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От Сильченко О.К.

Эпохалка от Ромео

- Romeo A., Mogotsi K.M. 2018, MNRAS v.480, L23.
- Romeo A. 2020, MNRAS v.491, 4843
- Romeo A., Agertz O., Renaud F. 2020, MNRAS, submitted, arXiv:2006.09159

Почему критерий Toomre для газа плохо описывает эволюцию дисковых галактик

2.2 Tour through disc gravitational instability

To explore the link between disc gravitational instability and the relative mass content of atomic gas, molecular gas and stars in galaxies, we start from the simplest stability diagnostic: the Toomre (1964) parameter, $Q = \kappa\sigma/\pi G\Sigma$. It is commonly assumed that $Q \approx 1$, consistent with a process of self-regulation that keeps galaxy discs close to marginal stability (see sect. 1 of Krumholz et al. 2018 for an overview). How realistic is that assumption? Fig. 1 illustrates that atomic gas, molecular gas and stars have distinct radial distributions of Q, which differ both in median trend and in variance. While $Q_\star$ is quite close to unity, Q_{H2} is three times more offset and scattered, whereas Q_{HI} exhibits a two-orders-of-magnitude decline within the optical radius and an even larger median offset from unity than Q_{H2}. Thus the assumption that $Q \approx 1$ is not realistic enough to represent the diverse phenomenology of Q in galaxy discs.

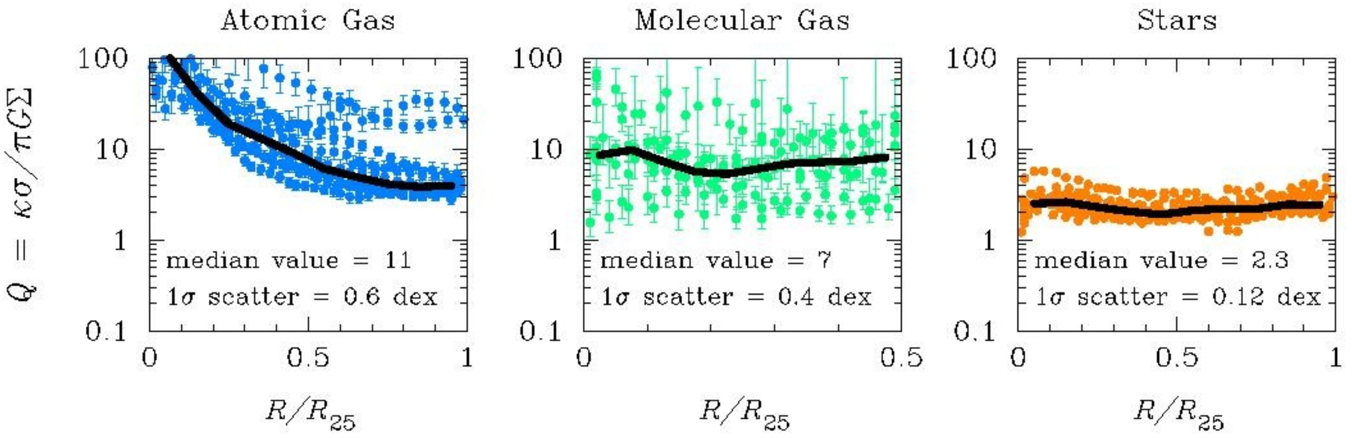

Figure 1. Radial profiles of the Toomre parameter for L08's sample of spirals, with the galactocentric distance measured in units of the optical radius (B-band isophotal radius at 25 mag arcsec^{-2}). Also shown is the local median of Q. In the case of molecular gas, the radial range is limited by the sparsity of sensitive CO measurements beyond half the optical radius.

