EXOSAT observations of Z sources
Kuulkers, E.

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GX 340+0 with EXOSAT: Its spectral and correlated timing behaviour

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To be submitted (1995)

Abstract

We report on three observations of GX 340+0 done with EXOSAT during 1985 and 1986. In two observations the source was in the horizontal branch and the upper normal branch, while in the third observation it was in the normal and flaring branches.

We found that the horizontal branch had different orientations and positions in the colour-colour diagram in the two horizontal branch observations. The different positions in the colour-colour diagram are related to long term variations in the position of the Z pattern, similar to Cyg X–2 and GX 5–1. In one of the observations, the horizontal branch was vertically oriented, comparable to GX 17+2 and Sco X–1, while in the other it was more diagonal, comparable to Cyg X–2 and GX 5–1. In the latter horizontal branch observation we found evidence for the presence of a harmonic of the horizontal branch quasi-periodic oscillations, which was not reported before.

We discuss the above described behaviour of GX 340+0 in the framework of viewing geometry. As a consequence of this study we suggest that GX 340+0 is viewed at an inclination intermediate between the high-inclination systems GX 5–1 and Cyg X–2 on the one hand, and the low-inclination systems GX 17+2, Sco X–1 and GX 349+2 on the other.

7.1 Introduction

GX 340+0 is a bright LMXB (see e.g. Van Paradijs 1995b) which belongs to the class of Z sources (Hasinger & van der Klis 1989). Z sources show roughly Z shaped tracks in their so-called colour-colour diagram (CD; colour is defined as the ratio of count rates in two X-ray energy bands). The three branches of the Z have been named (for historical reasons, see e.g. van der Klis 1989a) horizontal branch (HB; upper limb of the Z), normal branch (NB; middle limb) and flaring branch (FB; lower limb). The so-called hard apex connects the HB with the NB, while the so-called soft apex connects the NB with the FB. The Z sources move along these branches, and never jump from branch to branch. The movement along the branches has been
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suggested to be governed by the mass accretion rate, which increases from the HB, through the NB, into the FB (Hasinger et al. 1990). In each branch Z sources show characteristic rapid time variability, with several power spectral noise components and quasi-periodic oscillations (see Hasinger & van der Klis 1989).

The group of six Z sources (Sco X-1, Cyg X-2, GX 5-1, GX 17+2, GX 349+2 and GX 340+0) on the one hand show very similar behaviour (i.e. occurrence of three branches and correlated timing behaviour), but on the other hand also show properties which divides the group in two (Hasinger & van der Klis 1989, Penninx et al. 1991, Kuulkers et al. 1994a [Chapter 3]). Cyg X-2 and GX 5-1 show secular variations in the position of the Z pattern in the CD and in the so-called hardness-intensity diagram (HID; colour vs. X-ray intensity), while in Sco X-1, GX 17+2 and probably GX 349+2 no evidence for Z pattern variability is found (see Kuulkers et al. 1994a [Chapter 3], and references therein). Moreover, Cyg X-2, GX 5-1 and GX 340+0 show intensity dips when the sources are in the FB, while in Sco X-1, GX 17+2 and GX 349+2 the intensity increases (i.e. really flares) along the FB (see Kuulkers et al. 1994a [Chapter 3], and references therein). Several timing properties are also different in the two sub-groups, such as non-peaked low-frequency noise (LFN) in the former group, and peaked LFN in the latter group. Also, in the latter group one sees clear QPO in the FB (FBO), while in the former group no FBO has been reported to date (see Hasinger & van der Klis 1989). This division of the Z sources is thought to be a result of differences in the viewing angle under which we look at the sources (Hasinger et al. 1989, Hasinger & van der Klis 1989, Hasinger et al. 1990, Kuulkers et al. 1994a [Chapter 3]).

This paper describes all observations of GX 340+0 performed with EXOSAT. We examined these observations for the first time in a detailed way, using a homogenous analysis, as was similarly done for GX 5-1 (Kuulkers et al. 1994a, Chapter 3), Sco X-1 (Dieters & van der Klis 1995) and GX 17+2 (Kuulkers et al. 1995a, Chapter 8). Parts of these data have already been reported elsewhere (Van Paradijs et al. 1988a, Schulz et al. 1989, Hasinger & van der Klis 1989).

