Disentangling the Impacts of Feedback, Environment, and Galaxy Interactions

Xingyao Cai[1,2] Xi Kang[1] Hassen M. Yesuf[2]

[1]Institute for Astronomy, Zhejiang University [2]Shanghai Astronomical Observatory

Abstract

In this study, we explore the connection between HI gas and dark matter halos to disentangle the impacts of internal feedback mechanisms and environmental factors on galaxy evolution, using the IllustrisTNG-100 simulation. By calculating the HI content and distribution within galaxies, we investigate the role of HI gas in galaxy quenching. This analysis reflects how feedback processes and large-scale environments influence the evolution of galaxies. Our key findings show distinct differences in HI distribution between AGN and non-AGN galaxies. We observe an inverse relationship between HI content and dark matter halo mass. In massive galaxies, HI is predominantly located beyond 10 kpc from the center, leaving a gas depletion zone in the core. Furthermore, the correlation between HI content and dark matter halo mass weakens when controlling for stellar mass. These results highlight the importance of HI gas distribution in understanding the interplay between internal feedback and environmental effects, providing new insights into the HI gas–dark matter halo connection in galaxy evolution.

The missing gas in the central region of galaxies

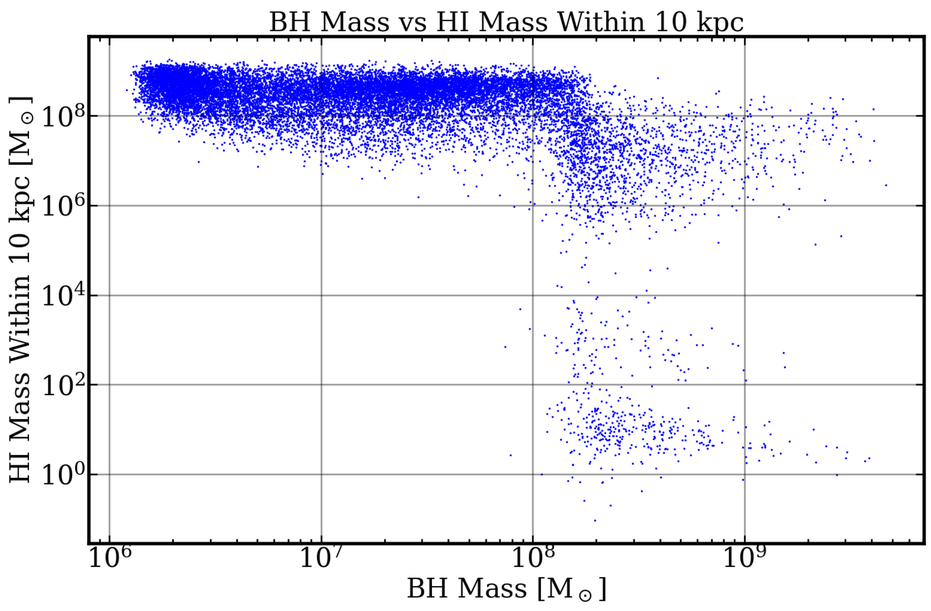

Figure 1. The HI masses within 10 kpc of the central galaxy as a function of the black hole mass. Data from Illustris-TNG 100.

A drop in the HI mass is observed for galaxies with black hole masses above $10^8 M_\odot$. This suggests that the gas is missing in the central region of galaxies, which has a significant link to the black hole mass.

