The Discovery of a State Dependent Hard Tail in the X-ray Spectrum of the Luminous Z-source GX 17+2

T. Di Salvo¹, L. Stella², N. R. Robba¹, M. van der Klis⁴, L. Burderi², G.L. Israel²,3, J. Homan⁴, S. Campana³,5, F. Frontera⁶, A.N. Parmar⁷

ABSTRACT

We report results of a BeppoSAX (0.1–200 keV) observation of the Z-type low mass X-ray binary GX 17+2. The source was on the so-called Horizontal and Normal branches. Energy spectra were selected based on the source position in the X-ray hardness-intensity diagram. The continuum could be fairly well described by the sum of a ∼ 0.6 keV blackbody, contributing ∼ 10% of the observed 0.1 – 200 keV flux, and a Comptonized component, resulting from upscattering of ∼ 1 keV seed photons by an electron cloud with temperature of ∼ 3 keV and optical depth of ∼ 10. Iron K-line and edge were also present at energies ∼ 6.7 and ∼ 8.5 keV, respectively. In the spectra of the Horizontal branch a hard tail was clearly detected at energies above ∼ 30 keV. It could be fit by a power law of photon index ∼ 2.7, contributing ∼ 8% of the source flux. This component gradually faded as the source moved towards the Normal branch, where it was no longer detectable. We discuss the possible origin of this component and the similarities with the spectra of Atoll sources and black hole X-ray binaries.


¹Dipartimento di Scienze Fisiche ed Astronomiche, Università di Palermo, Via Archirafi 36, 90123 Palermo, Italy; disalvo@gifco.fisica.unipa.it.
²Osservatorio Astronomico di Roma, Via Frascati 33, 00040 Monteporzio Catone (Roma), Italy; stella@ulysses.mporzio.astro.it.
³Affiliated with the International Center for Relativistic Astrophysics.
⁴Astronomical Institute "Anton Pannekoek," University of Amsterdam and Center for High-Energy Astrophysics, Kruislaan 403, NL 1098 SJ Amsterdam, the Netherlands.
⁵Osservatorio Astronomico di Brera, Via Bianchi 46, I-23807 Merate, Italy.
⁶Istituto Tecnologie e Studio Radiazioni Extraterrestri, CNR, Via Gobetti 101, 40129, Bologna, Italy.
⁷Astrophysics Division, Space Science Department of ESA, ESTEC, P.O. Box 299, 2200 AG Noordwijk, Netherlands.
1. Introduction

Low Mass X-ray Binaries (hereafter LMXBs) hosting an old accreting neutron star (NS) display X-ray spectra that are still relatively poorly understood. The modern classification of LMXBs relies upon the branching displayed by individual sources in the X-ray color-color diagram (Hasinger & van der Klis 1989), and comprises a Z-class (source luminosities close to the Eddington luminosity, $L_{\text{edd}}$) and an Atoll-class (usually luminosities of $\sim 0.01 - 0.1 L_{\text{edd}}$). Considerable evidence has been found that the mass accretion rate of individual Z-sources increases from the top left to the bottom right of the Z-pattern (e.g. Hasinger et al. 1990), i.e. along the so called horizontal, normal and flaring branches (hereafter HB, NB and FB, respectively). While the spectra of Atoll sources often extend up to energies of $\geq 100$ keV and present interesting analogies with the hard X-ray component of black hole candidate (BHC) binaries, the X-ray spectra of Z sources are comparatively soft and dominated by thermal-like components with exponential cutoff at energies $\leq 10$ keV. Attempts at decomposing the X-ray spectra of Z sources have employed two (or more) components, the origin of which is still debated (e.g. Mitsuda et al. 1984; White et al. 1986; 1988; Psaltis, Lamb, & Miller 1995). A tracking of the spectral variations along the Z pattern was attempted (see e.g. Hasinger et al. 1990; Hoshi & Mitsuda 1991; Schulz & Wijers 1993; Asai et al. 1994, and references therein); the results were inconclusive, since in different decompositions the spectral variations can be ascribed to different components. Moreover it is not clear whether any of the proposed components evolve with continuity from Z to Atoll sources. The timing properties of LMXBs, on the contrary, possess a clear continuity along the different branches of each source and also a remarkable similarity across Z and Atoll sources (e.g. Wijnands & van der Klis 1999; Psaltis, Belloni, & van der Klis 1999).

