Evidence for the Accretion of Gas in Star-Forming Galaxies: High N/O Abundances in Regions of Anomalously-Low Metallicity

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ABSTRACT

While all models for the evolution of galaxies require the accretion of gas to sustain their growth via on-going star formation, it has proven difficult to directly detect this inflowing material. In this paper we use data of nearby star-forming galaxies in the SDSS IV Mapping Nearby Galaxies at Apache Point Observatory (MaNGA) survey to search for evidence of accretion imprinted in the chemical composition of the interstellar medium. We measure both the O/H and N/O abundance ratios in regions previously identified as having anomalously low values of O/H. We show that the unusual locations of these regions in the N/O vs. O/H plane indicate that they have been created through the mixing of disk gas having higher metallicity with accreted gas having lower metallicity. Taken together with previous analysis on these anomalously low-metallicity regions, these results imply that accretion of metal-poor gas can probably sustain star formation in present-day late-type galaxies.

Проблема и постановка задачи

- Нерешенный вопрос: где же аккреция на галактики, ожидаемая из филаментов?
- Имеющиеся наблюдения линий поглощения «на просвет» чаще свидетельствует о выбросе газа, чем о его падении.
- Подход: исследование локальных областей, отличающихся низкой металличностью, на предмет содержания азота в таком газе.
- (ALM: anomalously low-metallicity)

Предыдущая работа

ANOMALOUSLY LOW METALLICITY REGIONS IN MANGA STAR-FORMING GALAXIES: ACCRETION CAUGHT IN ACTION?

ApJ 2019

Hsiang-Chih Hwang[1], Jorge K. Barrera-Ballesteros[1], Timothy M. Heckman[1], Kate Rowlands[1], Lihwai Lin[2], Vicente Rodriguez-Gomez[1], Hsi-An Pan[2], Bau-Ching Hsieh[2], Sebastian Sánchez[3], Dmitry Bizyaev[4,5], Jorge Sánchez Almeida[6,7], David A. Thilker[1], Jennifer M. Lotz[1,8], Amy Jones[9], Preethi Nair[9], Brett H. Andrews[10,11,12], Niv Drory[13]

H\alpha map

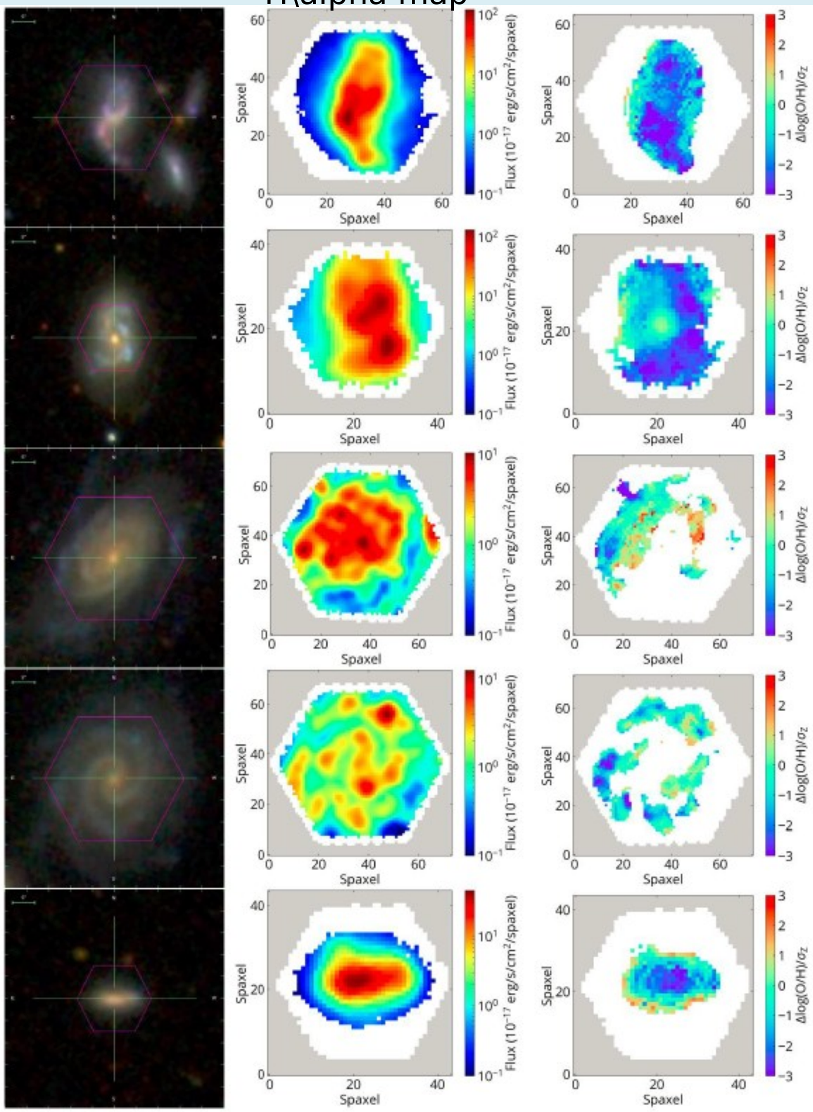
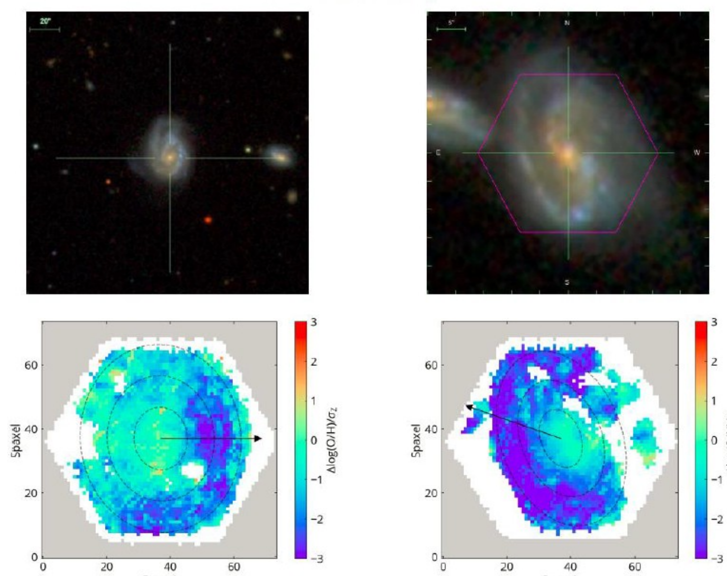


