First Beppo-SAX results on AGN

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In the following paper, some first Beppo-SAX results on AGN are presented. Main on-flight calibration features and observational properties are discussed at the light of possible future AGN studies

Key words: AGN - SAX satellite - X-ray observations

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1. The Beppo-SAX scientific payload

Beppo-SAX (Boella et al., 1997a) is a joint Italian-Dutch mission aimed at the study of X-ray emission from celestial objects in the energy range 0.1–300 keV, with high spatial and good energy and time resolution. The scientific payload consists of 4 coaligned Narrow Field Instruments (NFI) and a couple of Wide Field Cameras (WFC), pointing orthogonally to the NFI direction. Two NFI are proportional counters with imaging capabilities: the Low Energy Concentrator Spectrometer (LECS), Parmar et al. 1997, and the Medium Energy Concentrator Spectrometer (MECS), Boella et al. 1997b. The others are collimated instruments mounted on a rocking system to achieve a continuous monitoring of the background along the orbit: the High Pressure Gas Scintillator Proportional Counter (HPGSPC), Manzo et al. 1997, and the Phoswich Detector System (PDS), Frontera et al. 1997. In Table 1 the main properties of the NFI are briefly summarized. A package for data reduction and analysis and a complete set of calibrations are available from December 31st 1996. The residuals on the deconvolved spectrum of the Crab nebula are less than 5% for all NFI in the energy ranges reported in Table 1.

In the following paper, the first results obtained by Beppo-SAX on Active Galactic Nuclei (AGN) are presented. We will follow a scientifically-driven approach, focusing some astrophysical issues on which Beppo-SAX is starting to give interesting insights; the presence of warm absorbing matter in both Seyfert 1 and blazar objects (§2.1), the detection of hard ($E > 20$ keV) tails in both radio–quiet and radio–loud AGN (§2.2). The Beppo-SAX capability of detecting sub-milliCrab sources in the mid X-ray band is briefly discussed in §2.3.

\begin{table}
\begin{tabular}{lllll}
\hline
 & LECS & MECS & HPGSPC & PDS \\
\hline
Energy band (keV) & 0.1–10 & 1.8–10.5 & 7–60 & 20–200 \\
Energy resolution$^{a}$ & 8.84 \texttimes (E/6 keV)$^{-0.5}$ & 8.02 \texttimes (E/6 keV)$^{-0.5}$ & 11.0 \texttimes (E/6 keV)$^{-0.5}$ & 15 \texttimes (E/60 keV)$^{-0.5}$ \\
Encircled energy fraction$^{c}$ & 2.1 \texttimes (E/6 keV)$^{-0.5}$ & ... & ... & ... \\
Effective area ($cm^2$) & 150 @ 6 keV & 50 @ 6 keV & 260 @ 20 keV & 650 @ 60 keV \\
\hline
\end{tabular}
\caption{Properties of the scientific payload onboard Beppo-SAX}
\end{table}

$^{a}$the energy ranges are quoted for which the response matrices are currently calibrated

$^{b}$$\Delta E/E(\%)$ Full Width Half Maximum (FWHM)

$^{c}$arcmin FWHM
Table 2: AGN observed during Beppo-SAX SVP. MECS exposure times are reported.

| Object        | Start Time (UT) | End Time (UT) | $T_{exp}$ (s) | MECS count rate (s$^{-1}$) | PDS count rate (s$^{-1}$) | Reference |
|---------------|-----------------|---------------|---------------|-----------------------------|---------------------------|-----------|
| 3C273         | 18-Jul-96 02:03:25 | 21-07-96 08:35:00 | 132000        | 1.084 ± 0.003               | 1.09 ± 0.03               | 1         |
| MGC-6-30-15   | 29-Jul-96 18:49:46 | 03-Aug-96 03:15:00 | 185000        | 0.869 ± 0.002               | 0.39 ± 0.02               | 2, 3      |
| NGC4151$^a$  | 06-Jul-96 16:37:34 | 10-Jul-96 04:12:39 | 71840         | 1.516 ± 0.004               | 2.08 ± 0.03               | 4         |
| PKS2155-304   | 20-Nov-96 00:15:58 | 22-Nov-96 13:30:06 | 107700        | 1.089 ± 0.003               | 0.20 ± 0.03               | 5         |

$^a$ A second observation has been performed five months later for a total exposure time $\sim 35000$ s to complete the originally scheduled 100 ks

1. Grandi et al., 1997, A&A, submitted
2. Orr et al., 1997, A&A, submitted
3. Molendi et al., 1997, A&A, submitted
4. Piro et al., 1997, A&A, submitted
5. Giommi et al., 1997, A&A, submitted

Beppo-SAX Science Verification Phase (SVP) took place from July to September 1996 (but a couple of targets which were observed two months later). More than 30 targets were observed; among them 4 bright AGN: the Seyfert MCG-6-30-15 and NGC4151, the core-jet quasar 3C273 and the blazar PKS2155-304. In Table 2 the log of such observations is reported. The papers quoted in table contains a preliminary analysis of the data and the reader should refer to them for any result regarding the individual sources.

