Spectral classification of S0 galaxies in the nearby Universe: a tale of two sub-populations

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ABSTRACT:

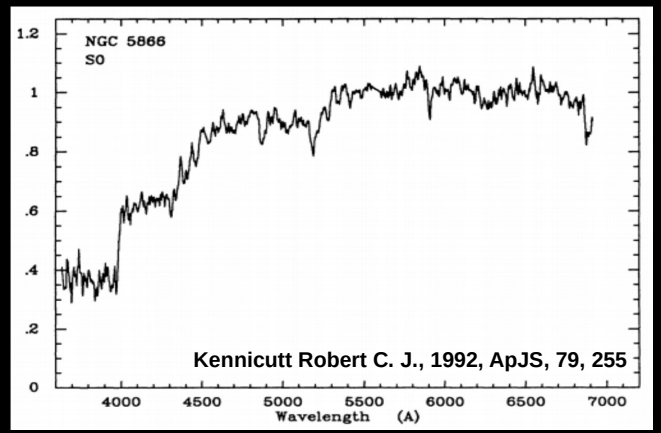
In a recent work published in MNRAS (Tous J. L., Solanes J. M., Perea J. D., 2020, MNRAS, 495, 4135), we review the main properties of galaxies designated S0 in the Hubble classification system. Our aim is to gather abundant and, above all, robust information on the most relevant physical parameters of this poorly understood morphological type and their possible dependence on the environment, which could later be used to assess their possible formation channel(s). The adopted approach combines the characterization of the fundamental features of the optical spectra of 68043 S0 with heliocentric $z \leq 0.1$ with the exploration of a comprehensive set of their global attributes. A principal component analysis is used to reduce the huge number of dimensions of the spectral data to a low-dimensional space facilitating a bias-free machine-learning-based classification of the galaxies. This procedure has revealed that objects bearing the S0 designation consist, despite their similar morphology, of two separate subpopulations with statistically inconsistent physical properties. Compared to the absorption-dominated S0, those with significant nebular emission are, on average, somewhat less massive, more luminous with less concentrated light profiles, have a younger, bluer, and metal-poorer stellar component, and avoid high-galaxy-density regions. Noteworthy is the fact that the majority of members of this latter class, which accounts for at least a quarter of the local S0 population, show star formation rates and spectral characteristics entirely similar to those seen in late spirals. Our findings suggest that star-forming S0 might be less rare than hitherto believed and raise the interesting possibility of identifying them with plausible progenitors of their quiescent counterparts.

Context of the research


NGC 4111, ESA/Hubble & NASA
Acknowledgement: Judy Schmidt

Lenticular (S0) galaxies are the morphological family situated at the crossroads between the branches of the ellipticals (E) and the spirals (S) of the Hubble tuning fork diagram.

They present a characteristic lenticular shape, sharing structural elements from both E and S: a central luminous spheroidal component (bulge) surrounded by an arm-less disk.



Kennicutt Robert C. J., 1992, ApJS, 79, 255

A classical view of these objects is that they typically host red and old stellar populations and that their interstellar medium (ISM) is rather gas-poor, so star formation is marginal or absent.

The S0 galaxies of the local Universe might have followed very different formation pathways depending on the environment in which they reside.

(I) Field → gravity ($v_G \sim v_*$)


NGC 2207 & IC 2163, NASA/ESA and The Hubble Heritage Team (STScI)

Tidal interactions, collisions or mergers involving spirals may remove most of their ISM either directly or from a starburst and change their morphology.

(II) Clusters → hydrodynamics ($v_G >> v_*$)


NGC 4402, NASA & ESA

Mechanisms such as the ram-pressure stripping can remove the ISM of the disks of spirals moving through the intracluster medium. Galaxy harassment can facilitate structural changes in the disk.

