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Observation of second cyclotron line feature in the spectrum of Her X-1

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Abstract. Hard X-ray spectrum of Her X-1 was measured during a balloon flight experiment launched on March 30, 1997 using a large area scintillation counter telescope. The instrument code named LASE, operates in the 20-200 keV energy region and has high spectral and temporal sensitivity for the study of X-ray pulsators. The source observations were made on the 7th day of the 35^d on cycle and at the binary orbital phase of 0.5. The measured source flux in the 20-50 keV region was found to be lower by a factor of about 3, the continuum spectrum was found to be extremely hard ? Apart from the primary cyclotron feature at 48 keV, the present data provides a clear confirmation of the absorption line feature around 96 keV corresponding to the second harmonic. We discuss the implication of hard X-ray spectrum and the line energy in terms of the properties of the emission region.

1. Introduction

The neutron star binary X-ray pulsating source Her X-1 was discovered by UHURU satellite (Tananbaum et al., 1972). The source exhibits a variety of temporal features namely 1.24 second pulsation, a 1.7d binary orbital period, 1.62d intensity dips and 35d on-off periodic intensity variations. The hard X-ray spectrum of the source was first measured by Manchanda et al. (1973) and was later confirmed by several authors (Iyengar et al., 1974; Trumper et al., 1978; Joss et al., 1977; Manchanda 1977, Maurer et al., 1979; Dennis et al., 1978; Gruber et al., 1980; Tueller et al., 1984). A significant high energy variability by a factor of ~2-3 is discernible in various observations and those made from the HEAO-1 A4 experiment (Gruber et al., 1980). On occasions however, the observed intensity variations could be much larger. The intensity variation is an accepted feature of the source but the spectral evolution with the intensity level has not been established so far.

The presence of a cyclotron emission / absorption feature in the spectrum of Her X-1 was first discovered by Trumper et al. (1978). This first observation revealed the existence of a narrow spectral line feature at ~ 58 keV and a second one at ~ 110 keV assuming an emission line model. These features were interpreted in terms of electron-cyclotron resonance effect due to intense magnetic field in the X-ray emission region near the polar caps of the compact object.

The corresponding magnetic field strength of 3 – 5 x 10^{12}G was inferred. Since its discovery, there have been a number of confirmations of primary cyclotron feature at ~ 50 keV (Gruber et al., 1980; Scheepmaker et al., 1981; Ubertini et al., 1981; Voges et al., 1982; Manchand et al.; 1984). The data in general have been fitted both by absorption and emission features, consistent with a narrow line of ~ 10 keV. The second feature at ~ 110 keV observed in the first experiment and interpreted as the second harmonic has never been confirmed. It is generally believed that a confirmation of the second harmonic may resolve the emission or absorption nature of the observed features. An attempt to fit the data with a smoothly varying spectral form from the low energy end by Mihara (1990), supports an absorption line model for this source.

Her X-1 spectral data observed by the HEAO-1 A4 (Soong et al. 1990) and recent observations in the 0.1-200 keV band using detectors on-board BeppoSAX satellite (Dal fiume et al. 1998) and HEXE detector on board RXTE satellite (Gruber et al. 1998), fit with the cyclotron feature in absorption with an energy for the first harmonic around 40 keV. The spectral fitting for the data above 20 keV corresponds to a power law plus high energy exponential cut-off along with a gaussian absorption feature. No statistically significant feature at the energy corresponding to the second harmonic is reported from these data. The data from BeppoSAC, however, does indicate a 115 keV feature.

In this paper I present the hard X-ray observations of Her X-1 between the 20-200 keV made at the low intensity level of the source during the On-state. The observed time averaged spectrum is found to be very hard and two cyclotron absorption line features corresponding to the primary and the second harmonic are clearly seen in the data. We discuss the present results in terms of the circumstances which may lead to emission of hard X-ray photons and and a variation in the cyclotron energy.

2. The X-ray Instrument and the observations

The X-ray observation were carried out using a balloon borne instrument flown from Hyderabad, India on March 30th, 1997. The cut-off rigidity at this near-equatorial launch site is 16.4 GeV and thus provides the added advantage of low ambient background flux. The newly developed balloon-borne payload code named LASE consists of an X-ray telescope made of three identical modules of specially developed large area scintillation detectors having both passive and active shielding and fitted on a fully steerable equatorial mount. During the March 1997 flight, only two modules were fitted on the gondola.

