

IGR J22517+2218 = MG3 J225155+2217: A NEW GAMMA-RAY LIGHTHOUSE IN THE DISTANT UNIVERSE

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Received 2007 June 19; accepted 2007 September 18; published 2007 October 11

ABSTRACT

We report on the identification of a new soft gamma-ray source, namely, IGR J22517+2218, detected with *INTEGRAL* IBIS. The source, which has an observed 20–100 keV flux of $\sim 4 \times 10^{-11}$ ergs cm⁻² s⁻¹, is spatially coincident with MG3 J225155+2217, a quasar at $z = 3.668$. The *Swift* XRT 0.5–10 keV continuum is flat ($\Gamma = 1.5$) with evidence for a spectral curvature below 1–2 keV either due to intrinsic absorption ($N_{\text{H}} = 3 \pm 2 \times 10^{22}$ cm⁻²) or to a change in slope ($\Delta\Gamma = 0.5$). X-ray observations indicate flux variability over a 6 day period that is further supported by a flux mismatch between *Swift* and *INTEGRAL* spectra. IGR J22517+2218 is radio-loud and has a flat radio spectrum; optically, it is a broad-line emitting quasar with the atypical property of hosting a narrow-line absorption system. The source spectral energy distribution is unusual compared to blazars of similar type: either it has the synchrotron peak in the X-ray/gamma-ray band (i.e., much higher than generally observed) or the Compton peak in the MeV range (i.e., lower than typically measured). IGR J22517+2218 = MG3 J225155+2217 is the second most distant blazar detected above 20 keV and a gamma-ray lighthouse shining from the edge of our universe.

Subject headings: gamma rays: observations — quasars: individual (IGR J22517+2218, MG3 J225155+2217)

Online material: color figures

1. INTRODUCTION

Blazars are the most powerful of all AGNs seen in the observable universe; their continuously emitting radiation covers the entire electromagnetic spectrum from radio to gamma-ray frequencies. Because of their enormous luminosities, blazars are visible to very large distances/redshifts. In the widely adopted scenario of blazars, a single population of high-energy electrons in a relativistic jet radiate from the radio/FIR to the UV- soft X-rays by the synchrotron process and at higher frequencies by inverse Compton scattering soft-target photons present either in the jet, in the surrounding material, or in both (Ghisellini et al. 1998). Therefore, a strong signature of the blazar nature of a source is a double-peaked structure in the spectral energy distribution (SED), with the synchrotron component peaking anywhere from infrared to X-rays and the inverse Compton extending up to GeV/TeV gamma rays. To explain all the different SEDs observed in blazars, Fossati et al. (1998) proposed the blazar’s sequence, which claims an inverse relation between peak energies and source luminosity: the more luminous sources have both synchrotron and inverse Compton peaks at lower energies than their fainter (and generally at lower redshift) counterparts. Within the blazar population, high-redshift objects, which belong to the class of flat spectrum radio quasars (FSRQs), tend to be the most luminous ones. Their SED peak at IR/optical (first peak) and GeV (second peak) frequencies and only a handful of objects show both peaks at lower energies (Blom et al. 1996). Furthermore, FSRQs with a synchrotron peak above the optical band are extremely rare (Giommi et al. 2007) and not predicted by the blazar’s sequence. In less luminous blazars, on the other hand, the first peak can reach the ~ 100 keV band, while the second

one goes well into the TeV range. Observations above 10 keV are therefore extremely important as they can select rare types of blazars, i.e., those with the synchrotron or Inverse Compton peak at hard X-ray/gamma-ray energies. Finding either type of objects is crucial to test the validity of the blazar’s sequence and to study jet parameters in extreme blazars or, in other words, to stretch blazar theories to the limit. Unfortunately, observational progress in blazar studies above 10 keV has been slow, particularly for the most distant sources. Nonetheless, a few objects at high- z have been detected by *BeppoSAX* PDS first (less than 10 in the 1–4.7 z range; Donato et al. 2005) and more recently by *INTEGRAL* IBIS (Bird et al. 2007) and *Swift* BAT (Sambruna et al. 2007). Here we provide evidence for the identification of a newly discovered *INTEGRAL* IBIS source, IGR J22517+2218, with a quasar (QSO) at $z = 3.668$ by means of follow-up observations with *Swift* XRT; we also present the combined X-ray/gamma-ray spectrum of the source and discuss its peculiar SED. This is the second most distant blazar ever detected above 20 keV.

