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Quenching of star formation from a lack of inflowing gas to galaxies

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Star formation in half of massive galaxies was quenched by the time the Universe was three billion years old[1]. Very low amounts of molecular gas appear responsible for this, at least in some cases[2-7], though morphological gas stabilization, shock heating, or activity associated with accretion onto a central supermassive black hole is invoked in other cases[8-11]. Recent studies of quenching by gas depletion have been based upon upper limits that are insufficiently sensitive to determine this robustly[2-7], or stacked emission with its problems of averaging[8,9]. Here we report 1.3mm observations of dust emission from six strongly lensed galaxies where star formation has been quenched, with magnifications of up to a factor of 30. Four of the six galaxies are undetected in dust emission, with an estimated upper limit on the dust mass of 0.0001 times the stellar mass, and by proxy (assuming a Milky Way molecular gas-to-dust ratio) 0.01 times the stellar mass in molecular gas. This is two orders of magnitude less molecular gas per unit stellar mass than seen in star forming galaxies at similar redshifts[12-14]. It remains difficult to extrapolate from these small samples,

Шесть галактик с ALMA, 1.3мм

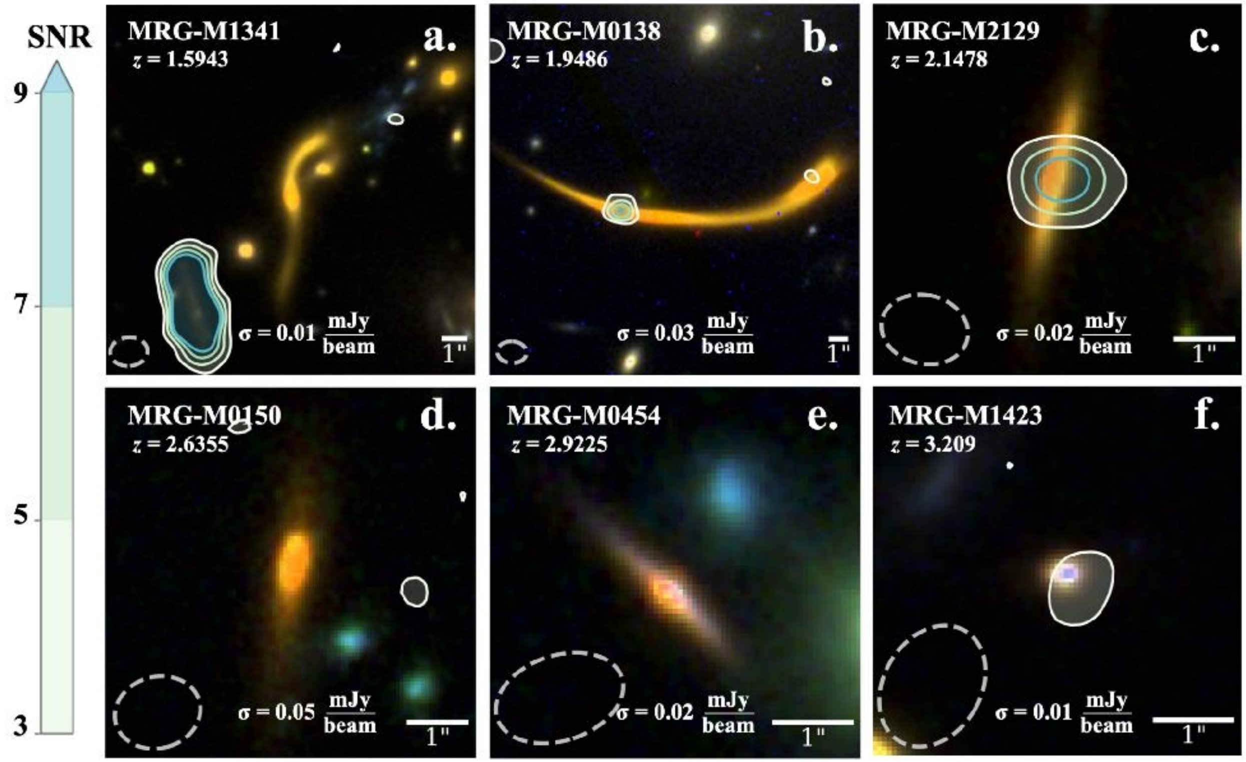

Figure 1 | Images of six massive lensed galaxies where star formation has been quenched. The panels are rank-ordered from z=1.6 to z=3.2 (labeled a-f), showing a composite *Hubble Space Telescope* (*HST*) color image (i_{F814W}, J_{F125W}, H_{F160W} generally, substituting J_{F110W} for panel e) and contours of ALMA/Band 6 dust continuum observations. Each image is centered on the target galaxy, whose redshift