Each module consists of a combination of thin and thick Sodium Iodide detector arranged in a back-to-back configuration and has a geometric area of 400 cm^2. In the detector assembly, a 3 mm thick single crystal is placed above a similar detector of 30 mm thickness and the two crystals are optically decoupled by a 5 mil aluminum foil. A 1.0 mm thick quartz window is provided for the thin crystal which also acts as an entrance window for the X-ray photons. The glass window attenuates ~40% of the X-ray at 20 keV. Main detector is seen by two 5” EMI 9530 phototubes using a diffuse box arrangement. The bottom detector is viewed by a directly coupled 5” phototubes. The top of the diffuse box is Aluminum-laminated black paper so as to avoid further attenuation of the incoming flux. The field of view of each module is 4.5^o x 4.5^o and is defined by a dis-mountable 1.3 mm thick slat collimator made with 0.5 mm lead sandwiched on both sides by 0.25 mm tin and 0.12 mm copper. Both modules have independent event-selection modules and 8-bit ADC, which provides a 127 channel energy resolution in the calibrated dynamic range of 20-180 keV. Similarly, the data from the anti detectors between 70-350 keV is also PHA analyzed in 127 channels. The pre-flight calibration of the X-ray detectors is done at different energies using radioactive sources, Cd^{109} (22.1 and 87.5 keV), Am^{241} (24.7 and 59.6 keV) and Ba^{133} (32.4 and 81 keV). In addition, an Am^{241} source is mounted on the payload for calibration of the detectors during flight. This mode is activated using a ground command. The measured energy resolution for the main detectors is 28% at 60 keV. PHA data from each detector is sourced once in each frame and two words per frame are assigned for sub-commutated information from detector rates, house keeping data and other auxiliary measurements including orientation data from shaft-encoders, fluxgate magnetometers, inclinometers and star tracker. A 25 μsec temporal resolution is achieved by referencing the event arrival with the frame start pulse.

Both detectors are mounted on a cradle which is supported on the payload platform, which in turn is servo-stabilized with reference to earth's magnetic field using a flux gate magnetometer. Azimuth control is achieved by a combination of anti-twist motor between the balloon and the gondola and from the torque of a heavy reaction wheel with respect to gondola frame. Detector elevation with respect to vertical is controlled by a DC motor along with a shaft encoder read-out and an independent high resolution inclinometer. The absolute azimuthal stability and the pointing capability of the platform is 0.15^{o}. The target X-ray source and the corresponding background region are tracked as per the flight plan using an on-board micro-processor controlled tracker, which computes the instantaneous azimuth and zenith coordinates of the target using the RA-Dec coordinates from its memory. The data are transmitted at 40 kHz using a PCM/FM telemetry system. The detailed description of the LASE payload and its performance characteristics are published elsewhere (D'Silva et al., 1998).

Her X-1 was observed for a continuous stretch of 50 min between 2240 and 2330 UT on March 29th and the background was measured for 20 min each before and after the observation. The off-source pointing location was a carefully selected blank field from the known X-ray source catalog. A total of 13800 excess counts due to the source were recorded in both the detectors. This corresponds to a combined significance of 37σ. Using the ephemeris of JD 2446208.3 for the cyclic turn-on with an average period of 34.85 ± 0.001 days and JD 2443805.03 for the mid-eclipse of the $1^{d}.70016772$ binary period, the corresponding phases at the time of observations are $\phi_{1.7} = 0.57$ and $\phi_{35} = 0.208$. A detailed look of the RXTE soft-X-ray monitor data indicates that high state of the source during the present turn-on cycle persisted for ~ 12 days during JD 2450529 to 2450540 (RXTE archival data). Accordingly, our observation made on JD 2450537.45 are during the 5th binary orbit.

