THE HOTTEST WHITE DWARFS IN THE LOCAL GROUP

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ABSTRACT

The nature of the progenitor stars of supernovae of type Ia, the ”standard candles” on which much of what we know on the dynamics and geometry of the Universe is based, is still a matter of debate. Close binary supersoft X-ray sources (CBSS) are among likely progenitors: they are often observed, yet are still elusive for many observational and technical difficulties involved. Our own galactic backyard, the Local Group, is ideal to study these stars, because of to the low column density of neutral hydrogen (N(H)). I compare XMM-Newton observations of the sample of these sources in known in the Local Group galaxies. Because of the peculiar spectrum of these sources, it turns out that the first, basic parameter that determines what type of population we detect, is the intrinsic absorption inside the galaxy or a given region of it. This poses a large bias in comparing these populations. For instance supersoft X-ray sources found in the SMC, observed with very low N(H), have a surprisingly constant or almost constant X-ray flux. However, apparent variability in regions of much higher N(H), like some peripheral areas of M31, may be due to poor statistics or to only very small fluctuations in X-ray flux. Nevertheless, there are ”hints” of some intrinsic differences in the populations. Some of the LMC sources seem to be be intrinsically very variable, more than sources observed in M31 and the SMC. I discuss the possibility that the symbiotics among CBSS, and SSS that seem to exceed Eddington luminosity and be regulated by a wind, may be important as type Ia supernova progenitors.

Key words: binaries: close–novae, cataclysmic variables–galaxies: stellar content– galaxies: individual, LMC, SMC,M31– X-rays: galaxies.

1. INTRODUCTION

Supersoft X-ray sources (SSS) are defined phenomenologically as X-ray sources that have virtually no counts above 1 keV. Their spectra can be approximately fitted with a blackbody at temperature in the range 20-100 eV, and they are intrinsically extremely luminous (10^{36-38} erg s^{-1} but very absorbed. These sources are detected at large distances, but only if the equivalent column density of neutral hydrogen, N(H), is low. The Local Group is ideal to discover and study SSS, which as a matter of fact were first discovered in the Magellanic Clouds.

SSS are a non-homogeneous class, but they are mostly thought to include very hot white dwarfs, of which many are undergoing thermonuclear burning of hydrogen in an accreted shell in a close binary. Close binary supersoft sources (CBSS) are extremely interesting as type Ia supernovae progenitors. More than a quarter of the CBSS are classical novae. However, no recurrent novae (RN) so far were observed as SSS for a significant amount of time. This is interesting because RN may be very relevant as SNe Ia progenitors, but only if they are observed as bright, hydrogen burning sources after the outburst, because this means they retain accreted material and the WD can grow towards the Chandrasekhar mass. CBSS can be wind/nebular sources (e,g. Cal 87, Greiner et al. 2004 and Orio et al. 2004, usually in low end of luminosity distribution), but often we may be seeing a hot WD atmosphere (e.g. Cal 83, on the high end of luminosity distribution). Although we now know a statistically significant number of SSS, it turns out that caution is necessary in order to derive statistics. Single white dwarfs like PG 1059 stars and planetary nebulae nuclei may appear as SSS, and in addition also supernova remnants (SNR), neutron stars in the foreground and not, background AGN may be all be picked up in the phenomenological classification. We would gain very important astrophysical information if we could sort them out in a statistically significant way.

Recently, Di Stefano and Kong (2003, 2004) and Di Stefano et al. (2004) have studied SSS in external galaxies, even outside the Local Group, using Chandra's ACIS-S detector. ACIS-S offers has the necessary spatial resolution to resolve sources even in the 2 innermost arcminutes^2 in the inner core off M31, inaccessible to EPIC because of source confusion), and it sensitive to softest X-ray range. However, the above authors had to propose an “ACIS-S-suitable” definition of SSS. Di Stefano & Kong (2003) studied therefore an algorithm based

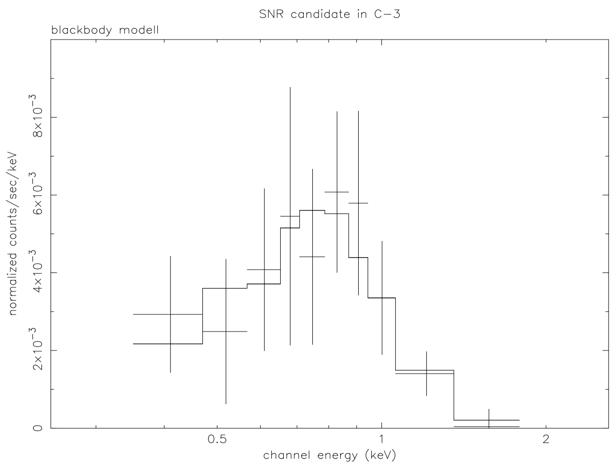

Figure 1. The spectrum of a SNR in M31, RX J004344.1+411219.

