The Darkest Bright Star: Chandra Observations of Vega

Deron Pease, Jeremy Drake, Vinay Kashyap
Smithsonian Astrophysical Observatory

Abstract

We present X-ray observations of Vega obtained with the Chandra High Resolution Camera and Advanced CCD Imaging Spectrometer. After a total of 29 ks of observation with Chandra, X-rays from Vega remain undetected. We derive upper limits to the X-ray luminosity of Vega as a function of temperature over the range of $10^{49} - 10^{50}$ erg s$^{-1}$ and find a 99.7% upper limit as low as $2 \times 10^{46}$ erg s$^{-1}$ at $T = 10^{63}$ K. We also compare these new deeper observations with the limits derived in a reanalysis of ROSAT PSPC data. Our X-ray luminosity limit for Vega is still greater than predictions of post-Beige Ae phase X-rays from the shear dynamic model proposed by Tout & Pringle for a Vega age of 300 Myr. If the age of Vega is closer to 100 Myr, as suggested by some indicators, our X-ray limit is then similar to Tout-Pringle model predictions. Current X-ray observations of Vega are therefore unable to discriminate between different scenarios explaining the X-ray activity of the convectively stable Herbig Ae/Be stars. Further progress in understanding is more likely achieved through X-ray observations of younger main sequence early-type A stars whose more conjectured residual post-Beige Ae phase X-ray activity would be significantly higher.

Upper Limit Determination

A source is detectable in HRC data at a $\alpha$ level if its counts are at least 5 times that expected by background.

- Estimate counts that would be observed in absence of a source by averaging 10 neighboring pixels for each of the two images.
- Create an ADU background image for the source image.
- Use a Poisson probability distribution for background counts.
- Count the number of counts in a given background.
- Probability that the mean background from the counts is not a statistical fluctuation:

$$ P(<D|\mu) = \frac{e^{-\frac{D^2}{2\mu}}}{\sqrt{2\pi\mu}} $$

- For a specific probability threshold $\alpha$ upper limit $\sqrt{D} = D(\alpha) = \sqrt{\ln(\frac{1}{1-\alpha})}$

Example:

- $D = 5 \alpha$, $\alpha = 0.002$ corresponds to $\alpha = 0.002$
- A Gaussian equivalent $5\sigma$ probability level matches $\mu = 0.002$ and hence is the best case scenario can be considered detected.

Allowing a statistical variation in background counts via Monte Carlo simulations where the background counts are sampled from a Poisson distribution.

Table 1: HRC Counts Upper Limit for Vega

<table>
<thead>
<tr>
<th>Monitor</th>
<th>Exposure</th>
<th>Background Region</th>
<th>Source Region</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chandra/HRC</td>
<td>2000</td>
<td>60</td>
<td>181</td>
<td>9</td>
</tr>
<tr>
<td>Chandra/ACIS</td>
<td>1600</td>
<td>40</td>
<td>118</td>
<td>0</td>
</tr>
<tr>
<td>ROSAT PSPC</td>
<td>350</td>
<td>48000</td>
<td>105</td>
<td>90</td>
</tr>
</tbody>
</table>

Results & Conclusions

Most outstanding is lowest X-ray luminosity by upper limit for early-A stars to date

- $L_x < 10^{33}$ erg s$^{-1}$ for $L_x/L_B < 0.10^4$ and temperature $T = 10^{63}$ K

- Proposing theories of post-Beige phase X-ray activity (Drake, 2006)

- Define over $\sim$ 300 Myr due to internal shear energy dissipation leading to dissipation of magnetic fields at outer edge (Tout & Pringle, 1991)

- Abate due to magnetic field dissipation from termination of starlink interaction (Hanasz, 2006)

- Current observations unable to discriminate (Figure 2c)

- If X-ray $< 300$ Myr (Spits \\& Spits, 2006) our upper limit is significantly higher (Drake, 2006)

- If X-ray $< 100$ Myr then our upper limit is in order of magnitude as Tout-Pringle (1991)

- Further progress on Vega with Chandra (or XMM-Newton for that matter) is required
due to UV mangolight gap

Future tests of Tout-Pringle model is best pursued in significantly younger main sequence early-type A stars.

References

This paper is a follow-up of Pease et al. 2006, to appear in ApJ


Stothers, R., & L. B., A., A., 638, 329

Previous ROSAT/Chandra results:

Schmitt, J., A., 638, 329