Simulating the X-ray evolution of late-type galaxies with evolutionary population synthesis

XIAN JIAOTONG UNIVERSITY

Zhao-yu Zuo and Xiang-dong Li

zuozyu@mail.xjtu.edu.cn

Department of Physics,

Xi'an Jiaotong University, Xi'an 710049, China

Abstract

We have modeled the X-ray evolution of late-type galaxies over the ~14 Gyr of cosmic history, with an evolutionary population synthesis (*EPS*) code. Our calculations reveal a decrease in the X-ray luminosity-to-mass ratio L_X/M with time, in agreement with observations. We show that this decrease is a natural consequence of stellar and binary evolution and the mass accumulating process in galaxies. The X-ray-to-optical luminosity ratio L_X/L_B is found to be fairly constant , and insensitive to the star formation (SF) history in the galaxies. The nearly constant value of L_X/L_B is in conflict with the observed increase in L_X/L_B from z = 0 to 1.4. The discrepancy may be caused by intense obscured SF activity that leads to a nonlinear relationship between X-ray and *B*-band emission.

1.Introduction

Using *Chandra* data, Lehmer et al. (2008) found that there is a significant increase (by a factor of about 5–10) in the X-ray-to-optical luminosity ratio (L_X/L_B) and the X-ray-to-stellar mass ratio (L_X/M) for the galaxy populations selected by L_B and M, respectively, over the red-shift range of z =0–1.4. The X-ray luminosity-to-SFR ratio (L_X/SFR) is constant over the entire red-shift range for galaxies with SFR = 1–100$M_\odot$/yr selected by SFR. In this work, we used an *EPS* code to investigate the X-ray evolution of late-type galaxy populations and its dependence on the physical properties of galaxies (e.g., optical luminosity, stellar mass, and mass-to-light ratio) and on the star formation history (SFH). We also examined how the key parameters, such as initial mass function (IMF), common envelope (CE) efficiency, the binary fraction, and metallicity, may affect the X-ray emission of the galaxies.

2. Models

2.1. Assumptions and Input Parameters

We constructed three cases, i.e., constant SF, starburst SF, and cosmic SF cases, to examine its dependence on SF activities.

(1) Constant star formation case

In this case, We examined several key parameters, such as the IMF, CE efficiency parameter, the binary fraction, and metallicity (listed in Table 1 of **Zuo & Li 2011, *ApJ*, 733, 5**), to explore their influence on the X-ray evolution of the galaxies.

(2) Starburst star formation case

We take three combinations of SF duration and metallicities: 100 Myr/Z, 20 Myr/Z, and 100 Myr/0.02Z to reveal the effect of SFH.

(3) Cosmic star formation case

We adopt the derived expression of the SFH in Hopkins & Beacom (2006), and an empirical equation $Z/Z_\odot \propto 10^{-\gamma z}$ for metallicity evolution. We also vary the Kroupa (2001, hereafter KROUPA01) IMF to a steeper one (KTG93) and a shallower one (Baldry & Glazebrook 2003, BG03 for short) to examine its effect in this case.

$$\dot{\rho}_{\rm SF}(z) \propto \begin{cases} (1+z)^{3.44} & z \leqslant 0.97 \\ (1+z)^{-0.26} & 0.97 \leqslant z \leqslant 4.48 \\ (1+z)^{-7.8} & 4.48 \leqslant z, \end{cases}$$

2.2. X-ray Luminosity

The simulated X-ray luminosity is described as the right formula:

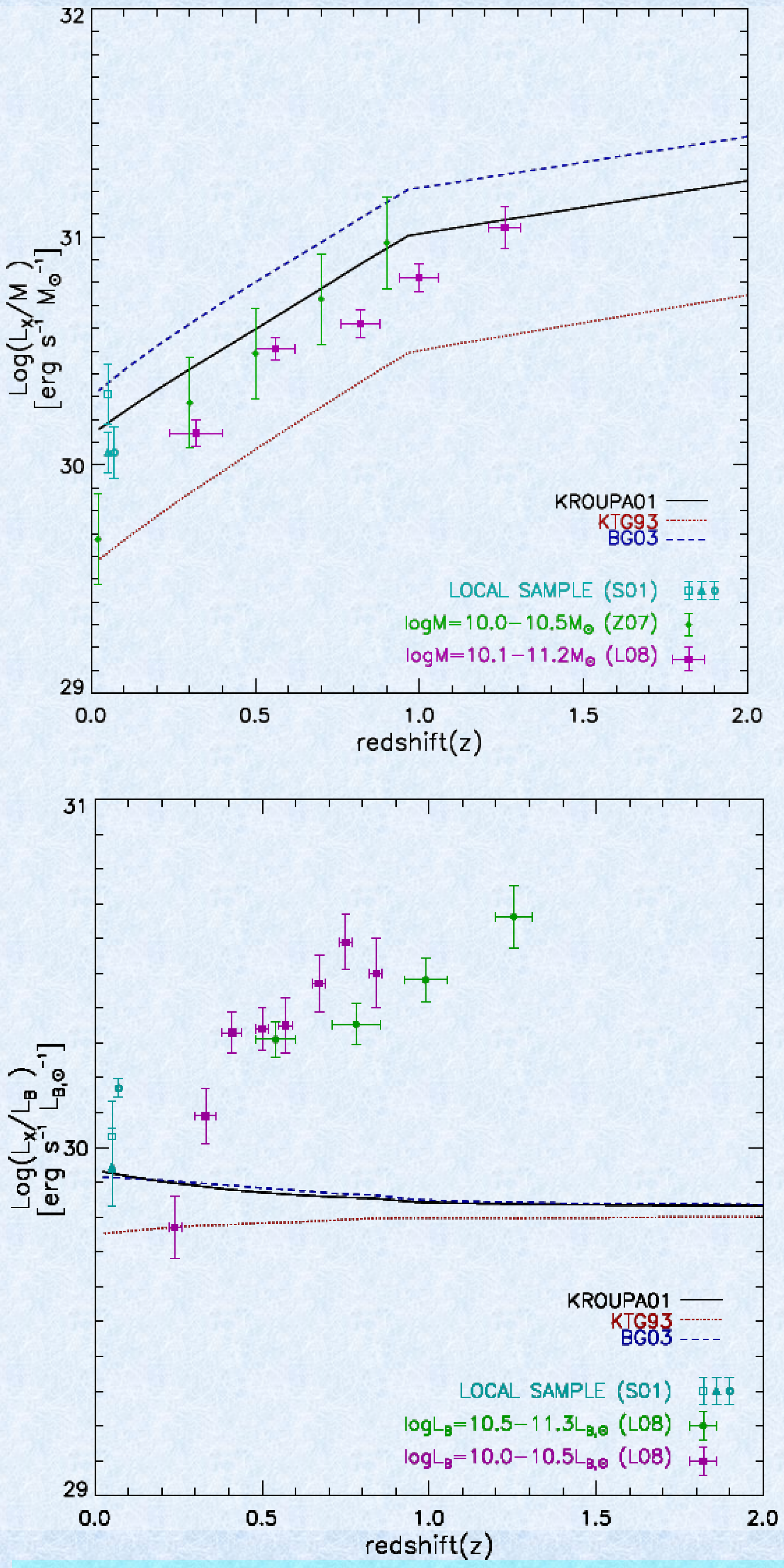
$$L_{\rm X,0.5-8\,keV} = \begin{cases} \eta_{\rm bol}\eta_{\rm out}L_{\rm Edd} & \text{transients in outbursts,} \\ \eta_{\rm bol}\min(L_{\rm bol}, \eta_{\rm Edd}L_{\rm Edd}) & \text{persistent systems,} \end{cases}$$

