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The origin and properties of red spirals: Insights from cosmological simulations

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ABSTRACT

A significant fraction of spiral galaxies are red, gas-poor, and have low star formation rates (SFRs). We study these unusual objects using the IllustrisTNG100 simulation. Among 1912 well-resolved disk galaxies selected from the last simulation output, we identify 377 red objects and describe their properties and origins using a few representative examples. The simulated red spirals turn out to be typically very gas-poor, have very low SFRs, are more metal-rich, and have larger stellar masses than the remaining disks. Only about 13% of red spirals suffered strong mass loss and thus could have resulted from environmental quenching by ram pressure and tidal stripping of the gas, or similar processes. The majority of red disks were probably quenched by feedback from the active galactic nucleus (AGN). This conclusion is supported by the higher black hole masses and lower accretion rates of red disks, as well as the larger total AGN feedback energies injected into the surrounding gas in the kinetic feedback mode implemented in the IllustrisTNG simulations. The timescales of the gas loss correlate with the black hole growth for the AGN-quenched galaxies and with the dark-matter loss for the environmentally quenched ones. The red spirals are more likely to possess bars, and their bars are stronger than in the remaining disks, which is probably the effect of gas loss rather than the reason for quenching.

Key words. galaxies: evolution – galaxies: formation – galaxies: interactions – galaxies: kinematics and dynamics – galaxies: spiral – galaxies: structure

Проблемы:

- Fraction
- Окружение
- Как образовались?
- Может быть просто закончился газ?

Illustris TNG

The simulations follow the evolution of galaxies from early times to the present by solving gravity and hydrodynamics, and applying, in addition to AGN feedback, prescriptions for star formation, galactic winds, and magnetic fields. The set of simulations comprises the results obtained with different resolutions in boxes of size 300, 100, and 50 Mpc (labeled TNG300, TNG100, and TNG50, respectively).

Как отбирали галактики?

First choosing 6507 subhalos with total stellar masses greater than 10^10 M☉

↓

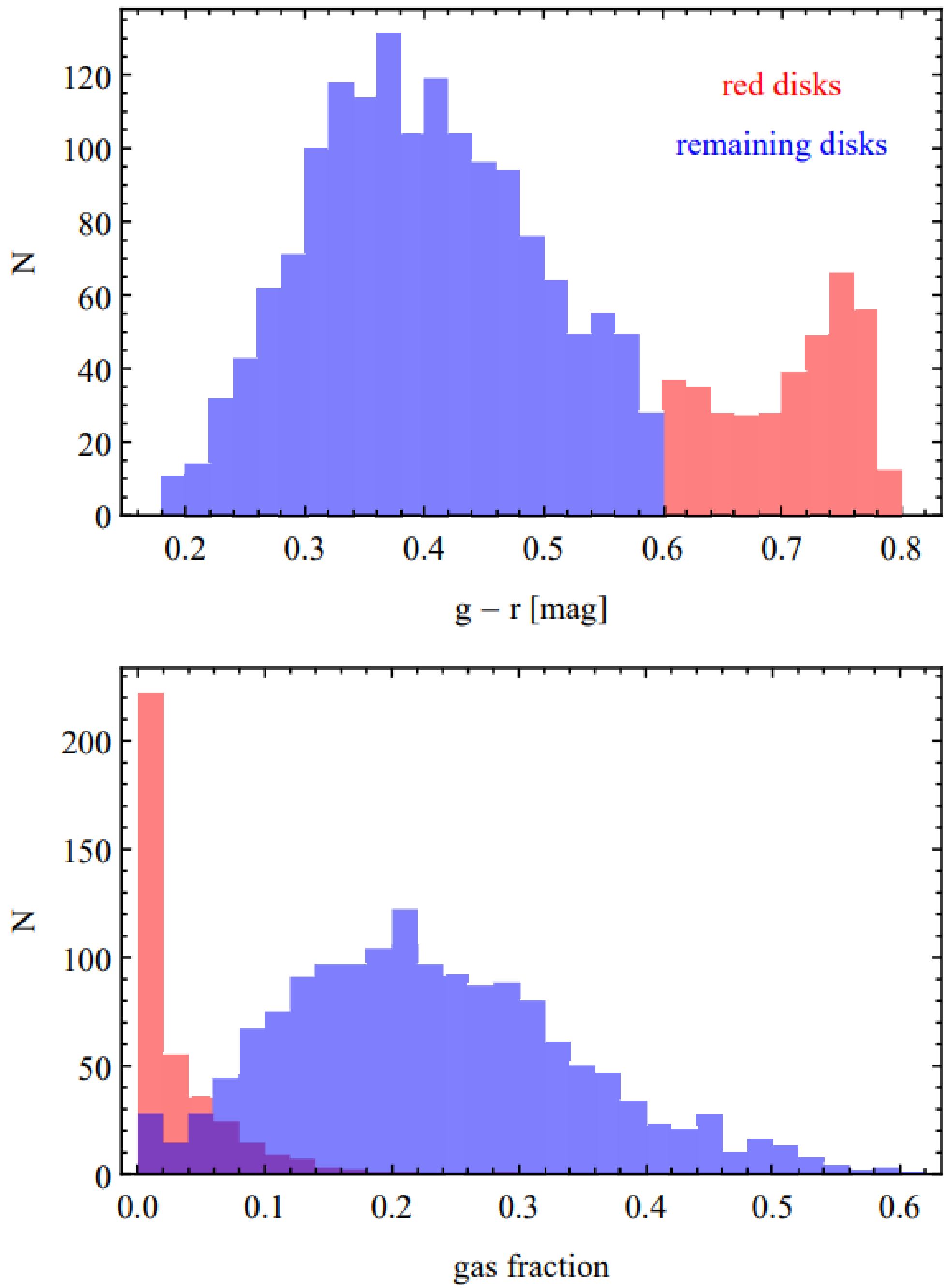
Next, the galaxies were assumed to be disky if they were rotationally supported and rather thin.