Газа(по отношению к звездам) МАЛО

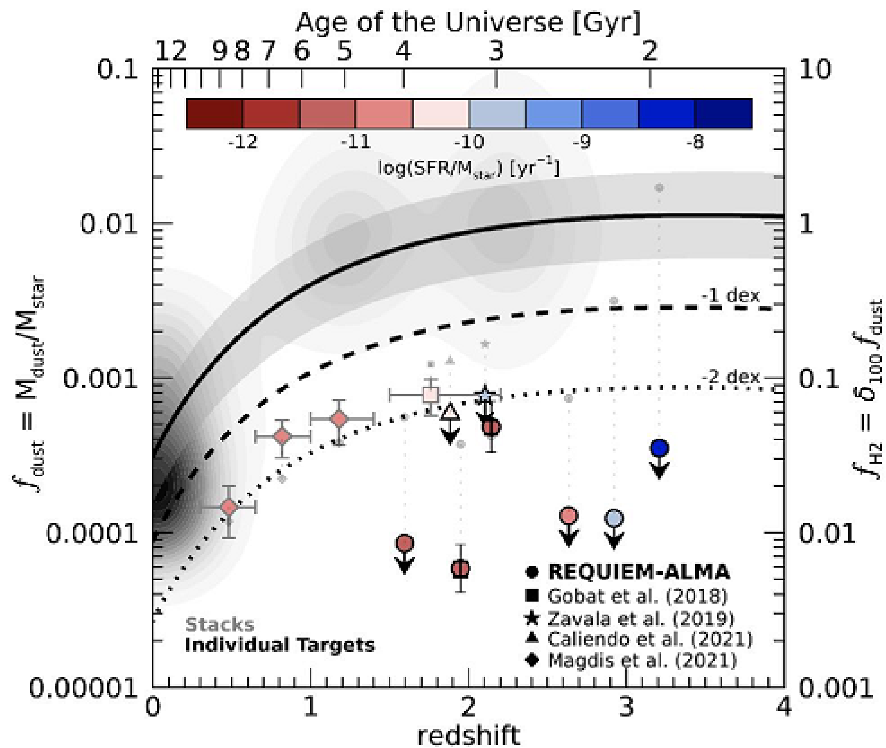

Figure 2 | Low dust masses for quenched galaxies. Measurements of f_{dust} for distant lensed quiescent galaxies (circles) are extremely low given their star-formation rate per unit stellar mass (sSFR). We compare existing dust continuum measurements in the literature of individual quiescent galaxies at $z>1.5$[5,6] (individual black symbols) and stacked quiescent galaxies[8,9] from JCMT/SCUBA and ASTE/AzTEC data out to $z\sim2$ (large grey symbols), using identical conversions herein to our sample (see Methods). The thick black error bars are the formal 1σ measurement uncertainty in our 1.3mm flux density and the thin black error bars represent systematic uncertainties when varying dust temperature. The smaller transparent symbols represent the predicted f_{H2} from empirical scaling relations[4] given sSFR. The inferred f_{H2} (right axis) and scaling relations[14] for $\log(M_\star/M_\odot)=11$ on the average $\log(SFR)$-$\log(M_\star)$ relation (solid), 1 dex (dashed), and 2 dex below (dotted) assume a molecular gas to dust mass ratio of 100. The shaded region shows the upper bound set by the lowest stellar mass in our sample ($\log(M_\star/M_\odot)=10.1$), and vice versa for the highest stellar mass ($\log(M_\star/M_\odot)=11.7$), with the literature dust/CO compilation out to $z=3$ shown as a grayscale contour, note that local quiescent galaxies with $f_{H2}\sim1\%$ at $z=0$ are artificially high because the majority are upper limits.

