The SAMI Galaxy Survey: Gas velocity dispersions in low-z star-forming galaxies and the drivers of turbulence

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Проблема с дисперсией скоростей ионизованного газа (сверхзвуковая турбулентность):

z>1: σ=50-100 км/с
z~0: σ=20-50 км/с, но это все равно много
Тепловая ширина H-альфа при T=10000 K – 9 км/с, турбулентные движения на бОльших скоростях диссипируют с тепловыми скоростями (galaxy<100 Myr, GMS: 10 Myr)
=> есть постоянная подпитка этой турбулентности:

- star-formation feedback processes (SNs, winds)
- gravitational transport of gas onto or through the disc

Предсказания вида SFR-σ

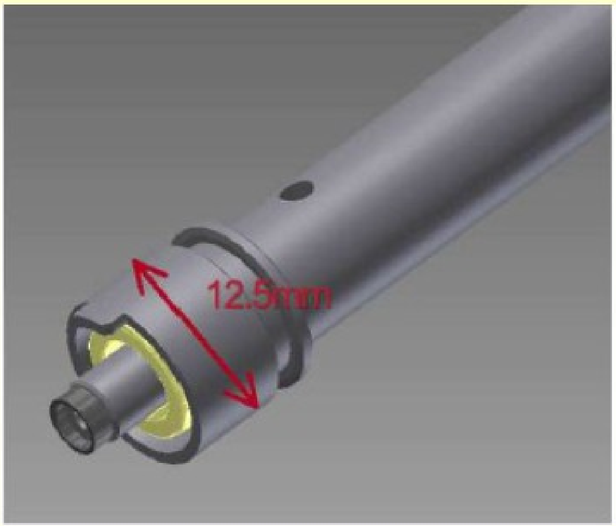
- dynamical drivers such as shear and differential rotations across the disc
- interactions between galaxy components

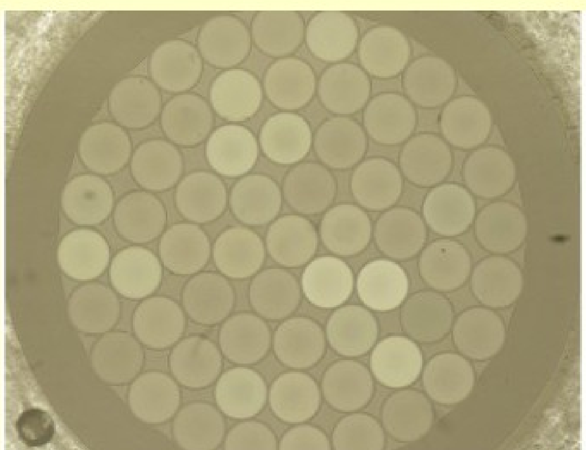
  \+ вириальные движения для гигантских областей HII (добавка от меня)

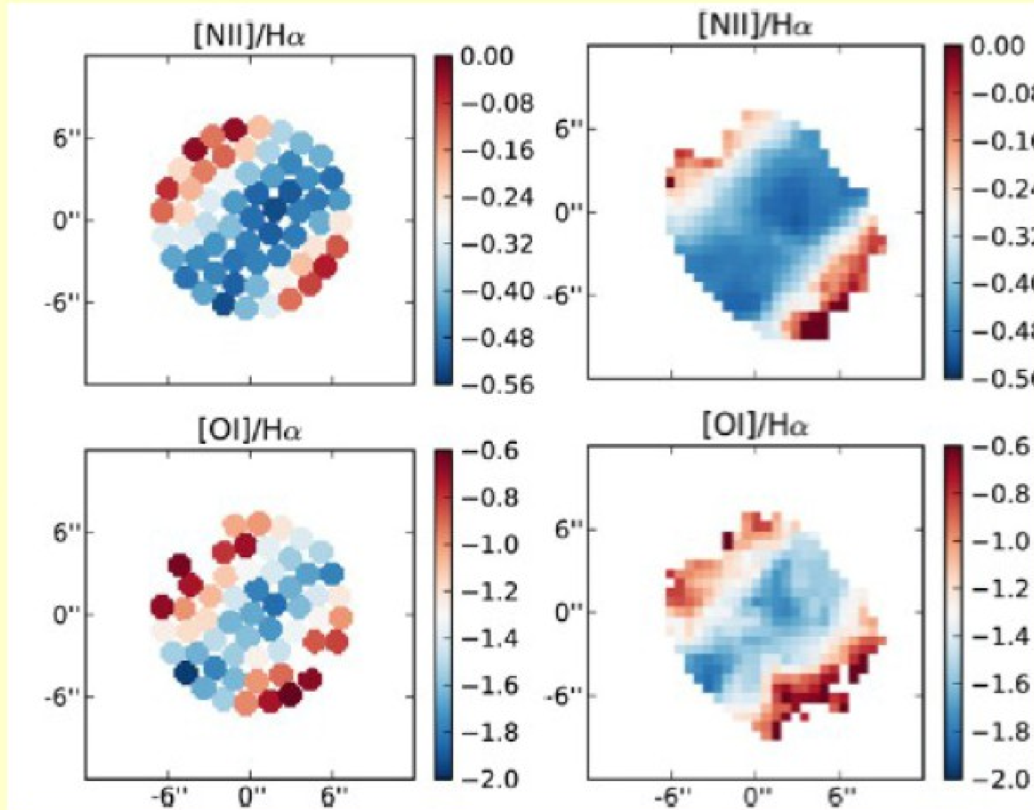
Нужно достаточно высокое разрешение (σ=20 km/s → FWHM~ 1 A (Ha) → R>6000))

