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# X-ray stellar population of the LMC

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**Abstract.** In the study of stars, the high energy domain occupies a place of choice, since it is the only one able to directly probe the most violent phenomena: indeed, young pre-main sequence objects, hot massive stars, or X-ray binaries are best revealed in X-rays. However, previously available X-ray observatories often provided only crude information on individual objects in the Magellanic Clouds. The advent of the highly efficient X-ray facilities XMM-Newton and Chandra has now dramatically increased the sensitivity and the spatial resolution available to X-ray astronomers, thus enabling a fairly easy determination of the properties of individual sources in the LMC.

**Keywords.** X-rays: stars, X-rays: binaries, galaxies: individual (LMC), stars: early-type

## 1. X-ray surveys of the LMC

In the range of astronomical tools, X-rays are of particular interest. Indeed, the high-energy domain unveils the most energetic phenomena taking place in our Universe. Such processes are usually difficult to perceive at other wavelengths, though they provide important constraints for astrophysics.

In this context, the MCs are targets of choice. Their advantages are multiple: the known and small distance, together with the small angular size, small inclination, different metallicities, and recent star formation episodes are here as crucial as at other wavelengths. In addition, the low obscuration towards the MCs renders soft X-ray observations much easier while the numerous available data taken at other wavelengths ensure a correct, global analysis of the LMC X-ray sources.

X-rays associated with the LMC were first detected 40 years ago by a rocket experiment (Mark *et al.* 1969): the source appeared extended and soft, with a total luminosity estimated to $4{\times}10^{38}\,\mathrm{erg\,s^{-1}}$. It did not take long to distinguish a few individual sources in this X-ray emission, nicknamed LMC X-1 to 6, thanks to the joint effort of the satellites Uhuru, Copenicus, OSO-7, and Ariel V (Leong *et al.* 1971, Rapley & Tuohy 1974, Markert & Clark 1975, Griffiths & Seward 1977). In the following decade, the Einstein observatory increased the number of known X-ray sources in the direction of the LMC to about a hundred (Long *et al.* 1981, Wang *et al.* 1991). Finally, a sensitive survey undertaken by ROSAT provided another ten-fold increase in the total source number (Haberl & Pietsch 1999a, Sasaki *et al.* 2000).

However, only half of the detected X-ray sources truly belonged to the LMC and an even smaller fraction appeared to be associated with LMC stars. For example, of the 758 ROSAT-PSPC sources, only 144 were identified at first (Haberl & Pietsch 1999a): 15 as

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background AGNs or galaxies behind the LMC, 57 as foreground Galactic stars, 46 as SNRs and SNRs candidates, 17 as X-ray binaries (XRBs) and candidates, 9 as Supersoft sources (SSSs) and candidates. Using the observed X-ray properties (especially the hardness ratios), Haberl & Pietsch (1999a) further proposed additional identifications (3 AGNs, 27 foreground stars, 9 SNRs and 3 SSSs) which yields a fraction of 20% of X-ray sources associated with LMC stars. Similar results were obtained with the ROSAT-HRI (Sasaki *et al.* 2000): 397 detections among which 138 in common with the PSPC and 115 identified (10 AGNs, 52 foreground stars, 33 SNRs, 12 XRBs, 5 SSSs, and 3 hard sources which could either be AGNs or XRBs). If one considers the variable X-ray sources, the contamination by non-LMC objects is smaller. For the PSPC survey, the proposed identification of the 27 variable X-ray sources is 12 XRBs, 5 SSSs, 9 foreground stars and 1 Seyfert galaxy (Haberl & Pietsch 1999b); for the HRI survey, 26 variable sources were detected among which 8 XRBs, 4 SSSs, 6 foreground stars, 2 AGNs and 1 nova (Sasaki *et al.* 2000): the fraction of LMC stellar objects among variable X-ray sources is thus 60%.