We report here the results of an extensive study with BeppoSAX of the Z source GX 17+2. The source usually describes a complete Z-pattern in the color-color diagram in a relatively short time (3–4 days). The parameters of the noise components as well as the frequency of the QPOs are well correlated with the position in the color-color diagram (e.g. Langmeier et al. 1990; Kuulkers et al. 1997; Wijnands et al. 1997). The source occasionally shows X-ray bursts which are often long and involve a moderate increase of the X-ray flux ($\sim 50\%$; Kahn & Grindlay 1984; Tawara et al. 1984); Sztajno et al. (1986) interpret them as type-I X-ray bursts. Studies of the source X-ray spectrum were carried out by White, Stella, & Parmar (1988), Langmeier et al. (1990), Schulz & Wijers (1993), based on EXOSAT spectra, and Hoshi & Asaoka (1993) based on Ginga spectra. In all cases the spectrum was found to steepen rapidly above energies of a few tens of keV.

2. Observations and Analysis

A pointed observation of GX 17+2 was carried out between 1999 October 4 04:52 UT and October 9 01:10 UT, with the Narrow Field Instruments, NFIs, on board BeppoSAX (Boella et al. 1997). These consist of four co-aligned instruments covering the 0.1–200 keV energy range: LECS (0.1–10 keV), two MECS (1.3–10 keV), HPGSPC (7–60 keV), and PDS (13–200 keV). The effective
exposure was 56 ks in the LECS, 193 ks in the two MECS, 160 ks in the HPGSPC, and 78 ks in the PDS. In the LECS and MECS images data were extracted from circular regions centered on GX 17+2, with radii of 8′ and 4′ respectively. Data extracted from the same detector regions during blank field observations were used for background subtraction. Background subtraction was obtained in the PDS from data accumulated during the off-source intervals, and in the HPGSPC by using spectra accumulated from Dark Earth data. All the available evidence indicates that there were no significant contaminating sources in the field of view of the HPGSPC and PDS: the off-source PDS count rates are in the expected range; the HPGSPC and PDS spectra align well with each other and with the MECS spectra; finally, evidence for a hard X-ray component in GX 17+2 was found only when the source was in a specific state (see below).

Four bursts occurred during our observation; these were excluded from the subsequent analysis. Figure 1 shows the Hardness-Intensity Diagram, HID, where the Hard Color, HC, is the ratio of the 7–10.5 keV to the 4.5–7 keV MECS count rates and the intensity is the 4.5-10.5 keV count rate. The HB and NB are clearly seen. A comparison with a longer RXTE observation, simultaneous to the BeppoSAX observation, shows that the BeppoSAX HID covers the entire HB and NB (Homan et al. 2001). In order to investigate the source spectrum in different regions of the HID, we accumulated the energy spectra of each NFI over the seven different HC intervals defined by the following boundaries: 0.26, 0.288, 0.3, 0.31, 0.315, 0.32, 0.335, 0.37. These spectra are indicated with A, B, ..., G in order of decreasing HC. A systematic error of 1% was added to the data of each spectrum. As customary, in the spectral fitting procedure we allowed for different normalizations in the LECS, HPGSPC and PDS spectra relative to the MECS spectra, and checked a posteriori that derived values are in the standard range for each instrument (see http://www.sdc.asi.it/software).