А звездообразование еще затухло не совсем…

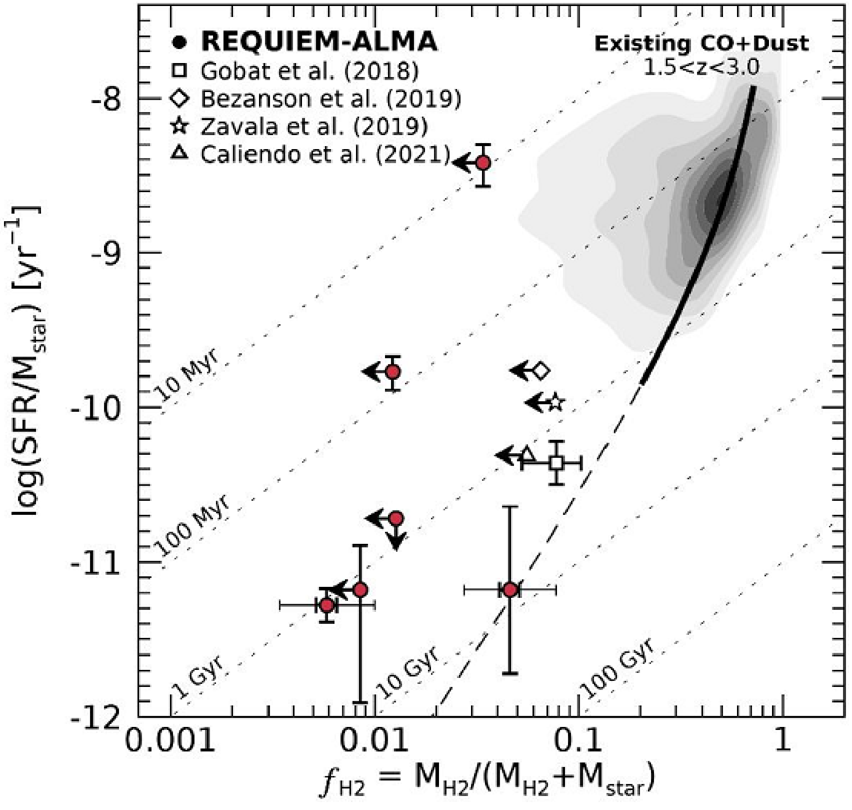

Figure 3 | Low molecular gas masses compared to star forming galaxies. The molecular gas fraction f_{H2} is significantly lower at a given star-formation rate per stellar mass (sSFR≡SFR/$M_\star$) for distant lensed quiescent galaxies at z>1.5 when compared to the compilation of existing CO and dust measurements of similarly-massive star-forming galaxies (contours, see Methods). Our sample explores an order of magnitude lower sSFR and higher redshifts, finding median molecular gas fractions a factor of 10 lower than existing measurements for distant quiescent galaxies[4-6,8] (see Methods). The thick horizontal error bars for the two new detections represent formal 1σ measurement uncertainty in our 1.3mm flux density and the thin horizontal error bars represent systematic uncertainties when varying dust temperature and

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NGC 5746: formation history of a massive disc-dominated galaxy

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ABSTRACT

The existence of massive galaxies lacking a classical bulge has often been proposed as a challenge to ΛCDM. However, recent simulations propose that a fraction of massive disc galaxies might have had very quiescent merger histories, and also that mergers do not necessarily build classical bulges. We test these ideas with deep MUSE observations of NGC 5746, a massive ($\sim 10^{11}$ $M_{\odot}$) edge-on disc galaxy with no classical bulge. We analyse its stellar kinematics and stellar populations, and infer that a massive and extended disc formed very early: 80% of the galaxy's stellar mass formed more than 10 Gyr ago. Most of the thick disc and the bar formed during that early phase. The bar drove gas towards the center and triggered the formation of the nuclear disc followed by the growth of a boxy/peanut-shaped bulge. Around ∼ 8 Gyr ago, a ∼1:10 merger happened, possibly on a low-inclination orbit. The satellite did not cause significant vertical heating, did not contribute to the growth of a classical

NGC 5746: Sb(?) со сложной структурой, но БЕЗ БАЛДЖА

Table 1. Main properties of NGC 5746 (references: [1]Springob et al. 2007, [2]Bianchi 2007, [3]Jiang et al. 2019, [4]de Vaucouleurs et al. 1991)

Distance[1]	26.5 Mpc
Inclination[2]	86 deg
Stellar mass[3]	1–1.2×10^{11} $M_\odot$
SFR[3]	0.8 – 0.9 $M_\odot$ yr^{-1}
D_{25}^4	7.4' (59 kpc)
R_{50} (W1,W2)[3]	28–30" (3.6–3.8 kpc)
R_{90} (W1,W2)[3]	128" (16 kpc)

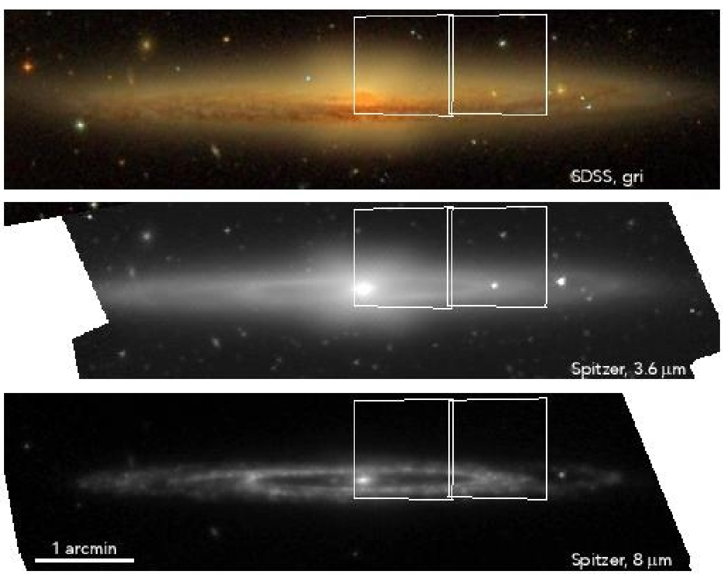


Figure 1. Our two MUSE pointings superimposed on a *gri* SDSS image (top panel), and two Spitzer images (middle and bottom panel), at 3.6 and 8 μm (the Spitzer images were downloaded from DustPedia[2], Clark et al. 2018)

