The impact of environment on the lives of disk galaxies as revealed by SDSS-IV MaNGA

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ABSTRACT
Environment has long been known to have significant impact on the evolution of galaxies, but here we seek to quantify the subtler differences that might be found in disk galaxies, depending on whether they are isolated, the most massive galaxy in a group (centrals), or a lesser member (satellites). The MaNGA survey allows us to define a large mass-matched sample of 574 galaxies with high-quality integrated spectra in each category. Initial examination of their spectral indices indicates significant differences, particularly in low-mass galaxies. Semi-analytic spectral fitting of a full chemical evolution model to these spectra confirms these differences, with low-mass satellites having a shorter period of star formation and chemical enrichment typical of a closed box, while central galaxies have more extended histories, with evidence of on-going gas accretion over their lifetimes. The derived parameters for gas infall timescale and wind strength suggest that low-mass satellite galaxies have their hot halos of gas effectively removed, while central galaxies retain a larger fraction of gas than isolated galaxies due to the deeper group potential well in which they sit. S0 galaxies form a distinct subset within the sample, particularly at higher masses, but do not bias the inferred lower-mass environmental impact significantly. The consistent picture that emerges underlines the wealth of archaeological information that can be extracted from high-quality spectral data using techniques like semi-analytic spectral fitting.

Key words: galaxies: fundamental parameters – galaxies: stellar content –galaxies: formation – galaxies: evolution

- В плотном окружении галактики краснее и содержат меньше газа, а звезды – менее металличные, чем у одиночных галактик (хотя по химии- противоречивые данные для satellite galaxies (SG)). Эти эффекты носят глобальный характер, т.е. проявляются как правило для галактики в целом (e.g. Zheng et al. 2017; Spindler et al. 2018).
- **The intent of this paper is to investigate how the stellar population properties in galaxies depend on the environment that they inhabit, specifically whether they are central (CG) or satellite (SG) galaxies in groups, or are isolated (IG) objects**

- Физические механизмы:
- Ram pressure
- Strangulation
- Tidal interactions с галактиками или гало скопления.

Выборка: MaNGA survey SDSS-IV Data Release 17 (ок.10 тыс. галактик с $z<0.15$).

- Спектральные данные до 1.5 Re.
- Морфология: MaNGA Morphology Deep Learning catalogue (Domínguez Sánchez et al. 2022), включ. visual classification
- Всего отобрано 5125 spirals and 891 S0s.
- Из них оставлены галактики с низким наклоном диска и с $9.5 < \log(M=M) < 11.5$.

$$\frac{\mathrm{SFR}}{\mathrm{M}_{\odot}\mathrm{yr}^{-1}} = 5.37 \times 10^{-42} \frac{\mathrm{L(H}\alpha)}{\mathrm{erg\ s}^{-1}},$$

