The European Large Area ISO Survey V: a BeppoSAX hard X-ray survey of the S1 region

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ABSTRACT

We present BeppoSAX observations of the Southern S1 region in the European Large Area ISO Survey (ELAIS). These observations cover an area of \(\sim1.7\) sq. deg. and reach an on-axis (\(\sim0.7\) sq. deg) 2-10 keV (HX) sensitivity of \(\sim10^{-13}\) erg s\(^{-1}\) cm\(^{-2}\). This is the first HX analysis of an ISOCAM survey. We detect 9 sources with a signal
to noise ratio $\text{SNR}_{HX} > 3$, 4 additional sources with a 1.3 to 10 keV (T) $\text{SNR}_T > 3$ and 2 additional sources which appear to be associated with QSOs with $\text{SNR}_T > 2.9$. The number densities of the $\text{SNR}_{HX} > 3$ sources are consistent with the ASCA and BeppoSAX logN-logS functions. Six BeppoSAX sources have reliable ISOCAM 15\(\mu\)m counterparts within ~60 arcsec. All these ISOCAM sources have optical counterparts of $R < 20$ mags. Five of these sources have been previously optically classified giving 4 QSOs and 1 BALQSO at $z = 2.2$. The remaining unclassified source has X-ray and photometric properties consistent with that of a nearby Seyfert galaxy. One further HX source has a $2.6\sigma$ ISOCAM counterpart associated with a galaxy at $z = 0.325$. If this ISOCAM source is real, the HX/MIR properties suggest either an unusual QSO or a cD cluster galaxy. We have constructed MIR and HX spectral energy distributions to compute the expected HX/MIR ratios for these classes of objects up to $z = 3.2$ and assess the HX/MIR survey depth.

The BALQSO has an observed X-ray softness ratio and HX/MIR flux ratio similar to QSOs but different to those found for low redshift BALQSOs. This difference can be explained in terms of absorption, and suggests that high redshift BALQSOs should be comparatively easy to detect in the HX band, allowing their true fraction in the high redshift QSO population to be determined.

The QSOs cover a wide redshift range ($0.4 < z < 2.6$) and have HX/MIR flux ratios consistent with those found for nearby IRAS and optically selected PG QSOs. This suggests that MIR selected QSOs of $R < 20$ mags come from the same population as optically selected QSOs. We confirm this with a comparison of the B/MIR flux ratios of MIR and blue band selected QSOs.

**Subject headings:** cosmology: observations — infrared: galaxies — surveys — X-rays: galaxies — galaxies: active

### 1. INTRODUCTION

Unified models of Active Galactic Nuclei (AGN) propose that all types of AGN are fundamentally the same although the presence of a dusty molecular torus prevents the observation of the broad line region for particular line of sights. In this picture Type 1 AGN (e.g. Seyfert 1/QSO) are those for which the nucleus can be directly observed, while in Type 2 AGN (e.g. Seyfert 2) it is obscured by the torus (e.g. Lawrence and Elvis, 1982 and Antonucci, 1993). Strong support for this model has been given by X-ray, near-IR and mid-IR observations showing that Type 2 AGN are characterized by strong absorption whilst Type 1 AGN are relatively unabsorbed (Turner et al. 1997, Alonso-Herrero, Ward, Kotilainen, 1997, Maiolino et al. 1998 and Clavel et al. 2000). In this framework the infrared radiation is interpreted in terms of thermal emission from hot dust grains heated by the high energy central source emission (optical to X-ray continuum, see e.g. Granato, Danese, Franceschini 1997).
Barcons et al. (1995 hereafter B95) investigated the 12µm to hard X-ray (HX, 2 to 10 keV) flux ratios of a sample of nearby AGN and galaxies using IRAS and HEAO1 A-2 observations. They found that Type 1 AGN have larger HX/12µm flux ratios than Type 2 AGN whilst normal galaxies have very weak HX emission. This implies high column densities (log(N_H) > 22 cm^{-2}) in the Type 2 objects, supporting the basic unified model hypothesis. The study of B95 was necessarily restricted to nearby objects. The investigation of this flux ratio to deeper fluxes and higher redshifts will probe the properties of luminous sources such as QSOs and Broad Absorption Line QSOs (BALQSOs) and provide clues to the constancy of AGN activity in the universe.

The ASCA and BeppoSAX X-ray satellites have been successful in determining the HX properties of AGN and have resolved ~30% of the HX background into discrete sources, mostly Type 1 and Type 2 AGN (e.g. Ueda et al. 1998, 1999, Cagnoni et al. 1998, Fiore et al. 1999 and Akiyama et al. 2000). The recent launch of the Chandra and XMM-Newton X-ray satellites have now made it possible to probe to fainter fluxes at HX energies. Recent Chandra observations (e.g. Mushotzky et al. 2000, Fiore et al. 2000a, Brandt et al. 2000, Giacconi et al. 2000 and Hornschemeier et al. 2000) have uncovered a number of HX emitting, but optically apparently normal galaxies. The HX slopes of the sources are sufficiently hard that, when combined with the HX emitting AGN sources, they can account for >75% of the HX background (e.g. Mushotzky et al. 2000, Giacconi et al. 2000 and Hornschemeier et al. 2001). Comparisons to deep sub-mm surveys have shown that these HX sources are almost always unassociated with sub-mm sources (e.g. Hornschemeier et al. 2000; Severgnini et al. 2000; Barger et al. 2000), which instead appear to be star forming systems. Due to the expected association between HX and MIR emission a closer correlation should be found in the mid-IR band.

