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SUPPLEMENTS

RXTE Observations of the Starburst Galaxy M82

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The two nearby starburst galaxies M82 and NGC 253 were recently observed with the PCA and HEXTE experiments aboard RXTE. Here we present first results from a preliminary analysis of ~ 75% of the M82 data. A power-law, photon index 2.0 ± 0.1, and thermal emission at $kT = 7.4 \pm 0.7$ keV, are both acceptable spectral fits to the data. For the first time, we find evidence for iron lines; there is no evidence for temporal variability.

1. INTRODUCTION

Nearby spiral galaxies have been studied extensively in essentially all regions of the electromagnetic spectrum at energies up to ~ 10 keV. Some nearby galaxies have been observed at higher energies, including mostly those with active nuclei (AGNs), and (only) two starburst galaxies (SBGs). While interest in high energy X-ray (> 10 keV; HEX) emission from AGNs is obvious, less recognized is the motivation for its observation from SBGs: This stems from the diverse radiative activity which is powered by an abundant population of massive, young stars. The enhanced star formation rate in these gas and dust rich galaxies leads to intense far-infrared (FIR) radiation from warm interstellar dust heated by the massive stars [1]. The higher supernova (SN) rate (and perhaps also a more abundant population of X-ray binaries) results in enhanced X-ray emission from the SN and their remnants, and the hot wind driven by SN shocks [2]. Moreover, since SN remnants are prime sites for shock-acceleration of particles to relativistic energies, electron Compton scattering off the local radiation fields will significantly enhance the X-ray emission of a SBG. This expectation is heightened by the fact that in a SBG the energy density of the FIR radiation field can be much higher than that of the cosmic microwave background (CMB) radiation ([3,4].

The SB phase may occur in various types of galaxies (triggered, perhaps, by galactic mergers). A SBG may also have an active, compact nucleus, so the class of SBGs may not be a distinct one. Indeed, one of the primary issues in the study of SBGs is the possible connection between low-luminosity AGN and SB activities. Since both phenomena may occur in at least some active galaxies, it is important to determine their respective emission properties. Observations of X-ray emission from SBGs are also of interest in order to determine their contribution to the cosmic X-ray background [5,6].

High energy phenomena are at the root of the SB activity, and because of the obscuration of optical emission and considerable re-processing of IR emission, X-rays allow a penetrating view of SBGs. Major open issues are the dominant X-ray emission mechanisms – thermal emission from massive X-ray binaries, SN and their remnants, galactic wind, or diffuse nonthermal emission due to Compton scattering – and main emitting sites, including a nuclear region, the galactic disk and halo. Irrespective of the exact X-ray emitting mechanism, the IR and X-ray outputs of a SBG are expected to be directly correlated, as they are largely powered by the same parent population of massive stars.

M82 and NGC 253 are the closest nearby SBGs. These 'archytypical' SBGs were observed with all the major X-ray satellites (e.g., [7–10]). Their low energy emission is quite substantial, ~ 10^{41} erg/s, and the best-fit spectra include both thermal and power-law components. The low energy emission

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seems to extend well beyond the optical size of these galaxies.

These two SBGs were recently observed with the PCA and HEXTE experiments aboard RXTE. Here we report the results of our initial analysis of most of the data taken during the 100 ksec measurement of M82.

2. OBSERVATIONS

A key issue in interpretation of the x-ray observations is whether the emission can be dominated by a small agn-like core, and thus not fit the starburst picture. Observationally, we tested for this possibility by searching for variability on the widest possible range of time scales to a sensitivity not substantially less than for the combined spectral results. We have taken advantage of the flexible RXTE scheduling and based a sampling scheme on the 15-element cyclic difference set, applied on four different intervals: 1-15 orbits, 0.5-7.5 days, 4-60 days, and 24-360 days. Each set contains 8 observations which provide 28 pairwise baselines, resulting in roughly uniform sampling of the elementary frequencies on the interval. The overlaps help to compensate for the overall window function for each set. We have not convinced ourselves that the cyclic difference set provides optimal sampling, but we have determined empirically that it samples the elementary frequencies roughly equally. Since each period longer than one orbit is sampled by one quarter of the total data set, sensitivity at each frequency is approximately one half of that for the average. We obtained in total 32 orbits, or 100000 seconds, in round numbers. Analysis for variability could not be completed in time for this report.

3. SPECTRAL ANALYSIS

About 80 ksec of data were accumulated from both the PCA and HEXTE instruments for an average spectrum. Correction for internal background was accomplished with off-source rocking with HEXTE, and with the released background model for PCA. The PCA background estimate appears to be quite accurate at all energies, but has random statistical errors a factor of a few larger than from the counting statistics of the PCA itself. Correction for this extra random error introduces the biggest uncertainty into the estimates of best-fit spectral errors, particularly in the case of a thermal fit, for which the HEXTE data are less constraining than for a power law. Fitting was performed with XSPEC, using detector response matrices from the standard release. The best-fit power law spectrum is shown in Figure 1.

