Galaxy Zoo: Finding offset discs and bars in SDSS galaxies

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ABSTRACT

We use multi-wavelength SDSS images and Galaxy Zoo morphologies to identify a sample of $\sim$270 late-type galaxies with an off-centre bar. We measure offsets in the range 0.2-2.5 kpc between the photometric centres of the stellar disc and stellar bar. The measured offsets correlate with global asymmetries of the galaxies, with those with largest offsets showing higher lopsidedness. These findings are in good agreement with predictions from simulations of dwarf-dwarf tidal interactions producing off-centre bars. We find that the majority of galaxies with off-centre bars are of Magellanic type, with a median mass of $10^{9.6} M_\odot$, and 91% of them having $M_\star < 3 \times 10^{10} M_\odot$, the characteristic mass at which galaxies start having higher central concentrations attributed to the presence of bulges. We conduct a search for companions to test the hypothesis of tidal interactions, but find that a similar fraction of galaxies with offset bars have companions within 100 kpc as galaxies with centred bars. Although this may be due to the incompleteness of the SDSS spectroscopic survey at the faint end, alternative scenarios that give rise to offset bars such as interactions with dark companions or the effect of lopsided halo potentials should be considered. Future observations are needed to confirm possible low mass companion candidates and to determine the shape of the dark matter halo, in order to find the explanation for the off-centre bars in these galaxies.

Key words: galaxies: dwarf, galaxies: interactions, galaxies: irregular, galaxies: struc-

A peculiar feature: a bar that appears to be offset from the photometric centre of the galaxy discs.
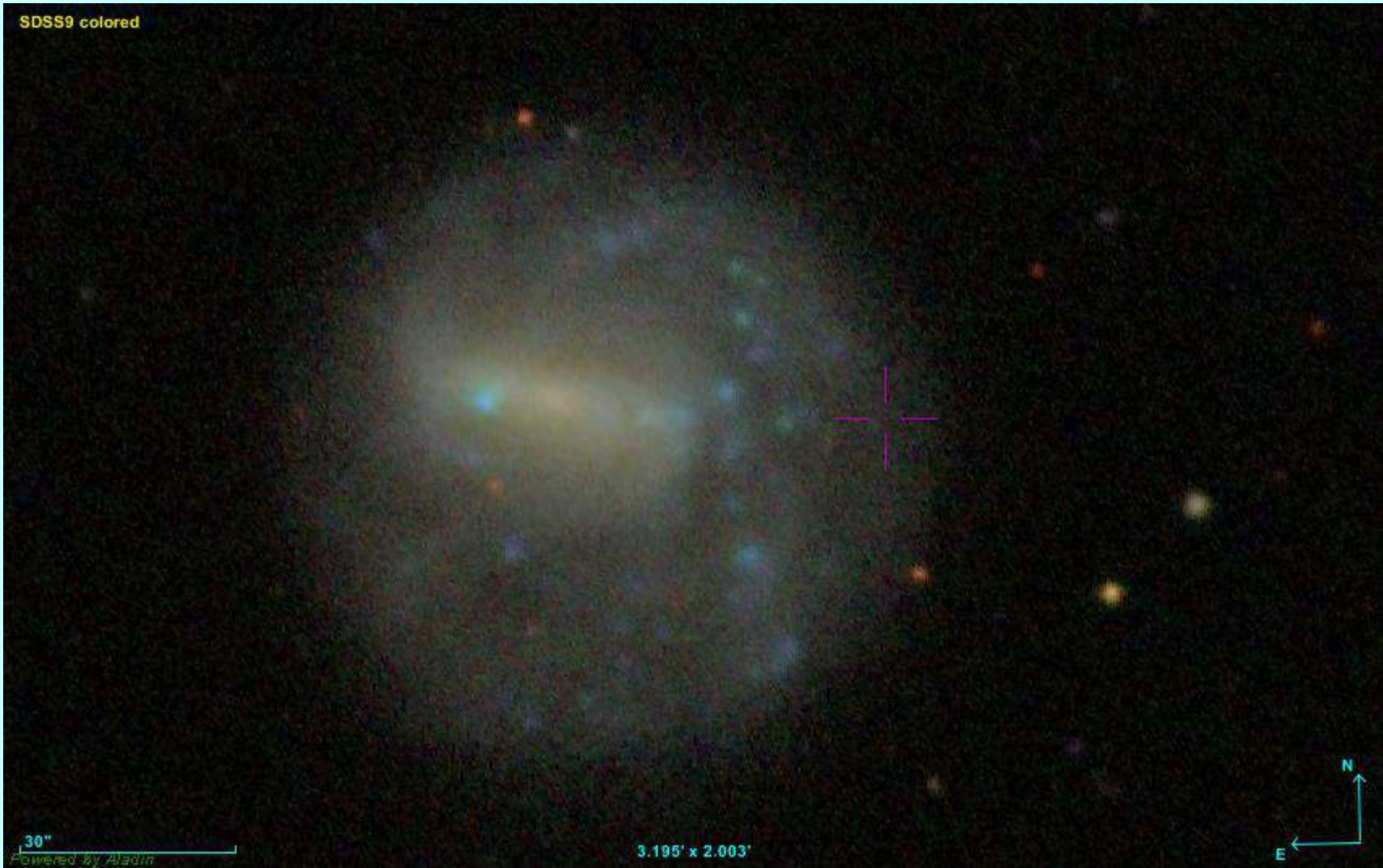
- LMC: смещение на 0.4-0.8 кпс

