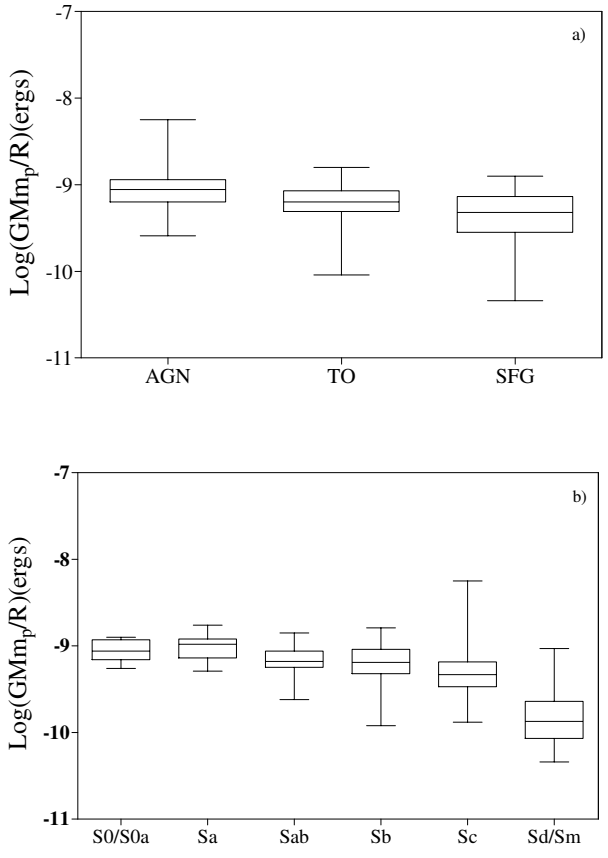

Fig. 19. Box-whisker plot of gravitational potential energy per baryon of the isolated NELGs, (a) with different activity types, (b) with different morphologies.

Figure 18 that the AGNs and TOs have higher gravitational binding energies than the SFGs. This trend is better seen in Figure 19a, which shows the box-whisker plots for the gravitational binding energies. The trend is also confirmed to be statistically significant in Table A1 of the Appendix.

The variation of gravitational binding energies with galaxy morphologies is shown in Figure 19b, and the trend is statistically tested in Table A2 of the Appendix. Galaxies with massive bulges, S0, S0a, and Sa, have comparable gravitational binding energies, which are significantly higher than those of galaxies having less massive bulges, Sab and later. These results are in good agreement with the hypothesis of a SMBH in the NLAGNs (and possibly also in the TOs).

4.1. *Masses of SMBHs vs. accretion rates*

Our analysis of the NLAGNs in our sample is consistent with the standard AGN interpretation: this phenomenon is the product of the accretion of matter onto a SMBH that developed at the same time as the massive bulge of the galaxy. According to this interpretation, the nearby NLAGNs in our sample are possibly scaled-down (and/or powered-down) versions of quasars and broad-line AGNs (BLAGNs). One good example is our own galaxy, with an intermediate Sb or SBb morphology (Binney & Merrifield 1998), where evidence was found in its center for both a SBMH, with a mass of the order of 3 or $\sim 4\times10^6$ $M_\odot$ (Genzel & Townes 1987; Ghez, Morris, & Becklin 2000; Schödel, Merritt, & Eckart 2009), and of recent star formation episodes (Figer et al. 2004), which suggests it could be classified as a LINER or a TO by outside observers.

In Häring & Rix (2004) a strong correlation was found between bulge mass and black hole mass (see also Gültekin et al. 2009, and references therein). In Shemmer et al. (2004) and Matsuoka et al. (2011), a strong correlation was also found between the black hole mass and the gas metallicity. These two correlations are fully consistent with our observations: while the formation of the SMBH follows (or self-regulates) the formation of the bulge, the gas metallicity, being a product of the evolution of the stars, also depends on the bulge formation through typically high astration rates (Sandage 1986). Based on these observations, we may therefore expect the NLAGNs to follow the same correlations as the quasars and BLAGNs.

To calculate the black hole masses, $M_{\rm BH}$, as reported in Column 3 of Table 4, we used the relation between the bulge mass and black hole mass as determined by Häring & Rix (2004). For the isolated NLAGNs we find a median value of 4.8×10^6 $M_\odot$, which is two to three orders below the value found in BLAGNs, but in good agreement with the black hole mass found in the center of our galaxy (Genzel & Townes 1987; Ghez et al. 2000; Schödel et al. 2009).

In Figure 20 we compare the gas metallicities and black hole masses for the NLAGNs of our sample with those measured in quasars and BLAGNs (Shemmer et al. 2004). The metallicities measured by Shemmer et al. (2004) were transformed to the units used in our study by Neri-Larios et al. (2011). The NLAGNs seem to continue the linear correlation found for the quasars and BLAGNs in the lower metallicity regime. A linear fit with a correlation coefficient of $r_{\rm Pearson} = 0.77$ and $r_{\rm Spearman} = 0.83$, both with chance probability $P(r_{\rm Pearson})$ and $P(r_{\rm Spearman})$ practically equal to zero, suggests the metallicity increases with the black hole mass as:

$$\log([{\rm O/H}]) = -2.56 + 0.3590 \times \log(M_{\rm BH})\,. \quad (6)$$