Extreme Tidal Waves in Binary Star Systems

Jim Fuller is...

If you have ever been to the beach, you have seen tides at work. The ocean slowly recedes from the shore, revealing colonies of sea shells on the sand deposited the water's wake. A few hours later, the ocean creeps back, slowly devouring the sand castles misfortune enough to stand within its watery grasp. The tides in the ocean are caused by the gravitational pull of the Moon (and to a smaller extent, the Sun). As the Earth rotates through the gravitational field of the Moon, it is stretched by tidal forces, slightly distorting the Earth into an elliptical shape. The ocean rises and recedes in order to adjust to the changing shape of its basin, causing the smooth ebb and flow of daily tides. On Earth, theses tides are peaceful, predictable, and passive.

In binary star systems, tides can be much more volatile. Tidal interactions are particularly intense in compact binary white dwarf systems. White dwarfs are the burnt out cores of stars like the Sun. They are small compared to their living stellar counterparts: most white dwarfs are approximately the size of the Earth. Yet despite their small size, white dwarfs are roughly the same mass as the Sun, meaning that they are about a million times denser than the water in our ocean, and a billion times denser than the air in our atmosphere. The small size and large mass of white dwarfs means that they can orbit each other at relatively small distances. Since tides are much stronger in stars that orbit each other closely, the tides in compact binary white dwarfs can be extremely powerful. For instance, consider the binary white dwarf system SDSS J0651. This system is composed of two white dwarfs slightly larger than the Earth and nearly as massive as the Sun, but closer to one another than the Earth is to the Moon. Whereas it takes the Moon nearly a month to orbit around the Earth, these stars orbit each other in just under thirteen minutes. On Earth, the tides raised by the Moon are a couple feet high. In SDSS J0651, the tides are over 100 miles high.

In star systems like SDSS J0651, the tides are not only impressively large, but they also have important consequences for the evolution of the stars. One of the effects of tides is to synchronize the spin and orbital periods of the stars, such that one side of each star is always facing its companion. In the Earth-Moon system, tides have synchronized the Moon with the Earth, so we only see the near side of the Moon. It will take another few billion years to synchronize the Earth with the Moon, and once this happens, the Moon will only be visible from one side of the Earth! However, the physics of tidal synchronization is poorly understood, and astronomers have been unsure.

The two white dwarfs of J0651 where once like our sun, but they have burned down to become much smaller and more massive. The larger star is about the size of Neptune and about a quarter of the mass of the sun. The other one is half the sun's mass and only about the size of the earth. A penny made of this white dwarf’s material would weigh about 1,000 pounds on earth. They are closer to each other than the earth is to the moon and orbit each other at a speed of 70 miles per second, or 180 times faster than the fastest jet on earth. Not only do they make a complete orbit in just 13 minutes, they also exert a mutual gravitational pull so strong that the lower-mass star is deformed by three percent. If the earth bulged by the same amount, we would have tides 120 miles high.

Image: XXXXXXXXXXXXXXXXX.

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The enormous gravitational pull of Jupiter on Io is compounded by that of other nearby moons—Europa, Callisto, and Ganymede. Jupiter pulls Io toward itself, while the gravity of the outer moons pulls it in the opposite direction. These tidal forces alternately squeeze and stretch Io’s interior, making its surface rise and fall by some 300 ft. This friction generates enormous amounts of heat and pressure, causing molten material and gases to rise through fractures in the crust and erupt onto the surface of Io as volcanoes.

Image: NASA/JPL.
how tidal processes operate in white dwarfs. Since the orbits of these stars decay until they merge, it is unknown whether the stars will be able to synchronize before the collision. And what happens during the collision (it could create a supernova) is dependent on whether the stars are synchronized.

Furthermore, the friction created by large tides will induce substantial heating of the stars. In Jupiter’s moon, Io, tidal forces scrunch the moon back and forth, causing frictional heating in its interior. These kinds of tides are similar to the heating of a racquet ball after it is hit repetitively. Such tidal heating powers huge volcanoes on Io, and they may create a giant ocean capable of sustaining life on Europa, another moon of Jupiter. In systems like J0651, the heating may make the stars shine much brighter than they otherwise would. In some cases, it may even be powerful enough to reignite thermonuclear fusion in the white dwarfs.

There are two ways that tides can synchronize (and heat) stars in compact binary systems. The first is through the force of friction waves that move within the stars. These waves are periodic global deformations of the star, similar to the ringing of a bell. As the stars orbit one another, they continually “ring” one another, and the friction created by the waves within the stars helps synchronize them and heat them. My research has shown that this second method is extremely important for white dwarfs, and that it is able to quickly synchronize systems such as J0651. Furthermore, the heat produced by this ringing can reignite thermonuclear fusion within the stars, causing them to erupt in a violent outburst called a nova.

In addition to binary white dwarf systems, the effects of tides have important implications for newly discovered exoplanetary systems. In many of the recently discovered solar systems beyond our own, there are planets that orbit their star in a matter of days, much faster than Mercury orbits our Sun. For these planets, the tides are strong enough to synchronize the planet with the star, such that it is permanent day time on one side of the planet and permanent night time on the other. In some cases, tides may cause the orbits of the planets to decay until they are swallowed by their host stars. In other cases, tides may heat the planet enough to melt it entirely, or cause its atmosphere to escape into space.

Even in less extreme cases, tides will have a profound impact on the planetary climate and on the prospects for life on other planets. Without tidal interactions between the Earth and Moon, the day would only be a few hours long, and life as we know it would not be able to exist. We must therefore continue to study tidal interactions as we search for life beyond Earth. In the process, we can learn a little more about how tides have affected life right here at home, and what we can expect as we look into the future.

–Jim Fuller