Figure 7. Examples of galaxies having ALM regions. MaNGA plate-IFU ID from top: 8252-9102, 9883-3701, 8466-12702, 8945-12705, 8551-3701. From left to right: SDSS optical images, Hα maps, and metallicity deviation maps where $\sigma_Z = 0.07$ dex. Some galaxies are associated with strong interaction, while some are isolated. The size of the spaxels is 0.5 arcsec on each side. Spaxels without metallicity measurement are either not purely star-forming regions, or have emission lines below the adopted S/N ratio cuts.

Аномалия (O/H) – по положению на зависимости Σ_* - Z для галактик в разных интервалах M_*.



Examples of azimuthally asymmetric metallicity distributions (left: 8454-12703; right: 8313-12702). The metallicities on the sides closer to the companions are lowered by 0.1 – 0.15 dex at distances > 0.5Re.

Предыдущая работа

We found that late type galaxies commonly have regions where the oxygen abundance (12 + log(O/H)) in the interstellar medium (ISM) is significantly lower than expected (relative to the tight empirical correlation between the oxygen abundance and the local stellar surface mass density for a fixed stellar mass).

We showed that they correspond to regions of higher than average rates of star formation. We speculated that these ALM regions are sites in which low-metallicity gas has been recently accreted, gotten mixed with the pre-existing more metal-rich gas, and triggered star formation.

The CGM (окологалактический газ) is a plausible source for such material

Общая идея

- Идея: рассмотреть отношение содержаний первичных и вторичных элементов:

N/O vs O/H в химически аномальных областяч.

В низкометалличных звездах N можно рассматривать как первичный элемент, и N/O ~ const. В обогащенном газе N/O должен расти с O/H. Это согласуется с наблюдениями.

Падение обедненного газа уменьшает O/H, оставляя высоким N/O.

- Исходные данные: the MaNGA survey, which is part of Sloan Digital Sky Survey (SDSS)-IV, 2D спектры около 8000 галактик с R = 2000.
- Sample: SF galaxies with deprojected local stellar surface mass density > 10^7Ms kpc^{-2} , total stellar mass > 10^9Ms, (b/a) > 0.3 (to exclude edge-on galaxies). We also require SNR > 10 for the emission lines used in BPT diagrams and metallicity calculations.
- Выделение ALM – по отклонению областей от зависимости ($\Sigma* - Z$).