2. IGR J22517+2218

IGR J22517+2218 was first reported by Krivonos et al. (2007) as an unidentified object detected during revolution 316 (150 ks exposure). Here we have combined slightly more data to reach a total exposure of 190 ks. IBIS data have been reduced following the same procedure used for our survey work (Bird et al. 2007). The source is detected with a significance of $\sim 7 \sigma$ at R.A.(J2000.0) = $22^{\text{h}}51^{\text{m}}42.72^{\text{s}}$ and decl.(J2000.0) = $+22^{\circ}17'56.4''$ with a positional uncertainty of $4.5'$ (90% confidence level; see Fig. 1); this position is 32° above the Galactic plane, suggestive of an extragalactic nature. Our position is compatible with that reported by Krivonos et al. (2007; note that their $2.1'$ error radius corresponds to 68% confidence level). The source count rate in the 20–100 keV band is 0.4 ± 0.06 counts s⁻¹ (or 2.17 ± 0.33 mcrab). We have divided all available observations in three sets of data to find evidence of flux variability but found none. The IBIS spectrum

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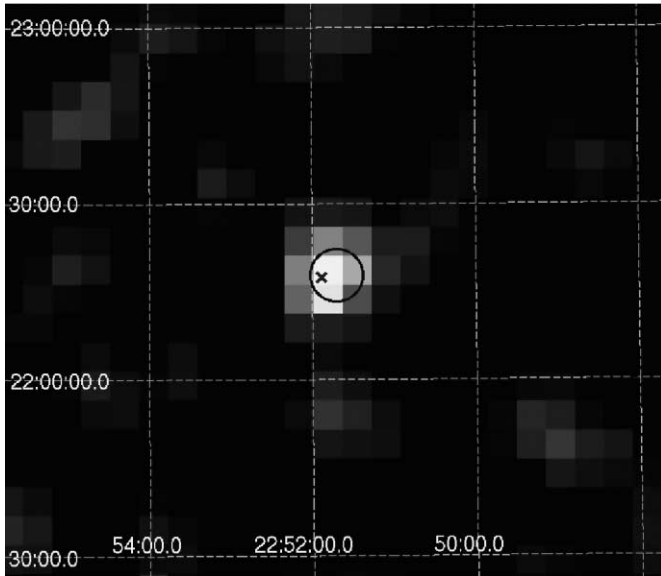


FIG. 1.—IBIS/ISGRI 20–100 keV image of IGR J22517+2218. The circle corresponds to the *INTEGRAL* IBIS error box, while the cross is the optical position of MG3 J225155+2217. [See the electronic edition of the *Journal* for a color version of this figure.]

was extracted using the standard Off-line Scientific Analysis (OSA ver. 5.1) software released by the Integral Scientific Data Centre. Here and in the following, spectral analysis was performed with the XSPEC version 11.3.2 package, and errors are quoted at 90% confidence level for one interesting parameter ($\Delta\chi^2 = 2.71$). A simple power law provides a good fit to the IBIS data ($\chi^2 = 6.5$ for 8 dof) and a photon index $\Gamma = 1.4 \pm 0.6$ combined to an observed 20–100 keV flux of 4×10^{-11} ergs $\text{cm}^{-2} \text{s}^{-1}$. Within the *INTEGRAL* IBIS error circle, we find the QSO MG3 J225155+2217 at $z = 3.668$; however, its association with IGR J22517+2218 is not straightforward as (1) there are other potential candidates in the high-energy error box for example at radio frequencies and (2) it is surprising to detect such a distant object in a short exposure with *INTEGRAL*. For this reason we have requested and obtained follow-up observations of this sky region with the XRT (Hill et al. 2004) on board the *Swift* satellite (Gehrels et al. 2004).

