A phase/time dependent HETG Chandra study of the Wolf-Rayet X-ray binary Cygnus X-3

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Abstract

Cygnus X-3 (Cyg X-3)is a well known high mass X-ray binary (HXRB) which is also a Wolf-Rayet (WR) X-ray binary. It is believed that this type of system will be a progenitor of a double compact object binary. This will, in turn, lead to a merger that produces gravitational waves. In this study, we examine the interaction of the winds from the massive WR star with the compact object using Chandra HETG data. The Chandra HETG data for Cygnus X-3 show many strong lines (emission and absorption), Radiative Recombination Continua (RRCs), and P-Cygni profiles on many of the emission lines. The 3rd order HETG spectra provide a more detailed look at the Fe K alpha spectral region, in particular, the He-like Fe line. During Cygnus X-3's hypersoft/quenched state we a find variable absorption feature which is "blue-ward" of Fe K alpha. Some of the other features show a phase/time dependencies which will be examined in this presentation.

Introduction

Cygnus X-3 is an unusual X-ray binary containing a compact object and a Wolf-Rayet (WR) companion, making it a high mass system. But its orbital period (4.8 hrs) is typical for a low mass system. It is a strong radio source routinely producing radio flares of over a Jy and up to ~ 20 Jy (at 2.25 GHz). Even during radio quiescence it can be relatively bright in the radio (60-100 mJy). It has been shown to produce radio jets and also demonstrates correlations of the Radio with both the hard X-ray and soft X-ray (McCollough et al. 1999, Szostek et al. 2008, and Koljonen et al. 2010).

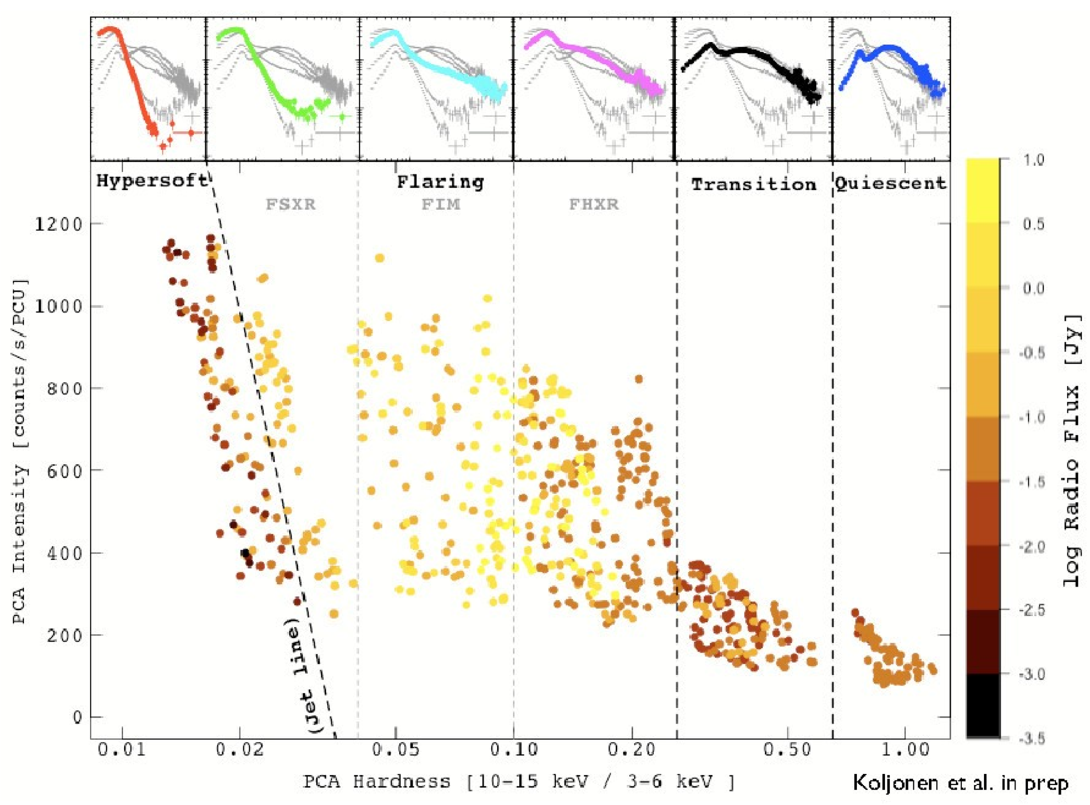

Figure 1: Hardness-Intensity/Radio plot from Koljonen et al. 2010. The different shading indicated the radio emission and hence a measure of jet activity.