We present here BeppoSAX hard X-ray observations of the S1 region of the European Large Area ISO Survey (ELAIS) at 15µm. ELAIS (Oliver et al. 2000) was the largest program undertaken by ISO and, covering an area of ~12 sq. deg, is the largest 15µm (Serjeant et al. 2000) and 90µm (Efstathiou et al. 2000) survey before SIRTF and FIRST come into play. In this paper we focus on observations in the Southern S1 region. In addition to the ISO observations this region has been covered in the U, B, R and I (La Franca et al. in prep., Heraudeau et al. in prep.) optical bands and the 1.4 GHz radio (Gruppioni et al. 1999) band. Selected objects have been observed spectroscopically in the optical (La Franca et al. in prep., Gruppioni et al. in prep.) and photometrically in the near-IR (Heraudeau et al. in prep.). The field of view of the BeppoSAX MECS (25 arcminutes of radius; Boella et al, 1997a,b) matches well with that of the ELAIS sub-fields, covering a considerably larger area than both Chandra and XMM-Newton (see Fig. 1). It is thus ideal for a shallow X-ray survey of ELAIS fields. Throughout this paper H_0=50 kms^{-1}, \Lambda=0 and q_0=0.5 are used.

2. OBSERVATIONS

The BeppoSAX observations were taken with both the LECS and MECS instruments. The LECS observations are not considered here due to their lower sensitivity and much poorer PSF
below 2 keV.

The MECS observations (Boella et al. 1997b), from 1.3 to 10 keV, cover 5 of the 9 sub-fields in the S1 region of ELAIS (see Fig. 1). The total area covered is $\sim 1.7$ sq.deg., although the sensitivity of MECS varies with off-axis distance with the most sensitive observations covering 0.7 sq.deg. The on-source exposure time for these 5 pointings was on average $\sim 36$ ksec, corresponding to a flux limit of $\sim 10^{-13}$ erg s$^{-1}$ cm$^{-2}$ on-axis (see Table 1).

The BeppoSAX positional accuracy is dependent on many factors (see Fiore et al. 2000b for details) leading to a 95% error radius of one arcmin at off-axis distances $< 12$ arcmin and 1.5 arcmin at greater distances. Slightly better accuracies have been achieved in those fields where we have been able to identify more than one source at another wavelength and perform a positional shift of the X-ray sources to match the more accurate optical positions (see Table 1).

3. DATA

3.1. ELAIS data

As discussed in the introduction, the characteristics of the ELAIS selection and the IR counts have been presented by Oliver et al. (2000) and Serjeant et al. (2000). The survey has covered an area of $\sim 12$ deg$^2$ down to $\sim 1$ mJy in the 15$\mu$m lw3 filter (referred to here as MIR, Cersarksky et al, 1996). In this paper we focus on observations in the S1 region centered at $\alpha(2000) = 00^h 34^m 44.4^s$, $\delta(2000) = -43^\circ 28' 12''$, which covers an area of about $2^\circ \times 2^\circ$. About 100 sources of the Preliminary Analysis of ELAIS (Serjeant et al. 2000) down to R$\sim 20.5$ mags have been spectroscopically identified during three spectroscopic identification campaigns in 1998 (La Franca et al. in prep., Gruppioni et al. in prep).

3.2. BeppoSAX data

The BeppoSAX observations were cleaned and linearized using the SDC on-line analysis. The MECS2 and MECS3 images were co-added together and binned by a factor of 2. Source detection was performed using XIMAGE with the interactive routine sosta. When measuring the counts of a source a box of 13 pixels (each pixel corresponds to 8 arcsecs) was used. This was found to maximize the signal to noise. As the PSF is much wider than the positional uncertainty, the effect on the flux from poor centroiding with weak sources is negligible. The net counts were automatically corrected for vignetting, sampling dead time and the point spread function. For each source the background was measured in large apertures at nearby orthogonal sky positions.

The conversion from counts to fluxes was determined using a power law of $\alpha = 0.7$ ($f_\nu \propto \nu^{-\alpha}$). We experimented with a range of column densities ($20 < \log(N_H) < 23$) but found small differences
(∼10%) in the conversion factors as compared to the uncertainty in the counts of the X-ray sources and the flux uncertainties of the MIR sources, which are of the order of 30% (Serjeant et al. 2000). The overall conclusions are not affected by these uncertainties.