3. SWIFT XRT FOLLOW-UP OBSERVATION

On 2007 May 21, 22, and 26, *Swift* XRT carried out observations of IGR J225155+2217 lasting 1.6, 12.5, and 11.3 ks, respectively. Data were collected in photon-counting mode, and reduction was performed using the XRTDAS version 2.0.1 standard data pipeline package. Events for spectral analysis were extracted within a circular region of radius $20''$ (which encloses about 90% of the PSF at 1.5 keV; Moretti et al. 2004) centered on the source position. The background was taken from various source-free regions close to the X-ray source using circular/an-

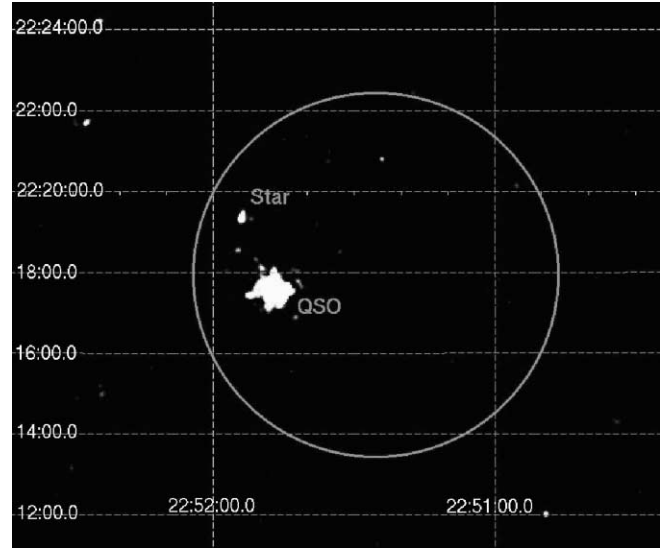


FIG. 2.—*Swift* XRT (2–10 keV) image of IGR J225155+2217. The circle corresponds to the *INTEGRAL* IBIS error box. [See the electronic edition of the *Journal* for a color version of this figure.]

nular regions with different radii, in order to ensure an evenly sampled background. In all cases, the spectra were extracted from the corresponding event files using XSELECT software and binned using GRPPHA in an appropriate way, so that the χ^2 statistic could reliably be used. We used the latest version (ver. 008) of the response matrices and create individual ancillary response files (ARF) using XRTMKARF. In all our fitting procedures we have used a Galactic column density, which in the direction of IGR J225155+2217 is $5 \times 10^{20} \text{ cm}^{-2}$ (Dickey & Lockman 1990). Using the XIMAGE detection algorithm, we searched the XRT images (0.3–10 keV band) for significant excesses (above 3σ level) falling within the *INTEGRAL* IBIS 90% confidence circle (Fig. 2); only one source (N1) was clearly detected in all three observations (at 10, 27, and 20 σ), while a second one (N2) was seen (at 4.5 σ) only in the longest XRT exposure. None of the other potential candidates in the IBIS error box is detected in X-rays. Table 1 reports for source N1 and N2 the XRT position, associated error radius, and, for each observation, net count rates and fluxes. Source N1 is the high-redshift QSO MG3 J225155+2217. Its XRT spectrum is hard and bright: a simple power-law fit to the two longest observations provides $\Gamma = 1.41 \pm 0.12$ ($\chi^2 = 28.9, 17$) and $\Gamma = 1.30 \pm 0.08$ ($\chi^2 = 34.4, 41$ dof) together with a 2–10 keV flux in the range $(2.6\text{--}3.4) \times 10^{-12}$ ergs $\text{cm}^{-2} \text{s}^{-1}$. The XRT spectrum of source N2 is, instead, very soft as no emission is detected above 3 keV; it is well fitted by a thermal bremsstrahlung model with $kT = 0.4^{+0.1}_{-0.3}$ ($\chi^2 = 4, 3$ dof) and a 2–10 keV flux of $\sim 10^{-15}$ ergs $\text{cm}^{-2} \text{s}^{-1}$. Its positional coincidence with either a double (CCDM J22519+2219AB) or a single (TYC 1710-969-1) star suggests that the X-ray emission comes from a stellar corona;

TABLE 1
SWIFT XRT DETECTIONS

Source	R.A. ^a	Decl. ^a	Error ^a	CR/Flux(obs1) ^b	CR/Flux(obs2) ^b	CR/Flux(obs3) ^b
N1	22 51 53.44	+22 17 35.86	3.6	$8.77 \pm 0.85 / 4.4 \pm 0.4$	$8.36 \pm 0.31 / 3.4 \pm 0.1$	$7.05 \pm 0.35 / 2.6 \pm 0.1$
N2	22 51 56.70	+22 19 22.90	4.6	$0.59 \pm 0.22 / \leq 0.003$	$0.21 \pm 0.06 / 0.001 \pm 0.0002$	$0.18 \pm 0.06 / \leq 0.001$

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

^a Positions and relative uncertainties (in arcseconds) are calculated using the xrtcentroid (ver. 0.27) task.

