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Catalog: WGACAT**

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THE SOFTEST X-RAY SOURCES IN THE ROSAT POINTED CATALOG: WGACAT

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Received 4/26/95; accepted 6/21/95

To appear in *The Astrophysical Journal*, 1995 Dec. 20

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ABSTRACT

We present a selection of X-ray sources with the softest observed spectral characteristics, and discuss their nature. These 'ultrasoft' sources were detected in 3 years of pointings with the *ROSAT*. These sources are predominantly found to be white dwarfs, magnetic cataclysmic variables, nearby late-type stars, and very X-ray soft active galactic nuclei. The broad-band colors of the unidentified ultrasoft sources suggest that a number of them may have at least two components in their spectrum, as for example, is found in most cataclysmic variables. Some of these objects may represent the extreme of their respective populations, for example, unusual galaxies, 'supersoft' sources with steep low energy spectrum and high X-ray luminosity ($\sim 10^{38}$ ergs s $^{-1}$), active galactic nuclei, stars etc. Follow-up studies in the optical and other wavebands are needed.

Subject headings: X-rays: sources — White dwarfs — Cataclysmic variables — AGN

1. INTRODUCTION

The recent availability of the soft X-ray source catalog of 62,000 sources by White, Giommi, & Angelini (1994), henceforth WGACAT, constructed from 3 years of *ROSAT* pointings is a very valuable resource for identifying and studying many different classes of X-ray emitters. For example, a new class of 'supersoft' X-ray sources, characterized by a blackbody spectrum with a temperature of a $\sim \text{few} \times 10$ eV and a bolometric luminosity of $\sim 10^{38}$ ergs s $^{-1}$, has recently been discovered with *ROSAT* (Hasinger 1994). Although first discovered in the Magellanic Clouds, examples of supersoft sources have also been found in our galaxy (Beuermann et al. 1995), and in the M31 galaxy (White et al. 1995). In addition to this new type of supersoft sources, believed to be accreting white dwarfs (van den Heuvel et al. 1992), there are other classes of objects which have extremely soft X-ray spectra. The most prominent of these are white dwarfs (WDs) (see Barstow et al. 1993), magnetic cataclysmic variables (MCVs, magnetic field $B \geq 100$ kG), and some late-type stars. We have attempted to isolate the softest X-ray sources listed in the latest version (Rev 1.0) of the WGACAT. These detections have spectral properties similar to that of WDs, MCVs, late-type stars, and some active galactic nuclei (AGN). Therefore, we believe that we have identified many new MCVs, WDs, and other assorted classes of objects worthy of follow-up observations at other wavelengths.

2. ROSAT PSPC : SOFTNESS AND HARDNESS RATIOS

WGACAT is based on observations with the *ROSAT* X-ray telescope and a position sensitive proportional counter (PSPC) as the detector (Trümper 1983; Pfeffermann et al. 1987). The PSPC has an energy resolution ($\Delta E/E$) of $\simeq 0.42$ at 1 keV and a bandwidth of 0.1 - 2.4 keV. The energy of X-rays is analyzed using a pulse height analyser (PHA) with

256 channels. The source counts for WGACAT are calculated for 3 broad-bands of PHA channels – low-band for PHA channels 11 – 39 corresponding to energy range of 0.1 – 0.4 keV, mid-band for PHA channels 40 – 85 corresponding to energy range of 0.4 – 0.9 keV, and a high-band for PHA channels 86 – 200 corresponding to energy range 0.9 – 2.0 keV. The softness and hardness ratios (henceforth, SR and HR, respectively) of the sources are then defined as the ratio of low-band to mid-band counts, and the ratio of high-band to mid-band counts, respectively.

3. DISTRIBUTIONS OF SOFTNESS RATIO

We examined the softness ratio distribution for the WGACAT sources identified with the most commonly known classes of sources, viz., active galactic nuclei (AGN), stars, and galaxies from several catalogs (White et al. 1994 [for details please refer to the *ROSAT* home page on the World Wide Web at the address given in the reference section]). For this purpose we selected all available entries of identified sources with a signal-to-noise ratio of ≥ 3.0 , and $SR \geq 2\sigma_{SR}$ where σ_{SR} is the one sigma error in SR. All observations of a particular source were accepted, so that effects of variability are included in the analysis. The histograms of SR for different classes are shown in Figures 1(a) and 1(b). Figure 1(a) is based on 4414 observations of late-type stars, and 1137 observations of early-type stars, Figure 1(b) is based on 1854 observations of AGN, and 2625 observations of galaxies. The distribution of SR for AGN and late-type stars seems to level off around a median value of 2, whereas that for galaxies and early-type stars continues to rise. All the distributions in Figs. 1(a) and 1(b) drop sharply near 10, signifying the difficulty of detecting very soft objects or their lack thereof among the commonly known populations of sources. Very few or a negligible fraction of AGN, galaxies and early-type stars have $SR > 10$. Some late-type stars, however, do have $SR > 10$ and for some of them SR even extends beyond

the referenced limit of 14.5 in the Figs.1(a) and 1(b). The distributions shown in Fig.1(a) and 1(b) can be compared with the histogram of SR shown in Figure 2 for a sample of $\simeq 15000$ well-defined sources detected in the WGACAT, and which remain unidentified in the catalog. The comparison shows that the distribution in Fig.2 is much broader than in Fig.1, and that there is a significant number of unidentified objects with $SR \geq 8$, the tail end of the distribution in Fig.1. To examine what kind of objects are likely to have such large values of SR, we looked at other classes of objects and found that those classified as WDs (McCook & Sion 1987), and CVs (Shara, Shara & McLean 1993) are the most likely ones to have large values of SR. A histogram of SR for WDs and CVs is shown in Figure 3, which shows a broad distribution for WDs in the range 0 - 20 and a secondary peak near 100. The distribution of CVs, however, is almost similar to that of other objects in Fig.1, with the exception of a possible secondary peak in the range 20 - 40 for the CVs. The identification of CVs in the WGACAT is based mostly on the catalog by Shara et al. (1993), and a number of recently discovered CVs have been missed (see below). Based on the data in Figs. 1 and 3, we have quantified the frequency of occurrence of broad categories of identified objects in a histogram in Figure 4, which displays the percentage distribution of SR for (i) late and early-type stars, (ii) galaxies & AGN, and (iii) CVs & WDs. The different classes in Figs. 1 and 3 were merged for convenience of representation. This diagram shows that the frequency of occurrence with $SR \geq 10$ is highest for CVs and WDs. Although a few stars may also have a high value of SR, it is possible that some of these objects may be misclassified. Based on the distributions shown in Figs. 1 to 4, we assign the name of Ultrasoft Sources (to distinguish them from the so-called Supersoft Sources [Hasinger, 1994]) to all sources with $SR \geq 10$.

