Stellar rotation

Stellar rotation is the angular motion of a star about its axis . The rate of rotation can be measured from the spectrum of the star , or by timing the movements of active features on the surface .

The rotation of a star produces an equatorial bulge due to centrifugal force . As stars are not solid bodies , they can also undergo differential rotation . Thus the equator of the star can rotate at a different angular velocity than the higher latitudes . These differences in the rate of rotation within a star may have a significant role in the generation of a stellar magnetic field .

The magnetic field of a star interacts with the stellar wind . As the wind moves away from the star its rate of angular velocity slows . The magnetic field of the star interacts with the wind , which applies a drag to the stellar rotation . As a result , angular momentum is transferred from the star to the wind , and over time this gradually slows the star 's rate of rotation .

Measurement

Unless a star is being observed from the direction of its pole , sections of the surface have some amount of movement toward or away from the observer . The component of movement that is in the direction of the observer is called the radial velocity . For the portion of the surface with a radial velocity component toward the observer , the radiation is shifted to a higher frequency because of Doppler shift . Likewise the region that has a component moving away from the observer is shifted to a lower frequency . When the absorption lines of a star are observed , this shift at each end of the spectrum causes the line to broaden . However , this broadening must be carefully separated from other effects that can increase the line width .

The component of the radial velocity observed through line broadening depends on the inclination of the star 's pole to the line of sight . The derived value is given as <formula> , where ve is the rotational velocity at the equator and i is the inclination . However , i is not always known , so the result gives a minimum value for the star 's rotational velocity . That is , if i is not a right angle , then the actual velocity is greater than <formula> . This is sometimes referred to as the projected rotational velocity .

For giant stars , the atmospheric microturbulence can result in line broadening that is much larger than effects of rotational , effectively drowning out the signal . However , an alternate approach can be employed that makes use of gravitational microlensing events . These occur when a massive object passes in front of the more distant star and functions like a lens , briefly magnifying the image . The more detailed information gathered by this means allows the effects of microturbulence to be distinguished from rotation .

If a star displays magnetic surface activity such as starspots , then these features can be tracked to estimate the rotation rate . However , such features can form at locations other than equator and can migrate across latitudes over the course of their life span , so differential rotation of a star can produce varying measurements . Stellar magnetic activity is often associated with rapid rotation , so this technique can be used for measurement of such stars . Observation of starspots has shown that these features can actually vary the rotation rate of a star , as the magnetic fields modify the flow of gases in the star .

Physical effects

Equatorial bulge

Gravity tends to contract celestial bodies into a perfect sphere , the shape where all the mass is as close to the center of gravity as possible . But a rotating star is not spherical in shape , it has an equatorial bulge .

As a rotating proto @-@ stellar disk contracts to form a star its shape becomes more and more spherical , but the contraction doesn 't proceed all the way to a perfect sphere . At the poles all of the gravity acts to increase the contraction , but at the equator the effective gravity is diminished by the centrifugal force . The final shape of the star after star formation is an equilibrium shape , in the sense that the effective gravity in the equatorial region (being diminished) cannot pull the star to a more spherical shape . The rotation also gives rise to gravity darkening at the equator , as described by the von Zeipel theorem .

An extreme example of an equatorial bulge is found on the star Regulus A (? Leonis A) . The equator of this star has a measured rotational velocity of 317 ± 3 km / s . This corresponds to a rotation period of 15 @.@ 9 hours , which is 86 % of the velocity at which the star would break apart . The equatorial radius of this star is 32 % larger than polar radius . Other rapidly rotating stars include Alpha Arae , Pleione , Vega and Achernar .

The break @-@ up velocity of a star is an expression that is used to describe the case where the centrifugal force at the equator is equal to the gravitational force . For a star to be stable the rotational velocity must be below this value .

Differential rotation

Surface differential rotation is observed on stars such as the Sun when the angular velocity varies with latitude . Typically the angular velocity decreases with increasing latitude . However the reverse has also been observed , such as on the star designated HD 31993 . The first such star , other than the Sun , to have its differential rotation mapped in detail is AB Doradus .

The underlying mechanism that causes differential rotation is turbulent convection inside a star . Convective motion carries energy toward the surface through the mass movement of plasma . This mass of plasma carries a portion of the angular velocity of the star . When turbulence occurs through shear and rotation , the angular momentum can become redistributed to different latitudes through meridional flow .

The interfaces between regions with sharp differences in rotation are believed to be efficient sites for the dynamo processes that generate the stellar magnetic field . There is also a complex interaction between a star 's rotation distribution and its magnetic field , with the conversion of magnetic energy into kinetic energy modifying the velocity distribution .

Rotation braking

During formation

Stars are believed to form as the result of a collapse of a low @-@ temperature cloud of gas and dust . As the cloud collapses , conservation of angular momentum causes any small net rotation of the cloud to increase , forcing the material into a rotating disk . At the dense center of this disk a protostar forms , which gains heat from the gravitational energy of the collapse .