The current facilities possess much higher sensitivities and spatial/spectral resolution but unfortunately they also have a smaller field-of-view. Its non-zero extension penalizes the LMC, especially in comparison with the SMC (~59 sq. deg. vs. ~18). This explains why, up to now, no full survey of the LMC has been performed with XMM-*Newton* or *Chandra*. Nevertheless, smaller fields have been observed and it should be underlined that, though its coverage is patchy, the 2XMM catalog currently lists 5421 entries in the area of the ROSAT surveys! In addition, Haberl *et al.* (2003) reported the analysis of one deep XMM-*Newton* observation of a northern region of the LMC (on the rim of the supergiant shell LMC4). While ROSAT had detected 34 sources in this field, XMM-*Newton* data reveal 150 objects (detection limit $6\times10^{32}$ erg s$^{-1}$). In a selection of 20 bright or peculiar sources, the majority (10) are AGNs, but there are also 3 foreground stars, 2 SNRs, 4 HMXBs, and 1 SSSs †. In addition, Shtykovskiy & Gilfanov (2005) analyzed 23 XMM-*Newton* archival observations covering 3.8 sq. degrees of the LMC. With a detection limit of $3\times10^{33}$ erg s$^{-1}$, they detected 460 sources in the 2–8 keV band, in vast majority AGNs, and focused on 9 good XRBs candidates and 19 possible XRBs (see below for more details). Finally, a sensitive survey of the LMC in the hard X-ray domain (15 keV–10 MeV) has been performed with INTEGRAL (Götz *et al.* 2006). Only a few sources have been detected: the X-ray binaries LMC X-1, LMC X-4, and PSR B0540–69, as well as two hard sources which might correspond to LMC binaries. These encouraging first results in both the soft and hard X-ray domains enlight the detection potential of the sensitive observatories of the current generation.

## 2. Supersoft X-ray sources

As their names indicate, SSSs display very soft spectra: they can be fitted with thermal models with kT of only 20–80 eV. These often bright ($10^{36-38}$ erg s$^{-1}$) objects became a category of their own after the discovery of several such sources in the LMC - indeed, their identification is most difficult in the Galatic plane, where high absorption prevents their detection. Including recent XMM-*Newton* detections, 18 SSSs are now identified in the LMC and several other examples are also known in >10 galaxies (Kahabka *et al.* 2008).

† This source was not confirmed by Kahabka *et al.* (2008).

It is generally believed that the X-ray emission of SSSs corresponds to steady nuclear burning on the surface of a white dwarf accreting matter from its companion. SSSs would therefore trace rather old stellar populations, and they are accordingly found along the rim of the LMC optical bar (Haberl & Pietsch 1999a,b). Other possible origins for SSSs have been proposed and the LMC SSSs confirmed this fact: of the 18 known SSSs, 5 (+1?) reside in close binaries (as expected from the above picture), but 5 others correspond respectively to a post-nova object, a WD+Be binary, a symbiotic star, a planetary nebula, a transition (WD–central star of PN) object - 7 remain unidentified transients (Kahabka *et al.* 2008).

The X-ray spectrum of SSSs often presents 'photospheric' characteristics, i.e. it consists of numerous absorption lines from highly ionized metals (generally Si, S, Ar, Ca, Fe) superimposed on a blackbody emission. One important contribution from XMM-*Newton* and *Chandra* is the availability of high-resolution spectroscopy. Combining high-res spectra and (preferentially NLTE) atmosphere modelling, it is possible to derive precise stellar parameters, notably the WD mass. Such an analysis was undertaken for CAL83 by Lanz *et al.* (2005), who found $M_{WD}$=1.3±0.3 $M_\odot$ and T=0.55±0.03 MK. Many absorption lines were still blended, preventing any detailed chemical analysis. Looking closer at the lines, there seems to be no evidence for emission components, large line shifts or asymmetries (which would indicate fast outflows), or large line widths (which would be associated with a fast rotation). A similar study of the SSS associated with nova LMC 1995 led to $M_{WD}$=0.91 $M_\odot$ and T=0.40–0.47 MK (Orio *et al.* 2003) and showed that the abundance of carbon is not enhanced, suggesting the X-ray emitting matter to be accreted material from the companion.

