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"X-Ray Emission from Wolf-Rayet Stars with Recurrent Dust Formation"

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Final Research Report for contract no. S-93065-E

"X-ray Emission from Wolf-Rayet Stars with Recurrent Dust Formation"

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We were granted a *ROSAT* observation of the Wolf-Rayet star WR 137 (= HD 192641) to test a proposed mechanism for producing the infrared variability reported by Williams *et al.* (1987). These studies showed one clear infrared outburst preceded by what may be the dimming of a previous outburst. The recurrent dust formation model was put forward by Williams *et al.* (1990) to account for similar variability seen in WR 140, which varies in both the infrared and X-ray bands. The detected X-ray flux from WR 140 was observed to decrease from its normally high (for Wolf-Rayet stars) level as the infrared flux increased. Observation of two apparently-periodic infrared outbursts led to the hypothesis that WR 140 had an O star companion in an eccentric orbit, and that the increase in infrared flux came from a dust formation episode triggered by the compression of the O star and Wolf-Rayet star winds. The absorption of the X-rays by the increased material explained the decrease in flux at those wavelengths.

If the infrared variability in WR 137 were caused by a similar interaction of the Wolf-Rayet star with a companion, we might expect that WR 137 would show corresponding X-ray variability and an X-ray luminosity somewhat higher than typical WC stars, as well as a phase-dependent nonthermal X-ray spectrum.

Our goals in this study were

a) to obtain luminosity estimates from our counting rates for comparison with previous observations of WR 137 and other WC class stars, especially WR 140,

b) to compare the luminosity with the IR lightcurve, and

c) to characterize the spectral shape of the X-ray emission, including the column density.

Luminosity estimates:

WR 137 is clearly visible in the center of the *ROSAT* PSPC image. (See Table 1 for the observation log.) We have estimated the source count rate using a maximum likelihood technique similar to that described in Pollock (1987). We give the net source counting rate in Table 2 below. As in Pollock (1987), the errors quoted are approximately 2 σ. We determined the flux estimate from our spectral analysis (see below); the value quoted has been corrected for absorption. We have assumed a distance to the source of 1.8 kpc in determining the luminosity given below.

Table 1. ROSAT Observation Log

Observation time (UTC)	Exposure time (s)
14 May 1992 05:41:06 - 06:20:23	1842
14 May 1992 07:16:16 - 07:56:13	1654
14 May 1992 09:04:52 - 09:28:29	1276
14 May 1992 10:25:20 - 10:58:37	690
15 May 1992 04:06:14 - 04:40:13	1998
15 May 1992 07:23:51 - 07:49:44	1490
Total exposure time:	8950 s

Table 2. Count rate and luminosity

Count rate:	$(5.2 \pm 1.5) \times 10^{-3}$ s^{-1}
Lambda (likelihood parameter):	50.
Background:	0.8 s^{-1}
Effective exposure on this source:	8723 s
Flux (0.2-2.4 keV):	$(1.0 \pm 0.2) \times 10^{-13}$ ergs cm^{-2} s^{-1}
Luminosity:	$(3.9 \pm 1.0) \times 10^{31}$ ergs s^{-1}

Spectral analysis:

Our spectral analysis was done using the *XSPEC* program over a region similar to that used in the luminosity determination. Because of the small number of source counts, we have binned the background-subtracted data into seven bins as suggested in *ROSAT Status Report #58*. Figure 1 shows the binned data as points with error bars. The data were fitted to two models: thermal line emission using a Raymond-Smith model and a power law. The former has been found to give a reasonable description of other Wolf-Rayet and O star spectra, while the latter is the best-fit model to WR 140 (Williams *et al.* 1990). In both cases we have fixed the interstellar absorption to the source at $n_H = 2 \times 10^{21}$ cm^2, as the data were not sufficient to measure it independently. Figure 1 shows the best fit to the thermal model; Table 3 gives the fit results for the two models. The data prefer the thermal line model.

Table 3. Spectral fit results

$n_H = 2 \times 10^{21}$ cm^2

Thermal line	Power law
χ^2 / d.o.f. = 6.1 / 5	χ^2 / d.o.f. = 10.8 / 5
kT = 1.1 keV	photon index = 1.8

Comparison to previous measurements:

WR 137 was previously observed by the *Einstein* IPC. The analysis of the IPC data by Pollock (1987) found a somewhat higher X-ray luminosity ($(1.6 \pm 1.1) \times 10^{32}$ ergs s^{-1}). Our results barely agree within the errors, although the size of the uncertainties precludes a definitive statement of variability. Compared to Pollock's (1987) results for IPC observations of WR stars as a whole, and WC stars in particular, the luminosity of WR 137 is lower than average. There is certainly no sign of the extremely high luminosity observed by various instruments for WR 140. In addition, White and Long (1986) report a bolometric luminosity of 6.3×10^{38} ergs s^{-1}, giving a ratio L_X/L_{bol} of 6.2×10^{-8}, about half that typical for hot stars.