We report here new features in GX 340+0, and derive conclusions about its viewing geometry.

7.2 Observations and analysis

GX 340+0 was observed three times with the Medium Energy (ME) experiment (Turner et al. 1981, White & Peacock 1988) onboard EXOSAT (see Table 7.1). In this paper we present the argon (2-20keV) related data obtained with the ME. Simultaneous energy resolved data (HER-mode) to study the spectral behaviour and high time resolved data (HTR-mode) to study the rapid time variability were obtained. Either the whole array of eight detectors was pointed towards the source, or only half of the array, where the other half was used to monitor the background. In the latter configuration so-called array swaps were performed, i.e. the two array halves were interchanged to alternately observe the source and the background.

For the study of the spectral behaviour we use CDs and HIDs (see e.g. Hasinger & van der Klis 1989). For these diagrams one generally divides the X-ray spectrum into three or four bands. The soft colour is then defined as the ratio of the count rates in the two lowest (=soft) energy bands, whereas the hard colour is defined as the ratio of the count rates in the two highest (=hard) energy bands. In the cases of Sco X-1 (Dieters & van der Klis 1995), GX 5-1

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1All Z sources show all three branches, except GX 349+2, which has never been reported to show HB behaviour, see e.g. Hasinger & van der Klis (1989).

2QPO during a dip have been found when Cyg X-2 was in the upper FB (Kuulkers & van der Klis 1995a, Chapter 5). This QPO is probably related to a viewing geometry effect, and not the same as the usual FBO.

3On 1985 day 232 one of the detectors broke down, leaving seven operational detectors in the whole array and three and four in the two half arrays.
Table 7.1: EXOSAT ME argon observation log of GX340+0

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>Day*</th>
<th>Start (UT) hr:min</th>
<th>End (UT) hr:min</th>
<th>Obs.† Mode</th>
<th>Time Resolution</th>
<th>Spectral State</th>
<th>Config.‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>Mar 29/30</td>
<td>088/089</td>
<td>16:35</td>
<td>05:29</td>
<td>E4/T3</td>
<td>10s/31ms</td>
<td>HB/NB</td>
<td>H1/H2</td>
</tr>
<tr>
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<td>Mar 31/Apr 1</td>
<td>090/091</td>
<td>18:38</td>
<td>18:08</td>
<td>E5/T5</td>
<td>0.5s/2ms</td>
<td>HB/NB</td>
<td>H1/H2</td>
</tr>
<tr>
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<td>Apr 6/7</td>
<td>096/097</td>
<td>20:04</td>
<td>07:21</td>
<td>E5/T5</td>
<td>0.6s/1ms</td>
<td>NB/FB</td>
<td>WA</td>
</tr>
</tbody>
</table>

*Jan 1 = day 1.
†E (High Energy Resolution, or HER) and T (High Time Resolution or HTR) observation mode.
‡From 16:35 to 19:59 and 22:40 to 01:21 H1 on source, rest H2 on source.
§From 18:38 to 23:24 and 07:08 to 14:27 H2 on source on source.

(Kuulkers et al. 1994a, Chapter 3), GX17+2 (Kuulkers et al. 1995b, Chapter 8) and Cyg X-2 (Kuulkers et al. 1995c, Chapter 4) the HER7 data (high time resolution data in four energy bands) constrained the choice of the energy boundaries for the diagrams. For GX340+0 we were free in our choice of the energy boundaries. We therefore tried several energy boundaries, and found that using the same energy boundaries as used for GX17+2 (see Kuulkers et al. 1995b, Chapter 8) gave a good representation of the behaviour of GX340+0: these bands were 1.2–4.7 keV, 4.7–6.6 keV and 6.6–19.9 keV. Soft colour is the count rate ratio of the second to the first band, the hard colour as the count rate ratio of the third to the second band. The intensity used in this paper is the count rate in the 1.2 to 19.9 keV band, corrected for dead time, background and collimator response as determined by Kuulkers et al. (1994a, see Chapter 1).

Two observations were made at the end of the lifetime of EXOSAT in 1986 (day 090/091 and day 096/097). During this time (from day 086 to day 99) the pointing was only moderately stable within (~5 arcmin; White 1986). Due to the corresponding collimator response changes this resulted in uncertainties in the intensity which could not be corrected for. Inspecting the star tracker attitude control data of both observations we found that the collimator response changed between 90 and 100%.