SAMI: Sydney-AAO Multi-object Integral-field spectrograph

13 hexabundles (15 “ FOV: 61 fibers x 1.6 arcsec)







Моисеев, «Методы панорамной спектроскопии», 2017, лекция 3

AAO 3.9м, отснято около 3000 галактик. R~2000 (blue) 4300 (red)

Sample and analysis

SAMI DR2: **1523** galaxies

- EW(Ha)>3A
- Without AGN/LINER
- Withiut mergers
- inclination: 0-60 deg (avoid beam smearing)
- > 300 spaxels with S/N>3 (Re>1")

=> **342 galaxies (z=0.05-0.08)**

DYnamics of Newly Assembled Massive Objects (DYNAMO): 67 galaxies

-
- star-forming galaxies, z<0.1, SFR: 1-100
- at 2.3 & 3.9 m
- SPIRAL IFU (R~12000, 22x11")
- WiFES IFU (R~7000, 25x38")
-
- => 41 galaxies with i<60

Blobby3D code (Varidel + 2019): spatial gas distribution + kinematics, broadening PSF, LSF

Сравнение с 3D BAROLO:

(e.g. Oliva-Altamirano et al. 2018). Blobby3D was found to infer the intrinsic velocity dispersion more accurately than these alternative methods, particular for galaxies where the PSF or velocity gradient were greatest.

Но приняли, что sigma постоянна по радиусу, а кривая вращения – по Courteau(1997)

$$v(r) = v_c \frac{(1 + r_t/r)^{\beta}}{(1 + (r_t/r)^{\gamma})^{1/\gamma}} \sin(i)\cos(\theta) + v_{sys}.$$