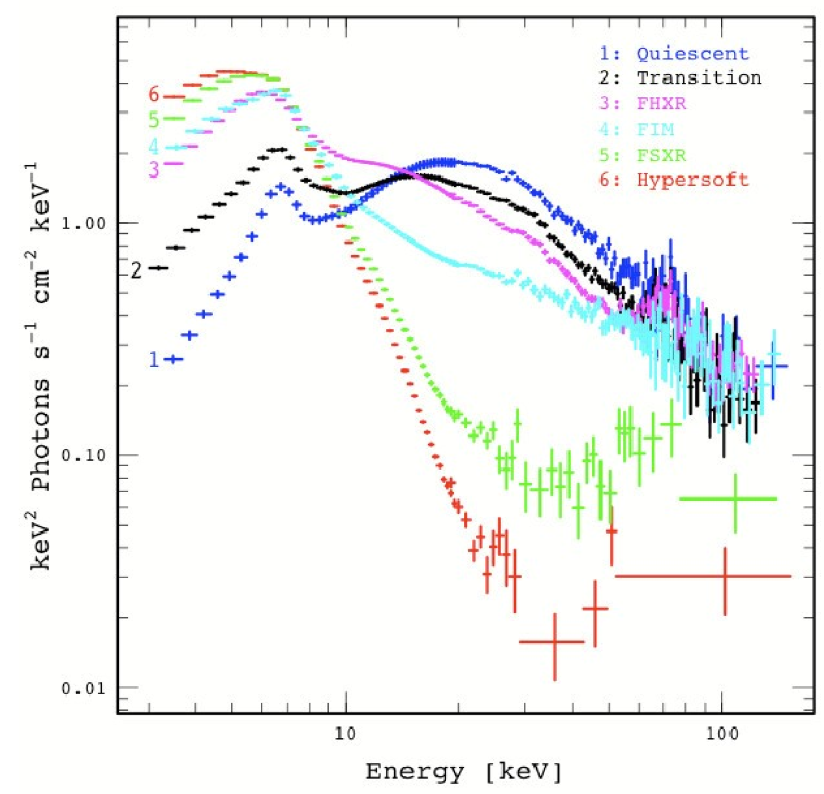

Figure 2: RXTE spectral plot taken from Koljonen et al. 2010 which has an example RXTE spectra for each of the states.