In line with previous studies (Mitsuda et al. 1984; White et al. 1988), we tried several two-component models to fit the X-ray continuum of GX 17+2. These were a blackbody or a disk multicolor blackbody (diskbb, Mitsuda et al. 1984) for the soft component, together with a blackbody or models of thermal Comptonization, such as a power law with cutoff, comptst (based on the solution of the Kompaneets equation given by Sunyaev & Titarchuk 1980), or comptt (in which relativistic effects are included and the dependence of the scattering opacity on seed photon energy, a free parameter of the model, is taken into account, Titarchuk 1994), for the harder component. In all cases the addition of a Fe Kα line at ∼ 6.7 keV proved necessary (probability of chance improvement ∼ 10^{-7} – 10^{-8}), while an edge at ∼ 8.5 keV improved the fits at ∼ 98 – 99% confidence level. The best fit to the continuum of GX 17+2 was obtained using a blackbody plus the comptt Comptonization model (reduced chisquare, averaged on the intervals, of χ^2_r ∼ 1.26 vs. χ^2 ∼ 1.31 – 1.51 for the other models). The blackbody had a temperature of kT_{BB} ∼ 0.6 keV and contributed ∼ 10% of the observed 0.1-200 keV flux. The blackbody equivalent radius was R_{BB} ∼ 37 km (using a distance of 7.5 kpc, Penninx et al. 1988). The temperature of the seed photons for the Comptonized component was kT_{W} ∼ 1 keV. Following In ’t Zand et al. (1999), we derived the effective Wien radius of the seed photons; this was R_{W} = 12 − 17 km. The temperature and optical depth of the (spherical) Comptonizing region were kT_{e} ∼ 3 keV and τ ∼ 10 – 12,
A marked excess of counts above $\sim 30$ keV was clearly apparent in the spectrum from the upper HB (spectrum A, $HC > 0.335$). This excess could not be fit by any of the two-component continuum models that we tried. Therefore we added an extra component to the model above. With the addition of a power law the $\chi^2$ decreased from 339 (for 239 d.o.f) to 254 (237 d.o.f.) in the case of spectrum A. An F-test indicates that the probability of chance improvement is negligible ($\sim 10^{-13}$). This additional component was detected up to energies of $\sim 100$ keV, had a best fit photon index $\sim 2.7$ and contributed $\sim 8\%$ of the 0.1-200 keV source flux. Other models (e.g. a thermal bremsstrahlung with $kT \sim 30$ keV) gave comparably good results. The addition of a power law component, with photon index 2.7, also improved the fit of spectra B, C and D (from the lower HB, $0.31 < HC < 0.33$). We note that the source went back several times to the same regions of the HB, each time with the same effect on the hard tail. Results from these three-component fits to the BeppoSAX spectra of GX 17+2 are given in Table 1.

On the contrary, the spectra from the NB (spectra E, F and G) did not show any evidence for a high energy excess. To study the flux variations of the high energy component across the HB and NB we fixed the photon index to 2.7 (i.e. the best fit value for spectrum A) and derived upper limits on the normalization. It is apparent from Table 1 that the flux in the high energy power law must have decreased by at least a factor of $\sim 20$, from the upper HB (spectrum A) to the lower NB (spectrum G). See also Figure 2, which shows spectra A and G and the residuals with respect to the corresponding best fits.

3. Discussion

Our observation of GX 17+2, the first to extensively study the X-ray spectrum of a Z source with sensitive instrumentation covering a broad energy range, led to the discovery of a high energy component extending up to $\sim 100$ keV, at least. This component was detected in the HB of the source, where it contributed up to $\sim 8\%$ of the 0.1–200 keV source flux. On the contrary the NB spectrum did not show any evidence for a high energy excess (upper limit of $\sim 0.4\%$ in the lower NB). Our modelling of the X-ray continuum up to energies of $\sim 20–30$ keV comprises a blackbody, contributing $\sim 10\%$ of the 0.1–200 keV flux, and a Comptonized spectrum, resulting from the upscattering of seed photons emitted by a $\sim 1$ keV Wien spectrum. This continuum model might be regarded as a generalization of the so-called “western” model, with several important differences (see White et al. 1986, 1988): (a) the blackbody has a lower temperature ($\sim 0.6$ vs. $\sim 1–2$ keV) and contributes a lower fraction of the X-ray flux ($\sim 10\%$ vs. $\sim 10–40\%$); the corresponding effective radii are $\sim 40$ km, i.e. larger than the NS radius; (b) the seed photons of the Comptonized spectrum are emitted at X-ray energies (as opposed to UV energies), perhaps by the NS surface or boundary layer, or by the magnetosphere of the NS for self-absorbed cyclotron emission (see Psaltis et al. 1995). The spectral evolution across the HB to the lower NB can be ascribed mainly to a monotonic decrease of the electron temperature and optical depth of the Comptonized component.
(see Table 1), which, within the spectral decomposition adopted here, are mainly responsible for the decrease of the HC from the HB to the NB. On the contrary, the soft part of the spectra remains nearly unchanged, in agreement with the fact that the HB and NB of GX 17+2 are almost vertical in the color-color diagram (soft color on the x-axis, see Wijnands et al. 1997). A more detailed discussion of the new continuum model for the X-ray spectrum of GX 17+2 in relation to the properties of the X-ray bursts from the source will be presented elsewhere. We note that the same continuum model has been used to describe the X-ray spectrum of Atoll sources (*e.g.* Guainazzi et al. 1998; Barret et al. 2000). A broad iron emission line is also present at $\sim 6.7 \text{ keV}$, with a FWHM of 0.4–0.6 keV and an equivalent width of $\sim 40 \text{ eV}$; these values are similar to those reported by White et al. (1986). The detection of an absorption edge at $\sim 8.5 \text{ keV}$ is new. The energy of the line and absorption edge indicate a high ionization stage of Fe (Fe XXIII–XXV).