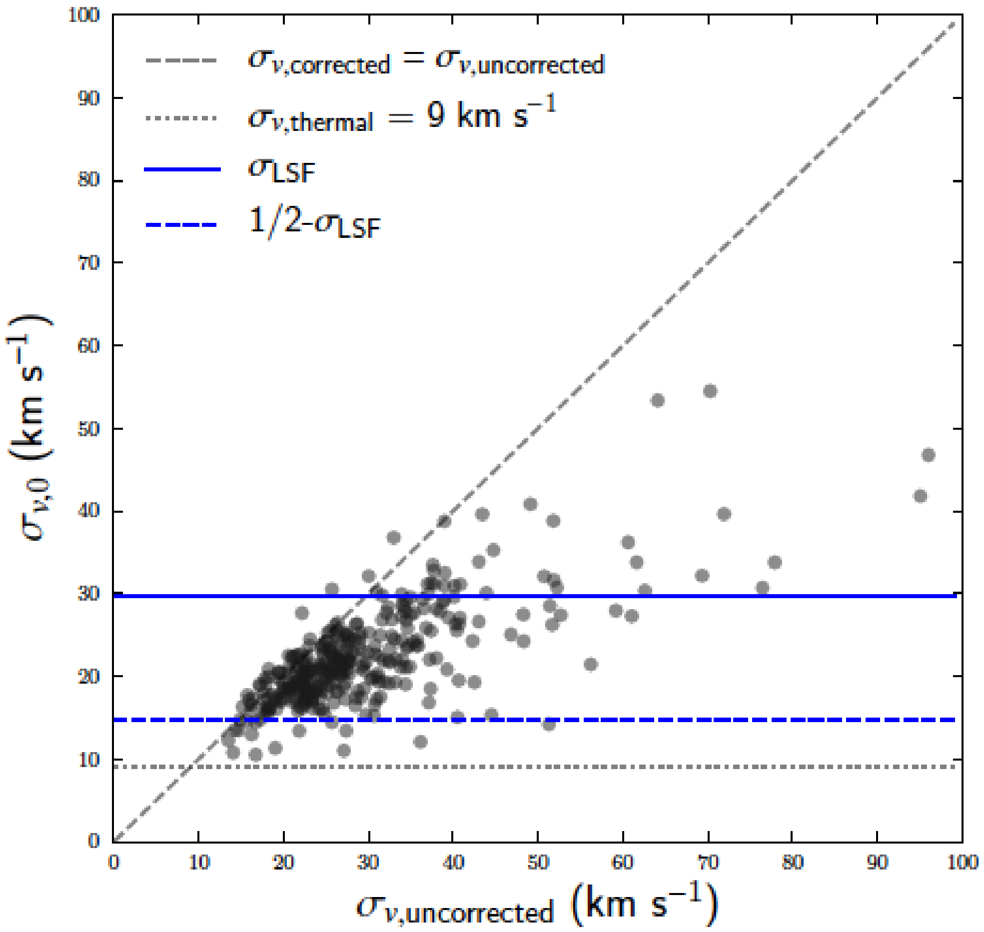


Figure 3. $\sigma_{v,0}$ estimated using BLOBBY3D compared to the arithmetic mean of the single-component fits per spaxel ($\sigma_{v,\mathrm{uncorrected}}$) to each galaxy from the SAMI Galaxy Survey sample. Estimates for the velocity dispersion are typically lower using BLOBBY3D as it mitigates the effects of beam smearing.

т.е. с формальной точки зрения, спектрального разрешения хватает на пределе (не то что у нас с ИФП)

Переход к вертикальной sigma:

$$\sigma^2_{v,\mathrm{LoS}} = (\sigma^2_{v,R}\sin^2\phi + \sigma^2_{v,\phi}\cos^2\phi)\sin^2 i + \sigma^2_{v,z}\cos^2 i.$$

assume spatially constant velocity dispersion components and that $\sigma^2_{v,\perp} \equiv \sigma^2_{v,R} \approx \sigma^2_{v,\phi}$ then the average LoS velocity dispersion is given by,

Setting $\gamma^2 = \sigma^2_{v,z}/\sigma^2_{v,\perp}$, and rearranging, then

$$\sigma_{v,\mathrm{LoS}} = \sigma_{v,z}\sqrt{\sin^2 i/\gamma^2 + \cos^2 i}$$

The above model predicts changing $\sigma_{v,\mathrm{LoS}}$ as a function of i if $\gamma \neq 1$. For $\gamma > 1$, $\sigma_{v,\mathrm{LoS}}$ increases with increasing i, whereas $\sigma_{v,\mathrm{LoS}}$ decreases with i when $\gamma < 1$.

Из анализа распределений:

We estimate $\gamma = 0.80^{+0.06}_{-0.05}$ as shown in Figure 4, suggesting that the vertical velocity dispersion is less than the averaged azimuthal and radial components. This anal-

Ранее, по звездам gamma~0.6

sigma(LOS) vs sigma(Z)