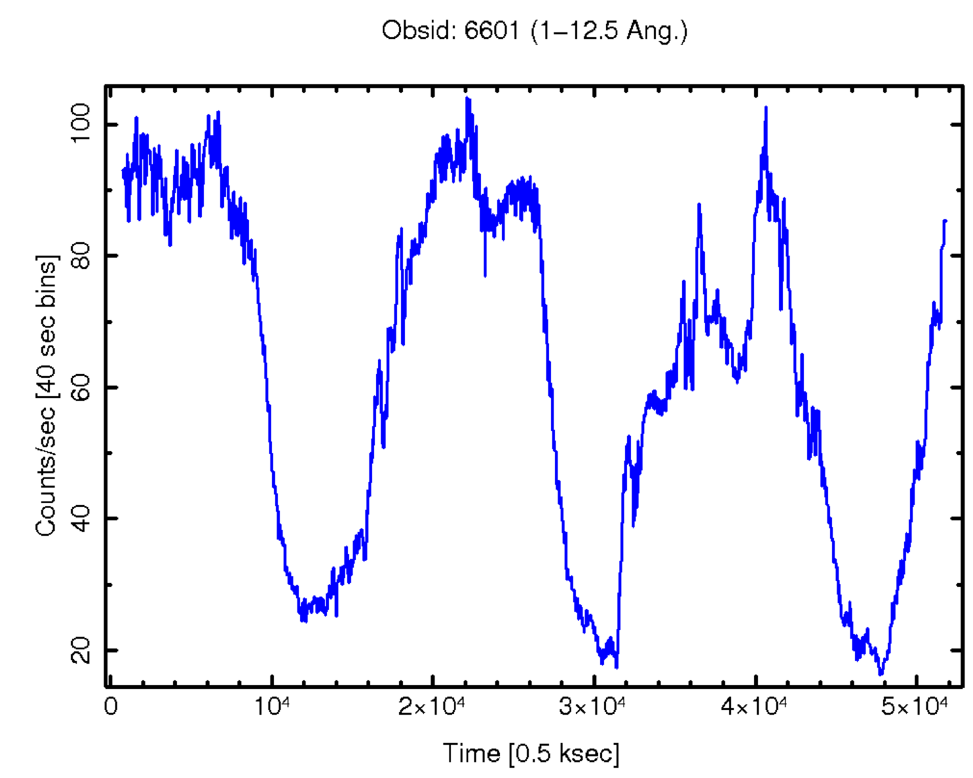

Figure 3: This is a light curve for a combined (+ & -) 1^{st}, 2^{nd} and 3^{rd} order HEG & MEG spectra from 1- 12.5 Å taken during a hypersoft/quenched state (50 ksec). Note the 4.8 hr orbital modulation and flaring behavior near the peak of the modulation.

Chandra HETG Observations of Cygnus X-3 during a hypersoft/quenched state

Chandra HETG observations of Cygnus X-3 show a rich spectrum with many H-like and He-like emission lines with many showing P-Cygni profiles. Additional one find Radiation Recombination Continua (RRC) and evidence for an absorption /disk wind feature. This observations was taken during a hypersoft/quenched state just before a major radio flare occurred in the system. Beyond 10 Å the spectrum is heavily impacted by interstellar extinction (absorption and scattering). See Fig. 4-6.

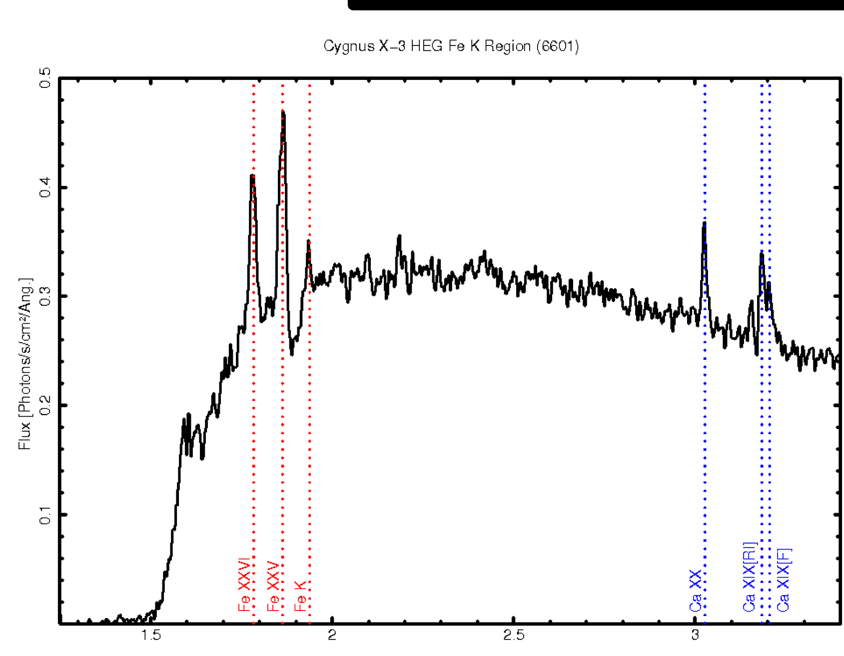

Figure 4: This is a combined (+ & -) 1^{st} order HEG spectrum from 1.25 to 3.4 Å, taken during a hypersoft /quenched state (50 ksec). Note the strong H-like, He-like Fe and Ca lines. Also, note the weak Fe K line and the absorption dip blue-ward of it. This feature may be the result of a disk wind from the accretion disk.

