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CONNECTING CLUMP SIZES IN TURBULENT DISK GALAXIES TO INSTABILITY THEORY

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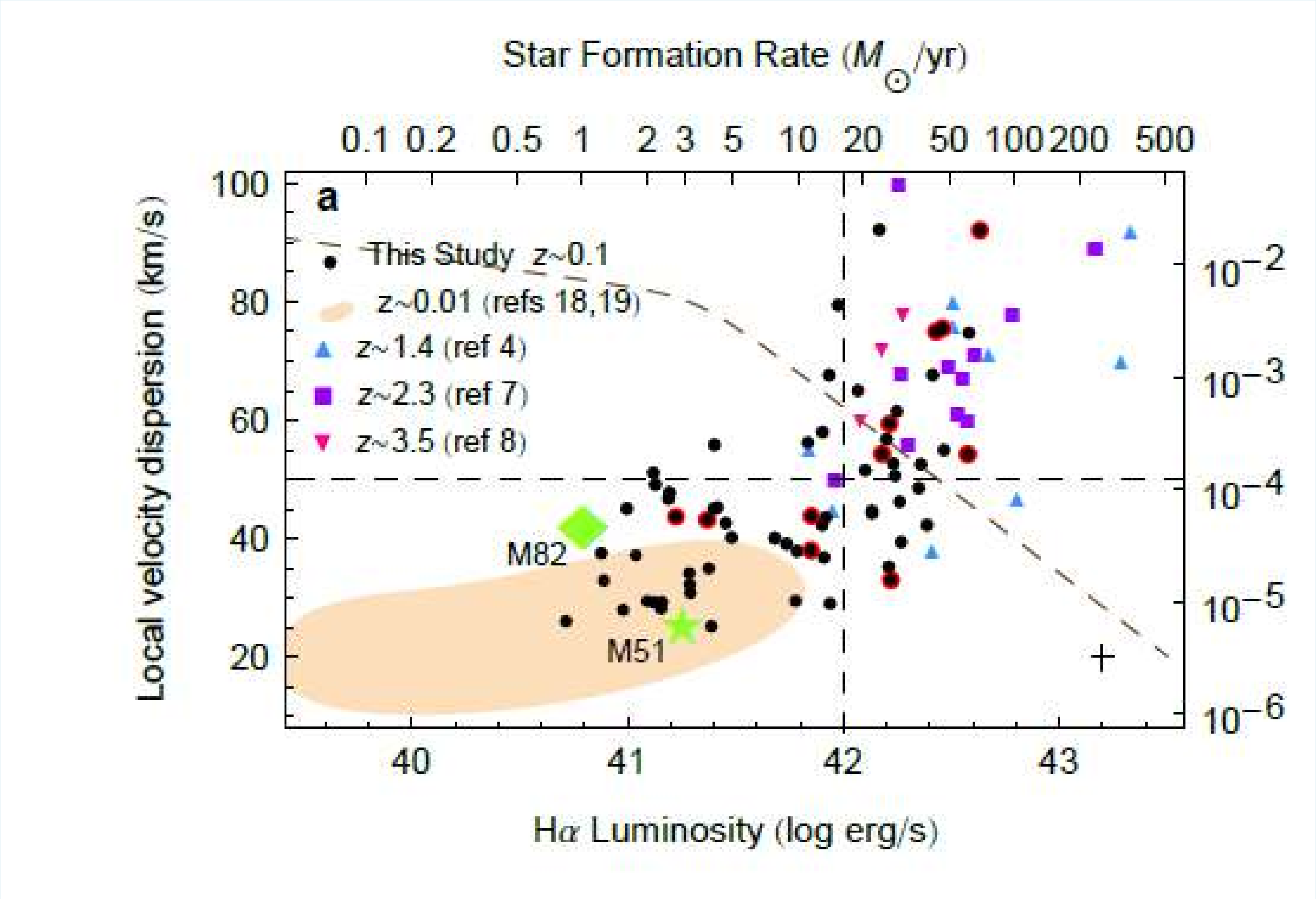
ABSTRACT

