AN EXPLANATION FOR METALLICITY EFFECTS ON X-RAY BINARY PROPERTIES

THOMAS J. MACCARONE1, ARUNAV KUNDU2 AND STEPHEN E. ZEPF2

ABSTRACT

We show that irradiation induced stellar winds can explain two important metallicity effects in X-ray binaries - the higher numbers and the softer spectra of the X-ray binaries in metal rich globular clusters compared to the metal poor ones. As has been previously noted by Iben, Tutukov and Fedorova, the winds should be stronger at lower metallicity due to less efficient line cooling. This will speed up the evolution of the LMXBs in metal poor clusters, hence reducing their numbers. These winds can also provide extra material near the accreting object which may create an intrinsic absorber to harden the X-ray spectra of the metal poor cluster systems relative to the metal rich ones, as suggested by observations. We outline some additional observational predictions of the model.

Subject headings: stars:winds, outflows - stars: neutron - stars: binaries: close - galaxies: star clusters - globular clusters: general - X-rays: binaries

1. INTRODUCTION

Globular clusters (GCs) are important laboratories for studying stellar populations, both main sequence and exotic. X-ray binaries are about 100 times overabundant in GCs compared to in the field compared to the field (see e.g. the compilation of X-ray binary properties in Liu, van Paradijs & van den Heuvel 2001) due to dynamical effects such as tidal capture and/or three and four body interactions (e.g. Clark 1975; Fabian, Pringle & Rees 1975; Hills 1976). Furthermore, since detailed population studies of X-ray binaries require more sources than the ~100 in the Local Group, the extragalactic case must be studied. Given that the ages and metallicities of individual extragalactic field stars are nearly impossible to determine, but that these properties can be inferred from integrated light of GCs, the GC X-ray binaries in other galaxies represent an ideal place to study how age and metallicity affect X-ray binary populations.

Clearly, the dynamical properties of a GC are most important for predicting whether it will have an X-ray binary (e.g. Pooley et al. 2003; Heinke et al. 2003). In addition, there also exists a strong residual correlation between the number densities of X-ray binaries and the metallicities of the GCs. This was first suggested to be the case in the Local Group (Grindlay 1993; Bellazzini et al. 1995), and was shown more conclusively and dramatically in NGC 4472 (Kundu, Maccarone & Zepf 2002 - KMZ02). The possibility that this represents an age effect rather than a metallicity effect has been tested and found not to be the case using data on NGC 3115 and NGC 4365 (Kundu et al. 2003 - K03). In NGC 3115, where the age spread is small, but the metallicity spread is large, the metallicity effect was found to be at least as strong as that in other early type galaxies. Conversely, in NGC 4365, where the age spread is large, the fraction of globular clusters with LMXBs did not vary much with age and was similar to that of older GCs with similar metallicities in other galaxies. It thus seems most likely that the LMXB population enhancement effects first associated with the metallicity are, in fact, related directly to the metallicity and not to some other correlated property such as age, half-light radius, or distance from the center of the galaxy. It has also been noted that the metal poor Large Magellanic Cloud has a lower ratio of LMXBs to HMXBs than the more metal rich Milky Way (Cowley 1994; Iben, Tutukov & Fedorova 1997 - ITF97), which may be a combination of the metallicity effects and the difference in their star formation histories.

An additional metallicity effect can be found in the differences of the soft X-ray spectra of these sources. It has been found that the spectra of the blue (i.e. metal poor) GCs are harder than those of the red (i.e. metal rich) GCs in the Milky Way and M31 (Irwin & Bregman 1998 - IB) and in NGC 4472 (Maccarone, Kundu & Zepf 2003 - MKZ03). On the other hand, the quiescent LMXBs seem to show no evidence of a metallicity effect on the spectrum (e.g. Heinke et al. 2003), and the effect becomes much weaker or disappears at higher X-ray energies (Trinchieri et al. 1999; Di Stefano et al. 2002; Sidoli et al. 2001; MKZ03).