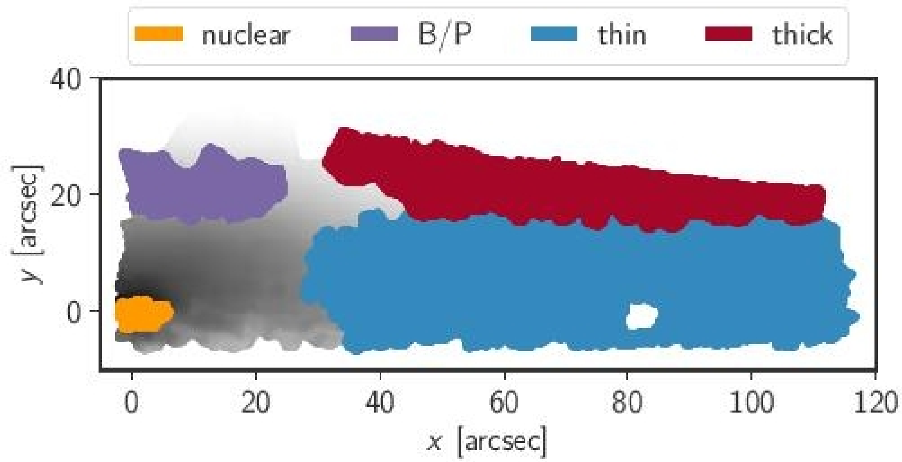
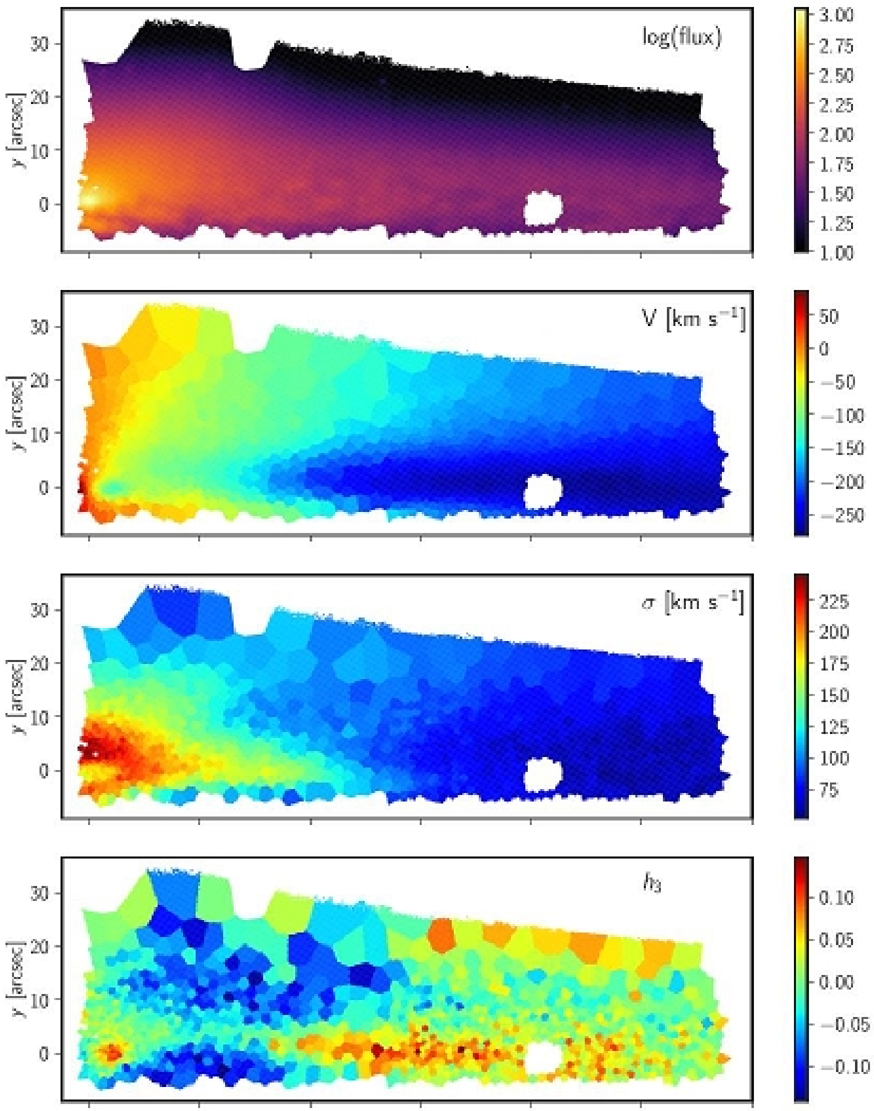


Figure 3. On top of a grey scale image of NGC 5746 (computed from the flux extracted from our MUSE data cube), we show which Voronoi bins we have attributed to each galactic component (nuclear disc, B/P bulge, thin and thick disc) after following the procedure described in Section 3.5.

