Chandra HETG Observations of Fe K in Cygnus X-3

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I. Introduction

Cyg X-3 is one of the most enigmatic X-ray binaries to have been studied. Its X-ray flux shows a 4.79 hr modulation associated with its orbital period. While the period is typical of a low mass system, IR observations have shown that the mass donating companion is a Wolf-Rayet star making the binary a high mass system. Cyg X-3 has two major states (low/hard and high/soft), shows correlative activity between the radio and hard X-ray (McCollough et al. 1999), and relativistic jets have been observed in the system (Miduszewski et al. 2001).

Cyg X-3 is well-known to be the brightest source of 6.7 keV K-line photons in the X-ray sky (Smale et al. 1993 and references contained within). Previous ASCA (Liedahl & Paerels 1996) and Chandra (Paerels et al. 2000) observations have shown that the Fe K spectral region spectra is composed of H-like, He-like and neutral Fe lines.

We present an preliminary analysis of all of the current *Chandra HETG* observations of the Fe K region of the spectrum of Cyg X-3. Given below is a discussion of what lines and features are observed and how they vary as both a function of state and orbital phase.

II. Observations

Chandra has observed Cygnus X-3 with the *Chandra HETG* on five occasions. These observations include a hard/low state (radio quiescent), soft/high (major radio flares), and a transitional period between these states. The observations are:

- **Obsid 1456(2)**: This was a 8.4 ksec *Chandra HETG* observation taken in December 1999 when Cyg X-3 was in a low/hard state (radio quiescent).
- **Obsids 1456(0) & 101**: These were two *Chandra HETG* observations (taken back to back) in October 1999 for a total of 14.1 ksec. Cyg X-3 was in the process of making a transition from a high/soft to a low/hard state. These observations were reported on by Paerels et al. 2000.
- **Obsid 425 & 426**: These were two *Chandra HETG* observations in April 2000 following a major flare in the radio (they were for 21.5 ksec and 18.3 ksec duration respectively). 425 was 3 days past the peak of a major radio flare and 426 was roughly 3 days later. Cyg X-3 was in a high/soft state. A preliminary report of these observations was given by McCollough et al. 2000 and Liedahl et al. 2000.

III. Cygnus X-3 Fe K Spectra

The following is a summary of what was found in each of the spectra.

Low/Hard (Radio Quiescent): Cyg X-3 was in a quiescent state with a low *RXTE/ASM* count rate ($\sim 6-8$ cts/s) with a hard spectrum which extends out to over 100 keV. The following features were found (see Fig. 1):

- Strong lines of H-Like Fe and He-like Fe.
- Strong neutral Fe line (Fe Kα) and evidence for a weak (Fe Kβ) feature.

Transition: Cyg X-3 was making a transition from a high/soft state to a low/hard state with a *RXTE/ASM* count rates of $\sim 10-20$ cts/s) with hard X-ray emission above 20 keV. The following features were found (see Fig. 2):

- Strong lines of H-Like Fe and He-like Fe. Intensities and profiles have changed relative to the quiescent observations.
- Strong neutral Fe line (Fe Kα) and no evidence for a (Fe Kβ) feature.

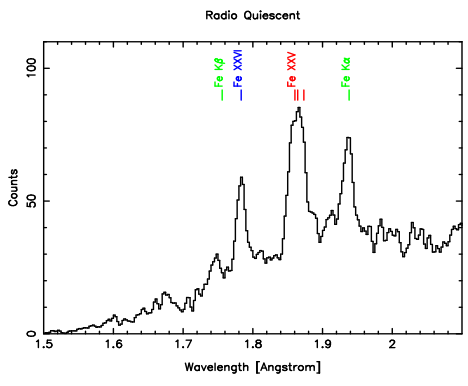

Fig. 1: Chandra HETG observation during a Cyg X–3 low/hard state. Note the H–like, He–like, and neutral Fe lines.

High/Soft (Major Radio Flare): Cyg X-3 was in a high/soft state. The *RXTE/ASM* count rates was of order $\sim 35-40$ cts/s with no hard X-ray emission above 20 keV for either of the observations. The following features were found (see Figs. 3 and 4):

- **Obsid 425**: *Chandra HETG* observations 3 days after a major radio flare:
  - Strong lines of He-Like Fe and a weaker H-like Fe. Intensities and profiles have changed relative to the quiescent and transient observations.
  - Weak neutral Fe line (Fe Kα) and no evidence for a (Fe Kβ) feature.
  - Evidence for the formation of an absorption edge blue-ward of the (Fe Kα) line.
- **Obsid 426**: *Chandra HETG* observations 3 days after obsid 425:
  - Strong lines of He-Like Fe and a weaker H-like Fe. Intensities and profiles have changed relative to the quiescent and transient observations. But similar to Obsid 425 observation.
  - No neutral Fe lines (either Fe Kα or Fe Kβ).
  - Formation of an absorption edge blue-ward of where Fe Kα would be located.
  - The H-like and He-like Fe lines now show P Cygni profiles.

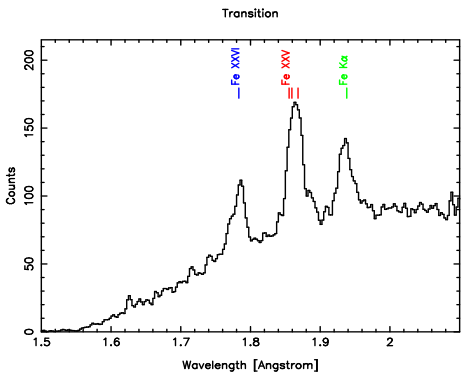

Fig. 2: Chandra HETG observations duirng a Cyg X–3 transition from a high soft state to a low/hard state. Note the H–like, He–like and neutral Fe lines.

