



Subluminous X-ray Binaries

M. Armas Padilla

English summary

Black holes (BHs) and neutron stars (NSs) are among the most interesting stellar bodies. Their huge compactness and immense densities are not possible to reproduce on the Earth, and therefore their study leads to new insights in fundamental fields like the behaviour of ultra-dense matter or in the theory of general relativity in extreme gravitational fields, among others. A typical neutron star has roughly the same mass of the Sun, but it is compressed in an sphere with a radius of only 10 km or, equivalently, to take the Sun and compress all its mass inside a sphere with the same diameter as Amsterdam (Fig. A). The density is so high, that only a spoon of this material weights 100 millions of tonnes. The black holes are even more compact: they can have 10 times the mass of the Sun compressed in less than 34 km. Their gravitational field is so intense, that even light can not escape. Therefore, since black holes do not emit light and neutron stars are so small that they emit at a very low level in the optical bands, making them difficult to detect, the best way to study their properties is via their interaction with the environment. This is the case for NSs and BHs in close binary systems, i.e. systems that harbour an ordinary star and a compact object (NS or BH). The huge gravitational force produced by the compact object catches material from the regular star which eventually falls onto the NS or BH. But this accretion of material does not occur directly from the companion star onto the compact object. The accretion of the material takes place via a disc which is formed around the compact object in order to conserve the angular momentum of the infalling matter. The friction between the layers of material in this disc produces very high temperatures; high enough to produce a large amount of X-ray emission. For this reason they are called X-ray binaries (Fig. B).

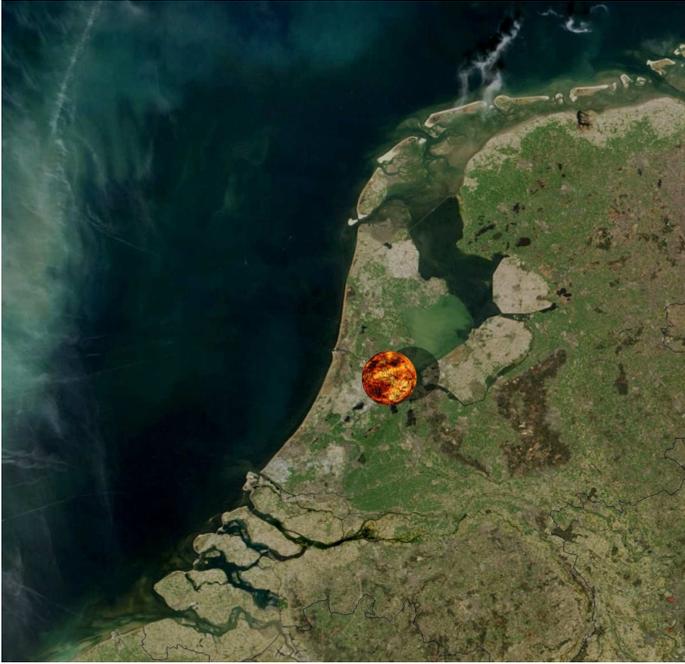


Figure A: The size of an NS compared to Amsterdam.

Accretion can occur at different rates. As a result, X-ray binaries exhibit a variety of states that are reflected in changes in their spectral and temporal properties, as well as display a wide range of accreting luminosities. The study of such properties provide information about the stellar parameters (e.g., masses or radii), accretion physics or ultra-dense matter, among others.

X-rays are filtered by the Earth's atmosphere, making life possible on our planet but inconvenient for astronomers. Therefore, to be able to observe at these wavelengths, the X-ray instruments are on board rockets or satellites outside of the atmosphere. The discovery of the first X-ray binary, Scorpius X-1, with the first generation of X-ray rockets and observatories, marked the birth of X-ray astronomy. Half a century later and after several generations of X-ray instruments, many new phenomena have been discovered and studied. In particular, thanks to the improvement in sensitivity and spatial resolution of the new generation of X-ray instruments, a new family of subluminescent X-ray binaries have been found.

This thesis is focused on the study of very faint X-ray binaries (VFXBs), a subgroup of X-ray binaries that display maximum luminosities of only $L_X \sim 10^{34-36} \text{ erg s}^{-1}$, several orders of magnitude lower than the ordinary well studied X-ray binaries. These low luminosities imply that they are accreting at low rates. Therefore, they



Figure B: Artistic impression of an X-ray binary. Illustration by Brian Christensen.