SDSS+IMFIT: бар, псевдобалдж и три (!) диска, все экспоненциальны

The best fit parameters show that the thin disc has a scale-length of 47.8 arcsec (6.1 kpc), and a scale-height of 3.9 arcsec (0.5 kpc). It contributes 50% of the total 3.6 micron luminosity of NGC 5746. The thick disc has a scale-length of 64.2 arcsec (8.2 kpc), a scale-height of 11.2 arcsec (1.4 kpc), and contributes 21% of the total luminosity. We do not find signs of flaring either in the thin or thick disc with our simple analysis.

MUSE: звездная кинематика



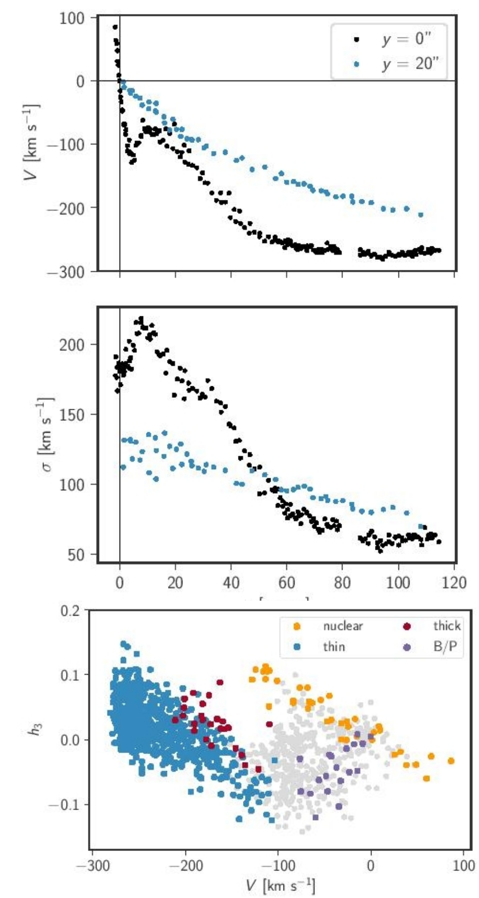


Figure 6. h_3 as a function of V for bins in the thin disc (blue), the thick disc (red), the nuclear disc (orange) and the B/P bulge (purple). The grey points are bins that cannot be unambiguously attributed to a single component, most of them are in the inner region, particularly in the bar. As expected, both the main disc (thin and thick) and the nuclear disc show a clear anti-correlation between V and h_3, while the bar (most of the grey points) and the B/P bulge show a distinct behaviour with a correlation between V and h_3.