Поэтому в 2018 предлагается новый критерий, связанный со звездами

2.1 The route to $\langle \mathcal{Q}_\star \rangle$

To explore the link between angular momentum and local gravitational instability in nearby star-forming spirals, we need a reliable disc instability diagnostic. Contrary to what is commonly assumed, the gas Toomre parameter is not a reliable diagnostic: stars, and not molecular or atomic gas, are the primary driver of disc instabilities in spiral galaxies, at least at the spatial resolution of current extragalactic surveys (Romeo & Mogotsi 2017). This is confirmed by other investigations (Marchuk 2018; Marchuk & Sotnikova 2018; Mogotsi & Romeo 2018), and is true even for a powerful starburst+Seyfert galaxy like NGC 1068 (Romeo & Fathi 2016). The stellar Toomre parameter is a more reliable diagnostic, but it does not include the stabilizing effect of disc thickness, which is important and should be taken into account (Romeo & Falstad 2013). The simplest diagnostic that does this accurately is the Romeo-Falstad $\mathcal{Q}_N$ stability parameter for one-component ($N = 1$) stellar ($\star$) discs, which we consider as a function of galactocentric distance R:

$$\mathcal{Q}_\star(R) = Q_\star(R)\, T_\star\,, \qquad (1)$$

where $Q_\star = \kappa\sigma_\star/\pi G\Sigma_\star$ is the stellar Toomre parameter (σ denotes the radial velocity dispersion), and $T_\star$ is a factor that encapsulates the stabilizing effect of disc thickness for the whole range of velocity dispersion anisotropy (σ_z/σ_R) observed in galactic discs:

$$T_\star = \begin{cases} 1 + 0.6\left(\dfrac{\sigma_z}{\sigma_R}\right)_\star^2 & \text{if } 0 \le (\sigma_z/\sigma_R)_\star \le 0.5\,, \\[2ex] 0.8 + 0.7\left(\dfrac{\sigma_z}{\sigma_R}\right)_\star & \text{if } 0.5 \le (\sigma_z/\sigma_R)_\star \le 1\,. \end{cases} \qquad (2)$$

As $\mathcal{Q}_\star(R)$ is a local quantity, it cannot be directly related to the stellar specific angular momentum,

$$j_\star = \frac{1}{M_\star}\int_0^\infty R v_c(R)\, \Sigma_\star(R)\, 2\pi R\, \mathrm{d}R \qquad (3)$$

(e.g., Romanowsky & Fall 2012). This equation tells us that $j_\star$ is the mass-weighted average of $Rv_c(R)$, the orbital specific angular momentum. So it is natural to consider the mass-weighted average of $\mathcal{Q}_\star(R)$. Current integral-field-unit (IFU) surveys allow deriving reliable radial profiles of $\mathcal{Q}_\star$ up to $R \approx R_e$, the effective (half-light) radius. This limit

Mogotsi & Romeo 2018). In view of these facts, we take the mass-weighted average of $\mathcal{Q}_\star(R)$ over one effective radius:

$$\langle \mathcal{Q}_\star \rangle = \frac{1}{M_\star(R_e)}\int_0^{R_e} \mathcal{Q}_\star(R)\, \Sigma_\star(R)\, 2\pi R\, \mathrm{d}R\,. \qquad (4)$$

This ensures that $\langle \mathcal{Q}_\star \rangle$ and $j_\star$ have a similar relation to their local counterparts, which simplifies the following analysis.

To illustrate the usefulness of Eq. (4), let us calculate $\langle \mathcal{Q}_\star \rangle$ for a galaxy model that is behind the simple, accurate and widely used approximation $j_\star = 1.19\, R_e v_c$: an exponential disc having a constant mass-to-light ratio and rotating at a constant circular speed (e.g., Romanowsky & Fall 2012). For this galaxy model, $M_\star(R_e) = \frac{1}{2}M_\star$ and $\kappa(R) = \sqrt{2}\, v_c/R$ (see, e.g., Binney & Tremaine 2008), which can be expressed in terms of $j_\star$ using the approximation above. The resulting $\langle \mathcal{Q}_\star \rangle$ is given by

$$\langle \mathcal{Q}_\star \rangle = 4.75\, \frac{j_\star \overline{\sigma}_\star}{G M_\star}\, T_\star\,, \qquad (5)$$

where $j_\star$ is the total stellar specific angular momentum and $M_\star$ is the total stellar mass, while $\overline{\sigma}_\star$ is the radial average of $\sigma_\star(R)$ over one effective radius:

$$\overline{\sigma}_\star = \frac{1}{R_e}\int_0^{R_e} \sigma_\star(R)\, \mathrm{d}R\,. \qquad (6)$$

Он хорош!

