This document is the response to item #10 in form CRG-99-1, the final report on our Chandra grant, GO2-3030A: "High-Resolution X-ray Spectroscopy of Beta Crucis: A Nearby Hot Star with a High X-ray Count Rate," PI Prof. David H. Cohen, Swarthmore College.

10. Explain the objectives of the research and the results obtained.

X-ray emission from hot stars was an unexpected discovery of the first generation of X-ray satellites, in the 1970s. Hot stars are thought to lack the convective envelopes, and hence the alpha-omega dynamos, that power the X-ray emission of late-type stars. High-resolution X-ray spectroscopy is a powerful tool for studying the production of X-rays on hot stars, for identifying differences between the emission from hot stars and from cool stars, and for testing competing models. Specifically, Doppler broadened emission lines and the associated line profile shapes are a powerful diagnostic of wind-shock activity (Owocki & Cohen 2001, ApJ, 559, 1108; Kramer, Cohen, & Owocki 2003, ApJ, 592, 532), while line ratios can provide information about the hot plasma location with respect to the star's photosphere (Kahn et al. 2001, A&A, 365, 312) and the plasma temperature distribution. Time-variability, in the form of flaring, can be a sign of magnetic activity, which is generally not expected in hot stars.

These diagnostics have been applied to a handful of X-ray-bright hot stars, which have very strong winds (e.g. zeta Pupis, zeta Ori, delta Ori) or are very young (theta^1 Ori C, tau Sco). In this project, we have obtained HETGS spectra of a somewhat cooler hot star - beta Cru has spectral type B0.5, compared with O4 for zeta Pup, which shows strong evidence of wind-shock X-ray - with a much weaker wind than O stars have. Our results include the following:

- The spectrum is very soft (dominant thermal component has $T < 2$ MK). While not definitive, magnetic/coronal emission is rarely associated with such soft X-ray emission. In fact, the spectrum of beta Cru is so soft, that our prediction of the HETGS count rate was significantly higher than what we observed, because we had based it on the star's ROSAT count rate, and ROSAT is more sensitive to very soft X-rays than is Chandra (and since ROSAT's spectral resolution is so poor, the model fits to those data didn't, ultimately, provide a reliable extrapolation to the Chandra bandpass).

- The emission lines are unresolved in the HETGS. While consistent with the coronal picture (surprisingly for a hot star), we cannot entirely rule out wind-based emission, if the X-ray emitting plasma is produced in the slower-moving, base of the accelerating wind.

- The line ratios are not definitive (because the spectrum is so soft, that we do not measure the MG XI and Si XIII lines that would put firm constraints on source location), but they also are consistent with emission from a region near the photosphere. (Note that we are still working on this analysis, as we have only just finished programming our custom-code for modeling these line ratios.)

- There is no significant variability seen in the data. So, no magnetic flares were detected in roughly 100 ks. This is, of course, not a definitive statement about the lack of purported magnetic activity.

- Finally, we unexpectedly detected a companion to beta Cru, at a separation of a little more than 2 arc seconds. This companion was undetected by previous X-ray observations, which lacked the requisite spatial resolution. Interestingly, it was also undetected by numerous previous optical observations, as the primary, beta Cru itself, is so bright that the companion's optical signal was lost in the wings of the PSF of the primary. The companion's X-ray brightness is thus much more commensurate with the primary's, compared to its optical brightness. We are still working on the binary analysis (verifying that it is not a background object). Its dispersed spectrum is weak, but has enough counts for us to determine that it is much harder than that of the primary. Its properties are consistent with those expected from PMS stars. And in fact, there is a small association of PMS stars in the field around beta Cru.

Thus, it appears that we have discovered a new PMS star in the beta Cru association (Park & Finley 1996, AJ, 112, 693), which would render beta Cru a Lindroos binary (B star plus PMS star; Lindroos 1985, A&AS, 60, 183). As for the primary, which was the proposed object of study, it appears that there are very significant differences between the X-ray emission of early-B stars with weaker winds, on the one hand, and O stars with stronger winds on the other. While we find no direct evidence for magnetic/coronal activity on beta Cru, the Chandra spectroscopy places very strong constraints on the nature of any wind-shock activity.

We will post ongoing results of our analysis, plus our eventual paper, at astro.swarthmore.edu/~cohen/projects/betacru/

When the paper is ready for submission, we will contact the CXC regarding a press release (focusing on the surprise discovery of the binary companion).