The main result of our study is the discovery of a hard component in the X-ray spectrum of GX 17+2. This component was detected only in the HB, dominating the spectrum between $\sim 40$ and $\sim 100 \text{ keV}$. A $\Gamma \simeq 2.7$ power law model provided an adequate fit. This is the first time that a hard X-ray component is detected in the HB of a Z-source. Previously a power law-like hard excess was detected in the Ginga data of GX 5–1 (Asai et al. 1994). GX 5–1 was in the NB and FB during the *Ginga* observation, and the intensity of the power law component decreased from the NB to the FB. A hard X-ray component was also detected in the BeppoSAX data of Cyg X-2, but the source state was not reported (Frontera et al. 1998). These results indicate that hard components are probably a common feature of Z sources and that their intensity decreases from the HB to the NB and the FB, *i.e.* for increasing mass accretion rates. We note that this behavior is similar to that observed in LMXBs of the Atoll group and BHCs, where the relative importance of the hard X-ray component is often highest in the low-luminosity source states (the island state of Atoll source and the low and intermediate states of BHCs, see *e.g.* Nowak 1995; Barret et al. 2000). Theoretical interpretations for this effect have already been discussed: for example at high accretion rates the corona might be efficiently cooled by increased Comptonization losses, or swept away by radiation pressure (Popham & Sunyaev 2000).

Di Matteo & Psaltis (1999) found an interesting correlation between the QPO frequency and the slope of the power-law energy spectra in BHCs. If the QPO frequency is related to the size of the innermost (optically thick, geometrically thin) disk region, that changes in response to accretion rate variations (as indeed envisaged in a number of QPO models, see van der Klis 2000 for a review), then this correlation might simply reflect variations of the Comptonization parameter $y$ in response to variations of the innermost disk radius. We note that, owing to poor statistics, the BeppoSAX GX 17+2 data presented here do not provide independent evidence that the hard component steepens as the source moves from the upper HB and to the NB, *i.e.* the path along which the QPO frequency increases. Yet the data are consistent with this behavior. We note that there might exist a relationship between the presence of the hard X-ray component and QPOs. This is suggested by the fact that: (a) the hard X-ray component of GX 17+2 is most pronounced over the source state(s) in which both the kHz and HB QPOs are detected and reach the highest rms
amplitudes; (b) both these rms amplitudes and the contribution from the hard X-ray component to the total spectrum increase dramatically with energy (Wijnands et al. 1997).

The spectrum of GX 17+2 in the HB is similar to the spectra of BHCs in some soft states (intermediate or very high states). These are dominated by soft emission with characteristic temperatures of $\sim 1 - 2$ keV, and display a hard power-law component of photon index $\sim 2 - 3$, extending to several hundreds keV and contributing a few per cent of the total luminosity (see e.g. Grove et al. 1998). At a purely phenomenological level, the presence of a similar high energy tail in an otherwise soft NS system indicates that this tail should not be considered a signature of BHC accretion. The origin of this extended power-law tail in some soft states of BHCs is still debated. A model that might explain the hard power-law component in the soft state of both NS and BHC systems is the hybrid thermal/non-thermal corona (see e.g. Gierliński et al. 1999), where a fraction of the energy can be injected in form of electrons with a non-thermal velocity distribution. On the other hand the bulk-motion Comptonization model (Ebisawa, Titarchuk, & Chakrabarti 1996) is unlikely to work in luminous NS systems where the radial bulk motion would be slowed down by the radiation emitted close to the NS surface.