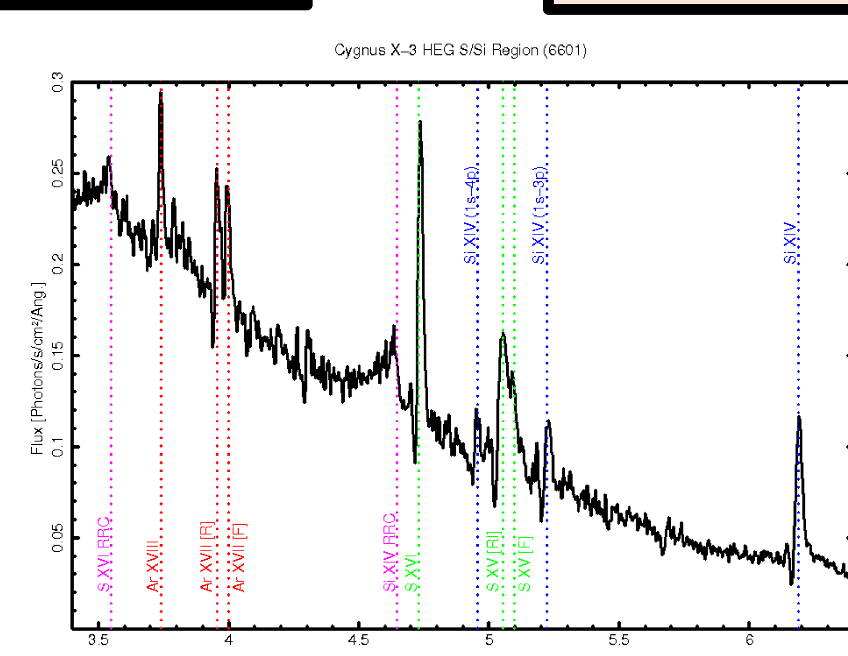

Figure 5: This is a combined (+ & -) 1^{st} order HEG spectrum from 3.4 to 6.4 Å, taken during a hypersoft /quenched state (50 ksec). Note the strong H-like, He-like Ar,S, AND Si lines. We can also see strong RRCs of S XVI and Si XIV. Note for the strong H-like and He-like lines they have P-Cygni profiles.

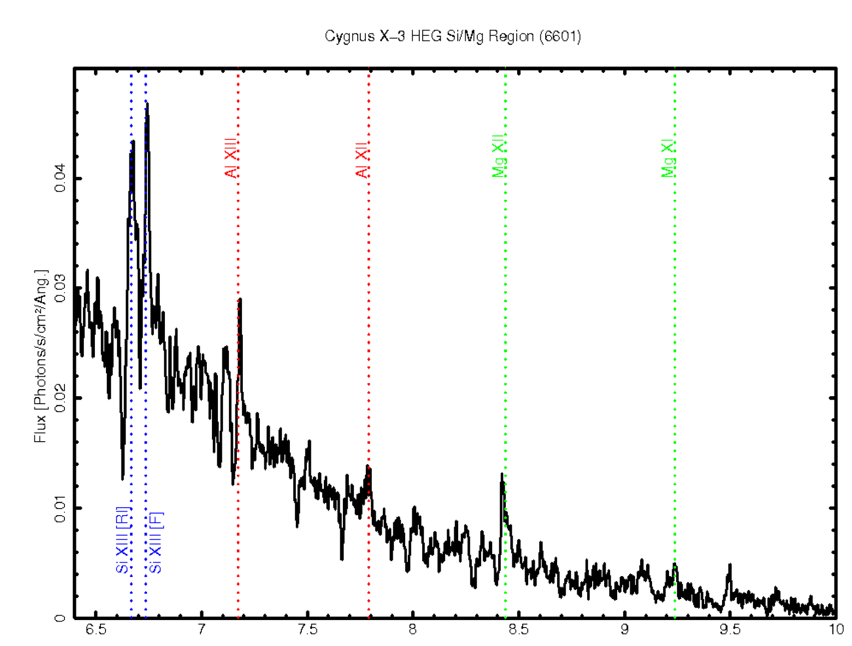

Figure 6: This is a combined (+ & -) 1^{st} order HEG spectrum from 6.4 to 10 Å, taken during a hypersoft /quenched state (50 ksec). Note the strong H-like, He-like Si, Al, and Mg lines. Beyond 10 Å the spectrum is heavily impacted by interstellar extinction (absorption and scattering).

Phase cut HETG spectra of Cygnus X-3 during a hypersoft/quenched state

To examine the variation of Cygnus X-3 as a function of orbital phase the data set was divided into four equal phase bins of: 0.0 (0.857 – 0.125), 0.25 (0.125 – 0.375), 0.50 (0.375 – 0.625), and 0.75 (0.625 – 0.875). See Fig.7-9