3. Results

The combined time averaged energy spectrum of the source in the energy region 20-160 keV as measured by the two detectors is shown in the figure 1. The error bars represent the $\pm 1\sigma$ statistical errors. The data are corrected for the atmospheric and window transmission, detection, efficiency and the energy resolution effects. We have also plotted the spectral data of Dal

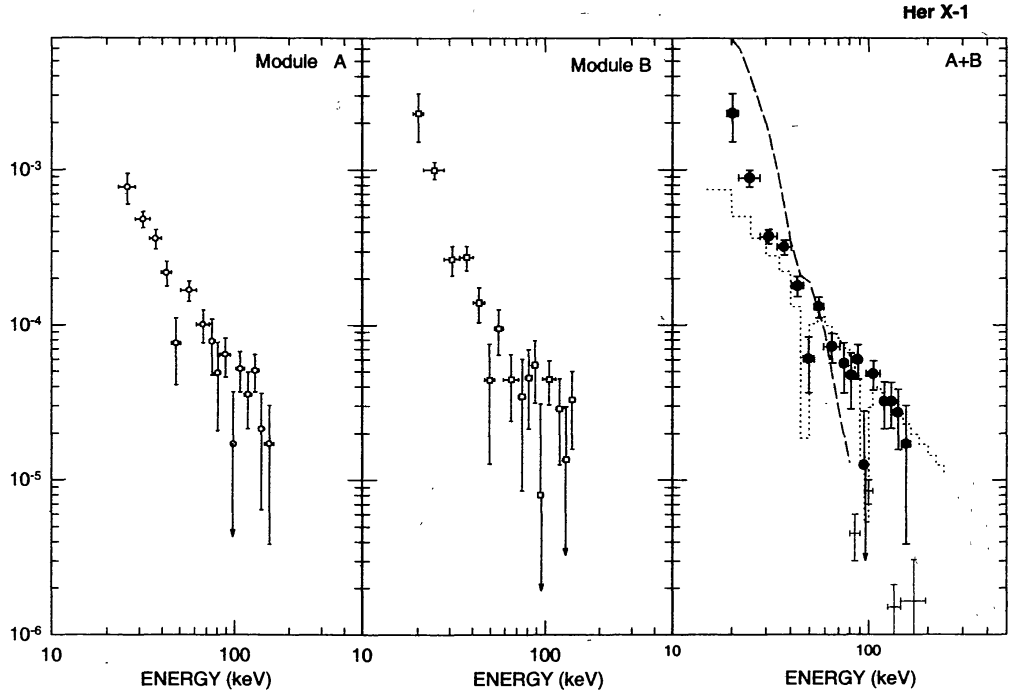

Figure 1. Time averaged spectrum of Her X-1 for module A, module B and the sum spectrum. Spectral data of Dal Fiume et al. (1998) is shown for comparison by dashed line and data points with + marks. The dotted histogram corresponds to computed values with best fit parameters.

Fiume et al. (1998) in the figure for comparison. Their values are time averaged over two binary cycles and the observations correspond to orbital phase $\phi_{35} \sim 0.093$. A clear difference in the form of the two measurements is apparent from the figure.

Two main points can be clearly noted from the present data (a) two absorption features at E~ 48 keV and E~96 keV, arising due to cyclotron absorption stand out clearly in the intensity spectrum of the source, thereby confirming the second harmonic as observed earlier by Trumper et al. (1978) and (b) unlike earlier observations, the present spectrum extends right up to 160 keV and the spectral shape does not indicate any cut-off at higher energies. The data in the Fig. 1, also suggest that the underlying spectrum is not a simple power-law distribution. Even though a single power-law index with $\alpha \sim 2.0$ can be fitted through the data, an independent fit to the data below 50 keV best fits a spectral index $\alpha \sim 2.8$ and the data above

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50 keV gives the α value of ~1.6. The intensity distribution of the source is therefore, consistent with a composite of two power law components. However, to deduce the parameters of the absorption lines, we assumed a single power-law for the intensity distribution from the source and the line energy of the second feature was assumed to be twice the value of the primary line. The fitting model for the observed photon flux containing 7 parameters corresponding to an underlying power-law and two absorption line features with Gaussian distribution is given by;

$$\frac{dN}{dE} = AE^{-\alpha} - I_1 e^{-\left(\frac{E-E_1}{\sigma_1}\right)^2} - I_2 e^{-\left(\frac{E-2xE_2}{\sigma_2}\right)^2}$$

