Chandra Observations of Zeta Pup

**INTRODUCTION**

Hot stars such as Zeta Pup are strong X-ray emitters but the precise mechanism causing their X-ray emission is unclear. In this project we examine the temporal behavior of the X-ray emission from this star. If the X-rays are formed far out in the stellar wind, we would expect the X-ray output to fluctuate randomly. If the X-rays are formed close to the stellar surface (e.g. in magnetic structures), we would expect X-rays to vary clock-like on a rotational time scale. Recent work (Howarth and Stevens, “Time-series photometry of the O4 I(n)fp star ζ Puppis”) has identified a 1.78-day rotational period for this star, so we folded the data on this time scale to try to identify rotationally-modulated variation.

In addition to examining the overall X-ray photon count rate, we evenly divided the data into short-wavelength (“hard”) X-ray counts (from high-temperature gas) and long-wavelength (“soft”) X-ray counts (from low-temperature gas). This allowed us to construct the “hardness ratio” by calculating the difference between the hard and soft count rates and dividing by the total count rate.

When examining the folded total, hard, soft, and hardness ratio data we found no case where there was unambiguous evidence for variation on the rotational time scale.

**TERMINOLOGY/EQUIPMENT**

- **Chandra**: Satellite telescope designed to detect X-rays
- **CIAO**: “Chandra Interactive Analysis of Observations” software designed to interface with data obtained by Chandra
- **ACIS**: “Advanced CCD Imaging Spectrometer”
- **MEG**: “Medium Energy Grating”
- **LibreOffice Calc**: Data manipulation software
- **Zeta Puppis (Zeta Pup)**: Blue supergiant star

Twelve observations were taken by Chandra from 1 July to 24 August, 2018 and a colleague (Dr. Jennifer Lauer, Harvard-Smithsonian Center for Astrophysics) subsequently divided these observations into ~9,000 second observations being approximate integer values of this time interval.

**ERROR ANALYSIS**

Poisson Error Analysis was used for the relative error for the counts. This is given by:

\[ \text{Error} = \sqrt{\text{Number of Counts}} \]

The Hardness Ratio Error was calculated using standard Propagation of Uncertainty given by the general form:

\[ \text{Error} = \sqrt{\left( \frac{\text{Difference}}{\text{Total}} \right)^2} \]

**RESULTS**

With the analysis complete, the last thing to do was graph everything as see if a pattern emerges.

The orange sine waves were made with an iterated use of a best-fit program in Linux. The R² value for the total, hard, and soft count rates are approximately 0.20 and the R² value for the hardness ratio is 0.07. These values indicate that while there may be a very weak variation of the overall X-ray flux as a function of the rotational period, the X-ray color (hardness ratio) is even less effected by the rotational phase.