Zhao & Evans (2000) suggested that the bar in

the LMC is off-centre as a

consequence of a recent

tidal interaction with SMC

and MW.

Pardy+(2016): N-body

Hydrodynamics LMC+SMC

-объясняет ситуацию
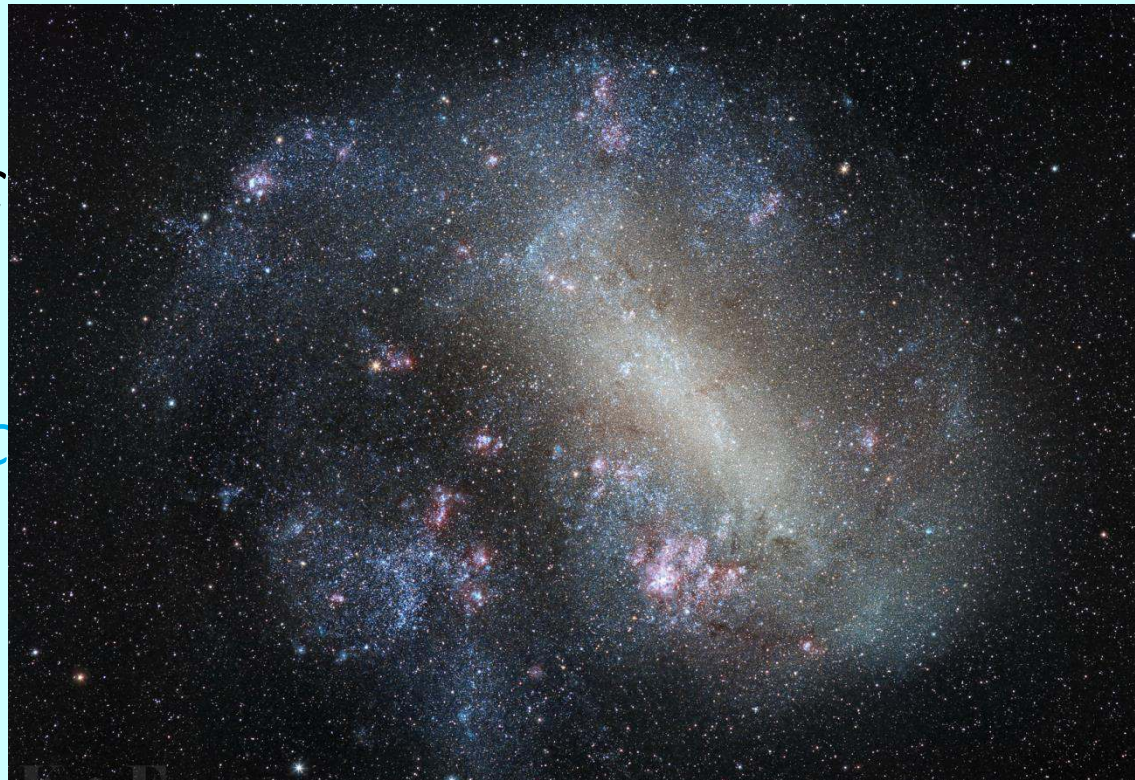
Однако, к примеру, NGC3906-изолирована
(что отмечено в этой работе)

In this paper, we conduct the first systematic search for galaxies with offsets between the stellar bar and the discs in the largest survey in the local Universe (SDSS)

