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The redshift evolution of the S0 fraction for $z < 1$ in COSMOS

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ABSTRACT

Lenticular (S0) galaxies are galaxies that exhibit a bulge and disk component, yet lack any clear spiral features. With features considered intermediary between spirals and ellipticals, S0s have been proposed to be a transitional morphology, however their exact origin and nature is still debated. In this work, we study the redshift evolution of the S0 fraction out to $z \sim 1$ using deep learning to classify F814W (i-band) HST-ACS images of 85,378 galaxies in the Cosmological Evolution Survey (COSMOS). We classify galaxies into four morphological categories: elliptical (E), S0, spiral (Sp), and irregular/miscellaneous (IrrM). Our deep learning models, initially trained to classify SDSS images with known morphologies, have been successfully adapted to classify high-redshift COSMOS images via transfer learning and data augmentation, enabling us to classify S0s with superior accuracy. We find that there is an increase in the fraction of S0 galaxies with decreasing redshift, along with a corresponding reduction in the fraction of spirals. We find a bimodality in the mass distribution of our classified S0s, from which we find two separate S0s populations: high-mass S0s, which are mostly red and quiescent; and low-mass S0s, which are generally bluer and include both passive and star-forming S0s, the latter of which cannot solely be explained via the faded spiral formation pathway. We also find that the S0 fraction in high-mass galaxies begins rising at higher z than in low-mass galaxies, implying that high-mass S0s evolved earlier.

Key words: galaxies: evolution – galaxies: elliptical and lenticular, cD – galaxies: general

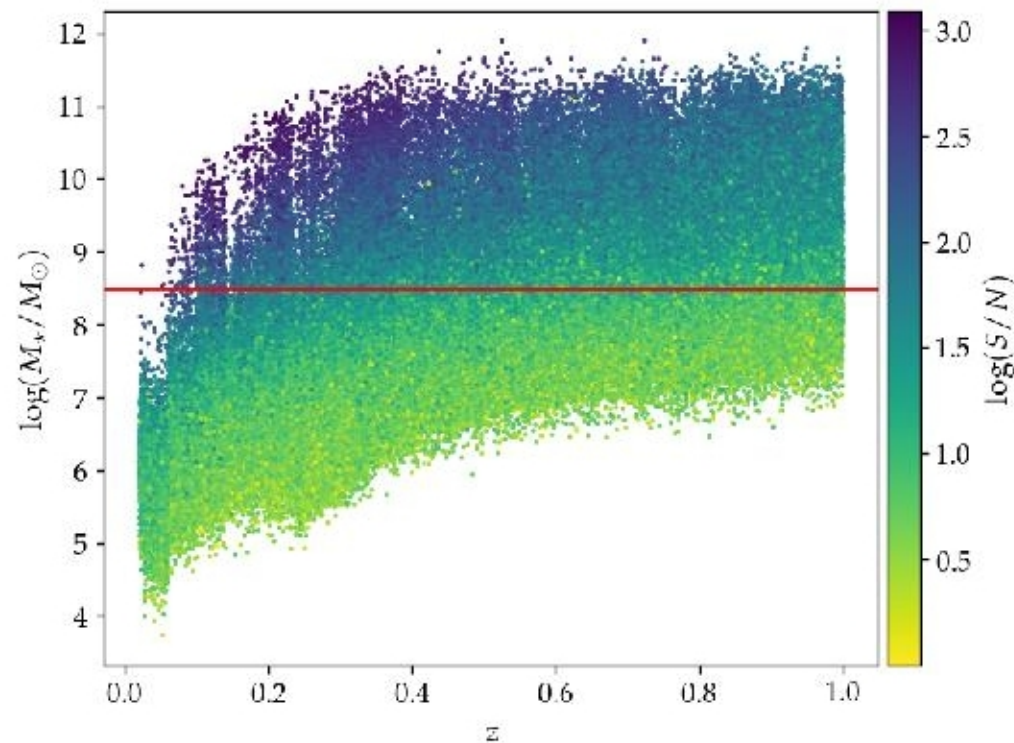# Из обзора COSMOS: >85 тыс. галактик, 50-килопарсековые снимки HST

Figure 1. Full COSMOS sample for redshifts $z < 1$ with redshift on the x-axis and stellar mass on the y-axis. Samples are shaded according to their signal-to-noise ratio $\log(S/N)$. The solid, red line denotes the minimum mass considered for this study.

