The Darkest Bright Star: Chandra Observations of Vega

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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 $10^5 - 10^7$ K and find a 99.7% upper limit as low as $\sim 2 \times 10^{25}$ erg s^{-1} at $T = 10^{6.2}$ K. We also compare these new deeper observations with the limit derived from a re-analysis of *ROSAT* PSPC data. Our X-ray luminosity limit for Vega is still greater than predictions of post-Herbig Ae phase X-rays from the shear dynamo model proposed by Tout & Pringle for a Vega age of 350 My. 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 is more likely achieved through X-ray observations of younger main sequence early-type A stars whose conjectured residual post-Herbig Ae phase X-ray activity would be significantly higher.

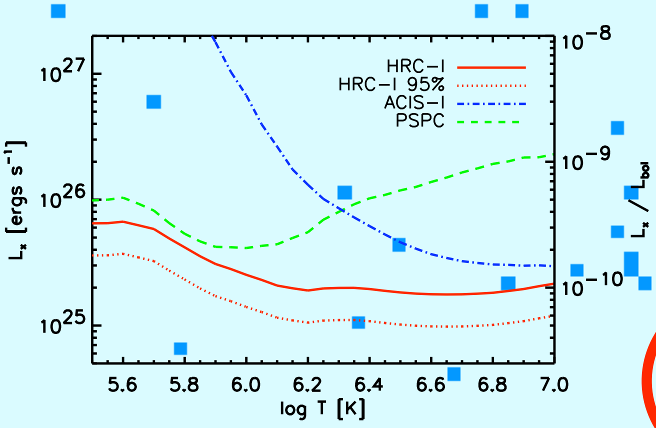

Figure 1: The 99.7% significance upper limit for the X-ray luminosity of Vega as a function of coronal temperature. The estimates derived using data from *Chandra* HRC-I (solid line), *Chandra* ACIS-I (dot-dashed line), and *ROSAT* PSPC (dashed line) are shown. For comparison, the 95% significance upper limit to the X-ray luminosity derived from *Chandra* HRC-I data is also shown (dotted line). The corresponding values of L_X/L_{bol} are given along the axis on the right side.

Src

Vega
d = 7.76 pc
SpType = A0
Age = 100–400 Myr
V = 0.03
B − V = 0.0

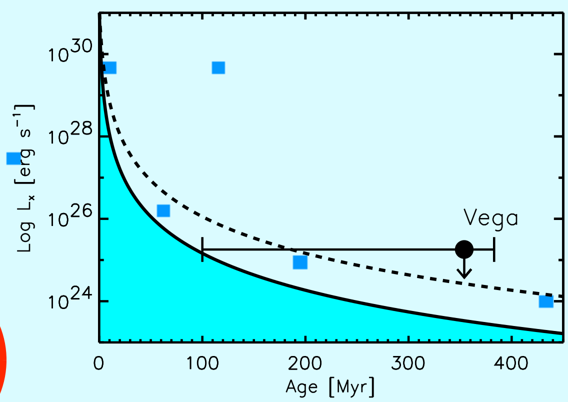

Figure 2: The Tout & Pringle (1995) model prediction for the decline in X-ray luminosity for an early A-type star for two different values of the decay timescales $t_0 = 1 \times 10^6$ yr (solid curve, shaded region) and 2×10^6 yr (dashed curve). The X-ray luminosity upper limit obtained in this work for Vega for the current age range uncertainty is also illustrated.

Upper Limit Determination

A source is detectable in HRC-I data – 4 ct within a 1″ radius. However, the counts are consistent with expected UV leak of ~ 9 ct.

- Estimate counts that would need to be observed in order to detect the source for a given background
  - Assume Poisson probability distribution for background counts
  - Include UV leak photon estimate as contaminating counts
- Probability that at most D counts would be observed as a statistical fluctuation, given a background b,

$$p(\leq D \mid b) = \sum_{i=0}^{D} \frac{b^i e^{-b}}{i!}$$

- For a specific probability threshold p, upper limit, $ul(p) = D(p) - b$
- Example:
  - $b = 5$ ct, $D = 12$ ct corresponds to $p = 0.002$
  - a Gaussian-equivalent "3σ" probability level matches $p = 0.0027$ and hence in the above case the source can be considered detected.
- Allow for statistical variation in background counts via Monte Carlo simulations where the background counts are sampled from a Poisson distribution.

Table 1. 3σ Counts Upper Limits on Vega

Detector	Exposure	Background Region		Source Region			Upper Limit
	t_{exp}	a_{bkg}	N_{bkg}	a_{src}	N_{src}	b_{UV}	$D - b$
	[ks]	[pix]	[ct]	[pix]	[ct]	[ct]	[ct]
Chandra/HRC-I	25.9	64730	324	156	4	9	10^{+4}_{-5}
Chandra/ACIS-I	2.9	65220	14	115	0	0	2
ROSAT/PSPC	10.2	2343903	1105	15393	20	22	16^{+6}_{-7}

Results & Conclusions

Most stringent & lowest X-ray luminosity 3σ upper limit for early A-type star to date (Figure 1):

- $L_X < 1.8 \times 10^{25}$ erg s^{-1}, or $L_X/L_{bol} < 9 \times 10^{-11}$ at a temperature $T = 1.6 \times 10^6$ K

Prevailing theories on post-Herbig phase X-ray activity decline:

1. Decline over ~ 100 Myr due to internal shear energy dissipation leading to dissipation of magnetic fields at stellar surface (Tout & Pringle 1995)
2. Abrupt decline due to magnetic field dissipation from termination of star-disk interactions (Hamaguchi et al. 2005)

Current observations unable to discriminate (Figure 2):

- If Age $\simeq 350$ Myr (Song et al. 2001) then our X-ray limit is significantly higher than Tout-Pringle model
- If Age $\simeq 100$ Myr then our X-ray limit is same order of magnitude as Tout-Pringle model

Further progress on Vega with *Chandra* (or *XMM-Newton* for that matter) is rendered difficult due to UV throughput

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

References

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