We initially found 13 sources at the SNR>3 Poisson level in either the 1.3 to 10 keV (T) or 2 to 10 keV (HX) band although 2 of these sources could be unreliable because of possible source confusion (sources s2 and s4), and are included in a supplementary table (see Tables 2 and 3 and Fig. 1). Based on the source box size we would expect <1 spurious source due to background fluctuations. Considering the relatively small cosmic volume sampled, the SNR_{HX}>3 number counts of sources are reasonably consistent with those found by Giommi, Perri and Fiore (2000), see Fig. 2. We have added to the supplementary list, Table 3, 2 sources just below the detection threshold, with SNR_T=2.9, but which are close (∼60 arcsec) to the position of an ELAIS 15µm QSO. These sources are used in all the further analysis.

The softness ratios of the sources were determined following the procedure of Fiore et al. (2000b) with the ratio defined as (S-H)/(S+H) where S=count rate in 1.3 to 4.5 keV band and H=count rate in 4.5 to 10 keV band, see Fig. 3 and Tables 2 and 3. The distribution of ratios is consistent with that found in the BeppoSAX HELLAS survey (i.e. −1<(S-H)/(S+H)<1, Fiore et al. 2000b).

3.3. Positional correlation between the BeppoSAX and the ISO sources

We have positionally correlated the HX sources to the MIR sources finding 6 matches (Table 4, Fig. 4). One further match is made with a 2.6σ ISOCAM source. This source is included in the further analysis although it should be noted that this is not a significant ISOCAM detection. The separation between the X-ray and optical centroids are < 60.5 arcsecs in all cases. The optical counterparts of the ISOCAM sources have magnitudes of R<20 mags. This optical magnitude limit is consistent with that found for \( f_{HX} > 10^{-13} \) erg s\(^{-1}\) cm\(^{-2}\), the depth of this survey, in other HX surveys (e.g. Schmidt et al, 1998, Akiyama et al, 2000 and Hornschemeier et al, 2001).

The surface density of the ISOCAM sources is ∼150 sources/deg\(^2\), and therefore the chance of a mis-association with a BeppoSAX error box (60 arcsec radius) is 13%. In previous BeppoSAX and ASCA surveys (e.g. Akiyama et al., 2000 and La Franca et al. 2000) sources have been matched to optical counterparts. In these studies the high optical source density often results in >1 possible optical counterpart within the large BeppoSAX and ASCA error boxes. The relatively low source density of MIR in this study results in less ambiguous source matching although we are implicitly assuming that an ISOCAM source within a BeppoSAX error box is associated with the HX source. This association is expected within the Unified model of AGN (Antonucci, 1993) and is found from both observational and theoretical tests of this model (e.g. B95, Granato, Danese and Franceschini, 1997, Krabbe, Boker and Maiolino, 2000 and Alonso-Herrero et al., 2001). These X-ray and infrared observations are two orders of magnitude deeper than those of B95 (see Fig. 5).
3.4. Hard X-ray upper limits of ISO sources

We measured $3\sigma$ X-ray upper limits for all the spectroscopically classified MIR sources, labeled in Fig 1. This was performed by measuring the counts at an MIR source position in the same fashion as for the detected sources. The measured upper limits depend on the off-axis distance and range from $10^{-13}$ erg s$^{-1}$ cm$^{-2}$ on-axis to $3-5\times10^{-13}$ erg s$^{-1}$ cm$^{-2}$ off-axis.

4. DISCUSSION

In this discussion we comment on the HX-MIR source identifications and compare the observed HX-MIR properties of the BeppoSAX and ISOCAM objects to those of other samples previously reported in the literature (e.g. B95 and Elvis et al. 1994, hereafter E94).

4.1. The spectroscopic object identifications

As already discussed we found 7 MIR sources (including the $2.6\sigma$ ISOCAM source) within the 16 error-boxes ($\sim 60$ arcsec, 95% significance, see section 2) of the BeppoSAX detections. We have obtained optical spectroscopy for 6 of these sources (La Franca et al. in prep. and Gruppioni et al. in prep.), see Table 4. As the optical spectroscopic campaign targeted those sources with $17 < R < 20.5$ mags, we did not obtain a spectroscopic identification for the brightest source. We find 4 normal broad emission line QSOs, with $0.4 < z < 2.6$ and $10^{44} < L_{HX} < 10^{46}$ erg s$^{-1}$ and 1 Broad Absorption Line QSO (BALQSO) at $z=2.2$ and $L_{HX}=6\times10^{45}$ erg s$^{-1}$. The $2.6\sigma$ ISOCAM source is associated with a galaxy at $z=0.325$ and has $L_{HX} \sim 10^{44}$ erg s$^{-1}$ if the association is real. Based on the distribution of object types found in other BeppoSAX and ASCA surveys (e.g. Akiyama et al, 2000 and La Franca et al. 2000) we would expect to find two Type 2 sources in our study. We find none which seems surprising but is not significant ($1\sigma$) given the small number of sources. One of the two low redshift QSOs ($z < 1$) is radio detected (source 3, $z=0.559$, $f_{1.4\text{GHz}} = 1.5$ mJy, Gruppioni et al. 1999). BALQSOs are rarely detected in the X-ray, particularly in the soft band, possibly due to large absorption of the X-ray emission (Gallagher et al. 1999). This is the first time a high redshift BALQSO has been detected in both the MIR and HX.