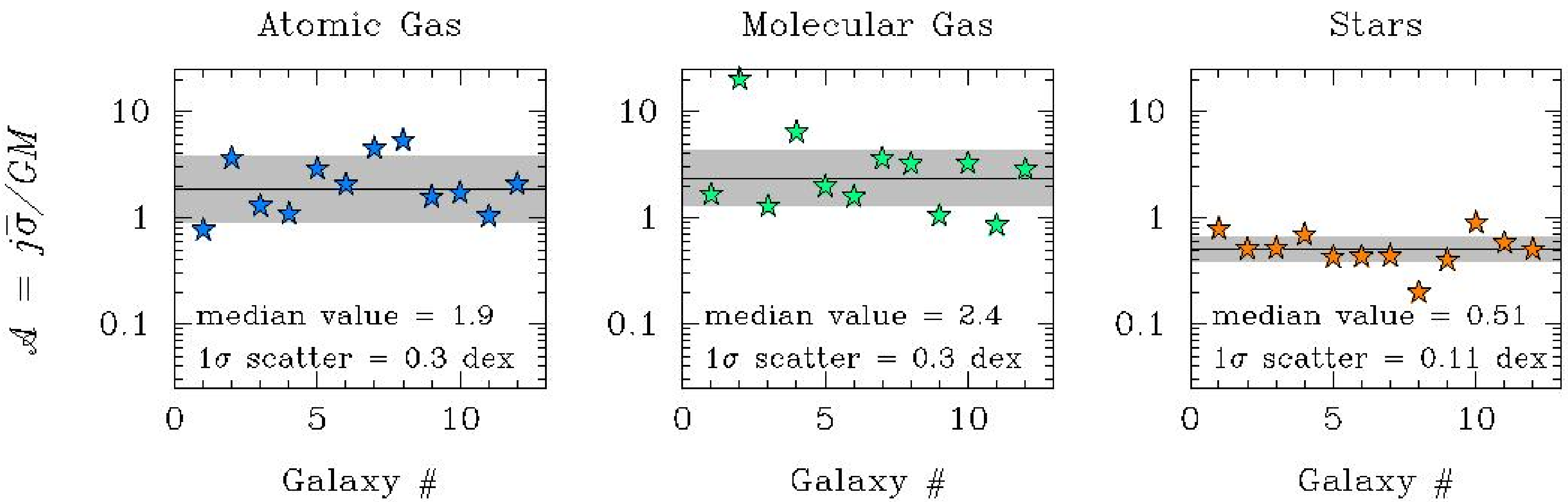

Figure 2. Galaxy-to-galaxy variation of the $\mathcal{A}$ stability parameter for L08's sample of spirals (the galaxy list is given in the first paragraph of Sect. 2.1). Also shown are the median value and 1σ scatter of $\mathcal{A}$.

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From lenticulars to blue compact dwarfs: the stellar mass fraction is regulated by disc gravitational instability