4. IDENTIFICATION CONTENT OF THE ULTRASOFT SOURCES

Following the same selection criterion for observations as in §3, we now select all the observations of ultrasoft sources i.e., those with softness ratio of ≥ 10 . These were further divided into identified and unidentified sources. The classification was not restricted to the 6 classes used in Figs. 1 & 3, rather we used all the identities provided in WGACAT, followed by a search of the SIMBAD database using an error circle of 1 arcmin radius. A list of all the identified ultrasoft objects is given in Table 1, and that of the unidentified ultrasoft sources is given in Table 2. The catalog name, the right ascension (2000), the declination (2000), the observed count rate, and the variability parameter χ^2 (Giommi, White, & Angelini 1995) as given in the WGACAT are listed in the Tables. The identities of the sources are also given in Table 1. In Table 2, we give the uncertainty of the source position (error radius) in arcsec, which depends on the offset of the source from the center of the field, and the values of SR and HR. The χ^2 values are for 2 degrees of freedom obtained from a Kolmogorov-Smirnov test performed on all sources using the method described in Giommi et al. (1995). Values greater than 12-15 indicate significant variability. Since the method compares the light curve of the source with that of the entire image, significant χ^2 values might also mean that the background is variable (a rare event in which all bright sources in the image have high χ^2 values). All variability events were, therefore, confirmed individually. Significant variability is confirmed in 13 of the 14 sources with suspected variability. The only unconfirmed case is that of a weak unidentified source, J2200.1-3035. Among these variable sources, 7 are known AM Her type CVs, 1 is a late-type star, and 5 are unidentified sources. The unidentified variable sources, therefore, have a good chance of being identified as AM Her type CVs or stars. The light curves of 10 of these sources that have the most interesting variations, including 3 that are unidentified, are shown in Figure 5.

Some of the weak ultrasoft sources were found, on a closer examination of the images, to be likely “ghost” images (Nousek & Lesser 1993) of nearby bright soft X-ray sources and

were deleted from Table 2 and ignored in the following analysis. There are thus, a total of 79 unidentified ultrasoft sources in Table 2. Most of these have well-defined image quality expected from a point source, however, some of them have complex morphology due to large offset and therefore, a poorer quality of the point spread function, or are in complex regions of diffuse X-ray emission. These so-called complex sources are: J0336.1-2612, J0347.0-1224, J0458.6-3852, J1003.3+4808, J1008.4+3520, J1115.5+1738, J1115.6+4102, J1309.9+3534, J1310.0+3451, J1341.2+4109, J1646.3+5841, J1657.8+4347, J2200.1-3035.

The observations of all the ultrasoft X-ray sources selected were plotted as SR versus HR color-color diagrams, to better understand their nature. In Figure 6 we show the color-color diagram from observations of all the ultrasoft sources that have been identified with known objects, and similarly in Figure 7 we show all such measurements from 87 observations of 79 unidentified objects. The most prominent classes of objects that can be identified in Table 1 and Figure 6 are the white dwarfs (106 observations of 38 WDs where HZ 43 and 1629+78 were observed 66 times), MCVs (30 observations of 15 CVs), late-type stars (18 observations of 9 stars), some early-type stars (one of which is an O star in a planetary nebula), and some unclassified stars (most of which have blue colors). In Figure 6, the WDs occupy the most exclusive region having the softest colors. The MCVs (and a few late-type stars) are somewhat harder. There are, however, some WDs too with a harder spectra that co-exist with the MCVs. The spectral properties of these sources will be discussed in §5. Apart from these WDs and MCVs, we also find some other interesting types of sources which are briefly discussed below.

- (a) Three of the supersoft sources discovered in the Magellanic Clouds viz., J0037.3-7214, J0058.5-7135, and J0439.8-6809 (Hasinger 1994), and a recently discovered Galactic supersoft source J0019.8+2157 (Beuermann et al.1995). Only 3 of the many supersoft sources in the Magellanic Clouds appear in this color-color plot because the high

absorption in the direction of the other supersoft sources hardens their observed colors.

- (b) Three sources associated with other external galaxies viz., FRL 738, KUG 1259+280, and KUG 1331+382. The first one is a compact galaxy with a bright nucleus at a redshift of 0.0591 (Fairall 1984). Its X-ray luminosity of $\sim 2 \times 10^{42}$ ergs s⁻¹ is like that of a low-luminosity AGN but with an unusually soft spectrum. The second of these galaxies is a starburst spiral and appears to be in a small group of 4 galaxies within an arcmin, and near the Coma cluster. KUG 1259+280 is the brightest among these 4 galaxies with a magnitude of 15.4 (Takase & Miyauchi-Isobe 1985) and has a heliocentric radial velocity of 7203 km s⁻¹. It is closest to the X-ray source position. The second brightest galaxy with a magnitude of 17.1 and radial velocity of 6816 km s⁻¹ was earlier identified as an X-ray source in the *EXOSAT* high galactic latitude survey by Giommi et al. (1991). The other 2 galaxies in the group are much fainter and their velocities are unknown. Assuming that the ultrasoft source is associated with KUG 1259+280 we obtain an X-ray luminosity of $\sim 3 \times 10^{42}$ ergs s⁻¹ for this source, similar to that of a low-luminosity AGN. KUG 1331+382 is a another spiral galaxy with a magnitude of 17.5 but its radial velocity is not known (Takase & Miyauchi-Isobe 1989). The ultrasoft X-ray source associated with this galaxy could be variable based on another exposure and therefore, may signify a highly luminous point source or an AGN in the galaxy. Similarly unusual ultrasoft AGN has recently been found in a Seyfert type galaxy, Zwicky 159.034 (RE J1237+264), by Brandt, Pounds & Fink (1995).
- (c) Four early-type (O - A3) stars, one of which is in a planetary nebula NGC 1360 (Feibelman 1994). This was previously detected by the *EXOSAT* and *Einstein* observatories (Apparao & Tarafdar 1989).