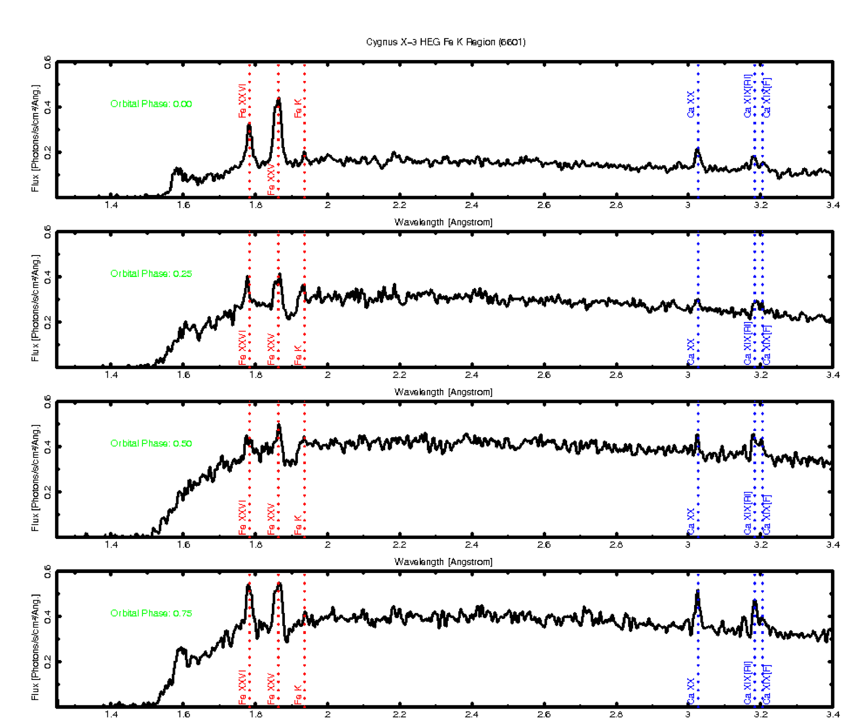

Figure 7: This is a combined (+ & -) 1^{st} order HEG spectra from 1.25 to 3.4 Å, taken during a hypersoft/quenched state (50 ksec). Each plot is a phase slice of equal length. The H-like and He-like Fe lines are strongest in phase 0.0 and 0.75. At 0.75 they appear equal in strength. They are weakest at phase 0.5. The Fe K line is strongest at phase 0.5 and very low at the other phases. The absorption/disk wind feature is absent at phase 0.0 and is very strong in phase 0.25 through 0.5. The Ca H-like and He-like lines are weakest at phase 0.25 and reach their maximum at phase 0.75. Also in phase 0.5-0.75 can see P-Cygni profiles on he lines.

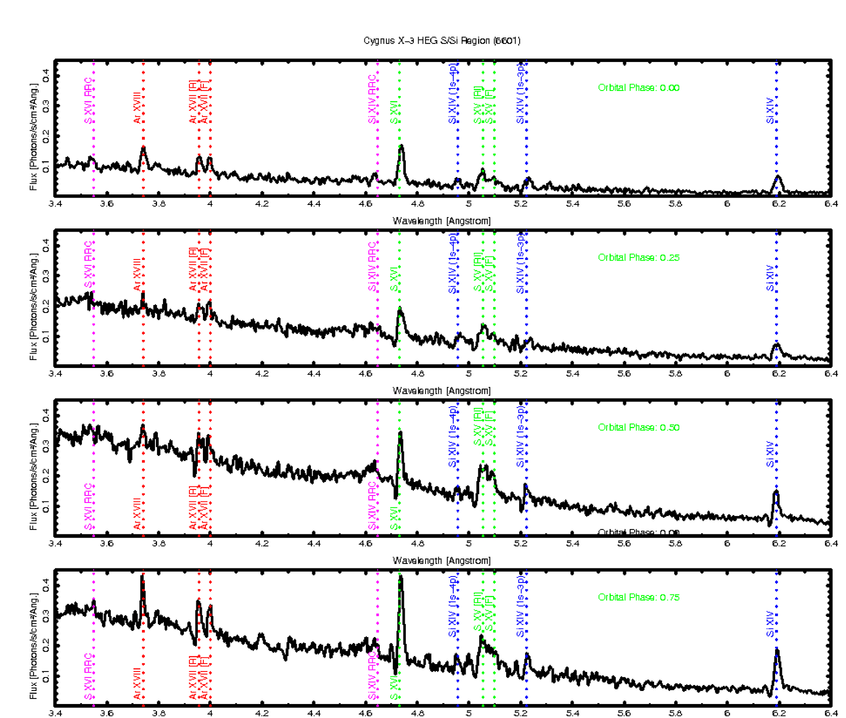

Figure 8: This is a combined (+ & -) 1^{st} order HEG spectra from 3.4 to 6.4 Å, taken during a hypersoft/quenched state (50 ksec). Each plot is a phase slice of equal length. The H-like and He-like Ar lines behave similar to the Ca lines. Whereas the S and Si lines in general appear weaker in phase 0.0 and reach their maximum in phase 0.75. As the lines become stronger they develop P-Cygni profiles. The S and Si RRCs appears weakest at phase 0.0 and reaches their maximum at phases 0.5 – 0.75.

