Interacting Close Binaries: X-Ray

Mauro Jélvez

1. Introducción

2.

An X-ray binary is a close system of two stars, one of which is transfering matter to the companion. The transfer might take the form of a stellar wind or of a stream due to overflow of the critical Roche lobe. The companion must be compact enough, so that the infalling matter radiates in X-Ray binaries, wich requieres the compact component to be either a neutron star or a black hole. So, for our purposes, an X-Ray Binary is composed of an optical componentes like a MS star, WD or RG, and an X-Ray component like we said before. In this graph, we can see the photon flux with its energy, we have two main contributions, the first dashed line corresponds to the thermal emission in the accretion disk which is optically thick, its behavior is close to that of a black body, and the other contribution is due to the optically thin hot plasma as corona.

The matter attracted by a neutron star or a black hole is falling down an enormous well of gravitational potential and is accelerated to extremally high velocities. The free fall velocities at the region where the kinetic energy can be thermalized and radiated away are of the order of half of the velocity of light. Therefore, accretion on a very compact object is a very efficient way of releasing energy, much more efficient than nuclear reactions, the accretion luminosity for this kind of binaries are in the order of ten raised to 35 to 39 ergs/s in the X-Ray band.

3.

This is the spectra on X-Rays of an accreting black hole of a system called Cygnus X-1, accretion can occour in two main spectral states.
In the soft state, the accretion disk approaches the black hole, becomes denser, and becomes very hot. Emission of low-energy X-rays ("soft" photons) dominates. The spectrum becomes more like that of a blackbody.
In contrast, in the hard state, the accretion disk is fainter and receding from the black hole. The X-ray emission is dominated by a "corona" of extremely energetic particles surrounding the black hole. This corona produces high-energy X-rays ("hard" photons). The spectrum is more like a power law.

And for the other side we have the varaibility of Cygnus X-1, that is anything but stable. In high energy X-Ray emission what we call the hard band, fluctuates dramaticlly over time, as evidenced by these peaks and valleys that extend over 4 years.
This variability is not random. It is direct signature of the violence surrounding the black hole, it is telling us a story about how it feeds. We see that the material from the companion star doesn't fall in smoothly and orderly. It does so chaotically, tiny instabilities in the disk of gas that form around the black hole are amplified, causing these brutal changes in brightness that we observe.
This variability on the hard state, show us how the black hole feed more violently, heating up a corona of energetic particles that emits these powerful X-Rays.

4.

The spectrum of a neutron star displays two key components: thermal emission, which is the glow from its hot surface, and coronal or magnetospheric emission, identified by an abrupt energy cutoff caused by its intense magnetic field. Together, these two signatures form the unique spectral fingerprint that confirms the presence of a neutron star and distinguishes it from other compact objects such as black holes.

5.

This kind of binaries can be further divided into two different classes, regardless the nature of the compact object, and this classify is according to the mass of the companion star,
The first of them are the high mass X-Ray binaries wich involves a compact object with a massive star, typically O or B type, the accretion occurs primarilly through stellar wind capture, usually this kind of XRBs have shorter lifespans in the order of millions of years, and this is due to the fast evolution of massive stars, they're are concentred in the galactic plane, especially in spiral arms. As an example we can see the system Cygnus X-1 with a massive star, it doesn't seem on this gif but the BH it's accresing this star. And for this system, Cygnus X-1 is the first case in which the presence of a black hole could be proven, because it was discovered in 1964 as an intense source of X-Rays.Then, in 1971, they noticed that this source turned out to have a massive and unseen companion. The next year, the object was proposed to be a black hole, and finally in 1973, the astronomical community had accepted Cygnus X-1 as the first firm candidate for a black hole.

For the other types, the low mass X-Ray binaries features a compact with a low mass star, usually K or M type, the accretion happens mainly through Roche lobe overflow, contrary to high mass x ray binaries, this systems have a longer lifespans in order of billion of years, due to the slower evolution of low mass stars and are located toward galactic center, many of them are found in globular clusters. For the example of low mass x ray binaries we have MAXI J1659, which is the fastest known orbit of an accreting black hole, the components of this system are separated just for 1 million of kilometers.

6.

This table summarizes the differences in initial orbital parameters between the two classes of XRBs. LMXBs are very compact systems, with orbital periods of hours to a few days, small separations, and nearly circular orbits due to tidal effects and their orbits usually are sinchronized. In contrast, HMXBs have very massive companion stars, much wider orbits that can be eccentric, and orbital periods that range from days to even a year. These differences reflect both stellar evolution and the mass transfer mechanisms that fuel the compact object.