- 2D decomposition SB-галактик по Galaxy Zoo (эксп.диск, балдж с n=2, бар)
- Всего – 5282 галактики с b/a >0.5.
- Удалось профиттировать 3357 галактик.
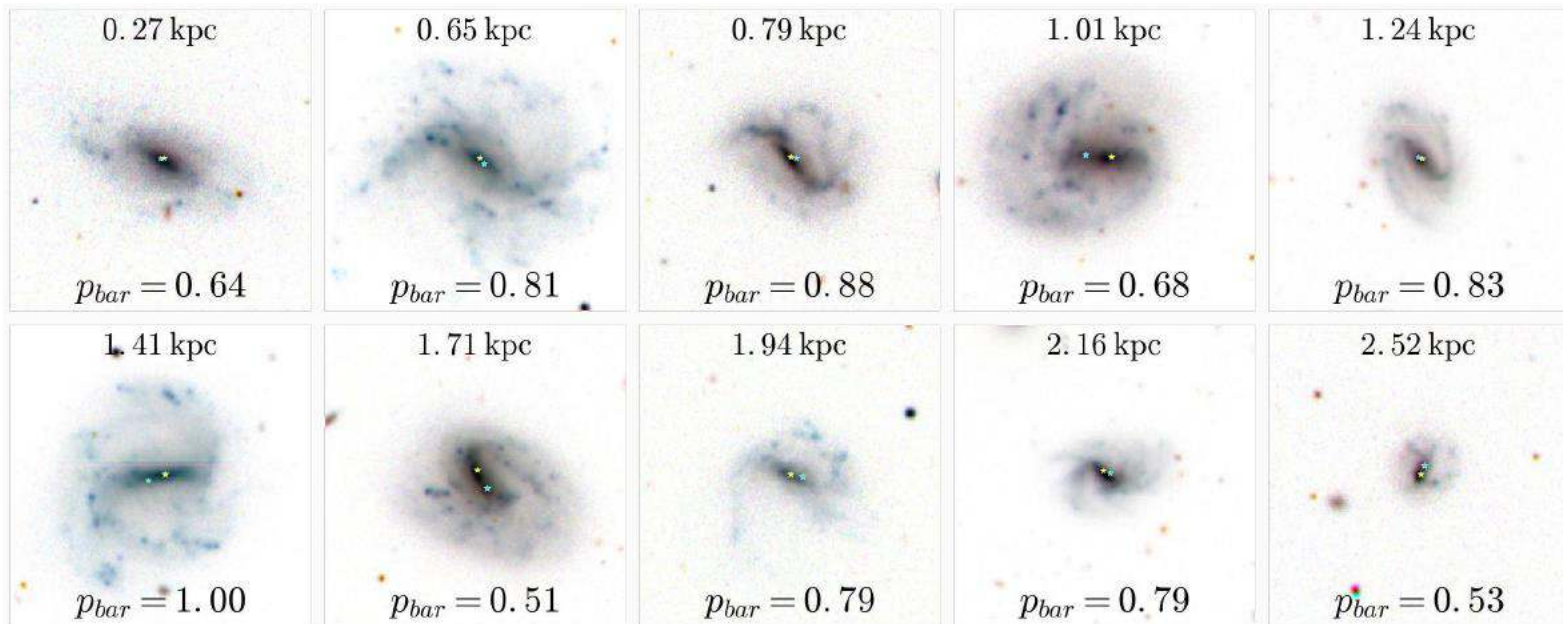- Смещение бара (в проекции на диск)- модельный параметр

Figure 3. Examples of galaxies with offset discs and bars in SDSS; inverted colour *gri* composite images. The measured deprojected photometric offset between the bar and the disc is given at the top of each image. The GZ2 debiased likelihood that the galaxy has a bar is given at the bottom of each image. The centre of the bar component, according to the best fit model, is marked with a yellow star, while the photometric centre of the disc is marked with a cyan star. The images are 1 arcmin x 1 arcmin.

OFFSET SAMPLE – 271 GALAXY

Измерялась также **lopsidedness of the galaxy disc (m=1)**

$$r(x, y) = r_0(x, y)\left(1 + \sum_{m=1}^{N} a_m \cos(m\phi + \phi_m)\right),$$
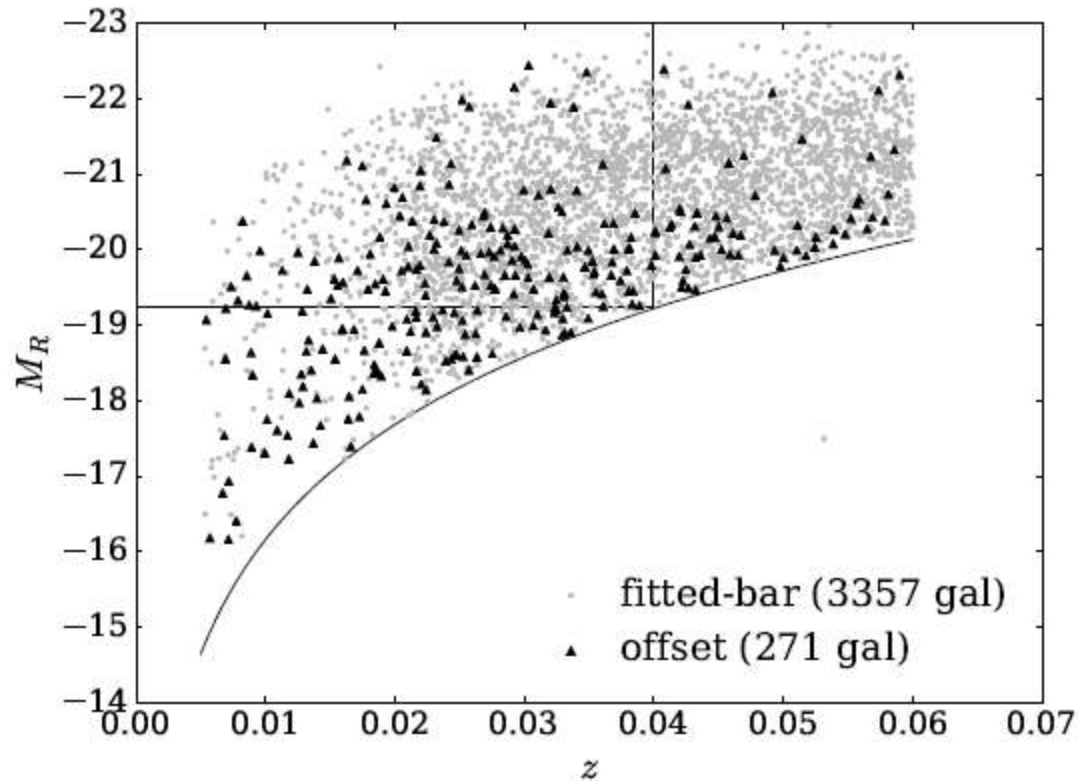
Figure 2. The r-band Petrosian absolute magnitudes of the samples used in the paper: the FITTED-BAR SAMPLE and the OFFSET SAMPLE, as identified in Section 3.2. The box contains the galaxies in the VOLUME-LIMITED SAMPLE (1,583 galaxies) as defined in Section 4.3. The curved line corresponds to the GZ2 completeness limit of 17 magnitudes, at a particular redshift.

