RR PIC (1925): A CHANDRA X-RAY VIEW

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ABSTRACT

We present the ***Chandra*** **ACIS-S3** data of the old classical nova **RR Pic (1925)**. The source has a count rate of 0.067 ± 0.002 c/s in the 0.3-5.0 keV energy range. We detect the orbital period of the underlying binary system in the X-ray wavelengths. We also find that the neutral Hydrogen column density differs for orbital minimum and orbital maximum spectra with values (0.07-0.48)x10^{22} cm^{-2} and (0.5-0.77)x10^{22} cm^{-2} at 3σ confidence level. The X-ray spectrum of **RR Pic** can be represented by a composite model of bremsstrahlung with a photoelectric absorption, two absorption lines centered around 1.1-1.4 keV and 5 Gaussian lines centered at emission lines around 0.3-1.1 keV corresponding to various transitions of S, N, O, C, Ne and Fe. The bremsstrahlung temperature derived from the fits range from 0.99 to 1.60 keV and the unabsorbed X-ray flux is found to be (1.3-2.9)x10^{-13} erg/cm^2/s in the 0.3-5.0 keV range with a luminosity of (1.1 ± 0.2)x10^{31} erg/s at 600 pc. We also detect excess emission in the spectrum possibly originating from the reverse shock in the ejecta. A fit with a cooling flow plasma emission model show enhanced abundances of He, C, N, O and Ne in the X-ray emitting region indicating existence of diffusive mixing.

INTRODUCTION

Classical nova RR Pic had an outburst in 1925 as a slow nova (expansion speed ~ 400 km/s). The shell shows "equatorial ring and polar cap/blob" geometry. There are similarities and important differences between the spectra in the ring and blob regions (in C and O lines) with a shell size of 30"x21" and expansion rate of 850 km/s for the ring (Gill & O'Brien 1998). The distance of the nova is measured to be 600 ± 60 pc (Gill & O'Brien 1998). RR Pic has an orbital period of P_{orb}~0.14502545(7) days (Kubiak 1984). Polarization measurements indicate the existence of two components of emission, one associated with a hot spot in the disc and the other in the preceding side of the disc opposite of the hot spot (Haefner & Metz 1982). Kubiak (1984) stated that the main optical light source in the system and the optical eclipse is due to the eclipse of the hot spot by the secondary. However, Schmidtobreick, Tappert & Saviane (2003) conclude that the eclipse is due to occultation of the emission from the preceding side rather than the hot spot.

RR Pic and its vicinity was observed using the *Chandra* ACIS-S for 25 ksec on 2001 October. For spectral analysis, background subtracted spectrum was created using the CIAO tools and the spectrum was binned such that each bin contained data with signal-to-noise ratio higher than 3. The data were then fitted with XSPEC. In general, data bins below 0.3 keV and above 5.0 keV were omitted due to low statistical quality. For the timing analysis, data times were barycentrically corrected and a background subtracted light curve was extracted using CIAO. The light curve was then folded. The phase resolved spectroscopy was performed by extracting spectra using the appropriate phases with the *Chandra* tools, then fitted using XSPEC.

RESULTS

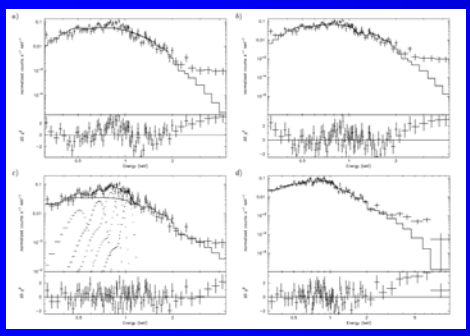
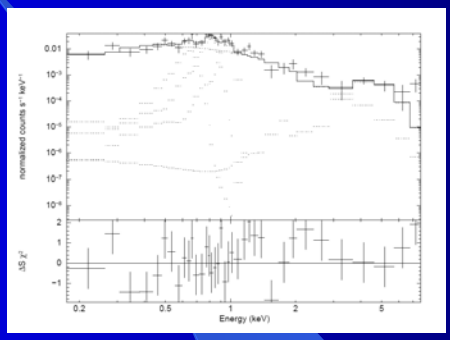


Figure 1. Various spectral fits to the RR Pic data in the 0.3-5 keV range. The crosses show the data with error bars, solid lines the composite fitted model and the dashed lines show the individual models. The panels under the spectra show residuals in standard deviations. The models fitted to the spectra are as follows: a) Simple Bremsstrahlung b) Bremsstrahlung with 2 absorption lines c) Bremsstrahlung with 2 absorption and 5 emission lines d) VMCFLOW



The fit residuals, in general, show some excess (particularly with VMCFLOW model) on the harder energy part of the spectrum. In order to understand the nature of the excess, spatially resolved spectra around the position of the source was extracted from the south-southeast and north-northwest regions of the source in accordance with the results of Balman 2006. Both regions fit well with the composite model noted in **Figure 3** of bremsstrahlung and emission lines. However, a 2-3 σ hard excess in the south-southeast region needs an additional bremsstrahlung component to be added to decrease the reduced χ^2 values down to desirable levels below 2. This component has very high absorption around 50x10^{22} cm^{-2} and plasma temperature in a range 0.36-0.70 keV. The range of the temperatures are in accordance with the shock temperatures of the expanding shell and ring.