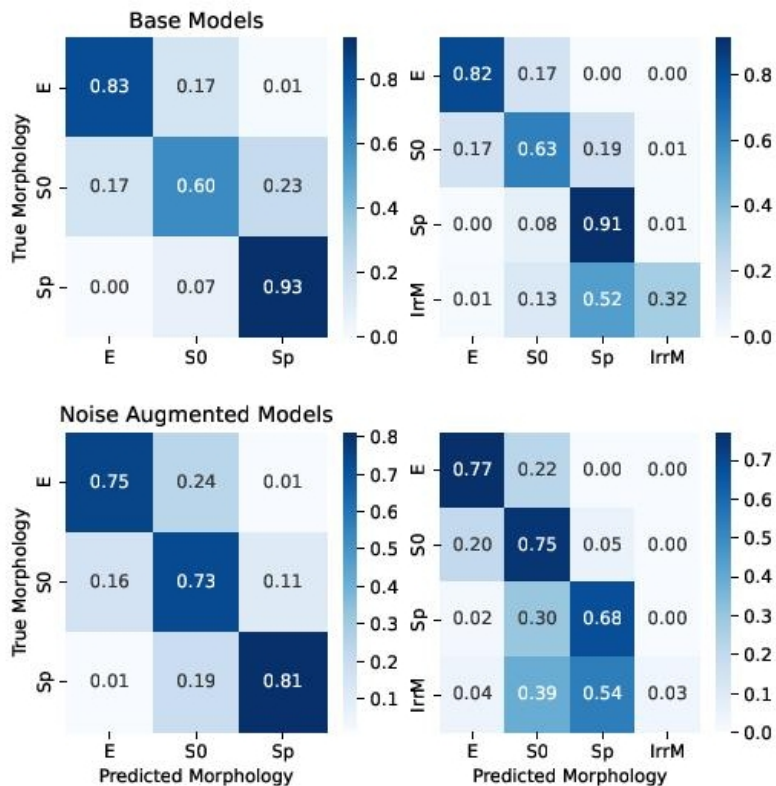# Машинное обучение на зашумленных снимках из SDSS

Figure 4. Confusion matrices for the base 3-class and 4-class models (top row), as well as the noise-augmented 3-class and 4-class models (bottom row), based on final evaluation with the holdout NA10 test set. Rows denote the true morphologies, while columns denote the predicted morphologies. The entries i, j denote the fractions of samples with true morphology i that are classified as the predicted morphology j. The diagonal entries correspond to recall (a.k.a. per-class accuracy). The same test set is used for both models, with the augmented models tested on augmented images. For the noise augmented models, the predictions (and hence accuracies) are based on the