Some SSSs present however very different spectral characteristics. At high resolution, the X-ray spectrum of CAL87 appears composed exclusively of numerous *emission* lines (mostly from O, N, and Fe). These lines which come from recombination and resonant scattering are clearly redshifted, with a double-peaked structure observable in the brightest features (Greiner *et al.* 2004, Orio *et al.* 2004). In addition, the broad X-ray eclipse suggests the X-ray source to be extended, about 1.5 $R_\odot$ in size (to be compared to the orbital separation of 3.5 $R_\odot$). The X-rays thus originate in a fast (2000 km s$^{-1}$) and non-spherical outflow, e.g. an accretion disk corona.

The brightest SSS is RX J0513.9–6951. Its spectrum is a mixture of absorption and emission lines superimposed on a continuum, indicating the superposition of emissions from a hot atmosphere and from an optically-thin corona (McGowan *et al.* 2005, Burwitz *et al.* 2007). The absorption lines exhibit several blueshifted velocity components, a typical signature of an outflow, which vary with time (the deepest absorptions were observed when the X-ray flux was lowest). High abundances are observed for N, S, and Ar; they may imply that the outflowing material was affected by nova nucleosynthesis (McGowan *et al.* 2005). Two temperature components may in fact be present and would be linked to a fast rotation of the WD (cool equatorial regions + hot polar caps, Burwitz *et al.* 2007).

SSSs are also variable X-ray sources: they exhibit a variety of flux changes occuring on a variety of timescales. For example, CAL83 displays recurrent X-ray low states and short-term variations of smaller amplitude (Lanz *et al.* 2005). The presence of 38m oscillations at some epochs was also claimed for this object by Schmidtke & Cowley (2006) who attributed them to non-radial pulsations. Another SSS, RX J0513.9–6951, displays every 100–200d optically faint/X-ray bright episodes of duration 20–40d. The exact recurrence timescale varies, which is probably related to variations in the accretion rate by a factor of 5 (Burwitz *et al.* 2008). The high-res X-ray data were acquired during one of the low optical state but the last XMM-*Newton* observation samples the beginning of the recovering to 'normal' optical/UV intensity (McGowan *et al.* 2005, Burwitz *et al.* 2007). As the recovering progresses, the X-ray luminosity decreases, as well as the temperature of the blackbody: it thus seems that the peak emission slowly shifts towards longer wavelengths (McGowan *et al.* 2005). At the same time, the radius of the blackbody emitter becomes larger. This is consistent with the global picture of the WD contraction model: the accretion rate is high during the low optical state; when it drops, the WD contracts and the emission becomes more energetic; the enhanced X-ray emission then influences the WD environment and provokes a new increase in the accretion rate, thereby inflating again the WD (McGowan *et al.* 2005). Another interpretation implies changes in the accretion disk's size and the wind outflow, but observations seem to contradict the predictions from that particular model (Burwitz *et al.* 2007).

## 3. X-ray binaries

### 3.1. *HMXBs*

In high-mass X-ray binaries, the primary is a compact object (neutron star, NS, or black hole, BH) while the secondary can either be a Be star or a supergiant star. In the first case, the binary is generally eccentric and accretion onto the compact companion occurs only when the latter crosses the dense equatorial regions of the Be star, producing recurrent X-ray outbursts. Most HMXBs of the LMC are of this type. In the second case, when the secondary is a supergiant, the accretion occurs either through wind capture or Roche-lobe overflow. In the LMC, there are one or two candidates for wind accretion and two or three candidates for RLOF (see e.g. Negueruela & Coe 2002).

As they contain massive secondaries, HMXBs reveal young stellar populations. However, they are not instantaneous tracers of star formation, since one needs to wait until the compact object forms: while the number of HMXBs certainly decreases for populations older than 20Myr, no HMXB is expected when the stellar population is younger than 3Myr. This explains why 30 Doradus, one of the most active star-forming regions in the LMC, contains few HMXBs while the ∼10 Myr supergiant shell LMC4 harbors many of them (Haberl & Pietsch 1999a,b, Shtykovskiy & Gilfanov 2005).