- (d) The planetary nebula known as the Dumbbell (NGC 6853, M27), the X-ray emission from which is most probably extended (Kreysing et al. 1992).
- (e) A well known symbiotic nova – RR Tel (Allen 1981).
- (f) The Geminga pulsar (Halpern & Holt 1992), with a very soft blackbody component and low N_H .
- (g) Two QSOs in an extended field around 1338+27, both of which are weak emission line objects in a spectroscopic survey of quasars in that field (Crampton et al. 1988). The brighter of the two QSOs, J1342.3+2720, has a magnitude of 17.2 and is at a redshift of 0.704. The other object, J1336.7+2721, is of 19.4 magnitude and a redshift of 1.95.

5. UNIDENTIFIED ULTRASOFT SOURCES AND THEIR LIKELY SPECTRAL PROPERTIES

To further learn about the sources in Table 2 and Figure 7 (also Table 1 & Fig. 6), we have investigated their general spectral properties by simulating the SR and HR expected for some standard types of spectral models. We choose to present SR and HR for the models that can be appropriately used for a variety of objects listed in Table 1. These models are:

- (i) Blackbody emission or thermal plasma emission models at different temperatures (Raymond & Smith 1978; Raymond 1990), useful for WDs, MCVs and late-type stars.
- (ii) Power-laws of varying photon index (Γ), useful for AGN.
- (iii) A powerlaw with flat ($\Gamma=1$) slope, having various exponential cut-off energies (cut-off powerlaw), and 4 edges at 0.391 keV, 0.487 keV, 0.665 keV and 0.758 keV for mimicing the emission from a white-dwarf atmosphere (Heise 1995).

- (iv) Combinations of a blackbody and a very hot ($kT = 25$ keV) thermal bremsstrahlung component as is characteristic of the spectra of MCVs. In this example, the normalizations of both components were kept equal.

A cold absorber model for the interstellar medium assuming absorption cross-sections given by Morrison & McCammon (1983), was used along with each of the above models. The colors generated from such simulations for different values of intervening interstellar absorption columns (N_H) ranging from $0.1 - 30.0 \times 10^{19} \text{ cm}^{-2}$ are shown in Figures 8(a)-(d), and can be directly compared with those of Figs. 6 & 7. The range of other parameters that produce the colors shown in Figs. 8(a)-(d) are

- (i) a kT of 45 (60) - 90 eV (120 eV) for blackbody temperature (plasma emission temperature) [Figs. 8(a) & (b)],
- (ii) a Γ of 2 - 10 for the power laws [Fig. 8(c)],
- (iii) an exponential cut-off energy of 90 - 400 eV [Fig. 8(d)], and
- (iv) a kT of 15 - 75 eV for the blackbody temperature in the two-component spectra [Fig. 8(a)].

For lower values of kT in (i) and (iii), and higher values of Γ in (ii) above, the SR continues to rise but the HR drops very rapidly. Because of the limited range of the log scale on the y-axis in Figs. 8(a)-(d), this range is not fully represented in the Figures.

A general feature for all types of spectra in Figs. 8(a)-(d) is that SR decreases with increasing N_H . Therefore, one immediate result of comparison of Fig. 8 with Figs. 6 & 7 is that, for most ultrasoft sources the N_H must be quite low ($\leq 10^{19} \text{ cm}^{-2}$). This is consistent with the distribution of these sources in the galactic coordinates which shows that nearly all the unidentified sources avoid the galactic plane and the galactic center

regions, being at latitudes $\geq 10^\circ$. Some of the identified sources which are at lower galactic latitudes are known to be nearby. Secondly, for models (i) - (iii) above, the SR decreases with increasing kT for models (i), decreasing Γ for models (ii), and increasing cut-off energy for models (iii). For the 2-component spectra as in model (iv), the HR decreases whereas the SR first increases and then decreases, as the blackbody temperature increases. This leads to the following results:

For sources with $SR \geq 100$ but with negligible HR, if represented by the thermal spectra, the N_H must be $\leq 10^{19} \text{ cm}^{-2}$ and the kT also must be very low e.g., for an RS plasma with kT of 45 eV and $N_H = 0.1 \times 10^{19} \text{ cm}^{-2}$, $SR = 119$ and $HR \simeq 0$. However, in the case of a powerlaw, N_H can be upto $30 \times 10^{19} \text{ cm}^{-2}$ but the spectrum is still required to be very steep ($\Gamma \geq 4$). Most sources in this region are WDs (see Fig. 6). For sources with $SR \leq 100$ there are many more possibilities depending on their value of HR. For $HR \leq 0.1$ similarly steep models with higher N_H are needed. For higher values of HR, the sources in Figs. 6 & 7 cannot have spectra consisting of a single component blackbody or thermal plasma. Such sources could have a power-law type spectra which is somewhat flatter, $\Gamma = 2.0 - 4.0$, or cut-off power-law resembling a WD atmosphere. In either case, a wide range of values for N_H of $0.1 - 30.0 \times 10^{19} \text{ cm}^{-2}$ would be possible. Other possible spectra for such sources are two-component spectra of which we give one example, the combination of a blackbody and thermal bremsstrahlung. The last of these is taken to represent MCVs, and in fact, overlaps the same range in the color-color plots that is occupied by the MCVs in Fig. 6. A comparison of Fig. 6 with Figs. 8(a)-(d) shows that there are some WDs that have $SR \geq 100$ and $HR \sim 0.5$, a region avoided by the models used by us in Figs. 8(a)-(d). This could be due to either a larger error in the observed values of HR of these sources which are particularly sensitive to the background subtraction or the failure of the coarse models used to mimic the WD atmospheres. Most of the unidentified sources (see Fig. 7) appear to have SR in the range of 10 to 30 and $HR \geq 0.1$, thus their X-ray spectra either

need to be of a composite nature like that of MCVs or have less steep power-laws ($\Gamma \leq 2.0$), and moderate N_H .