The unclassified source 8 is a bright optical source with an extended optical profile and is possibly detected at $90\mu$m ($f_{90\mu m} = 81$ mJy, Efthathiou et al. 2000). Its soft HX ratio (section 4.2) is consistent with either an AGN or a thermal Bremsstrahlung emitting source. Its high HX/MIR flux ratio (section 4.3) suggests the former and it is probably a nearby Seyfert galaxy.

The detection of a normal galaxy seems surprising although many apparently normal galaxies have been detected in recent Chandra surveys (e.g. Mushotzky et al. 2000, Fiore et al. 2000a, Brandt et al. 2000, Giacconi et al. 2000 and Hornschemeier et al. 2000) although none have such a high X-ray luminosity and many tend to have harder X-ray spectral slopes. This object has an HX/MIR flux
ratio, X-ray spectral slope and luminosity similar to QSOs although lacks the typical QSO broad optical emission lines. Other interesting possibilities are that it is a BL Lac object, although the lack of radio emission and a strong Calcium break suggest against this, or a dominant cD cluster galaxy with the X-ray emission coming from the cluster medium. The expected log(HX/MIR) ratio for this latter possibility is $-4.7 \pm 0.4$ (e.g. Edge and Stewart, 1991 and Bregman, McNamara and O’Connell, 1990). Due to the uncertain nature of this source these possibilities are not further pursued.

4.2. Softness ratios

We have compared the softness ratios (see Fiore et al. 2000b) to those expected for various HX SEDs, see Fig. 6. The softness ratios of the QSOs, although extremely uncertain, show a variety of soft and hard sources $0.5 < (S-H)/(S+H) < -0.5$, similar to those found in the BeppoSAX HELLAS survey (Fiore et al. 2000b).

4.3. The HX/MIR flux ratios

We have compared the observed HX/MIR flux ratios to those expected for a variety of object types. B95 statistically studied the correlation between HX and 12µm for the IRAS 12µm sample of AGN and emission line galaxies (Rush, Malkan, Spinoglio, 1993, hereafter RMS). The 12µm sample represents the properties of MIR sources in the local universe whilst the redshifts of these ISOCAM/BeppoSAX objects are substantially higher. Therefore in order to compare this study to that of B95 it is necessary to take into account the effects of redshift and the construction of spectral energy distributions (SEDs) are necessary. In the generation of SEDs we have decided to take an empirical approach due to the uncertain contribution of AGN and galactic activity at mid-IR wavelengths (e.g. see the detailed modelling of Cen A which is clearly an AGN although its infrared emission appears to be dominated by galactic processes, Alexander et al., 1999). To do this we firstly evaluated and constructed HX and infrared SEDs of QSOs, Seyfert 2 and HII galaxies and then normalized the X-ray SED to reproduce the HX/MIR flux ratios of the local value at $z \sim 0$ as determined by E94 for QSOs, and by B95 for Seyfert 2 and HII galaxies. Only a few Seyfert 2s were detected at HX energies by B95 although the HX/MIR flux ratio distribution is very similar to the IRAS 60µm selected, HX detected 16 Seyfert 2 galaxies in Alexander (2001) (log(HX/MIR)=-7.0±0.7). The B95 HX/MIR flux ratio for the HII galaxies is an upper limit.

The HX SEDs were taken from Pompilio, La Franca and Matt (2000) for the cases of QSO and Seyfert 2; the QSO SED is a two part power law whilst the Seyfert 2 SED uses this same spectrum convolved with the Seyfert 2 absorbing column density distribution found by Maiolino et al. (1998). The Seyfert 2 galaxies in the Maiolino et al. study were not MIR selected. However, the column density distribution is very similar to that found for far-IR selected Seyfert 2 galaxies.
(i.e. \( \log(N_H) \sim 22 \) to 25 cm\(^{-2} \), Alexander, 2001). The HII galaxy HX SED was determined assuming a Bremsstrahlung thermal spectrum with \( kT = 5.8 \) keV, as found for the starburst galaxy NGC253 (Cappi et al. 1999).

The Seyfert 2 and HII galaxy infrared SEDs were determined using the Xu et al. (1998) empirical algorithm which takes the four IRAS band fluxes to predict an overall 2 to 120\( \mu \)m SED assuming three basic components: AGN, starburst and cirrus. The \(<12\mu \)m emission is predicted from the IRAS colours and produced using AGN, starburst and cirrus observational templates which include PAH emission and dust absorption features. The sample used to determine these SEDs was the RMS sample as classified by Alexander and Aussel (2000). These SEDs do not account for starlight, which can potentially be a large contributor for \( \lambda < 7\mu \)m and would lead to underestimates of the HX/MIR ratios. Therefore we have only used these SEDs for \( z < 1 \), which is sufficient for the non-QSO sources. For the QSOs we have used the empirically determined SED of E94 which includes the contribution from starlight and gives a good match to the low redshift optically selected PG QSOs (Schmidt and Green, 1983). As this SED is derived mostly from low redshift sources, we are assuming little SED evolution for \( z < 3 \) (see section 4.3.1 for discussion).