2.1. Warm absorber: an ubiquitous feature in AGN?

Recent ASCA results have demonstrated narrow absorption features by highly ionized matter to be a common feature in Seyfert 1 spectra (Reynolds et al., 1997; Mushotzky et al., 1997). The MCG-6-30-15 Beppo-SAX low-energy spectrum is consistent with a warm absorber scenario where highly ionized specied of Oxygen and Neon are responsible for the most prominent absorption features at $E \lesssim 1$ keV. Typical numerical density ion ratio $n_{\text{OII}}/n_{\text{OIII}}$ range from 0.2 to 1.7, corresponding to a thermal equilibrium photoionized plasma by an AGN-like continuum if the ionization parameter $\xi \sim 40 \div 70$ erg s$^{-1}$ cm$^{-1}$ and $T \sim$ few $10^5$ K. However, the low energy light curves display a pattern of variability that cannot easily be explained by simple one-zone photoionization-driven warm absorber in thermal equilibrium. Figure 1 shows the light curves in the 0.7–1.5 keV and 1.5–2.5 keV energy bands. The former (LECS) should be the most affected by any ionized absorbed, while the latter (MECS) is likely to be dominated by the bare nuclear continuum. Let’s consider the first 100 ks, which are characterized by a quasi-symmetric flux modulation by a factor $\sim 5$. A sharp rise of the hard flux (two-fold time $\sim 10000$ s) is followed by the soft flux with a delay $\Delta t \sim 20000$ s and the HR value is therefore significantly different from the mean measured along the whole observation. The soft peak appears also smoother then the hard, suggesting a longer stay time in the high state, although the not even sampling could be partly responsible for such an effect. Such findings suggest the ionization and recombination timescales to be typically longer than the variability timescales in such a source. That makes difficult to think that photoionization equilibrium is always effective. We stress moreover that no significant variation of the HR is present in the rest of the observation, despite flux variation wider than 5.

Similar absorption structures are starting to be detected in the low energy spectrum of other kinds of AGN, where they had not been observed yet, or show a much more complex structure than previously seen. In 3C273 a narrow-band absorption feature at $E_{\text{observer}} \simeq 0.5$–0.6 keV, has been unambiguously detected for the first time (see Figure 2). It can be phenomenologically modelled with either with a photoionization absorption edge or with a saturated absorption line. In the former scenario, the rest frame energy is consistent with an average Oxygen ionization stage from O III to O V. An explanation of such a feature as a comoving warm absorbing matter with the host galaxy can be ruled out since stronger continuum opacity and absorption features from moderate
Figure 1: Light curves from the Beppo-SAX observation of MGC-6-30-15 in the 0.7–1.5 keV (upper panel) and 1.5–2.5 keV energy ranges (middle panel) and hardness ratio (HR, lower panel) (binning time 1000 s). Dotted and dash-dotted lines in the lower panel are 1 \( \sigma \) and 3 \( \sigma \) around the mean \( \bar{HR} = 1.67 \).

Figure 2: Energy vs. optical depth (left) and covering fraction (right) of the edge and saturated line model of the absorption structure in the low-energy spectrum of 3C273. The observer energies of an O vii edge and Ly-\( \alpha \) O viii notch at the source reshift are shown for comparison.
ionized elements like C\textit{vi}, C\textit{iv} or helium should be detected in the spectrum as well. An MCG-6-30-15-like warm absorber would require an inflowing matter with bulk velocity $\sim 60000 \text{--} 90000 \text{ km s}^{-1}$. Alternatively, the most likely candidate for a saturated absorption is the resonant Ly-$\alpha$ absorption in O\textit{viii}. In such a case the observed energy can be reconciled with the laboratory one if the absorption occur in a matter with a bulk velocity towards the observer $\sim 60000 \text{ km s}^{-1}$, and could be therefore associated with the outflowing jet already seen at radio-optical wavelengths. Both such extreme interpretations are however quite puzzling.

PKS2155-304 is a BL Lac object with a very steep X-ray spectrum in the mid X-ray ($\Gamma_{3\text{--}10\text{keV}} \simeq 2.6$). EXOSAT (Madjeski et al. 1991) and BBRXT (Madjeski et al. 1997) observations have already showed a notch structure at rest frame energy consistent with a resonant Ly-$\alpha$ absorption from O\textit{viii}. The Beppo-SAX spectrum, extending in the low-energy band down to 0.1 keV, has revealed instead a much more complex spectrum; the notch feature is likely to be accompanied by a further absorption edge at $E_{\text{observer}} \sim 0.22 \text{ keV}$ or an even more complex multicomponent edge structure could well model the observational data.