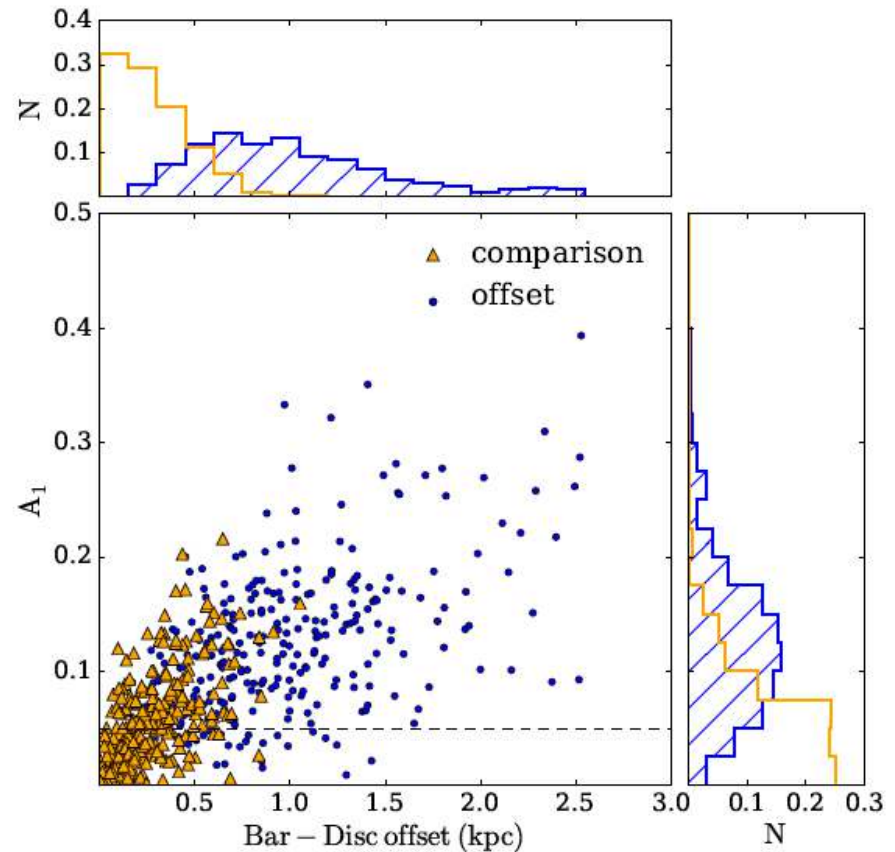# Lopsidedness vs offset

- Слабая корреляция

Figure 5. The Fourier $m = 1$ mode amplitude, A_1, is correlated with the offset between the disc and the bar. $A_1 > 0.05$ is an indicator of lopsidedness, shown by the dotted line in the plot. The normalized histograms show the distributions of A_1 for the OFFSET SAMPLE and COMPARISON SAMPLE (on the vertical) and the distribution of the deprojected offsets for the two data sets

- Zaritsky et al. (2013) noted that the lopsidedness is not correlated with the presence and strength of a bar as many non-barred galaxies are also lopsided.

