Spiral Structure Boosts Star Formation in Disk Galaxies

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ABSTRACT

We investigate the impact of spiral structure on global star formation using a sample of 2226 nearby bright disk galaxies. Examining the relationship between spiral arms, star formation rate (SFR), and stellar mass, we find that arm strength correlates well with the variation of SFR as a function of stellar mass. Arms are stronger above the star-forming galaxy main sequence (MS) and weaker below it: arm strength increases with higher $\log(\mathrm{SFR}/\mathrm{SFR}_{\mathrm{MS}})$, where $\mathrm{SFR}_{\mathrm{MS}}$ is the SFR along the MS. Likewise, stronger arms are associated with higher specific SFR. We confirm this trend using the optical colors of a larger sample of 4378 disk galaxies, whose position on the blue cloud also depends systematically on spiral arm strength. This link is independent of other galaxy structural parameters. For the subset of galaxies with cold gas measurements, arm strength positively correlates with H I and H_2 mass fraction, even after removing the mutual dependence on $\log(\mathrm{SFR}/\mathrm{SFR}_{\mathrm{MS}})$, consistent with the notion that spiral arms are maintained by dynamical cooling provided by gas damping. For a given gas fraction, stronger arms lead to higher $\log(\mathrm{SFR}/\mathrm{SFR}_{\mathrm{MS}})$, resulting in a trend of increasing arm strength with shorter gas depletion time. We suggest a physical picture in which the dissipation process provided by gas damping maintains spiral structure, which, in turn, boosts the star formation efficiency of the gas reservoir.

Важная зависимость: SFR -M*

• От чего зависит расстояние Галактики от MS?
Известно, что от Mgas/M* (Saintonge, 2012,2016) и от SFE (Wang et al.,2020).
Вопрос – как положение галактик вдоль MS и перпендикулярно MS зависит от амплитуды спиральны ветвей, содержания газа и други характеристик?

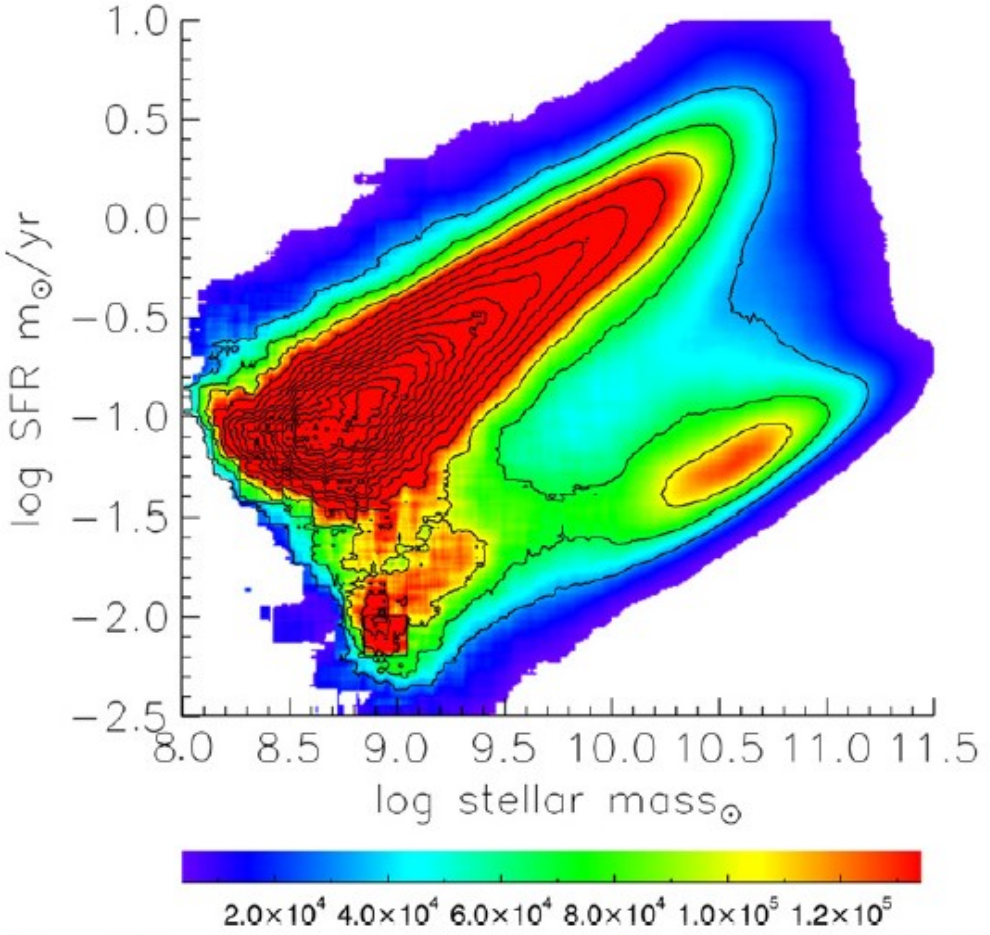


Figure 4. Projection of the 3D surface shown in Figure 1 over the SFR–$M*$ plane. Level contours for the number density of galaxies are shown, with colors ranging from blue to red as a function of number density. The V/V_{max} correction was applied for this plot.