The HX/MIR flux ratios of the BeppoSAX/ISO sample are shown in Fig. 7a. The errorbars associated with the SEDs take into account the statistical spread in the HX/MIR ratios measured locally by B95. In the case of Seyfert 2s and QSOs the effect of redshift is to increase the HX flux with respect to the MIR flux. The difference with redshift is not dramatic for either object type because the assumed HX column densities are quite low, although see section 4.3.2 for the case of a Compton thick source (\( \log(N_H) > 24 \) cm\(^{-2} \)). The HII galaxies are difficult to detect in the HX at any redshift but particularly at high redshift where the HX K-correction is positive. In the case of a higher temperature of the X-ray emitting gas than that assumed here, the HX/MIR ratio will stay constant to higher redshifts, dropping off significantly at the exponential cut-off energy (i.e. at \( z = (T_{HX}/2)^{-1} \), where \( T_{HX} \) is the Bremsstrahlung temperature in keV).

The flux ratio distribution of the HX/MIR upper limits are shown in Fig. 7b. The mean HX upper limit and \( \log(\text{HX/MIR}) \) are \( 3.3 \times 10^{-13} \) erg s\(^{-1} \) cm\(^{-2} \) and \(-5.1 \) respectively. To detect all the sources requires significantly deeper X-ray observations. HX observations of the Northern ELAIS fields will be carried out by Chandra and XMM-Newton to limiting fluxes of \( \sim 3 \times 10^{-15} \) and \( 10^{-14} \) erg s\(^{-1} \) cm\(^{-2} \) respectively. Assuming the mean flux and HX/MIR flux ratio of this BeppoSAX survey, the Chandra and XMM-Newton surveys should reach mean flux ratios of \( \log(\text{HX/MIR}) \sim -7.1 \) and \( \log(\text{HX/MIR}) \sim -6.6 \) although clearly some objects with lower ratios will also be detected. The Chandra survey (two ACIS-I 16 arcmin pointings) covers a small area but should detect all the AGN and some HII galaxies within the field of view whilst the XMM-Newton survey covers a similar area to this survey and should detect all the QSOs, most of the Seyfert 2 galaxies and a few HII galaxies.
4.3.1. The QSOs

The majority of the HX-MIR associated sources are QSOs. The observed QSO HX/MIR flux ratios appear consistent with that of the median E94 QSO SED. The E94 UVSX sample includes 47 quasars selected to have at least 300 counts in the Einstein IPC and with \( V < 17 \) mags to be observable by IUE; 29 members are radio quiet and 18 radio loud. The sample is consequently biased toward objects at low redshifts (although 7 objects have \( z > 1 \), 4 \( z > 2 \), 1 \( z > 3 \)), of moderate luminosity and with high X-ray to optical flux ratios.

In order to increase the statistics of our comparison we added to the MIR sample QSOs from Andreani, Franceschini and Granato (1999) with \( f_{12\mu m} > 200 \) mJy, and created as a comparison an optically selected sample using 12\( \mu m \) detections or upper limits of the PG optically selected QSOs from Sanders et al. (1989). To increase the number of objects at high redshift we have taken those objects from Neugebauer et al. (1986) with \( z > 2 \). We have determined which of these are BALQSOs using the list of Junkkarinen, Hewitt and Burbidge (1991). The data are shown in Fig. 8. The mean log(HX/MIR) ratios of the low redshift QSOs (\( z < 0.6 \)) are \( -5.7 \pm 0.7 \) and \( -5.6 \pm 0.3 \) for the MIR and optically selected objects respectively. These flux ratios are consistent with each other and with the E94 SED. This suggests that MIR selected QSOs of \( R < 20 \) mags come from the same population as optically selected QSOs and that there is little SED evolution for \( z < 3 \).

As a further and more definitive test we have compared the log(B/MIR) ratios of all the MIR detected QSOs in the S1 region to those of the PG QSO sample (Schmidt and Green, 1983 and Sanders et al., 1989), see Fig. 9. The advantage of this comparison is that we can use the full QSO set from both the ELAIS and PG surveys. The MIR QSOs are consistent with the flux ratios of the E94 SED and the PG QSOs. This further strengthens the evidence that MIR selected QSOs of \( R < 20 \) mags come from the same population as optically selected QSOs.