↓

The sample of 1912 disk galaxies selected from the final (z = 0) output of the IllustrisTNG100-1 simulation (using color estimates from the catalogs of synthetic stellar photometry calculated including the effects of dust obscuration and provided with the IllustrisTNG data **)**

↓

$g - r > 0.6$



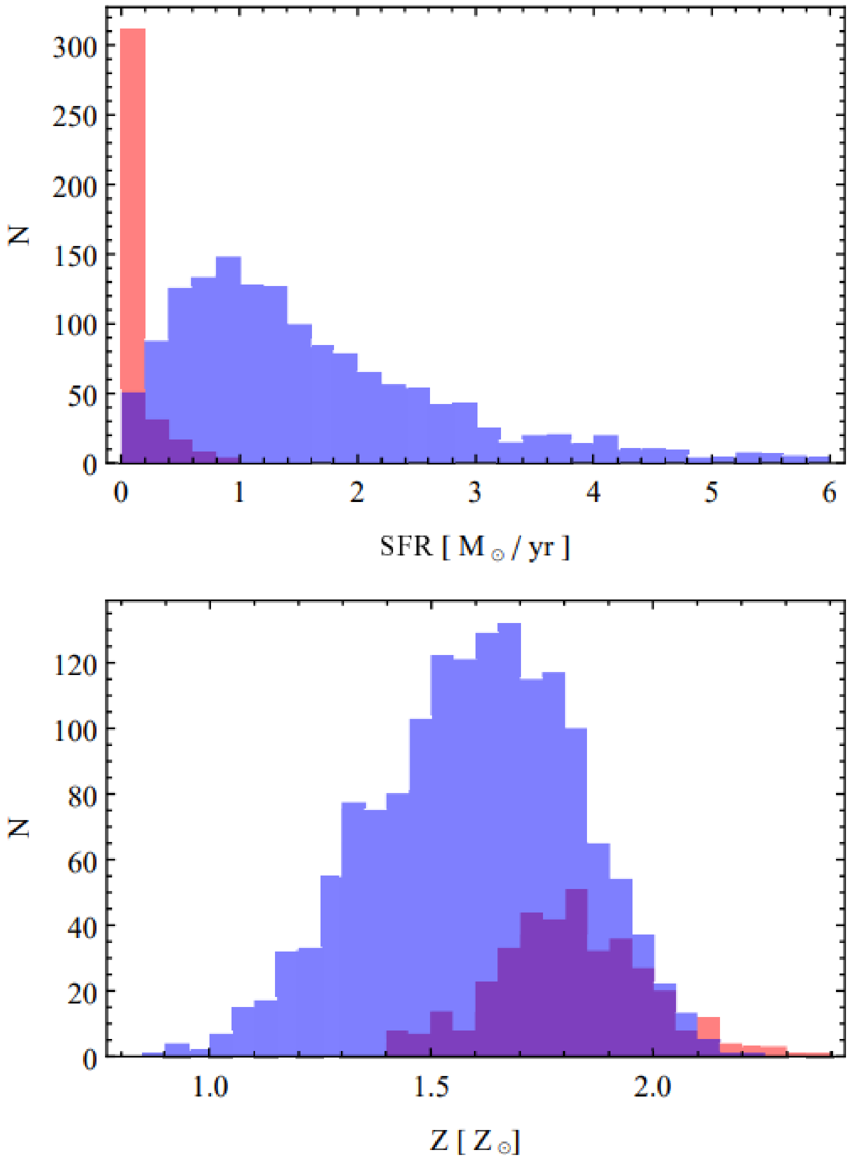
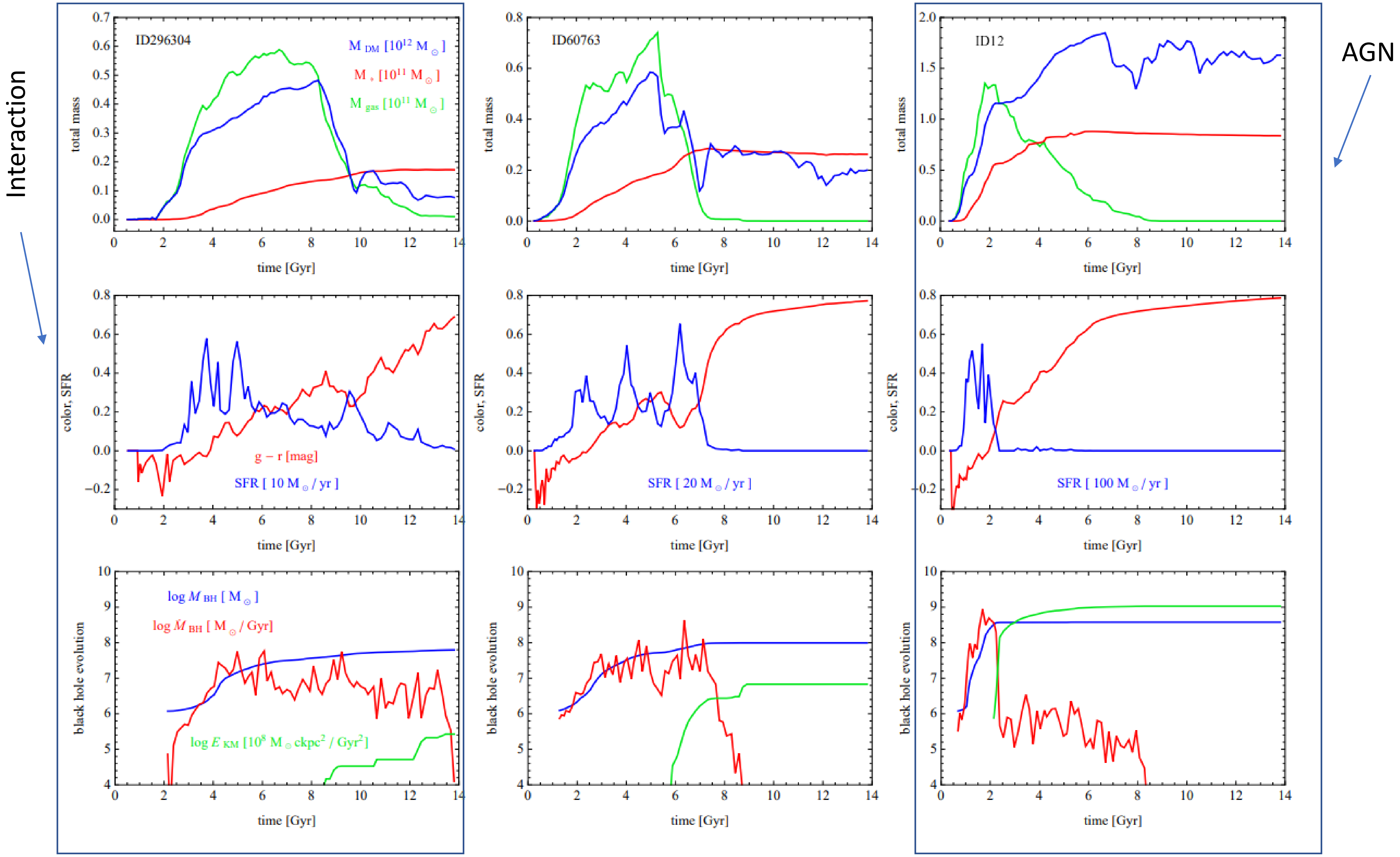