In this letter we study the mean sizes of Hα clumps in turbulent disk galaxies relative to kinematics, gas fractions, and Toomre Q. We use ~ 100 pc resolution HST images, IFU kinematics, and gas fractions of a sample of rare, nearby turbulent disks with properties closely matched to $z \sim 1.5-2$ main-sequence galaxies (the DYNAMO sample). We find linear correlations of normalized mean clump sizes with both the gas fraction and the velocity dispersion-to-rotation velocity ratio of the host galaxy. We show that these correlations are consistent with predictions derived from a model of instabilities in a self-gravitating disk (the so-called "violent disk instability model"). We also observe, using a two-fluid model for Q, a correlation between the size of clumps and self-gravity driven unstable regions. These results are most consistent with the hypothesis that massive star forming clumps in turbulent disks are the result of instabilities in self-gravitating gas-rich disks, and therefore provide a direct connection between resolved clump sizes and this *in situ* mechanism.

High star formation rates as the origin of turbulence in early and modern disk galaxies

Green, Andrew W.[1]; Glazebrook, Karl[1]; McGregor, Peter J.[2]; Abraham, Roberto G.[3]; Poole, Gregory B.[1]; Damjanov, Ivana[3]; McCarthy, Patrick J.[4], Colless, Matthew[5] & Sharp, Robert G.[5]

High spatial and spectral resolution observations of star formation and kinematics in early galaxies have shown that two-thirds are massive rotating disk galaxies[1–5] with the remainder being less massive non-rotating objects[2,4,6–8]. The line of sight averaged velocity dispersions are typically five times higher than in today's disk galaxies. This has suggested that gravitationally-unstable, gas-rich disks in the early Universe are fuelled by cold, dense accreting gas flowing along cosmic filaments and penetrating hot galactic gas halos[9,10]. However these accreting flows have not been observed[11], and cosmic accretion cannot power the observed level of turbulence[12]. Here we report on a new sample of rare high-velocity-dispersion disk galaxies we have discovered in the nearby Universe where cold accretion is unlikely to drive their high star-formation rates. We find that the velocity dispersion is most fundamentally correlated with their star-formation rates, and not their mass nor gas fraction, which leads to a new picture where star formation itself is the energetic driver of galaxy disk turbulence at all cosmic epochs.



Star Formation Rate (M⊙/yr)
0.1 0.2 0.5 1 2 3 5 10 20 50 100 200 500
a
This Study z~0.1
z~0.01 (refs 18,19)
z~1.4 (ref 4)
z~2.3 (ref 7)
z~3.5 (ref 8)
M82
M51
Local velocity dispersion (km/s)
100
80
60
40
20
10−2
10−3
10−4
10−5
10−6
40
41
42
43
Hα Luminosity (log erg/s)

Природа clumps и высокой дисперсии скоростей

- Теория: self-gravitating disc model

$$R_{rot} \propto \frac{G\Sigma}{\Omega^2},$$

- Mergings?

Non-axisymmetric instabilities?

Выборка галактик DYNAMO sample (Green et al. 2010) (DYnamics of Newly-Assembled Massive Objects).
DYNAMO disks are very similar to main-sequence disks at Z =1.5-2, yet DYNAMO galaxies are at z ~0.1.
DYNAMO disk galaxies have high star formation rates, gas fractions (fgas 20 - 40%) (Fisher et al. 2014) and H velocity dispersions (30-80 km s-1)
10-15 clumps per galaxy.
Отбирались галактики с вращением и экспон. профилем.

- DYNAMO disks are very similar to main-sequence disks at Z =1.5-2, yet DYNAMO galaxies are at z ~0.1.

DYNAMO disk galaxies have high star formation rates, gas fractions (fgas 20 - 40%) (Fisher et al. 2014) and H velocity dispersions (30-80 km s-1)

- Our data set includes galaxies with H-narrowband imaging from the Hubble Space Telescope with 0.05-0.2 kpc resolution.
- Газ- по CO со стандартным фактором конверсии.