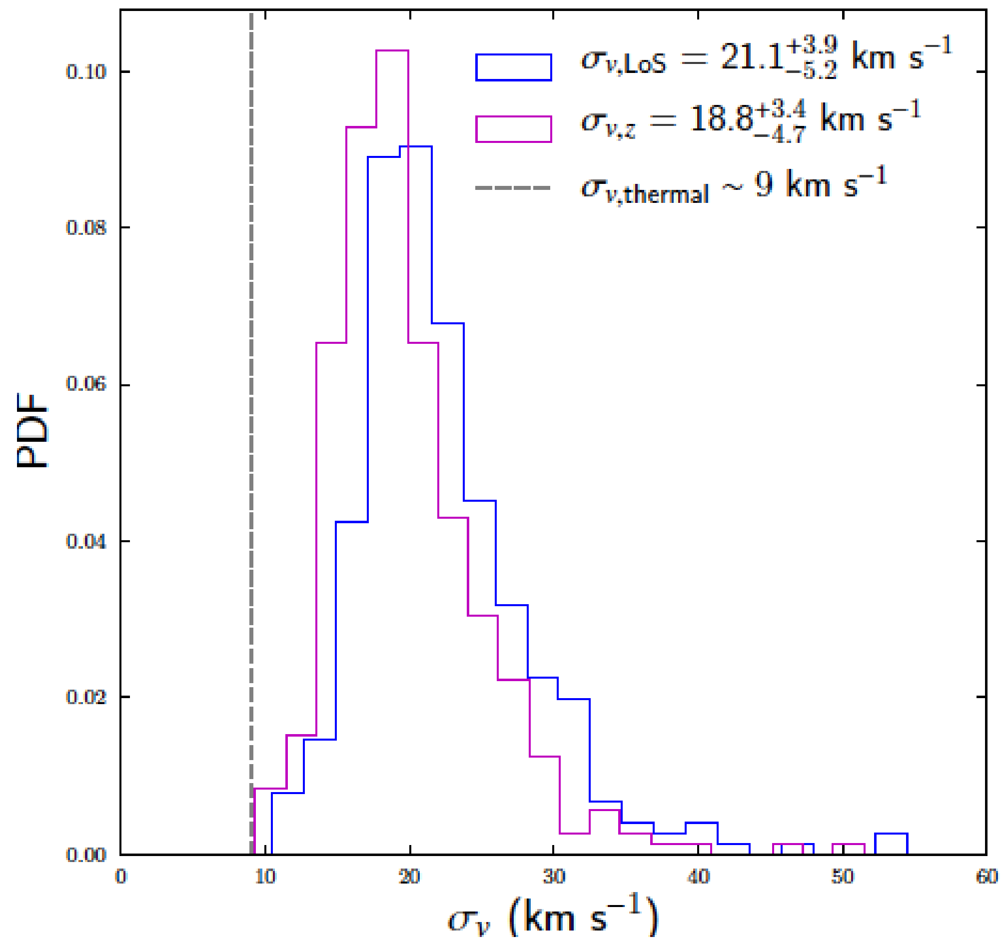


Figure 6. The distribution of the LoS ($\sigma_{v,\mathrm{LoS}}$, blue) and vertical ($\sigma_{v,z}$, red) velocity dispersion for our sample of galaxies from the SAMI Galaxy Survey. The estimated vertical velocity dispersion is adjusted down with respect to $\sigma_{v,\mathrm{LoS}}$ by a couple of km s^{-1} in accordance with the inclination correction described in Section 3.2.3.

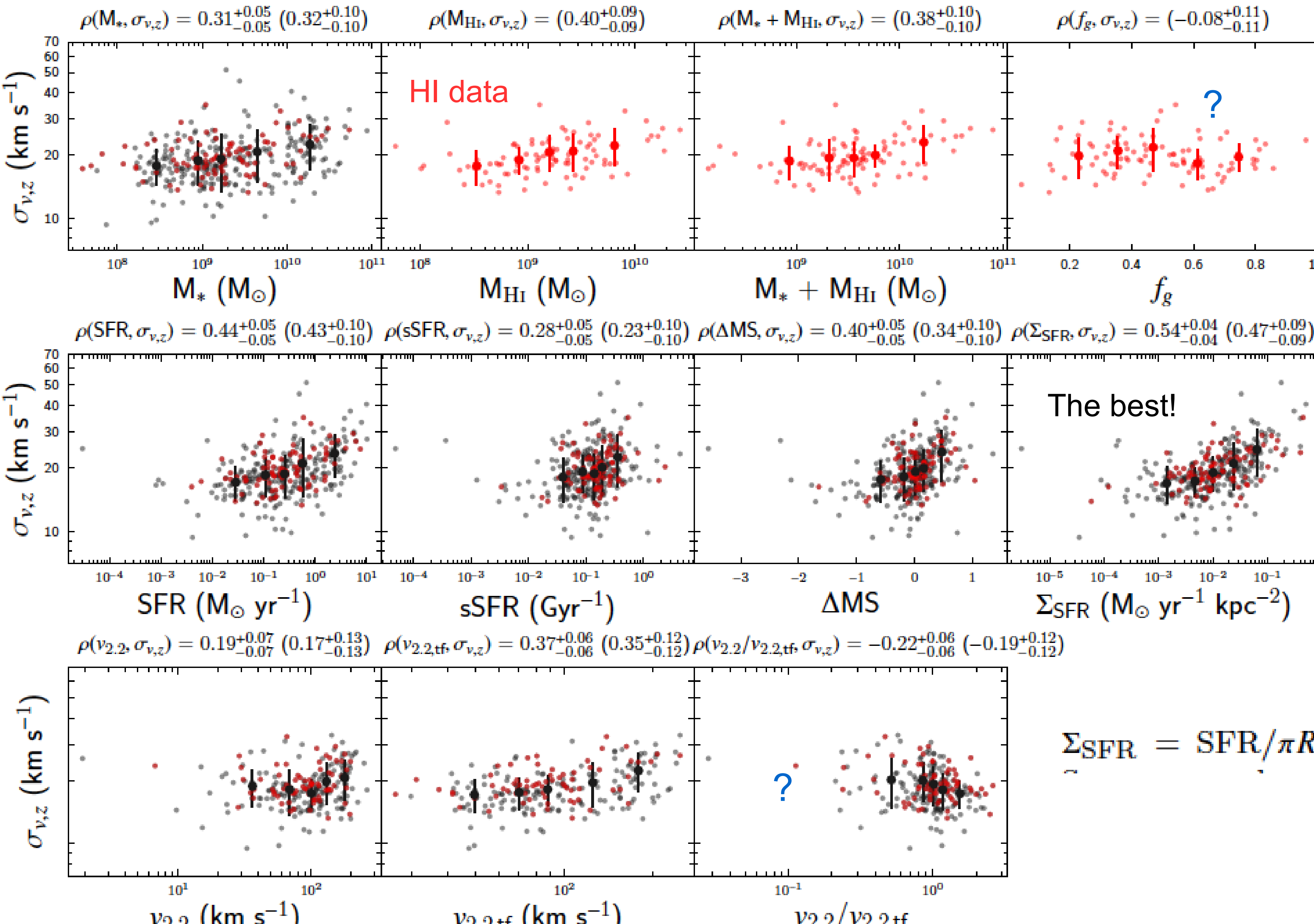
Разница не очень велика, но в дальнейшем старались оперировать именно вертикальной дисперсией скоростей