Fig. 1. Distributions of different properties of disky galaxies. The four panels, from top to bottom, show the distributions of color, gas fraction, SFR, and metallicity for red disks with $g - r > 0.6$ (red) and the remaining disks with $g - r < 0.6$ (blue). Measurements of the properties were done within $2r_{1/2}$ except for the color, which is estimated from all stars in the galaxy.


Interaction
AGN
ID296304
ID60763
ID12
total mass
color, SFR
black hole evolution
time [Gyr]
M DM [10^12 M ⊙]
M * [10^11 M ⊙]
M gas [10^11 M ⊙]
g − r [mag]
SFR [10 M ⊙ / yr]
SFR [20 M ⊙ / yr]
SFR [100 M ⊙ / yr]
log M BH [M ⊙]
log Ṁ BH [M ⊙ / Gyr]
log E KM [10^8 M ⊙ ckpc^2 / Gyr^2]

We only identified 48 galaxies, from our sample of 377 objects, that experienced significant mass loss (they lost more than half of their maximum dark mass), which means that this is not a dominant channel for the formation of red spirals.

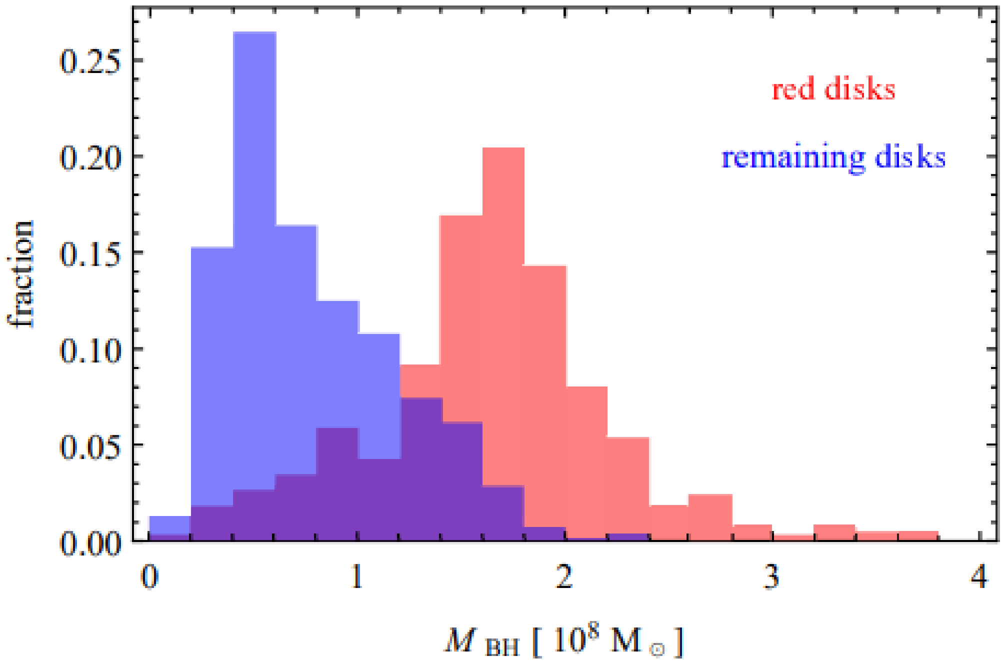
Given that most of the galaxies in our red disk sample are isolated and did not experience significant interactions in their history, it seems that the scenario involving the feedback from a supermassive black hole is the dominant one.

