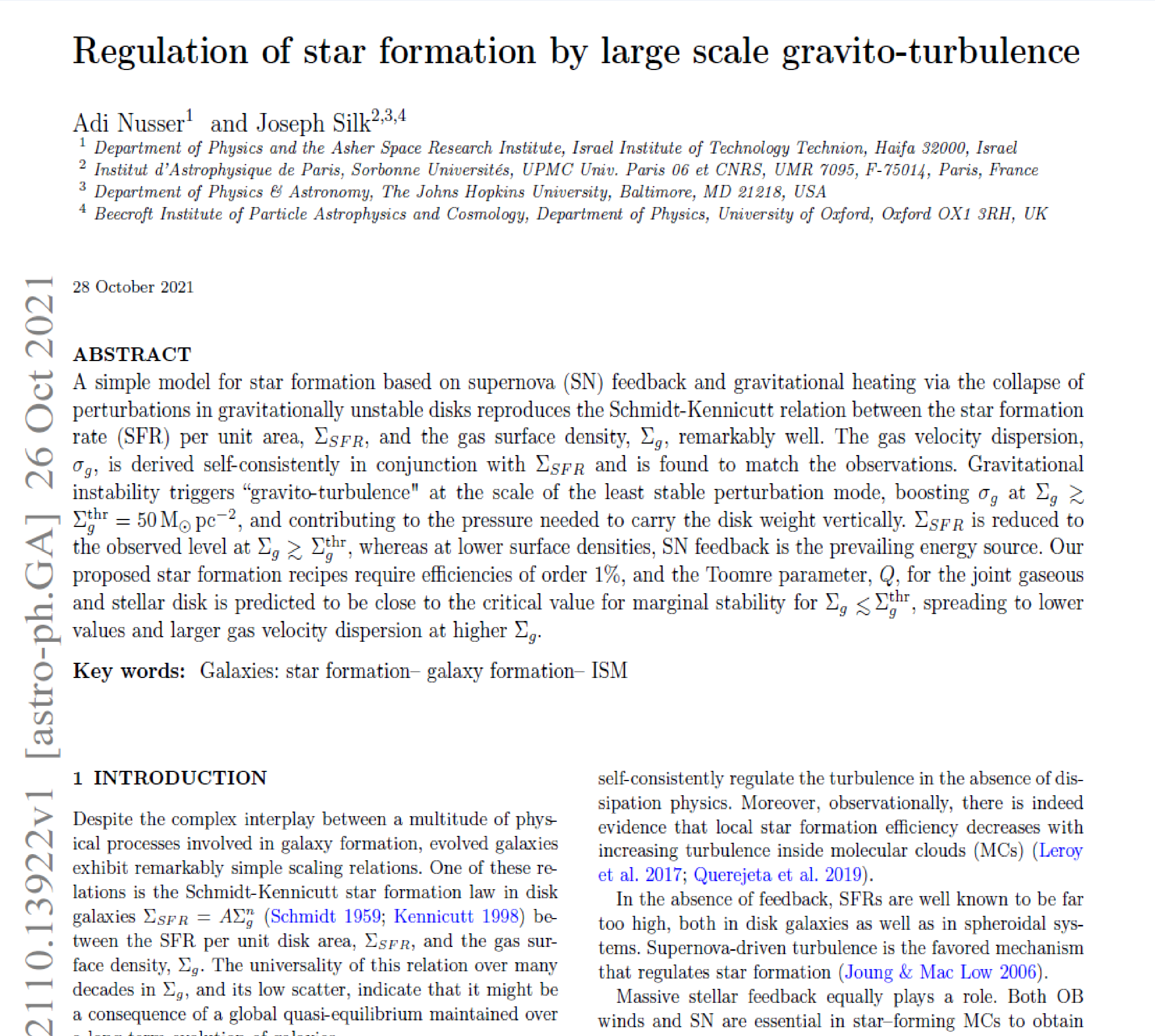
Регулирование SF гравито-турбулентн газа