И еще:

SFR: GAMA survey (Davies +16): from SED fitting 21 bands UV-FAR

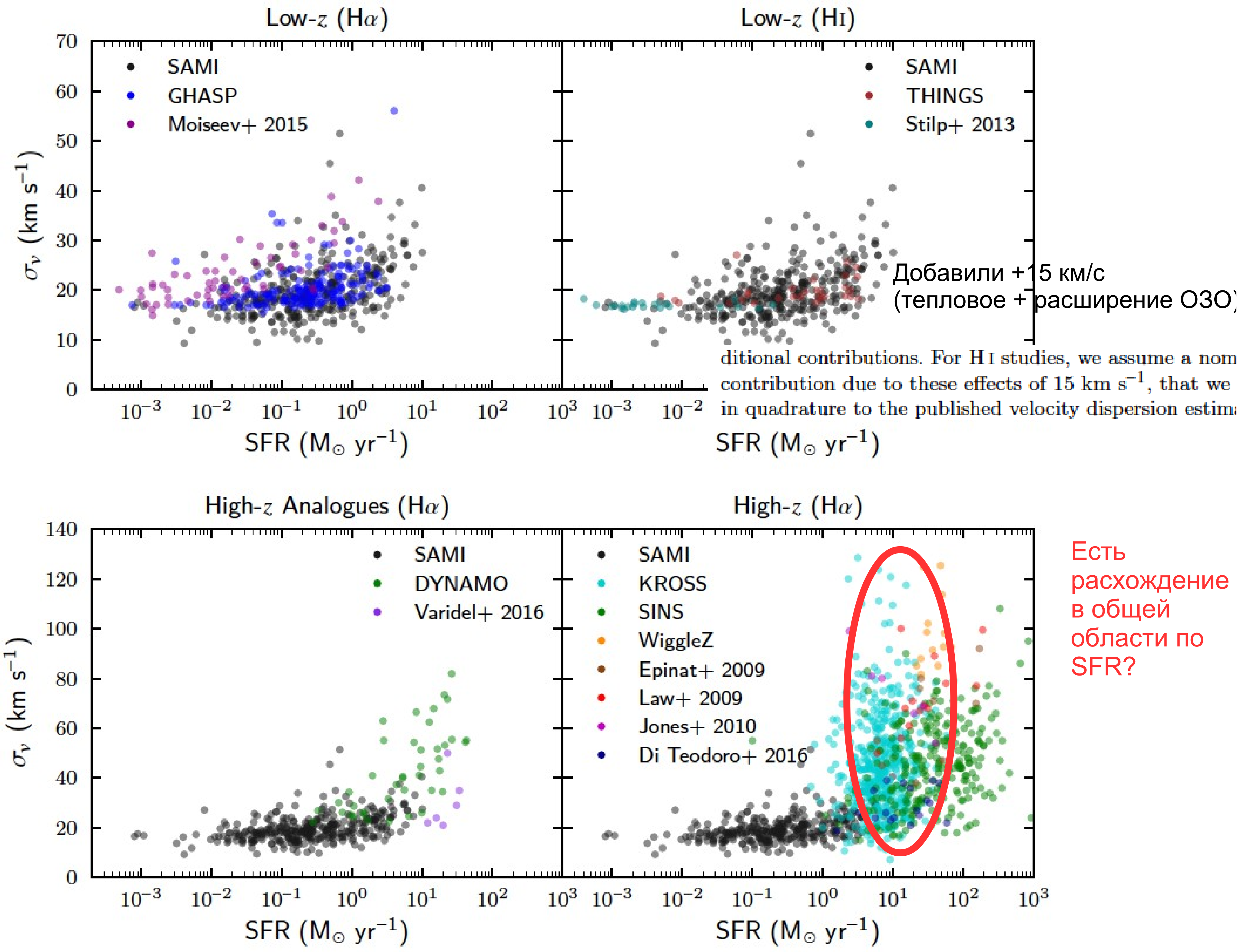
DYNAMO: SFR from Halpha

HI: Aresibo 21 cm SAMI-HI + ALFALFA => 95 galaxies overlap



$$\Sigma_{SFR} = SFR/\pi R_e^2$$

ΔMS is calculated as the log difference between the SFR and the star-forming main sequence relation as proposed by Renzini & Peng (2015). We find that the correlation between


Low-z (Hα)
Low-z (HI)
High-z Analogues (Hα)
High-z (Hα)
σ_v (km s⁻¹)
SFR (M☉ yr⁻¹)
SAMI
GHASP
Moiseev+ 2015
THINGS
Stilp+ 2013
DYNAMO
Varidel+ 2016
KROSS
SINS
WiggleZ
Epinat+ 2009
Law+ 2009
Jones+ 2010
Di Teodoro+ 2016
Добавили +15 км/с
(тепловое + расширение ОЗО)
ditional contributions. For H I studies, we assume a nom
contribution due to these effects of 15 km s⁻¹, that we
in quadrature to the published velocity dispersion estima
Есть
расхождение
в общей
области по
SFR?