4.3.2. The BALQSO

Although the statistics are still poor, low redshift BALQSOs seem to be located in a different region of the HX/MIR plane to QSOs, see Fig. 8. This is consistent with that expected from an absorbed source. The low-redshift QSO, that lies close to the BALQSOs in the HX/MIR plane shown in Fig. 8, is a narrow line Seyfert 1 galaxy (IZw1), an unusually red source (e.g. see E94) which may be different to the general QSO population (e.g. see Brandt and Gallagher, 2000). Our BALQSO has a HX/MIR flux ratio similar to that found for normal QSOs, apparently in contradiction with that found for low redshift BALQSOs. This difference could be due to the negative HX K-correction effect of an absorbed HX spectrum, see Fig. 6. We can test whether the observed HX/MIR flux ratio is compatible with that expected for an absorbed HX source by constructing a possible BALQSO SED. We have chosen to use the Compton thick HX spectrum of the Type 2 QSO object IRAS09104+4109 (Franceschini et al. 2000) and the QSO infrared SED of E94, normalised to the HX/MIR ratio of IRAS09104+4109. The positive effect of redshift on
the HX emission can clearly be seen (see Fig. 8) showing that a high redshift HX absorbed source can have a similar HX/MIR flux ratio to an unabsorbed source. Therefore, in contrast to low redshift BALQSOs, high redshift BALQSOs should be comparatively easy to detect in the HX band, allowing a determination of their true fraction in the high-z QSO population.

5. CONCLUSIONS

We have presented shallow BeppoSAX observations, reaching an on-axis (\(\sim 0.7\) sq. deg) 2-10 keV sensitivity of \(\sim 10^{-13}\) erg s\(^{-1}\) cm\(^{-2}\), of the Southern S1 region of ELAIS, reaching a 15\(\mu\)m sensitivity of 1 mJy. This is the first HX analysis of an ISOCAM survey. We have constructed HX and infrared SEDs to determine the expected flux ratios for QSOs and BALQSOs up to \(z=3.2\) and for Seyfert 2s and normal galaxies up to \(z=1.0\). Our main findings are:

(i) we detect 13 sources with SNR>3 in the 1.3-10 keV or 2-10 keV X-ray bands and a further 2 sources with less reliable detections that have positions close (\(\sim 60\) arcsec) to QSOs. The number densities of the SNR\(_{HX}\) >3 sources are consistent with the ASCA and BeppoSAX logN-logS function.

(ii) 6 of these sources have a reliable ISOCAM counterpart and one further source has a less reliable (2.6\(\sigma\)) ISOCAM counterpart. We have optical spectroscopic classifications for 6 of these sources finding 4 QSOs, 1 BALQSO at \(z=2.2\) and 1 apparently normal galaxy (the 2.6\(\sigma\) ISOCAM source). The unclassified object has X-ray and photometric properties consistent with that of a nearby Seyfert galaxy. The galaxy has properties suggesting either an unusual QSO or a galaxy cluster.

(iii) the QSOs cover a wide redshift range (0.4<\(z<2.6\)), and have HX/MIR flux ratios consistent with those found for nearby IRAS and optically selected PG QSOs and the QSO SED of Elvis et al (1994). By further comparing the B/MIR flux ratios of the MIR QSOs to those of the blue band selected PG sample, we suggest that MIR selected QSOs of \(R<20\) mags come from the same population as optically selected QSOs.

(iv) the high redshift BALQSO has a HX/MIR ratio similar to that of QSOs, but different to that found for low redshift BALQSOs. This difference can be explained as the negative K-correction effect of an absorbed X-ray spectrum observed at high redshift. This suggests that high redshift BALQSOs should be comparatively easy to detect in the HX band, allowing the true fraction of BALQSOs in the high redshift QSO population to be determined.

We acknowledge the EC TMR network (FMRX-CT960068) for financial support and MURST Cofin-98-032 and ASI contracts for partial support. DMA additionally thanks the NSF CAREERS grant AST-998 3783 for post-doctoral support. This research has made use of SAXDAS (SAX Data Analysis System) linearized and cleaned event files (Rev.2.0) produced at the BeppoSAX
Science Data Center and the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. We gratefully thank Belinda Wilkes, the referee, for an efficient and thorough reading of this manuscript. We further thank Cong Xu for providing the code to determine the mid-IR SEDs used in this paper and Sarah Gallagher, Ann Hornschemeier and Niel Brandt for valuable comments on earlier drafts of this paper.

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Table 1: BeppoSAX MECS observations.

| Field | Centre position | Exp Date | X-offset | Y-offset | X-ray position | SNR | Date | RA correction (deg) | Dec correction (deg) |
|-------|-----------------|----------|---------|----------|-----------------|-----|------|---------------------|---------------------|
| S1.2  | 0 30 57.3 -43 38 12.9 | 15/12/99 | 0.0222 | 0.0040 | 0.0 | 57.3 | -43 38 12.9 | 15/12/99 | 0.0222 | 0.0040 |
| S1.4  | 0 33 43.6 -43 50 25.0 | 20/12/99 | 0.0222 | 0.0040 | 0.0 | 43.6 | -43 50 25.0 | 20/12/99 | 0.0222 | 0.0040 |
| S1.5  | 0 34 32.6 -43 29 42.0 | 19/12/99 | 0.0222 | 0.0040 | 0.0 | 32.6 | -43 29 42.0 | 19/12/99 | 0.0222 | 0.0040 |
| S1.7  | 0 37 30.3 -42 38 2.2 | 18/07/99 | -0.0206 | 0.0041 | 15.4 | 30.3 | -42 38 2.2 | 18/07/99 | -0.0206 | 0.0041 |
| S1.8  | 0 38 26.7 -43 17 31.2 | 17/07/99 | 0.0000 | 0.0062 | 0.0 | 26.7 | -43 17 31.2 | 17/07/99 | 0.0000 | 0.0062 |

Notes: Col.(1) ELAIS region; (2) uncorrected X-ray field centre position (J2000); (3) observation exposure time (ksec); (4) date of observation; (5) and (6) RA and Dec corrections (deg), see section 2.