While only 10 HMXBs were known in the MCs before 1995, their number now exceeds 100. In the LMC, 36 cases are listed by Liu *et al.* (2005). Shtykovskiy & Gilfanov (2005) studied the cumulative distribution of X-ray luminosities (the X-ray luminosity function) of HMXBs and candidates found in 23 XMM-*Newton* fields. They reported a possible flattening of the luminosity function at high luminosities. If confirmed, this would indicate a deficit of low-luminosity sources, probably linked to the 'propeller effect' (i.e. inhibition of accretion, and therefore decrease of the X-ray luminosity, by fast-rotating NS with low accretion rates).

Among the HMXBs of the LMC, two could contain black holes: LMC X-1 and LMC X-3 ($m_{BH} \sim 4\,M_\odot$, see e.g. Yao *et al.* 2005). Such systems display two spectral states: a high/soft state and a low/hard state. In the former case, the X-ray luminosity is high while the X-ray spectrum is soft and the X-ray emission is believed to be mostly thermal emission from the accretion disk. In the latter case, the situation is opposite and the X-ray emission is attributed to comptonization of the soft photons from the accretion disk by hot electrons in the surrounding corona. In most cases, the spectrum is thus fitted by the combination of a multi-temperature blackbody model (where the temperature decreases while the radius increases) and a power-law. This yields rather good results, especially when the photon statistics is poor, but is clearly oversimplistic (presence of an intense gravitational field in the inner regions, interrelations between the comptonized emission and the seed blackbody spectrum,...) and can be improved in many ways (Yao *et al.* 2005 and references therein).

LMC X-1 comprises an O8III-V star in a 4.2d orbit around a BH (Negueruela & Coe 2002). Up to now, it has only been observed in the high/soft state but variations of its X-ray emission were detected, even for the hardest X-rays (detection in the 20–40 keV range in 2003 but not in 2004, Götz *et al.* 2006). Only a disk blackbody was requested to fit its spectrum and no discrete features were found in the high-resolution X-ray spectrum, though one would have expected the Ne K edge to be detected (Cui *et al.* 2002).

LMC X-3 harbours a B star of uncertain type (B2.5V, Negueruela & Coe 2002, or B5IV, Wu *et al.* 2001) in a 1.7d orbit around a BH. This system is often - but not always - seen in the high/soft state and a combination of a multicolour blackbody and a power law is needed to describe its X-ray spectrum (Cui *et al.* 2002). Peaks in the power-law flux are related to drops in the blackbody flux: accreting matter thus appears diverted from the accretion disk to feed the surrounding hot corona (Smith *et al.* 2007). The transfer of material occurs most probably through Roche lobe overflow since there is no evidence for the presence of a wind (no emission lines, no absorption edges, and low absorbing column for neutral/ionized matter compatible with Galactic values, Wu *et al.* 2001, Page *et al.* 2003). Turning to the X-ray lightcurve of LMC X-3, there appear to be no significant variations on very short timescales; however, modulations with the orbital period and with twice this period were detected (Boyd *et al.* 2001). The former, which is particularly obvious when the X-ray flux is lower, could be attributed to the presence of a hot spot (e.g. where the gas stream impacts the accretion disk). On the other hand, the abrupt flux decrease seen each $2\times P_{orb}$ may be caused by a large perturbation of the disk, such as a global density wave periodically obscuring our view of the inner regions (Boyd *et al.* 2001).

The NS involved in the other HMXBs is sometimes a pulsar. In the last decade, detailed timing studies were made possible, especially thanks to the RXTE satellite. In PSR B0540–69 (50ms), the pulse profile, found to be similar in optical and in different X-ray bands, appears composed of two gaussians whose ratio does not vary with the energy considered (de Plaa *et al.* 2003). Over the 8 years of RXTE observations, only one change in the pulsar period (‘glitch’) was observed (Livingstone *et al.* 2005). Compared to the Crab, this pulsar has a much lower ‘glitching’ activity though otherwise both objects share similar properties (age, magnetic field strength, rotation,...). This probably indicates that another physical parameter, overlooked up to now, plays here a crucial role. In contrast, the much older PSR J0537–6910 (16.1ms, in N157B) displays a large ‘glitching’ activity: 23 glitches were observed in the 7 years of RXTE data (Middleditch *et al.* 2006). The timing analysis yielded interesting results: (1) the amplitude $\Delta\nu$ of a glitch is proportional to the interval to the next glitch; (2) the longer the time before a glitch, the larger the change $|\Delta\dot{\nu}|$ but there is a maximum value for this variation; (3) the gain in $|\dot{\nu}|$ across one glitch is not completely given back before the next glitch; (4) microglitches often precede large glitches. The overall activity of PSR J0537–6910 is much higher than that of the Crab; on the other hand, its glitches are smaller but more frequent than for Vela, to which it is often compared. The analysis of PSR J0537–6910 indicates that glitch models relying on sudden onsets are not compatible with the observed glitches and that observations of PSR J0537–6910 appear in agreement with the picture of cracks at the NS surface combined to unstable vortices in the neutron superfluid (Middleditch *et al.* 2006).