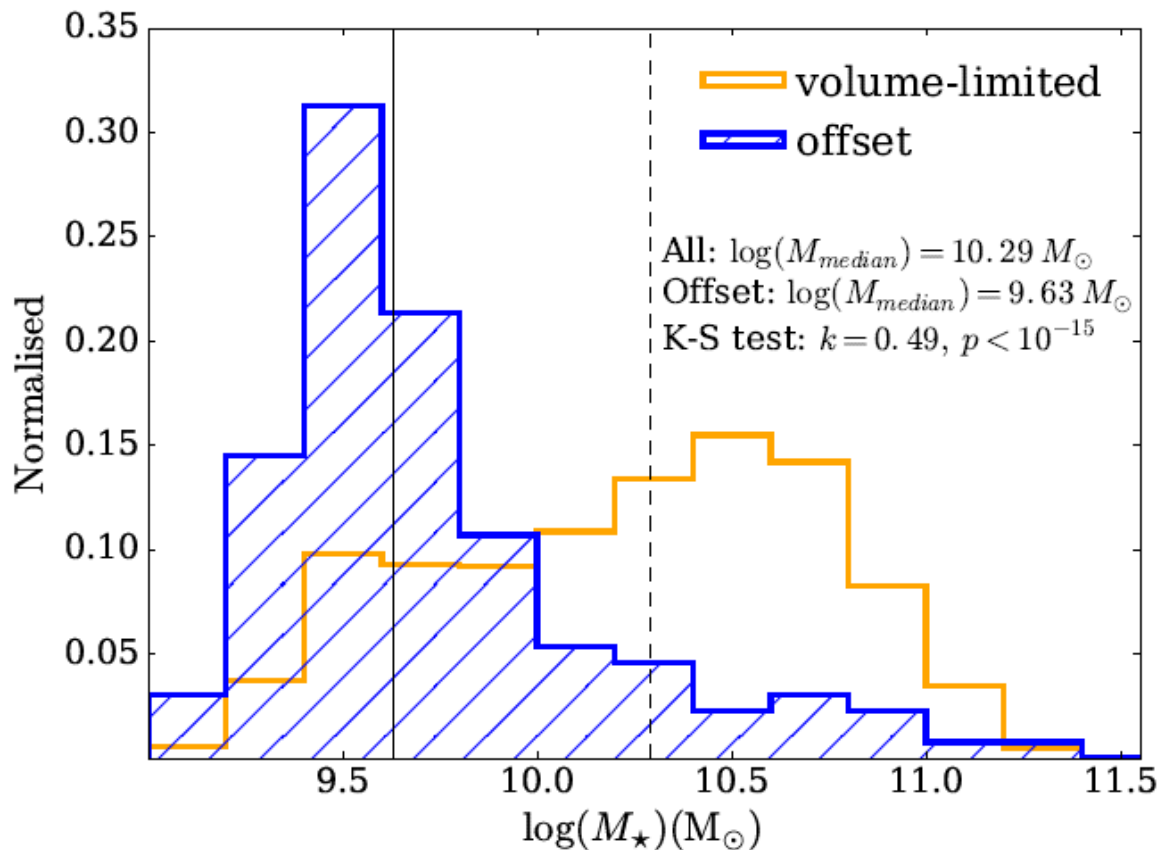- However they did not make a distinction between galaxies with off-centre bars and those with centred bars.