This model fits the general trend of the data shown in figure 1. The best fit parameters obtained using gradient method (Bevington, 1969) are given in Table I. χ^2_7 value for the weighted fit is 2.91. As noted by Mihara (1998), the underlying power law spectrum, itself appears to have a changing power index and a more realistic fit will improve the value of χ^2 even further. Following Lampton et al (1976), the mean value of the statistics for the χ^2 distribution with 7 parameters for 68% confidence level is > 4.7. The value of $\chi^2 = 2.9$ for the parameters listed above therefore, lies in the 95% confidence level contour in the minimum χ^2 space. Even though the significance of deviation from the continuum for the second harmonic is ~ 2.8σ, the appearance of the signal at the predicted energy in the 94-100 keV energy bin, twice the energy of the first feature at 48 keV, increases the confidence level to ~ 99%. The estimated luminosity of the source from our observations is 10^{36} ergs s^{-1} at a source distance of 4 kpc.

Table 1. Range of model parameters for the Her X-1 spectrum

Parameter	Value
A	$6.8 \pm 1.5 \times 10^{-2}$
α	1.52 ± 0.2
I_1	$1.2 \pm 0.6 \times 10^{-4}$
E_1	47.8 ± 1.7
σ_1	5.5 ± 1.3
I_2	$4.8 \pm 2,6 \times 10^{-5}$
$E_2 = 2 \times E_1$	96 ± 3.5
σ_2	7.8 ± 4.7
X^2_7/dof	2.91

4. Discussion

Two important questions need to be answered in support of present results and these are; (i) the energy spectrum obtained in the present observations are radically different from the earlier reported measurements and shows an extremely hard nature and (ii) the appearance of the second harmonic, even though its presence was indicated in the data of Trumper et al. (1978).

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The second harmonic was not seen in any of the subsequent observations made so far. Both of these questions are inter-related and second results as a direct consequence of the first since the absorption features arise due to resonance scattering of the continuum. The second harmonic will not be visible if there was no detectable emission from the source above 80 keV.

The continuum flux derived from our data gives a value of ~ 5 x 10^{-4} ph $cm^{-2}s^{-1}keV^{-1}$ in the 20-50 keV which is lower by a factor of ~ 3 from the 1972-1976 high intensity level and thus represents a low luminosity level of the source. As seen in Fig. 1, the observed energy spectrum suggests a changing power index. This form can arise by a combination of a steep primary spectrum and a superposed Comption tail at higher energies. An apparent change in the value of spectral index α by ~ 1 does support such a hypothesis. In the following discussion we present the analysis of the pulsed features of the source from our data and the X-ray emission behaviour during the 11^d on-period in the 35^d cycle analyzed using BATSE archival data. The source characteristics suggest unusual source activity which lead to extremely hard spectrum during our observation.

4.1 Pulsed behaviour

Figure 2 shows the pulsation light curve derived from the On-source data from each of the two detectors. The number of counts corresponding to 20-50 keV energy channels were folded in 20 phase-bins at various periods. The light curves shown in the figure correspond to the period which maximizes the χ^2 deviation of the phase-bins from the phase averaged value. The best period of 1237.782 ± 0.006 millisec is quite consistent with the value of 1237.775 seen in the one day averaged data from CGRO satellite (BATSE archival data). No significant pulsed flux was seen in the higher energy channels.

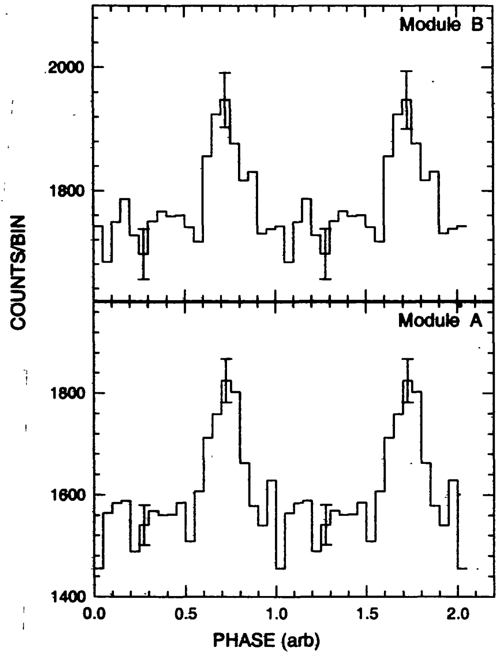

Figure 2. Observed pulse profile of Her X-1 in two modules.