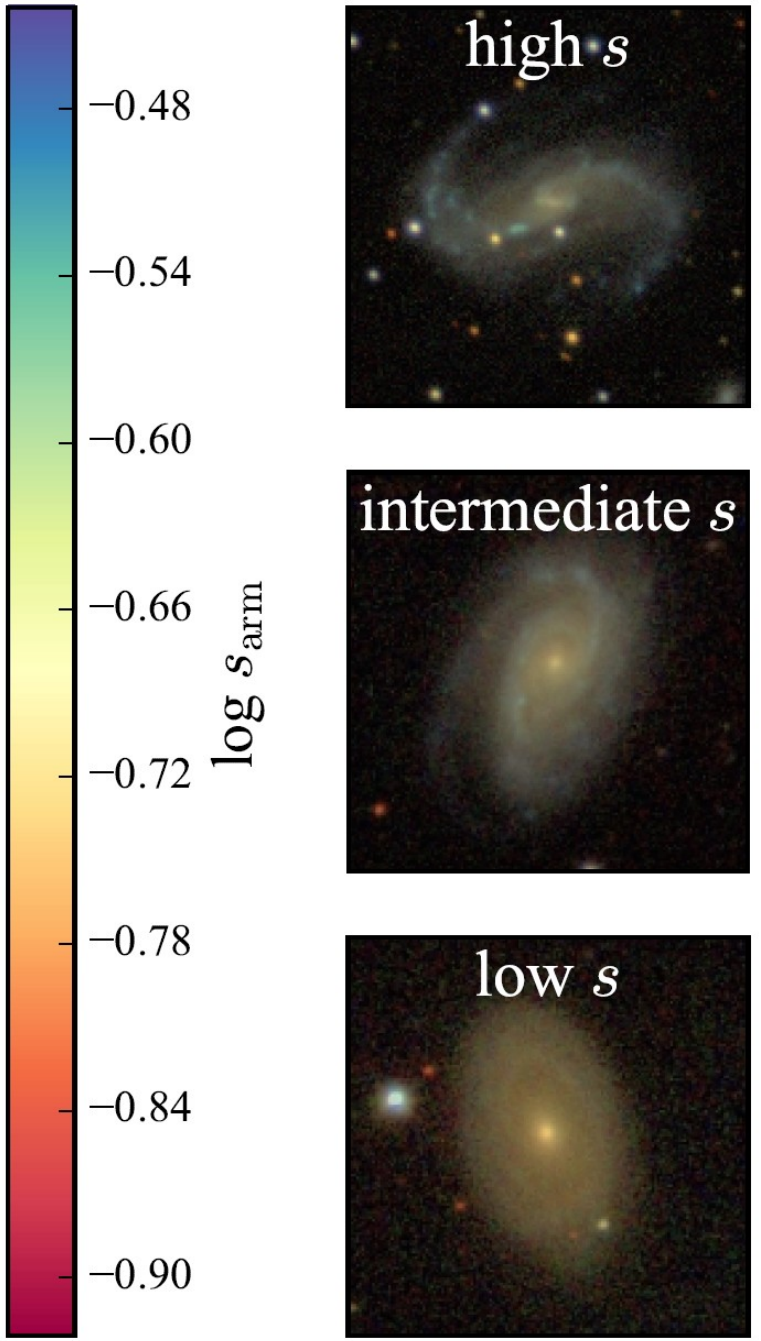
Используется каталог Spiral arms strength by Yu, Ho, 2020

The Statistical Properties of Spiral Arms in Nearby Disk Galaxies

- Yu, Si-Yue, ; Ho, Luis C.
- Abstract
- We analyze 4378 nearby bright disk (S0 and spiral) galaxies selected from the Sloan Digital Sky Survey to characterize their spiral structure and systematically investigate the relationships between spiral arm properties (strength, pitch angle, and number) and the global properties of the host galaxies. This is to date the largest sample of galaxies with comprehensive measurements of spiral properties based on Fourier decomposition. We find that spiral pitch angle decreases (arms become more tightly wound) toward galaxies of earlier Hubble type, higher stellar mass, redder color, and greater degree of central concentration. The dependence of pitch angle on stellar mass is mainly driven by color, and for a given concentration, spiral arms are more tightly wound in redder galaxies. Spiral pitch angles show a bimodal distribution, peaking at $i = 12° \pm 3.4$ and $23° \pm 4.3$. Spiral arms weaken in galaxies of earlier type, redder color, and higher concentration

