ESAC Traineeship

of Manfred Hanke
(tutor: Andy Pollock)

during June, July and August of 2007

1 Scientific projects

The original plan for this traineeship was to study the stellar wind in the Vela X-1 system with *XMM*/RGS by analyzing the grating-data of the *XMM*-observation # 0406430201 of Peter Kretschmar. During the project, the main interest was, however, also extended to related subjects, as it turned out that the RGS data alone does not contain enough information.

1.1 High resolution spectroscopy of Vela X-1

To start the investigation of the high-mass X-ray binary (HMXB) system Vela X-1, other (*Chandra*) grating observations, which have already been reported in literature (Schulz et al., 2002; Goldstein et al., 2004; Watanabe et al., 2006), have been reanalyzed. The properties of emission lines, fluorescent Kα lines and radiative recombination continua have been determined and compared with the published results. (The investigation of Kα lines was especially useful as they could also explain formerly not understood features in a spectrum of a similar system, Cyg X-1, I was working on for my diploma thesis.)

1.2 Investigation of the flare during the *XMM*-observation of Vela X-1

The most special feature of the *XMM*-observation is an enormous flare, which changes the RGS spectra in a very unexpected way: While there is hardly any flux detected before the flare and the spectrum is dominated by emission lines, a strong and extremely hard continuum appears suddenly, which can not be sensibly modeled with RGS data alone.

To verify the existence of the flare, light curves from the *RXTE* All Sky Monitor (ASM) have been compared with the XMM-observation. It was found that the flare is also visible in these data. Investigation of longer term light curves showed that source state observed with *XMM* before the flare is the most common one, but also that such a flare is not unique and that they can occur at any orbital phase, provided that the neutron star is not eclipsed by its companion. Further statistical investigations were performed, which finally also allowed to comment to Ingo Kreykenbohm's publication of a flare detected with *INTEGRAL*, which is also present in the ASM data.

1.3 Stellar winds and soft excesses of Vela X-1 and other HMXB in the literature

Strong X-radiation influences the stellar wind by photoionization. As only material in a low ionization state can be accelerated by a star's radiation pressure, the density structure and mass flow around an accretion powered X-ray source can be very complex. It is necessary to understand the physical origin of these effects in order to explain the observed facts (shadow wind, photoionization wake, ...). For this reason, the papers by Blondin (1994) have been studied.

It seems that the decrease in absorbing column density after eclipse egress, as previously detected in the PN-data of the *XMM*-observation of Vela X-1 by the local work group (Martin Stuhlinger, Peter Kretschmar), just represents this shadow wind of the companion star, which is not related to the flare.

However, these PN-spectra, especially after the flare, also show a strong "low energy excess", which has not yet been sufficiently modeled (but excluded). The study of reports of old observations (e.g. with EXOSAT) of Vela X-1 and similar systems (e.g., 4U 1700–37) – for example, by Haberl, White & Kallmann (1989) or Haberl & White (1990) – suggests that this might be explained by photoabsorption of ionized material close to the X-ray source.

1.4 The warm absorber model and other models for the PN-data

Absorption by ionized material can usually be described by Tim Kallmann's warm absorber model, which is based on the XSTAR package for the simulation of photoionized plasmas. In collaboration with Maria Diaz-Trigo, this software was prepared for its use with the spectral fitting program ISIS. Due to the enormous computational requirements and the fact, that the spectra do not show pronounced absorption edges or lines, no results have been obtained yet.

Also other spectral models than those previosly used were investigated to describe the PN-data.

1.5 Analysis of *RXTE*/ASM data of other high-mass X-ray binaries

Continuing the ASM-analysis mentioned above, it was found that folding the whole light curve with the orbital period gives good average intensities in 3 energy bands of the orbital light curve. The eclipse is clearly visible, and hardness ratios indicate the enhanced absorption after egress (from the shadow wind) and also before ingress.

To draw more general conclusions, this analysis has been repeated for almost 50 other HMXB systems. It was found that it is very crucial to work with the optimal orbital period, and that the values published in a review on HMXB by Liu et al. (2006) are often not accurate enough. Therefore, different methods of finding the period were implemented and

compared. A self-developed method, searching for the minimum variance of folded data, works only for systems with a clear signal. The standard epoch folding method (maximizing χ^2) and the Z^2 test can find periodicities in more cases. However, for some sources, no variability with the orbital period can be found, which is likely due to the low inclination.