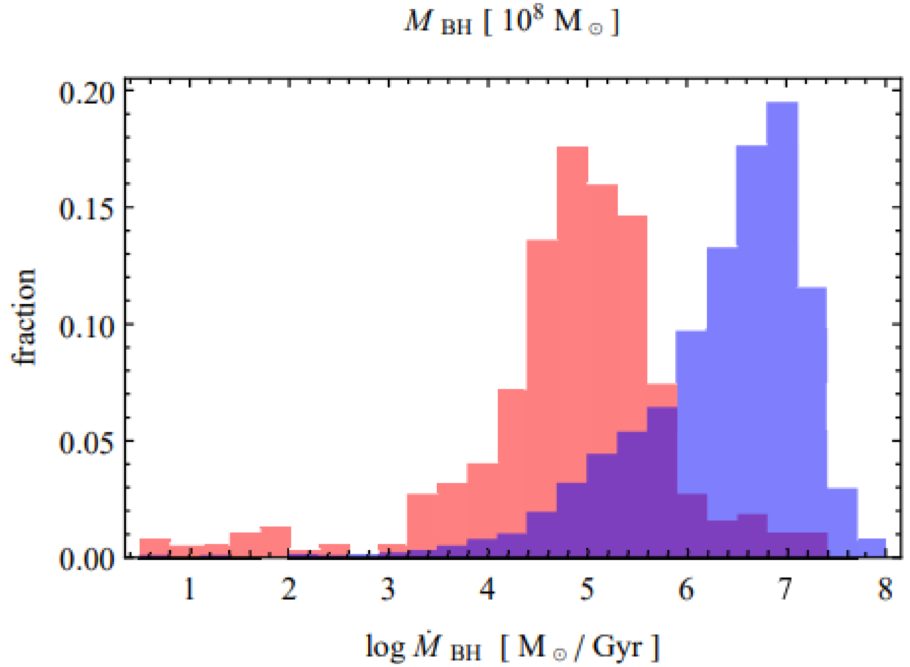
We found that only about 13% of the red disks experienced strong mass loss during their evolution.

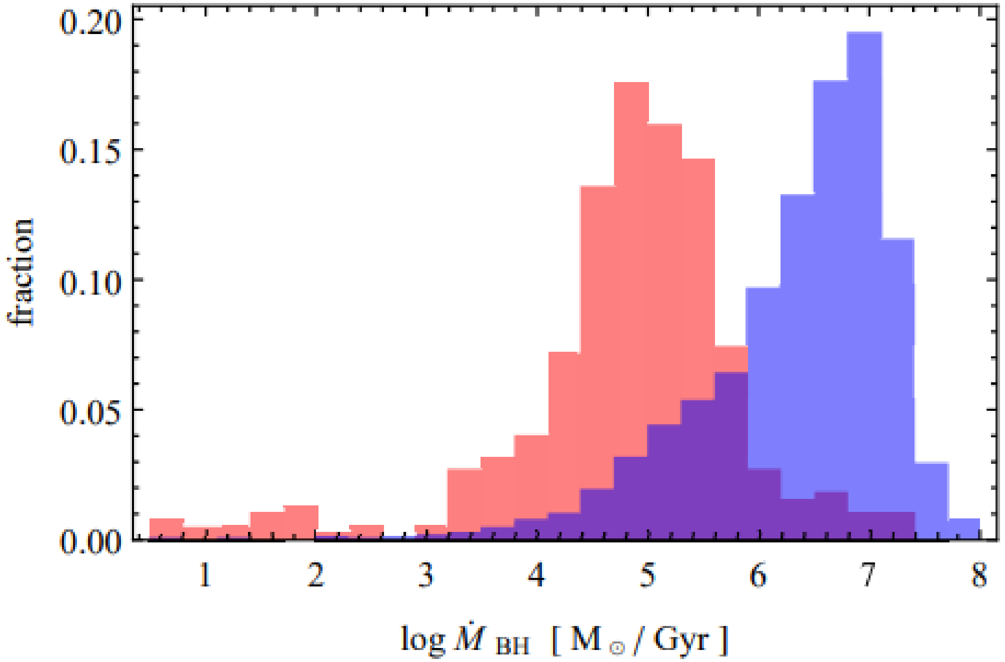
The characteristic timescales of gas loss also correlate more convincingly with the timescales of black hole growth rather than those of mass loss.