In this paper, we will show that the current theoretical explanations for the overabundance effect are unlikely to match the typical factor of 3 difference between the probabilities of metal poor and metal rich GCs' having X-ray LMXBs. We will put forth a new scenario invoking the effects of irradiation induced winds (IIWs) can explain the population difference. We will also show that IIWs can explain the previously unexplained spectral difference effects as a result of the same physical process, with the same parameter values.

2. PAST THEORETICAL WORK

2.1. IMF variations?

Several attempts have been made to explain why metal rich GCs have more LMXBs, but as yet, none seems satisfactory. Grindlay (1993) suggested that the correlation might be due to a flatter initial mass function in higher
metallicity GCs. The general consensus seems to be that the IMF is fairly universal (e.g. Kroupa 2002), and star formation theory suggests that any metallicity dependence is likely to be such that metal rich stars have typically lower masses since the Jeans mass will be lower for the more efficiently cooling metal rich gas (Larson 1998). Although the present day mass functions of metal rich Galactic GCs are flatter than those of metal poor Galactic GCs (McClure et al. 1986), this seems to be largely due to the fact that the metal rich systems are located more centrally within the Milky Way and hence experience more extreme dynamical stripping of their low mass stars, as seen observationally (Piotto & Zoccali 1999) and expected theoretically (Vesperini & Heggie 1997; Baumgardt & Makino 2003).

2.2. Effects of stellar radius

Later, Bellazzini et al. (1995) suggested that the larger stellar radii of the stars in metal rich globular clusters might contribute to their increased number densities of X-ray binaries. Larger stars should have a higher cross section for tidal captures and should overflow their Roche lobes at larger separations. The physics of tidal capture are a hotly contested issue and some workers have suggested that tidal captures have great difficulty in forming systems similar to the X-ray binaries we observe (see e.g. Rasio & Shapiro 1991; Rasio, Pfahl & Rappaport 2000 and references within), while others have suggested that the bulk of recycled pulsars may have been formed in tidal capture systems (e.g. Di Stefano & Rappaport 1992). The alternative to formation of X-ray binaries by tidal captures is formation through exchange interactions. These are most commonly three-body interactions where a neutron star encounters a binary system composed of two non-compact stars and replaces one of those two stars and forms a binary system with the other (see e.g. Clark 1975; Hills 1976), or four-body interactions, where the neutron star is already in a binary system when it interacts with another binary system (see e.g. Mikola 1984; see also Fregeau et al. 2003 for a discussion of recent numerical work on 3-and 4-body interactions).

The easier Roche lobe overflow can be calculated using the standard assumption of a binary separation distribution which is logarithmic, i.e. \( P(a) \propto 1/a \). Taking Kepler's law and the period-mass relation [equation (4.9) of Frank, King & Raine (1992 - FKR92)] we find that for a neutron star accretor and a typical (i.e. a 0.6 \( M_\odot \)) main sequence GC star donor, the Roche lobe overflow orbital separation will be about 3 stellar radii, and varies little with the donor star's mass. The separation at which Roche lobe overflow will occur increases linearly with the stellar radius for a fixed stellar mass. Given the logarithmic distribution of separations and a metallicity dependence of radius such that \( R_a \propto Z^{1/8} \) (estimated from the stellar model interpolation formulae of Tout et al. 1996), the contribution of the term related to the increase in the number of Roche lobe overflowing systems will be 1 + \[ \frac{\log(\frac{R_{\min}}{r_{\text{eq}}})}{\log(\frac{R_{\min}}{r_{\text{eq}}})} \], which is about 1.3 for a metallicity ratio of 10. Numerical calculations suggest that the tidal capture rate goes as \( R_a^{0.33} \), (e.g. Lee & Ostriker 1986), so the number of neutron star binaries formed by tidal capture will go as \( Z^{0.12} \) which gives another factor of about 1.3 for a ratio of metallicities of 10. An additional small increase in the tidal capture probability might come from the higher turnover masses for the stars in metal rich GCs (see e.g. Chaboyer et al. 1996), but this factor should be no more than about 5-10%. Stellar radius effects thus seem unlikely to make more than a \( \sim 60\% \) difference (i.e. the product of the two 30\% effects) in X-ray binary populations as a function of metallicity. In fact, since tidal captures are not likely to produce binary systems that are similar to the observed parameters, it seems more likely that the bulk of the LMXBs are formed in three and four body exchanges (see e.g. Rasio et al. 2000), and so the overabundance factor in red clusters due to larger stellar radii is likely to be closer to the factor of 1.3 than 1.6.

