A Massive Star Odyssey, from Main Sequence to Supernova
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An X-ray survey of Wolf-Rayet stars in the Magellanic Clouds

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Abstract. We have used archival *Chandra*-ACIS observations to search for X-ray emission from WR stars in the Magellanic Clouds (MCs), where the low interstellar absorption and known distances make it easy to compare X-ray luminosities with spectral types and binary status of WR stars. We have detected X-ray emission from ~ 20 WR stars in the MCs with X-ray luminosities of 6.6×10^{32} - 1.4×10^{35} ergs s^{-1}. The analysis of the X-ray spectra of the brightest sources indicates that the X-ray emitting gas has temperatures $\geq 1.0\times10^{7}$ K, as expected in colliding winds. We will compare these results with the binary status of the WR stars to determine the amounts of the X-ray emission produced in the colliding winds for WR stars in binary systems and to assess the X-ray emission from single WR stars.

1. Introduction

Wolf-Rayet (WR) stars have the most powerful stellar winds with typical $\dot{M}$ a few times $10^{-5}\,M_\odot\,yr^{-1}$ and $L_w \approx 10^{37-38}$ erg s^{-1}. The energetic WR winds produce shocked gas that emits X-rays. Three types of X-ray sources can be produced by a WR wind: (*i*) shocks in wind, shocks in the WR wind itself; (*ii*) colliding winds, collision with a massive companion's fast wind; and (*iii*) wind-blown bubble, shocked WR wind in the interior of the circumstellar bubble.

Previous X-ray observatories (*Einstein*, *ROSAT*) detected X-ray emission from ~ 30 WR stars in the Galaxy. The distances to these WR stars and their binary nature are notoriously uncertain; furthermore, the X-ray emission is greatly affected by the large interstellar absorption in the Galactic plane. Thus, it has been difficult to compare L_x with L_{bol} in single stars or to determine the fraction of X-ray emission produced by colliding winds for WR stars in massive binaries.

The Large and Small Magellanic Clouds, at known distances and with much smaller foreground and internal absorption, provide a unique opportunity to study X-ray emission from WR stars. More importantly, there has been a systematic spectroscopic search for binaries for all WR stars in the MCs (Foellmi, Moffat & Guerrero 2003a,b; Foellmi, Moffat & Guerrero, these Proceedings; Schnurr *et al.* in preparation) that will provide an invaluable binary database to interpret the X-ray emission from these WR stars.

Previous *ROSAT*-PSPC observations of the MCs provided little insight on the X-ray emission from WR stars in these galaxies. *Chandra*-ACIS and *XXM*-EPIC instruments have much finer angular resolutions, $\sim 1''$ and $\sim 6''$, respec-

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tively, and higher sensitivities, 3 - 10 times that of *ROSAT*-PSPC. They thus provide the first opportunity to observe and study the X-ray emission from WR stars in the MCs.

2. Preliminary results

We have searched the *Chandra* archive for ACIS observations of WR stars in the MCs. As of Spring 2002, public *Chandra*-ACIS observations are available for 50 of the 134 WR stars in the LMC (Breysacher, Azzopardi & Testor 1999) and 3 of the 11 WR stars in the SMC (Massey & Duffy 2001). We have used these observations to search for X-ray emission from WR stars by comparing the ACIS X-ray images with optical images extracted from the Digitized Sky Survey (DSS). We have detected X-ray emission with $\geq 3\,\sigma$ confidence from 19 WR stars in the LMC and the 3 WR stars in the SMC.

We have further analyzed the X-ray spectra of the sources with numbers of counts ≥ 100 by fitting the observed spectra with a thin plasma emission model. This has allowed us to determine the plasma temperature $T_{\rm x}$, the absorption column density $N_{\rm H}$, and the X-ray luminosity $L_{\rm x}$. We find $T_{\rm x} \geq 1.0 \times 10^7$ K, as expected in colliding winds. For the sources which are detected but with insufficient number of counts to perform a spectral analysis, we have qualitatively assessed their spectra and adopted reasonable values of $T_{\rm x}$ and $N_{\rm H}$ to derive $L_{\rm x}$. Similarly, for the sources which are not detected, we have adopted a thin plasma emission model with reasonable $T_{\rm x}$ and $N_{\rm H}$ to compute the $3\,\sigma$ upper limit of $L_{\rm x}$ from the measured detection limit.

Further details of these results will be reported in a future paper (Guerrero & Chu, in preparation). In that paper we will also use public data from the *XMM-Newton* archive to enlarge the sample of WR stars in the MCs with X-ray observations. The possible X-ray variability will also be investigated.

3. Summary

A very preliminary analysis shows that the occurrence of X-ray emission among WR stars in the MCs seems higher for WR stars with massive binary companions. The spectroscopic search for binaries for all WR stars in the MCs being carried out by Foellmi, Moffat & Guerrero (2003a,b) and Schnurr *et al.* (in preparation) will provide a complete census of WR stars in binary systems in the MCs. A detailed comparison of the binary status of WR stars in the MCs and their X-ray properties will help us determine more accurately the X-ray emission from shocks in the wind of single WR stars and understand better the colliding winds in binary systems.

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