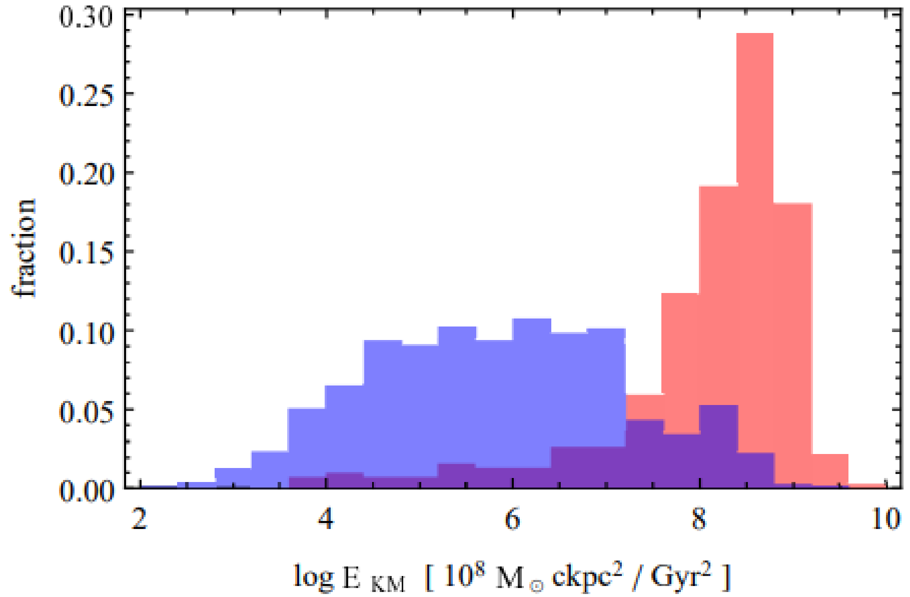
SMBH

В пользу сценария с AGN



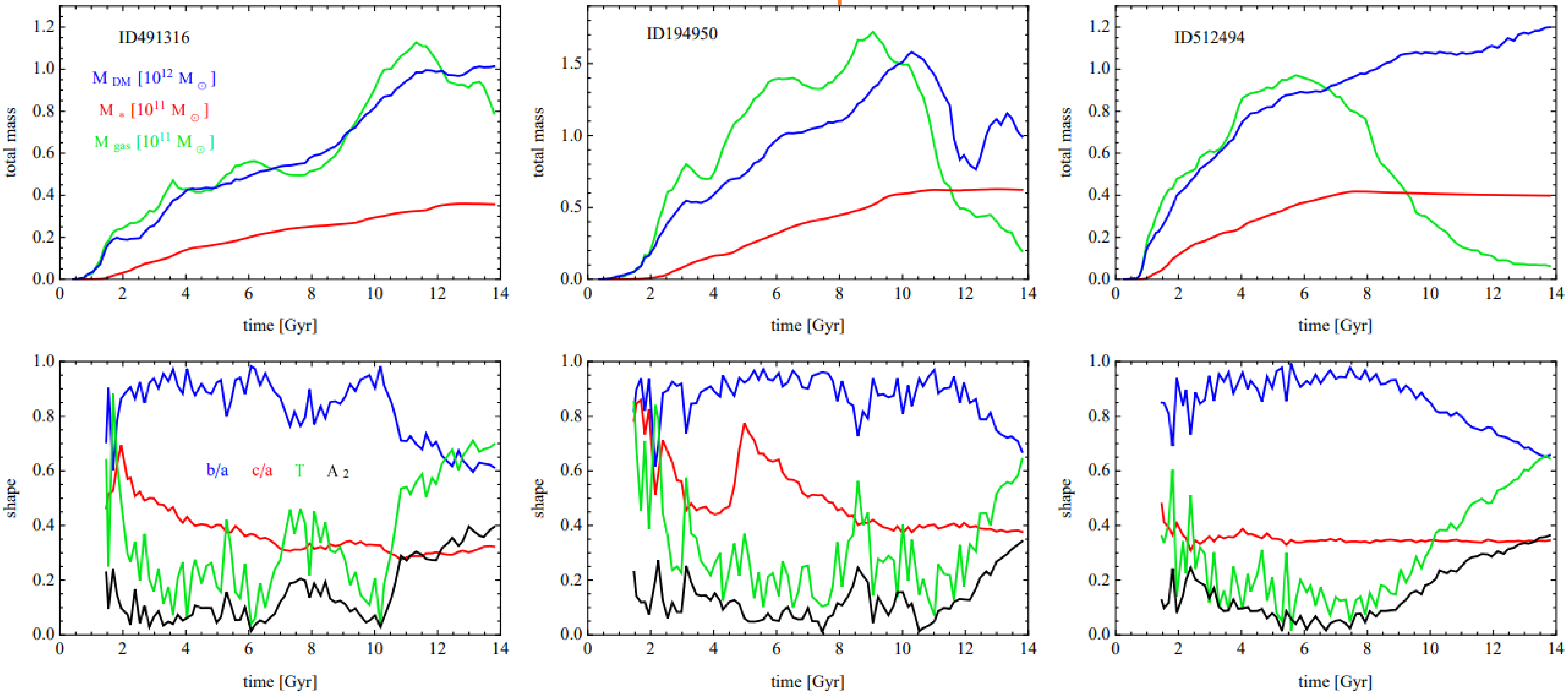






The trend of redder galaxies hosting more massive black holes is also present in observations

Что с барами?



The shape is described using the shortest to-longest and intermediate-to-longest axis ratios, c/a and b/a, determined from the mass tensor of stellar particles, as well as the triaxiality parameter T = [1 − (b/a) 2]/[1 − (c/a) 2], all measured using stars within 2r1/2.

And global value of the bar mode -- A2 (The decline in the A2 profile with radius can be used to estimate the length of the bar as the radius where the value of A2 drops to half the maximum.)