3. The irradiation induced wind model

The mass donors in X-ray binaries can absorb and reprocess luminosities comparable to their intrinsic luminosities. The mass donor may then be “puffed up” to larger radii (e.g. Tutukov & Yungelson 1980; Podsiadlowski 1991; Harpaz & Rappaport 1991) and that the extra kinetic energy added to the envelope may drive off an evaporative wind with a velocity of order the escape velocity from the stellar surface (Arons 1973; Ruderman et al. 1989; Tavani & London 1993; Pfahl, Rappaport & Podsiadlowski 2003). A fraction (\( \sim 10\% \)) of the gas lost by the mass donor will be accreted by the compact star in much the same way that more typical stellar winds are accreted in HMXBs. The lifetimes of LMXBs will also be accelerated by the extra mass loss in the I IWs (Tavani 1991a).

In addition to driving the evolution of the system, the irradiation induced wind will also leave a large amount of gas in the environment of the X-ray binary. Most high mass X-ray binaries show clear orbital modulations of the X-ray flux, especially at soft X-ray energies, and this is taken to be evidence of internal absorption by the material in the stellar wind. An I IW from a low mass star will likely have a velocity much closer to the orbital velocities in the binary system, so the orbital modulation will not necessarily be as strong as in the HMXBs. Still, the increased absorption will have an effect on the spectrum.

Let us summarize a few key past results on irradiation induced winds. It is generally found that these winds should be more important in low mass X-ray binaries than in high mass X-ray binaries, since in low mass X-ray binaries the amount of radiation absorbed by the mass donor from the accretion flow may far exceed the nuclear energy generation rate and may hence have a significant effect on the structure of the donor star (see e.g. Tutukov & Yungelson 1980; Podsiadlowski 1991; ITf97). I IWs may affect HMXBs as well (see e.g. Day & Stevens 1993), but have been much less well studied and are far less likely to dominate the overall mass transfer. Strong coronal winds are likely to result from I IWs and may be self-sustaining even if the mass donor does not fill its Roche lobe (see e.g. Basko & Sunyaev 1973; Arons 1973); in fact, ITf97 have found that self-sustaining winds can produce large luminosities even if the mass donor fills only \( \sim 80\% \) of its Roche lobe, in agreement with past results that a mass donor need not fill its Roche lobe if it is sufficiently irradiated (Tavani, Ruderman & Shaham 1989). Some initial Roche lobe overflow is likely to be required in order to start
accretion, but if the irradiation induced winds cause the mass loss to be substantially faster than what would be caused by orbital and stellar evolution, then the star may cease to fill its Roche lobe even as mass loss and accretion continue. Metal rich stars can dissipate much of their absorbed energy through line cooling, while metal poor stars dissipate this energy primarily through IIWs. Interpolating from the stellar cooling rate tables of Sutherland & Dopita (1993), the mass loss rate due to the IIWs should scale as $Z^{-0.35}$; the system lifetime should scale as $Z^{0.35}$ if the mass loss is dominated by these winds and the lifetime is determined by the timescale for the mass donor to lose all its mass (ITF97).

As a caveat, we note that the treatment of ITF97, is based in part on the analytical irradiation treatment in Iben, Tutukov & Yungelson (1995); while the results do agree well with the numerical work of Tavani & London (1993) within the parameter space of their models, but ITF97 extrapolate outside this range. A more sophisticated numerical treatment may be in order for future work, but is clearly outside the scope of this paper.