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ABSTRACT
The stellar-to-halo mass relation (SHMR) is one of the main sources of information we have on the connection between galaxies and their dark matter haloes. Here we analyse in detail two popular forms of the SHMR, $M_\star/M_\mathrm{h}$ vs M_h and $M_\star/M_\mathrm{h}$ vs $M_\star$, and compare them with another physically motivated scaling relation, $M_\star/M_\mathrm{h}$ vs $GM_\mathrm{h}/j_\star\hat{\sigma}_\star$. Although this relation cannot predict the halo mass explicitely, it connects the stellar mass fraction to fundamental galaxy properties such as specific angular momentum ($j_\star$) and velocity dispersion ($\hat{\sigma}_\star$) via disc gravitational instability. Our detailed comparative analysis is based on one of the largest sample of galaxies with both high-quality rotation curves and near-infrared surface photometry, and leads to the following results: (i) $M_\star/M_\mathrm{h}$ vs M_h and $M_\star/M_\mathrm{h}$ vs $M_\star$ are not just two alternative parametrizations of the same relation, but two significantly different relations; (ii) $M_\star/M_\mathrm{h}$ vs $GM_\mathrm{h}/j_\star\hat{\sigma}_\star$ outperforms the two popular relations in terms of tightness, correlation strength and significance; (iii) $j_\star$ and $\hat{\sigma}_\star$ play an equally important role in our scaling relation, and it is their interplay that constrains $M_\star/M_\mathrm{h}$ so tightly; (iv) the evolution of $M_\star/M_\mathrm{h}$, $j_\star$ and $\hat{\sigma}_\star$ is regulated by disc gravitational instability: when $M_\star/M_\mathrm{h}$ varies, $j_\star$ and $\hat{\sigma}_\star$ also vary as predicted by our scaling relation, thus erasing the memory of such evolution. This implies that the process of disc gravitational