Примеры 4х морфологических типов
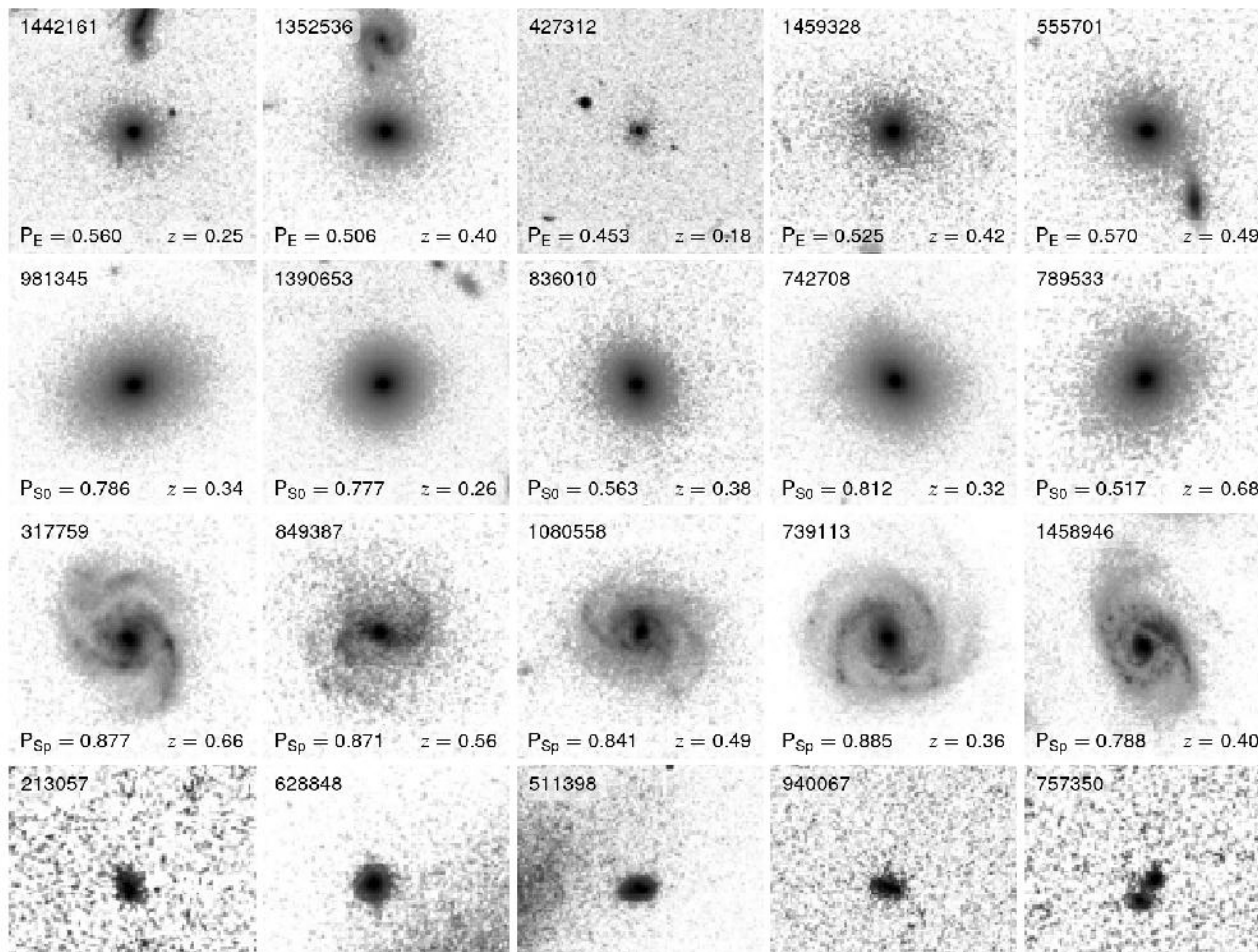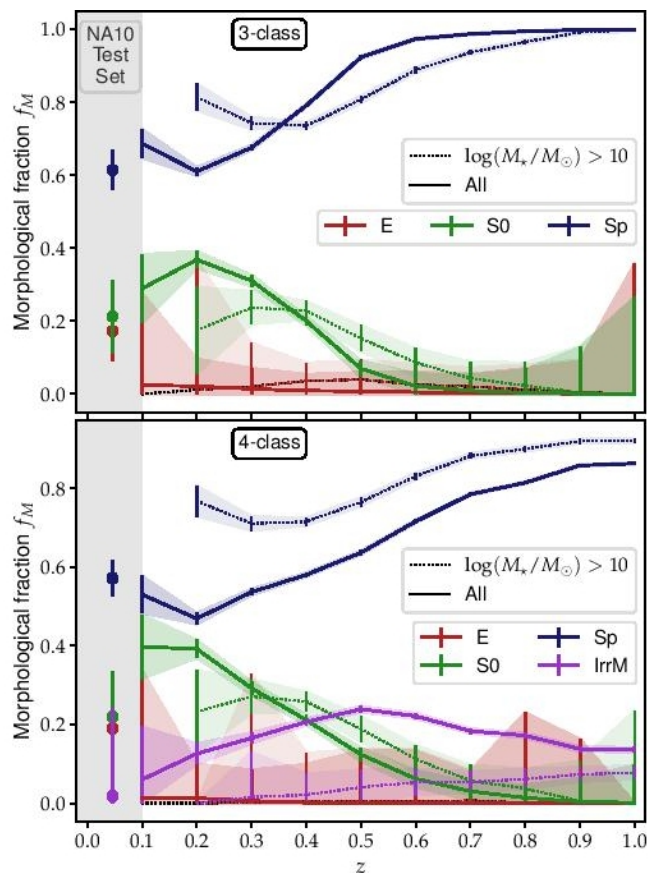
Эволюция «долей» морфологических типов