For a wind emitted at the escape velocity from the mass donor, equation (4.35) of FKR92 shows that the fraction of the wind captured by the compact object will go as:

$$\frac{\dot{M}}{-M_w} = \frac{1}{4} \left( \frac{M_{CO}}{M_d} \right)^2 \left( \frac{R_d}{a} \right)^2$$

(1)

where $\dot{M}$ is the mass accretion rate of the compact object, $M_w$ is the wind mass loss rate, $M_{CO}$ is compact object’s mass, $M_d$ and $R_d$ are the mass and radius of the donor star, and $a$ is the orbital separation. Given typical values of $a = 4 \times 10^{13}$ cm, $R_d = 7 \times 10^{10}$ cm, $M_d = 0.6M_\odot$ and $M_{CO} = 1.4M_\odot$, about 5% of the wind is accreted.

To simplify the calculation, we make one additional assumption, that the red GCs accrete from a combination of Roche lobe overflow and IIWs, while the bright LMXBs in blue GCs accrete from a self-sustaining wind. We will later revisit this assumption and show that it is not necessary in order to reproduce roughly the observations. We now define the notation for the following 5 equations - $\dot{m}$ indicates the mass accretion rate onto the compact object, while $\dot{M}$ is the mass loss rate. The subscript $w$ indicates wind mass loss, $RL$ indicates Roche lobe overflow effects, $p$ indicates systems with metal poor donors, and $r$ indicates systems with metal rich donors, $N$ indicates the number of systems and $Z$ indicates metallicity. Then

$$\dot{m} = \epsilon \dot{M}_w + \dot{M}_{RL},$$

(2)

where $\epsilon$ is the fraction of the mass lost in the wind that is accreted by the compact object and is given by equation (1). Then, starting from the assumption outlined above that the Roche lobe overflow component is negligible for the metal poor systems, we have:

$$\dot{m}_p = \epsilon \dot{M}_{w,p},$$

(3)

while for metal rich stars,

$$\dot{m}_r = \epsilon \left( \frac{Z_r}{Z_p} \right)^{0.35} \dot{M}_{w,p} + \dot{M}_{RL},$$

(4)

where $\dot{M}_{RL}$ is the mass loss rate due to the Roche lobe overflowing component of the accretion flow, and is assumed to be much smaller than the irradiation driven mass loss rate for the case of a metal poor donor. Combining equations (3) & (4), we find that, for the same luminosity,

$$\frac{M_r}{M_p} = \left( \frac{Z_r}{Z_p} \right)^{-0.35} + \epsilon - \epsilon \left( \frac{Z_r}{Z_p} \right)^{-0.35}. $$

(5)

The fraction of the mass loss in the metal rich systems coming from the IIW is $\left( \frac{Z_p}{Z_r} \right)^{-0.35}$.

The number of X-ray binaries should scale as the formation rate times the lifetime. The formation rate effects have been studied by Bellazzini et al. (1995), and given their lines of argument, we found in Section 2.2 that the stellar radius effects should produce a difference by a factor of about 1.3 (if exchange interactions dominate) to 1.6 (if tidal captures dominate).

The effects of IIWs are predominantly on the system lifetimes. For systems at a given luminosity, equation 5 shows the difference in mass loss rate, the inverse of which gives the ratio of source lifetimes. Thus we find that

$$\frac{N_r}{N_p} = \frac{1}{\left( \frac{Z_r}{Z_p} \right)^{-0.35} + \epsilon - \epsilon \left( \frac{Z_r}{Z_p} \right)^{-0.35}}$$

(6)

To compute the actual ratio of the number of red to blue GC X-ray sources, it is necessary to multiply the factor of 1.3 to 1.6 from the stellar radius effects by the value from equation 6, which should be about 2.1 for the typical parameters $\epsilon = 0.05$ and $\frac{Z_r}{Z_p} = 10$. This gives a factor between about 2.6 and 3.4, although this factor is likely a slight overestimate, because even the X-ray sources in the most metal poor GCs are likely to have at least some Roche lobe overflow contribution to their X-ray luminosities.