- We utilize estimates of SFR and stellar mass (M*) based on ultraviolet, optical, and mid-infrared photometry from
- the xGASS catalog (Extended GALEX Arecibo SDSS survey;
- Catinella et al. 2018) for galaxies contained therein, and from the catalog of Salim et al. (2018) for the rest. **This results in 2226 (1751 spiral and 475 lenticular) galaxies, the main sample studied in this work.**
- The sample covers a wide range of M* (10^8.8 -10^11.4M) and SFR (0.001 – 10 Ms/yr).

- S-STRENGTH
- They define the arm amplitude (sarm) as the average Fourier amplitude (quadratic sum of m = 2, 3, and 4 modes) relative to an axisymmetric disk (m = 0 mode) over a radial range that starts at the end of the bulge or bar and ends at R90, the radius that encloses 90% of the total flux and encompasses the majority of the spiral structure



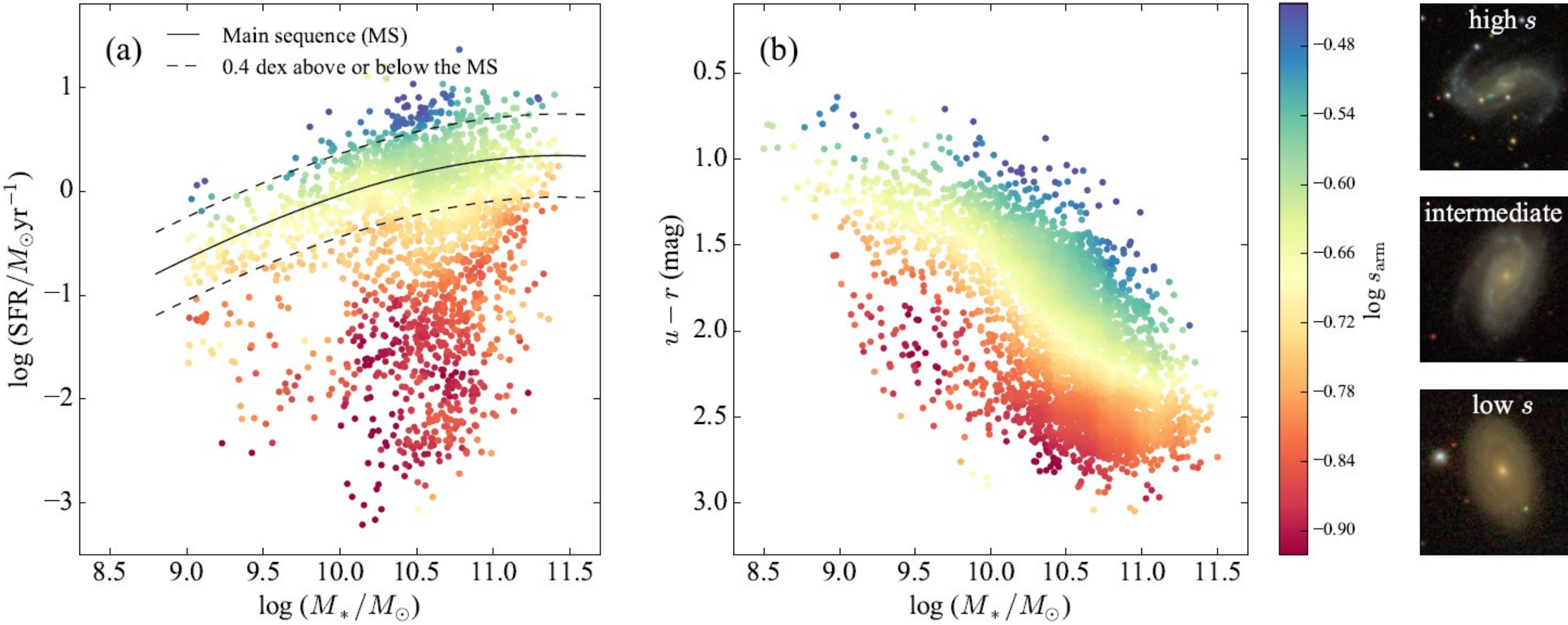
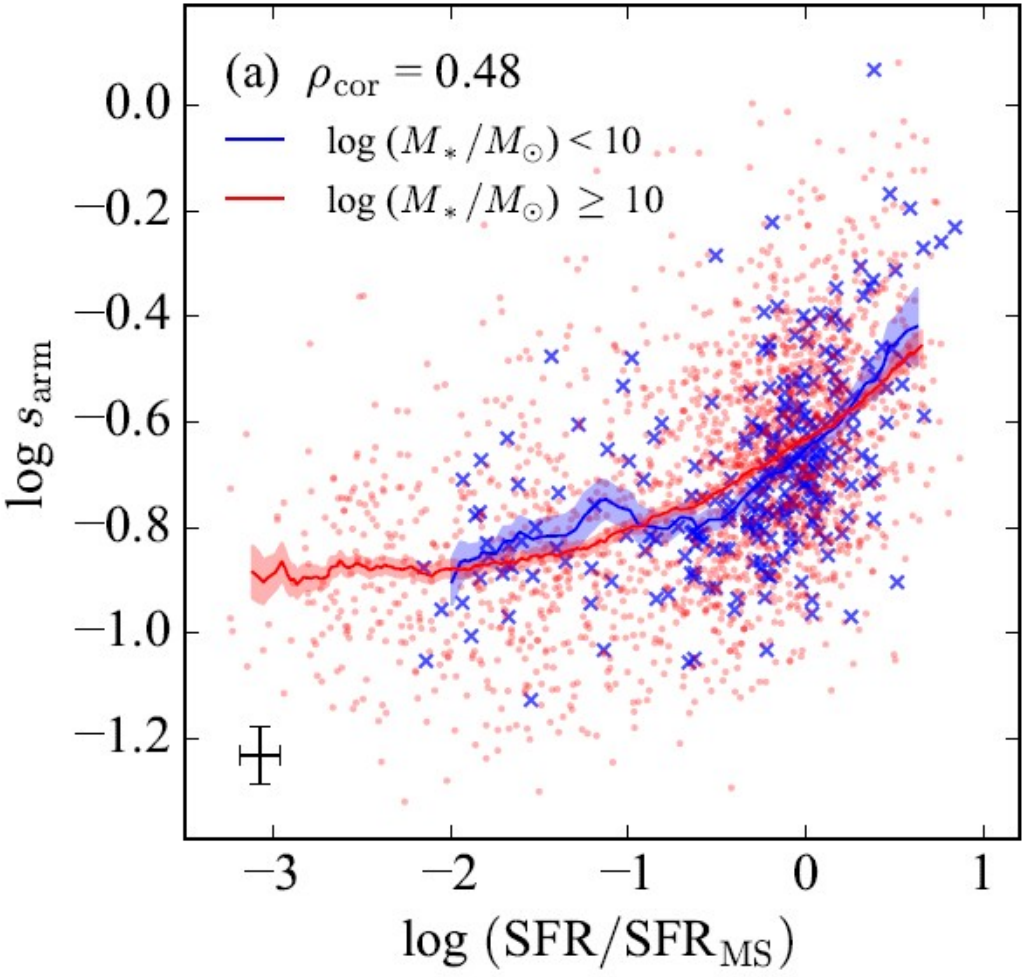