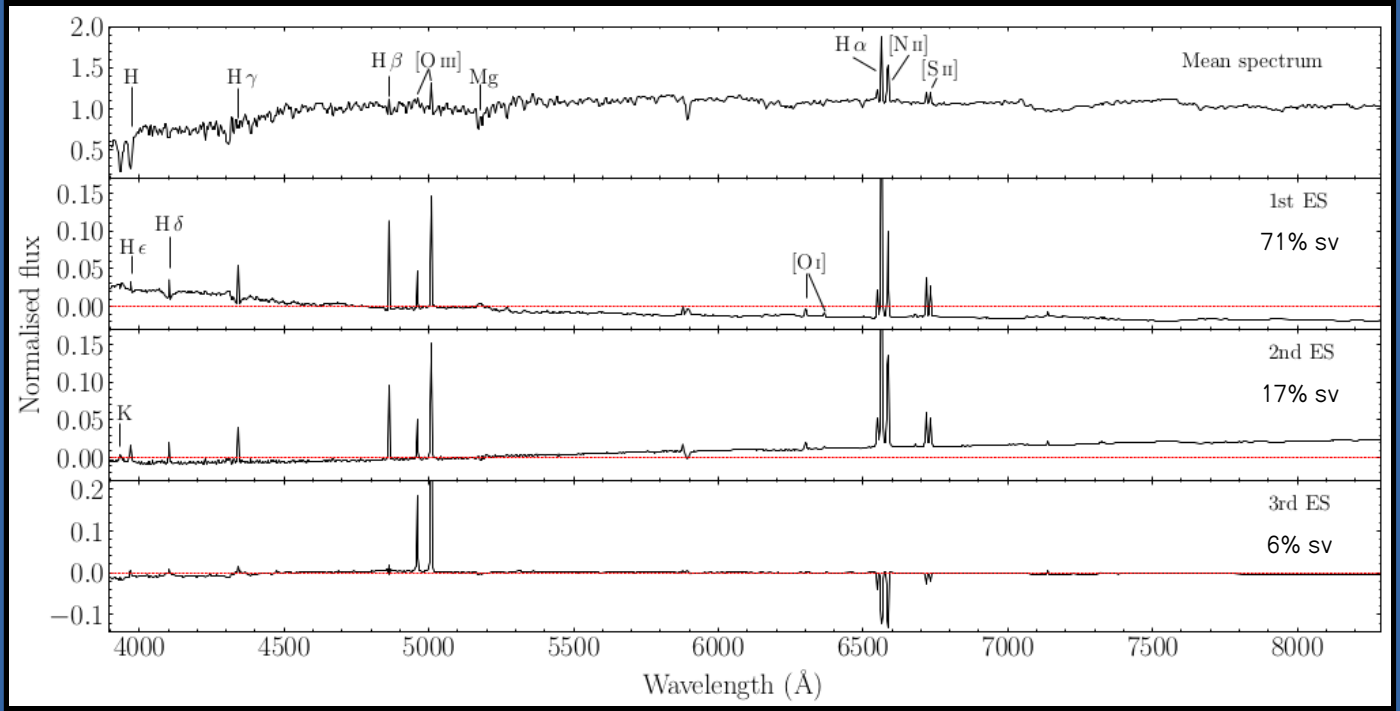
Goal: we expect to be able to detect the imprint left by such different formation channels in the properties of S0 galaxies and, eventually, identify them.