6. CONCLUSIONS

We have used broad-band X-ray colors to isolate the softest population of X-ray sources detected in 3 years of *ROSAT* PSPC pointings. In most cases, the extreme softness of these sources is due to a very low column density in their direction, as a consequence, most of the low galactic latitude sources are expected to be nearby. The softest among these sources have been identified with white dwarfs. The other sources mostly represent polar-type CVs or late-type stars. Although our selection criterion is efficient in picking up white dwarfs, MCVs, late-type stars, and unusual AGN, it does not pick up all such objects and all such objects do not necessarily have ultrasoft spectra. A few examples of luminous soft sources in external galaxies also show up in our sample and may have some extremely interesting and unusual properties. This list of unidentified sources probably contains many MCVs, WDs, AGN, and, possibly, a new class of objects with composite spectra. Follow-up optical study of these unidentified ultrasoft sources is now required. Most of them have no optical counterpart in the Guide Star Catalog (GSC), suggesting that they are typically fainter than 16th magnitude. It should, however, be borne in mind that the GSC is not a complete list of stars brighter than 16th magnitude and hence brighter objects may be found in the error circles of this unidentified population. An application of similar selection criteria to the *ROSAT* Sky Survey data should reveal many more such objects.

7. Acknowledgements

We thank Steve Fantasia for providing the variability curves, and Steve Drake for his general comments and suggestions. This research has made use of *ROSAT* archival data obtained through the High Energy Astrophysics Science Archive Research Center, HEASARC, Online Service, provided by the NASA-Goddard Space Flight Center. The HEASARC database, the Simbad database, operated at CDS, Strasbourg, France; and the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, Caltech, under contract with the NASA were used to identify some of the objects.

TABLE 1
LIST OF IDENTIFIED ULTRASOFT X-RAY SOURCES IN THE WGACAT

NAME (1WGA)	RA(2000) (hh mm ss)	DEC(2000) (° ' ")	Count Rate (Counts s ⁻¹)	χ^2	Type	Other Names
White Dwarfs						
J0029.9-6324	00 29 56.9	-63 24 59	0.389 ± 0.0130	8.0	DA	RE J0029-632
J0039.8+3132	00 39 52.0	31 32 33	0.046 ± 0.0021	3.3	DA	GD 8, WD 0037+312
J0053.2-3300	00 53 17.2	-33 00 02	0.277 ± 0.0094	9.4	DA	GD 659, RE J0053-325
J0118.6-2254	01 18 36.4	-22 54 53	0.001 ± 0.0003	1.7	DA	GD 695, WD 0116-231
J0134.4-1607	01 34 24.2	-16 07 20	0.188 ± 0.0150	7.1	DA	GD 984, RE J0134-160
J0138.8+2523	01 38 52.8	25 23 19	0.080 ± 0.0065	1.0	DA	PG 0136+251, RE J0138+252
J0322.2-5345	03 22 14.6	-53 45 11	0.036 ± 0.0015	1.6	DA	BPS CS 22968-036
J0417.1-5457	04 17 11.7	-54 57 54	0.003 ± 0.0008	9.9		WD 0416-551, EXO 0416.1-5505
J0443.0-0346	04 43 05.6	-03 46 16	0.975 ± 0.0150	0.1	DA	RE J0443-034
J0534.3-0213	05 34 21.7	-02 13 54	0.008 ± 0.0020	2.7	DA	RE J0534-021
J0550.6+0005	05 50 37.1	00 05 47	0.081 ± 0.0045	1.5	DAw	GD 257, RE J0550+000
J0633.7+1041	06 33 42.9	10 41 25	0.018 ± 0.0038	1.7	DA	RE J0633+104
J0715.2-7025	07 15 16.6	-70 25 10	0.399 ± 0.0120	0.9	DA	RE J0715-702
J0739.3+0513	07 39 18.3	05 13 27	1.330 ± 0.0170	0.5	F	GJ 280B, WD 0736+053
J0827.0+2844	08 27 05.1	28 44 10	0.068 ± 0.0052	6.2	DA	RE J0827+284
J0907.7+5058	09 07 47.2	50 58 19	0.032 ± 0.0028	0.7	DA	PG 0904+511, RE J0907+505
J0916.9-1946	09 16 58.0	-19 46 19	0.193 ± 0.0086	5.5	DA	RE J0916-194
J1013.4+0612	10 13 27.8	06 12 05	0.014 ± 0.0016	5.5	DA	PG 1010+064
J1032.1+5329	10 32 07.5	53 29 20	0.964 ± 0.0110	1.0	DA	RE J1032+532
J1043.5+4454	10 43 32.2	44 54 03	0.048 ± 0.0032	0.5	sd:B	PG 1040+451, RE J1043+445
J1146.5+0012	11 46 34.8	00 12 23	0.010 ± 0.0015	5.4	DO	WD 1144+004
J1201.7-0345	12 01 45.7	-03 45 14	0.029 ± 0.0017	0.2	DO	GW Vir, RE J1201-034
J1236.7+4755	12 36 45.6	47 55 29	0.315 ± 0.0120	2.8	sd:B	PG 1234+482, RE J1236+475
J1257.0+2201	12 57 02.9	22 01 46	0.375 ± 0.0069	0.7	DAw	GD 153, RE J1257+220, LTT 13724, PG 1254+223

Table 1 (contd.)