^b Count rates (CR) are extracted from the 0.3–10 keV band image using the XIMAGE detection algorithm and are in units of 10^{-2} counts s^{-1} in the band. Fluxes are in units of 10^{-12} ergs $\text{cm}^{-2} \text{s}^{-1}$ in the 2–10 keV band.

the late spectral type (F5) of CCDM J22519+2219AB is fully compatible with this hypothesis. In any case, the much lower flux (more than 3 orders of magnitude) and softer spectrum of source N2 compared to source N1 indicates that its emission is unlikely to extend into the *INTEGRAL* energy range and strongly argues in favor of the association of IGR J225155+2217 with the only other detected X-ray counterpart, i.e., the high- z QSO.

To better characterize the QSO X-ray spectrum and in view of the fact that the *INTEGRAL* detection is over a few revolutions, i.e., provides an average flux, we have combined the two most statistically significant XRT spectra and repeated the spectral analysis. To account for the high- z value, all modeling has been carried out in the source rest frame. A simple power-law fit to this stacked spectrum still provides a flat photon index ($\Gamma = 1.31 \pm 0.09$) and an acceptable $\chi^2(46.9/53)$. However, inspection of the residuals to this model reveals some curvature, possibly due to intrinsic absorption in the QSO rest frame. Addition of this extra component provides a significant fit improvement (99.98% confidence level using the F test), a steeper spectrum ($\Gamma = 1.53 \pm 0.16$), and a column density $N_{\text{H}} = 3 \pm 2 \times 10^{22} \text{ cm}^{-2}$. Intrinsic absorption is a common property of radio-loud/high-redshift QSOs (Page et al. 2005), and it is generally ascribed to the presence of absorbing material in the jet. However, this interpretation poses some difficulties as jets are expected to be efficient in removing gas in their vicinity. An alternative possibility is that the continuum is intrinsically curved (Tavecchio et al. 2007) and well described by a broken power law; indeed this model provides an equally significant improvement in the fit, a break energy at $1.55 \pm 0.15 \text{ keV}$, and a spectral flattening below 1–2 keV of $\Delta\Gamma = 0.5$ ($\Gamma_1 = 0.7 \pm 0.3$ and $\Gamma_2 = 1.2 \pm 0.4$). Finally, a joint spectral fit to the *Swift* XRT and *INTEGRAL* IBIS data was also attempted. While we find a perfect match in spectral shape with $\Gamma = 1.5 \pm 0.1$ (for an absorbed power law), the XRT data fall short of the *INTEGRAL* detection by a factor in the range 3–7 (much higher than the XRT/IBIS cross calibration constant which is typically around 1, Masetti et al. 2007), implying some variability in the source flux between observations (see Fig. 3). Indeed, when the shorter XRT observation is also used (see Table 1), a decrease in the source intensity becomes evident over the 6 day period of the *Swift* observational campaign. Variability in QSOs is not unexpected and can be used to further characterize this new gamma-ray source. Assuming that the IBIS observation represents the average state of the source, we obtain rest-frame luminosities⁶ of $0.3 \times 10^{48} \text{ ergs s}^{-1}$ in the X-ray (2–10 keV) band, $2 \times 10^{48} \text{ ergs s}^{-1}$ at hard X-rays (20–100 keV), and $5 \times 10^{48} \text{ ergs s}^{-1}$ in the soft gamma-ray (100–500 keV) interval; i.e., MG3 J225155+2217 is an X-ray/gamma-ray lighthouse shining from the edge of our universe.