Unfortunately, no further infrared measurements have been reported in the literature for this source, so we can only conjecture about its IR state at the time of the observations.

Our spectral analysis shows that the spectrum prefers the thermal line emission model typical of hot stars to the power law favored by the nonthermal emitter WR 140.

Conclusions:

The observed X-ray luminosity of WR 137 at the time of these *ROSAT* observations was smaller than we expected from the previous *Einstein* IPC measurement. Our measurements indicate that this star is far less luminous in X-rays than WR 140. The spectrum seems to be that from typical thermal line emission and different from that of nonthermal WR 140. If the difference in emission between the Einstein measurement and ours is due to the presence of interaction-generated material, therefore, its only effect appears to be absorbing X-ray flux rather than changing the spectral character of the emission.

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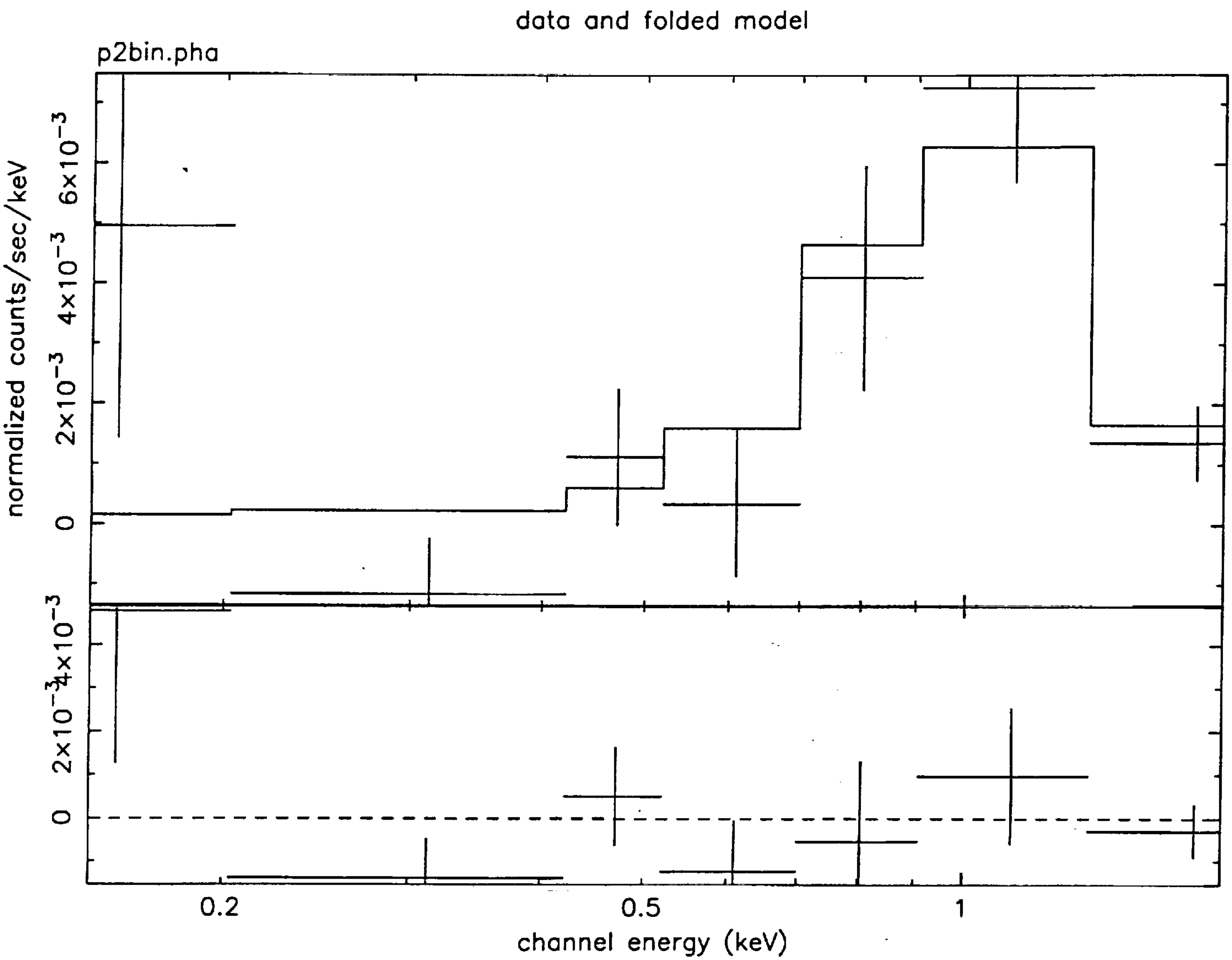

Figure 1. X-ray spectrum of WR 137 (points with errors) and best fit thermal model.

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16. Abstract

We have observed WR137, a Wolf-Rayet Star whose infrared variability indicates recurrent dust formation, with the ROSAT PSPC. We find a low level of X-ray emission, smaller than expected from the previous Einstein measurement. The spectrum we find for WR137 is best described by thermal line emission.

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