### 7.3 Results

#### 7.3.1 Light curves

In Figs. 7.1a-c we show the light curves of the three observation periods at a 5s time resolution (compare Figs. 7.1a and b with figure 1 of Van Paradijs et al. 1988a, where these light curves are given at a much lower time resolution, giving less detailed information). The different branches in which the source moved during the the observations are indicated. In Fig. 7.1a we see that the variations on a time scale of ~1000 s are small, which is typical for a source near the HB/NB vertex (see e.g. Kuulkers et al. 1994a [Chapter 3], 1995c [Chapter 4]). Occasional decreases in intensity correspond to transitions from the NB into the HB. In Fig. 7.1b we see that the source displays different behaviour as compared to Fig. 7.1a. Now the source intensity changes more rapidly on time scales of ~100 s, which is typical for NB and FB behaviour (see e.g. Kuulkers et al. 1994a [Chapter 3], 1995c [Chapter 4]). Flaring behaviour is clearly seen in the beginning of the observation and near the end of the observation. The effect of changing collimator response during the 1986 observations (see Section 7.7.2) can be seen in Fig. 7.1c, where the various sharp drops in intensity correspond to jitter in the satellite pointing. However, one can still see that the overall intensity variations are comparable to that in Fig. 7.1a, corresponding also to HB/NB behaviour.
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Figure 7.1. EXOSAT ME light curves of all three observation periods (a 1985 day 088/089, b 1986 day 096/097, and c 1986 day 090/091) of GX 340+0 at a time resolution of 5s. Intensity is the dead-time, background and (mean) collimator response (see text) corrected count rate in the 1.2-19.9keV range. Indicated are the branches in which the source was during the observations. The short decreases in intensity (dips) in the 1986 day 090/091 data (c) are due to jitter in the satellite pointing (see text). Start times for the different observation periods can be found in Table 7.1.

7.3.2 Broad band spectral behaviour

The appearance of the different branches are evident in plots of the CD and HID of GX 340+0 (Figs. 7.2a–c). New is the observation of the little FB in EXOSAT data. In Figs. 7.3a–c we show the CD and HID of the 1986 day 096/097 again, with the data points connected to more clearly demonstrate the presence of a separate branch, i.e. the FB, connecting to the NB only via the soft apex. The corresponding power spectral data indicate an increase in the VLFN during the FB stage. The increase in VLFN is due to the flaring visible during this period (see Section 7.3.1).
7.3 Results

Figure 7.2. (a) EXOSAT X-ray colour-colour diagram and (b, c) hardness-intensity diagrams of GX 340+0. Soft colour is defined as the ratio of the count rate in the 1.2–4.7 keV and the 4.7–6.6 keV bands, hard colour as the ratio of the counts in the 6.6–19.9 keV and the 4.7–6.6 keV bands. The intensity (corrected for background, dead-time and collimator response) is defined as the count rate in the 1.2–19.9 keV band. Different symbols refer to different observation periods, which are given in the upper left part of (a). Each point represents a 200 s average. Typical error bars are given in each frame. Indicated are the locations of the different branches.

Another feature which is new in the EXOSAT data, is the presence of two HB/NB tracks (1985 day 088/089 and 1986 day 090/091) which do not overlap each other (especially clear in the CD). Comparing Figs. 7.2a–c, we see that the differences in the soft colour are ~6%. In hard colour and intensity the differences are consistent with changes of less than ~3%. One way to verify if the shift is real and not a detector effect (due to e.g. changes in the detector gain during the lifetime of EXOSAT, see Haberl 1992), is to inspect the colour and intensity values of data of Crab (Kuulkers et al. 1994a [Chapter 3], see also Kuulkers et al. 1995c [Chapter 4]). As Crab is supposed to be a steady X-ray source (see Kuulkers et al. 1994a [Chapter 3] and references therein), one expects to see no changes in its colour and intensity over a period of time. Any changes in the observed Crab values may then be attributed to changes in the detector efficiency (Kuulkers et al. 1994a, Chapter 3).