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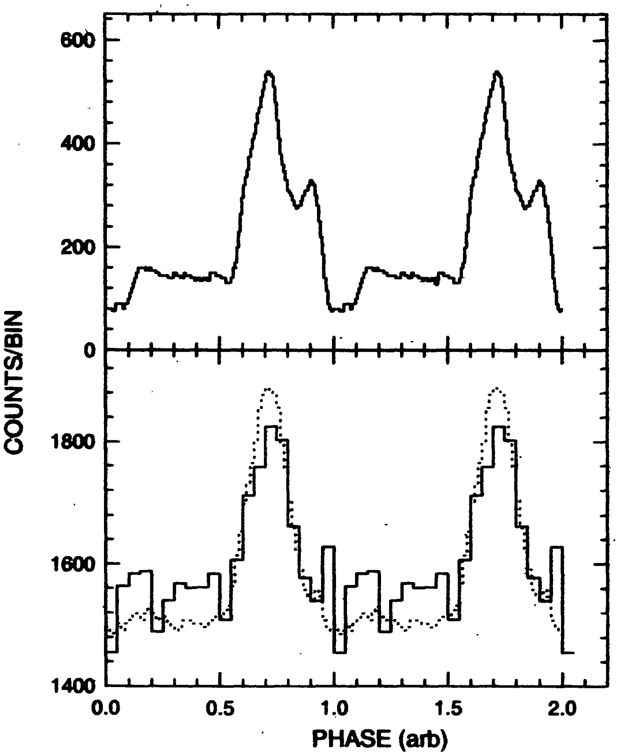

Figure 3. Comparison of the observed pulse profiles of Her X-1 with BATSE (lower panel) and EXOSAT data (upper panel). Dotted curve corresponds to the present data.

Apart from the similarity of the pulse shape between the two detectors, the hard X-ray pulse profile obtained during the present observations is in complete agreement with the 1^d time-averaged data from GRO. The data is plotted in figure 3 in the lower panel. Phase-shifted BATSE data is shown in dotted line and was scaled to have the same excess counts under the main peak as seen in our data. The main points to note from this comparison is the remarkable overlap of the snap-shot pulse profile to the daily averaged data. However, this profile is notably different from the measurements of the ME detectors onboard EXOSAT in the 1-30 keV energy band (upper panel) even though the EXOSAT observation is selected for the cyclic phase of $\phi_{35} = 0.23$, similar to the present observation. The ME pulse prfile shows a double peaked main pulse. While the match with BATSE pulse profile confirms our observation about the characteristics of the pulse forming in the source, the comparison with the EXOSAT data points to a changing beaming pattern of the X-ray source.

In addition, the pulse fraction derived from our data in the 20-50 keV band corresponds to ~ 35% of the total emission from the source. The presence of such a large pulsed fraction in the 5th binary cycle during the On-state of the source is quite anomalous and is in complete contrast to the earlier reported data. In the low energy region below 10 keV, the pulse fraction from source has been observed to be 70%-100%. Beyond 20 keV, the observations of the source during on-state both by balloons and satellite-borne detectors suggest a reduction in the pulsed fraction with the binary cycle number during the on-state (Maurer et al. 1979). A comparison of different data is summarized in the Table 2.

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Table 2. Pulse fraction vs. binary behaviour

Pulsed frac. %	Energy range	Binary cycle no.	Reference
< 10	20-45 keV	end of 4th	Iyengar et al. (1974)
not significant	> 100 keV	6th	Kurfess & Crosa (1973)
~ 50	18-54 keV	3rd	Kendziorra et al. (1977)
35	19-30 keV	beginning 3rd	Joss et al. (1977)
32 0	16-33 keV	for 1-4th 5th	Maurer et al. (1979)
35	20-50 keV	5th	present

The presence of large pulsed flux as seen during the present measurements undoubtedly points to unusual conditions in the accretion phase. The X-ray source was indeed in the chaotic phase during present observations and which is also borne out by the analysis of the pulse period history of the source during the On-state derived from the BATSE archival data and is shown in Fig. 4 The data in the figure gives the daily averaged pulse period during the turn-on cycle in which present observations are made (middle panel). Top and bottom panel give the data for the preceding and succeeding turn-on cycle. It is clearly seen from the figure that while the period changes are more orderly during the other two cycle, the measured period for our observation epoch varied almost on daily basis. Additionally, the pulse period and pulse fraction are generally measurable only for the first 6-7 days of the On-cycle, the measurements during the turn-on cycle of our data are extended right up to 12 days.

