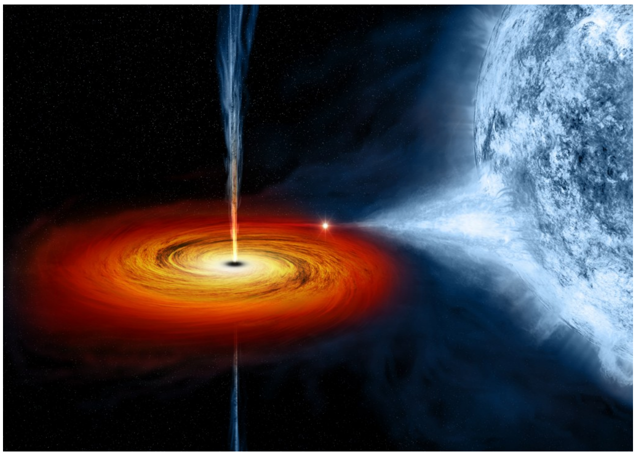
Bachelor and Master Theses Projects

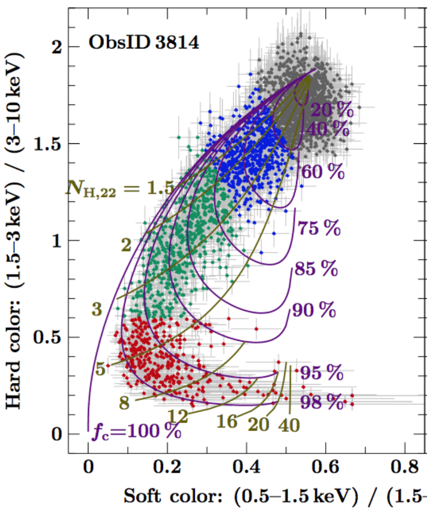
with Dr. Victoria Grinberg
victoria.grinberg@fau.de   @vicgrinberg



An artist's impression of a high mass black hole X-ray binary. The black hole accretes matter from the focussed stellar wind of the O-star companion; accretion disk and jets form around the black hole. Source: NASA.

Since its birth in 1962 with the first rocket flights of X-ray detectors, high energy astronomy has opened a new window into out universe, allowing us to study some of the most energetic objects in the universe, the co-called X-ray binaries: neutron stars and black holes that accrete matter from a normal stellar companion in a binary system. We can use the X-ray radiation created in the accretion process close to black holes and neutron stars to learn more about these enigmatic objects themselves. But we can also use the X-ray emission to investigate the environment in these systems, in particular the complex stellar wind in high mass X-ray binaries, where the companion is a supergiant O- or B-star.

In all the following projects, you will learn how to analyze observations from different space-based X-ray telescopes such as NASA's *Chandra* and *RXTE* and ESA's *INTEGRAL* and *XMM-Newton*, compare them to models, and so help disentangle the mystery of X-ray binaries. Since all projects include data analysis of some kind, they will require willingness to program and to learn at least some basic scripting – no prior coding experience required, you can learn everything on the job! Please get in touch (best: via e-mail) if you are interested in a project.



Color-color diagram of a *Chandra* observation of the X-ray binary Cyg X-1. Source: PhD thesis of M. Hanke, 2011.

Da alle wissenschaftliche Literatur aus dem Bereich der Astrophysik heutzutage auf Englisch veröffentlich wird, sollten interessierte Studierende die Bereitschaft mitbringen, wissenschaftliche Texte auf Englisch zu lesen. Ob die Arbeit auf Englisch oder Deutsch verfasst wird, kann im Einzelfall entschieden werden. Da alle Arbeiten aber entweder zu wissenschaftlichen Veröffentlichungen beitragen oder, im Falle der Masterarbeiten, im Idealfall zu einer eigenständigen wissenschaftlichen Veröffentlichung führen sollen, ist Englisch in den meisten Fällen allerdings sinnvoller. Hilfestellung bei English-Problemen wird selbstverständlich geleistet! Und sobald man mehr wissenschaftliches auf Englisch als Deutsch liest, fällt es einem sowieso einfacher, auf Englisch als auf Deutsch zu schreiben.