Methodology

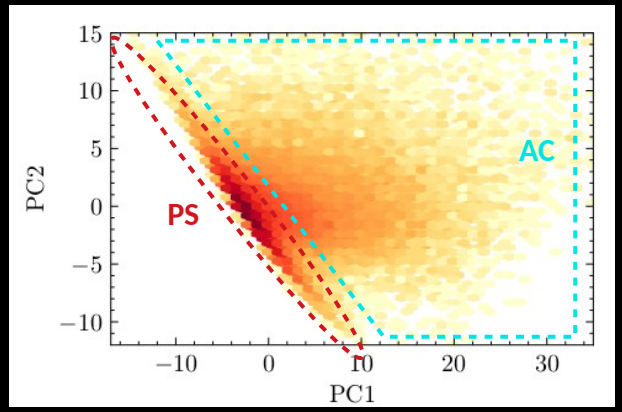
1) **Sample selection.** A magnitude-limited sample of 68043 SDSS optical spectra of S0 galaxies with z ≤ 0.1 (MLSS0). Morphologies are taken from Domínguez Sánchez et al. (2018) + spectrophotometric properties from a large number of public catalogs [NASA-Sloan Atlas, GALEX-SDSS-WISE Legacy Catalog, Portsmouth Value-Added Catalog (VAC), Firefly VAC].

2) **Preparing the spectra**. The spectra are properly corrected for Galactic extinction, rest-frame shifted, rebinned and normalized. Gaps within spectra due to different problematics are reconstructed following the Yip et al. (2004)'s algorithm.

3) **PCA**. A set of 3 principal components is derived from a subset of ~6500 S0 galaxies with high S/N (> 30) recovering more than 90% of the sample variance (sv).

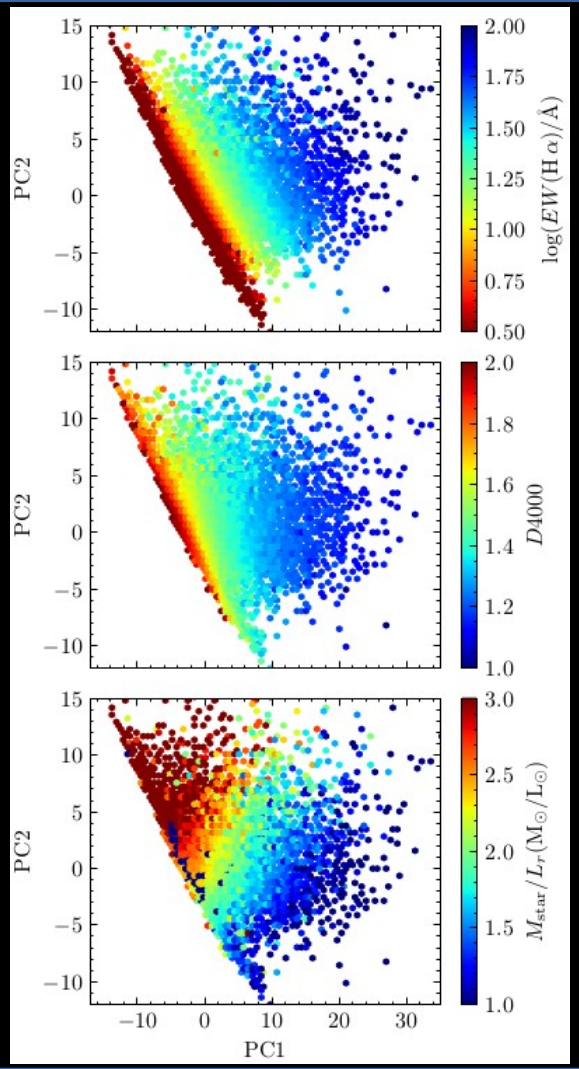


4) **Dimensionality reduction**. The projection of the MLSS0 on the first 2 principal components reveals 2 main spectral modes: a compact one, for which PC1 and PC2 are strongly correlated and that is dominated by non-star forming S0, which we refer to as the Passive Sequence (PS), and a much more scattered region containing actively star-forming lenticulars, which we dubbed the Active Cloud (AC).



5) **Classification**. Using a logistic regression + Otsu's method at the 95% of the inter-class variance, the galaxies in the MLSS0 are classified according to which spectral mode they belong to. Sixty-nine percent of the local S0 galaxies belong to the PS mode, while a 25% belong to the AC mode. The rest of lenticulars are located in an intermediate Transition Region (TR).

Results (I)



For the comparison of the physical properties we use a volume-limited subset of 32188 S0.