Figure 7. The redshift evolution of the morphological fractions f_M for
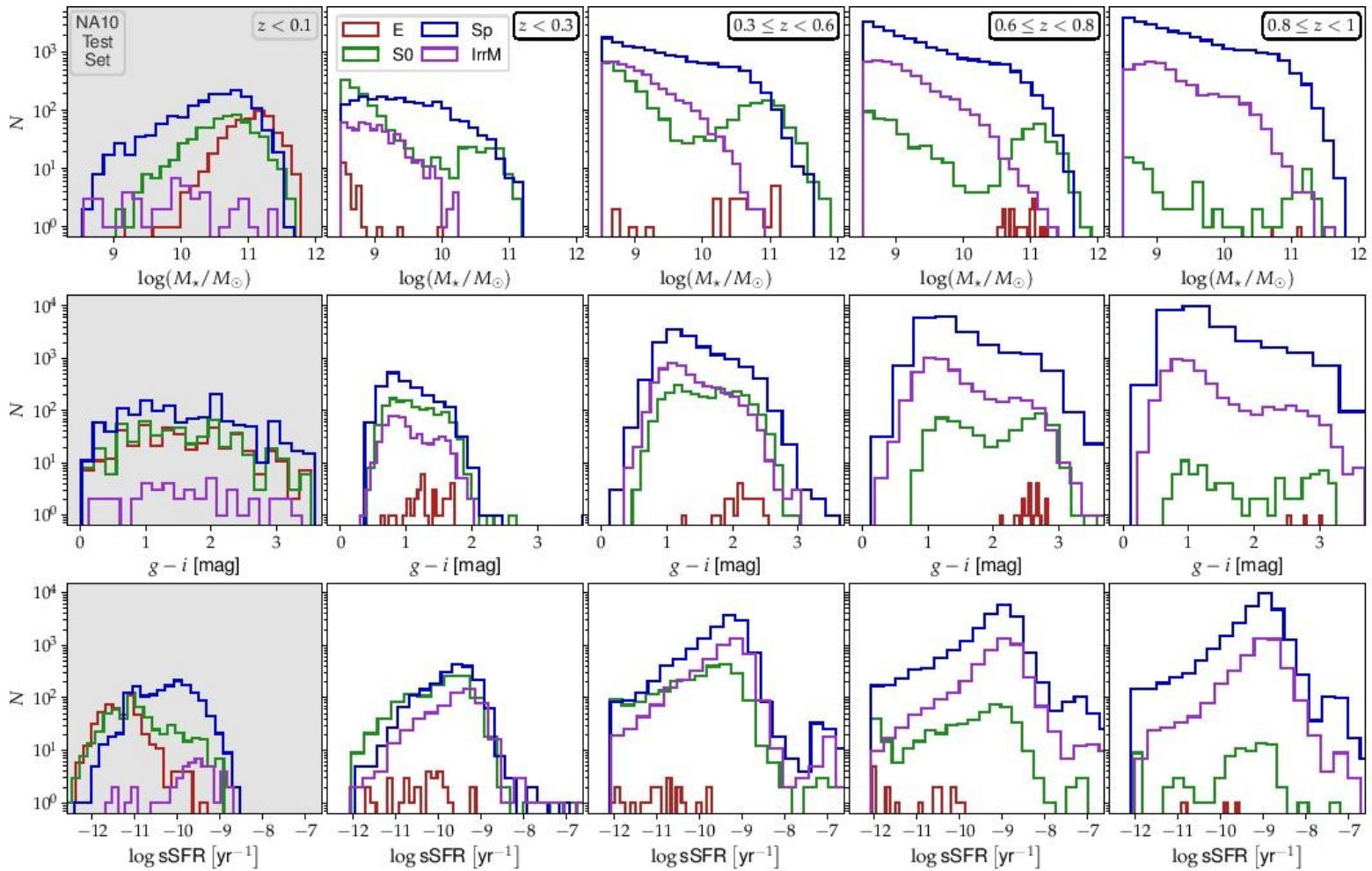
Бимодальность у S0