Figure 2. The influence of spiral arms on star formation in disk galaxies. Panel (a) illustrates the spiral arm strength (log $s_{\rm arm}$) as a functi of SFR and M_* for 2226 face-on disk galaxies with available SFRs based on multi-band photometry. The solid curve marks the MS (Sainton et al. 2016), with the dashed curves indicating 0.4 dex above and below it. Panel (b) gives the spiral arm strength as a function of rest-fram

Зависимость между силой спиральных ветвей и отклонением от MS SFR

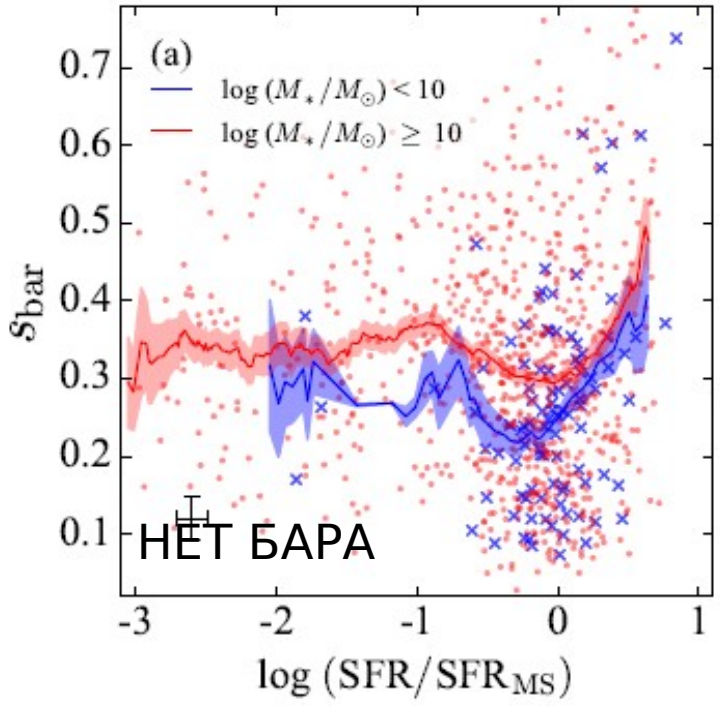
• Одинаковая картина для галактик разной массы.