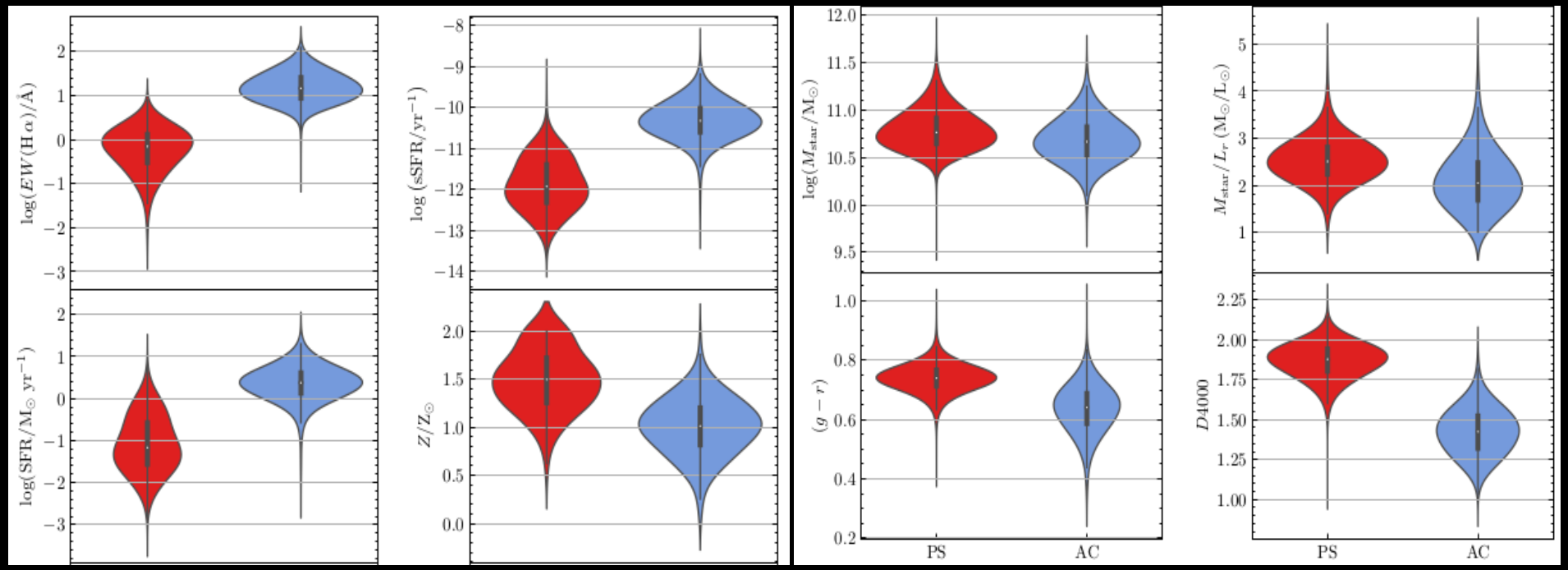
Clear correspondence of the modal division with SF properties of S0, particularly with the strength of the Hα emission line:

→ galaxies in the AC show active spectra with strong emission lines;
→ expected differences in, at least, those physical properties related with the SF.

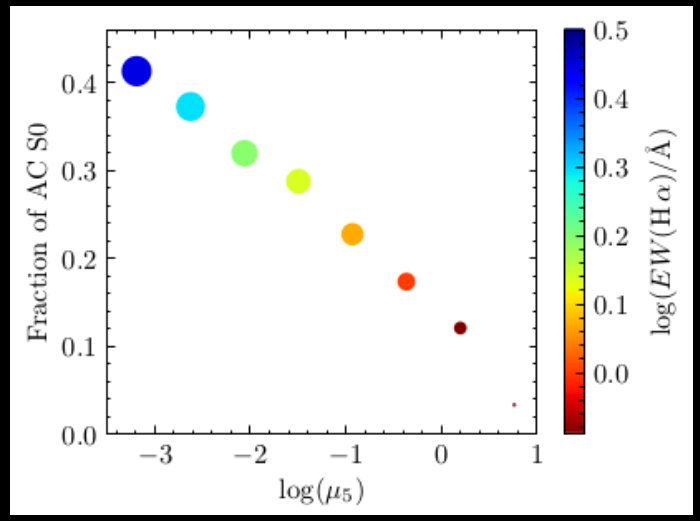
Linear correlations between the derived components and some of the main physical properties of the galaxies.