	BREMSS+2ABS+5GAUSS	VMCFLOW
N_H (× 10^{22} atoms/cm^2)	$0.008^{+0.014}_{-}$	$0.008^{+0.008}_{-0.007}$
kT_{Bremss} (keV)	$1.3^{+0.3}_{-0.3}$	N/A1
LowT (keV)	N/A	$0.14^{+0.10}_{-}$
HighT (keV)	N/A	$1.8^{+0.2}_{-0.2}$
K_{Bremss}	$0.00097^{+0.00003}_{-0.00002}$	N/A
$K_{VMCFLOW}$ (× 10^{-9})	N/A	$1.8^{+0.1}_{-0.1}$
He	N/A	$18.4^{+2.1}_{-2.1}$
C	N/A	$1.7^{+0.2}_{-0.2}$
N	N/A	$8.7^{+7.1}_{-}$
O	N/A	$1.9^{+1.1}_{-0.7}$
Ne	N/A	1 (frozen)
Gabs LineE (keV)	A1: $1.14^{+0.03}_{-0.02}$	N/A
	A2: $1.28^{+0.02}_{-0.02}$	
Gaussian LineE (keV)	G1: $0.53^{+0.05}_{-0.09}$	N/A
	G2: $0.66^{+0.04}_{-0.02}$	
	G3: $0.80^{+0.02}_{-0.02}$	
	G4: $0.90^{+0.02}_{-0.02}$	
	G5: $1.02^{+0.02}_{-0.02}$	
K_G (× 10^{-6})	G1: $7.3^{+1.4}_{-1.1}$	N/A
	G2: $9.4^{+1.1}_{-1.1}$	
	G3: 14^{+2}_{-2}	
	G4: $8.4^{+2.3}_{-2.4}$	
	G5: $6.2^{+1.0}_{-2.0}$	
Flux (× 10^{-13} ergs/cm^2/s)	$2.5^{+0.4}_{-0.7}$	$2.2^{+0.3}_{-0.6}$
	Bremss: $0.4^{+0.46}_{-0.28}$	
	G1: $0.07^{+0.05}_{-0.06}$	
	G2: $0.11^{+0.08}_{-0.02}$	
	G3: $0.19^{+0.08}_{-0.07}$	
	G4: $0.13^{+0.10}_{-0.08}$	
	G5: $0.11^{+0.10}_{-0.08}$	
χ^2	1.13 (73 d.o.f.)	1.58 (66 d.o.f)

Figure 3. Spectral parameters of the entire spectrum of the RR Pic in the energy range 0.3-5 keV. N_H is the absorbing column, kT_{Bremss} is bremsstrahlung temperature, Gabs LineE is the absorption line centers for the absorption lines, (the sigma and Tau parameters are frozen at 0.005 and 50 for the first line and 0.01 and 20 for the second line), Gaussian LineE is the line center for the emission lines (the sigma values for the lines are frozen at 0.001); K_{Bremss} , $K_{VMCFLOW}$ and K_G are the normalizations for bremsstrahlung, VMCFLOW and Gaussian models respectively. The fluxes are given for the entire model in the first row and then for each of the components in the following rows. All error ranges are given in %90 confidence level (Δ χ^2 =2.71 for a single parameter)

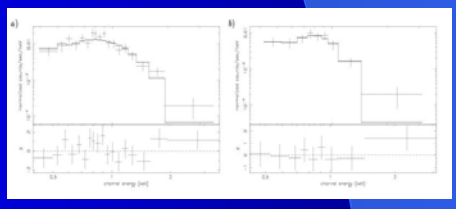


Figure 3. The spectra of orbital phase maximum (a) and minimum (b). Both spectra were fitted with a bremsstrahlung and photoelectric temperatures absorption. The crosses show the data with error bars and solid lines show the composite fitted model. The panels under the spectra show residuals in standard deviations.

	Maxima	Minima
N_H (×10^{22} atoms/cm^2)	$0.25^{+0.23}_{-0.18}$	$0.64^{+0.14}_{-0.13}$
kT_{Bremss} (keV)	$0.35^{+0.2}_{-0.13}$	$0.14^{+0.37}_{-0.04}$
K_{Bremss}	$0.0004^{+0.0028}_{-}$	$0.03^{<}_{-0.03}$
χ^2_ν	1.05 (15 d.o.f.)	0.49 (6 d.o.f.)

Figure 4. Spectral parameters of maximum and minimum spectra in the 0.3-5 keV region. Both spectra were fit with a bremsstrahlung and photoelectric absorption. N_H is the absorbing coloumn, kT_{Bremss} is the bremsstrahlung temperature and K_{Bremss} is the bremsstrahlung normalization. Error ranges for kT_{Bremss} and K_{Bremss} correspond to 2σ confidence level, error and range for N_H correspond to 3σ confidence level.

CONCLUSIONS

- **The source spectrum of RR Pic is best fitted with a composite model of bremsstrahlung, photoelectric absorption, two absorption lines around 1.1-1.4 keV and 5 gaussian lines around 0.3-1.05 keV.**
- **Two possible absorption lines corresponding to Fe (transitions between XVII and XXIV) were detected in the data, which is the first time an absorption feature is detected in CVs at these energies.**
- **The possible emission lines correspond to Fe (transitions between XVII and XXIV (Fe L complex)), Ne (IX, X) and O (VII, VIII).**
- **Spectrum can be best explained by a shocked cooling flow plasma rather than the photoionized plasma.**
- **Enhanced abundances indicate diffusive mixing in the boundary layer.**
- **Clear X-ray modulation and difference of absorption in the orbital maximum and minimum indicate a model where warm/cold region on the disc and/or in the line of sight is responsible for the absorption.**
- **Excess emission on the hard X-rays can be attributed to the emission from the shocked nova shell.**

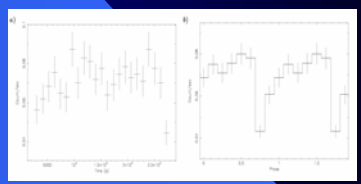


Figure 5. a) The light curve of RR Pic with a bin time of 1100 s. b) Light curve of RR Pic folded over the orbital period of 0.145025 days.

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