Здесь присутствуют два эффекта: стимулирующая роль спиралей в SF, и связь силы спиральной ветви с количеством холодного газа в диске, без которого мощных спиралей не образуется



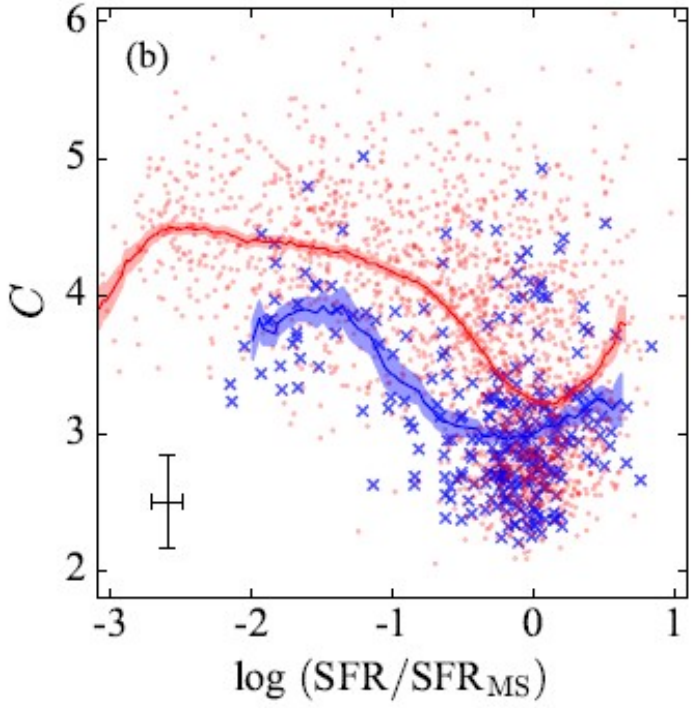
Влияние на SFR наличия бара, индекса концентрации и поверхностной яркости