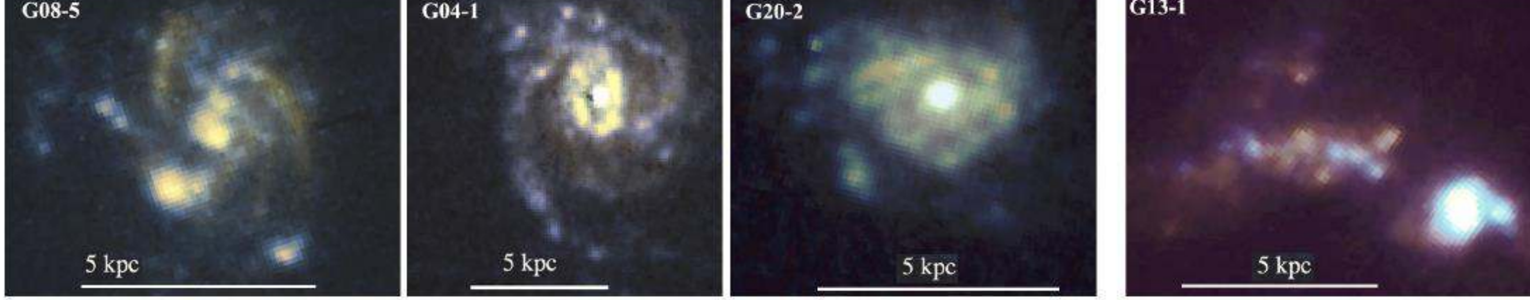


Figure 1. Two color HST images of DYNAMO galaxies are shown. Blue represents Hα and yellow represents 600 nm continuum. The Hα clumps in DYNAMO galaxies have been shown to be very similar in properties to those in high redshift galaxies. The left three galaxies are identified as clumpy disks, for comparison we also show G13-1 a galaxy classified as an ongoing merger in the DYNAMO-HST sample.