The HMXB LMC X-4 also harbours a pulsar (period 13.5s) in a 1.4d orbit around an O8III star (Negueruela & Coe 2002). The X-ray flux is modulated with a 30d timescale (Lang *et al.* 1981, see also Naik & Paul 2003 and Götz *et al.* 2006), which likely reflects the precession period of the tilted accretion disk as in Her X-1. While the orbital period appears very stable, the disk precessing period may vary non-uniformly (Tsygankov & Lutovinov 2005). Pulses and eclipses are also seen in the hard X-ray range by INTEGRAL (Götz *et al.* 2006). The eclipses suggest a size for the hard X-ray emitting region of $0.38\,R_\odot$, i.e. larger than the size of a NS and more typical of that of a hot corona. LMC X-4 is also varying at these high energies by an order of magnitude (Götz *et al.* 2006, Tsygankov & Lutovinov 2005). Finally, LMC X-4 experiences X-ray flares and at these times, mHz quasi-periodic oscillations have been detected (Moon & Eikenberry 2001): strong, burstlike-features with a timescale of 700–1500s and weak oscillation with periods of 50–500s. The former could be explained by beating frequencies between the pulsar frequency and the orbital frequencies of big clumps on the verge of being accreted, while the latter is more compatible with Keplerian periods of clumps outside the corotation radius (Moon & Eikenberry 2001).

### 3.2. *LMXBs*

Low-mass X-ray binaries are systems composed of a compact object (NS, BH) and a faint, low-mass (generally $<1\,M_\odot$) companion. The X-ray emission is a consequence of the mass transfer via Roche-lobe overflow towards the compact object. Only one such object (or maybe two: LMC X-2 and possibly RX J0532.7−6926, Liu *et al.* 2007)† is known in the LMC, implying that the proportion of LMXBs with respect to HMXBs is much smaller in the LMC than in the Galaxy. This can be explained by the different star formation history of the two galaxies since LMXBs are associated with an older stellar population than HMXBs (Liu *et al.* 2005).

LMC X-2 is a binary of period 8h (Cornelisse *et al.* 2007), similar in many respects to Sco X-1. A monitoring has indicated that, during the bright X-ray states, the optical lightcurve lags $\lesssim$20s behind the X-ray lightcurve (McGowan *et al.* 2003). There thus seems to be some light reprocessing in the system, but the location where it takes place is unclear since the lower limit for the delay is larger than the light traveltime across the accretion disk and smaller than the light traveltime to the secondary (McGowan *et al.* 2003). The X-ray spectrum is well fitted by the combination of a disk multi-temperature blackbody and a hot blackbody (kT of 1.5 keV, probably associated with regions at or close to the surface of the NS, Lavagetto *et al.* 2008). The inner parts of the disk are not seen: as the source's luminosity is close to the Eddington limit, some material can be ejected, which would obscure our view towards those inner regions. The Fe K$\alpha$ line stays undetected while the O VIII Ly$\alpha$ is present: this is most probably a metallicity effect, which needs to be further investigated (Lavagetto *et al.* 2008).

† The status of RX J0532.7−6926 is still debated. On the one hand, Haberl & Pietsch (1999b) strongly advocate in favor of a LMXB nature on the basis of the shape of the X-ray lightcurve. On the other hand, Haberl & Pietsch (1999a) and Sasaki *et al.* (2000) only categorize it as a candidate LMXB ("LMXB?") while Kahabka (2002) mentions the source as a possible LMXB or AGN. At the present time, no counterpart has been detected for this source.