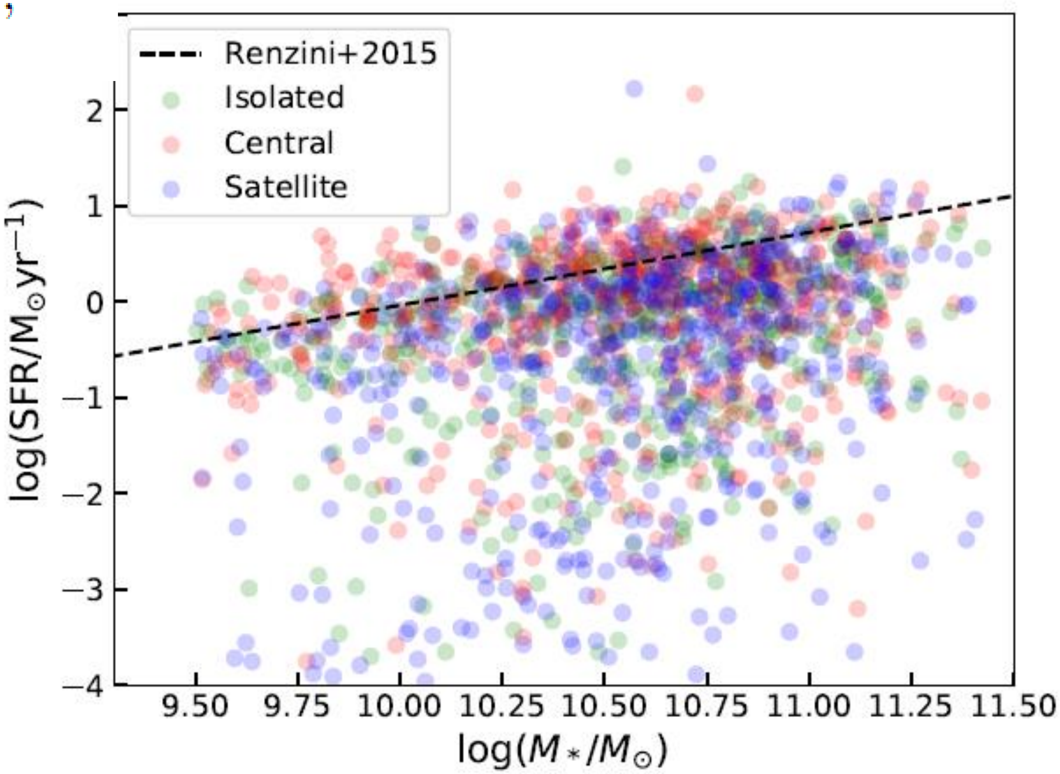


Figure 1. The star formation rate as a function of stellar mass for our sample galaxies. Isolated, central and satellite galaxies are shown in green, red and blue, respectively. The black dash line shows the star forming main sequence obtained by Renzini & Peng (2015) as reference.

Индексы Dn4000 (большие значения - SFR
упал неск.млрд лет назад)
and Mg/Fe (относит.обилие альфа-элементов).

The satellite galaxies show stronger values of both indices, indicating relatively little recent star formation, consistent with what we have learned from Ha, and a shorter timescale for their formation.

The higher alpha- element abundance in low-mass satellites flags their shorter star formation timescales.

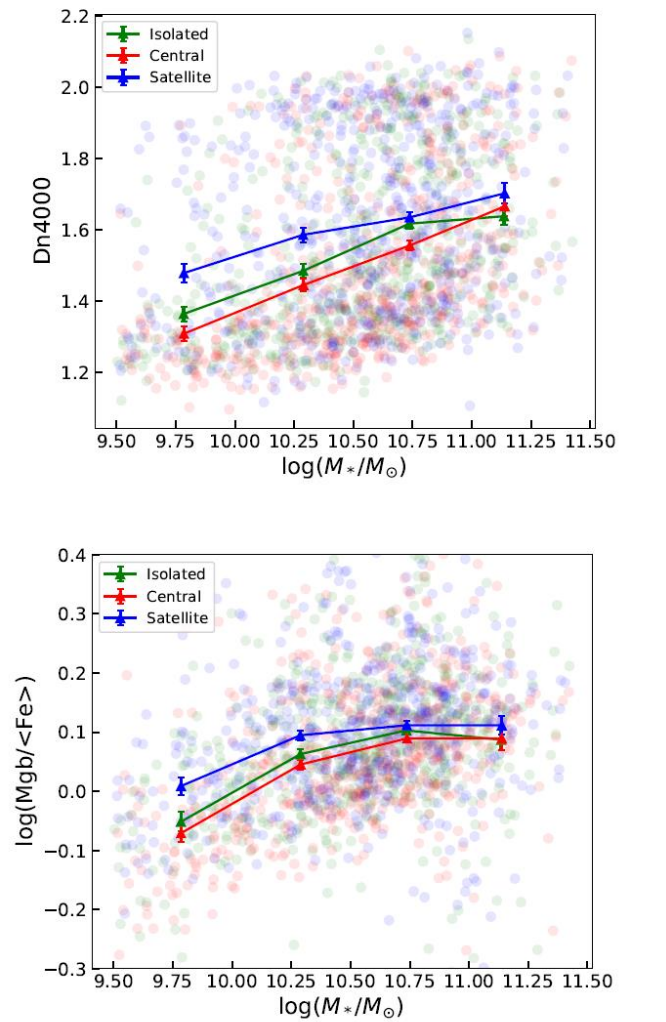


Figure 2. Dn4000 (top) and Mgb/⟨Fe⟩ (bottom) as functions of stellar mass for our sample galaxies. Isolated, central and satellite galaxies are shown in green, red and blue, respectively. Triangles linked by lines are mean results in different stellar mass bins, with error bar showing the error estimated from the jackknife resampling method.