Здесь корреляции практически нет

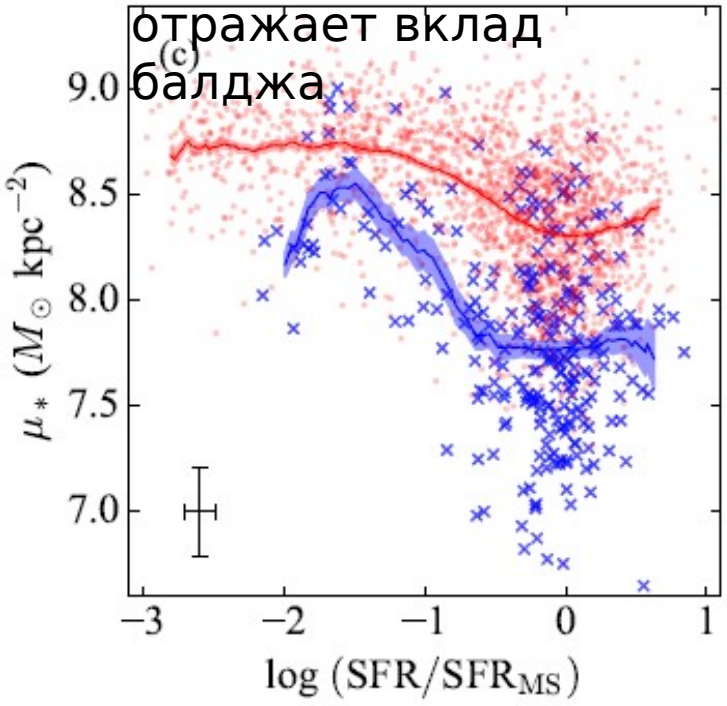


НЕТ БАРА

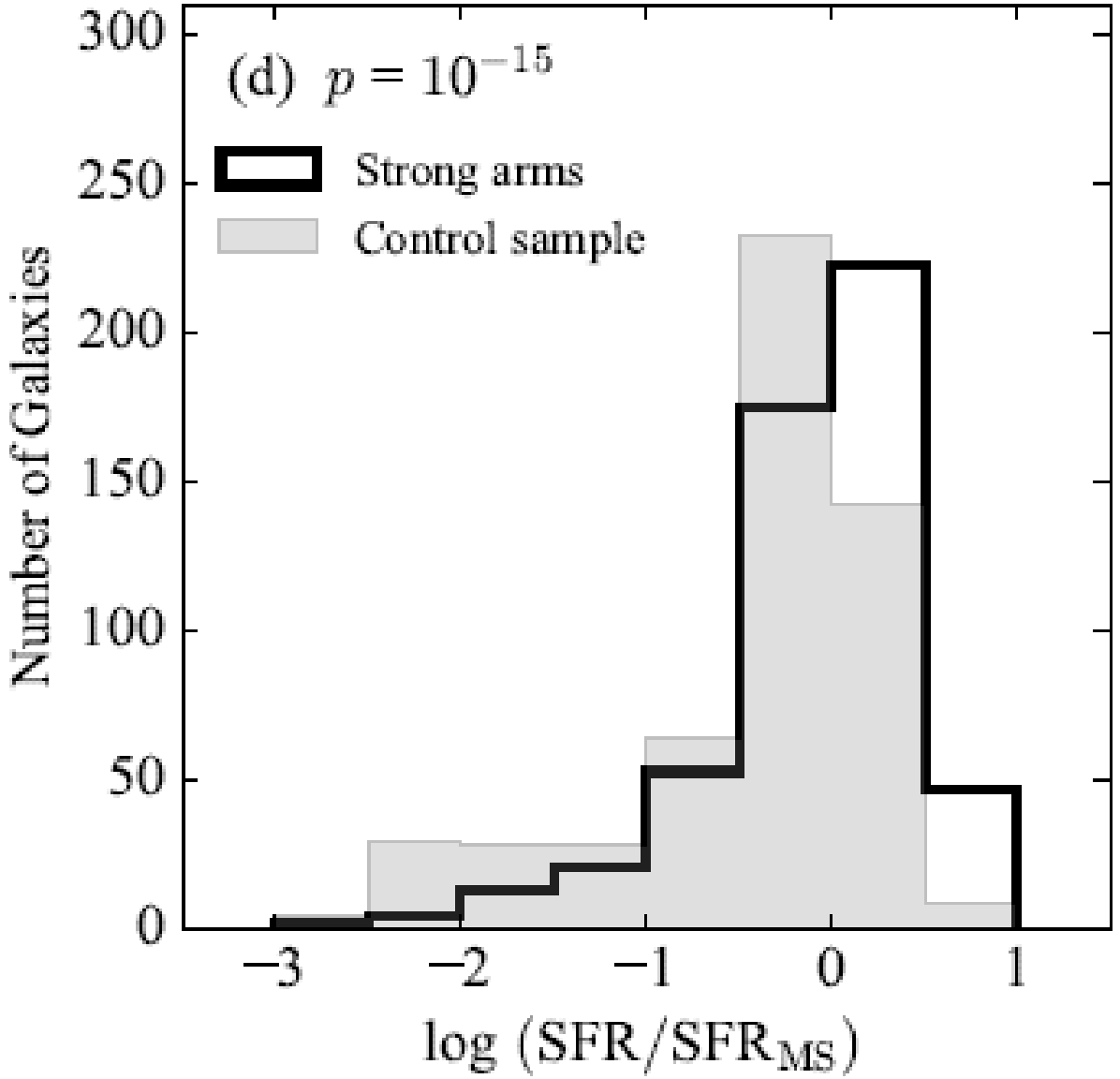
Индекс концентрации C характеризует светимость балджа



Яркость в пределах Reff отражает вклад балджа



• Сила спир.ветвей сказывае
на SFR, особенно при повыш
темпе звездообразования
по отношению к MS.