Figure 9. Histograms showing the distributions of stellar mass $\log(M_\star/M_\odot)$ (top row), colour $g - i$ (middle row) and specific star formation rate (sSFR) (bottom row), for samples classified as elliptical, S0, spiral and irregular over different redshift ranges. The leftmost, shaded column shows the corresponding distributions
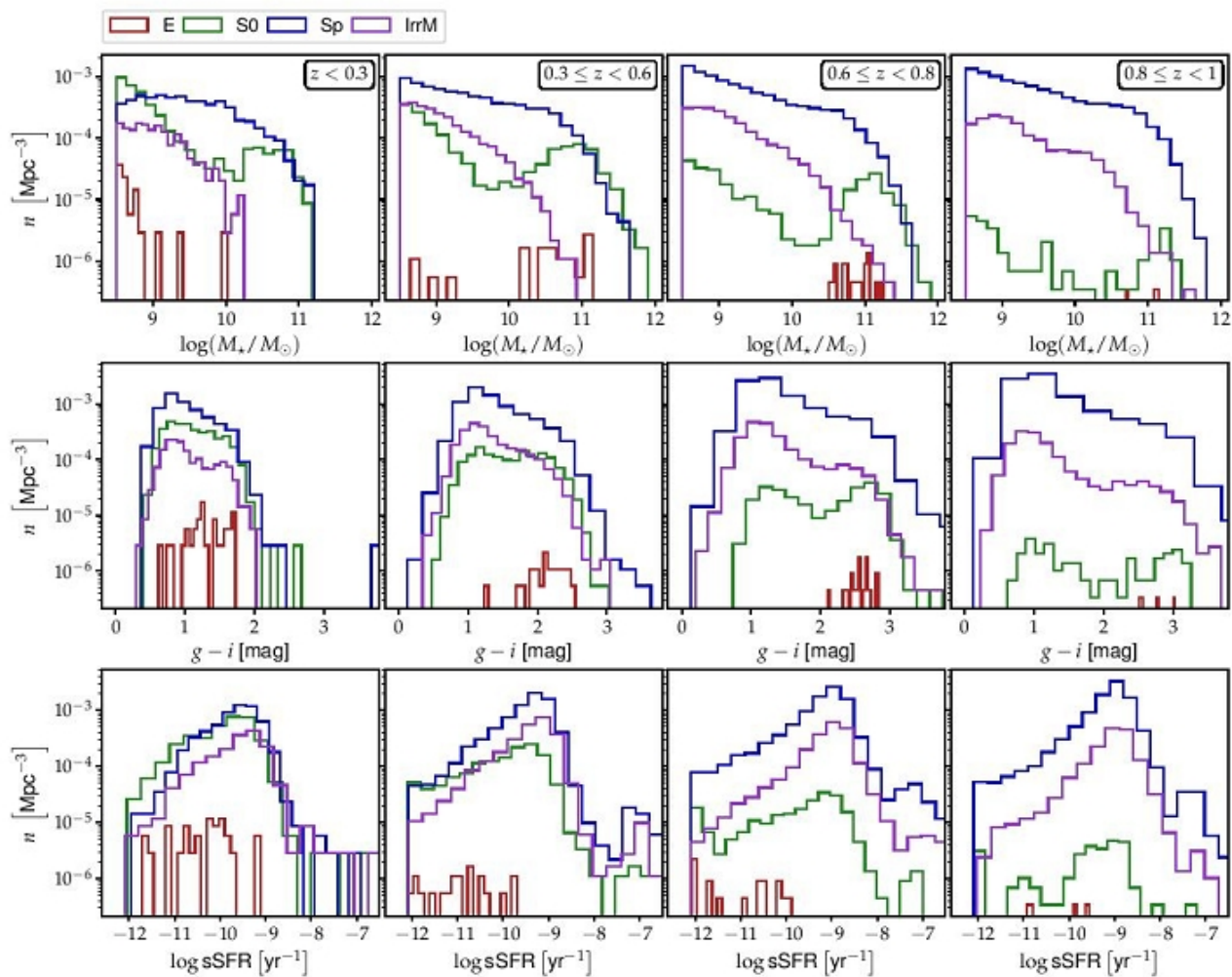
То же самое – в пространственных плотностях

Figure 10. Number density histograms showing the distributions of stellar mass $\log(M_\star/M_\odot)$, colour $g - i$ and sSFR for samples classified as elliptical, S0, spiral and irregular over different redshift ranges.