2.3. Optical Luminosity L_B and Stellar Mass of the Galaxy

We consider the optical luminosity L_B from both normal stars (both binary and single stars) and accretion disks in X-ray Binaries. The stellar mass here is the sum of the masses of currently living stars.

3. Our Result

Here we only present the results in the cosmic SF case for simplicity, while summarize concisely all our findings in the **conclusion** part. Further details, please refer to Zuo & Li (2011).



Evolution of the X-ray luminosity-to-stellar mass ratio (L_X/M, upper panel) and X-ray-to-*B*-band luminosity ratio (L_X/L_B, lower panel) with red-shift z, respectively. Here we have assumed a cosmic SFH (from Hopkins & Beacom 2006) and a cosmic metallicity evolution history (from Langer & Norman 2006). The solid, dotted, and dashed lines represent modeled results with IMFs of Kroupa (2001, KROUPA01), Kroupa et al. (1993, KTG93), and Baldry & Glazebrook (2003, BG03), respectively. Also shown are the measured values of log(L_X/M) (upper panel) selected by M (square) and log(L_X/L_B) (lower panel) selected by L_B (filled circles and squares) respectively, for stacked normal late-type galaxy samples derived by Lehmer et al. (2008, L08). We converted the SSFR to L_X/M in Zheng et al. (2007, Z07) samples of the corresponding stellar mass bin (diamonds), using the local L_X–SFR relation derived by Persic & Rephaeli (2007). The data for normal late-type galaxies in the local universe (open symbols) are from the Shapley et al. (2001, S01) samples.

(1) Our simulated log(L_X/M) versus z relations match the observations quite well. Our calculations reveal that the modeled stellar masses are similar to each other within 10% when we use different types of IMFs, suggesting that the variation of the L_X/M ratio is mainly caused by the differences in L_X. The values of L_X/M can vary by a factor of ~7 between models (KTG93 *vs* BG03), as seen in the upper panel.

(2) The nearly constant values of L_X/L_B in the lower panel seem to not properly match the observed increase in L_X/L_B with z. The discrepancy originates from the fact that in our simulations we have roughly $L_X \propto L_B$, giving a flat $L_X/L_B - z$ relation, while observationally it was found that $L_X \propto L_B^{1.5}$, leading to increasing L_X/L_B with z. Fabbiano & Shapley (2002) suggested that the nonlinear power-law dependency in disk galaxies is likely to be due to extinction in dusty star-forming regions, which attenuates light from the *B* band more effectively than it does in the X-ray band. If it does, our results are compatible with the observational data at least qualitatively.

4. Conclusion

In different cases of SF (i.e., constant, starburst and cosmic SF), we find a common feature of decreasing X-ray luminosity-to-mass ratio L_X/M with time, in agreement with observations. We show that the decrease of L_X/M results from slow evolution of L_X of X-ray binaries and the stellar mass accumulation with time in galaxies, without requiring that lower mass galaxies have higher SSFR than more massive ones as suggested before. The L_X/L_B ratios in all cases rise rapidly in the first $\sim 10^8$ yr to $\sim 10^{30}$ erg s^{-1} $L_{B,\odot}^{-1}$, then stay nearly constant afterward for a given model, and are not sensitive to the SFH details in the galaxies. This seems to be in conflict with the observed increase in L_X/L_B with z. The discrepancy may be due to different obscured SF activities in galaxies at higher redshifts. This will be investigated by future high-resolution X-ray and optical observations of galaxies at high redshifts.

References:

[1] Lehmer, B. D., et al. 2008, ApJ, 681, 1163 [L08] [2] Zheng, X. Z. et al, 2007, ApJ, 661, L41 [Z07]

[3] Shapley, A., Fabbiano, G., & Eskridge, P. B. 2001, ApJS, 137, 139 [S01]