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Titles of Research:

(1) **Eclipsing Cataclysmic Variables**

(2) **Deep Eclipses in H0928+501**

(3) **YY Draconis, the Whirling Dervish**

(4) **New X-ray Pulsar Candidates from HEAO-1**

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(NASA-CR-194027) ECLIPSING CATACLYSMIC VARIABLES. DEEP ECLIPSES IN H0928+501. YY DRACONIS, THE WHIRLING DERVISH. NEW X RAY PULSAR CANDIDATES FROM HEAO-1 Annual Status Report, 1 Jun. 1992 - 31 May 1993 (Columbia Univ.) 19 p

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ANNUAL STATUS REPORT FOR NASA GRANT NAG 5-1958

(1) "Eclipsing Cataclysmic Variables" and

(2) "Deep Eclipses in H0928+501"

Data has been received from several brief (few Ksec) ROSAT PSPC observations of five eclipsing cataclysmic variables (VZ Scl, IP Peg, V2051 Oph, V347 Pup, H0928+501). All were detected, and all were very weak, in the range 0.007-0.03 counts/sec. Unfortunately, despite the fact that these were "time-critical" observations and correct eclipse ephemerides were provided, the observations were carried out at times which appeared to bear no relation to the eclipse phase (which was the whole point of the experiment). I suppose the simplest interpretation of this is that the time-critical flag managed to fall off somewhere along the line. My conversations with NASA and other Guest Observers who have attempted time-critical observations suggest that very few if any time-critical observations have ever been successfully executed by ROSAT.

We did manage to learn something anyway, though. The great weakness of these sources was quite a surprise, and suggests to me that X-ray emission probably has quite a bit to do with binary inclination. These data will be published as soon as subsequent observations manage to specify the X-ray flux for stars with exceptionally low binary inclination.

(3) "YY Draconis, The Whirling Dervish"

Data was received from a 12 Ksec ROSAT HRI observation of YY Dra. The data were quite satisfactory, yielded the expected effect, and the paper is now in press (*PASP*, late 1993 - probably November). The paper is attached.

(4) "New X-ray Pulsar Candidates from HEAO-1"

Data was received from a 20 Ksec ROSAT PSPC observation of H0459+248. The source was fairly weak, about 0.05 counts/sec, but also showed a low-energy cutoff at about 2 KeV, somewhat typical of X-ray pulsars of the white dwarf variety ("DQ Herculis stars"). Some evidence for X-ray pulsations was also seen with $P \sim 60$ min, as suggested by the EXOSAT ME data. But analysis of the pulsations is still incomplete, and is hampered by the combination of data gaps and large random variability of the source.

RAPID OSCILLATIONS IN CATACLYSMIC VARIABLES.

XI. X-RAY PULSES IN YY DRACONIS

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ABSTRACT

ROSAT observations of the cataclysmic variable YY Draconis reveal pulses with a period of 265.1 ± 1.2 seconds, confirming the presence of a rapidly rotating, magnetic white dwarf. Comparison with the periods seen in ultraviolet and blue light indicates that the 275 s ultraviolet signal arises from the reprocessing of X-ray pulsations in structures fixed in the binary reference frame. Only harmonics and orbital sidebands of the white dwarf spin frequency are observed, not the spin frequency itself.

YY Dra was observed twice by *ROSAT*, with the PSPC for 4245 s on 1991 Nov 29, and with the HRI for 13500 s over the interval 1992 Oct 20-24. Details of the telescope and instruments are given by Trumper et al. (1983). A detailed log of the observations of YY Dra is given in Table 1.

2.1 *X-ray Spectrum, Flux, Luminosity*

We have fitted thermal bremsstrahlung models to the raw pulse-height data from the PSPC observation. The best fit is found for log N_H = 19.8 cm^{-2} and kT_{brems} = 3.8 keV, with the 68%, 90%, and 99% confidence contours shown in Figure 1. This is consistent with the *Einstein* IPC observation, which gave kT>4 keV, log N_H<20.5 (Eracleous, Halpern, & Patterson 1991).