4. WHAT TYPE OF QSO IS IGR J22517+2218/MG3 J225155+2217?

Although a search in the NED database only shows 10 references, the sparse information available is sufficient to broadly characterize this new *INTEGRAL* source. The NVSS (NRAO VLA Sky Survey; Condon et al. 1998) image of MG3 J225155+2217 shows the source to be core-dominated with no extended radio features and a 20 cm flux of 190 mJy. From the available data Kuhn (2004) estimated a radio loudness $\log R = 3.9$ (well above the value used to define a source as radio-loud) and a radio spectral index ($F_\nu \propto \nu^\alpha$) = -0.02 (flat enough to classify the object as a FSRQ). Incidentally, the chance

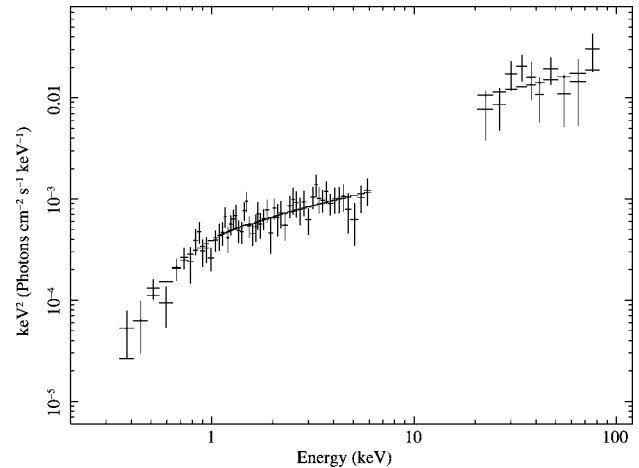


FIG. 3.—Broad-band spectrum of IGR J22517+2218/MG3 J225155+2217 fitted with an intrinsically absorbed power law (solid line): stacked XRT data to the left and IBIS data to the right

probability of finding such a bright radio source in the *INTEGRAL* error box is 0.01, further supporting the association between IGR J22517+2218 and the QSO. Optically, MG3 J225155+2217 is a broad emission line AGN (FWHM $\geq 2000 \text{ km s}^{-1}$ in the source rest frames, Falco et al. 1998); it is further labeled as a narrow absorption line (NAL) system due to the presence of absorption lines that are significantly narrower than the emission lines. These absorption features are seen in $\sim 10\%$ of the spectra of high-redshift QSOs (Boksenberg 1978) and are either intrinsic to the source or the result of intervening gas between us and the QSOs. Observations indicate that radio-loud objects with flat radio spectra tend to avoid strong NALs, intrinsic or otherwise, and this makes MG3 J225155+2217 peculiar in this respect (Ganguly et al. 2001). In X-rays/gamma-rays, the source is bright with a hard X-ray spectral shape ($\Gamma = 1.5$); a deficit of soft photons in the spectrum can be either due to absorption local to the QSO or to intrinsic spectral curvature. The source is likely variable at high energies and possibly also at lower frequencies (Kuhn 2004). Most of the above properties strongly suggest that MG3 J225155+2217 is a bright blazar, in which the emission is relativistically beamed and the SED double-peaked. In Figure 4 we construct the nonsimultaneous rest-frame SED of this enigmatic object by combining data from this work, from the HEASARC archive, and from Kuhn (2004); to cover as many frequencies as possible we have also used upper limits obtained from the *IRAS* (Moshir et al. 1990) and EGRET (Hartmann et al. 1999) surveys. To deal with high-energy variability, we have used in the SED the absorbed power-law X-ray/gamma-ray spectrum normalized to the IBIS flux. For comparison, we have also plotted in Figure 4 the synchrotron inverse Compton model used to reproduce the SED of a blazar at comparable distance ([HB89] 0836+710, $z = 2.17$; Tavecchio et al. 2000) scaled to match both the high-energy data and the redshift of MG3 J225155+2217. The first striking feature of Figure 4 is the extreme brightness of the source at X-ray/gamma-ray energies compared to the emission at lower frequencies; the X-ray to radio flux ratio is ~ 1000 (or $\alpha_x < 0.75$), which makes it similar to high-energy peaked blazars, i.e., those with the synchrotron peak in the X-ray band. The second important point is the shape of the infrared to optical continuum, which is at odds with the location of the synchrotron peak at infrared frequencies as generally observed in FSRQs like [HB89] 0836+710. Taken together, this indicates that this is a peculiar

⁶ We adopt $H_0 = 71 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_\Lambda = 0.73$, and $\Omega_M = 0.27$.