Regulation of star formation by large scale gravito-turbulence

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ABSTRACT

A simple model for star formation based on supernova (SN) feedback and gravitational heating via the collapse of perturbations in gravitationally unstable disks reproduces the Schmidt-Kennicutt relation between the star formation rate (SFR) per unit area, Σ_{SFR}, and the gas surface density, Σ_g, remarkably well. The gas velocity dispersion, σ_g, is derived self-consistently in conjunction with Σ_{SFR} and is found to match the observations. Gravitational instability triggers "gravito-turbulence" at the scale of the least stable perturbation mode, boosting σ_g at $\Sigma_g \gtrsim \Sigma_g^{\rm thr} = 50\,{\rm M_\odot\,pc^{-2}}$, and contributing to the pressure needed to carry the disk weight vertically. Σ_{SFR} is reduced to the observed level at $\Sigma_g \gtrsim \Sigma_g^{\rm thr}$, whereas at lower surface densities, SN feedback is the prevailing energy source. Our proposed star formation recipes require efficiencies of order 1%, and the Toomre parameter, Q, for the joint gaseous and stellar disk is predicted to be close to the critical value for marginal stability for $\Sigma_g \lesssim \Sigma_g^{\rm thr}$, spreading to lower values and larger gas velocity dispersion at higher Σ_g.

Key words: Galaxies: star formation– galaxy formation– ISM

1 INTRODUCTION

Despite the complex interplay between a multitude of physical processes involved in galaxy formation, evolved galaxies exhibit remarkably simple scaling relations. One of these relations is the Schmidt-Kennicutt star formation law in disk galaxies $\Sigma_{SFR} = A\Sigma_g^n$ (Schmidt 1959; Kennicutt 1998) between the SFR per unit disk area, Σ_{SFR}, and the gas surface density, Σ_g. The universality of this relation over many decades in Σ_g, and its low scatter, indicate that it might be a consequence of a global quasi-equilibrium maintained over

self-consistently regulate the turbulence in the absence of dissipation physics. Moreover, observationally, there is indeed evidence that local star formation efficiency decreases with increasing turbulence inside molecular clouds (MCs) (Leroy et al. 2017; Querejeta et al. 2019).

In the absence of feedback, SFRs are well known to be far too high, both in disk galaxies as well as in spheroidal systems. Supernova-driven turbulence is the favored mechanism that regulates star formation (Joung & Mac Low 2006).

Massive stellar feedback equally plays a role. Both OB winds and SN are essential in star–forming MCs to obtain

Общая идея:

- Два мех-ма перекачки энергии турбулентных движений:
- Сжатие возмущенных областей при грав.неустойчивости
- и SN feedback.

Цель: воспроизвест … для диска в квази-равновесно …

$$\frac{3}{2}\frac{\mathrm{d}\Sigma_g\sigma_g^2}{\mathrm{d}t} = \left(\mathcal{G}_{\mathrm{SN}} + \mathcal{G}_{\mathrm{gr}} - \mathcal{L}\right)\Sigma_g$$

$$Q_g = \frac{\kappa\sigma_g}{\pi G\Sigma_g}\ ,$$

$$\frac{1}{Q} = \frac{W}{Q_>} + \frac{1}{Q_<}$$

where $W = 2\sigma_*\sigma_g/(\sigma_*^2 + \sigma_g^2)$, $Q_> = \max(Q_*, Q_g)$

Вертикальный баланс сил

$$\frac{1}{\rho_g^z}\frac{\mathrm{d}p^z}{\mathrm{d}z} = g_g + g_* + g_h \ .$$

Давление в плоскости диска

$$p = \frac{\pi}{2} G \Sigma_g \widetilde{\Sigma} + \frac{\Omega^2}{2\pi}\frac{\Sigma_g^2}{\rho_g} \ ,$$

where

$$\widetilde{\Sigma} = \begin{cases} \Sigma_g + \frac{\sigma_g}{\sigma_*}\Sigma_* & \text{for} \quad \sigma_* \geq \sigma_g \\ \Sigma_{tot} + \left(1 - \frac{\sigma_*}{\sigma_g}\right)\Sigma_* & \text{for} \quad \sigma_* < \sigma_g \ . \end{cases}$$

ЗВЕЗДООБРАЗОВАНИЕ

$$\Sigma_{SFR} = \epsilon_{SF} \frac{\Sigma_g}{t_{SF}} ,$$

Два варианта для t_{SF}:

1. Обратно пропорционально критической частоте наиболее неустойчивой моды,
2. Равно времени свободного падения для данной плотности ∑/H.

$$t_{SF}^{-1} = \sqrt{G\rho_g} .$$

Энергия SN на единицу массы га

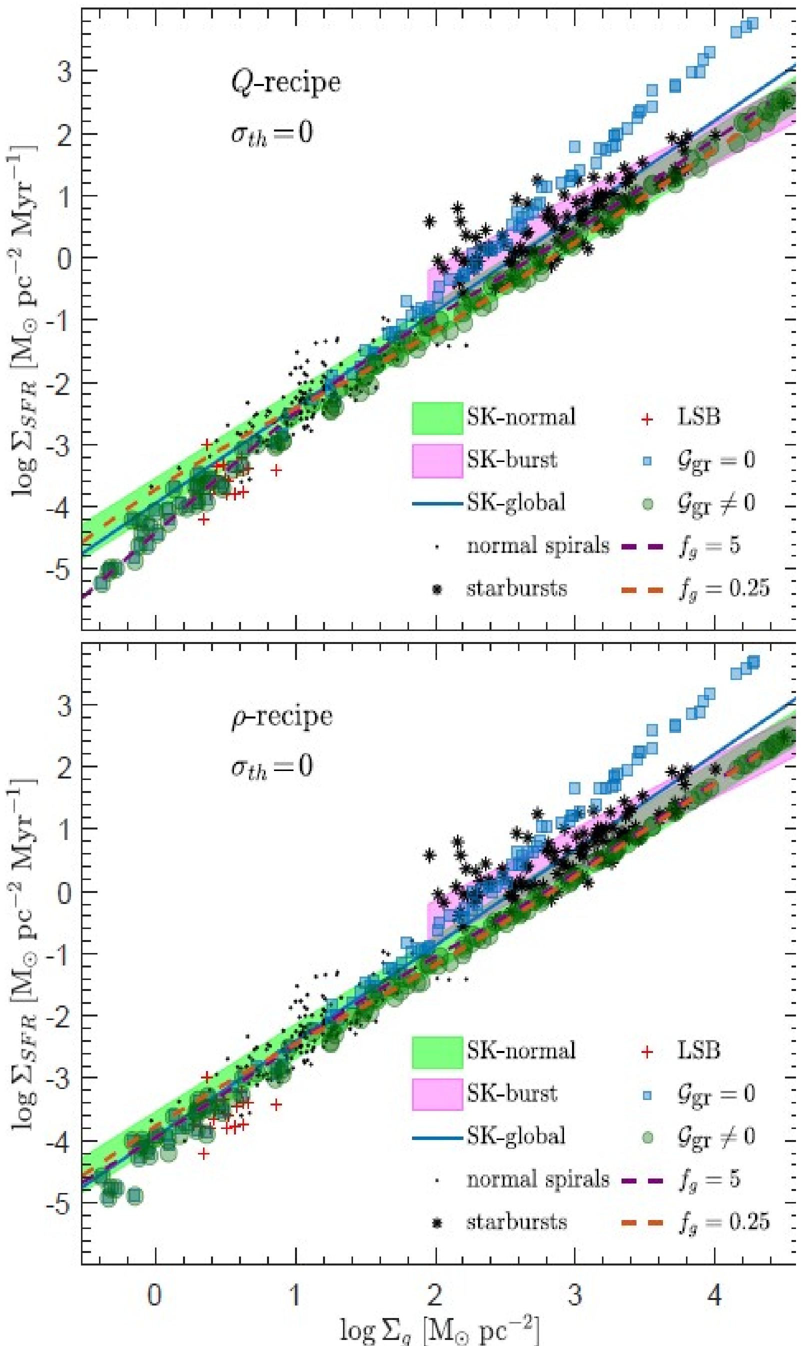
$$\mathcal{G}_{\rm SN} = \frac{\Sigma_{SFR}}{\Sigma_g} \frac{p_*}{m_*} \sigma_g$$

Потеря энергии

$$\mathcal{L}_t = \eta \sigma_t^2 \frac{\sigma_t}{L_t} . \qquad (22)$$

where η is a constant and the turbulence dissipation timescale is proportional to σ_t / L_t with L_t being the scale of the largest eddy at which turbulence energy is injected. For the Q-recipe,

Figure 1. The star formation rate per unit area versus the gas surface density for 100 sets of random parameters generated as described in the text. Blue squares are obtained with only SN feedback, while the green circles also include gravitational heating. The dashed lines illustrate the dependence on the ratio $f_g = \Sigma_g/\Sigma_*$. Green and pink shaded areas represent the SK laws inferred, respectively, from observations of normal spirals (De Los Reyes & Kennicutt 2019) and starbursts (Kennicutt & De Los Reyes 2021).