4. DISCUSSION

Detection of significant low energy X-ray emission from M82 is, of course, not surprising. What might prove important is evidence in the HEXTE data that the emission extends to energies $\sim$ 30 keV. If the emission is thermal with an equivalent temperature of $\sim$ 7 keV, then an Fe K line is expected, along with some higher energy emission. However, given the current stage of the analysis, we cannot preclude the possibility that the spectrum is a superposition of a low temperature $\sim$ 1 keV component and and a power-law component. In a recent analysis of *Rosat* and *ASCA* measurements of M82 it was deduced that a power-law component, with a photon index $\sim$ 1.7, dominates the emission, with two additional thermal components, at 0.3 K and 0.6 K, required to best-fit the combined spectrum [11]. Our results are weighed by evidence in the PCA for a spectral feature at 6.6 ± 0.1 keV, whereas there is no evidence for Fe lines in the ASCA data.

The high best-fit temperature deduced here is uncommon in galaxies in which hot gas temperatures are typically $\leq$ 3. While we do expect the intense star formation activity to drive a hot galactic wind, it is not at all clear that the wind emission can be sufficiently high that it constitutes the dominant spectral component in M82. The observed emission may perhaps be a superposition of thermal emission from SN and their remnants, as well as emission from a population of massive X-ray binaries. At this point in the analysis we cannot quantitatively assess these and other origins of thermal emission.

Neither can we at present be more specific about the likely origin of a dominant power-law

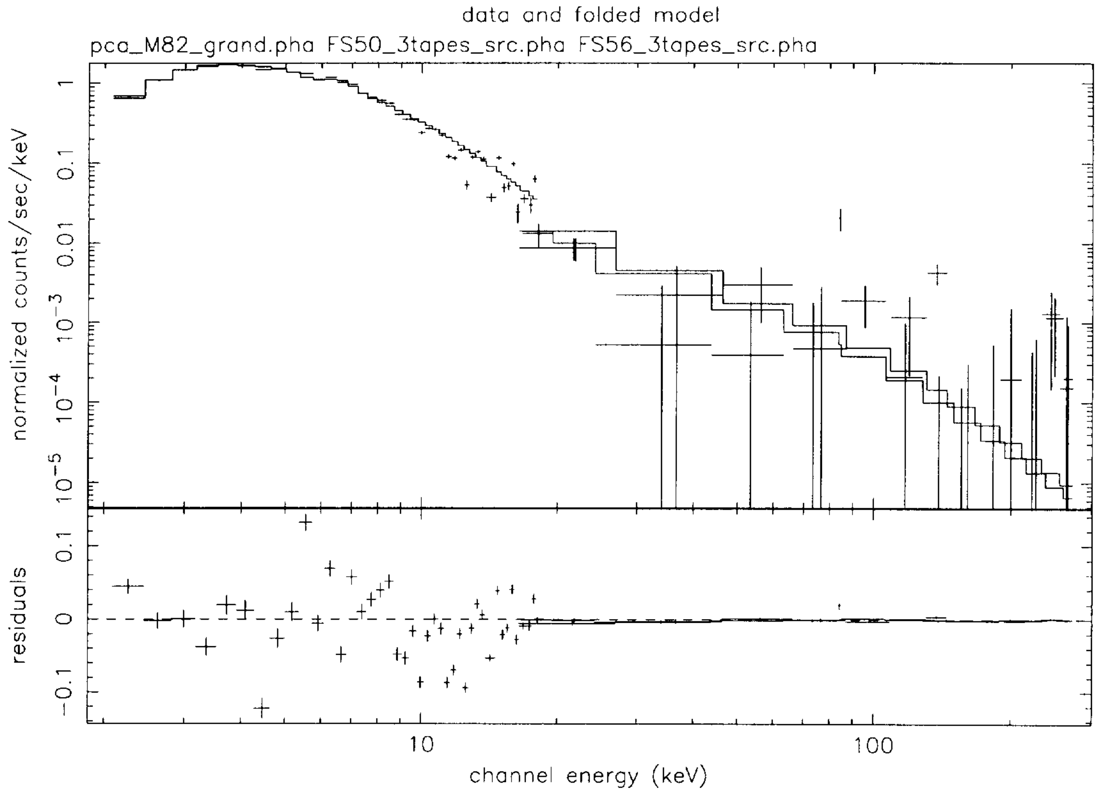

Figure 1. Observed average spectrum of M82 from RXTE, with best-fit power law spectrum of index 2.1. An iron line at 6.6 keV is evident. Errows shown are statistical, and the scatter beyond this statistical level is caused by error propagation in the PCA background model. A fit to thin thermal bremsstrahlung has similar goodness of fit, and gives a best fit $kT = 7.5\ keV$, with no allowance for the background model errors.

component. As has been shown by Goldshmidt & Rephaeli [12], Compton scattering of radio producing relativistic electrons by the far infrared radiation field can account for the substantial high energy (50−150) emission detected by OSSE from NGC 253 [13]. The similarities in radio properties of M82 and NGC 253 and their common starburst nature are strong enough indications that Compton scattering may play a significant role also in M82. This may be so even though our best-fit power-law index seems to be appreciably steeper than the radio index. However, even with improved spectral analysis of the full RXTE dataset, spatial information will still be needed in order to determine the truly extended nature of a likely Compton emission. This is in sharp contrast to the spatially unresolved emission that would be expected from a compact nuclear region. We note again that no temporal variability could be determined in the current data (and probably also in the full dataset when available).

A more complete analysis will be performed on the full set of observations which will soon be available. It should then be possible to obtain more precise spectral information on the 2 – 40 keV emission from M82.

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