Sample	z	$\log_{10}(M_*/M_\odot)$	$\log_{10}(SFR\ /\ M_\odot\ yr^{-1})$	σ_v (km s^{-1})
SAMI (this work)	[0.005, 0.08]	[7.5, 11]	[-3, 1]	[10, 60]
SAMI (Johnson et al. 2018)	< 0.1	[7.5, 11]	[-3, 1]	[20, 90]
SAMI (Zhou et al. 2017)	< 0.1	[9.8, 10.8]	-	[20, 90]
DYNAMO (this work)	[0.06, 0.15]	[9, 11]	[-1, 2]	[10, 80]
DYNAMO (Green et al. 2014)	[0.06, 0.15]	[9, 11]	[-1, 2]	[10, 90]
GHASP (Epinat et al. 2008)	~ 0.01	-	[-3, 1]	[15, 30]
Moiseev et al. (2015)	< 90 Mpc	-	[-3, 1]	[15, 40]
Varidel et al. (2016)	[0.01, 0.04]	[10.5, 11]	[1, 1.6]	[20, 50]
MaNGA (Yu et al. 2019)	[0.01, 0.15]	[8.5, 11.5]	[-2, 1]	[10, 130]

were of similar magnitude (see Table 1). As such, we conclude that our results are approximately consistent with the analyses of Moiseev et al. (2015) and Epinat et al. (2008) at low-z using ionised gas, albeit with different selection and methodologies in inferring the intrinsic velocity dispersion. The only exception in inferred velocity dispersions at low-z using the ionised gas is the results of Yu et al. (2019) using MaNGA data where we estimate systematically lower σ_v.

Потому что с ИФП разрещение лучше, а у MaNGa – хуже, чем в SAMI... :)

Более пологая корреляция на малых SFR/sigma?

Сверхновые:

of these studies. The momentum injection per mass of stars is often assumed to be on the order of $\langle p_*/m_* \rangle = 3000$ km s^{-1}. Incorporating this momentum injection into theoretical models results in assuming that the rate of momentum injection is proportional to the star-formation rate surface density, thus $\dot{P} \propto \langle p_*/m_* \rangle \, \Sigma_{\rm SFR}$ (e.g. Ostriker & Shetty 2011; Faucher-Giguère et al. 2013; Krumholz et al. 2018). Therefore, we expect the velocity dispersion to be positively correlated with star-formation rate surface density, if star-formation feedback processes is playing a role in driving turbulence in the ISM.

a function of the star-forming molecular gas fraction ($f_{\rm sf}$) of the gas surface density ($\Sigma_{\rm gas}$), that is then converted to stars at a star-formation rate efficiency per free-fall time ($\epsilon_{\rm ff}$). Following Krumholz et al. (2018) this can be written as,

$$\Sigma_{\rm SFR} = \frac{\epsilon_{\rm ff}}{t_{\rm ff}} f_{\rm sf} \Sigma_{\rm gas},$$

Или гравитация ?

5.2 Gravity driven turbulence

An alternative to star-formation feedback processes is driving of turbulence due to gravitational mechanisms. In such models, the gravitational potential energy of the gas is converted to kinetic energy, thus driving the turbulence in the ISM.

Включая аккрецию:

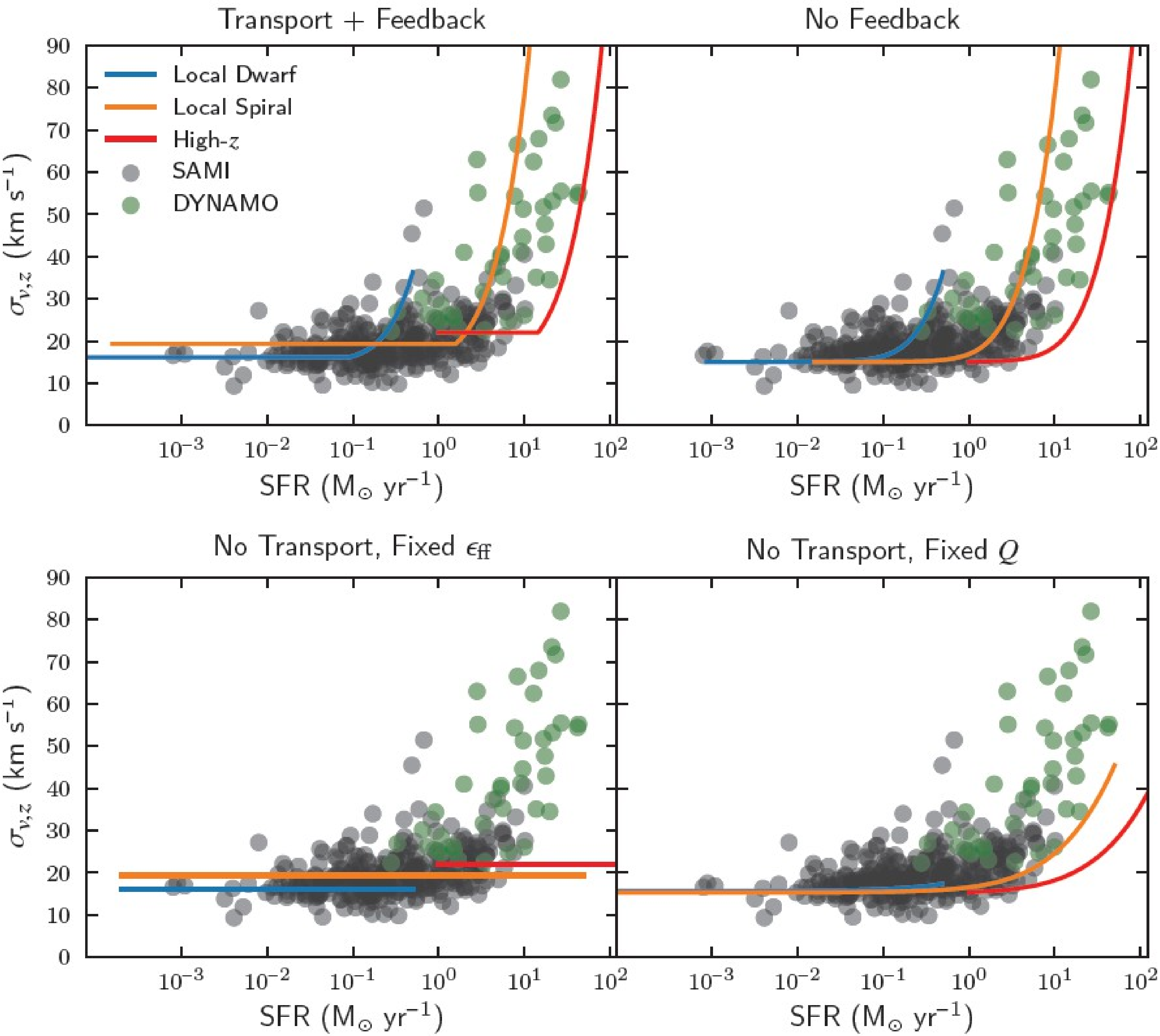
The above model is an instantaneous steady state solution, that is a function of the gas accretion rate and energy loss at the time. As the gas accretion rate has decreased over epochs, this model predicts lower gas turbulence in the ISM of galaxies at low-z. In Section 4.3.2 we highlighted that velocity dispersions were $\sim$ 5 km s^{-1} higher in the high-z

5.3 Combining star-formation feedback and gravity driven turbulence

Krumholz et al. (2018) recently pointed out that star-formation feedback processes can be added as an extra source of energy to the transport equation derived in Krumholz & Burkert (2010). Similar to the previously mentioned models