For a spectrum of this type, the 0.1-2.4 keV flux detected in the PSPC observation is 7.8x10^{-12} ergs cm^{-2} s^{-1}. The *Einstein* observation gave F(0.2-4.0 keV)=1.0x10^{-11} ergs cm^{-2} s^{-1}. The average 2-10 keV flux for 3A1148+719 in the *Ariel V* data is 4.5x10^{-11} ergs cm^{-2} s^{-1} (McHardy et al. 1981). The latter is ~3x greater than would be expected from the low-energy observations, but this appears to be a quite general phenomenon in the X-ray spectra of CVs (see Figure 6 of Patterson & Raymond 1985). Because of this discrepancy, and because most of YY Dra's X-ray flux clearly falls outside the *ROSAT* bandpass, we do not assign high weight to the "3.8 keV" temperature measurement.

Using these fluxes and a 155 pc distance derived from the spectral type of the secondary (M4 ± 1; Mateo, Szkody, & Garnavich 1991), we estimate a "bolometric" X-ray luminosity L_X(0.1-10 keV)=1.2×10^{32} erg s^{-1}.

2.2 *Light Curve and Periodicity Search*

The light curve from the PSPC observation, at a time resolution of 68 s, is shown in Figure 2. The source displayed only small fluctuations about a mean count rate of 0.82 cts/s. The HRI observation also showed only small fluctuations in the raw light curves.

For each data set, we condensed the X-ray light curve into ~30 s bins and calculated the power spectrum with a discrete Fourier transform. In the upper frame of Figure 3 we show the result for the PSPC observation, with a strong peak visible at 265.1 ± 1.8 s. For the HRI observation, the extremely sparse distribution hindered period-finding efforts for all but the initial 3600 s segment of data. The power spectrum for this segment is shown in the lower frame of Figure 3, and again shows the highest peak at a period of 264.1 ± 1.5 s.

To within measurement error, these periods are consistent with the period in blue-light photometry, namely 265.8 ± 1.3 s. We have therefore used the average of these three estimates (265.1 s) to synchronously sum the X-ray light curves on the three separate days of observation. These are shown in Figure 4. All three frames show a fairly smooth waveform, with a pulsed fraction [defined as $(F_{max}-F_{min})/F_{max}$] of 0.25 ± 0.03. We note that the observed flux dropped ~40% between the first and second HRI observations.

Maximum light was found to occur at $MJD_{\odot}$ 48589.56909, 48916.32918, and 48920.72918. Eventually it may be possible to use these numbers to produce a long-term ephemeris, but at present the density of observations is too low.

3. *DISCUSSION*

The principal result is that the stable signal found in blue light does have an X-ray counterpart at the same period, suggesting that the "DQ Her" model peddled by Patterson et al. (1992) is correct. What about the two other short periods discussed in that paper?

3.1 *Period Machinations*

Ultraviolet light (3200-4000 A) reveals a dominant signal at a slightly longer period; the most likely value is 274.87 (±0.10) s, with a possible one-day alias at 275.76 s. There is also a subharmonic at ~550 s. Patterson et al. also reported broad-band photometry through a copper sulfate filter, which admits all light between 3200 and 5500 A (referred to as "blue light"). Even though this includes that portion of the spectrum which exhibited a 275 s pulse, the observed pulsation was found to occur at 265 s. This was interpreted to mean that the continuum is predominantly pulsed at 265 s, but the 3200-4000 A pulsation arises mainly from the strong emission lines in that region. This could be physically reasonable if the emission-line source is in a prograde orbit around the white dwarf, and if the actual rotation period is not 265 but 530 s.

We hoped that *ROSAT* observations would test this hypothesis, and it appears that they have, by revealing the X-ray pulsation that is the signature of a rapidly rotating magnetic white dwarf. It appears that there are two accreting poles which are about equally luminous in X-rays, and also in blue light, concealing any sign of the true 530 s rotation period. The 275/550 s signals then arise from the reprocessing of the white dwarf's pulsed light in structures moving around the white dwarf with the binary period of 3.96 hrs.

3.2 *Period Refinement*

We have studied the periods carefully to try to improve their accuracy. Although we have basically failed, we can at least give information likely to be of later use.