MUSE: Звездное население

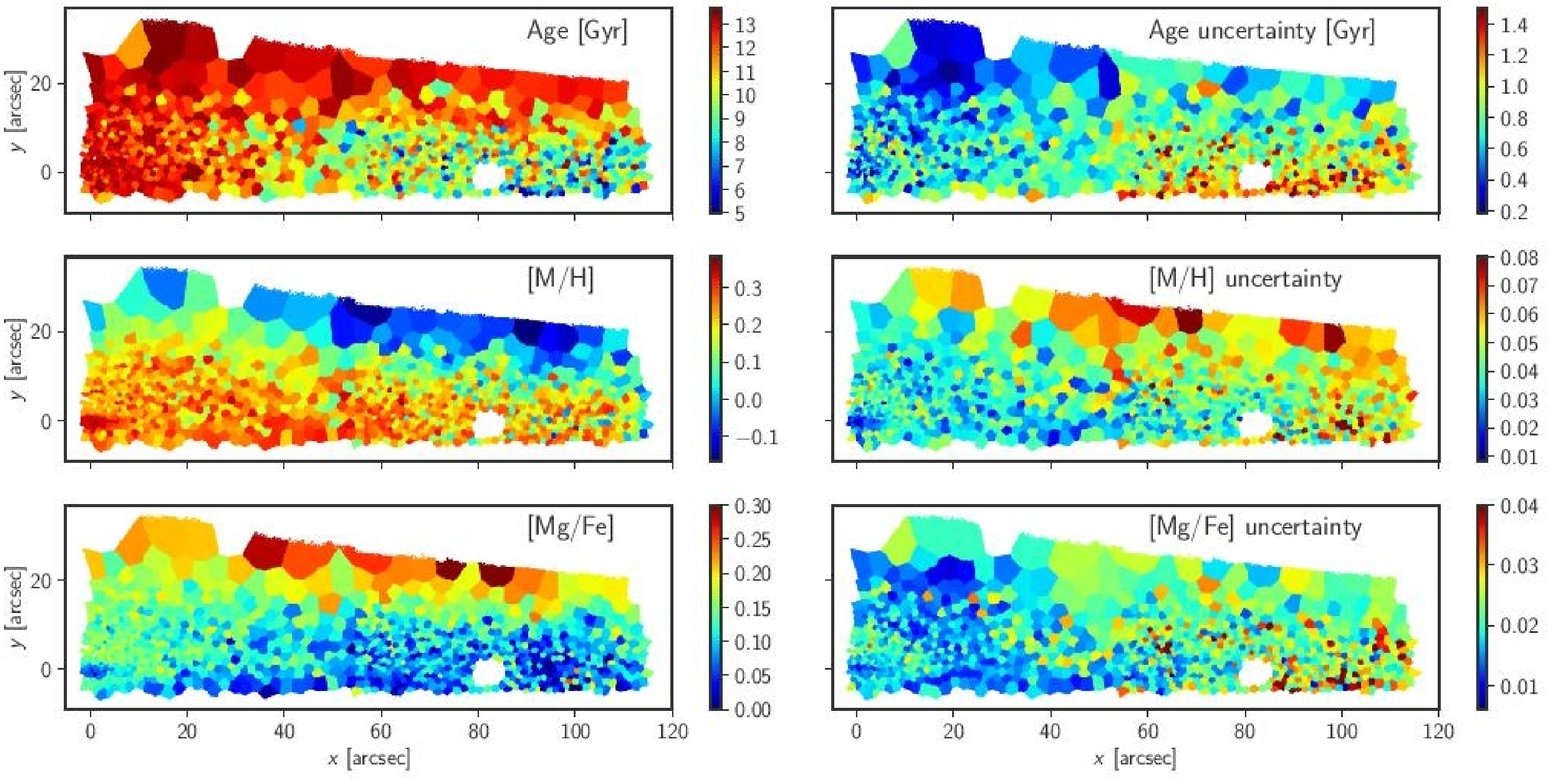


Figure 7. Stellar populations maps. The left column shows the spatial distribution of the mean mass-weighted age, [M/H] and [Mg/Fe] obtained from full spectrum fitting. The right column shows the corresponding uncertainties derived from our bootstrap analysis described in Section 3.4.

История формирования компонент

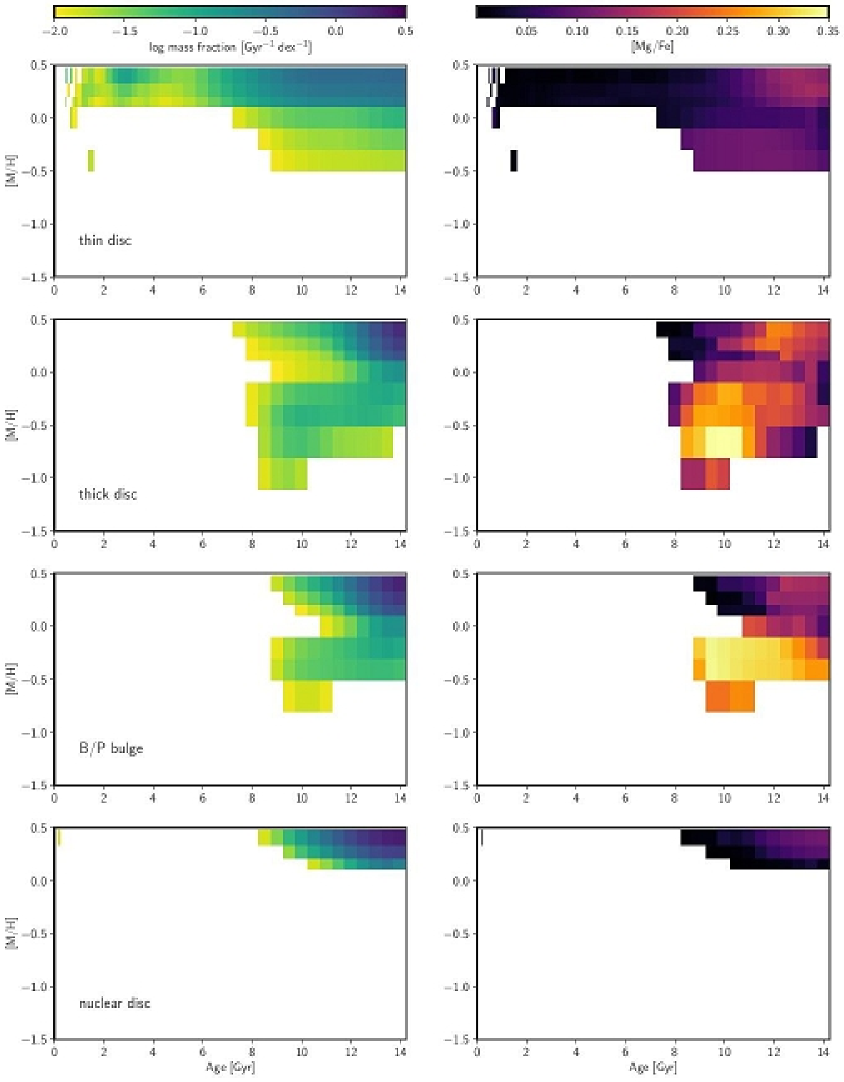


Figure 10. Left column: mass distribution in age and [M/H] space for each component of NGC 5746 (each bin is weighted by its stellar mass) — from top