Δlog(O/H) = (12 + log(O/H))obs − (12 + log(O/H))exp

Метод оценки химии:

O/H -метод

RS32 =[OIII]5007/Ha + [SII]6717,6731/

from Curti et al.(2020).

Калибратор не использует линий азо

слабо зависит от параметра ионизац

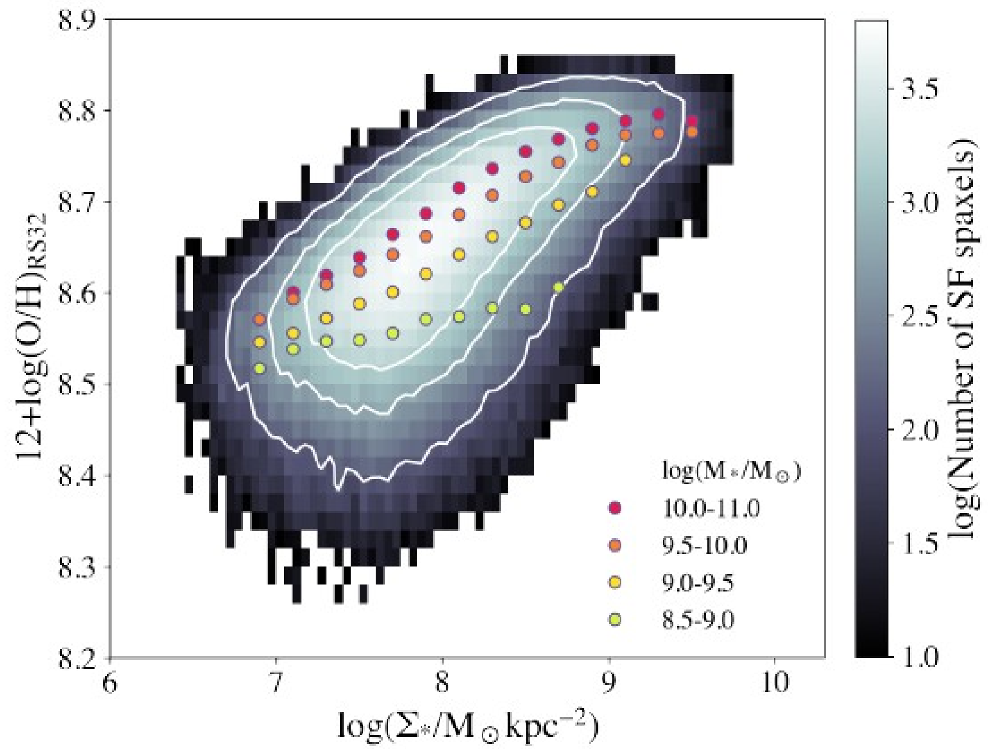


Figure 1. Local relation between metallicity and stellar surface mass density. The circles represent the peaks of metallicity distributions in each stellar mass bin. The background distribution and contours show the distribution of all pure star-forming spaxels in late-type galaxies with stellar masses $> 10^{8.5} M_{\odot}$. The bin of $10^{8.5} - 10^{9} M_{\odot}$ is only used for interpolation, and we do not further analyze the galaxies in this bin.