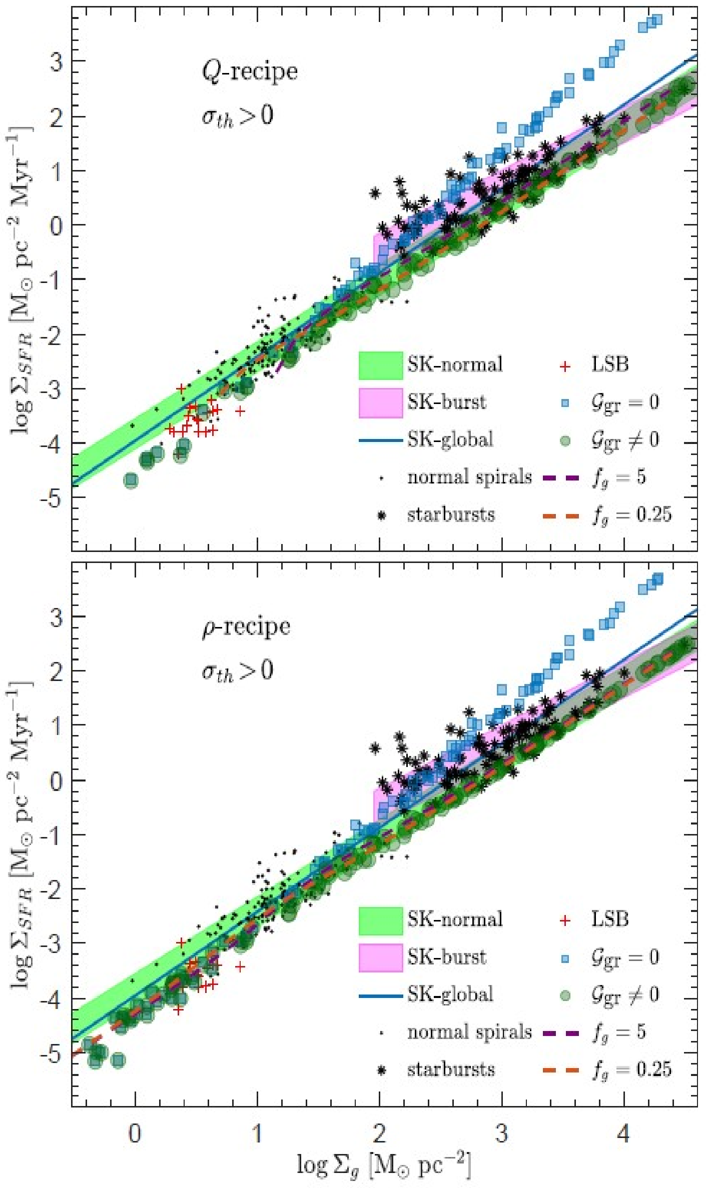


Figure 2. The same as the previous figure, but with a non-vanishing thermal floor in the velocity dispersion.