Сглаженные распределения по параметрам: почему-то у массивных S0 на z<0.3 усилилось звездообразование, без последствий для их типа
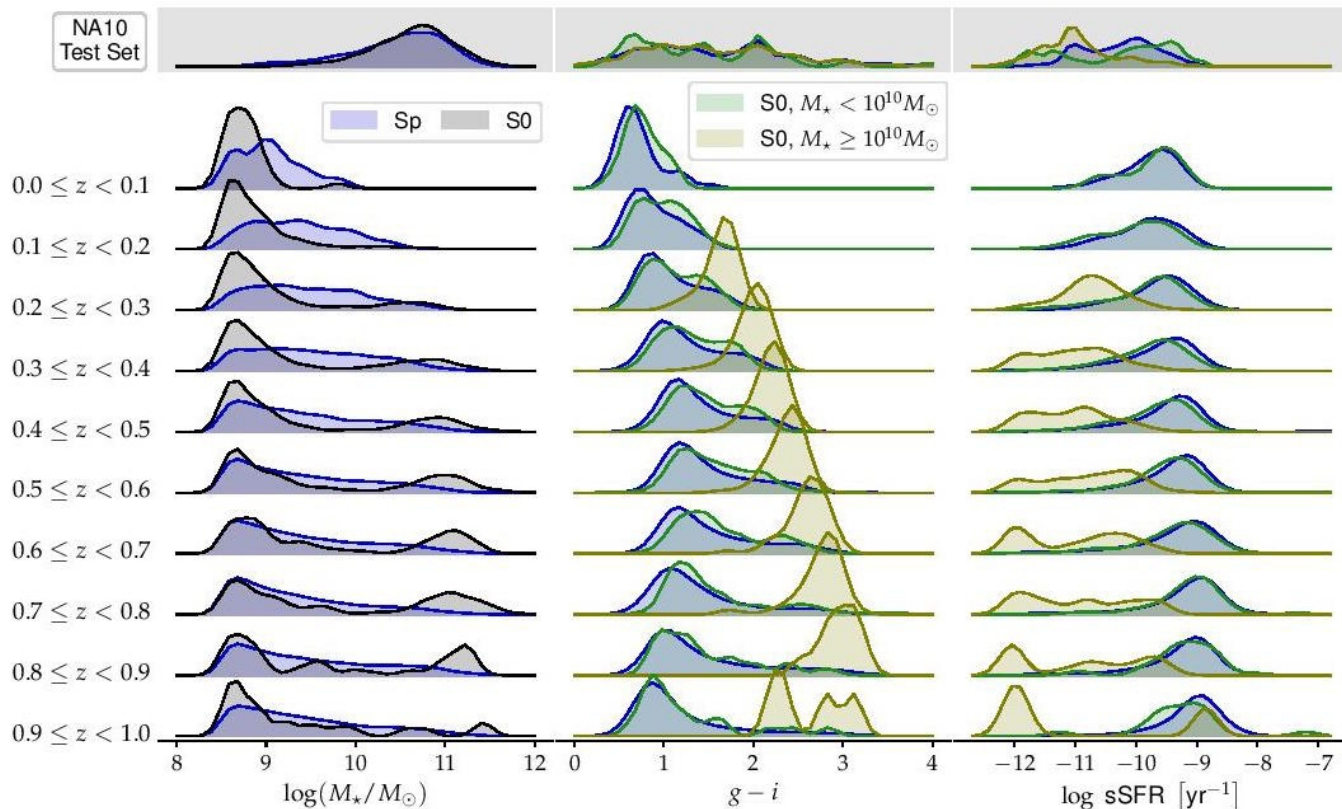