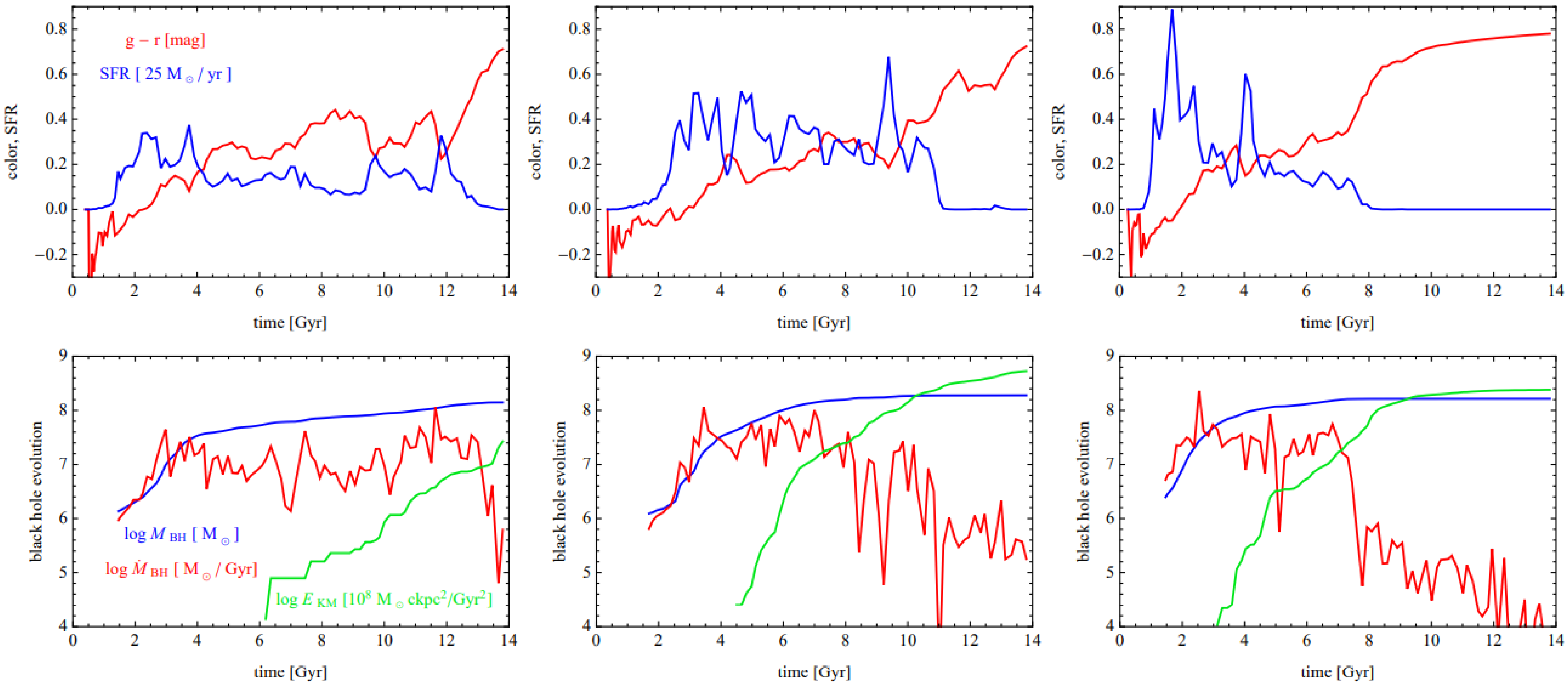


Fig. 8. Evolution of selected red disk galaxies with bars. The columns present the results for different galaxies, ID491316, ID194950, and ID512494. First row: Evolution of the total dark, stellar, and gas mass shown with the blue, red, and green lines, respectively. Second row: Evolution of four structural properties of the galaxies: the axis ratios b/a (blue line) and c/a (red), the triaxiality parameter T (green), and the bar strength A_2 (black). Third row: Evolution of color (red line) and SFR (blue). Fourth row: Evolution of the mass of the black hole (blue), its accretion rate (red), and the cumulative AGN feedback energy injected into the surrounding gas in the kinetic mode (green). The units are given in the left column.

Discussion

- no single mechanism can be identified as the unique cause of the quenching of spiral galaxies
- У наблюдателей другие результаты: Hughes & Cortese (2009) claim that environment is more important than AGN feedback for their observed sample, while Fraser-McKelvie et al. (2018) find evidence for both quenching via internal processes and environment in their passive spirals. Shimakawa et al. (2022) find the average passive fraction of spiral galaxies in clusters to be approximately three times higher than in random fields.
- В предыдущих работах по этой теме с использованием Illustris TNG получалось то же самое. В этой работе: we benefited from the higher resolution of the TNG100 run, which allowed for a more reliable selection of disk galaxies and a detailed look into morphological features such as bars.
- The red spiral galaxies we identified in the IllustrisTNG100 simulation are much more likely to possess bars than the remaining disks, and their bars are typically stronger. This finding is in very good agreement with the results from the Galaxy Zoo survey.
- The causal relation between the formation of bars and quenching in red spirals remains unclear. Among our barred red disks, we identified cases of bars forming prior to, simultaneously with, and after quenching.
- The correlation between the presence of the bar and quenching may thus instead originate from the fact that bars are more likely to form in galaxies with low gas content (Athanassoula et al. 2013; Łokas 2020a)