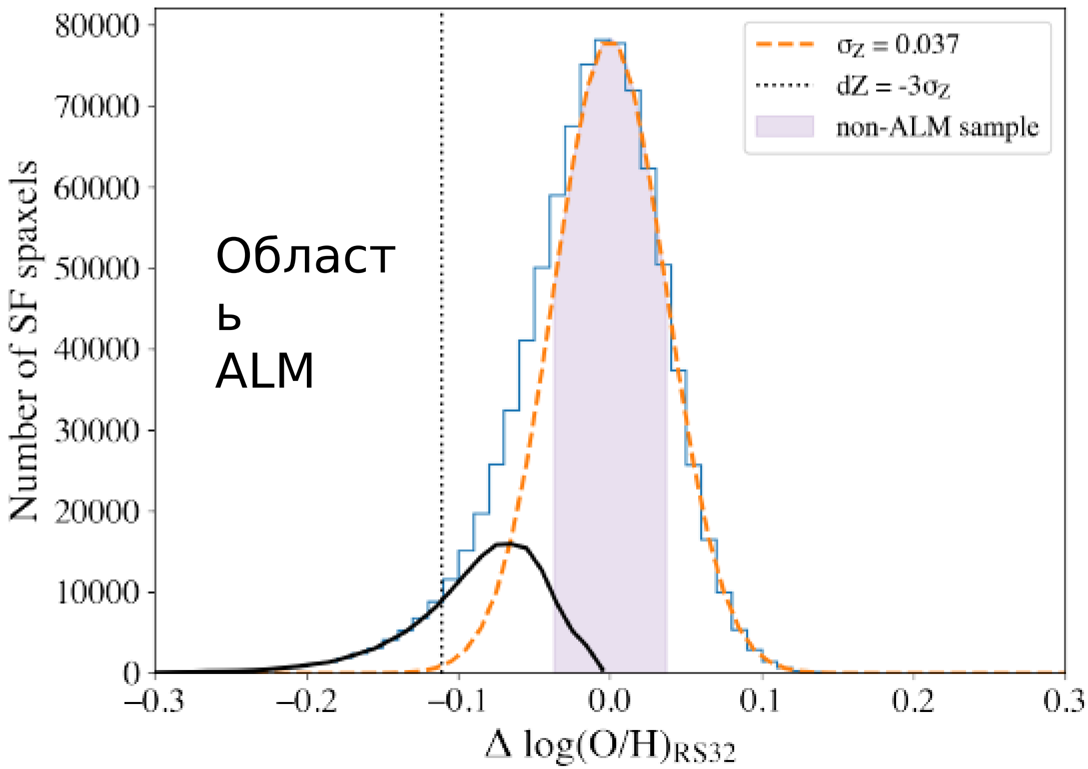


Figure 2. Distribution of the metallicity deviation of star-forming spaxels in late-type galaxies with stellar mass $> 10^9 M_\odot$ (blue histogram). The orange dashed line is a Gaussian profile for "normal" spaxels, with a standard deviation $\sigma_Z = 0.037$. The black solid line is the residual after subtracting the fitted Gaussian profile from the negative side of the histogram . The vertical dotted line marks where $\Delta\log(\mathrm{O/H}) = -0.111$, and we refer to those spaxels deviating to lower metallicity by more than this value as ALM spaxels. The control sample (non-ALM) consisting of spaxels with $|\Delta\log(\mathrm{O/H})| \leqslant \sigma_Z$ are shaded in purple.

N/O - using the empirical relation found
in Loaiza-Agudelo et al. (2020):
log(N/O) = 0.73 N2O2 - 0:58
where N2O2 = [NII]6584/[OII]3727, 3729
(corrected forextinction). Our estimations
O/H and N/O are quite independent as diff
lines are used.

We interpret this as a signature of the mix
of metal-rich gas (on the linear part of the
N/O vs. O/H relation) with metalpoor gas
(on the at part of the N/O vs. O/H relation)