Figure 11. Ridgeplots showing the probability density distributions of stellar mass $\log(M_\star/M_\odot)$, colour $g-i$ and sSFR for lenticulars and spirals in finer $0.1z$ redshift increments from $0 \leq z < 0.1$ to $0.9 \leq z < 1$. The columns for colour and sSFR split the S0s into samples with mass $< 10^{10} M_\odot$ in green and $\geq 10^{10} M_\odot$ in olive.
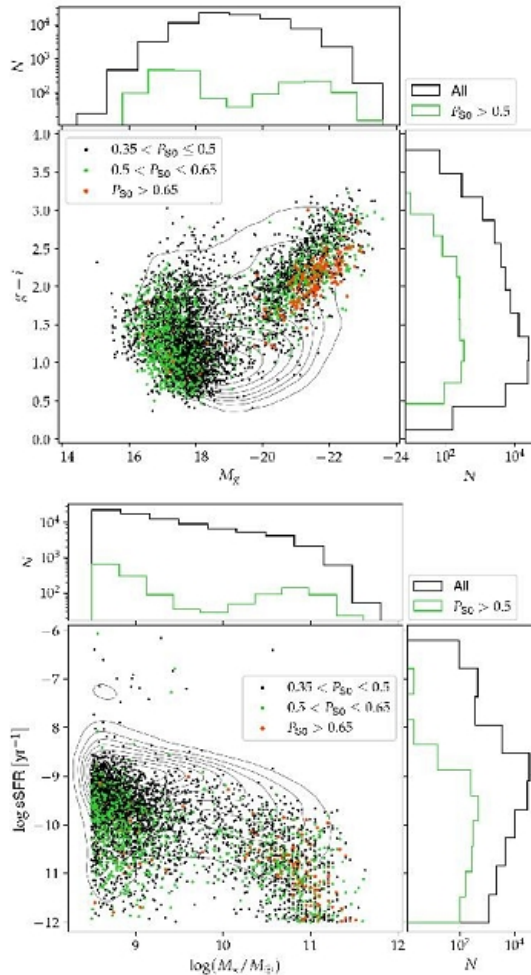
Различия массивных и маломассивных S0s

Figure 12. (Top) Absolute g magnitude M_g vs. colour $g - i$. (Bottom) Stellar mass $\log(M_\star/M_\odot)$ vs. sSFR. Contours denote smoothed kernel density estimates of the distribution of the entire sample. Samples with $P_{S0} > 0.35$ are directly plotted and shaded according to their mean S0 output probability, as predicted by the augmented 4-class model ensemble.
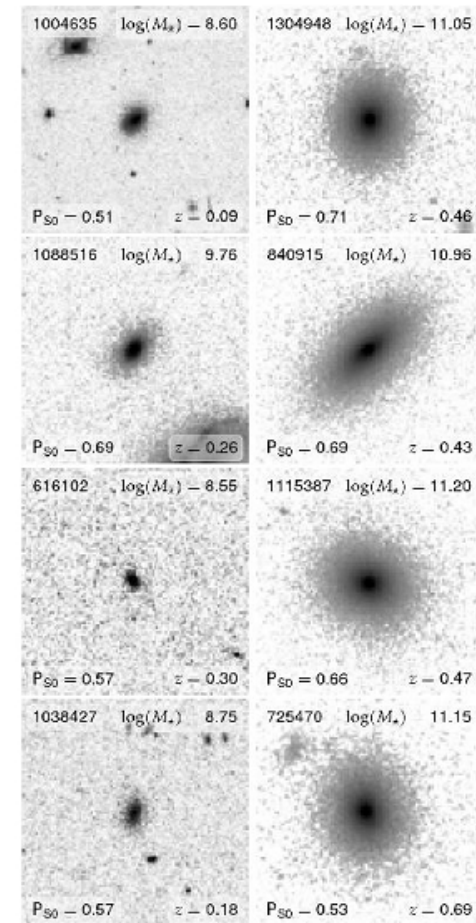

Figure 13. Random selection of example S0 galaxies classified with at least a confidence $P_{S0} > 0.5$. The left column shows a selection of low mass S0s, and the right row shows a selection of high mass S0s. Samples are annotated with their COSMOS ID in the top left, stellar mass in the top right in units of $\log(M_\star/M_\odot)$, confidence P_{S0} in the bottom left, and redshift z in the bottom right.