Модель эволюции

$$\dot{M}_{\rm g}(t) = \dot{M}_{\rm in}(t) - \psi(t) + \dot{M}_{\rm re}(t) - \dot{M}_{\rm out}(t). \quad (2)$$

$$\psi(t) = S \times M_{\rm g}(t),$$

The first term characterises the gas inflow, v
an exponentially decaying form

$$\dot{M}_{\rm in}(t) = Ae^{-(t-t_0)/\tau}, \quad t > t_0. \quad (3)$$

$$\dot{M}_{\rm out}(t) = \lambda\psi(t), \quad \lambda(t) = \lambda_{\rm b} + (\lambda_{\rm e} - \lambda_{\rm b})t/(14\,{\rm Gyr}).$$

The second term represents th
third term accounting for the mass ejection from dying stars, and the final term describing mass lost from the system. We assume

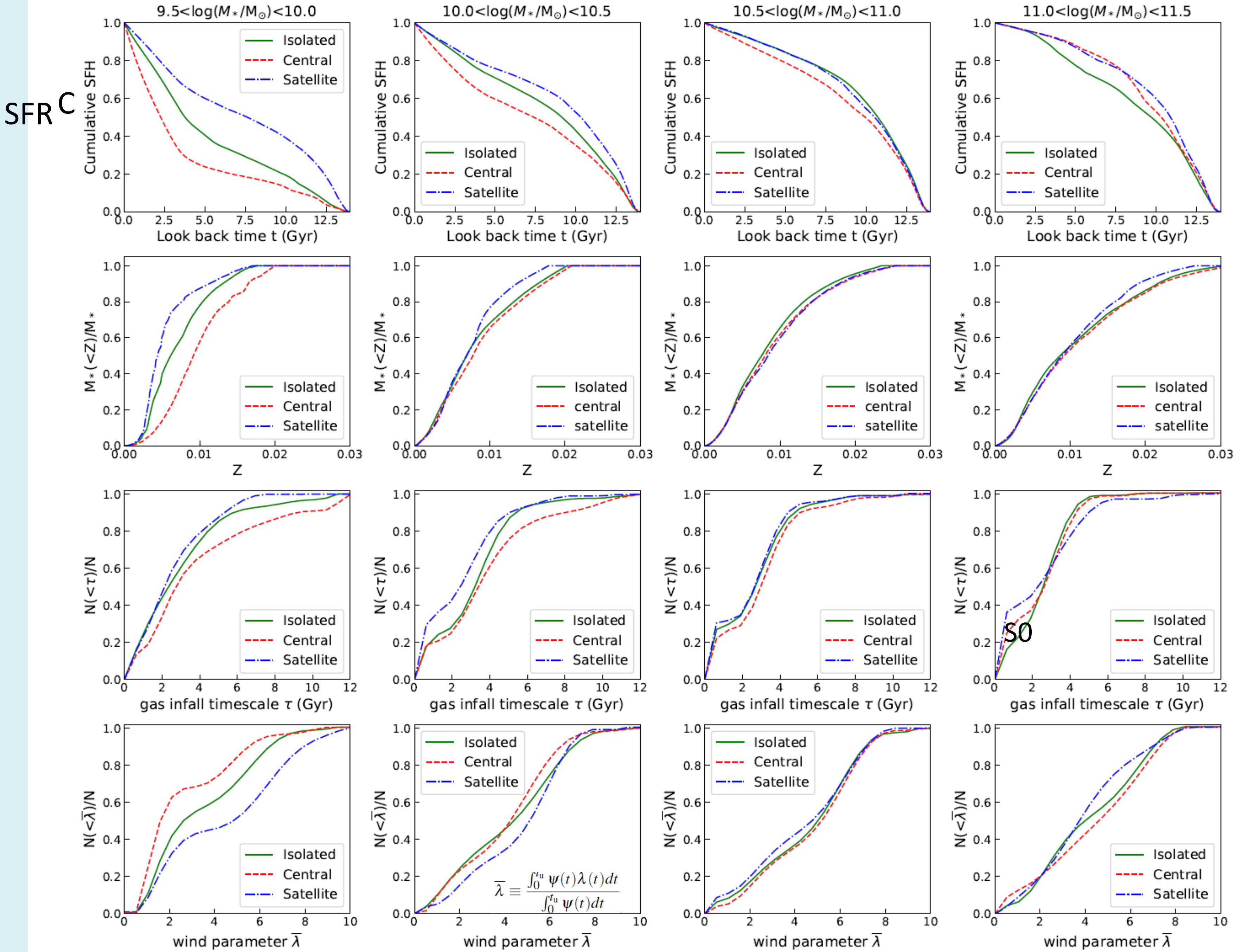
Using the Bruzual & Charlot (2003) stellar population models, we calculate a model spectrum corresponding to the SFH and ChEH following the standard stellar population synthesis approach. We use the ‘Padova1994’ isochrones, the Chabrier (Chabrier 2003) IMF and the Le Borgne et al. 2003 stellar templates, which covers metallicities from Z = 0:0001 to Z = 0:05, and ages from
0:0001Gyr to 20Gyr.