### 2.2. Hard tails

The very low in-flight background in the PDS detector has allowed the detection of hard tail emission in the 20–100 keV from several AGN. In NGC1068 (Matt et al. 1997) it has been the first detection reported so far, and has allowed an independent confirmation of the predominance of the cold reflector in the double-mirror scenario that had been already invoked to explain the multicomponent profile of the iron line K$_\alpha$ fluorescence line (Iwasawa et al. 1997). An analogously important case is PKS2155-304, where the hard tail has been for the first time reobserved after the first putative detection by Urry et al. (1982). In this case the emission is likely to be associated with inverse Compton scattering of the synchrotron radiation and confirm the interpretative unified scenario for the blazar spectral energy distribution as suggested by Padovani & Giommi (1995).

The net count rates in the PDS are $0.20 \pm 0.03$ and $0.12 \pm 0.03$ for PKS2155-304 and NGC1068 respectively, corresponding to a $3.5 \sigma$ detection in the latter case. In both cases the associated flux in the 20–100 keV band is $\sim 1.2 \text{ mCrab}$. Such a low flux level corresponds to a less than $\simeq 1\%$ of the net count rate in the PDS units. A very strong control of the systematics associated with the background subtraction procedure is needed. PDS sensitivity has been widely investigated during the SVP (Guainazzi & Matteuzzi 1997). In Figure 3 a blank sky PDS spectrum accumulated on $\sim 225 \text{ ks}$, is shown, and 1 mCrab power-law spectra with spectral photon index $\Gamma = 1.5$ and $\Gamma = 2$ are superimposed for comparison. The residual systematics are well below the simulated spectrum up to $E \simeq 50 \text{ keV}$. Such a striking sensitivity can be achieved due to the good reproducibility of the instrumental background on timescales as low as 100 seconds. mCrab sources with moderate soft spectra can therefore be measured with high confidence by Beppo-SAX, with a much higher sensitivity than any analogous past and/or foreseeable in the next future mission. A refinement of the selection criteria in the nearby future will probably allow to achieve sensitivities up to few fraction of mCrab.

The broad-band coverage of Beppo-SAX instruments has also allowed the first robust detection of a Compton reflection component in the intermediate Seyfert galaxy NGC4151. In Figure 4 the spectrum in the whole 3.5–
Figure 4: 3.5–200 keV Spectrum (upper panel) and residuals in units of data/model ratio (lower panel) when a simple power-law model is applied to the data of the intermediate Seyfert galaxy NGC4151. Note the “emission bump” between 20 and 50 keV.

200 keV is shown when a simple power-law model with index fixed to the intermediate (i.e.: MECS) band is used. The spectral points between 20 and 50 keV lay well above the extrapolation of the intrinsic continuum, in analogy to what already observed in most Seyfert 1s (Pounds et al. 1990, Matsuoka et al. 1990, Nandra & Pounds 1994). The ratio between the reflected and direct component normalizations ranges between 13% and 40% and appears not to be strictly correlated with the highly variable (more than a factor 2) nuclear flux, either during the first long (≃ 3 days) observation or between the two observations performed, which were several months apart; such an evidence suggest any reprocessing matter to be distant at least ≃ 350 AU from the central engine.

2.3. Sub-millicrab AGN

The MECS detector has shown a very low and stable background level. For comparison, the GIS background level is ≃ a factor of 2 higher. Such a feature has a strong impact on the determination of the spectral properties of sub-millCrab AGN. Currently at least two Guest Observer programs are ongoing that take full advantage of such a feature. Beppo-SAX has been observing a sample of Narrow Line Seyfert 1 Galaxies with exposure times 20–40 ksec. The first results (Comastri et al. 1997) allow a much better determination of the spectral shape in the $E > 2$ keV band than in the past, revealing evidence of spectral curvature around $E ≃ 3$ keV, and $\Gamma_{\text{hard}}$ slightly higher or marginally consistent with typical Seyfert 1 ones. On the other hand, the first results from a sample of optically selected Seyfert 2 galaxies according to their O [iii] luminosity has produced a 100% detection rate (Salvati et al. 1997a and 1997b in preparation), and several sigma detections of Compton-thick (thin) objects as faint as $\sim 10^{41}$ erg s$^{-1}$ ($\sim 10^{40}$ erg s$^{-1}$) can be achieved.

3. What Beppo-SAX can provide to future AGN studies

We can therefore summarize the best features that Beppo-SAX can provide to the international community of AGN researchers as follow:

- broadband spectral capability in the whole 0.1–200 keV, with imaging capability at the highest resolution ever flown in the mid-hard X-ray band and good spectral resolution
- high quality calibration (residuals less than 5% on the deconvolved Crab spectrum for all NFI)
- unprecedented low background both in the intermediate and in the hard band. Targets as faint as a fraction of mCrab (in the 2–10 keV energy range) or ~ mCrab in the 20–100 keV range can be detected at several sigma level of significance and reliable determination of flux and rough spectral shape is at hand
- increasing availability of time allocation for guest observers’ proposals (40% of next Announcement of Opportunity time will be open to the international community)
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