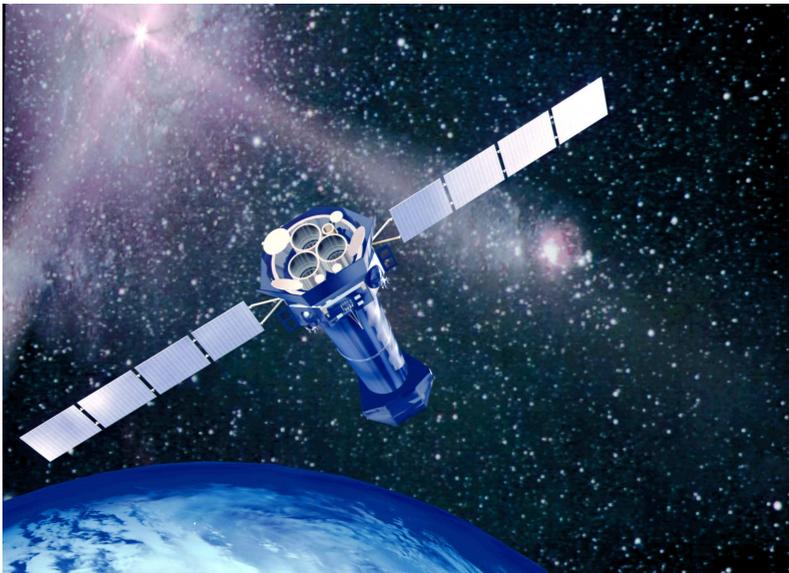


Figure C: Artistic impression of the *XMM-Newton* space telescope.

are ideal to study the relatively unexplored low accretion rate regimes and therefore provide valuable input in several accretion related phenomena, such as accretion physics, binary evolution models and the theory of nuclear burning on the surface of accreting NSs.

I present the analysis of several VFXBs in order to investigate their properties. I make use of the X-ray observatories *XMM-Newton* (Fig. C), *Swift*, *Chandra*, and *RXTE*. Each of these observatories has its own strengths, and the instruments were chosen depending on the science case.

The first part of this thesis (Chapter 2) investigates the spectral properties of persistent VFXBs. The persistent systems are those which always show similar luminosities, and in the case of the very faint ones, are always displaying luminosities in the range of $L_X \sim 10^{34-36} \text{ erg s}^{-1}$. The persistent behaviour at such low accretion rates challenges the current accretion physics models. I present the analysis of the currently available high-quality spectra of three persistent sub-luminous NSs. One of the main results reported is the detection of a thermal component when the luminosity is below $L_X \sim 10^{35} \text{ erg s}^{-1}$. The most probable origin for this component is the NS surface.

In the second part (Chapter 3 and Chapter 4) I studied VFXBs containing, most probably, a NS as accretor. However, in this case their luminosity varies by a few orders of magnitude. They spend most of their lives in a dim, quiescent state, but experience sporadic and bright outbursts as a result of a sudden increase in the accretion rate onto the accretor. I combine studies of the overall evolution of the outburst with detailed observations with the highest-quality data during certain phases of the outburst. High quality spectral studies of both persistent and transient sources yields analogous results. A relatively cold thermal component is found below certain luminosities, indicating a NS origin (e.g., Fig. D). In particular, in Chapter 4 the evolution of this thermal component is examined in detail, pointing to low level accretion onto the NS surface as the most likely origin. Furthermore, our observations during the outburst (Chapter 3) show that at low luminosities ($L_X < 10^{36} \text{ erg s}^{-1}$) the spectra become softer with decreasing luminosity. The latter is consistent with the advection-dominated accretion flow (ADAF) model.

The last part of the thesis is dedicated to the study of the so far only known VFXB harbouring a confirmed BH accretor, namely *Swift* J1357.2–0933. The properties of the source (e.g. its proximity and high Galactic latitude) make it possible to obtain good quality data at low luminosities. Hence, in Chapter 5 I present also studies on the spectral evolution during the outburst which show the usual softening behaviour at these low luminosities. In addition, I present the correlation between the X-ray and ultraviolet/optical emission during the outburst which suggests that the BH is accreting via a non-irradiated or only marginally irradiated disc. In Chapter 6 I report

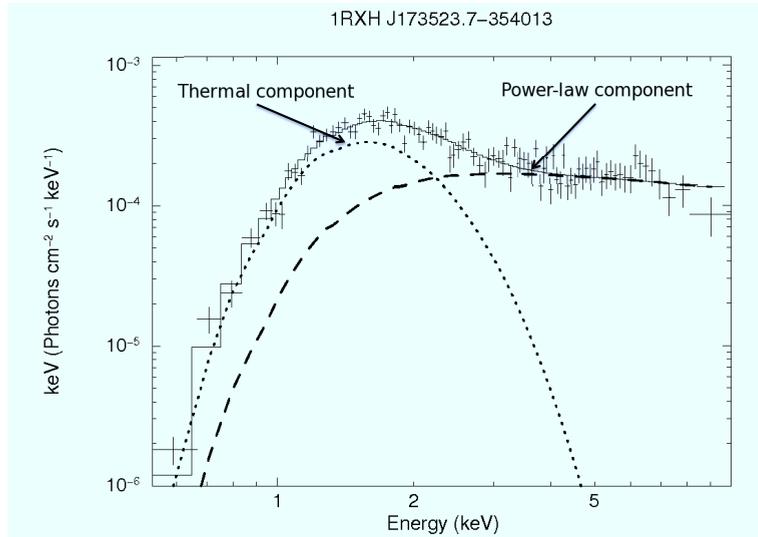


Figure D: Typical NS spectrum at low luminosities. One can identify two components: a soft thermal component, most likely originating on the NS surface, and a hard power-law component, probably produced by up-scattering in a hot cloud of electrons in the vicinity of the compact object. See more details in Chapter 1.

the spectral and temporal analysis of an *XMM-Newton* observation triggered at the peak of the outburst. Its properties are consistent with a BH at low luminosities.