This project is by far not yet finished, but I will continue on it during my PhD work when I'm back in Bamberg, Germany. This will contain a modeling of stellar winds and orbital column densities to give predictions that can be compared with the actual ASM measurements.

1.6 Pulse-timing analysis of Vela X-1

Vela X-1 is not only a HMXB, but its neutron star is also a pulsar. I could learn from Antonio Martin-Carrillo how the period is determined after all barycentric corrections (for the motion of the *XMM*-satellite around the Earth and the Earth itself around the sun, as well as the neutron star in the binary system) have been applied to the event list, and how pulse profiles are extracted.

The first investigations seemed to show changes in the pulse shape (which is quite complex anyway), after the flare, but this has still to be proved by the final detailed analysis. Problems might arise from the flaring flux variations.

As a future project, I want to calculate the GR light bending in the strong gravitational field of a neutron star, which has to be a starting point to understand the complex pulse profile of Vela X-1.

1.7 Planing the RGS-modus of a future *XMM*-observation of Cyg X-1

In order to decide how to operate RGS in a future observation of Cygnus X-1 (# 05008801, PI: Jörn Wilms), I had many discussions with Maria Santos-Lleo and Maria Diaz-Trigo. Archived *XMM*-observations of this source have been reduced to see if the effects of photon pile-up can be sufficiently modeled.

But at the beginning, it was found that the spectral fitting software ISIS did not support the AREASCAL column of the RGS spectral files, and that it was not possible as well to change the response files manually within ISIS. Therefore, I suggested to the developer John Houck to change this, which is now already implemented, such that ISIS v. $\geq$1.4.7-7 can also be used for the analysis of *XMM*/RGS spectra.

2 Participation in ESAC events

2.1 Trainee alumni meeting (2007/07/09)

The general concepts of a high-mass X-ray binary system, the properties of Vela X-1 in particular and the peculiarities of the *XMM*-observation this project was mainly focusing on have been presented at the trainee meeting.

2.2 Workshops, meetings and seminars

Workshops

- 2007/06/04–06: 2007 Science Workshop "XMM-Newton: The Next Decade"
- 2007/06/19–22: 7$^{\text{th}}$ XMM-Newton SAS Workshop

Meetings of the Vela X-1 work group (Peter Kretschmar, Martin Stuhlinger, Andy Pollock and me)

- 2007/06/07, with Chris Mauche and Ingo Kreykenbohm
- 2007/08/07, with Antonio Martin-Carrillo
- 2007/08/23, with Isabel Caballero and Antonio Martin-Carrillo

Meetings of the X-ray binary group (org. by Erik Kuulkers)

- 2007/06/08: presentation of the work of Ingo Kreykenbohm, Sonja Fritz and Chris Mauche's simulations
- 2007/06/22: discussion of new discoveries, my work on Cygnus X-1 and Vela X-1, ...

Meetings of the trainee students (organized by Marcus Kirsch)

- 2007/06/13: introduction of new trainees and the projects
- 2007/06/27, 07/04: presentation dry runs
- 2007/07/09: Trainee meeting with presentation
- 2007/08/30: introduction of new trainees and the projects, plans for the winter term

Seminars

- 2007/06/14: science seminar/talk by Mark Kidger: "Apophis: the End of the World is Nigh?"
- 2007/06/14: seminar by Michael Dovciak: "The general relativistic KY suite of models for XSPEC"
- 2007/07/12: science seminar/talk by Achille Nucita: "Relativistic effects at the center of the Galaxy"

3 Personal conclusions

I have not only gained insight in the work with *XMM-Newton* during this traineeship, but also learned a lot from different fields a priori not directly related to my main topic, which used to be high-resolution spectroscopy. It was a great opportunity of this project that it was broad enough that I also had the freedom to learn other techniques (e.g., in timing analysis) and work with different instruments (*XMM*/RGS, MOS, PN; *Chandra*/HETGS; *RXTE*/ASM). I appreciate very much to have established contacts with many scientists apart from the direct work group on the Vela X-1 observation, in which I will stay involved in the future. I will also stay in contact with my tutor Andy Pollock for the project on stellar winds of HMXB systems as seen with *RXTE*/ASM, which might be worth being published.

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