Linear correlation index								
	EW(Hα)	log(sSFR)	log(SFR)	$Z/Z_{\odot}$	log(M_*)	M_*/L_r	(g - r)	D4000
PC1	0.85	0.58	0.55	-0.32	-0.47	-0.62	-0.78	-0.81
PC2	0.32	0.13	0.24	0.09	0.33	0.46	0.27	-0.05
PC3	-0.47	-0.36	-0.39	0.14	0.09	0.11	0.29	0.45

Comparison of the physical properties of the two spectral modes shows that, compared to their PS counterparts, AC galaxies are slightly less massive on average, although somewhat more luminous; have a younger, bluer stellar population, that is poorer in metals and are almost entirely actively star-forming systems with average star formation rates, of about 2 $M_{\odot}$ yr^{-1}, that are more than one order of magnitude higher. In all cases, these differences are statistically significant.



Results (II)

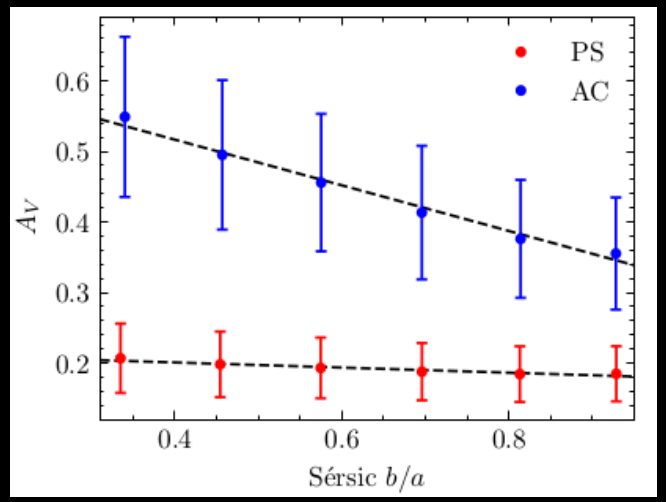


The fraction of AC lenticulars decreases nearly linearly with the log of the local galaxy density (μ_5). The strength of the emission lines and, therefore, the SFR of these galaxies is also reduced with increasing density.