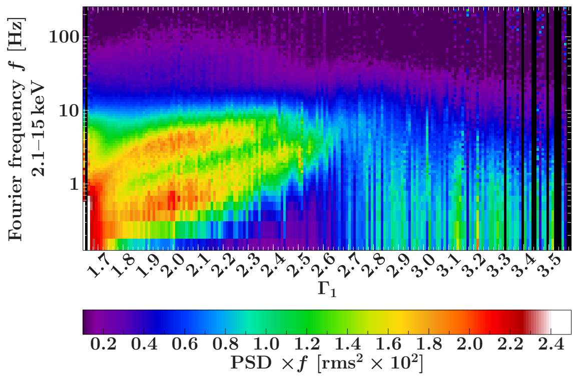
Bachelor thesis projects: clumpy stellar winds in high mass X-ray binaries

High mass X-ray binaries consist of a black hole or neutron star orbiting an O/B type supergiant star. These stars have highly structured winds that consists of cold, dense clumps embedded in a hot gas. When such a clump passes through our line of sight towards the black hole or neutron star, it absorbs some of its radiation and we see characteristic changes in the observed emission. Such changes can happen on very short timescales of below minutes. We are currently developing a new method to derive properties of these clumps (sizes, temperature, density) from X-ray color-color diagrams. You will be able to directly contribute to this effort.

Bachelor thesis project 1:
You will use observation of high mass X-ray binaries made with NASA's *Chandra* and/or ESA's *XMM-Newton* satellites and apply this new method to a sample of sources. You will test which sources this method is applicable to and derive the properties of the stellar winds in several different high mass X-ray binaries.

Bachelor thesis project 2:
Theoretical models for winds in high mass X-ray binaries exist but the comparisons to observations are lacking. Based on some of the most modern simulations of stellar winds that our colleagues in Leuven have developed, you will simulate observations with different current and future X-ray telescopes to understand what kind of observations are needed to be able to disentangle the different wind properties.

Bachelor thesis projects: black holes twinkling – variability of X-ray binaries



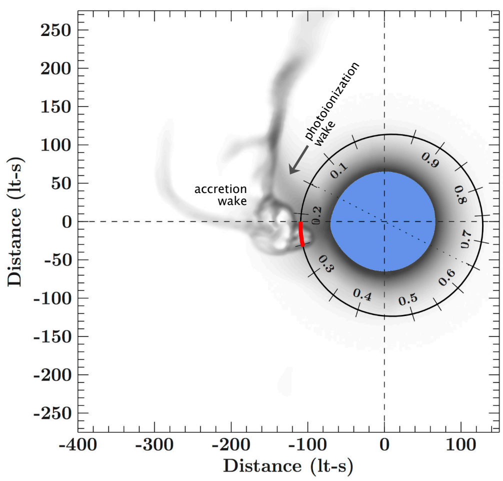
Map of the variability (power spectra times frequency) of the X-ray binary Cyg X-1 depending on Fourier frequency f and the spectral shape expressed through Γ_1, the power law photon index. Source: Grinberg et al., 2014

Different emission processed do not only give the X-ray spectra a different shape, they also lead to different variability properties of the emission. This is especially important because different physical processes will often produce a similar spectral shape, so the variability is the only way to distinguish what is actually happening with the material when it falls towards the black hole.

Bachelor thesis project 3:
In this project, you will analyze the short-term variability of the black hole X-ray binary GX 339-4 using archival data from NASA's *RXTE* satellite. You will use Fourier-based methods to investigate how much different frequencies contribute to the overall variability of the source and how these changes in variability correlate with changes in spectral shape.

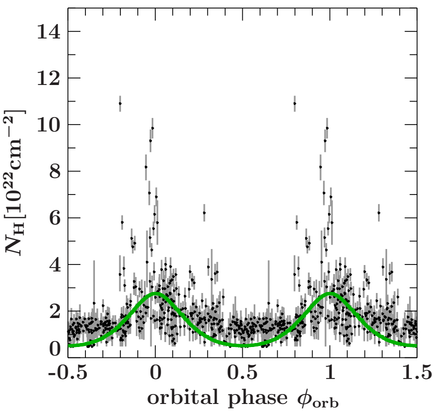
Master thesis projects: Feeding the moster – wind and accretion structure in the high mass X-ray binary Vela X-1