Известные масштабирующие соотношения

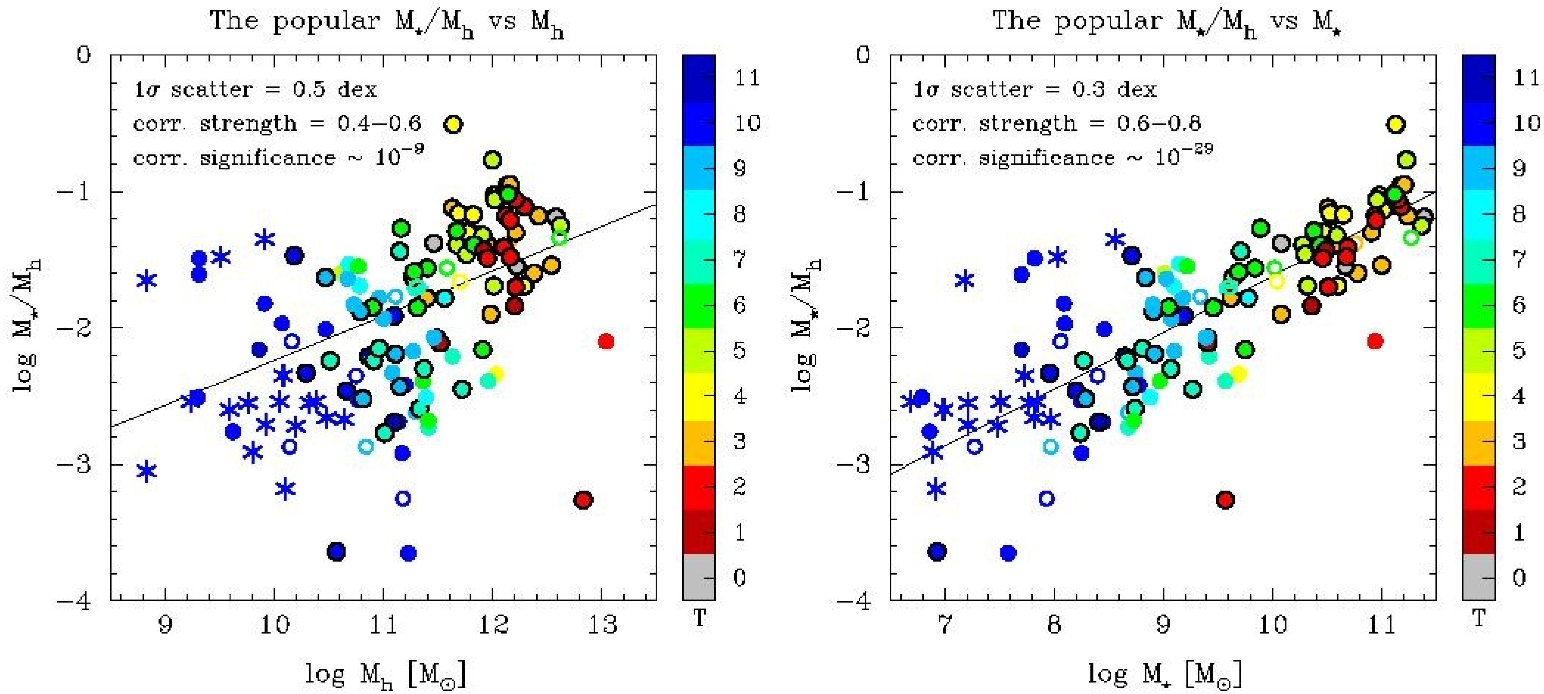

Figure 1. Comparison between two popular forms of the SHMR. Galaxies are colour-coded by Hubble stage, and galaxy samples are symbol-coded by the accuracy of the $M_\star$, M_h and $j_\star$ measurements (see Sect. 2 for more information): SPARC+++ (solid circles with black ouline), SPARC++ (solid circles), SPARC+ (hollow circles), LITTLE THINGS (asterisks). The lines in the left and right panels, $\log(M_\star/M_h) = 0.33 \log M_h - 5.51$ and $\log(M_\star/M_h) = 0.41 \log M_\star - 5.76$, are robust median-based fits to the data points. Statistical information about the data is given in summary form and simplified notation (see Sect. 2 for more information).

Разброс велик!

А с новым критерием (не-)устойчивости?

The origin of such relations is the low galaxy-to-galaxy variance of Toomre's (1964) Q stability parameter, which leads to Romeo's (2020) key equation:

$$\frac{j_i \hat{\sigma}_i}{G M_i} \approx 1 \,. \tag{1}$$

Note that this is not a marginal stability condition, but a tight statistical relation between mass (M), specific angular momentum ($j \equiv J/M$) and velocity dispersion ($\hat{\sigma}$) for each baryonic component in the disc plus bulge: atomic gas ($i = \mathrm{H\,I}$), molecular gas ($i = \mathrm{H_2}$) and stars ($i = \star$). More precisely, $\hat{\sigma}_i$ is the radial velocity dispersion of component i, σ_i, properly averaged and rescaled. This quantity can be evaluated using two alternative equations, depending on whether there are reliable σ_i measurements available or not. Unfortunately, such measurements are highly non-trivial (e.g., Ianjamasimanana et al. 2017; Marchuk & Sotnikova 2017), hence very sparse (e.g., Romeo & Mogotsi 2017; Mogotsi & Romeo 2019). Therefore, if one wants to analyse a large galaxy sample, then the appropriate equation to use is

$$\hat{\sigma}_i = \begin{cases} 11\ \mathrm{km\,s^{-1}} & \text{if } i = \mathrm{H\,I}\,, \\ 8\ \mathrm{km\,s^{-1}} & \text{if } i = \mathrm{H_2}\,, \\ 130\ \mathrm{km\,s^{-1}} \times (M_\star/10^{10.6}\,\mathrm{M_\odot})^{0.5} & \text{if } i = \star\,. \end{cases} \tag{2}$$

Note that these are not observationally motivated values of the gas and stellar velocity dispersions, but rigorously derived values of the velocity dispersion–based quantity $\hat{\sigma}_i$.