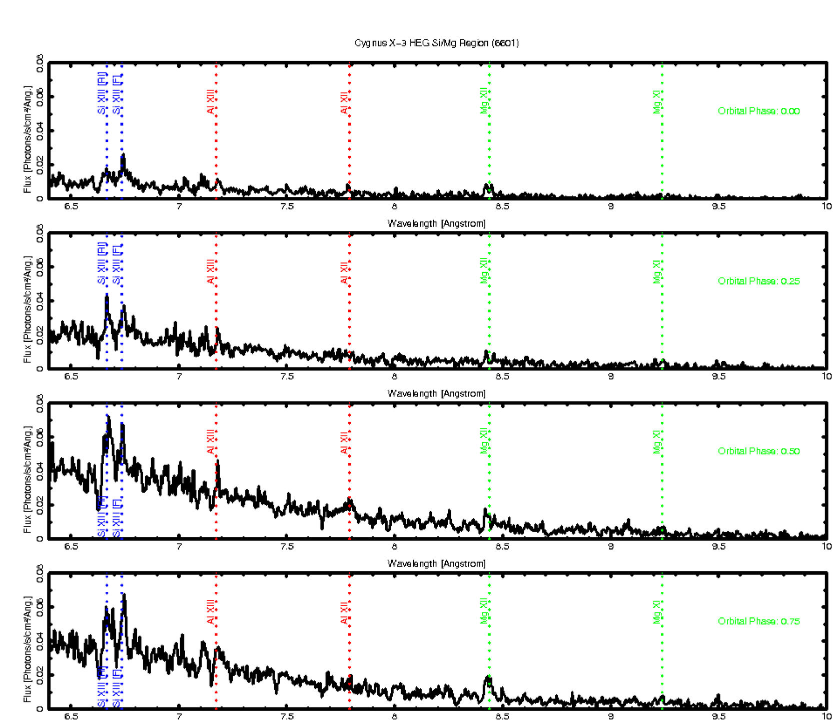

Figure 9: This is a combined (+ & -) 1^{st} order HEG spectra from 6.4 to 10 Å, taken during a hypersoft/quenched state (50 ksec). Each plot is a phase slice of equal length. The H-like and He-like Si, Al, and Mg lines in general appear to behave like the other S and Si lines. Also the lines become stronger they develop P-Cygni profiles.

HETG spectra of Cygnus X-3 during a transition state

When Cygnus X-3 goes to a low state (transition & Quiescent) the spectrum changes. In particular, there is no absorption feature and the Fe K lines becomes strong. See Fig. 10.