HI Mass in Radii

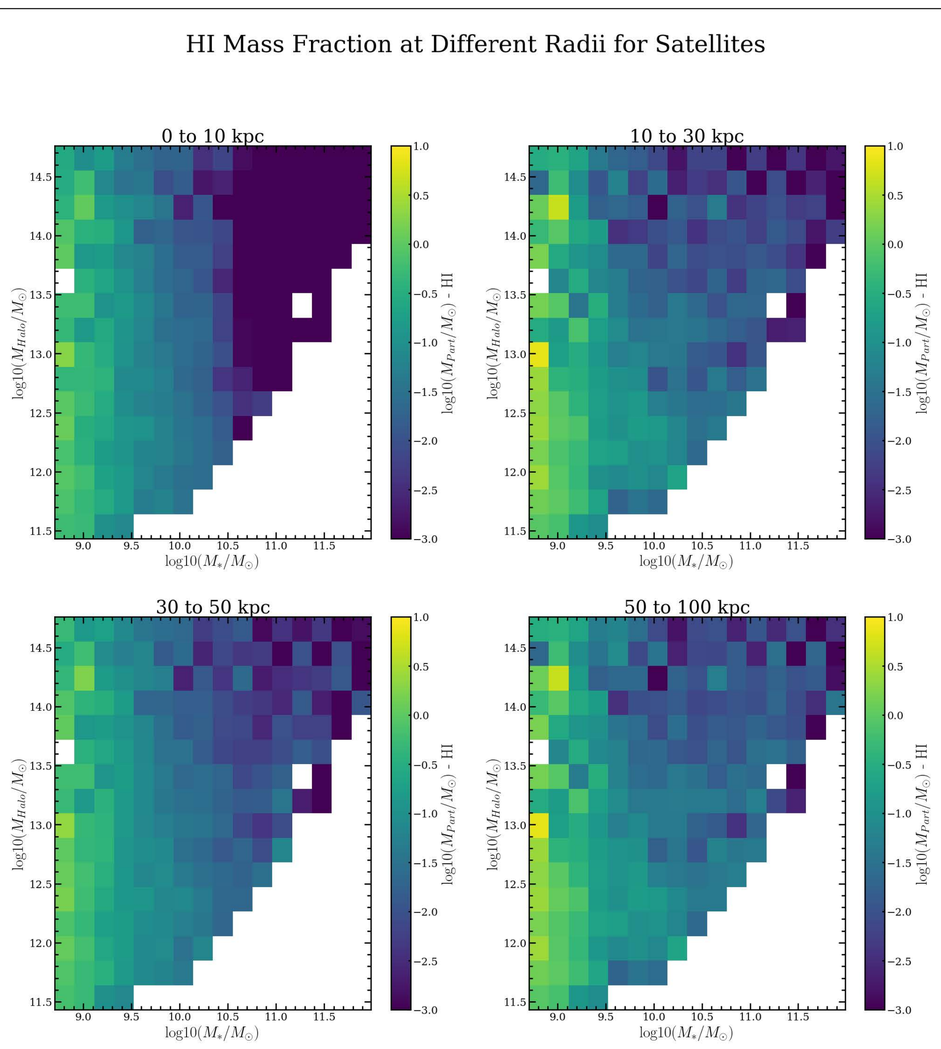

Figure 2. The HI fraction within different radii of the central galaxy as a function of the stellar mass and the halo mass. Data from Illustris-TNG 100.

Key Findings

- The HI fraction within 10 kpc of the central galaxy decreases with increasing stellar mass, and as the stellar masses exceed $10^{10.5} M_\odot$, the HI fraction drops significantly and generates a gas depletion zone in the central region.
- The HI fraction doesn't show a strong correlation with the halo mass, indicating the environmental effects on the HI content are weaker than the internal feedback mechanisms.

HI Fraction Calculation

$$n_{HI}\Gamma_{\mathrm{TOT}} = \alpha_{\mathrm{A}} n_e n_{\mathrm{H_II}} \tag{1}$$

$$\alpha_{\mathrm{A}} = 1.269 \times 10^{-13} \frac{\lambda^{1.503}}{\left(1 + (\lambda/0.522)^{0.47}\right)^{1.923}} \mathrm{cm^3 s^{-1}} \tag{2}$$

where $\lambda = 315614/T$. Use $\eta = n_{\mathrm{HI+H_2}}/n_{\mathrm{H}} = n_{\mathrm{H_0}}/n_{\mathrm{H}}$, we have

$$\eta\Gamma_{\mathrm{TOT}} = \alpha_{\mathrm{A}} (1-\eta)^2 n_{\mathrm{H}} \tag{3}$$

$$\Gamma_{\mathrm{TOT}} = \Gamma_{\mathrm{Phot}} + \Gamma_{\mathrm{Col}} \tag{4}$$

$$\Gamma_{\mathrm{Col}} = \Lambda_{\mathrm{T}} \left(1 - \eta^2\right) n_{\mathrm{H}} \tag{5}$$

$$\Lambda_{\mathrm{T}} = 1.17 \times 10^{-10} \frac{T^{1/2} \exp\left(157809/T\right)}{1 + \sqrt{T/10^5}} \tag{6}$$

$$A\eta^2 - B\eta + C = 0 \tag{7}$$

$A = \alpha_{\mathrm{A}} + \Lambda_{\mathrm{T}}$, $B = 2\alpha_{\mathrm{A}} + \frac{\Gamma_{\mathrm{Phot}}}{n_{\mathrm{H}}} + \Lambda_{\mathrm{T}}$, $C = \alpha_{\mathrm{A}}$.