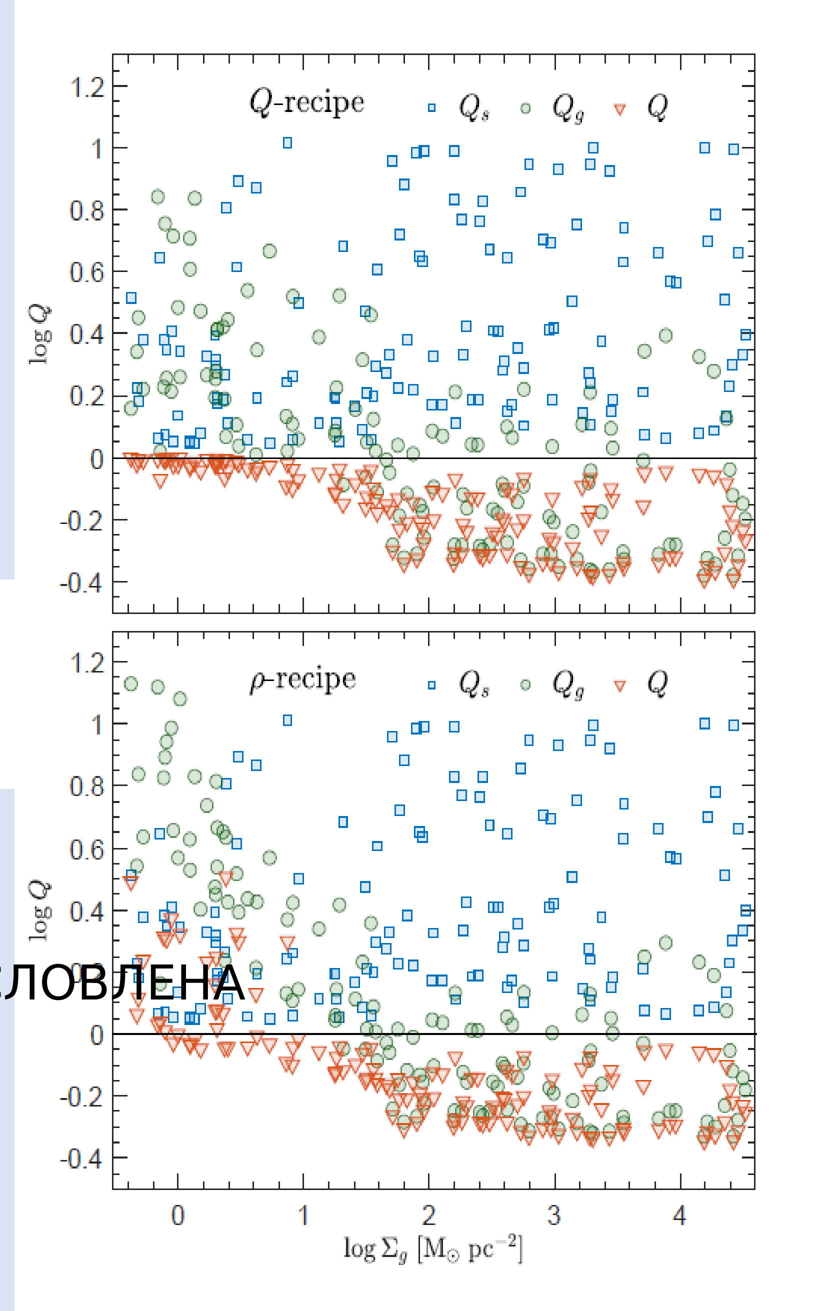


Figure 4. The global, stellar and gas Toomre parameters obtained in the two star formation recipes. Top and bottom panels are for the Q- and ρ-recipes, as indicated in the figure.

ИЗКОЙ ПОВ.ПЛОТНОСТИ ТУРБУЛЕНТНОСТЬ СРЕДЫ ОБУСЛОВЛЕНА
ОВНОМ SN, а ПРИ ВЫСОКОЙ - НЕУСТОЙЧИВОСТЬЮ

A robust prediction of the model is that disks of normal spirals above a threshold surface density $\Sigma_g \sim 50\,\mathrm{M}_\odot\,\mathrm{pc}^{-2}$, cannot be regulated by SN feedback if the observed SK law is to be recovered. Gravito-turbulence dominates these disks, leading to Σ_{SFR} consistent with the observations. Below this threshold, the disks are marginally stable with $Q \approx 1$. At higher surface densities, only disks dominated by the stellar component have $Q \approx 1$. Disks above the threshold but having a low ratio Σ_* / Σ_g, are associated with $Q < 1$.

- Our proposed star formation recipes require efficiencies of order 1%, and the Toomre parameter, Q, for the joint gaseous and stellar disk is predicted to be close to the critical value f $\Sigma_g \lesssim \Sigma_g^{\rm thr}$ nal stabil $\Sigma_g^{\rm thr} = 50\,{\rm M}_\odot\,{\rm pc}^{-2}$, s density

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