Эффект зависит от массы галактик

«Дефицит» SFR обусловлен низкой относительной масс молекулярного газа

Практически нет Корреляции с HI

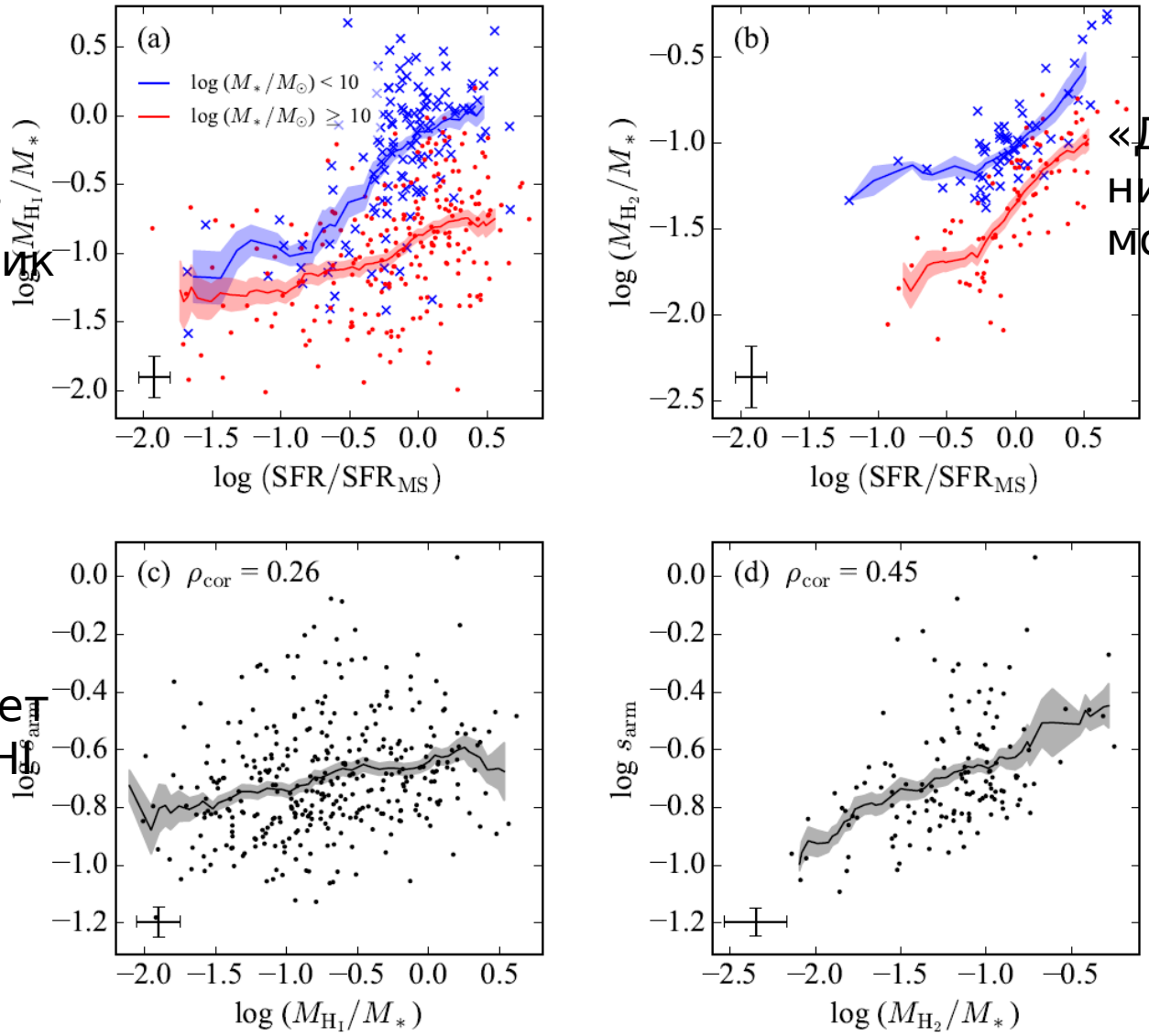


Figure 5. The relationship between atomic ($M_{\rm H\,I}/M_*$) and molecular ($M_{\rm H_2}/M_*$) gas fraction, distance from the MS [log (SFR/SFR$_{\rm MS}$)], and spiral arm strength (log $s_{\rm arm}$). Panels (a) and (b) show the variation of log (SFR/SFR$_{\rm MS}$) with $M_{\rm H\,I}/M_*$ and $M_{\rm H_2}/M_*$. The blue crosses and red points denote the galaxies with log $(M_*/M_\odot) < 10$ and log $(M_*/M_\odot) \geq 10$. Panels (c) and (d) present the dependence of spiral arm strength (log $s_{\rm arm}$) on $M_{\rm H\,I}/M_*$ and $M_{\rm H_2}/M_*$; the correlation coefficient $\rho_{\rm cor}$ is given. Solid curves mark the mean value, while shaded regions mark the error of the mean value. The bars indicate typical measurement uncertainties.

- Интерпретация – в русле имеющихся представлений:
- Газ «демпфирует» спиральную структуру. Сильные спирали ослабляются, но долго сохраняются. Низкое содержание газа приводит к тому, что спиральные волны плотности (как и транзиентные ветви) быстрее нагревают диск, а сами спирали становятся слабыми, и затухают.