Table 2: BeppoSAX sources.

| Obj. no. | X-ray position | SNR_T | Counts_HX | SNR_HX | HX | Softness |
|----------|----------------|-------|-----------|--------|-----|----------|
| 1        | 0 30 13.1 -43 53 31.3 | 5.1 5.7±1.2 4.8 5.7±1.2 | -0.11±0.28 |
| 2        | 0 30 50.2 -43 37 15.4 | 3.6 1.5±0.4 3.7 1.4±0.4 | -0.51±0.39 |
| 3        | 0 32 13.8 -43 32 56.9 | 3.9 2.2±0.7 3.4 2.0±0.7 | 0.32±0.44 |
| 4        | 0 32 24.3 -43 57 15.6 | 3.1 2.7±1.0 2.8 2.5±1.0 | -0.39±0.56 |
| 5        | 0 33 45.7 -43 18 44.7 | 3.9 2.7±0.7 3.6 2.5±0.7 | 0.18±0.35 |
| 6        | 0 34 01.7 -43 52 38.6 | 2.9 1.3±0.4 3.3 1.2±0.4 | -0.37±0.47 |
| 7        | 0 34 22.3 -43 18 38.3 | 2.0 1.5±0.5 3.1 1.4±0.5 | -0.46±0.36 |
| 8        | 0 35 11.7 -43 33 42.2 | 8.7 4.0±0.6 6.8 3.7±0.6 | 0.59±0.14 |
| 9        | 0 37 08.4 -37 07 6.5 | 6.5 2.4±0.4 6.0 2.2±0.4 | 0.31±0.20 |
| 10       | 0 37 14.3 -42 34 55.6 | 5.5 1.9±0.4 5.0 1.8±0.4 | 0.22±0.26 |
| 11       | 0 37 50.5 -43 27 53.1 | 3.3 1.8±0.6 2.9 1.7±0.6 | -0.08±0.43 |

Notes: Col. (1) BeppoSAX source number; (2) BeppoSAX position (J2000), see text for positional accuracy; (3) total X-ray (1.3-10 keV) SNR; (4), (5), (6) hard X-ray (2-10 keV) count rate, SNR, flux in units of 10^{-13} erg s^{-1} cm^{-2}; (7) softness ratio (S-H)/(S+H), see section 4.2.

Table 3: Supplementary BeppoSAX sources.

| Obj. no. | X-ray position | SNR_T | Counts_HX | SNR_HX | HX | Softness | Reason for inclusion |
|----------|----------------|-------|-----------|--------|-----|----------|---------------------|
| s1       | 0 29 57.1 -43 48 44.3 | 2.9 2.2±0.9 2.4 2.0±0.9 | -0.58±0.43 SNR_T=2.9 but 33 arcsec from QSO |
| s2       | 0 32 00.4 -43 31 14.9 | 3.8 1.3±0.5 2.5 1.2±0.5 | 0.46±0.42 close to source 3, maybe one source |
| s3       | 0 33 55.1 -43 55 41.8 | 2.9 1.0±0.4 2.3 0.9±0.4 | -0.15±0.46 SNR_T=2.9 but 60 arcsec from QSO |
| s4       | 0 37 17.1 -43 17 22.1 | 3.4 1.2±0.4 2.4 1.1±0.4 | 0.32±0.44 possibly 2 sources in HX band |

Notes: Col. (1) BeppoSAX source number; (2) BeppoSAX position (J2000), see text for positional accuracy; (3) total X-ray (1.3-10 keV) SNR; (4), (5), (6) hard X-ray (2-10 keV) count rate, SNR, flux in units of 10^{-13} erg s^{-1} cm^{-2}; (7) softness ratio (S-H)/(S+H), see text; (8) reason why included in the supplementary table.
Table 4: ISOCAM detected BeppoSAX sources.