## 4. Massive stars and clusters

Massive stars, of spectral types O and early B, are soft and moderate X-ray emitters. In our Galaxy, their overall luminosity scales with their bolometric luminosity ($L_X \sim 10^{-7} L_{BOL}$) and their spectra reveal emission lines from an optically-thin hot plasma with kT=0.3–0.7 keV. Such objects are the progenitors of SNe, GRBs, NSs and BHs, and are often responsible for the presence of diffuse X-ray emissions (SNRs and wind-blown bubbles, see Chu, these proceedings). One of their main characteristics is the presence of strong stellar winds, driven through resonant scattering of their intense UV radiation by metals. The mass-loss rate and wind velocities of massive stars are typically $10^{-6}\,M_{\odot}\,yr^{-1}$ and $2000\,km\,s^{-1}$, respectively. The X-ray emission is generally believed to arise in these winds, through collisions of structures travelling at different velocities (for a review, see Güdel & Nazé, in prep.).

Since winds are heavily dependent on the metallicity of their host galaxy, LMC observations of massive stars are crucially important. A first test can be performed on Wolf-Rayet stars, the evolved descendents of O-type stars which display the strongest and densest winds. WRs mostly come in two flavours, WN if their spectrum is enriched in nitrogen and WC in the case of a carbon enrichment. In the Galaxy, no single WC star has ever been observed in the X-ray domain, most probably because of the high absorption of their stellar winds; the situation for WN is less clear and slight differences in wind structures and composition could play an important role (for a review, see Güdel & Nazé, in prep.). For the LMC, Guerrero & Chu (2008a,b) and Guerrero *et al.* (2008) have analyzed all ROSAT, *Chandra*, and XMM-*Newton* observations available, which cover more than 90% of the known WRs in the LMC. Of the 125 observed objects, only 32 were detected, mostly binaries: the detection rate is 50% for binaries but only 10% for supposedly single objects. There are similarities with the Galactic case (non-detection of single WC stars, binaries preferentially detected) but there are also clear differences. Notably, the X-ray luminosity and $L_X/L_{BOL}$ ratio are larger for LMC objects, which could be explained by a lower opacity of the winds.

Peculiar phenomena can enhance and harden the stellar X-ray emission: (1) in single objects, intense magnetic fields channel the wind streams towards the equatorial regions where they collide, producing a very hot plasma; (2) in binaries composed of two massive objects, the wind of one star can interact with that of the other, again leading to the formation of a hot plasma (for a review, see Güdel & Nazé, in prep.). Bright, hard X-ray sources associated with massive stars have therefore often been attributed to one or the other phenomenon, depending on the authors involved (see e.g. for colliding wind binaries in the LMC: Portegies Zwart *et al.* 2002). However, one must be cautious about such conclusions. First of all, a spectral monitoring in the IR, optical, or UV domain is needed to ascertain the binary nature of the object. This is however no definite proof of colliding-wind binaries, since magnetic objects (single or in binaries) are also overluminous, and it should be noted that not all massive binaries are overluminous even if both components possess significant stellar winds. Second, a monitoring is requested in the X-ray domain. Indeed, phase-locked variations are the signature of peculiar phenomena and help reject the simple line-of-sight coincidence. The X-ray emission of a magnetic oblique rotator is modulated by the (usually short) rotation period of the star, while the X-ray emission from wind-wind interactions changes with the orbital period because of varying absorptions crossing the line-of-sight or the varying distance between the two stars (hence a changing strength of the wind-wind collision). Up to now, variability as

**Figure 1.** *Chandra* observation of N11. Note the large number of point sources, scattered all over the field-of-view, without any correlation with the positions of the clusters (LH10 is in the middle-left of the image and LH9 just below), suggesting a large contamination from background/foreground objects (from Chu, Wang, Nazé *et al.* in prep.).

just described could be established only in one massive system of the MCs, HD 5980 in the SMC where an XMM-*Newton* monitoring was performed to ascertain the colliding-wind nature of the emission (Nazé *et al.* 2007).