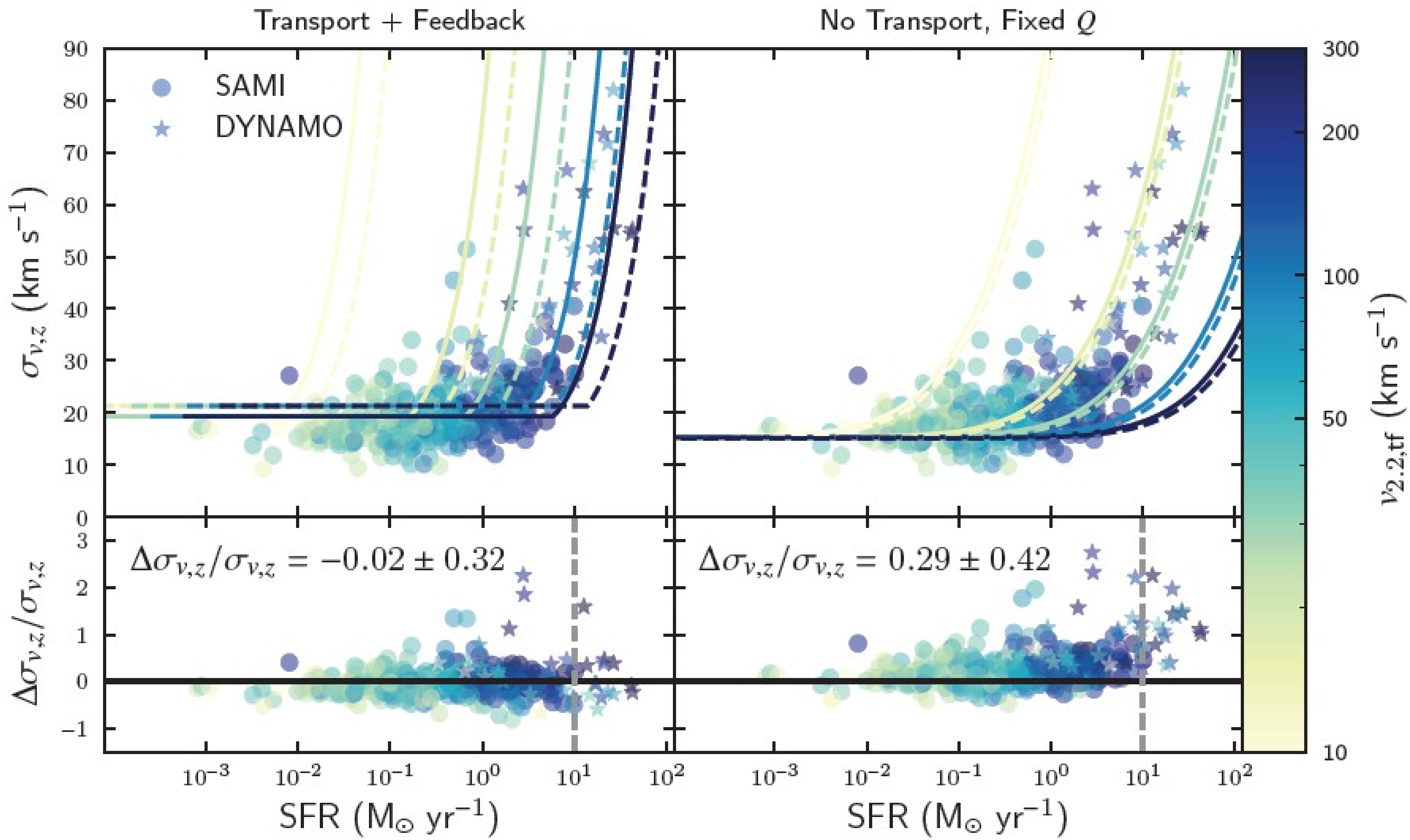
Their full 'Transport + Feedback' model gives a SFR – $\sigma_{v,z}$ relation of the form,

$$\mathrm{SFR} = \frac{2}{1+\beta} \frac{\phi_a f_{\rm sf}}{\pi G Q} f_{g,Q} v_c^2 \sigma_{v,z} \times \max\left[\sqrt{\frac{2(1+\beta)}{3 f_{g,P}}} \phi_{\rm mp} \frac{8 \epsilon_{\rm ff} f_{g,Q}}{Q}, \frac{t_{\rm orb,out}}{t_{\rm sf,\, max}}\right] \quad (16)$$



Transport + Feedback
No Feedback
No Transport, Fixed ϵ_{ff}
No Transport, Fixed Q
Local Dwarf
Local Spiral
High-z
SAMI
DYNAMO
$\sigma_{v,z}$ (km s^{-1})
SFR ($M_\odot$ yr^{-1})

Попытка менять скорость



As a further caveat to the above analysis, we note that the theoretical models assume that we are observing the star-forming molecular gas, rather than the ionised gas. The full set of differences between the kinematics of the molecular star-forming gas compared to the ionised gas is not complete. For example, there is evidence that ionised gas may have systematically lower rotation and higher velocity dispersions compared to the molecular gas (Levy et al. 2018). However,

В общем, все равно далеко от реальности...

Основные выводы работы:

- Хорошая корреляция σ с SFR, А еще лучше - с Σ_SFR
- А также с M*, M_HI (особенно хорошо!) и скоростью вращения
- Есть еще не очень внятные корреляции, если убирать звездную массу (через T-F),

  и с относительным содержанием газа (обратные). Но модели Krumholz + 2018 завязаны на плотность газа в срединной плоскости и его гравитацию, а мы об этом из наблюдений не знаем => нужны пространственно-разрешенные данные HI, H_2
- Неплохое согласие с и моделью `Transport + Feedback', а ситуация на больших z связана с переходом к наблюдением галактик с бОльшими скоростями вращения и массой молекулярного газа

<u>От себя:</u> наиболее последовательная работа в этом направлении, нет путаницы с дисперсией HI и HII

Похоже, что на малых SFR feedback играет бОльшую роль, но странно, что модели дают очень слабый рост σ в этом диапазоне.