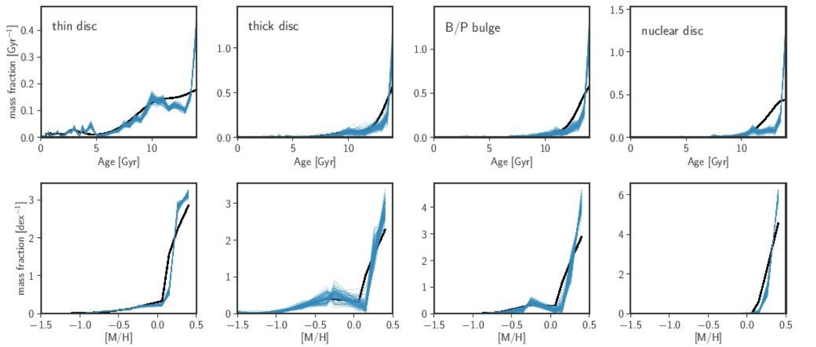


Figure 11. Age distribution (top row) and [M/H] distribution (bottom row) for each component of NGC 5746 (each bin is weighted by its stellar mass) — from left to right: the thin disc, the thick disc, the B/P bulge and the nuclear disc. In each panel, the black line shows the regularized pPXF best fit, while the 100 thin blue lines correspond to the 100 bootstrap realizations.

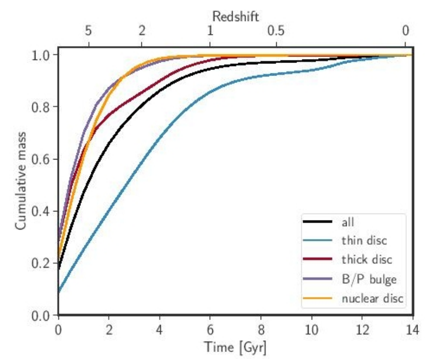


Figure 12. Cumulative mass growth of NGC 5746 (black line) and its different components. This shows that 80% of the stellar mass formed before $z = 2$ (10 Gyr ago) and that the nuclear disc, the B/P bulge and the thick disc are all in place by $z = 1$ (or 8 Gyr ago). By contrast, star formation continues in the thin disc down to the present time.