on broad bands, especially with a very broad "soft" S band 0.2-1 keV. The reason for this choice is that ACIS-S is not very sensitive in the S band, unlike Chandra HRC (which however cannot be used because it does not offer spectral resolution) or the XMM-Newton EPIC detectors (which lack sufficiently good spatial resolution). Searching faint sources, in external galaxies, the band has to be broad enough to collect photons and not miss sources. Previous definitions adopted in ROSAT investigations (e.g. Supper et al. 1997, 2002) included more CBSS. The new definition has the disadvantage of selecting more different types of sources, like foreground neutron stars and especially SNR, and less CBSS, making SSS an even less homogeneous class. The spectrum shown in Fig.1 is not the softest SNR in M31, yet most of the flux is below 1 keV. It is obvious that soft SNR of this type may be classified as SSS, although probably only the youngest SNR of M31, the remnant associated with S And, would remain a CBSS in the Supper et al. 91997) definition. Another problem of the Chandra-suitable algorithm is the difficulty to adapt it to XMM-Newton EPIC pn and MOS, which do not have a sensitive M band (1.1-2 keV). For the EPIC instruments the ratio of number of photons collected in the S and M band is disproportionately high. However, this may have been the price to pay to compare SSS in the Local Group and in galaxies outside it.

2. A COMPARISON BETWEEN THE LOCAL GROUP GALAXIES

The only way to attempt a statistical study and obtain at least a preliminary census is to examine the spectrum in detail, when possible, and to limit the study to the Local Group, especially using XMM-Newton EPIC, which is extremely sensitive in the band 0.2-0.5 keV. Up to now, extrapolating from the ROSAT surveys and from partial coverage of M31 with XMM-Newton and ACIS-S, we know that about 40 SSS are observed in M31 at a given time, of which 25-30% are novae within 10 years from outburst (Orio 2005). 7 SSS were observed in the LMC (see Greiner 2000). The LMC sources are a nova, a wind source (Cal 87, which incidentally seems to be the only only non variable one, except for X-ray flux modulation with the orbital period: see Orio et al. 2004), a recurrent source, two transient ones, and another variable one.

The catalog of Kahabka et al. (1999) of the SMC includes 9 SSS, of which at least 7 are confirmed as SMC sources. The SMC however has only 1/5th the luminous mass of the LMC and one 80th the one of M31. A thorough search in the archives reveals that 6 SMC sources are persistent SSS, including two planetary nebulae, two symbiotics, and a not yet identified object known to be a constant and strong U source. Finally, 5 SSS were observed in M33 (one of them was also nova , see Pietsch et al. 2005); and one source was observed in the dwarf spheroidal Draco galaxy (a symbiotic, see Mürset et al. 1997).

The comparison shows that there are probably more transient/ highly variable sources in the LMC. We find many low temperature, softer sources in the SMC. This however may be just an effect of low N(H) and smaller population. The value of N(H) plays a very important role in SSS discovery and detection. Are these softer sources systematically missed in other galaxies? If this is the case, rather than being an effect of the low metallicity, statistical comparisons may be heavily biased. A possible solution would be to compare a number of regions of low and comparable N(H) in both the LMC, SMC and M31.

3. MASS ACCRETION REGULATED BY A WIND

Two variable SSS in M31 are extremely interesting. They are called r2-12 and r3-8 in the Chandra catalogs, and reach a luminosity of a few times 10^{39} erg s^{-1}. Such high luminosity seems to be also a characteristic of SSS detected outside the Local Group. One can only speculate that there may be a mechanism at work which is the same as in Ultraluminous X-ray Sources (ULX). The spectrum of the less variable of these two sources, r2-12, is shown in Fig.2. The core of M31 was observed four times with XMM-Newton: it seems that when these two sources reach high luminosity, the spectrum becomes harder, and even has a power-law component for r2-12. Although there is no identification of these sources at optical wavelength, this phenomenon can be understood in the framework of a CBSS: probably a wind that starts when the luminosity is above Eddington (e.g.) and implies that $\dot{m}$ is very high, of order 10^{-7} M$_{\odot}$ year^{-1}. With such a high transfer rate, it would be crucial to study the optical spectrum of such sources and find out whether they are loosing a significant amount of mass in a wind. If this is not the case, they may reach the Chandrasekhar mass and become type Ia SNe.