An alternative possibility is that the hard X-ray component in GX 17+2 originates from the scattering off non-thermal electrons of a jet, that is probably present in the source at low accretion rates. In fact GX 17+2 is associated with a variable radio source, the flux of which decreases from the HB to the FB (Penninx et al. 1988). This is a general characteristic of Z sources, but not of Atoll sources (Hjellming & Han 1995; Fender & Hendry 2000, and references therein).

We thank D. Psaltis for useful suggestions. This work was partially supported by the Italian Space Agency (ASI) and the Ministero della Ricerca Scientifica e Tecnologica (MURST).
REFERENCES

Asai, K., et al., 1994, PASJ, 46, 479
Hoshi, R., & Asaoka, I., 1993, PASJ, 45, 567

This preprint was prepared with the AAS LaTeX macros v4.0.
Table 1: Results of the fit of GX 17+2 spectra in the energy band 0.12–200 keV. The model consists of blackbody, \texttt{comptt}, power law, a Gaussian emission line, and an absorption edge. For each spectrum the corresponding range of HC is indicated. Uncertainties are at the 90\% confidence level for a single parameter. The power-law normalization is in units of ph keV$^{-1}$ cm$^{-2}$ s$^{-1}$ at 1 keV. The total flux is in the 0.1–200 keV energy range. F-test is the probability of chance improvement when the power law is included in the spectral model.