In Figs. 7.4a–c we plot the observed average soft colour, hard colour and intensity of Crab during the lifetime of EXOSAT. From these figures we infer that the overall changes are ~3%,
\( \sim 2\% \), and \( \sim 5\% \) for the soft colour, hard colour and intensity, respectively. If we only take into account Crab observations which were done close in time to the the observations of GX 340+0 (indicated by o in Figs. 7.4a–c), we find that detector effects are smaller: less than \( \sim 1\% \) in the soft and hard colour, and about \( 2\% \) in intensity. We conclude that the observed shift in the HB/NB tracks in the soft colour is intrinsic to the source.

Since the X-ray spectrum of LMXBs such as GX 340+0 is somewhat different from that of Crab it may be that the magnitude of the detector effects is different for the two sources. One way to estimate this difference is by using the fact that individual detectors have different responses (see Kuulkin et al. 1994a, Chapter 3). Only the 1985 day 088/089 HER4-mode observations of GX 340+0 provided us with information on the count rates per detector. For Crab we use the observations nearest in time to the GX 340+0 observations, i.e. 1985 day 036. We find that the differences in Crab soft colour and and intensity due to the different detector efficiencies are a factor of \( \sim 2 \) larger than for GX 340+0. No significant differences in the effect of efficiency between Crab and GX 340+0 in the hard colour are found. Assuming that the effect of the different detector efficiencies is similar during the whole EXOSAT era, we estimate that the detector effects may have contributed in the CD and HID up to \( \sim 0.5\% \) in the soft colour, and \( \sim 1\% \) in the hard colour and intensity. This strengthens our conclusion that the differences in the position of the HB/NB tracks in the soft colour are due to the source itself, and not due to detector effects.

Another feature in the CD is that the orientation of the HB is different in the two HB/NB observations. The presence of an HB in the 1985 day 088/089 and 1986 day 090/091 observations is clear from the HID in Figs. 7.2b and c. In the CD (Fig. 7.2a) the HB of 1985 day 088/089 is more vertically oriented and that of 1986 day 090/091 observations more diagonally oriented (the HB in this diagram is located at hard colour values larger than \( \sim 0.64 \)). Changes in the energy bands may also change the orientation of the HB (compare the CD of 1986 day 090/091 in Fig. 7.2a with figures 3c and 1a of Schuls et al. 1989 and Hasinger & van der Klis 1989, respectively). However, since we have used the same energy boundaries for both observation periods, we infer this effect to be intrinsic to GX 340+0 itself.
7.3 Results

Figure 7.3. (a) Colour-colour diagram and (b, c) hardness-intensity diagrams of GX 340+0 of the 1986 day 096/097 data. The colours and intensity are as defined in Fig. 7.2. The points represent 200 s averages and are connected to show more clearly (a and c) the presence of a separate limb, i.e. the FB, connected to the lower NB.

7.3.3 Rapid time variability

7.3.3.1 Position in the Z

We investigated the power spectral behaviour as a function of position in the Z, i.e. $S_Z$, in a similar way as was already performed for GX 5–1 (Kuulkers et al. 1994a, Chapter 3), Sco X–1 (Dieters & van der Klis 1995) and GX 17+2 (Kuulkers et al. 1995b, Chapter 8). $S_Z$ is a one-dimensional parameter which is thought to represent the mass accretion rate, $\dot{M}$ (see Hasinger et al. 1990, Dieters & van der Klis 1995). Spline fits were made through the Z tracks, and the distance (in the colour-colour plane) along the splines towards one of the apexes, i.e. the HB/NB or the NB/FB apex, were determined. The scale was fixed by setting the average HB/NB apex to 1 and the NB/FB apex to 2. In this way our $S_Z$ values range from $\sim$0.84 in the HB to $\sim$2.2 in the FB.

7.3.3.2 Power spectral components

The fast timing behaviour of the source was investigated using power spectra as determined with the FFT algorithm. The power spectra were arranged according to different $S_Z$ ranges and then averaged. We performed fits to the logarithmically rebinned Leahy normalised power spectra. A combination of different functions, corresponding to the different power spectral components normally present in Z-sources (see e.g. Hasinger & van der Klis 1989), were used to describe the power spectra. These components are the very-low-frequency noise (VLFN), low-frequency noise (LFN), high-frequency noise (HFN) and the quasi-periodic oscillations (QPO). The fit-functions for the different components and the frequency range used to estimate their strength are the same as described by Kuulkers et al. (1994a, Chapter 3). The Poisson level was determined from the relation between observed count rate and Poisson level using the dead time as determined by Berger & van der Klis (1994) for the HTR data. In Tables 7.2a, 7.2b and 7.3 we give the results of our fits.