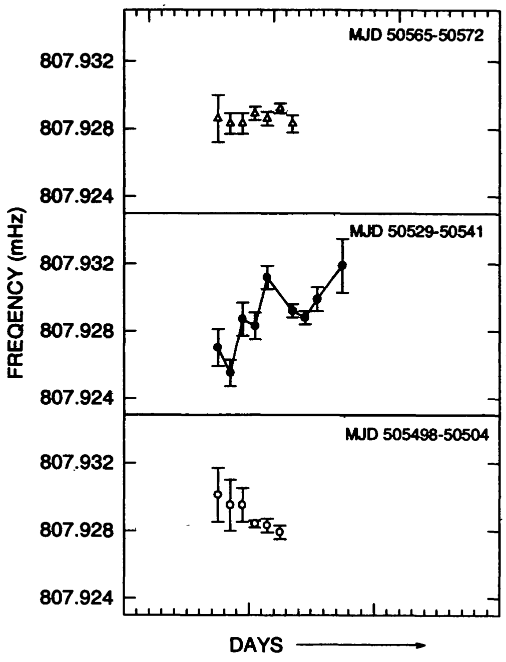

Figure 4. Pulse period of Her X-1 during 3 turn-on cycles (BATSE archival data). The data points in the middle panel correspond to the present observations.

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In the standard picture of accreting close binary X-ray systems, the all important transfer of mass from the primary to the compact companion takes place by Roche lobe overflow or by a stellar wind. A co-rotating accretion disk is thus formed around the compact object and powers the X-ray emission process. In this picture, the observed long term spin-up of the pulsating X-ray sources is caused due to accretion torque generated by the accreting material. However, the magnitude of the torque reduces for the fast rotators since the magnetic and viscous stresses at the inner edge of the accretion disk cancels the materials stress and thus results in a smaller value of $\dot{P}$ and long term changes in the rotation period.

Among the known X-ray pulsars, Her X-1 occupies the boundary between the fast and the slow rotating compact objects. Long term study of the source shows the gradual changes both in intensity and the pulse period. Since, the binary orbit of Her X-1 is nearly circular, mass function and orbital elements are very well determined, it is difficult to postulate free unknown variables. Therefore, sharp secular changes as seen in the present epoch can only be ascribed due to chaotic changes in the accretion rate resulting into the torque noise. The Roche geometry and the finite resident time of the incoming material in the accretion disk tend to moderate the sharp changes and thus it is difficult to reproduce the magnitude of period variation.

From the detailed disk accretion model of Ghosh and Lamb (1978, 1979), the rate of change of the rotation period due to accretion torque can be written as

$$-\dot{P} \approx 5.8 \times 10^{-5} P L_{37}^{3/7}$$

for a neutron star with $M = 1M_{\odot}$, $R = 10$ km and magnetic moment $\mu_{30} = 0.48$. The period fluctuations will therefore clearly result in large variation of source luminosity. Unfortunately, in the absence of secular changes in the true averaged integral flux in the hard X-ray energy band during the entire turn-on cycle, it is difficult to co-relate the magnitude of fluctuations in the accretion rate, however, the resulting chaotic phase of the source during the observation epoch is quite evident.

4.2 Compton tail

It is clear from the above discussion that even though Her X-1 exhibited normal pulsed behaviour, the accretion rate was highly variable. A large pulsed flux clearly leads to enhanced emission of X-ray photons near to the magnetic poles thereby leading to comptonization of the emergent flux as observed in the present data. It is seen from Fig. 1, that there is clear indication of steep rise at the lowest energies. If we ignore the high energy data points above 100 keV, a much steeper power law can be equally well fitted to the present data similar to the earlier observations. The higher sensitivity of the present instrument has provided a significant data above 100 keV, thereby indicating a completely different picture of the source. The observation of flat spectrum at low intensity level demonstrates the bimodal behaviour of this source similar to the low mass X-ray binaries. A possible excess above 100 keV due to a Compton tail is also seen in the data of Dal Fiume et al. (1998).