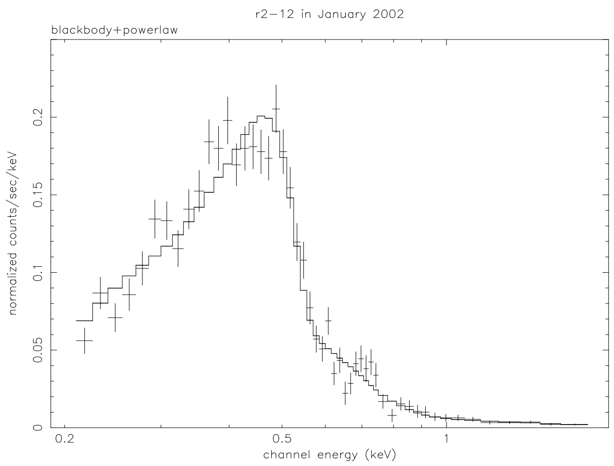

Figure 2. The spectrum of the super-luminous SSS r2-12 in M31: it is fitted with a blackbody at temperature ≈60 eV and a power law component.

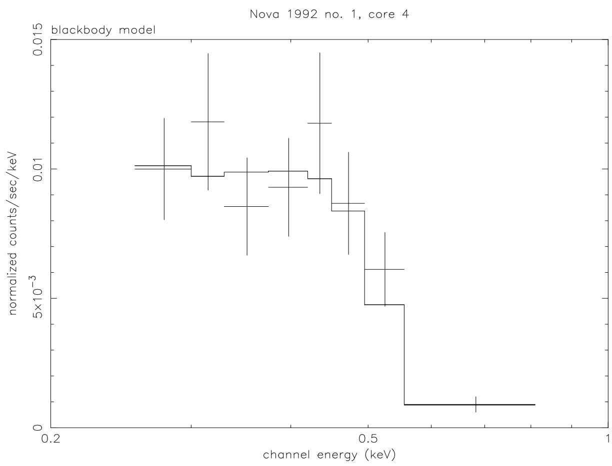

Figure 3. The very soft spectrum of nova 1992-1 in M31. This spectrum, approximately fit with a blackbody at 55 eV, is typical for a SSS nova a few years after the outburst.

4. THE ROLE OF NOVAE AND SYMBIOTIC STARS

Interestingly, three SSS in the Local Group were identified with symbiotics, but only in two very metal poor galaxies: the SMC and Draco (Mürset et al. 1997). The three symbiotics do not have any recorded nova outbursts. They have all been luminous in supersoft X-rays for several years, the two in the SMC for more than 10 years (Orio et al. 2005b). There is a possibility that they may be just accreting "quietly" at too high a rate to undergo nova eruptions with mass loss. Could they eventually reach the Chandrasekhar mass and become SNe Ia? The hope is that in the future we will be able to determine the WD mass in these systems, using large telescopes.

Only about 10-30% of post-outburst novae remain SSS for more than a couple of months and for up to 10 years (Orio et al. 2002, Orio 2005), even if novae make up a significant fraction of SSS in M31 (Orio 2005, Pietsch et al. 2005). Only one nova was observed among 10 novae observed within 10 years from the outburst with ROSAT in the LMC (Orio & Greiner 1998, Orio et al. 2002). The fraction among SSS in M31 seems to be higher, although probably only close to 30%. This is unlikely to be a metallicity effect, since the SSS phase should be shorter with higher metallicity (Sala & Hernanz 2005).

As Fig. 3 shows, the spectrum of classical novae is really extremely soft, and although the ejecta also emit X-ray flux, the supersoft spectrum is due to the hot WD.

5. SUPERSOFT X-RAY SOURCES IN THE XMM-NEWTON OBSERVATIONS OF M31

Fig. 4 shows the innermost 6x6 arcmin of the M31 core, observed with EPIC-pn and with Chandra ACIS-S. It appears immediately that the sources at the center cannot be resolved. If we look closely, we realize however that source confusion is a problem only in the innermost 2x2 arcmin (see close up in Fig. 5). Using the criteria of Di Stefano et al. (2004), 21 sources are selected as SSS in the XMM-Newton observations, which cover about a 4th of the area of the galaxy, by far the most crowded part (Orio 2005): the core and most of the regions along the axis. 5 of them are SNR, of which 4, however, would not be selected as SSS with ROSAT-like criteria, the very young remnant associated with S And being probably the exception. 5 of the M31 SSS observed with XMM-Newton are classical novae that exploded in 1992, 1995 (2), 1996 and 2000. As mentioned above, only ≈10% of novae of the last 25 years are SSS, and none after 10 years. We do not have information on symbiotic stars of M31. Of the other sources, only two were real transient, and the above mentioned r3-8 is seen to vary in flux by more than one order of magnitude on time scales of months. Most other sources disappear from the X-ray window only of they are faint and in areas of high N(H), so large variations are not necessary to explain that they are not repeatedly observed. As a matter of fact, most of the ROSAT SSS that are no longer visible in the new M31 observations done with Chandra and XMM-Newton, are quite faint and/or in regions of high N(H).

