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Understanding super bright mysteries of the universe

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Observations of distant astronomical sources highlight what we know and do not know about the way our universe works. Among the mysteries of the cosmos are ultra-luminous X-ray sources, which are too bright to be explained by classical physics. New study now sheds light on their possible source.

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Observing a faraway astronomical object is the current best way to understand it. If we could travel to a distant star, and look at what is going on up close, the whole process of science would be a lot faster. But our best option is studying the light that has travelled from the faraway source, traversing lightyears to reach us.

These observations can validate our theories about how the universe works. For instance, by observing astronomical objects such as neutron stars and black holes (that have small sizes and very high density), we confirmed that the process of depositing matter from the surrounding environment on such a compact object results in observable X-ray radiation. However, theory tells us that there is a limit to the luminosity that you can expect from such a physical process, called the Eddington limit. This limit is based on the balance between the incoming matter and the outgoing radiation. If the deposition rate of matter exceeds this limit, the outgoing radiation is so strong that it blows away additional matter. The Eddington limit depends directly on the mass of the compact object, so heavier masses correspond to higher Eddington limits.

The caveat is that this limit is defined for a simplified case where there is no preferred direction of deposition on the compact object surface, it is "isotropic". The deposited matter is provided by another star (like our Sun) and is pulled by the gravity of the compact object. These astronomical star-and-compact-object duos are referred to as X-ray binaries. The compact object in X-ray binaries can range from black holes to neutron stars and give a range of luminosities (energy produced per unit time by the source).

Naturally, when we observe something that does not fit with accepted theory, we have to explore different ideas to explain it and adjust our understanding of how the universe works. In 1989, the Einstein Observatory observed X-ray sources that seemed brighter than 10 to 1000 times a typical X-ray binary! These are known as ultra-luminous X-ray sources (or ULXs). Following the classical idea of X-ray binaries, these "super-Eddington" luminosities should not be possible.

There were many theories regarding ULXs, mainly that they contain either regular compact objects emitting super-Eddington X-rays, or very massive compact objects emitting high luminosities that are limited by a correspondingly high Eddington limit. To figure out the nature of ULXs, understanding the compact objects is paramount, and that starts with their mass. In general, the mass of a typical neutron star is 1.4 solar masses (meaning, 1.4 times the mass of our Sun) and a typical black hole (associated with X-ray binaries) is about 10 solar masses. To put more perspective on the issue, ULXs are way brighter than the Eddington limit of a 10 solar mass black hole! So, neutron stars were not considered as ULX candidates and researchers were primarily looking towards very massive black holes (with masses 100 to 100,000 solar masses).

It all changed in 2014, with the discovery of X-ray pulses in the observations of the ULX X-2 in the galaxy M82. Surprisingly, X-ray pulses are produced only when the compact object involved has a hard surface. Incoming matter that deposits on this hard surface creates a "hot spot" which appears like a lighthouse beam as the compact object spins around. Black holes do not have a well-defined hard surface, whereas neutron stars do! Since then some more ULXs have been shown to have neutron stars.

In order to explain this sub-population of ULXs that have neutron stars, we considered the deviation from the assumption of isotropic mass deposition. Normally, material approaching a neutron star, forms a thin disk around it before depositing on the neutron star. According to the theory suggested in 1974, when the mass-transfer rate is high enough, the disk puffs up to withstand the high radiation produced. This thick disk is like a cloud almost-enveloping the neutron star that forces most of the light to leave the X-ray binary through a small area. This concentrating action increases the observed luminosity. Using detailed calculations of the evolution of binaries, we found that this description of the neutron star accretion disk is easily able to reach luminosities attained by ULXs.

Motivated by this work, we are working to carry out statistical studies of X-ray binaries that would be ULXs and constrain the physics involved. These sources open the door for us to discover new and exciting physics and challenge our understanding of the universe.