It has been assumed that the stellar wind velocity is equal to the escape velocity from the surface of the star; this need not be the case. The extra wind energy for the metal poor stars may be dissipated as a higher velocity wind rather than as a more dense wind. The fraction of the mass lost that is accreted scales as $v_{\text{wind}}^{-4}$ (FKR92), which alternatively scales as the inverse of the wind power squared, for a constant mass loss rate. The luminosity of the LMXBs in metal poor GCs would then be suppressed by a factor of about $\left( \frac{Z_r}{Z_p} \right)^{0.70}$, while the lifetimes of the two classes of systems would be about the same. Because the luminosity function has a slope of about $-0.55$ (KMN02), the ratio of the number of metal rich and metal poor cluster X-ray systems would then be $\left( \frac{Z_r}{Z_p} \right)^{0.39}$, which, for the canonical factor of 10 difference between the two modes gives a factor of about 2.5 difference in the expected number of observed systems. We do note that the there might be systematic variations in the slope of the luminosity functions as a function of metallicity, but absent measurements or a theoretical model, we assume they will be the same.

We wish now to estimate the contribution to the column density with which these systems will typically be observed due to the IIW. We find an average density of mass in a sphere around the mass donor with radius equal to the diameter of the orbit. For a path length of the orbital radius, the column density $N_H$ is then:

$$N_H = \frac{\dot{M}}{8u_w v_{\text{orb}} R_\mu}$$

(7)

where $\mu$ is the mean molecular weight of the gas in the wind, $u_w$ is the wind velocity, and $R_{\text{orb}}$ is the orbital separation. This value, $\approx 6 \times 10^{21}$ cm$^{-2}$, should give a good
approximation over orbital phase and inclination angle for the column density observed. Edge-on sources might be expected to have higher column densities, but the inclination angles for the GC LMXBs are not well constrained.

4. OBSERVATIONAL EVIDENCE FOR THE SCENARIO

4.1. NGC 4472 - number of sources

NGC 4472 is the first galaxy where the metal rich mode was shown to have a higher fraction of GCs with LMXBs than the metal poor mode (KMZ02). It seems unlikely that the GCs in NGC 4472 span a wide range of ages; they are all likely to be within a factor of 1.5 to 2 in age (Beasley et al. 2000; Cohen, Blakeslee & Côté 2003). The metallicity effects on the number of globular cluster X-ray sources thus are not likely due to an age difference between the metal rich and metal poor GCs. The age measurements are rather sensitive to the stellar populations models for the Balmer lines and there could still be a rather substantial age difference between the two samples. More strict constraints are the age measurements of Puzia et al. (2002) which confirm that the correlation between metallicity and LMXB specific frequency in NGC 3115 is due to metallicity and not age (K03), but this system has fewer X-ray sources, so the ratio of the number of LMXBs in metal rich and poor clusters cannot be as well determined. Finally there is the case of NGC 4365, where the ages do span a rather wide range, but do not seem to be strongly correlated with the LMXB number density (K03).

The two modes in color for NGC 4472 peak at V − I of 0.98 and 1.23 (KMZ02), corresponding to values of [Fe/H] of −1.26 and −0.08, respectively, according to the scaling law of Kundu & Whitmore (1998). Defining the metal rich/metal poor mode boundary to be V − I=1.10, we find that 23 of the 450 metal rich GCs and only 7 of the 370 metal poor GCs contain X-ray sources. The metal rich GCs are thus 2.7 ± 1.2 times as likely to contain X-ray sources as the metal poor GCs.

4.2. NGC 4472 - source spectra

The spectra also show a difference as a function of metallicity. While the individual spectra cannot be easily measured because of the low count rates, we have found that the summed spectra in NGC 4472 are harder in the blue GCs than in the red ones (MKZ03). If we hold the neutral hydrogen column in both cases to the Galactic value of 1.6×10^{20} cm$^{-2}$ and fit a power law model to the data, we find a spectral index of 1.02±0.27 for the blue GCs while we find a spectral index of 1.46±0.10 for the red GCs (90% error contours). Allowing the column to float freely for the red GCs, we find $N_H$ to be 4.8×10^{20} cm$^{-2}$ and the power law index to be 1.57. Then, we fix the power law index for the blue GCs and find that the data is best fit with a column density of 1.1×10^{21} cm$^{-2}$.