As the collapse continues , the rotation rate can increase to the point where the accreting protostar can break up due to centrifugal force at the equator . Thus the rotation rate must be braked during the first 100 @,@ 000 years to avoid this scenario . One possible explanation for the braking is the interaction of the protostar 's magnetic field with the stellar wind in magnetic braking . The expanding wind carries away the angular momentum and slows down the rotation rate of the collapsing protostar .

Most main @-@ sequence stars with a spectral class between O5 and F5 have been found to rotate rapidly . For stars in this range , the measured rotation velocity increases with mass . This increase in rotation peaks among young , massive B @-@ class stars . As the expected life span of a star decreases with increasing mass , this can be explained as a decline in rotational velocity with age .

After formation

For main @-@ sequence stars , the decline in rotation can be approximated by a mathematical relation :

<formula>

where <formula> is the angular velocity at the equator and t is the star 's age . This relation is named Skumanich 's law after Andrew P. Skumanich who discovered it in 1972 . Gyrochronology is the determination of a star 's age based on the rotation rate , calibrated using the Sun .

Stars slowly lose mass by the emission of a stellar wind from the photosphere . The star 's magnetic field exerts a torque on the ejected matter , resulting in a steady transfer of angular momentum away from the star . Stars with a rate of rotation greater than 15 km / s also exhibit more rapid mass loss , and consequently a faster rate of rotation decay . Thus as the rotation of a star is slowed because of braking , there is a decrease in rate of loss of angular momentum . Under these conditions , stars gradually approach , but never quite reach , a condition of zero rotation .

= = Close binary systems = =

A close binary star system occurs when two stars orbit each other with an average separation that is of the same order of magnitude as their diameters . At these distances , more complex interactions can occur , such as tidal effects , transfer of mass and even collisions . Tidal interactions in a close binary system can result in modification of the orbital and rotational parameters . The total angular momentum of the system is conserved , but the angular momentum can be transferred between the orbital periods and the rotation rates .

Each of the members of a close binary system raises tides on the other through gravitational interaction . However the bulges can be slightly misaligned with respect to the direction of gravitational attraction . Thus the force of gravity produces a torque component on the bulge , resulting in the transfer of angular momentum (tidal acceleration) . This causes the system to steadily evolve , although it can approach a stable equilibrium . The effect can be more complex in cases where the axis of rotation is not perpendicular to the orbital plane .

For contact or semi @-@ detached binaries , the transfer of mass from a star to its companion can also result in a significant transfer of angular momentum . The accreting companion can spin up to the point where it reaches its critical rotation rate and begins losing mass along the equator .

= = Degenerate stars = =

After a star has finished generating energy through thermonuclear fusion , it evolves into a more compact , degenerate state . During this process the dimensions of the star are significantly reduced , which can result in a corresponding increase in angular velocity .

= = = White dwarf = = =

A white dwarf is a star that consists of material that is the by @-@ product of thermonuclear fusion during the earlier part of its life , but lacks the mass to burn those more massive elements . It is a compact body that is supported by a quantum mechanical effect known as electron degeneracy pressure that will not allow the star to collapse any further . Generally most white dwarfs have a low rate of rotation , most likely as the result of rotational braking or by shedding angular momentum when the progenitor star lost its outer envelope . (See planetary nebula .)

A slow @-@ rotating white dwarf star can not exceed the Chandrasekhar limit of 1 @.@ 44 solar masses without collapsing to form a neutron star or exploding as a Type Ia supernova . Once the white dwarf reaches this mass , such as by accretion or collision , the gravitational force would exceed the pressure exerted by the electrons . If the white dwarf is rotating rapidly , however , the effective gravity is diminished in the equatorial region , thus allowing the white dwarf to exceed the Chandrasekhar limit . Such rapid rotation can occur , for example , as a result of mass accretion that results in a transfer of angular momentum .

Neutron star

A neutron star is a highly dense remnant of a star that is primarily composed of neutrons ? a particle that is found in most atomic nuclei and has no net electrical charge . The mass of a neutron star is in the range of 1 @.@ 2 to 2 @.@ 1 times the mass of the Sun . As a result of the collapse , a newly formed neutron star can have a very rapid rate of rotation ; on the order of a hundred rotations per second .

Pulsars are rotating neutron stars that have a magnetic field . A narrow beam of electromagnetic radiation is emitted from the poles of rotating pulsars . If the beam sweeps past the direction of the Solar System then the pulsar will produce a periodic pulse that can be detected from the Earth . The energy radiated by the magnetic field gradually slows down the rotation rate , so that older pulsars can require as long as several seconds between each pulse .

Black hole

A black hole is an object with a gravitational field that is sufficiently powerful that it can prevent light from escaping . When they are formed from the collapse of a rotating mass , they retain all of the angular momentum that is not shed in the form of ejected gas . This rotation causes the space within an oblate spheroid @-@ shaped volume , called the " ergosphere " , to be dragged around with the black hole . Mass falling into this volume gains energy by this process and some portion of the mass can then be ejected without falling into the black hole . When the mass is ejected , the black hole loses angular momentum (the " Penrose process ") . The rotation rate of a black hole has been measured as high as 98 @.@ 7 % of the speed of light .