7.

How we detect this binaries? they're detected primarily through the intense X-ray emission produced when the companion star's gas falls onto the compact object. In LMXBs, mass transfer occurs through Roche lobe overflow, generating a hot, soft-X-ray-bright accretion disk with rapid variability and, in some cases, X-ray bursts which can be detected, produced by the accretion of hydrogen and helium.

In HMXBs, on the other hand, detection is usually based on the hard X-rays pulsations produced by the accretion of massive stellar winds. These systems exhibit pulsations in the case of magnetized neutron stars and are also easily identified because their companion is a very luminous OB star in the optical. In both cases, we combine X-ray observations with optical, spectroscopic, and, in some systems, radio studies to confirm the binary nature and estimate orbital parameters and masses, the pulsations of this binaries are result from rotating neutron stars with strong magentic fields.
Now, let's talk about this differences, in great majory of massive XRBs, the XRAY component as we said before, is explained by rotation of a strongly magnetized accreting neutron star. Due to presence of stron magnetosphere, the accretion is possible only on small areas in the vicinity of magentic poles. As a result X-Ray emission is beamed. This beaming together with rotation leads to the observed X-Ray pulses.
By the other side we have the X-Ray Busters as a result of an unstable nuclear burning of hydrogen and helium in the matter accumulating on the surface of a neutron star in the process of accretion, usually systems wich show this Busters have a relatively weak magentic field.

8.

Mass transfer is the key process that powers compact objects in X-ray binaries and exists two main mechanisms, the first of them it's the Roche lobe overflow this occurs in compact systems, typical of LMXBs, where the companion star fills its Roche lobe. The gas flows through the Lagrange point into the compact object, forming a stable and highly X-ray-efficient accretion disk.
For the other side we have the wind stellar accretion wich predominates in HMXBs. The massive companion star loses mass through an intense stellar wind, part of which is captured by the compact object's gravity. This process is less efficient than the RLOF, but produces hard X-rays and, in systems with neutron stars, the pulsations are associated with the magnetic field.
On the bottom we can see this figure where we compare the two main mass transfer mechanisms in X-ray binaries. On the left, in low-mass systems, the companion star fills its Roche lobe, and gas flows directly toward the compact object, forming a large, stable accretion disk. On the right, in high-mass systems, the massive companion loses material in the form of a stellar wind; some of this gas is captured by the compact object, resulting in less efficient accretion and smaller disks. These differences in accretion geometry explain why the spectra and variability of LMXBs and HMXBs are so distinct.

9.

The angular momentum of X-ray binaries is lost through various mechanisms that depend on the type of system and its initial conditions.

In LMXBs, where the companion is low-mass, the two main drivers of orbital evolution are magnetic braking and gravitational wave emission. Magnetic braking occurs because the star's stellar wind drags magnetic field lines, stripping away angular momentum and slowing the star's spin; as it is tidally locked to the orbit, the star also slows down, causing the separation between the two objects to decrease. In the most compact systems, with orbital periods of just a few hours, gravitational wave emission becomes dominant and acts as a very efficient angular momentum loss mechanism, keeping the mass flow toward the compact object active.
For other side, in HMXBs, the situation is different: the companion is a massive star that expels enormous amounts of material in the form of a stellar wind. Some of this gas is captured and produces X-rays, but much of it escapes the system, taking angular momentum with it. Furthermore, many of these systems form after a supernova explosion, which leaves the compact object in an eccentric orbit. This eccentricity can persist, leading to unstable orbits or even the disruption of the system.

In summary, angular momentum loss processes govern the evolution of X-ray binaries, for the of LMXBs, it's by contracting the orbit and sustaining stable accretion over long periods and for HMXBs, by modulating the efficiency of wind accretion and determining whether the system remains bound or disperses. The life and fate of each binary depend largely on which AML mechanism dominates.

10.

The fate of X-ray binaries depends on their type. In LMXBs, the donor star eventually loses almost all of its mass, ending up as a light white dwarf or even a planetary-like object, while the system can evolve into a recycled millisecond pulsar.
In HMXBs, the massive companion explodes as a supernova: sometimes disrupting the system, and other times leaving behind a pair of compact objects that, over time, may merge, emitting gravitational waves and producing phenomena such as kilonovae.
In all cases, the life of the binary ends being shaped by mass loss and angular momentum loss, which determine whether the system survives or dissolves.

Cual es la diferencia entre

$$C_r^n = \frac{n!}{r!(n-r)!}$$

Y

$$C_r^n = \frac{n!}{(n-r)!}$$