Vela X-1 consists of a neutron star orbiting a B-type supergiant at a distance of a fraction of the star's radius. It is one of the brightest high mass X-ray binaries in the sky and thus the prime source for studies of the accretion onto highly magnetized neutron stars and of the wind structure in high mass X-ray binaries. The presence of the neutron stars deforms the wind that it is embedded in. Our line of sights towards the neutron star goes through different parts of the binary system and thus through different parts of the wind at different orbital phases. Denser and colder regions absorbe more X-rays than less dense regions, leading to variable absorption. Dense regions can be either intrinsic to the winds as the winds of high mass stars are known to be highly inhomogeneous of "clumpy" or they can be induced by the gravitational and radiative interaction of the neutron star with the surrounding material.



The high mass X-ray binary Vela X-1. Shown are the orbit of the neutron star around the B-type companion and an artist's impression of the structures in the stellar wind, based on simulations. Source: Grinberg et al., 2017

We have recently shown that the material close to the neutron star is structured, in agreement with recent simulations of wind accretion (Grinberg et al., 2017). But we also have several more new and archival observations that await analysis to help us understand the system better. You will work on the intersection between stellar and X-ray astronomy, building a solid expertise in both fields while helping to understand one of the most fascinating objects in the (X-ray) sky.



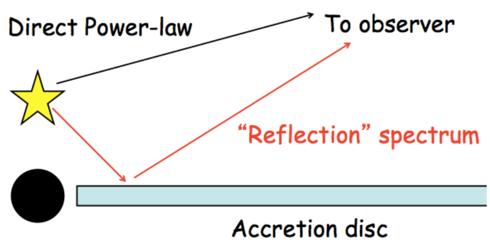
Equivalent hydrogen column density (N_H, a measure for absorption) vs. orbital phase in Cyg X-1. A smooth wind model (green) does not describe the variability we see, i.e., the wind has to be clumpy. Source: Grinberg et al., 2015

Master thesis project 1:
In this project, you will use observations taken with the *RXTE* satellite at different orbital phases to probe the absorption variability in Vela X-1. In the high mass X-ray binary we could show that the wind clumps define the observed variability, especially around the orbital phase 0 (Grinberg et al., 2015). You will investigate whether this is also the case for Vela X-1 and compare your results with the most modern simulations of the wind accretion in the system made by colleagues from KU Leuven (El Mellah et al., in print) and NASA/GSFC to constrain the wind parameters and the detailed geometry of accretion in this system.

Master thesis project 2:
High resolution observations are key to understanding the material close to the neutron star: temperature, density, and velocity of the gas get imprinted into emission and absorption lines. Observing these lines, we can decipher the properties of the material in our line of sight. In this project, you will use new high resolution observation with NASA's *Chandra* telescope to investigate the gas along out line of sight at orbital phase $\phi_{orb} \approx 0.75$ using methods that we are currently developing and testing with colleagues from MIT. Are two gas phases present, just like at the orbital phase 0.25 (Grinberg et al., 2017)? What are the dynamics of the cold and hot gas?

Master thesis projects: Reflection and accretion geometry in X-ray binaries

Most X-ray emission from accreting black holes and low magnetic-field neutron stars emerges from within a few tens of gravitational radii from the compact object. However, not all emission arrives at the observer directly - some of it first impacts onto the accretion disk and is reflected. The shape of that reflected emission will depend on the location of the primary emitter and on the properties of the reflecting gas. We can thus use it to learn more about the accretion geometry (does the X-ray emission come from the jet or the corona? does the accretion disk extend all the way to the compact object or it is truncated at some radius?) and the properties of the compact object itself (how high is its spin?).



Sketch of the reflection geometry close to a compact object. Source Fabian et al., 2013

Master thesis project 3:
You will use data from NASA's *NuSTAR* observatory to contrain the reflection spectrum from the neutron star X-ray binary GX 354-0 using the most modern reflection models developed by colleagues in Bamberg and at CalTech (Dauser et al. 2013, García et al. 2016). You will so constrain the location of the source of the primary emission and of the inner edge of the accretion disk in this system. You will then use variability properties to measure the truncation of the accretion disk and test whether these two independent methods give consistent results.