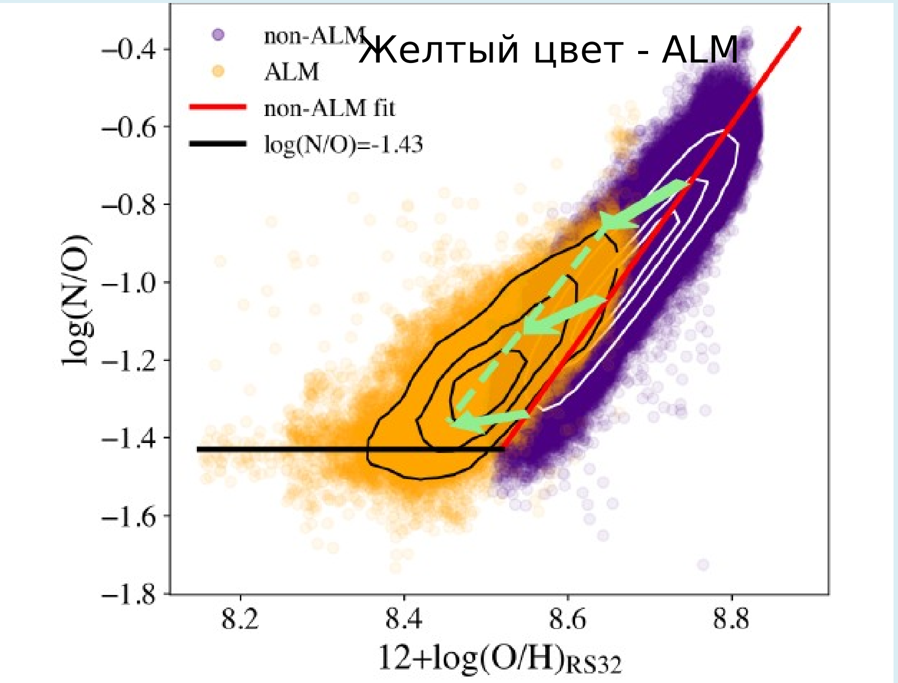
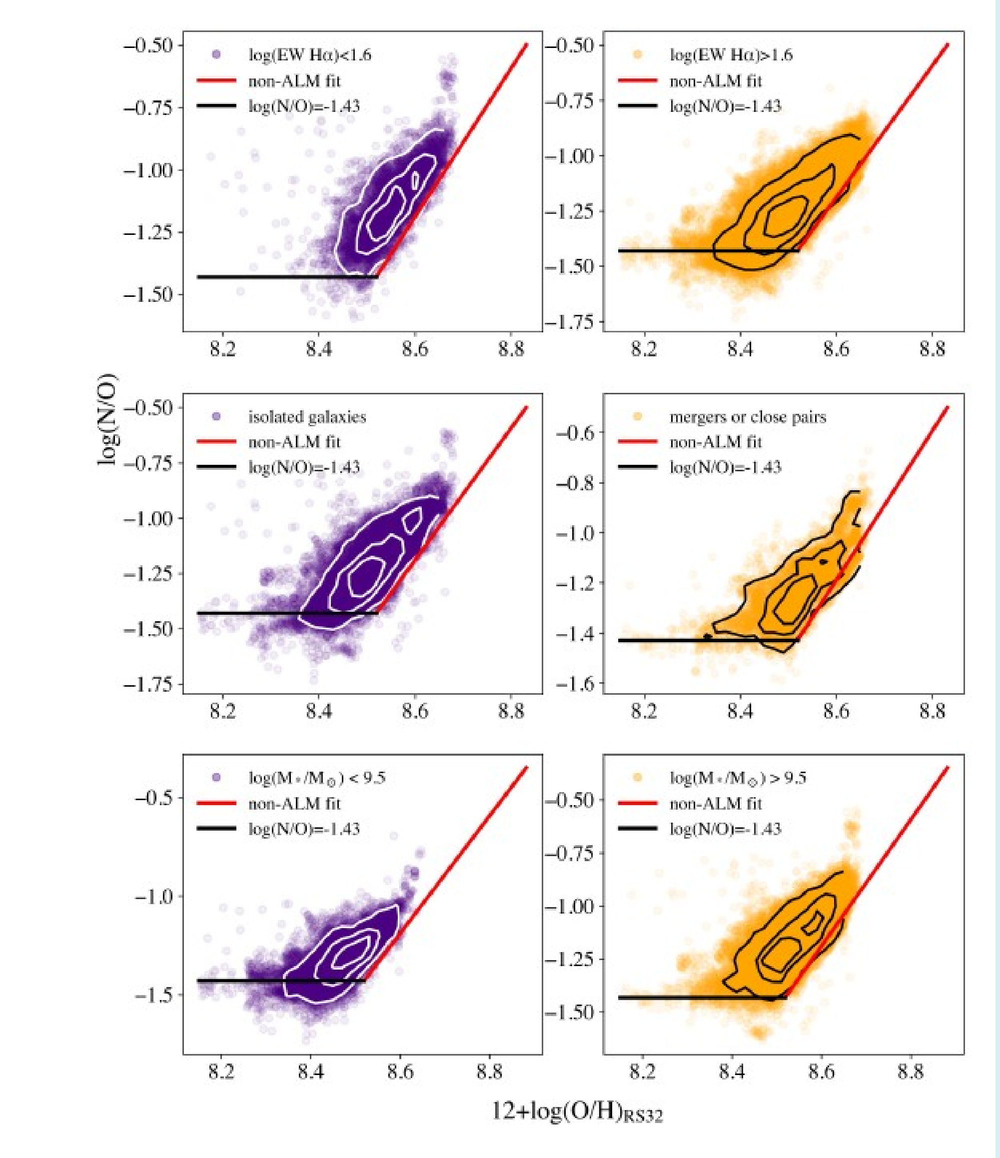


Figure 3. ALM and non-ALM spaxels plotted on the N/O vs. O/H plane. The contours enclose 90%, 60%, 30% percent of total data points, from the outermost line to the innermost line, respectively. Arrows show initial metallicities (ends of the arrows) and final metallicities (heads of the arrows) after 60% original gas + 40% low-metallicity gas (half the initial O/H ratio, log(N/O) = −1.43) mixing. We observe a clear offset between the distributions of ALM and non-ALM spaxels, and the hypothetical mixing model provides a good description to our results.