Gas Properties After the Black Hole Mass Exceeds $10^8 M_\odot$

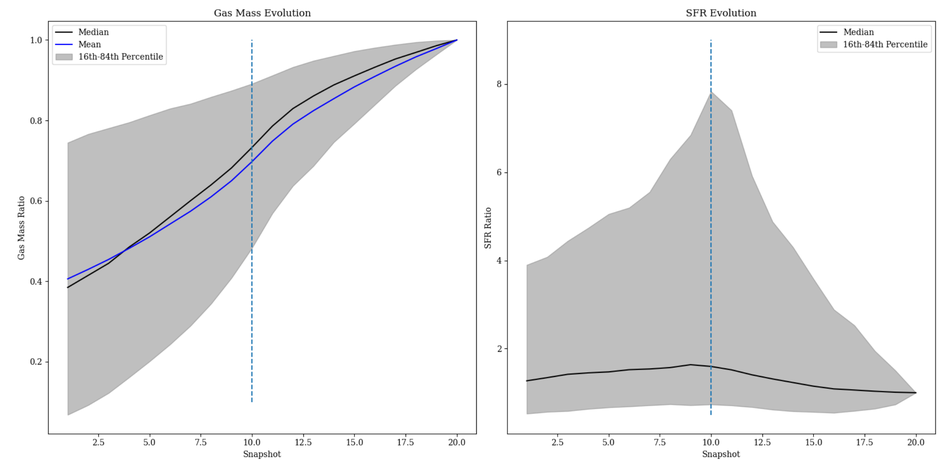

Figure 3. The total gas mass and the star formation rate as a function of time. The vertical dashed line indicates the snapshot when the black hole mass exceeds $10^8 M_\odot$. Grey shaded regions represent the 16th and 84th percentiles. Data from Illustris-TNG 100.

The total gas mass and the star formation rate decrease significantly after the black hole mass exceeds $10^8 M_\odot$. This suggests that the gas depletion in the central region of galaxies is related to the black hole mass. Also we can see this trend in the HI mass within 10 kpc and 30 kpc of the central galaxy. From a stastical perspective, the HI mass within 10 kpc (30 kpc)of the central galaxy decreases significantly after the black hole mass exceeds $10^8 M_\odot$. These figures indicate that the gas depletion in the central region of galaxies is related to the black hole mass, as the black hole mass exceeds $10^8 M_\odot$, the feedback from the black hole will suppress the gas accretion and star formation in the central region of galaxies, generating a "gas hole" in the central region of galaxies.

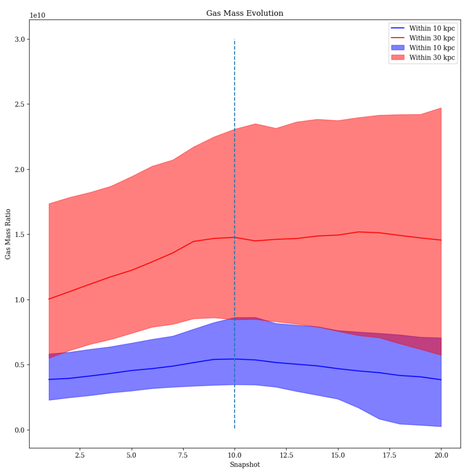

Figure 4. The HI mass within 10 kpc (30 kpc) of the central galaxy as a function of time. Blue (red) shaded regions represent the 16th and 84th percentiles. Data from Illustris-TNG 100.

Conclusions

- The HI content within 10 kpc of the central galaxy decreases with increasing stellar mass, and as the stellar masses exceed $10^{10.5} M_\odot$, the HI content drops significantly and generates a gas depletion zone in the central region.
- The HI content doesn't show a strong correlation with the halo mass, indicating the environmental effects on the HI content are weaker than the internal feedback mechanisms.
- The gas depletion in the central region of galaxies is related to the black hole mass, as the black hole mass exceeds $10^8 M_\odot$, the feedback mode of the central black hole will change from thermal mode to kinetic mode, which will suppress the gas accretion and star formation in the central region of galaxies, generating a "gas hole" in the central region of galaxies.

3200100276@zju.edu.cn

xingyaocai.github.io