Table 1. Properties of DYNAMO-*HST* Sample

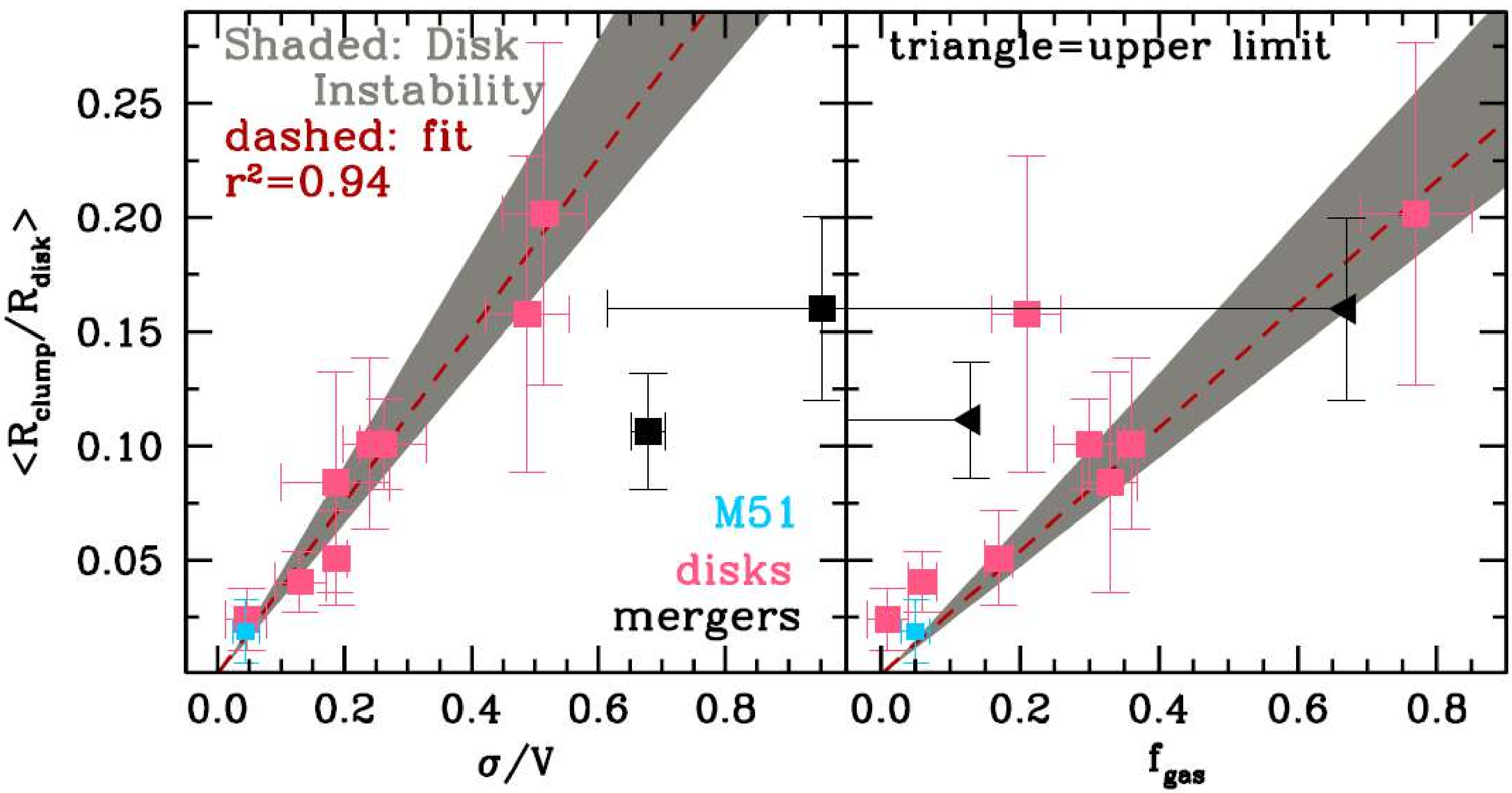
Galaxy	z	SFR	M_{star}	Type	$R_{1/2}$(disk)[a]	$<R_{clump}>$[b]	σ/V	f_{gas}[c]
		$M_\odot$ yr^{-1}	log($M_\odot$)		kpc	kpc		
G04-1	0.12981	21.32	10.81	disk	2.75	0.46 ± 0.26	0.19 ± 0.09	0.33 ± 0.04
G20-2	0.14113	18.24	10.33	disk	2.1	0.66 ± 0.29	0.49 ± 0.07	0.21 ± 0.05
D13-5	0.0753	17.48	10.73	disk	2.04	0.41 ± 0.15	0.24 ± 0.02	0.36 ± 0.02
G08-5	0.13217	10.04	10.24	disk	1.84	0.37 ± 0.07	0.26 ± 0.07	0.3 ± 0.05
D15-3	0.06712	8.29	10.73	disk	2.2	0.22 ± 0.09	0.19 ± 0.02	0.17 ± 0.02
G14-1	0.13233	6.90	10.35	disk	1.12	0.45 ± 0.17	0.51 ± 0.07	0.77 ± 0.08
C13-1	0.07876	5.06	10.55	disk	4.21	0.34 ± 0.11	0.13 ± 0.04	0.06 ± 0.02
A04-3	0.06907	2.42	10.63	disk	3.58	0.17 ± 0.10	0.05 ± 0.03	$.01 \pm 0.01$
H10-2	0.14907	15.49	9.98	merger	2.55	0.82 ± 0.21	0.95 ± 0.34	<0.67
G13-1	0.13876	12.71	10.05	merger	2.59	0.55 ± 0.13	0.68 ± 0.03	<0.13

^{a} R_{disk} is measured as twice $R_{1/2}$ for Hα light.

^{b} R_{clump} represents an average for each galaxy.

^{c} Galaxy A04-3 does not have a CO(1-0) measurement, for this target we assume that $M_{gas} = 10^9 \times$SFR, where SFR is calculated from the extinction corrected Hα luminosity using Hao et al. (2011) calibration.

- Наблюдения: GEMINI
- Разрешение по кинематике 1-2 кпс



igure 2. The pink points denote DYNAMO disk galaxies. The black points represent the 2 DYNAMO galaxies that are consistent with ergersFisher et al. (2017). The light blue point represents the same analysis for M51. In each panel the dashed line represents a fit to the disk ılaxies only. The gray shaded region represents the prediction from the violent disk instability model.