Figure 6. Normalized histograms of the mass distribution of galaxies with offset bars in the volume-limited sample (131 galaxies) and the VOLUME-LIMITED SAMPLE of barred galaxies (1,583 galaxies). The median mass of galaxies with off-centre bars is $10^{9.63}\,M_{\odot}$ (as shown by the vertical solid line), while the median mass of barred galaxies is $10^{10.29}\,M_{\odot}$ (as shown by the vertical dashed line). Only 12 galaxies with $3 \times 10^{10}\,M_{\odot}$ are seen to have off-centre bars.
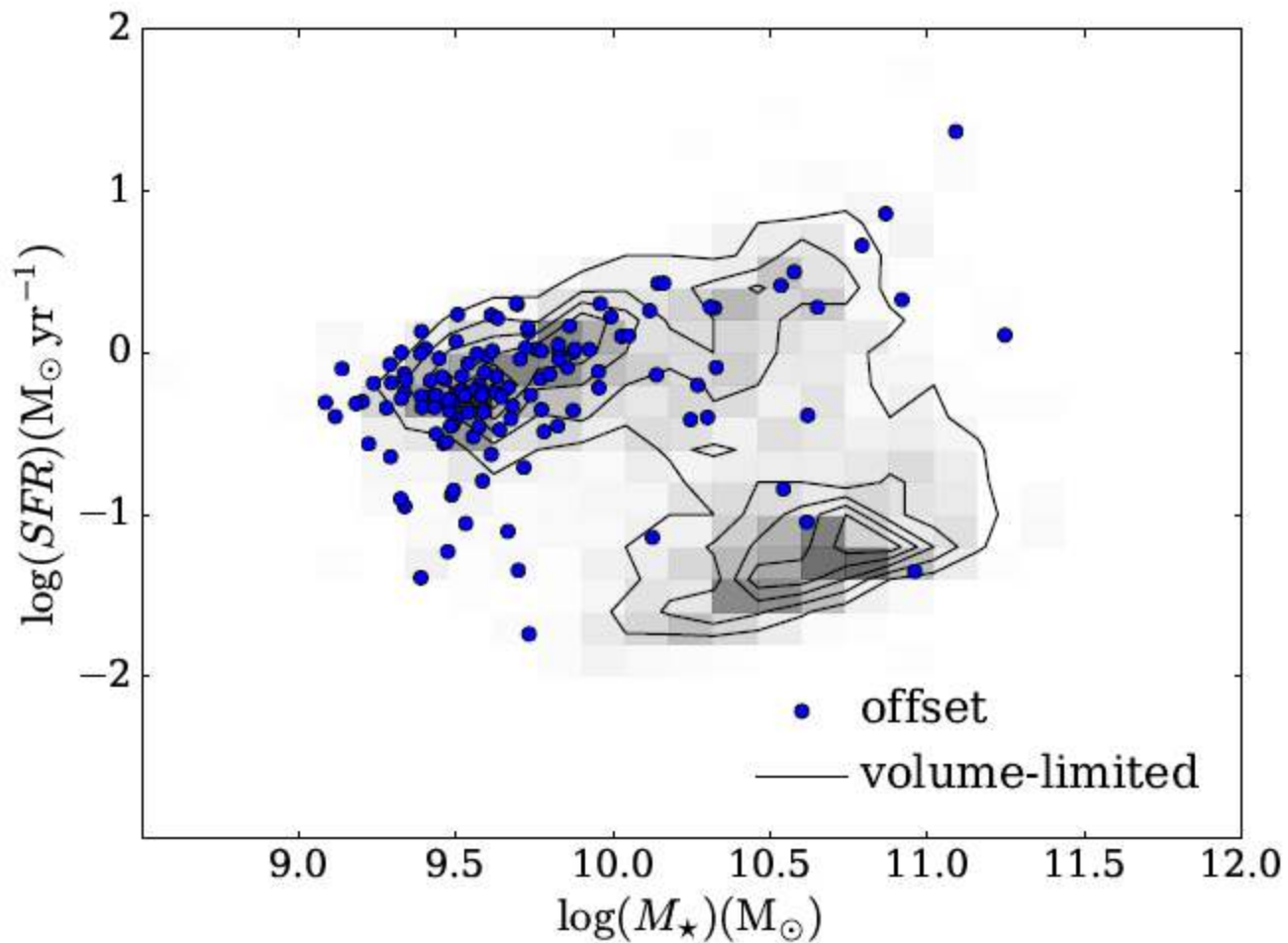
Figure 7. The location of the offset systems on a SFR-Mass plot, overlaid on the VOLUME-LIMITED SAMPLE of barred galaxies. Galaxies with offset bars are located almost entirely on the star forming main sequence.

4.3.4 Bulges

Only 10% of the offset galaxies (14 out of 131) have 'obvious bulges', while 90% (117 out of 131) have 'just noticeable' or 'no bulges'. This is in striking contrast with the distribution of bulge types of the VOLUME-LIMITED SAMPLE of which 56% are 'obvious bulges' and 44% are 'disc dominated', suggesting that the presence of an off-centre bar is connected to the absence of a considerable bulge.

We find that 642 out of the 3,357 galaxies ($\sim$19%) in the FITTED-BAR SAMPLE have close companions, defined as within a projected separation of $r_p < 100$ kpc. With a similar percentage, 17%, 46 galaxies in the OFFSET SAMPLE have a close companion.