We use a population-wide relation instead, at least for the metallicity constraint. Specifically, Andrews & Martini (2013) demonstrated that there is quite a tight relationship between mass and gas-phase metallicity, so we can assign an expected gas-phase oxygen abundance using

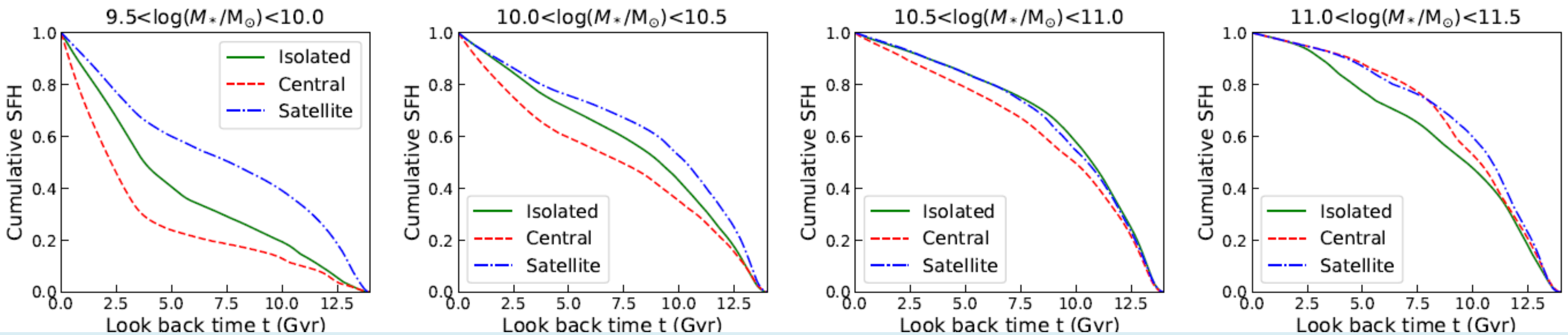
$$12 + \log(\mathrm{O/H}) = 8.798 - \log\left(1 + \left(\frac{10^{8.901}}{M_\star/\mathrm{M}_\odot}\right)^{0.64}\right). \qquad (10)$$

This oxygen abundance is then converted to total metallicity using a solar metallicity of 0.02 and oxygen abundance of $12 + \log(\mathrm{O/H}) = 8.83$ (Anders & Grevesse 1989).

Нет анализа или обоснования этой формулы, принимавшейся как к галактикам CG, так и SG.


SFR C
9.5<log(M_*/M$_\odot$)<10.0
10.0<log(M_*/M$_\odot$)<10.5
10.5<log(M_*/M$_\odot$)<11.0
11.0<log(M_*/M$_\odot$)<11.5
Cumulative SFH
Look back time t (Gyr)
$M_*(<Z)/M_*$
Z
$N(<\tau)/N$
gas infall timescale τ (Gyr)
$N(<\bar{\lambda})/N$
wind parameter $\bar{\lambda}$
Isolated
Central
Satellite
central
satellite
S0
$\bar{\lambda} \equiv \frac{\int_0^{t_u} \psi(t)\lambda(t)dt}{\int_0^{t_u} \psi(t)dt}$