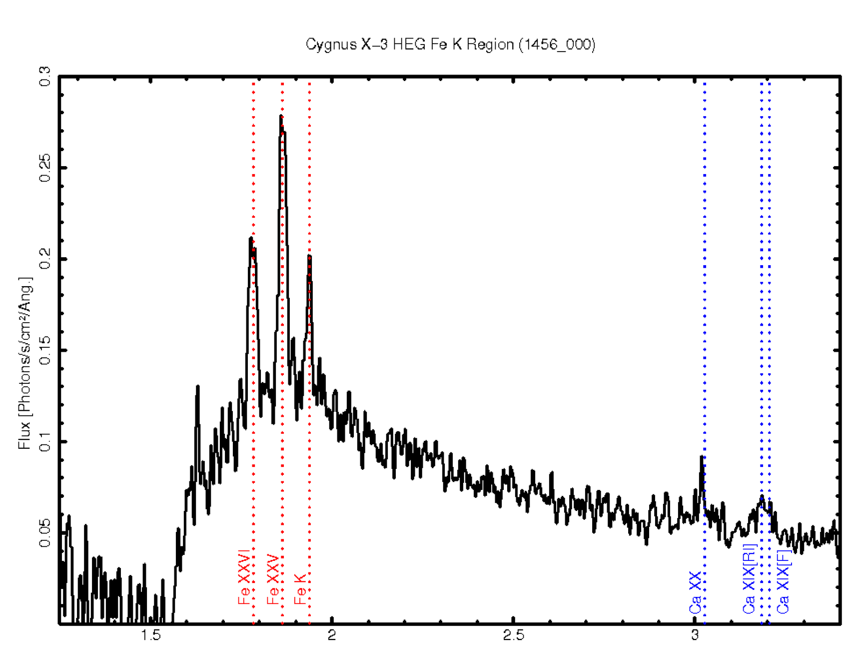

Figure 10: This is a spectrum of the combined (+ & -) 1^{st} order HEG spectra from 1.25 to 3.4 Å, taken during a transition state (12 ksec) Note the absence of the absorption feature seen in hypersoft/quenched state and strong Fe K line.

3^{rd} Order HETG Spectra of Cygnus X-3

For most observations with the HETG there are too few counts in the higher order to be useful. But in the case of the quenched state observations of Cygnus X-3 when the source was at it brightest in 1-8 keV band and observations were long enough (50) for useful spectra can be obtained. This allows us to start to resolve the Fe He "triplet" and examine the conditions near the compact object. See Fig. 11

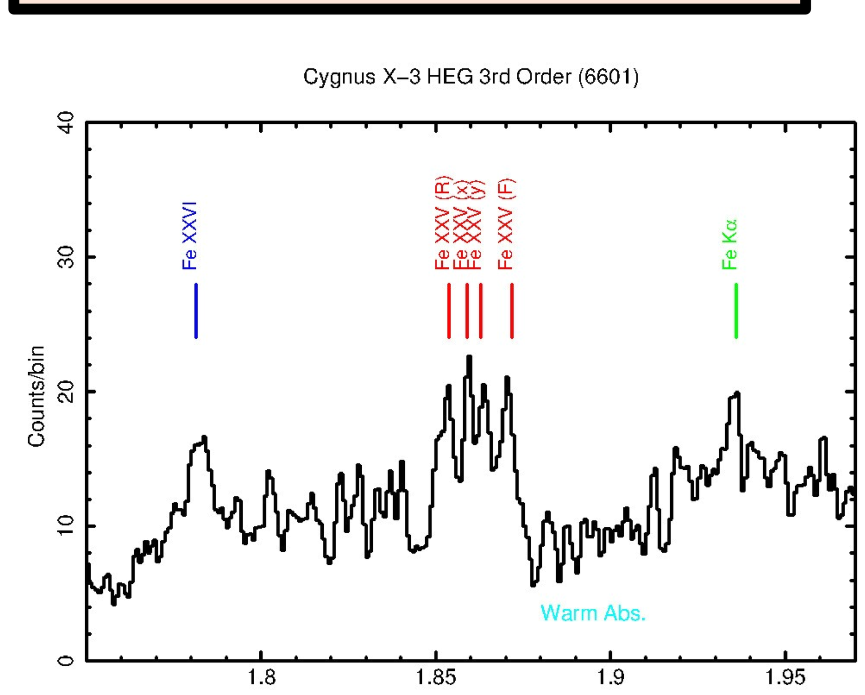

Figure 11: This is a combined (+ & -) 3^{rd} order HEG spectrum of the Fe Kα region taken during a quenched state (50 ksec). H-like Fe line appears to be broadened with a velocity shift of ~570 km/sec. The He-like Fe line now breaks into four lines which match the four expected He-like lines with a velocity shift of ~570 km/sec. The "weak" "neutral" Fe lines shows no velocity shift. Also note the presence of an absorption/disk wind. The data have been smoothed at the binning of the grating data.

From a very crude estimate of the He-line Fe line fluxes we get G = (F+I)/R≈4 and R=F/I≈1 where I=x+y. This indicated the plasma is photo-ionized as would be expected from the present of H-like and He-like Fe.

Analysis

We are currently modeling the data using XSTAR (Kallman in prep). Some our findings to date:

Models: Most lines can be crudely fit by a single component photoionized model. But the Fe K lines do not fit this model.

Ionization Regions: There appear to be two distinct ionization regions to explain the strength and orbital variation of the lines.

Density of Line Emission Regions: The density of the region responsible for most of the line emission region is ≥ 10^{12} cm^{-3} .

Line Fits: For many of the lines there appear to appears the need for two components. With one component broader.