We note that the solution to the spectral difference problem is not unique and is prone to numerous systematic uncertainties. The photoelectric absorption models we have used assume a solar composition for the absorbing medium, and that the medium is cold (i.e. completely ionized). The underlying spectrum for accreting neutron stars and black holes in the 0.5-8 keV range is unlikely to be a single power law. Finally, we have averaged over many systems with different values of $N_H$ and with different underlying spectra. Still, the rough information given, that the metal poor GCs have an intrinsic absorption of about 10^{21} cm$^{-2}$ and that the column density is about 3 times as large for the metal poor GCs as it is for the metal rich GCs seems to be a reasonable inference to draw from the data. The theoretical model predicts a higher value for the blue clusters, but the linear averaging tends to overestimate the effects on the spectrum, so the fact that our crude calculation over-predicts the amount of absorption is to be expected. Furthermore, the fact that the gas is likely to be partly ionized and will make the fitted value of the $N_H$ less than the actual value, and also some of the gas mass will condense into a geometrically thin accretion disk, and hence will have an effect of absorbing X-rays only if the inclination angle is very low. That the values are on the same order of magnitude and that the blue clusters have about 3 times as much absorption in the fits is about as good an agreement as can be expected given the crude modelling and the considerable theoretical uncertainties in the models of IIWs.

4.3. Local Group Sources

Both the Milky Way and the Magellanic Clouds have been rather well studied in terms of their X-ray stellar populations, and they, show a metallicity difference on the same order as that between the metal rich and metal poor modes for GCs - about a factor of 10. As only a small fraction of the X-ray sources in any of these galaxies is in a GC, the star formation rate has a substantial effect on the relative number densities of X-ray binaries, so merely comparing number counts per unit stellar mass is not likely to prove fruitful. However, one can be fairly confident that the high mass X-ray binary population is not heavily affected by IIWs because the luminosities of high mass stars are much larger than the intercepted and absorbed luminosities. Therefore, the ratio of LMXBs to HMXBs might give a rough estimate of how important the IIWs are. The suggestion of ITF97 that the difference of this ratio might be indicating that irradiation induced winds are playing an important role is therefore additional evidence in favor of this scenario.

5. POTENTIAL OBSERVATIONAL TESTS

This model makes several testable predictions. The first is that there should be a monotonic dependence between the number of LMXBs per unit stellar mass and the metallicity; given enough statistics we should see a difference in the LMXB specific frequency as a function of the metallicity itself, and not just as a function of whether a cluster is in the metal rich or metal poor mode. Much new data has recently entered the Chandra archives, so it is now possible to test this prediction. There is already a correlation over a range of metallicities in the ROSAT spectral indices of GC X-ray sources which does not show a “critical metallicity” (IB), so our model seems to pass this test so far.

This scenario also predicts that neutron star LMXBs will be affected far more than other types of “dynamically interesting” sources. Blue stragglers and cataclysmic variables will not generate high enough X-ray luminosities to
excite substantial IIWs. Black hole systems, because of the higher mass compact objects, will accrete the IIW gas much more efficiently.

IIWs have been suggested to explain why systems such as 4U 1820-30 show different period evolution than would be expected from conservative mass transfer driven by gravitational radiation (Tavani 1991b). An alternative is that the system is being affected by the interactions with the GC potential (van der Klis et al. 1993). Gravitational wave observations from future missions such as LISA may help break this degeneracy.