The problem is that cycle count uncertainty during the daily 24-hour gaps in the optical data produced two acceptable periods in blue light, 265.49 and 264.61 s, and two acceptable periods in ultraviolet light, 275.76 and 274.87 s. The X-ray period of 264.6 ± 1.4 s is not of sufficient accuracy to distinguish between them. A more intricate argument might, which goes as follows. If we assume that the optical and X-ray periods coincide[1], then we can use the 4-day gap between HRI

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[1] And also that no period change has occurred. The ultraviolet light curves presented by Patterson et al. (1992) demonstrate that the 275 s period changed by less than 0.06 s over 9 years, yielding $|\dot{P}|<2.1\times 10^{-10}$. This is certainly stable enough to justify applying the

estimate of the 265 s blue-light period obtained in 1990 to data obtained over baselines of only a few days in 1991/2.

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pulse maxima to deduce a period of 265.475 ± 0.015 or 264.550 ± 0.015 s. If we further assume that the short-period clocks accumulate a phase difference of exactly two cycles per orbital period, then the alternate cycle counts yield orbital periods of 3.954 ± 0.027 and 3.914 ± 0.027 hr. The actual orbital period is 3.96 ± 0.01 hr (Mateo, Szkody, & Garnavich 1991). So under these assumptions, there is a substantial but not quite decisive preference for the slightly longer periods (265.475 and 275.76 s). We do not quite trust this result, though, because the argument is a bit intricate, because the preference is not decisive, and because the second HRI pulse maximum is somewhat doubtful (having been assembled from many short observations over a time interval longer than we can maintain cycle count with certainty). More extensive X-ray or blue-light photometry should resolve this matter.

3.3 *Spectral Dependence on Pulse Phase?*

Finally, we segregated the PSPC observation into "pulse-on" and "pulse-off" segments and repeated the spectral fit, to see if there are any spectral changes on the pulse period. No changes were seen.

4. *SUMMARY*

1. X-ray observations confirm the membership of YY Dra among the DQ Herculis stars, in which a magnetic field channels accreting gas

radially along field lines to the white dwarf's magnetic poles. The white dwarf's spin period is 530 s. The X-ray pulse at 265 s indicates that both poles are probably active and nearly identical. This is surprising, since our viewing location well away from the orbital plane ($i=42\pm5^{\circ}$, Mateo et al. 1991) should give us a much better view of one pole than the other. This may indicate that the X-ray emission stands far above the white dwarf surface, or that the magnetic axis is nearly on the white dwarf's equator.

2. The 275/550 s signal in ultraviolet light arises from the reprocessing of the white dwarf's pulsed flux in a structure moving with the binary period. The emission lines and Balmer continuum from the "hot spot" could be responsible for this signal; some contribution from the secondary is also possible.

3. A minor variant on this interpretation of the period structure, also discussed by Patterson et al. (1992), remains possible: that the period in blue/UV light depends on the star's *luminosity state* rather than the bandpass. High-speed multicolor photometry can resolve this important point.

4. The most likely values for the short periods, the first harmonics of the real signals, are 265.475 s (spin) and 275.76 s (orbital sideband). There is still an annoying uncertainty in cycle count over a 24-hour interval.

5. Strangely enough, of the four short periods which appear to be important in the system, the period which represents the underlying

clock, the actual spin of the white dwarf at P=530 s, is the only one not seen. *Caveat emptor, in unum et in omnia*!

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TABLE 1 -- ROSAT OBSERVATIONS OF YY DRA

UT Date	(48000 +) MJD Start -- Stop	(sec) Exposure	Detector	(counts/sec) Count Rate
1991 Nov 29	589.56672 - .57924	1082	PSPC	0.82
	.60874 - .64572	3195		
1992 Oct 20	916.32686 - .34587	1642		
	.39341 - .41618	1967	HRI	0.160
	.41624 - .42764	985*		
1992 Oct 24	920.72908 - 921.72544	8900*	HRI	0.105

*Sum of several dozen short segments of good data.