J1316.3+2905	13 16 22.5	29 05 57	64.15 ± 0.14	0.4	DAw	HZ 43A, RE J1316+290, WD 1314+293, PG 1314+294
J1406.0-0758	14 06 04.8	-07 58 17	0.034 ± 0.0029	4.5	DA	PG 1403-077, WD 1403-077
J1446.0+6329	14 46 01.1	63 29 13	0.034 ± 0.0032	0.8	DA	RE J1446+632, F8 BD+64 1026
J1502.1+6612	15 02 10.3	66 12 11	2.460 ± 0.0230	1.5	DZ	PG 1501+664, RE J1502+661
J1629.1+7804	16 29 10.6	78 04 30	0.915 ± 0.0150	0.2	DA	WD 1631+78, RE J1629+780
J1638.4+3500	16 38 25.8	35 00 05	0.068 ± 0.0043	1.3	DA	PG 1636+351, RE J1638+350
J1658.8+3418	16 58 50.7	34 18 52	0.028 ± 0.0023	1.8	DA	PG 1657+344, WD 1657+343
J1659.8+4400	16 59 48.7	44 00 58	0.017 ± 0.0018	3.0	DAP	PG 1658+440, RE J1659+440
J1820.4+5805	18 20 24.6	58 05 30	0.196 ± 0.0140	9.8	DA	RE J1820+580
J1821.8+6422	18 21 52.0	64 22 00	0.035 ± 0.0045	1.7	PN	DS Dra, RE J1821+642
J2004.2-5602	20 04 15.9	-56 02 29	0.009 ± 0.0027	6.3	DA	RE J2004-560, EXO 2000.3-5611
J2013.1+4002	20 13 09.2	40 02 14	0.127 ± 0.0069	1.9	DA	RE J2013+400
J2312.3+1047	23 12 21.3	10 47 00	0.578 ± 0.0078	0.1	DAw	GD 246, RE J2312+104
J2324.5-5441	23 24 31.0	-54 41 35	0.158 ± 0.0065	0.6	DA	RE J2324-544
Cataclysmic Variables						
J0140.9-6753	01 40 58.6	-67 53 24	0.455 ± 0.005	8.0	AM Her	BL Hyi, RE J0141-675
J0335.4-2544	03 35 28.0	-25 44 19	$(0.24-0.90) \pm 0.06$	16.0	AM Her	UZ For, EXO 0333.3-2554
J0350.3+1715	03 50 21.9	17 15 35	$(0.02-0.04) \pm 0.01$	1.3	WD*	V471 Tau, RE J0350+171
J0453.4-4213	04 53 25.6	-42 13 35	$(0.16-0.29) \pm 0.005$	2.9	AM Her	RE J0453-42
J0751.2+1444	07 51 17.0	14 44 05	1.960 ± 0.020	1.5	DQ Her	RE J0751+144
J0815.1-1903	08 15 06.7	-19 03 09	2.530 ± 0.0130	52.1	AM Her	VV Pup, J0815-190
J1051.5+5404	10 51 34.2	54 04 39	$(0.375-0.647) \pm 0.01$	93.7	AM Her	EK UMa, J1051+540
J1104.4+4503	11 04 27.3	45 03 38	0.512 ± 0.015	38.0	AM Her	AN UMa, RE J1104+450
J1117.2+1757	11 17 15.3	17 57 42	0.055 ± 0.002	12.1	AM Her	DP Leo, 1E 1114.6+1814
J1409.1-4517	14 09 06.3	-45 17 24	$(2.27-3.35) \pm 0.005$	1.8	AM Her	V834 Cen, EXO 1405-451
J1816.2+4952	18 16 14.0	49 52 18	74.37 ± 0.13	0.5	AM Her	AM Her, 1E 1815.0+4948

Table 1 (contd.)

J1844.8-7418	18 44 48.1	-74 18 36	1.140 ± 0.0180	8.4	AM Her	RE J1844-741
J1938.5-4613	19 38 35.7	-46 13 03	0.350 ± 0.0057	4.0	AM Her	RE J1938-461
J2005.6+2240	20 05 41.8	22 40 06	1.190 ± 0.0093	36.3	AM Her	QQ Vul, RE J2005+224
J2107.9-0517	21 07 58.4	-05 17 36	0.518 ± 0.0077	11.2	AM Her	RE J2107-051
Late Type Stars						
J0025.6-7715	00 25 38.4	-77 15 23	0.018 ± 0.0027	2.2	G2IV	HD 2151, β Hyi
J0610.2-7445	06 10 15.9	-74 45 06	0.027 ± 0.0034	12.8	G6V	HD 43834, α Men
J1439.6-6050	14 39 38.9	-60 50 23	1.810 ± 0.0240	0.2	G2V	HD 128621, α Cen
J1538.0+6603	15 38 01.1	66 03 32	0.002 ± 0.0006	3.3	K0	BD+66 914, SAO 16793
J1601.6+6648	16 01 39.8	66 48 09	0.325 ± 0.0150	1.3	K0	BD+67 922, AG Dra
J1631.9+4358	16 31 54.5	43 58 52	0.114 ± 0.0099	1.6	G0	BD+44 2586
J2100.0-4238	21 00 05.1	-42 38 48	0.013 ± 0.0015	6.7	K3	CD-43 14304
J2347.7-2610	23 47 42.8	-26 10 52	0.024 ± 0.0051	5.8	G8	HD 223219, CD-26 16784
J2339.3+7737	23 39 18.9	77 37 10	0.006 ± 0.0011	3.4	K1III	HD 222404, γ Cep
Early Type Stars						
J0333.2-2551	03 33 13.3	-25 51 56	0.023 ± 0.0026	2.1	O/PN	NGC 1360, PHL 1556
J0648.0-4418	06 48 04.6	-44 18 54	0.090 ± 0.0043	0.4	O6p	HD 49798, CD-44 2920
J1104.4+3814	11 04 29.7	38 14 15	$(0.01-0.013) \pm 0.0014$	6.0	A3III	HD 95934, 51 UMa
J1135.8-6301	11 35 48.5	-63 01 02	0.041 ± 0.0048	2.4	B9III	HD 100841, λ Cen
Unclassified Stars						
J0514.1-4001	05 14 06.4	-40 01 22	0.005 ± 0.0008	3.3		NGC 1851
J1059.2+5124	10 59 16.4	51 24 49	0.742 ± 0.0160	1.5	Blue	LB 1919, RE J1059+512
J1312.5+2832	13 12 30.6	28 32 09	0.031 ± 0.0033	0.7	Blue	US 423
J1328.2+3617	13 28 14.0	36 17 32	0.025 ± 0.0044	2.7		CSO 989

Table 1 (contd.)