Универсальность химической аномалии

- Здесь только области
- 6 разных выборок,

а результат одинаков



Самые большие отклонения от зависимости для нормальных областей – на большом расстояни от центра.

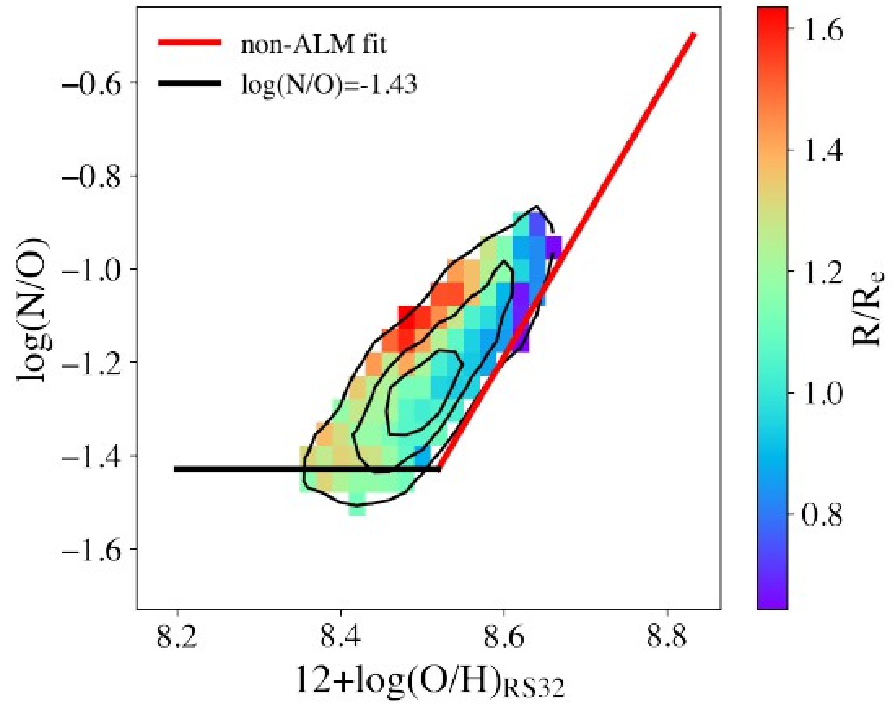


Figure 6. ALM spaxels color-coded by R/R_e, the distance to the center of the galaxy normalized by the galaxy half-light radius. The contours enclose 90%, 60%, 30% percent of total data points, from the outermost line to the innermost line, respectively. Spaxels with the largest offset from the normal relation are preferentially found in the outer region ($R > 1.5R_e$).

Другие варианты объяснения повышенного отношения N/O

Обогащенный ветер от WR также увеличивает N/O. Были проанализированы структуры ALM с самым высоким SNR – в них нет деталей, характерных для WR.

A selective loss of oxygen via supernovae-driven galactic-winds during the burst phase could also contribute to a high N/O value during the post-burst phase. However, we emphasize that this scenario is inconsistent with the properties of the ALM spaxels, which are shown to be tracing on-going bursts of star formation with a signicant population of short-lived massive stars.

The fact that the ALM spaxels have an excess N/O for a given O/H rules out the interpretation that they are simply less chemically-evolved regions (in which case they would have lower O/H but still follow the normal N/O vs. O/H relation).

Основные выводы

- Based on the tight empirical relation between metallicity and local stellar surface mass density at fixed stellar mass, we identfied ALM regions as spaxels with observed metallicity lower than the expected value by more than 0.111 dex. This resulted in 37288 ALM spaxels in 685 star-forming galaxies with M > 10^9Ms.
- Our results show that the ALM regions lie in the region of the N/O vs. O/H plot where N/O is unusually large for a given O/H value. This scenario is in agreement with a mixing (accretion) model and thus rules out the alternative interpretation that the ALM regions are just regions that are less chemically-evolved due to less prior star formation.
- Our results provide confirmation that ALM regions are indeed accretion sites, and thereby supported the idea that we are witnessing galaxy building in action.