SFR

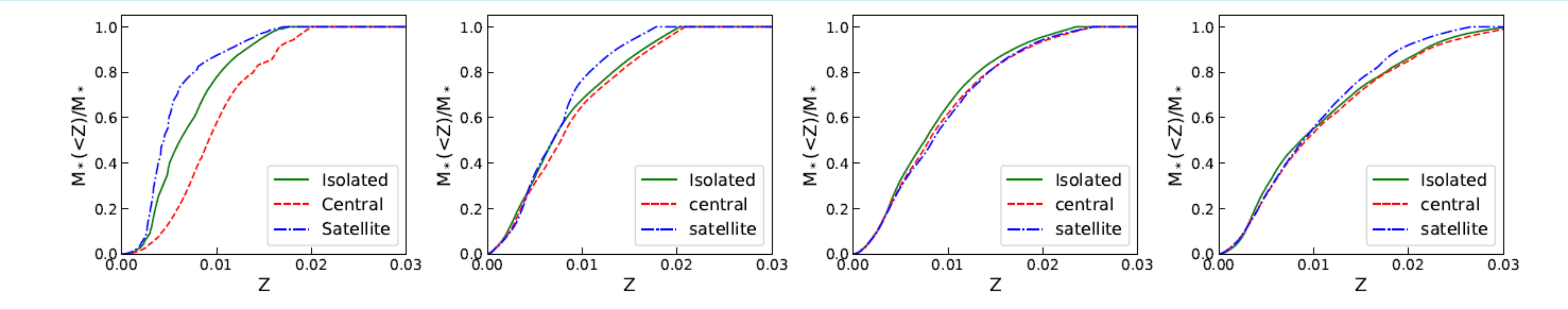


Central galaxies accumulate their stellar mass significantly later than satellite galaxies. The difference between central and satellite galaxies becomes weaker in higher mass galaxies, and in galaxies with $M = M_* > 10^{10.5}$ the difference is almost negligible.

S0

$$\overline{\lambda} \equiv \frac{\int_0^{t_u} \psi(t)\lambda(t)dt}{\int_0^{t_u} \psi(t)dt}$$

Central galaxies accumulate their stellar mass significantly later than satellite galaxies

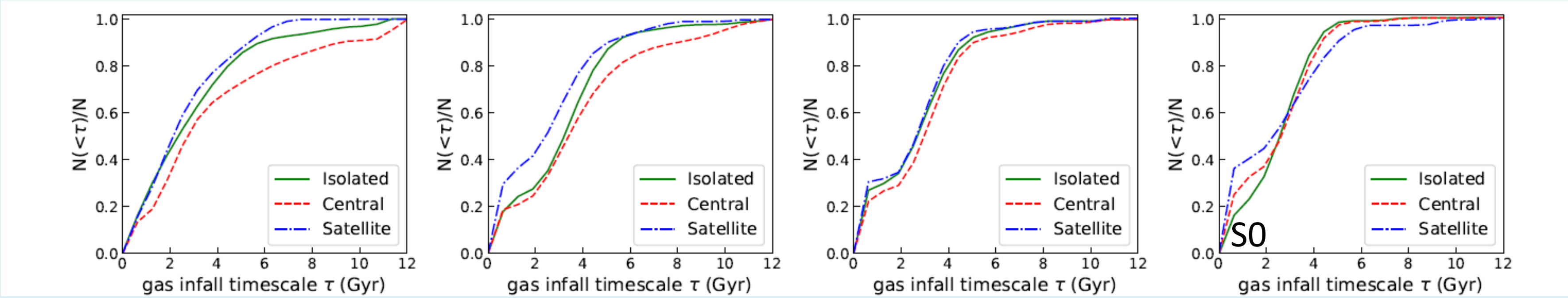


Satellite galaxies have 80% of stars with Z < 0.005, while in central galaxies of similar stellar mass this fraction decreases to 20%. The low-metal-rich CMDF of low mass satellite galaxies is characteristic of the so-call ‘closed-box’

$$\overline{\lambda} \equiv \frac{\int_0^{t_u} \psi(t)\lambda(t)dt}{\int_0^{t_u} \psi(t)dt}$$