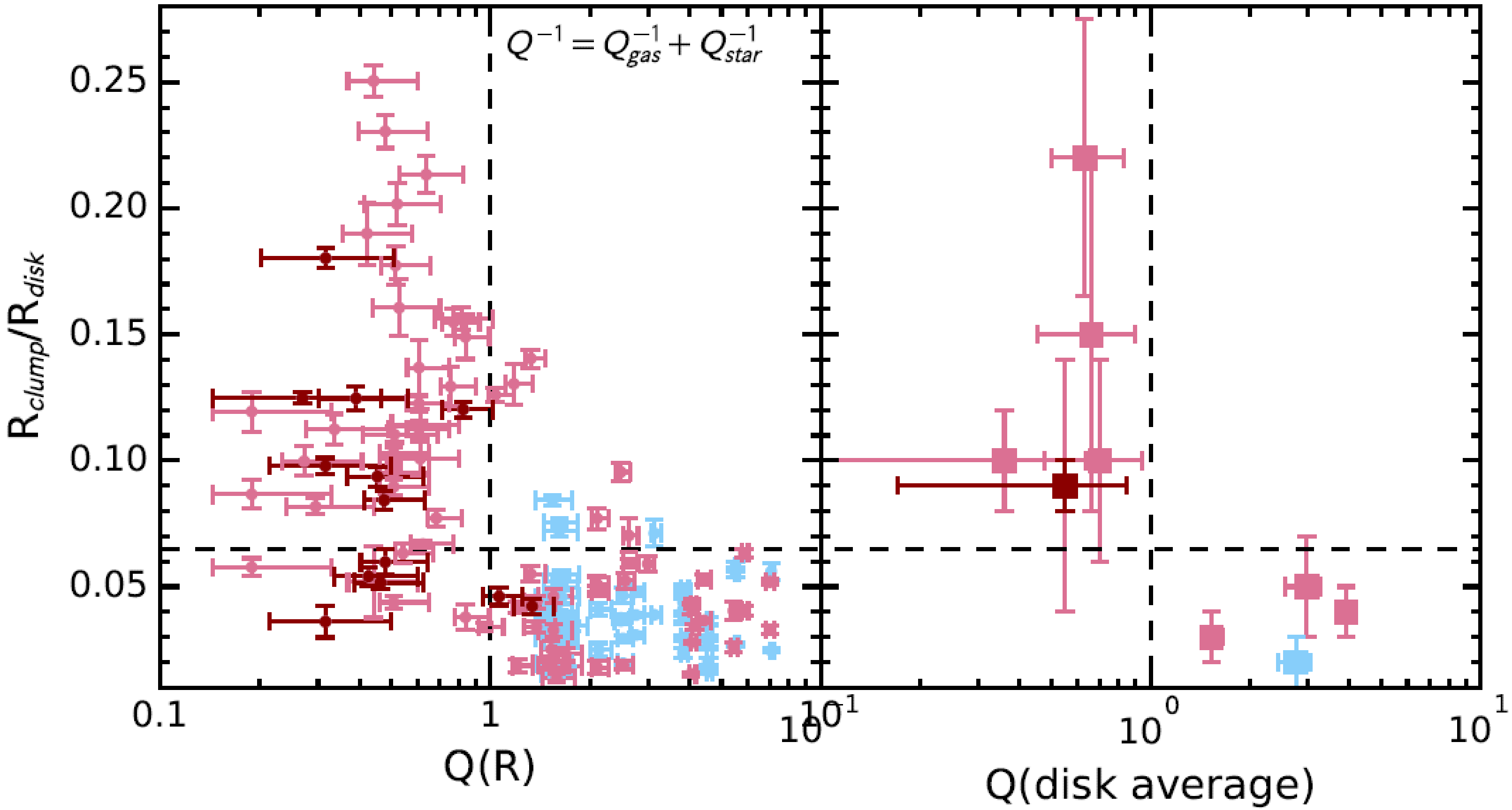


Figure 3. The normalized sizes for all clumps are compared to the value of the Toomre stability criteria. The left panel compares individual clump measurements to the azimuthally averaged Q(R). The right panel compares disk averaged values for both R_{clump}/R_{disk} and Q. The pink symbols represent clumps in the DYNAMO disks, the blue symbols represent those in M51, and the dark red symbols represent DYNAMO disk G04-1. The horizontal line represents R_{clump}/R_{disk} value for which 90% of points with $Q > 1$ are smaller than.

- We find strong consistency of clump

sizes with predictions of the model in which self-gravity is the origin of large clumps.

- Our results therefore demonstrate a rigorous, quantifiable and direct connection between the clumpy mode of star formation that dominates z ~ 1 - 3 main-sequence galaxies and a such a mechanism that occurs naturally in gas rich, turbulent disks.