| Obj. no. | X-ray position | L$_{HX}$ | HX-Optical offset | $f_{MIR}$ | L$_{MIR}$ | $f_{HX}/f_{MIR}$ | Optical position $R$ | $M_R$ | $z$ | Classification |
|----------|----------------|---------|-------------------|----------|---------|-----------------|---------------------|------|----|----------------|
| s1       | 0 29 57.1 -43 48 44.3 | 45.9    | 32.8             | 4.2      | 45.9    | -5.5±0.2        | 0 29 59.2 -43 48 35.3 | 17.4 | -29.4 | 2.039 QSO     |
| 3        | 0 32 13.8 -43 32 56.9 | 44.6    | 47.3             | 1.8      | 44.4    | -5.3±0.1        | 0 32 11.1 -43 33 22.3 | 18.7 | -24.5 | 0.559 QSO     |
| s3       | 0 33 55.1 -42 55 41.8 | 45.8    | 60.2             | 0.5      | 45.3    | -5.0±0.2        | 0 33 52.8 -42 54 52.4 | 18.5 | -28.9 | 2.584 QSO     |
| 8        | 0 35 11.7 -43 33 42.2 | 45.8    | 60.5             | 15.8     | 5.0     | -6.0±0.1        | 0 35 15.6 -43 33 57.7 | 16.4 |        |               |
| 9        | 0 37 08.4 -42 37 07.6 | 44.2    | 13.3             | 1.2      | 43.8    | -5.1±0.1        | 0 37 07.9 -42 37 18.6 | 19.4 | -22.5 | 0.325 Galaxy  |
| 10       | 0 37 14.3 -42 34 55.6 | 45.8    | 25.7             | 1.7      | 46.0    | -5.8±0.1        | 0 37 15.5 -42 35 14.0 | 18.3 | -28.7 | 2.190 BALQSO  |
| 11       | 0 37 50.5 -43 27 53.1 | 44.2    | 50.1             | 1.6      | 44.0    | -5.1±0.2        | 0 37 53.1 -43 28 24.5 | 19.2 | -23.1 | 0.398 QSO     |

Notes: Col. (1) BeppoSAX source number; (2) BeppoSAX position (J2000), see text for positional accuracy; (3) log hard X-ray (2-10 keV) luminosity (erg s$^{-1}$); (4) offset from the optical source position (arcsec); (5) 15µm flux density (mJy) from Serjeant et al (2000), the superscript (a) refers to the 2.6σ ISOCAM source, see section 3.3; (6) log 15µm luminosity (erg s$^{-1}$); (7) HX/MIR flux ratio; (8) optical position (J2000); (9), (10) apparent and absolute R band magnitudes (mags) from La Franca et al (in prep.); (11) redshift; (12) source classification from La Franca et al (in prep.) and Gruppioni et al (in prep.)
Fig. 1.— The observed ELAIS S1 sub-fields overlayed with the *ISOCAM* 15μm sources (points), classified sources (crosses, La Franca *et al.* in prep., Gruppioni *et al.* in prep.) and *BeppoSAX* detected sources (small circles). The overall field of view of the MECS instrument (∼50 arcmin diameter, solid circle) and the highest sensitivity (broken circle) regions are shown.

Fig. 2.— The cumulative 2-10 keV (HX) logN-logS function compared to that found by Giommi, Perri and Fiore (2000). Only those sources with $SNR_{HX}>3$ are shown.

Fig. 3.— The softness ratios of the *BeppoSAX* sources as a function of HX count rate. The open circles refer to the QSOs, the filled circles refer to the BALQSO, the star refers to the galaxy and the open square refers to objects without an optical ID. The small circles refer to the QSO supplementary sources, see Table 3 and text.

Fig. 4.— HX to optical source matching distances. The symbol size for both the MIR (15μm) and HX fluxes represent the source flux where a larger symbol denotes a larger flux, see Fig. 3 for object type key.

Fig. 5.— The HX and MIR fluxes of the MIR detected HX sources, see Fig. 3 for object type key.

Fig. 6.— The softness ratios of the MIR detected HX sources shown as a function of redshift. The dotted lines show the expected intrinsically absorbed and unabsorbed flux ratios of an AGN source and the flux ratio of a thermal Bremsstrahlung emitting galaxy or galaxy cluster. See Fig. 3 for object type key.

Fig. 7.— Expected log(HX/MIR) flux ratios for QSOs, Seyfert 2s and HII galaxies over-plotted with (a) the MIR detected HX sources and (b) the MIR sources with HX upper limits. The error bars are from B95 and correspond to the statistical spread in HX/MIR colors for each source type. The crosses refer to HII galaxies and the filled squares refer to Seyfert 2 galaxies, see Fig. 3 for the object type key of the other object types. The mean depths of the *BeppoSAX* and the predicted depths of the forthcoming *XMM-Newton* (P.I. R. Mann) and *Chandra* (P.I. O. Almaini) surveys of the Northern ELAIS regions are shown.

Fig. 8.— log(HX/MIR) flux ratios of MIR and optically selected QSOs. The curves show the mean QSO and BALQSO values. The statistical spread of values are calculated from the QSOs of E94. The narrow line Seyfert 1 object IZwI is indicated as well as the two nearby BALQSOs MKN231 and IRAS07599+6508. See Fig. 7 for the object type key. The additional HX data was taken from Turner and Pounds (1989), Della Ceca et al (1990), Turner et al (1990), Williams et al (1992), Lawson et al (1992), Saxton et al (1993), Sambruna et al (1994), Ceballos and Barcons (1996), Alonso-Herrero et al (1997), Lawson and Turner (1997), Reeves et al (1997) and Gallagher et al (1999).

Fig. 9.— log(B/MIR) flux ratios of MIR and optically selected QSOs. The curves show the mean QSO value. The statistical spread is calculated from the QSOs of E94. See Fig. 7 for the object type key.
type key. The data for the PG objects was taken from Schmidt and Green (1983) and Sanders et al (1989).