ВЗАИМОДЕЙСТВИЕ ЗДЕСЬ НЕ ПРИ ЧЕМ???
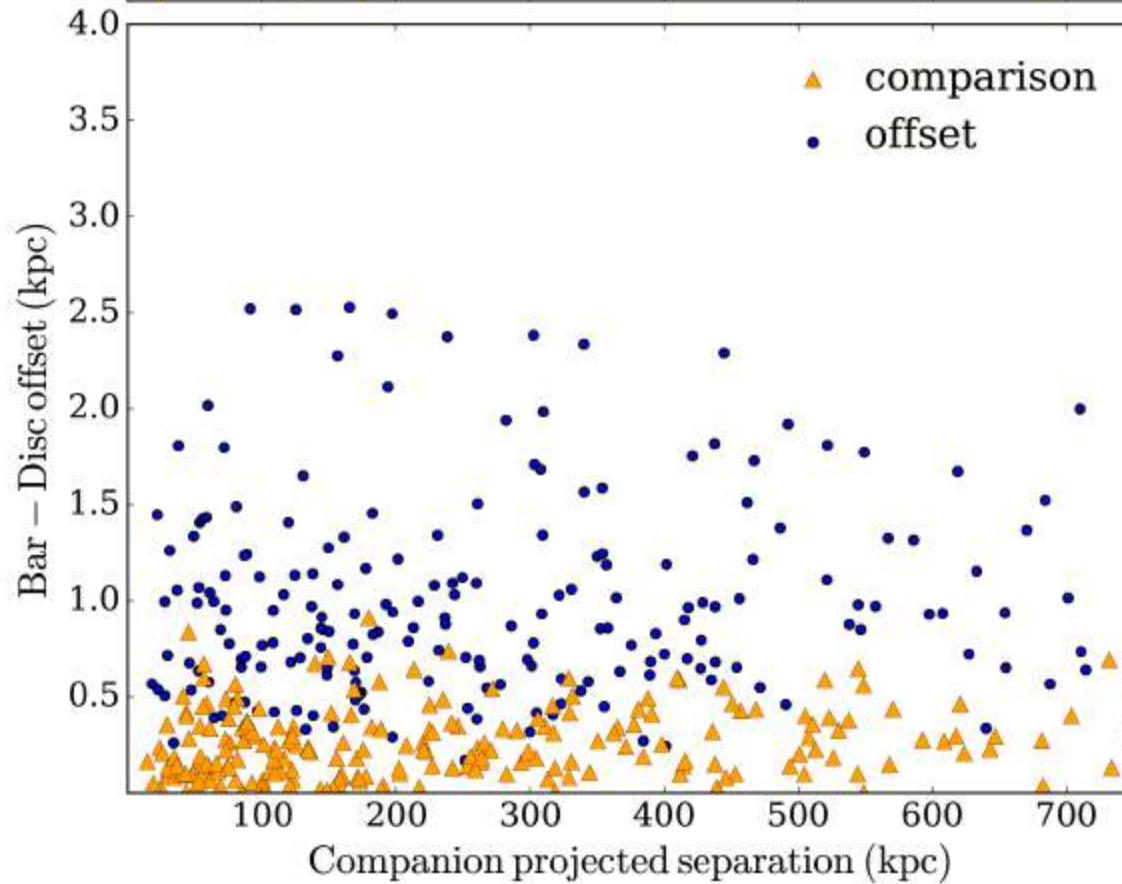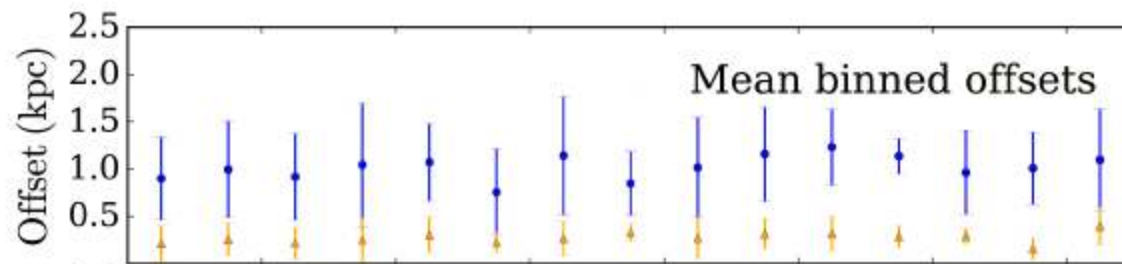
Основные выводы

- Our observations show that there is a mass of $3*10^{10}$Mc above which the galactic discs are stable against disc-bar offsets.

- Many isolated galaxies show evidence of an offset bar, which cannot be attributed to a dwarf-dwarf interaction. Other possible explanations for the offset should also be considered, such as an interaction with a dark matter subhalo or an asymmetry in the dark matter distribution in the halo.