Massive stars generally reside in clusters. In the LMC, only two of them were studied in the X-ray domain: 30 Doradus and N11. A 20ks *Chandra* observation of 30 Doradus revealed 180 sources with $L_X > 10^{33}\,\mathrm{erg\,s^{-1}}$, 109 of them being within 30" of R136 (Townsley *et al.* 2006a,b). Half of the X-ray sources possess counterparts at other wavelengths, generally massive stars: some bright, hard sources are considered as potential colliding-wind binaries. Some non-detection should also be underlined: no star from the embedded new stellar generation has been detected and not all early-type objects (e.g. O3) are detected. A longer exposure (100ks) has now been obtained and is still under analysis. In N11, the coarse spatial resolution of XMM-*Newton* data failed to provide clear detections of individual stars, though hints in this direction were found in the clusters LH10 and LH13 (Nazé *et al.* 2004). A 283ks *Chandra* observation found 165 point sources in the central area of N11 (clusters LH9/LH10) with $L_X > 10^{32}\,\mathrm{erg\,s^{-1}}$ (Chu, Wang, Nazé *et al.*, in prep.). Fifteen of these are associated with massive objects (10 with O/WR, 2 with B stars, 3 with compact groups of massive stars), yielding an overall detection rate of 16% (indeed, the brightest and/or earliest objects display the highest detection fraction). Known binaries constitute only 20% of the detected objects: comparing with the clusters's binary fraction of about 36%, this suggests that massive binaries are NOT preferentially detected, contrary to what happens in the Galaxy. Moreover, if the 15 detected objects can be considered as truly typical, the $L_X - L_{BOL}$ relation would be 0.4 dex higher in the LMC than in the Galaxy, again contrary to expectations. However, it remains to be confirmed that no peculiar object (magnetic star, colliding wind binary) contaminates the sample. This is indeed a plausible hypothesis since stars of apparently similar spectral types display very different X-ray fluxes (as for 30 Doradus).

## 5. Perspectives

Many stellar objects emit X-rays. The brightest ones, involving compact objects (XRBs and SSSs, $L_X \sim 10^{36-38}\,\mathrm{erg\,s^{-1}}$), have been detected in the LMC more than 3 decades ago; the current instruments have now provided the first detailed timing sequences and high-resolution spectra, which often led to changes or refinements of the initial models. For these sources, it is now necessary to reach even higher spectral resolutions and sensitivity to get more precise observational constraints. Moderate X-ray sources such as massive stars ($10^{31-34}\,\mathrm{erg\,s^{-1}}$) now enter the picture. At least the brightest examples have been detected, notably in 30 Doradus and N11. Beyond enlarging the number of X-ray detections, the future lies in getting high-resolution spectroscopy of LMC massive stars: since their X-ray emission is linked to their stellar winds, which crucially depend on metallicity, high-res data are necessary to test our X-ray generation models. Indeed, in the Galaxy, such high-res observations have already initiated a shift in thought - but it is essential to check the new theories in a different metallicity environment like that of the LMC. Finally, the future generation of X-ray telescopes should be able to detect even fainter X-ray sources such as low-mass/coronal sources ($10^{26-33}\,\mathrm{erg\,s^{-1}}$) and young pre-main sequence objects (flaring T Tauri stars can reach $10^{31-32}\,\mathrm{erg\,s^{-1}}$)†.

Once all this is accomplished, a full picture of the LMC at high energies will be available. Of course, acquiring such data is not a simple question of 'filling the catalogues'. It must always be kept in mind that, with its lower metallicity, the LMC provides a crucial test of theoretical models - see e.g. the case of massive stars. The astronomical community should thus promote the advent of a new generation of X-ray facilities possessing three concommitant characteristics: high sensitivity (to detect the faintest X-ray sources in nearby galaxies), high spatial resolution (to disentangle blended stellar objects in nearby galaxies), and high spectral resolution.

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† Note that cataclysmic variables (CVs) can also be rather bright X-ray sources, but they are difficult to identify in the Magellanic Clouds due to the faintness of their optical counterparts. Currently, there are no clear identification of a LMC X-ray source as a CV and this is why CVs were not considered in this review.

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