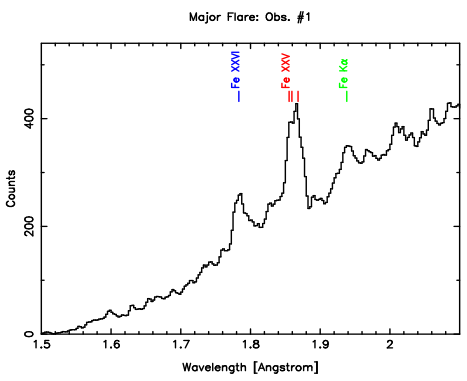

Fig. 3: Chandra HETG observation during a Cyg X–3 high/soft state (Major Radio Flare). Note the H–like, He–like, and weak neutral Fe lines.

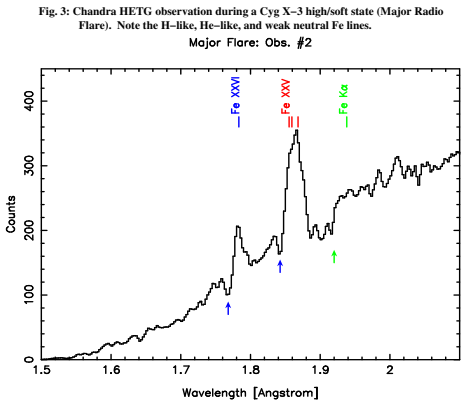

Fig. 4: Chandra HETG observation during a Cyg X–3 high/soft state (Major Radio Flare). Note the H–like and He–like lines and the absence of neutral Fe line. Note the absorption edge (green arrow) and the P Cygni profiles (blue arrows).

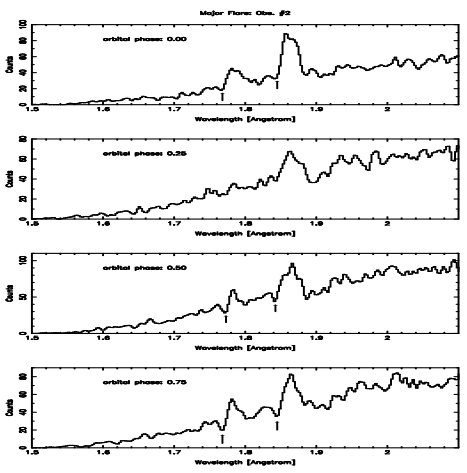

Fig. 5: Phase resolved Chandra HETG observations for Cyg X–3 during observation 426. Note the variation of the H–like and He–like lines as a function of phase. Also note the changing of the P Cygni profiles as a function of phase (arrows).

IV. Spectral Phase Variations

Cyg X-3 undergoes a factor of two modulation in its X-ray flux. Also associated with these flux variations are changes in the spectra. Some of the changes noted during the high soft state (see Fig. 5):

- **Phase 0.00**: The H-like and He-like Fe line are strong and relatively broad. The absorption edge is at its weakest and there is evidence for P Cygni profiles.
- **Phase 0.25**: The H-like Fe line is either weak or absent. The He-like Fe line is weak and broad. There is evidence of a broad absorption feature. But no P Cygni profiles.
- **Phase 0.50**: Narrower H-like Fe and He-like lines present with P Cygni profiles. Absorption edge is present.
- **Phase 0.75**: Strong H-like Fe and He-like lines with deeper P Cygni profiles. Absorption edge is present.

V. Summary

Among some of the results of this study are:

- **Prominent Lines**: Prominent lines of H-like Fe, He-like Fe, and neutral Fe (Fe Kα and in the low/hard also Fe Kβ) are found. The presence of neutral lines appear to depend the shape of the continuum spectrum and possibly to a lesser extend on the density of the wind.
- **P Cygni Profile and Absorption Edges**: In the high/soft state the H-like and He-like Fe lines can exhibit P Cygni profiles indicating a dense outflow from the system. This is also accompanied by the presence an absorption edge indicating there is additional absorption occurring in the system.
- **Phase Variations**: The spectra show distinctive changes with phase. This indicates changes in the ionizational regions being observed and well as a phase dependence of the wind density in the system.

VI. Future Work

Among the issues being pursued:

- **Continuum**: In order to better measure the lines a better determination of the continuum is being worked. In particular there are several *RXTE* pointed observations near and in one case overlapping the two high/soft state observations. These will be used to constraint the continuum in *Chandra HETG* observations.
- **XSTAR Modeling**: Modeling using the latest version of XSTAR is underway in order to better determine the degree of ionization, which lines are present, and degree of extra absorption that is contained within the system.
- **Lines Profile Modeling**: Various fits are being made to determine if multiple lines are present in the H-like and He-like Fe line profiles. These fits may give us insight into ioniziational state and dynamics of the line emitting regions.
- **Orbital Modeling**: Once the nature of the lines and their profiles are understood we will see if these lines can give us any information on orbital modulation which may help us constrain the dynamics of the systems.

This work is supported by NASA contract NAS8-03060 (CXC).

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