In the next paragraphs we describe the various components which were present in the power spectral data.
7.3.3.2.1 Very-low-frequency noise (VLFN)

Since the satellite pointing was changing during the 1986 observations (see Sect. 7.2) the VLFN is influenced by this effect (see also Kuulkers et al. 1995b, Chapter 8). Only the 1985 day 088/089 do not suffer from the changing collimator response. These data indicate that near the HB/NB vertex the VLFN rms is near 1%, with a possible minimum just at the vertex, ~0.7%. From the trend in the 1986 day 090/091 data we infer that the VLFN rms indeed decreases from the left HB to the NB vertex. The trend in the 1986 day 096/097 data suggests that the rms increases from the middle NB into the FB, as expected from the increasing variability seen in the light curve of Fig. 7.1b. It can be inferred from the HB/NB data that the fluctuating collimator response has an effect of about 3% to the VLFN. The power law indices are also strongly influenced by the changing response in the 1986 day 090/091 and 096/097 data. The 1985 day 088/089 data indicate a (source) VLFN power law index of between 1.4 and 2.

7.3.3.2.2 Low-frequency noise (LFN) and high-frequency noise (HFN)

The LFN in GX 340+0 is strongest in the left HB (~6%) and decreases towards the NB (Fig. 7.5a). In the upper NB it is about 3%. The LFN power law index (Fig. 7.5b) shows no clear dependence on $S_2$; it has values between 0.1 and 0.6. The LFN cut-off is not very well determined in various power spectra. In the 1985 day 088/089 observations this is due to the low Nyquist frequency (16 Hz).

The HFN could only be determined in the power spectra with high enough Nyquist frequencies. Also, when LFN was present, it was not possible to fit the HFN due to interference with the LFN component (see also Kuulkers et al. 1994a, Chapter 3). This left us with reliable HFN...
### Table 7.2a: Results of power spectral fits of 512s FFTs\(^a\)

<table>
<thead>
<tr>
<th>Obs. period</th>
<th>(S_z)</th>
<th>(\sigma)</th>
<th>rms [%]</th>
<th>(\Delta f)</th>
<th>(\sigma_V)</th>
<th>rms [%]</th>
<th>(\Delta f)</th>
<th>(\sigma_L)</th>
<th>rms [%]</th>
<th>(\Delta f)</th>
<th>QPO</th>
<th>(\nu)</th>
<th>(\Delta \nu)</th>
<th>(\nu)</th>
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<th>(\chi^2_{red})</th>
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<td>0.929</td>
<td>0.052</td>
<td>9.5</td>
<td>±0.51</td>
<td>8.5</td>
<td>±1.8</td>
<td>0.2</td>
<td>±0.32</td>
<td>15</td>
<td>±0.35</td>
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<td>1.0</td>
<td>9</td>
<td>0</td>
<td>0.9</td>
<td>31</td>
<td></td>
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<tr>
<td>1985 day 089</td>
<td>0.886</td>
<td>0.062</td>
<td>9.5</td>
<td>±0.99</td>
<td>8.5</td>
<td>±0.36</td>
<td>0.2</td>
<td>±0.29</td>
<td>15</td>
<td>±0.32</td>
<td>15</td>
<td>0</td>
<td>0.9</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985 day 089</td>
<td>1.007</td>
<td>0.041</td>
<td>1.04</td>
<td>±0.71</td>
<td>8.5</td>
<td>±0.72</td>
<td>0.2</td>
<td>±0.71</td>
<td>15</td>
<td>±0.71</td>
<td>15</td>
<td>0</td>
<td>0.9</td>
<td>31</td>
<td></td>
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\(^a\)Whenever a component was not present in the average power spectrum or \(\Delta \chi^2 \leq 1\) it is indicated by ". . .".