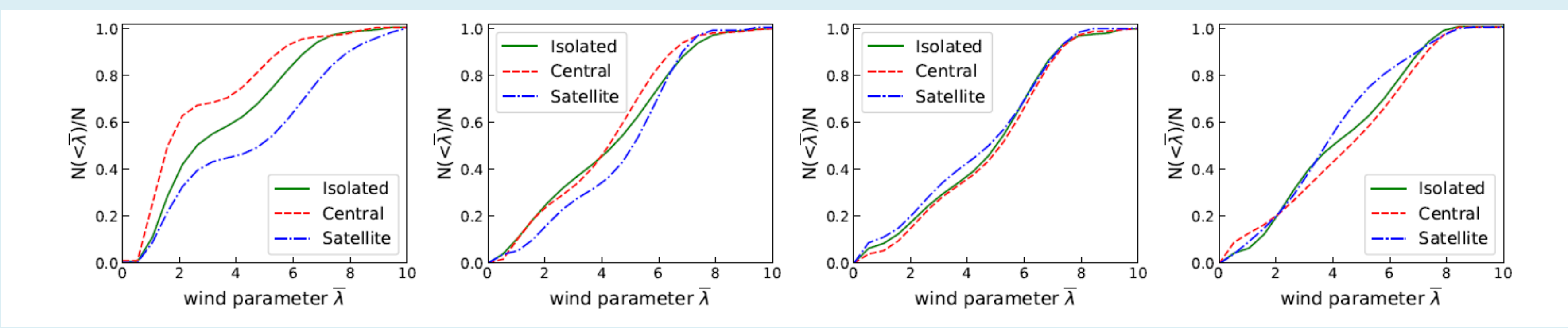
The gas infall timescale, as a function of both environment and mass. It is apparent that, at low and intermediate masses, central galaxies tend to have longer gas infall timescales, while the gas infall occurs over a systematically shorter period in satellite galaxies. In the lowest mass bin ($10^{9:5}$ <M=M < $10^{10:0}$), almost all of the satellite galaxies have gas infall timescale less than 5 Gyr, while around 40% of central galaxies have timescales greater than 5 Gyr. The median gas infall timescales for satellite, isolated and central galaxies are 2.6, 2.9 and 3.9 Gyr, respectively.

In more massive galaxies (M=M > $10^{10:5}$) these differences become less systematic: the median gas infall timescales for all the three categories becomes shorter, and all converge to around 2.5 Gyr



$$\overline{\lambda} \equiv \frac{\int_0^{t_u} \psi(t)\lambda(t)dt}{\int_0^{t_u} \psi(t)dt}$$

- Although this parameter was formulated in terms of a star-formation-driven wind, it really just measures the effectiveness of the loss of processed gas from the galaxy. The relatively high rate of loss from satellites therefore fits with a picture in which a system falling into a more massive halo might be expected to lose its own extended halo of hot processed gas through interaction with other group members.
- The disappearance of difference between the wind-parameters in galaxies with stellar masses higher than $10^{10.0}M_*$ implies that massive satellite galaxies do not lose more gas than centrals.



Основной вывод: различие между центральными галактиками, спутниками и изолированными галактиками значительно только для маломассивных галактик

Результаты

- The cumulative SFHs derived from the sample galaxies reveal an earlier cessation of star formation activities in low-mass ($10^{9.5} < M_*/M_\odot < 10^{10.0}$) satellite galaxies than their central equivalents: less than 40% of the stellar masses in satellite galaxies formed within the most recent 5 Gyrs, while central galaxies of similar mass accumulated more than 70% of their stellar masses over the same period. Isolated galaxies have intermediate properties.
- The environmental dependence of disk galaxy evolution, as well as its mass dependence, is also seen in the chemical evolution of the galaxies. Low-mass ($10^{9.5} < M_*/M_\odot < 10^{10.0}$) satellite galaxies contain a high fraction of low metallicity stars compared to central galaxies, indicating that they are more likely to be 'closed-box' or 'leaky-box' systems, while central galaxies of similar masses contain lower fractions of low metallicity stars, suggesting that on-going accretion played a more important role in their formation.
- The gas accretion history inferred from the semi-analytic fitting process drives the variations in timescale: in low-mass central galaxies, the average gas infall timescale is found to be systematically longer than comparable satellite galaxies, leading to their more extended star formation histories. Again, this variation disappears in more massive galaxies, where we also start to see a differ-
- Central galaxies have weaker wind parameters than their isolated equivalents, as would be expected if the deeper potential well of a group were better at retaining such processed material.