Super Soft Sources						
J0019.8+2157	00 19 49.7	21 57 01	$(0.93-1.06) \pm 0.01$	0.8		Galactic source
J0037.3-7214	00 37 18.5	-72 14 03	0.208 ± 0.006	7.5		SMC (WW 13), 1E 0035.4-7230
J0058.5-7135	00 58 35.7	-71 35 43	0.249 ± 0.005	0.2		SMC (WW 43), 1E 0056.8-7154
J0439.8-6809	04 39 50.3	-68 09 08	0.584 ± 0.015	0.4		LMC source
Galaxies and AGN						
J0308.5-4743	03 08 35.8	-47 43 29	0.011 ± 0.0018	0.8		FRL 738
J1301.9+2746	13 01 59.5	27 46 51	0.086 ± 0.0030	1.7	S0/Sp	KUG 1259+280, EXO 1259.6+2803
J1334.1+3800	13 34 11.0	38 00 21	0.005 ± 0.0013	8.2	S	KUG 1331+382
J1336.7+2721	13 36 47.0	27 21 18	0.005 ± 0.0011	1.9	QSO	1334.5+2736
J1342.3+2720	13 42 21.3	27 20 58	0.017 ± 0.0036	1.5	QSO	1340+275
Assorted Types						
J0633.9+1746	06 33 54.3	17 46 12	0.214 ± 0.0075	2.1	Pulsar	Geminga, 1E 0630.9+1748
J1959.6+2243	19 59 36.6	22 43 26	$(0.034-0.045) \pm 0.0027$	3.2	PN	Dumbbell, M27, NGC 6853, RE J1959+224
J2004.3-5543	20 04 19.0	-55 43 24	$(0.043-0.057) \pm 0.005$	2.7	Nova	RR Tel, IRAS 20003-5552

Notes:

1. The χ^2 is the variability parameter in the WGACAT (see text). The variability seen in different observations is indicated as the range of values in columns 4 and 5.
2. RE: EUV source (Pye et al. 1995); 1E: Einstein X-ray source (Harris et al. 1990, Plummer et al. 1991); EXO: EXOSAT source (Giommi et al. 1991).

TABLE 2
LIST OF UNIDENTIFIED ULTRASOFT X-RAY SOURCES IN THE WGACAT

NAME (1WGA)	RA (2000) (h m s)	DEC (2000) (° ' ")	Error Radius (")	Count Rate (Counts s ⁻¹)	SR	HR	χ^2
J0016.0-3914	00 16 01.0	-39 14 36	13	0.0045±0.0006	10.9±3.4	0.18±0.14	2.0
J0139.2-5430	01 39 13.4	-54 30 05	13	0.0124±0.0015	13.9±4.3	0.27±0.18	1.5
J0205.7-1337	02 05 45.9	-13 37 53	50	0.0536±0.0059	16.5±3.4	0.6±0.2	1.3
J0309.3-4741	03 09 19.8	-47 41 39	50	0.0050±0.0012	10.6±5.0	2.4±1.3	1.8
J0335.5-3449	03 35 34.4	-34 49 58	13	0.0280±0.0016	74±17	0.25±0.12	19.1
J0336.1-2612	03 36 07.9	-26 12 07	50	0.0096±0.0019	11.7±3.9	1.5±0.6	8.8
J0347.0-1224	03 47 04.1	-12 24 42	50	0.0041±0.0012	10.3±4.1	1.4±0.7	2.4
J0406.4-3112	04 06 29.1	-31 12 31	50	0.0070±0.0017	10.7±3.7	1.8±0.7	0.5
J0415.5-1140	04 15 35.3	-11 40 34	13	0.0033±0.0008	11.6±4.6	0.0	2.0
J0447.9-4403	04 47 57.5	-44 03 01	70	0.0079±0.0015	10.2±3.6	1.4±0.63	0.7
J0453.4-4213	04 53 25.6	-42 13 35	13	(0.16-0.30)±0.005	(36-40)±4.0	(0.14-0.28)±0.06	2.9
J0458.6-3852	04 58 36.8	-38 52 33	50	0.0067±0.0015	21.5±9.0	2.0±1.0	1.6
J0505.6+0158	05 05 38.4	01 58 28	50	0.0343±0.0025	13.1±1.7	0.63±0.12	1.5
J0633.3-2311	06 33 22.0	-23 11 10	50	0.0135±0.0013	15.6±3.3	0.38±0.15	2.4
J0639.4-6224	06 39 29.7	-62 24 09	50	0.1210±0.0081	15.9±3.0	0.24±0.10	58.3
J0800.4-4745	08 00 24.5	-47 45 57	13	0.2890±0.0110	31.7±5.0	0.0	3.0
J0803.7-4748	08 03 44.6	-47 48 30	50	0.2570±0.0140	13.3±2.0	0.21±0.07	22.1
J0854.0+1336	08 54 01.9	13 36 36	50	0.0115±0.0010	14.1±3.2	0.9±0.3	1.2
J0855.9+1812	08 55 54.5	18 12 13	50	0.0781±0.0066	11.2±1.6	0.61±0.14	0.6
J0959.6-2603	09 59 37.3	-26 03 55	50	(0.048-0.076)±0.004	(12-25)±1.5	(0.3-0.7)±0.06	2.5
J1003.3+4808	10 03 22.6	48 08 49	50	0.0346±0.0078	12.0±5.1	2.8±1.3	4.3
J1007.5-2017	10 07 34.9	-20 17 24	13	0.1940±0.0044	12.5±0.8	0.24±0.03	4.1
J1008.4+3520	10 08 25.9	35 20 11	50	0.0119±0.0028	10.4±2.6	1.1±0.4	3.6
J1008.9+5224	10 08 54.3	52 24 09	50	0.0044±0.0010	10.4±3.3	2.4±0.8	3.2
J1011.1+5259	10 11 09.3	52 59 28	13	0.0023±0.0007	12.4±5.8	3.0±1.5	4.6
J1019.7+5225	10 19 43.2	52 25 33	50	0.0035±0.0008	13.3±5.6	1.8±0.9	2.7

TABLE 2 (contd.)