### Table 7.2b: Results of power spectral fits of 512s FFTs\(^a\)

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<th>(S_z)</th>
<th>(\sigma)</th>
<th>rms [%]</th>
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<th>(\nu)</th>
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<td>1985 day 089</td>
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<td>1985 day 089</td>
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<td>0.2</td>
<td>±0.71</td>
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</table>

\(^a\)Whenever a component was not present in the average power spectrum it is indicated by ". . .".

\(^b\)This is determined from the standard deviation in the mean of the \(S_z\) points in a chosen segment.

\(^c\)All errors are determined from an error scan through the \(\chi^2\) space using \(\Delta \chi^2 = 1\).

\(^d\)Harmonic also present, see Table 7.3b.

\(^e\)HHF also present, see Table 7.3b.
Table 7.3: Results of power spectral fits of 8/16s FFTs

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<th>rms</th>
<th>err</th>
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<th>err</th>
<th>$\nu_0$ (Hz)</th>
<th>err</th>
<th>rms</th>
<th>err</th>
<th>$\Delta \nu$ (Hz)</th>
<th>err</th>
<th>$\nu$</th>
<th>err</th>
<th>$\chi^2_{red}$</th>
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aWhenever a component was not present in the average power spectrum it is indicated by - - -.

bHBO or NBO.

cThis is determined from the standard deviation in the mean of the $S_2$ points in a chosen segment.

dAll errors are determined from an error seen through the $\chi^2$ space using $\Delta \chi^2 = 1$.

eParameter fixed.
7.3 Results

7.3.3.2.3 Quasi-periodic oscillations (QPO)

Quasi-periodic oscillations were detected in the HB (HBO) and the NB (NBO). In our observations during 1986 day 090/091 the HBO increased in frequency from ~35 in the left HB to ~45 Hz in the right HB (Fig. 7.5d). From the right HB to the upper NB no significant increase was found in the frequency; it stayed at a constant level at 45±3 Hz. The full width at half maximum (FWHM) increases from about 4 Hz in the left HB to about 20 Hz near the HB/NB vertex (Fig. 7.5f). No clear trend could be detected in the HBO rms (see Fig. 7.5e); it had values between ~3 and ~5%.

In the 512 s power spectra we found evidence for the presence of a second harmonic of the
HBO at $S_Z$ values below $\sim$0.9 (see Fig. 7.6). The frequency of the harmonic was consistent with being twice the HBO centroid frequency, and it had an rms of between 2 and 3%. Its FWHM was around 15 Hz. The ratio of the rms of the harmonic to the HBO was between 0.5 and 0.7 (Table 7.2b). The ratio of the FWHM of the harmonic to the HBO was less well defined.

In the NB QPO were detected between $S_Z$ values $\sim$1.2 and $\sim$1.7, with a strength between 2 and 3% rms. The NBO was seen at frequencies between 5 and 7 Hz, while its FWHM was between 2 and 10 Hz. No clear dependence on position in the Z could be found.
7.4 Discussion

7.4.1 Secular motion of the Z pattern

We have found for the first time that the CD of GX 340+0 showed two HB/NB tracks which were shifted (primarily in the soft colour) with respect to each other. This confirms a prediction made by Kuulkers et al. (1994a, Chapter 3) on the basis of a comparison between the six Z sources. GX 340+0 shares properties with Cyg X-2 and GX 5-1, which are different from Sco X-1, GX 17+2 and GX 349+2 (see Hasinger & van der Klis 1989, Kuulkers et al. 1994a, Chapter 3). The former group shows intensity decreases when the sources are in the FB (see Kuulkers et al. 1994a [Chapter 3], 1995c [Chapter 4], and references therein), while the latter group show intensity increases (i.e. flares) in the FB (see e.g. Schulz et al. 1989). Moreover, the latter group was shown to exhibit no significant changes in the Z pattern from observation to observation (see Dieters & van der Klis 1995, Kuulkers et al. 1995b [Chapter 8]), while Cyg X-2 (Hasinger 1987, Hasinger et al. 1990, Kuulkers et al. 1995c [Chapter 4]) and GX 5-1 (Kuulkers et al. 1994a, Chapter 3) show clear changes in the position of the Z from observation to observation. Also part of the power spectral behaviour is different between the two groups (see Hasinger & van der Klis 1989). This bimodal behaviour pattern is attributed to differences in the inclination at which we view the sources (Hasinger & van der Klis 1989, Hasinger et al. 1989, Kuulkers et al. 1994a [Chapter 3]). The sources Cyg X-2, GX 5-1 and GX 340+0 are thought to be viewed at a high inclination, while the other sources are thought to be viewed at lower inclinations. The only direct evidence for the inclination of Z sources comes from the optical observations of Sco X-1 (15-40°, Crampton et al. 1976) and Cyg X-2 (65-75°, Cowley et al. 1979).