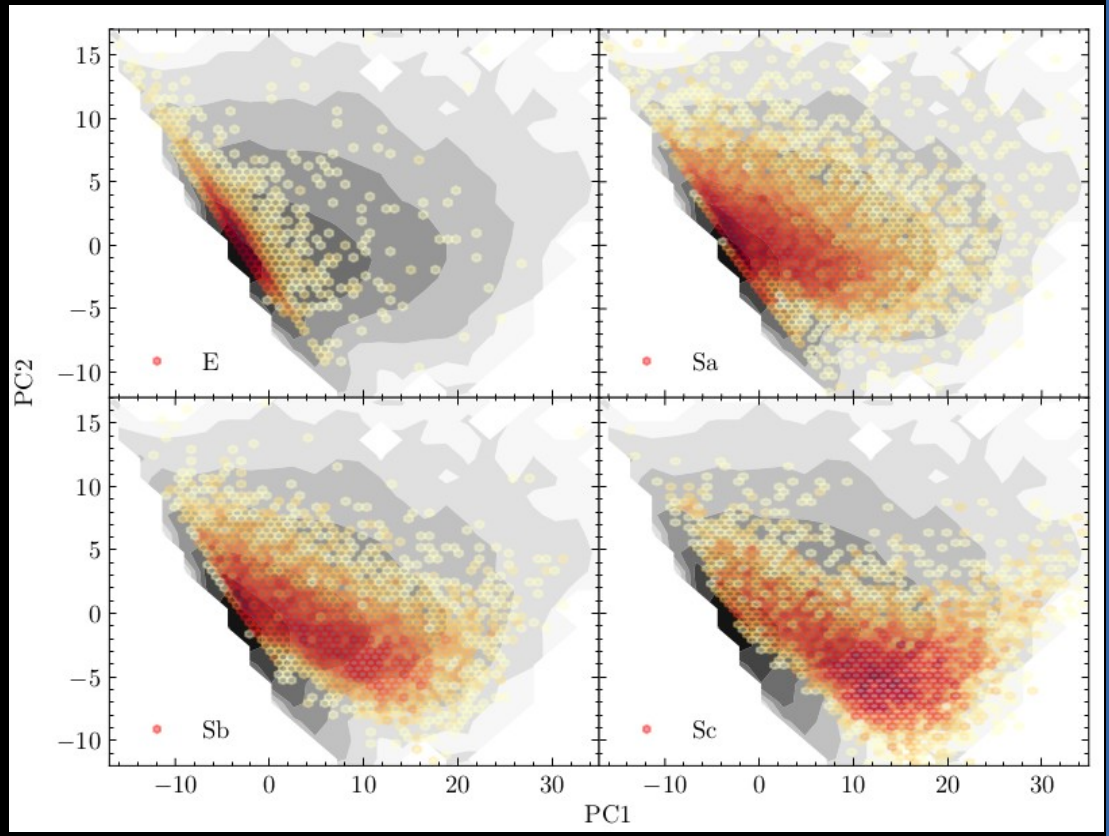
→ AC S0 prefer low galaxy-density environments, whereas PS S0 are found in all kind of environments.

The ISM of each subpopulation of lenticular galaxies is also different. While the members of the PS mode do not show any trend between the total internal extinction in the V band (A_V) and the inclination (or apparent axis ratio b/a), AC lenticulars exhibit a significantly higher extinction that linearly grows with inclination.

Exhaustive tests of our spectral PS-AC classificaction have demostrated that it is very robust against the effects of internal extinction.



Projection of the optical spectra of the other Hubble types on the principal components derived for the S0 shows that the concordance between the AC objects and late-type disk galaxies is not restricted to their similar levels of star formation, but extends to the whole optical spectrum. On the other hand, PS lenticulars occupy the same region in the PC1-PC2 subspace than E galaxies.



Impact and prospects for the future

- This is the first ever systematic and unbiased statistical study of the spectral properties of the S0 population of galaxies in the local Universe.

- Uncovered two main subpopulations of S0 galaxies in the local Universe: about 3/4 of them conform to the traditional view of S0 as passive systems. However, ~ 25% of the local lenticulars show spectra with strong emission lines typical of disk galaxies with active star formation. Indeed, most of these active S0 have SFR comparable or higher than the current value of this property measured for the Milky Way:

  → there is a significant fraction of S0 that are not red and dead objects!

- We have demonstrated that, at least for S0 galaxies, there is no clean one-to-one relationship between morphology and spectral class:

  → this suggests a difference between dynamic and star-formation time-scales for (S0) galaxies.

- We have also quantified for the first time the relative abundances of passive and active S0, not just globally, but in terms of the local density of galaxies too. We find a steady, nearly linear decline in both the fraction of star-forming S0 and the strength of their star-formation activity with the logarithm of the density that extends across more than four decades of the latter property. In contrast, passive S0 populate all kinds of environments.

- Our PCA is now being extended to integral-field spectroscopy through the analysis of the data on S0 galaxies gathered in the latest release of the MaNGA survey.