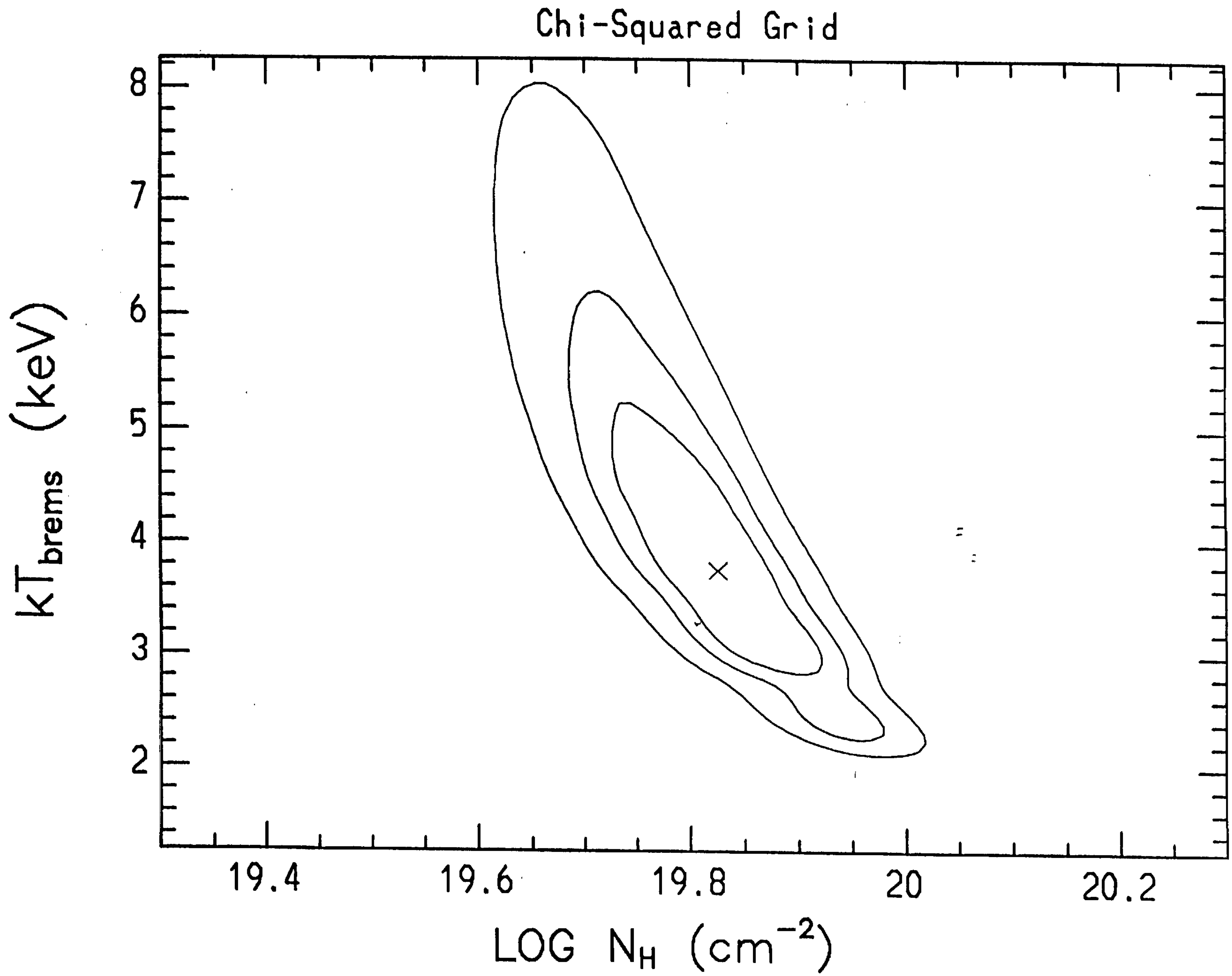
FIGURE CAPTIONS

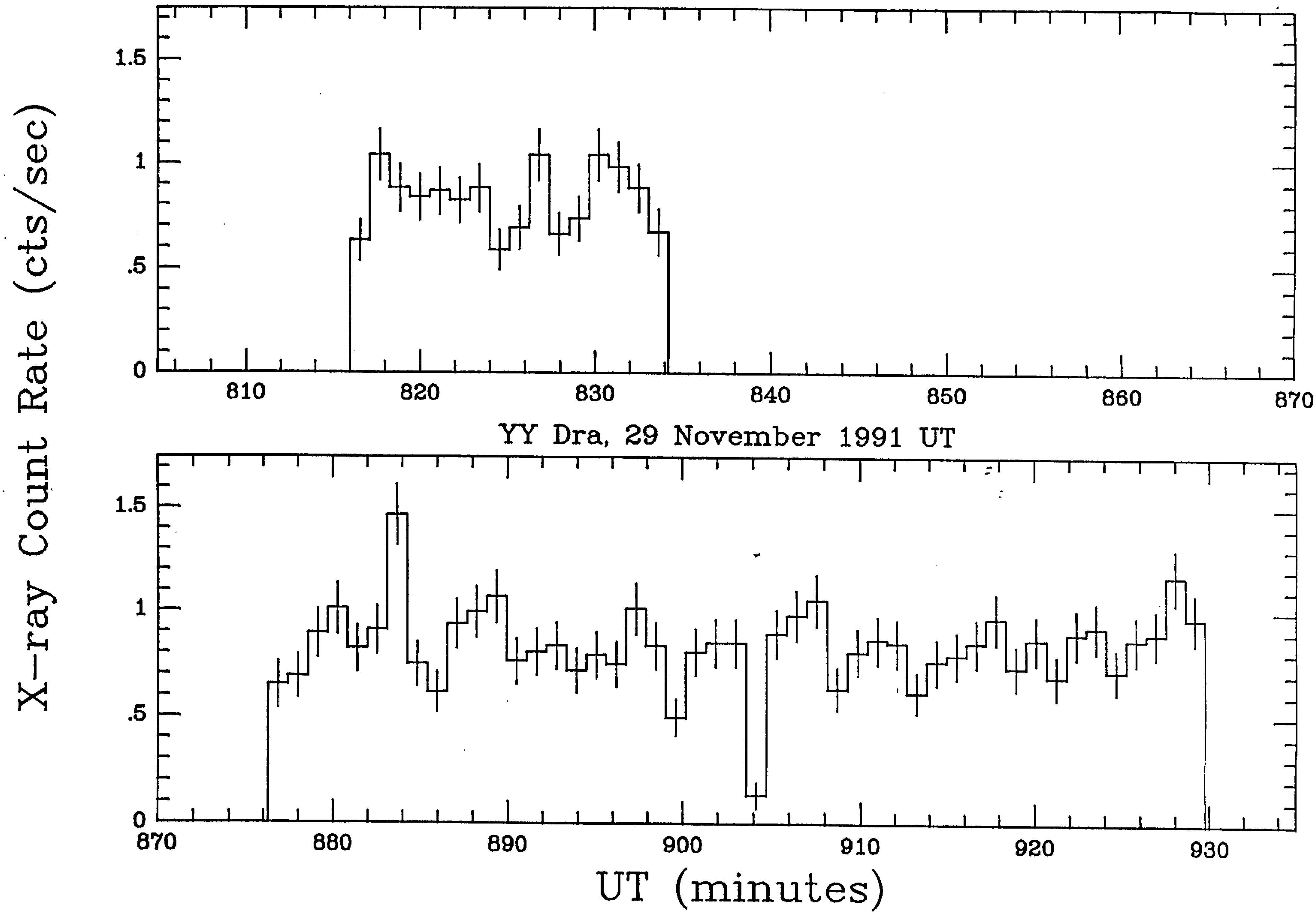
Figure 1. 68%, 90%, and 99% confidence contours in the X-ray spectral fit. The best fit is found for kT = 3.8 keV, log $N_H = 19.8$ cm^{-2}. Unlike many DQ Her stars, the spectrum is only lightly absorbed.

