 , Cassini imaged 2685 Masursky in 2000 , Stardust imaged 5535 Annefrank in 2002 , New Horizons imaged 132524 APL in 2006 , Rosetta imaged 2867 ?teins in September 2008 and 21 Lutetia in July 2010 , and Dawn orbited Vesta between July 2011 and September 2012 and has orbited Ceres since March 2015 . On its way to Jupiter , Juno traversed the asteroid belt without collecting science data . Due to the low density of materials within the belt , the odds of a probe running into an asteroid are now estimated at less than one in a billion .

Most belt asteroids imaged to date have come from brief flyby opportunities by probes headed for other targets . Only the Dawn , NEAR and Hayabusa missions have studied asteroids for a protracted period in orbit and at the surface . Dawn explored Vesta from July 2011 to September 2012 , and has been orbiting Ceres since March 2015 .