Избыточное» SF –
это совокупность
льных спиралей
высокое содержание газа

Характерное время исчерпания газа
слабо зависит от силы спиралей

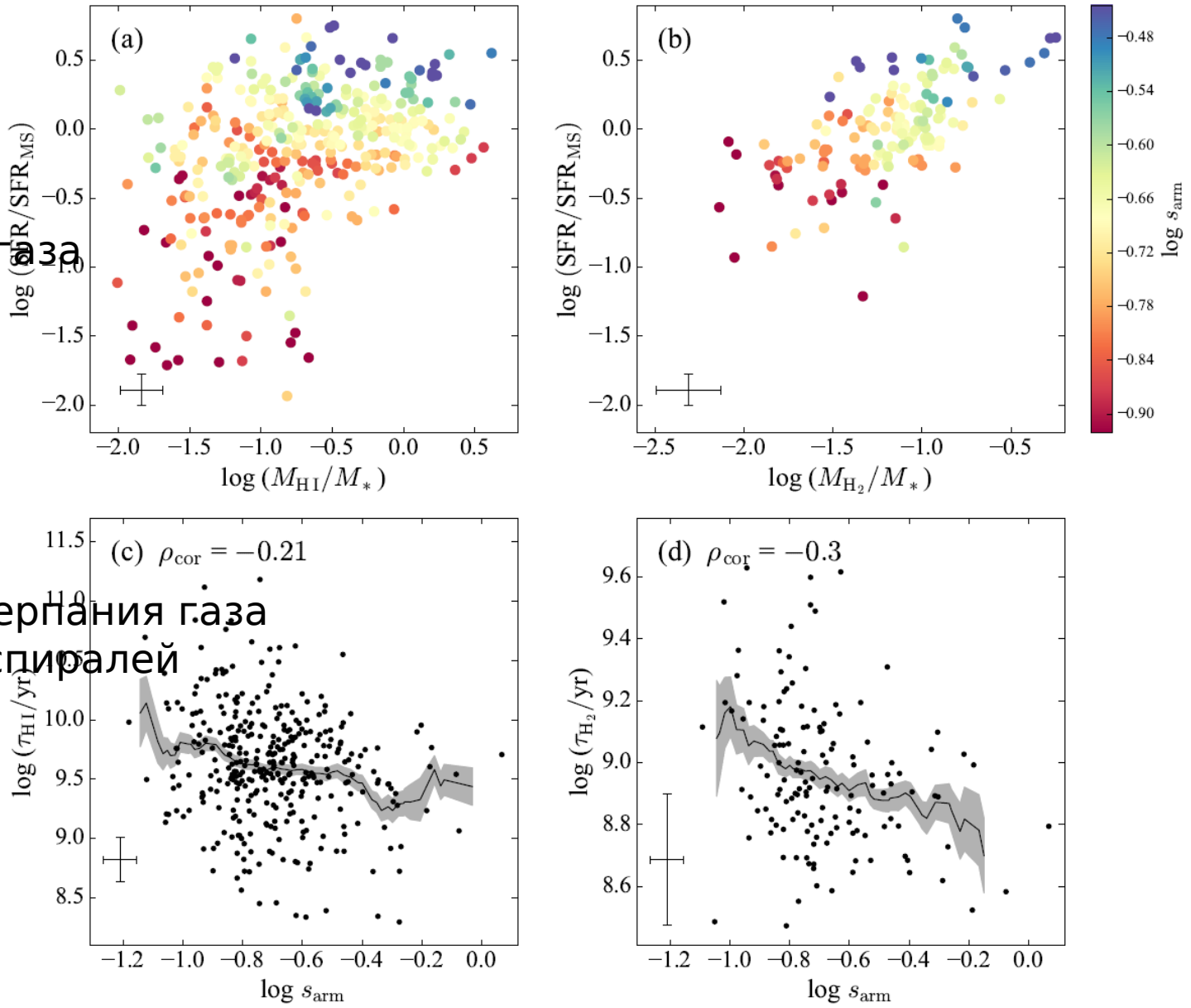


Figure 6. The connection between spiral arms and global star formation efficiency. Panels (a) and (b) examine the influence of spiral arm strength ($\log s_{arm}$) on the relation between the distance to the MS [$\log (\mathrm{SFR}/\mathrm{SFR_{MS}})$] and the atomic gas mass fraction (M_{HI}/M_*) and molecular gas mass fraction (M_{H_2}/M_*). The color associated with each data point encodes the average arm strength of surrounding galaxies

Самые главные выводы

- С ростом силы спиральных ветвей связано как усиленное звездообразование по отношению к MS (независимо от других характеристик галактик, напр., бара), так и более высокий удельный темп звездообразования (sSFR).
- Сила спиральных ветвей коррелирует с относительным содержанием газа (независимо от положения галактик относительно MS)
- Т.обр., на SF одновременно влияют два фактора: относительное количество газа, и сила спиральных ветвей.
- ***The correlations suggest that spiral arms enhance star formation efficiency, and that the relationship between spiral arms and star formation is driven only in part by gas fraction.***