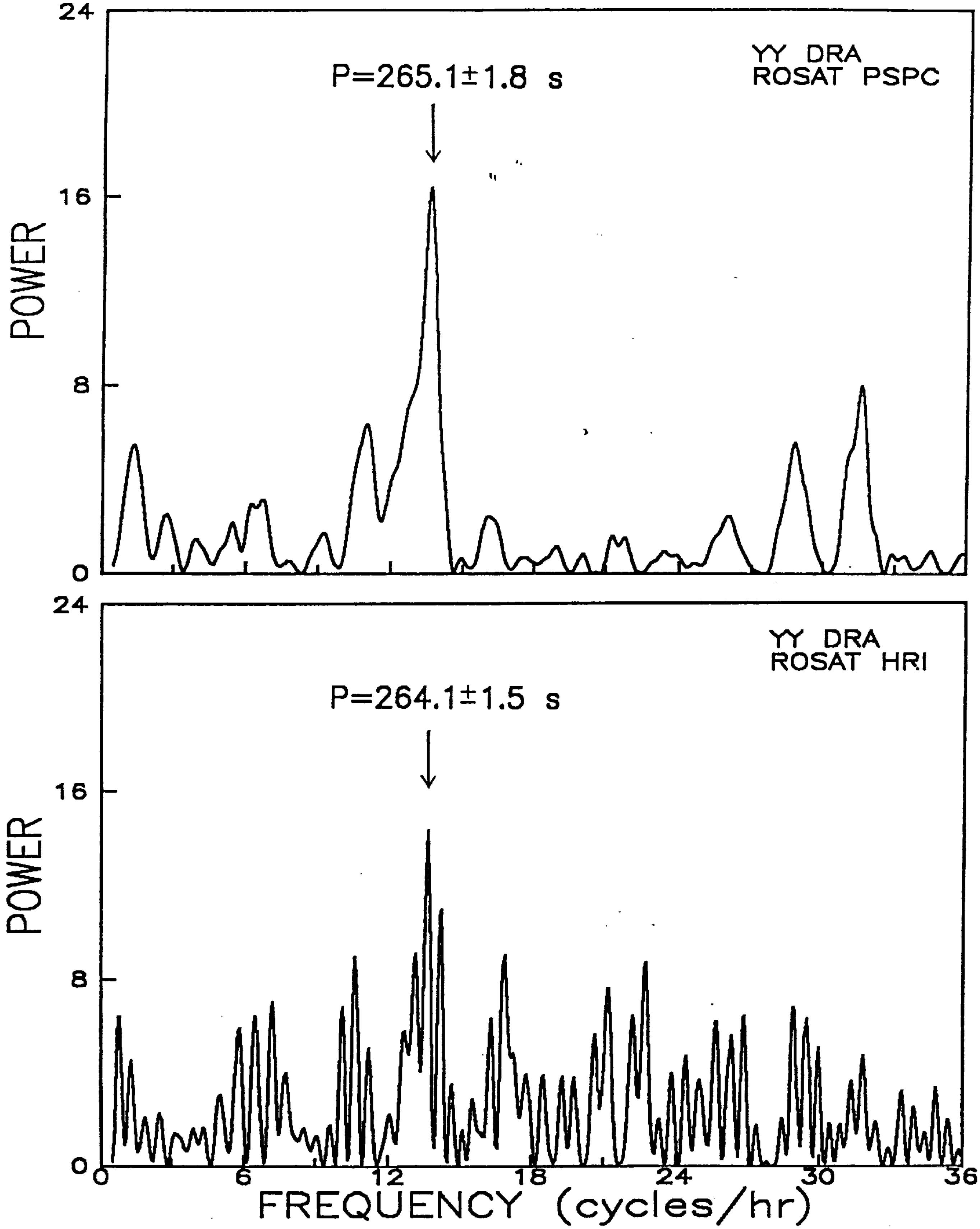
Figure 2. Light curve of the PSPC observation, at a time resolution of 68 s. Only small fluctuations are seen.

Figure 3. *Upper frame*, power spectrum of the PSPC light curve. *Lower frame*, power spectrum of the HRI light curve (segments 1 and 2, where the density of coverage is not too low). The arrows indicate the presence of a periodic signal, at one of the known optical periods.