6. CONCLUSIONS

Although XMM-Newton and Chandra observations so far have not significantly increased the population of SSS and identify new CBSS in the Magellanic Clouds, significant new statistics of SSS have been obtained for M31. A large enough number of sources are known by now, that statistical comparisons are beginning to be possible. We can definitely say that softer, persistent sources have been detected in the SMC, as opposed to harder, more variable sources in other galaxies and especially in the LMC. Classical novae are a significant fraction of the

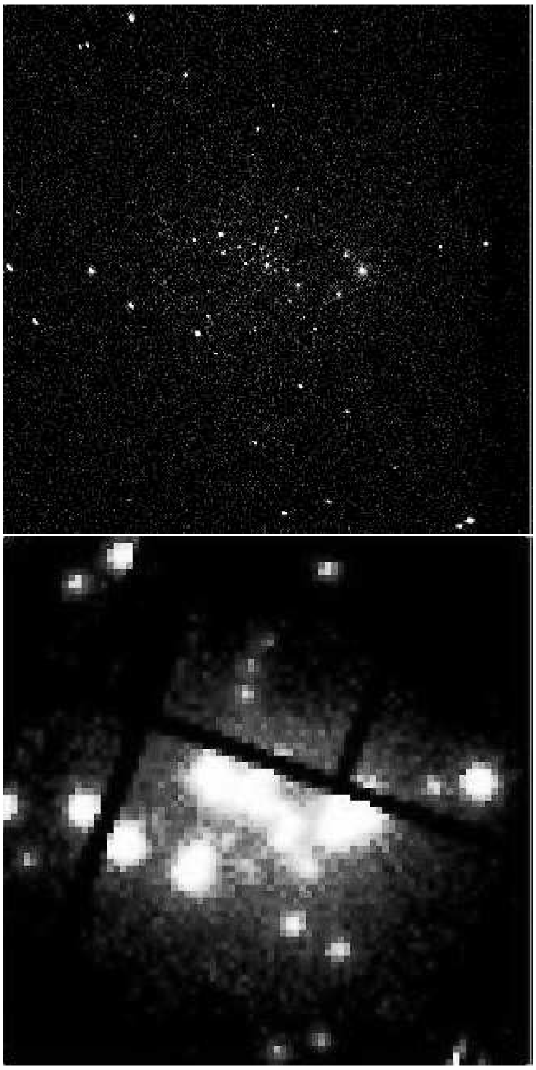

Figure 4. The central 6 arcmin of the core of M31 imagined with XMM-Newton EPIC-pn and with Chandra ACIS-S. The junctions between CCDs and the rows of picsels flagged as "bad" are black and the images are not smoothed or elaborated in any way.

CBSS population, but they are not necessarily interesting as type Ia SN progenitors. On the other hand, a few symbiotics and very luminous "wind-regulated sources" are observed the Local Group galaxies. These two last classes may indeed be relevant as type Ia supernova progenitors, if it can be proved that no significant mass loss occurs.

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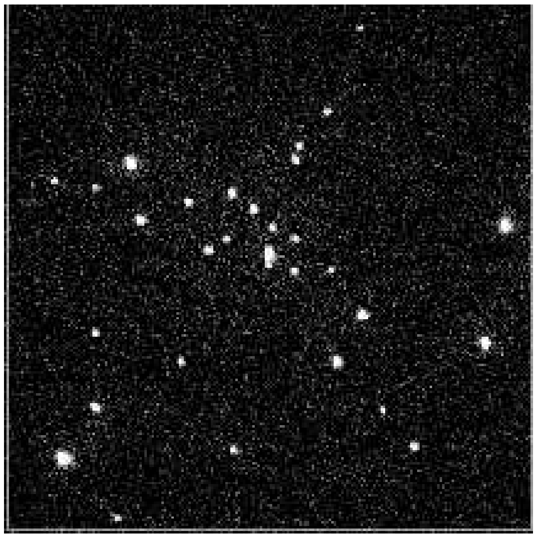

Figure 5. A close up of the innermost 2x2 arcmin with Chandra ACIS-S.

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