The presence of a HB in the two observations is established using the HID. A closer inspection of the two HB/NB tracks shows that in the CD the shape of these tracks was different. In one observation the HB was more diagonally oriented in the CD, while in the other observation the HB was almost vertical (Section 7.3.2). Vertically oriented HBs were previously only observed in GX 17+2 and Sco X-1 and they have never been seen in GX 5-1 and Cyg X-2 (see Hasinger & van der Klis 1989). For this reason the HB orientation has been used as one of the signatures of the division into two groups. GX 340+0 appears to alternately show the signature of each group.

Figure 7.6. Average power spectrum corresponding to $S_2 \sim 0.88$ (i.e. left HB). The corresponding fit is shown for clarity. The HBO can be seen near $\sim 37$ Hz. A harmonic of the HBO is visible at exactly twice the HBO frequency, i.e. 74 Hz.
During a third observation period (1986 day 096/097) we found typical FB behaviour, which was not reported before in the EXOSAT data. In the energy bands used by previous authors (Van Paradijs et al. 1988a, Schulz et al. 1989, Hasinger & van der Klis 1989) this FB overlapped with the NB, and thus remained undetected. As shown by Penninx et al. (1991) the use of different energy bands in Ginga data of GX 340+0 leads to differently oriented FBs (and, too a smaller extent, HBs). The presence of the FB is established by the increase of the VLFN, which is always strongest in this branch (Hasinger & van der Klis 1989). The light curve of this observation period shows clear flares in intensity, reminiscent to the flares observed in Sco X–1, GX 17+2 and GX 349+2. The flares in GX 340+0 are, however, of relatively shorter duration (~200 s). No clear dips are detected in the FB. This is somewhat different from the behaviour reported by Penninx et al. (1991). Using Ginga data they established the presence of a FB in GX 340+0 (an indication for a FB was found earlier by Garcia [1989]). In their observations the intensity first increased when coming into the FB, but then dipped half way up the FB. This difference might be due to the differences in time resolution and the energy bands used for the CD and HIDs in our EXOSAT data and the Ginga data of Penninx et al. (1991). Since Ginga has a larger collecting area (by a factor of ~2.5) than EXOSAT, it has a higher sensitivity. Penninx et al. (1991) were therefore able to use a short time resolution (32 s) for their colour/intensity points, and could study the behaviour at high energies (14.0–18.6 keV) in more detail. In EXOSAT we used a time resolution of 200 s, while at high energies (>12 keV) background effects becomes important in EXOSAT. If the dips in intensity as seen in the Ginga observations are of short duration (e.g. <100 s) and occurred primarily in the highest energies where background becomes dominant, we may have missed these dips in our FB observation. The presence or not of dips in the FB is also one of the signatures of the division of the two groups (see above).

Since the mass accretion rate is near Eddington in the Z sources radiation pressure may push matter out of the orbital plane and create an inner disk torus (e.g. Lamb 1989). It was suggested by Kuulkers & van der Klis (1995a, Chapter 5), that viewing geometry determines the shape of the FB and the presence of QPO in the lower NB and lower FB. As a source moves into the FB its intensity increases, and the torus grows. When we view a Z source at higher inclinations (e.g. GX 340+0) at some point on the FB the torus may enter the line of sight and start to obscure parts of the inner disk regions. As a result the intensity drops. At even higher inclinations the intensity starts to decrease earlier in the FB (e.g. Cyg X–2). It was therefore proposed (Kuulkers & van der Klis 1995a, Chapter 5) that GX 340+0 is viewed at intermediate inclinations (but still high enough to show detectable secular variations in the position of the Z track) between GX 5–1 and Cyg X–2 on the one hand, and Sco X–1, GX 349+2 and GX 17+2 on the other. Our observation of different HB shapes in the CD, i.e. a diagonally oriented HB reminiscent to the shape of the HB normally seen in high inclination sources and a vertically oriented HB similar to that normally seen in the low inclination sources, supports this hypothesis.