J1028.2+5340	10 28 16.9	53 40 31	13	0.0024±0.0005	10.5±4.5	0.5±0.3	2.6
J1042.3+5549	10 42 20.3	55 49 18	50	0.0195±0.0040	12.0±5.6	2.8±1.5	6.0
J1047.1+6335	10 47 09.5	63 35 11	50	(0.035-0.05)±0.003	(20-25)±4.0	(0.3-0.9)±0.2	.7
J1053.6+5358	10 53 36.4	53 58 18	50	0.0027±0.0007	10.0±4.7	1.2±0.7	3.9
J1106.4+6050	11 06 24.7	60 50 14	50	0.0042±0.0008	10.9±3.0	1.5±0.5	2.1
J1108.6+4521	11 08 41.3	45 21 29	50	0.0084±0.0024	10.0±4.7	1.0±0.6	3.4
J1115.5+1738	11 15 34.5	17 38 21	50	0.0050±0.0010	10.2±1.9	0.9±0.2	1.1
J1115.6+4102	11 15 41.6	41 02 26	50	0.0048±0.0011	12.5±3.2	1.4±0.4	2.0
J1118.0+1830	11 18 04.5	18 30 59	50	0.0093±0.0012	10.6±1.8	0.7±0.2	1.6
J1209.3+0953	12 09 21.3	09 53 27	50	0.0066±0.0016	10.3±3.6	0.4±0.3	0.8
J1210.2+3856	12 10 15.8	38 56 04	50	0.0102±0.0028	10.0±4.3	0.8±0.5	1.7
J1215.5+3305	12 15 33.7	33 05 46	13	0.0025±0.0004	10.0±4.3	2.8±1.3	1.8
J1219.7+3407	12 19 45.7	34 07 37	50	(0.022-0.046)±0.004	(12-19)±4.1	(0.4-1.0)±0.3	.1
J1221.8+0350	12 21 51.2	03 50 44	50	0.0091±0.0016	10.4±3.3	1.5±0.6	1.4
J1229.4+2416	12 29 29.9	24 16 02	50	0.0187±0.0051	13.6±6.3	1.2±0.7	4.0
J1236.9+2656	12 36 57.0	26 56 50	13	0.0199±0.0024	11.0±3.5	0.9±0.4	28.0
J1249.8+2558	12 49 48.8	25 58 51	50	0.0163±0.0044	10.2±4.8	1.8±1.0	1.1
J1256.4-0613	12 56 25.1	-06 13 59	50	0.0067±0.0022	10.7±5.6	1.0±0.7	2.9
J1309.9+3534	13 09 56.1	35 34 16	50	0.0102±0.0026	10.2±3.1	1.2±0.5	5.3
J1310.0+3451	13 10 00.9	34 51 29	50	0.0248±0.0037	10.6±2.3	1.1±0.3	2.0
J1332.8+0133	13 32 48.6	01 33 20	50	0.0165±0.0019	10.8±2.5	1.0±0.3	1.1
J1334.0+5117	13 34 00.3	51 17 42	50	0.0319±0.0042	10.9±3.0	0.9±0.3	3.0
J1339.8+4015	13 39 53.6	40 15 52	50	0.0103±0.0021	10.0±2.8	1.1±0.4	2.3
J1340.8+5128	13 40 52.6	51 28 17	50	0.0052±0.0009	10.7±2.6	1.8±0.5	1.0
J1341.2+4109	13 41 15.7	41 09 51	50	0.0102±0.0018	11.0±3.5	1.7±0.6	9.8
J1342.6+4024	13 42 39.2	40 24 33	13	(0.006-0.017)±0.0014	(3.4-11.4)±1.0	(0.6-2.0)±0.3	8.2
J1342.6+3512	13 42 41.2	35 12 33	50	0.0117±0.0023	10.3±3.6	0.8±0.4	5.0
J1344.8+5602	13 44 49.8	56 02 16	13	0.0013±0.0004	10.4±4.7	2.8±1.5	2.6
J1427.9+4720	14 27 55.4	47 20 29	50	0.0071±0.0019	12.9±5.0	1.0±0.5	1.5

TABLE 2 (contd.)