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The presence of high energy Compton tail in the hard X-ray spectrum of the source is also consistent with the standard model in which the accreting material forms a funnel geometry on the polar caps. The X-ray emitting layer of the hot plasma is situated at the base of the funnel nearer to the polar caps, while the super high layer-temperature of ~ 3 x 10^8K is caused due to the Compton collisions in the accreted gas. The underlying X-ray spectrum is, therefore, free-free emission in nature. The emergent spectrum however will be hardened due to Compton collision of the X-ray photons in the outer layers of the cold gas in the funnel and which will thus depend on the column density and exact location of the hot spot and the direction angles for the line of sight (Shapiro and Teukolsky, 1983). During the low luminosity state of the source, the X-ray emitting boundary layers will move closer to the stellar surface due to reduced density and consequent Compton collisions in the accreting material. Such a picture will then lead to an increased Compton scattering for the escaping photons making the emergent spectrum harder in nature. A downward displacement of the emitting layers will also lead to an increase in the energy of the cyclotron resonance scattering due to the enhanced magnetic field near the poles. Such a simple picture clearly predicts that measured absorption line energy should have generic relation to the hardening of the source spectrum. In a similar scenario, Mihara (1998) has explained the change in the cyclotron energy as due to changing column height in the accretion funnel.

4.3 Absorption line features

It is seen from Fig. 1., that the observed spectrum quite convincingly indicates the presence of features in absorption at around 48 and 96 keV. The corresponding magnetic field value B is ≈ 5 x 10^{12} G (non-relativistic derivation). An equivalent width of ~ 5 keV for the absorption lines is quite consistent with the earlier observations. In large probability, the non-detection of X-ray flux at higher energy above 80 keV in earlier experiments have lead the authors to fit the emission feature in their respective data. A comparison of the present result with the original observations of Trumper et al. (1978) show that the flux dips at the two line features are comparable except for the slight change in the line energies.

It is generally believed, that whether the cyclotron resonance scattering will lead to an absorption or an emission feature may depend on the density and temperature distribution in the X-ray emitting plasma and its location with respect to the polar cap. However, in a detailed analytical analysis of the effects due to anisotropy and comptonization during the radiative transfer in a strongly magnetized plasma, Nagel (1981a, 1981b) clearly states that the cyclotron features in Her X-1 will be seen in absorption. This conclusion is consistent with the present observations.

Within the errors of statistical uncertainties of the two experiments, the line energy measured during the present observation compares with the recent measurements by Dal Fiume et al. (1998), who report a centroid value of 42.1 keV and a FWHM of 14.7 keV. However, a comparison with the data of Gruber et al. (1998), who report a mean value of 38.9 keV for the centroid energy and a σ value of 7.5 keV, indicates a possible variability in the line energy. A variation in line energy has been reported earlier from the HEAO A-1 observations (Gruber et al. 1980). Among the other observations, the absorption line fit for the primary cyclotron feature in the data of Tueller et al. (1984) is at 35 keV, while Coe et al. (1977) reported a zero flux at around 53 keV. Similarly, the corresponding absorption edges in the data of Matteson et al. (1978) and Manchanda et al. (1980) are around 55 keV and 48 keV respectively.

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From a recent analysis of 4 data sets taken from RXTE observations Gruber et al. (1998) have claimed the stability of the cyclotron line feature at 38.9 keV. All these observations are made at $\phi_{35} < 0.1$, near to the start of the 11 day on period in the corresponding 35^d cycle. However, the majority of the earlier observations were taken by balloon-borne instruments and were logistically constrained to the later part of the respective On-cycle i.e. $\phi_{35} \sim 0.2$. Only the observation of Tueller et al. (1984), corresponds $\phi_{35} \sim 0.05$ and the energy for the absorption line was measured to be 35 keV. The BeppoSAX data of Dal Fiume et al. (1998), corresponds to $\phi_{35} \sim 0.1$ and the centroid energy is found to be 42.1 keV. Original data reported by Trumper et al. (1976) corresponded to $\phi_{35} \sim 0.18$ and the reported emission feature was at 56 keV. The 35 day phase for the present observation is ~ 0.21 and the measured energy for the primary cyclotron line feature is 48 keV. It is thus clear that there is an apparent correlation between the centroid energy of the absorption line and the 35^d cyclic phase and the claims of stability of the line energy is not supported by the entirety of the data.