### 7.4.2 Fast timing properties

We studied the fast timing behaviour of GX 340+0 as a function of position in the Z, i.e. $S_Z$, a one-dimensional parameter which is a measure of $\dot{M}$, the mass accretion rate (Hasinger et al. 1990, Dieters & van der Klis 1995). We confirm the fast timing properties reported earlier in EXOSAT data by Van Paradijs et al. (1988a) and Hasinger & van der Klis (1989) and in Ginga data by Penninx et al. (1991).

NB QPO with centroid frequencies of ~6 Hz were detected between $S_Z$ values ~1.2 and ~1.7. No clear dependence on $\dot{M}$ was found.

HBO QPO (HBO) were detected in the HB and upper NB. We found HBO frequencies between 35 and 50 Hz, i.e. in accordance with the frequency range reported earlier by Penninx
et al. (1991, ~32–50 Hz). The frequency increases from the left HB to the right HB. When the source moves into the NB, the HBO frequency does not change significantly from its value in the right HB. This behaviour, interpreted as due to a small M range on the NB (e.g. Lamb 1989), was previously seen in Cyg X–2 (Hasinger et al. 1990) and GX 5–1 (Lewin et al. 1992, Kuulkers et al. 1994a [Chapter 3]), but not in GX 340+0.

We report here for the first time the detection of a harmonic in the HBO of GX 340+0, at the lowest $S_z$ values found in our EXOSAT observations. The harmonic (which had a frequency twice the HBO frequency, i.e. 70–78 Hz) had an rms strength of around 2.5%. The FWHM was 15±10 Hz. The reason Penninx et al. (1991) could not find a harmonic probably is that their Ginga MPC3 data had Nyquist frequencies of 64 Hz, while their PC data (Nyquist frequencies of 256 Hz) only covered the right portion of the HB (i.e. at the highest $S_z$ values in the HB). Harmonics of the HBO were previously found in GX 5–1 (e.g. Lewin et al. 1992, Kuulkers et al. 1994a [Chapter 3] and GX 17+2 (e.g. Penninx et al. 1990, Kuulkers et al. 1995b [Chapter 8]). The harmonics in GX 340+0, GX 5–1 and GX 17+2 all occurred when the HBO frequency was lower than ~40 Hz (i.e. it is always present when GX 17+2 displays HBO, which has centroid frequencies between 18–30 Hz). The HBO and its harmonic become strongest at the lowest $S_z$ values. This behaviour can be explained in terms of magnetospheric accretion. When at lower $S_z$ M becomes lower (e.g. Hasinger et al. 1990) the magnetospheric radius increases, which reduces the polar cap angle. The modulation of the luminosity of the polar caps (which presents itself as a HBO) then gets a smaller duty cycle, which increases the strength of the harmonic content of the HBO.

The three noise components normally present in Z-sources were detected in our observations, i.e. VLFN, LFN and HFN. Only one of the observations (1985 day 088/089) was free of the contaminating effect of collimator response variations. There the VLFN strength is in accordance with previous observations (~1% from 0.001–1 Hz) around the HB/NB vertex (see also Hasinger & van der Klis 1989). It shows some evidence for a minimum near the HB/NB vertex, which is also present in the Ginga data of Penninx et al. (1991), as well as in the other Z sources (see Kuulkers et al. 1995b [Chapter 8], and references therein). We found power law indices of 1.5±0.5, similar to Van Paradijs et al. (1988a).

LFN was only detected in the HB and upper NB, and had properties comparable to those previously seen in this source (Van Paradijs et al. 1988a, Penninx et al. 1991). The HFN could only be fitted in the NB and FB, due to contamination in the HB by LFN (see also Kuulkers et al. 1994, Chapter 3). It had rms strengths (0.01–100 Hz) of around 3%. Contributions from the fluctuating collimator response are not expected in this frequency range (see Kuulkers et al. 1995b, Chapter 8). It was recently suggested that instrumental HFN is present in EXOSAT power spectral data at levels of up to an rms of ~2.3% (Berger & van der Klis 1994, van der Klis & Kuulkers 1995). We therefore attribute our observation of HFN to the ME instrument, and not to GX 340+0 itself.