3.3 Our scaling relation, and the roles of specific angular momentum and velocity dispersion

Now that we know how to make good use of Eq. (1), let us apply such a simple formula in practice. Choosing the mass of the dark matter halo as the reference mass, we get the following predictor for the stellar mass fraction:

$$\frac{M_\star}{M_\mathrm{h}} \approx \frac{j_\star \hat{\sigma}_\star}{G M_\mathrm{h}} \,. \tag{3}$$

Прикладывают к SPARC и LITTLE THINGS

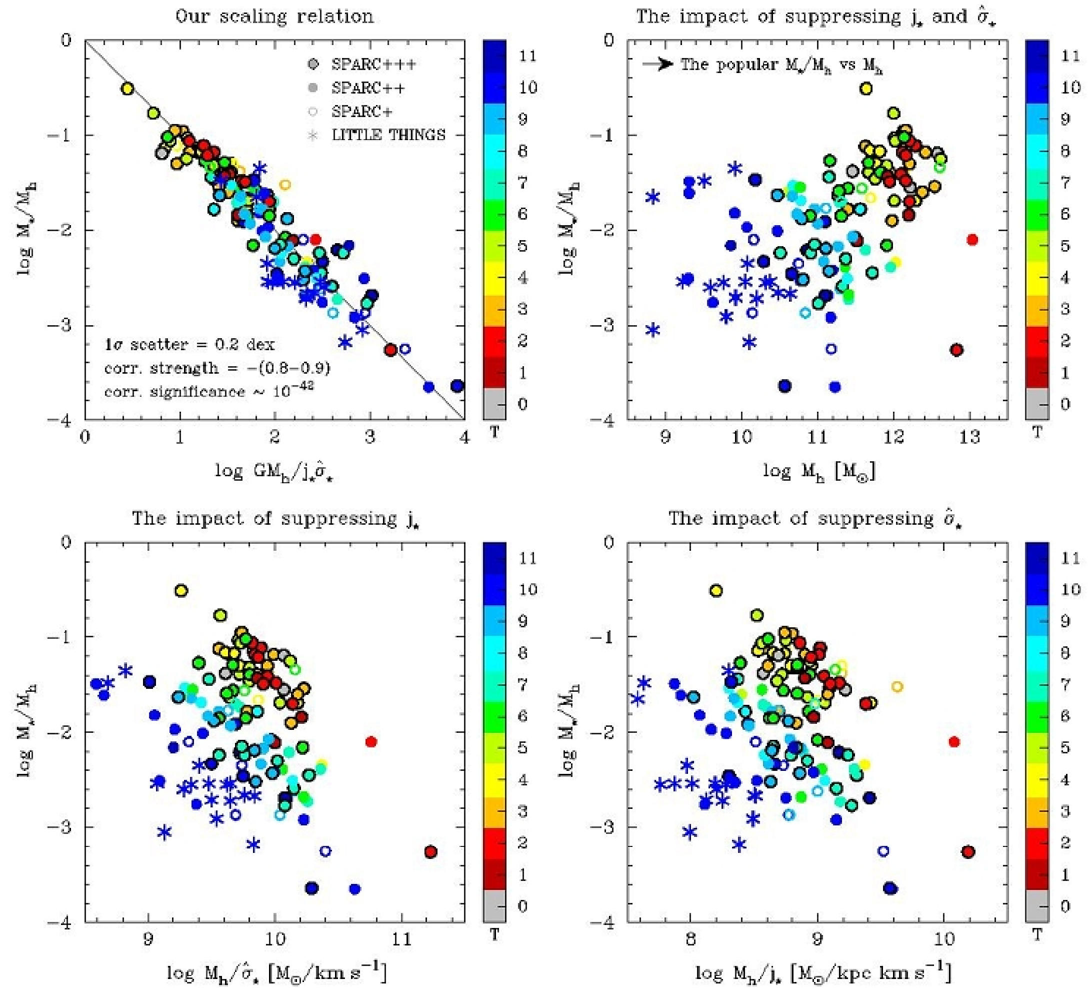

Figure 2. Our scaling relation, $M_\star/M_h$ vs $GM_h/j_\star\hat{\sigma}_\star$, and the impact of suppressing $j_\star$ and/or $\hat{\sigma}_\star$. Galaxies are colour-coded by Hubble stage, and galaxy samples are denoted as in Sect. 2. In the top-left panel, the diagonal line is the prediction based on disc gravitational instability, and statistical information about the data is given in summary form and simplified notation (see Sect. 2 for more information).