J1443.9+5227	14 43 58.9	52 27 02	50	0.0050±0.0015	10.4±4.9	2.8±1.5	2.2
J1511.7+3343	15 11 44.8	33 43 32	50	0.0044±0.0012	10.7±4.6	2.3±1.1	4.7
J1522.9+6604	15 22 56.0	66 04 50	13	0.0674±0.0040	57.1±16.0	0.1±0.1	5.8
J1547.0-3644	15 47 00.7	-36 44 59	50	(0.115-0.135)±0.021	(11-14)±2.4	0.7±0.2	2.9
J1621.3+6119	16 21 20.7	61 19 13	50	0.0062±0.0013	10.0±4.0	0.9±0.5	3.6
J1622.3+4627	16 22 19.8	46 27 44	50	0.0110±0.0028	10.0±4.0	0.6±0.4	1.8
J1622.9+4639	16 22 59.5	46 39 28	50	0.0128±0.0037	15.3±6.5	1.3±0.7	7.0
J1625.5+4043	16 25 35.3	40 43 35	50	0.0084±0.0014	10.7±3.2	2.4±0.8	3.8
J1626.4+4114	16 26 25.5	41 14 51	50	0.0037±0.0010	16.0±7.4	1.6±0.9	1.5
J1628.9+4008	16 28 58.3	40 08 29	50	(0.29-0.37)±0.013	(9.5-10.5)±0.5	(0.5-0.6)±0.04	0.3
J1630.7+4020	16 30 42.2	40 20 00	50	0.0056±0.0017	10.8±5.0	1.0±0.6	3.0
J1644.9+3849	16 44 56.9	38 49 16	50	0.0059±0.0018	11.3±4.4	0.7±0.4	2.5
J1646.3+5841	16 46 19.4	58 41 28	50	0.0094±0.0019	11.0±4.1	1.2±0.6	2.0
J1657.8+4347	16 57 50.6	43 47 47	50	0.0092±0.0019	10.1±3.5	1.2±0.5	2.4
J1701.4+6044	17 01 24.3	60 44 59	50	0.0041±0.0009	11.6±4.0	1.8±0.7	2.8
J1757.8+0440	17 57 48.6	04 40 15	13	0.0094±0.0017	10.0±4.0	0.6±0.4	15.7
J1802.1+1804	18 02 06.4	18 04 48	13	(0.4-3.3)±0.03	(20-22)±1.0	(0.1-0.8)±0.04	6.4
J1856.5-3754	18 56 35.4	-37 54 40	13	1.8700±0.0200	10.0±0.3	0.02±0.004	0.1
J2131.3+7036	21 31 18.5	70 36 51	13	0.0035±0.0006	11.9±4.7	0.3±0.2	4.7
J2153.3-1514	21 53 19.6	-15 14 27	50	0.0200±0.0020	10.7±1.5	0.8±0.2	3.3
J2200.1-3035	22 00 09.7	-30 35 36	50	0.0105±0.0021	14.0±4.8	1.8±0.7	13.8
J2216.2-3022	22 16 16.0	-30 22 31	50	0.0062±0.0013	10.5±3.2	0.9±0.4	1.8
J2304.7-3514	23 04 45.7	-35 14 59	13	0.0032±0.0008	11.4±5.3	0.2±0.2	1.7
J2314.7-4948	23 14 42.3	-49 48 04	13	0.0051±0.0007	16.1±5.9	1.0±0.5	3.2

Note: 1. The χ^2 is the variability parameter in the WGACAT, based on a single observation. The variability seen in different observations is indicated as the range of values in columns 4 and 5.

Note: 2. Fourteen sources have poorly defined image due to the deterioration of the point spread function off-axis, or due to the presence of complex emission. These are listed in the text in §4.

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Note added in Proofs

After the paper was accepted, 4 objects in Table 2 have been identified optically, and are listed here (the details will be published elsewhere). Using the digitized sky survey we identified J0016.0-3914 as a 'supersoft' X-ray source ($L_x = 3 \times 10^{37}$ ergs s $^{-1}$; $H_0 = 50$ km s $^{-1}$ Mpc $^{-1}$) close to an HII region and IRAS 00134-3932 in the nearby galaxy NGC 55. In an on going collaborative effort with P. Szkody and her co-workers, who are carrying out optical spectroscopy and photometry of the objects, J1047.1+6335, appears to be a $\simeq 19.4$ magnitude object most probably belonging to a new class of soft intermediate polars, J1802.1+1804 is a brighter ($\simeq 15$ magnitude) AM Her type binary, whereas, the variable X-ray source J1236.9+2656 seems to be a 17.5 magnitude quasar with narrow emission lines and redshift of ~ 0.2 . Another variable source, J1219.7+3407, appears to have no optical counterpart down to the limiting magnitude (~ 21) in the digitized sky survey.

Fig. 1.— Histogram of softness ratio for observations of sources identified with (a) late-type stars and early-type stars, (b) AGN and galaxies, in the WGACAT.

Fig. 2.— Histogram of softness ratio based on ~ 15000 observations of unidentified objects detected in the WGACAT. The distribution is broader than in Figs. 1 (a) and 1(b)

Fig. 3.— Histogram of softness ratio for observations of sources identified with CVs, and white dwarfs. Total number of observations are 138 for CVs, and 124 for WDs. Notice the broad distribution and secondary peaks beyond $SR = 10$.

Fig. 4.— Percentage distribution of SR for (a) stars versus CVs & WDs, (b) galaxies & AGN versus CVs & WDs, identified in the WGACAT. Notice that the distribution of stars, galaxies & AGN decreases rapidly near $SR = 10$ leaving mostly MCVs and WDs at higher SRs.

Fig. 5.— X-ray light curves of the variable sources: (a) UZ For, (b) VV Pup, (c) EK UMa, (d) AN UMa, (e) DP Leo, (f) QQ Vul, (g) New AM Her type: J2107.9-0517, (h) J0639.4-6224, (i) J0803.7-4748, and (j) J1236.9+2656. The last 3 sources are unidentified.

Fig. 6.— SR vs. HR color-color diagram of the identified ultrasoft ($SR \geq 10$) X-ray sources. Total number of objects of each class and the number of data points plotted are: WDs (38, 106), CVs (15, 30), Late-type stars (9, 18), Early-type stars (4, 6), Unclassified stars (4, 4), Supersoft sources (4, 5), Galaxies and AGN (5, 6), and assorted types (3, 7). The first number in the parentheses is the number of objects (also see text).

Fig. 7.— Same as in Fig. 6 for the unidentified ultrasoft X-ray sources.

Fig. 8.— Simulated colors for 5 types of spectra of ultrasoft sources. Different curves represent different values of N_H (0.1, 3, 10, 30) in units of 10^{19} cm^{-2} . (a) is for a blackbody, and combinations of a blackbody and thermal bremsstrahlung, (b) is for thermal plasma emission, (c) is for simple power laws, and (d) is for cut-off power laws mimicking the WD atmosphere. The variables along the curves are blackbody temperature in eV for (a), plasma temperature in eV for (b), photon index (Γ) for (c), and exponential cut-off in eV for (d).

Fig. 1(a)

Fig. 1(b)

Fig. 2

Fig.3

Fig. 4(a)

Fig. 4 (b)

UZ For

1WGA J0335.4-2544

Bin Time: 500s

Fig. 5(a)

W Pup

1WGA J0815.1-1903

Bin Time: 120s

Fig. 5(b)

Fig. 5(c)

Fig. 5(d)

Fig. 5(e)

Fig. 5(f)

Fig.5(g)

Fig.5(h)

WGACAT Ultrasoft Sources with IDs

WGACAT Ultrasoft Sources without IDs

Fig. 8(b)

Fig. 8 (d)