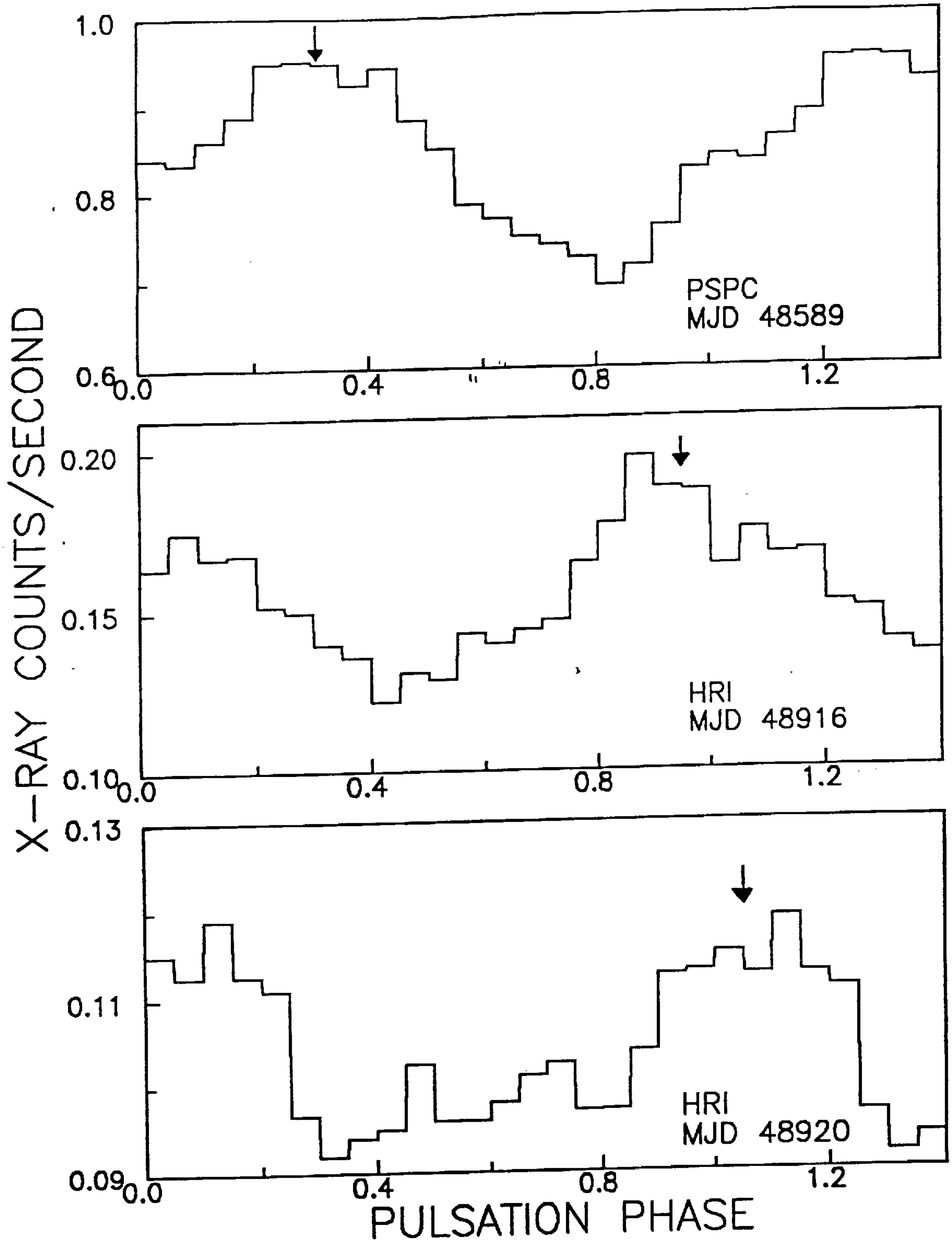
Figure 4. X-ray light curves folded on the 265 s period, and lightly smoothed with a 3-bin triangular filter. In this figure, zero phase corresponds to the beginning of each observation (listed in Table 1), and the arrows indicate the time of maximum light (stated in the text). The three observations are also labelled by their MJD dates.


Chi-Squared Grid
kT_{brems} (keV)
8
7
6
5
4
3
2
19.4
19.6
19.8
20
20.2
LOG N_H (cm^{-2})


X-ray Count Rate (cts/sec)
YY Dra, 29 November 1991 UT
UT (minutes)
1.5
1
.5
0
810
820
830
840
850
860
870
880
890
900
910
920
930



YY DRA
ROSAT PSPC
P=265.1±1.8 s
POWER
YY DRA
ROSAT HRI
P=264.1±1.5 s
POWER
24
16
8
0
0
6
12
18
24
30
36
FREQUENCY (cycles/hr)



X-RAY COUNTS/SECOND
PULSATION PHASE
PSPC
MJD 48589
HRI
MJD 48916
HRI
MJD 48920
1.0
0.8
0.6
0.20
0.15
0.10
0.13
0.11
0.09
0.0
0.4
0.8
1.2