Apart from the fact that the visibility of the absorption line due to second harmonic is dependent on the existence of high energy flux from the source, all the previous measurements taken together also suggest that the energy of the absorption edges caused by the resonant scattering may be related to the hardness ratio of the source spectrum. Such an inference

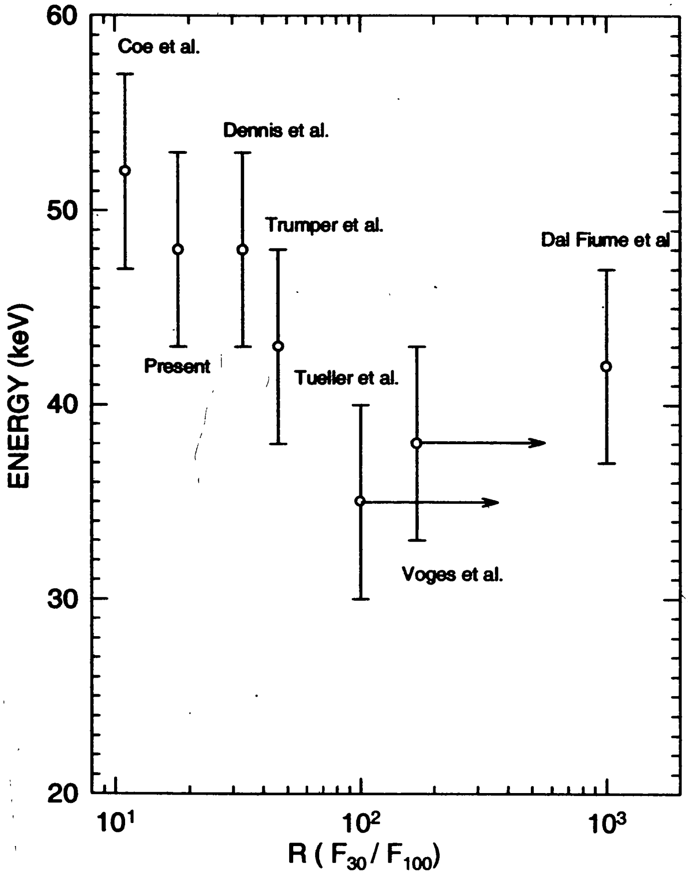

Figure 5. Absorption line energy vs. softness index.

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follows naturally from the standard model in which any variation in the physical location of the emitting region will manifest in the shape of the source spectrum and the magnitude of line energy due to varying magnetic field. We have re-analyzed the available data to test this hypothesis and the results are shown in Figure 5. In order to determine the spectral hardness, the *softness index* was defined as ratio of F_{30} / F_{100}. This choice is contrary to the normal definition of the hardness ratio computed by taking the flux ratio in two energy bands and is necessitated due to the fact that in some observations, the line emission dominates the observed flux at energies beyond 50 keV and variability of this feature makes it difficult to select unique energy band. The choice of flux value at 30 keV is due to the fact that majority of the measurements are made in balloon-borne observations and the systematic corrections are negligible at ~ 30 keV. An additional difficulty in this analysis arises due to the fact that some of the published spectra are pulse-off pulse or pulse-off source. Since both the pulse profile and the pulsed energy spectrum can vary with the pulse emission geometry i.e. pencil or fan beam; the present analysis is only indicative in nature. The line energy for the absorption feature in different data was obtained through visual analysis (where not published) and a fixed line width of ± 5 keV assumed for the present analysis. Figure 5, does indicate a positive correlation between hardening of the source spectrum and the energy of the observed absorption feature.

5. Summary

The present results clearly demonstrate the existence of cyclotron absorption features both at the primary energy and the second harmonic. The data provides a clear evidence that on occasions the source spectrum may extend up to 160 keV and even beyond due to a strong Compton tail and which in fact made the observation of second harmonic possible. Analysis of the pulse features and the archival data from CGRO suggests that Her X-1 was in an unusual chaotic phase during the epoch of our observation and which may have caused the emission of high energy X-rays above 80 keV. We have also discussed that there appears to be dependence of the line energy on the 35^d cyclic phase and within the standard model geometry, the line energy may even be correlated to the spectral hardness.

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