Соотношение масс+равномерное распределение аккрецированных звезд

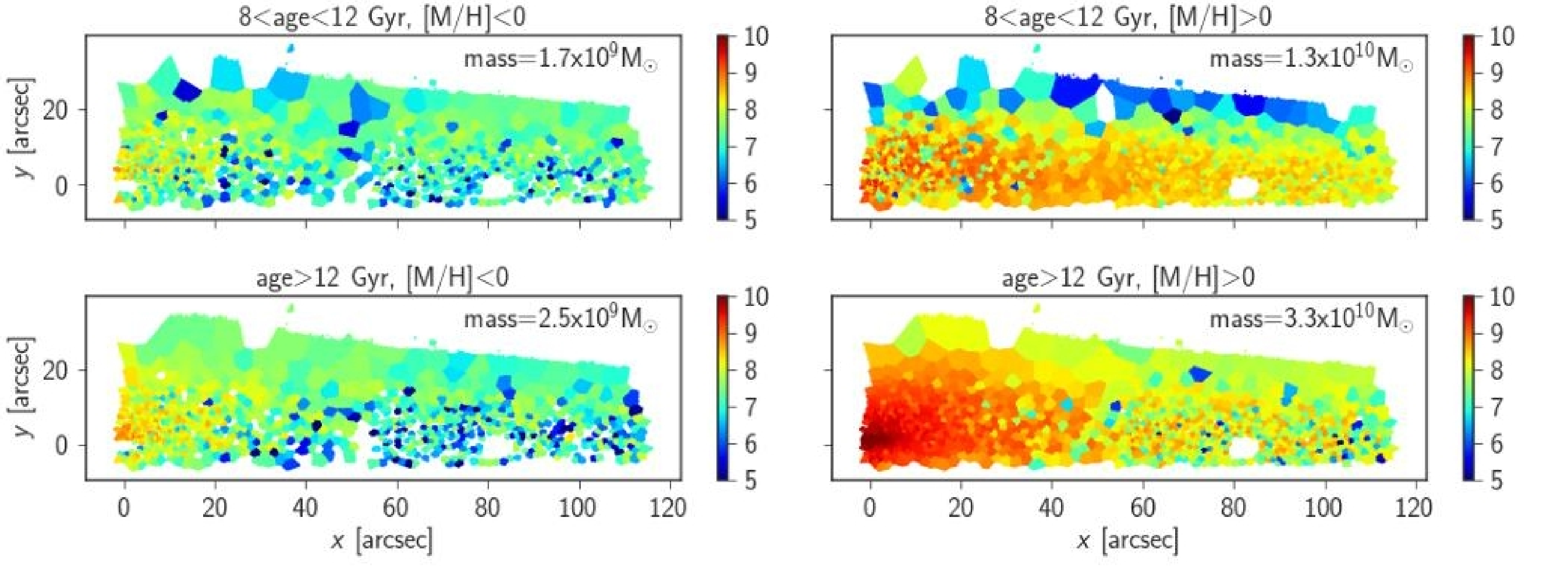


Figure 15. Surface density maps of stellar populations binned by age and [M/H]. The colorbars correspond to the logarithm of the surface density, in units of $M_\odot$ kpc^{-2}. We interpret the metal-poor population (left column) as mostly made of accreted stars, brought by a ~1:10 merger happening ~ 8 Gyr ago.

Ядерный диск: самый старый

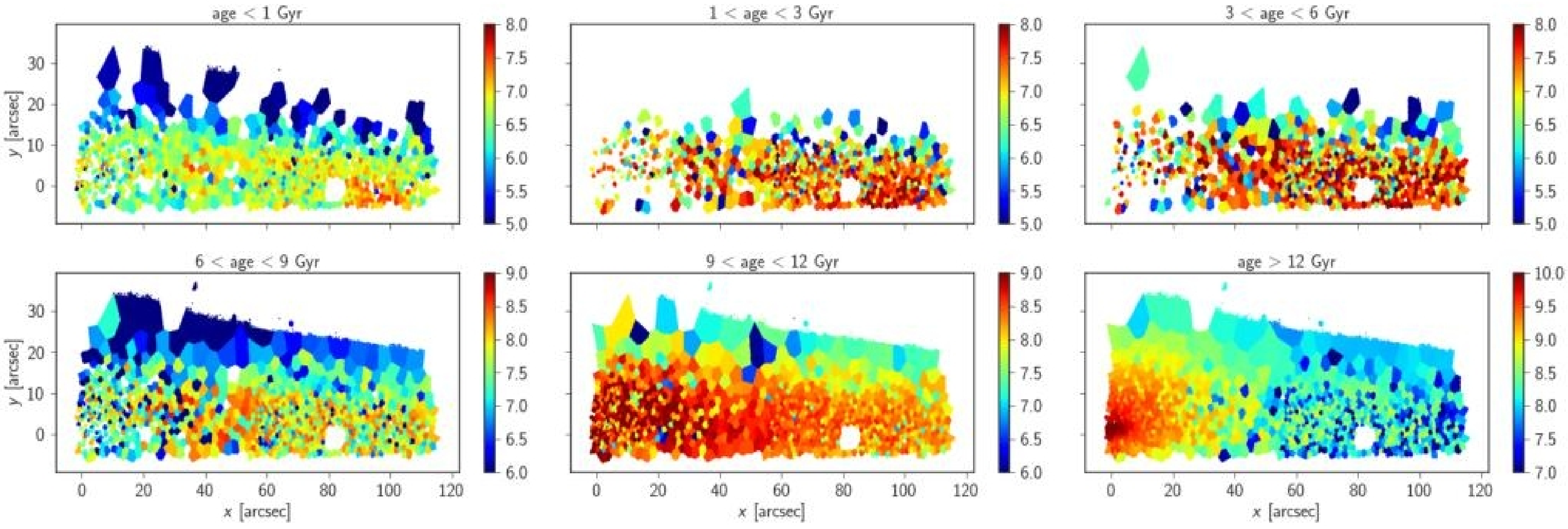


Figure 13. Surface density maps of stellar populations binned by age, from the youngest stars in the top left panel, to the oldest in the bottom right panel. The colorbars correspond to the logarithm of the surface density, in units of $M_\odot$ kpc^{-2}. Stars older than 12 Gyr are very centrally concentrated, while stars younger than 9 Gyr are mostly found in the thin disc.

Выводы авторов по NGC5746:

- 8 млрд лет назад случился малый мержинг, 1:10, который произошел в экваториальной плоскости, НЕ нагрел диск, НЕ сформировал балдж, а распределил звезды спутника по всему объему диска.
- Бар (и его псевдобалдж) – старый, не имеет никакого отношения к тонкому диску, а вырос в старом звездном диске (э-э-э… толстом и неустойчивым одновременно???).
- А вот как существенно раньше события малого мержинга сформировался толстый диск – кто его знает…