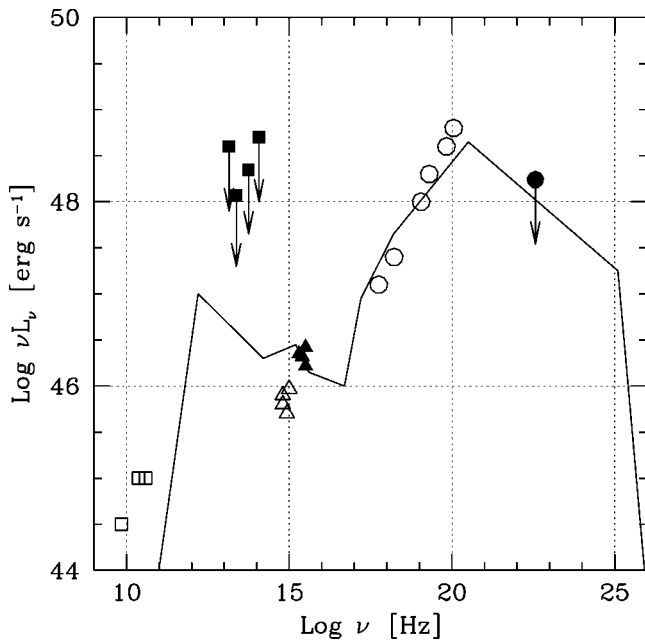


FIG. 4.—Nonsimultaneous rest-frame SED of IGR J22517+2218=MG3 J225155+2217. Data have been taken from the HEASARC archive (radio: *open squares*; optical: *filled triangles*), Moshir et al. (1990; far-infrared/IRAS: *filled squares*), Kuhn (2004; near-infrared: *open triangles*), this work (X-rays/XRT-IBIS: *open circles*), and Hartman et al. (1999; gamma rays/EGRET: *filled circle*). The line represents the SED of [HB89] 0836+710 normalized to MG3 J225155+2217 (see text)

and rare object within the blazar population (Padovani 2007). Until recently, no high-energy peaked FSRQ seemed to exist, but some are now emerging such as the very powerful $z \sim 4$ FSRQ ROXA J081009.9+384757.0, with a possible synchrotron peak in the X-ray band (Giommi et al. 2007). If the peak we see at ~ 100 keV (or ~ 400 keV in the source rest frame) is due to the synchrotron component, then (1) the blazar sequence in its simple formulation (Fossati et al. 1998) would be severely questioned by this result, (2) the observed peak energy would be the highest ever measured in a FSRQ meaning that no dif-

ference in this parameter exists between low- and high-luminosity blazars, and (3) the Compton peak would be well into the gamma-ray band, making the source a good target for AGILE and GLAST. Obviously, the sparse and nonsimultaneous data coverage still leaves open the possibility of a more classical double-humped interpretation of the source SED; but even in this case the object is strange as not only the above peculiarities have to be explained, but in this case the Compton peak would be at MeV energies, i.e., at lower energies than those typically observed in FSRQs. Either way, MG3 J225155+2217 is quite atypical for its class and an extreme object in the blazar population; this makes it an interesting laboratory in which to test current blazars theories and so an object worth following up at all wave bands.

5. CONCLUSIONS

Through X-ray follow-up observations with *Swift* XRT, we have been able to identify the newly discovered *INTEGRAL* source, IGR J22517+2218 with MG3 J225155+2217, a QSO at $z = 3.668$. This makes IGR J22517+2218 the most distant object so far detected by *INTEGRAL* and the second most distant blazar ever observed above 20 keV. The source has many peculiar features that deserve more in depth studies: it is a radio-loud object with a flat spectrum, it hosts an NAL system in optical, it shows a spectral curvature in X-rays either intrinsic or due to high absorption in the source rest frame, and it is variable at high energies. The source SED is also unusual among FSRQs as it is compatible with having the synchrotron peak in the X-ray/gamma-ray band (i.e., much higher than generally observed) or alternatively with the Compton peak in the MeV range (i.e., lower than typically measured).

We acknowledge financial support from ASI (contracts I/R/008/07/0 and I/023/05/0) and PPARC (grant PP/C000714/1). This research has made use of the NED NASA/IPAC Extragalactic Database (NED) operated by JPL (Caltech) laboratory and of the HEASARC archive provided by NASA's Goddard Space Flight Center.

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