Additionally, our scenario predicts that the metallicity effects should be essentially the same for field sources as they are for globular cluster sources. Given two galaxies with similar star formation histories, the more metal rich galaxy should have more field X-ray binaries. The natural way to test this hypothesis would be to look at the field X-ray binary populations of elliptical galaxies, as (1) they have very little recent star formation and (2) metallicity tends to scale with galaxy mass. A potential problem with this approach is that a fraction (and indeed, perhaps a large fraction) of the field X-ray binaries may have been created through stellar interactions in GCs and released into the field through dynamical ejections or through tidal destruction of the GCs (see MKZ03 and references within; see also Grindlay 1988). Given that both the tidal destruction rate and the metallicity are likely to be correlated with the mass, applying this test is not straightforward. On the other hand, the field sources of elliptical galaxies should show a metallicity effect on their energy spectra regardless of concerns over formation processes.

A better test might then be to extend the suggestion of ITTF97 that the difference in the ratio of LMXBs to HMXBs in the Milky Way and the LMC is due to the metallicity difference. Since most HMXBs are accretion powered pulsars, a reasonably good separation between the bright ends of the luminosity distributions of HMXBs and LMXBs should be possible given good Chandra spectra of nearby spiral galaxies. We note that this is a generic prediction of any model in which the metallicity effects are strictly due to metallicity, but will provide a way to distinguish between true metallicity effects and effects of metallicity being correlated with more difficult to measure parameters, such as the dynamics of the system.

Past work on detailed spectral fitting on Milky Way GCs has been suggested to indicate that there is little evidence for intrinsic absorption in these systems (Sidoli et al. 2001). We note that this is not in conflict with our model. Sidoli et al (2001) did not obtain a satisfactory spectral fit to the data for M 15, the most metal poor of the Milky Way’s globular clusters with an X-ray source, probably because BeppoSax was not capable of resolving the two bright X-ray sources in the cluster (White & Angelini 2001). The other two most metal poor clusters, NGC 1851 and NGC 6712 do show excess absorption in the X-rays compared with the optical, and the other globular clusters in the Milky Way all have optical extinctions significantly higher than the excess predicted by our model, so the fits would not be very sensitive to intrinsic absorption. Additionally, we note that the fitting of Sidoli et al. (2001) was done using the standard assumption that the absorber would be cold material of solar composition. Since BeppoSax is sensitive to absorption edges in the ~ few keV range, this may cause a systematic error in the fitted absorption value, as noted above. The results of Sidoli et al. (2001) certainly place upper limits on the amount of intrinsic absorption in the Milky Way’s LMXBs, but these upper limits are mostly too high to place strong constraints on our model. A more sensitive test would come from XMM-Newton spectra of M31 globular cluster X-ray sources, where there will be little non-intrinsic absorption since the globular clusters will not be viewed through the disk of the Galaxy. In fact, many of the M31 globular cluster X-ray sources show evidence for intrinsic absorption, and the ones that do are predominantly in metal poor clusters (Irwin & Bregman 1999).

Differences in the luminosity functions between red and blue globular cluster X-ray sources should also, in principle, provide a way to discriminate between models for formation and evolution of their X-ray binaries. Unfortunately, it is difficult at this time to make a prediction from our scenario. It is not clear on theoretical grounds whether the extra wind energy in metal poor systems manifests itself as a higher mass loss rate, yielding probably slightly higher luminosities, albeit for much shorter amounts of time, or as higher wind velocities, in which case the efficiency of wind capture is lower, so the luminosity will be lower at a given mass loss rate, or as some combination of the two. Furthermore, there is not yet a sufficiently large sample of X-ray binaries in globular clusters for making a good comparison of the luminosity functions. This does remain a good test to bear in mind for future work.

6. CONCLUSIONS

We have outlined a scenario whereby the two metallicity effects seen in LMXBs in globular clusters, higher number density in metal rich clusters, and harder low energy X-ray spectral in metal poor clusters, can be explained via the same mechanism – irradiation induced stellar winds. We have presented additional feasible observational tests of this picture. While we have shown that the physics of the irradiation induced winds required to reproduce the observations is consistent with the most recent theoretical work, we also note that this is a rather complicated problem which is deserving of considerable additional attention by experts in binary stellar structure and evolution. We hope this paper will help to stimulate such work in the future.

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