Does the LMC Possess a Dark Bulge?
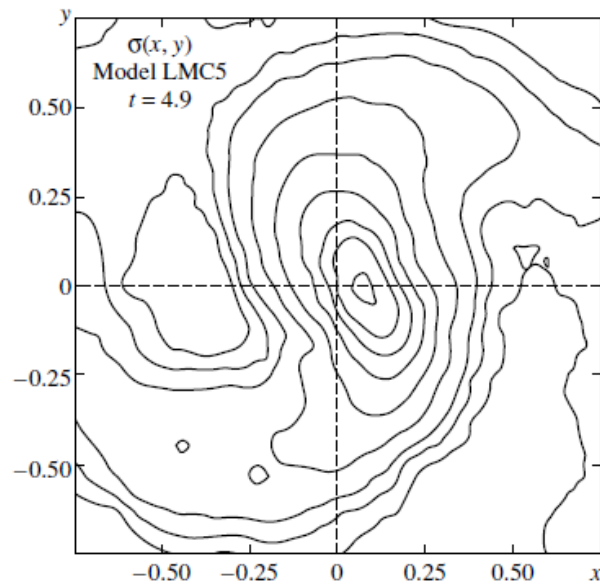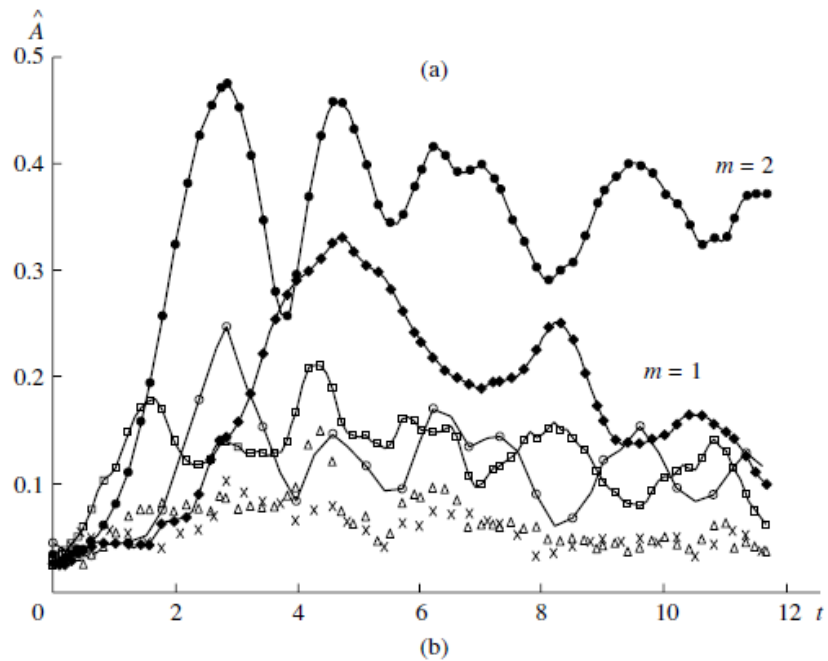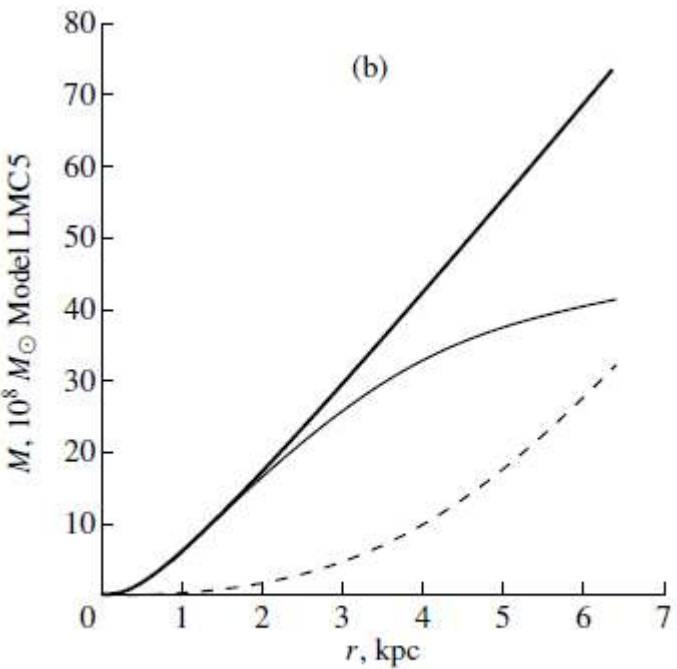
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Abstract—A series of numerical dynamical models for the LMC are constructed in order to fit the observed rotational velocities and stellar velocity dispersions at various galactocentric distances. The models include a three-dimensional spherical disk and nonevolving spherical components with various relative masses. The two LMC rotation curves presented by Kim *et al.* (1998) and Sofue (2000), which differ strongly in the inner region of the galaxy, are compared. The latter curve requires the presence of a massive dark bulge. Models based on the rotation curve of Sofue (2000) cannot account for the observed velocity dispersion or the presence of a long-lived bar in the galaxy. A model with no dark bulge is in good agreement with the observations if we assume that the disk dominates over the halo in terms of the mass within the optical radius (about 7 kpc). © 2002 MAIK "*Nauka/Interperiodica*".

- «Бары со смещенным центром не так уж редки среди галактик поздних типов. Численные модели показывают, что такая ситуация возникает, когда бар формируется в первоначально «холодном» звездном диске, в котором развивается одно-ветвевая неустойчивость (мода m=1). Это происходит в том случае, если масса диска существенно выше массы сферических компонент на большом протяжении диска.

- # N-body

- # N ~ 10^5

Fig. 7. Radial dependences of the mass contained within the radius r for the disk and spherical subsystems for

Time dependence of the integrated amplitudes of Fourier harmonics. At the initial stage of its evolution, the initially exhibits a large perturbation amplitude with azimuthal number $m = 1$. Notation is the same as in Fig. 3. (b) Contours density at $t = 4.9$ (one orbital period of the disk). The kinematic center and center of mass are located at the on of the dashed lines.