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>A (0.335–0.37)</th>
<th>B (0.32–0.335)</th>
<th>C (0.315–0.32)</th>
<th>D (0.31–0.315)</th>
<th>E (0.3–0.31)</th>
<th>F (0.298–0.3)</th>
<th>G (0.26–0.288)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N$_{bb}$ (×10$^{27}$ cm$^{-2}$)</td>
<td>2.2 ± 0.2</td>
<td>2.12 ± 0.08</td>
<td>1.92 ± 0.07</td>
<td>1.97 ± 0.06</td>
<td>1.83 ± 0.06</td>
<td>1.80 ± 0.05</td>
<td>1.85 ± 0.06</td>
</tr>
<tr>
<td>$kT_{bb}$ (keV)</td>
<td>0.63 ± 0.06</td>
<td>0.52 ± 0.04</td>
<td>0.58 ± 0.04</td>
<td>0.57 ± 0.04</td>
<td>0.54 ± 0.04</td>
<td>0.56 ± 0.04</td>
<td>0.56 ± 0.04</td>
</tr>
<tr>
<td>$R_{sh}$ (km)</td>
<td>35 ± 7</td>
<td>47 ± 8</td>
<td>38 ± 6</td>
<td>40 ± 6</td>
<td>43 ± 7</td>
<td>41 ± 6</td>
<td>41 ± 6</td>
</tr>
<tr>
<td>$kT_{pl}$ (keV)</td>
<td>1.07 ± 0.09</td>
<td>0.95 ± 0.05</td>
<td>1.01 ± 0.05</td>
<td>1.01 ± 0.05</td>
<td>1.01 ± 0.03</td>
<td>1.03 ± 0.04</td>
<td>1.03 ± 0.04</td>
</tr>
<tr>
<td>$kT_{g}$ (keV)</td>
<td>3.28 ± 0.06</td>
<td>3.21 ± 0.05</td>
<td>3.25 ± 0.05</td>
<td>3.15 ± 0.04</td>
<td>3.08 ± 0.04</td>
<td>3.13 ± 0.04</td>
<td>3.04 ± 0.04</td>
</tr>
<tr>
<td>Photon Index</td>
<td>11.6 ± 0.4</td>
<td>11.0 ± 0.3</td>
<td>10.6 ± 0.2</td>
<td>10.6 ± 0.2</td>
<td>9.8 ± 0.2</td>
<td>9.9 ± 0.2</td>
<td>9.5 ± 0.2</td>
</tr>
<tr>
<td>$E_{\text{cut}}$ (keV)</td>
<td>12 ± 2</td>
<td>17 ± 2</td>
<td>15 ± 1</td>
<td>15 ± 1</td>
<td>16 ± 1</td>
<td>15 ± 1</td>
<td>15 ± 1</td>
</tr>
<tr>
<td>Power-law N</td>
<td>3.7 ± 0.2</td>
<td>2.7 (fixed)</td>
<td>2.7 (fixed)</td>
<td>2.7 (fixed)</td>
<td>2.7 (fixed)</td>
<td>2.7 (fixed)</td>
<td>2.7 (fixed)</td>
</tr>
<tr>
<td>$E_{\text{min}}$ (keV)</td>
<td>1.3 ± 0.7</td>
<td>0.6 ± 0.2</td>
<td>0.4 ± 0.2</td>
<td>0.4 ± 0.1</td>
<td>0.27</td>
<td>0.25</td>
<td>&lt; 4.3 × 10$^{-2}$</td>
</tr>
<tr>
<td>$F_{\text{w}}$ (keV)</td>
<td>6.74 ± 0.09</td>
<td>6.78 ± 0.09</td>
<td>6.7 ± 0.1</td>
<td>6.7 ± 0.1</td>
<td>6.7 ± 0.1</td>
<td>6.7 ± 0.1</td>
<td>6.74 ± 0.08</td>
</tr>
<tr>
<td>$F_{\text{w}}$ (keV)</td>
<td>0.6 ± 0.3</td>
<td>0.4 ± 0.3</td>
<td>0.5 ± 0.3</td>
<td>0.5 ± 0.3</td>
<td>0.5 ± 0.3</td>
<td>0.5 ± 0.3</td>
<td>0.5 ± 0.3</td>
</tr>
<tr>
<td>$F_{\text{w}}$ (eV)</td>
<td>(6 ± 2) × 10$^{-3}$</td>
<td>(5 ± 1) × 10$^{-3}$</td>
<td>(5 ± 1) × 10$^{-3}$</td>
<td>(4 ± 1) × 10$^{-3}$</td>
<td>(4 ± 1) × 10$^{-3}$</td>
<td>(4 ± 1) × 10$^{-3}$</td>
<td>(5 ± 1) × 10$^{-3}$</td>
</tr>
<tr>
<td>$F_{\text{Fe}}$ (eV)</td>
<td>41</td>
<td>30</td>
<td>31</td>
<td>30</td>
<td>30</td>
<td>29</td>
<td>39</td>
</tr>
<tr>
<td>$F_{\text{Fe}}$ (eV)</td>
<td>8.7 ± 0.3</td>
<td>8.8 ± 0.3</td>
<td>8.5 ± 0.3</td>
<td>8.6 ± 0.3</td>
<td>8.6 ± 0.3</td>
<td>8.5 ± 0.3</td>
<td>8.5 ± 0.2</td>
</tr>
<tr>
<td>$E_{\text{edge}}$ (eV)</td>
<td>3 ± 1</td>
<td>3 ± 1</td>
<td>3 ± 1</td>
<td>3 ± 1</td>
<td>3 ± 1</td>
<td>3 ± 1</td>
<td>3 ± 1</td>
</tr>
<tr>
<td>$F_{\text{edge}}$ (ergs cm$^{-2}$ s$^{-1}$)</td>
<td>1.84 × 10$^{-8}$</td>
<td>1.82 × 10$^{-8}$</td>
<td>1.81 × 10$^{-8}$</td>
<td>1.81 × 10$^{-8}$</td>
<td>1.69 × 10$^{-8}$</td>
<td>1.71 × 10$^{-8}$</td>
<td>1.52 × 10$^{-8}$</td>
</tr>
<tr>
<td>$F_{\text{edge}}$ (d.o.f.)</td>
<td>1.07 (237)</td>
<td>1.21 (238)</td>
<td>1.04 (237)</td>
<td>1.11 (237)</td>
<td>1.27 (236)</td>
<td>1.26 (237)</td>
<td>1.22 (236)</td>
</tr>
<tr>
<td>$F_{\text{test}}$</td>
<td>1.2 × 10$^{-13}$</td>
<td>1.1 × 10$^{-4}$</td>
<td>4.9 × 10$^{-2}$</td>
<td>2.1 × 10$^{-4}$</td>
<td>0.14</td>
<td>0.30</td>
<td>0.98</td>
</tr>
</tbody>
</table>
Fig. 1.— Hardness-Intensity Diagram of GX 17+2. HC is the ratio of the counts in the 7–10.5 keV and 4.5–7 keV energy bands. Each point corresponds to a 400 s integration. A typical error bar is shown at the top left corner.
Fig. 2.— Spectra A (upper HB, left panels) and G (lower NB, right panels) and the corresponding best fit models (upper panels), and residuals in unit of $\sigma$ (lower panels).